# Heavy Ion Physics with the CMS experiment at the LHC

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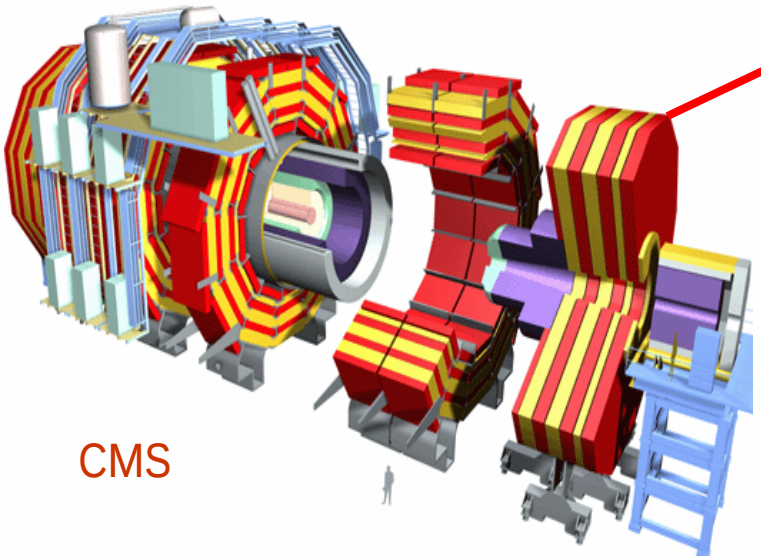
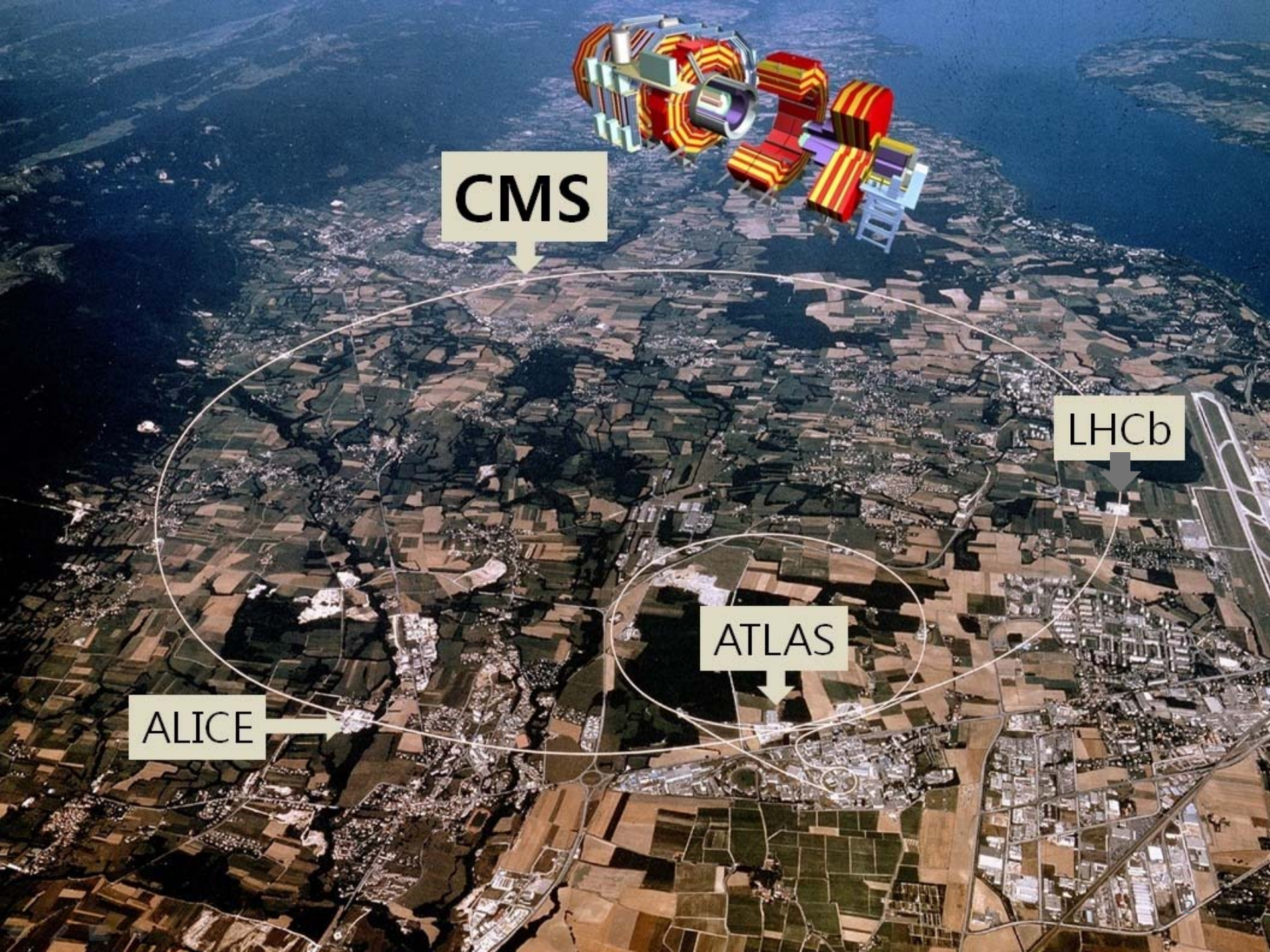
**École Polytechnique/LLR & MIT**

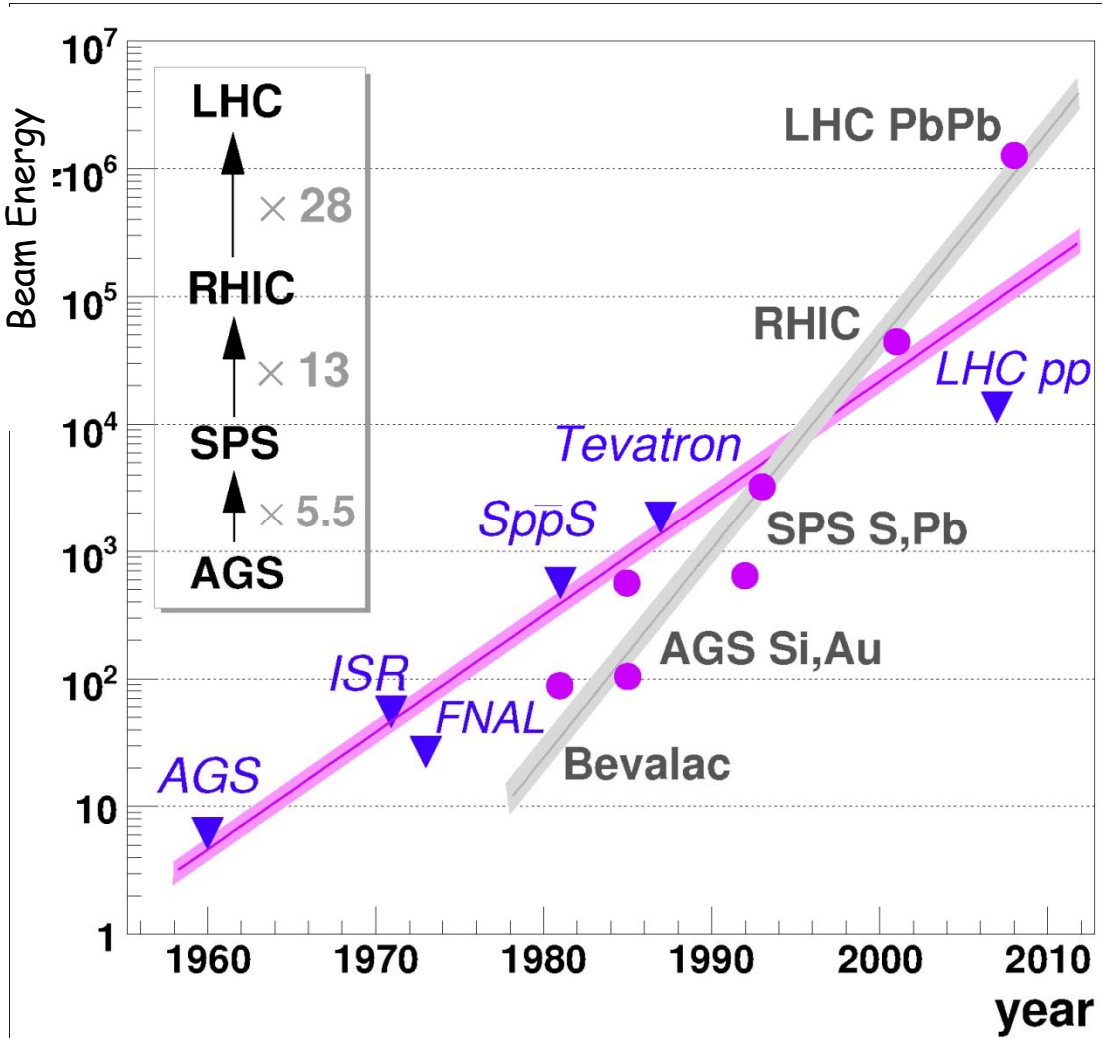
**SACLAY**
**22 October 2010**



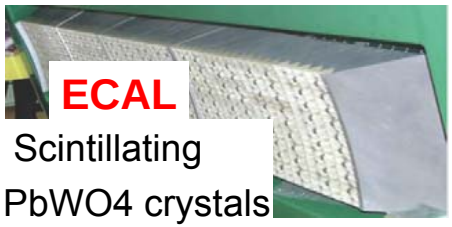


CMS
LHCb
ATLAS
ALICE

# Large Hadron Collider

- **LHC is running:**
  - **2009-2011**
    - p+p at 7 TeV
  - **2010, 2011**
    - Pb+Pb at 2.8 TeV per nucleon pair
  - **2013 and beyond**
    - p+p at 14 TeV
    - Pb+Pb at 5.5 TeV per nucleon pair
- **Heavy Ions**
  - **Expect ~1 month of heavy ion collisions each year, starting in 10 weeks from now**
- **Start with very low luminosity in 2010, 2011, go to nominal in 2013**
  - **10 $\mu b^{-1}$, 20 $\mu b^{-1}$, 0.5 $nb^{-1}$**

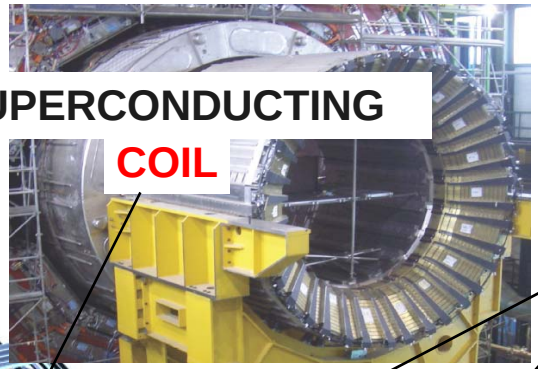


# CMS detector at the LHC



**ECAL**

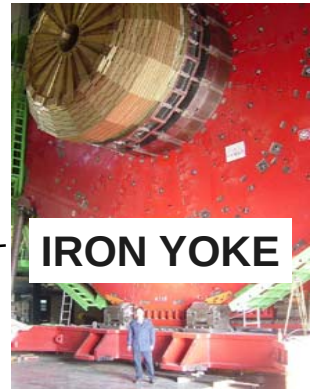
Scintillating PbWO4 crystals



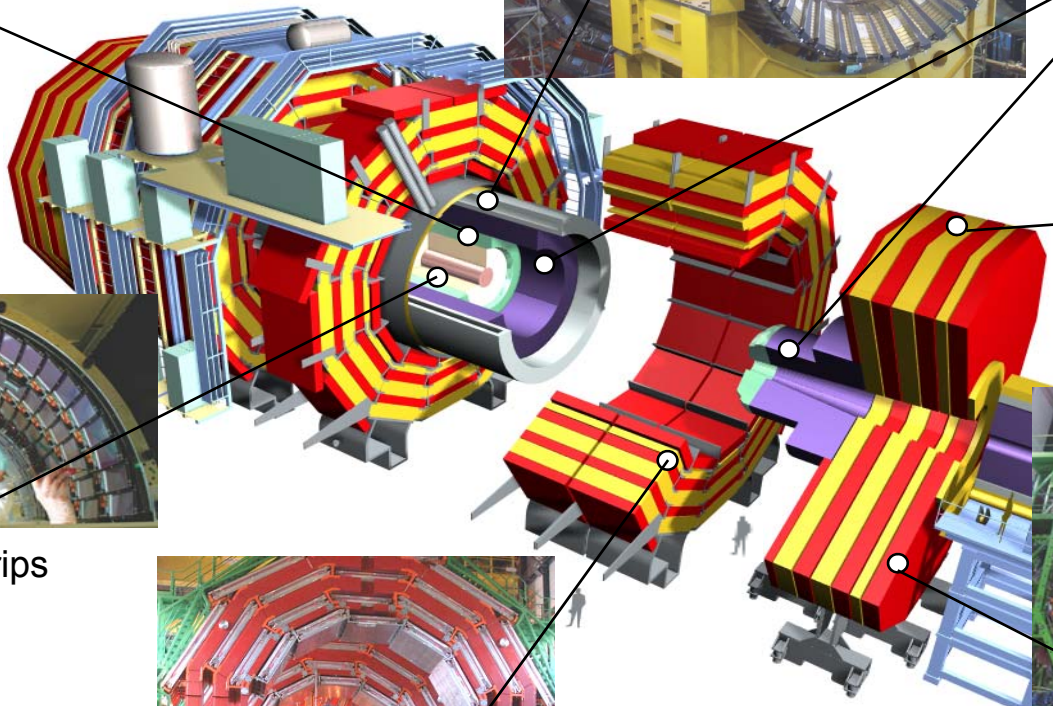
**SUPERCONDUCTING COIL**

**HCAL**

Plastic scintillator/brass sandwich



**IRON YOKE**



**TRACKER**

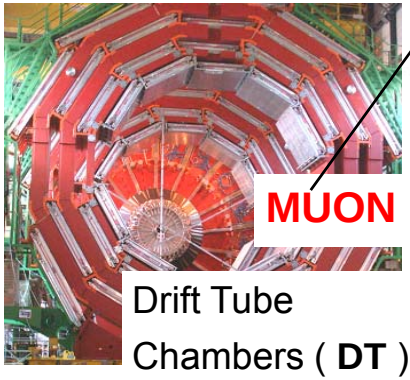
Silicon Microstrips
Si Pixels

**Length: 21.6 m**

**Diameter: 15 m**

**Weight: ~12500 tons**

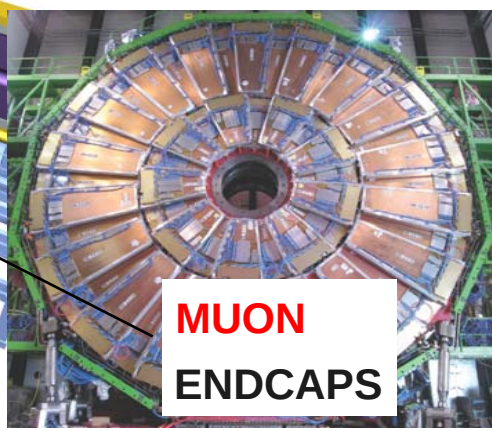
**Magnetic Field: 3.8 Tesla**



**MUON BARREL**

Drift Tube Chambers ( **DT** )

Resistive Plate Chambers ( **RPC** )

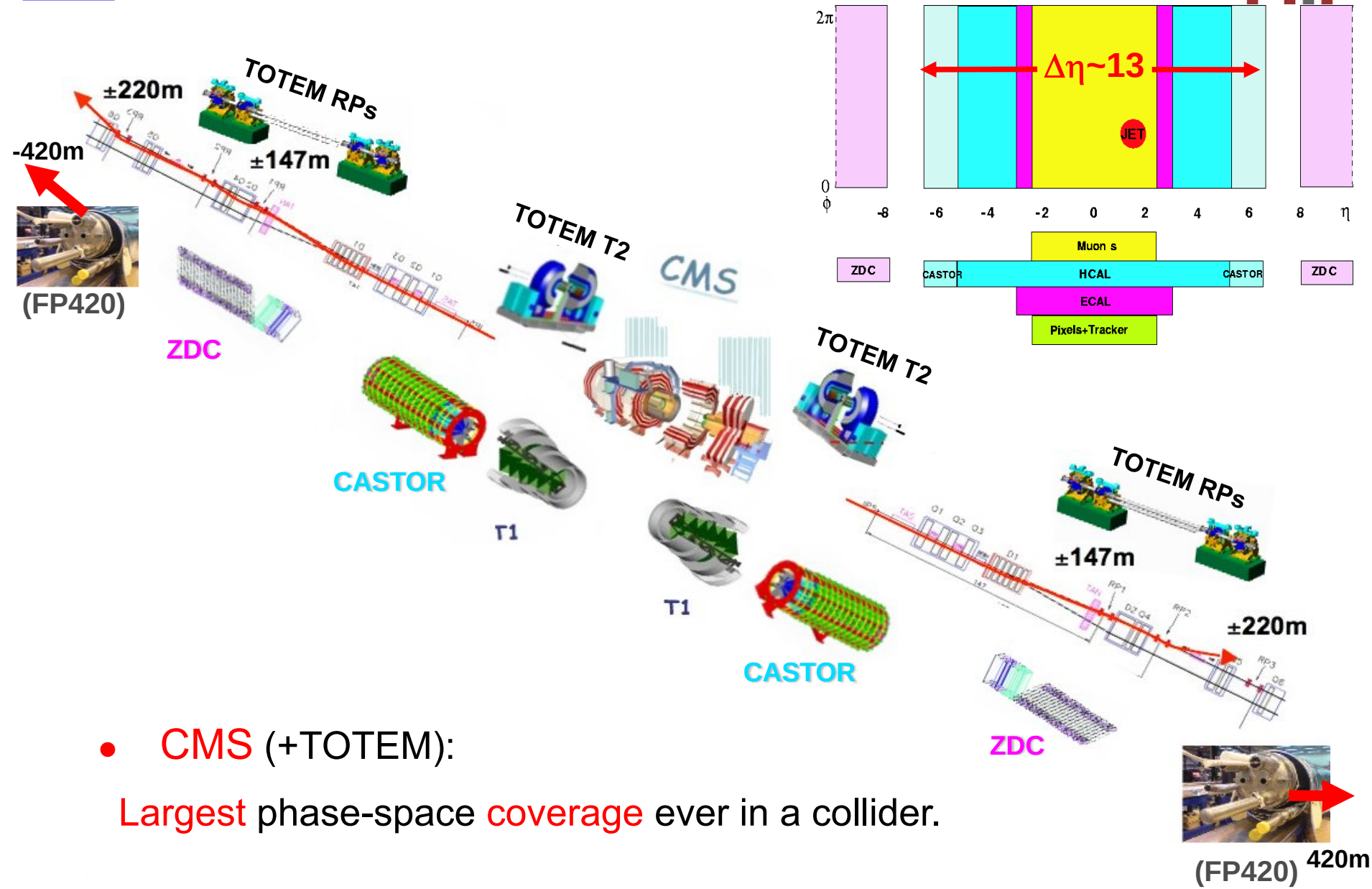


**MUON ENDCAPS**

Cathode Strip Chambers (**CSC** )

Resistive Plate Chambers (**RPC**)

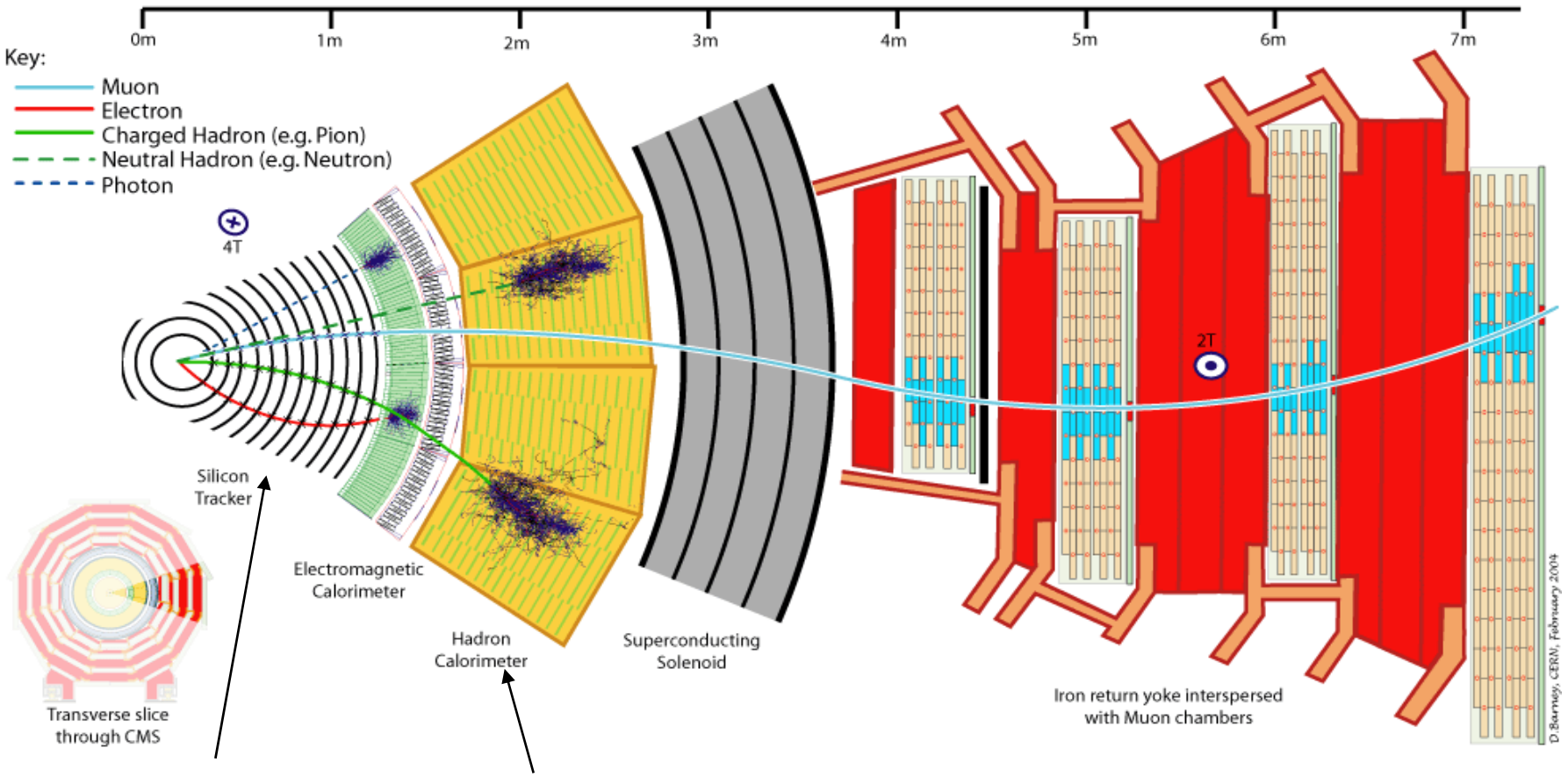
# CMS detector at the LHC




- CMS (+TOTEM):

  Largest phase-space coverage ever in a collider.

# $h^{\pm}$, $e^{\pm}$, $\gamma$ , $\mu^{\pm}$ measurement in CMS ($|\eta|<2.5$)




## Si TRACKER

Silicon Microstrips and Pixels

## CALORIMETERS

**ECAL**
$PbWO_4$

**HCAL**
Plastic Sci/Steel sandwich

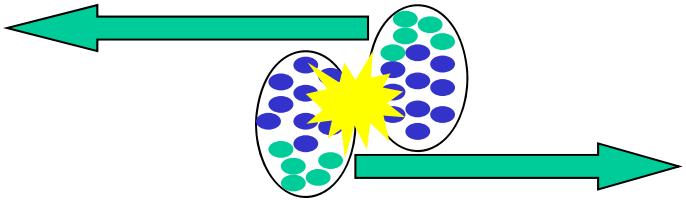
## MUON BARREL

Drift Tube Chambers (**DT**)

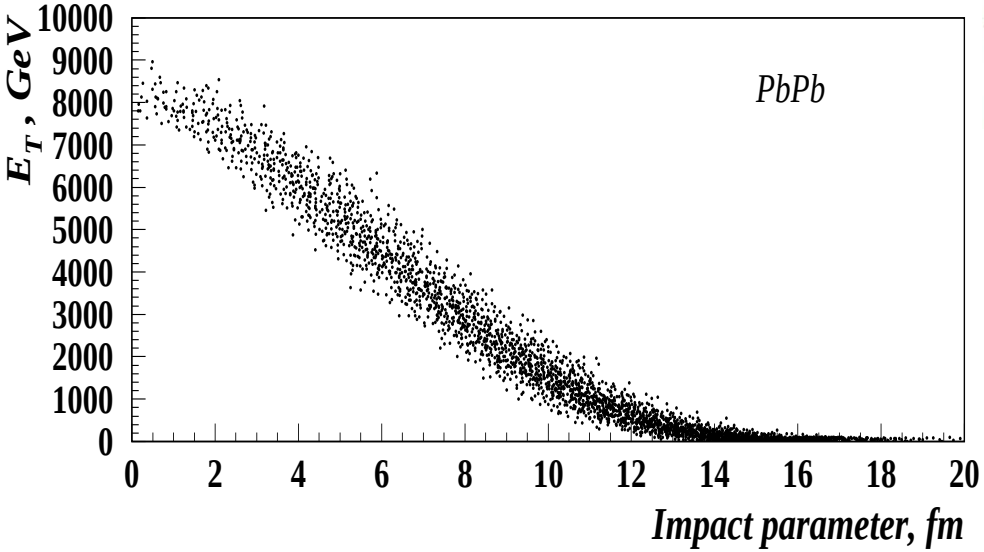
Resistive Plate Chambers (**RPC**)

# Centrality and forward detectors

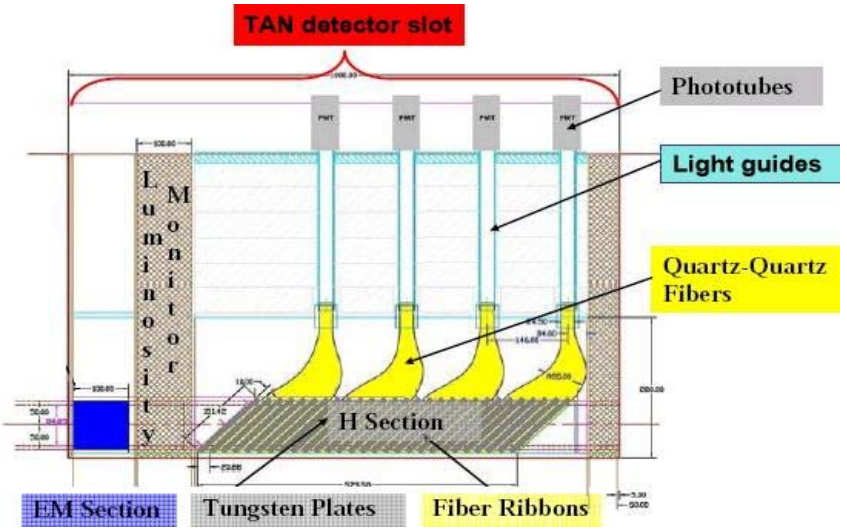
Centrality (impact parameter) determination is needed for most physics analyses



Energy in the forward hadronic calorimeter

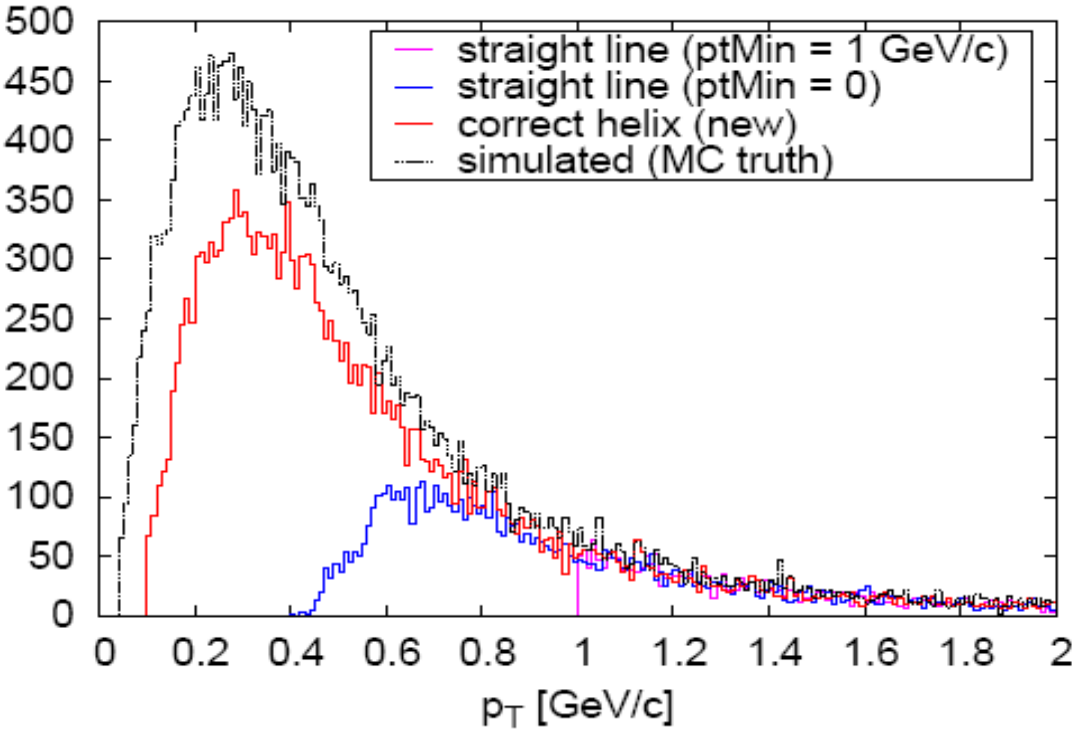


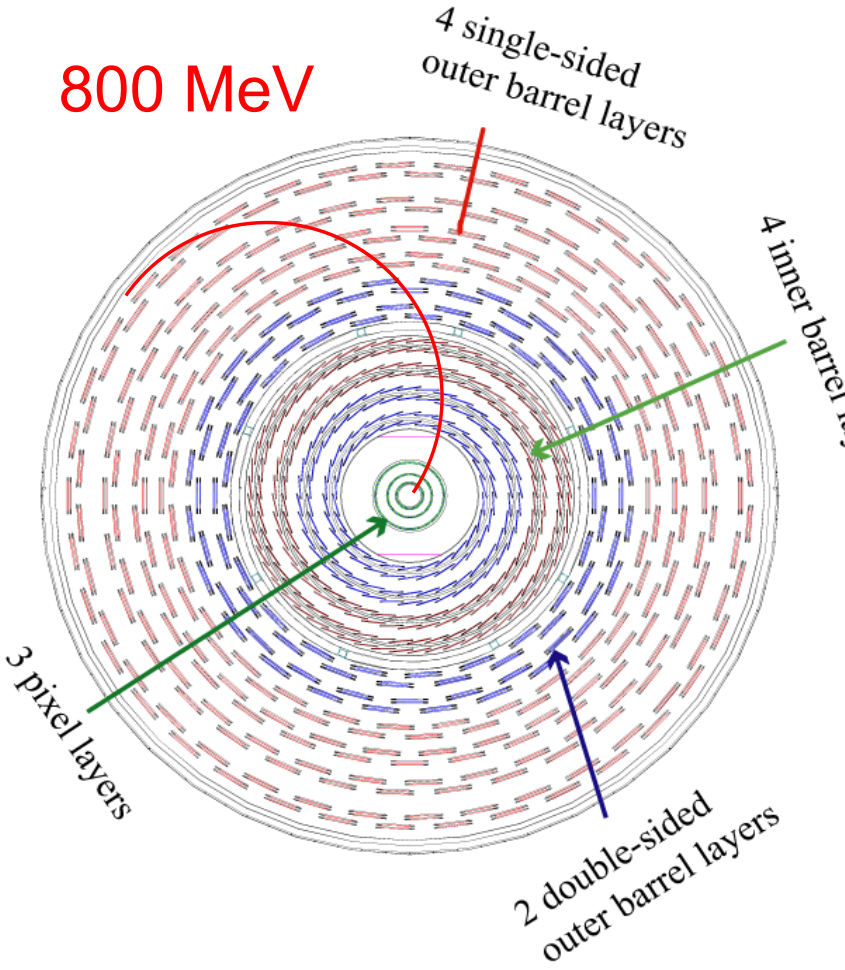

Zero Degree Calorimeter




- Tungsten-quartz fibre structure
- electromagnetic section: $19X_0$
- hadronic section $5.6\lambda_0$
- Rad. hard to ~20 Grad (AA, pp low lum.)
- Energy resolution (n,γ): $\sigma_E$~E·10%
- Position resolution: ~2 mm (EM sect.)
- ~140 meters from CMS IP

# Pixel Tracking, low $p_T$ reach of CMS



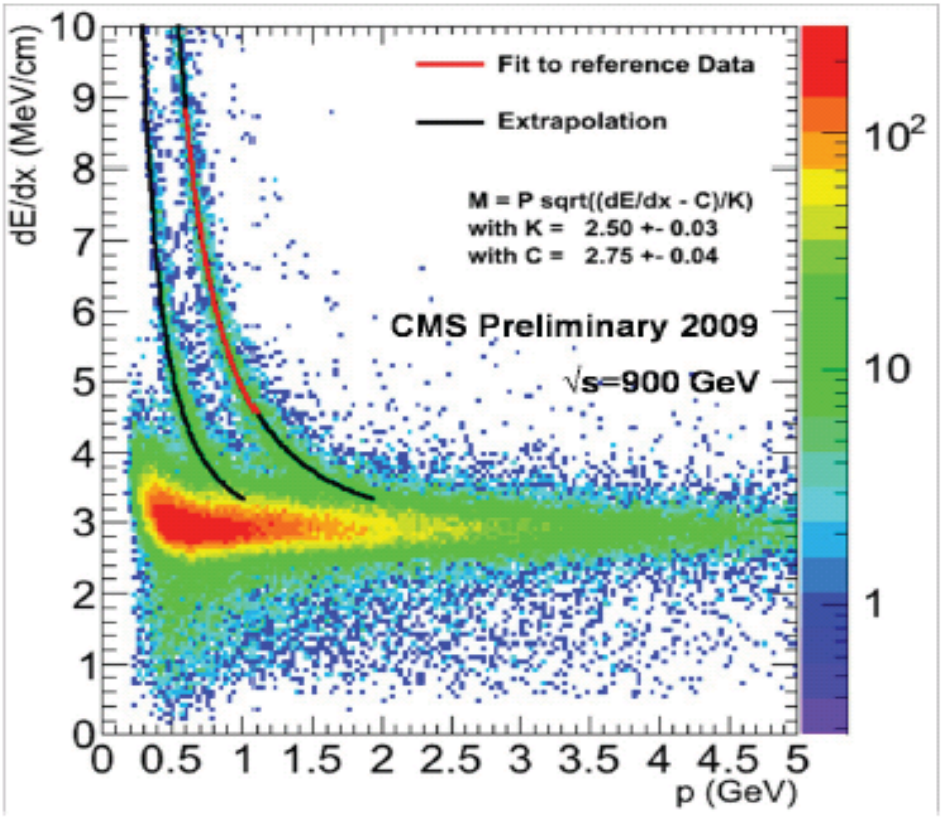

Pixel tracking

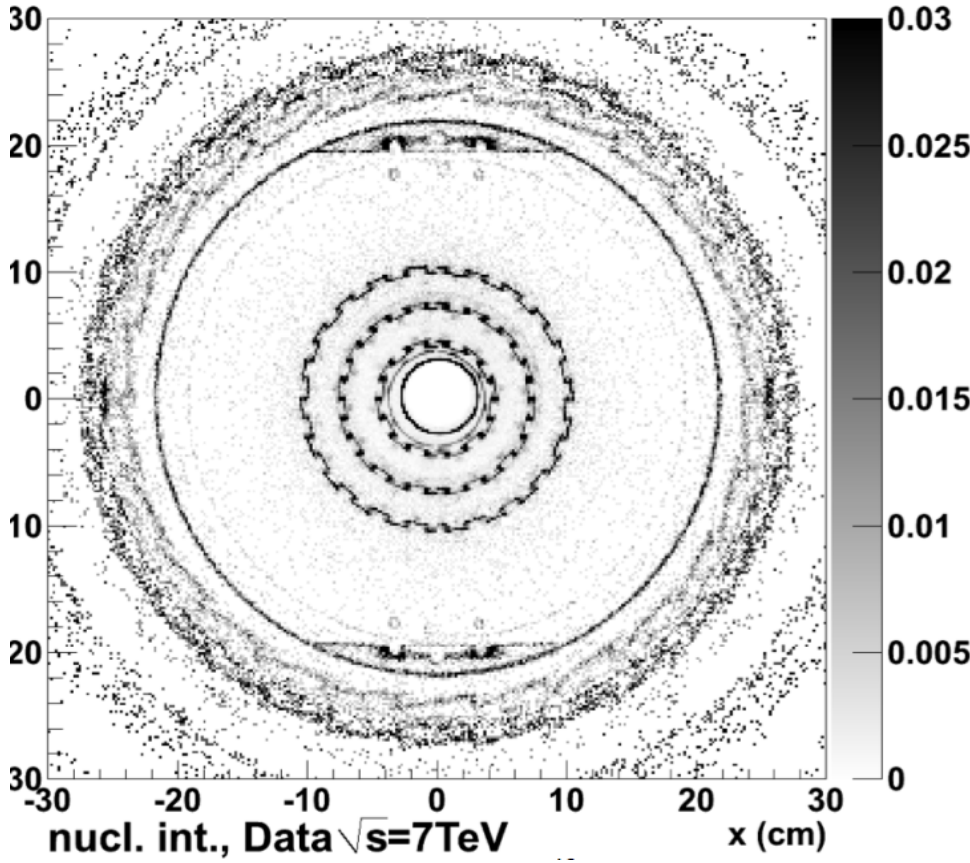
All tracker fitting

# Getting to know the tracker

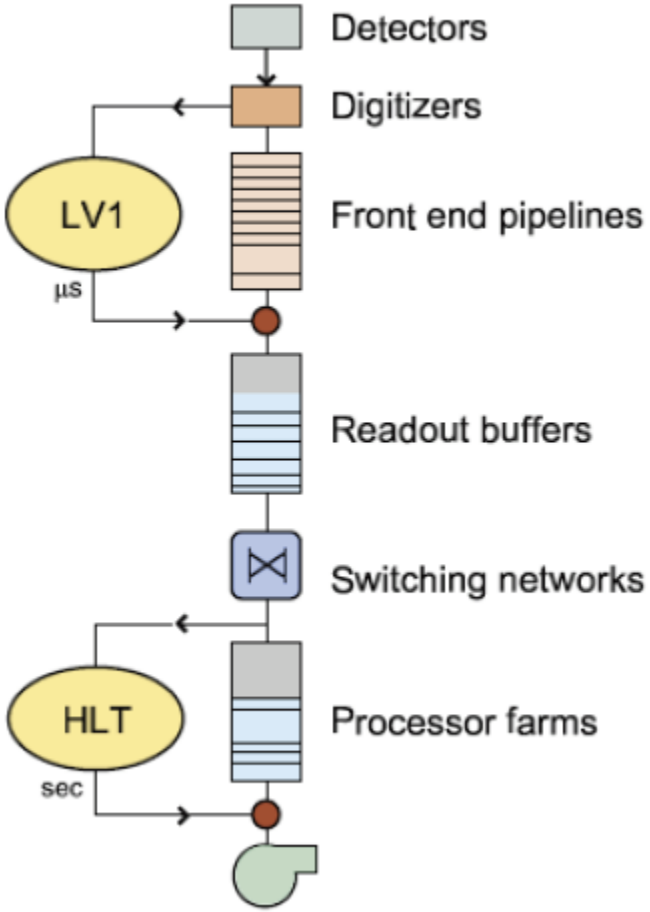
- **Excellent performance of tracker**
- **Studying material, readout, alignment…**

## Silicon strip PID



# CMS Trigger and DAQ in p+p




## Level 1 trigger

- Uses custom hardware
- Muon tracks + calorimeter information
- Decision after ~ 3µsec

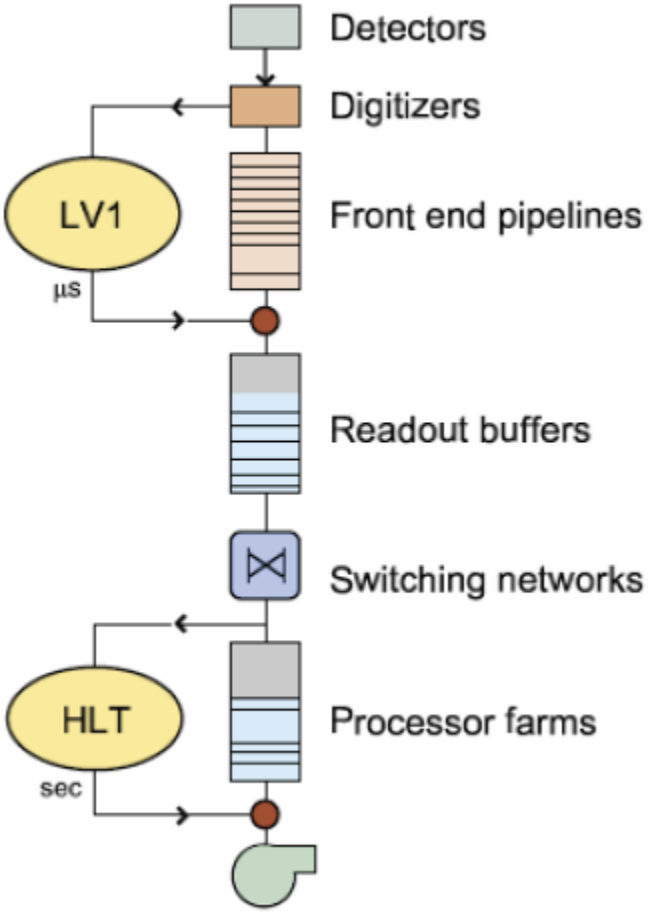
| Level-1 | | p+p |
|---|---|---|
| Collision rate | | 1GHz |
| Event rate | | 32MHz |
| Output bandwidth | | 100 GByte/sec |
| Rejection | | 99.7% |

## High level Trigger

- ~1500 Linux servers (~10k CPU cores)
- Full event information available
- Runs “offline” algorithms

| High Level Trigger | | p+p |
|---|---|---|
| Input event rate | | 100kHz |
| Output bandwidth | | 225 MByte/sec |
| Output rate | | 150Hz |
| Rejection | | 99.85% |

# CMS Trigger and DAQ in Pb+Pb vs p+p




## Level 1 trigger

- Uses custom hardware
- Muon tracks + calorimeter information
- Decision after ~ 3μsec

| Level-1 | Pb+Pb | p+p |
|---|---|---|
| Collision rate | 3kHz (8kHz peak) | 1GHz |
| Event rate | 3kHz (8kHz peak) | 32MHz |
| Output bandwidth | 100 GByte/sec | 100 GByte/sec |
| Rejection | none | 99.7% |

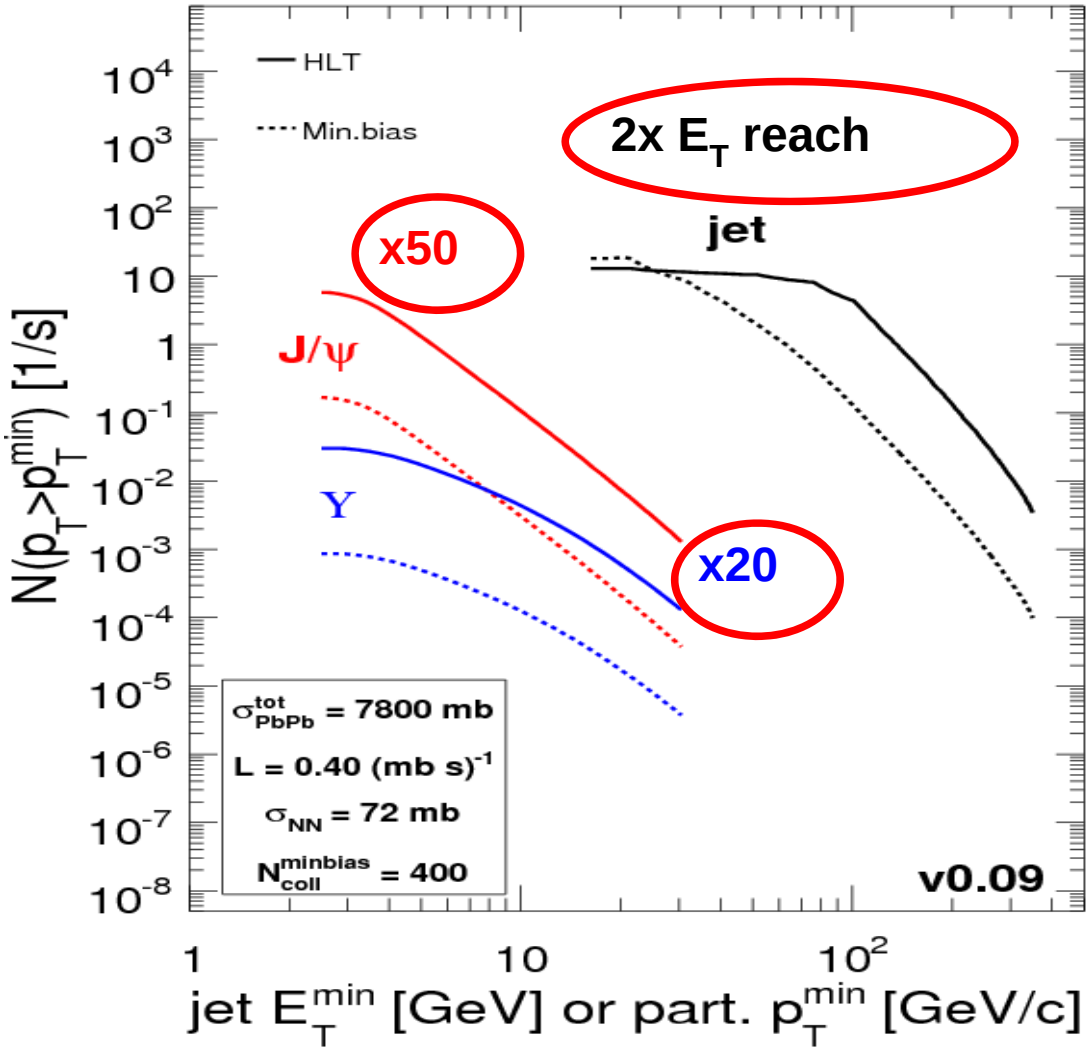
## High level Trigger

- ~1500 Linux servers (~10k CPU cores)
- Full event information available
- Runs “offline” algorithms

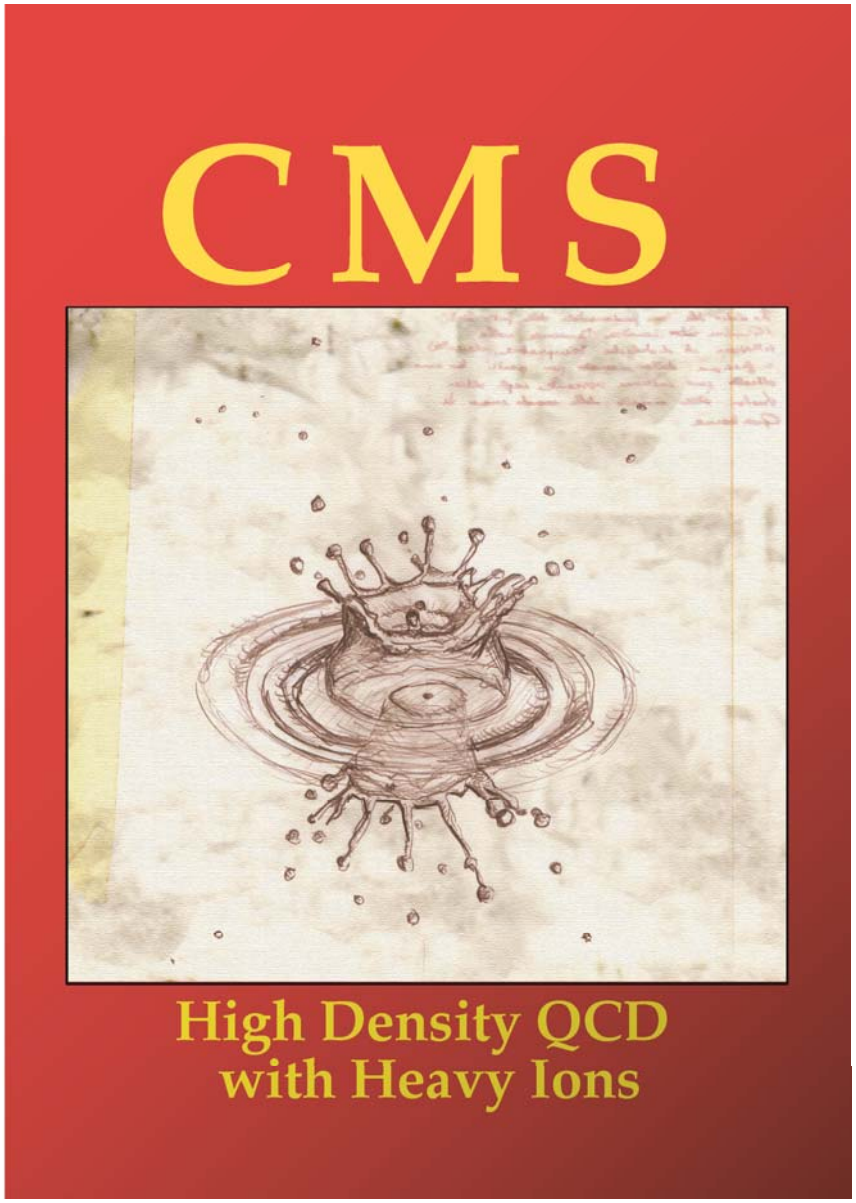
| High Level Trigger | Pb+Pb | p+p |
|---|---|---|
| Input event rate | 3kHz (8kHz peak) | 100kHz |
| Output bandwidth | 225 MByte/sec | 225 MByte/sec |
| Output rate | 10-100Hz | 150Hz |
| Rejection | 97-99.7% | 99.85% |

# Pb-Pb High-Level Triggering

Significantly enhanced statistical reach for hard probes: x20 – x300



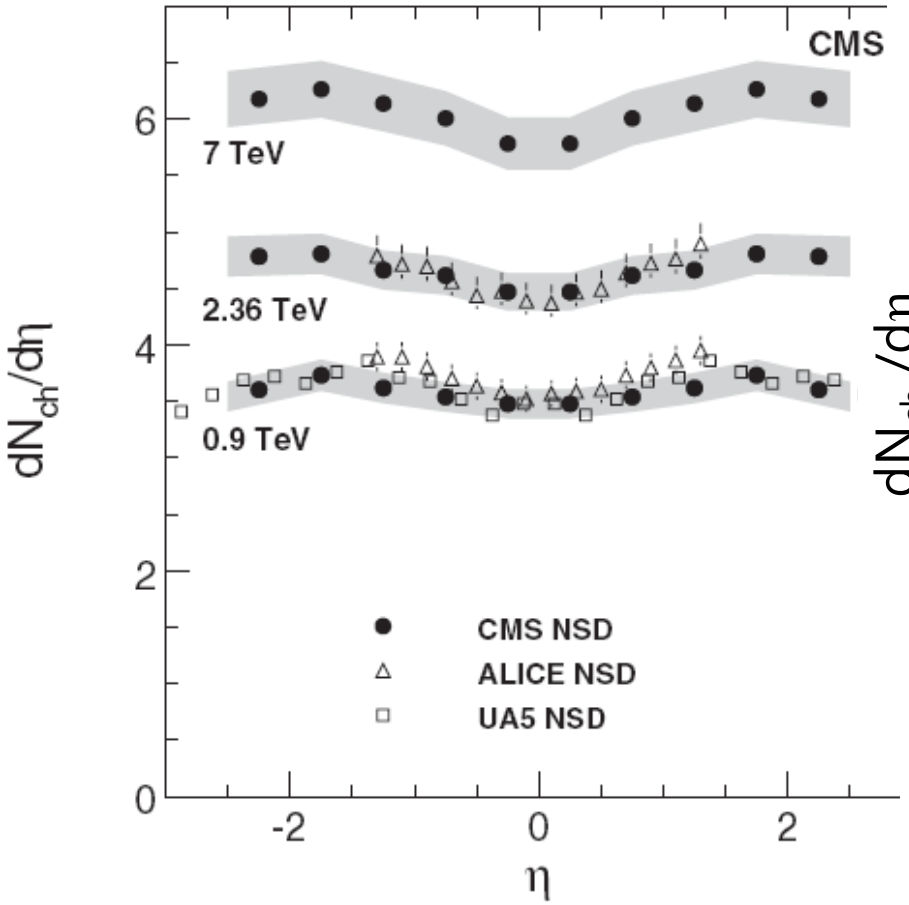
# CMS Heavy Ion Multi-Year Physics Plan

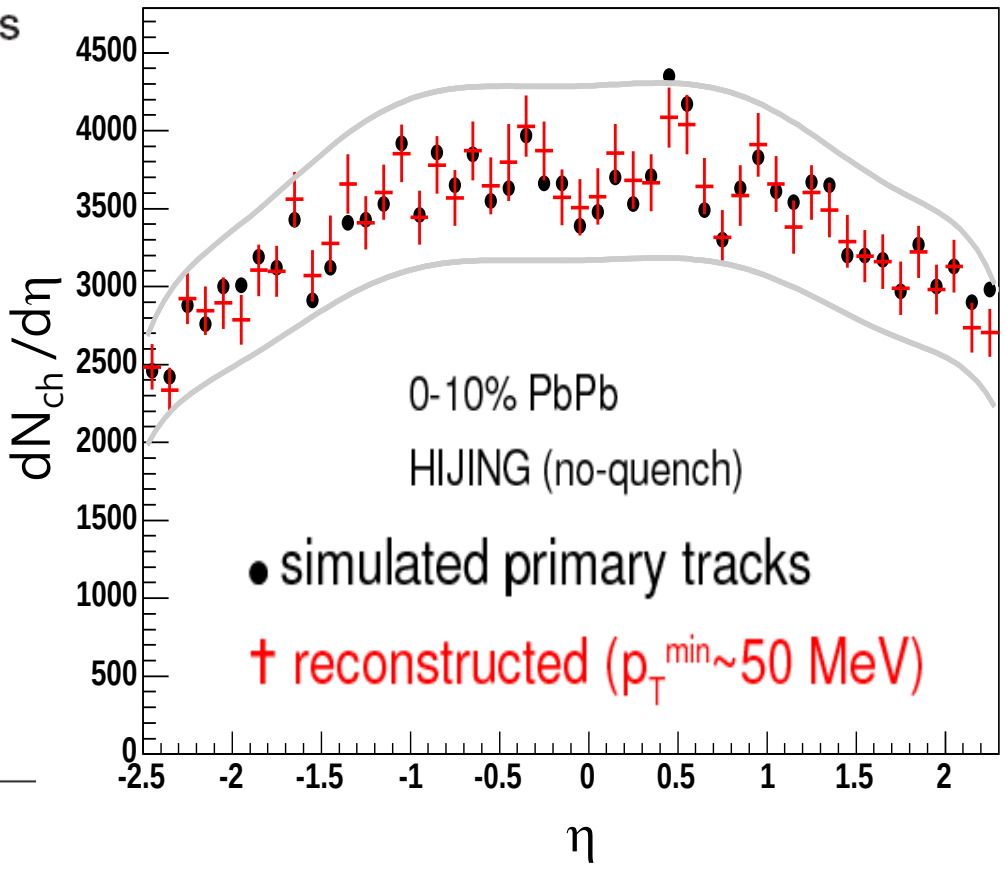



- Particle production: multiplicity, azimuthal asymmetry, particle spectra, photons
- Two particle correlations
- Jet physics: fragmentation, flavor dependence, jet+$\gamma$, jet+$Z^0$
- Quarkonia physics: J/$\psi$, $\Upsilon$ family
- Vector bosons: $Z^0$ production
- Forward Energy Flow
- Ultra Peripheral Collisions
- and more...

- Many simulations will be updated with better knowledge of multiplicity as soon as we get data. PTDR was at 5.5 TeV/A

# Charged Particle Multiplicity

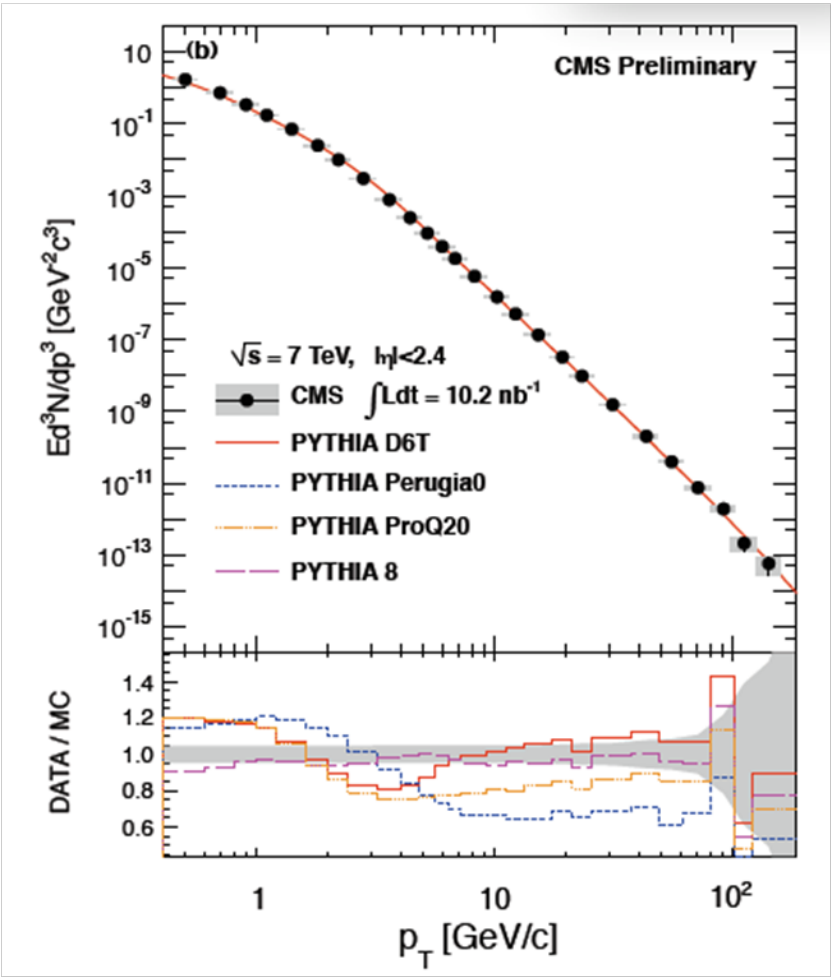


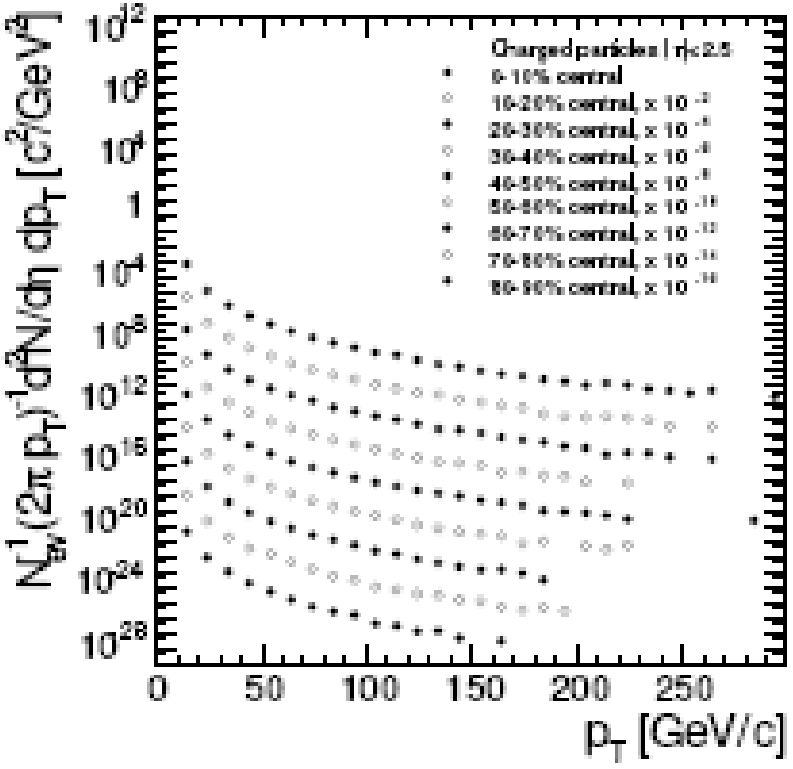




**proton-proton data**

**Pb-Pb simulation, PTDR**

# Charged Hadron Spectra $p_T$




**CMS proton-proton data**

**Pb-Pb simulation**

# Two particle correlations

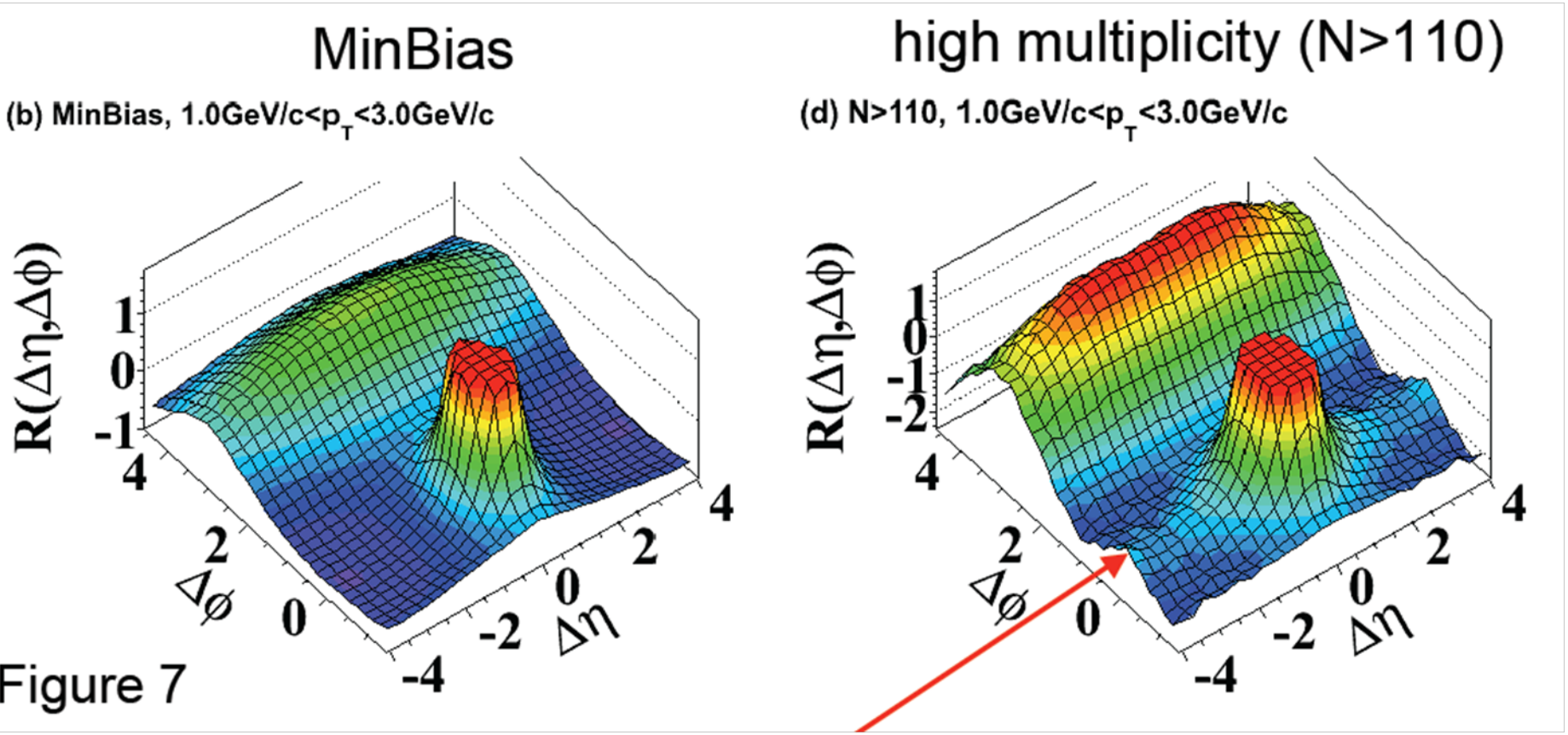
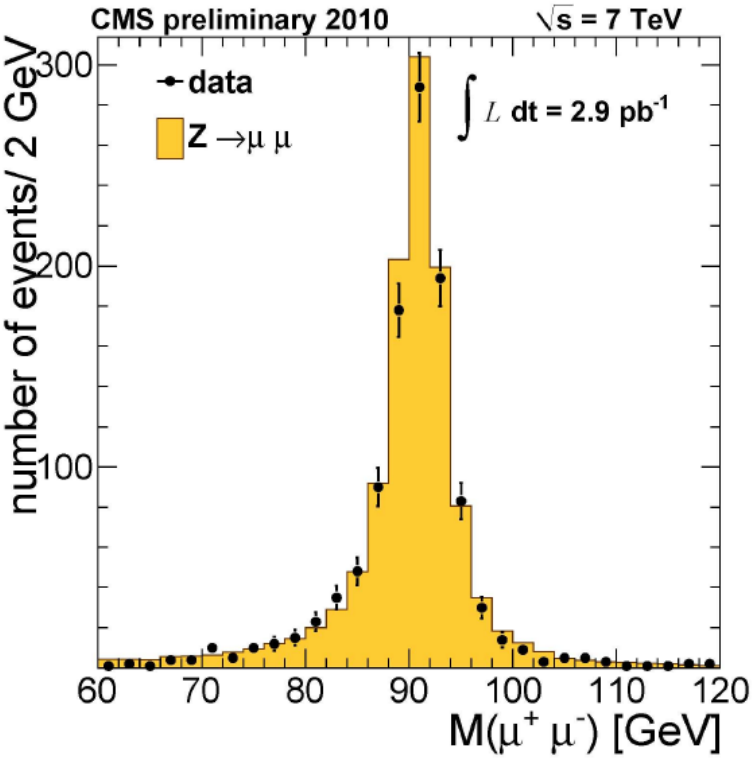
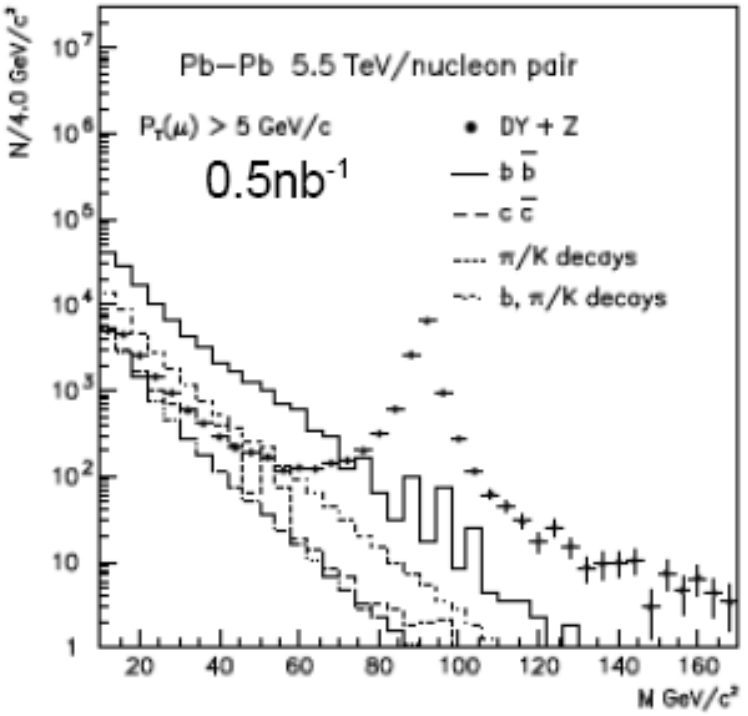



Figure 7

**CMS proton-proton data**

# $Z^0$ production

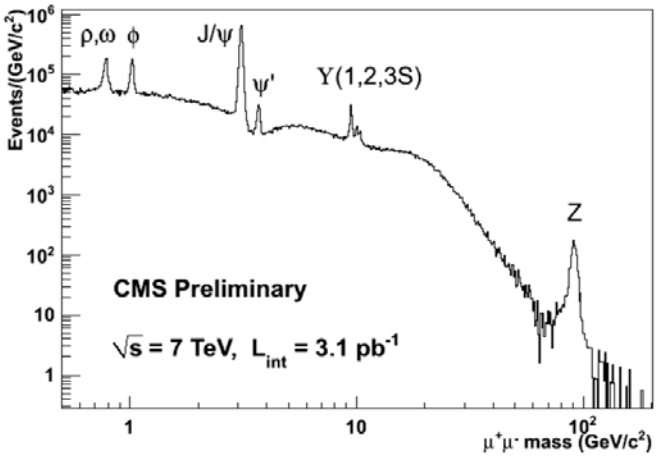


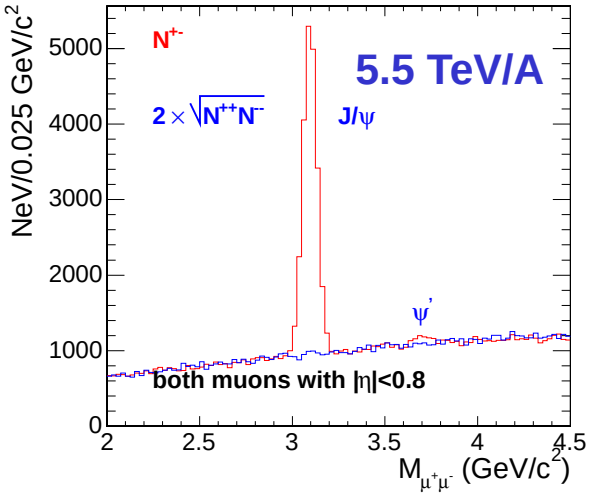



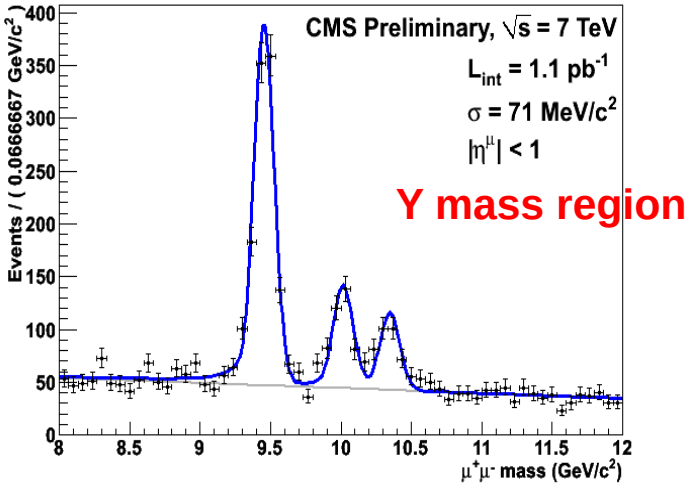

**CMS proton-proton data**

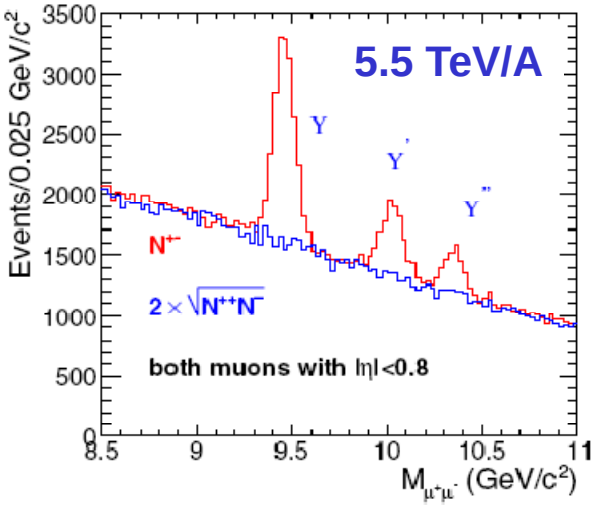
**Pb-Pb simulation**

# Heavy Flavor (J/ψ ,ϒ)



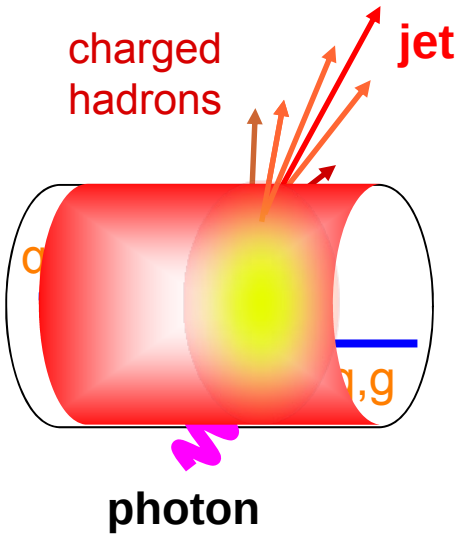



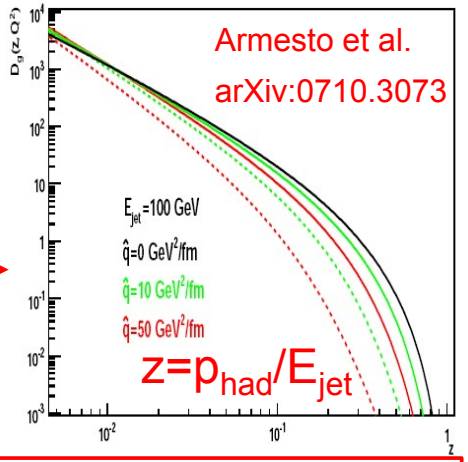

**CMS proton-proton data**

**Pb-Pb simulation, PTDR**

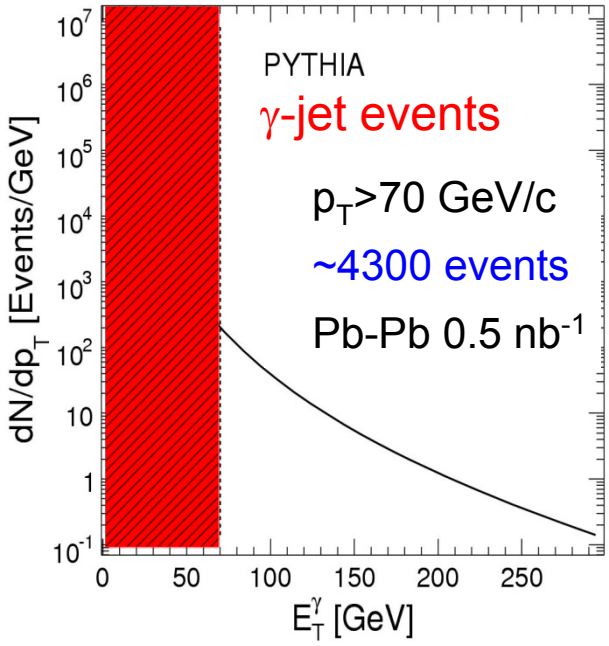
# γ– jet in Pb-Pb (I): medium fragmentation functions

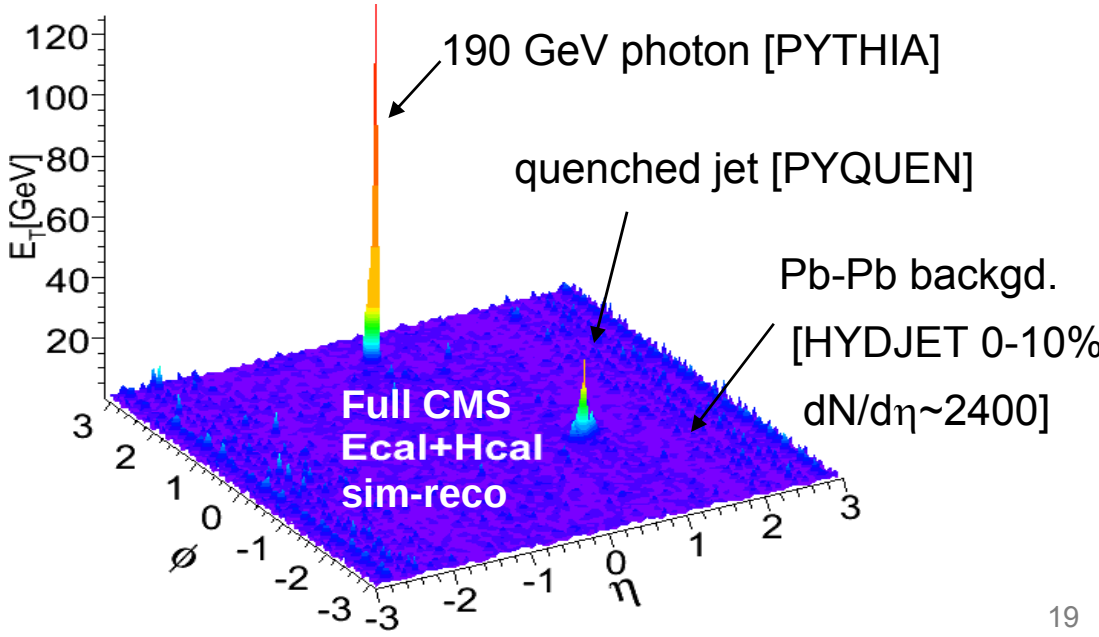



- Isolated γ ($|\eta|<2$, $R_{isol}<0.5$): $E_T^{parton}$
- Jet ($|\eta|<2$, $|\Delta\phi_{jet-\gamma}|>3$): away axis
- Hadrons ($|\eta|<2.5$, $R_{jet}<0.5$): $p_T^{had}$



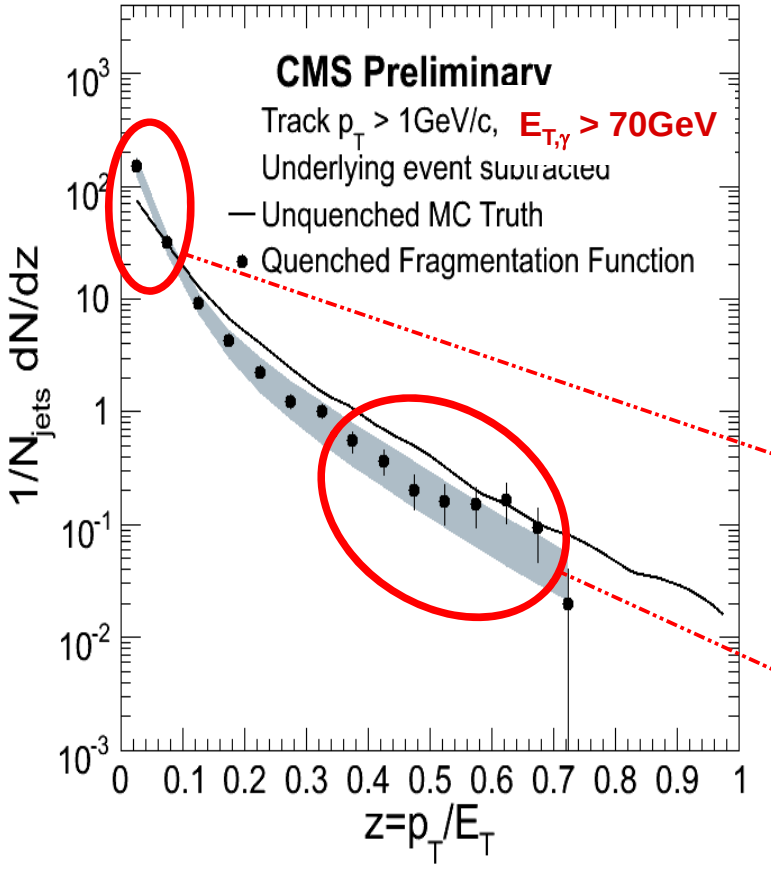

FF(z,$\hat{q}$): dN/dz,dN/dξ



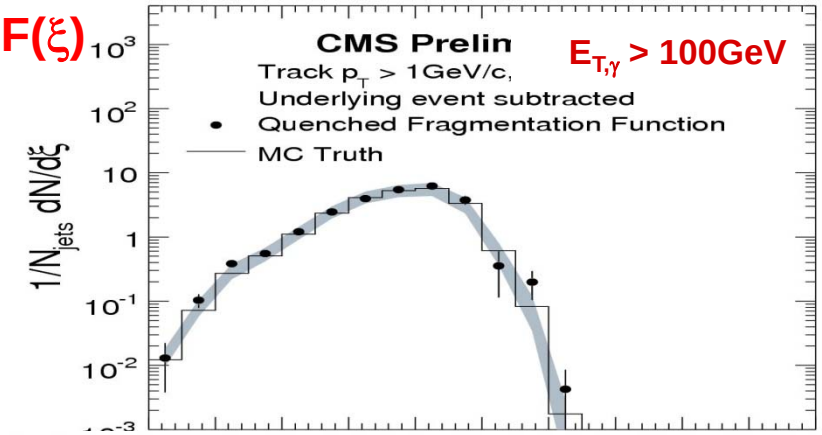



# Medium-modified Fragmentation Functions

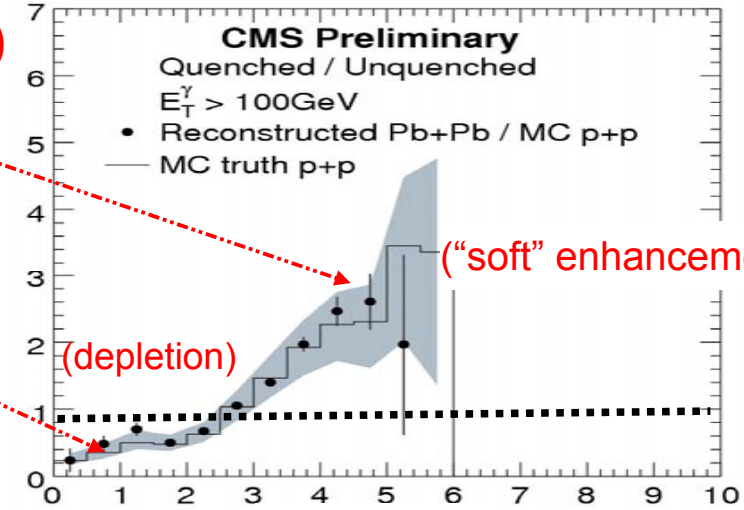
**FF(z)**




**FF(ξ)**



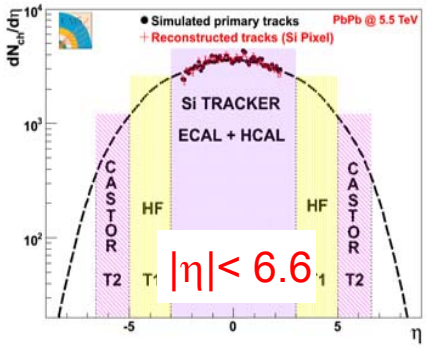

**$R_{FF}(\xi)$**



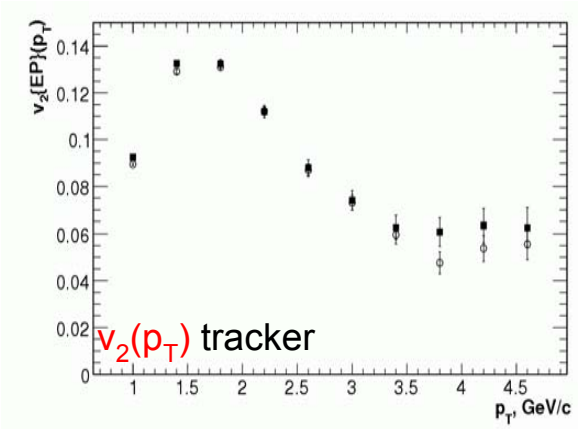

- Medium mod. FFs measurable for $z<0.7$ & $0.2<\xi<5$ with high significance
- Syst. uncertainties dominated by (low) jet reco effic. 30-70 GeV

# Summary: QCD matter with CMS @ LHC

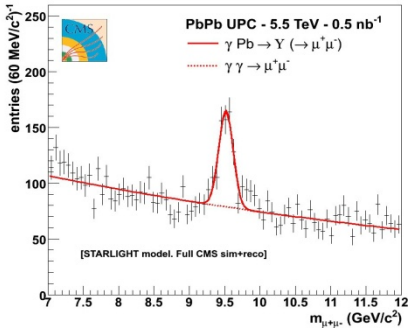
## multiplicity: entropy




## $v_2$: QGP viscosity

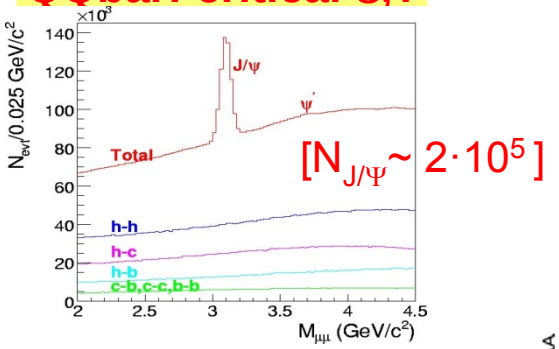



## UPC: low-x gluons

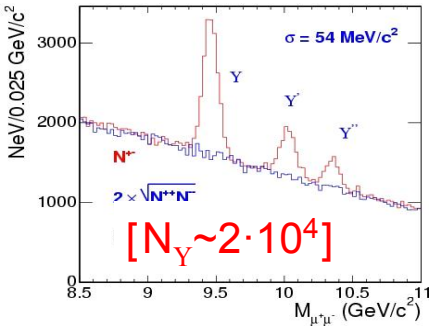



[$N_\Upsilon$~500]

## QQbar: critical ε,T

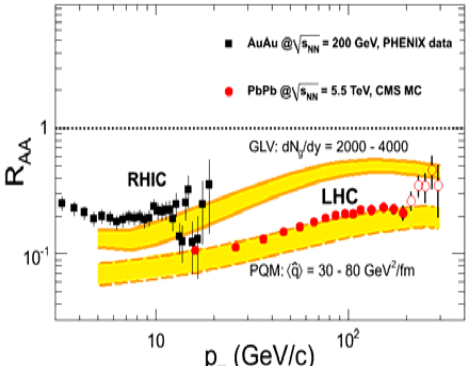



[$N_{J/\Psi}$~ 2·10$^5$ ]

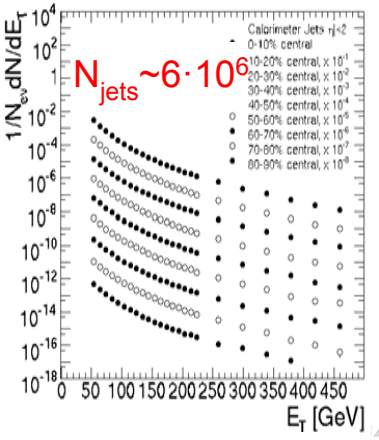



[$N_\Upsilon$~2·10$^4$]

## high-$p_T$ hadrons, jets, γ - jet: ⟨q⟩, dN$^g$/dy

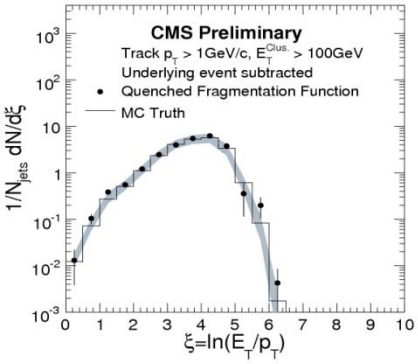



[$p_T$~300 GeV/c]




N$_{jets}$~6·10$^6$

[$E_T$~0.5 TeV ]




**FFs** [0.2<ξ< 5]

# Conclusions

- LHC will extend energy range and in particular high $p_T$ reach of heavy-ion physics
- CMS is preparing to take advantage of its capabilities
  - Excellent rapidity and azimuthal coverage and high resolution
    - Quarkonia
    - Jets
  - Centrality, Multiplicity, Energy Flow reaching very low $p_T$
  - Essentially no modification to the detector hardware
  - New High Level Trigger algorithms specific for A+A
  - Zero Degree Calorimeter, CASTOR and TOTEM will be important additions extending forward coverage
  - Heavy-Ion program is well integrated into the overall CMS Physics Program
- Initial performance of CMS indicates that we will be able to do great Heavy-Ion physics
- The knowledge gained at RHIC&SPS will be extended to the new energy domain