Fizyka cząstek: detektory

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Wykład X

- Detektory przy kolajderach

Kalorymetry

Projektując kalorymetr chcielibyśmy zoptymalizować:

- dokładność pomiaru energii (w rozważanym zakresie)
- dokładność rekonstrukcji pozycji (pęd poprzeczny, matching toru)
- możliwość pomiaru kierunku i/lub czasu
- możliwość rekonstrukcji profilu kaskady (identyfikacja)

Niestety nie można wszystkich tych parametrów polepszyć jednocześnie

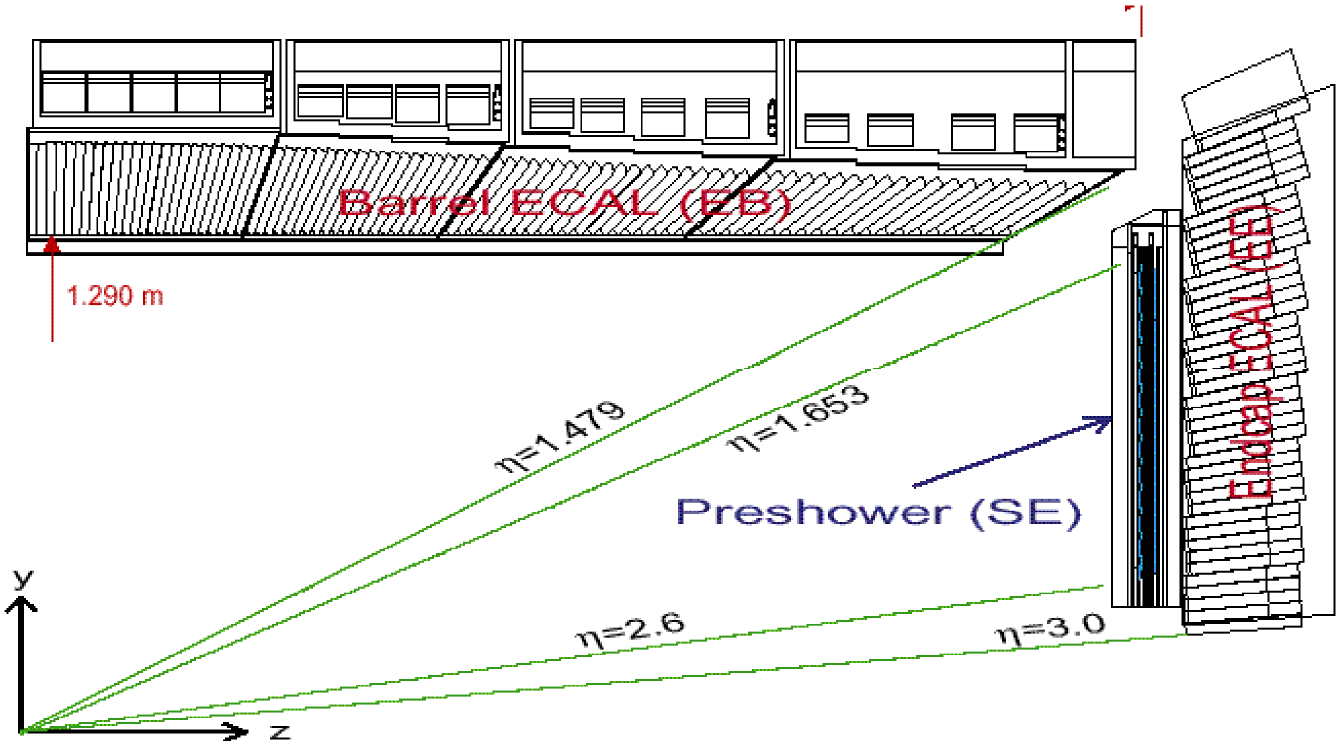
Pomiar energii: kalorymetr jednorodny, minimalna segmentacji
Pomiar pozycji: duża segmentacja poprzeczna
Pomiar kierunku i profilu kaskady: duża segmentacja podłużna

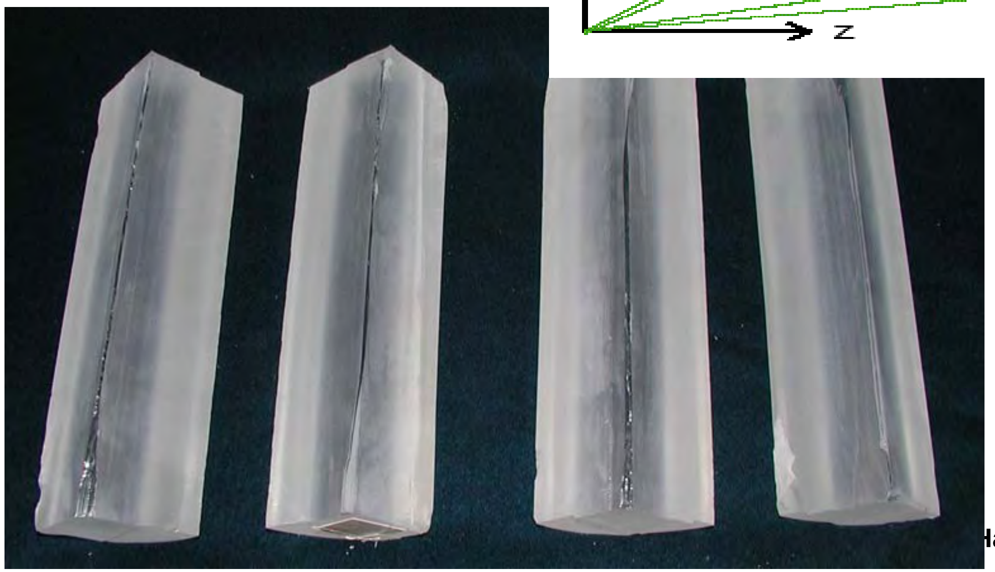
Trzeba optymalizować pod kątem fizyki: procesy "wzorcowe"

Koszt ogranicza wybór materiałów, rozmiary i liczbę kanałów...

Electrons and photons in ATLAS/CMS

CMS $PbWO_4$ crystal calorimeter

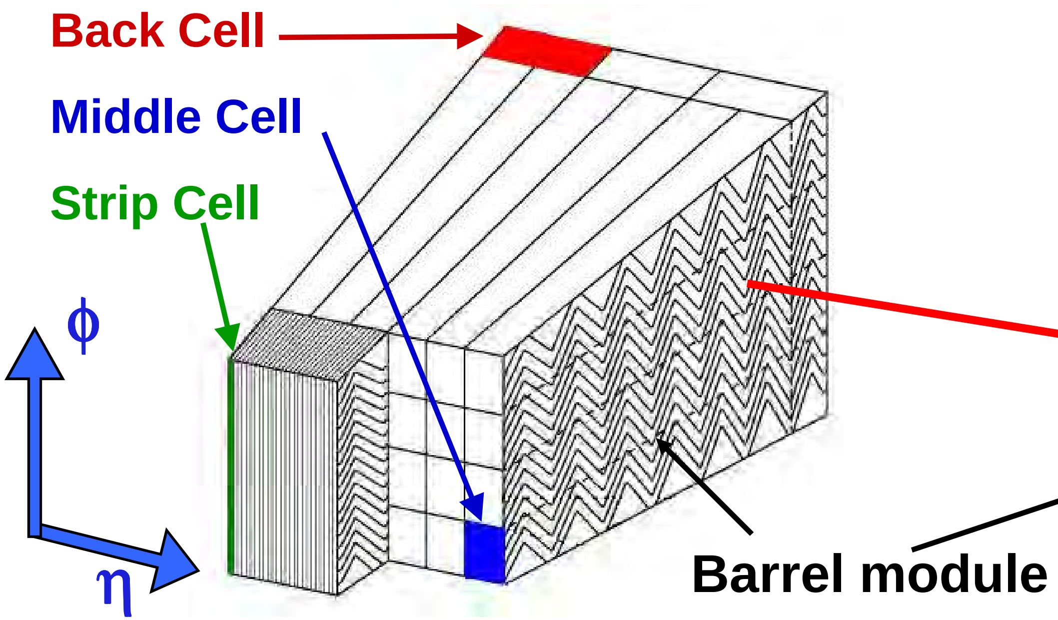


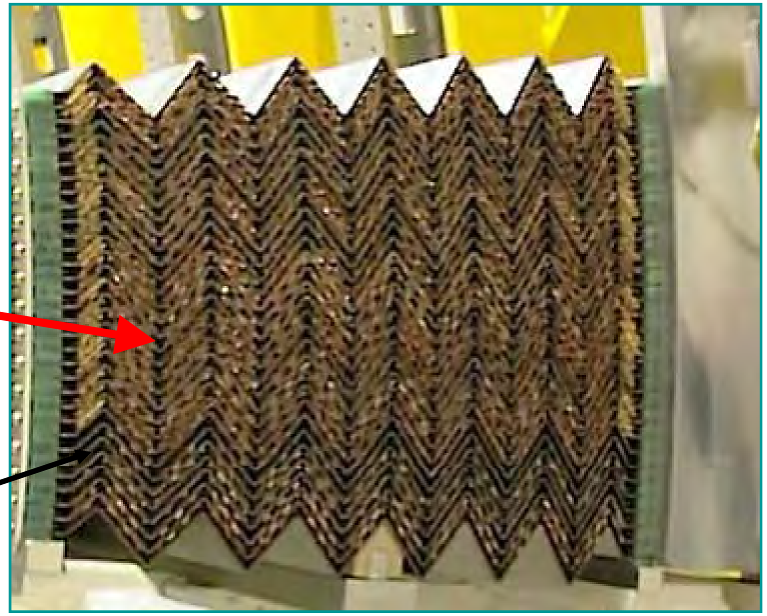


- Barrel: 62k crystals 2.2 x 2.2 x23 cm
- End-caps: 15k crystals 3 x 3 x 22 cm

Electrons and photons in ATLAS/CMS

ATLAS LAr EM Calorimeter description





EM Calo (Presampler + 3 layers):

- **Presampler** 0.025x0.1 (ηxϕ)
  ⇒ *Energy lost in upstream material*
- **Strips** 0.003x0.1 (ηxϕ)
  ⇒ *optimal separation of showers in non-bending plane, pointing*
- **Middle** 0.025x0.025 (ηxϕ)
  ⇒ *Cluster seeds*
- **Back** 0.05x0.025 (ηxϕ)
  ⇒ *Longitudinal leakage*

•LAr-Pb sampling calorimeter (barrel)
•Accordion shaped electrodes
•Fine longitudinal and transverse segmentation
•EM showers (for $e^{\pm}$ and photons) are reconstructed using calorimeter cell-clustering

ATLAS & CMS em calorimetry

Homogeneous calorimeter made of 75000 **$PbWO_4$ scintillating crystals** + PS FW

- Very compact R_M=2.0cm
- Excellent energy resolution
- Fast << 100 ns
- High granularity
- No longitudinal segmentation
- No angular measurement
- Radiation tolerance : needs follow up
- Room Temperature
- T sensitive 5%/°K
- Requires uniformisation by calibration

Sampling LAr-Pb, 3 Longitudinal layers + PS

- R_M=7.3cm
- Good energy resolution
- Not so fast (450 ns), requires shaping
- High granularity
- Longitudinally segmented
- Angular measurement
- Radiation resistance

- Cryogenic detector (cryostat)
- T sensitive 5%/°K
- Instrinsically uniform

CMS ECAL Calibration & Monitoring

➢ECAL Calibration (Resolution : 'Constant Term of the Resolution Formula') :

Raw (uncalibrated) Supermodule : 6%-10% 'Resolution'
Spread among channels before calibration

➡

Beam Test Precalibration : 2 % 'Resolution'
With a 'fast' calibration
'Lab Precalibration' : 4 % 'Resolution'

➡

In-Situ Physics Calibration : 0.5 % 'Resolution'
Timescale for calibration : Weeks

➢ECAL Monitoring (Monitor Stability and Measure Radiation Effects) :

ECAL Stability (<< 0.5%) , Monitored with Laser Monitoring System

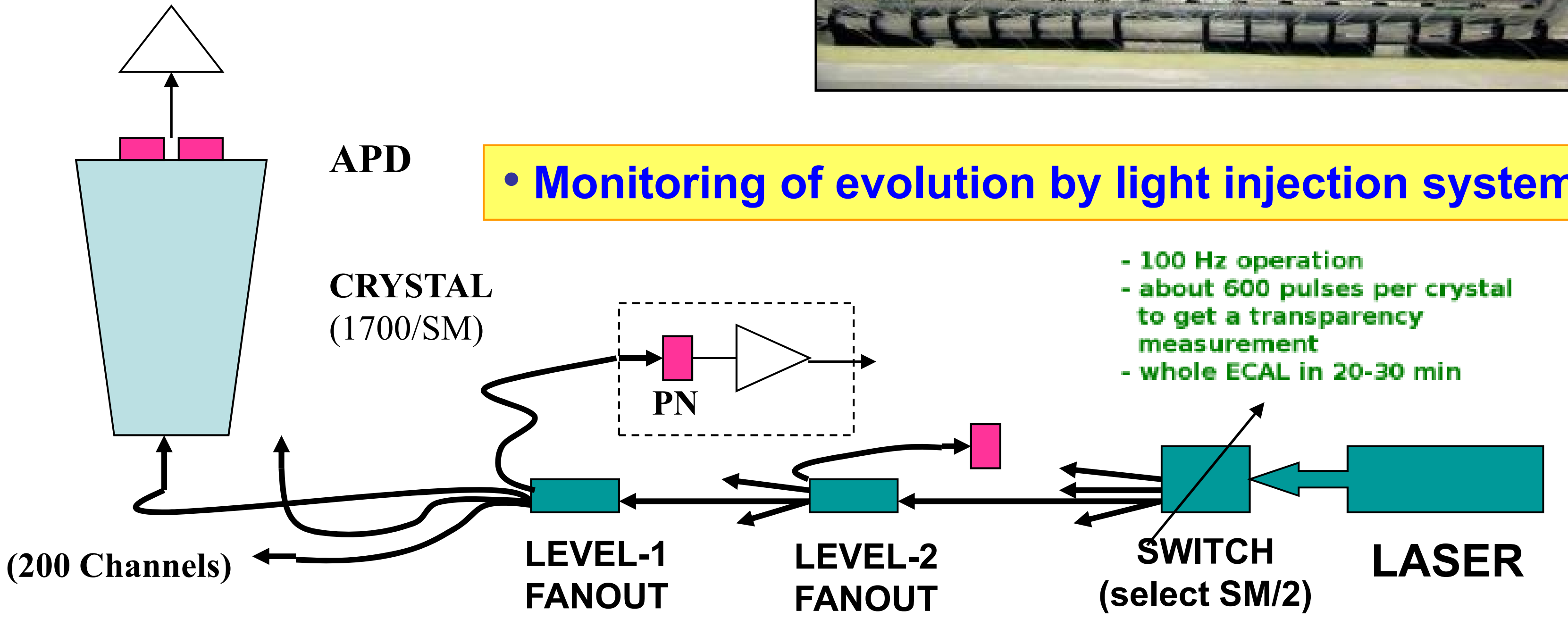
➡

Transparency Loss Correction, Signal Change under Irradiation ~5% Measured with Laser Monitoring System

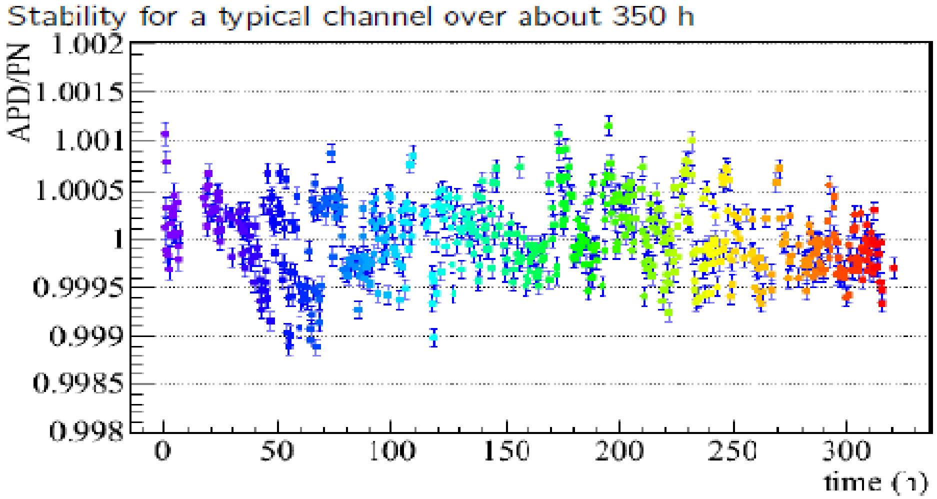
CMS ECAL monitoring system

The Solution:
Damage and recovery during LHC cycles tracked with a laser monitoring system
2 wavelengths are used:
440 nm and 796 nm
Light is injected into each crystal
Normalisation given by PN diodes (0.1%)

- Monitoring of evolution by light injection system



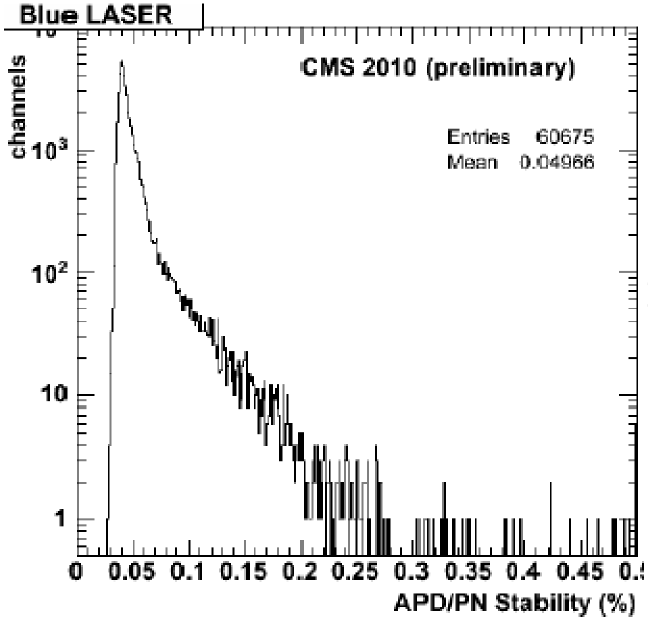
ECAL monitoring system

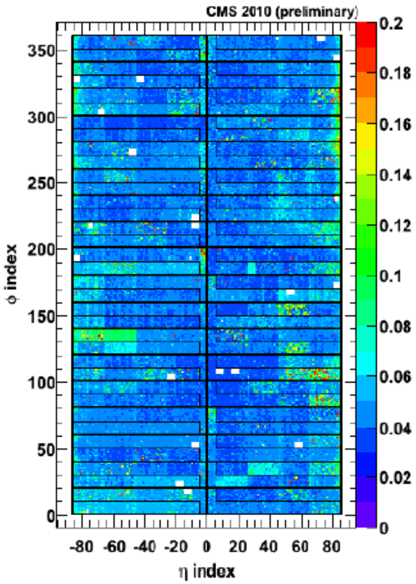


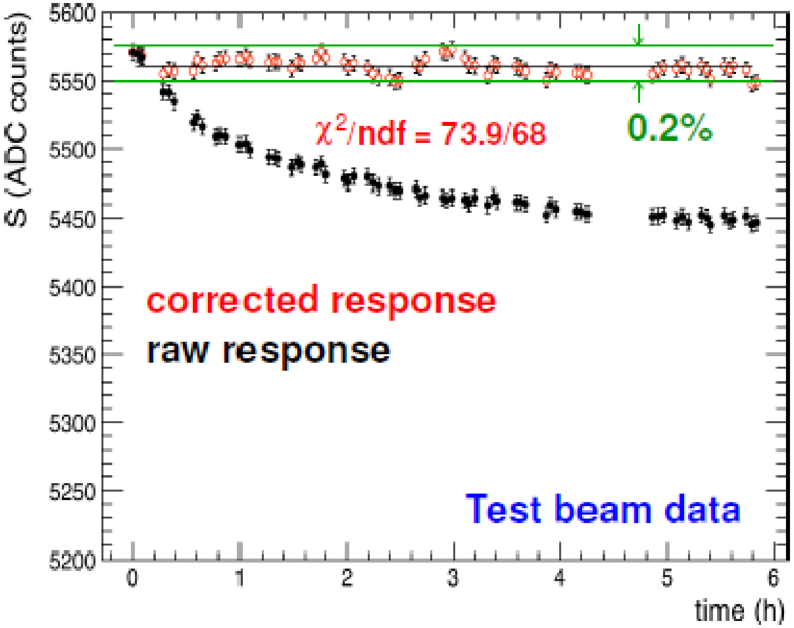
Measure a loss of transparency:
S (particle signal) and R(laser signal)

$$S_{cor} = S\left(\frac{R}{R_0}\right)^{\alpha}$$

NB: α is ~ the same for all crystals!



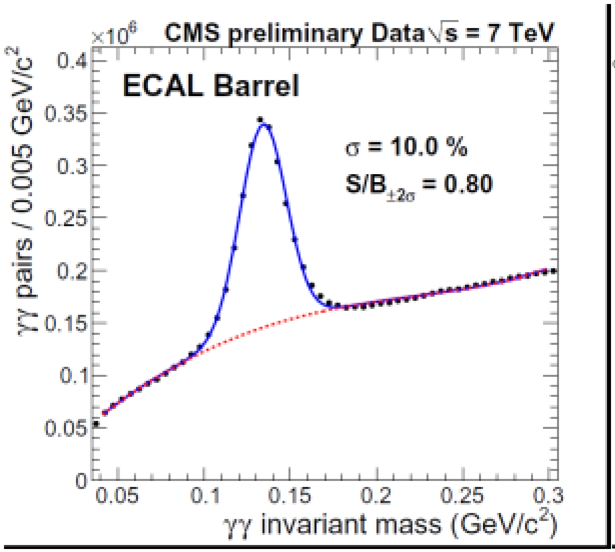


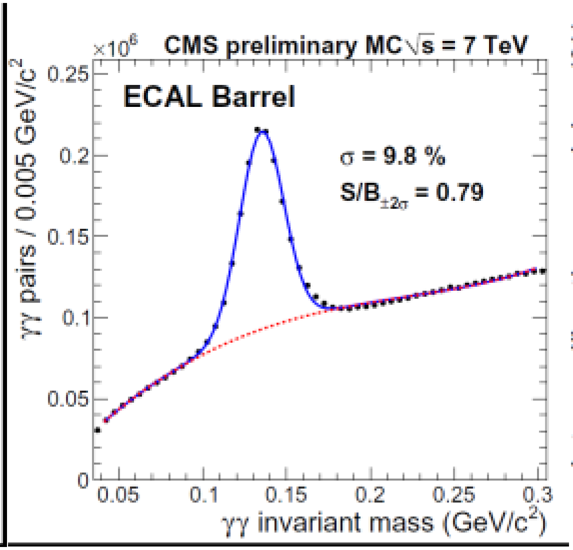


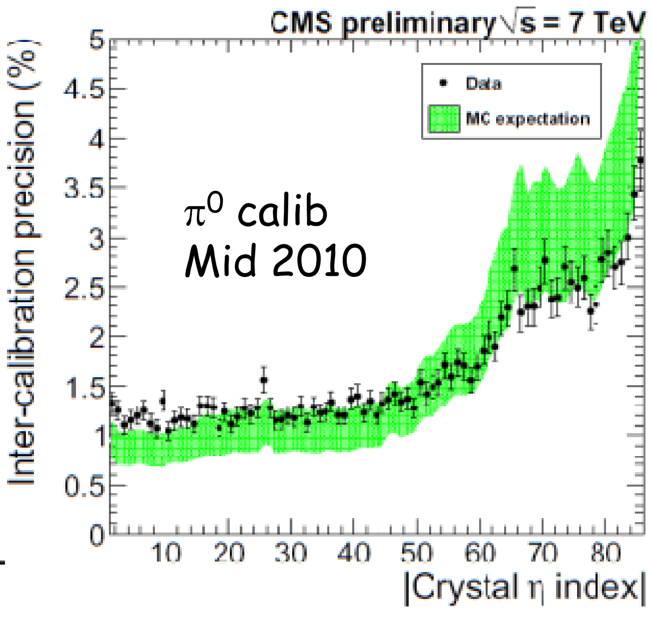
Energy resolution: how to keep it?

- **Intercalibration**

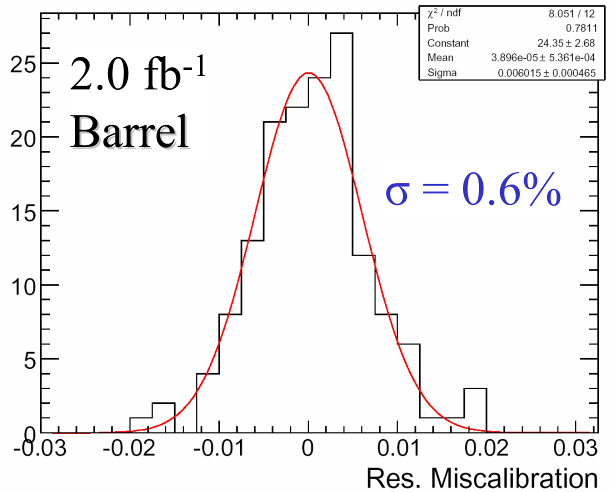
  requires several steps before, during and after data taking
  - test beam precalibration
  - continuous monitoring during data taking (short term changes)
  - Intercalibration by physics reactions during the experiment (π^0, η) with specialized data-stream or ϕ symmetry

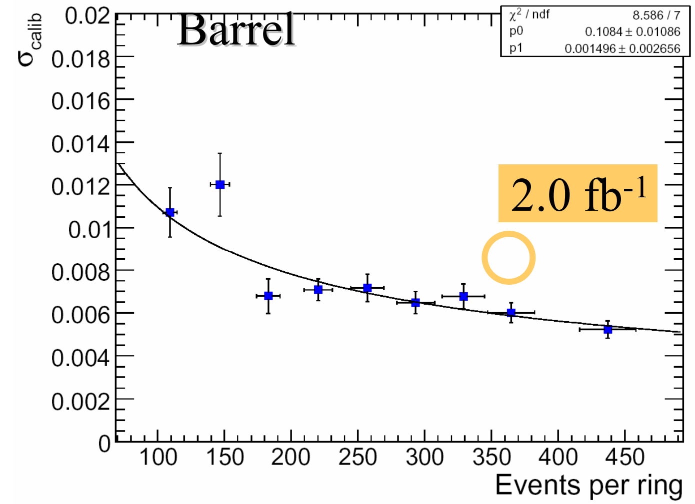






CMS In-situ: using $Z \to e^+e^-$





Method:

Z mass constraint

Use cases:

- Inter-calibrate crystals in ECAL regions
- Inter-calibrate ECAL regions (i.e.rings in φ-symmetry method)
- Set the absolute energy scale
- Tune algorithmic corrections for electron reconstruction

Events Selection: Low brem electrons.

Algorithm:

Iterative (~10-15), constants are obtained from the peak of ε^i distribution.

$$\bar{\epsilon}^i = \frac{1}{2} \cdot \left[\left(\frac{M^i_{inv}}{M_Z} \right)^2 - 1 \right]$$

Results:

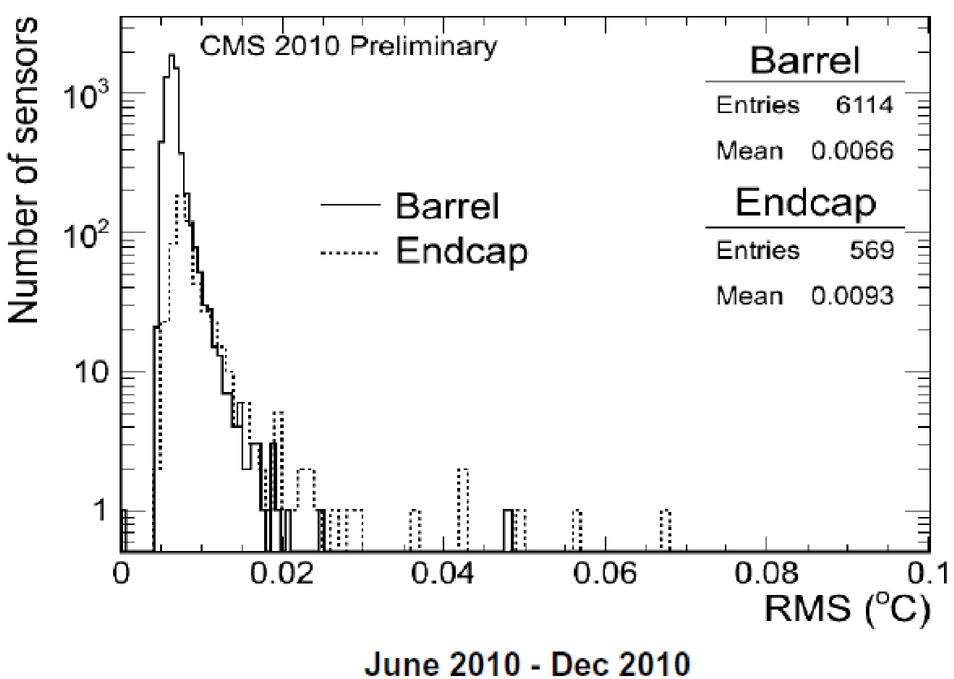
Assuming 5% mis-calibration between the rings and 2% mis-calibration between the crystals within a ring

⇓ *Statistics: **2.0 fb^{-1}***

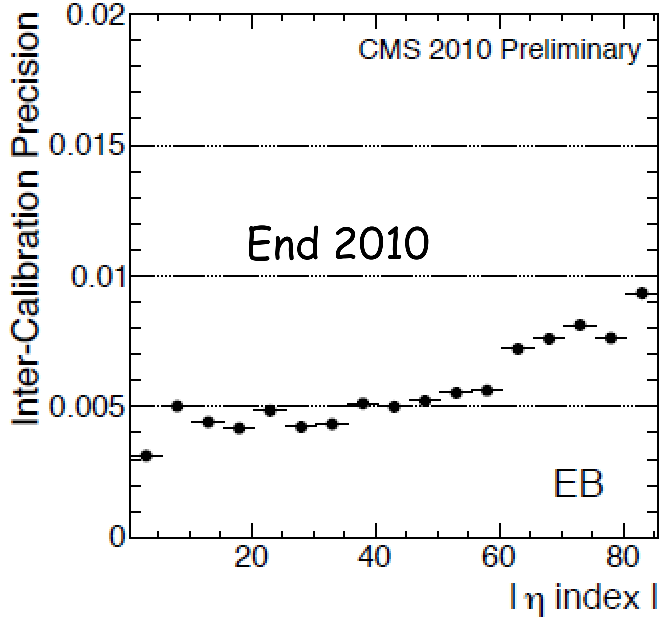
0.6% ring inter-calibration precision

Performance in situ CMS

$\varepsilon_{\text{Barrel ECAL}}$ 99.1% in 2010
$\varepsilon_{\text{Endcap ECAL}}$ 98.6% in 2010



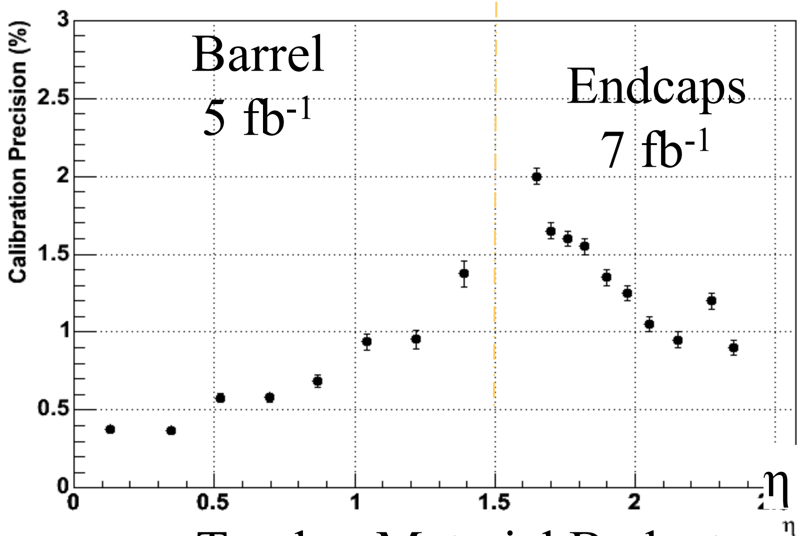
Temperature stability



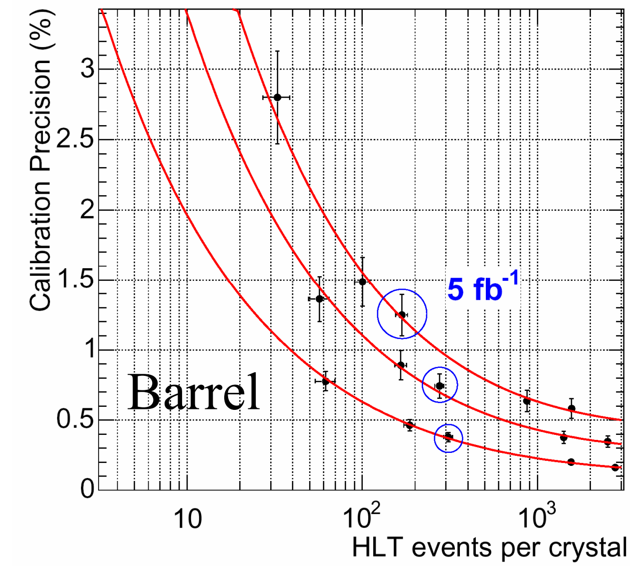
Intercalibration precision

In-situ: using isolated electrons

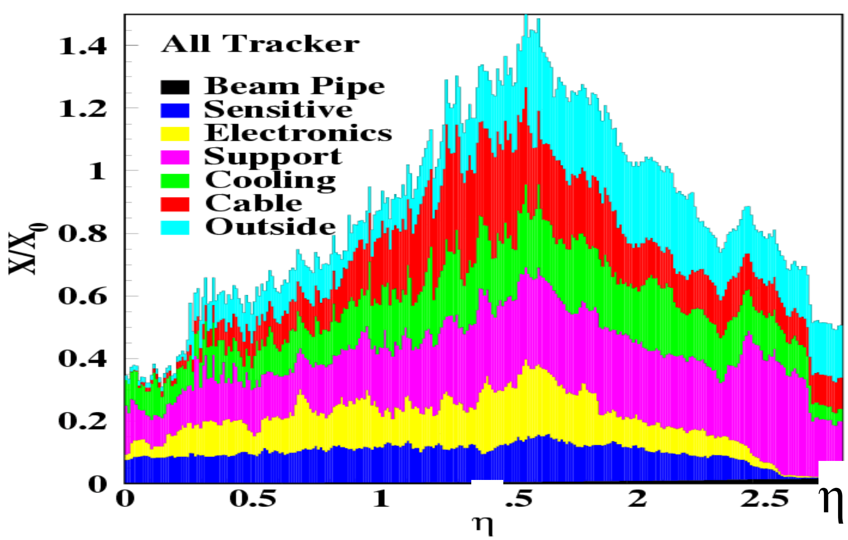
Calibration Precision versus η



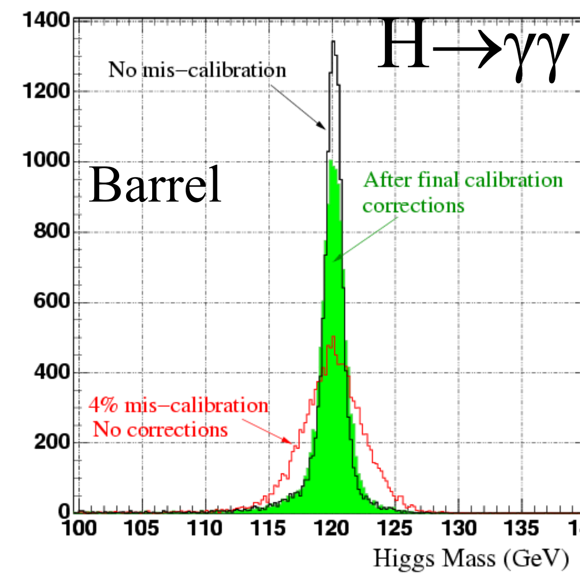
Precision versus Statistics



Tracker Material Budget

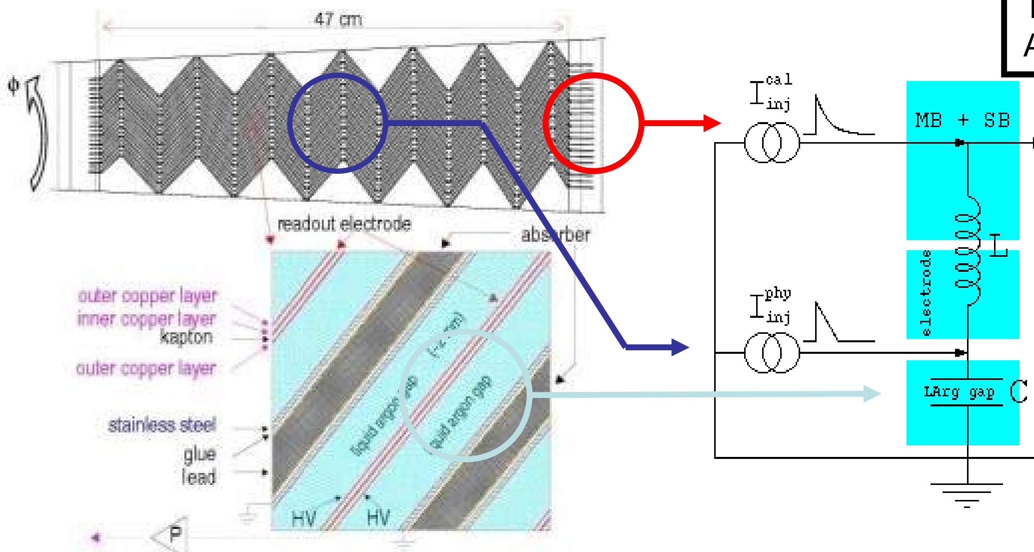


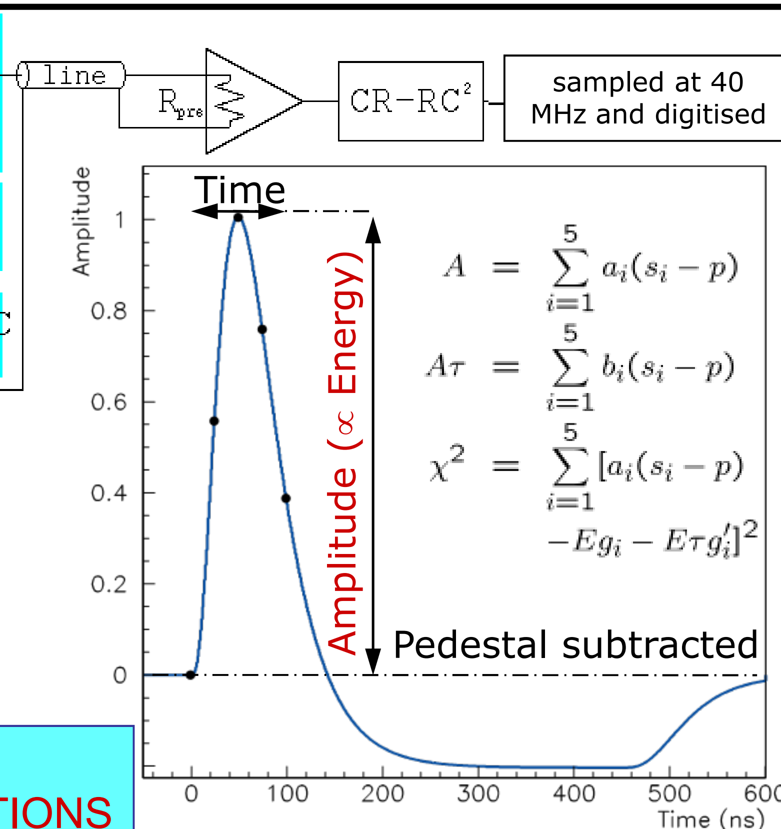
Higgs Boson Mass Resolution

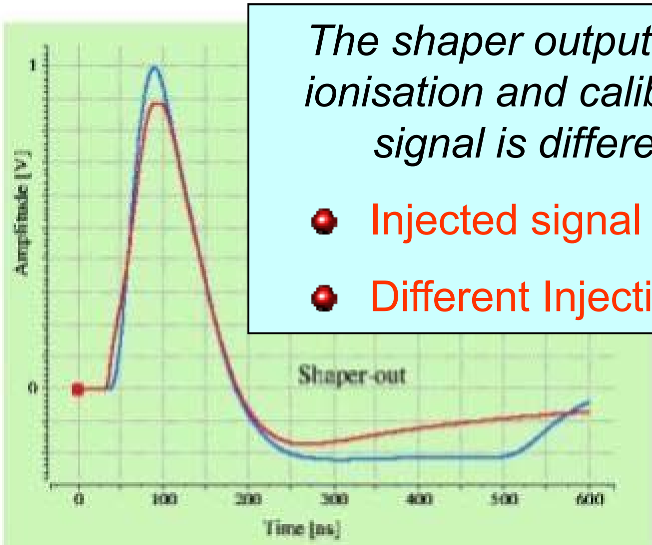


LAr electronics calibration

The ionization signal is sampled every 25 ns by a 12 bits ADC in 3 gains. 5 samples are recorded at ATLAS.







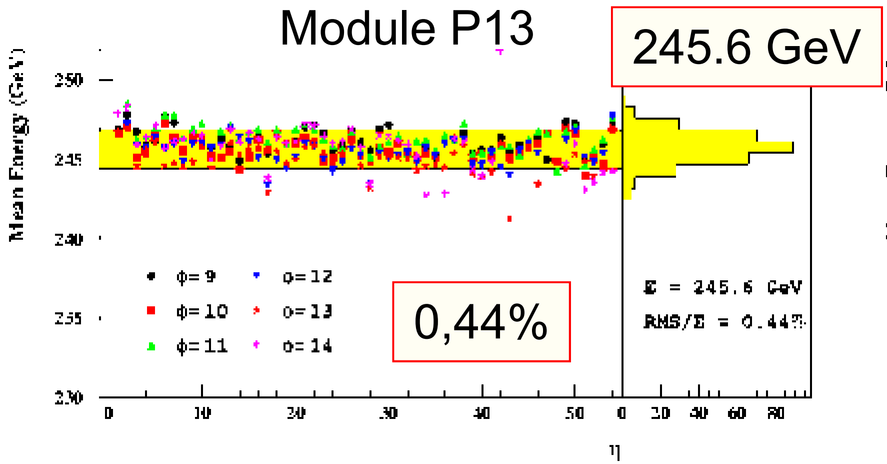
The shaper output of the ionisation and calibration signal is different!

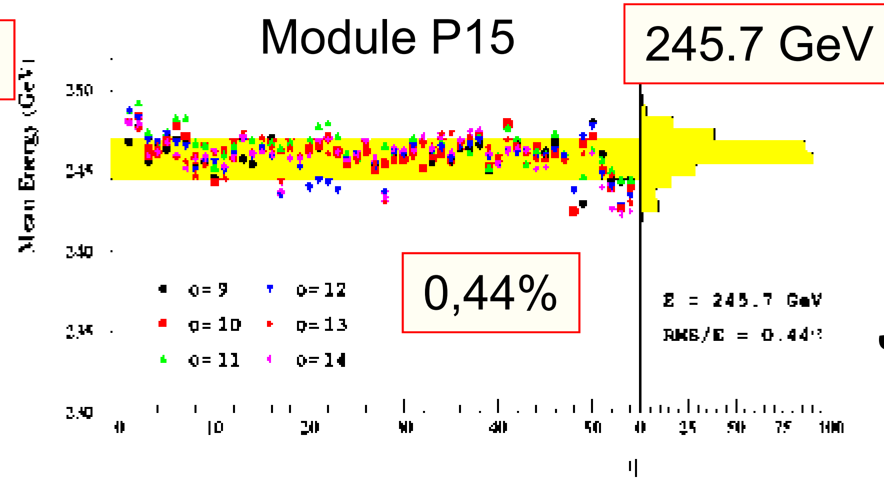
- Injected signal shape
- Different Injection point

NEED CORRECTIONS

The equalization of the electronic readout. Requires to know the shaping function of each cell at few percent level
→ equalization with an electronic control signal

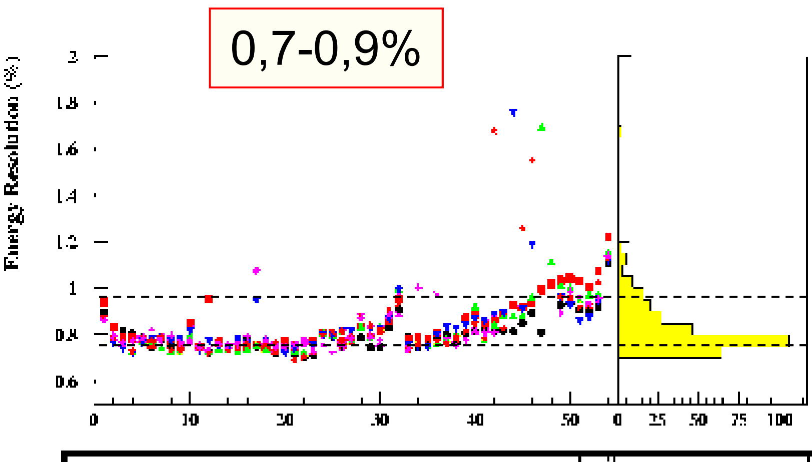
ATLAS EM uniformity (test beam)

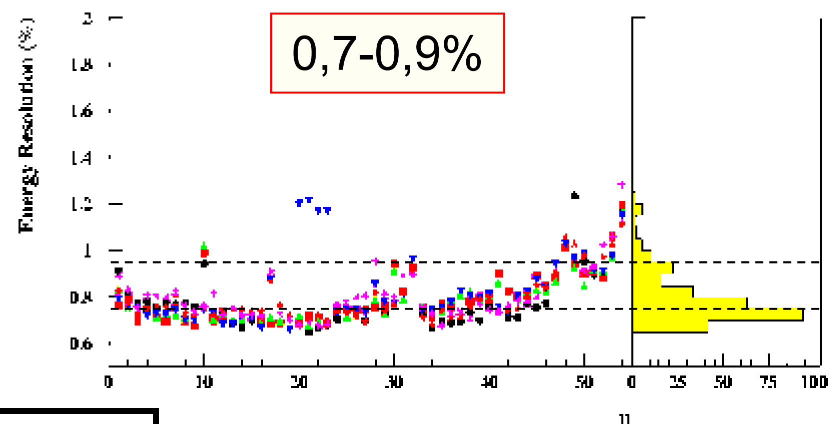




Uniformity

Scan modules with monochromatic electrons





Resolution

Module	**P13**	**P15**
Global constant term	**0.62%**	**0.56%**

P13/P15 ~ 0.05%

Ratio of absolute response

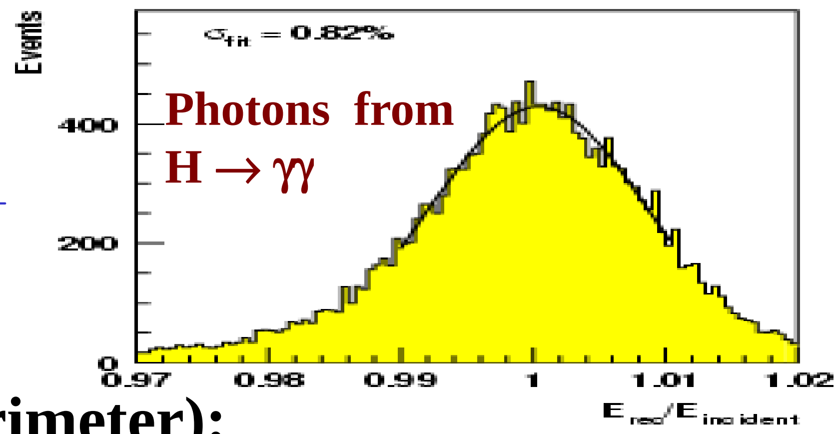
LHC benchmark: SM H→ γγ

1) Irreducible background from qq → γγ and gg → γγ (box)

2) Reducible background from π^0,η (→ γγ) in jet fragmentation:
   - final states with many photons → look for single photons
   - non-isolated photons inside jets → look for isolated photons
   - Very difficult problem: at $p_T \approx$ 50 GeV, jet-jet / γγ ≈ 10^7 → need to reject each jet by a factor 10,000 to bring the reducible background well below the irreducible one
   - However, at $p_T \approx$ 50 GeV, π^0/jet ≈ 10^{-3}
     → separate isolated photons from π^0 decays at 50 GeV
     → photons from π^0 decays will be distant by ≈ 1 cm
     → need granular position detector after ~ 4-5 X_0 in

SM H$\rightarrow\gamma\gamma$

CMS, full simulation high L



Energy resolution

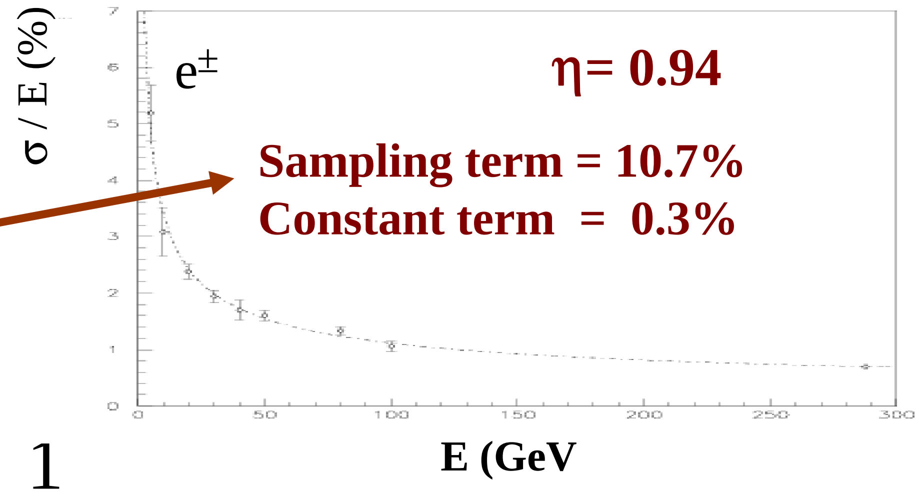
CMS EM calorimeter (crystals):

$$\frac{\sigma(E)}{E} \approx \frac{3\text{-}5\%}{\sqrt{E}}$$

ATLAS EM calorimeter (liquid-argon/lead sampling calorimeter):

$$\frac{\sigma(E)}{E} \approx \frac{10\%}{\sqrt{E}}$$

Module zero test beam data



Mass resolution

(m_H=100 GeV, low L):

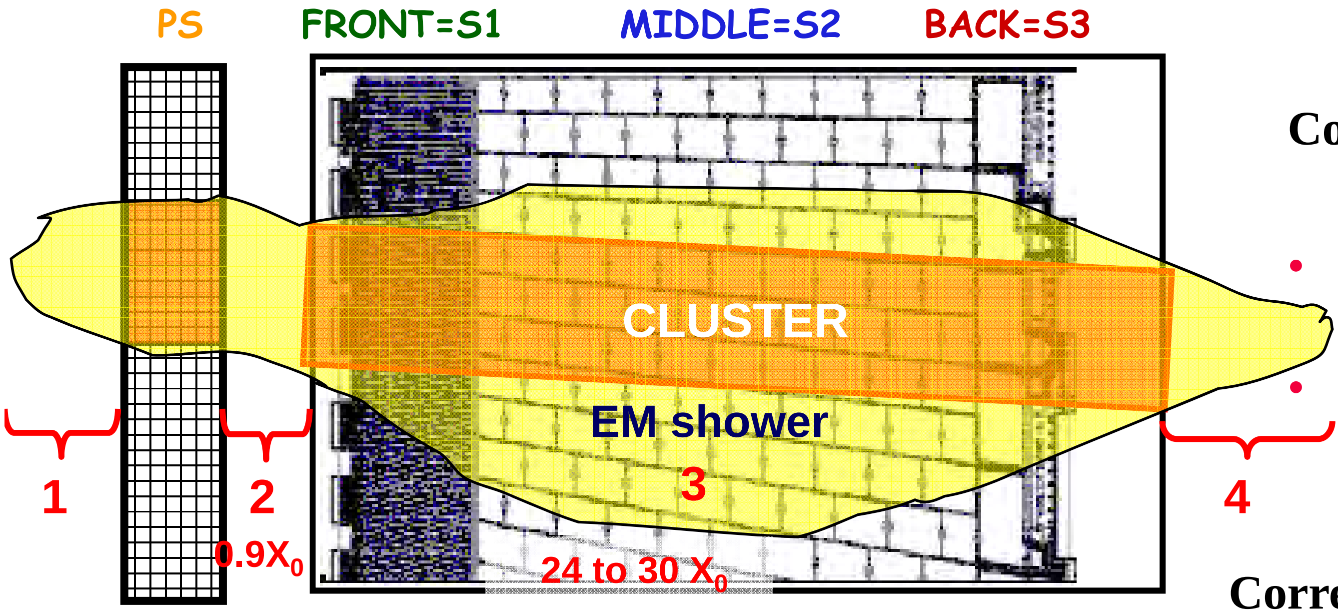
ATLAS : 1.1 GeV

CMS : 0.6 GeV

$$\frac{S}{\sqrt{B}} \sim \frac{1}{\sqrt{\sigma_m}}$$

Electrons and photons in ATLAS/CMS

ATLAS EM Calorimeter energy reconstruction



Corrections due to cluster position:

- Δη (S-shape modulation) ±0.005
- Δϕ (offset in accordion) ±0.001

Corrections for energy losses:

1. Before PS
2. Between PS & Calo
3. Outside cluster: depends on clustering method
4. After calorimeter: ~ Energy in BACK

2-7% overall energy correction

>7% at low energy, high η

Two main clusterization methods:

- Fixed size sliding window:
  - 3×3, 3×7… cells, 2nd sampling η×ϕ;
  - Some energy left out, especially for small sizes.
- Topological clusters:
  - Variable size cluster, minimize noise impact;
  - Additional splitting algorithm is also provided.

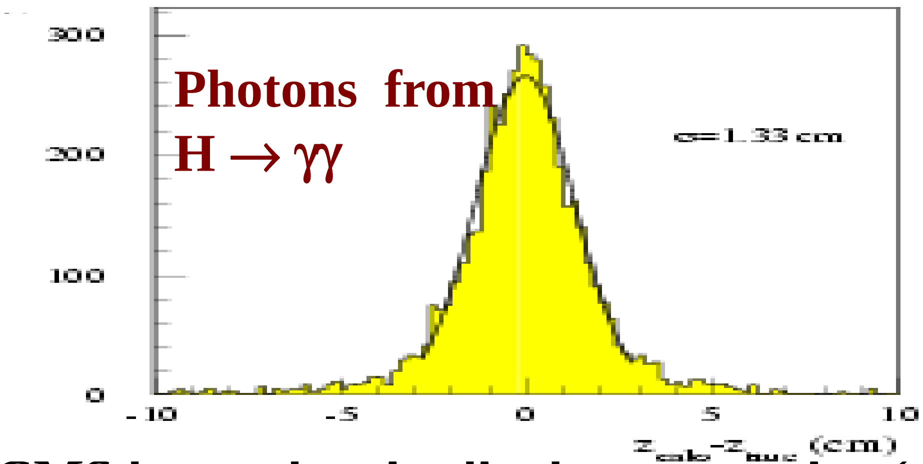
SM H$\rightarrow \gamma\gamma$

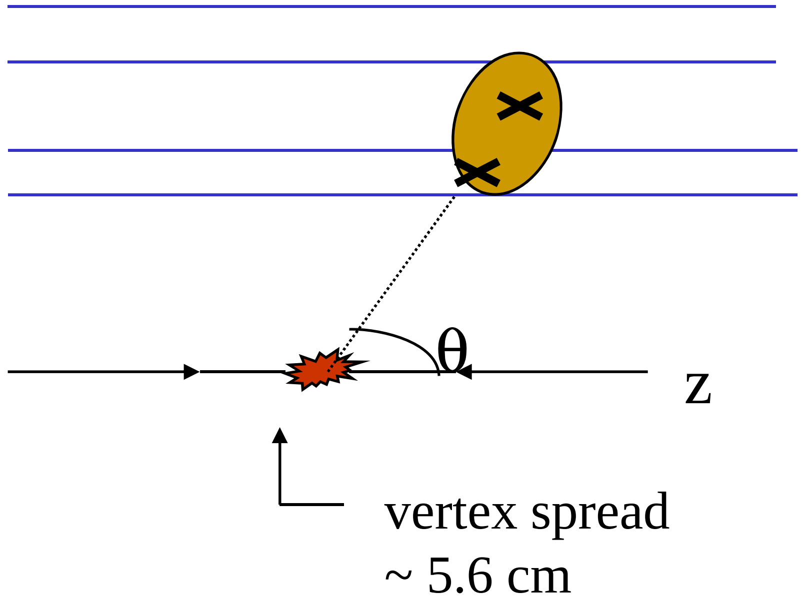
<u>Angular resolution and acceptance</u>

- ATLAS calorimeter has longitudinal segmentation

$\rightarrow$ **can measure γ direction**

ATLAS, full simulation
Vertex resolution using EM
calo longitudinal segmentation



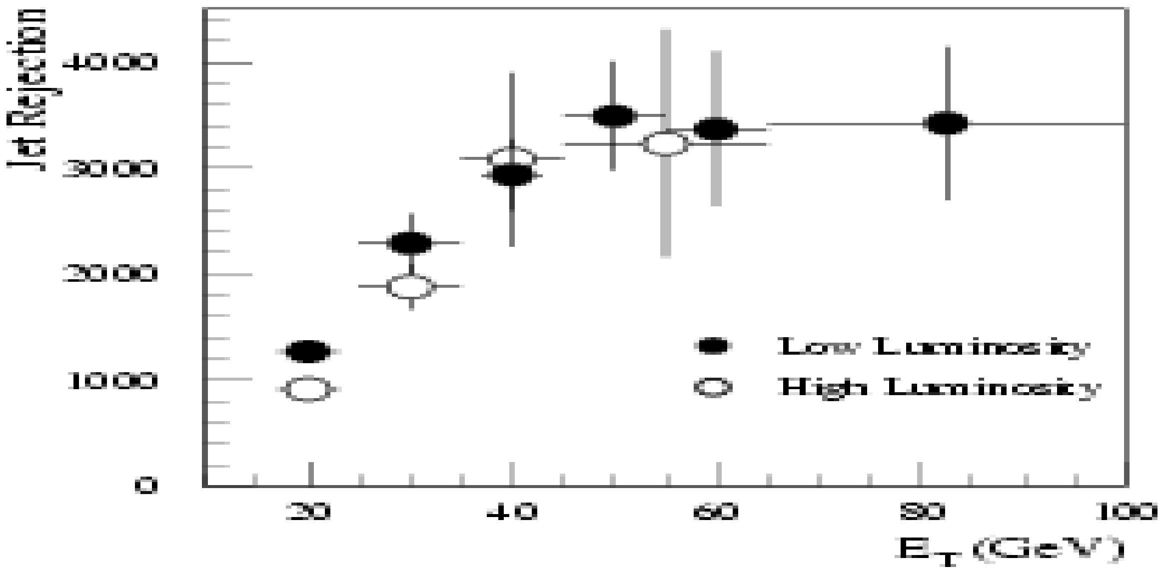


$$\sigma(\theta) \approx \frac{50 \text{ mrad}}{\sqrt{E}}$$

CMS has no longitudinal segmentation (and no preshower in barrel)
$\rightarrow$ vertex measured using secondary tracks from underlying event
$\rightarrow$ often pick up the wrong vertex
$\rightarrow$ smaller acceptance in the Higgs mass window

SM H$\rightarrow \gamma\gamma$

Rejection of QCD jet background



ATLAS EM calo : full simulation

$\varepsilon_\gamma = 80\%$

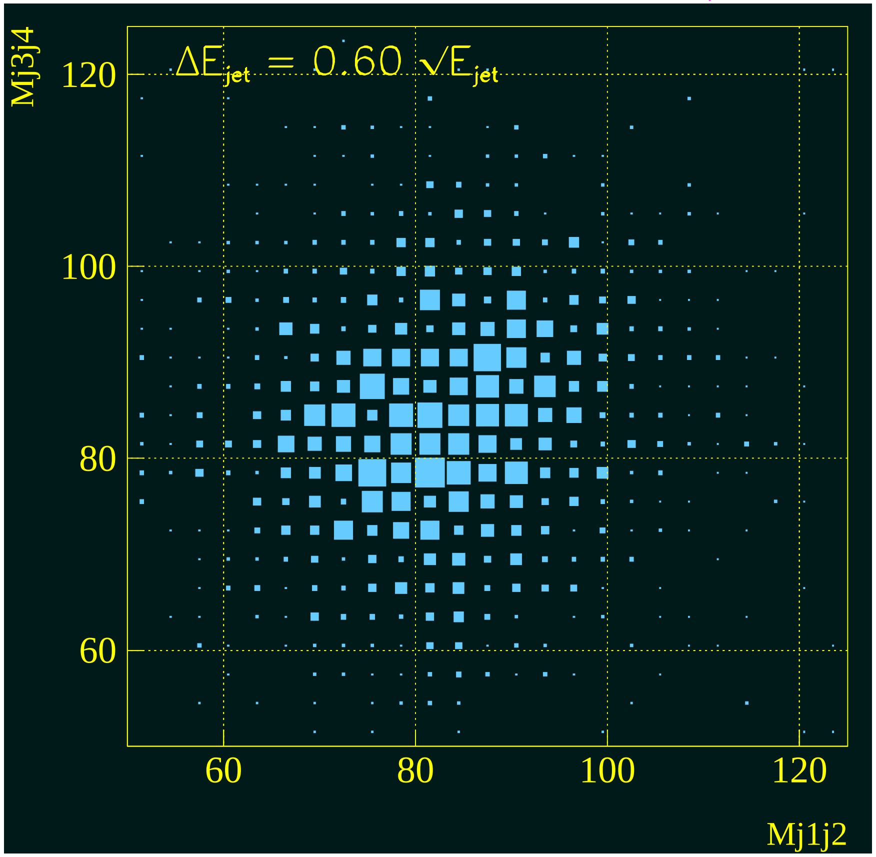
Most rejection from longitudinal calo segmentation and 4 mm η-strips in first compartment (γ / π^0 separation)

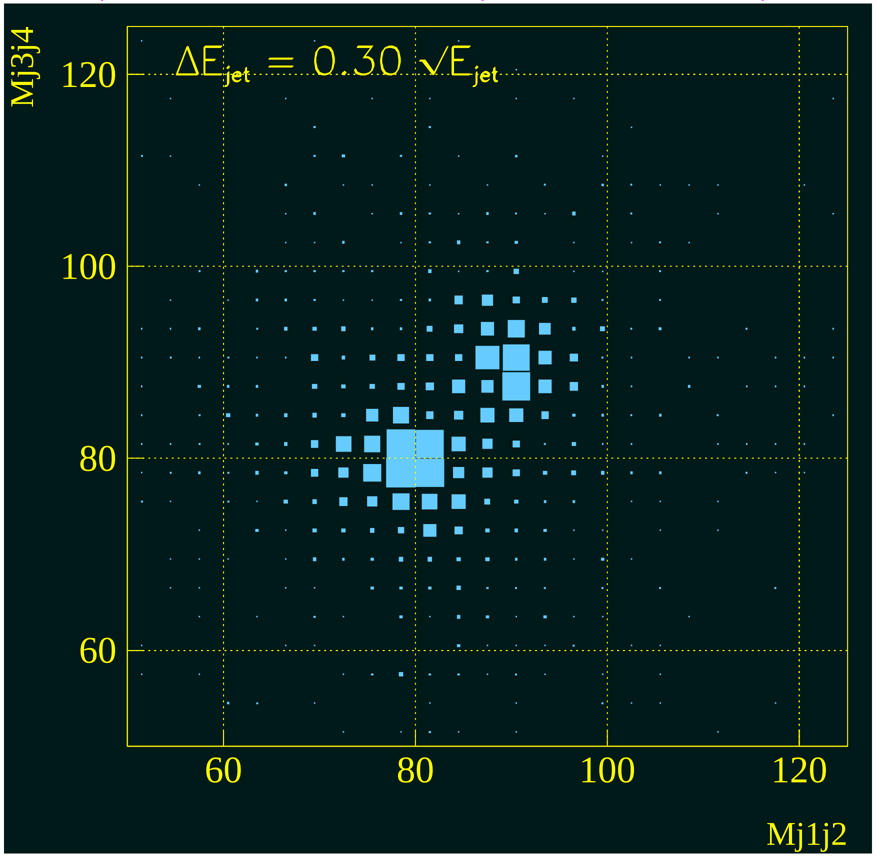
Optymalizacja pomiaru energii jetów

Energy flow in jets

- Some processes where WW and ZZ need to be separated without beam constraints (e.g. $e^+e^- \rightarrow \nu\nu WW, \nu\nu ZZ$)
- This requires a resolution of about $\Delta E/E = 30\%/\sqrt{E}$

WW-ZZ separation for $\Delta E/E = 60\%/\sqrt{E}$ and $\Delta E/E = 30\%/\sqrt{E}$





Jet Reconstruction @ ILC

- Q. How to achieve the best attainable jet energy resolution?

- A. Since the momentum resolution for the charged particle measured by trackers is much better than the energy resolution of calorimeters, the best energy resolution is obtained by reconstructing momenta of individual particles avoiding double counting among Trackers and Calorimeters.
    - Charged particles (~60%) measured by Tracker.
    - Photons (~30%) by electromagnetic CAL (ECAL).
    - Neutral hadrons (~10%) by ECAL + hadron CAL (HCAL).

$$E_{TOT} = p_e + p_\mu + p_{\text{charged hadron}} + E_\gamma + E_{\text{neutral hadron}}$$

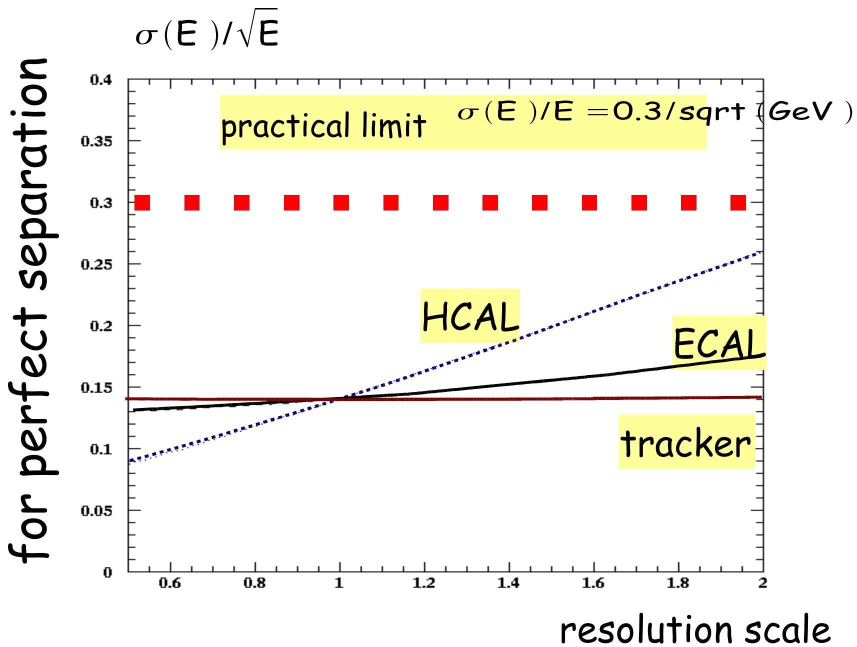
[tracks only] [calorimeter only]

Particle Flow Algorithm (PFA)

Particle Flow: Basics

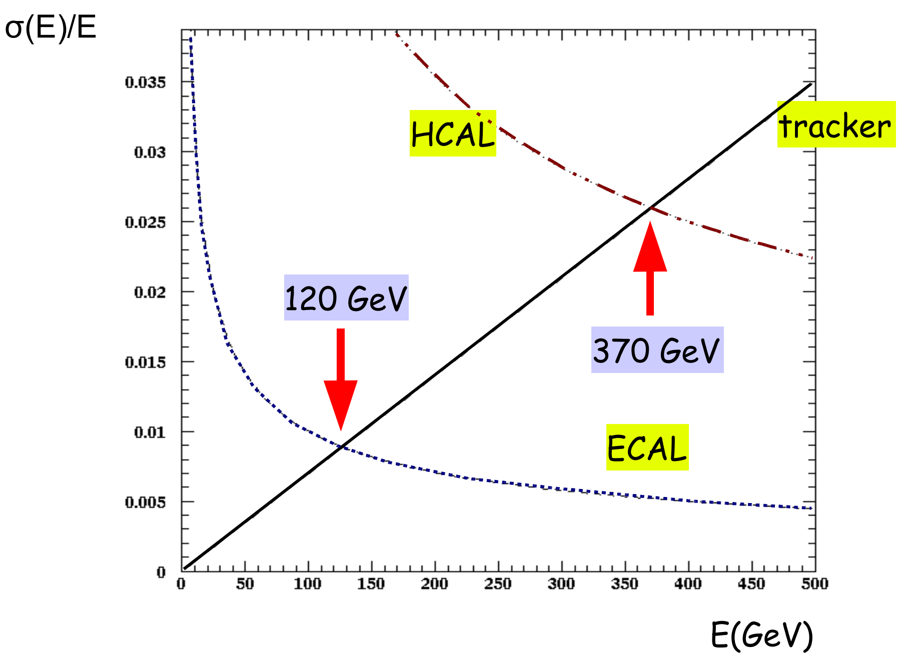
$$\sigma(Jet) = \sqrt{\sum \epsilon_T^2 E_i^4 + \sum \epsilon_{ECAL}^2 E_i + \sum \epsilon_{HCAL}^2 E_i}$$

Resolution is dominated by HCAL
and by
"confusion" term



Effect of changing the resolutions by a scale factor

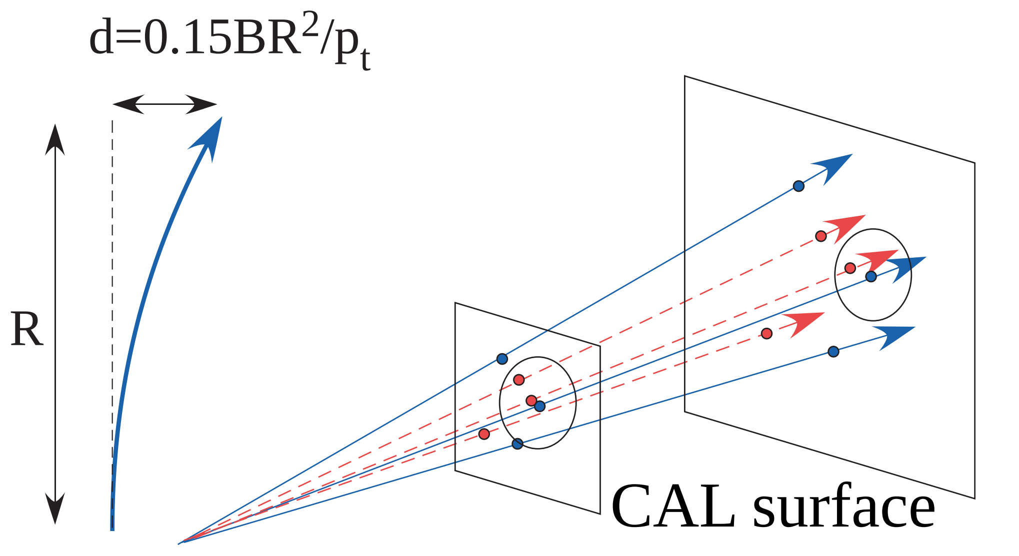
Resolution tracker - Calorimeter



design detector to
- minimize confusion term
- minimize the role of the HCAL
- for the rest: build the best HCAL possible

Particle Flow Algorithm

- In order to get good energy resolution by PFA, separation of particles is important. → Reduce the density of charged and neutral particles at calorimeter surface.



Often quoted "Figure of Merit"

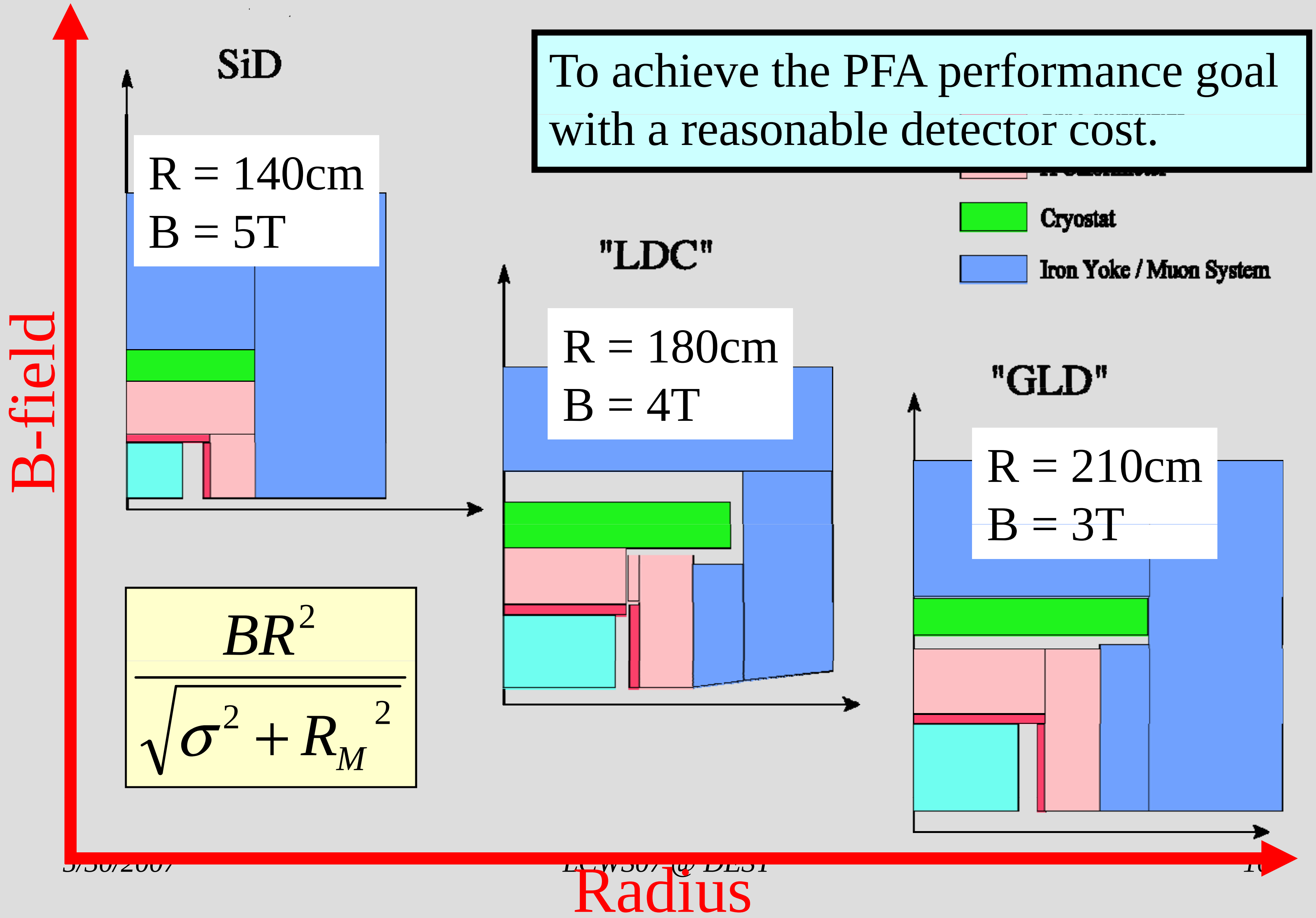
$$\frac{BR^2}{\sqrt{\sigma^2 + R_M{}^2}}$$

B : Magnetic field
R : CAL inner radius
σ: CAL granularity
R_M : Effective Moliere length

- For transverse separation of particles at the ECAL surface, stronger B-field and/or large ECAL radius are preferable.

* Fine segmentation of CAL is also important for pattern recognition.

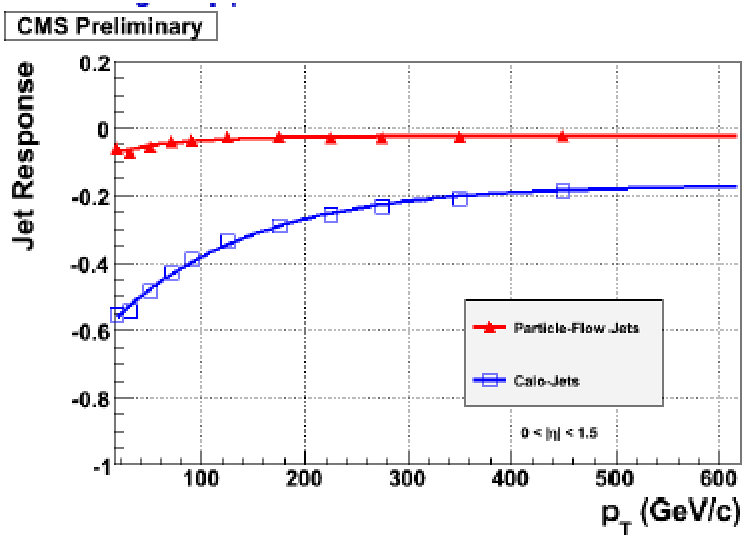
Radius vs. B-field



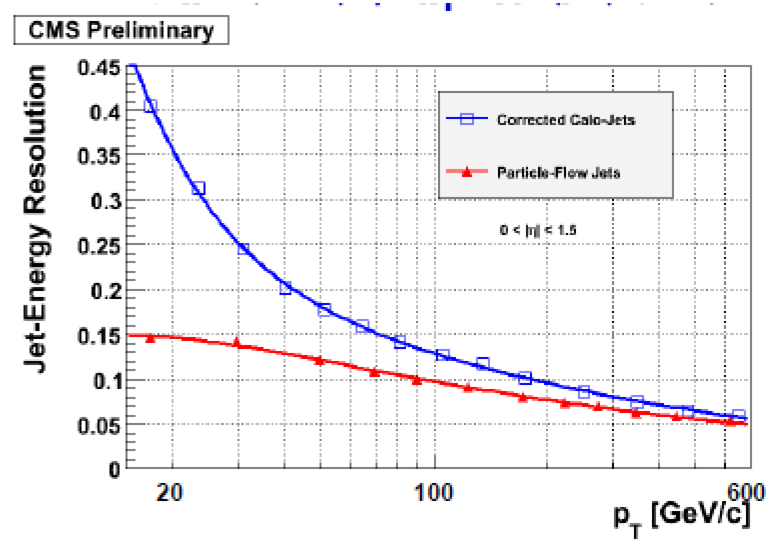
To achieve the PFA performance goal with a reasonable detector cost.

$$\frac{BR^2}{\sqrt{\sigma^2 + R_M^2}}$$

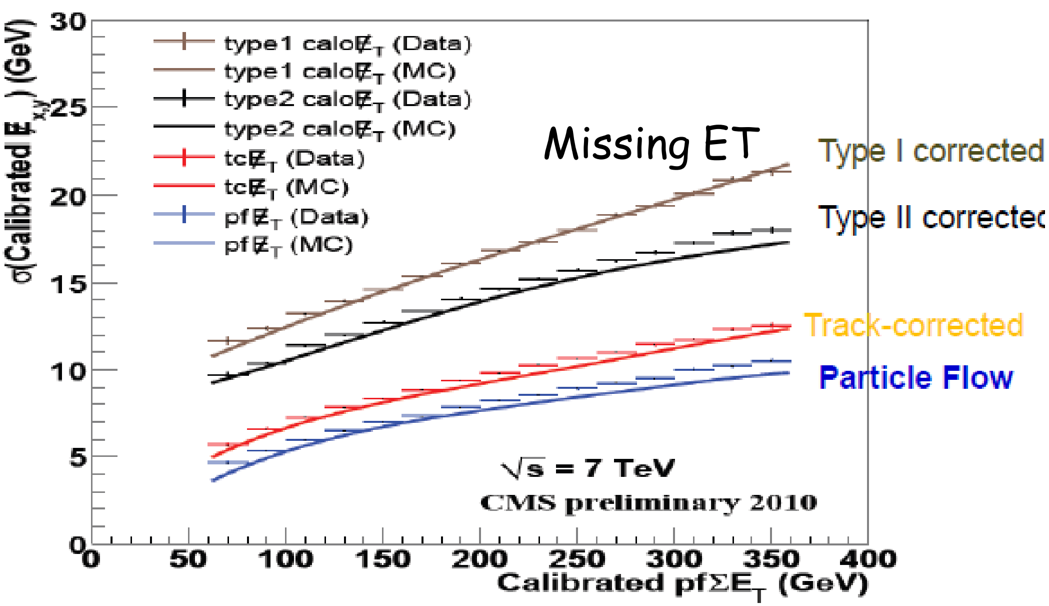
Particle Flow : CMS case (2010 data)

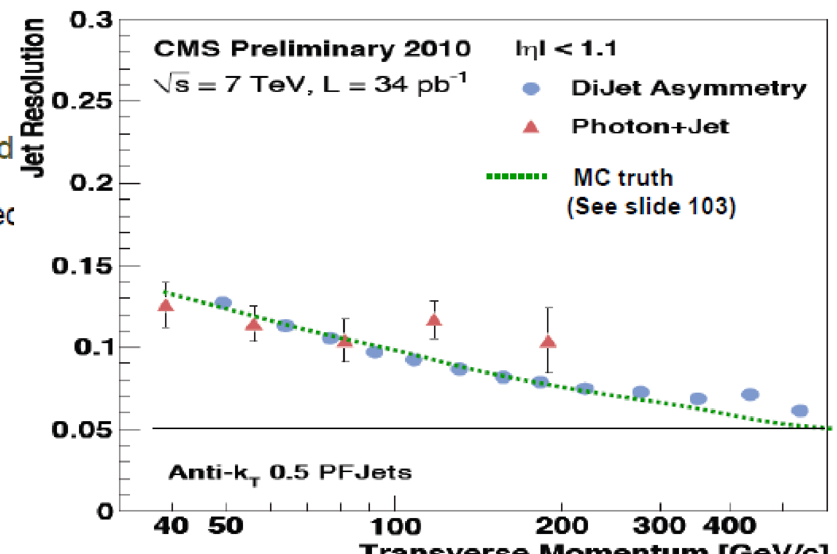


Simulation: energy scale



Simulation: Jet energy resolution

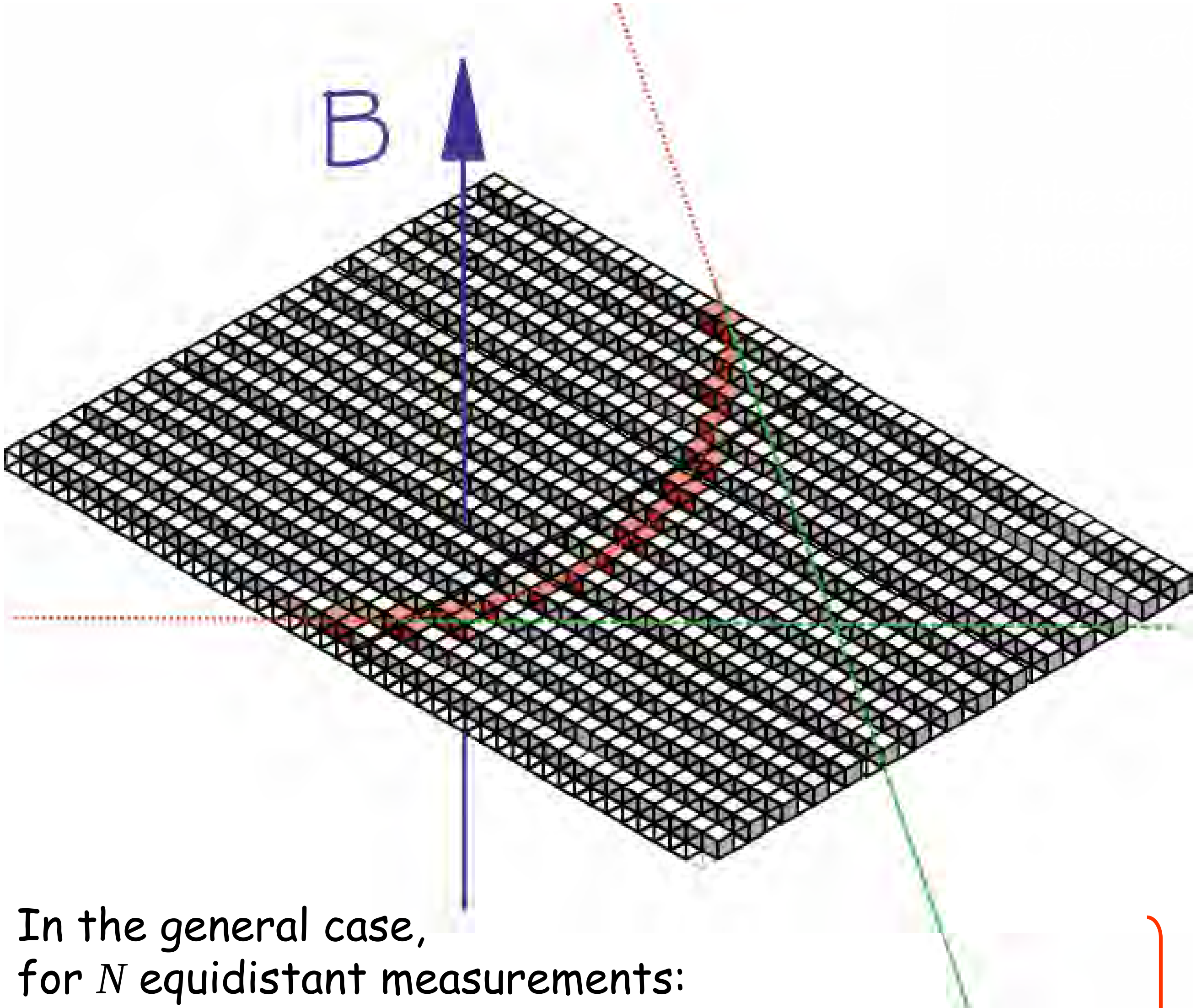




Data: Jet energy resolution

Spektrometr mionowy

Error in momentum measurement



In the general case,
for N equidistant measurements:

$$\left.\frac{\sigma(p_\perp)}{p_\perp}\right|_{measured} = \frac{1}{0.3}\frac{\sigma(x)\cdot p_\perp}{BL^2}\sqrt{\frac{720}{N+4}}$$

for $N \geq \sim 10$

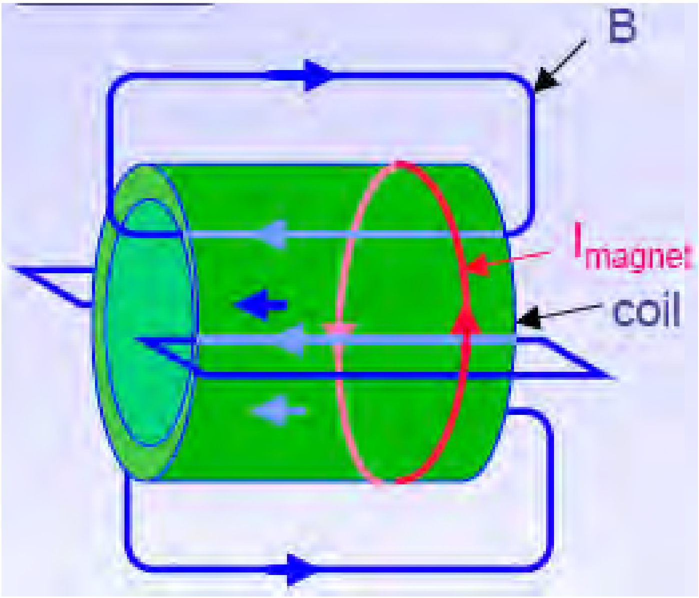
In short → $$\frac{\sigma(p_\perp)}{p_\perp^2} = const.$$

O. Ullaland/2006

Magnets for 4π Detectors

Solenoid

+ Large homogeneous field inside
- Weak opposite field in return yoke
- Size limited by cost
- Relatively large material budget



Examples:

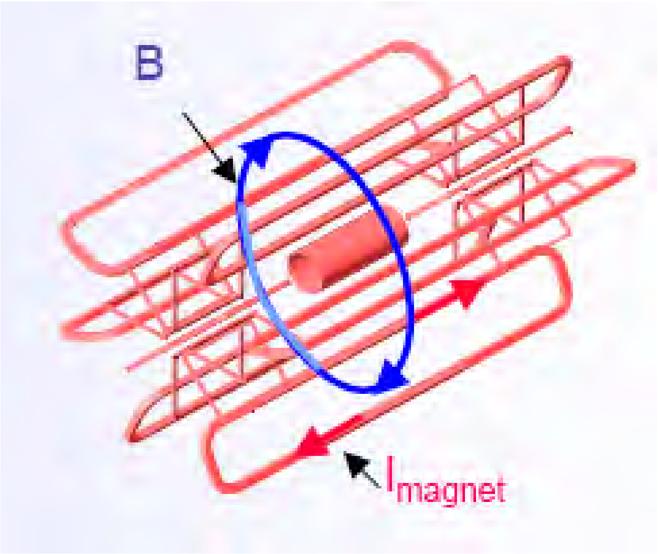
•Delphi: SC, 1.2 T, 5.2 m, L 7.4 m

•CDF: SC, 1.4T, 2 m, L 6m

•CMS: SC, 4 T, 5.9 m, L 12.5 m

Toroid

+ Field always perpendicular to p
+ Rel. large fields over large volume
+ Rel. low material budget
- Non-uniform field
- Complex structural design

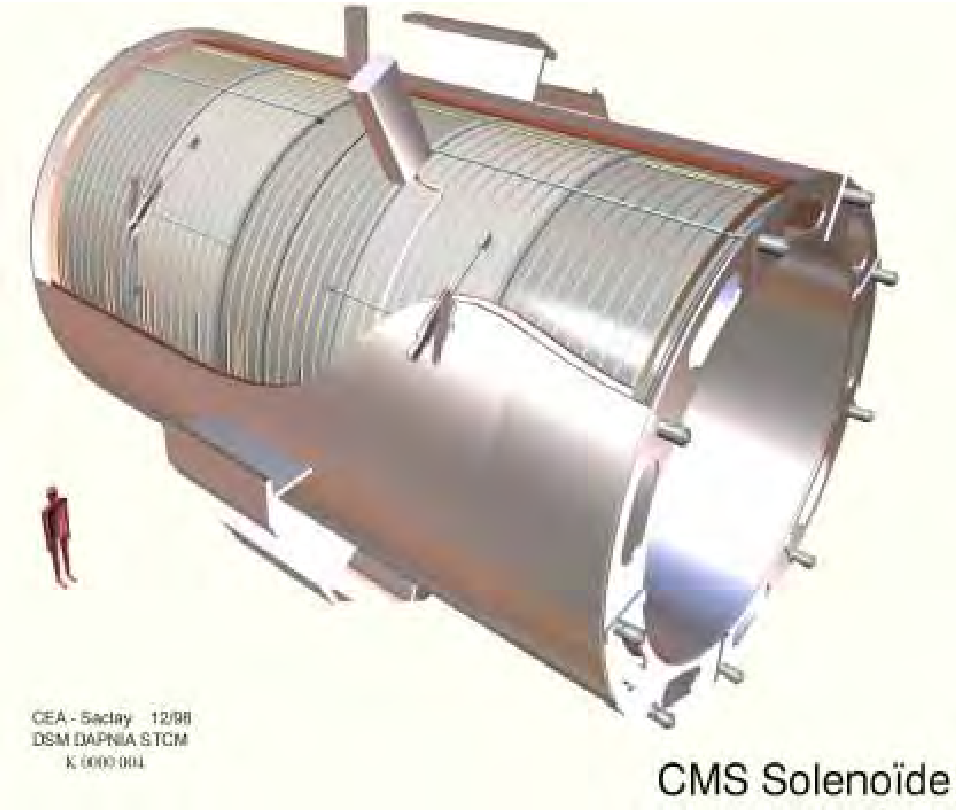


Example:

•ATLAS: Barrel air toroid, SC, ~1 T, 9.4 m, L 24.3 m

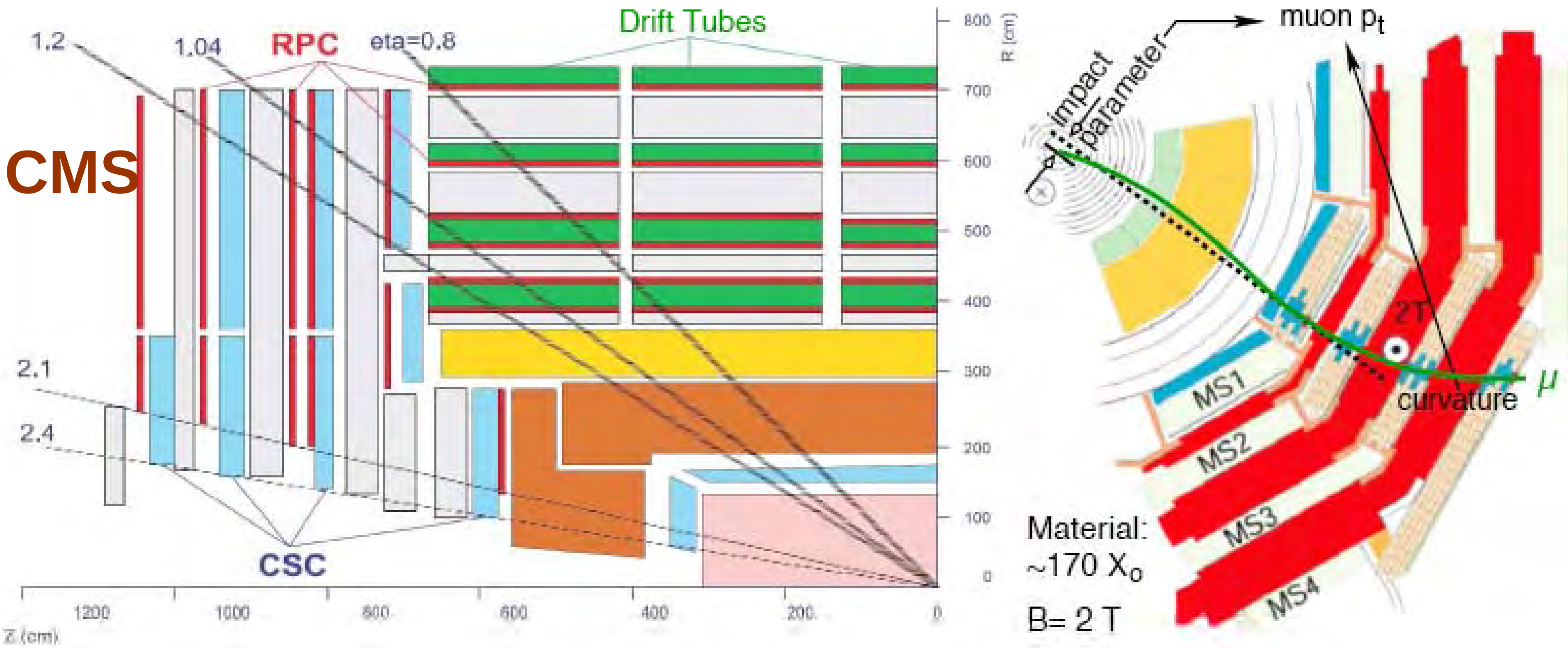
Charge and Momentum

Two ATLAS toroid coils



Superconducting CMS Solenoid Design

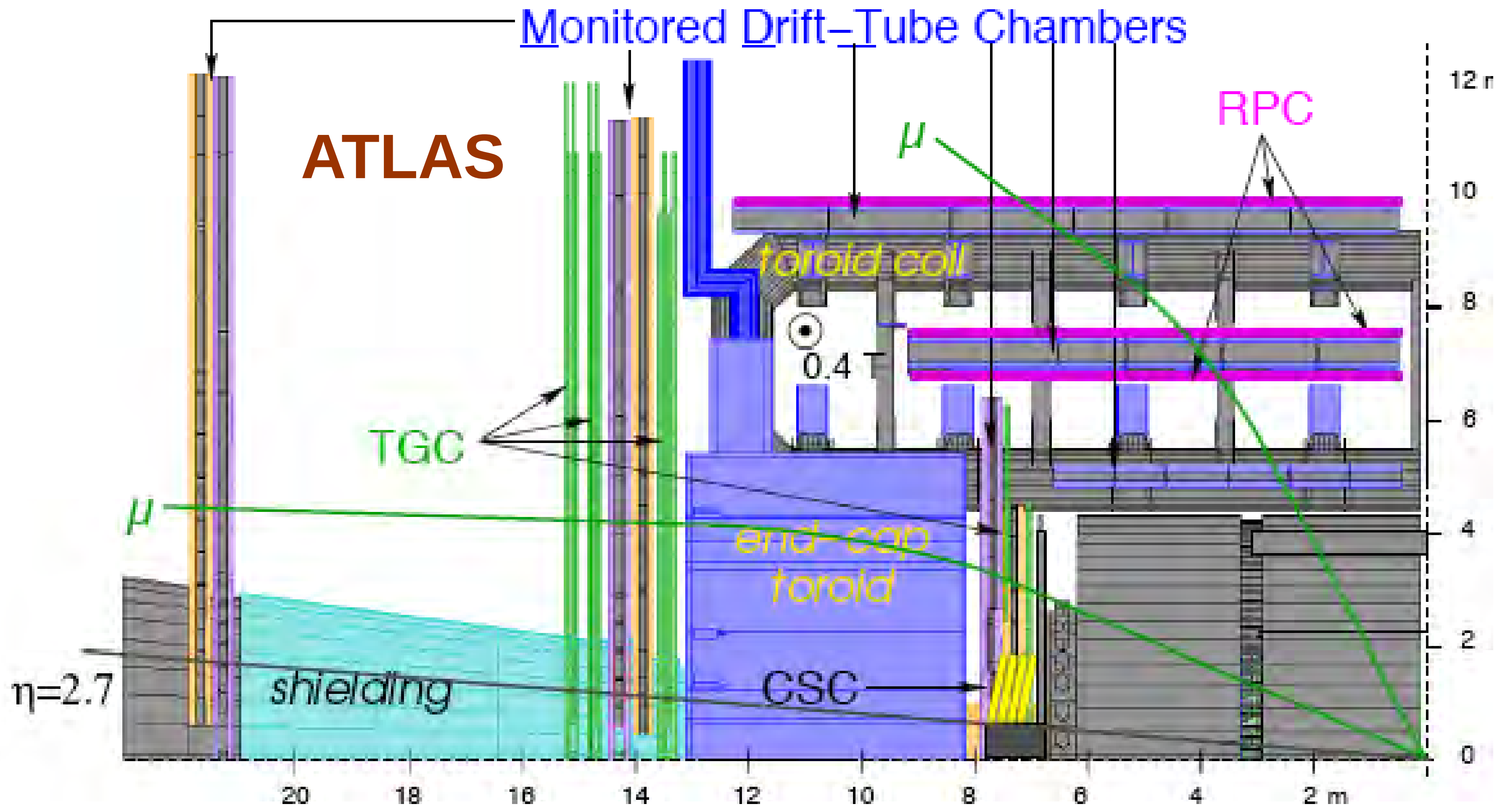
ATLAS/CMS: muon measurements



CMS muon spectrometer

- **Superior combined momentum resolution in central region**
- **Limited stand-alone resolution and trigger (at very high luminosities) due to multiple scattering in iron**
- **Degraded overall resolution in the forward regions ($|\eta| > 2.0$) where solenoid bending power becomes insufficient**

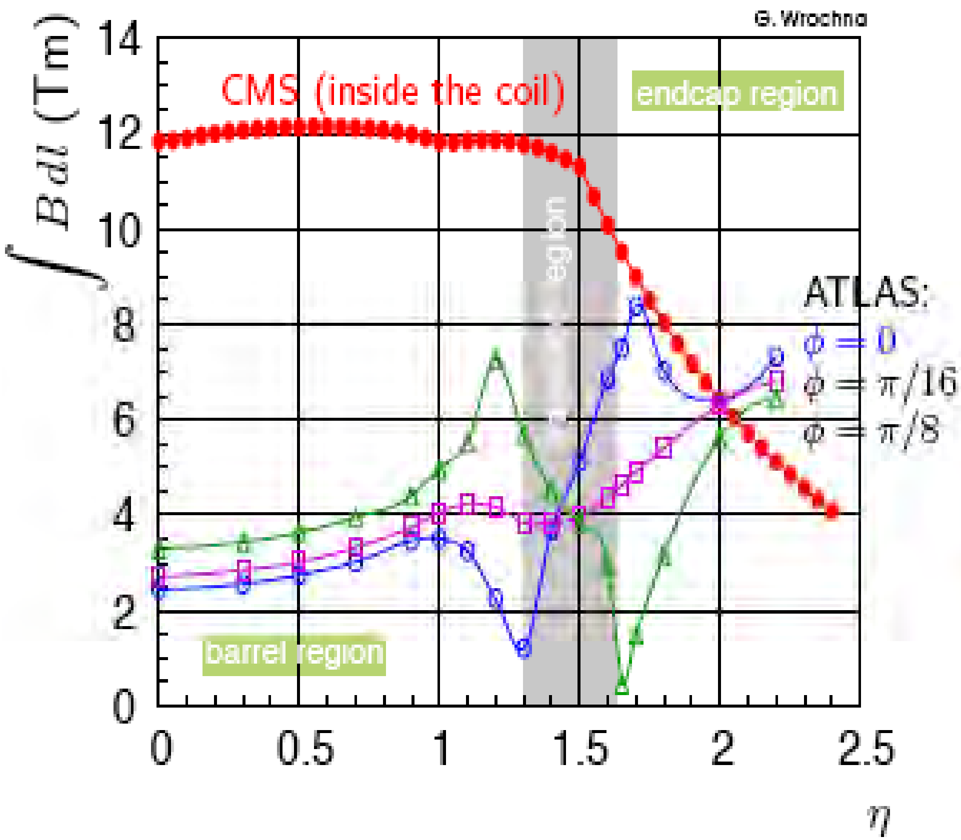
ATLAS/CMS: muon measurements



ATLAS muon spectrometer

- **Excellent stand-alone capabilities and coverage in open geometry**
- **Complicated geometry and field configuration (large fluctuations in acceptance and performance over full potential η x φ coverage (|η| < 2.7)**

ATLAS/CMS: muon measurements



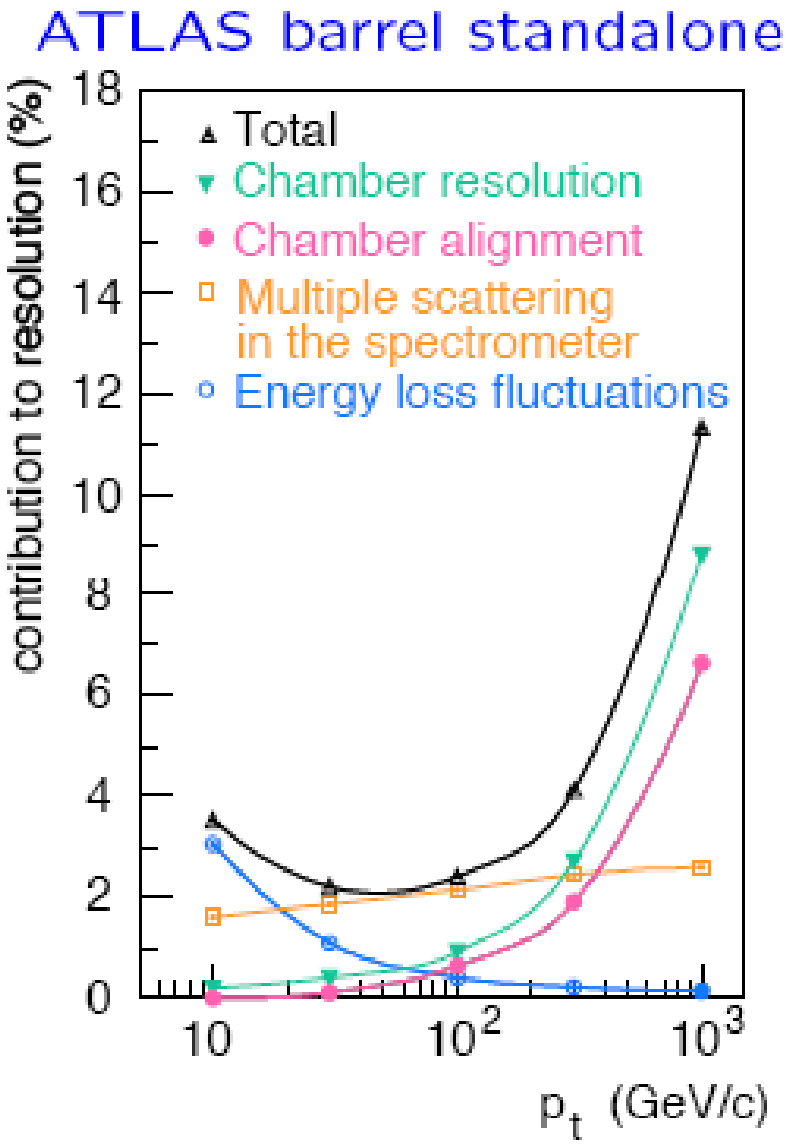
Barrel: $\approx 5\times$ higher bending power in CMS, **but** $\approx 14\times$ larger multiple scattering.

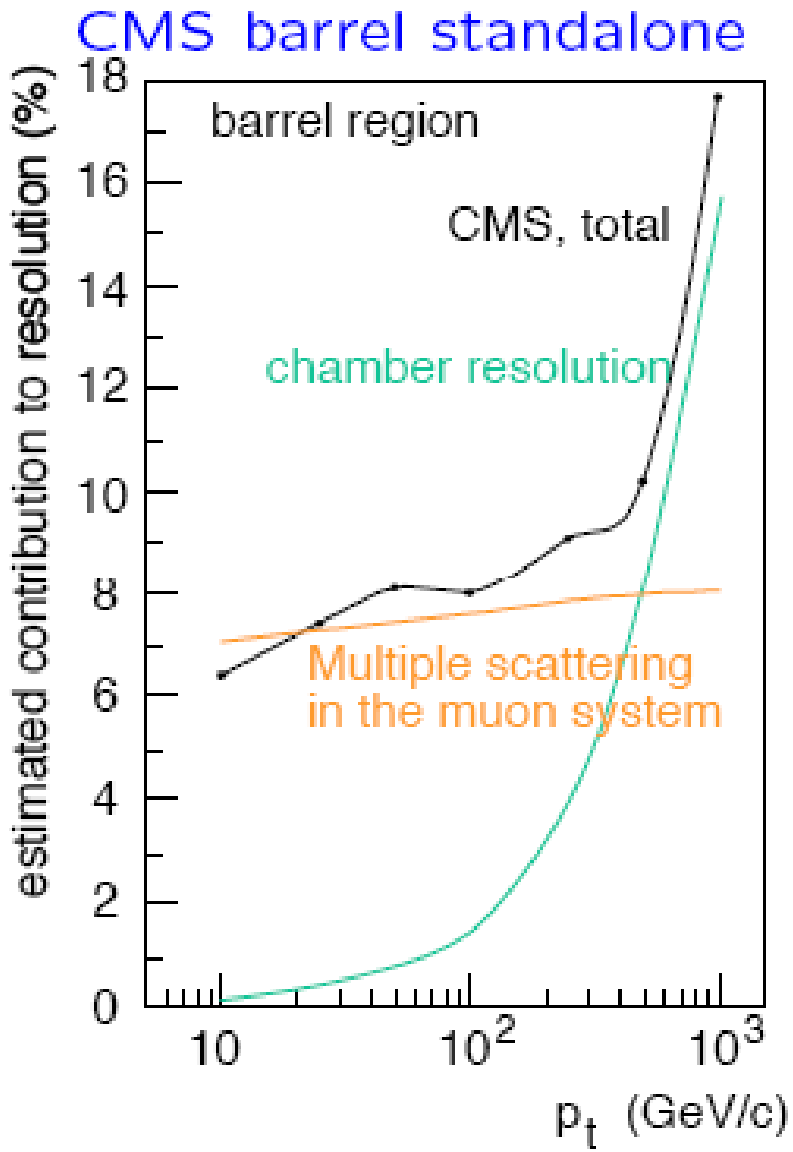
$\rightarrow$ $\approx 3\times$ worse p_t resolution in CMS.

Endcap: similar bending powers, $\approx 10\times$ large multiple scattering.

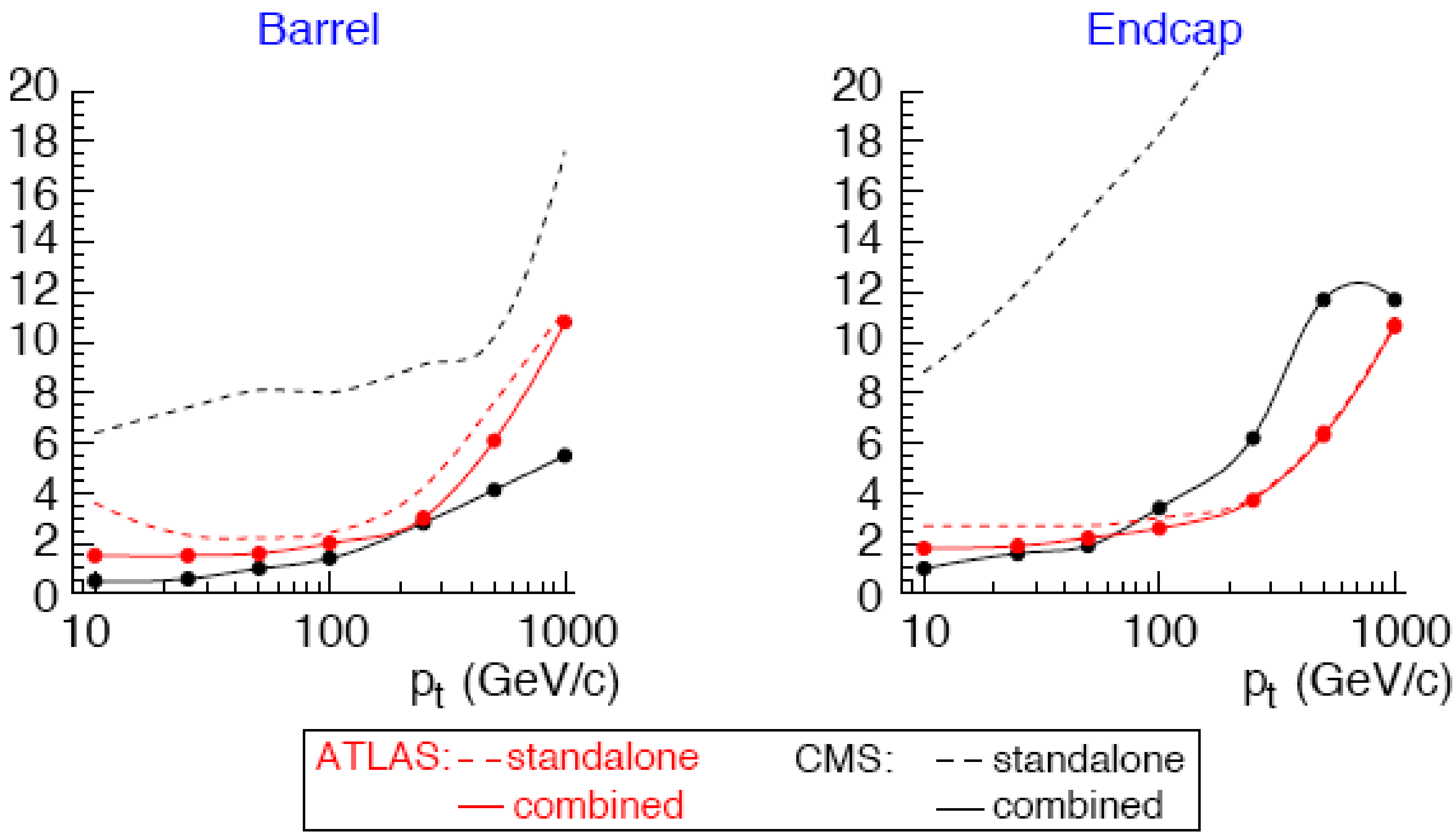
$\rightarrow$ $\approx 5\times$ worse p_t resolution in CMS.

ATLAS/CMS: muon measurements





ATLAS/CMS: muon measurements



Alignment Strategy

- **Applies to tracking detectors including muon chambers.**
  - Then use tracks to align calorimeters as trackers measure position better (usually) than calorimeters

- **Typically 3 step process**
  1. Measure element (e.g. wire, pixel) position during construction of subdetector using coordinate measuring machines and similar devices.
  2. Measure relative position of subdetectors after assembly using surveying techniques such as lasers.
     - Only works for detectors you can see.
  3. Track based alignment

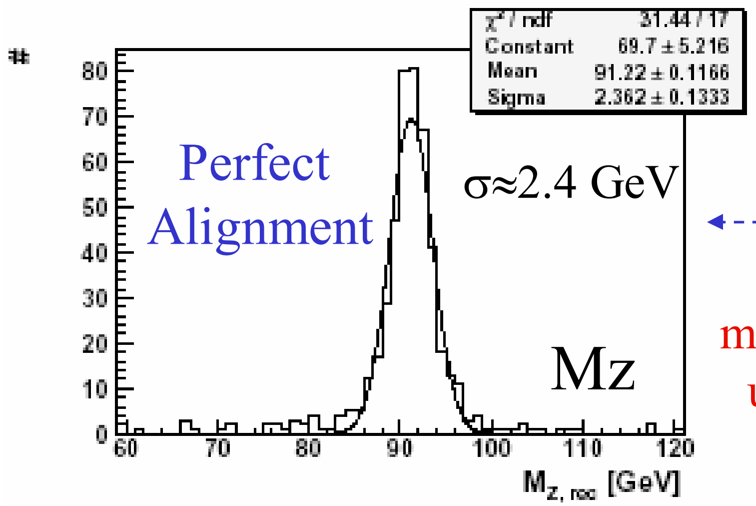
Alignment Concept & Typical Numbers

	Muon	Tracker: Strip	Tracker: Pixel
Assembly:	O(mm)	0.1-0.5mm	50-100 μm
+ Hardware Alignment:	~<100μm	<100μm	50-100 μm (no HA foreseen)
+ Track Based Alignment	~100μm (perhaps below)	~10μm	~5 μm
Remarks:	Hardware Alignment will provide the operational alignment level. Track based alignment will be a cross check and eventually a completion	Hardware Alignment will insure pattern recognition. Track Based Alignment must provide the final alignment	Only Track based Alignment. Nothing else!

Nick Hadley

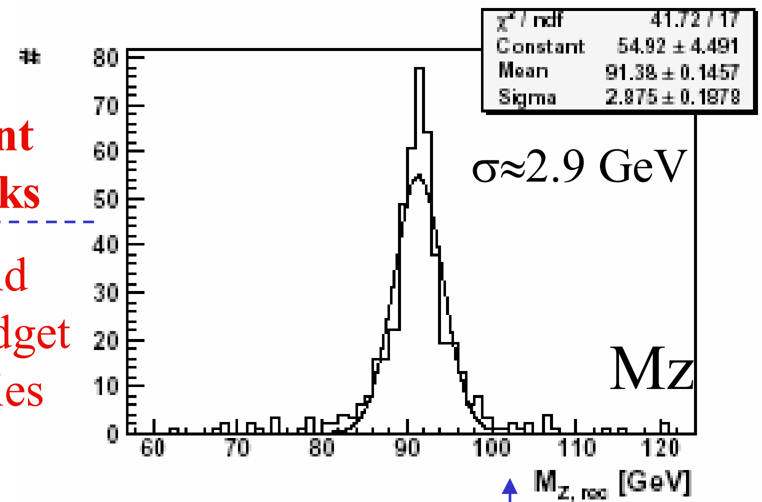
Mis-Alignment: Impact on Physics (important for Z′, LED)

⇒ Use Z→μμ to illustrate the impact of mis-alignment on physics



Alignment with tracks

B field and material budget uncertainties



First Data Taking

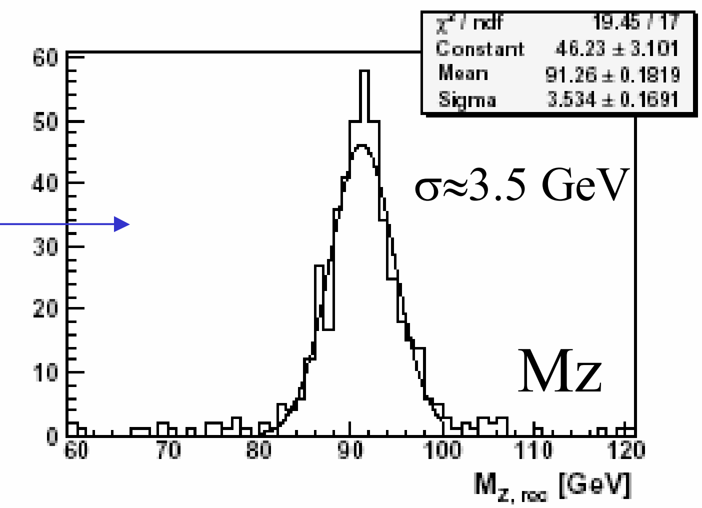
<1fb^{-1}

Laser Alignment

⊗

Mechanical Constraints

⇒≈100μm alignment uncertainties



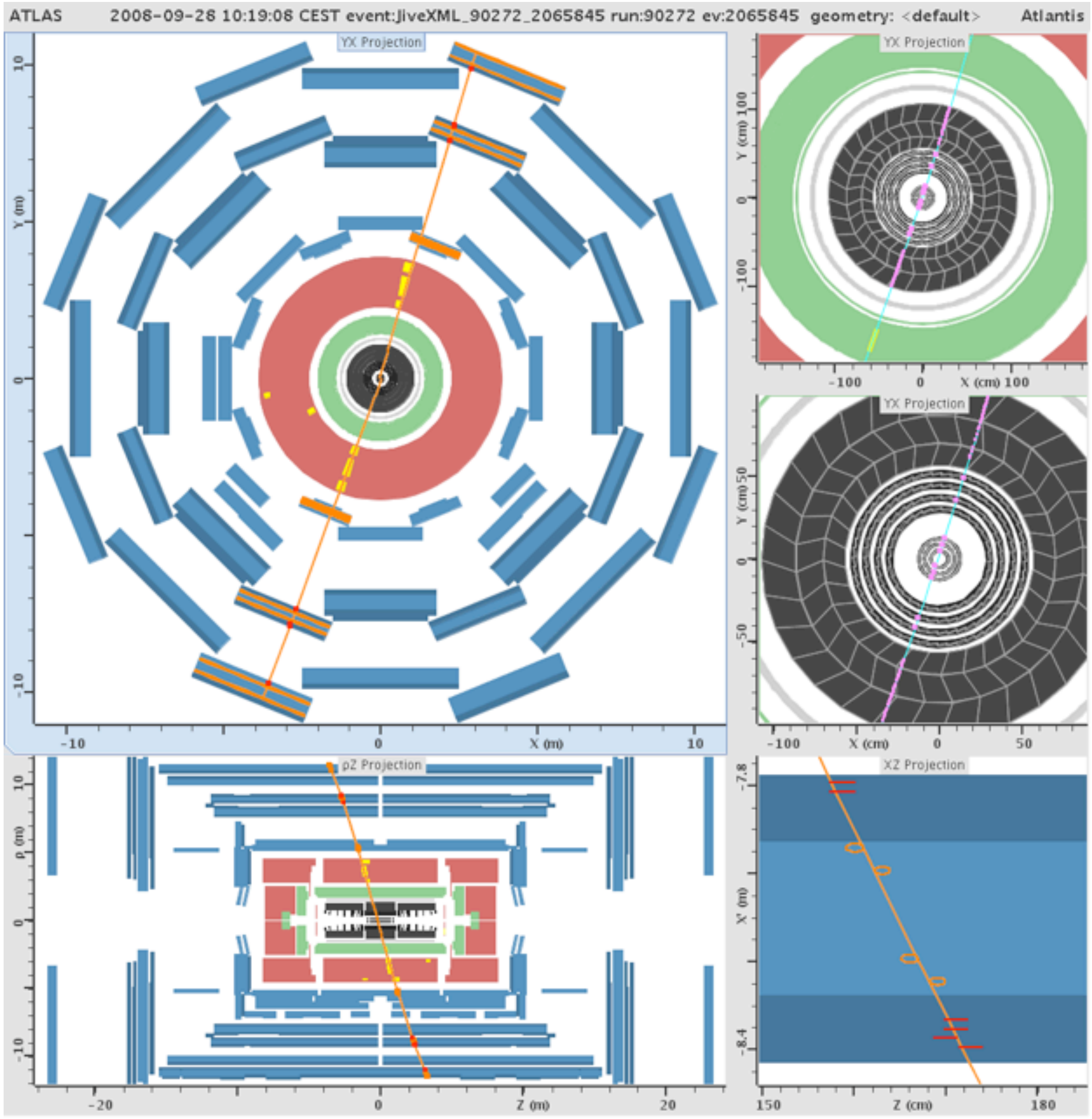
Long(er) Term:

≈>1fb^{-1}

First results of Alignment with tracks

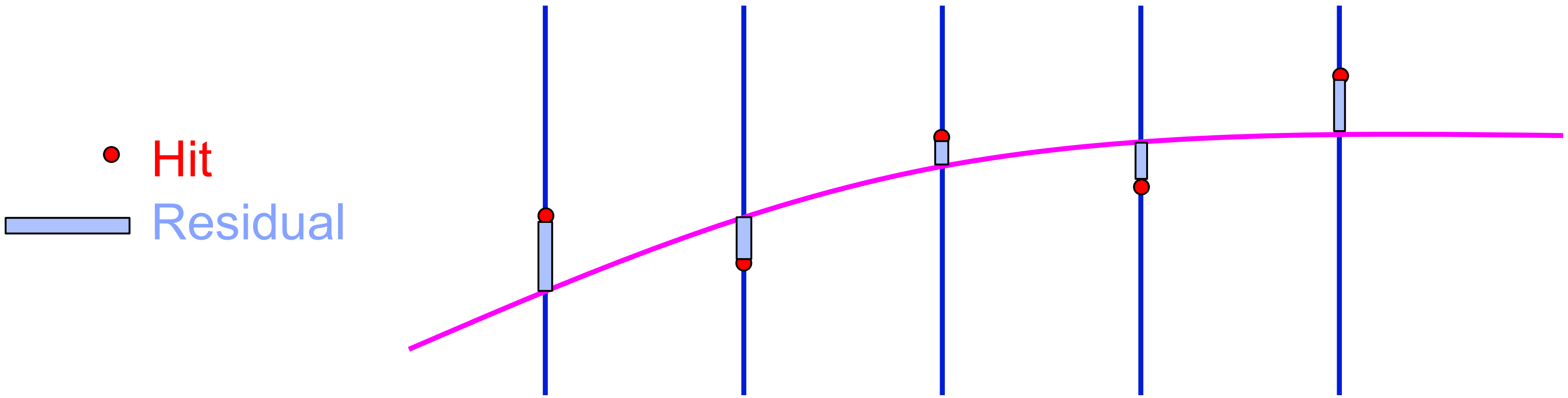
⇒≈20μm alignment uncertainties

14. ATLAS Cosmic Event



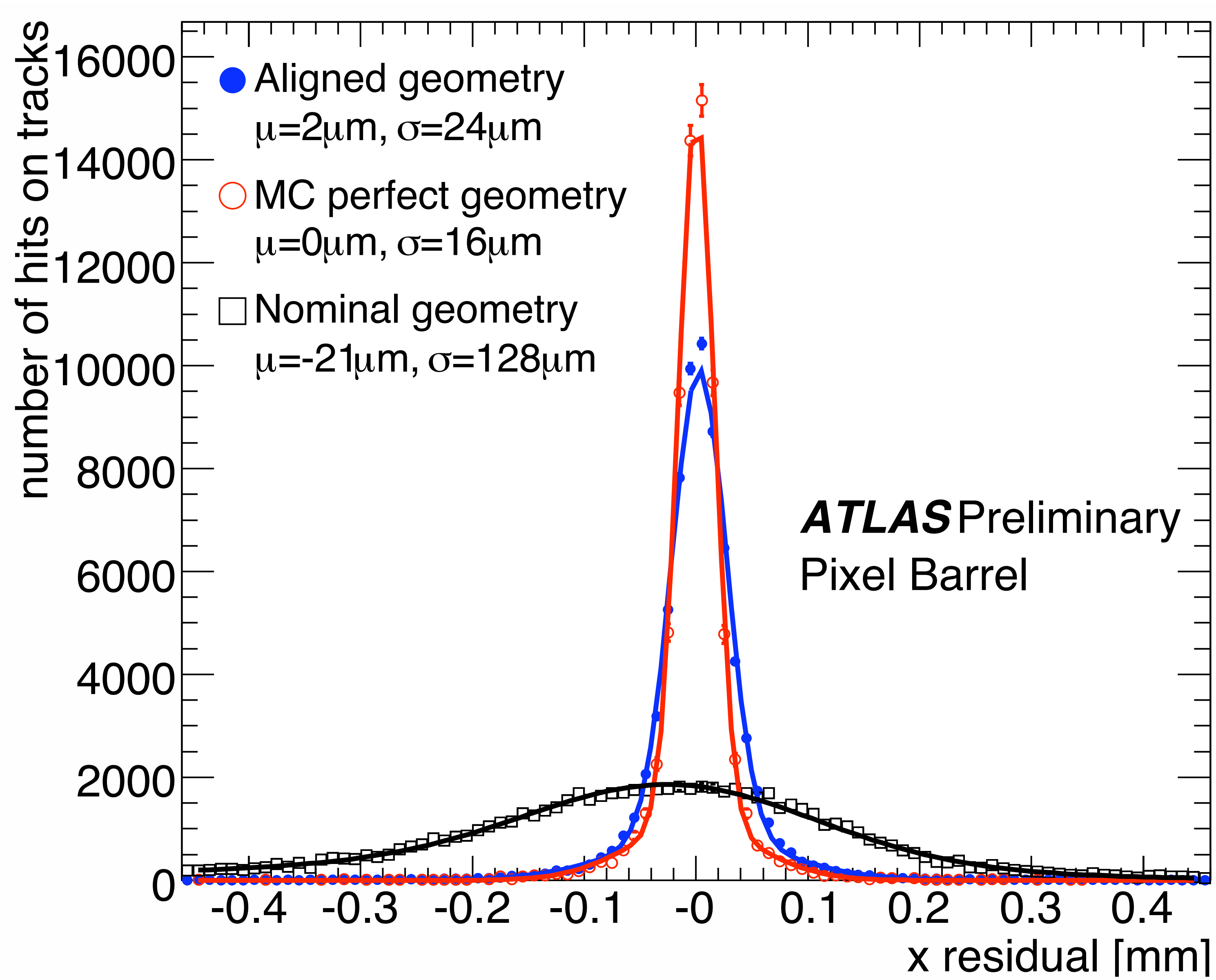
Alignment performance

- Track based alignment minimises residuals for a sample of tracks, by adjusting position of sensitive elements.
- Position and width of known mass objects allows momentum resolution measurement.



from F. Meier

14. ATLAS Pixel Results: Cosmic Rays

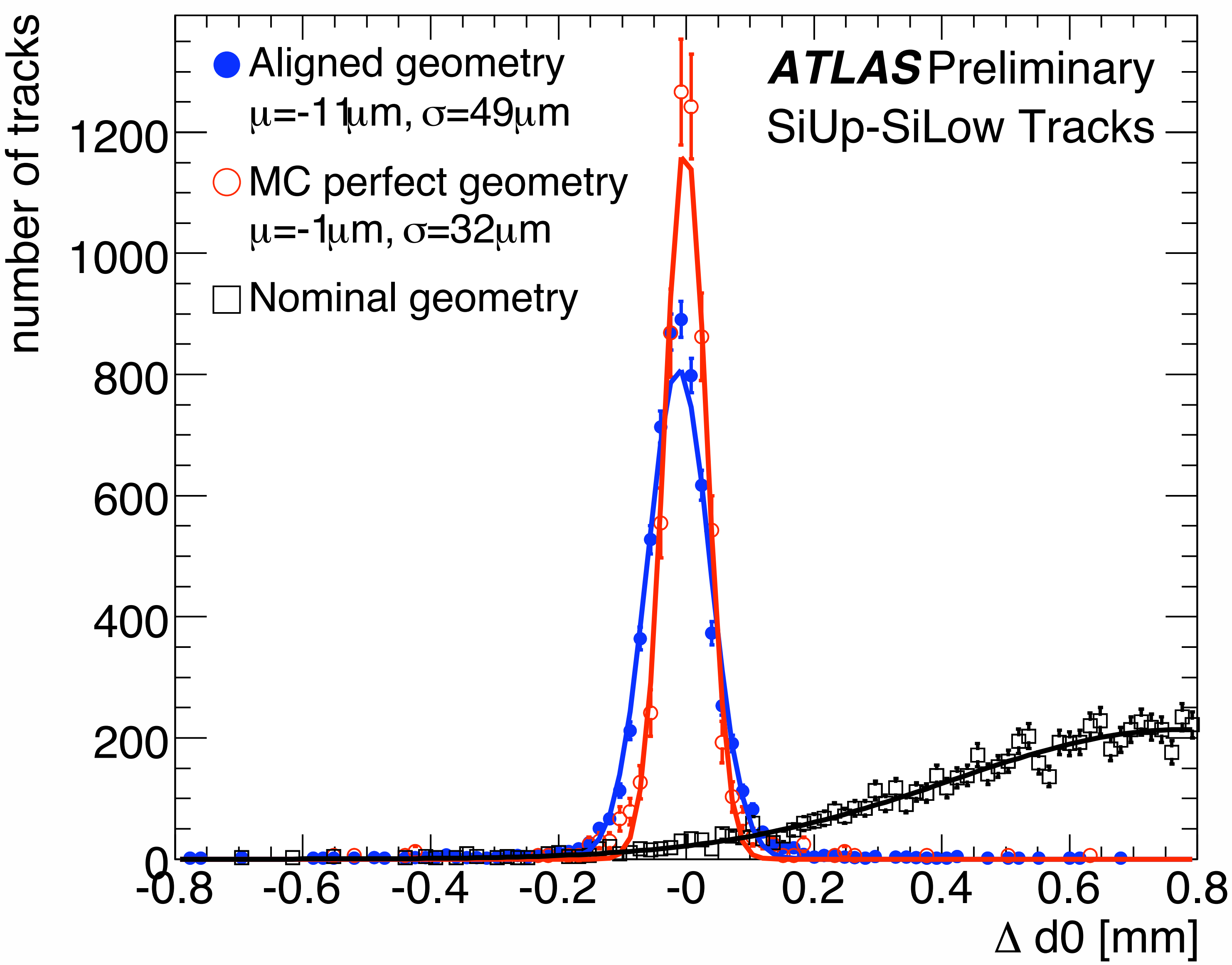


Residual distribution in x, integrated over all hits-on-tracks in the pixel barrel for the nominal geometry and the preliminary aligned geometry.

The residual is defined as the measured hit position minus the expected hit position from the track extrapolation. Shown is the projection onto the local x coordinate, which is the precision coordinate.

Tracks are selected to have pT > 2 GeV, ld0l<50mm, lz0l<400mm (in other words they are required to go through the pixel L0).

14. ATLAS ID Results: Cosmic Rays



Cosmic tracks crossing the entire ID leave hits in both the upper and lower halves of the ID.

These tracks can be split near the interaction point and fit separately, resulting in two collision-like tracks that can then be compared.

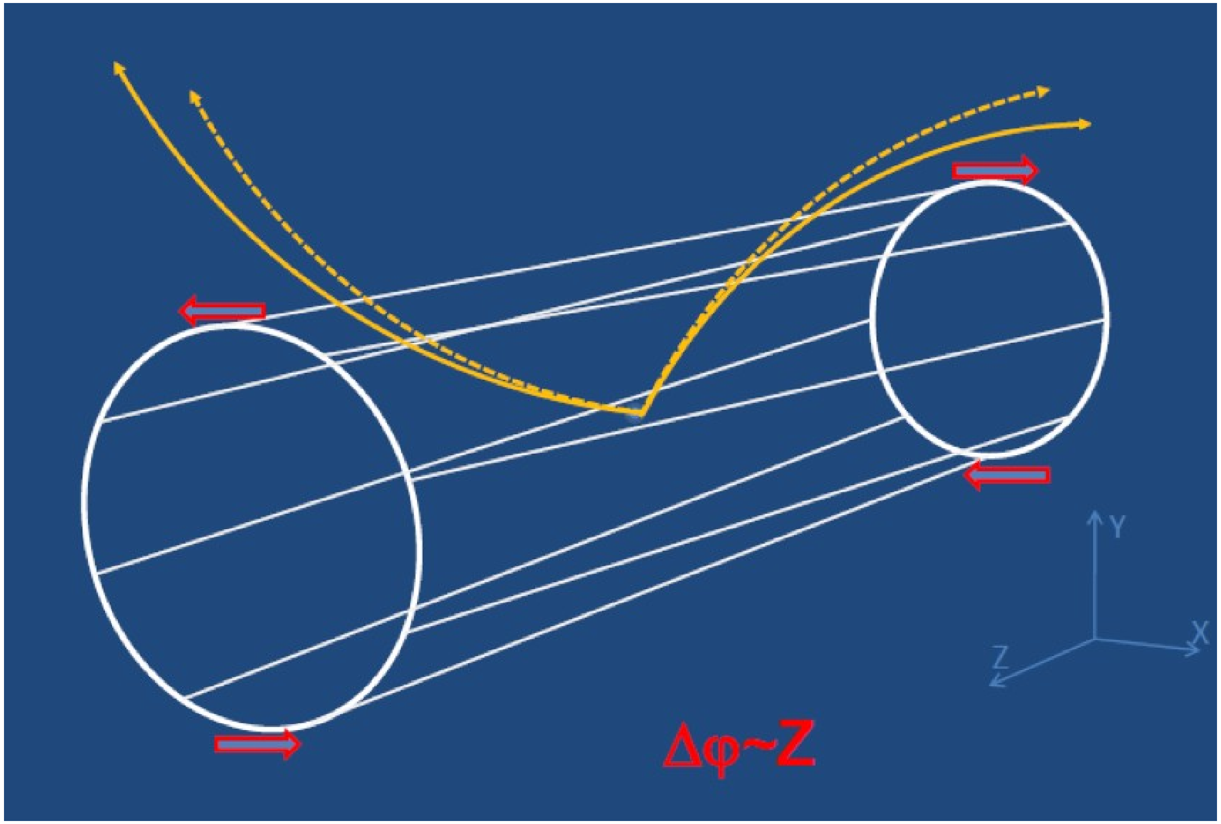
The plots shows the difference in the d0 track parameter between the two split tracks. Tracks are selected to have pT > 2 GeV, |d0|<50mm, |z0|<400mm (in other words they are required to go through the pixel L0).

Tracks also are required to have a hit in the Pixel B layer, 3 Pixel hits and in total 7 Silicon hits.

Alignment performance

Systematic distortions, example a twist, are hard to detect.

Track residuals can be minimised but p_T is biassed.



from P. Brückman de Renstrom

$K^0_s \rightarrow \pi^+\pi^-$

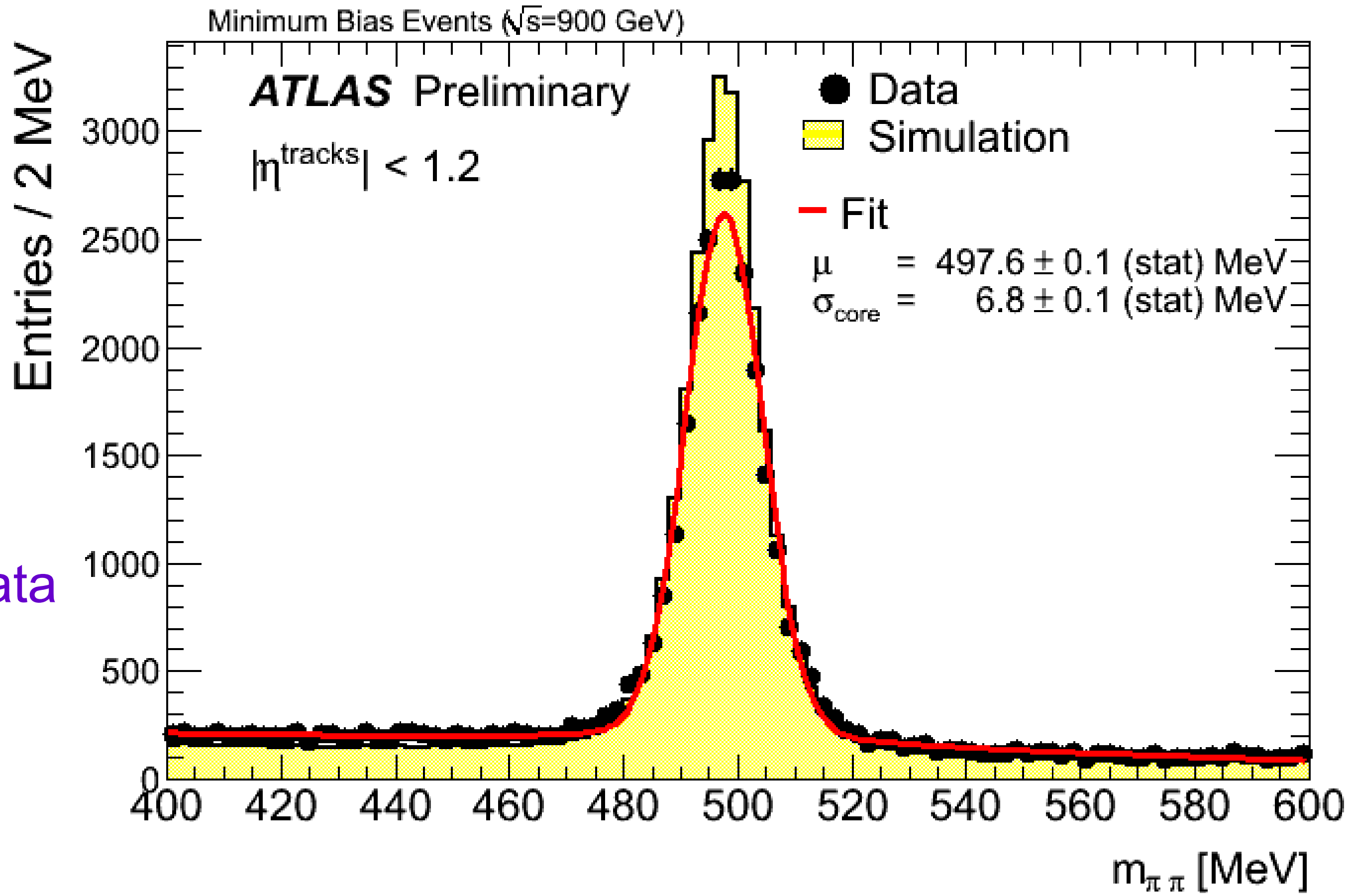
Two oppositely charged tracks, consistent with the same vertex.

Assume the tracks are pions. Reconstruct the pair invariant mass.

World Average PDG value 497.614 ± 0.024 MeV

ATLAS example:2009 data slightly broader than simulation

ATLAS-CONF-2010-019



$K^0_s \rightarrow \pi^+\pi^-$

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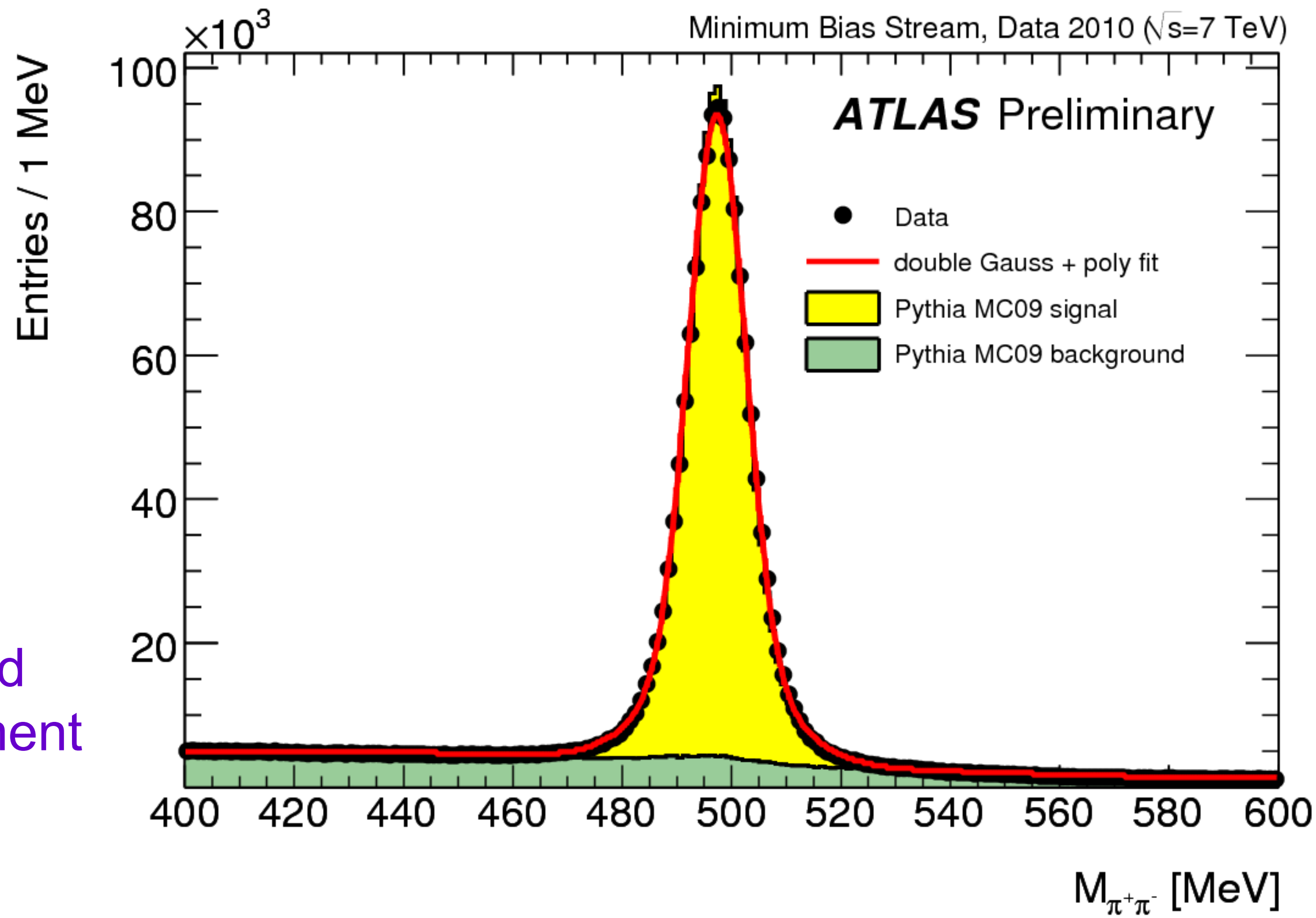


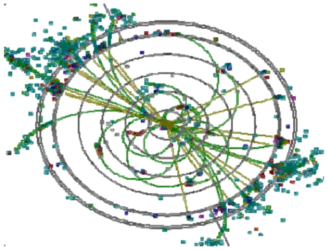
Much better agreement with 2010 sample and improved alignment

ATLAS-CONF-2010-033

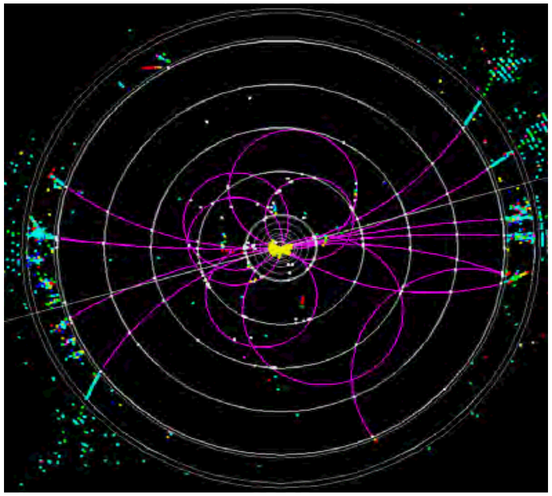
Optymalizacja detektora

Decydujące znaczenie mają, niestety, pieniądze...

Na przykładzie projektu SiD dla ILC.



SiD (the Silicon Detector)

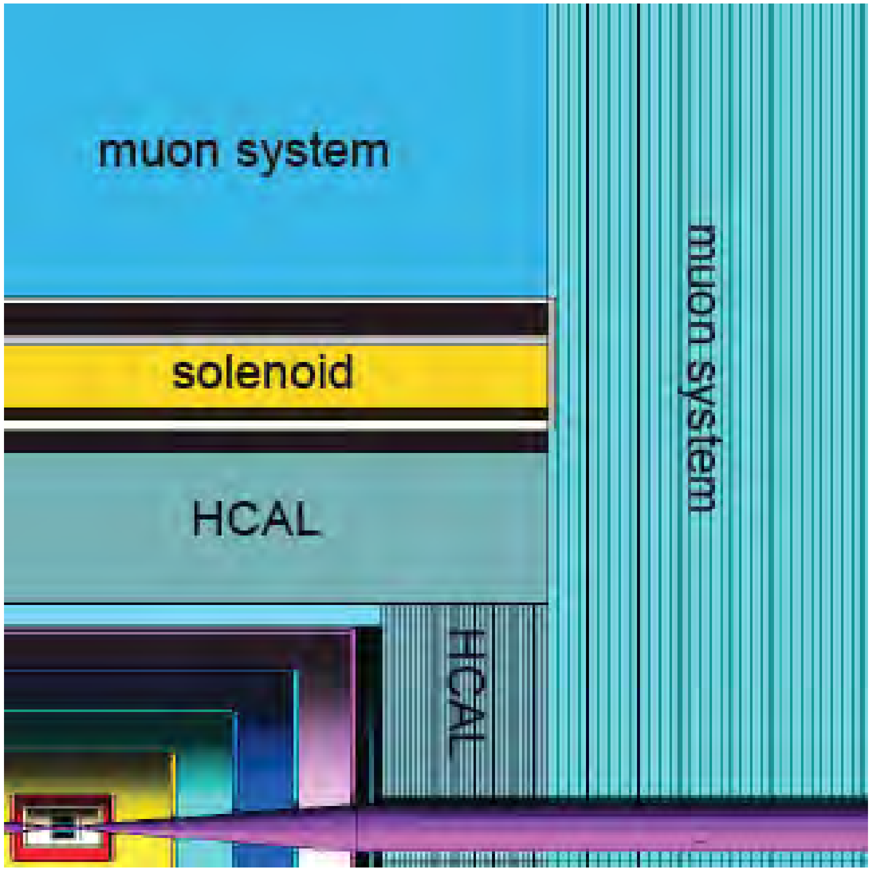


CALORIMETRY IS THE STARTING POINT IN THE SiD DESIGN

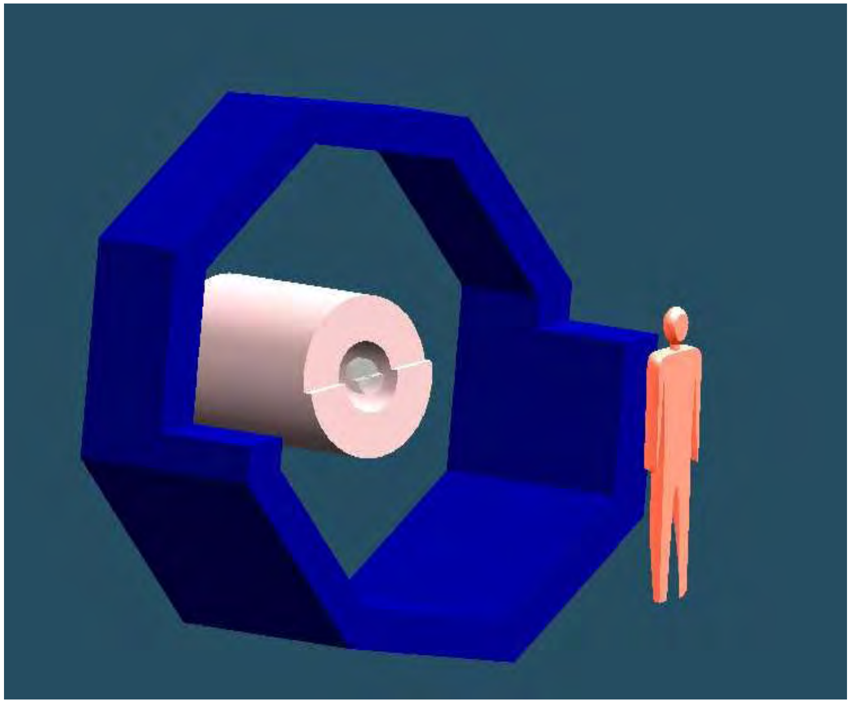
assumptions

- Particle Flow Calorimetry will result in the best possible performance
- Silicon/tungsten is the best approach for the EM calorimeter
- Silicon tracking delivers excellent resolution in smaller volume
- Large B field desirable to contain electron-positron pairs in beamline
- Cost is constrained

SiD Configuration



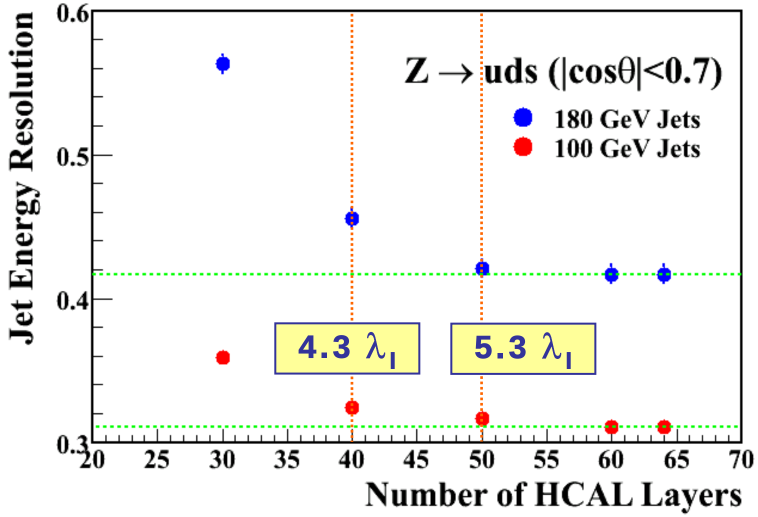
5 Tesla

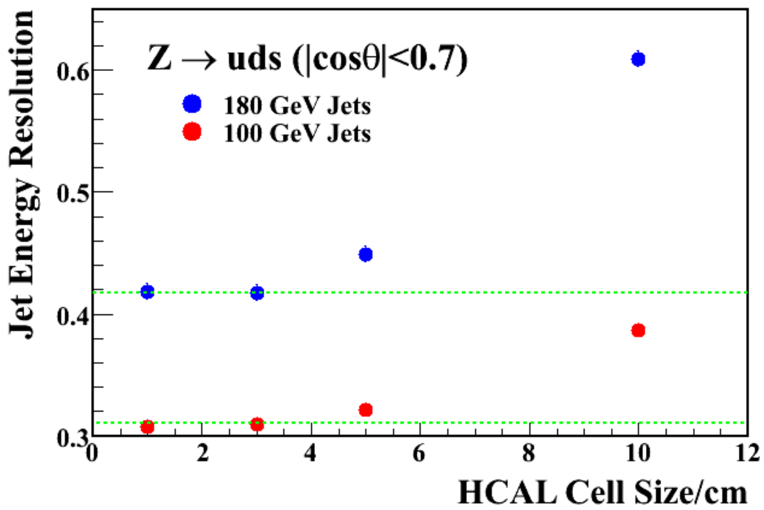


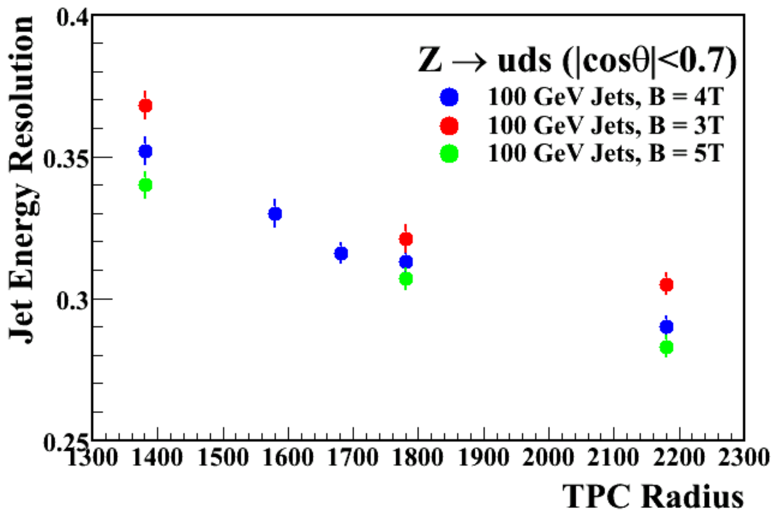
Scale of EMCal & Vertex Detector

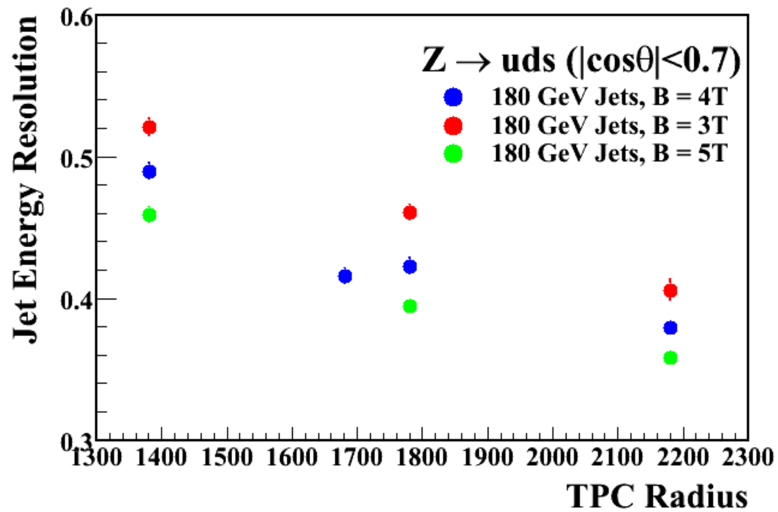
❻ Detector Optimisation Studies

★ Lots of progress… …no time





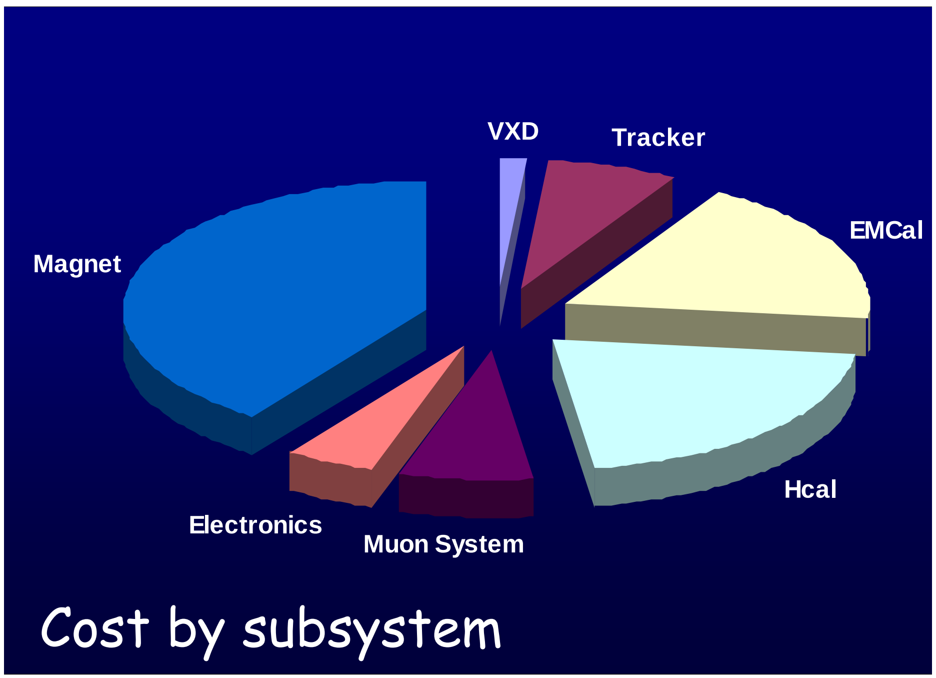


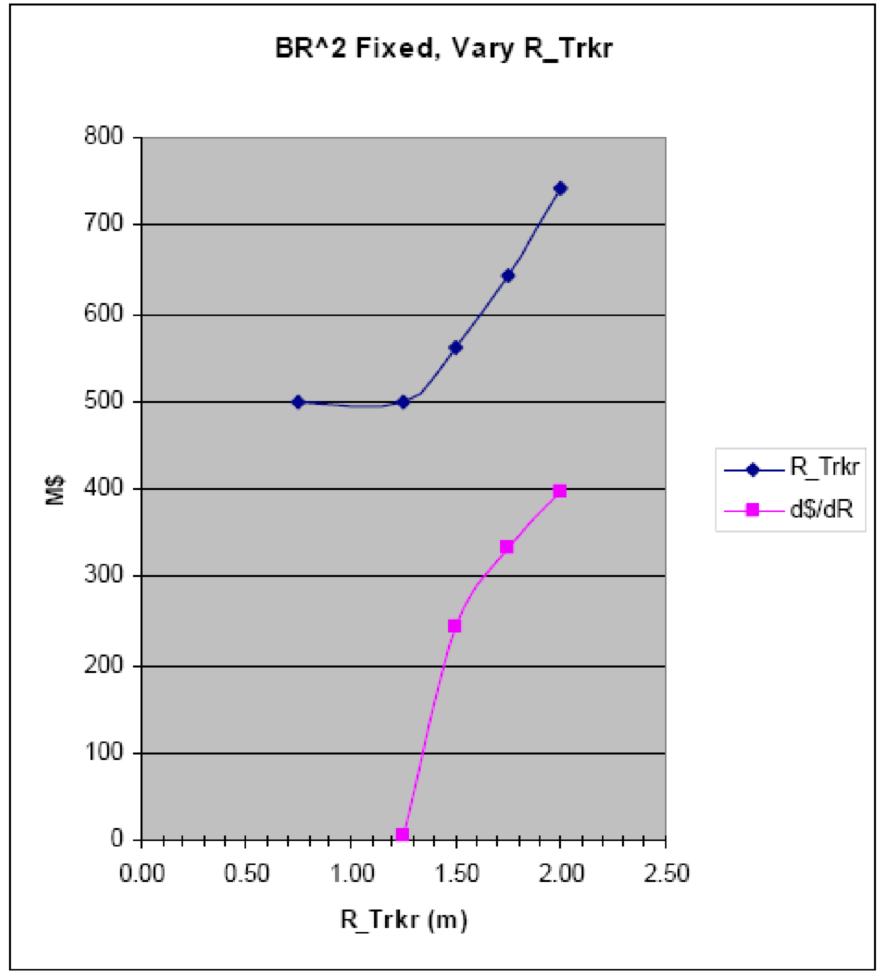


Cost

Parametric Cost Model

Cost = f (B-field, R_{TRK}, ….)

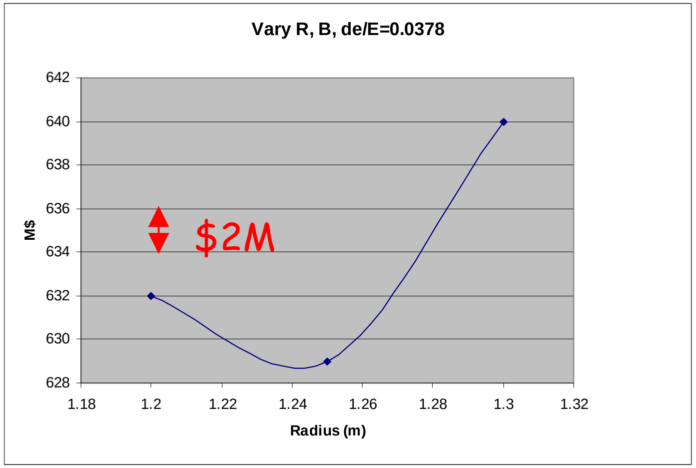


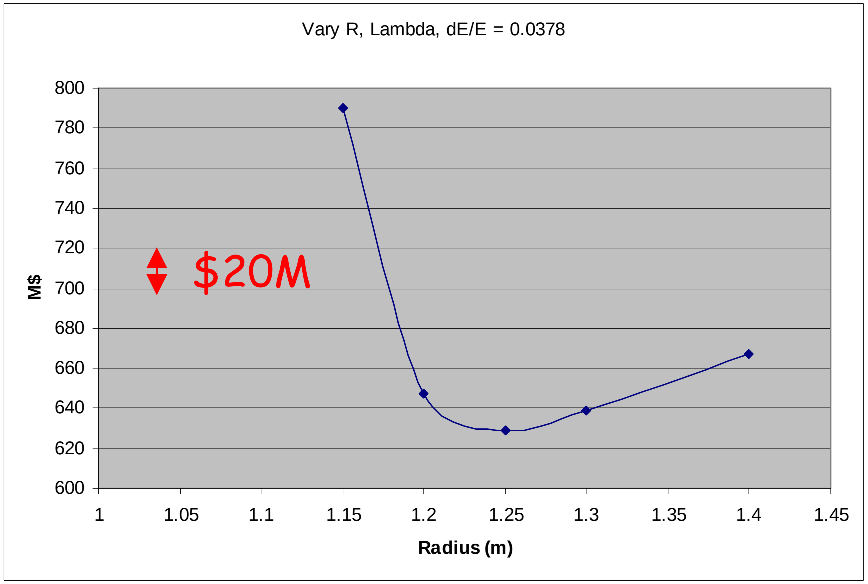


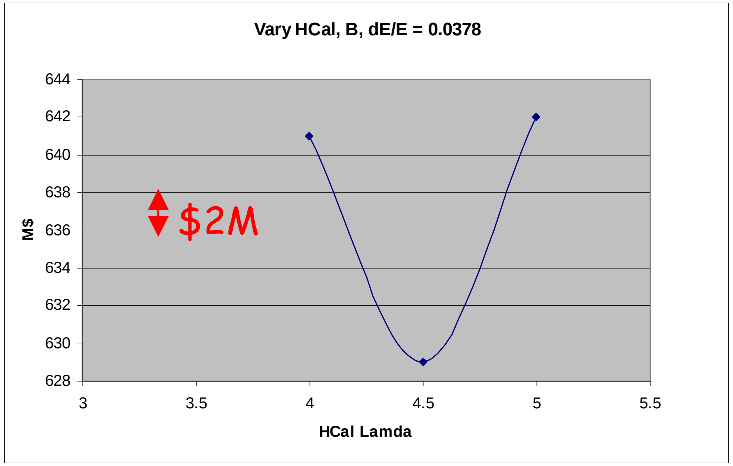
Cost vs. tracker radius

SiD "Baseline"

- Rtrkr = 1.25 m
- B = 5 T
- HCalλ = 4.5
- ΔE/E(180 Gev) = 0.0378

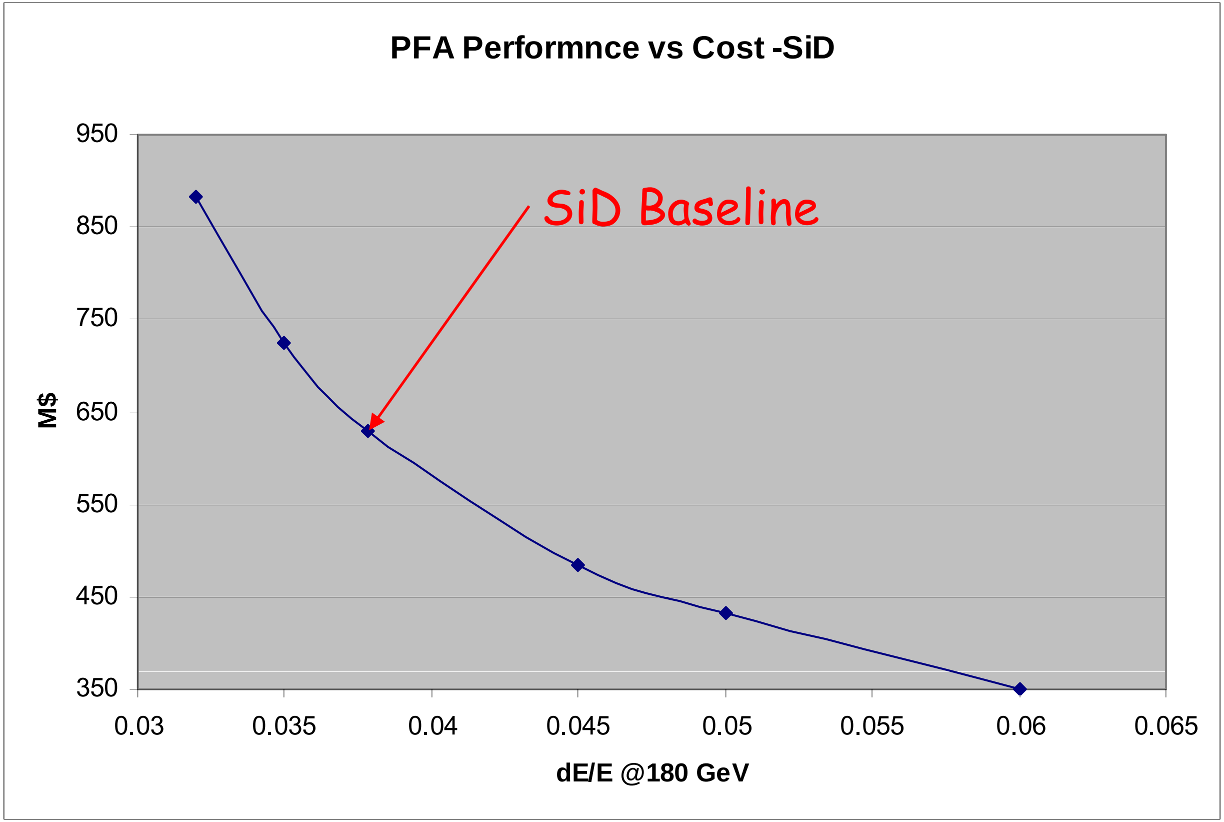




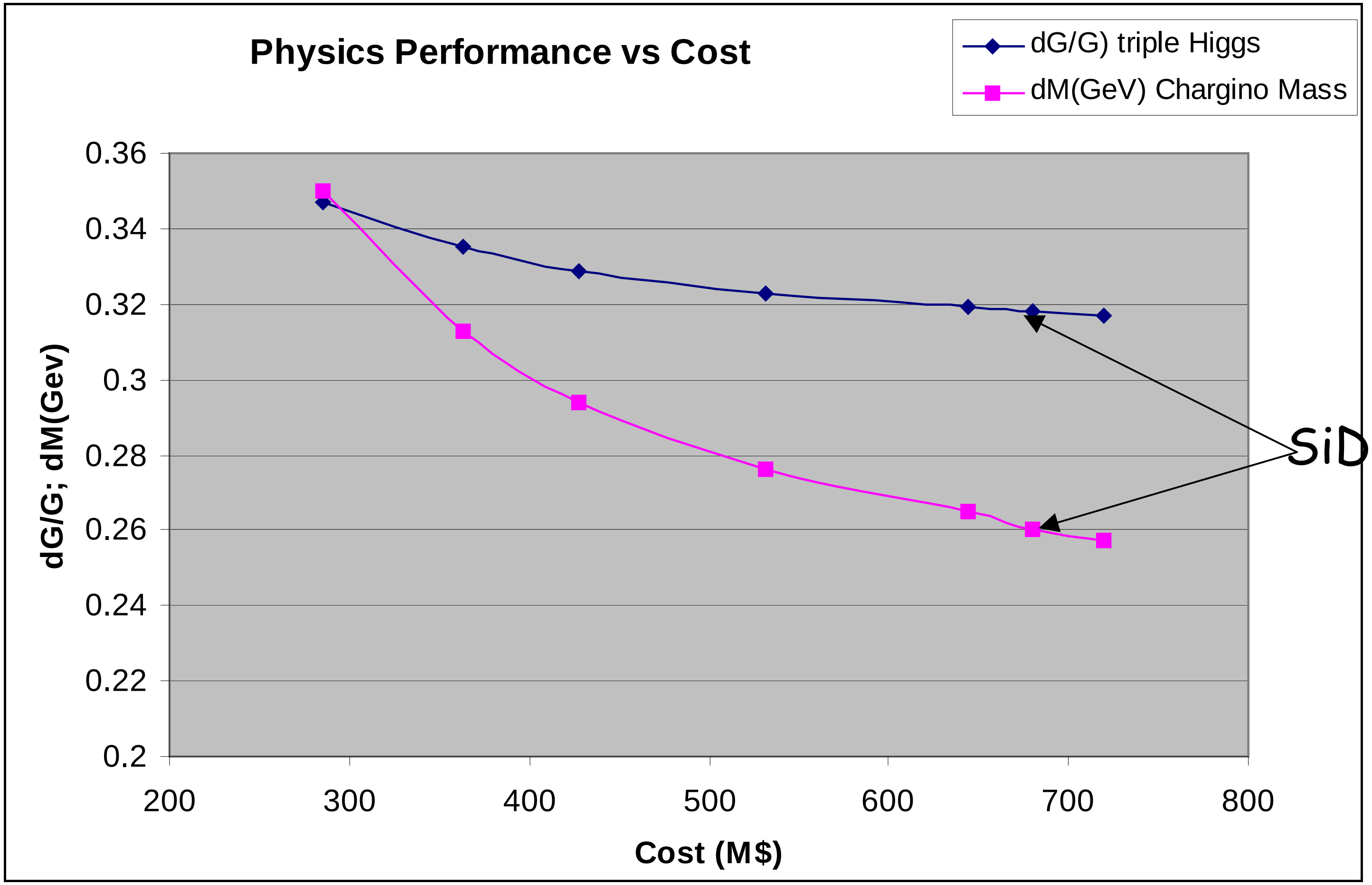


SiD "Baseline" is optimal for this value of ΔE/E(180 Gev) (Pandora parameterization, Checked with Pandora version of SiD, SiD PFA)

A sequence of "Optimized SiD's"



Selected Physics Process Errors vs Cost



Selekcja przypadków

W każdym eksperymencie (a zwłaszcza przy kolajderach) potrzebujemy jakiś narzędzi do selekcji przypadków.

Każdy pomiar fizyczny/odkrycie oparte jest na starannie wybranej próbce danych. Wiemy dokładnie jakiego typu przypadki badamy...

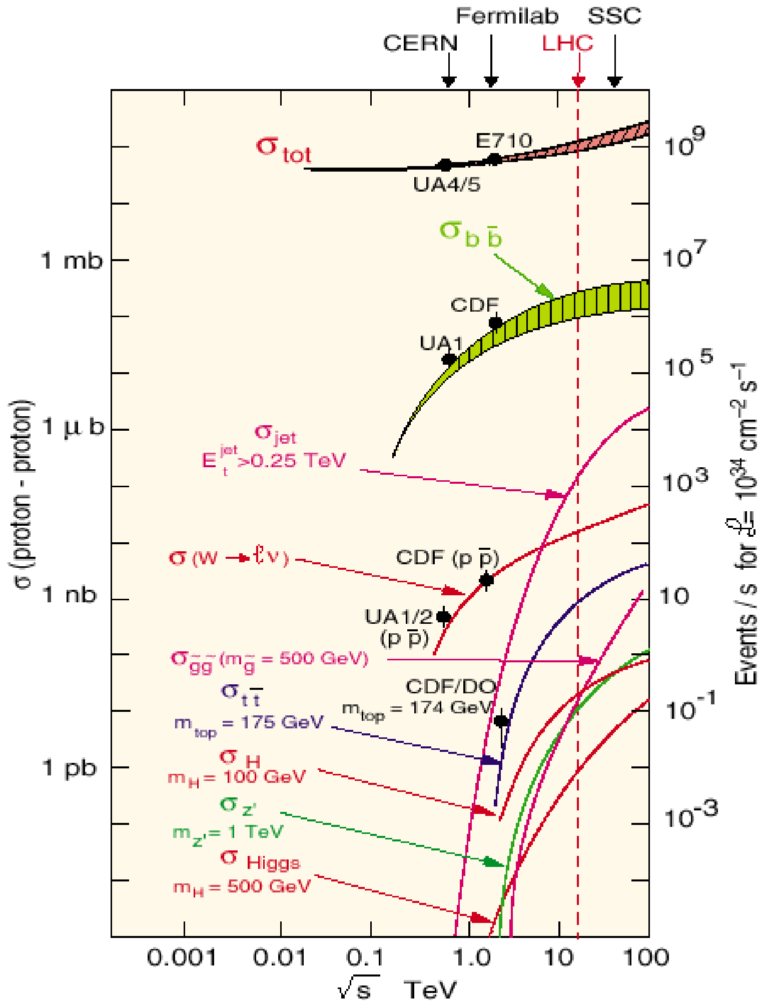
Ostateczna selekcja jest wielokrotnie zmieniana, optymalizowana. Aby nie zabierała zbyt dużo czasu trzeba wcześniej dokonać wstępnej selekcji, która odrzuci niepotrzebne przypadki.

Można sobie wyobrazić eksperyment, który zapisuje wszystkie rejestrowane przypadki i cała selekcja odbywa się off-line.

Jednak w wiekszości przypadków jest to niemożliwe, wstępnej selecji trzeba dokonać w trakcie zbierania danych: on-line.

Selectivity: the physics

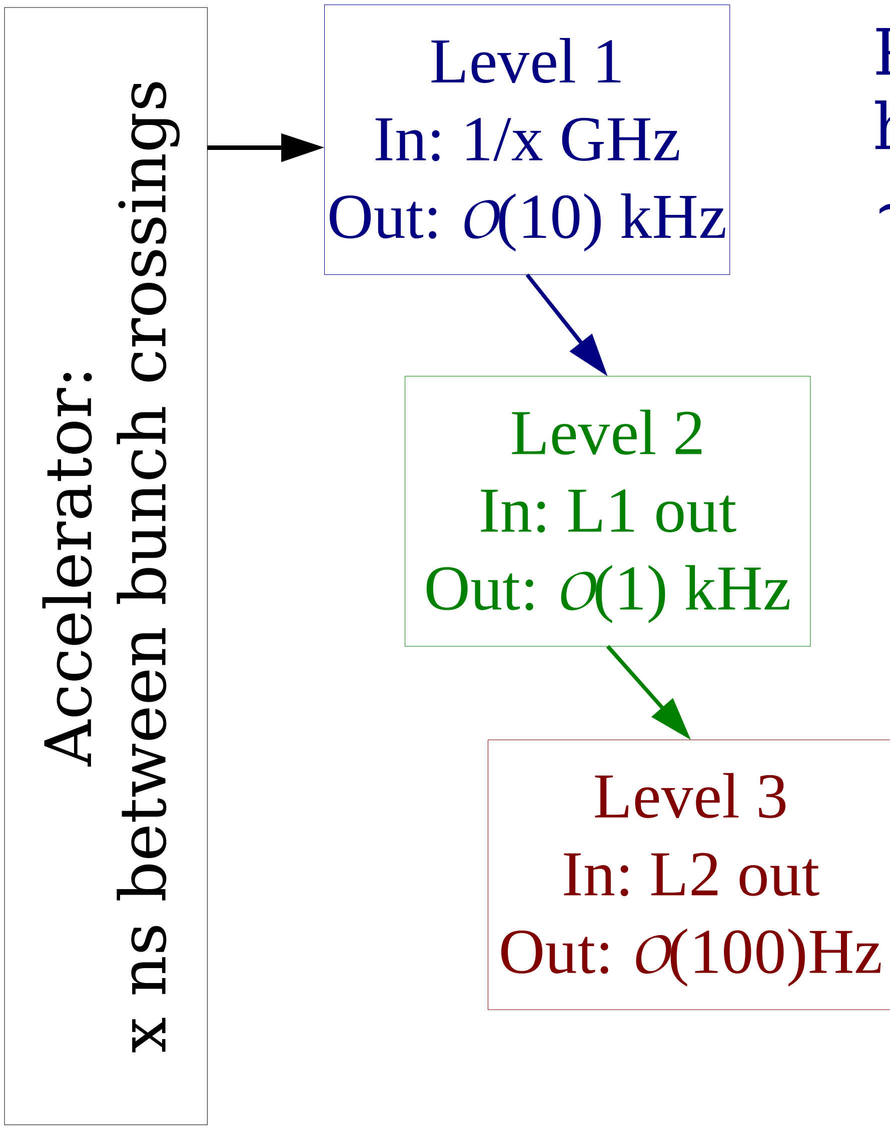
- Cross sections for various physics processes vary over many orders of magnitude
  - Inelastic: 10^9 Hz
  - $W \to \ell \nu$: 10^2 Hz
  - $t\bar{t}$ production: 10 Hz
  - Higgs (100 GeV/c^2): 0.1 Hz
  - Higgs (600 GeV/c^2): 10^{-2} Hz
- Selection needed: $1:10^{10-11}$
  - Before branching fractions...



Trigger/DAQ requirements/challenges

- N (channels) ~ O(10^7); ≈20 interactions every 25 ns
  - need huge number of connections
  - need information super-highway
- Calorimeter information should correspond to tracker info
  - need to synchronize detector elements to (better than) 25 ns
- In some cases: detector signal/time of Flight > 25 ns
  - integrate more than one bunch crossing's worth of information
  - need to identify bunch crossing...
- Can store data at ≈ 10^2 Hz
  - need to reject most interactions
- It's On-Line (cannot go back and recover events)
  - need to monitor selection

“Traditional” Architecture



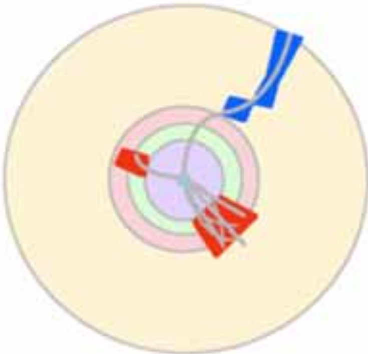
Pipelined (often deadtimeless), hardware only, coarse readout, ~few μs latency

Hardware/Software mix, L1 inputs, ~100 μs latency

CPU farm, access to full event information, $\mathcal{O}$(1)s/event

LHC Trigger Levels

10^{-7} s



Collision rate 10^9 Hz

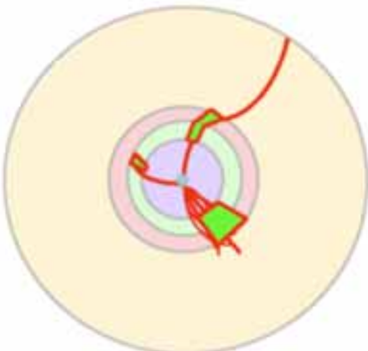
Channel data sampling at 40 MHz

Level-1 selected events 10^5 Hz

Particle identification (High p_T e, μ, jets, missing E_T)

- Local pattern recognition
- Energy evaluation on prompt macro-granular information

10^{-6} s

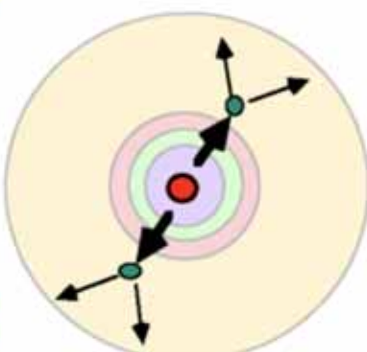


Level-2 selected events 10^3 Hz

Clean particle signature (Z, W, ..)

- Finer granularity precise measurement
- Kinematics. effective mass cuts and event topology
- Track reconstruction and detector matching

10^{-3} s



Level-3 events to tape **100- 300 Hz**

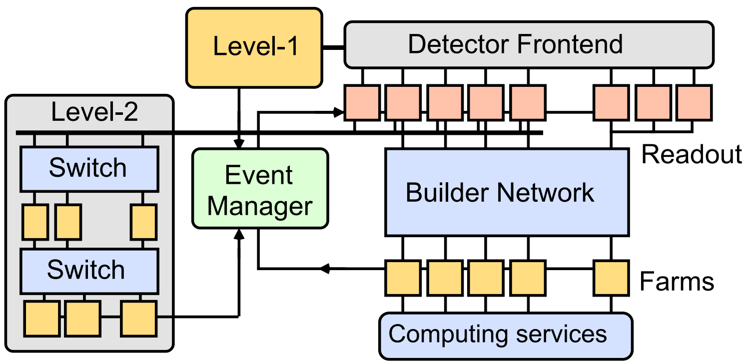
Physics process identification

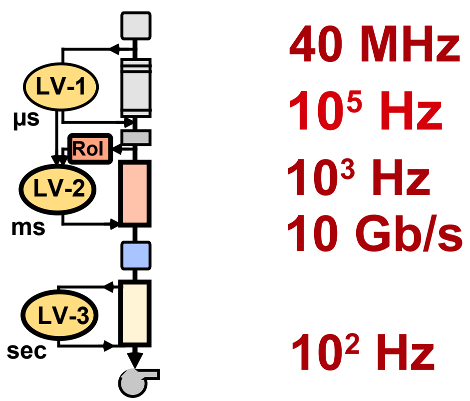
- Event reconstruction and analysis

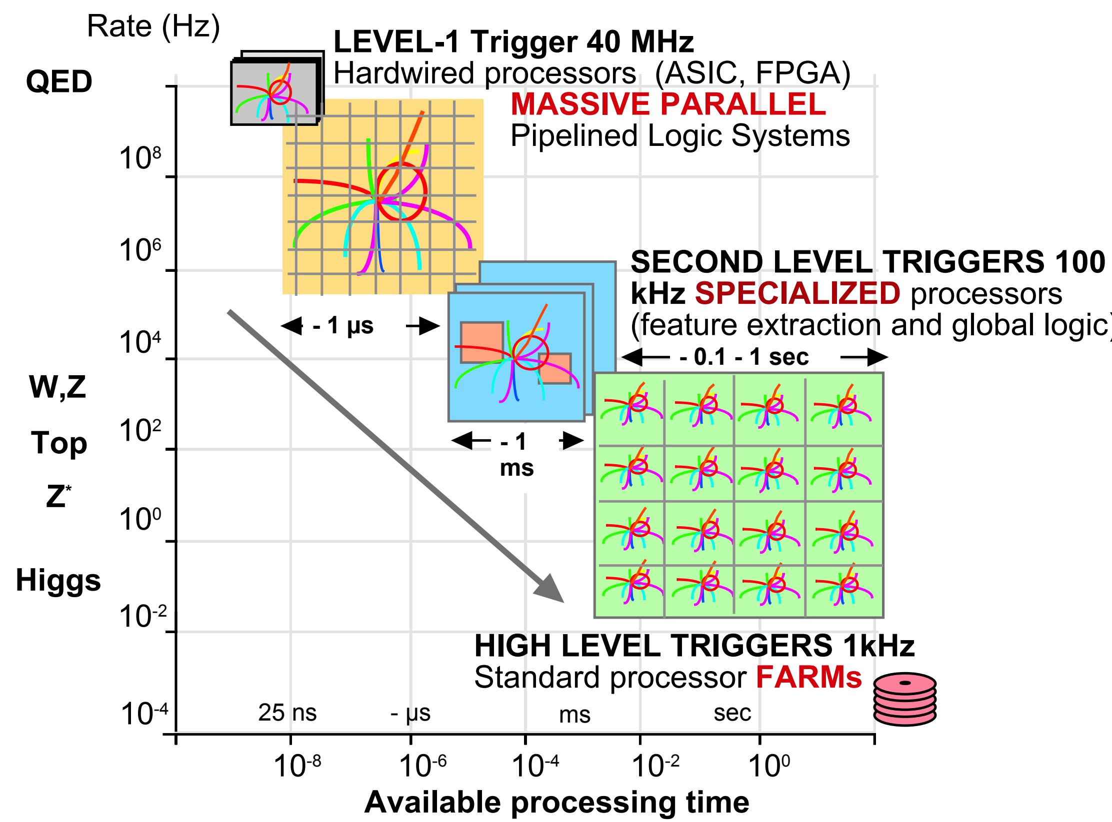
10^{-0} s

Three physical entities

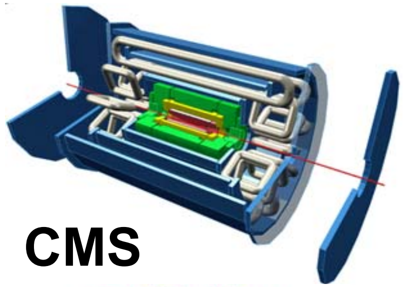
- Additional processing in LV-2: reduce network bandwidth requirements

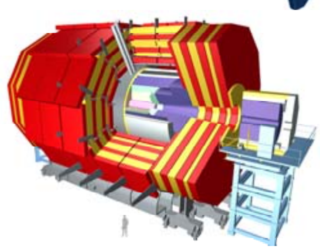


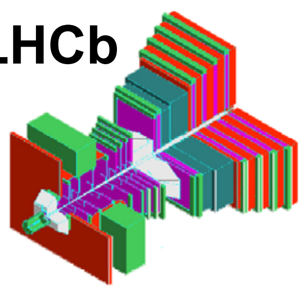


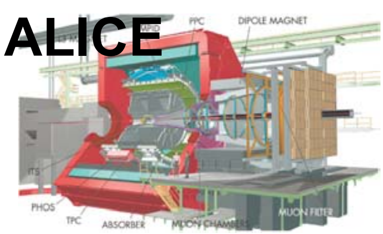


Trigger/DAQ parameters: summary



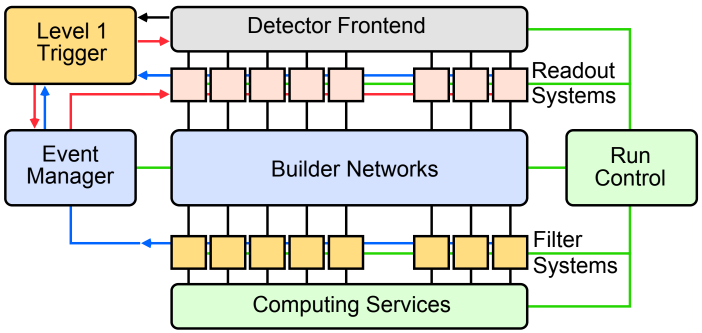


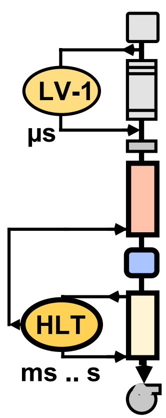




	No.Levels Trigger	Level-1 Rate (Hz)	Event Size (Byte)	Readout Bandw.(GB/s)	Filter Out MB/s (Event/s)
ATLAS	3	10^5 LV-2 10^3	10^6	10	100 (10^2)
CMS	2	10^5	10^6	100	100 (10^2)
LHCb	3	LV-0 10^6 LV-1 $4\ 10^4$	2×10^5	4	40 (2×10^2)
ALICE	4	Pp-Pp 500 p-p 10^3	5×10^7 2×10^6	5	1250 (10^2) 200 (10^2)

Two physical entities



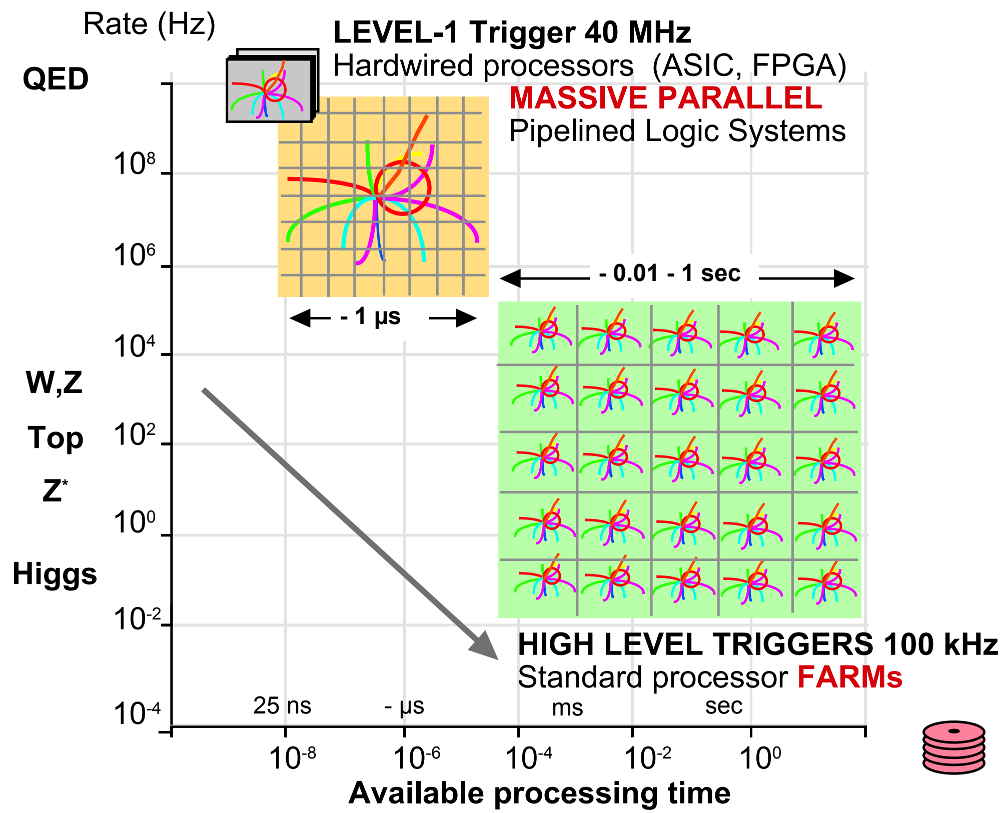


40 MHz

10^5 Hz

1000 Gb/s

10^2 Hz



- Reduce number of building blocks
- Rely on commercial components (especially processing and communications)

Level-1 trigger

Najważniejsza i najtrudniejsza część układu wyzwalania

* bardzo mało czasu na podjęcie decyzji
* możliwe tylko najprostsze operacje na danych:
    - dodawanie
    - mnożenie
    - adresowanie pamięci (!)

  => jedyny sposób na wykonanie bardziej złożonych operacji to policzyć wcześniej wszystkie możliwości i zapisac w LUT (Look-Up Table)

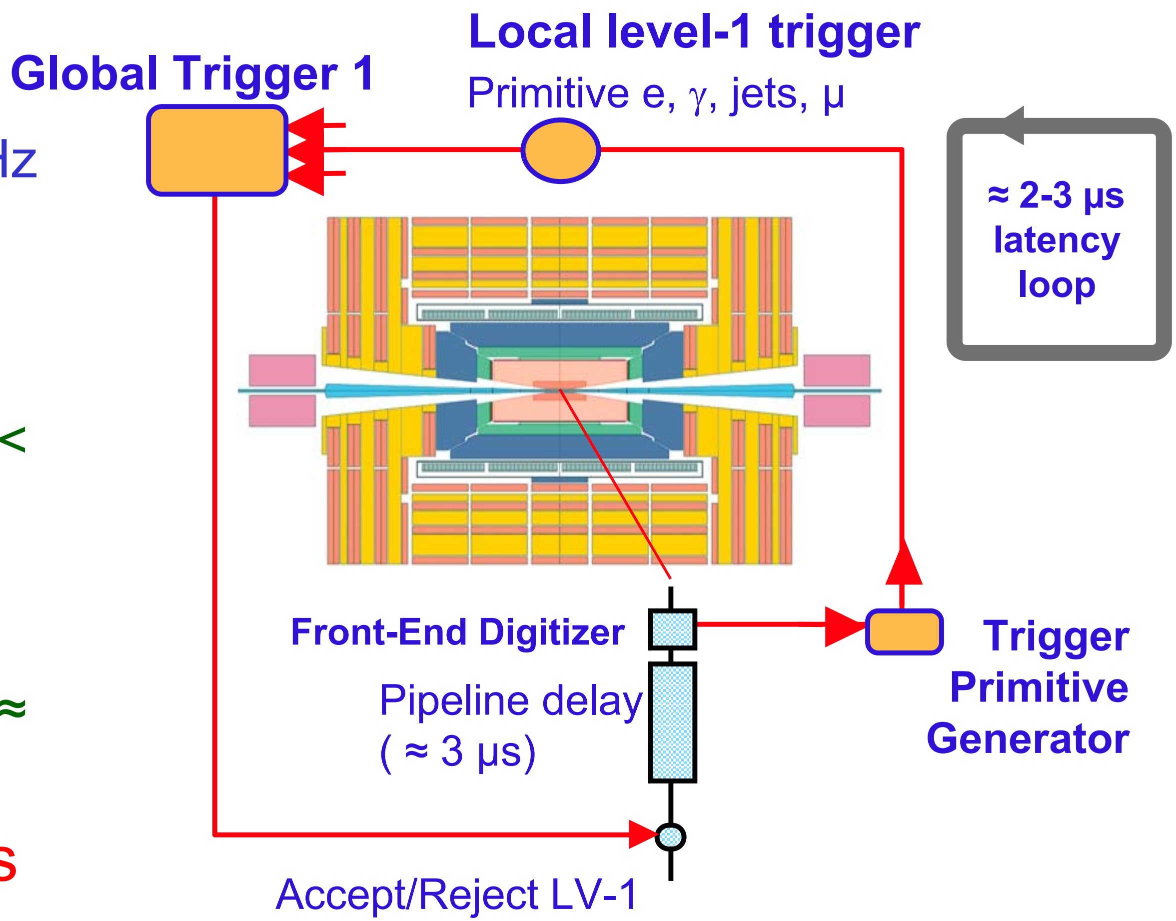
* musimy wprowadzać uproszczenia

  (ograniczenie strumienia danych => przestrzeni adresowej)
* musimy się pogodzić z dużymi błędami

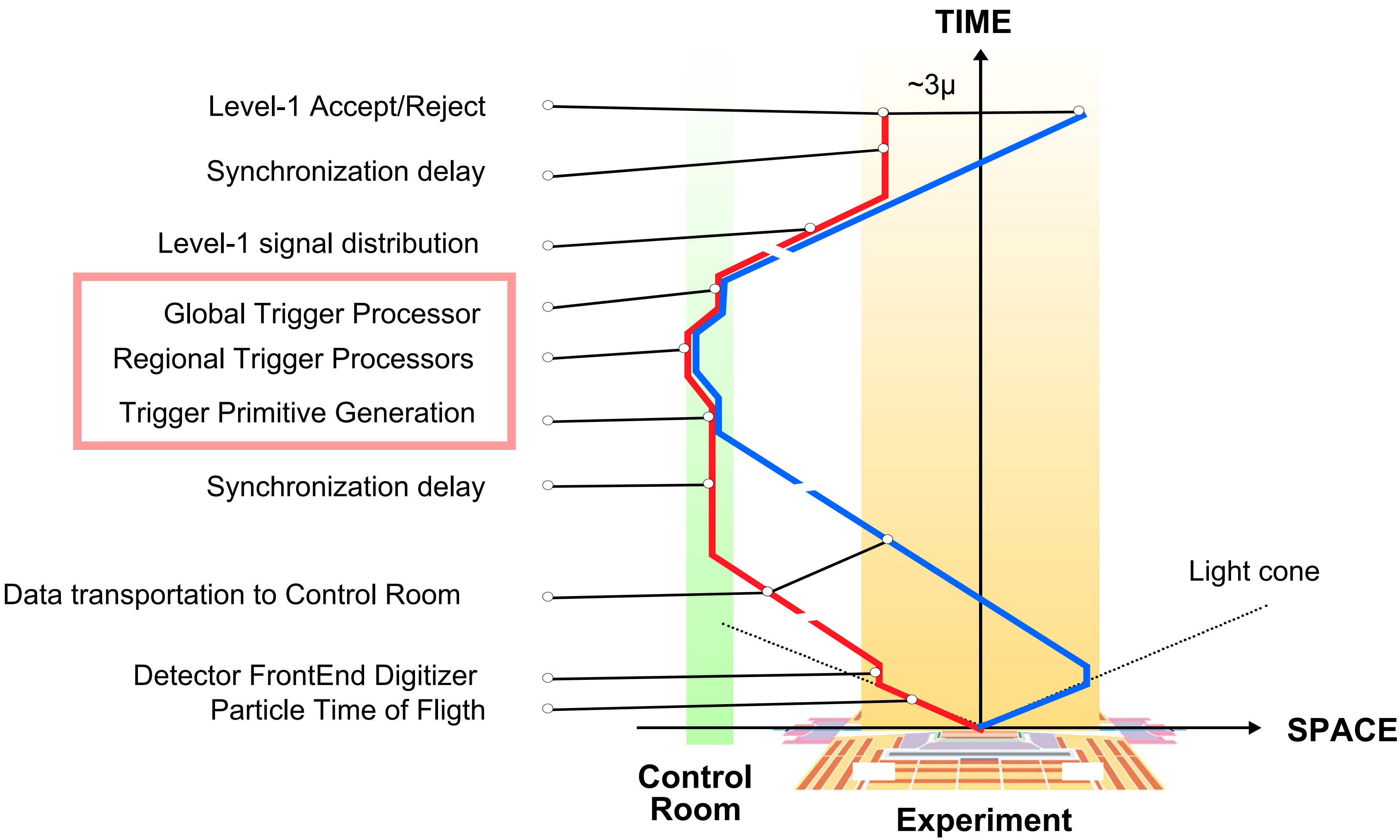
* najważniejsza jest efektywność (czystość zapewnimy potem)

Level-1 Trigger: decision loop

- Synchronous 40 MHz digital system
  - Typical: 160 MHz internal pipeline
  - Latencies:
    - Readout + processing: < 1μs
    - Signal collection & distribution: ≈ 2μs
- At Lvl-1: process only calo+μ info



Signaling and pipelining (II)



Level-1 trigger

Wykorzystuje tylko niewielką część informacji płynącej z detektora:

- dające możliwość szybkiego odczytu
- niosące najważniejsze informacje
- proste do przetworzenia
  (nie ma możliwości wykonywania skomplikowanych obliczeń, np. dopasowywania toru)

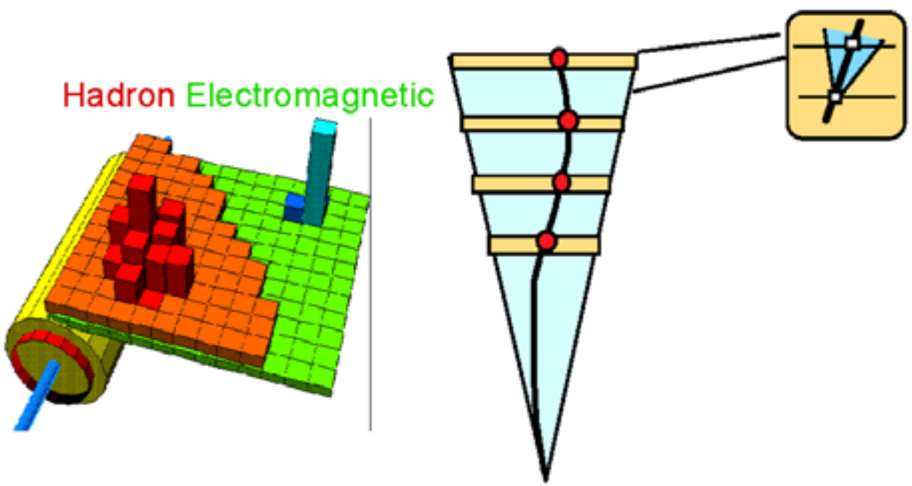
Często odczytujemy tylko podpróbke pomiarów z danego detektora lub sumaryczne wyniki (bez pełnej granulacji)

Pełny przypadek czeka w buforach elektroniki odczytowej na decyzję globalnego układu wyzwalania!

ATLAS & CMS Level 1: Only Calorimeter & Muon

High Occupancy in high granularity tracking detectors

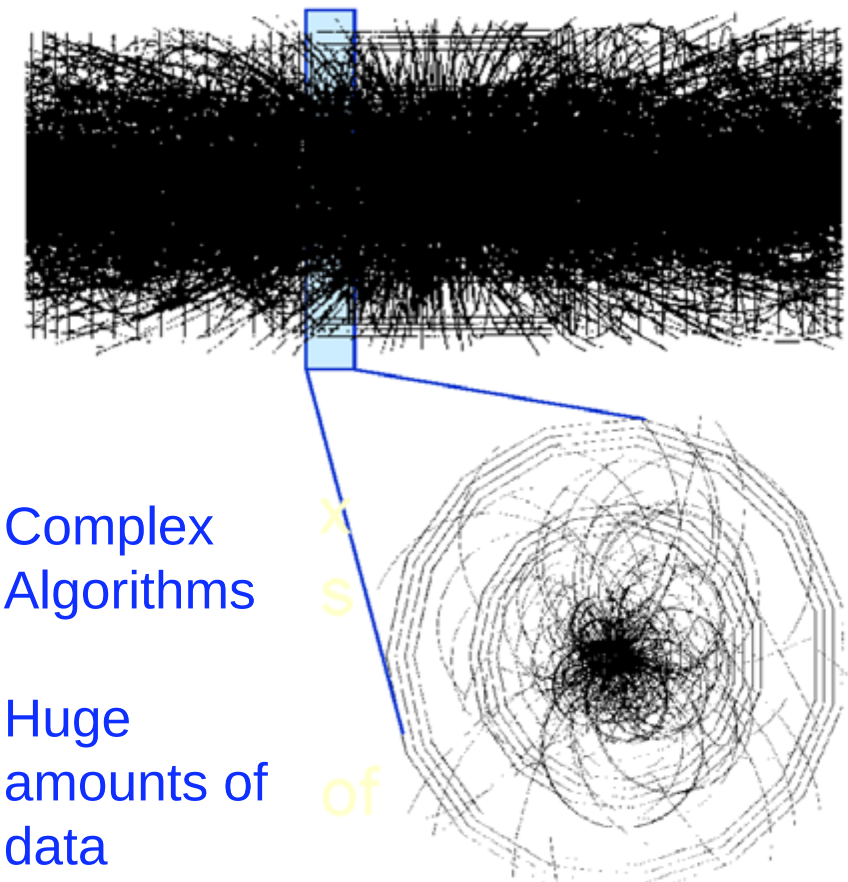
- **Pattern recognition much faster/easier**



Simple Algorithms

Small amounts of data

- **Compare to tracker info**



Complex Algorithms

Huge amounts of data