

***FOUR SEAS CONFERENCE***  
IASI 2007

# **The CMS muon system**

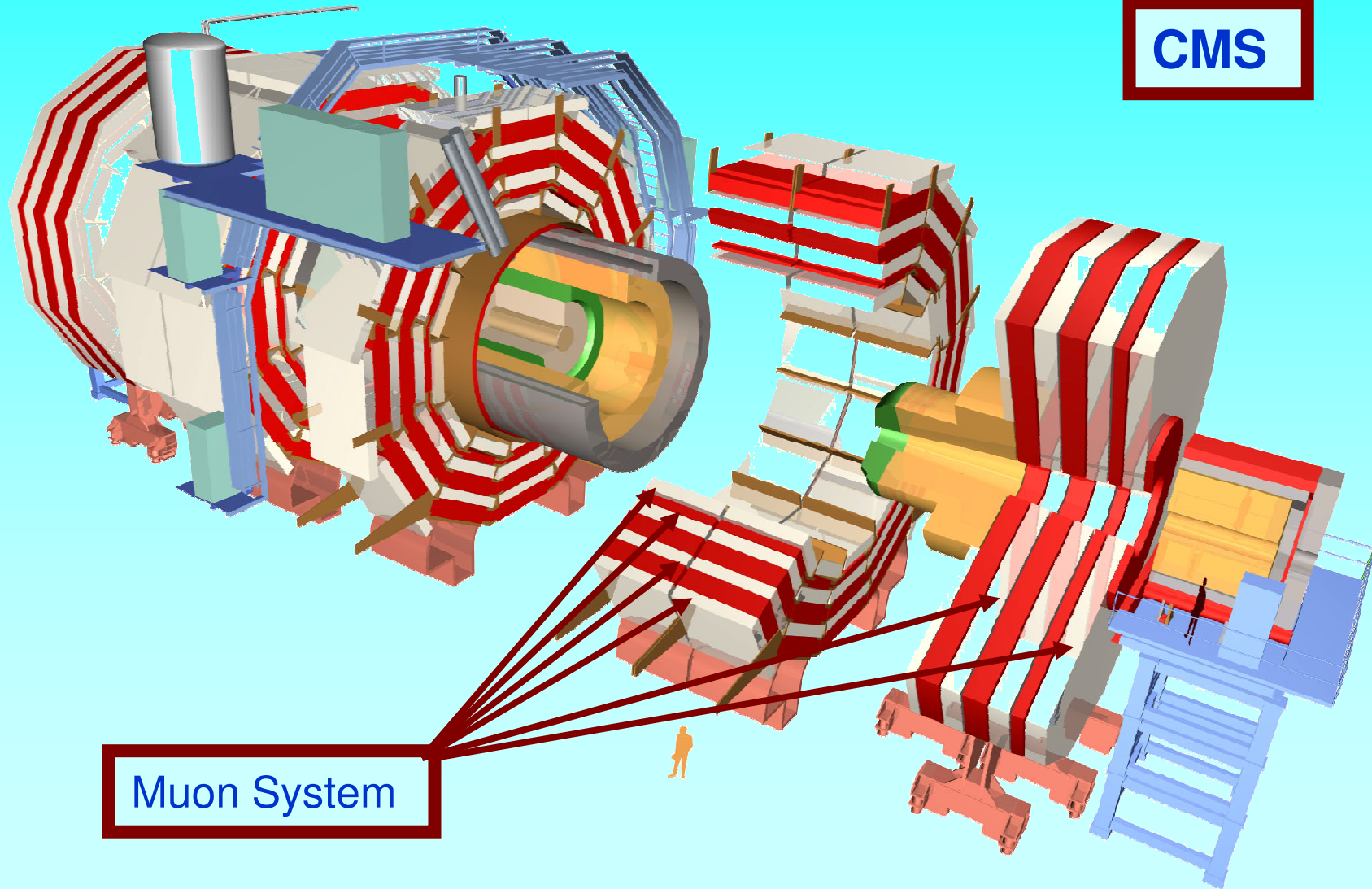
L. Litov  
University of Sofia



# CMS: design & construction



CMS



Muon System



# System Conditions & Requirements



## System Conditions

**Barel**  $\eta < 1.3$

Particle rates  $< 10 \text{ Hz/cm}^2$

Low Magnetic field

**Endcap**  $0.9 < \eta < 2.4$

Particle rates **100-1000 Hz/cm<sup>2</sup>**

Magnetic field

Uniform axial  **$> 3 \text{ T}$  in ME1/1**

Highly non-uniform radial field

**Up to 1 T in ME1/2**

## Requirements

❖ **Muon identification**

❖ **Muon Trigger**

- **Unambiguous BX identification**
- **Trigger single and multimMuon with well defined pt thresholds few GeV to 100 GeV**

❖ **Muon momentum measurement**

- **Charge assignment correct to 99% confidence level up to 7 TeV**

➤ **Momentum resolution**

➤ **Stand alone**

**$dp_t/p_t = 8 - 15\%$  at  $p_t = 10 \text{ GeV}$**

**$dp_t/p_t = 20 - 40\%$  at  $p_t = 1 \text{ TeV}$**

➤ **Global**

**$dp_t/p_t = 1 - 1.5\%$  at  $p_t = 10 \text{ GeV}$**

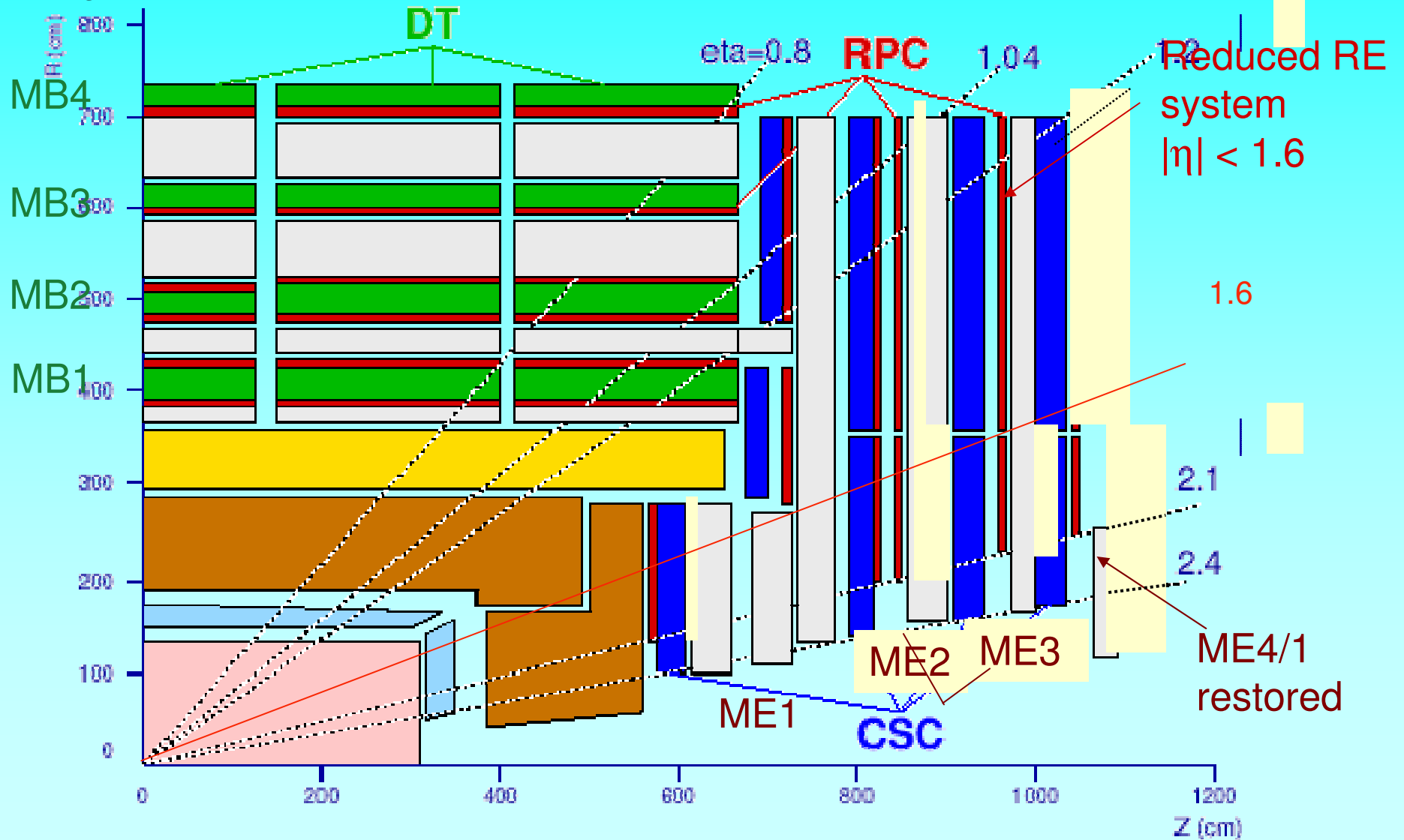
**$dp_t/p_t = 6 - 17\%$  at  $p_t = 1 \text{ TeV}$**



# CMS Muon System



1/4 longitudinal slice







# Requirements



## Resolution (per station)

Position  $R\Phi$  : 100  $\mu\text{m}$   
Z : 150  $\mu\text{m}$

Angle: 1 mrad

BX identification Efficiency  
>98% per station

Spatial resolution ( $\Phi$ ) (per station)

75  $\mu\text{m}$  ME1/1 and ME1/2

150  $\mu\text{m}$  for the others

(At the trigger level < 2mm)

Correct BX identification

> 92% per chamber ( $\rightarrow$  99% global)

Trigger Track Efficiency >99 % per chamber

Drift Tubes - DT

Cathode Strip Chambers - CSC

BARREL

ENDCAP

## Resistive Plate Chambers - RPC

(Dedicated Trigger Detector)

- Good timing : Resolution < 3ns (RMS), 98% within a 20ns window
- Good Rate capability
- Low cluster size
- High efficiency > 90% per chamber ( $\rightarrow$  95% global)
- $r\Phi$  resolution  $\sim$  1cm



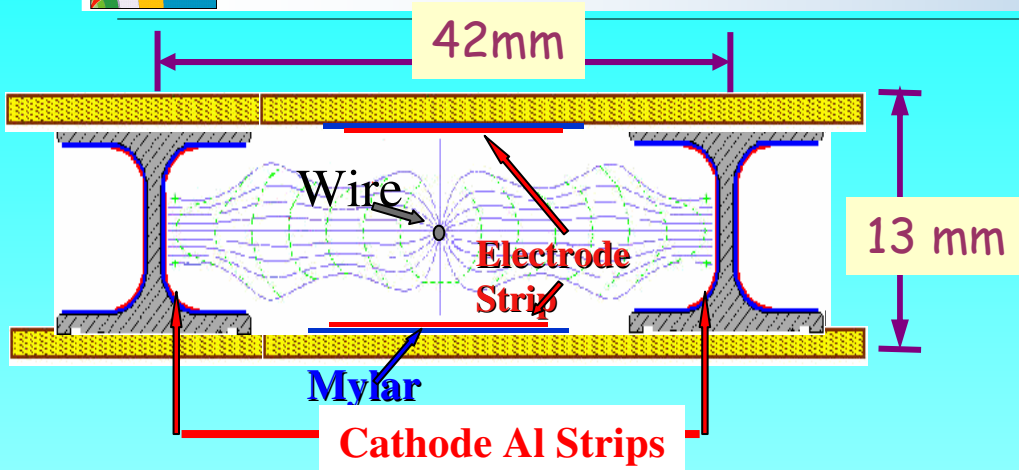
## Drift tube chambers



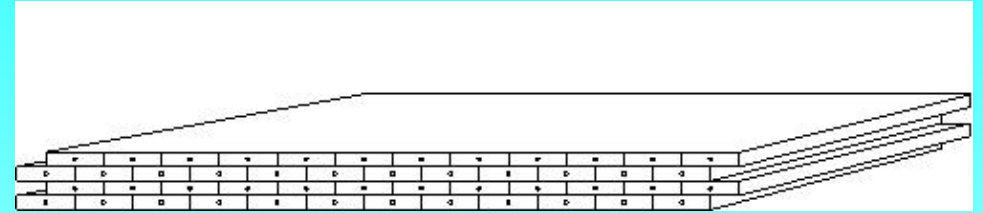
# Barrel Drift tube chambers



# Drift Tube Chambers



**4 Layers = 1 Superlayer (SL)**



**Independent Subunit**

(Gas tightness, HV, Front End)

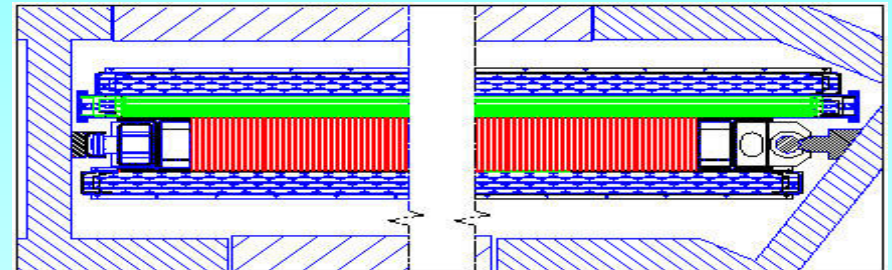
**GAS:** Ar/CO<sub>2</sub> (85/15)

**HV:** Wires 3600 V

Strips 1800 V

I-beams -1200 V

Φ SL  
θ SL  
Honeycomb  
Φ SL



**T<sub>max</sub>:** 380 ns

**Drift Velocity :** ~ 55 μm/ns

**Single Wire**



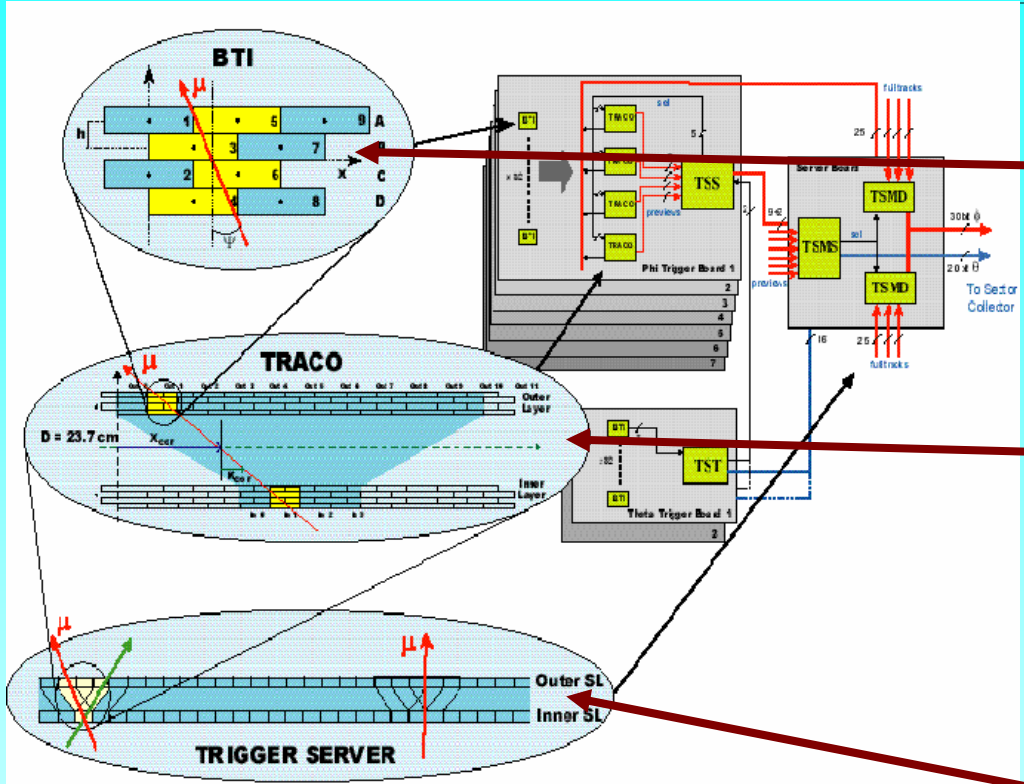
100 μm Φ

**Resolution :** < 300 μm

150 μm θ



# DT Local Trigger



**Bunch Track Identifier (BTI)**

- Combines superlayer hits in track segments
- Allows effective BX identification

**TRACK COrellator**

Combines segments from 2  $\Phi$  SL

**Trigger Server (TS)**

Collects TRACO combinations and  $\eta$  segments

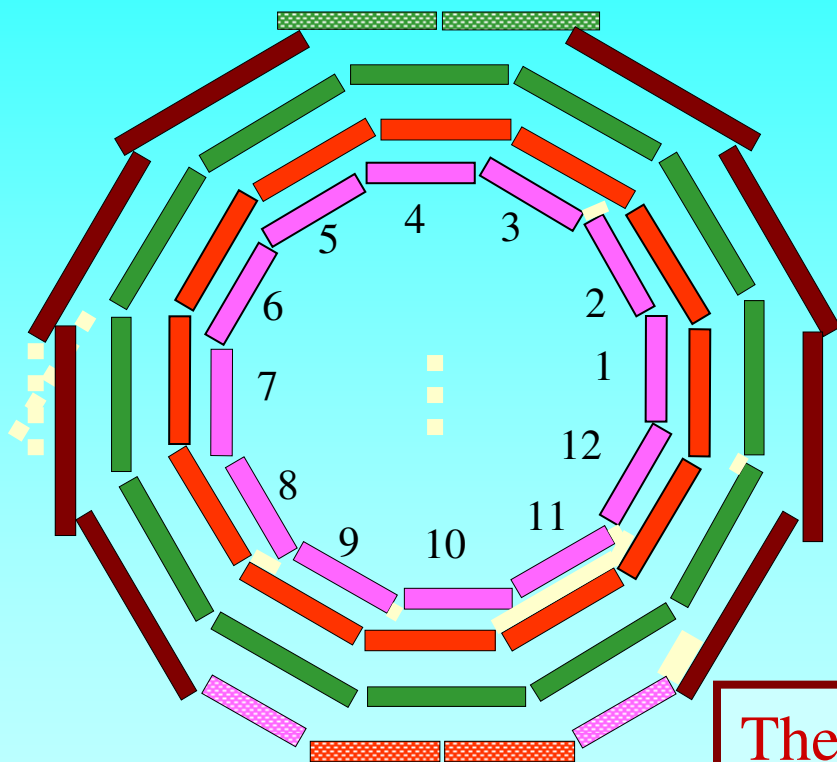
Selects the 2 best segments for the DT Track Finder

**Track Finder**

Connects the track segments into a full track and assigns  $P_t$ ,  $\Phi$  and  $\eta \rightarrow$  2 best track are send to **Global Muon Trigger**



# Barrel Muon DT

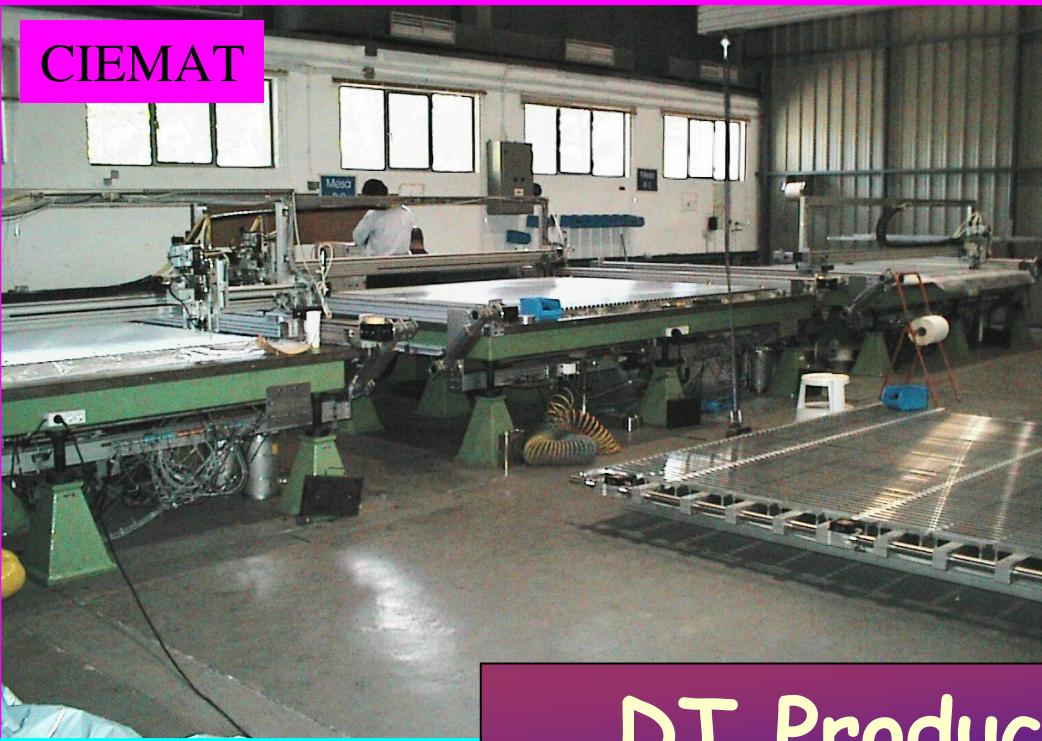


	60 MB1	3SL	2 RPC	$\sim 2.0 \times 2.54 \text{ m}^2$	960kg
	60 MB2	3SL	2 RPC	$\sim 2.5 \times 2.54 \text{ m}^2$	1200kg
	60 MB3	3SL	1 RPC	$\sim 3.0 \times 2.54 \text{ m}^2$	1300kg
	40 MB4	2SL	1 RPC	$\sim 4.2 \times 2.54 \text{ m}^2$	1800kg
	10 MB1	2SL	1 RPC		
	10 MB2	2SL	1 RPC		
	10 MB3	2SL	1 RPC		

The Barrel Muon system comprises 250 chambers  
In 7 flavors for 5 wheels  
Total 1700 m<sup>2</sup>



CIEMAT



AACHEN



DT Production Sites

LEGNARO



TORINO





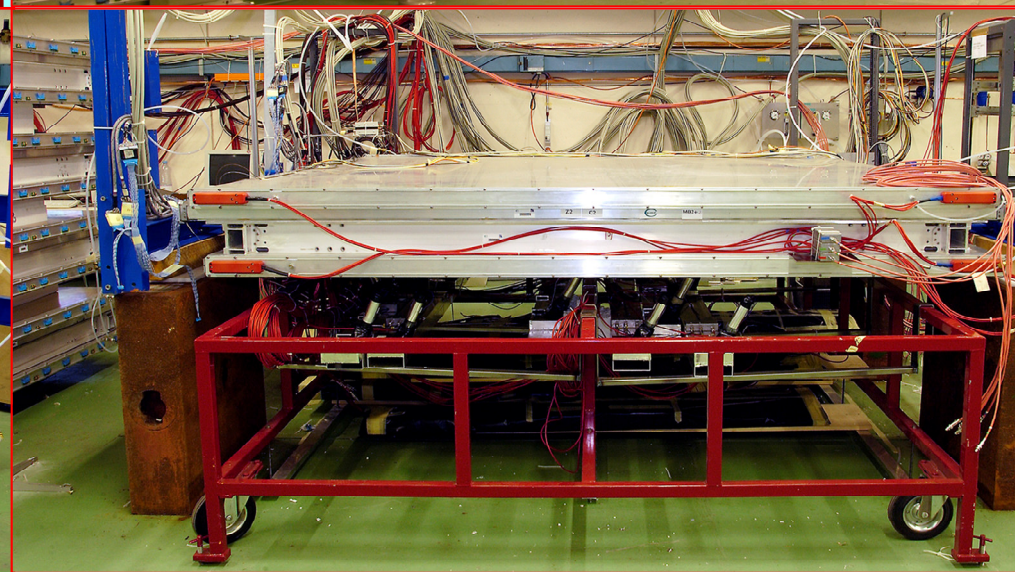
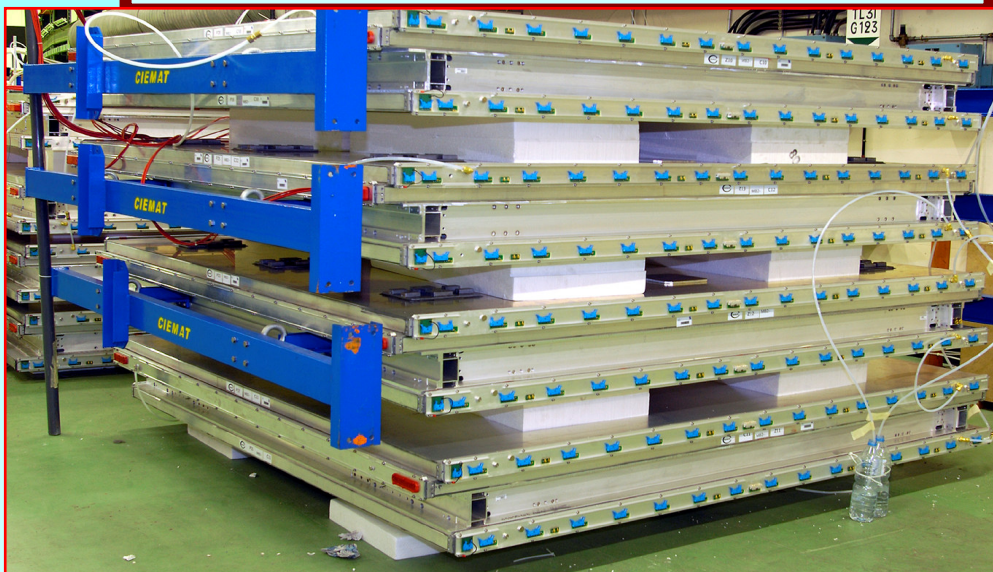


# ISR Chamber preparation



DT chambers are sent to the ISR for full tests

1. Acceptance tests: HV, Leak-rate, noise, cosmics
  2. DT alignment calibration
  3. DT cabling+services
  4. DT assembly with RPCs
- Storage in transport frames



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# CMS Endcap Muon Detector

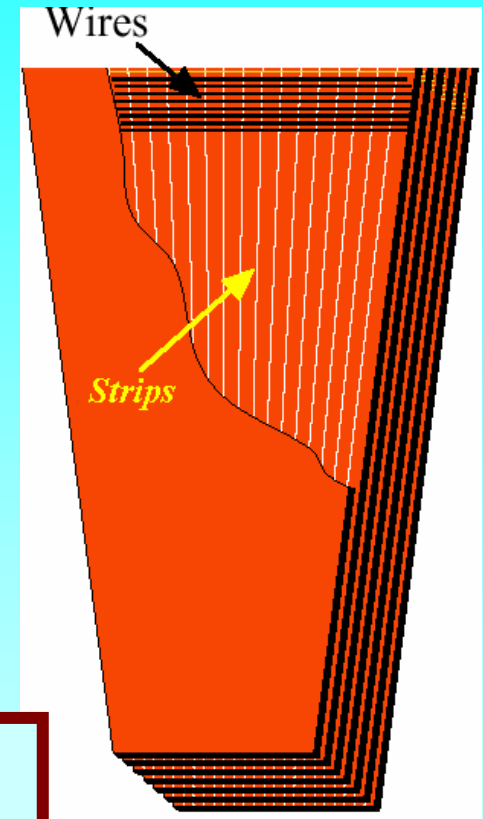
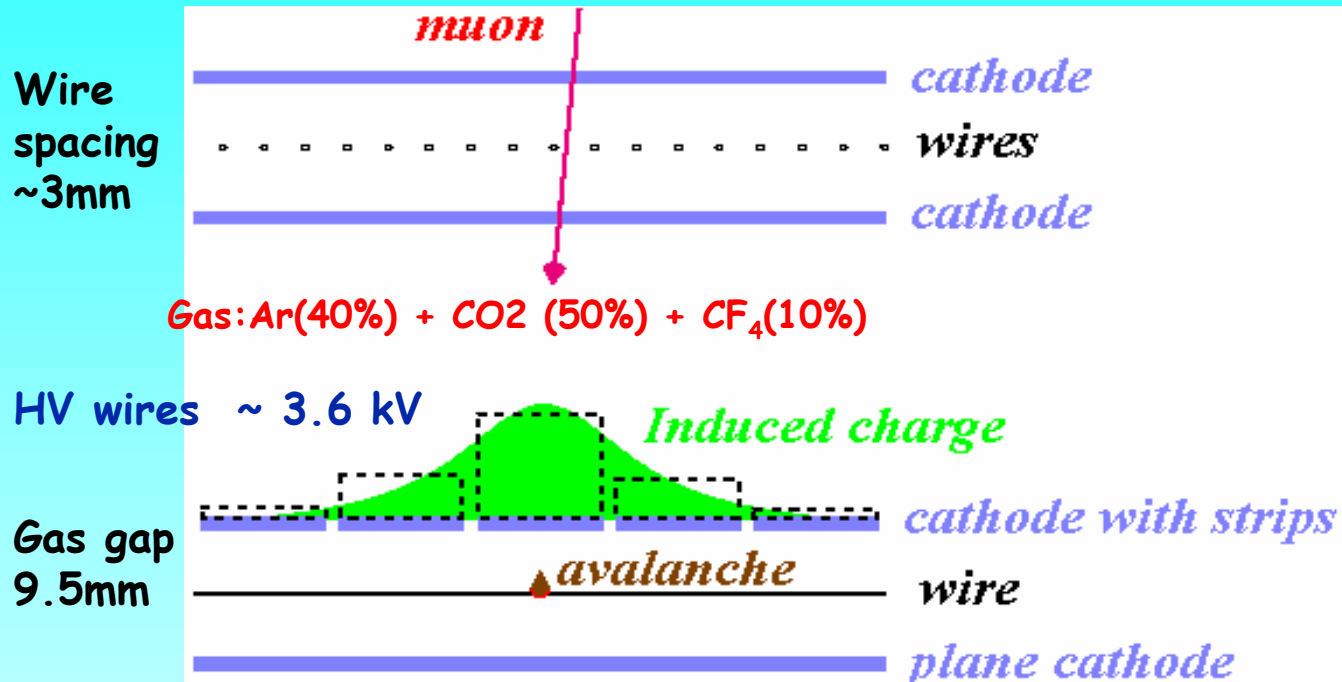


## Cathode Strip Chambers





# Cathode Strip Chambers (CSC)



- Trapezoidal Chambers ( $10^0$  or  $20^0$  in  $\Phi$ ), 6 layers
- Radial cathode strips – measure  $\Phi$  (75-150  $\mu\text{m}$ )
- Wires orthogonal to strips
- Precise timing measurement (BX) - ~4.5 ns
- Coarse measurement of the radial position (16-54 mm)



## CSC Local Trigger



**Cathode trigger** – Optimized to measure  $\Phi$  precisely  
By combining 6 layers (1 chamber)  $\rightarrow$  0.15 –strip  $\sim$ 1,2 mm

**Anode trigger** – Optimized to efficient BX identification  
For each spatial pattern a low level coincidence ( $\geq 2$  layers ) is used to establish timing  
A higher level coincidence ( $\geq 4$  layers ) is required to establish a muon track

**ALCT+CLCT  $\rightarrow$  Time + Location+Angle are send to CSC Track Finder**

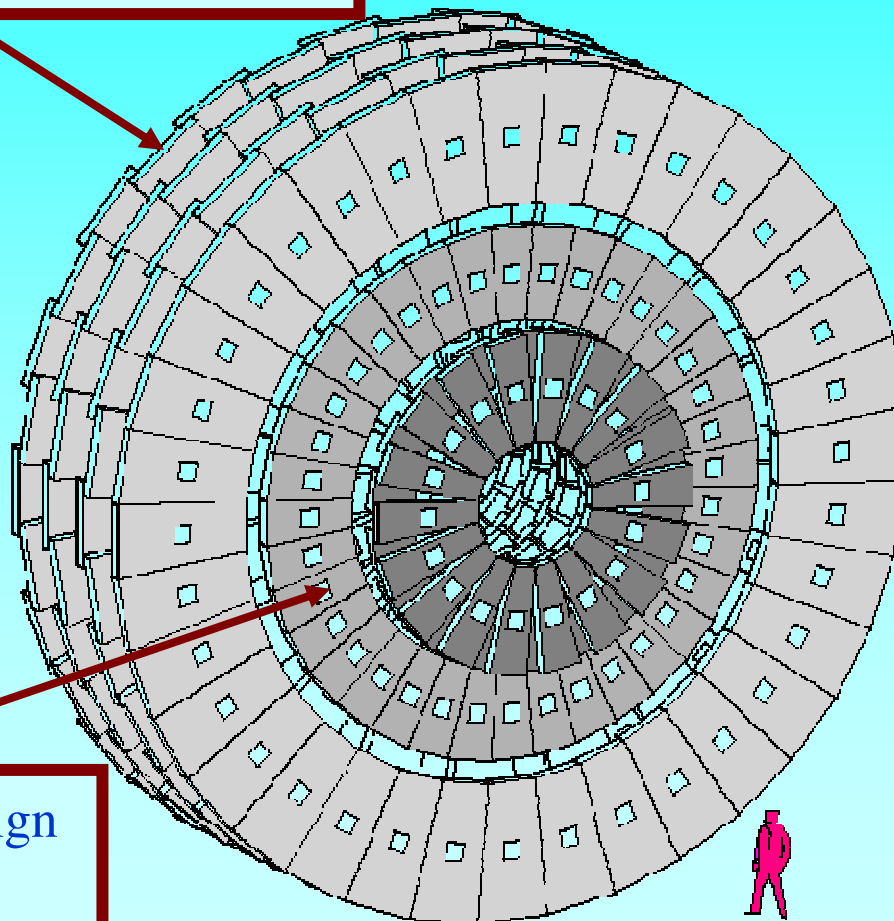
**Track Finder** =reconstruct tracks using 3-D spatial information Assigns pt,  $\Phi$  and  $\eta$   
Select the 4 highest quality candidates and sends them to the **Global Muon Trigger**



# CSC



Outer section of 4'th station staged

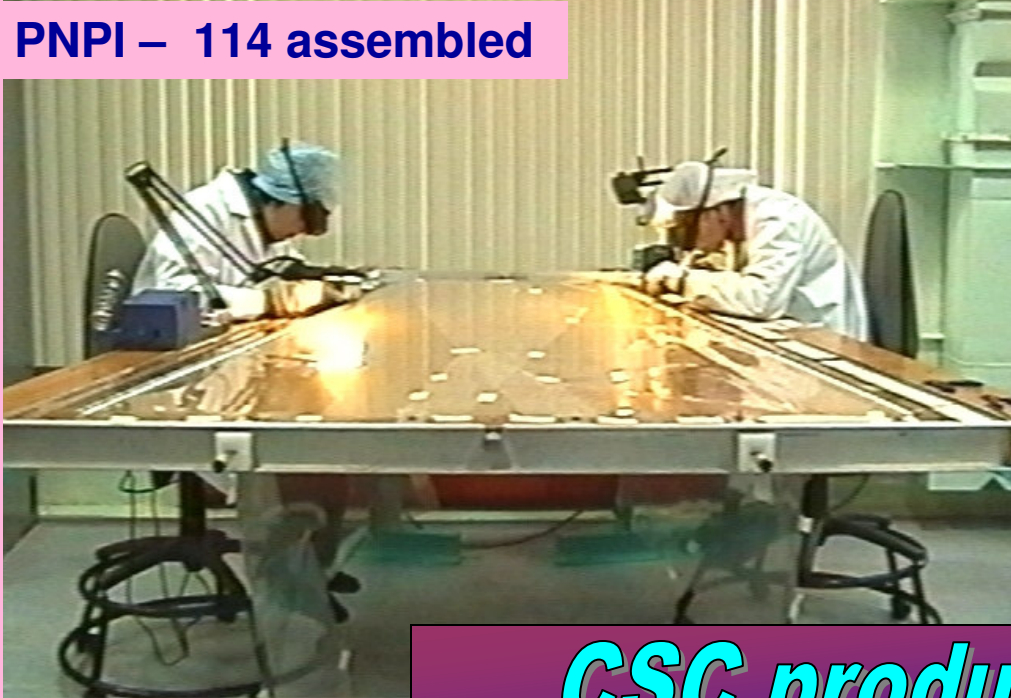


ME1/1 –special design  
Inserted in end-cap  
Calorimeter support

6 planes per chamber  
468 chambers  
6000 m<sup>2</sup> sensitive area  
2 Million wires  
220 K cathode channels  
1 chamber ~ 1000  
readout channels



**PNPI – 114 assembled**



**IHEP – 148 assembled**

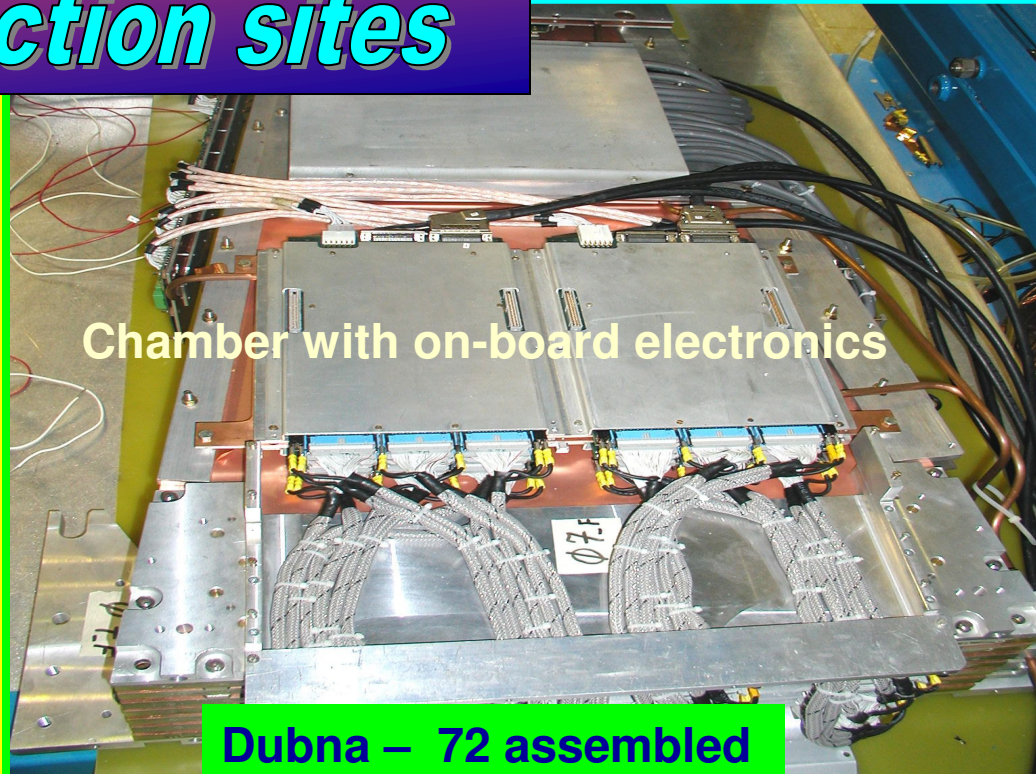


***CSC production sites***

**FNAL – 148 assembled**



**Chamber with on-board electronics**



**Dubna – 72 assembled**





# ISR FAST Site

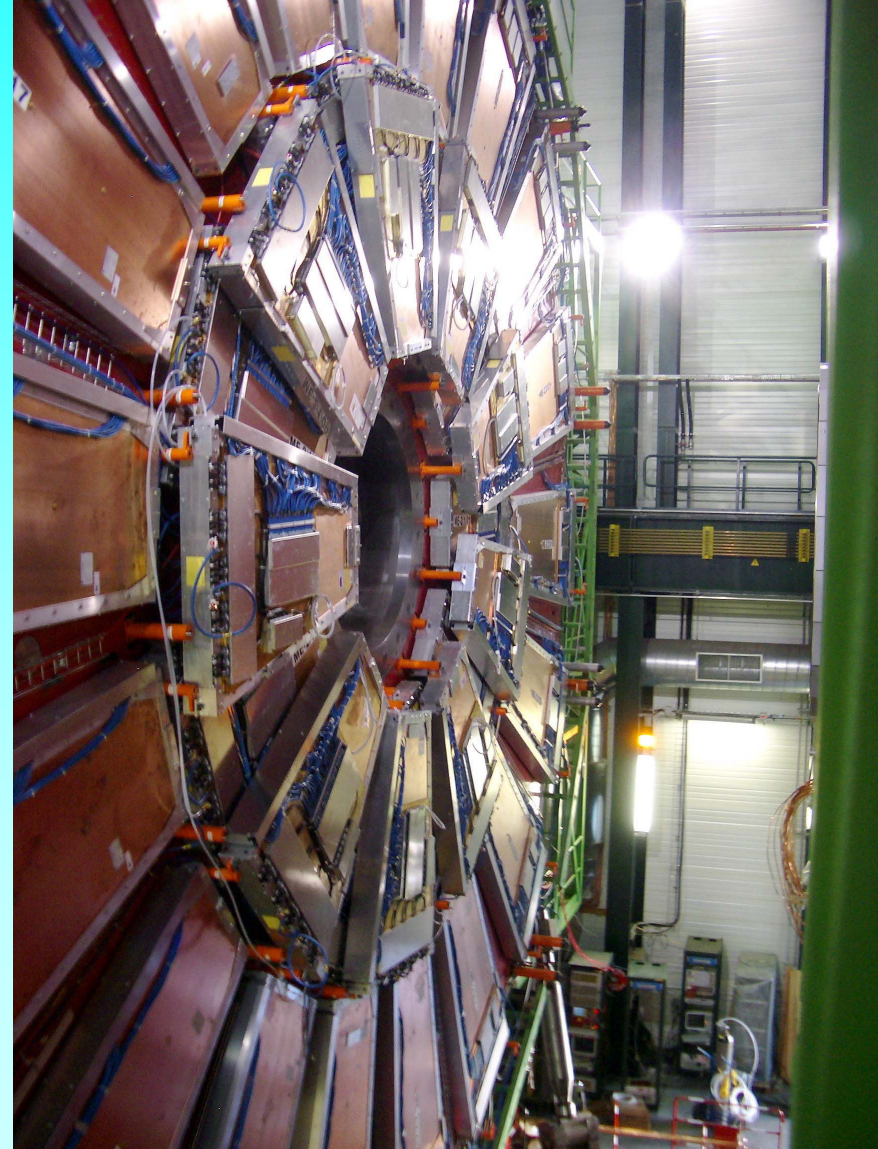


## Final Testing before installation at SX5





# CSC Installation



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# Readout cables & Walkway







## Chamber commissioning at SX5



Commissioning of CSCs+on chamber electronics follows installation

Use a subset of FAST site tests

Some additional tests: e.g. skew-clear cable delays, long term tests under



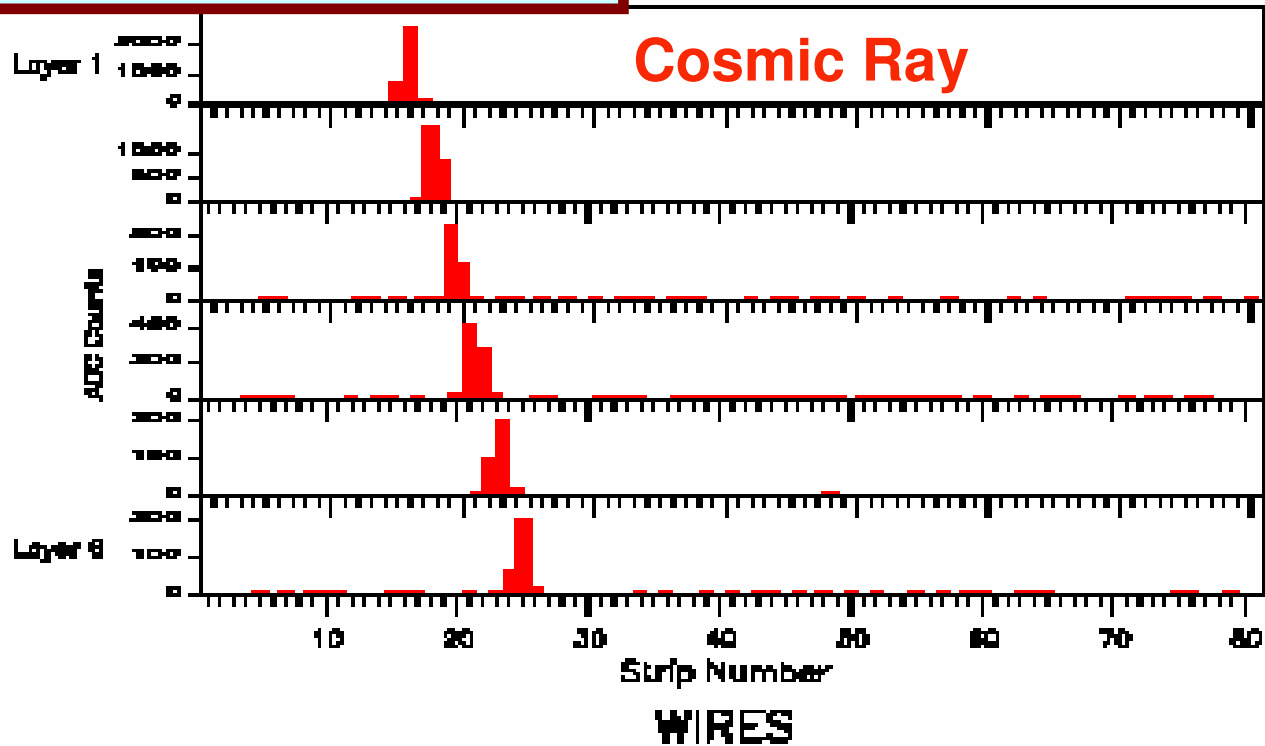


# Chamber commissioning at SX5

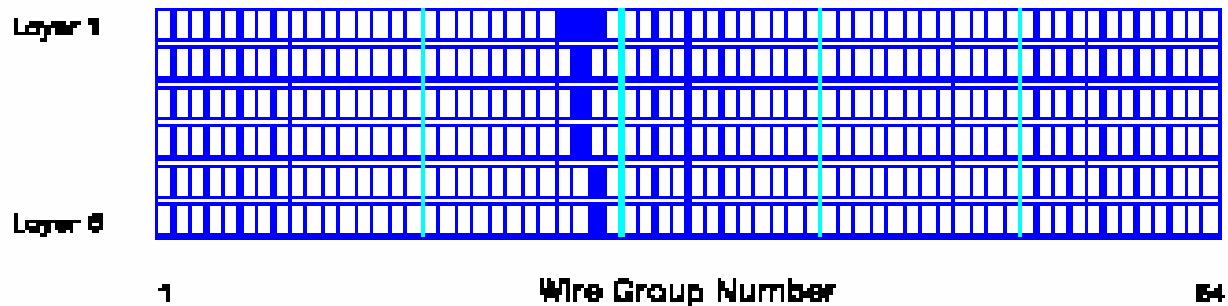


using test pulses and cosmic rays

STRIPS



First particles detected by installed "CMS" subsystem!!





# Resistive Plate Chambers (RPC)



## Resistive Plate Chambers



# Resistive Plate Chambers



**Resistive Plates** – bakelite with bulk resistivity  $(2 \pm 1) \cdot 10^{10} \Omega \text{cm}$

**Gas gap** ( $2 \text{mm} \pm 20 \mu\text{m}$  wide)

**Gas mixture, containing**

96%  $\text{C}_2\text{H}_2\text{F}_4$  (Freon),

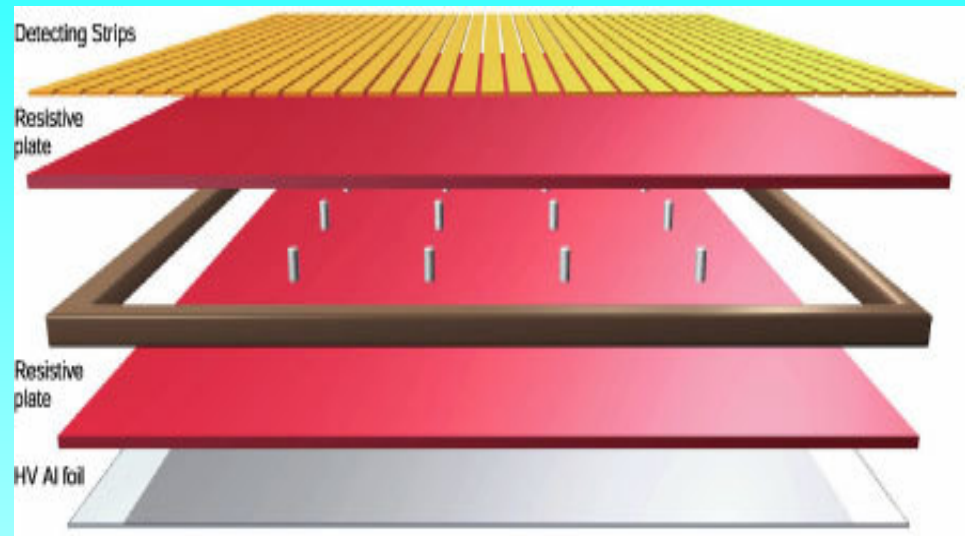
3,5 % isobutan,  $\text{SF}_6$  – 0.5 %

**Graphite electrodes** with resistivity  $300 \text{ k}\Omega / \text{cm}$

**Insulating PET film** (0.3 mm thick)

**Detecting copper strips**

$40 \mu\text{m}$  thick, 2–4 cm wide and 1250 mm long



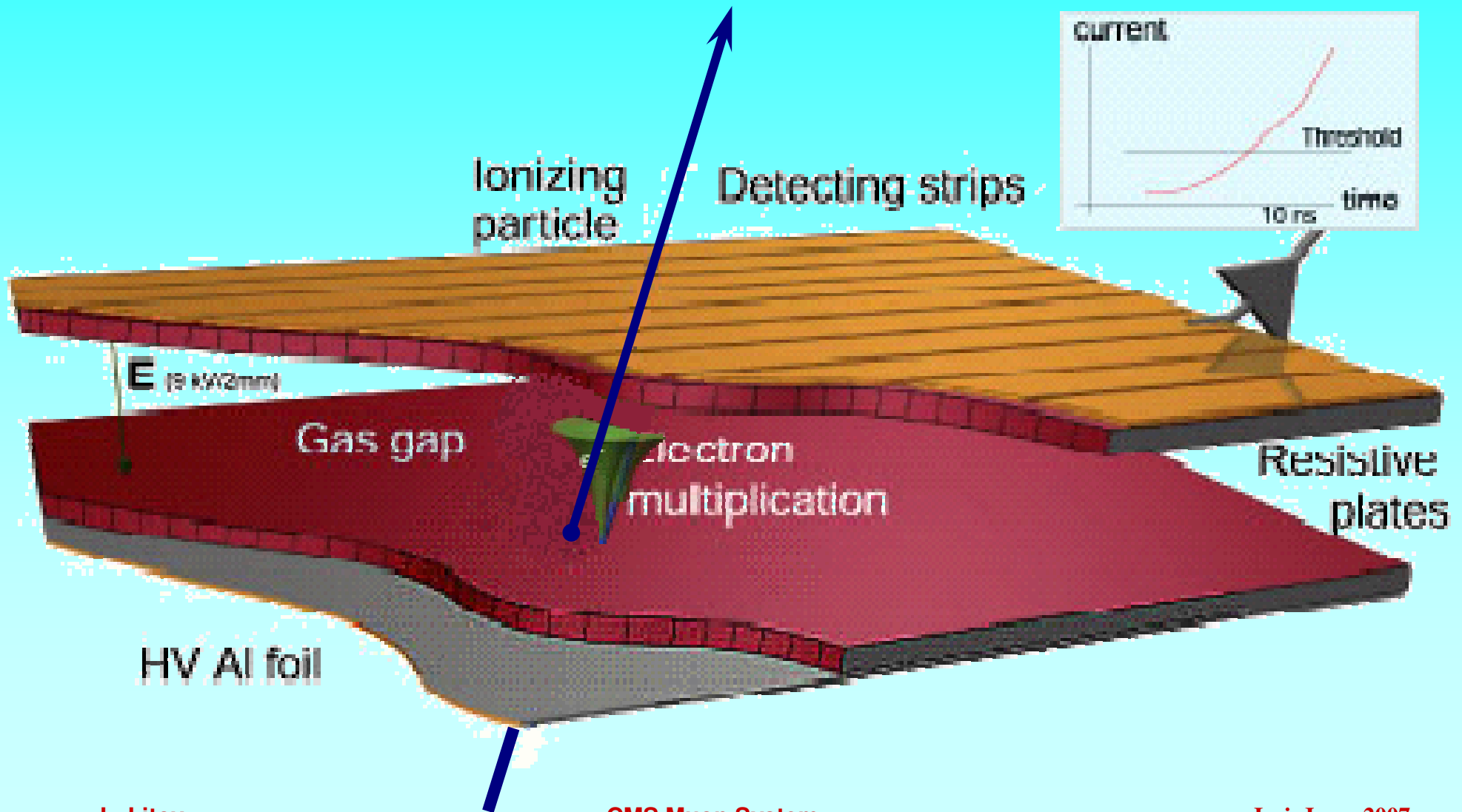
**Spacers** (cylinders with diameter 10 mm and height 2mm)

**Copper shielding**

**Linseed oil treatment**



# RPC - Principle of Action





**Fast detectors for the first level trigger of the experiment**

**Considerably good space resolution**

**Able to work in areas with background  $\sim 10^3$  Hz/cm<sup>2</sup>**

**Price – as low as possible**

## Requirements

Time resolution  $\leq 1.8$  ns  
(98 % within 20 ns)

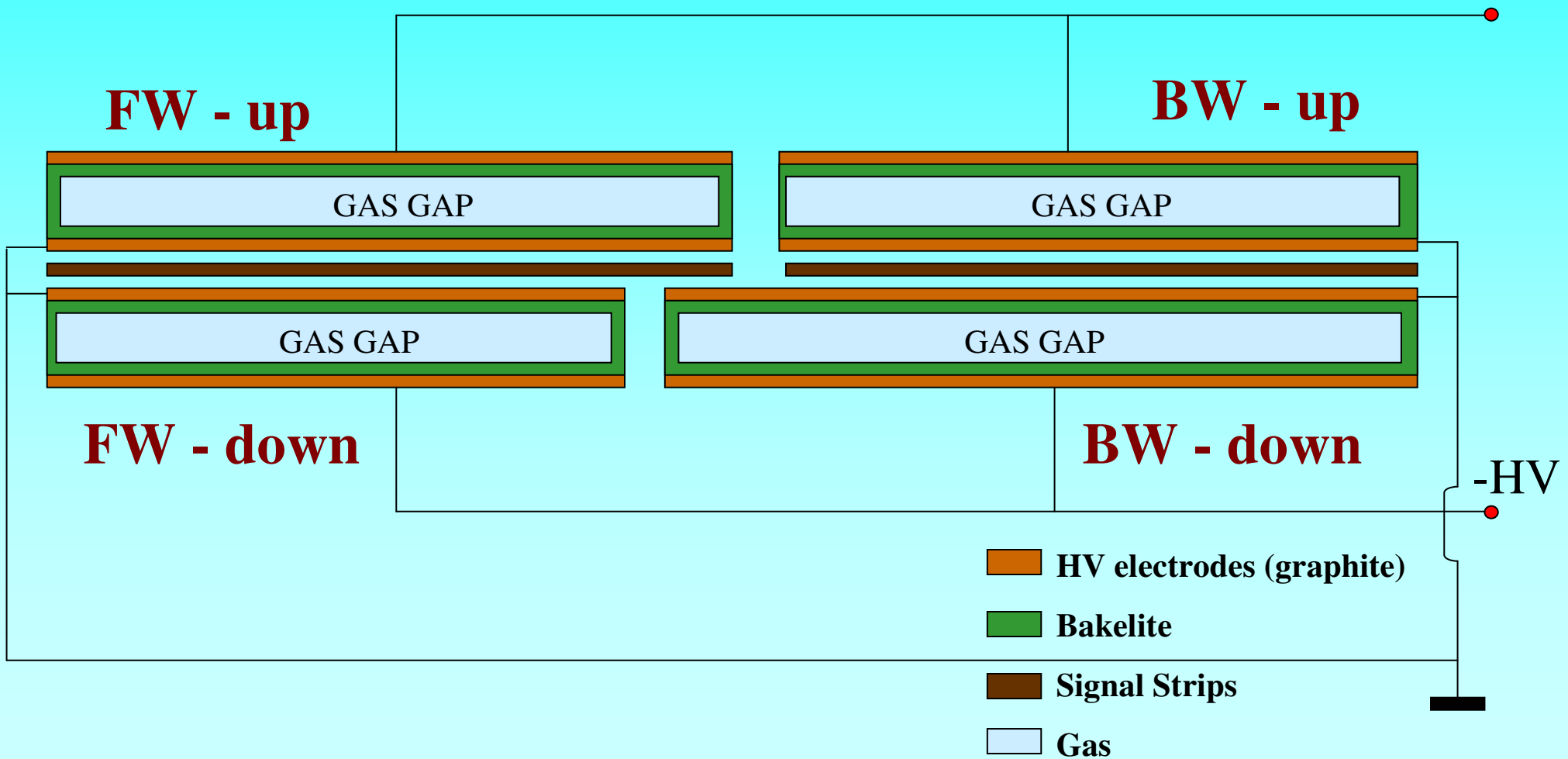
Efficiency  $> 95$  %

Rate capability  $\leq 1$  kHz/cm<sup>2</sup>

- Average cluster size  $< 2$  strips
- Number of streamers  $< 10\%$
- Operation plateau  $> 300$  V
- Power consumption 2-3 W/m<sup>2</sup>
- Operational voltage 8.5 – 10 kV



# Double gap design

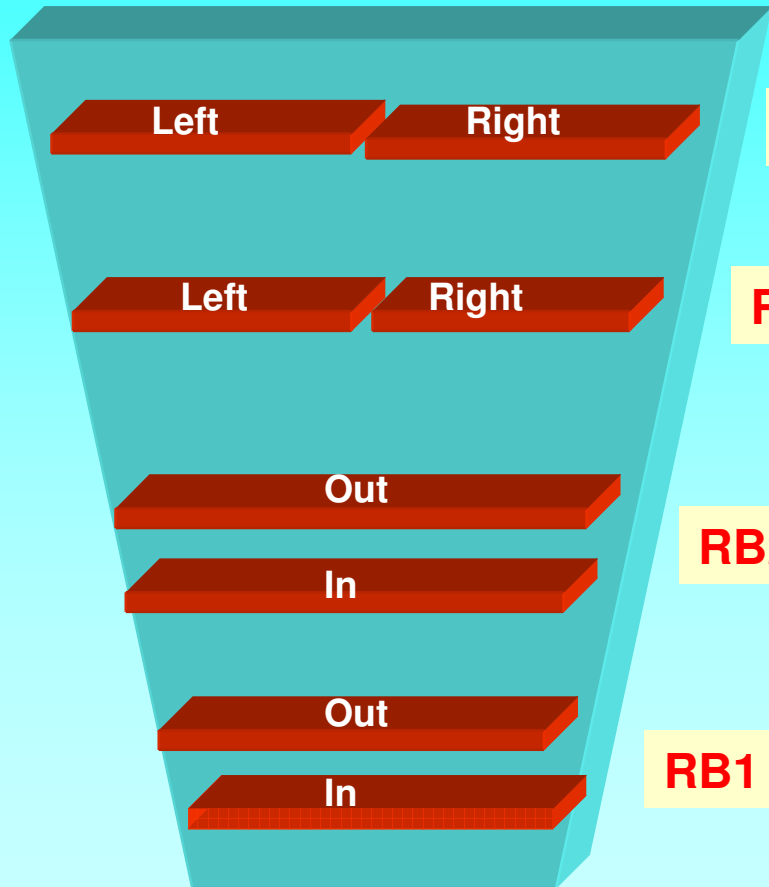




# Main Barrel RPC Types



**Length: 2.455 m**



**RB4**

**Width: 1.5, 2.0 , 2.5 m**  
**Pitch: 40.8, 40.6, 41.0 mm**  
**# Strips for Gap: 48, 36, 48, 60**

**RB3**

**Width: 1.48 m**  
**Pitch: 34.8 mm**  
**# Strips for Gap: 42**

**RB2**

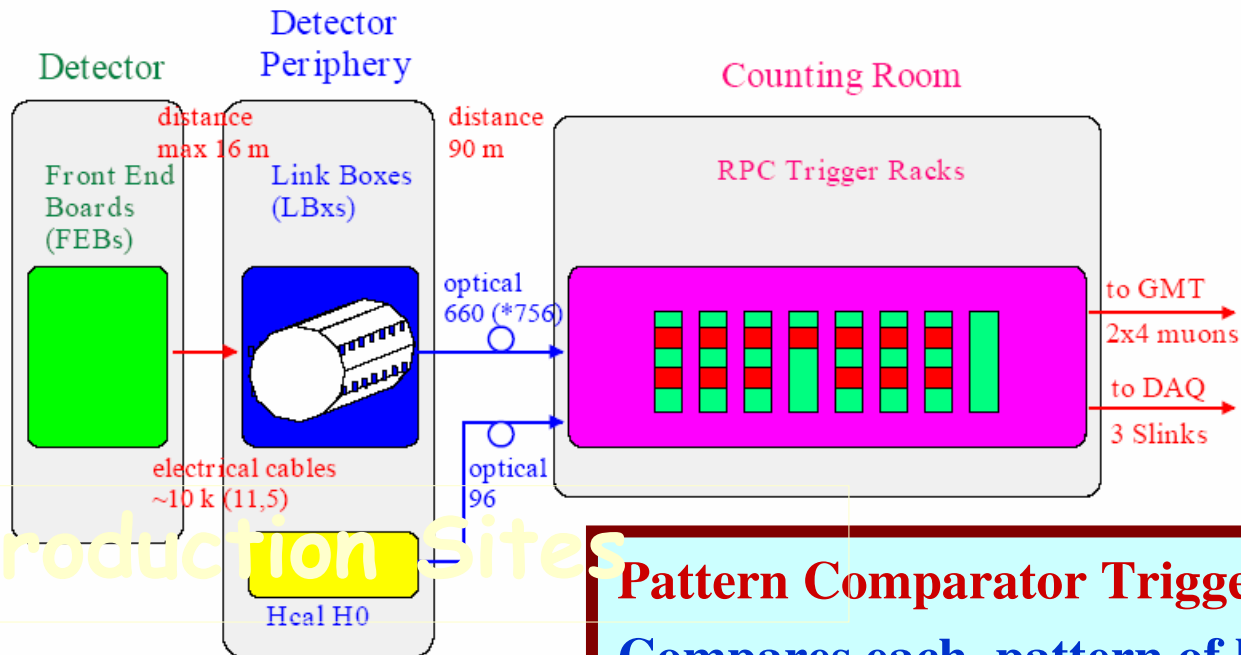
**Width: 1.5, 2.0 , 2.5 m**  
**Pitch: 27.3, 29.3 mm**  
**# Strips for Gap: 84, 90**

**RB1**

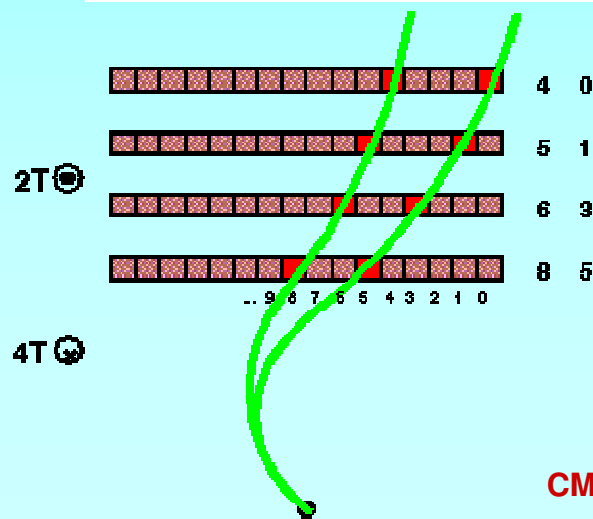
**Width: 1.5, 2.0 , 2.5 m**  
**Pitch: 22.7, 24.3 mm**  
**# Strips for Gap: 84, 90**



# RPC data flow and trigger



## RPC Production Sites



## Pattern Comparator Trigger

Compares each pattern of hit strips to predefined patterns corresponding to various pt

## RPC Muon sorter

Selects 4 highest pt muons from the barrel and 4 from the end-caps and sends them to the **Global Muon Trigger**

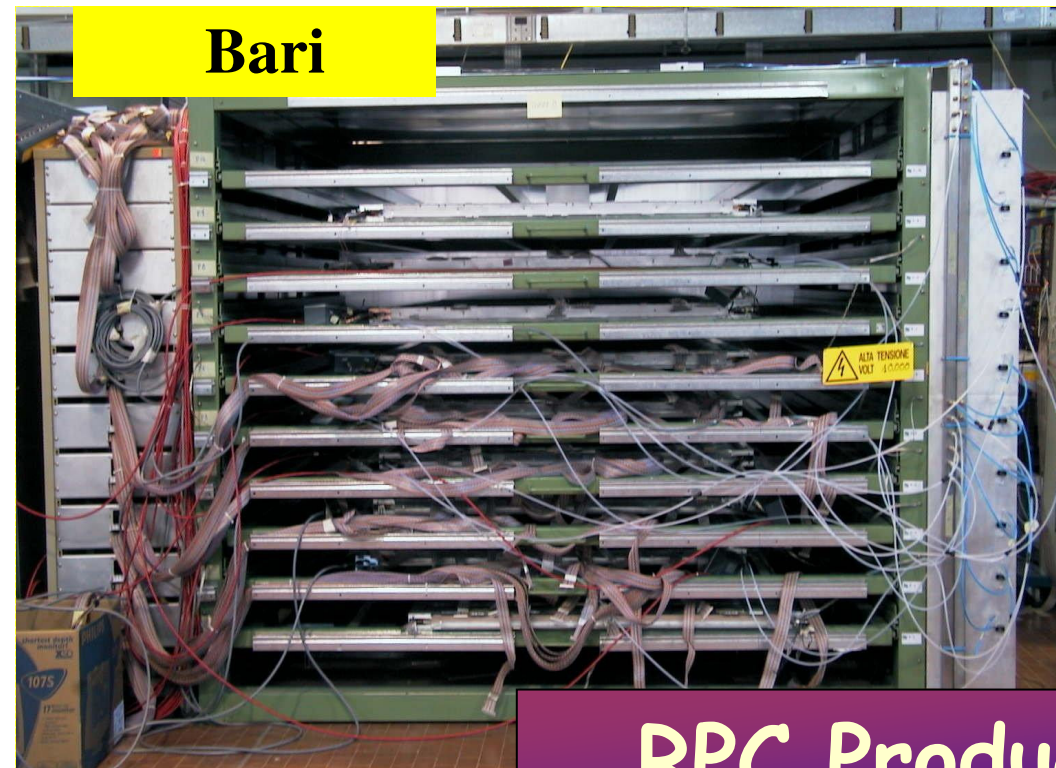


**Bari**

**Sofia**

**RPC Production Sites**

**Pavia**











# Installation of DT and RPC



**At ISR**

**Coupling RPC to DT**

**Fast test**

**Transportation to SX5( CMS surface hall)**

**At SX5**

**Installation in the CMS Detector**

**Started in June**



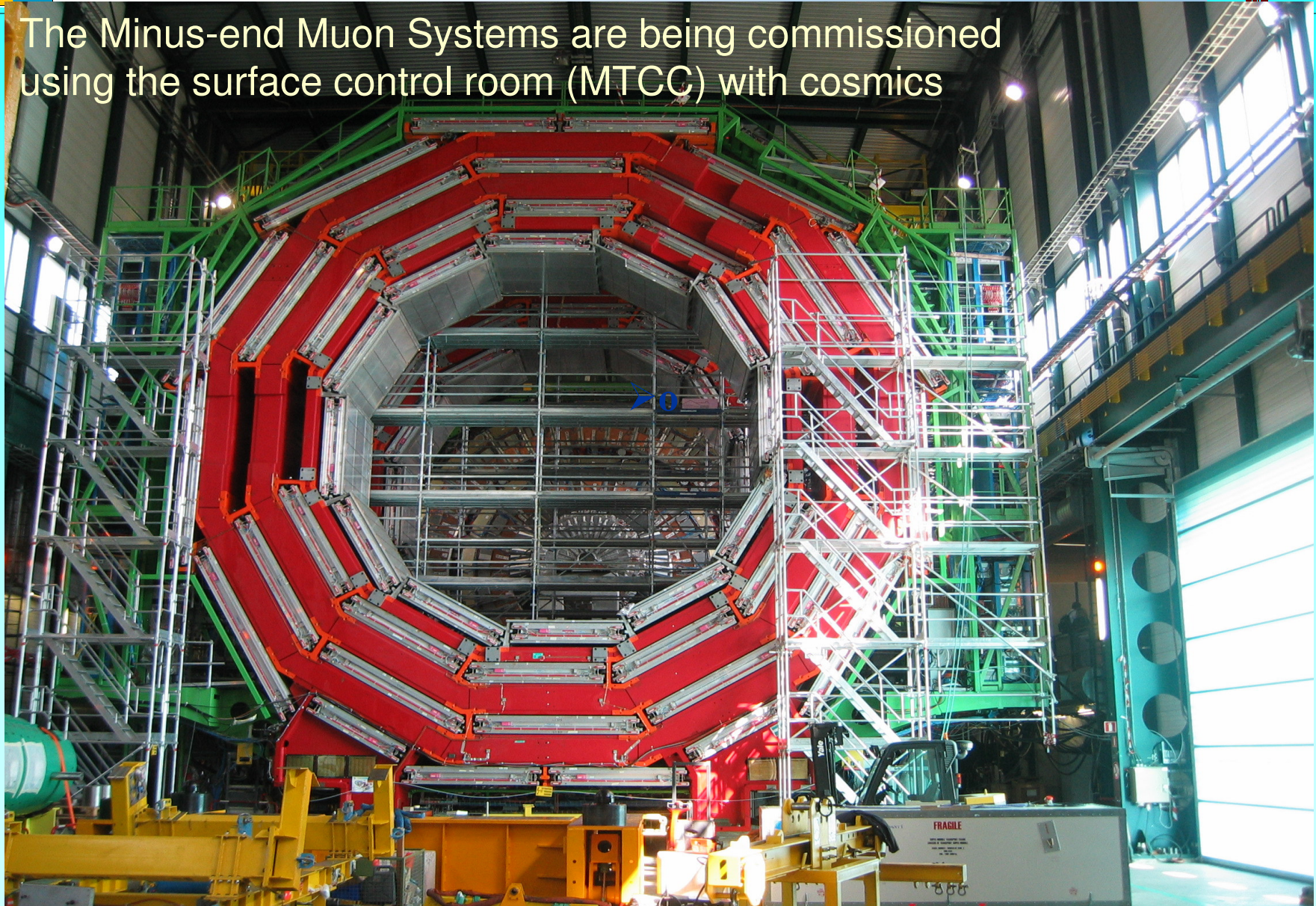




## Situation in SX



The Minus-end Muon Systems are being commissioned using the surface control room (MTCC) with cosmics



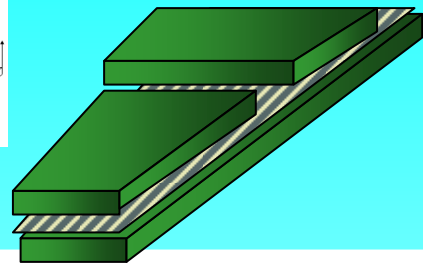
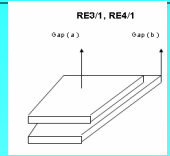




# Endcap RPC



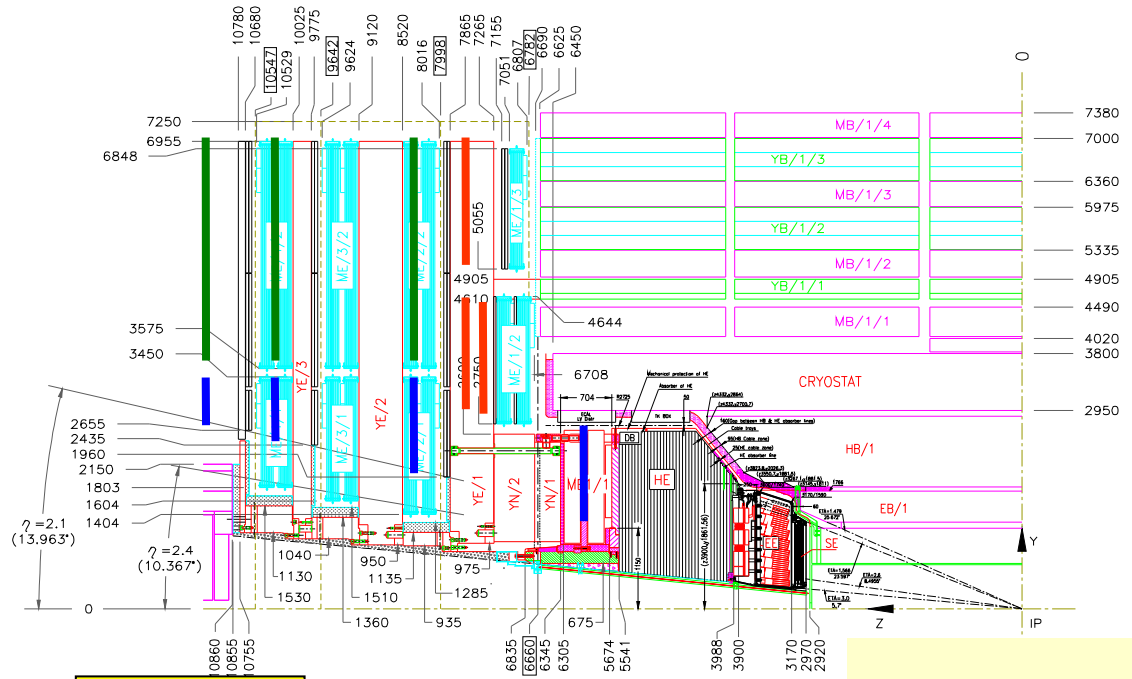
- China
- Korea
- Pakistan



**CERN**  
**Project Co-ordination**  
**ISR Assembly Station**

**Gap production**  
**Korea**

**Front-end electronics**  
**Pakistan**



	RE 1/1		RE 2/1		RE 3/1	RE 3/2	RE 3/3	RE 4/1	RE 4/2
No. of chambers	36*2		18*2		18*2	36*2	36*2	18*2	36*



**Korea**

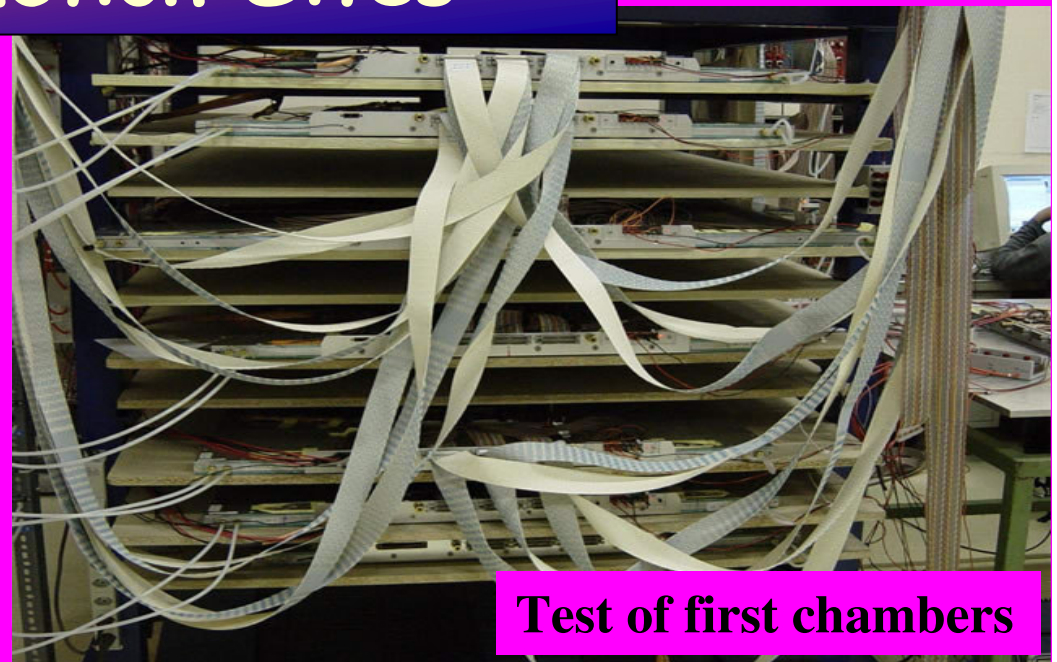
**Pakistan**

**RPC Production Sites**

**ISR Lab**

2004 7 14

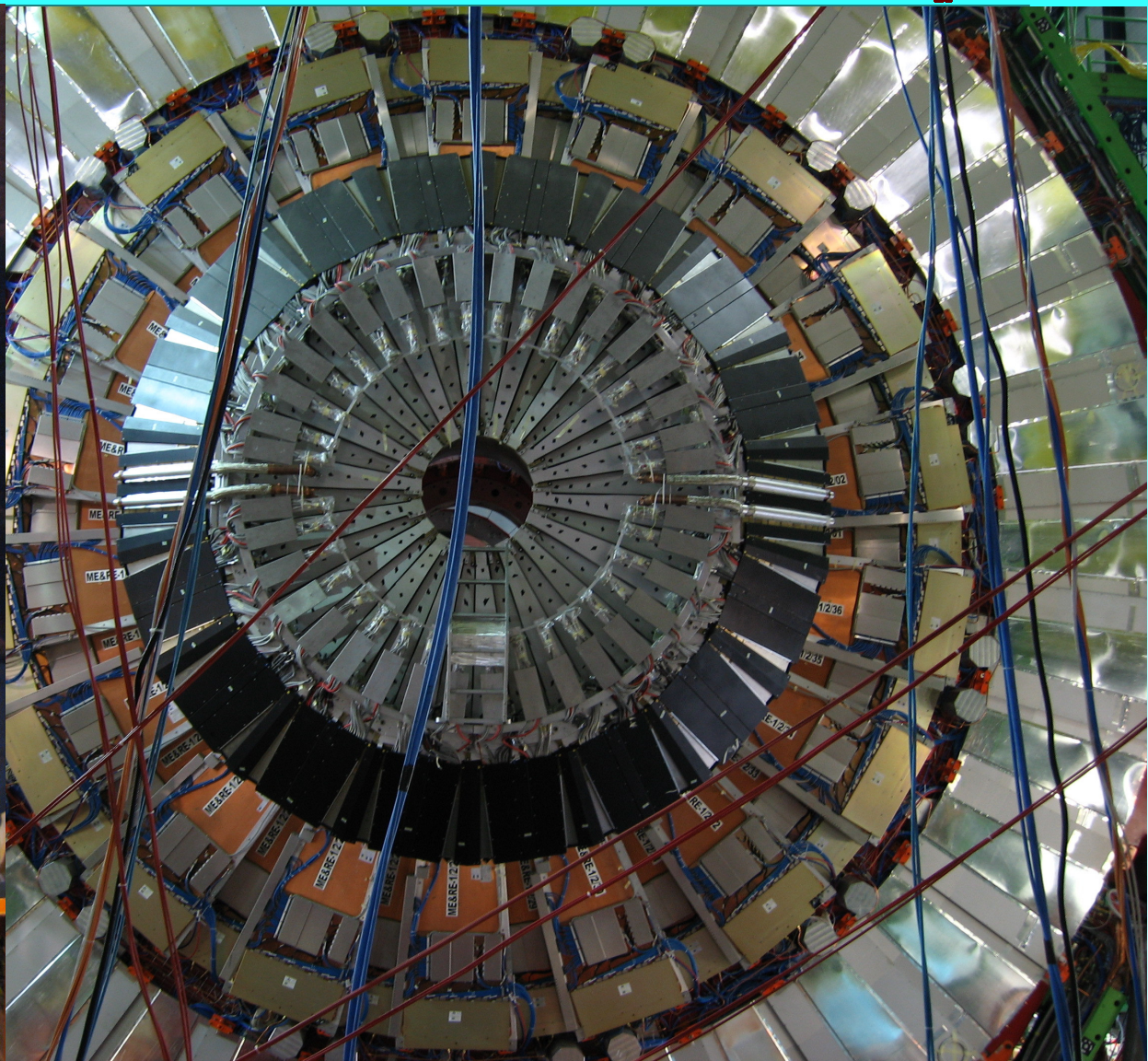
**Test of first chambers**







# RPC station 1



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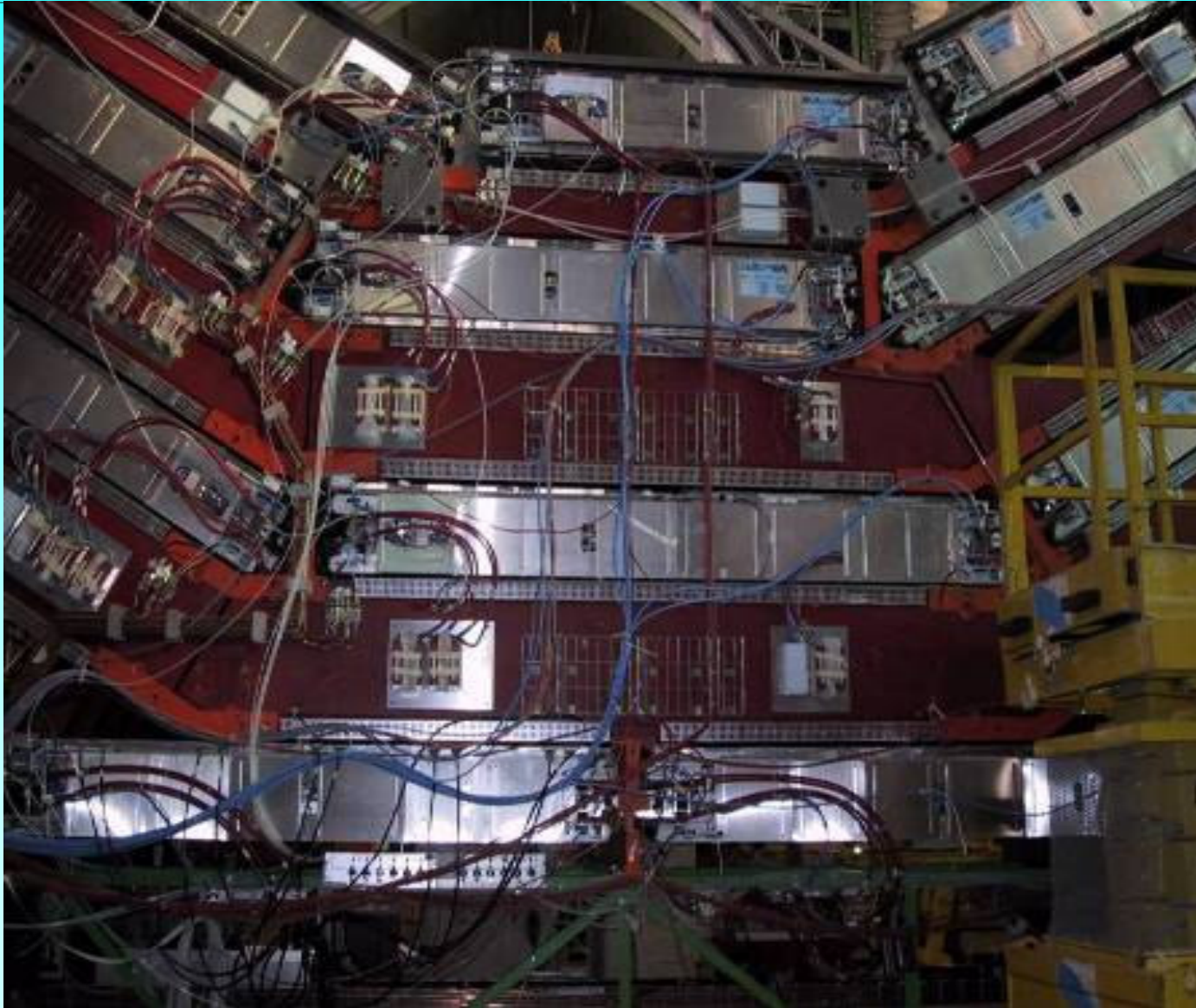
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# Commissioning at SX5



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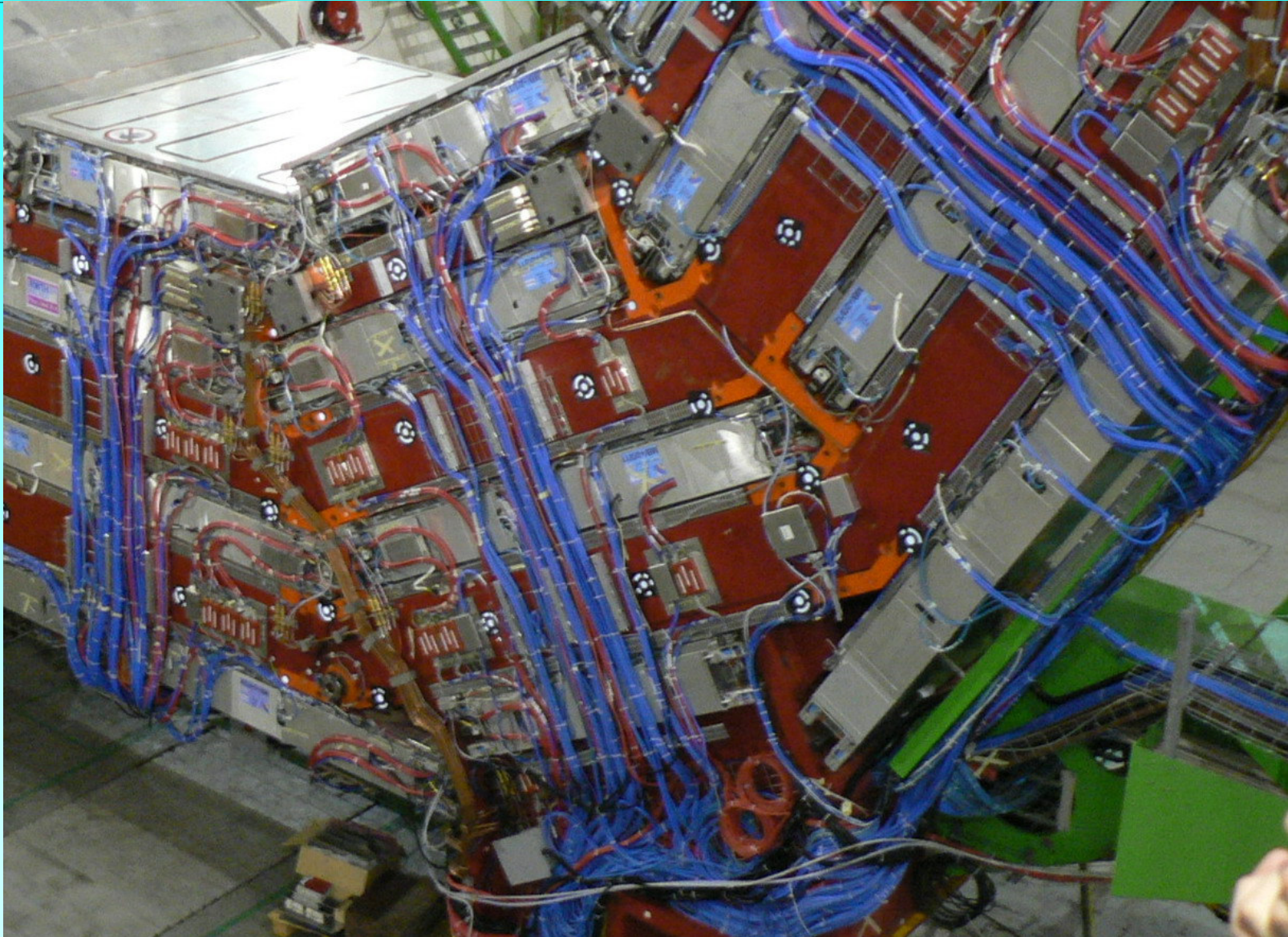
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# Final cabling



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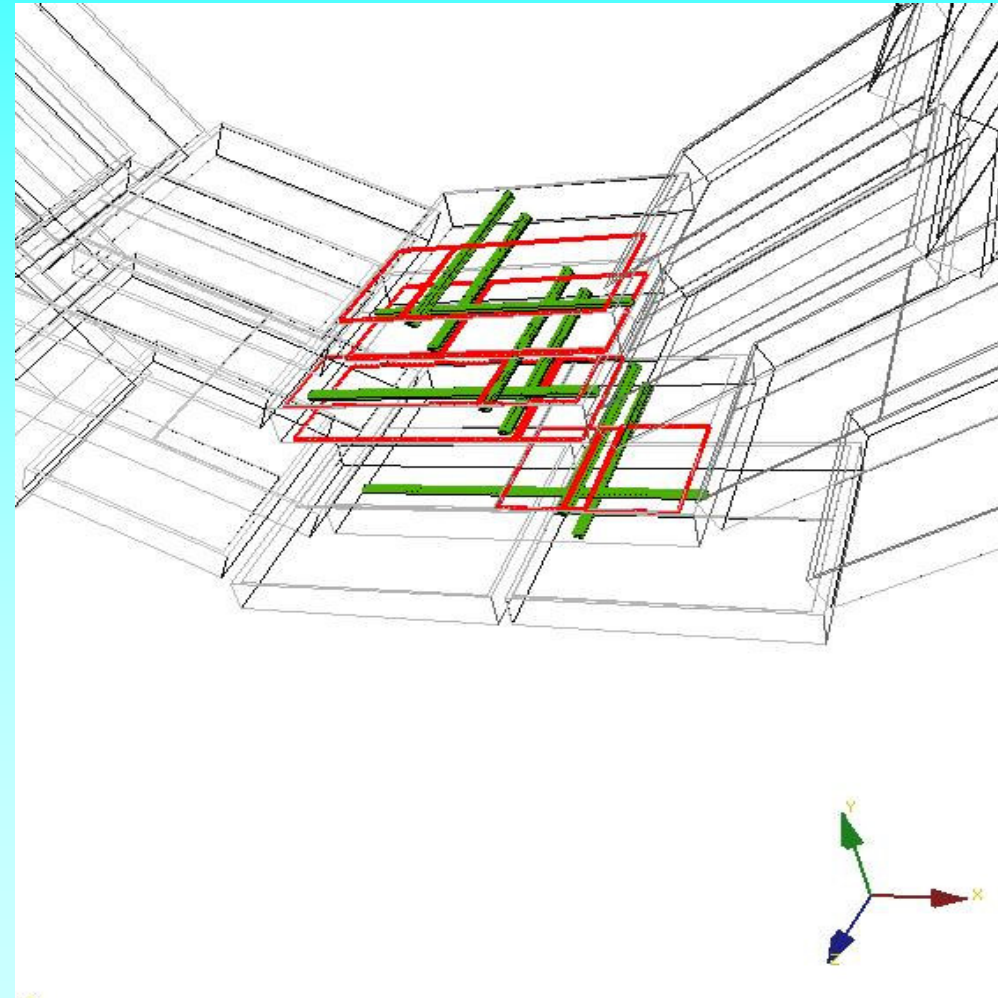
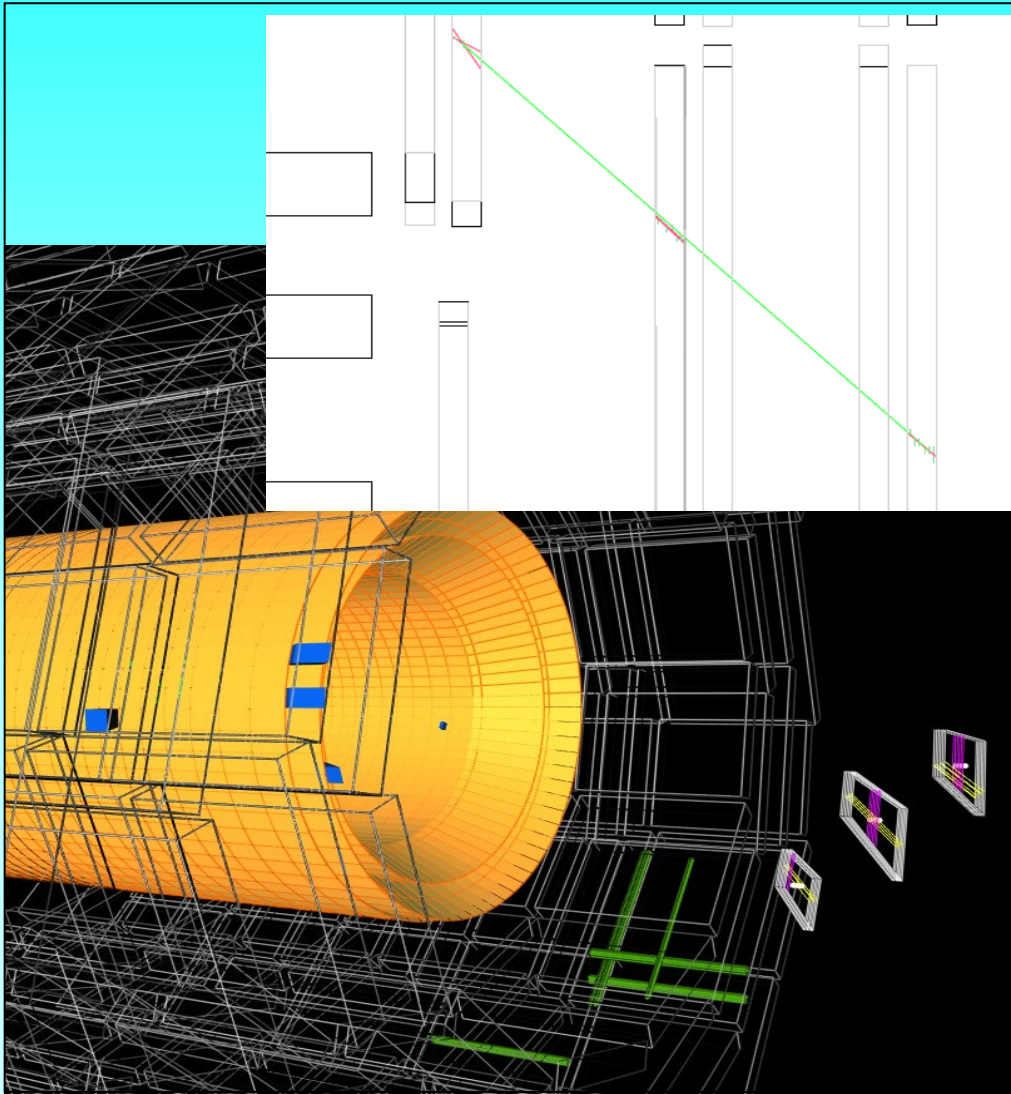
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# MTTC 2006



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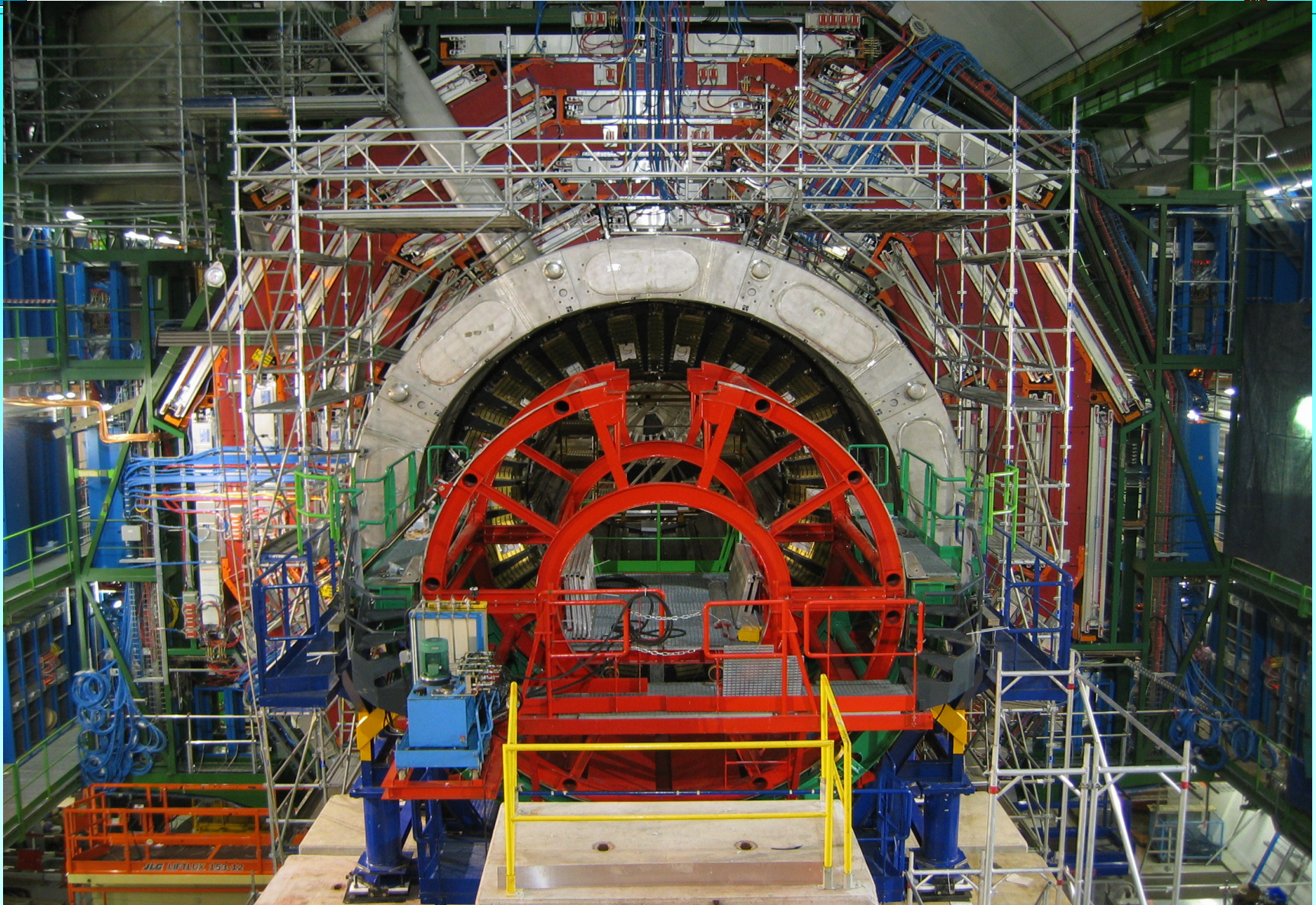
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# Situation in UXC



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## Summary



**CMS Muon System – big international project - 3 Continents**

### **DT Chambers**

DT production ended (266 out of 250)  
Delivered to CERN - 262  
Installed - 242

### **CSC Chambers**

Production finished (496 out of 468 CSCs)  
Delivered to CERN – 495  
Installed - 468

**Final commissioning of the full chain – CH, TRIG, DAQ is going on**

### **RPC Chambers**

460 (out of 480) barrel RPCs assembled.  
RPC production ended (480)  
Delivered to CERN – 480  
Installed - 464  
End-cap RPC – stations 1,2 and 3 installed, station 4 staged