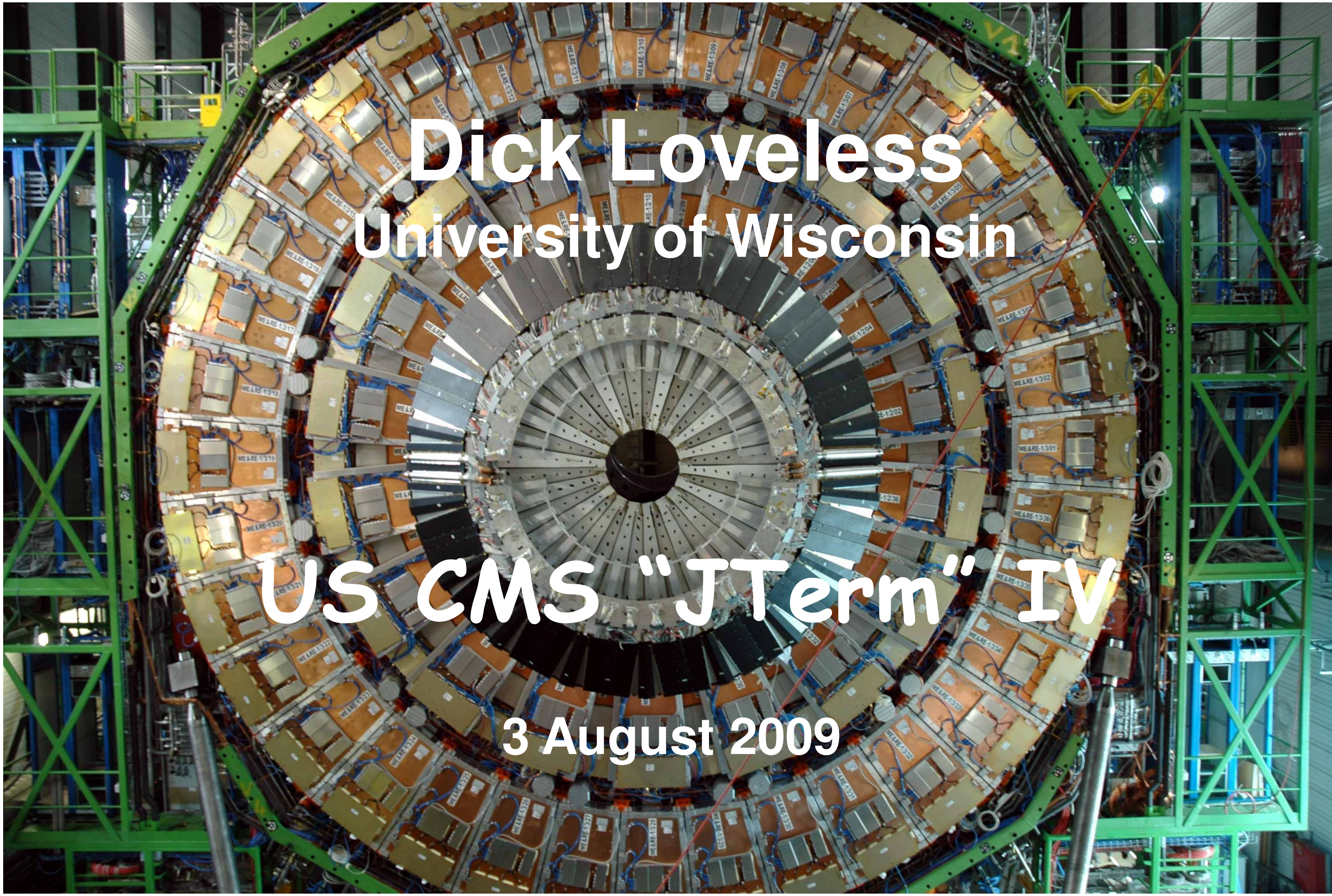
Muon Systems



Dick Loveless

University of Wisconsin

US CMS “JTerm” IV

3 August 2009

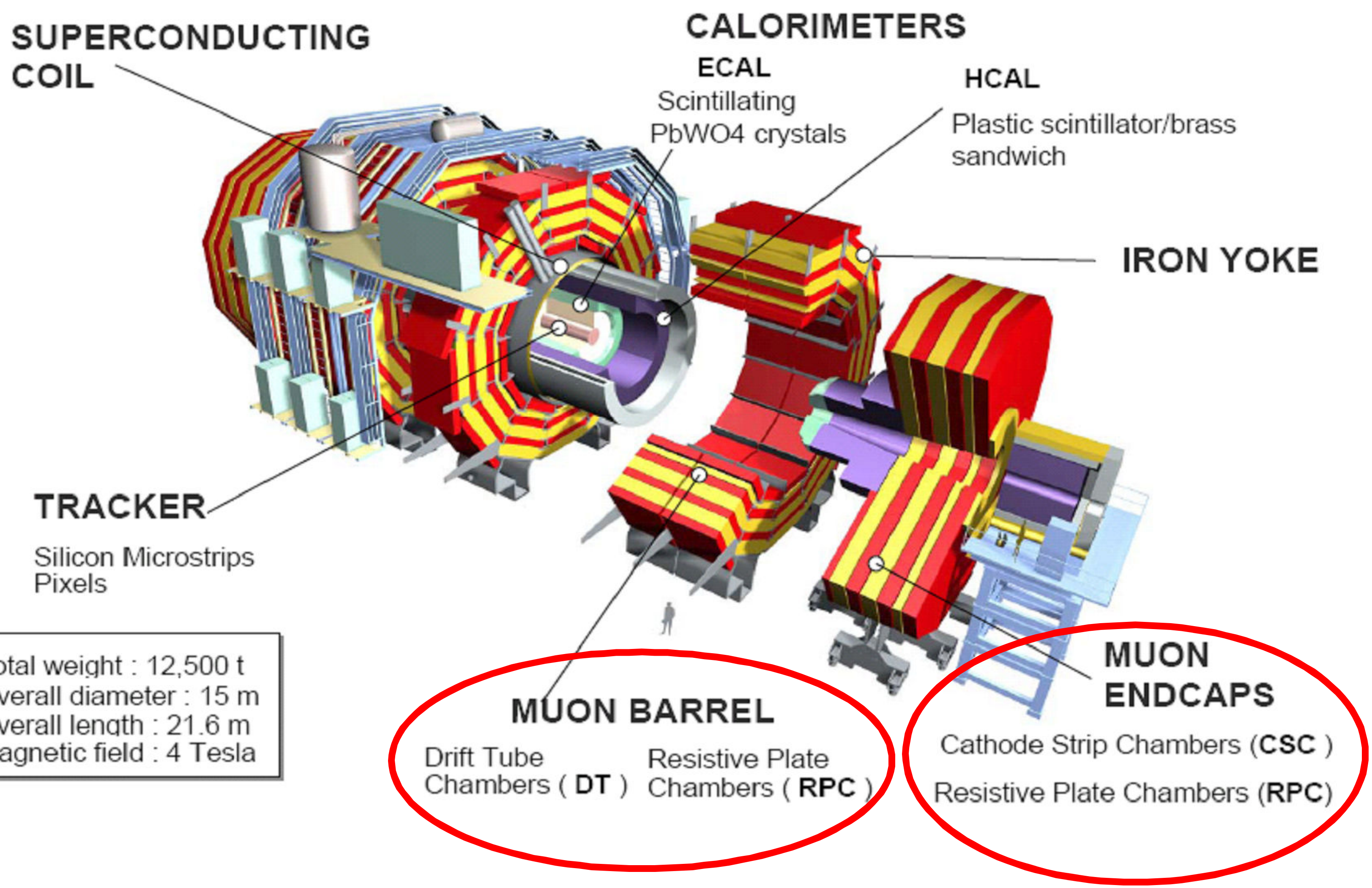
Muon Systems in CMS

- **Why muons?**
  - **Good signature for interesting/exciting events**
    - Higgs → $\mu\mu\mu\mu$, $Z \to \mu\mu$, W→$\mu\nu$
  - **Muons pass through large amount of material**
    - Small cross-section for interactions, brem, etc.
    - Multiple scattering reduces resolution
  - **Relatively easy to trigger on**
    - Most backgrounds reduced by steel yoke, calorimeter
    - Charged particle → easy to measure momentum

Muon System Design

- **Atlas**
  - **Toroidal field to bend muons**
    - Complicated geometry for reconstruction
  - **Build very high resolution muon wire chambers (50μ)**
    - Need very accurate alignment of chambers
  - **Keep multiple scattering to a minimum**
    - No iron return yoke, small filtering of background
- **CMS**
  - **Solenoidal field to bend muons in ϕ direction**
    - Easy geometry for reconstruction (also for strip chambers)
  - **Use wire chambers to identify tracks as muons**
    - Lower resolution needed (150μ)
  - **Measure momentum accurately in Silicon Tracker**
    - Tracker resolution about 25μ

CMS Detector



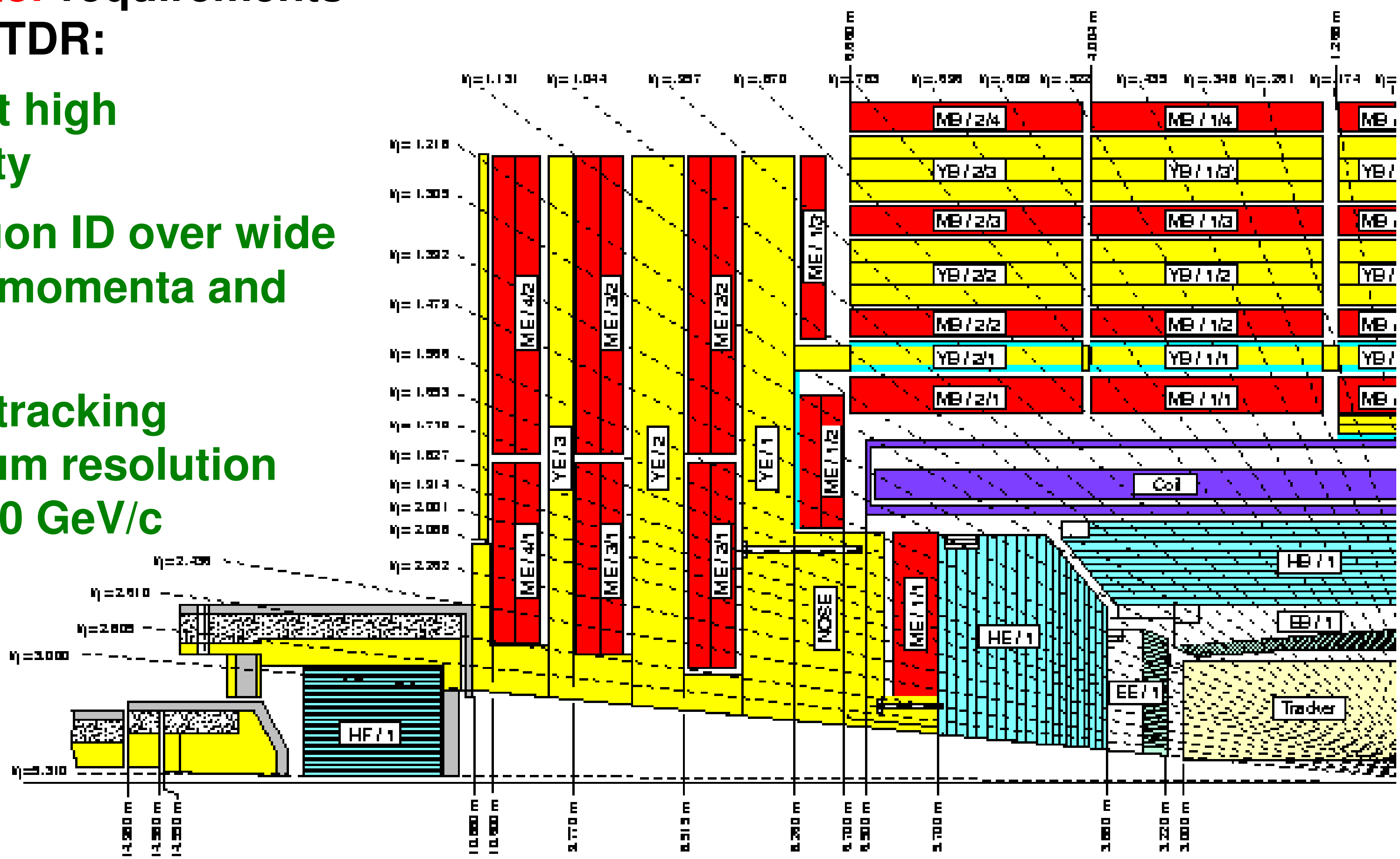
Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

Muon System Layout

CMS muon detectors: Cathode Strip Chambers, Resistive Plate Chambers, Drift Tubes

Muon detector requirements from the TDR:

- Trigger at high luminosity
- Good muon ID over wide range of momenta and angles
- Improve tracking momentum resolution above 200 GeV/c



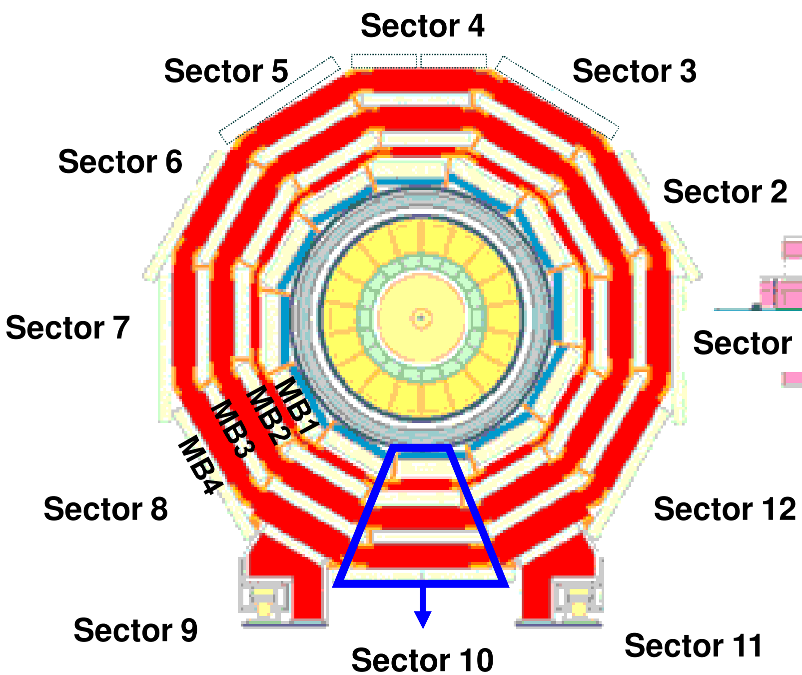
CMS Muon Technologies

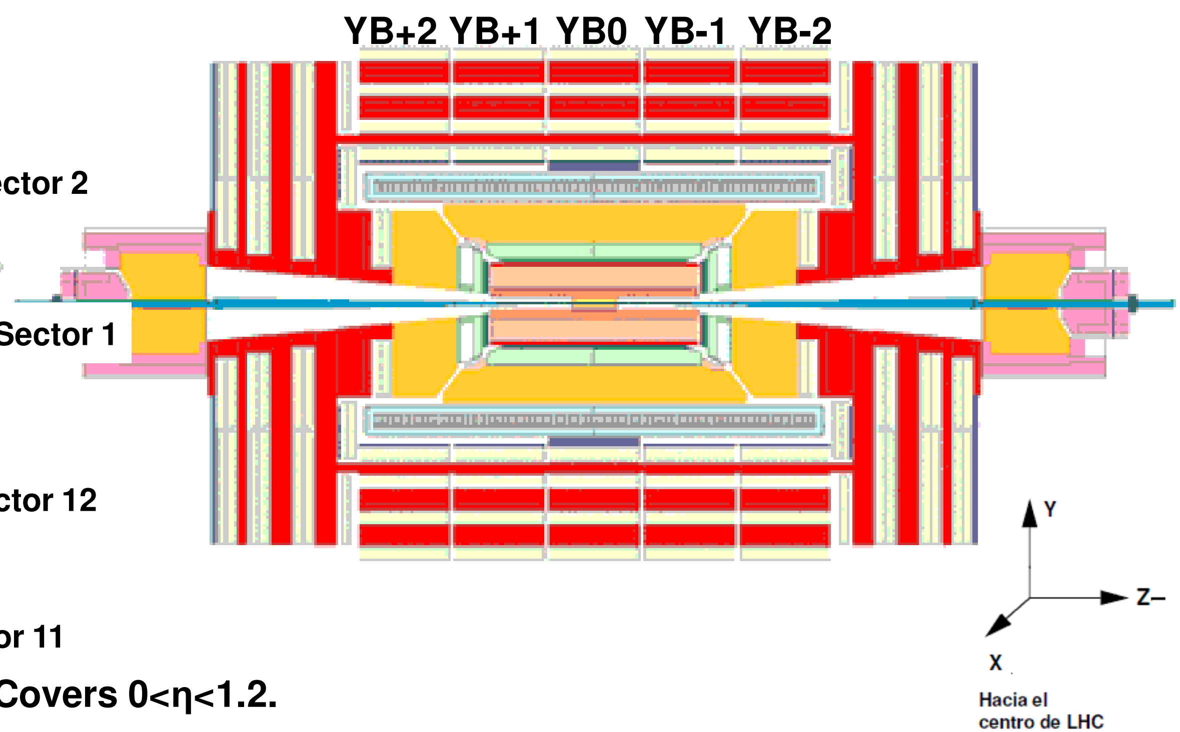
- Requirement: CMS must have two independent muon triggering systems
  - Barrel region – Drift Tubes (DT)
  - Forward region -- Cathode Strip chambers (CSC)
  - Both regions -- Resistive Plate chambers (RPC)

•RPC have very good timing (<3 nsec) but not as good resolution
•DT have good resolution but not as good timing
•CSC have good resolution and acceptable timing

→ Complementary Trigger Systems

Drift Tube (DT) Chambers





250 chambers

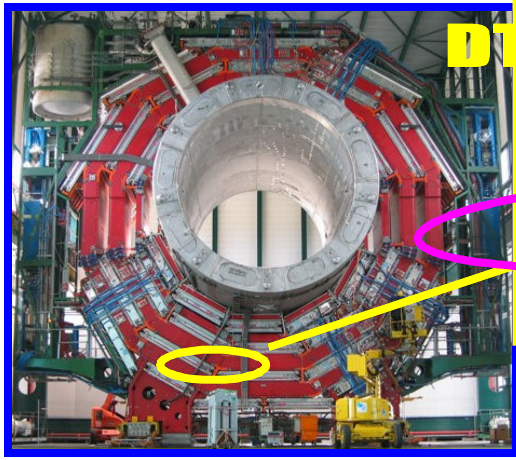
5 wheels
12 sectors/wheel
4 layers/sector:
MB1, MB2, MB3, MB4

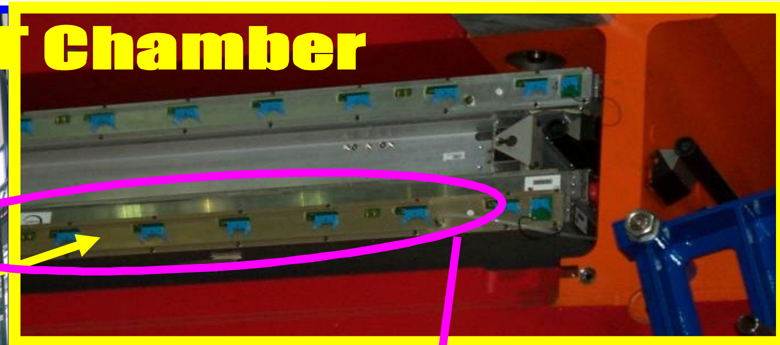
172,200 drift cells

Covers $0<\eta<1.2$.

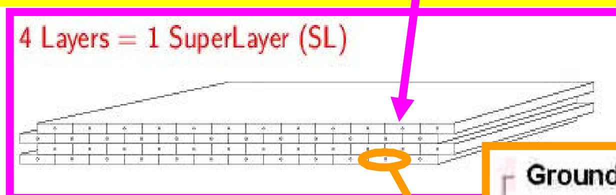
- Provide muon identification
- Precise momentum measurement. Good p_T resolution at high transverse momenta: $\sigma(p_T)/p_T \sim 10\%$ @ 1TeV/c
- Reliable and robust trigger:
  p_T standalone measurement @ Level-1 and High Level Trigger and precise Bunch Crossing (BX) assignment.

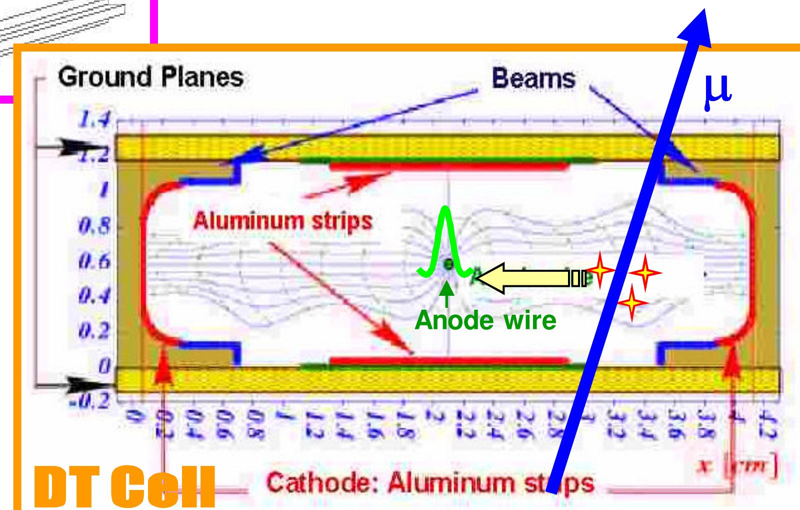
DT Design



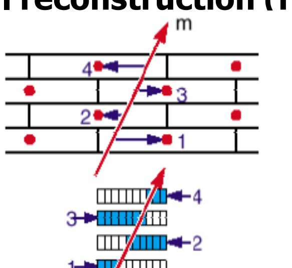


T_{max} < 400 ns
Efficiency ~ 99%
Drift velocity ~ 55 μm/ns





- 3 Superlayers per chamber, 2 for Φ coordinate and 1 for θ coordinate.
- Almost linear space-time relationship.
- Single wire resolution ~ 250 μm
- Local reconstruction (rΦ) ~ 100 μm



Meantimers recognize tracks and form vector / quartet.

$$\frac{(t_1+t_3)}{2}+t_2=T_{MAX}$$

meantimer

Gas: Ar/CO2 (85/15)%
High Voltage: wires 3.6 kV
strips 1.8 kV
cathodes -1.2 kV

DT Builders

INFN Legnaro & University of Padova, Italy

INFN Bologna, Italy

INFN Torino, Italy

CIEMAT, Spain

RWTH Aachen, Germany

HEPHY, Austria

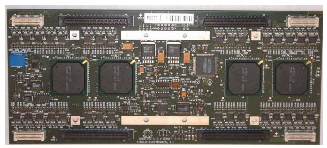
UAM, Spain

DT Read-out System

UXC55 | USC55

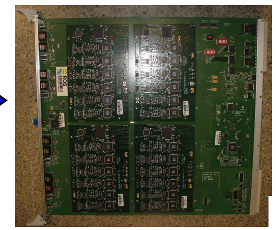
DT CHAMBERS

ROB



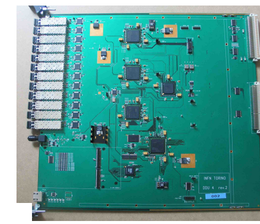
30 m copper
240 Mbps
~16 Mbps
throughput

ROS



100 m optical
800 Mbps
~80 Mbps
throughput

DDU



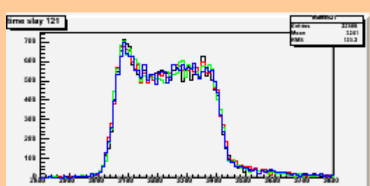
S-LINK64
320 MB/s
~ 200 MB/s
throughput

Chambers

- 5 wheels
- 60 sectors
- 250 chambers
- 660 super-layers
- 1640 layers
- ~172200 channels

Minicrates

- 1500 ROB
- 128 ch/ROB
- Time digitalization (0.7 ns resolution)
- 1 µs time window



Sector Collector

- 60 ROS
- 25 ch/ROS => 1 sector
- Data merging
- Data quality monitoring

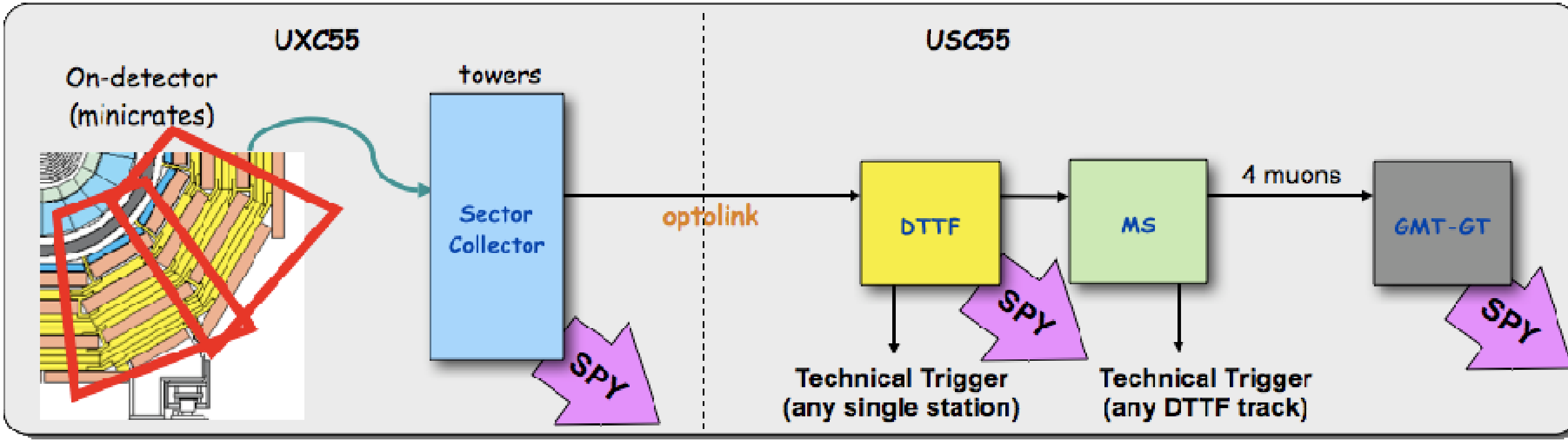
- ~ 260 bytes muon event size/ROS

DDU (FED)

- 10 DDU => half a wheel
- 12 ch/DDU (only half needed)
- Data merging
- Data quality monitoring
- TTS interface

- ~ 0.7 kB muon event size/DDU

DT Trigger System



Minicrates
(1/chamber = 250)

- Track Segment and BX Identification
- Ghost busting
- Best 2 TS / chamber sorting

Sector Collector
(1/sector = 60)

- Trigger synchronization
- Local trigger spy
  (timing and quality data of TS injected to DAQ)

Track Finder
(Phi: 1/sector = 72
+ Eta: 1/wedge = 12)

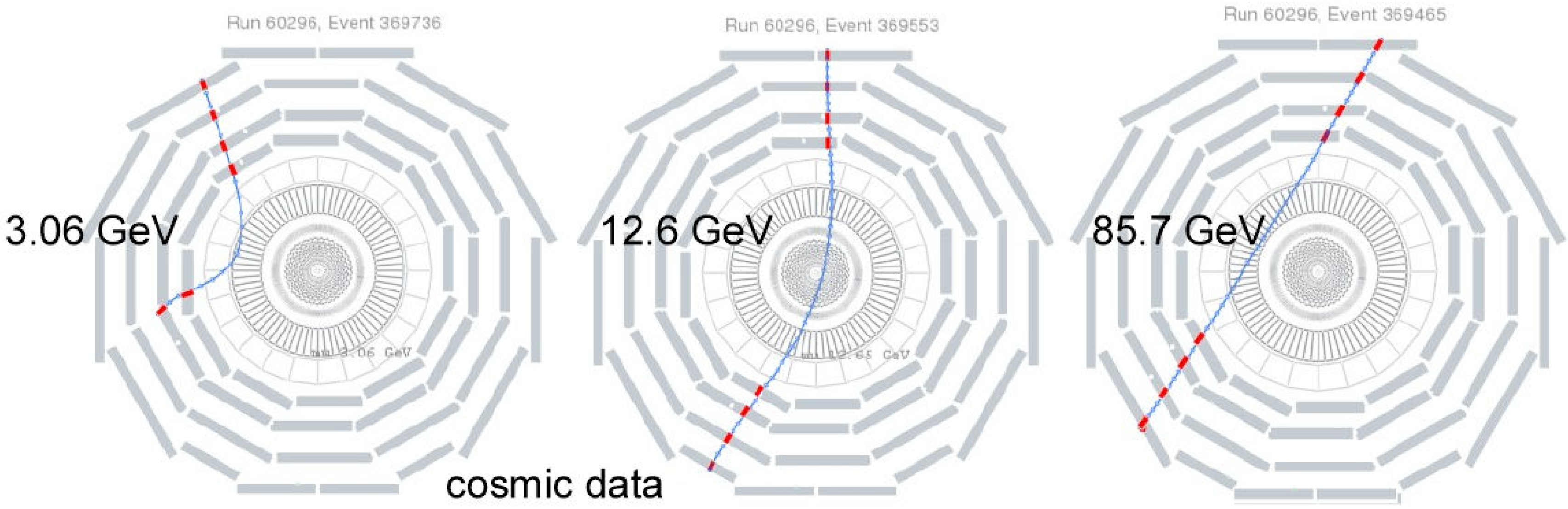
- Extrapolation and matching of TS (build full muon tracks)
- Local phi assignment
- Eta value assignment
- Pt assignment
- Full In/Out spy

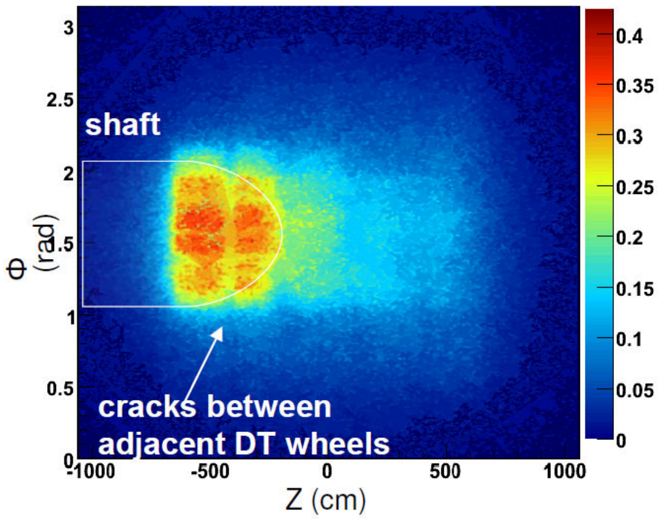
Muon Sorter
(1 / wedge = 12
+1 barrel)

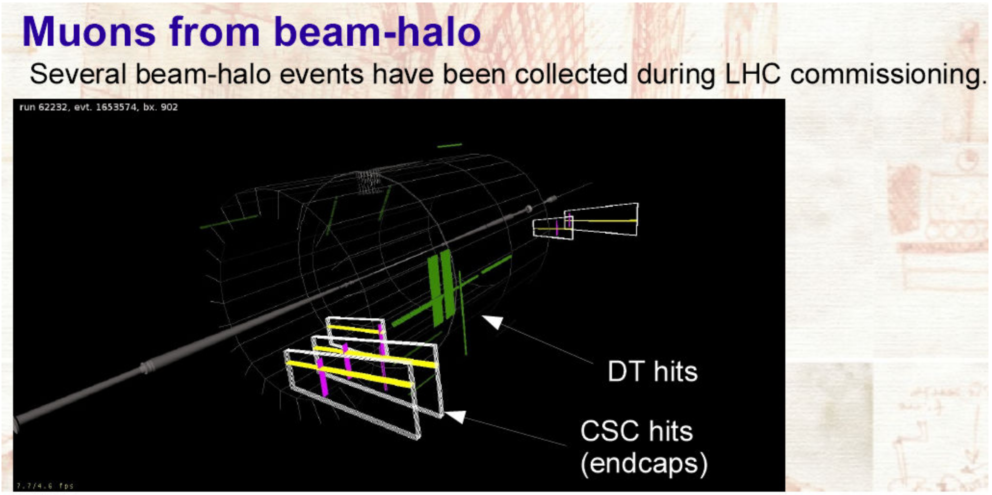
- Ghost busting
- Global phi assignment
- Final sorting of 4 best muon candidates for the Global Muon Trig

.

Some nice DT plots…..







Cathode Strip Chambers

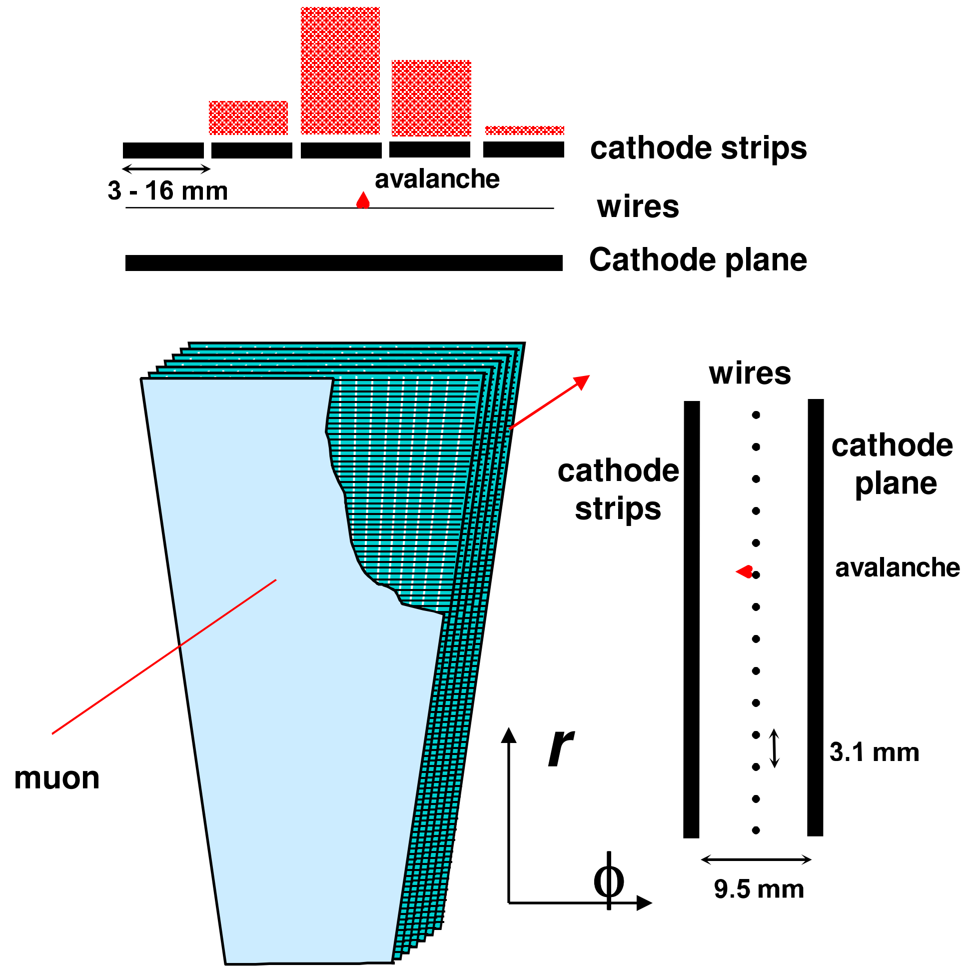
6-layer planar chambers…

Anode wires:

- Wires ganged in groups of 5 -16 for *r* (θ) coordinate
- Closely-spaced azimuthal anode wires → fast timing

Cathode strips:

- Radial, trapezoidal strips for ϕ coordinate
- Charge induced on strips → precision measurement in bend direction of magnetic field



Typical size: 3.3m x 1.3m

Gas: Ar – CO_2 – CF_4

CSC Organization

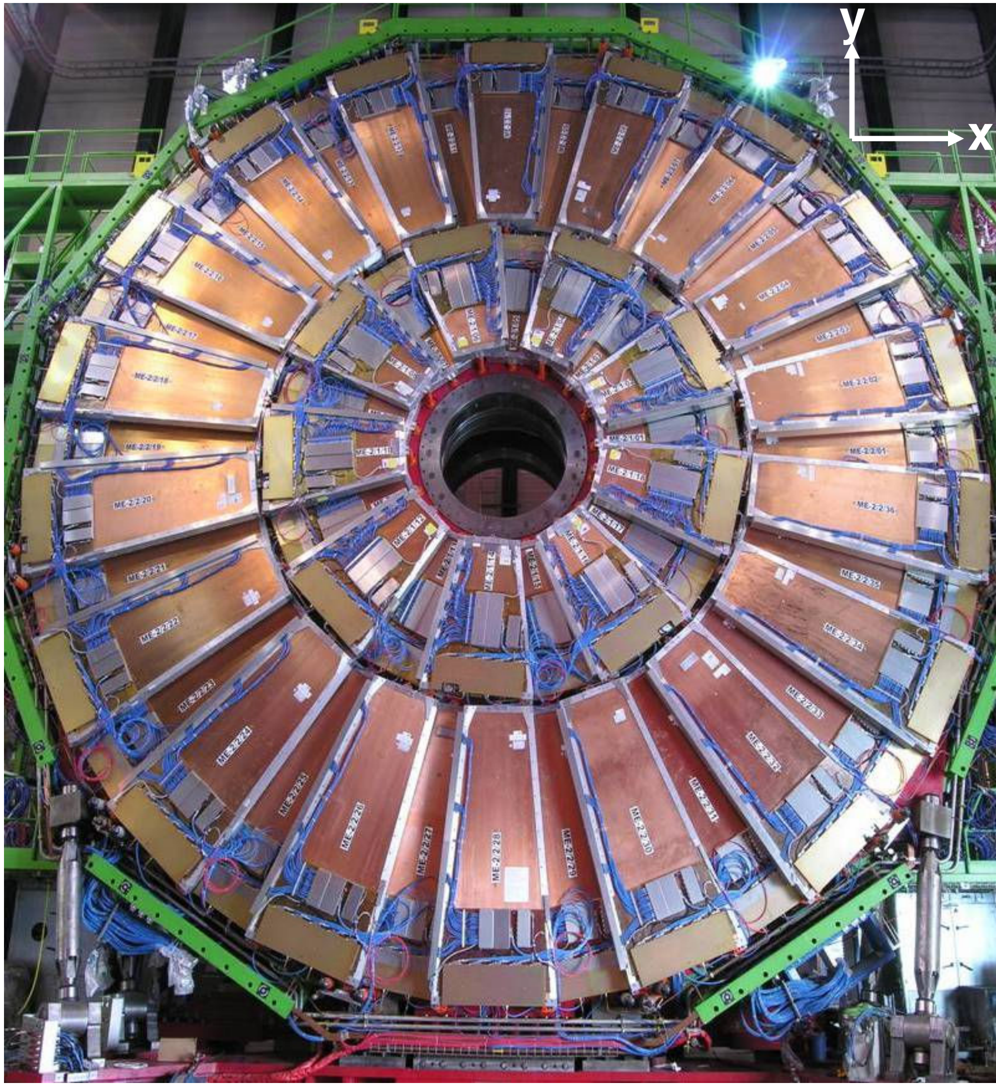
CSC detector supported (almost) entirely by US CMS

- Carnegie Mellon
- Florida
- Fermilab
- Northeastern
- Northwestern
- Ohio State
- Purdue
- Rice
- UC Davis
- UCLA
- UC Riverside
- Wisconsin
- Wayne State

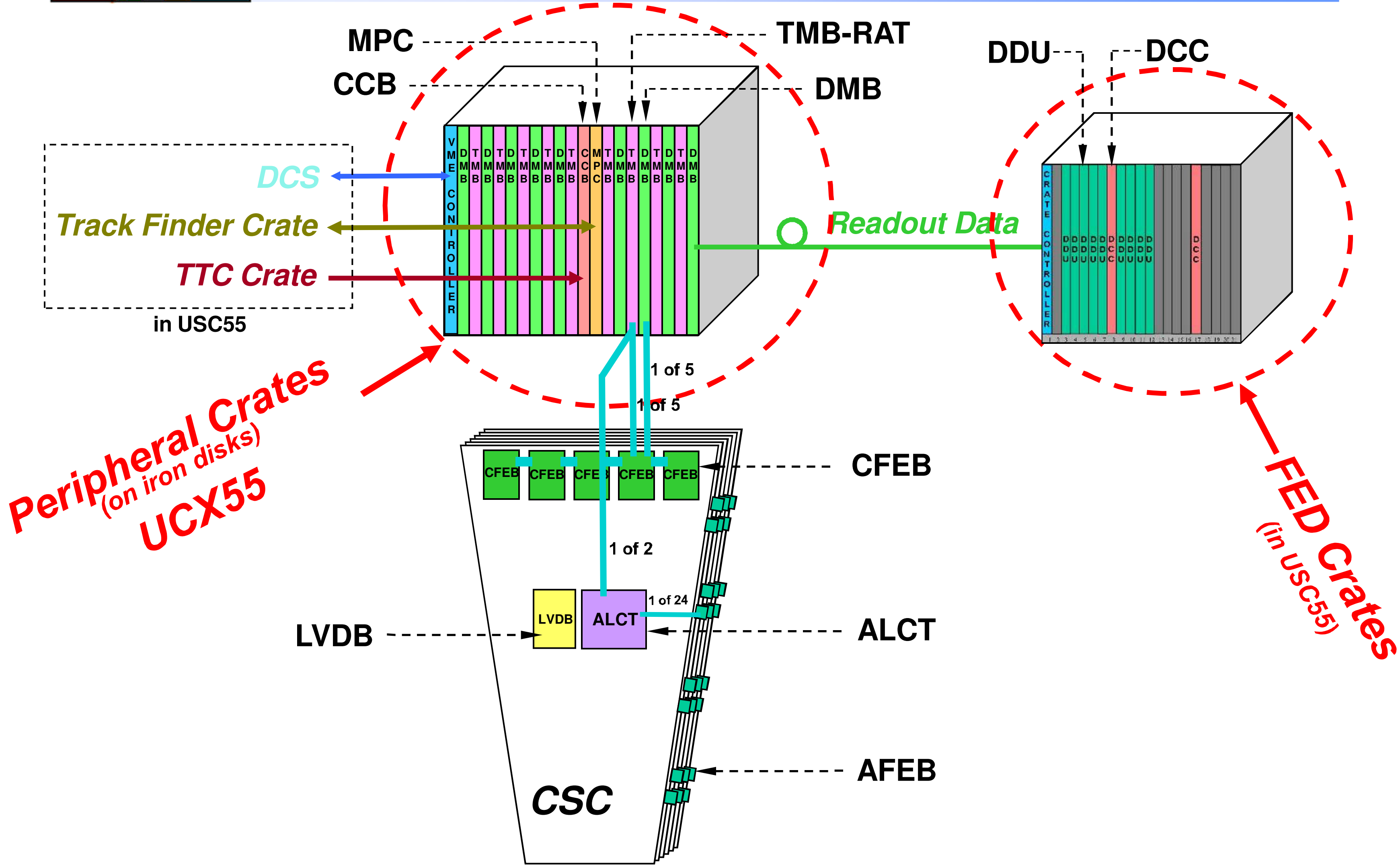
CSC group also includes JINR (Dubna), PNPI (St. Petersburg), IHEP (Beijing)

Scope of the CSC System

- 468 CSCs with 4 stations per endcap
- Shown is 1 station with 54 CSCs
- Over 2 million wires
- More than 17,000 electronics boards
- 400,000 readout chan.
- 9,000 HV channels
- 5,500 skewclear cables
- 1400 gigabit optical fibers



CSC Electronics System

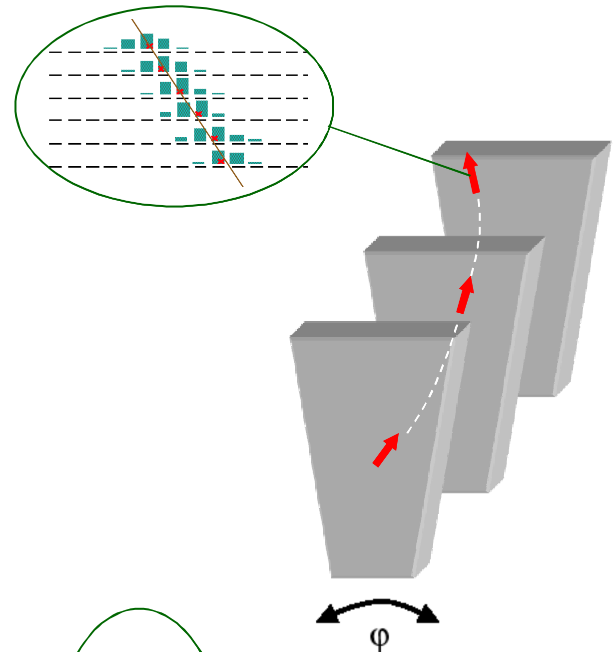


Trigger Primitives

Local Charged Tracks (LCT) are formed by comparing hits to patterns…

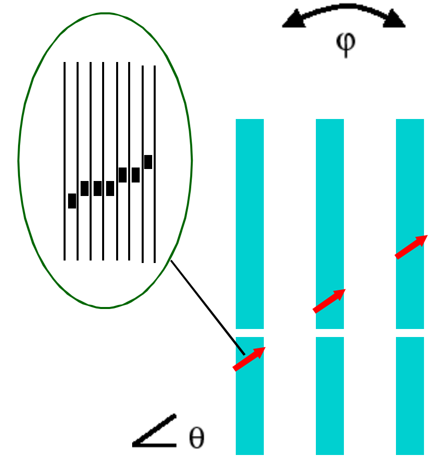
Cathode LCT (CLCT) from strips

- Comparator network rapidly determines hits to ½-strip resolution per layer
- Measures ϕ
- Pattern $\rightarrow$ Radius of curvature $\propto$ momentum

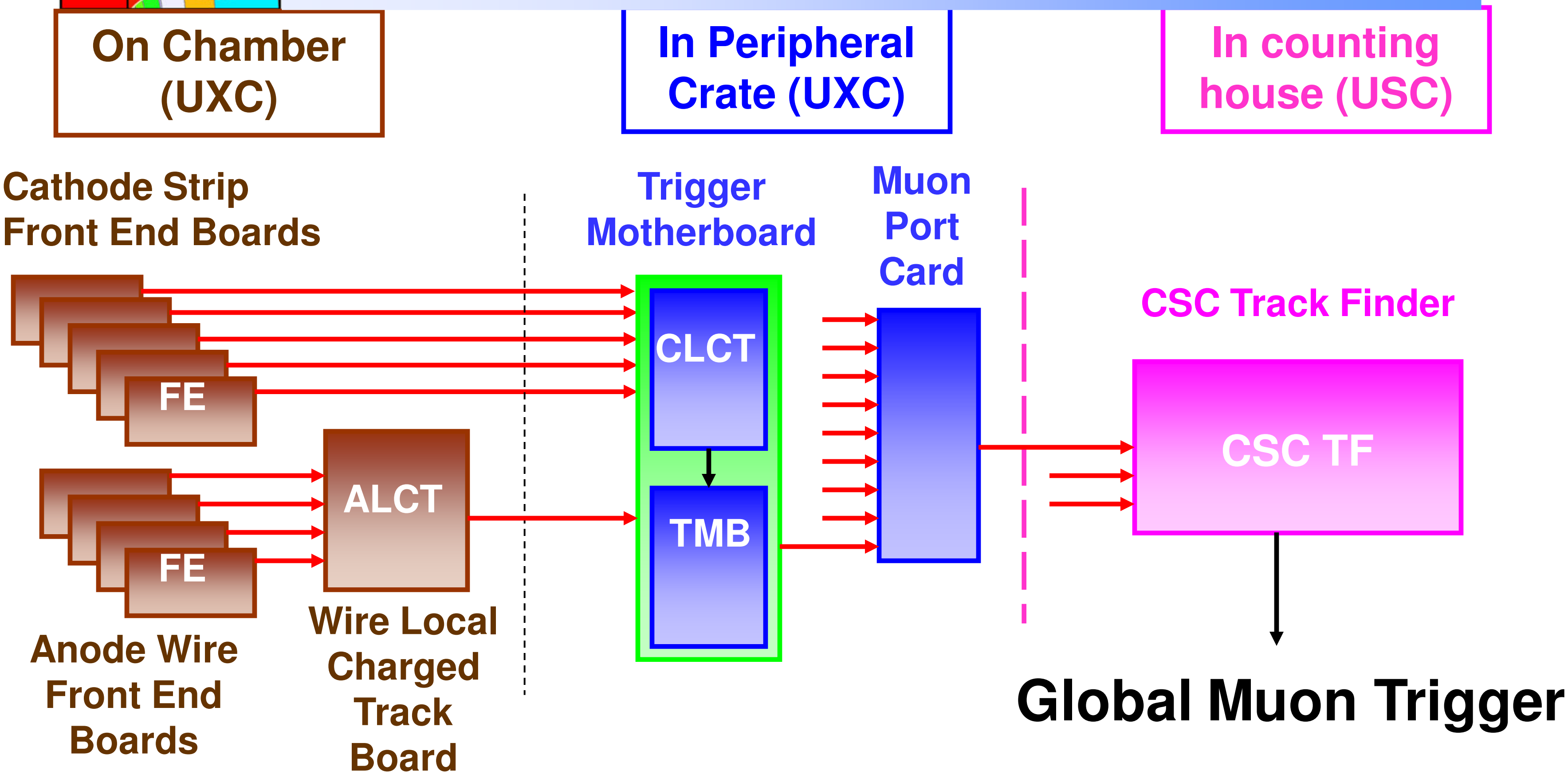


Anode LCT (ALCT) from wire groups

- Defines trigger timing
- Measures θ, bx
- Pattern $\rightarrow$ envelope pointing to Interaction Point



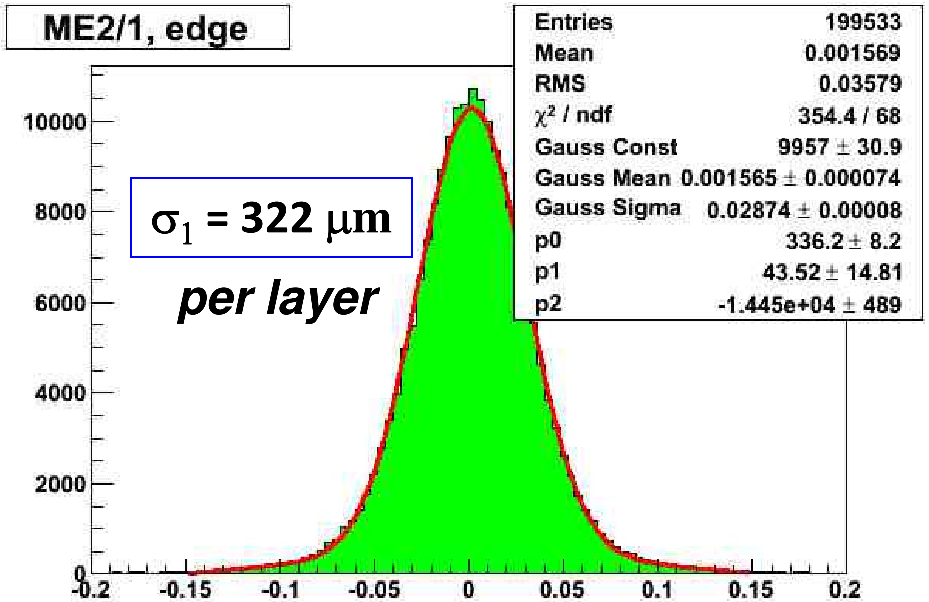
CSC Trigger Schematic



The CSC L1 trigger is a fast tracking system

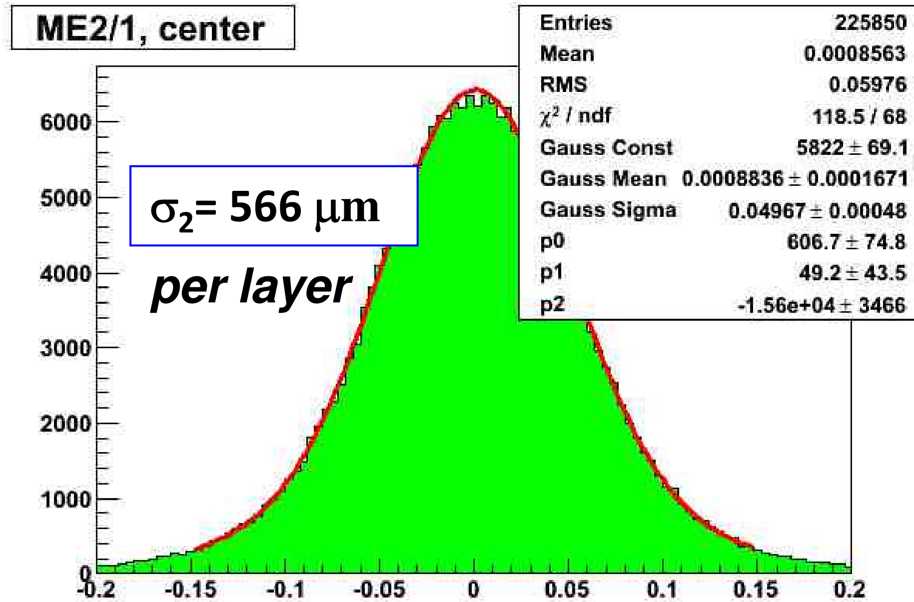
CSC Residuals – ME2/1

Near the edges: |strip coordinate| > 0.25



position within the strip

Near the center: |strip coordinate| < 0.25



position within the strip

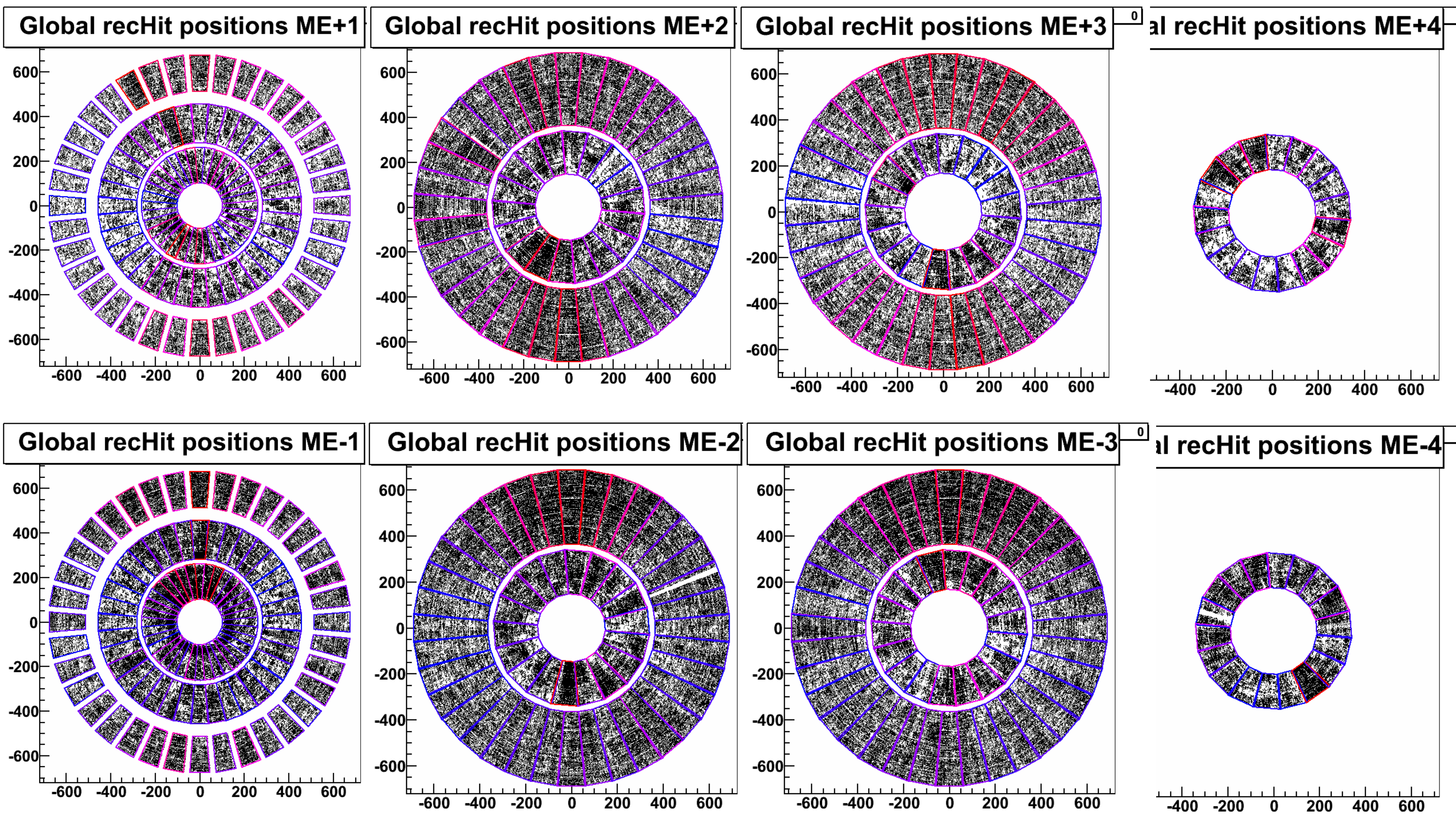
With the strip-staggering, the resolution of a chamber can be estimated by

$$1/\sigma^2\,(\text{chamber}) = 3/\sigma_1^2 + 3/\sigma_2^2$$

→ σ(ME2/1) = 161μm **(c.f. TDR value = 150μm)**

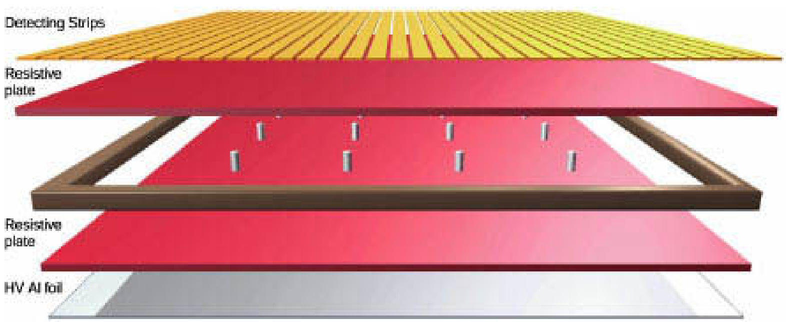
100% of CSCs Operational

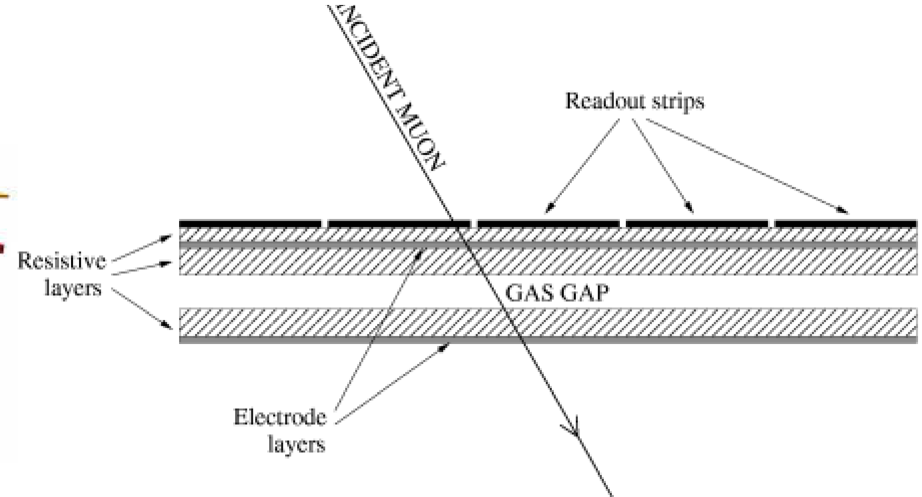
Run 97324 25 May '09 **Plots by A. Kubik (Northwestern)**



Resistive Plate Chambers (RPC)

Developed by R. Santonico (Roma) in the early 80's



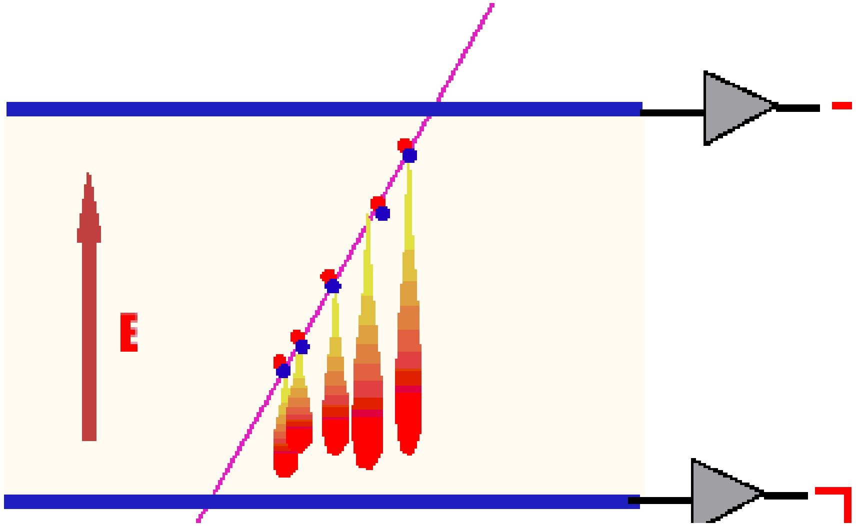


Fast chambers, relatively inexpensive (no wires, large strips)

- **Gap: 2 mm**
- **HV electrodes : 100 μm graphite**
- **Gas pressure : ~ 1 Atm**
- **Gas mixture: 70% Ar, 29% iso-Butane, 1% Freon**
- **Gas flow: 0.1 vol/hour**

Bakelite resistivity 10^{10}- 10^{12} Ωcm
Coated with linseed oil

RPC Operating Points



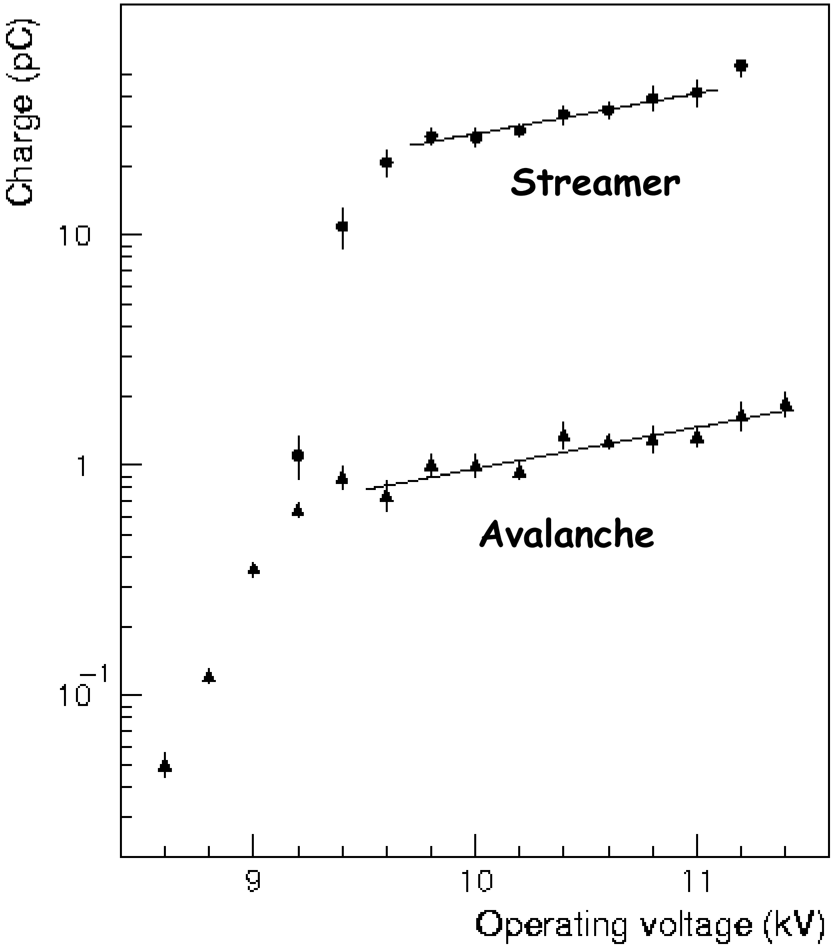
The avalanche size depends on the anode distance

RPC is not a proportional counter

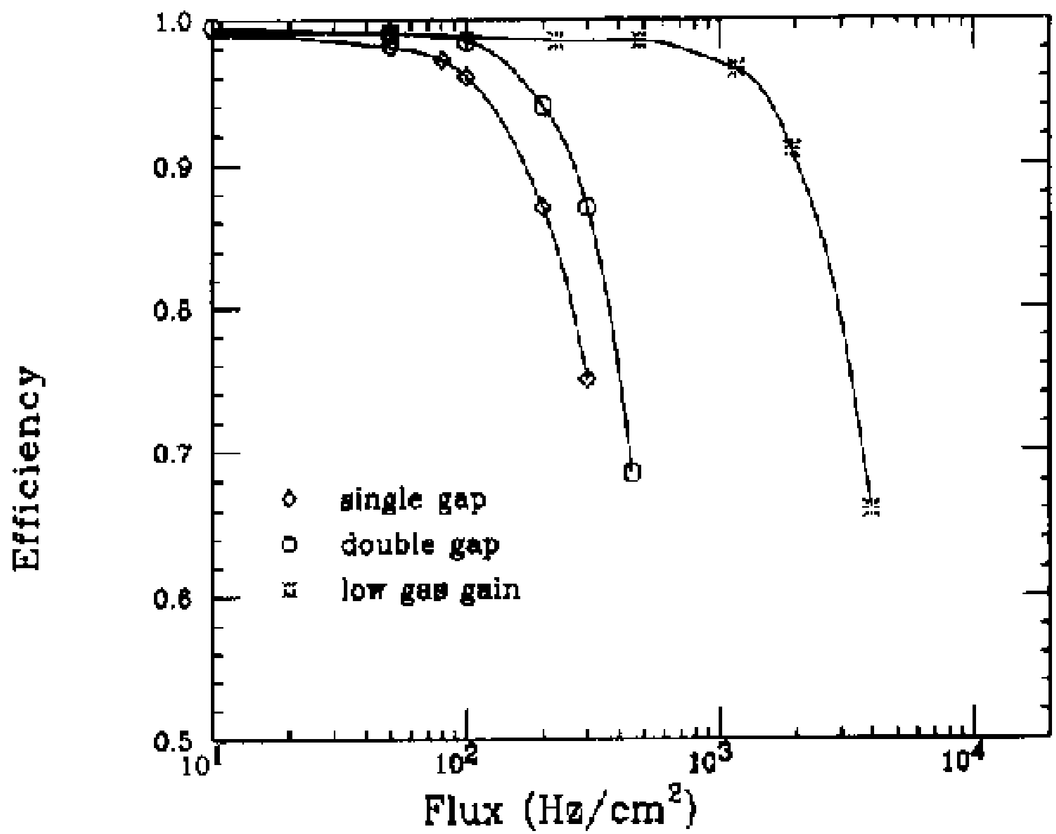
Different regimes with different HV:

Spark chambers	highest HV/cm
Resistive plate chambers	
Avalanche chambers	lowest HV/cm

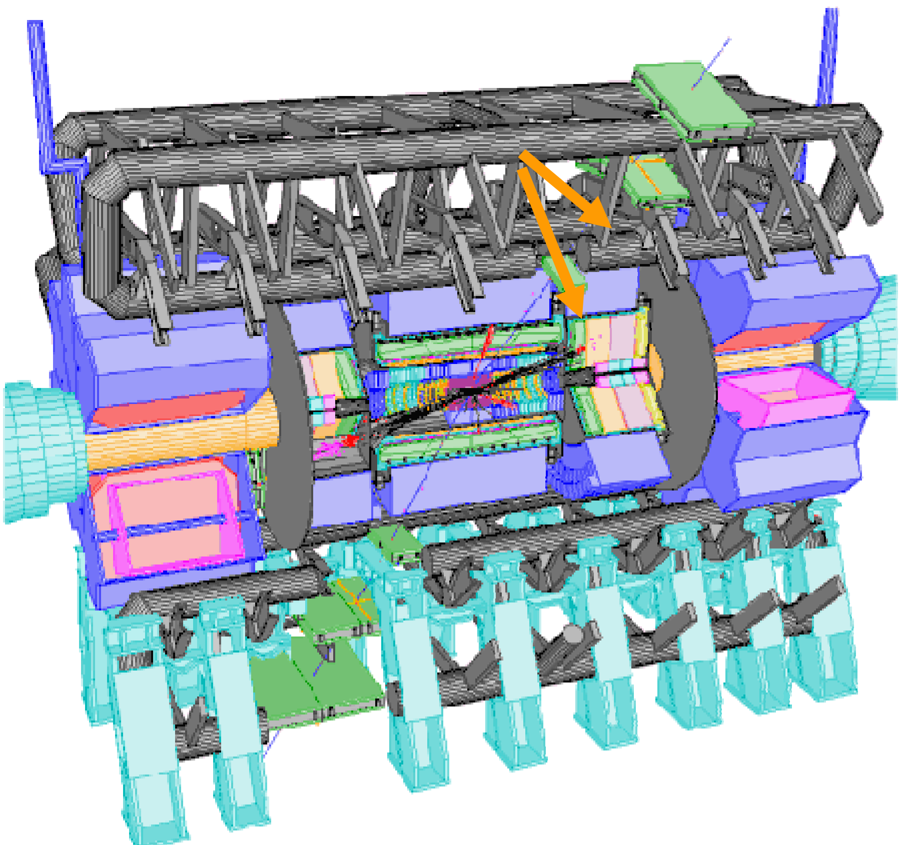
Run RPCs in Avalanche Mode



Rate capability increases by a factor 10



RPCs in Atlas

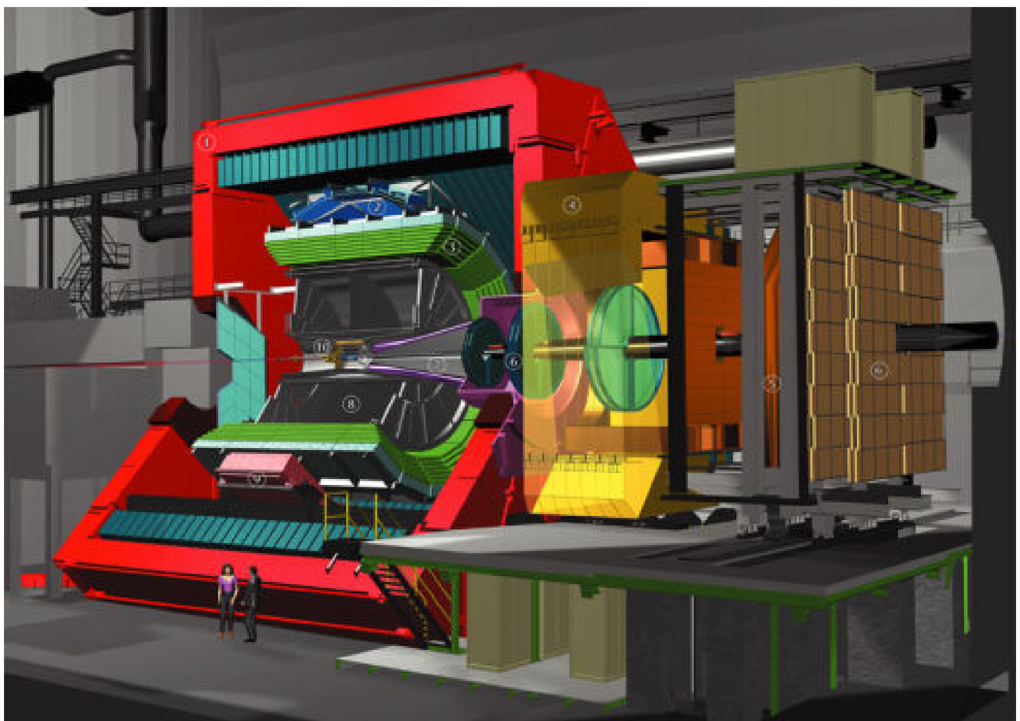


[ATLAS TDR 10, CERN/LHCC/97-22, http://atlas.web.cern.ch/Atlas/Welcome.html]

- Trigger RPCs in muon system
  - Avalanche mode
  - Area: 3650 m^2
  - 355,000 channels
  - Efficiency: >95%
  - Time resolution: <3ns
  - Rate capability: 1kHz/cm^2

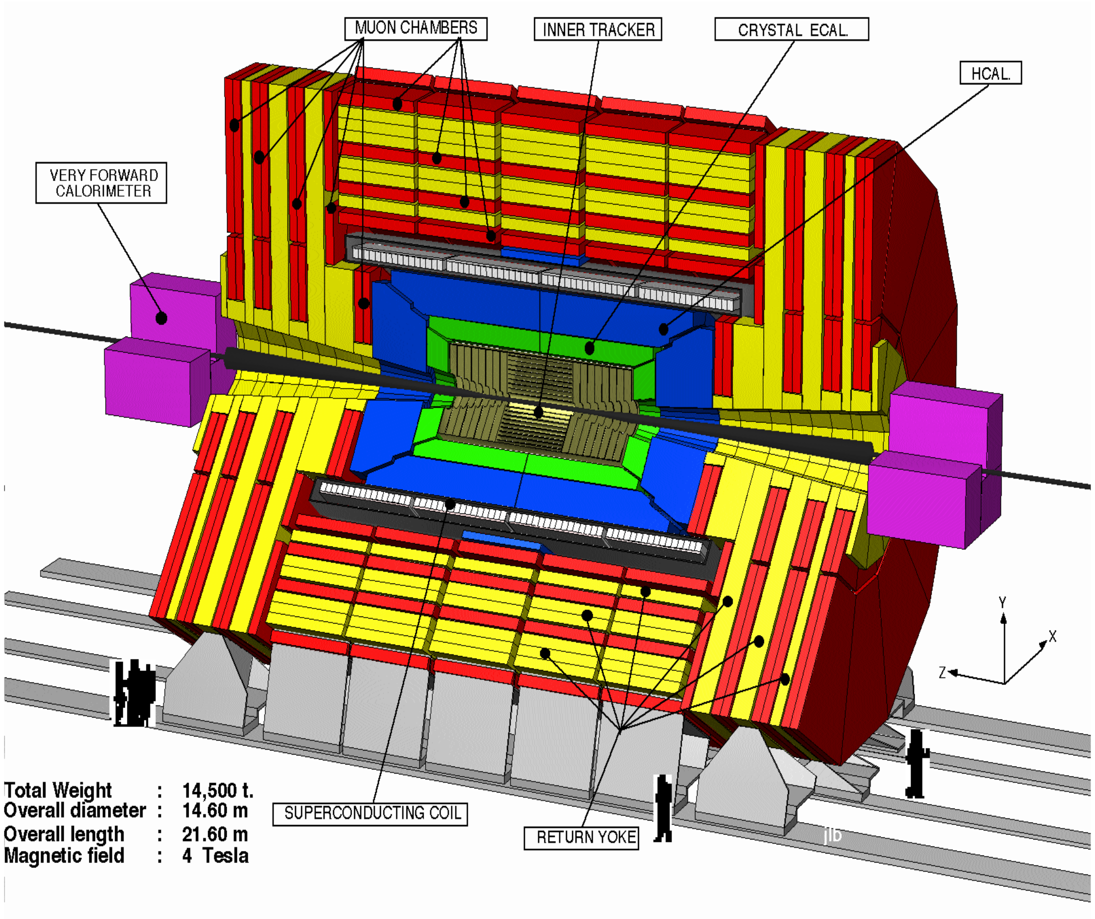
RPCs in Alice

Multigap Timing RPCs are used to identify particles (e/π-, π/K-, K/p- Separation) via time-of-flight (TOF)



- **Area: 176 m^2**
- **160,000 channels**
- **Efficiency: >98%**
- **Time resolution: <70 ps**
- **Rate Capability: up to 50 Hz/cm^2**

RPCs in CMS



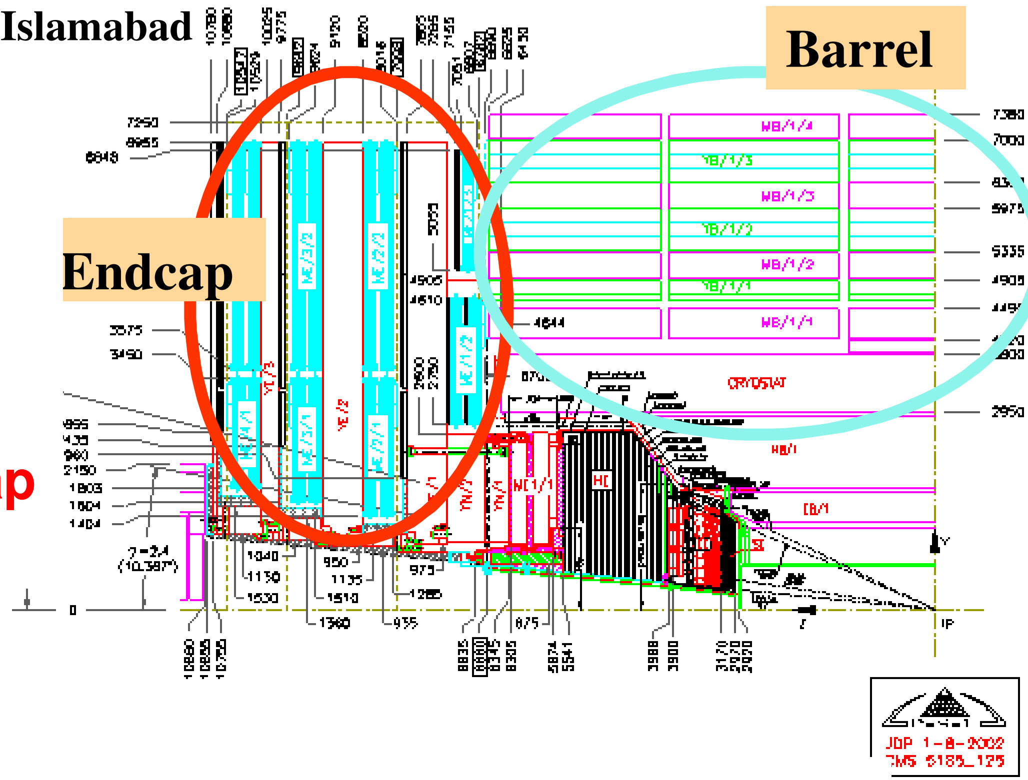
- **Trigger RPCs**
  - **Avalanche mode**
  - **Bakelite**
  - **2mm gaps**
  - **E ≈ 50kV/cm**
  - **Gas: Freon + Isobutane**
  - **Time Resolution < 3ns**
  - **Efficiency > 95%**
  - **Rate capability: 1kHz/cm^2**

RPC System

Barrel: Bari, Frascati, Naples, Pavia, Peking, Sofia

End cap: Bari, , Peking, Seoul, Islamabad

Trigger: Laparanta, Warsaw

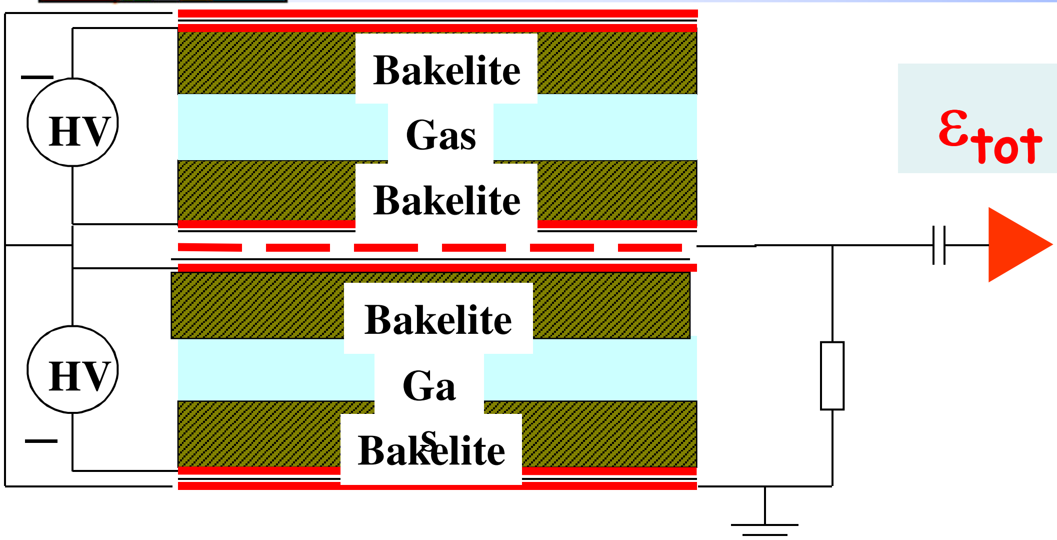


Baseline

- **Six stations in the Barrel**
- **Four station in the Endcap up to $\eta = 2.1$**

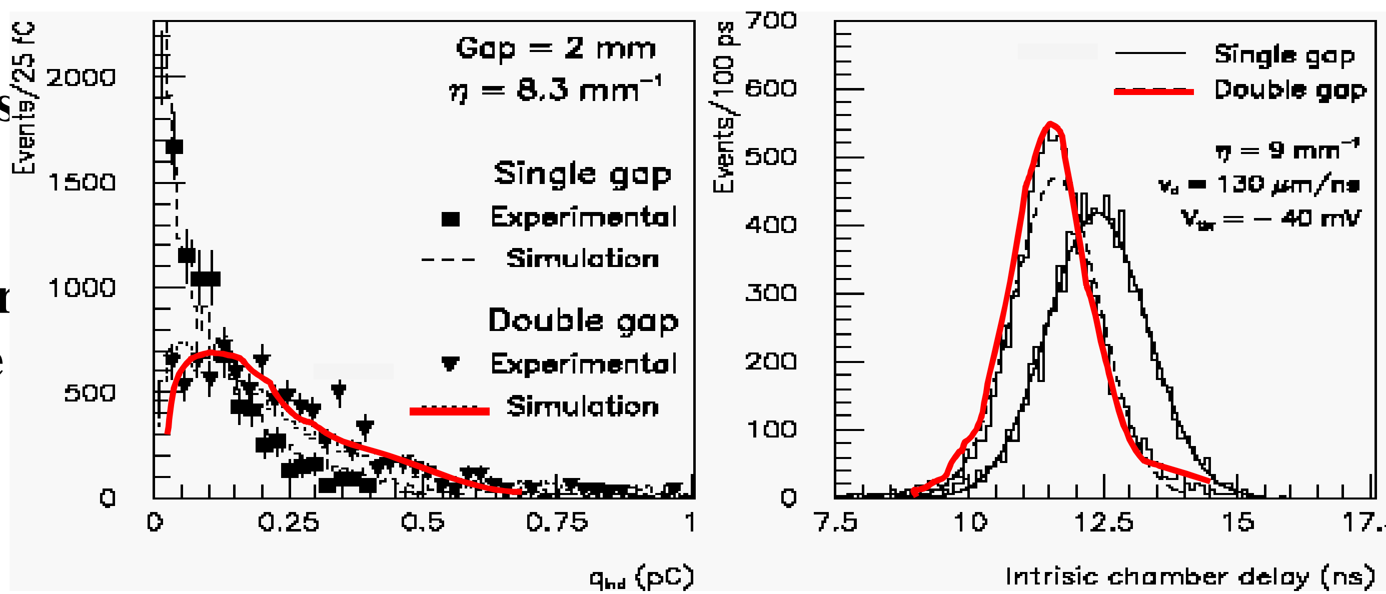
However, due to technical and financial reasons, only three layers up to $\eta = 1.6$ in the endcap region are in place at the start up

Double Gap RPCs

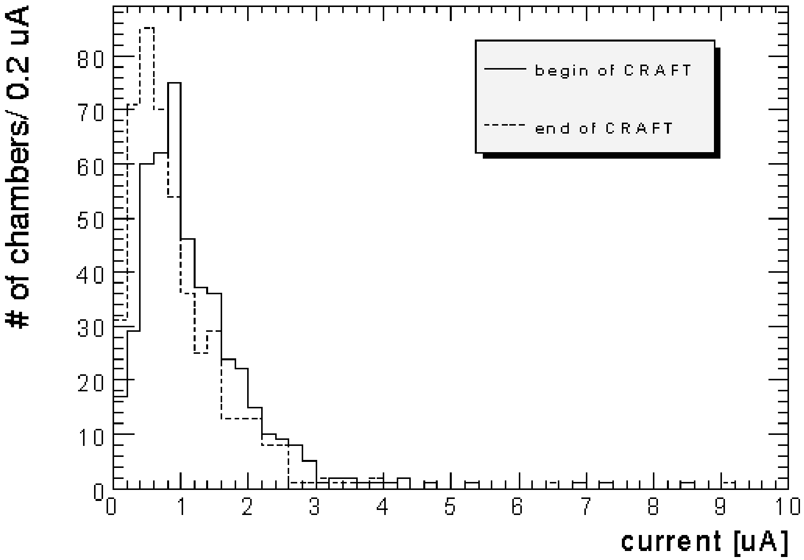


$$\varepsilon_{tot} = \varepsilon_1 + \varepsilon_2 - \varepsilon_1\varepsilon_2$$

Double gap geometry improves the efficiency and allows safer operation at higher threshold. Also the time resolution improves.

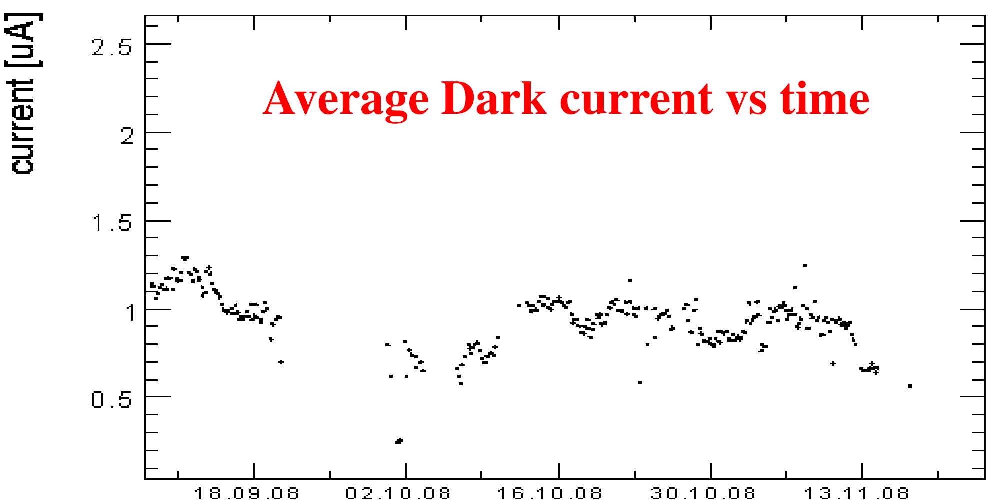


RPC Dark Currents



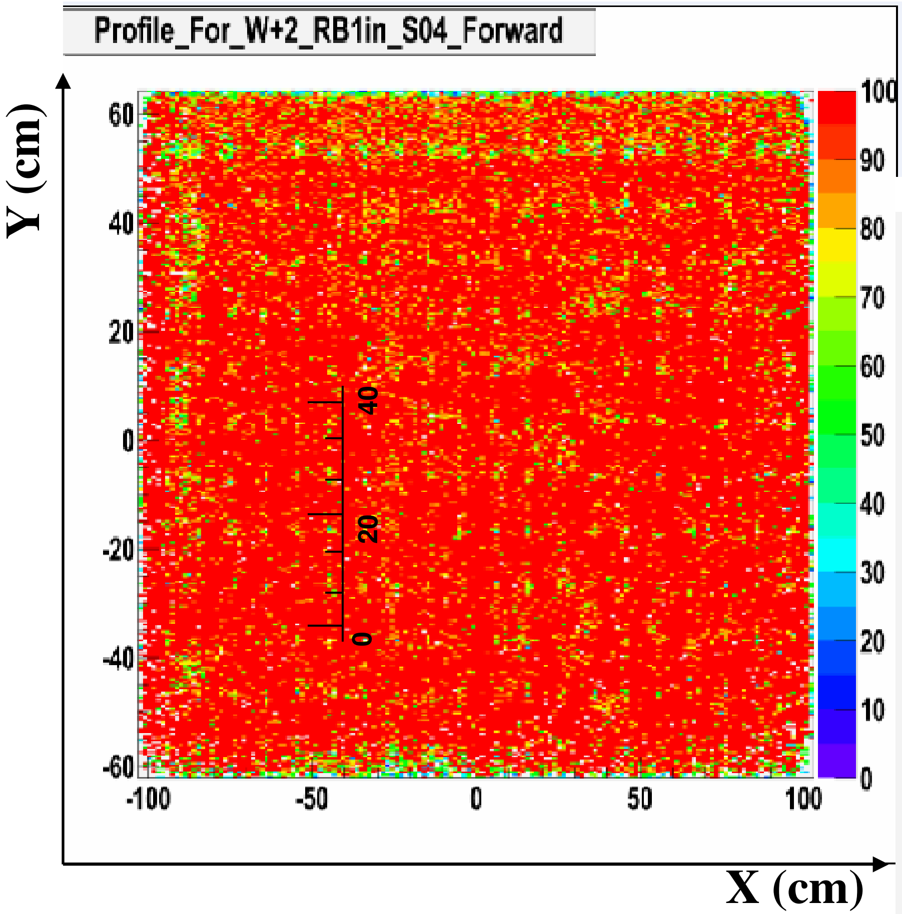
CRAFT results (Nov '08)

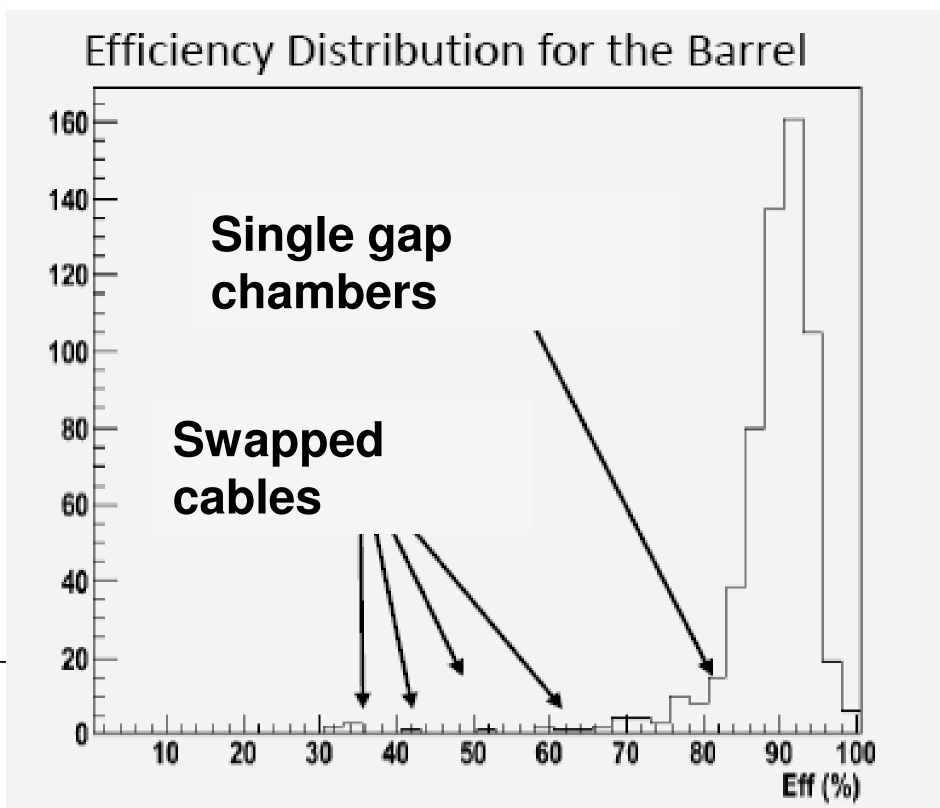
Barrel dark current/chamber below 1.5 μA on average. Temperature of the chambers was kept stable at about 22 ºC



RPC Efficiencies

CRAFT results (Nov '08)





Summary

- All Muon systems built, installed, and operational
  - Channel efficiencies typically 99% (or better)
  - CSCs and DTs deliver reliable, efficient triggers
    - Debug other subsystems
- Extensive running on cosmic rays
  - Repair infant mortality, hardware problems
  - Develop more efficient software/firmware
    - DTs uncovered ~30% error in B field map
  - Later speakers will show muon results
- Ready for LHC data!!!!