CMS at LNF

Davide Piccolo
On behalf of the LNF CMS group

Outline

- The LNF group in CMS
- LNF group activities:
  – Resistive Plate Chambers performance
  – Muons in CMS
  – Analysis of Z ➔ $\mu^+ \mu^-$
- Conclusions

CMS Frascati 2010

G.Altobelli[c], R.Aurilio[c], E. Basile[c], L.Benussi[a], S.Bianco[a],
M.A.Caponero[b], S.Colafranceschi[c],
F.L.Fabbri[a], F.Felli[c], M.Ferrini[c], M.Giardoni[a], T.Greci[c], M.Pallotta[a],
A.Paolozzi[d], M.Parvis[e], L.Passamonti[a], D.Piccolo[a]
D.Pierluigi[a], C. Pucci[c], A.Russo[a], G.Saviano[c]

[a]Laboratori Nazionali di Frascati dell'INFN, Italy
[b]Laboratori Nazionali di Frascati dell'INFN and ENEA Frascati, Italy
[c]Laboratori Nazionali di Frascati dell'INFN and Facolta' di Ingegneria Roma1, Italy
[d]Laboratori Nazionali di Frascati dell'INFN and Scuola di Ingegneria aerospaziale Roma 1, Italy
[e] Laboratori Nazionali di Frascati dell'INFN and Politecnico di Torino, Italy

13.5/15 FTE staff+PhD+undergrads
1.5/3 FTE technicians

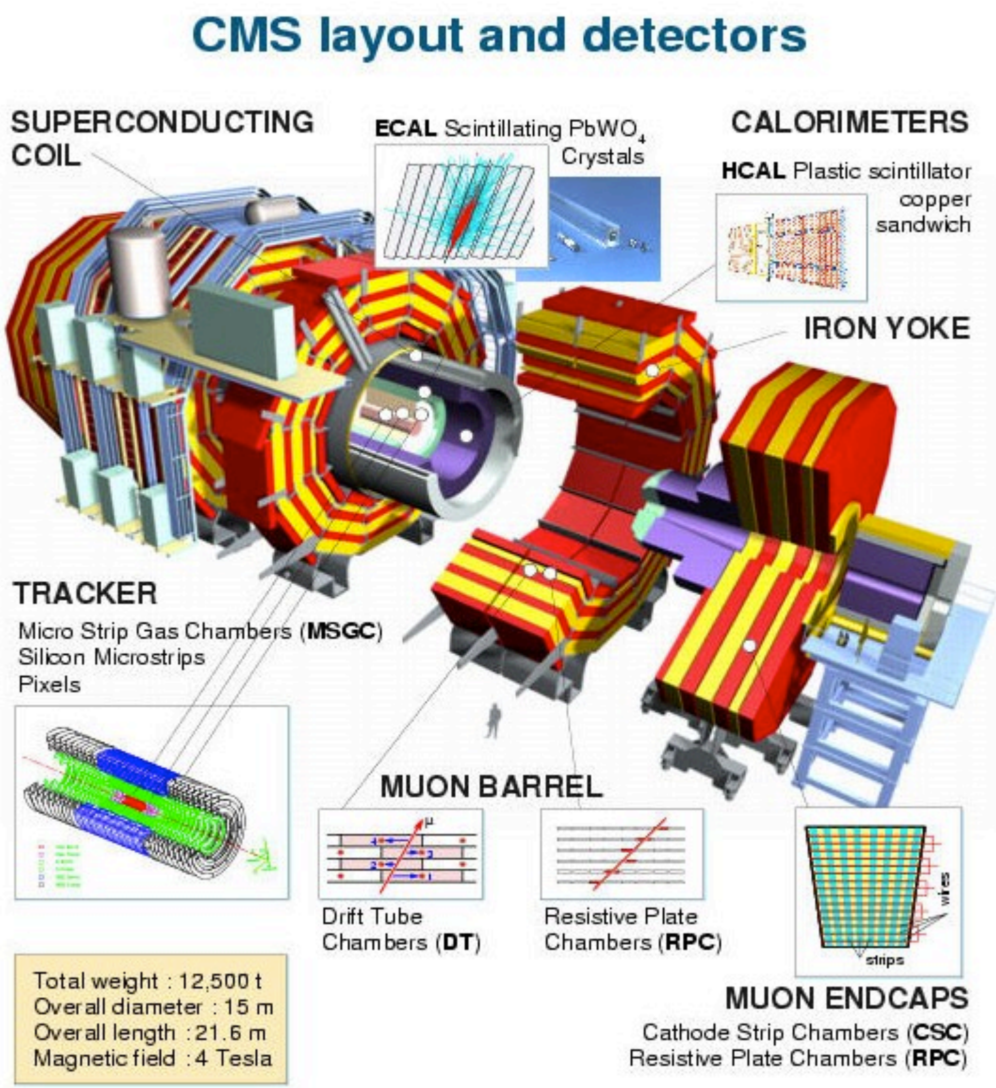
In collaboration with
A.Cecchetti, D.Orecchini, B.Dulach, B.Ponzio, G. Raffone, C. Bisegni

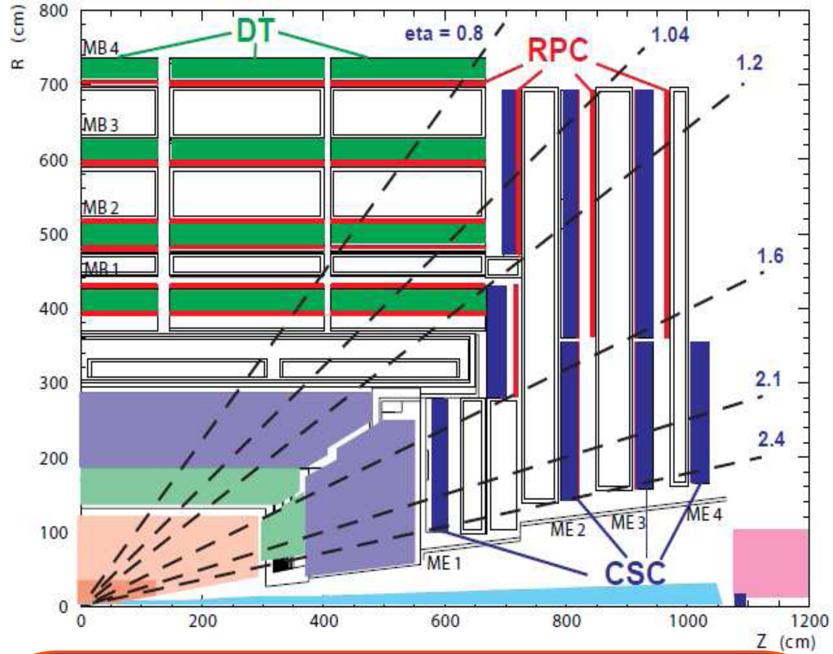
Tasks and Responsibilities in CMS

In green topics covered in this talk

- Main Responsibilities:
  - 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
- side activities:
  - Muon system performance
  - CMS RPC Upscope and Upgrade
  - R&D on optical sensors for gas contaminants (PRIN project co-funded by MIUR)
  - T3 computing
- **Physics Analysis:**
  - **Analysis of Z → $\mu^+\mu^-$ Cross section**

The CMS detector





The MUON System

3 different technologies of gaseous detectors

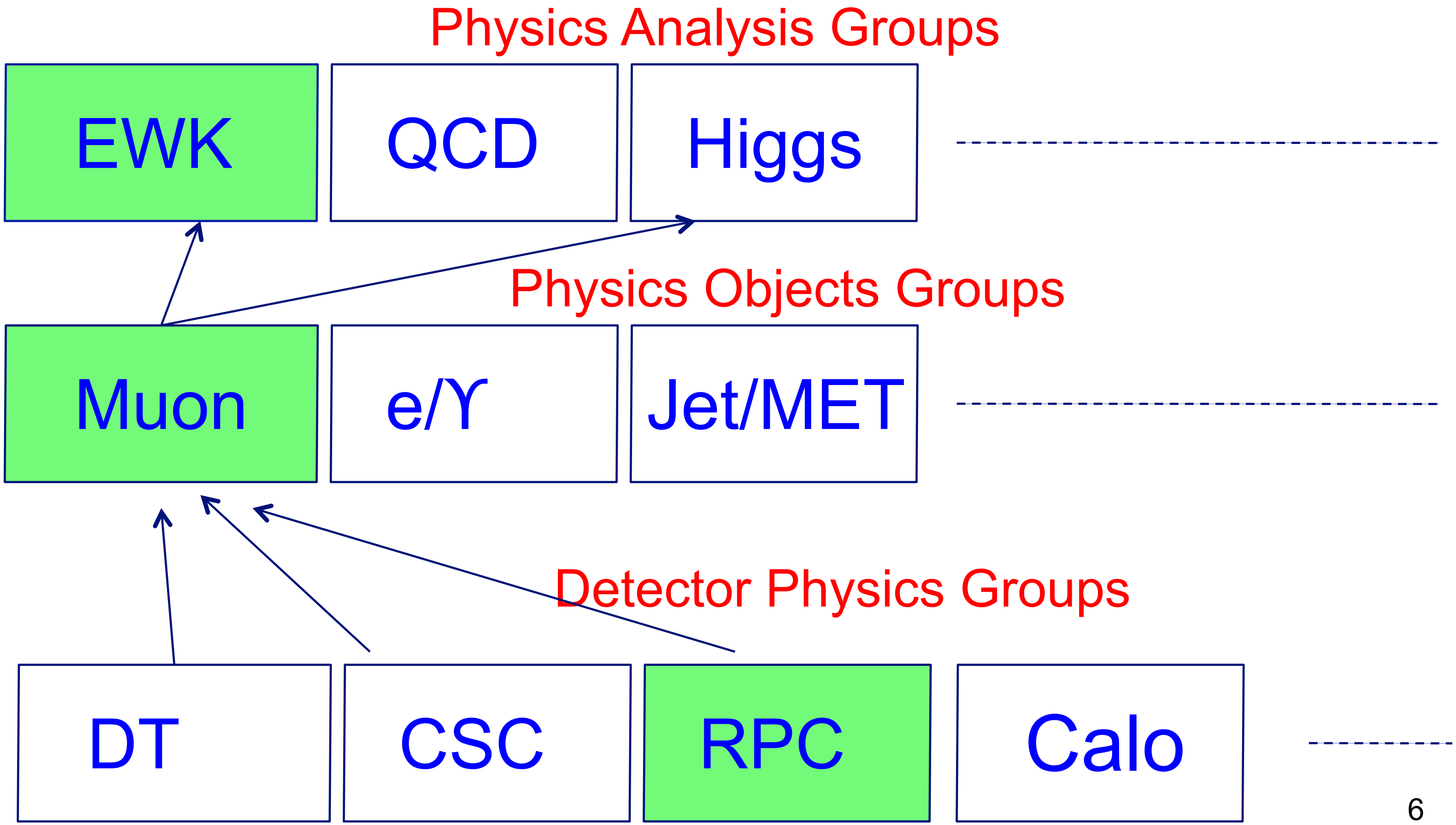
Drift Tube (DT) in the barrel ($|\eta|<1.2$)
Cathode Strip Chambers (CSC) in the endcaps ($0.9 < |\eta| < 2.4$)
Resistive Plate Chambers (RPC) both in barrel and endcaps (up to $|\eta|=1.6$)

All detectors used both in triggering and reconstruction

The CMS organization

Istituto Nazionale di Fisica Nucleare

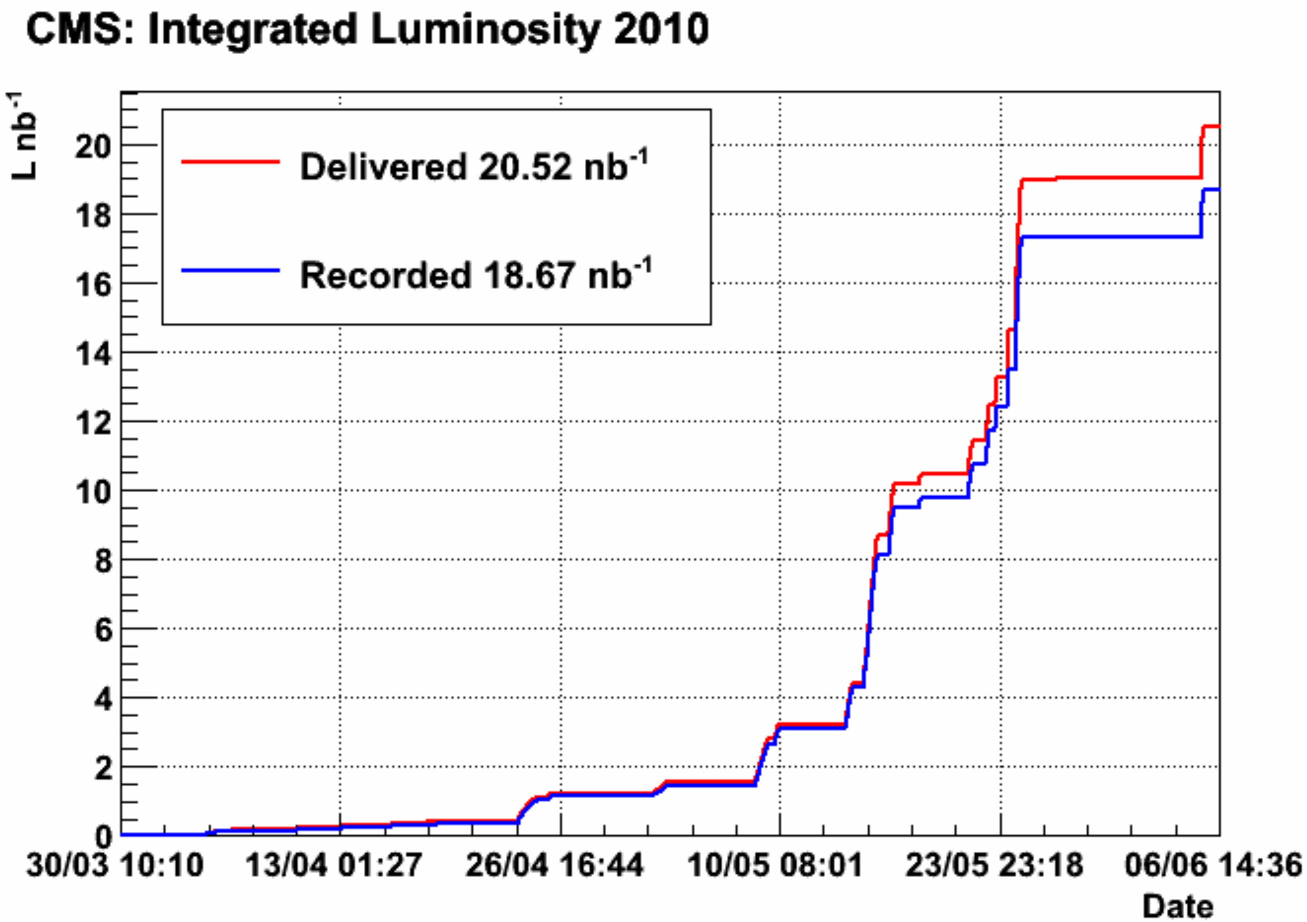
Frascati group is deeply involved in all green items



Hardware operations Software and Analysis

First 2.5 months of 7 TeV operations

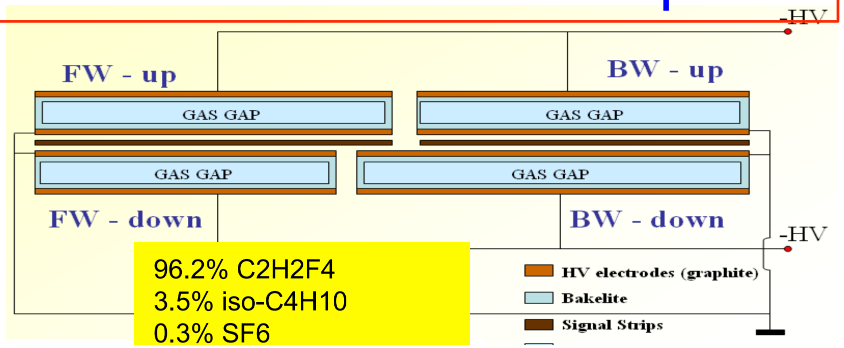
About **20.5nb^{-1}** delivered by LHC and **~18.7nb^{-1}** of data collected by CMS. Overall data taking efficiency **~91%.** After quality flags and data certification for physic (**~90%**) we end up with **~17nb^{-1}** of good data for physics.



The RPC system

Fast Trigger dedicated detector both in Barrel and Endcap

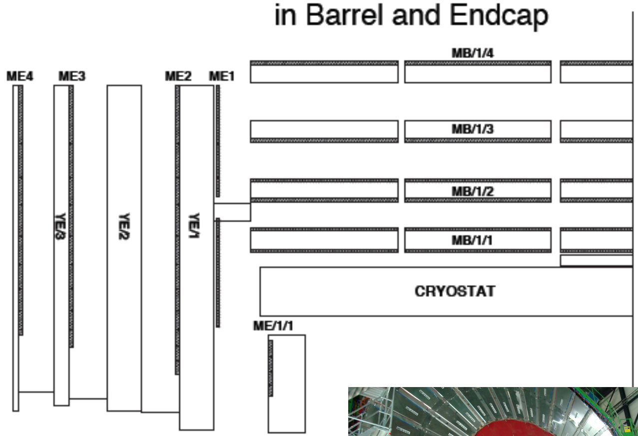
Double gap bakelite plates with graphite electrodes and strips readout

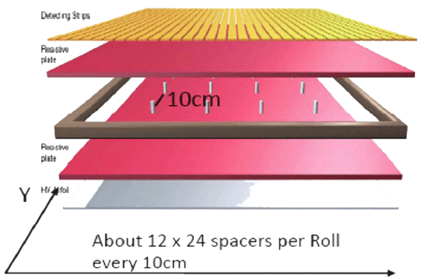


96.2% $C_2H_2F_4$
3.5% iso-C_4H_{10}
0.3% SF_6

Double gap RPCs in Avalanche mode:
- lower gain (to cope with high rate up to 1kHz/cm2)
- higher amplification

RPC Location in Barrel and Endcap

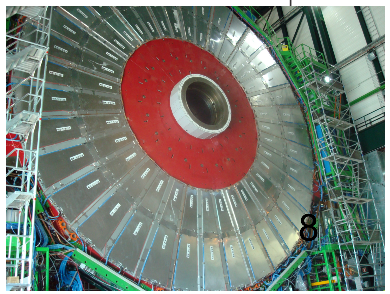




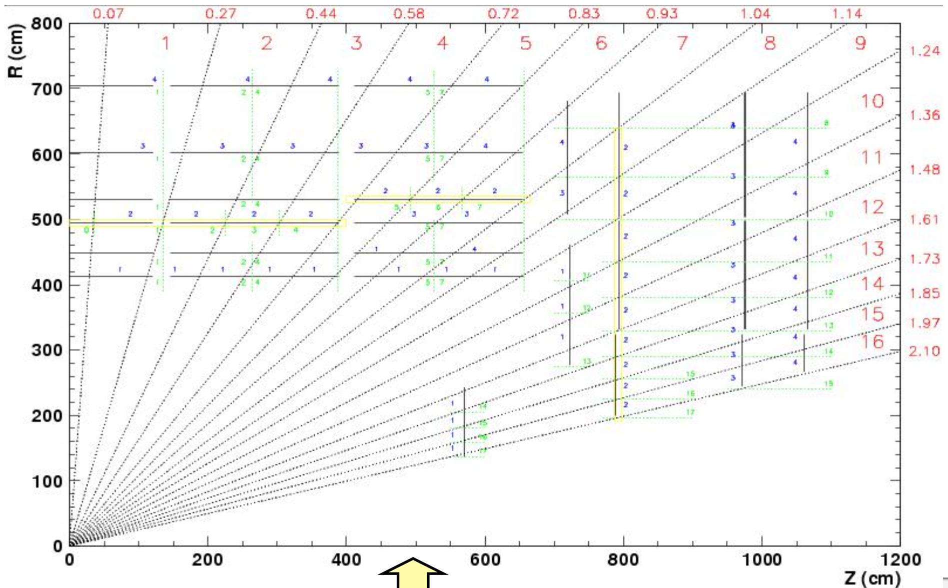
A time resolution of ~2 ns allows BX tag without ambiguity

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



The RPC trigger

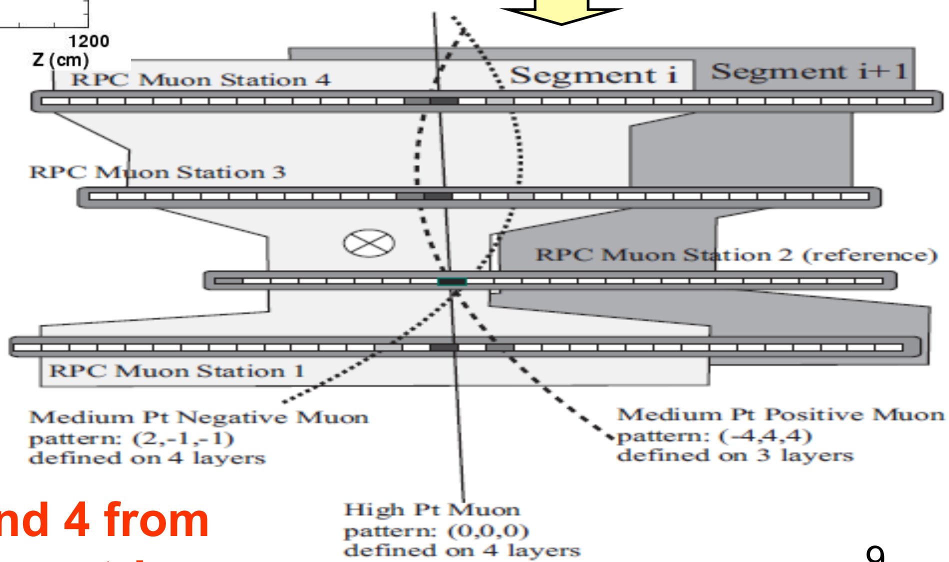


The detector is divided in 33 geometrical regions (towers) along the η coordinate according to the position on a reference layer

Cones cover 2.5 ° in ϕ (8 strips) on the reference layer

3-6 layers per cone depending on the tower.

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



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

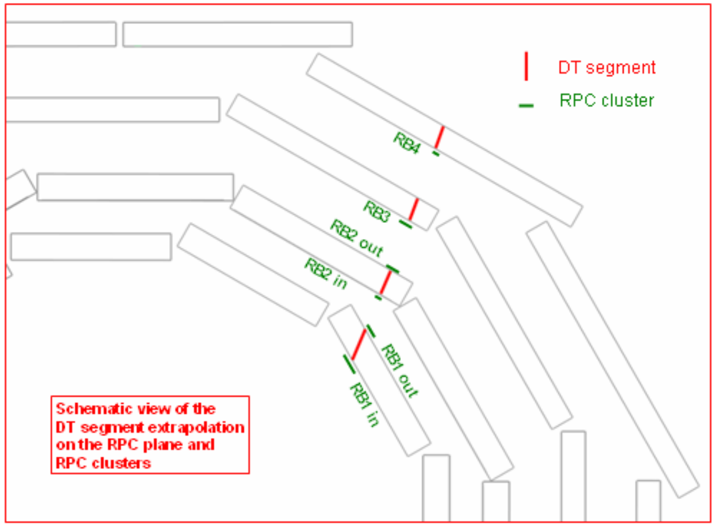
RPC Detector and trigger studies

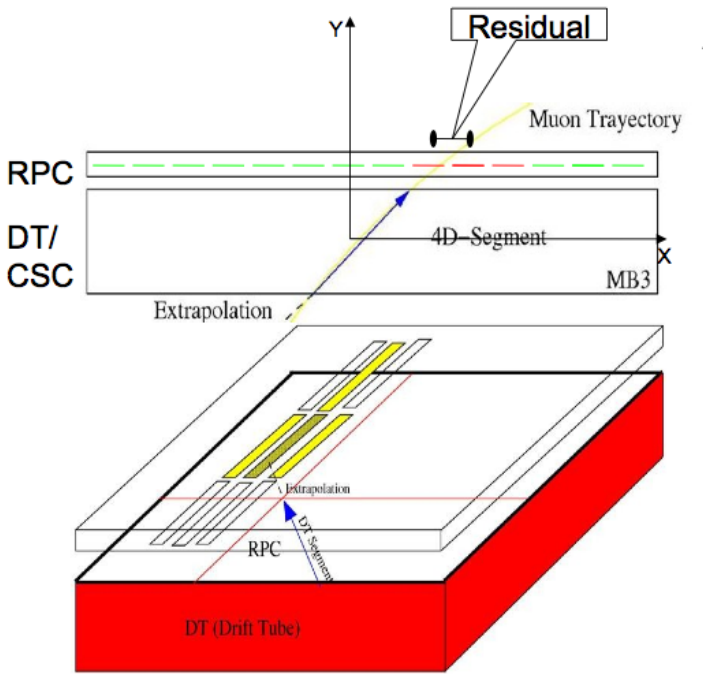
- More than 1 year of Cosmic Data tacking
  - Detector commissioned in detail
- Several thousands of inclusive muons collected since the start of LHC:
  - Fine time synchronization of the detector
  - Detection efficiency
  - Trigger performance:
    - Work in progress still not official results

Detector Performance: the method

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

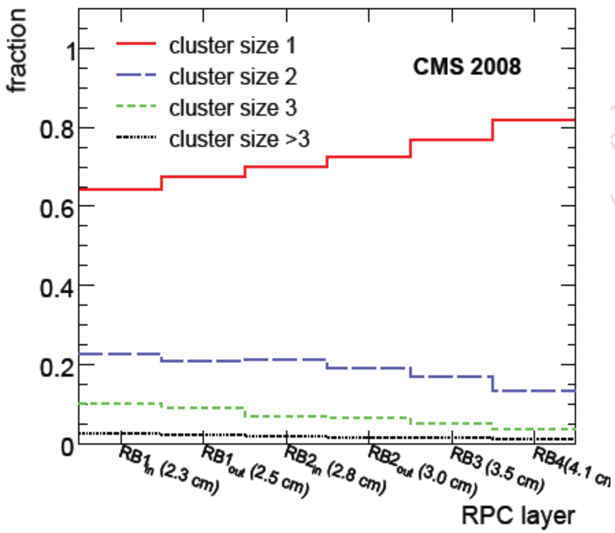
Extrapolate segments used in the muon
Reconstruction on the RPC plane

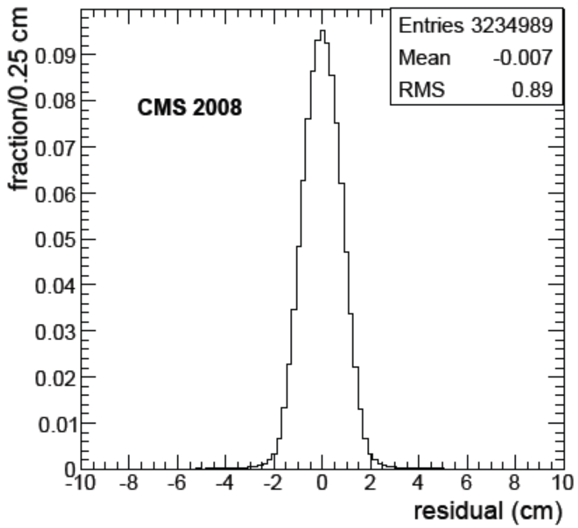


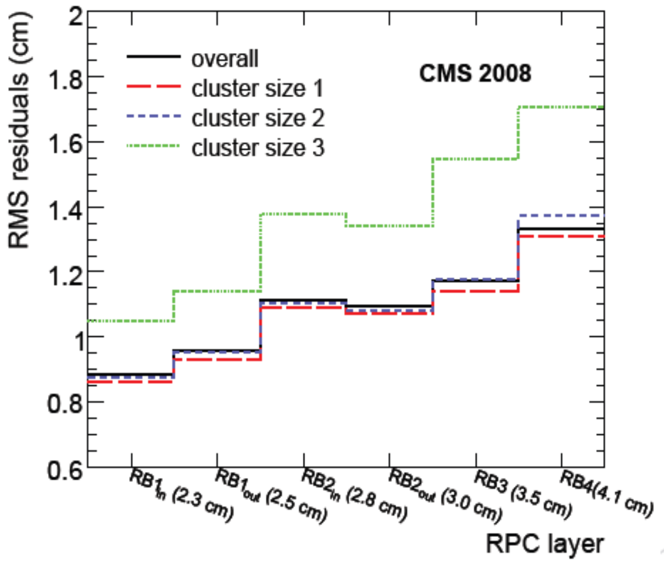


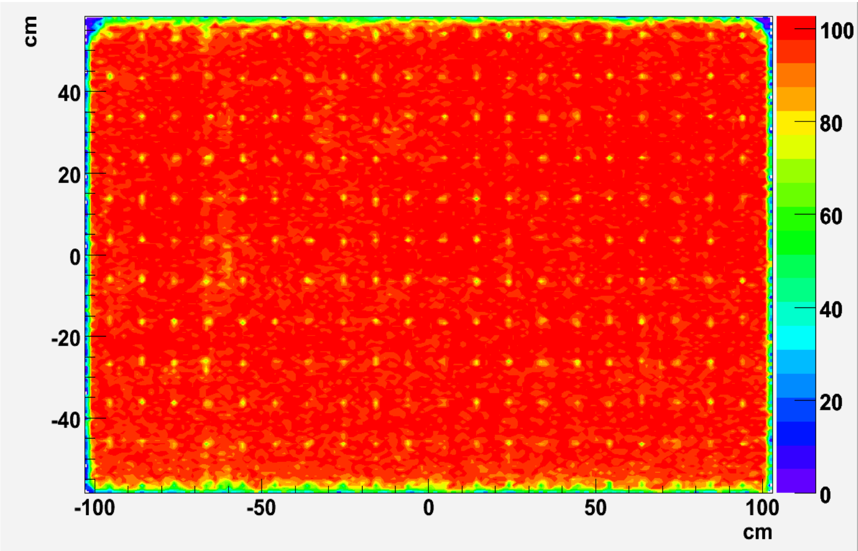
For each extrapolation on a given chamber
Check if a RPC hit is present at a distance below
2 strips from the impact point

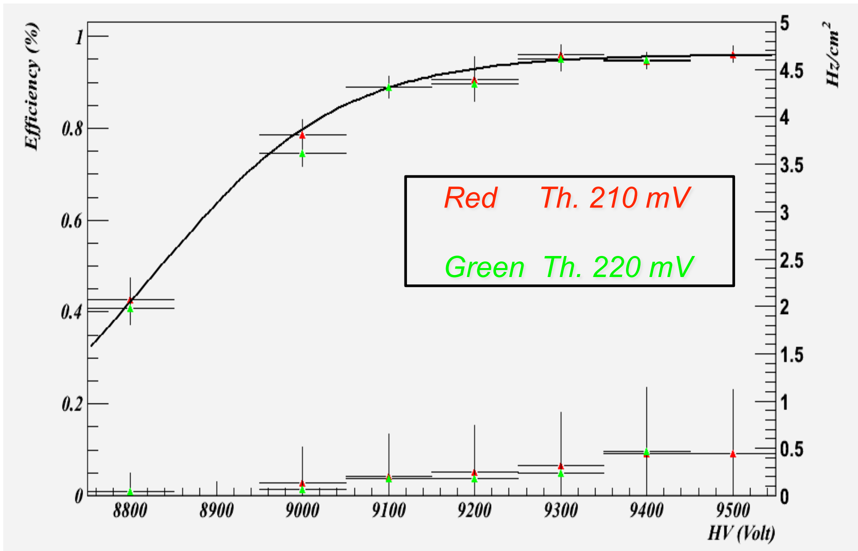
RPC performance during Cosmic Runs





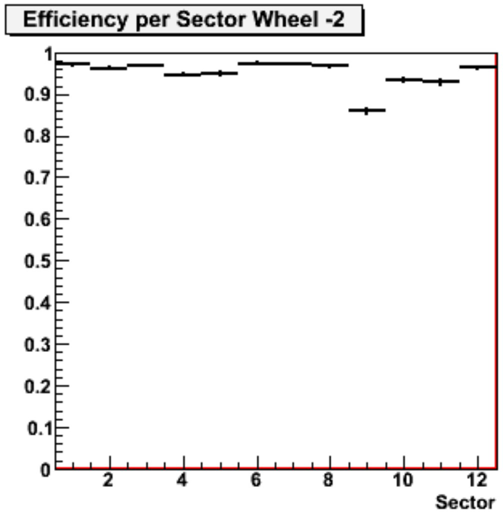


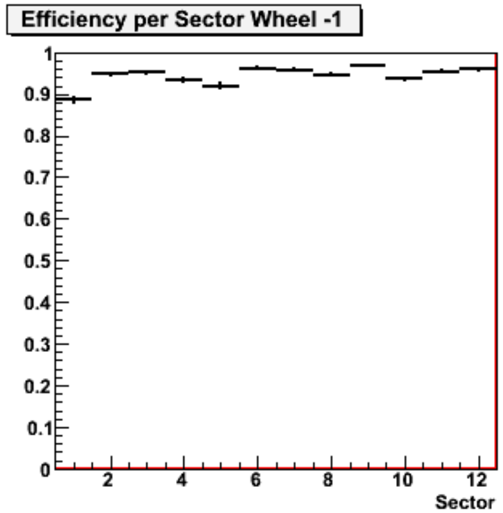


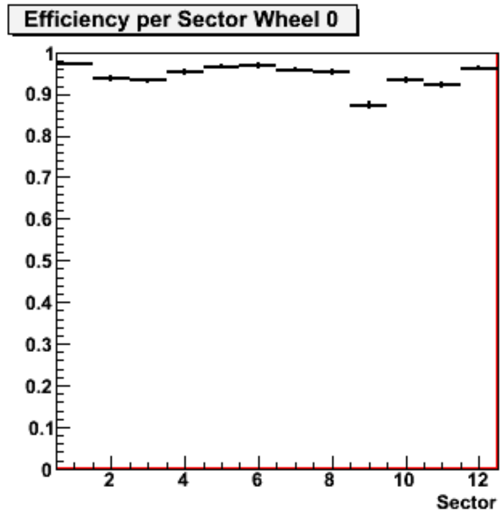


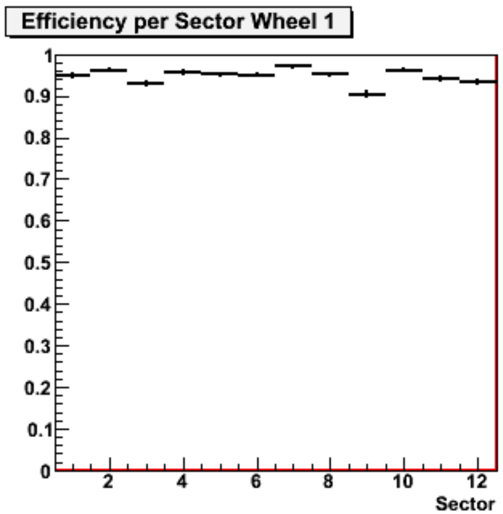
RPC performance during LHC Collisions

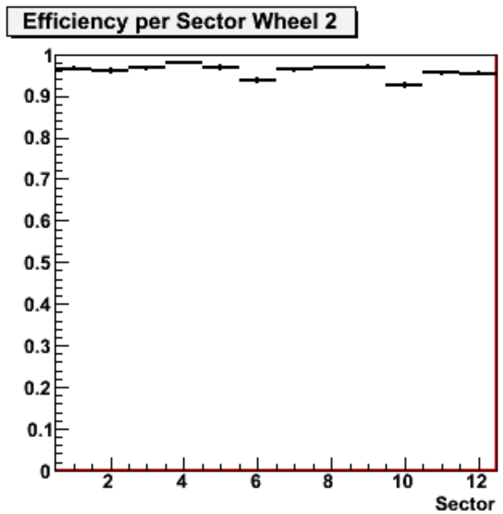
PRELIMINARY







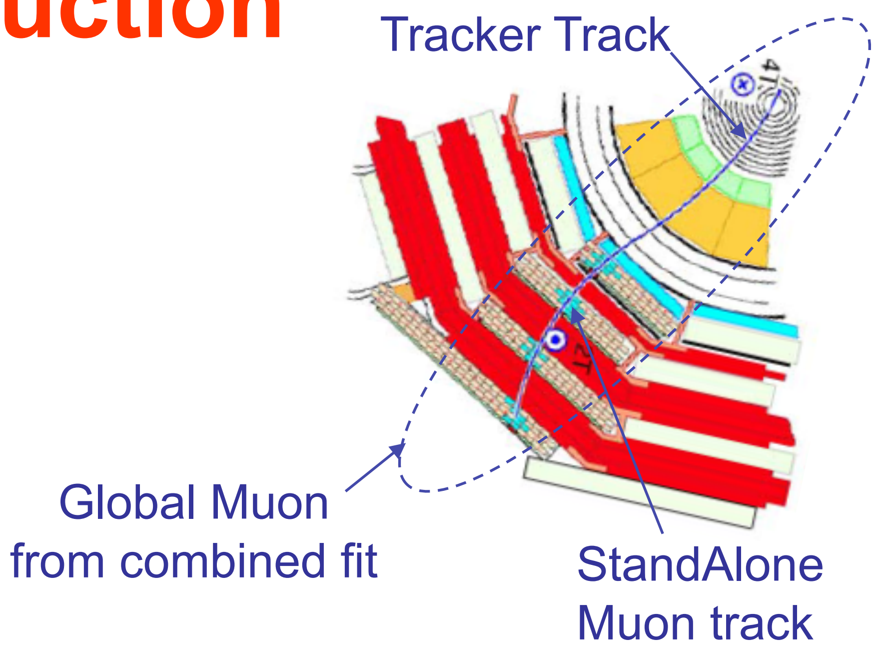




Average Efficiency:
95.0 ± 0.2 %
Fully meeting design specs.

Detector details under study

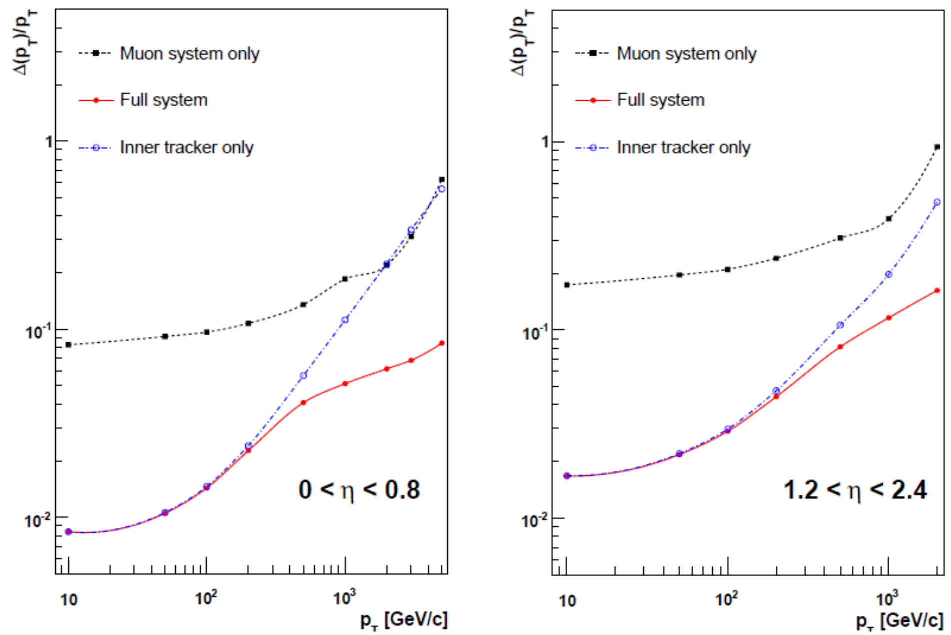
Muon Reconstruction



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



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

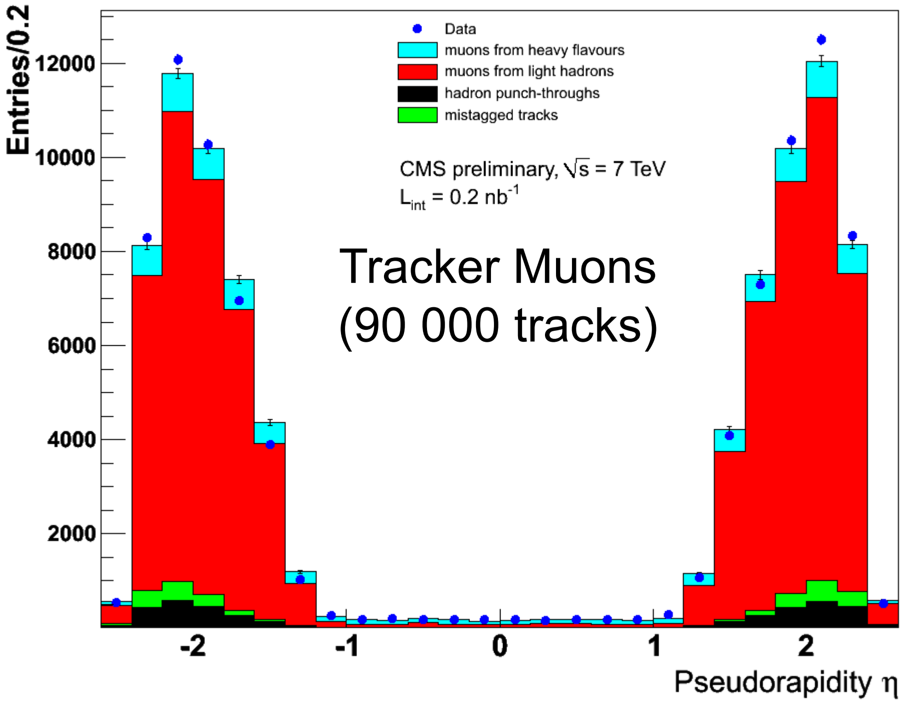
First Data collected used
To xCheck Reconstruction algorithms

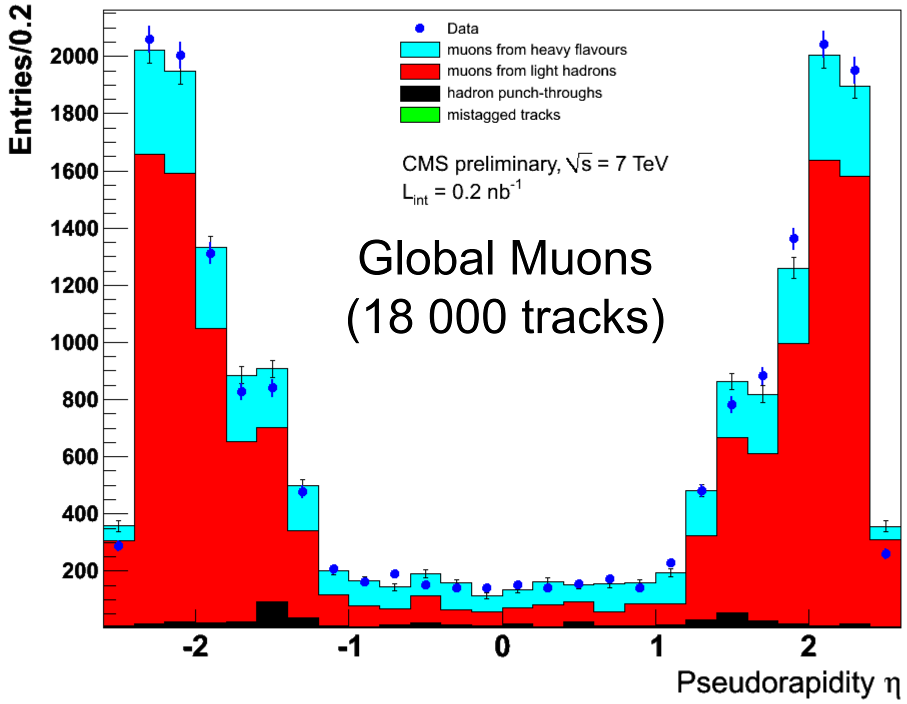
Pseudorapidity distributions

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 .





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

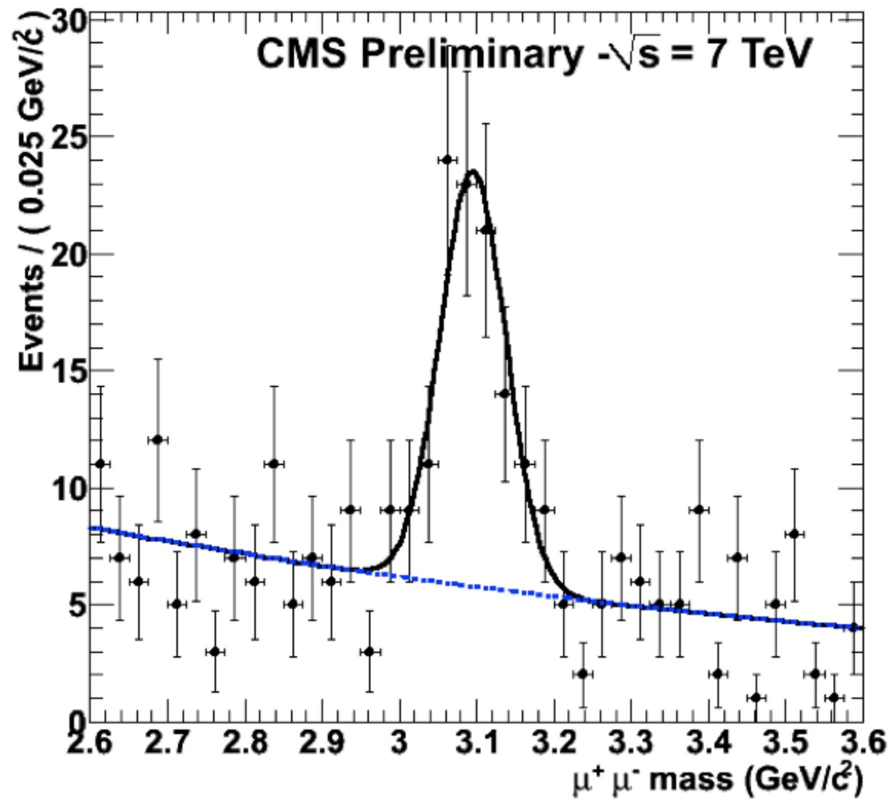
More Plots in Backup slides

Good agreement with MC prediction including heavy-flavor (b- and c-quark) decays (cyan), hadron punch-through (black), and mistags due to accidental matches of non-muon tracks with segments in the muon chambers produced by muons (green).

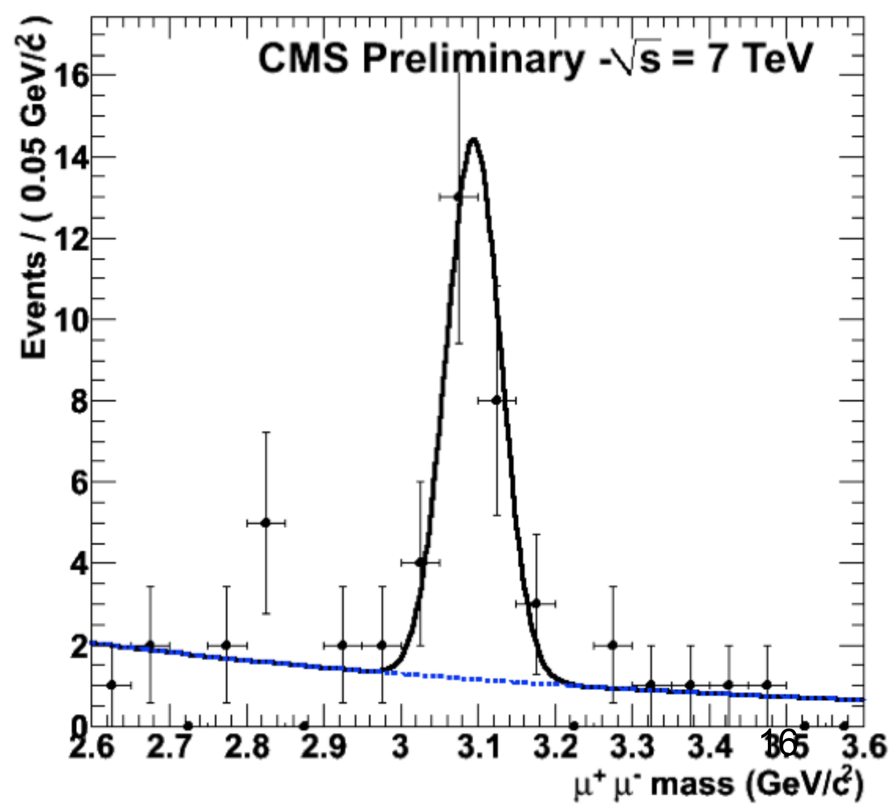
Dimuons (J/Ψ)

- 0.985/nb of pp collisions at 7 TeV (now 18/nb)

Global + glabal or tracker muon



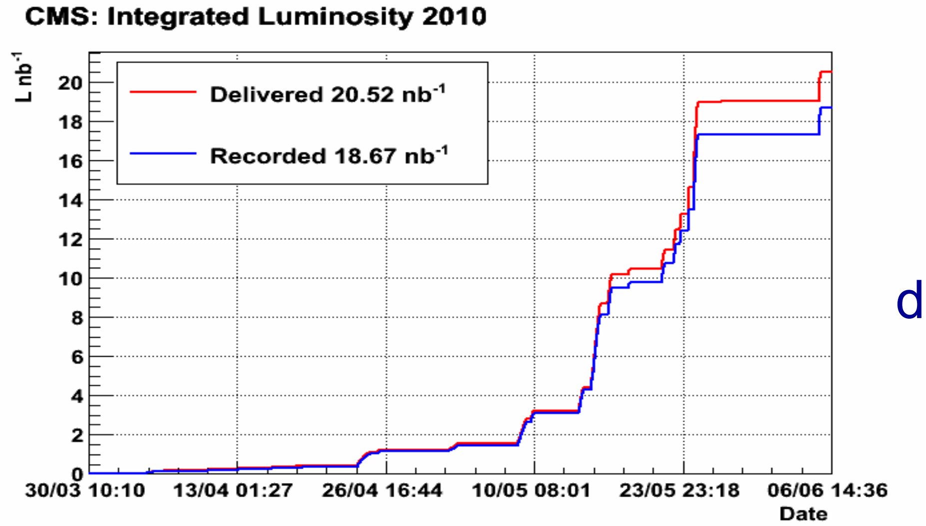
Global + glabal muon



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

- Benchmark for muon reconstruction and identification
- Precision test of perturbative QCD and parton distribution function of the proton
- Together with W corss section is the first electroweak process to be masured at LHC
- Starting point for other EWK studies and background for new physics

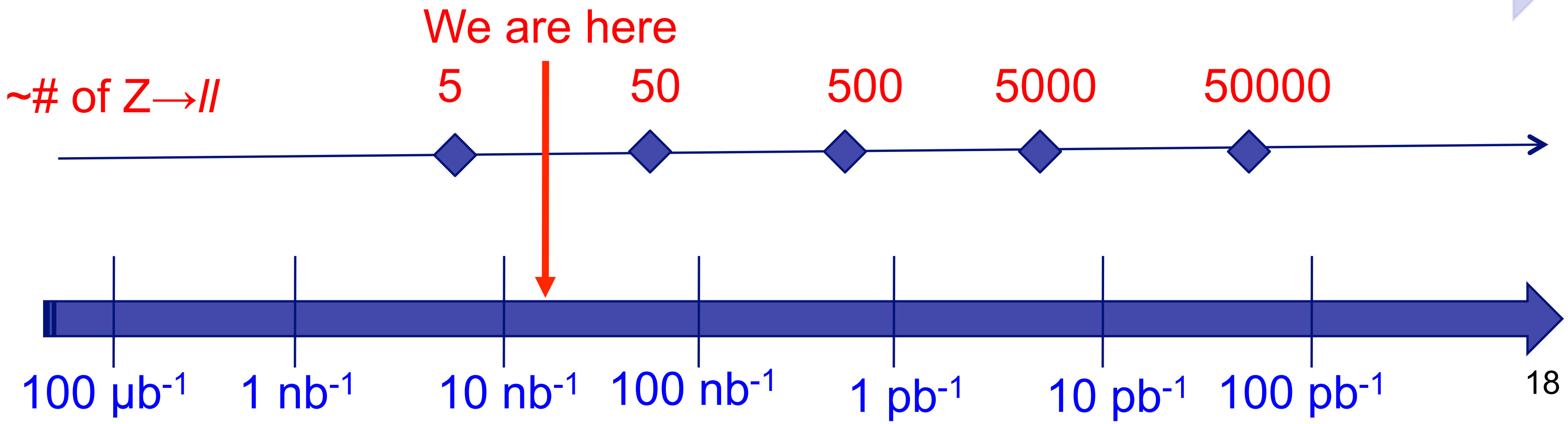
Z Timeline



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

data-driven inputs to σ_Z

candidate hunting, rediscovery



Z ➔ $\mu^+ \mu^-$ cross section

Z→μμ (2 global muons)
– quality cuts relaxed so far
– both muons with pt > 20 GeV/c
– at least one with |η|<2.1, other with |η|<2.4
– trk iso < 3 GeV/c (ΔR<0.3)

Short term approach:
-Cut and count Nmm
(negligible background)
-fix efficiency from MC

Longer term approach:
-Global fit to Nmm and efficiencies
- Tag & Probe

Gemetrical acceptance

Trigger efficiency

$$\sigma_{\gamma^* Z} \times BR(\gamma^*/Z \to \mu^+\mu^-) \times A = \frac{N_{\mu\mu}}{\varepsilon^2_{rec}\, \varepsilon_{qual}\, \varepsilon^2_{iso}\, [1 - (1-\varepsilon_{trg})^2]\, L_{int}}$$

Reco efficiency

Quality cuts efficiency

Isolation efficiency

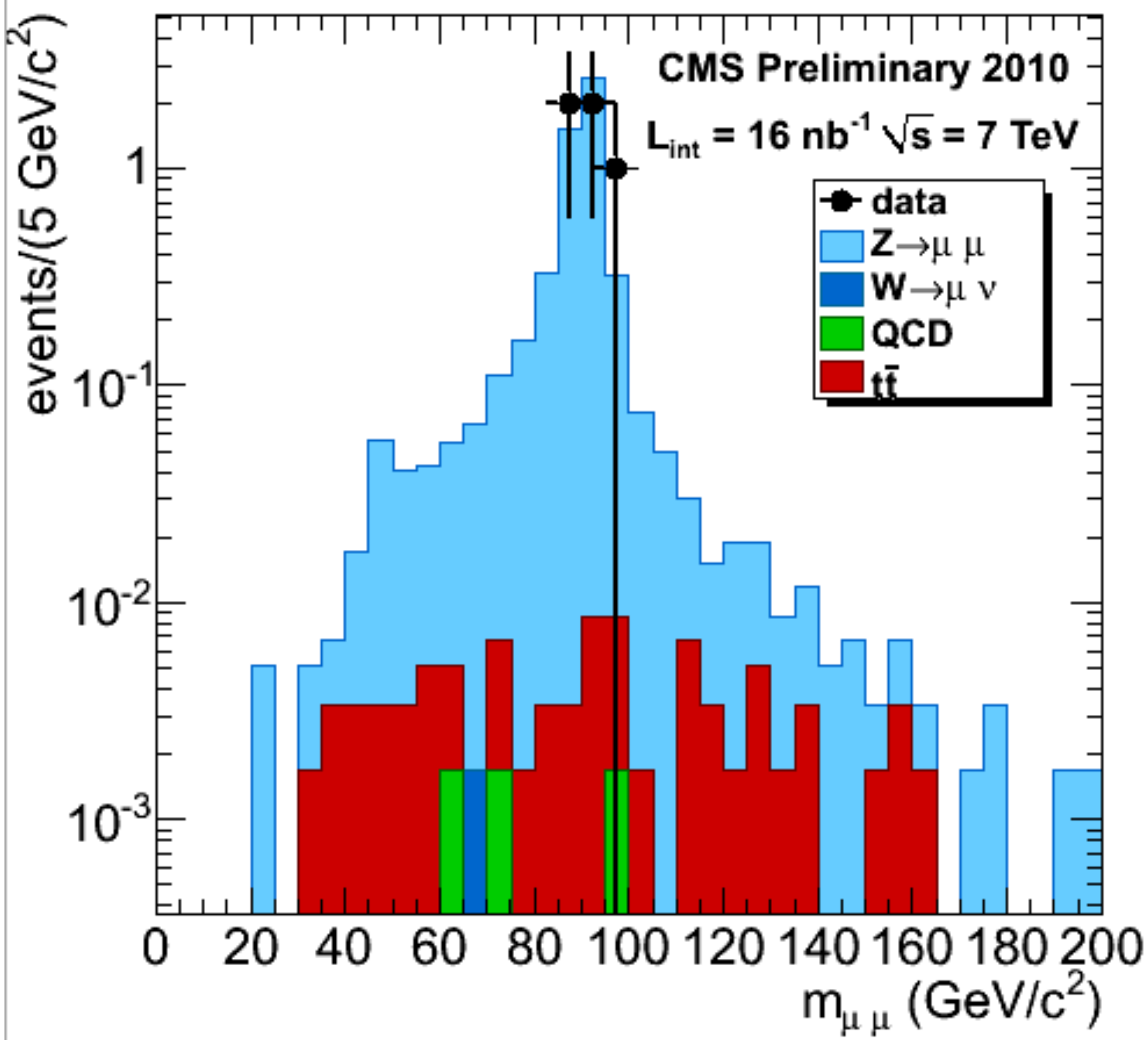
Data collected

5 candidates
Z to 2 global muons

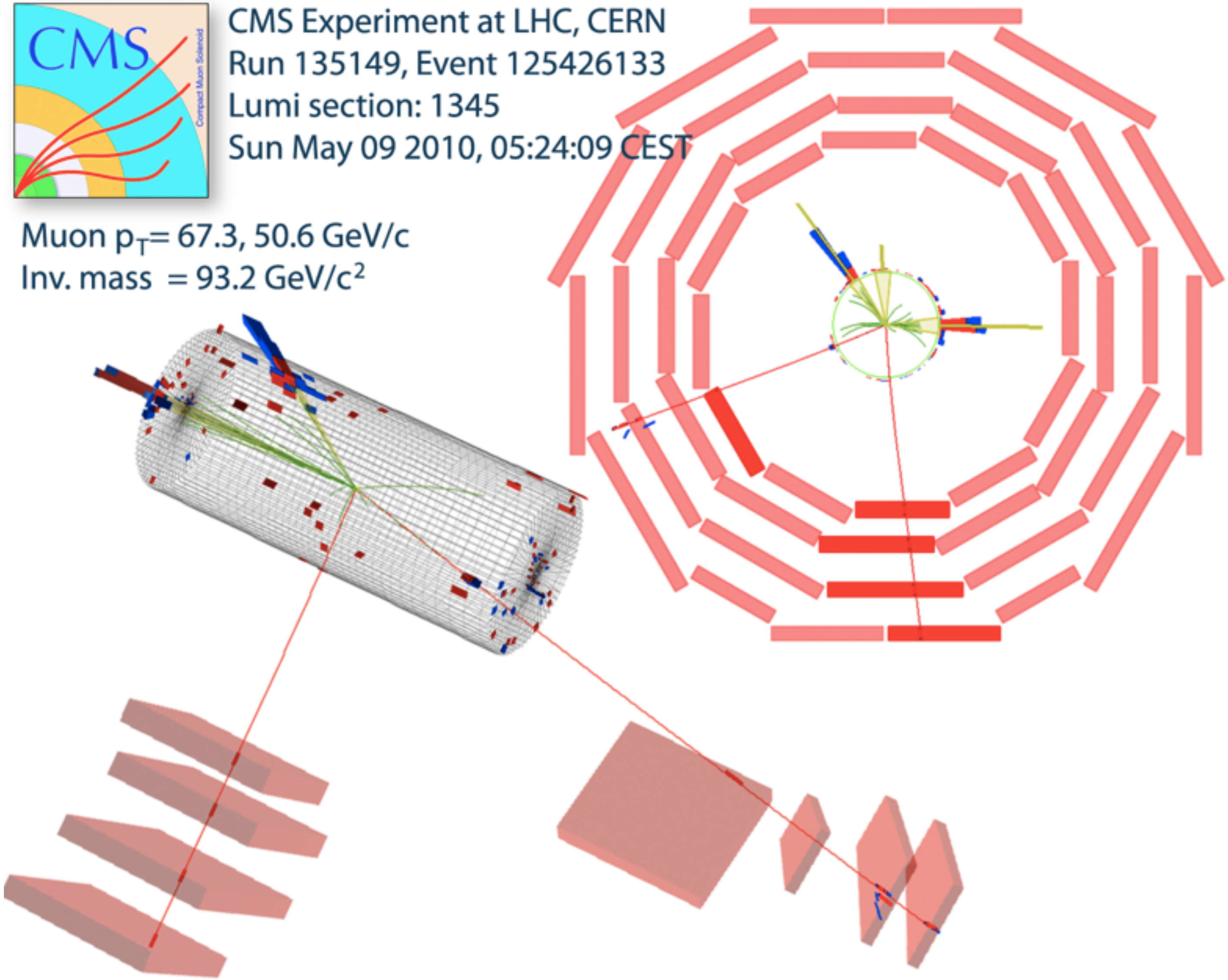
Expected number of event per nb^{-1}:

$Z \rightarrow \mu\mu$ (60-120) = 0.313 ev/nb^{-1}
$W \rightarrow \mu\nu$ (60-120) = 0.0001 ev/nb^{-1}
QCD (60-120) = 0.0003 ev/nb^{-1}
ttbar (60-120) = 0.0026 ev/nb^{-1}

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



Candidate event



Scenarios from 0.1 to 10 pb^{-1}

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
Zμμ	1	3	14	26	53	82	111	136	167	199	231	257	286	559	839	1104	1386	1653	1948	2211	2473	2753
εtrk	fix to MC value (~1)																Fit from data					
εsa	fix to MC value (~1)														Fit from data							
εiso	fix to MC value					Fit from data																
εhlt	fix to MC value					Fit from data																
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 ?

By the end of year ?

Very soon we will enter a new domain where we could use Data driven method for efficiency and Background estimates

Data driven methods: alternative approach

LNF group involved with other Italian groups

5 independent samples of Z candidates selected

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

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

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

3) $Z_{\mu\mu}^{non\ iso}$ = 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

Fitting procedure

10 pb^{-1} equivalent statistics

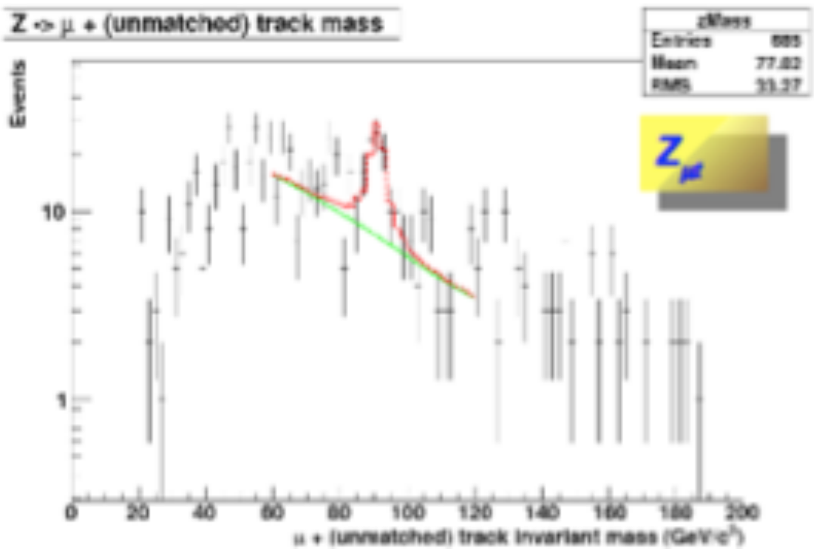
Global chi2

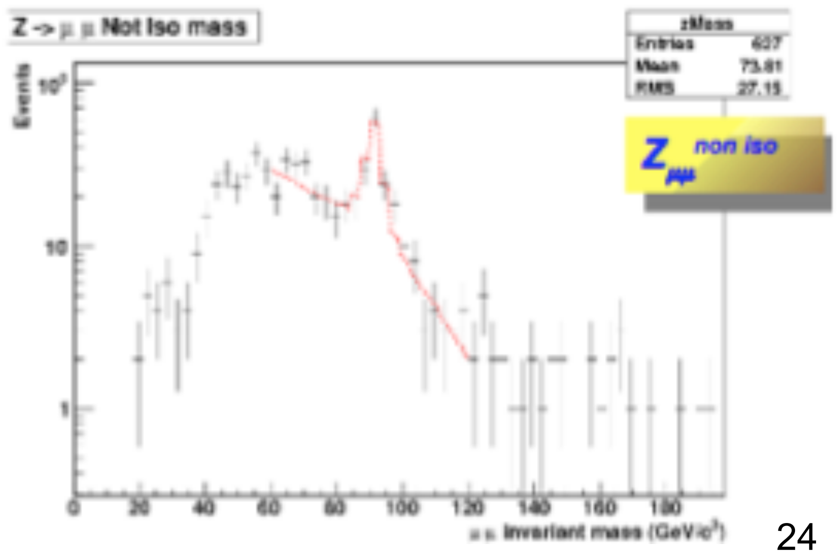
$$\chi^2 = \frac{(N_{\mu\mu}^{2\mathrm{HLT}} - N_{Z\to\mu^+\mu^-}\epsilon_{\mathrm{HLT}}^2\epsilon_{\mathrm{iso}}^2\epsilon_{trk}^2\epsilon_{sa}^2)^2}{N_{\mu\mu}} + \frac{(N_{\mu\mu}^{1\mathrm{HLT}} - 2N_{Z\to\mu^+\mu^-}\epsilon_{\mathrm{HLT}}(1-\epsilon_{\mathrm{HLT}})\epsilon_{\mathrm{iso}}^2\epsilon_{trk}^2\epsilon_{sa}^2)^2}{N_{\mu\mu}}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

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

Get the Z Yield and Efficiencies in the same fit

More details in Backup slides





Future planning

- We will continue to work on Z➔ μμ analysis
- In 2011 we will reduce our efforts on hardware and will devote more time to analysis tasks
- The Group of Physicists involved in Data analysis is small (3 people were 2 in 2008) but well integrated in CMS and fruitfully collaborating with other CMS Italian groups

•Possible future involvements:

- •Z'
- •Higgs ➔ ZZ
- •Other channels involving muons

CMS Computing in Frascati

The CMS Frascati group actively contributed to the design of a Scientific Computing Center in Frascati within the Scientific Computing Service Working group LNF report **LNF - 10 / 5(IR)**

Computing needs are presently minimal (small T3) and completely met by the Computing Service support, in a spirit of full collaboration

2009-10 Papers

- 2 Physics papers published
- 2 Physics papers submitted
- About 30 detector performance with cosmic ray published
- 6 presentation at Conferences from LNF group
- 8 Technical papers published

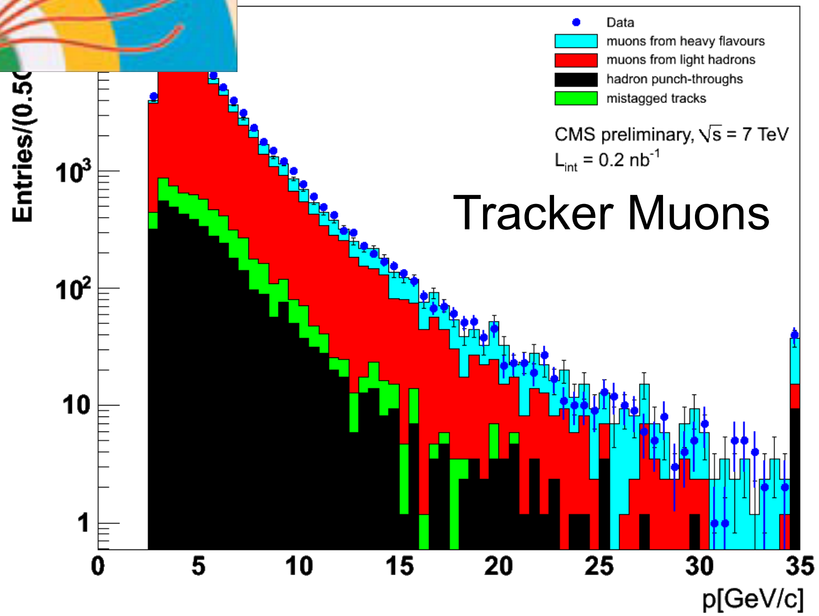
CONCLUSIONS

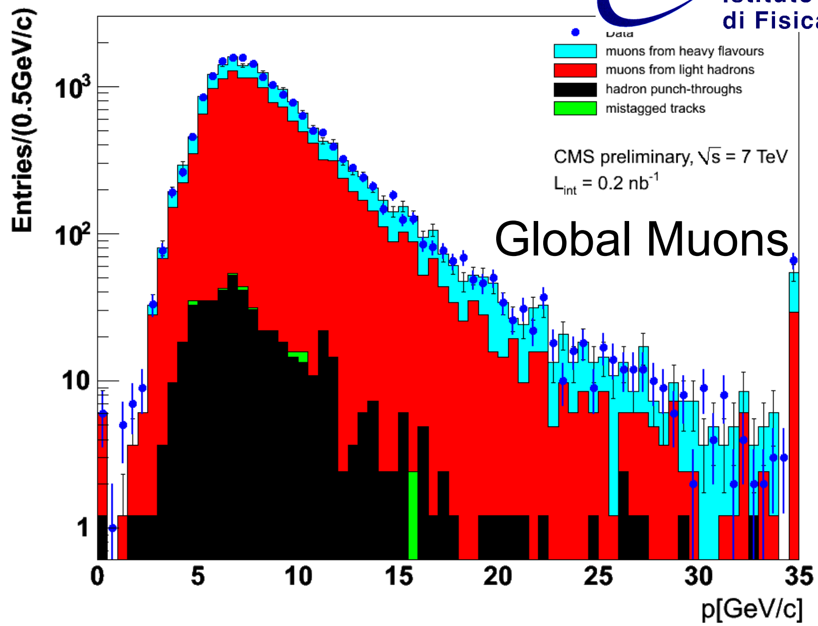
- CMS RPC is a unique playground for well-motivated students for both Physics and Engineering.
- Many responsibilities on the detector side (Operation Management, Gas system, Detector Performance)
- Involvement in CMS on muon studies from the detector to the physics
- The group is active in SM topics, several young candidates are eligible for temporary contracts (we submitted a request to the Lab)
- In 2011 our Detector effort will be reduced and we will be more involved in Physics Analysis

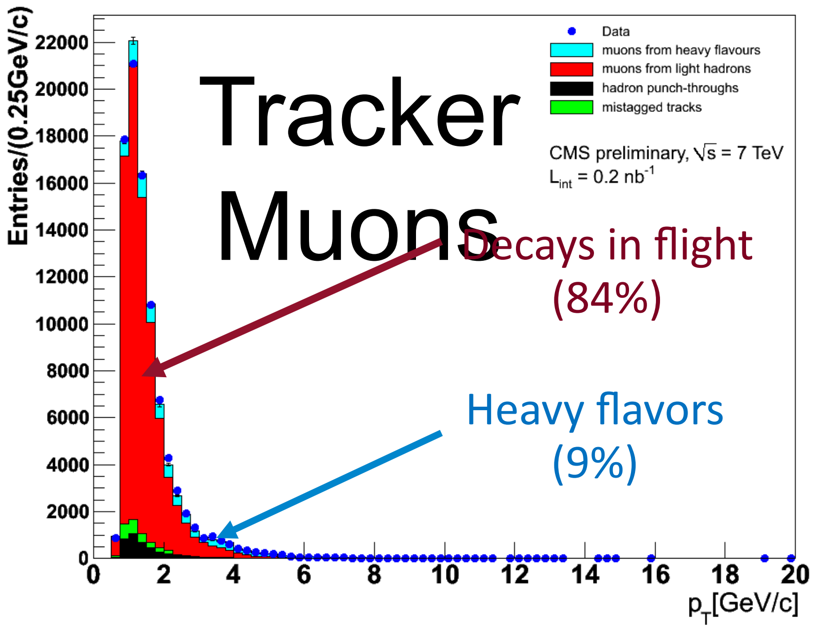
BACKUP

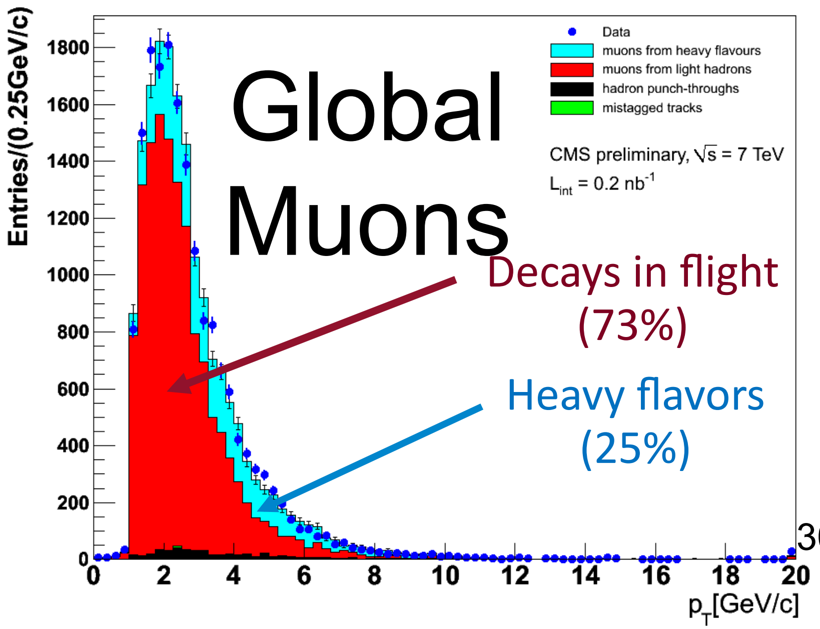
Good data-MC agreement

p and p_T spectra

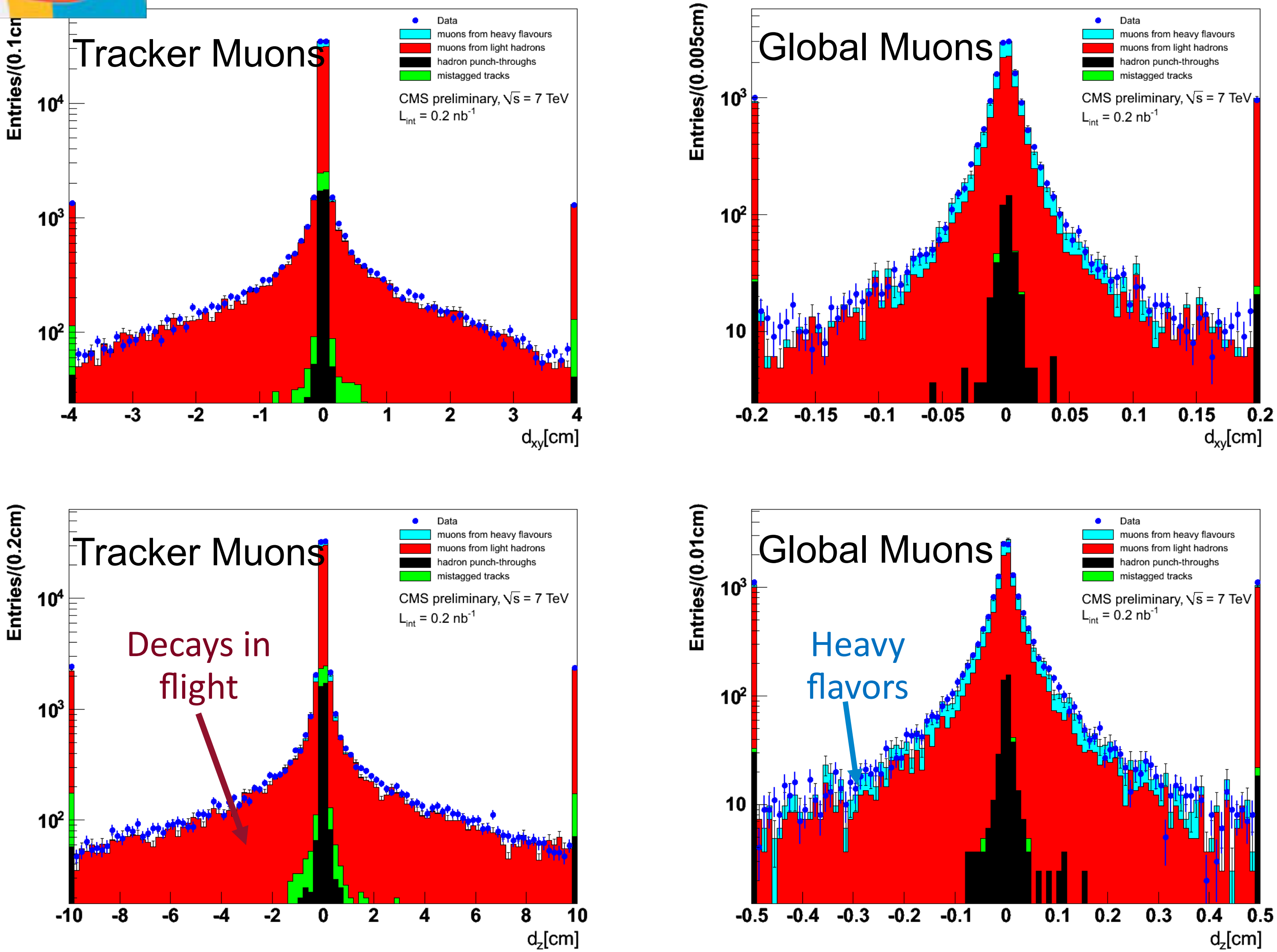






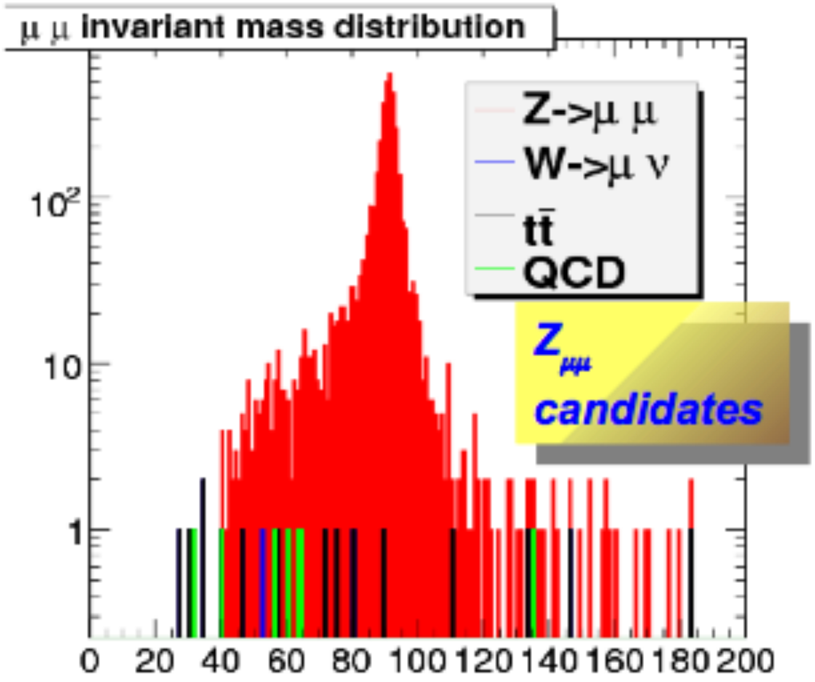


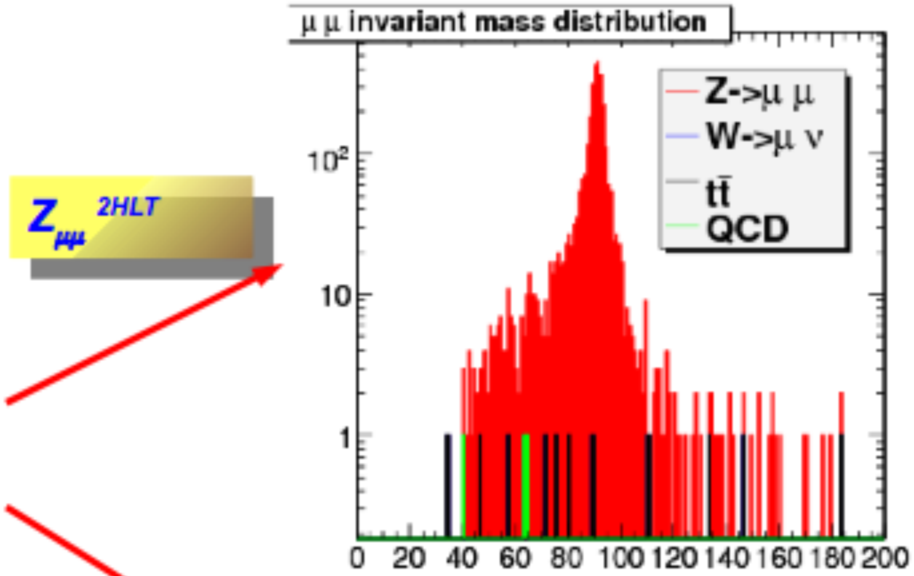
Impact parameter w.r.t. primary vertex

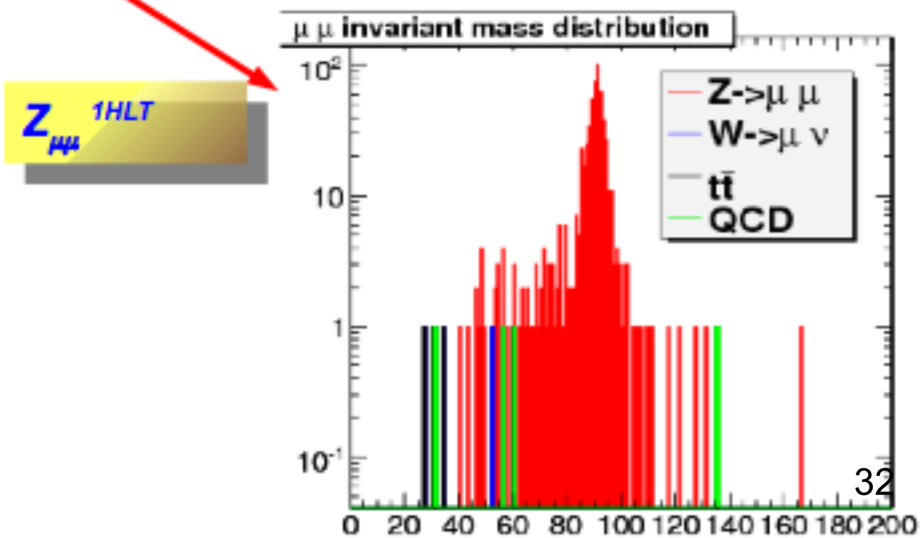


MC analysis with 10 pb-1 (2)

$10\ pb^{-1}$ equivalent statistics







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

($60<M<120\ GeV/c^2$)

splitted in 2991 2HLT and 569 1HLT

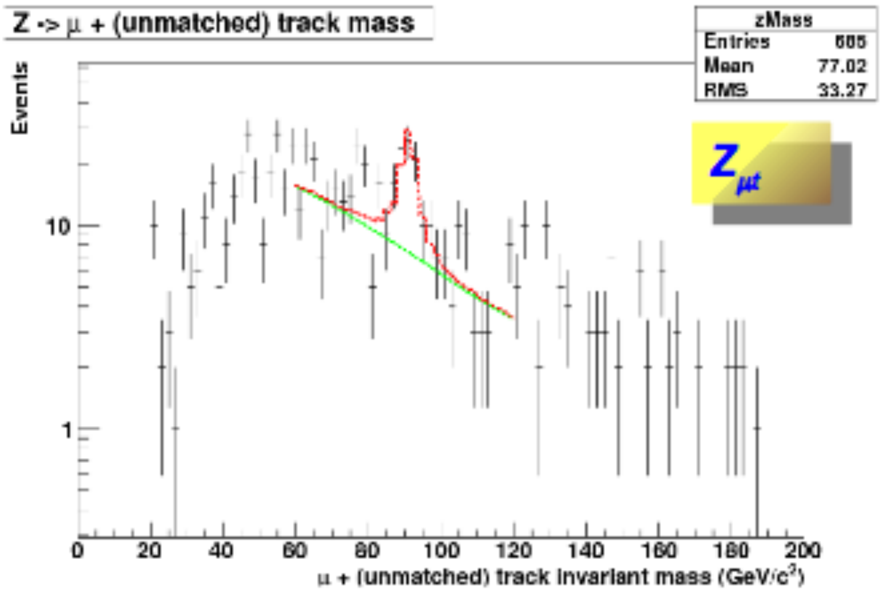
Very few bkg under the peak

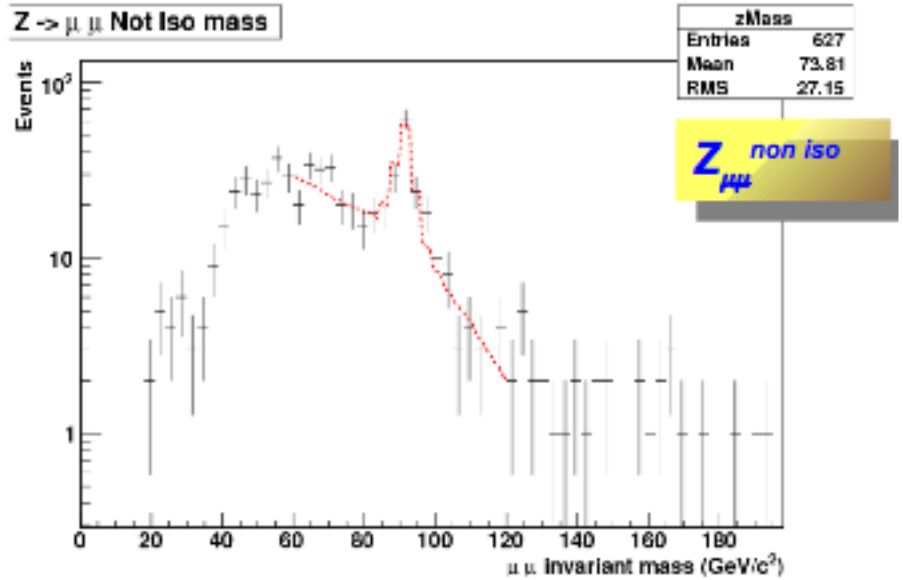
Data driven methods

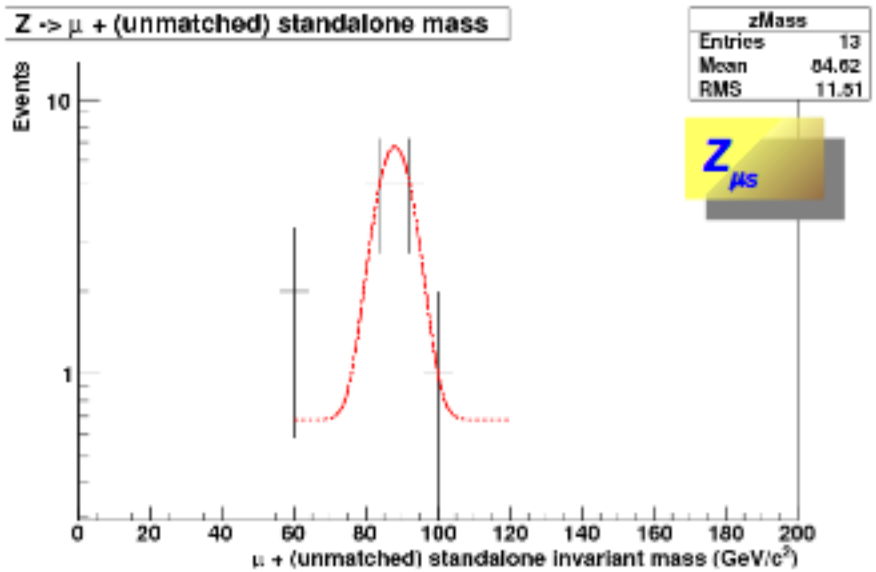
Tag & Probe methods:

- 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 loos muon to be identified with tighter criteria
- Define maps of efficiency vs η Φ Pt
- correct the sample of good dimuons (with negligible background) with efficiency from T&P event by event

Fit results (10 pb^{-1} norm.)







Chi2/ndof = 67.5/30 = 2.2

Parameter	Fit value
$N_{Z\to\mu\mu}$	3818 ± 64
M_s	88.2 ± 1.7 GeV/c²
σ_s	4.1 ± 2.7 GeV/c²

Fitting strategy

Fit model

$$\frac{\mathrm{d}N_{\mu\mu}}{\mathrm{d}m} = f_{\mu\mu}(m) = N_{\mu\mu} f_{peak}(m)$$

$$\frac{\mathrm{d}N^{2\mathrm{HLT}}_{\mu\mu}}{\mathrm{d}m} = f_{\mu\mu}(m) = N^{2\mathrm{HLT}}_{\mu\mu} f_{peak}(m)$$

$$\frac{\mathrm{d}N^{1\mathrm{HLT}}_{\mu\mu}}{\mathrm{d}m} = f_{\mu\mu}(m) = N^{1\mathrm{HLT}}_{\mu\mu} f_{peak}(m)$$

$$\frac{\mathrm{d}N_{\mu s}}{\mathrm{d}m} = f_{\mu s}(m) = N_{\mu s} f^{s}_{peak}(m) + b_{\mu s}(m)$$

$$\frac{\mathrm{d}N_{\mu t}}{\mathrm{d}m} = f_{\mu t}(m) = N_{\mu t} f_{peak}(m) + b_{\mu s}(m)$$

$$\frac{\mathrm{d}N^{\mathrm{non\ iso}}_{\mu\mu}}{\mathrm{d}m} = f^{\mathrm{non\ iso}}_{\mu\mu}(m) = N^{\mathrm{non\ iso}}_{\mu\mu} f_{peak}(m) + b^{\mathrm{non\ iso}}_{\mu\mu}(m)$$

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^{-1} equivalent statistics