Leptons and Photons at the (S)LHC

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ILC Physics and Detector workshop

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Outline:

- Introduction.
- e/γ.
- Muons.
- Tau leptons.
- SLHC.
- Summary.

The LHC Environment

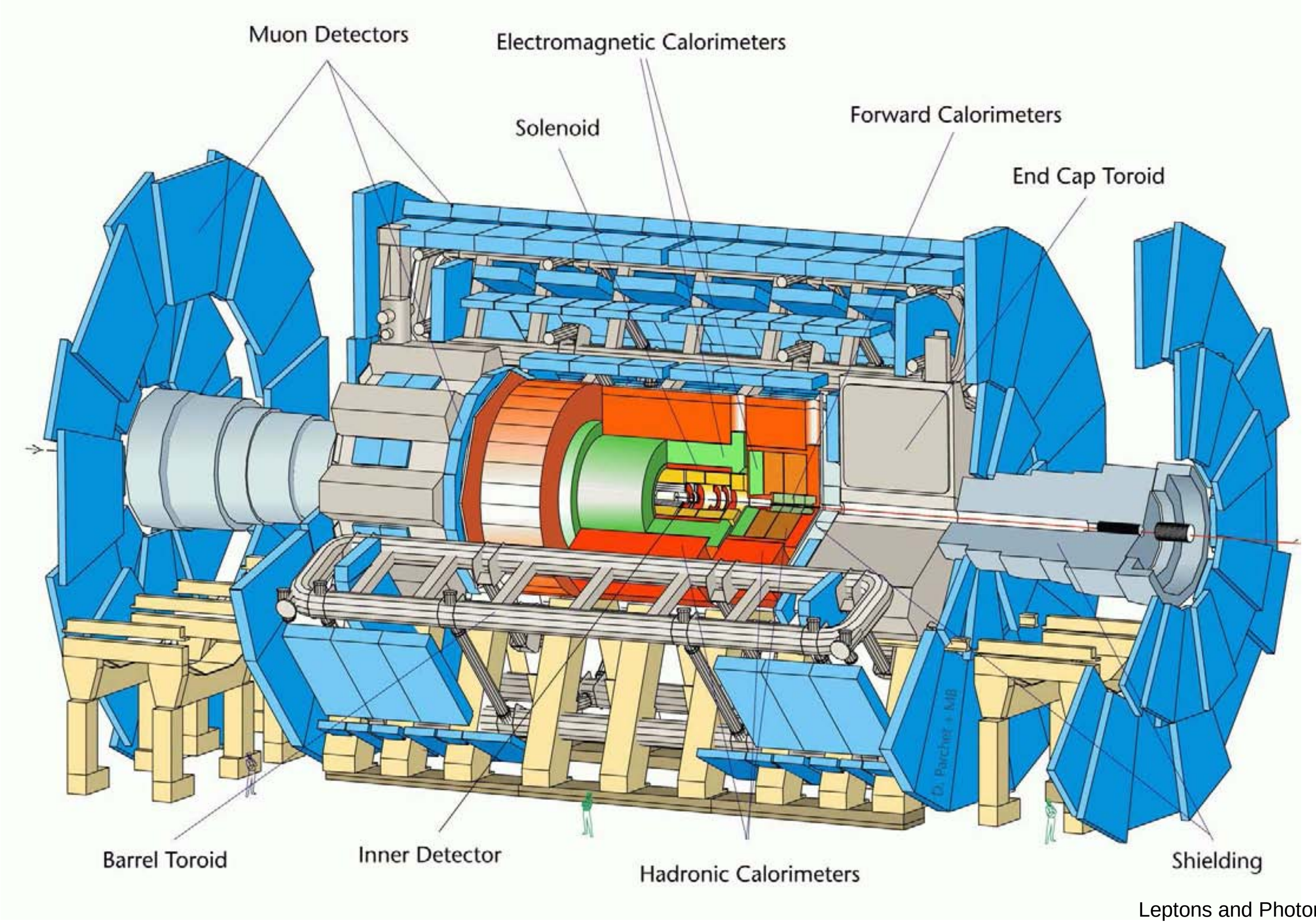
- Basic LHC parameters:

Beams	$p \times p$
C.O.M. energy	14 TeV
Luminosity	10^{33} cm^{-2} s (low)
	10^{34} cm^{-2} s (design)
Avg. interactions per crossing	23
Crossing period	25 ns

- The big detector design challenge is dealing with the large luminosity (and small bunch spacing and large pile-up).
- Example: muon systems designed to produce useful physics standalone at the highest luminosities, in case the inner tracking is degraded.
- There will be a period of low-luminosity running before high-luminosity running. Some detector capabilities may degrade at high luminosity (such as b-tagging).
- Two major, general-purpose pp detectors: ATLAS and CMS.

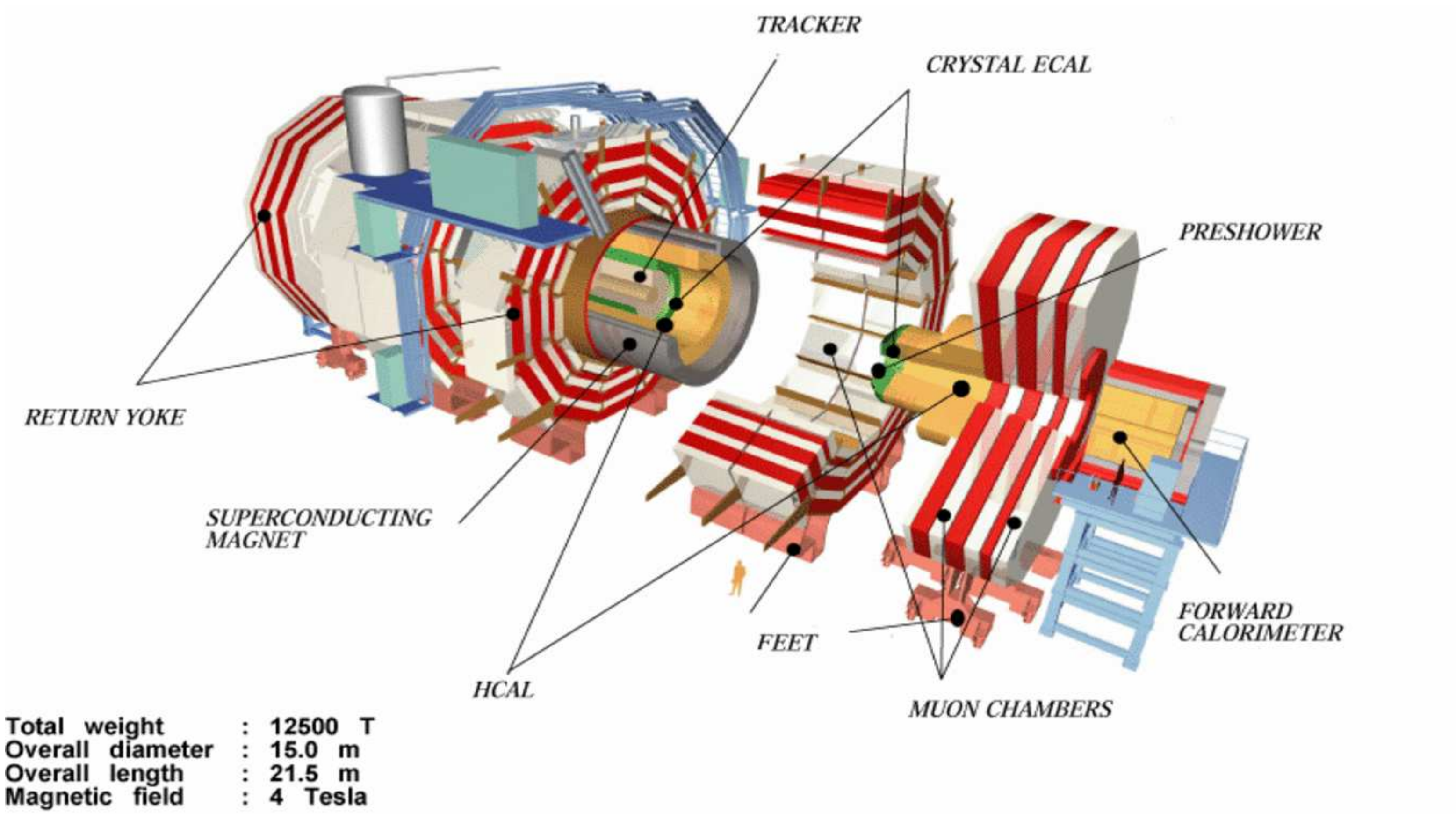
ATLAS

- Inner detector and solenoid contained within calorimeters.
- LAr/Pb (EM), LAr/Cu (forward had), and Fe/scintillator (central had) calorimetry.
- Large air-core toroid muon system.



CMS

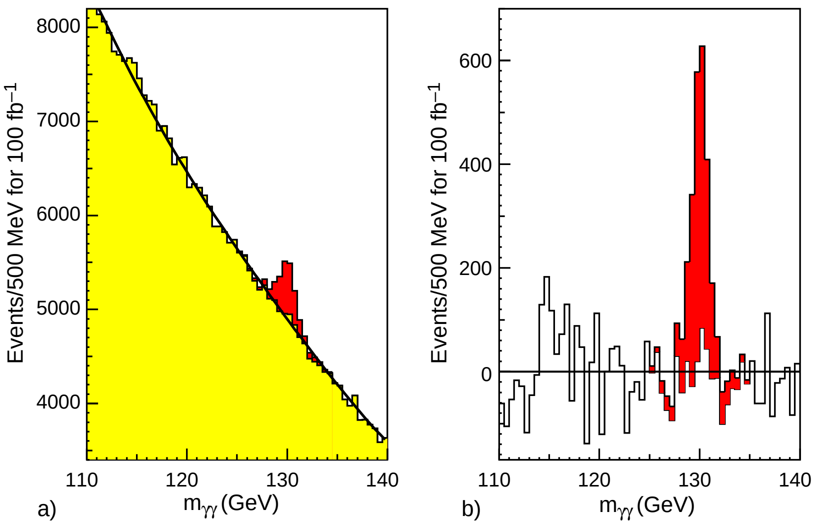
- Major feature is the solenoid — 13.5 m $\times$ 6 m with a 4 T field. Calorimeters are contained within the solenoid.
- Muon chambers interspersed with iron flux return.
- Crystal $PbWO_4$ EM calorimeter. Cu/scintillator hadronic calorimetry.



e/γ Performance Requirements

- Set by benchmark physics processes.
- Z', W' searches require electron sensitivity up to 5 TeV.
- Should have sensitivity down to 1–2 GeV for $b \rightarrow e$.
- Resolution requirements set by $H \rightarrow \gamma\gamma$ channel.
  - Need mass resolution of $\sim 1\%$.
  - Requires both good energy and angle measurements.
  - Also need very good γ/jet separation.
- Performance must not degrade unduly at the highest LHC luminosities.

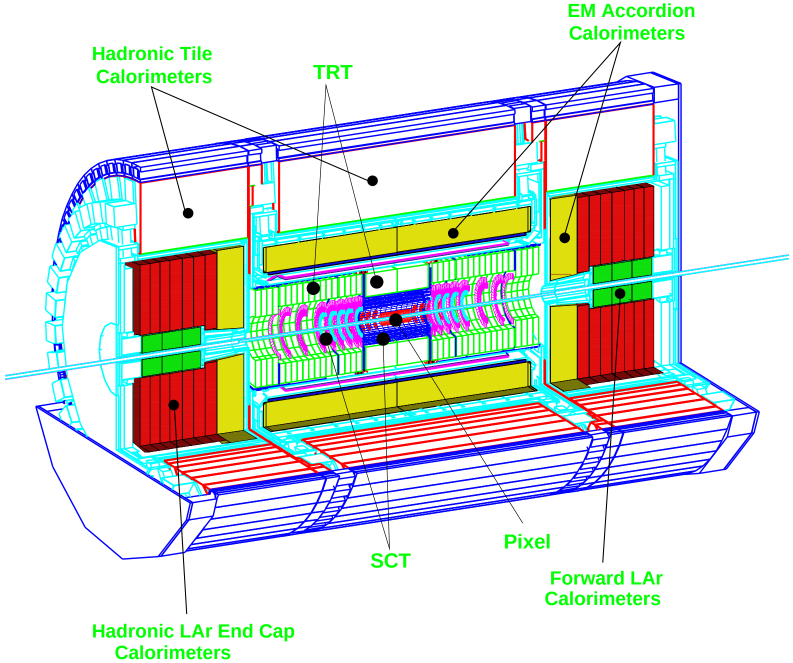
- CMS: Mass resolution < 700 MeV.
- Mass peak from $H \rightarrow \gamma\gamma$ with $m_H = 130$ GeV (100fb^{-1}):

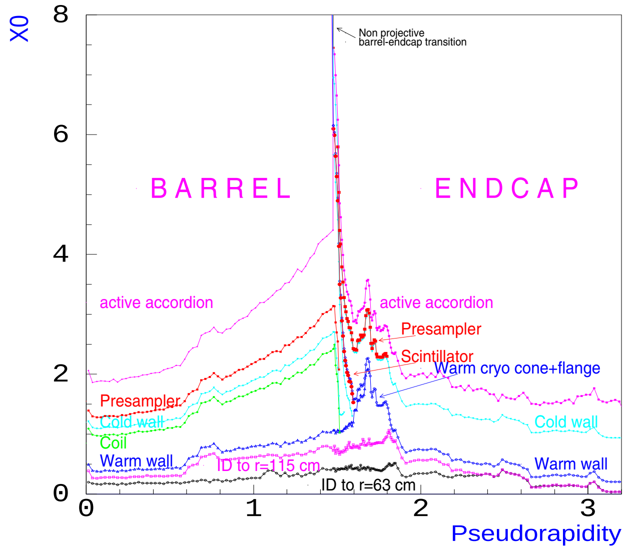


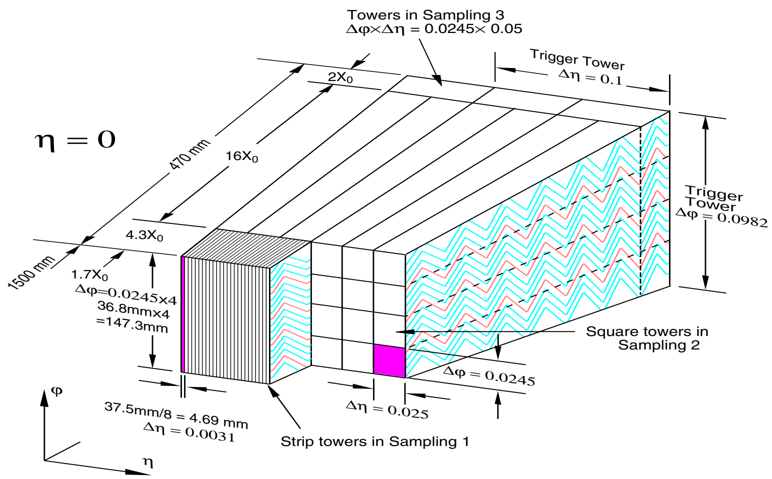
- Gives 5σ significance for 30 fb^{-1}.

ATLAS e/γ measurement

- Pb/LAr sampling calorimeter.
- Accordion geometry.
- Presampler plus three longitudinal samplings; 22-33 X_0.
- Granularity: Strips: 0.003×0.1, middle: 0.025×0.025, back: 0.05×0.025.
- Tracking: Pixels + Si strips (SCT) + straw tubes with transition radiation detection (TRT).

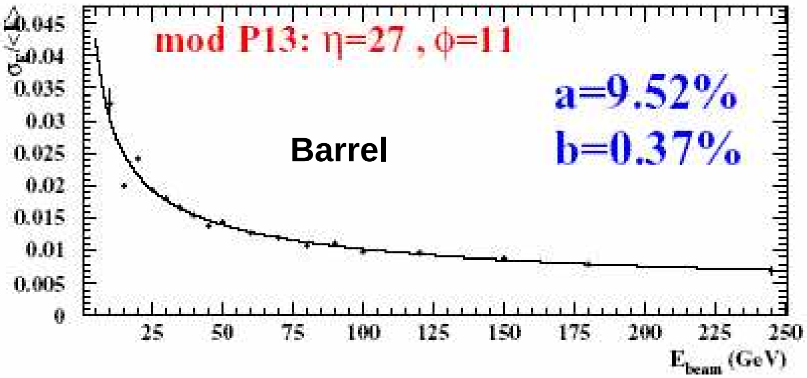


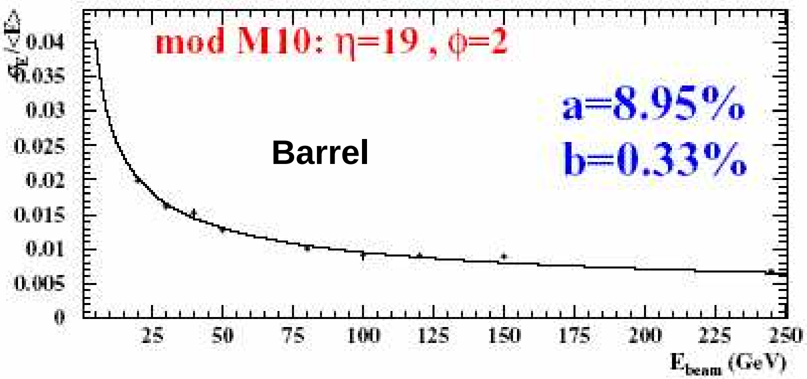


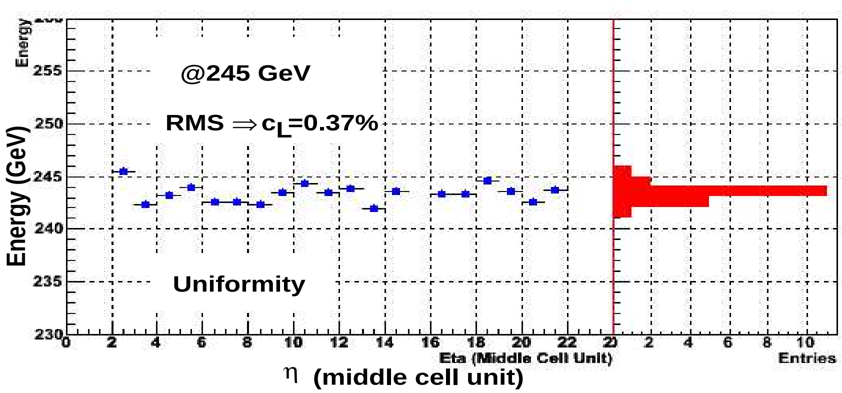


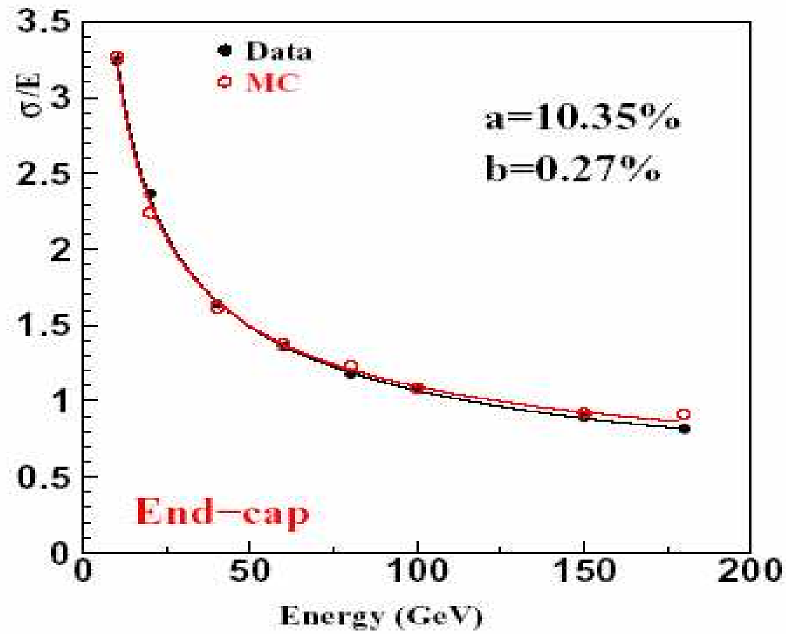
ATLAS LArEM test beam results

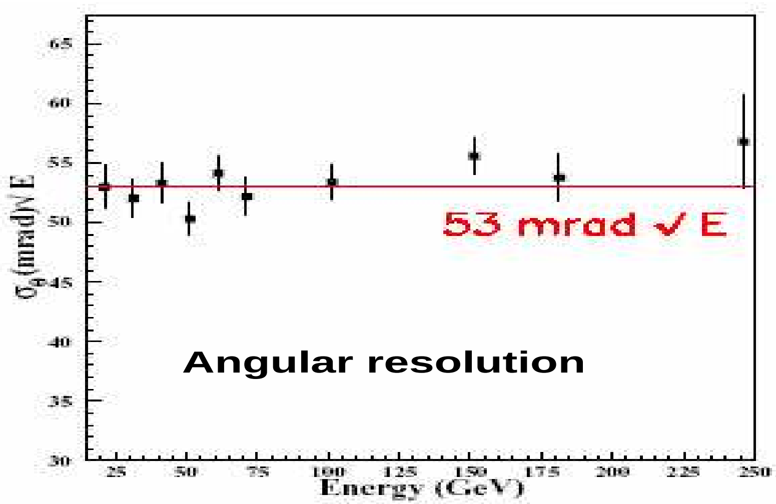
$\sigma_E/E = a/\sqrt{E} \oplus b$. Goal: $a \sim 10\%$, $b < 0.7\%$.





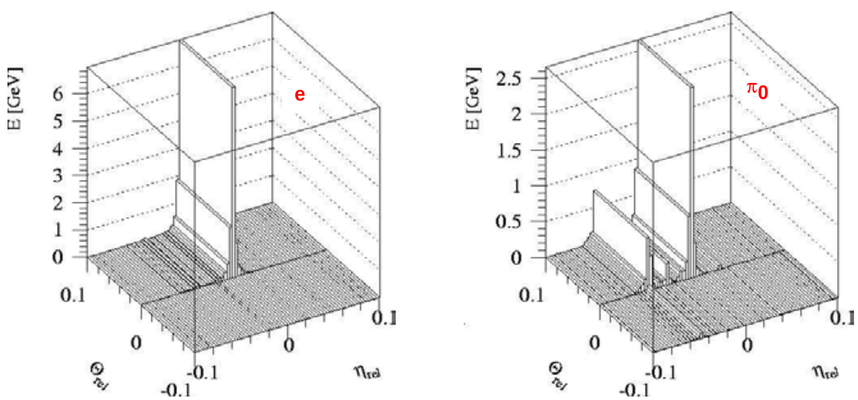


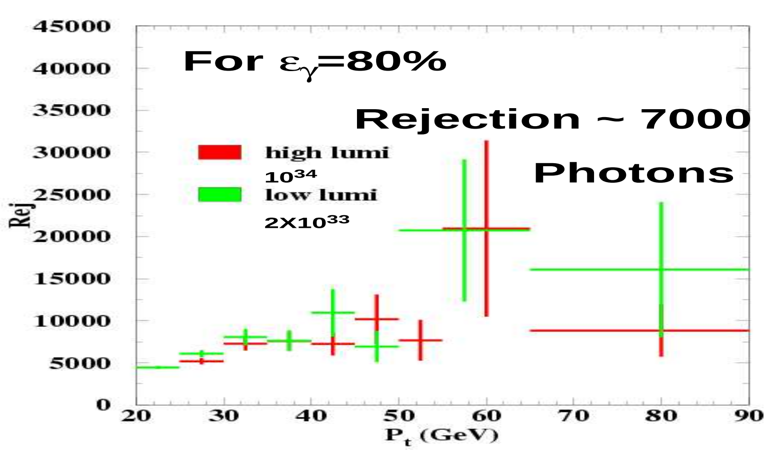




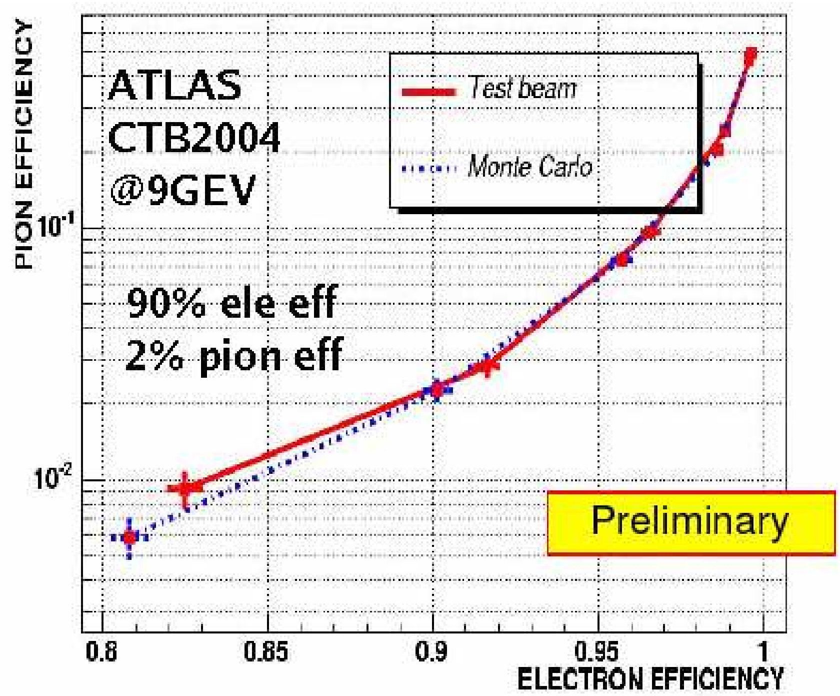
ATLAS e/γ ID

- Use hadronic leakage, longitudinal profile, transverse shape in middle sampling.
- Use narrow strips to reject π_0.





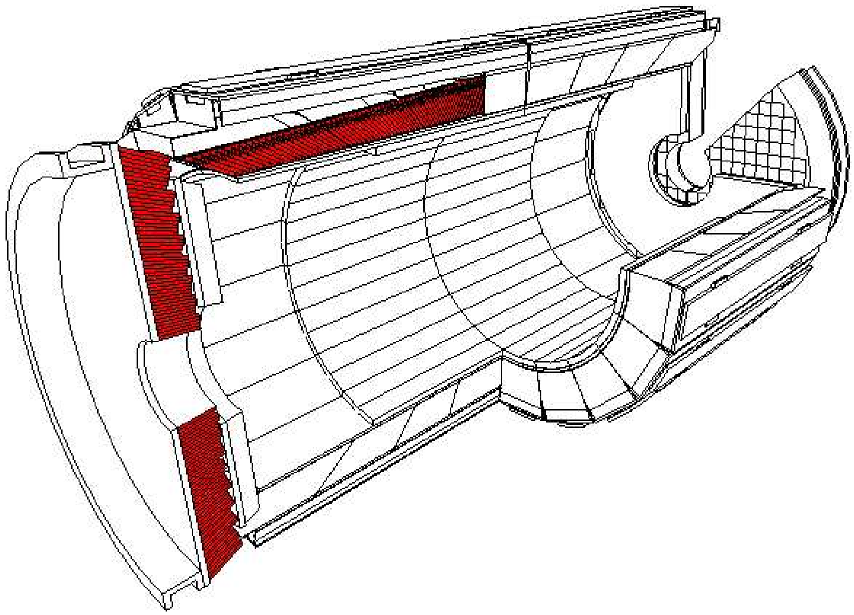
- Can also use TRT information.

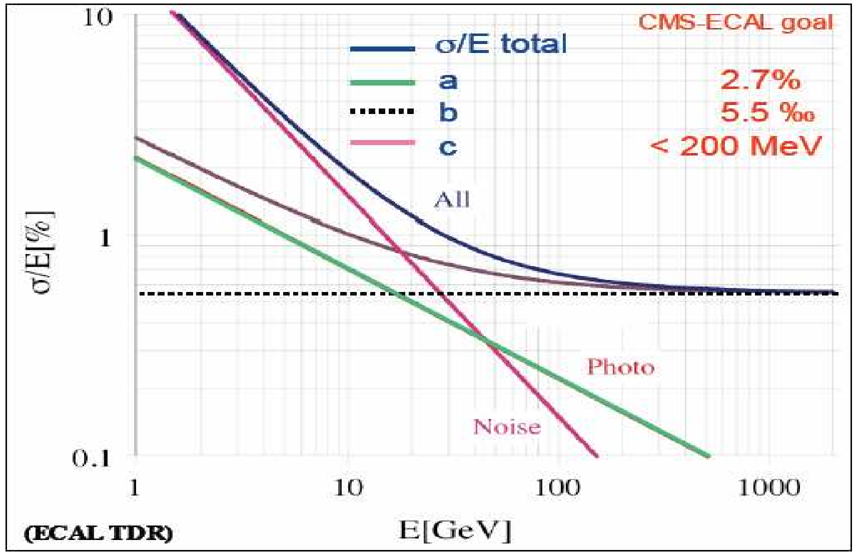


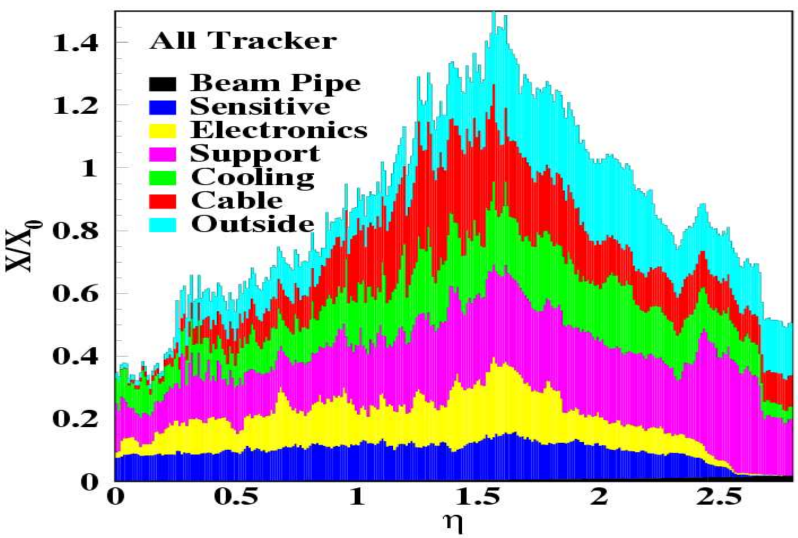
e ID cut	$\epsilon(\%)$	$R_{\rm jet}(p_T > 17\,\text{GeV})$
Calo shape	91.5 ± 0.4	3000
Track exists	87.4 ± 0.05	36000
Track match	82.2 ± 0.6	103000
TRT	79.0 ± 0.6	222000

CMS e/γ measurement

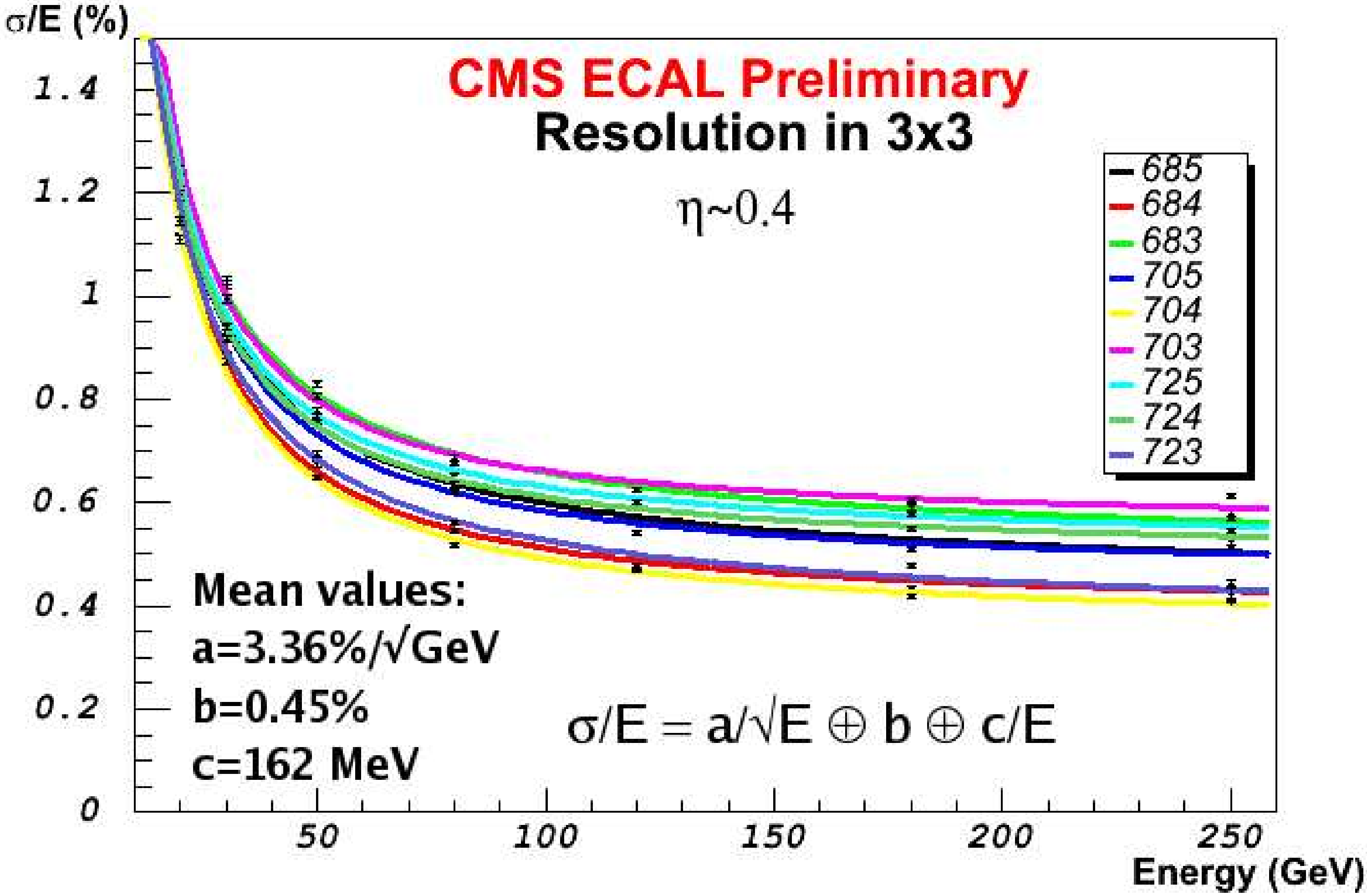
- Fully active crystal EM calorimeter.
- ~ 80000 $PbWO_4$ crystals. Thickness $26X_0$ (22–23 cm). Granularity: 0.0175×0.0175 (barrel).
- Readout: avalanche photodiodes (barrel) and vacuum phototriodes (endcap).
- Tracking: pixels and Si strips. Calorimeters inside solenoid. Upstream material $\sim 1X_0$.
- Pb/Si strip preshower in endcaps.





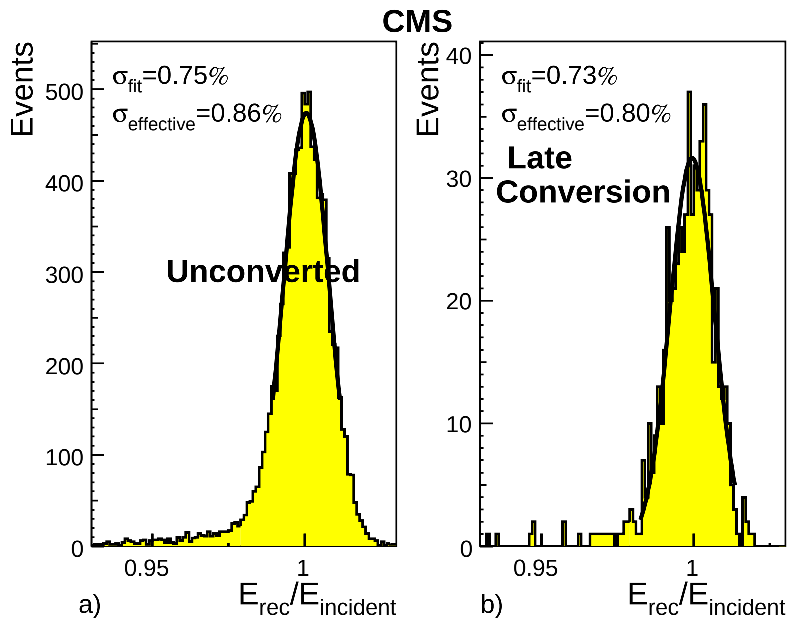


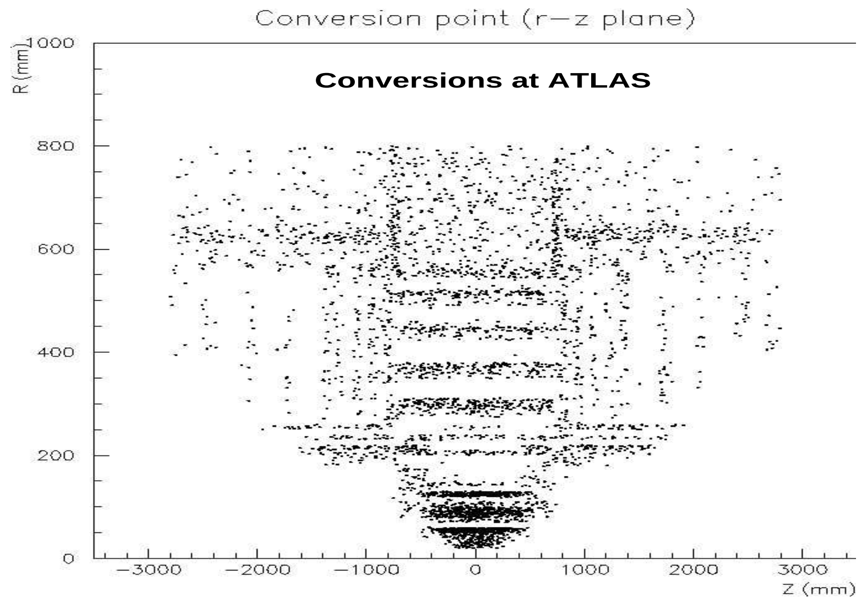
CMS EM Test Beam Results

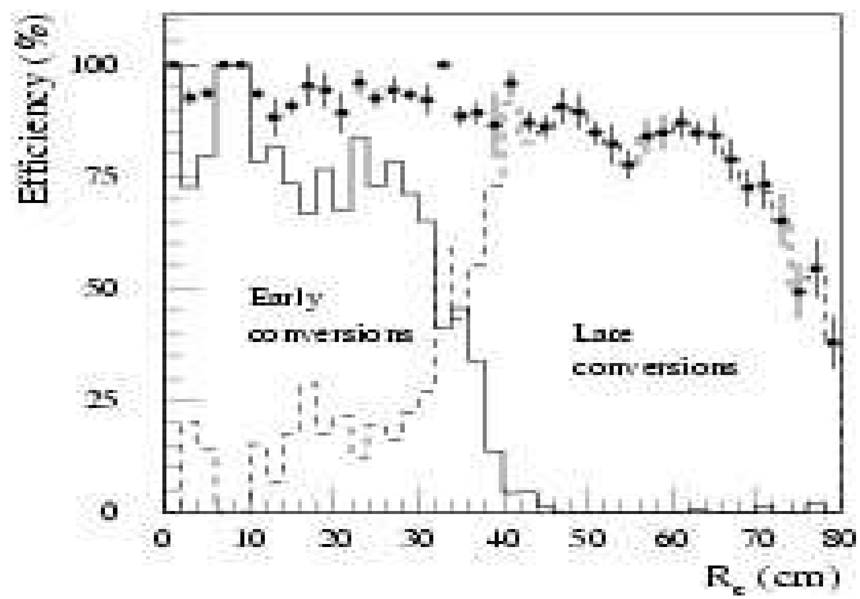


Conversions

- 20–30% of photons convert within the tracker.
- $\sim 80\%$ of those can be reconstructed. (Both expts.)
- Conversions after the tracker do not degrade resolution much.

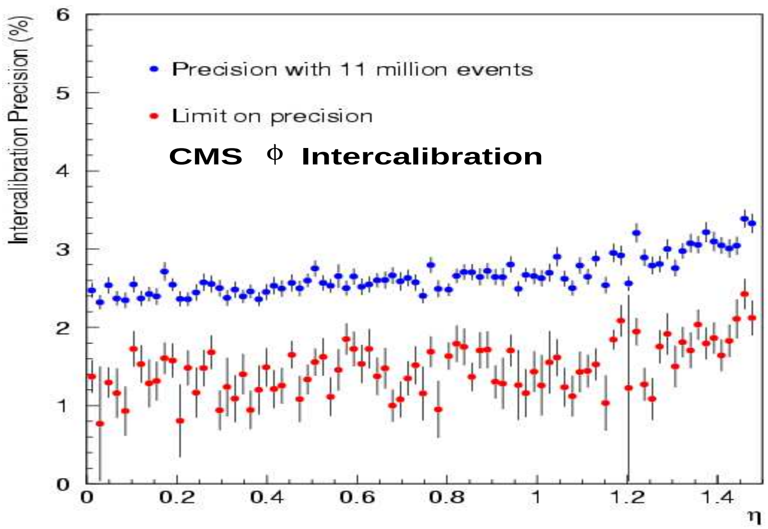


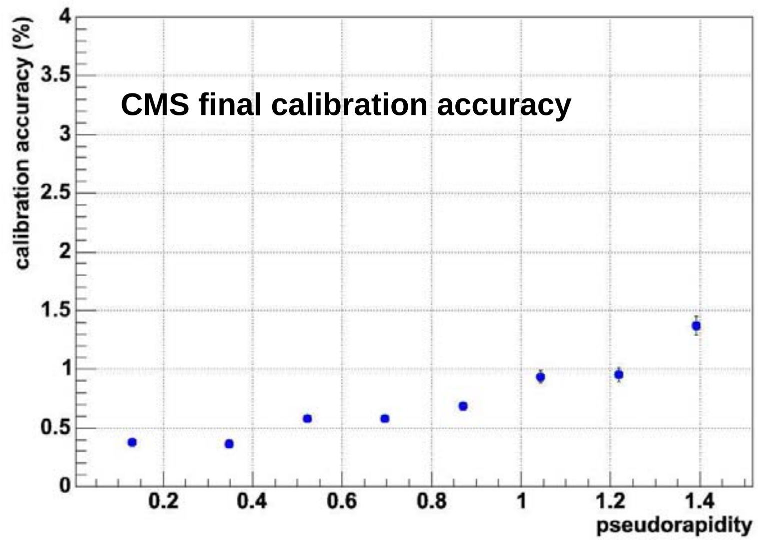




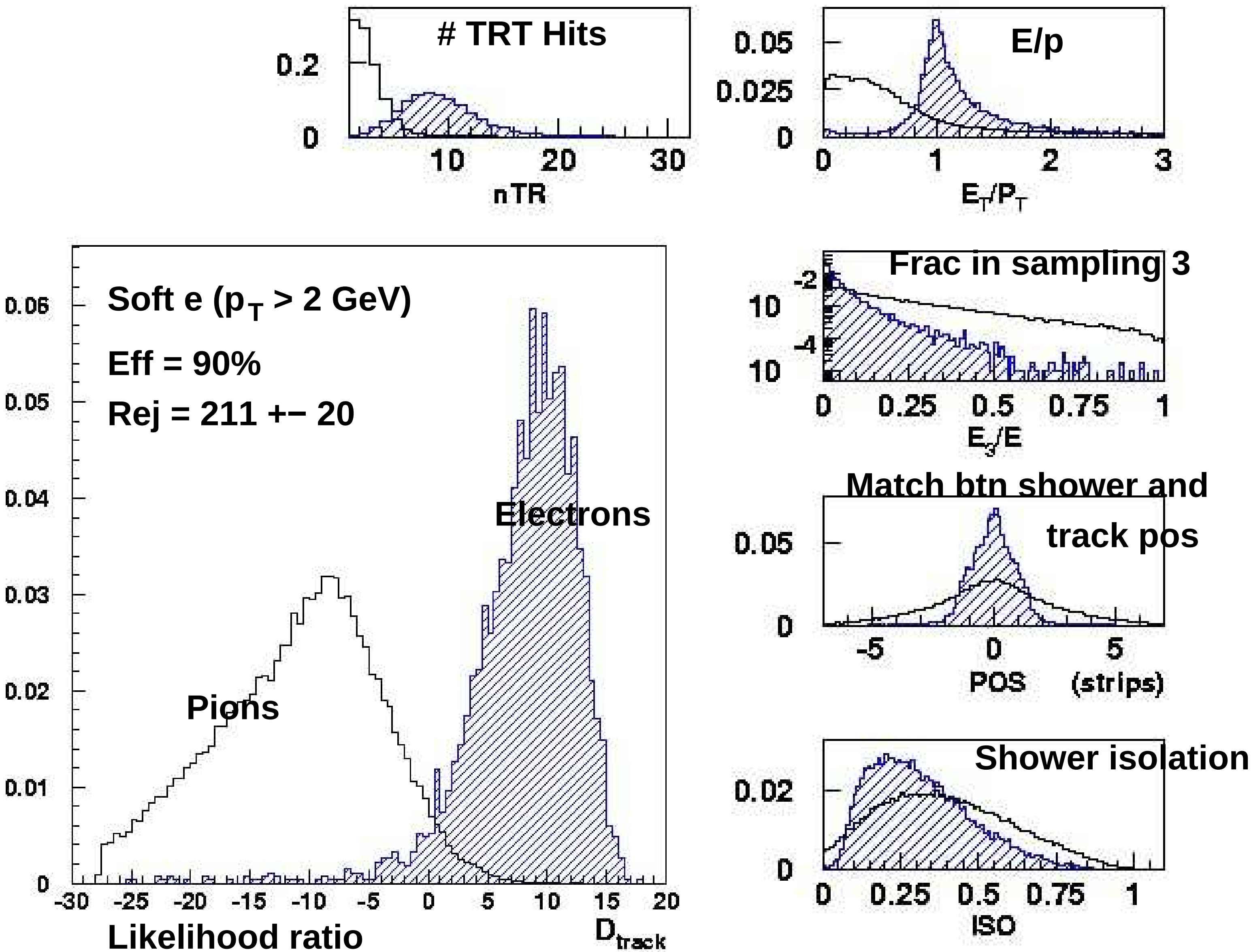
Calibration

- CMS calibration scheme. Goal is to reduce constant term b to $\sim 0.5\%$.
- Precalibration via lab measurements gives $\sim 4\%$.
- ϕ uniformity: Intercalibration using min bias or jet triggers at start of running gives 2–3% precision with a few hours' data.
- $Z \to ee$ gives $< 1\%$ in $\sim$ 1 day.
- Longer term: calibrate against inner detector using E/p from $W \to e\nu$. Limited by of brem effects.
- Monitor crystal transparency with laser system.
- ATLAS: Local contribution b_L (within module) contribution to $b < 0.5\%$.
- Calibrate long-range variations b_{LR} with $Z \to ee$.
- With 10^5 $Z \to ee$ (few days), expect $b_{LR} < 0.4\%$ and $b < 0.7\%$.



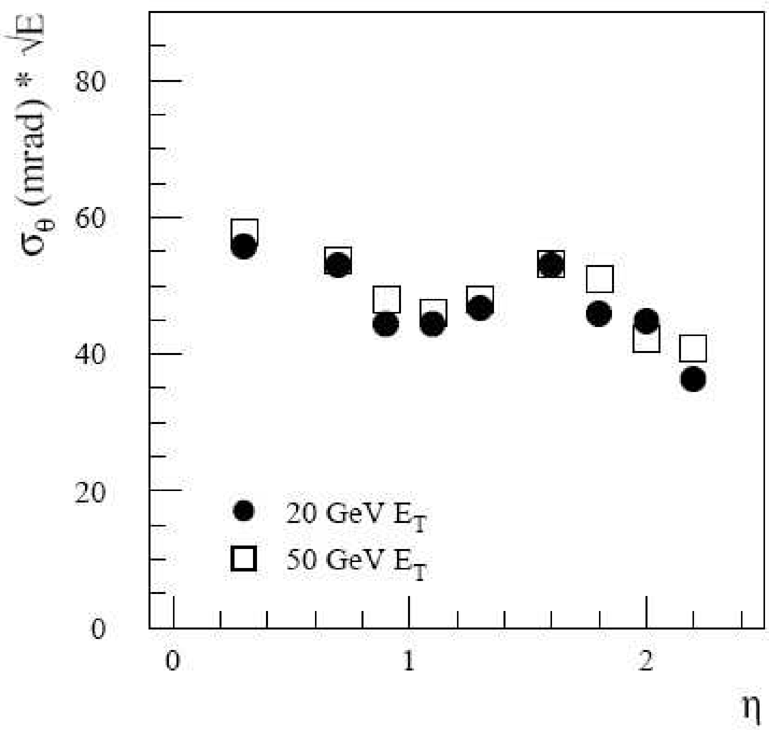


Soft Electrons (ATLAS)

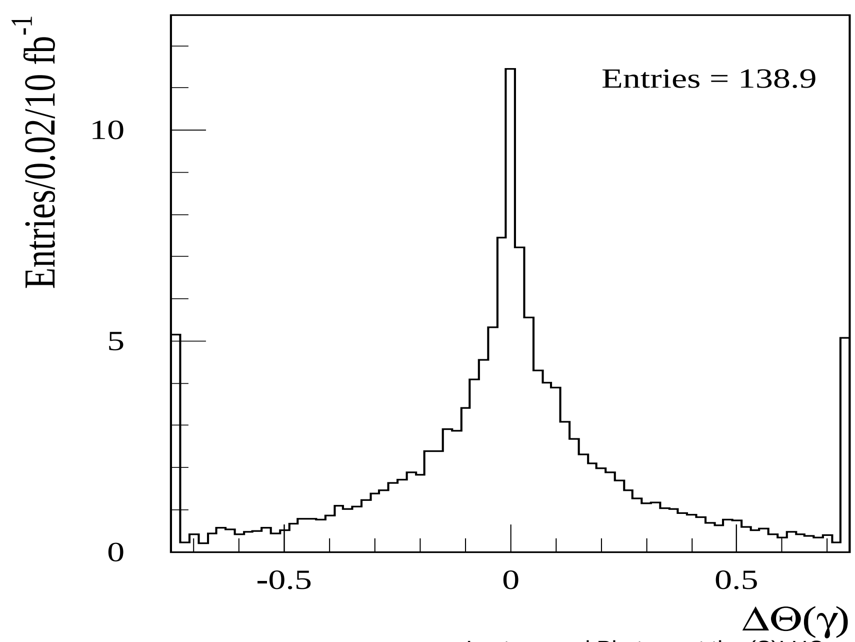


Pointing with Photons

- CMS relies on other charged tracks in event or converted photons.
- ATLAS can extrapolate using first ($\Delta\eta = 0.003$) and second ($\Delta\eta = 0.025$) samplings.

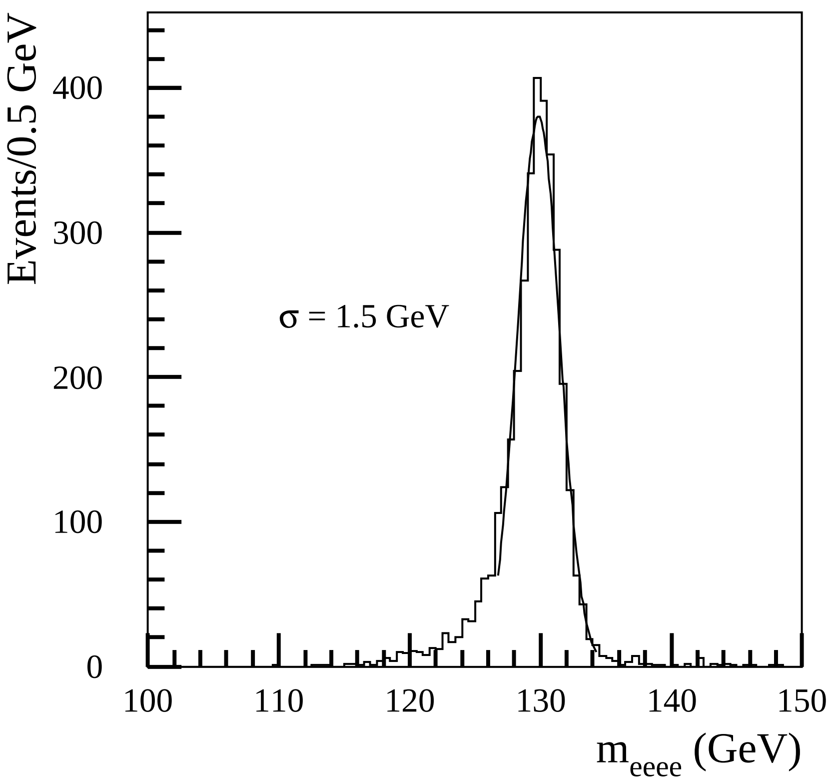


- $\Delta\theta(\gamma)$ from $\chi^0 \to \tilde{G}\gamma$ for $c\tau = 1.1$ km.
- In $10\,\text{fb}^{-1}$, $\sim$ 180 will decay in tracker volume.
- Demand $\Delta\theta > 5\sigma$; gives 82% efficiency.
- Set limit $c\tau > 100$ km with $30\,\text{fb}^{-1}$ (if no candidates).

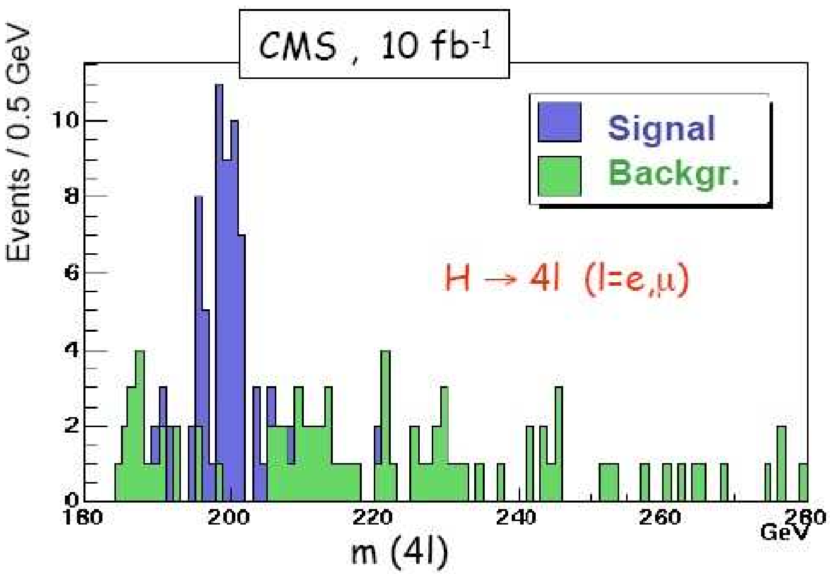


$H \to eeee$

- ATLAS:
- Resolution @ 10^{33}: 1.54 GeV
- Resolution @ 10^{34}: 1.87 GeV
- $4e$ ID eff: 69%

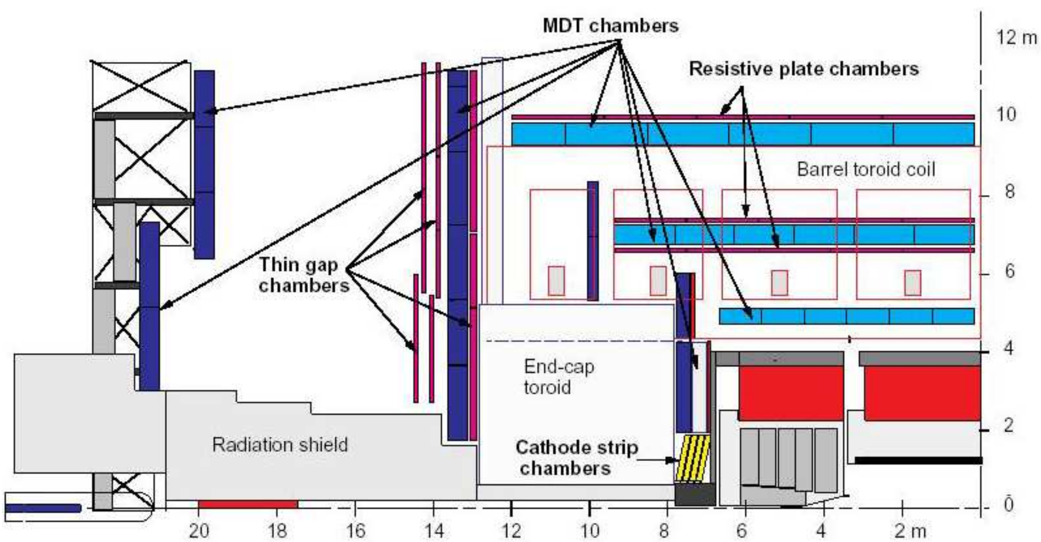


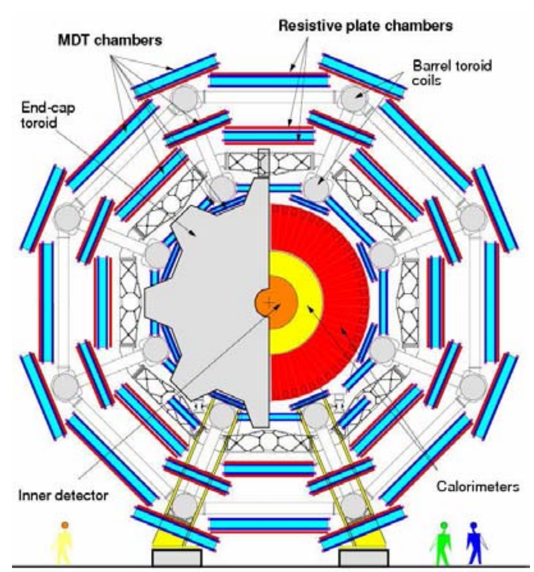
- 5σ discovery potential for $m_H = 200$ GeV.
- Requires good E, p measurements to limit tails to keep H width $< 1\%$.



ATLAS Muon System

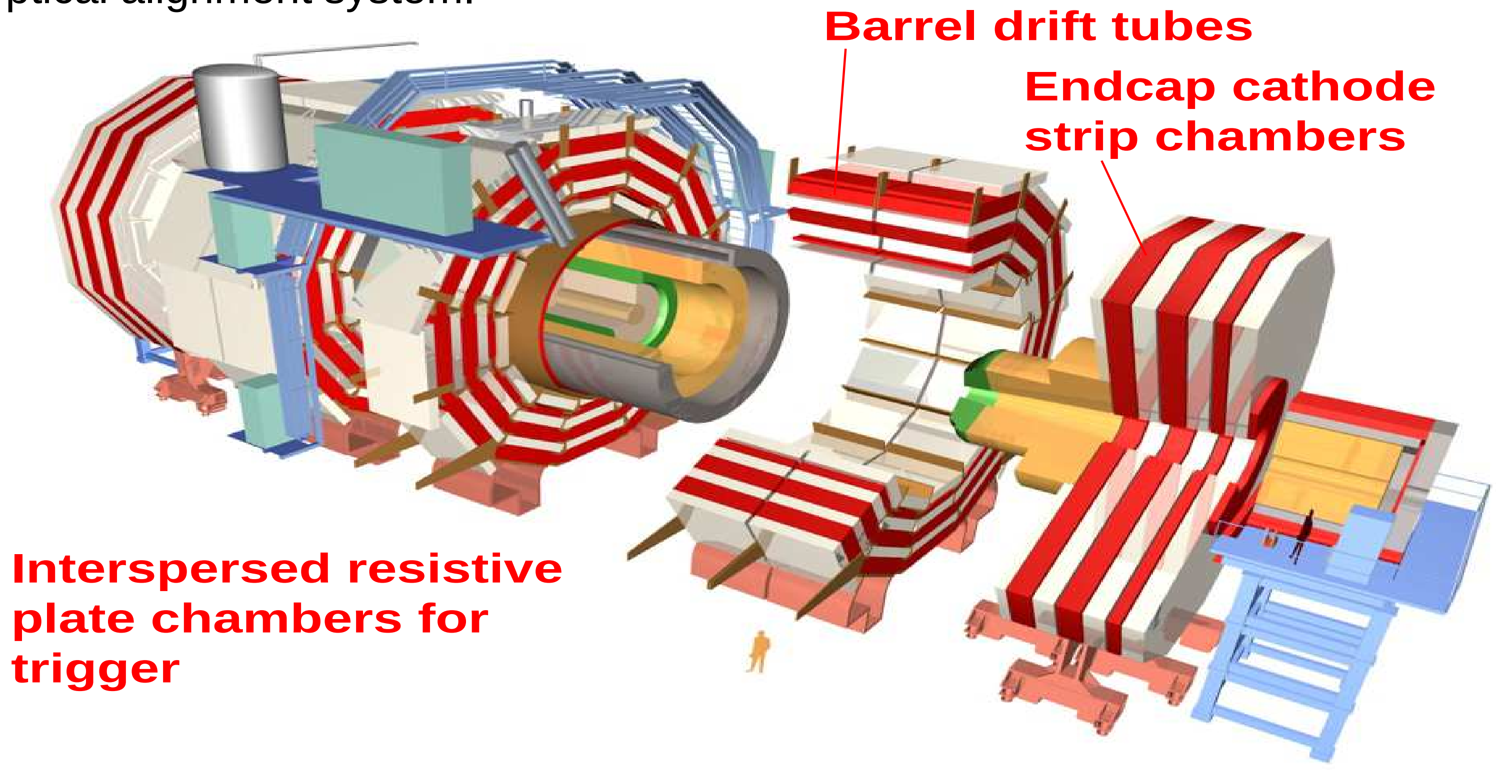
- Air-core superconducting solenoid. $\int B \cdot dl$: 2–6 Tm in barrel, 4–8 Tm in endcap.
- Precision measurement: Monitored drift tubes (MDT) ($|\eta| < 2$), cathode strip chambers (CSC) ($2 < |\eta| < 2.7$). Station resolution $\sim 40\,\mu$m.
- Trigger detectors: resistive plate chambers (RPC) (barrel), thin gap chambers (TGC) (endcap, $|\eta| < 2.4$).
- Design resolution (standalone): 10% at 1 TeV, $< 3\%$ for 10 GeV $< p_T < 250$ GeV.
- Chamber positions and deformations continually monitored with optical alignment system.





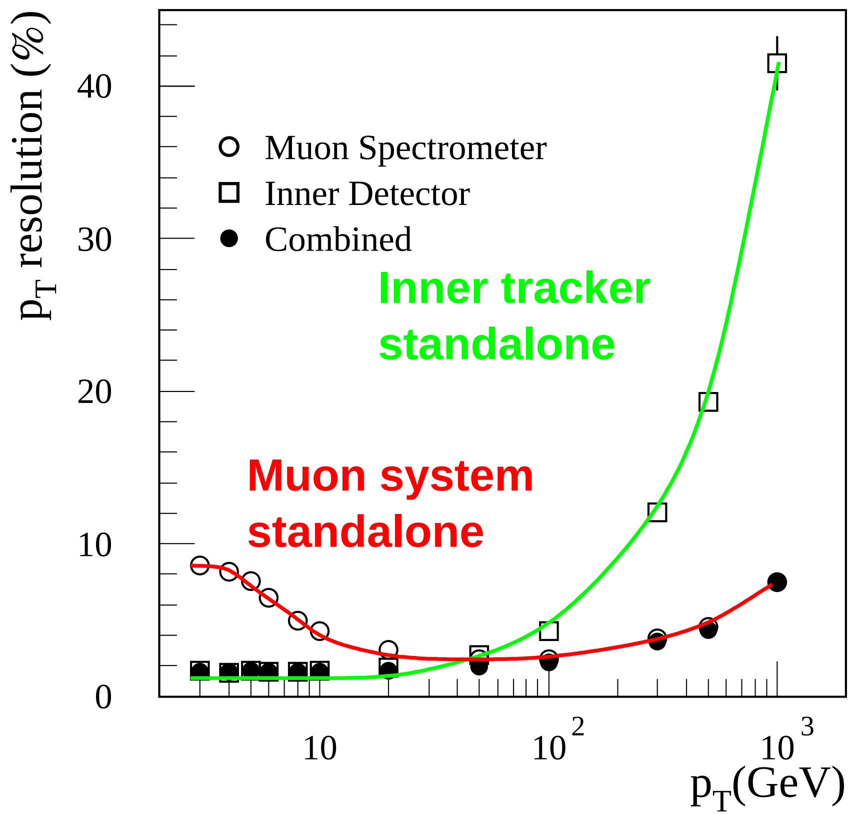
CMS Muon System

- Chambers interspersed between iron plate flux return. $\int B \cdot dl$: 1–4 Tm.
- Precision measurement: Drift tubes (barrel), cathode strip chambers (endcap). Single station resolution $\sim 100 - 200\,\mu$m.
- Trigger detectors: resistive plate chambers.
- Design resolution, Standalone (with inner tracker): 8–15% (1–1.5%) at 10 GeV, 20–40% (6–17%) at 1 TeV.
- Optical alignment system.



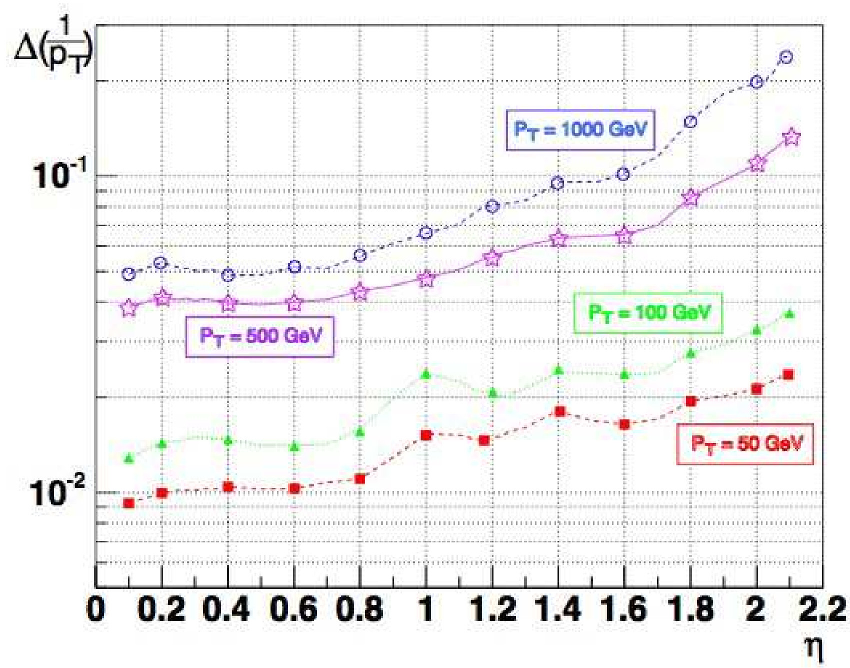
Muon Performance

ATLAS TDR



- Muon spectrometer resolution dominates for $p_T > 50\,$GeV
- Resolution fairly constant over η.
- Coverage $|\eta| < 2.7$.

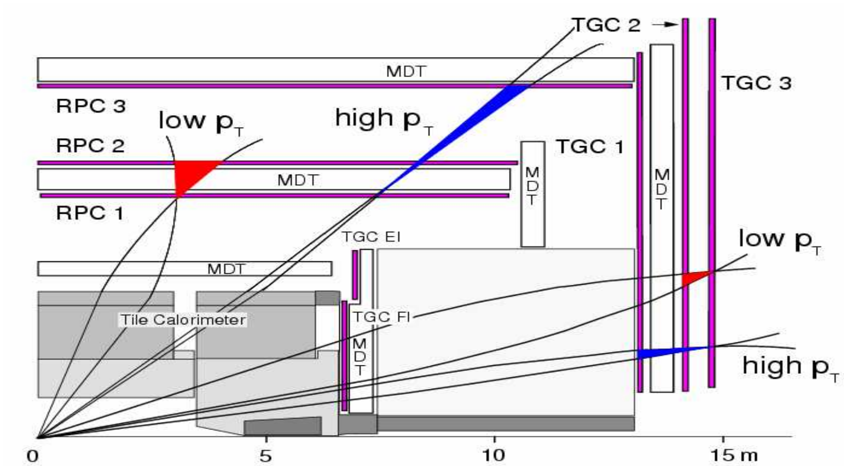
CMS: M. Neumeister CHEP04

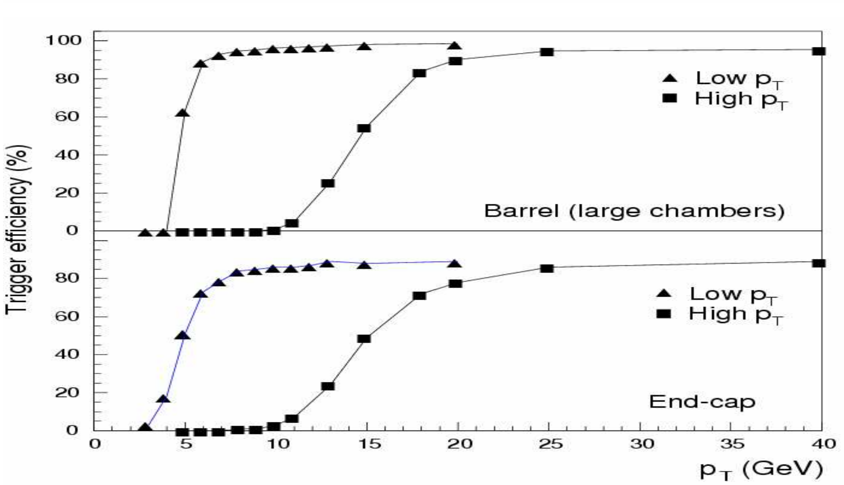


- Silicon tracker resolution dominates for all p_T.
- Excellent p_T resolution in barrel; worse in endcap.
- Coverage $|\eta| < 2.4$.

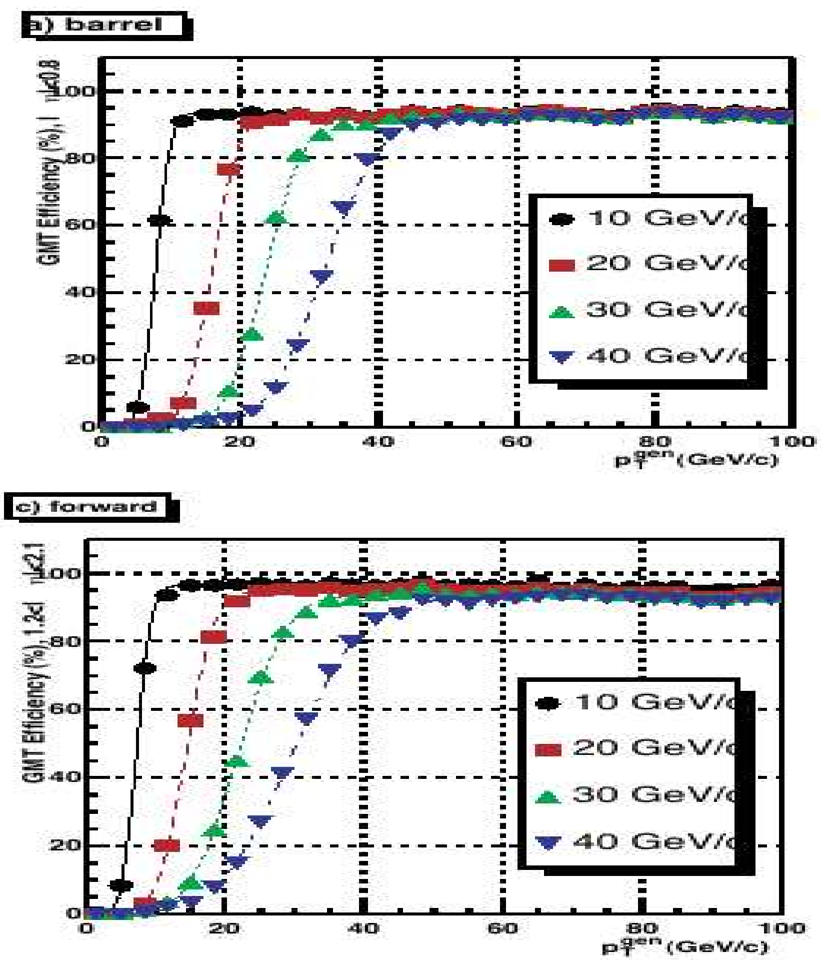
Level-1 Muon trigger

- ATLAS: Based on coincidences between RPC/TGC hits.
- Low ($>\sim 6$ GeV) and high ($>\sim 20$ GeV) p_T trigger schemes.



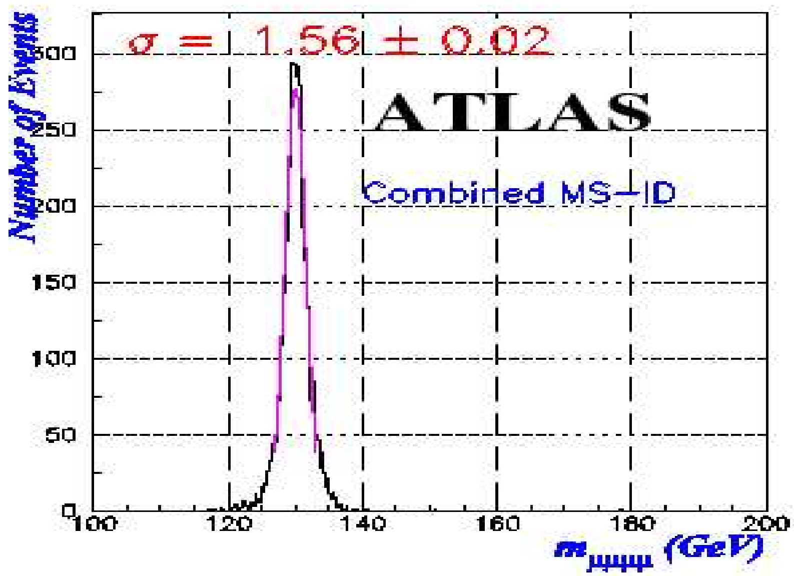


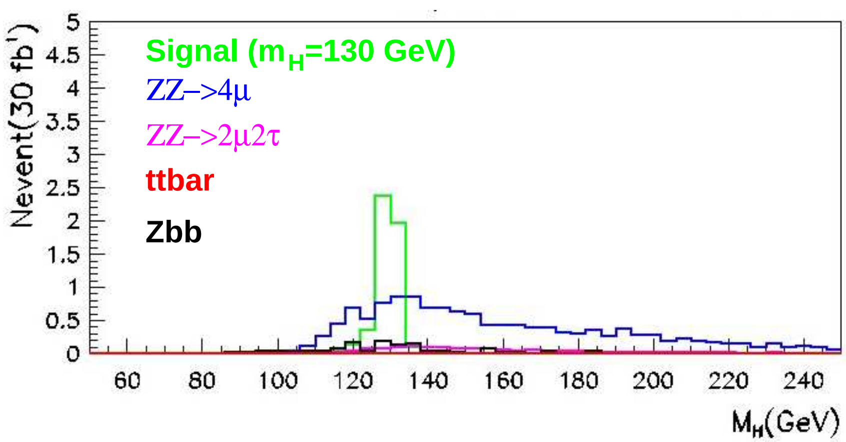
- CMS: Find local track segments in DT and CSC.
- Combine segments and RPC hits.

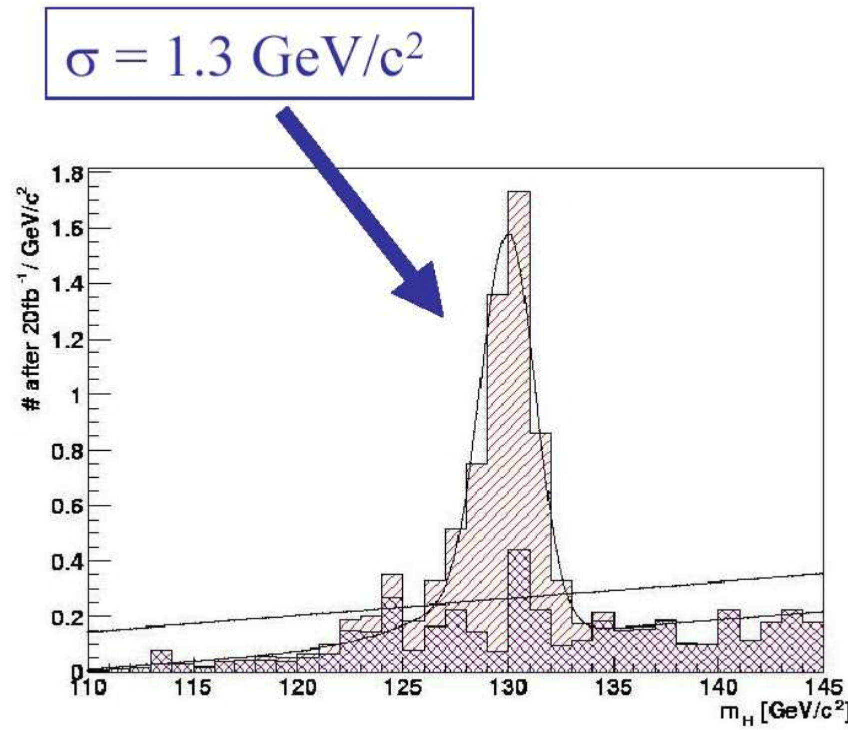


$H \to ZZ^* \to 4\mu$

From “Physics at the LHC,” Vienna, July 2004



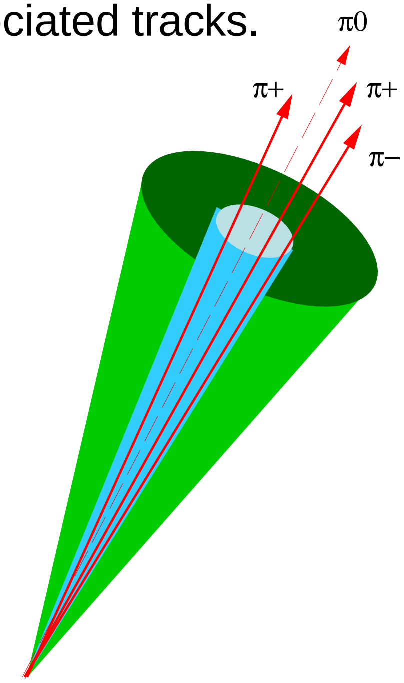




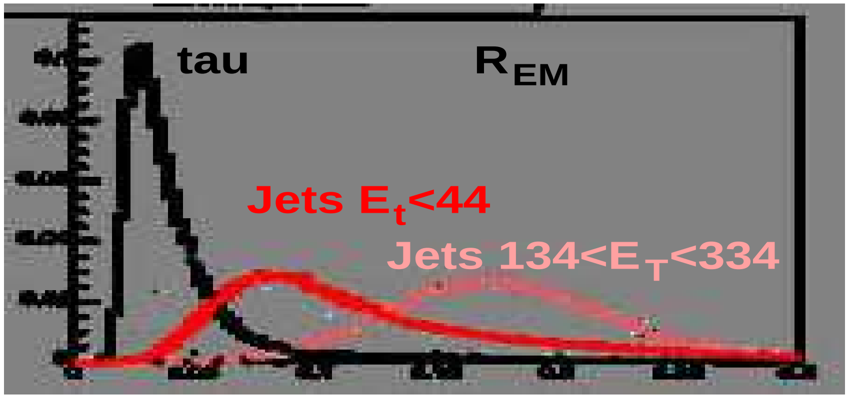
- Mass resolution for $m_H = 130$ GeV:
  - $\sigma = 1.6$ GeV (ATLAS)
  - $\sigma = 1.3$ GeV (CMS)

τ leptons

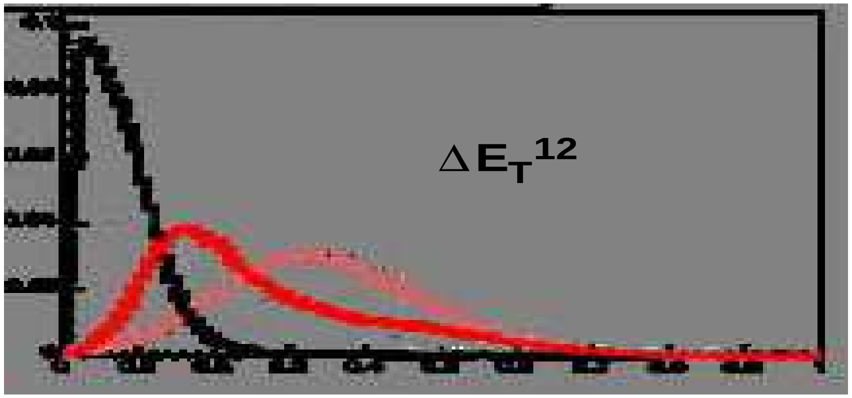
- Reconstructing τ decays is critical for numerous physics topics, including many Higgs channels.
- τ decays:
  - $\tau \rightarrow \nu + e, \mu$
  - $\tau \rightarrow \nu + \pi^{\pm}/K^{\pm} + n\pi_0$
  - $\tau \rightarrow \nu + 3\pi^{\pm} + \pi_0$
- Hadronic τ characteristics: narrow calorimeter cluster with 1/3 associated tracks.



- Useful variables (ATLAS):
  - R_{EM}: Size of EM cluster.



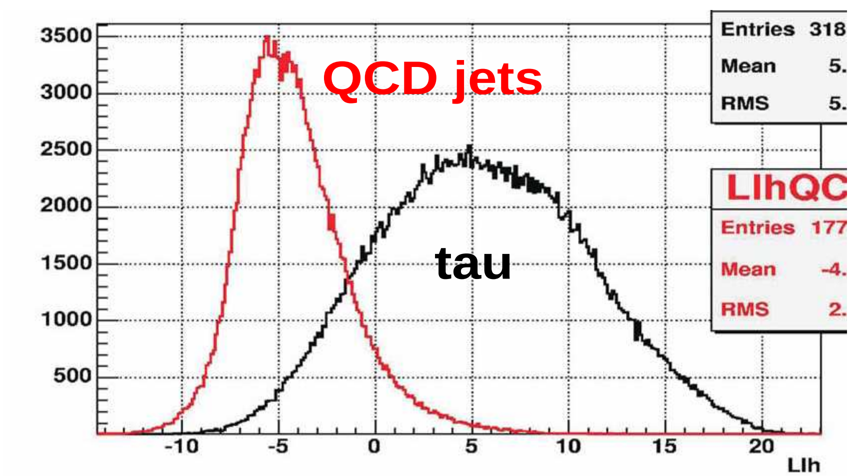
  - ΔE_T^{12}: Fraction of cluster energy within $0.1 < R < 0.2$.

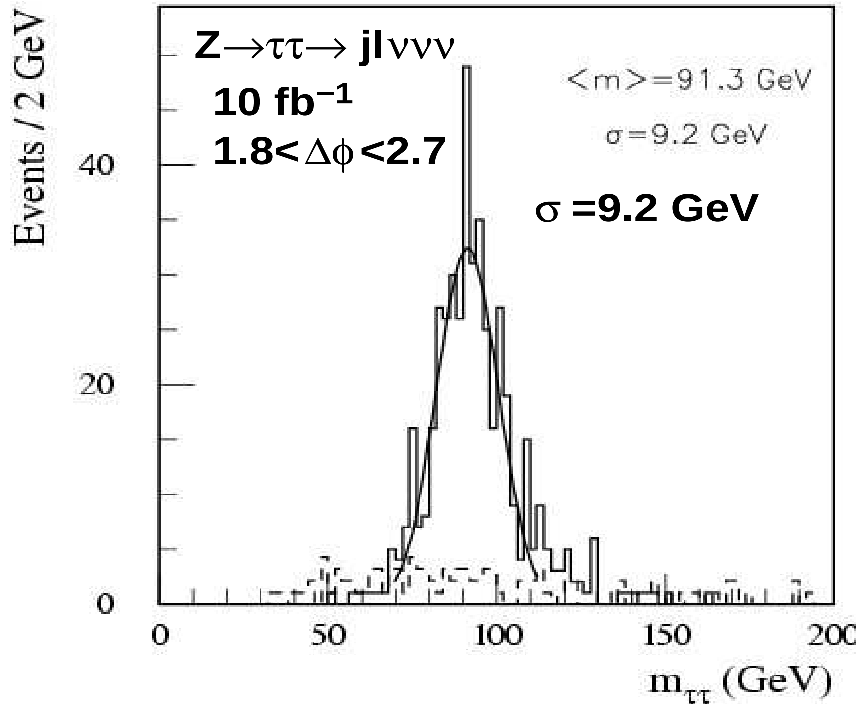


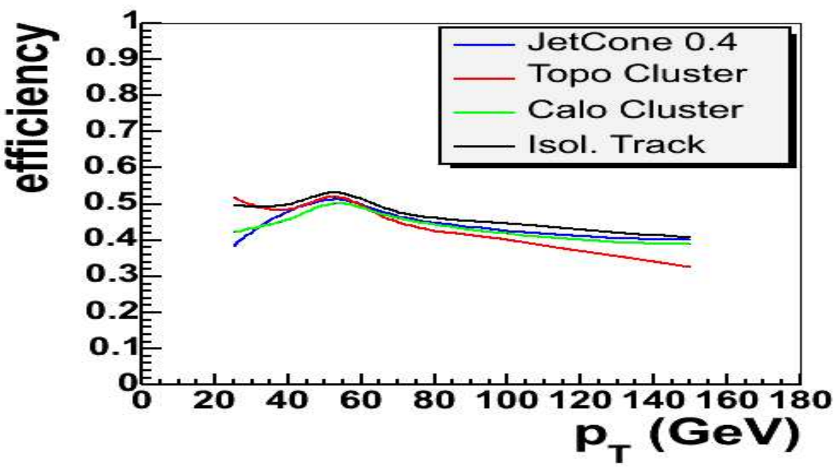
  - N_{tracks}, charge, impact parameter.

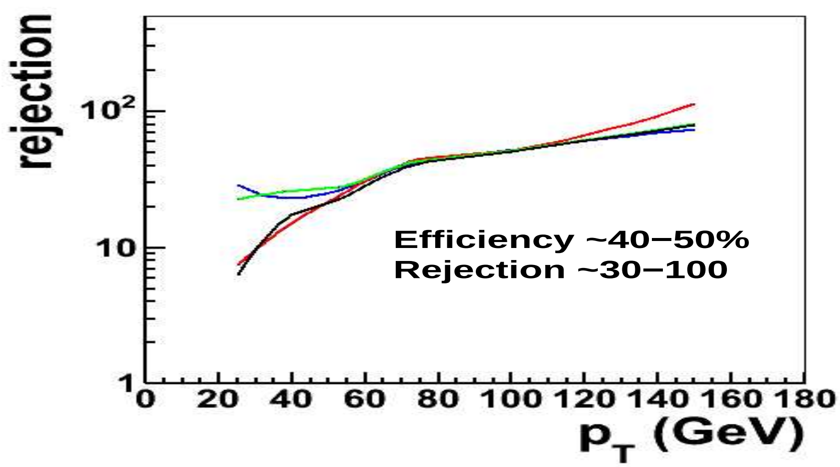
τ ID (ATLAS)

- Form likelihood from variables R_{EM}, ΔE_T^{12}, N_{track}, strip width, N_{strip}, charge, impact parameter, $E_T/p_T(\mathrm{track1})$



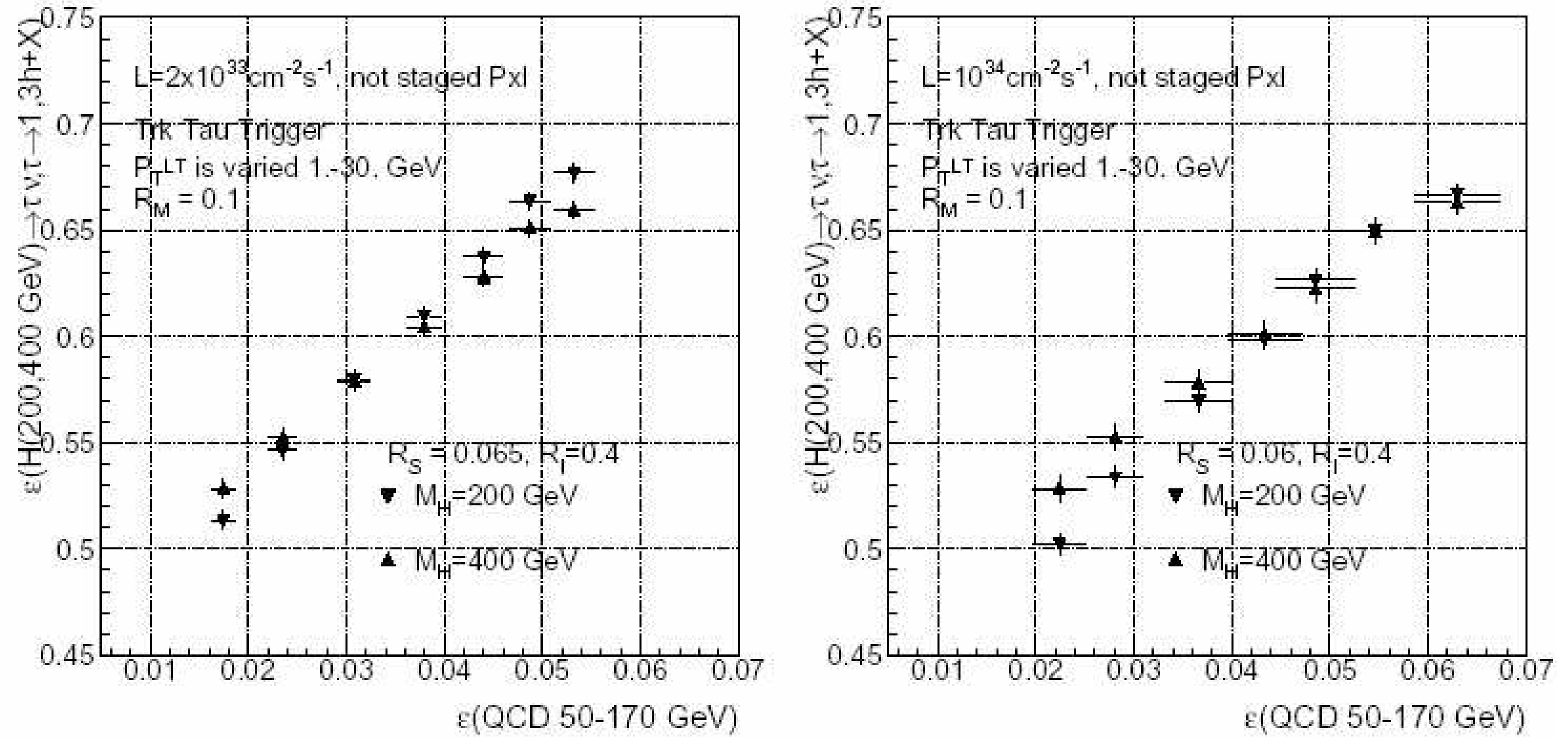






τ trigger (CMS)

- Cuts on calorimeter, track isolation, and p_T of leading track.
- HLT results, with track p_T from 1–30 GeV.
- Get rejection of ~ 30 for efficiency of ~ 0.55.



Super LHC (SLHC)

ref: Gianotti, *et el.*, hep-ph/0204087

- Proposed luminosity and energy upgrades to the LHC.
- Luminosity might increase another order of magnitude, to 10^{35} cm^{-2} s^{-1}. Energy might double to 28 TeV (more speculative, requires new magnets).
- Bunch spacing may go from 25 ns to 12.5 ns.
- Effect on detectors?
- Existing tracking detectors will not function at this luminosity. Complete replacement of inner tracking will be required.
  - Reduce cell size by $\sim 10\times$ to deal with increased occupancy.
  - Existing Si strip technology could work > 60 cm, and existing pixel technology > 20 cm.
  - New detector technologies are likely needed to survive in the region < 20 cm.
- Calorimeters.
  - Existing barrel calorimeters will likely still work.
  - Endcap calorimeters may need changes. ATLAS may need to use a different liquid, such as LKr. CMS endcap HCAL scintillator is a problem.
  - Pile-up noise in the calorimeter will increase by $\sim 3\times$.
    - For $E_T = 30$ GeV, $\sigma E/E$ goes from $\sim 2.5\%$ to 3.6%.
    - For $E_T = 40$ GeV and fixed electron efficiency, jet rejection decreases by about 50% (pile-up effects on isolation and shower shape requirements).
  - Trigger and readout systems may need only minor changes.

SLHC

- Muons.
  - Muon systems will probably continue to work without major changes in the detectors themselves.
  - But background rates are not currently well known. (Detectors were designed with a 3–$5\times$ safety margin on background rates at 10^{34}.) Rates must be measured from actual running.
  - The forward regions $|\eta| > 2$ may need to be replaced with shielding, reducing the angular coverage.
  - Trigger and readout may need major changes to cope with the reduced bunch spacing.
- Trigger/DAQ upgrades will also be needed.
- Significant new R&D work will be required to design a detector that can run at 10^{35} cm$^{-2}s^{-1}$ with the desired performance.
- Experience from running the present designs will be crucial.

Summary

- Installation is in progress for LHC and both detectors, for turn-on in 2007.
- The large luminosity of the LHC makes it a challenging environment.
- But the detector collaborations have converged on designs that should give excellent performance for detecting leptons and photons.
- Looking forward to the start of data-taking!