ETH Institute for Particle Physics

The latest results from LHC

Günther Dissertori

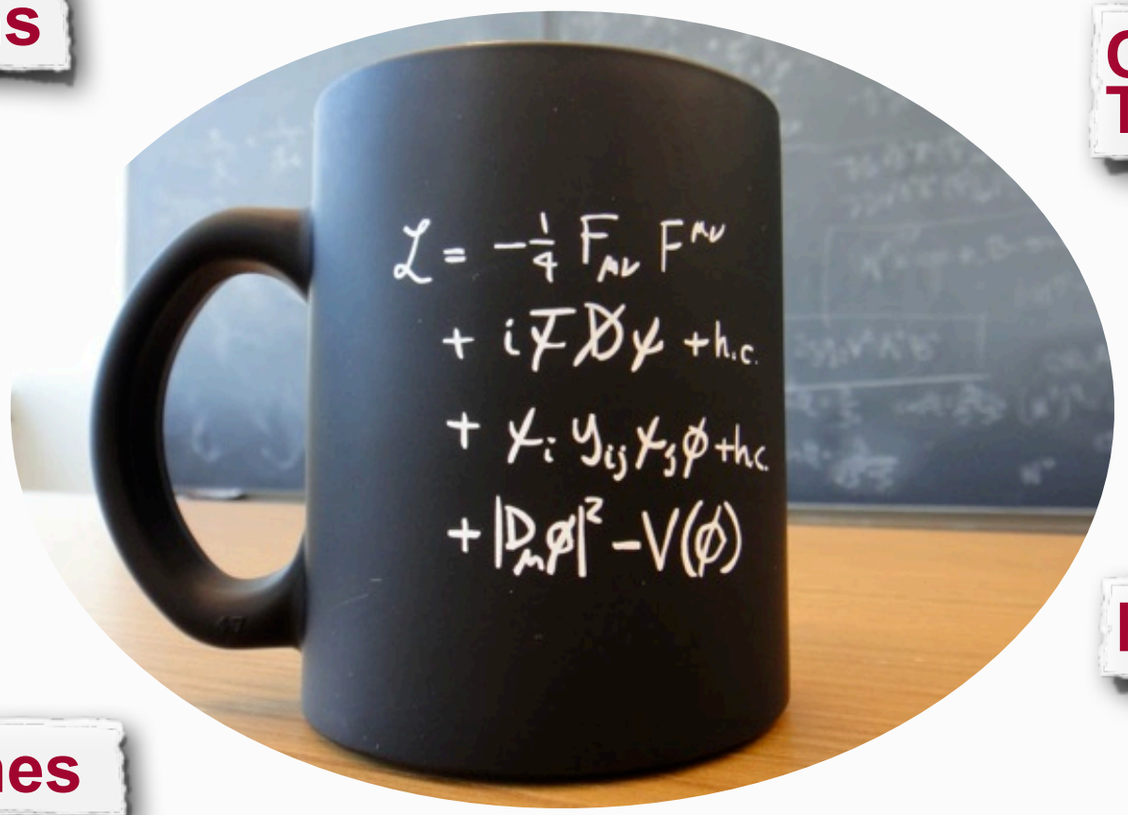
ETH Zürich

Outline

ETH Institute for Particle Physics

Heavy Ions

QCD, EWK and Top physics



Heavy Flavours

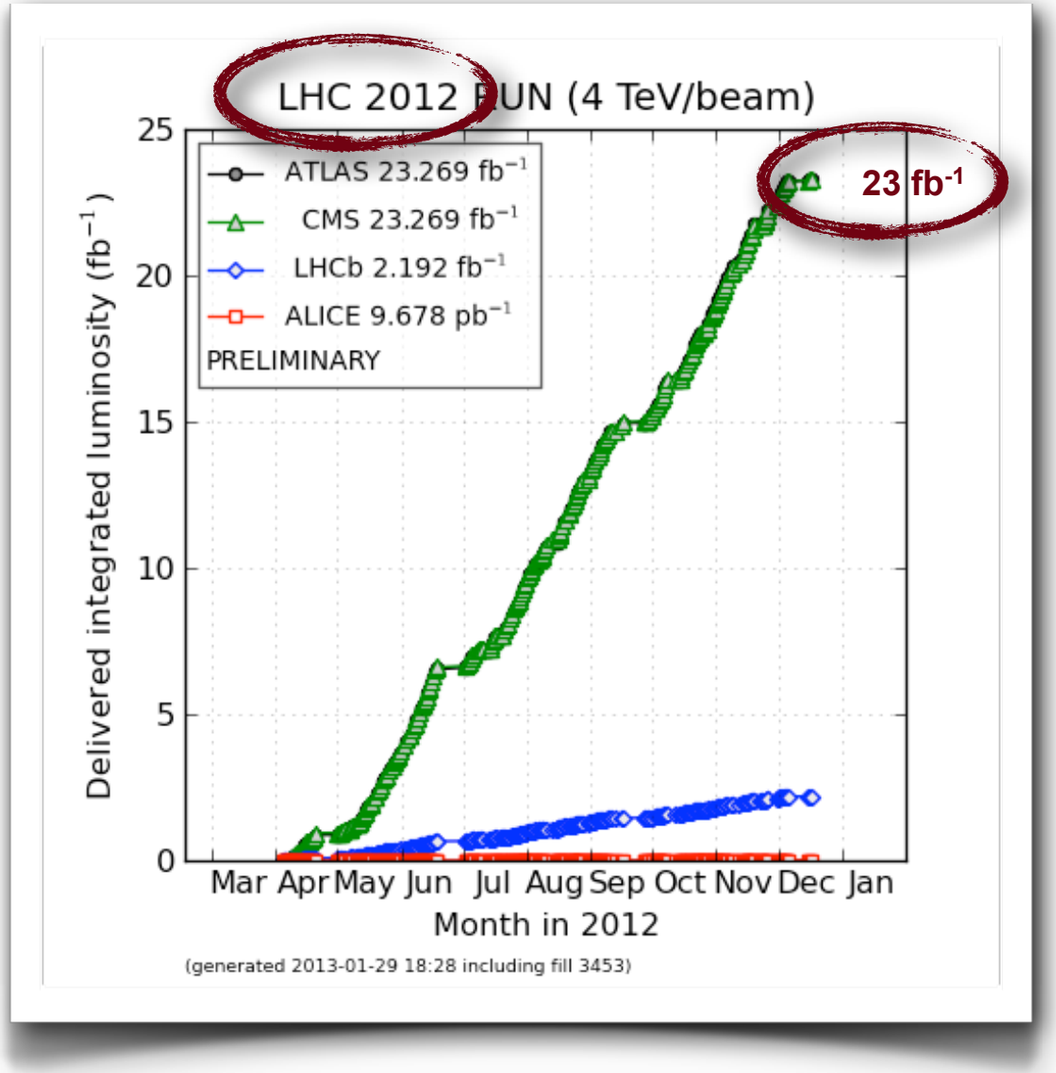
Higgs physics

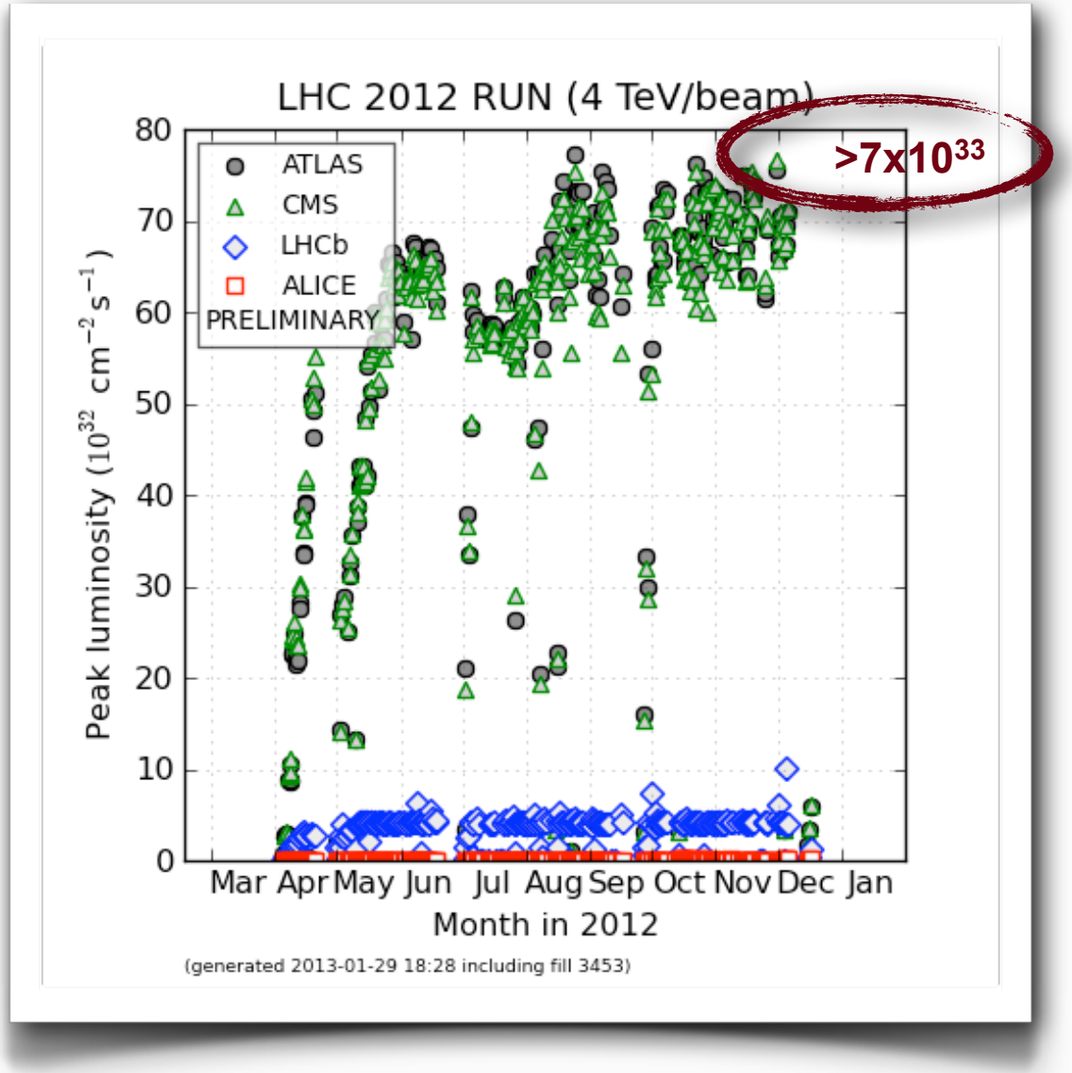
BSM searches

***Remarks**:*
- a selection only, with focus on most recent results

the preparation of this talk has been "depressing"....
because it is close to impossible to do justice to the wealth of results....

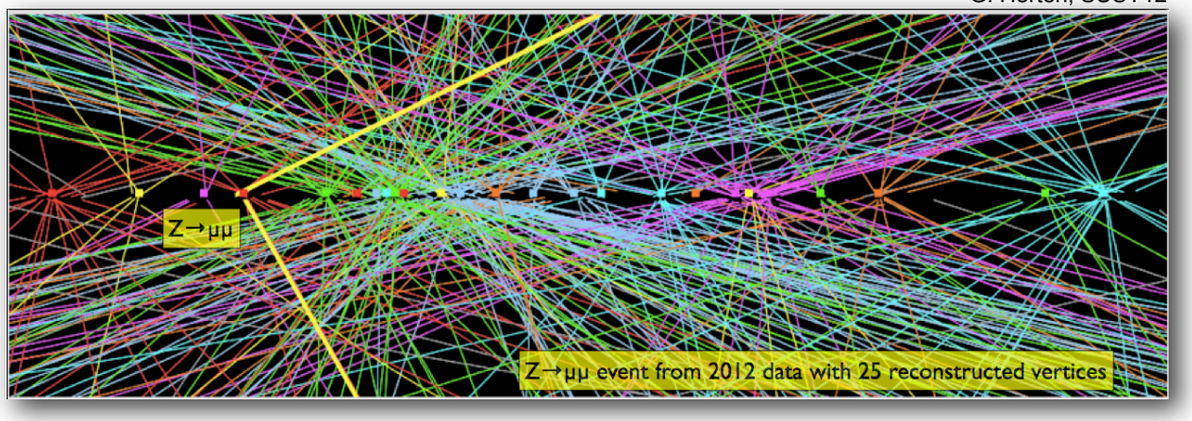
Excellent performance of our microscopes





Experiments: excellent data taking efficiencies, performances according to or often beyond expectations
High LHC luminosity came at the price of large pile-up: experiments coping well with it, so far

G. Herten, SUSY12

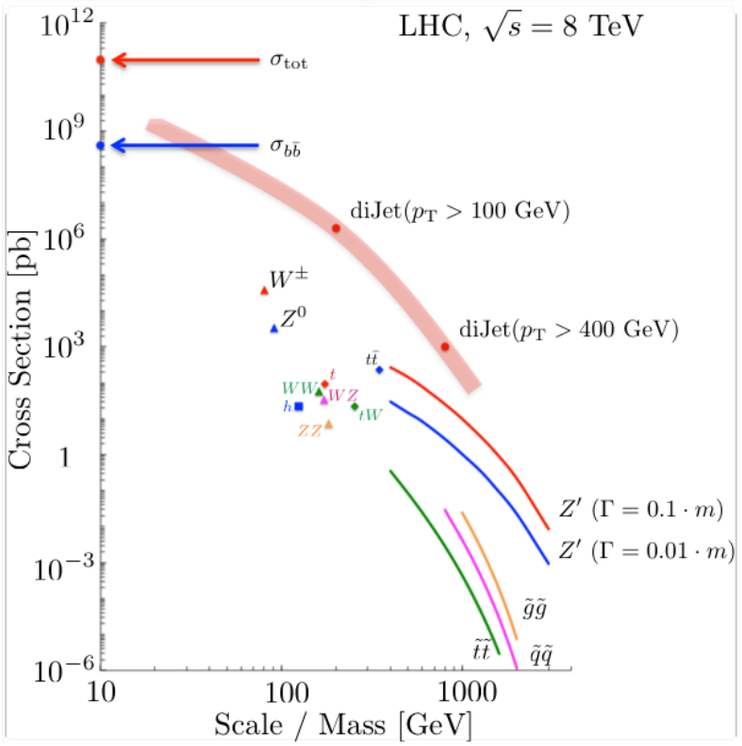


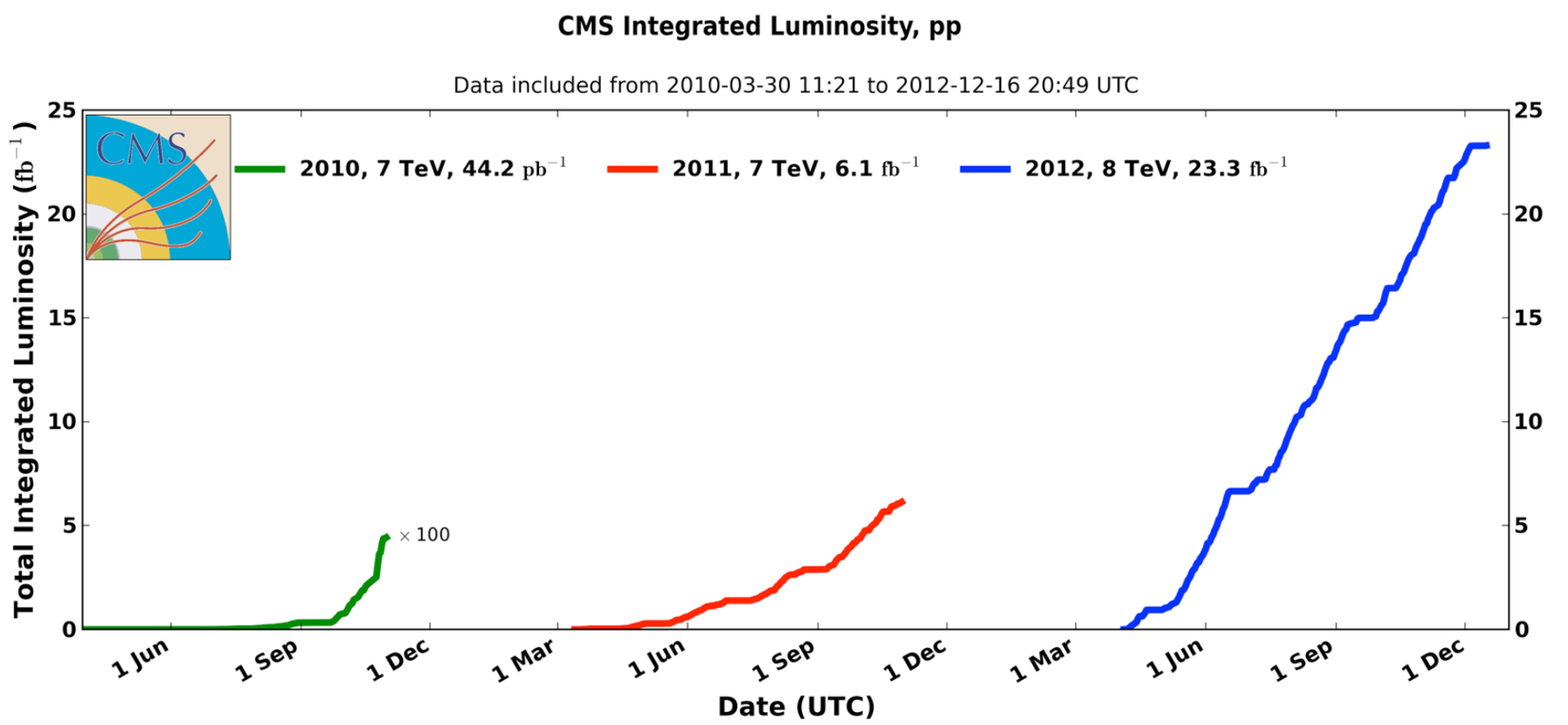
A 3-year long sprint....

CMS as example ...

ETH Institute for Particle Physics

Ch. Sander





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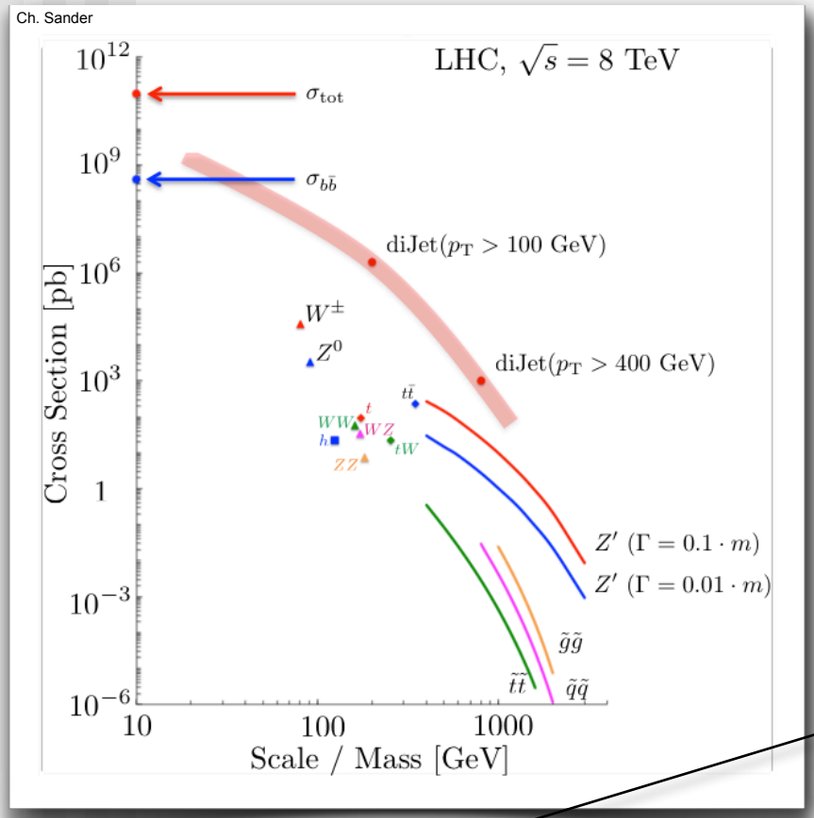

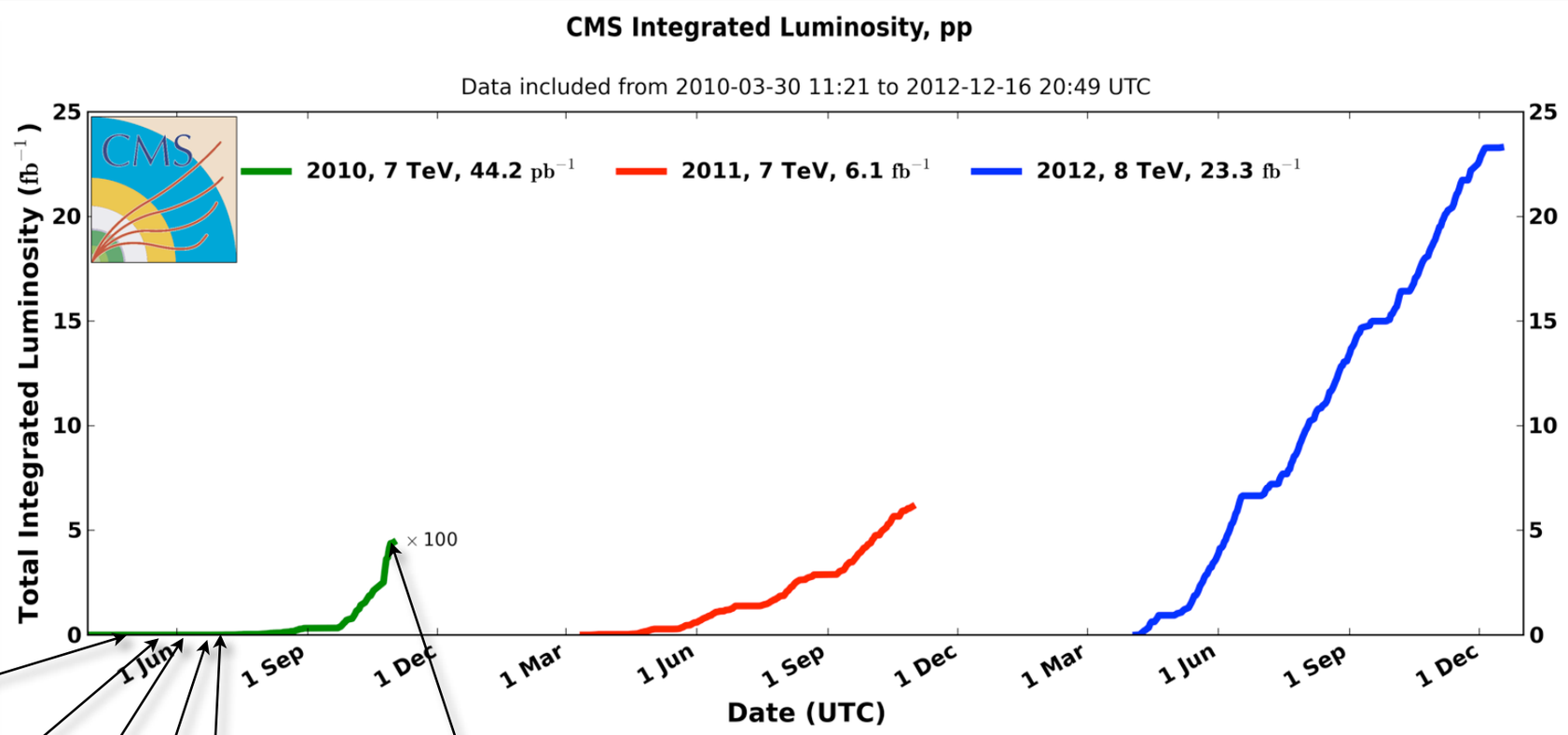

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studies, particle multiplicities

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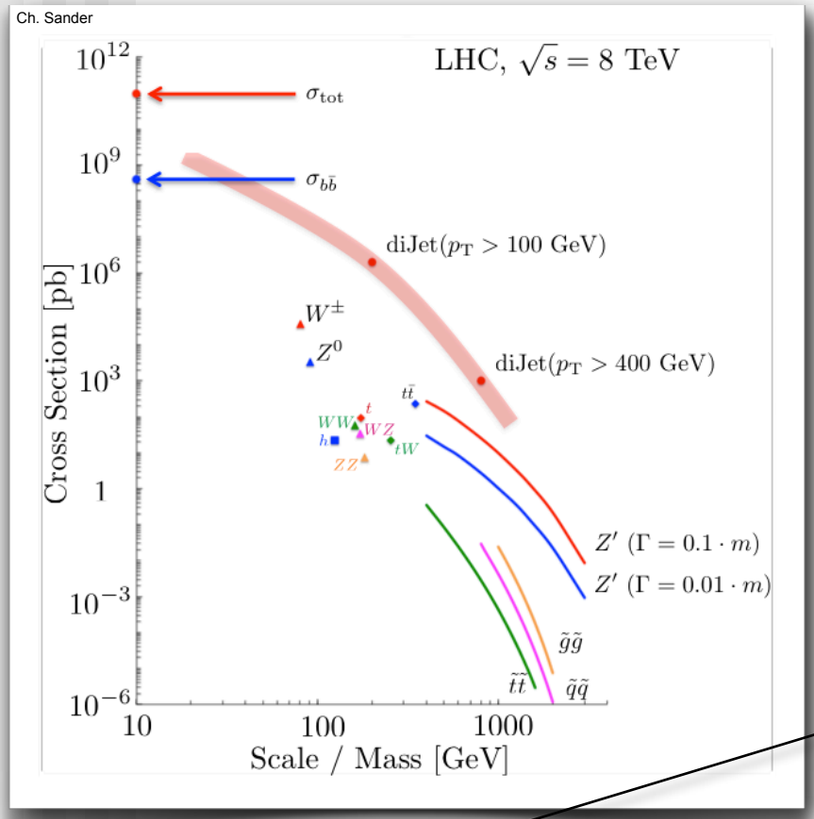

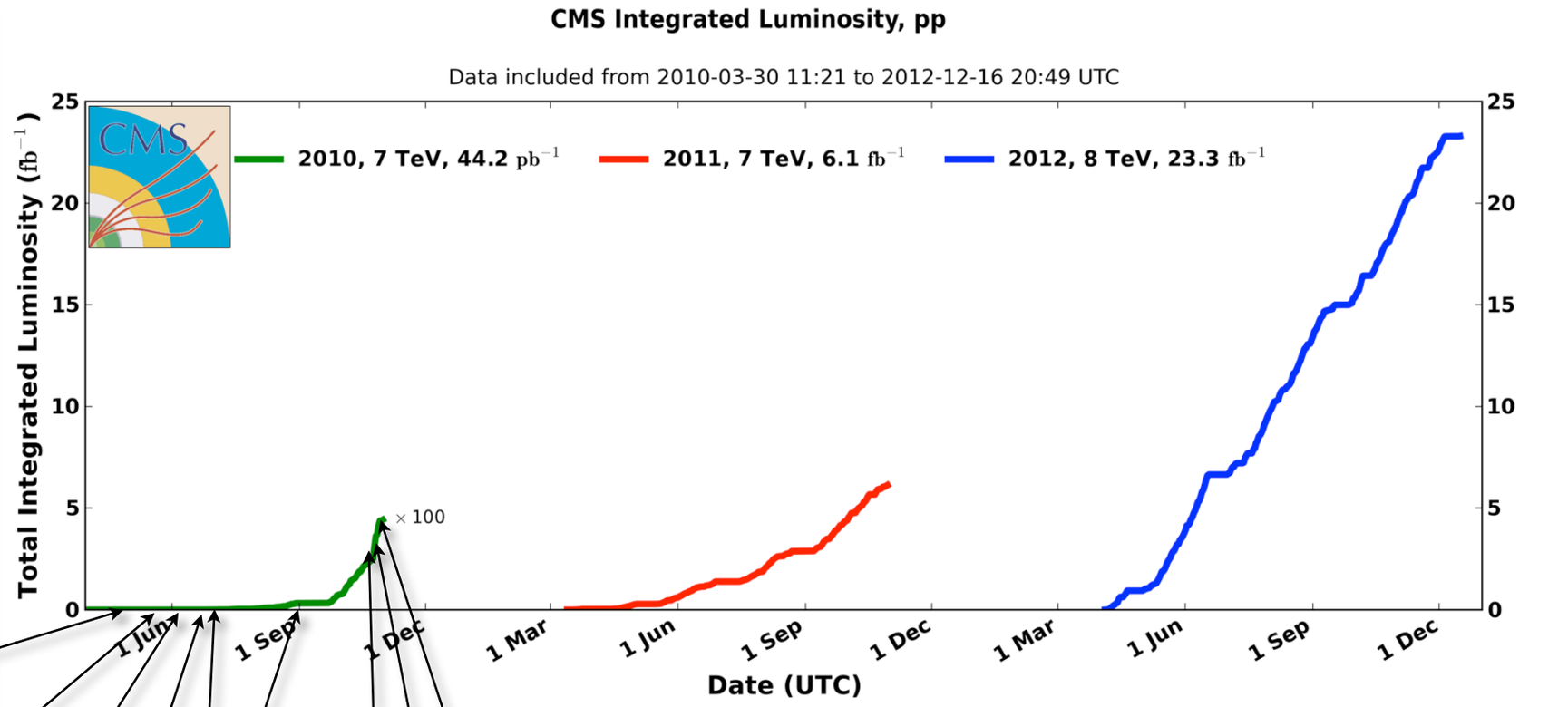

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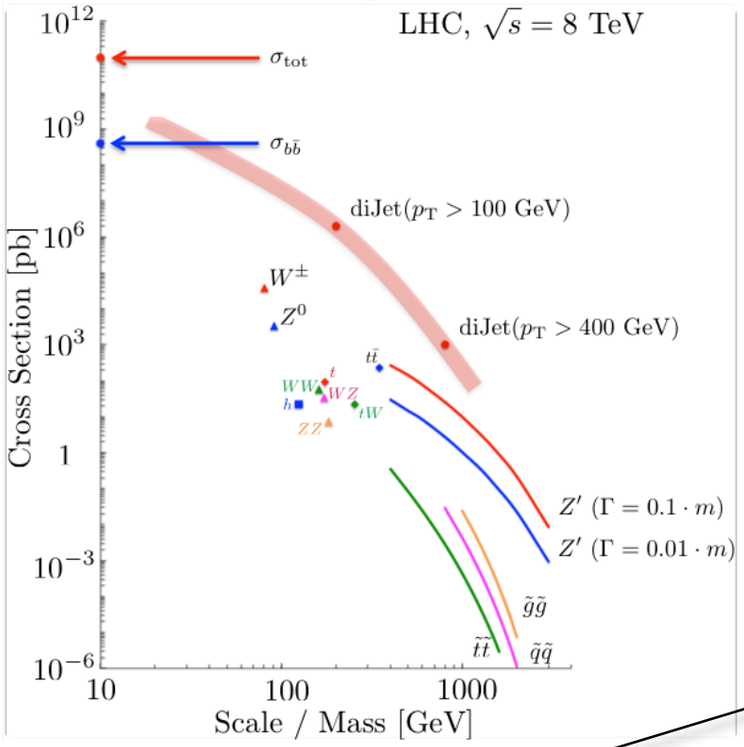

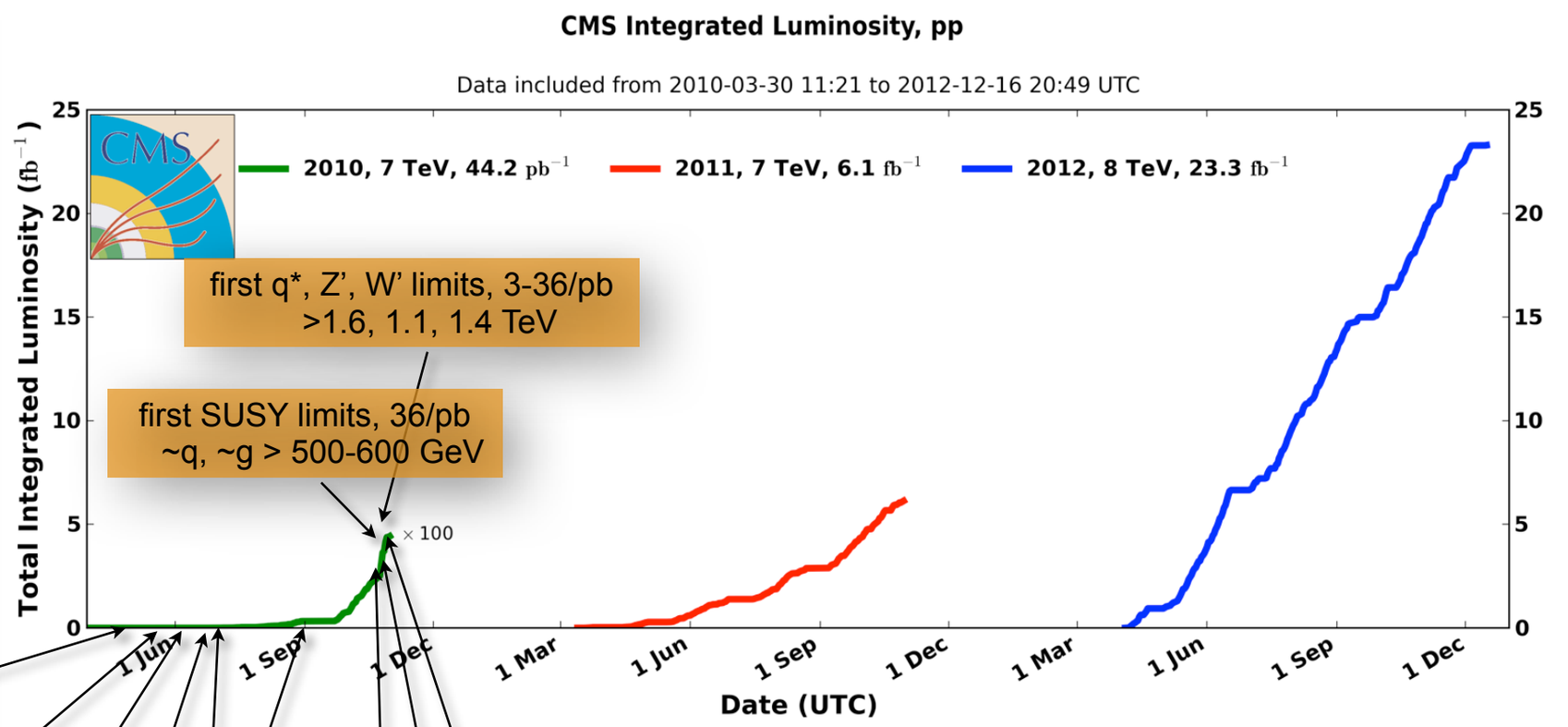

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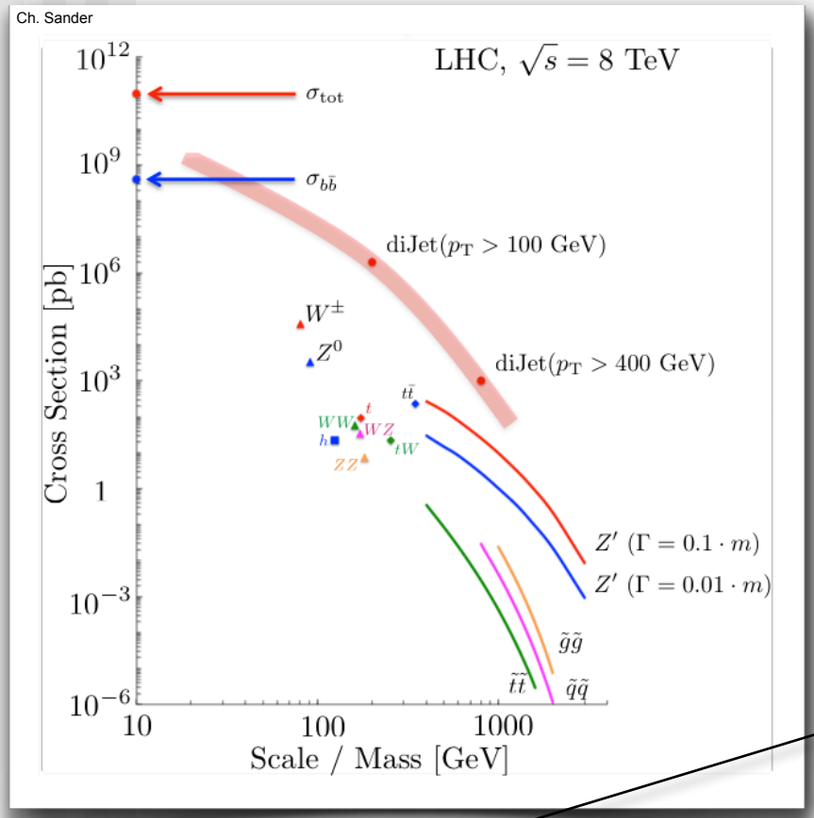

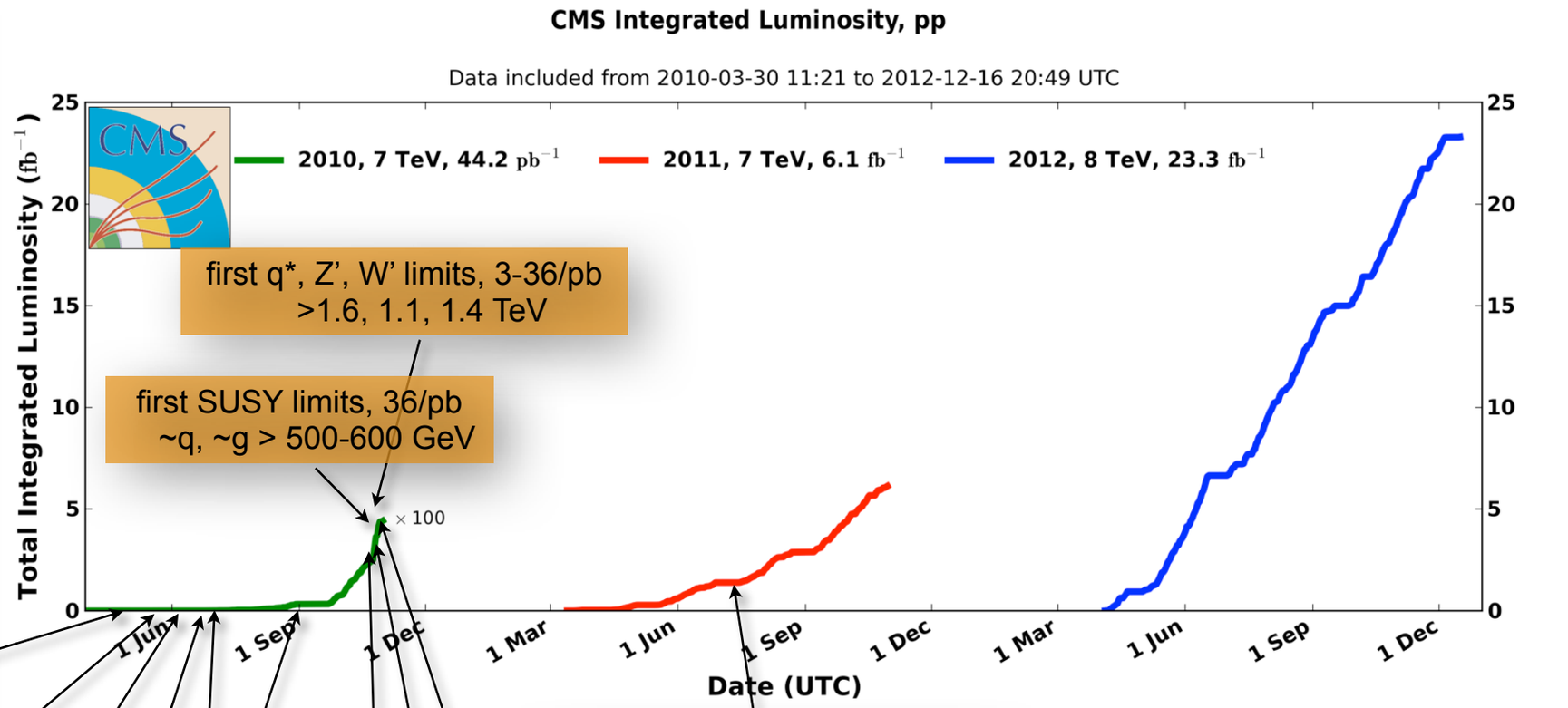

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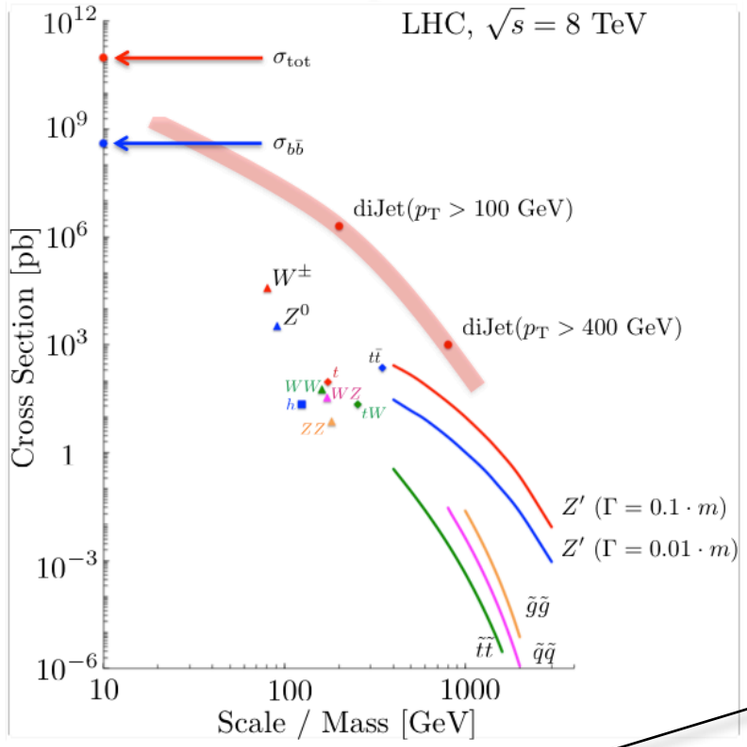

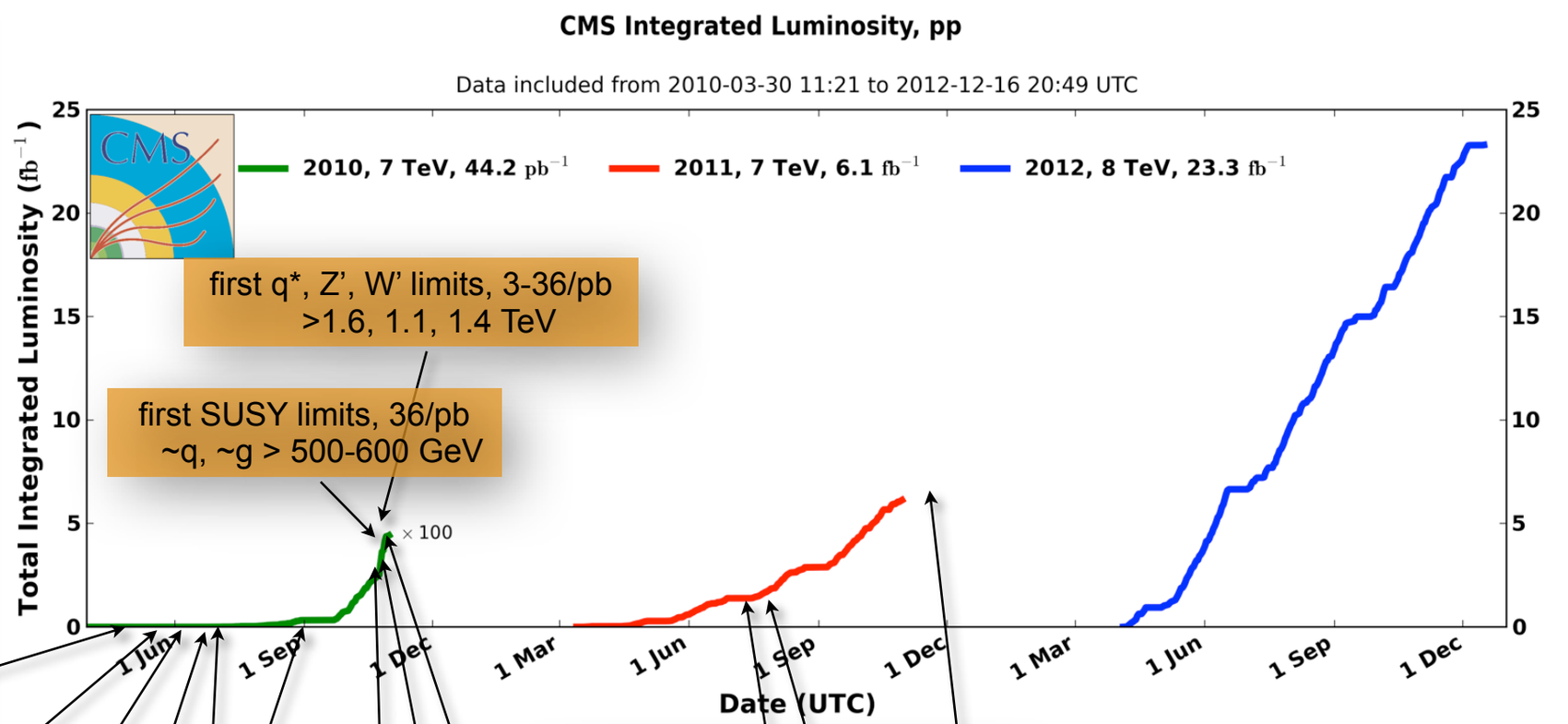

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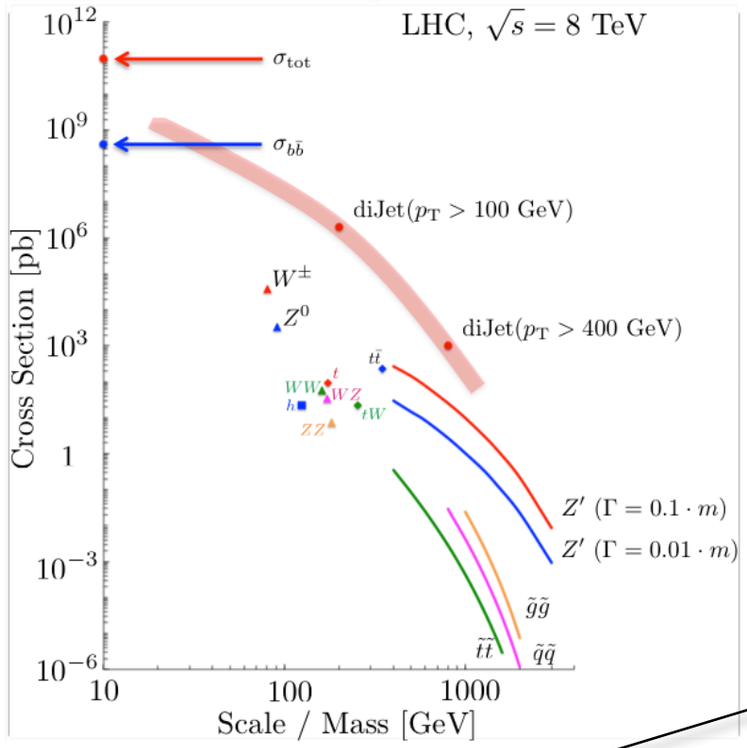

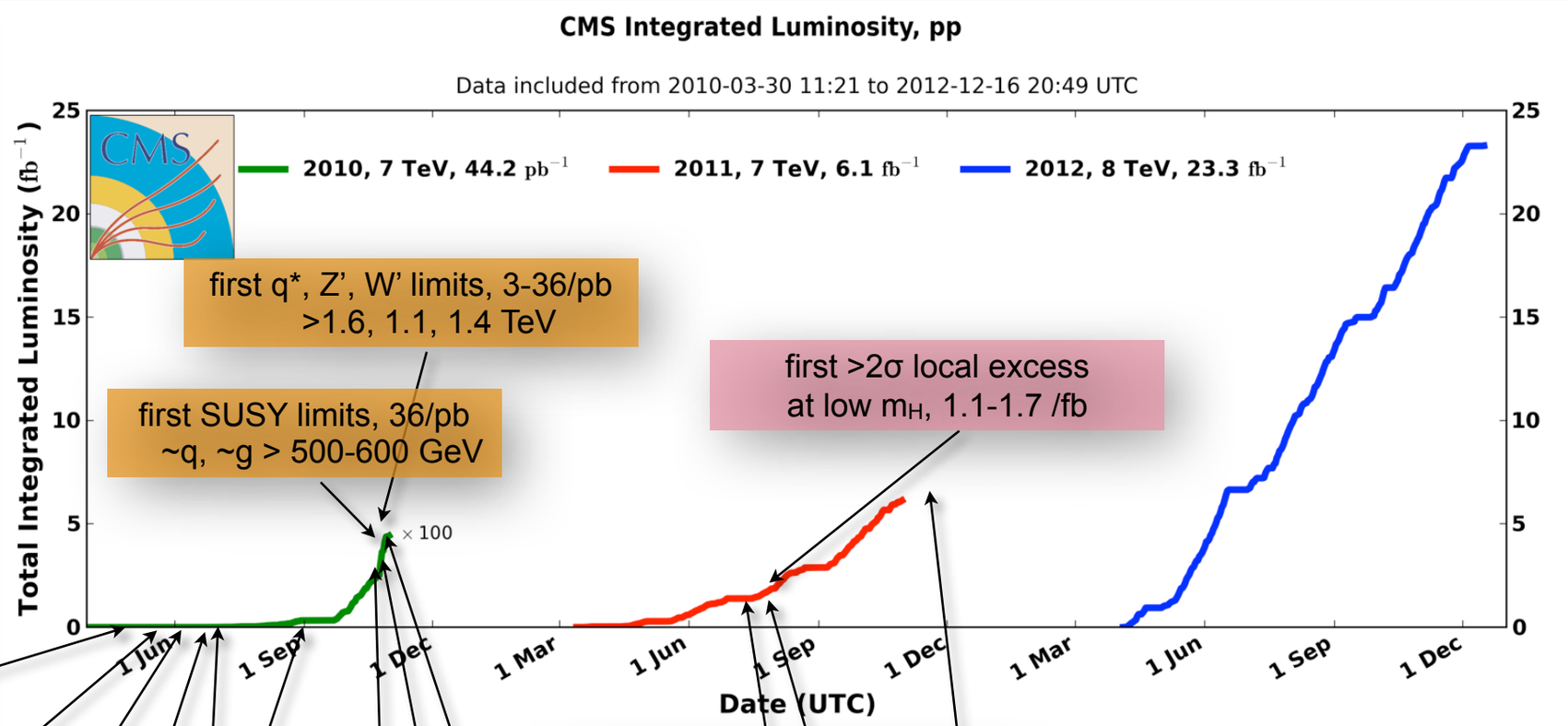

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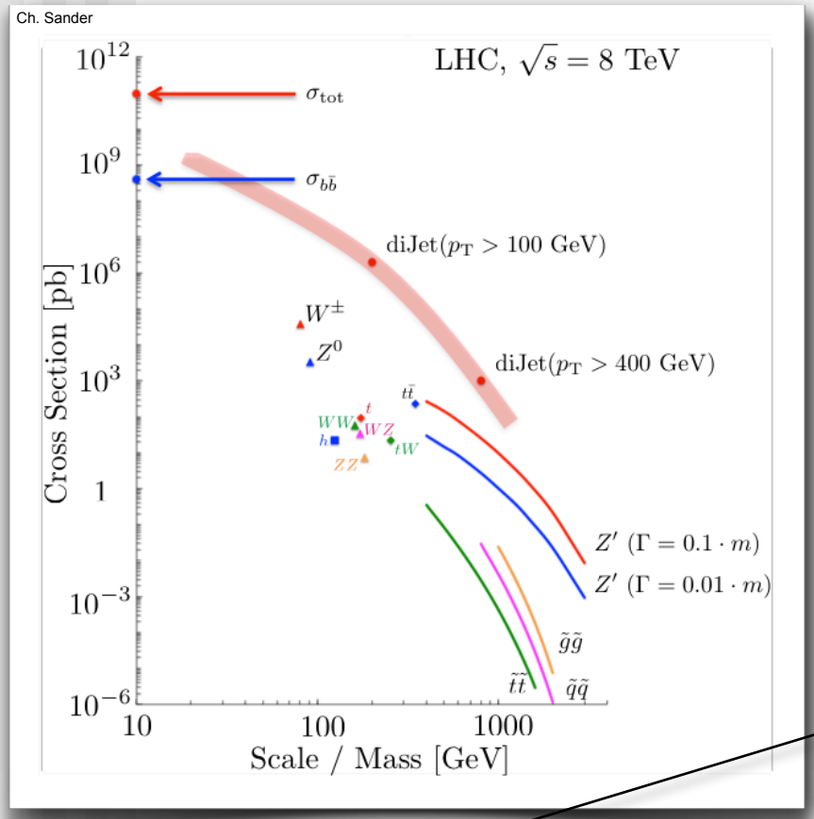

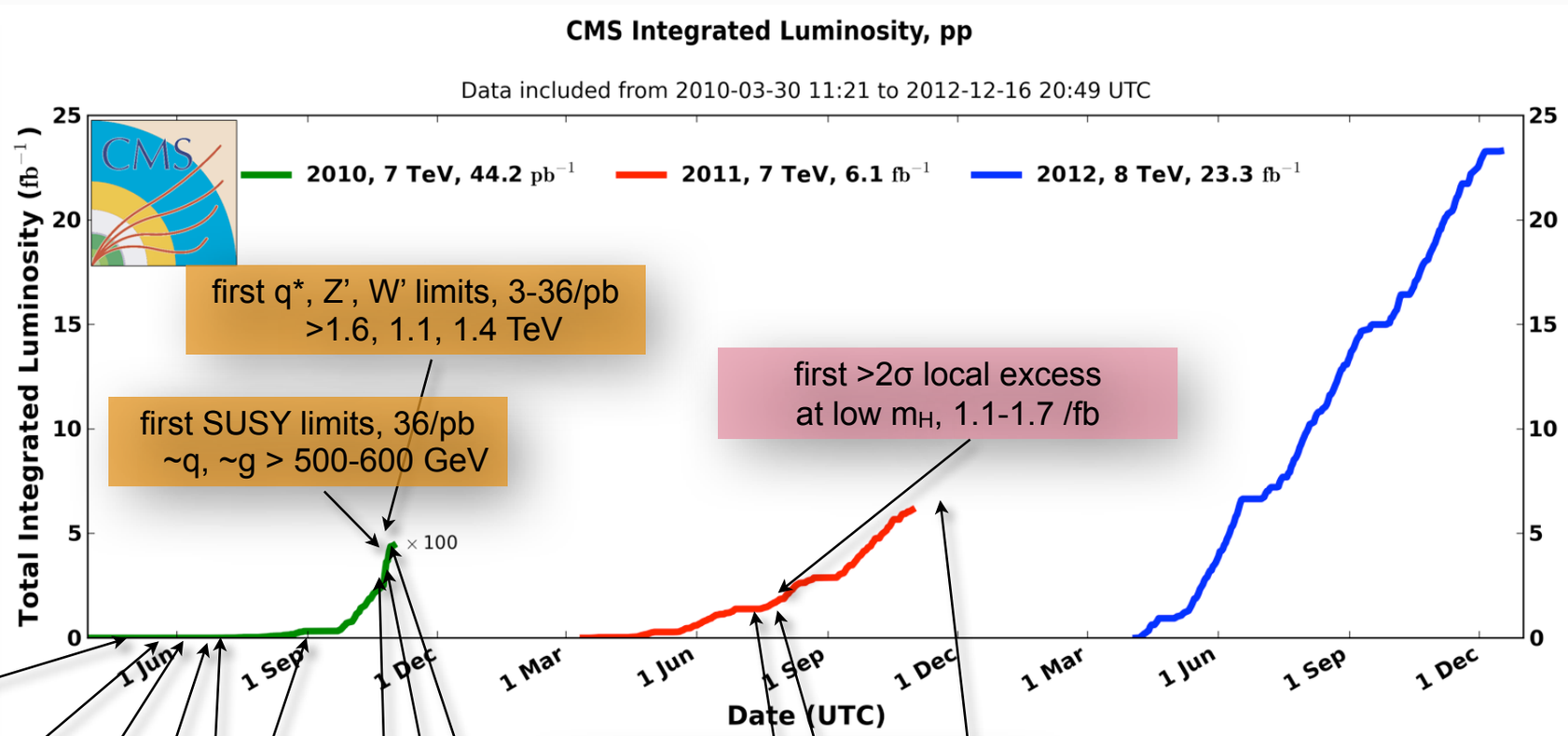

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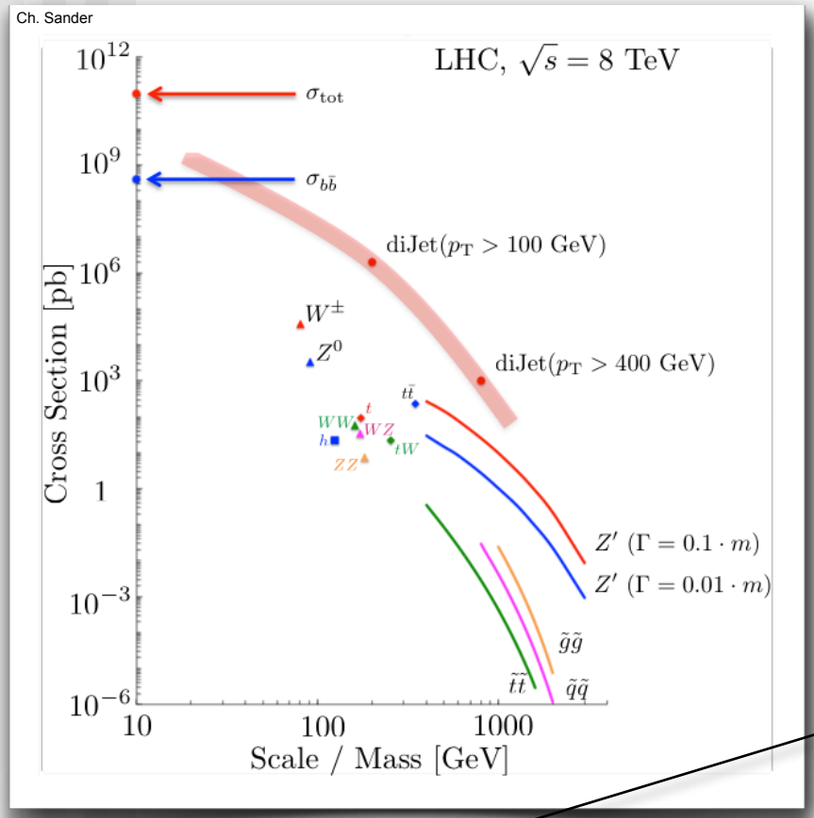

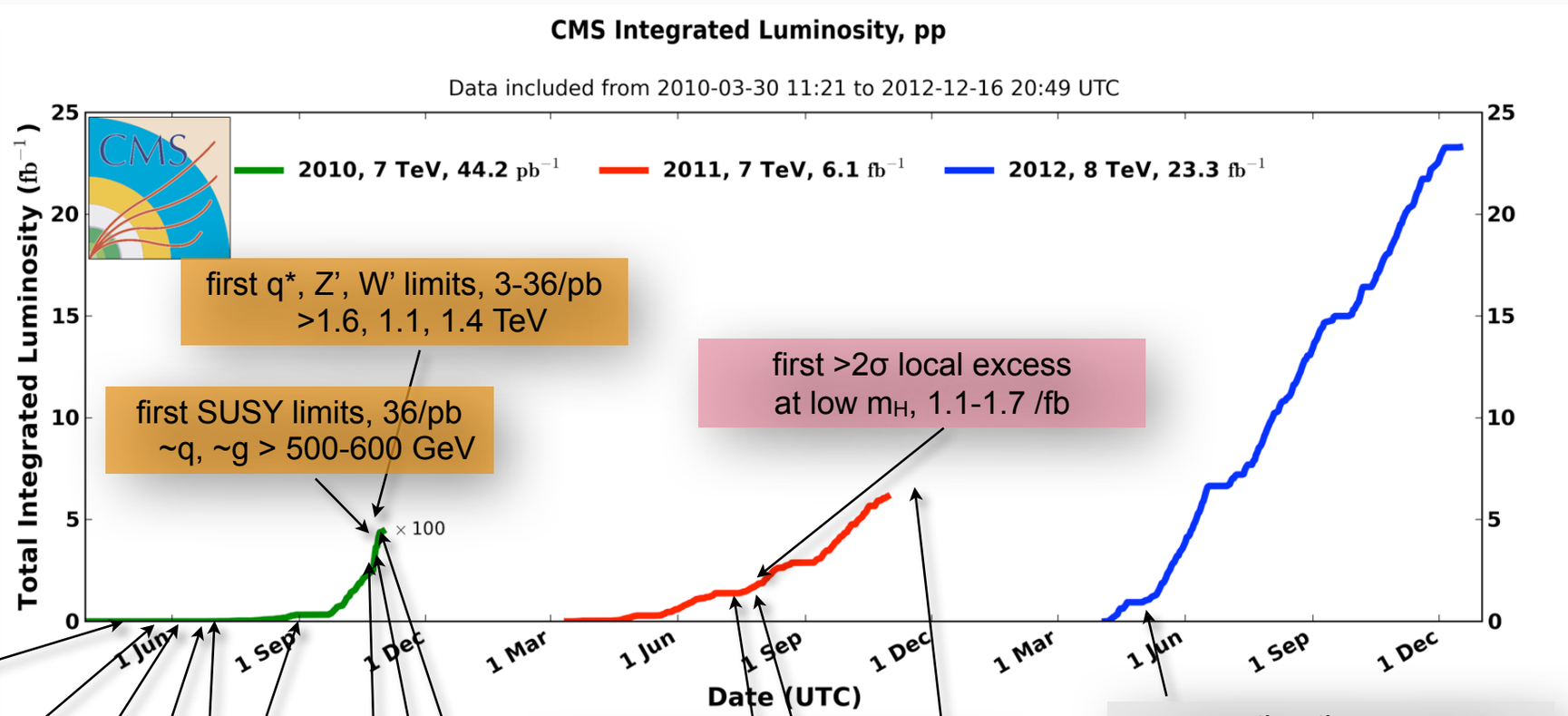

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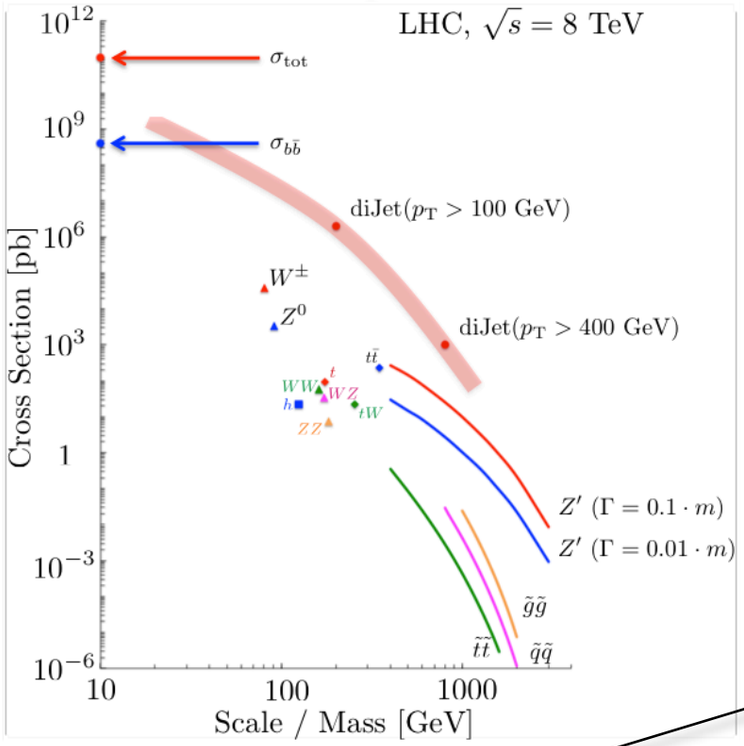

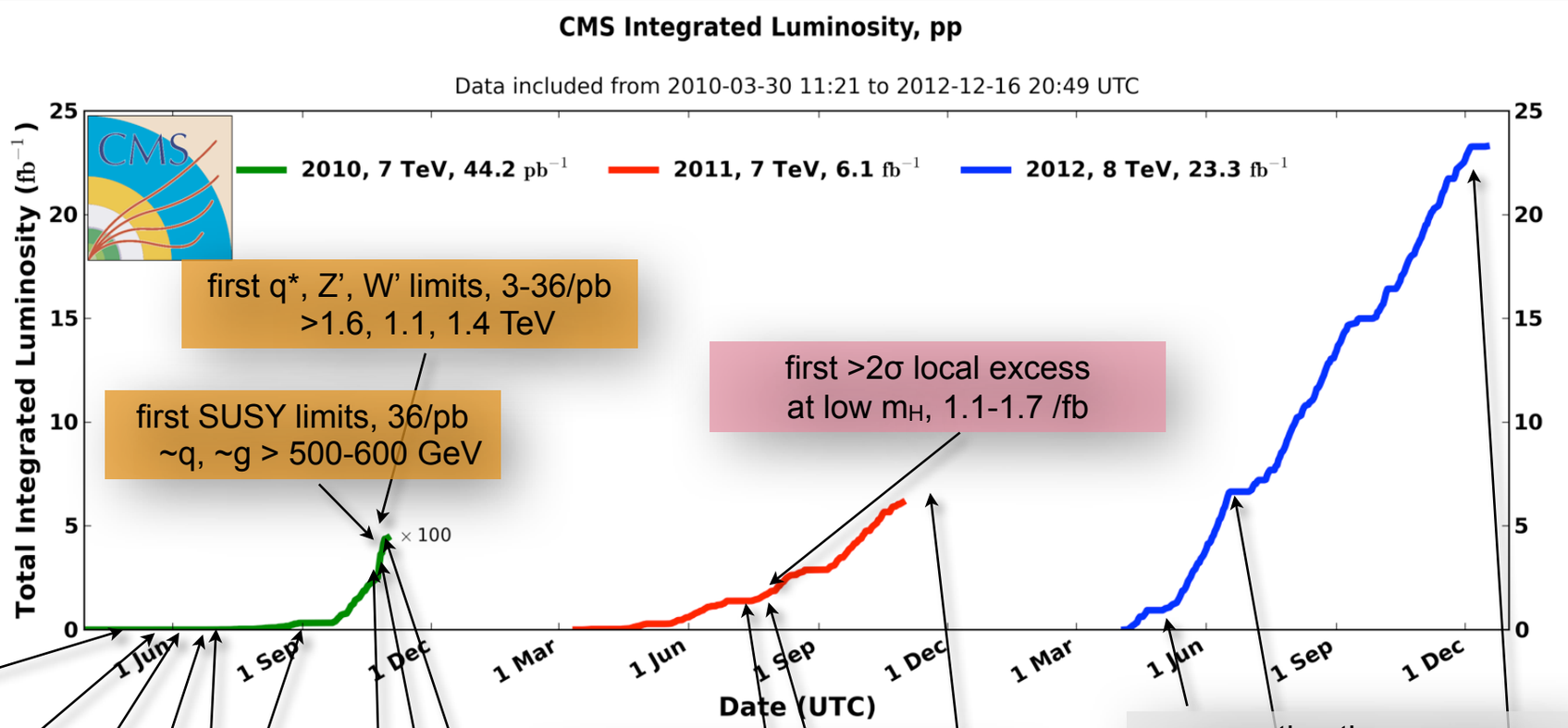

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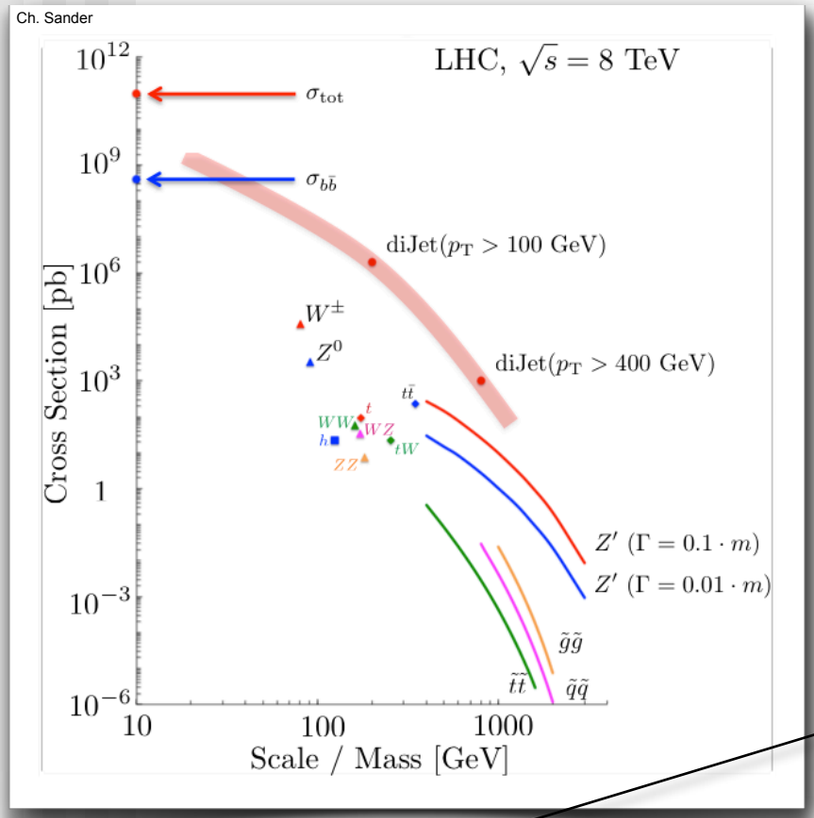

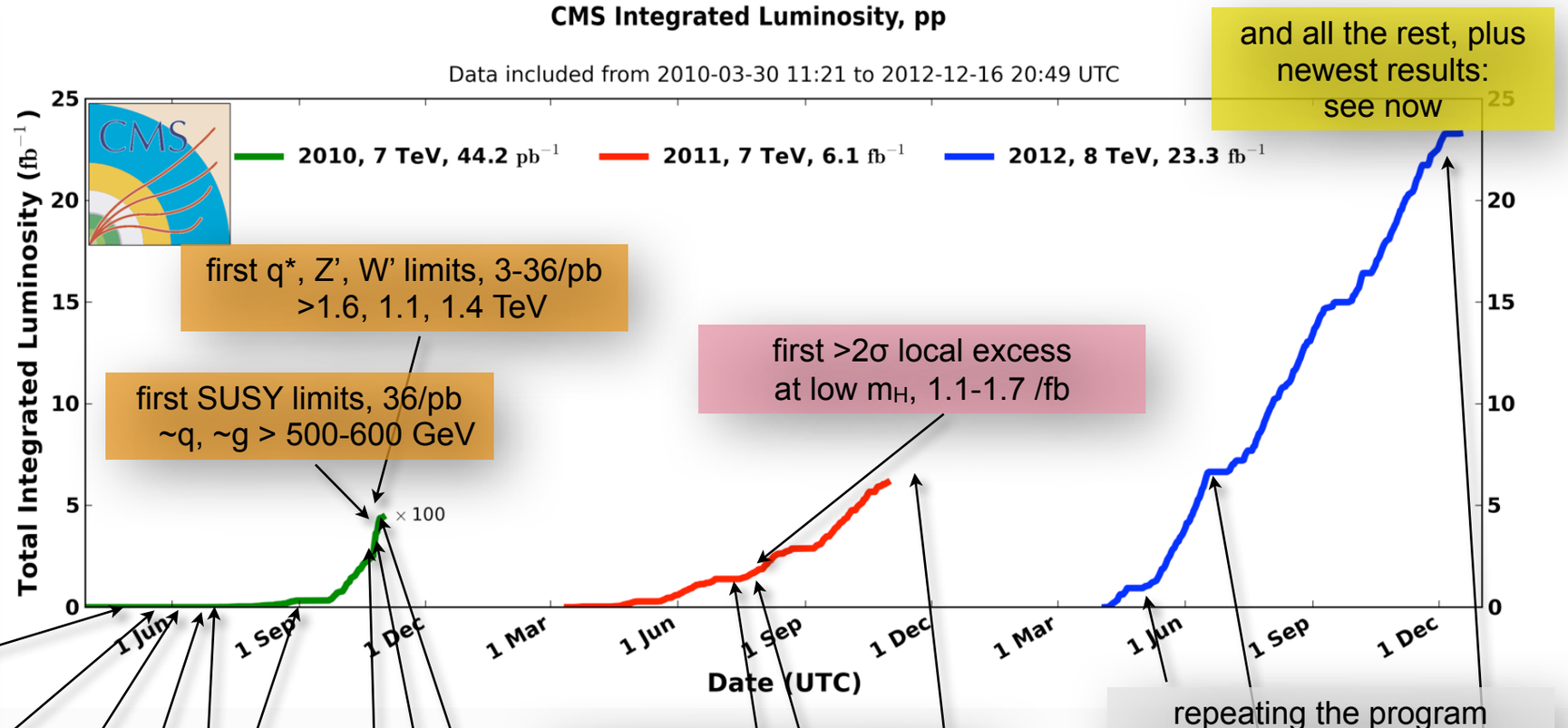

and all the rest, plus newest results: see now

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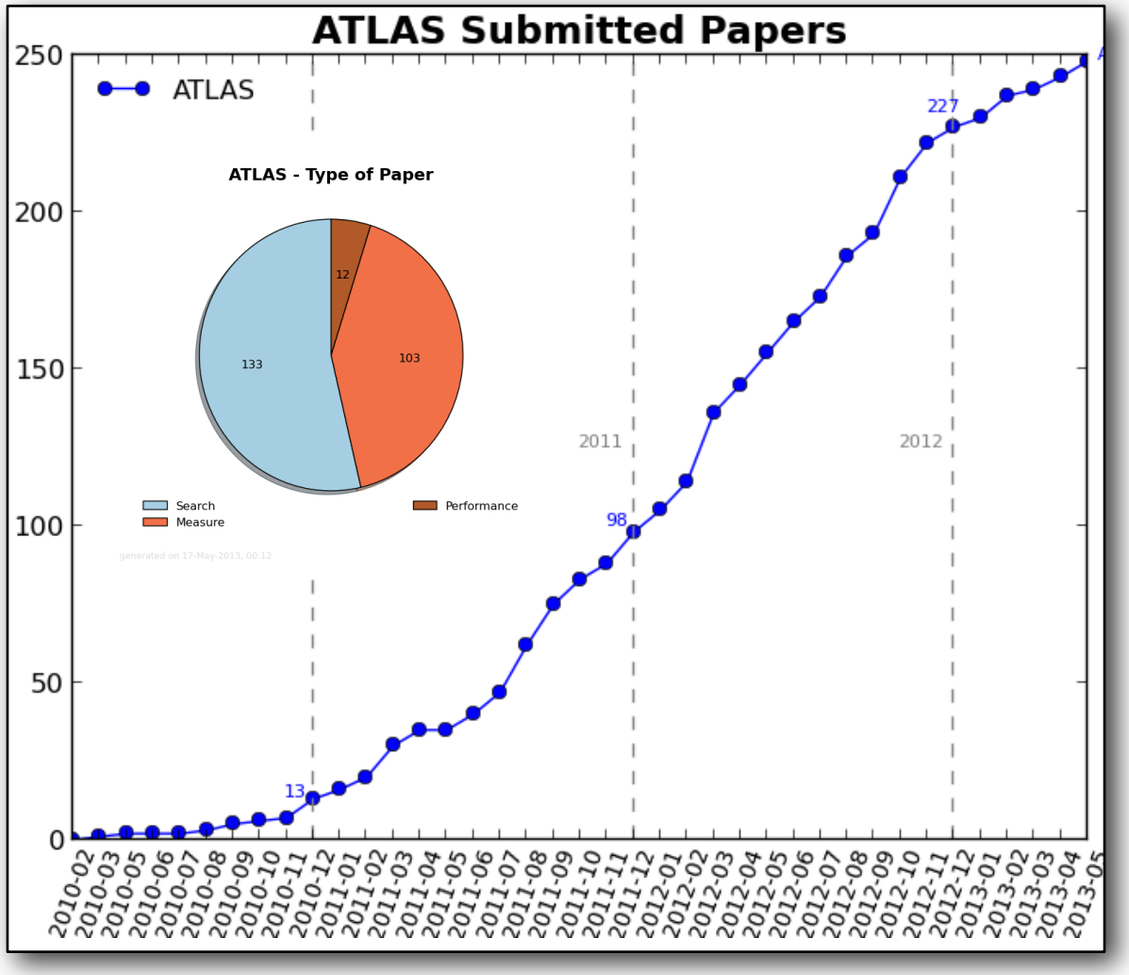
The consequence: a lot of reading material

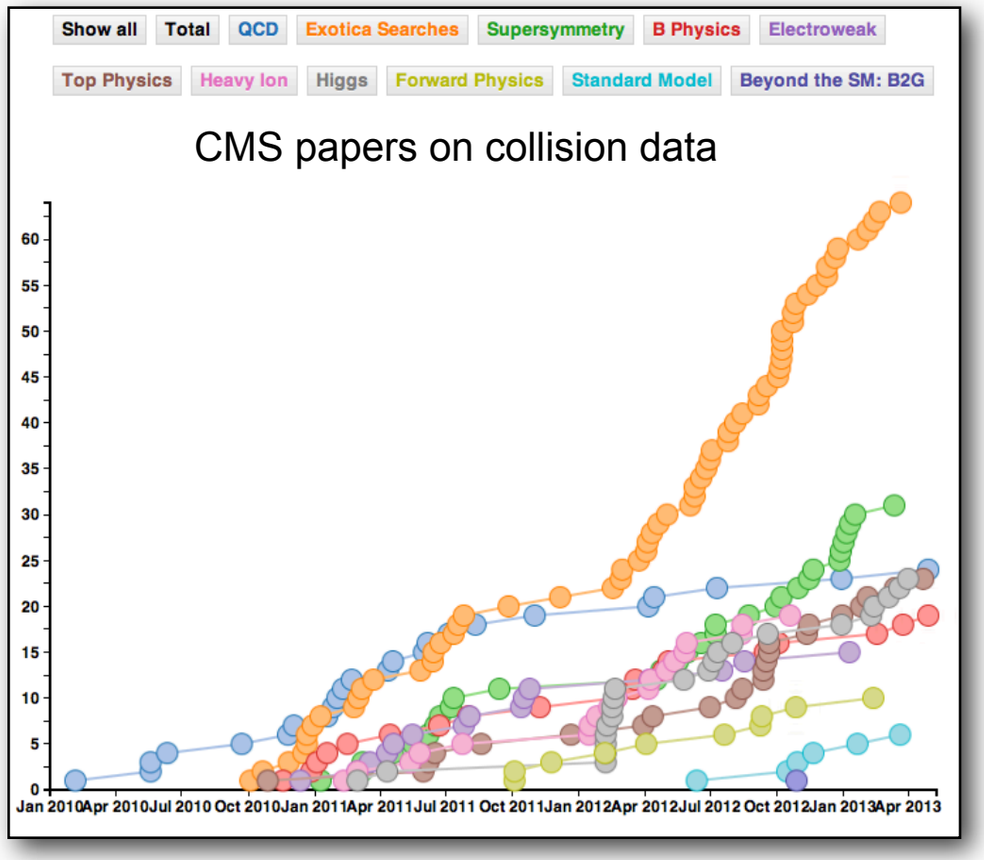


- ATLAS : **257**
- CMS : **270**
- ALICE : **63**
- LHCb : **118**
- LHCf : **8**
- Totem : **12**

- plus even bigger number of conf. contr.

- and more to come....

http://cds.cern.ch/collection/LHC%20Experiments?ln=en



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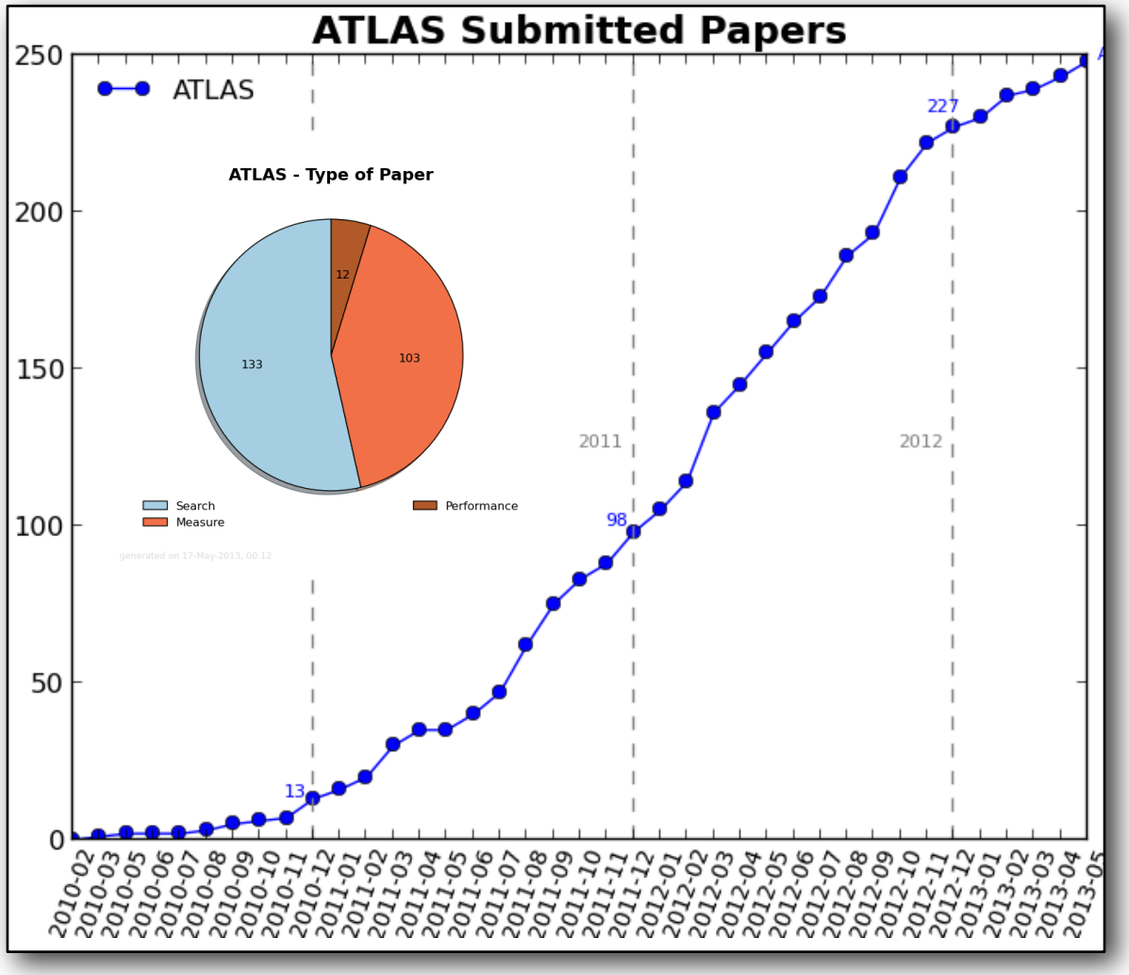

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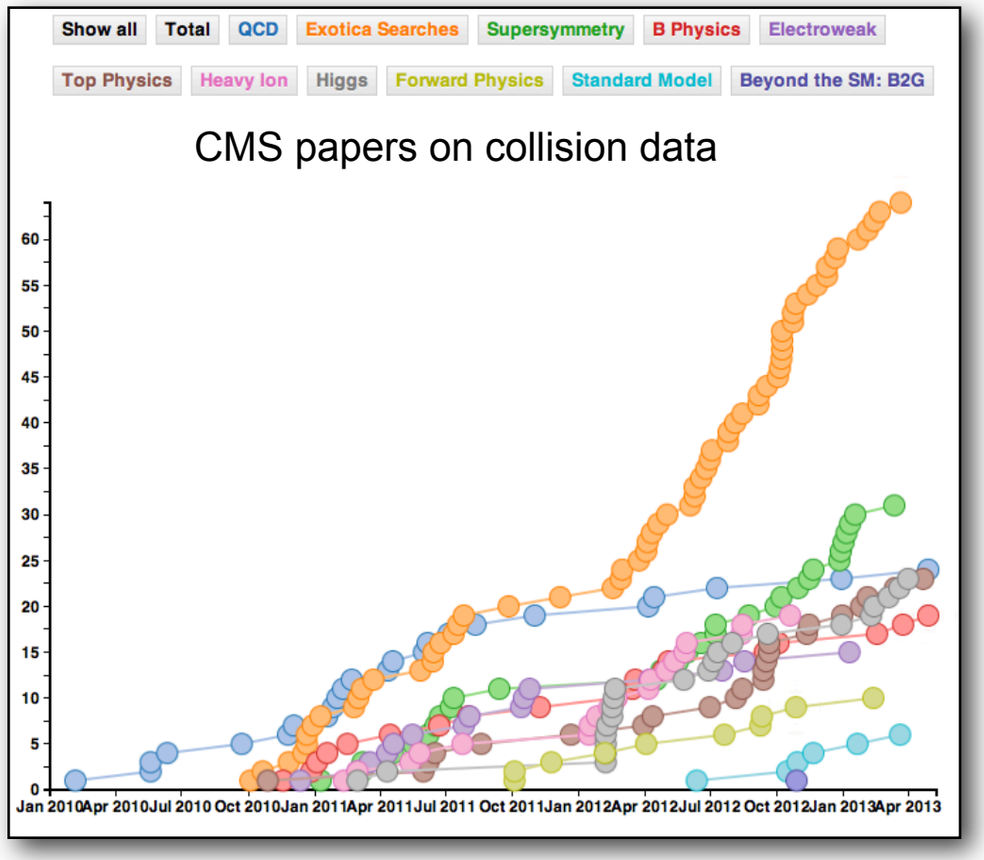

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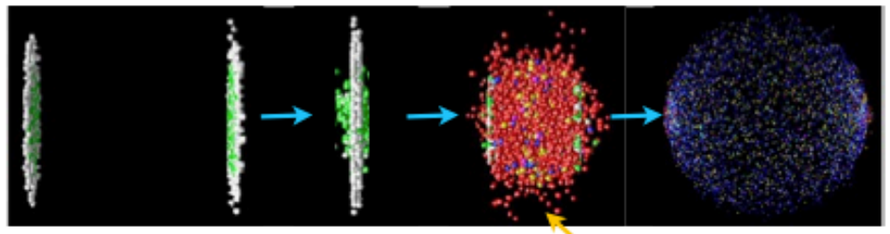
Heavy Ion Physics
a few highlights

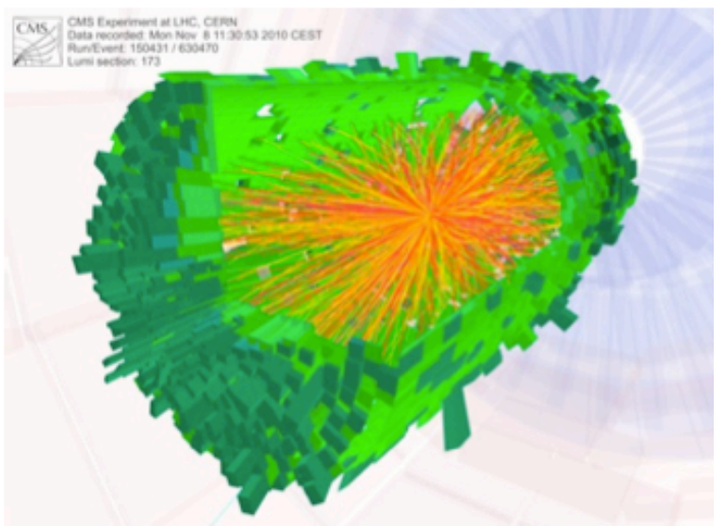


One of the main purposes of heavy-ion physics is to study the Quark-Gluon Plasma (QGP)

Quark-Gluon Plasma

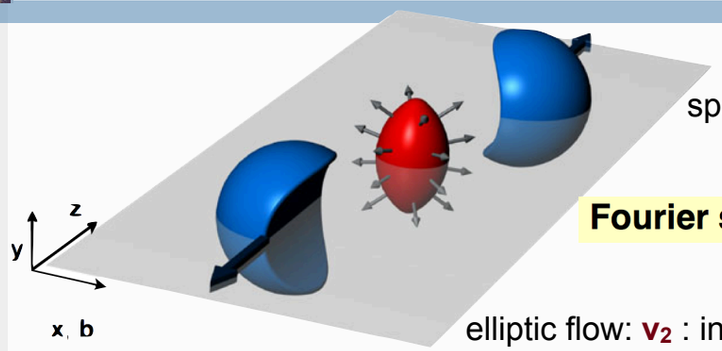
Properties

- Hydrodynamic behavior
- Jet quenching
- Quarkonia suppression
- Opaque to colored partons
- Transparent to EM and weakly interacting particles



Rylan Conway

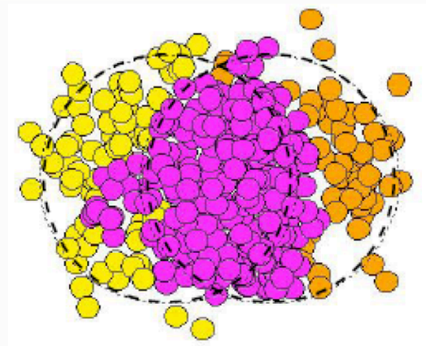
Collective phenomena

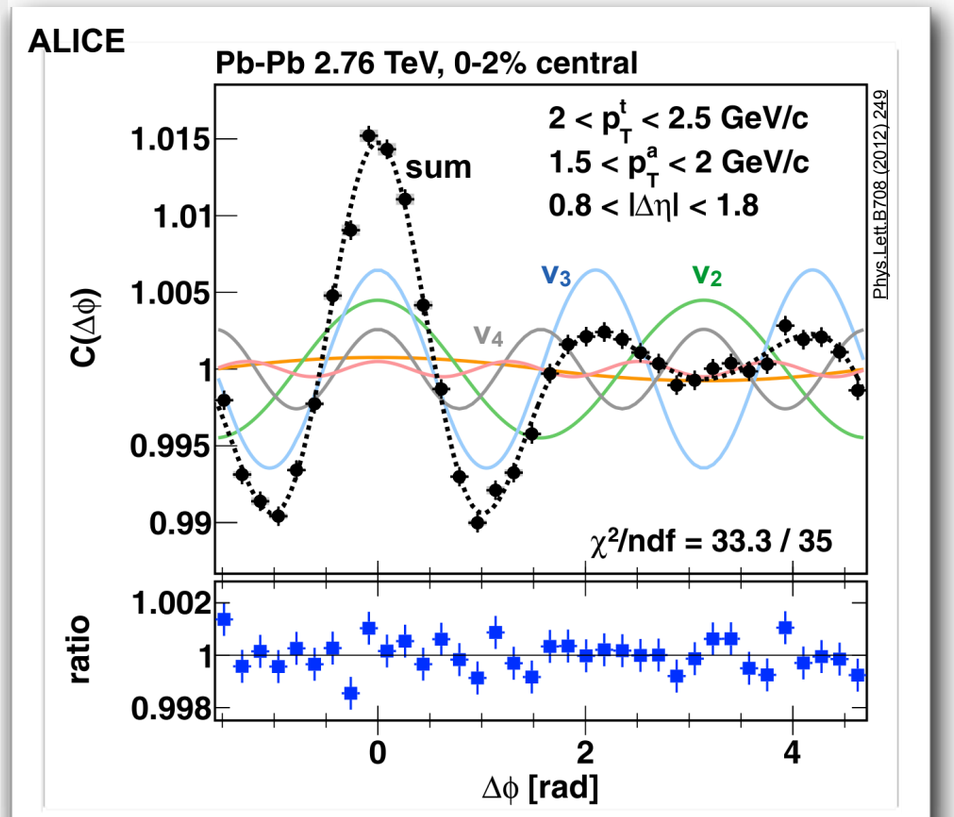


spatial deformation -> azimuthal pressure gradient -> anisotropic flow:

Fourier series: $dN/d\phi = 1 + 2\,v_1\cos(\phi) + 2\,v_2\cos(2\phi) + 2\,v_3\cos(3\phi) + \ldots$

elliptic flow: v_2 : initial conditions (geometry), fluid properties, eg. shear viscosity





- complex structures from hydrodynamic flow
- event-by-event fluctuations, higher harmonics
- **all characteristics as expected from hydrodyn. flow**, eg. strength, mass/centrality/momentum dep.
- examples: measurements of v_2 for phi and D-mesons (ALICE), eg. charm quarks taking part in the collective expansion, neutral pions (CMS), and study of event by event fluctuations (ATLAS)

Collective phenomena

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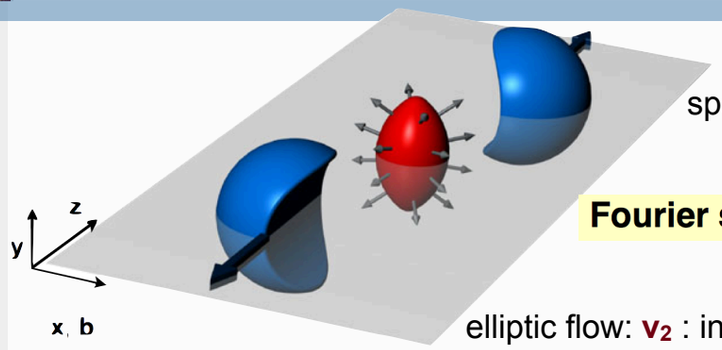

spatial deformation -> azimuthal pressure gradient -> anisotropic flow:

Fourier series: $dN/d\phi = 1 + 2\,v_1\cos(\phi) + 2\,v_2\cos(2\phi) + 2\,v_3\cos(3\phi) + \ldots$

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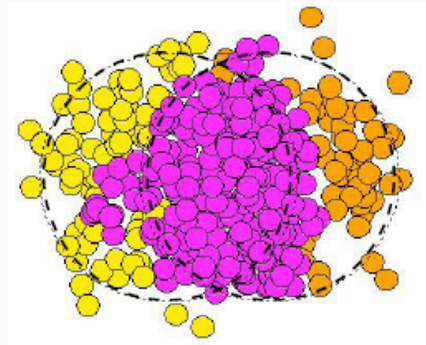

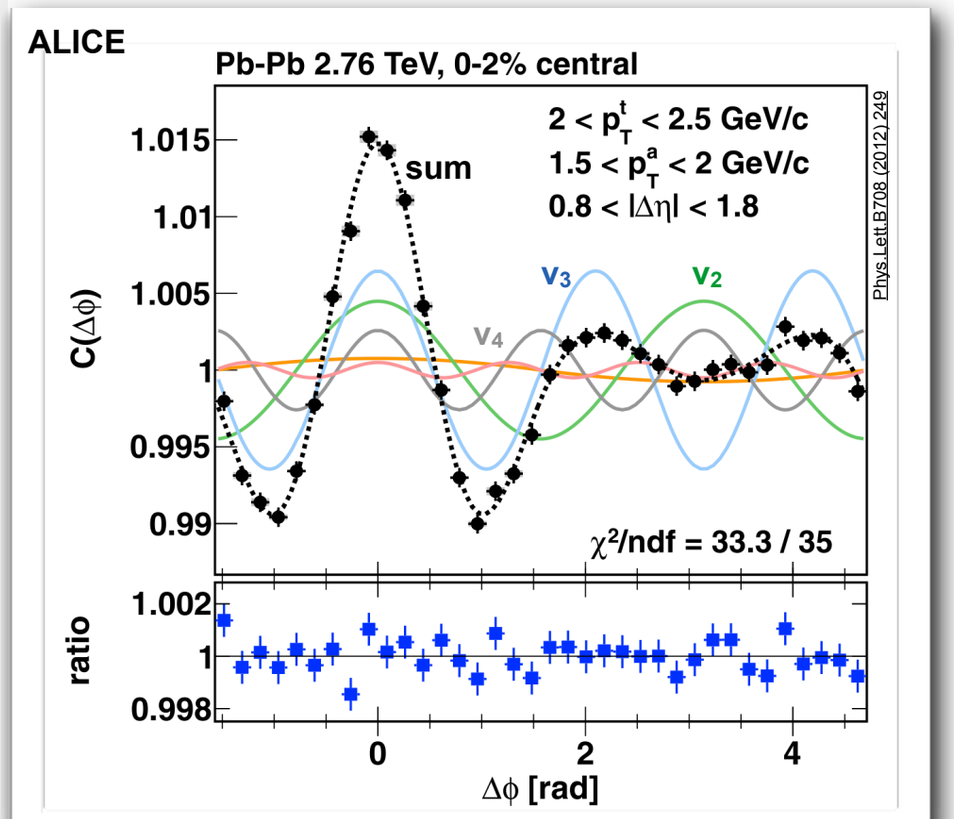

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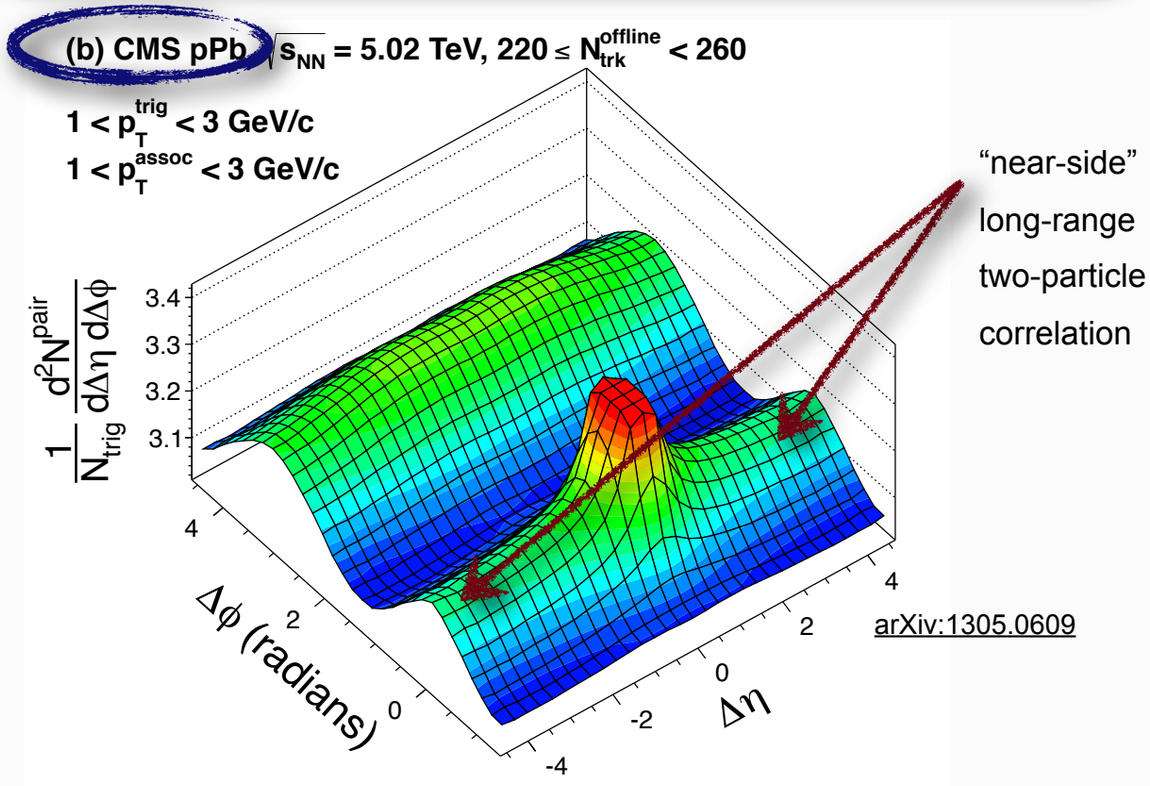
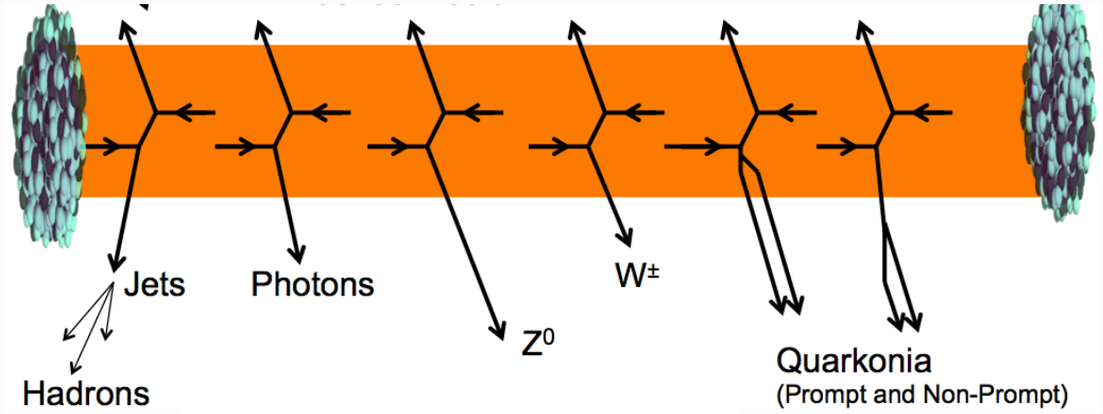
"**The ridge**" : also in pp, most "surprising" discovery so far ?

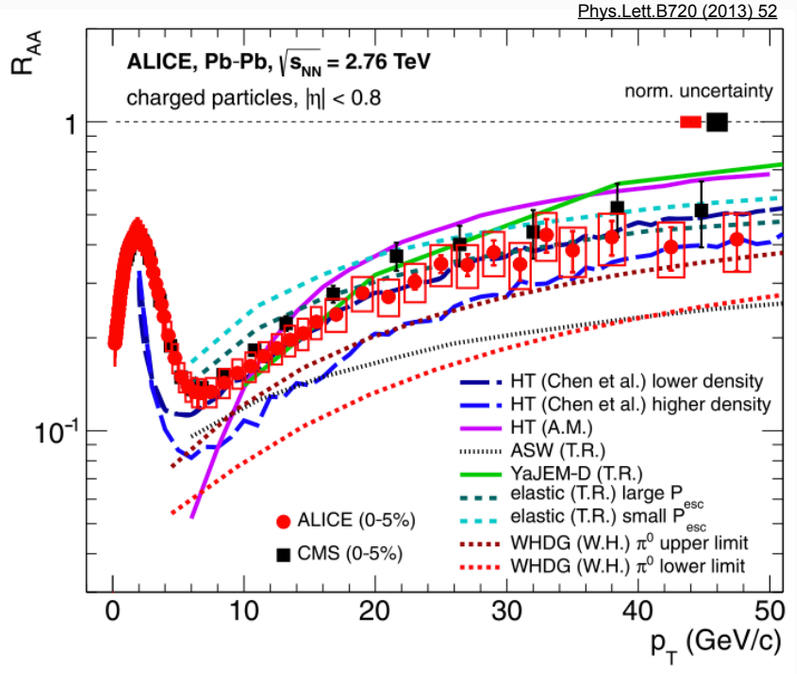


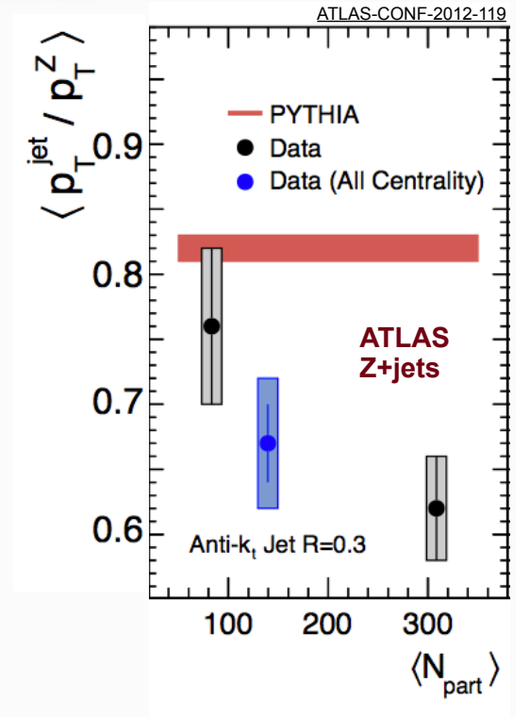
- observed in **high-multiplicity** pp, pPb and PbPb, with increasing strength
- in PbPb and pPb seen by all experiments
- this (and other results) show that hydrodynamic description may also be applicable to pPb or even to pp systems

“Hard” Probes

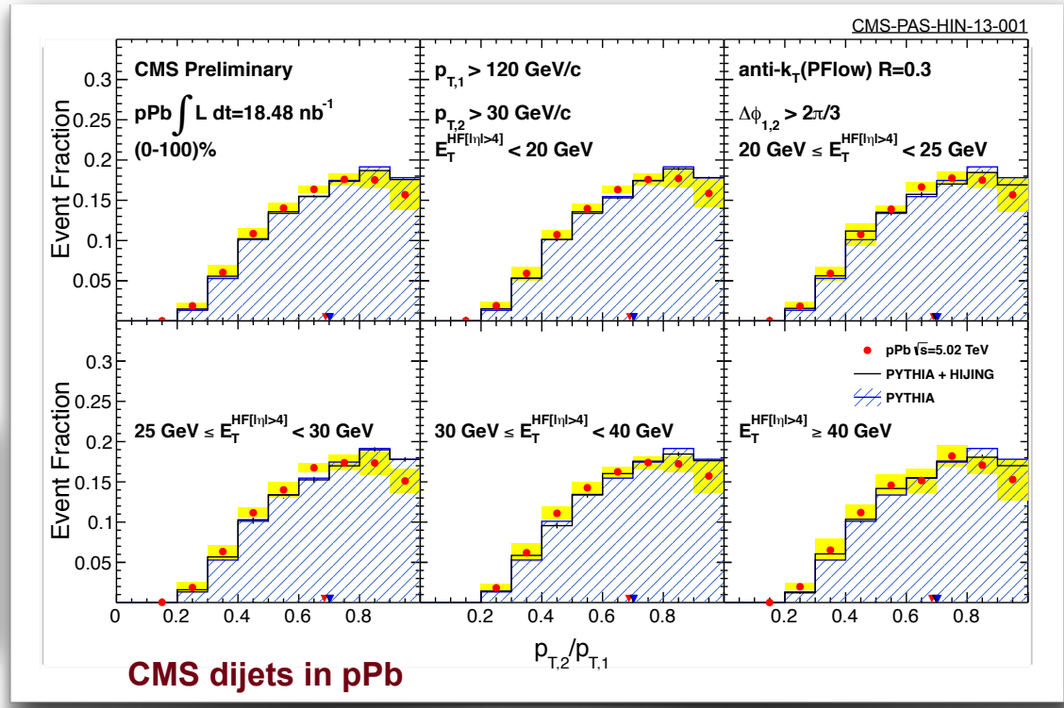


High p_T Hadrons, b, photons, Z, W



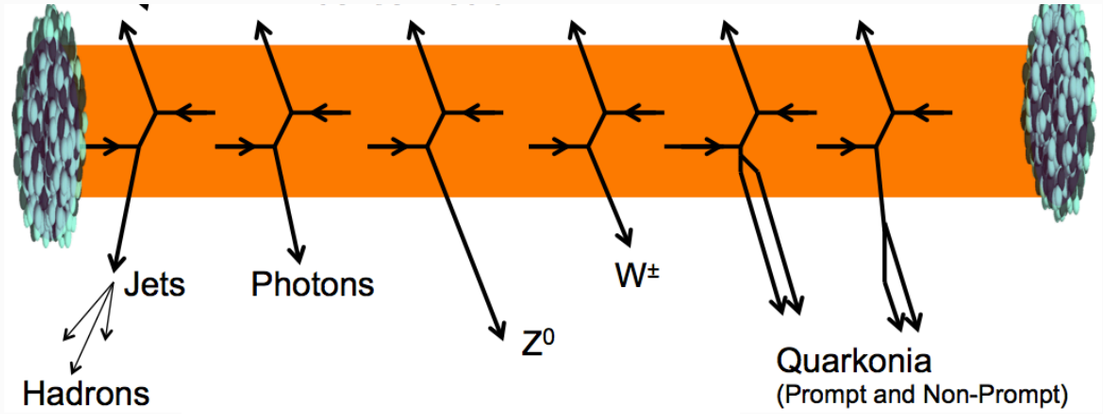


- Strong suppression for hadrons, none for photons, Z, W
- clear signature of jet quenching in central PbPb collisions
- extensive studies of jet energy loss mechanisms
- new jet data in pPb: no significant dijet momentum imbalance →



CMS dijets in pPb

“Hard” Probes



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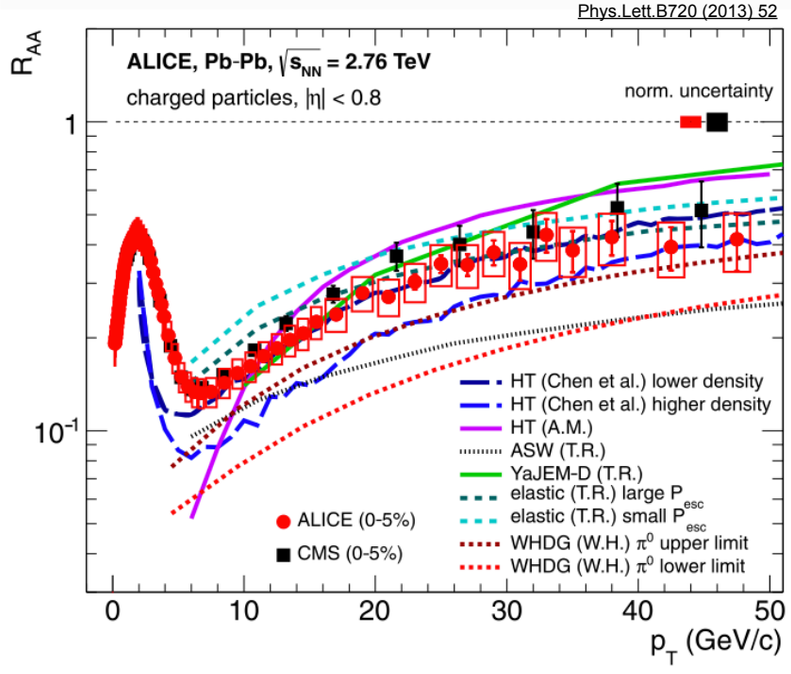

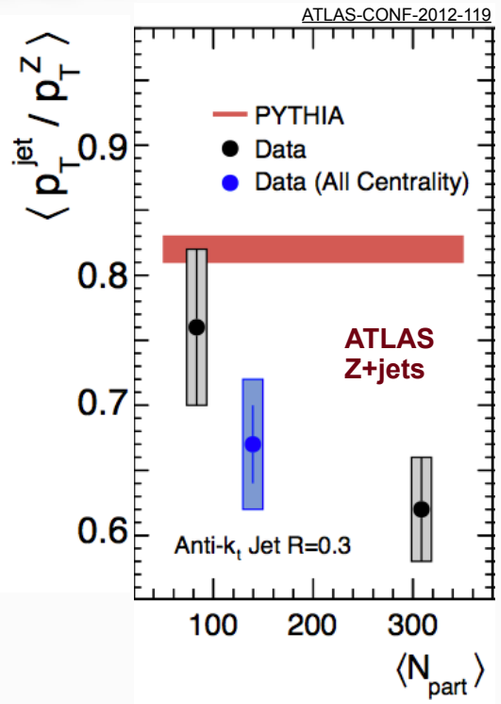

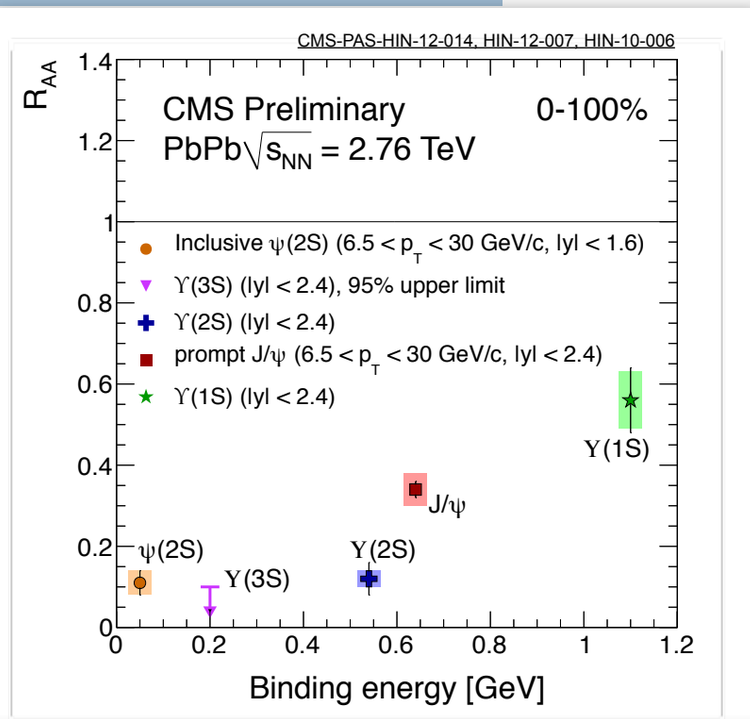

Sequential quarkonium suppression as expected from deconfinement!

But: feed-down from bb states and initial state effects (via pPb) to be sorted out

- Strong suppression for hadrons, none for photons, Z, W
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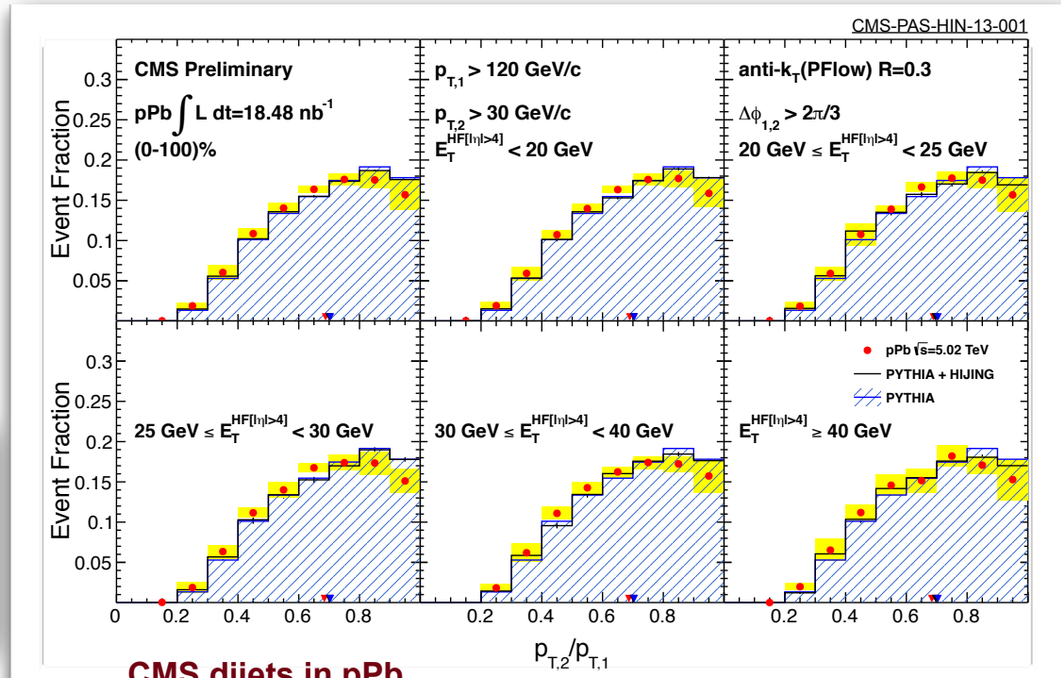

CMS dijets in pPb

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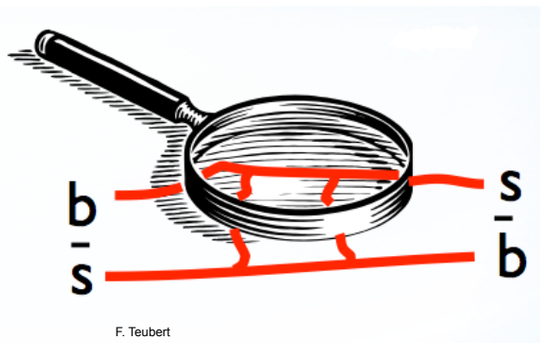
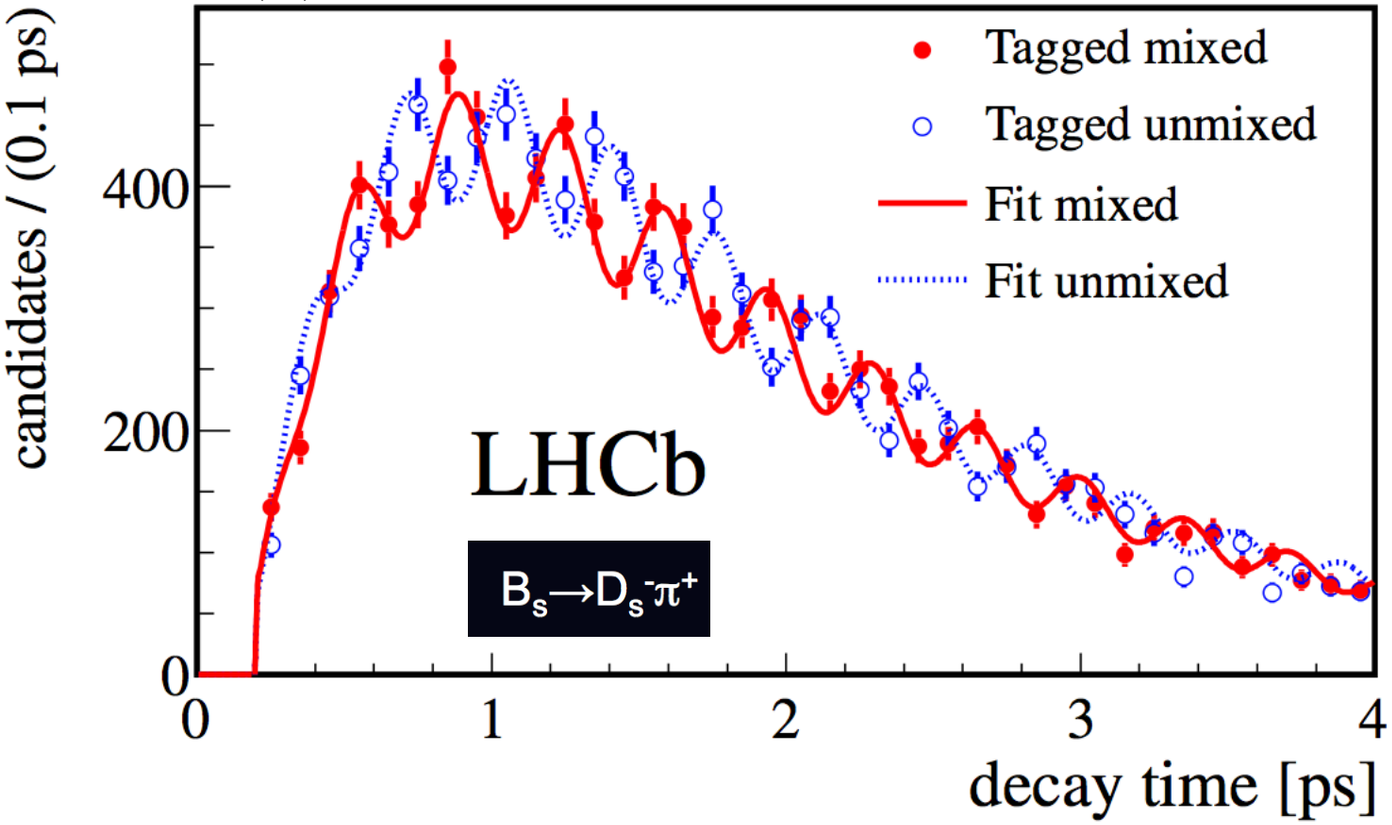
Heavy Flavour Physics
recent highlights

NJP 15 (2013) 053021





b-Quark and Quarkonia production

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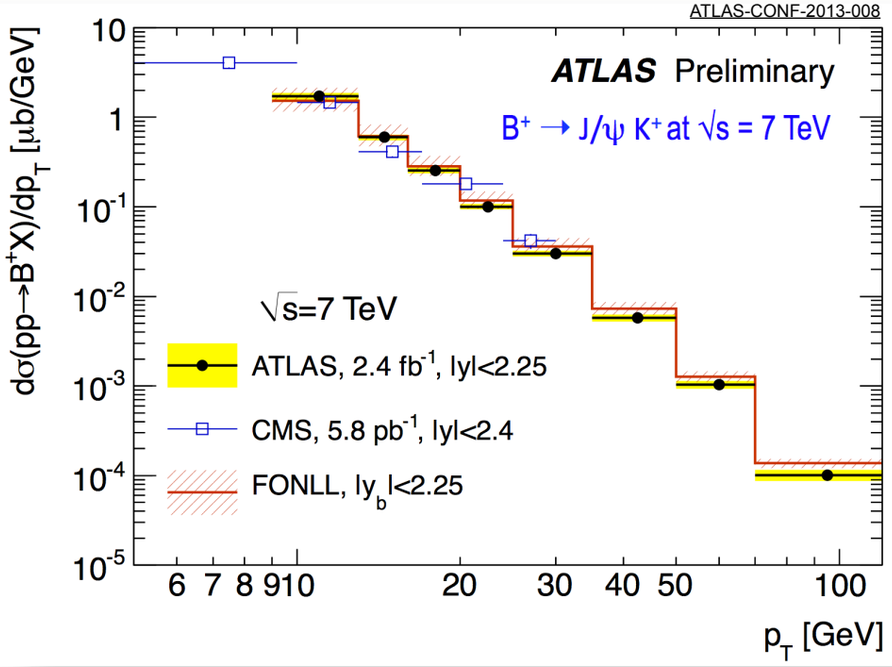
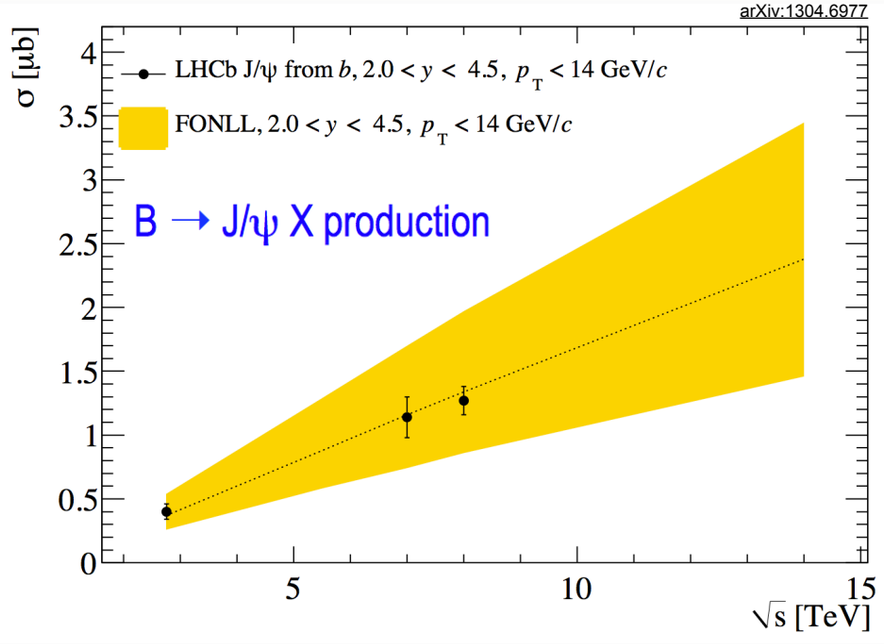
ATLAS-CONF-2013-008



arXiv:1304.6977



Overall, for open b, B hadron, b-jet and Quarkonia production:

- pQCD (and/or MC models) in reasonable agreement, but some discrepancies seen (in p_T and/or eta); ~10% precision
- bb angular correlations studied, low-angle region not well modeled
- Λ_b : steeper spectrum than B mesons, new lifetime measurements
- extensive studies of Quarkonia production and comparison with NRQCD predictions (see, eg. Wöhri, LHCP2013)

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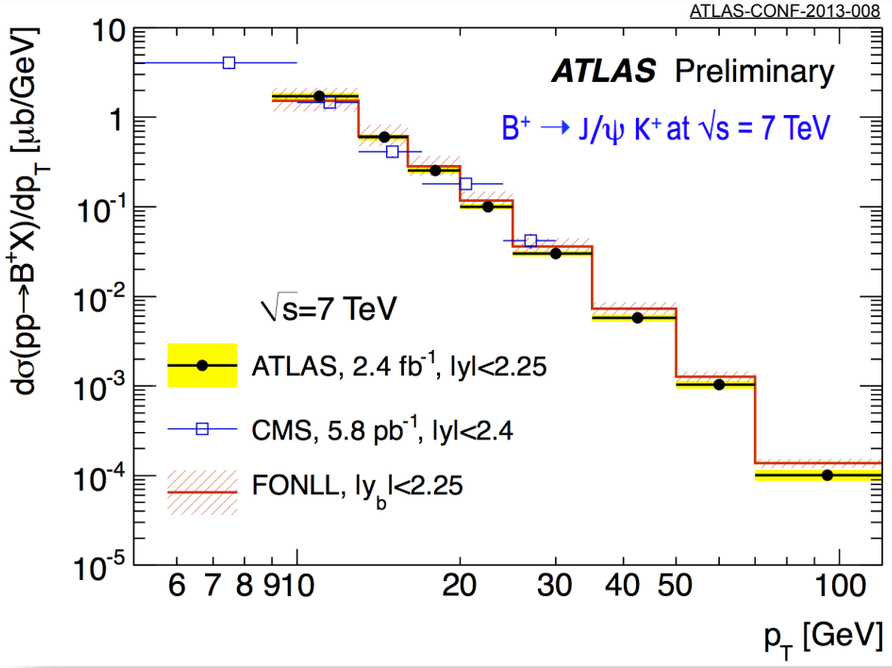

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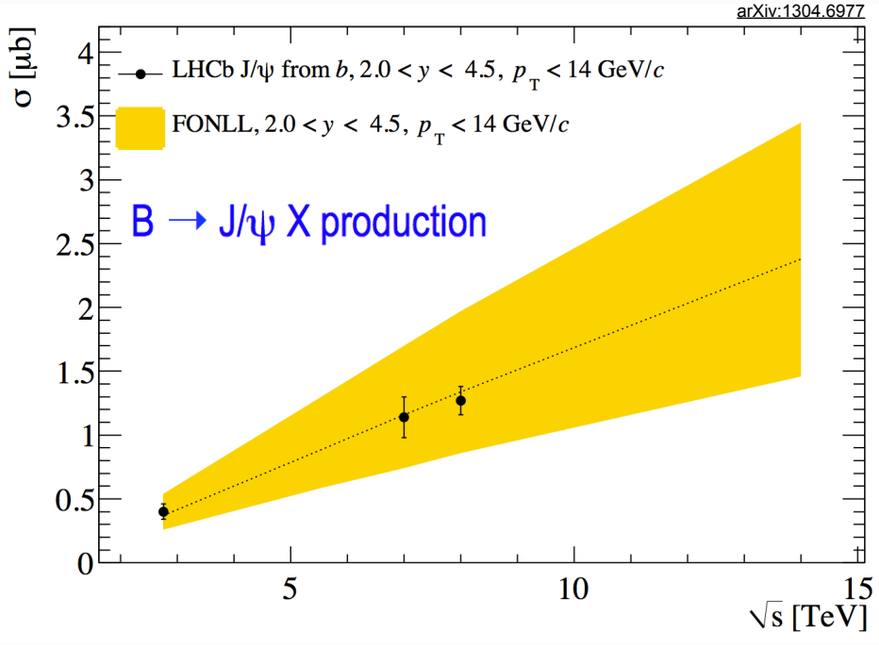
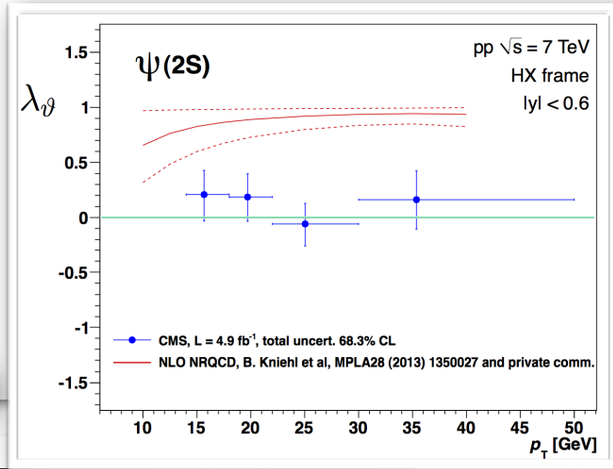


CMS-PAS-BPH-13-003



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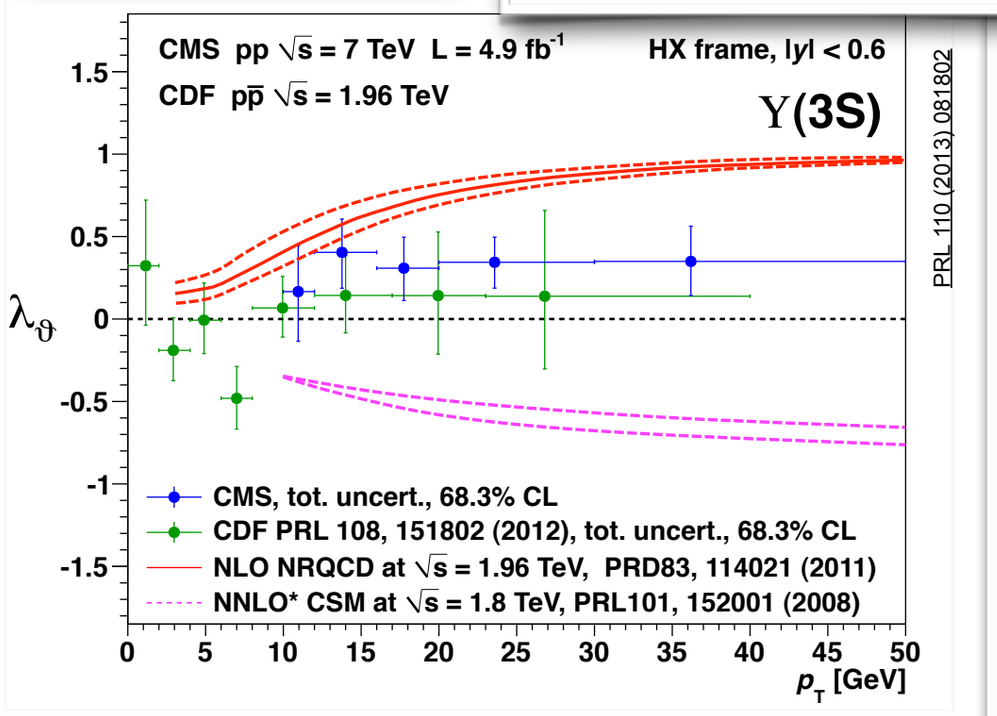
Y and Psi(2S) polarization



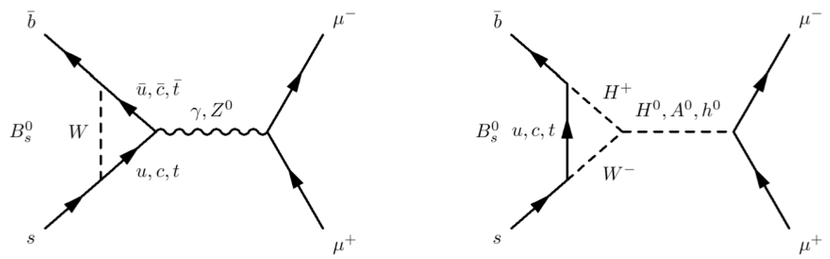
- First LHC measurement of Υ(1S), Υ(2S), Υ(3S) and Psi (2S) polarization. **No evidence for significant polarization** and thus significant discrepancy with TH pred.!

Rare Decays

ETH Institute for Particle Physics

cf. talk by Ch. Elsasser, LHCP2013

The Decay $B^0_{(s)} \to \mu^+\mu^-$

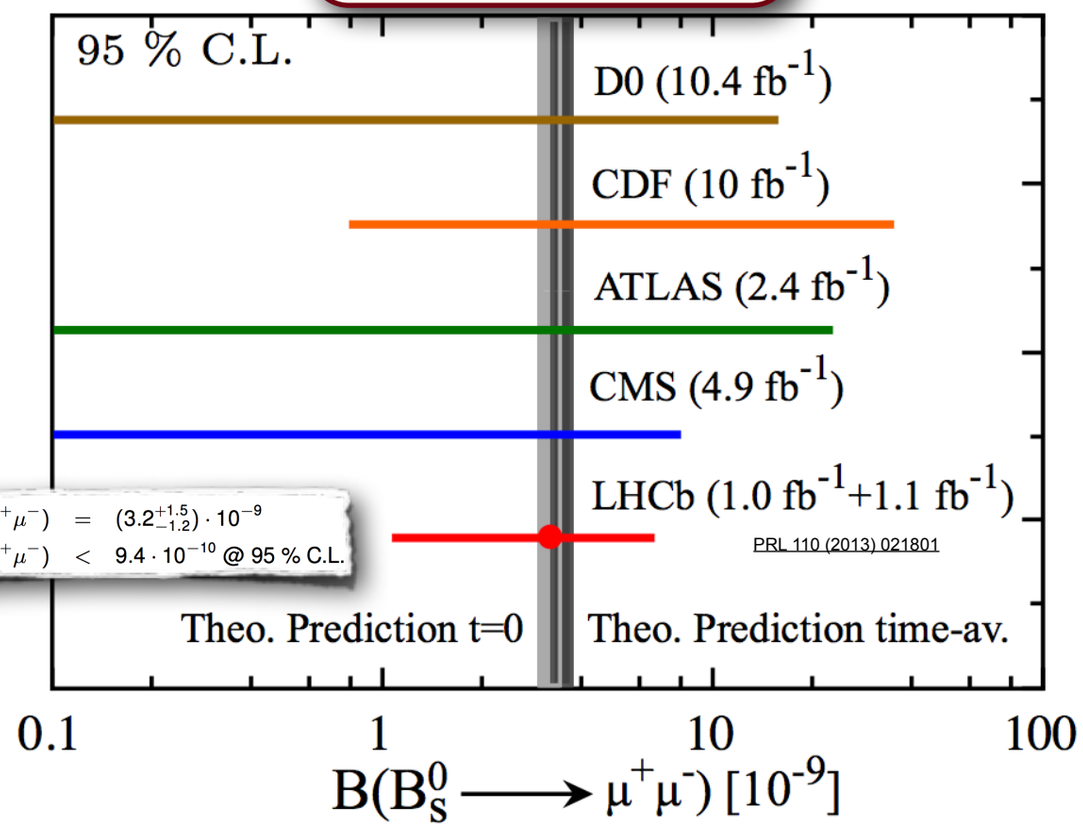


Suppression by FCNC and helicity ⇒

$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.25 \pm 0.17) \cdot 10^{-9}$

$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.07 \pm 0.10) \cdot 10^{-10}$ (Buras et al. [arXiv:1303.3820])

Current status:



LHCb: **first evidence, 3.5 σ deviation from bkg-only hypothesis**

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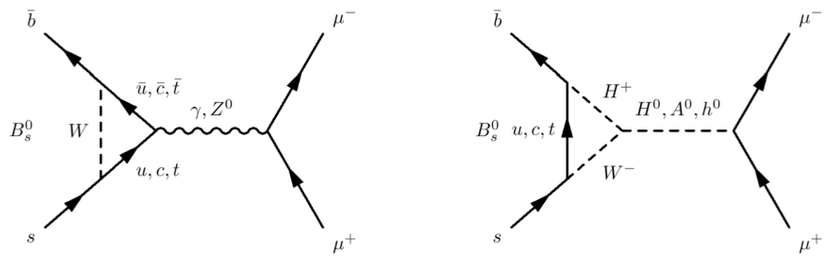

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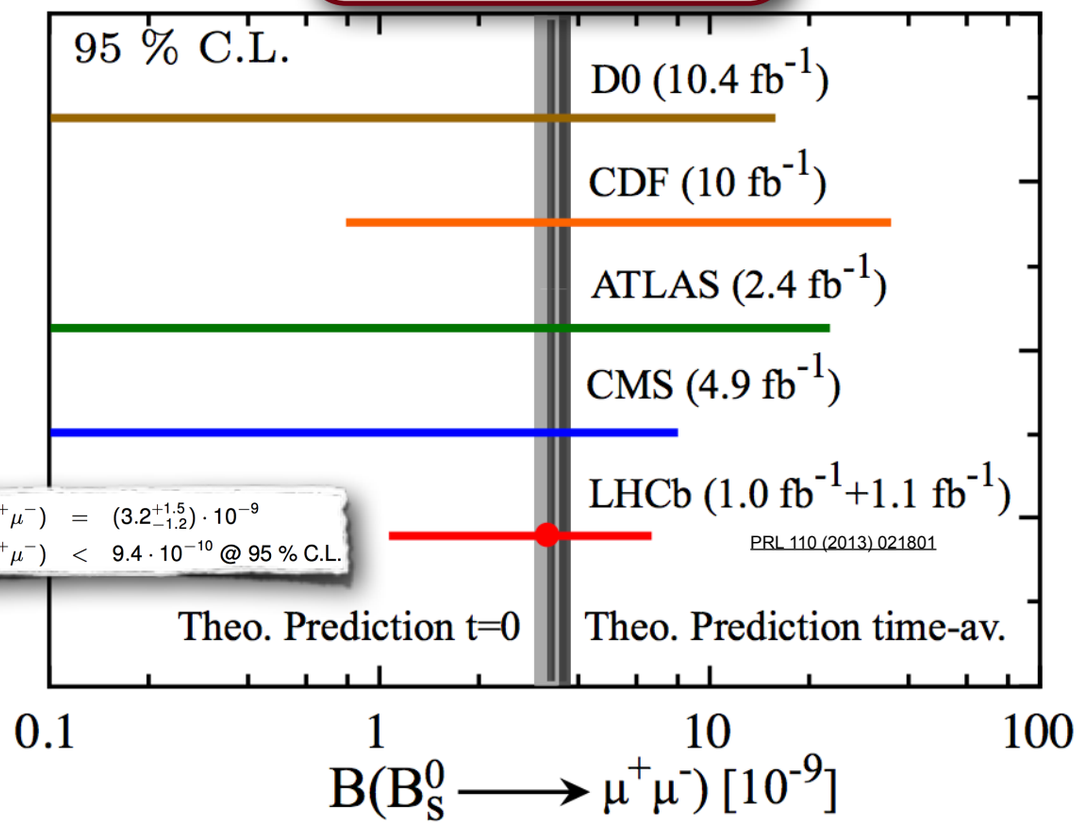
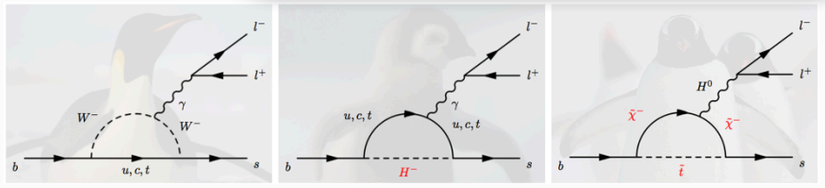
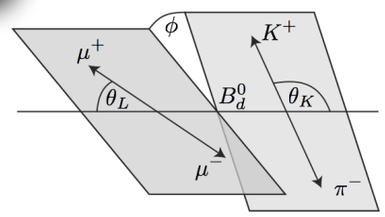
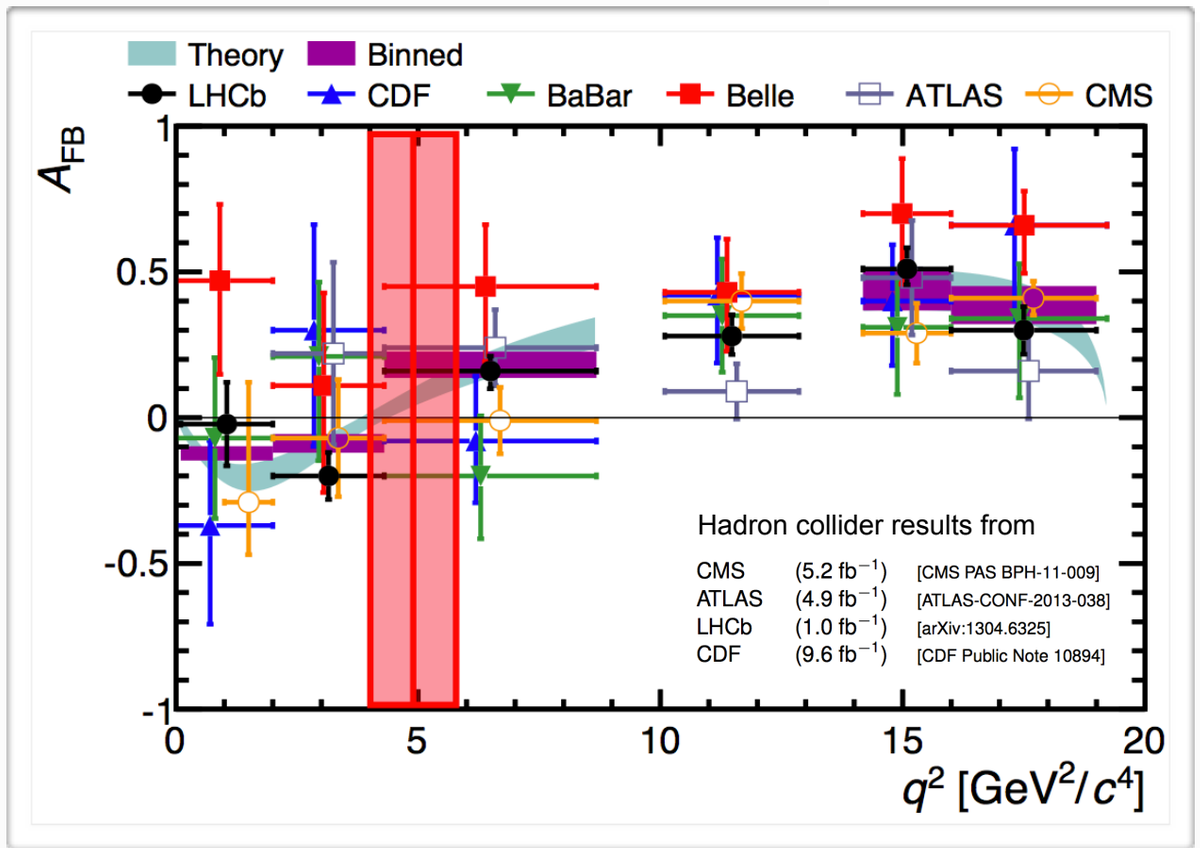


- LHCb: **first evidence, 3.5 σ deviation from bkg-only hypothesis**

A_{FB} in $B \to K^* \mu \mu$







Especially clean theoretical prediction of q_0^2 s.t. $A_{FB}(q_0^2) = 0$ (zero-crossing point)

SM prediction: $3.9 - 4.3$ GeV^2/c^4

$q_0^2 = (4.9 \pm 0.9)$ GeV^2/c^4 LHCb arXiv:1304.6325

- also, very recent LHCb angular analysis for $B_s \to \Phi \mu \mu$

- **rare decays: no deviations** seen from the SM predictions
  -> strong impact for limits on New Physics
- see also talk by M. Elsing, right afterwards

NP in CP violations ?

cf. talks by J.v.Tilburg, LHCP2013,
Y. Xie, recent CERN seminar,
R. Currie, Pheno. Symp., May 2013

ETH Institute for Particle Physics

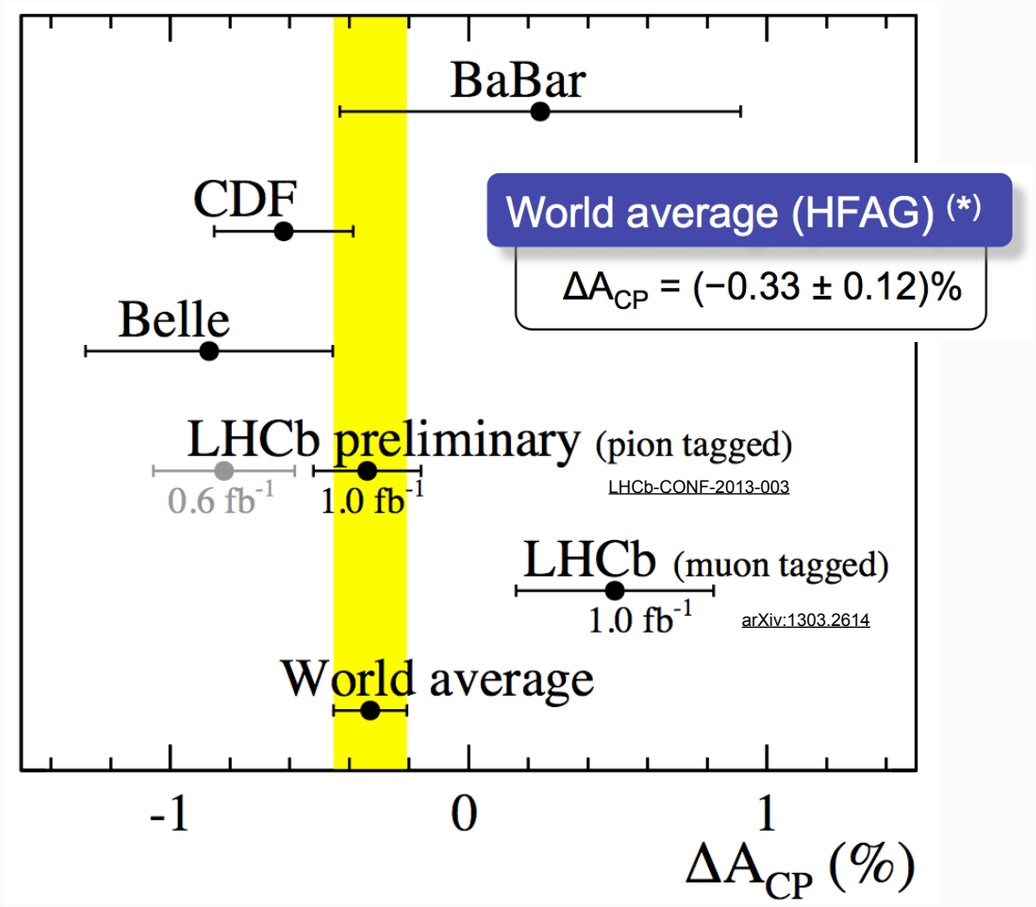
CP violation in the charm system?

- Charm system special: FCNC processes with up-type quarks
- Complementary to those with down quarks (*B* or *K* mesons).
- Direct CP violation possible in singly-Cabibbo suppressed decays
  - Interference between tree and penguin. Naïve expectation ≤ 0.1%
- Indirect CP violation prediction much smaller

$$\Delta A_{CP} = A_{\rm raw}(K^-K^+) - A_{\rm raw}(\pi^-\pi^+) = A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+)$$

$$A_{\rm raw} = \frac{N(D^0 \to f) - N(\overline{D}^0 \to f)}{N(D^0 \to f) + N(\overline{D}^0 \to f)}$$

recent updates by LHCb:



World average (HFAG) (*)

$\Delta A_{CP} = (-0.33 \pm 0.12)\%$

earlier indications of possible large CP violation in charm sector not (yet) confirmed

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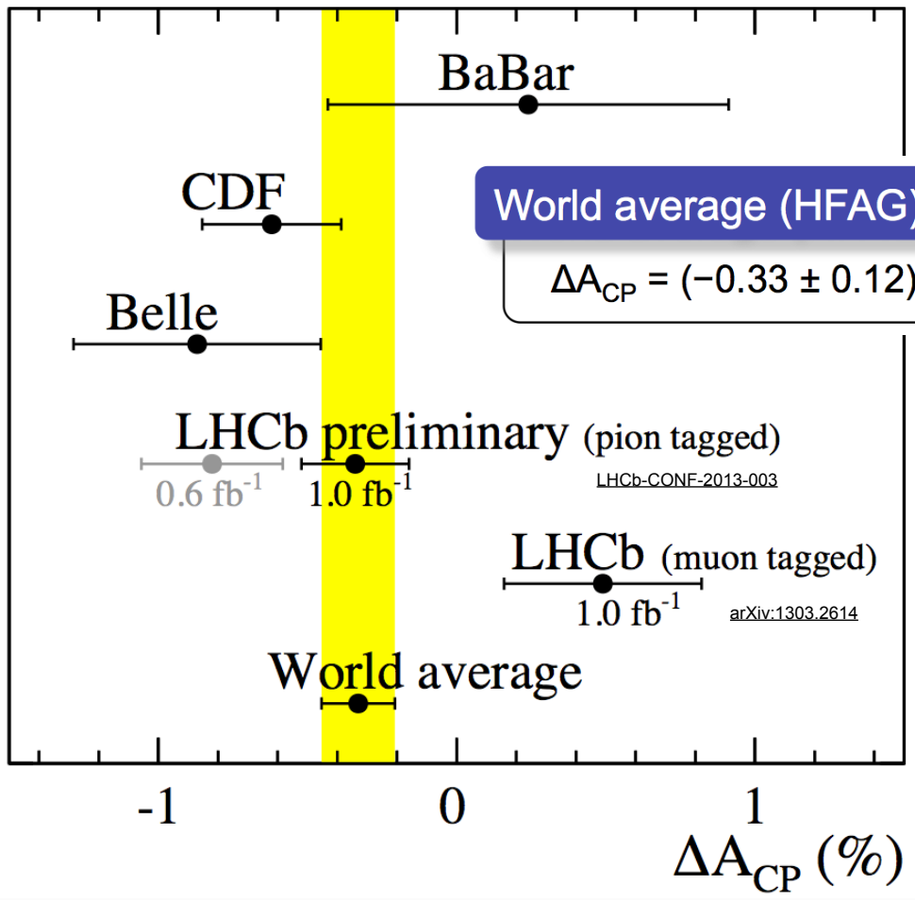

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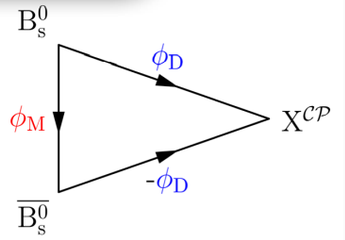
B_s mixing and CP violation

ϕ_s is defined as the phase for $\mathcal{CP}$-violation between mixing(ϕ_M) and decay(ϕ_D):



$$\phi_s = \phi_M - 2\phi_D$$

New physics could modify box diagrams and alter ϕ_M.

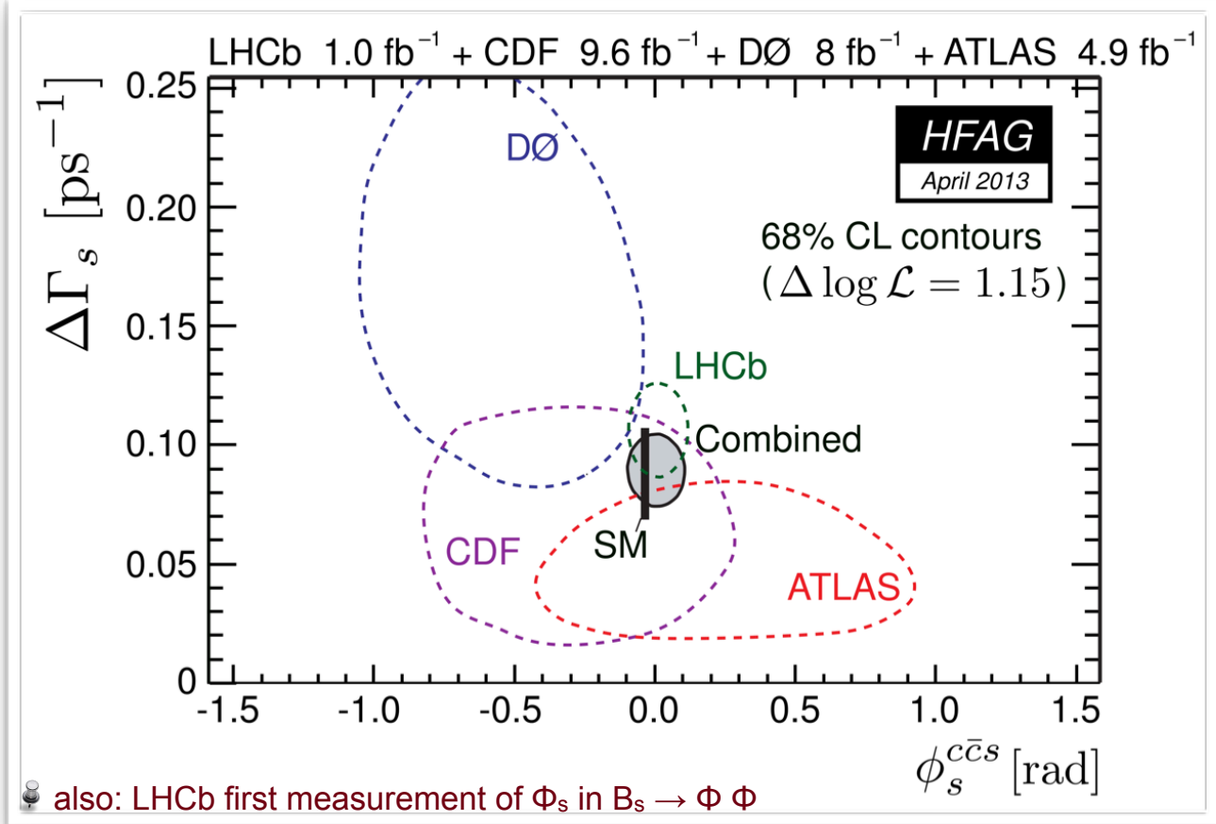
R. Currie

$B_s^0 \to J/\psi\, K^+K^-$ and $B_s^0 \to J/\psi\, \pi^+\pi^-$

Combined result gives the most precise measurements of:

see LHCb: arXiv:1304.2600

ϕ_s	$= 0.01$	± 0.07 (stat)	± 0.01 (syst)	rad,
Γ_s	$= 0.661$	± 0.004 (stat)	± 0.006 (syst)	ps^{-1},
$\Delta\Gamma_s$	$= 0.106$	± 0.011 (stat)	± 0.007 (syst)	ps^{-1}.



also: LHCb first measurement of Φ_s in $B_s \to \Phi\,\Phi$

again: no deviations from the SM so far

see also talk by M. Elsing, right afterwards

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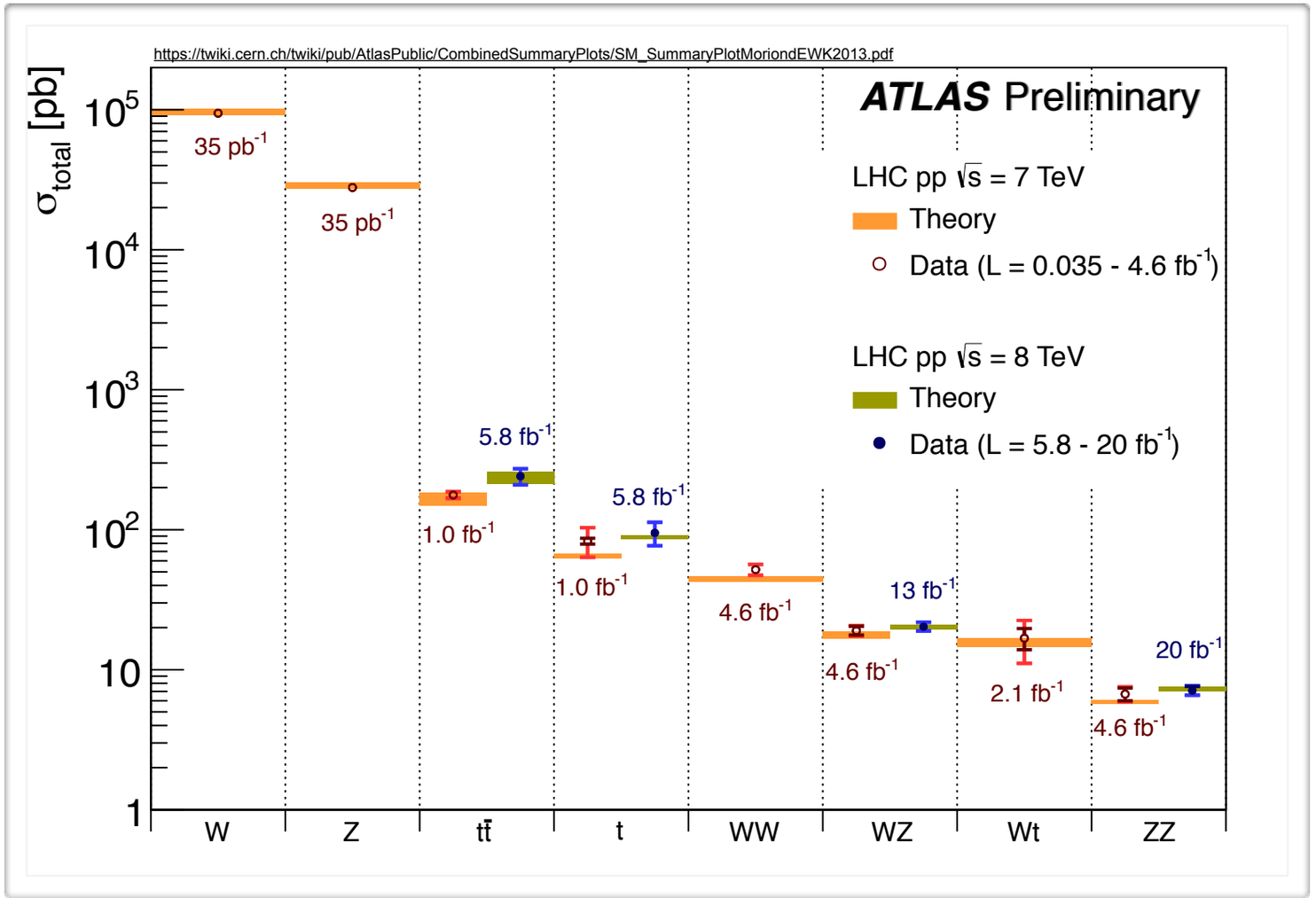
QCD, EWK and Top physics



Jet Production

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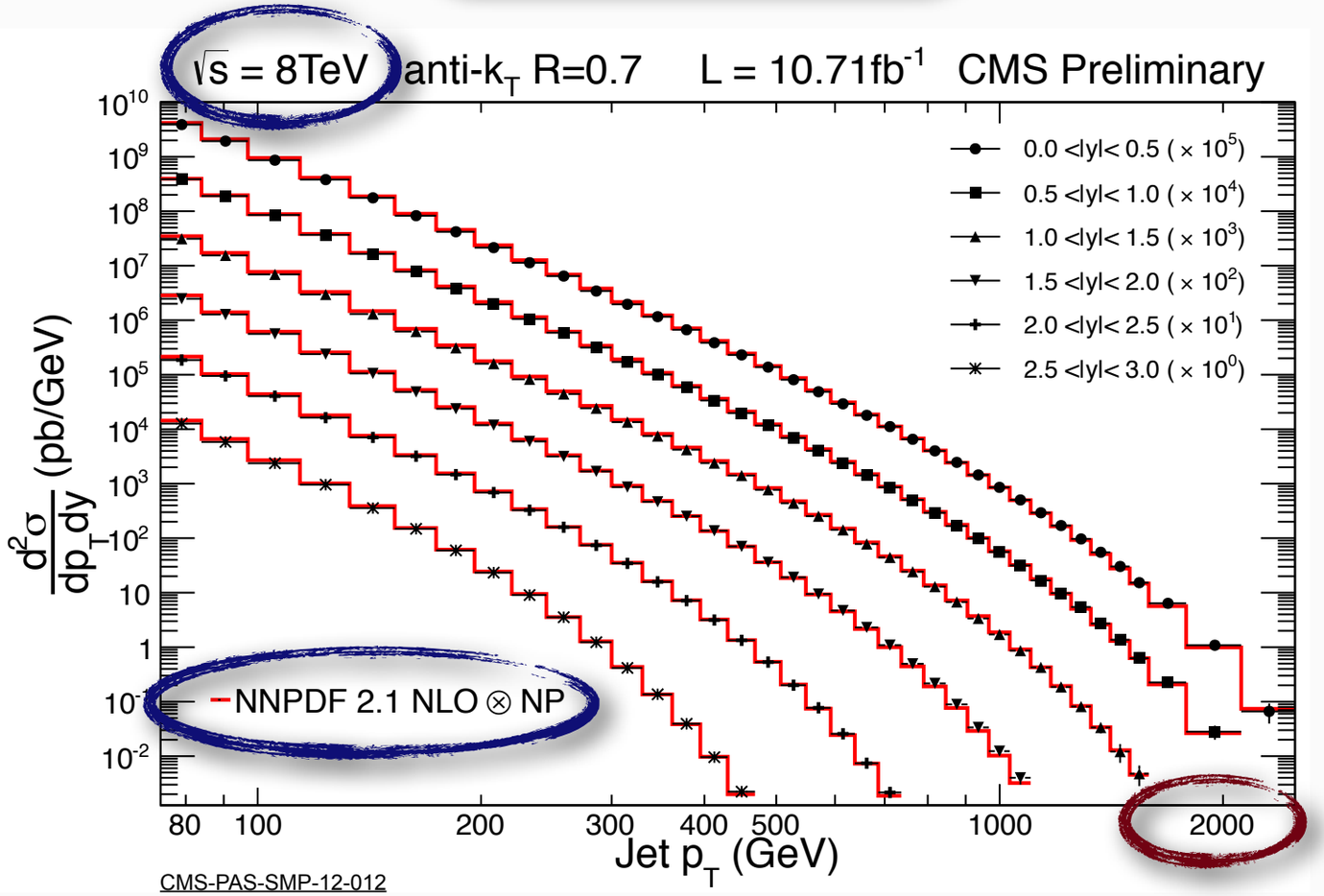
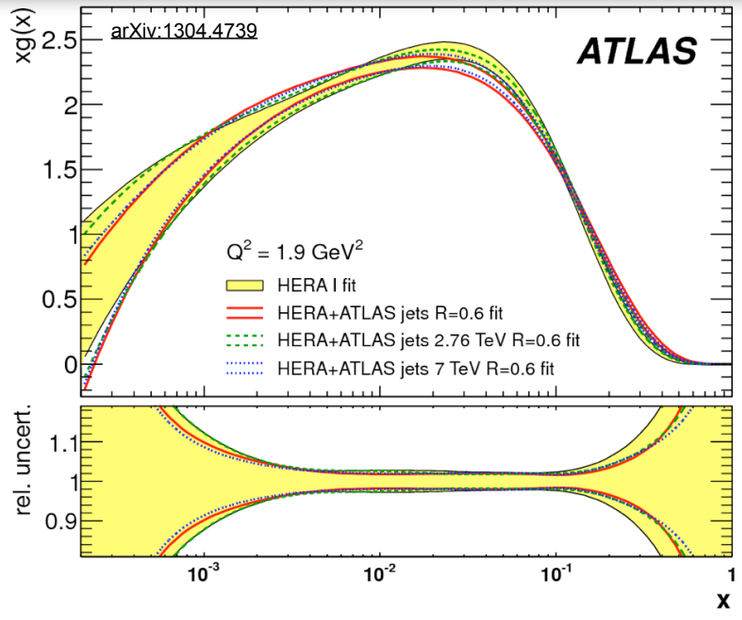
inclusive jet production



ratio of incl. jet cross sections : 7 vs 2.76 TeV



- NLO QCD describes data over ~10 orders of magnitude!
- excellent exp. progress: jet energy scale uncertainties at the **1-2%** level
- for central rapidities: similar exp. and theo. uncertainties, **5 - 10%**
- inclusive jet data : start to be important tool for constraining PDFs

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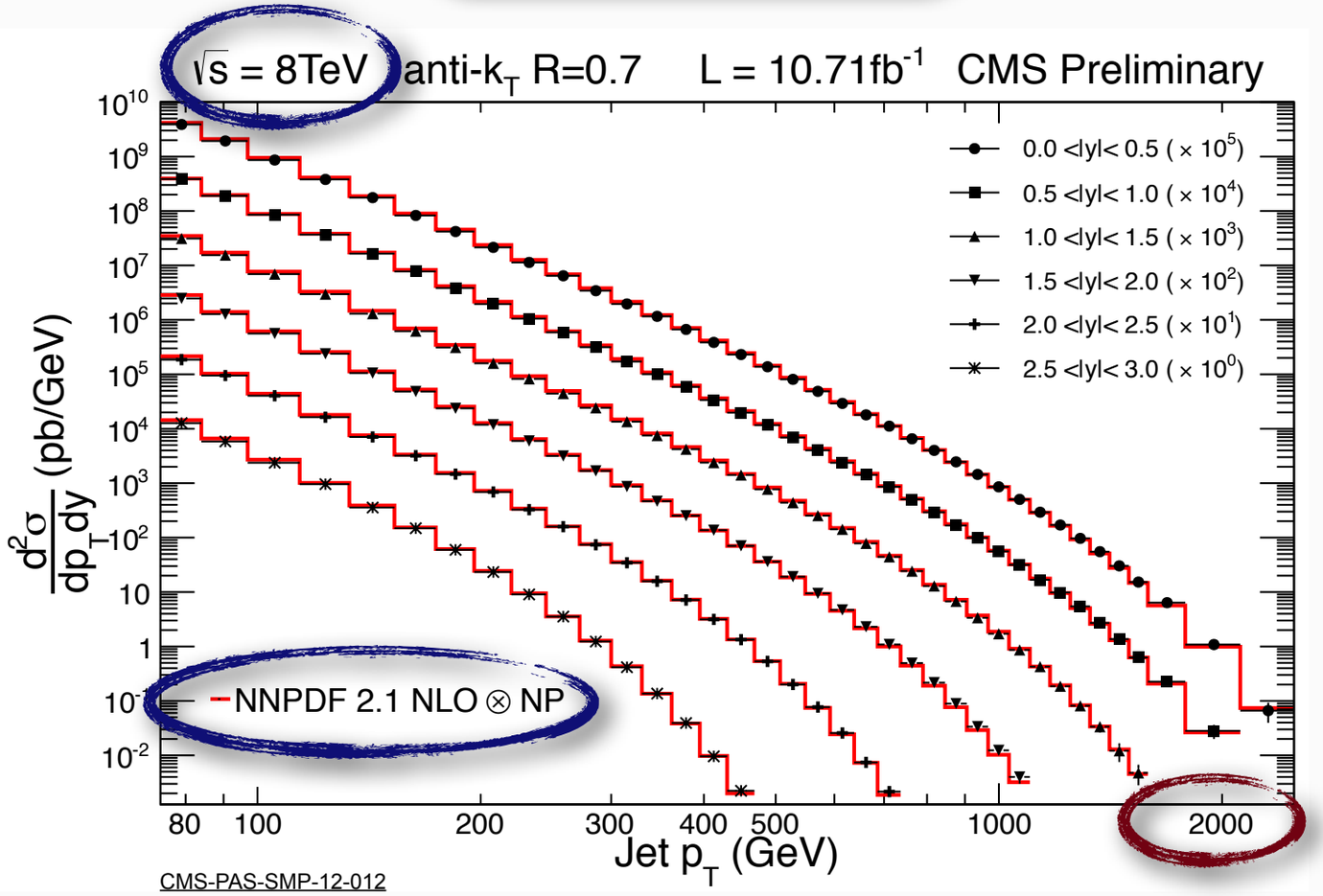

CMS-PAS-SMP-12-012

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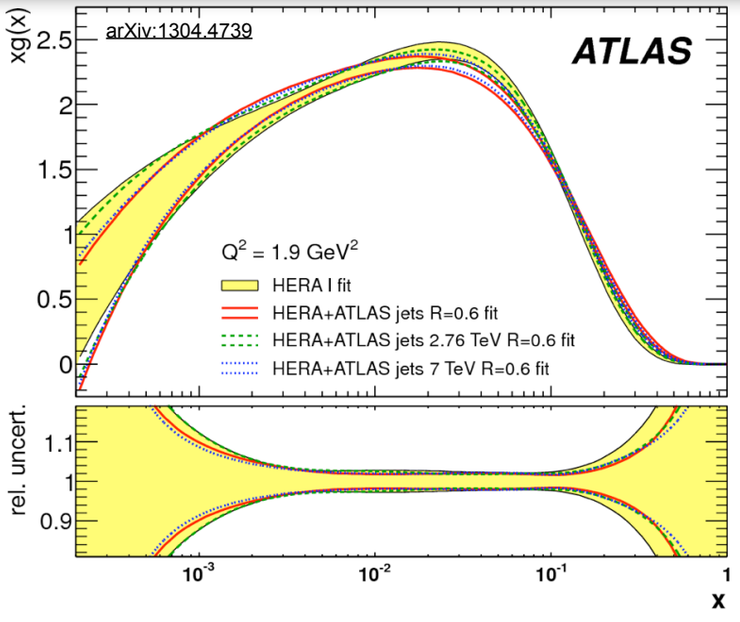
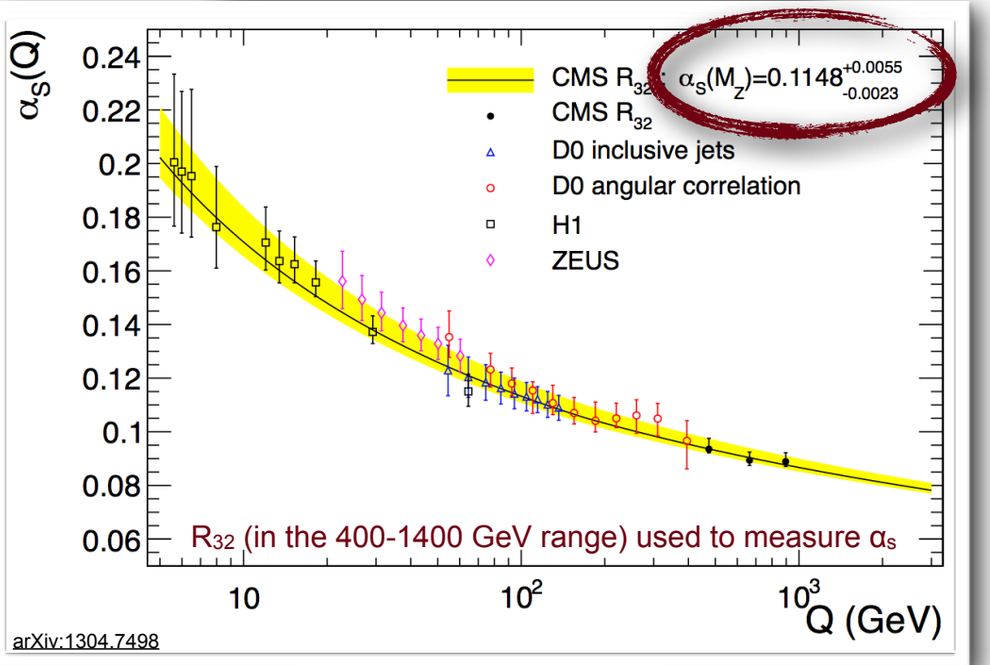


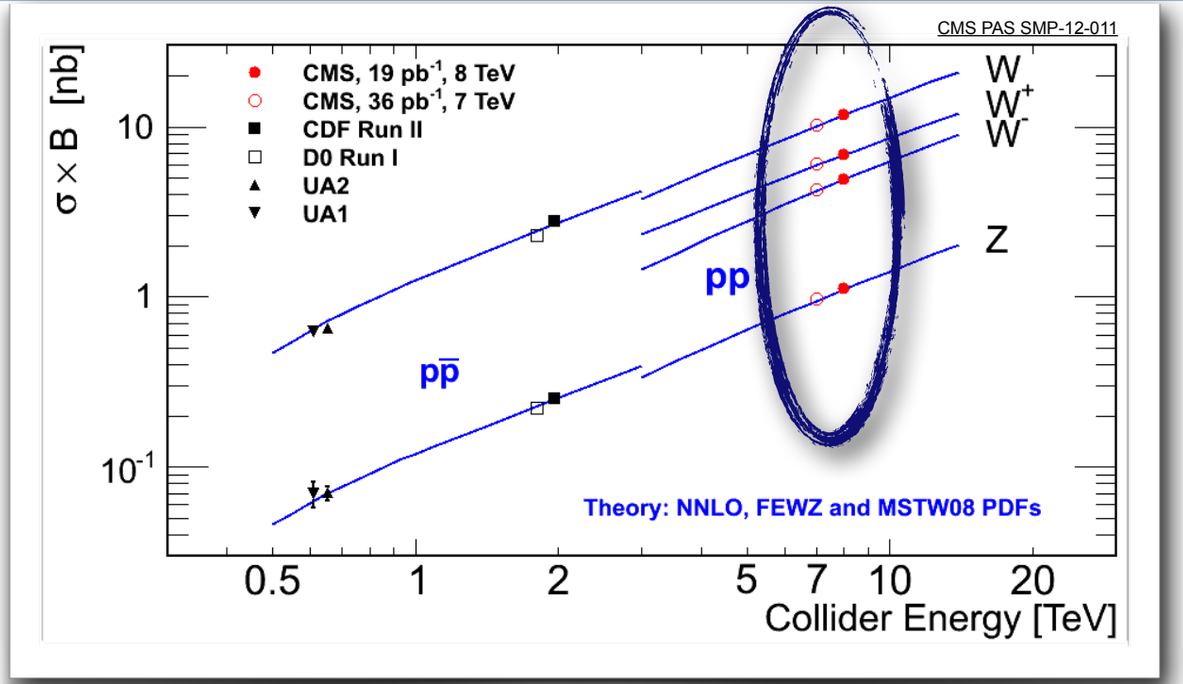
Strong coupling measurements



arXiv:1304.7498

- similar method: prel. measurement from ATLAS
- also: **first $\alpha_S(M_Z)$ extraction from top x-section** (CMS-PAS-TOP-12-022)

Incl. W/Z Production



- **incl. cross sections:**
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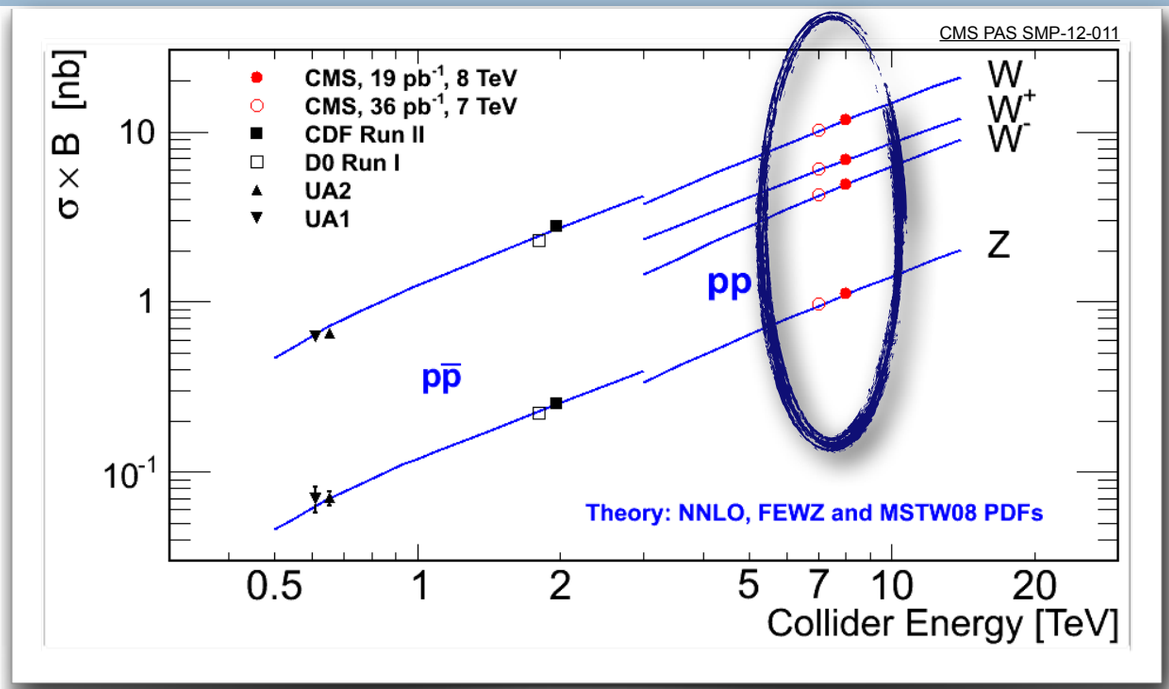

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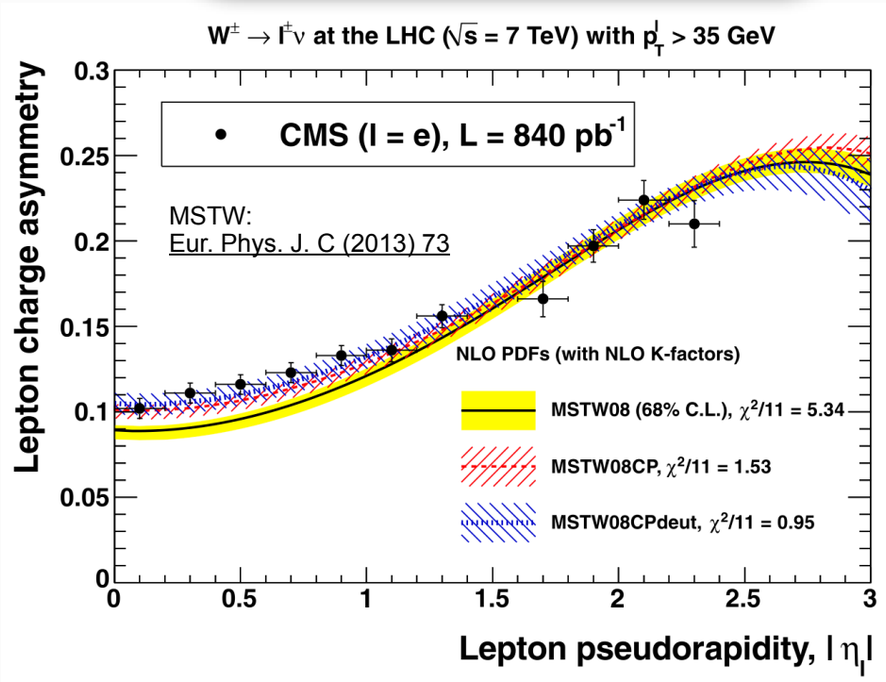
PDF constraints?



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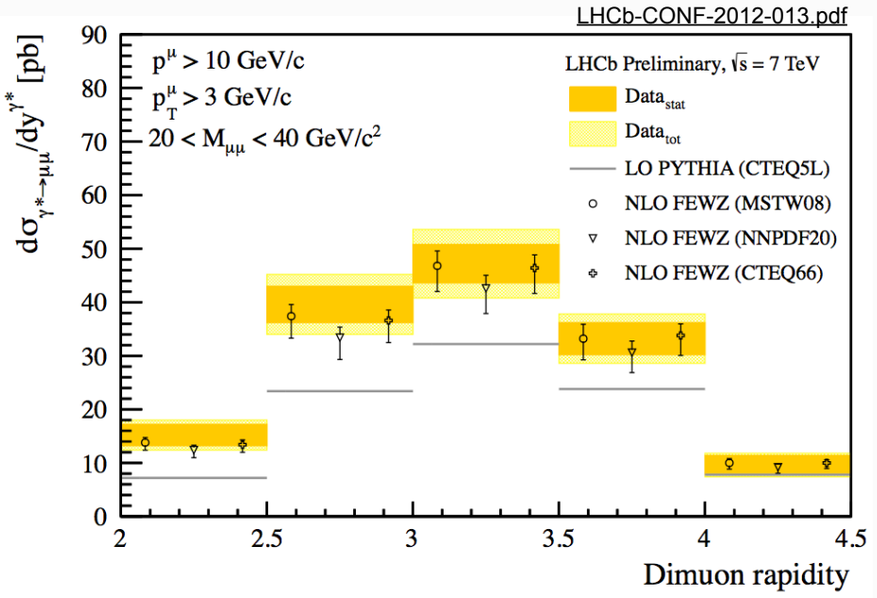

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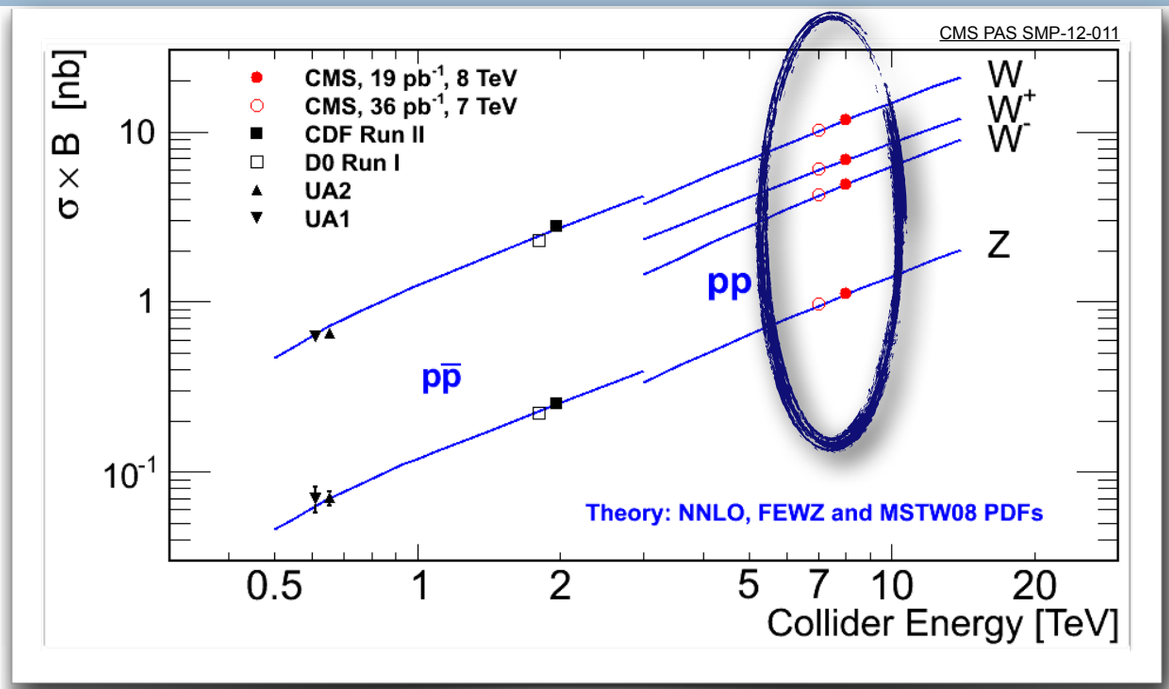

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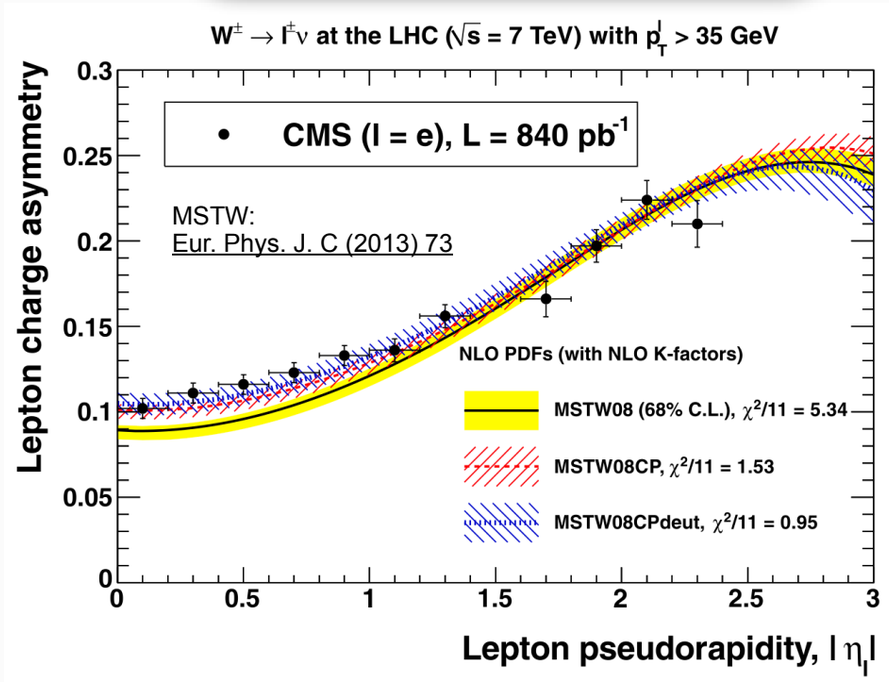
- **Also new**: ATLAS A_{FB} measurement (ATLAS-CONF-2013-043)

$$\sin^2\theta_W^{\text{eff}} = 0.2297 \pm 0.0004(\text{stat.}) \pm 0.0009(\text{syst.})$$

- best Tevatron precision reached already

PDF constraints?



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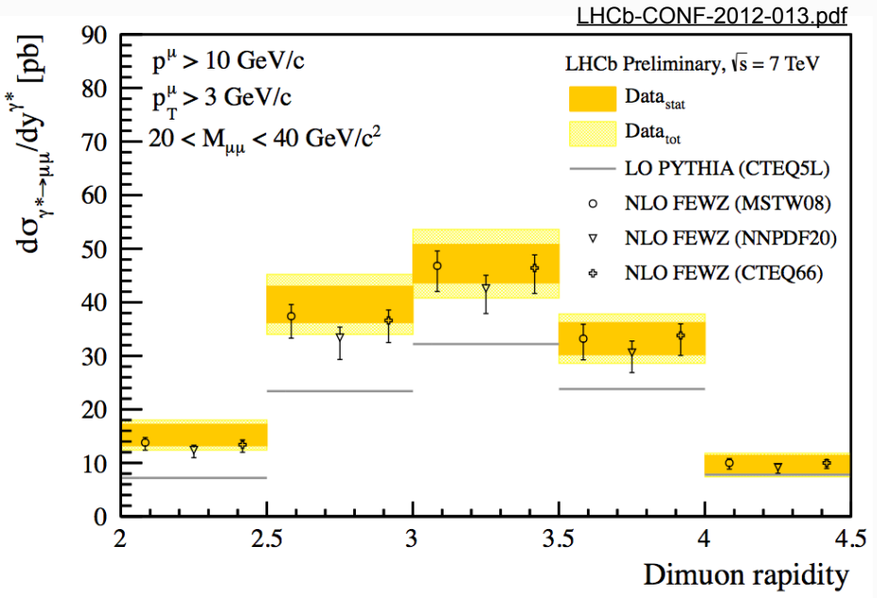
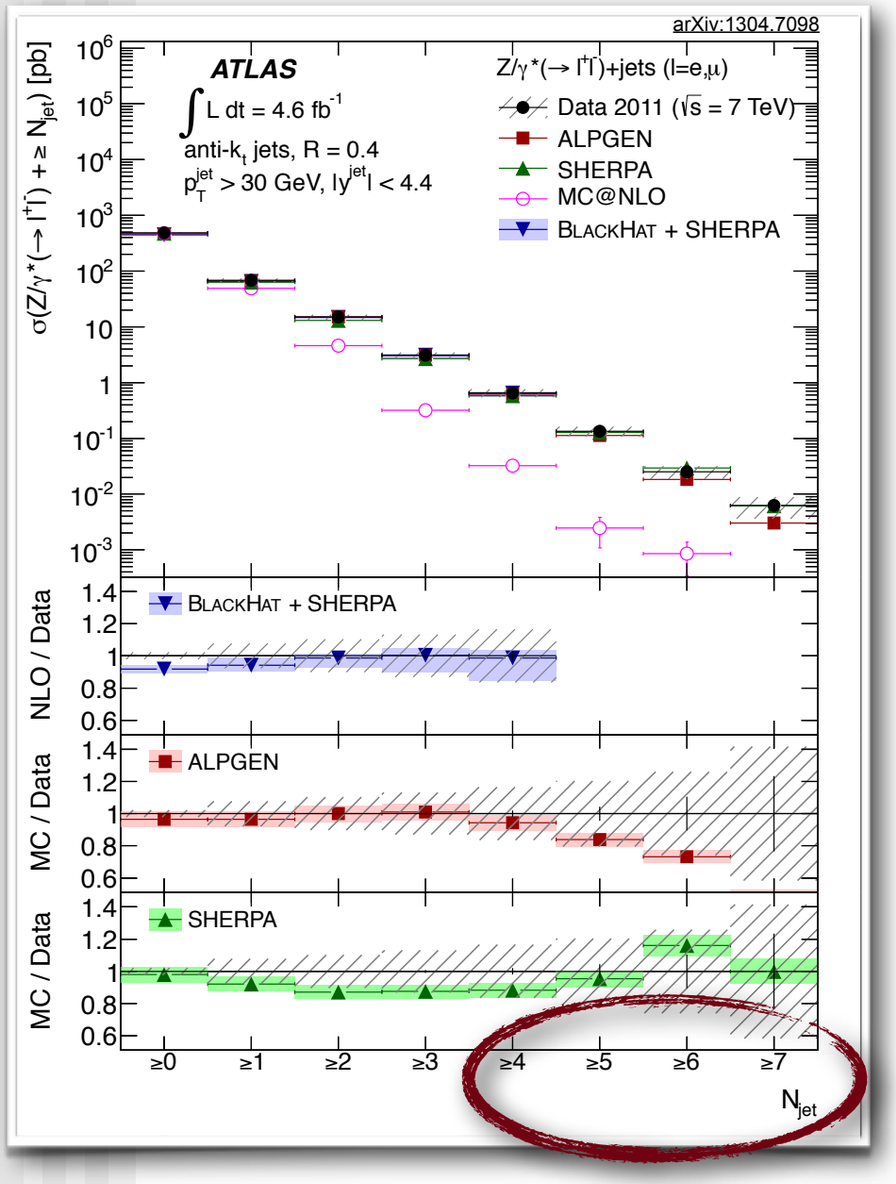


New results on V + jet / HF production



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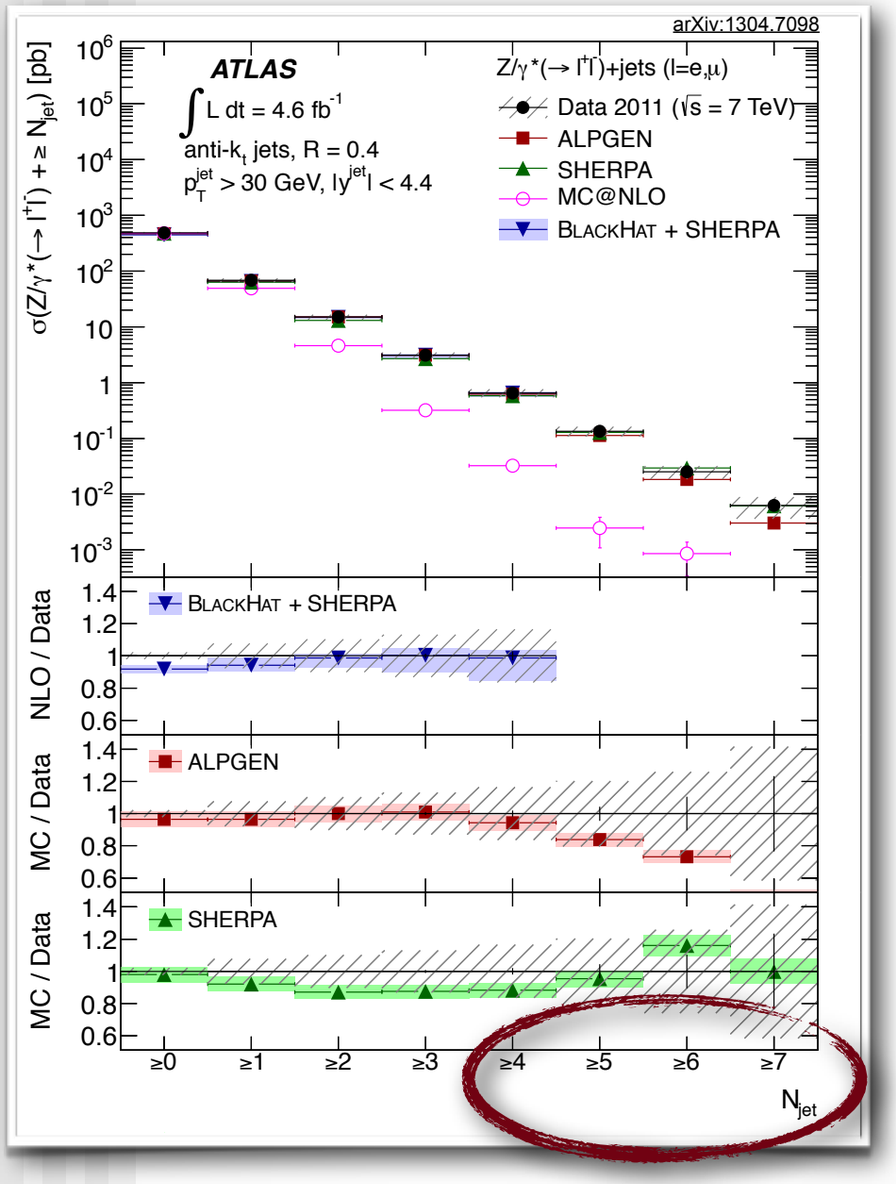

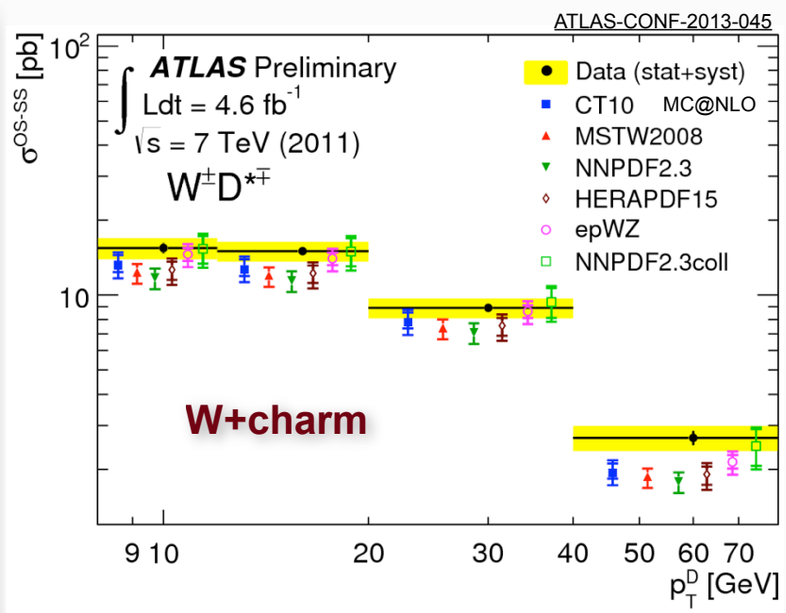

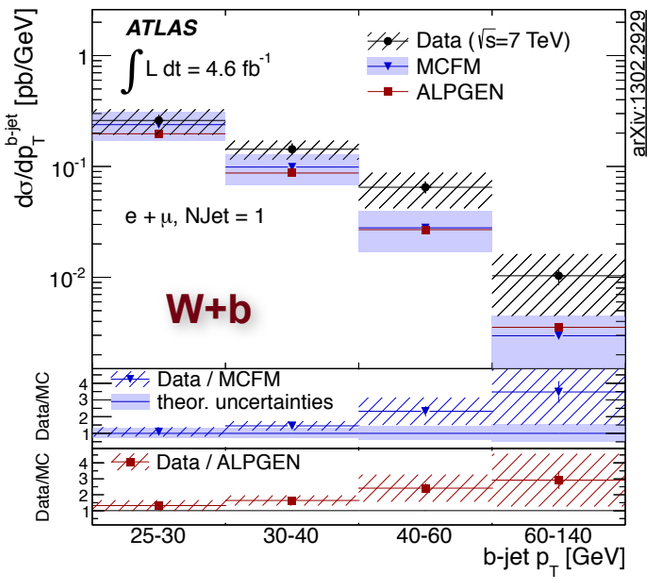

- **more and more probing a large phase space:**
- eg. angular correlations (incl. and for large Z p_T) (CMS, PLB 722 (2013) 238)
- ... and many other kinematic observables.

  In general: spectacular success of ME+PS models and NLO predictions.
- **V+heavy flavours**: Z+b(b), W+b(b), W+c
  - new W+charm: best agreement for PDFs with enhanced strange content.

New results on V + jet / HF production

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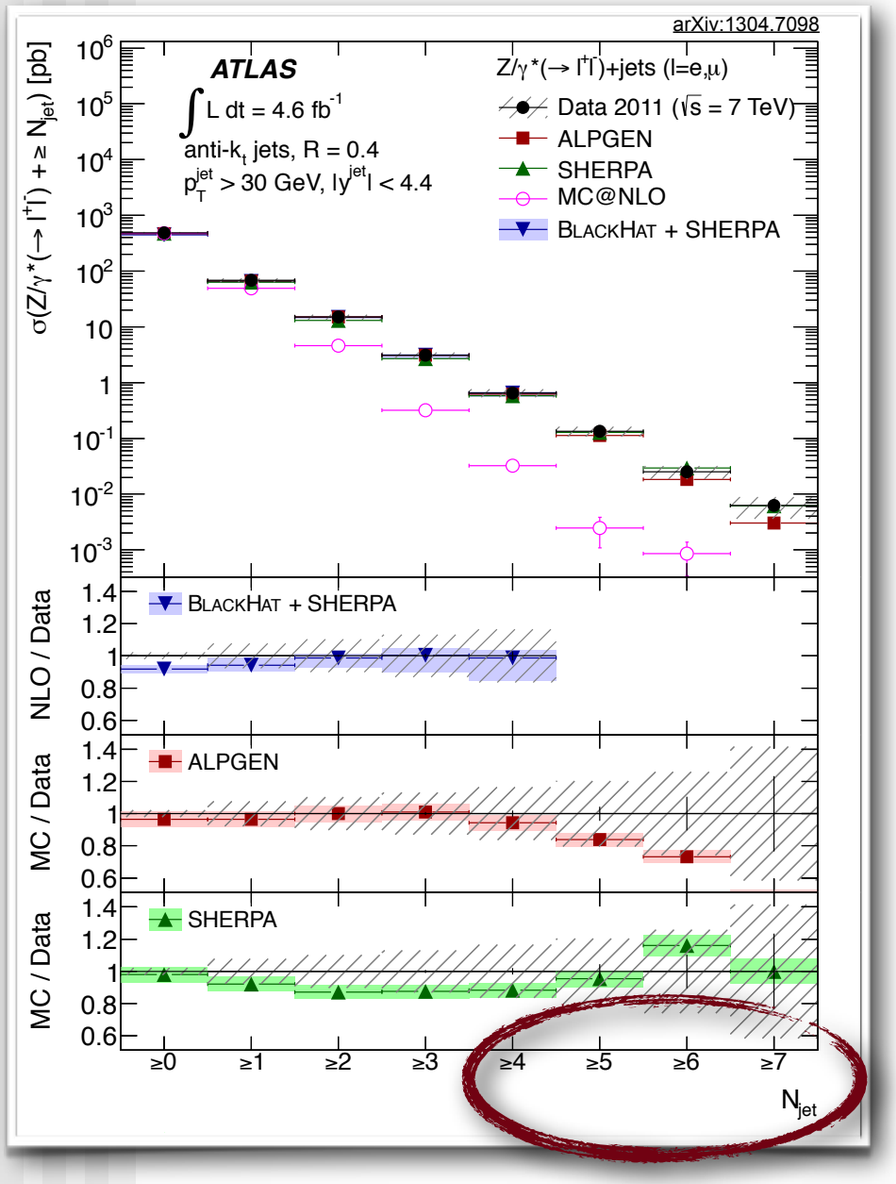
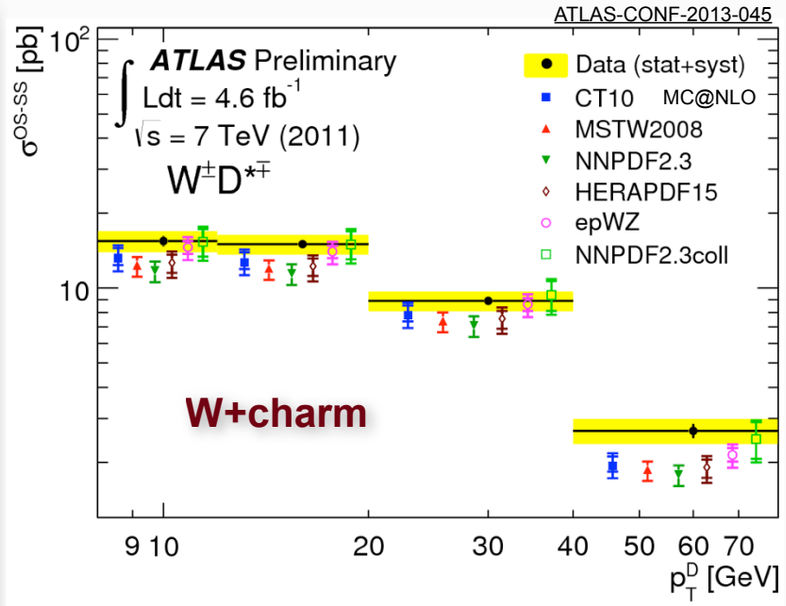
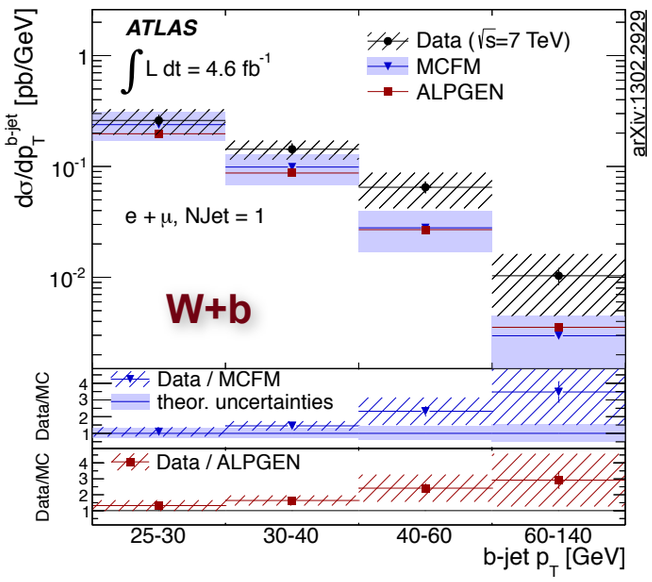
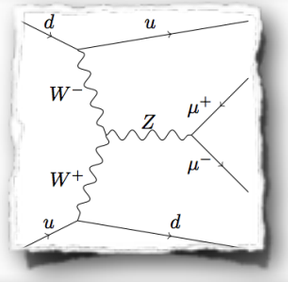
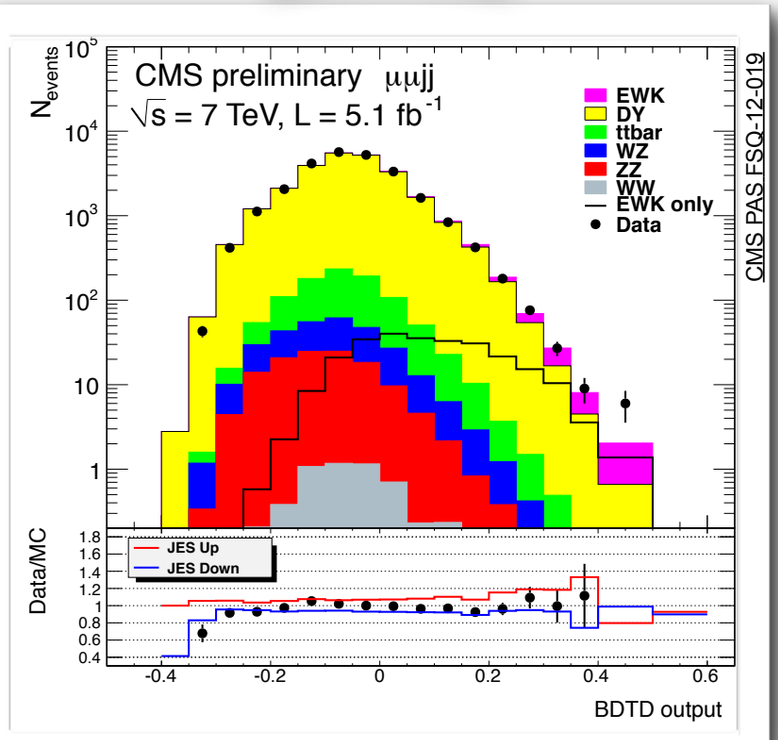






first evidence (~3 sigma) for electroweak Z+jets production





- measured cross section in agreement with NLO prediction

- **more and more probing a large phase space:**
- eg. angular correlations (incl. and for large Z p_T) (CMS, PLB 722 (2013) 238)
- ... and many other kinematic observables.

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Di-Boson production

cf. talk by P. Ward, LHCP2013

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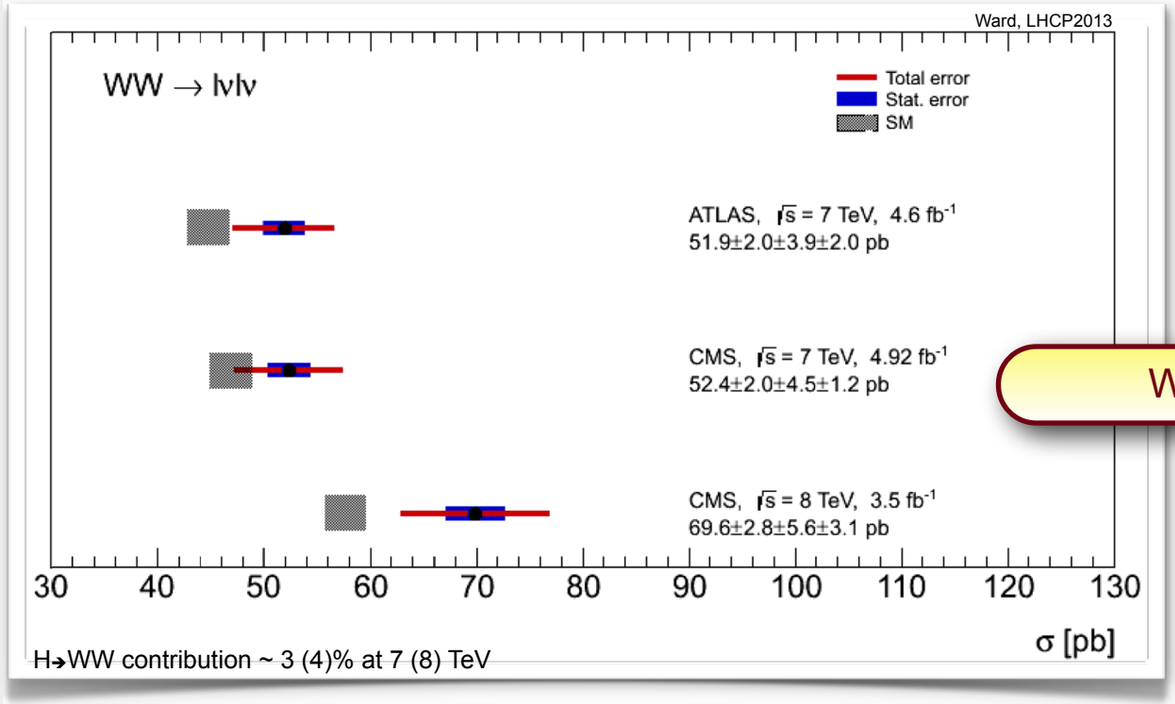
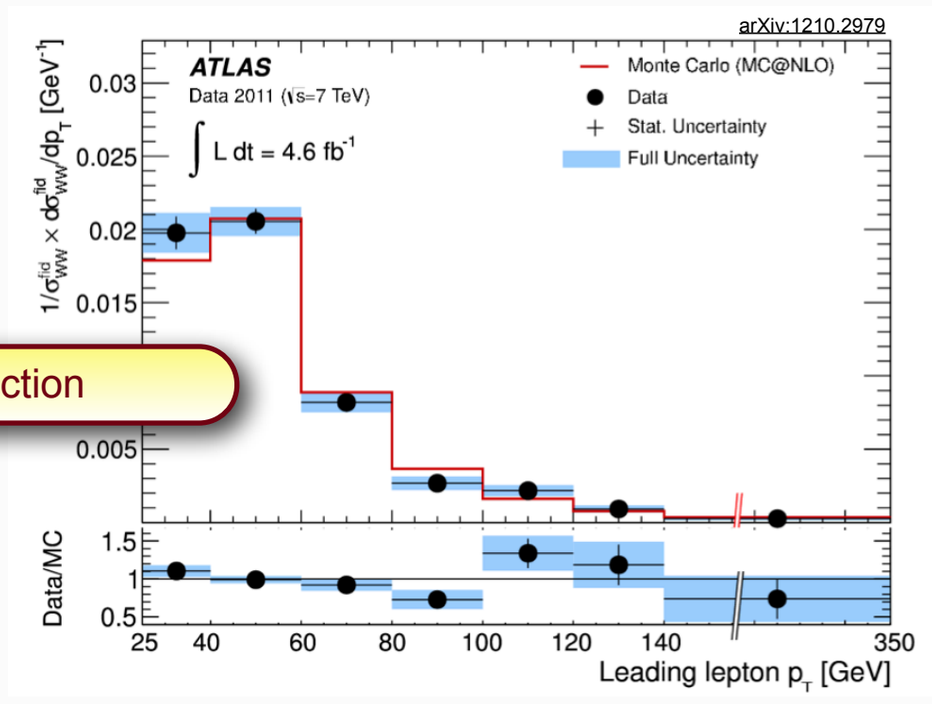


WW production



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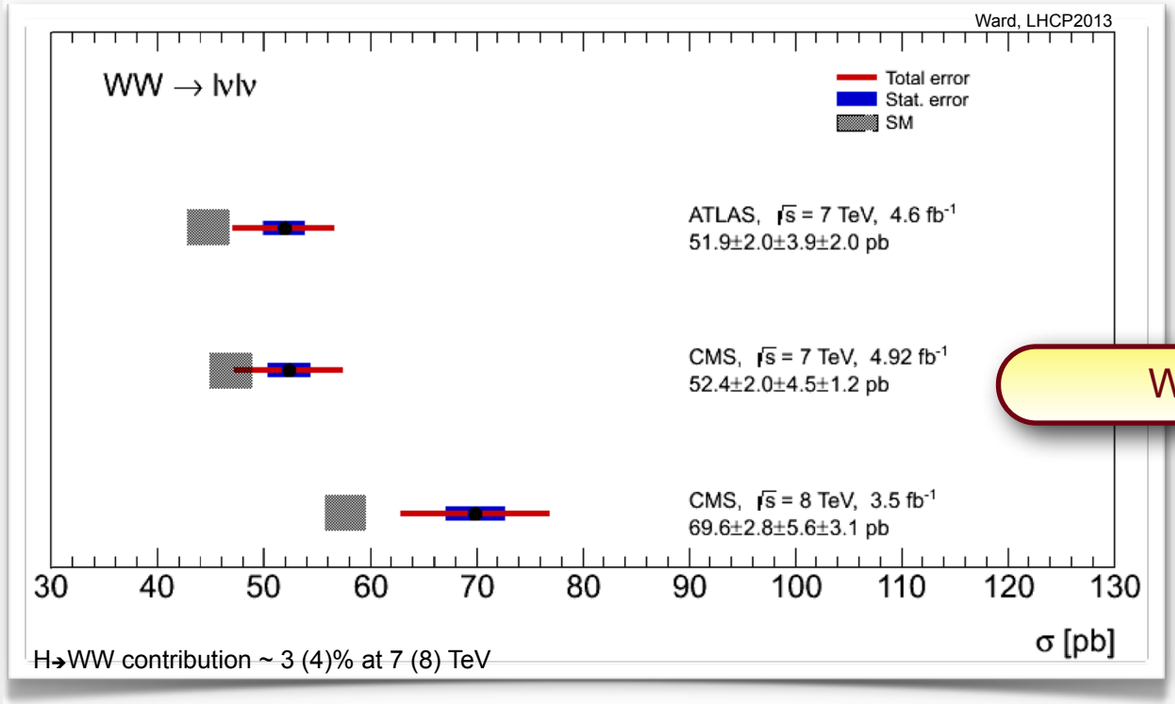

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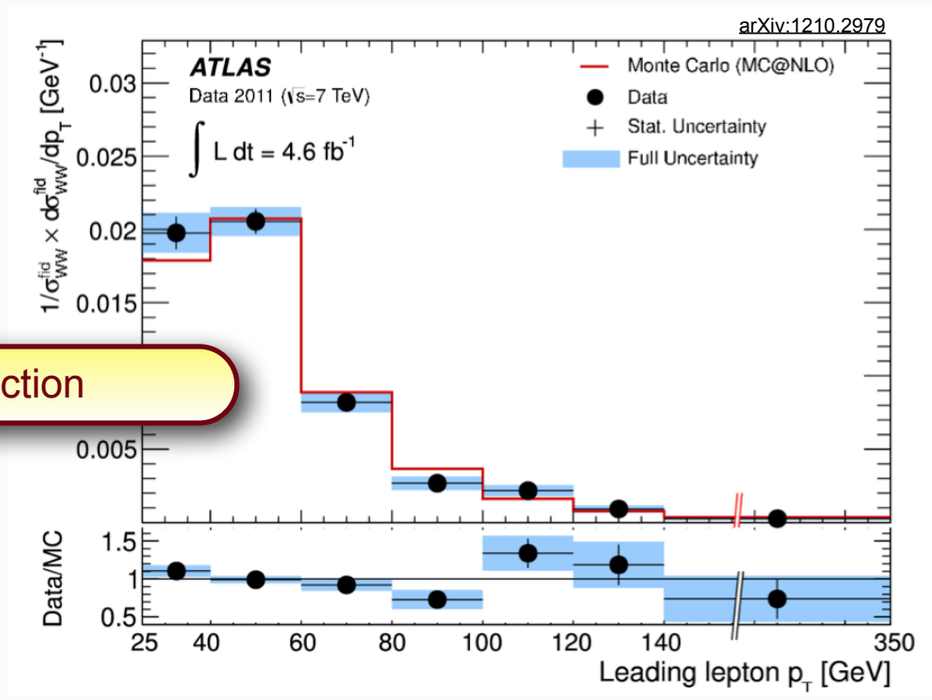
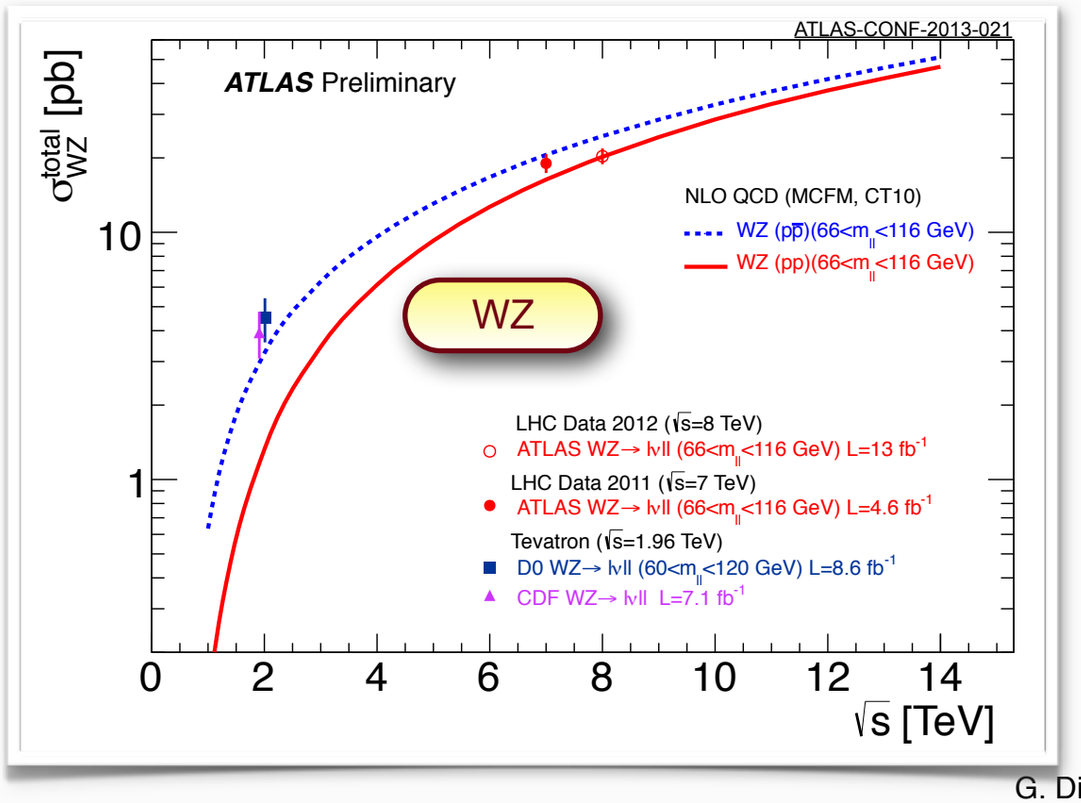
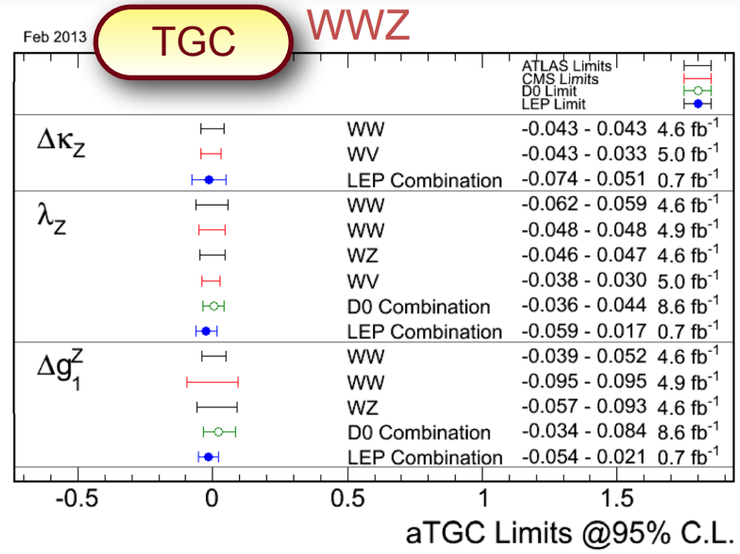


- **Experimental uncertainties on total cross-sections (> 8% for most precise channels) still larger than theoretical uncertainties (~ 5%)**





- **WW** consistently above NLO pred. (by 10-20%)
- Charged TGC: approaching/exceeding LEP
- Neutral TGC: order of magnitude more stringent than LEP
- **new: excl. WW production**: (CMS PAS FSQ-12-010)
  first upper limit on xsec, limits on QGC exceeding LEP

TOP prod. @ 7 and 8 TeV

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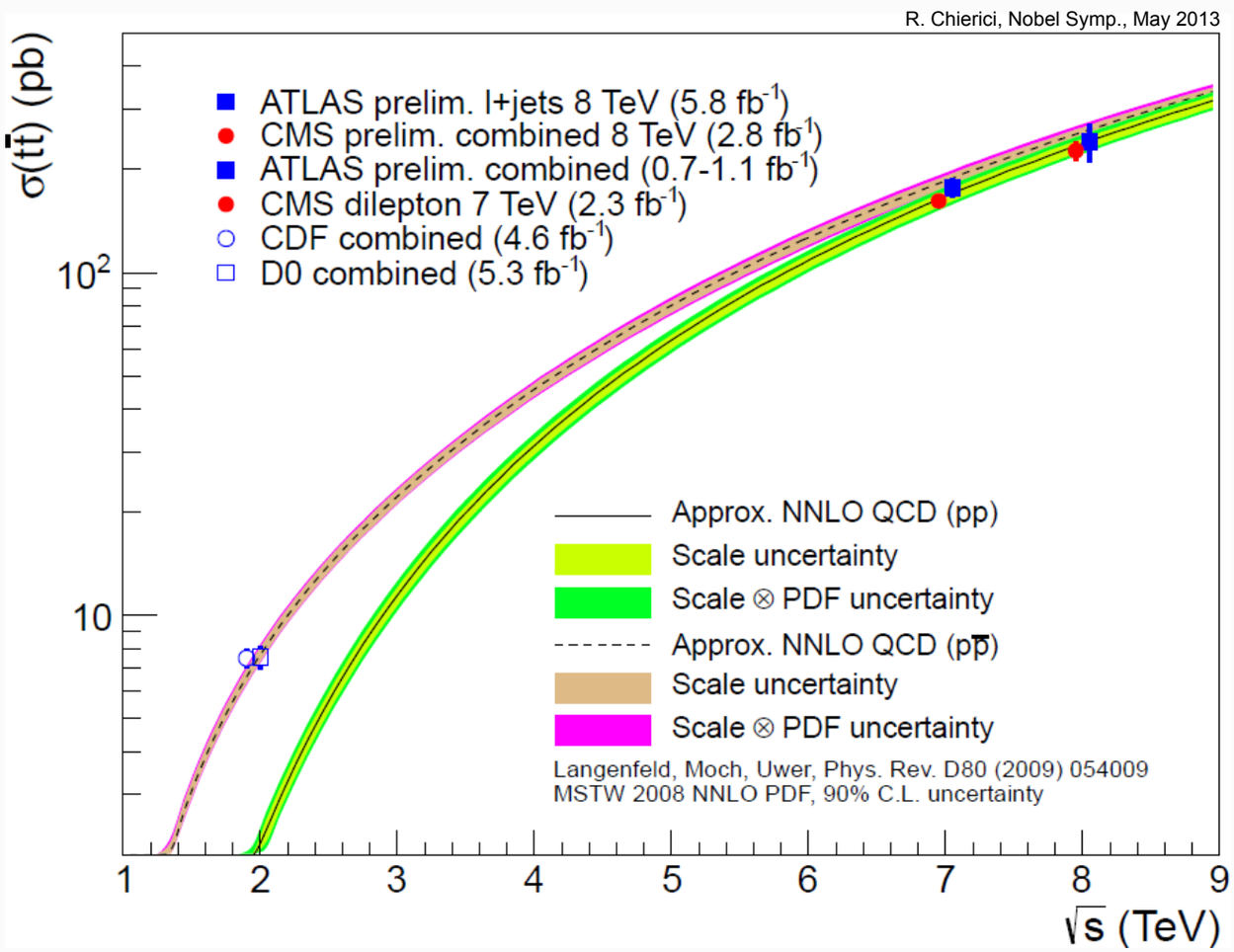
cf. talk by Schwanenberger, LHCP2013

R. Chierici, Nobel Symp., May 2013



TOP pair production:

- Consistency across all channels, **experimental uncertainty ~ 5% - 15 %** !
- similar to theoretical uncertainty (scales + PDF), compatible with approx. NNLO predictions
- very recently: significant theoretical improvement (full NNLO), **4% uncert.**,
  now making top production a gluon pdf tester?

Single TOP:

- new measurements of t-ch. prod. at 8 TeV (~13-19% uncert), V_{tb} with 10% uncert. ATLAS-CONF-2012-132 CMS PAS TOP-12-011
- also : ratio t vs anti-top production tested ATLAS-CONF-2012-056 CMS PAS TOP-12-038

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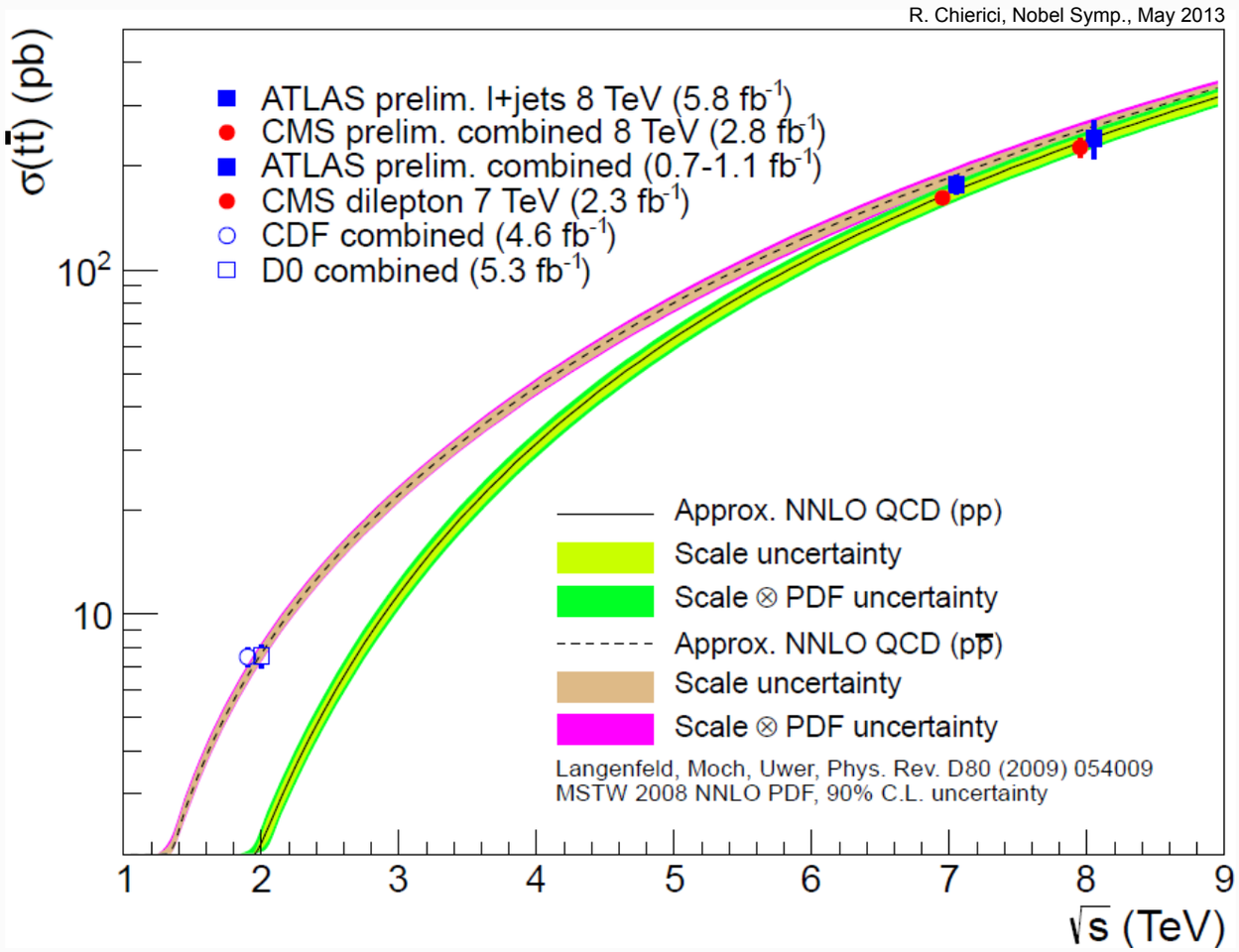
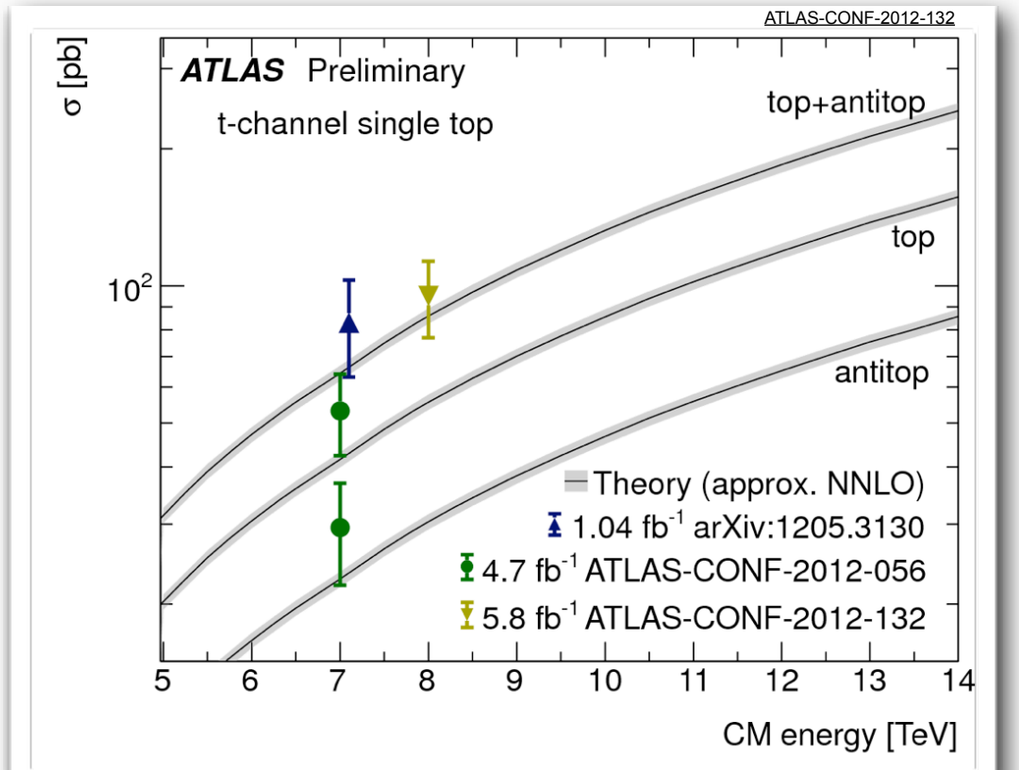


ATLAS-CONF-2012-132



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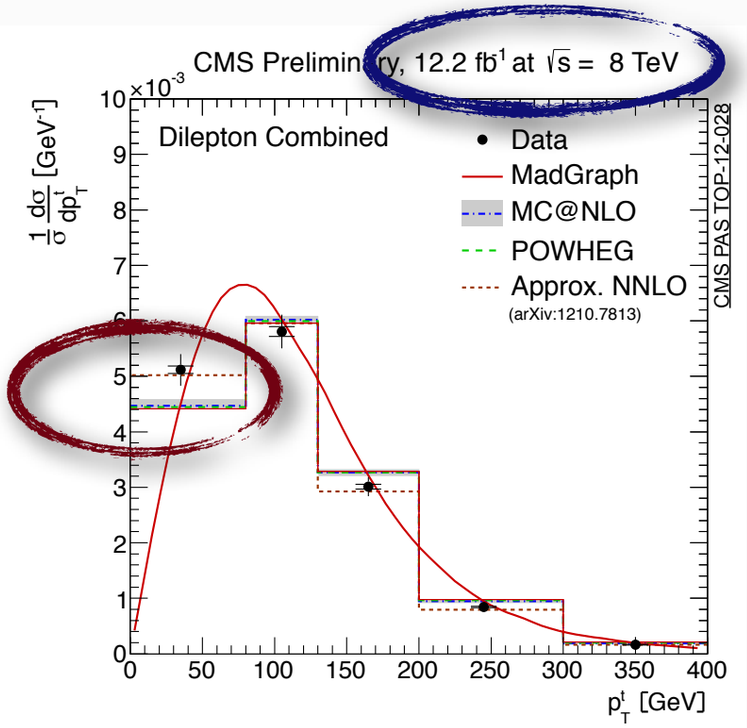
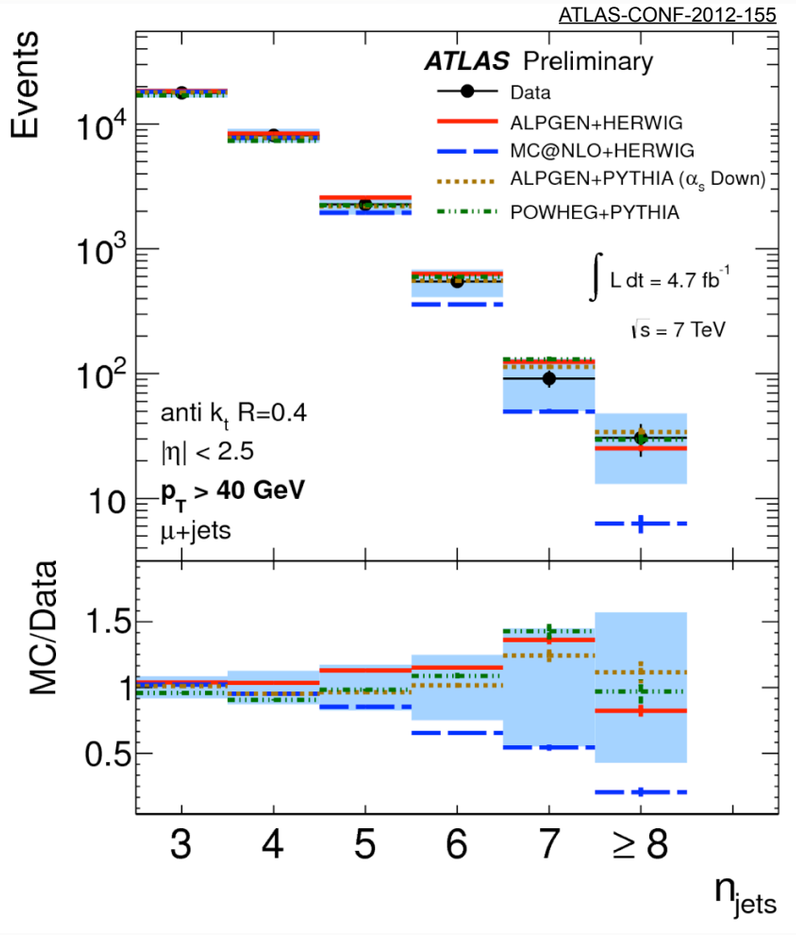
Probing the TOP



differential cross sections

- many kinematic properties (unfolded) of top final state measured
- in general :
  good description by MCs and/or approx. NNLO
- **Also tested :**
  tT+jets, tT+HF jets, (tT+bb)/(tT+jj), tT+MET



Probing the TOP

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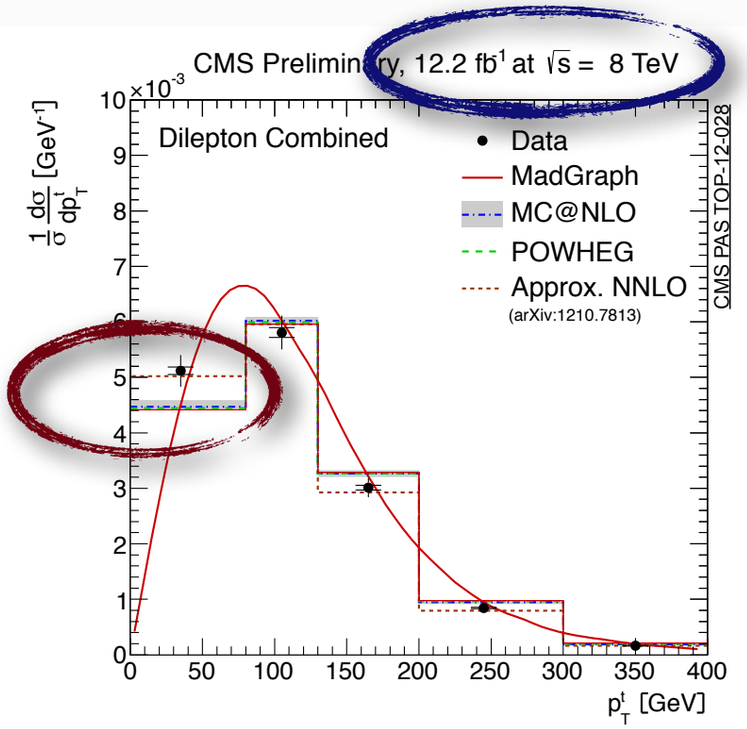

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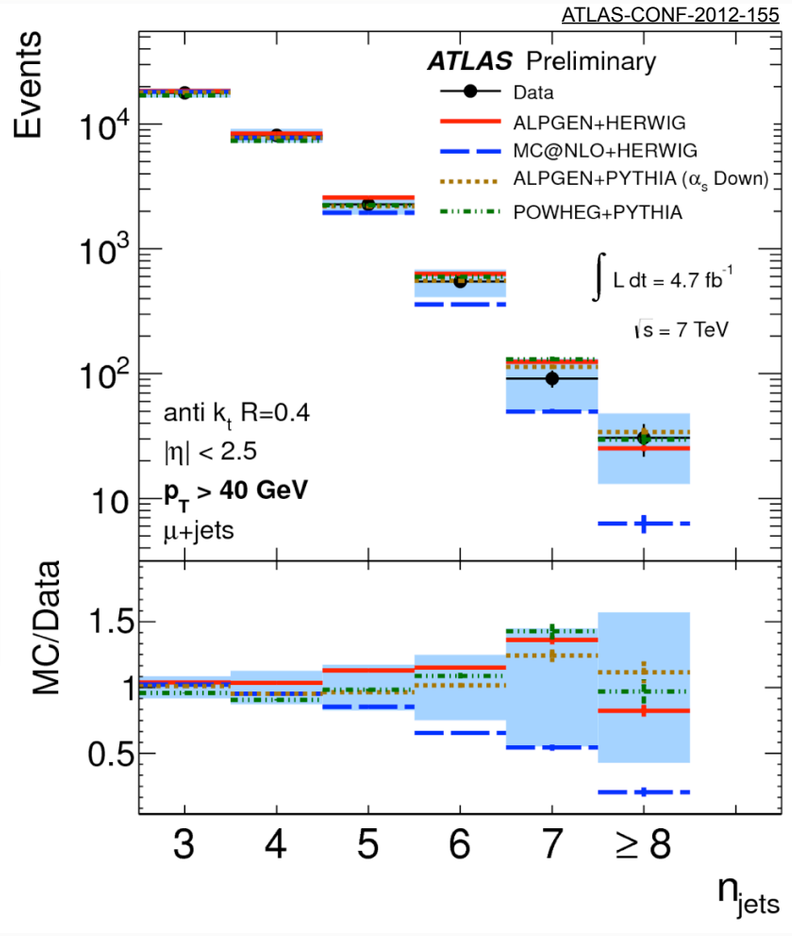
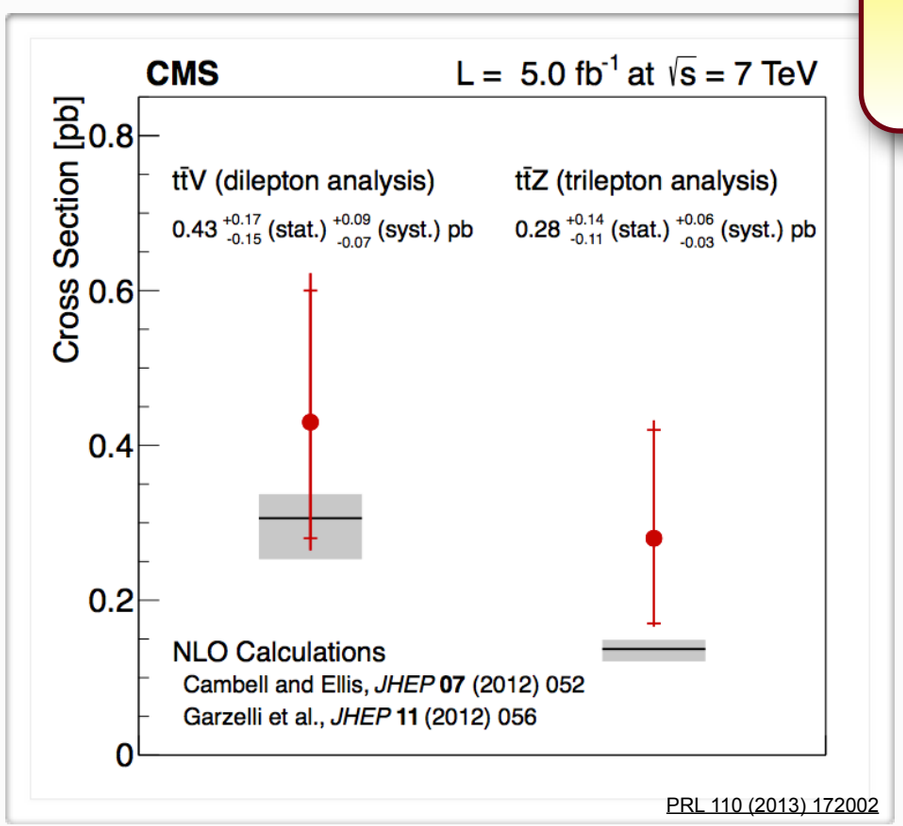


first evidence for tT+V (W, Z)



PRL 110 (2013) 172002

- **Other properties, some examples:**
  - **New**: world's best measurement (CMS) of b-content in top decays, extracting R=B(t→ Wb)/B(t→ Wq) --> |Vtb| > 0.972 @ 95% CL
  - **New**: W helicity measurements in dilepton channel and single-top topologies and **LHC combination of W helicity measurements**
    (ATLAS-CONF-2013-033, CMS-TOP-12-025)

TOP mass

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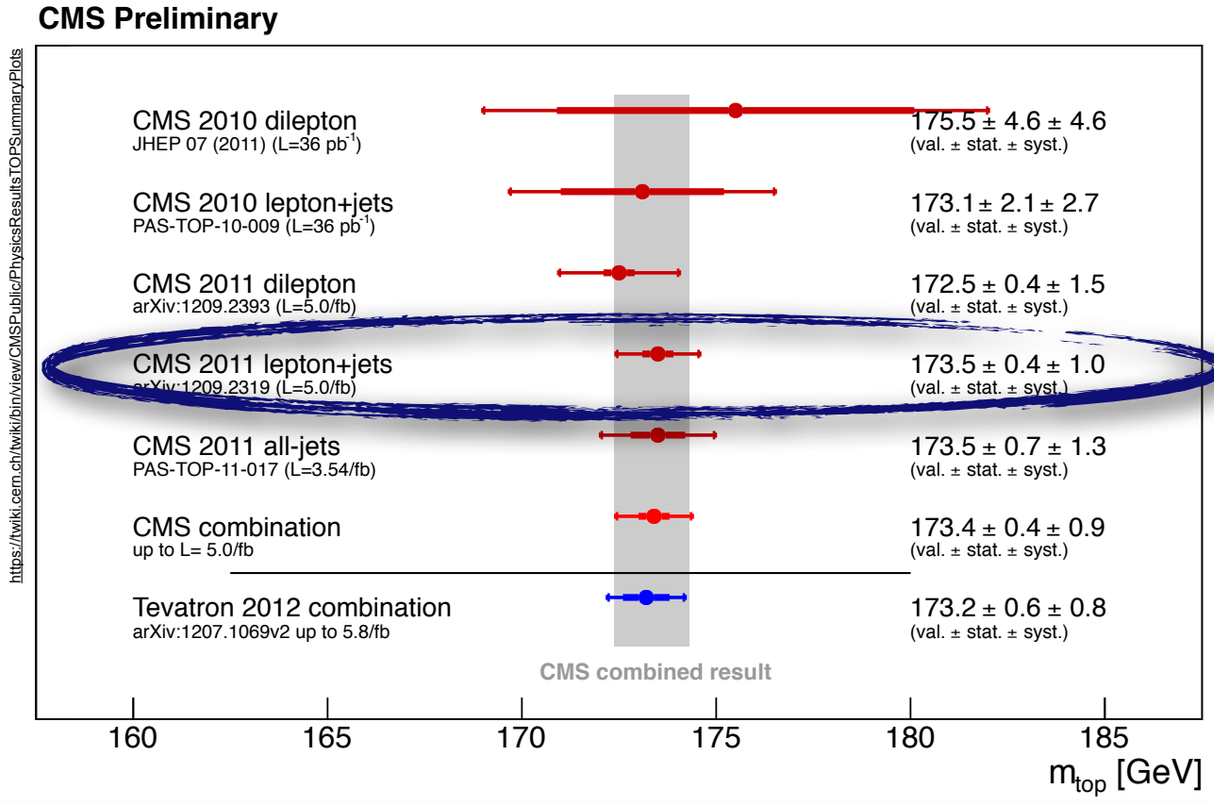

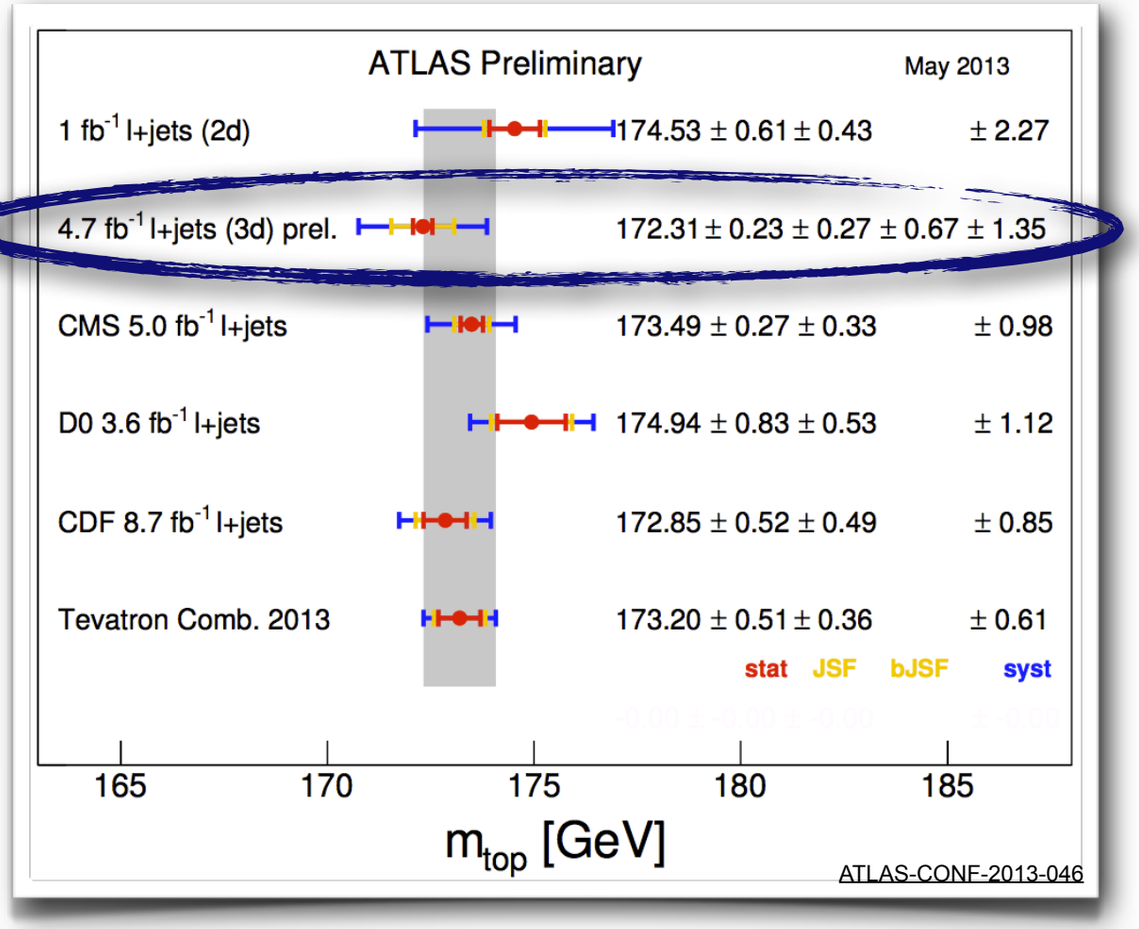

TOP mass

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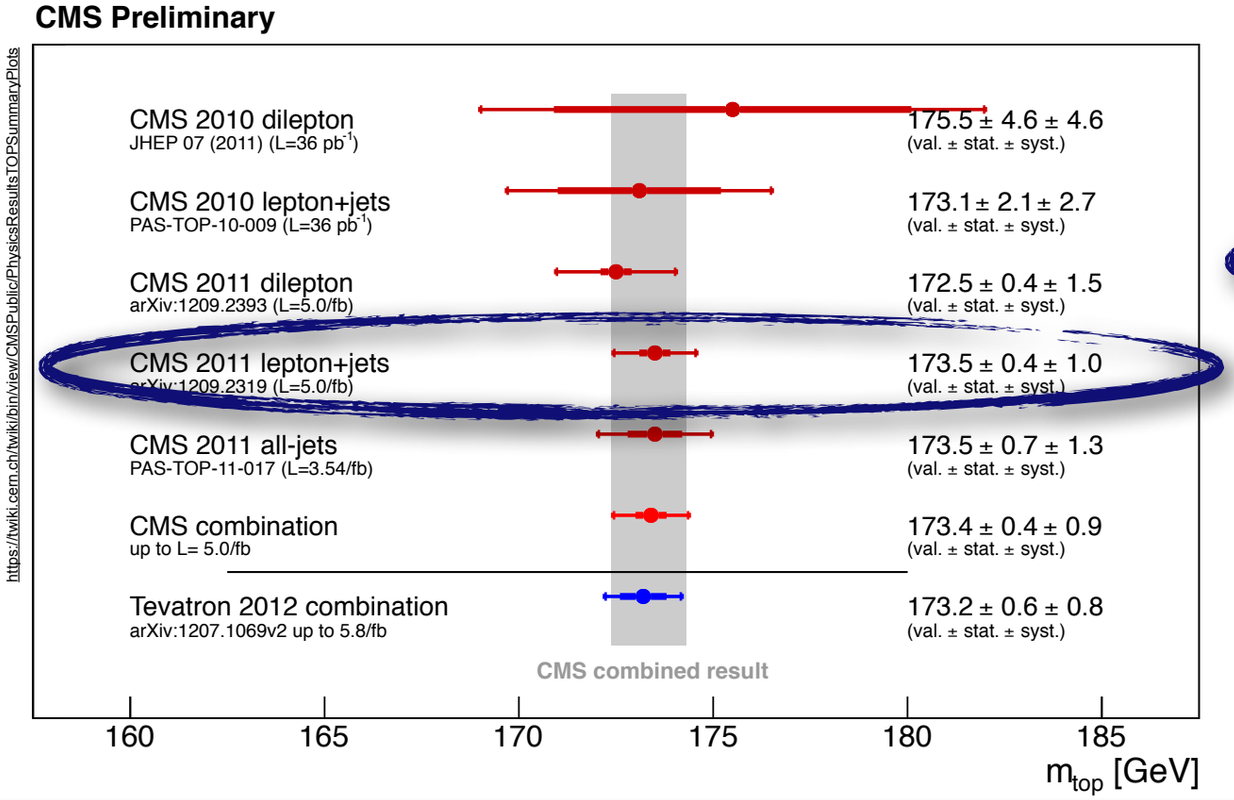

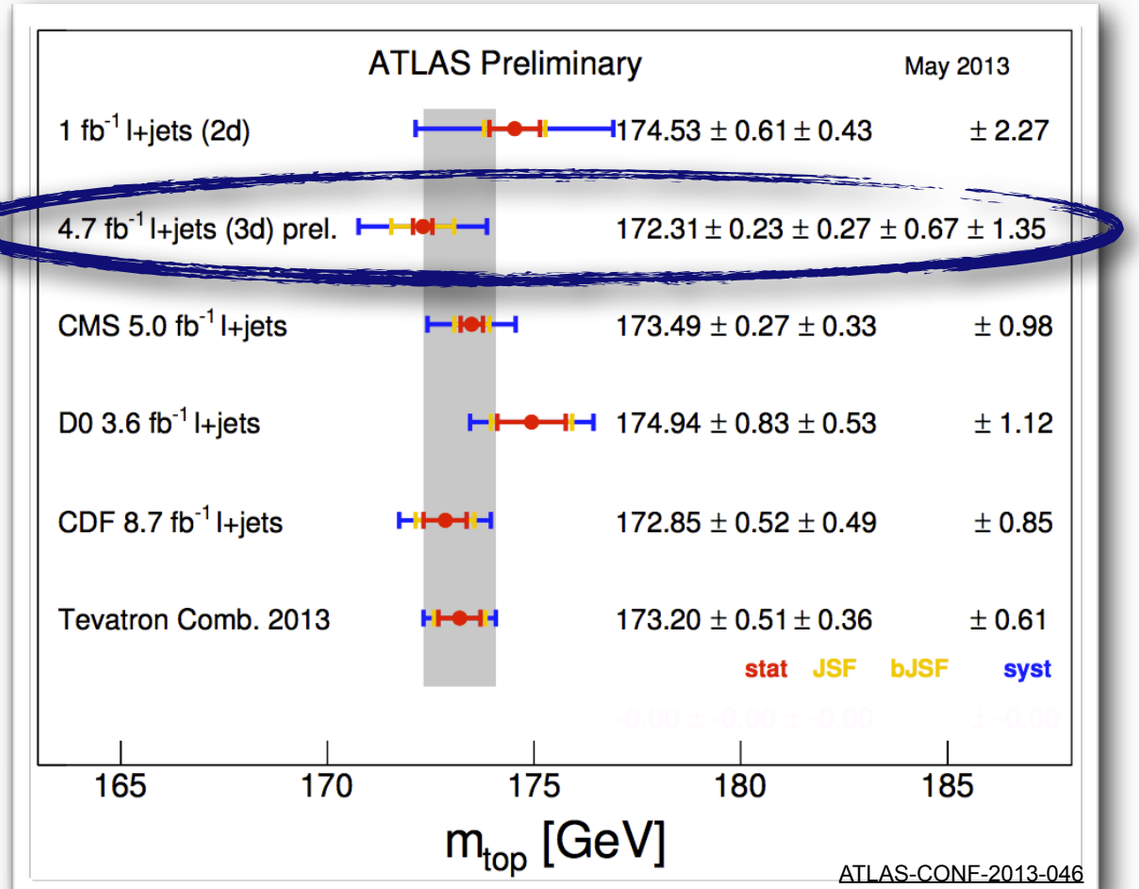

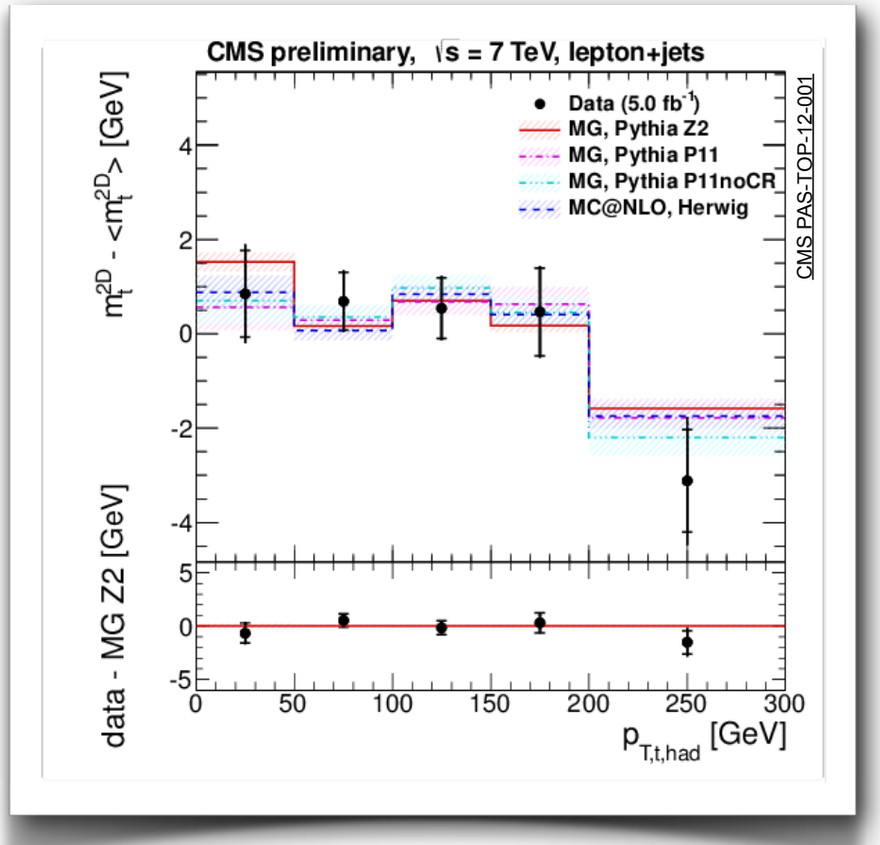

- **Top mass:**
  - combination has syst. uncert. < 1 GeV, same precision as Tevatron comb.
  - **New (CMS)**: detailed study of top mass dependence on event kinematics (test for colour reconnection, ISR, FSR, b-quark kin.) - excellent stability observed!
  - **New (ATLAS)** : 3d template fit, rel. bjet/light jet JES significantly reduced
  - **New (CMS)** : alternative measurement, based on kinematic endpoints in dilepton channel: $m_t = 173.9 \pm 0.9$ (stat.) $^{+1.6}_{-2.0}$ (syst.) **GeV**
  - **CMS** : top-antitop mass diff: $\Delta m_t = -272 \pm 196$ (stat.) ± 122 (syst.) **MeV**

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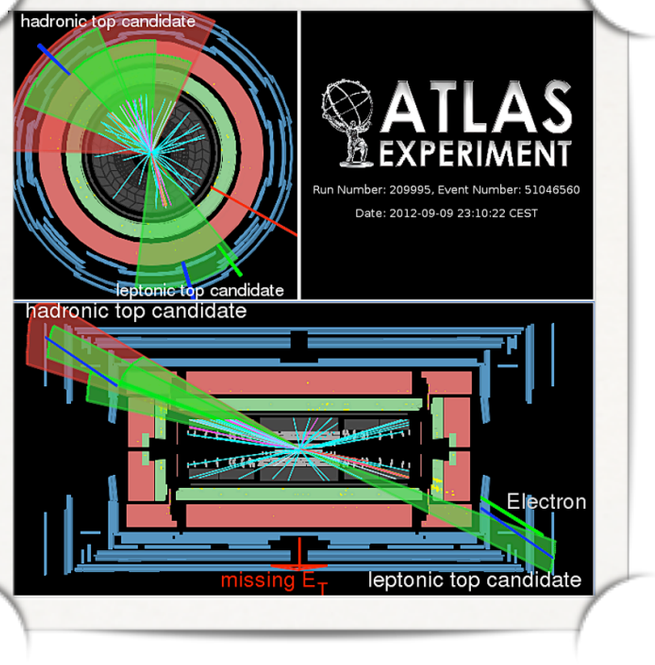
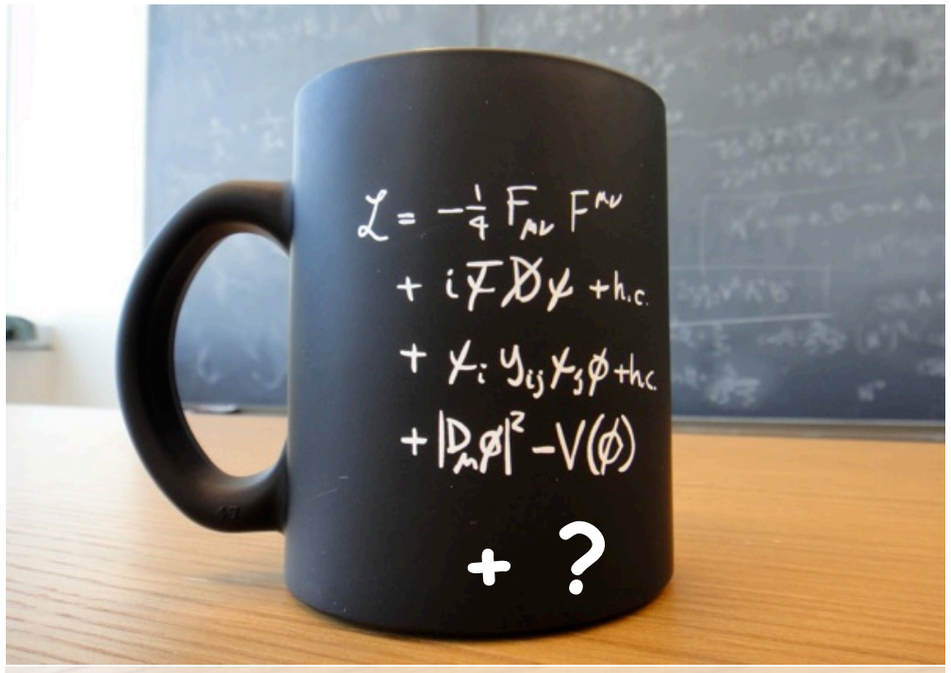
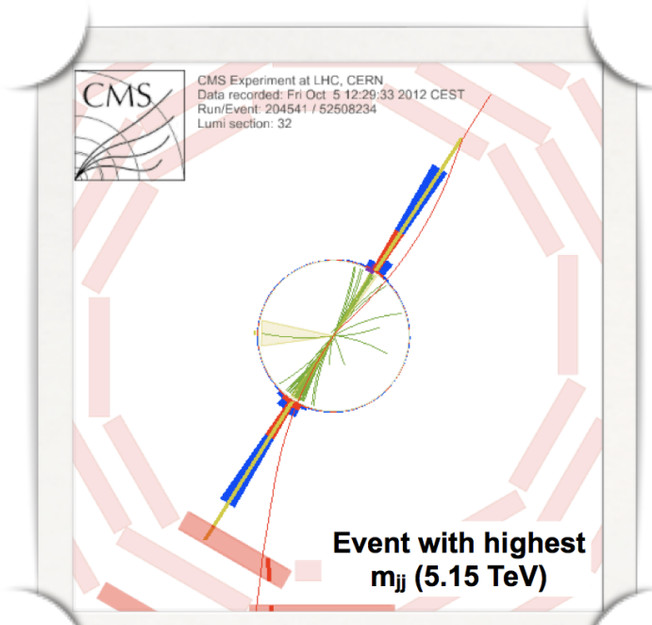
what about BSM physics?







BSM Searches: Executive Summary

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$$\infty \cdot 0 == ?$$

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number of already performed BSM searches

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BSM Searches: Executive Summary

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$$\infty \cdot 0 == ?$$

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general state of (our) mind (?)

SUSY searches: The approach

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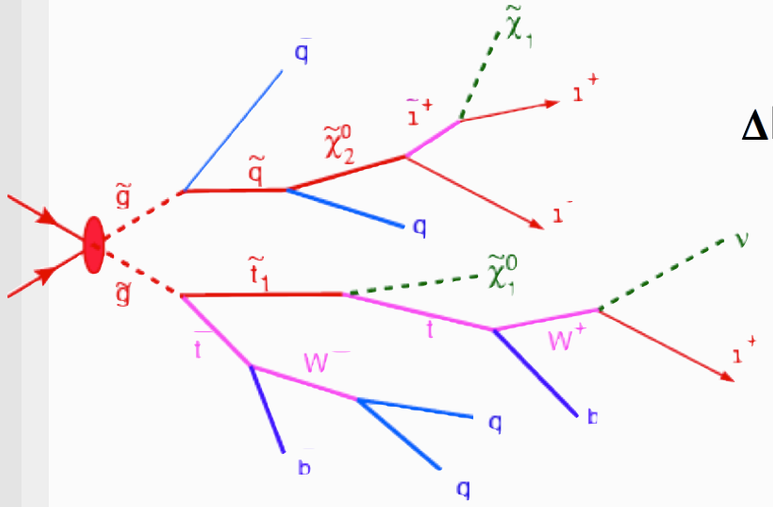
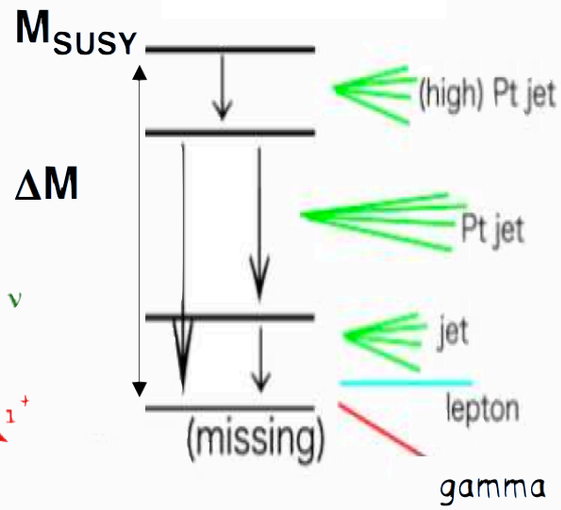
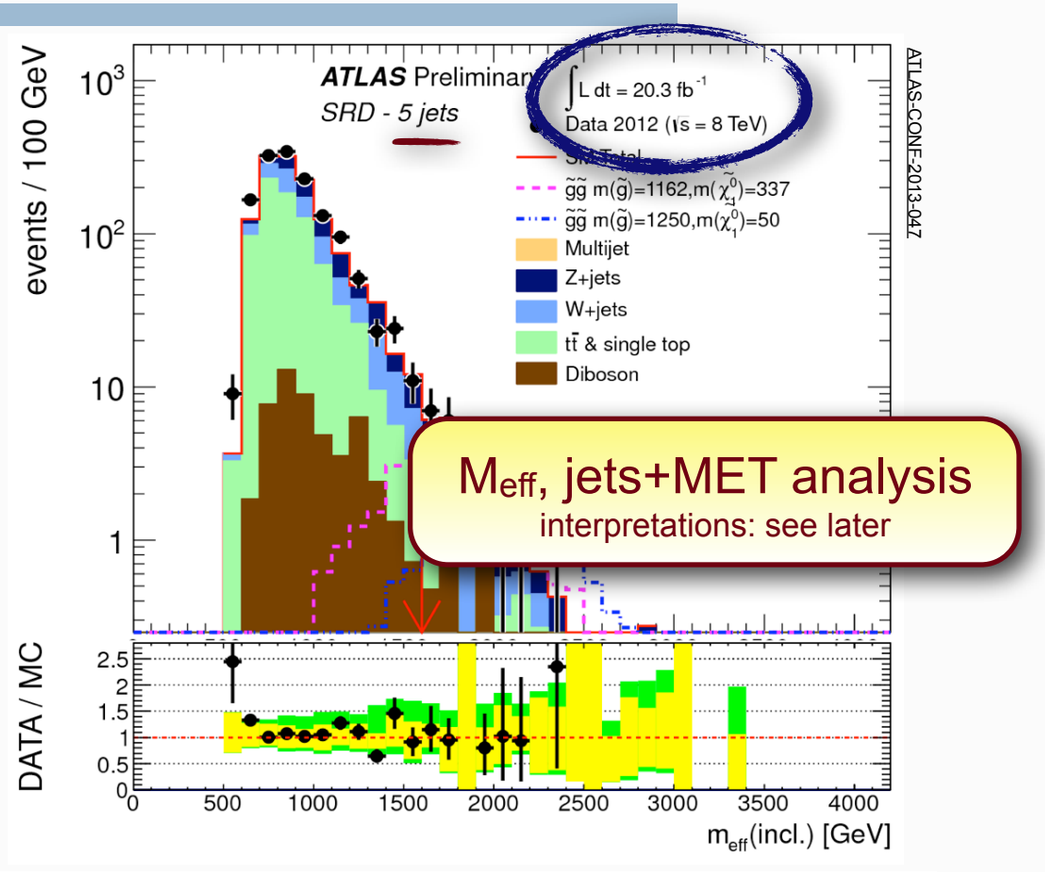




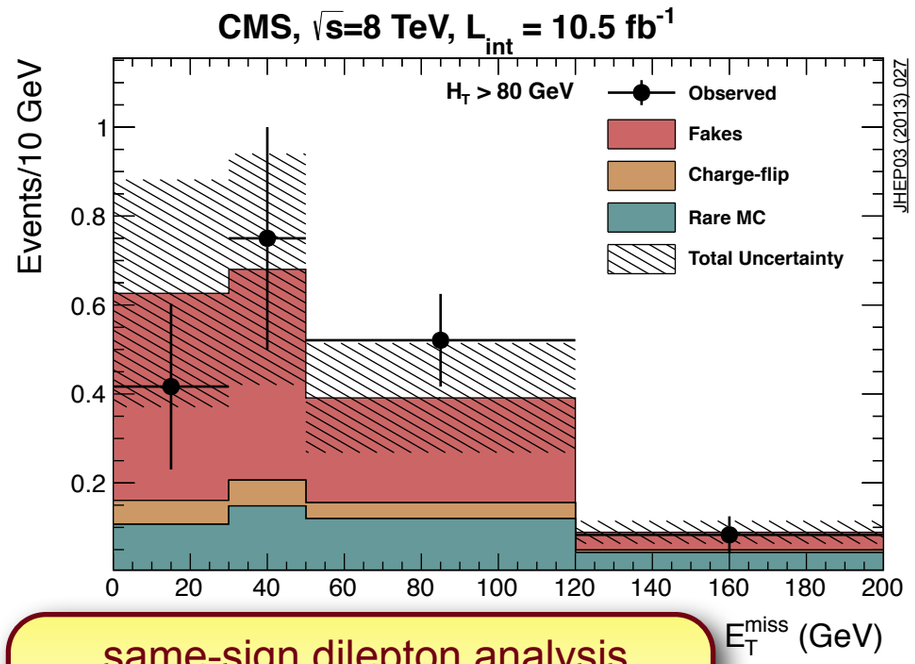
MET ~ ΔM
$H_T = \Sigma\, p_T$ (jet) [+ p_T (l,γ)]
$M_{Eff} = MET + H_T = 2\, M_{SUSY}$

from Pallavorio, SUSY2012



M_{eff}, jets+MET analysis
interpretations: see later

- **generic approach**: search for strongly produced (heavy) sparticles, which decay via cascades
- RPC: assume a stable LSP → missing energy (MET)
- signatures: (many) jets, **large overall (transverse) energy in the event plus MET** (these are also basic trigger req.)
  - plus: lepton(s) and/or photon(s)
- design robust (inclusive searches), backgrounds derived/ controlled from data as much as possible
- Then: define signal regions, count events, including shape information, interpretations



same-sign dilepton analysis

(+b jets) : interpretations in context of several models, as well as generic eff*acc info given, for further interpretations

Interpretations of generic searches

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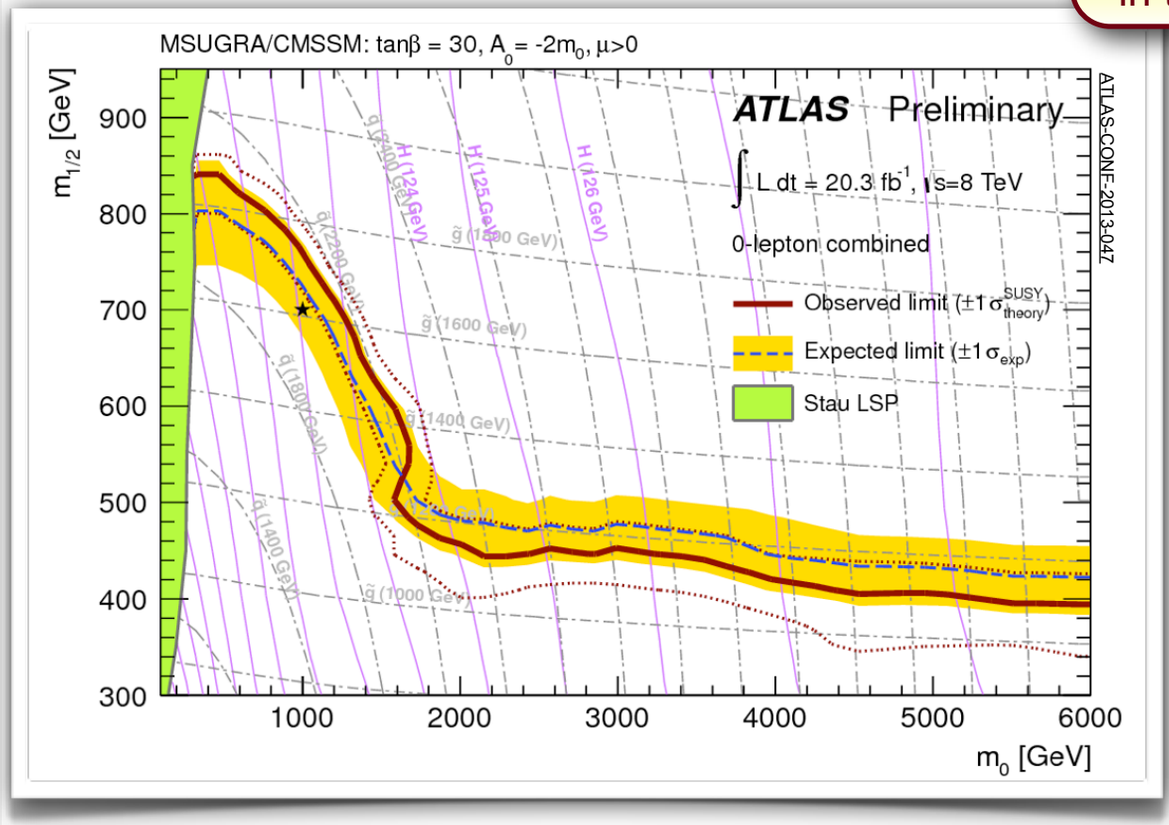
in the context of a concrete model, here MSUGRA/cMSSM



here: example of scenario compatible with a low-mass Higgs as recently discovered

Interpretations of generic searches

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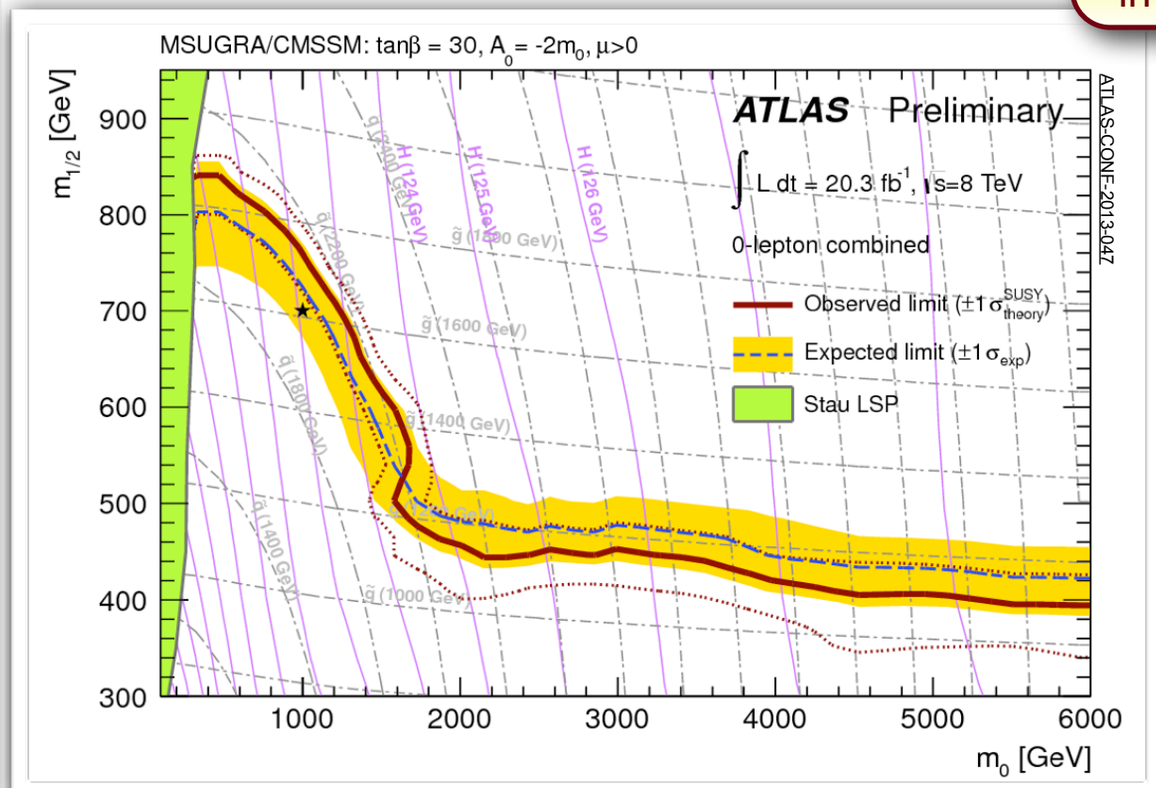
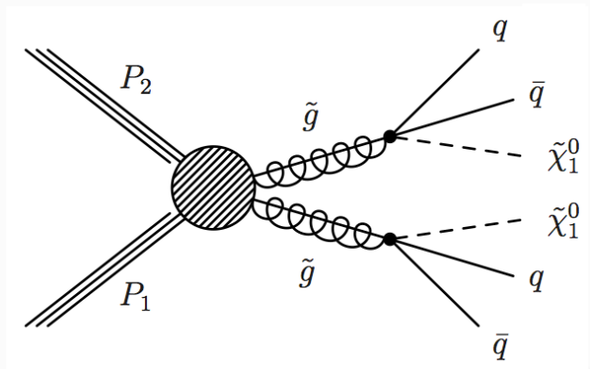
in the context of a concrete model, here MSUGRA/cMSSM

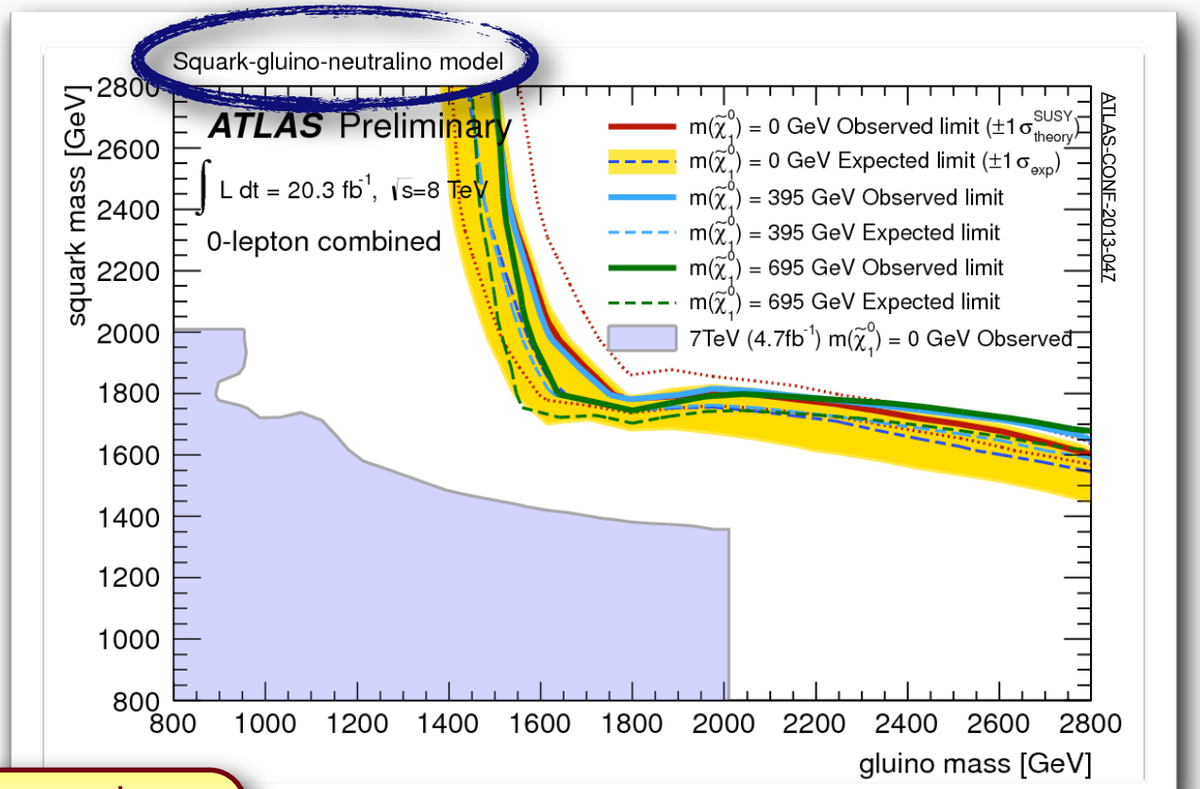


here: example of scenario compatible with a low-mass Higgs as recently discovered

- **eg. for m(squark) = m(gluino), exclude below ~1800 GeV**
- these searches typically target large M_{eff} and large difference m(SUSY) - m(LSP)
- the very inclusive searches keep sensitivity even for m(LSP) up to several hundreds of GeV (at some stage trigger-constrained)

- recently also targeting more compressed spectra and higher jet multiplicities





in the context of a simplified MSSM scenario

Focus on 3rd generation and EW prod.

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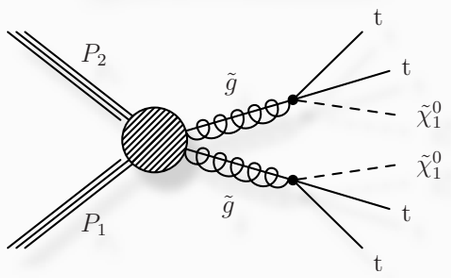
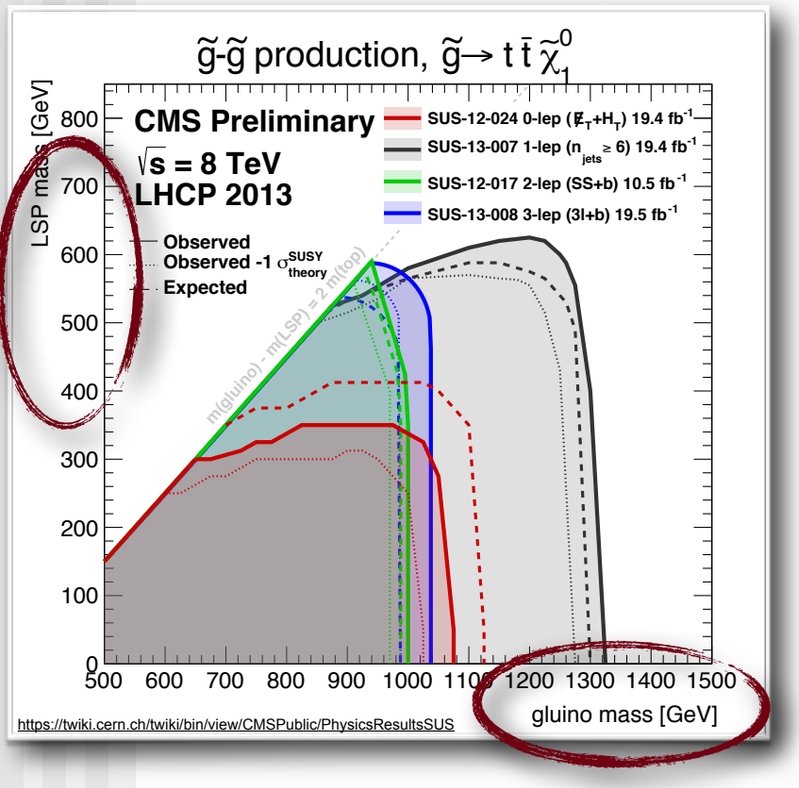
gluino-mediated



- a lot of focus on **"natural" SUSY scenarios, with "light" sbottom/stop**
  - and other squarks very heavy
- targeting direct or gluino-mediated sbottom/stop production
- eg. extending generic searches by adding b-tags, or "ttbar+MET" searches
- as well as direct production of "EWKinos" (charginos, neutralinos)



new 8 TeV results!

see also ATLAS summary plot

Focus on 3rd generation and EW prod.

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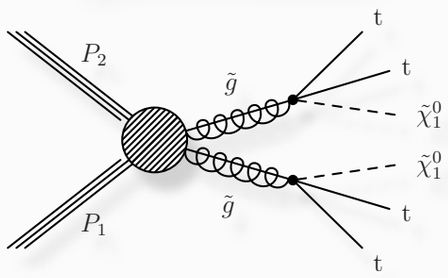

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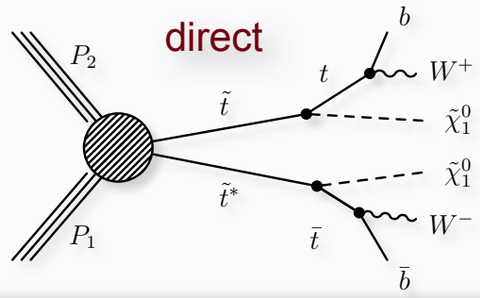
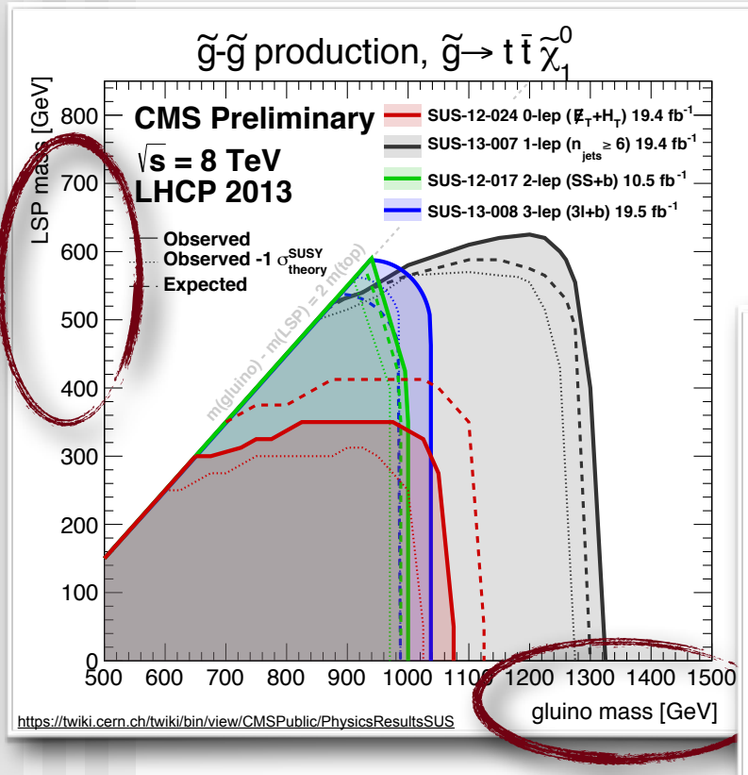
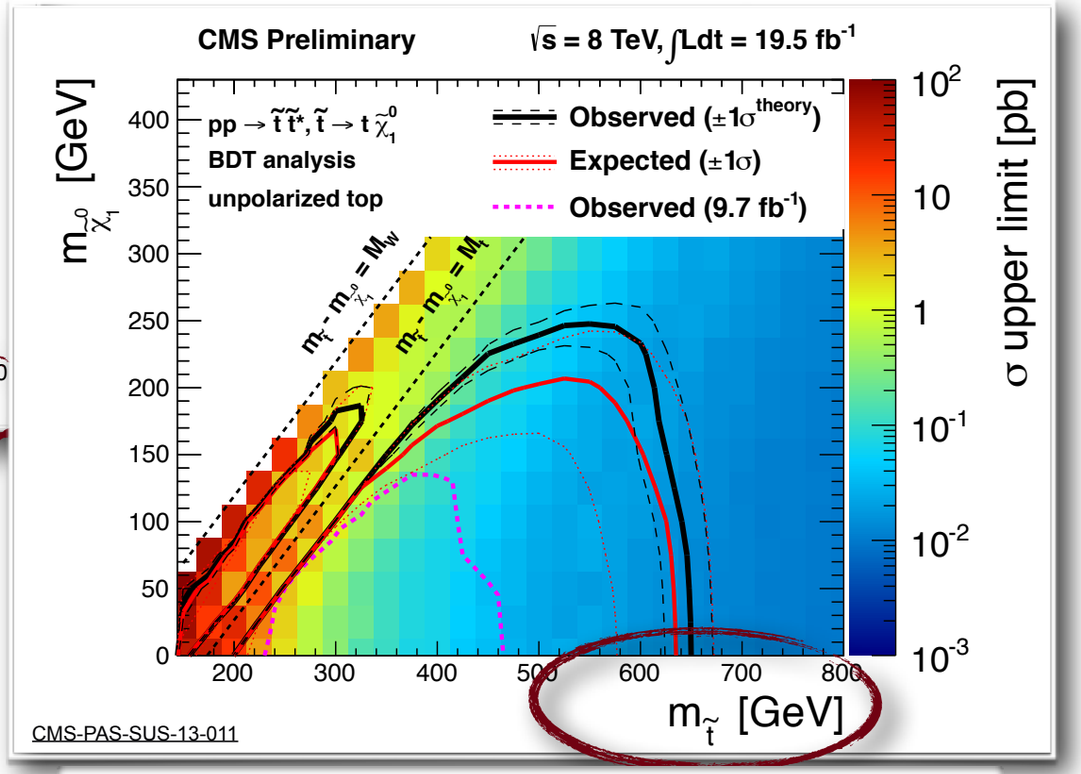
direct







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- impressive reach towards high stop and LSP masses
- good reach even for $m_{Stop} - m_{LSP}$ between m_W and m_{Top}
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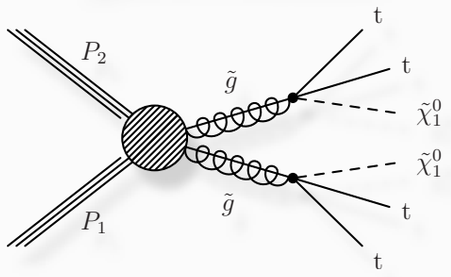

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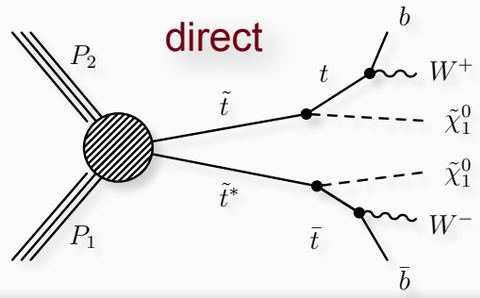
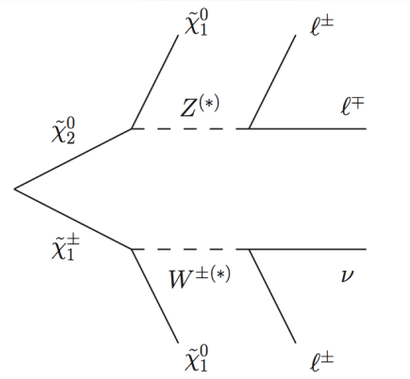
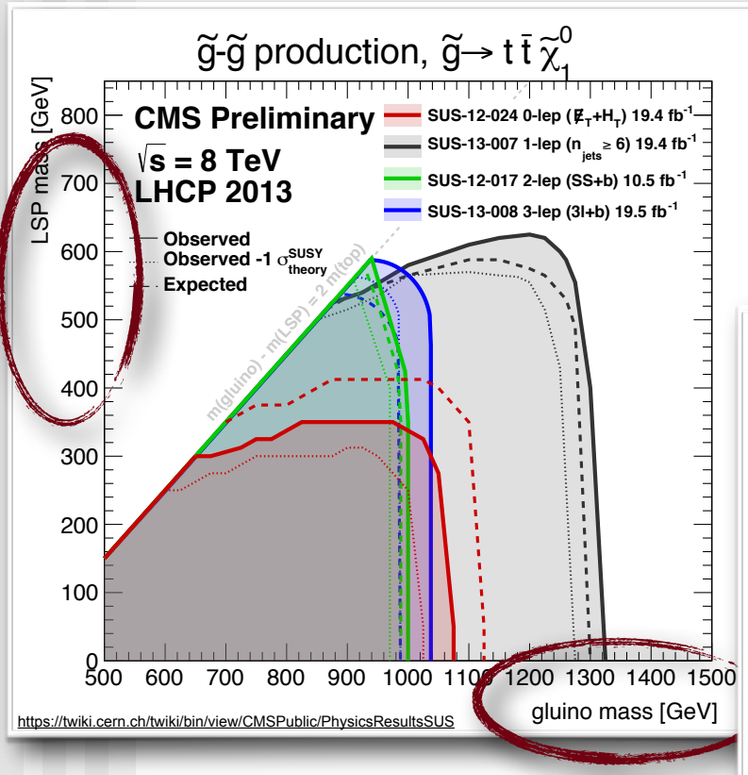
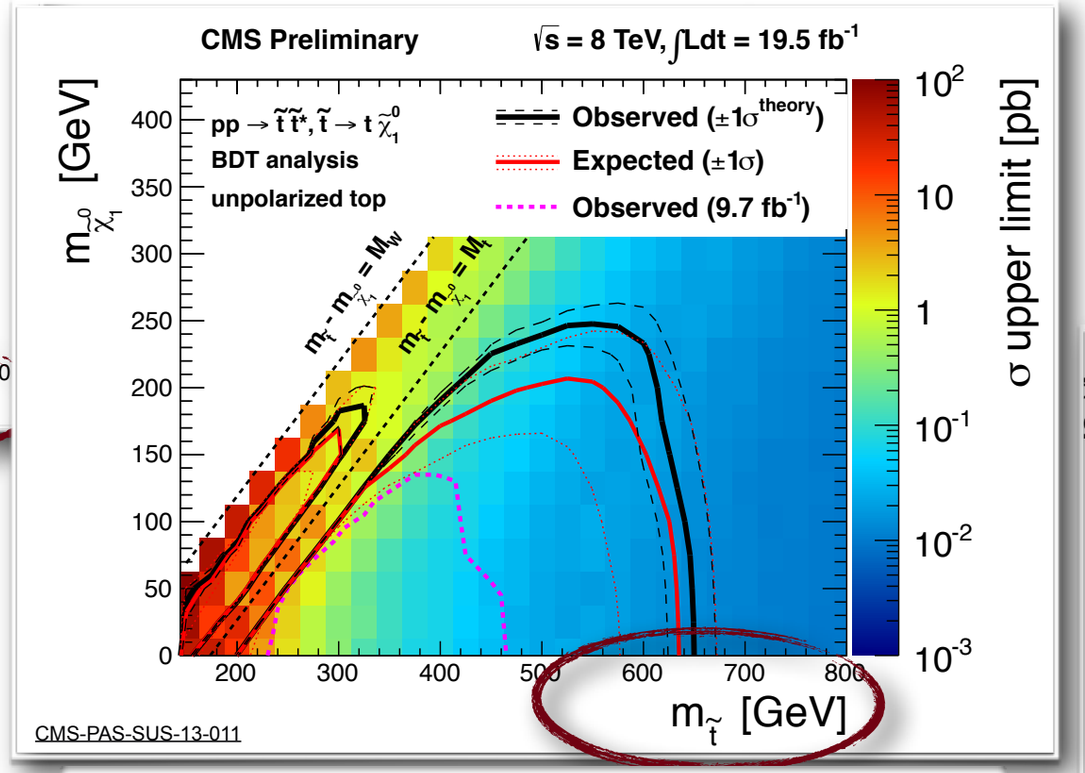
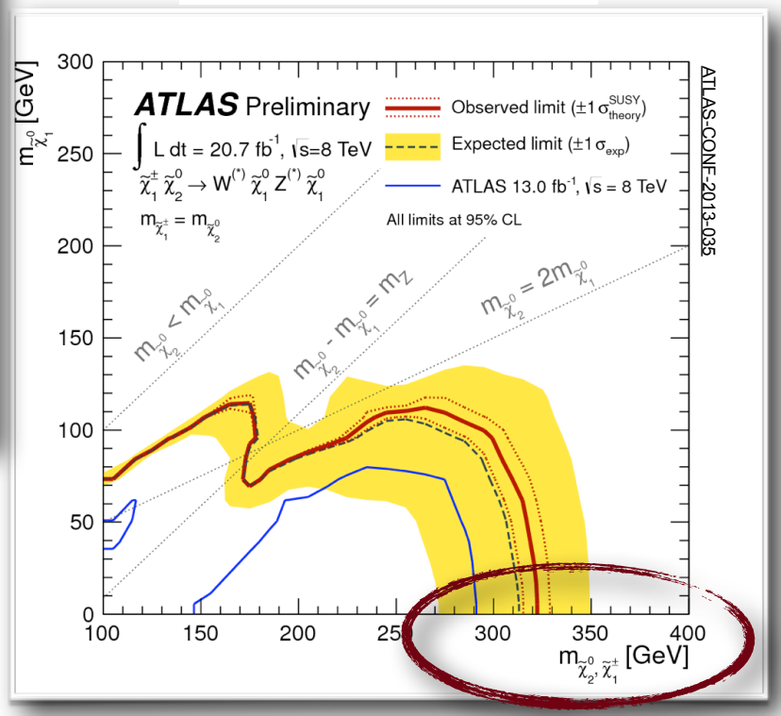


"EWKinos"









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The big picture

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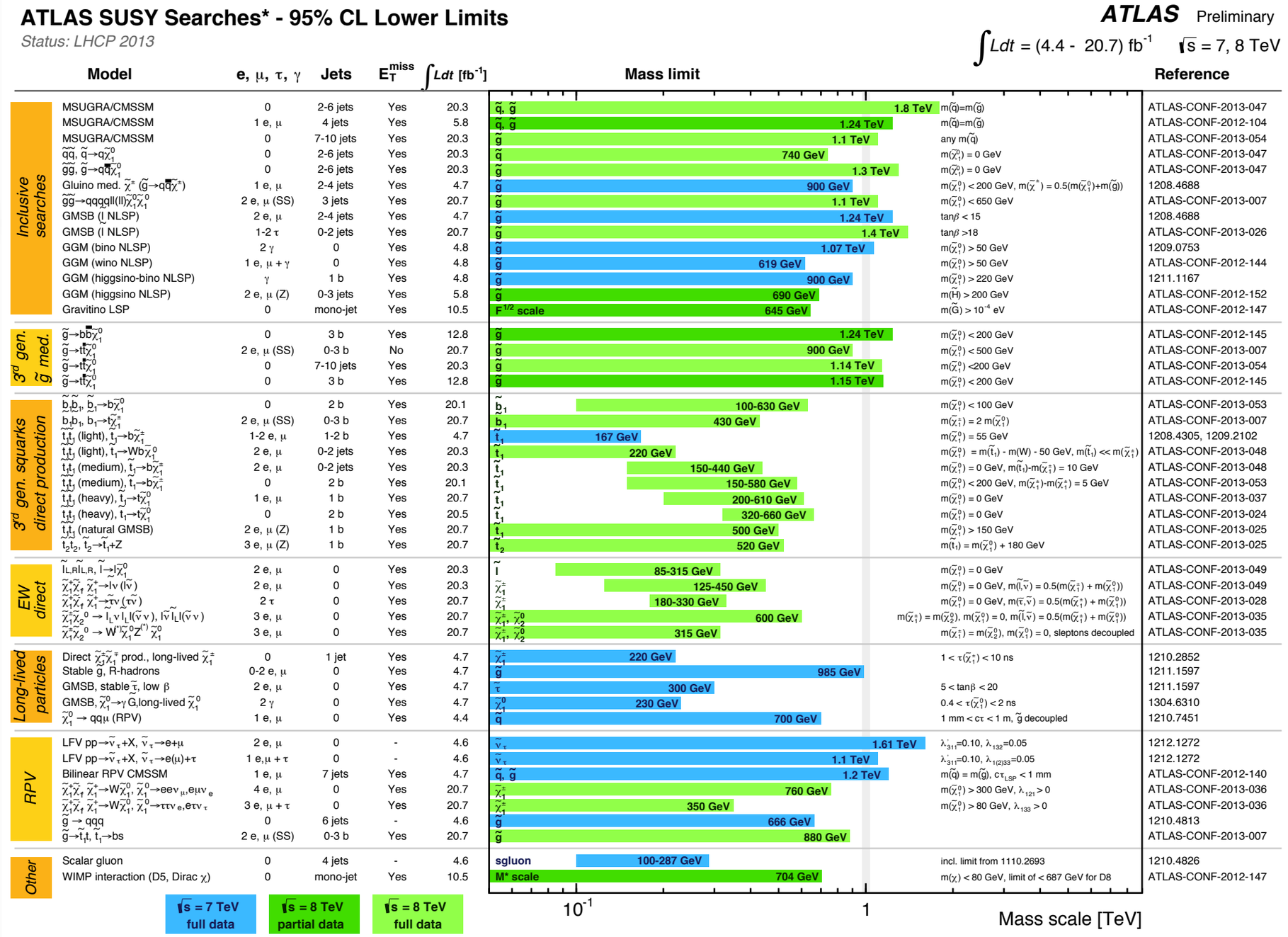
inclusive searches

Natural SUSY and EW prod.

long-lived particles, eg. split SUSY

RPV



*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/CombinedSummaryPlots

- limits **dependent on assumptions for m(LSP), intermediate states, ...**

e.g.

- impressive list, similar plethora of results from CMS

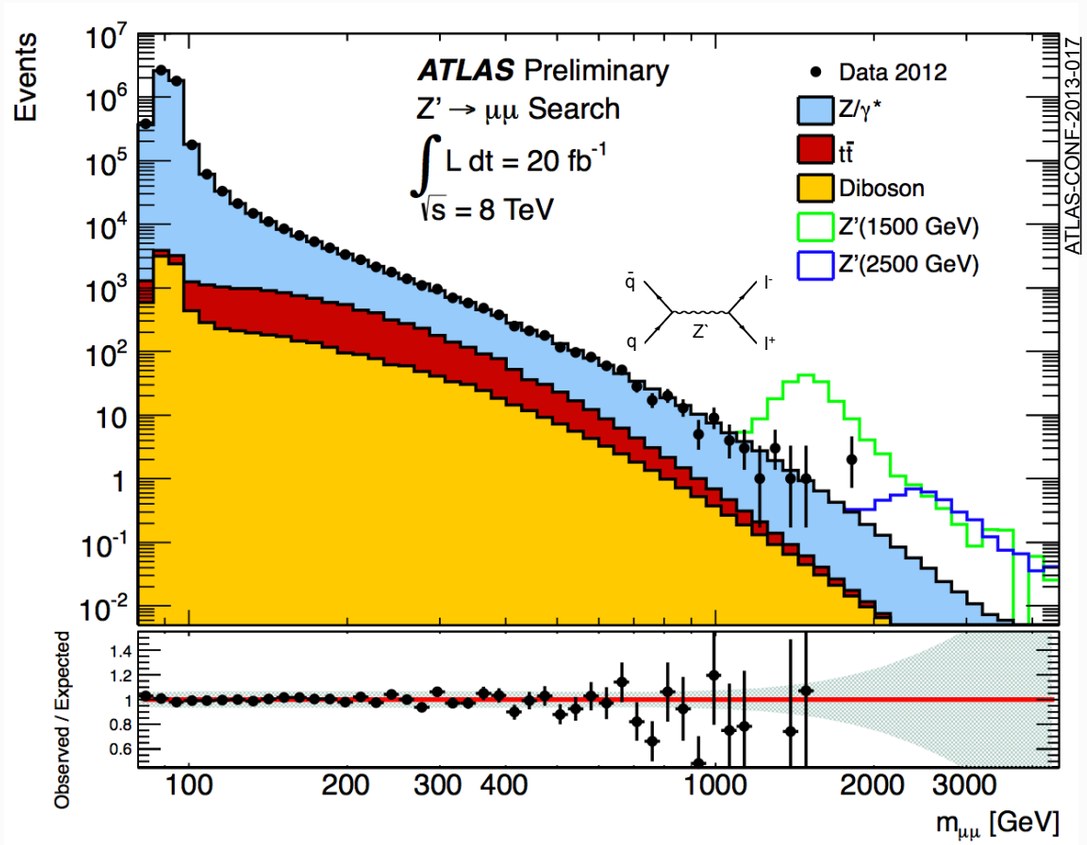
  see https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

- but: **read the fine-print** !!

Exotica : still looking....

cf. Talk by S. Worm

- the philosophy: leave no stone unturned...
- two “classical examples”:



Z’ with SM-like couplings > 2.9 TeV

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ETH Institute for Particle Physics

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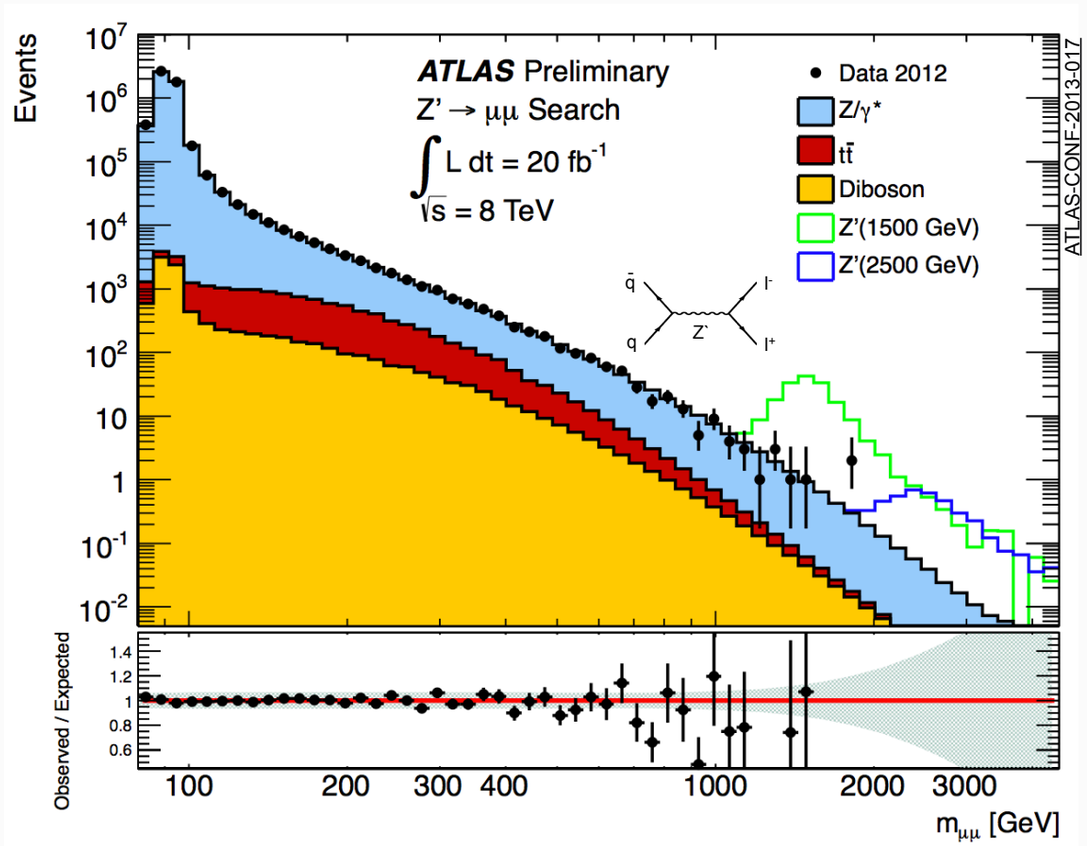
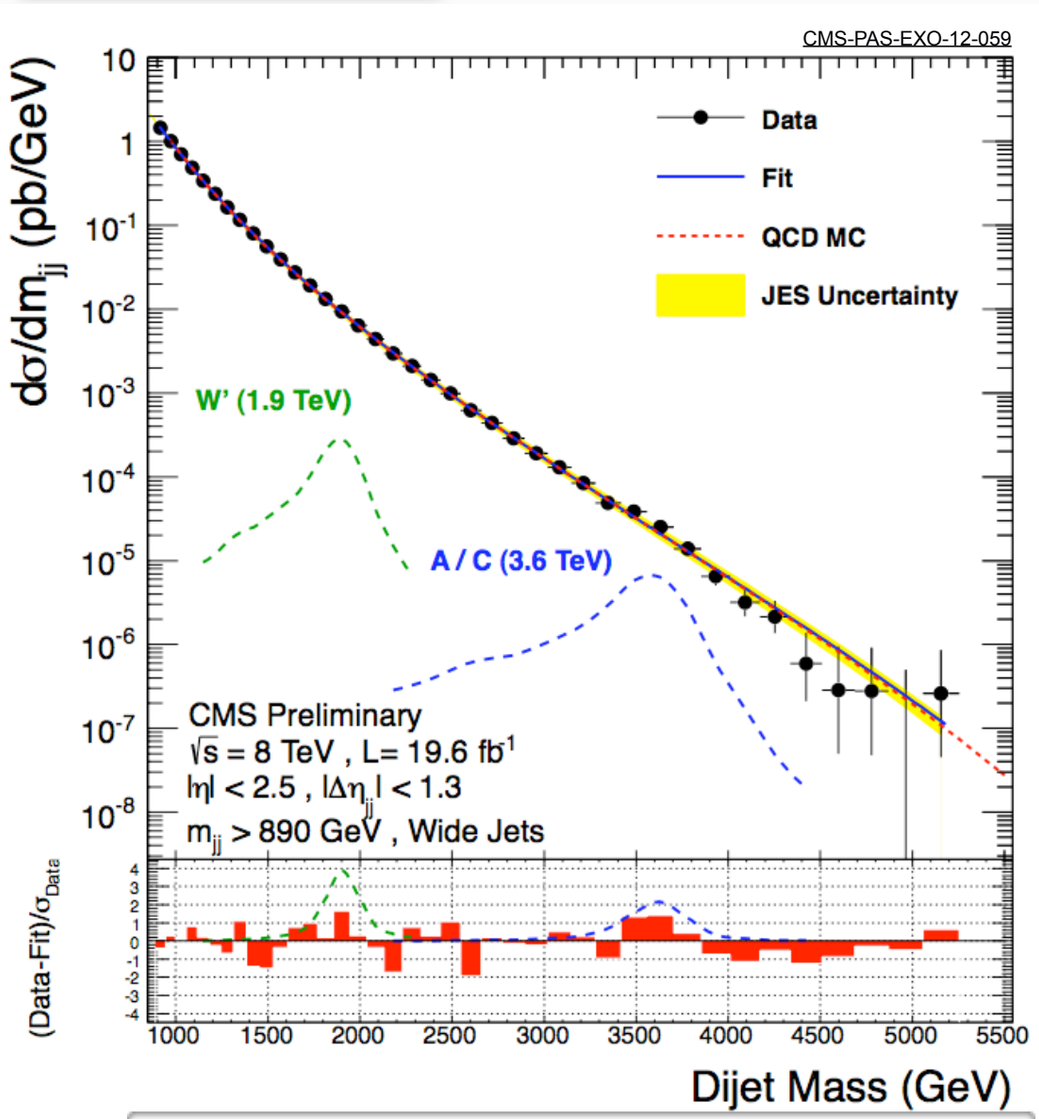


- **Z’ with SM-like couplings > 2.9 TeV**

Also, new on full statistics, 8 TeV: some CMS examples

- W’ with SM-like couplings > 3.35 TeV
- Update on long-lived particles (HSCP)
- Top partners, T5/3, exclude [550-770] GeV
- Limits on large extra dimensions from dielectron, dimuon evts



- **q* excluded for [1.2, 3.5] TeV**
- **string resonance for [1.2, 5.08] TeV**
- plus a number of other interpretations

Exotica : still looking...

cf. Talk by S. Worm

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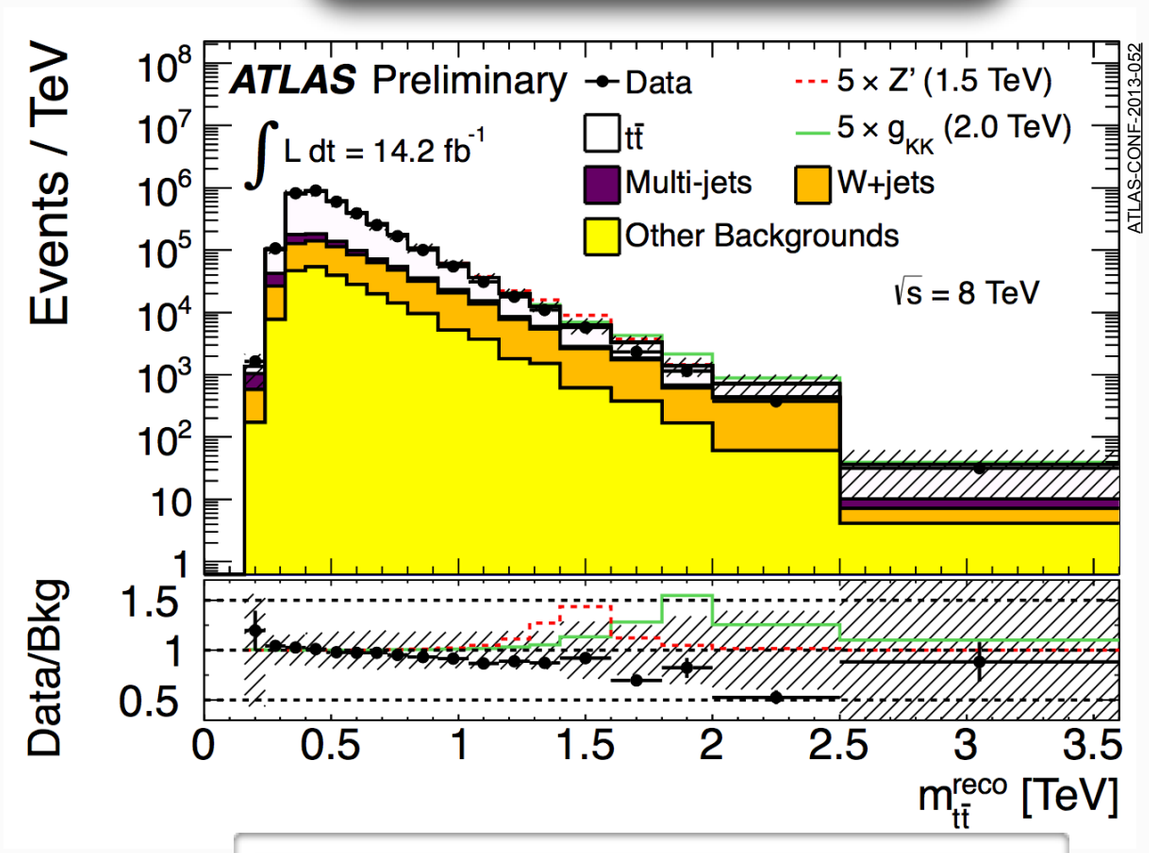
- further examples:

search for ttbar resonances



Kaluza-Klein gluon excluded for m< 2 TeV

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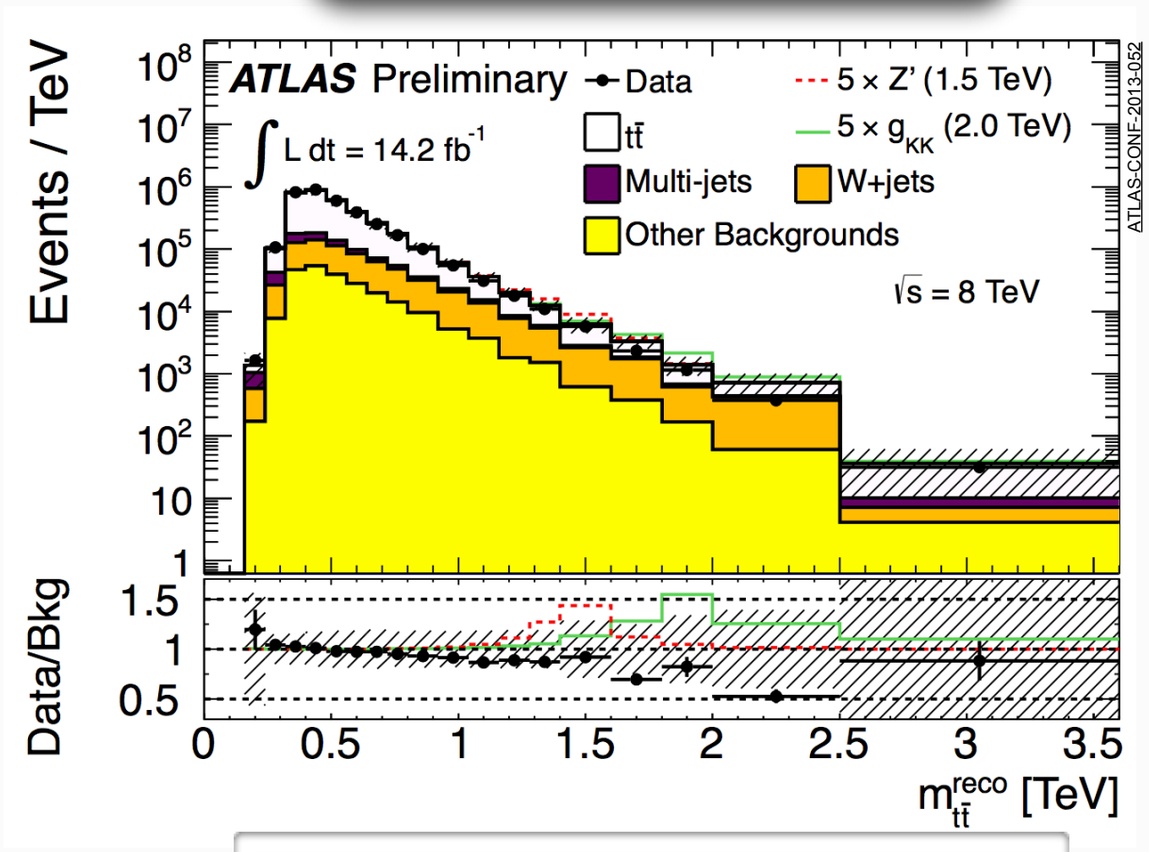
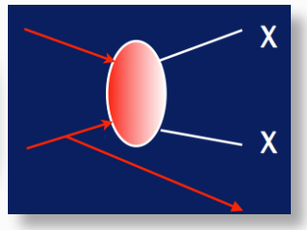
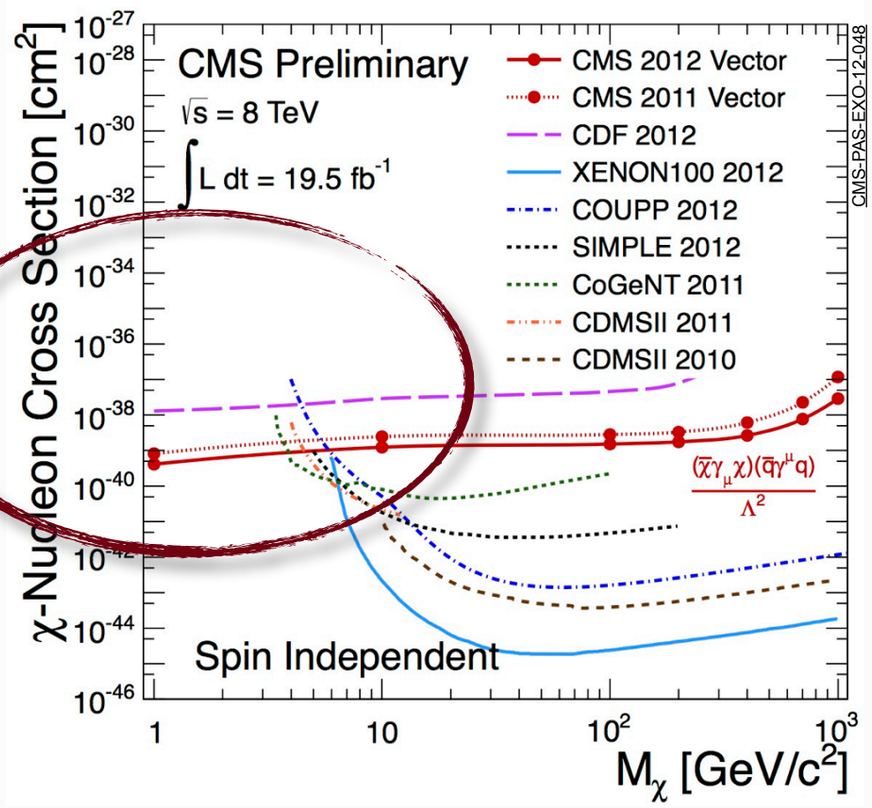
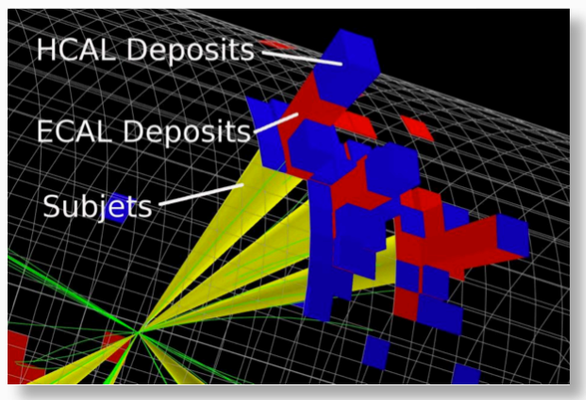


- **Kaluza-Klein gluon excluded for m< 2 TeV**

mono-jet and mono-photon searches







- **ttbar inv. mass spectrum** : no anomalies seen so far
- modern tools deployed (boosted top reconstruction)
- **mono-jet/photon searches**: nice complementarity with direct DM searches

Exotica: Executive summary

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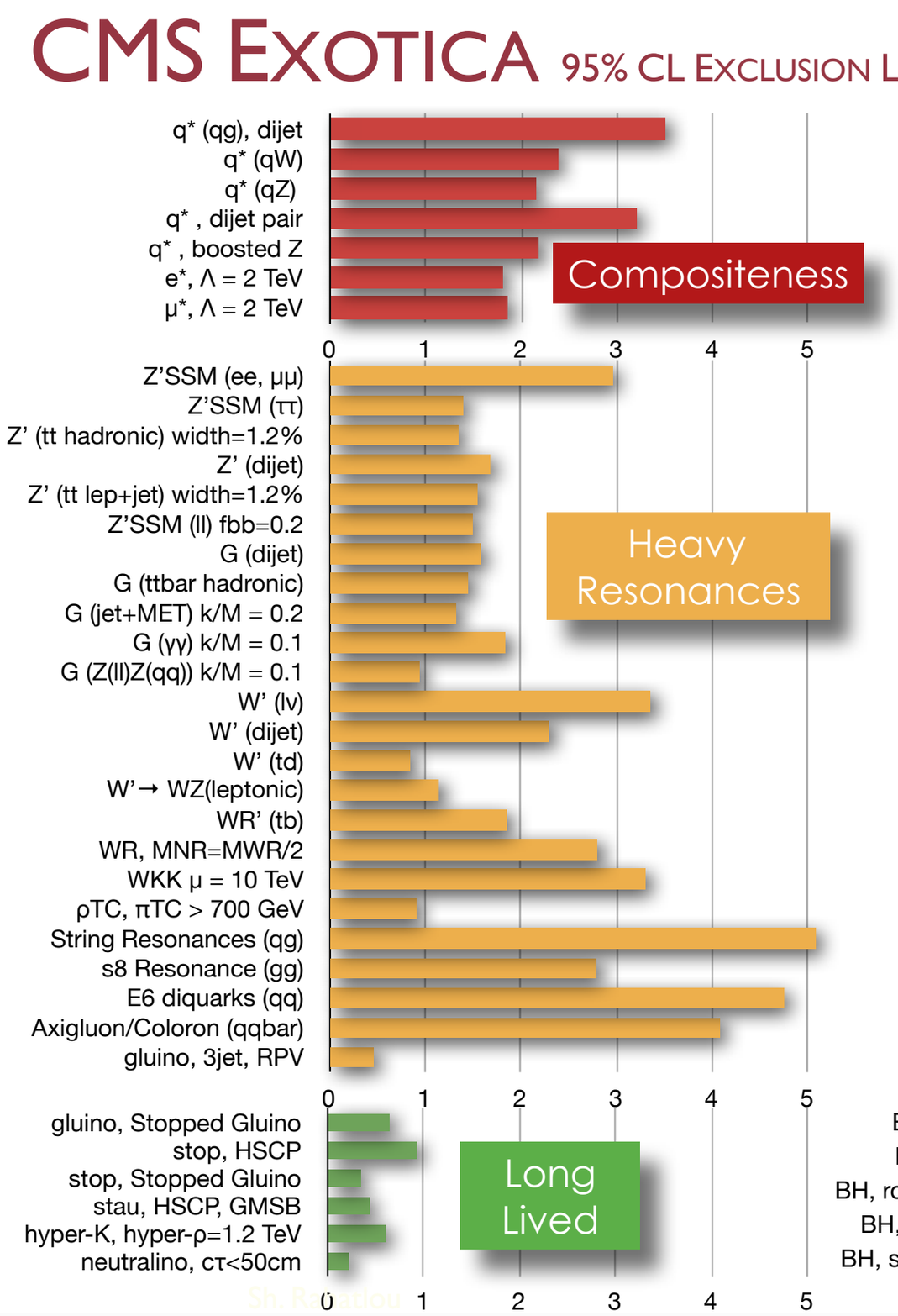
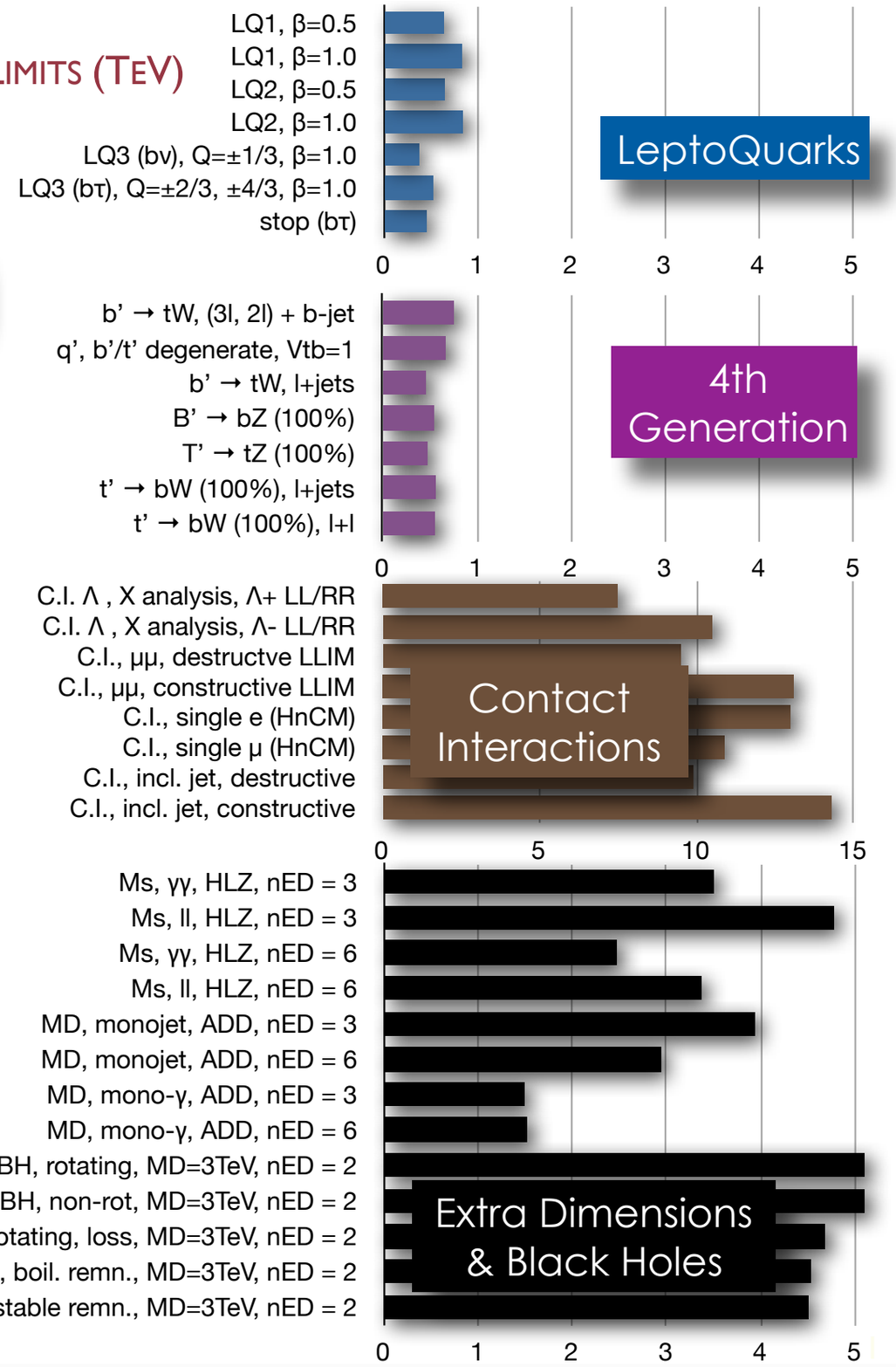
https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsEXO/CMS-EXO-Moriond2013.pdf

CMS EXOTICA 95% CL EXCLUSION LIMITS (TEV)





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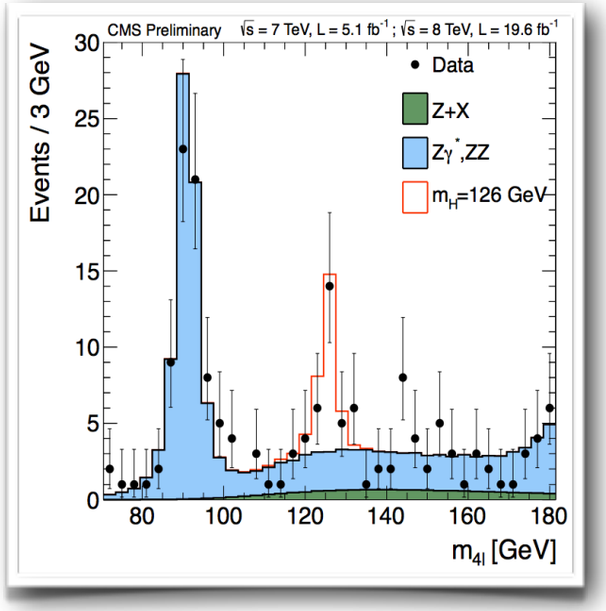
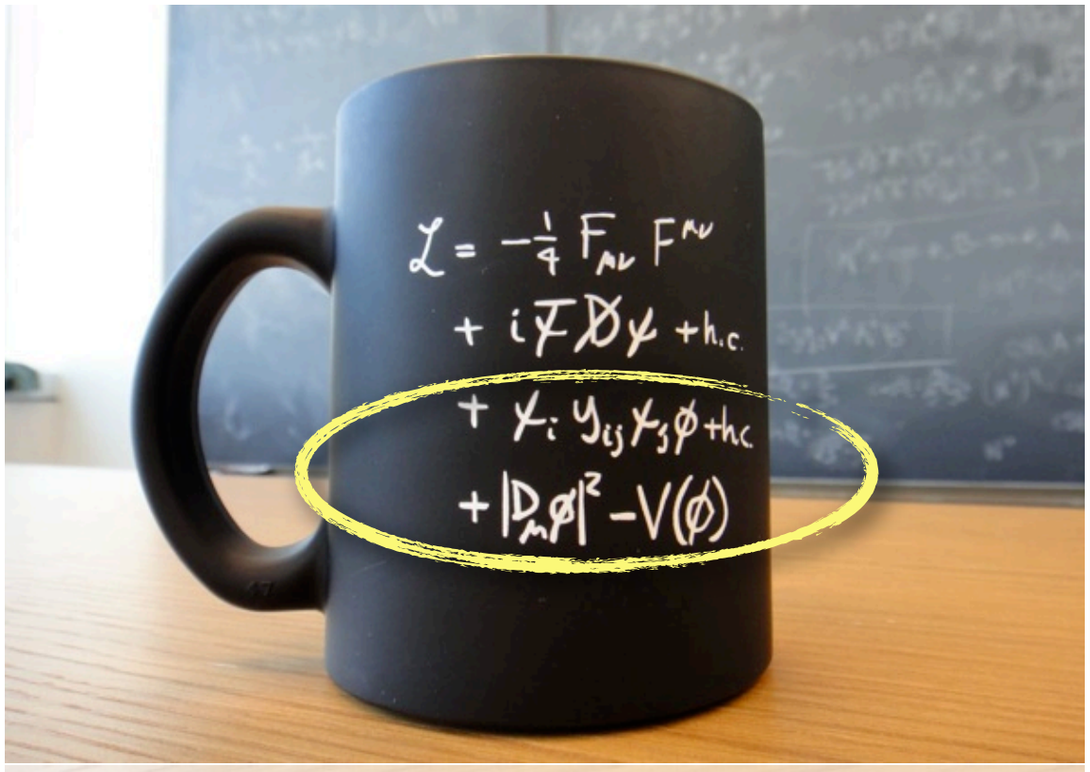
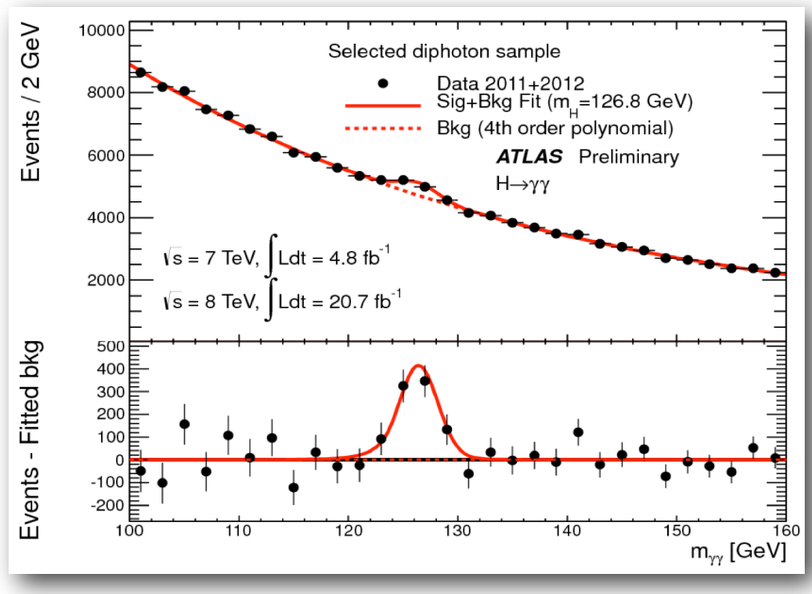
Higgs physics







see also the talks in the dedicated sessions for more details

At a glance...

ETH Institute for Particle Physics

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H→WW	two leptons with opposite charge MET	medium O(1)	-	~10^3 ~120 (sel)	cross section, BR, couplings to V
H→γγ	two photons peak in inv. mass	low O(0.1)	2%	800 ~400 (sel)	H mass, couplings $K_V K_F$, discovery
H→ZZ	four leptons with right charge peaks in inv. mass (Z_1 and Higgs)	high >1	1-2%	40 ~12 (sel)	H mass, discovery

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~4 σ obs each

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~4 σ obs each

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close to 7σ obs each

Also new (based on full statistics):
ttH→γγ (CMS)
H→Zγ (ATLAS,CMS)
H→μμ (ATLAS)
WH→WWW→3l3ν (CMS)
H →ZZ→2l2τ, 2l2ν, WW→lνjet (high mass) (CMS)

Plus:
latest combinations, non-SM Higgs studies, see
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIG

Some highlights: 7+8 TeV, full stat.

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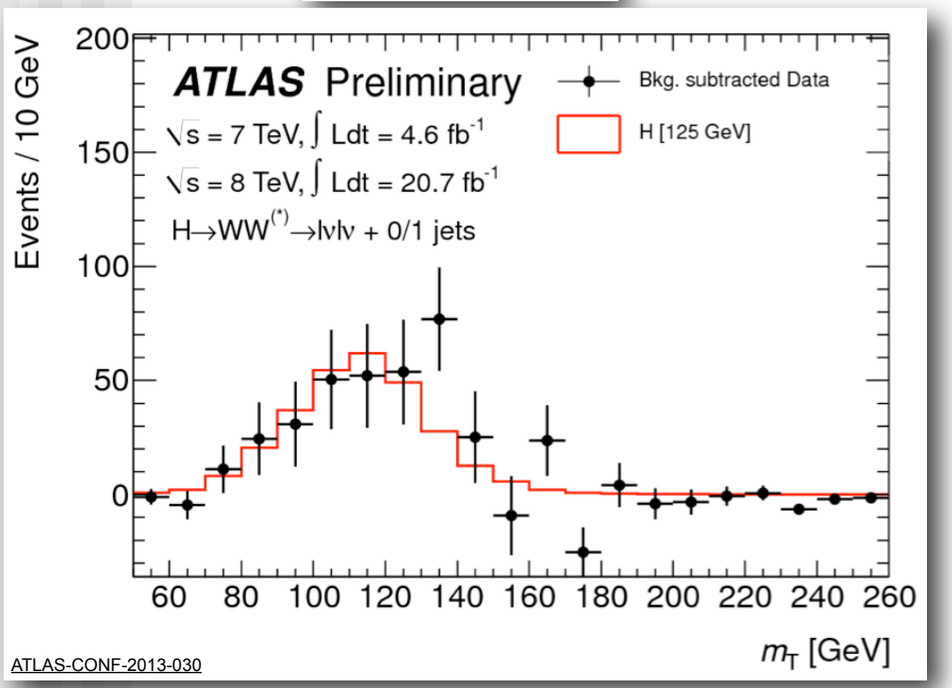
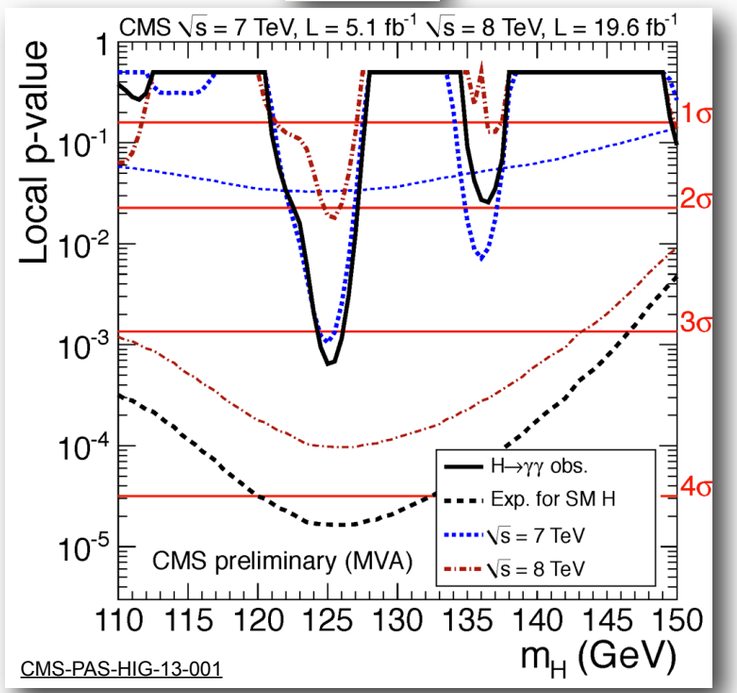
H→WW→2l2ν



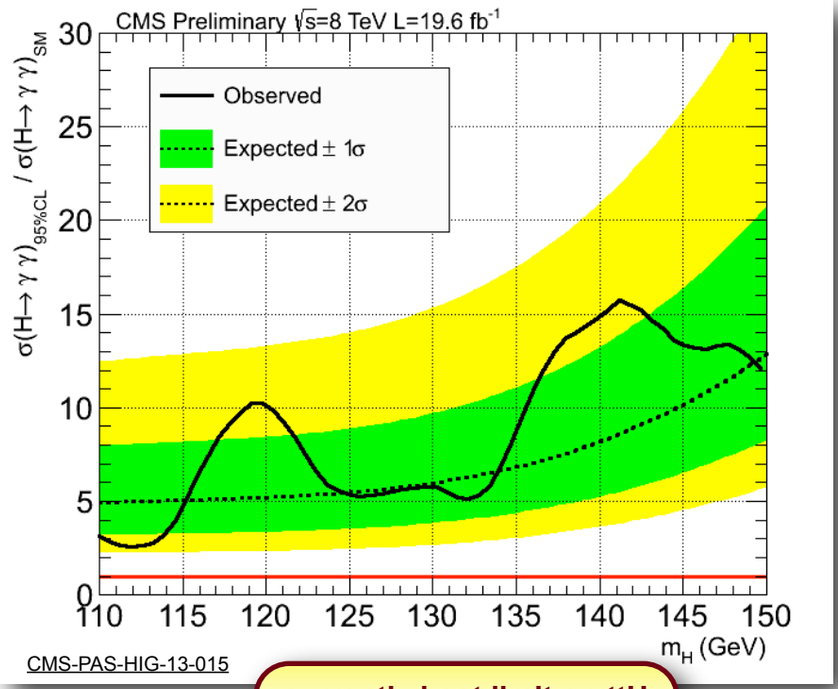
ATLAS-CONF-2013-030

H→γγ



CMS-PAS-HIG-13-001

ttH→γγ



CMS-PAS-HIG-13-015

currently best limit on ttH

Some highlights: 7+8 TeV, full stat.

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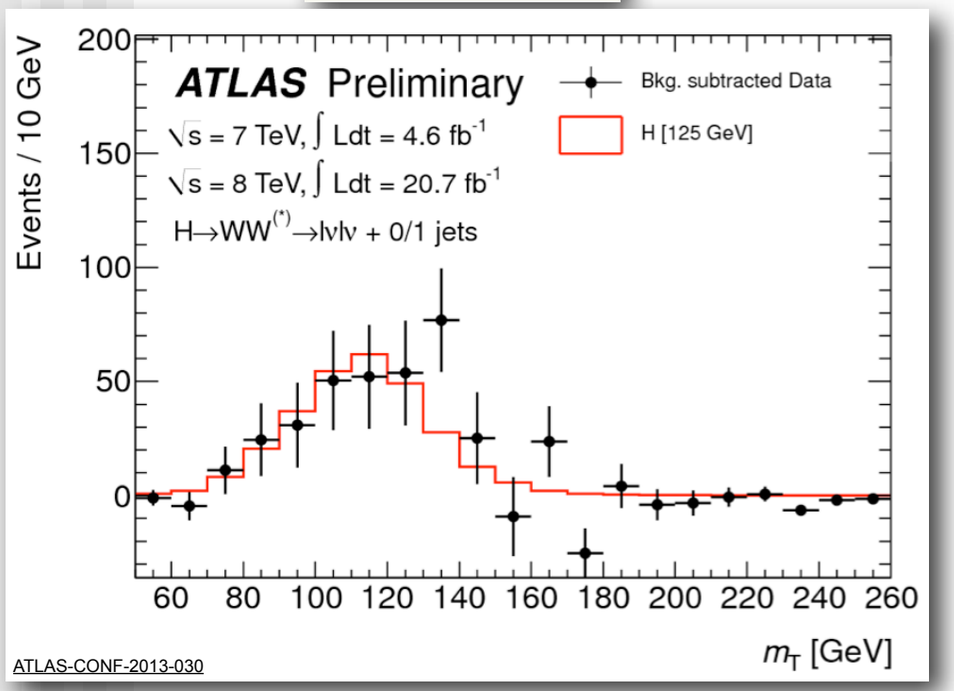
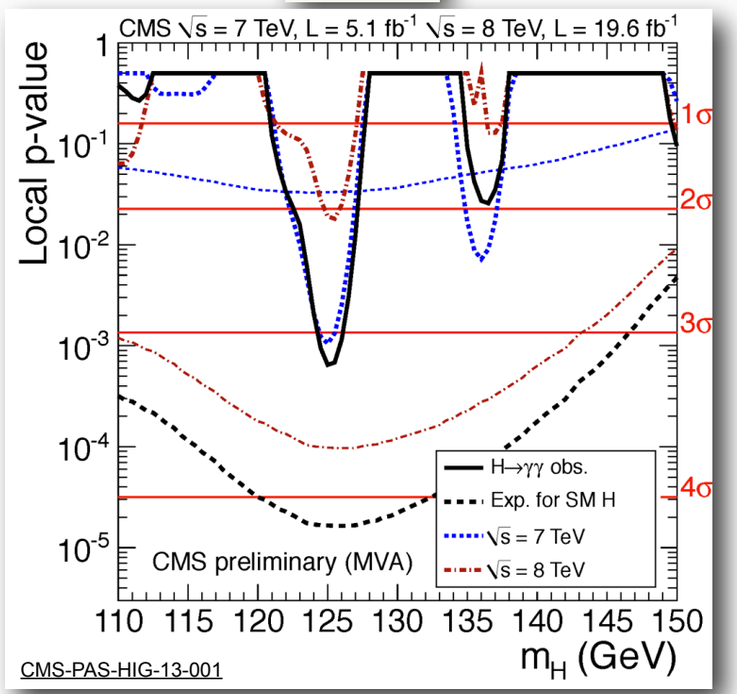
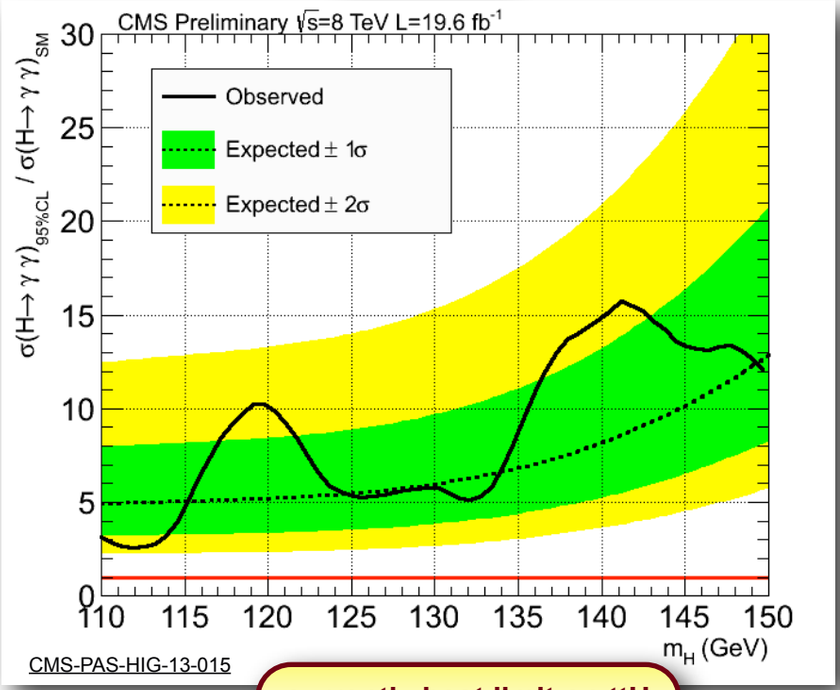
H→WW→2l2ν



H→γγ



ttH→γγ



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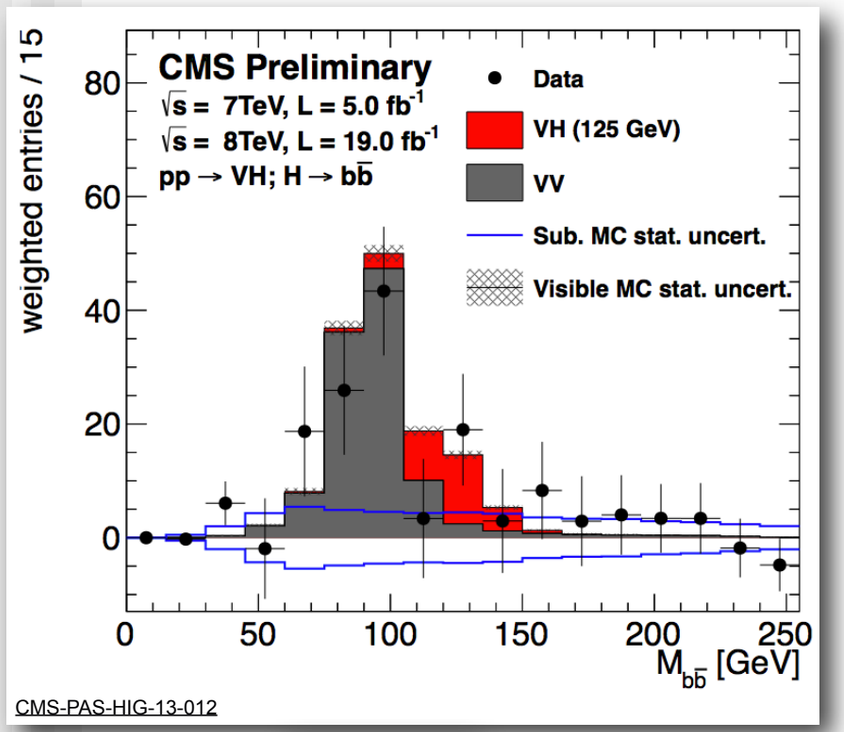
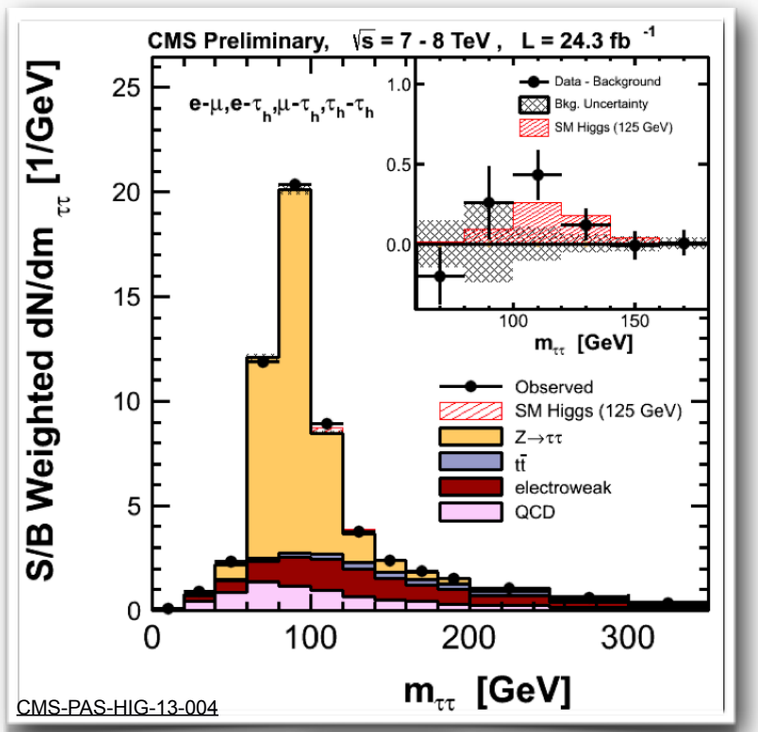
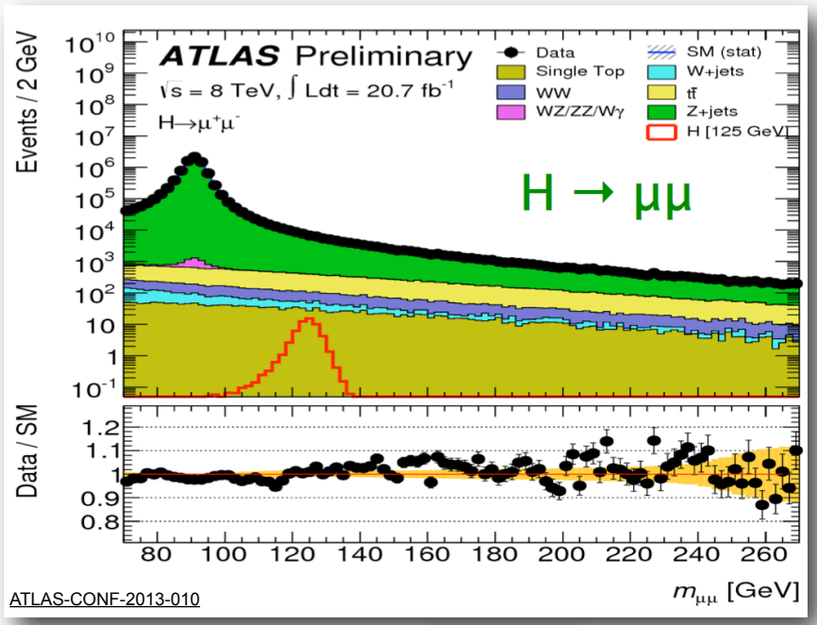


VH→bb



H→ττ



H→μμ

Questionnaire

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Question	Done?	How
Statistically significant?	yes	Estimate p-value on combination
Is it a boson?	yes	It decays in γγ
Mass?	yes (improving)	Use γγ and ZZ channels
Spin?	yes (improving)	Use kinematics of decay products
Parity?	yes (improving)	Use kinematics of decay products
Is it "the" Higgs boson?	progressing	Measure BRs and couplings
Is it "a" Higgs boson?	checking	Measure couplings and look at different mass regions

Daniele del Re, Lake Louise 2013

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Is it "a" Higgs boson?	checking	Measure co[illegible] different mass regions

new results from HZZ, HWW and Hγγ

recent extensive studies from combinations of all channels

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Signal strengths and mass

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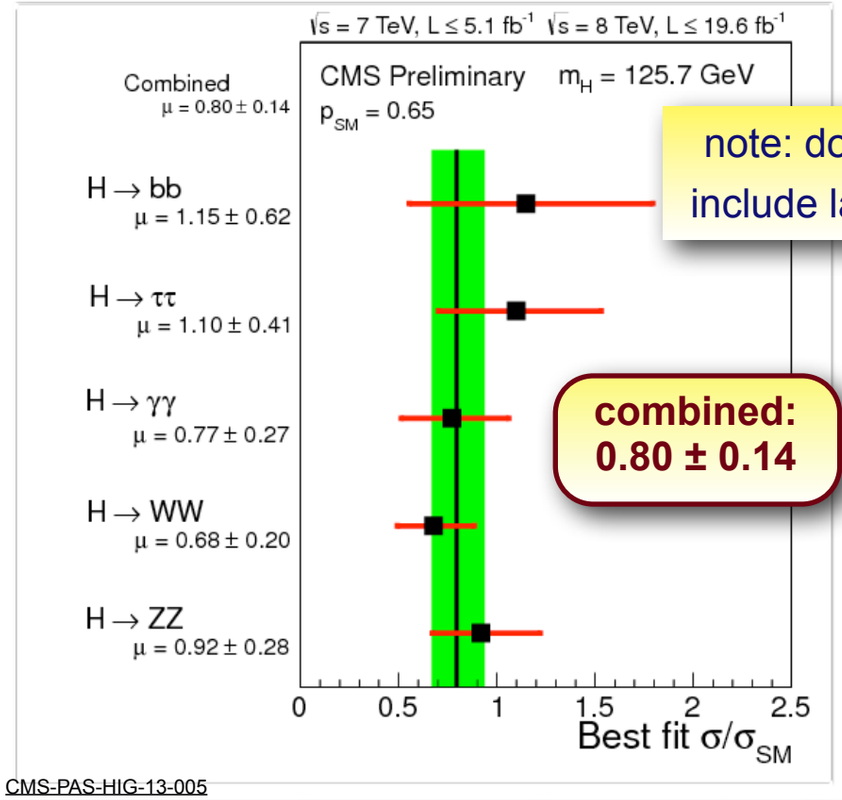
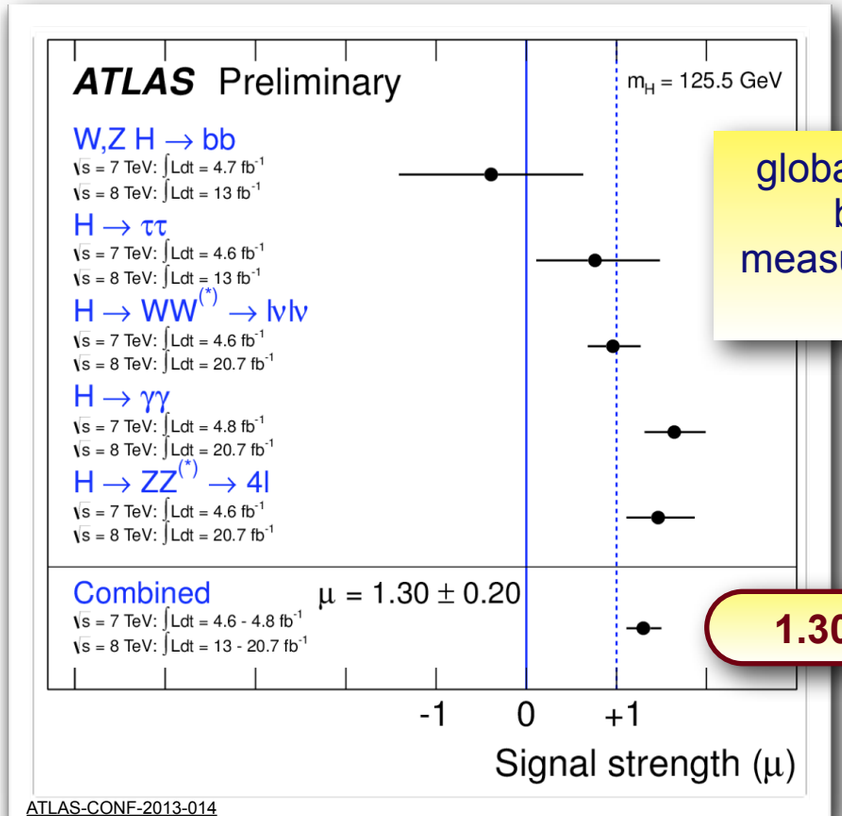
signal strength



note: does not yet include latest VHbb

combined: 0.80 ± 0.14

CMS-PAS-HIG-13-005



global compatibility between 5 measured μ and μ=1 is 8%

1.30 ± 0.20

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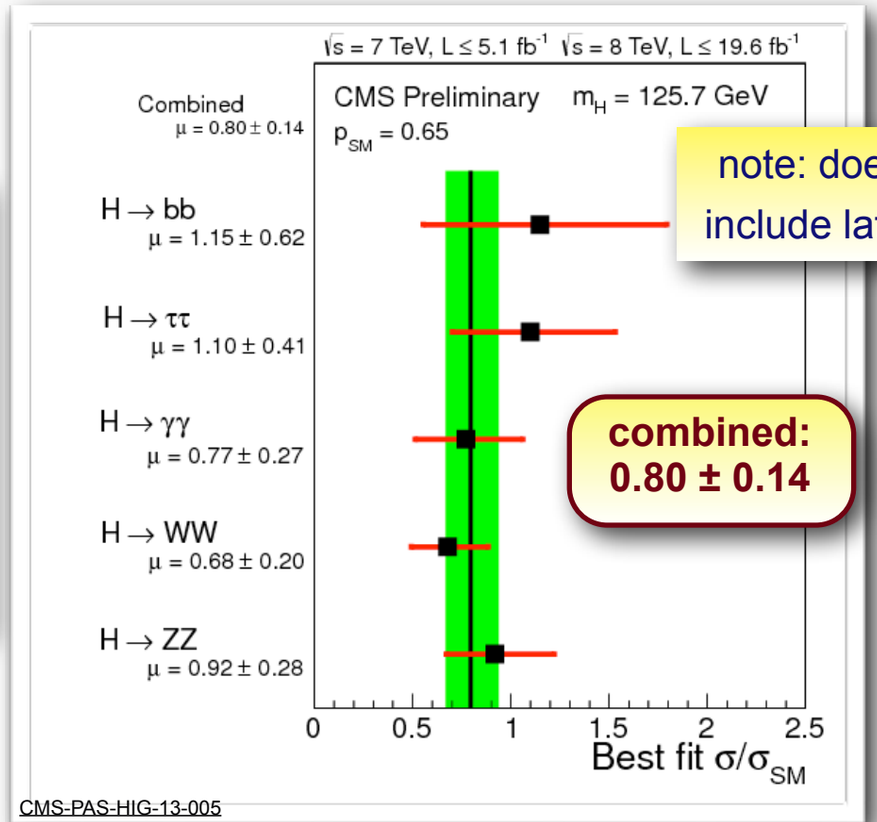
Signal strengths and mass

ETH Institute for Particle Physics

signal strength



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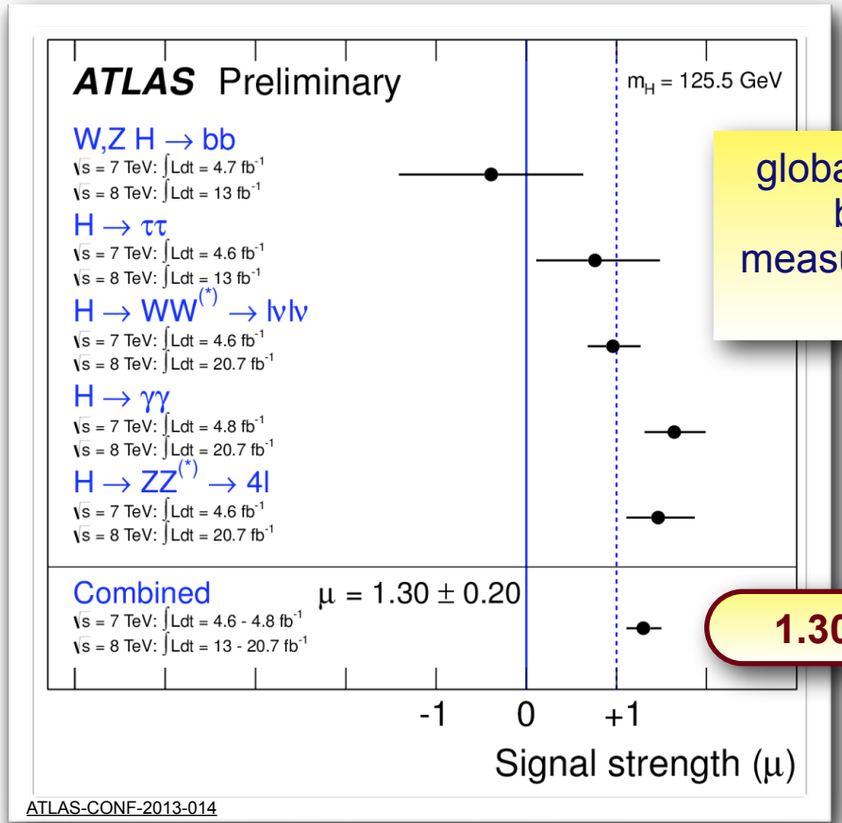

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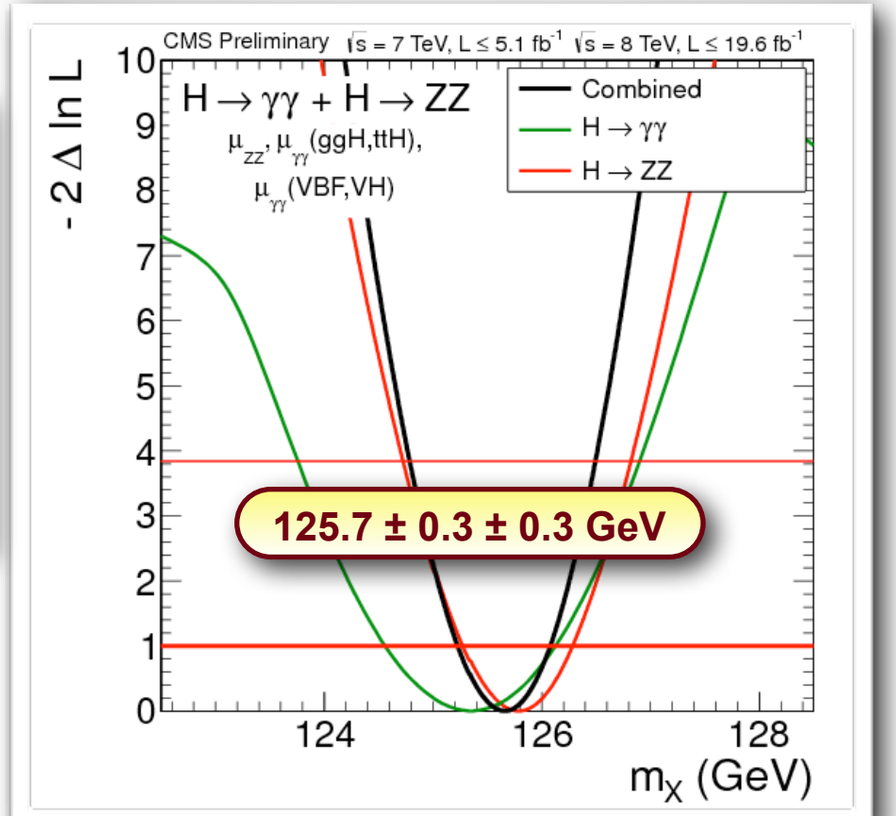
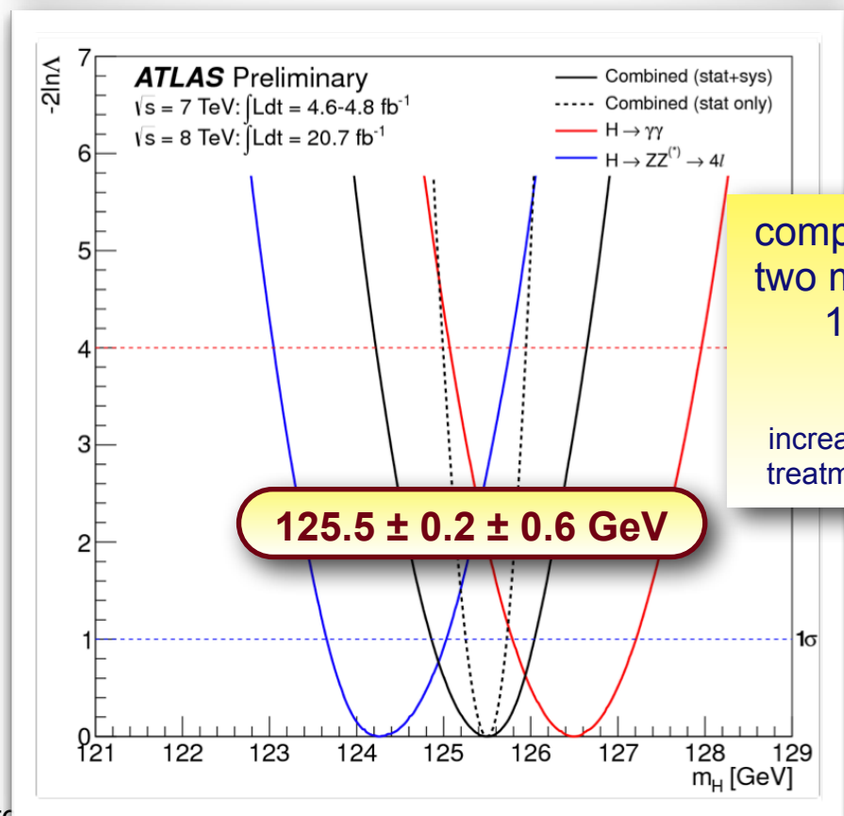
mass



125.7 ± 0.3 ± 0.3 GeV



125.5 ± 0.2 ± 0.6 GeV

compatibility between the two measurements at the 1.5% (2.4 σ) level

increases to 8% with alternative treatment of systematics uncert.

Spin - Parity

cf. recent talks at LHCP

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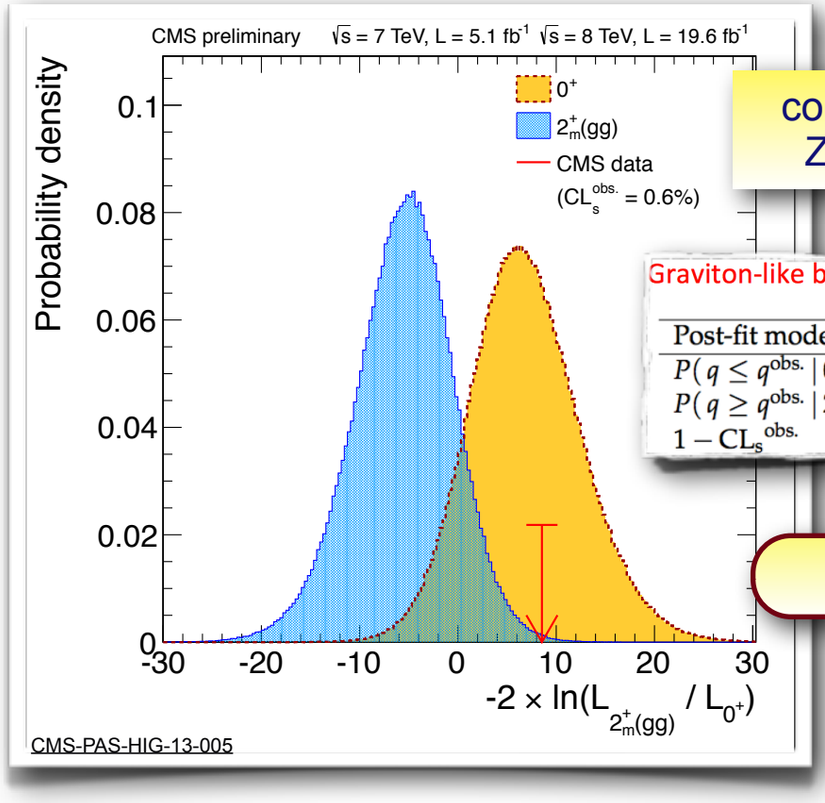
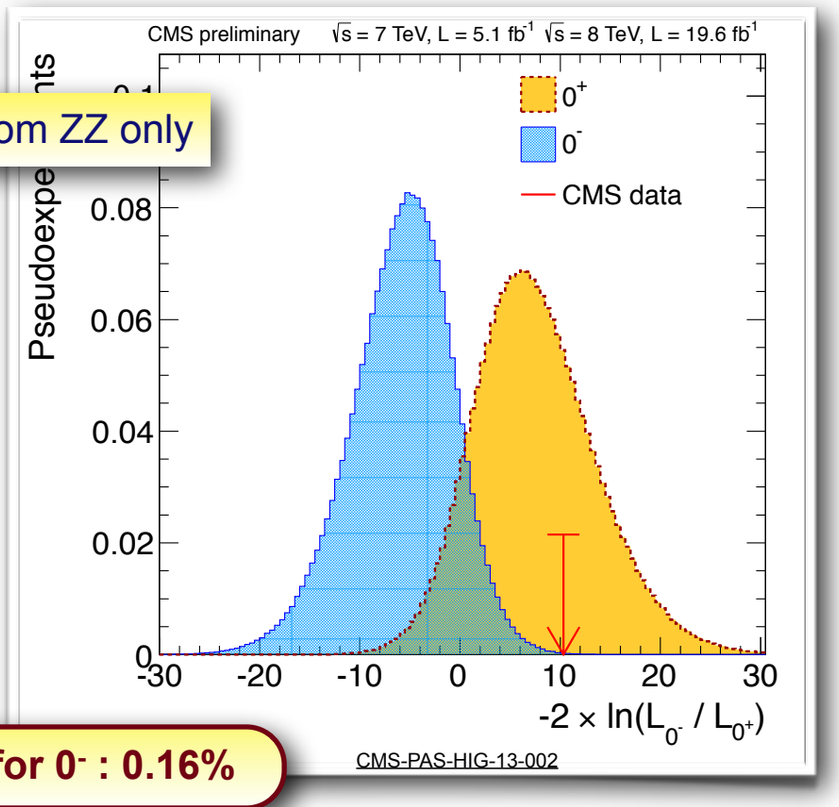


combination of ZZ and WW

Graviton-like boson with minimal couplings to gg disfavored by data

Post-fit model (μ_i profiled)	$ZZ \to 4\ell$	$WW \to \ell\nu\ell\nu$	Combined
$P(q \le q^{obs.} \mid 0^+)$	-0.90σ	0.44σ	-0.34σ
$P(q \ge q^{obs.} \mid 2^+_m(gg))$	2.81σ	1.32σ	2.84σ
$1 - CL_s^{obs.}$	98.6%	86.0%	99.4%

CL_s : 0.6%



from ZZ only

CL_s for 0^- : 0.16%

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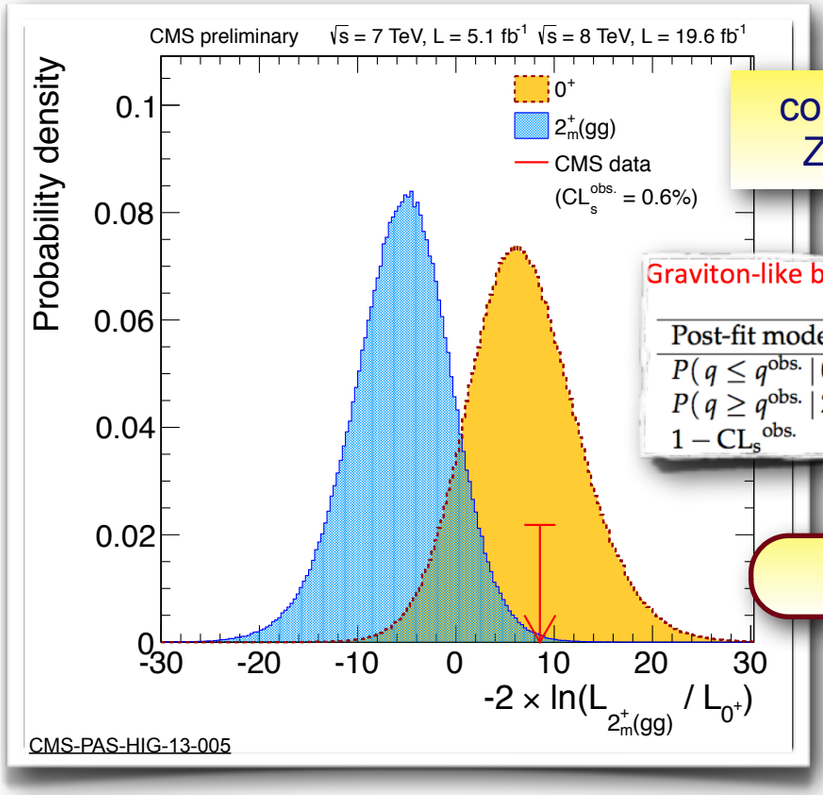

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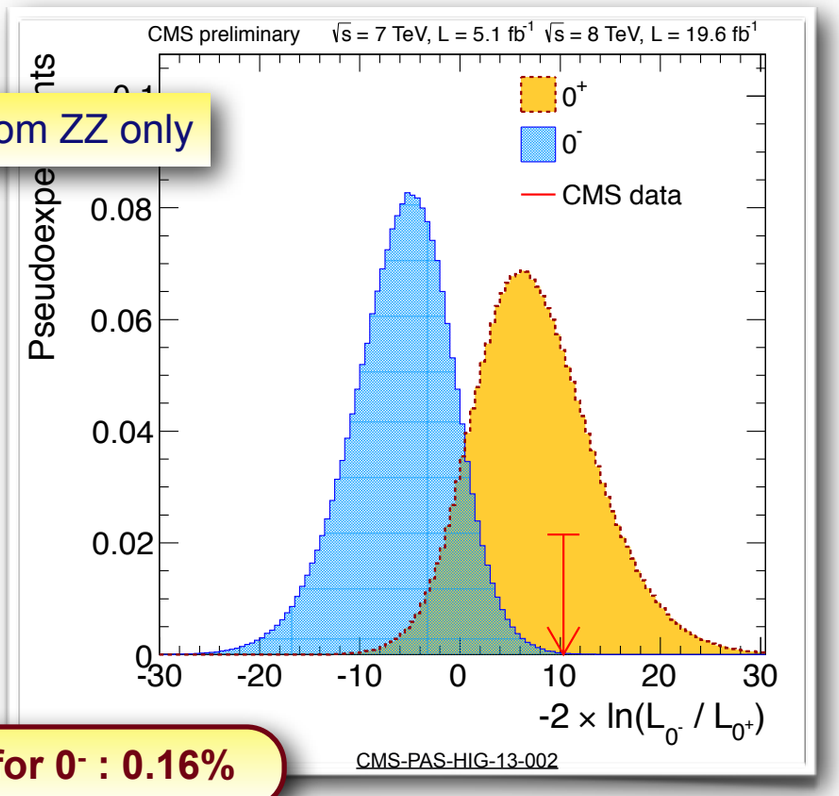

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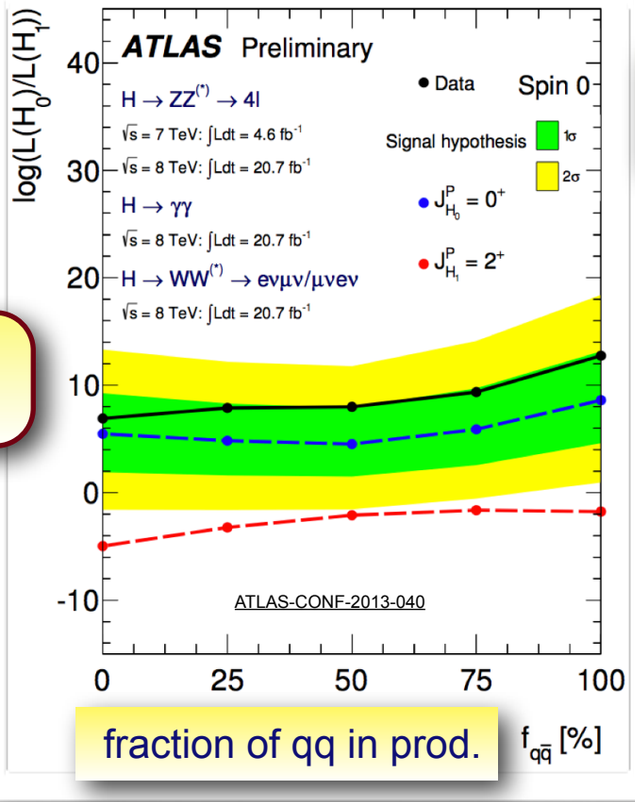

combination of HZZ, HWW and Hγγ

Test statistic comparing the signal JP hypotheses 0^+ and $2^+_m(gg)$ in the best fit to the data

- **in combination:**
  the 3 channels **exclude the 2^+_m** model at the **99.9% CL**
  - main sensitivity from WW (and γγ for pure ggF prod)
  - complementary sensitivity of channels for the different qq production fractions
- **ZZ analysis**:
  excludes 0^-, 1^+ and (1^-) hypotheses at the >95% (94%) CL

Couplings

$$(\sigma \cdot \mathrm{BR})\,(x \to \mathrm{H} \to ff) = \frac{\sigma_x \cdot \Gamma_{ff}}{\Gamma_{\mathrm{tot}}}$$

x is ggH, VBF, WH and ZH, and ttH
Γ_{ff} partial decay width, ff = W, Z, b, t, γ, Zγ;
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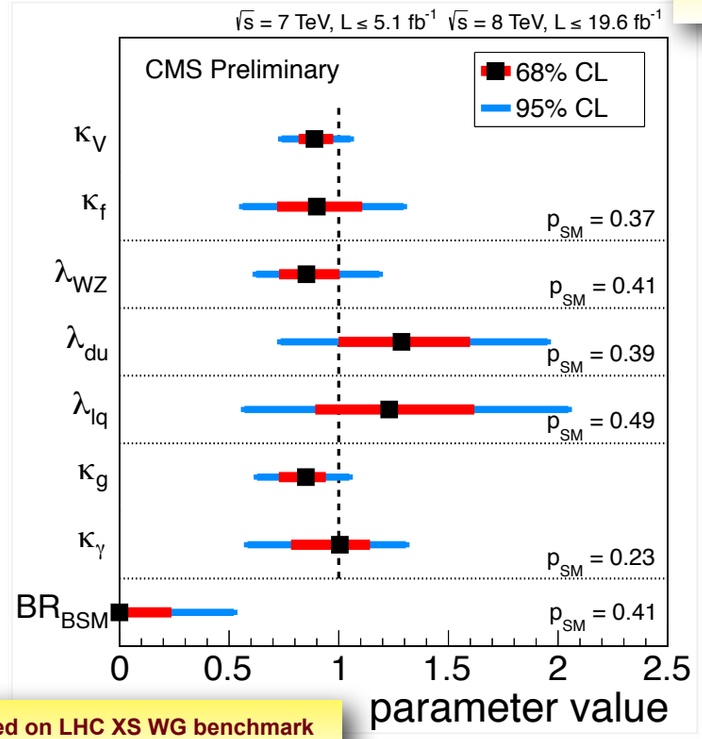
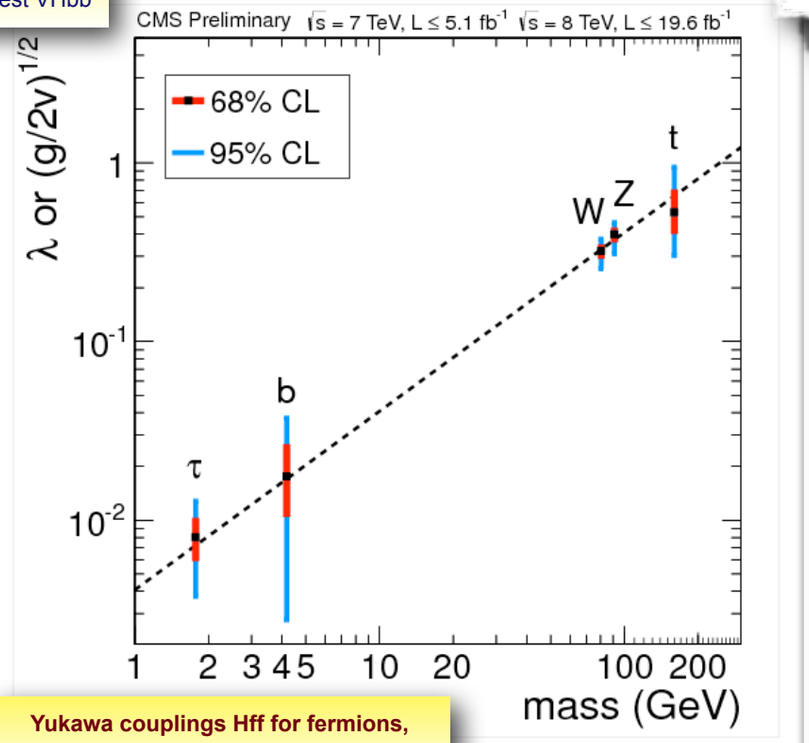
Γ_{ff} proportional to effective H couplings (g_i) → scale factors: $\kappa_i = g_i / g_i^{SM}$

Mass fixed to the measured value, 125.7 GeV

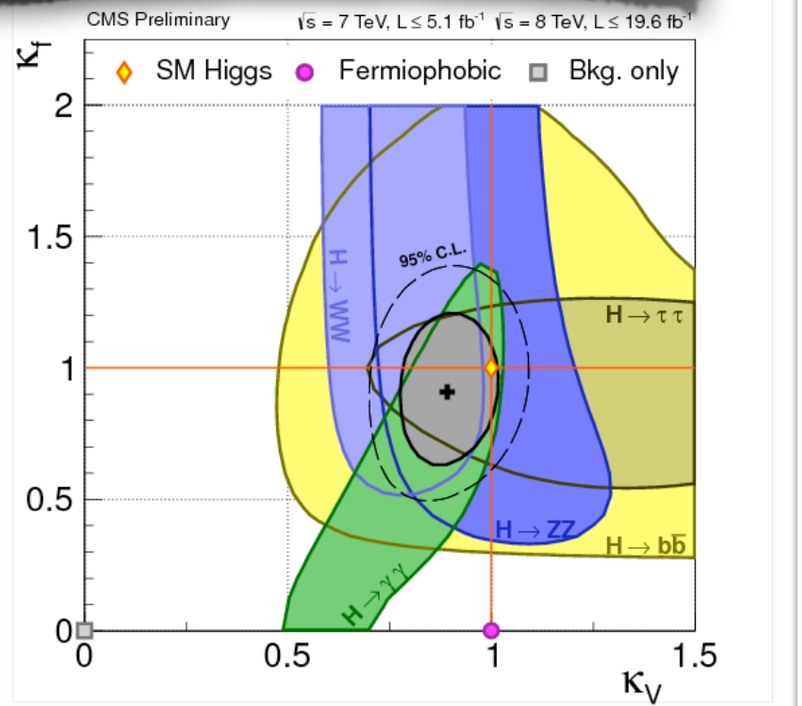
note: does not yet include latest VHbb



based on LHC XS WG benchmark models (arXiv:1209.0040)



Yukawa couplings Hff for fermions, sqrt(g/2v) for vector bosons



CMS-PAS-HIG-13-005

cf. talks by K. Peters, Ch. Mariotti, CERN Seminar

as well as talks at LHCP

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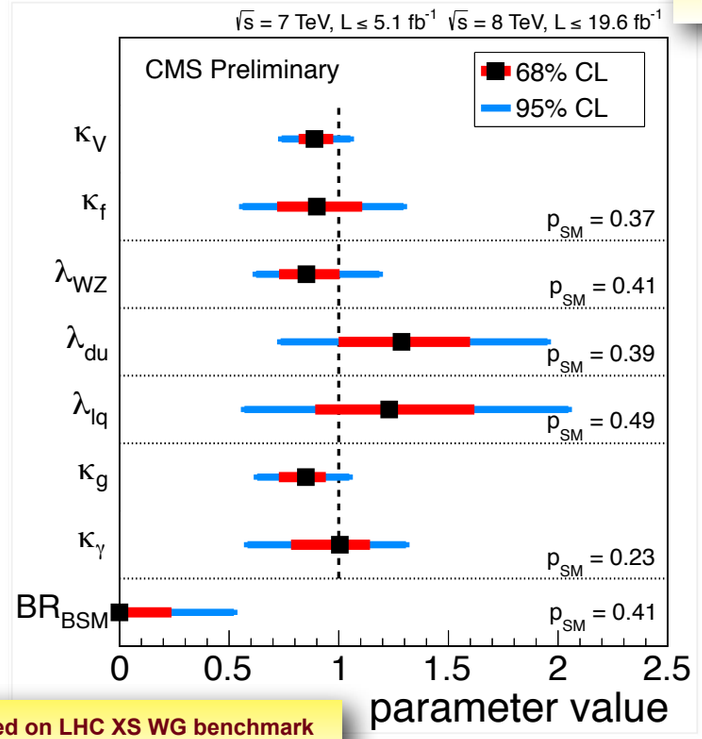

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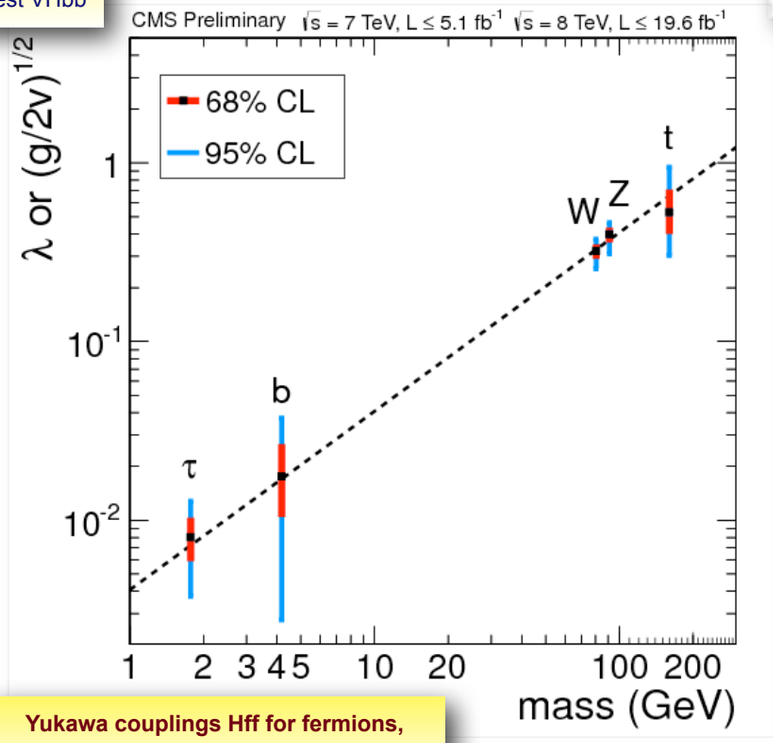

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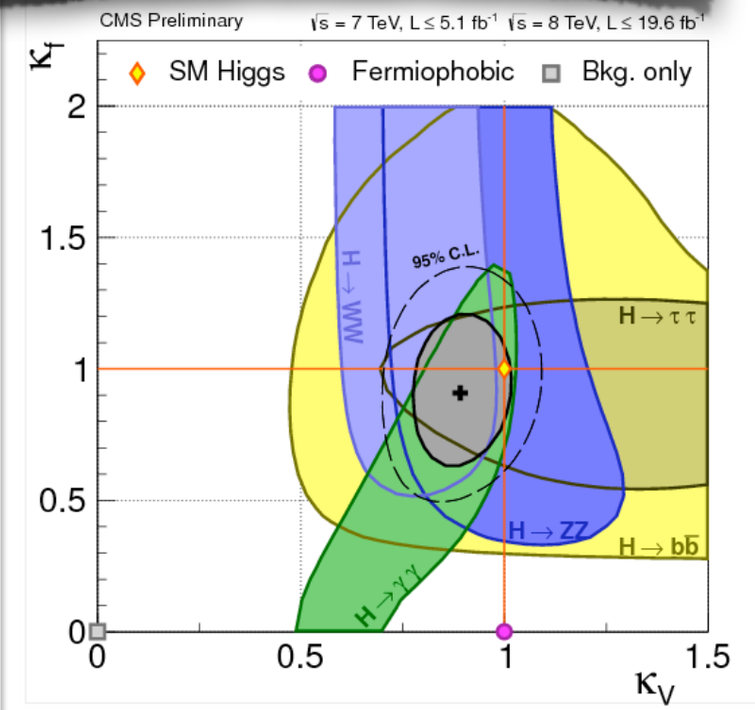

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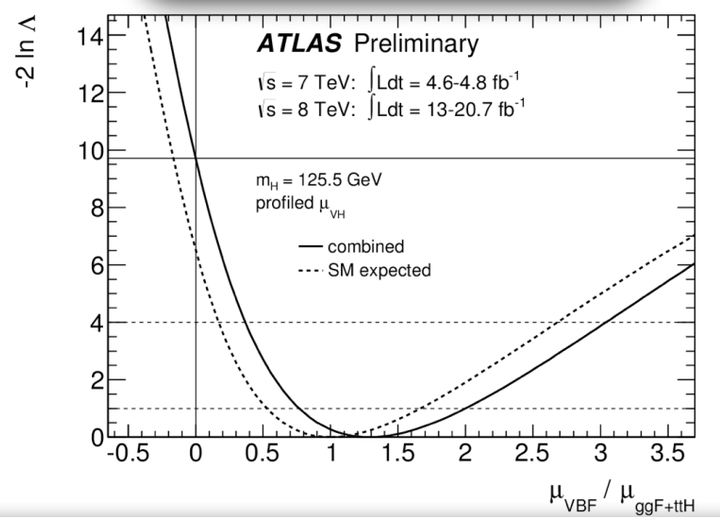
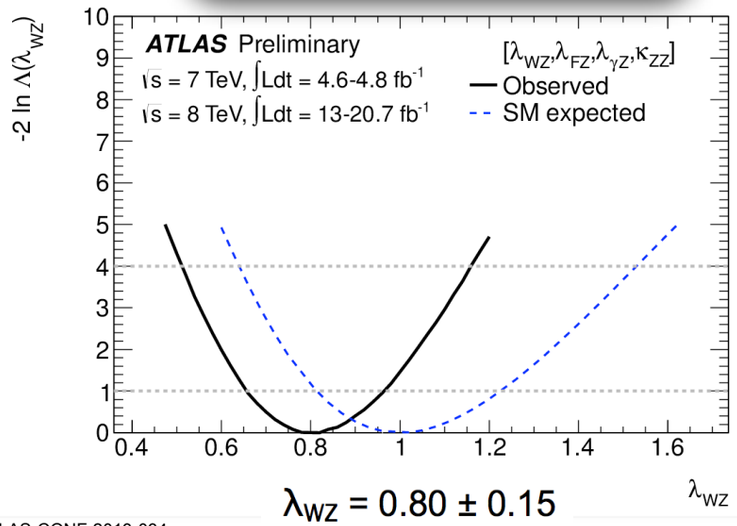
evidence for VBF prod.



$\mu_{VBF} / \mu_{ggF+ttH} = 1.2\,^{+0.7}_{-0.5}$ → 3.1σ evidence for VBF production

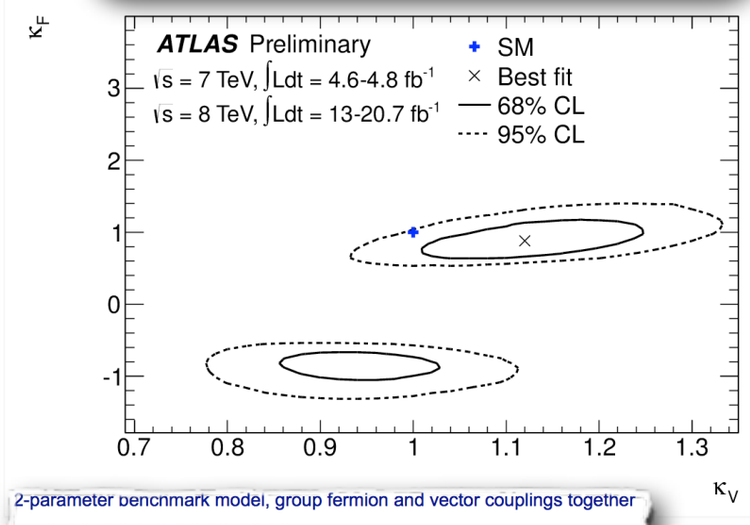
custodial symmetry



$\lambda_{WZ} = 0.80 \pm 0.15$

ATLAS-CONF-2013-034

2D compatibility with the SM: 8%



2-parameter benchmark model, group fermion and vector couplings together
- $\kappa_V = \kappa_W = \kappa_Z$; $\kappa_F = \kappa_t = \kappa_b = \kappa_\tau = \kappa_g$
- Here: assume only SM particles contribute to κ_g (gg→H) and κ_γ (H→γγ)

One overall not observable sign, choose $\kappa_V > 0$. Some sensitivity to κ_F sign from interference between top and W in H → γγ

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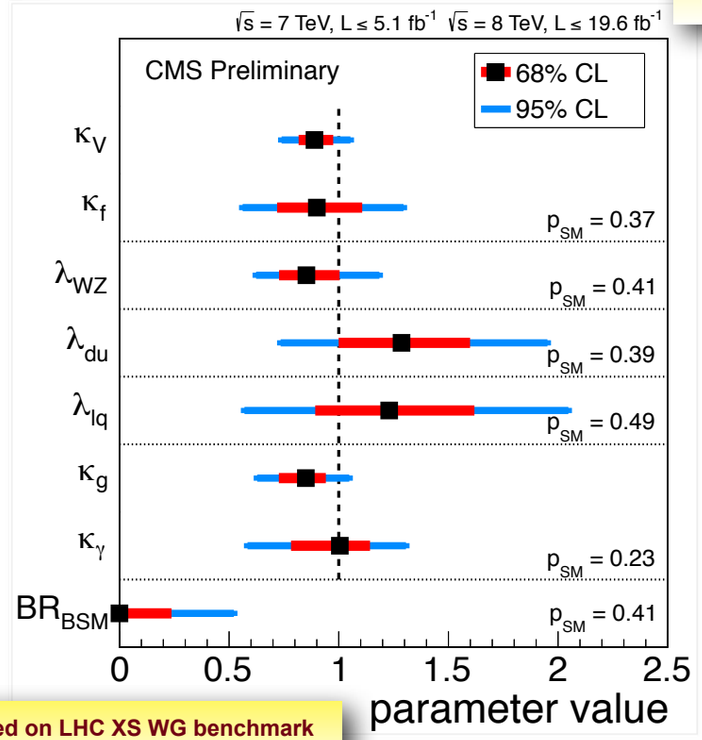

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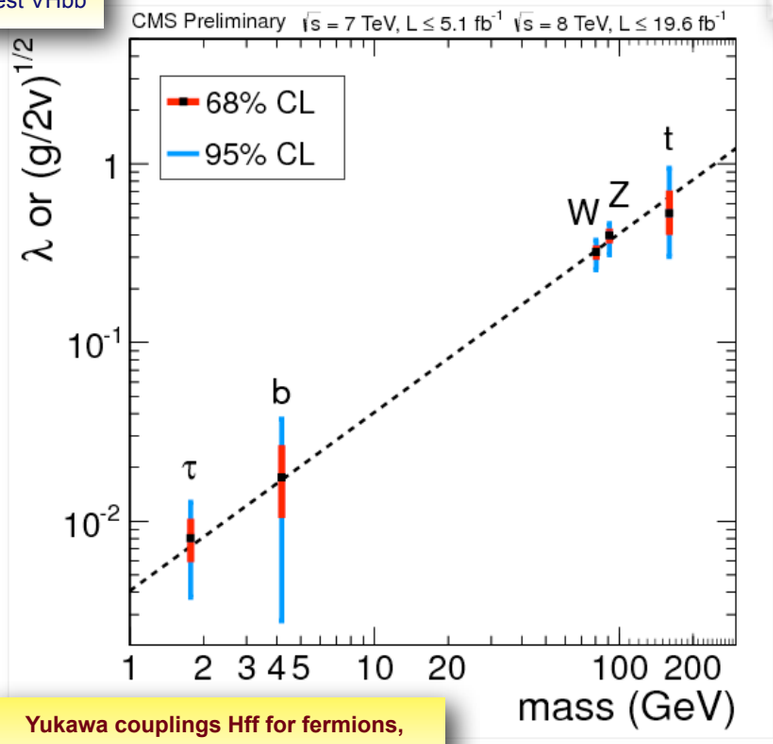

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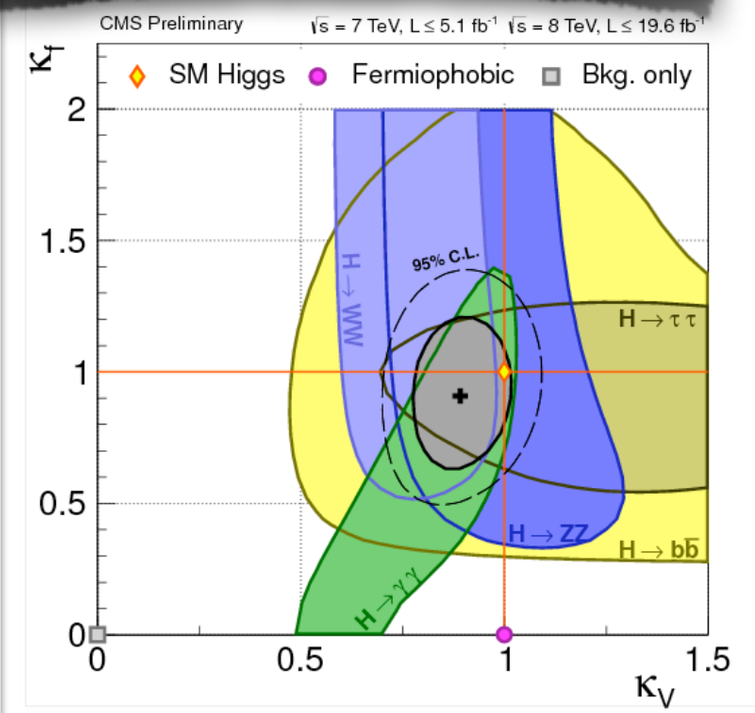
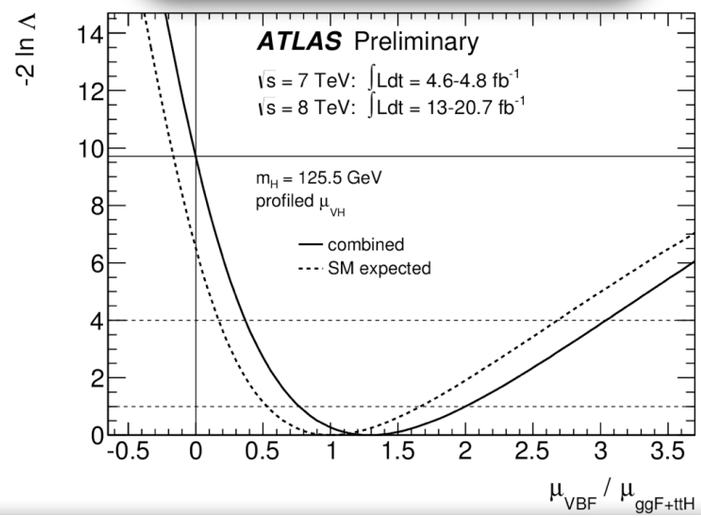


CMS-PAS-HIG-13-005

➡ **so far it really looks/smells/sounds/.... like the SM Higgs**

cf. talks by K. Peters, Ch. Mariotti, CERN Seminar as well as talks at LHCP

evidence for VBF prod.



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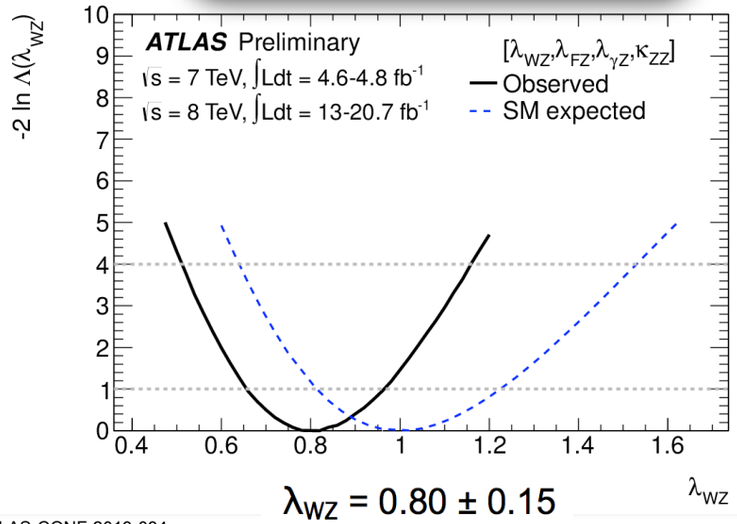

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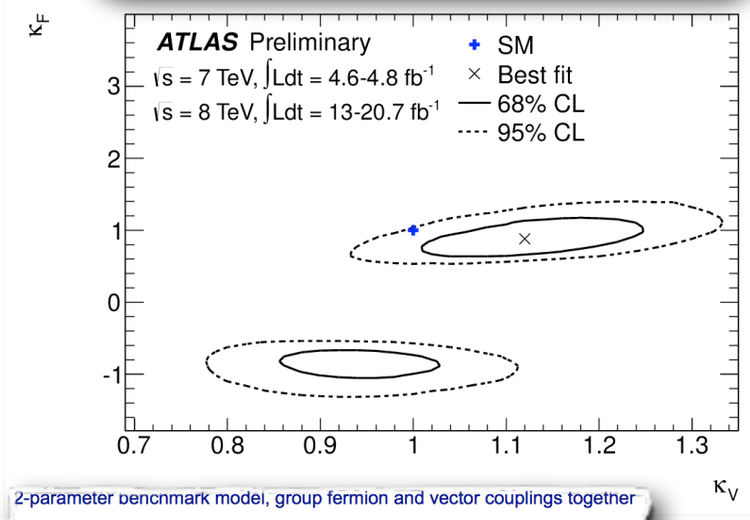

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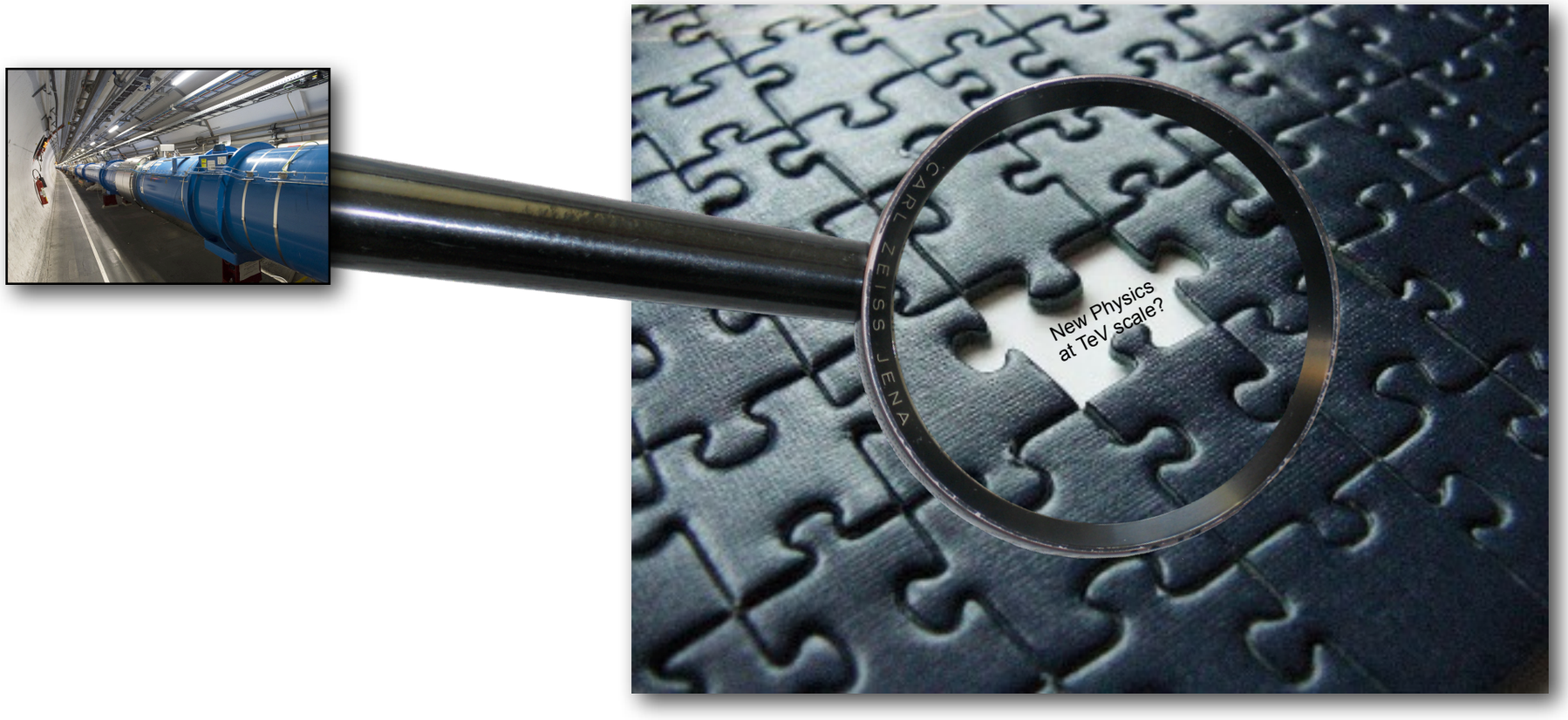
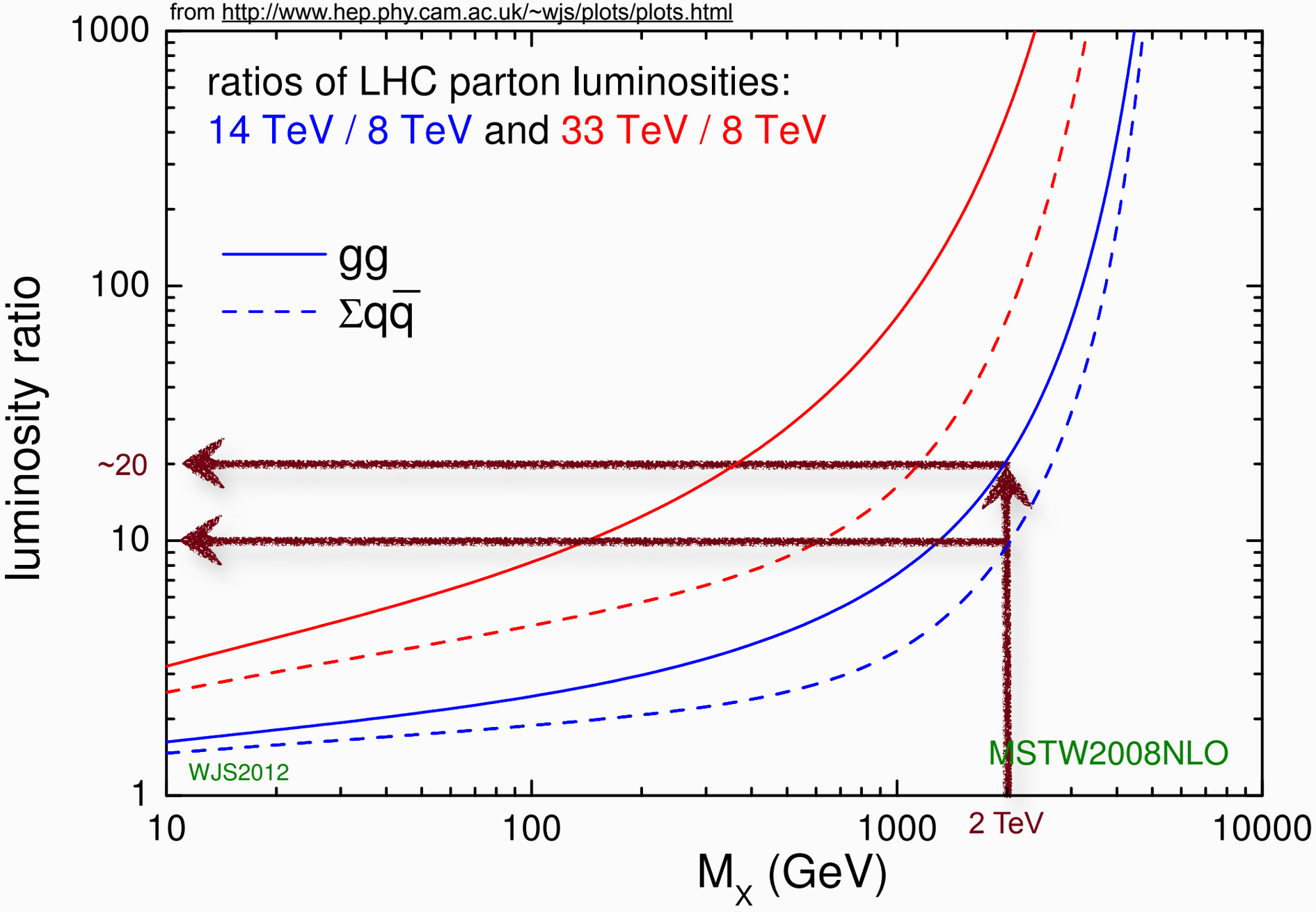


Parton luminosities

ETH Institute for Particle Physics

see now talk by M. Elsing

from http://www.hep.phy.cam.ac.uk/~wjs/plots/plots.html



for a fixed mass scale

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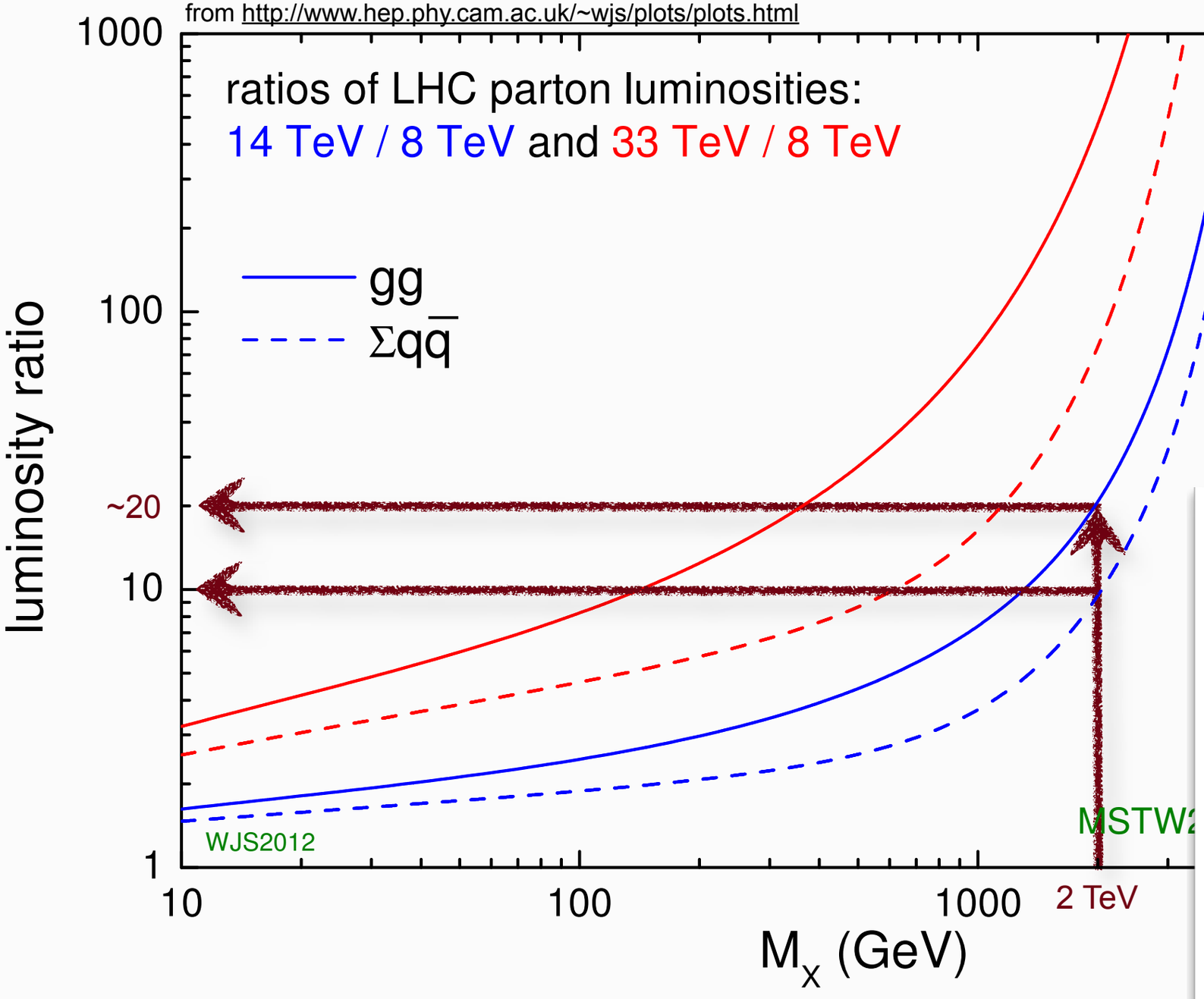

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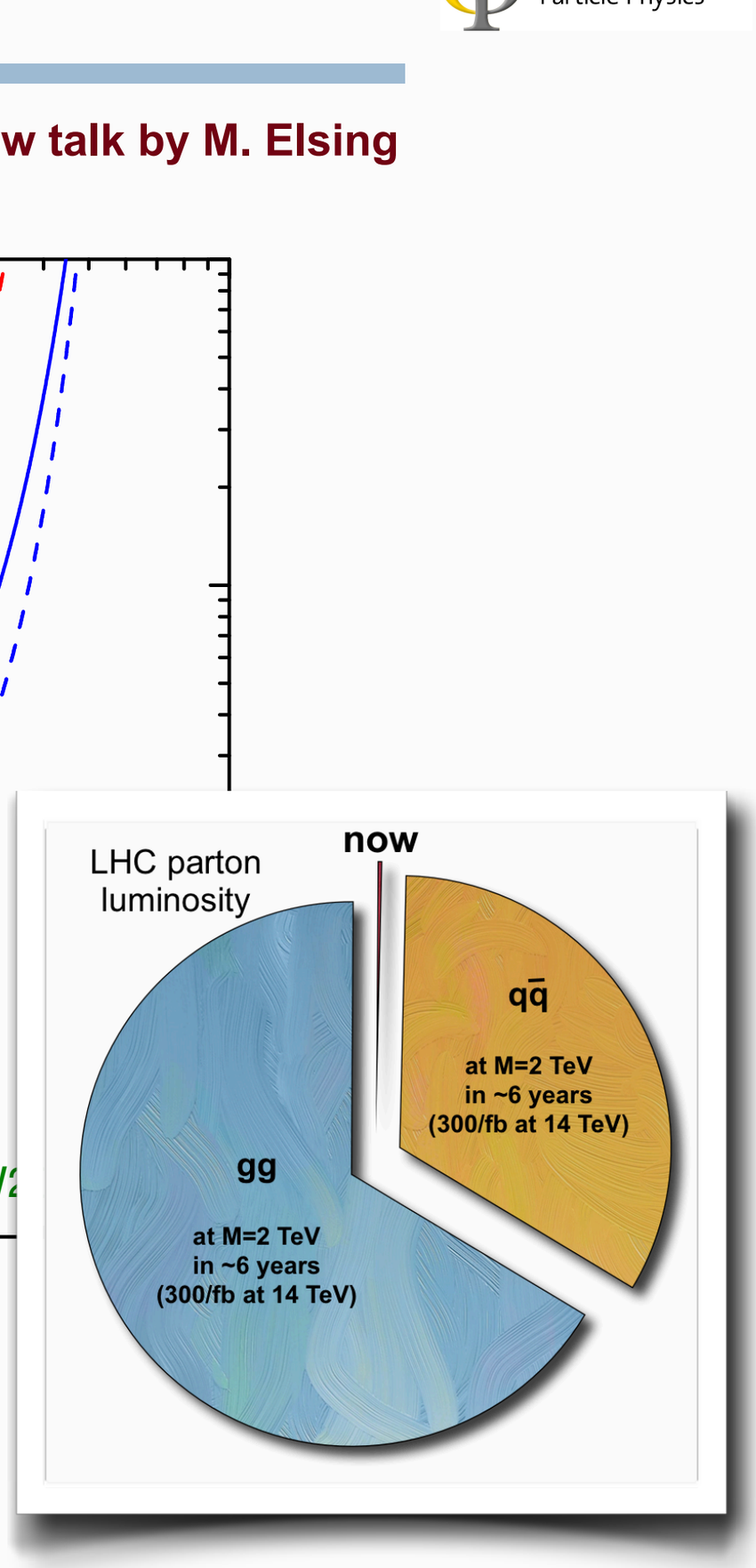

Summary

ETH Institute for Particle Physics

- The first 3 years: excellent performance of the machine and the experiments
- Extensive proof given of being able to deliver, at high quality and over short time scales
  - this promises well also for the coming years
- These years have been exciting, rewarding, tough,...
- **The adventure in the TeV energy regime has just begun!**

Big thanks to all colleagues who helped preparing this talk!