



ATLAS & CMS
La Fisica di Scoperta a LHC

Outline



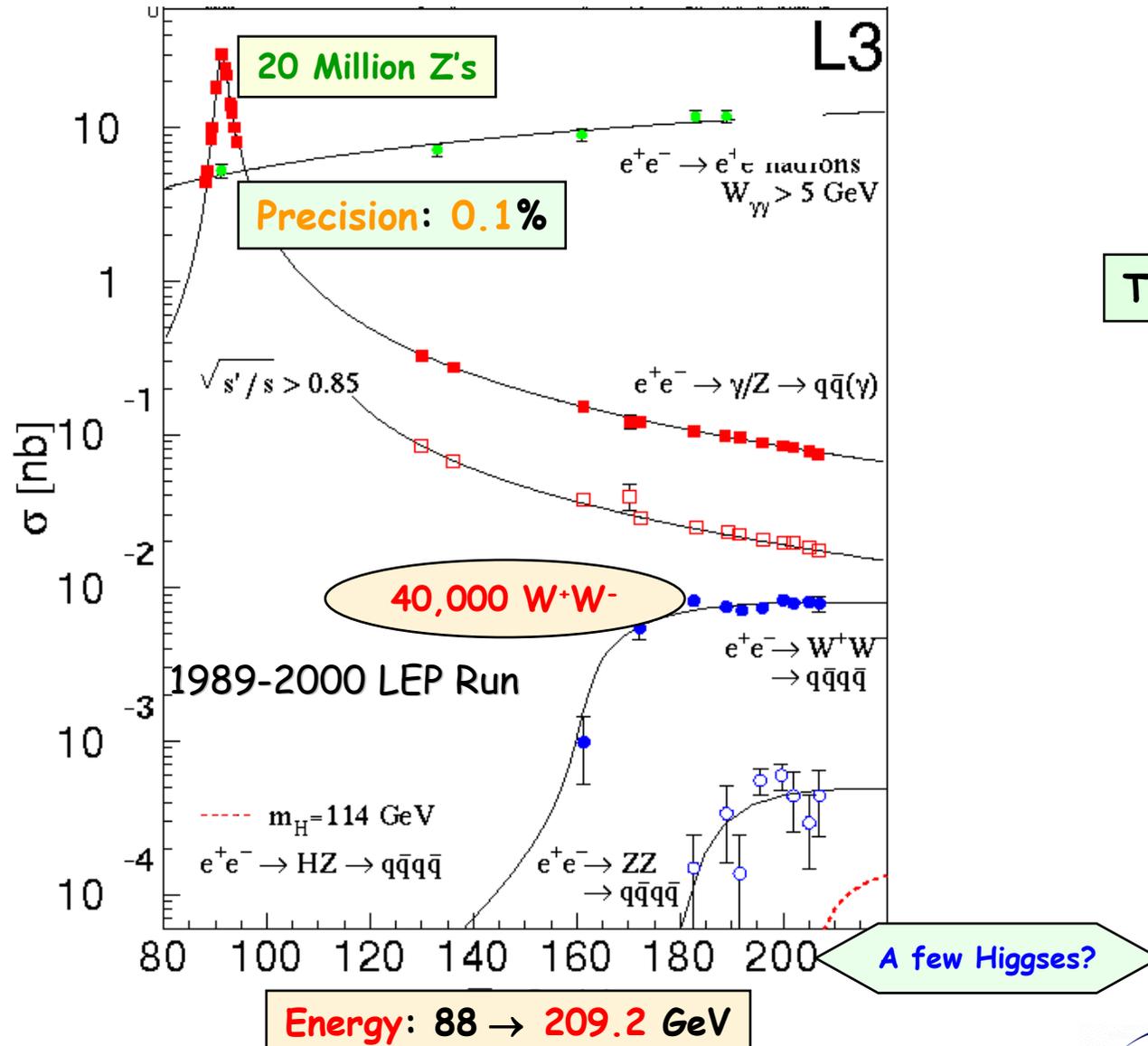
- ATLAS & CMS @ LHC
- Preparare e capire i rivelatori
- Higgs Search

Standard Model Dopo LEP

1989-->2000

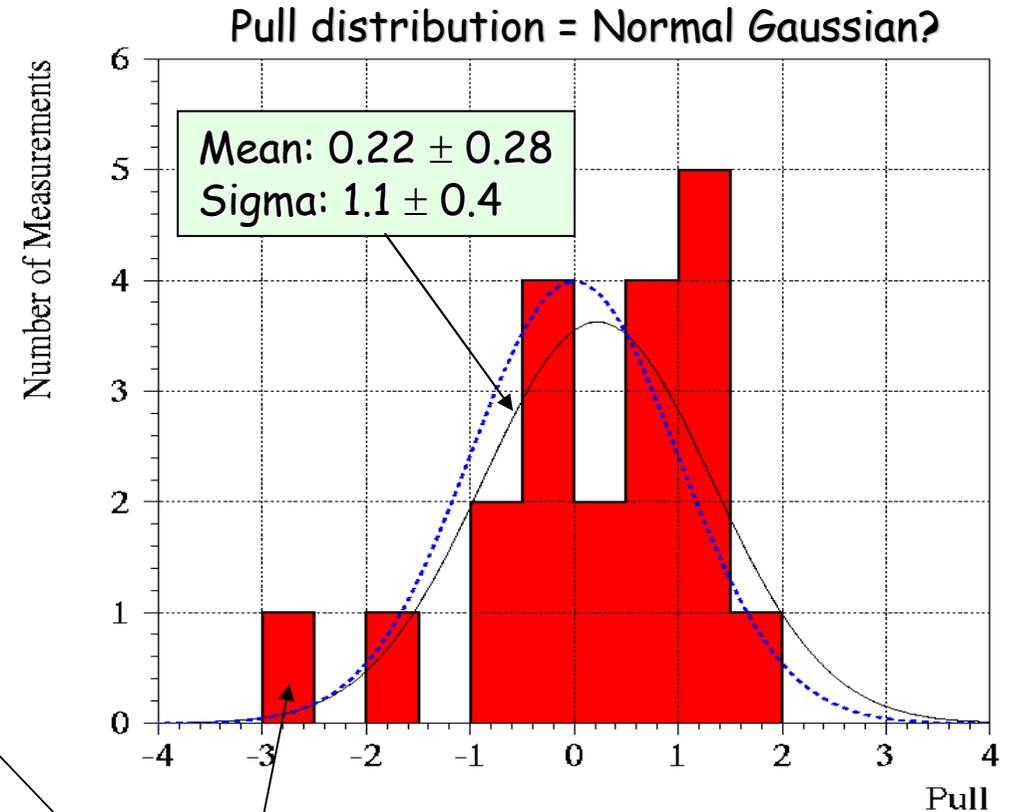
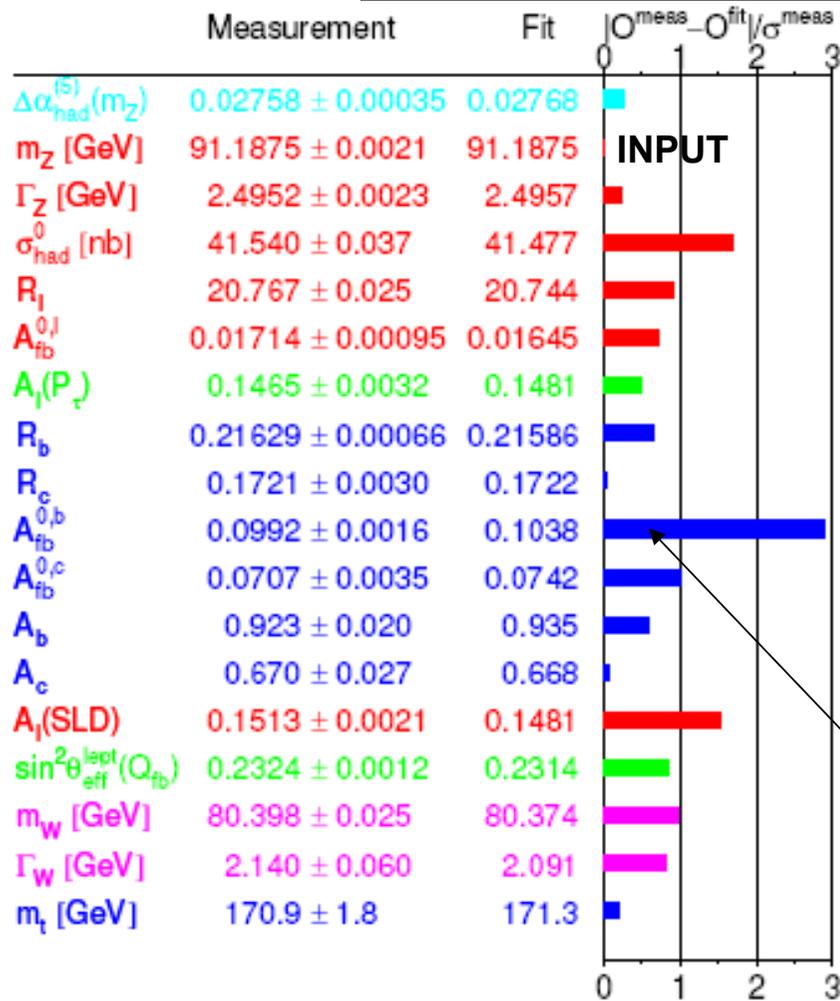
Total Luminosity: 1000 pb⁻¹

Courtesy of G. Rolandi



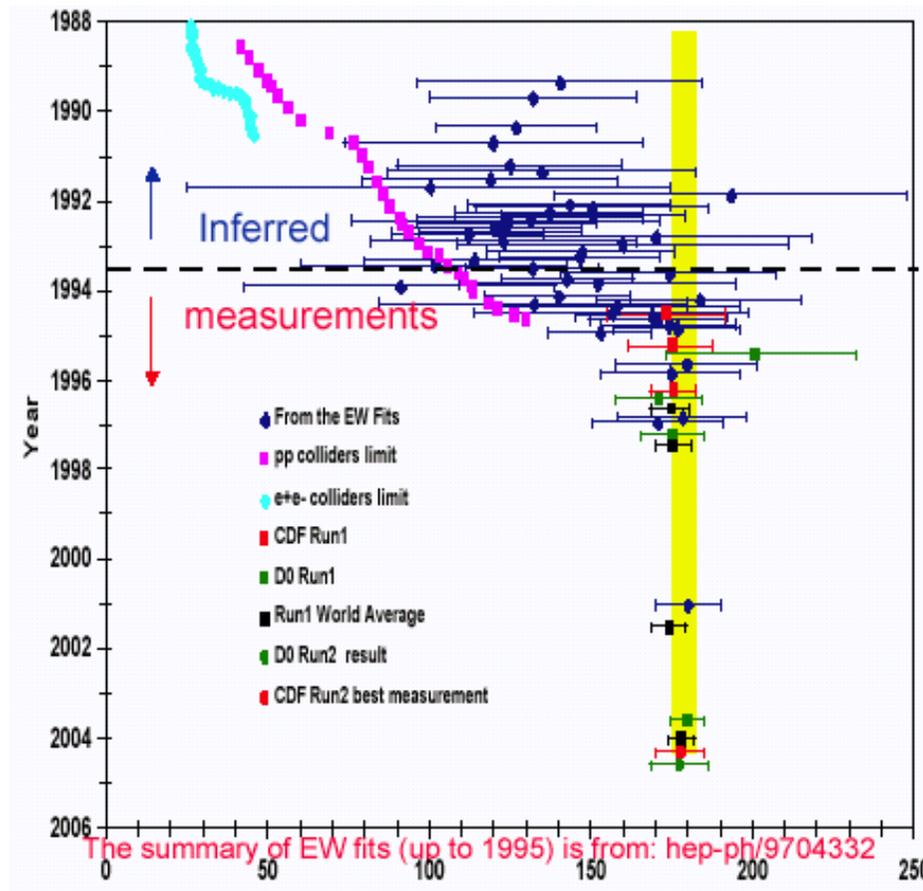
Global Fit allo SM

Internal Consistency of the Standard Model?



Largest discrepancy (-2.9σ) well inside statistical expectation;
 χ^2 probability = 8%. Just fine.

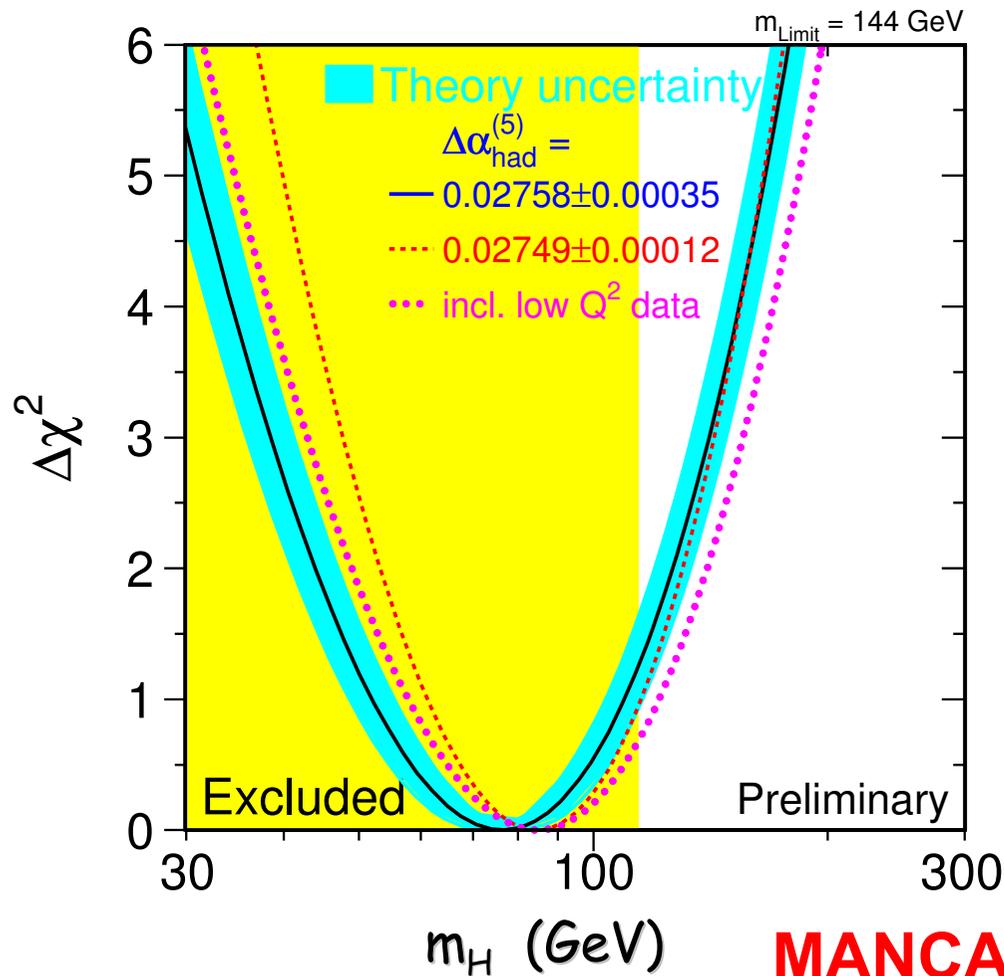
La misura indiretta della massa del top



m_{top} prediction from EW fit verified,
has been an impressive result!

Higgs dietro l'angolo?

Il Modello Standard gode di ottima salute:



SM Global Fit:

$m_H < 193 \text{ GeV}$ (95% CL)

Limite diretto LEP:

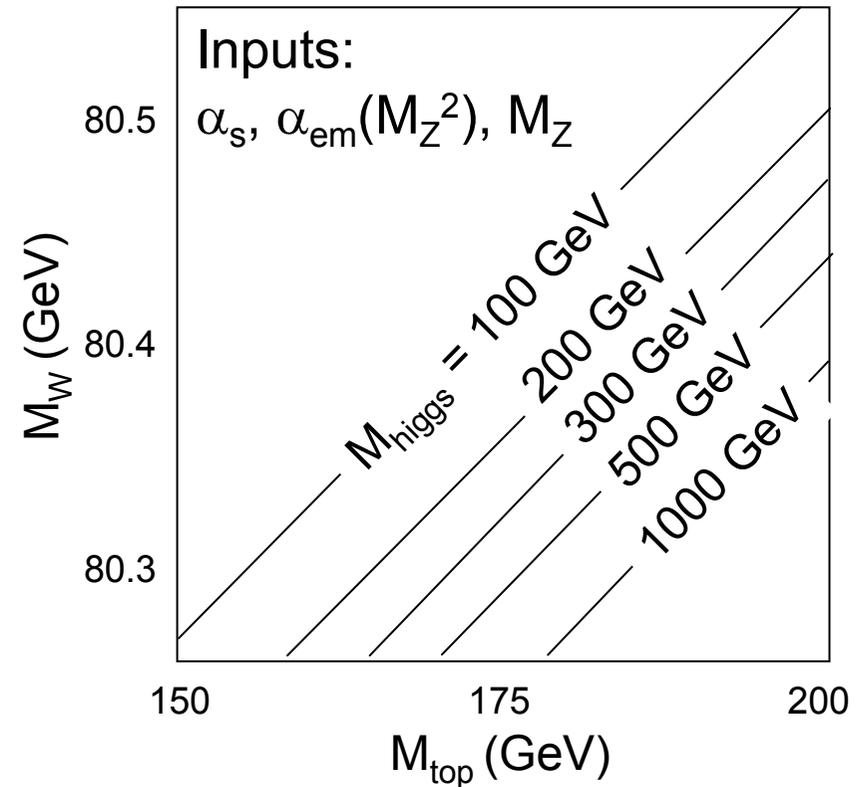
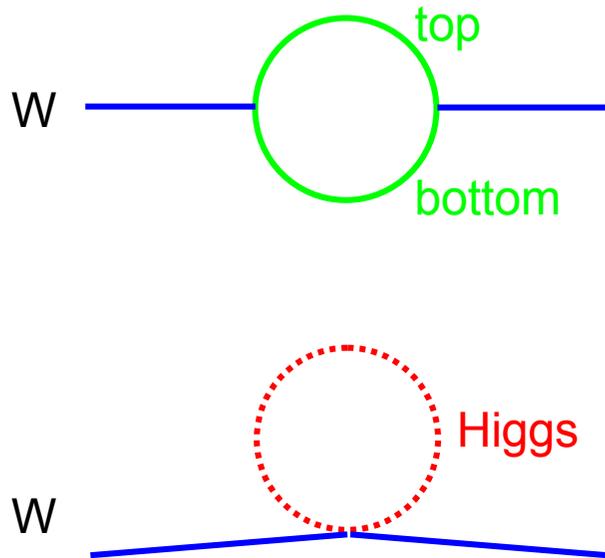
$m_H > 114.4 \text{ GeV}$ (95% CL)

MANCA UN PEZZO CRUCIALE!

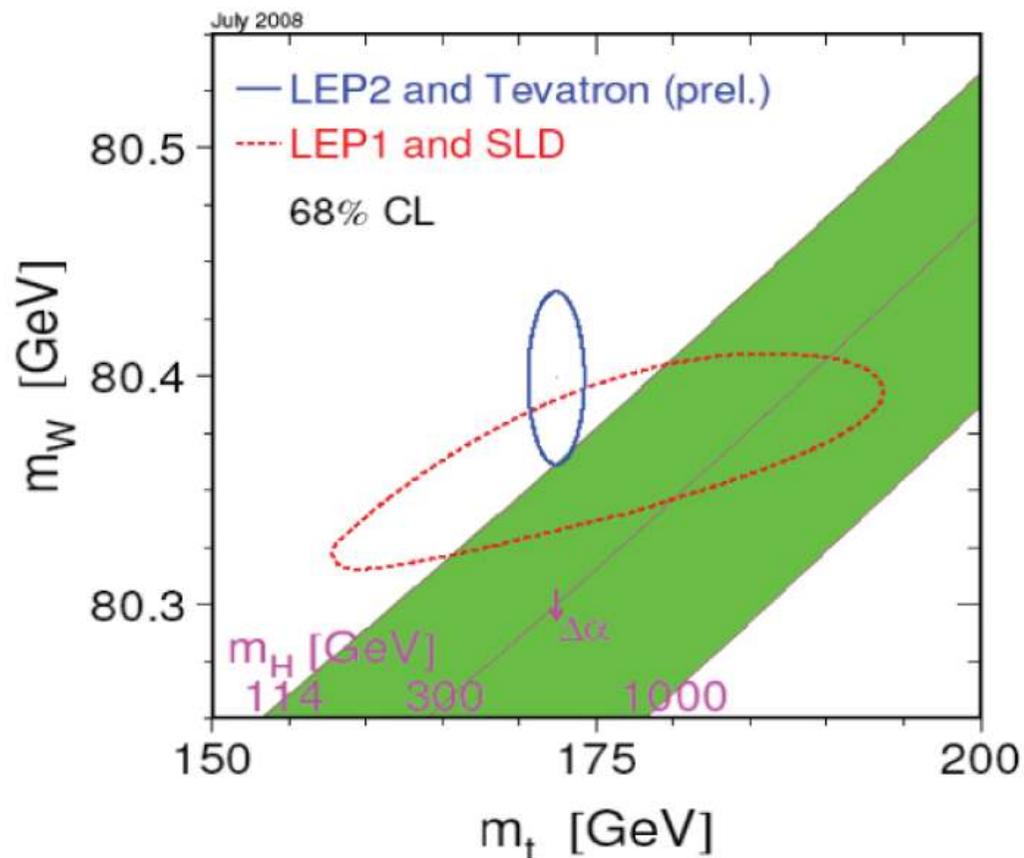
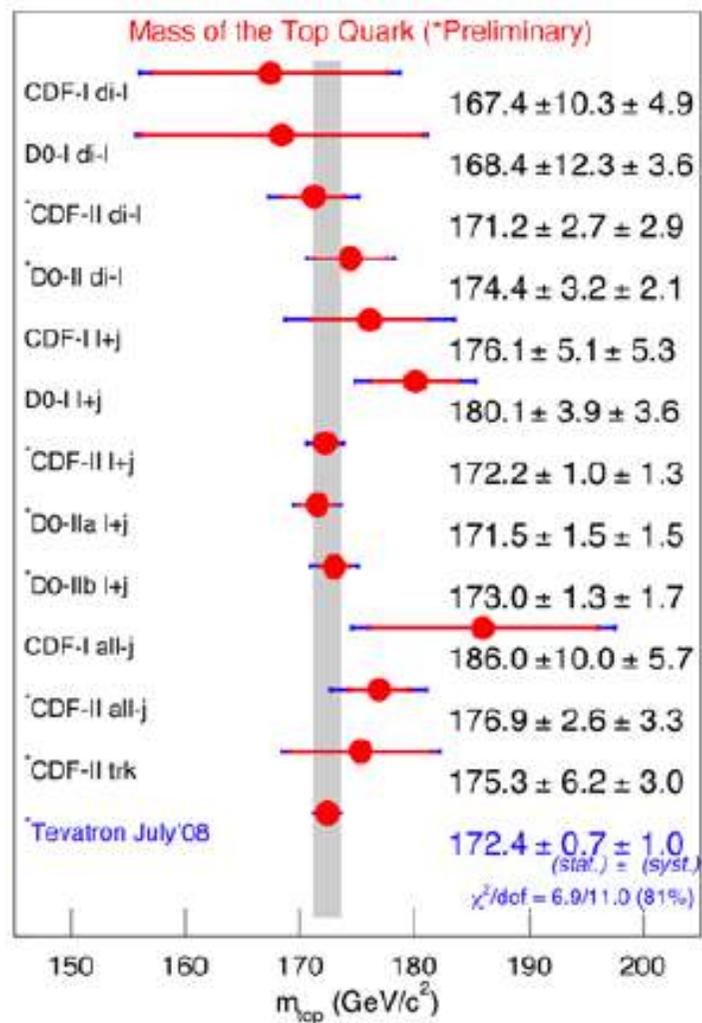
Misura di M_{top} & M_W

Misure precise da LEP200 & Tevatron

$$M_W = M_W^0 + C_1 M_{top}^2 + C_2 \ln(M_{Higgs}^2)$$



Misura di M_{top} & M_w



LHC: new energy frontier

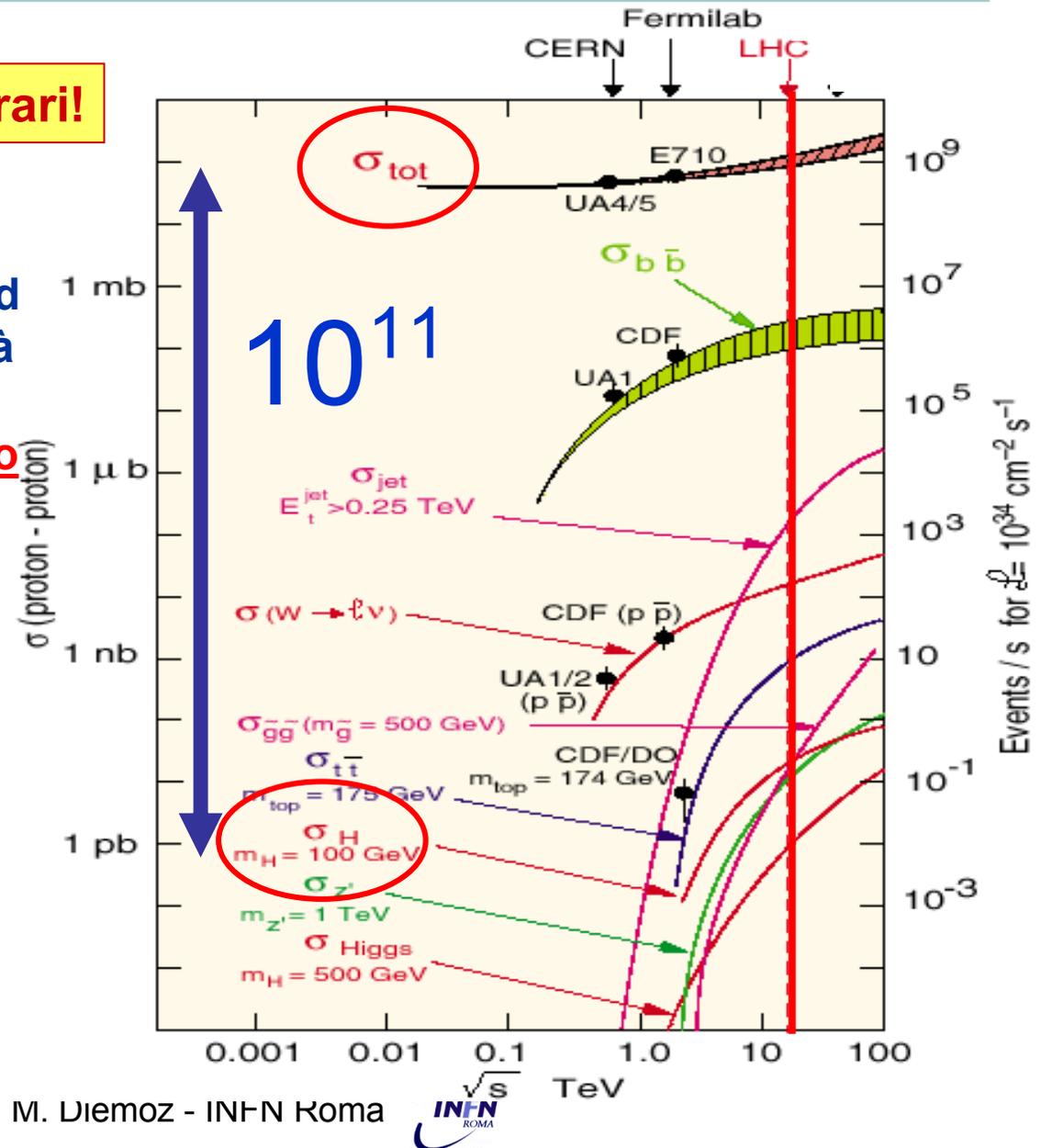
LHC alla caccia di segnali rari!

- A spanne:
un fattore 2 in s equivale ad
un fattore ~ 10 in luminosità

- Energia limitata dal raggio
dell'anello esistente

- LHC deve operare ad alta
luminosità:
luminosità finale di
disegno: $10^{34} \text{ cm}^{-2}\text{s}^{-1}$

- Alta frequenza eventi
- Grande fondo QCD

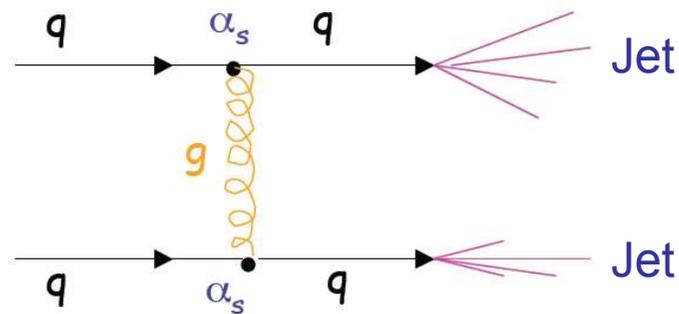


La luminosità

- La sezione d'urto dei processi interessanti (Higgs) sono assai piccole ($\sim \text{pb} = 10^{-36} \text{ cm}^2$)
- Se si vuole osservare un numero ragionevole di eventi in un anno ($1\text{y}=10^7 \text{ s}$) assumendo una qualche efficienza di rivelazione ($\varepsilon = 10\%$)

$$L = \frac{N_{obs} / \varepsilon}{t\sigma} = \frac{1000 / 0.1}{10^7 \text{ s } 10^{-36} \text{ cm}^2} = 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$$

Ma...



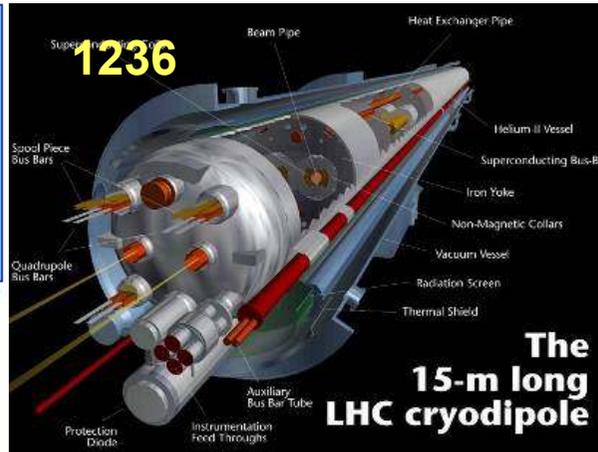
LHC è una “fabbrica”!

Frequenza di produzione di eventi a bassa luminosità $10^{34} \text{ cm}^{-2}\text{s}^{-1}$

Processo	σ	Eventi/s	Eventi/ anno	Altre macchine (Stat. totale)
QCD jets $p_T > 250 \text{ GeV}$	100 nb	100	10^9	10^7
$W \rightarrow e\nu$	15 nb	15	10^8	10^4 LEP/ 10^7 Tev.
$Z \rightarrow ee$	1.5 nb	1.5	10^7	10^7 LEP
$t\bar{t}$	800 pb	0.8	10^7	10^4 Tevatron
$b\bar{b}$	500 μb	10^5	10^{12}	10^8 Belle/BaBar
$\tilde{g}\tilde{g}$ (m=1 TeV)	1 pb	0.001	10^4	
H (m=0.8 TeV)	1 pb	0.001	10^4	

LHC @ CERN

7×10^{12} eV beam energy
 $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ luminosity
 2835 bunch/beam
 10^{11} protons/bunch



Magnetic Field

p (TeV) = 0.3 B(T) R(km)
 For $p=7$ TeV, $R=4.3$ km
 $\Rightarrow \mathbf{B} = 8.4 \text{ T}$

$$N_{ev} = \sigma_{ev} \int L$$

Measurement of:

- mass
- charge
- spin
- production cross section
- decay modes

“general-purpose” experiments covering as much of the solid angle as possible

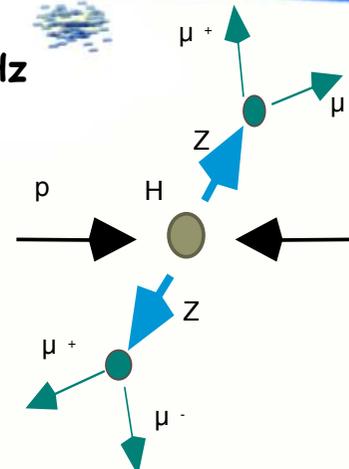
7.5 m (25 ns)

Beam crossing 10^7 Hz

Proton collisions 10^9 Hz

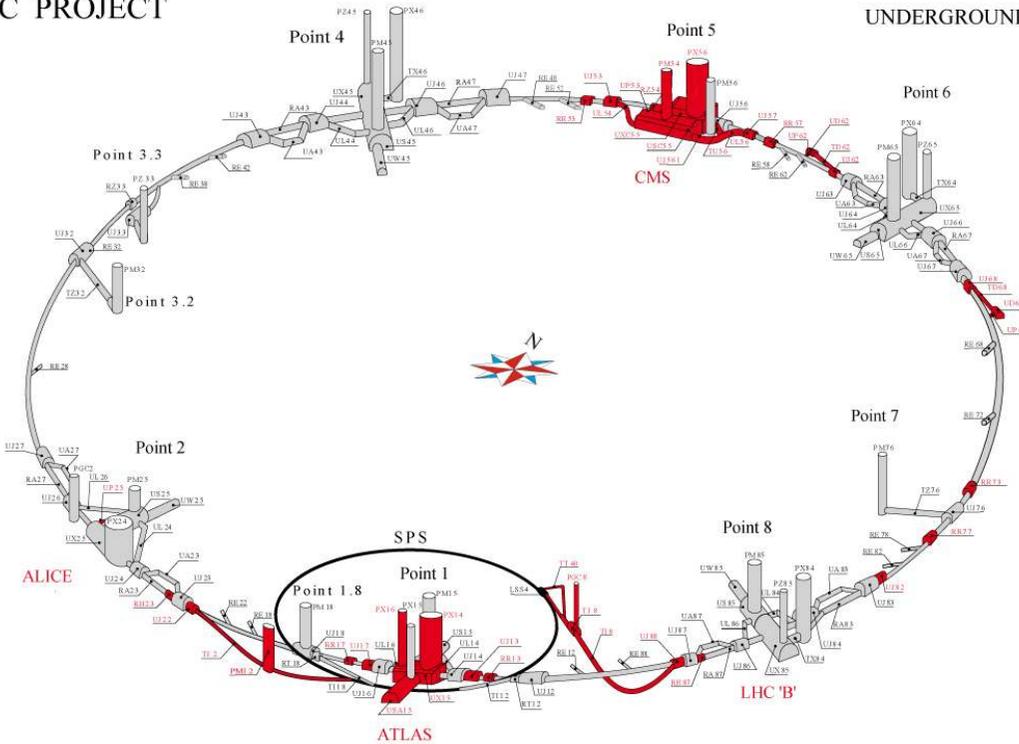
Parton collisions

New particle production 0.1 Hz
 Higgs, SUSY ...

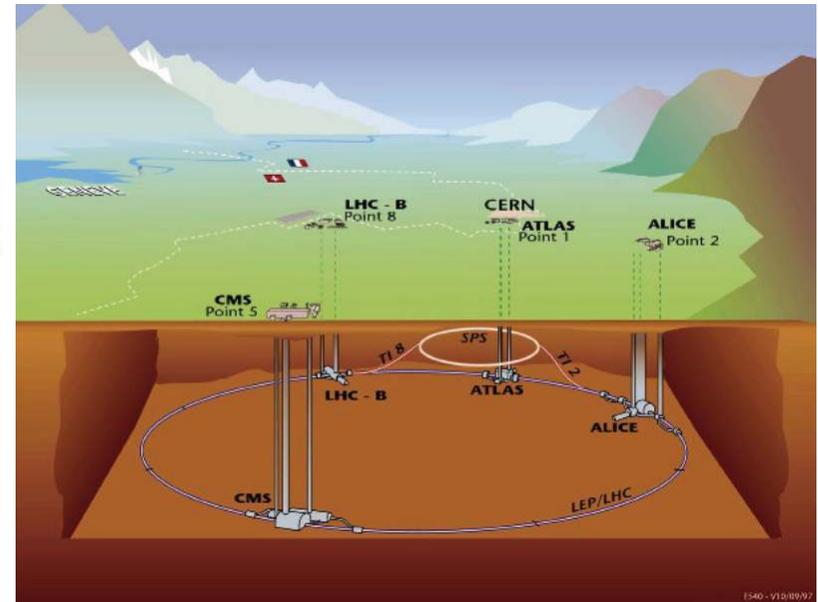


Gli Esperimenti "Generalisti" a LHC

LHC PROJECT



UNDERGROUND WORKS



Existing Structures
LHC Project Structures

ST-CE/JLB-hlm
18/04/2003

ATLAS A Toroidal LHC ApparatuS (general purpose)
CMS Compact Muon Solenoid (general purpose)

Alghero 02-06-09

M. Diemoz - INFN Roma



LHC EXPERIMENTAL CONDITIONS

Max Machine Luminosity $10^{34} \text{ cm}^{-2} \text{ s}^{-2}$

$\sigma_{\text{inel}} = 100 \text{ mb} \rightarrow 10^9 \text{ events/s}$

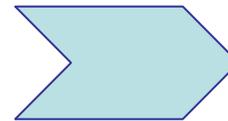
$\sigma_{\text{higgs}} = 1 \text{ pb} \rightarrow 10^{-2} \text{ events/s}$

1 crossing/25ns

20 events/crossing \rightarrow 1000 tracks

Neutrons: up to 10^{17} n/cm^2

Gammas: up to 10^7 Gy^*

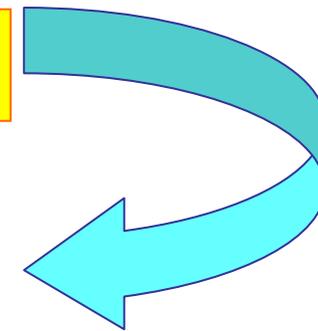


in 10 years

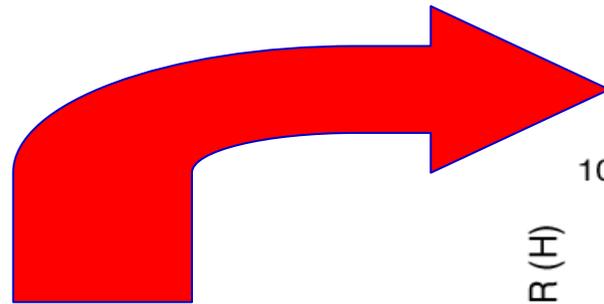
Life is not so easy!

Unprecedented conditions for detectors

- Granularity ($10^5 \div 10^7$ channels)
- Speed of response (25-50 ns)
- DAQ + trigger ($10^9 \rightarrow 10^2 \text{ ev/s}$)
- High radiation resistance

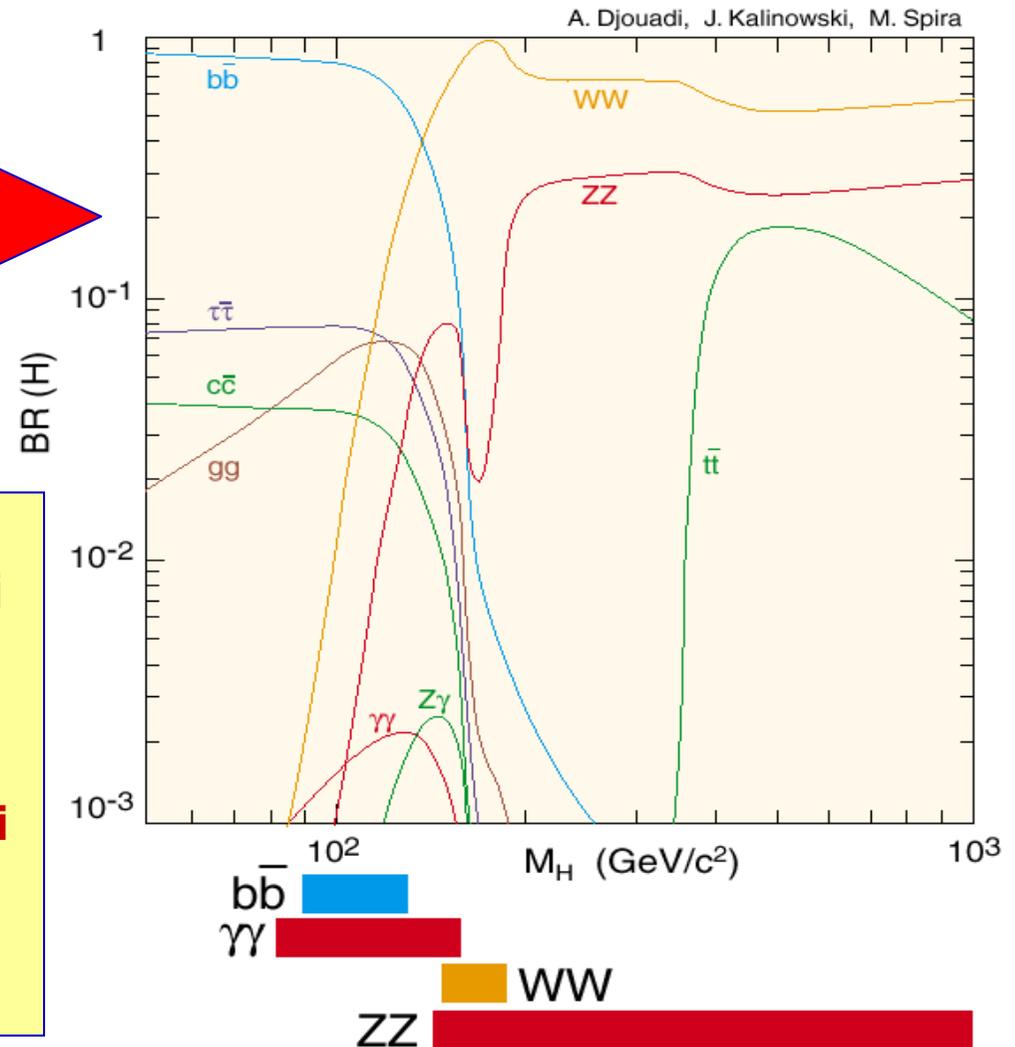


La particella guida: Bosone di Higgs



Gli stati finali completamente adronici dominano ma sono inutilizzabili a causa del fondo di QCD.

Cercare stati finali con leptoni e fotoni isolati (nonostante statisticamente sfavoriti)



Le abilità richieste ai rivelatori

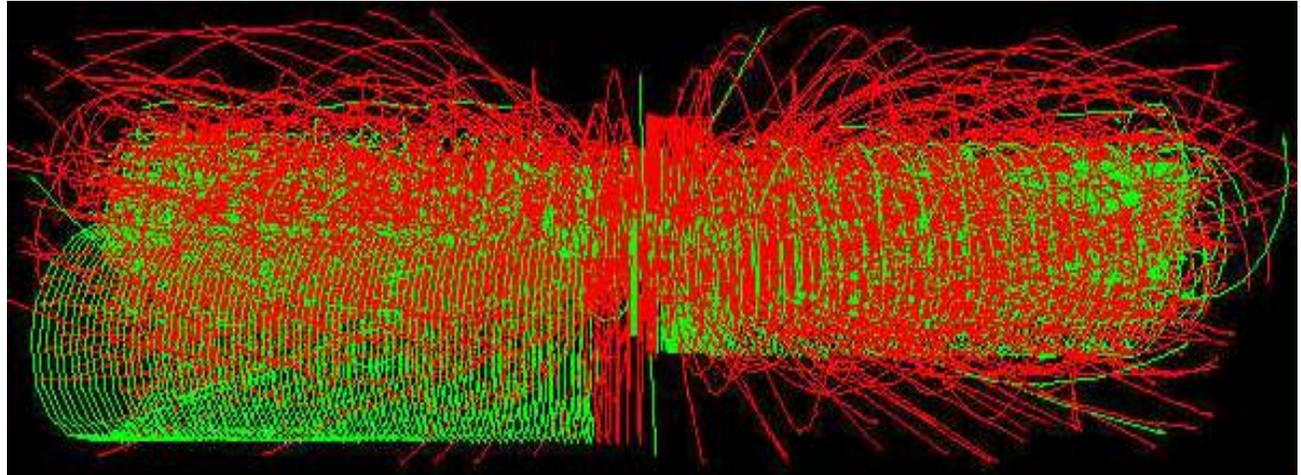
- **Buona risoluzione elettromagnetica ($|\eta| < 2.5$)**
 - $< 1\%$ sulla massa invariante di 2 elettroni a $100 \text{ GeV}/c^2$
 - Ricostruzione del vertice primario e/o misura direzione γ
 - Reiezione di π^0
- **Buona identificazione e risoluzione per mu ($|\eta| < 2.5$)**
 - $< 1\%$ sulla massa invariante di 2 muoni a $100 \text{ GeV}/c^2$
 - Riconoscimento della carica fino a $> 1 \text{ TeV}/c$
- **Buona risoluzione in energia mancante E_T^{miss} e massa invariante di sistemi a due jet**
 - Calorimetria adronica estesa fino a $|\eta| \sim 5$
 - Segmentazione laterale $\Delta\eta \times \Delta\phi < 0.1 \times 0.1$
- **Buona capacità di tracciatura nel rivelatore centrale**
 - B e τ tagging (rivelatori a pixel)

Collisioni pp at 14 TeV at $10^{34} \text{ cm}^{-2}\text{s}^{-1}$

20 min bias events
overlap +

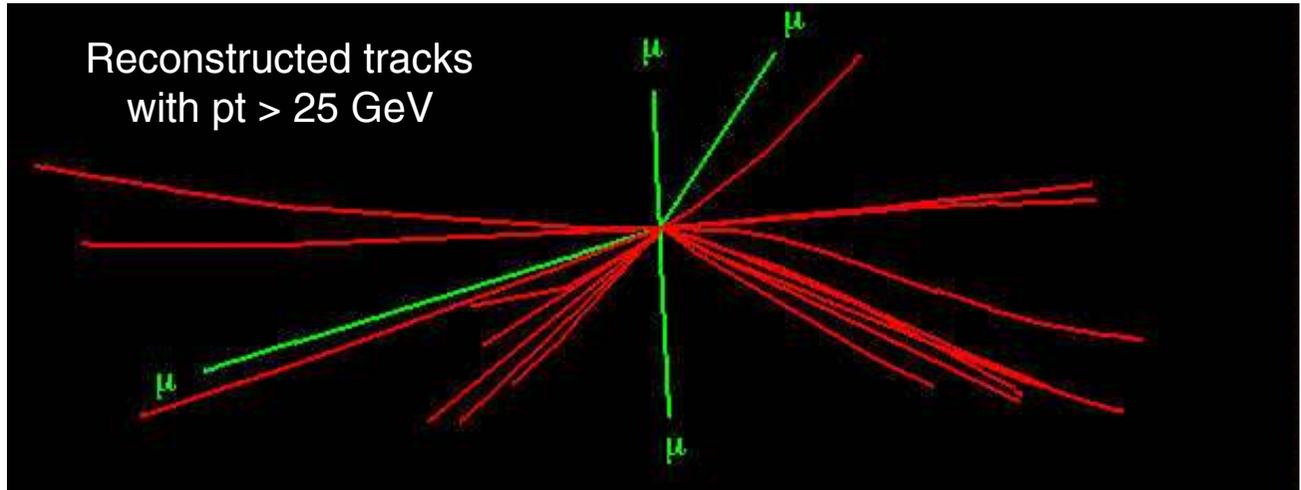
$H \rightarrow ZZ$

$Z \rightarrow \mu\mu$

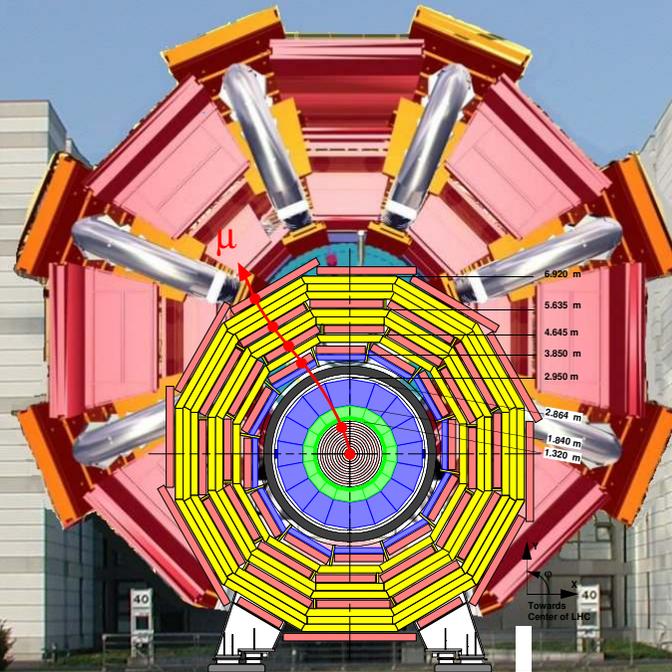


$H \rightarrow 4 \text{ muons}$:
the cleanest (“golden”)
signature

Reconstructed tracks
with $p_t > 25 \text{ GeV}$



5 floors building 40
at CERN

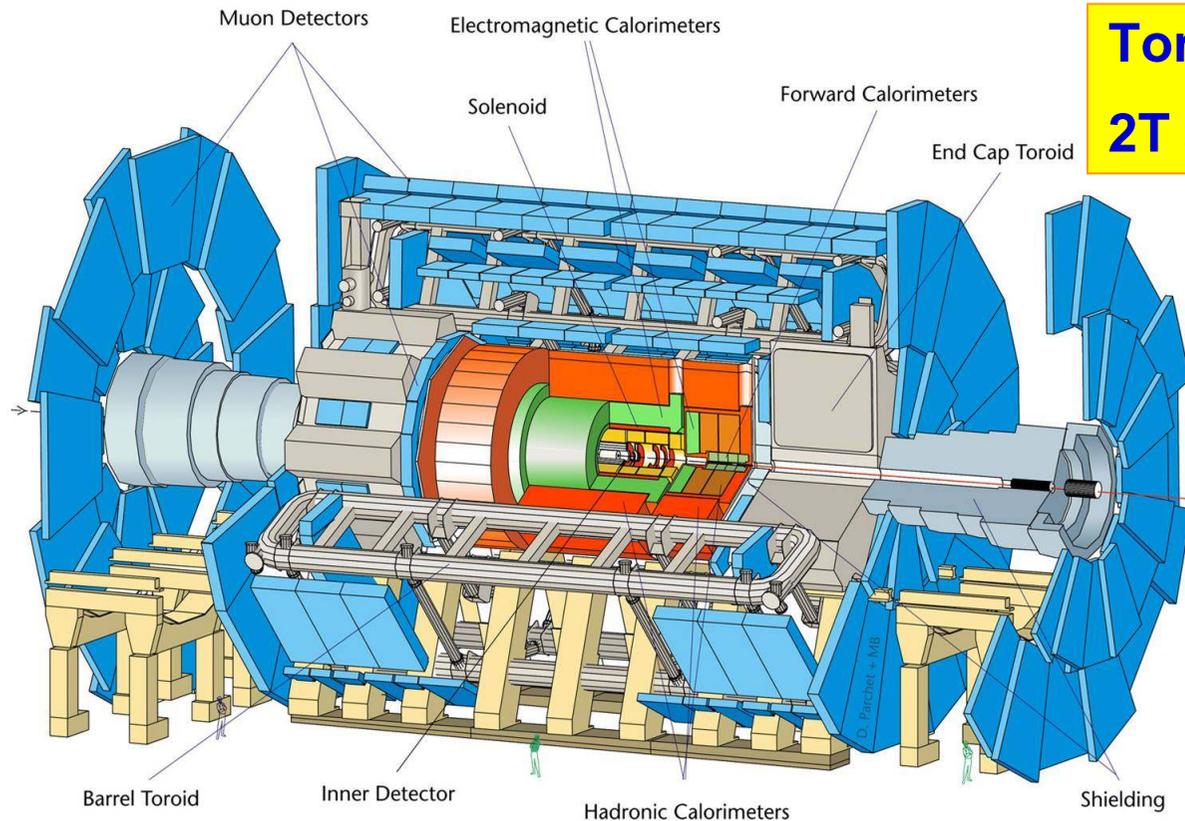


Transverse View

**ATLAS & CMS:
multipurpose detectors, same physics goals, different detection philosophy.
(ATLAS is the big one!)**

A Toroidal LHC Apparatus

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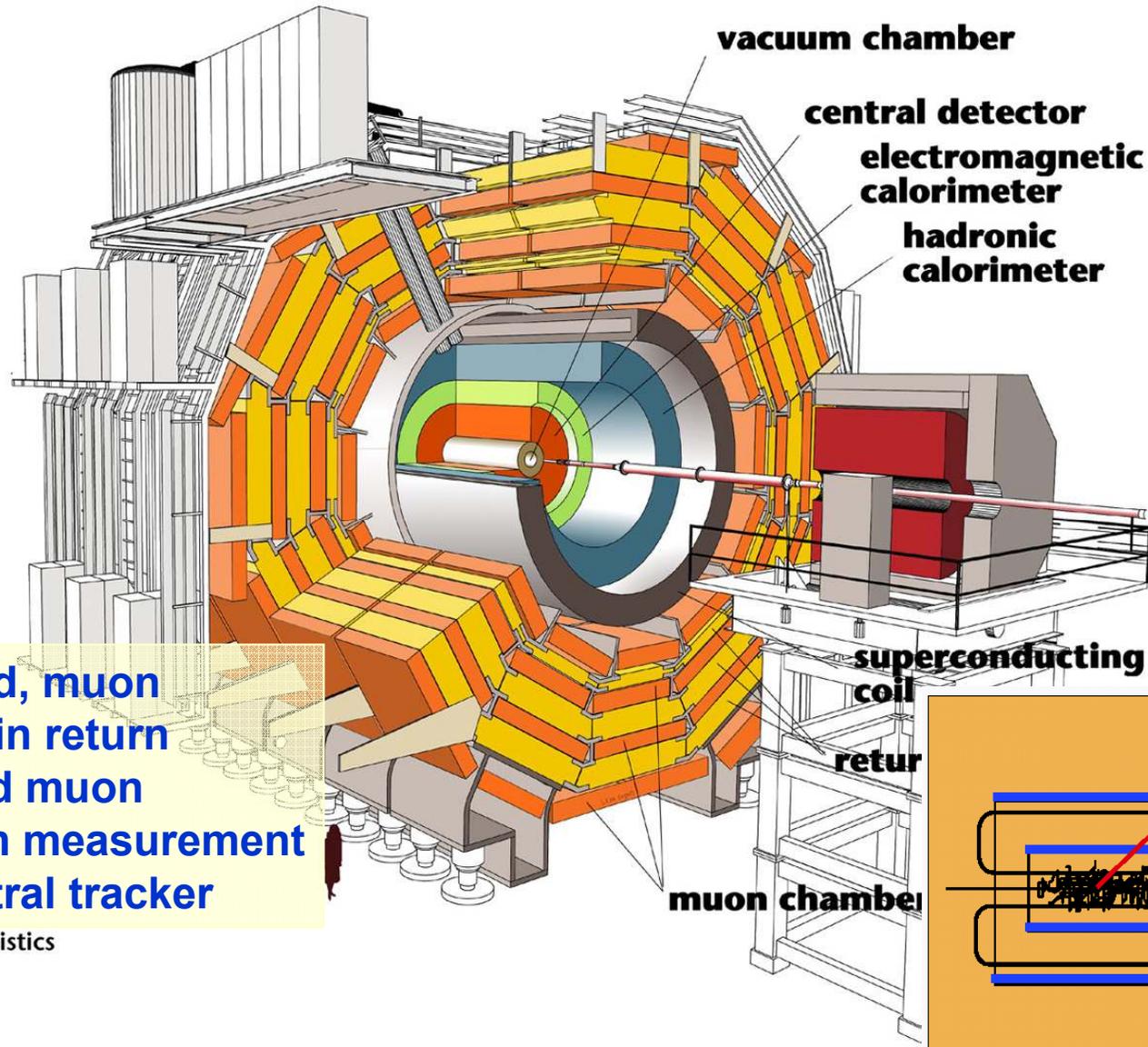
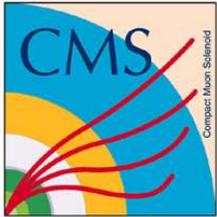


**Toroidal magnet $\langle B \rangle \sim 0.6\text{T}$ +
2T solenoid for inner TK**

**Toroidal magnet in air,
accurate standalone muon
momentum measurement
in muon chambers.
Needs solenoid for inner
tracking**

Diameter	25 m
Barrel toroid length	26 m
End-cap end-wall chamber span	46 m
Overall weight	7000 t

Compact Muon Solenoid



4T solenoid, muon chambers in return yoke. Good muon momentum measurement needs central tracker

Detector characteristics

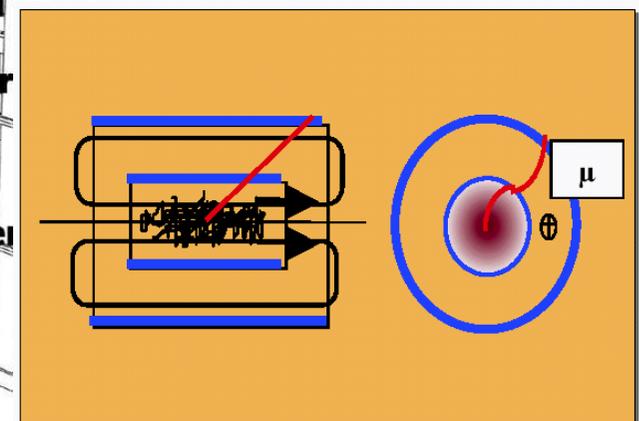
Width: 22m

Diameter: 15m

Weight: 14'500t

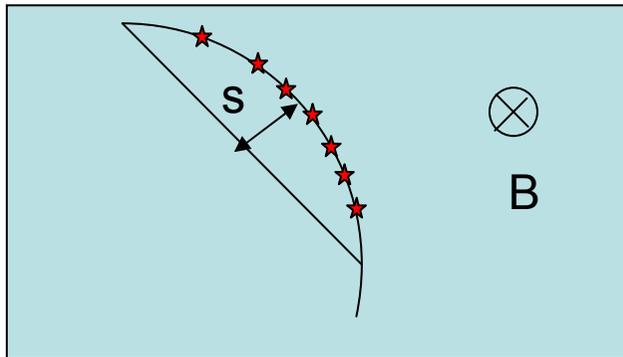
11/11/10 02-00-09

M. DIEMOZ - INFN ROMA



La Misura Chiave

- THE issue: measure momenta of charged particles (e.g. muons); so which measurement “architecture”?
- **Basic goal: measure 1 TeV muons with 10% resolution**
- Reminder: in a constant magnetic field B over trajectory length L , for N measurement points and spatial resolution σ per point



$$s \approx \frac{0.3BL^2}{8p_T}$$

$$\frac{\sigma(p_T)}{p_T} \approx \sqrt{\frac{720}{N+4}} \sigma \frac{p_T}{0.3BL^2}$$

– Need **high BL^2** and/or **small σ**

Choice of magnet: ATLAS

ATLAS: Toroidal magnet (polar angle bending)

$\langle B \rangle \sim 0.6\text{T}$ over 4.5 m \rightarrow $s=0.5\text{mm}$ \rightarrow need $\sigma < 50\mu\text{m}$

- With 8 coils, 2x2x30 turns: $I=20\text{kA}$ (superconducting), 1.5Gj
- Challenges: mechanics, spatial & alignment precision over large surface area

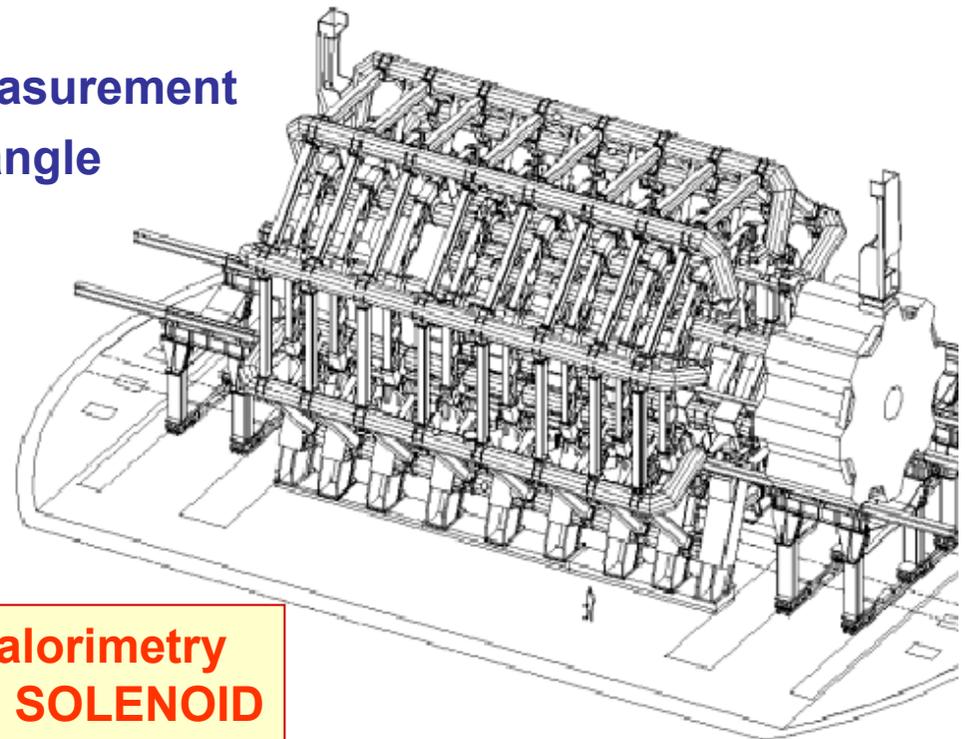
☺ Good stand-alone momentum measurement

☺ Resolution independent of polar angle

☹ does not benefit from small transverse beam spot (20 μm)

☹ need additional solenoid for internal track measurement

ATLAS: $B=2\text{T}$ solenoid



ATLAS Calorimetry
OUTSIDE SOLENOID

ATLAS – Barrel toroid



Coils in place waiting for the detectors!

Alghero 02-06-09

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Choice of magnet : CMS

CMS: SC Solenoid (azimuthal angle bending)

B=4T over 1.2m + 2T over 3m : Needs $\sigma=100\mu\text{m}$

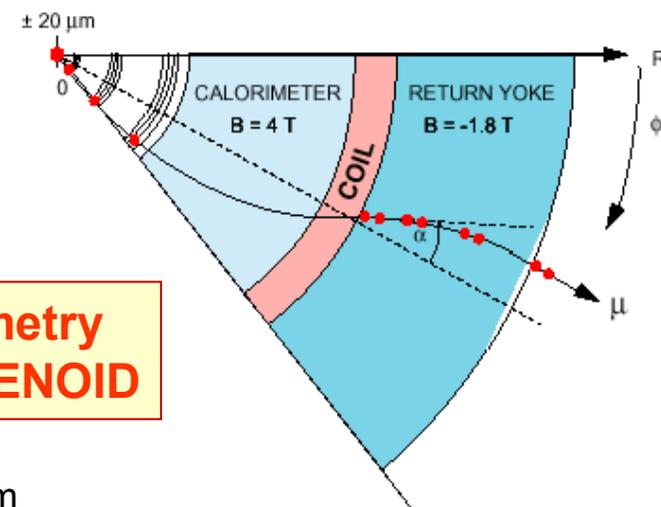
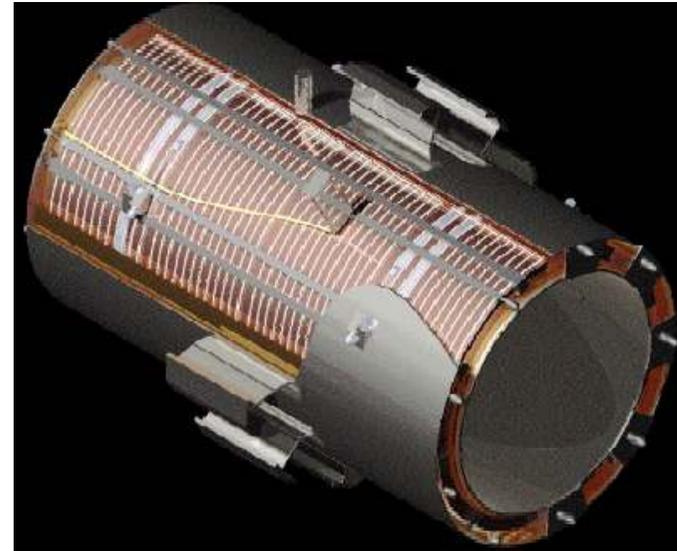
- I=20kA(SuperConducting), 2.4GJ
- Challenges: 4-layer winding to carry enough I, design of reinforced superC cable

☺ Uses $20\mu\text{m}$ beam spot redundancy

☺ Only one magnet

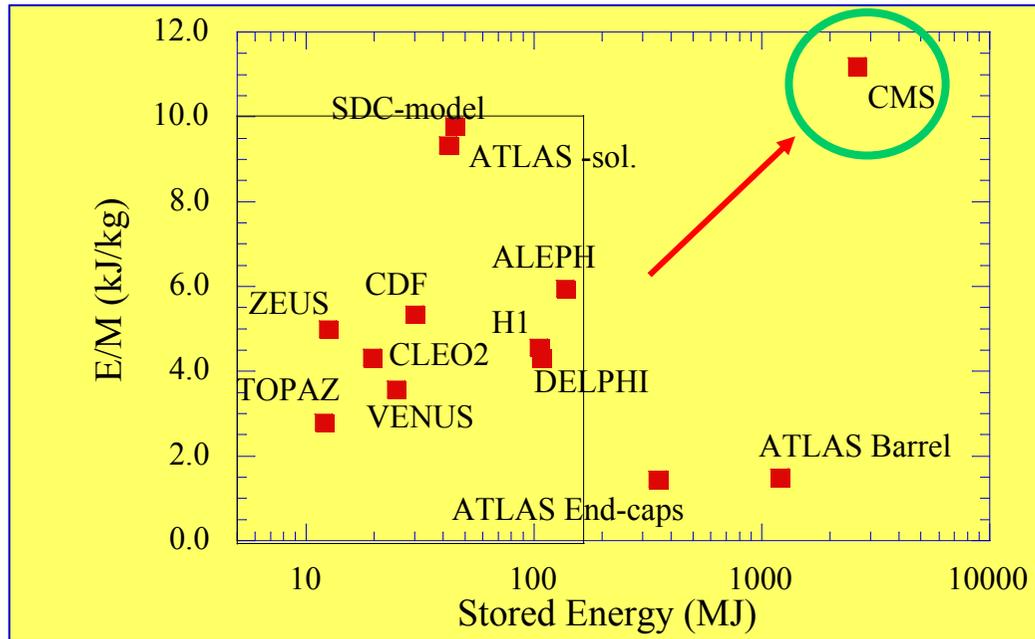
☹ Solenoid \rightarrow measures Pt
(and becomes worse in P as polar angle increases)

☹ Iron core \rightarrow dominated by multiple scattering; but excellent when combined with inner tracker



**CMS Calorimetry
INSIDE SOLENOID**

CMS – MAGNET SYSTEM



Solenoid composed by 5 modules
(CB-2, CB-1, CB0, CB+1, CB+2)



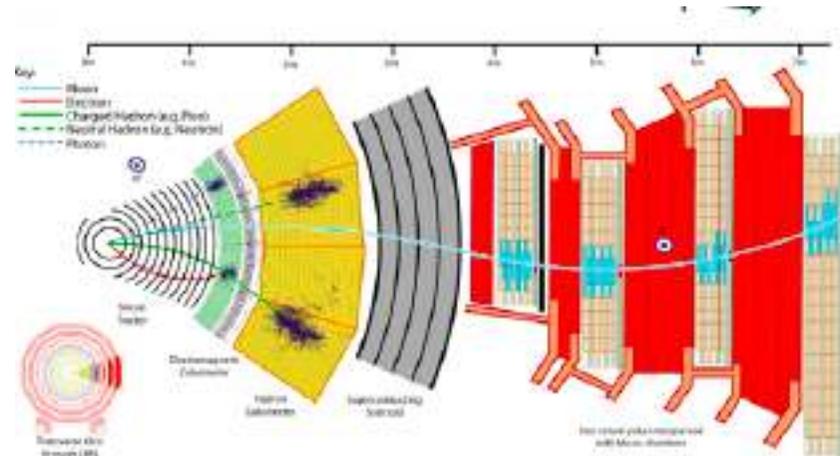
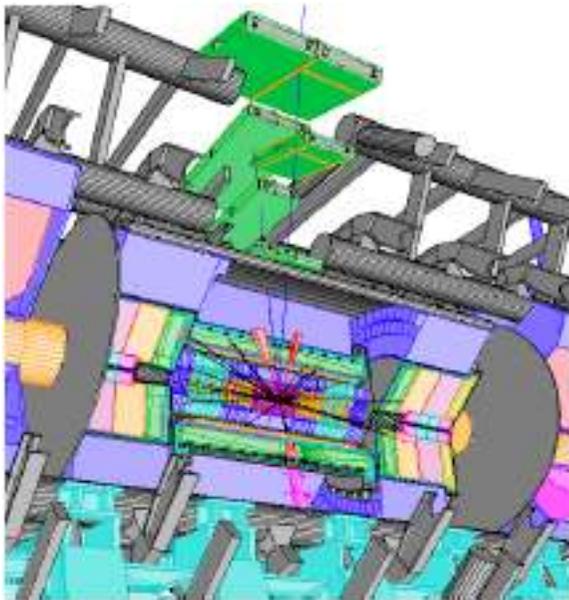
Sistemi Magnetici

TABLE 3 Main parameters of the CMS and ATLAS magnet systems

Parameter	CMS		ATLAS	
	Solenoid	Solenoid	Barrel toroid	End-cap toroids
Inner diameter	5.9 m	2.4 m	9.4 m	1.7 m
Outer diameter	6.5 m	2.6 m	20.1 m	10.7 m
Axial length	12.9 m	5.3 m	25.3 m	5.0 m
Number of coils	1	1	8	8
Number of turns per coil	2168	1173	120	116
Conductor size (mm ²)	64 × 22	30 × 4.25	57 × 12	41 × 12
Current	19.5 kA	7.7 kA	20.5 kA	20.0 kA
Stored energy	2700 MJ	38 MJ	1080 MJ	206 MJ

Detectors for ATLAS & CMS

The choice of the magnets influences the rest of detectors design, in particular CMS (should be compact...) made a challenging choice on electromagnetic calorimetry and tracking.



Densità di Tracce



Sistemi per Muoni

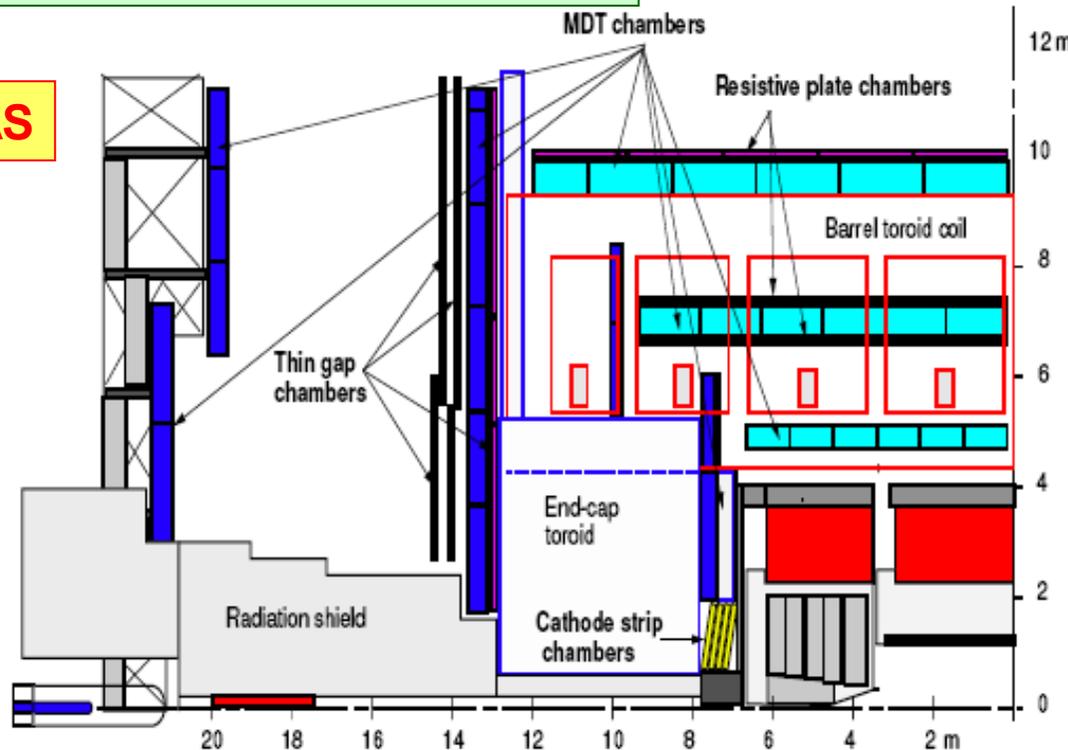
The muon chambers are installed at $r > 4$ m and are shielded by the calorimeters. Here the pileup is not an issue and the constraint on the response time is relaxed. Gas detectors can be used to cover the large surfaces needed for muon detection.

While these detectors integrates many bunch crossings they must be capable to identify the bunch crossing of each particle that they track.

Sistemi per Muoni

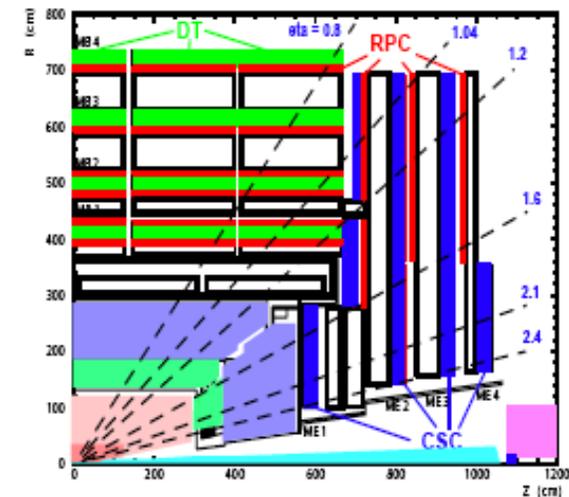
1170 MDTs 32 CSCs 1112 RPCs 1584 TGCs

ATLAS



CMS

250 DTs 468 CSCs 912 RPCs



The layouts of ATLAS and CMS are shown in figure 1. The most notable difference between the two detectors is the total volume, which is determined by the strategy to measure muon momenta. ATLAS has chosen a stand-alone system based on three superconducting toroid magnets and a set of very large and precise chambers the alignment of which is constantly monitored with optical devices [12]. CMS identifies and tracks muons in the iron of the yoke of a 4 Tesla, large bore magnet providing a coarse measurement of the sagitta, which is eventually refined by the association to the track measurement in the inner detector [13].

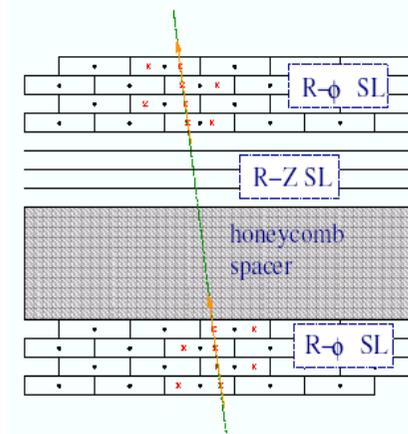
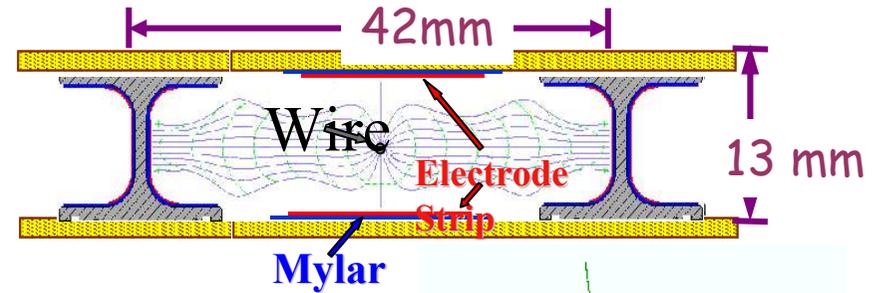
Muon Tracking Systems

TABLE 11 Main parameters of the ATLAS and CMS muon chambers

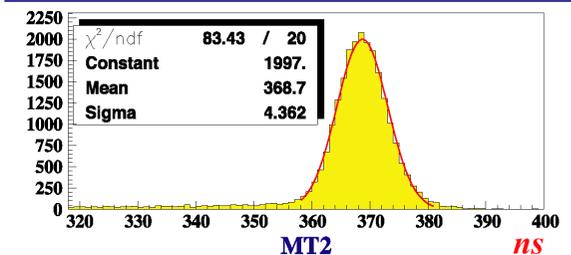
	ATLAS	CMS	
Drift Tubes	MDTs	DTs	
-Coverage	$ \eta < 2.0$	$ \eta < 1.2$	
-Number of chambers	1170	250	
-Number of channels	354,000	172,000	
-Function	Precision measurement	Precision measurement	triggering
Cathode Strip Chambers			
-Coverage	$2.0 < \eta < 2.7$	$1.2 < \eta < 2.4$	
-Number of chambers	32	468	
-Number of channels	31,000	500,000	
-Function	Precision measurement	Precision measurement	triggering
Resistive Plate Chambers			
-Coverage	$ \eta < 1.05$	$ \eta < 2.1$	
-Number of chambers	1112	912	
-Number of channels	374,000	160,000	
-Function	Triggering, second coordinate	Triggering	
Thin Gap Chambers			
-Coverage	$1.05 < \eta < 2.4$		—
-Number of chambers	1578		—
-Number of channels	322,000		—
-Function	Triggering, second coordinate		—

Algr

DT di CMS



Risoluzione spaziale:
Singola cella ~ 200 μm
Camera ~ 100 μm



Alghero C

MDT di ATLAS



End-cap MDT chamber

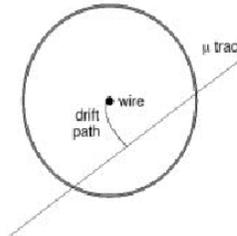


Figure 5-2 Drift tube operation in a magnetic field with curved drift path.

$\phi_{\text{wire}} = 50\mu\text{m}$ (W-Re)
 3 bar, 3270V,
 $t_d = 500\text{ns}$
 Gas gain = $2 \cdot 10^4$

Measured Spatial Resolution

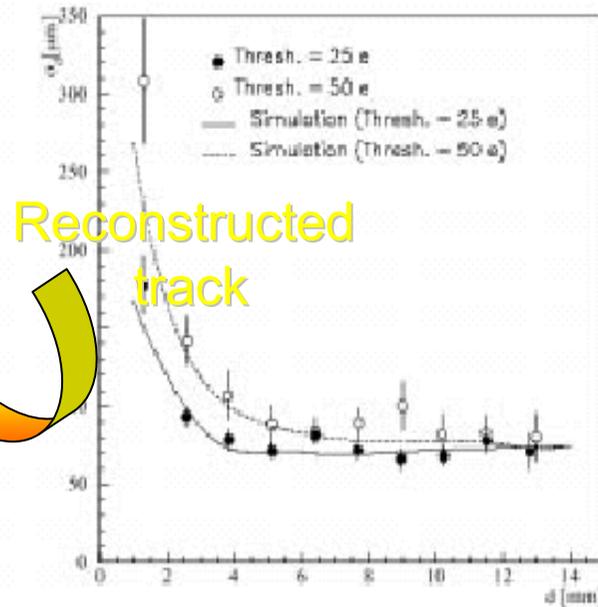
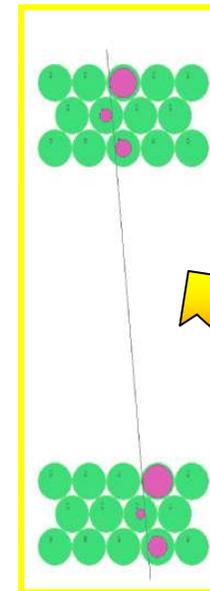
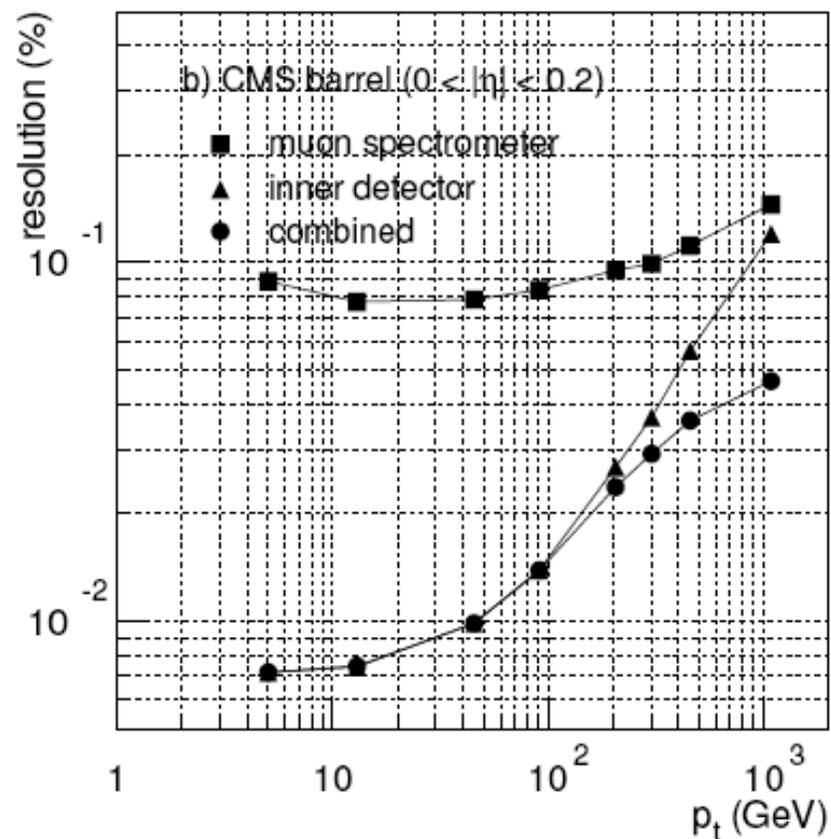
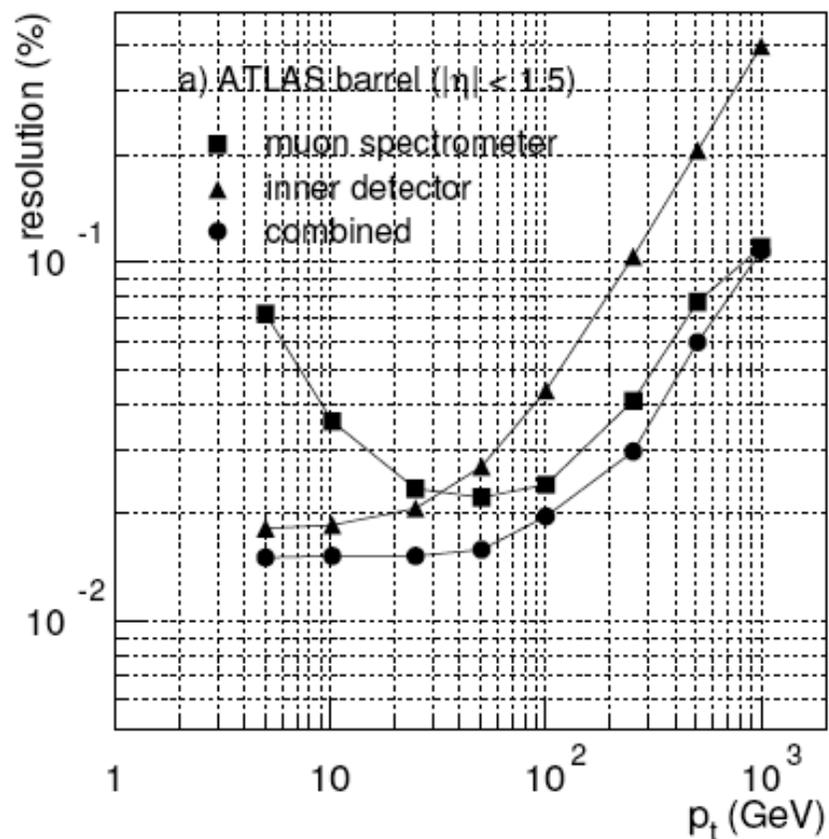
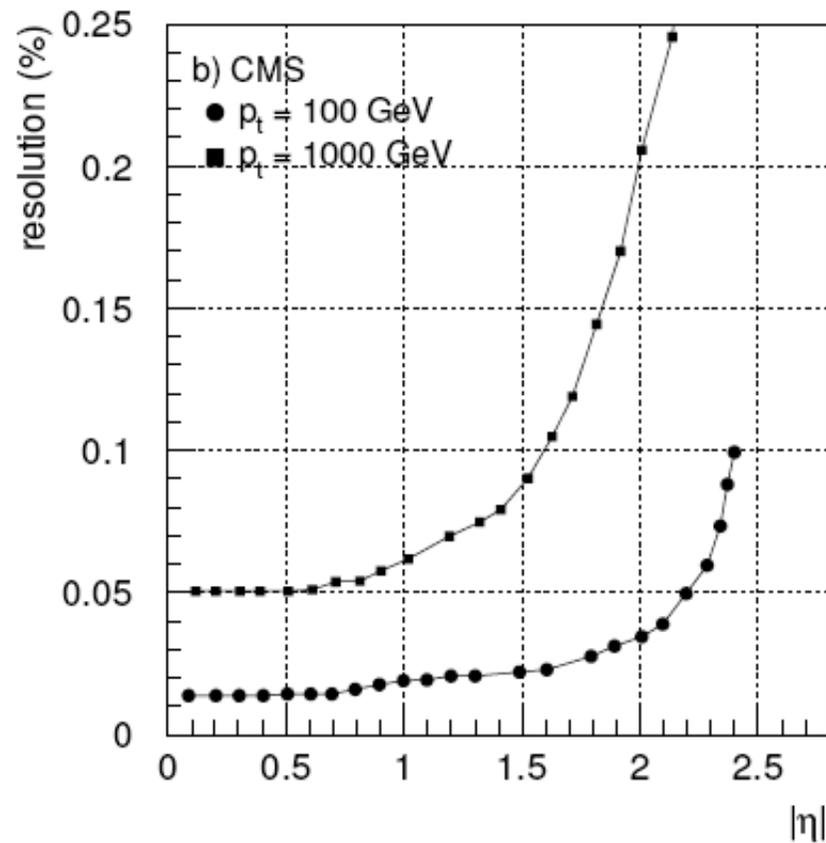
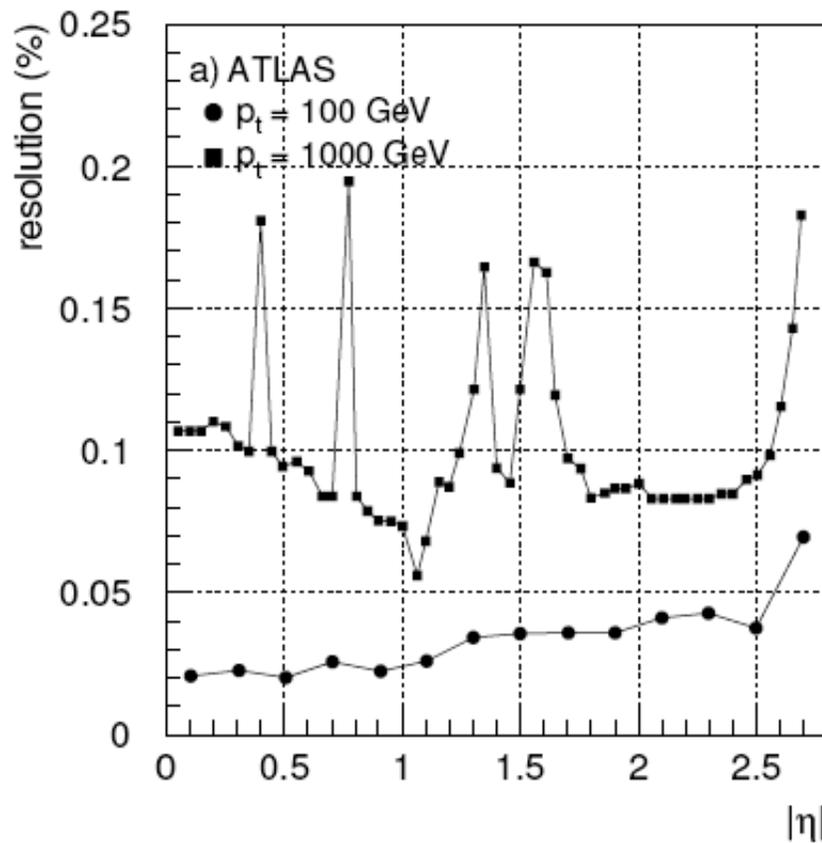


Figure 5-4 MDT resolution as a function of the drift distance, for an Ar/N₂/CH₄ (91/4/5 mixture). The curves correspond to two discriminator threshold settings.

Risoluzione in momento



Risoluzione in angolo



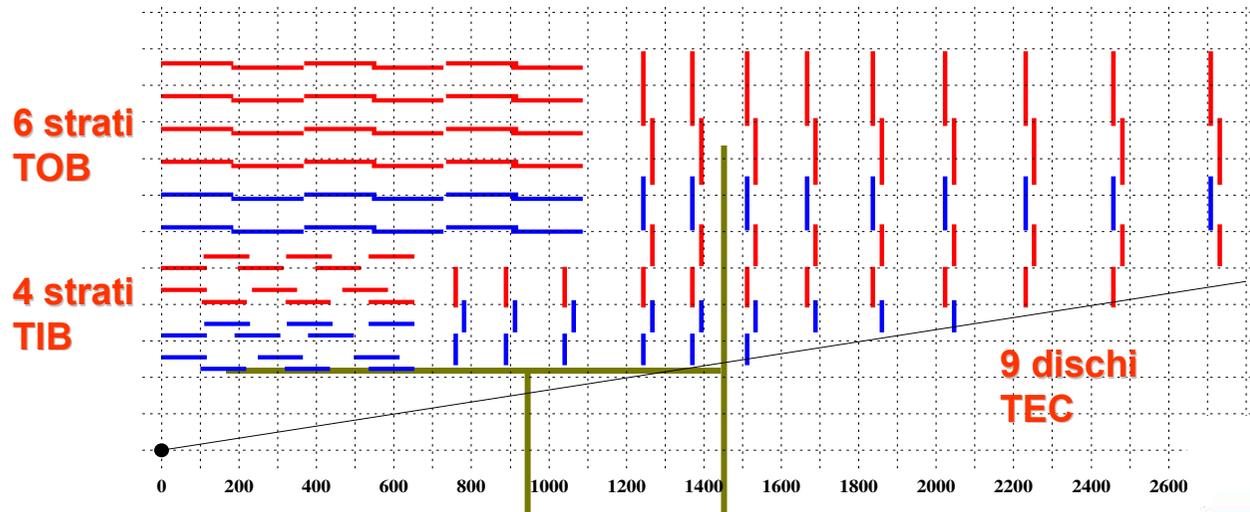
Tracciatori Interni

- ATLAS and CMS have chosen different options
 - CMS: 10-14 points, but extremely precise ($< 30 \mu\text{m}$) in $R\phi$ and low occupancy measurements (all silicon)
 - ATLAS: fewer (4) “clean” points at small radius ($< 50 \text{ cm}$), followed by ~ 40 points with smaller precision ($50 \mu\text{m}$) and larger occupancy (TRT straw tubes)
- Both have 3 layers of pixels between 4cm and $\sim 25 \text{ cm}$
- Silicon ST and pixels must be run at low Temperature (-10°C) to avoid long term deterioration by radiation.
 - This induces large material budget (cooling pipes and ledges)

CMS: Tracciatore tutto Silicio

- Pochi strati di misura molto precisi e puliti.
 - 2-3 Strati a Pixel di Silicio & 10-14 Strati di misura a Strisce di Silicio

Raggio ~ 110cm, Lunghezza ~ 270cm



Strisce: 10.6 milioni di canali di lettura
Pixel: 65 milioni di canali di lettura

Strip size

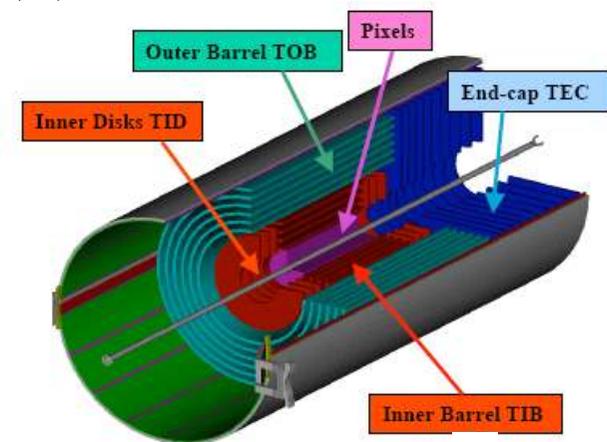
Strip length: 10cm (inner layers) to 20cm (outer layers).
Pitch: 80mm (inner layers) to 200mm (outer layers)

210 m² di Strisce Si
(Precedenti esperimenti 1m²)

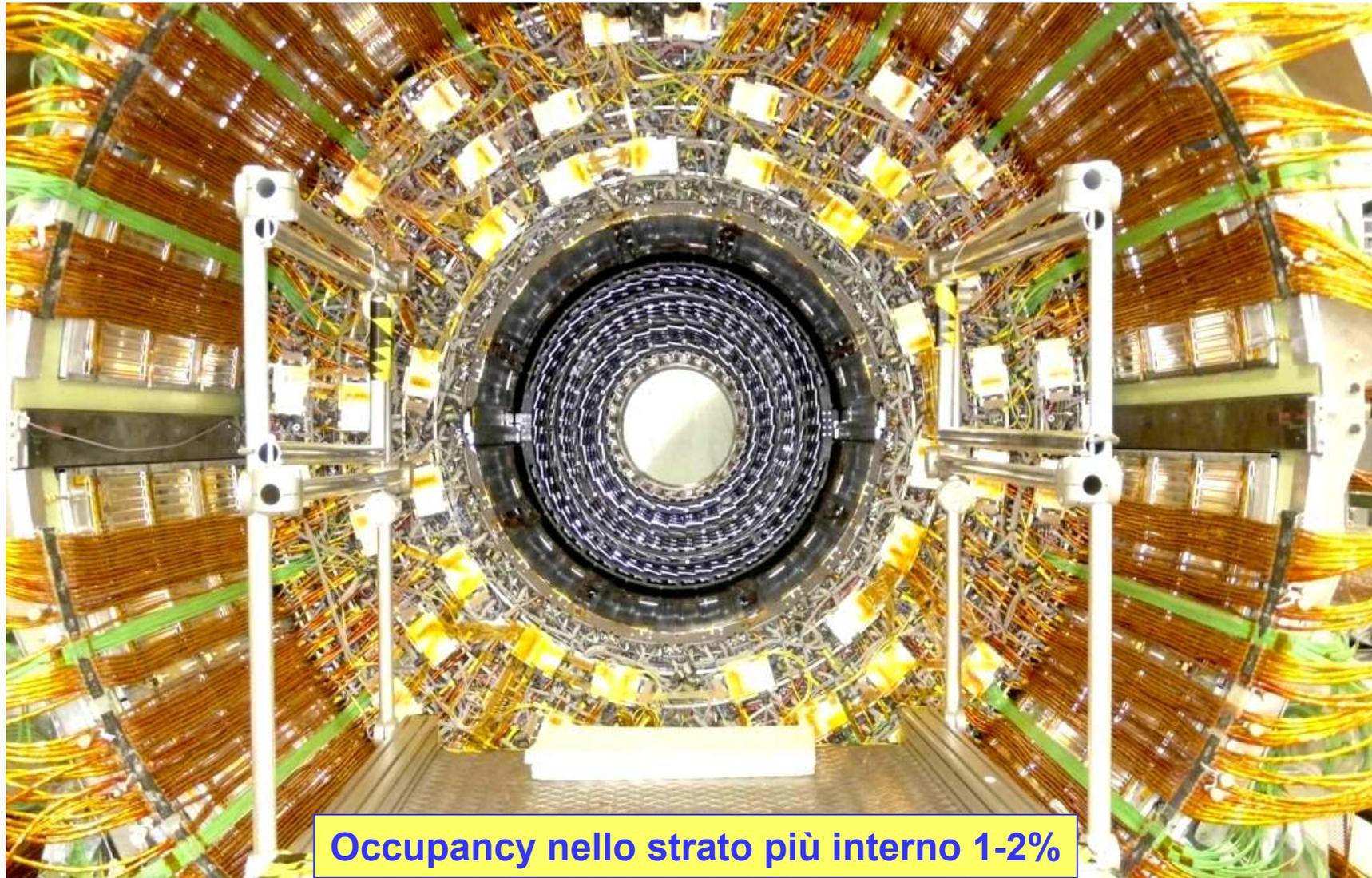
R-phi (Z-phi) only
measurement layers

R-phi (Z-phi) & Stereo
measurement layers

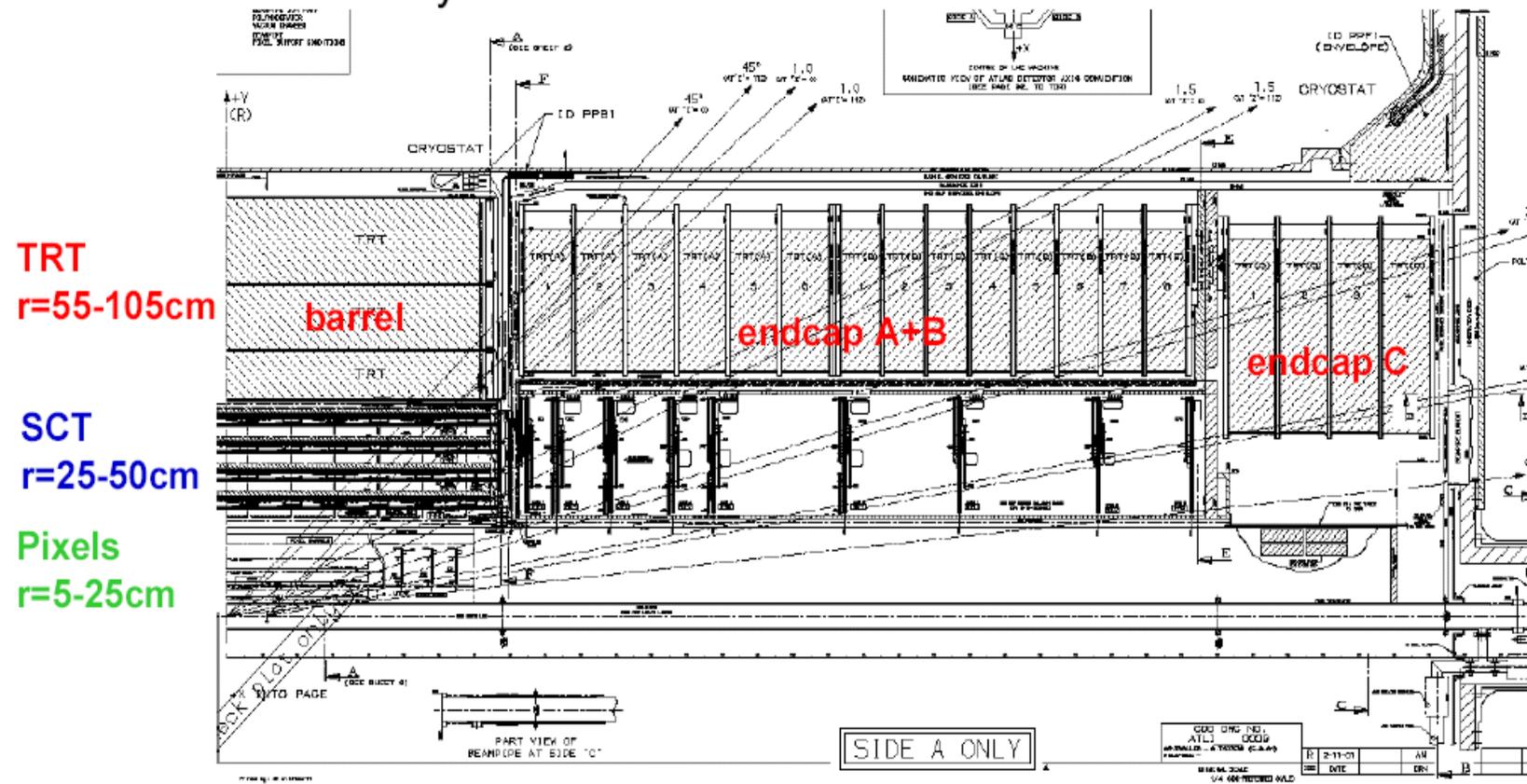
$\eta \sim 2.4$



Tracciatore di CMS



ATLAS Tracciatore Misto



Occupancy nel TRT varia tra 13% e 38%

Tracciatore di ATLAS



Alghero 02-06-09

M. Diemoz - INFN Roma



Performance

Since the trackers are massive, at low momenta the resolution is limited by multiple scattering

$$\frac{\delta p_t}{p_t} \approx \frac{1}{0.3B} \frac{0.0136}{\beta} \sqrt{\frac{1.3}{X_0 L}}$$

$$\delta p/p = 0.0136 * \text{sqrt}(0.4*1.3) / 0.3 / 4 = 0.8 \% \text{ (CMS)}$$

And a factor two larger in ATLAS because $BL(\text{ATLAS}) = 1/2 BL(\text{CMS})$

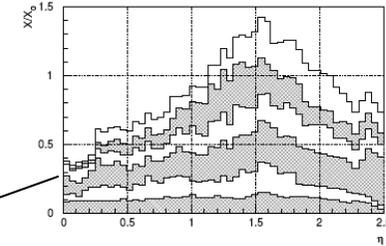
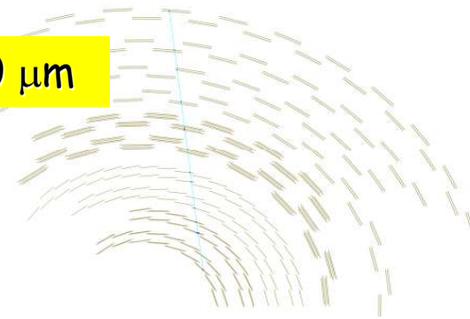


Figure 5. Typical distribution of the material in the central tracker as a function of η ; the different curves show the contributions of the different functional parts of the system. Bottom to top: active sensors, front-end electronics, support structures, cooling system, cables, other structures.

$$\frac{\Delta p}{p} \approx (0.8 \oplus 0.015 \cdot p(\text{GeV}))\%$$

CMS

$$\sigma(s) = 20 \mu\text{m}$$



$$\frac{\Delta p}{p} \approx (1.6 \oplus 0.034 \cdot p(\text{GeV}))\%$$

ATLAS

In entrambi i casi il
Multiplo scattering
domina per $p_t < 50 \text{ GeV}$

PIXEL: B - Tagging

- Pixel detectors
 - Both ATLAS and CMS
 - Very close to beam pipe (first point at 4cm)
 - Small pixel size ($150\mu\text{m}$).
Occupancy: 10^{-4} . Resolution: $\sim 20\mu\text{m}$.
- Pixels are essential for HLT and Pattern Recognition



Risoluzione sul parametro d'impatto

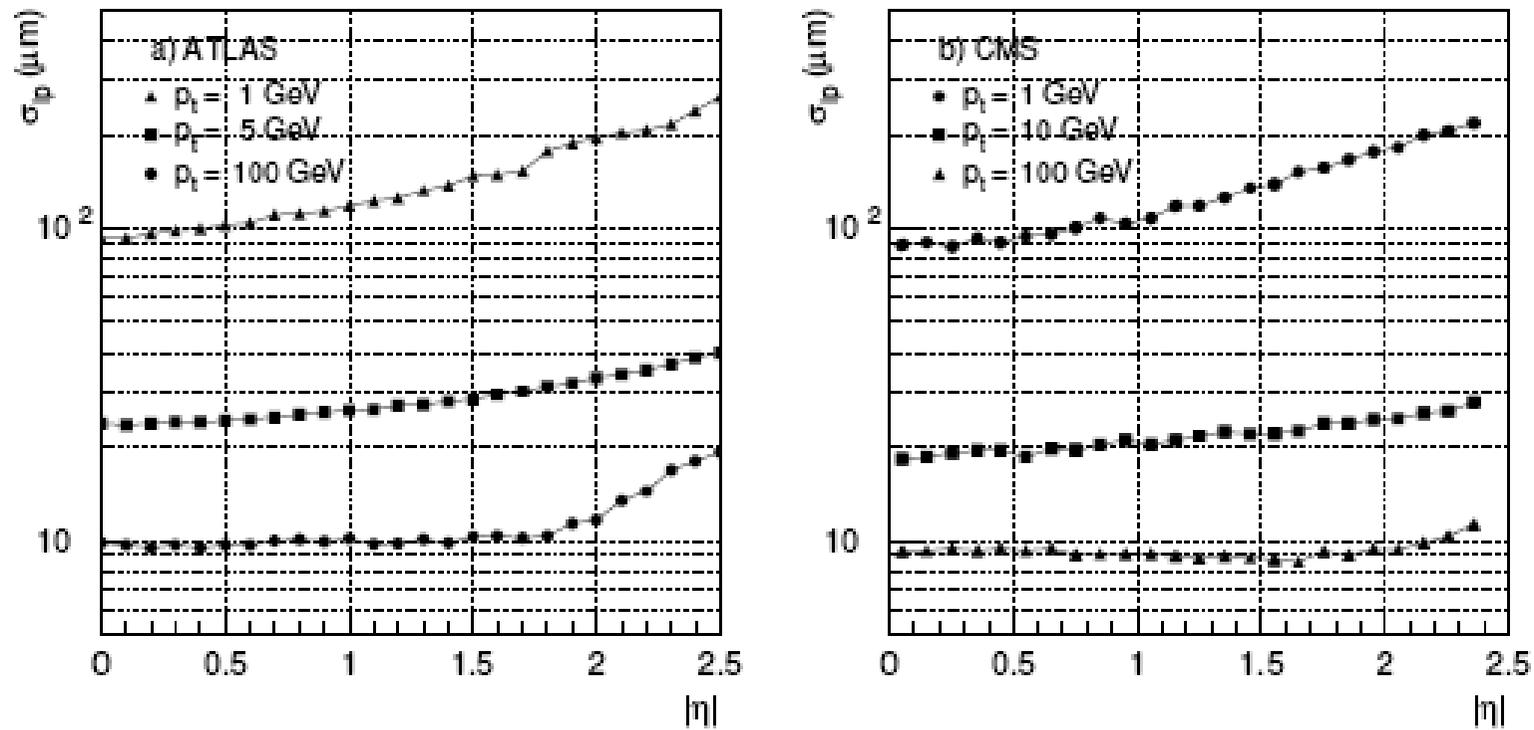
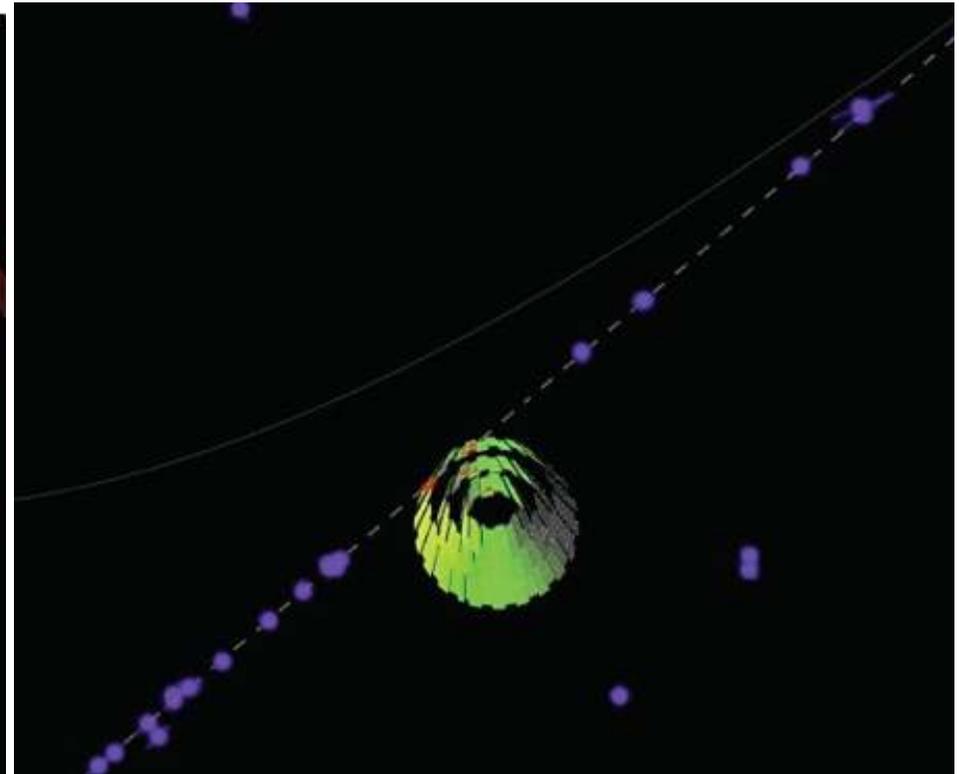
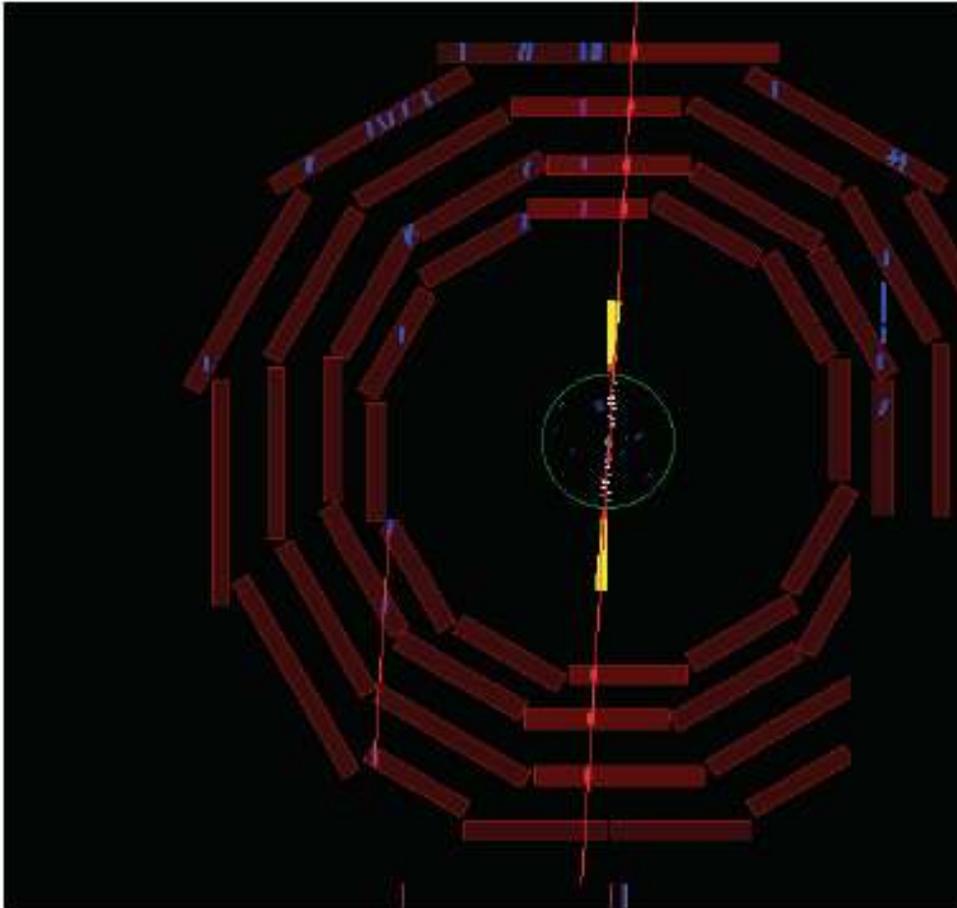


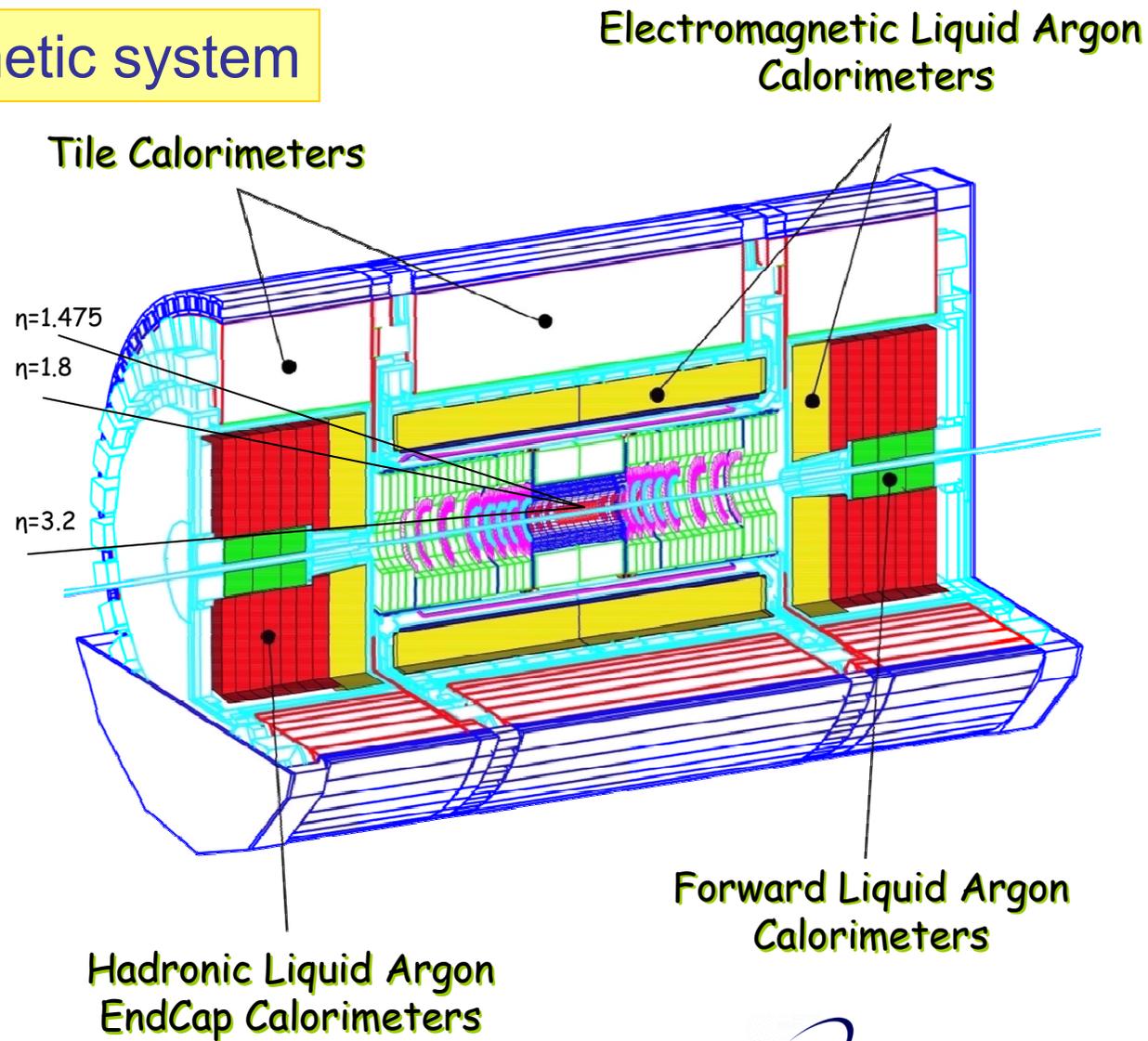
Figure 6. Impact parameter resolution of the ATLAS [2, 24] and CMS [3] detector as function of η for different values of the transverse momentum

Un evento vero (mu cosmici)!

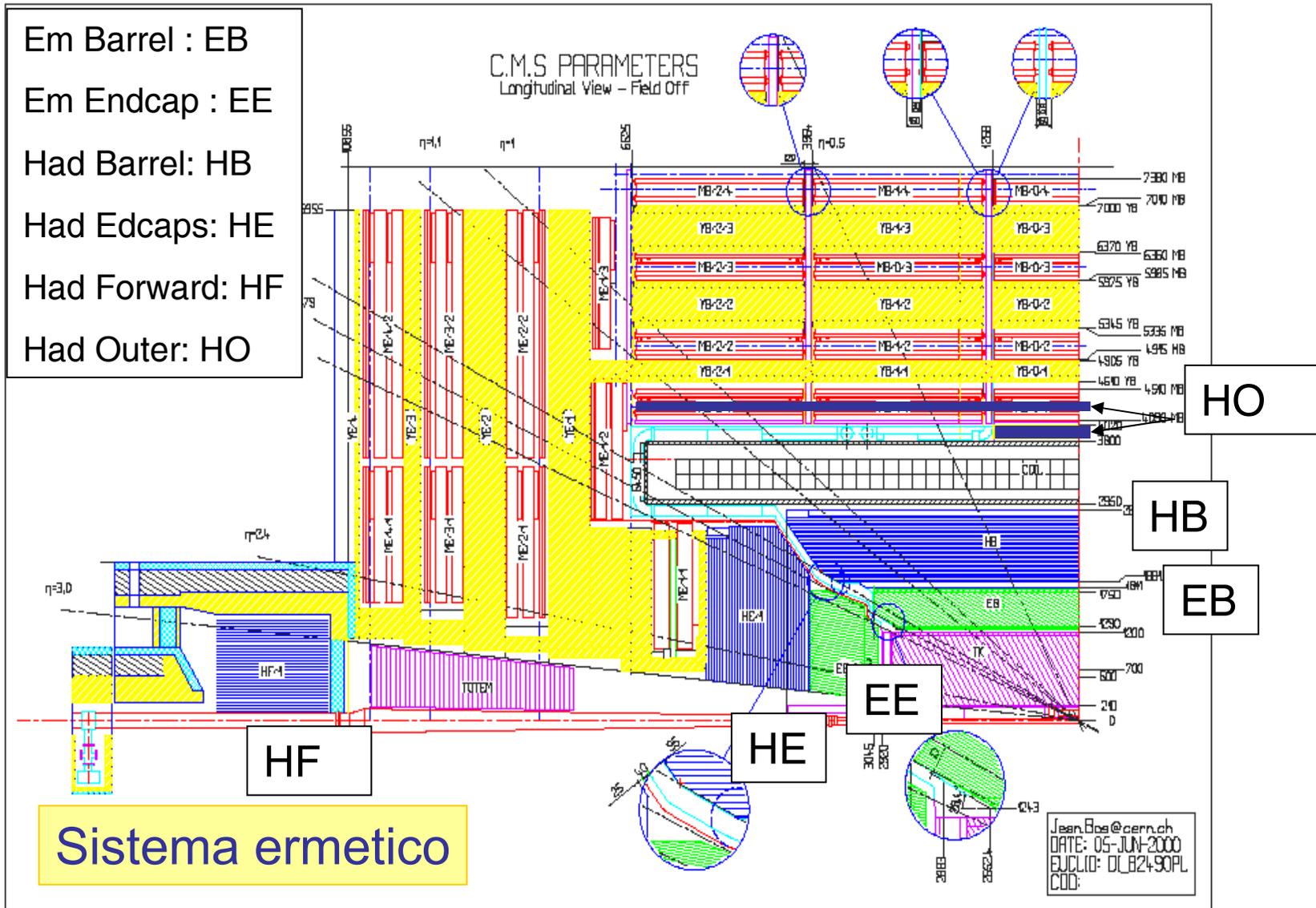


Calorimetri @ ATLAS

Hermetic system



Calorimetri @ CMS



ATLAS & CMS EM calorimetry

- Compact
- **Excellent energy resolution**
- Fast
- High granularity
- Radiation resistance
- E range MIP → TeV

• **Homogeneous calorimeter made of 75000 PbWO₄ scintillating crystals + PS FW**

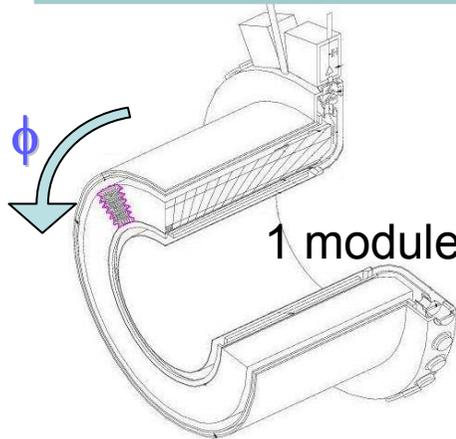
- Good energy resolution
 - Fast
 - High granularity
 - **Longitudinally segmented**
 - Radiation resistance
 - E range MIP → TeV
- **Sampling LAr-Pb, 3 Longitudinal layers + PS**

ATLAS and CMS makes different choices:

- **sampling calorimeter allow to have redundant measurement of γ angle**
- **homogenous calorimeter with very low stochastic term aims to excellent energy resolution, the mesure of γ angle relies on vertex reconstruction from tracking.**

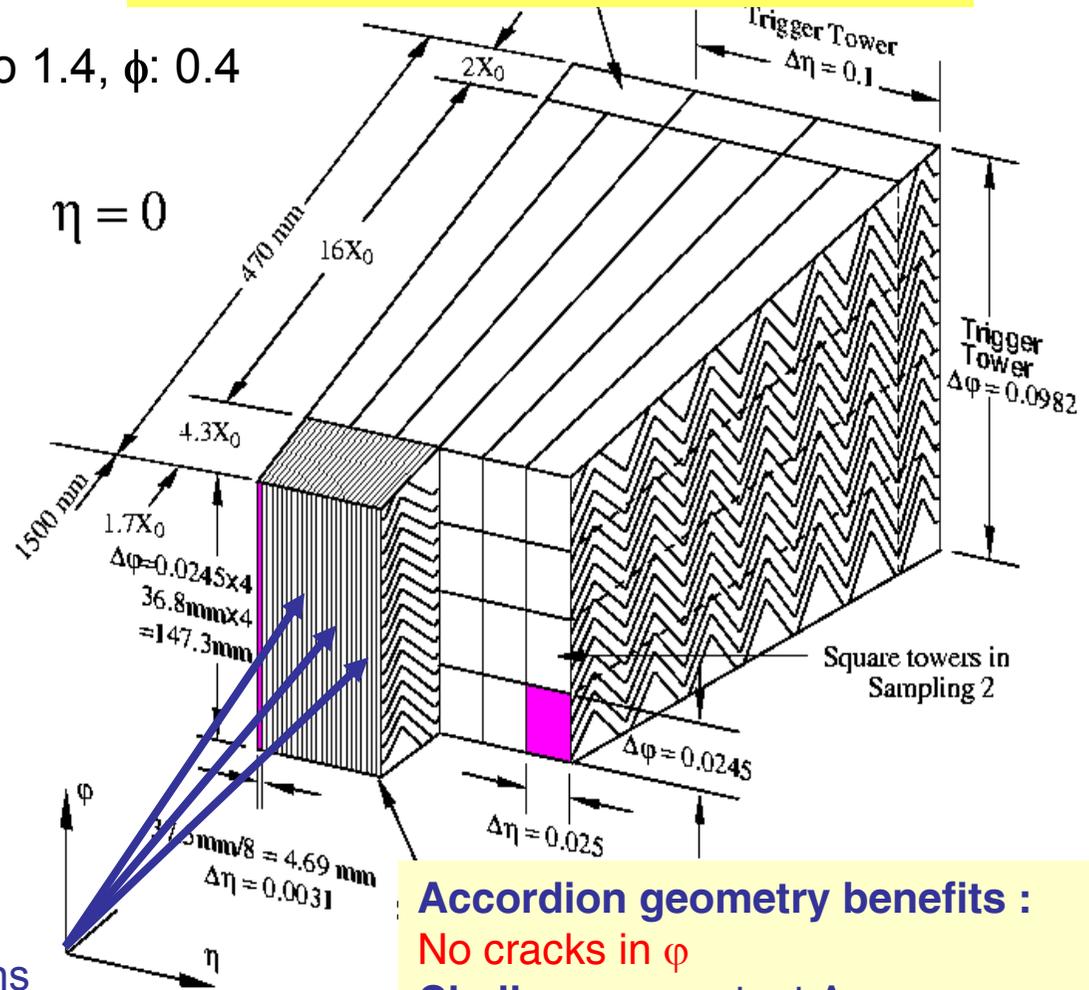
ECAL @ ATLAS

Sampling: accordion lead structure filled with LAr



1 module covers η : 0 to 1.4, ϕ : 0.4

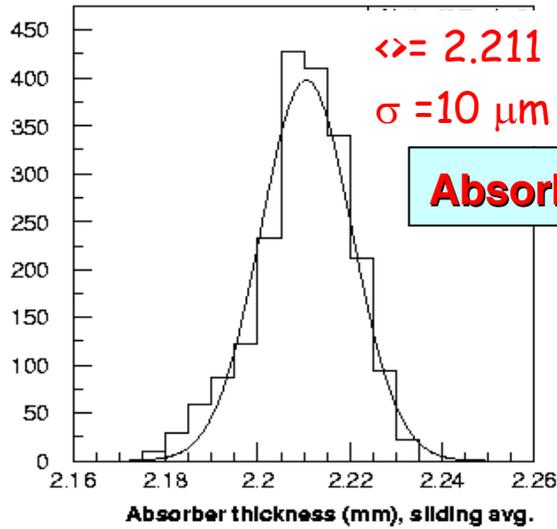
- Longitudinal dimension:
 $\approx 25 X_0 = 47 \text{ cm}$ (CMS 22 cm)
- 3 longitudinal layers
- $4 X_0 \pi^0$ rejections separation of 2 photons very fine grain in η
- $16 X_0$ for shower core
- $2 X_0$ evaluation of late started showers
- Total channels ≈ 170000



Accordion geometry benefits :
 No cracks in ϕ
 Challenge: constant Ar gap, very precise mechanics

Particles from collisions

The challenge of LAr

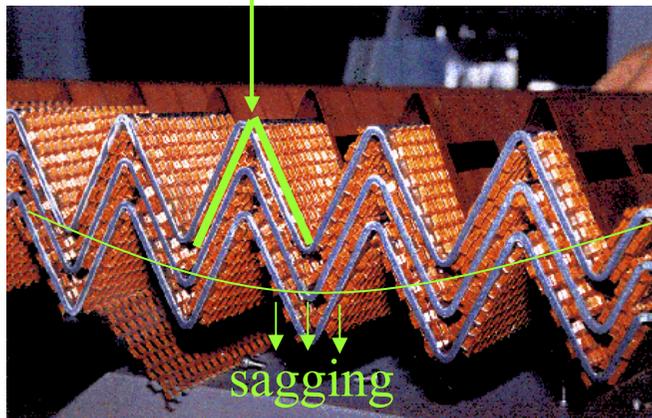


1% Pb variation \rightarrow 0.6% drop in response
 Measured dispersion $\sigma = 9 \mu\text{m}$ (calo)
 translates to $< 2 \text{‰}$ effect on constant term

Mechanical non uniformities: modifies electric field and detector response. Take care during construction, try to reproduce effects and apply corrections.



slant angle : $1^\circ \sim 100^\circ$ is sensitive

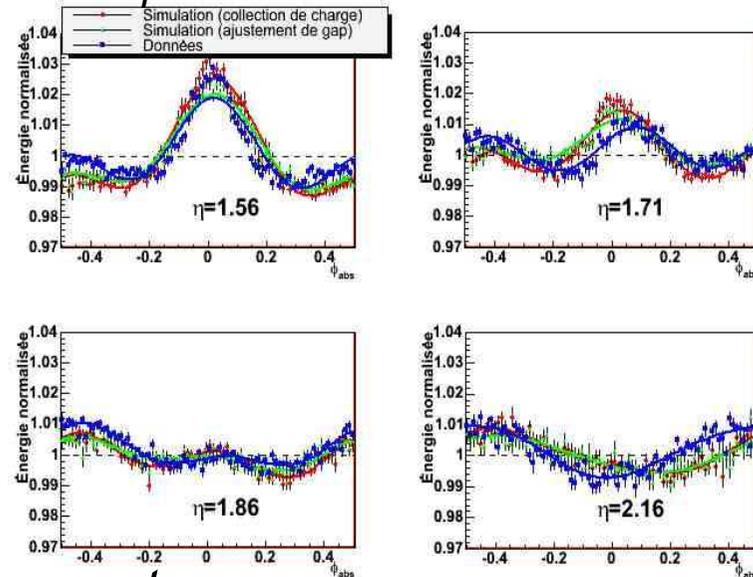


ϕ -modulations
 in the EMEC



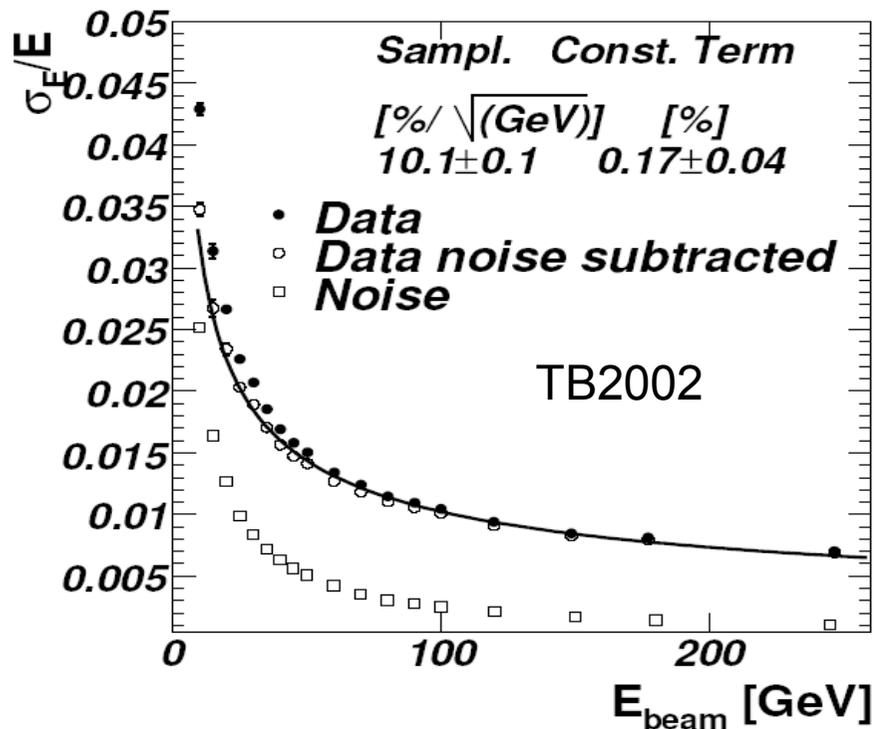
Calorimeter response is affected $\sim 3 \%$

Response to 120 GeV e-showers



\Rightarrow an 'as built detector' : HV, sagging, misalignment

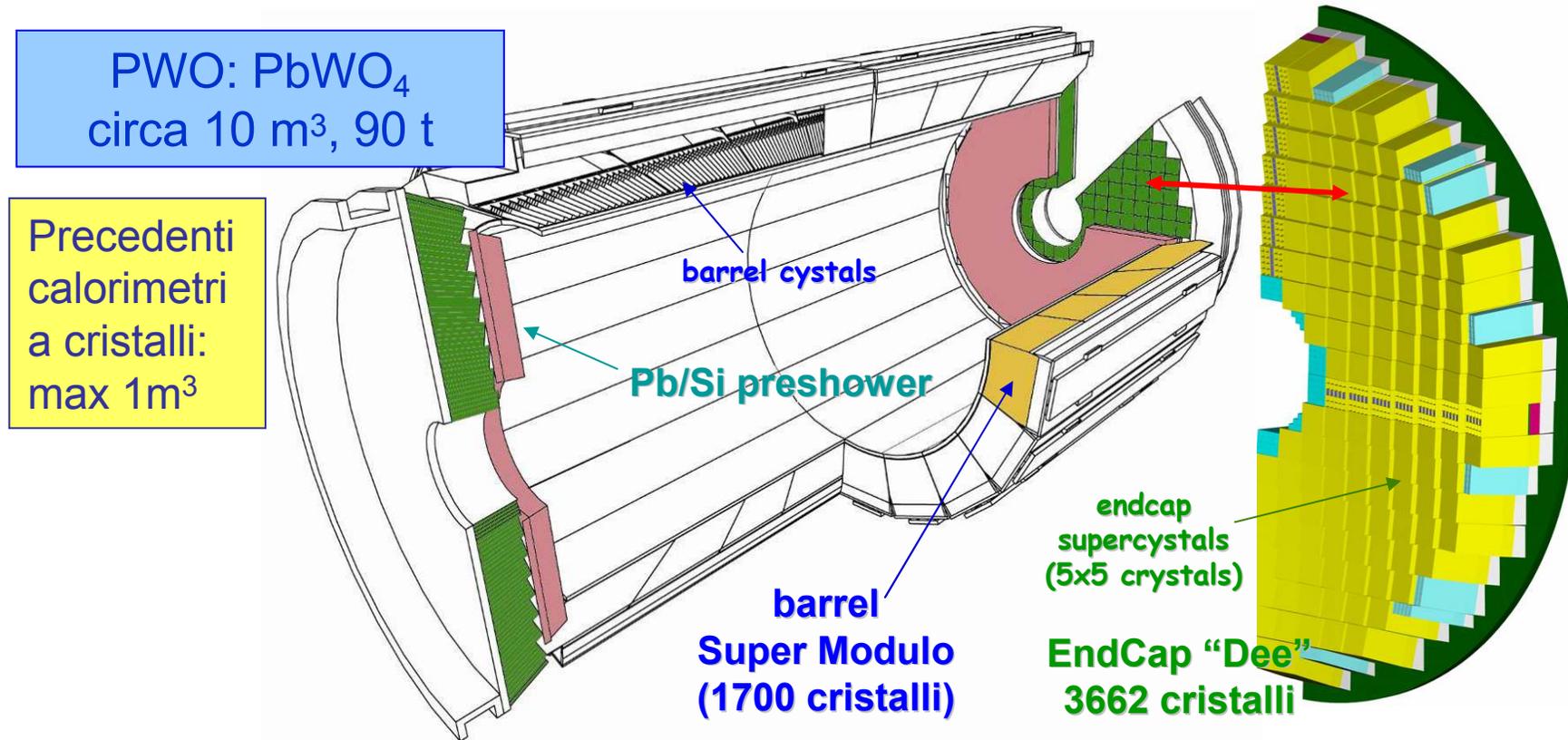
ATLAS EM: the performance



Module	P13	P15
Global constant term	0.62%	0.56%

- The constant term in the resolution is dominated by:
 - the equalization of the electronic readout.
 - the non uniformity in the electric field and in the sampling fraction introduced by the accordion structure.

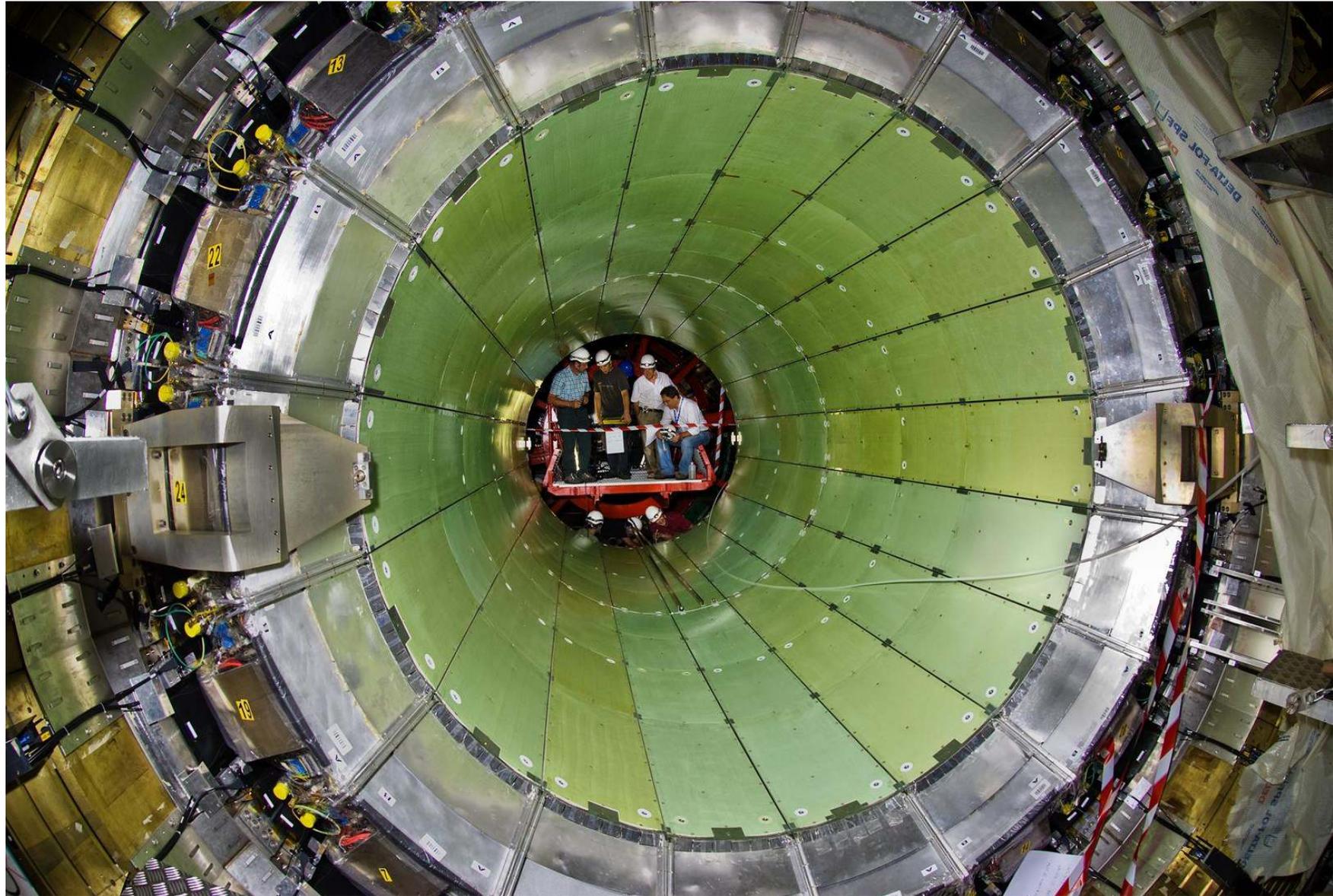
ECAL: omogeneo a cristalli



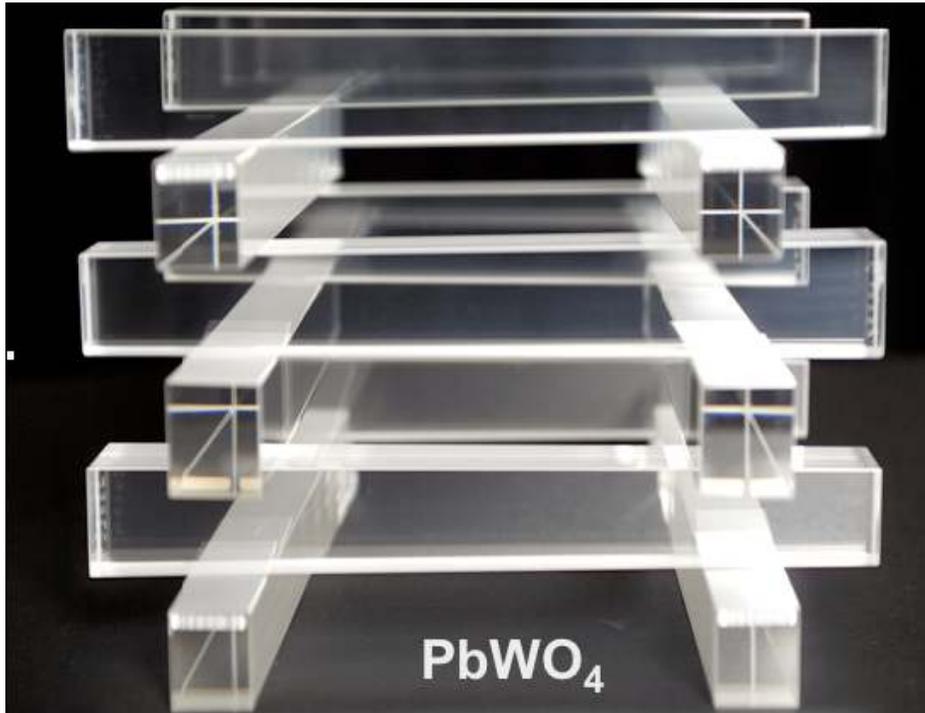
Barrel: $|\eta| < 1.48$
36 Super Moduli
61200 cristalli (2x2x23cm³)

EndCaps: $1.48 < |\eta| < 3.0$
4 Dees
14648 cristalli (3x3x22cm³)

ECAL BARREL



Tungstato di Piombo: PWO



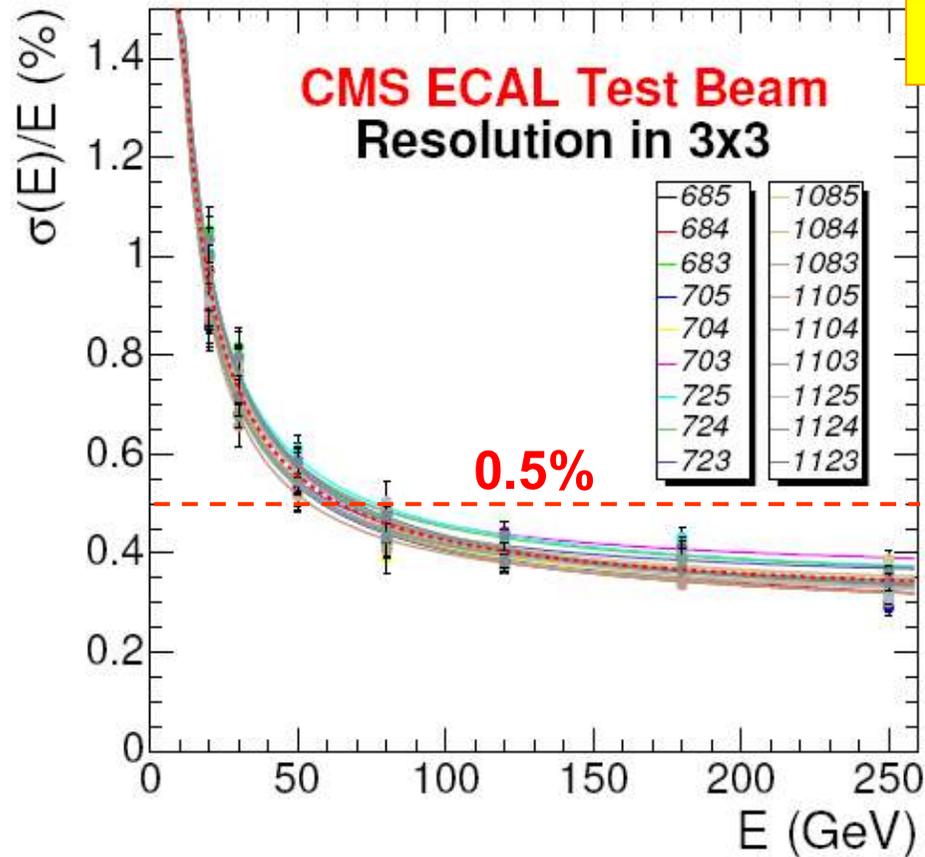
Parameter		Value
Radiation length	cm	0.89
Moliere radius	cm	2.2
Hardness	Moh	4
Refractive index		2.3
Peak emission	nm	440
% of light in 25 ns		80%
Light yield (23 cm)	γ/MeV	100

γ/e : contenimento molto efficace

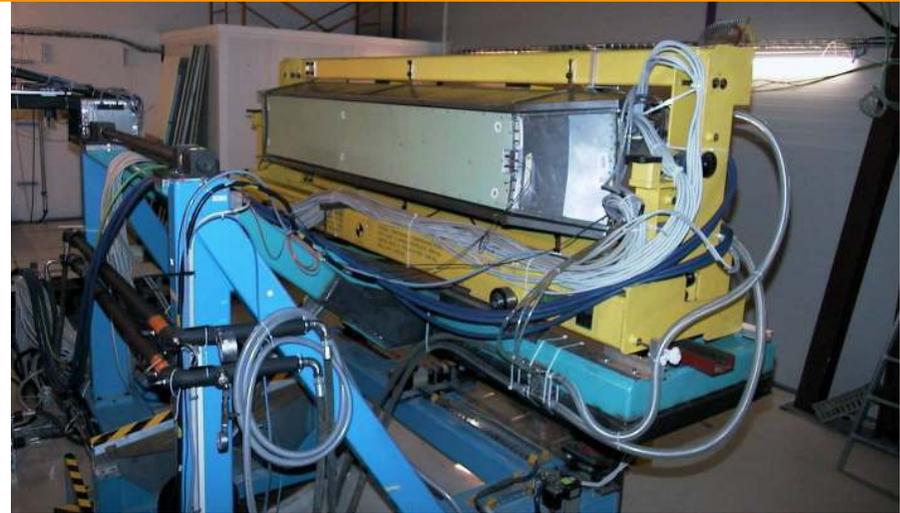
veloce

poca luce

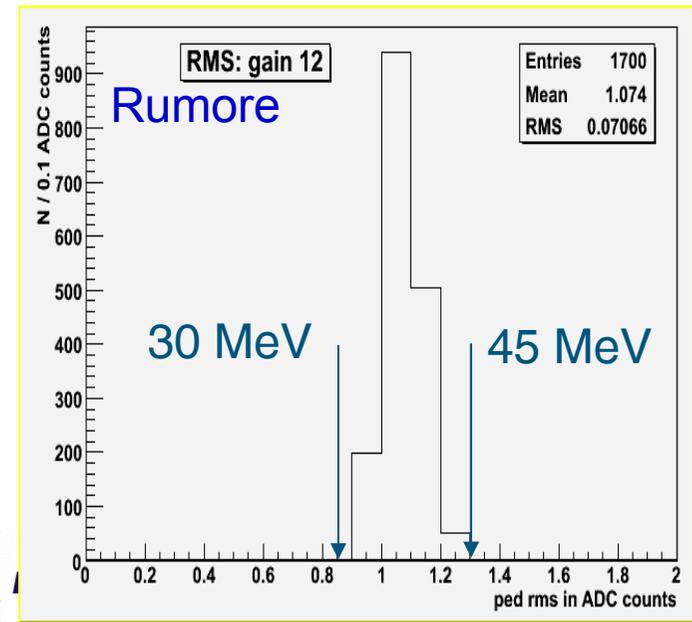
ECAL: la performance



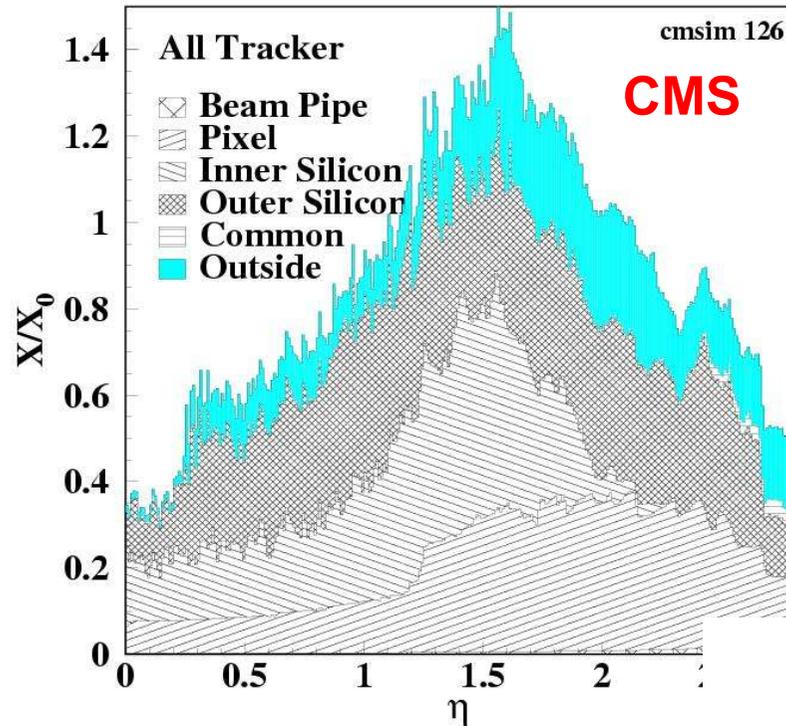
1 Super Modulo 1700 xl su fascio di test



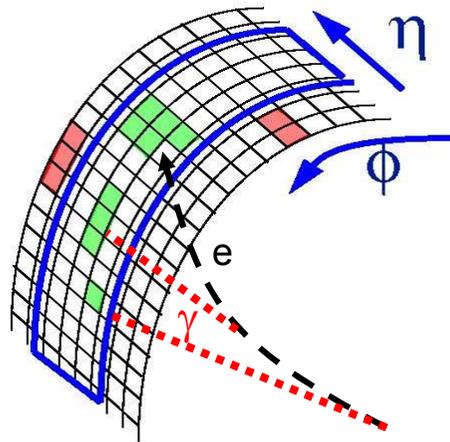
$$\frac{\sigma}{E} = \frac{2.8\%}{\sqrt{E(\text{GeV})}} \oplus \frac{125}{E(\text{MeV})} \oplus 0.3\%$$



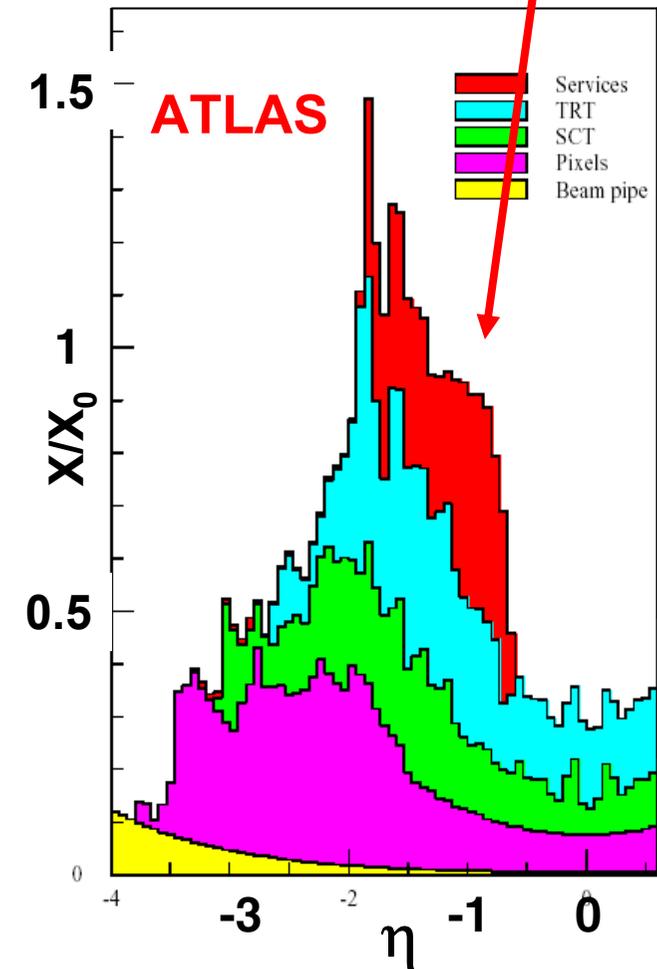
Punto dolente: materiale di fronte



Tough for both experiments...



+ THE SOLENOID



Tracker material :

- electrons loose energy via bremsstrahlung
- photons convert

4T (2T) solenoidal B field :

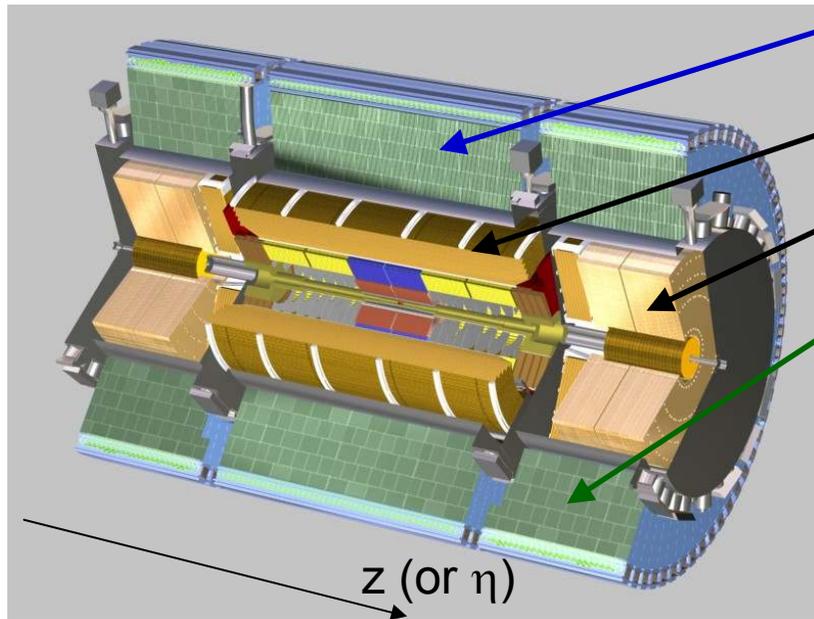
Electrons bend ⇒ radiated energy spread in φ

HCAL

Tecnologie simili

- The choices made for the hadronic central section by ATLAS and CMS are similar: sampling calorimeters with scintillator as active material.
- In both cases the dominant factor on resolution and linearity is the $e/h \neq 1$
- ATLAS & CMS: $e/h_{\text{had}} \approx 1.4$
- **ATLAS higher segmentation and containment gives better total resolution**

HCAL @ ATLAS



Hadronic Tiles Barrel

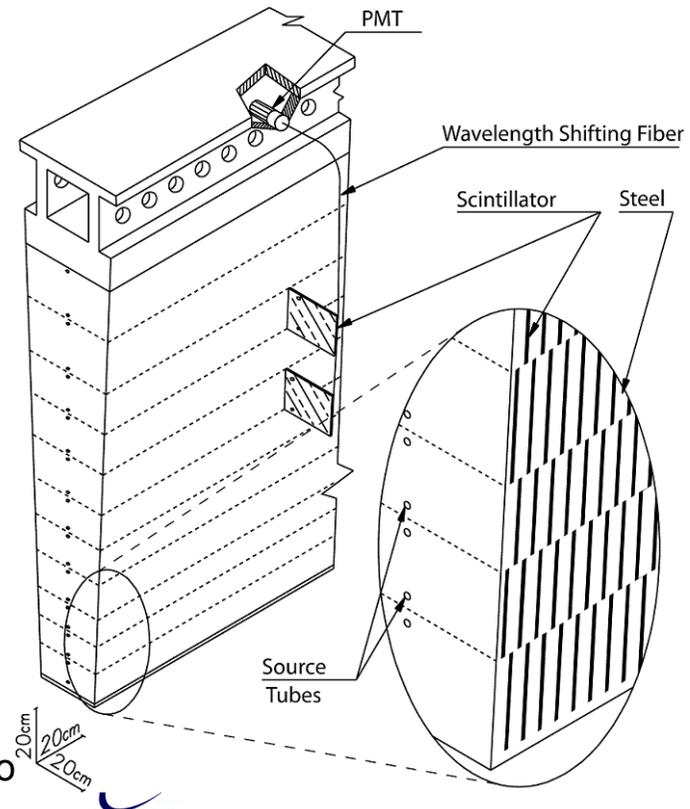
(Liq Arg EM calorimeter cryostat)

(Forward calorimeters cryostats)

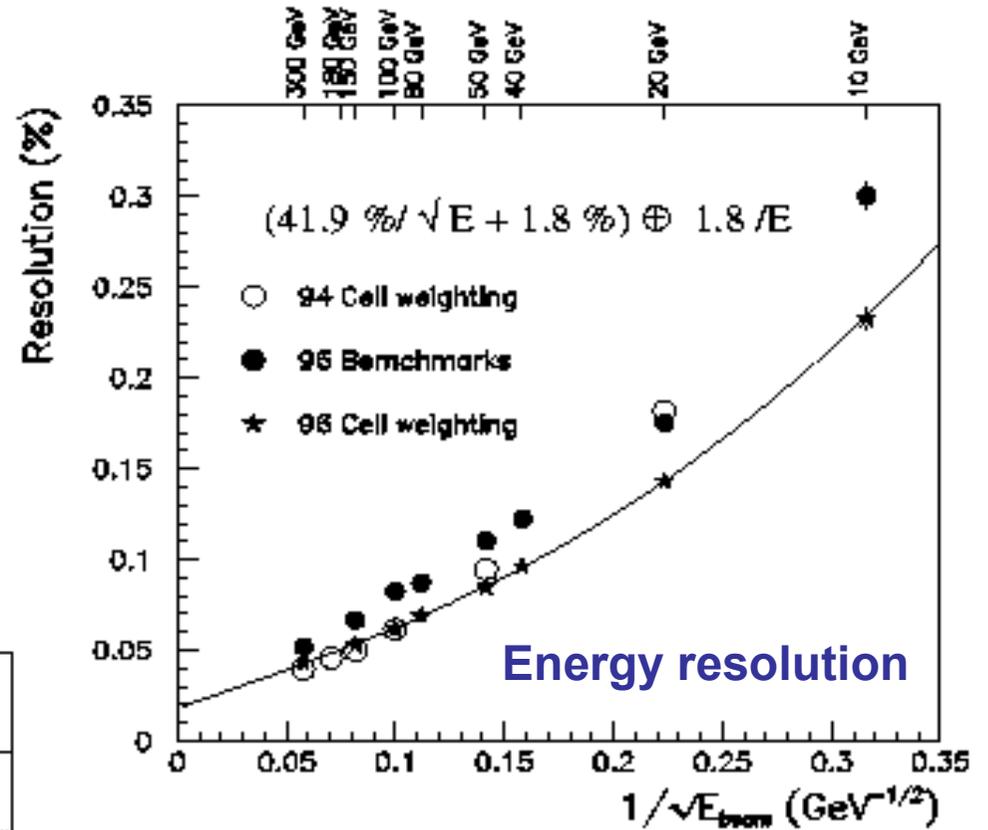
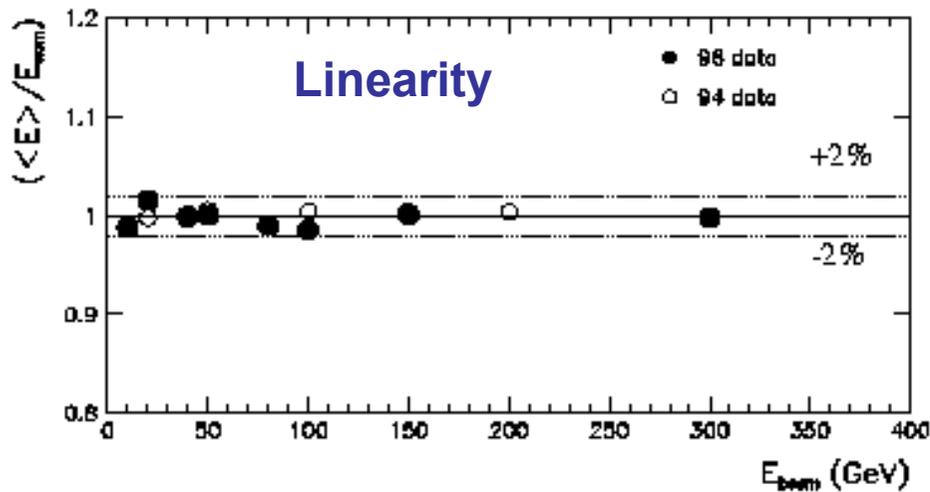
Hadronic Tiles Extended barrel

- Tiles perpendicular to beam axis
- Wavelength shifting fibers carry light to PMTs
- Covers $|\eta| < 1.7$

Hadronic Calorimeter:
Iron/Plastic scintillator
sampling calorimeter

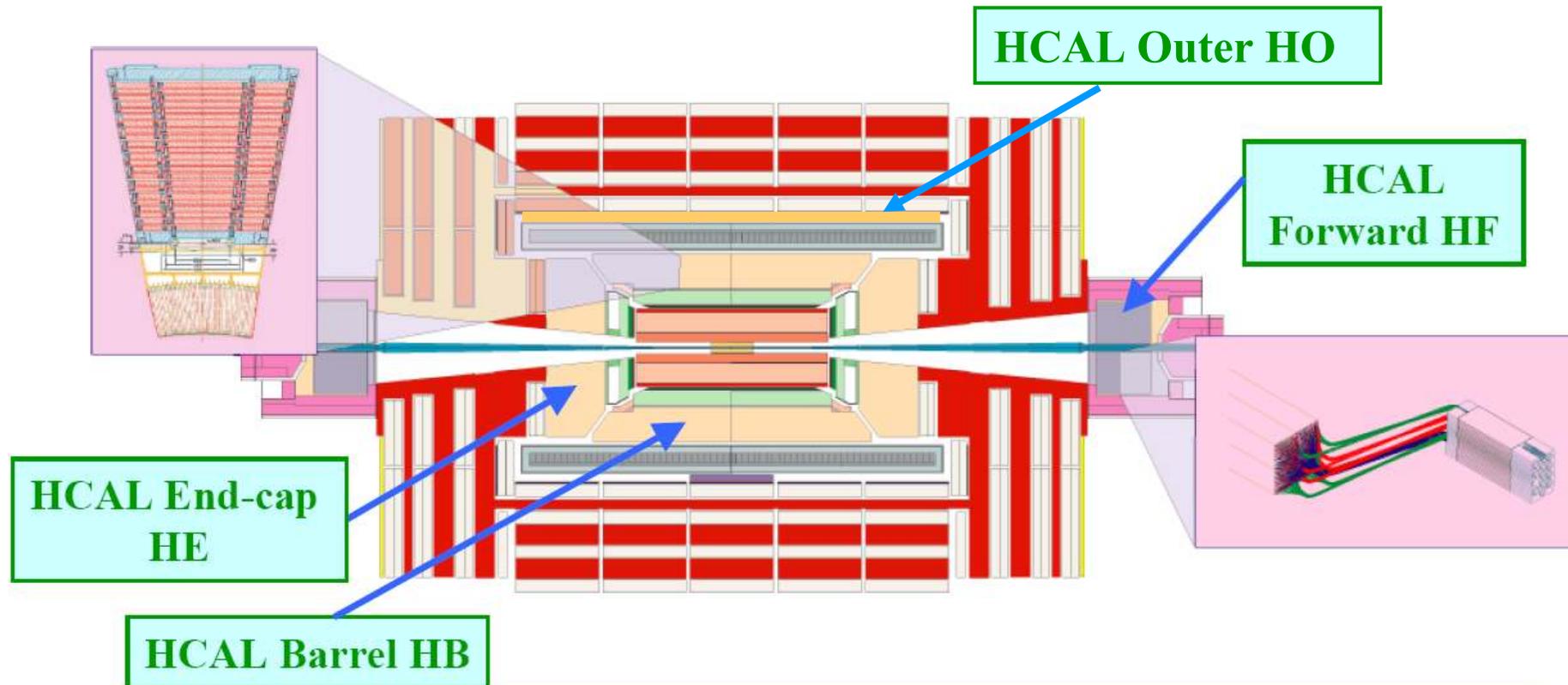


ATLAS HCAL



$$\frac{\sigma}{E} = \left(\frac{41.9\%}{\sqrt{E}} + 1.8\% \right) \oplus \frac{1.8}{E}$$

HCAL @ CMS

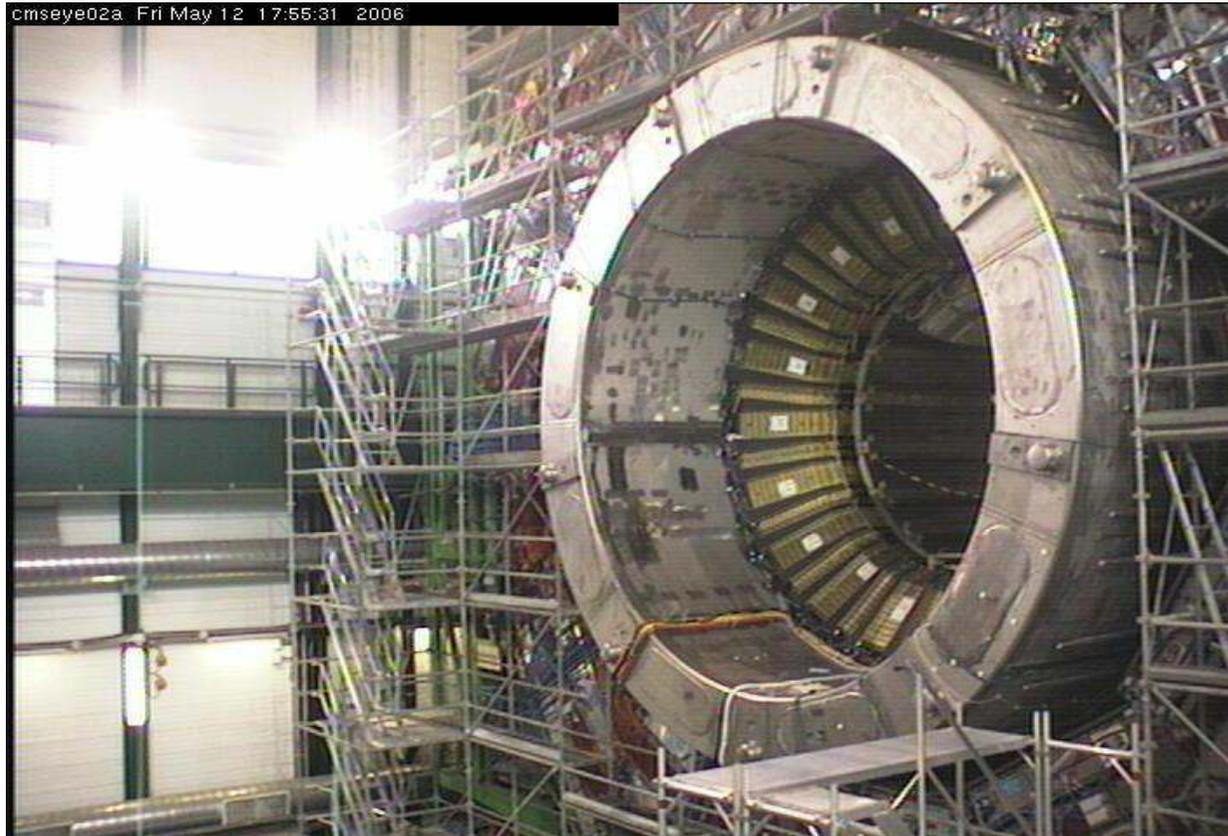


- Hadronic Barrel and End-cap calorimeters are sampling calorimeters with 50 mm thick copper absorber plates interleaved with 4 mm thick scintillator sheets.
- Hadronic Forward calorimeters are sampling calorimeters with steel absorbers and quartz fibers for read-out oriented ~parallel to the beam axis.

CMS HCAL

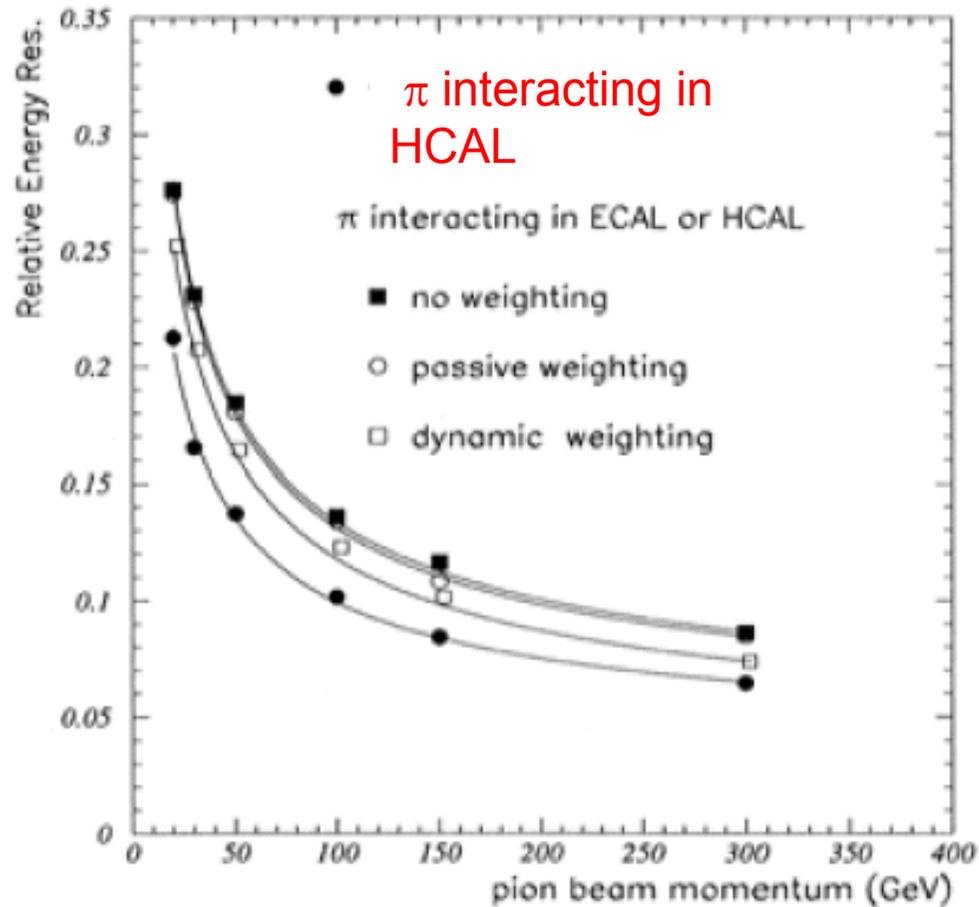


~ 5% of a 300 GeV π energy is leaked outside the HB (inside coil)



HB inside the coil not enough thick for shower containment: scintillator layers just after the coil (HO) improves π resolution by ~10% at 300 GeV & linearity

CMS HCAL



$$\frac{\sigma}{E} = \frac{101\%}{\sqrt{E}} \oplus 4\%$$

Effect of different e/h + no longitudinal sampling in EM

$$\frac{\sigma}{E} = \frac{122\%}{\sqrt{E}} \oplus 5\%$$

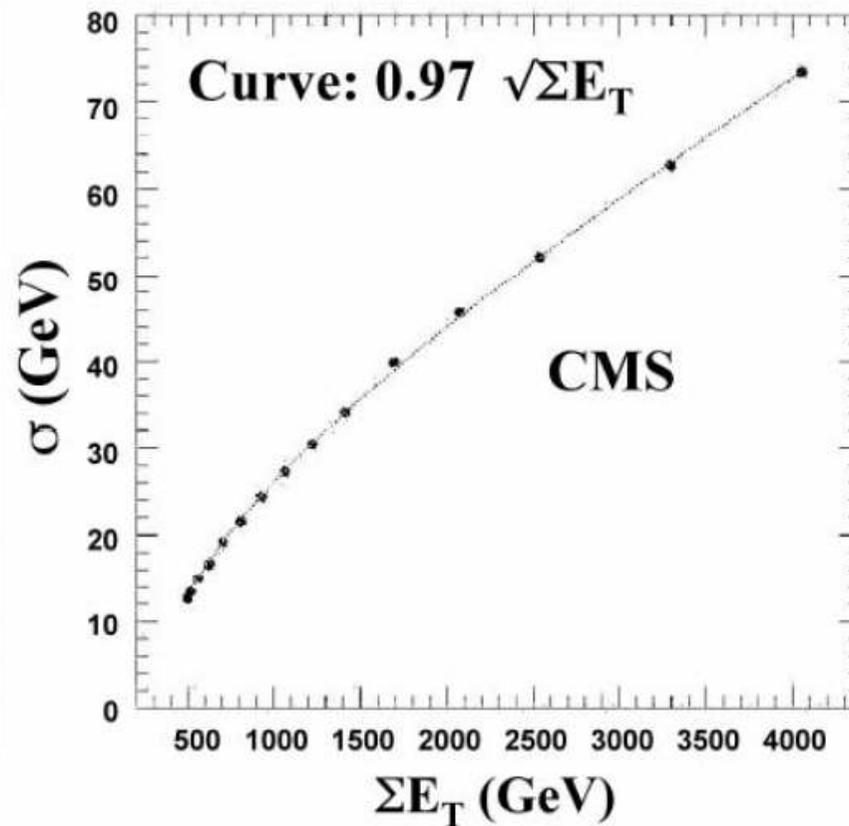
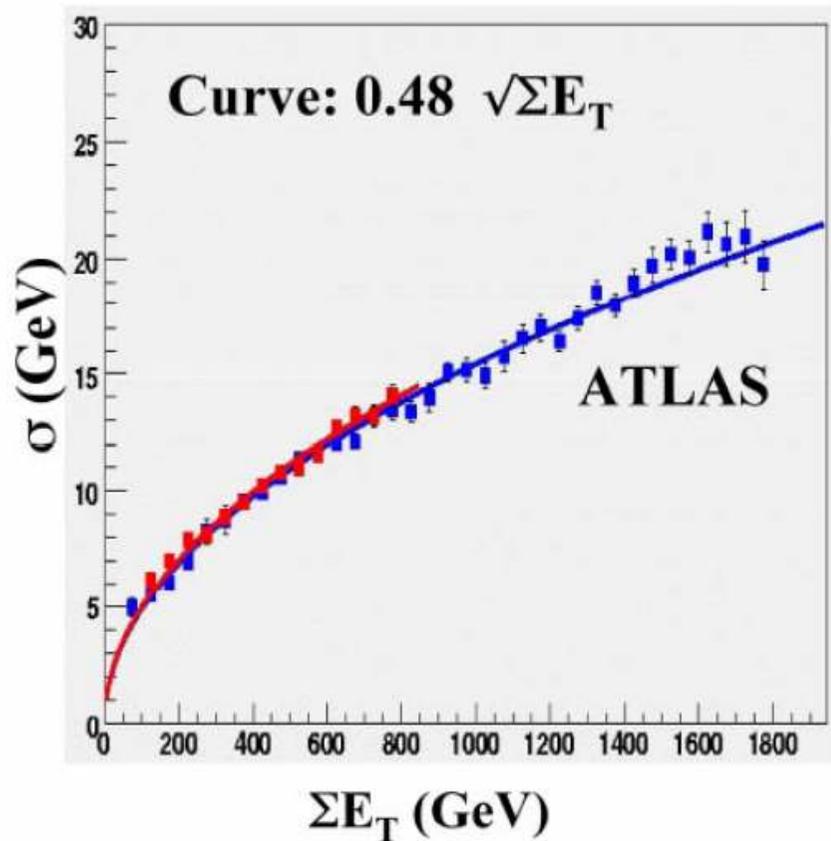
HCAL: Parametri a Confronto

	ATLAS	CMS
Technology		
Barrel / Ext. Barrel	14 mm iron / 3 mm scint.	50 mm brass / 4 mm scint.
End-caps	25 mm (front) - 50 mm (back) copper / 8.5 mm LAr	80 mm brass / 4 mm scint.
Forward	Copper (front) - Tungsten (back) 0.25 - 0.50 mm LAr	4.4 mm steel / 0.6 mm quartz
# Channels		
Barrel / Ext. Barrel	9852	2592
End-caps	5632	2592
Forward	3524	1728
Granularity ($\Delta\eta \times \Delta\phi$)		
Barrel / Ext. Barrel	0.1 x 0.1 to 0.2 x 0.1	0.087 x 0.087
End-caps	0.1 x 0.1 to 0.2 x 0.2	0.087 x 0.087 to 0.35 x 0.028
Forward	0.2 x 0.2	0.175 x 0.175
# Longitudinal Samplings		
Barrel / Ext. Barrel	Three	One
End-caps	Four	Two
Forward	Three	Two
Absorption lengths		
Barrel / Ext. Barrel	9.7 - 13.0	5.8 - 10.3 10 - 14 (with Coil / HO)
End-caps	9.7 - 12.5	9.0 - 10.0
Forward	9.5 - 10.5	9.8

Missing E_T : expected performances

Expected precision of measurement of missing ET as function of ET measured per event.

SHOULD BE 0 IN QCD EVENTS

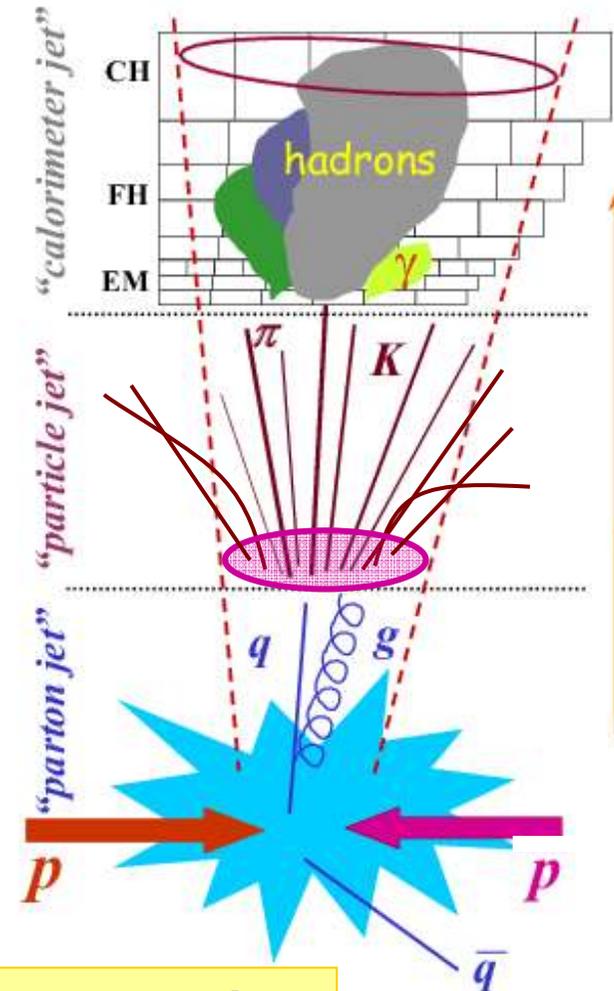


Oggetti fisici: Jet

We are not going to measure single hadrons...

Contribution from

- **Physics:**
 - Parton shower & fragmentation
 - Underlying events
 - Initial State Radiation & Final State Radiation
 - Pileup from minimum bias events
- **Detector:**
 - Resolution
 - Granularity
- **Clustering:**
 - Out of "cone" energy losses

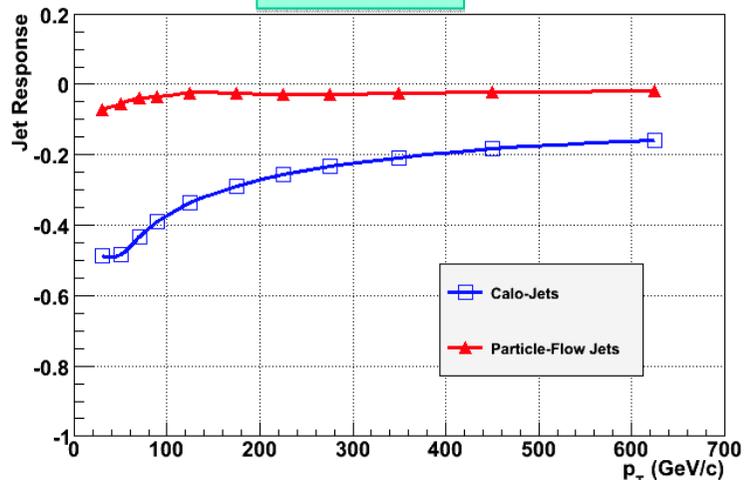


Use physics events to understand jet energy reconstruction:
 $\gamma / Z (\rightarrow ll) + \text{jet}, W \rightarrow \text{jet jet}, \dots$

Jet con Particle Flow

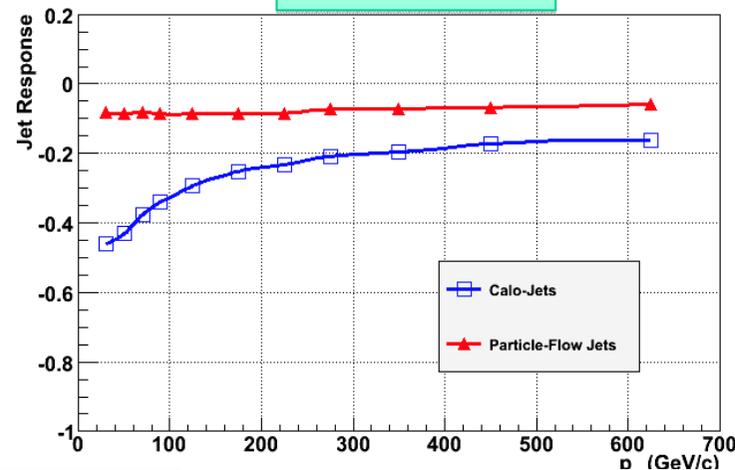
CMS Preliminary

Barrel

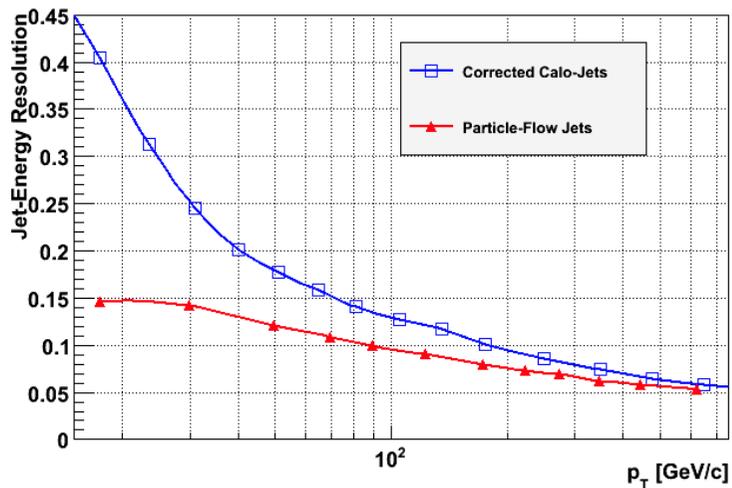


CMS Preliminary

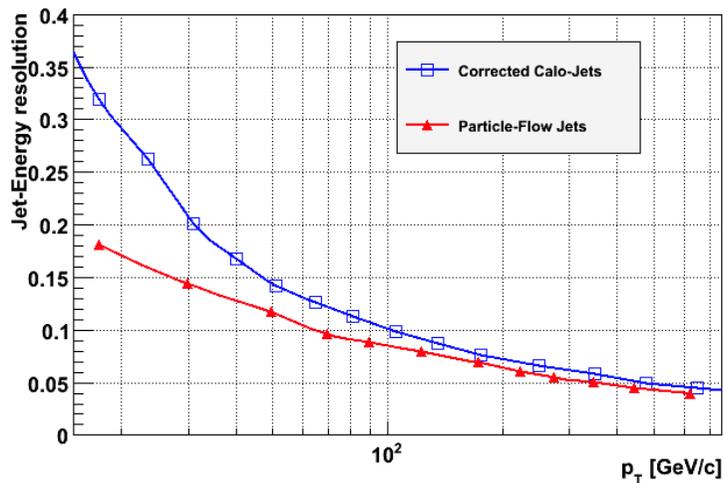
Endcaps



CMS Preliminary

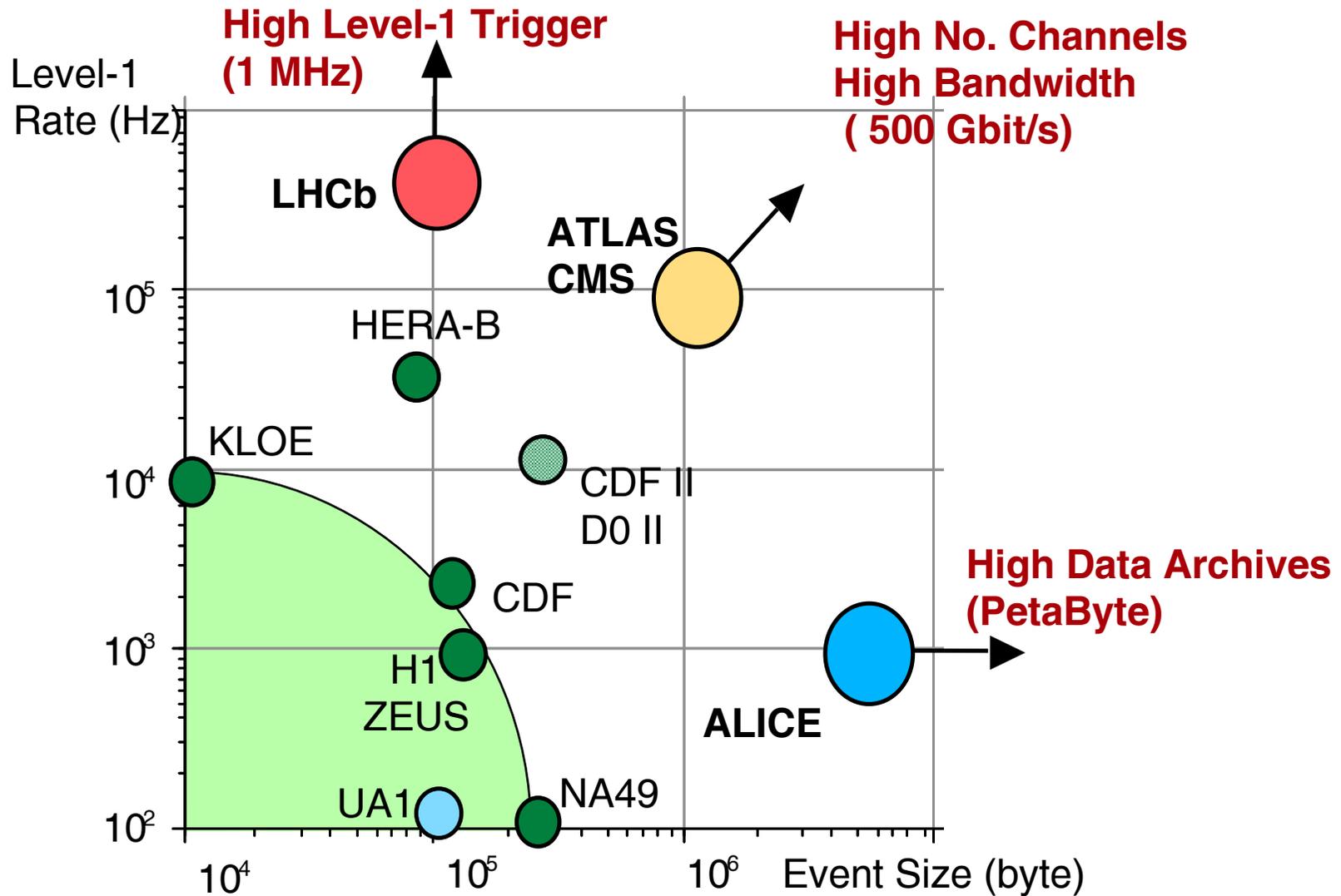


CMS Preliminary



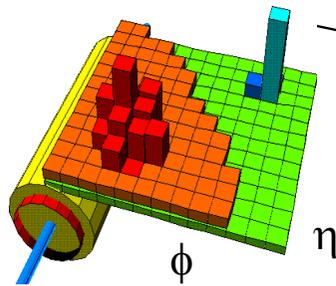
Utilizzare tutto il rivelatore: tracce per i carichi e cluster per i neutri

Challenges Data Acquisition

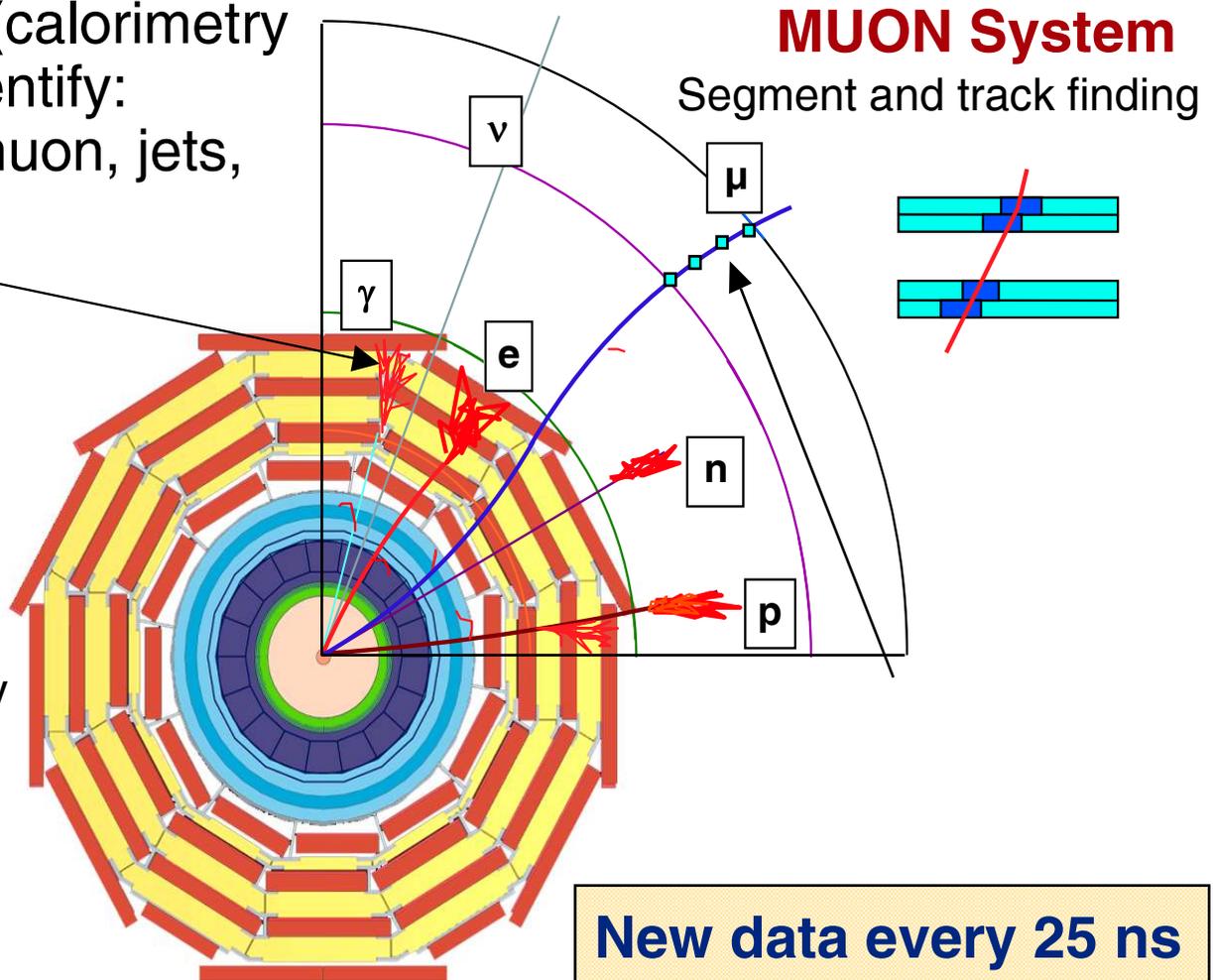


Level-1 Trigger

Use prompt data (calorimetry and muons) to identify:
High p_T electron, muon, jets,
missing E_T



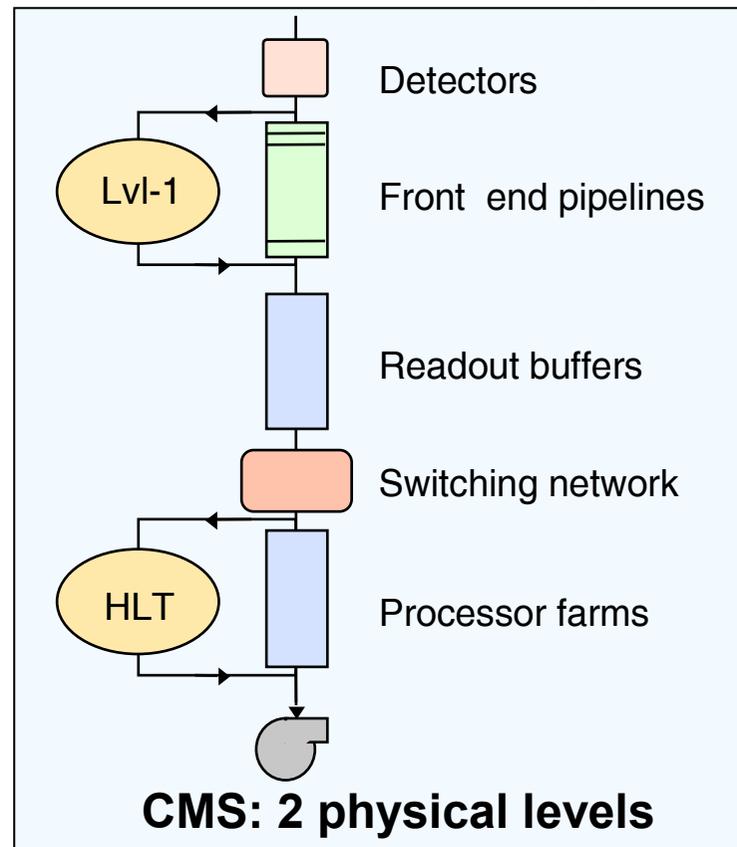
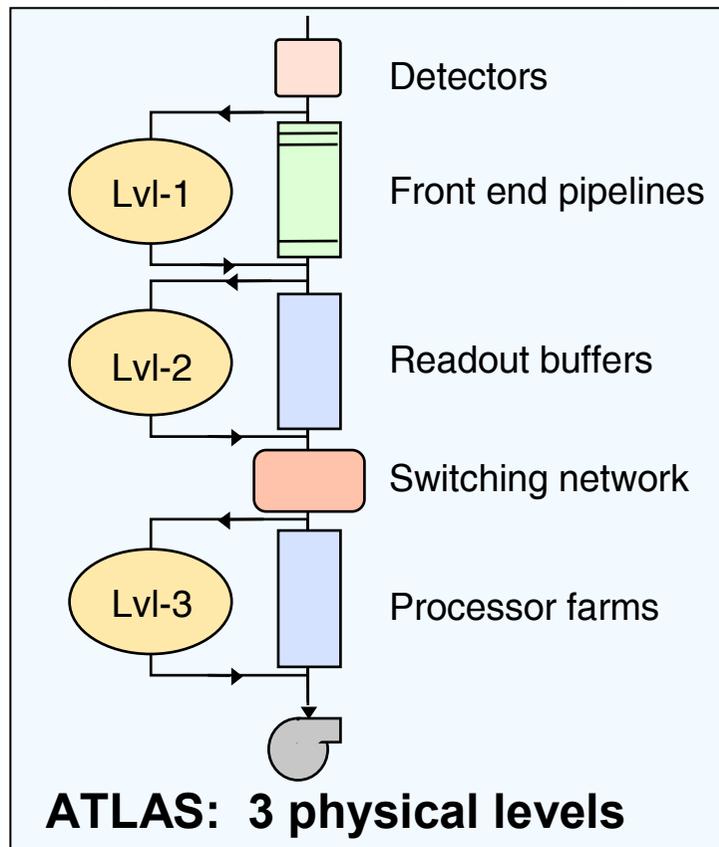
CALORIMETERS
Cluster finding and energy
deposition evaluation
+ isolation



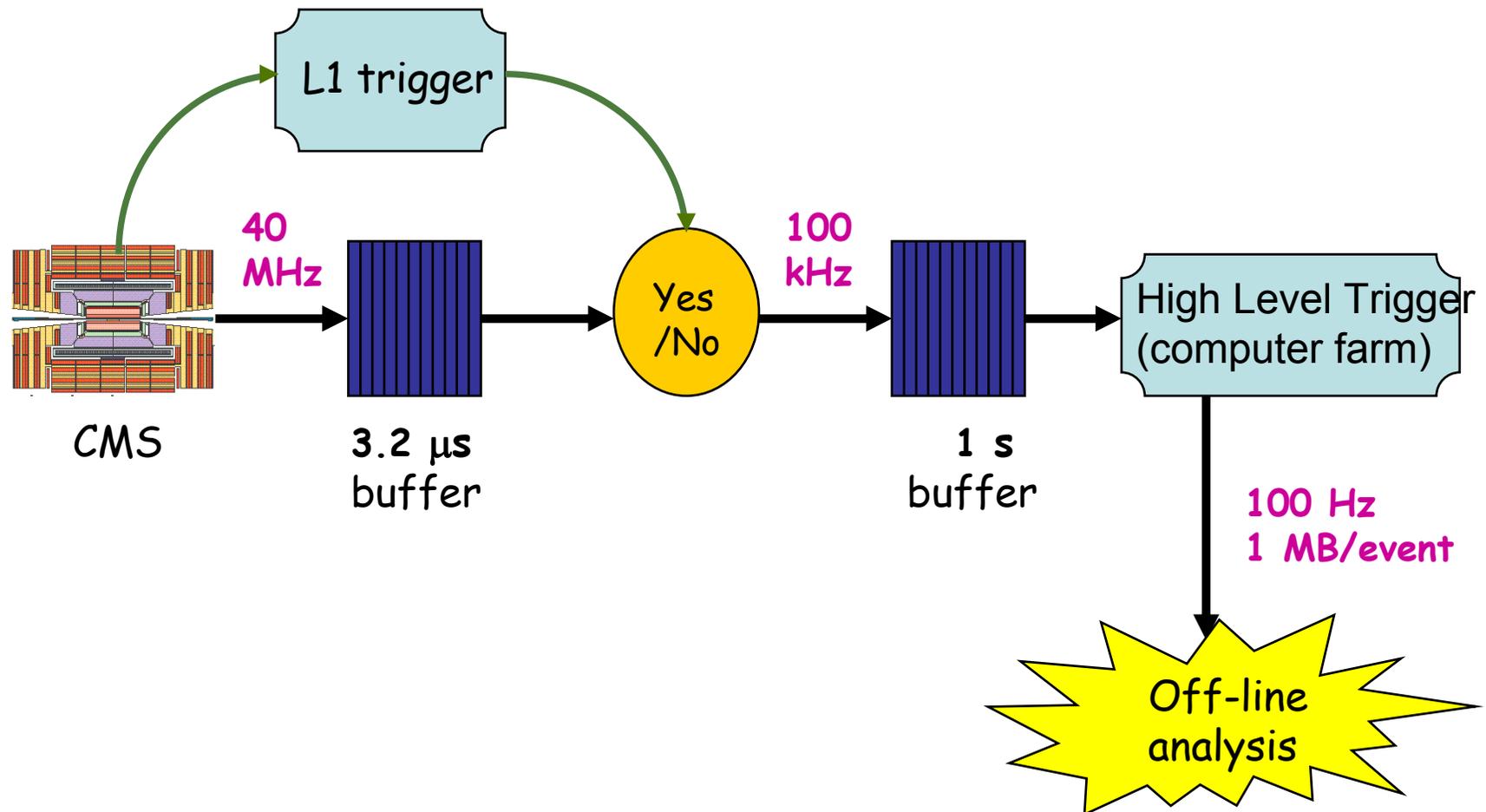
New data every 25 ns
Decision latency $\sim \mu\text{s}$

Online Selection Flow in pp

- Level-1 trigger: reduce 40 MHz to 10^5 Hz
 - This step is always there
 - Upstream: still need to get to 10^2 Hz; in 1 or 2 extra steps



Acquisizione e Selezione



Preparare e capire i rivelatori

- Calibrazioni & Allineamenti ma non solo
- La comprensione del rivelatore

Lavori in Corso

Cosmic Muons

High energetic muons that traverse the detector vertically

→ particular useful for alignment and calibration - *barrel region*.

Beam Halo Muons (Hadrons)

Machine induced secondary particles that cross the detector almost horizontally

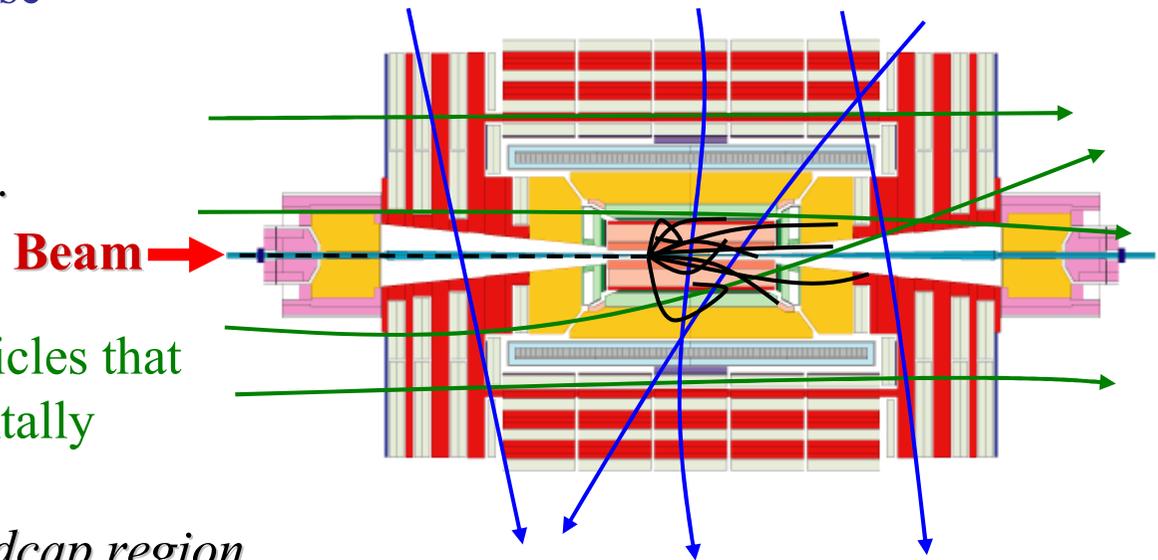
→ particular useful for alignment and calibration - *endcap region*.

Beam Gas Interactions

Proton-nucleon interaction in the active detector volume ($7\text{TeV} \rightarrow E_{\text{cm}} = 115\text{ GeV}$)

→ resemble collision events but with a rather soft p_{T} spectrum ($p_{\text{T}} < 2\text{ GeV}$)

“Pre-Collision Physics Structures”

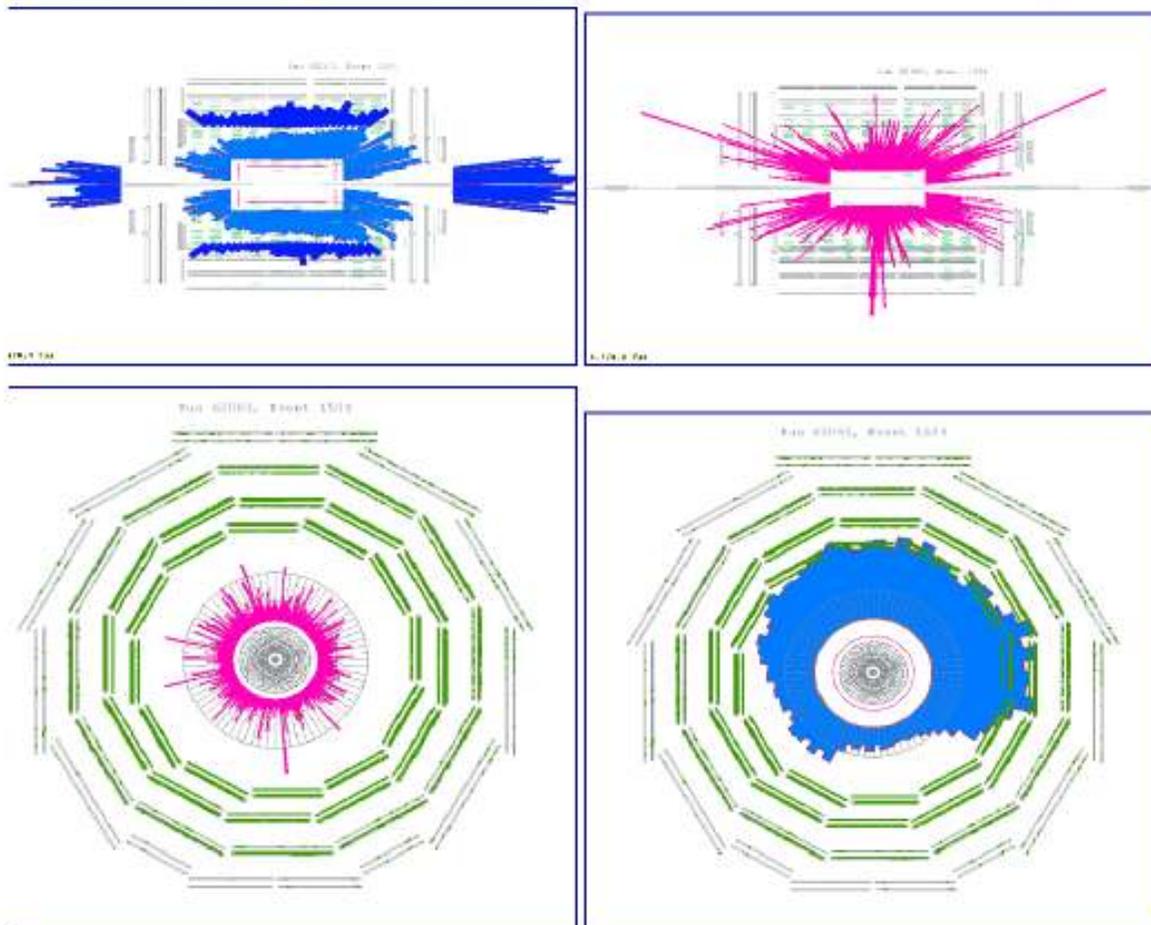


All three physics structures are interesting for alignment, calibration, gain operational experience, dead channels, debug readout, etc ...

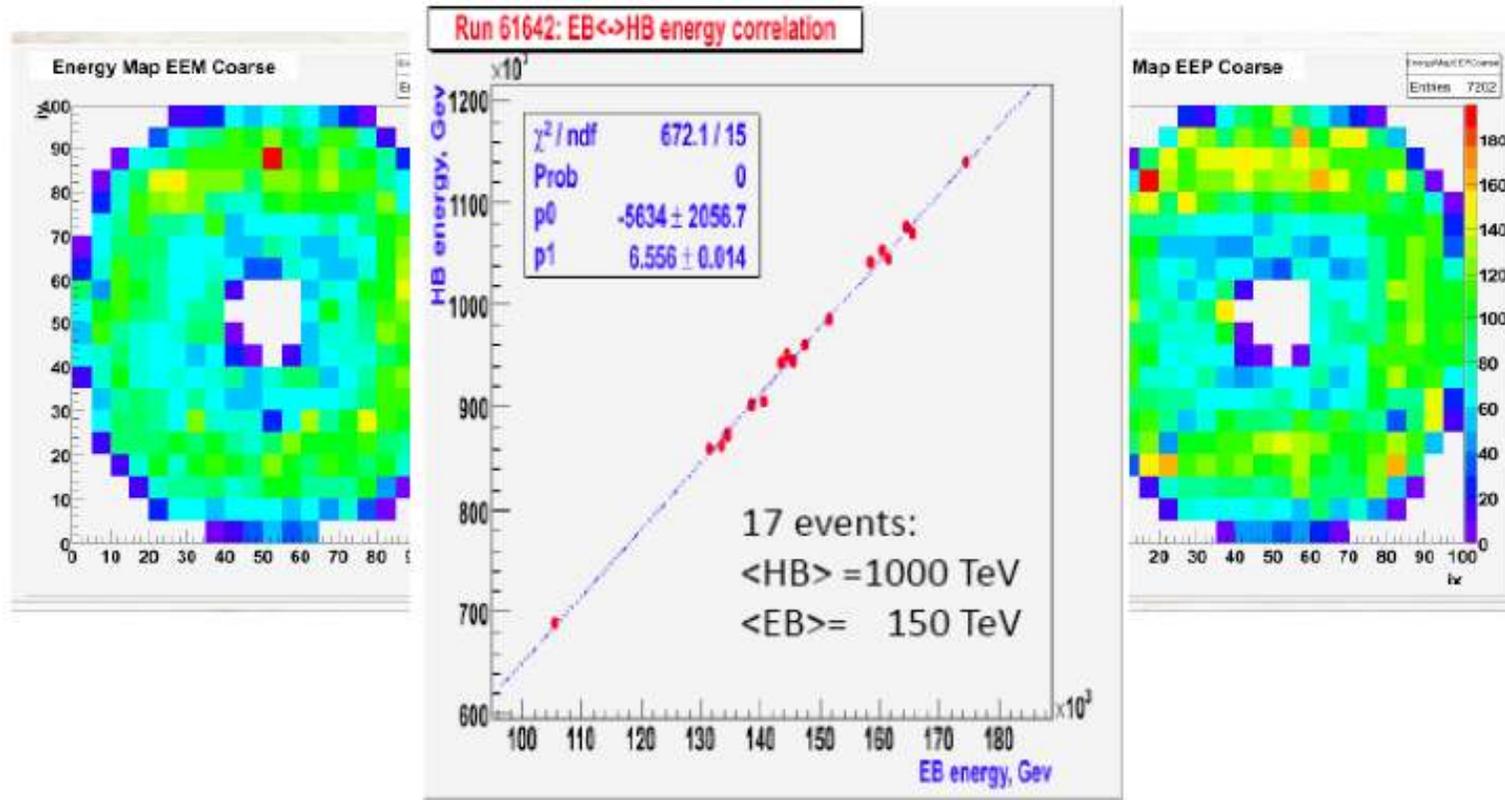
Eventi LHC in CMS

$\sim 2 \cdot 10^9$ protons on collimator ~ 150 m upstream of CMS

ECAL- pink; HB,HE - light blue; HO,HF - dark blue; Muon DT - green; Tracker Off

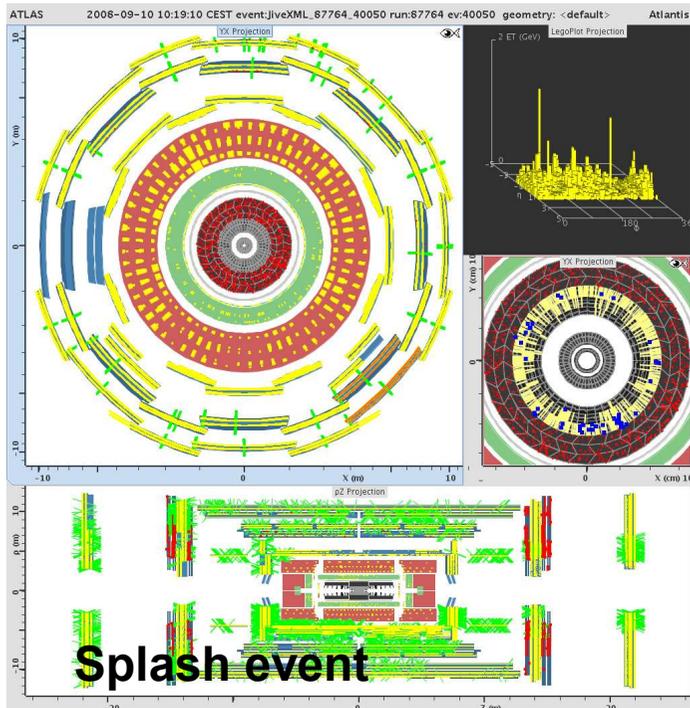


Eventi LHC in CMS

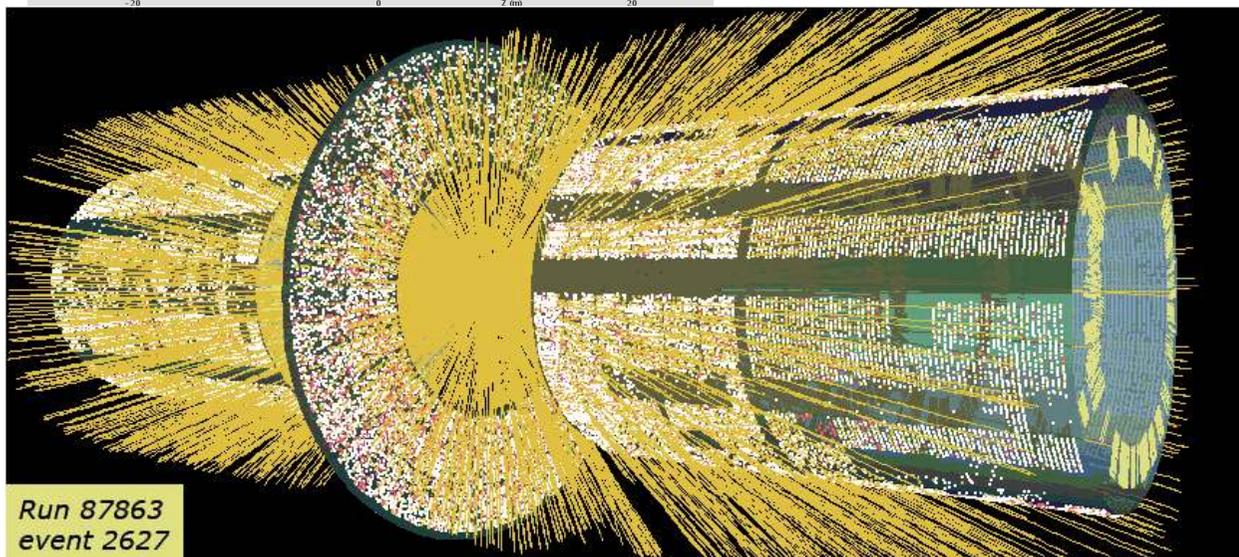
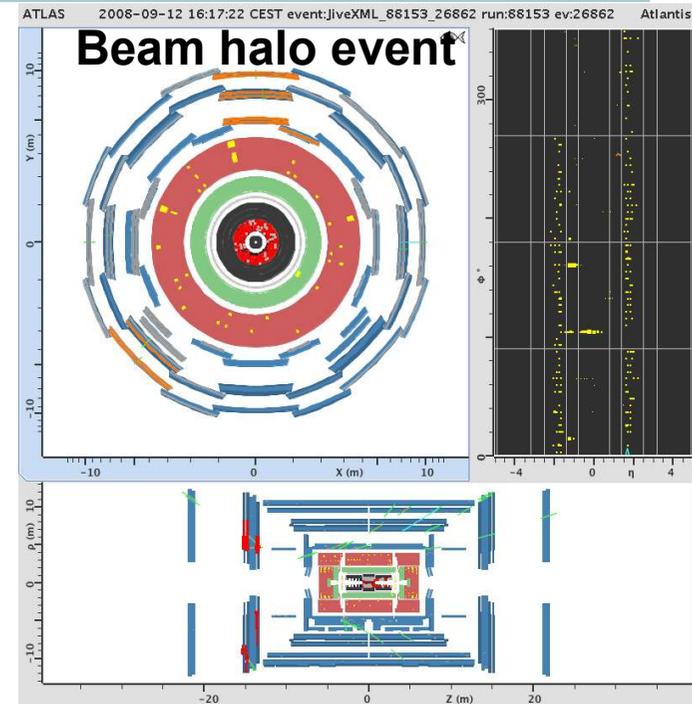


ECAL: Splash events provided a source for overall internal synchronization.
Crystals were time aligned to within 1ns !

Eventi LHC in ATLAS



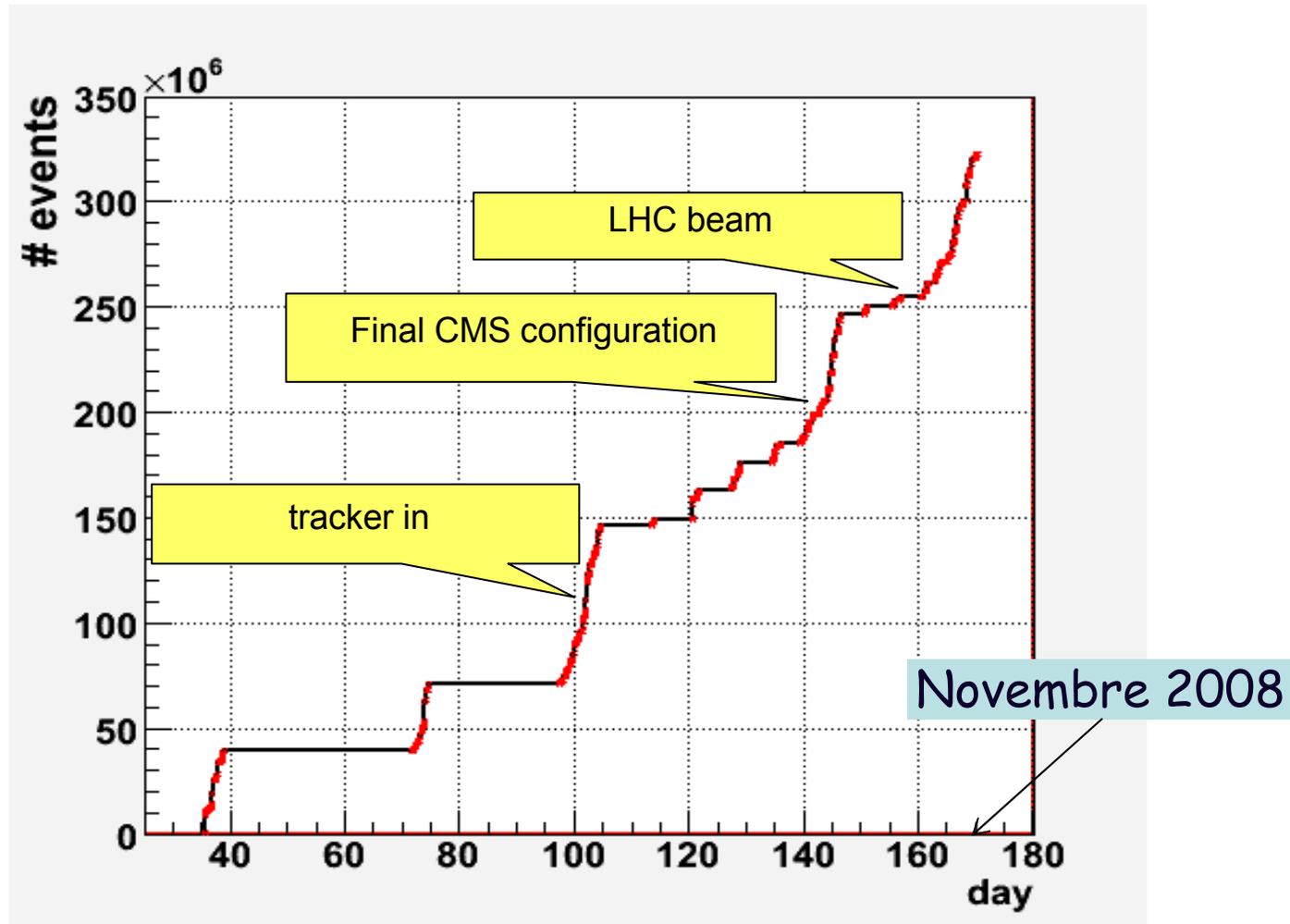
Beam halo events are important for Endcaps calibrations



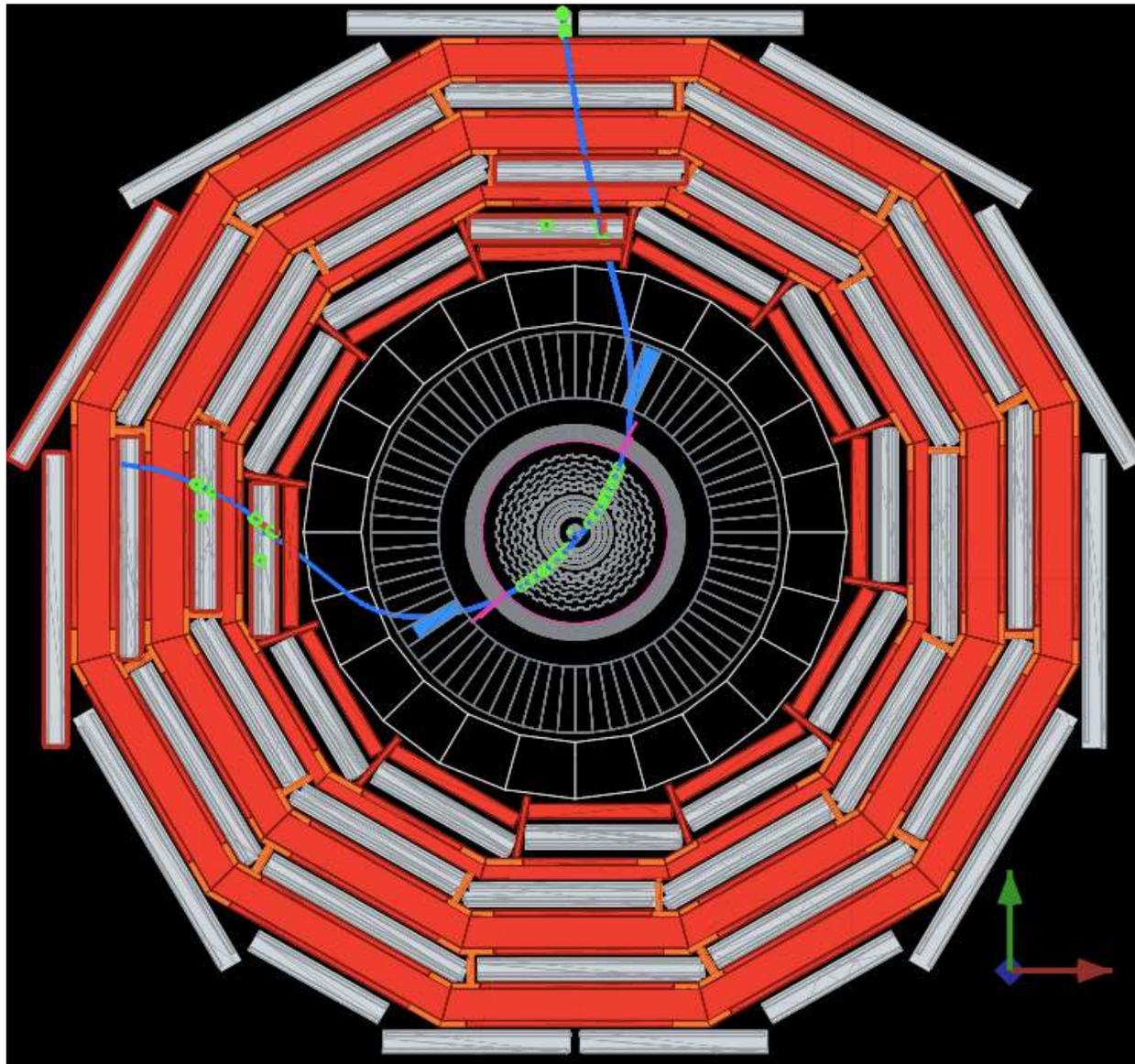
Beam dumped on closed collimators 140 m far from the IP, produced a **splash of particles**, useful for timing-in the L1 systems

Cosmici in CMS: statistica

$\sim 3.5 \times 10^8$ eventi



Cosmico in CMS



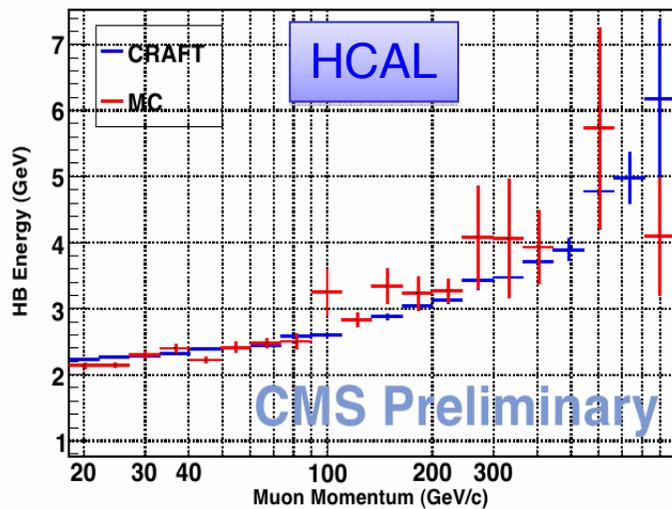
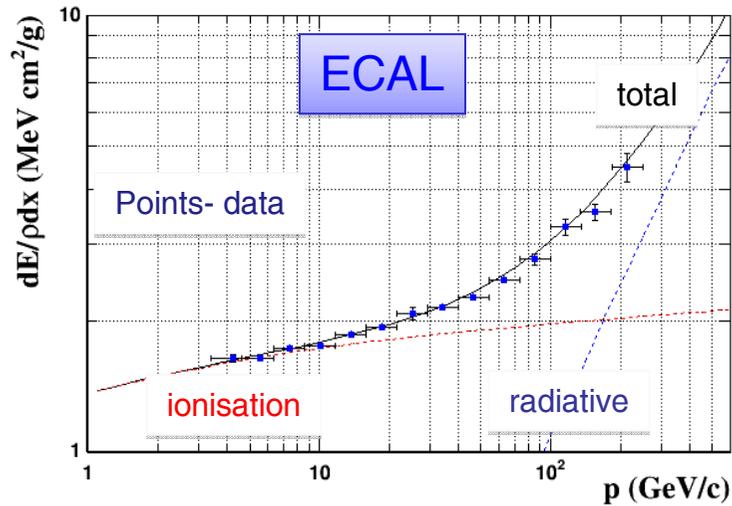
Alghero 02-06-09

M. Diemoz - INFN Roma

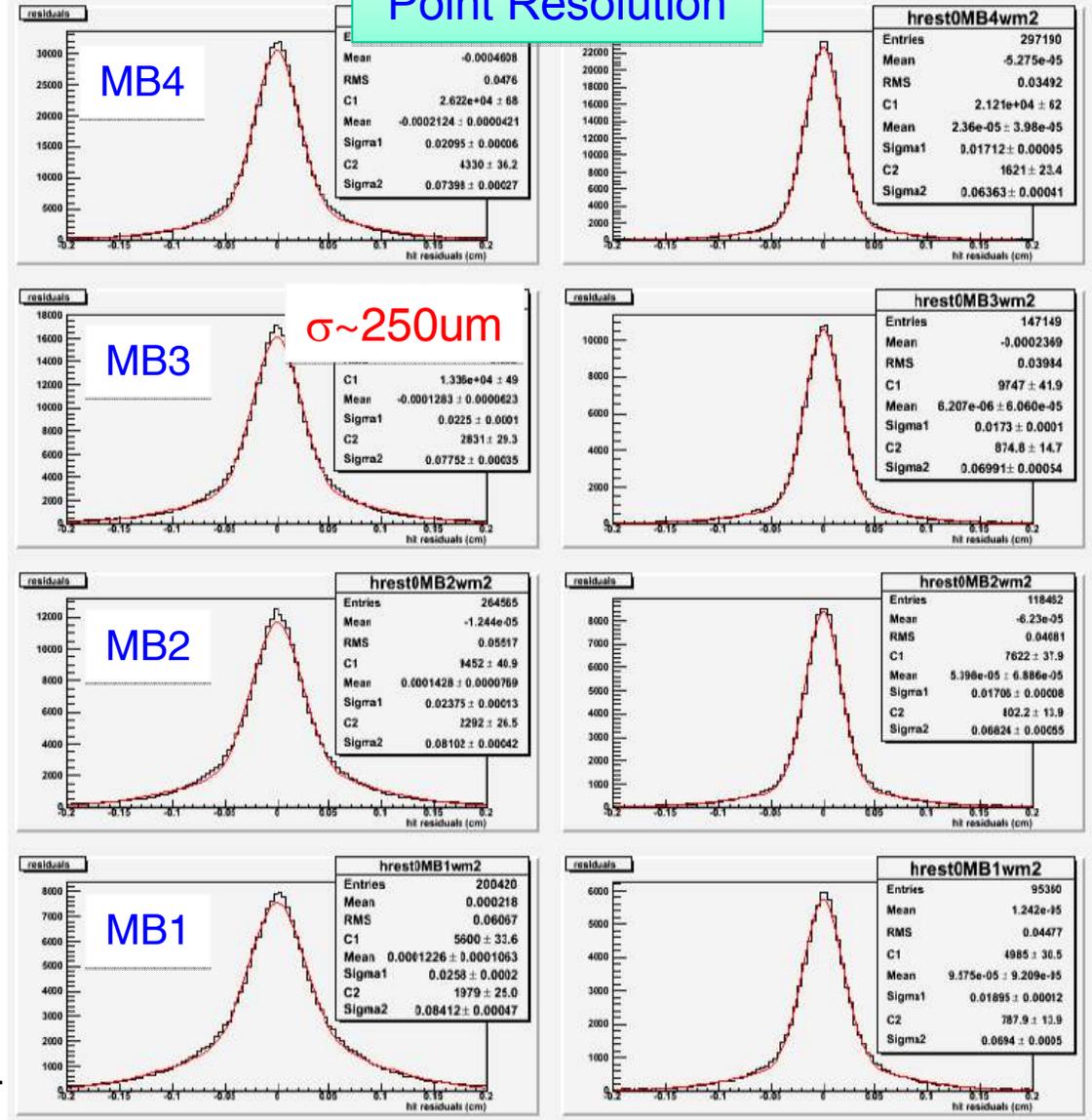


Cosmics in CMS

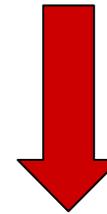
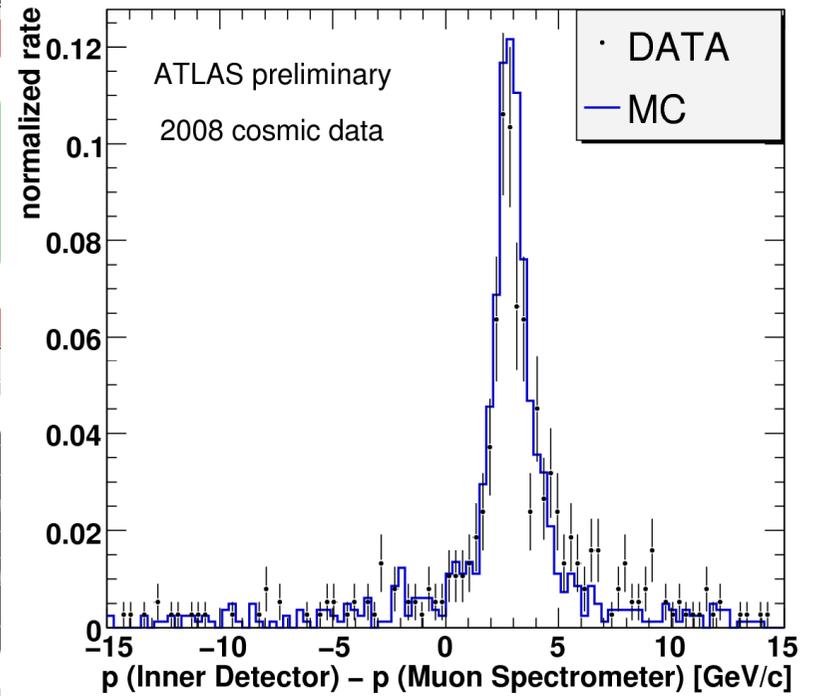
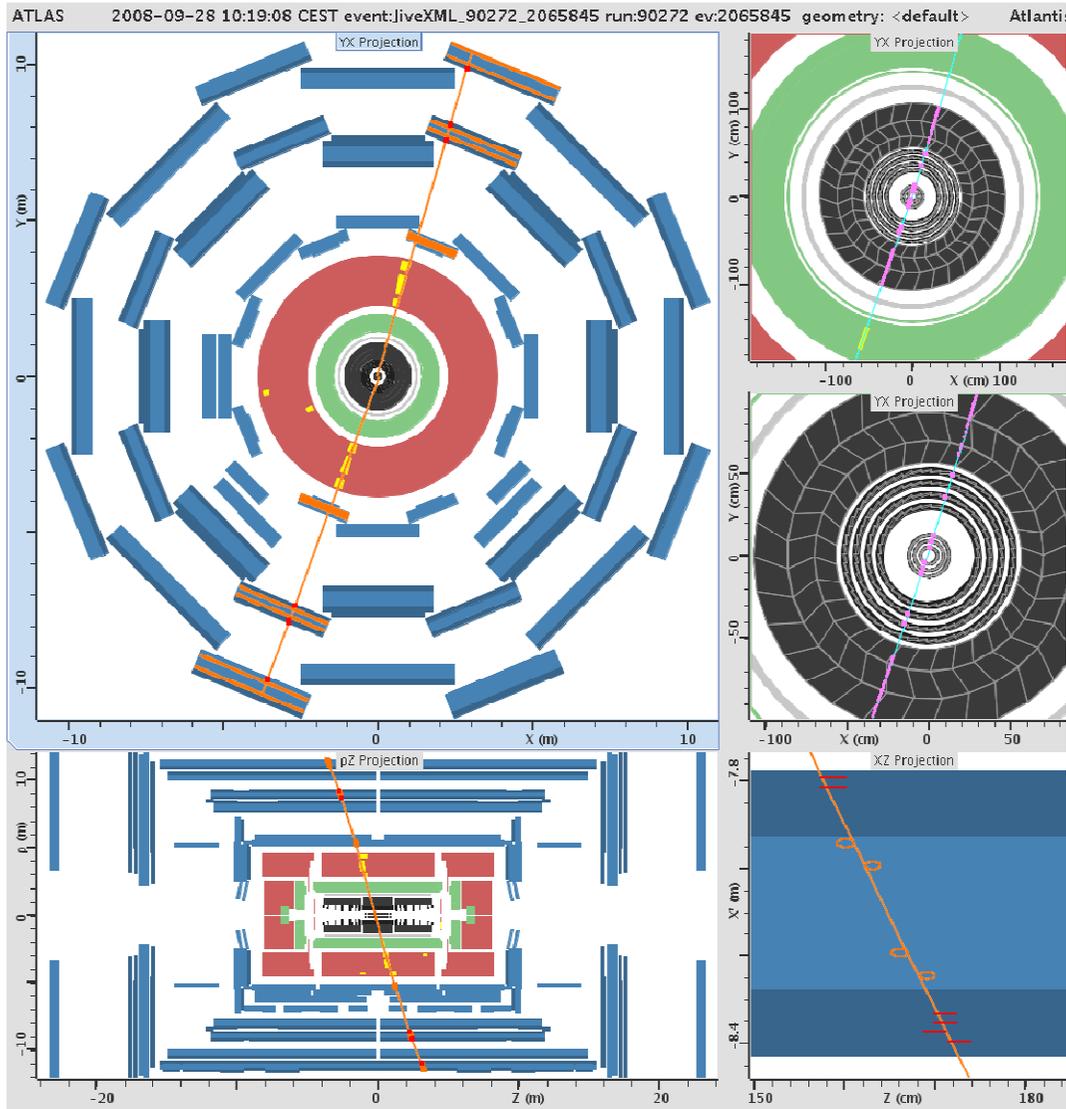
Energy deposited by muons



Muon Chambers Point Resolution



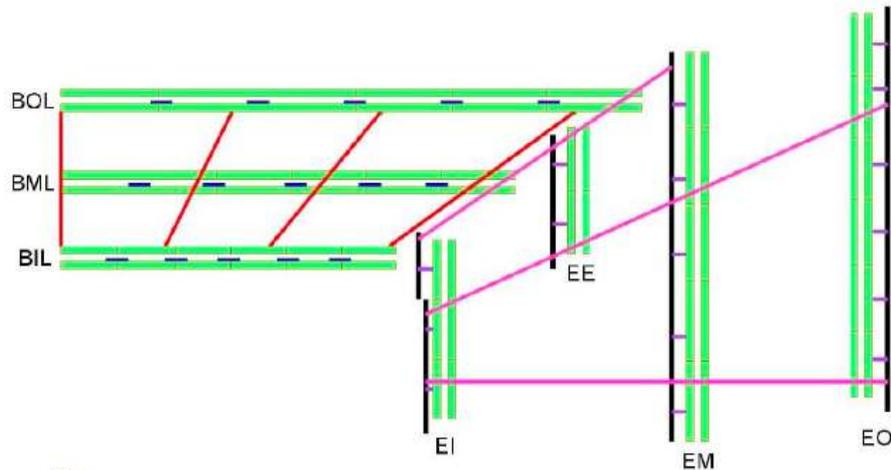
Cosmici in ATLAS



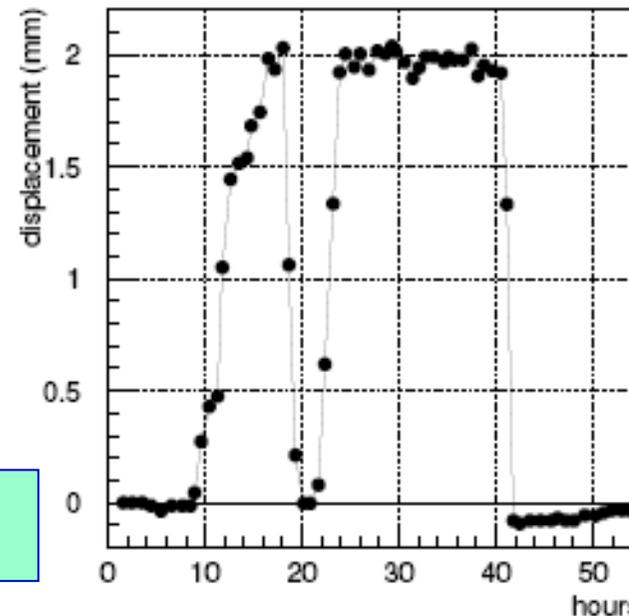
3 GeV/c energy loss
in the calorimeter

Allineamento: tutto si muove

I rivelatori si muovono nel tempo per effetto del campo magnetico e delle condizioni ambientali, es. variazioni di temperatura e umidità



Spostamenti di una delle bobine del magnete di ATLAS misurata dal sistema laser di allineamento delle camere mu



Procedure di allineamento: combinano sistemi ottici e tracce per seguire gli spostamenti recuperando la risoluzione intrinseca nella misura delle traiettorie delle particelle

- **Sistemi ottici (laser & LED): misura on-line, l'accuratezza è di pochi micron**
- **Tracce: ne servono tante, metodo non adatto a seguire movimenti "veloci" dei rivelatori**

Effetti disallineamento

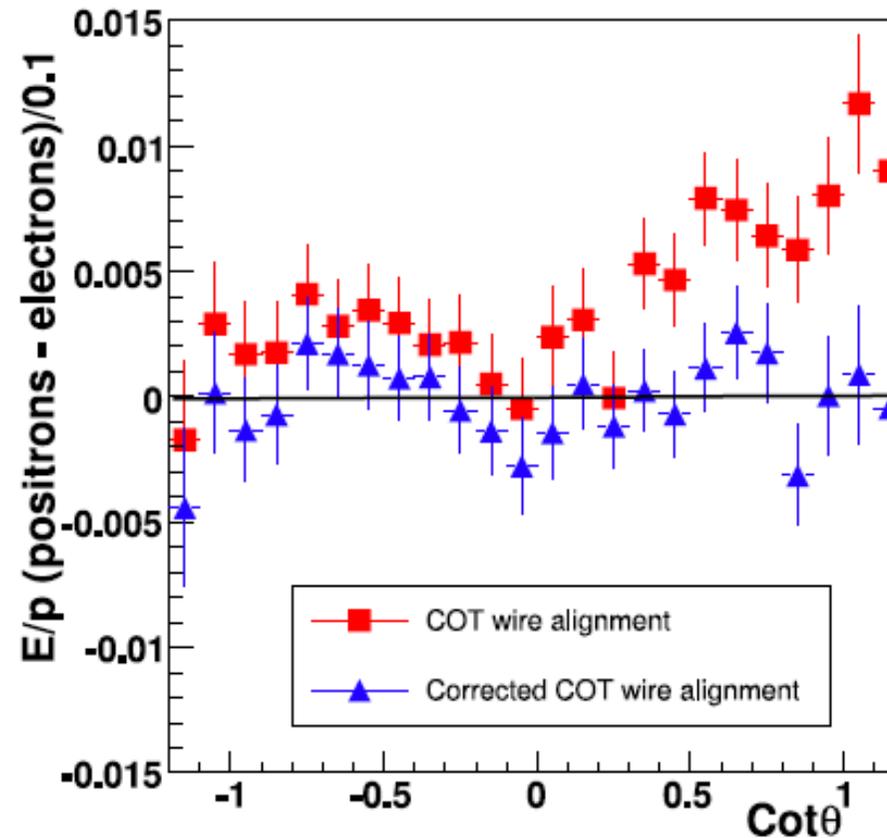
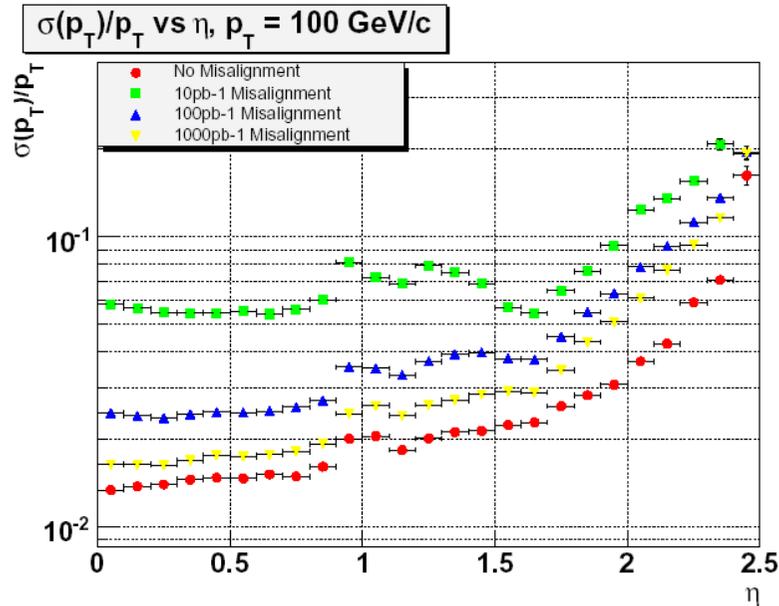


Fig. 3.10: Difference in E/p for positrons and electrons before and after a curvature correction applied to the alignment in CDF [18]

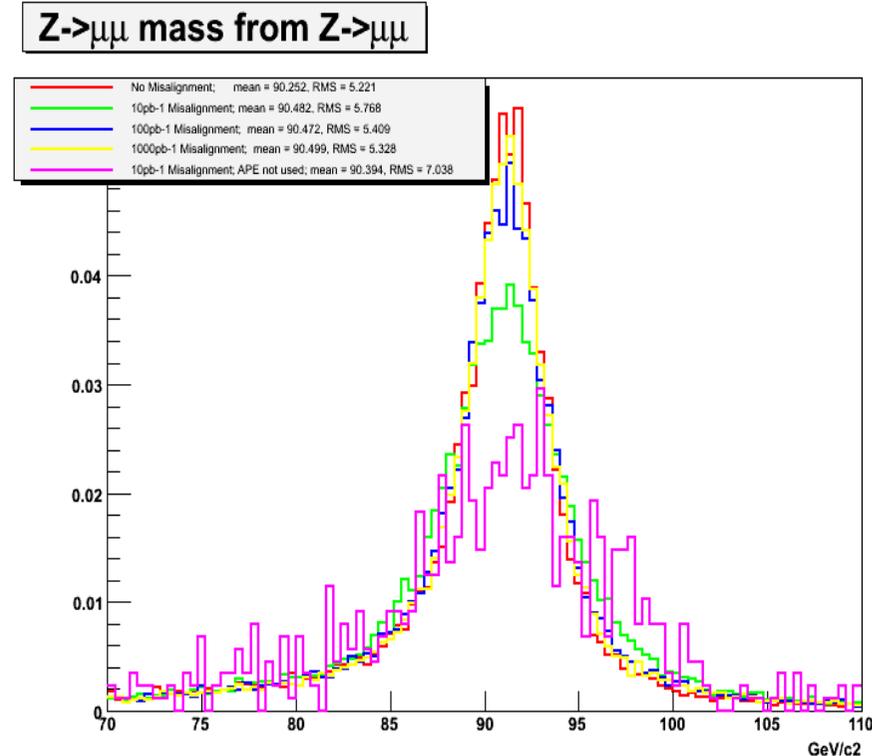
Allineamento Tracciatore



Pixel: 720 moduli (barile)
Si-Tracker: ~15,000 moduli

Goal $\leq 10 \mu\text{m}$ nei pixel
 $50 \mu\text{m}$ nelle strisce per 10 pb^{-1}
 con eventi di collisione
 Minimum bias/Jets
 J/Psi, Upsilon $\rightarrow \mu$
 W, Z $\rightarrow \mu$

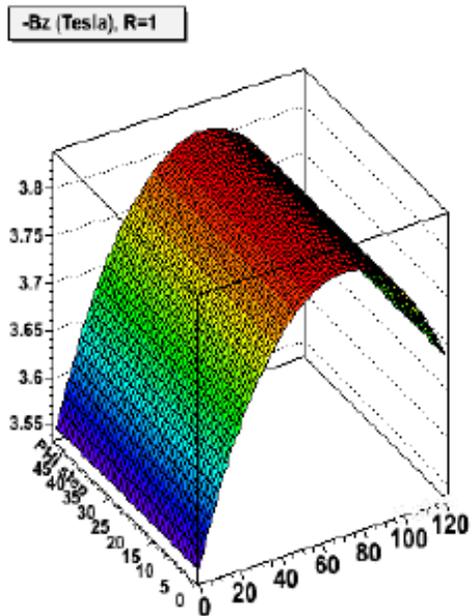
Esempio di studi di sistematica:
L'impatto di vari scenari di
misallineamento del Tracker sul picco
della Z Effetto a 10 pb^{-1} , 100 pb^{-1} , 1 fb^{-1}



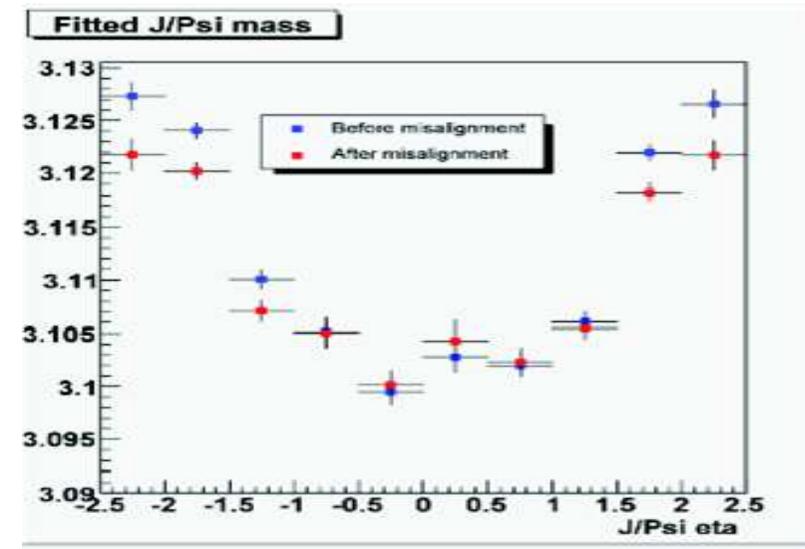
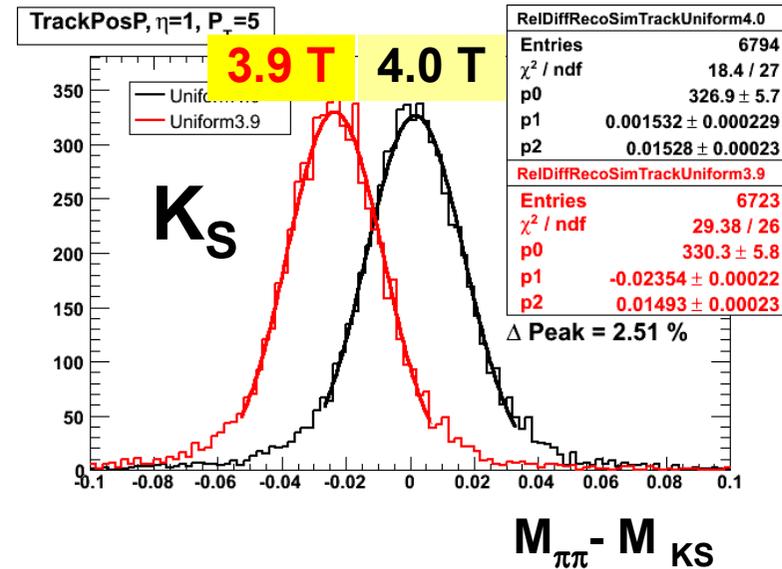
Campo Magnetico in CMS

- **Mappatura del campo effettuata in ottobre 2006**

– Precisione $\sim 5 \times 10^{-4}$



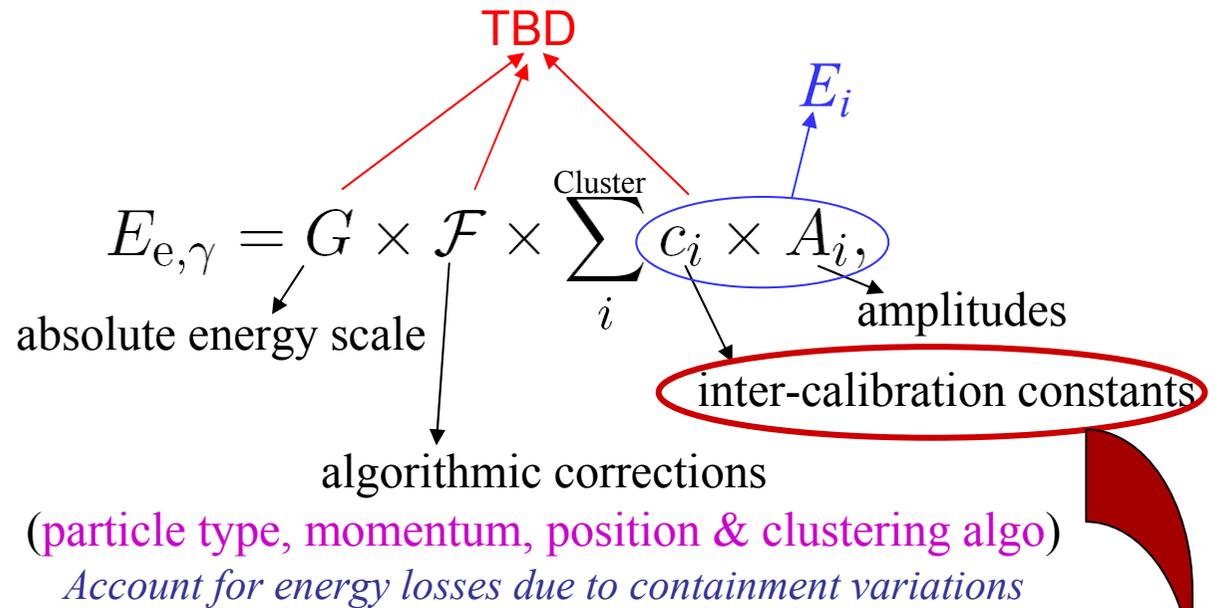
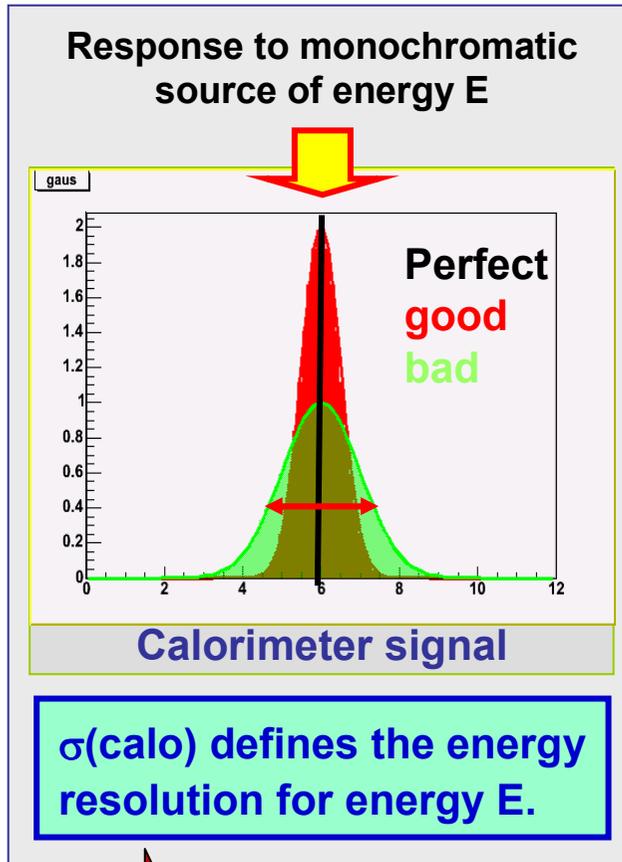
Idea: Determinare il campo magnetico usando il picco dei K_S e delle J/Ψ



ECAL: Calibrazione

Vale per calorimetri di precisione i.e.
 $\sigma(E)/\sqrt{E} \sim 2-3 \%$

From single channel electrical signal to $E_{e,\gamma}$

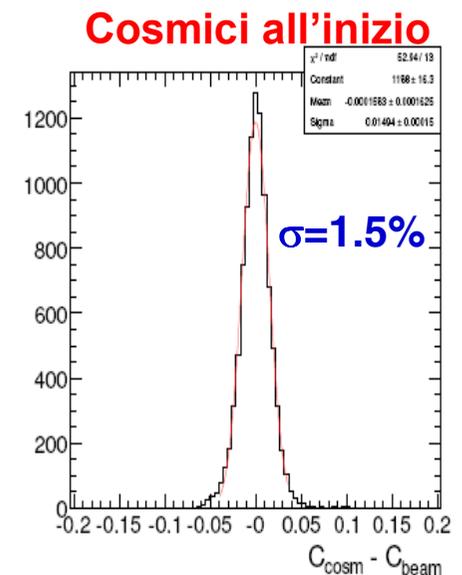
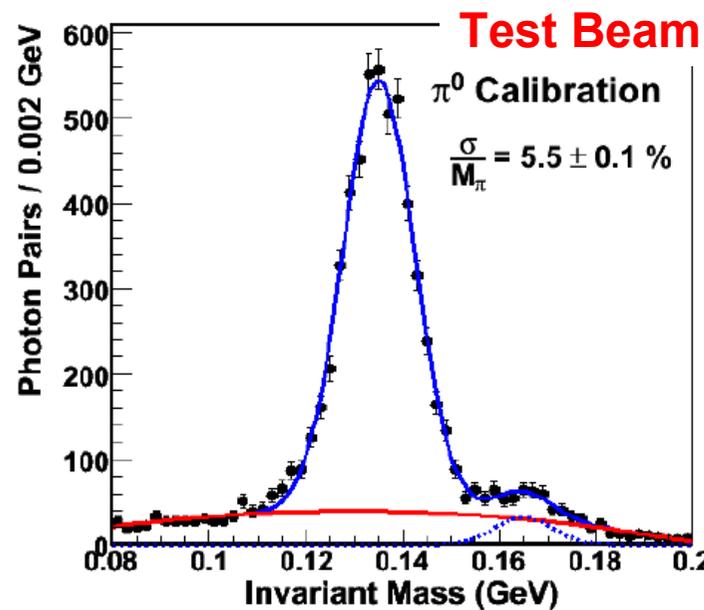
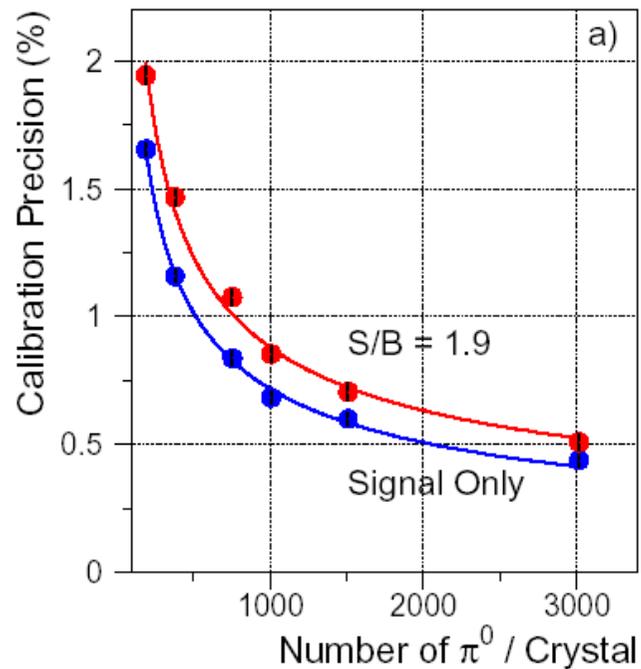
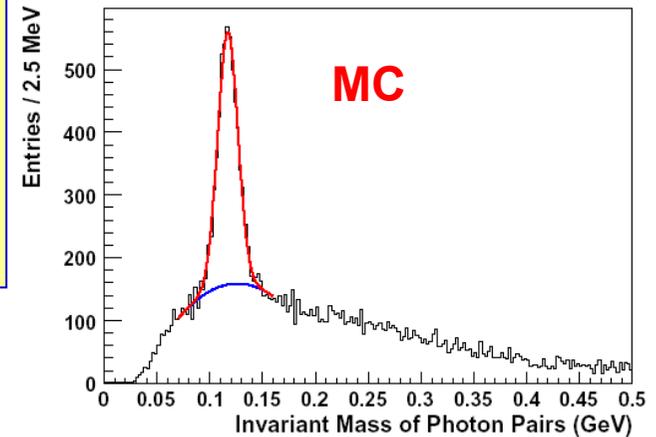


THIS IS THE KEY ISSUE TO MAINTAIN PHYSICS PERFORMANCE

Calibrazione di ECAL con π^0

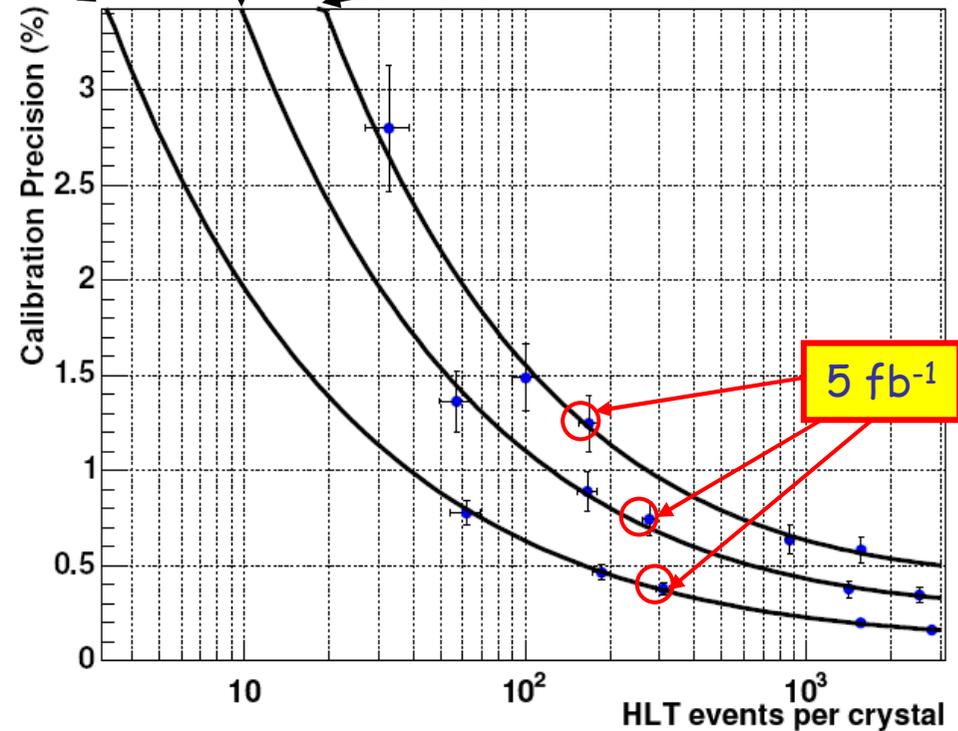
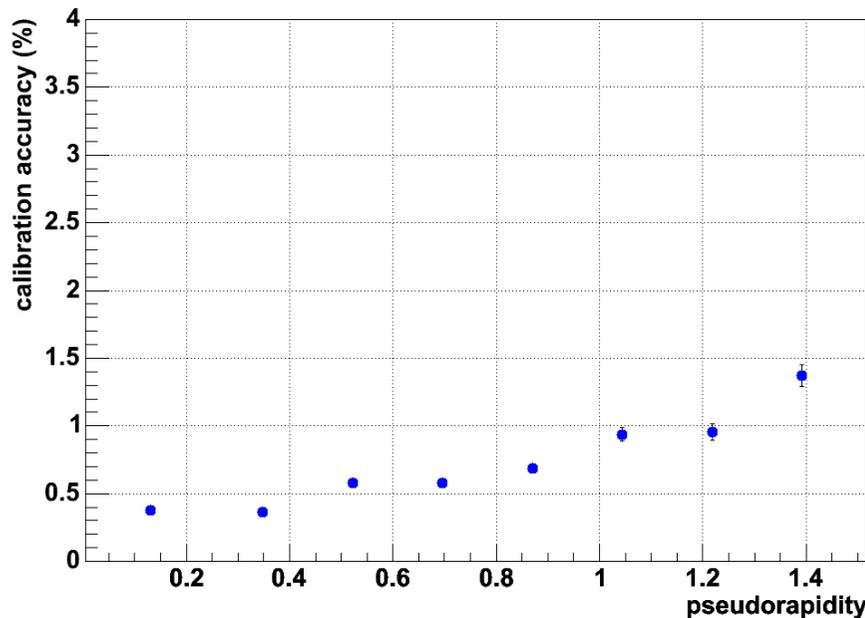
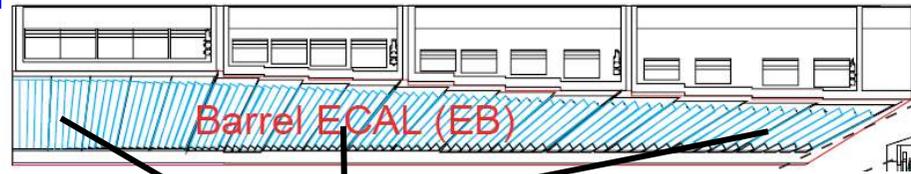
Frequenza di π^0 selezionati da da 10kHz di trigger QCD a L1

- 0.37 KHz a $\sim 2 \times 10^{33}$, S/B=1.5 (1.9 senza pileup)
 - $\sim 1.2\text{K } \pi^0$ per cristallo/giorno a 2×10^{33}
 - Intercalibrazione 1% in 1 giorno



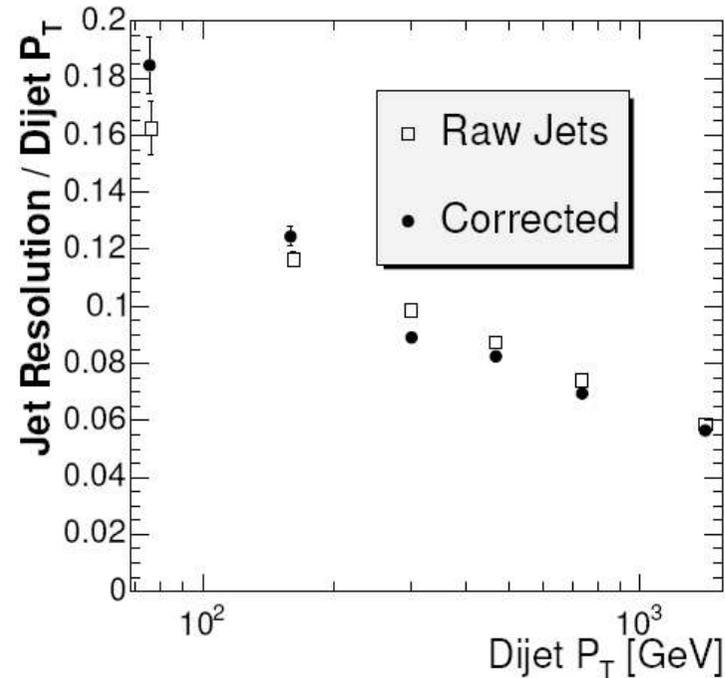
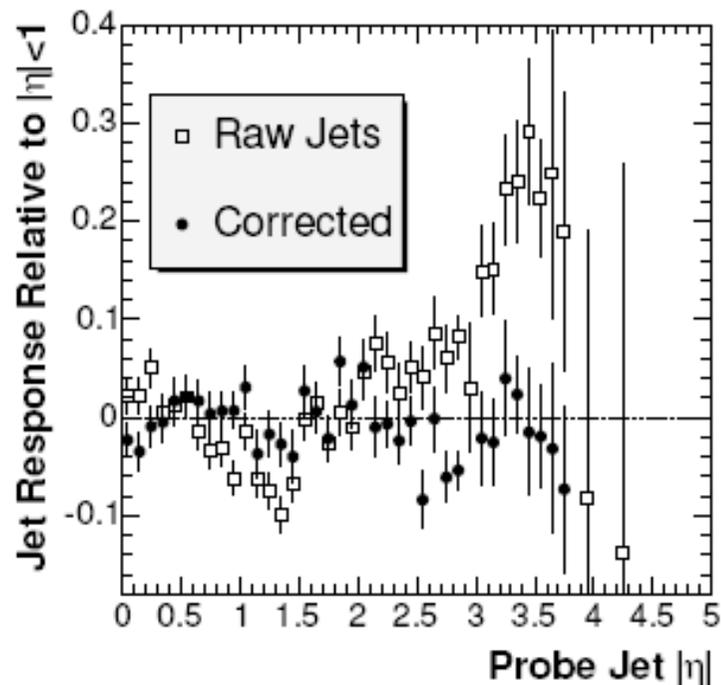
Calibration studies: $W \rightarrow e\nu$

A fully functional Tracker is assumed
 Method minimizes difference btw P_{TK}
 and E_{ECAL} .
 The main difficulty is the
 Bremsstrahlung in the tracker material
 in front of the ECAL
 Event selection aimed at rejecting
 events with high Bremsstrahlung



The calibration precision attained depends on η .

Equalizzazione dei Jet



- We can quickly equalize at “ low Et” and then we run out of statistics
- In a few days reach an absolute calibration at ~5% with jet – gamma balancing
- In both cases need MC to extrapolate to high energy jets

MET: un indicatore di nuova fisica!

**Missing Energy searches only after
you have understood the detector**

Measuring Missing Energy is an experimental challenge because all “anomalies” in the measured event will contribute to the missing energy tail.

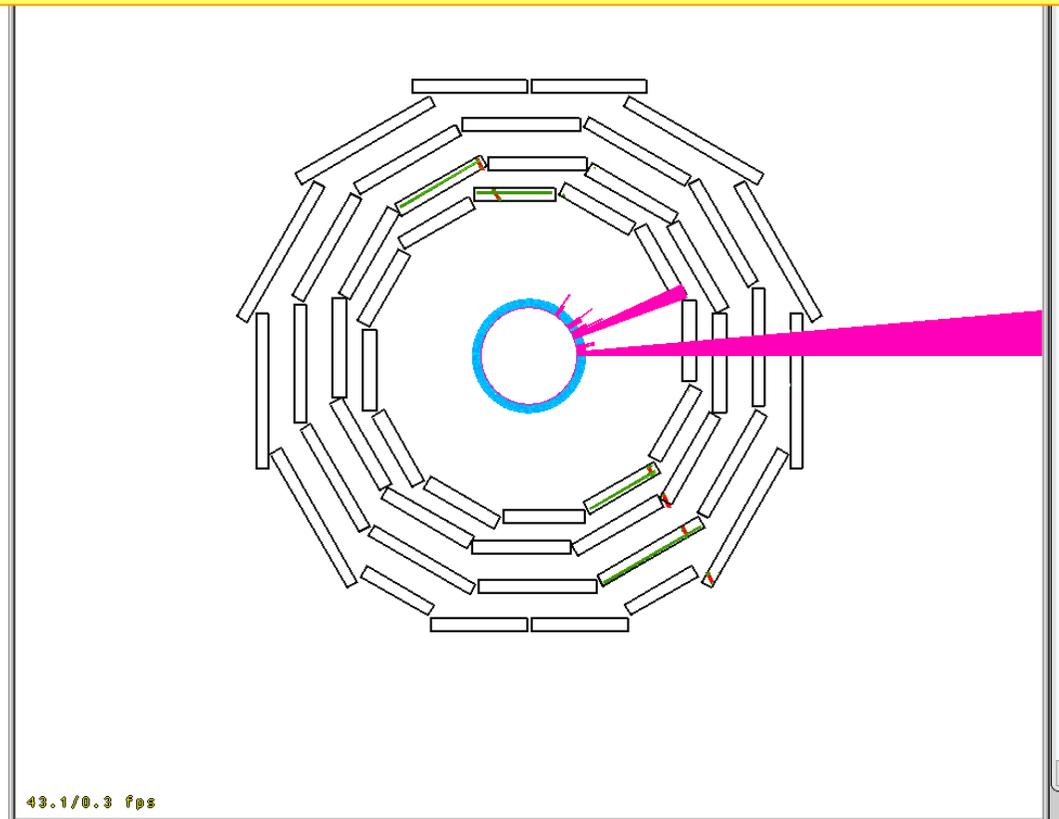
Unfortunately the “experimental” anomalies are more frequent than the “physics” anomalies !

Sorgenti primarie di MET:

- **Bakground dal fascio**
- **Cosmici**
- **Problemi nel rivelatore**

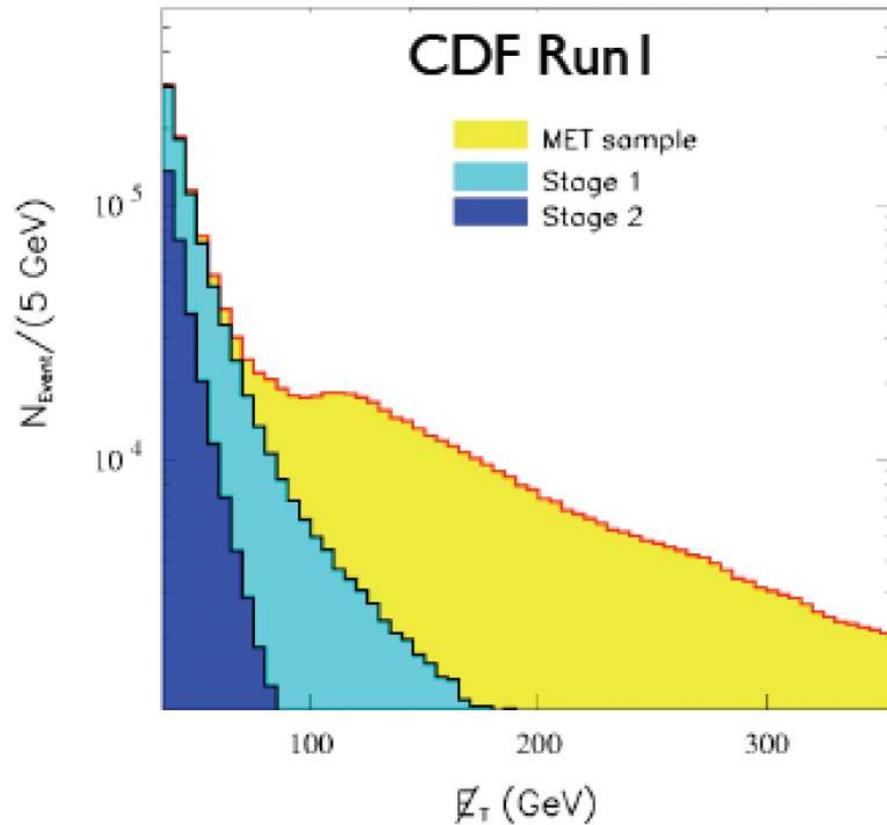
Eventi cosmici

Un perfetto segnale di SUSY se per qualche motivo sfuggono gli HIT nelle camere a mu (può capitare)!

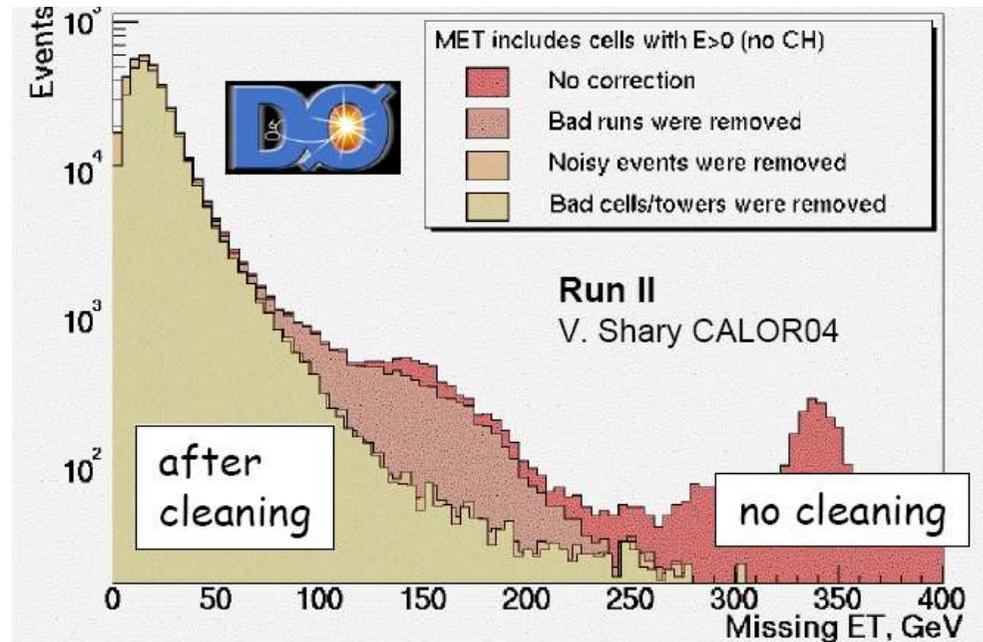


Ma i cosmici non sono in tempo con il Bunch Crossing...

MET & Detector

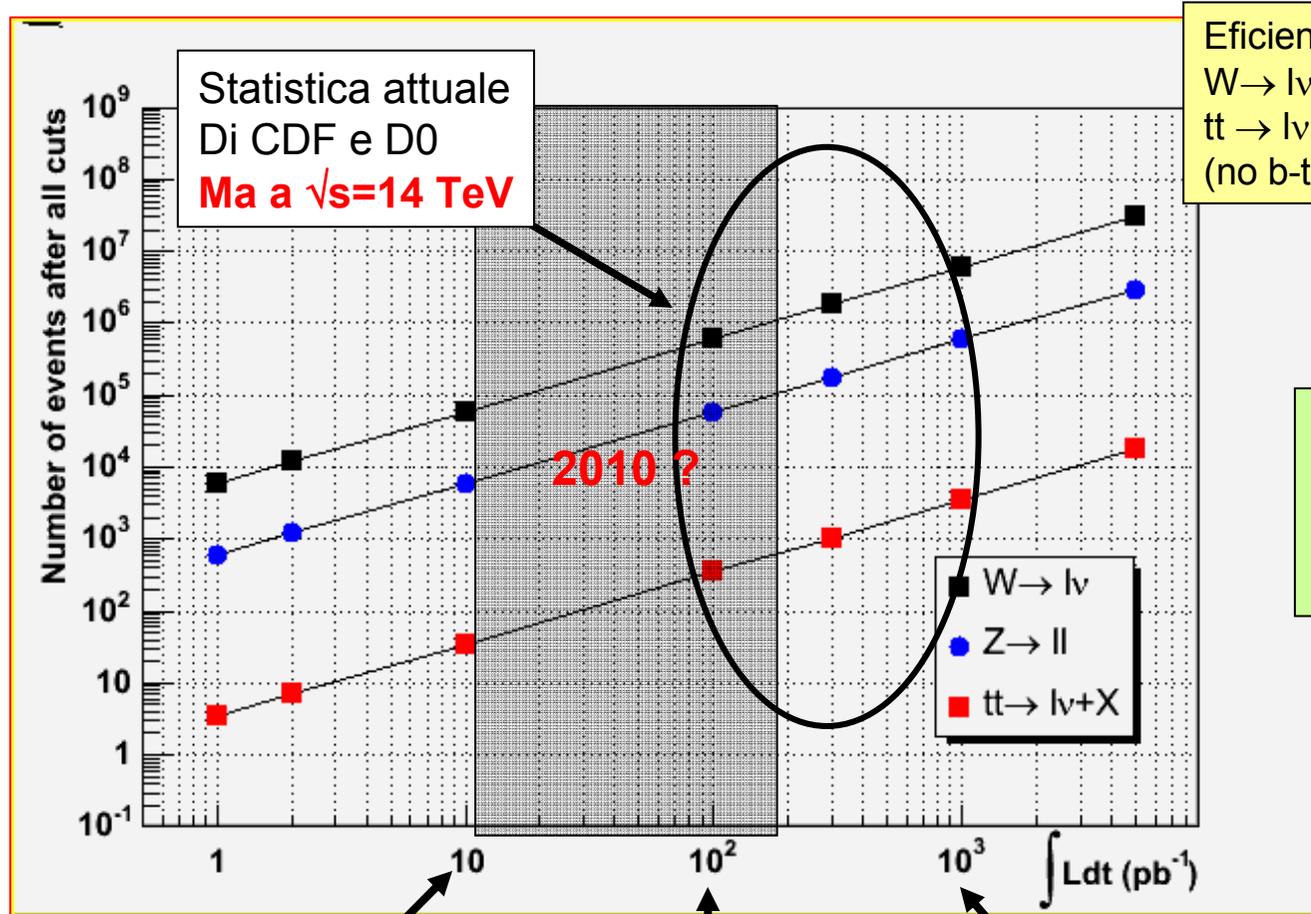


Evts Passing Trigger: **2.5M**
 Evts After Cleanup: **300K**



L'esperienza di esperimenti precedenti

Standard Model: capiamo il rivelatore?



Efficienza di selezione:
 $W \rightarrow l\nu, Z \rightarrow ll$: 20%
 $tt \rightarrow l\nu+X$: 1.5%
 (no b-tag, inside mass bin)

+ minimum-bias e jets
 (10^7 eventi in 2 settimane
 di presa dati con 20% della
 trigger bandwidth dedicata)

$10 pb^{-1} \equiv 1$ mese a 10^{30}
 < 2 settimane a 10^{31} ,
 $\epsilon=50\%$

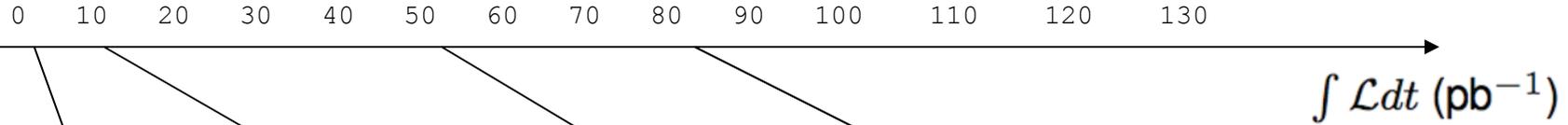
$100 pb^{-1} \equiv$ qualche giorno
 a 10^{32} , $\epsilon=50\%$

$1 fb^{-1}$

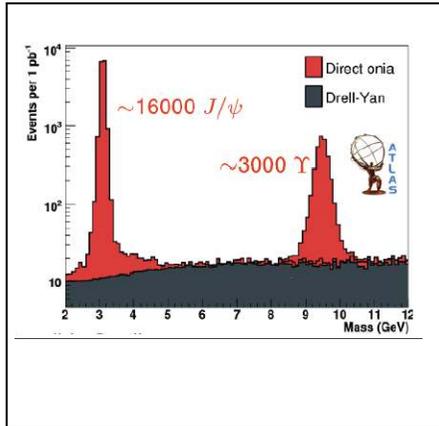
**Misure di sez. d'urto
 W, Z e Top a $\sqrt{s}=14$ TeV**

Leptoni: verso le scoperte

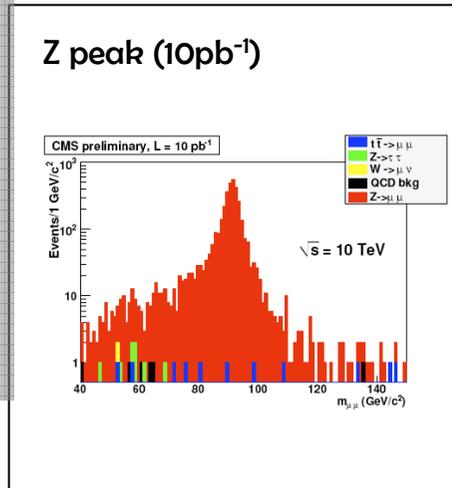
Roadmap towards discoveries with leptons at LHC



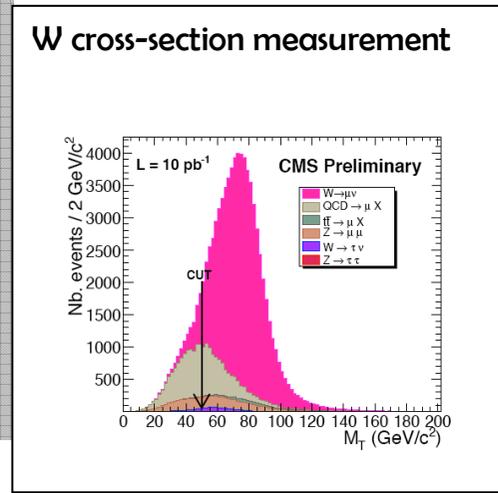
J/Ψ & Υ resonances (few pb⁻¹)



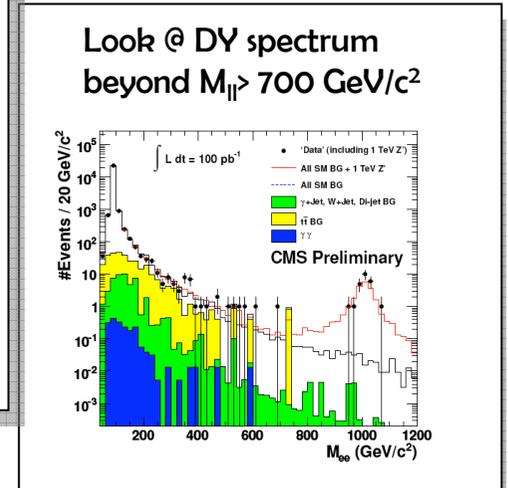
Z peak (10pb⁻¹)



W cross-section measurement

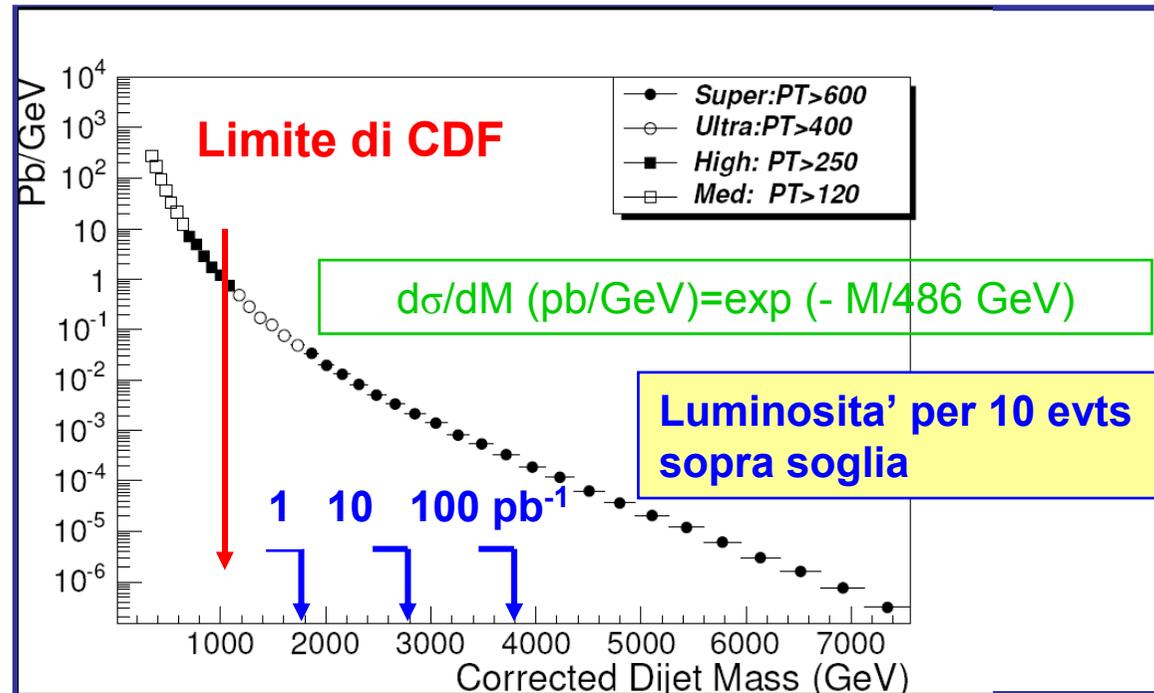


Look @ DY spectrum beyond $M_{ll} > 700 \text{ GeV}/c^2$



Courtesy of P. Meridiani

JET: Prime Misure

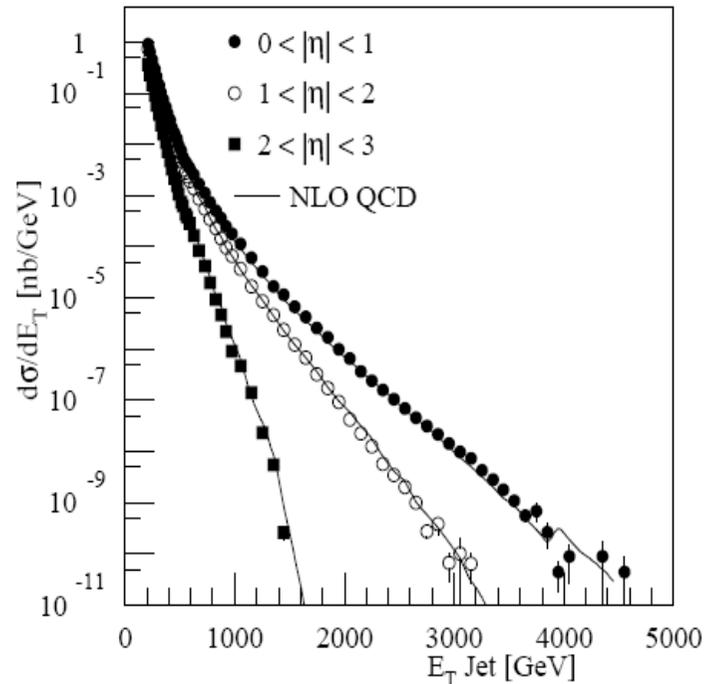


Tuttavia e' importante che la risposta del detector sia capita il prima possibile
Occorre passare attraverso la riscoperta della fisica del Modello Standard

Prime Misure

E.g. Jet Physics

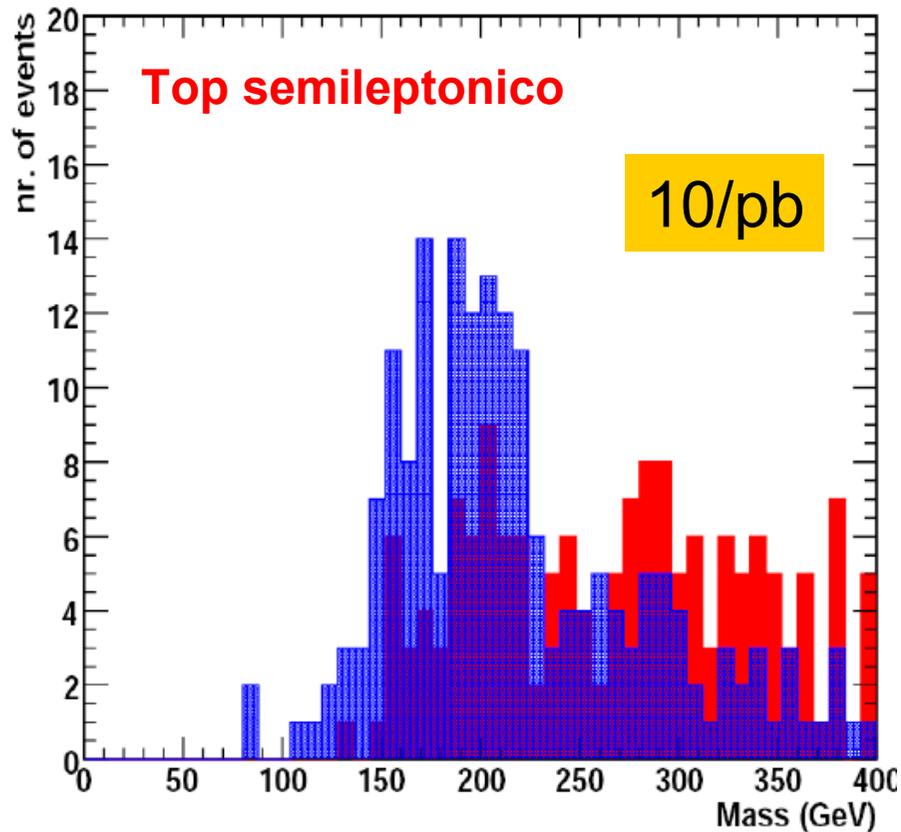
Huge cross sections:
e.g. for $1 \text{ fb}^{-1} \sim 10000$ events with $E_T > 1 \text{ TeV}$
100 events with $E_T > 2 \text{ TeV}$



- PDFs
- Jet shape
- Underlying event
- α_s
- Diffraction
- low-x
- New physics?
- ...

• Understanding QCD at $O(10) \text{ TeV}$ will be one of the first topics at LHC

Riscoperta del Top dai primi dati



$tt \rightarrow bW \ bW \rightarrow bl\nu \ bjj$

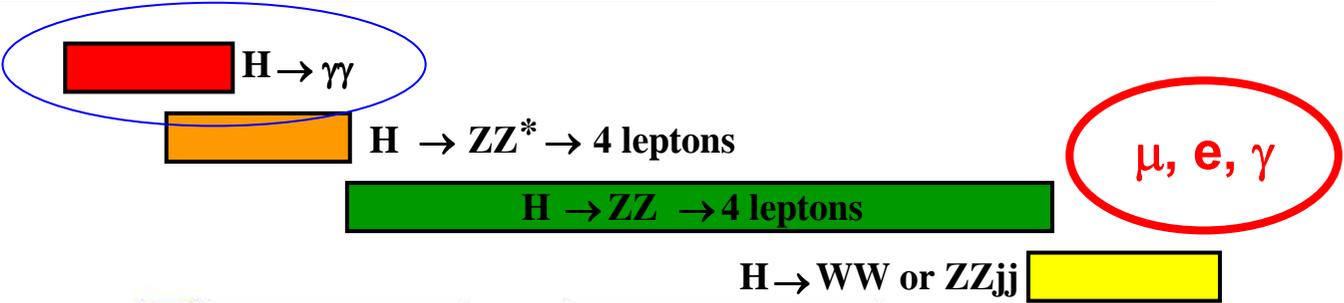
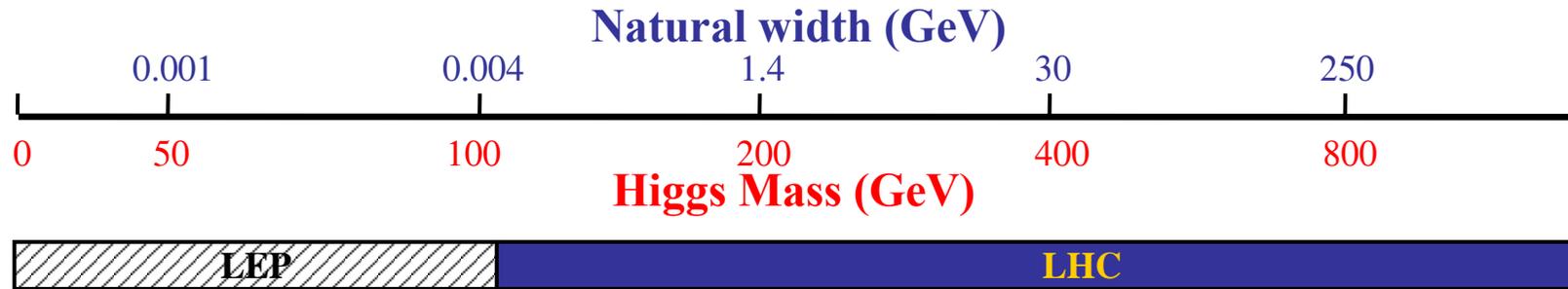
Campione da usare per:

- Commissioning del b-tagging
- Scala di energia dei Jet ($W \rightarrow jj$)
- Comprensione E_T^{miss}
- Aggiustamento MC
-

Il Goal

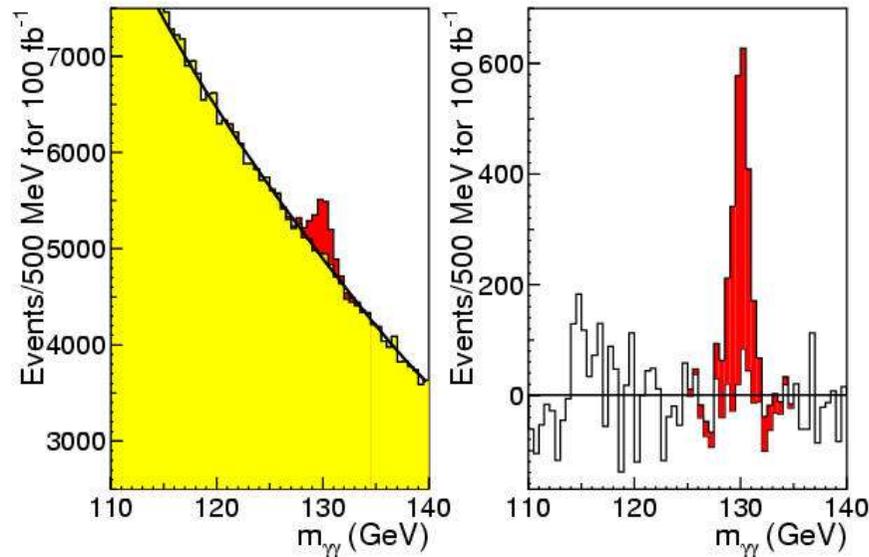
La caccia all' HIGGS
(rivelatore sotto controllo)

Large Hadron Collider: Higgs hunt



LEP observed an excess of events around 115 GeV

Alghero 02-06-09



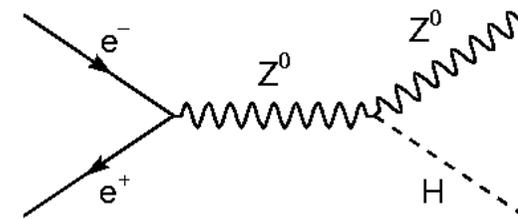
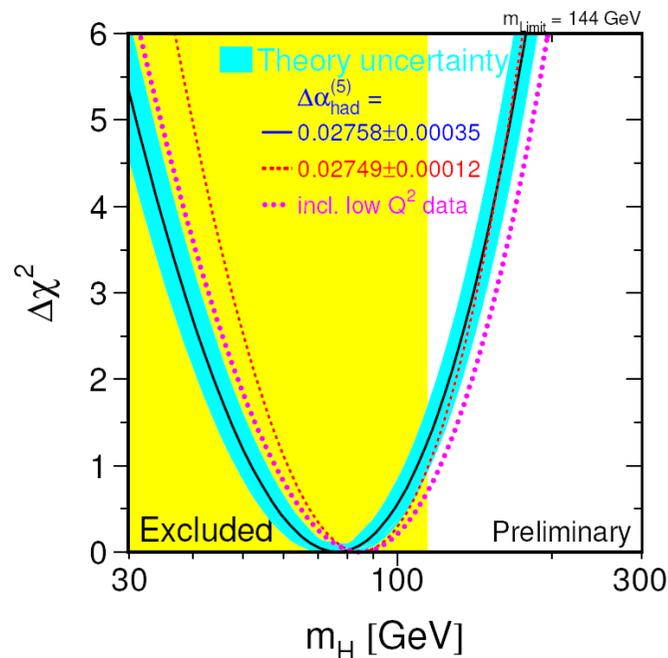
Only precision in γ detection will tell a peak ($H \rightarrow \gamma\gamma$ signal) from a huge background

M. Diemoz - INFN Roma



The Higgs Boson today

- Needed in the Standard Model to generate particle masses
- Mass not predicted by theory, except that $m_H < \sim 1000 \text{ GeV}$
- $m_H > 114.4 \text{ GeV}$ from direct searches at LEP Higgsstrahlung
- Indirect limits from electroweak precision measurements (LEP, Tevatron and other experiments....)



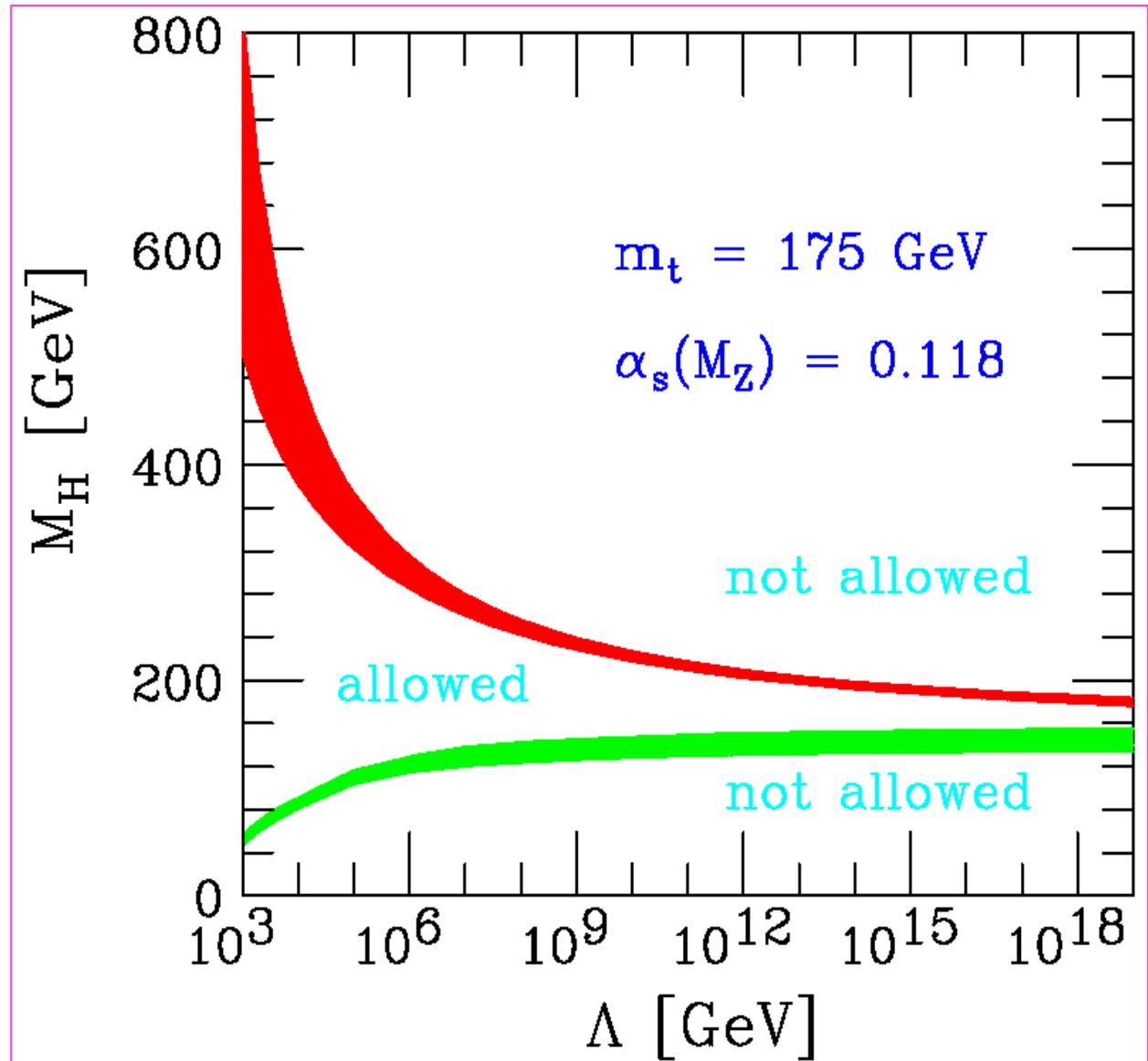
Results of the precision el.weak measurements:

$$M_H = 80 (+36) (-26) \text{ GeV}/c^2$$

$$M_H < 193 \text{ GeV}/c^2 \quad (95 \% \text{ CL})$$

Limits from Theory

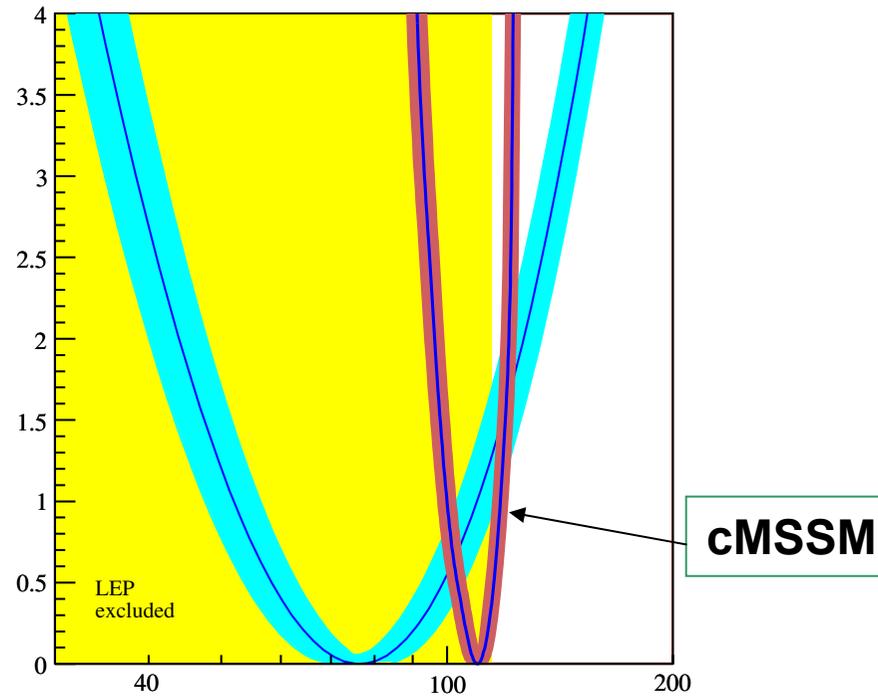
- Consistency of Standard Model up to a mass scale Λ gives an upper limit on M_H
- Vacuum stability gives a lower limit on M_H



What about SUSY Higgs?

How do the constraints look like in a supersymmetric theory ?

O. Buchmüller et al., arXiv:0707.3447

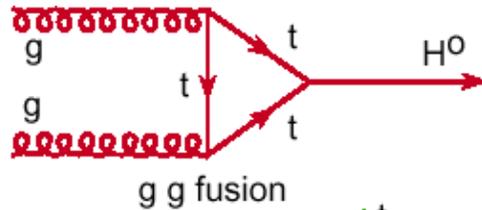


$$m_h = 110 (+8) (-10) \pm 3 \text{ (theo) GeV}/c^2$$

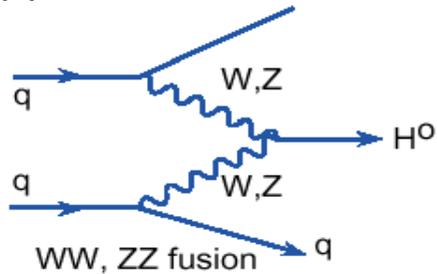
Comunque occhio alla regione di bassa massa!!!

Higgs Boson Production @ LHC

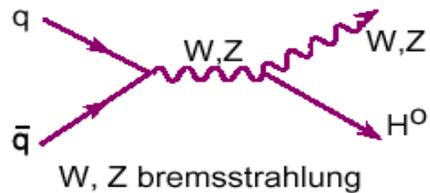
(i) Gluon fusion



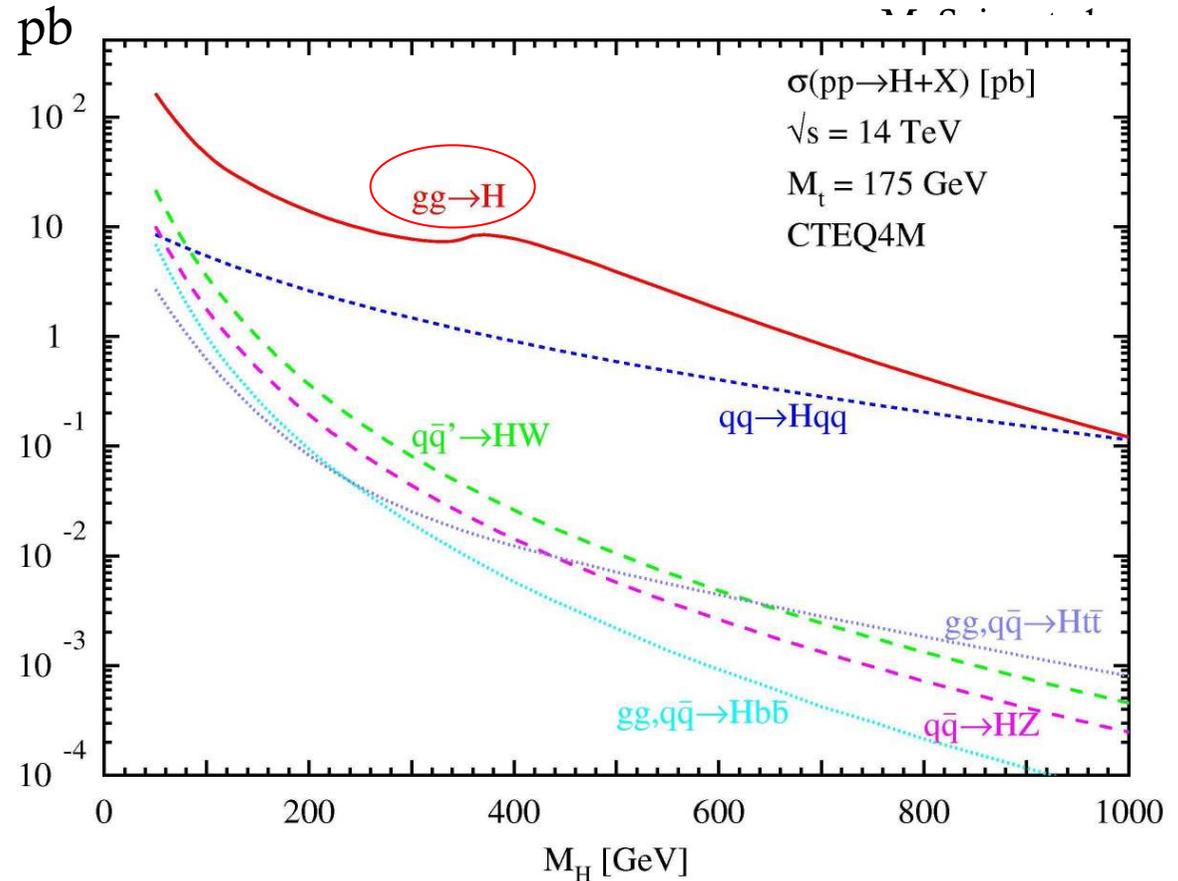
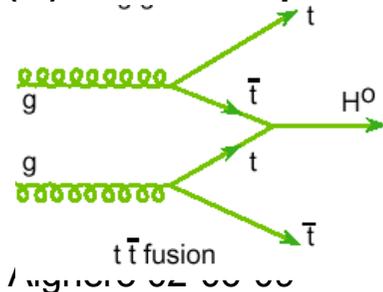
(ii) Vector boson fusion



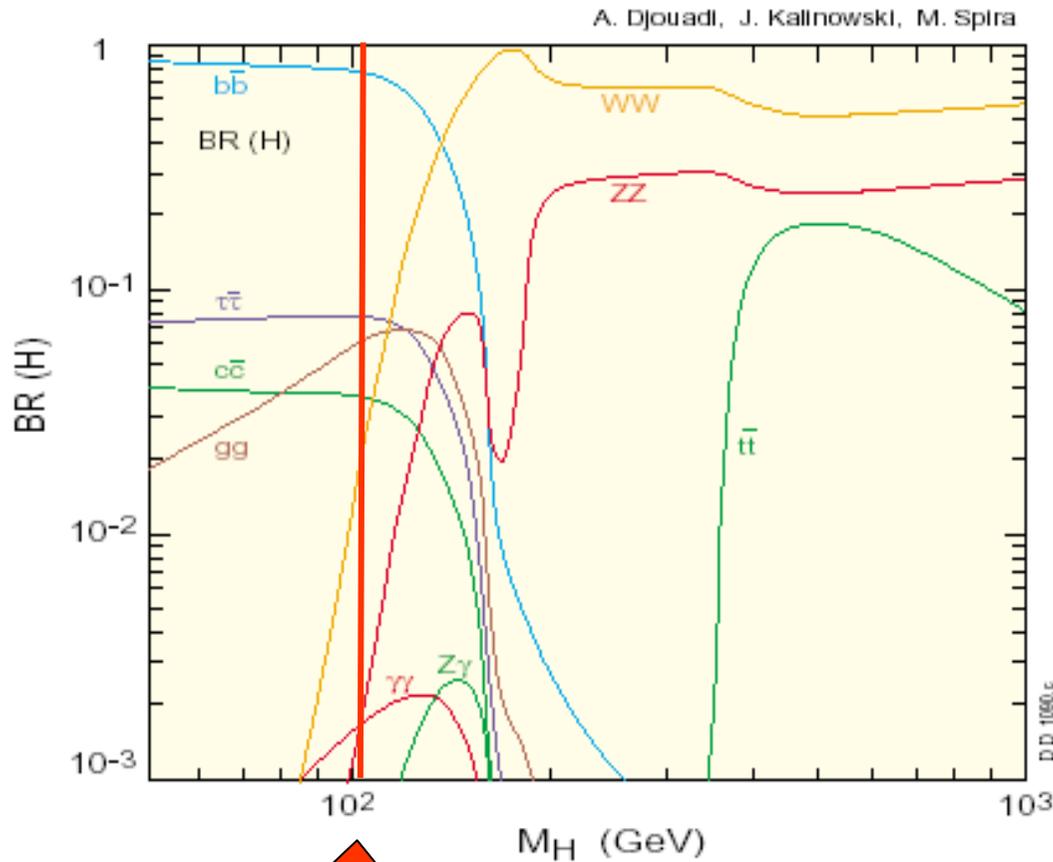
(iii) Associated production W/Z



(iv) Associated production tH



Higgs Boson Decays



LEP LIMIT

At high mass:

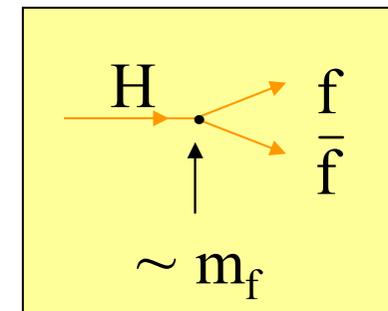
Lepton final states are essential
(via $H \rightarrow WW, ZZ$)

At low mass:

Lepton and Photon final states
(via $H \rightarrow WW^*, ZZ^*, \gamma\gamma$)

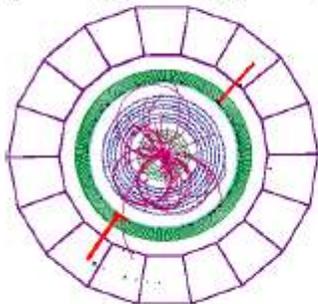
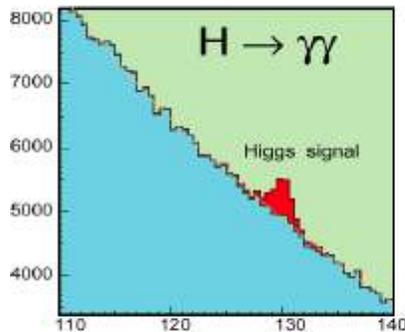
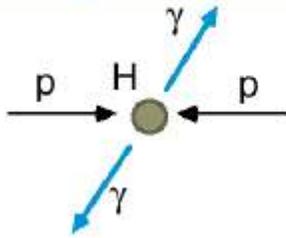
Tau final states

The dominant **bb decay mode** is only useable in the associated production mode (ttH)
(due to the huge QCD jet background)



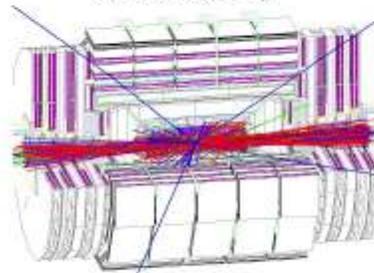
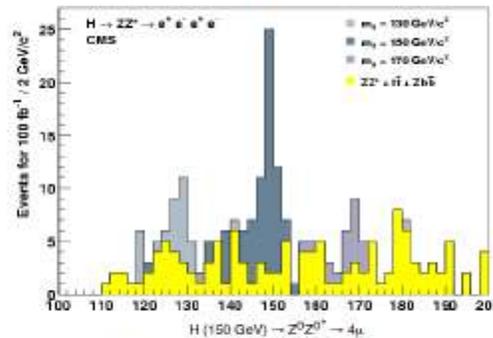
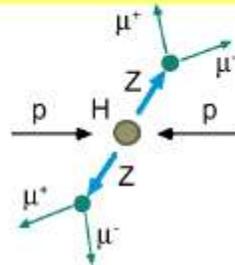
Regioni di massa

Low $M_H < 140 \text{ GeV}/c^2$



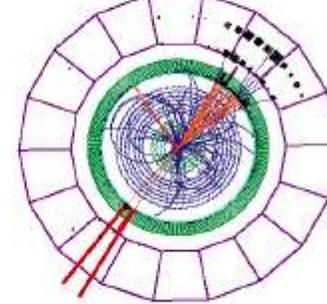
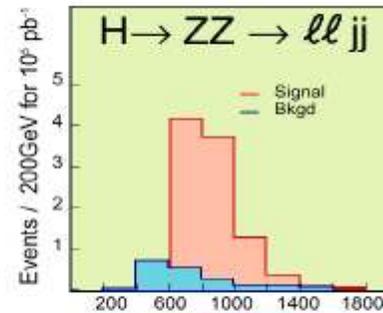
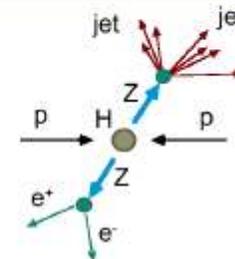
good e-m energy resolution

Medium $130 < M_H < 500 \text{ GeV}/c^2$



good μ ID and mom resolution in a wide en range

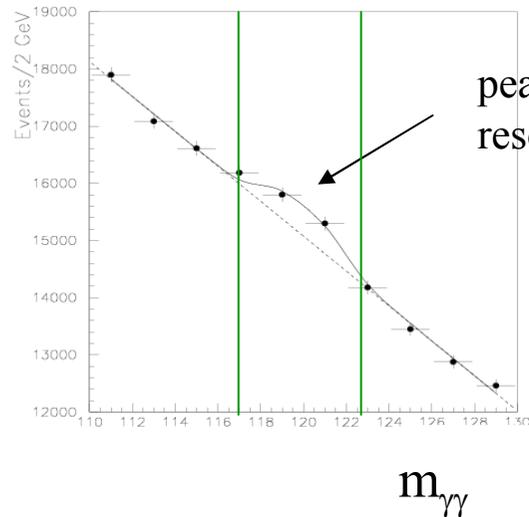
High $M_H > \sim 500 \text{ GeV}/c^2$



good dijet mass resol. fine segmentation in had. calo.

How can one claim a discovery ?

Suppose a new narrow particle $X \rightarrow \gamma\gamma$ is produced:



Signal significance:

$$S \sim N_S / \sqrt{N_B}$$

N_S = number of signal events

N_B = number of background events

} in peak region

$\sqrt{N_B} \equiv$ error on number of background events, for large numbers
otherwise: use Poisson statistics

**$S > 5$: the signal is larger than 5 times the error on background.
Gaussian probability that background fluctuates up by more than 5σ : $10^{-7} \rightarrow$ **discovery****

Two critical parameters to maximize S

1. Detector resolution:

If σ_m increases by e.g. a factor of two, then need to enlarge peak region by a factor of two to keep the same number of signal events

→ N_B increases by ~ 2
(assuming background flat)

⇒ $S = N_S/\sqrt{N_B}$ decreases by $\sqrt{2}$

$$\Rightarrow S \sim 1 / \sqrt{\sigma_m}$$

“A detector with better resolution has larger probability to find a signal”

Note: only valid if $\Gamma_H \ll \sigma_m$. If Higgs is broad detector resolution is not relevant.

$$m_H = 100 \text{ GeV} \rightarrow \Gamma_H \sim 0.001 \text{ GeV}$$

$$m_H = 200 \text{ GeV} \rightarrow \Gamma_H \sim 1 \text{ GeV}$$

$$m_H = 600 \text{ GeV} \rightarrow \Gamma_H \sim 100 \text{ GeV} \quad \Gamma_H \sim m_H^3$$

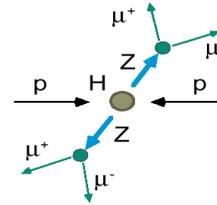
2. Integrated luminosity :

$$\left. \begin{array}{l} N_S \sim L \\ N_B \sim L \end{array} \right\}$$

$$\Rightarrow S \sim \sqrt{L}$$

H \rightarrow ZZ(*) \rightarrow $\ell\ell\ell\ell$

Signal: $\sigma \cdot \text{BR} = 5.7 \text{ fb}$ ($m_H = 140 \text{ GeV}$)



$P_T(1,2) > 20 \text{ GeV}$

$P_T(3,4) > 7 \text{ GeV}$

$|\eta| < 2.5$

Isolated leptons

$M(\ell\ell) \sim M_Z$

$M(\ell\ell') \sim < M_Z$

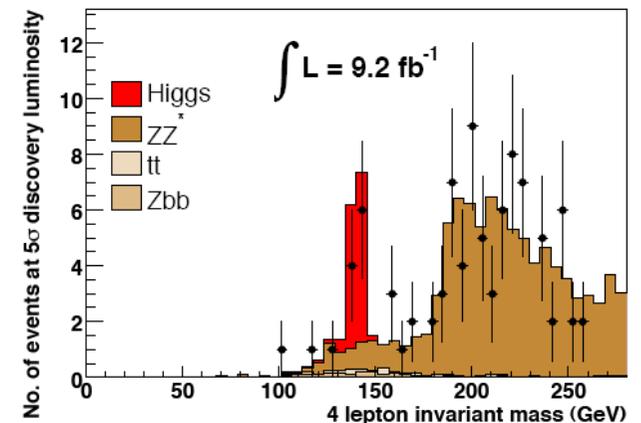
Background: Top production
 $tt \rightarrow Wb Wb \rightarrow \ell\nu c\ell\nu \ell\nu c\ell\nu$
 $\sigma \cdot \text{BR} \approx 1300 \text{ fb}$

Associated production Z bb

$Z bb \rightarrow \ell\ell c\ell\nu c\ell\nu$

Background rejection: Leptons from b-quark decays
 \rightarrow non isolated
 \rightarrow do not originate from primary vertex
 (B-meson lifetime: $\sim 1.5 \text{ ps}$)

Dominant background after isolation cuts: ZZ continuum

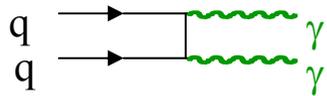


Discovery potential in mass range from ~ 130 to $\sim 600 \text{ GeV}/c^2$

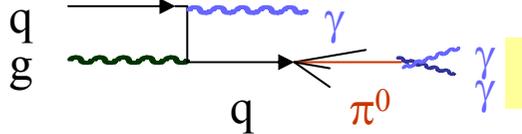
H → γγ

Main backgrounds:

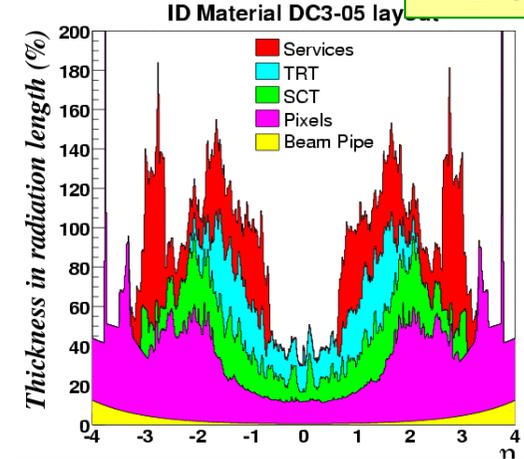
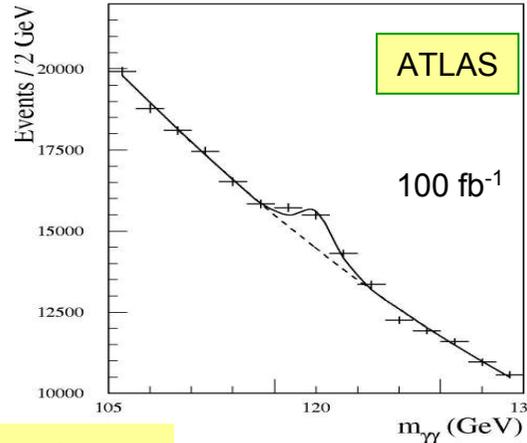
γγ irreducible background



γ-jet and jet-jet (reducible)



shower shape

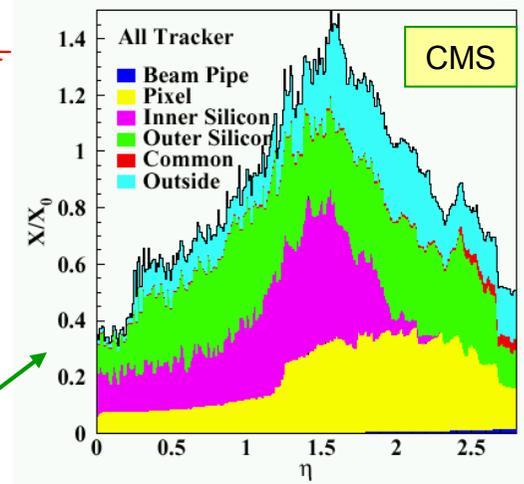


$\sigma_{\gamma j+jj} \sim 10^6 \sigma_{\gamma\gamma}$ with large uncertainties
 → need $R_j > 10^3$ for $\epsilon_\gamma \approx 80\%$ to get
 $\sigma_{\gamma j+jj} \ll \sigma_{\gamma\gamma}$

$$S = \frac{N_s}{\sqrt{N_B}}$$

Main exp. tools for background suppression:

- photon identification
- γ / jet separation (calorimeter + tracker)
- note: also converted photons need to be reconstructed (large material in LHC silicon trackers)

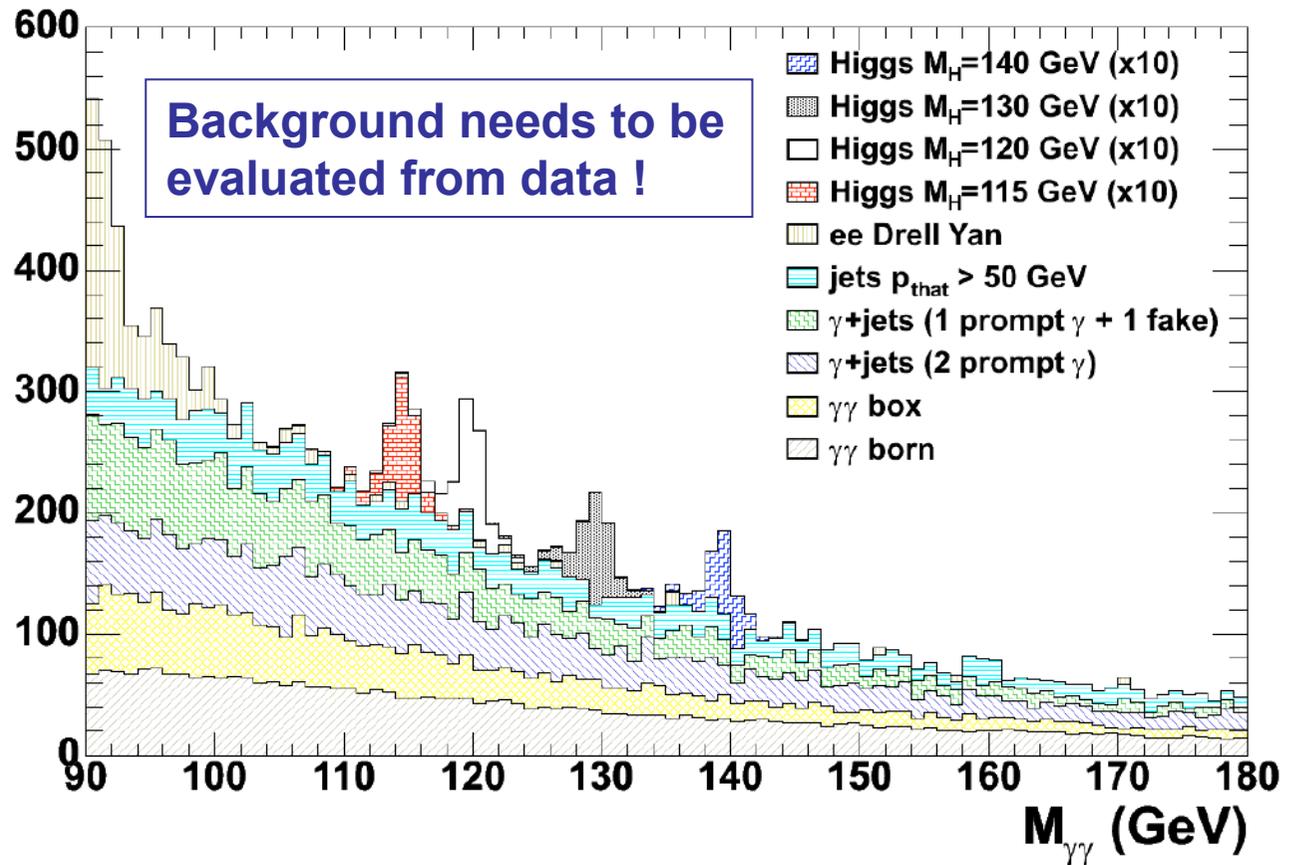
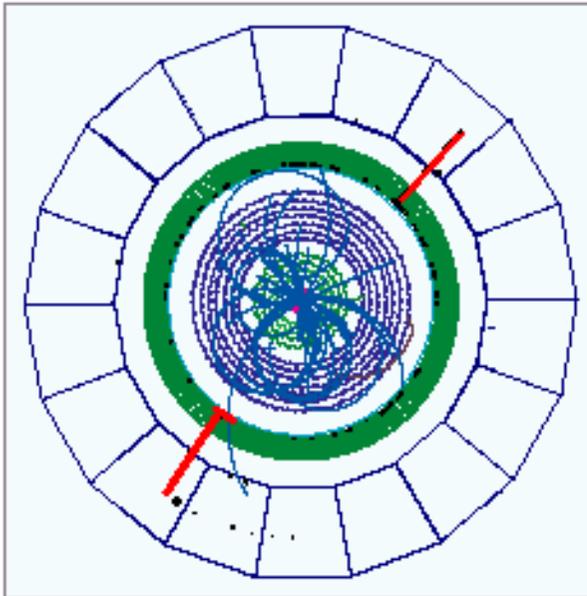


CMS: fraction of converted γs
 Barrel region: 42.0 %
 Endcap region: 59.5 %

→ most demanding channel for EM calorimeter performance :
 energy and angle resolution, acceptance, γ / jet and γ / π⁰ separation

How it might look like

- **Reducible** background (γ +jet)
- **Irreducible** background (two photons, from quark-antiquark annihilation, or gluon-gluon through box diagrams)



H → γγ : ECAL benchmark

$$\Gamma_H (m_H \cong 100 \text{ GeV}) \sim 2 - 100 \text{ MeV} \quad \longrightarrow \quad \Gamma_H / m_H \leq 10^{-3}$$

$$m_{\gamma\gamma} = 2 E_1 E_2 (1 - \cos\theta_{\gamma\gamma}) \quad \text{Precision given by experimental resolution}$$

$$\frac{\sigma_m}{m} = \frac{1}{2} \left[\left(\frac{\sigma_1}{E_1} \right)^2 + \left(\frac{\sigma_2}{E_2} \right)^2 + \left(\frac{\sigma_\theta}{\text{tg}\theta/2} \right)^2 + \dots \right]^{1/2}$$

$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

Homogeneous calo a can be ~ 2%,
to match it for $E_\gamma \sim 50 \text{ GeV}$:

$c \sim 0.5\%$ **CMS**
 $b \sim 200 \text{ MeV}$
 and an angular resolution
 $\sigma_\theta \sim 50 \text{ mrad}/\sqrt{E} \text{ (vertex)}$

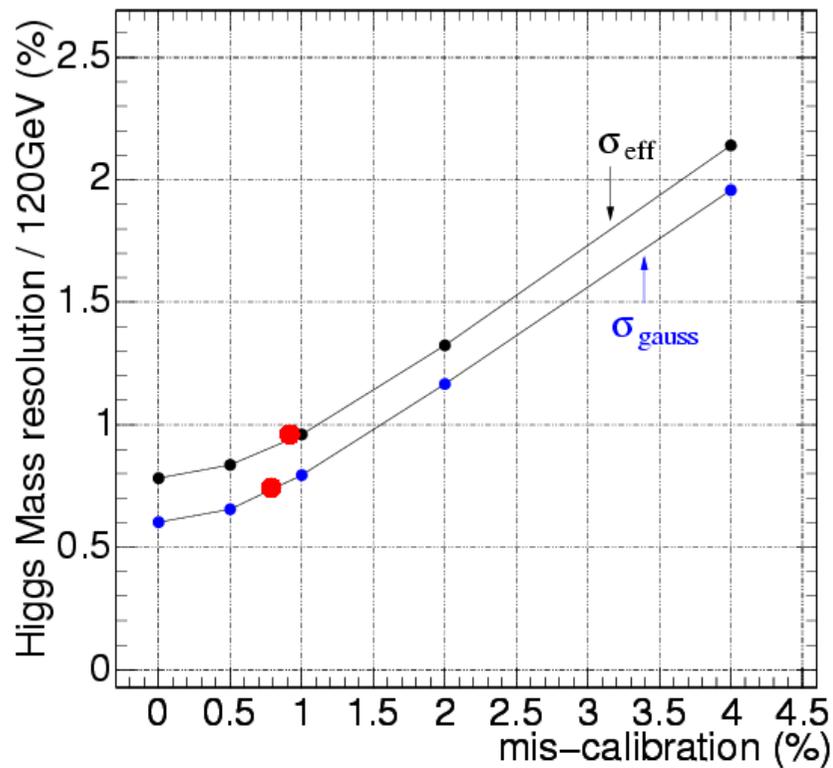
Sampling calo a can be ~ 10%,
to match it for $E_\gamma \sim 50 \text{ GeV}$:

$c \sim 0.7\%$ **ATLAS**
 $b \sim 300 \text{ MeV}$
 and an angular resolution
 $\sigma_\theta \sim 50 \text{ mrad}/\sqrt{E}$

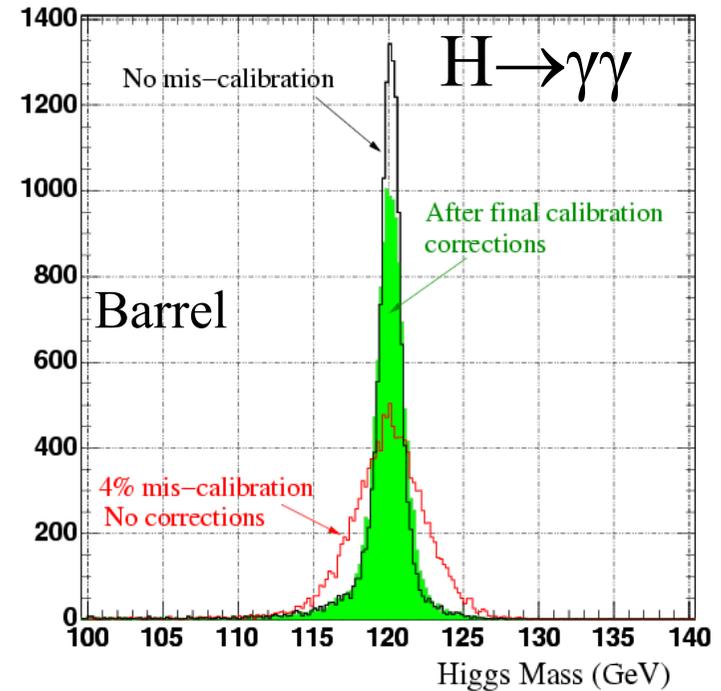
The effect of the resolution

If light, it will take a while...

Relative Higgs mass resolution versus mis-calibration.

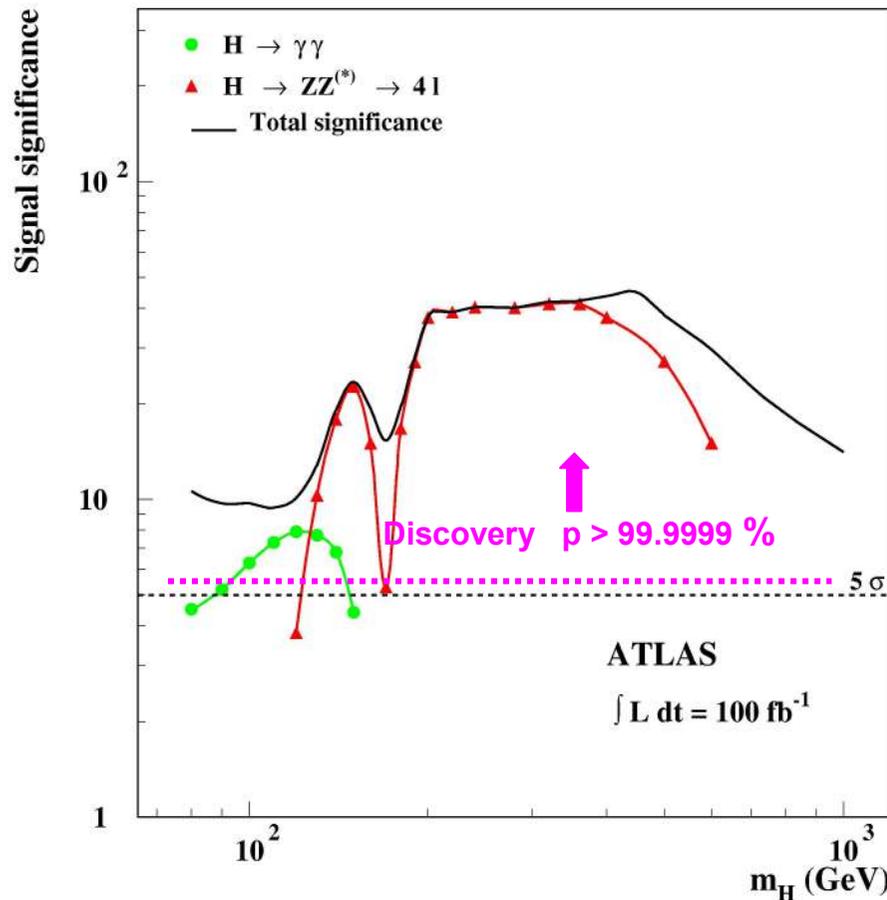


Higgs Boson Mass Resolution



**On paper resolution on $\gamma\gamma$ invariant mass:
CMS 0.7 GeV
ATLAS 1.2 GeV**

Higgs standard a LHC ok!

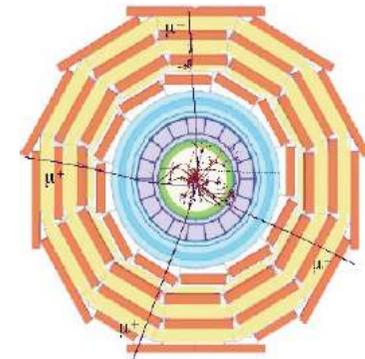


L'intervallo di massa permesso dal limite di LEP (114GeV) al limite teorico (1 TeV) è coperto da due canali "robusti" (leptoni e fotoni):

$$H \rightarrow ZZ \rightarrow \ell\ell \ell\ell$$

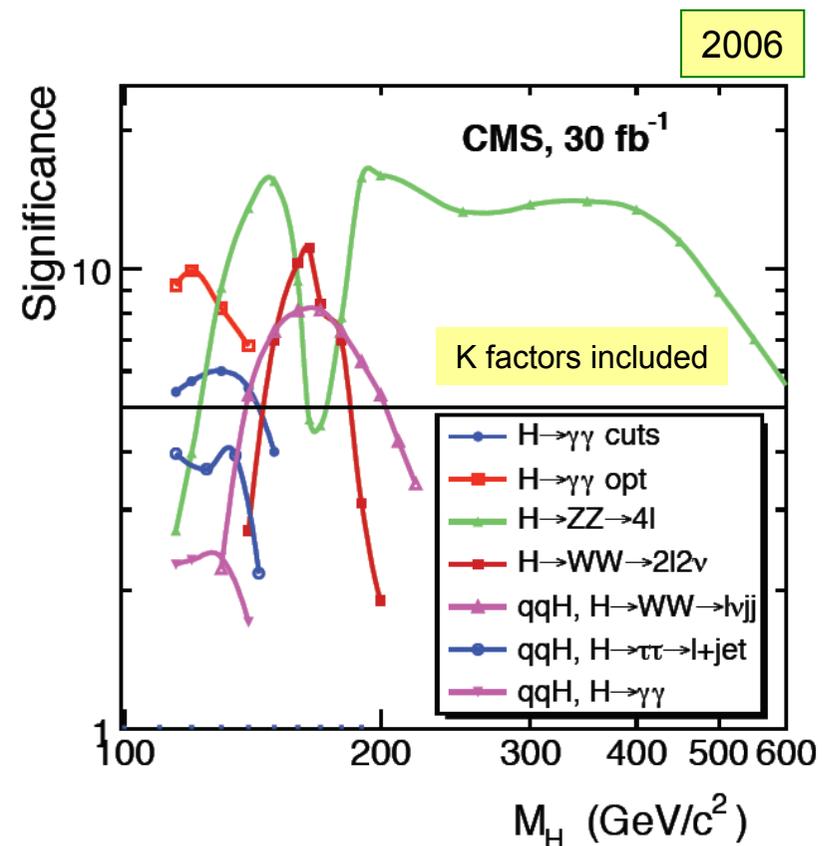
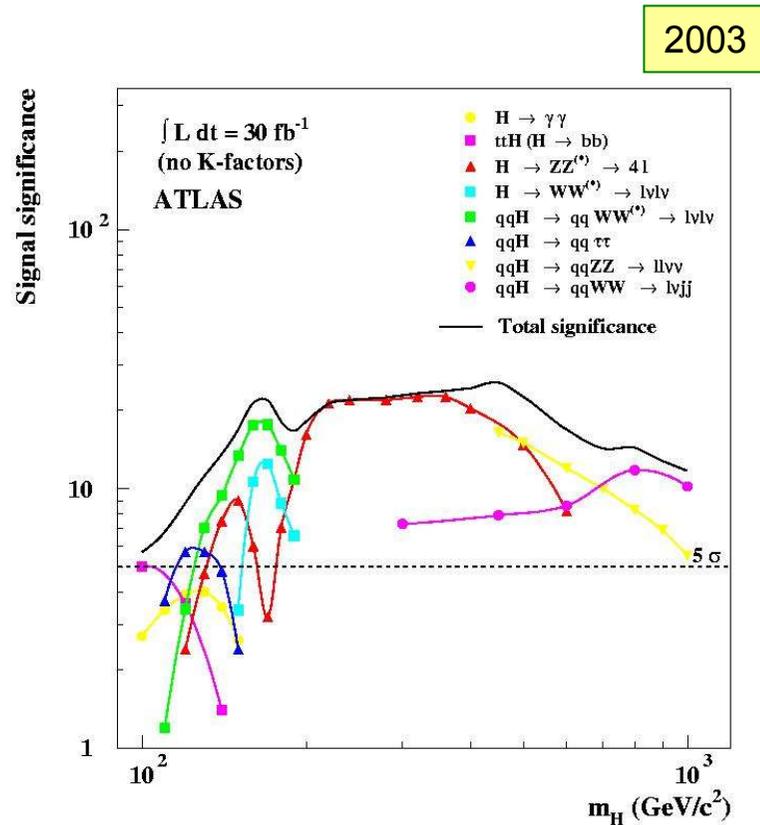
&

$$H \rightarrow \gamma\gamma$$



È una questione di pazienza...

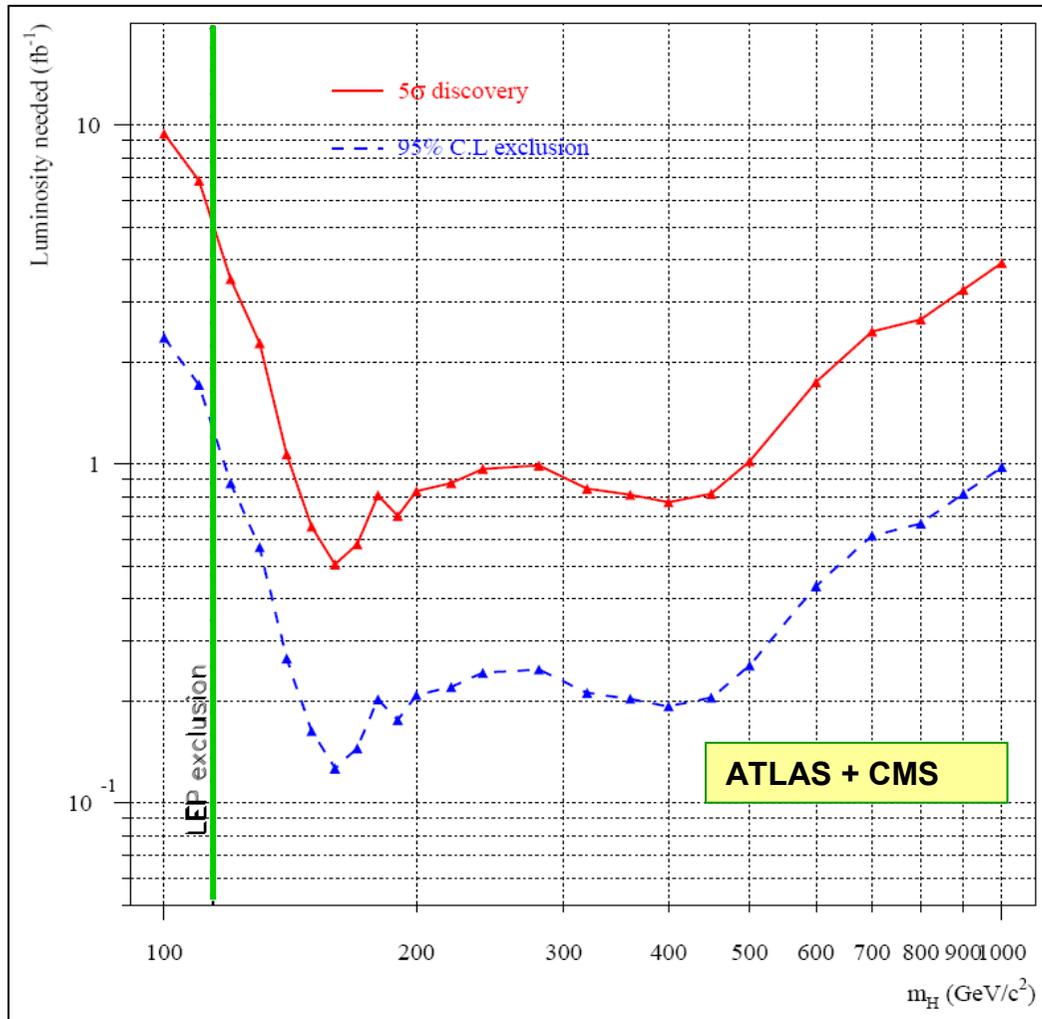
LHC discovery potential for 30 fb⁻¹



- Full mass range can already be covered after a few years at low luminosity
- Several channels available over a large range of masses

ATLAS + CMS combinati

Luminosity required for a 5σ discovery or a 95% CL exclusion



~ 5 fb⁻¹ needed to achieve a 5σ discovery
(well understood and calibrated detector)

~ < 1 fb⁻¹ needed to set a 95% CL limit
(low mass ~ 115 GeV/c² more difficult)

comments:

- systematic uncertainties assumed to be luminosity dependent
(no simple scaling, $\sigma \sim \sqrt{L}$, possible)

Is it a Higgs Boson?

-can the LHC measure its parameters ?-

1. Mass

Higgs boson mass can be measured with a precision of 0.1%
over a large mass range (130 - ~450 GeV/c²)

($\gamma\gamma$ and $ZZ \rightarrow 4\ell$ resonances, el.magn. calo. scale uncertainty assumed to be $\pm 0.1\%$)

2. Couplings to bosons and fermions

Only relative measurements

3. Spin and CP

Angular distributions in the decay channel $H \rightarrow ZZ(*) \rightarrow 4\mu$ are sensitive to spin
and CP eigenvalue

4. Higgs self coupling

Possible channel: $gg \rightarrow HH \rightarrow WW WW \rightarrow \mu\nu jj \mu\nu jj$ (like sign leptons)

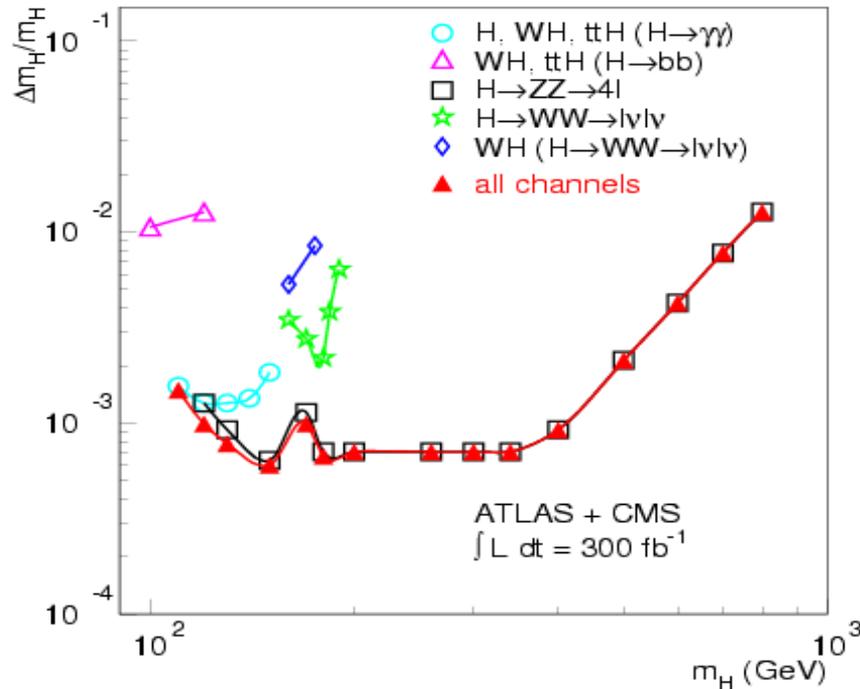
Small signal cross sections, large backgrounds from tt , WW , WZ , WWW , $tttt$, Wtt ,...

\Rightarrow no significant measurement possible at the LHC

very difficult at a possible SLHC (6000 fb⁻¹)

limited to mass region around 160 GeV/c²

H Boson Mass



Dominated by $ZZ \rightarrow 4\ell$ and $\gamma\gamma$ resonances !

well identified, measured with a good resolution

Dominant systematic uncertainty: γ/ℓ E scale.

Assumed 0.1 %

Goal 0.02 %

Scale from $Z \rightarrow \ell\ell$ (close to light Higgs)

Higgs boson mass can be measured with a precision of 0.1% over a large mass range (130 - ~450 GeV / c^2)

SUSY Higgs Sector

MSSM: minimal introduce il numero minimo di parametri necessari

Minimal Supersymmetric Standard Model:

2 doublet of Higgs fields ... 5 physical Higgs bosons

2 CP-even: h, H

1 Pseudoscalar: A

2 Charged; H^+ and H^-

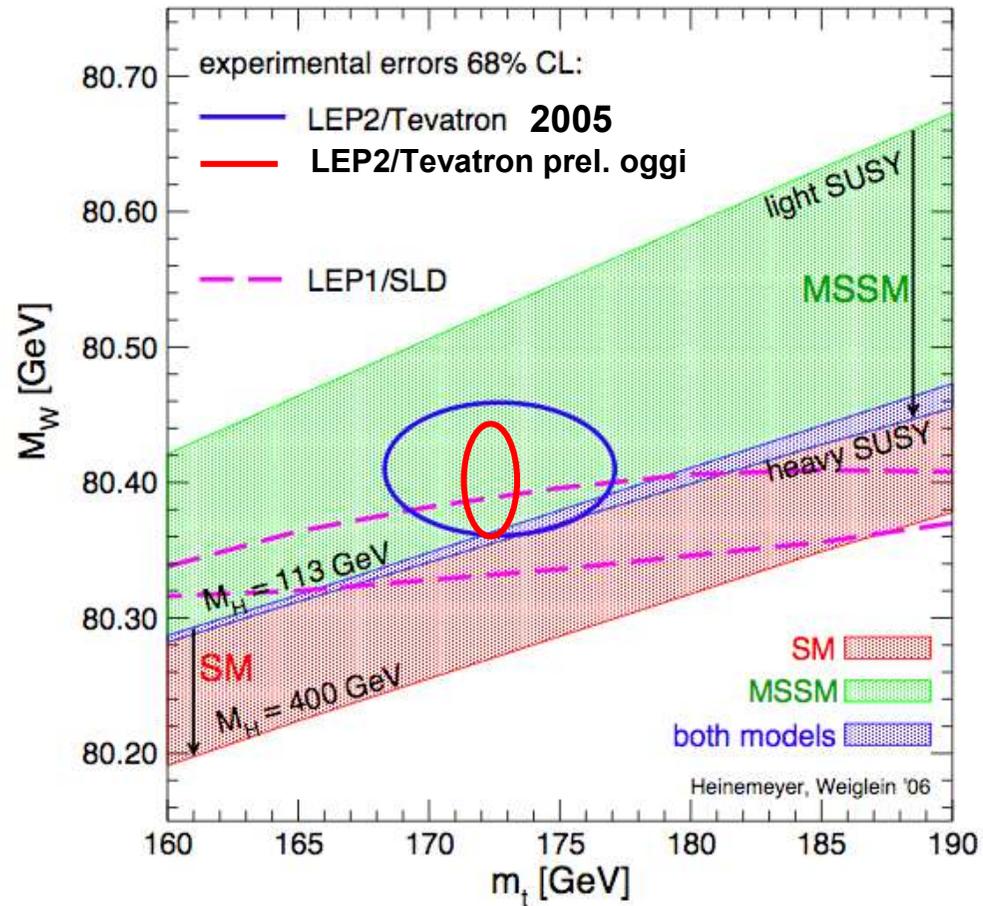
At tree level: The Higgs sector in the MSSM is determined by two parameters M_A and $\tan \beta$

Including radiative corrections: $M_h \leq 140 \text{ GeV}/c^2$

The others will most likely be heavy !

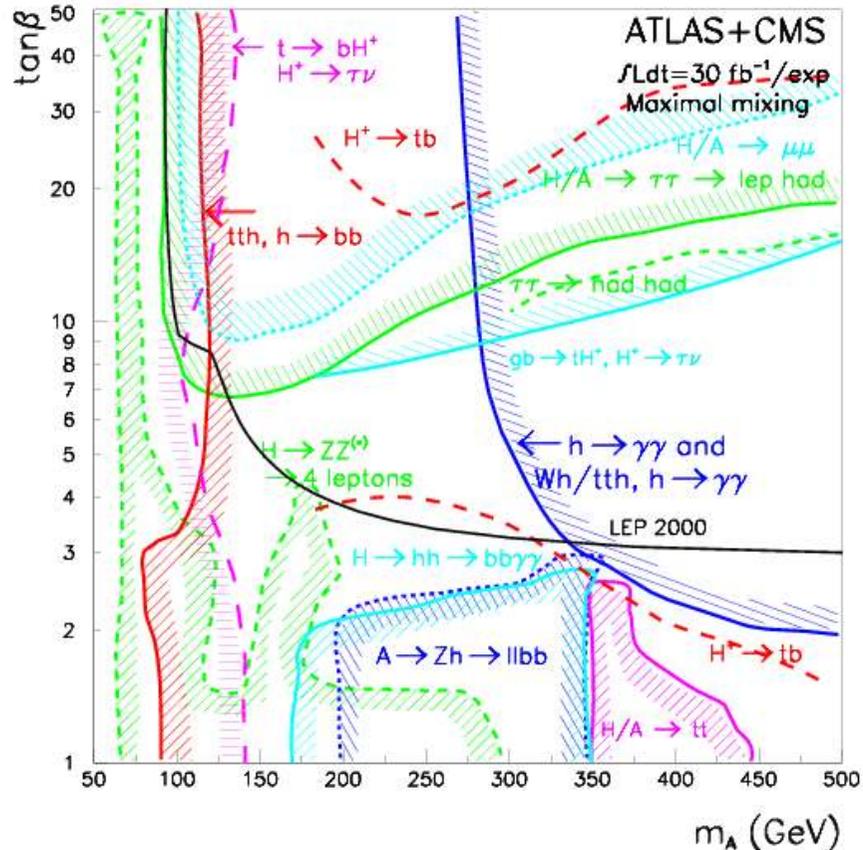
Correzioni radiative & SUSY

Additional quantum corrections from SUSY partners



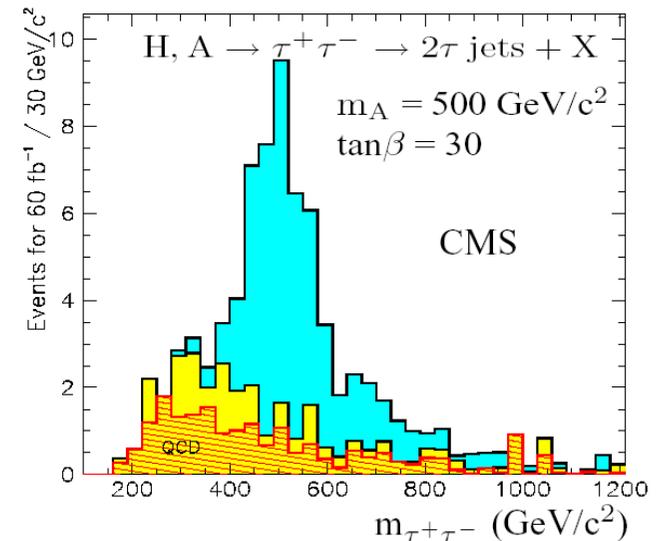
LHC: the SUSY Higgs Space

5 σ discovery in $m_A - \tan \beta$ plane



$$m_{\text{SUSY}} = 1 \text{ TeV}, m_{\text{top}} = 175 \text{ GeV}/c^2$$

Two or more Higgs can be observed over most of the parameter space \rightarrow disentangle SM / MSSM



- Plane fully covered (no holes) at low L (30 fb⁻¹)
- Main channels : $h \rightarrow \gamma\gamma, tth, h \rightarrow bb, A/H \rightarrow \mu\mu, \tau\tau, H^\pm \rightarrow \tau\nu$

Conclusione

- ATLAS e CMS sono pronti per i dati
- Le potenzialità di scoperta sono ben studiate
- Gli strumenti di analisi sono sotto controllo
- L'elemento chiave dello SM e estensioni SUSY il (o i) bosone di Higgs se esiste verrà osservato
- **Se no, in molti, non si è capito nulla !!! Possibile??**