CMS
Commissioning and Performance

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1. September 2010

Swiss CMS Members

	ETH		PSI	Uni ZH
	(mostly ECAL)		(mostly Tracker)	(Tracker)
Physicists:	22		10	10
Students:	10	3	4	4
Engineers & Technicians:	11		3	2

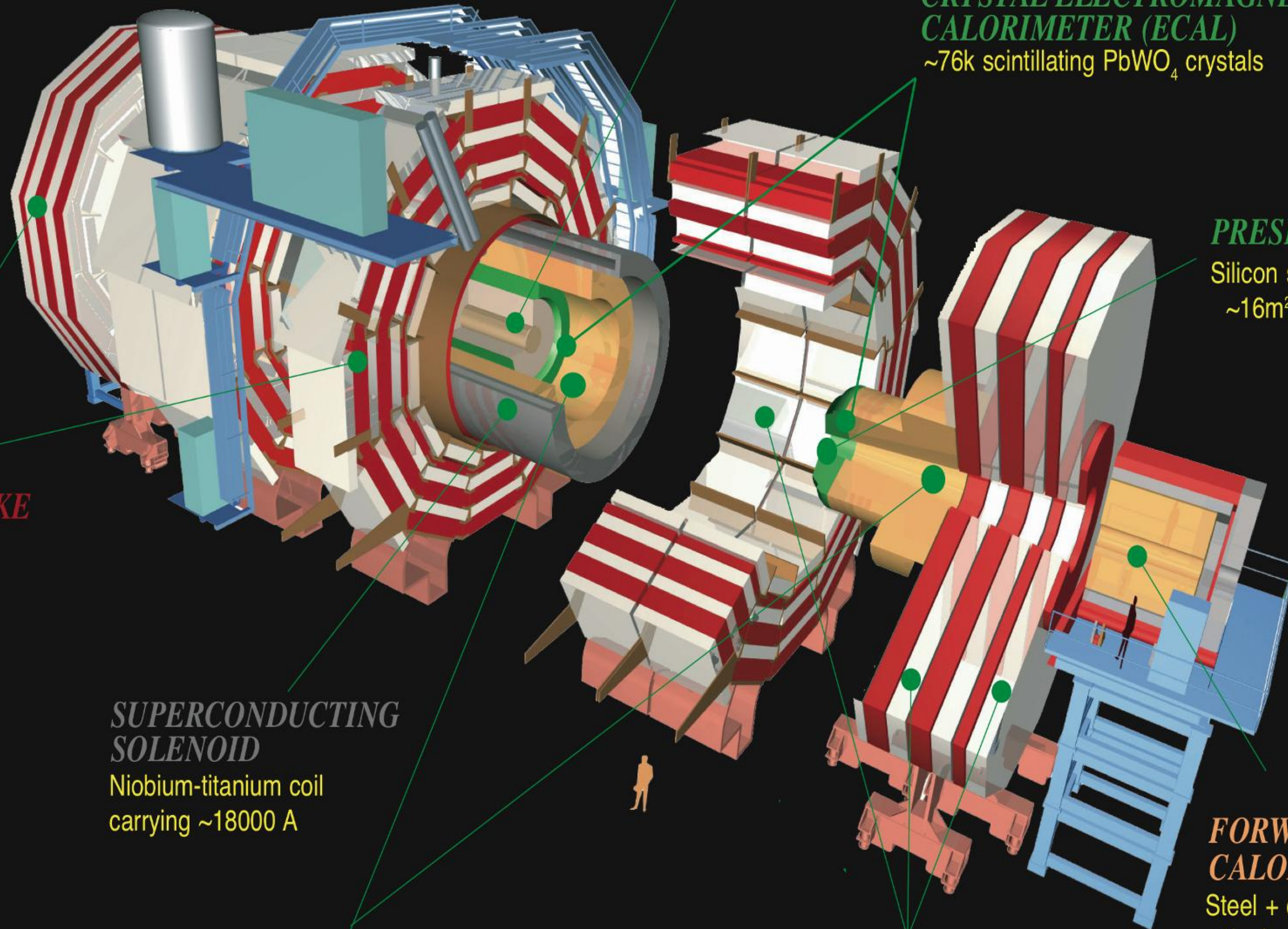
Total 42 Physicists, 21 Students, 16 Eng./Techn.

Outline

- Brief detector overview
- Appetizer
- Performance summary
- Some more details
- Even more details on selected topics in commissioning and calibration

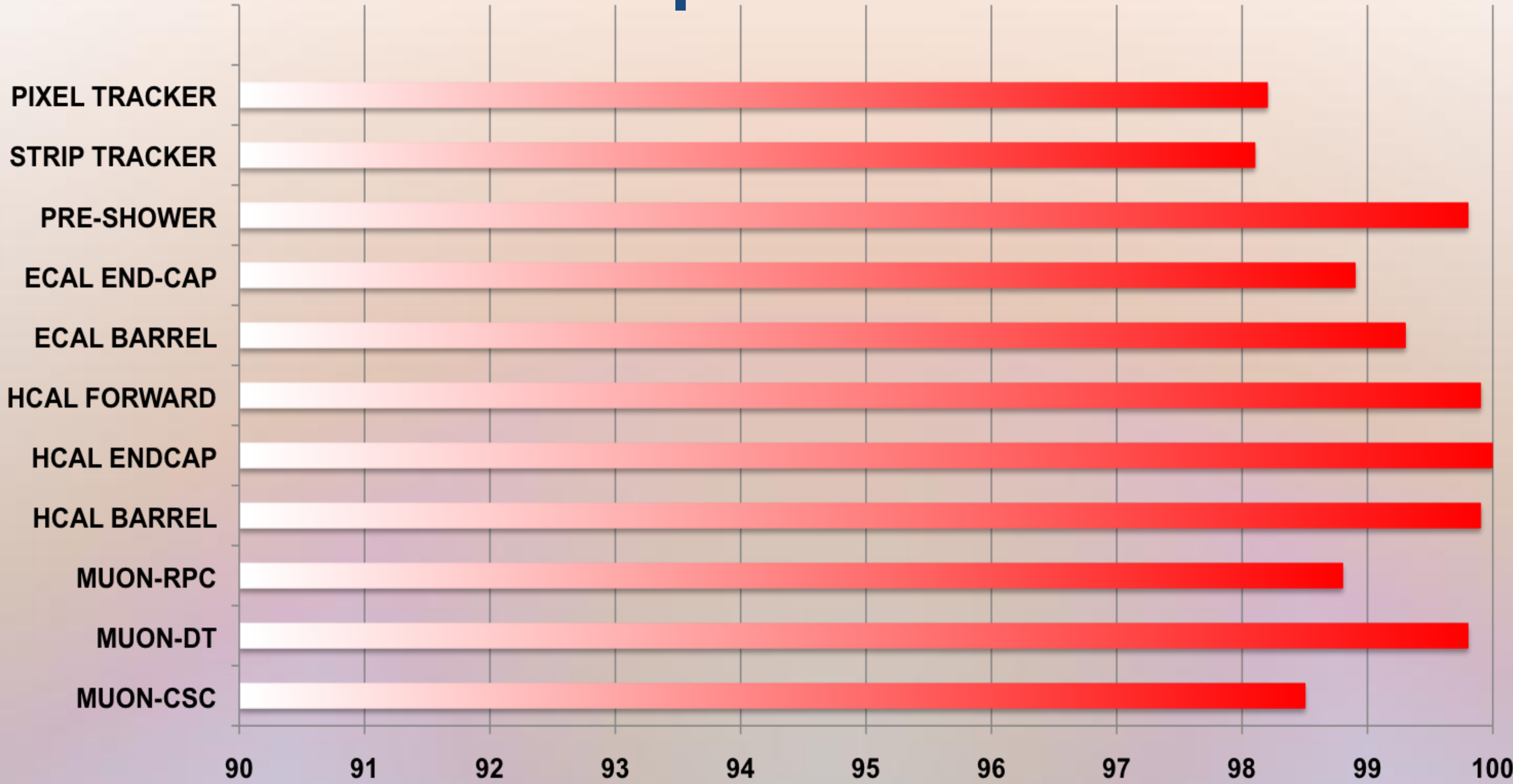
(only for sub-systems with substantial Swiss contributions: ECAL and Tracker)

CMS Detector



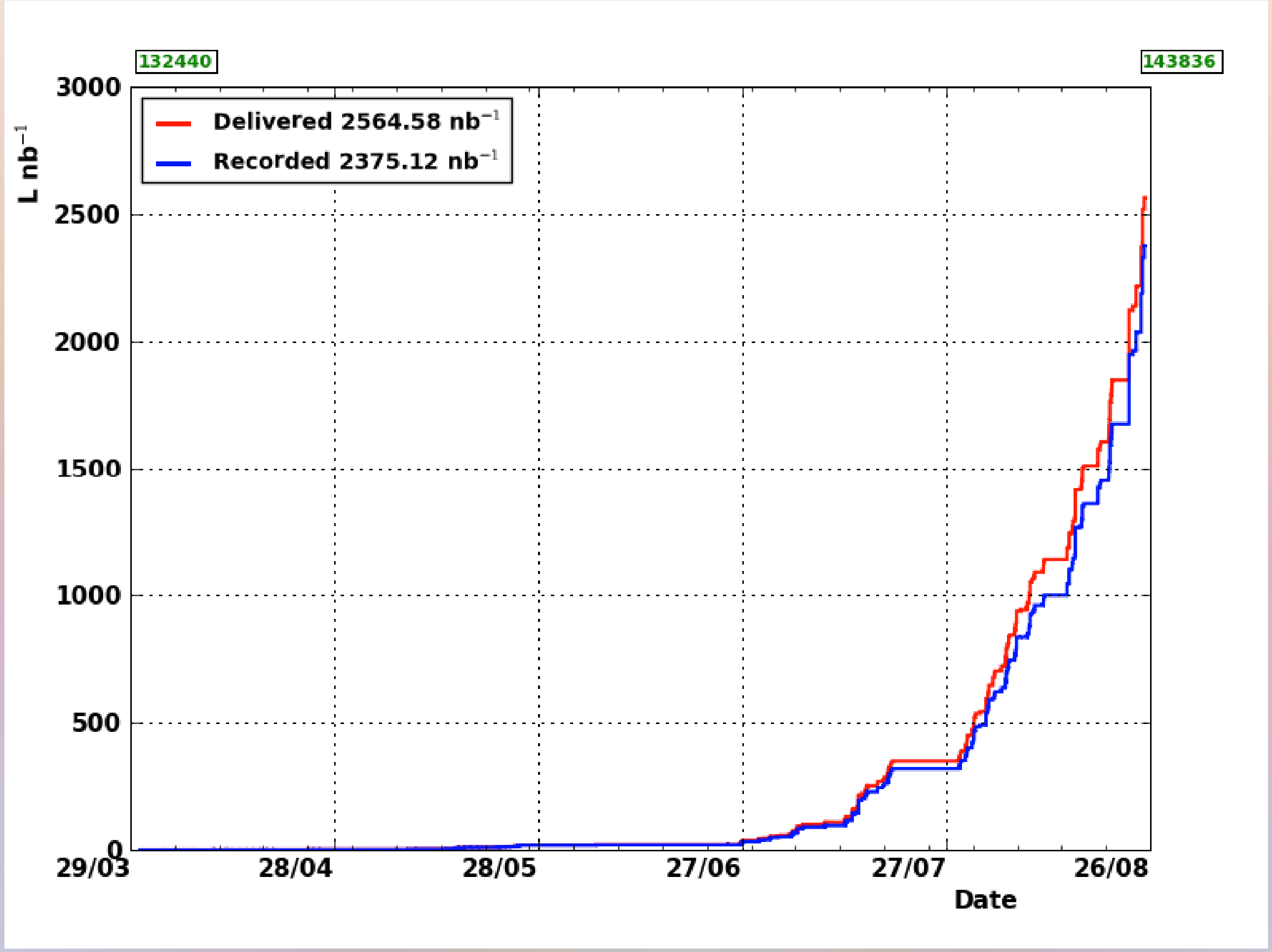
Total weight : **14000 tonnes**
Overall diameter : **15.0 m**
Overall length : **28.7 m**
Magnetic field : **3.8 T**

Sub-detectors operational status



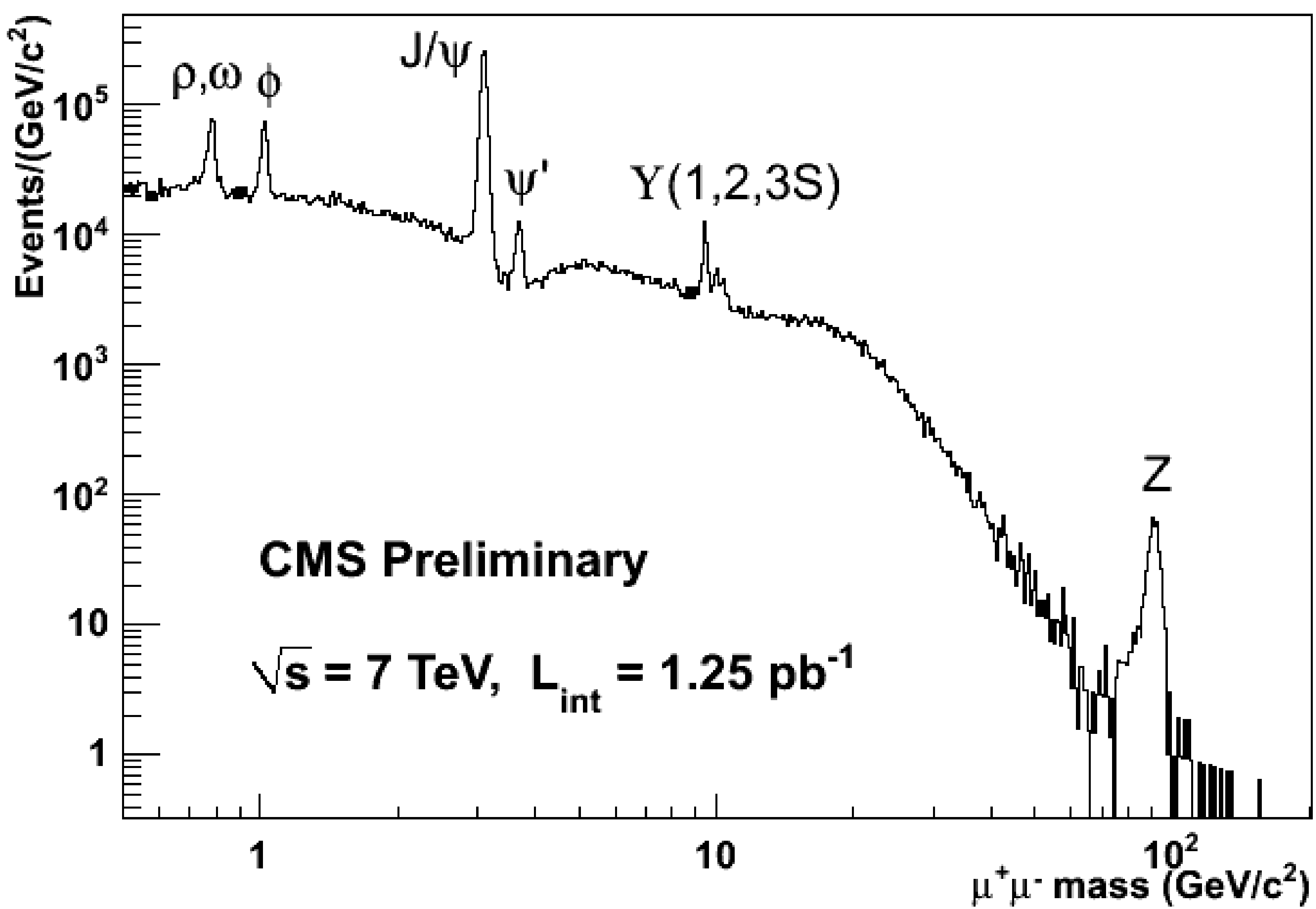
	MUON- CSC	MUON- DT	MUON- RPC	HCAL BARREL	HCAL ENDCAP	HCAL FORWAR D	ECAL BARREL	ECAL END- CAP	PRE- SHOWER	STRIP TRACKE R	PIXEL TRACKE R	
Series1	98.5	99.8	98.8	99.9	100	99.9	99.3	98.9	99.8	98.1	98.2	

LHC Luminosity as of last week

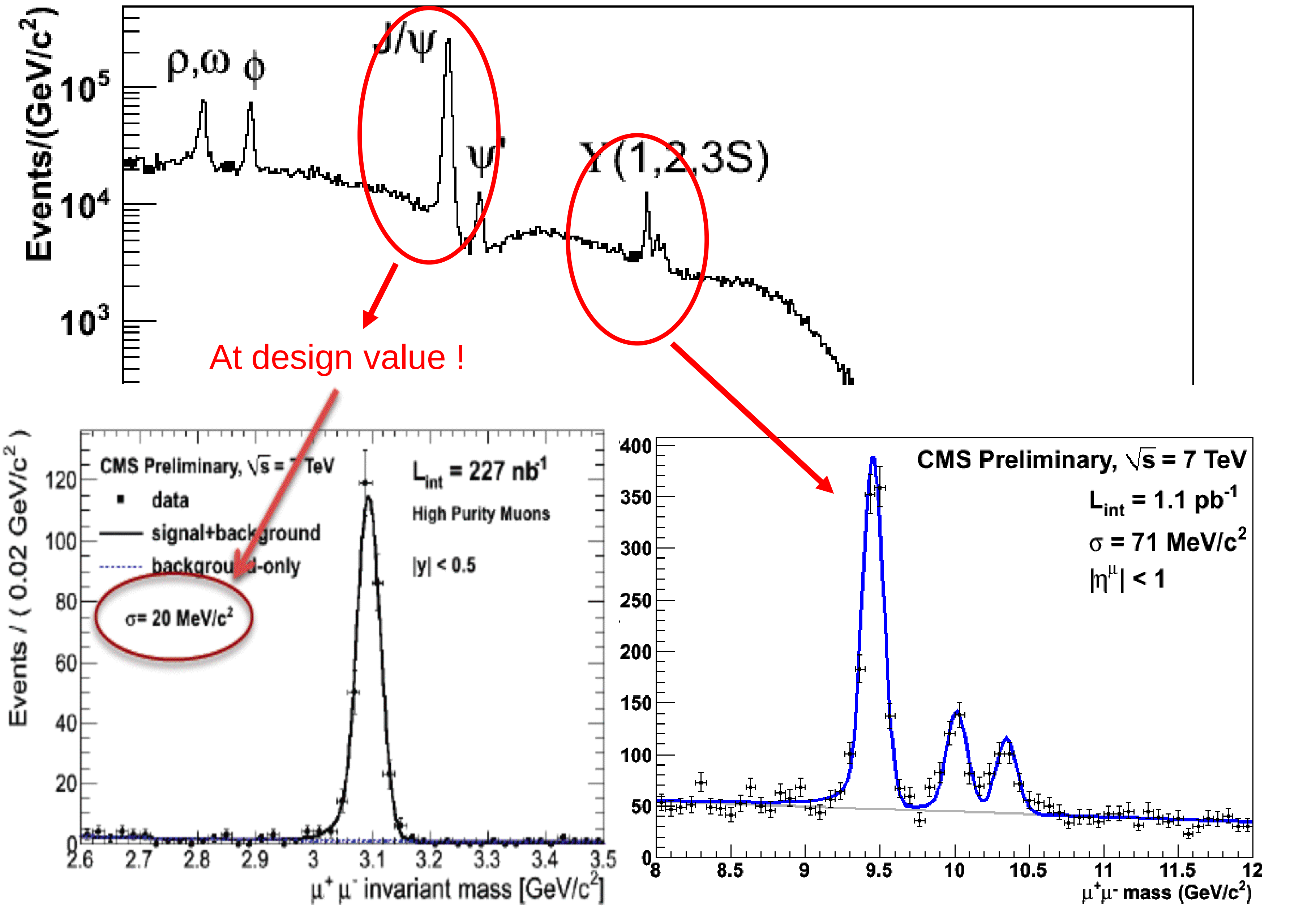


LHC machine progresses extremely well
CMS efficiency for data taking is good and increasing (last week 93%)

Appetizer: Dimuon mass spectrum

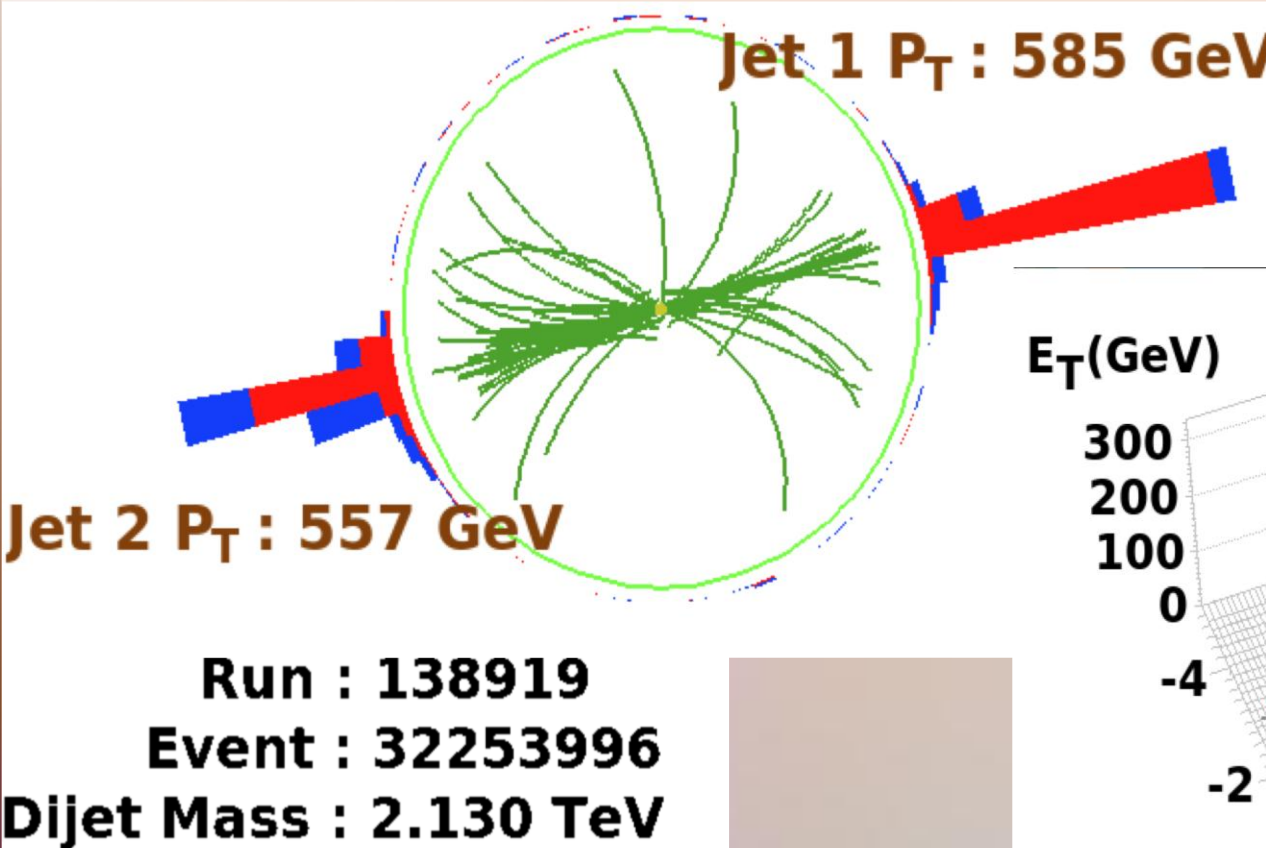


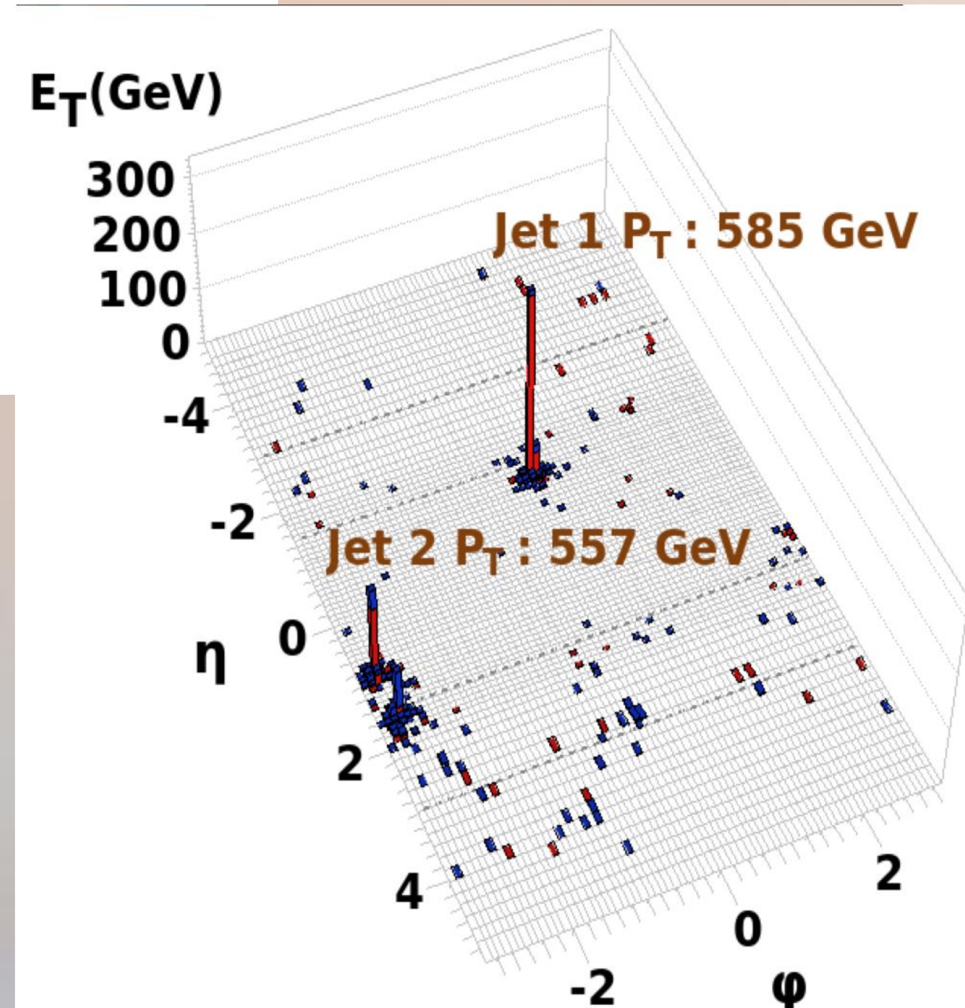
Appetizer: Dimuon mass spectrum



Performance

Jets and Missing E_T



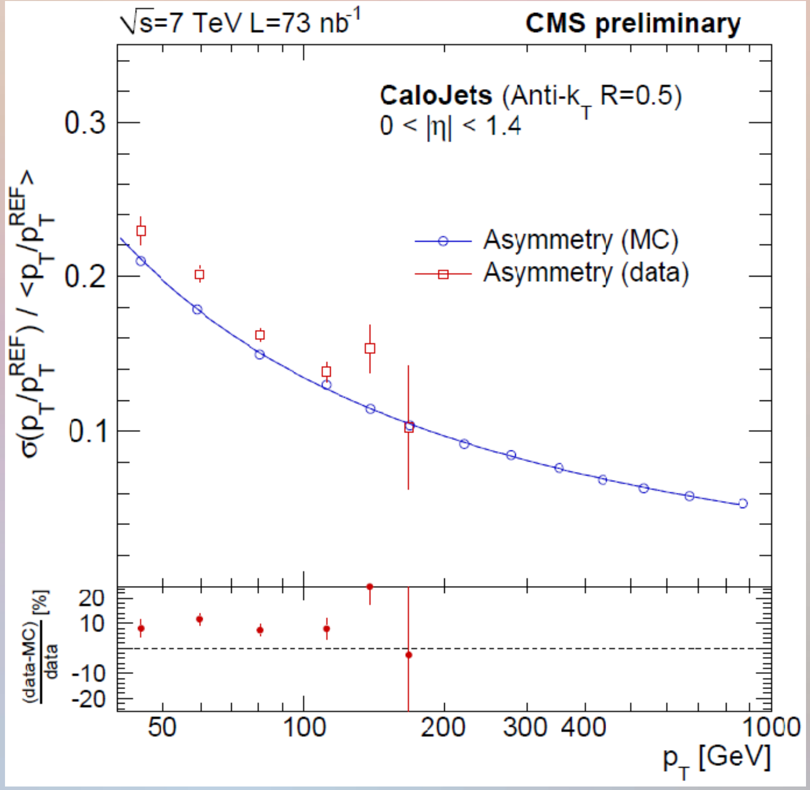


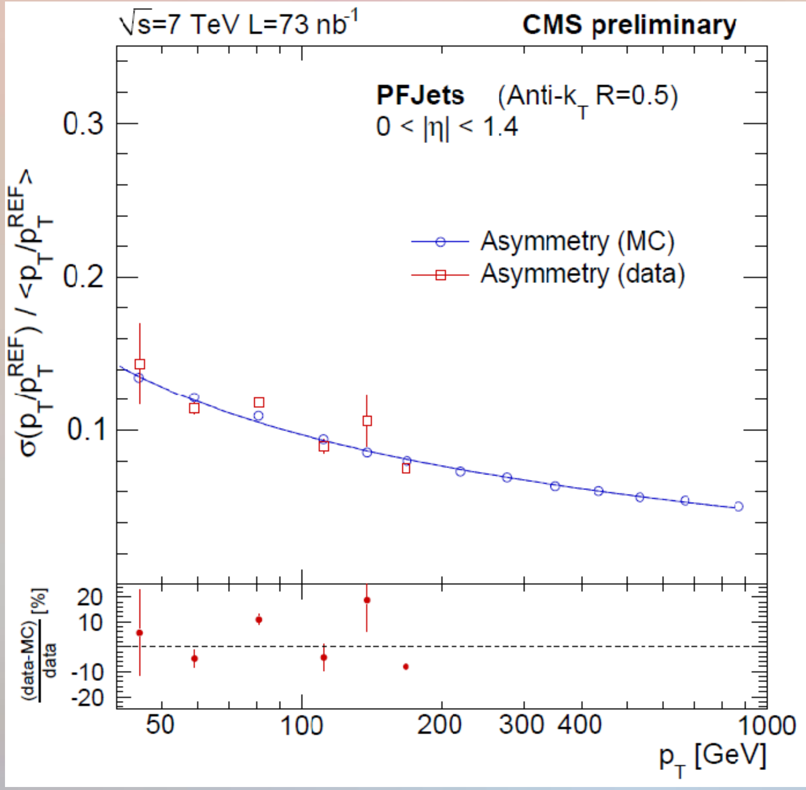
The highest mass dijet event in the first 120nb^{-1} of data

Jet Measurement Performance

Estimation of jet p_T resolution from data.
Measuring energy imbalance in dijet events
Left: energy from calorimeters only, right: particle flow techniques applied

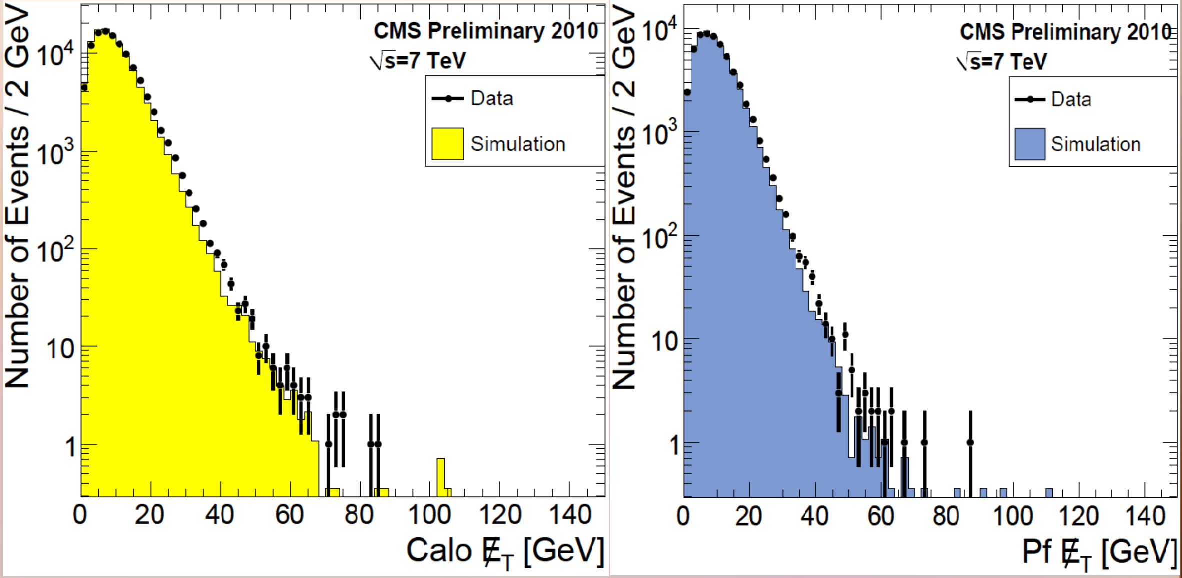
Better performance than design goal of 100%/Sqrt(E)+5%!



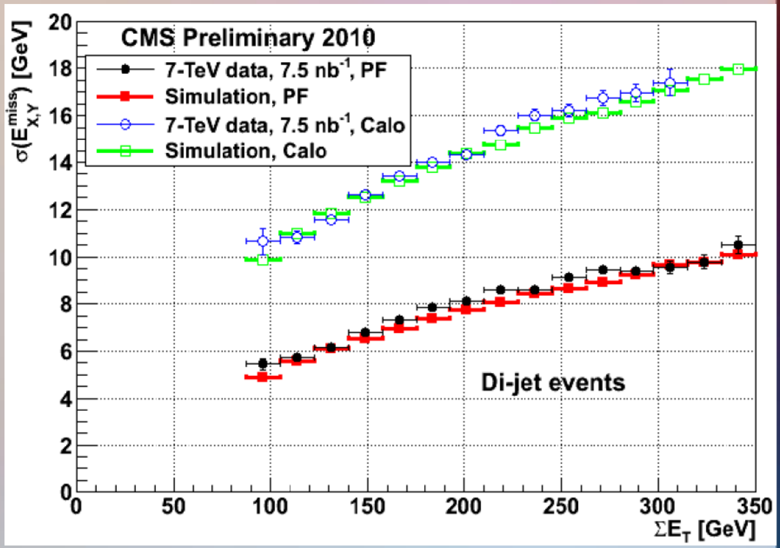


Missing E_T Measurement Performance

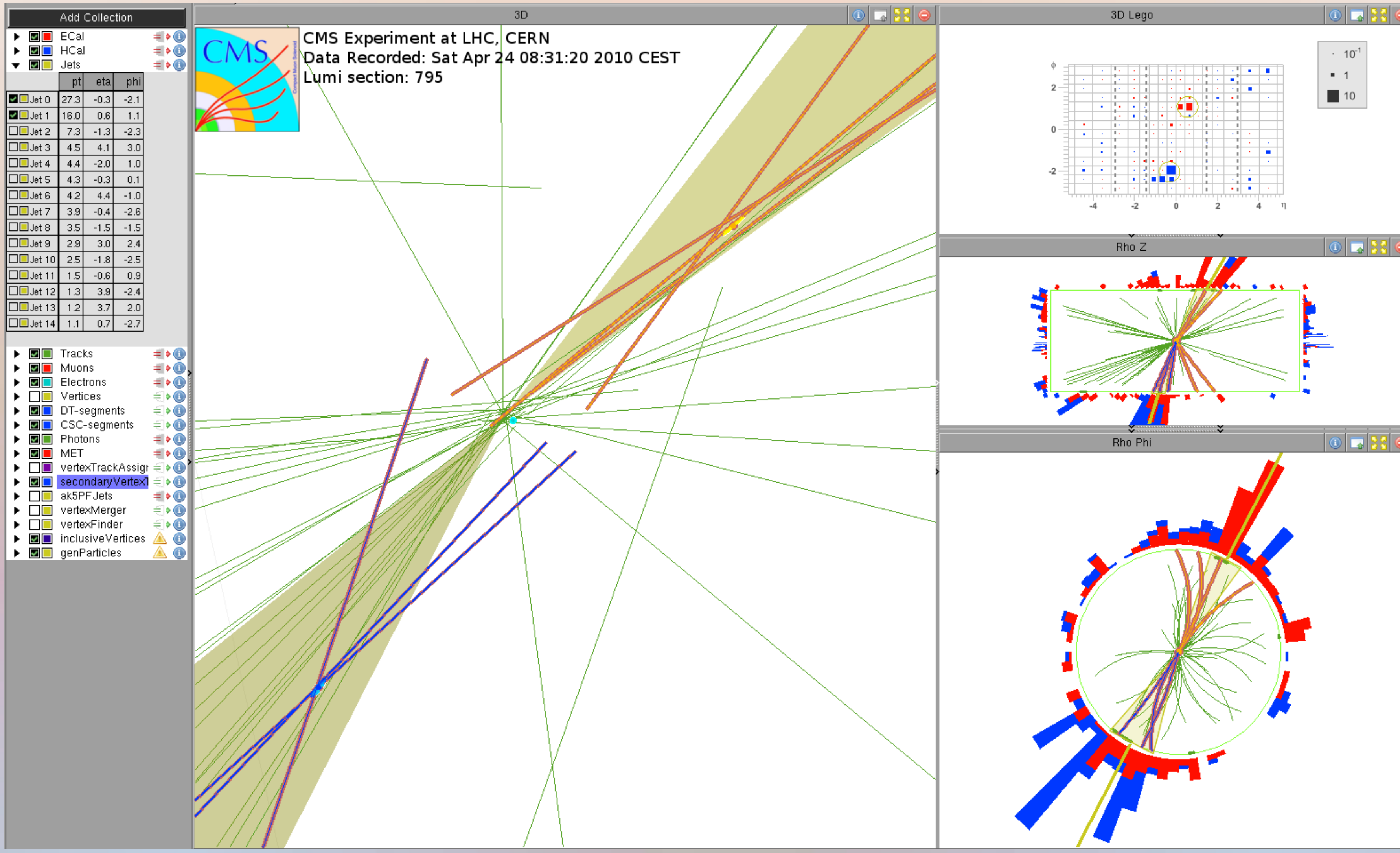
Missing E_T measurement in Dijet events with calorimeters alone (left) and with particle flow algorithms (right)
Data is very well described by MC over large energy range without tuning!



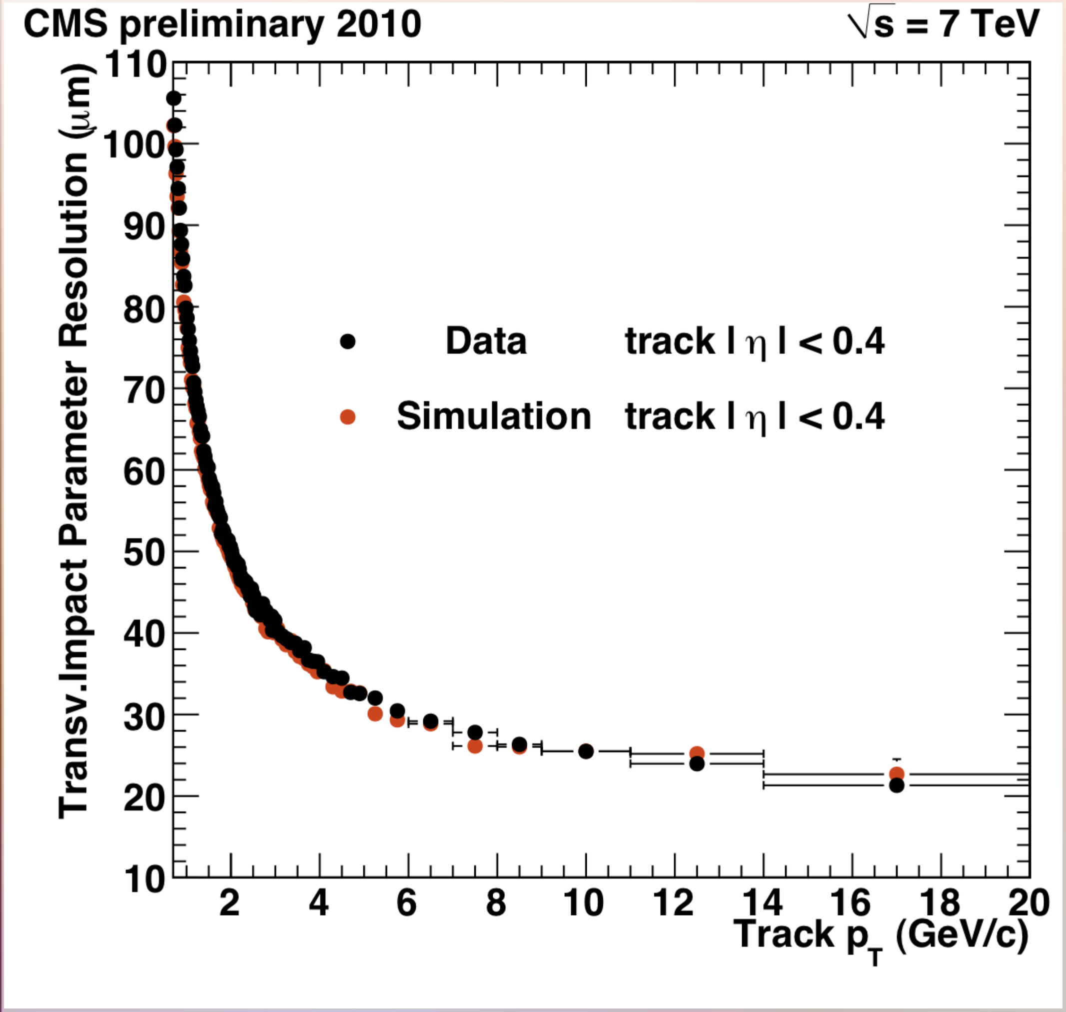
Missing E_T Gaussian core resolution:
< 10 GeV on whole missing E_T range up to 350GeV.
Factor 2 improvement with Particle Flow technique.

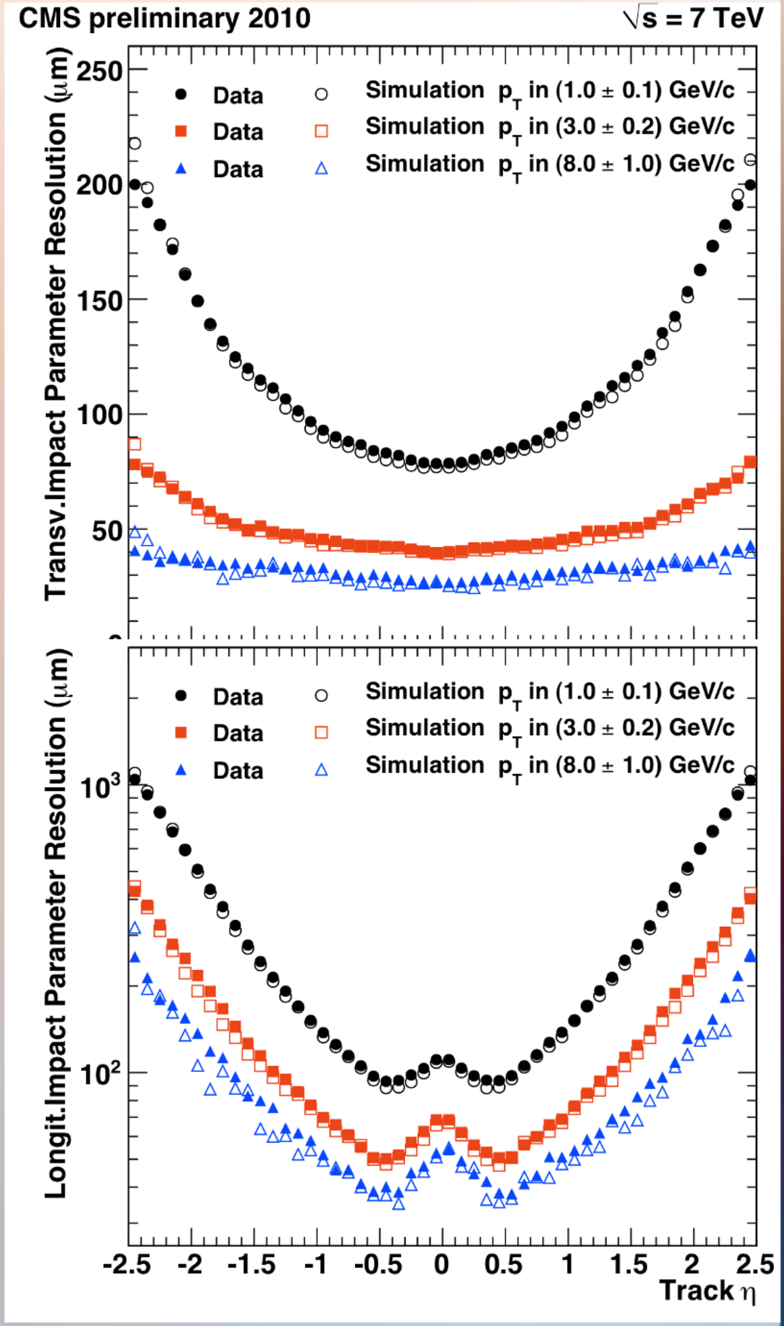


Tracking and B-tagging



Impact Parameter Resolutions





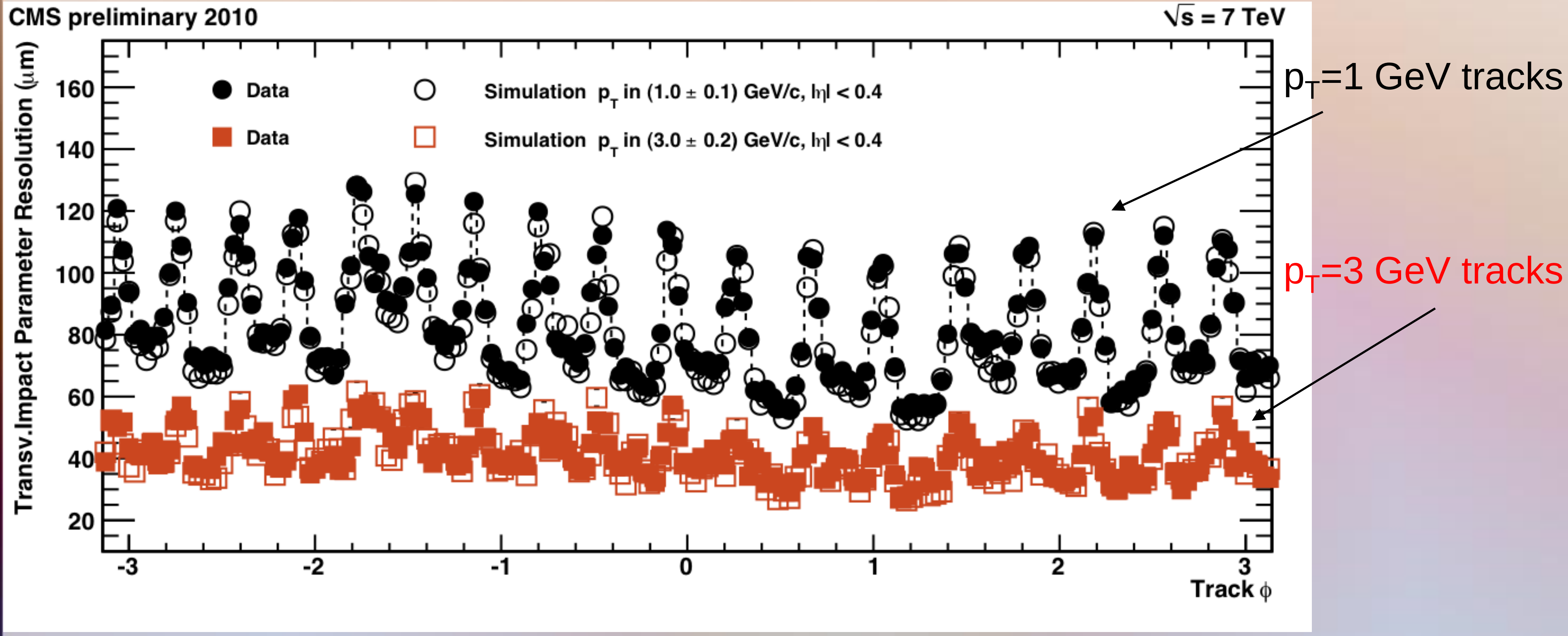
Good agreement between resolutions in DATA and MC for a wide range of track p_T and eta

$\sigma(IP_{trans})$=25μm for central high p_T tracks

Impact Parameter Resolutions

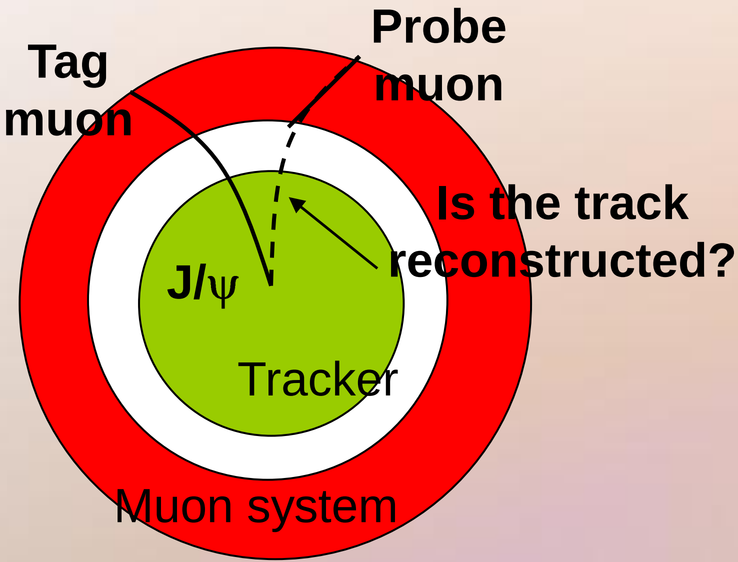
The 18 peaks in the resolution correspond to the 18 cooling pipes on the innermost detecting layer of the pixel system.

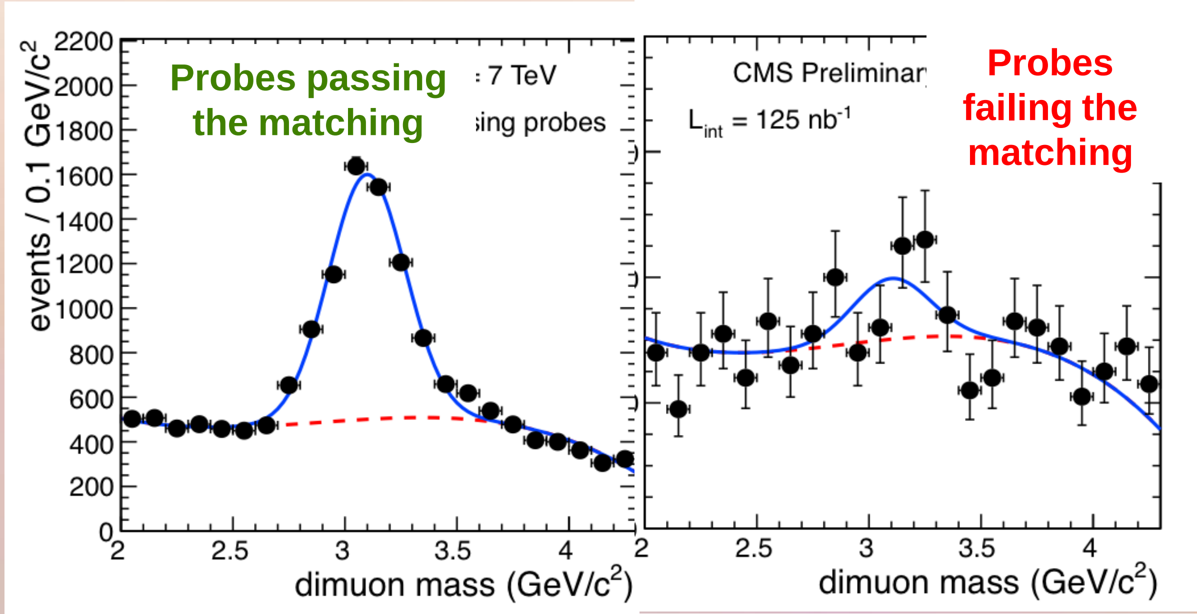
Sin(ϕ) modulation due to the displacement of the luminous region w.r.t. the center of CMS Tracker.



--> This motivates an early low mass upgrade of the pixel detector (see Rolands talk tomorrow)

Tracking Efficiency for muons (from J/ψ)





Reconstruction efficiency in the Tracker is estimated from the ratio of the yields of probes that either pass or fail the matching with a Tracker track.

Region	Data Eff. (%)	Sim Eff. (%)	Data/Sim
$0.0 \le \lvert\eta\rvert < 1.1$	$100.0^{+0.0}_{-0.3}$	$100.0^{+0.0}_{-0.1}$	$1.000^{+0.001}_{-0.003}$
$1.1 \le \lvert\eta\rvert < 1.6$	$99.2^{+0.8}_{-1.0}$	$99.8^{+0.1}_{-0.1}$	$0.994^{+0.009}_{-0.010}$
$1.6 \le \lvert\eta\rvert < 2.1$	$97.6^{+0.9}_{-1.0}$	$99.3^{+0.1}_{-0.1}$	$0.983^{+0.009}_{-0.010}$
$2.1 \le \lvert\eta\rvert < 2.4$	$98.5^{+1.5}_{-1.6}$	$97.6^{+0.2}_{-0.2}$	$1.010^{+0.015}_{-0.016}$
Combined	$98.8^{+0.5}_{-0.5}$	$99.2^{+0.1}_{-0.1}$	$0.996^{+0.005}_{-0.005}$

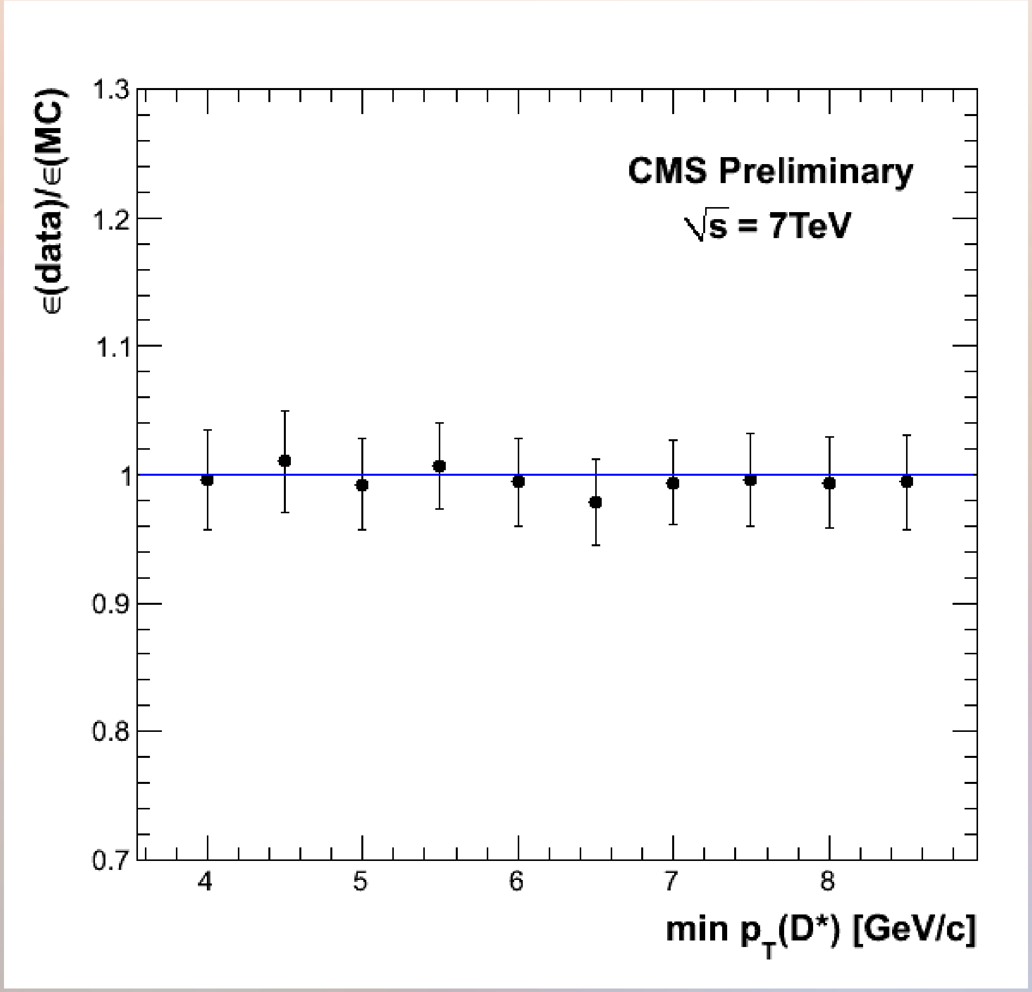
Measured tracking efficiency close to 99% and compatible with simulation

Pion reconstruction efficiency from D^0 decays

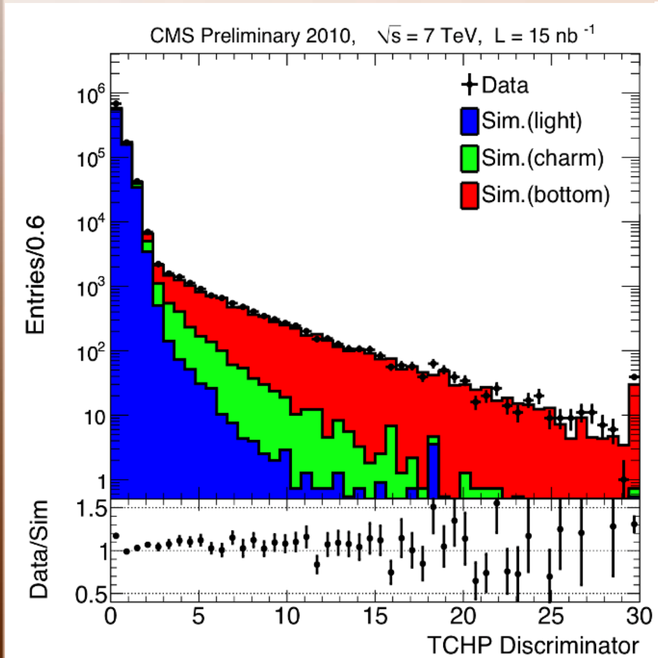
Ratio of yields of D^0--> K 3π and D^0--> $K\pi$, corrected by tracking efficiency:

$$\mathcal{R} = \frac{N_{K3\pi}}{N_{K\pi}} \cdot \frac{\epsilon_{K\pi}}{\epsilon_{K3\pi}}$$

$$\frac{\epsilon(\text{data})}{\epsilon(\text{MC})} = \sqrt{\frac{\mathcal{R}}{\mathcal{R}(\text{PDG})}}$$



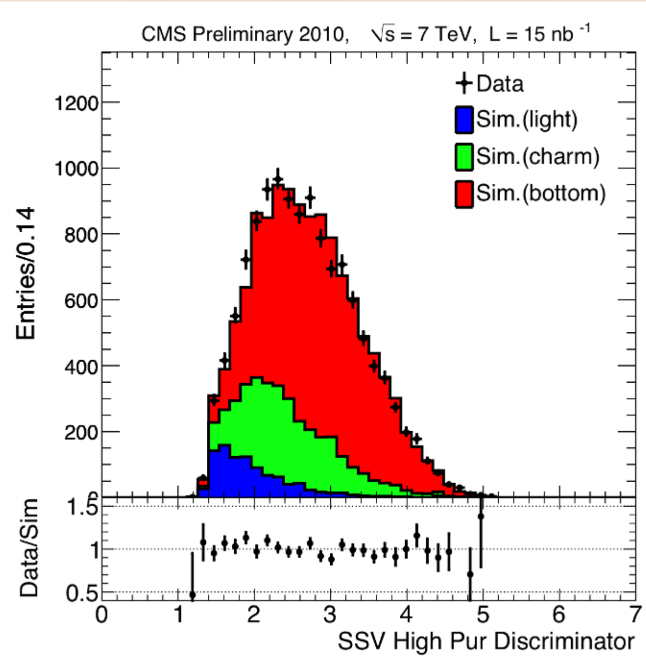
B-Tagging algorithms



Track Counting Algorithm

tags jets containing N tracks with Impact Parameter (IP) significance exceeding S

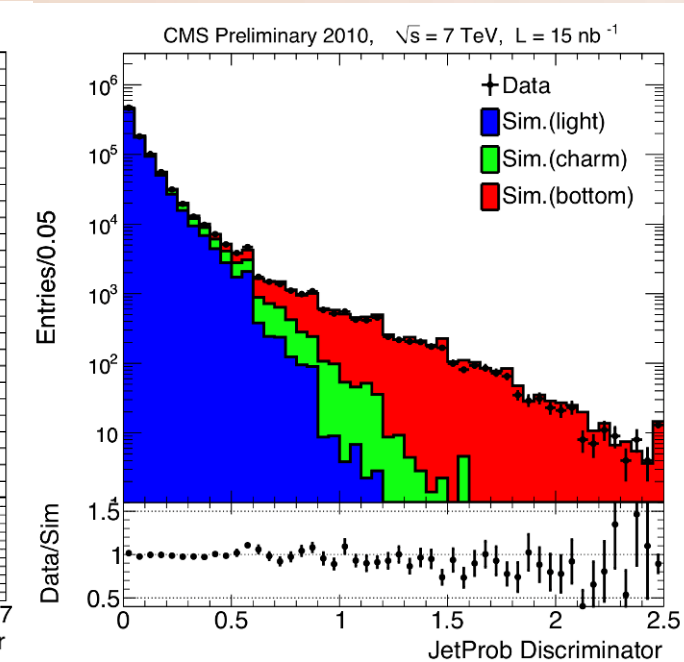
High Purity configuration: N=3



SSV Algorithm

tags jets according to the 3D flight distance significance of the reconstructed secondary vertex

High Purity configuration: Vertices with 3 or more tracks

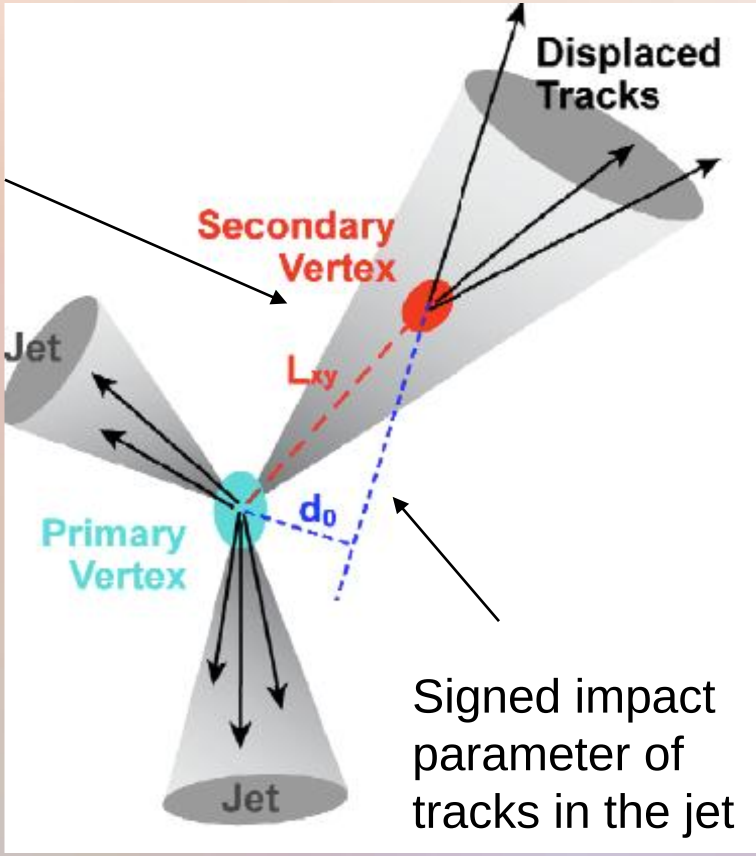


Jet Probability Algorithm

tags jets according to the probability of all the tracks in the jet to originate from the primary vertex, given their IP significances

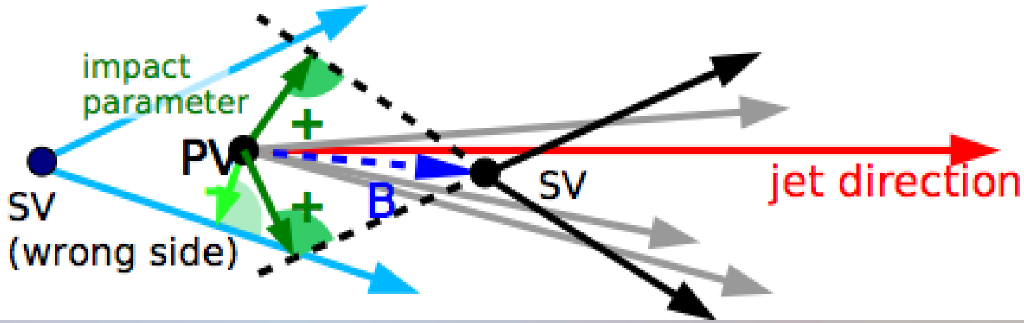
Main Observables used by B-tagging algorithms

Signed decay length of secondary vertexes

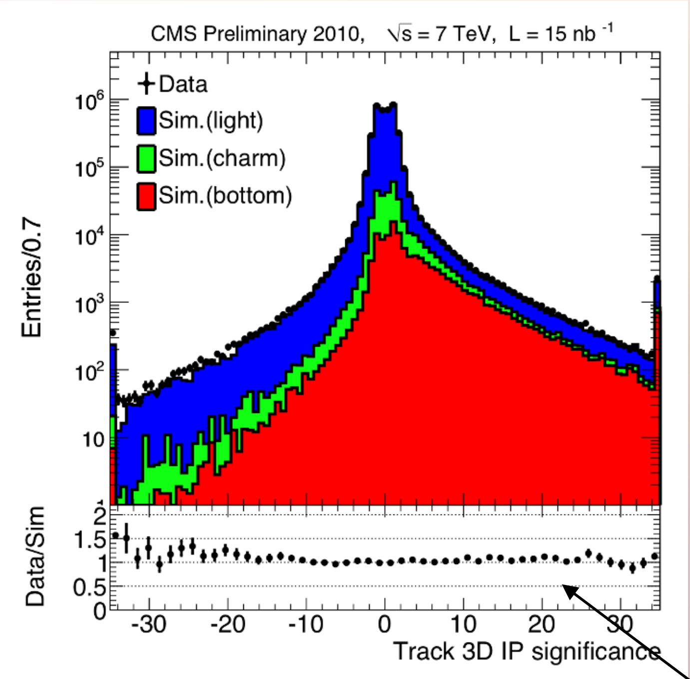


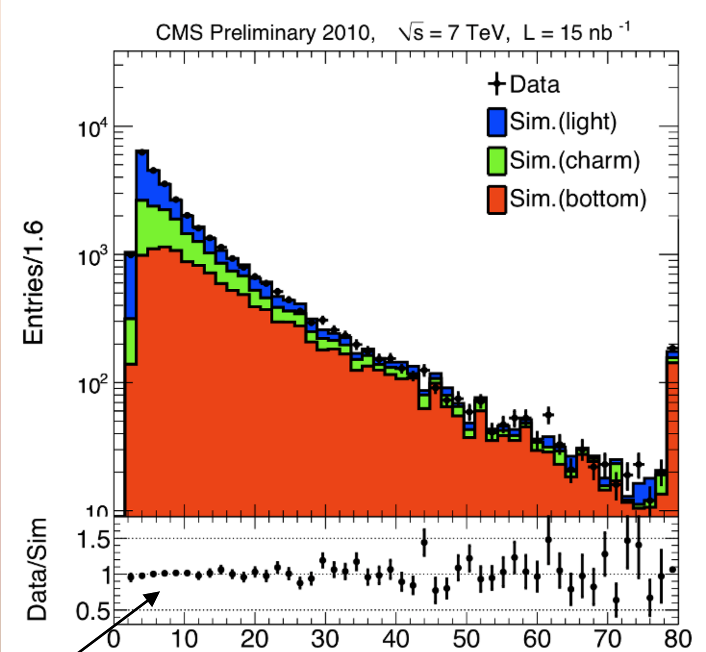
Signed impact parameter of tracks in the jet

Signs of Impact parameter and of vertex decay length are defined according to jet direction

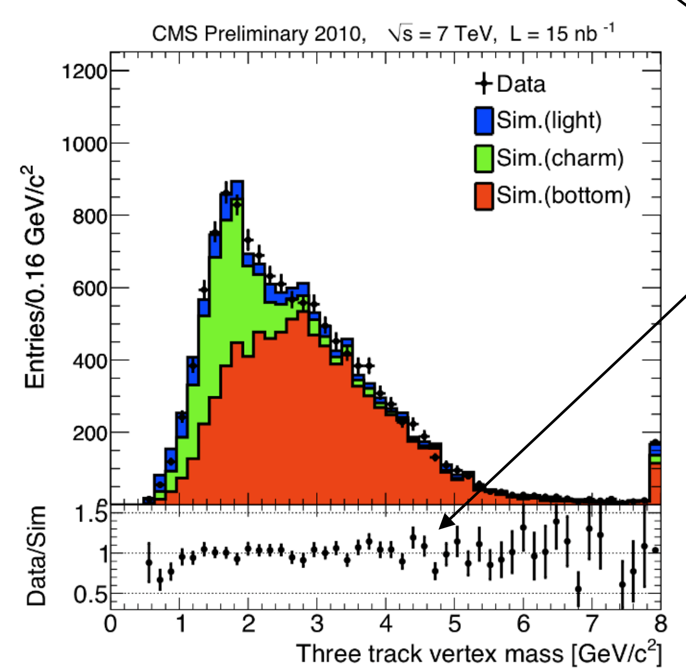


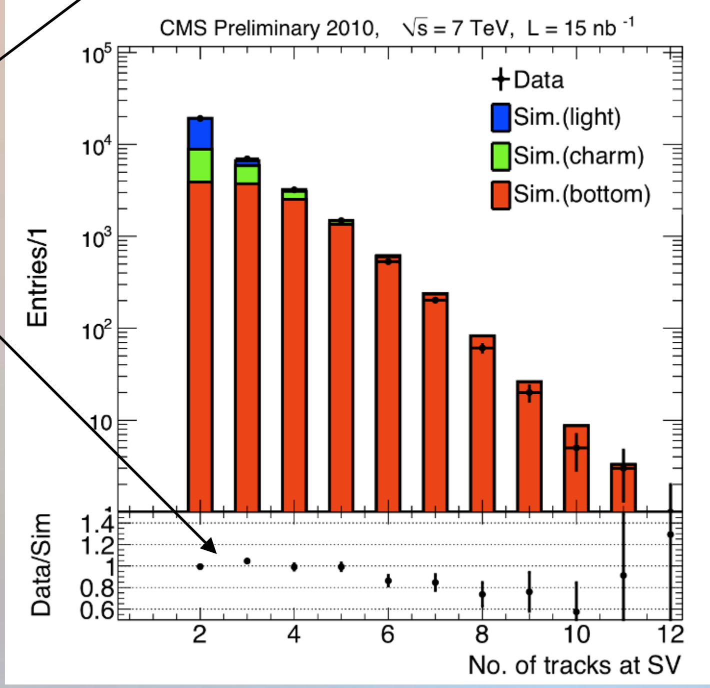
Data/MC comparison for B-Tagging observables





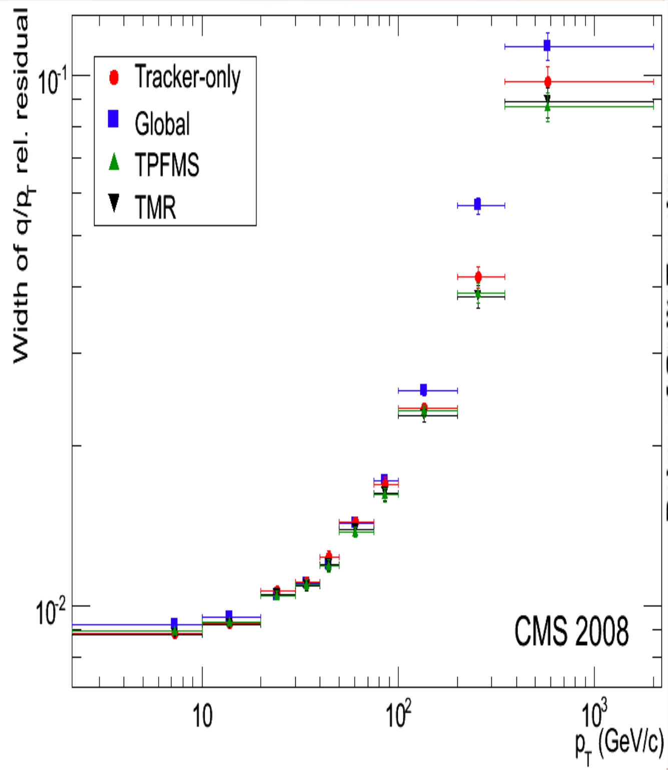
DATA/MC ratio is close to 1 for all observables (including those not shown)

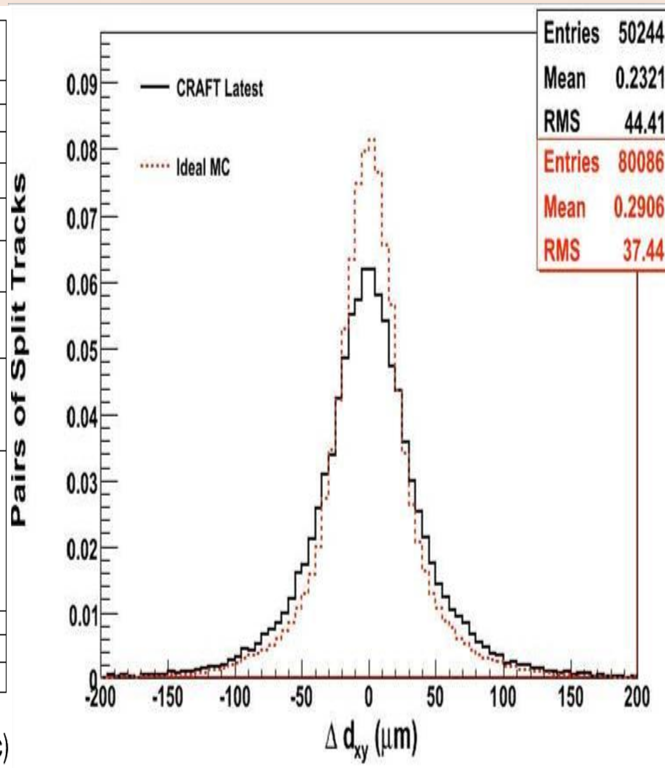


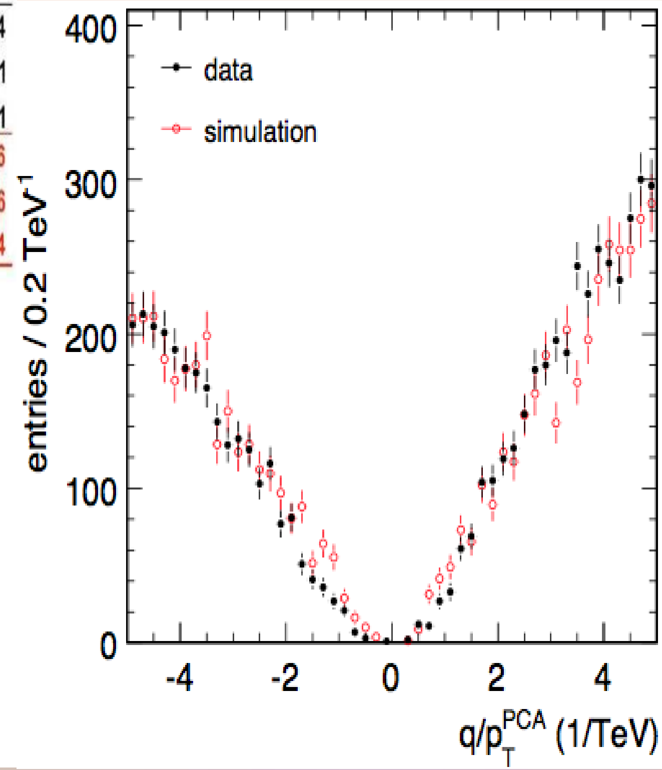


A (somewhat) closer look

Detailed understanding of detector performance







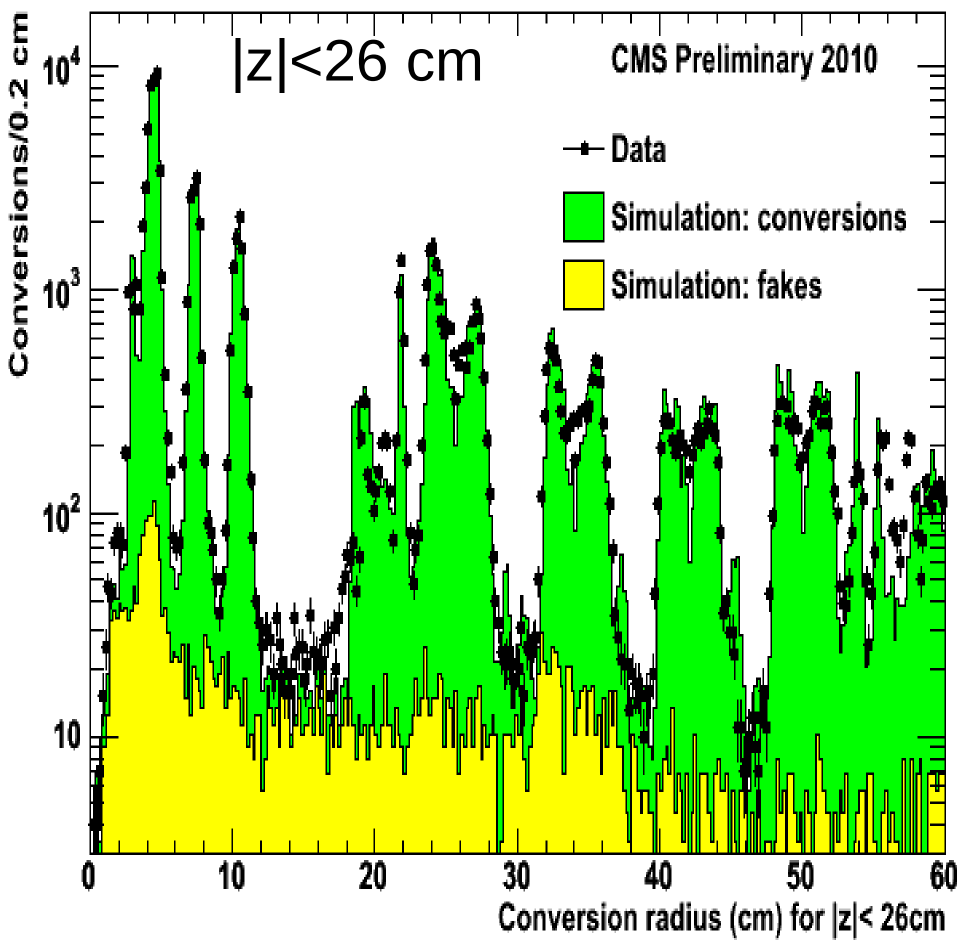
Momentum resolution vs p_T with 2-leg muons.

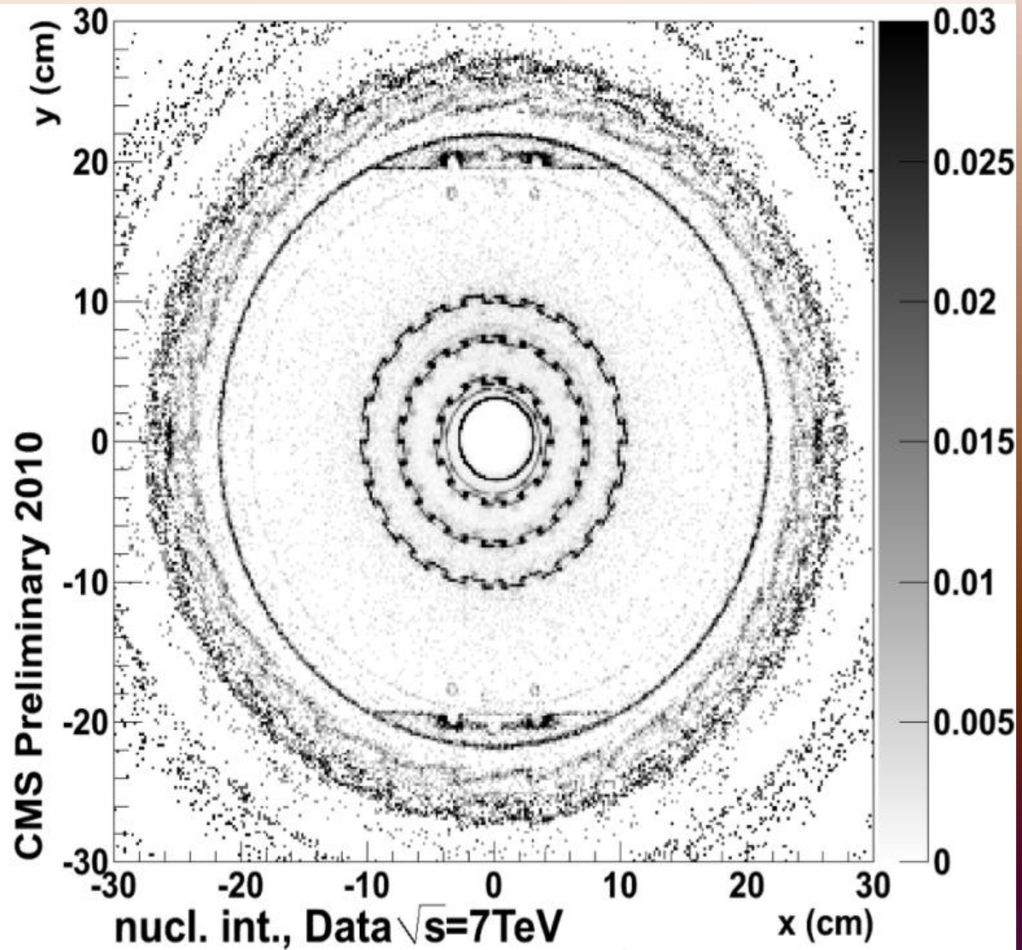
Distance of minimal approach with split tracks.

Excellent control of the momentum scale.

Good understanding of alignment and magnetic field; good description of the detector. Most of the tracker aligned at what was expected after 10pb^{-1} of collision data. Performance not too far from ideal.

Study of the tracker material





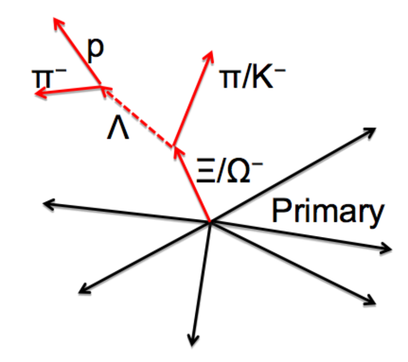
A complex activity is ongoing using many different, complementary methods: conversions, nuclear interactions, multiple scattering.

Check of the energy loss and of the momentum scale using **low mass resonances**.

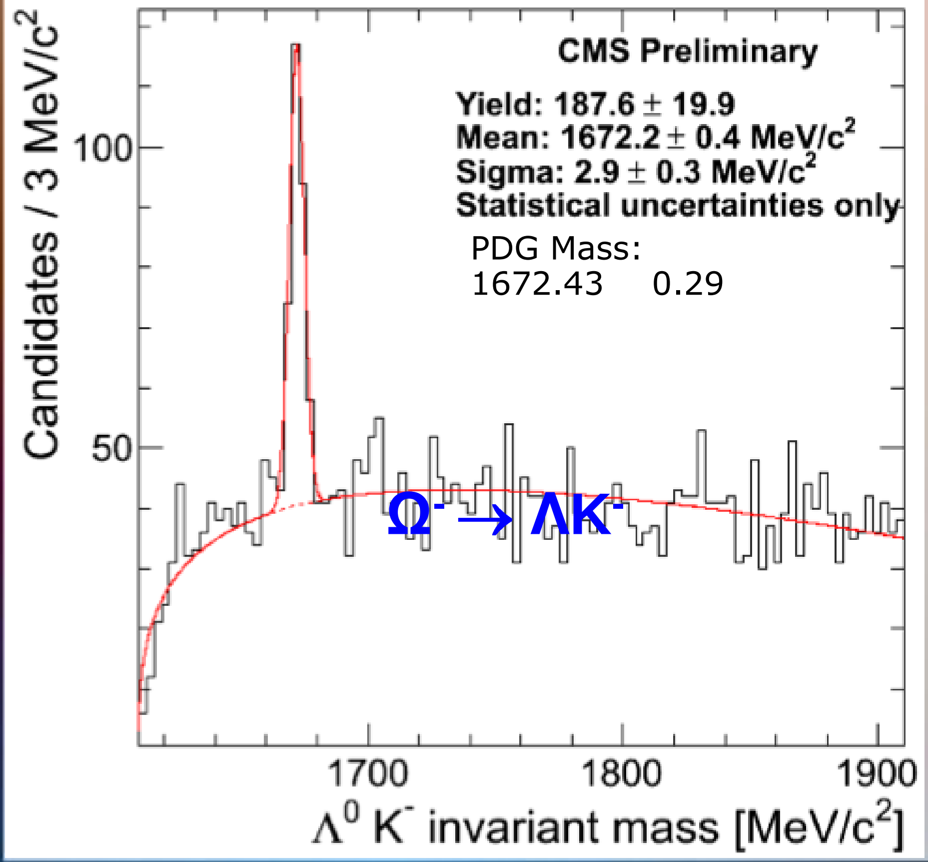
Material uncertainty today better than 10%→Systematics uncertainties on physics quantities related to material budget <1% .

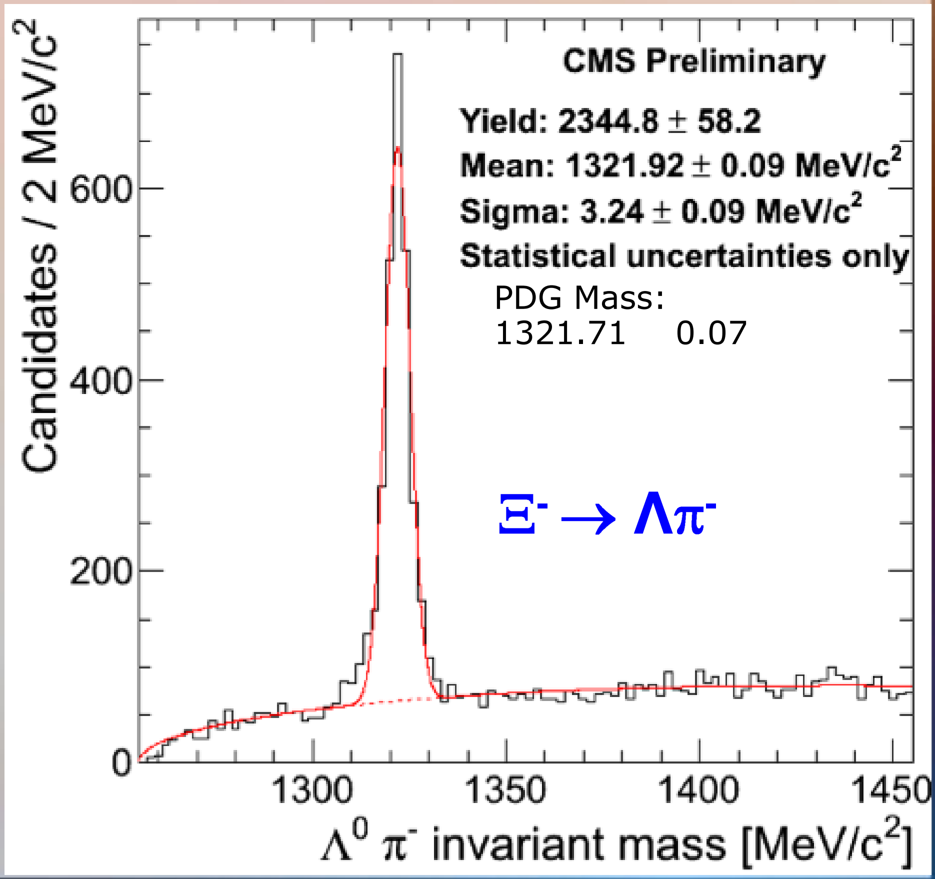
Low mass resonances

- Tracks displaced from primary vertex ($d_{3D} > 3\sigma$)
- Common displaced vertex ($L_{3D} > 10\sigma$)

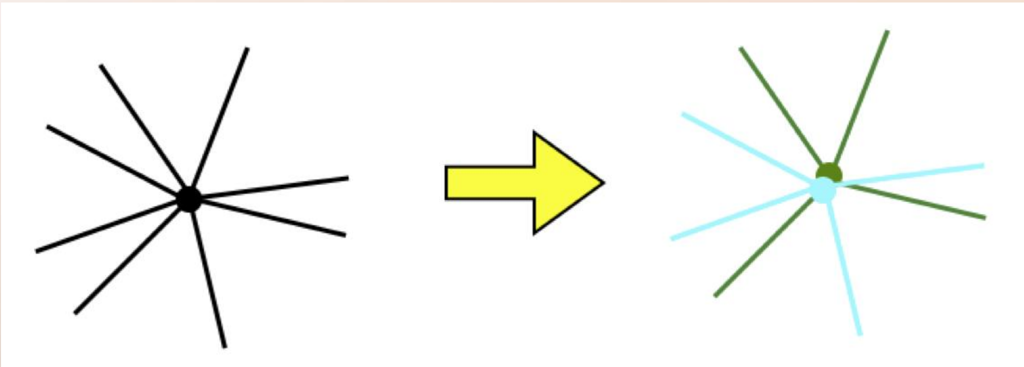


Invariant mass distribution for different combinations (Ω → ΛK or Ξ → Λπ) fit to a common vertex.





Primary Vertex Position Resolution

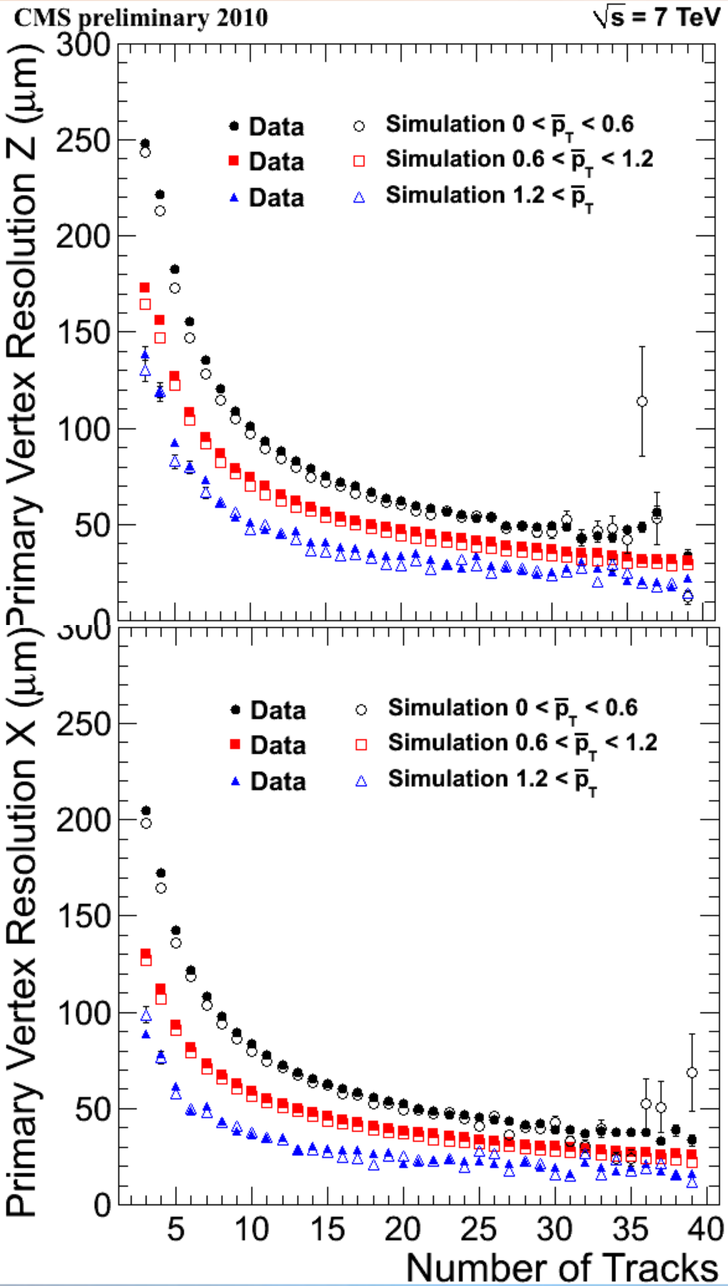


Single vertex reconstructed using “all” the tracks

Same collision point reconstructed **twice** using **half of the tracks**

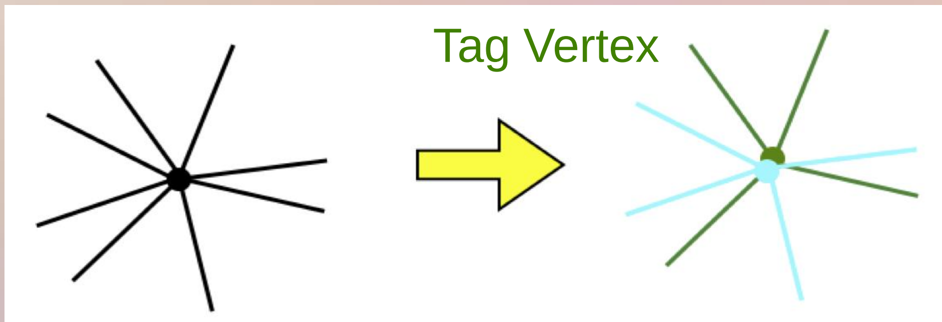
The position of one vertex is compared to the position of the other.

Repeating for many events, the intrinsic resolution of the primary vertex fitter is estimated directly from data.

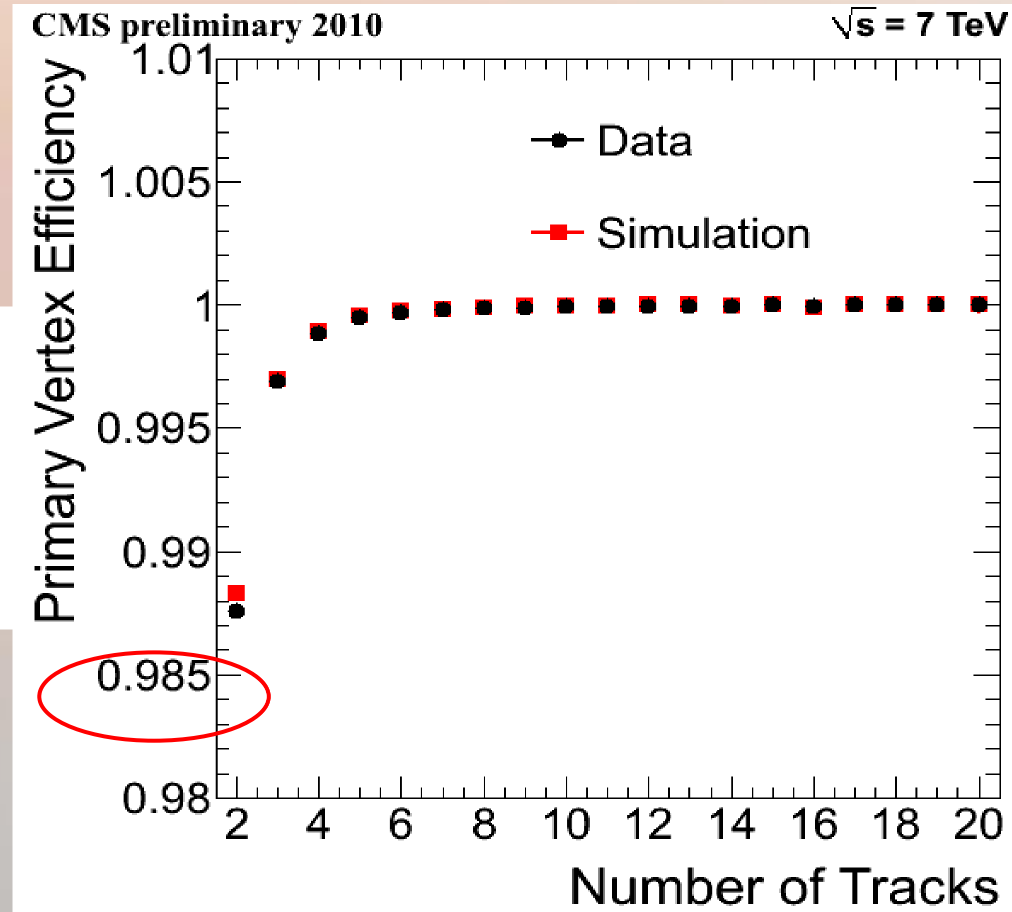


Primary Vertex Reconstruction Efficiency

Same technique also used to estimate, from DATA, the PV reconstruction ***efficiency***.



Is there a probe vertex ?



PV efficiency = #probes / #tags

The Pixel Detector: Status

>98% of pixels are on and working

Barrel: 98.8%

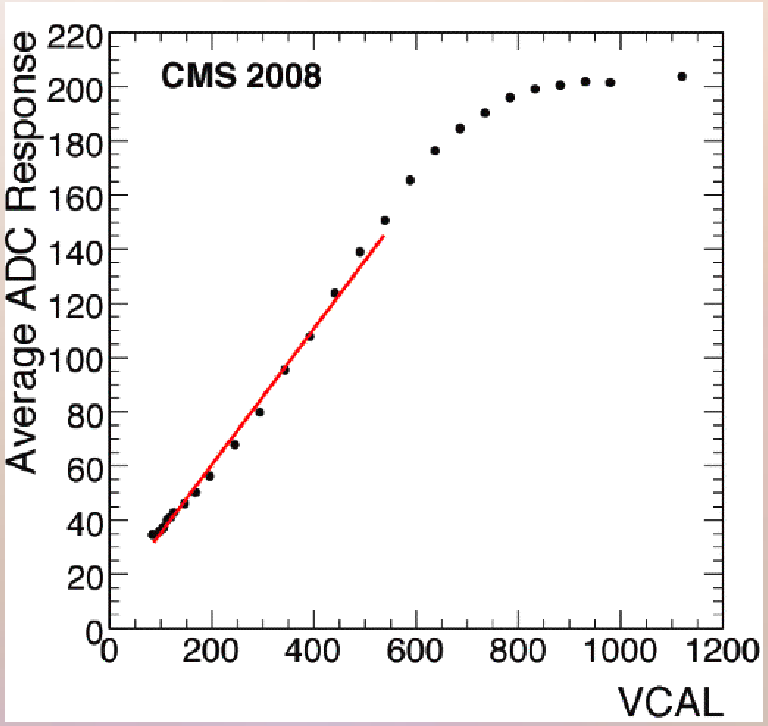
- bad wirebonds for readout or bias voltage
- most present at installation time
- very few recoverable problems

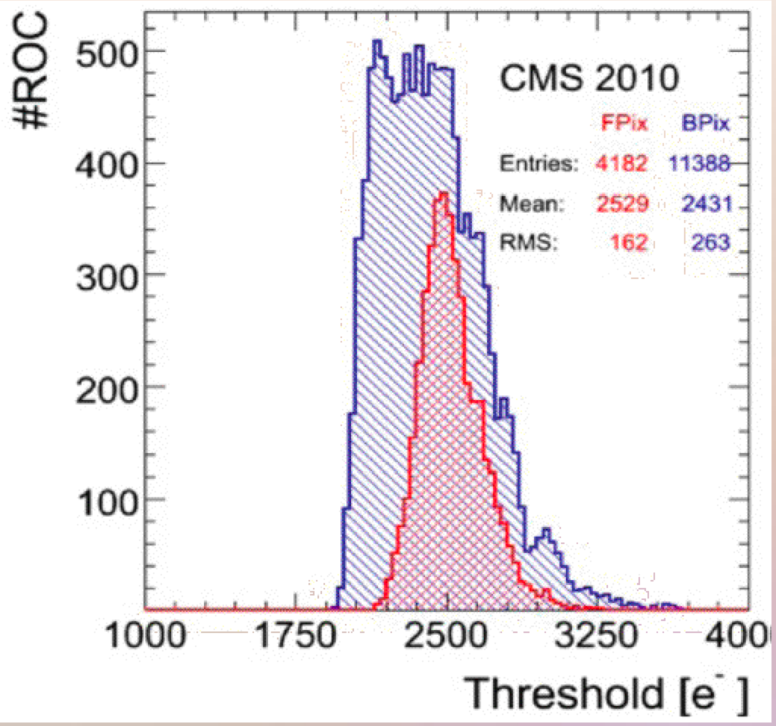
- Endcap: 96.4%
  - 5 panels with common symptom slow analog output (share AOH)
  - developed over time, but monotonic
  - panel with excessive noise - likely from dirty fiber connection
  - panel with 1 bad ROC can be recovered with software change

“Fast” extraction of pixel detector possible

- Repairs made to FPix in Early 2009
- Planning for opportunity in 2012 with LHC shutdown
- sufficient spare parts on hand for replacement and repair

Calibration of 66M channels!





Analog pulse height calibration
•With internal calibrate pulses (Vcal)
•Non-linear for high signals (around 1.5-2 MIPs))
•Determine gain and pedestal
•ROC average gain known from x-ray tests and MIPs

- Q(e-)=65.5*Vcal - 414

•Using tanh for more detailed studies

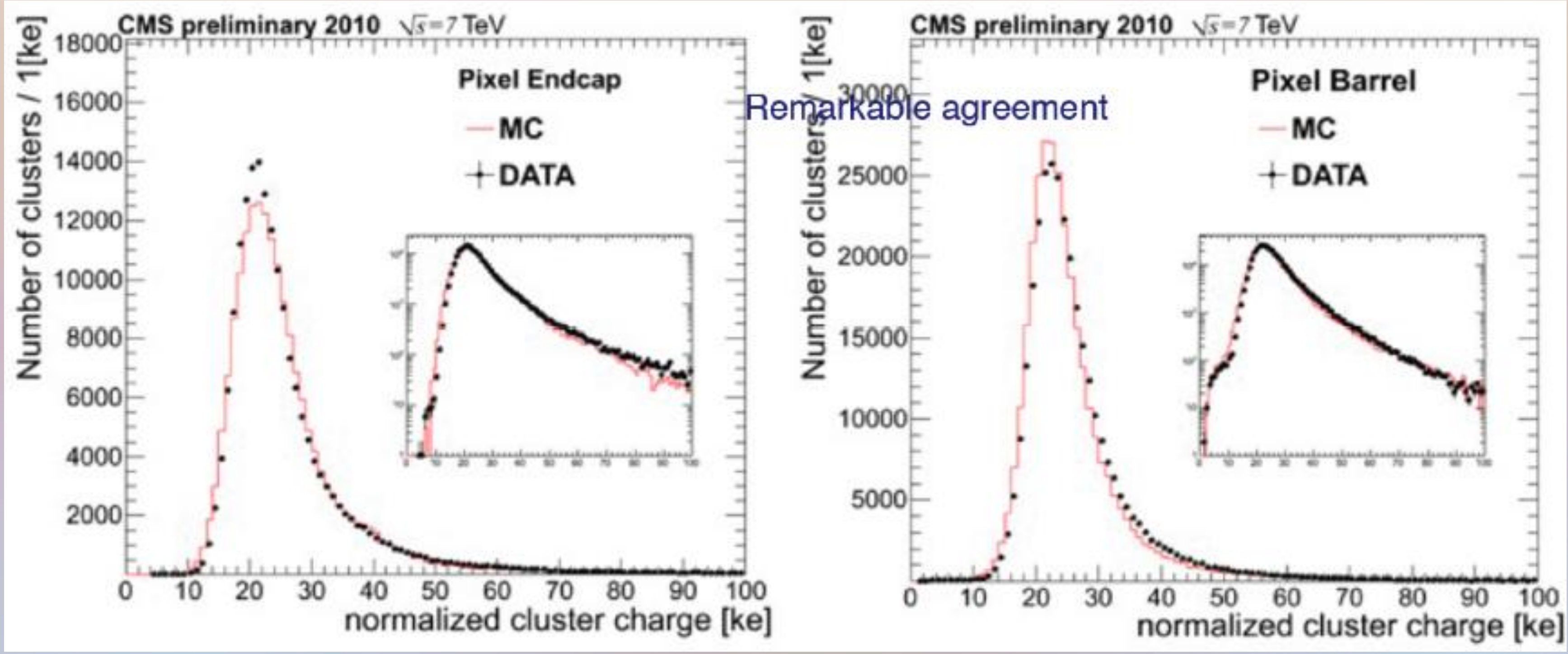
Threshold calibration
With internal calibrate signal
Absolute thresholds:

Barrel: 2.4ke-
Endcaps: 2.5 ke-
In-time threshold around 750 e- higher

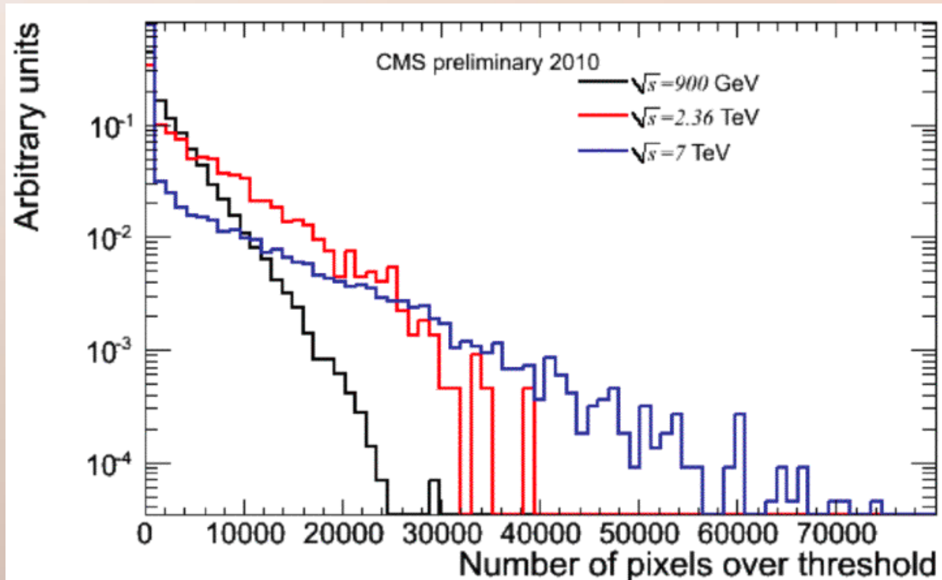
Pixel cluster charge

Cluster charge for hits on tracks (pt>2GeV/c)
Remarkable agreement between 7 TeV collision data and MC

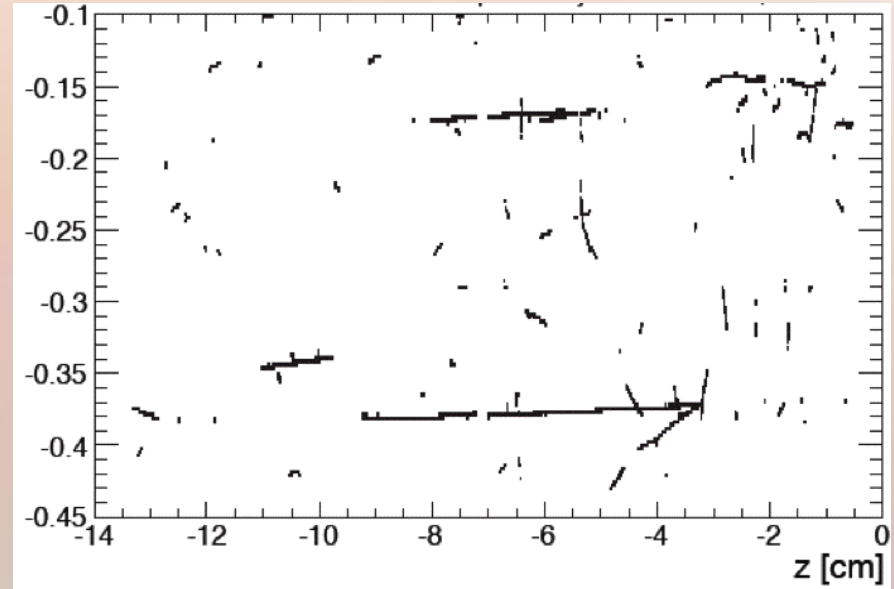
- Even the tails are ok
- Peak position correct to 2% (barrel) or 4% (endcaps)
- Widths slightly larger in data: 10% (barrel) and 15% (endcap)



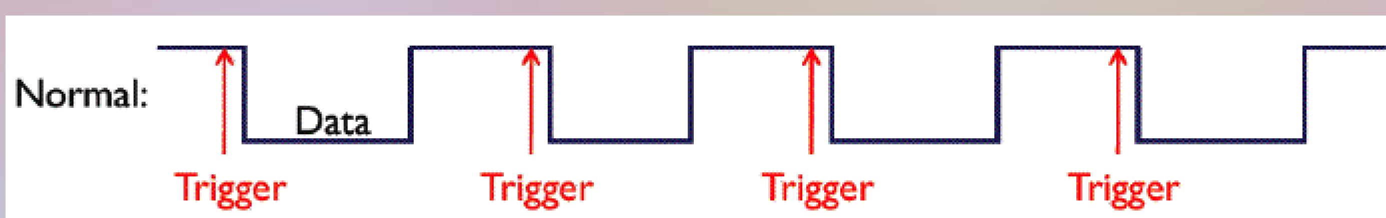
Large beam background events



Energy dependence of hit multiplicity



Hit map of one event. Area corresponds to about 2 modules



Occasional problems observed at high rates of large events (event synchronisation lost). Firmware modification was needed.

CMS Calorimeters

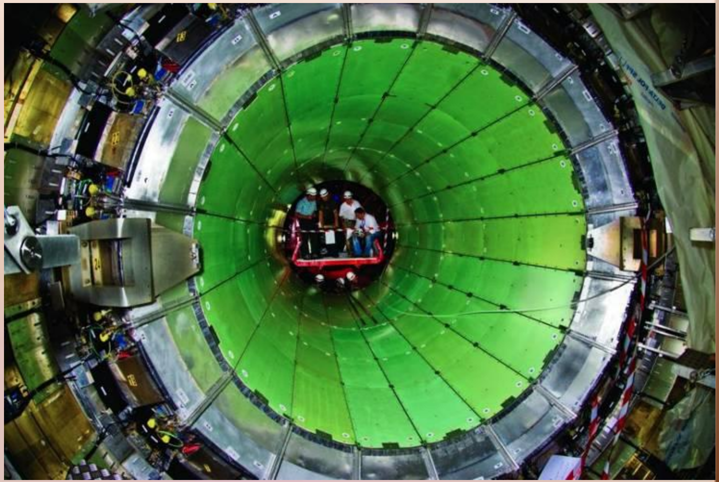
Electromagnetic calorimeter, ECAL:Homogeneous $PbWO_4$ crystal calorimeter

•Barrel (EB): $26X_0$, $\Delta\eta \times \Delta\varphi = 0.0174 \times 0.0174$

•Endcap (EE): $25X_0$, $\Delta\eta \times \Delta\varphi = 0.021 \times 0.021 \sim 0.050 \times 0.050$

•Preshower in endcap (ES): $3X_0$ lead with 2 planes of 61mm x 1.9mm Si strips

Target resolution: 0.5% at high energy



> 99% working channels (EB: 99.3, EE: 98.94, ES: 99.8)
stable conditions: temp. RMS $0.003^{o}C$ (EE: $0.015^{o}C$).
Laser response stability < 0.02%.

Hadronic calorimeter, HCAL:

•Barrel (HB): Brass + Scintillators
  - $\Delta\eta \times \Delta\varphi = 0.087 \times 0.087$

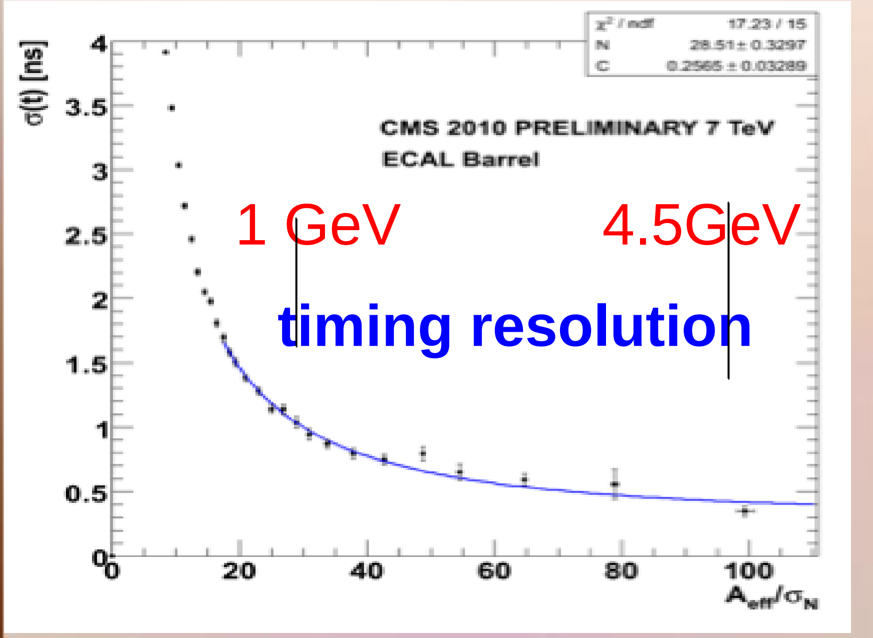
•Barrel tail catcher (HO): Scintillators

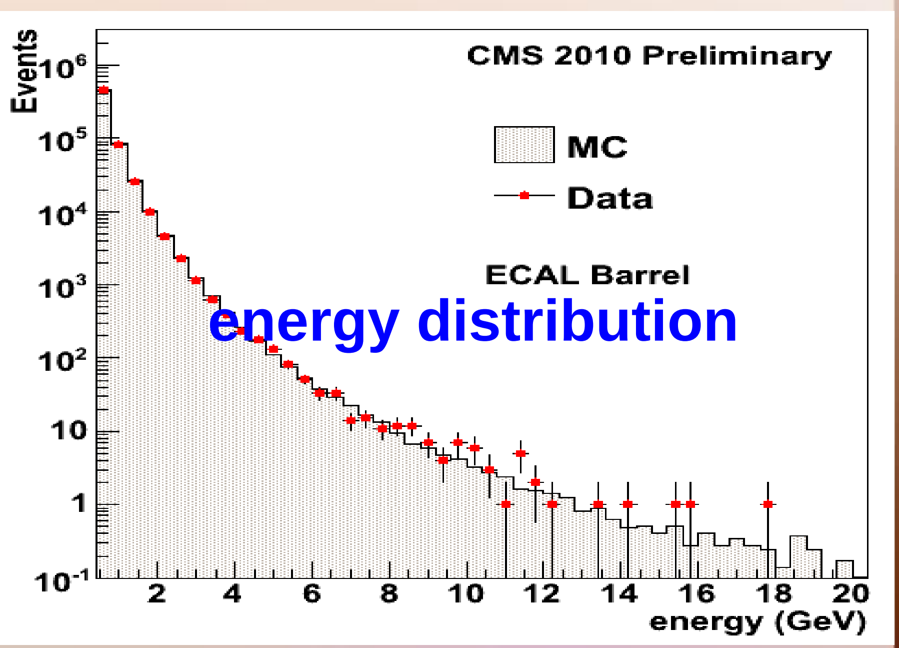
•Endcap (HE): Brass + Scintillators
  - $\Delta\eta \times \Delta\varphi = 0.087 \times 0.087 ... 0.35 \times 0.087$

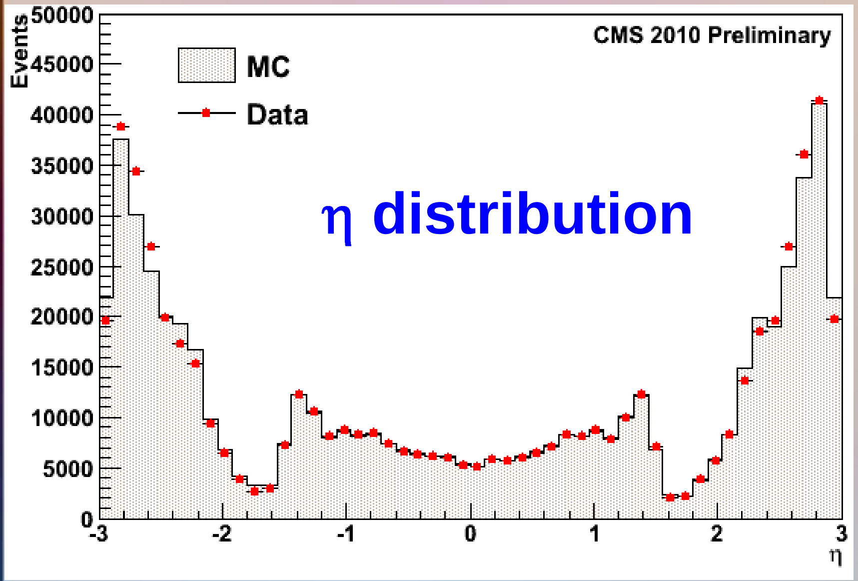
•Forward (HF): Steel + quartz fibre (Čerenkov)
  - $\Delta\eta \times \Delta\varphi = 0.349 \times (0.175 \text{ or } 0.35)$

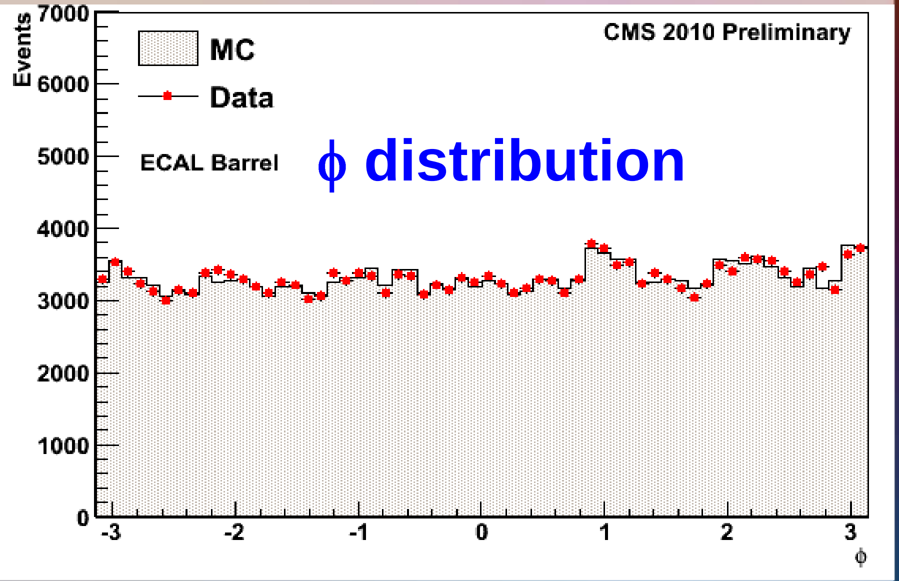
> 99.75% working channels (100% in HB/HE/HF)

ECAL clusters (electrons and photons)









Calibration

Synchronization

All channels synchronized. Providing a time measurement precision better than 1ns.

Calibration

Start-up calibration uses results from a 10-year campaign of test-beam and cosmics rays precalibation, in-situ "splash" events and π^0 calibration.

Precision of start-up calibration:

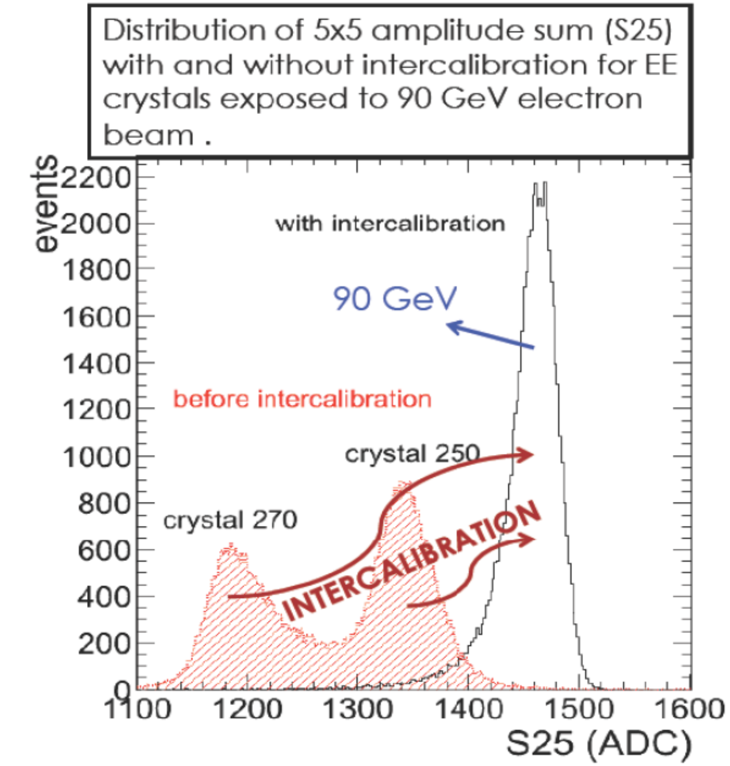
EB: 0.5% ~ 2.2% (1.2% in central region with first 120 nb-1)

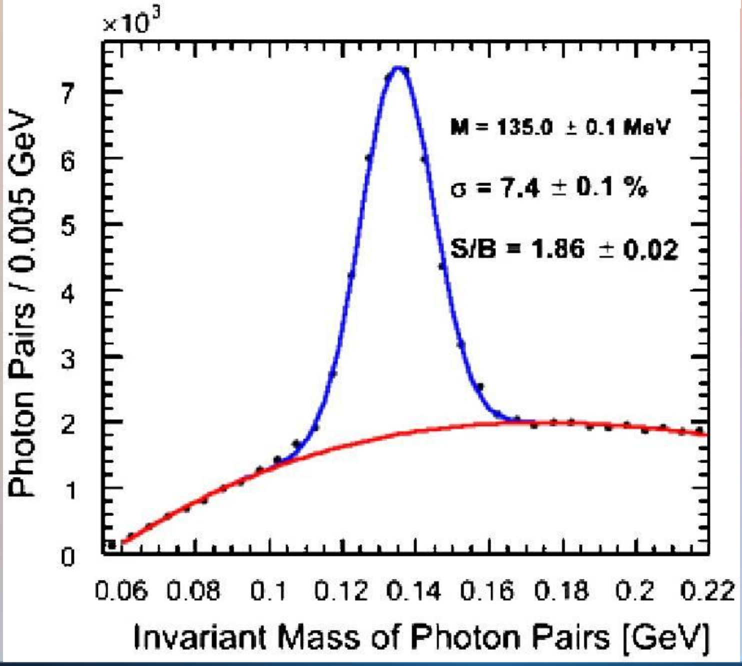
EE: 5%

ES: 2.2% (better than design goal)

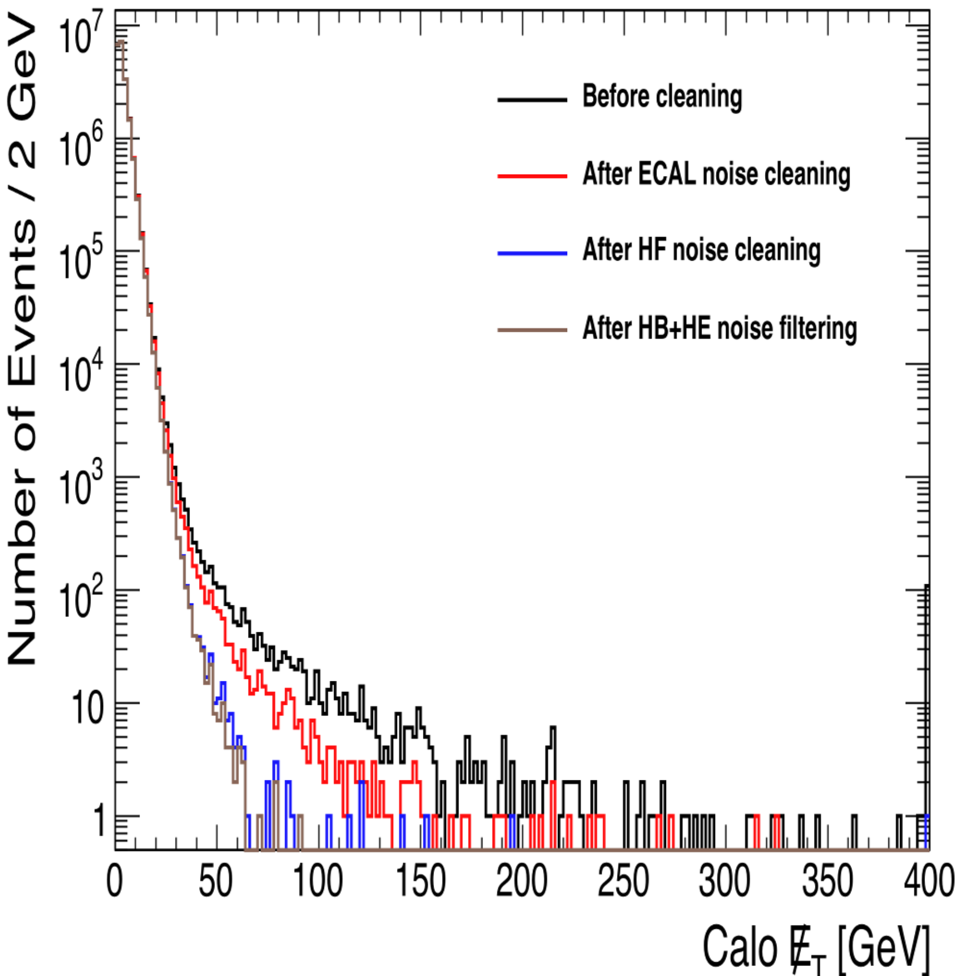
In-situ inter-calibration with $\pi\text{->}\gamma\gamma$ events

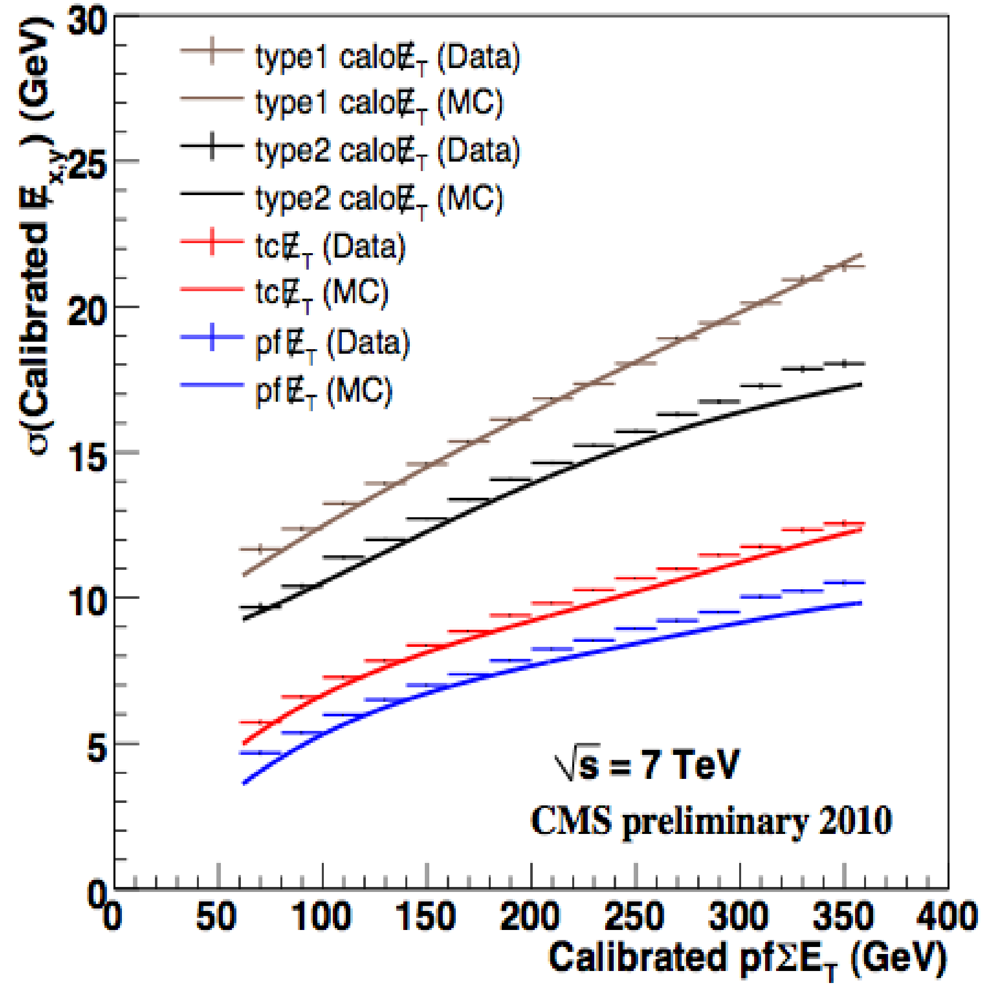
Target with 10 pb-1: 0.5% in EB; 1%~2% in EE





Progress in MET



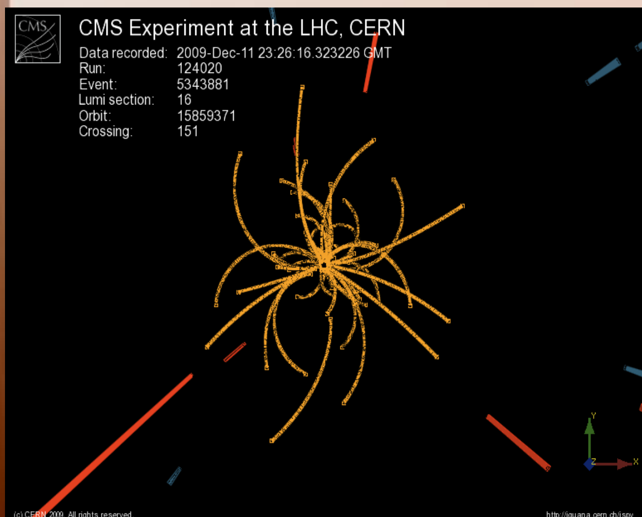


Excellent resolution and small non-gaussian tails. Understanding all sources of erratic noise is very important for cleaning the distributions. MET ready for physics.

Anomalous Signals in Calorimeters

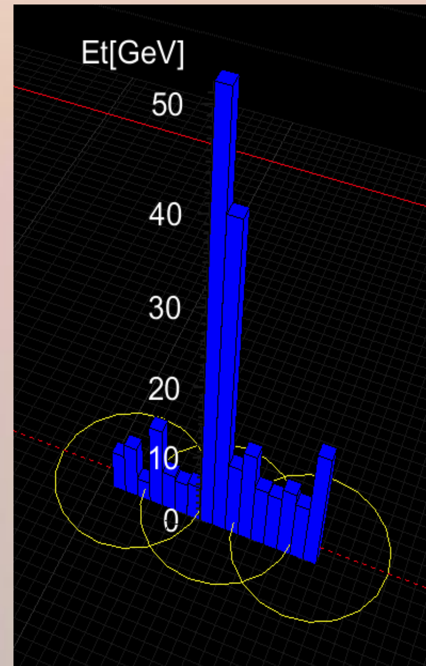
In collision data we observe some anomalous signals in ECAL and HCAL
Now reproduced in simulation.

ECAL



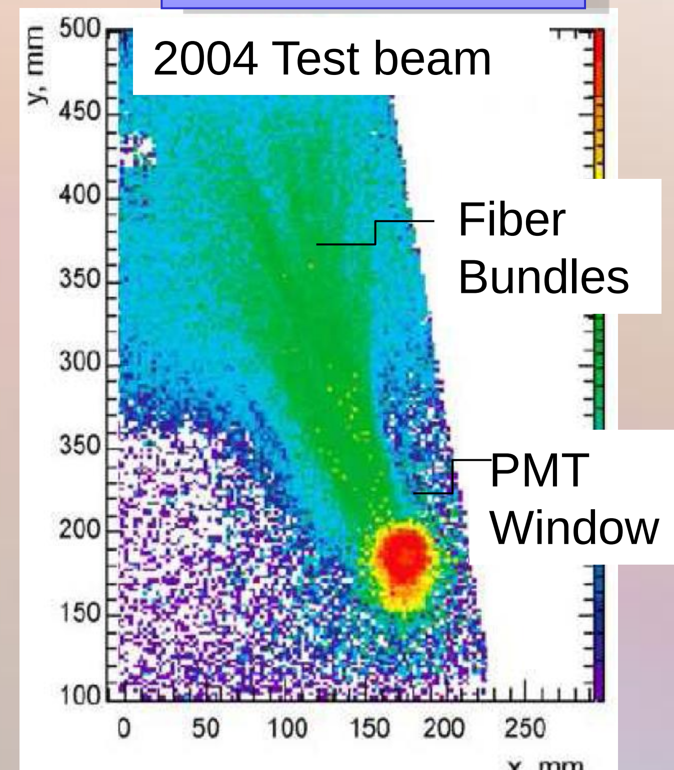
- Appear mostly in a single crystal
- In time with collisions but with wider time-spread (also occur in cosmics at a much lower rate)
- Caused mostly by deposits in APDs by highly ionising secondary particles.

HCAL: HB,HE



- Appear in 1-72 channels
- Random, low rate, ~ 10-20 Hz (E>20 GeV)
- Caused by ion feedback, noise & discharges in HPDs

HCAL: HF



- Appear mostly in one ch.
- In time with collisions
- Caused by C^v light by particles going through PMT glass

Conclusion

CMS is in good shape and deliveres excellent data quality

All sub-systems have >98% of the channels on

Understanding of detector is mostly very good

In some cases performance is already better than the design goal

A big thank you to the LHC machine group for the great performance

Backup Slides

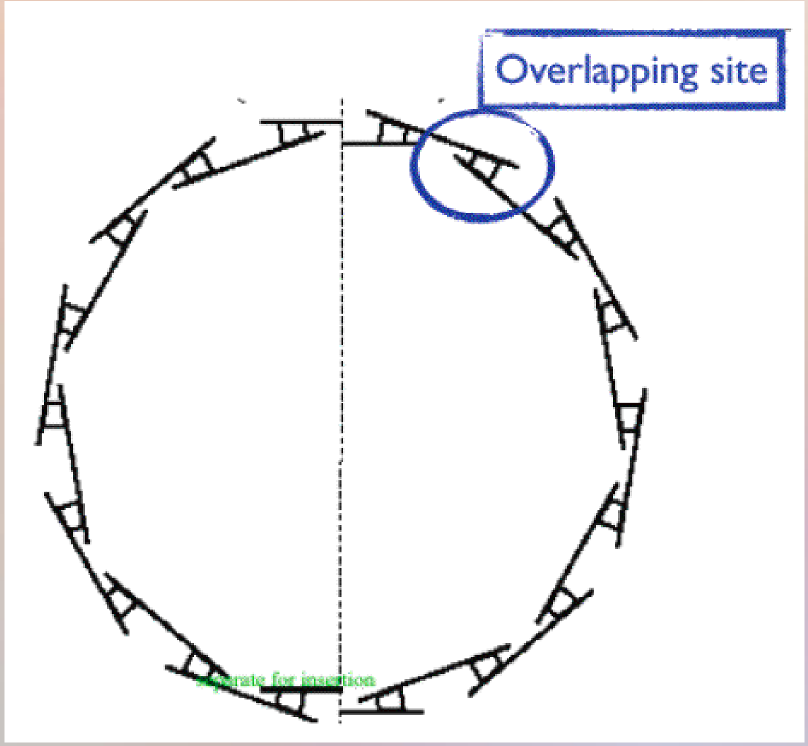
Pixel hit resolution

Using overlapping module pairs
With > 30 shared tracks
Double difference is sensitive to resolution
but insensitive to
- alignment
- multiple scattering
- track extrapolation

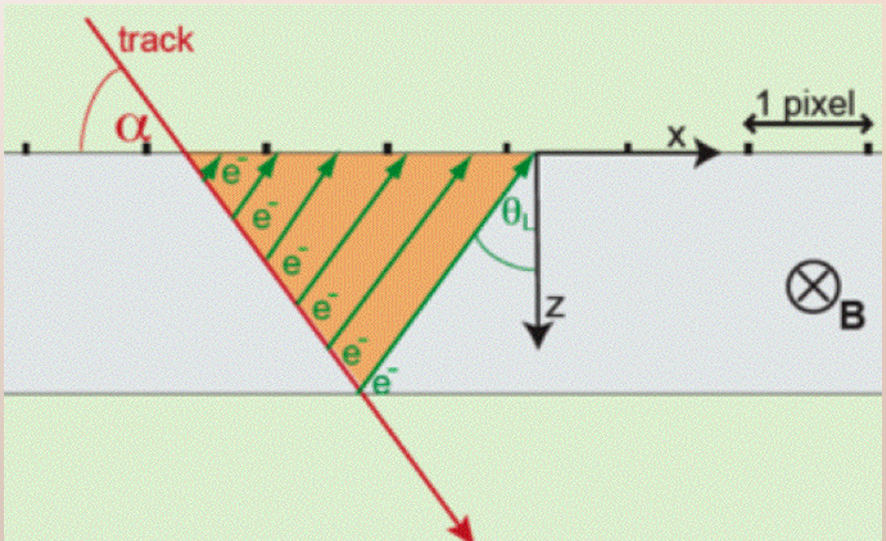
2009 LHC min-bias data
Barrel Modules (local coordinates)

All	No double-wide pix
σx=12.8±0.9 μm or	12.7±2.3 μm
σy=32.4±1.4 μm or	28.2±1.9 μm

Compares well to detailed
Simulation (PIXELAV)
σx=14.1±0.5 μm (no double-wide pix)
σy=24.1±0.5 μm



Lorentz Angle



Barrel: & & cot α= -0.462±0.003
(PIXELAV simulation: -0.452±0.002)
Forward: & cot α= -0.074±0.005
(PIXELAV simulation: -0.074±0.004)

Cluster Size Method
At minimum cluster size:
& α=θL + 90°
Measured with cosmic rays for
B=0 and 3.8 T
2008 T=14° C
2009 T=4° C