Lepton ID at the LHC

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February 5, 2005

TEV4LHC workshop

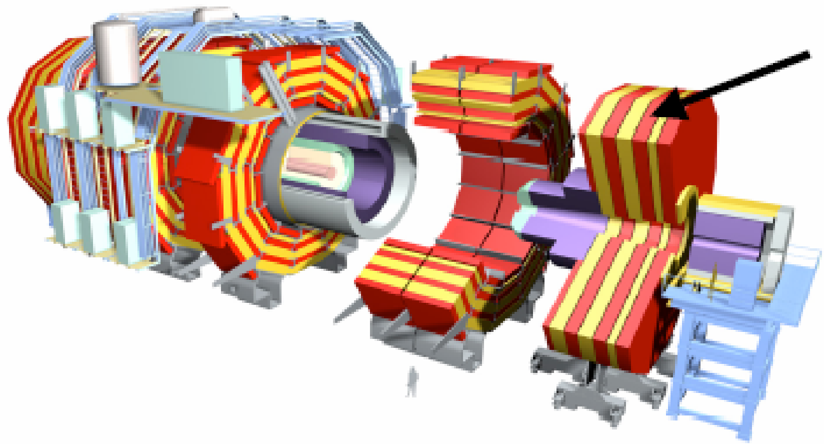
LHC turn on

- Summer 2007
  - Colliding beams in machine
  - L ~ Can expect 10^{31} during the early months
  - 3 month shutdown (Fall 07) followed by ~ 7 month of physics run
  - Can expect L to steadily increase to 2×10^{33}
- Can expect 1 to 10 fb^{-1} per experiment in the first year
  - Though a lot of uncertainties in schedule and luminosity
- Commissioning Phase: (starting summer 2005)
  - Sub-System Calibration + Cosmic Ray Commissioning
  - April 2007 : single beam in machine
    - Beam Gas, Beam Halo

Preparing for Day 1

- Will the detectors be operational?
  - Understand and calibrate the detector response
  - Validate SM signatures ($Z \rightarrow \ell\ell$, $W \rightarrow \ell\nu$, …)
  - Which will allow us to prepare the groundwork for discovery physics
- As with any previous experiments, can expect to spend the first few months
  - understanding the detector response
  - optimization of reconstruction algorithms, calibration/alignment
- It is here where we can benefit from the Tevatron experience
  - Understand what chaos we can expect on Day 1
  - Help us ensure that we go in prepared.

Initial layout

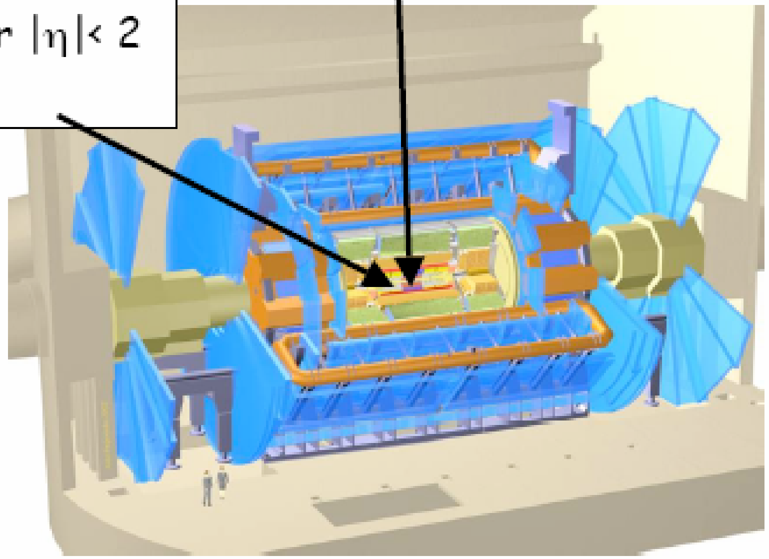


RPC over $|\eta|<1.6$ (instead of $|\eta|< 2.1$)
4th layer of end-cap chambers missing

Pixels and end-cap ECAL
installed during first shut-down

2 pixel layers/disks instead of 3

TRT acceptance over $|\eta|< 2$
(instead of $|\eta|< 2.4$)

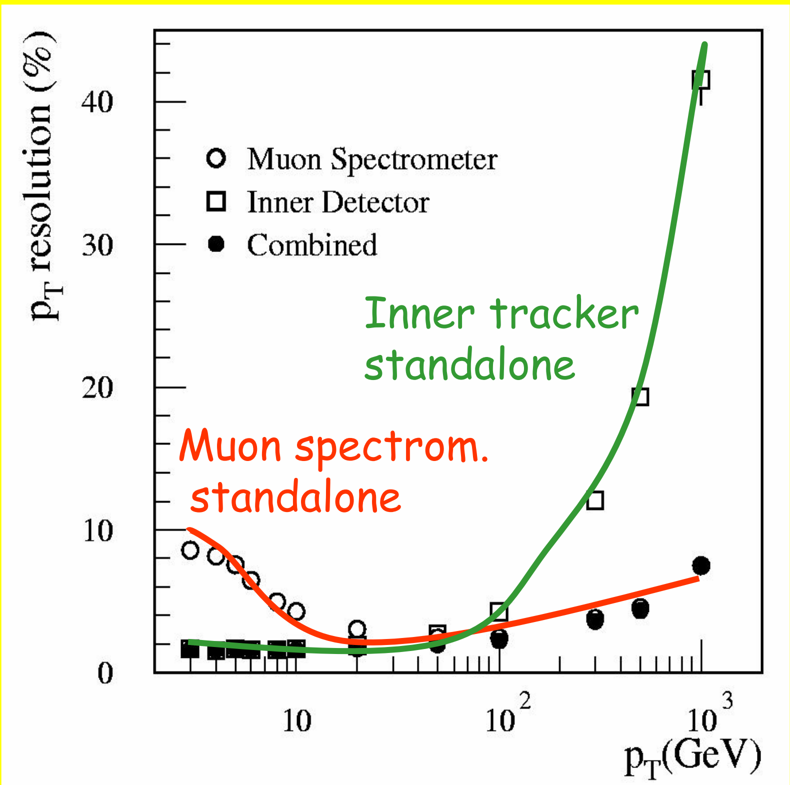


Both experiments:
deferrals of high-level Trigger/DAQ processors
→ LVL1 output rate limited to
~ 50 kHz CMS (instead of 100 kHz)
~ 25 kHz ATLAS (instead of 75 kHz)

Impact on physics visible but acceptable

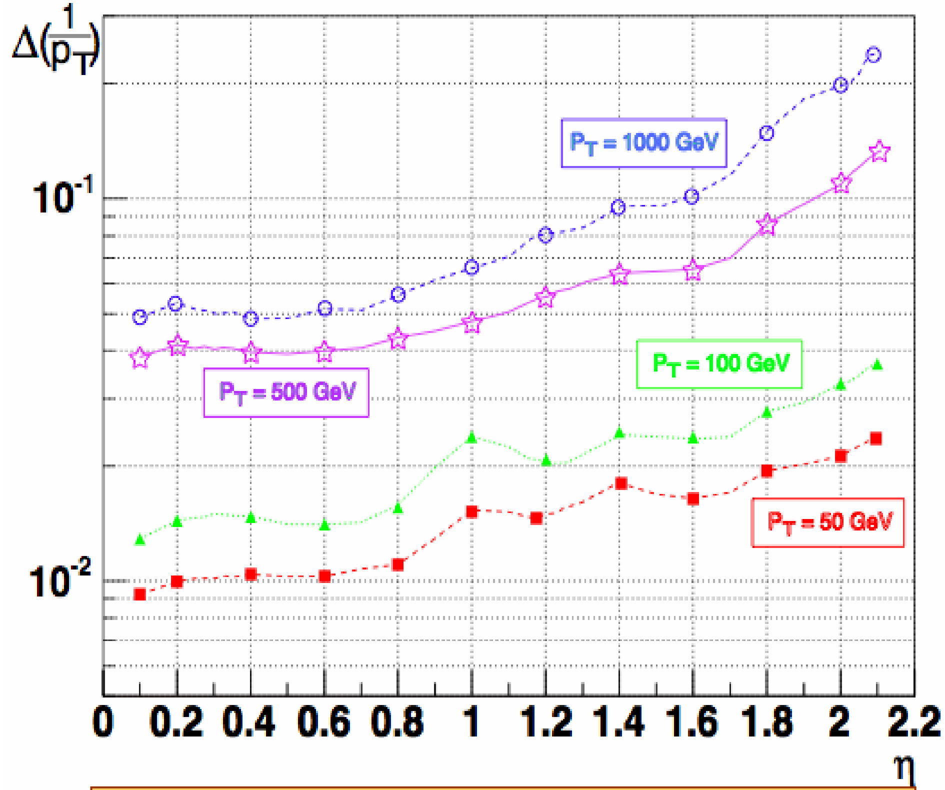
Muon Performance

ATLAS Physics TDR (1999)



- Muon Spectrometer resolution dominates for P_T > 100 GeV/c
- Resolution fairly constant over whole eta range
- Coverage $|\eta| < 2.7$

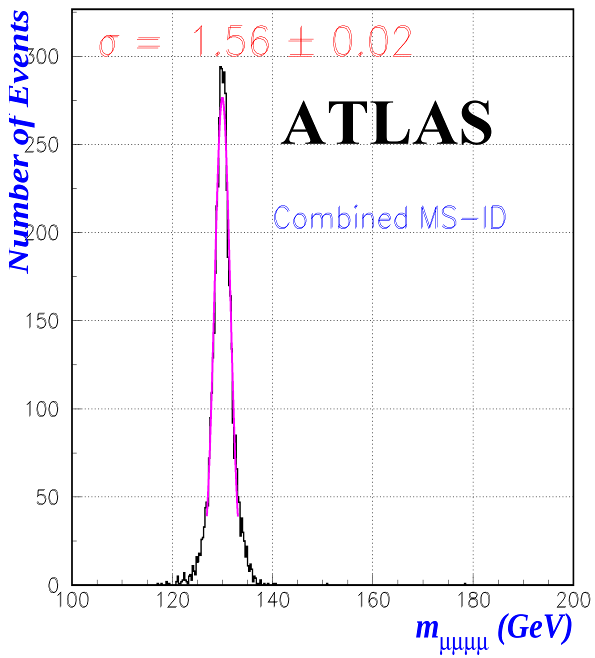
CMS: N. Neumeister CHEP04

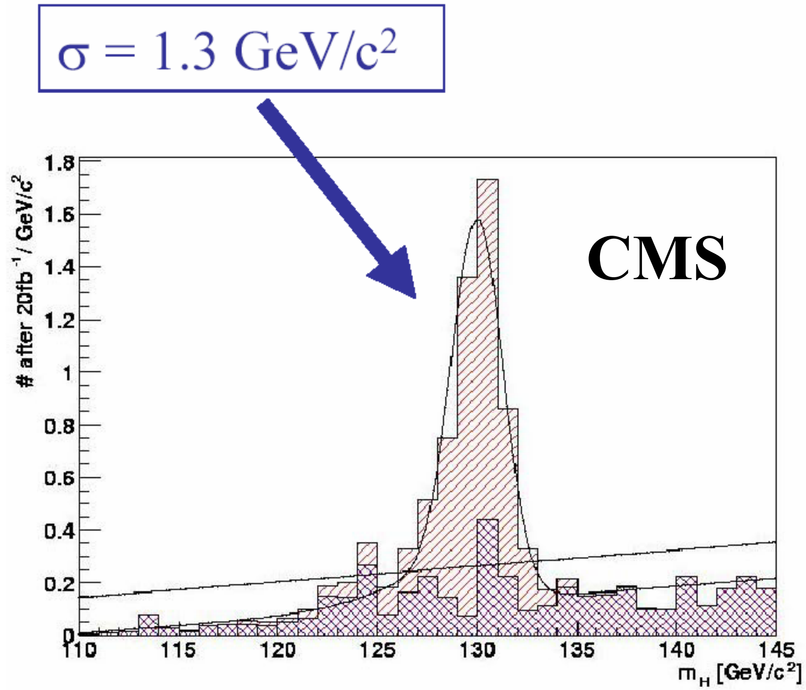


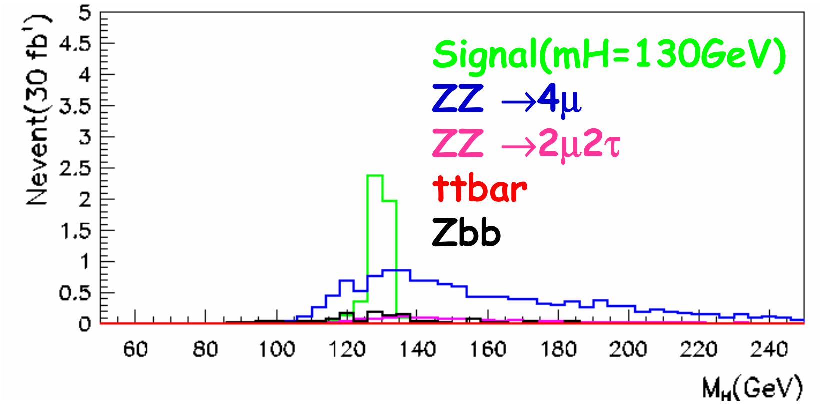
- Silicon Tracker resolution dominates for all P_T
- Excellent p_T resolution in barrel region, worse in endcap
- Coverage $|\eta| < 2.4$

H→ZZ*→4μ

From "Physics at LHC 2004", Vienna, July 2004







Mass resolution for
M_H = 130 GeV
σ = 1.6 GeV (ATLAS)
σ = 1.3 GeV (CMS)

EM Performance Requirement

H→γγ used as benchmark to assess EM Calorimeter performance

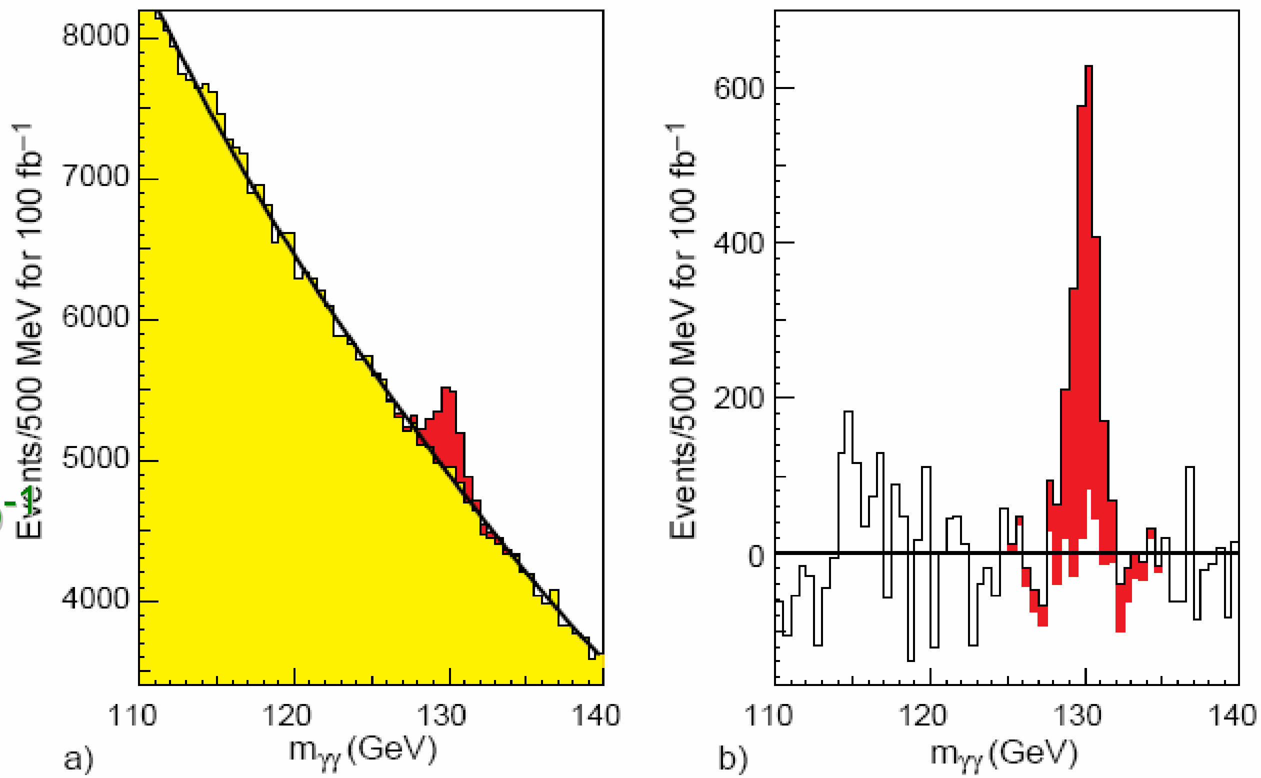
- ~ 1% mass resolution to observe signal over γγ continuum
- → Constant term in energy resolution < 0.7%

Mass resolution ~ 700 MeV

(at high luminosity)

5σ significance with L = 30 fb^{-1}

CMS, m_H = 130 GeV, 100 fb^{-1}

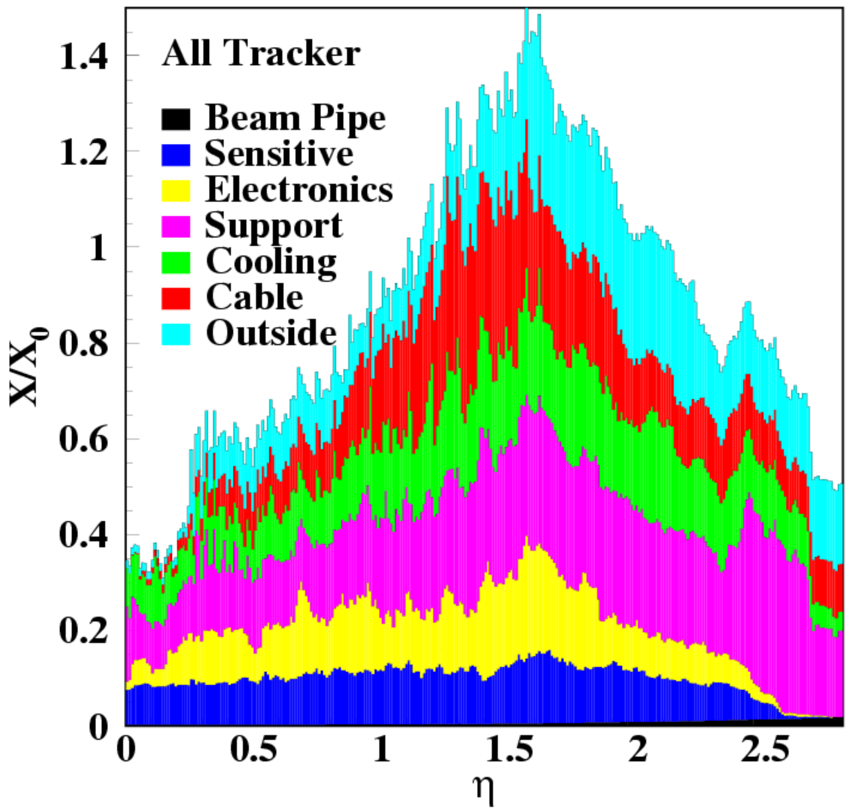


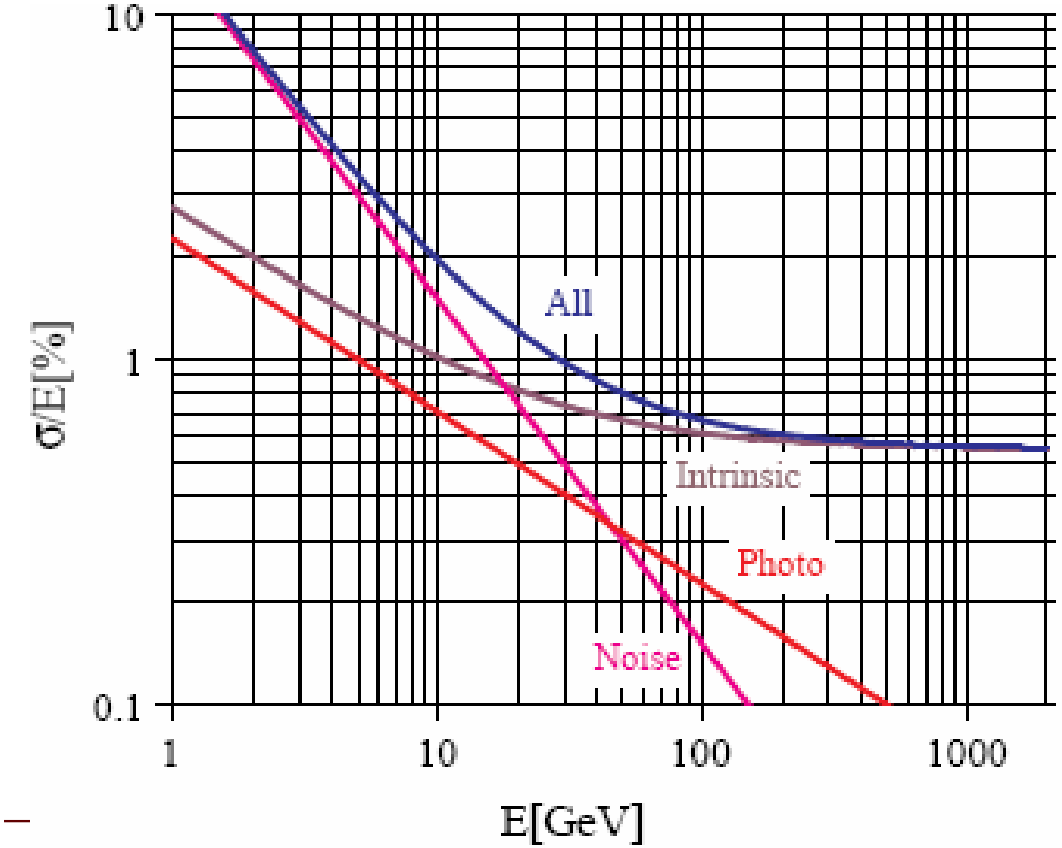
Calorimeter performance
Resolution (CMS)

Scintillating Crystal EM calorimeter, 75000 PbW04 crystals (0.0175x0.0175)

$$(\sigma/E)^2 = (2.7\%/\sqrt{E})^2 + (0.55\%/E)^2 + (0.155)^2 \quad @ \eta=0$$

$$(\sigma/E)^2 = (5.7\%/\sqrt{E})^2 + (0.55\%/E)^2 + (0.205)^2 \quad @ \eta=2$$





Inter Calibration of CMS crystals

To achieve ~ 0.5% constant term,

→ Long-term : Must rely on E/p from W→eν

→ uncertainty in tracking material (particularly endcaps)

→ studies ongoing to deal with brem effects

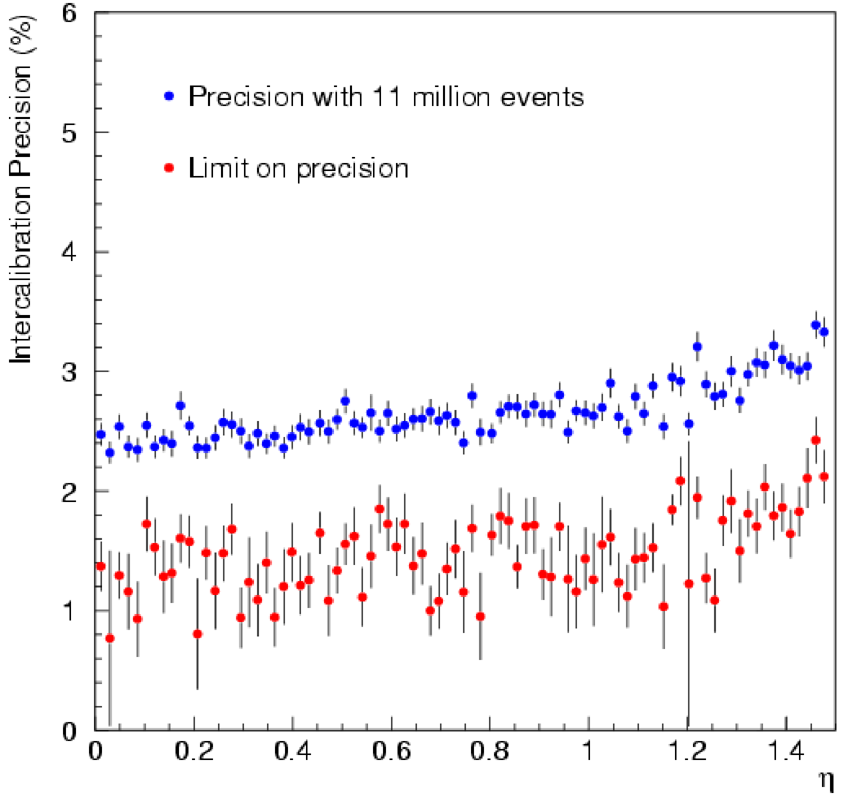
Early day running:

Intercalibration with min bias events or di-jet triggers (phi uniformity)

~ 2 – 3% precision in few hours

\+ Intercalibration of eta-rings with Z→ee

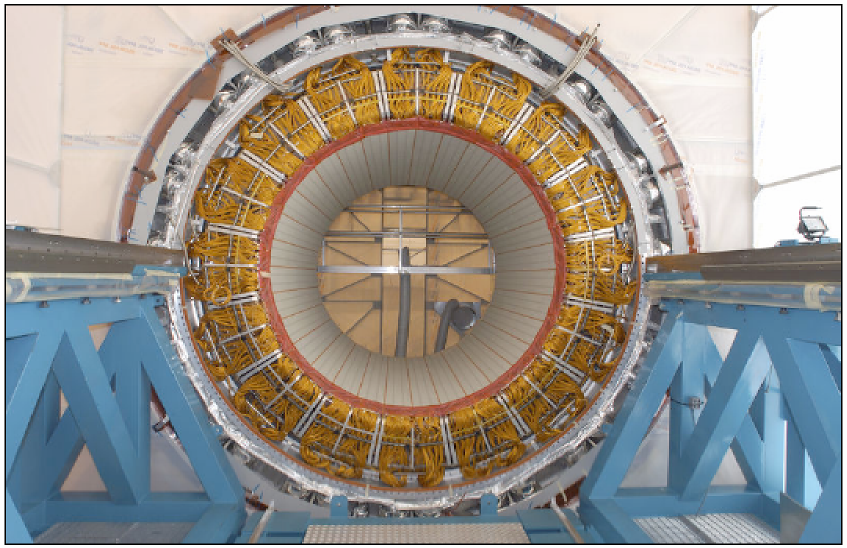
~ 1% precision in 1 day running.

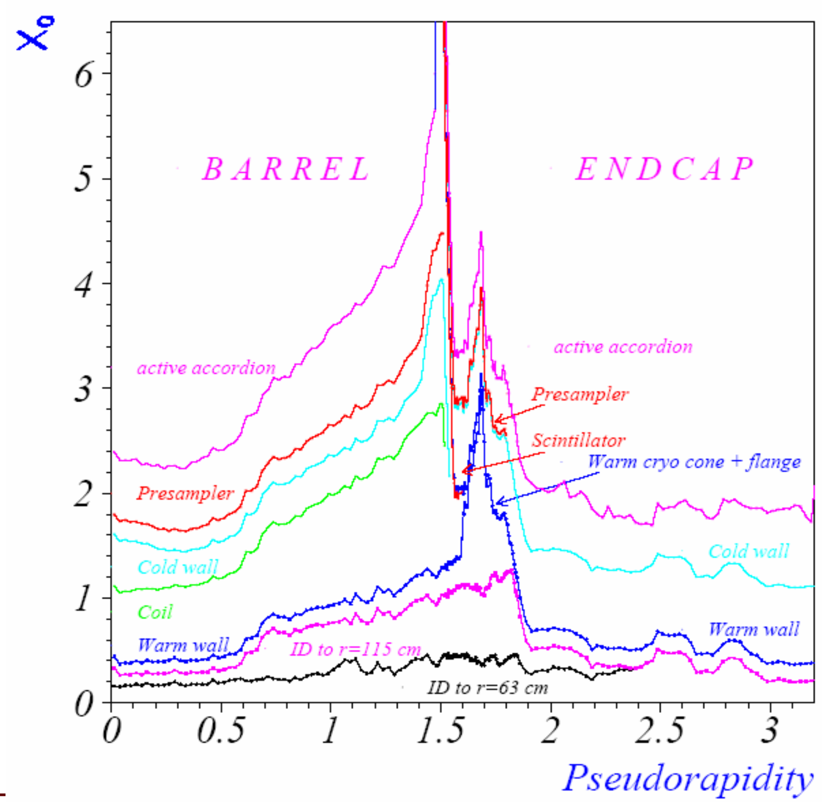


ATLAS EM Calorimeter

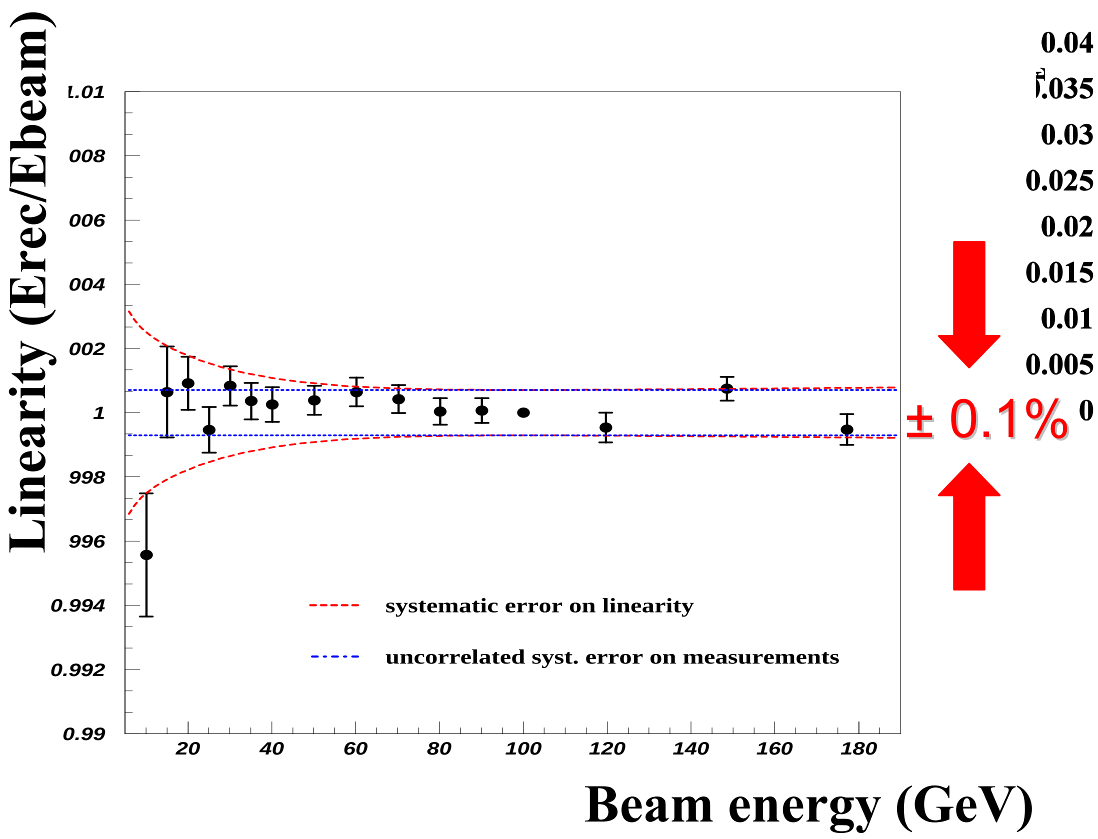
- Pb-LAr Accordion sampling calorimeter
  - Completed, Barrel calorimeter in the pit, Endcap under tests
  - Extensive tests of modules at test-beam
  - Commissioning in pit to commence mid-2005

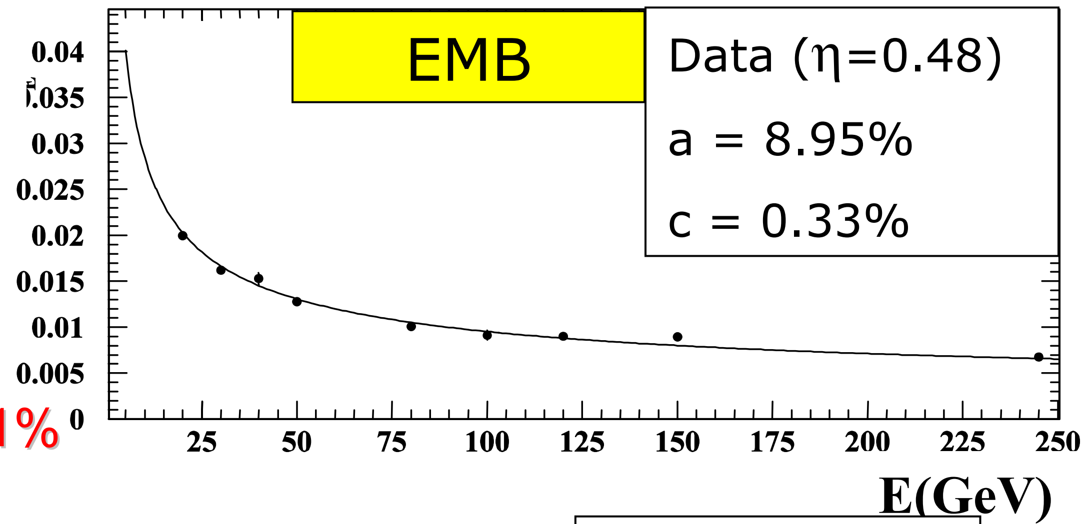
4 Longitudinal Samplings: ($\eta < 3.2$)
PS (0.025x0.1); Strips (0.003x0.1)
Middle(.025x.025), Back(.05x.025)

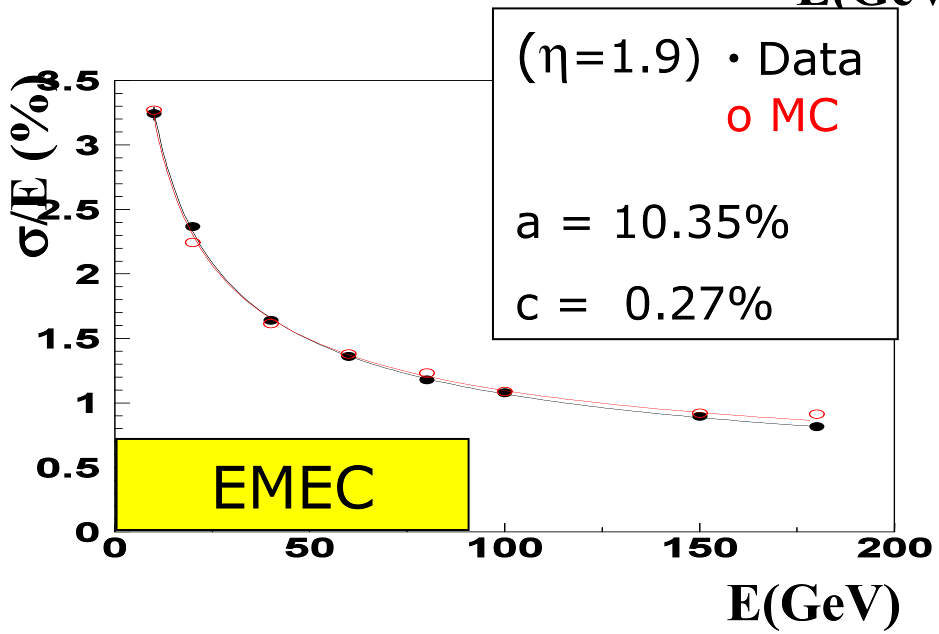




ATLAS EM Resolution/Linearity (test-beam data)





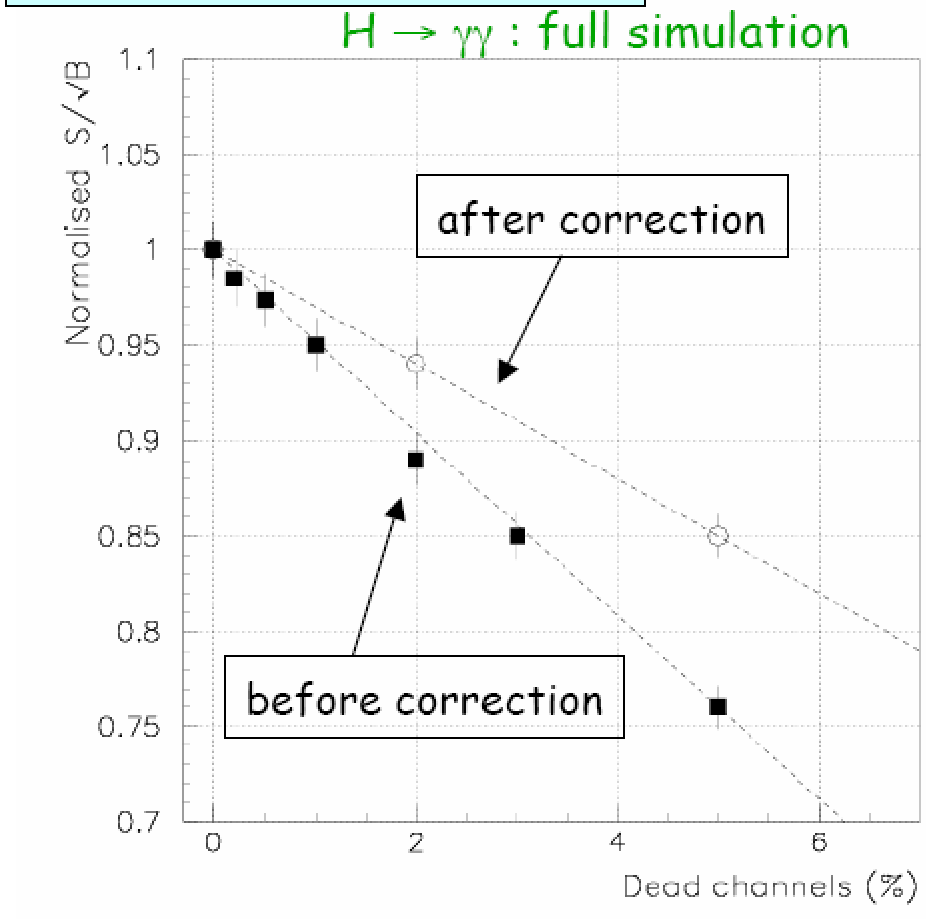


Intercalibration with Z→ee

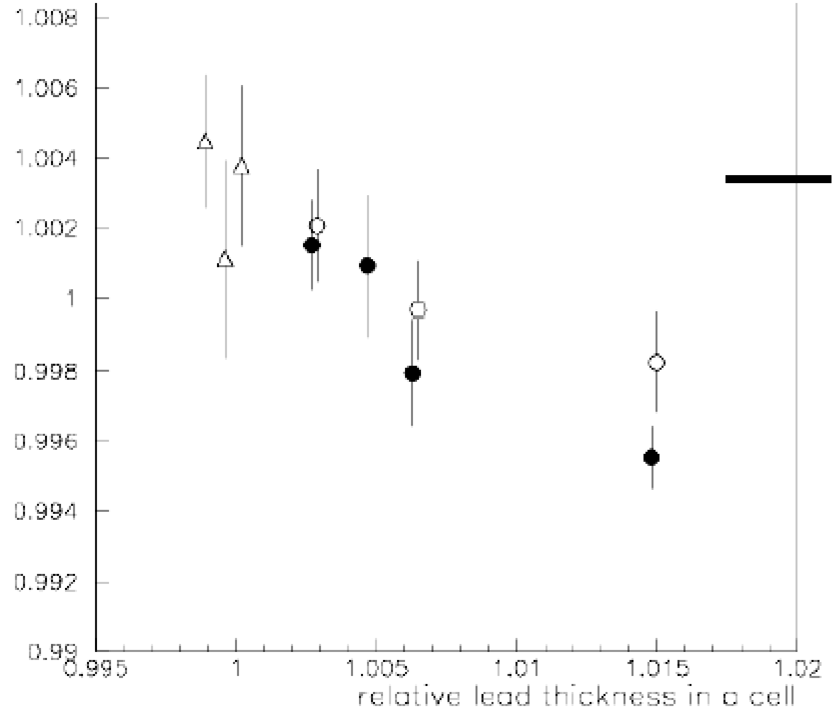
- Constant term $c = c_L \oplus c_{LR} < 0.7\%$ (goal)
- c_L = Local contribution to constant term < 0.5%
  - (variation in $\Delta\eta \times \Delta\phi = 0.2 \times 0.4$, measured in TB)
- c_{LR} = Long range variations corrected with Z→ee
  - ~250 electrons in each unit of $\Delta\eta \times \Delta\phi = 0.2 \times 0.4$
  - 10^5 Z→ee events (few days at 1 Hz)
  - → to achieve $c_{LR} < 0.4\%$
- Pessimistic scenario : constant term ~ 2%
  - H→γγ significance at m_H = 115 GeV degraded by 25%
  - Need 50% more L to recover the significance.

Examples of ongoing studies
(to understand detector effects)

Effect of dead channels



Effect of variation in lead thickness



1% variation → 0.6% drop in response

Measured variation σ = 9 μm

Translates to < 0.2% effect on constant term

Number of dead channels in calorimeter < 0.1 %

High PT electron id : efficiency/rejection

Several multi-variate analysis being explored

→ Simple Cuts, Likelihood methods, neural nets, …

Table below shows studies based on simple cuts

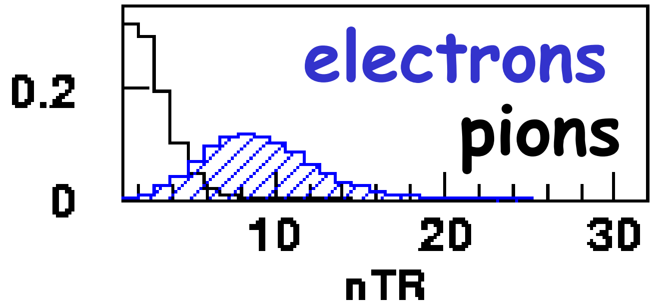
Electron Efficiency ~ 70% with stringent cuts, Jet Rejection Factors ~ 10^5

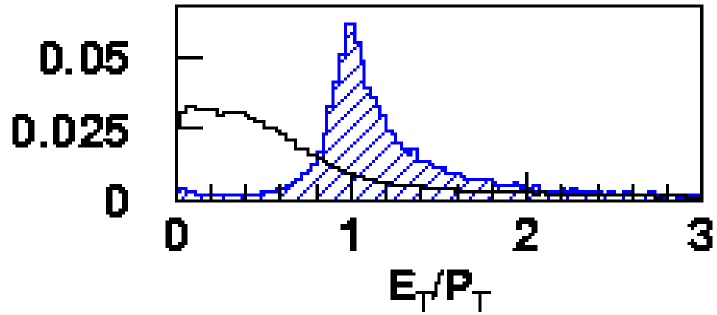
(large systematic errors, sensitive to fragmentation models)

Cuts	Low luminosity						High luminosity			
	Eff e_{20} (%)		Eff e_{30} (%)		Rej jets (10^3)		Eff e_{30} (%)		Rej jets (10^3)	
LVL1	94.0		99.0		0.08		96.1		0.09	
LVL2 Calo	90.5	(96.3)	96.9	(97.8)	0.39	(4.9)	92.1	(95.6)	0.48	(5.2)
LVL2 ID	82.5	(91.1)	87.9	(90.7)	3.5	(8.9)	82.5	(89.5)	3.7	(7.8)
Offline Calo	80.9	(98.1)	86.8	(98.6)	9.8	(2.8)	81.1	(98.3)	8.4	(2.2)
Offline ID	77.4	(93.8)	83.0	(94.5)	16.8	(1.7)	77.2	(93.6)	22.7	(2.7)
Matching	75.4	(97.5)	79.5	(95.7)	40	(2.4)	75.3	(97.4)	35.8	(1.6)
TR	68.5	(90.8)	72.7	(91.4)	>150		67.5	(89.7)	>45	

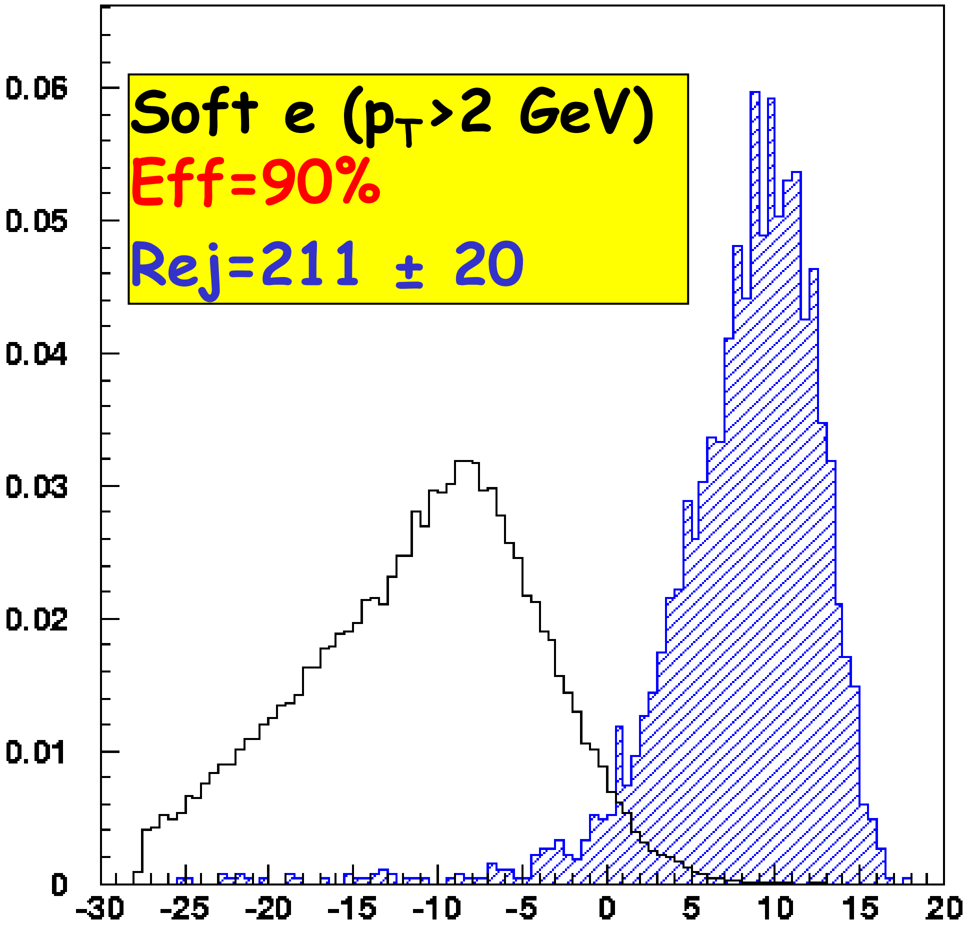
SOFT ELECTRONS

TR hits

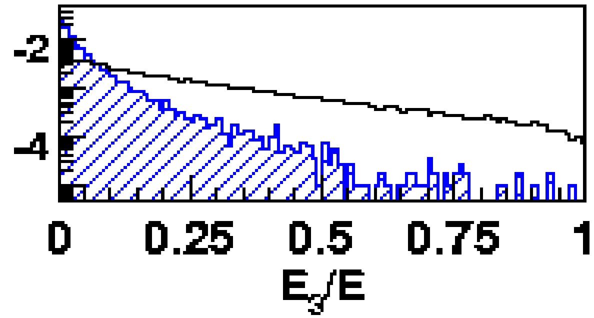




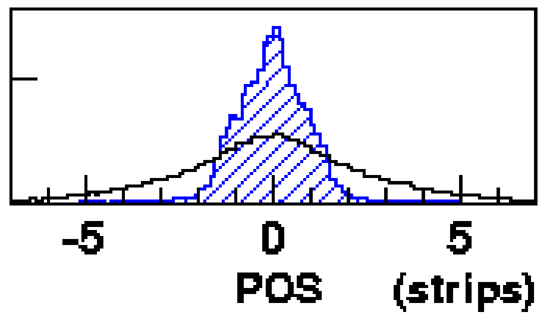
Et(calo)/pt



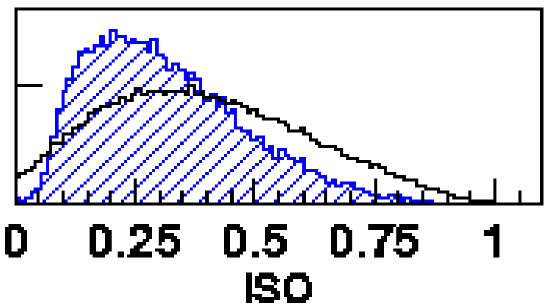
log(ΠPDF(e)/ΠPDF(h))



fraction of E in 3rd sampling



diff between shower and impact position



shower isolation

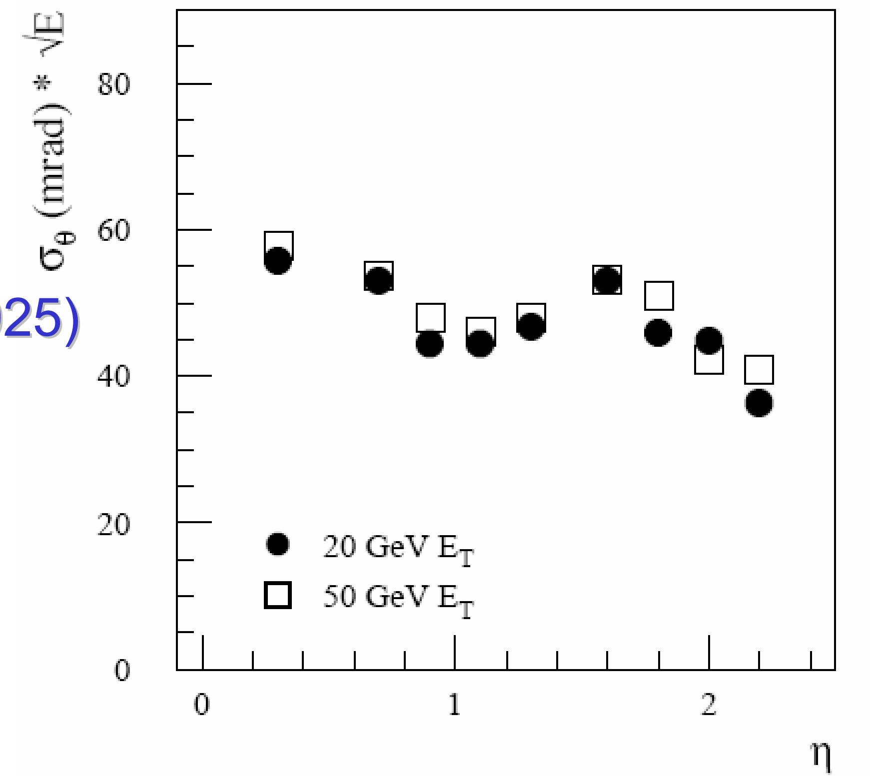
Pointing with Photons

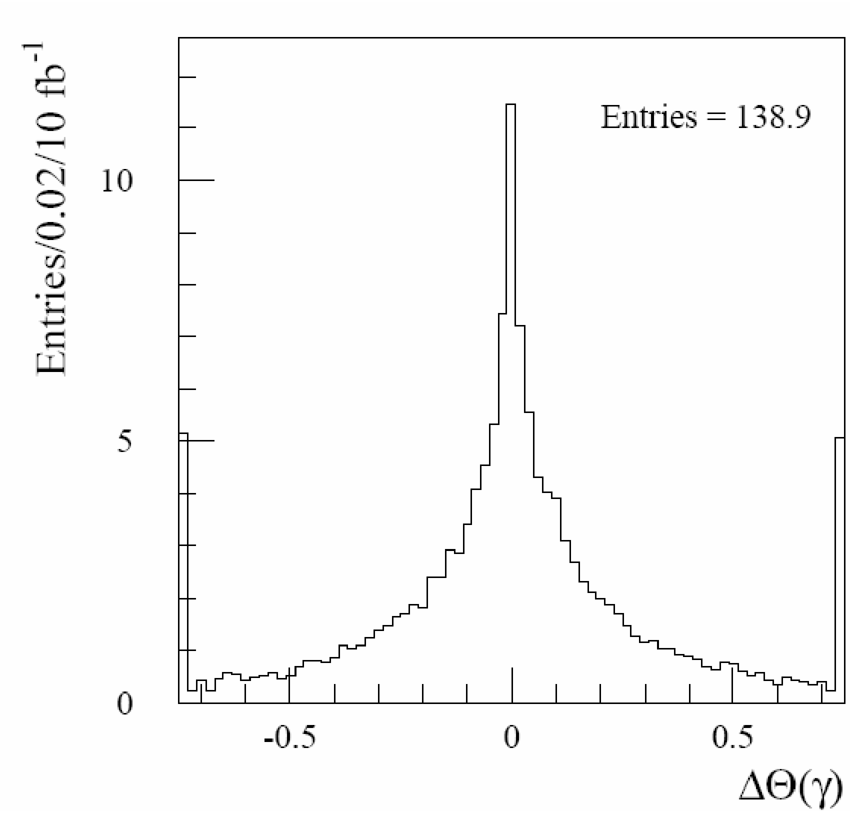
CMS relies on other charged tracks in event

or converted photons

ATLAS : Relies on extrapolation using

first ($\Delta\eta$ = 0.003) and second sampling ($\Delta\eta$ = 0.025)





$\Delta\Theta$ from $\chi^0 \rightarrow \hat{G}\gamma$ for $c\tau$ = 1.1 km

→ 180 will decay in tracker volume for 10 fb^{-1}

→82% efficiency for $\Delta\Theta > 5\sigma$

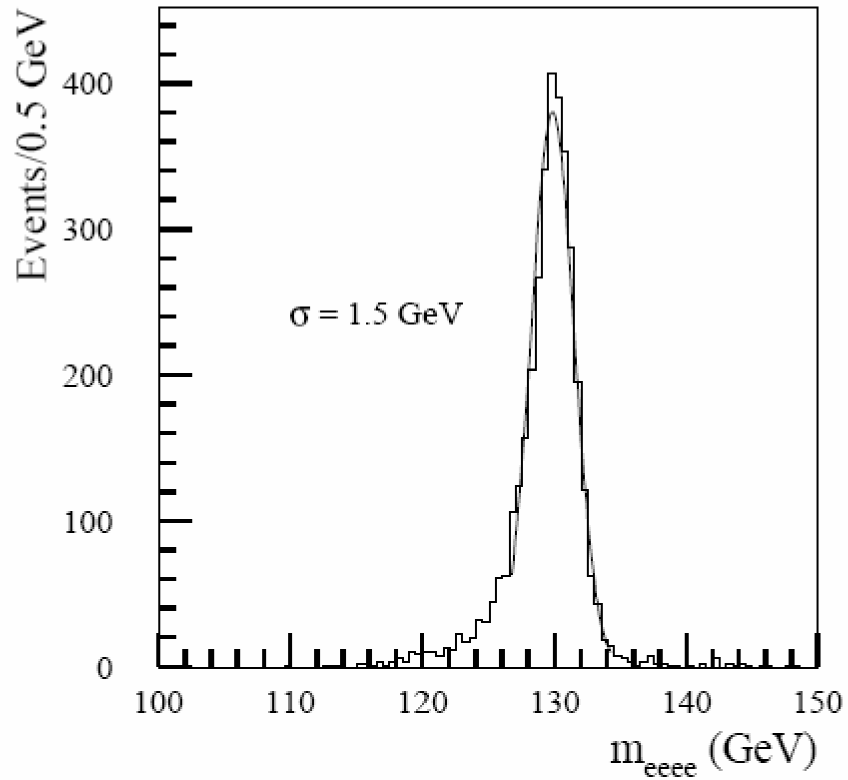
→Allows to set limit of $c\tau$ = 100 km with 30 fb^{-1}

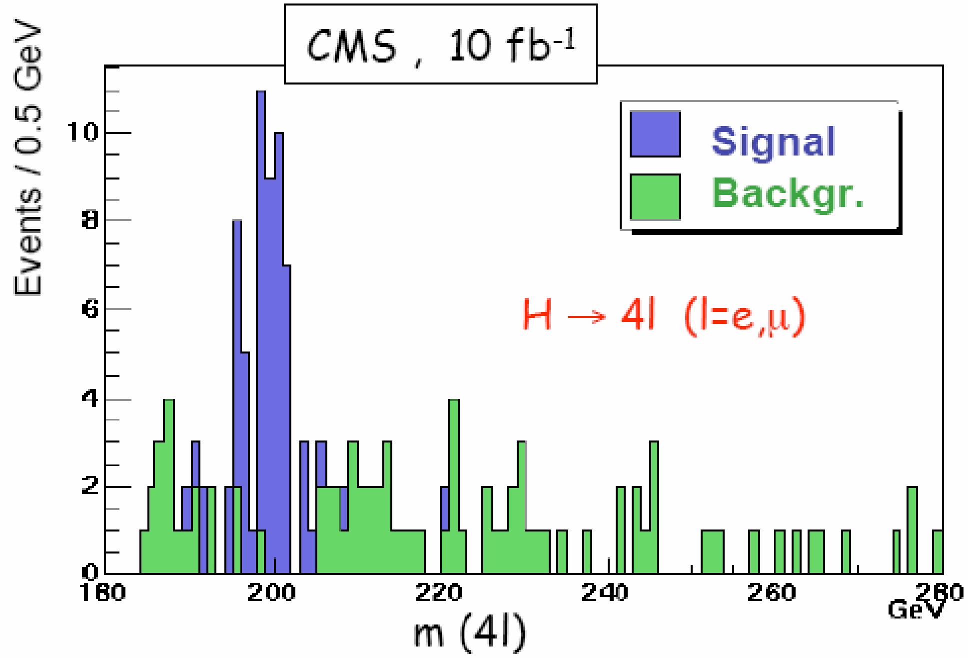
(If no non-pointing photons are found)

Impact on H→4ℓ

Mass resolution at 10^{33} = 1.54 GeV
Resolution at 10^{34} = 1.87 GeV
Acceptance in ± 2σ window ~ 85%
Efficiency of four electron id ~ 69%
→ Average Eff per electron ~ 91%

5σ discovery potential for m_H = 200 GeV
Requires good quality E, p measurement in ECAL and Tracker to limit tails and improve σ/m ~ 1%





Tau Identification

- Three primary cuts are used to identify tau's:
  - R_{EM} : Radius computed using EM cells
  - ΔE_T^{12} : E_T in $0.1 < \Delta R < 0.2$
  - N_{TR} : # of tracks with $P_T > 2$ GeV in $\Delta R < 0.3$

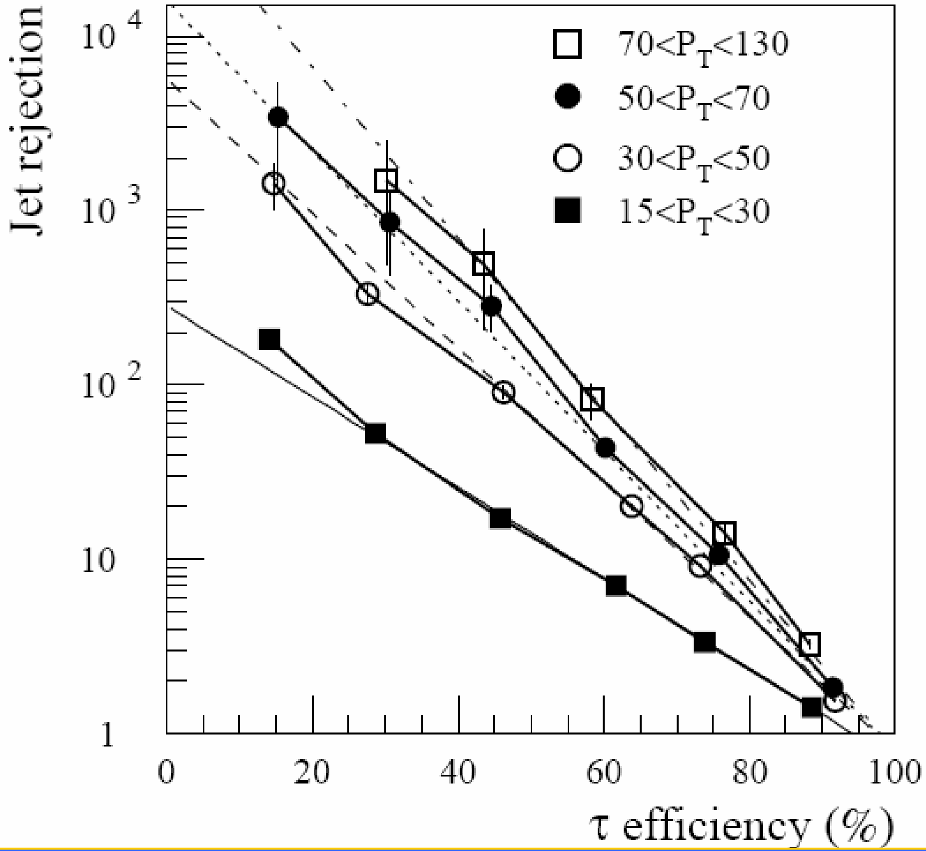
Identification Efficiency and background rejection:

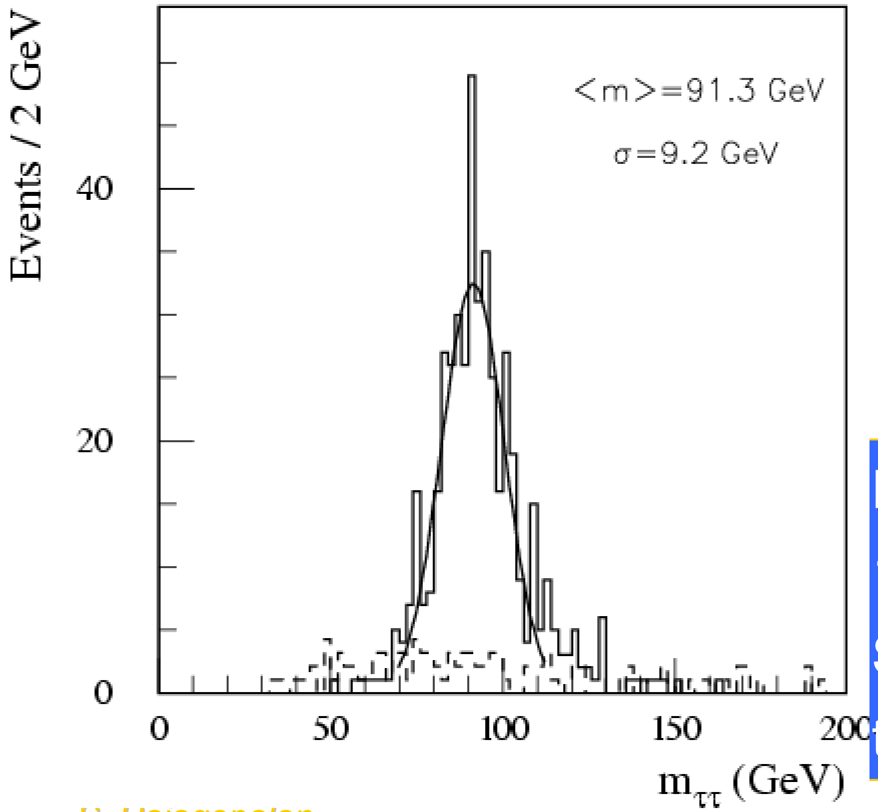
Variable	Cut	$b\bar{b}A \to \tau\tau$	$A \to \tau\tau$	QCD jets	*b*-jets	$t\bar{t}$	*W*+jets
$\langle p_T \rangle$ of τ–jet (GeV)		80	73	44	58	65	52
R_{em}	< 0.07	56 ± 1	45 ± 1	1.1 ± 0.1	1.9 ± 0.4	1.3 ± 0.2	2.9 ± 0.5
ΔE_T^{12}	< 0.1	40 ± 1	32 ± 1	0.6 ± 0.05	0.9 ± 0.2	0.7 ± 0.2	1.8 ± 0.5
N_{tr} ($p_T > 2$)	$= 1$	21 ± 1	17 ± 1	0.09 ± 0.02	< 0.06	0.08 ± 0.06	0.6 ± 0.3
N_{tr} ($p_T > 2$)	$= 1$ or $= 3$	32 ± 1	25 ± 1	0.19 ± 0.03	0.18 ± 0.1	0.2 ± 0.1	1.1 ± 0.3

Tau Identification (2)

Jet Rejection vs tau Efficiency

- Dependence on P_T mainly via R_{EM} cut
- Minimal change at high luminosity





Reconstructed $Z \rightarrow \tau\tau \rightarrow$ jet ν_τ ℓ ν_ℓ ν_τ mass spectrum

1300 events with 10 fb^{-1} (B = 6%)

Select high PT Z ($1.8<\Delta\Phi<2.7$, $3.6<\Delta\Phi<4.5$)

to use Missing ET for reconstruction

Tau Identification (3)

Other approaches being considered for tau identification

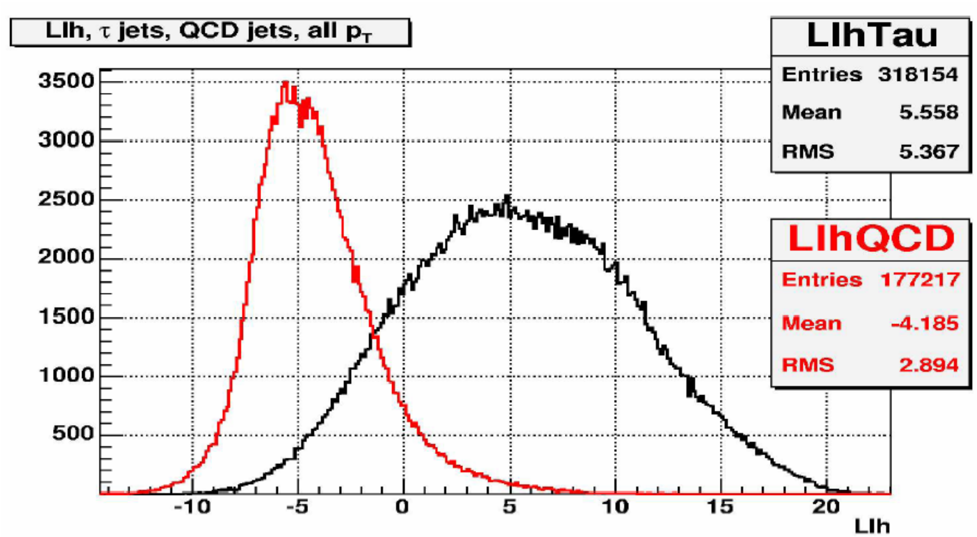
→ Work begun on Likelihood approach

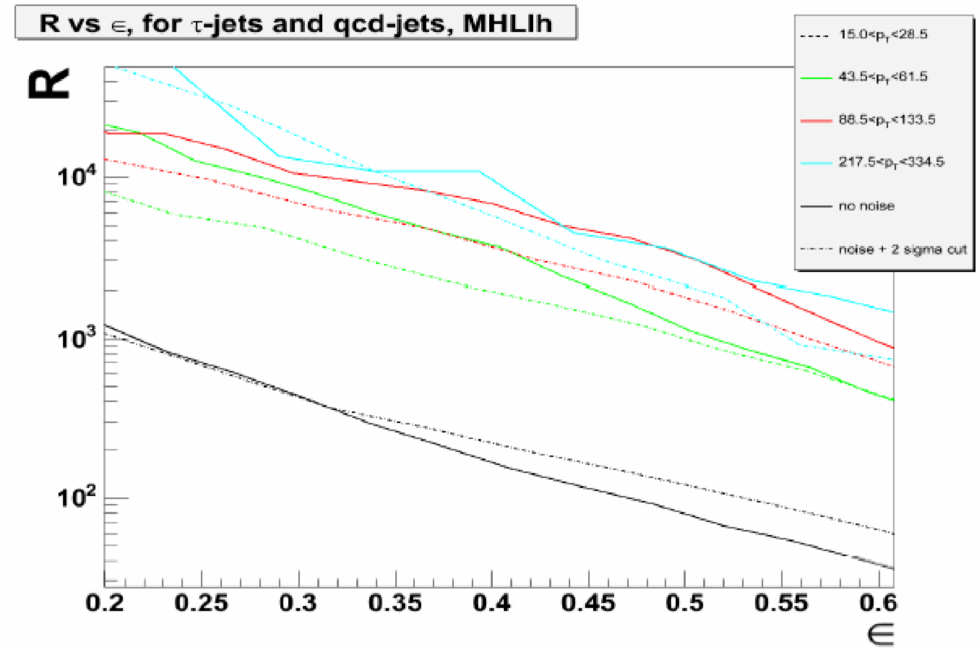
→: Seems to give factor of 2 to 5 improvement in rejection over simple cuts

→ Caveat: Different sample comparison,

more input variables (impact parameter), large errors (30%)

(Other approaches: Neural network, track based approach + energy flow being investigated)

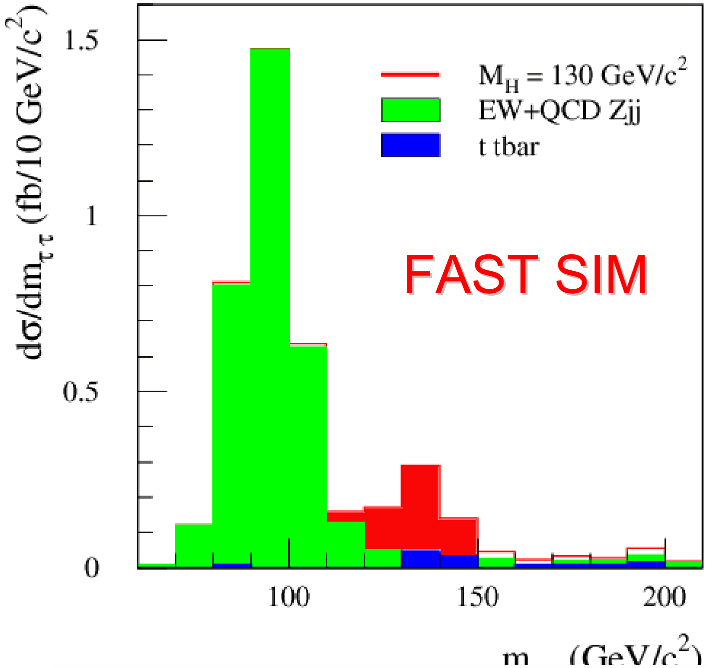


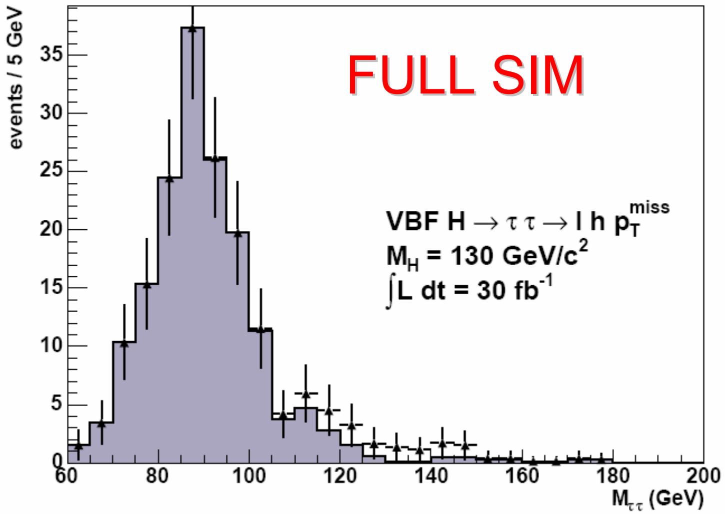


Tau Identification (4) impact on VBF H→ ττ

❄Likelihood approach:

- ❑ L > 1 give single tau efficiency of 70% with background of ~ x100
- ❑ 5σ significance for VBF H→ττ expected with 30 fb^{-1} (fast simulation)
- ❑ Studies with full simulation foretell smaller significance
  - ⌘ → realistic tau efficiencies and Missing ET resolutions
  - ⌘ Cuts need to be reoptimized to reflect realism
  - ⌘ Possibility to recover 30% more events which have unphysical solultion





Conclusion

- Lepton-ID studies and impact on physics being studied.
  - Geant-4 based simulation + new reconstruction software
- Experience being gained through
  - Test-beam exercises
  - Data Challenges
  - Commissioning phase to begin soon.
- Must prepare ourselves for Day 1 scenario
  - How to deal with limited understanding of detector sub-systems?
  - Experience from Tevatron can play a crucial role
  - To bring us up to speed quickly and be in a position for real physics

What are the elements of reconstruction

Digitized Output to Reconstructed Energy

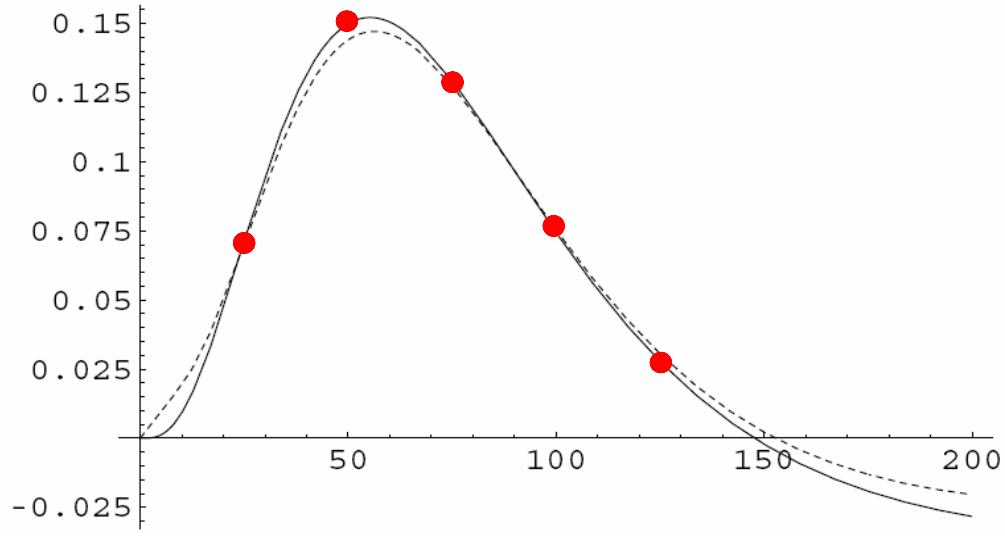
Compute cell energy from digitized waveform

$E = F * \sum a_i S_i$

S_i = digitized samples
(digitized every 25 nsec)

F = ADC→DAC→μA→GeV*SF

a_i = Optimal Filtering Coefficients
Measured using physics pulse shape (g_i)
→ Need to derive from calibration signals



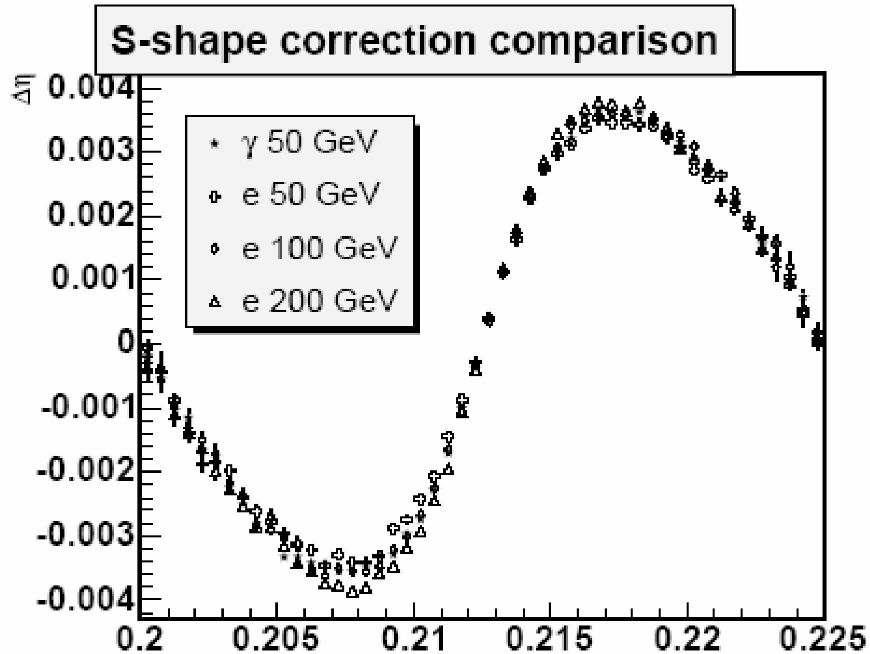
$$a_i = \frac{\sum_j B^{-1}_{i,j} g_j}{\sum_{j,k} g_j B^{-1}_{j,k} g_k}$$

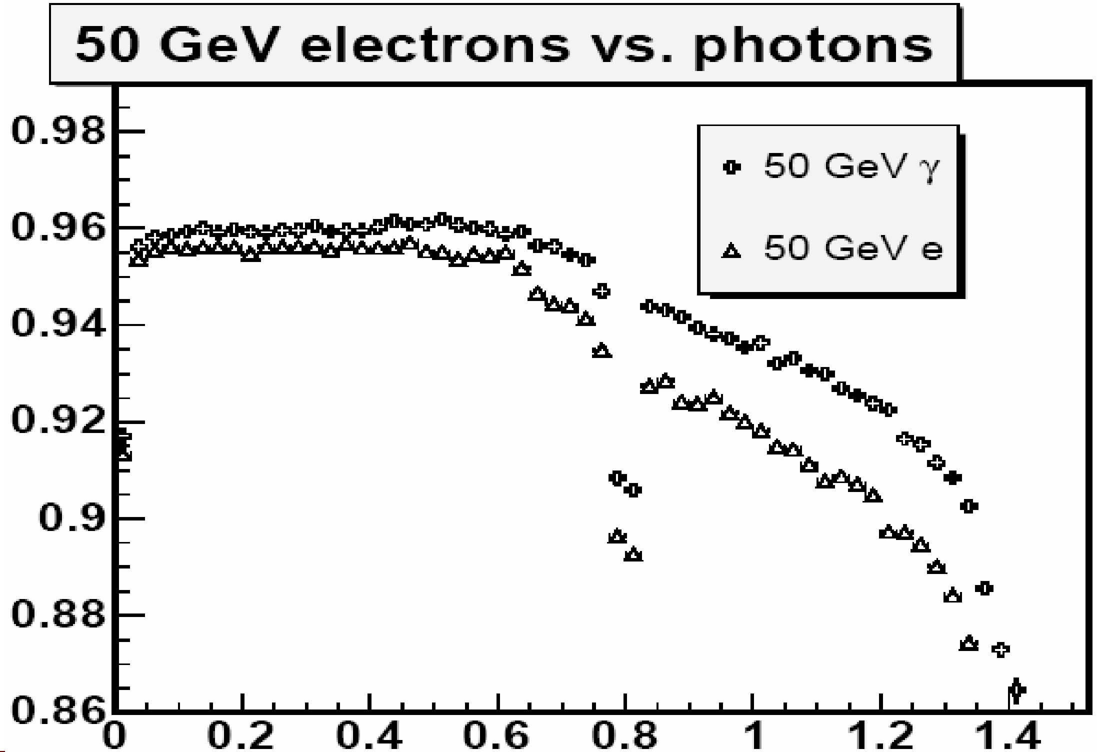
TB data has shown we can predict physics pulse shape from calibration signals to better than 0.2%. But need to understand underlying event effects

Need to verify during real data taking from a sample of isolated electrons

Clustering

- Measure Cell energy to EM scale
  - Correcting for HV, dead channels,…
- Calorimeter Clustering: (Cone, Nearest Neighbour)
  - Two clustering algorithms being studied : Cone and Nearest Neighbour
  - Correct for position biases, energy modulation, upstream material, cracks, containment, etc.





Combined reconstruction

- Combined Reconstruction
  - Identify EM clusters and correct for calorimeter effects
  - Look for well matched track (+ TRT confirmation)
  - Handle conversions and brem recovery
  - Corrections for electrons vs photons
  - → candidates for input to physics analysis.

- Soft electrons
  - Start with track as seed, extrapolate back to calorimeter and cluster.