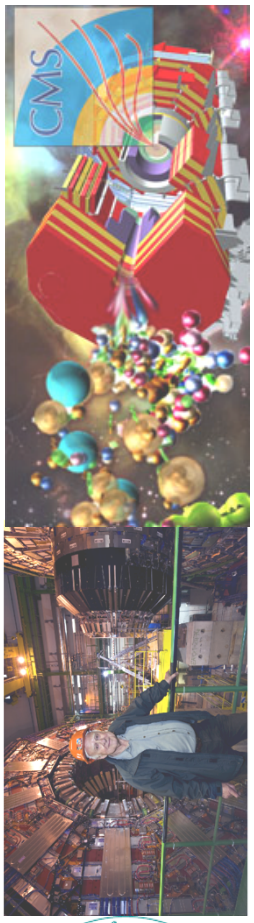

Multi-lepton physics in search for the Higgs boson

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Outline:

- Strategy for multi-lepton searches
- H→ZZ and H→WW searches results at 10/7 TeV
- Multi-lepton validation with 900 GeV data
- H→ZZ plans for ICHEP 2010

Strategy for multi-lepton searches in 2010

Main concepts:

- Real data taken in 2009 useful to start the physics object reconstruction validation
- Data going to be taken in 2010 will be used for reco. validation and physics
- Data driven techniques to be enforced and validated with real data
- Moving from single lepton to di-leptons (Z→ll) to multi-lepton (WW, ZZ, WZ) final state

  → a **"MULTI-LEPTON TASK FORCE"** going to be created

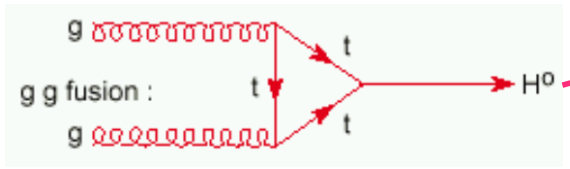
What we expect according to the lumi and √s:

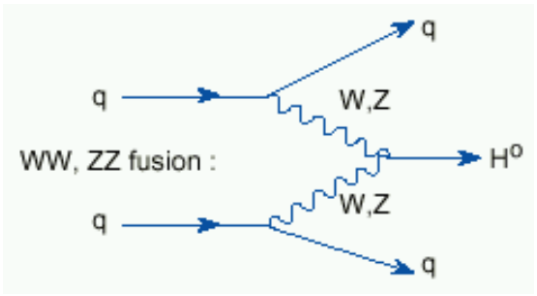
- O(0.1 pb^{-1}) → "MinBias" region, "Single-lepton" reco validation
- O(1 pb^{-1}) → "Jet" and "Single-lepton" validation in the full p_T spectrum
- O(10 pb^{-1}) → "Di-lepton" reconstruction and validation (3k Z→ee, Z→μμ)
- O(100 pb^{-1}) → "Di-boson" region; multi-lepton reconstruction
- O(500 pb^{-1}) at 7 TeV ≈ 200 pb^{-1} at 10 TeV → Higgs searches

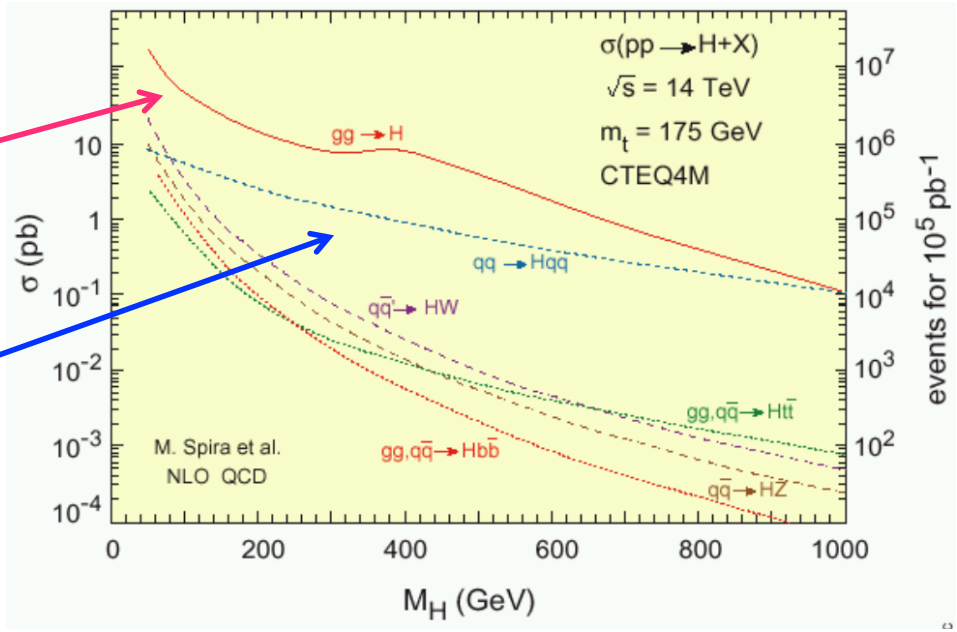
SM H→ZZ→4l (and H→WW→ lνlν) searches at 10/7 TeV

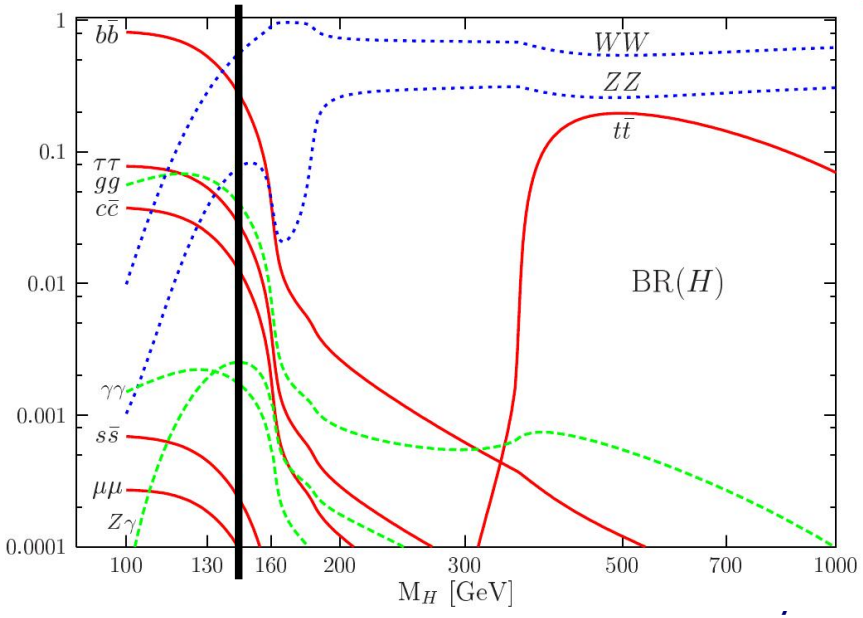
SM Higgs production at LHC

- Dominant Production Modes:









m_H <135 GeV:

$$H \to b\bar{b}/c\bar{c}/gg$$

$$H \to \gamma\gamma$$

$$H \to \tau^+\tau^-$$

Dominant decays but Multi-jets background too high…

m_H >135 GeV:

$$H \to W^+W^-$$

$$H \to ZZ^*$$

Exploit leptonic decays of W/Z (for trigger purpose)

SM H→ZZ→4l: basic concepts

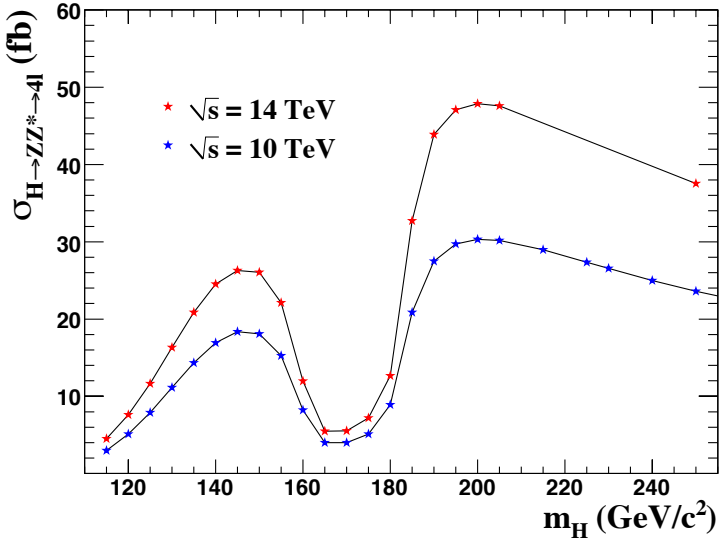
- Signatures: **4e,4mu and 2e2mu** final state
- Backgrounds:
  - ZZ , Zbb, tt+jets, Z+jets, W+jets, QCD

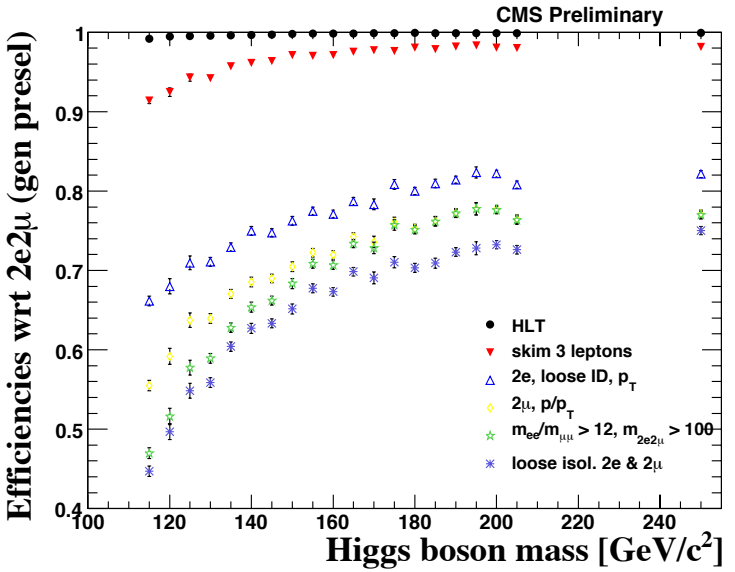
- Preselection strategy: (to get rid of QCD bkg with fake leptons)
  - Single & double lepton triggers
  - loose isolation on leptons opp. charge and ele Id
  - di-lepton and 4l-lepton invariant mass cuts

- Main selection:
  - tight isolation on leptons (against tt, Zbb)
  - impact parameter constraint (against tt, Zbb)
  - m_Z and m_{Z^*} constraint

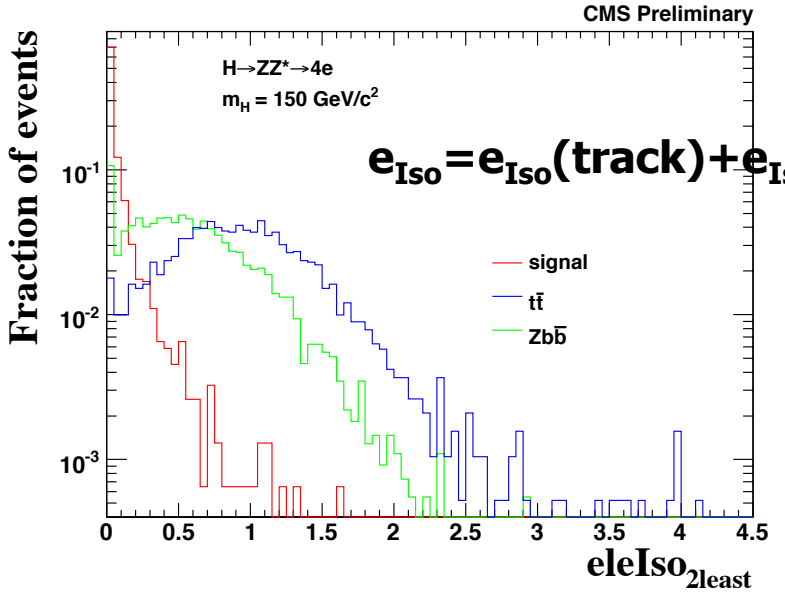
- Control from real data of
  - the lepton-related efficiencies
  - the rate of ZZ and Zbb bkg

→ **Baseline cut-based analysis, m_H-independent, able to get rid of main bkg**

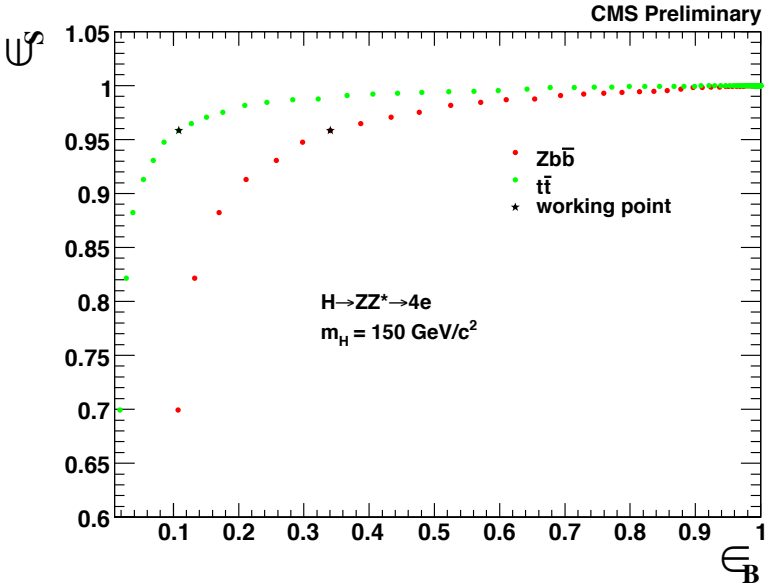


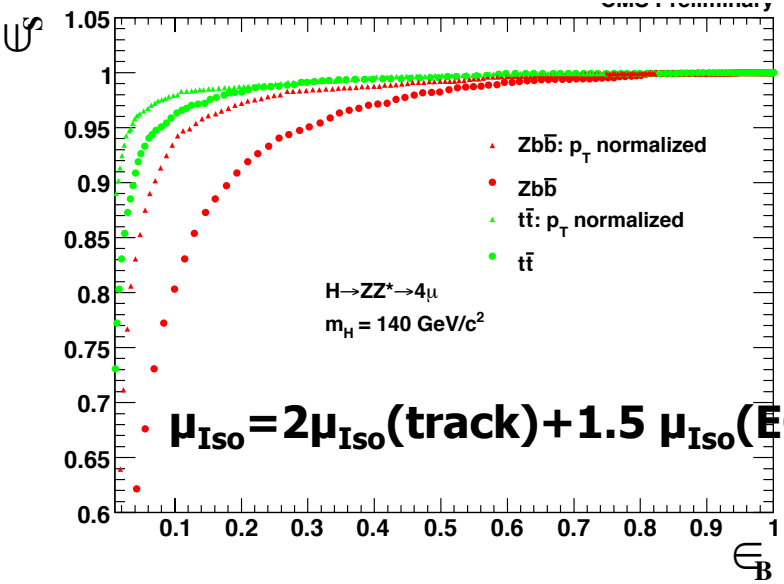


Observables: isolation

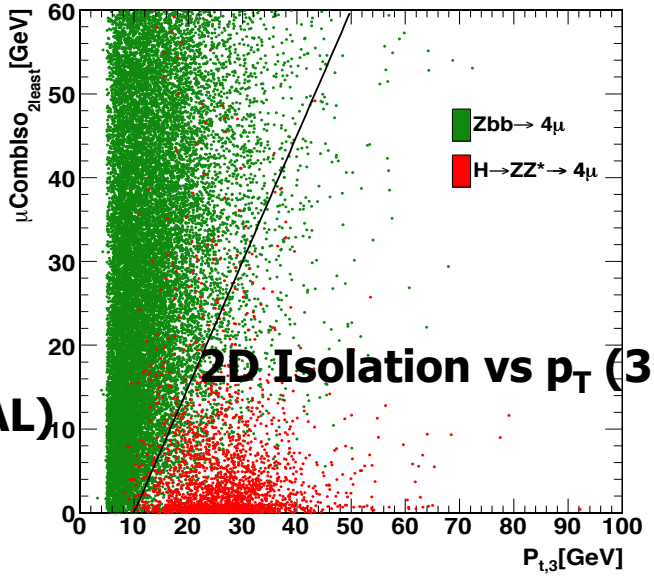


$e_{Iso}=e_{Iso}(track)+e_{Iso}(HCAL)$



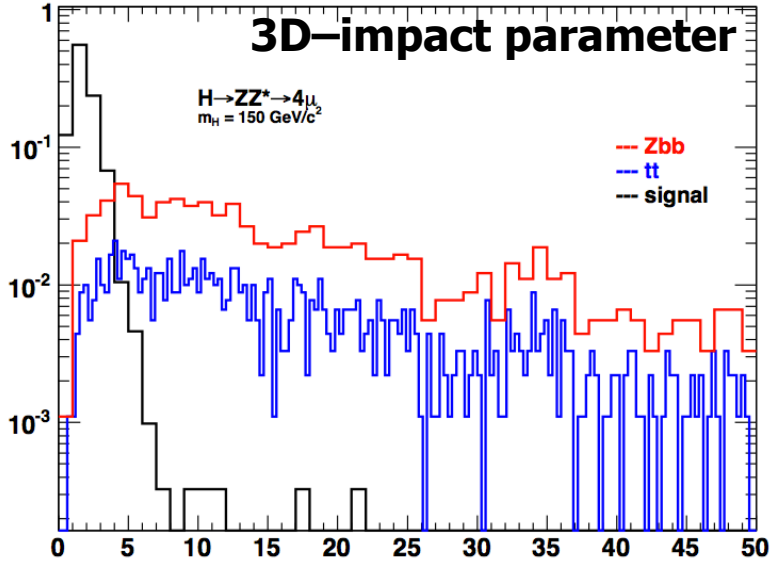


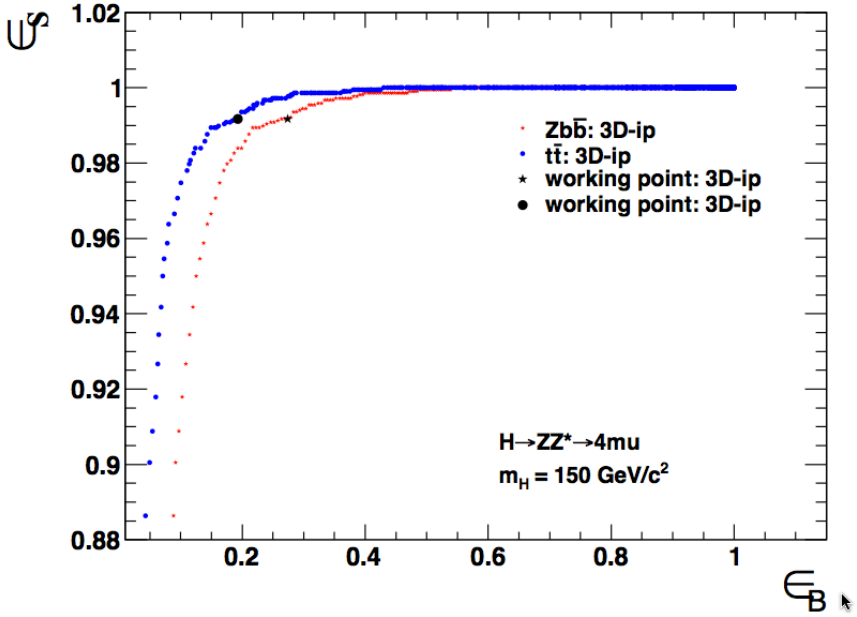
$\mu_{Iso}=2\mu_{Iso}(track)+1.5\ \mu_{Iso}(ECAL)+\mu_{Iso}(HCAL)$

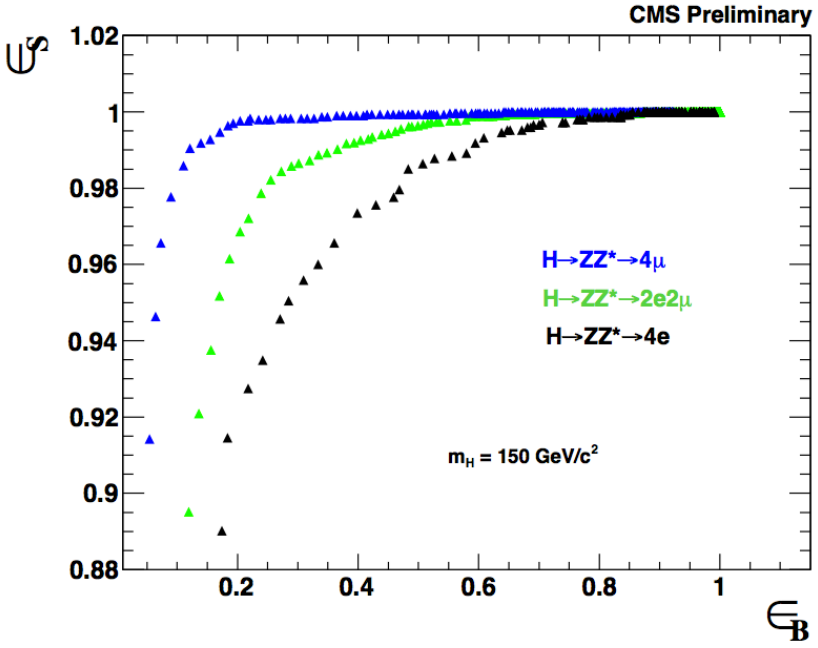


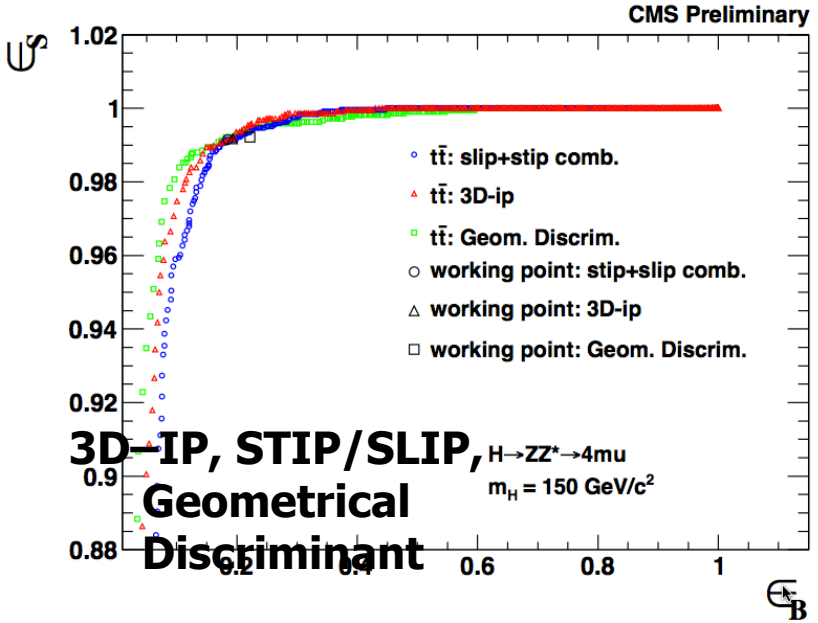
2D Isolation vs p_T (3^{rd})

Observables: impact parameter





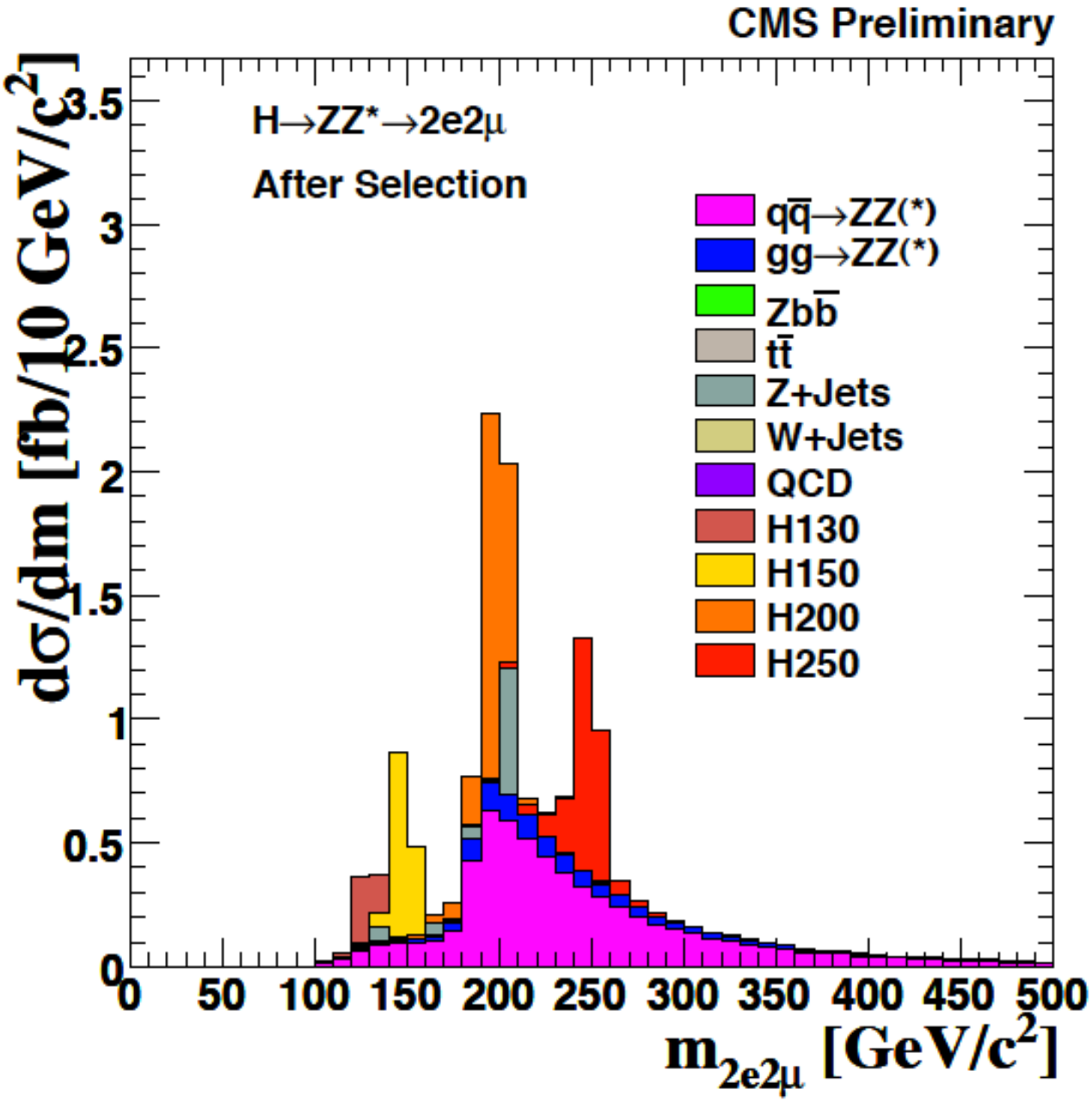


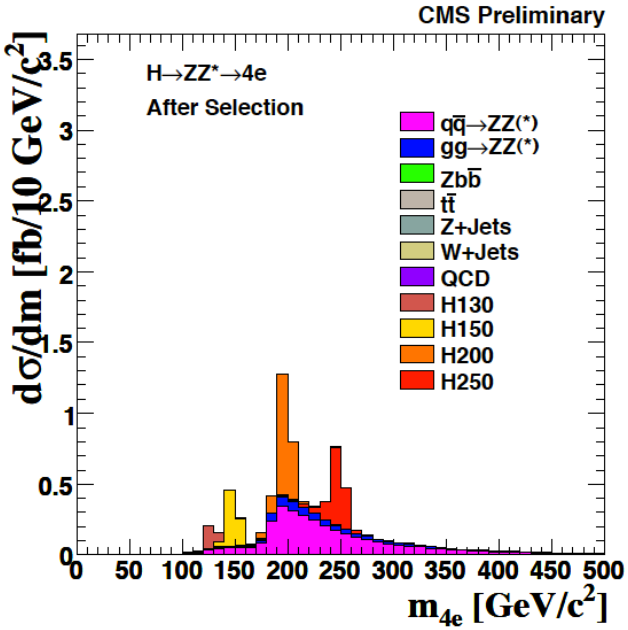


3D–IP, STIP/SLIP, Geometrical Discriminant

multi-leptor
:s at LHC, Li

Results: m_{4l}


CMS Preliminary
H→ZZ*→2e2μ
After Selection
qq̄→ZZ(*)
gg→ZZ(*)
Zbb̄
tt̄
Z+Jets
W+Jets
QCD
H130
H150
H200
H250
dσ/dm [fb/10 GeV/c²]
m2e2μ [GeV/c²]


CMS Preliminary
H→ZZ*→4e
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qq̄→ZZ(*)
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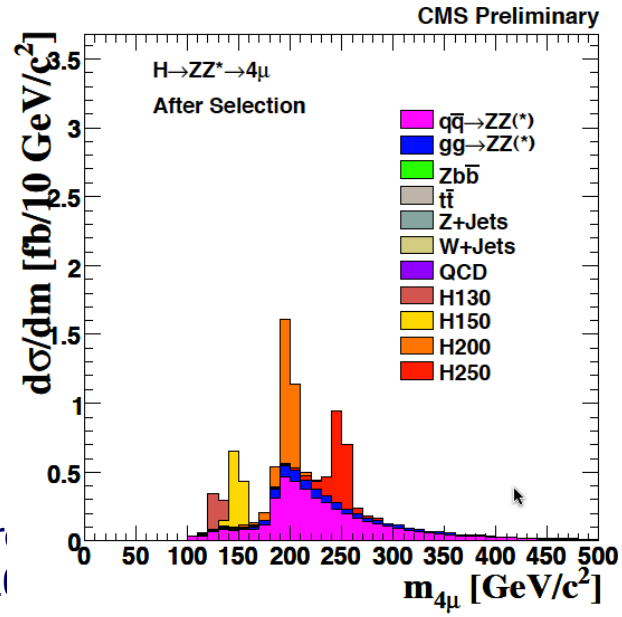
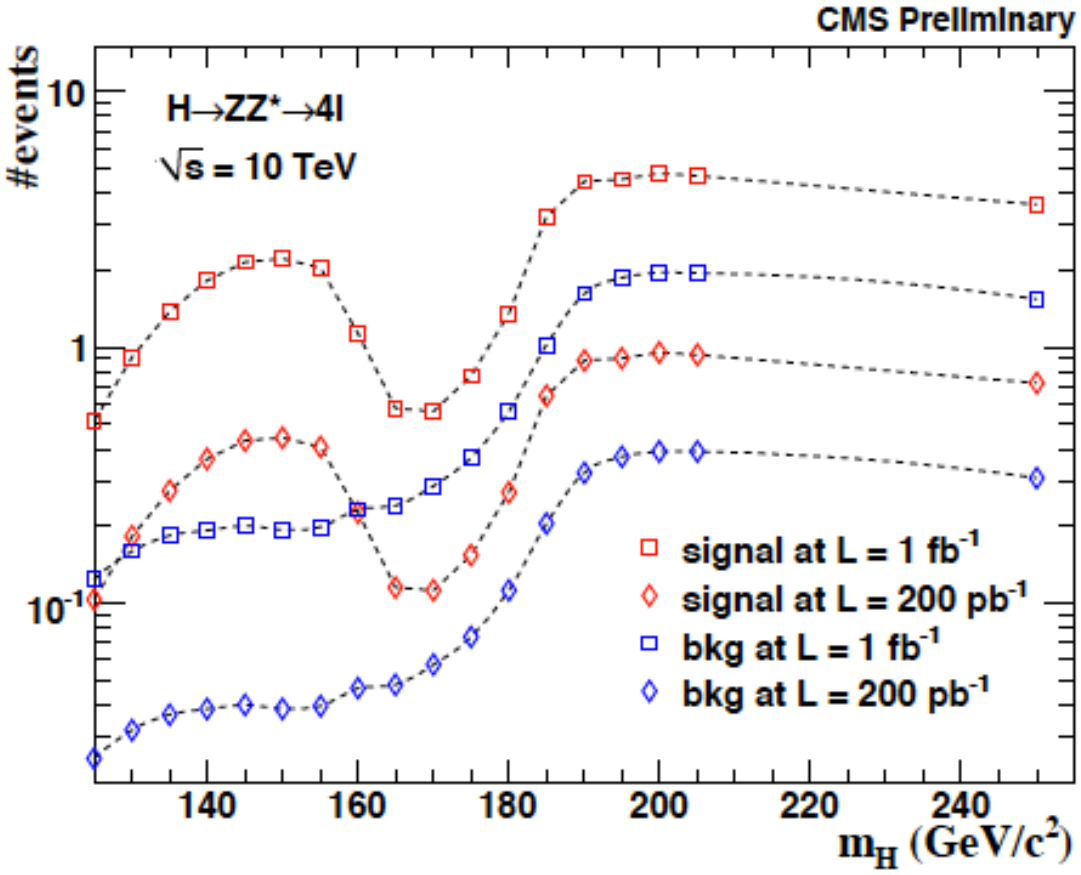
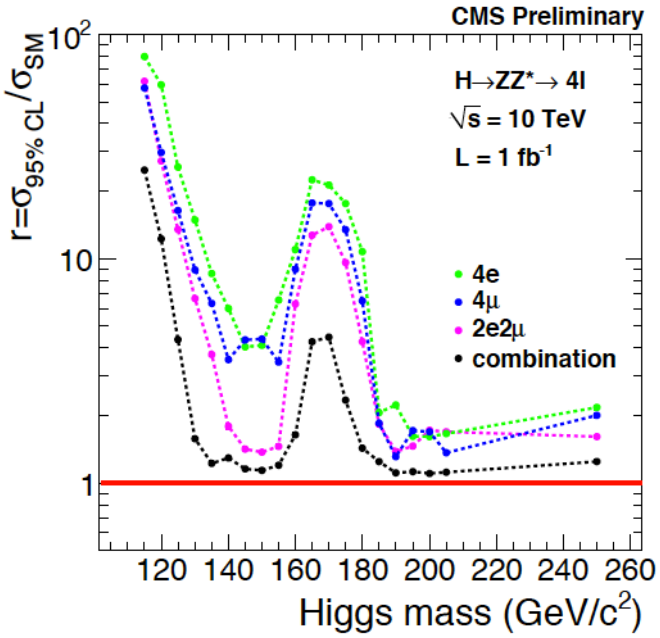
H200
H250
dσ/dm [fb/10 GeV/c²]
m4e [GeV/c²]

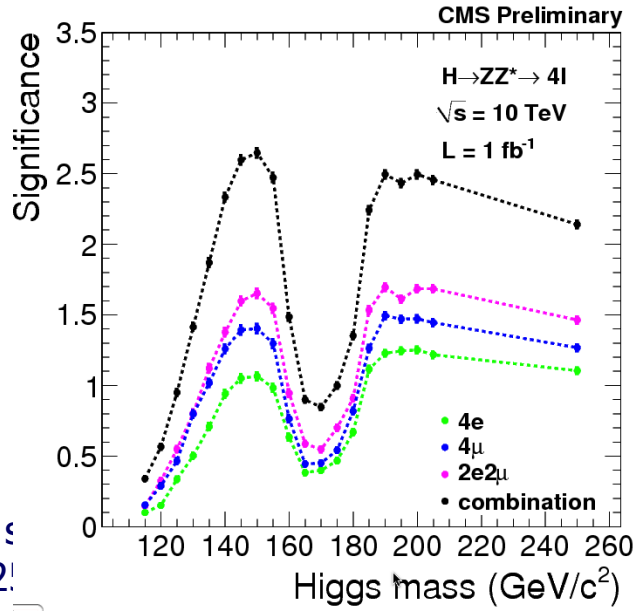

CMS Preliminary
H→ZZ*→4μ
After Selection
qq̄→ZZ(*)
gg→ZZ(*)
Zbb̄
tt̄
Z+Jets
W+Jets
QCD
H130
H150
H200
H250
dσ/dm [fb/10 GeV/c²]
m4μ [GeV/c²]

Results: counting experiment

- Events counted in a window: $\mathbf{m_{4l} \pm 2\sigma_{m4l}}$
- m_{4l} is taken from a Gaussian fit to the signal distribution for each given m_H hypothesis







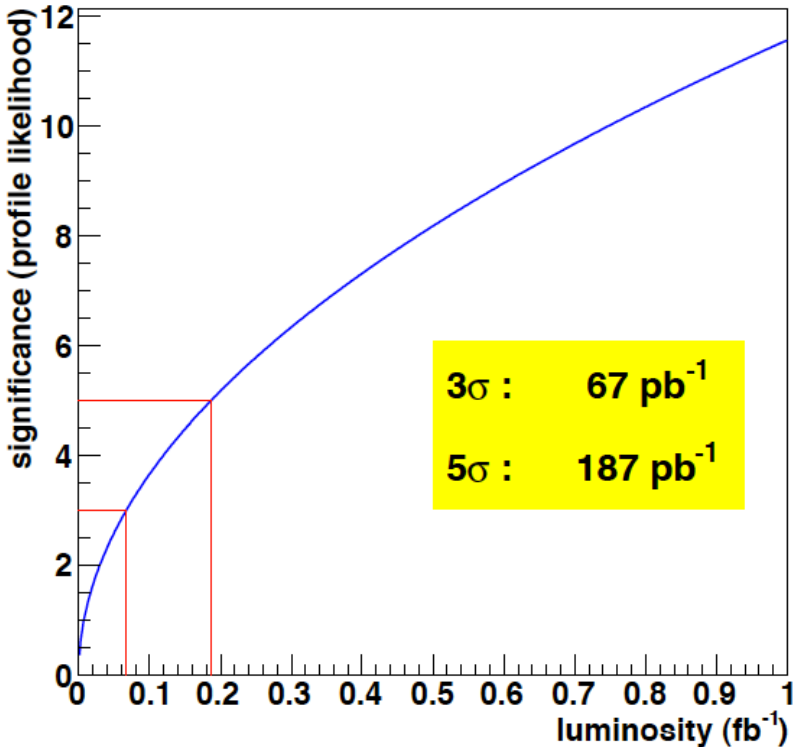
Control of background from data

ZZ measurement from data

Purpose: determination of the mean expected number of ZZ bkg events in the signal region (defined e.g. by a simple sliding window in the m_{4l} spectrum)

Selection:

- $80 < M_{Z1} < 100$ GeV
- $70 < M_{Z2} < 110$ GeV
- HZZ preselection cuts



1 fb^{-1}	4μ	4e	$2e2\mu$	Total
ZZ	4.696 ± 0.025	3.413 ± 0.017	8.178 ± 0.029	16.287 ± 0.042
$Zb\bar{b}$	0.006 ± 0.002	0.003 ± 0.001	0.015 ± 0.003	0.024 ± 0.004
$t\bar{t}$	$0. \pm 0.0044$	$0. \pm 0.0044$	0.040 ± 0.013	0.040 ± 0.013
$Z + jets$	$0.$	0.010 ± 0.006	0.109 ± 0.066	0.119 ± 0.066

ZZ extrapolation from data

Typical procedure consists of choosing a **control region** outside the signal phase space and then verifying that the events rate changes according to the expectations from MC:

$$N_{ZZ}^{predicted}(\Delta m) = \rho(m_H) \cdot N_{CR}^{measured}$$

$$\rho(m_H) = \frac{N_{ZZ}^{theory}(\Delta m) \cdot \varepsilon_{ZZ}}{N_{CR}^{theory} \cdot \varepsilon_{CR}} \leftarrow \text{From MC}$$

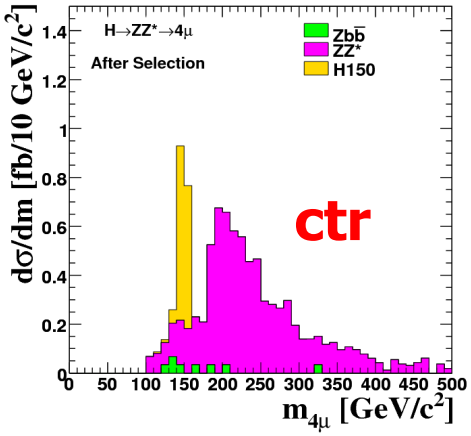
- Normalization to the **Z → ll** data:

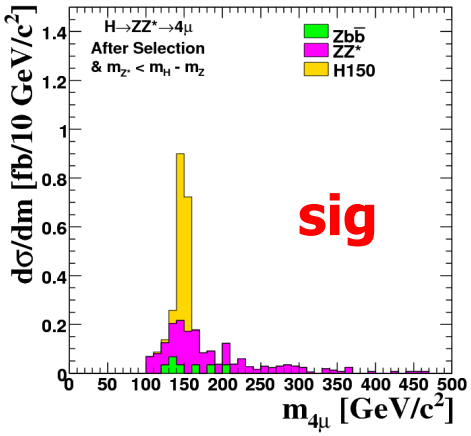
N_{ZZ}/N_Z: $R = \dfrac{(\sigma_{ZZ\to 4e} * \varepsilon_{4e} * \int Ldt)}{(\sigma_{Z\to 2e} * \varepsilon_{2e} * \int Ldt)}$

- Luminosity and (partially) reconstruction uncertainty cancellations
- **0.1 million Z→ee events at 200 pb^{-1}**
- **total uncertainty ≈ 0.3 %**

- Normalization to the **sidebands:**

- Luminosity and (totally) reconstruction uncertainty cancellations
- **4 ZZ→4l events at 200 pb^{-1}**
- **total uncertainty ≈ 58 %**





Zbb and tt control from data

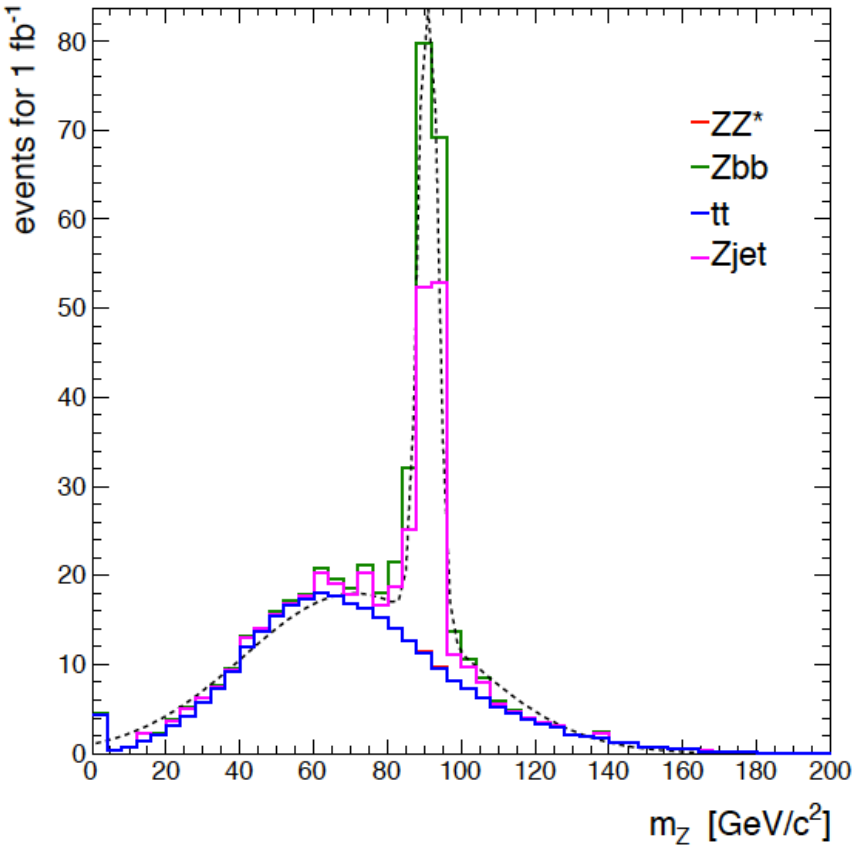
Particularly important for low higgs mass searches
Control region defined by:

- m_{4l} of any four lepton combinations > 100 GeV
- m_{Z^*} < 60 GeV in order to suppress the ZZ and Higgs signal contribution.
- 2D iso > 10 GeV (for muons)
- worst IP significance > 4

The signal and the ZZ background are fully absent in control region.

Best fit predicts: 1 fb^{-1} luminosity:

- tt = 380 ± 22 events
- Zbb + Z+jets = 160 ± 16 events

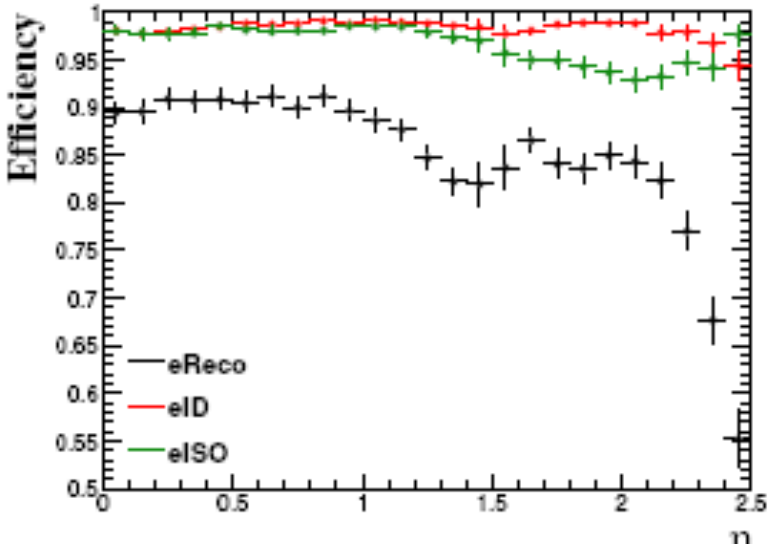


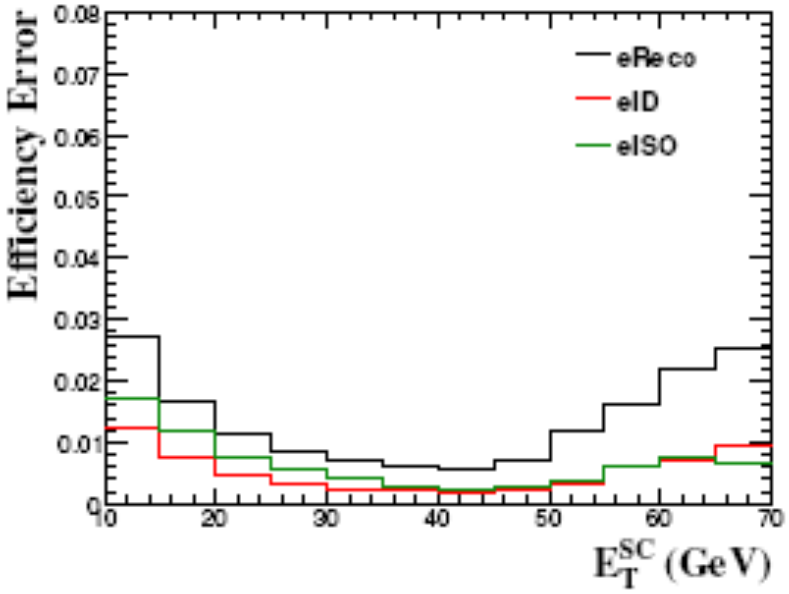
Control of efficiencies from data

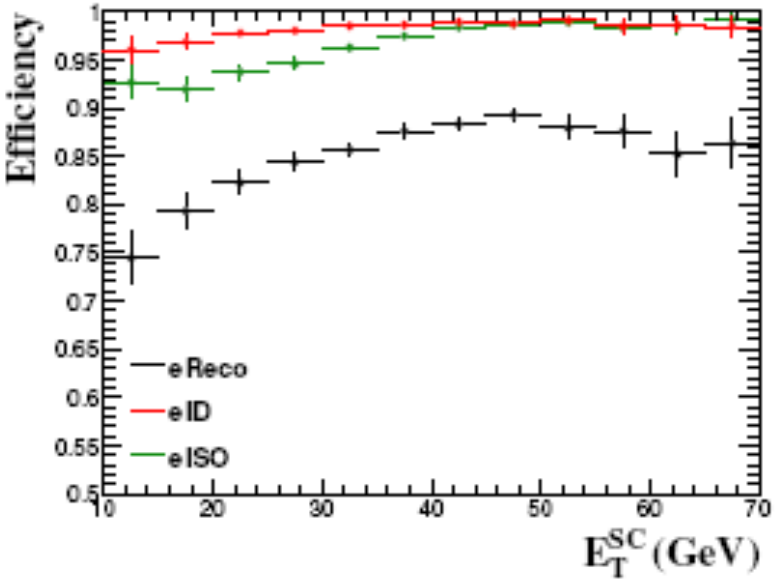
Electron efficiencies from data

Tag and probe method:

- $Z \rightarrow l^+l^-$ as high purity di-lepton sample
- **Tag**: lepton satisfying stingent ID
- **Probe**: other lepton constrained to the Z mass
- Probe is then used to evaulate the efficiency of a given selection or cut







→ **recontruction, ID, isolation eff can be measured after 100 pb^{-1} with uncertainty < 2.5%**

Isolation cut efficiency from data

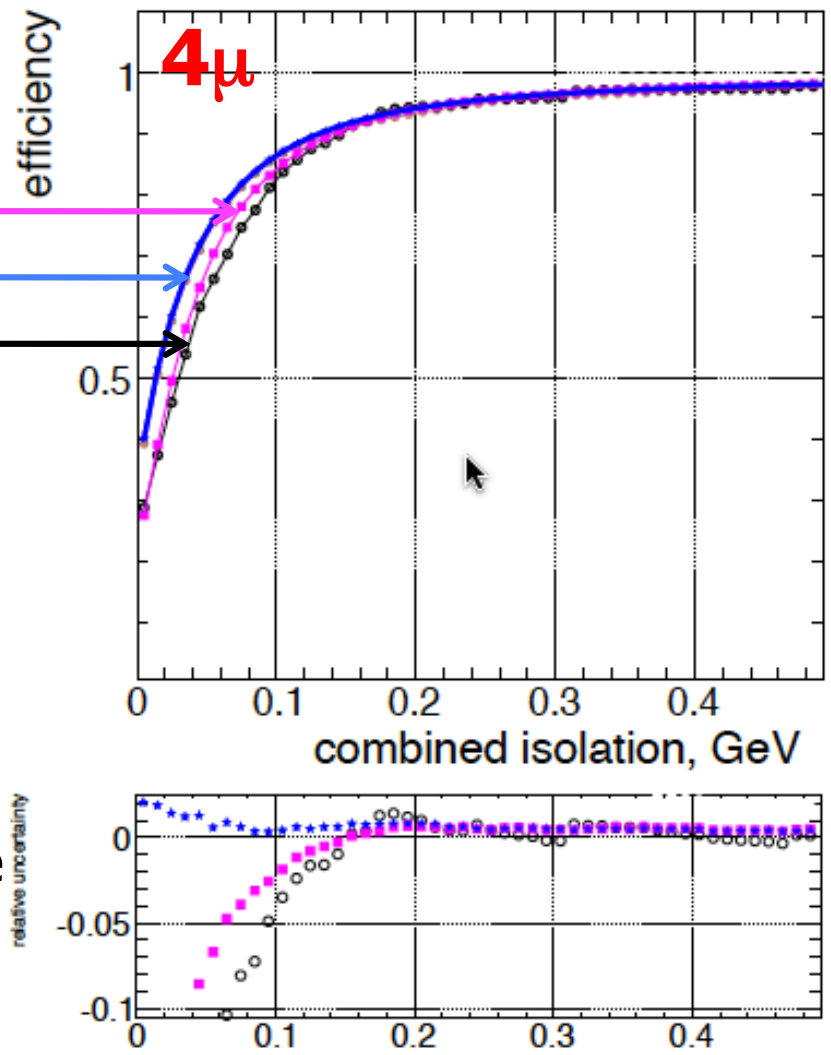
Strategy to measure the isolation cut efficiency from data by:

- random cone technique
- kinematical template method
- Tag & Probe

Control sample from data: **Z+jets**

HZZ requirements of isolation, invariant mass, identification, quality cuts on muons

The most precise prediction of the isolation cut efficiency comes from the kinematic templates method → **2%** error on efficiency

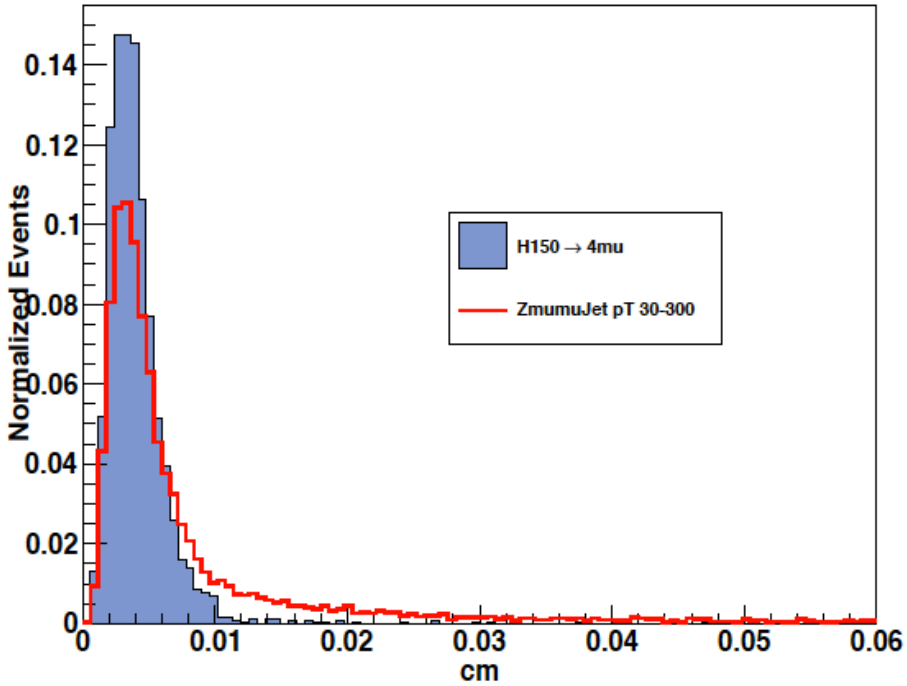


Vertexing efficiency from data

Control sample: Z+jets events with two muons from Z and two tracks

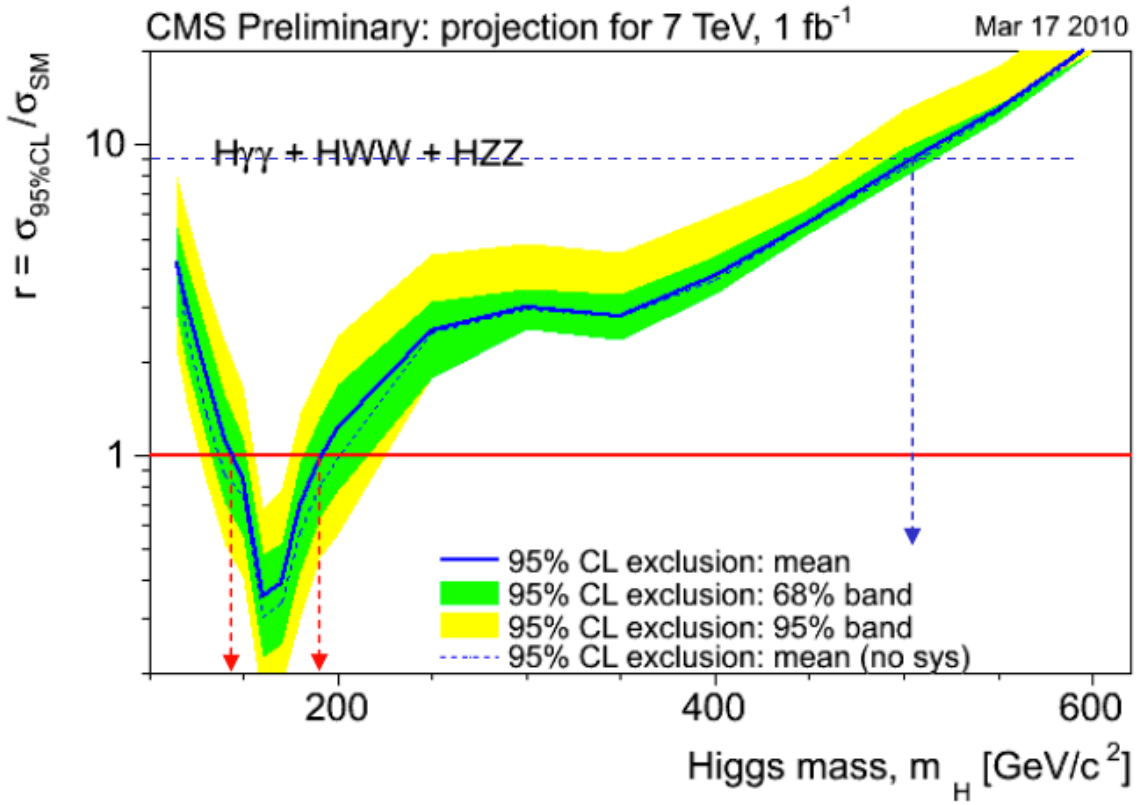
• **Signal vertexing efficiency:**
The distribution of the Geometrical discriminant from Z+jets similar to that for the four muons in the case of the Higgs signal events

→ similar cut efficiency ….vertexing cut efficiency for signal measured from data.



• **Background rejection efficiency** of the impact parameter–based algorithms evaluated tagging the jets by means of the "soft muon by p^{T}_{rel}" b-tagger algorithm foreseen for early real data (and not based on impact parameter info) → need to be evaluated yet

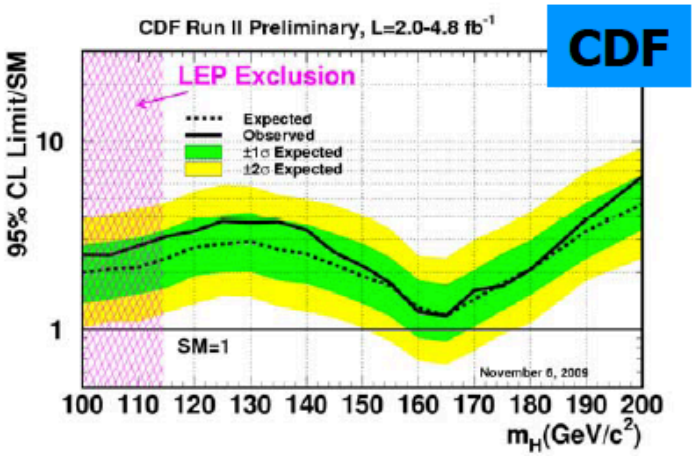
Projections at 7 TeV: HZZ + HWW + Hγγ

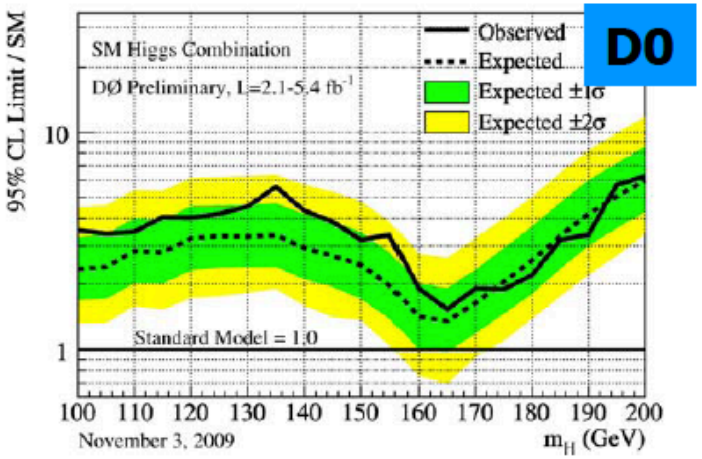


SM Higgs expected excluded range: **145-190 GeV**

SM Higgs with 4 generations — **up to 500 GeV**

TEVATRON

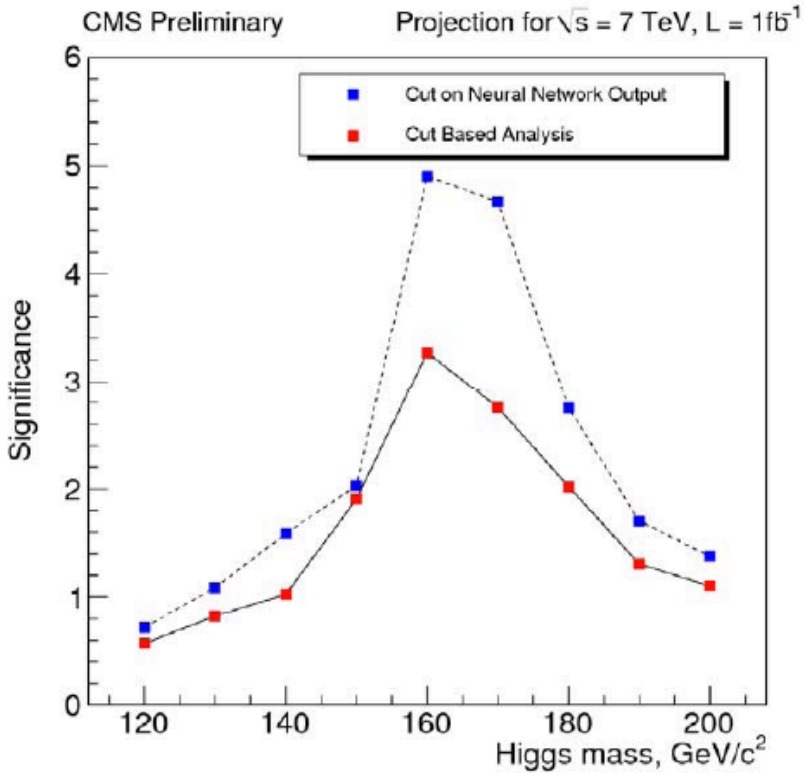


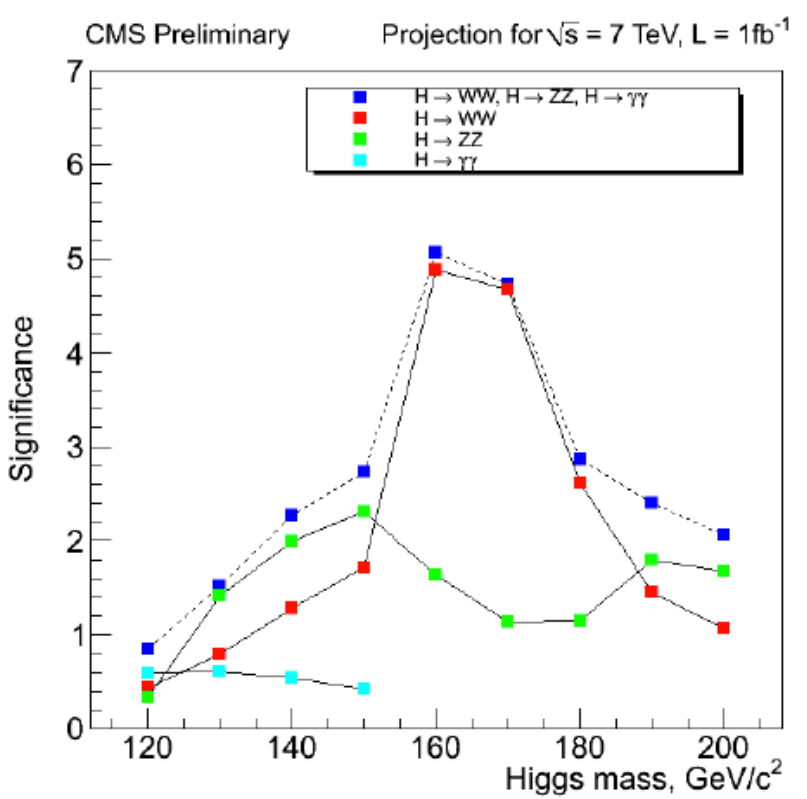


Projections at 7 TeV: HZZ + HWW + Hγγ

#6 HWW channel reaches a discovery level sensitivity for m_H=160-170 GeV

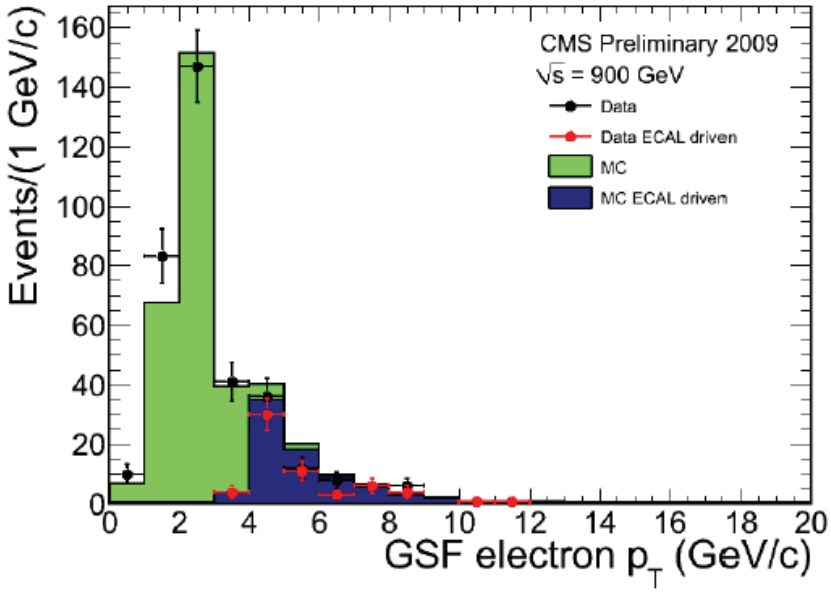
#7 Combining HWW+HZZ+Hγγ helps boost significance at the wings, but taking into account the look-elsewhere effect, very strong in Hγγ and HZZ, will largely wash out the apparent enhancement

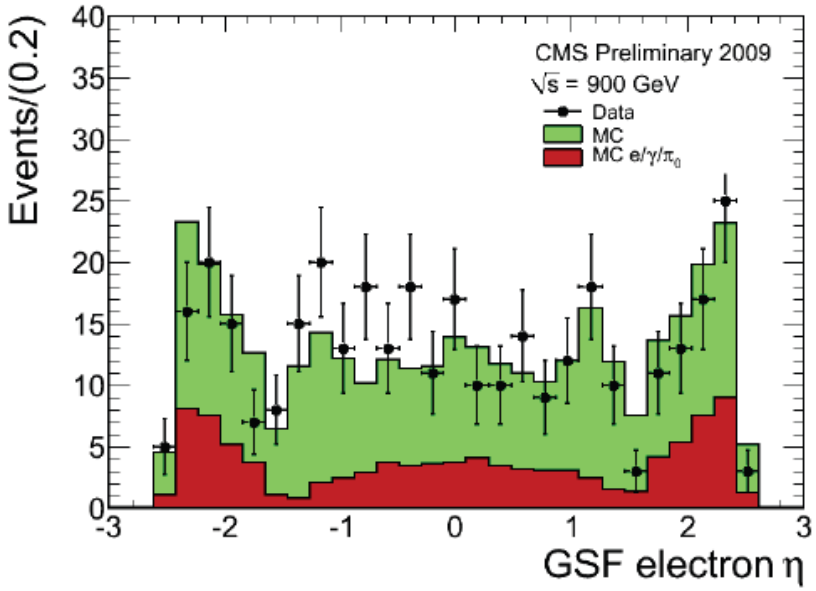


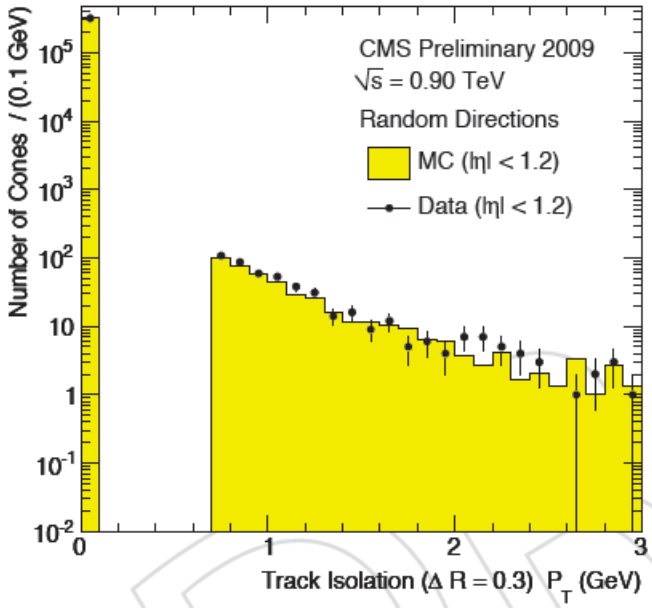


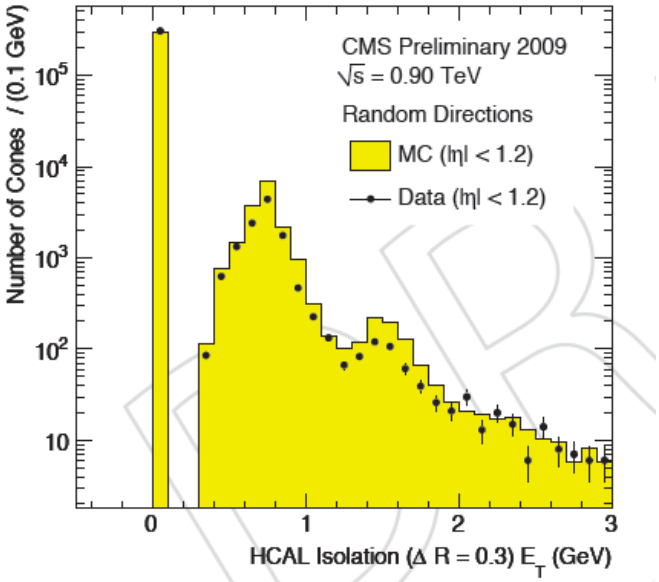
Multi-lepton validation with 900 GeV data

Electrons reco and isolation

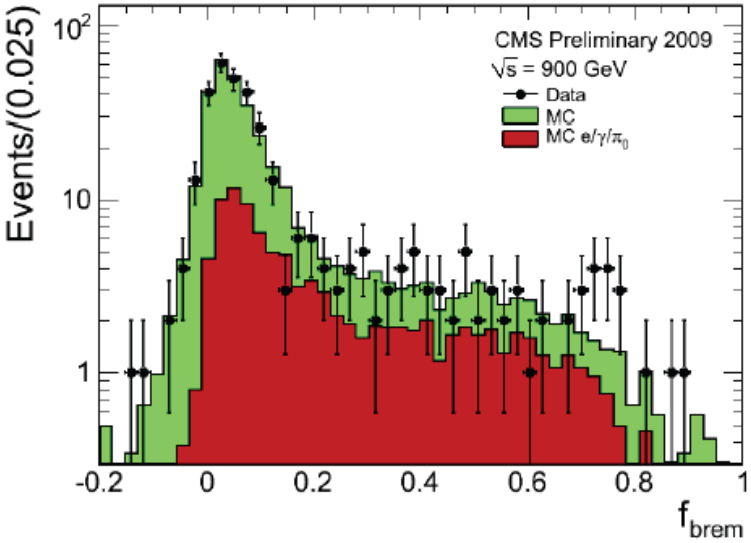


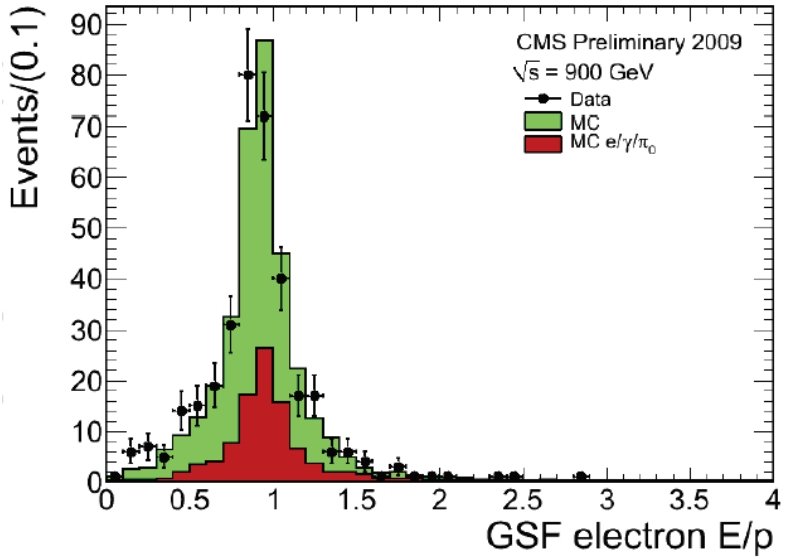




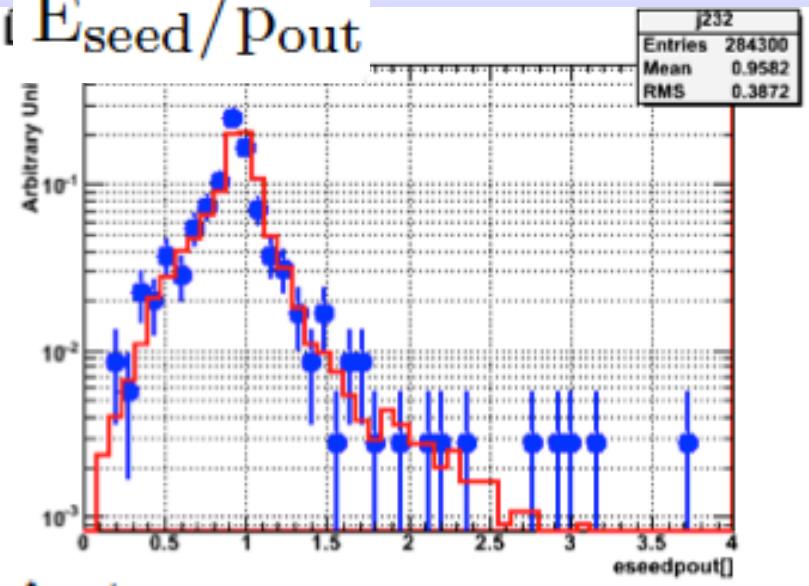


Electron classification and ID

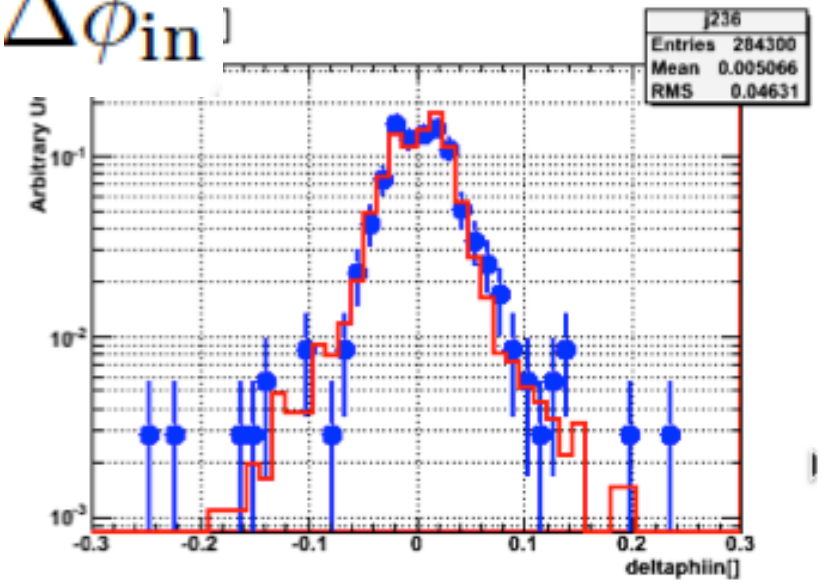




E_{seed}/p_{out}

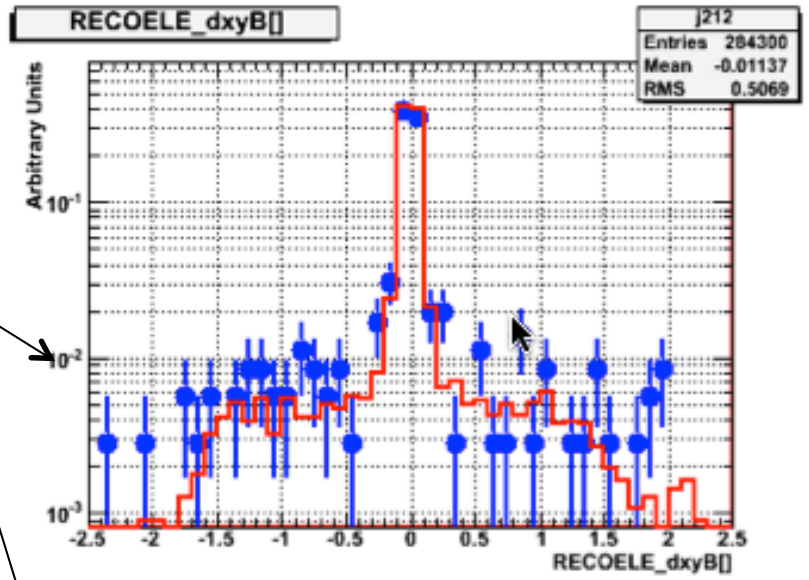


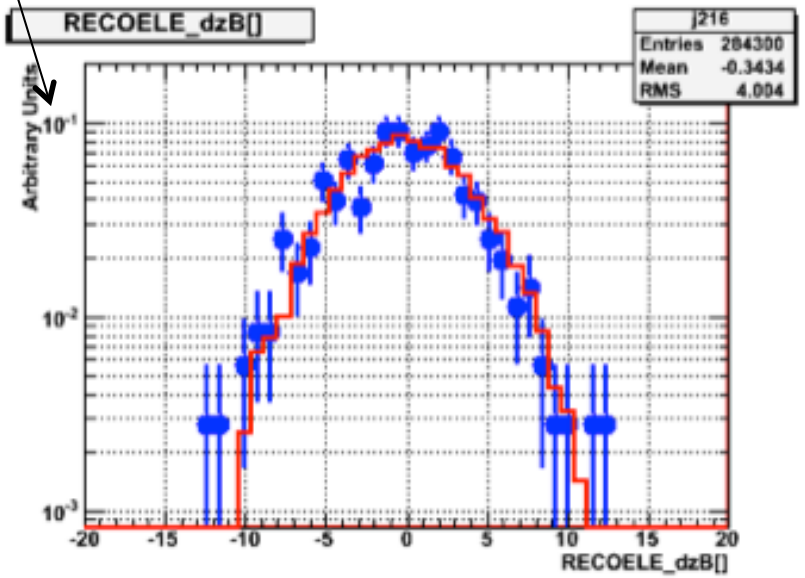
$\Delta\phi_{in}$



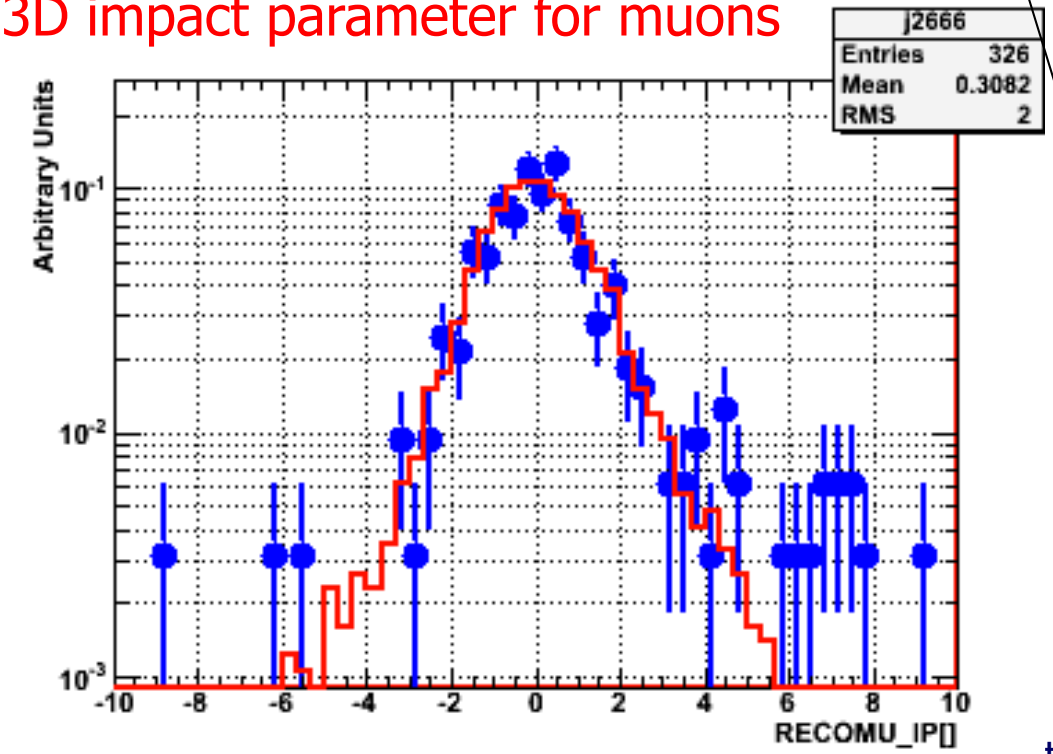
Electron/Muon impact parameter

Transverse and longitudinal
impact parameter for electrons





3D impact parameter for muons



Plans for ICHEP2010

- February/March/April:
  - Isolation variable and efficiency calculation algorithms on the market to be compared and checked with data
  - random cone techniques to be used for isolation cut efficiency
  - efficiency of vertexing algos from data by using non-prompt j/ψ ?
  - control of data rate evolution vs skimming/preselection cuts for HZZ
  - update and improve HZZ framework to cope with data –>work already on going

- June (1-10 pb-1)? as soon as we get some electrons/muons from Z
  - Z→ee, Z→μμ reco validation
  - Tag and Probe for:
    - -- commissioning of isolation variables on electrons
    - -- propagation of isolation efficiencies from Z to ZZ (even if there is no ZZ events)
  - Vertexing eff. with Z+bjets events

Conclusions

On the path to multi-lepton searches for Higgs WG:

@ validation with real data of

1. electron and global/tracker muon eff, electron Id
2. Isolation and vertexing observables

@ enforcing of data driven techniques for bkg estimation

@ crosscheck of the single Z production measurements

@ "discover" WZ and the ZZ production

@ optimization of MC analyses for the exclusion at low, intermediate and high higgs mass

@ **new task for multilepton Higgs searches** going to be created

Thanks to Michele and the LIP group for the kind invitation

Backup slides

Path for H→ZZ in 2010

Main priority of the H→ZZ subgroup in 2010:

@ to validate the HZZ analysis with data → already **STARTED** with 2009 data

@ to control electron and global/tracker muons eff vs fake rate, electron Id, low pT reco

@ to control bkg rate (mostly QCD) at skimming and preselection level

@ to enforce data driven techniques for:

@ background estimate: Zbb and ZZ

@ efficiency of algorithms (isolation and vertexing)

→ a clear picture of systematic uncertainties

@ to control the reliability of Z→2l to ZZ→4l extrapolation

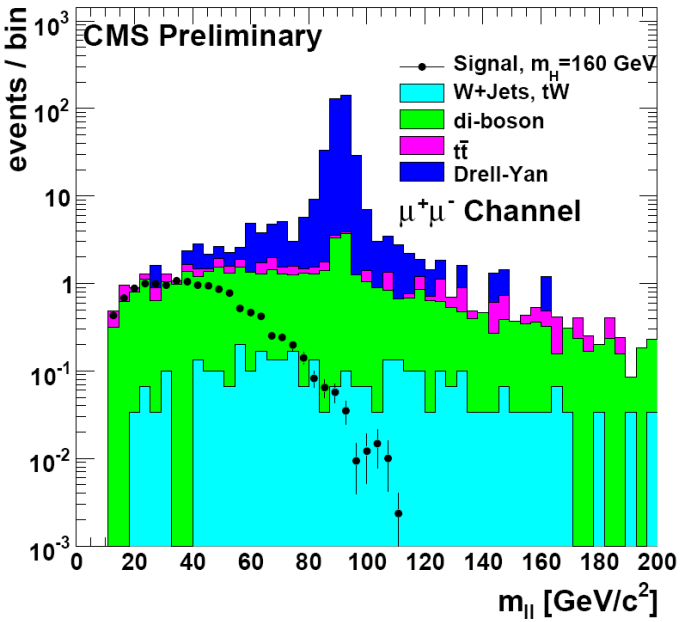
@ to crosscheck the single Z production measurements

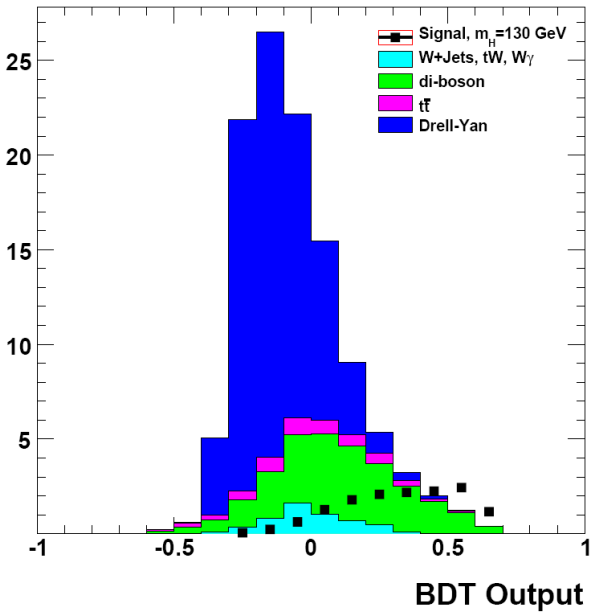
@ to "discover" WZ and the ZZ production liying on the higgs path

@ to optimize the analyses for the exclusion at low, intermediate and high higgs mass

SM H→WW→ lνlν: basic concepts

- Signatures: 2 isolated high p_T leptons + MET, no hard jet in the central region, no H mass peak
- Backgrounds: tt, DY, di-boson, tW, W+jets
- Preselection:
  - single lepton triggers + muon/ele ID
  - isolated leptons opp. charge, p_T
- Main selection observables:
  - Central jet veto
  - Angular correlations btw leptons
  - Di-lepton mass, MET, leptons p_T
- cut based and MVA approaches
- control from data of:
  - MET measurement and fake rate
  - tt and WW bkg



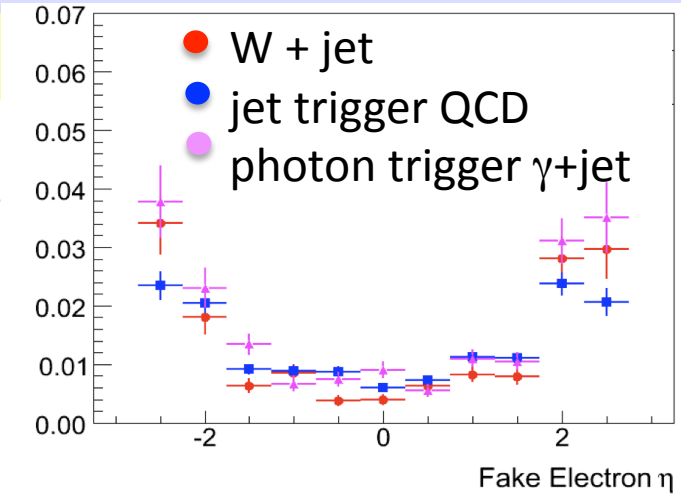


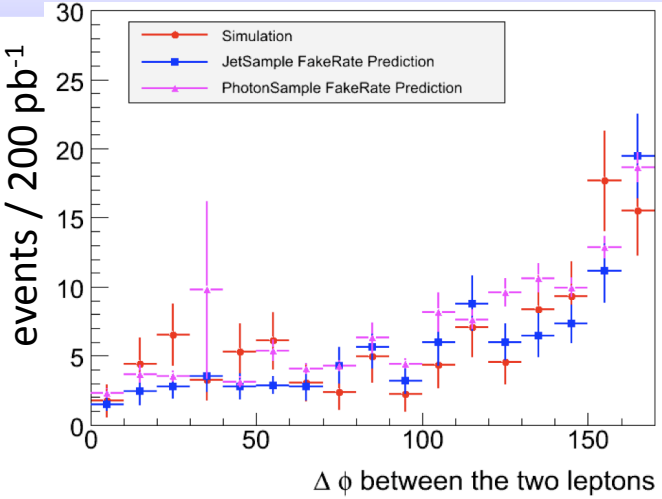
SM H→WW→ lνlν: physics objects

Fake rate:

$$f = \frac{\#(\text{tight ID lept})}{\#(\text{loose ID lept})}$$

- **compute *f*** on a control sample
- use *f* to estimate the **W +jet bkg**

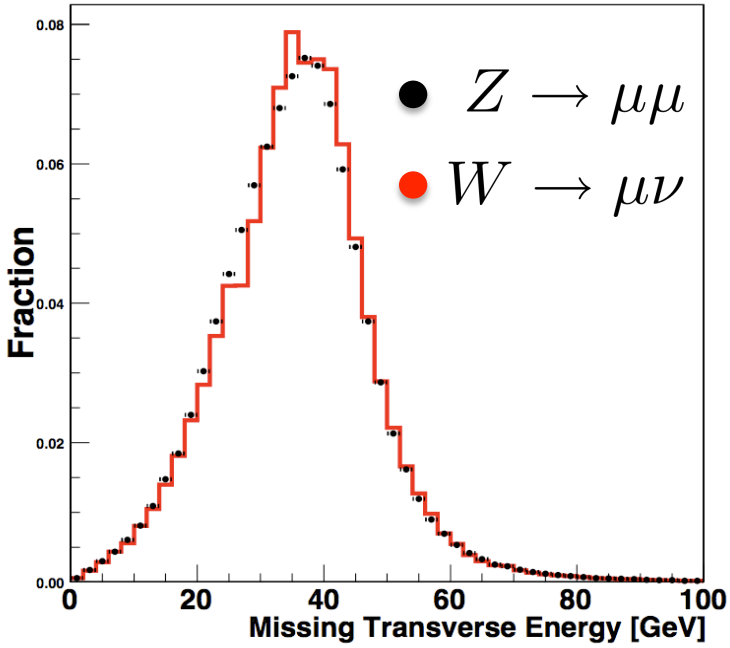




$$[\text{rate}]_{TT}^{\text{tight}} = f \times [\text{rate}]_{TL}^{\text{loose}}$$

Missing Energy control:

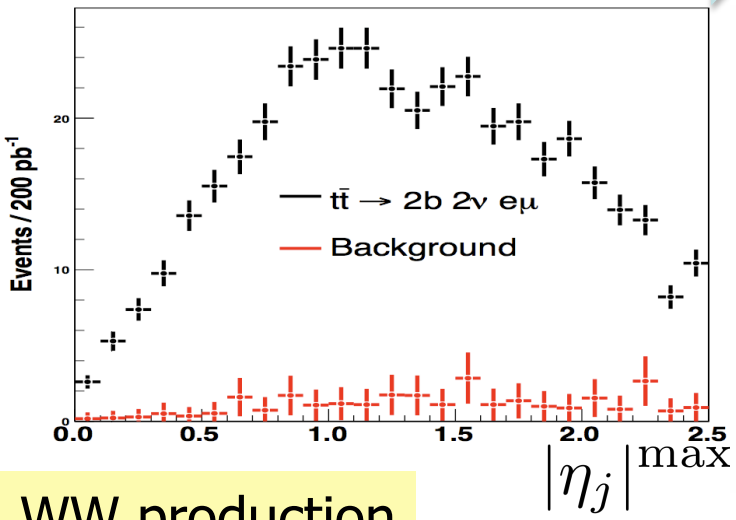
by comparing MC E_T^{miss} in W→eν to real data Z→μμ, where one muon is neglected (rescale for m_W/m_Z, impose the μ reco phase space to the ν)

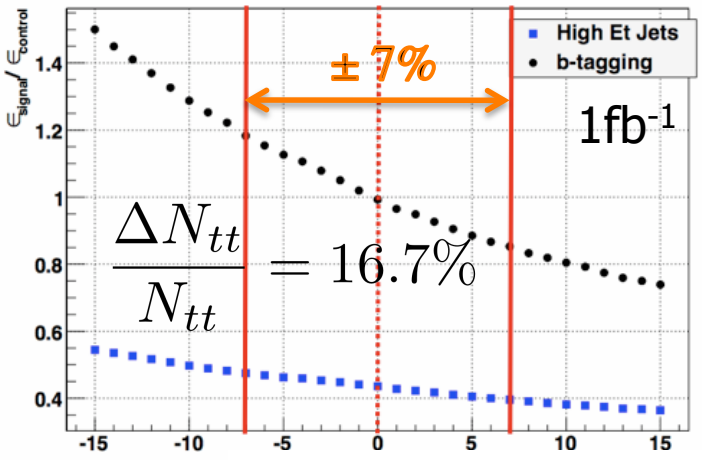


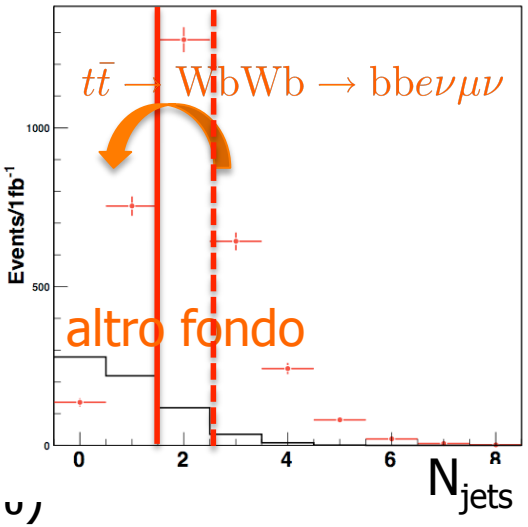
SM H→WW→ lνlν: bkg estimate

ttbar production

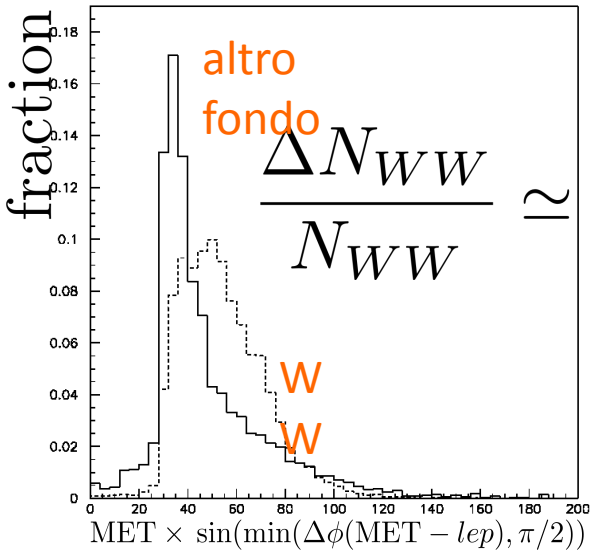
control of angular distrib. → effect of JES → extrapolation







WW production

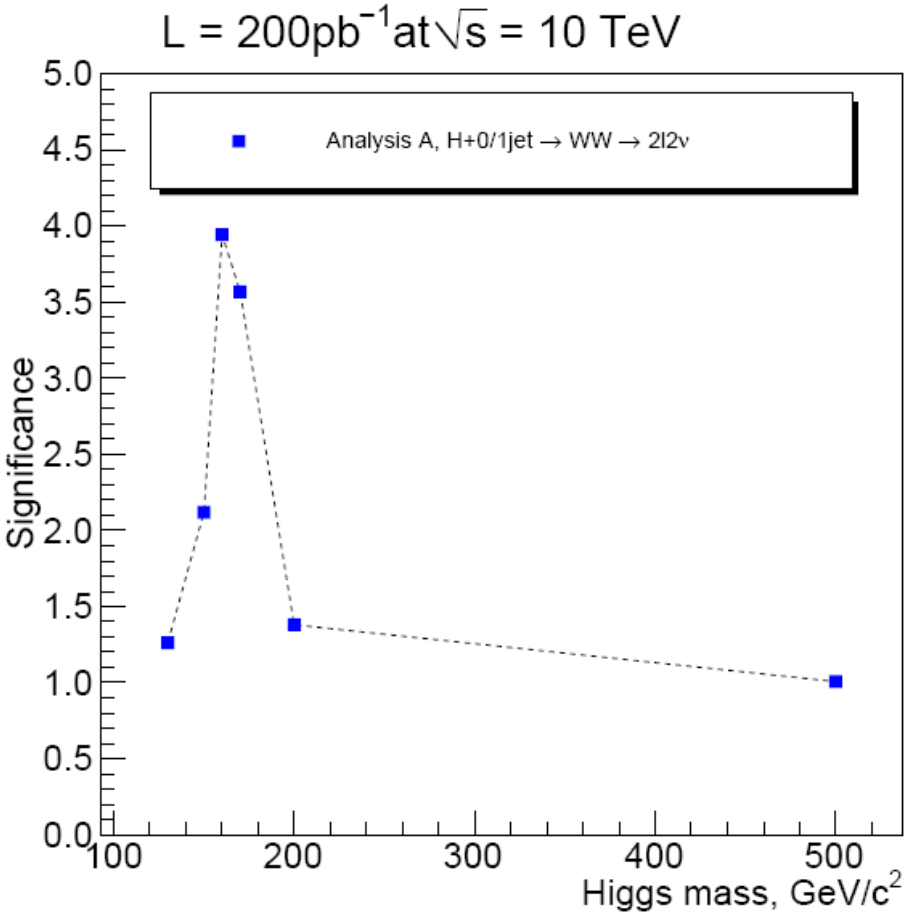


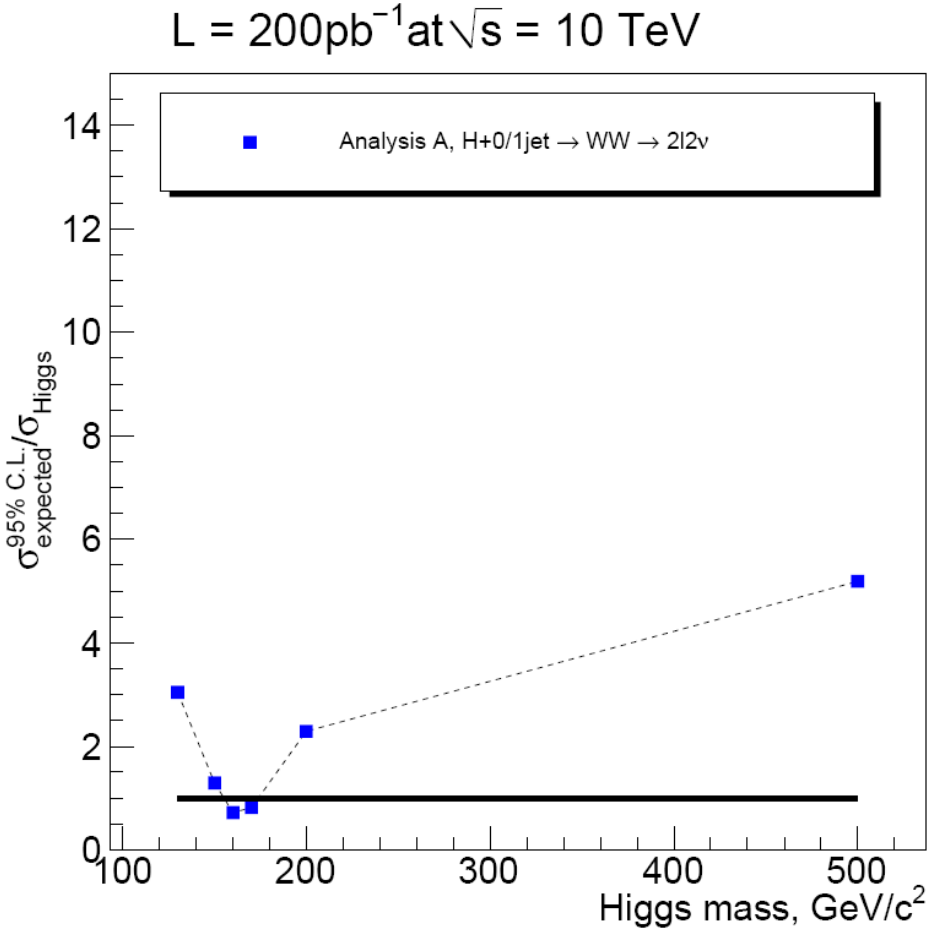
control region: analysis cut + m_{ll} > 115 GeV

events in 1fb^{-1}

Final state	$t\bar{t}$	WW	tW	WZ/ZZ	Drell-Yan/W+jets
$\mu\mu$	31	32	8	2	23
ee	15	14	3	1	14
$e\mu$	136	177	31	6	50

SM H→WW→ lνlν: results





TEVATRON: The optimistic expectation for end 2010 is to exclude **all m_H< 185** or a 2σ hint observed

CMS:
- can exclude **m_H=160-170 GeV** (important x-check of TEVATRON)
- for **m_H=200-500 GeV**, limit r~2.5-5 (best limit)