

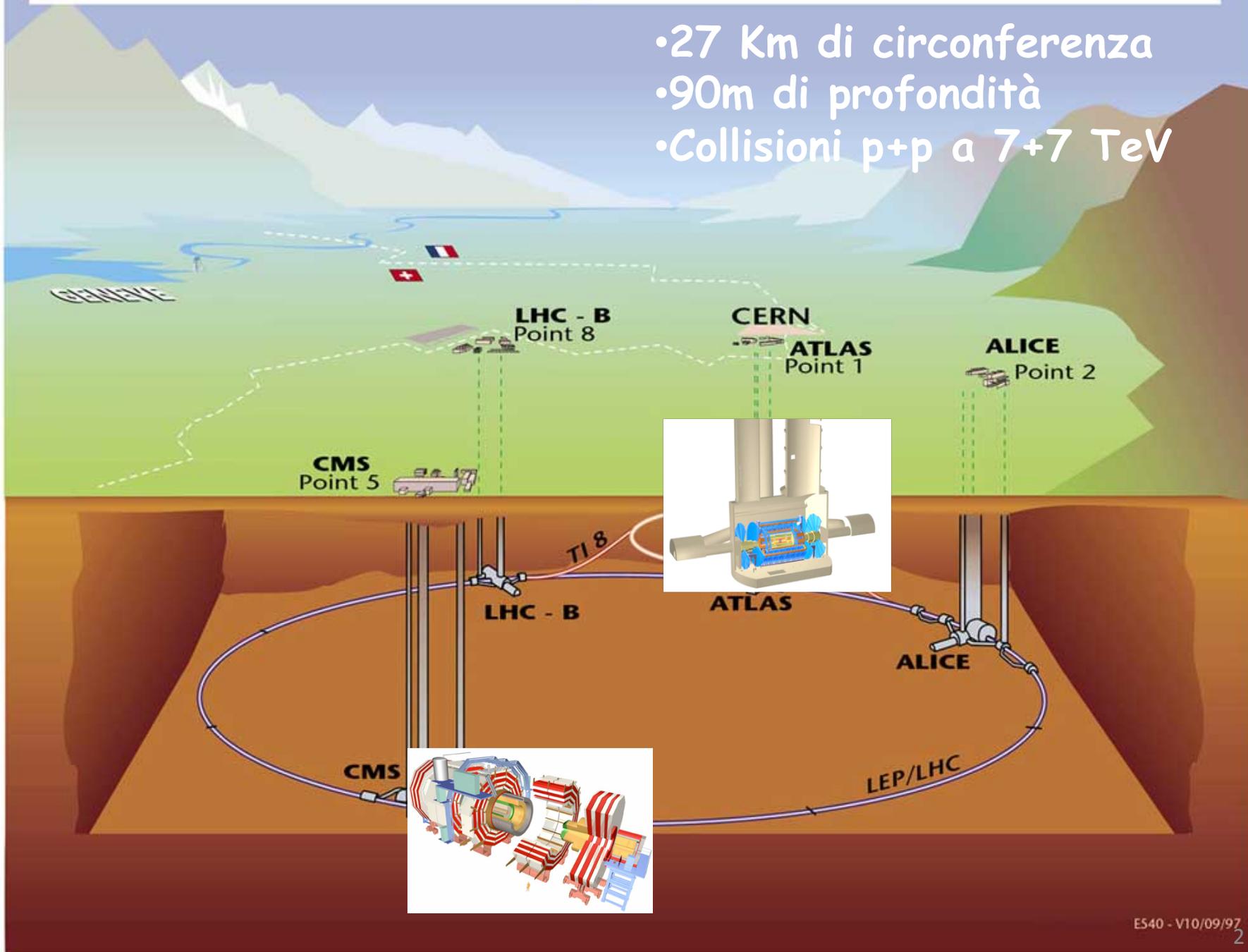
# Gli esperimenti ATLAS e CMS @ LHC

Mariagrazia Alviggi  
Università di Napoli "Federico II" & INFN

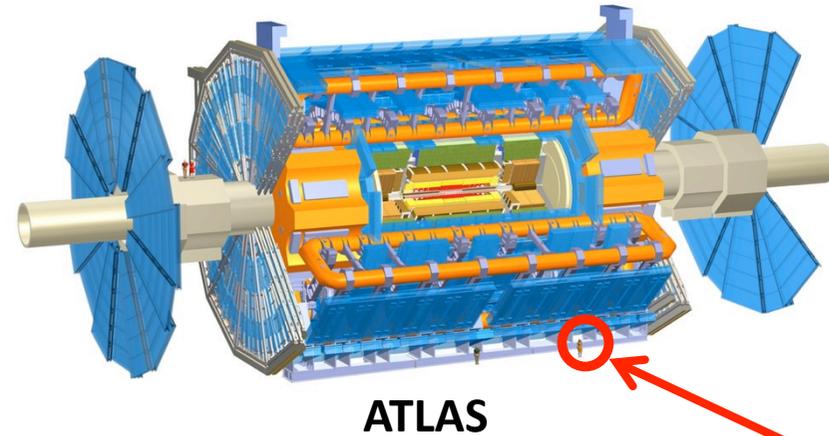
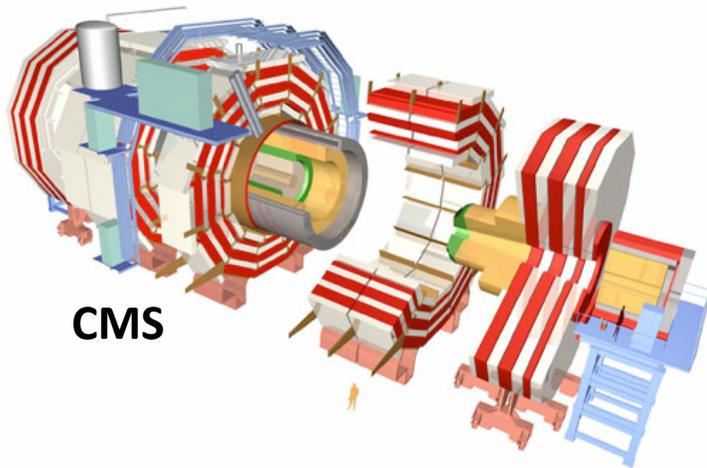


# Overall view of the LHC experiments.

- 27 Km di circonferenza
- 90m di profondità
- Collisioni p+p a 7+7 TeV



# ATLAS e CMS



esperimenti "General Purpose"

- perché due?: conferma indipendente di eventuali nuovi fenomeni tramite due apparati differenti e spesso complementari
- diversi strati di rivelatori per differenti particelle
- urto frontale nel CM  $\rightarrow$  simmetria cilindrica

	<b>ATLAS</b>	<b>CMS</b>
diametro	22 m	15 m
lunghezza	46 m	21 m
massa	7000 tonnellate = 	14000 tonnellate = 2500 x 
canali di lettura	100 milioni	75 milioni

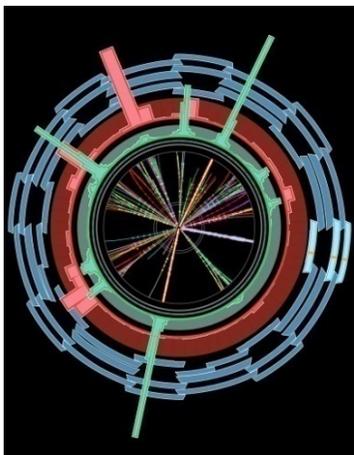
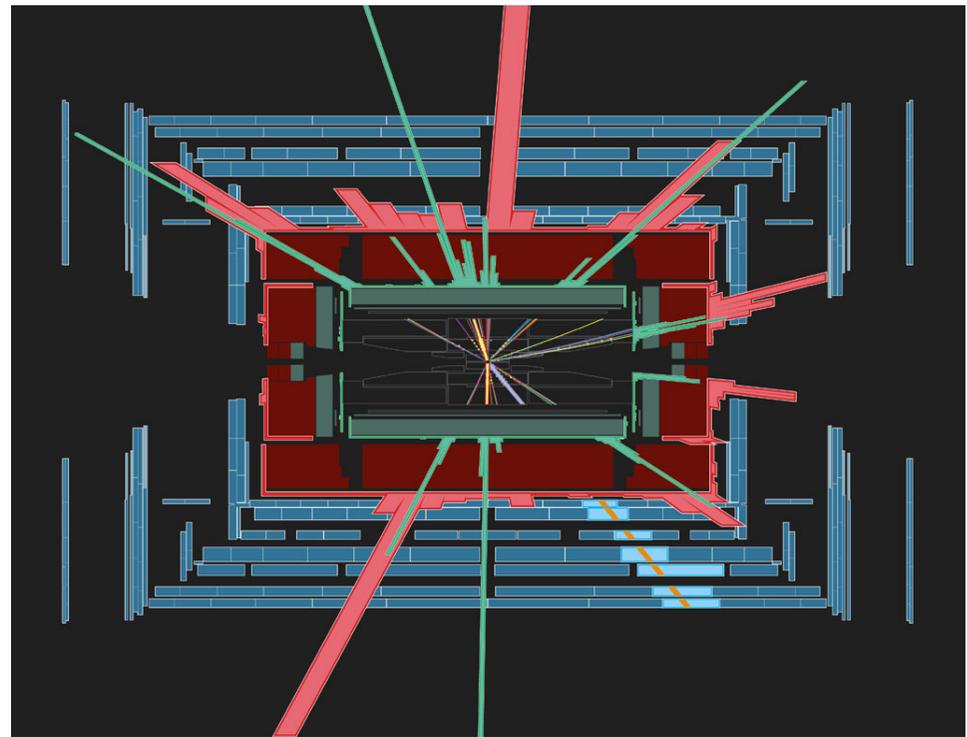


....a cosa serve....

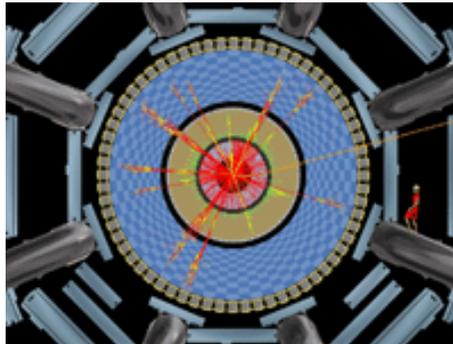
➤ 'vedere' le particelle prodotte dalle interazioni@LHC



3D-100Mpx-  
~100.000 foto/s



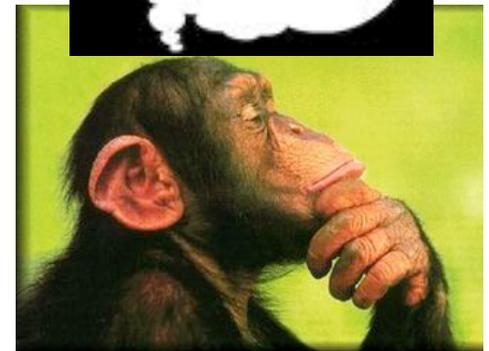
➤ scegliere gli eventi interessanti...



➤ conservarli



per l'analisi fisica successiva

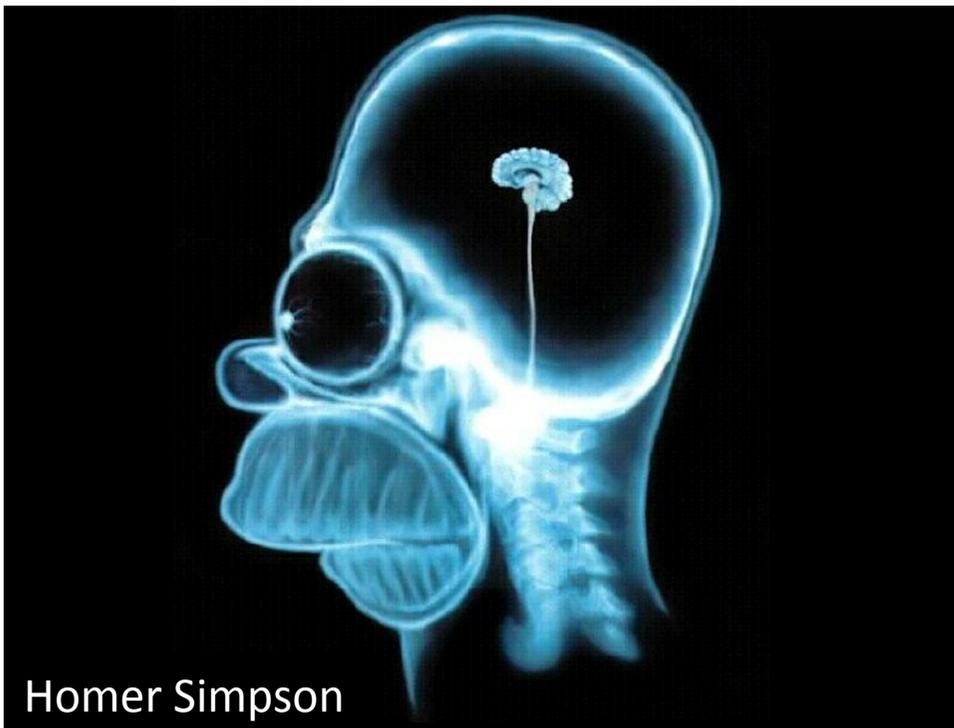


## come si rivelano le particelle?

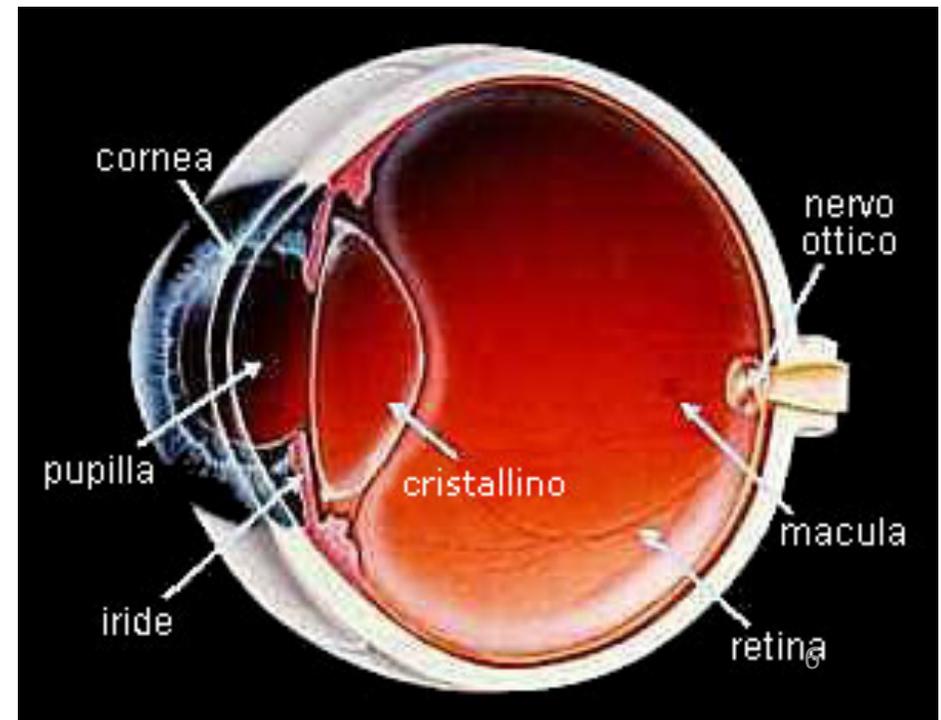
- tramite la loro interazione con la materia che attraversano

...esempi nella vita quotidiana...

Lastre fotografiche.....



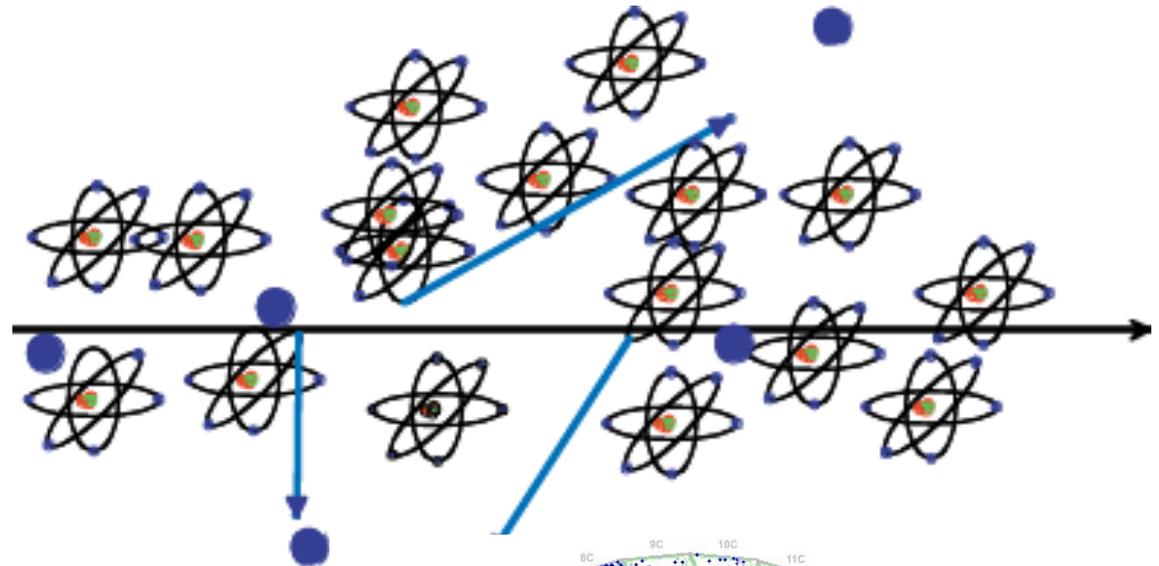
Occhio umano.....



## ...esempi alle energie di LHC...

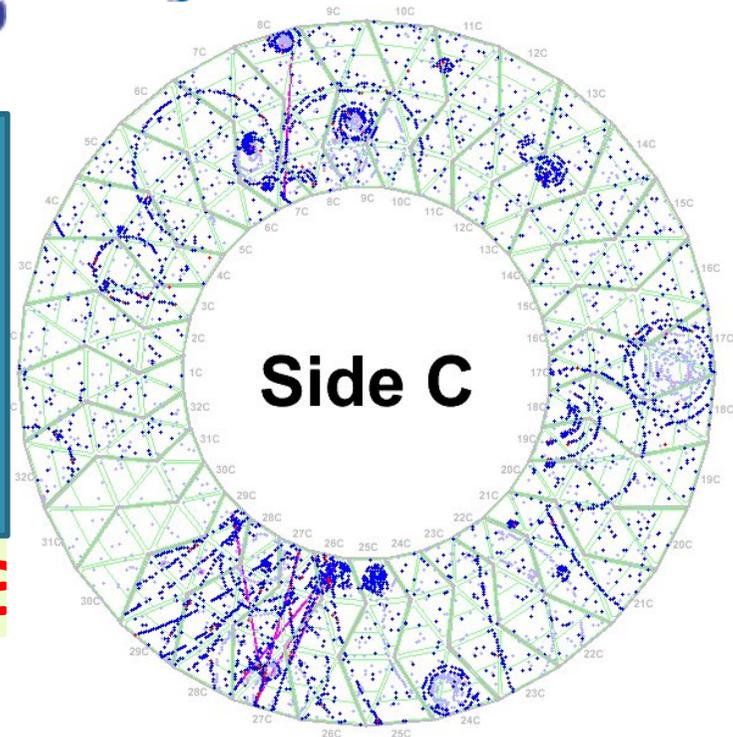
**Particelle cariche**  
interagiscono in genere  
em con gli elettroni  
atomici producendo

**IONIZZAZIONI e/o  
ECCITAZIONI**



...esempio di tracce nel rivelatore  
a radiazione di transizione +  
ionizzazione (TRT) di Atlas

**RADIAZIONE di TRANSIZIONE**



## ...esempi alle energie di LHC...

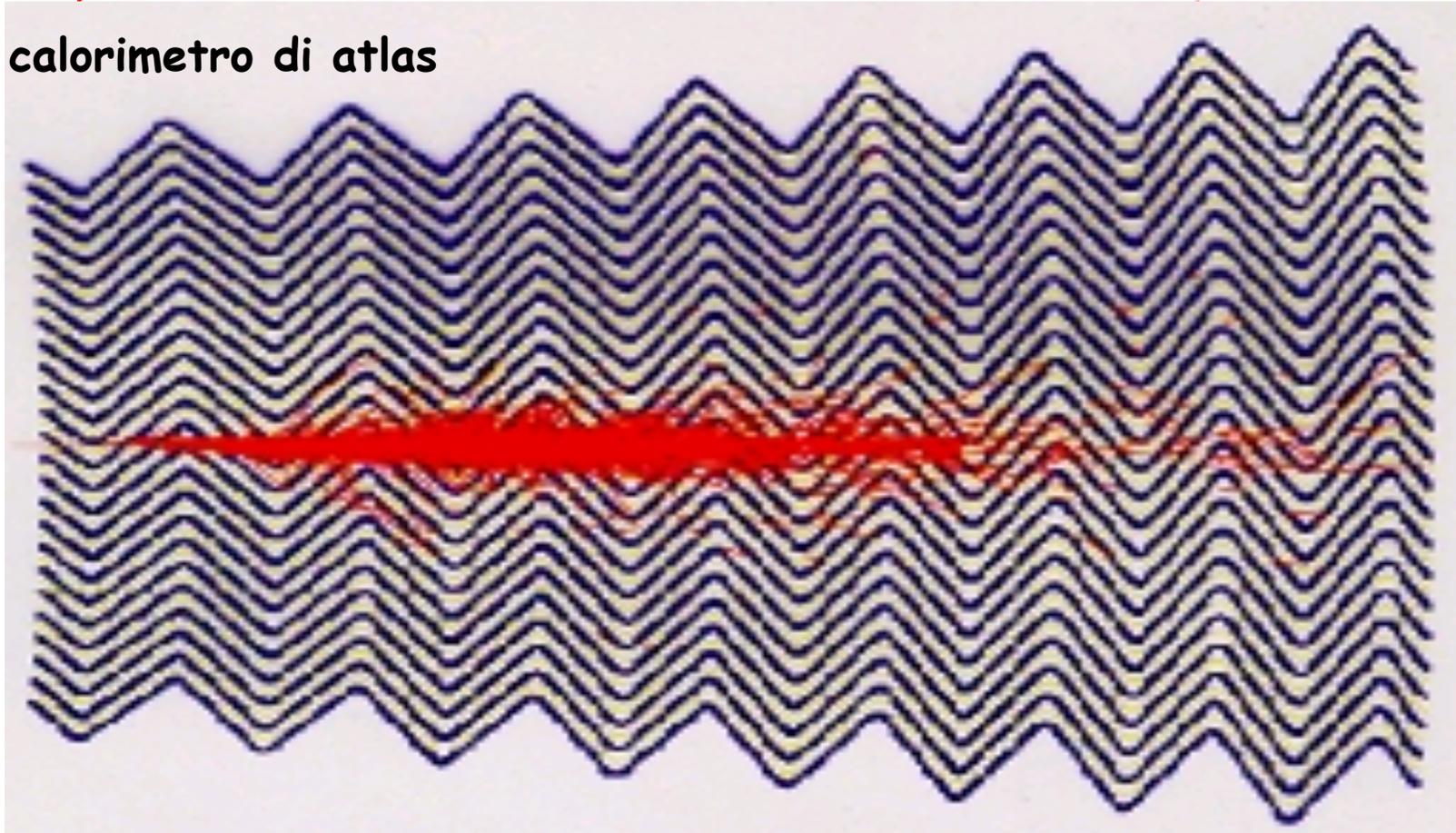
### -Elettroni e fotoni di alta energia:

-elettroni frenati dalla materia irradiano fotoni i quali 'convertono' in coppie elettrone-positrone



### **SCIAME ELETTROMAGNETICO**

calorimetro di atlas



## ...esempi alle energie di LHC...

- **Adroni** interagiscono 'forte' producendo 'getti' di particelle simili agli sciami em (oltre che ionizzare se carichi...)
- **Muoni** ionizzano ma poco....
- **Neutrini** interagiscono debolmente ...possono attraversare la Terra senza interagire.....

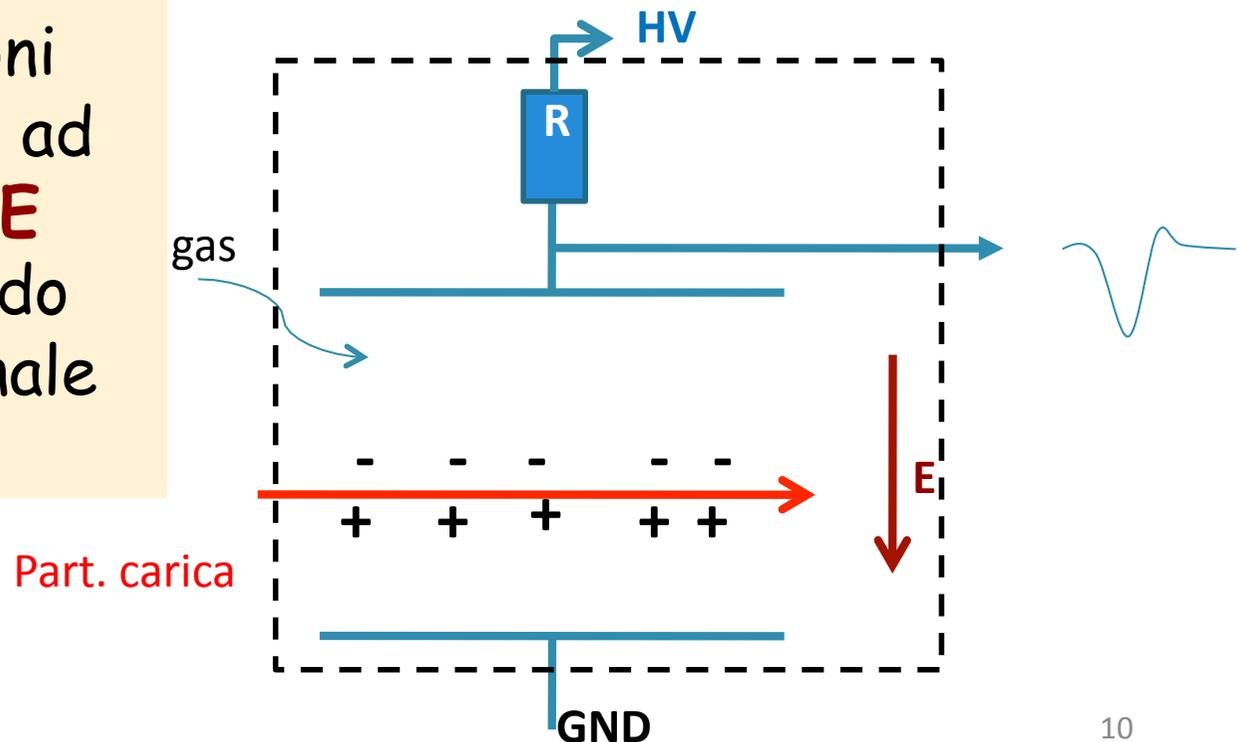


# I rivelatori

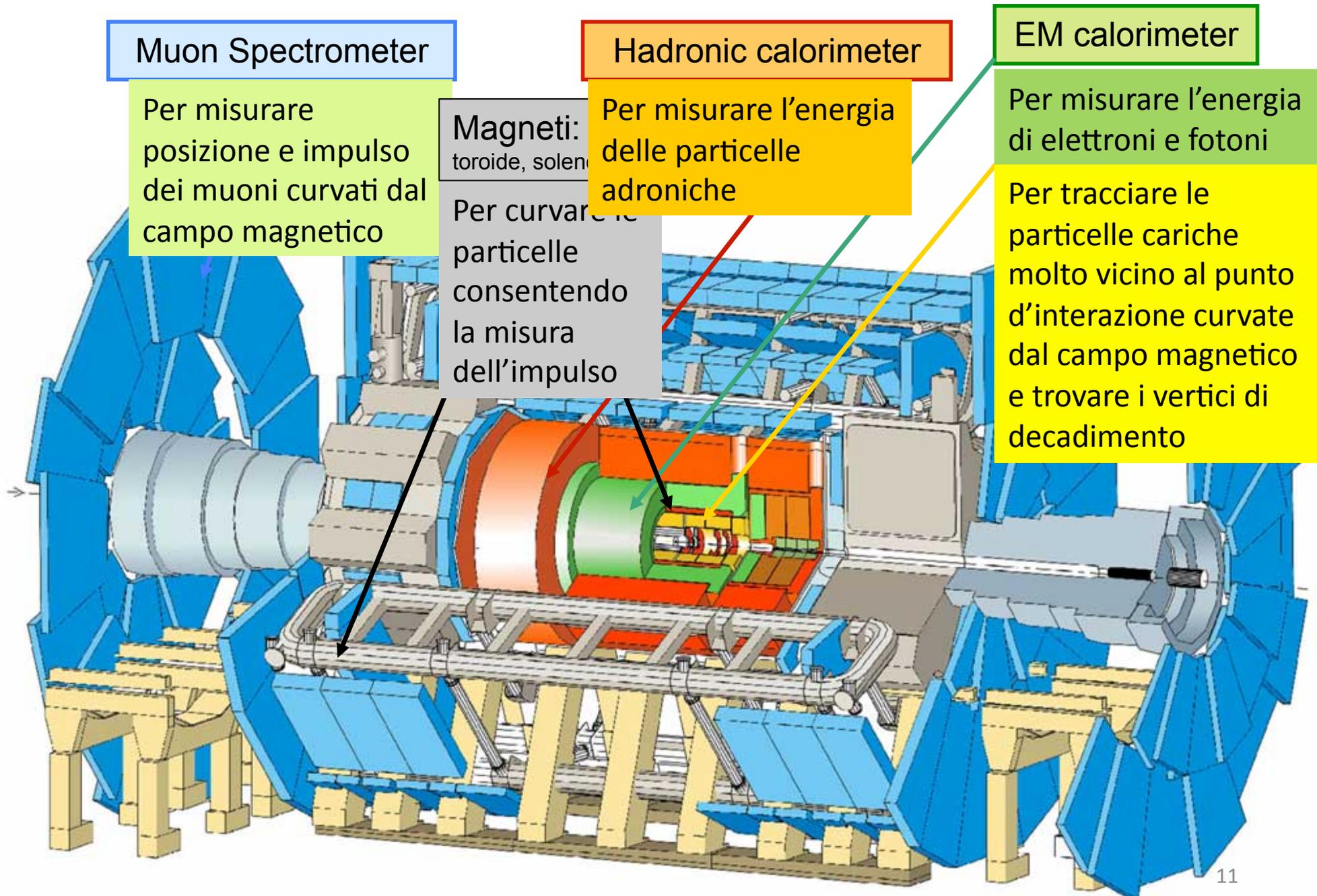
- Sfruttano i diversi tipi di interazione per produrre un segnale visibile, in genere elettrico, dal quale risalire al punto/istante di passaggio delle particelle, tracciarle e ricostruire gli eventi

Es. di rivelatore che sfrutta la ionizzazione nel gas:

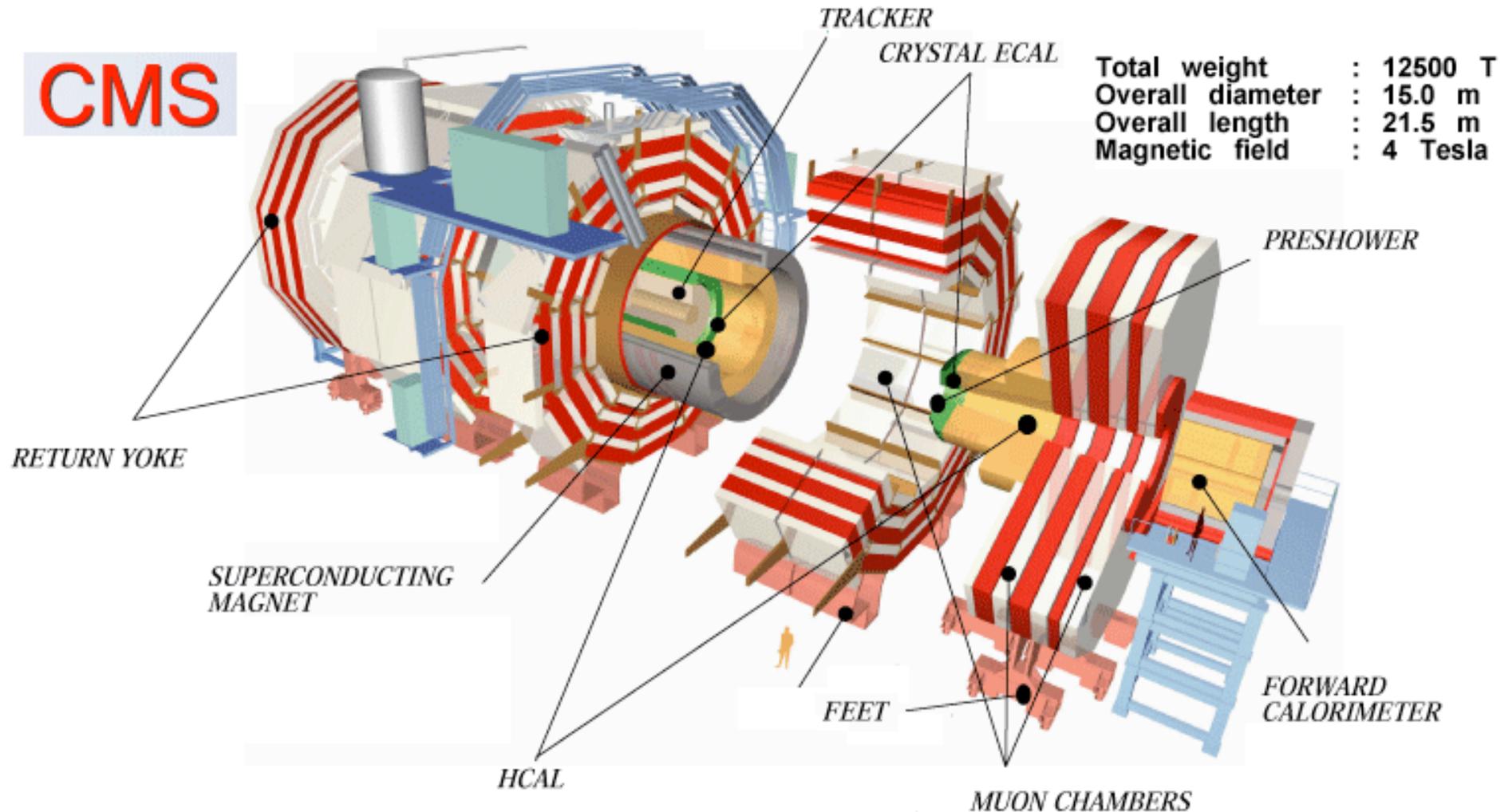
- Gli elettroni e gli ioni prodotti sottoposti ad un campo elettrico  $E$  migrano verso l'anodo producendo un segnale elettrico



## Rivediamo adesso la struttura di ATLAS....



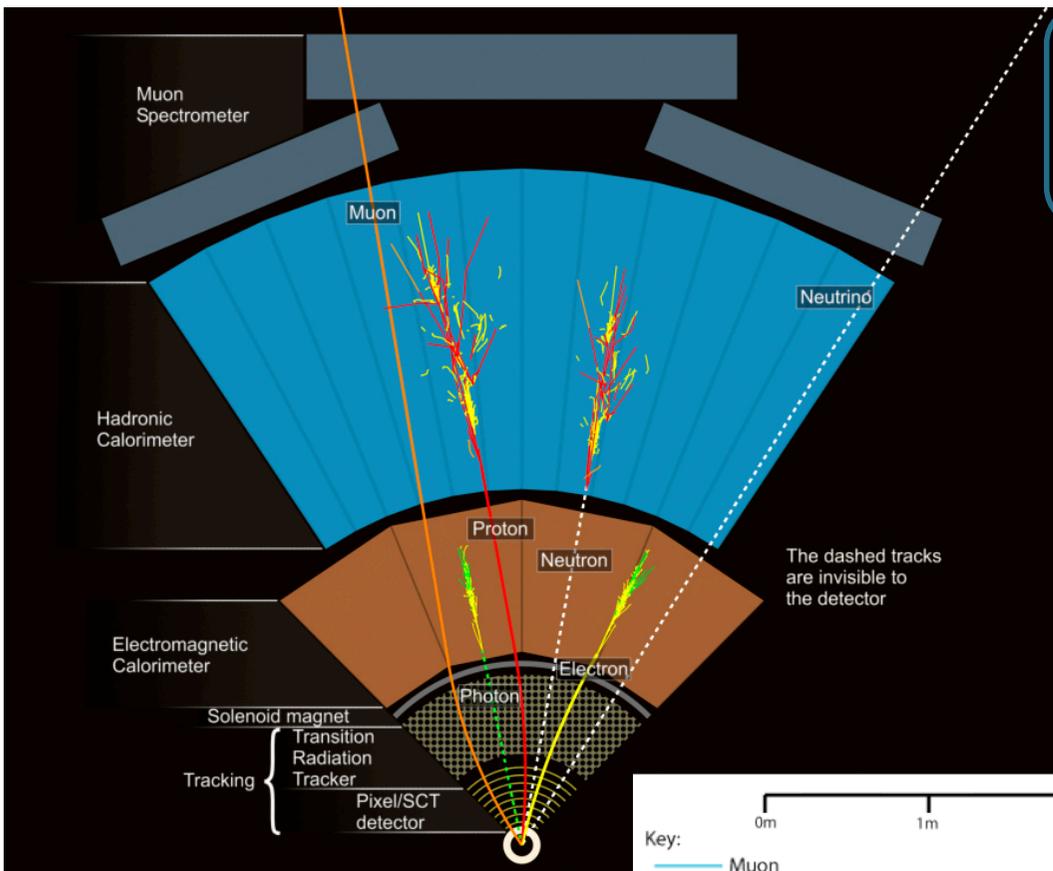
## ....e di CMS



**Differenze:** Magnete, Calorimetri

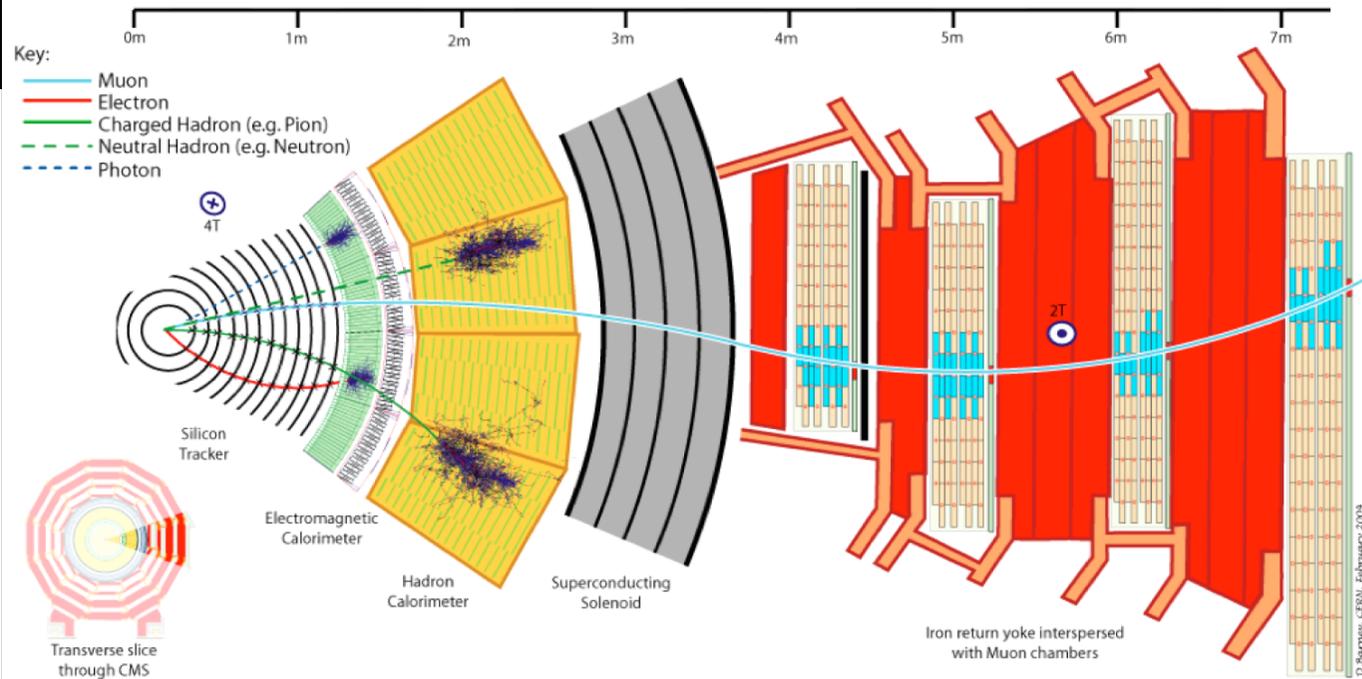
**Similitudini:** Tracciatore, Rivelatori di muoni

← slice di  
ATLAS

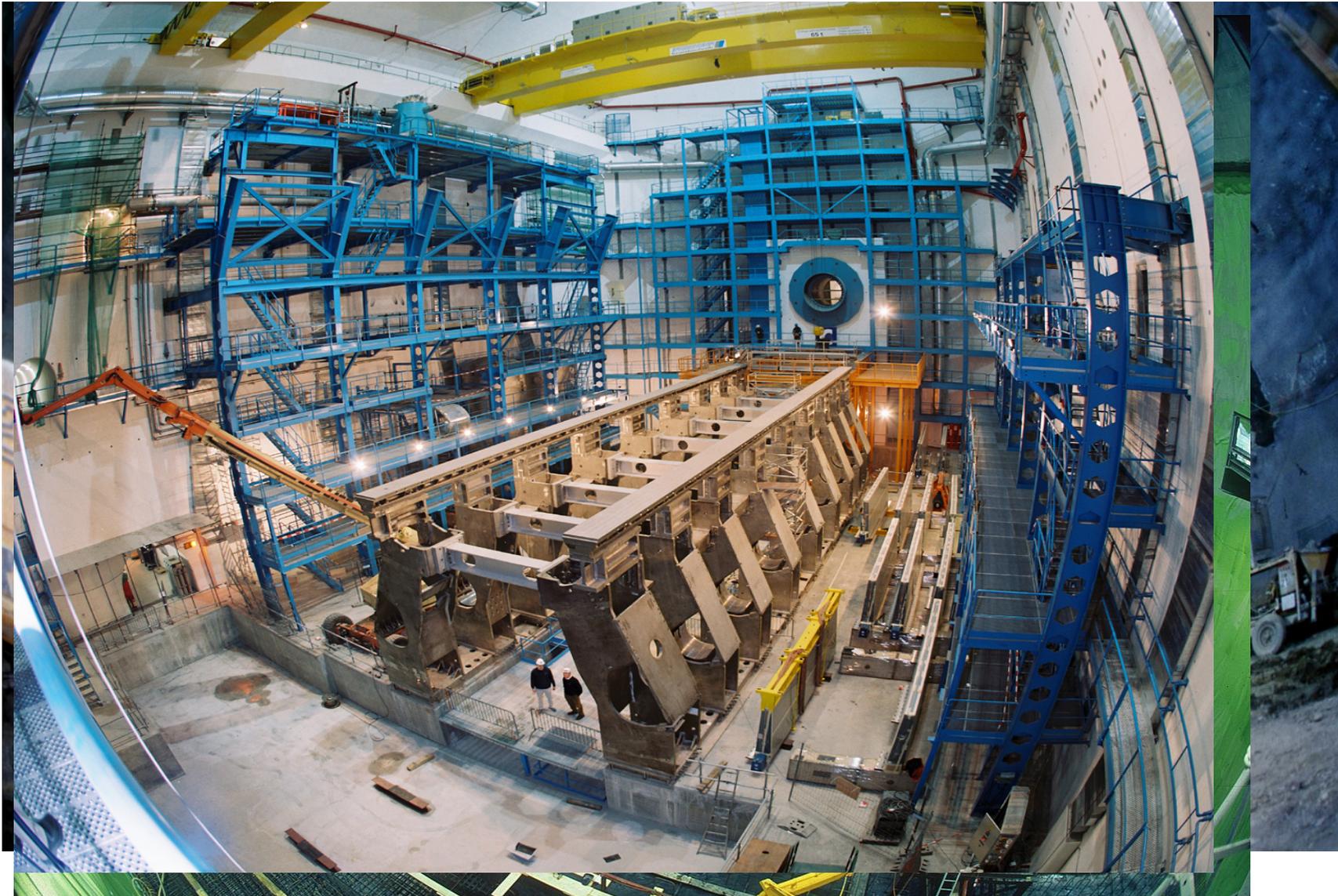


Deflection  $\sim BL^2/p \rightarrow$   
need high B and large magnets;  
need high resolution position  
measurements (10 -100 $\mu$ )  
at large p; also energy and  
position measurement through  
total absorption (photon,  
electron, hadron)

slice di  
CMS  $\rightarrow$



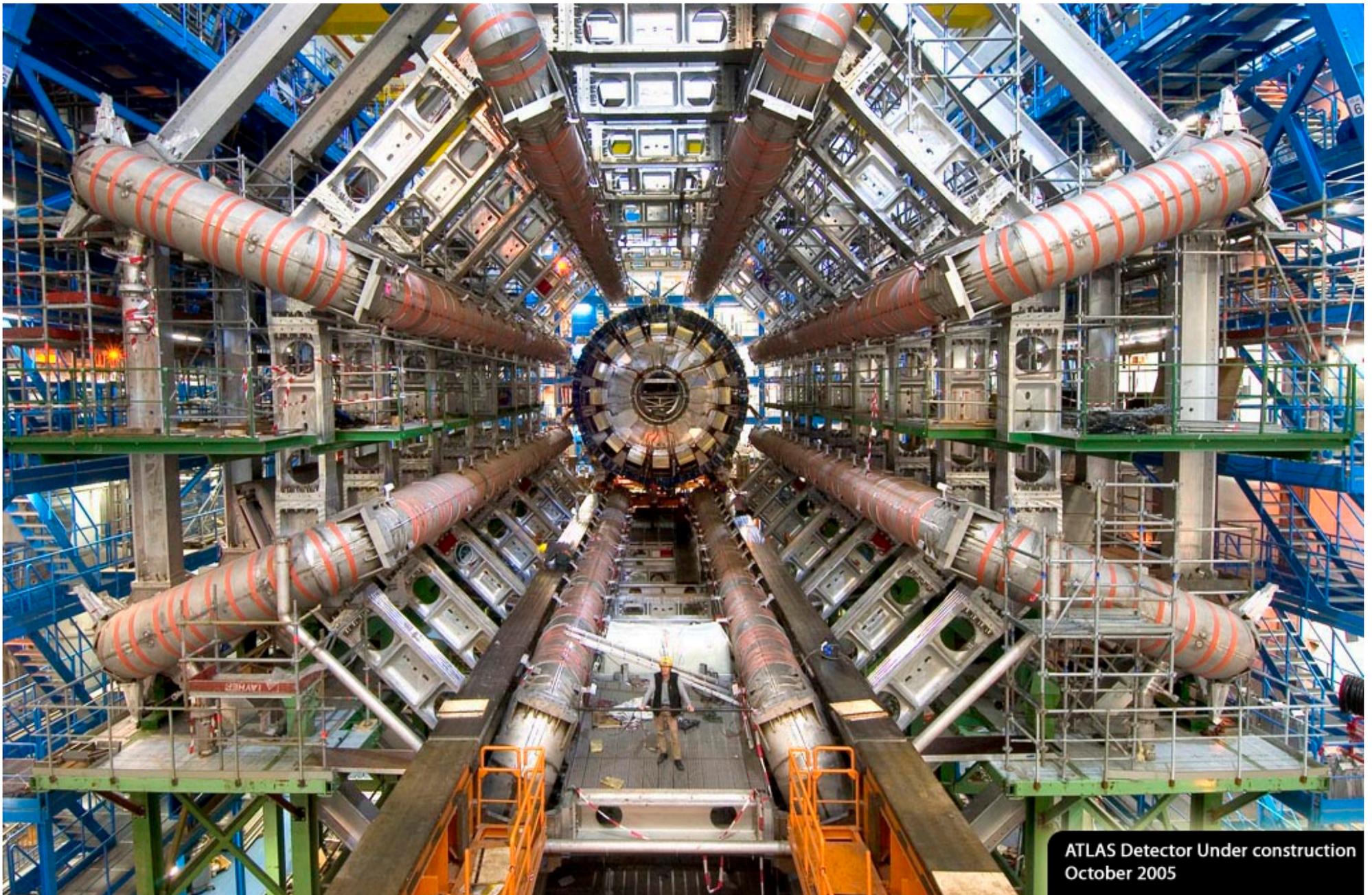
Atlas non è 'fotogenico' perché occupa praticamente tutta la caverna.....



2000

2002

2004

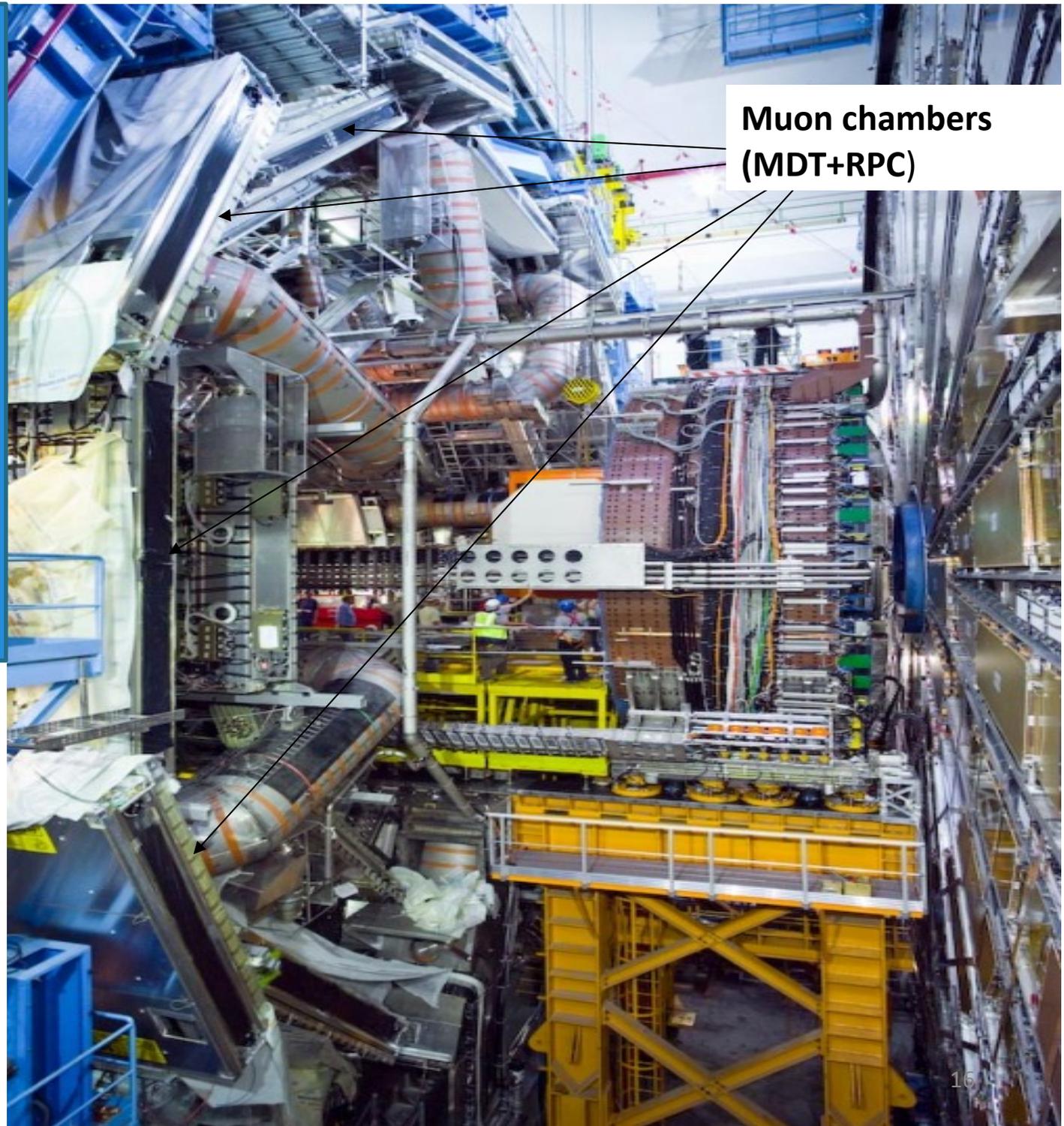
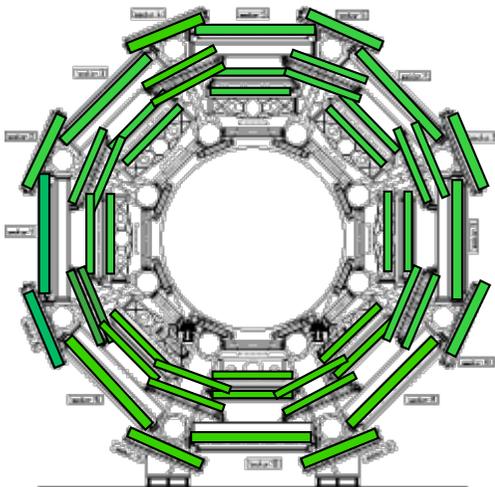


ATLAS Detector Under construction  
October 2005

# Lo Spettrometro di Muoni

di Atlas è una variante più complessa del semplice rivelatore a ionizzazione di cui abbiamo parlato

Napoli si è occupata degli RPC insieme a Bologna, Lecce e Roma

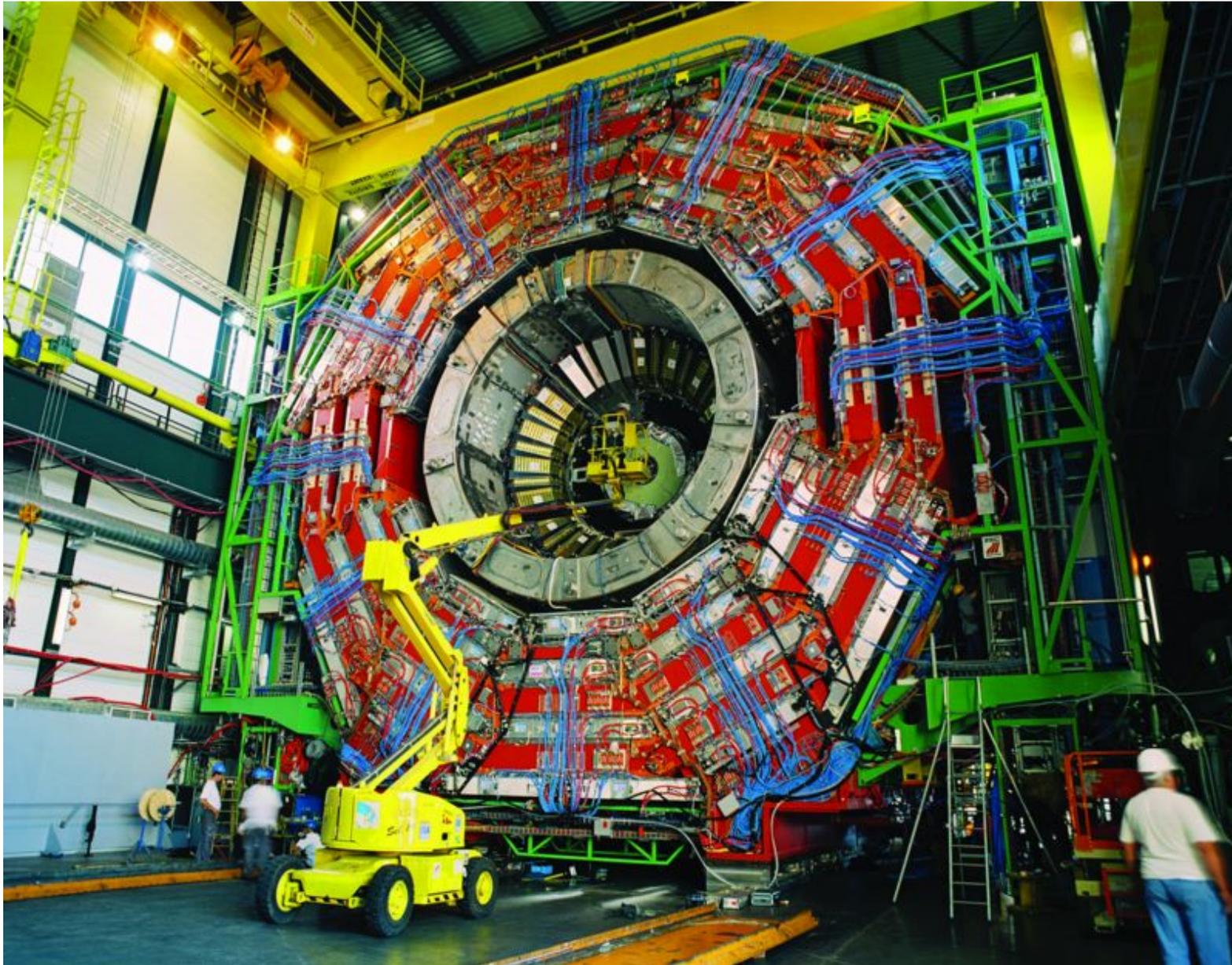


Muon chambers  
(MDT+RPC)

# Installazione dell' ultimo elemento di ATLAS



**CMS** invece è stato montato in superficie....



**... e poi calato 100m sottoterra!**

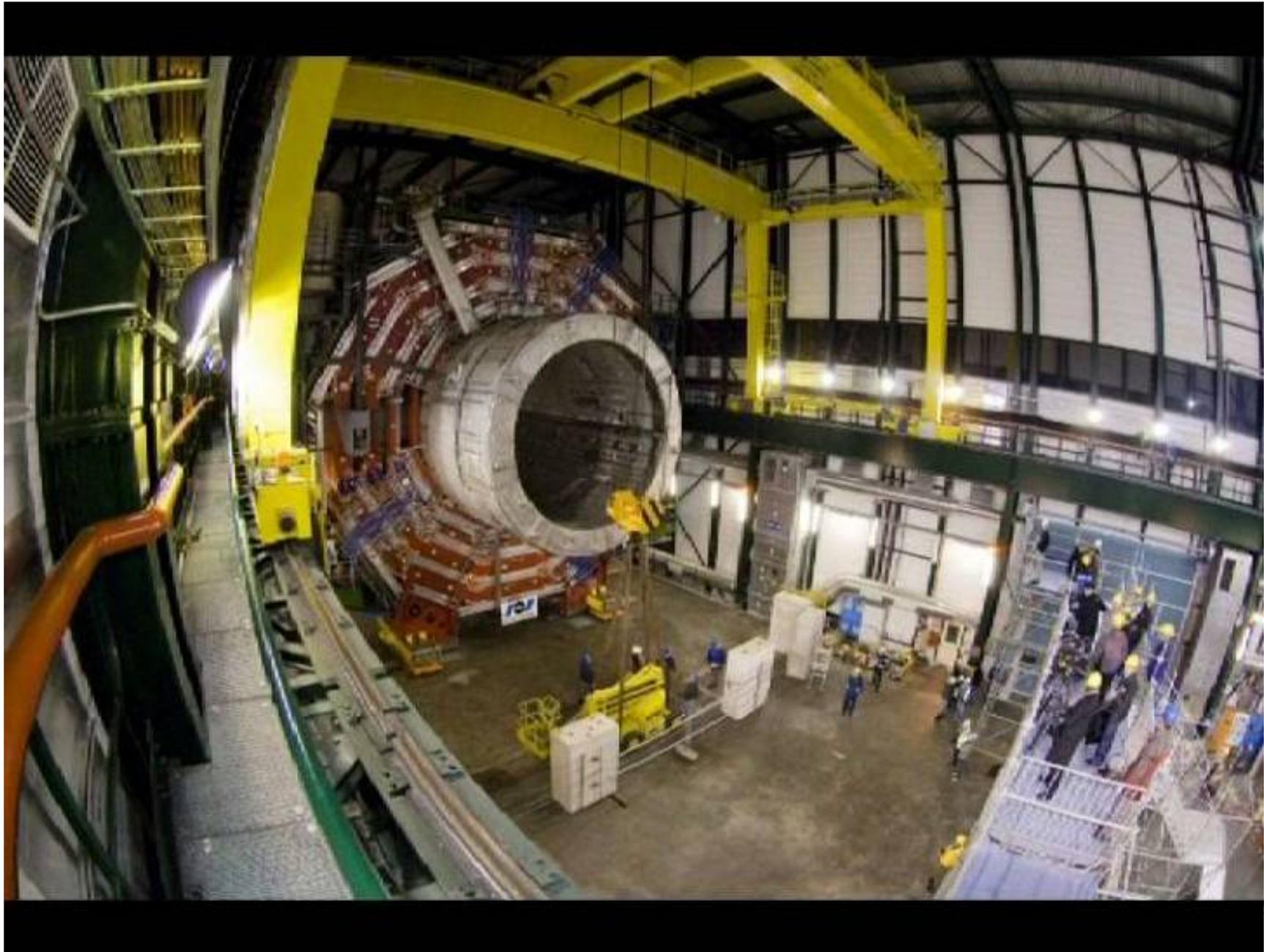
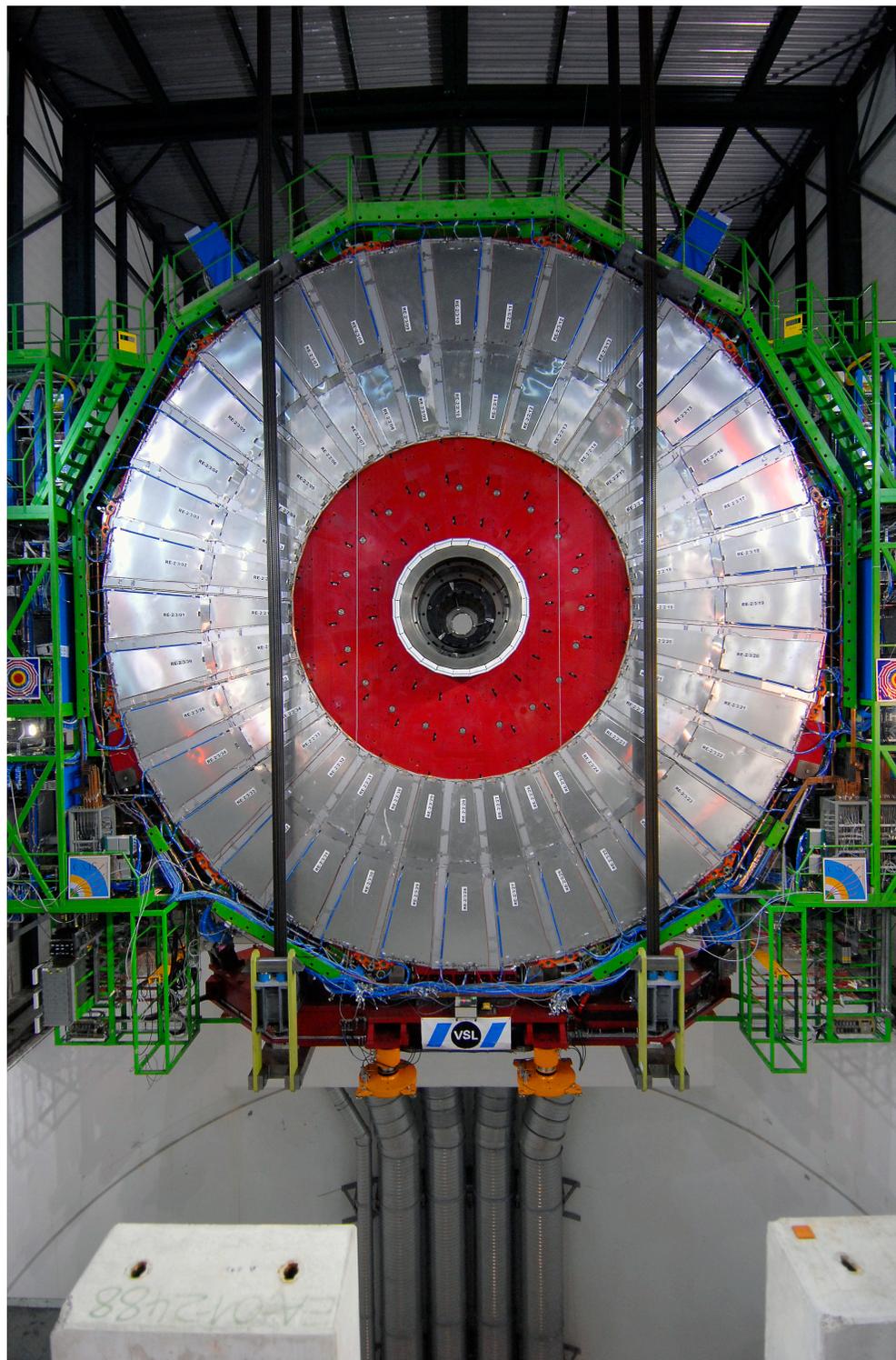
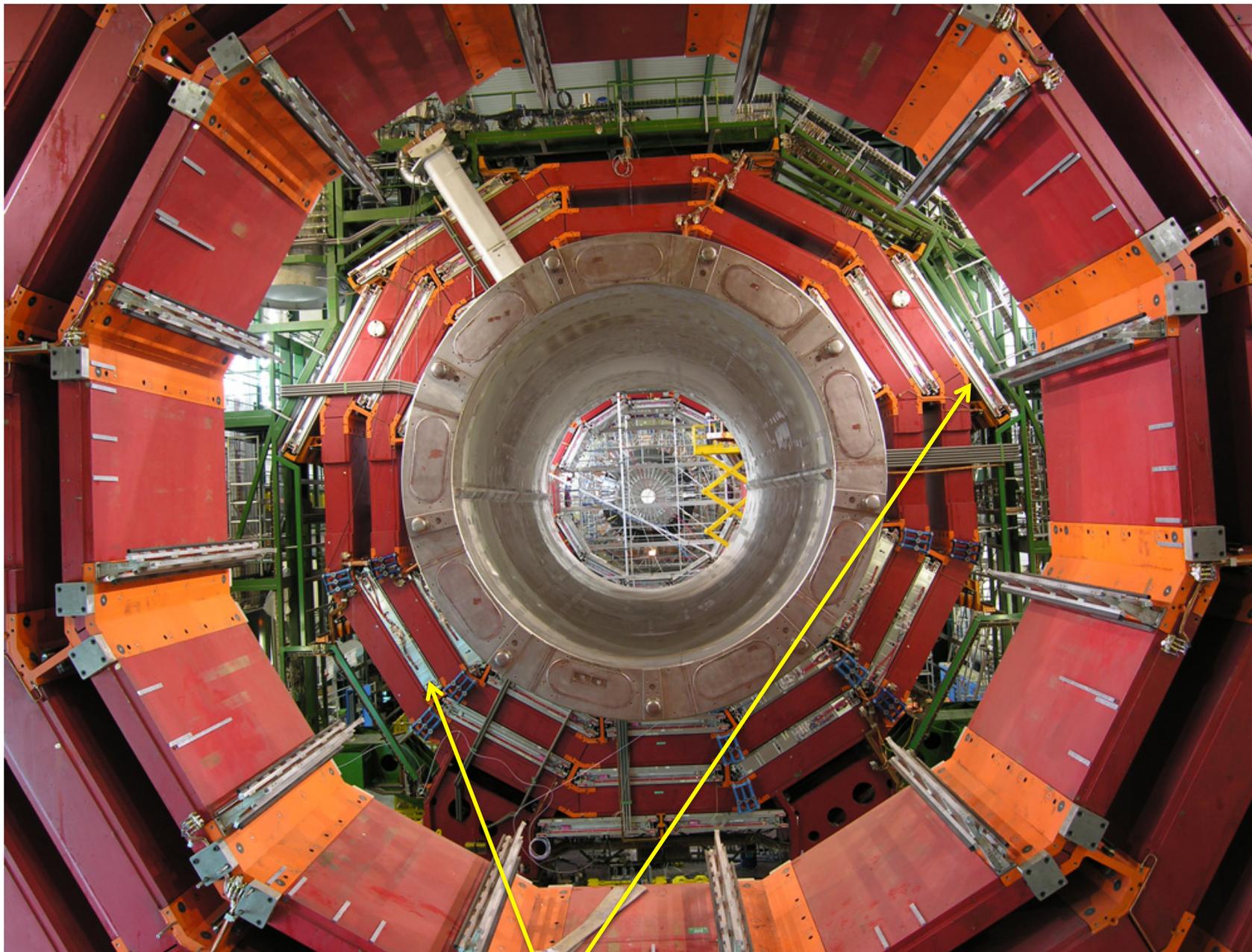
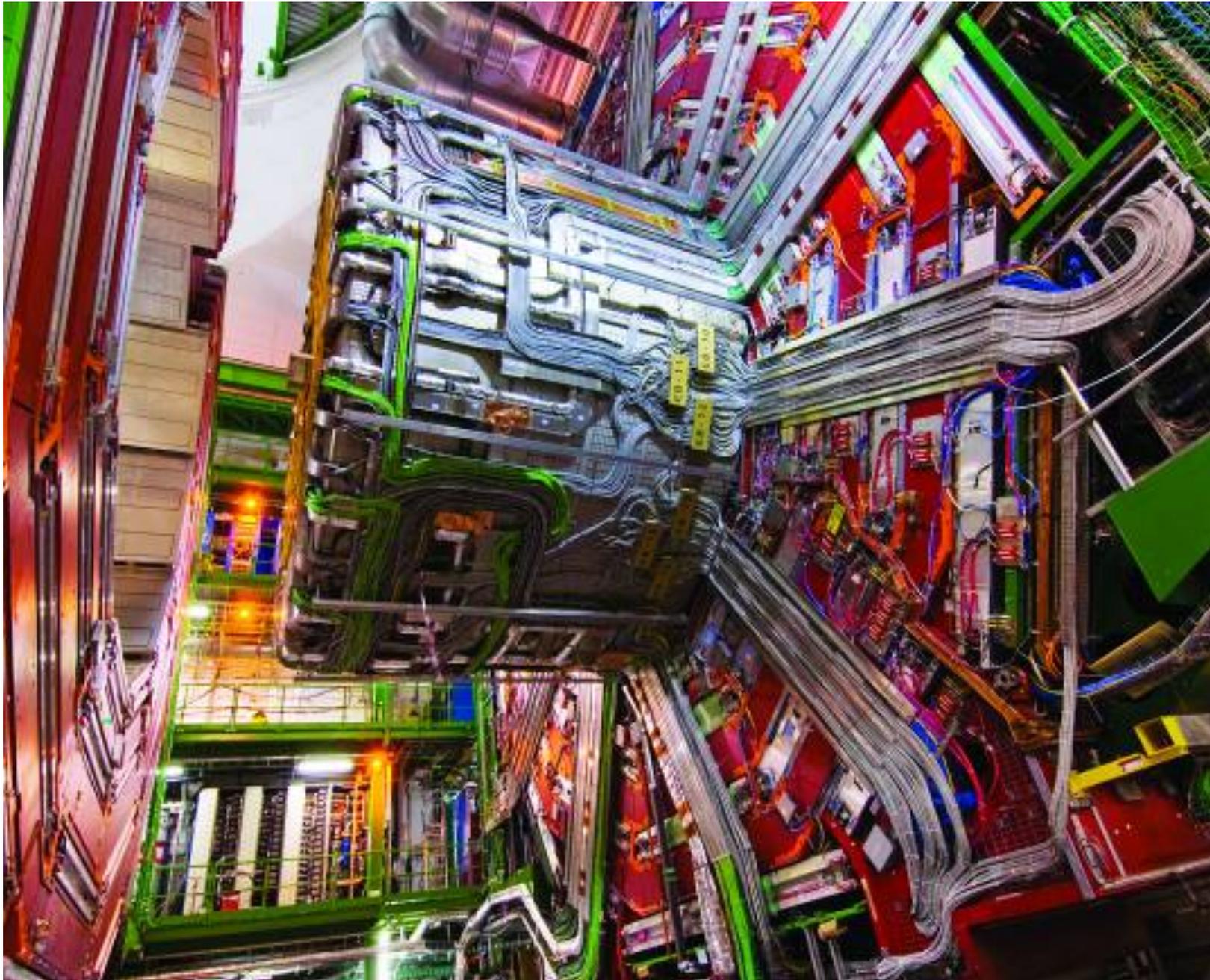


Foto della discesa  
di uno dei dischi nel  
pit



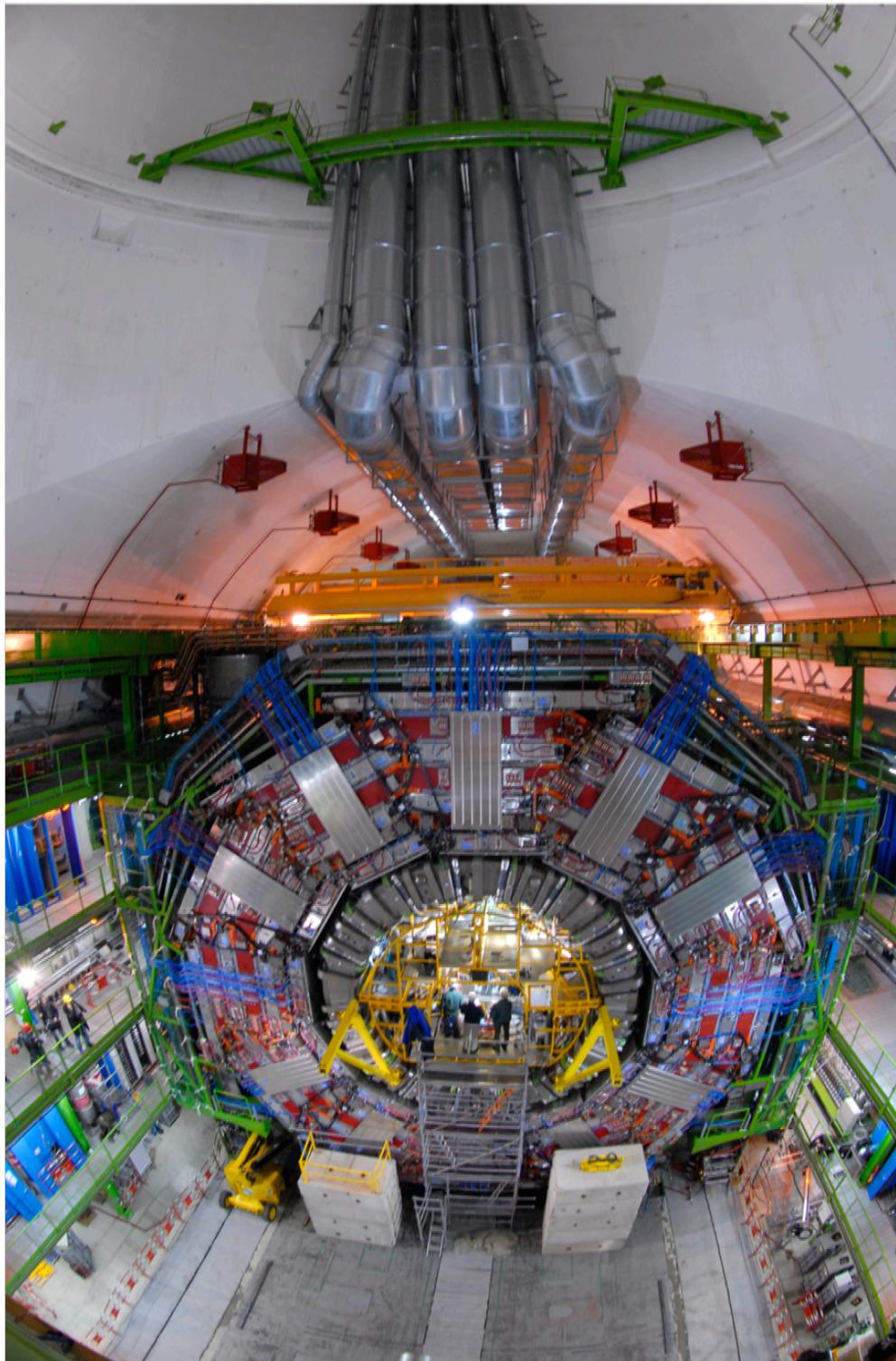


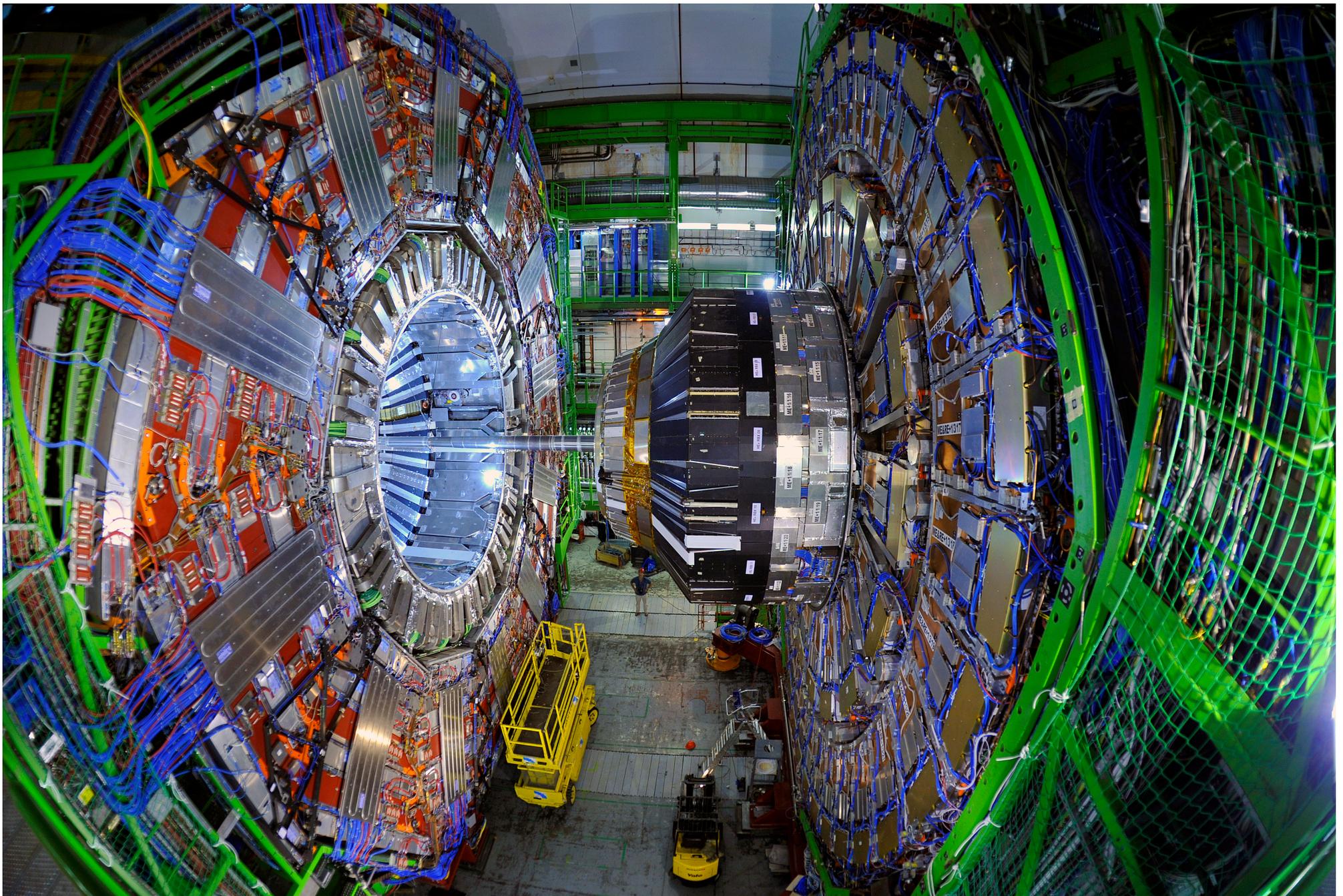
Napoli ha contribuito al sistema di camere per la rivelazione dei muoni (RPC)



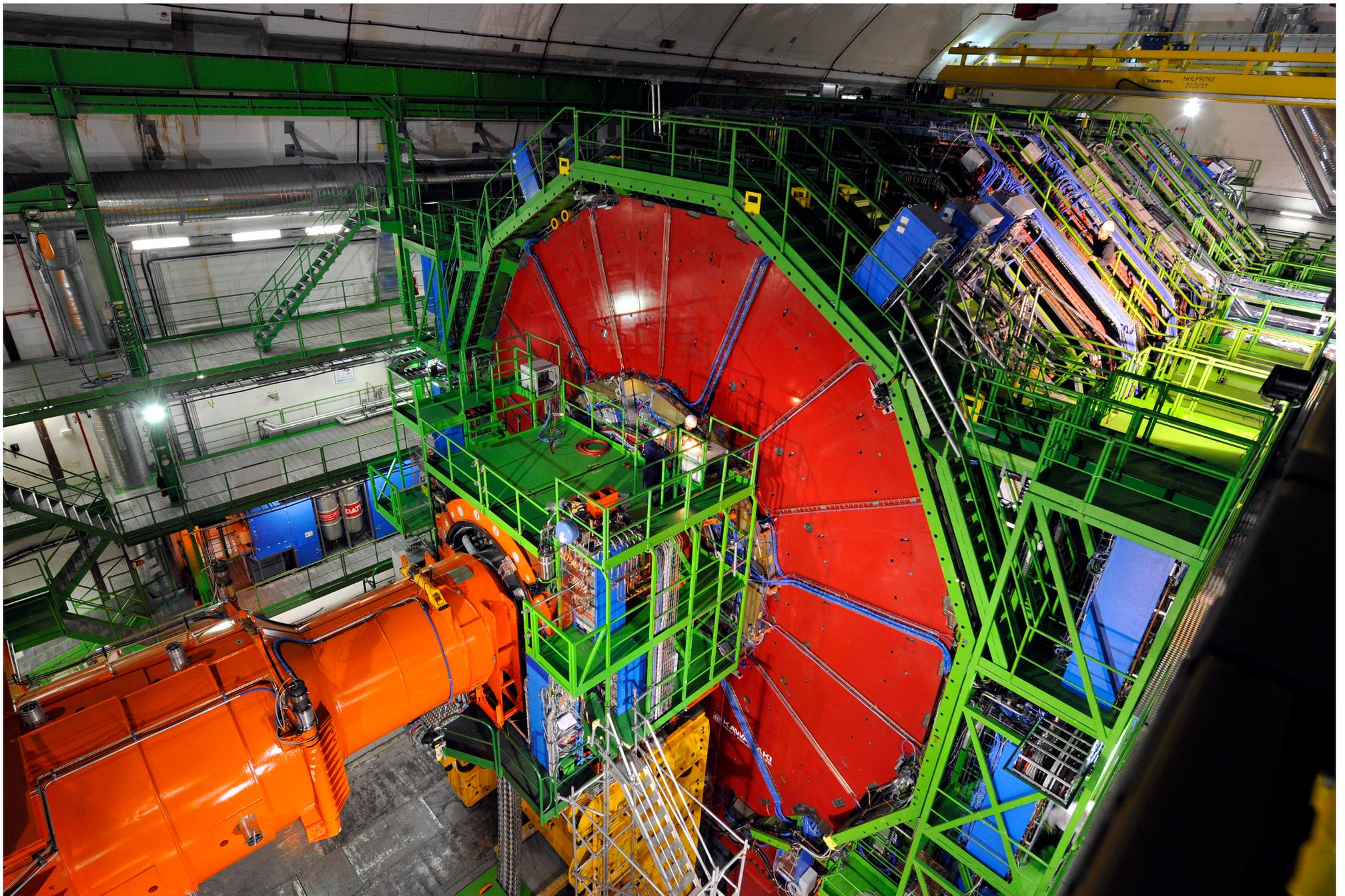
Particolare di CMS che mostra la complessità del cablaggio<sup>22</sup>

Vista frontale di  
CMS nel pit  
durante la  
costruzione



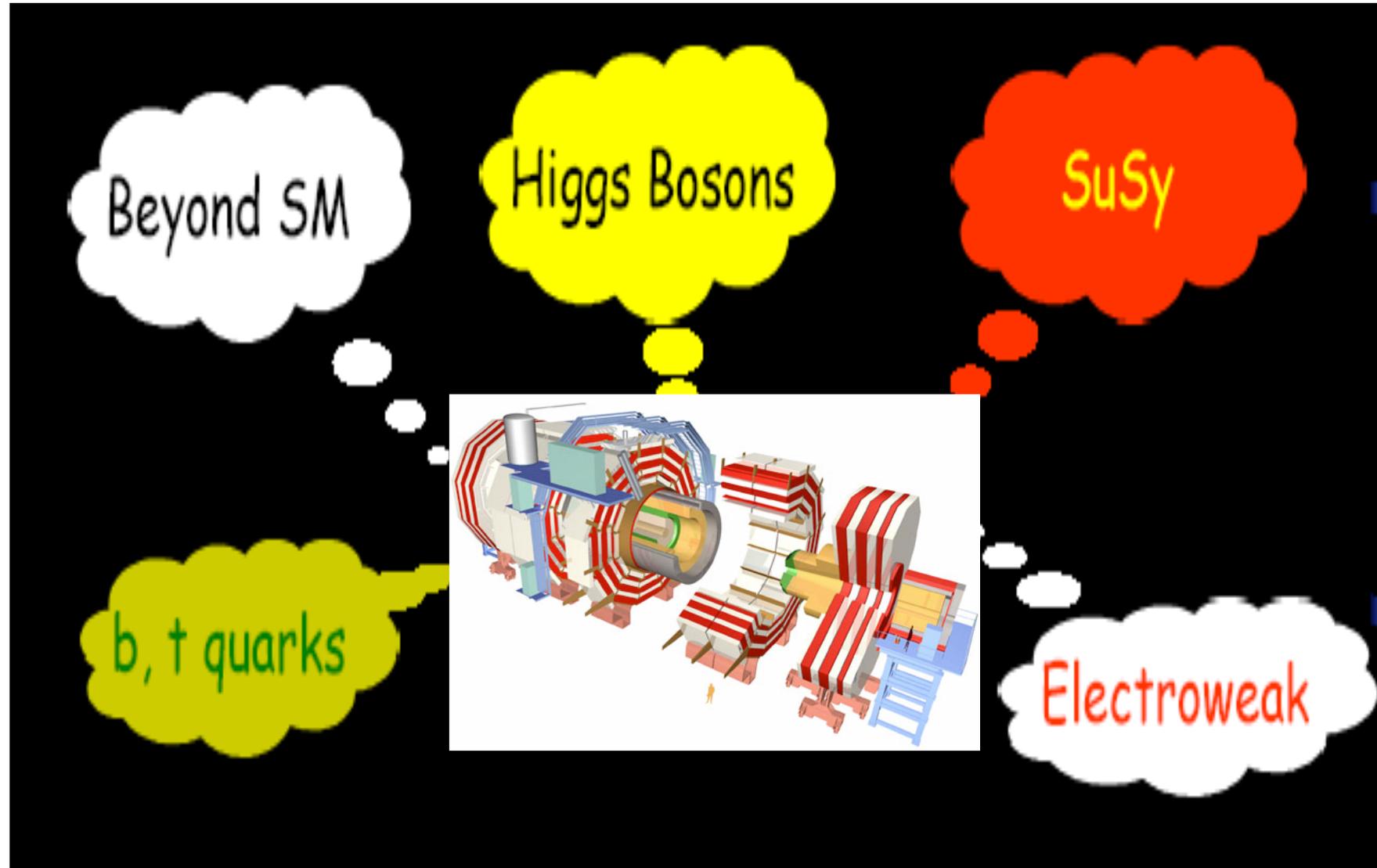


Vista laterale di CMS nel pit prima della chiusura



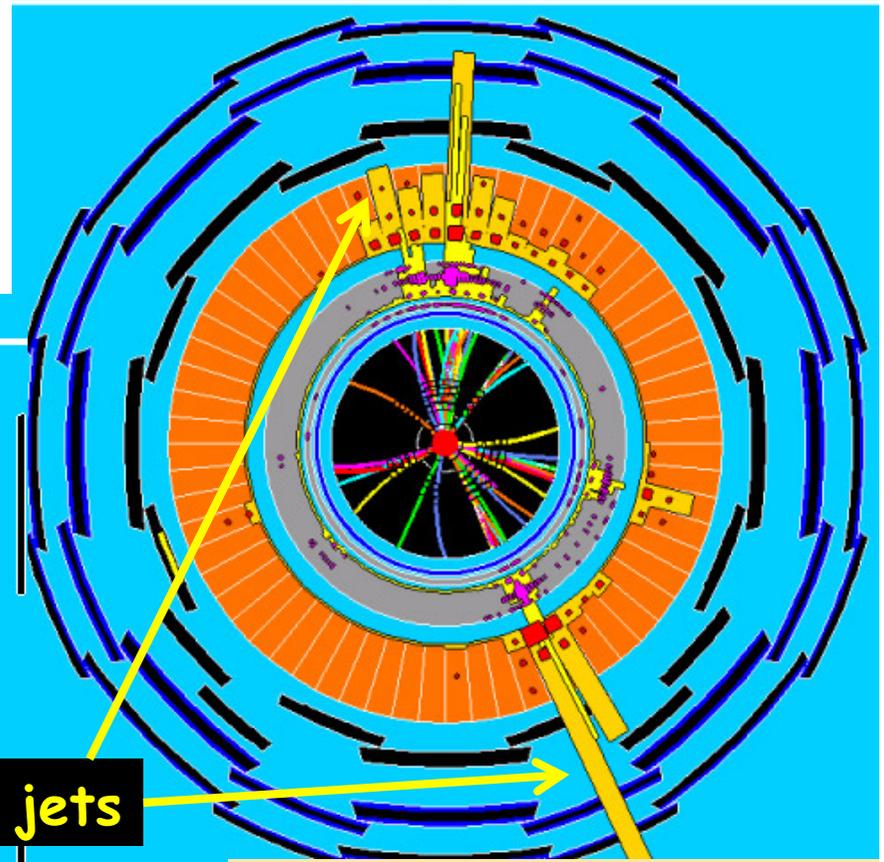
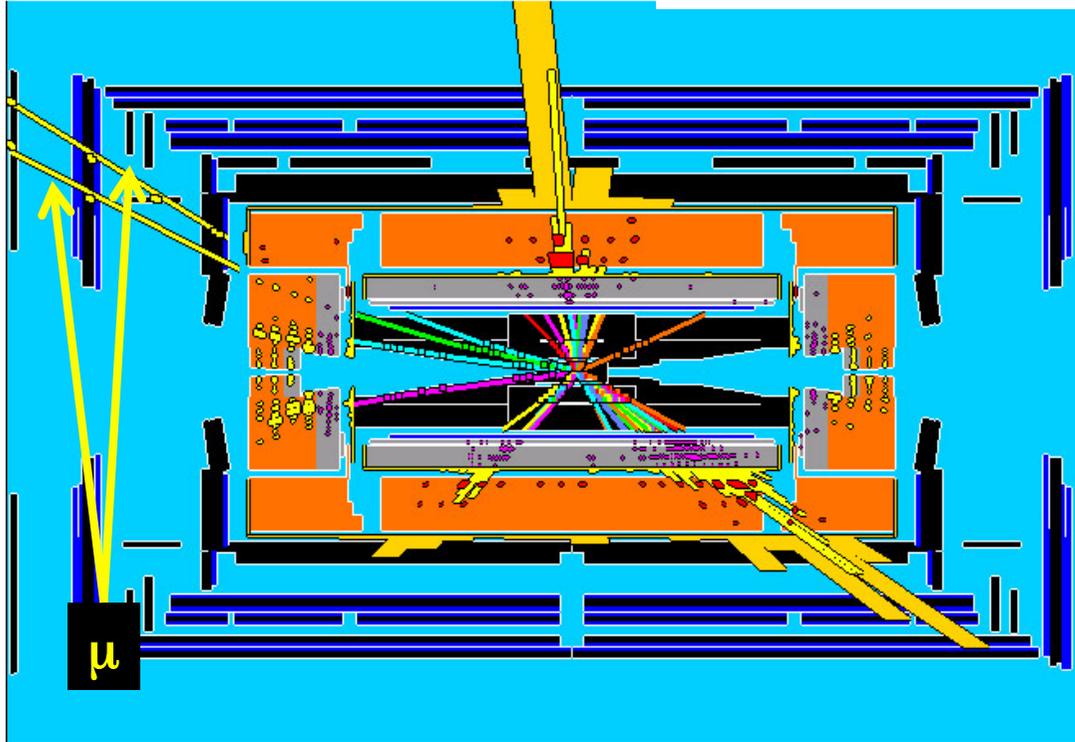
Vista dall'alto di CMS nel pit

# Obiettivi di 'fisica' ...



... come vediamo gli eventi?

ATLAS Atlantis Event: susyevent MC SUSY event

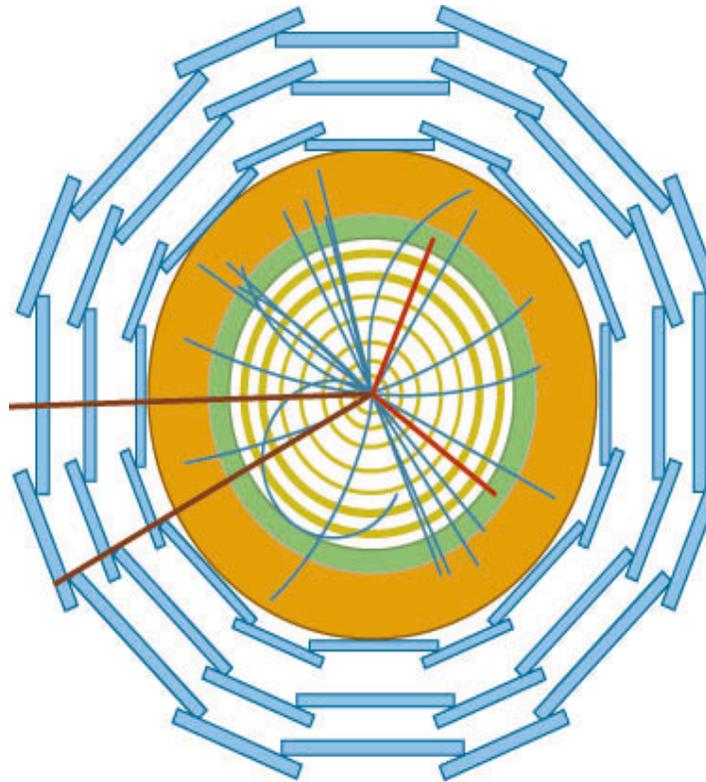
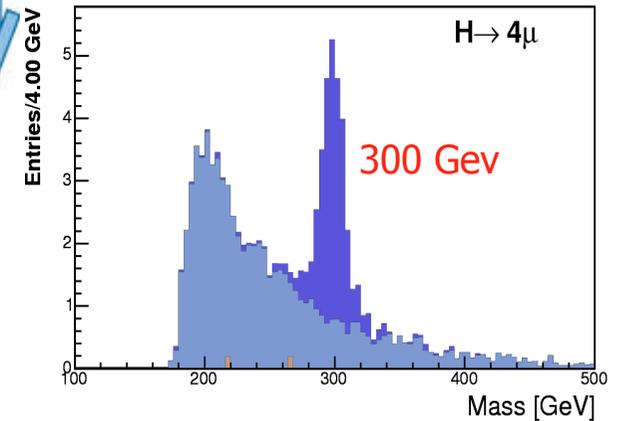
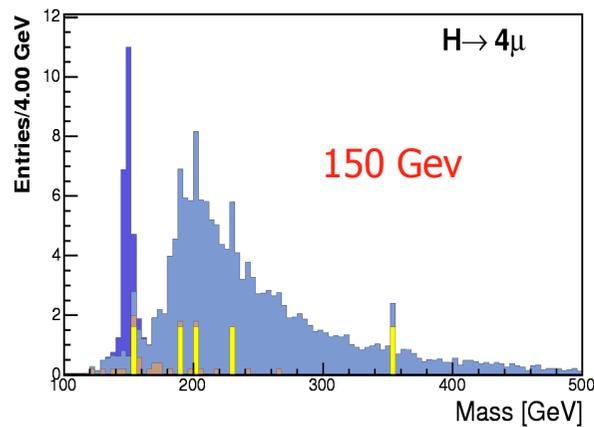
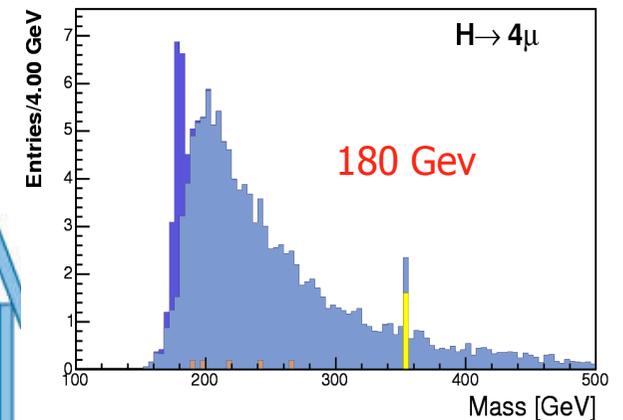
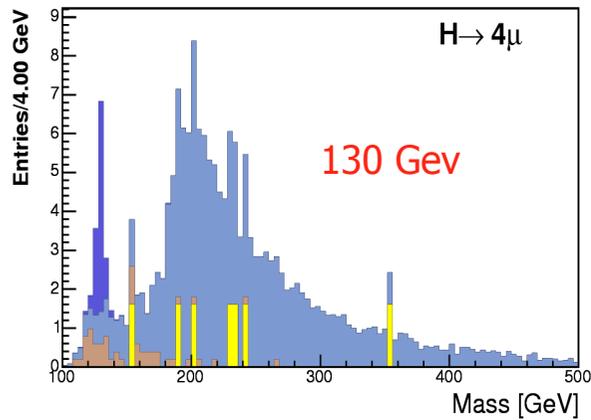


... ricostruendoli tramite misure di:

- traiettoria
- carica elettrica
- energia
- impulso
- massa
- vita media

... e producendo distribuzioni ...

# ... esempio: ricerca dell'Higgs ...



**H → ZZ\* → 4 l**

Massa invariante:

$$m = \frac{1}{c} \sqrt{\left( \sum_{i=1}^N p_i \right)^2} = \frac{1}{c} \sqrt{\left( \sum_{i=1}^N \frac{E_i}{c} \right)^2 - \left( \sum_{i=1}^N \vec{p}_i \right)^2}$$

*fino ad ora l'unico Higgs visto in Atlas e CMS è stato... il Prof. Higgs....*

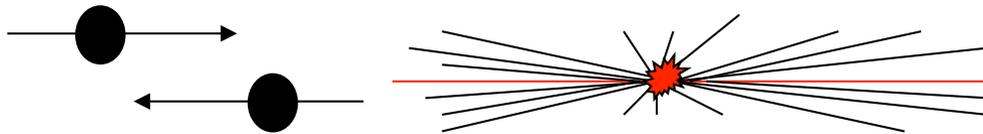


Prof. Higgs

# ... quanti eventi ?

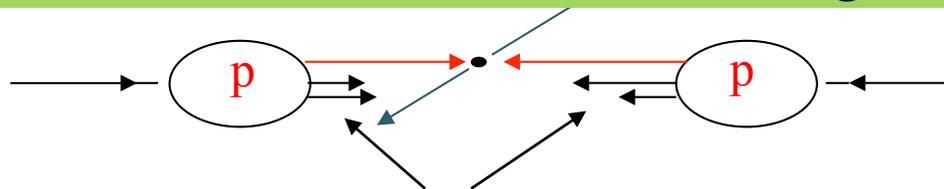
frequenza di eventi =  
 $7 \times 10^8$  interazioni/s

Minimum bias events: collisioni tra protoni 'a grande distanza':

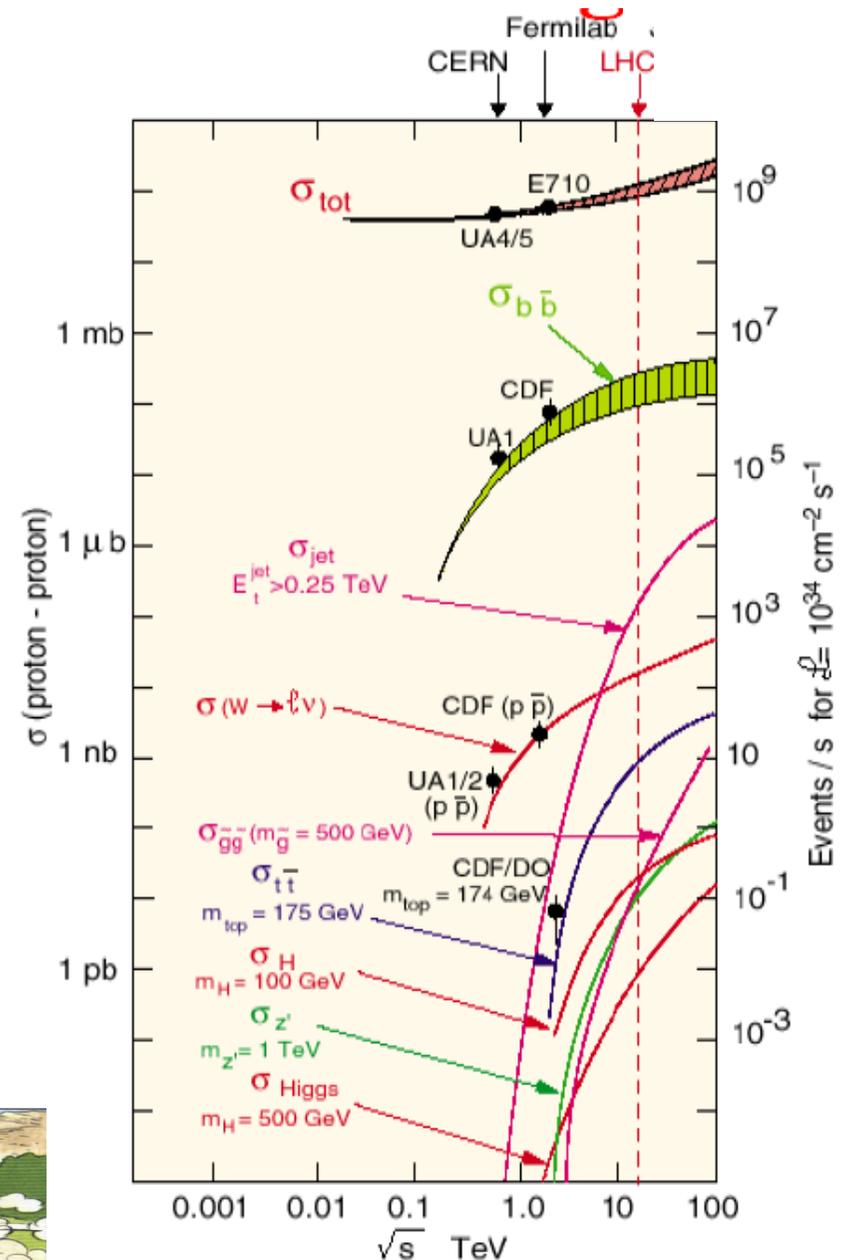
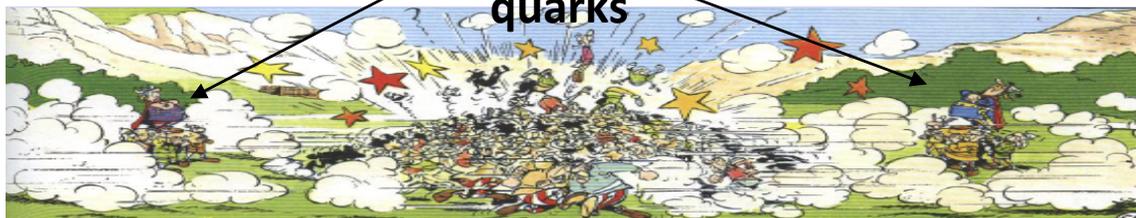


frequenza di collisione dei fasci = **40MHz**  
 → circa 20 eventi di questo tipo si sovrappongono ad ogni bunch crossing.

Occasionamente: 'hard scattering'



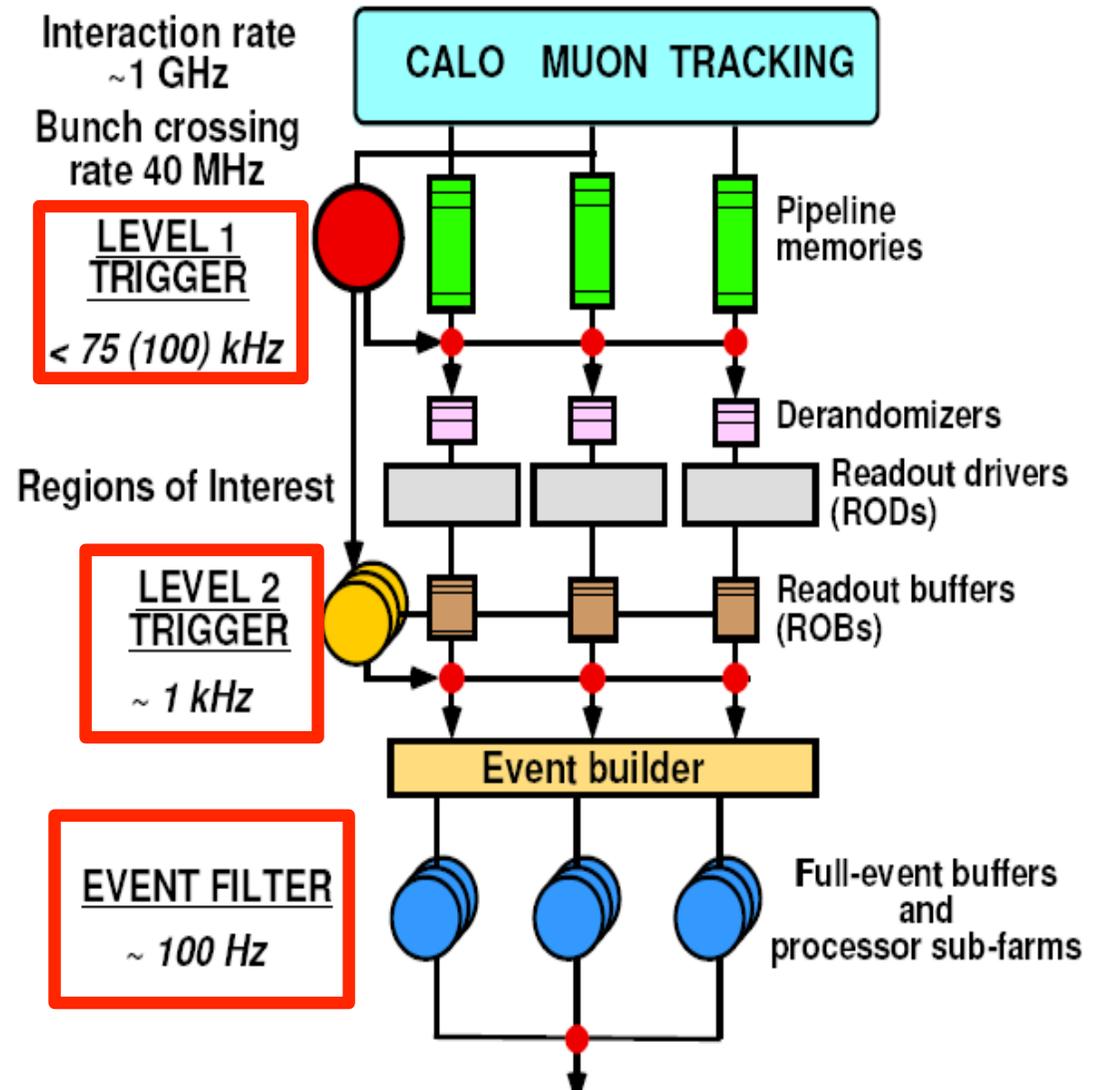
Spectator quarks



# Trigger & DAQ

- collisioni:  $10^9/s$
- collisioni che producono processi interessanti: ordine 100 al s
- collisioni che producono eventi rari di enorme interesse: 1 al giorno!

Sistema di Trigger e di DataAcquisition per selezionare gli eventi interessanti e scriverli su disco



Napoli ha dato contributo sia hardware che software ad entrambi

# gli eventi in Atlas & CMS...

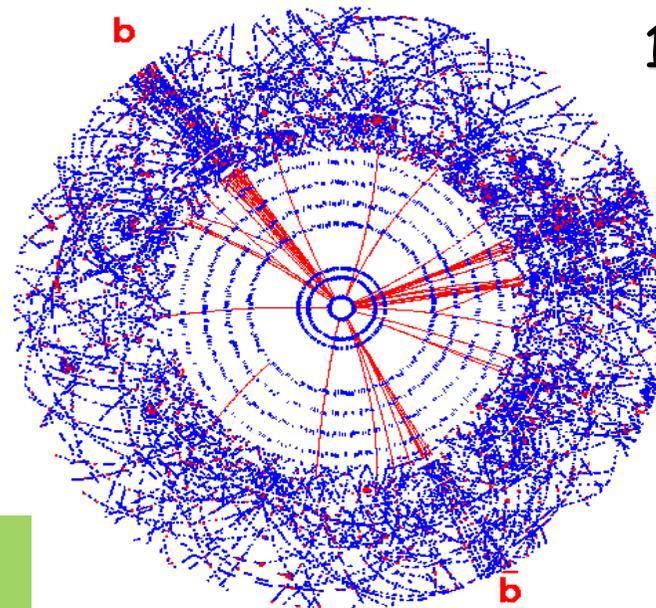
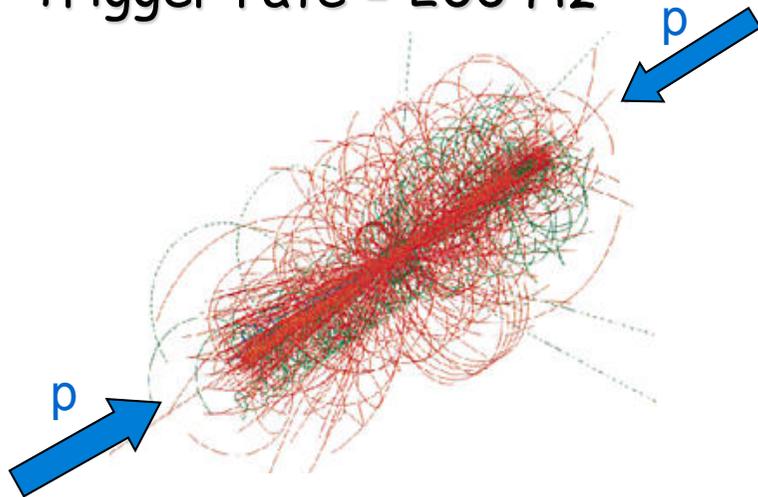
...sono molti....

...e sono

Trigger rate = 200 Hz

H  $\rightarrow$  bb event

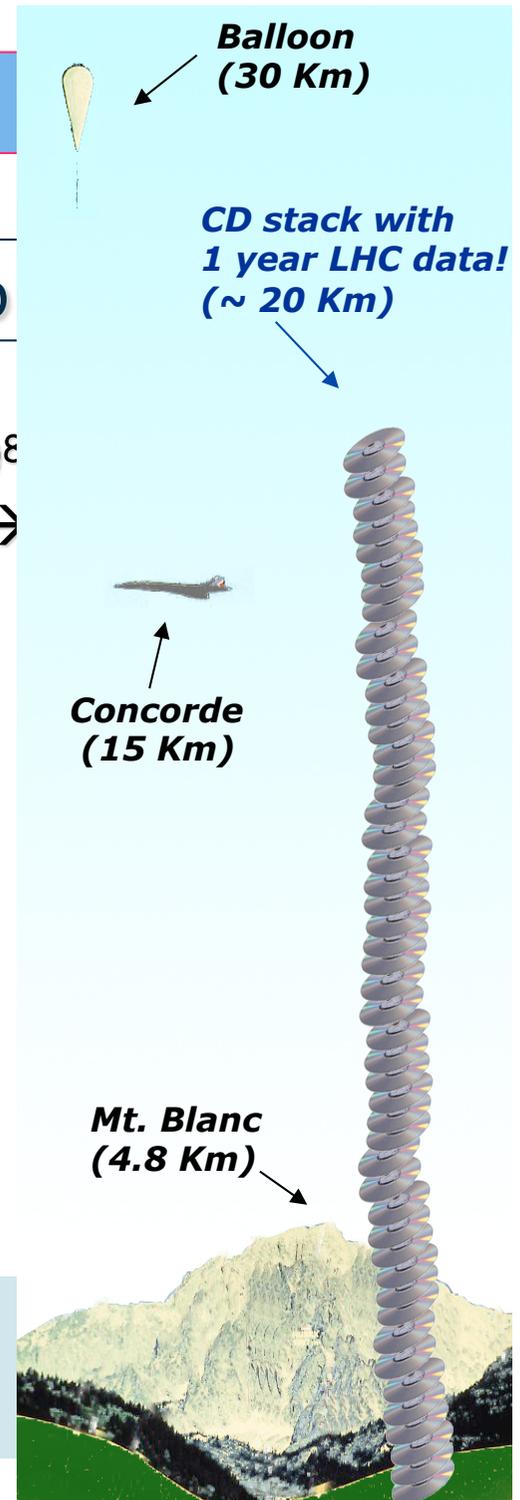
$10^8$   
 $\rightarrow$



400MB al secondo!  
1 CD ogni 2 secondi

~4 PetaBytes/anno

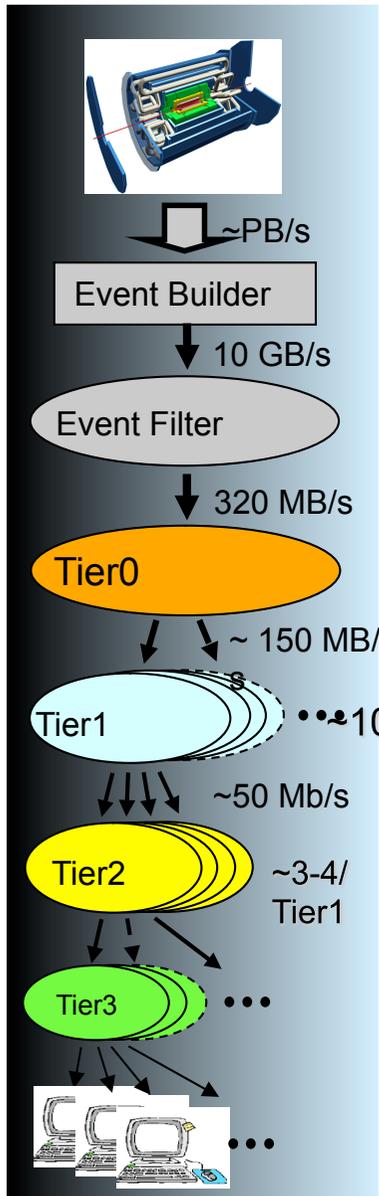
necessaria un enorme potenza di calcolo e  
capacità di storage.....



# GRID Computing

Struttura di calcolo distribuita organizzata in livelli (tier):

Tier-0 at CERN  $\Rightarrow$  10 Tier-1  $\Rightarrow$  35 Tier-2  
Tier2 in Italia: 4 Atlas (Napoli), 3 CMS



# Fasci @ LHC !

Novembre 2009:

→ prime collisioni a 450+450 GeV

Dicembre 2009:

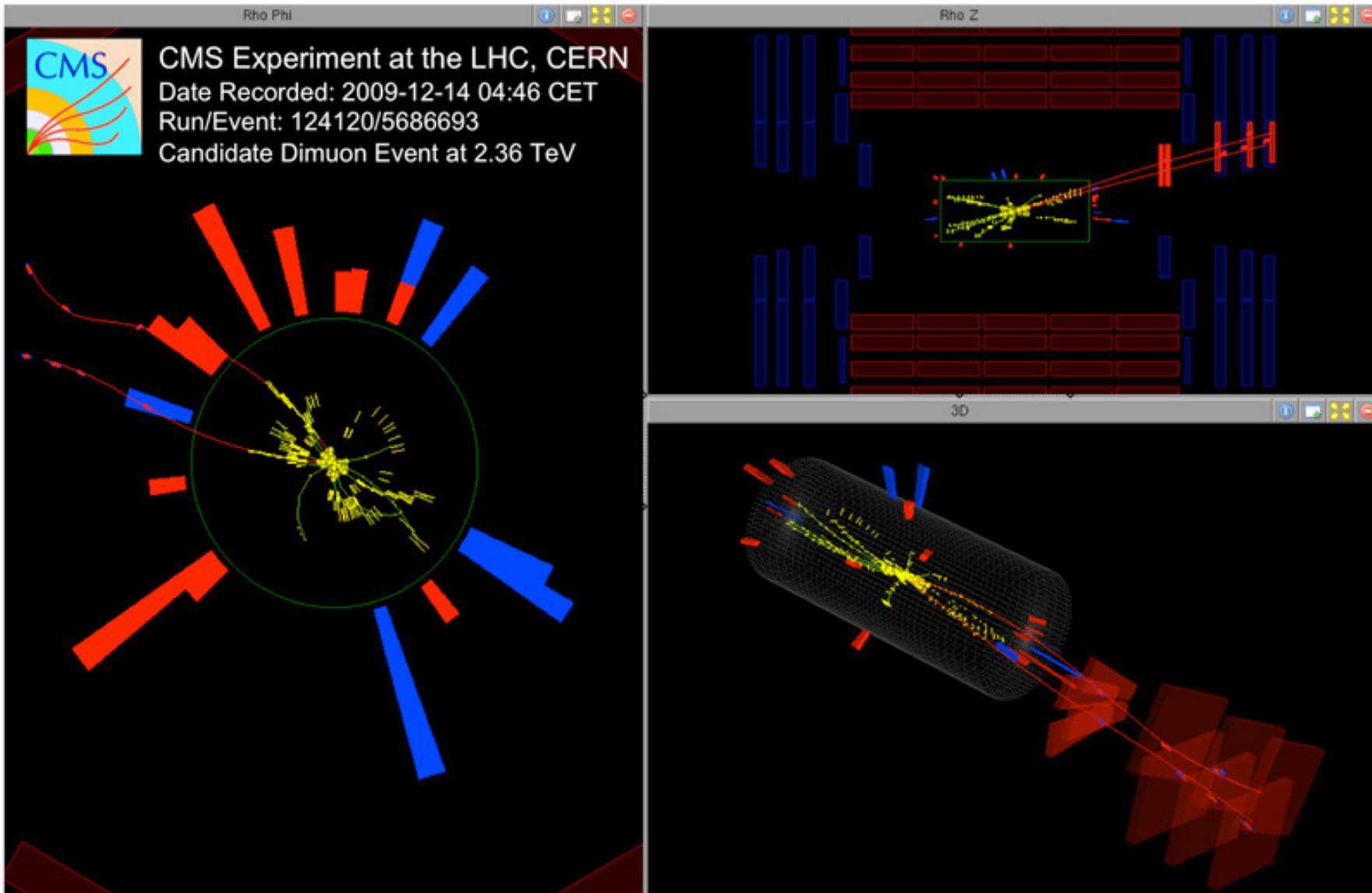
→ Collisioni @ 1,18+1,18 TeV!  
World record !!!

Febbraio 2010:

→ Collisioni a 3,5+3,5 TeV

...qualcuno dei primi eventi...

CMS di-muon event @ 2,36 TeV



# CMS event @ 7 TeV



## CMS Experiment at the LHC, CERN

Data recorded: 2010-Mar-30 11:41:09.816679 GMT(13:41:09 CEST)

Run: 132440

Event: 5441549

Lumi section: 233

Orbit: 60901732

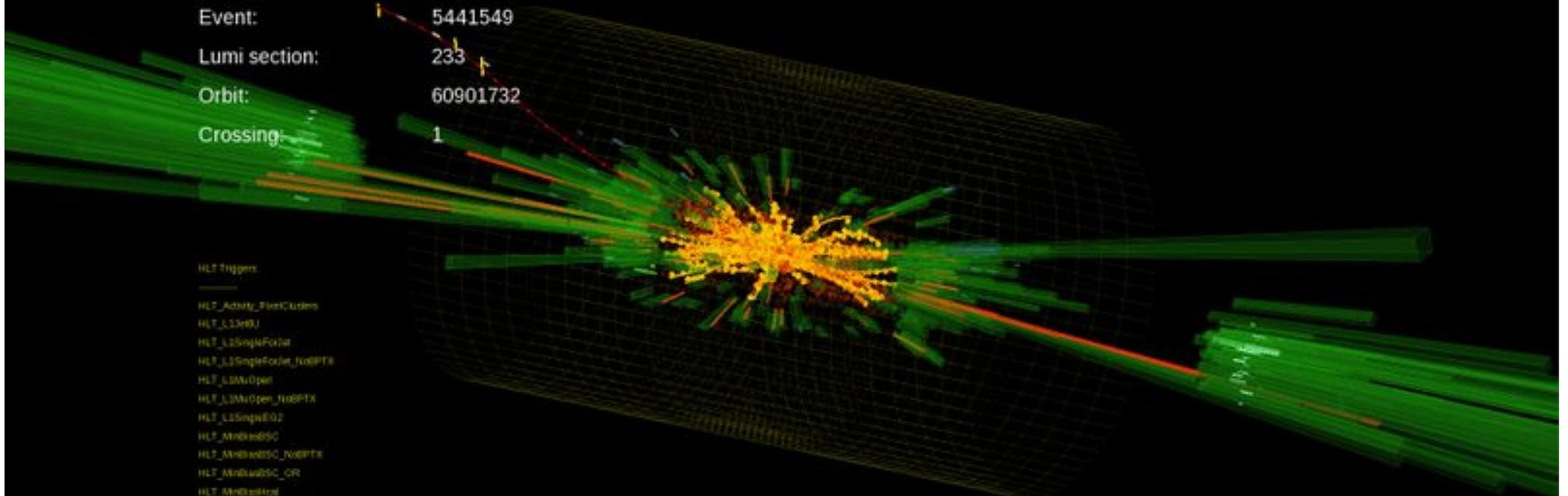
Crossing: 1

### HLT Triggers

- HLT\_Activty\_FuelCludes
- HLT\_L3HERU
- HLT\_L3SingleF0dr
- HLT\_L3SingleF0dr\_NoBPTX
- HLT\_L3Mu0pen
- HLT\_L3Mu0pen\_NoBPTX
- HLT\_L3SingleE02
- HLT\_MinHadBSC
- HLT\_MinHadBSC\_NoBPTX
- HLT\_MinHadBSC\_CR
- HLT\_MinHadEcal
- HLT\_MinHadEcal
- HLT\_ZendHadPrel\_SingleTrack
- HLT\_MinHadPrel\_SingleTrack
- HLT\_MinHadPrel\_DoubleTrack
- HLT\_MinHadPrel\_DoubleTrack5
- HLT\_HighMultiplicityBSC
- HLT\_SplashBSC
- HLT\_L3\_BsdMetBsdCR\_BsdPtwCRMinu
- HLT\_L3\_BsdMetBsdCR\_BsdPtwCRMinu\_NoBPTX

### Drawing cuts & scales

Name	Value/Unit	Energy scale factor
EDRborts_V0	0.050	1.00
EDRborts_V0	1.000	1.00
CRborts_V0	1.000	10.00
HRborts_V0	0.750	1.00
FRborts_V0	0.750	1.00
HRborts_V0	1.000	1.00
FRborts_V0	1.000	1.00



# Collision Event at 7 TeV



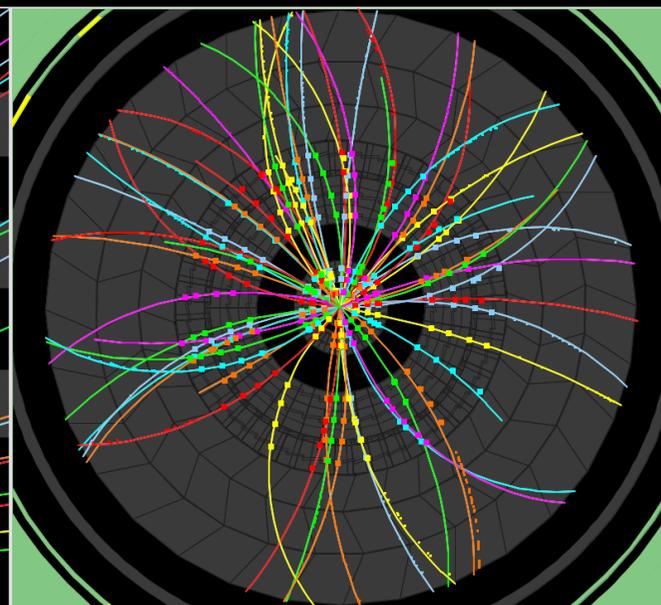
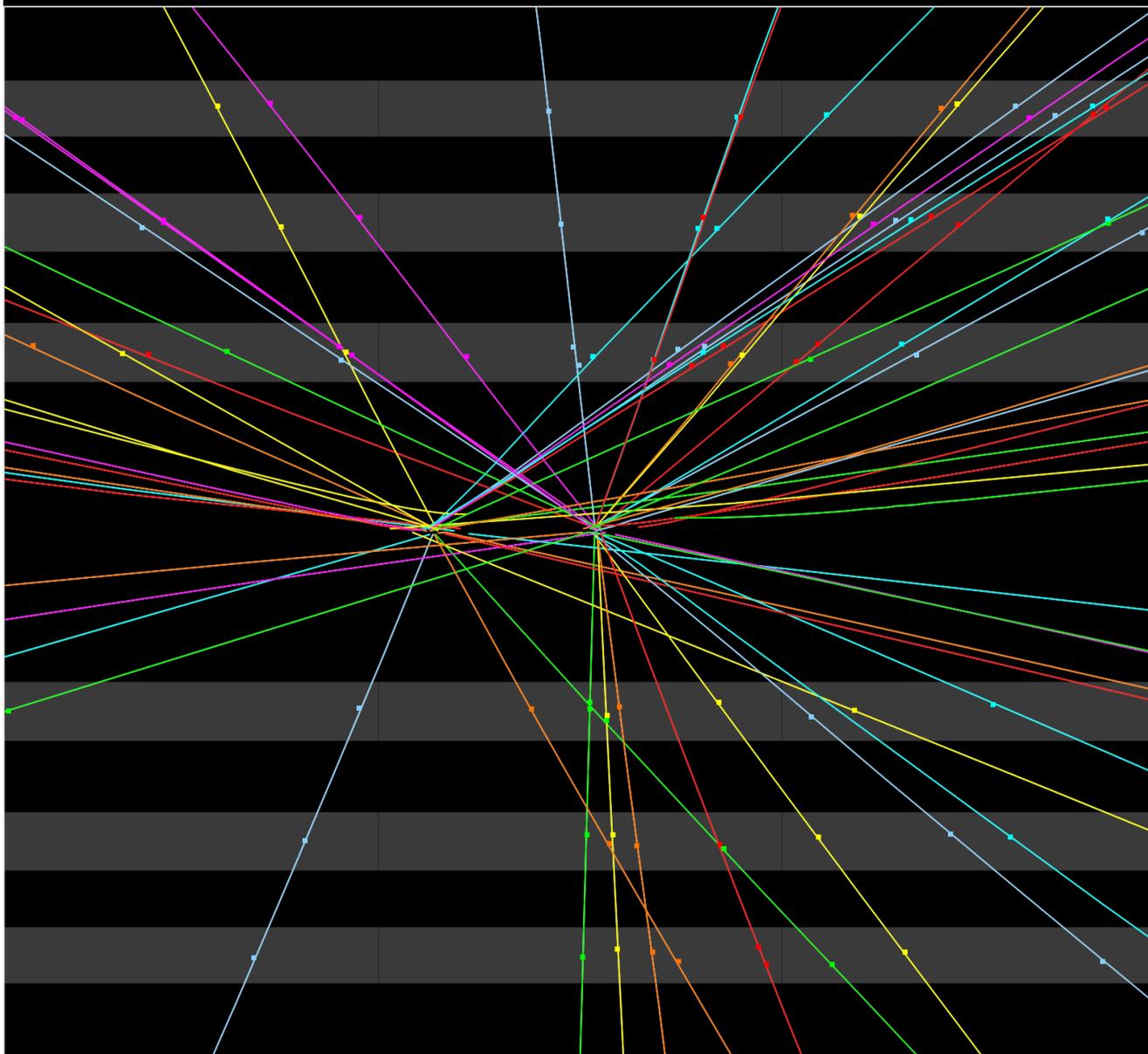
2010-03-30, 12:58 CEST

Run 152166, Event 316199

<http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html>

Sovrapposizione di due collisioni !

# Collision Event at 7 TeV with 2 Pile Up Vertices



Run Number: 152166, Event Number: 467774

Date: 2010-03-30 13:31:46 CEST

<http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html>

# ...con questi dati...

LHC raggiungerà l'energia (14TeV) e la luminosità di progetto ( $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ ) per passi (2012)

Fino ad ora:

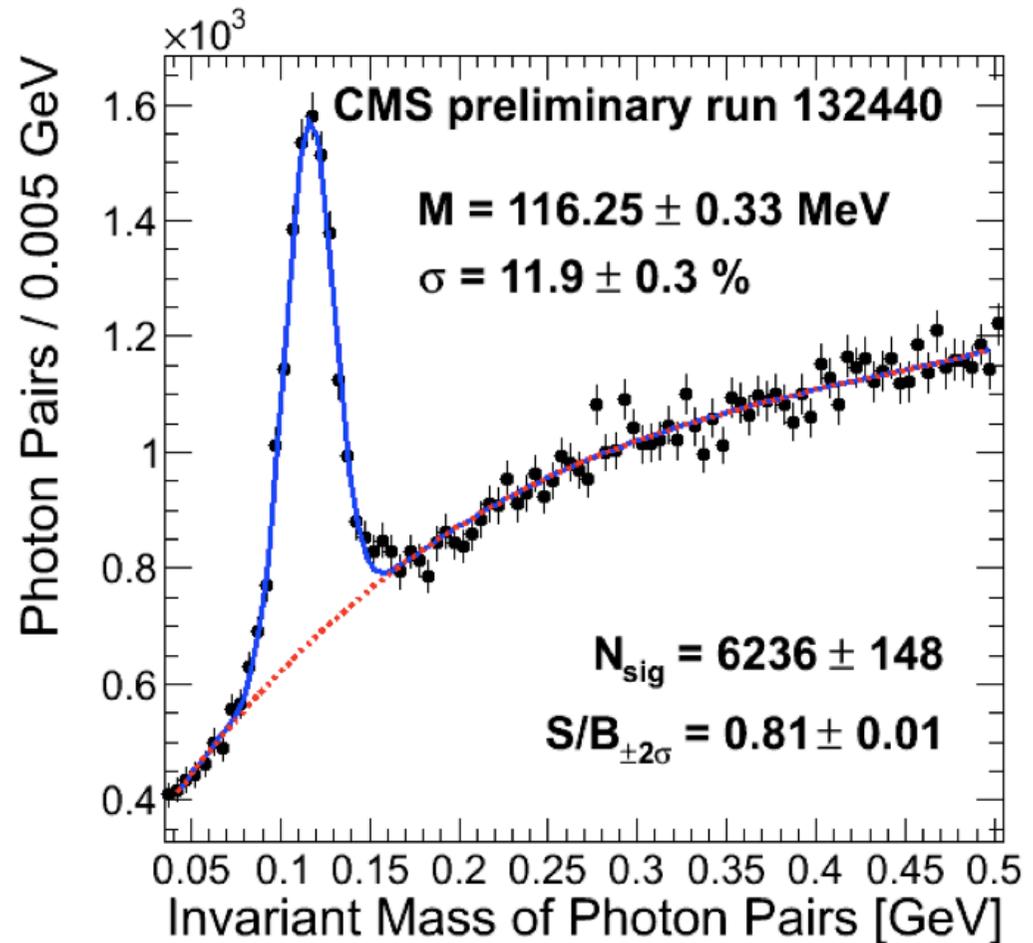
- bunches 2x2, carica/bunch=  $10^{10}$  p/bch,  $\rightarrow$   
 $L \sim 10^{28} \text{ cm}^{-2}\text{s}^{-1}$
- energia nel CM= 7TeV
- $L_{\text{int}} \sim 10 \text{ nb}^{-1}$



- 1) calibrare il rivelatore ed il trigger con canali di fisica ben noti
- 2) 'riscoprire' e misurare i parametri del Modello Standard a 7TeV
- 3) sempre 'aperti' ad eventuali scoperte...

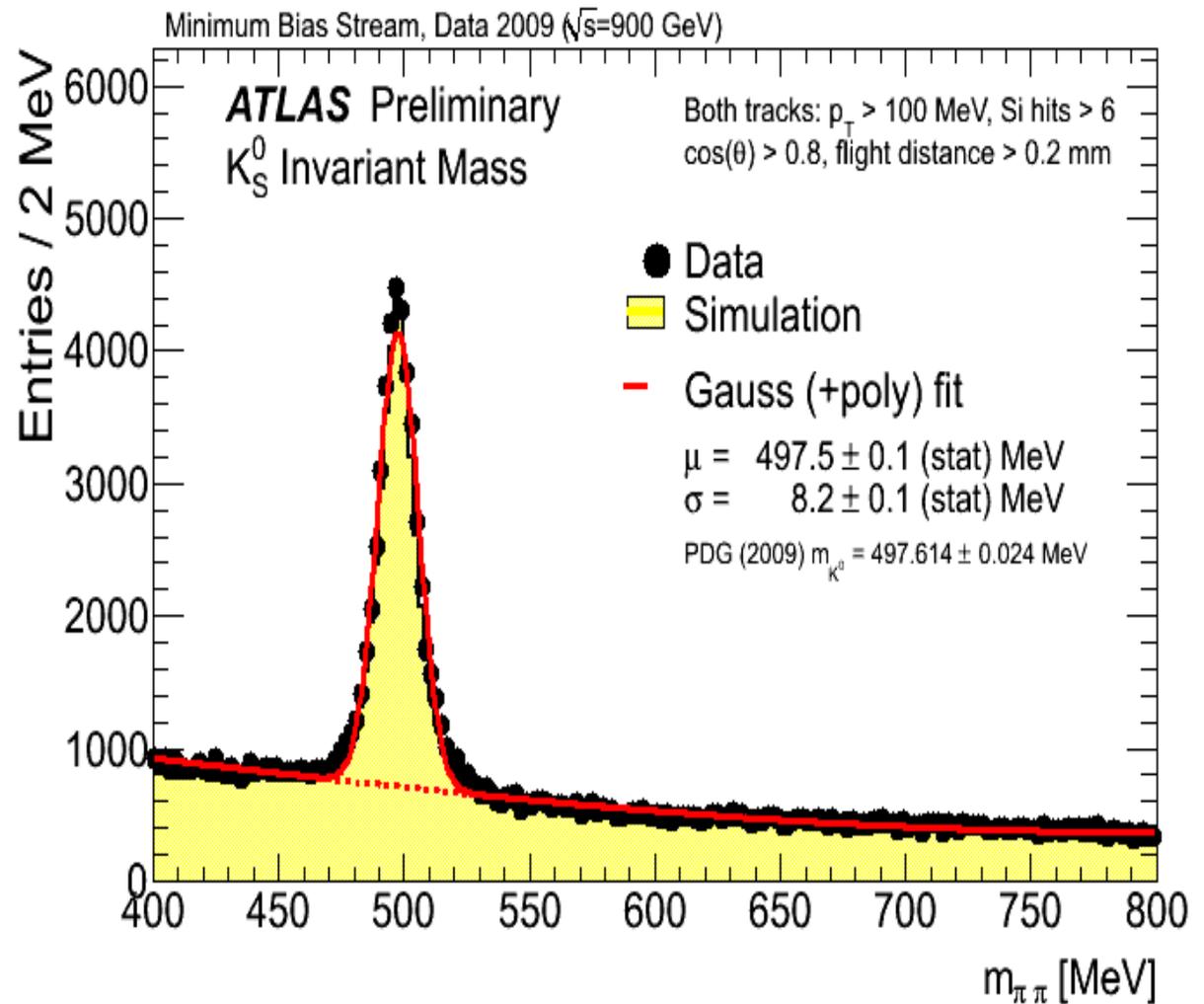
# Prime distribuzioni: $\pi^0$

- mesone (quarks u,d)
- $m=135,0 \text{ MeV}/c^2$
- $\tau=8,4 \times 10^{-17} \text{ s}$
- Decade nel 98,8% in:  
 $\pi^0 \rightarrow \gamma\gamma$

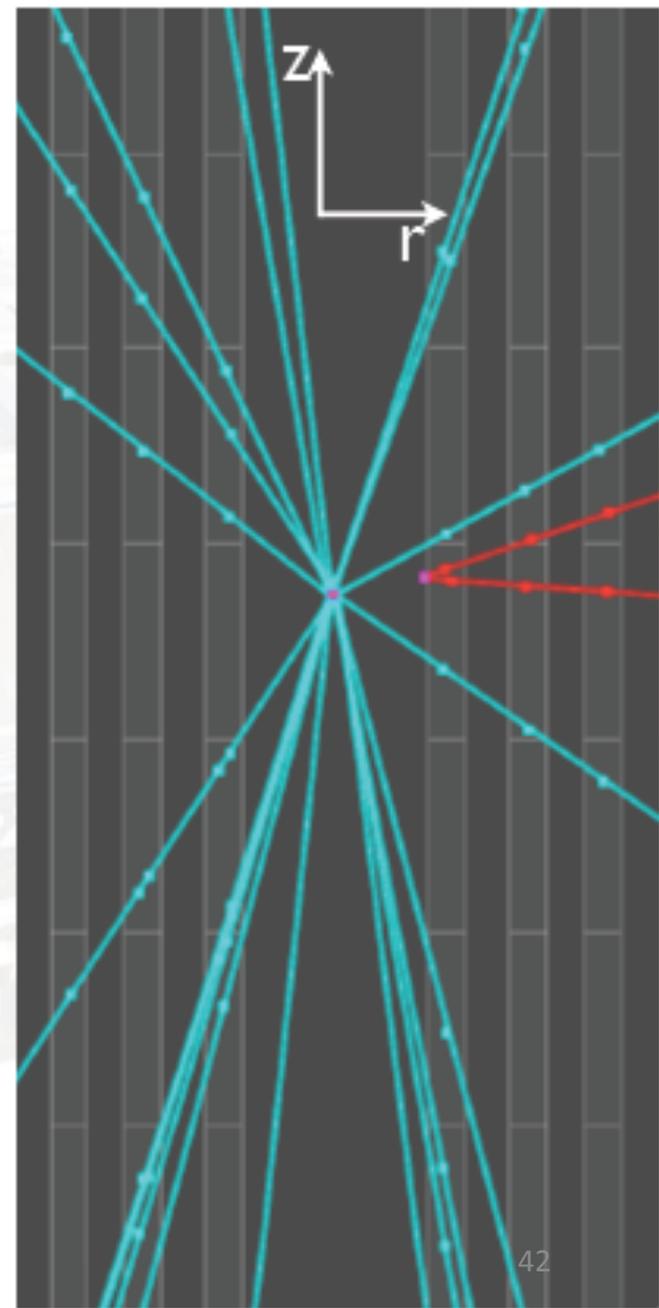
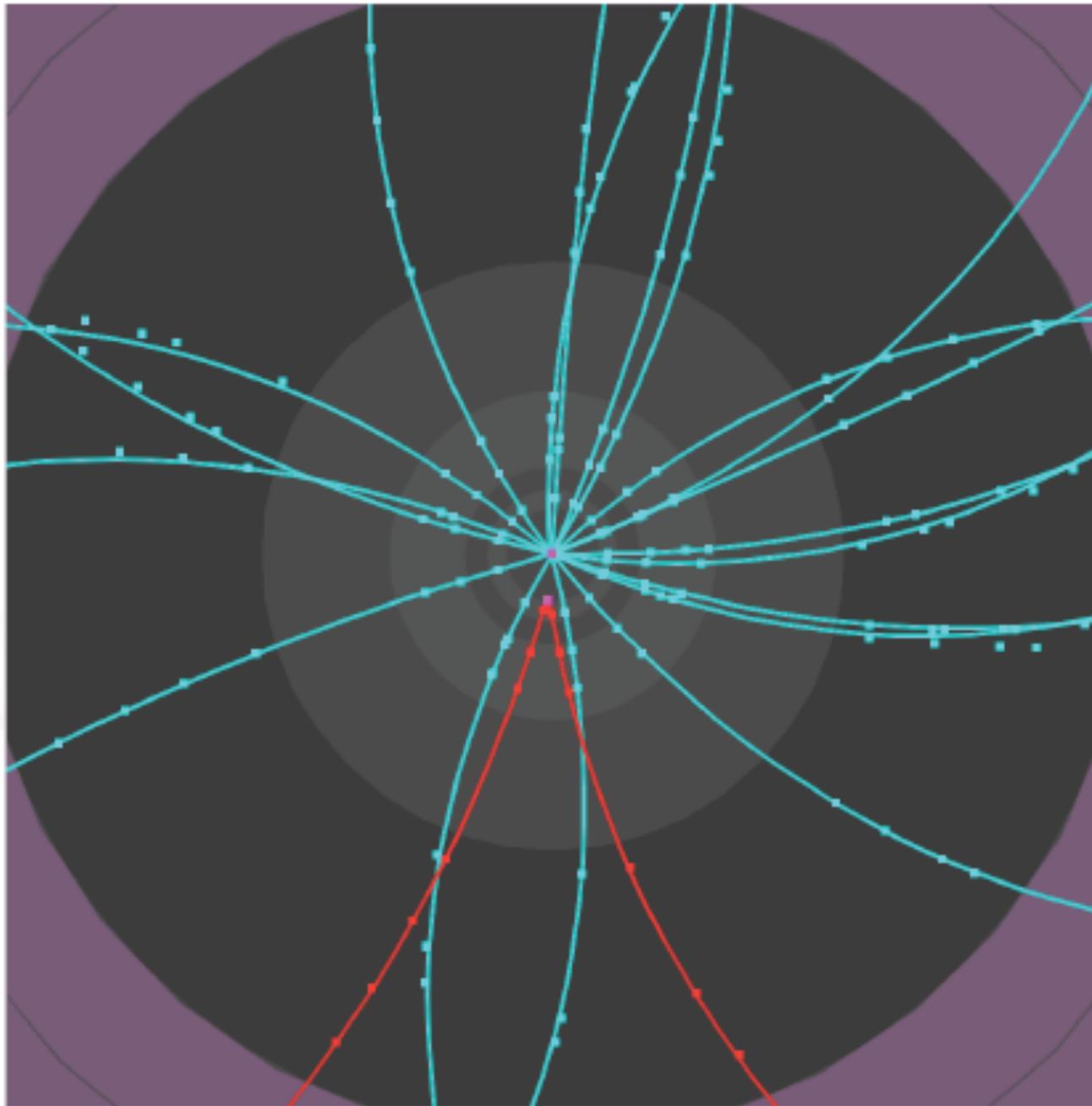


# Prime distribuzioni: $K_S^0$

- mesone (quarks  $d,s$ )
- $m=497.6\text{MeV}$
- $\tau=8.953\times 10^{-11}\text{ s}$
  
- Decade nel 31% in  $K_S^0 \rightarrow \pi^+\pi^-$



# $K_s^0 \rightarrow \pi^+\pi^-$ event display

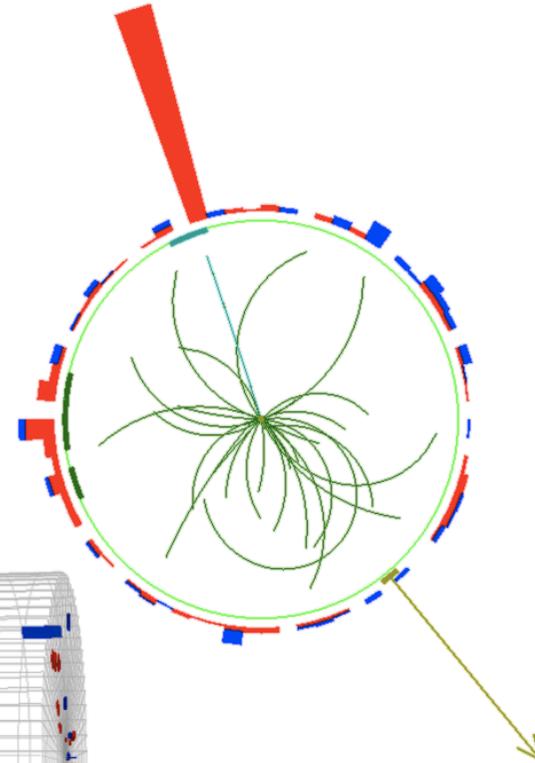
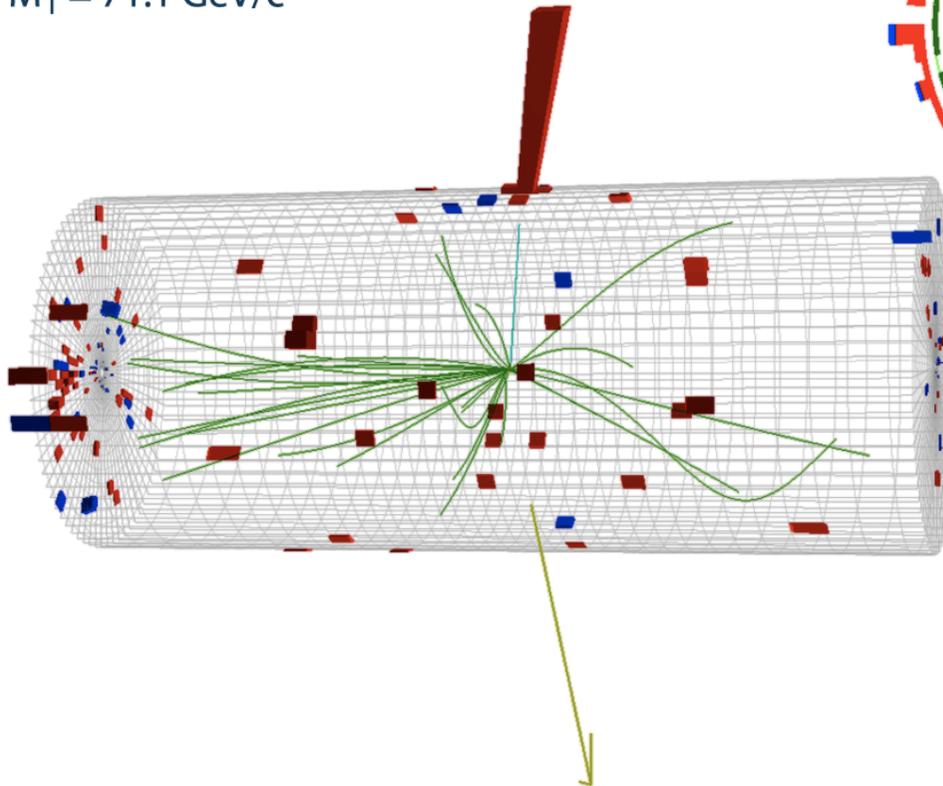


# ...primi eventi 'rari' interessanti...



CMS Experiment at LHC, CERN  
Run 133874, Event 21466935  
Lumi section: 301  
Sat Apr 24 2010, 05:19:21 CEST

Electron  $p_T = 35.6 \text{ GeV}/c$   
 $ME_T = 36.9 \text{ GeV}$   
 $M_T = 71.1 \text{ GeV}/c^2$



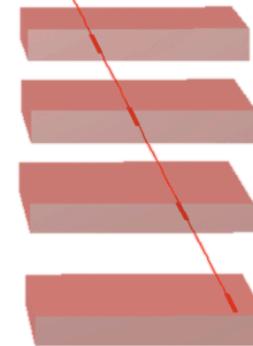
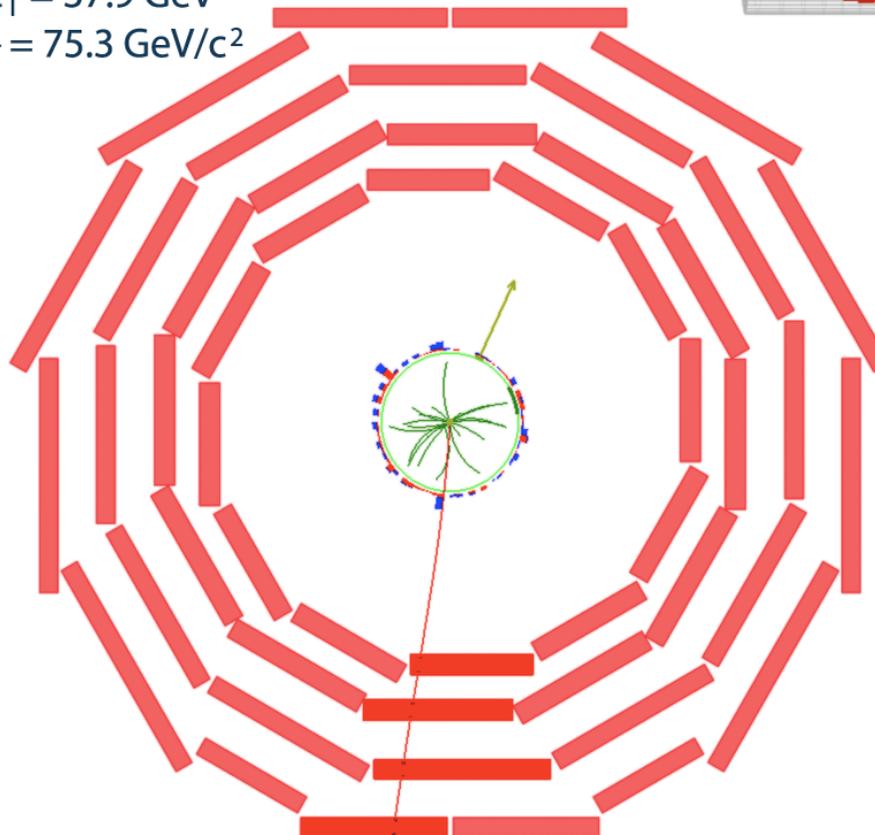
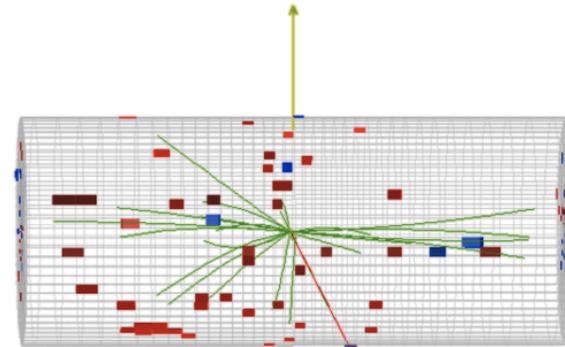
$W \rightarrow ev$

# evento $W \rightarrow \mu\nu$



CMS Experiment at LHC, CERN  
Run 133875, Event 1228182  
Lumi section: 16  
Sat Apr 24 2010, 09:08:46 CEST

Muon  $p_T = 38.7 \text{ GeV}/c$   
 $ME_T = 37.9 \text{ GeV}$   
 $M_T = 75.3 \text{ GeV}/c^2$

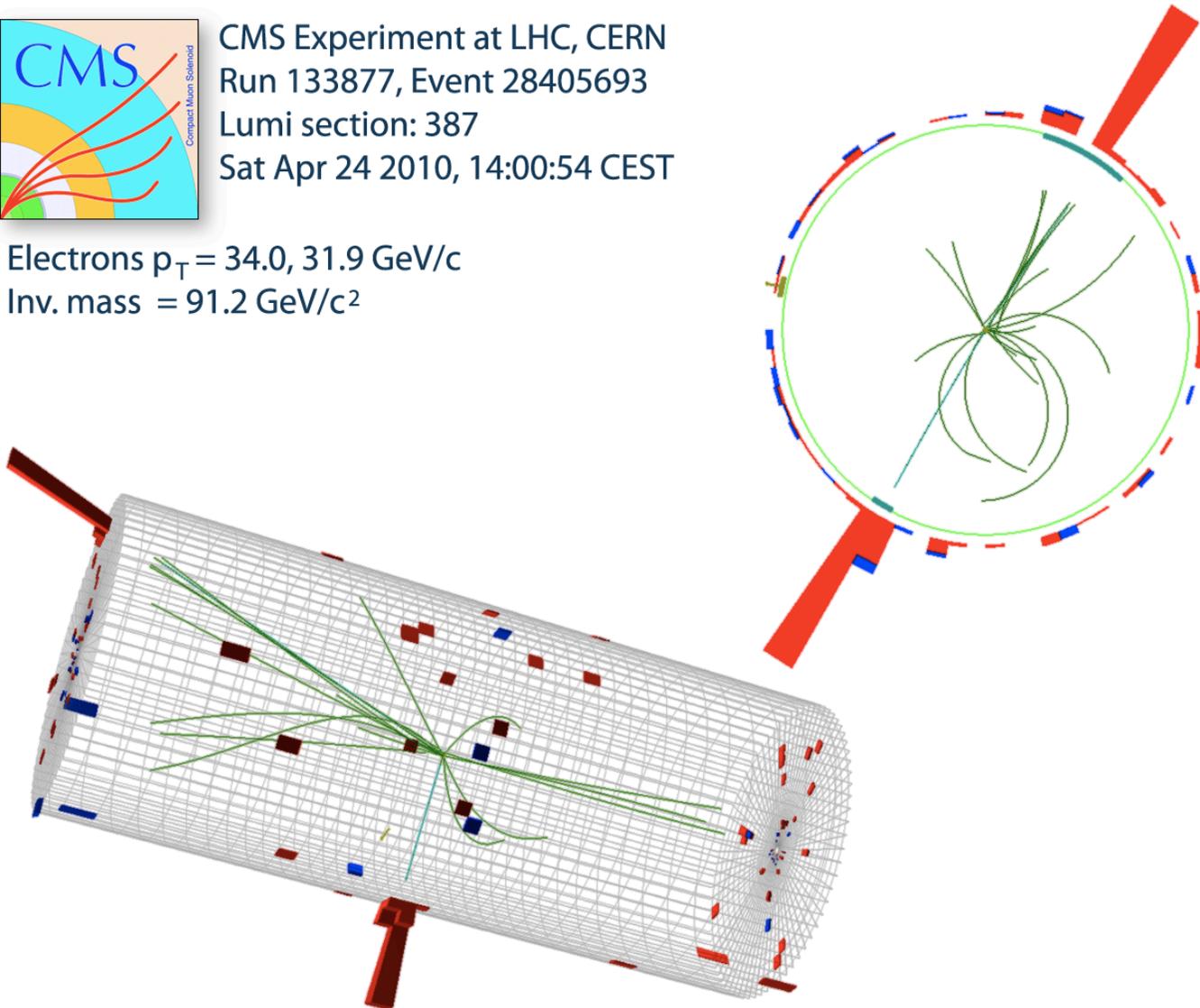


# evento $Z \rightarrow e^+ e^-$



CMS Experiment at LHC, CERN  
Run 133877, Event 28405693  
Lumi section: 387  
Sat Apr 24 2010, 14:00:54 CEST

Electrons  $p_T = 34.0, 31.9 \text{ GeV}/c$   
Inv. mass =  $91.2 \text{ GeV}/c^2$

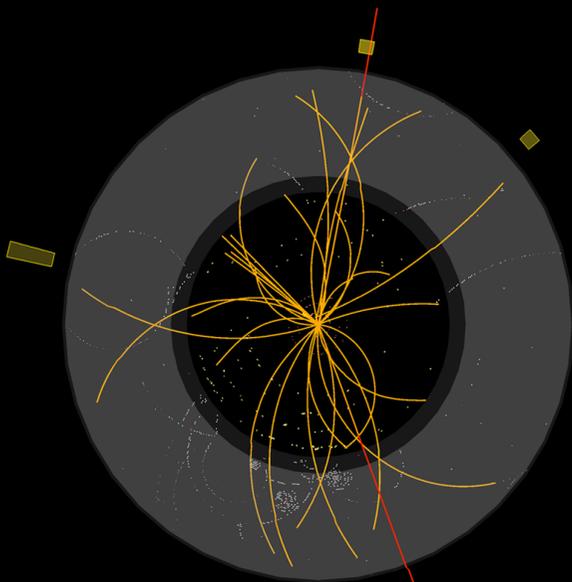


evento  $Z \rightarrow \mu^+ \mu^-$



**ATLAS**  
**EXPERIMENT**

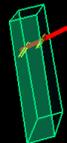
Run: 154822, Event: 14321500  
Date: 2010-05-10 02:07:22 CEST



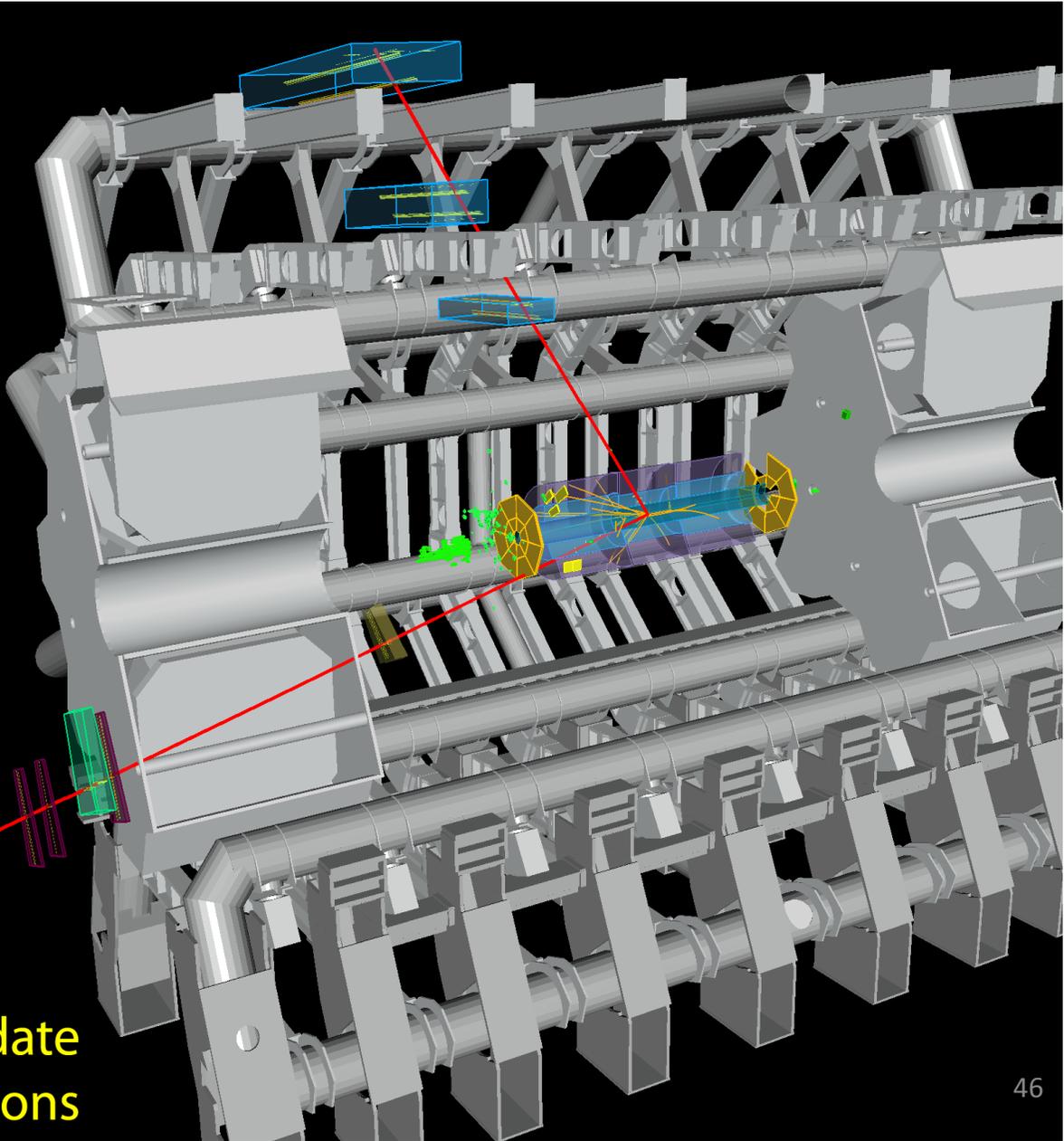
$p_T(\mu^-) = 27 \text{ GeV}$   $\eta(\mu^-) = 0.7$

$p_T(\mu^+) = 45 \text{ GeV}$   $\eta(\mu^+) = 2.2$

$M_{\mu\mu} = 87 \text{ GeV}$



**$Z \rightarrow \mu\mu$  candidate  
in 7 TeV collisions**



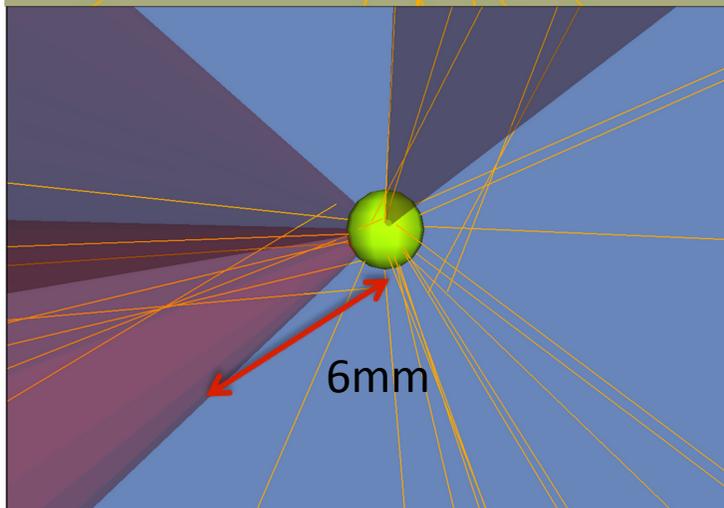
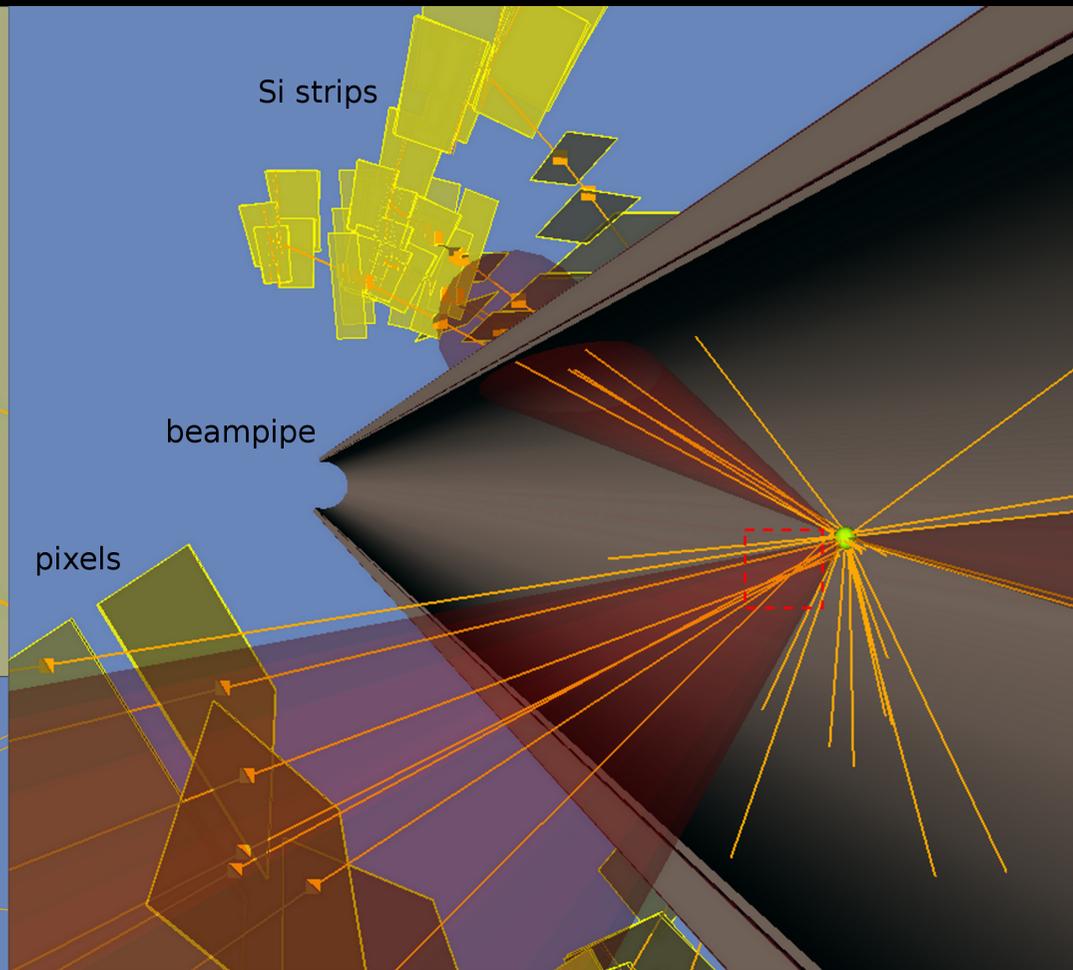
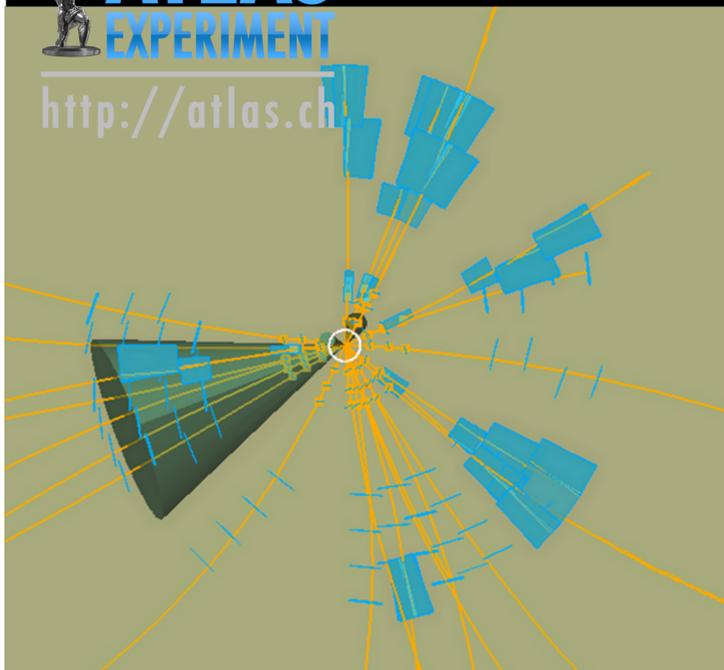
# evento con b-tagged jet



<http://atlas.ch>

Run 152166  
Event 817271

b-tagged jet in 7 TeV collisions



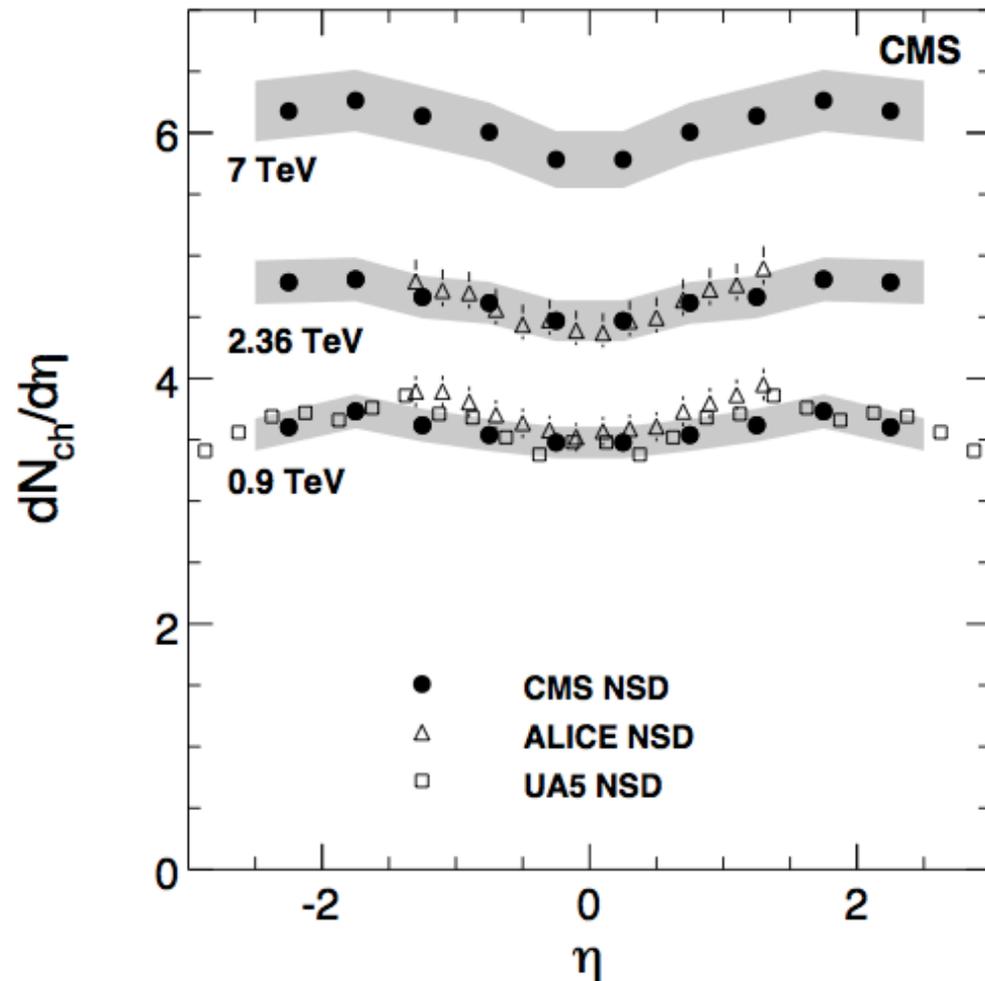
jet  
 $p_T = 19$  GeV

4 b-tagging quality tracks in the jet

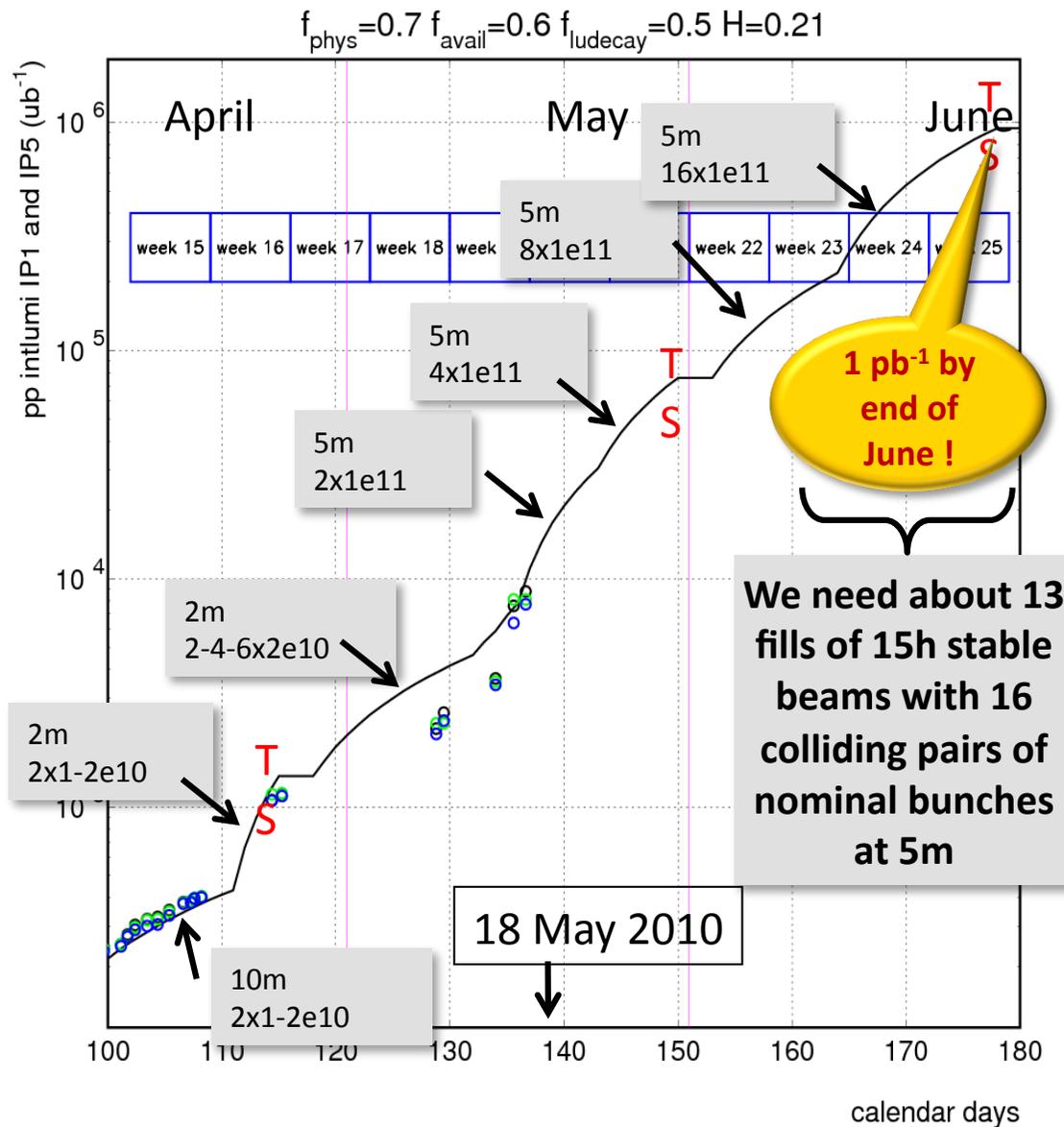
# Pubblicazioni dai dati acquisiti

Sia ATLAS che CMS hanno pubblicato:

- articolo sulla 'molteplicità di tracce cariche'
- vari articoli sulle 'performance' dei sottorivelatori



# ...LHC schedule...



fino a giugno:

- aumentare il numero di protoni per bunch a  $10^{11}$
- raddoppiare # bunch ogni 2 settimane fino a 16+16
- raggiungere  $1\text{pb}^{-1}$

• 2010-11, run fino ad accumulare  $1000\text{pb}^{-1}$

• 2011-12, shut down per lavori ad LHC →  
 $L=10^{34}\text{cm}^{-2}\text{s}^{-1}$  e  
 $E=14\text{TeV}$