SM Higgs Searches in CMS

The LHC Early Phase for the ILC

FNAL 12-14 April

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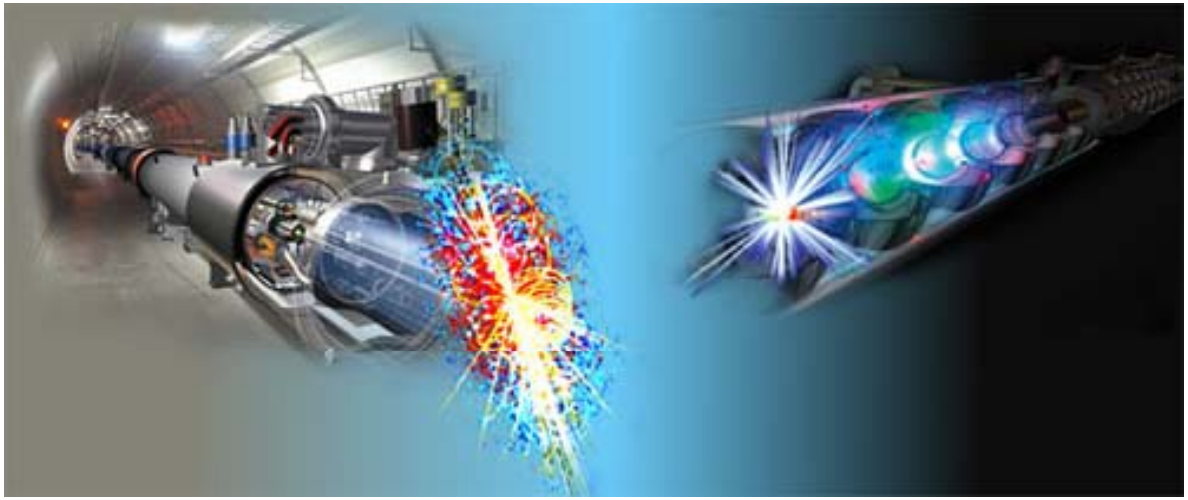
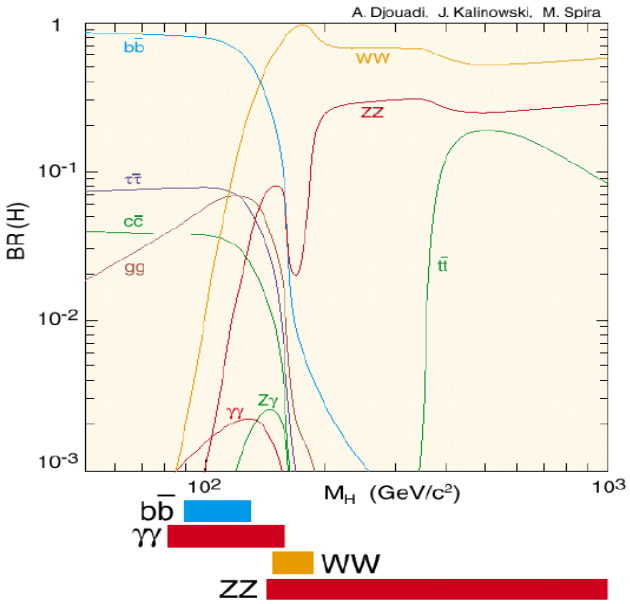
CERN
and University of Antwerp
and the IPPP Durham



SM Higgs Search Channels

Low mass $M_H \lesssim 200$ GeV

Production / DECAY	Inclusive	VBF	WH/ZH	ttH
$H \to \gamma\gamma$	YES	YES	YES	YES
$H \to bb$			YES	YES
$H \to \tau\tau$		YES		
$H \to WW^*$	YES	YES	YES	
$H \to ZZ^*$, $Z \to \ell^+\ell^-$, ℓ=e,μ	YES			
$H \to Z\gamma$, $Z \to \ell^+\ell^-$, ℓ=e,μ	very low σ			



Intermediate mass
(200 GeV $\lesssim M_H \lesssim$ 700 GeV)

inclusive $H \to WW$
inclusive $H \to ZZ$

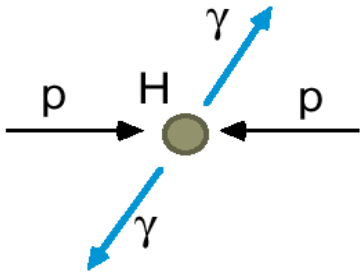
High mass ($M_H \gtrsim 700$ GeV)

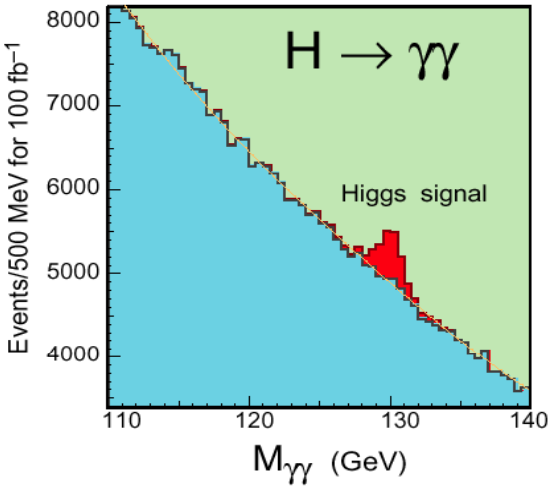
VBF $qqH \to ZZ \to \ell\ell\nu\nu$
VBF $qqH \to WW \to \ell\nu jj$

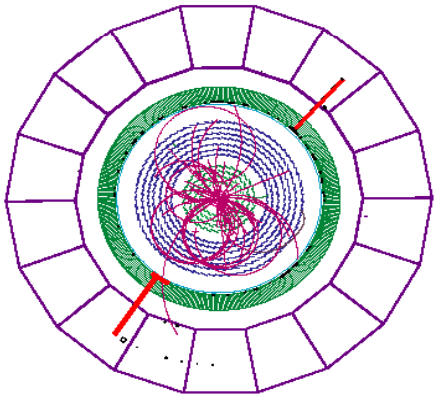
$H \to \gamma\gamma$ and $H \to ZZ^* \to 4\ell$ are the only channels with a very good mass resolution ~1%

Higgs Searches

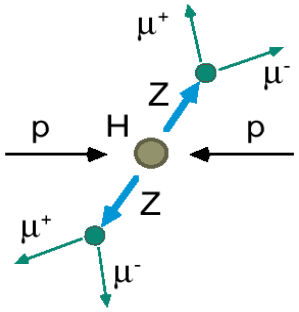
Low M_H < 140 GeV/c²

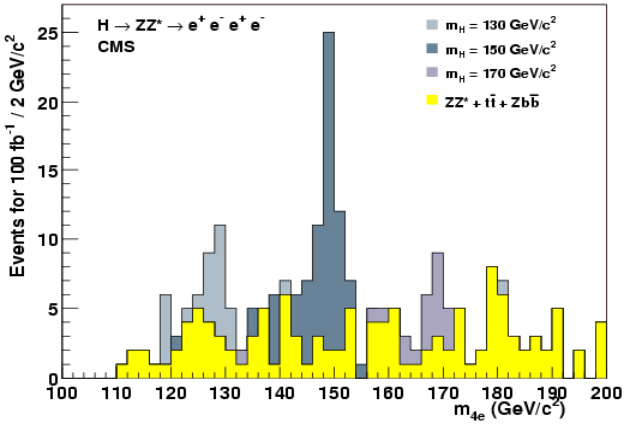


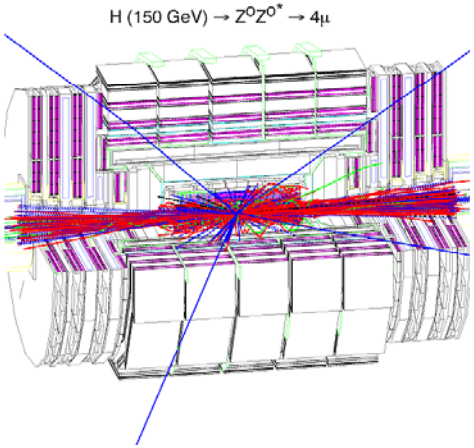




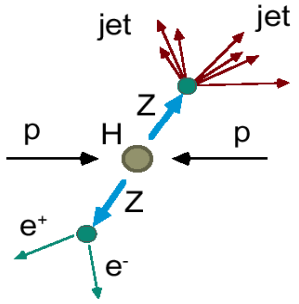
Medium 130<M_H<500 GeV/c²

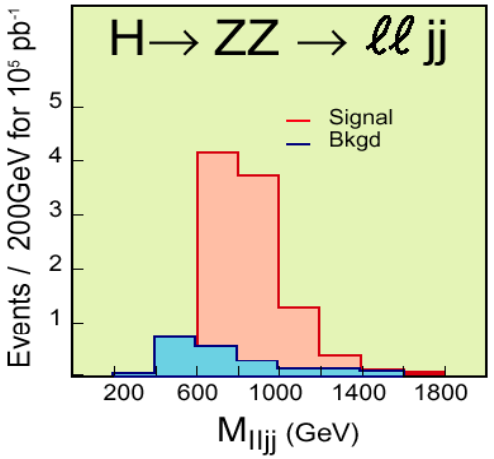


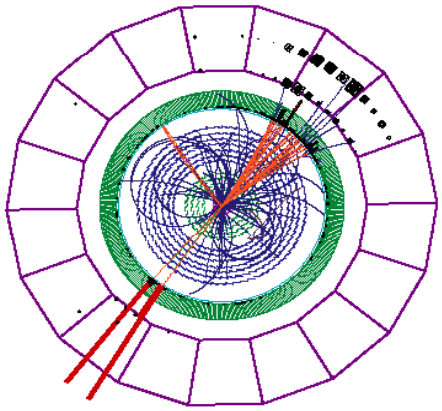




High M_H > ~500 GeV/c²







CMS→ PTDR: Improvements w.r.t. previous analyses

- Discovery potential for the Higgs boson was updated with:
  - Latest trigger table
  - Background estimates from "data", exp. systematics
  - ME generators for multi-jet events: ALPGEN, MadGraph, CompHEP, TopRex
  - all analyses based on full G4 simulation
  - $L = 2 \times 10^{33} cm^{-2} s^{-1}$ conditions (pile-up)
- NLO cross sections were used for Higgs boson production and backgrounds (when available)
  - SM Higgs production cross sections and branching ratios: HDECAY, HIGLU, VV2H, V2HV, HQQ.
    - Summary Tables provided by M. Spira.
    - Table with PDF uncertainties on H cross section from A. Djouadi
  - Most of the background NLO cross sections provided by John Campbell via the MCFM package

~ 10^{7-8} Z→ll, W→lν on tape during physics run in 2008-09 (~ 10fb^{-1} ?)

Z, W, tt cross sections and expected number of events after trigger in CMS with 10 fb^{-1}

channel, NLO σ x Br	Level-1 + HLT efficiency	events for10 fb^{-1}
W->e ν, 20.3 nb	0.25	5.1 x 10^7
W->μν, 20.3 nb	0.35	7.1 x 10^7
Z->ee, 1.87 nb	0.53	1.0 x 10^7
Z->μμ, 1.87 nb	0.65	1.2 x 10^7
tt~->μ+X, 187 pb	0.62	1.2 x 10^6

~ 10^6 tt->μ+X with 10 fb^{-1}

J. Campbell, R.K. Ellis, D. Rainwater hep-ph/0308195

W/Z+nJ+X NLO predictions at LHC with cuts :

p_T^l > 15 GeV
$|\eta l|$ < 2.4
p_T^j > 20 GeV
$|\eta^j|$ < 4.5
$\Delta R lj$ > 0.4
$\Delta R ll$ > 0.2

process	σ_{LO}	σ_{NLO}
$e^+\nu_e + X$	5670	6780^{+290}_{-130}
$e^-\bar{\nu}_e + X$	3970	4830^{+210}_{-90}
$e^+e^- + X$	803	915 ± 31
$e^+\nu_e\, j + X$	1660	1880^{+60}_{-50}
$e^-\bar{\nu}_e\, j + X$	1220	1420 ± 40
$e^+e^-\, j + X$	248	288^{+8}_{-7}
$e^+\nu_e\, jj + X$	773	669^{+0}_{-18}
$e^-\bar{\nu}_e\, jj + X$	558	491^{+0}_{-7}
$e^+e^-\, jj + X$	116	105^{+1}_{-5}

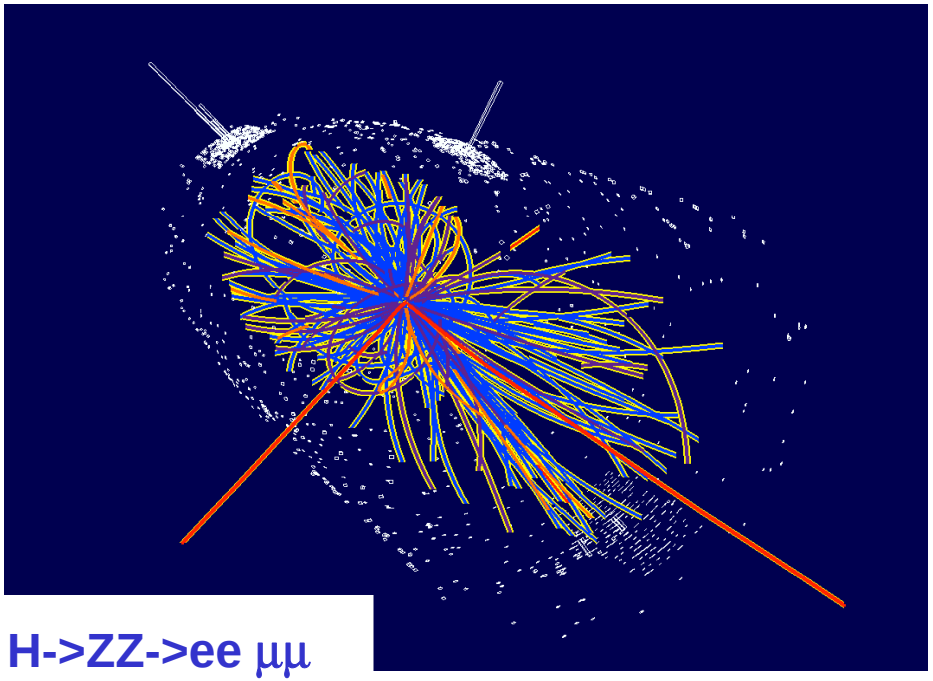
W/Z bb + X

$|\eta^b|$ < 2.5

process	σ_{LO}	σ_{NLO}
$e^+\nu_e\, b\bar{b} + X$	$1.30^{+0.21}_{-0.18}$	$3.06^{+0.62}_{-0.54}$
$e^-\nu_e\, b\bar{b} + X$	$0.90^{+0.14}_{-0.12}$	$2.11^{+0.46}_{-0.37}$
$e^+e^-\, b\bar{b} + X$	$1.80^{+0.60}_{-0.40}$	$2.28^{+0.32}_{-0.29}$

Higgs boson search in inclusive production.
"Golden" LHC modes:

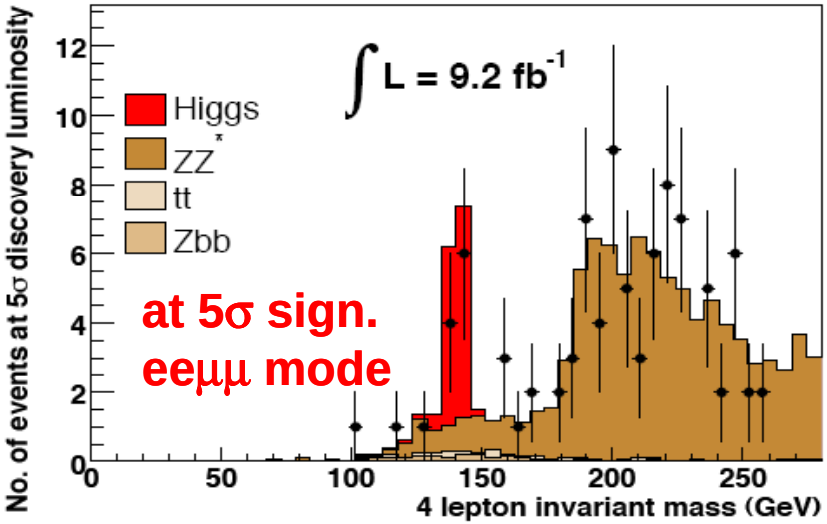
$ZZ^{(*)}->4l$, $WW->2l2\nu$, $\gamma\gamma$

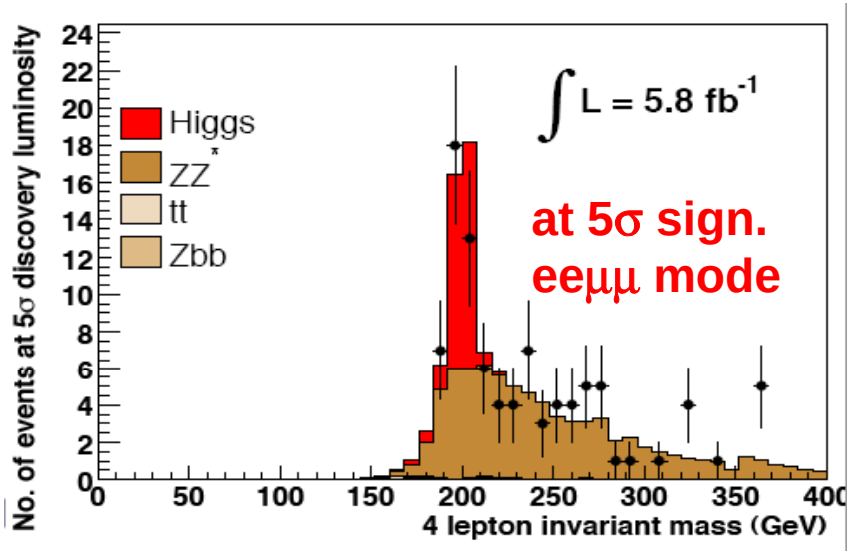


H->ZZ->ee μμ

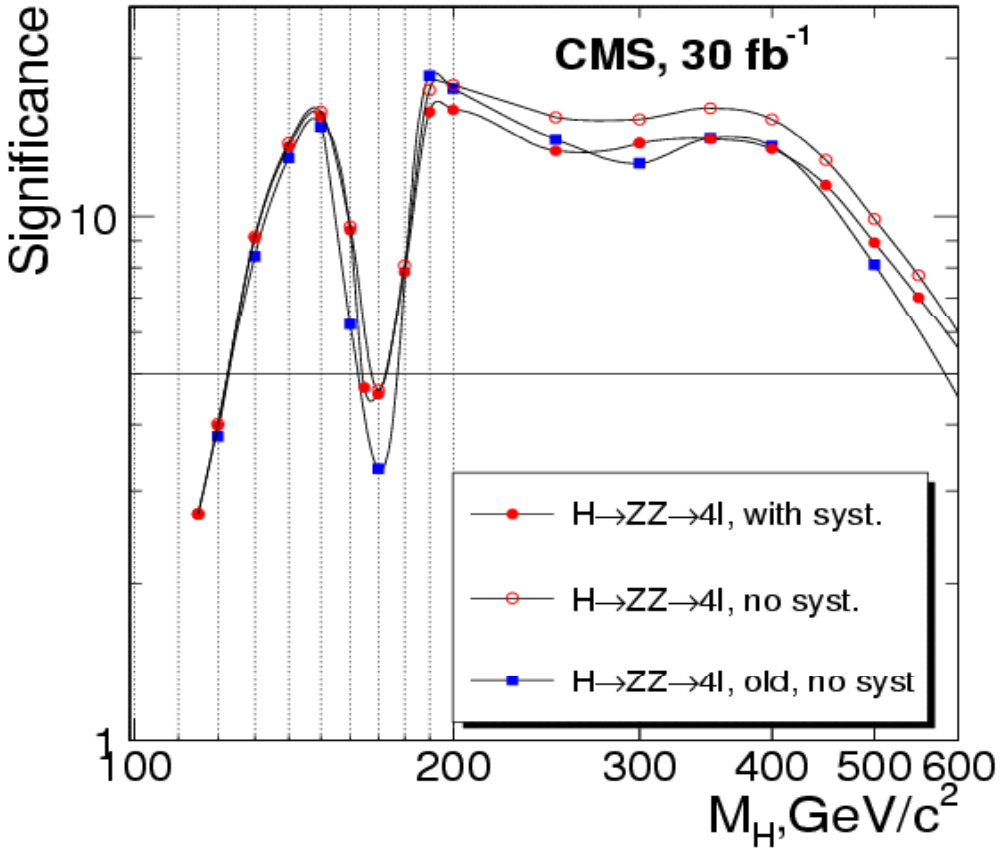
Higgs: H→ ZZ→ 4 leptons

ZZ background: NLO K-factor depends on mass of 4l
Background from side bands or from ZZ/Z;
(gg->ZZ is added as 20% of LO qq->ZZ)





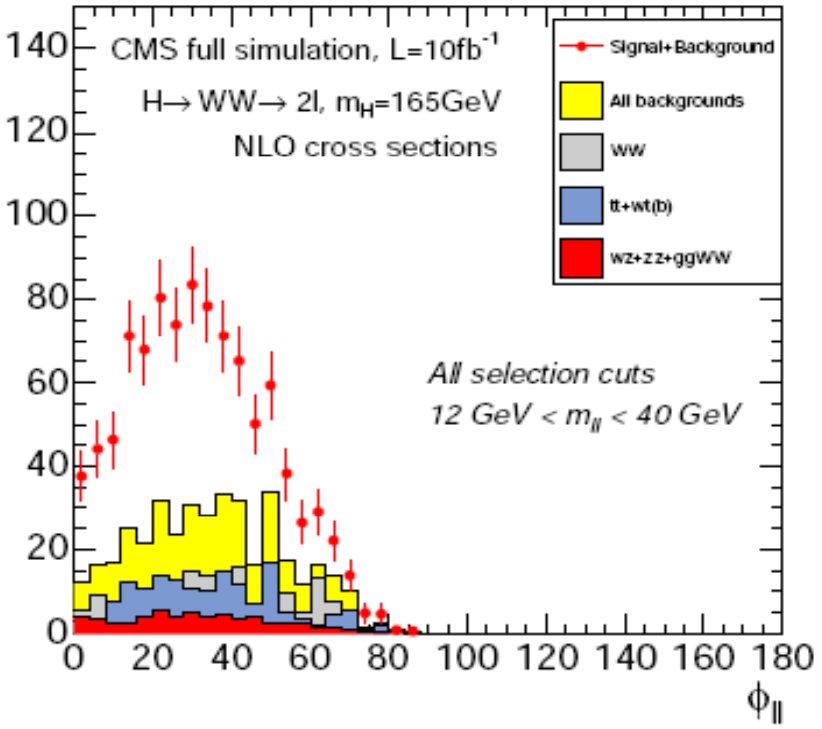
Combined 4μ, 4e, eeμμ signal significance



Early discovery in the channel H→WW→2l2ν? ...counting experiment...

- New for this analysis
  - P_T Higgs and WW bkg. at NLO (re-weighted in PYTHIA)
  - include box gg->WW bkg.
  - NLO Wt cross section after jet veto
- Background estimates from data (and theory)
  - tt from the data; uncertainty 16% at 5 fb^{-1}
  - WW from the data; uncertainty 17% at 5 fb^{-1}
  - Wt and gg->WW bkg from theor. uncertainties estimated to be 22% and 30%

CMS, 1 fb^{-1}

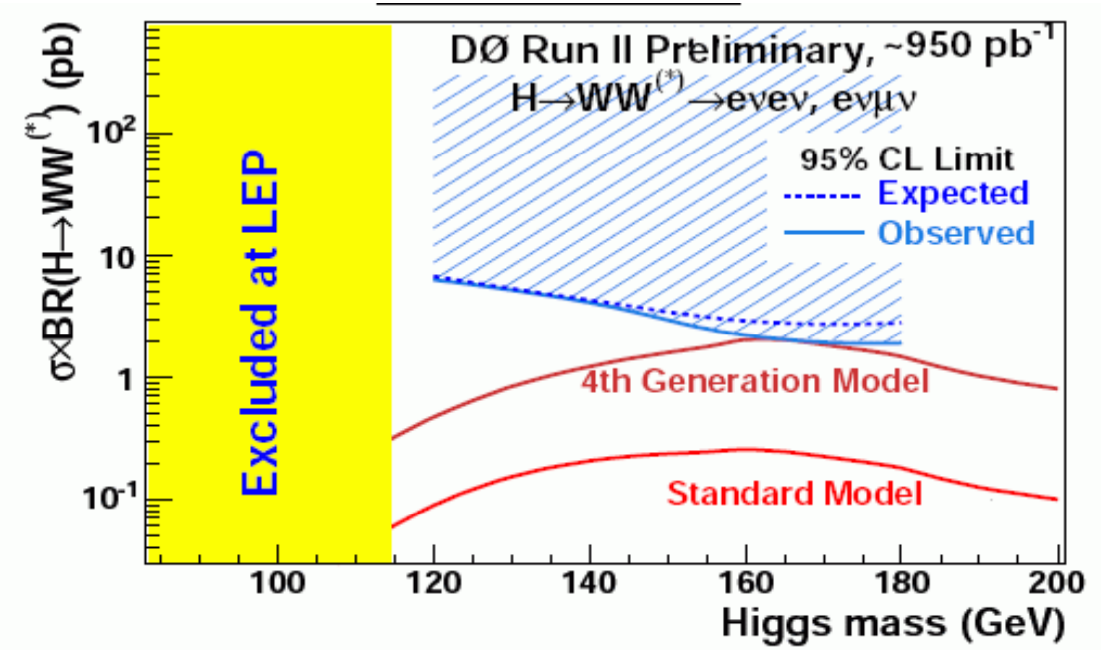


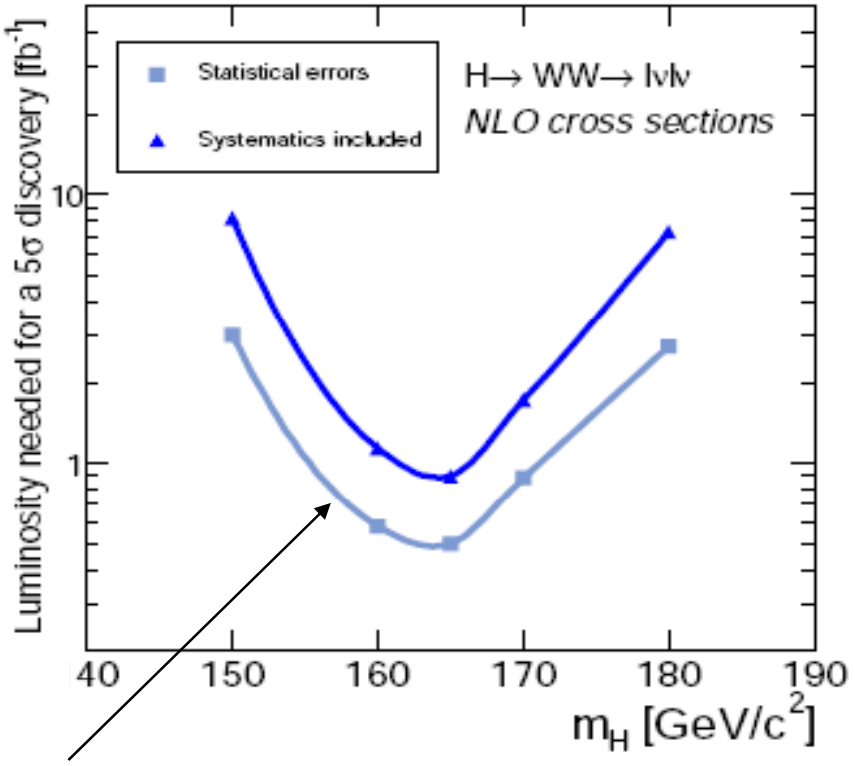
- E_T^{miss} > 50 GeV
- jet veto in η < 2.4
- 30 <$p_T^{l\,max}$<55 GeV
- $p_T^{l\,min}$ > 25 GeV
- 12 < m_{ll} < 40 GeV

Discovery reach with H→WW→2l2ν

Excluded cross section times Branching Ratio at 95% C.L.

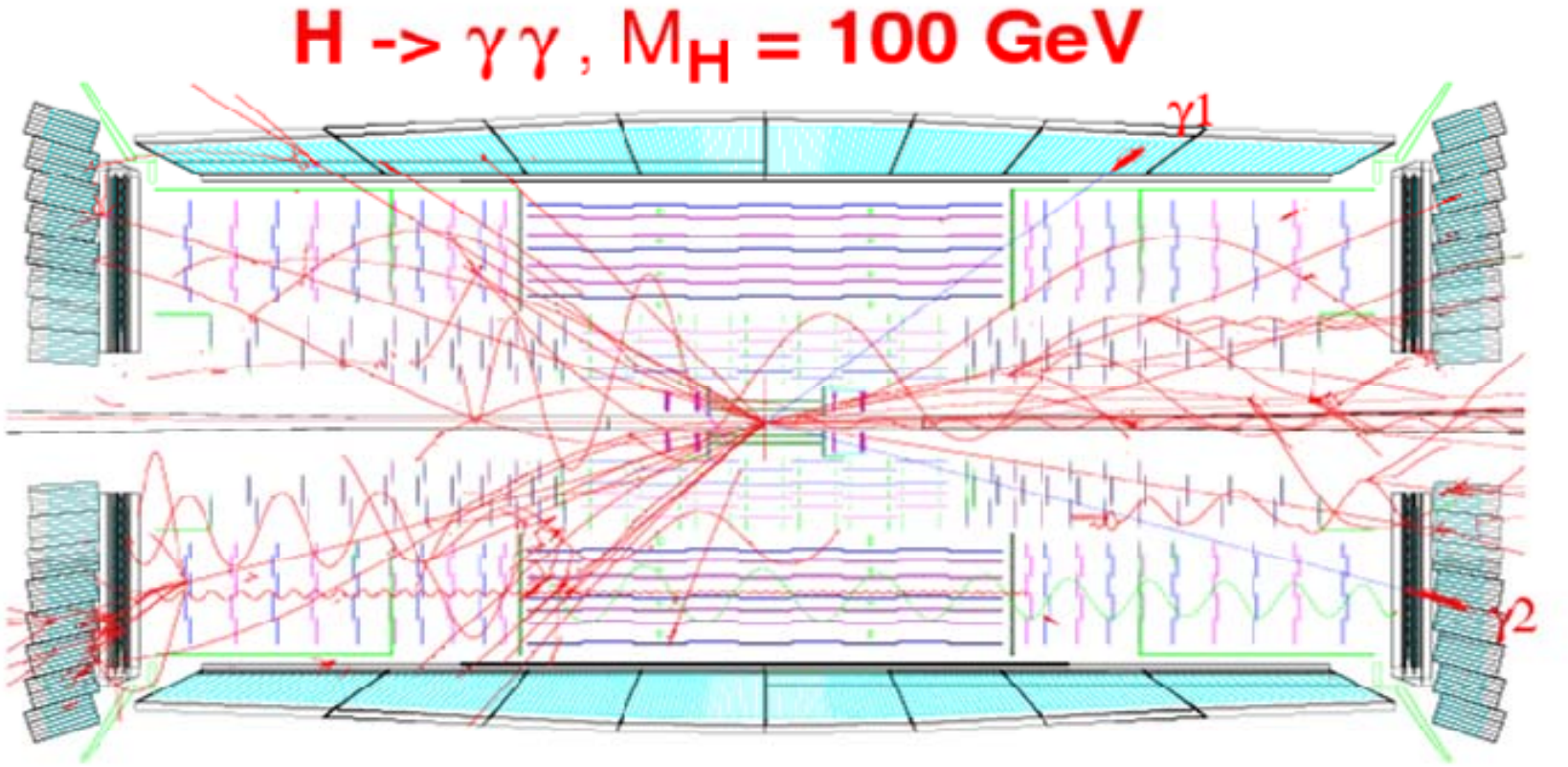
CMS Phys. TDR 2006





very similar to old results w/o syst.

Inclusive $H \rightarrow \gamma\gamma$



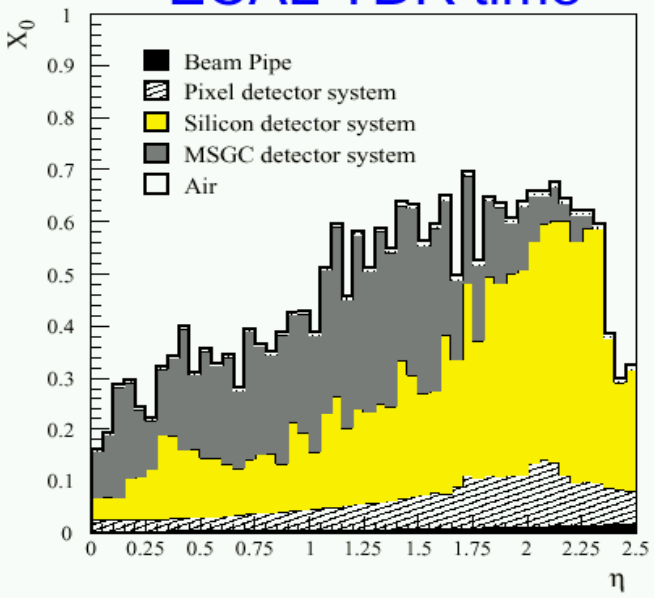
CMS plot of the ECAL TDR time : December 1997

Went then from hybrid silicon + gas chamber tracker to all silicon tracker

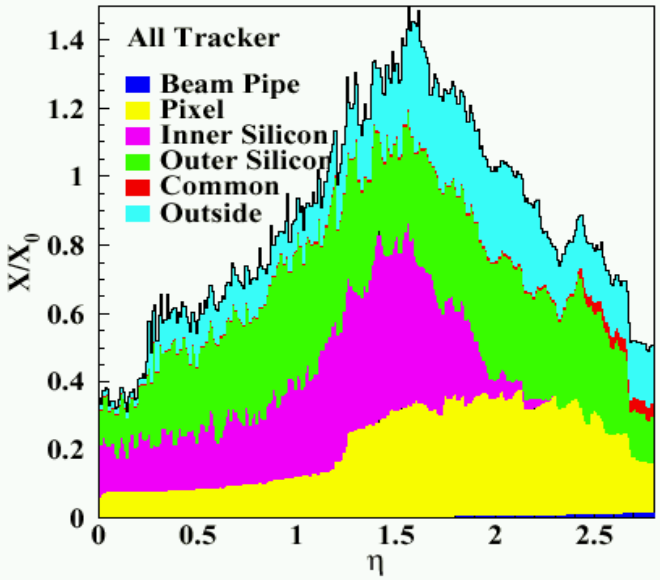
H→γγ: Tracker material budget

tracker material budget

ECAL TDR time



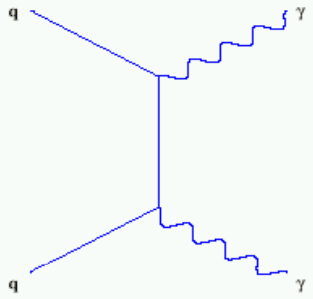
current design



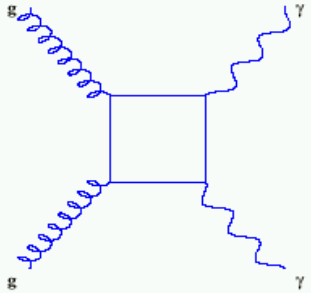
fraction of photons converting before ECAL

	Unconverted	Converted (Invisible)	Converted (Visible)
Barrel (ECAL TDR)	76.2 %	5.0 %	18.8 %
Barrel (present)	58.0 %	10.7 %	31.3 %
EndCap (ECAL TDR)	65.1 %	8.7 %	26.2 %
EndCap (present)	40.5 %	14.4 %	45.1 %

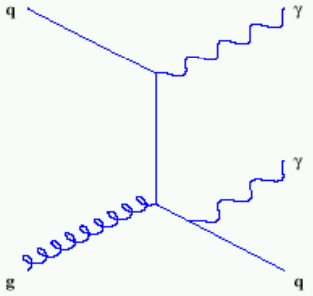
Inclusive H→γγ: Backgrounds and K-factors



born



box



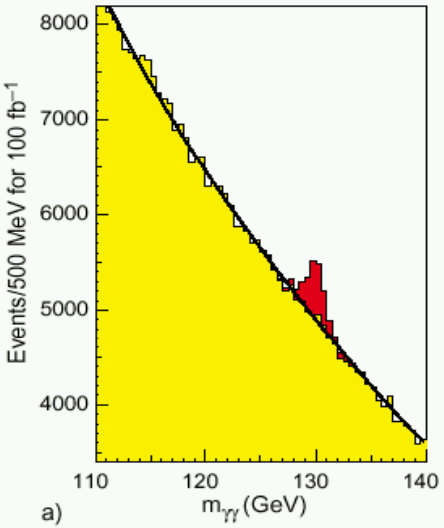
isol. brem

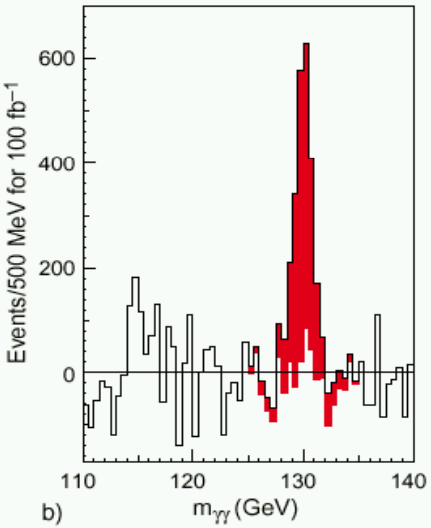
γ+j, j->π^0

j+j, jj->$2\pi^0$

was not in ECAL TDR

ECAL TDR plots, L=10^{34}cm^{-2}s^{-1}





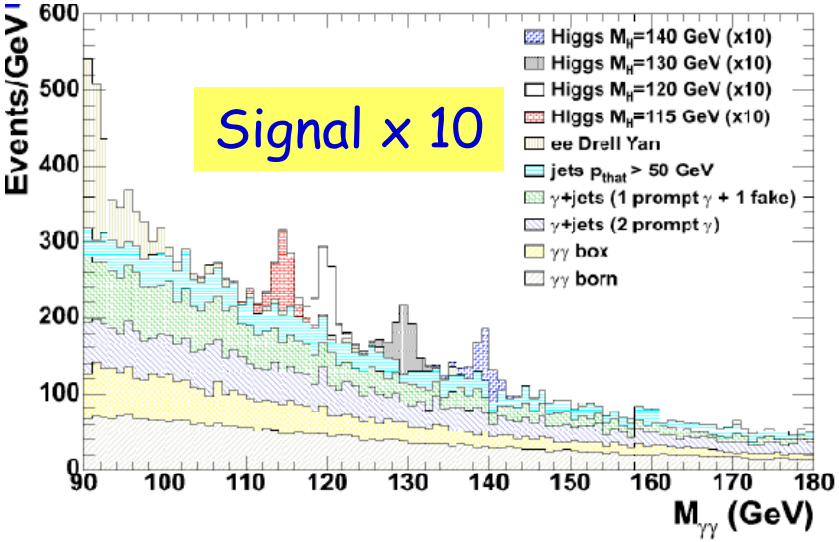
	ECAL TDR K factors	current K factors: DIPHOX(NLO) / PYTHIA
born	1	1.50 , uncertainty 10-20 %
box	1.85	1.20, uncertainty 10-20 % (Dixon et al)
isolated brem	1	1.72, uncertainty 20-30 %
γ+j, j->π^0	not simulated	1.00, uncertainty 30-40 %
j+j, jj->$2\pi^0$	not simulated	unknown; work in progress 1, uncert ~ 50%

Discovery Potential : H→γγ

Significance for SM Higgs
M_H=130 GeV for 30 fb^{-1}

New elements of CMS-PTDR 2006 analysis:

- Cut based analysis
  - Split into categories depending on photon reco quality and position
  - Usage of LLR for discovery, systematic
- Optimized analysis*
  - NN with kinematics and g isolation
  - s/b per event



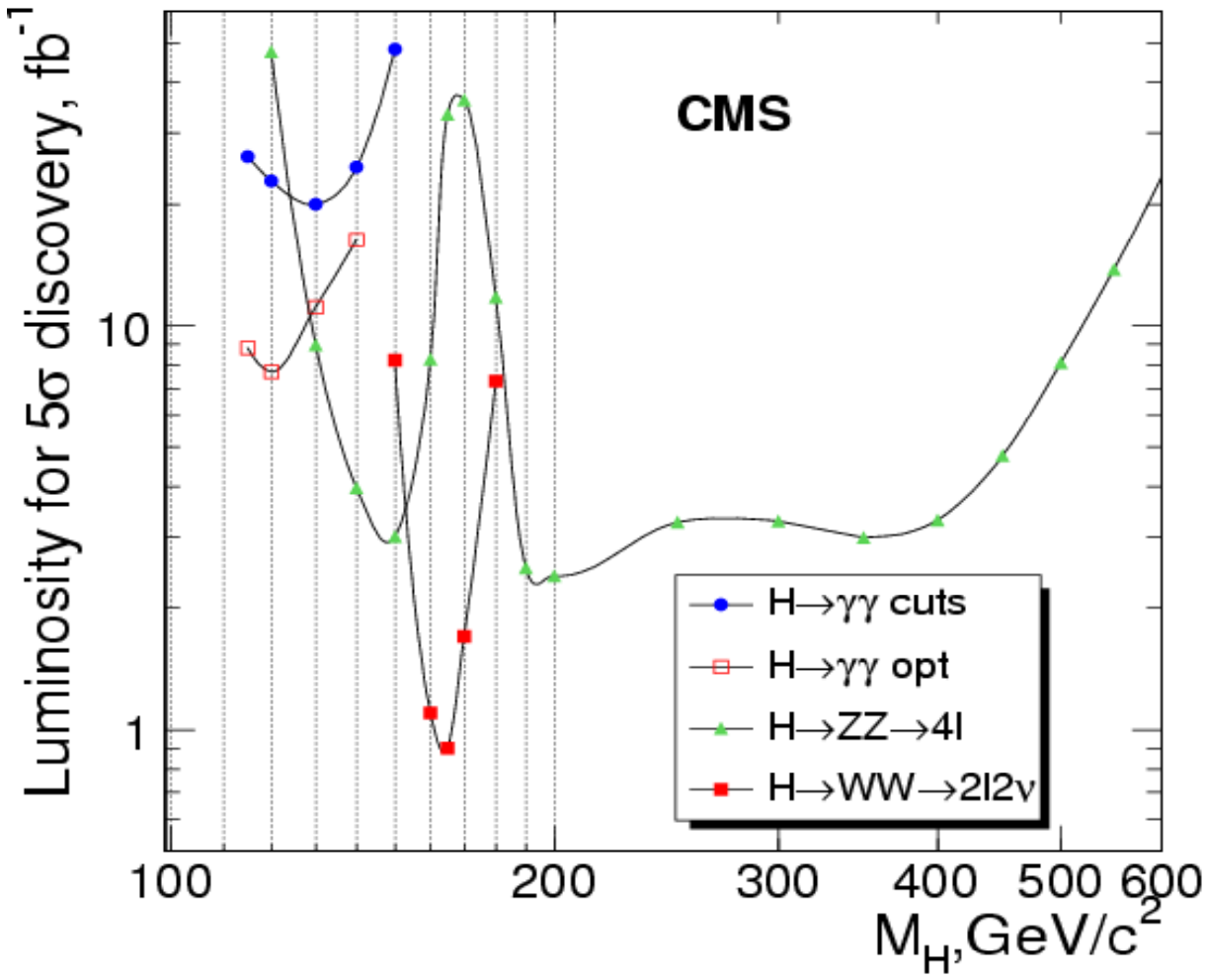
Final tracker→ all materials
More complete backgrounds

CMS ECAL TDR	CMS PTDR		ATLAS		
NLO count. exp	NLO cut based	NLO optimized*	TDR (LO)	New, NLO Cut based	New, NLO likelihood
~ 7.5	6.0	8.2	3.9	6.3	8.7

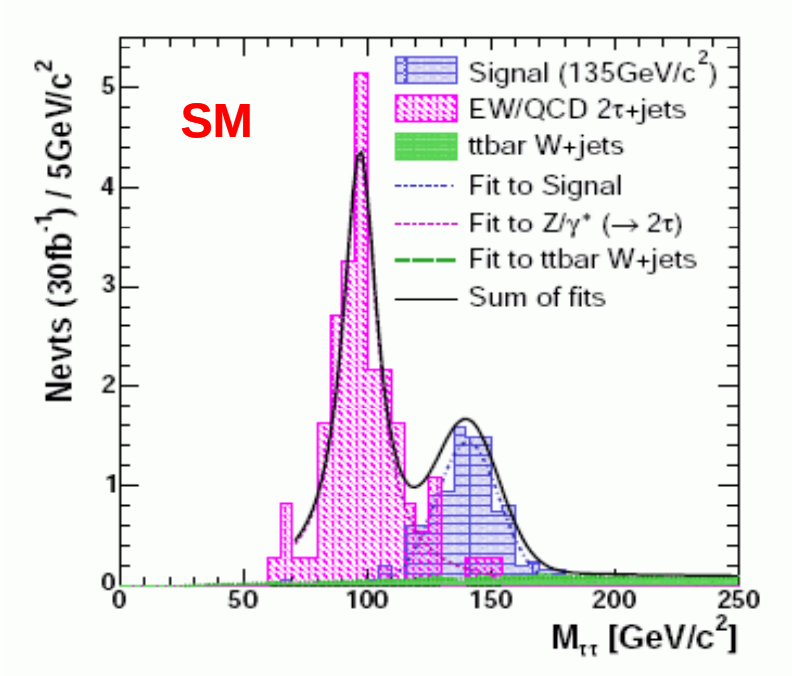
S. Dasu, Aspen 07

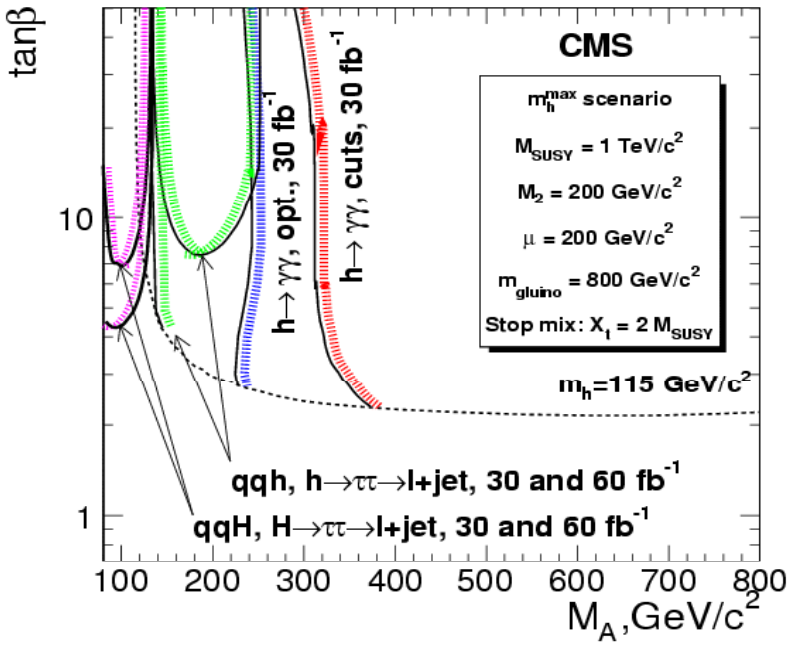
⇒Still the most promising channel for the low mass Higgs

Summary of SM Higgs boson discovery for inclusive production



Full simulation analysis of qqH, H→ττ →l+jet



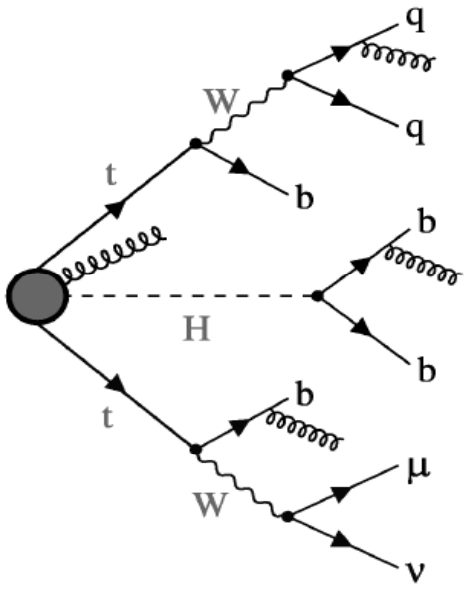


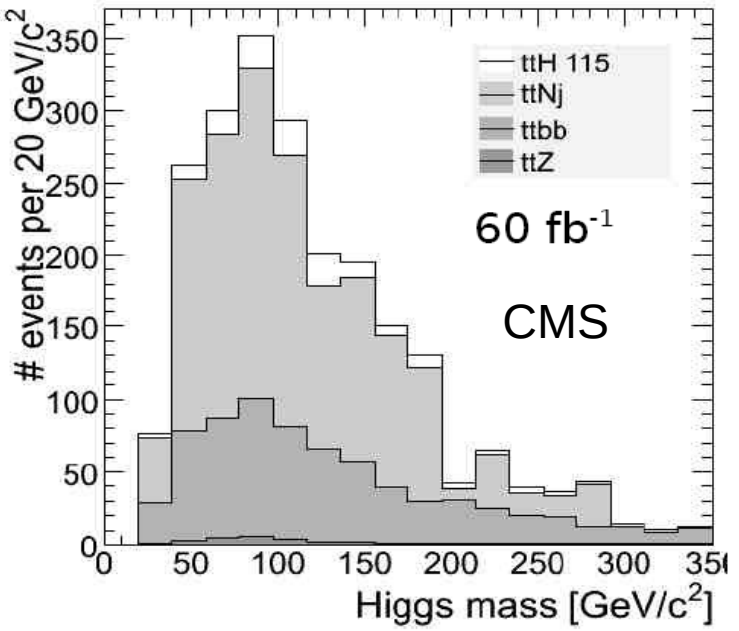
discovery light h in MSSM

Discovery in Standard Model

M_H [GeV]	115	125	135	145
Production σ [fb]	4.65×10^3	4.30×10^3	3.98×10^3	3.70×10^3
$\sigma\times$BR(H$\to\tau\tau\to lj$) [fb]	157.3	112.9	82.38	45.37
N_S at 30 fb^{-1}	10.5	7.8	7.9	3.6
N_B at 30 fb^{-1}	3.7	2.2	1.8	1.4
Significance at 30 fb^{-1} ($\sigma_B = 7.8\%$)	3.97	3.67	3.94	2.18
Significance at 60 fb^{-1} ($\sigma_B = 5.9\%$)	5.67	5.26	5.64	3.19

ttH, H→bb

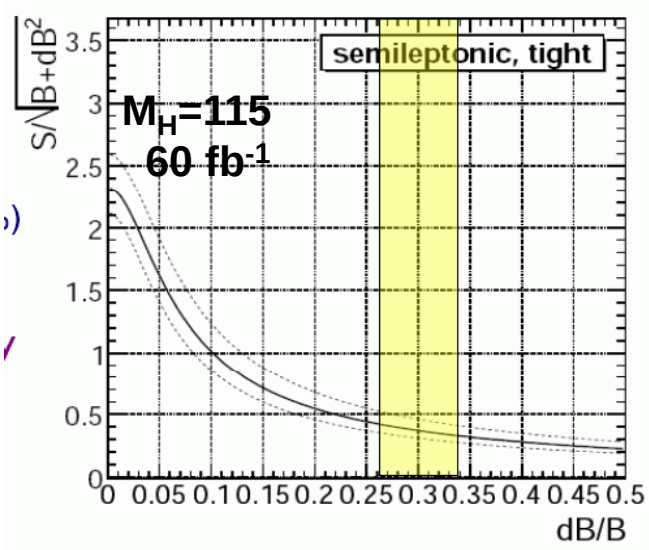




Latest CMS results are more pessimistic for this mode due to:

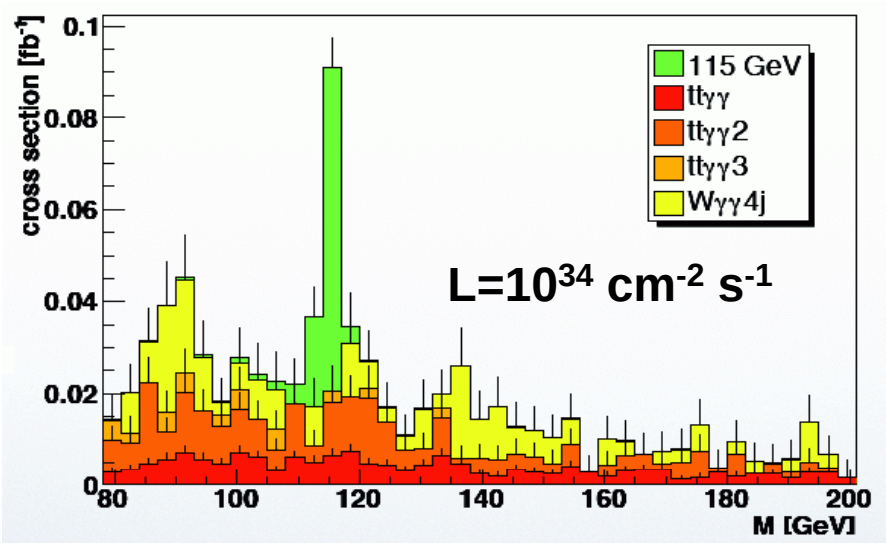
- effects of systematics
- backgrounds with ME Generator (ALPGEN)
- full detector simulation (b tagging, jet resolution)
- new K factors for signal

Improvements (eg. Particle Flow) still possible

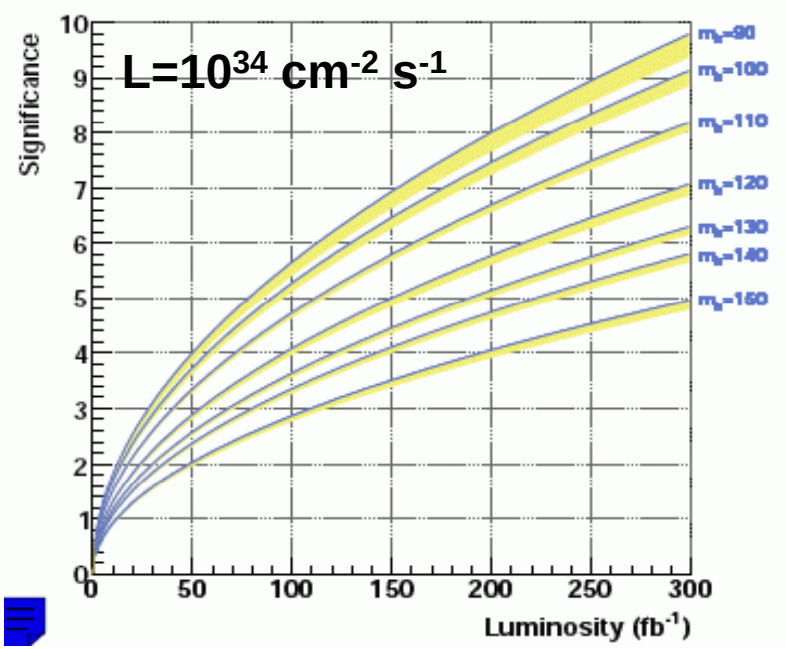


SM H→γγ in associated ttH and WH production at high luminosity

Discovery of tth, h->γγ



Discovery of Wh, h->γγ

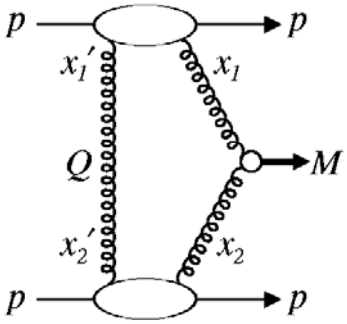


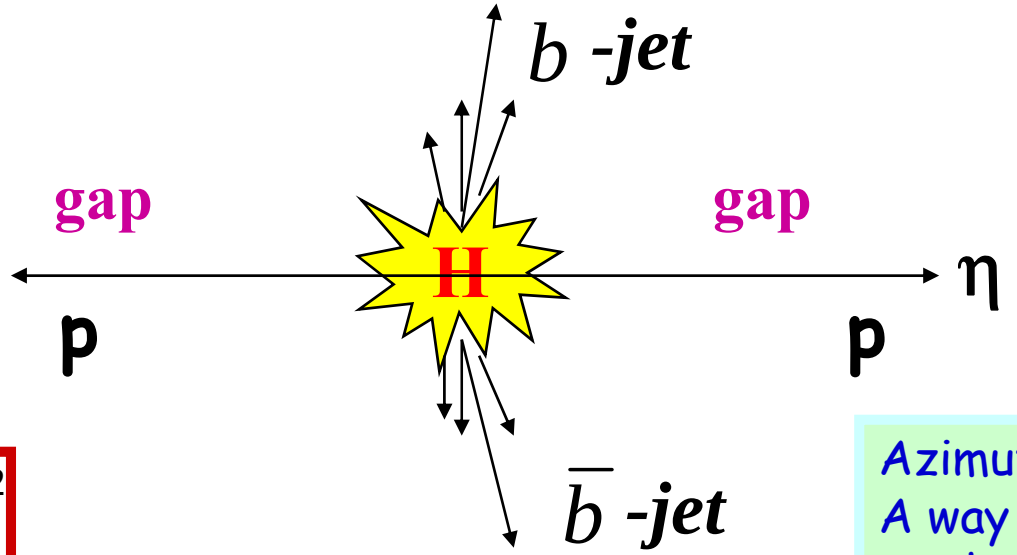
Significance of tth, h->γγ for 100 fb^{-1}

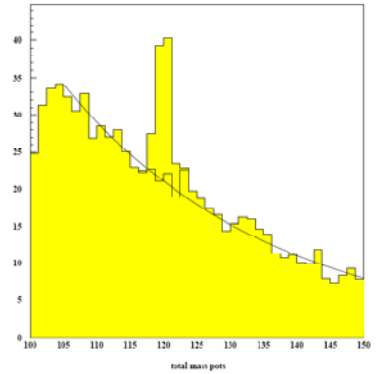
Higgs Boson Mass (GeV)	115	120	130	140
Sig. Selection Eff. (%)	10.7	11.2	11.3	11.3
Number Signal NS	7.42 ±0.33	7.33 ± 0.33	5.96±0.27	4.21±0.19
Total Number Bcgkd	1.61 ±0.53	2.79 ±0.62	1.98±0.66	1.10± 0.51
Total Number Bcgkd from fit w. syst.	2.23±0.34	1.94±0.32	1.60±0.22	1.39±0.22
Signal Significance (ScP)	3.541	3.662	3.257	2.510
Signal Significance (ScP) w. syst.	3.414	3.523	3.184	2.453

Central Exclusive Higgs Production

Exclusive central Higgs production pp→ p H p : 3-10 fb SM
>100 fb MSSM (high tanβ)



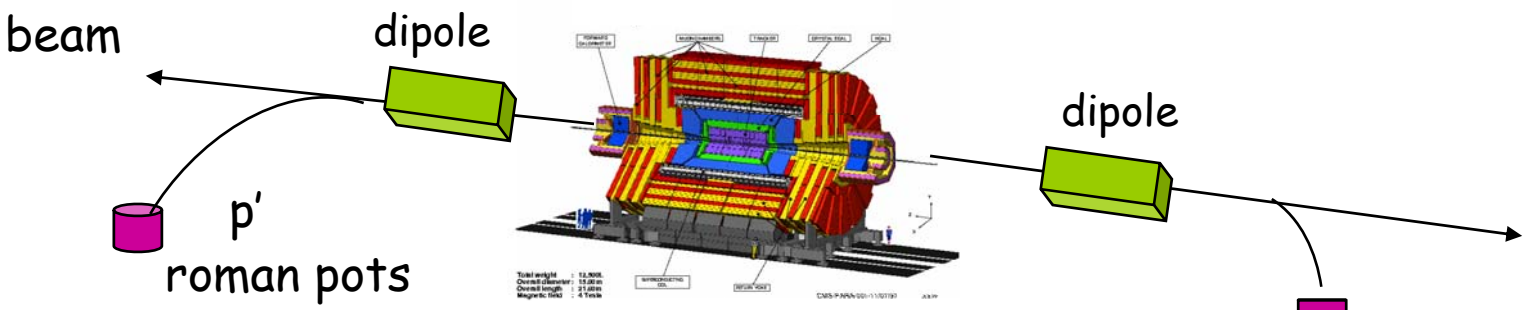


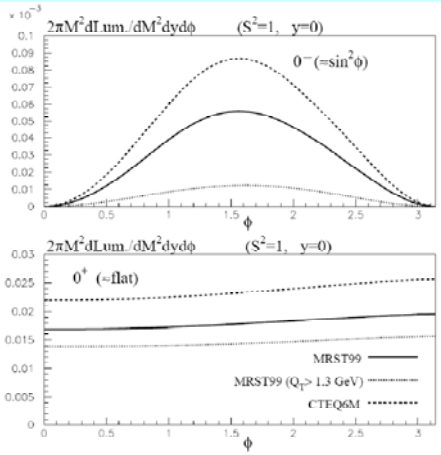


$$M_H^2 = (p + \bar{p} - p' - \bar{p}')^2$$

ΔM = O(1.0 - 2.0) GeV

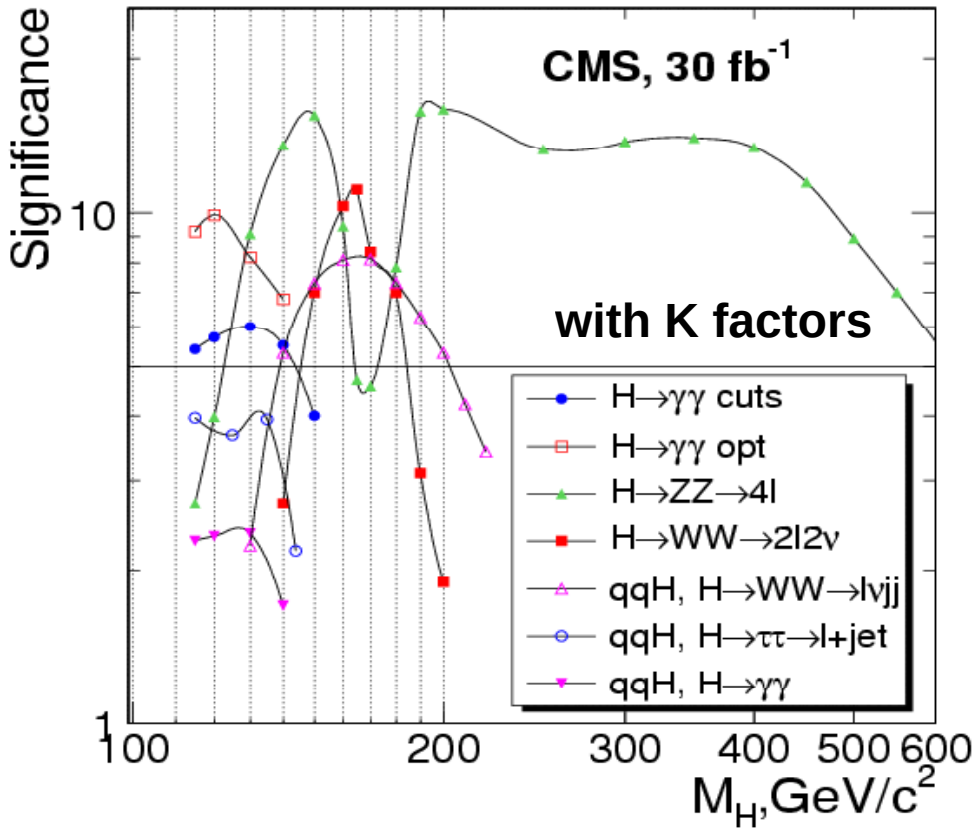
Azimuthal pp corelations:
A way to get information on the spin of the Higgs





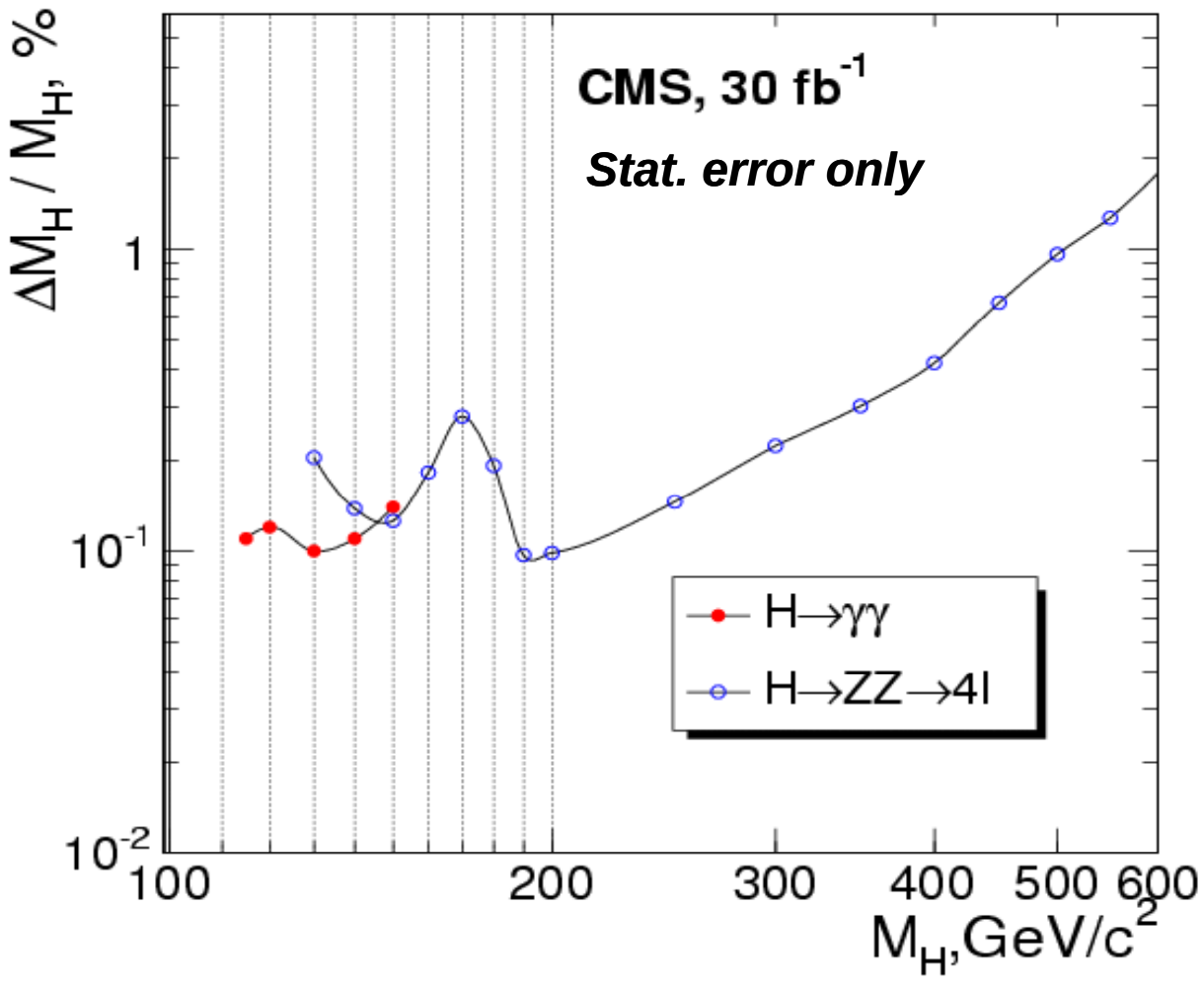
FP420 R&D Project
http://www.fp420.com

CMS SM Higgs boson discovery: Signal Significance for 30 fb^{-1}



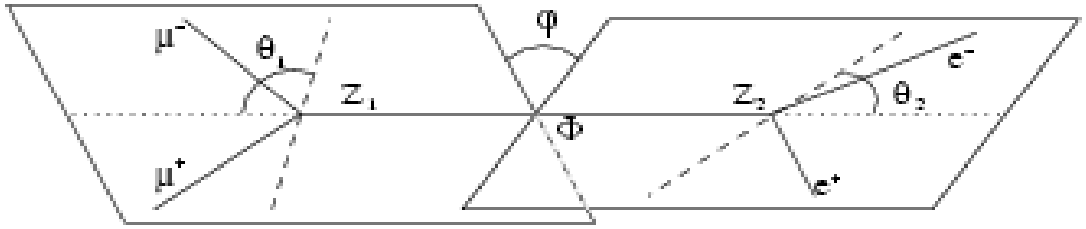
5σ significance with 10 fb^{-1} over essentially the full range

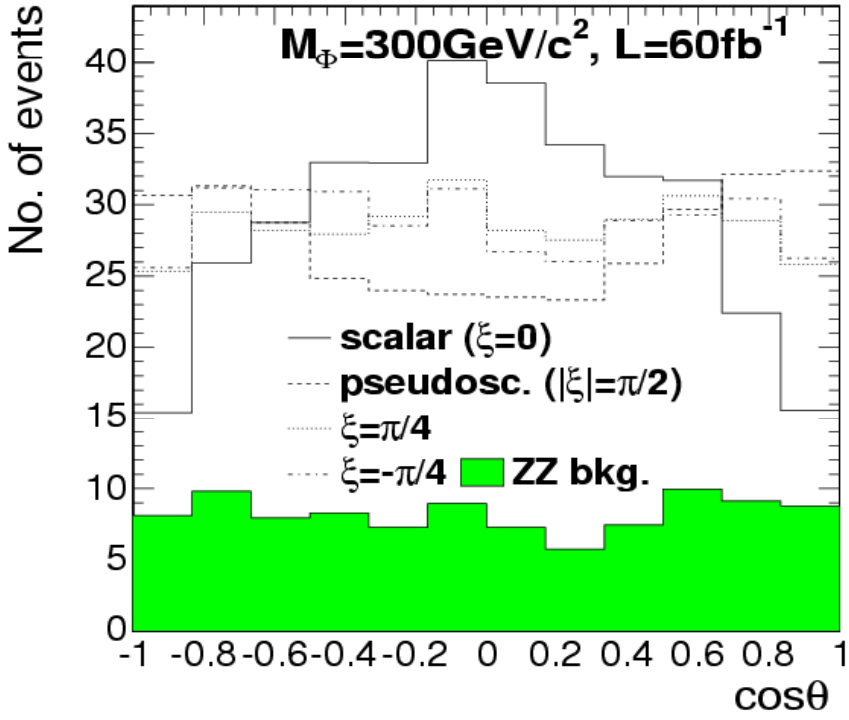
Mass measurement with H→ZZ→ 4 leptons and H→γγ



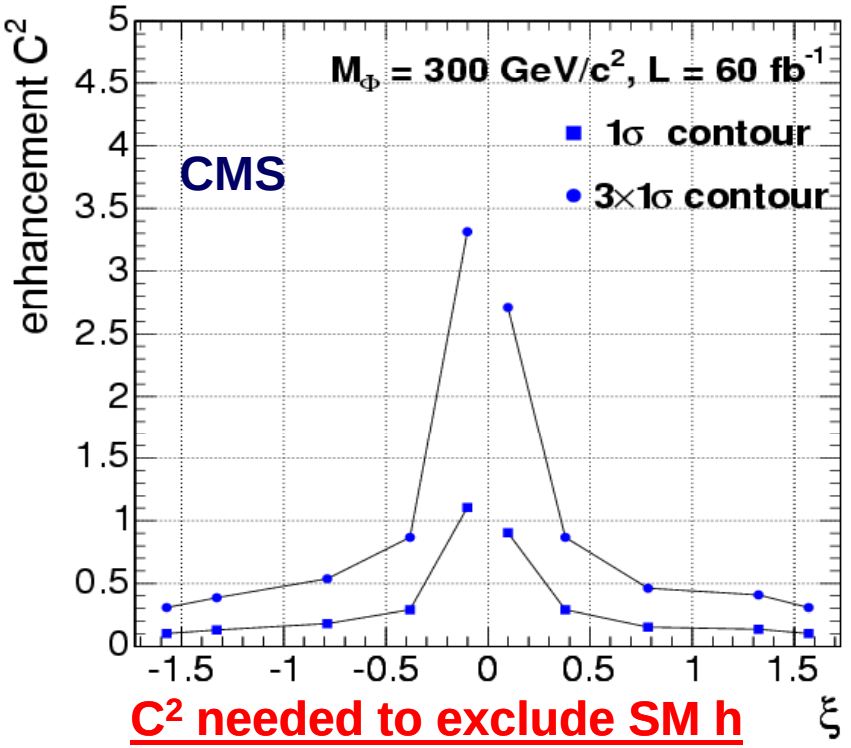
CP properties from H→ZZ→4 leptons

$d\Gamma(\eta) \sim H + \eta I + \eta^2 A$,
H scalar, A – pseudoscalar,
$\eta = \tan(\xi)$, $\xi = +/- \pi/2$ --> A





$C^2 = \sigma\,Br\,/\,\sigma_{SM}\,Br_{SM}$



C² needed to exclude SM h

Summary

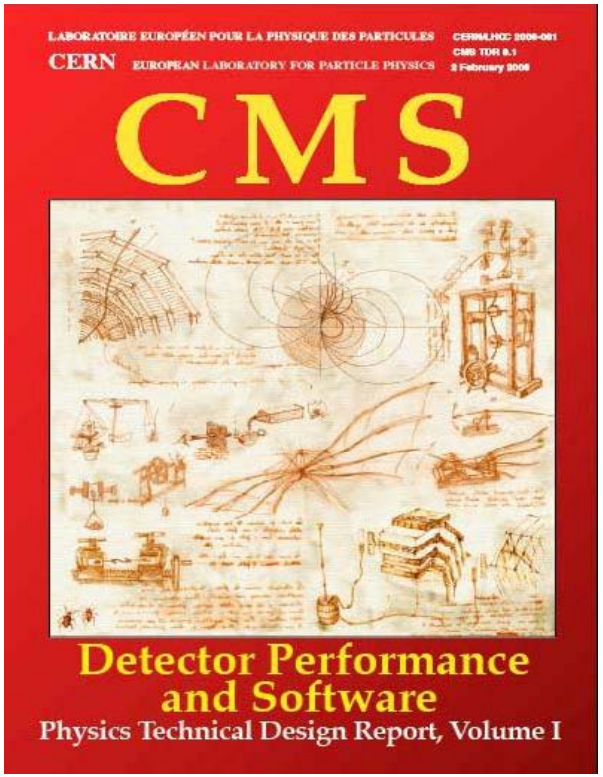
- The PTDR simulation studies show:
  - SM inclusive $H \rightarrow \gamma\gamma$ could be discovered with < 10fb^{-1}
    - associated with tt and W (tth, Wh): > ~100 fb^{-1} at high lumi
  - $H \rightarrow ZZ \rightarrow 4l$ and $H \rightarrow WW \rightarrow 2l2\nu$: almost no change in the discovery potential compared to previous results
    - First study of CP mixed Higgs with $H \rightarrow ZZ \rightarrow 4l$
  - tth, $h \rightarrow bb$ is lost as discovery channel
  - qqh, $h \rightarrow$ tau tau "survived" after full simulation !
    - The biggest discovery reach in MSSM M_A-tan(b) plane
  - Higgs boson parameter measurements:
    - Mass: ~ 0.1 % accuracy at 30 fb^{-1}
    - Couplings: ~ 5-20 % with 2x30 fb^{-1}

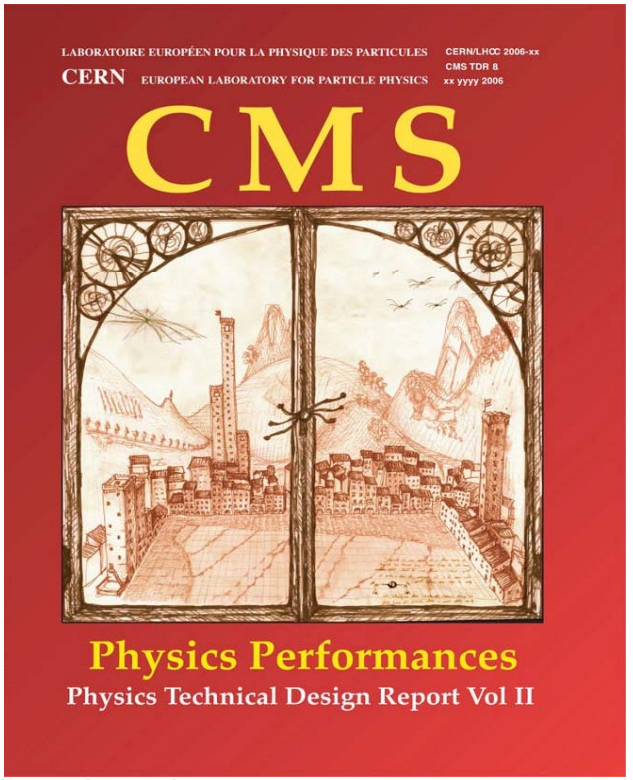
SM Higgs: 5σ significance with 10 fb^{-1} over essentially the full range

If there are no bad surprises…

BACKUP

CMS Analysis Projects
The Physics TDRs





http://cmsdoc.cern.ch/cms/cpt/tdr/

CERN/LHCC 2006-001 **CERN/LHCC 2006-021**