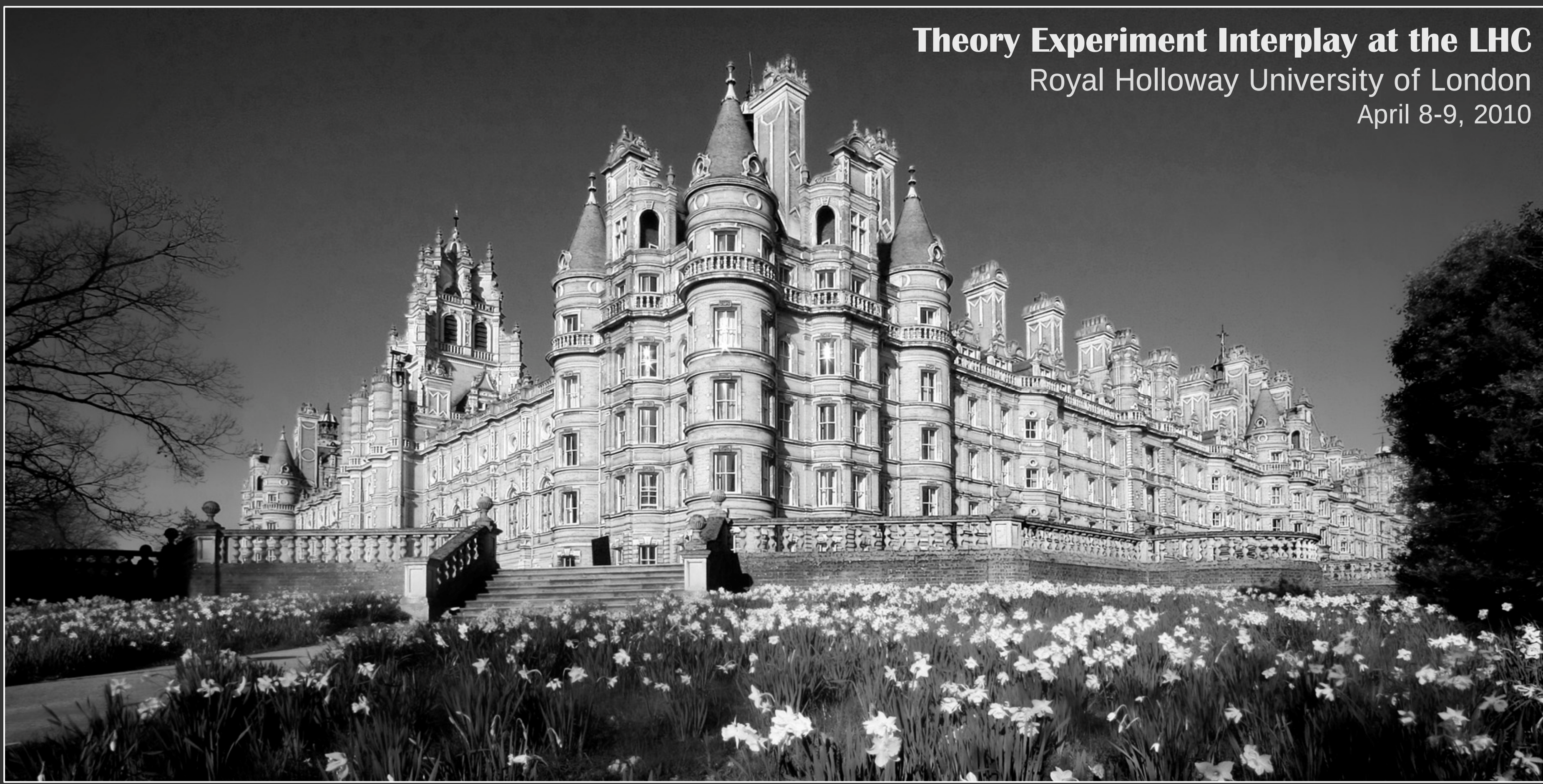
CMS: Higgs search prospects at 7 TeV, 1 fb^{-1}

Andrey Korytov
(for CMS Collaboration)



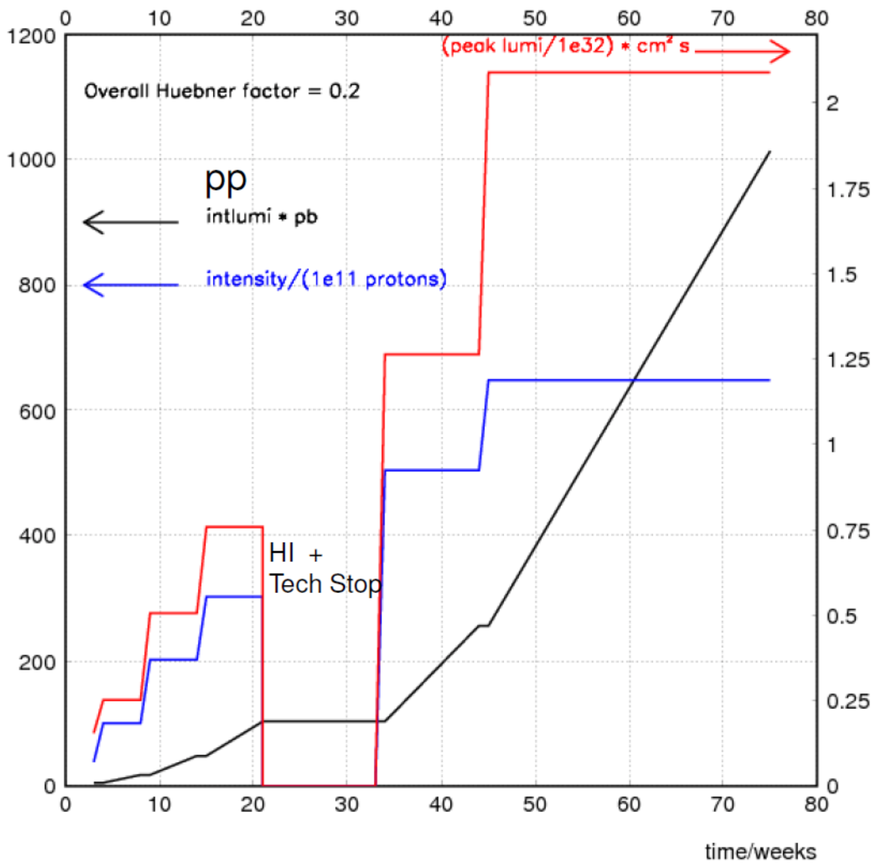
Outline

Stage for Higgs searches at LHC: current limits from LEP and Tevatron

CMS Projections for 7 TeV and 1 fb^{-1}

How did we start? – a look at the first data

Projected integrated luminosity



- **100 pb^{-1} by Nov 2010**
- Nov 2010: heavy ions
- Dec–Jan: technical stop
- **1 fb^{-1} by end of 2011**
- 2012: commissioning for higher energy and higher luminosity (may take more than a year)

Outline

Stage for Higgs searches at LHC: current limits from LEP and Tevatron

CMS Projections for 7 TeV and 1 fb^{-1}

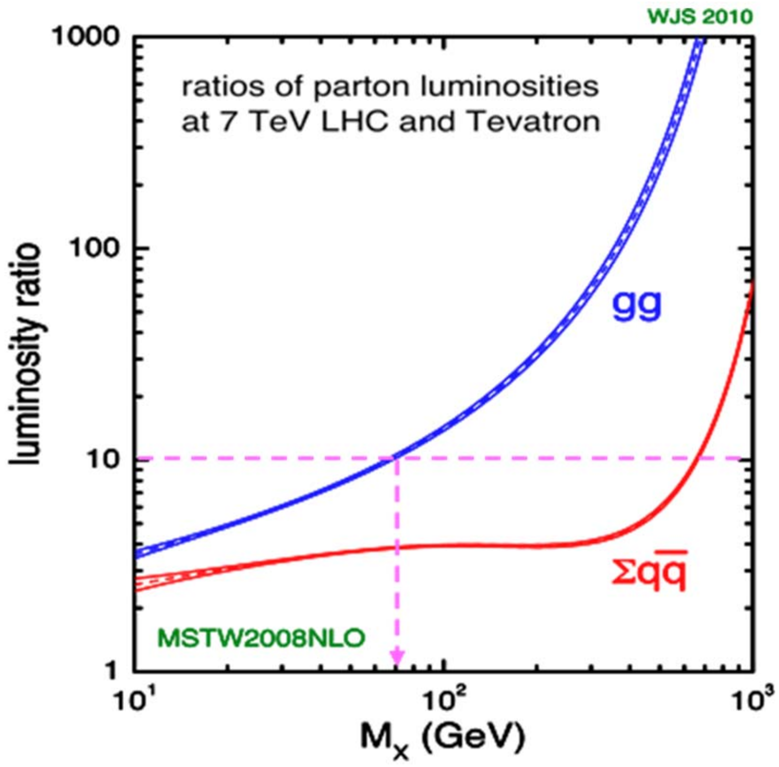
How did we start? – a look at the first data

LHC at 7 TeV: general considerations

LEP limits: not expected to change
Tevatron in 2011: 2 TeV, 10 fb^{-1}
LHC run 2010-2011: 7 TeV, 1 fb^{-1}

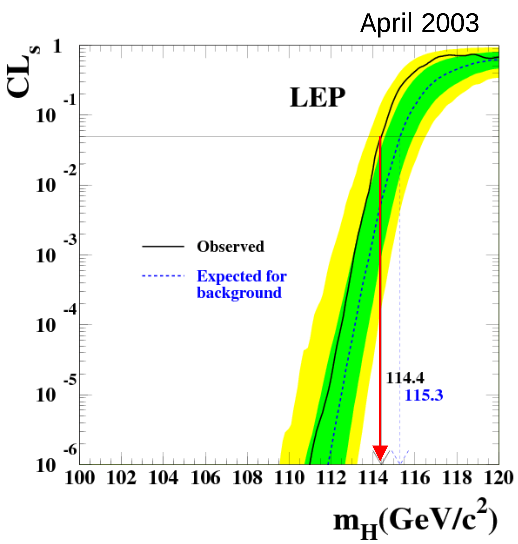
Channels of prime interest are those that will allow us to further the Higgs sensitivity

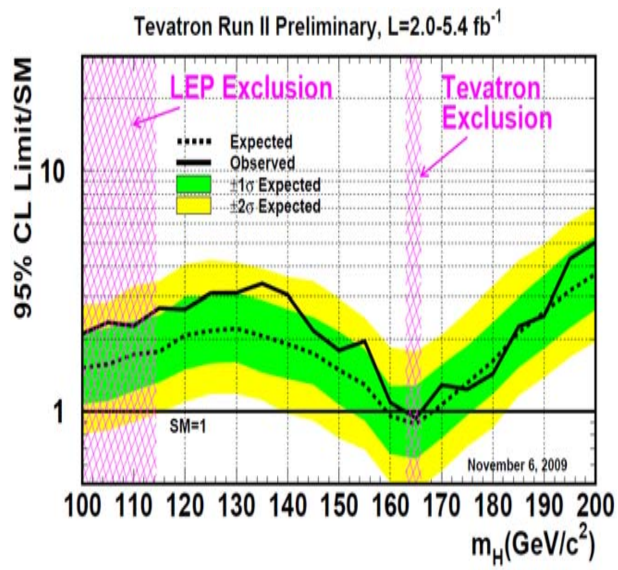
- **higher cross sections at LHC**
  - **e.g., gg luminosity with sqrt(s)>70 GeV at LHC is >10 times larger than at Tevatron**
- **better detector performance**
  - **e.g., $\gamma\gamma$ mass resolution of CMS is about 3 times better than that of CDF and D0 (3 GeV)**
- **and combination of the above**

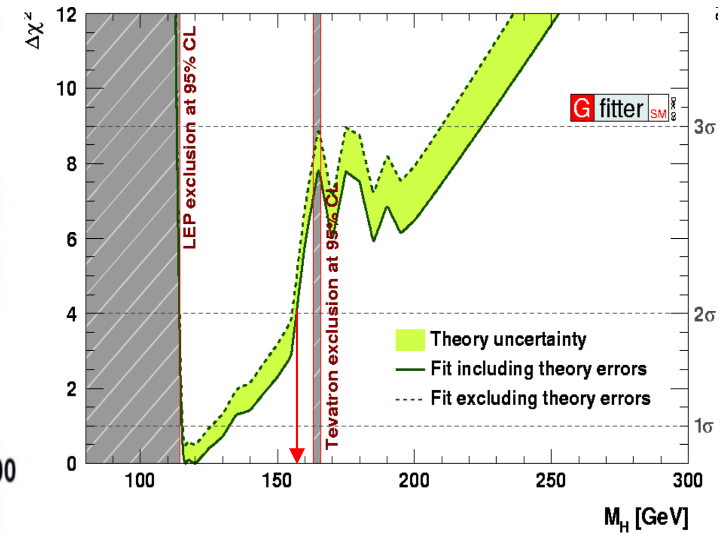


Higgs search landscape as of today:
SM Higgs

95 % CL exclusion limits







LEP:
m_H > 114.4 GeV

http://lephiggs.web.cern.ch/LEPHIGGS/

Tevatron:
$m_H \neq$ 163-166 GeV

http://tevnphwg.fnal.gov/

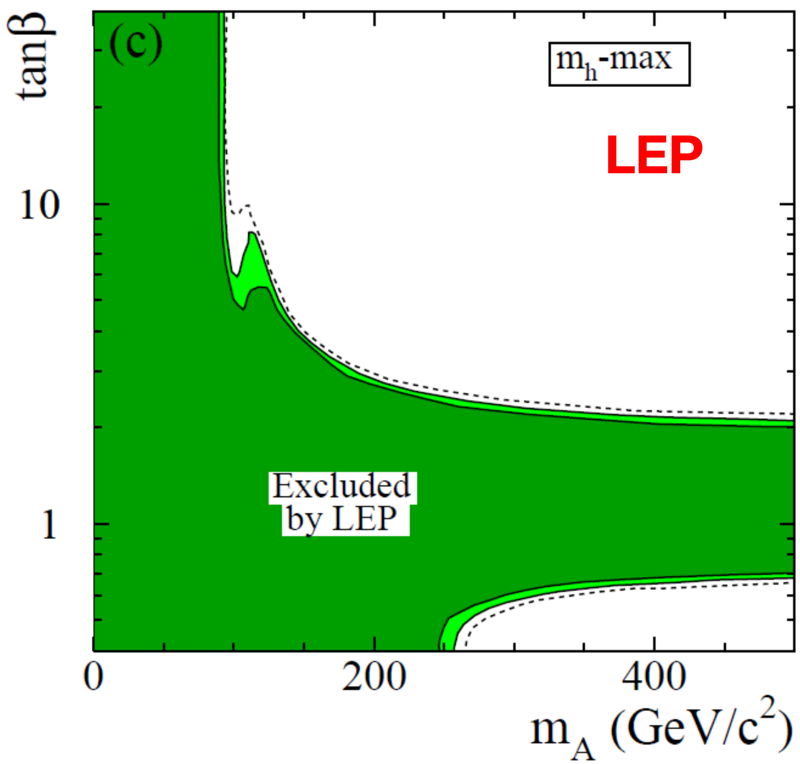
EWK + LEP + Tevatron
$m_H \lesssim$ 160 GeV

http://project-gfitter.web.cern.ch/project-gfitter/

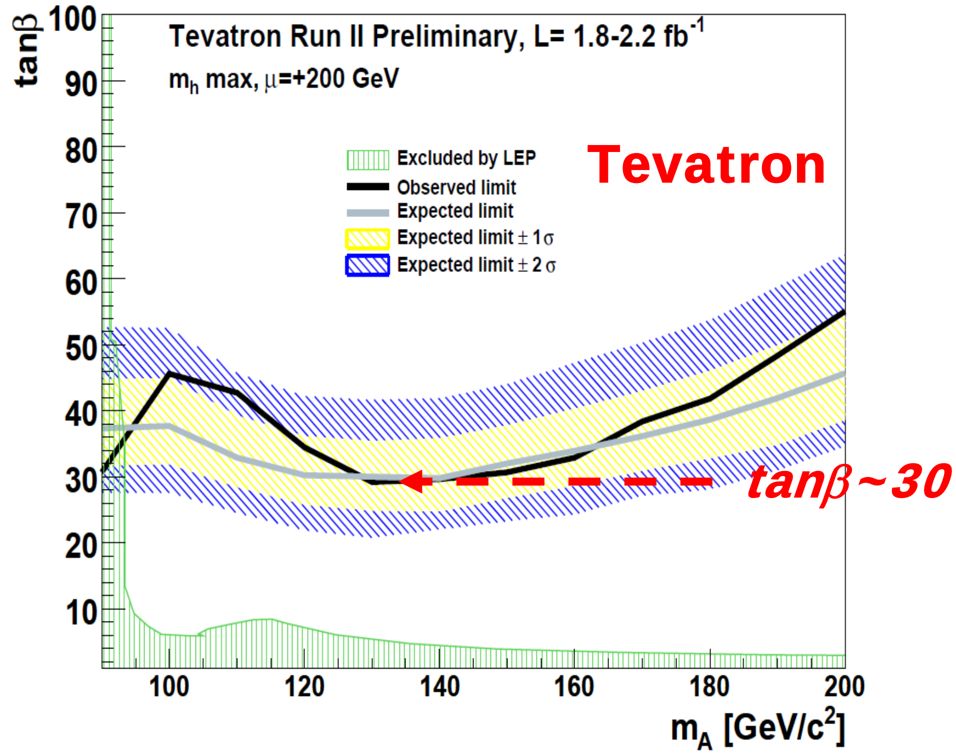
LHC : Tevatron
gg→H CS Ratio (m_H~160) ~20
VH CS Ratio (m_H~120) ~4

Higgs search landscape as of today:
MSSM Neutral Higgses

95 % CL exclusion limit



http://lephiggs.web.cern.ch/LEPHIGGS/



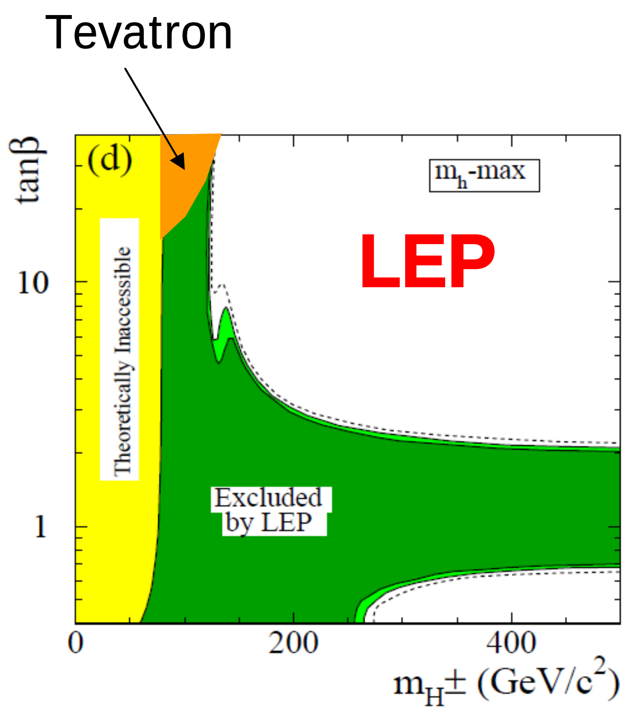
http://tevnphwg.fnal.gov/

mhmax scenario:
- least restrictive on the (m_A, tanβ) plane given the LEP search limits
- M_{SUSY}=1 TeV, X_t=2 TeV, M_2=200 GeV, M_3=800 GeV, μ=+200 GeV

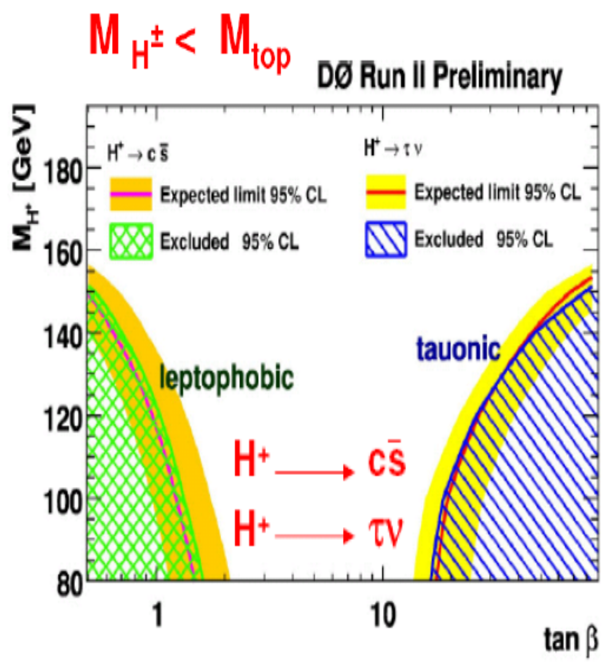
LHC : Tevatron
gg→bbΦ CS Ratio (m_Φ~100) ~20

Higgs search landscape as of today: MSSM Charged Higgs

95 % CL exclusion limits



http://lephiggs.web.cern.ch/LEPHIGGS/



LHC : Tevatron
pp→tt CS Ratio ~20

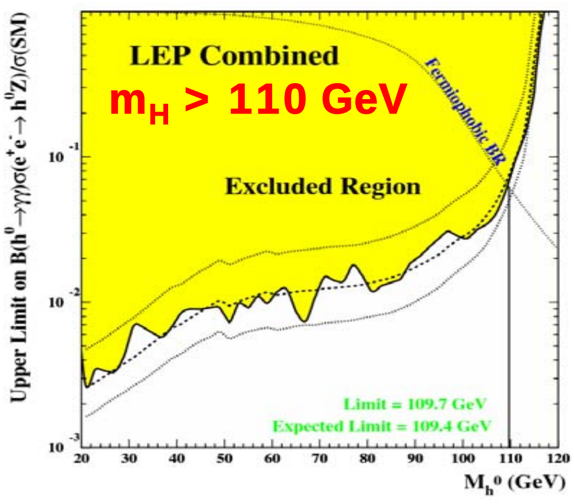
Higgs search landscape as of today: Beyond SM / MSSM (1st example)

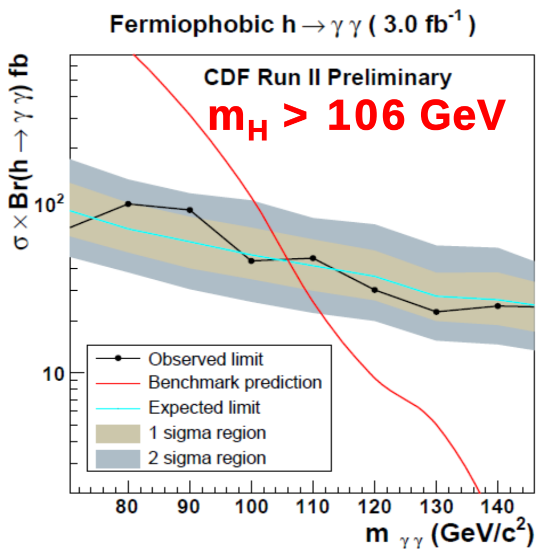
Fermiophobic Higgs

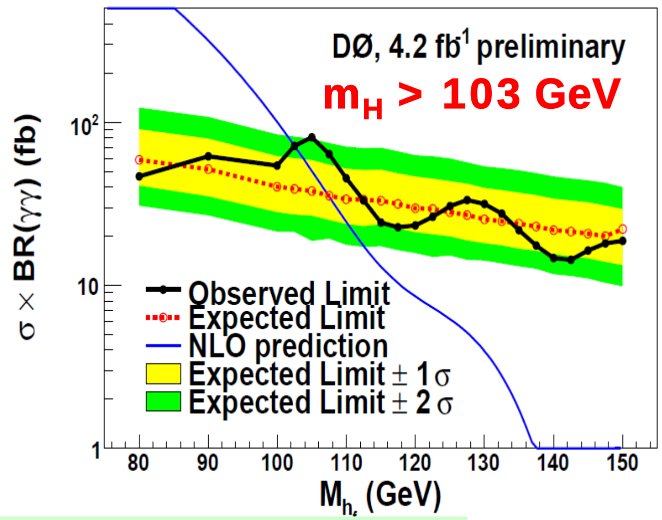
If the EWK symmetry breaking Higgs has nothing to do with fermion masses:

- **SM Higgs limits at Tevatron evaporate**
  - High mass: gg→h, h→WW *(decay mode is OK, but the production disappears)*
  - Low mass: VH, h→bb *(production is OK, but the decay mode disappears)*
- **Only one fermiophobic-specific Higgs search h→γγ remains** (also H and qqH, H→WW)

(How about fermion masses? E.g., all this can be self-consistently accommodated in models with two doublets of Higgs fields)







LHC : Tevatron VBF+VH CS Ratio ~7
γγ mass res. ratio ~3

Higgs search landscape as of today: Beyond SM / MSSM (2nd example)

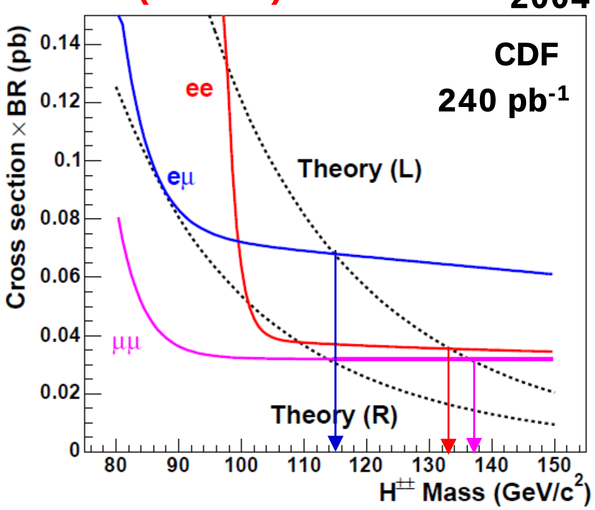
Double-charged Higgs

- **arises in models with extra higgs triplets**
- **strongly motivated, it allows for small neutrino masses**
  (an alternative to see-saw type mechanisms)

m_H > 104-150 GeV, depending on channel and assuming 100 % BR

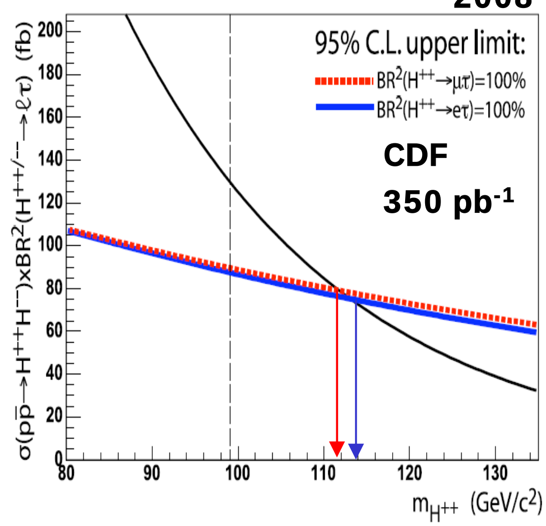
$BR(H^{\pm\pm}\to\mu\mu)=100\%$
$BR(H^{\pm\pm}\to e\mu)=100\%$
$BR(H^{\pm\pm}\to ee)=100\%$

2004



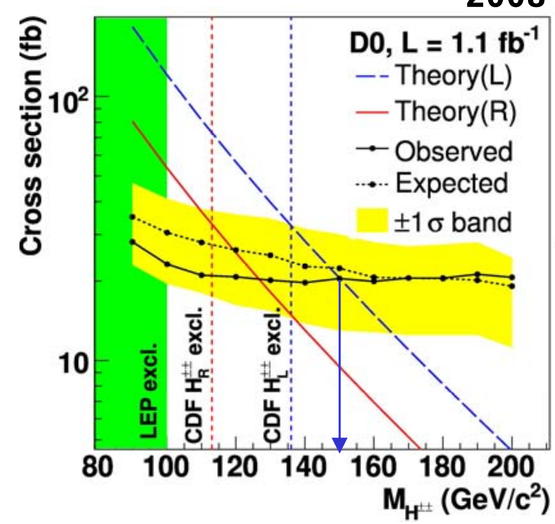
$BR(H^{\pm\pm}\to\mu\tau)=100\%$
$BR(H^{\pm\pm}\to e\tau)=100\%$

2008



$BR(H^{\pm\pm}\to\mu\mu)=100\%$

2008



LHC : Tevatron
$q\bar{q}\to H^{++}H^{--}$ CS Ratio ~3

Outline

Stage for Higgs searches at LHC: current limits from LEP and Tevatron

CMS Projections for 7 TeV and 1 fb^{-1}

How did we start? – a look at the first data

Projection workflow

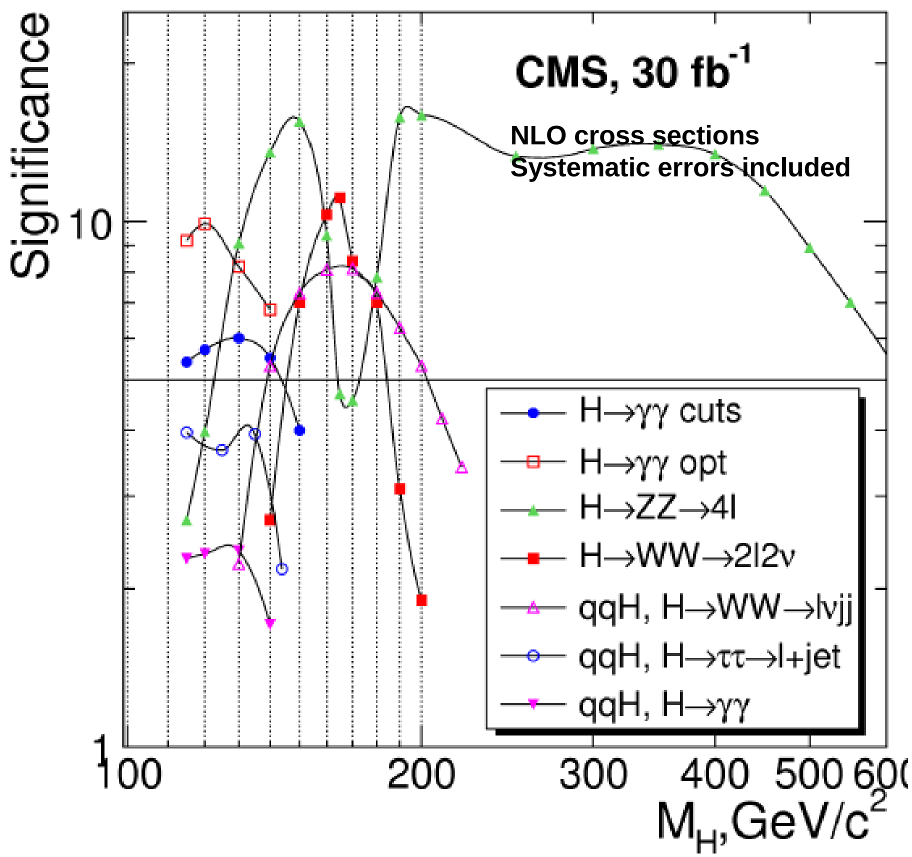
- **Projections to be shown are NOT new analyses done with 7 TeV MC samples and new detector simulation / reconstruction software**
- **We tried to strike the right balance: not too aggressive -- not too conservative**

- **Start out from public results at 14 TeV (int. luminosity from 1-30 fb^{-1})**
- **Re-scale signal and bkgd event counts by the ratio of 7 TeV : 14 TeV cross sections and project for the integrated luminosity of 1 fb^{-1}**
- **No corrections for higher acceptance at smaller sqrt(s),** up to ~20%
- **No corrections for improvements in reconstruction** (efficiencies, resolution)
- **Modify systematic errors:**
  - **for backgrounds derived from control samples, scale as** 1/sqrt(N)
  - **other errors: assess whether to keep as is (e.g. theoretical errors) or inflate to correspond to a smaller data set**
  - **take into account error correlations**

- **Statistical analysis:**
  - **Use re-scaled event counts and re-evaluated systematic errors**
  - **Exclusions:** Modified Frequentist (CL_s)
  - **Significance:** Profile Likelihood

SM Higgs: forerunner channels

CMS Physics Technical Design Report 2006



Updates since 2006
for 14 TeV and 1 fb^{-1}

https://twiki.cern.ch/twiki/bin/view/CMS/PublicPhysicsResults

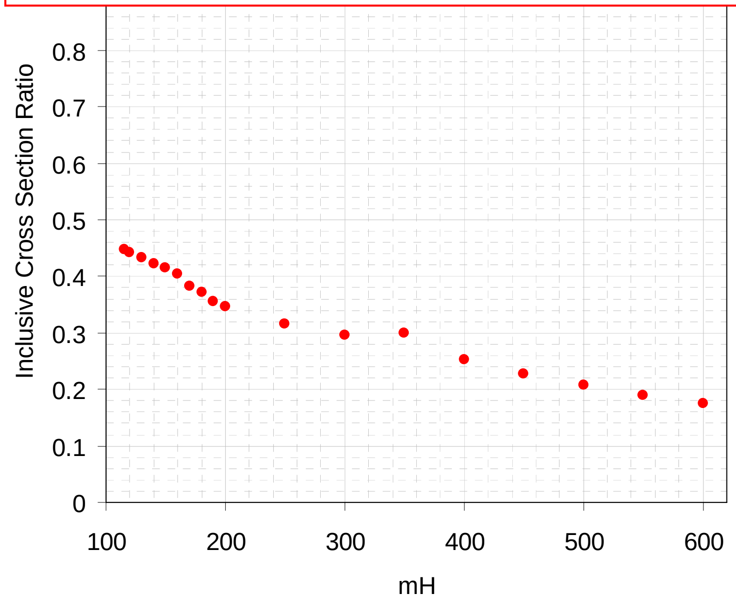
- **H→WW** PAS HIG-08/006
  sensitivity improved wrt 2006
- **H→ZZ** PAS HIG-08/003
  approx no changes in sensitivity
- **VBF H→ττ** PAS HIG-08/008
  fast loss of sensitivity [faster than 1/sqrt(L)]
  due to running out of signal events

Bottom line: depending on m_H, forerunners remain the same, i.e. inclusive WW, ZZ, γγ

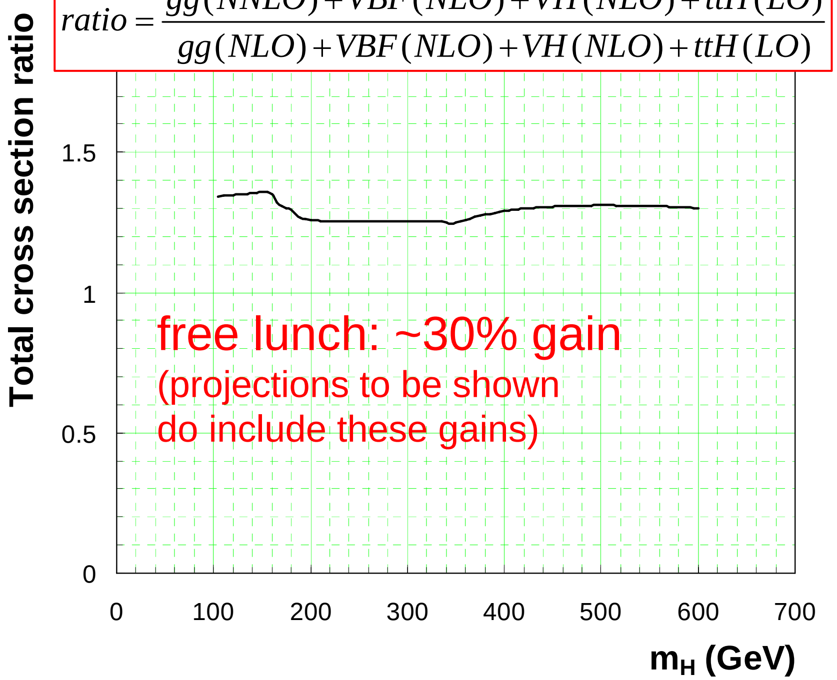
PAS – Physics Analysis Summary

SM Higgs cross sections at 7 TeV

(New 7 TeV) – to – (PTDR 14 TeV)



$$ratio = \frac{gg(NNLO) + VBF(NLO) + VH(NLO) + ttH(LO)}{gg(NLO) + VBF(NLO) + VH(NLO) + ttH(LO)}$$



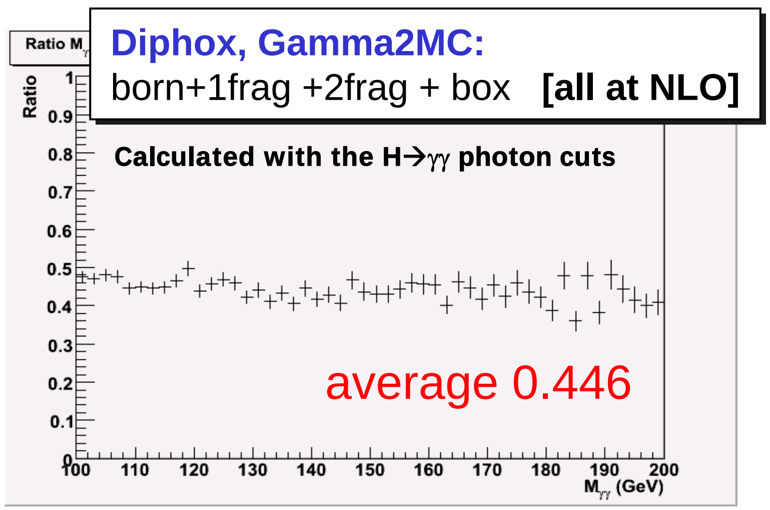
Sub-process	PTDR	now	tools used now
gg fusion	**NLO**	**NNLO**	**HggTotal**
VBF	**NLO**	**NLO**	**VV2H**
VH	**NLO**	**NLO**	**V2HV**
ttH	**LO**	**LO**	**HQQ**

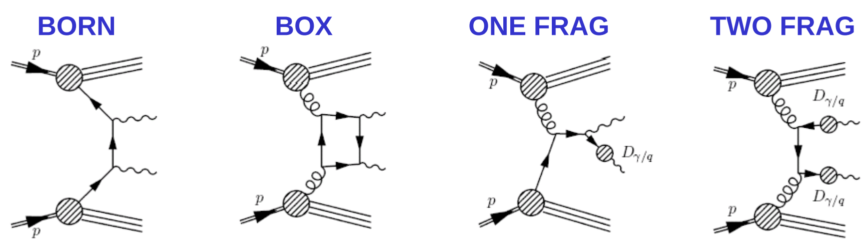
Rescaling backgrounds

General case backgrounds

process	ECM=14TeV	ECM=10TeV	ECM=7TeV	comment
W->lnu	3*20283.7	3*14253.7	3*9679.9	MCFM NLO
DY(20-inf)->ll	3*3259.7	3*2323.6	3*1606.6	MCFM NLO
WW	112.5	71.4	42.9	MCFM NLO
WZ	51.0	31.4	18.3	MCFM NLO
ZZ	15.6	9.9	5.9	MCFM NLO
ttbar	918	415	165	MCFM NLO
Wt	56.1	26.0	10.5	MCFM NLO
tq-t_channel	244.6	130.5	62.8	MCFM NLO
tq-s_channel	11.9	7.6	4.6	MSTW 2008 NNLO
W(->lnu)+gamma	54.7*1.8	35.4*1.8	23.2*1.8	NLO k-Factor from Bauer
Z(->ll)+gamma	17.5*1.8	11.3*1.8	7.3*1.8	NLO k-Factor from Bauer

Example of a special case background





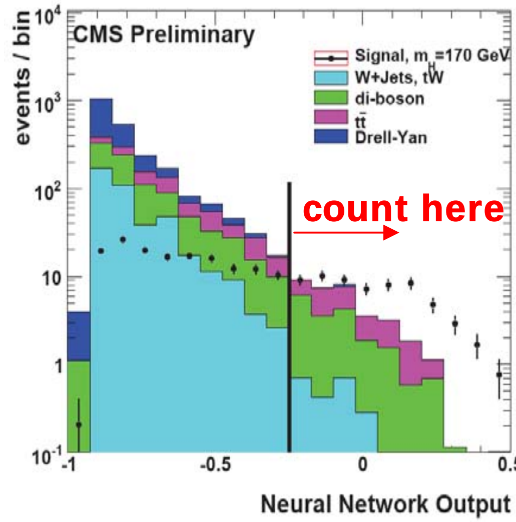
SM H→WW→2l2ν

Reference: HIG-08/006

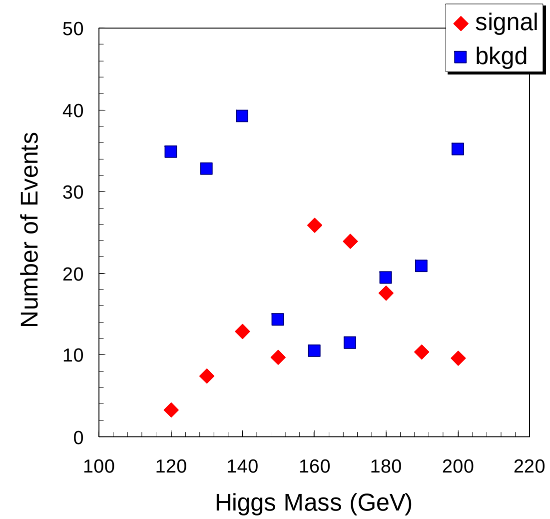
Method:

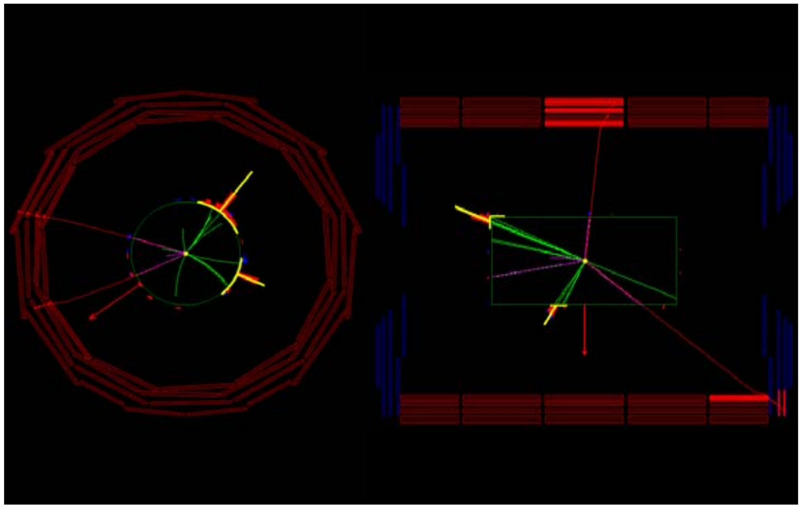
- **treat three final states μμ, *ee*, *e*μ separately**
- **two isolated leptons**
- **MET**
- **jet veto (0-jets bin)**
- **optimize in three mass ranges 120-140, 150-170, 180-200**
- **look for an excess above a cut on the MVA output [counting experiment]**
- **main backgrounds are assessed using data-driven techniques: WW, tt, W+jets, Drell-Yan**

14 TeV, 1 fb^{-1}



Events at 7 TeV, 1 fb^{-1}



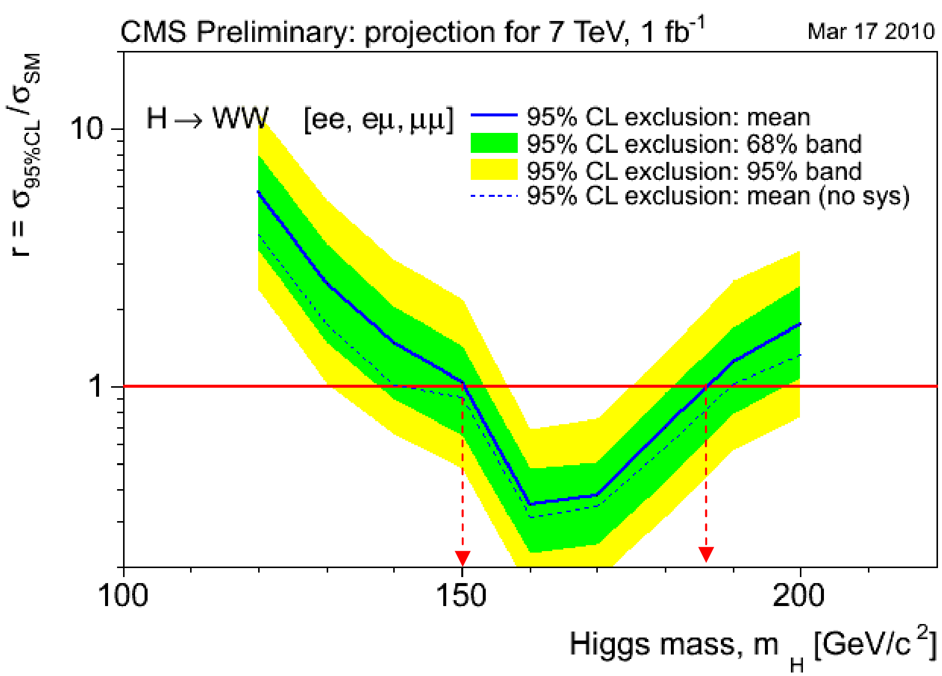


SM $H \to WW \to 2l2\nu$

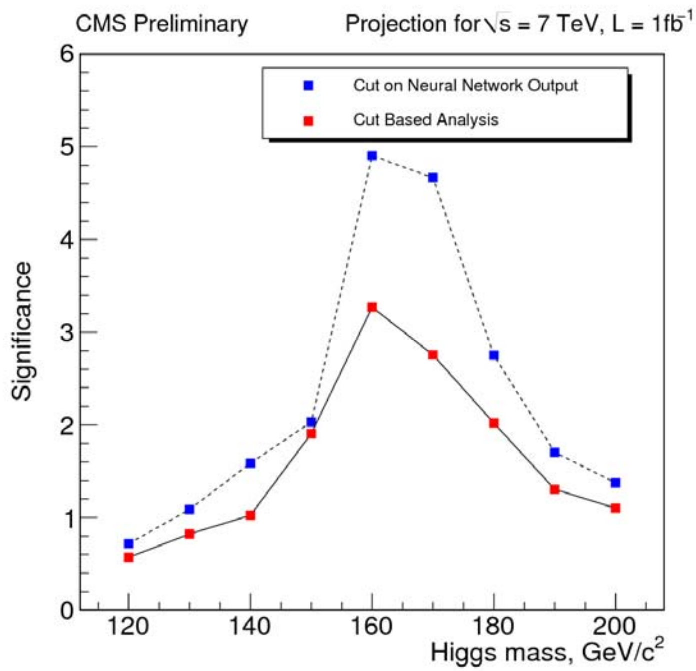
Reference: HIG-2008/006

Method: Counting above a MVA-output cut

Three sub-channels: ee, $\mu\mu$, $e\mu$



SM Higgs expected excluded range **150-185 GeV**



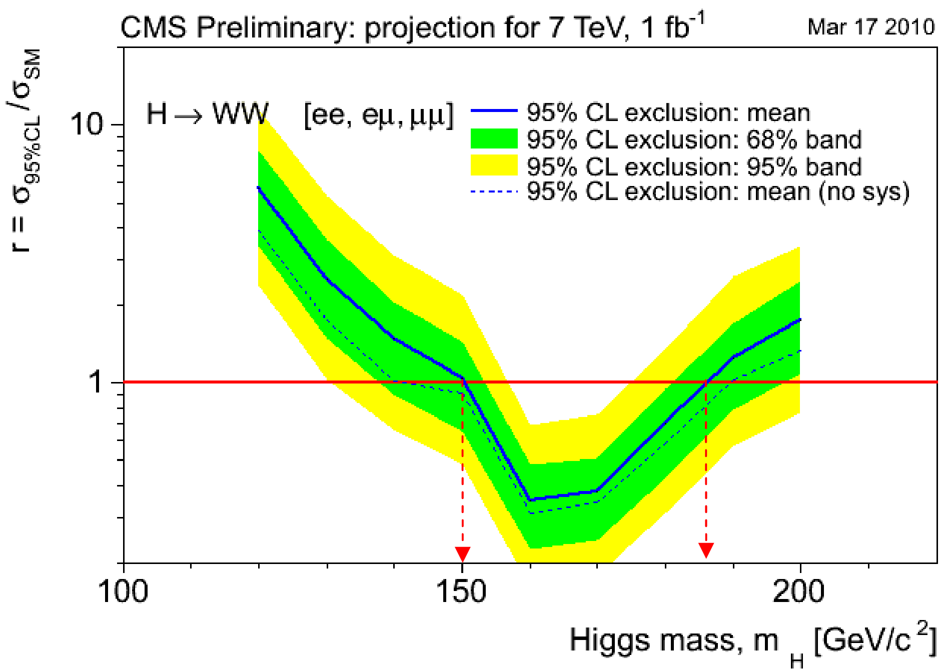
SM Higgs discovery level sensitivity **160-170 GeV**

SM H→WW→2l2ν

Reference: HIG-2008/006

Method: Counting above a MVA-output cut

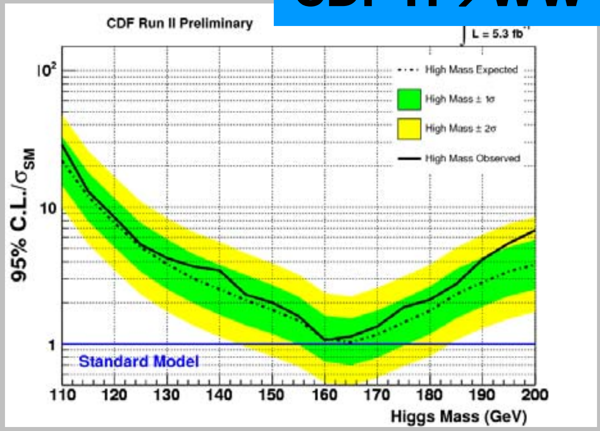
Three sub-channels: $2e$, 2μ, $e\mu$



SM Higgs expected excluded range: **150-185 GeV**

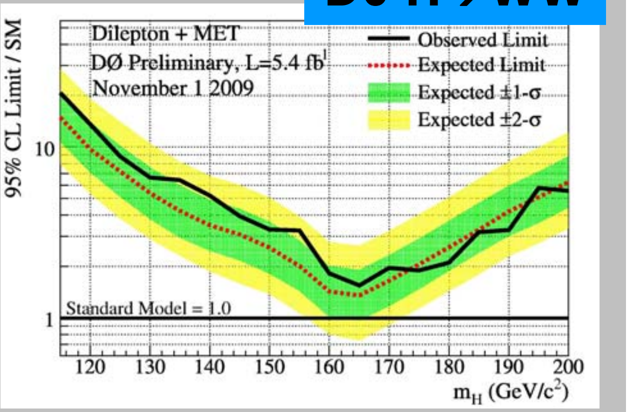
TEVATRON

CDF H→WW



CDF Note 1002, March 16, 2010

D0 H→WW

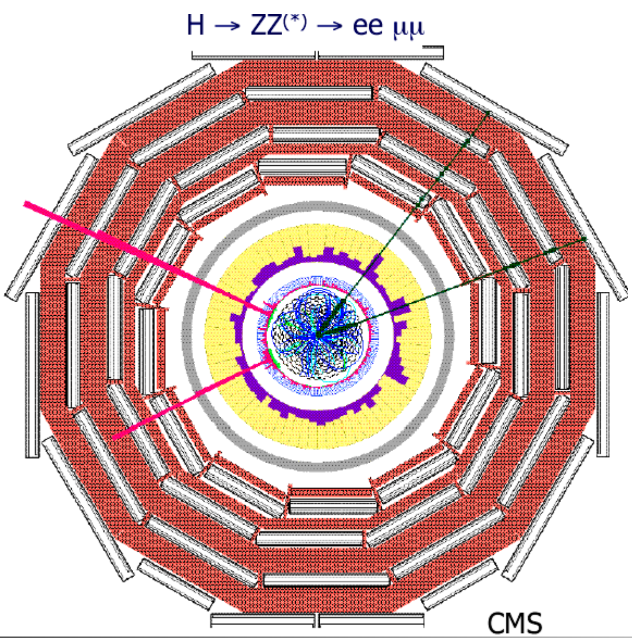


Phys. Rev. Lett. **104**, 061804 (2010) , Feb 12, 2010

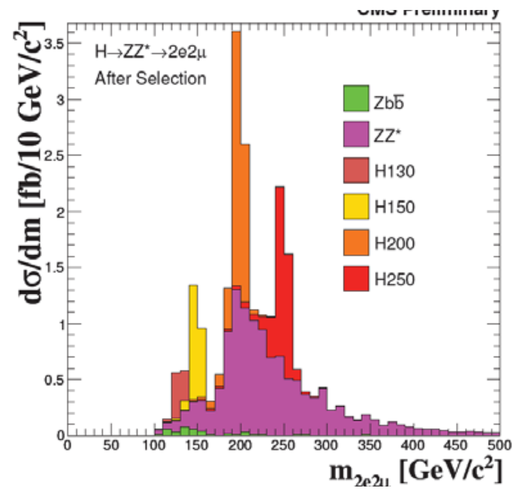
SM H→ZZ→4l

References:
HIG-08/003, NOTEs 2006/115, 2006/122, 2006/136

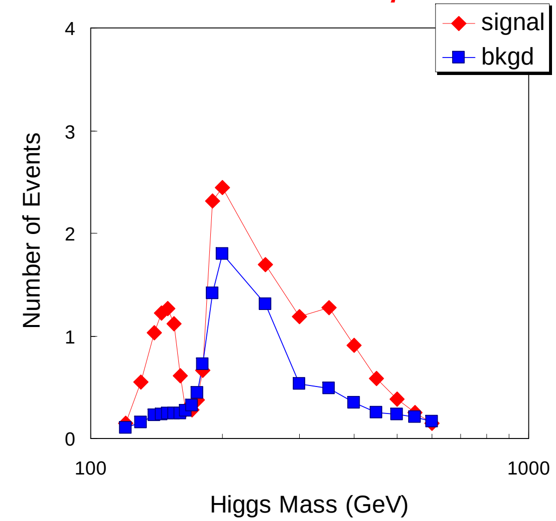
Method:
- **four isolated leptons**
- **lepton impact parameter veto**
- **look for a 4l-resonance mass peak [counting in a sliding mass window]**
- **dominant background ZZ [assessed from data—Z events]**



14 TeV, 1 fb^{-1}



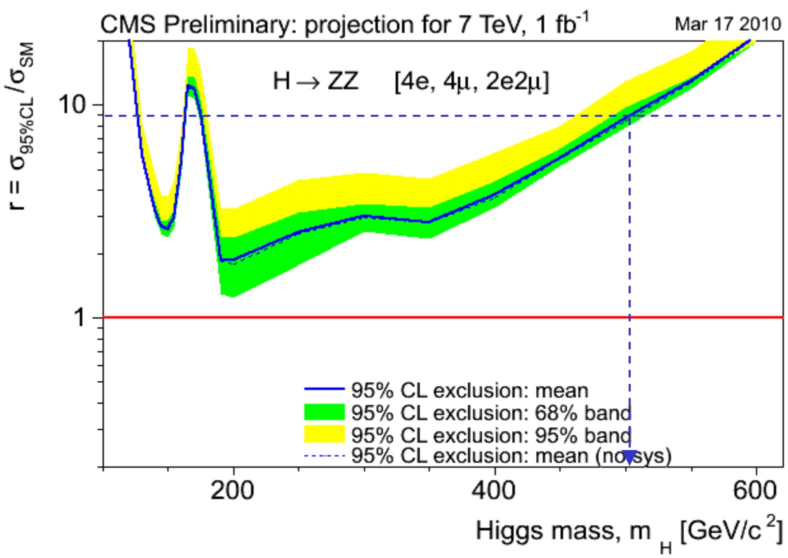
Events at 7 TeV, 1 fb^{-1}



SM H→ZZ→4l

References: HIG-2008/003 and
NOTEs 2006/115, 2006/122, 2006/136

Method: Counting in a 4l-mass window
Three sub-channels: $4e$, 4μ, $2e2\mu$

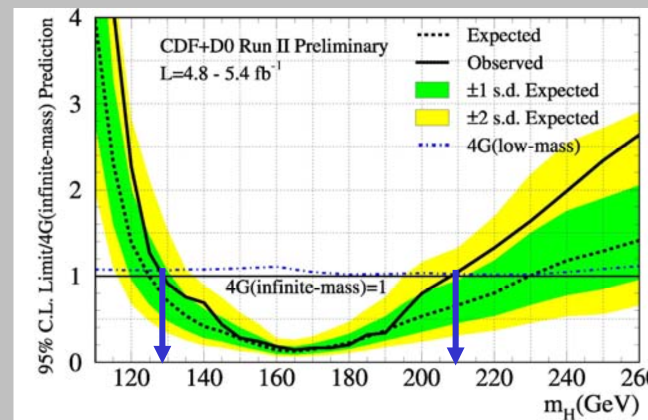


Sensitivity at m~200 is similar to H→WW (effect of low lumi)

TEVATRON

No H→ZZ public results, but...

4G (four-generation) Higgs limits from CDF+D0
H→WW channel



D0 Note 6039-CONF, March 11, 2010

SM Higgs with 4 fermion generations
- gg→H cross section goes up by a factor $3^2=9$ (regardless of how heavy the 4th generation quarks are)
- expected exclusion limit – **up to 500 GeV**

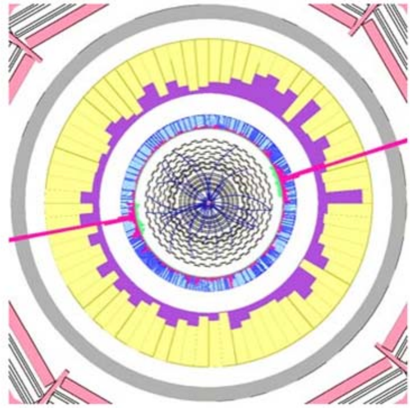
SM H→γγ

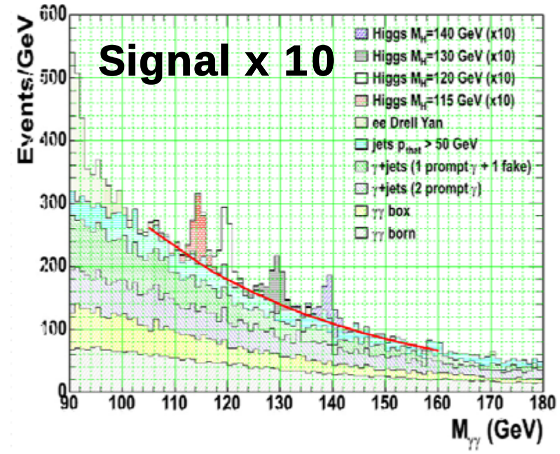
14 TeV, 30 fb^{-1}

Reference: NOTE-2006/112

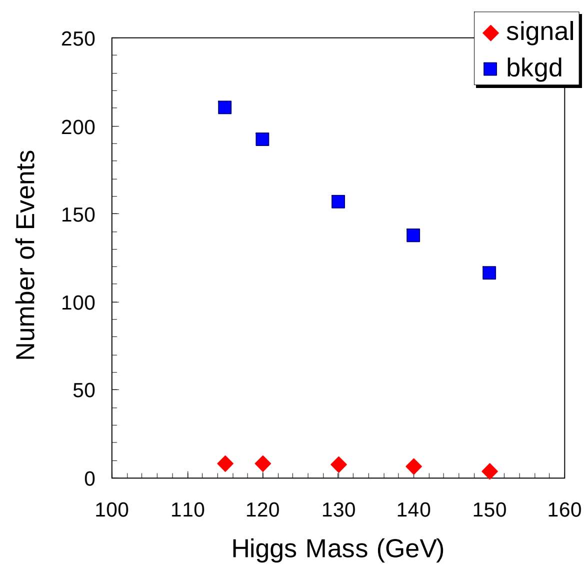
Method:

- **two isolated photons [no categories]**
- **look for γγ-resonance mass peak [counting in a sliding mass window]**
- **bkgd is assessed from sidebands**





Events at 7 TeV, 1 fb^{-1}

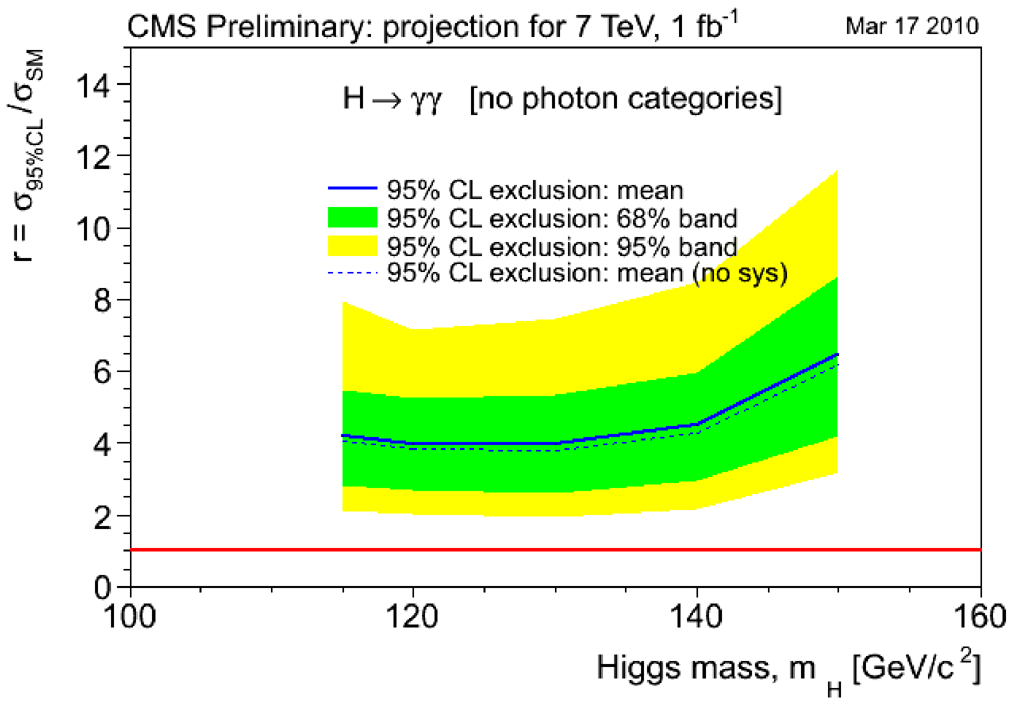


SM H→γγ

Reference: NOTE-2006/112

Method: Counting in a mass window

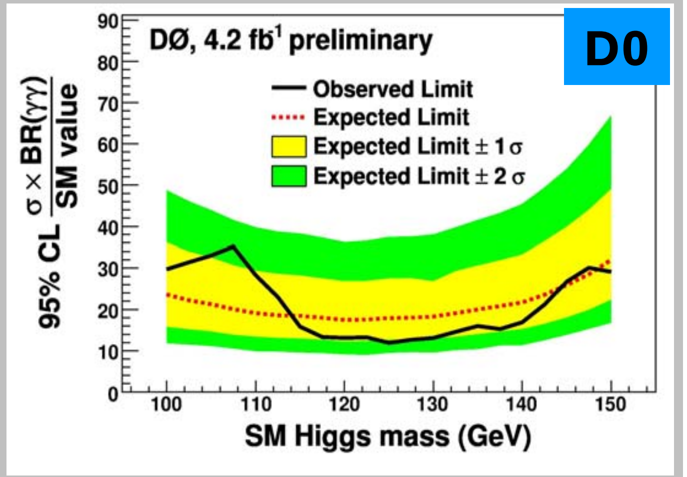
No photon categories



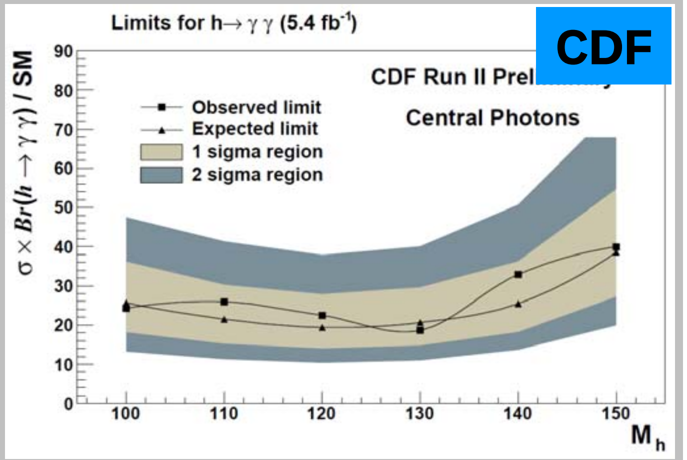
Note:

This projection does not rely on Higgs specific kinematics.
So, one can view it as a generic pp→X→γγ search

TEVATRON



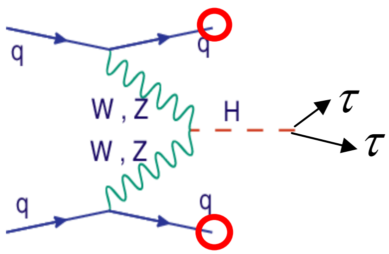
D0 Note 6580-CONF, 11 March 2009

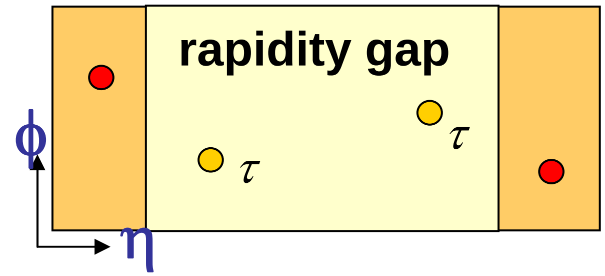


CDF Note 9586, Oct 30, 2008

SM VBF $H \to \tau\tau$ (1)

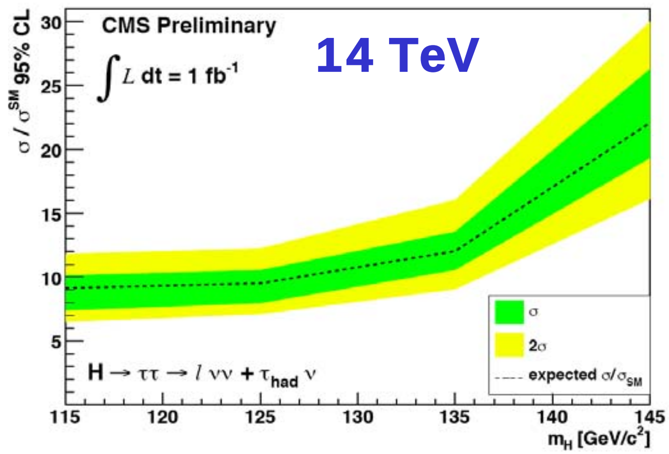
Reference:
NOTE-2006/088, PAS HIG-08/008





Method:
VBF signature
and counting events in a $\tau\tau$-mass window

Consider example of m_H=135



PTDR:
14 TeV and 30 fb^{-1}, signal=7.9, signal:bkgd ~ 4:1

PAS HIG-08/008 (re-optimized)
14 TeV and 1 fb^{-1}, signal=1.1, signal:bkgd ~ 1:10
exclusion limit r~12

Next year?
7 TeV and 1 fb^{-1}, signal drops by 50%,
r will get worse (it will be far behind r~4 for $H \to \gamma\gamma$)

This channel is certainly not a forerunner with early data…

SM VBF H→ττ (2)

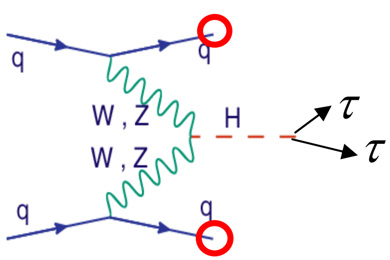
And there is one more problem with this channel…

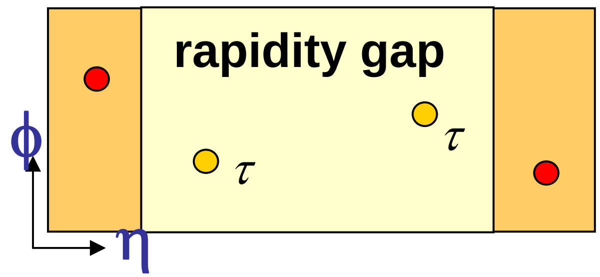
Recently, it was realized that

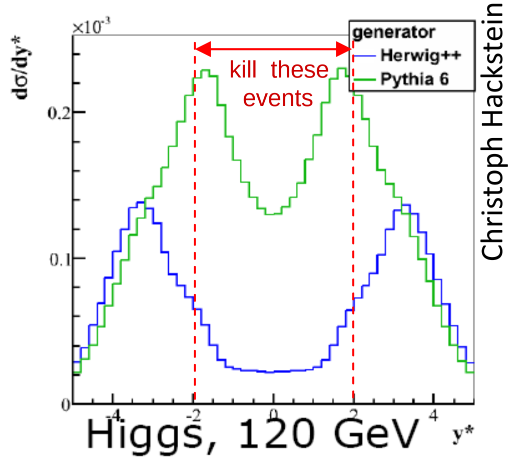
the classical VBF signature

- two highest E_T jets in forward-backward directions
- and large rapidity gap $|\eta_{jet1}-\eta_{jet2}|$ with no jets in between (jet veto)

may have large phenomenological uncertainties for signal efficiency





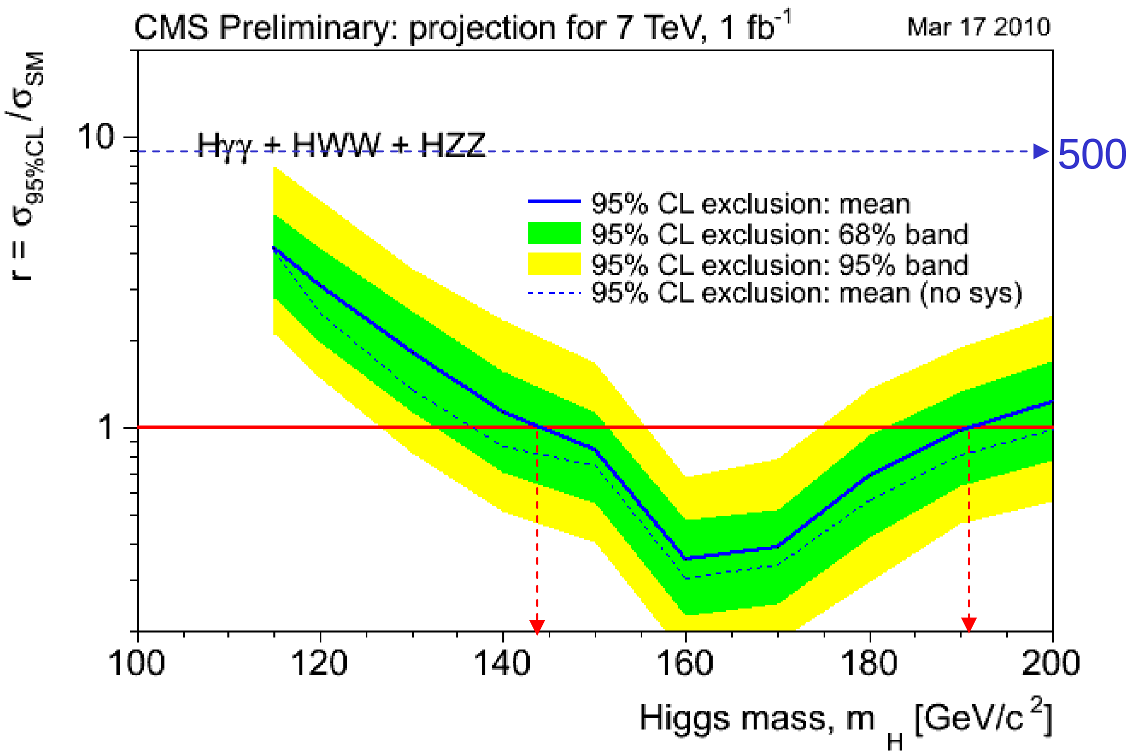


$y^* = y_i - ½ (y_1+y_2)$

For details:

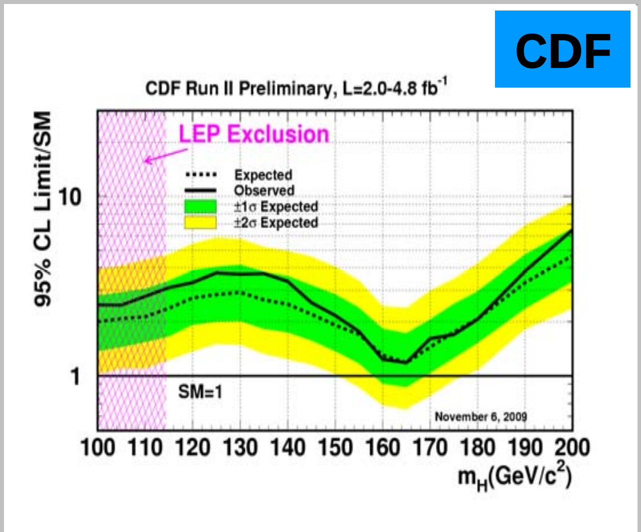
C. Hackstein at HGF-Alliance-2009: HGF-Alliance "Physics at the Terascale" annual meeting 2009, 11-13 Nov 2009, DESY, Hamburg
C. Hackstein at DPG-2010: Jahrestagung 2010 der DPG, Deutsche Physikalische Gesellschaft, 15-19 Mar 2010, Bonn University, Bonn

SM Higgs Combination $\gamma\gamma$+WW+ZZ

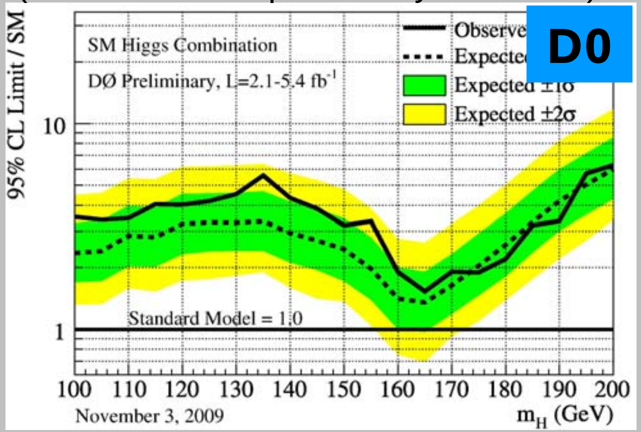


SM Higgs expected excluded range: **145-190 GeV**
SM Higgs with 4 fermion generations: **<500 GeV**

TEVATRON



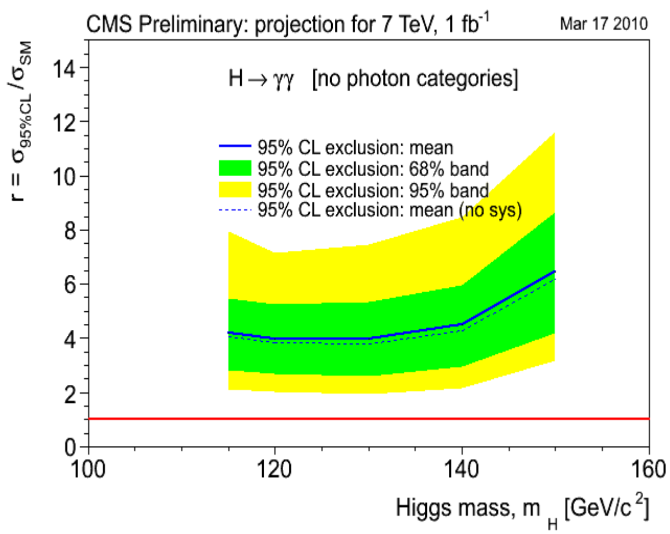
CDF Note 9999, Nov 17, 2009
(the recent WW update not yet included)



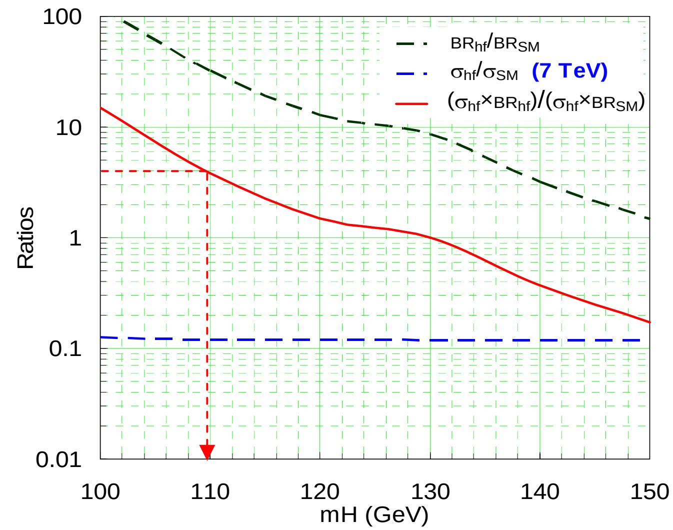
D0 Note 6008-CONF, 25 Feb 2010

Fermiophobic Higgs

SM H→γγ exclusion r~4



Fermiophobic/SM ratios



Fermiophobic/SM (see plot on the right)

lose a factor of 10 in cross section [blue line]

Gain a large factor in BR(H→gg) [black line]

CS x BR is larger than that of SM up to 130 GeV

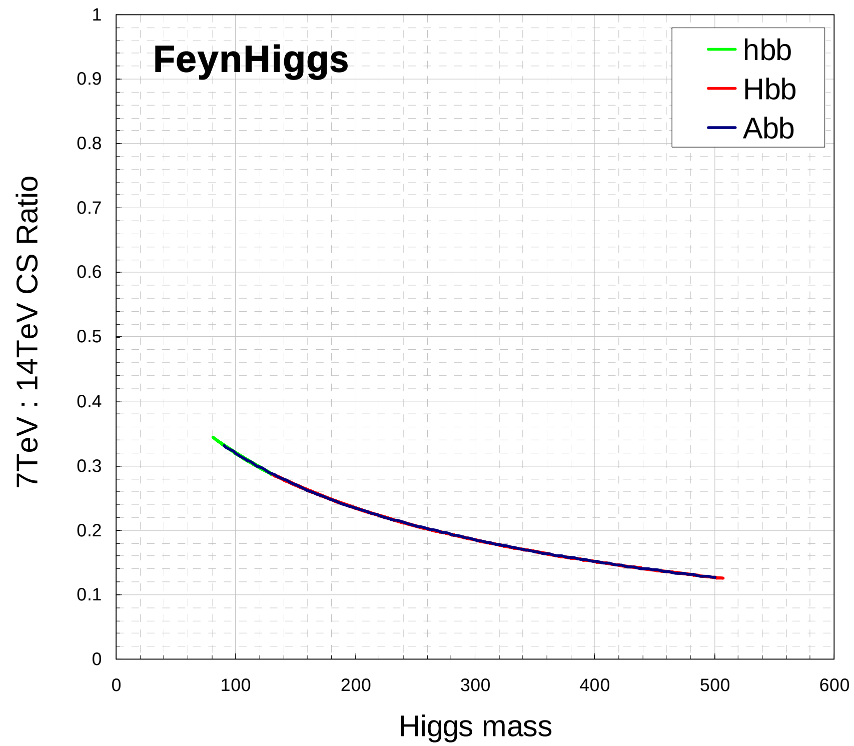
If we do <u>nothing</u> special for fermiophobic Higgs,

r~4 for SM Higgs (see left plot) implies that

we can exclude fermiophobic Higgs with m~110 GeV (see right plot), which is better than Tevatron, comparable to the Combined LEP limit

MSSM Higgs bbΦ at 7 TeV

Cross Section Ratios



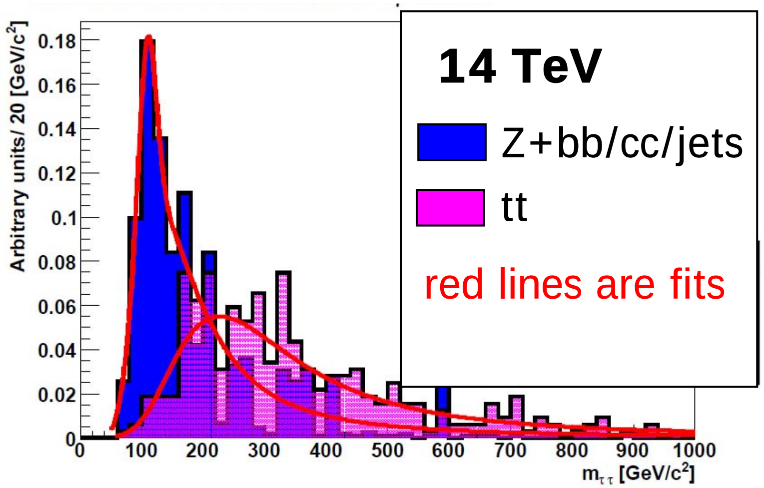
MSSM $bb\Phi$, $\Phi \rightarrow \tau\tau$

References:
NOTE 2006/075
NOTE 2006/101
NOTE 2006/105

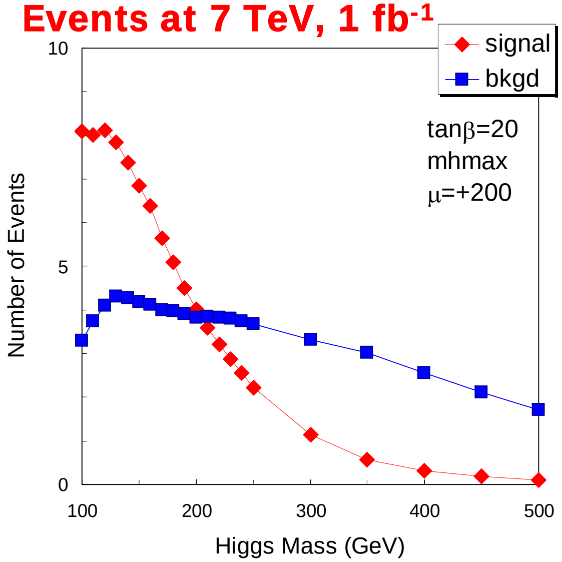
Method:

- **isolated** $\tau_{had}\tau_{\mu}$ $\tau_{had}\tau_{e}$ $\tau_{e}\tau_{\mu}$
- **MET**
- **one b-tagged jet**
- **veto extra jets**
- **build $\tau\tau$-mass using collinear approximation**
- **counting events in a sliding $\tau\tau$–mass window [counting experiment]**
- **dominant backgrounds [assessed from data]**
  - **Z+bb/cc/jets**
  - **tt**

Background pdf($m_{\tau\tau}$)



Events at 7 TeV, 1 fb^{-1}



MSSM $bb\Phi$, $\Phi \to \tau\tau$

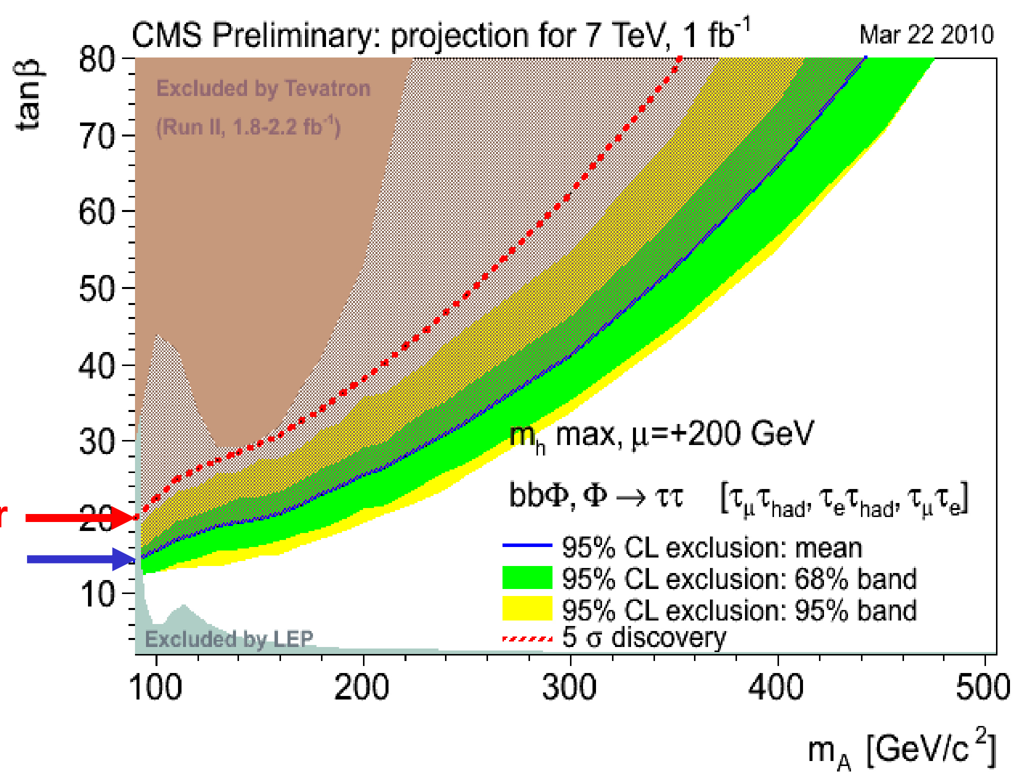
References: NOTEs 2006/075, 2006/101, 2006/105

Method: Counting in a $\tau\tau$-mass window

Three sub-channels: $\tau_\mu\tau_{had}$, $\tau_e\tau_{had}$, $\tau_e\tau_\mu$

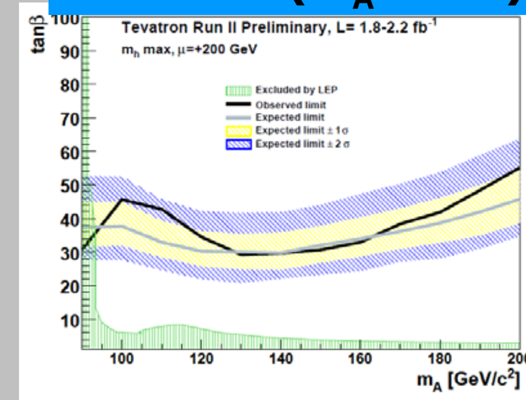
discover

exclude



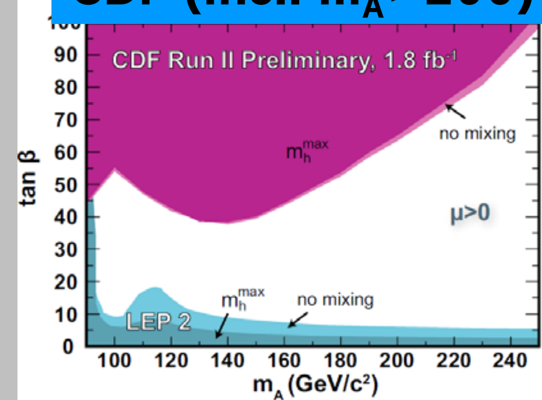
TEVATRON

D0+CDF (m_A<200)



arXiv:1003.3363, March 18, 2010

CDF (incl. m_A>200)



CDF note 9071, October 22, 2007

Outline

Stage for Higgs searches at LHC: current limits from LEP and Tevatron

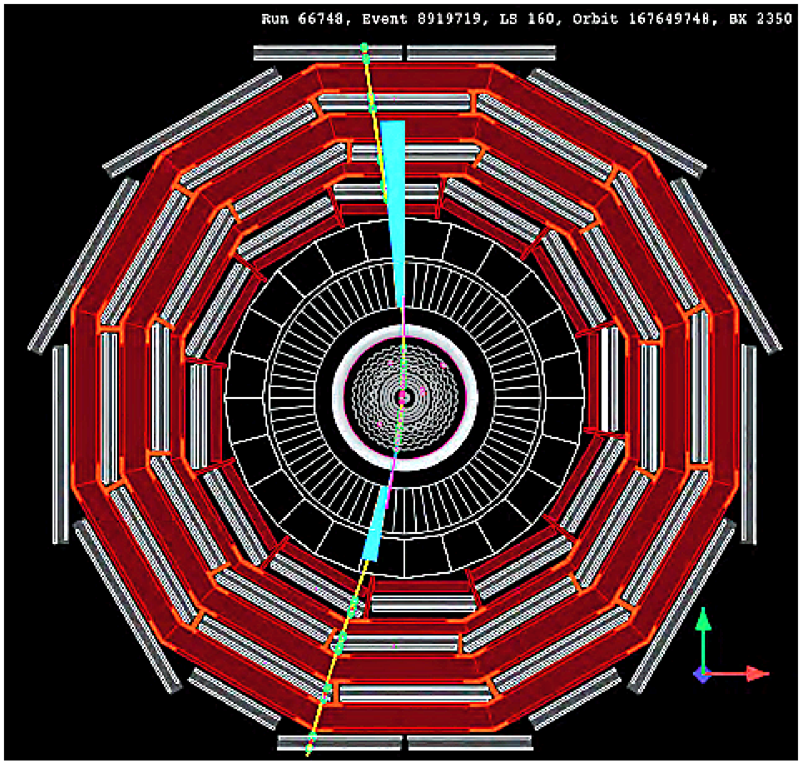
CMS Projections for 7 TeV and 1 fb^{-1}

How did we start? – a look at the first data

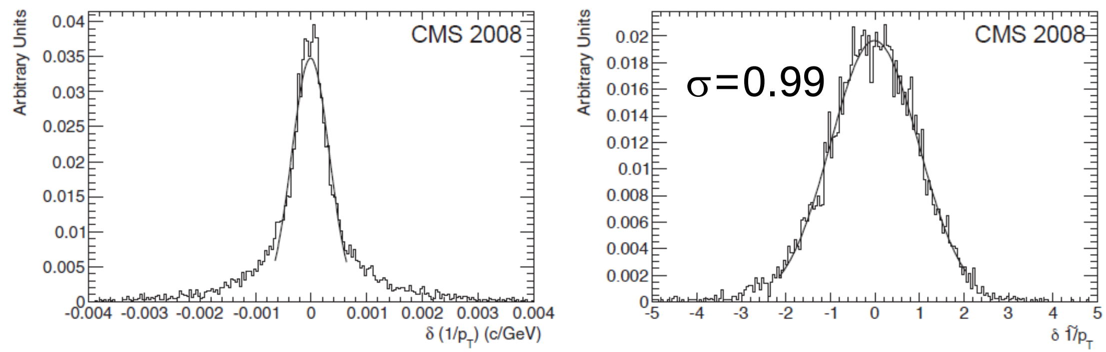
First steps with data: muons

J. Instrum. 5 (2010) T03008
J. Instrum. 5 (2010) T03007

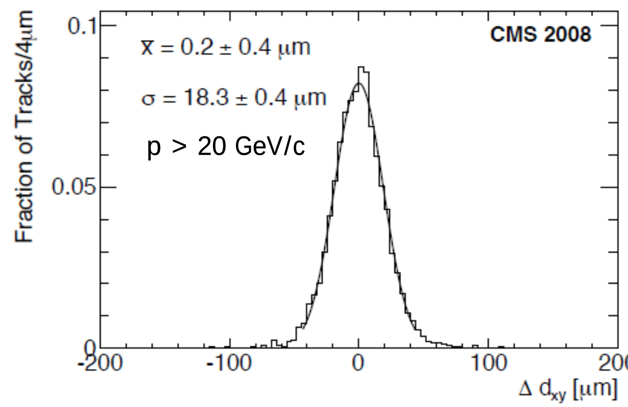
Cosmic Ray Muon



muon momentum resolution using split muons



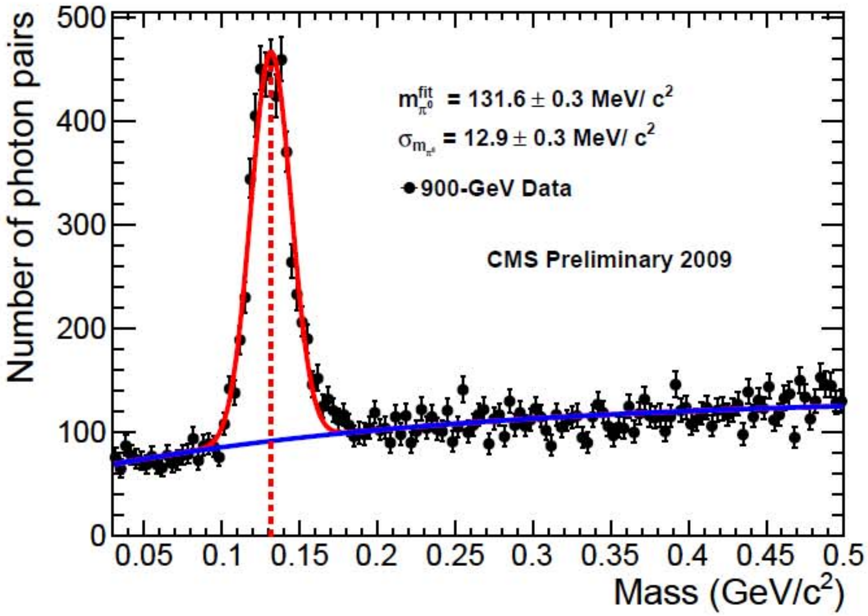
and impact parameter resolution

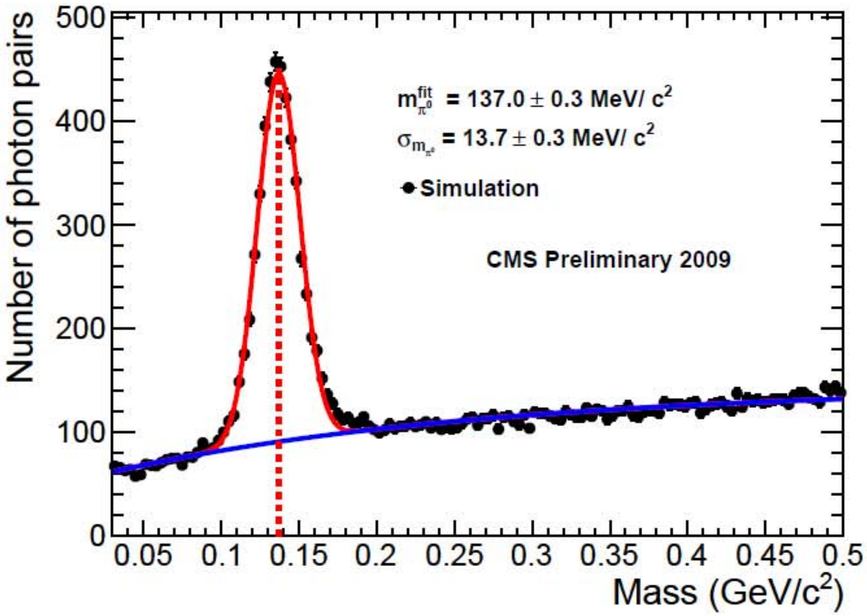


First steps with data: photons

CMS PAS PFT-10-001

Di-photon resonances

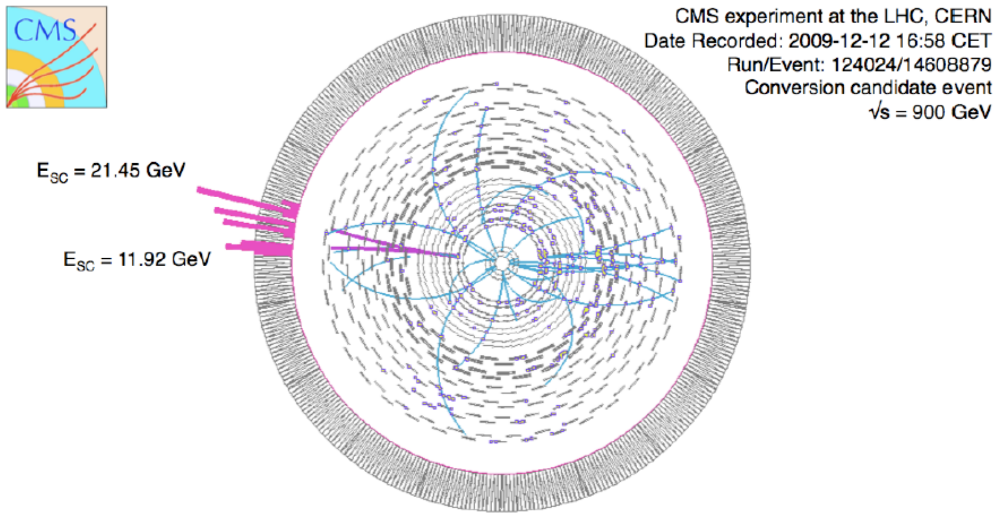




First steps with data: electrons

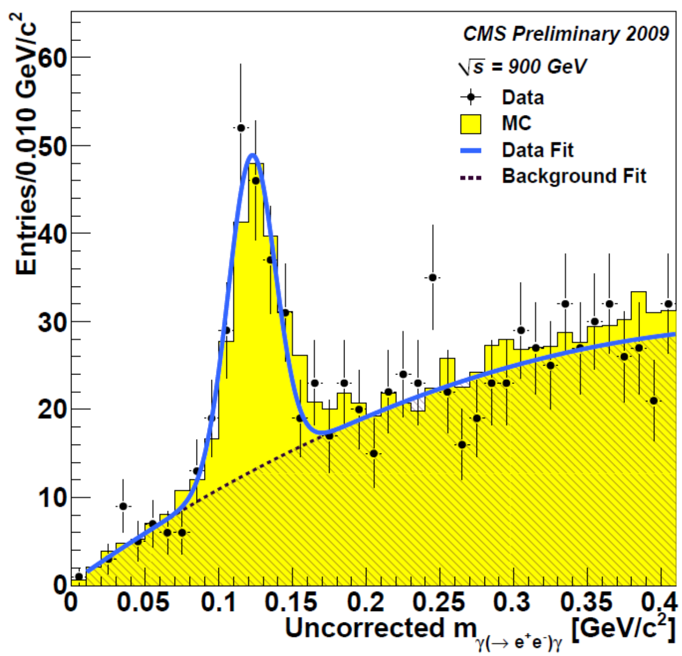
CMS PAS EGM-10-001

Electrons from conversions



Electron tracks are shown in purple, and their superclusters in pink in the ECAL.
General tracks are in blue and tracker clusters (silicon strips) are shown by small squares.

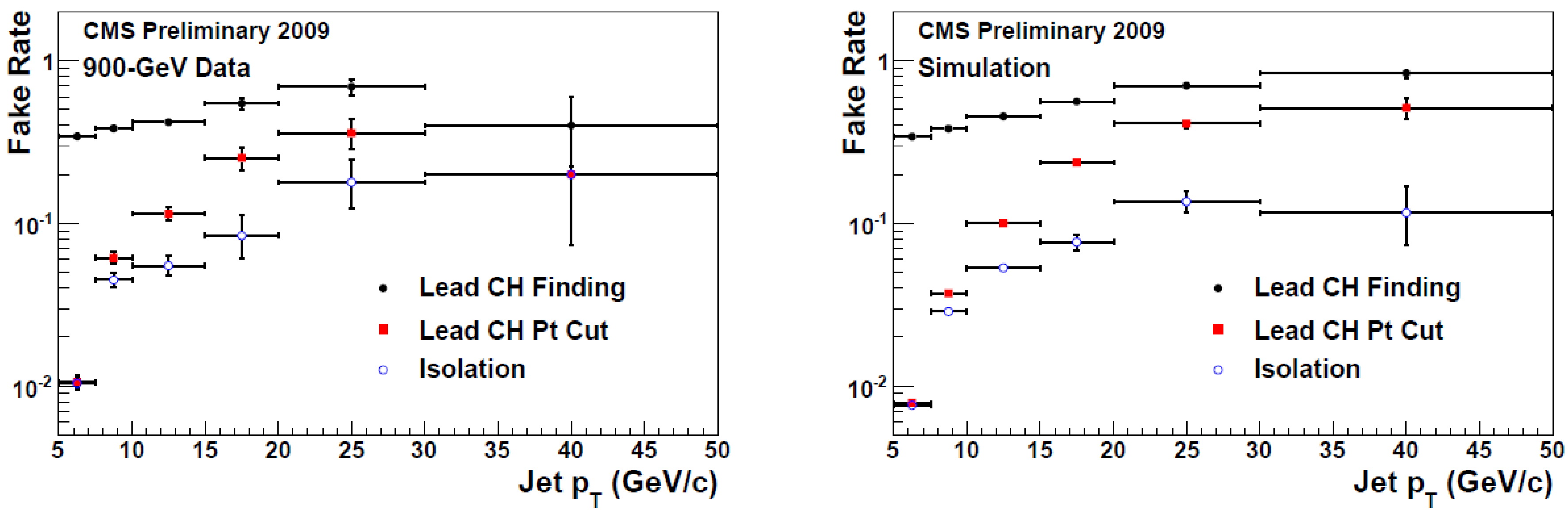
$\gamma(e^+e^-)_{\text{conv}}\ \pi^0$ peak



First steps with data: “taus”

CMS PAS PFT-10-001

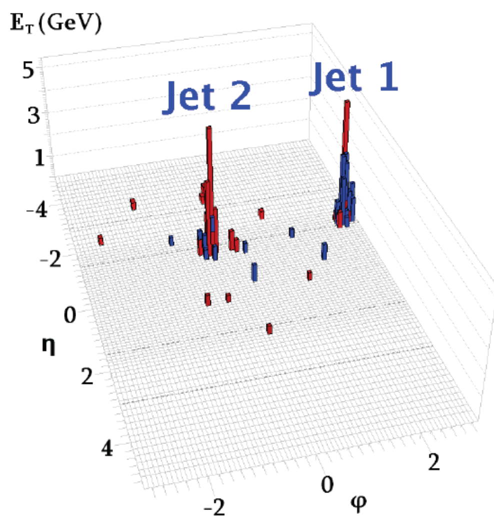
Fake-tau rate vs jet p_T

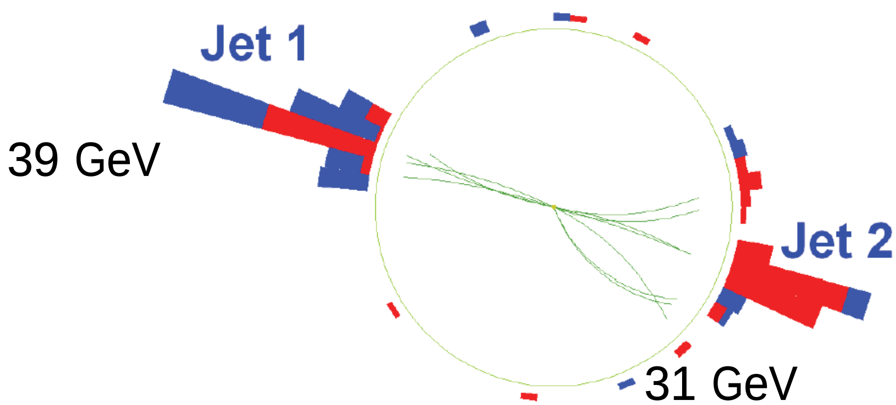


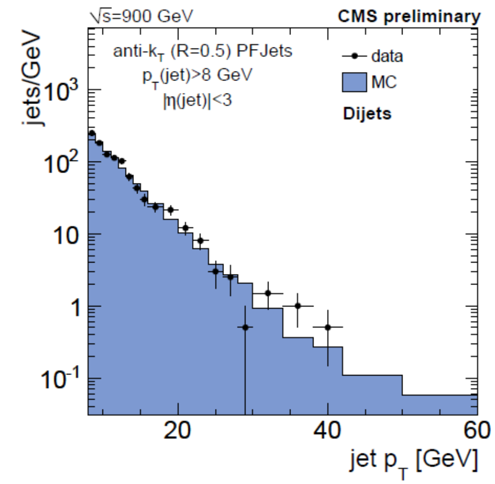
First steps with data: jets

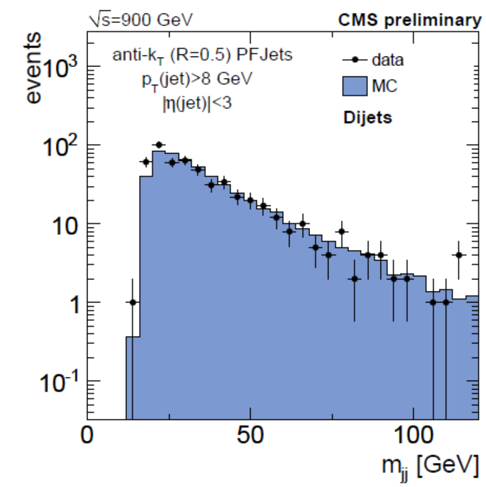
CMS PAS JME-10-001

Di-jet event









First steps with data: MET

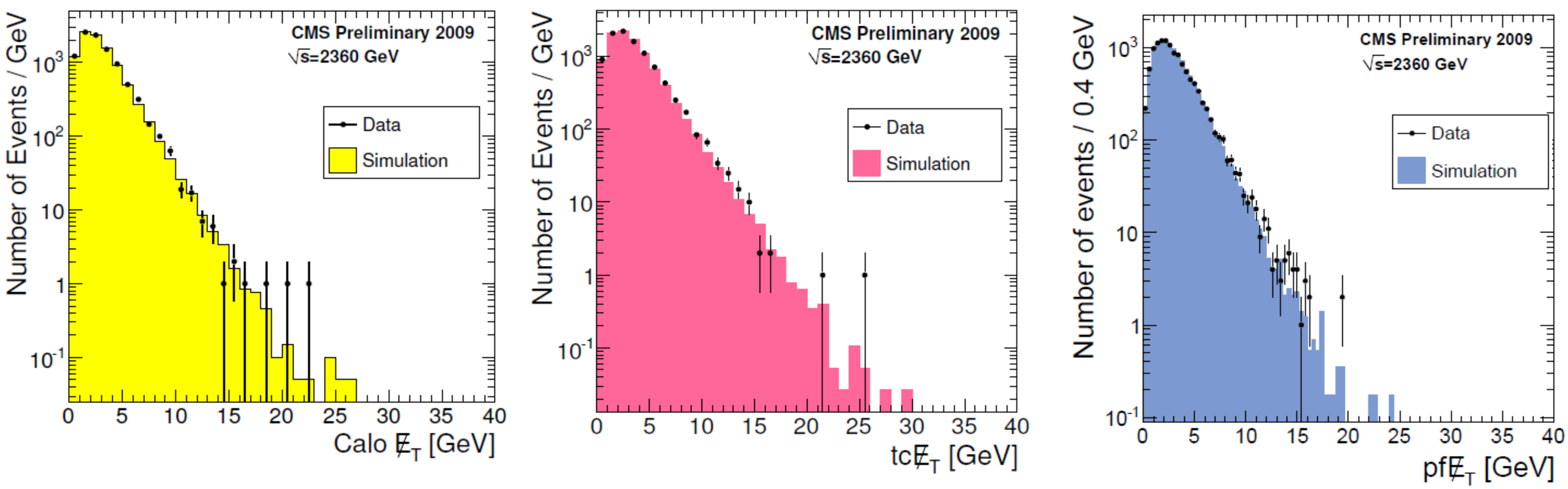
CMS PAS JME-10-002

Three different algorithms for MET

- **CaloMET: using calorimeter information only**
- **tcMET: HCal information is track-corrected**
- **pfMET: particle-flow information**

Important: in Higgs analyses, typical MET is very moderate, tens of GeV

Agreement between MC and data in this range is quite remarkable



Conclusions

With 7 TeV and 1 fb^{-1} of data,
CMS (and surely ATLAS) will be on the map for Higgs searches

CMS projections:

- **SM discovery sensitivity:** 160-170 GeV
- **SM exclusion sensitivity:** 145-190 GeV
- **MSSM neutral Higgs discovery rich:** down to tanβ~20 at low m_A
- **MSSM neutral Higgs exclusion rich:** down to tanβ~15 at low m_A
- **MSSM light charged Higgs:** production rate is higher than at Tevatron
- **Beyond SM / MSSM:** a number of opportunities are out there...

First look at data and running experience are very positive!