Prospects for Early LHC Results and Possible Input for Future Projects

Georg Weiglein

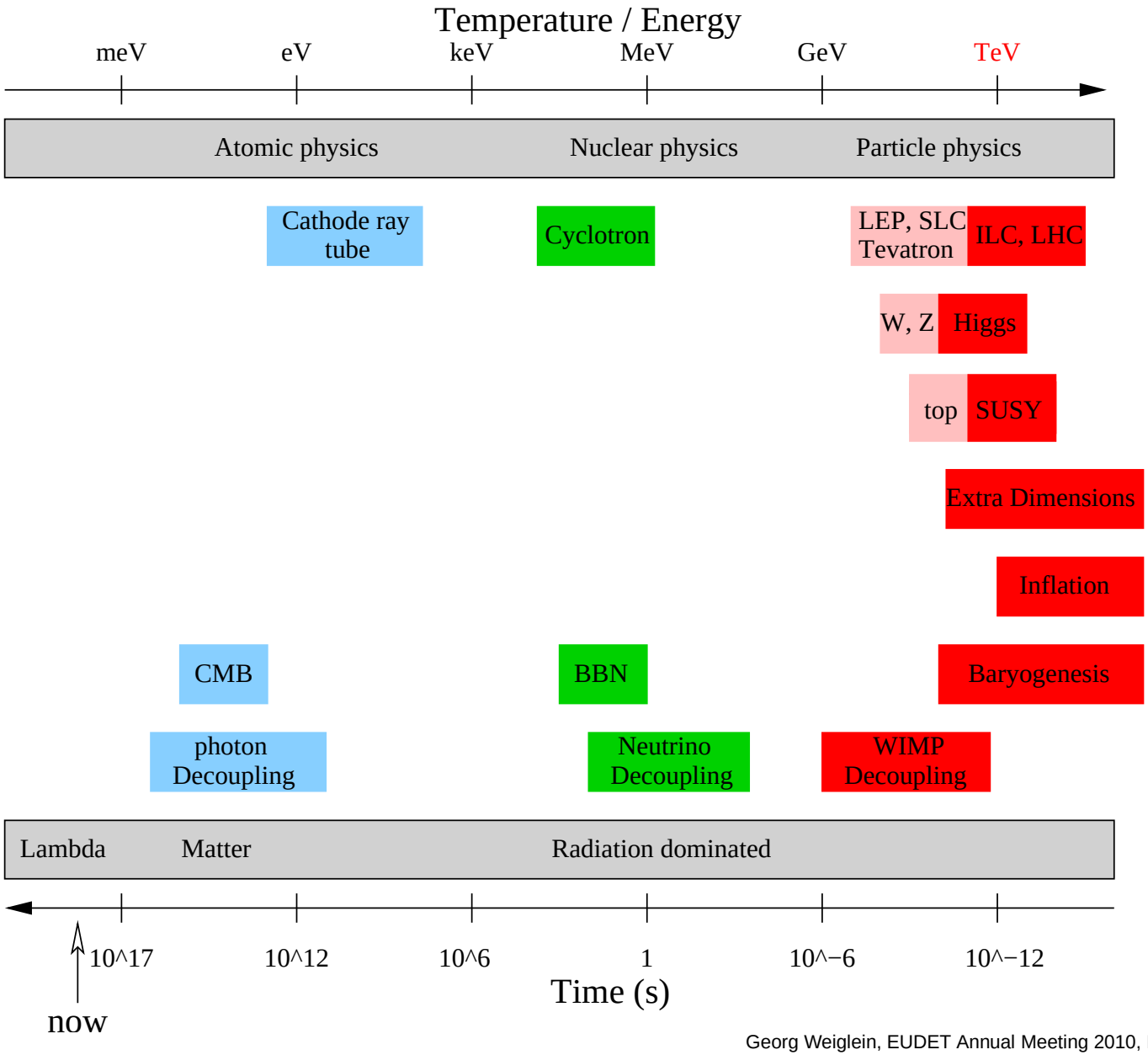
DESY

Hamburg, 09 / 2010

- Introduction: on the way to the TeV scale
- LHC physics: where do we stand?
- Prospects for the near future and possible implications

Introduction: on the way to the TeV scale

$$1\ \mathrm{TeV} \approx 1000 \times m_{\mathrm{proton}} \Leftrightarrow 2 \times 10^{-19}\ \mathrm{m}$$



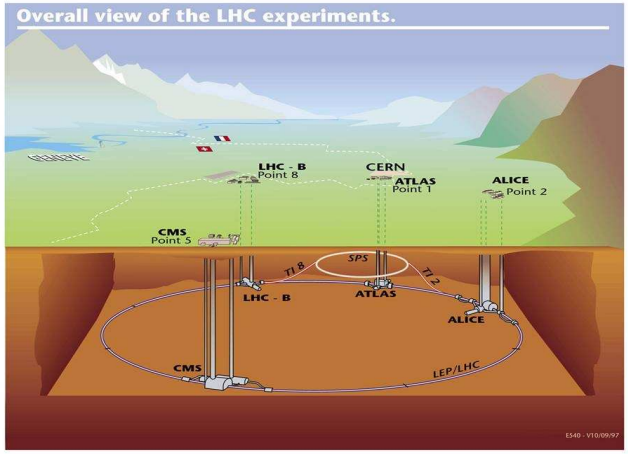
What can we learn from exploring the new territory of TeV-scale physics?

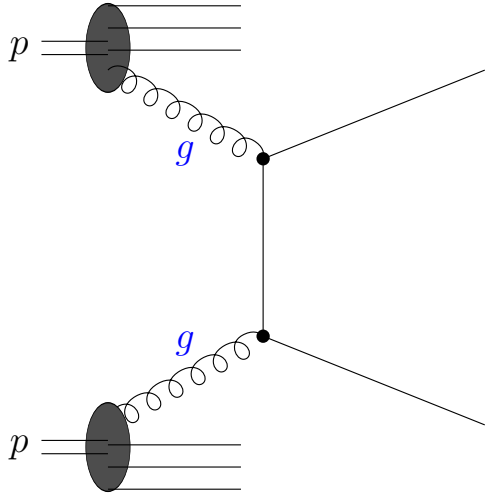
What can we learn from exploring the new territory of TeV-scale physics?

- How do elementary particles obtain the property of mass: what is the mechanism of electroweak symmetry breaking? Is there a Higgs boson (or more than one)?
- Do all the forces of nature arise from a single fundamental interaction?
- Are there more than three dimensions of space?
- Are space and time embedded into a “superspace”?
- What is dark matter? Can it be produced in the laboratory?
- Are there new sources of $\mathcal{CP}$-violation?
  Can they explain the asymmetry between matter and anti-matter in the Universe?
- . . .

The LHC and future collider projects

The Large Hadron Collider (LHC):
Proton–proton scattering at 7–14 TeV: composite objects of quarks and gluons, bound together by strong interaction





$\Rightarrow$ Opens up new energy domain

complicated scattering processes

10^9 scattering events$/s$ at LHC design luminosity

HE–LHC: Higher Energy LHC

Proposal: increase beam energy to 16.5 TeV

HE–LHC needs new magnets (dipole field: 20 T)

$\Rightarrow$ new machine

Significant increase of LHC search reach, but very good physics justification from future data needed

LHeC: electron–proton collisions in the LHC tunnel

Ring-Ring (RR) vs. Linac-Ring (LR) option

RR: energy limited, $\lesssim 70\ \mathrm{GeV}$, better prospects for higher luminosity

LR: energy not physics limited, considered $\lesssim 140\ \mathrm{GeV}$; somewhat lower luminosity

Baseline configuration:

60 GeV electron energy, luminosity $10^{33}\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$

Potential for new physics searches at LHeC

- Electron-quark resonances, leptoquarks, SUSY with R-parity violation, . . .
- R-parity conserving SUSY: selectron + squark production
- Higgs production in weak-boson fusion
- Excited leptons, anomalous top production, . . .
- . . .

CDR in preparation

Linear Colliders: ILC and CLIC

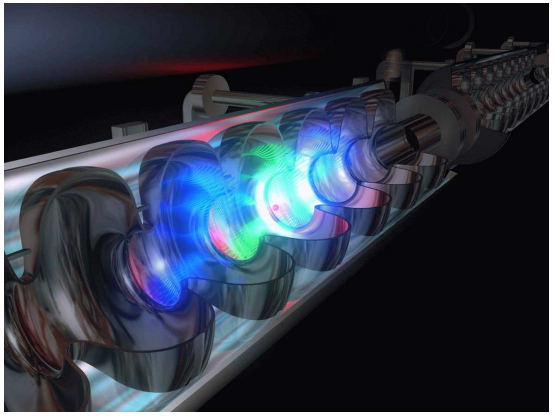
The International Linear Collider (ILC): RDR ($+$ costing) issued in 2007, Technical Design Phase in progress

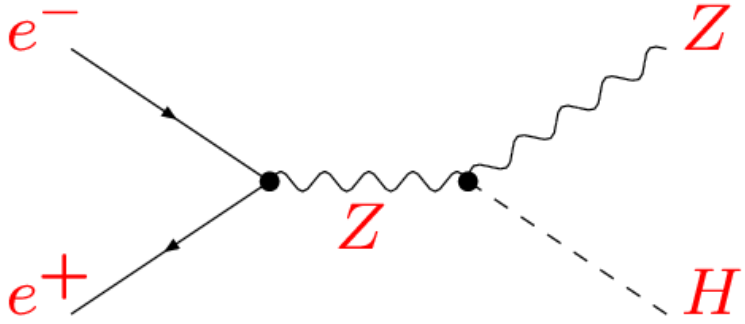
The Compact Linear Collider (CLIC): Ongoing R&D on feasibility issues, preparation of Conceptual Design Report

e^+e^- scattering at $\lesssim$ 1 TeV (ILC), $\approx$0.5–3 TeV (CLIC)

fundamental particles, point-like, electroweak interaction

well-defined initial state, full collision energy usable, tunable





$\Rightarrow$ high-precision physics

Linear Collider Physics

Key features:

- Precisely known centre-of-mass energy of hard process
- Tunable centre-of-mass energy
- Polarised beams
- Clean, fully reconstructable events (also for hadronic final states)
- Moderate backgrounds $\Rightarrow$ no trigger $\Rightarrow$ unbiased physics
- . . .

LHC / LC complementarity

The results of LHC and LC will be highly complementary

LHC: good prospects for producing new heavy states
(in particular strongly interacting new particles)

LC: direct production (in particular colour-neutral new particles)
$\oplus$ high sensitivity to effects of new physics via precision measurements

LHC / LC interplay
$\Rightarrow$ enhanced physics gain [*LHC / ILC Study Group Report '06*]
$\Rightarrow$ comprehensive picture of TeV scale physics

Muon collider

A $\mu^+\mu^-$ collider in the energy range of 100 GeV to several TeV could emerge as a (major) upgrade of a neutrino factory

Higgs production in the s-channel

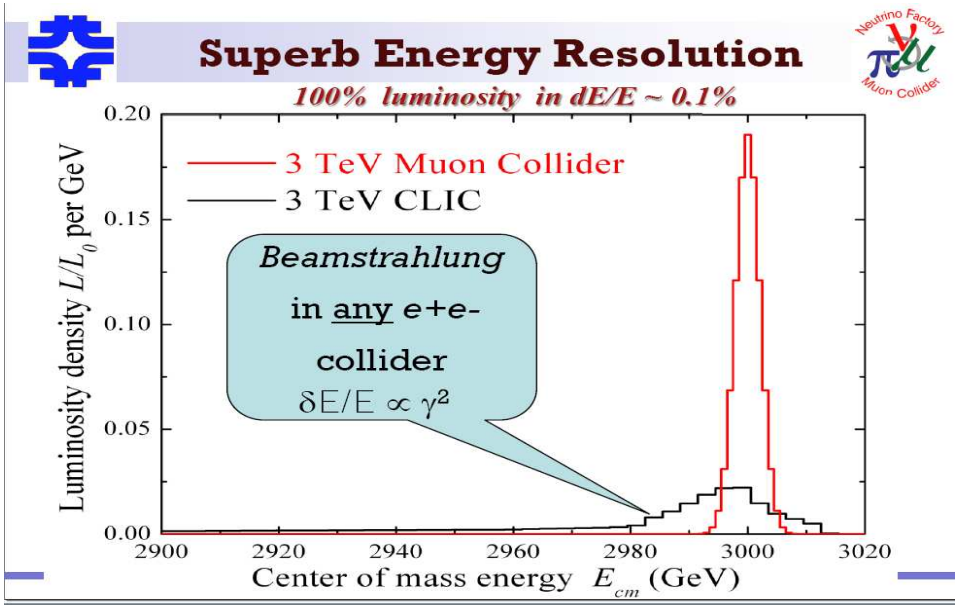
Physics potential of a multi-TeV muon collider is in principle similar to a multi-TeV e^+e^- collider
Can the same luminosity be achieved?

[*V. Shiltsev '08*]

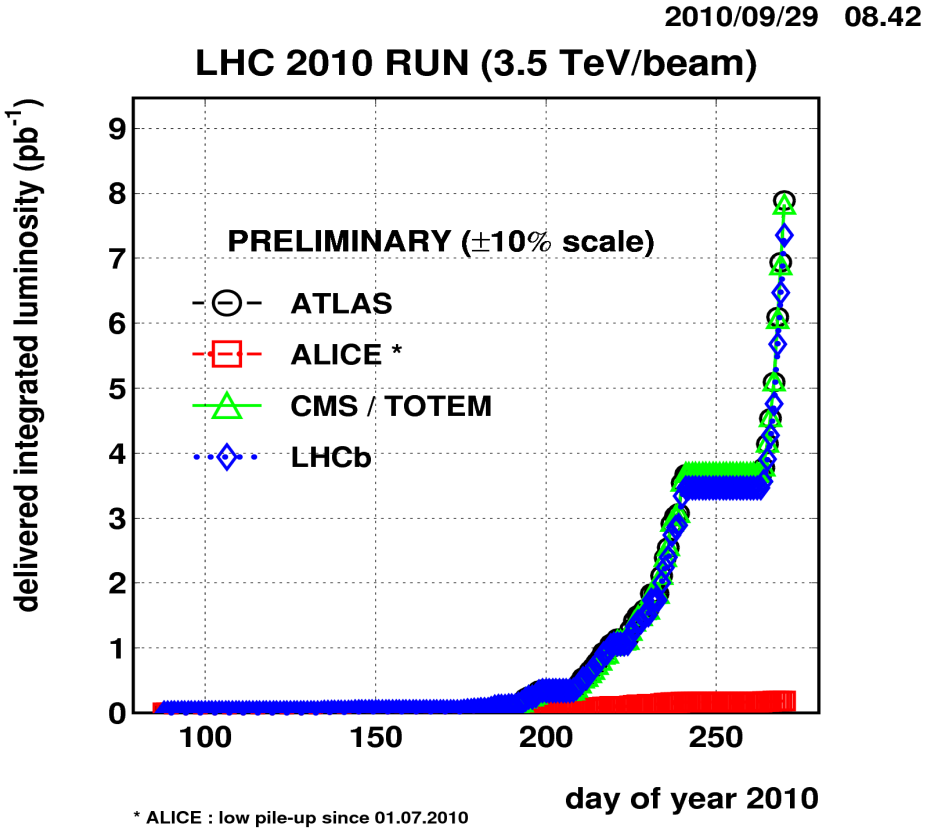
Small ISR, beamstrahlung,

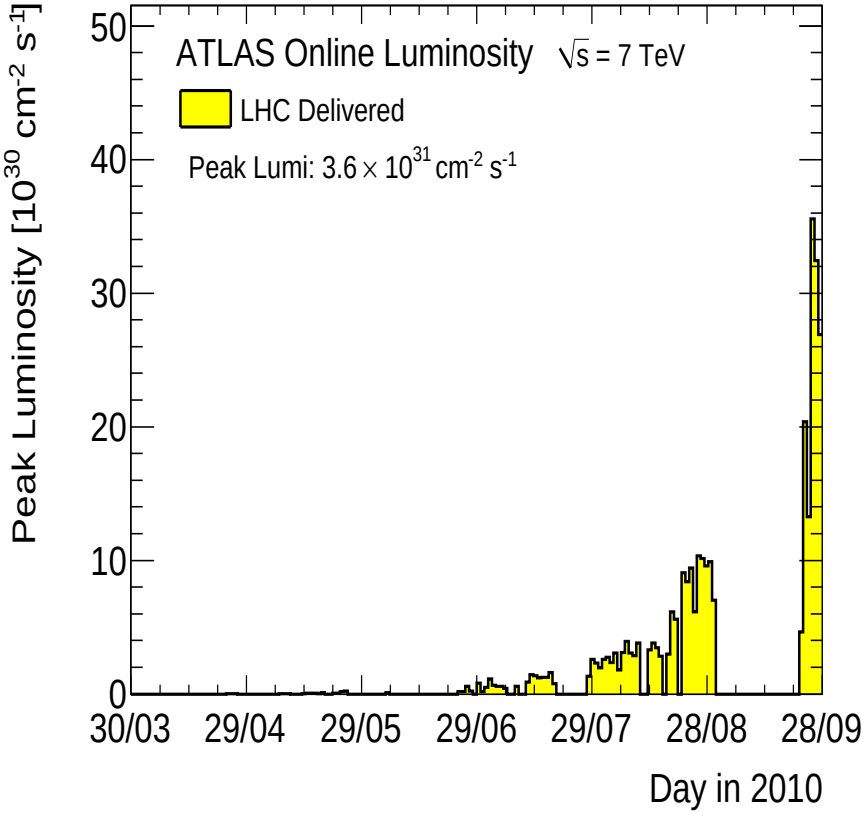
but huge backgrounds

from μ decay



LHC physics: where do we stand?

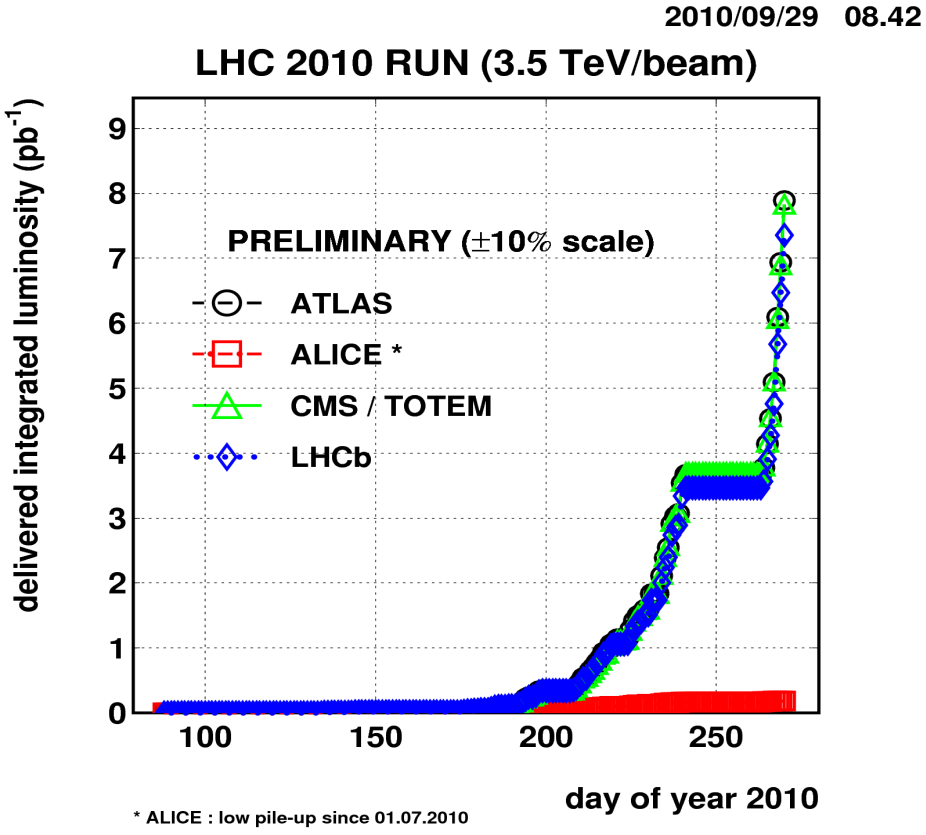


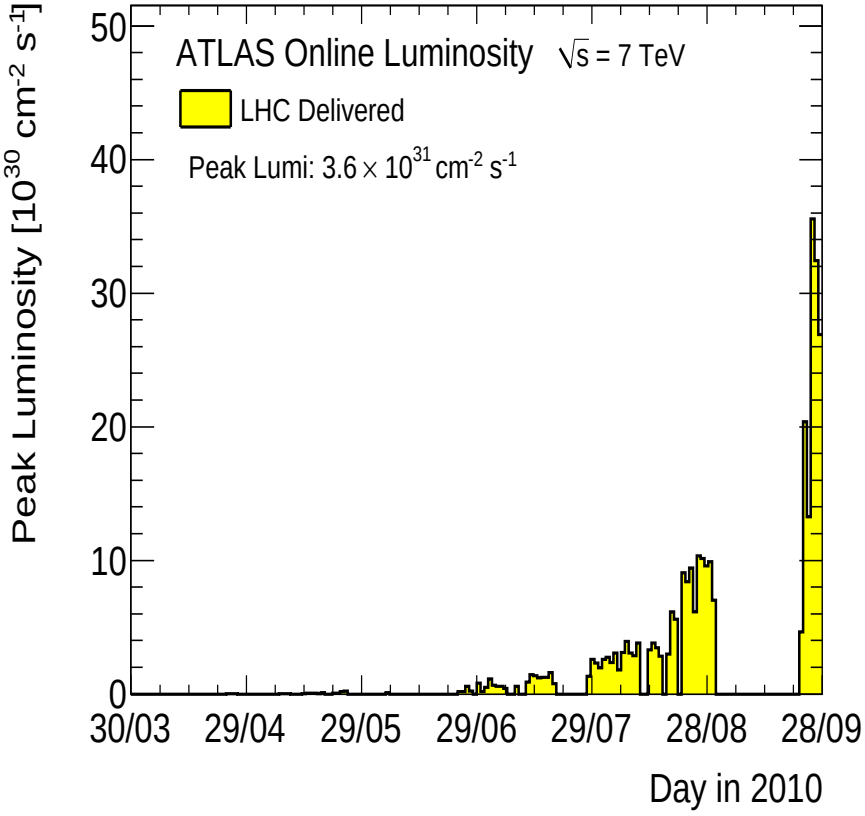


Goal of current LHC run (until $\approx$ end of 2011):

collect $1\ \mathrm{fb}^{-1}$ of data at $7\ \mathrm{TeV}$

LHC physics: where do we stand?





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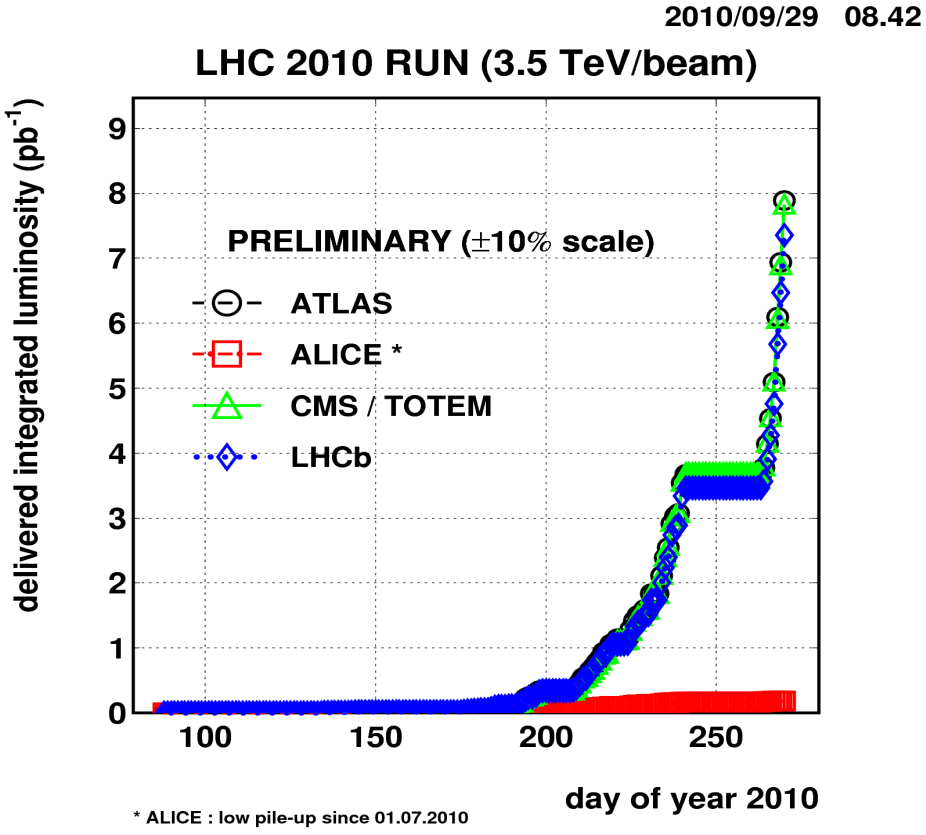
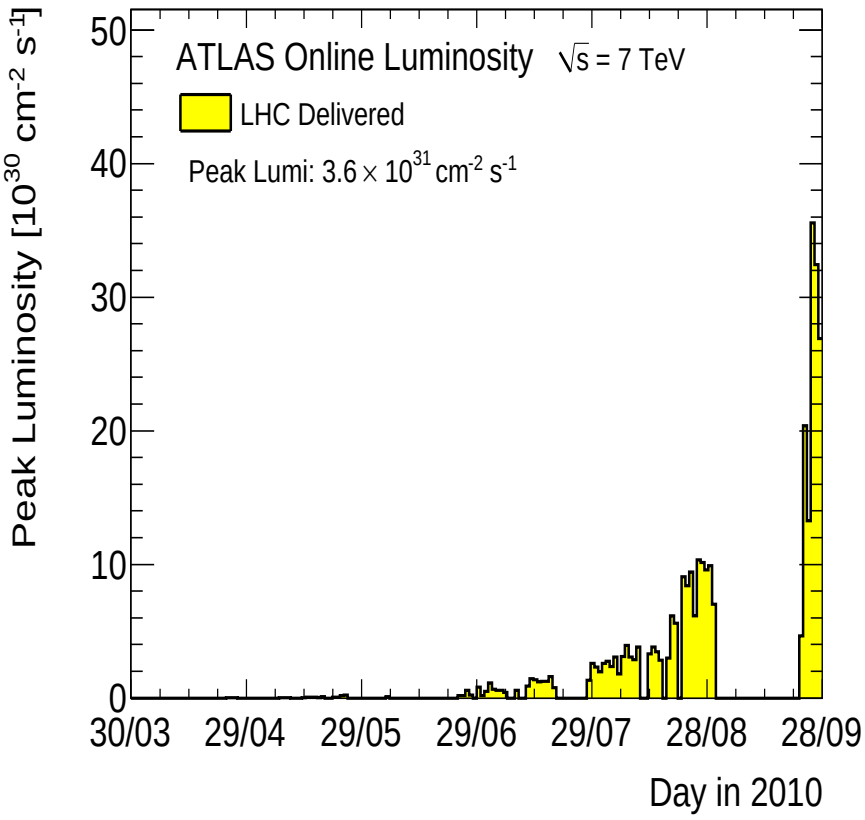
LHC physics: where do we stand?





Goal of current LHC run (until $\approx$ end of 2011):

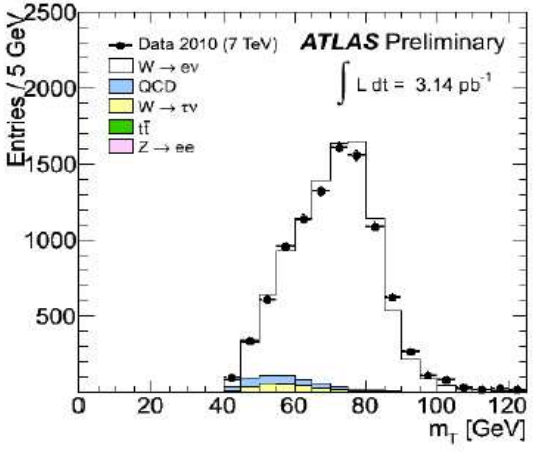
collect $1\ \mathrm{fb}^{-1}$ of data at $7\ \mathrm{TeV}$ + x?

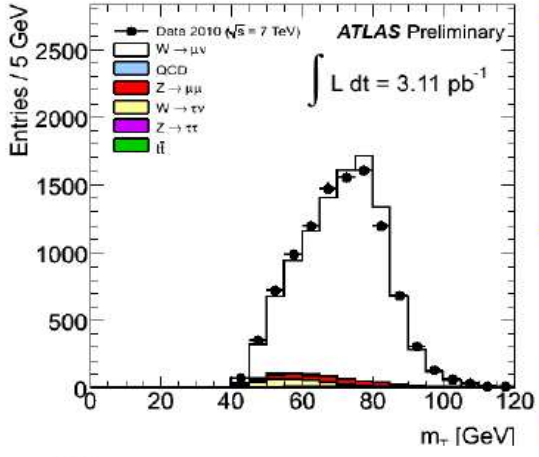
Afterwards: shutdown for upgrade to $14\ \mathrm{TeV}$ running

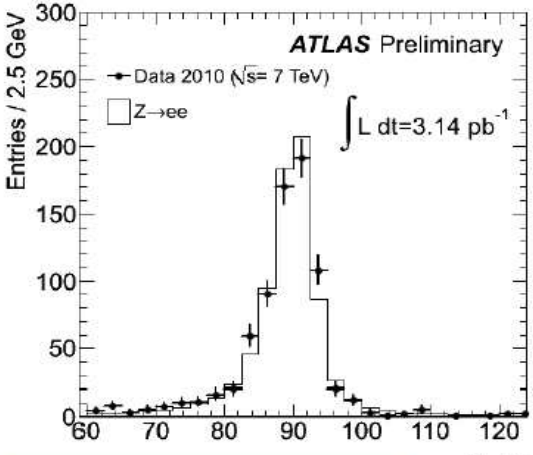
"Rediscovery" of the Standard Model: W and Z production

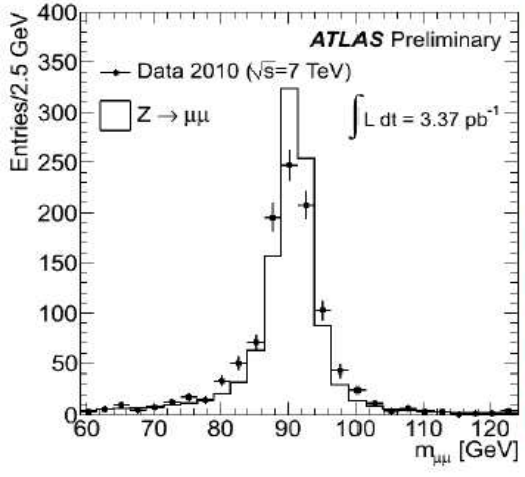
[*ATLAS Collaboration '10*]

Electroweak Bosons





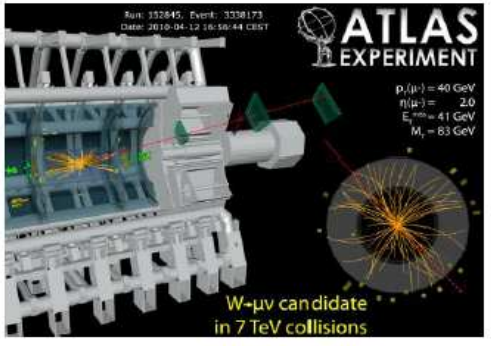


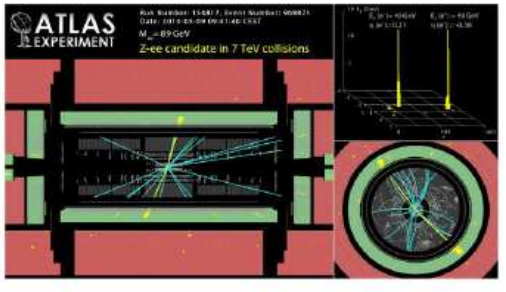


Based on 3+ pb^{-1} of data.

ATLAS has collected ~10^4 W's and ~10^3 Z's per channel.

Yield is between Tevatron 1A and 1B datasets.)



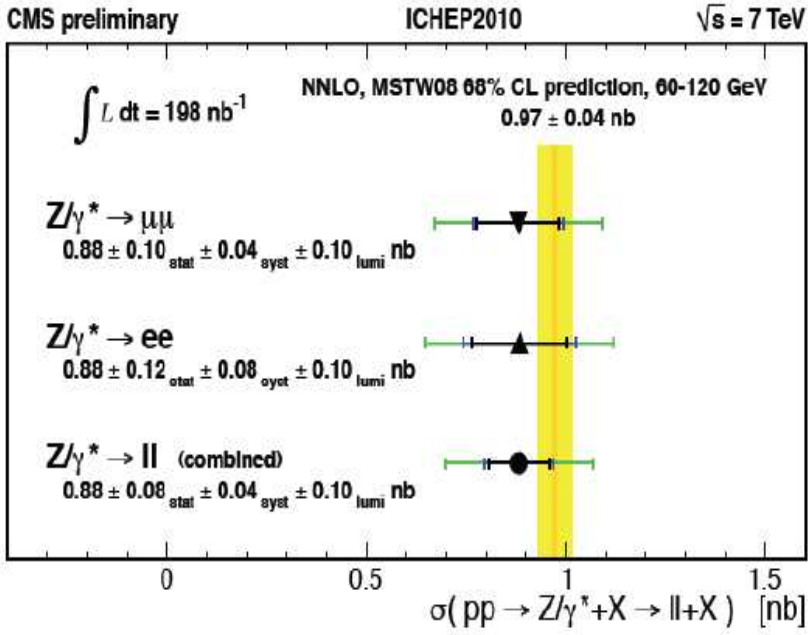


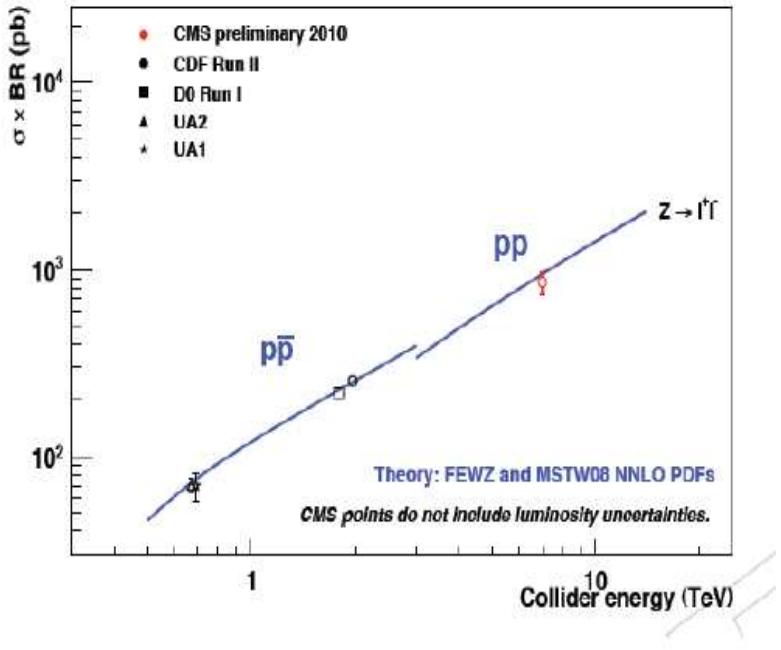
Cross section measurement for Z production

[*CMS Collaboration '10*]

Z cross section

EWK-10-002



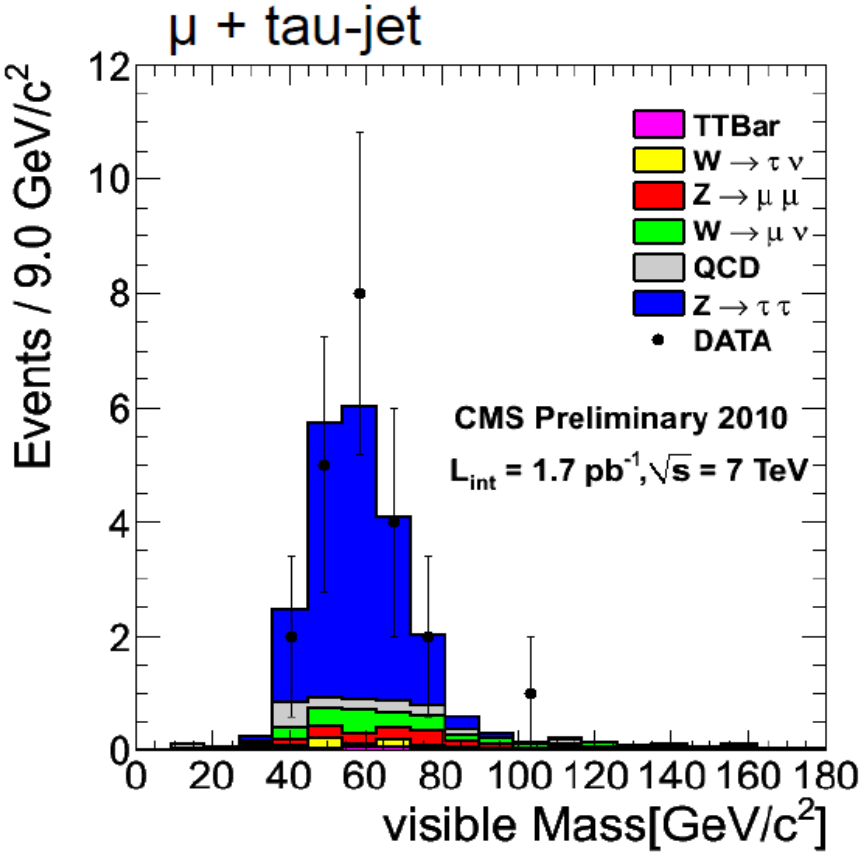


Reconstruction of τ final states

[*CMS Collaboration '10*]

Z->tau tau selection

PFT-10-004



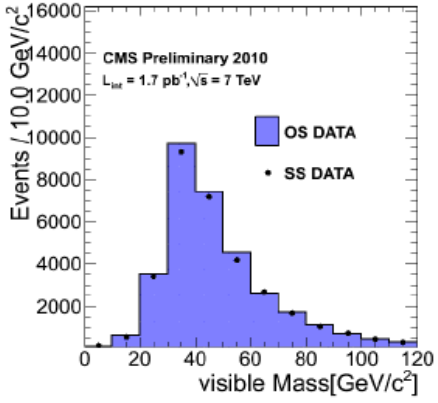
QCD Bkgr

Measured:

OS/SS = 1.03 +- 0.01(stat)

QCD MC expected value:

OS/LS = 1.036 +-0.002

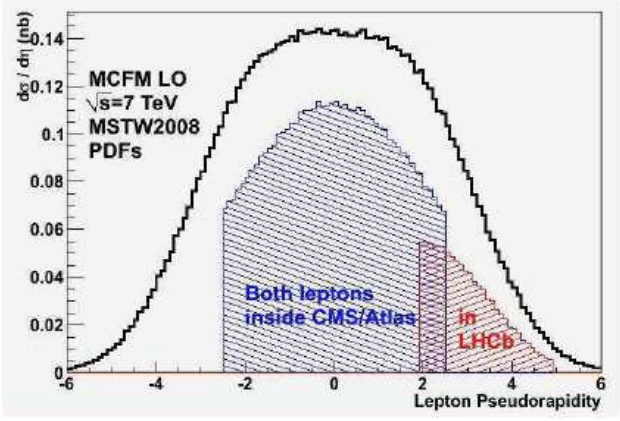


LHCb: charge asymmetry in W decays

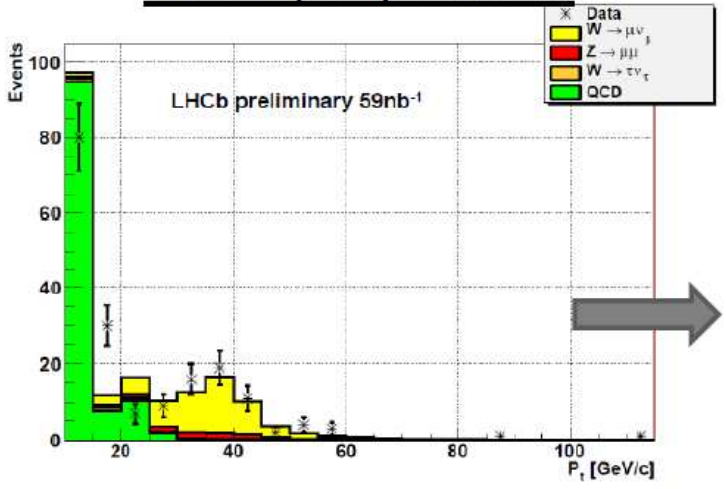
[*LHCb Collaboration '10*]

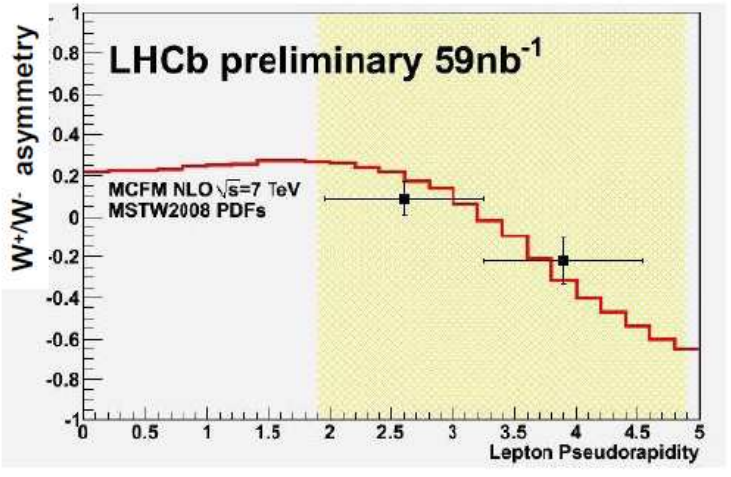
EW Physics at LHCb

- Unique LHCb η coverage, allows for interesting W,Z production studies
- First result: charge asymmetry in $W^{\pm} \rightarrow \mu^{\pm} \nu$ events



Muon pt spectrum

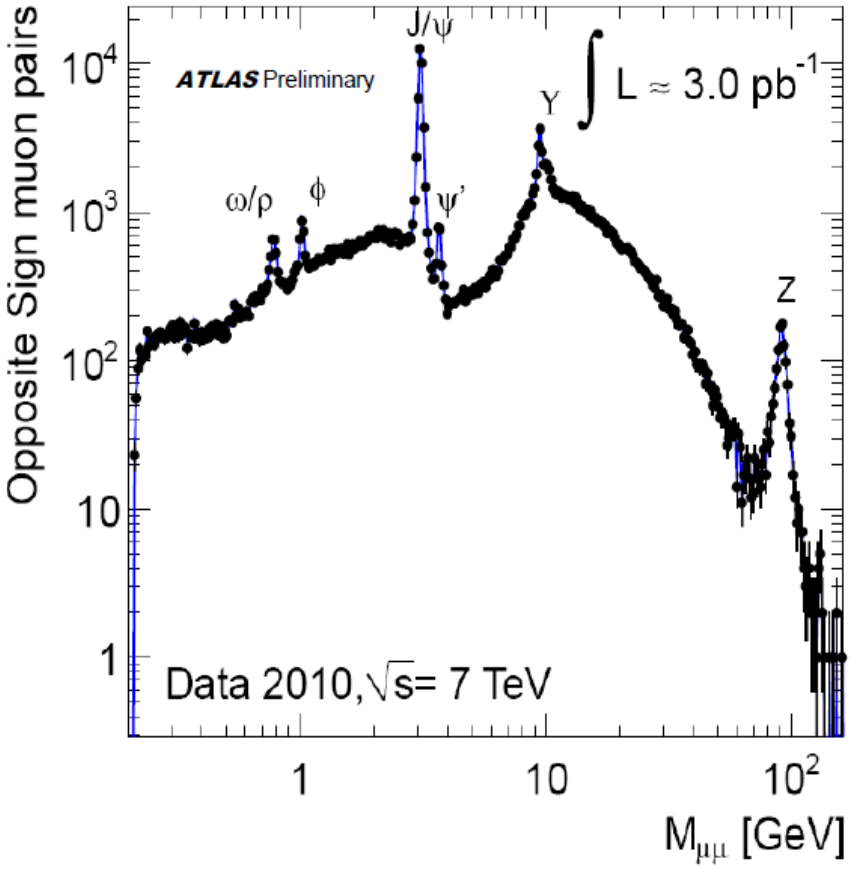




Di–muon invariant mass distribution

[*ATLAS Collaboration '10*]

Dimuon Resonances (+ the Z)



Simple analysis:

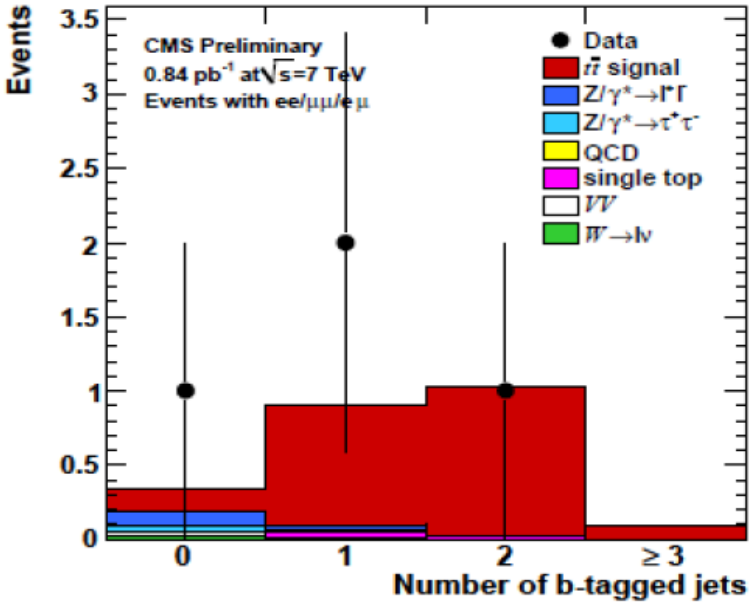
- LVL1 muon trigger with p_T ~ 6 GeV threshold
- 2 opposite-sign primary muons reconstructed by combining tracker and muon spectrometer

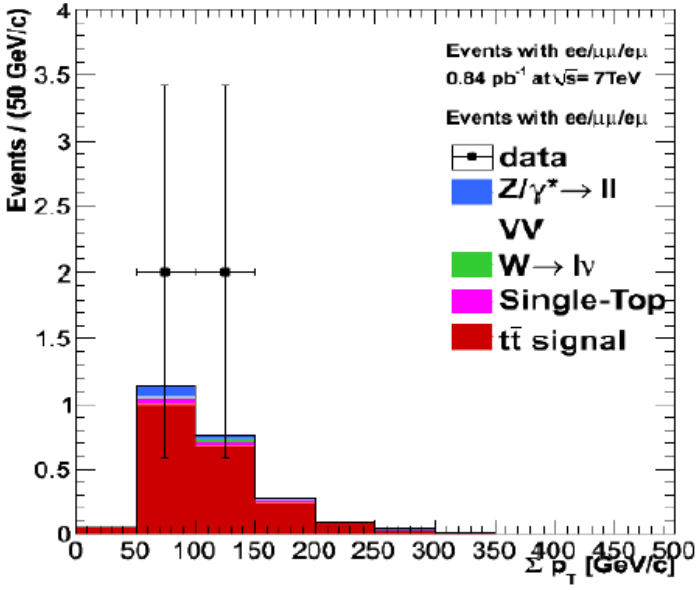
⇒ Good prospects for new physics searches: $Z' \to \mu^+\mu^-$

The top quark made it to Europe

[*CMS Collaboration '10*]

t-tbar: dileptonic channel





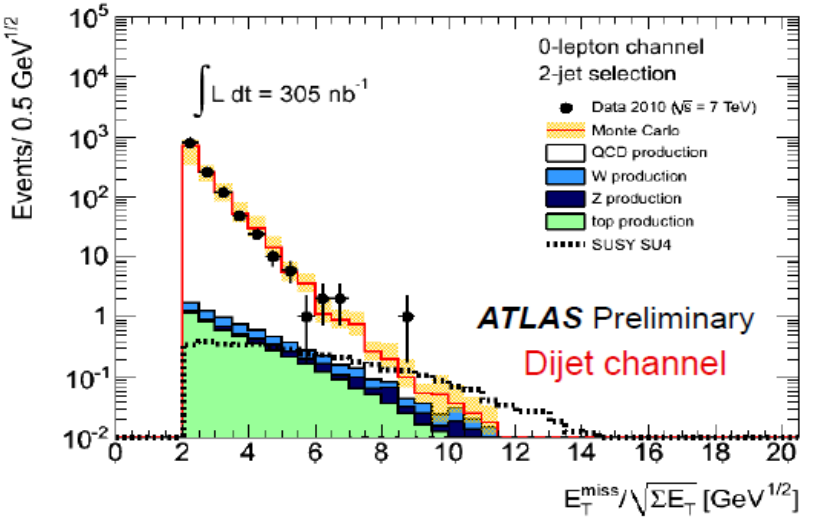
- Full selection applied: Z-bosonVeto, |M(ll)-M(Z)|>15 GeV
- MET >30 (20) GeV in ee,μμ, (eμ); N(jets) ≥2
- 4 tt candidates (1 eμ, 1 ee, 2 μμ) over a negligible background.
- Top signal at LHC established.

SUSY searches: events with b jets and missing energy

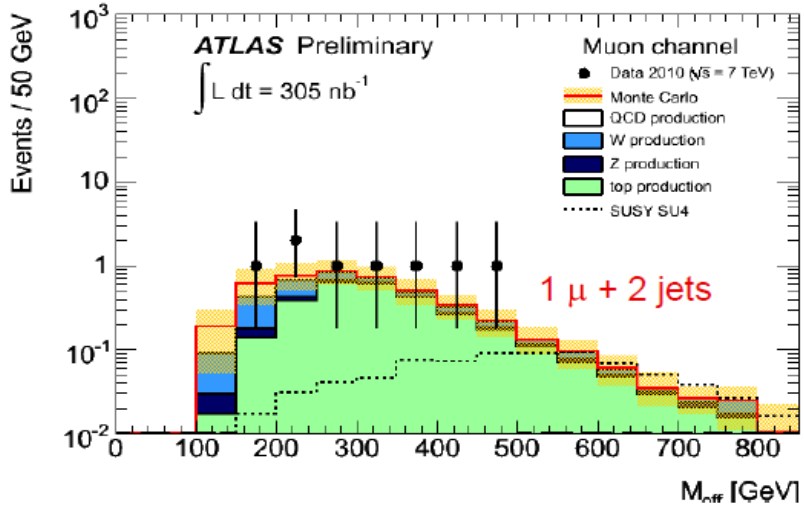
[*ATLAS Collaboration '10*]

SUSY Search in b-jets + Missing E_T

- Secondary vertex b-tagging algorithm:
  - Decay length significance: $L/\sigma > 6$
  - $\varepsilon_{b\text{-tagging}} \sim 50\%$
- Event selection (305 nb^{-1}):
  - channels: "≥2-j (70,30)", "≥1 lep (20) + 2 j (30,30)"
  - $E_{Tmiss}/\sqrt{\Sigma E_T} > 2$ $\sqrt{GeV}$, at least one b-jet



- Two things to take away from these plots:
  - The data are consistent with background
  - SUSY is not on this plot with the "x10" any more: a sign our sensitivity is getting close to where it needs to be to make a discovery..

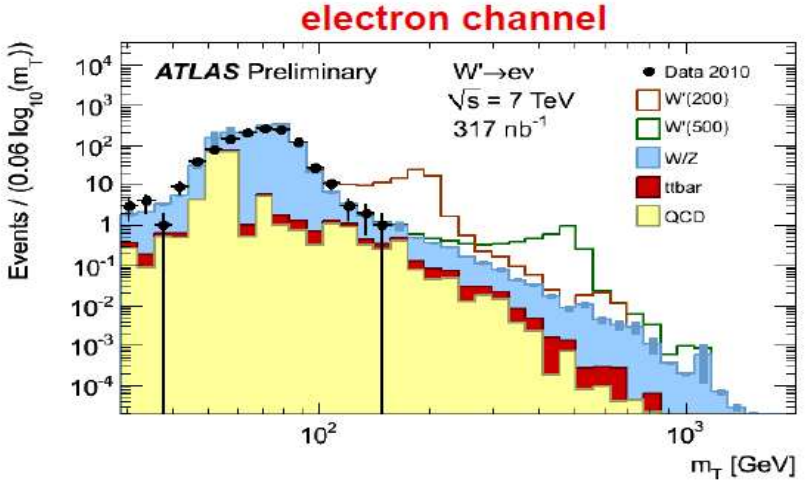


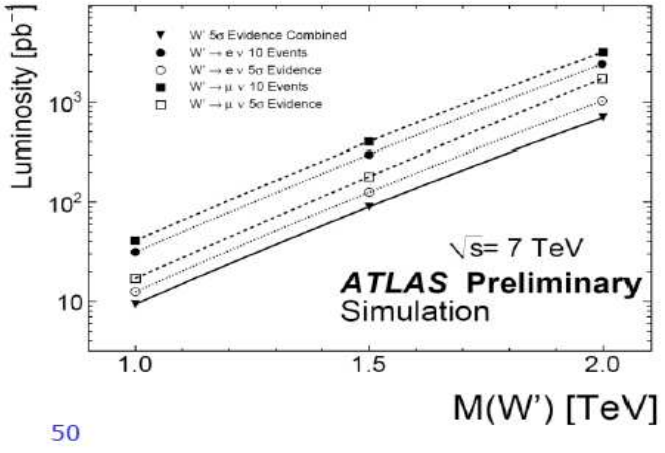
W' searches

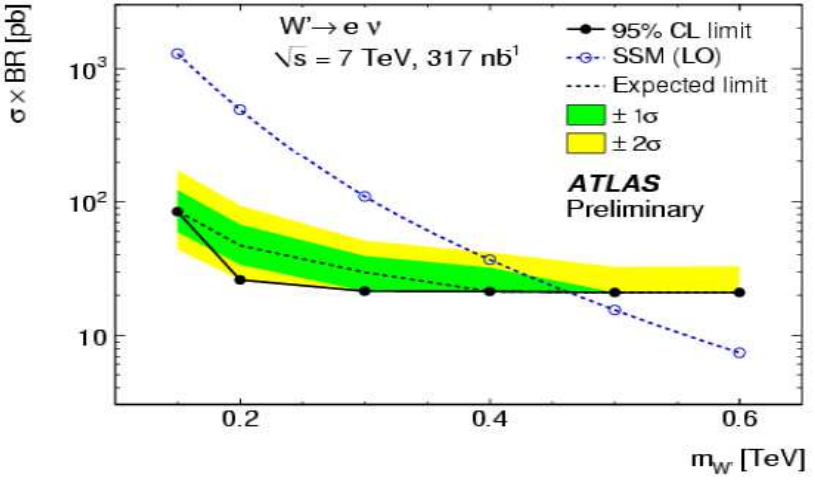
[*ATLAS Collaboration '10*]

Status of W' Search (example: electron channel)

- Analysis uses 317 nb-1 of data
- Data consistent with SM predictions
- Current limit that can be set (electrons): 465 GeV
  - Present Tevatron limit is 1 TeV
- Current results support estimates from previous MC sensitivity studies
  - Extend sensitivity around 5 pb^{-1}
  - Discovery potential at 10-20 pb^{-1}







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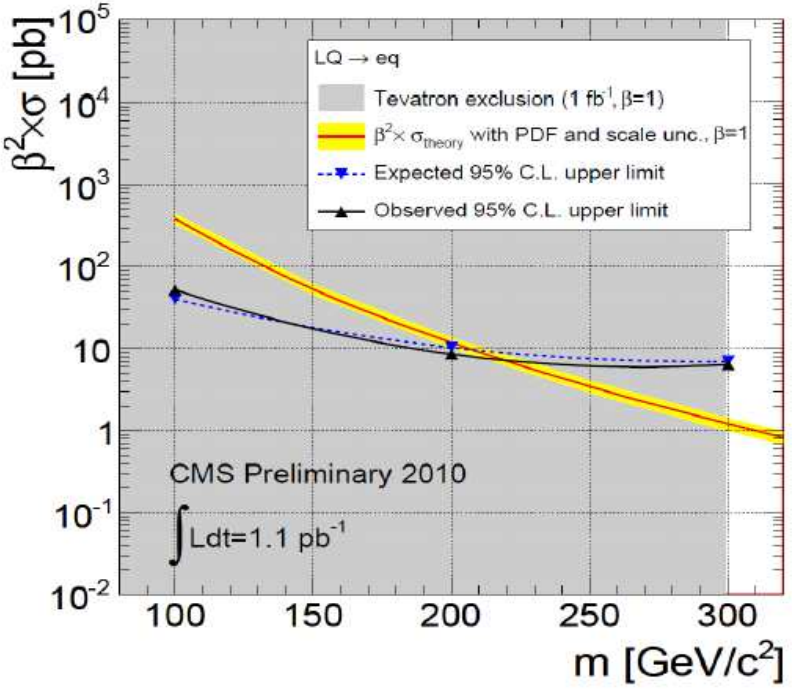
⇒ Searches will soon enter unexplored region

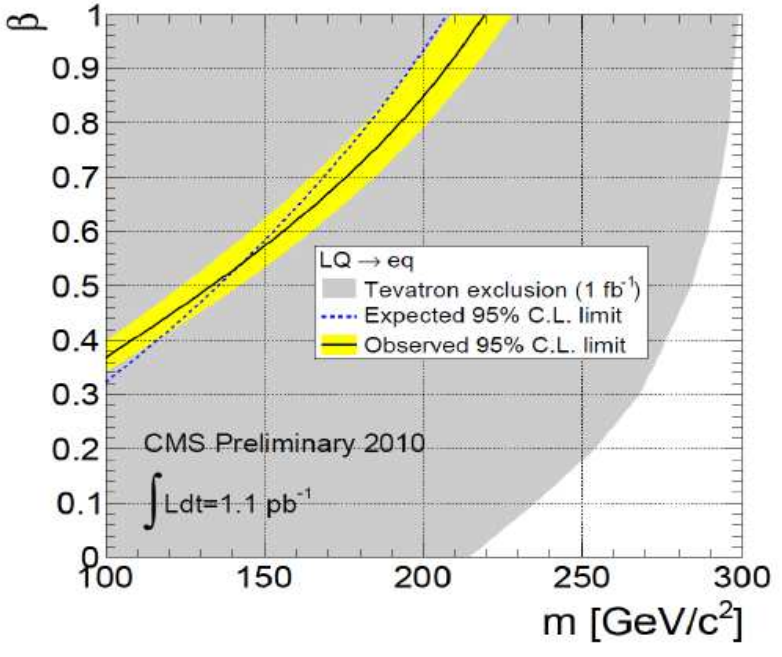
Leptoquark searches

[*CMS Collaboration '10*]

First Generation Leptoquark (2)

- Observation from data are consistent with SM bkg expectations
  - Set \upper limit on the LQ cross section (using a Bayesian approach)
  - Systematic uncertainties are included in the upper limit calculation
- A lower limit on the LQ mass is 220 GeV for β=1
  - The Tevatron limit is 299 GeV

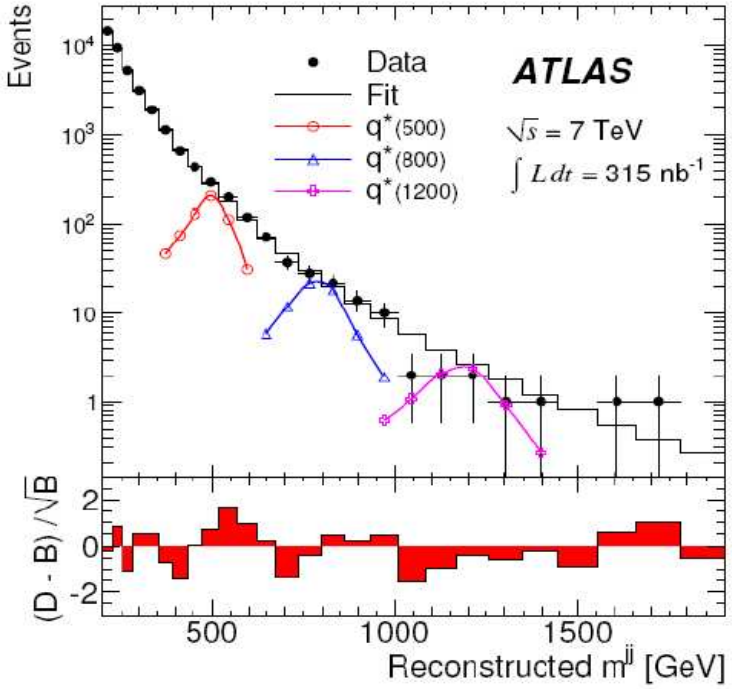


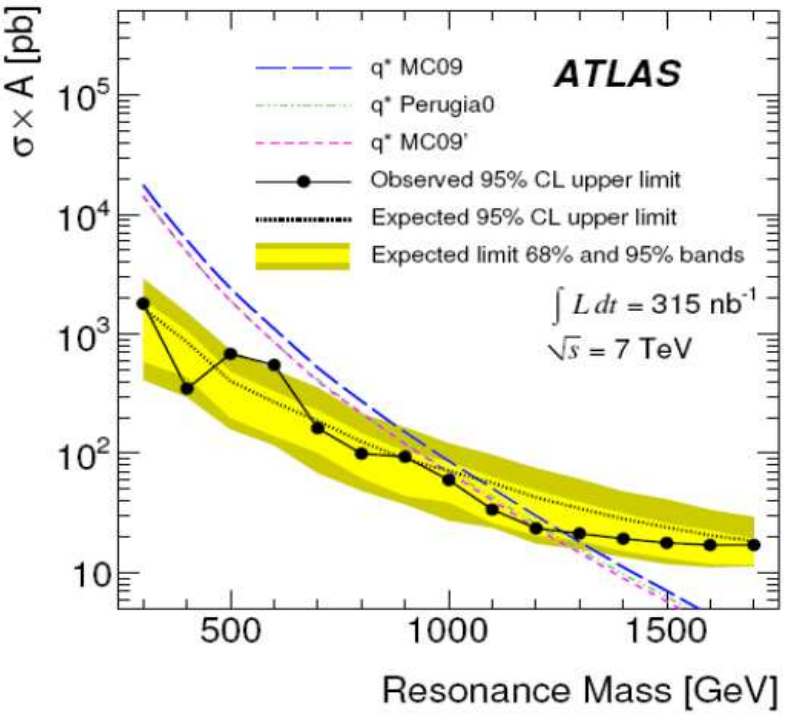


Di–jet resonance search

[*ATLAS Collaboration '10*]

Dijet Resonance Search: Outcome





- No evidence of a bump
- Set limit at m(q*) > **1.26 TeV** (expected limit 1.06 TeV)

This data was collected until Monday 19 July, and shown at ICHEP on Friday afternoon.

Accepted for publication in PRL
arXiv:1008.2461

Prospects for the near future and possible implications

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- LHC searches are starting to cover new ground

  $\Rightarrow$ Exciting prospects for the first run

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- How about searches elsewhere?

- What to expect?

  $\Rightarrow$ Explore constraints from electroweak precision data

Global fit in constrained SUSY model: indirect experimental and cosmological constraints

SUSY search prospects:

Global χ^2 fit in the CMSSM ($m_{1/2}$, m_0, A_0 (GUT scale), $\tan\beta$, $\mathrm{sign}(\mu)$ (weak scale))

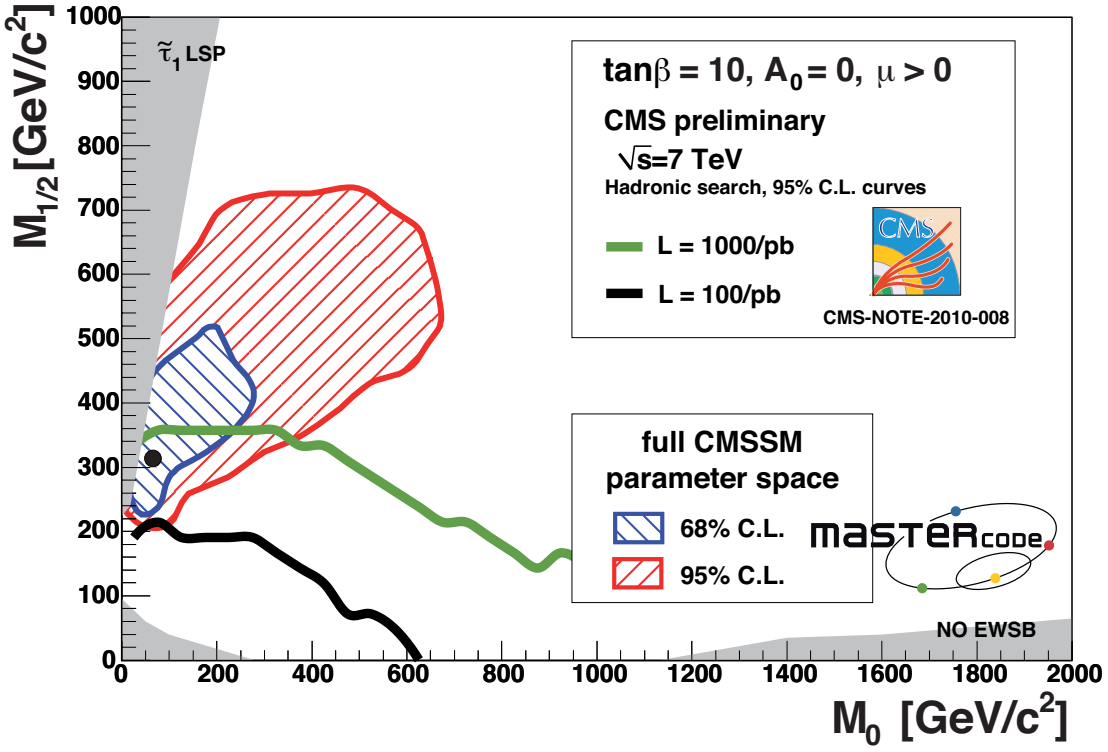
Fit includes (*MasterCode*, Markov-chain Monte Carlo sampling):
[*O. Buchmueller, R. Cavanaugh, A. De Roeck, J. Ellis, H. Flächer, S. Heinemeyer, G. Isidori, K. Olive, P. Paradisi, F. Ronga, G. W. '08*]

- Electroweak precision observables: M_{W}, $\sin^2\theta_{\mathrm{eff}}$, Γ_{Z}, ...
- $+$ Cold dark matter (CDM) density (WMAP, ...),
  $\Omega_{\mathrm{CDM}}\,h^2 = 0.1099 \pm 0.0062$
- $+\ (g-2)_\mu$
- $+$ BPO: $\mathrm{BR}(b \to s\gamma)$, $\mathrm{BR}(B_{\mathrm{s}} \to \mu^+\mu^-)$, $\mathrm{BR}(B \to \tau\nu)$, ...
- $+$ Kaon decay data: $\mathrm{BR}(K \to \mu\nu)$, ...

Predictions for the SUSY scale from precision data: CMSSM

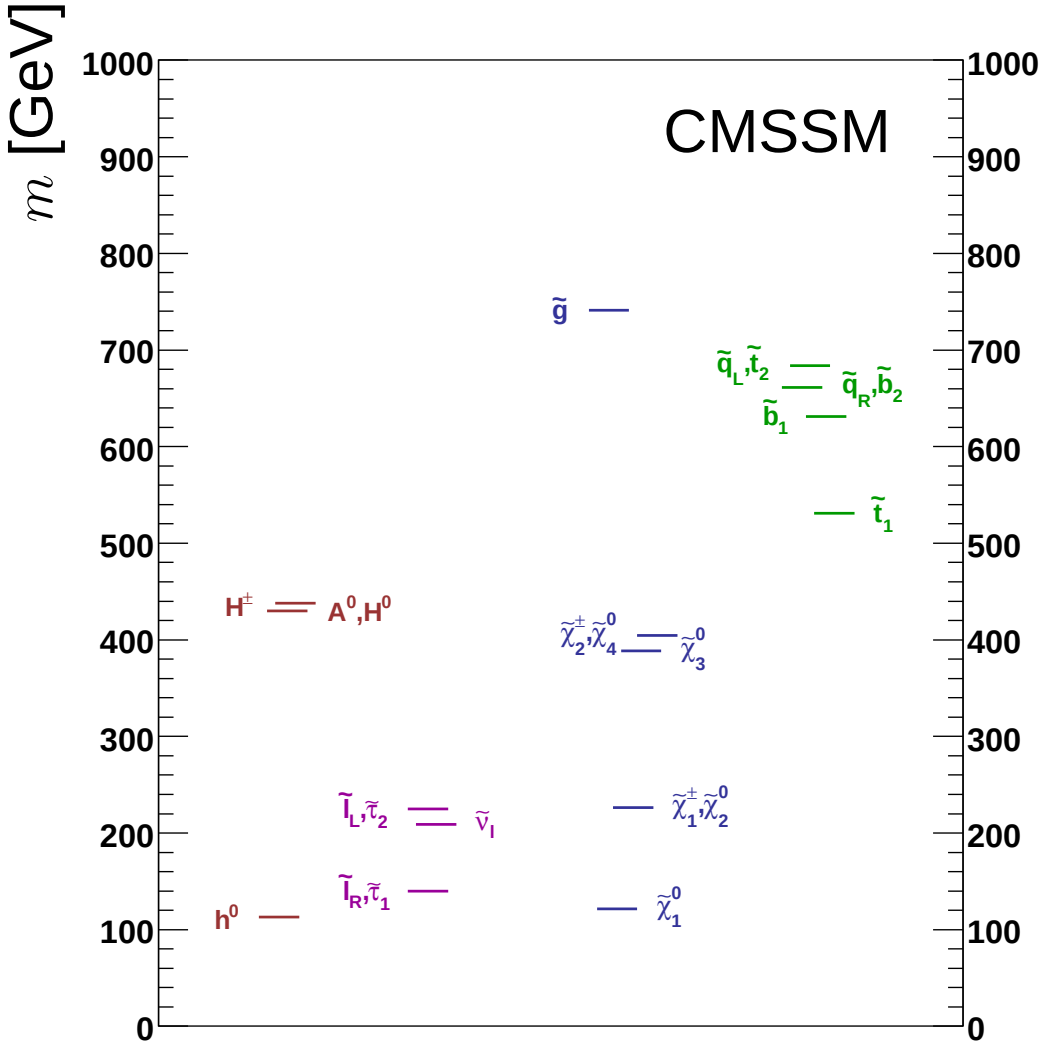
Comparison: preferred region in the m_0–$m_{1/2}$ plane vs. CMS 95% C.L. reach for $0.1, 1\ \mathrm{fb}^{-1}$ at $7\ \mathrm{TeV}$

[*O. Buchmueller, R. Cavanaugh, A. De Roeck, J. Ellis, H. Flächer, S. Heinemeyer, G. Isidori, K. Olive, P. Paradisi, F. Ronga, G. W. '10*]



⇒ Good prospects for early discovery! Get hint in first run?

Spectrum of the best-fit point

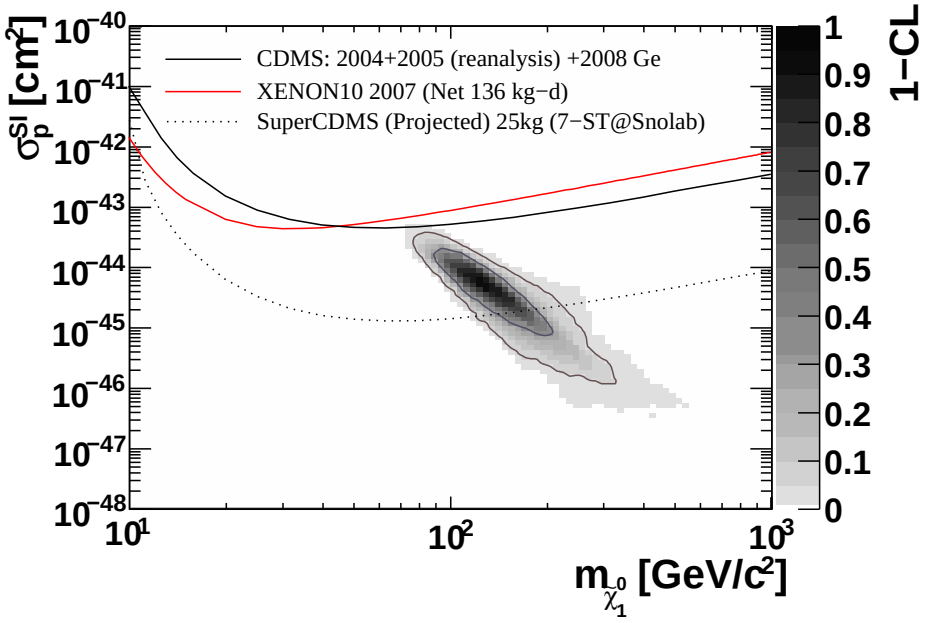


$\Rightarrow$ Good prospects for LHC and ILC

Prospects for dark matter direct detection

Present limit and future sensitivities on spin-indep. cross section vs. preferred regions of global fit (CMSSM):

[*O. Buchmueller, R. Cavanaugh, A. De Roeck, J. Ellis, H. Flächer, S. Heinemeyer, G. Isidori, K. Olive, F. Ronga, G. W. '09*]

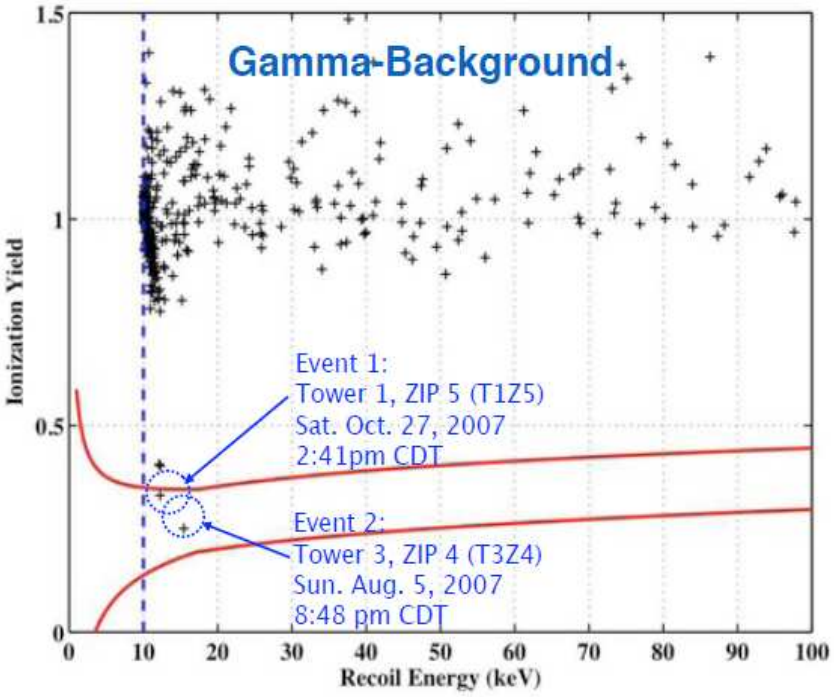


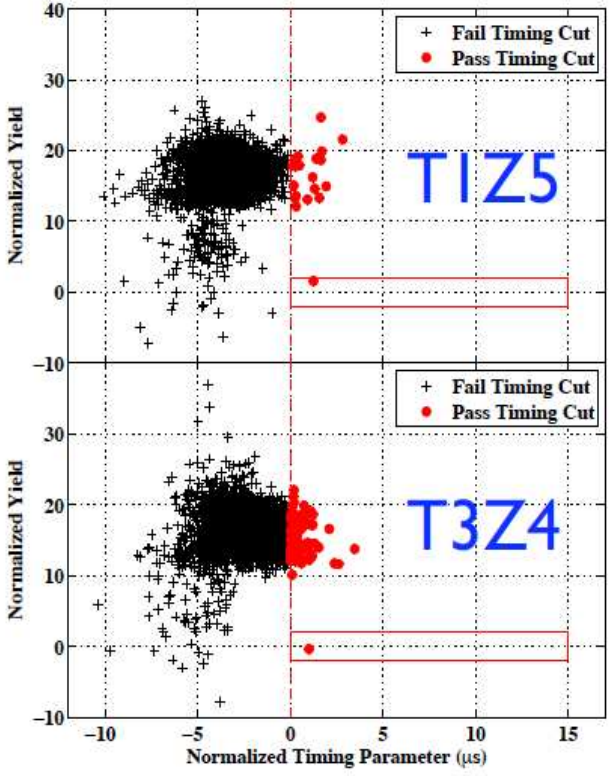
⇒ Projected sensitivity of the *SuperCDMS* (and *Xenon 100*) direct detection experiments will probe a sizable part of the preferred region in the CMSSM

CDMS results: two candidate events

[*CDMS Collaboration '09*]

Final CDMS WIMP Search Runs: 191 kg days





Two events passing all cuts

(which were set based on calibration and background data outside the WS region)

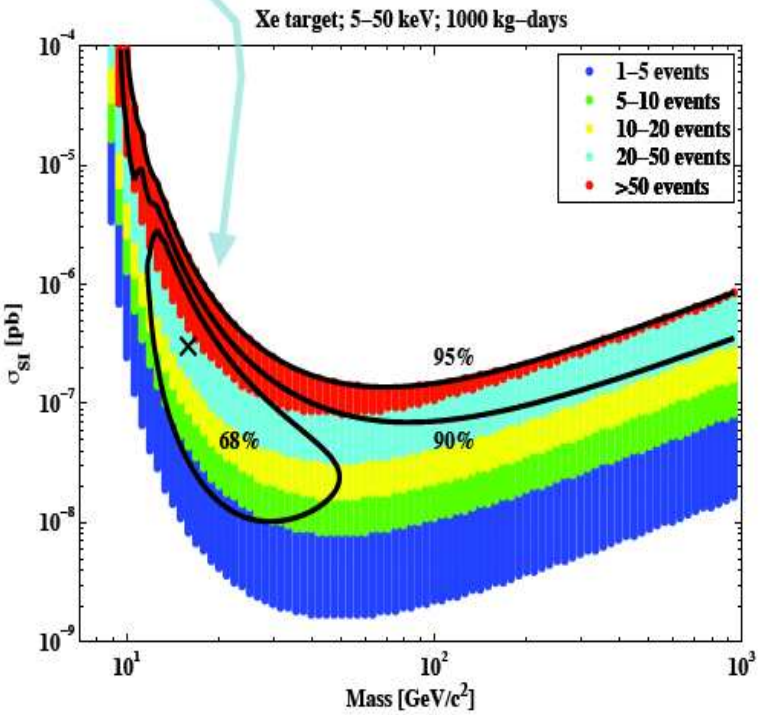
Direct detection: prospects for Xenon100

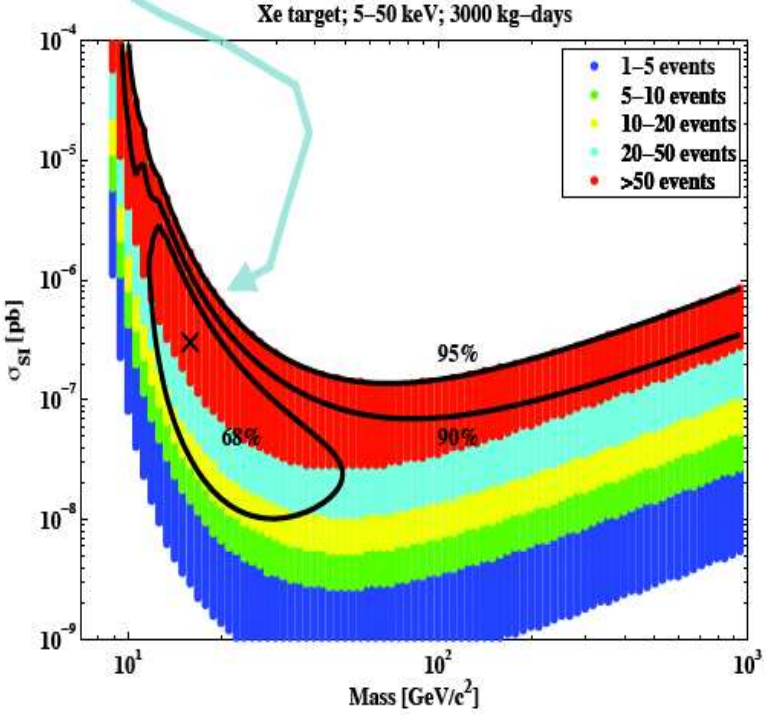
[*L. Baudis, SUSY10 Conference*]

- What if the two CDMS events are WIMPs?... *What would XENON100 see?*
- Assumptions:

➡ 50 kg x 40 days x 50% signal acceptance = **1000 kg days exposure**

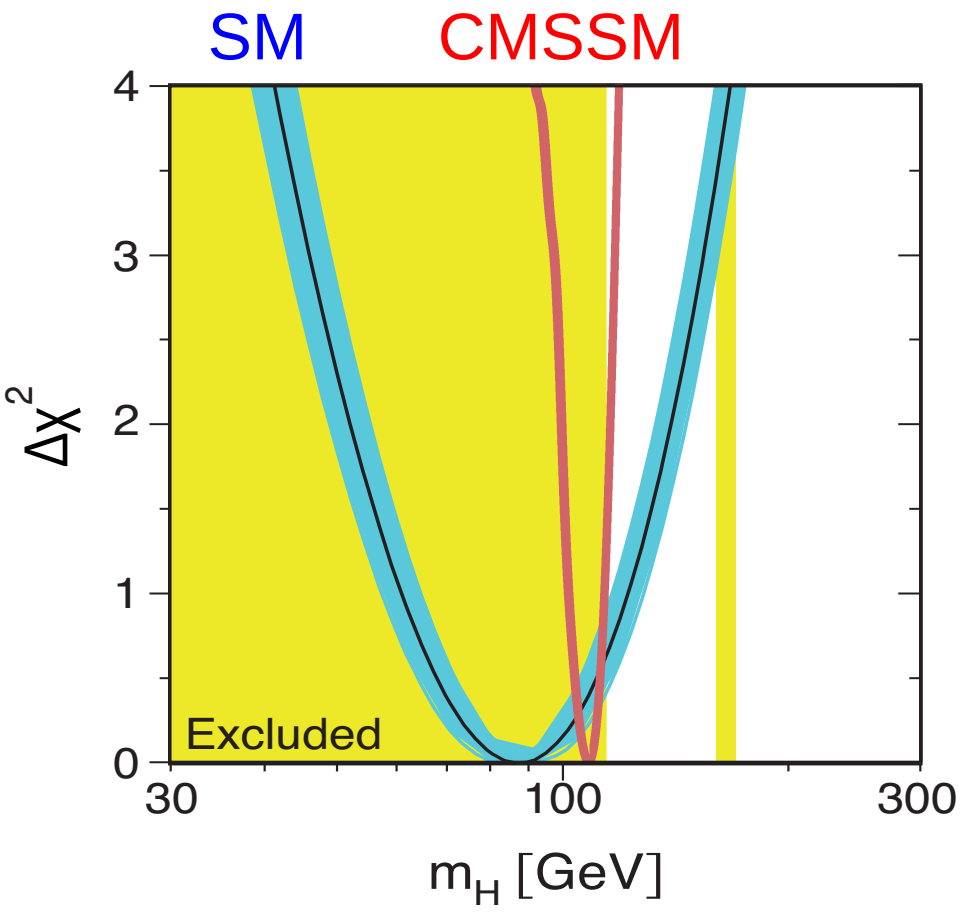
➡ 30 kg x 200 days x 50% signal acceptance = **3000 kg days exposure** (lower background)

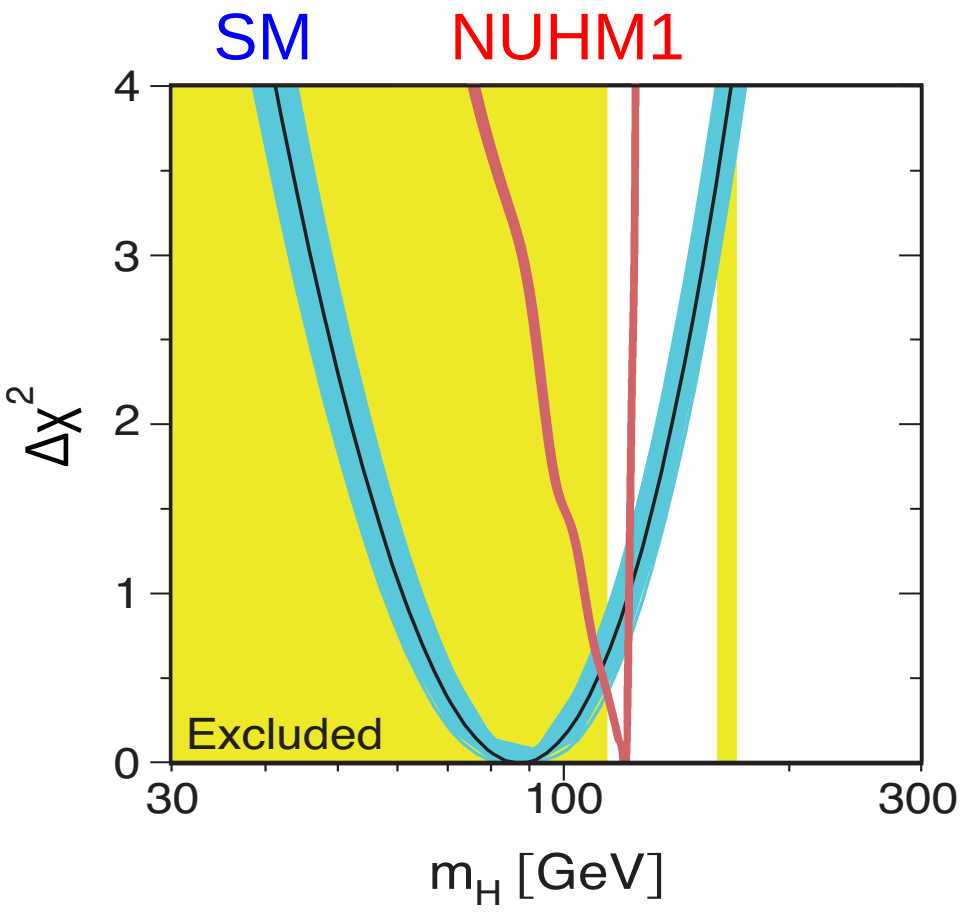




SM Higgs: indirect prediction from precision data in constrained SUSY models (CMSSM, NUHM1)

χ^2 fit for $M_{\rm h}$, without imposing direct search limit



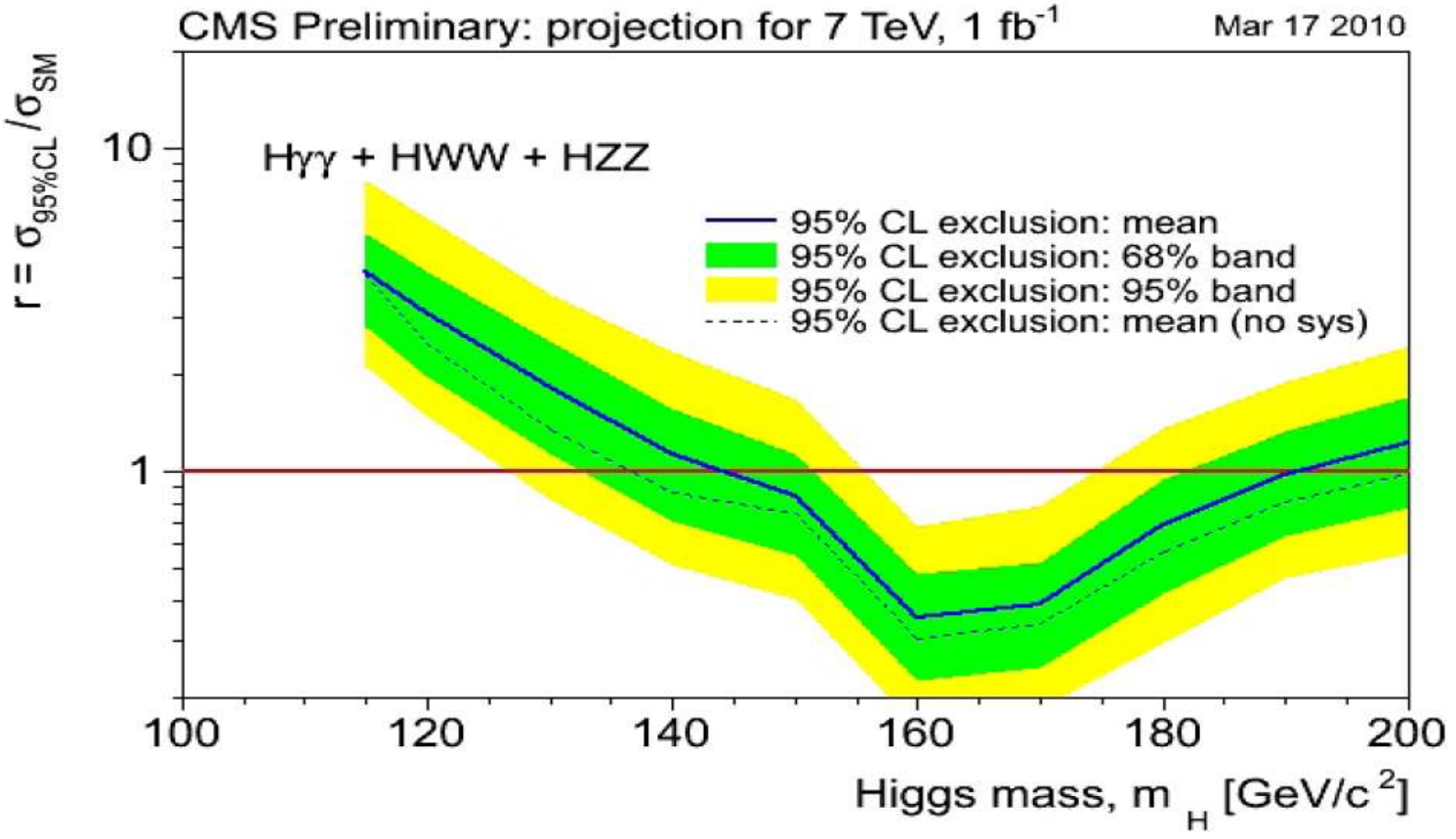


$$M_{\rm h}^{\rm CMSSM} = 108 \pm 6 \text{ GeV} \qquad M_{\rm h}^{\rm NUHM1} = 121^{+2}_{-14} \text{ GeV}$$

$\Rightarrow$ Accurate indirect prediction; Higgs "just around the corner"?

SM Higgs: LHC prospects with $1\ \mathrm{fb}^{-1}$ *at 7 TeV*

[*CMS Collaboration '10*]

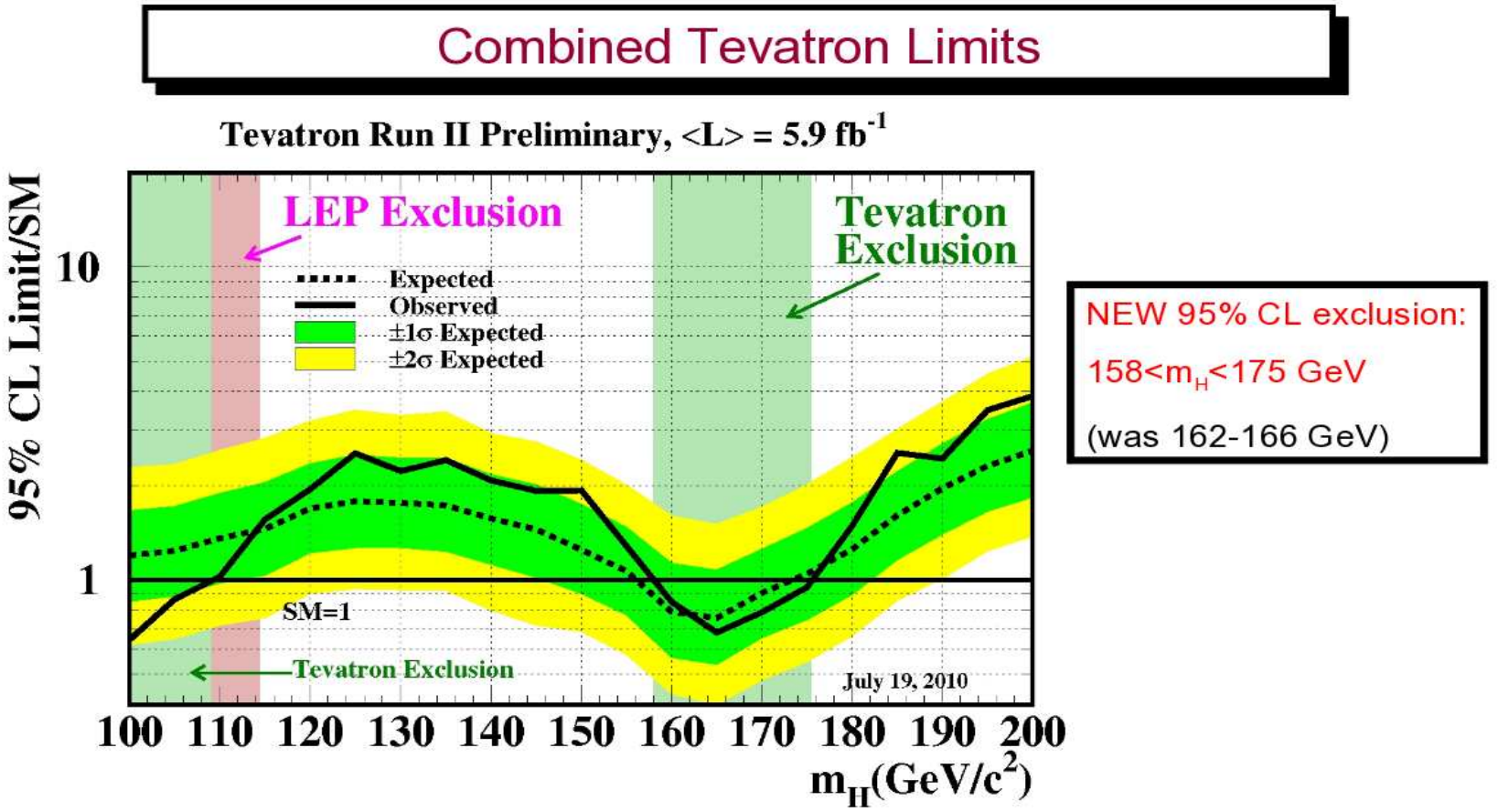


⇒ Sensitivity for 95% C.L. exclusion for $145\ \mathrm{GeV} \lesssim M_{\mathrm{H}} \lesssim 190\ \mathrm{GeV}$

More data needed to cover region preferred by ew prec. tests

SM Higgs: Tevatron limits

[*CDF and D0 Collaborations '10*]



NEW 95% CL exclusion:

$158 < m_H < 175$ GeV

(was 162-166 GeV)

Significant improvement in sensitivity across whole mass range probed:

- Expected exclusion range from 156 to 173 GeV
- Better than 1.78 x SM sensitivity for all mass points below 185 GeV
- At m_H=115 GeV expected limit 1.45 x SM

35

SM Higgs: Tevatron prospects until end of 2011

[*CDF and D0 Collaborations '10*]

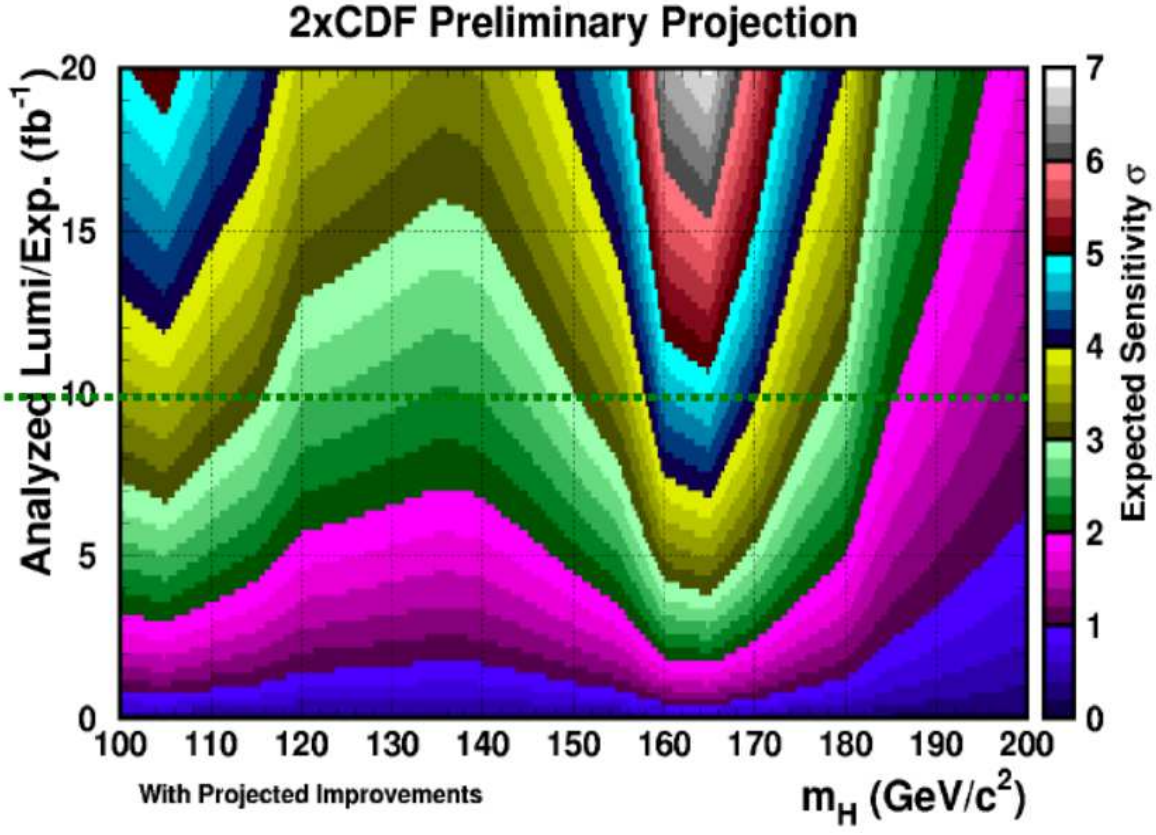
SM Higgs Prospects

- Median projected reach assuming improvements. These are "a-priori sensitivities" (i.e. not taking into account current observed limits).
- There is a band of possibilities around these lines.

End of 2011: 10 fb^{-1}/exp

>2.4σ for m_H<185 GeV

3σ for m_H~115 GeV



SM Higgs: Tevatron prospects until end of 2014

[*CDF and D0 Collaborations '10*]

SM Higgs Prospects

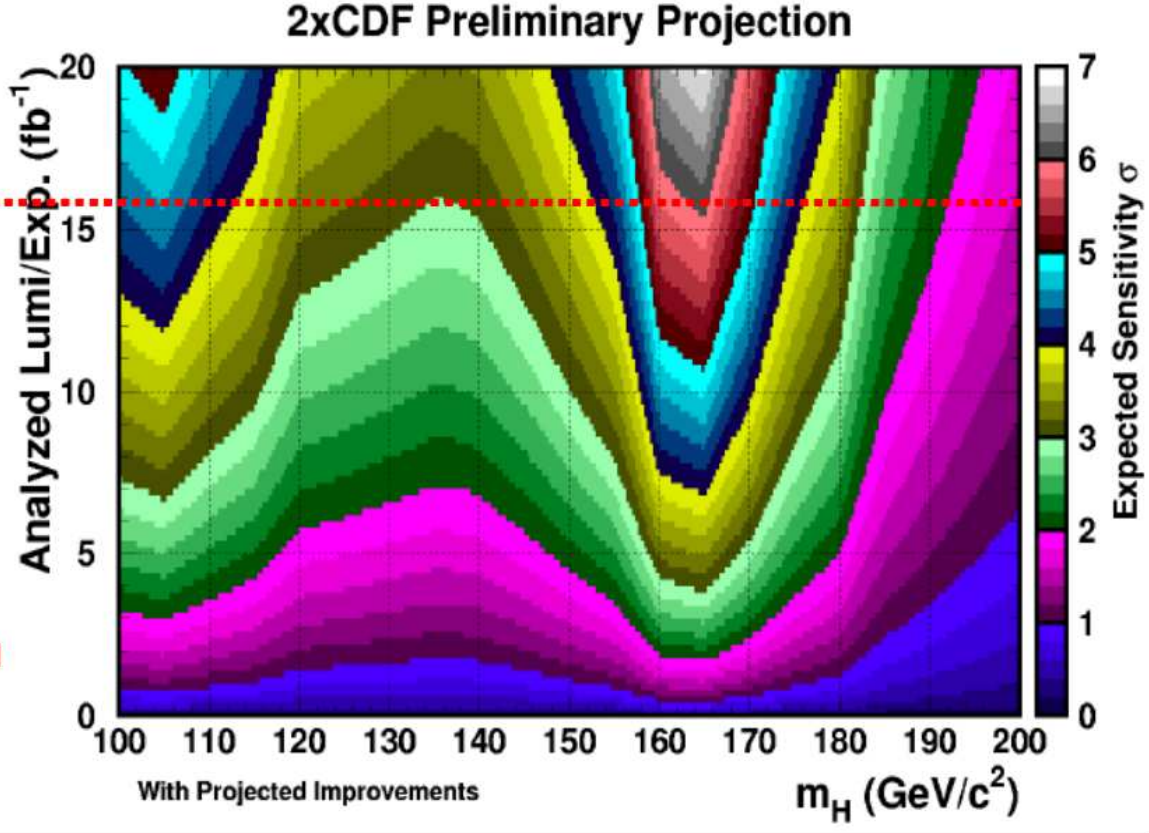
- Median projected reach assuming improvements. These are "a-priori sensitivities" (i.e. not taking into account current observed limits).
- There is a band of possibilities around these lines.

End of 2014: 16 fb^{-1}/exp (*)

>3σ for m_H<180 GeV

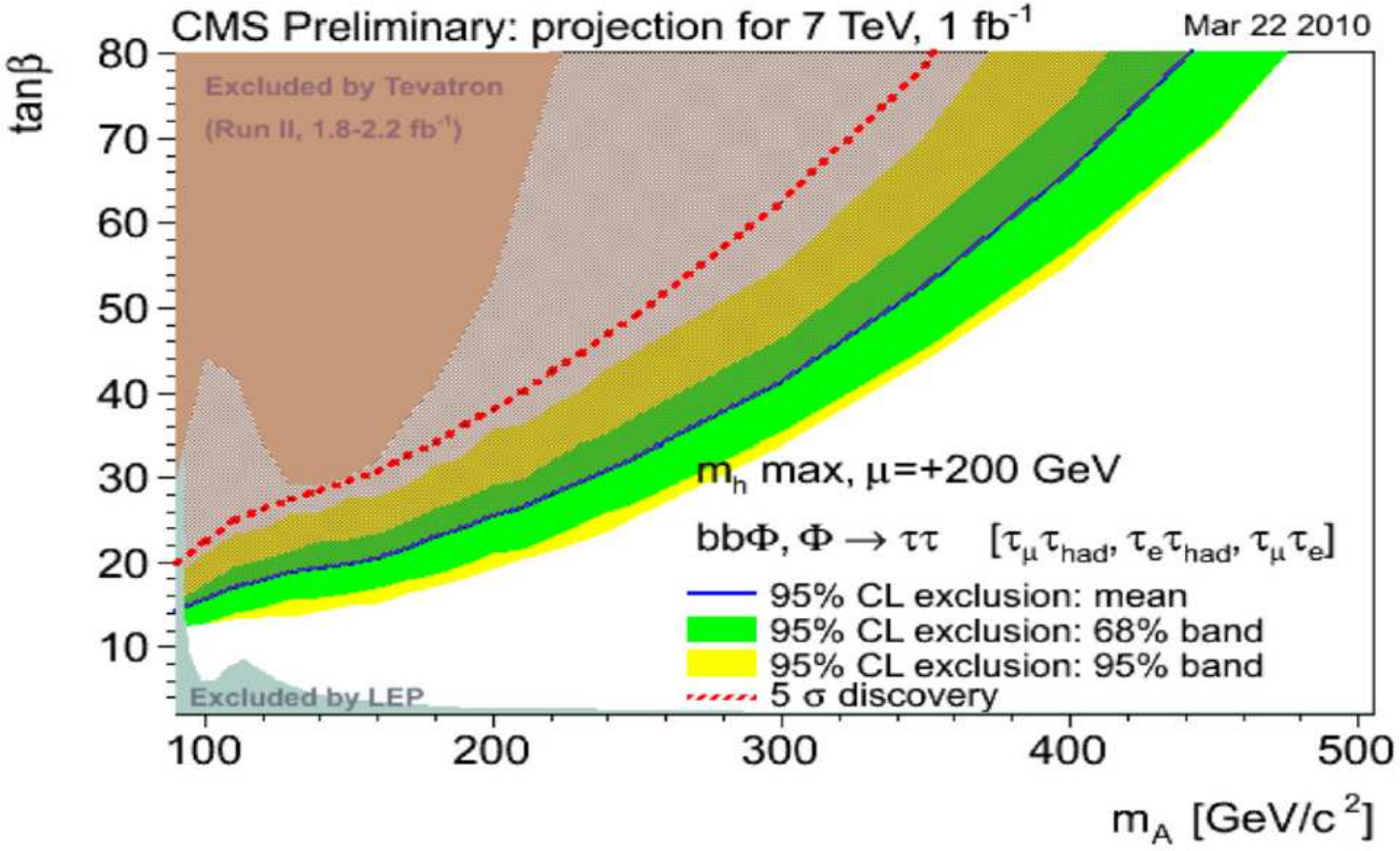
4σ for m_H~115 GeV

(*) Based on Run III proposal to run up to end of FY14



SUSY Higgs: LHC prospects with $1\ \mathrm{fb}^{-1}$ *at 7 TeV*

[*CMS Collaboration '10*]

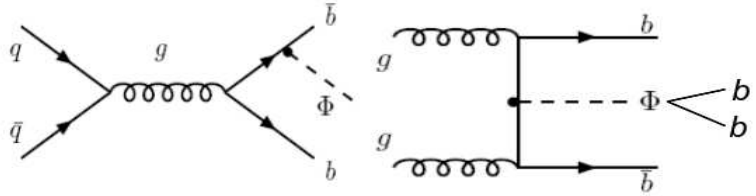


⇒ Higgs searches with early LHC data have a chance to discover the heavy MSSM Higgses H, A before a light SM-like Higgs h is found

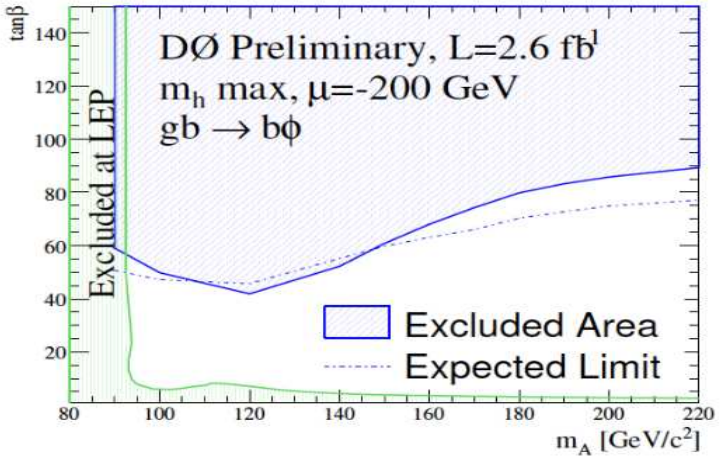
SUSY Higgs: Tevatron results

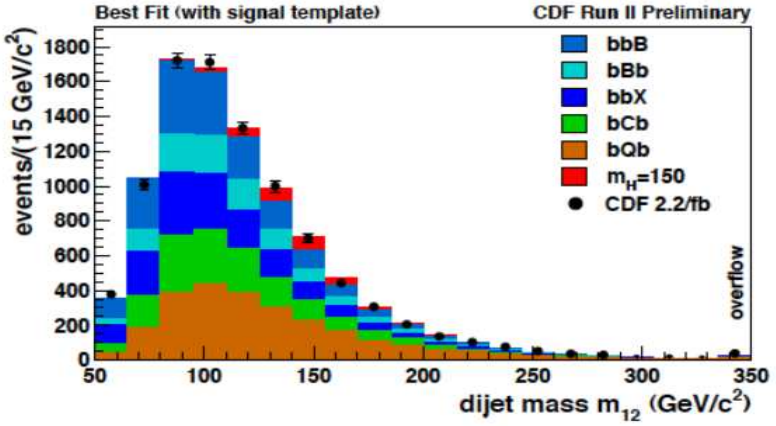
[*CDF and D0 Collaborations '10*]

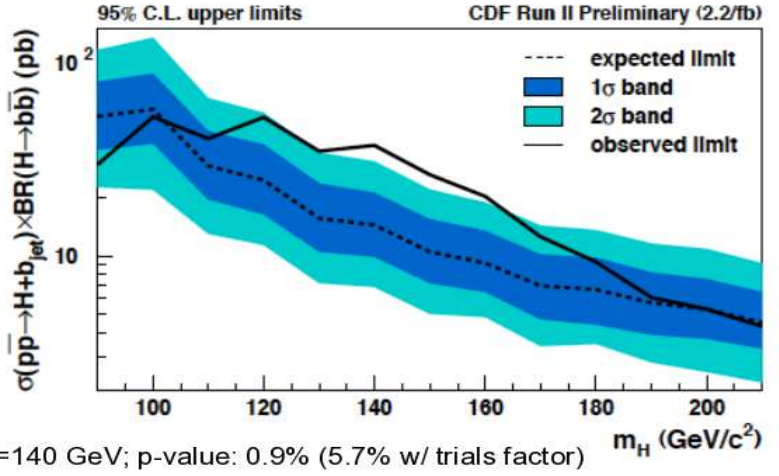
$b(b)+\Phi^0 \rightarrow bbb(b)$



- Experimental signature:
  - 3, 4 or ≥5 jets; ≥3 b-tags
  - Look for resonance in dijet mass
- Backgrounds dominated by heavy flavor-enriched QCD multijets:
  ➔estimated from data.







m_ϕ=140 GeV; p-value: 0.9% (5.7% w/ trials factor)

⇒ Slight excess in CDF search

SUSY Higgs: Tevatron prospects until end of 2014

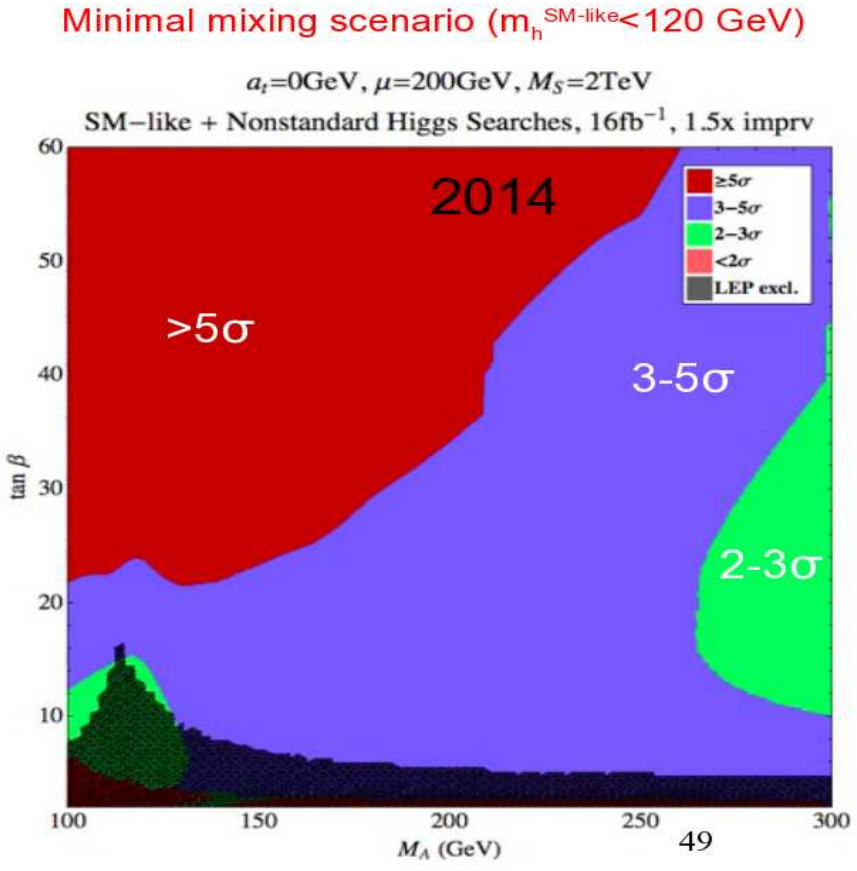
[*CDF and D0 Collaborations '10*]

MSSM Higgs Boson Prospects

- SM-like Higgs searches will be able to probe a significant fraction of the MSSM parameter space at the 2-3σ level.
- In combination with non-SM Higgs searches, most MSSM parameter space could be probed with quite "interesting" sensitivity!
- Caveat: only Vh(h→bb), h→WW→lνlν and ϕ→ττ considered in this projection.

  ➔ Reach may improve further upon including all search channels being pursued!

Phys. Rev. D 80, 035025 (2009)



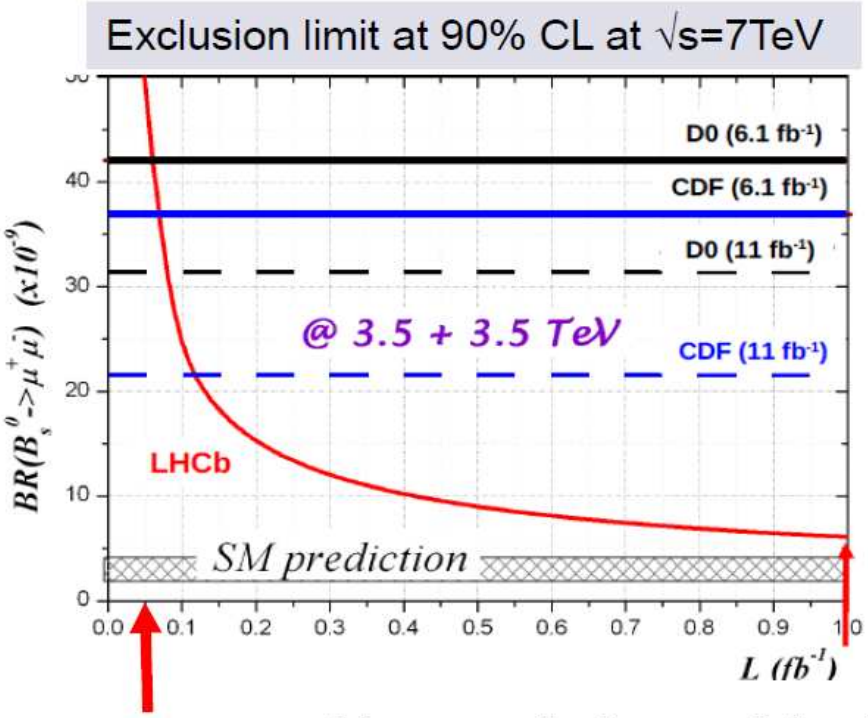
⇒ Interesting competition between LHC and Tevatron?

LHCb: sensitivity to $\mathrm{BR}(B_s \to \mu^+\mu^-)$

[*LHCb Collaboration '10*]

Prospects for $B_s \to \mu\mu$ at LHCb

Very rare decay in SM, well predicted $BR(B_s \to \mu\mu) = (3.35 \quad 0.32) \times 10^{-9}$.



- Sensitive to NP, in particular new scalars.
  In MSSM: $BR \propto \tan^6\beta / M_H^2$
- Sensitivity from MC assuming measured $b\bar{b}$ cross-section
- Expectation being confirmed by tests on data.

approaching new limit possible already with 50 pb^{-1}

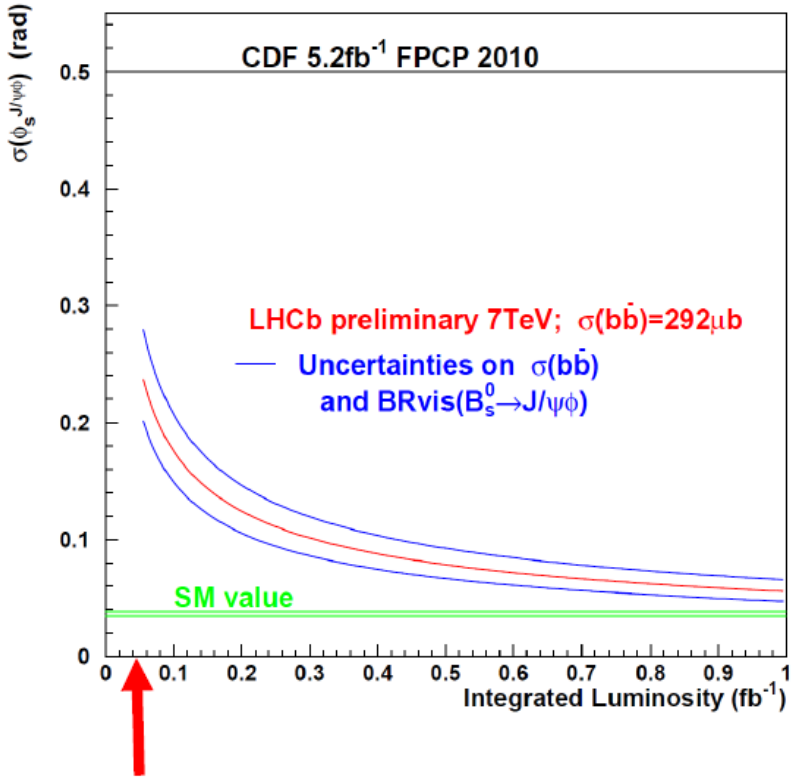
$\Rightarrow$ High sensitivity to effects of new physics

LHCb: sensitivity to $\mathcal{CP}$-violating effects

[*LHCb Collaboration '10*]

Prospects for CPV in $B_s \rightarrow J/\psi\phi$

Expected sensitivity



Working on data:

- Signal yield, mass and propertime resolution
- Control channels: preparing auxiliary measurements on B→J/ψX
- Flavour Tagging

First result possible already with 50 pb^{-1} data

Summary on prospects in the near future

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But: We'll need to be rather lucky to get to a firm discovery until 2012

Even if this is the case, the interpretation of what has been found will almost certainly not be unique

What can one infer from LHC searches for the discovery potential at the LC?

LHC with $1\ \mathrm{fb}^{-1}$ at 7 TeV:

Besides resonance-type production of a single state of new physics ($Z' \to \mu^+\mu^-$, $gg \to h, h \to \tau^+\tau^-$, ...) the early LHC searches will mainly be sensitive to coloured states of new physics

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Inferring the colour-neutral part of the spectrum of new physics states from the coloured part of the spectrum is only possible on the basis of model assumptions (SUSY: coloured states tend to be heavier than colour-neutral ones)

What can one infer from LHC searches for the discovery potential at the LC?

$\Rightarrow$ The observation of a SUSY-type signal at the LHC can most easily be interpreted in the context of the LC if the signal involves (e.g. via cascade decays) also colour-neutral states of new physics

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What about the observation of a Z' with a mass beyond the LC reach?

$\Rightarrow$ LC information can be crucial for revealing the mechanism of EWSB and the origin of a possible tension with the electrowealk precision observables

What next?

The interpretation of the early LHC results and their possible implications on future projects will obviously be an important topic in the near future

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  Physics scenarios at the LHC and their possible impact on the LC

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- Update of the European Strategy for Particle Physics
  (“to be concluded by the middle of 2012”)