CMS

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2009 electrons at CMS: a first step in the Higgs adventure

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LLR – Ecole Polytechnique

Overview

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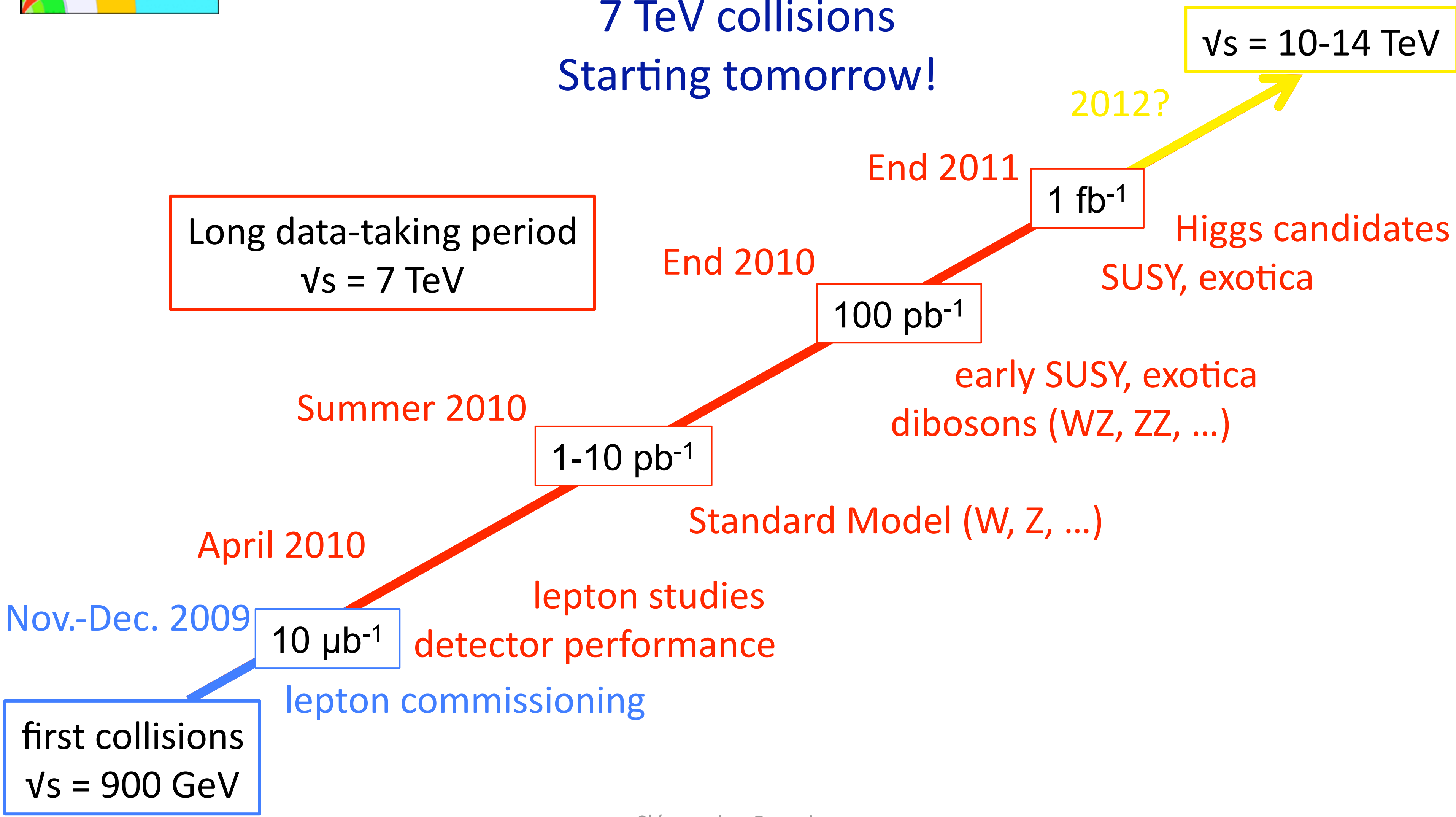
- The search for the Higgs boson is a main goal of LHC
  - The only missing stone of the Standard Model
  - Or the first confirmation of a more complicated world

- A presentation of its search strategy at the time of LHC restart *(emphasis on $H \rightarrow ZZ^{(*)} \rightarrow 4l$ analysis)*
  - First electrons from 2009 data in CMS
  - Related analyses and preparation for the Higgs
  - The Higgs boson at LHC in the next years

LHC timetable

7 TeV collisions

Starting tomorrow!



Higgs boson mass range

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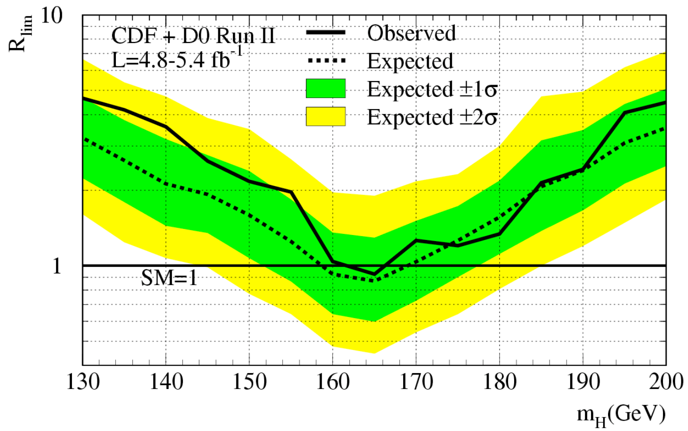

- Experimental bounds
  - M_H > 114.4 GeV (LEP)
  - Excl. region 162-166 GeV (TeVatron)

- Theoretical bounds
  - SM unitarity bound
    M_H < 780 GeV

  - Consistency fit (95% CL)
    (knowing that M_H > 115 GeV)
    M_H < 182 GeV

SM search mainly in the range: 115-200 GeV

$\sigma_{LHC,\ 7TeV} \sim (20 \text{ to } 30) * \sigma_{TeVatron}$

Other models suggest M_H > 200 GeV

Higgs boson production

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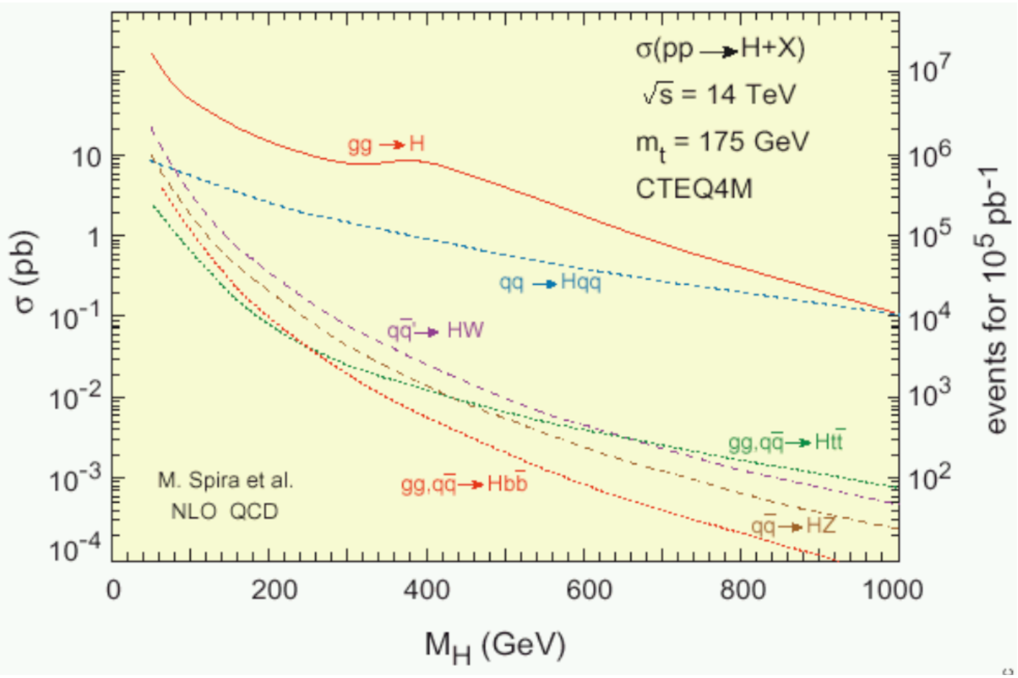
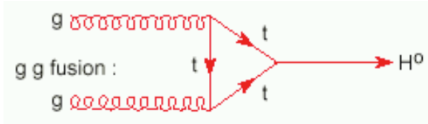
- Inclusive production

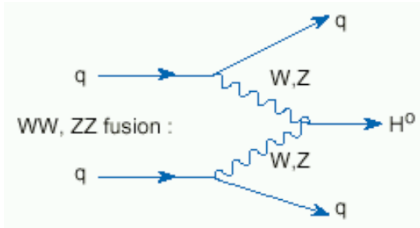


A. Djouadi

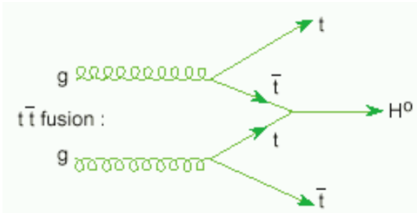
- gg fusion



- vector boson fusion



- $t\bar{t}$ fusion



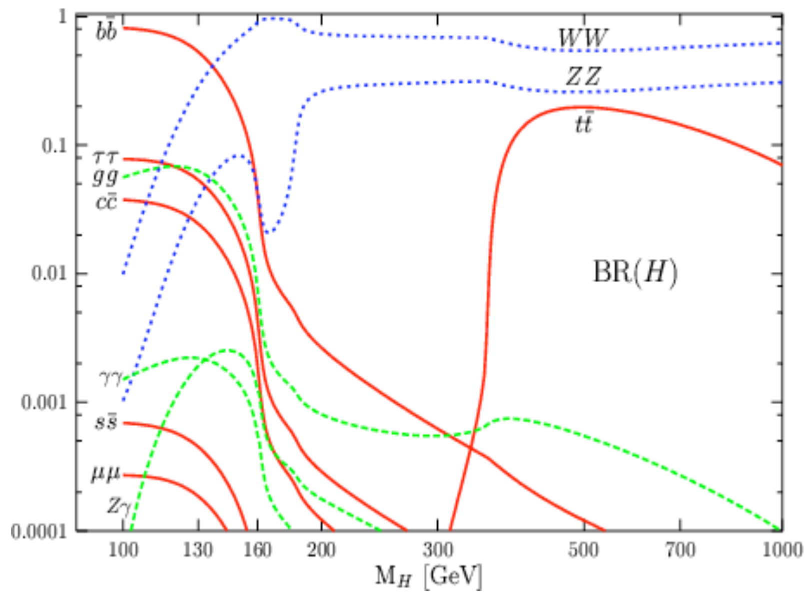
- associated production (W,Z)

Higgs boson decays

- Lower masses ($M_H \lesssim 150$ GeV)
  - H → γγ
  - H → ττ
- Higher masses ($M_H \gtrsim 150$ GeV)
  Diboson decays
  - H → WW$^{(*)}$ → ℓνℓν
  - H → ZZ$^{(*)}$ → 4ℓ

ℓ = e or μ

A. Djouadi



=> Detection of isolated electrons and muons

$H \rightarrow ZZ^{(*)} \rightarrow 4\ell$

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- A clean observation (resonance) in principle
- But a small cross section x branching ratio
  And huge QCD-driven backgrounds
  - Need very good efficiency on leptons, down to very low p_T^e
    Inefficiency will count at power 4 *(e.g. cannot afford fiducial cuts)*
  - Need to predict the ZZ(*) background from parton luminosities
    Not enough side-bands at discovery time
  - Need very accurate selection parameters
    lepton isolation and ID, charge, vertex …
    Precision is essential in this channel which will be used to disentangle S_{CP}

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First electrons in CMS

$e^{+/-}$ detection with CMS

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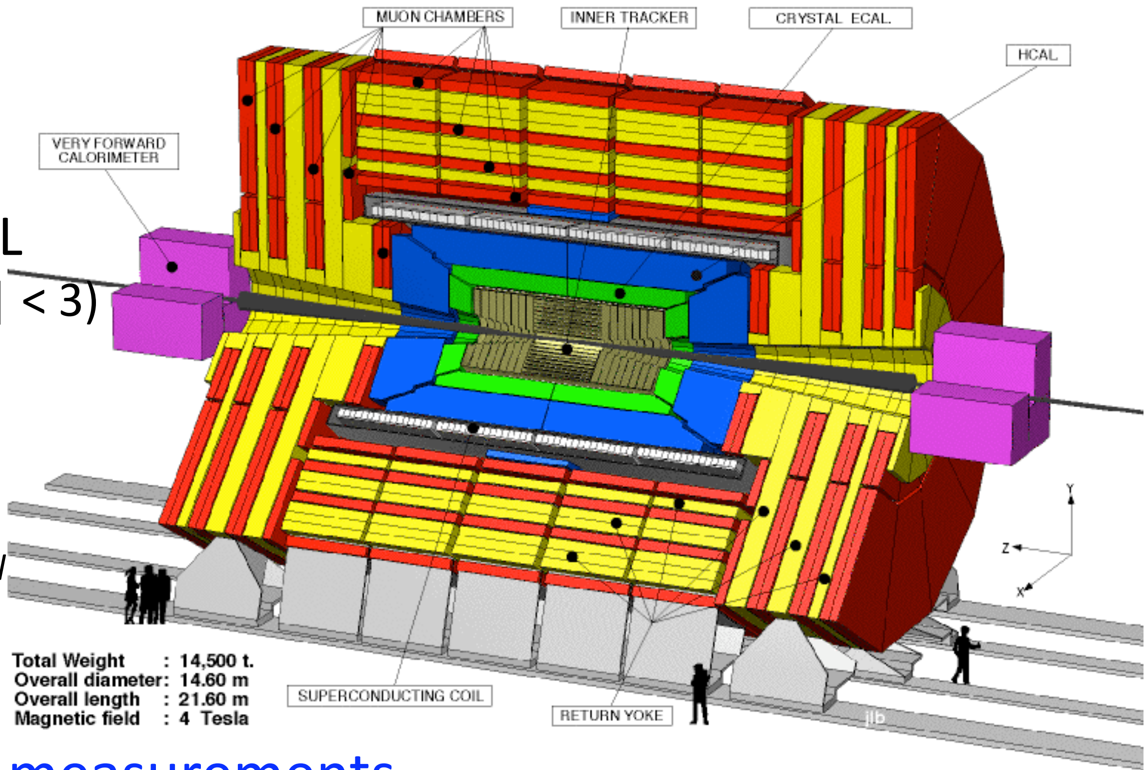
- Electrons
  - Track in the silicon tracker curved by B = 3.8 T

    Precision in p_T : ~ 1%

  - Energy clusters in the ECAL (Si tracker: |η| < 2.5, ECAL: |η| < 3)

    Precision in E: $\lesssim$ 1%

    Stochastic term: 2.8%/√E
    Noise term: 41.5 MeV / E per crystal
    Constant term: 0.5%
    (incl. local containment corrections)



Efficiency control via Z → e^+e^- measurements

e reconstruction with CMS

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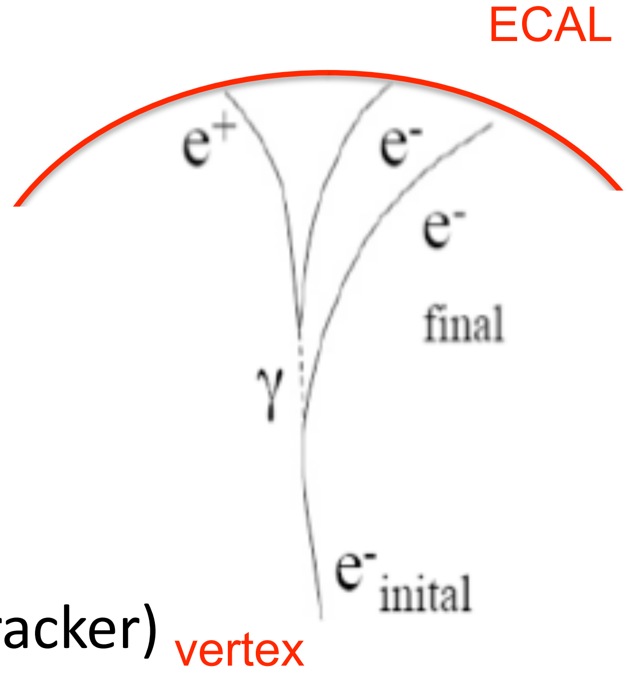
- ECAL-driven reconstruction

⚠ Si tracker: a lot of material budget
=> complicated tracks



- energy deposit in the ECAL crystals
- supercluster

(whole energy of the initial e in ECAL)

- Track seed (innermost layers of Si tracker)
- Track (Si tracker)

Efficiency (MC):
90% at p_T=10 GeV
95% at p_T=35 GeV

e reconstruction with CMS

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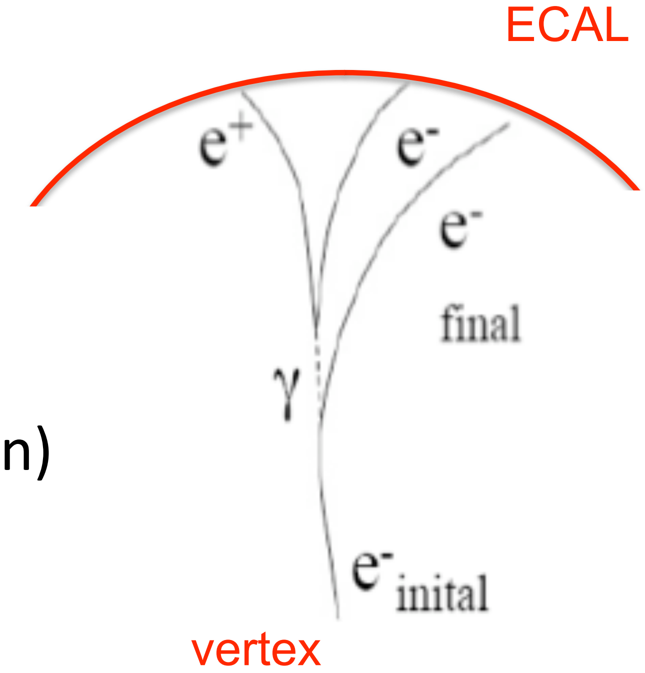
- Tracker-driven reconstruction
  - Build a track allowing energy loss (Bremm. γ)
  - Supercluster built step by step (energy deposits in tangent direction)



Merging of both collections

$\Rightarrow$ no double-counting

Preselection (track-SC concordance)

$\Rightarrow$ electron candidate

Gain in efficiency:
esp. at $p_T < 10$ GeV and in ECAL crack regions
New efficiency:
$> 95\%$ for $p_T \gtrsim 10$ GeV

First electrons in CMS

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2009 collisions at 900 GeV

- 351 electron candidates reconstructed on minimum bias events
  - very low p_T
  - mostly fake from charged hadrons
  - real $e^{+/-}$ come mainly from γ conversions

    MC: 4.6% of real, prompt electrons

$\Rightarrow$ Not the signal for which electron reconstruction has been optimized

$\Rightarrow$ But very nice results are obtained

First electrons in CMS

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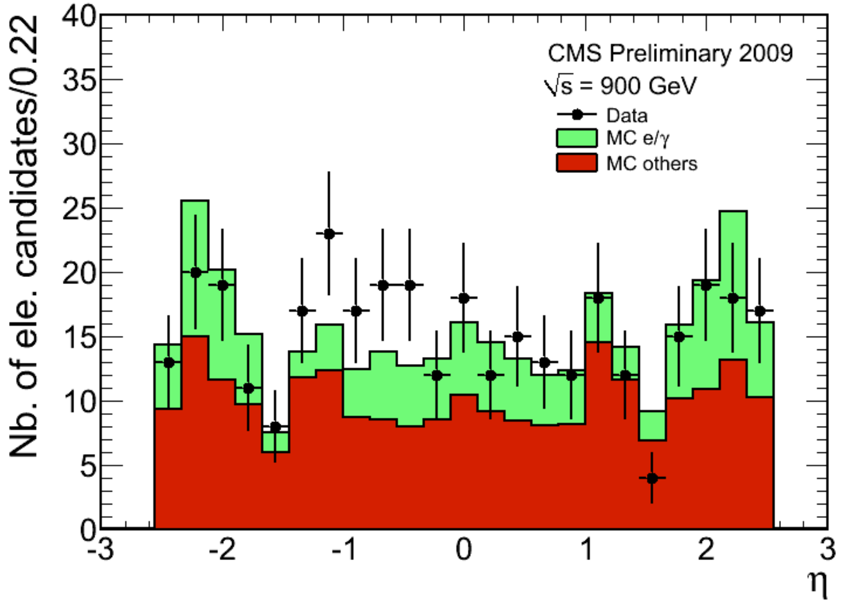

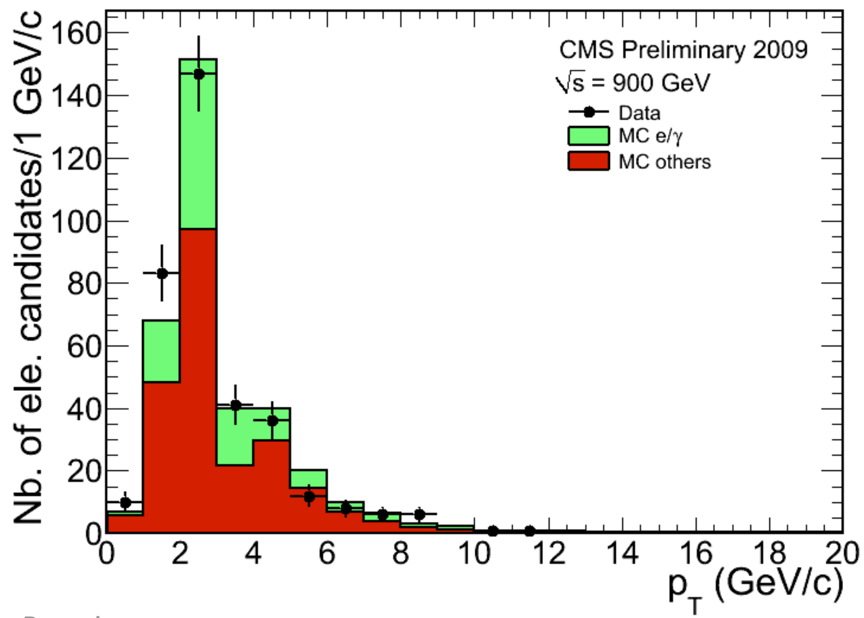

First electrons in CMS

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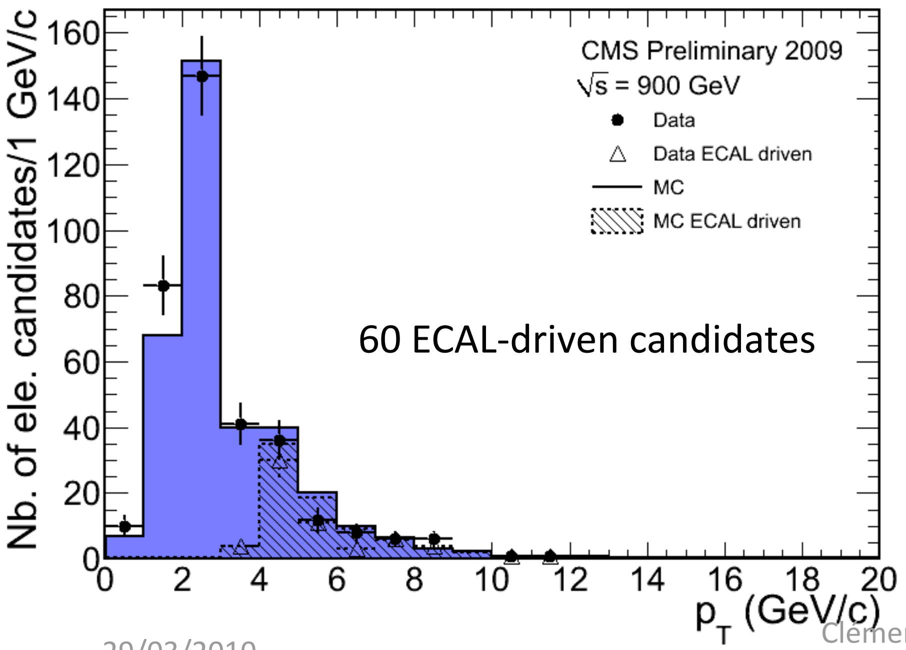
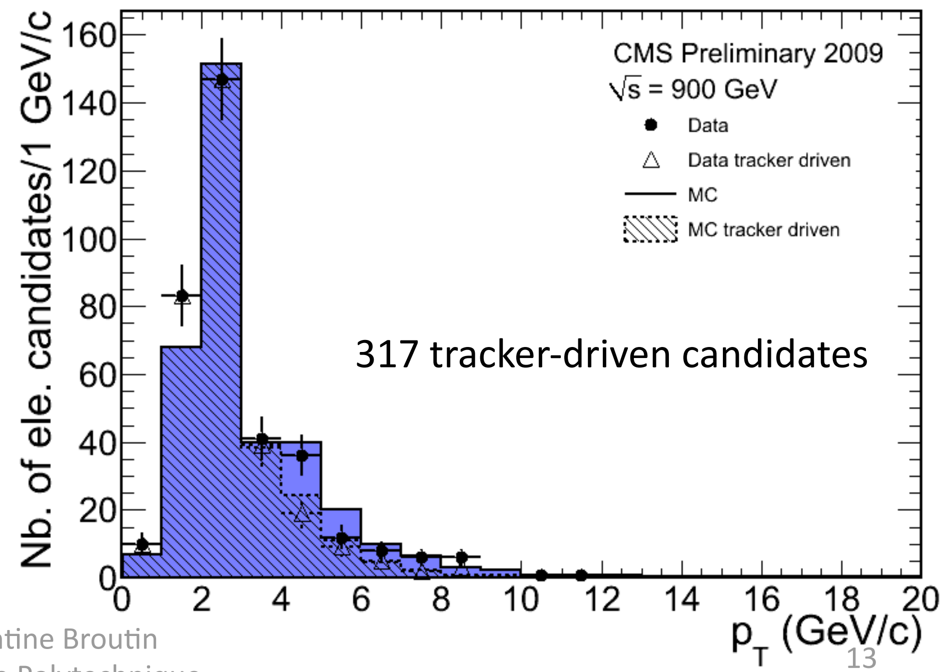


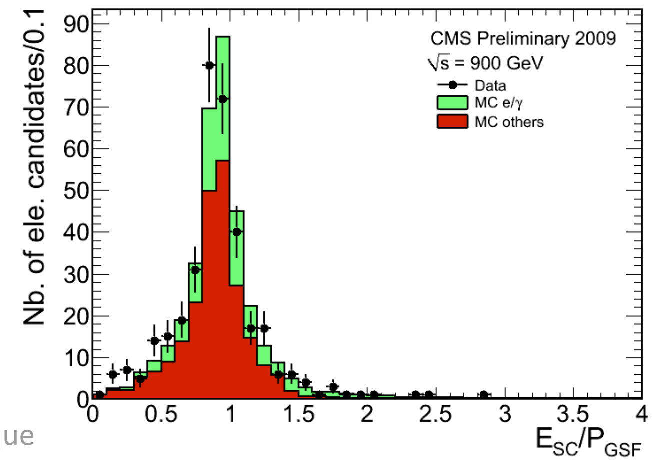


First electrons in CMS

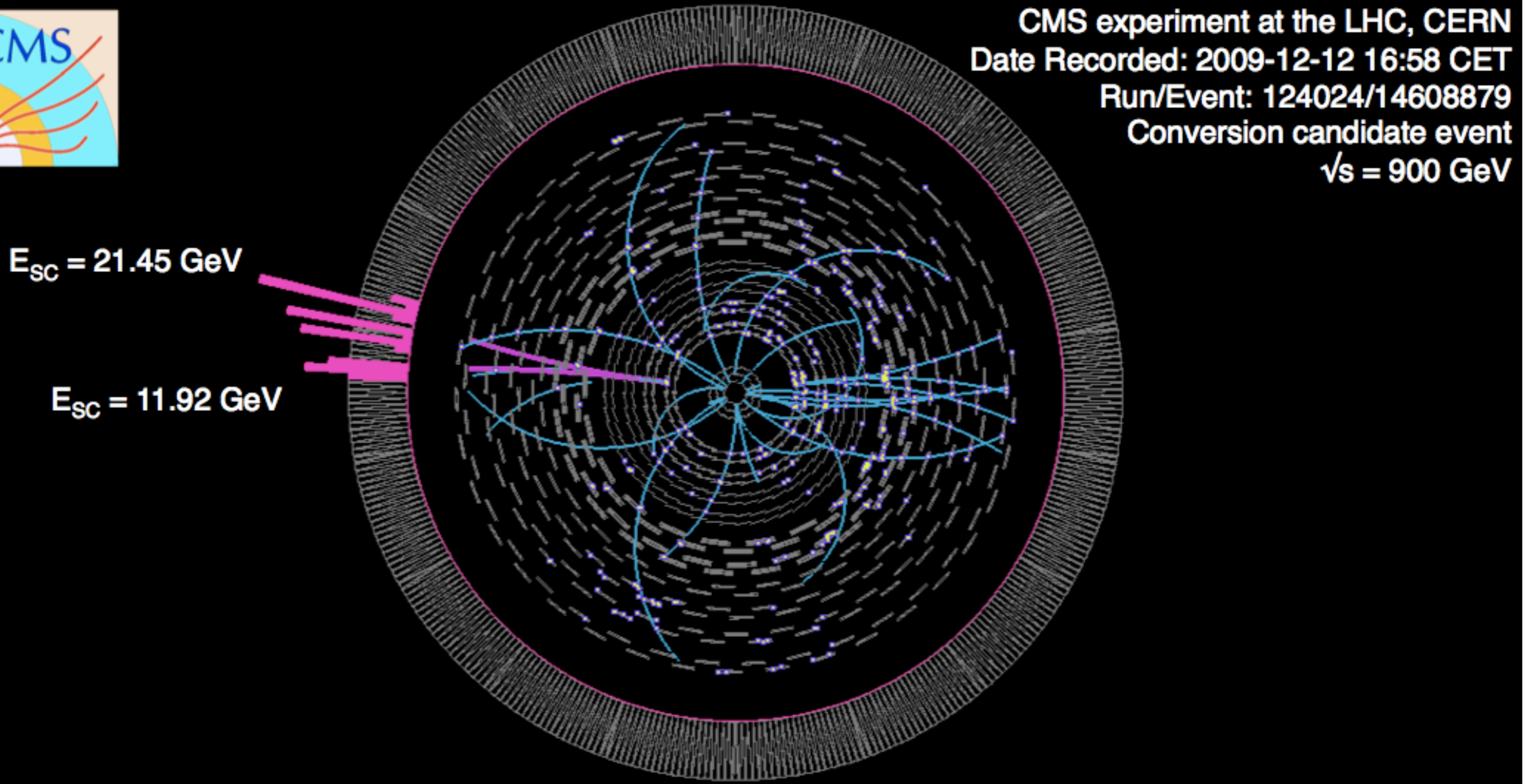
2009 collisions at 900 GeV

- 351 electron candidates reconstructed on minimum bias events
  - Very good data-MC agreement
  - No tuning done on the MC

  ⇒ Very good modeling of the detector
  - Also a very good ECAL-tracker agreement



First dielectrons in CMS: 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.

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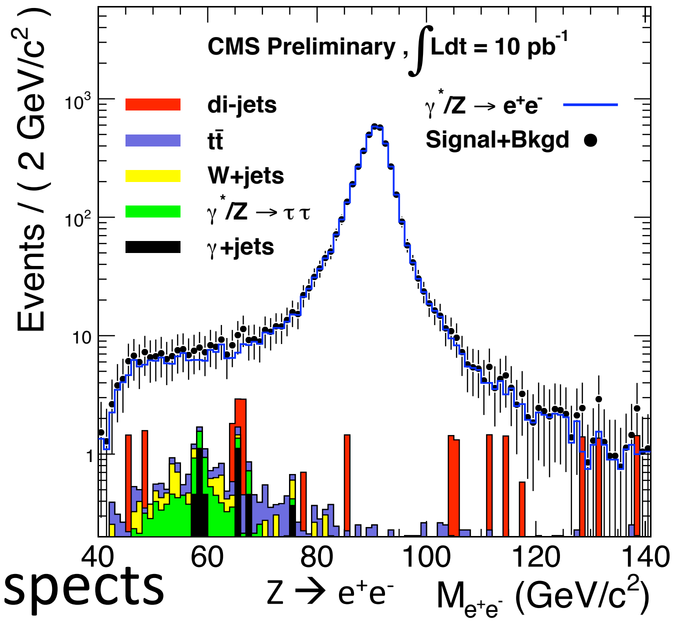
What comes next…

Lepton and dilepton studies

- Electron studies *(next months)* *Using $Z \rightarrow e^+e^-$ events*
  - Reconstruction efficiency (esp. at low p_T)
  - ID and isolation parameters, charge mis-ID, …
- Z boson analysis *(~2010)*
  - Very clean channel
    - Normalization of ZZ continuum
      Irreducible background
      for $H \rightarrow ZZ \rightarrow 4\ell$ analysis
    - Low p_T^e and efficiency are not key aspects
      crucial for Higgs analysis



$Z \rightarrow e^+e^-$
10 TeV, 10 pb^{-1}
Invariant mass (M_{ee})

3 to 4 leptons

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Study of the main Higgs backgrounds *(~2011)*

- W+jets, Z+jets, …

- WZ

  Importance of background subtraction

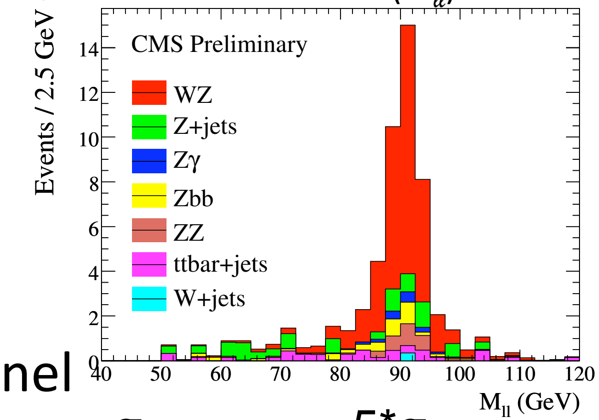
  ≠ Higgs analysis: will need to allow off-shell Z bosons

- Zbb

- ZZ

  May coincide with a discovery in the $H \rightarrow ZZ^{(*)}$ channel

$WZ \rightarrow \ell\nu\ell\ell$ (ℓ=e or μ)
14 TeV, 300 pb^{-1}
Z^0 mass ($M_{\ell\ell}$)



$\sigma_{LHC,\ 7TeV} \sim 5^{*}\sigma_{Tevatron}$

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… and finally the Higgs

$H \rightarrow ZZ \rightarrow 4\ell$ analysis

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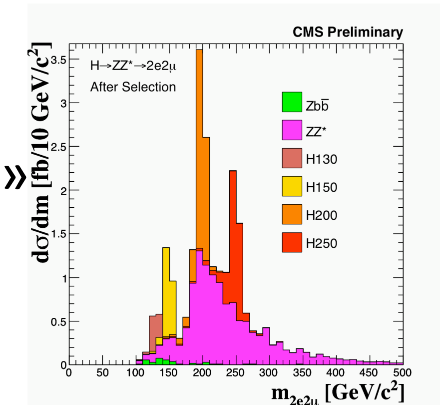
Counting experiment in a sliding 4ℓ-mass window

- Preselection *(QCD, Z/W+jets)*
  - *at least* 2 pairs of opposite charge, matching flavour leptons
  - Lower cuts on p_T^{ℓ}, $m_{\ell+\ell-}$, $m_{4\ell}$; loose isolation
  - Identification of the « Z pair » and the « Z* pair » [exactly 4ℓ]
- Further selection *(Z+jets, $t\bar{t}$, Zbb)*
  - isolation, $p_T^{\ell\,lowest}$, impact parameter
  - Restrictions on the reconstructed «m_Z», «m_{Z*}»
- Systematics and control from data *(ZZ)*
  - Efficiency measurement with Z production
  - Normalization ZZ/Z
  - Control of isolation using random cones

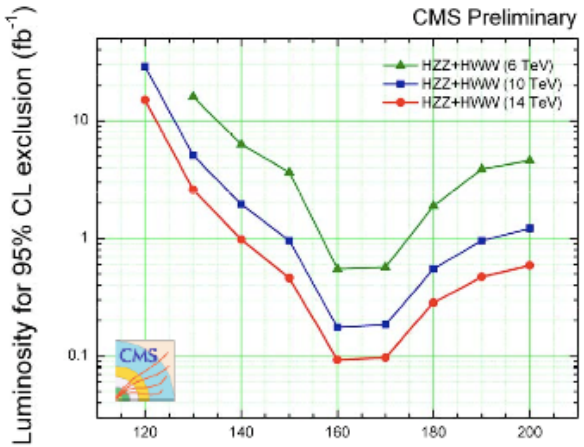


$H \rightarrow ZZ \rightarrow 4\ell$ (ℓ=e or μ)
14 TeV, 1 fb^{-1}
Higgs mass ($M_{4\ell}$)

Possible expectations for end 2011

7 TeV, ~ 1 fb^{-1} estimate

- Need a combination of H → WW and H → ZZ analyses
  - SM expected exclusion range: ~ 155-180 GeV
  - In case of a 4^{th} fermion generation: up to ~ 500 GeV



At higher energy or luminosity
H → ZZ analysis will be our guide to M_H > 180 GeV
=> Region not to be explored by TeVatron

Conclusion

Conclusion

- A good understanding of the detector and reconstruction from the Minimum Bias data
- A long way to go through before Higgs itself
- Main steps identified and expected
- LHC restart tomorrow, 7 TeV:

  good perspectives

Back-up Slides

Higgs boson mass range

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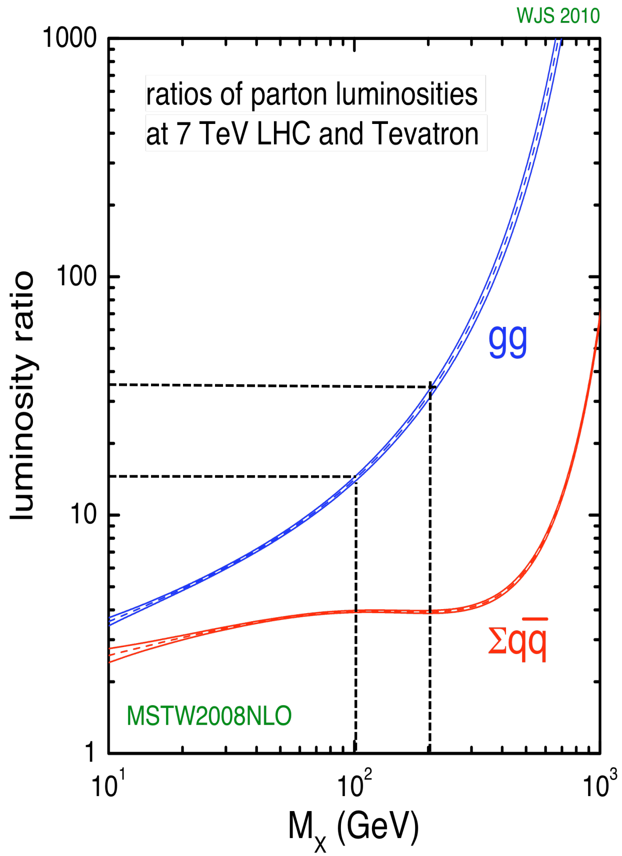

For 100 GeV < M_H < 200 GeV,
$\sigma_{LHC,\ 7TeV} \sim (\ 20 \text{ to } 30) * \sigma_{TeVatron}$

First electrons in CMS

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2009 collisions at 900 GeV

CMS: 351 electron candidates reconstructed after preselection

185 330 events after run selection (BX, BSC, vertex, HF, track purity)

MC composition:

- 66.1 %: fakes from hadrons
- 29.3 %: real electrons from conversions
- 4.6 %: real, prompt electrons

$\Rightarrow$ ~ 16 real prompt electrons

Atlas: 879 electron candidates reconstructed before ID cuts

384 186 events after run selection (BX/BPTX-like/good quality)

MC composition:

- ~ 66 %: background fakes
- ~ 33 %: real electrons from conversions
- < 1%: prompt electrons

$\Rightarrow$ $\lesssim$ 9 real prompt electrons

First electrons in CMS

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2009 collisions at 900 GeV

CMS: 351 electron candidates reconstructed on minimum bias events

MC composition:

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Atlas: 879 electron candidates reconstructed before ID cuts

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$\Rightarrow \lesssim$ 9 real prompt electrons

Comparison of 2 analyses

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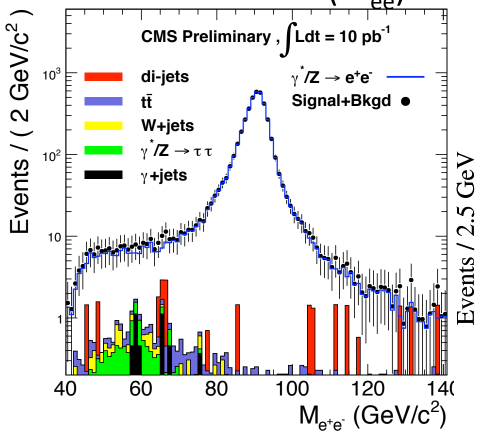
$Z \rightarrow e^+e^-$

- 2e, $p_T^e > 20$ GeV
- Simple iso, ID cuts
- Invariant mass constraint

$Z \rightarrow e^+e^-$
10 TeV, 10 pb^{-1}
Invariant mass (M_{ee})

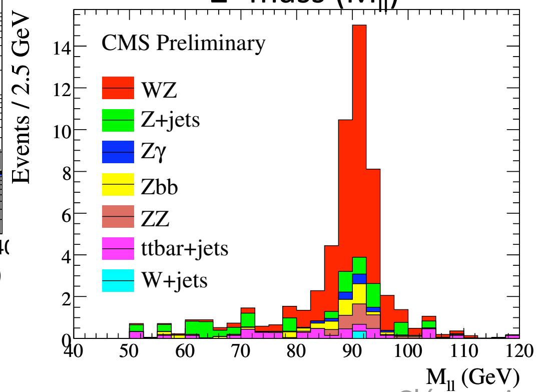


$WZ \rightarrow \ell\nu\ell\ell$ *(Z+jets, ZZ, Zγ)*

- 3ℓ, $p_T^\ell > 15$ GeV
- Z candidate:

  2ℓ same flavour, opp. charge
  - loose (normalized) iso, ID cuts
  - Invariant mass constraint
  - Remove events with 2 Z candidates
- W candidate: 3^{rd} ℓ, missing E_T
  - $p_T^\ell > 20$ GeV, tight ID, iso
  - $M_T(W) > 50$ GeV
- Background estimate

$WZ \rightarrow \ell\nu\ell\ell$ (ℓ=e or μ)
14 TeV, 300 pb^{-1}
Z^0 mass (M_{ll})



$H \rightarrow ZZ \rightarrow 4\ell$ analysis

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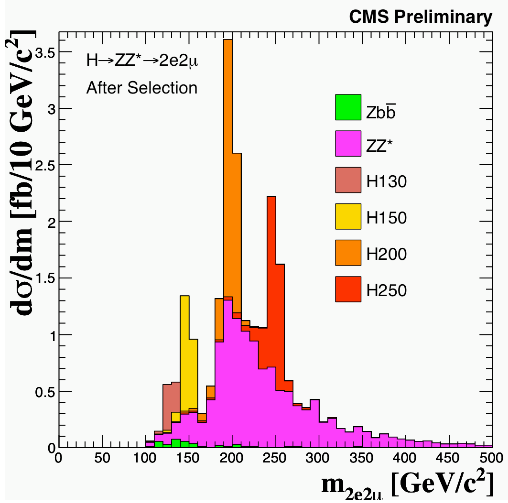
Counting experiment in a sliding 4ℓ-mass window

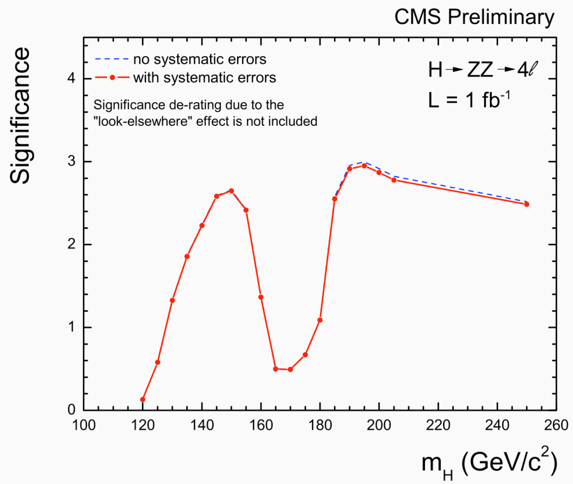
14 TeV

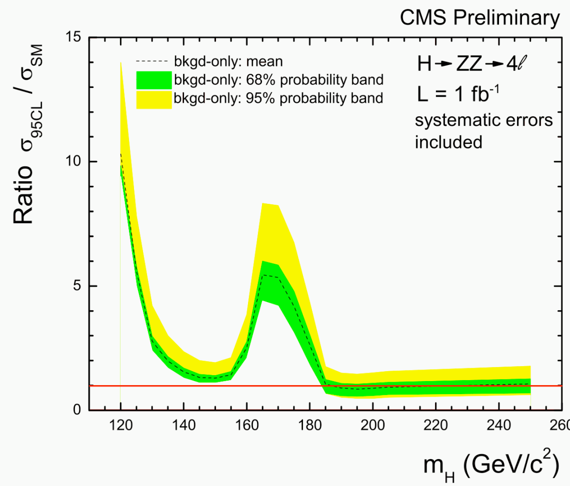
1 fb^{-1}

look-elsewhere effects

need to substract ~ 1σ in the significance







Not enough luminosity
for a discovery

~ exclusion for $M_H \gtrsim 185$ GeV

H → ZZ → 4ℓ analysis

Counting experiment in a sliding 4ℓ-mass window

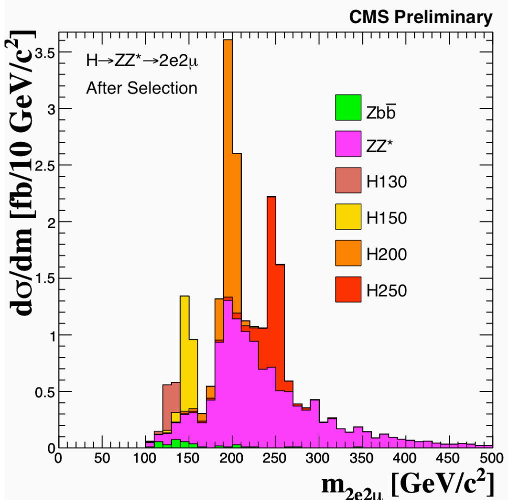
14 TeV

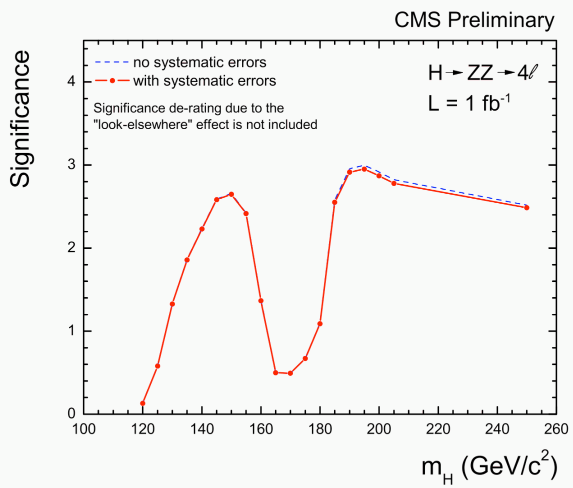
1 fb^{-1}

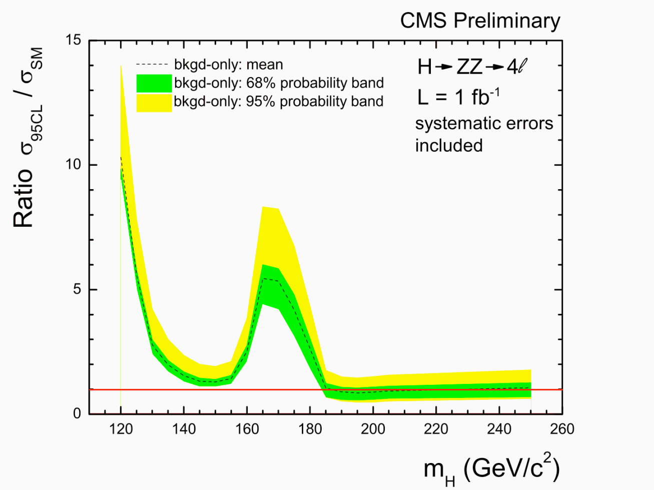
look-elsewhere effects

need to substract ~ 1σ in the significance

No results for this mass range at TeVatron
=> LHC results will be the first!







Not enough luminosity for a discovery

~ exclusion for $M_H \gtrsim 185$ GeV

On the road to $H \rightarrow ZZ \rightarrow 4\ell$

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Spring-summer 2010

- Leptons & Dileptons
  - electrons, muons
  - $Z \rightarrow e^+e^-$
    $p_T^e > 20$ GeV

- Commissioning, efficiency up to low p_T
- Extrapolation of ZZ continuum (irreducible Higgs background)

- 3 and more leptons
  - W/Z + Jets, Zb
  - WW, WZ

- First trilepton events
- Background removal

2011

- Zbb
- ZZ
- Higgs!

- First quadrilepton events
  Higgs main backgrounds
- Very interesting time!

Higgs boson production

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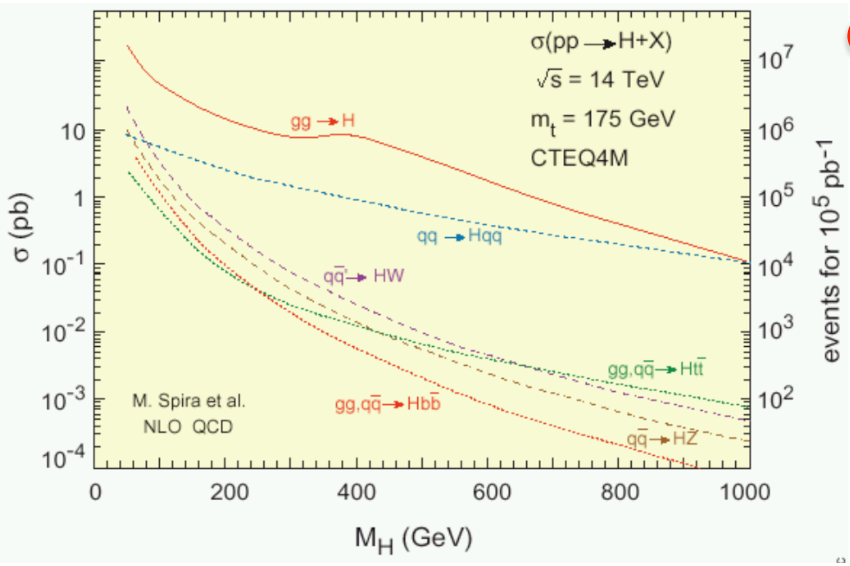
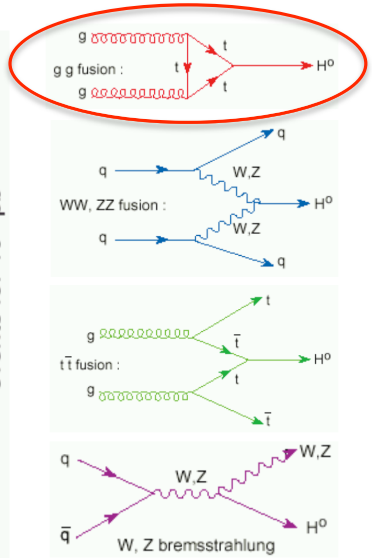
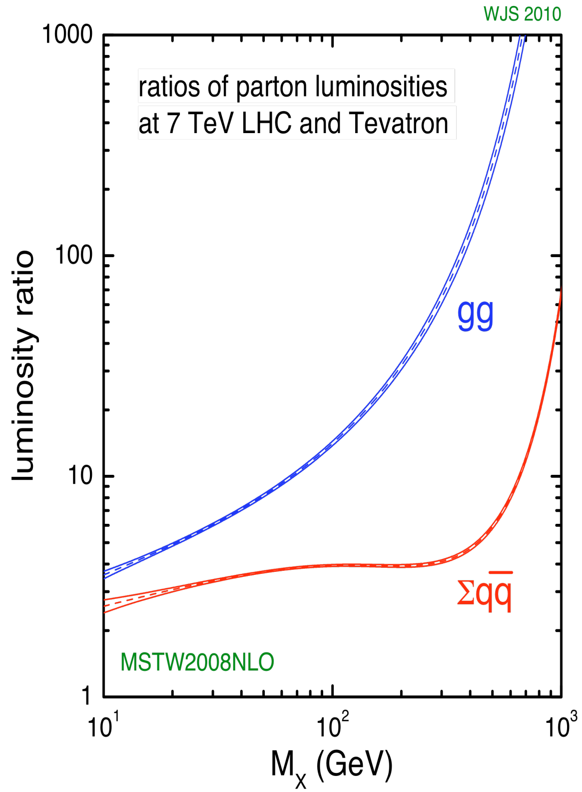
Inclusive production

- Mainly gg fusion

For 100 GeV < M_H < 200 GeV,
LHC@7TeV expected cross section is
~ 20-30 times higher than at TeVatron







A. Djouadi

Possible expectations for end 2011

7 TeV, ~ 1 fb^{-1} estimate

Personal estimate: projection for 7 TeV, 1 fb^{-1}