Higgs to 4 electrons in CMS
- full simulation -

Physics at LHC
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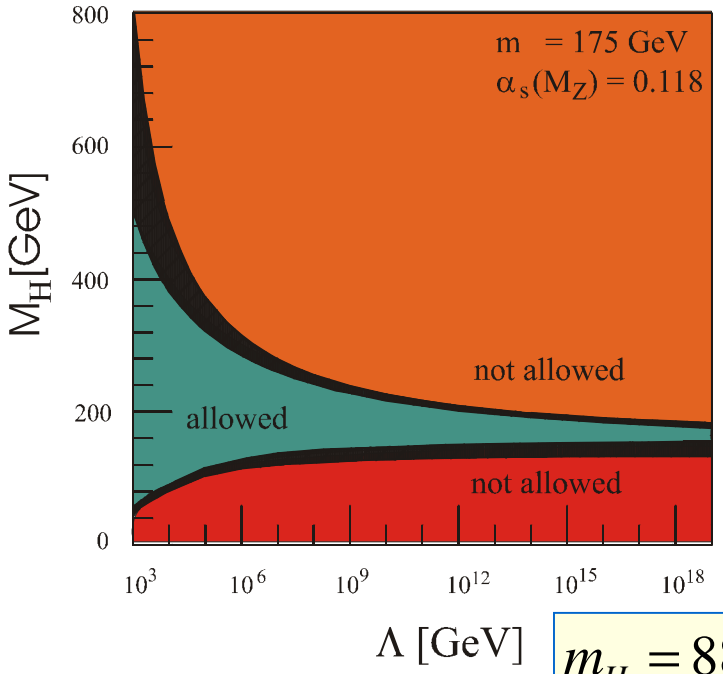
Outline

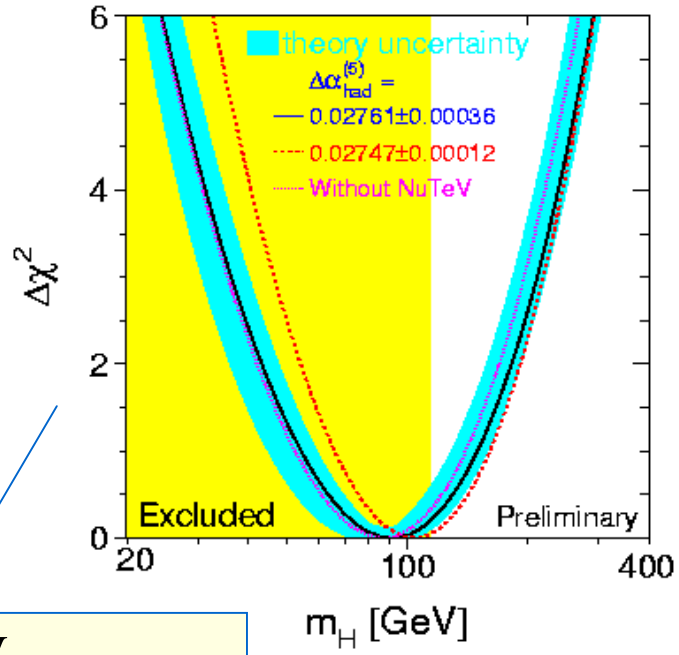
- Higgs production and decay
  - p_T study
- Backgrounds
  - ZZ*
  - $t\bar{t}$
  - $Zb\bar{b}$
- H→ZZ* →4 electrons
  - Electron reconstruction
  - Analysis cuts
  - Observability
- Conclusions

SM Higgs: Mass Limits

- Theoretical limits



- Experimental limits (indirect)

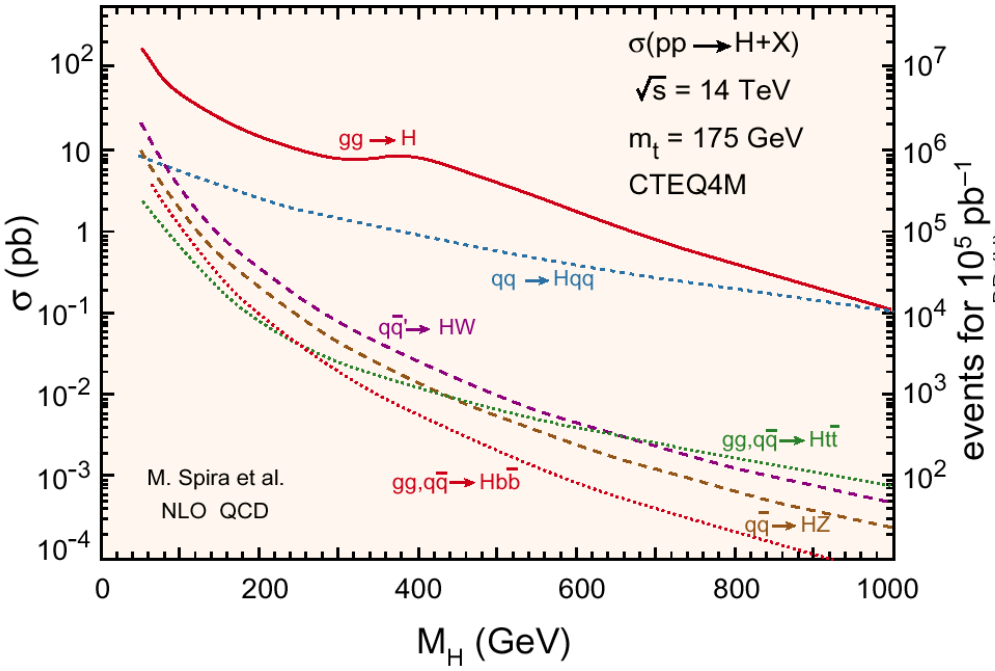


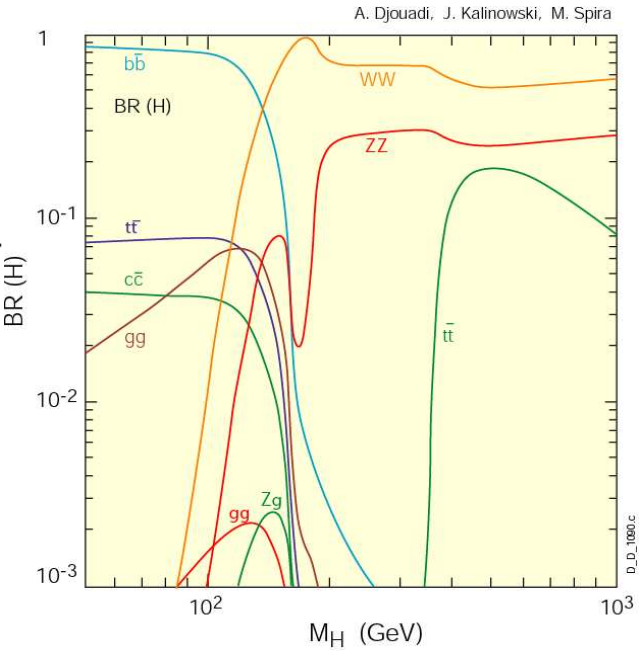
$$m_H = 88^{+53}_{-21}\ \text{GeV}$$

$$m_H < 211\ \text{GeV}\ @\ 95\%\ \text{CL}$$

- Theoretical and experimental arguments prefer an intermediate Higgs boson (M_H ≈ 200 GeV)
- Direct searches – LEP II: $M_H > 114.4$ GeV @ 95% CL
- Relevant searches @ Tevatron expected arround 2007-2008

SM Higgs: Production and decays



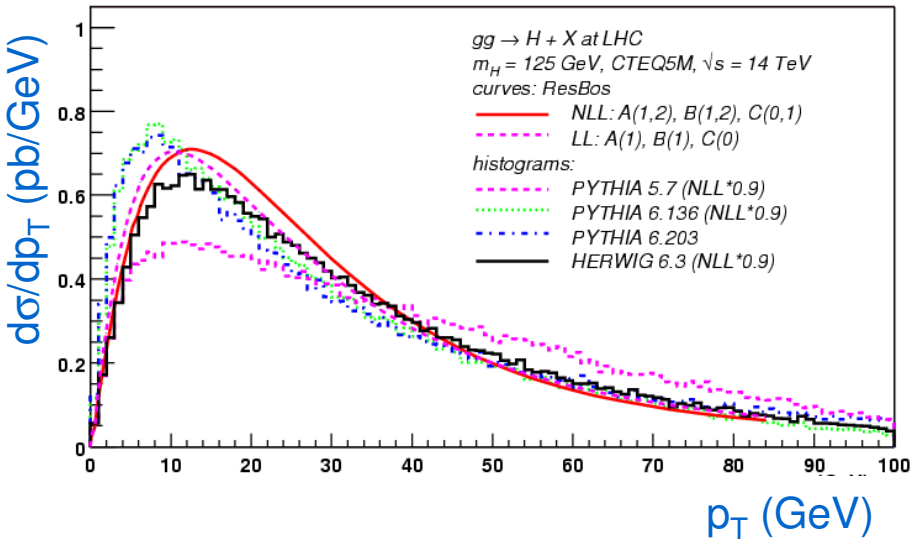


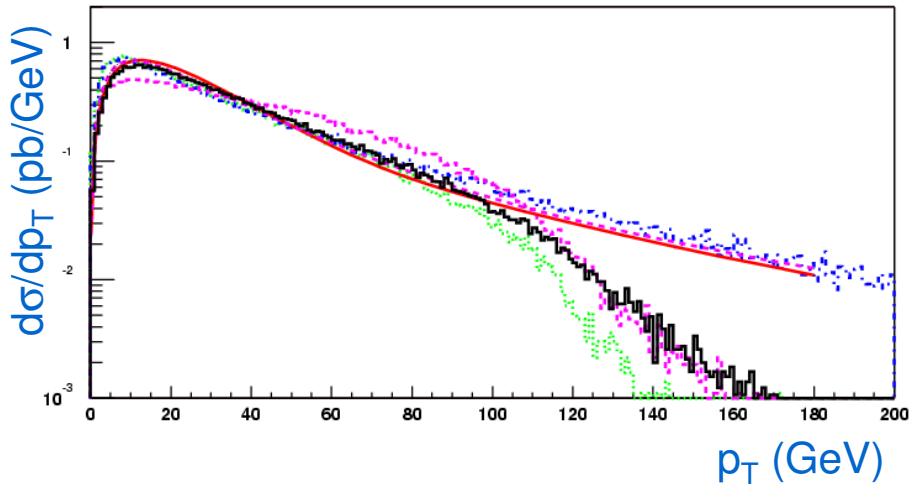
M_H (GeV)	$\sigma(gg \to H)$	$\sigma(qq \to qqH)$	$\sigma(q\bar{q} \to VH)$	$\sigma(q\bar{q}, gg \to Hq\bar{q})$	$BR(H \to ZZ^{(*)})$	$\sigma \cdot BR(H \to 4l)$
130	28.90	4.46	2.17	0.75	0.034	1.40
150	22.56	3.80	1.37	0.47	0.080	2.56
170	18.17	3.31	0.90	0.32	0.022	0.57

(fb)

Signal: p_T study

- To apply the K factor as a simple scaling, we have studied a kinematical reliability of MC event generator
- We compared MCEGs with analytical calculations using ressumation technique implemented in RESBOS
- Recent versions of PYTHIA and HERWIG in good agreement with ressumation
- In high p_T region (>100 GeV)
  - recent PYTHIA version can be tuned for better agreement with ResBos
  - HERWIG still underestimates p_T in that region
- For ***inclusive*** studies K factors can be implemented as simple scaling
  - Which is our case

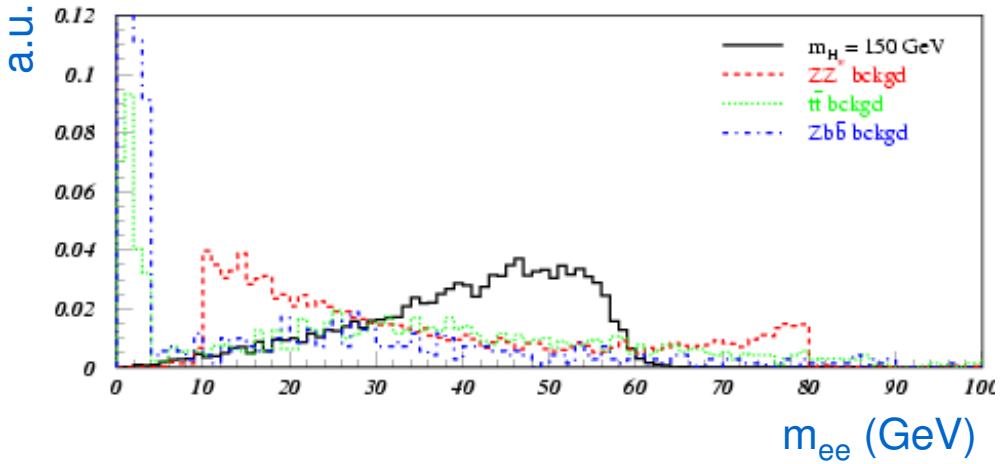




Backgrounds: $ZZ^{(*)}$

- Two processes at LO: $q\bar{q} \to ZZ^{(*)}$ and $gg \to ZZ^{(*)}$
- Only $q\bar{q} \to ZZ^{(*)}$ implemented in **PYTHIA**
  - QCD corrections:
    - K factor estimated to 1.44
    - PYTHIA underestimate p_T spectrum for $p_T(ZZ)$ ☞ 100 GeV
- For $gg \to ZZ^{(*)}$ we estimate:
  - $\sigma(gg \to ZZ)/\sigma(q\bar{q} \to ZZ) = 0.35$, neglecting kinematical differences
  - QCD corrections still unknown, but potentially important

- Angular correlations can be used for signal/background separation
  - But not used since correlated with p_T spectrum
- For ZZ* cut on smaller two-leptons mass can help
- Apart from above cuts, this background is considered as **"irreducible"**

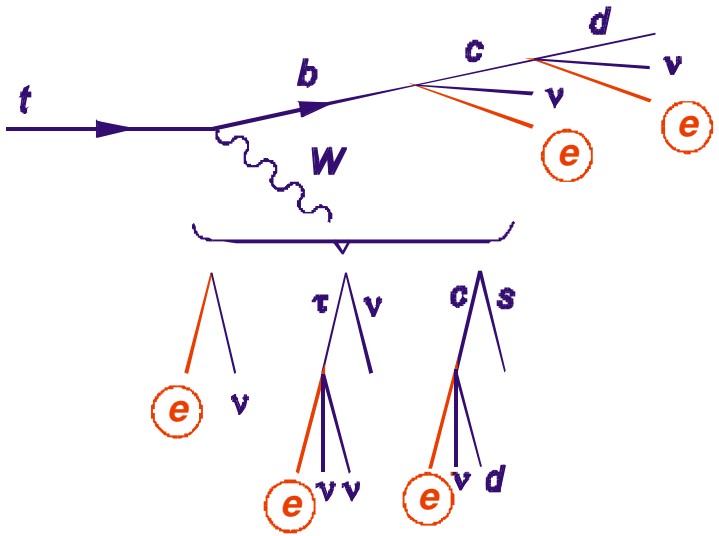


Backgrounds: $t\bar{t}$

- Many possible lepton sources
- Cross sections:

$$\sigma_{LO} = \left(515^{+128\ +167}_{-95\ -228}\right)$$

$$\sigma_{NLO} = \left(758.8 \pm 75^{+167}_{-228}\right)$$

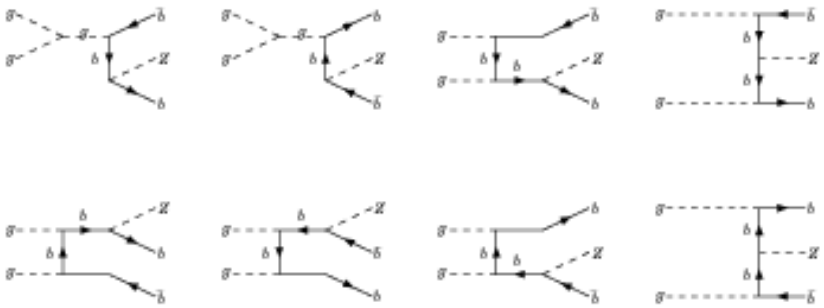


- pdf uncertainty at NLO about 7%
- Main "useful" characteristics:
  - Soft lepton p_T spectrum → ***lepton pT cuts***
  - Unisolated leptons → ***isolation cuts***
  - The higher 2-leptons mass distribution is relatively flat → ***Z mass cut***
  - The lower 2-lepton mass peaking at small masses (< 10 GeV) → ***$Z^{(*)}$ mass cut***
  - Secondary vertex → ***impact parameter cut***
- For practical reasons simulated events preselected
  - And forced $W \to l\mu$ decay

Backgrounds: $Zb\bar{b}$

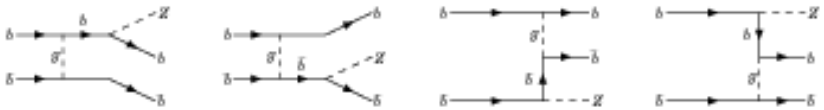
- LO production processes:

$g + g \to Z + b + \bar{b}$



$q + \bar{q} \to Z + b + \bar{b}$

$b + \bar{b} \to Z + b + \bar{b}$



- Problems in PYTHIA
  - Incorrect phase space generation
  - Does not exist in recent versions (6.x and more)
- We use:
  - **CompHEP**
    - For cross section calculations
    - For Zbb final state generation
  - **PYTHIA**
    - For decays and fragmentation
- LO cross sections
  - *CTEQ4L*, $Q = m_Z$, $a_s^{LO} = 0.132$

Inital state	gg	$q\bar{q}$
σ_{LO}(pb)	780.79	148.79

- "Usefull" characteristics similar to tt, except the Z mass cut
- Simulated events preselected
- NLO recently available in MCFM program

The Compact Muon Solenoid

CALORIMETERS

SUPERCONDUCTING COIL

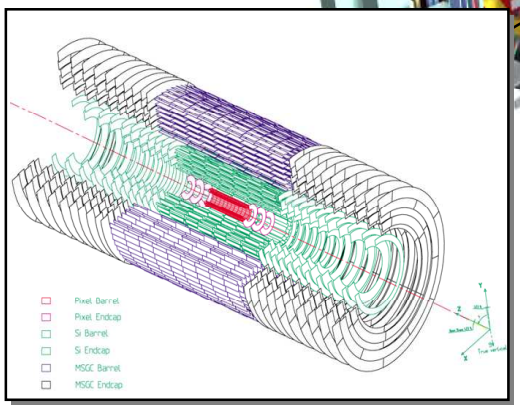
ECAL Scintillating $PbWO_4$ Crystals

HCAL Plastic scintillator copper sandwich

Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

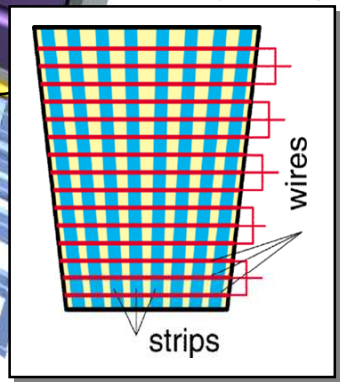
IRON YOKE

TRACKERs

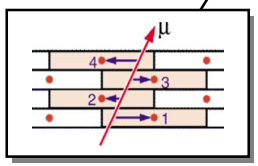


Silicon Microstrips
Pixels

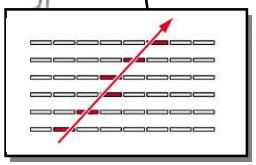
MUON ENDCAPS



MUON BARREL



Drift Tube Chambers (DT)



Resistive Plate Chambers (RPC)

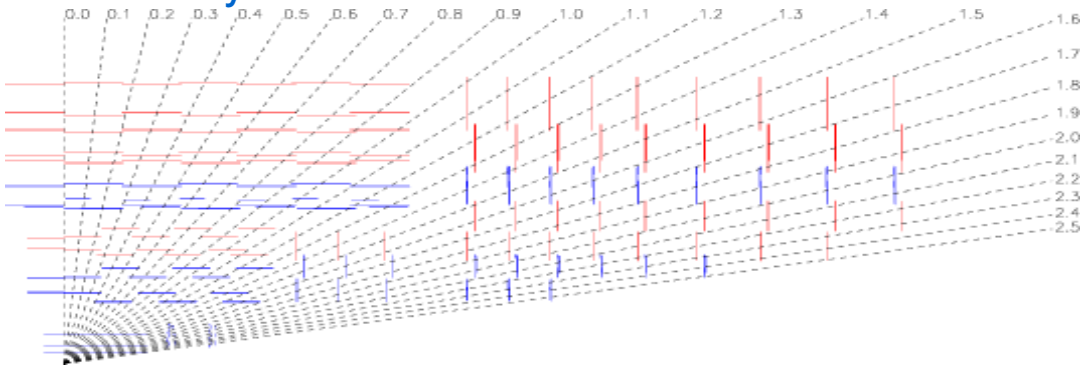
Cathode Strip Chambers (CSC)
Resistive Plate Chambers (RPC)

H→ZZ*→4e

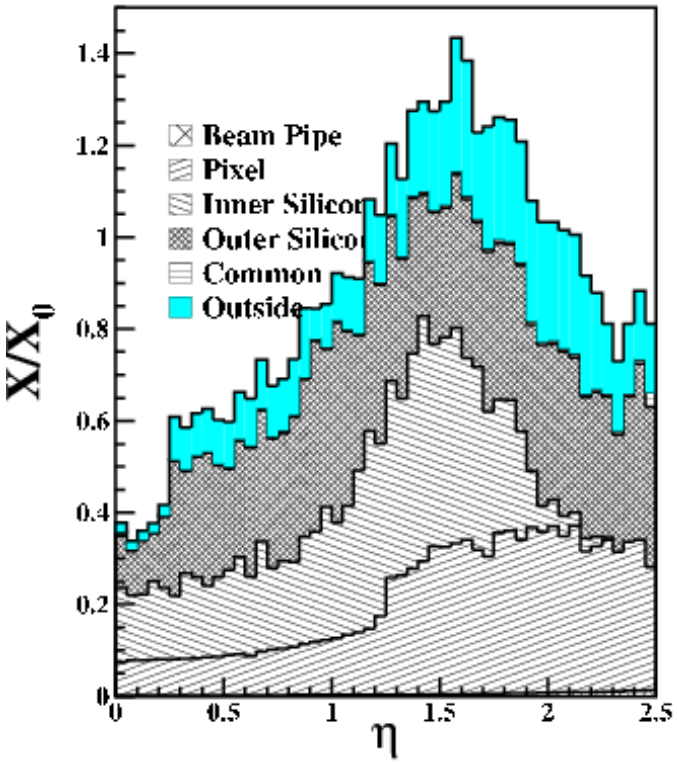
- Electron reconstruction
  - Bremsstrahlung problem
  - Track reconstruction
  - Cluster reconstruction
  - Weighting method for energy estimation
  - Final momentum estimation
- Cuts for signal/background separation
- Higgs mass reconstruction
- Example: single Monte Carlo experiment
- Observability in CMS and conclusions

Bremsstrahlung problem

Tracker layout



Tracker material budget



- Potential problems in
  - Reconstruction efficiency
  - Precision

  for both tracker and ECAL
- Fraction of electrons with

$$\frac{E_{impact}}{E_{generated}} < 0.1 = 12\%$$

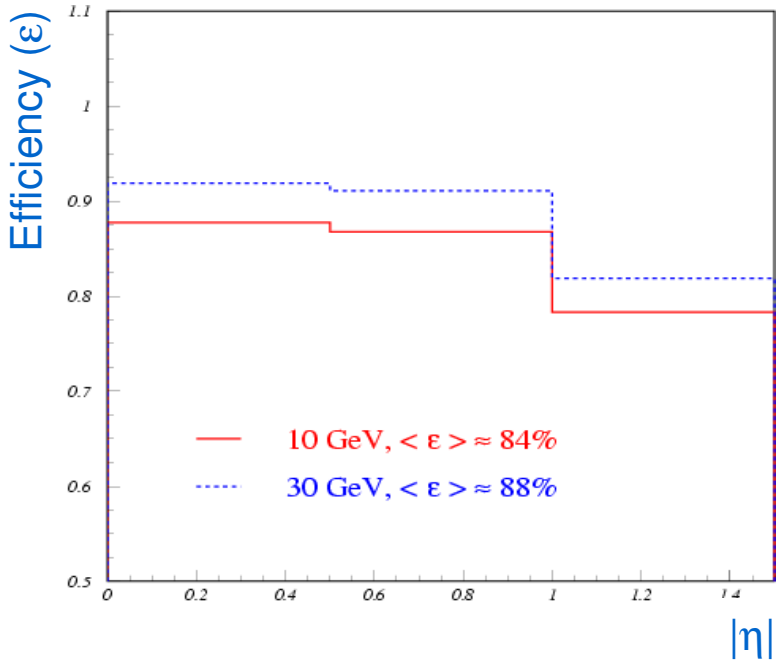
- Fraction of secondary photons with

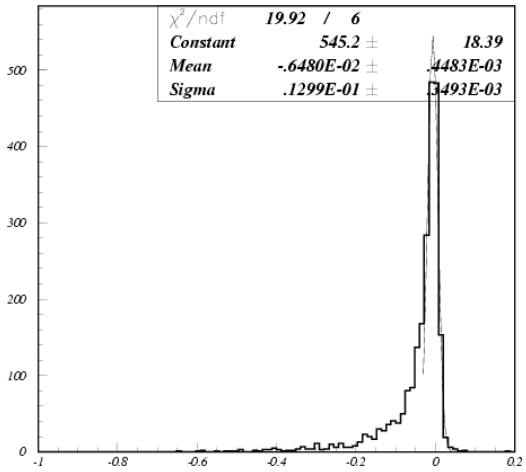
$$E_{\mathrm{sec}} > 1\ \mathrm{GeV} = 13\%$$

Numbers are for p_T=10 GeV electrons in the barrel

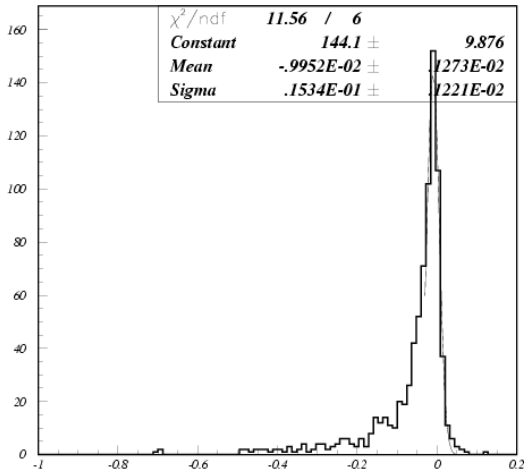
Track reconstruction

- **Forward Kalman Filter**:
  - Seed generation
    - Pixel layers
  - Track building
    - Forward
  - Track smoothing
    - Backward refitting
  - Choice here: minimum of 8 hits to build a track





$(p_{rec}-p_{gen})/p_{gen}$

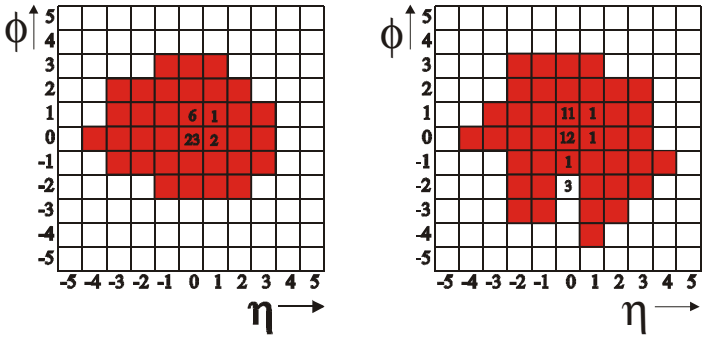


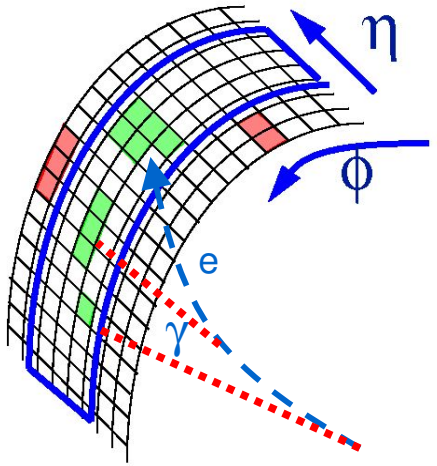
$(p_{rec}-p_{gen})/p_{gen}$

- This was the first attempt of full electron track reconstruction with a new software
- Possible improvements are under way
- Recent development: **Gaussian-Sum Filter**
  - Takes care of energy losses in tracker material

Cluster reconstruction

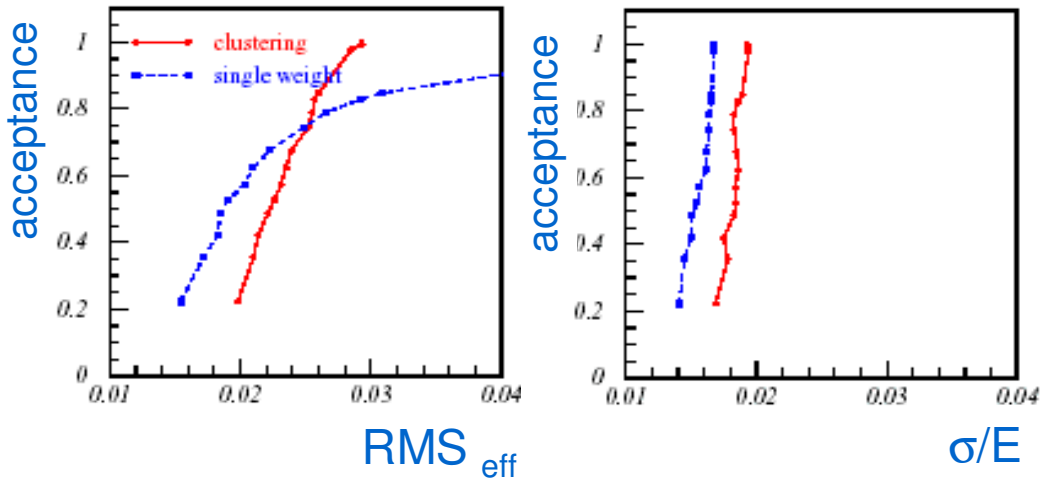
- Clustering algorithm should
  - Be able to follow event by event fluctuations in particle impact point and direction
  - Be small enough to minimize influence of noise
  - Be local enough to distinguish between close showers
- For this study we used ***Dynamical algorithm***
  - ***Search for seed***
    local maximum crystal
  - ***Cluster construction***
    Crystal attaching criteria based on neighbordness and energy content
- Search for bremsstrahlung photons
  - From the cluster E_T one can predict where to look for radiated photons
  - Clusters found are attached to the electron cluster
    → ***supercluster***
  - In case of hard brems matching algorithm is changed





Weighting method

- The simplest energy estimator: "cluster energy sum" $E_s = \sum_i e_i$
- Another estimator can be constructed:
  - Every crystal in which particle leaves a fraction (f_i) of its energy gives a total energy estimator: $\left\{ \tilde{E}_i = \frac{e_i}{f_i} \right\}, \quad i = 1, \ldots, n$
  - With a weighted sum as an optimal combination $E_w = \sum w_i' \tilde{E}_i = \sum w_i' \frac{e_i}{f_i} = \sum w_i e_i$
- For the implementation of this method one needs
  - ***shower model***
  - ***covariance matrix***
- Neglecting correlations and supposing $\sigma_i = \sqrt{e_i}$ we get $E_{sw} = \frac{\sum_{i=1}^{n} e_i}{\sum_{i=1}^{n} f_i}$



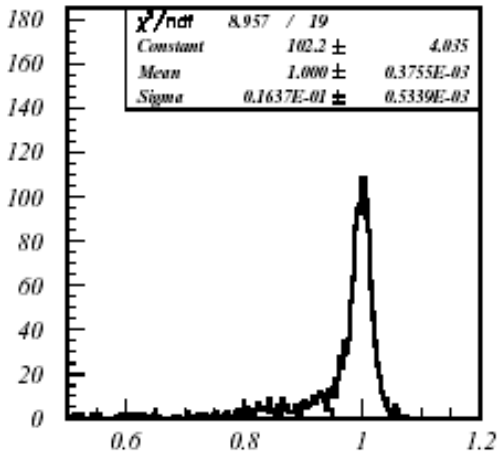
p_T	Acc.	RMS_{eff}	σ
10 GeV	50%	15%	19%
30 GeV	70%	10%	15%

Final momentum estimation

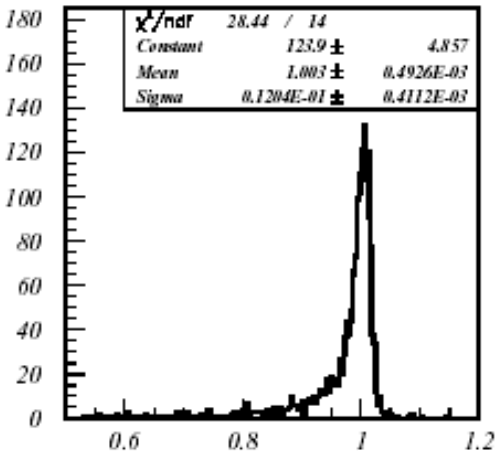
- Combination of ECAL and tracker measurements
- ***Example: p_T = 10 GeV in barrel***

$$\tilde{p} = \begin{cases} w_E \cdot E + w_p \cdot p \ , \text{if} \left| \frac{E}{p} - 1 \right| \le 2\sigma_{E/p} \\ E \qquad , \text{if} \ \frac{E}{p} > 1 + 2\sigma_{E/p} \\ p \qquad , \text{if} \ \frac{E}{p} < 1 - 2\sigma_{E/p} \end{cases}$$

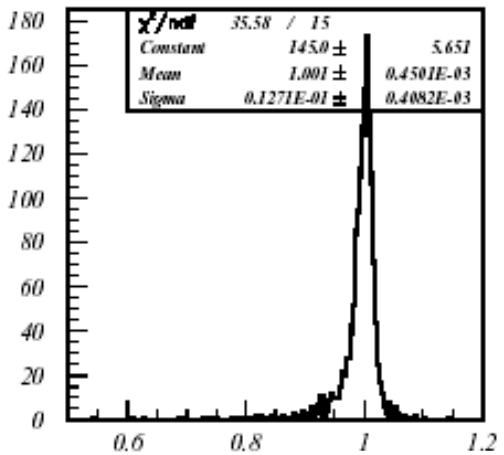
		RMS_{eff}	σ	$\varepsilon(\pm 2\sigma)$ (%)	$\varepsilon(\pm 3\sigma)$ (%)
p_T = 10 GeV	E	0.029	0.0164	71.5	78.5
	p	0.025	0.0120	67.1	74.2
	$\tilde{p}$	0.017	0.0127	79.1	86.5
p_T = 30 GeV	E	0.020	0.0080	62.3	69.9
	p	0.045	0.0175	59.7	68.1
	$\tilde{p}$	0.016	0.0084	69.4	75.5



E/E_{true}



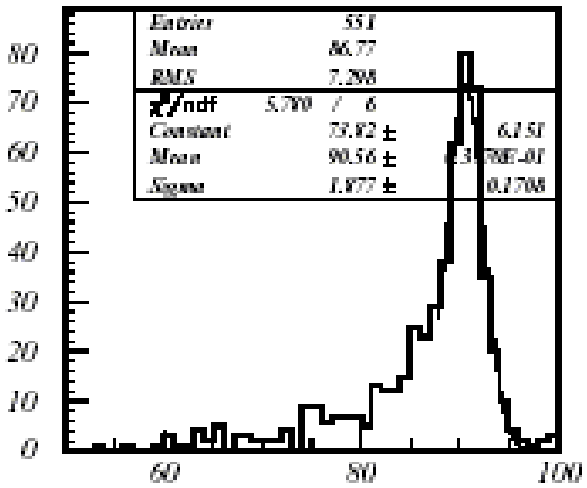
p/E_{true}



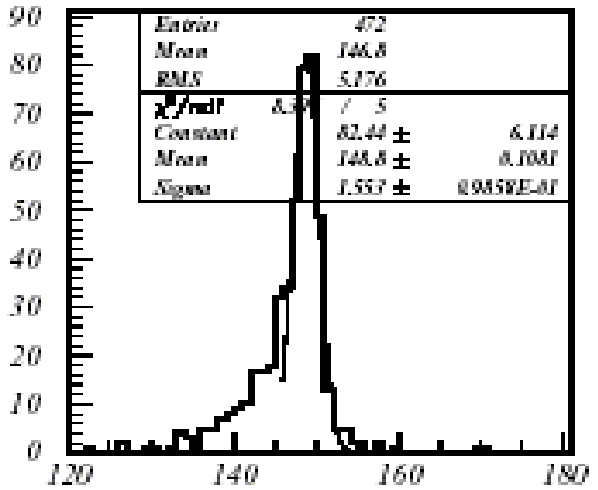
$\tilde{p}/E_{true}$

H→ZZ*→ 4e – Analysis cuts

m_H → (GeV)	130	150	170
Preselection	**0.49**	**0.57**	**0.62**
Reconstruction eff.	**0.64**	**0.65**	**0.67**
Isolation (high lumi)	**0.80**	**0.80**	**0.80**
p_T > 7, 10, 15, 20 GeV	**0.89**	**0.91**	**0.94**
15 < m_{Z^*} < 80 GeV	**0.90**	**0.94**	**0.95**
$m_Z - 13 < m_Z < m_Z + 6$	**0.77**	**0.86**	**0.92**
σ_H (GeV)	**1.29**	**1.58**	**1.78**
$\pm 2\sigma_H$	**0.68**	**0.67**	**0.67**
total acceptance	**0.11**	**0.15**	**0.18**



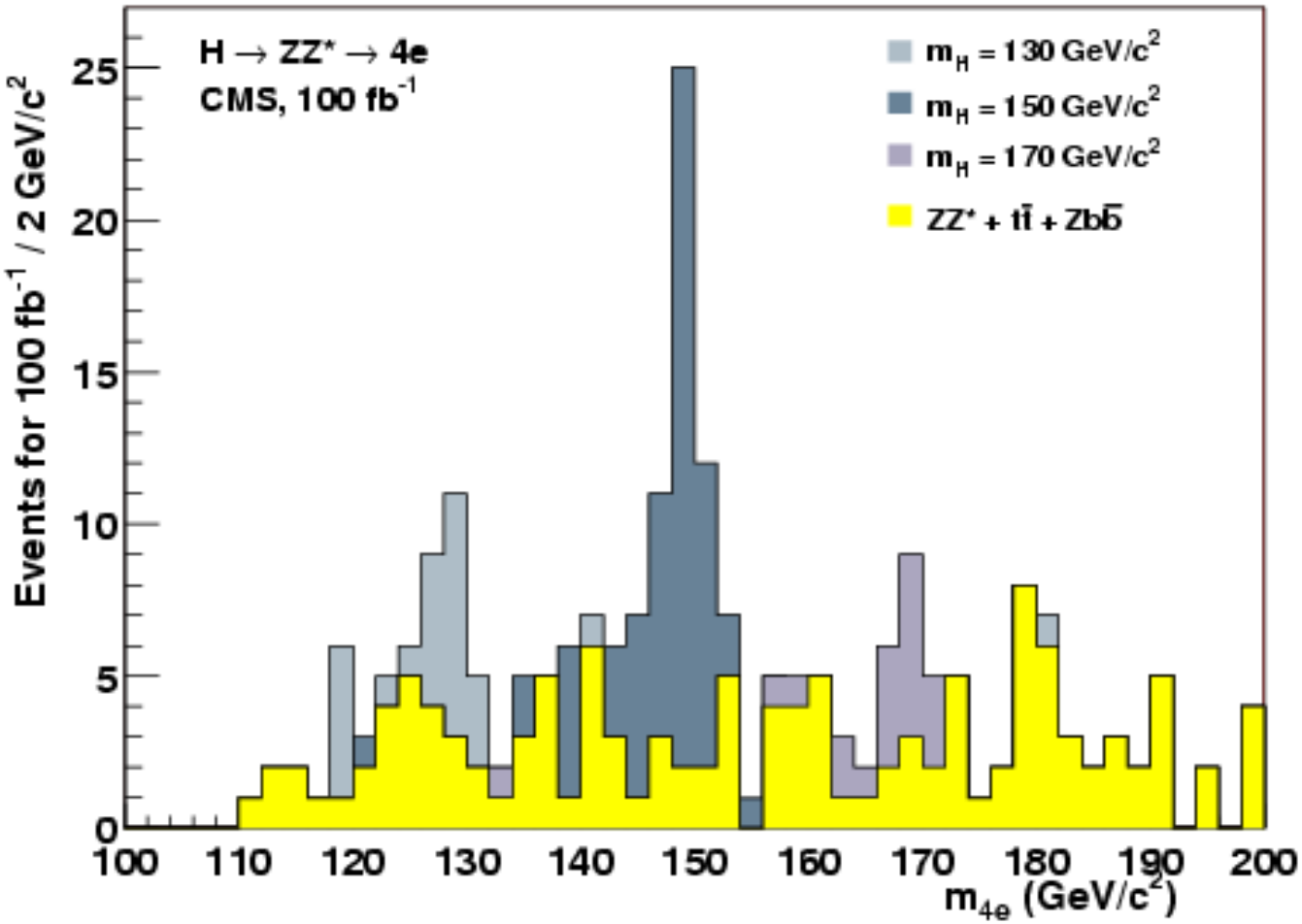
m_{2e} (GeV)



m_{4e} (GeV)

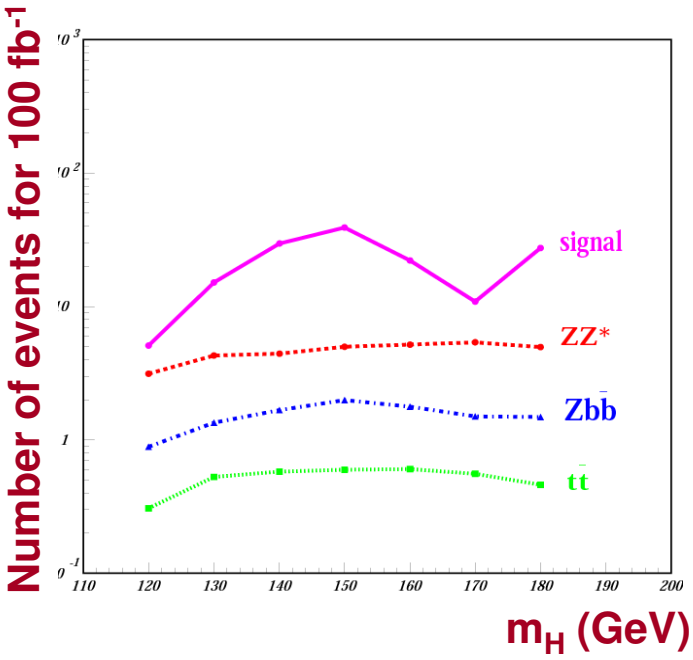
- Preselection: **$2e^-$ & $2e^+$ in $|\eta|<2.5$ with $p_T > 5$ GeV**
- Isolation at **high lumi: $\varepsilon \approx 0.8$**
  - results from parton level study
- Possible adjustment of cuts for a given Higgs mass

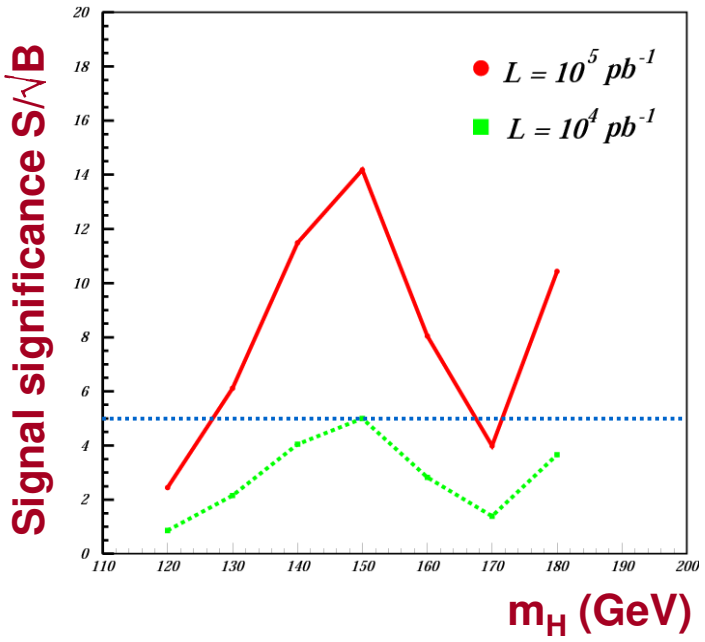
H→ZZ*→ 4e – Single MC experiment



H→ZZ*→ 4e – Observability and conclusions

Combined results from full simulation and parton level study





- Improvements are still possible in:
  - Signal and background description
  - Efficiency and precision of electron reconstruction
  - Search for internal bremsstrahlung photons
  - Optimisation of isolation cuts
  - Analysis cuts combinations
  - ...