



Stefano Bianco per CMS Frascati



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- Il gruppo CMS Frascati
- Attività' 2010
  - Resistive Plate Chambers performance
  - Muons in CMS
  - Analysis of  $Z \rightarrow \mu^+ \mu^-$
  - Studi di gas, filtri e materiali
- Attività' 2011
- Richieste economiche e al laboratorio
  
- Ulteriori info:
  - S.Bianco, Primi risultati da CMS, Frascati febbraio 2010
  - M.Caponero, Optical sensors, CMS week marzo 2010
  - D.Piccolo, CMS Status and Prospects, LNF Scientific Committee 40, June 2010
  - S.Bianco, Early physics from CMS, LNF Institute June 2010



# CMS Frascati



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PhD+laureandi in carattere sottolineato  
*tecnici* in carattere corsivo

*In collaborazione con*

*A.Cecchetti, D.Orecchini, B.Dulach, B.Ponzio, G. Raffone, C. Bisegni*



# Responsabilità nei rivelatori per muoni con RPC



In verde argomenti trattati  
dettagliatamente da Davide Piccolo  
al comitato scientifico giugno 2010

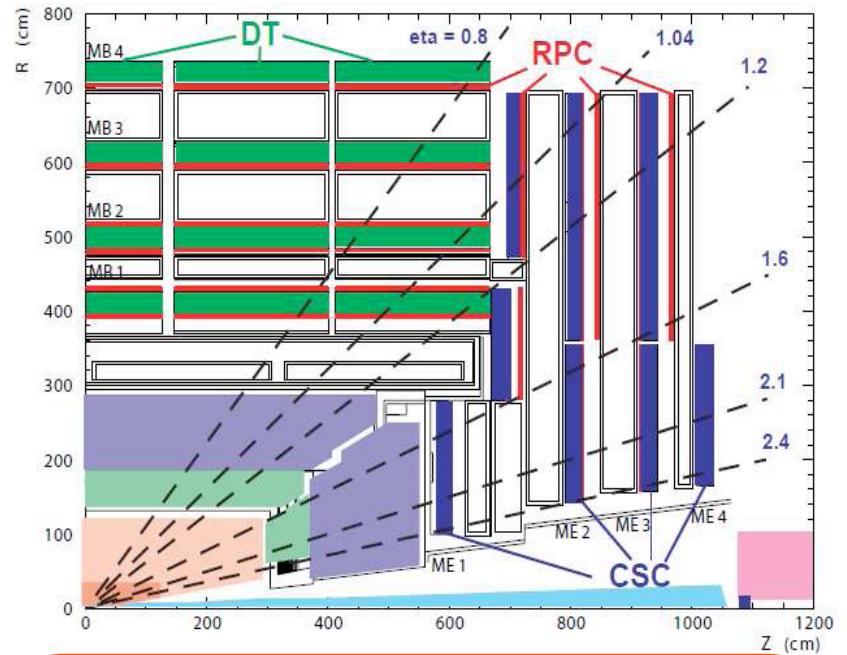
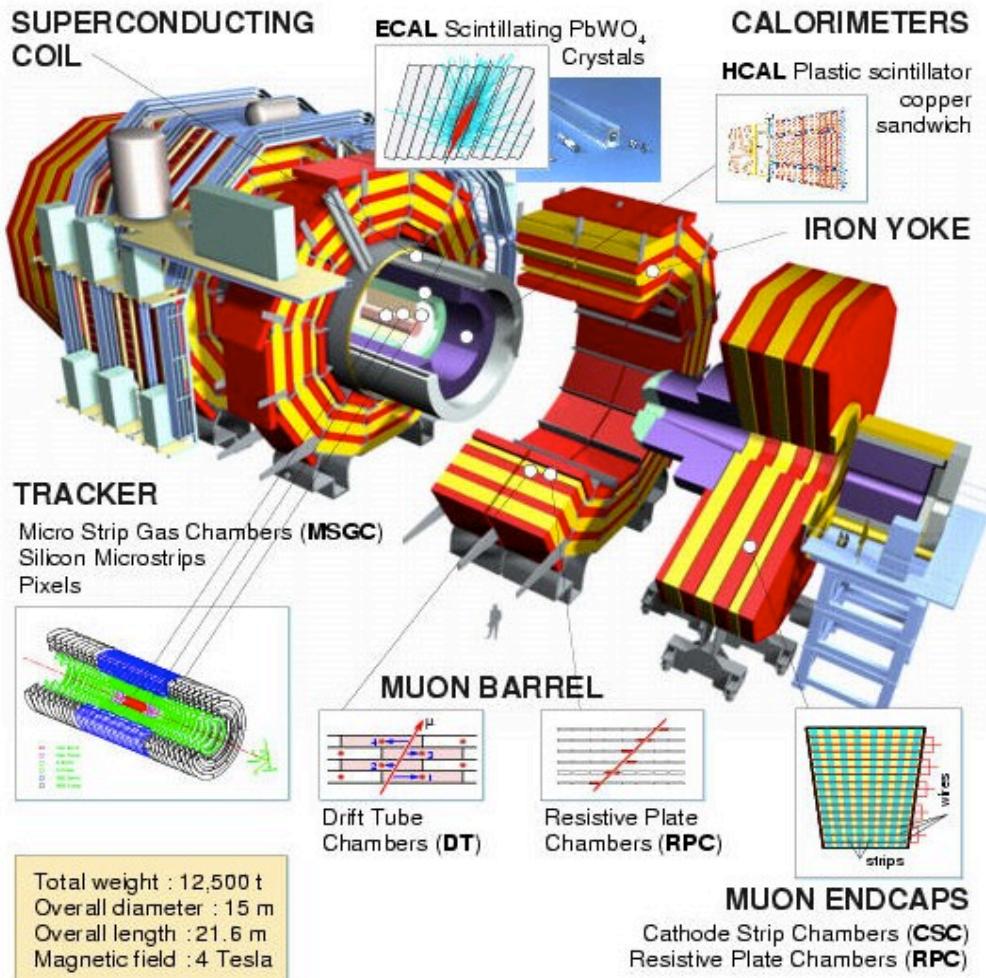
- Responsabilità principali:
  - Gas Gain Monitoring System for the RPC muon detector
    - L3 responsibility (S. Bianco)
  - RPC detector Operation Management
    - L2 responsibility (L. Benussi)
  - RPC Detector Performance Group Responsibility
    - L2 responsibility (D. Piccolo)
  - Gas purity and filters: studies and optimization
- Attività:
  - Muon system performance
  - CMS RPC Upscope and Upgrade
  - R&D sensori ottici per contaminanti gas (PRIN cofinanziato MIUR)
  - T3 computing
- Physics Analysis:
  - Analysis of  $Z \rightarrow \mu^+\mu^-$  Cross section



# Il rivelatore CMS



## CMS layout and detectors



### The MUON System

3 different technologies of gaseous detectors

Drift Tube (DT) in the barrel ( $|\eta| < 1.2$ )

Cathode Strip Chambers (CSC) in the endcaps ( $0.9 < |\eta| < 2.4$ )

Resistive Plate Chambers (RPC)  
both in barrel and endcaps (up to  $|\eta| = 1.6$ )

All detectors used both in triggering and reconstruction

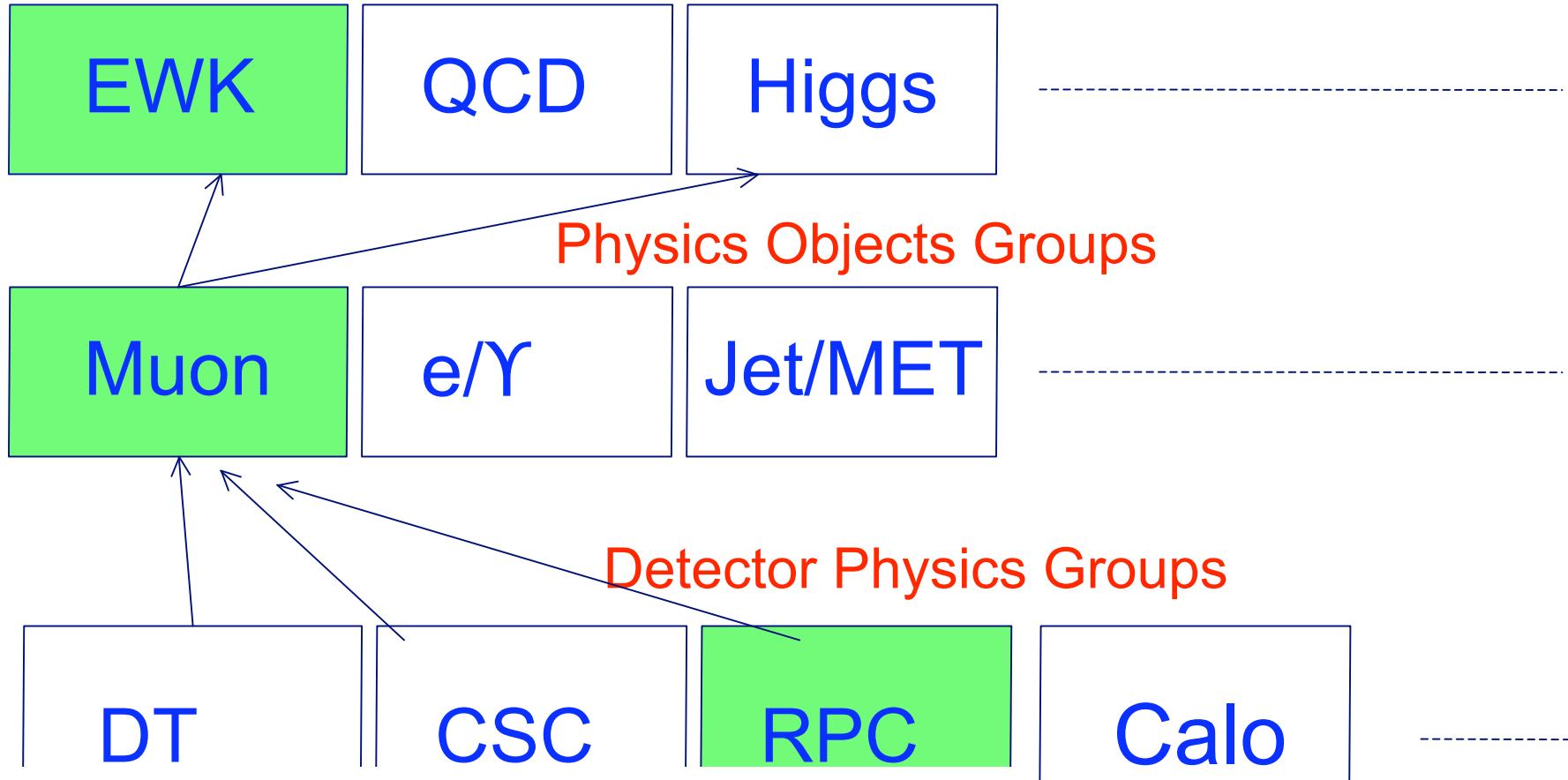


# Organizzazione di CMS

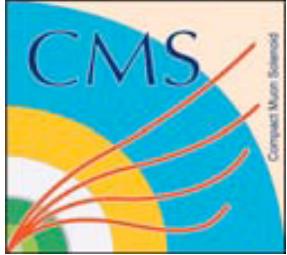


Il gruppo di Frascati ha responsabilità nei progetti in verde

## Physics Analysis Groups



Tutta la catena dei muoni, da Hardware operations  
al Software, all'Analisi



# I primi mesi di operazione a 7 TeV

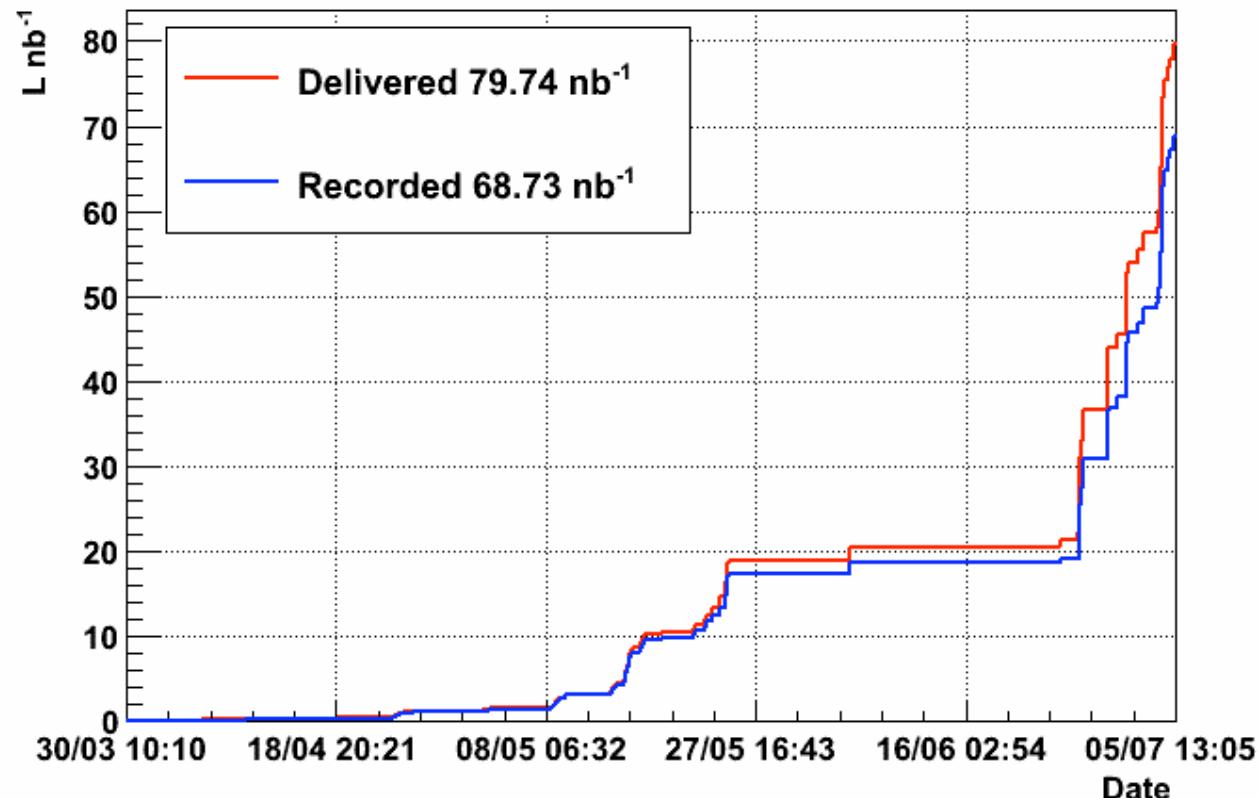


About **80nb<sup>-1</sup>** delivered by LHC and **~70nb<sup>-1</sup>** of data collected by CMS.

After quality flags and data certification

for physics (**~90%**) we end up with **~65nb<sup>-1</sup>** of good data for physics.

**CMS: Integrated Luminosity 2010**



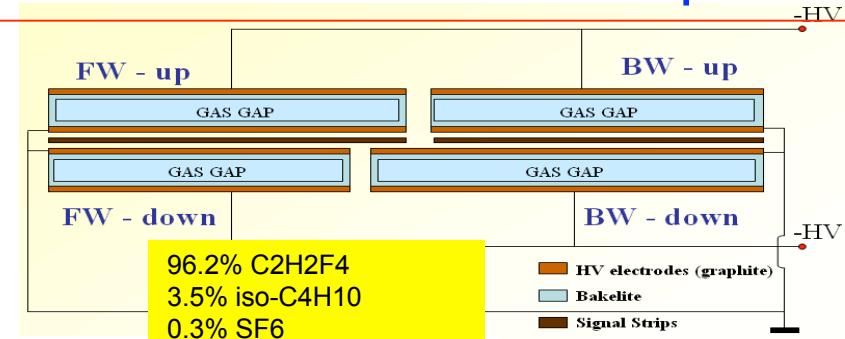


# Il sistema per muoni a RPC



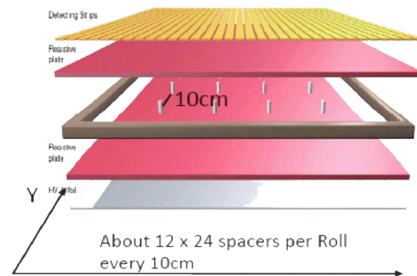
Fast Trigger dedicated detector both in Barrel and Endcap

Double gap bakelite plates with graphite electrodes and strips readout



Double gap RPCs in Avalanche mode:

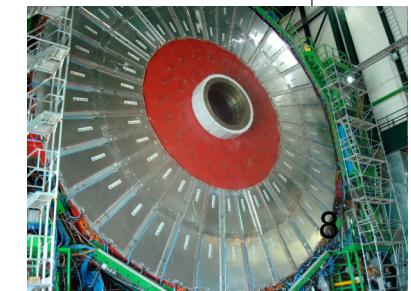
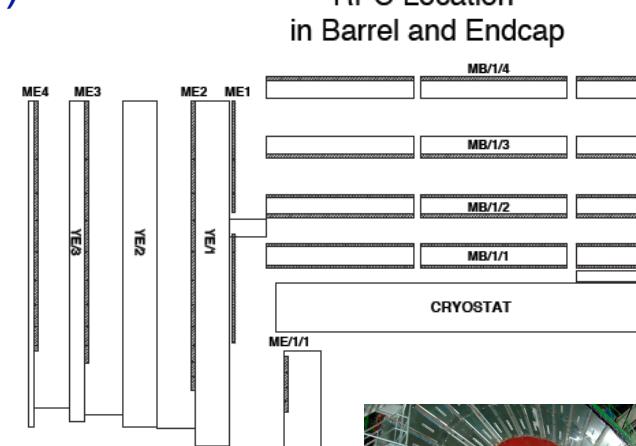
- lower gain (to cope with high rate up to 1kHz/cm<sup>2</sup>)
- higher amplification



A time resolution  
of ~2 ns allows BX  
tag without  
ambiguity

Good space resolution (~1cm)  
Trigger with pattern comparator

480 ch(barrel, 6 layers)  
432 ch (end-caps, 3 layers)  
At least 3 layers up to  $|\eta|=1.6$   
162k channels





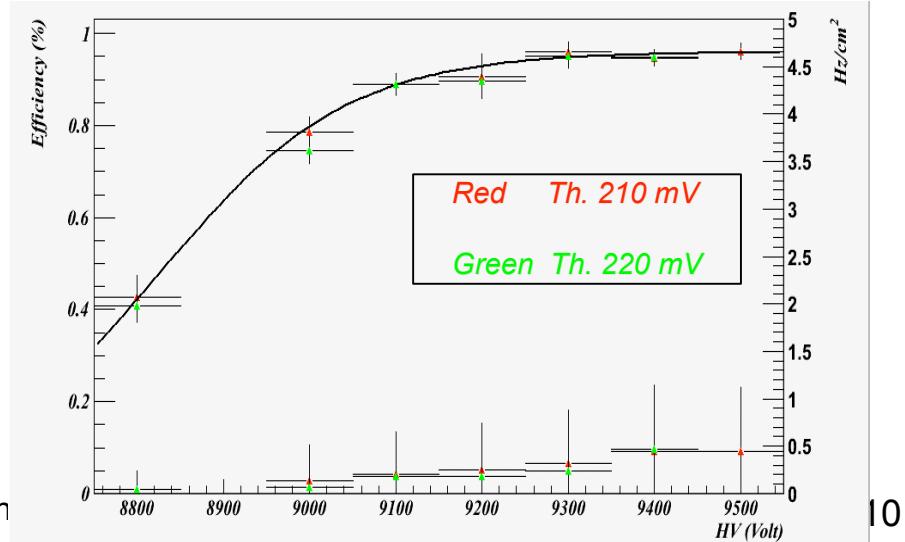
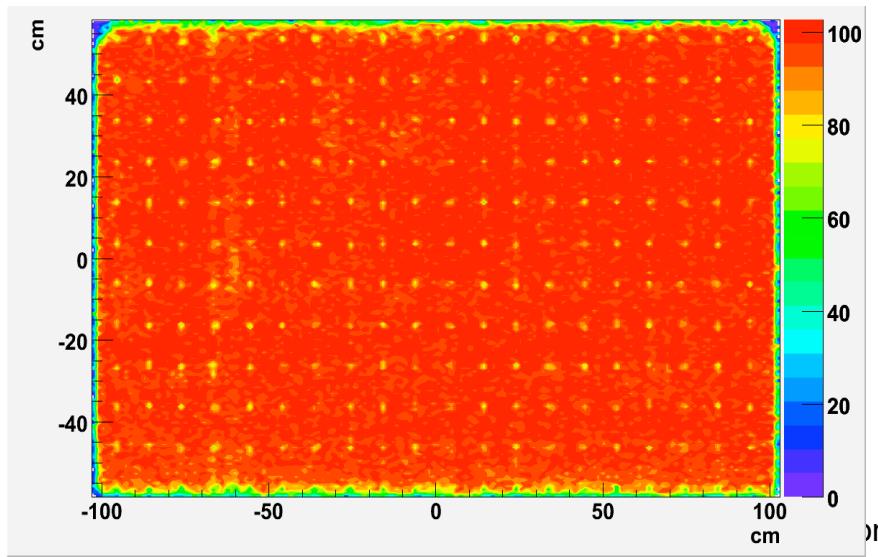
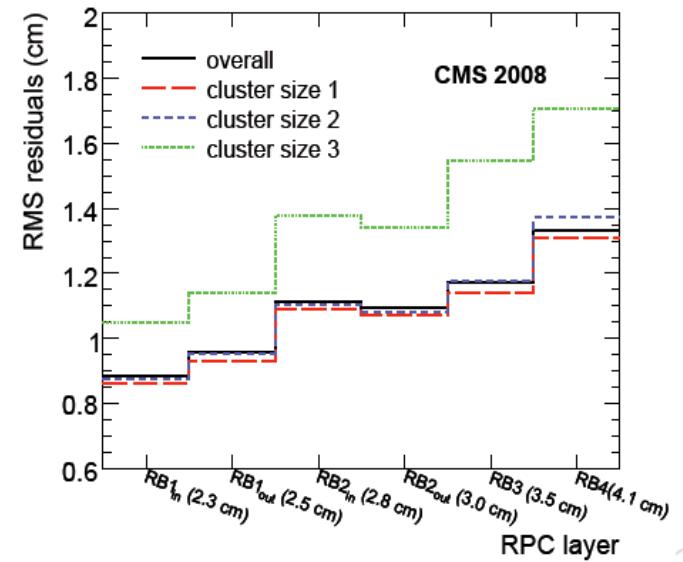
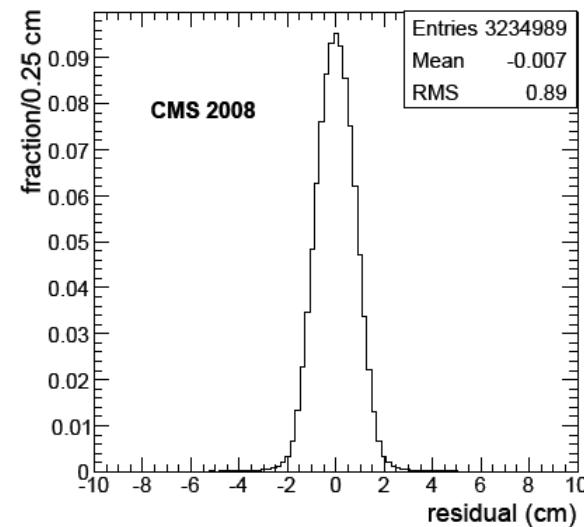
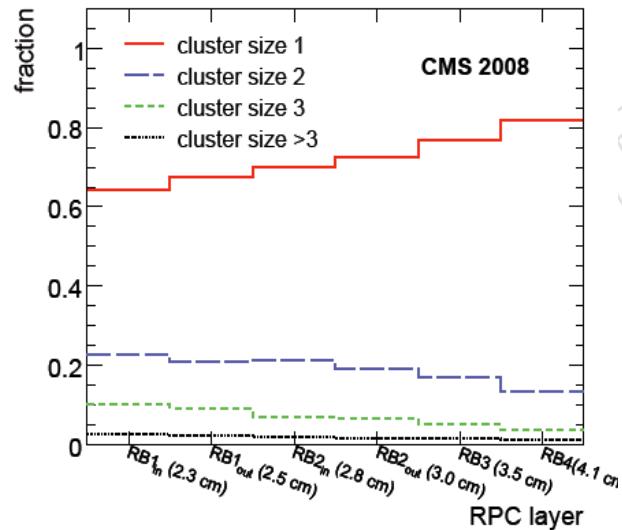
# Studi di rivelatore RPC e trigger



- Dopo l'incidente, piu' di 1 anno di data taking con raggi cosmici
  - Ottima conoscenza del rivelatore
- Siamo stati pronti a prendere dati sin dalle prime collisioni di LHC
  - Sincronizzazione
  - Efficienza
  - Trigger



# RPC performance con i raggi cosmici

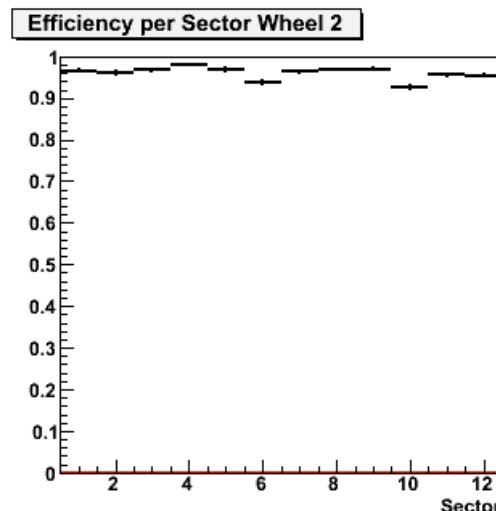
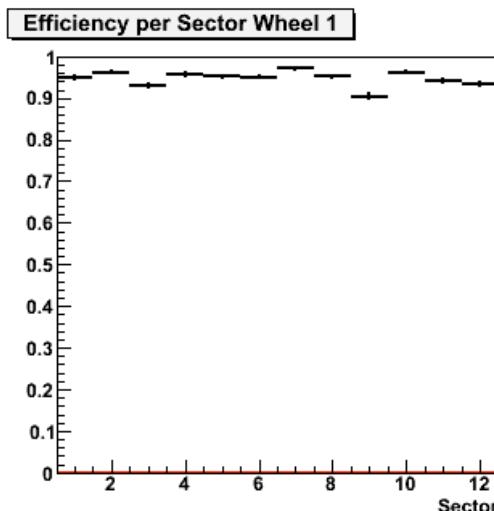
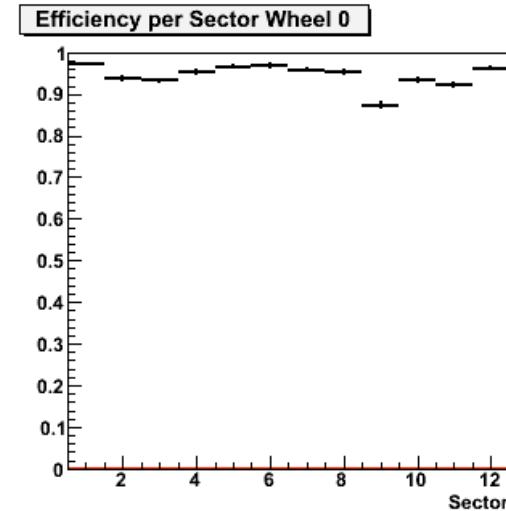
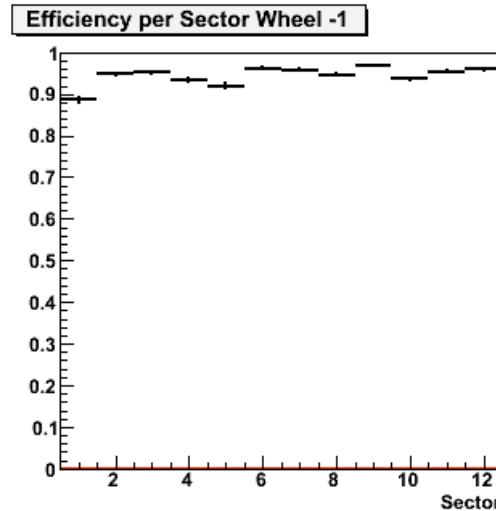
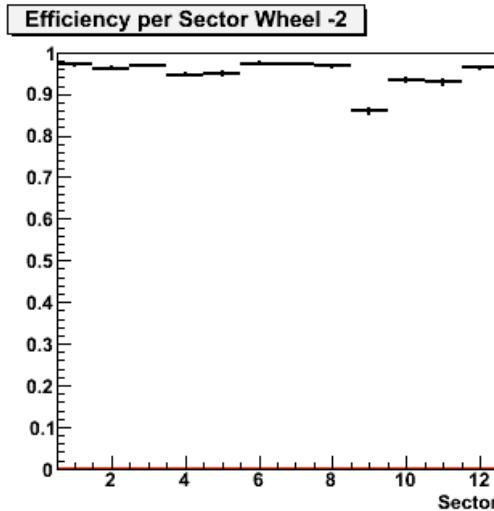




# RPC performance con le prime collisioni di LHC



PRELIMINARY



Average Efficiency:  
 $95.0 \pm 0.2 \%$   
Fully meeting design specs.

Detector details under study

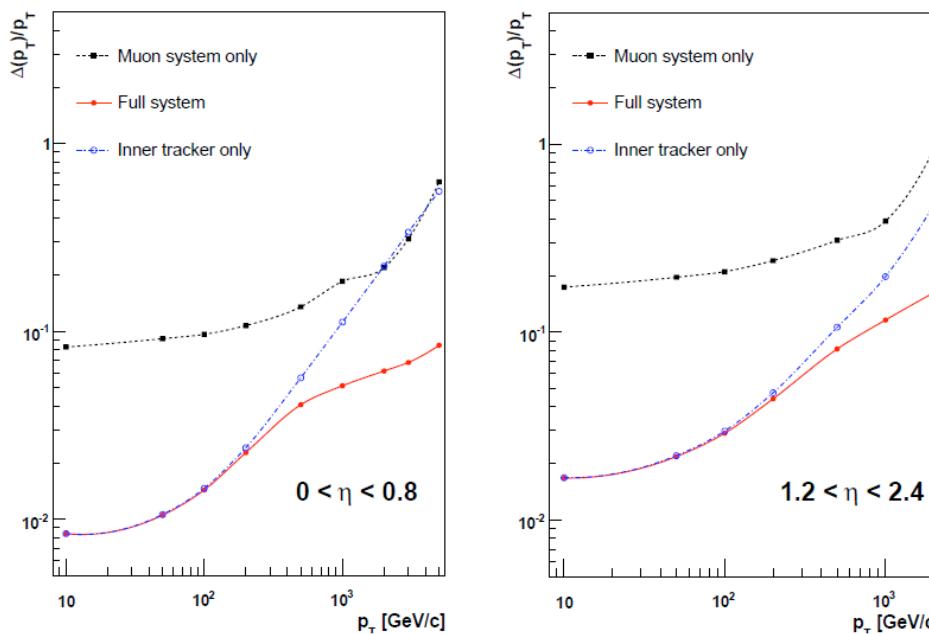


# Ricostruzione dei muoni

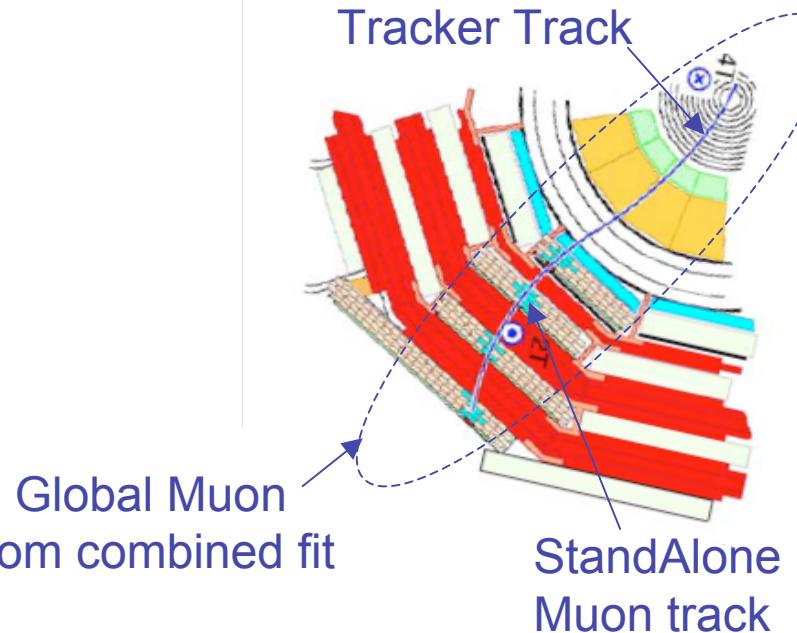
**Muon reconstructed independently both in Tracker and in muon system**

- Inner tracker dominates resolution up to 200 GeV/c due to multiple scattering in the iron
- Above 200 GeV/c, improvement from combined muon-tracker fit

**Resolution measured by comparing bottom and top leg of the cosmic track**



Global Muon  
from combined fit



One more muon type:  
Tracker Muons – match tracker track  
with muon segment

First Data collected used  
to cross-check reconstruction  
algorithms

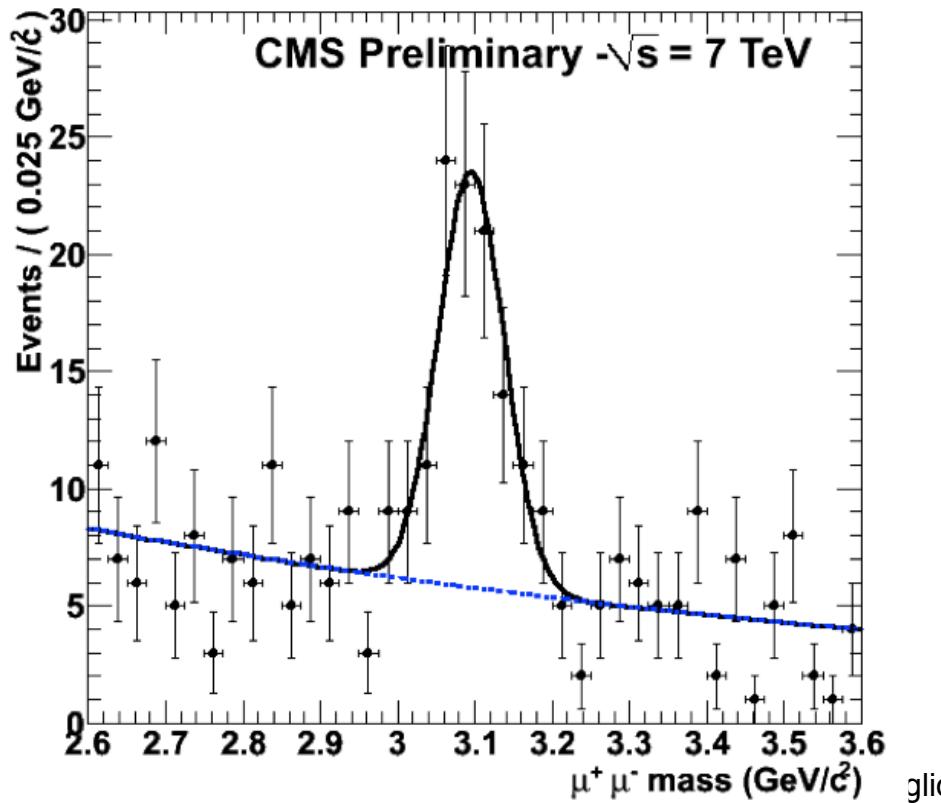


# Charmonium ( $J/\Psi$ )

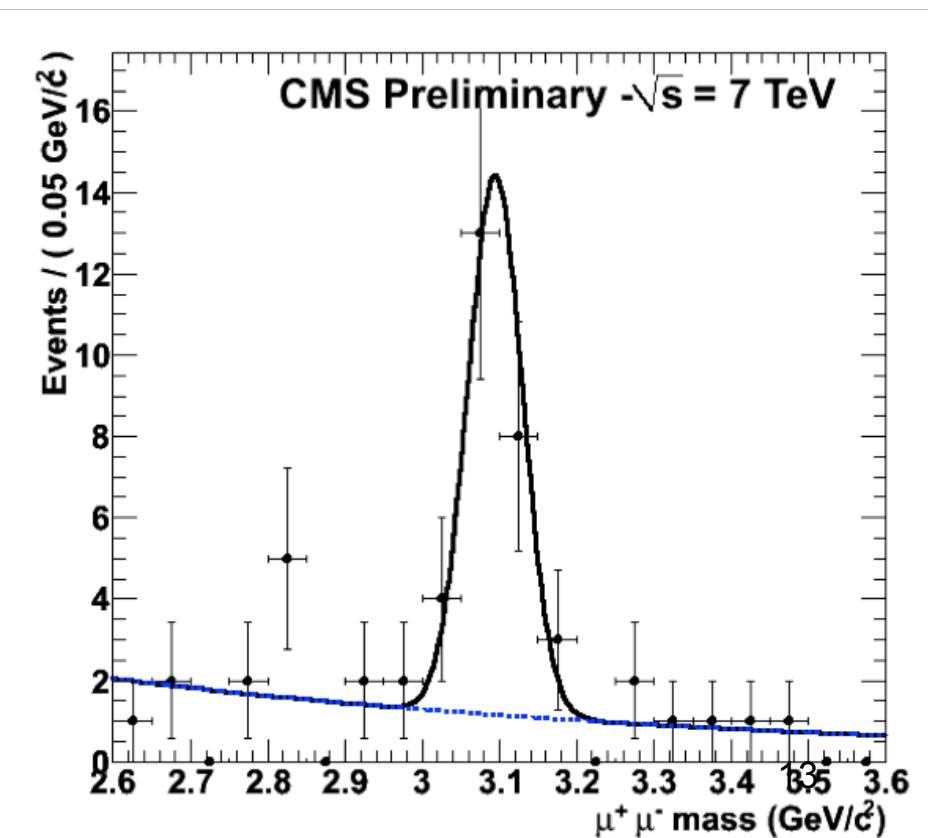


- 0.985/nb of pp collisions at 7 TeV (now 70/nb)

Global + global or tracker muon



Global + global muon





## Z → μ<sup>+</sup> μ<sup>-</sup> sezione d'urto



- Benchmark per la ricostruzione e l'identificazione dei muoni
- Test di precisione della QCD perturbativa
- Il primo processo EW insieme al W ad essere misurato all'LHC
- Punto di partenza di altri studi EWK e background per studi di nuova fisica

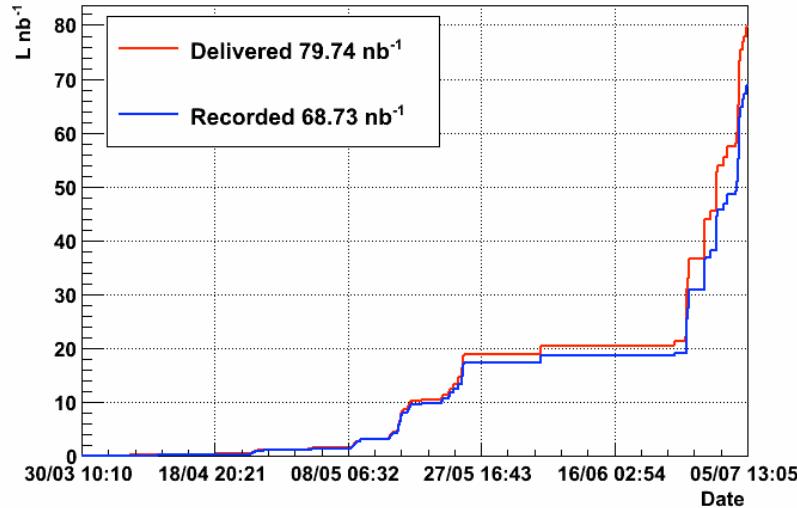


# Z Timeline

## Dove siamo e dove andiamo ?



CMS: Integrated Luminosity 2010



$\delta\sigma_Z/\sigma_Z$  at 5 % level →

data-driven inputs to  $\sigma_Z$  →

candidate hunting, rediscovery →

We are here

~# of  $Z \rightarrow ll$

5

50

500

5000

50000



$100 \mu\text{b}^{-1}$     $1 \text{ nb}^{-1}$     $10 \text{ nb}^{-1}$     $100 \text{ nb}^{-1}$     $1 \text{ pb}^{-1}$     $10 \text{ pb}^{-1}$     $100 \text{ pb}^{-1}$

S.Bianco - CMS Frascati 2010 Consiglio di laboratorio

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# $Z \rightarrow \mu^+ \mu^-$ cross section



$Z \rightarrow \mu\mu$  (2 global muons)

- quality cuts relaxed so far
- both muons with  $p_T > 20$  GeV/c
- at least one with  $|\eta| < 2.1$ , other with  $|\eta| < 2.4$
- trk iso  $< 3$  GeV/c ( $\Delta R < 0.3$ )

Short term approach:

- Cut and count N<sub>mm</sub>  
(negligible background)
- fix efficiency from MC

Longer term approach:

- Global fit to N<sub>mm</sub> and efficiencies
- Tag & Probe

Gemetrical acceptance

$$\sigma_{\gamma^* Z} \times \text{BR}(\gamma^*/Z \rightarrow \mu^+\mu^-) \times A = \frac{\epsilon_{\text{rec}}^2 \epsilon_{\text{qual}} \epsilon_{\text{iso}}^2}{N_{\mu\mu} [1 - (1 - \epsilon_{\text{trg}})^2] L_{\text{int}}}$$

Reco efficiency      Quality cuts efficiency      Isolation efficiency



# Segnale Z a 16/nb, oggi raccolti 70/nb



5 candidates  
Z to 2 global muons

Expected number of event per  $\text{nb}^{-1}$ :

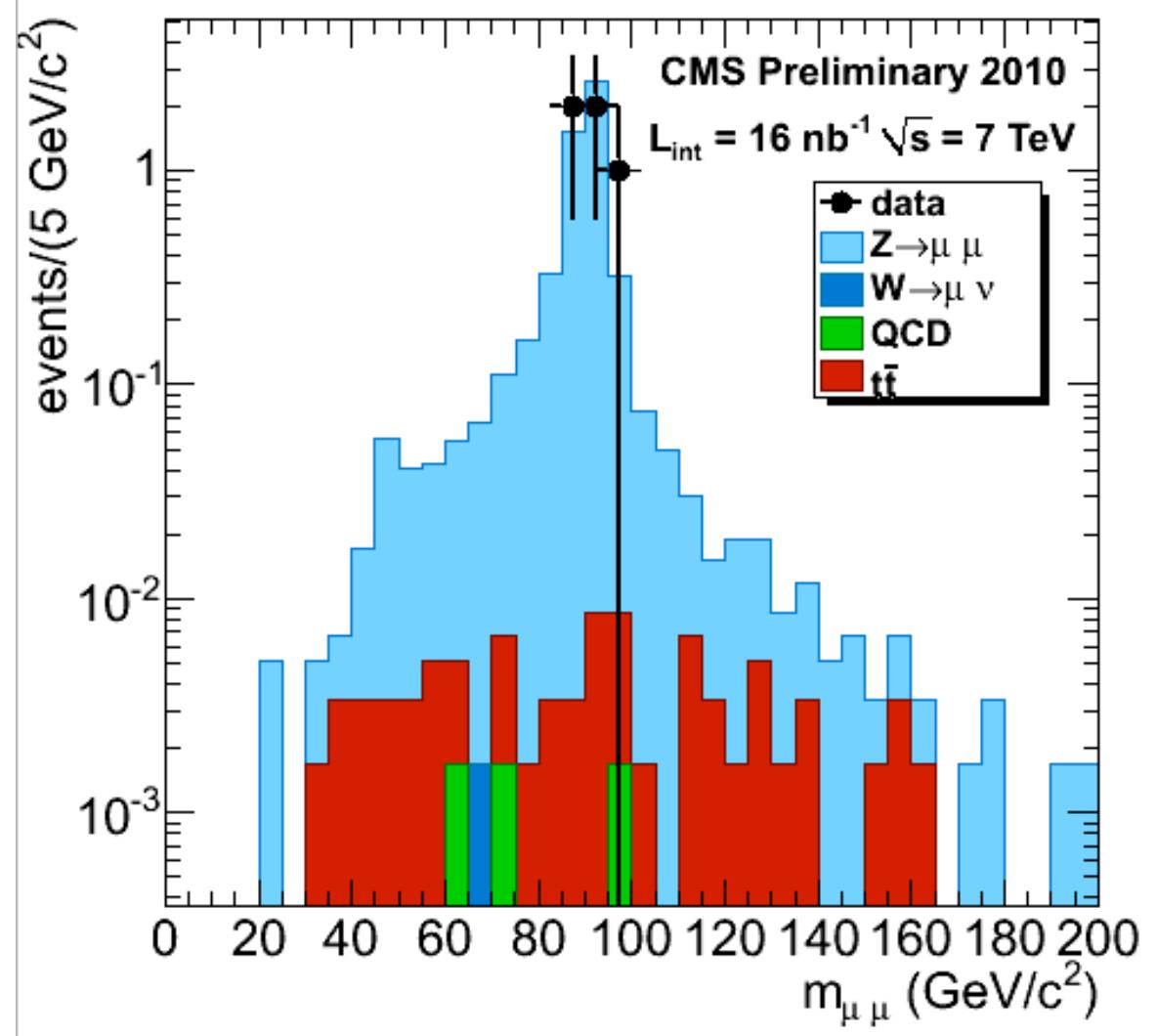
$Z \rightarrow \mu\mu$  (60-120) = 0.313 ev/ $\text{nb}^{-1}$

$W \rightarrow \mu\nu$  (60-120) = 0.0001 ev/ $\text{nb}^{-1}$

QCD (60-120) = 0.0003 ev/ $\text{nb}^{-1}$

$t\bar{t}$  (60-120) = 0.0026 ev/ $\text{nb}^{-1}$

With  $17\text{pb}^{-1}$  : 5.3 events expected



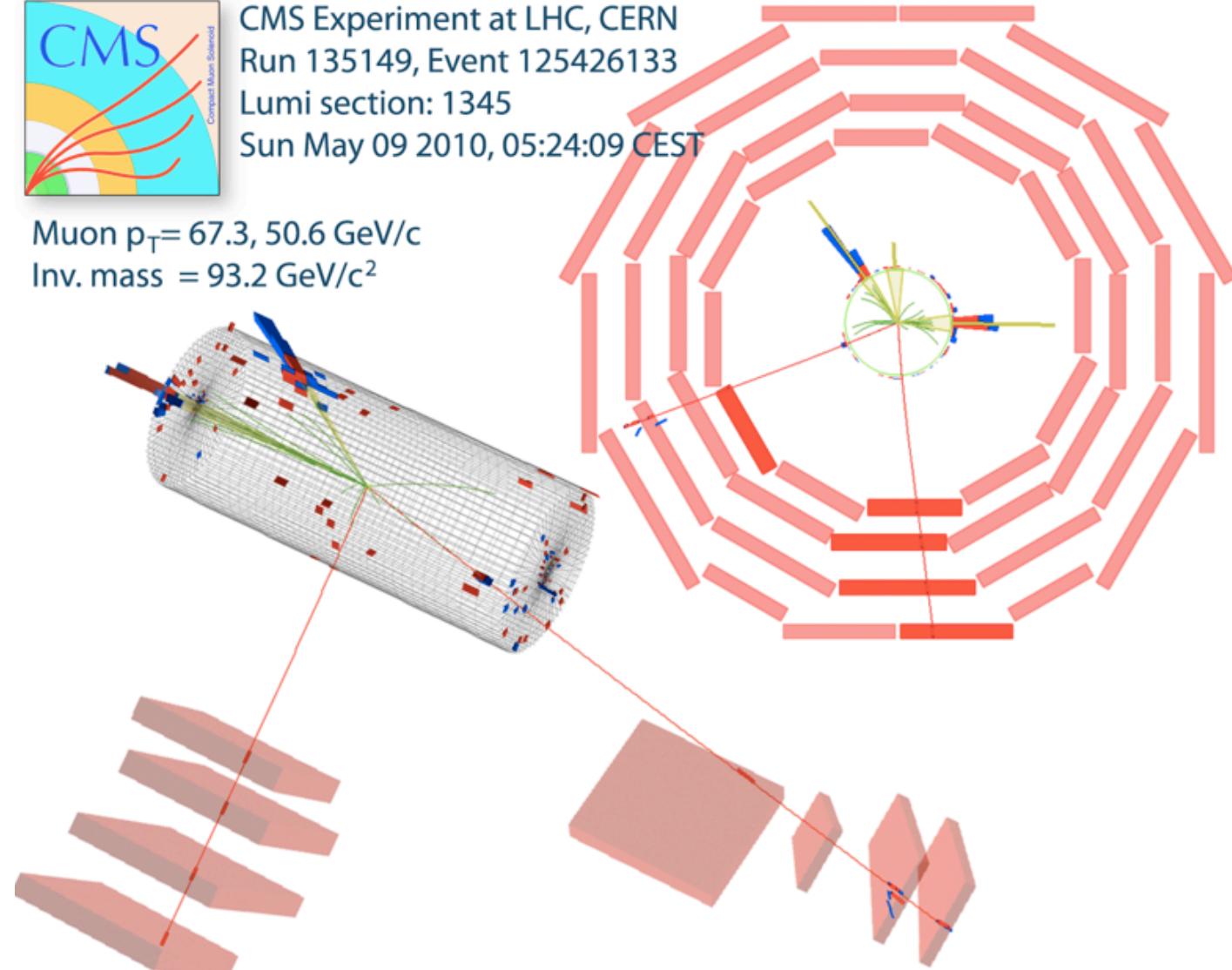


# Candidate event



CMS Experiment at LHC, CERN  
Run 135149, Event 125426133  
Lumi section: 1345  
Sun May 09 2010, 05:24:09 CEST

Muon  $p_T = 67.3, 50.6 \text{ GeV}/c$   
Inv. mass =  $93.2 \text{ GeV}/c^2$





# Scenari da 0.1 to 10 pb<sup>-1</sup>



| L(pb-1)                     | 0.003                | 0.01 | 0.05  | 0.1   | 0.2   | 0.3   | 0.4  | 0.5  | 0.6  | 0.7  | 0.8  | 0.9  | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9             | 10   |
|-----------------------------|----------------------|------|-------|-------|-------|-------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|---------------|------|
| Z <sub>μμ</sub>             | 1                    | 3    | 14    | 26    | 53    | 82    | 111  | 136  | 167  | 199  | 231  | 257  | 286  | 559  | 839  | 1104 | 1386 | 1653 | 1948 | 2211 | 2473          | 2753 |
| et <sub>rk</sub>            | fix to MC value (~1) |      |       |       |       |       |      |      |      |      |      |      |      |      |      |      |      |      |      |      | Fit from data |      |
| e <sub>sa</sub>             | fix to MC value (~1) |      |       |       |       |       |      |      |      |      |      |      |      |      |      |      |      |      |      |      | Fit from data |      |
| e <sub>iso</sub>            | fix to MC value      |      |       |       |       |       |      |      |      |      |      |      |      |      |      |      |      |      |      |      |               |      |
| e <sub>hl<sub>t</sub></sub> | fix to MC value      |      |       |       |       |       |      |      |      |      |      |      |      |      |      |      |      |      |      |      |               |      |
| dY/Y                        | 100%                 | 57%  | 26.0% | 19.1% | 13.4% | 10.7% | 9.6% | 8.6% | 7.6% | 7.4% | 6.6% | 6.3% | 6.1% | 4.2% | 3.6% | 3.1% | 2.8% | 2.5% | 2.4% | 2.2% | 2.0%          | 2.0% |



By the end of July ?  
**YES ! Oggi 70/nb !!!**

By the end of year ?

Con l'aumento della statistica si potranno impiegare metodi data-driven per la misura dell'efficienza



# Metodo Data driven (Frascati in collaborazione con Napoli)



Selezioniamo 5 campioni indipendenti  
di candidati Z in due muoni

- 1)  $Z_{\mu\mu}^{2\text{HLT}}$  = Two isolated global muons, both muons HLT-matched
- 2)  $Z_{\mu\mu}^{1\text{HLT}}$  = Two isolated global muons, only one muon HLT-matched

$$Z_{\mu\mu}^{2\text{HLT}} + Z_{\mu\mu}^{1\text{HLT}} = Z_{\mu\mu}$$

- 3)  $Z_{\mu\mu}^{\text{non iso}}$  = Two global muons, one of them not isolated, at least one muon HLT-matched
- 4)  $Z_{\mu s}$  = One global muon HLT-matched + one StandAloneMuon, no overlap with  $Z_{\mu\mu}$
- 5)  $Z_{\mu t}$  = One global muon HLT-matched + one tracker track,  
no overlap with  $Z_{\mu\mu}$  and  $Z_{\mu s}$

*Samples are mutually exclusive:*

*we fill sample n only if sample n-1 is empty after selection cuts*



# Procedura di fitting



10 pb<sup>-1</sup> equivalent statistics

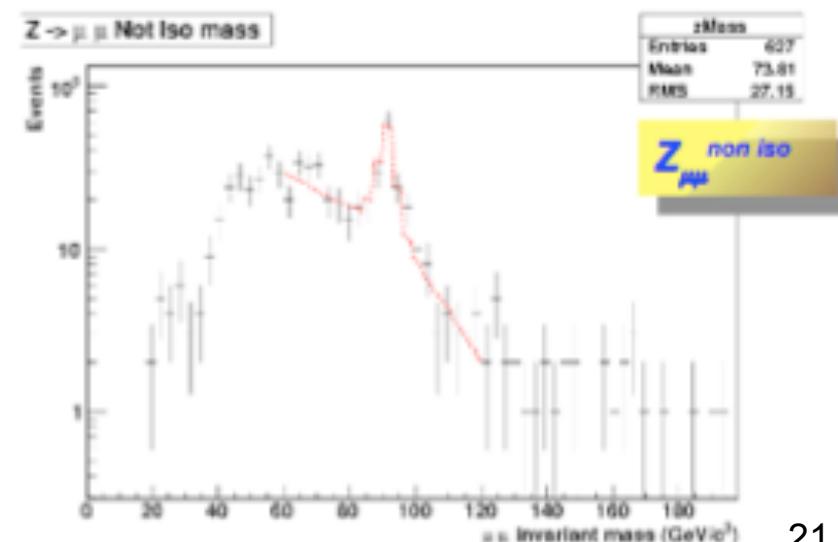
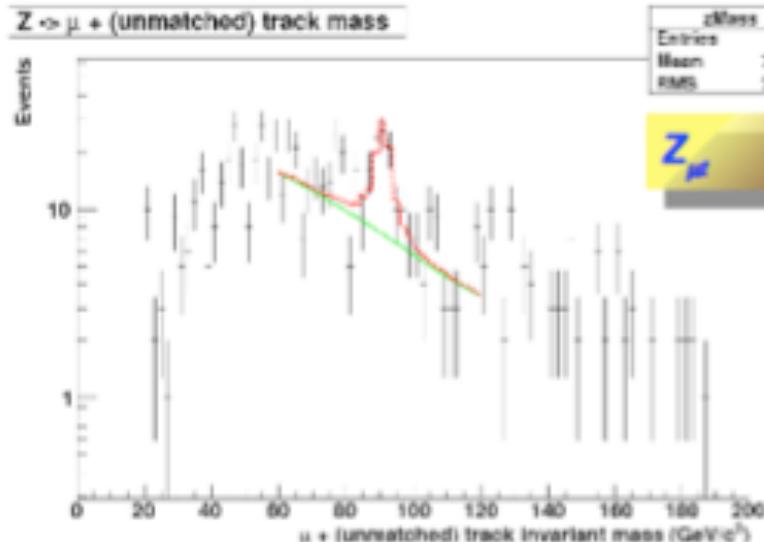
Global chi2

$$\chi^2 = \frac{(N_{\mu\mu}^{2\text{HLT}} - N_{Z \rightarrow \mu^+ \mu^-} \epsilon_{\text{HLT}}^2 \epsilon_{\text{iso}}^2 \epsilon_{\text{trk}}^2 \epsilon_{\text{sa}}^2)^2}{N_{\mu\mu}} + \\ \frac{(N_{\mu\mu}^{1\text{HLT}} - 2N_{Z \rightarrow \mu^+ \mu^-} \epsilon_{\text{HLT}} (1 - \epsilon_{\text{HLT}}) \epsilon_{\text{iso}}^2 \epsilon_{\text{trk}}^2 \epsilon_{\text{sa}}^2)^2}{N_{\mu\mu}} + \\ \chi_{\mu s}^2 + \chi_{\mu t}^2 + \chi_{\mu\mu}^{\text{non iso}} 2,$$

1-bin histograms for  
 $Z_{\mu\mu}^{2\text{HLT}}$  and  $Z_{\mu\mu}^{1\text{HLT}}$

Get the Z Yield and  
Efficiencies in the same fit

More details in Backup slides





# Pubblicazioni 2009-10



- 2 Physics papers pubblicate
- 2 Physics papers inviate a rivista
- Circa 30 articoli di prestazione del rivelatore con raggi cosmici pubblicate su JINST
- 5 presentazioni a conferenze di frascatani: IEEE09, RPC10, Vienna10
- CMS notes, articoli strumentazione
- Organizzazione conferenze: hql10 e rpc12<sup>22</sup>



# Attività` 2011 (1/2)



- Completamento analisi  $Z \rightarrow \mu\mu$
- Il rivelatore RPC e' funzionante e debuggato, nel 2011 il carico di lavoro sul rivelatore sara' ridotto rispetto al 2010.
- Il gruppo di Frascati e' ben integrato nell'analisi di CMS e collabora attivamente con altri gruppi italiani.
- Canali di analisi da affrontare successivamente:
  - $Z'$
  - Higgs  $\rightarrow ZZ$
  - altri canali con muoni



# Attività` 2011 (2/2)



- Studi di miscele negli RPC in lab. ASTRA
- Studi di gas, contaminanti e filtri in ambiente hi-rad. Sensori ottici per contaminanti, cofinanziamento con progetti approvati PRIN e EU (AIDA)
- CMS Centre - postazione di controllo CMS in lab. ASTRA per svolgere parzialmente i turni in remoto. Valore aggiunto: postazione disponibile per visite e attività divulgativa (display real time di eventi, webcam su sale controllo centrali CMS e LHC)
- Upscope (2012)
  - Sensori ottici FBG in 140 nuove camere degli endcap
  - Partecipazione alla revisione e piccole modifiche link board del trigger dei muoni
  - QC/QA della eventuale produzione di gap in General Technica
- Upgrade (2015)
  - GEM nella regione alto eta ?
  - Studi di tensionamento di fogli GEM grandi e trapezoidali (G.Raffone))
  - Studi di dimensionamento meccanico per raddoppio di gaps e doppia lettura (SPAS)



# CMS Computing a Frascati



Abbiamo contribuito al progetto del centro di calcolo  
Scientifico a Frascati nell'ambito del working group, vedi  
**LNF report LNF - 10 / 5(IR)**

Le richieste di computing sono minime ( a livello di un  
piccolo T3), e soddisfatte dal centro di calcolo in uno  
spirito di collaborazione.



RICHIESTE IN kEUR

FTE            8,5

|                |  |               |
|----------------|--|---------------|
| M.Interne      |  | 8,5           |
| M.Estere       | 10mesi shift, responsabilita', metabolismo, turni e servizi (3,7kEUR/meseUomo) | 120,3         |
| Consumi        | metabolismo, auto, attivita' alla GIF  | 27,75         |
| Inventoriale   | CMS Centre   | 10            |
| <b>Totale</b>  |  | <b>166,55</b> |
| bianco         | 0,9  |               |
| benussi        | 0,7  |               |
| caponero       | 1  |               |
| colafranceschi | 0 ( <a href="#">dottorando, parz. contr. CERN</a> )                            |               |
| fabbri         | 0,9  |               |
| felli          | 1  |               |
| ferrini        | 1  |               |
| piccolo        | 1  |               |
| saviano        | 1  |               |
| parvis         | 1  |               |
| <b>TOTALE</b>  | <b>8,5</b>   |               |

- 3FTE tecnici elettronici
- Spazio ASTRA e camera pulita
- 3mu Progettazione SPAS
- 2mu Servizio elettronica
- Modesto accesso officina SPCM da definire



# CONCLUSIONI

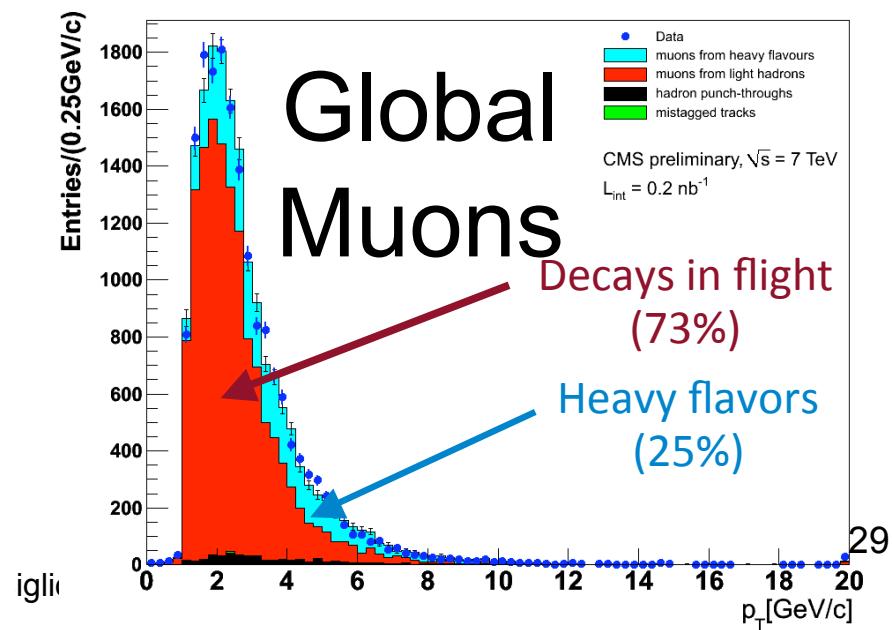
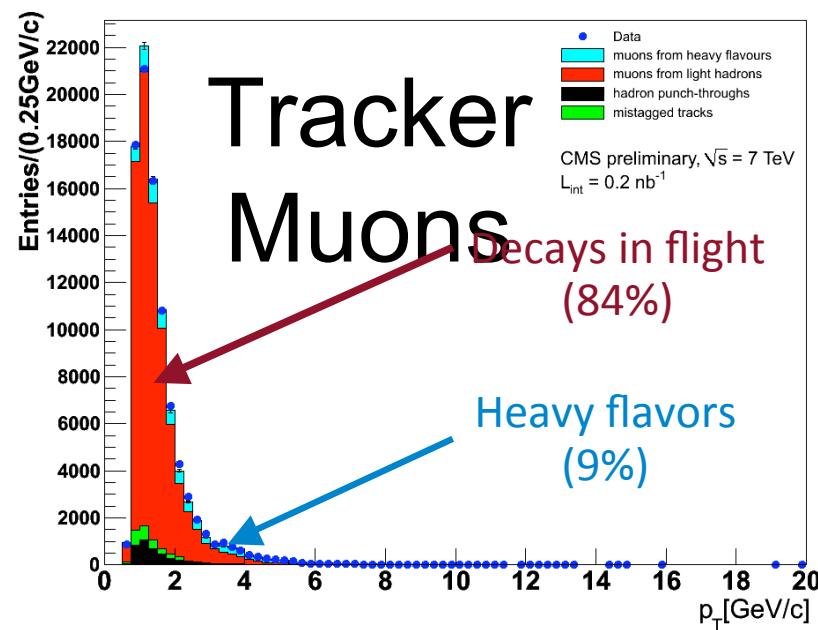
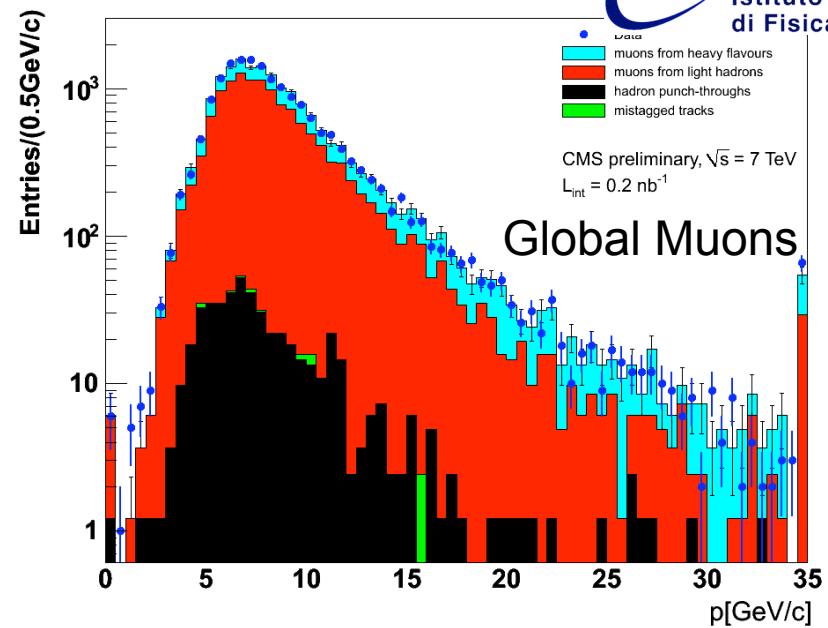
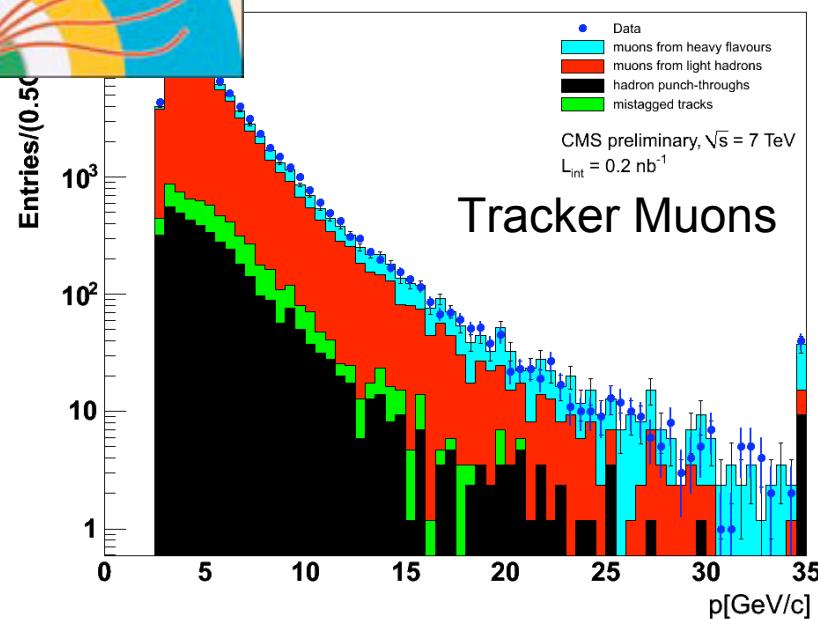


- Gli RPC di CMS sono un'opportunita` ideale per studenti di fisica e ingegneria.
- CMS Frascati ha molte responsabilita` sul rivelatore che forniscono una conoscenza approfondita dei muoni a tutti i livelli (Operation Management, Detector Performance)
- CMS Frascati e` profondamente coinvolto negli studi di muoni dal rivelatore alla fisica.
- **Ottima occasione per chiunque sia interessato alla fisica di scoperta con canali muonici, cerchiamo collaboratori !**
- Il gruppo e' attivo nella fisica dello Standard Model, e prevede di passare a Z' e Higgs.
- Nonostante l'impossibilita' di erogare dottorati e in mancanza di un diretto contatto con facolta' di fisica, siamo in collaborazione con gli altri gruppi CMS e a diretto contatto di giovani brillanti per i quali abbiamo chiesto sostegno al laboratorio in termini di assegni di ricerca.
- Il problema della mancanza di laureandi e dottorandi fisici per i laboratori nazionali e` ormai cronico e riconosciuto, ed e` fondamentale che adeguate misure correttive vengano chieste all'INFN

# BACKUP

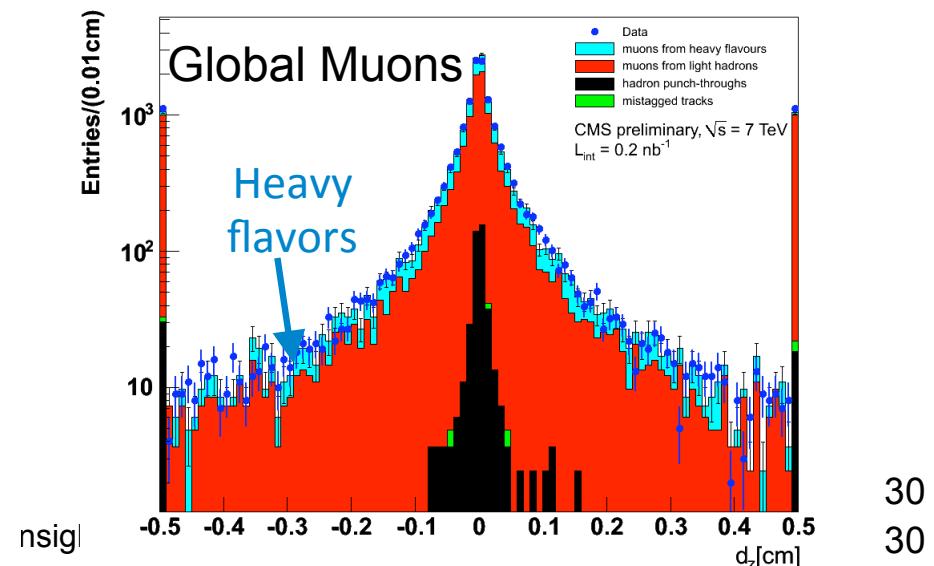
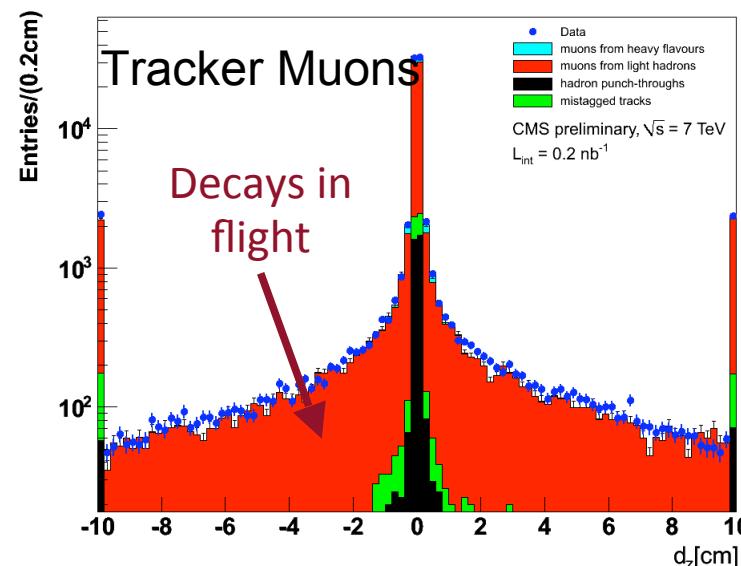
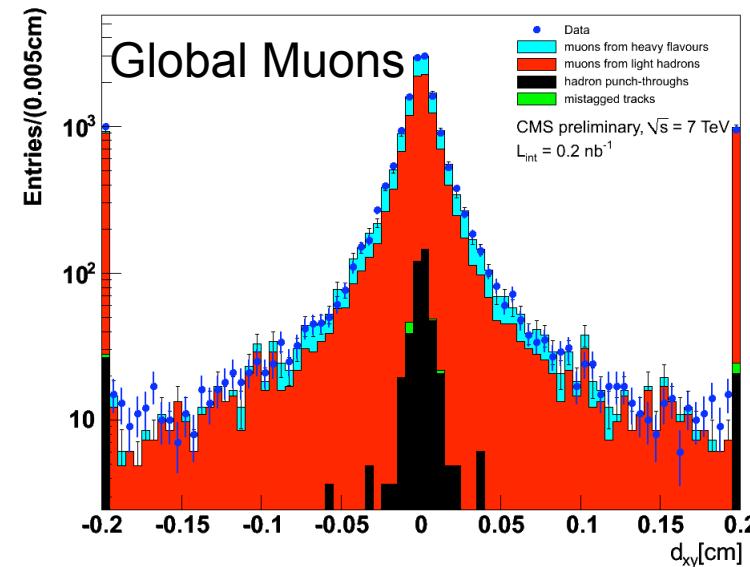
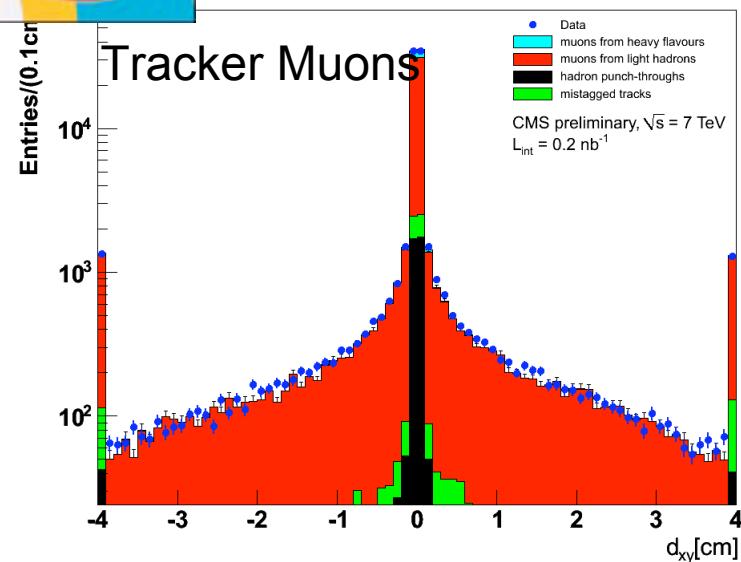


## Good data-MC agreement p and $p_T$ spectra





# Impact parameter w.r.t. primary vertex

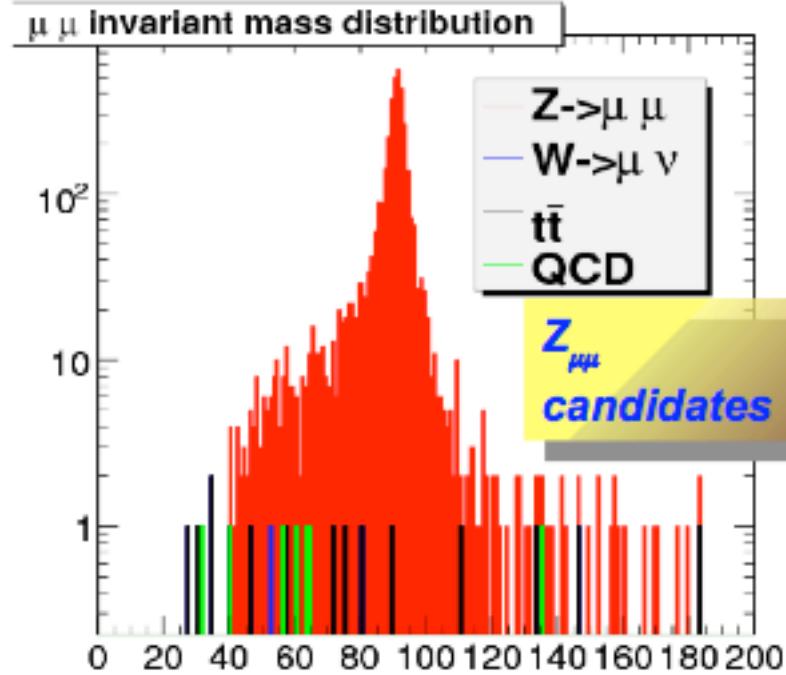




# MC analysis with 10 pb<sup>-1</sup> (2)



10 pb<sup>-1</sup> equivalent statistics



3560  $Z_{\mu\mu}$  candidates from signal

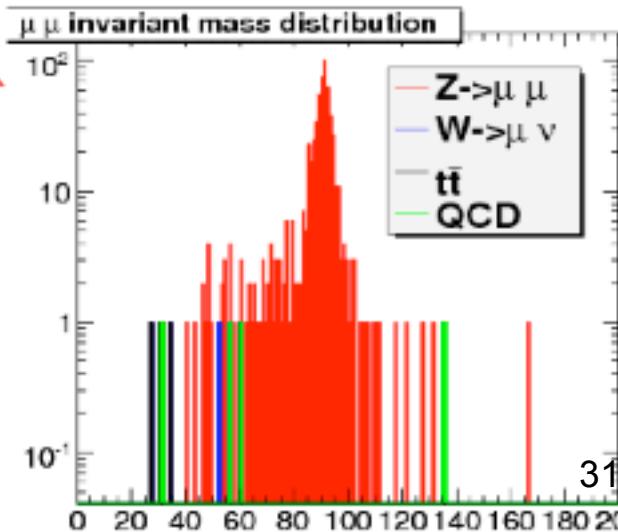
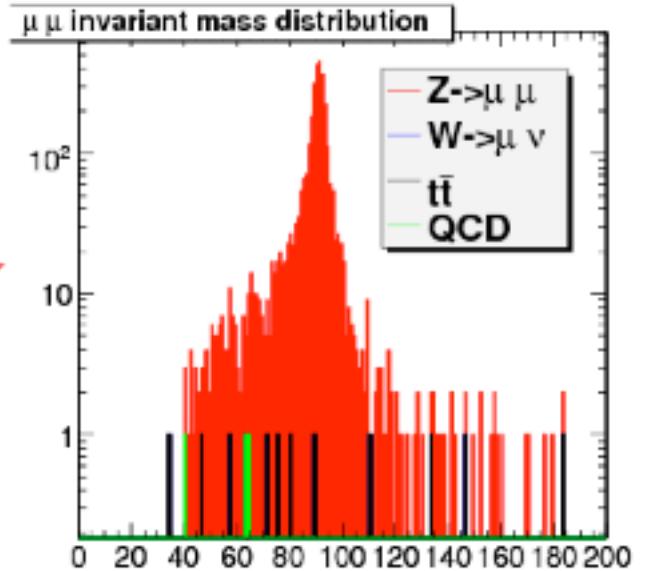
( $60 < M < 120$  GeV/c<sup>2</sup>)

splitted in 2991 2HLT and 569 1HLT

Very few bkg under the peak

$Z_{\mu\mu}^{2\text{HLT}}$

$Z_{\mu\mu}^{1\text{HLT}}$





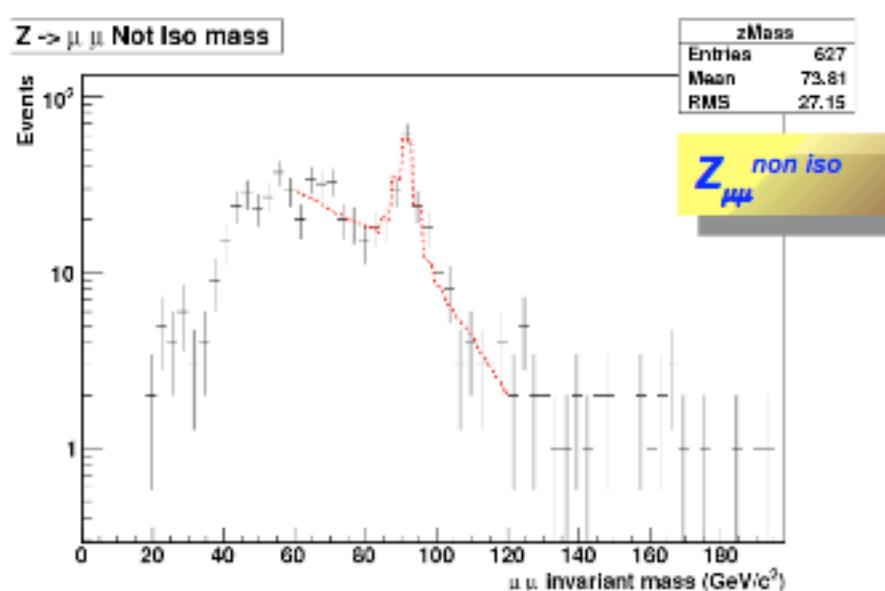
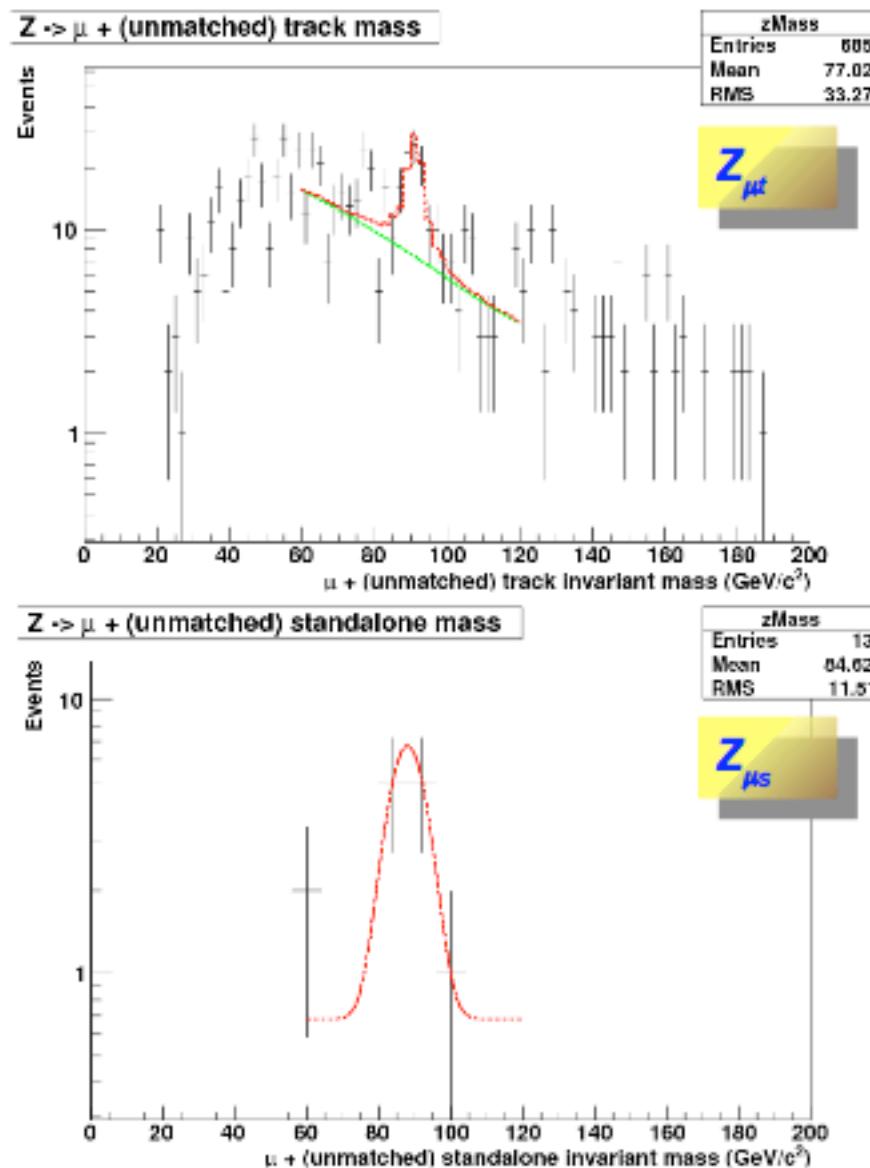
# Data driven methods



## Tag & Probe methods:

- Tag a muon in sample of Zmm with tight criteria
- Probe any loose defined muon
- Cinematic cuts to select Z invariant mass
- Check efficiency for the loose muon to be identified with tighter criteria
- Define maps of efficiency vs  $\eta$   $\Phi$   $P_t$
- correct the sample of good dimuons  
(with negligible background) with efficiency from T&P event by event

# Fit results (10 pb<sup>-1</sup> norm.)



Chi2/ndof = 67.5/30 = 2.2

| Parameter                   | Fit value                      |
|-----------------------------|--------------------------------|
| $N_{Z \rightarrow \mu \mu}$ | $3818 \pm 64$                  |
| $M_s$                       | $88.2 \pm 1.7 \text{ GeV/c}^2$ |
| $\sigma_s$                  | $4.1 \pm 2.7 \text{ GeV/c}^2$  |

# Fitting strategy

## Fit model

$$\frac{dN_{\mu\mu}}{dm} = f_{\mu\mu}(m) = N_{\mu\mu} f_{peak}(m)$$

$$\frac{dN_{\mu\mu}^{2\text{HLT}}}{dm} = f_{\mu\mu}(m) = N_{\mu\mu}^{2\text{HLT}} f_{peak}(m)$$

$$\frac{dN_{\mu\mu}^{1\text{HLT}}}{dm} = f_{\mu\mu}(m) = N_{\mu\mu}^{1\text{HLT}} f_{peak}(m)$$

$$\frac{dN_{\mu s}}{dm} = f_{\mu s}(m) = N_{\mu s} f_{peak}^s(m) + b_{\mu s}(m)$$

$$\frac{dN_{\mu t}}{dm} = f_{\mu t}(m) = N_{\mu t} f_{peak}(m) + b_{\mu t}(m)$$

$$\frac{dN_{\mu\mu}^{\text{non iso}}}{dm} = f_{\mu\mu}^{\text{non iso}}(m) = N_{\mu\mu}^{\text{non iso}} f_{peak}(m) + b_{\mu\mu}^{\text{non iso}}(m)$$

$f_{peak}$  shape is not fitted;  $Z_{\mu\mu}$  histogram is taken as template for it, since bkg is negligible

Bkg shapes: exponential + polynomial

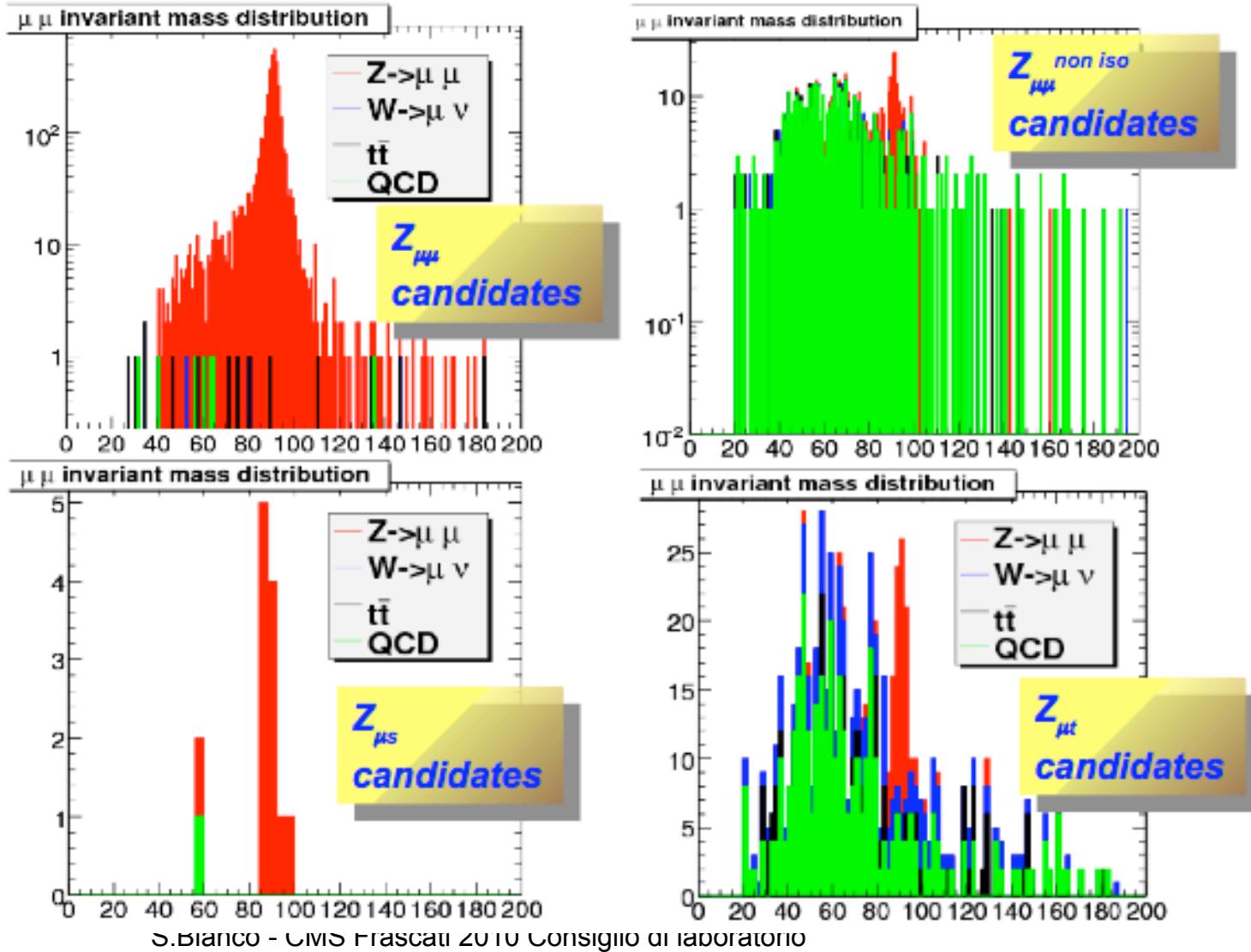
Signal shape in  $Z_{\mu s}$ : gaussian



# MC analysis with 10 pb-1



*10 pb<sup>-1</sup> equivalent statistics*



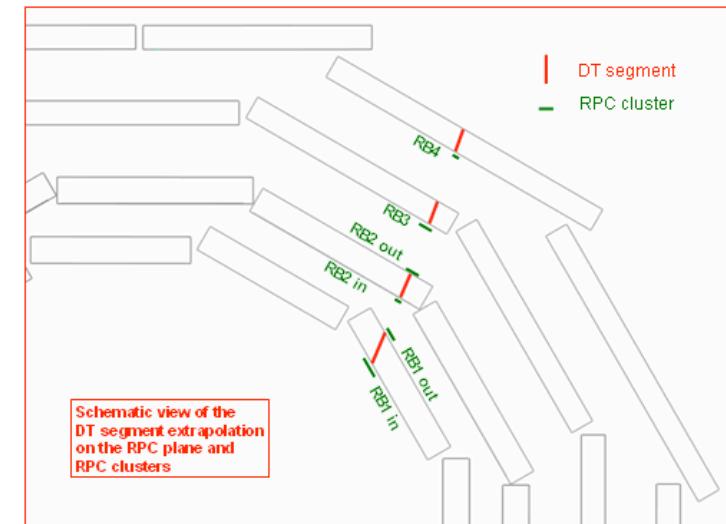
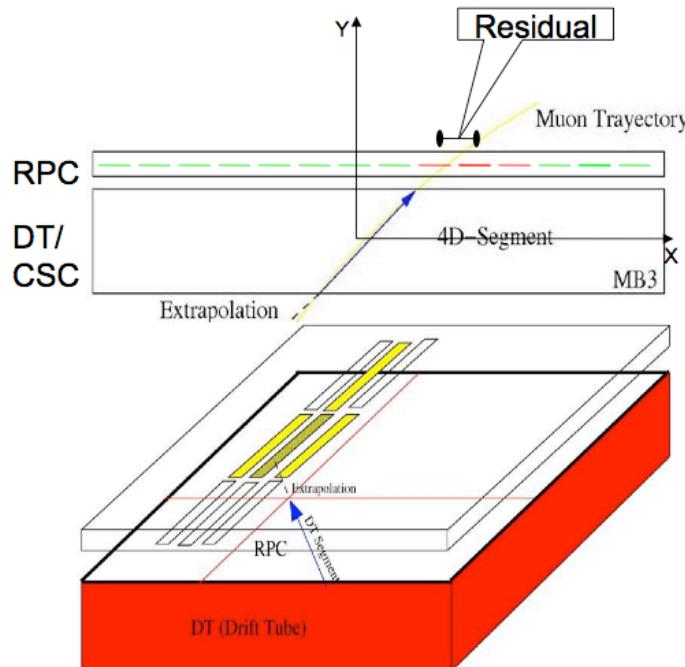


# Detector Performance: the method



Selection of muons according to reconstruction  
Quality (number of hits in the fit, good vertex)

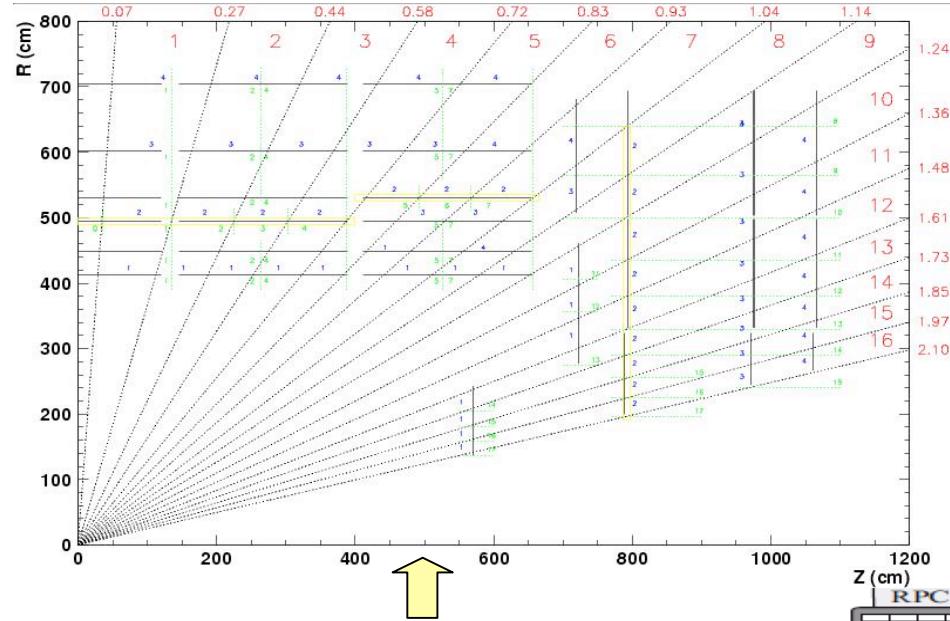
Extrapolate segments used in the muon  
Reconstruction on the RPC plane



For each extrapolation on a given chamber  
Check if a RPC hit is present at a distance below  
2 strips from the impact point



# II trigger RPC

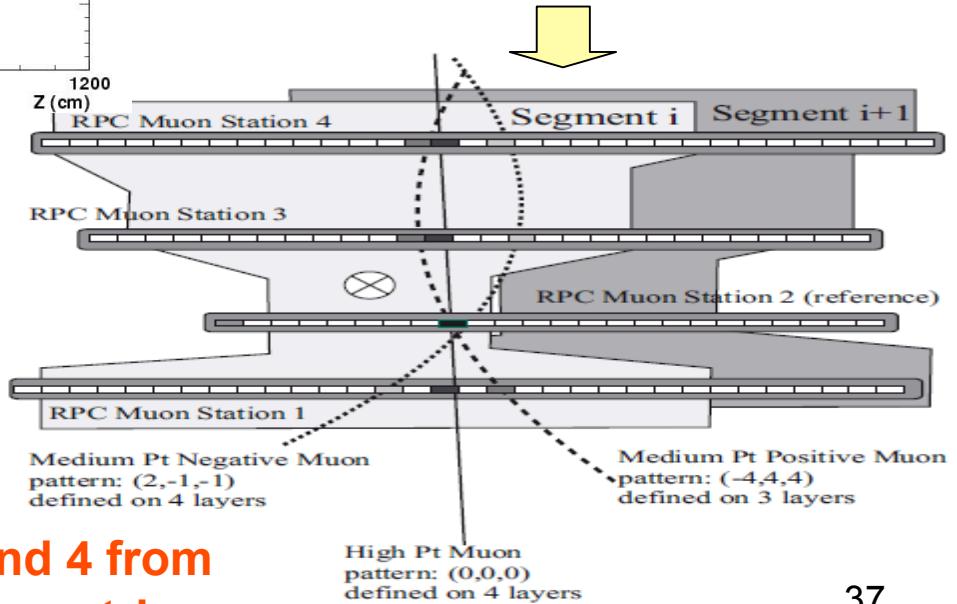


3-6 layers per cone depending on the tower.

PAC algorithm: strips in the cone matched to a set of pre-determined patterns.

The detector is divided in 33 geometrical regions (towers) along the  $\eta$  coordinate according to the position on a reference layer

Cones cover  $2.5^\circ$  in  $\phi$  (8 strips) on the reference layer



Select 4 higher pt muons from barrel and 4 from end-caps and deliver them to Global muon trigger

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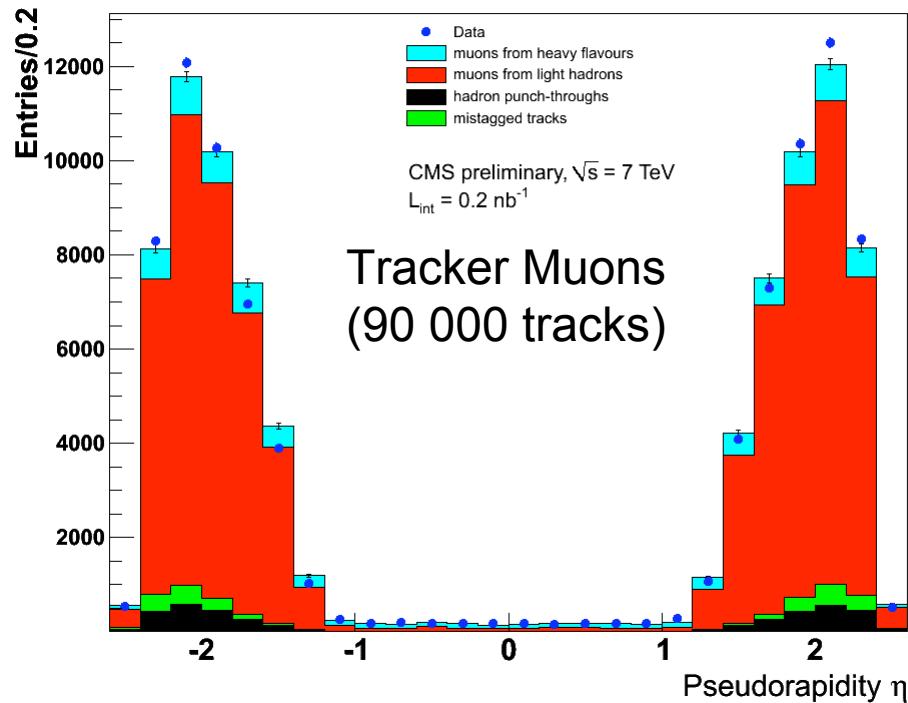


# Pseudorapidity distributions

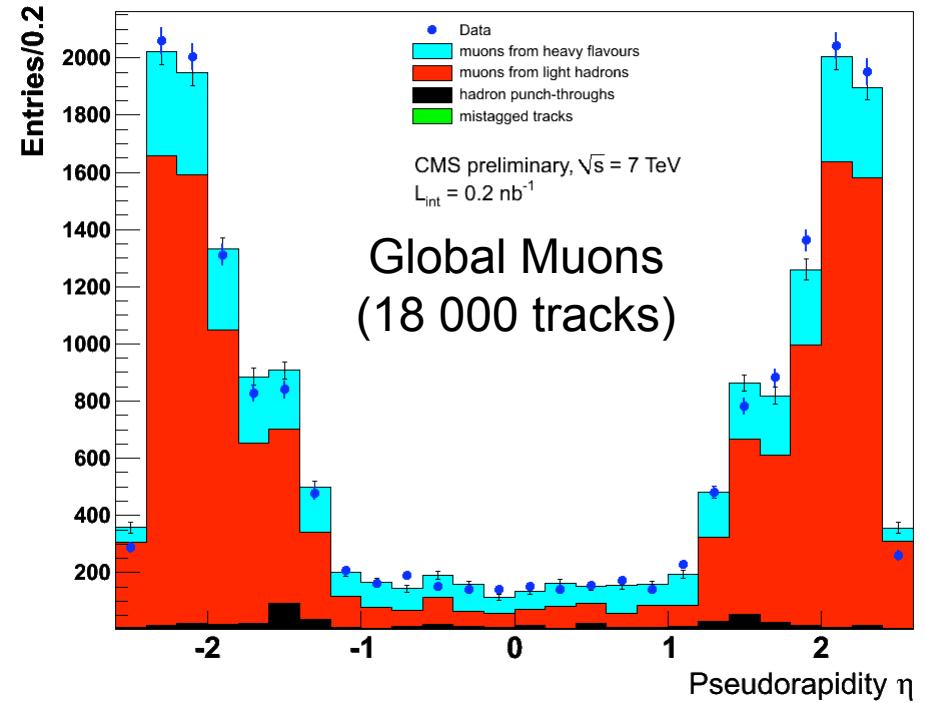


types of muon candidates:

- Tracker muons: tracker tracks matched to least one segment in the muon system.
- Global muons: combined fit of all tracker and muon



**Tracker Muons  
(90 000 tracks)**



**Global Muons  
(18 000 tracks)**

Pseudorapidity distribution peaks in the forward region because of a lower  $p_T$  threshold to reach muon stations.

More Plots in Backup slides