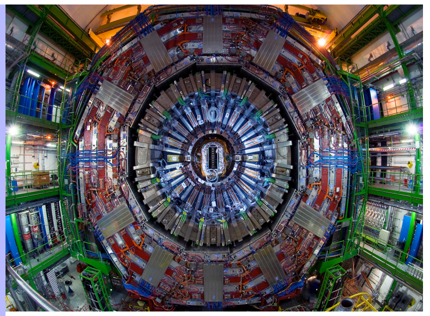
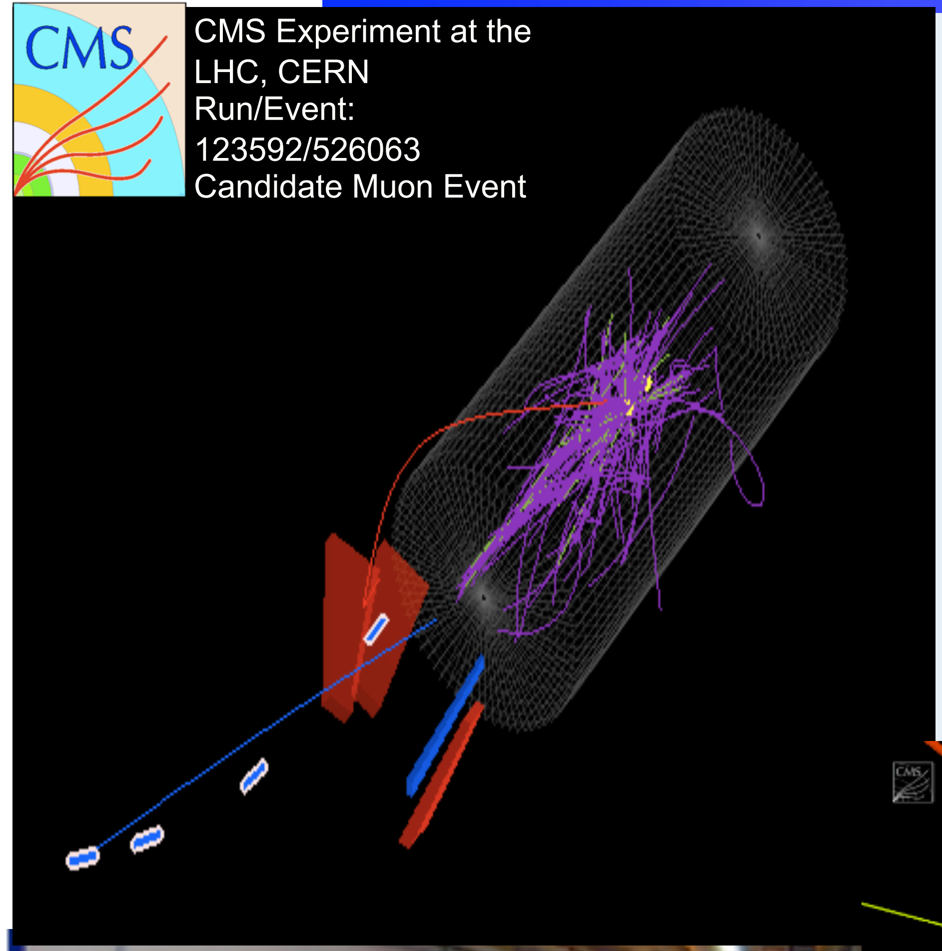


LHC Physics
Challenges and the First Results

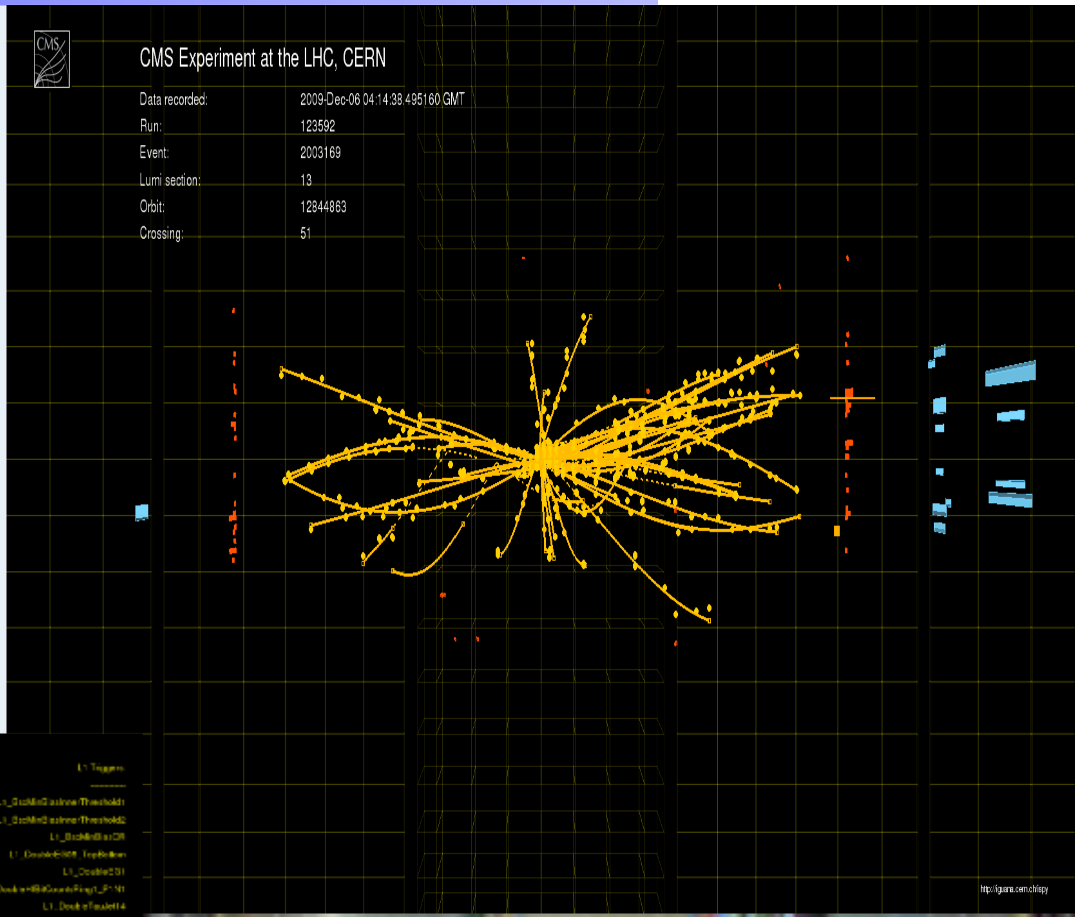


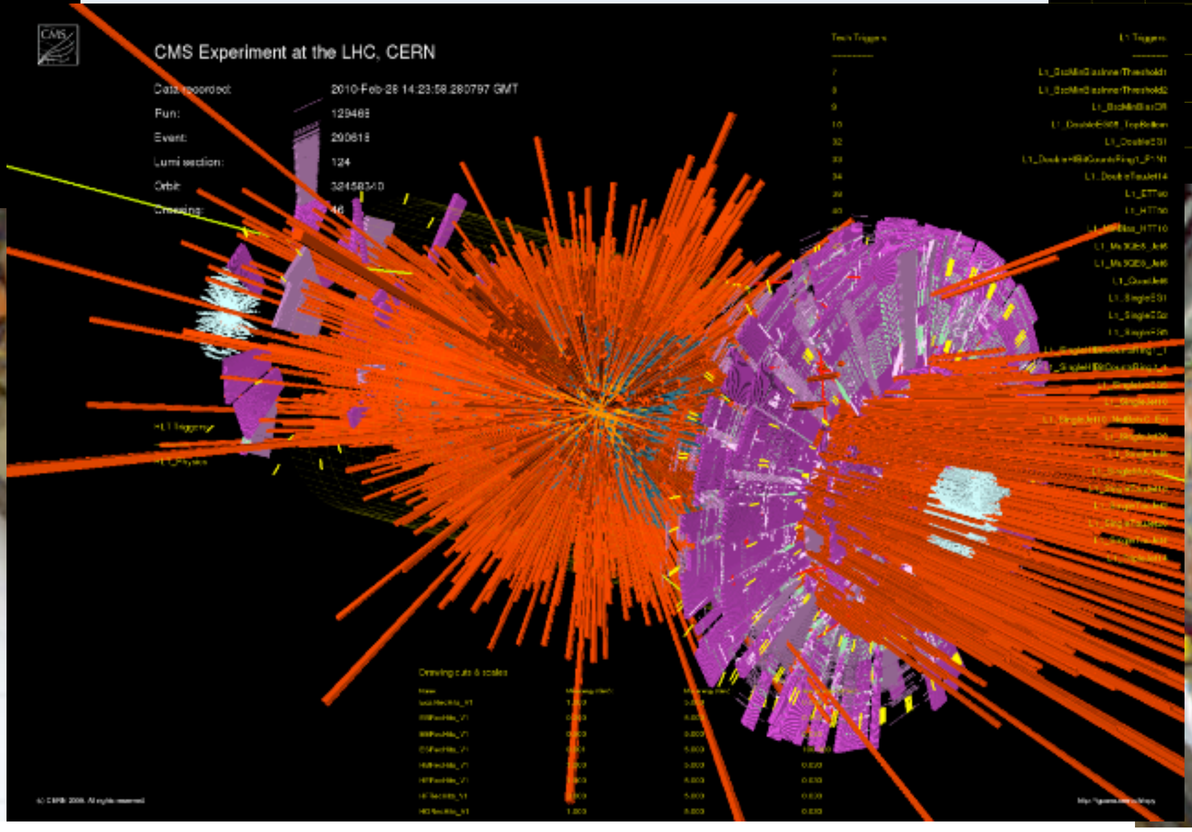
Slawek Tkaczyk
FNAL

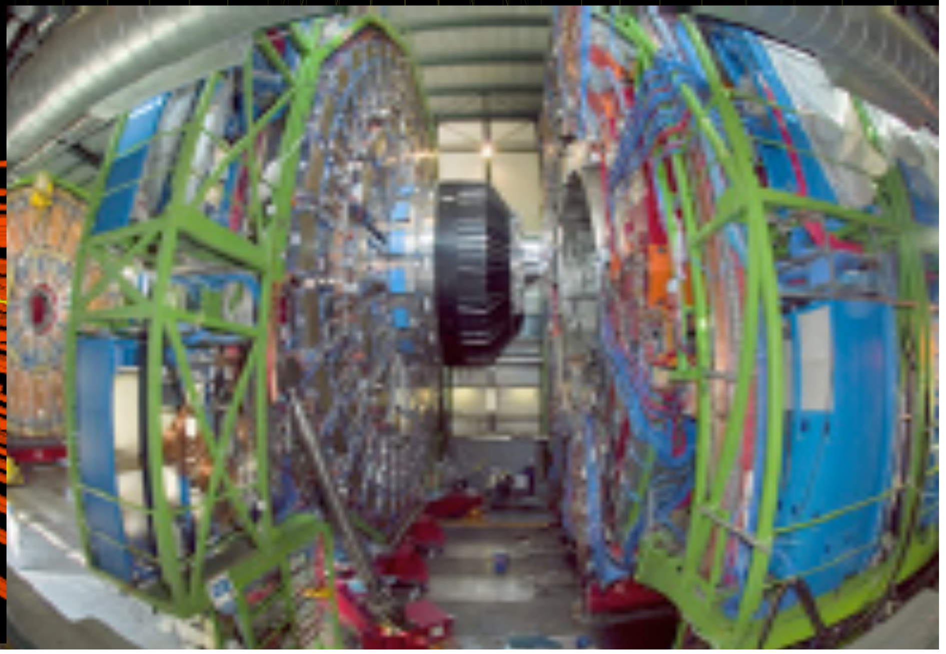
Representing CMS/Atlas collaborations

LATTICE 2010

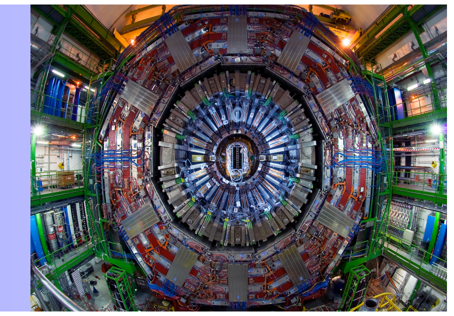
June 14-19, Villasimius, Sardinia, Italy





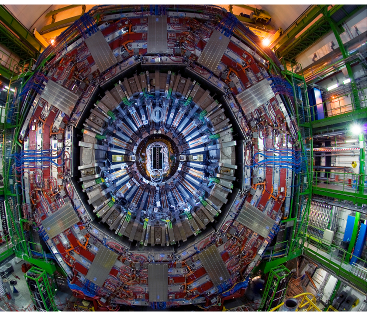


OUTLINE



- Introduction
  - –Machine Status
- From Commissioning to Operations and Analyses
  - –First LHC beams
  - –LHC Physics Run 2010 @7TeV
- Conclusions

Physics Cruxes of Today



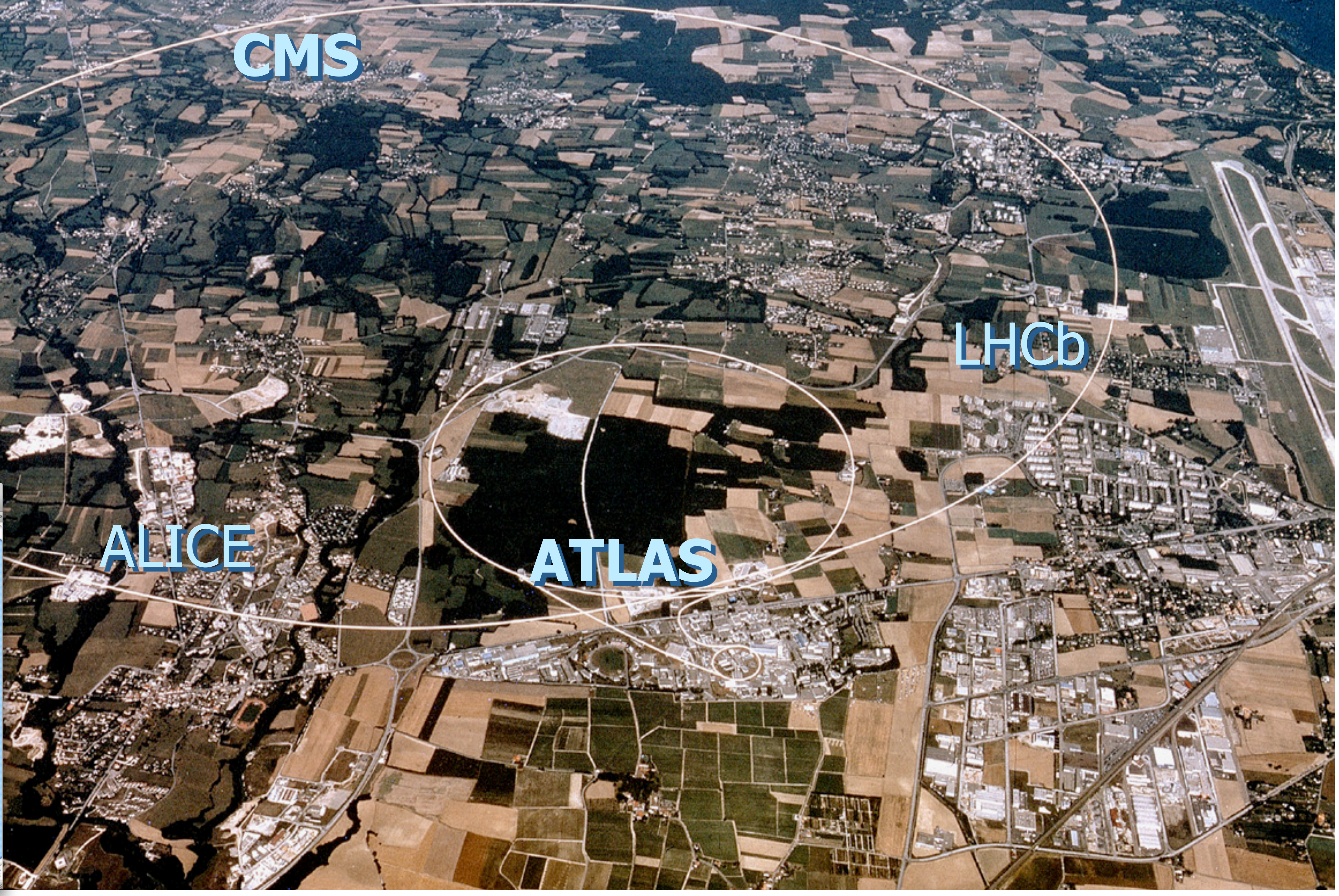
- How do particles acquire mass?
- What is the origin of the spontaneous symmetry breaking?
- Is the Universe super-symmetric?
- What explains dark matter?
- Are there extra dimensions?

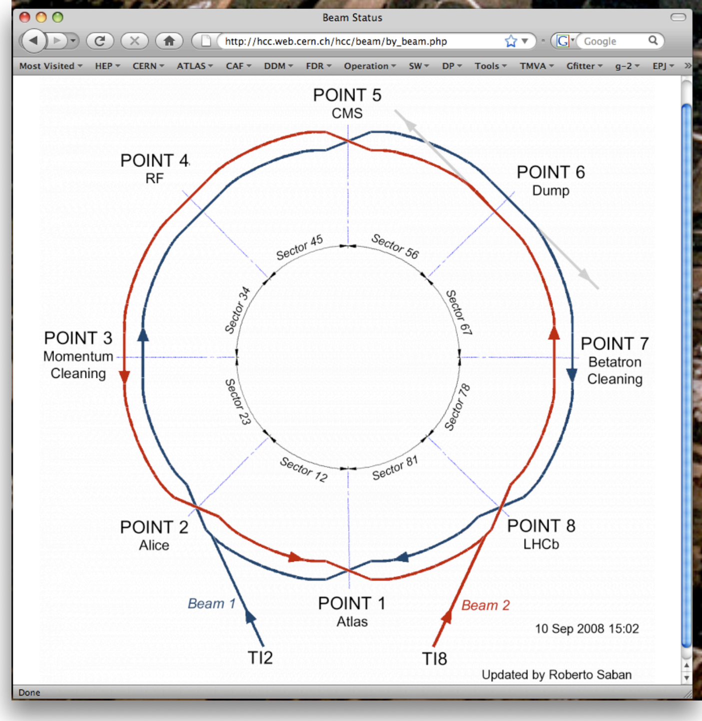
• **IMPORTANT** unsolved questions need **POWERFUL** apparatus to look for answers!

CERN LARGE HADRON COLLIDER

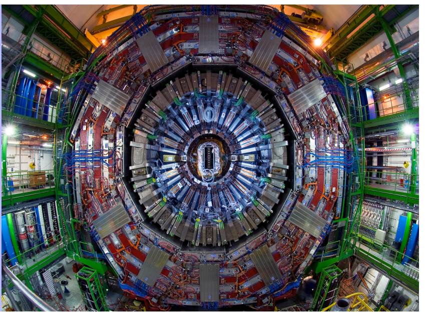
27 km circumference
1200 dipole magnets
- 14m long
- 8.4 T field
- Dual aperture

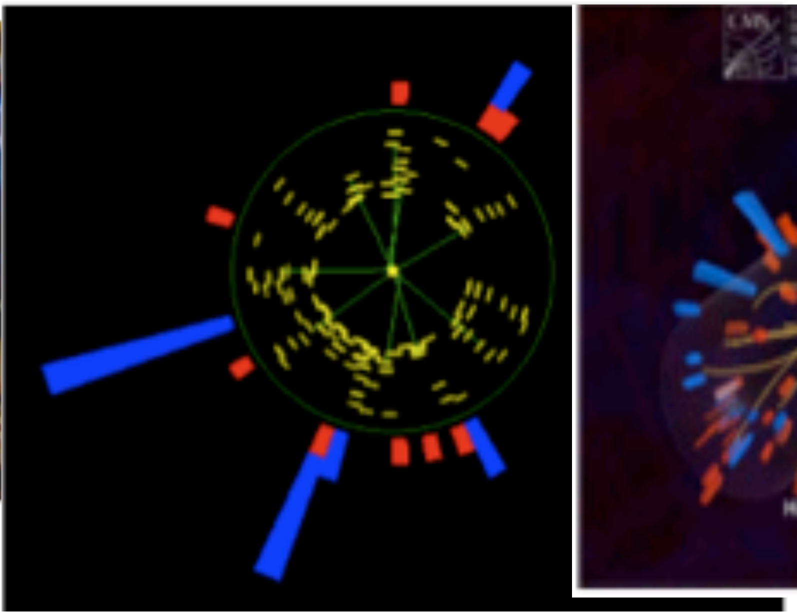
Proton-Proton collisions at 14 TeV
25ns between beam crossings
Peak Luminosity $10^{34} s^{-1} cm^{-2}$
20 collisions per beam crossing

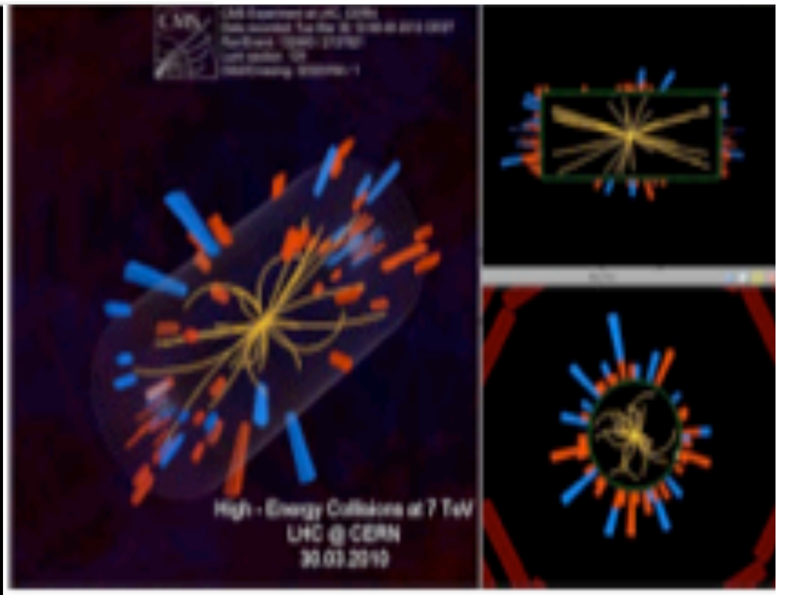




LHC First Beams Timeline







Sep 2008
First beam splashes

Jul 2009
Repairs in the LHC finished

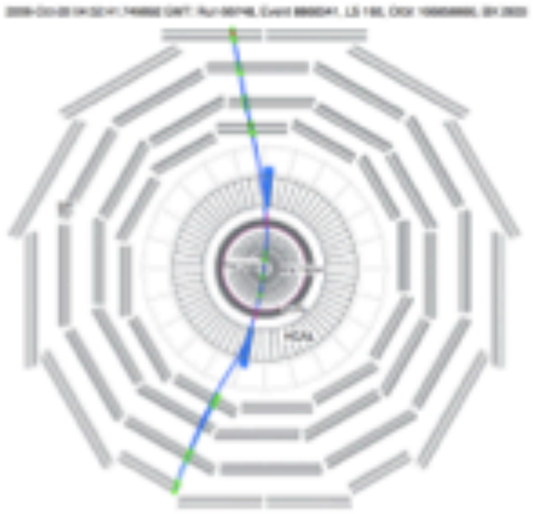
Dec 2009
First 0.9 & 2.36 TeV collisions

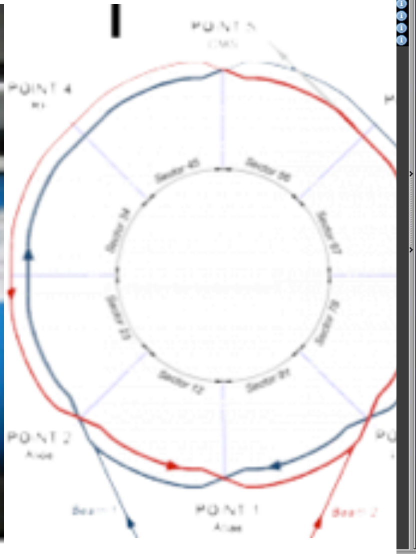
2008 Cosmic Data @3.8T Field

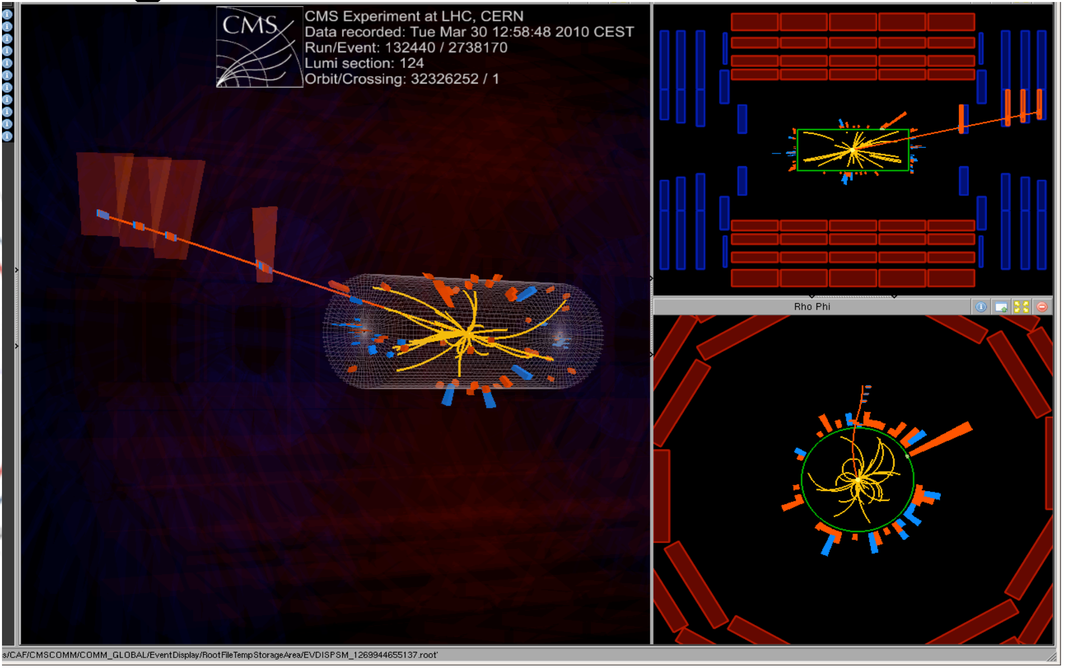
Sep 2008
Magnet incident, one year long LHC set back

Nov 2009
Two circulating beams

Mar 2010
7TeV collisions







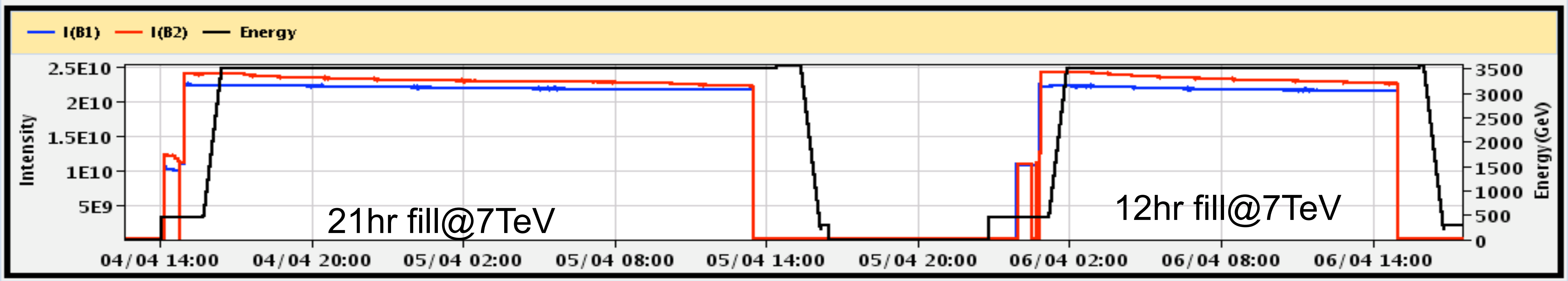
A Couple of Good Weekends

06-Apr-2010 17:27:13 Fill #: 1023 Energy: 297.4 GeV I(B1): 1.55e+08 I(B2): 7.01e+07

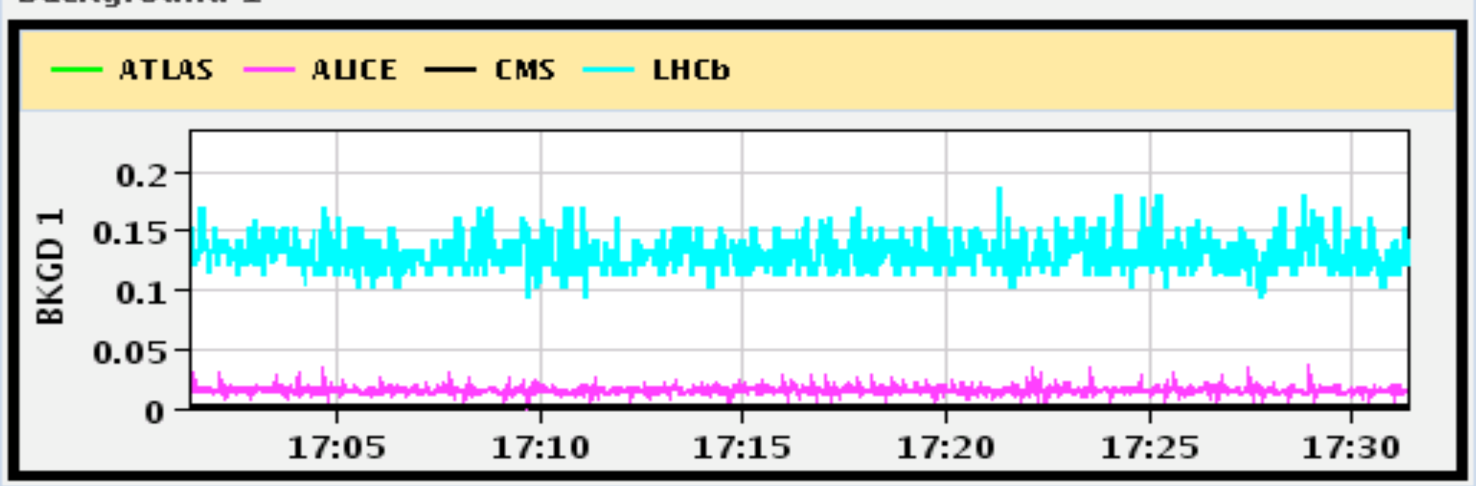
	ATLAS	ALICE	CMS	LHCb
Experiment Status	STANDBY	NOT READY	STANDBY	STANDBY
Instantaneous Luminosity	0.000e+00	0.000e+00	0.000e+00	8.989e-04
BRAN Count Rate	3.229e-07	4.059e-32	2.086e-11	1.635e-32
BKGD 1	0.002	0.014	0.002	0.131
BKGD 2	0.000	0.000	0.002	0.002
BKGD 3	0.000	0.005	0.003	0.037

LHCf STANDBY Count(Hz): 0.000 | LHCb VELO Position OUT Gap: 58.0 mm | TOTEM: CALIBRATION

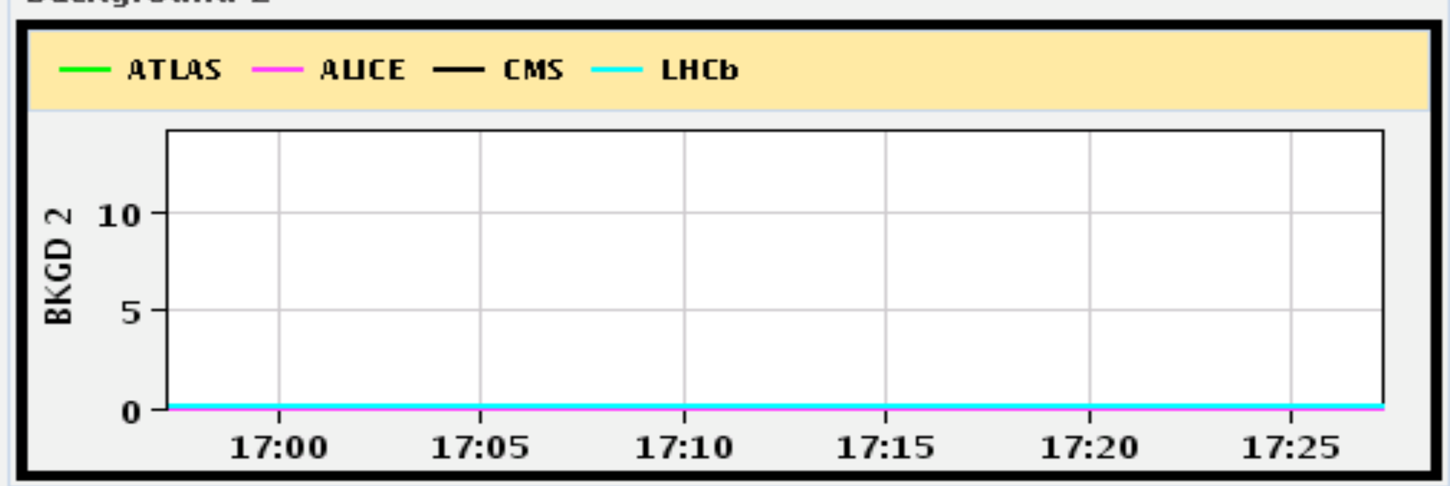
Performance over the last 12 Hrs



Background 1



Background 2



Beam Commissioning in 2010

Global machine checkout

450 GeV re-commissioning

Machine protection commissioning

Ramp commissioning

Establish stable safe beams at 3.5 TeV

Collisions at 3.5 TeV

System/beam commissioning continued
Squeeze

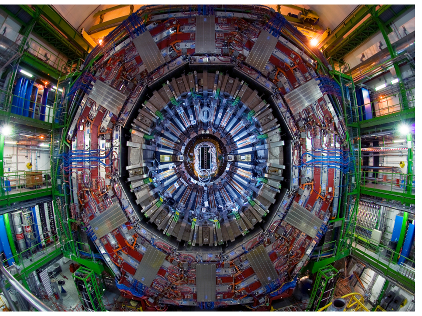
Collisions at 3.5 TeV squeezed

Full machine Protection qualification

today

Finish This!!

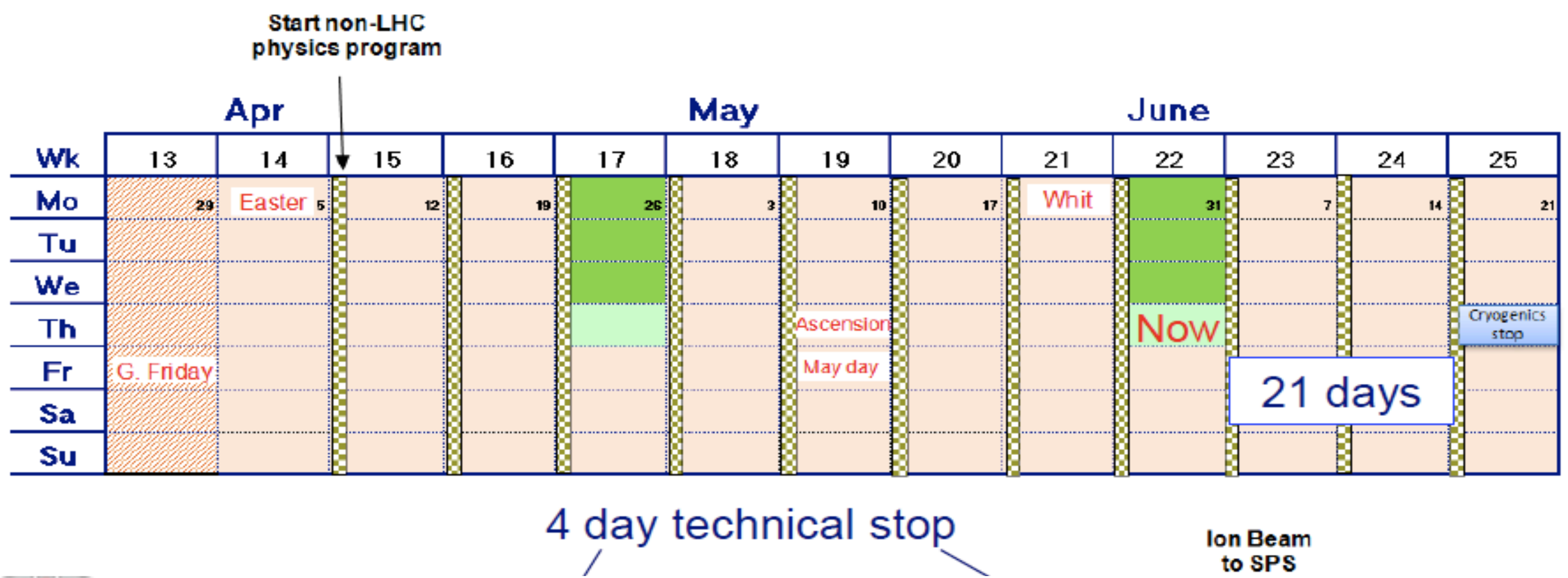
LHC Status



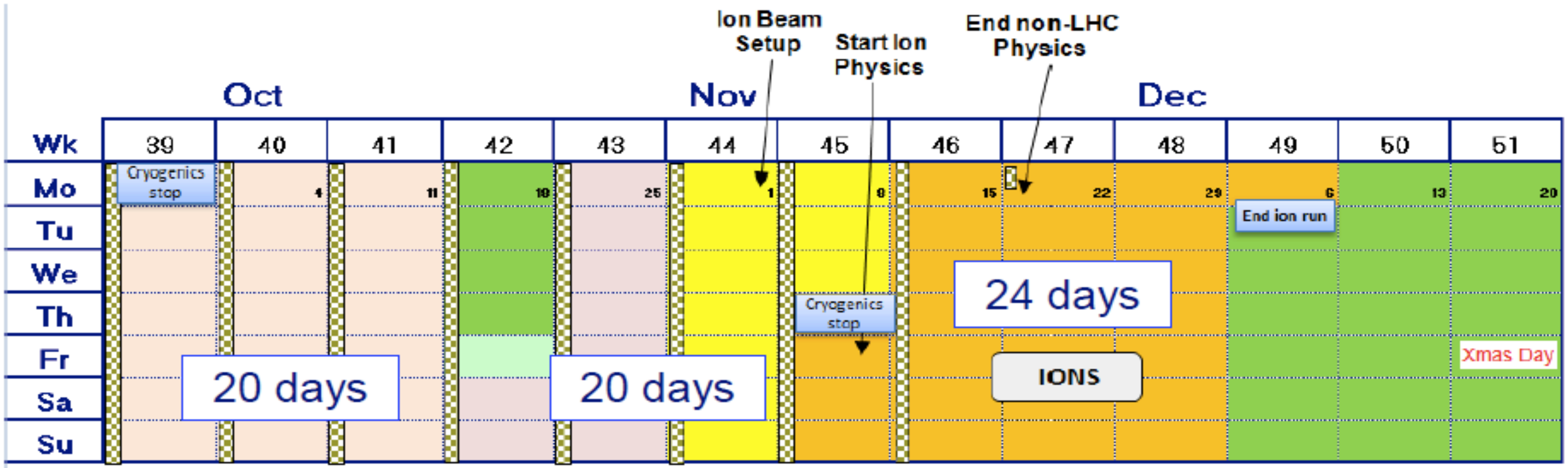
- **Remarkable knowledge of the LHC magnet model**
  - A key to successful commissioning with beams
  - Tunes, energy matching, optics close to the LHC model
- **Bunch intensities: 1.1E11 with excellent emittance**
- **Ramp&squeeze for physics @3.5TeV at higher intensities**
- **Machine protection super critical element**
- **Goal: delivery of $1fb^{-1}$ to the experiments by the end 2011**
  - 2010 Target: 3.5TeV, β^*=2m, with/w-out crossing angle
  - 2011 Target: 3.5TeV, β^*=2m, with crossing angle
- **Flat out running at $1\text{-}2x10^{32}cm^{-2}s^{-1}$ in 2011**
  - Correspond to 8E10 ppb, 700 bunches, with a stored energy of 35 MJ (with β^*=2 m and nominal emittance).

LHC Short Term Plan 2010

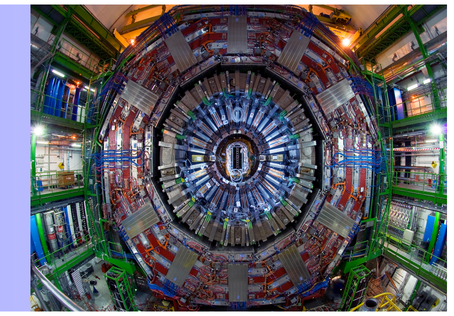
Revised schedule 1/2



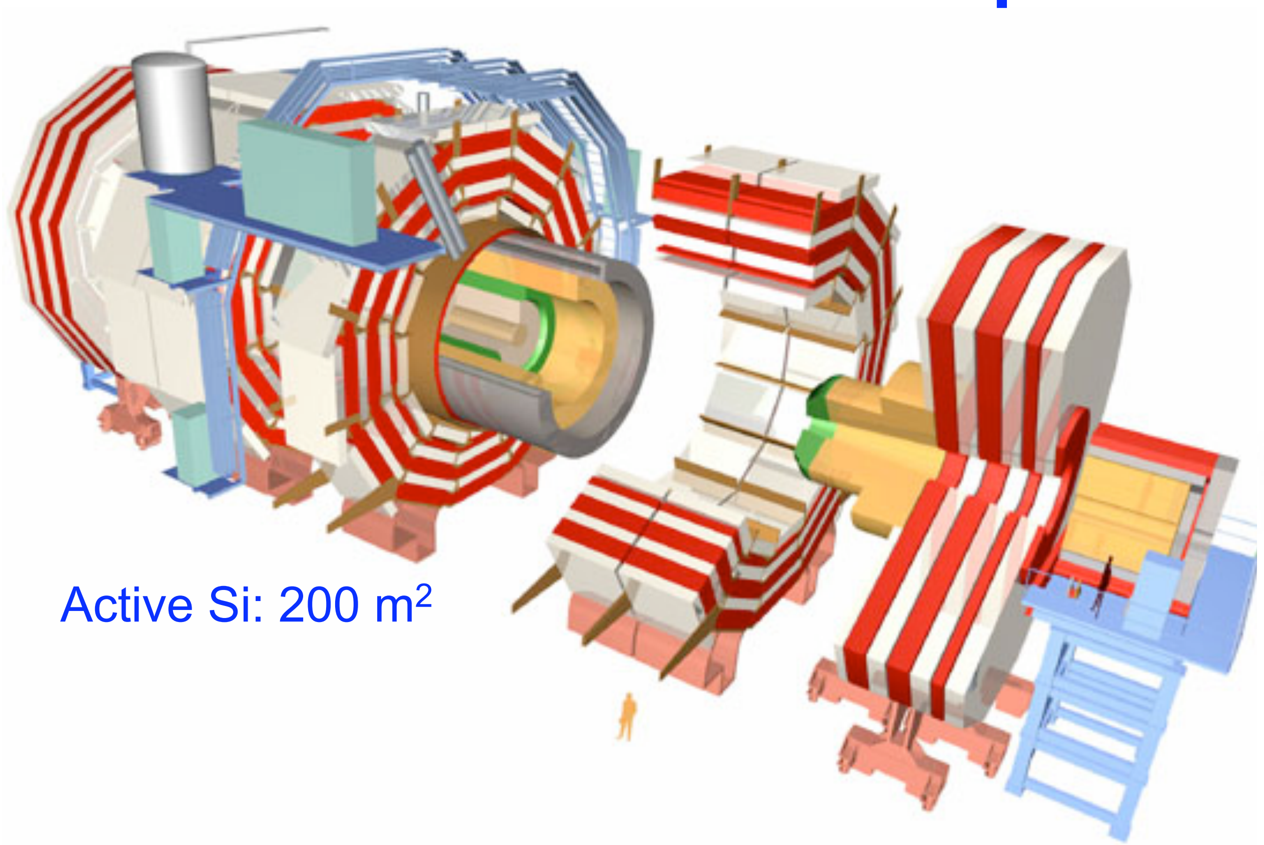
Revised schedule 2/2



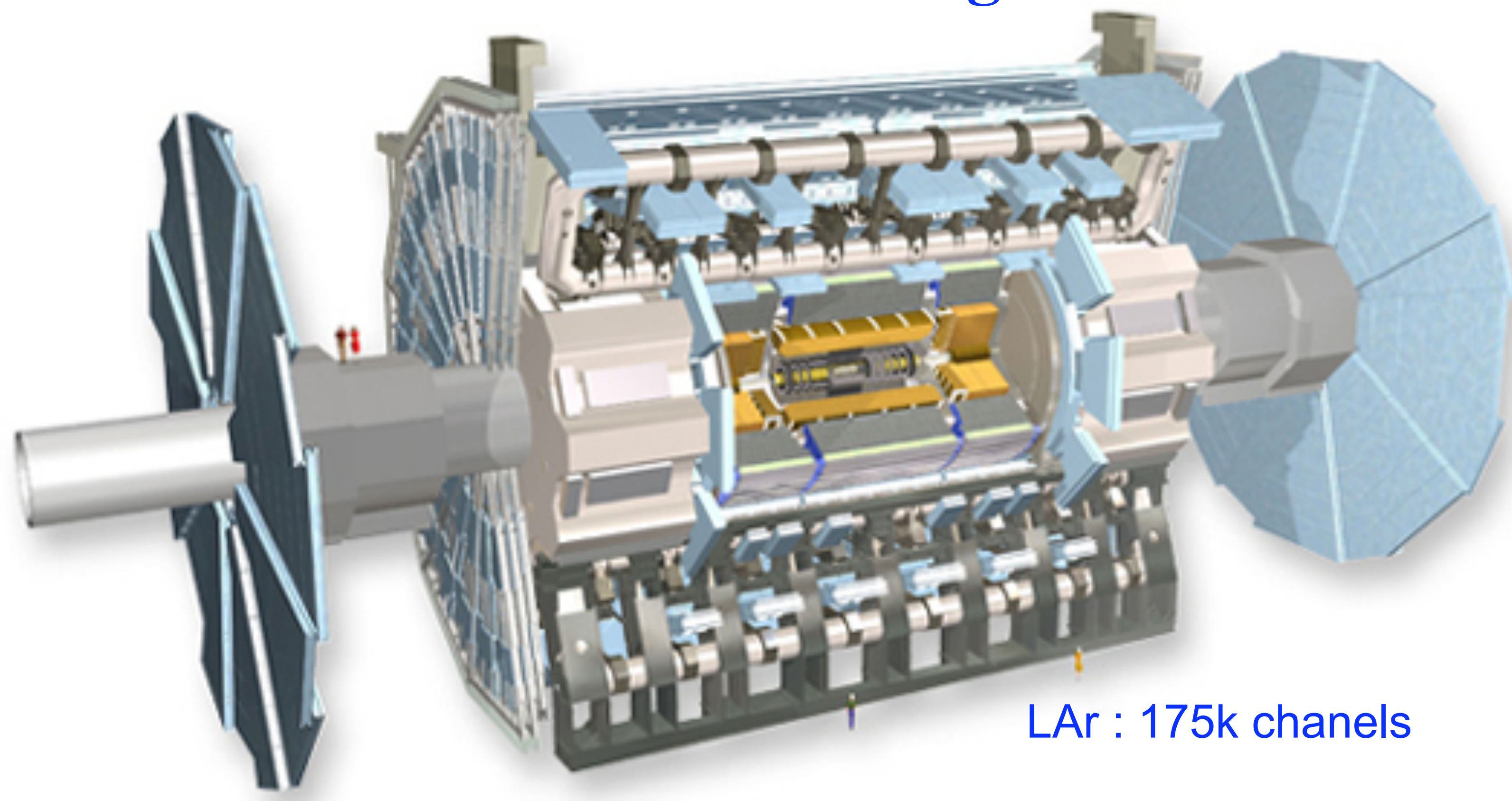
LHC Experiments



CMS - compact



ATLAS - Huge



Tracking: $|\eta| < 2.5$, B = 3.8T
- Si pixels and strips

Calorimetry: $|\eta|^{em} < 2.5$ $|\eta|^{had} < 5$
- EM: homogeneous $PbWO_4$ crystals
- HAD: Cu-Zn/scint. + Fe/Quartz

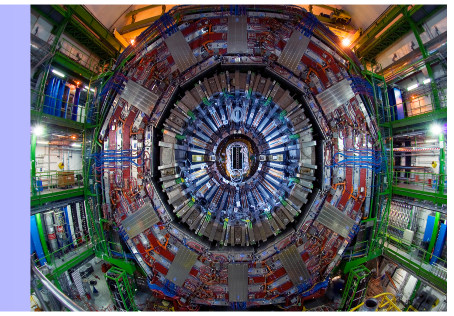
Muon Spectrometer: $|\eta| < 2.7$
- Solenoïd return yoke instrumented

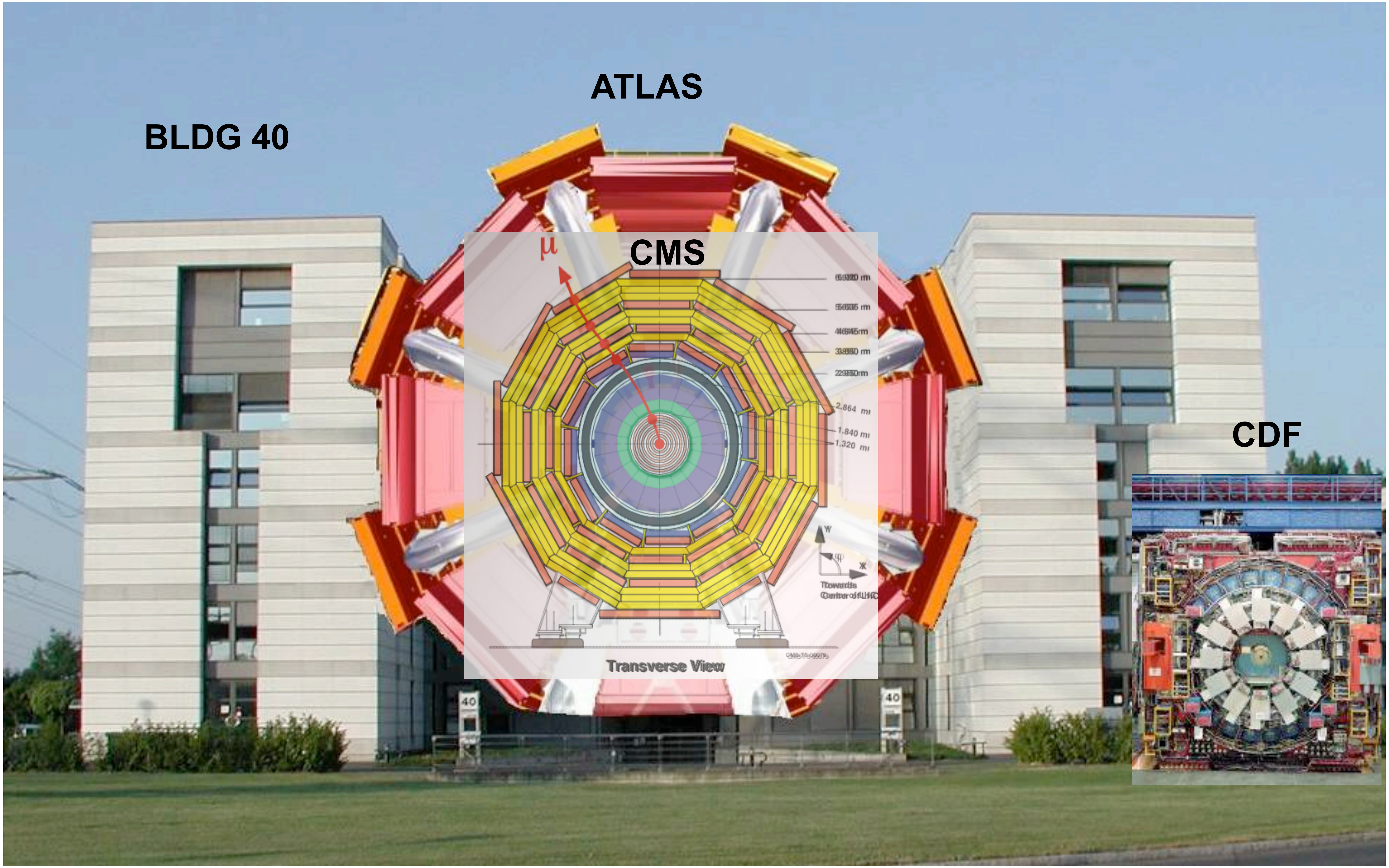
Tracking: $|\eta| < 2.5$, B = 2T
- Si pixels and strips
- Transition radiation detector

Calorimetry: $|\eta| < 5$
- EM: sampling; Pb/LAr accordeon
- HAD: Sampling Fe/scint. + Cu-W/LAr

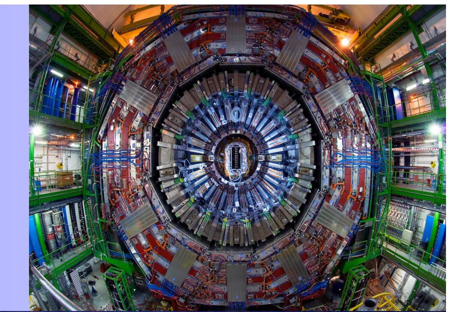
Muon Spectrometer: $|\eta| < 2.7$
- Air-core toroids with muon chambers

LHC Experiments

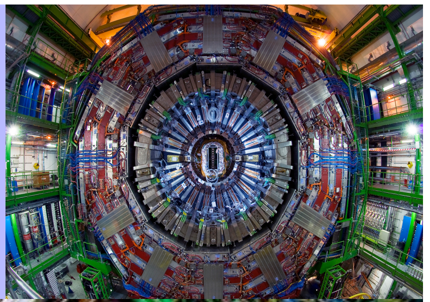


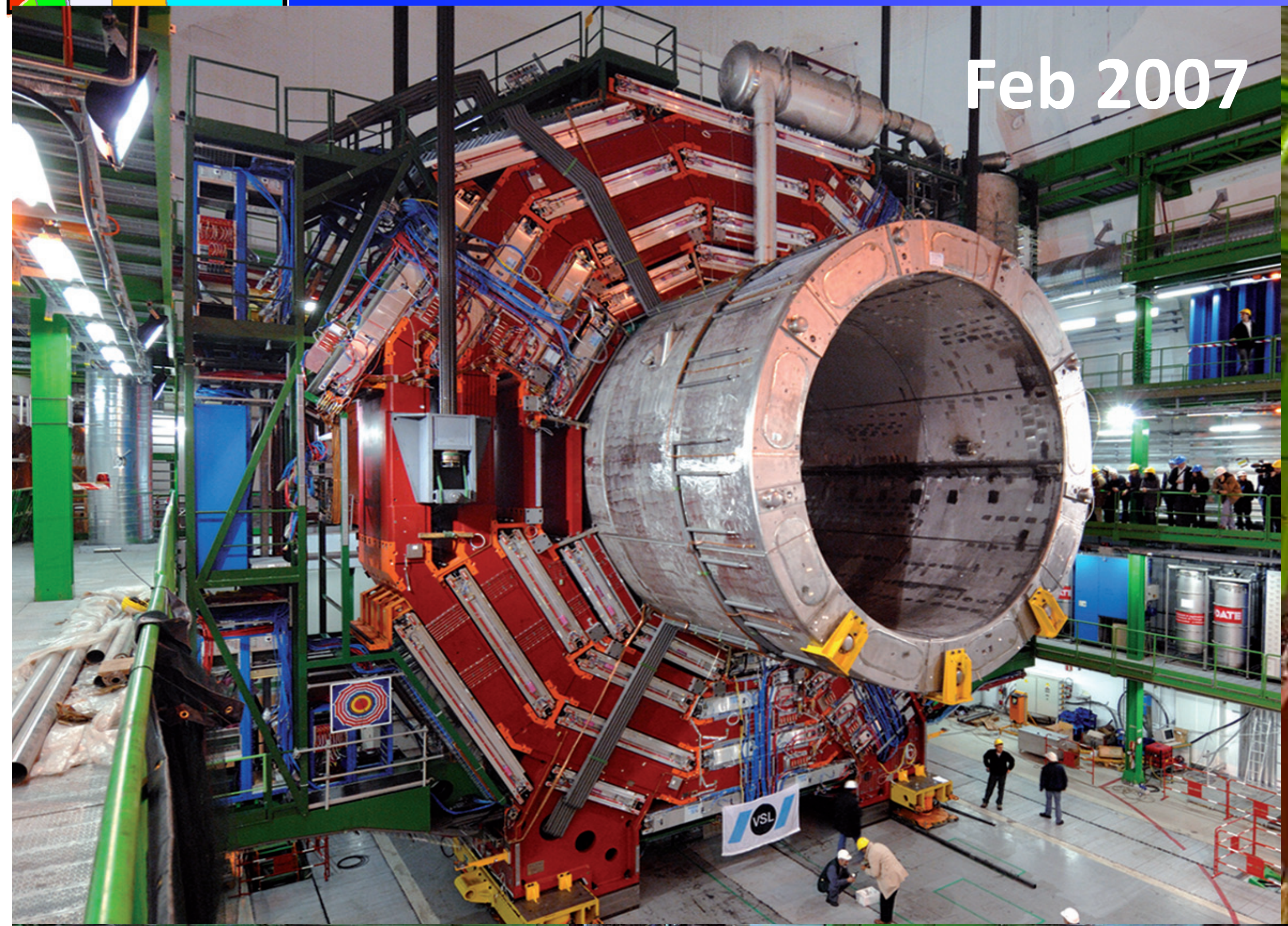


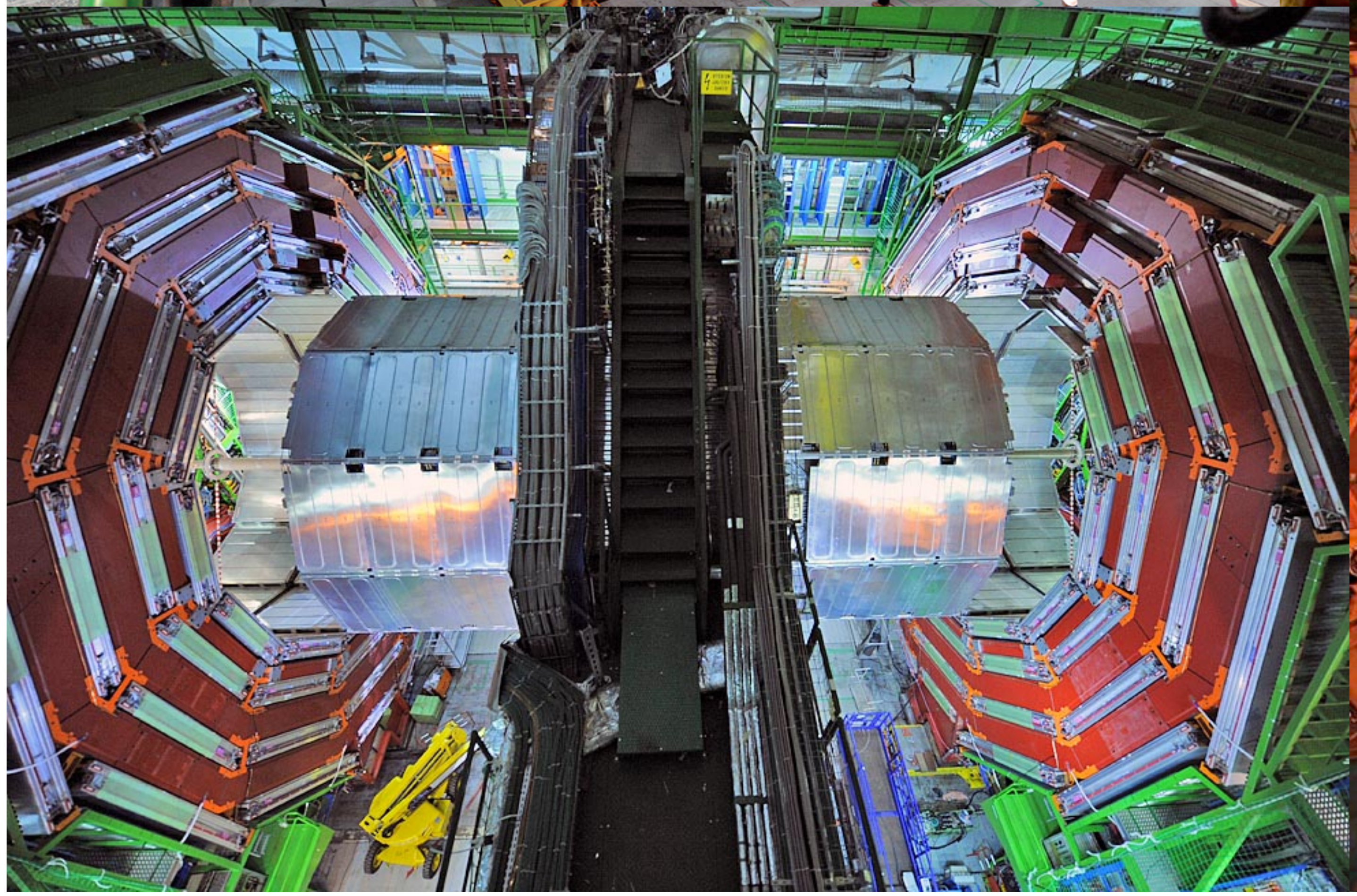
Aerial view of CMS Site@P5 - 1998
Gallo Roman vestiges



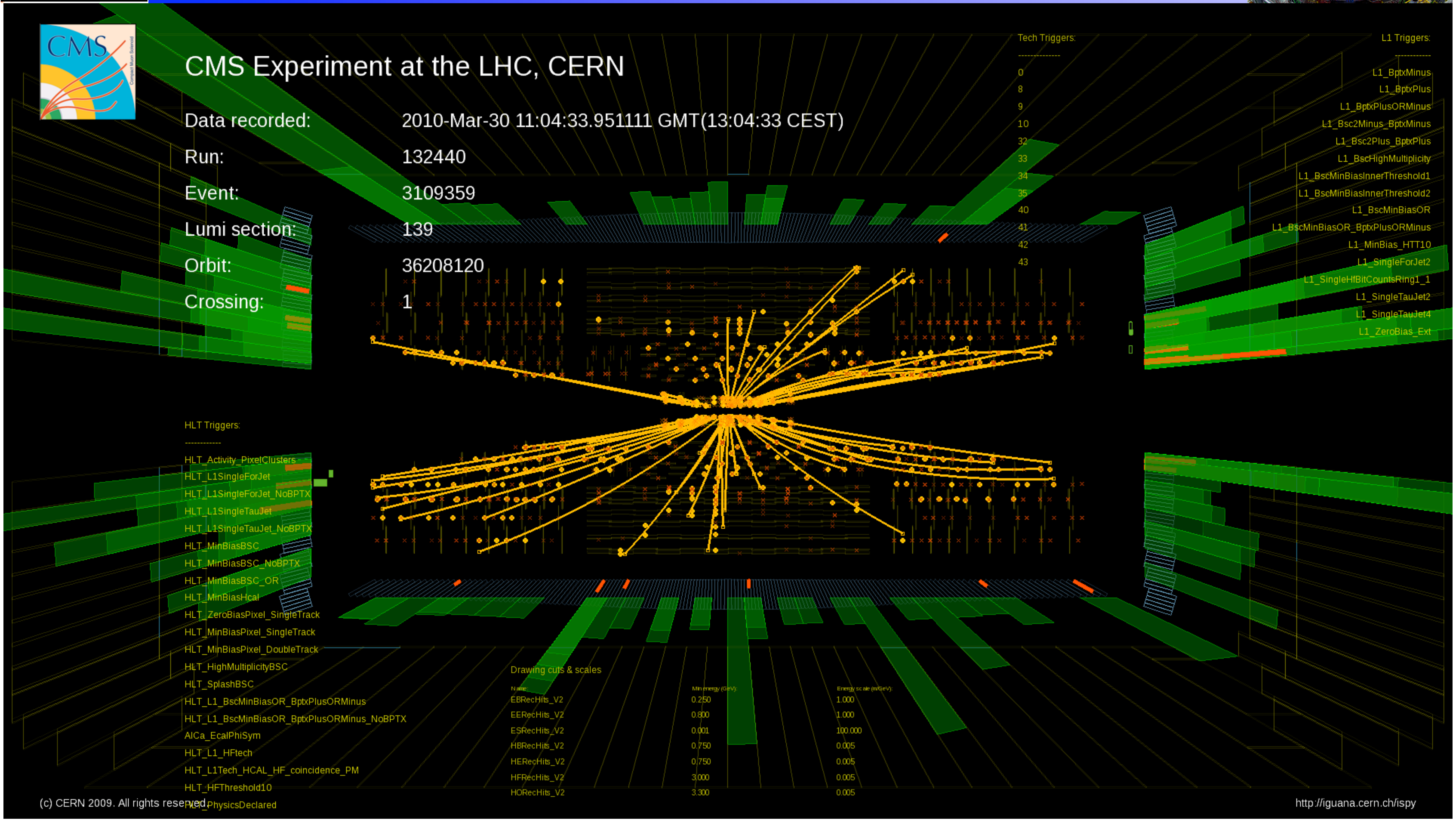
CMS Closed 3rd Sep 2008



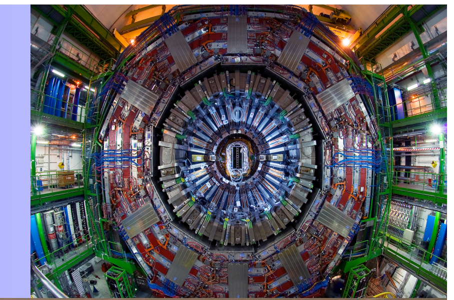




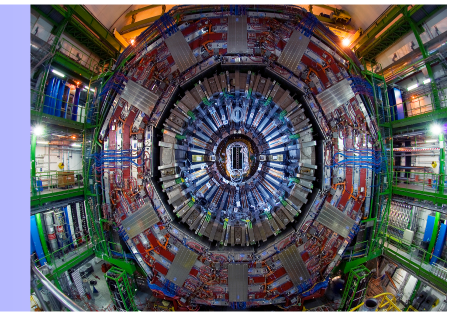
30 March 2010 – First 7 TeV Collisions

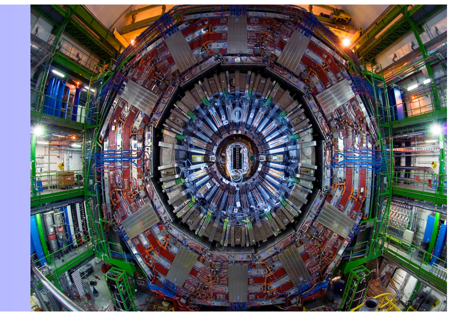


Unforgettable KODAK Moments

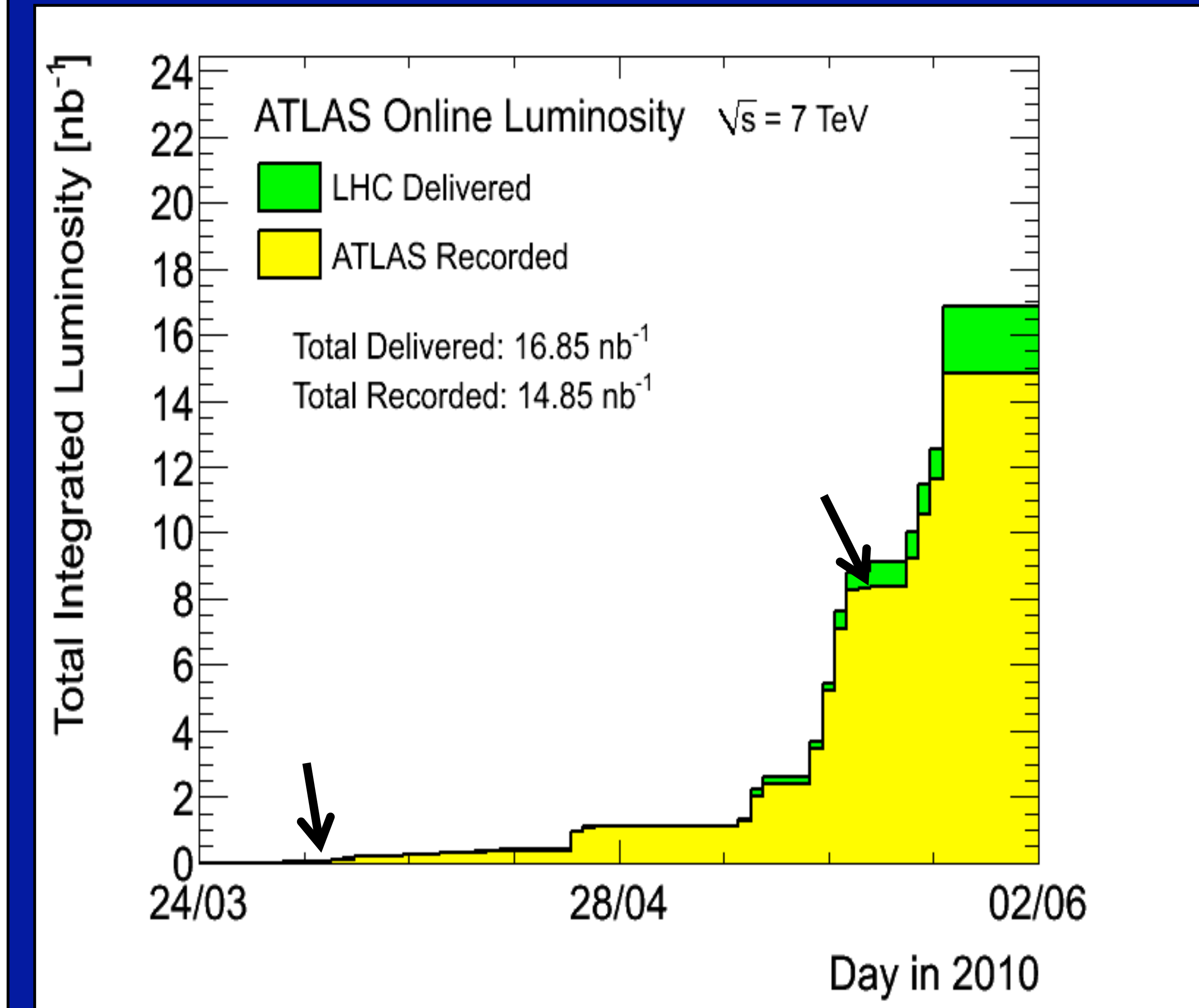


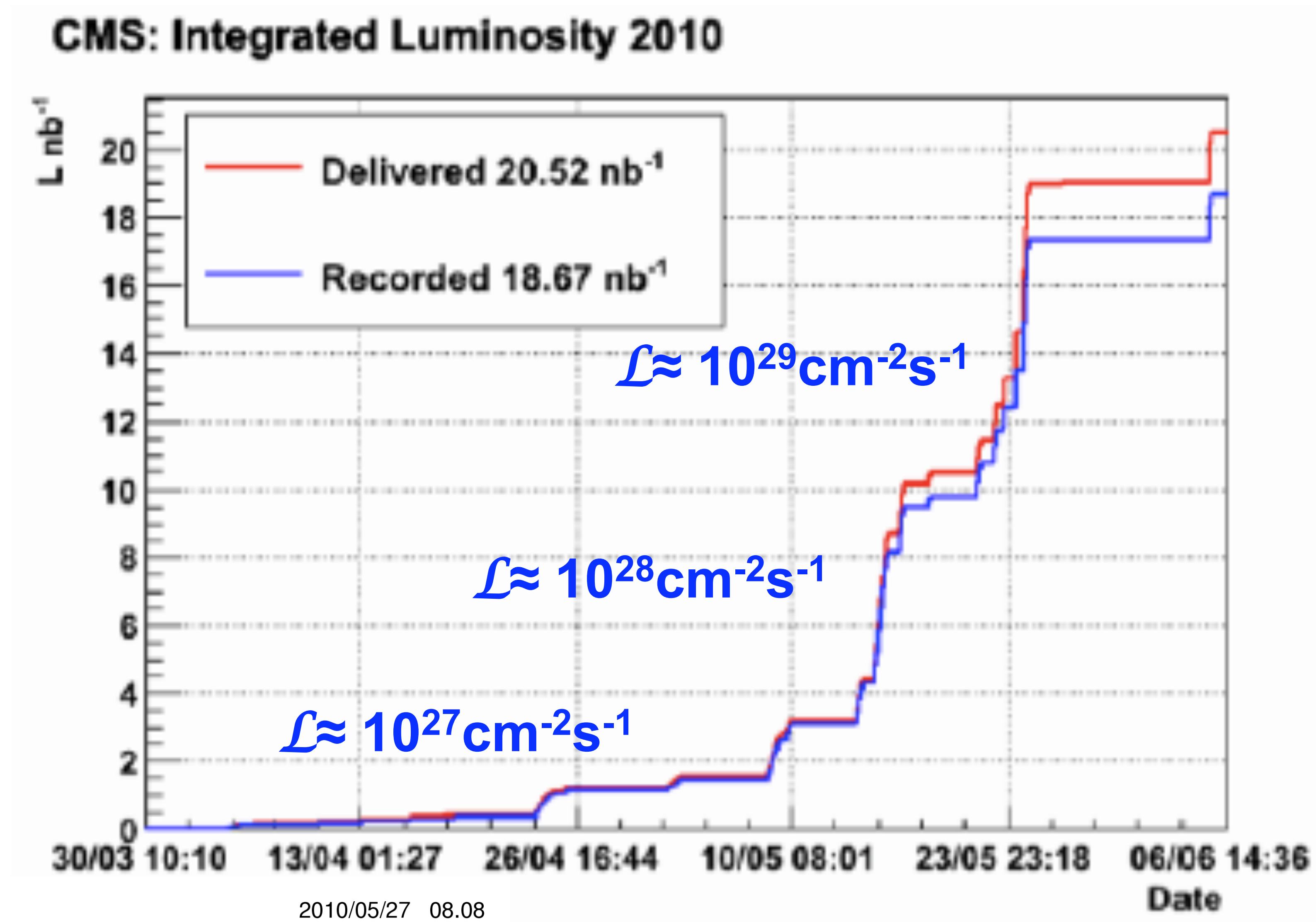
10Sep 08, 23Nov 09, 30Mar 10 – Media Splash Events

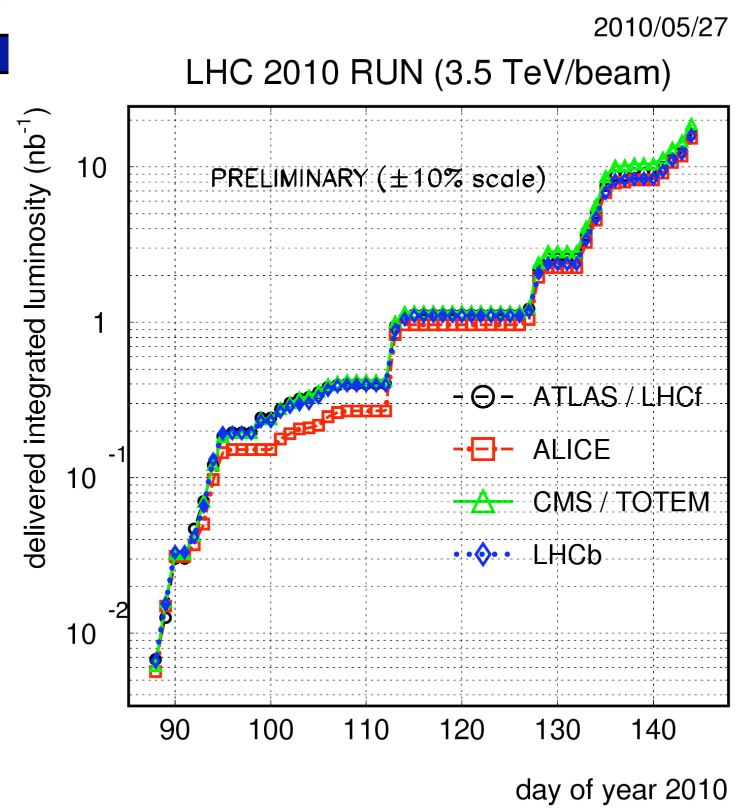




First 2 Months of Operation

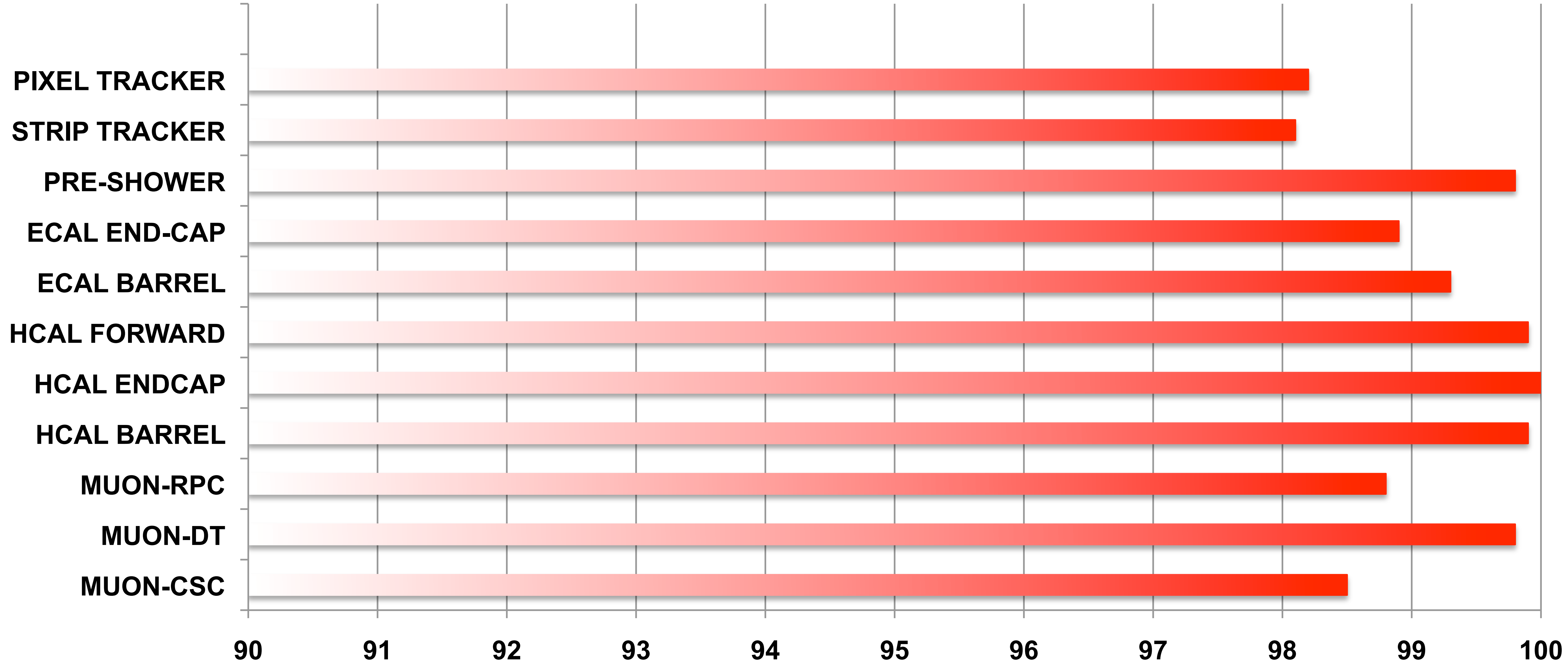






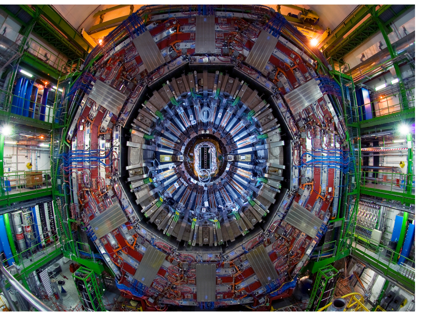
- **Reliable operation with ~21/nb delivered**
- **Overall data taking efficiency >90%**
- **Results based on luminosities**
  - up to ~7.9/nb – ATLAS
  - 17/nb – CMS

CMS Sub-detector Status

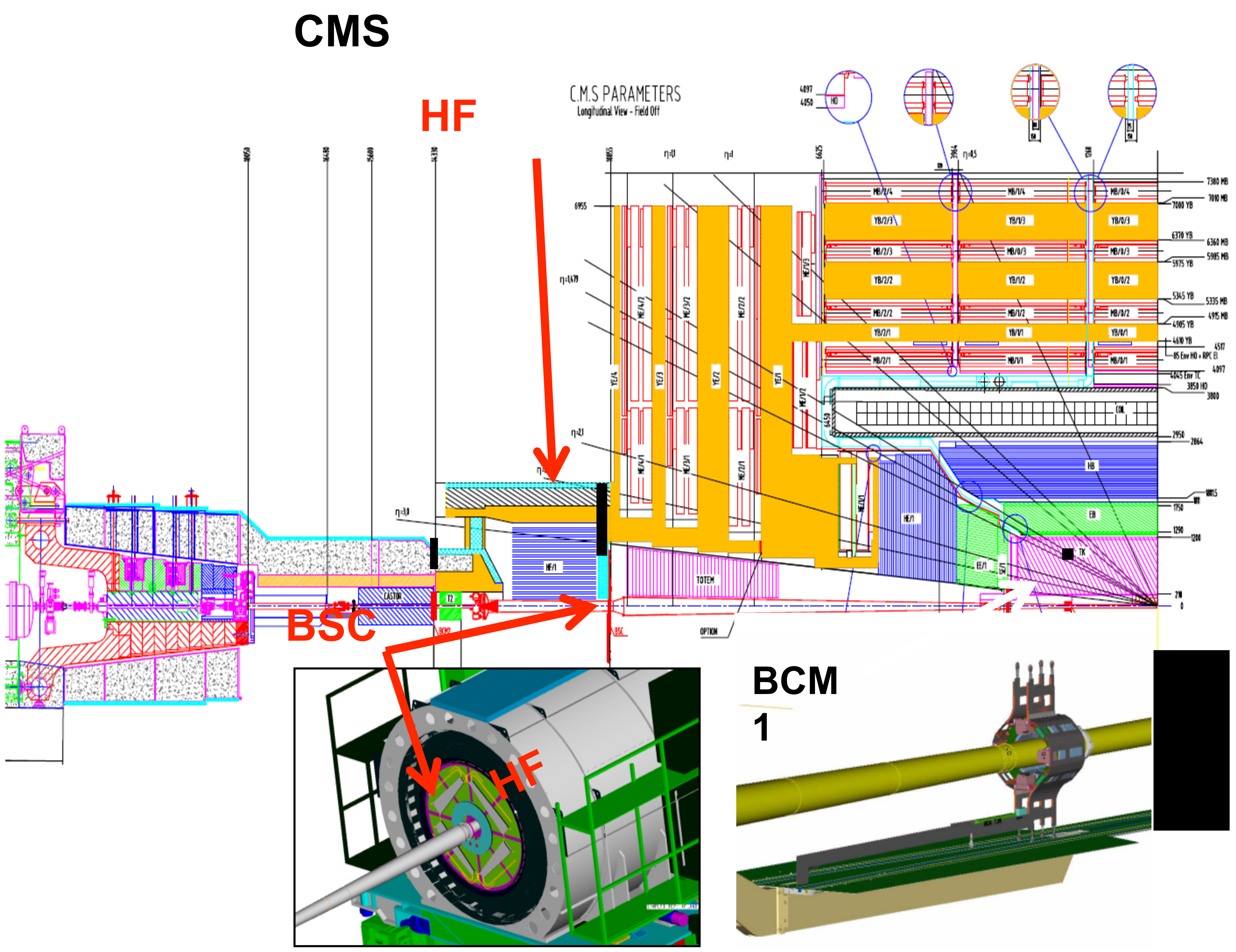


	MUON-CSC	MUON-DT	MUON-RPC	HCAL BARREL	HCAL ENDCAP	HCAL FORWARD	ECAL BARREL	ECAL END-CAP	PRE-SHOWER	STRIP TRACKER	PIXEL TRACKER	
Series1	98.5	99.8	98.8	99.9	100	99.9	99.3	98.9	99.8	98.1	98.2	

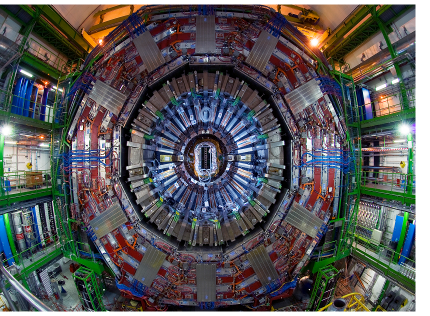
Zero and MinBias Triggers

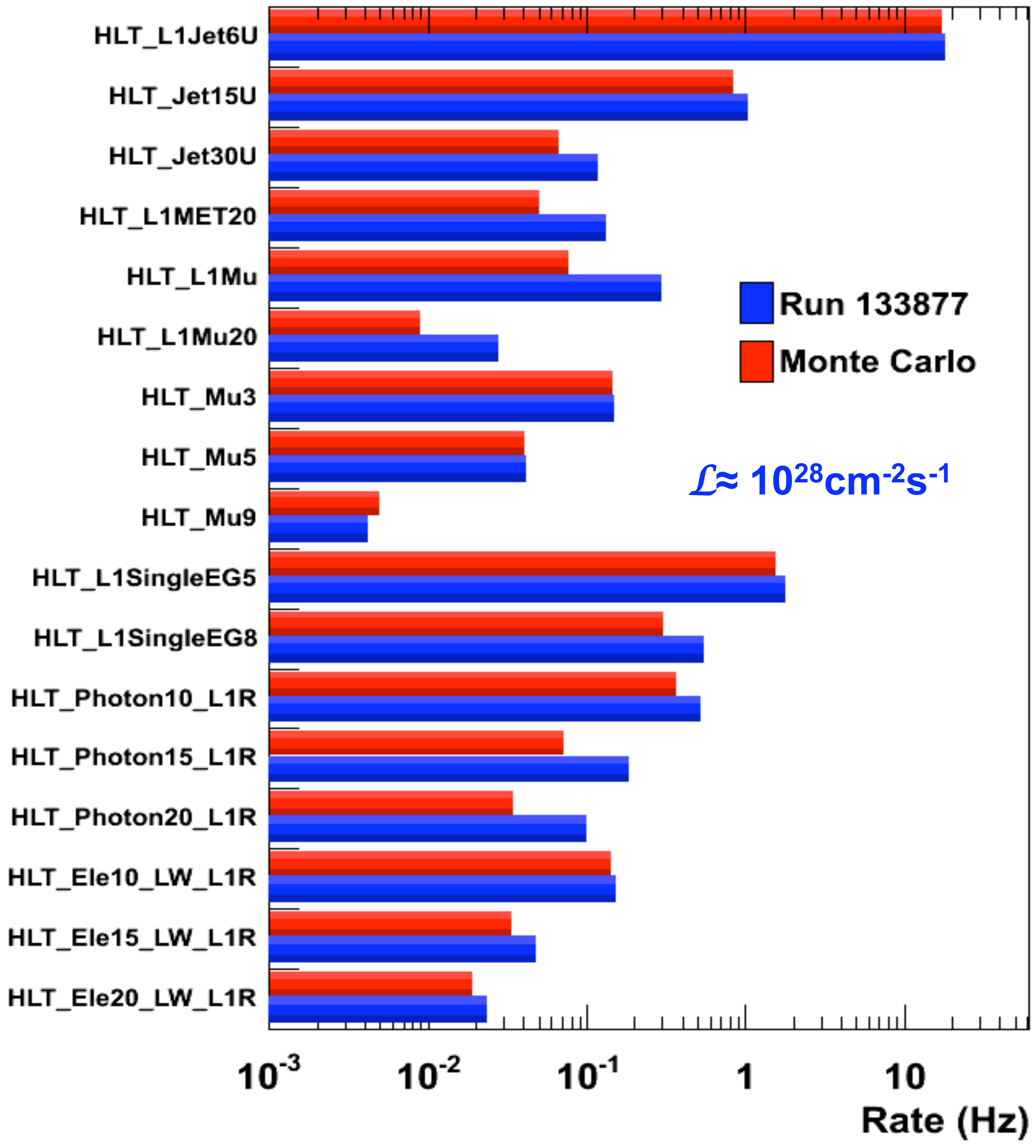


- Beam Pick-up Timing
  - BPTX: ± 175m from IP
- Beam Scintillator Counters
  - BSC: ± 10.5m from IP
- HCAL Forward
  - HF: $2.5 \leq |\eta| \leq 5.$
- Trigger: Min Bias & Zero Bias
  - L1 Beam Scintillator Counters
  - L1 Trigger "BPTX" prescaled
- Minimum Bias selection:
  - BSC (OR 2 planes) + vertex: $\epsilon \sim 90\%$
  - HF (E > 3 GeV both sides): $\epsilon \sim 90\%$



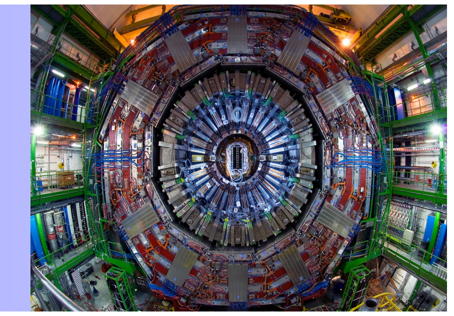
CMS DAQ, L1 and HLT

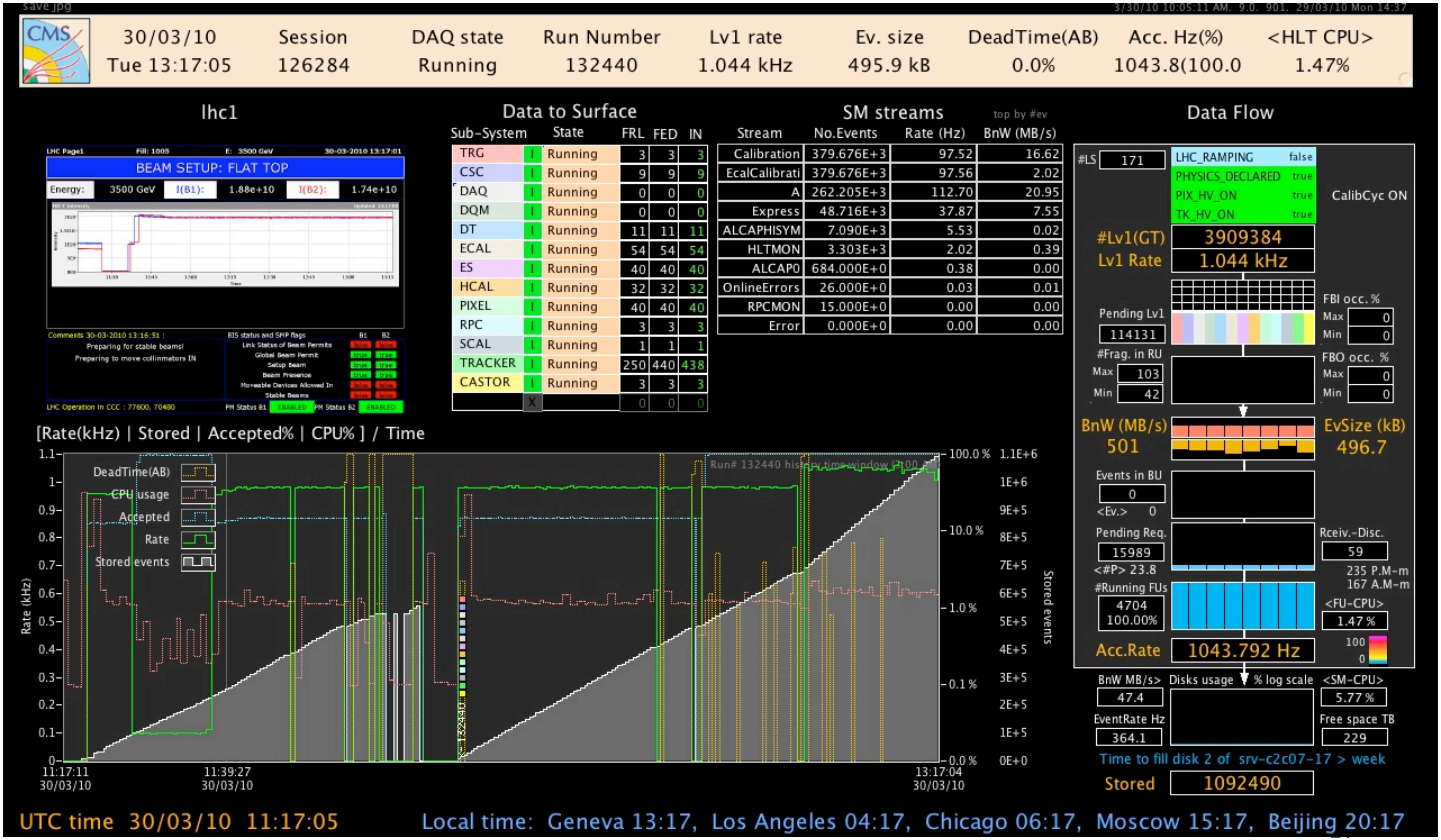




- **L1/DAQ RUNS VERY WELL**
  - **L1 ~ 1KHz, <500 kB/evt,**
  - **HLT ~ 2% CPU loaded**
- **HLT**
  - **Farm Capacity~100 ms/evt**
    - CPU processing time at L1 rate of 50 kHz
  - **Up to now we have spent ~15 ms/event (min bias dominated)**
  - **Expect ~ 40 ms/event for a lumi of 10^{30} $cm^{-2}s^{-1}$ on average**
- **Deployed trigger menus for 10^{27}, 10^{28} , $10^{29} cm^{-2}/s$ (in development for 10^{30}-$10^{31} cm^{-2}/s$)**
  - **Rate predictions based on MC & data**
  - **Primary datasets for $10^{29} cm^{-2}/s$**

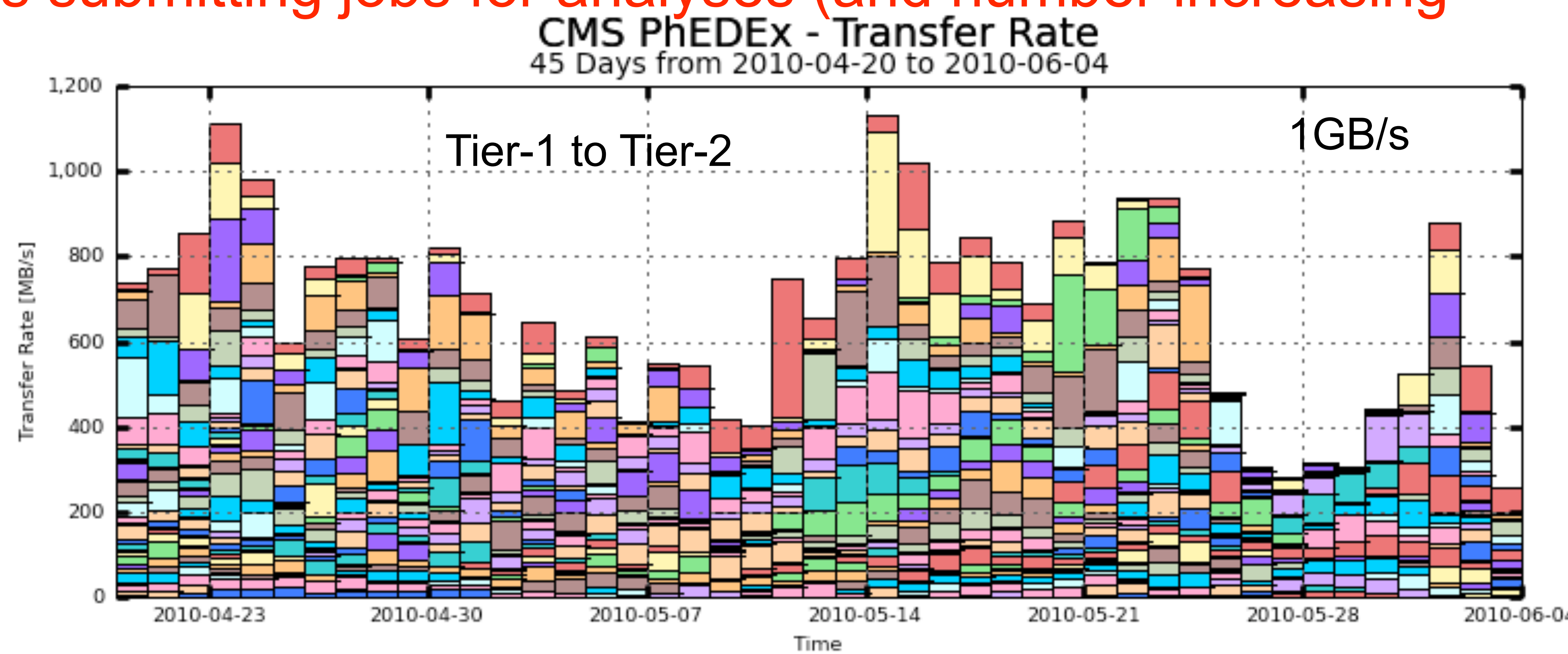
DATA Acquisition



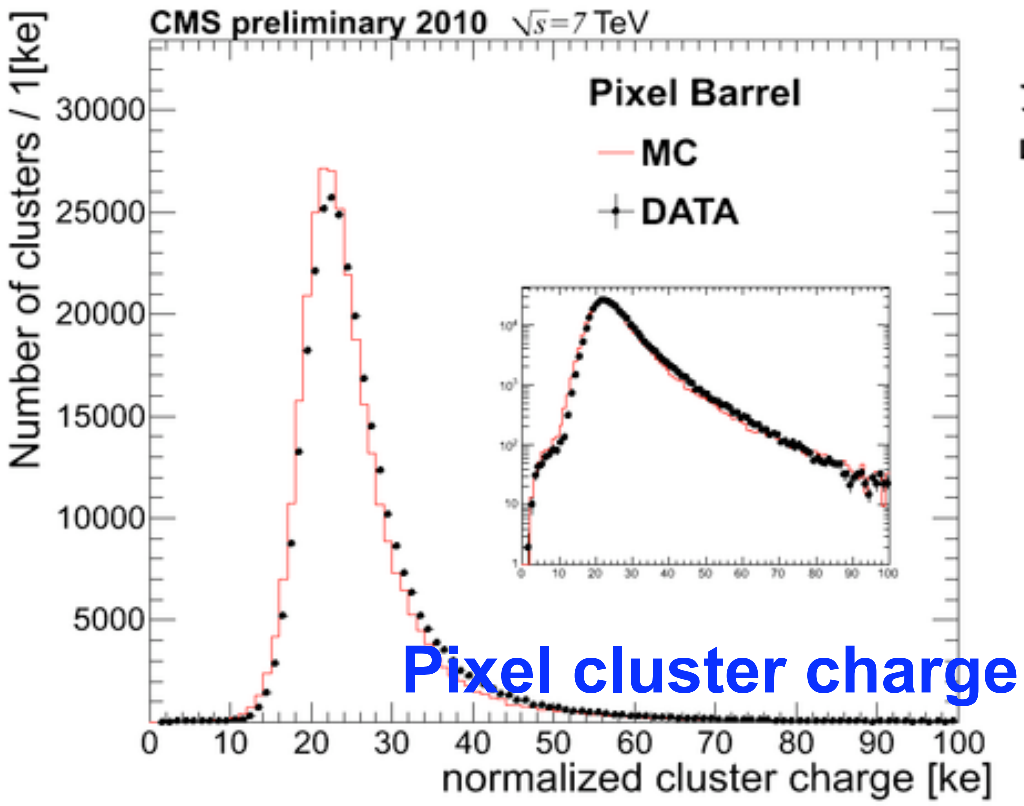


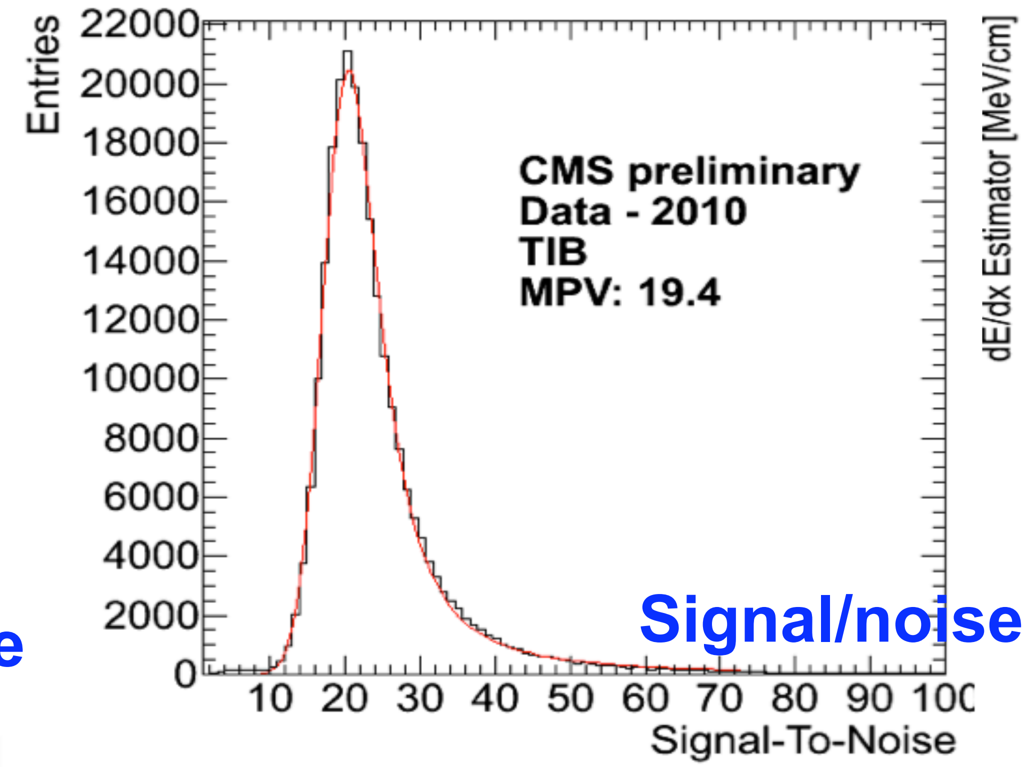
CMS Computing

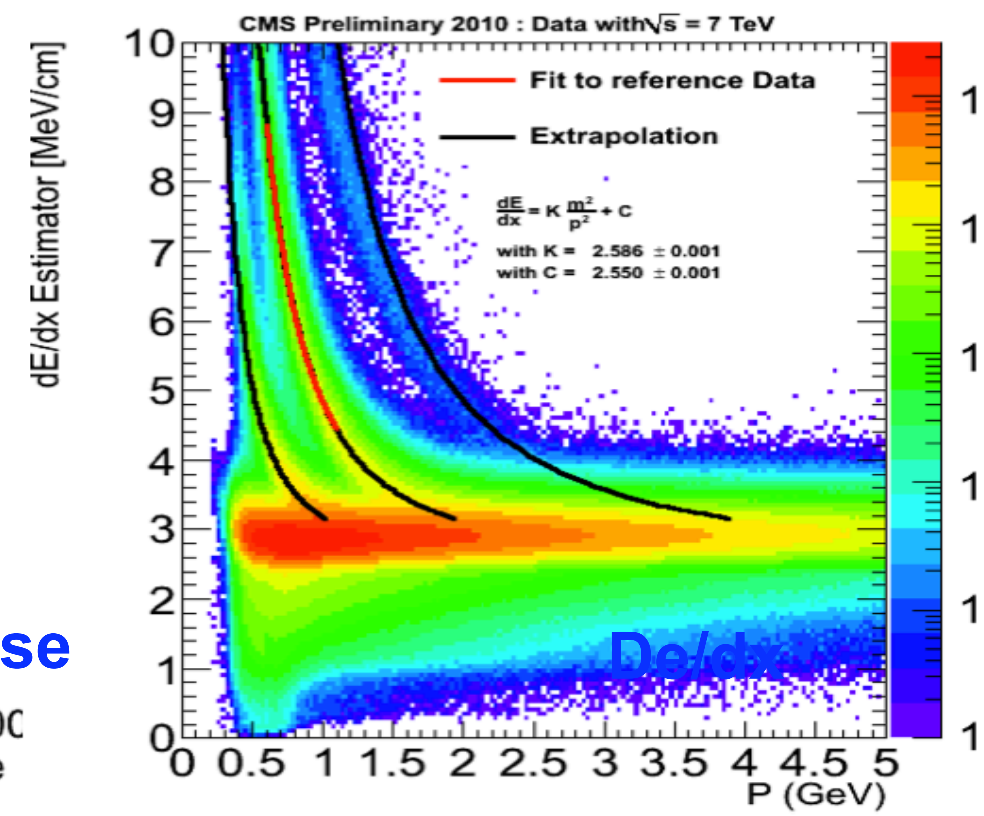
- Smooth Data Handling
  - Over 2 billion RAW events processed
  - Stable Software and Reliable Infrastructure @Tier-0
- Tier-1s and Tier-2s making reliable contributions
  - All 7 Tier-1 fully participating (FNAL, CNAF, FZK, IN2P3, RAL, PIC, ASGC)
  - Many re-processing cycles handled very well
  - 49 T2s received collision data and 57 T2s participate in MC simulation
- > 465 users submitting jobs for analyses (and number increasing weekly)

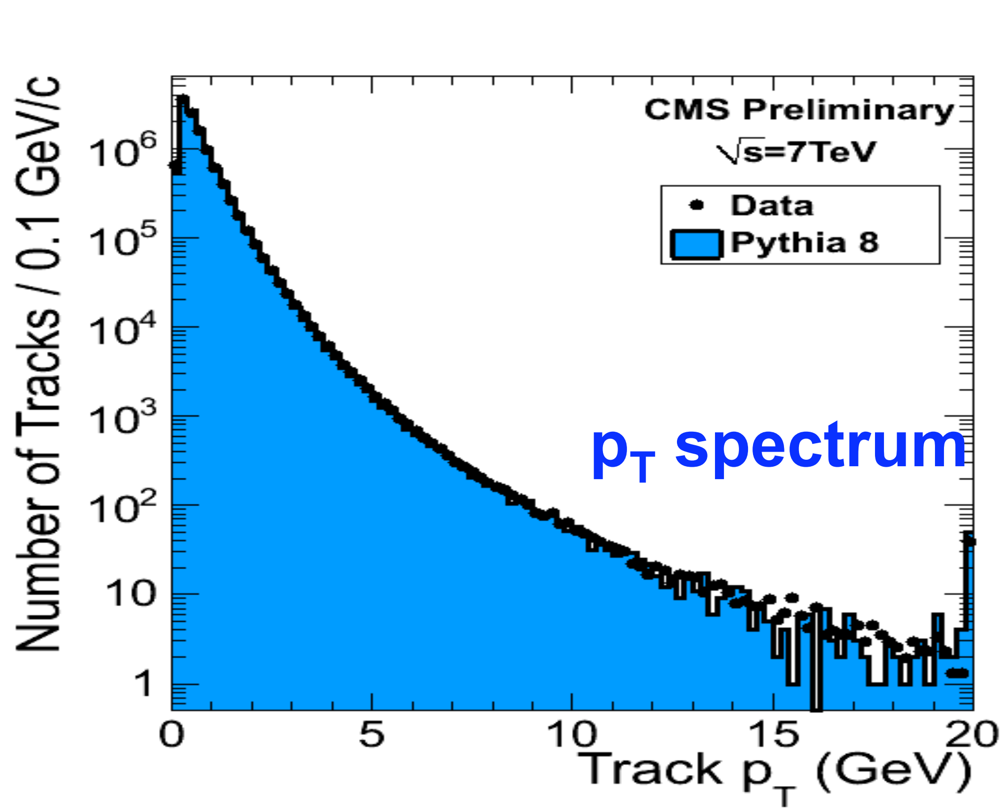


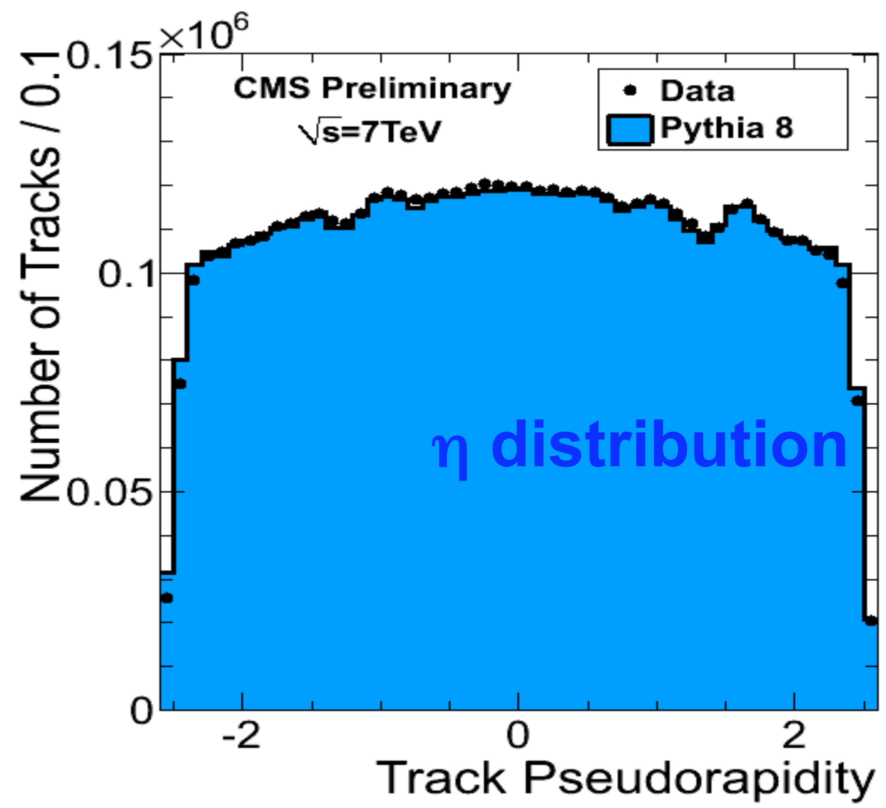
Tracker Performance

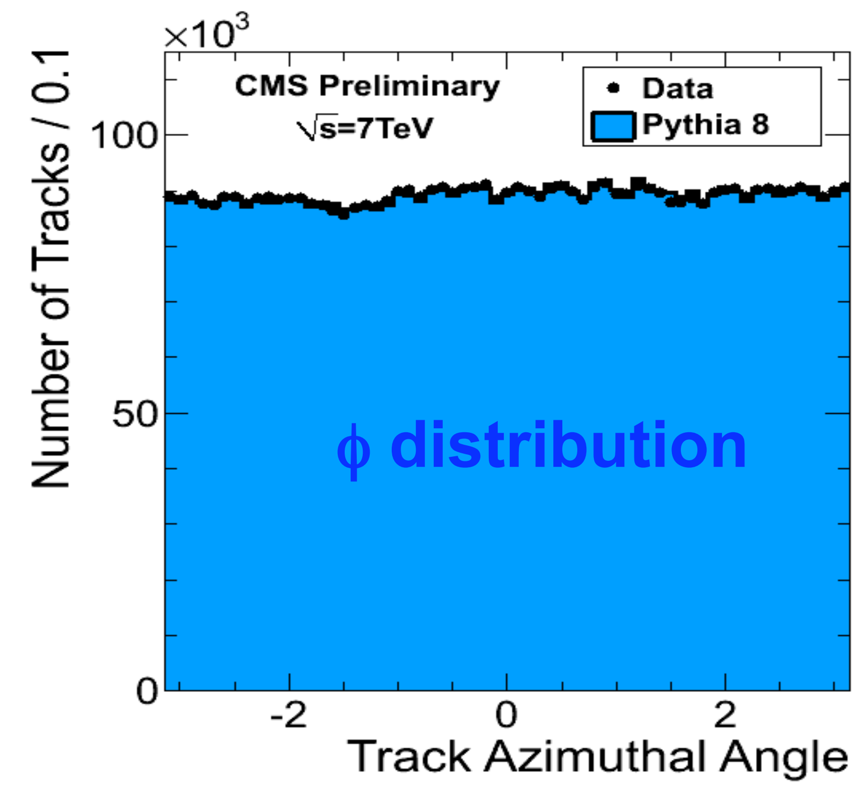




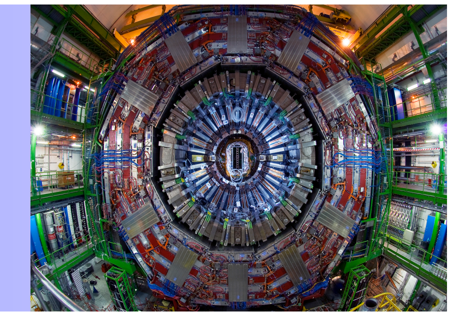


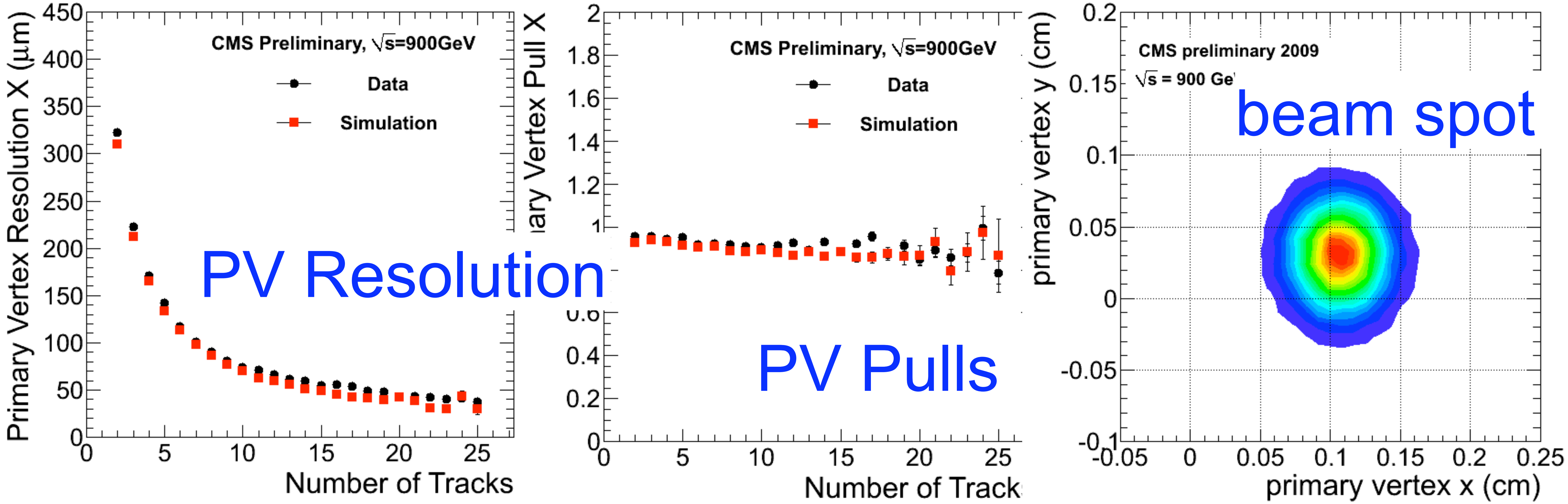






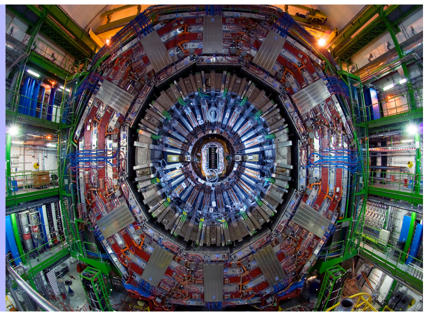
Primary Vertices

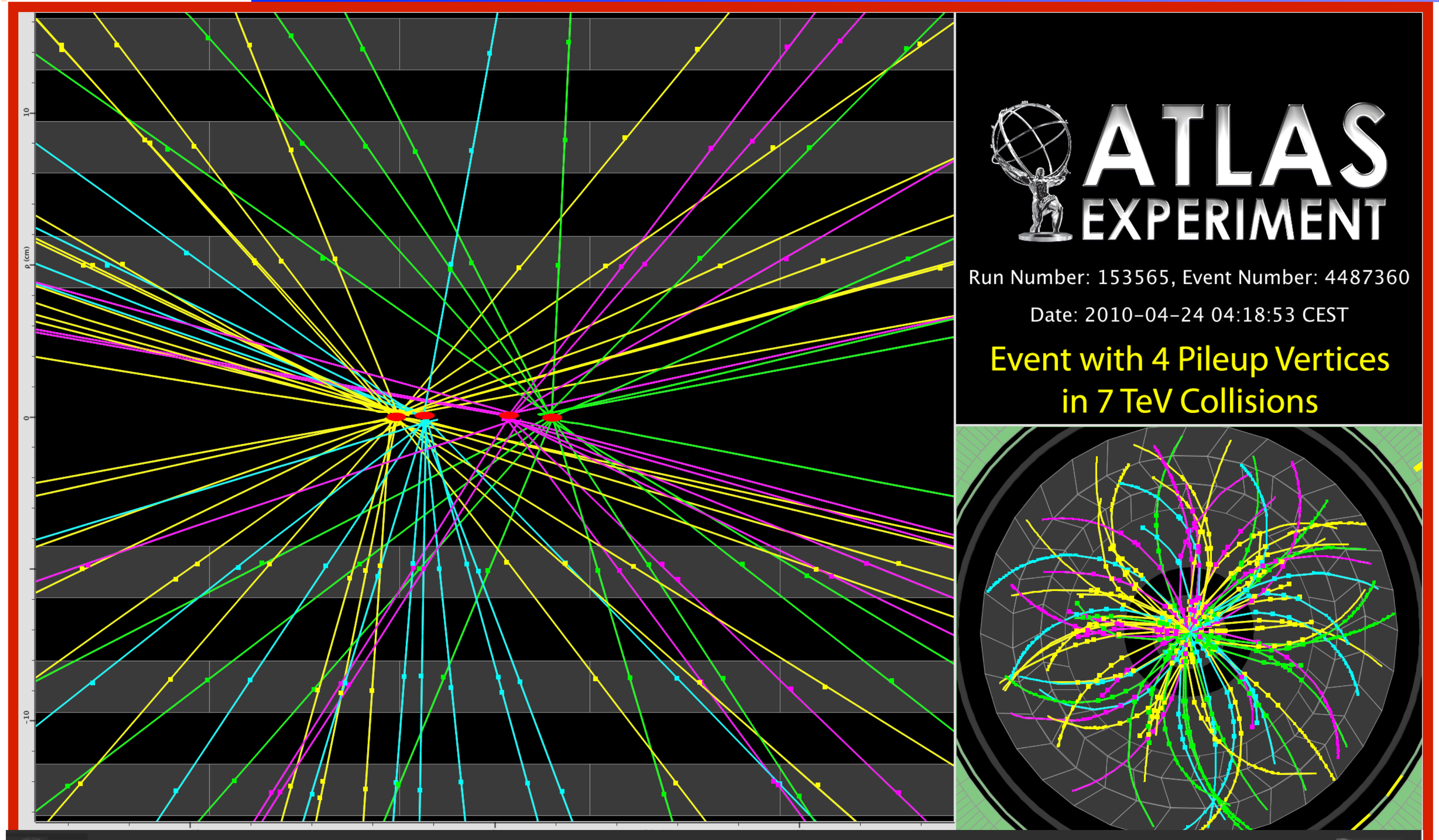


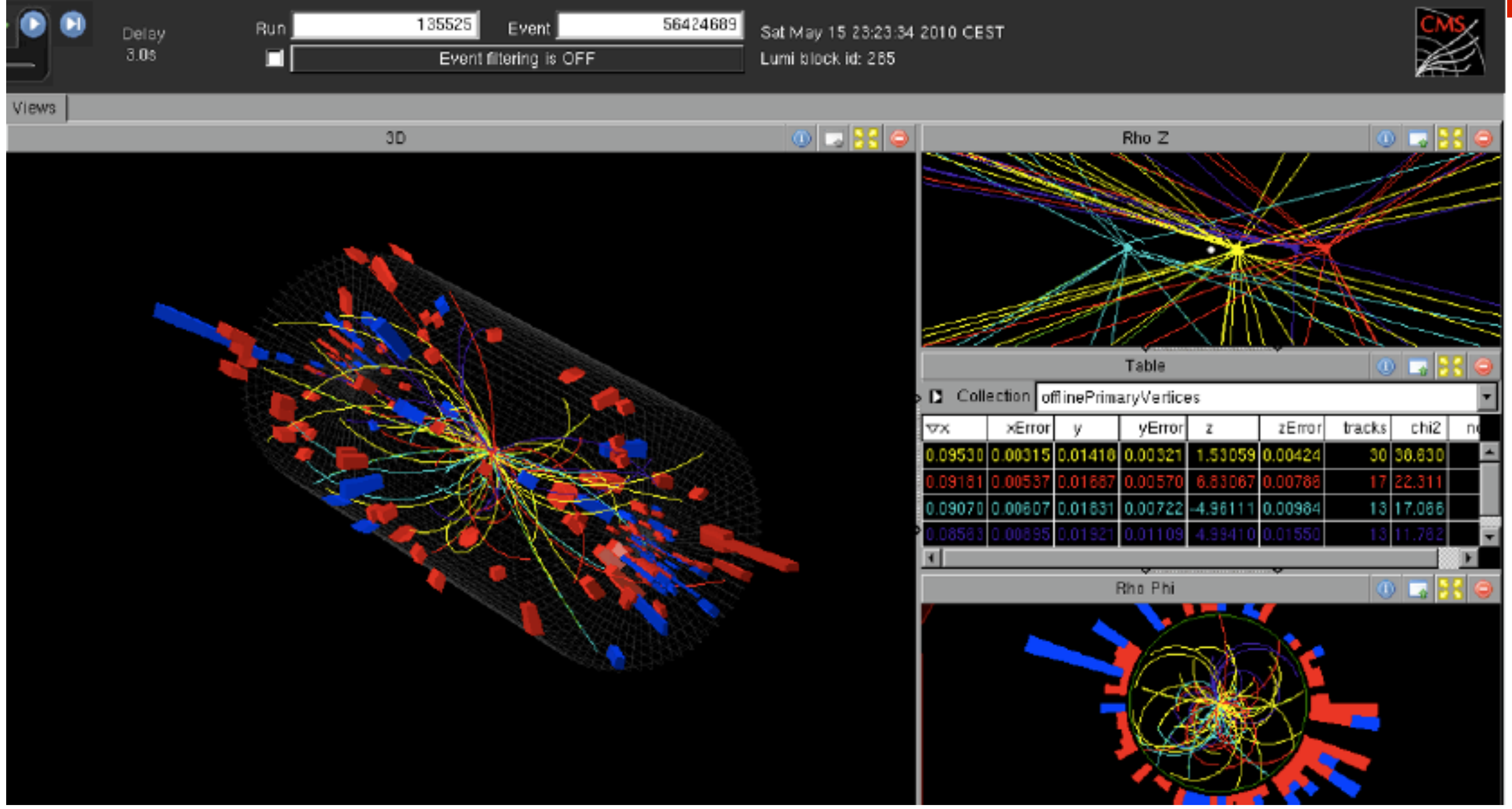


- Well understood uncertainties in tracking/vertexing
- Primary vertex resolution well modeled in simulation

PILE UP EVENTS@ $\mathcal{L}=10^{27}$!

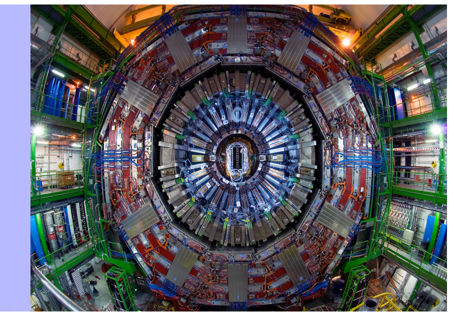


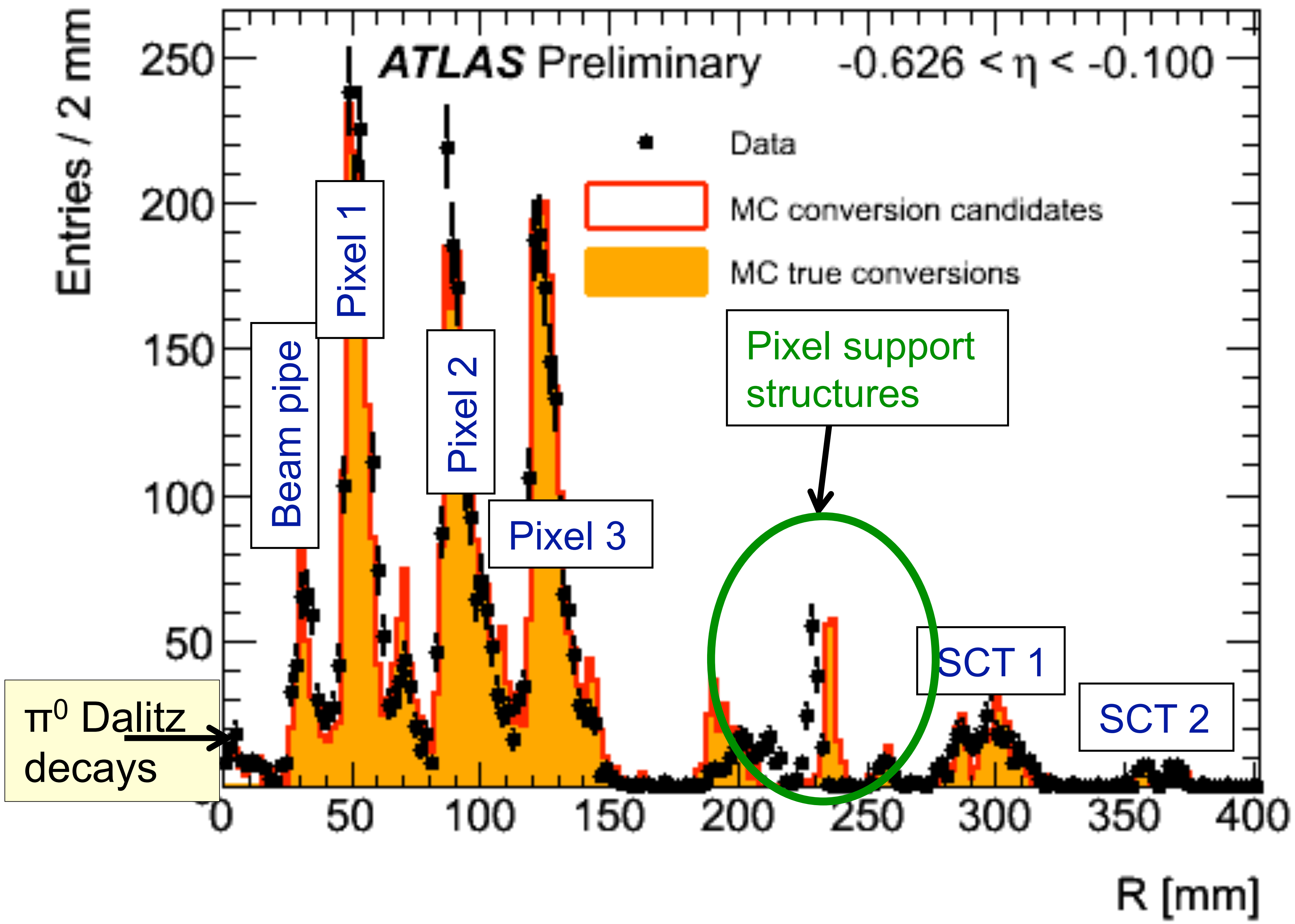


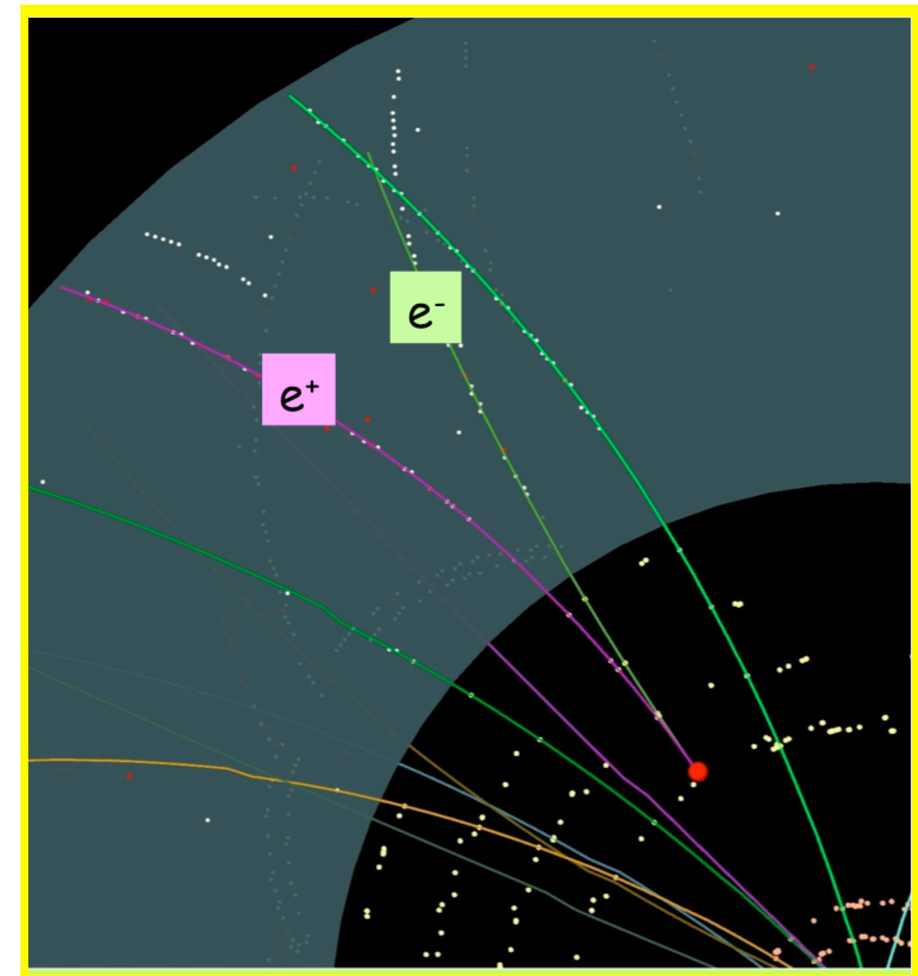


- Preparing for the future:
  - pile up reconstruction of 4 pp interactions in one bunch crossing
- Still rare but showing up
- Soon might become a major issue
- Plans for the luminosity increase of the machine seem to prefer 50ns high intensity bunches scheme.

Mapping Inner Detector Material with converted γ

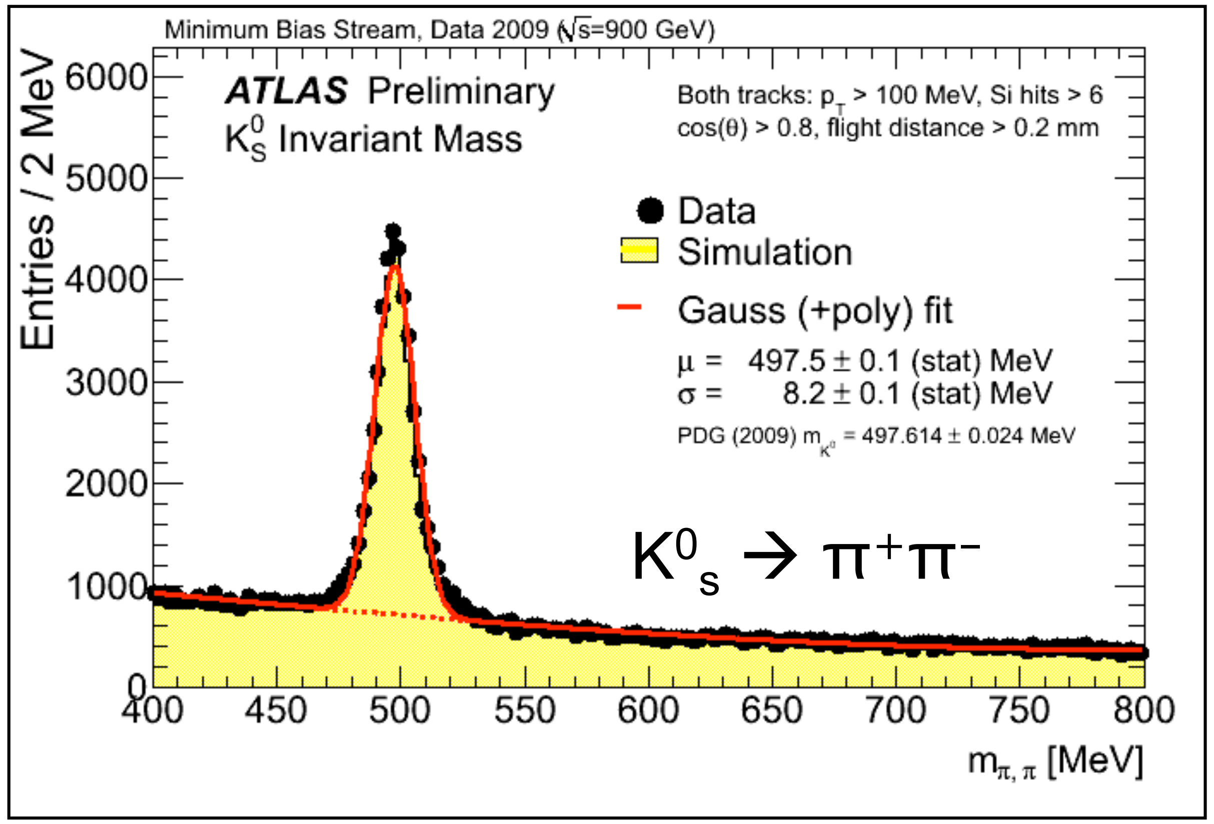


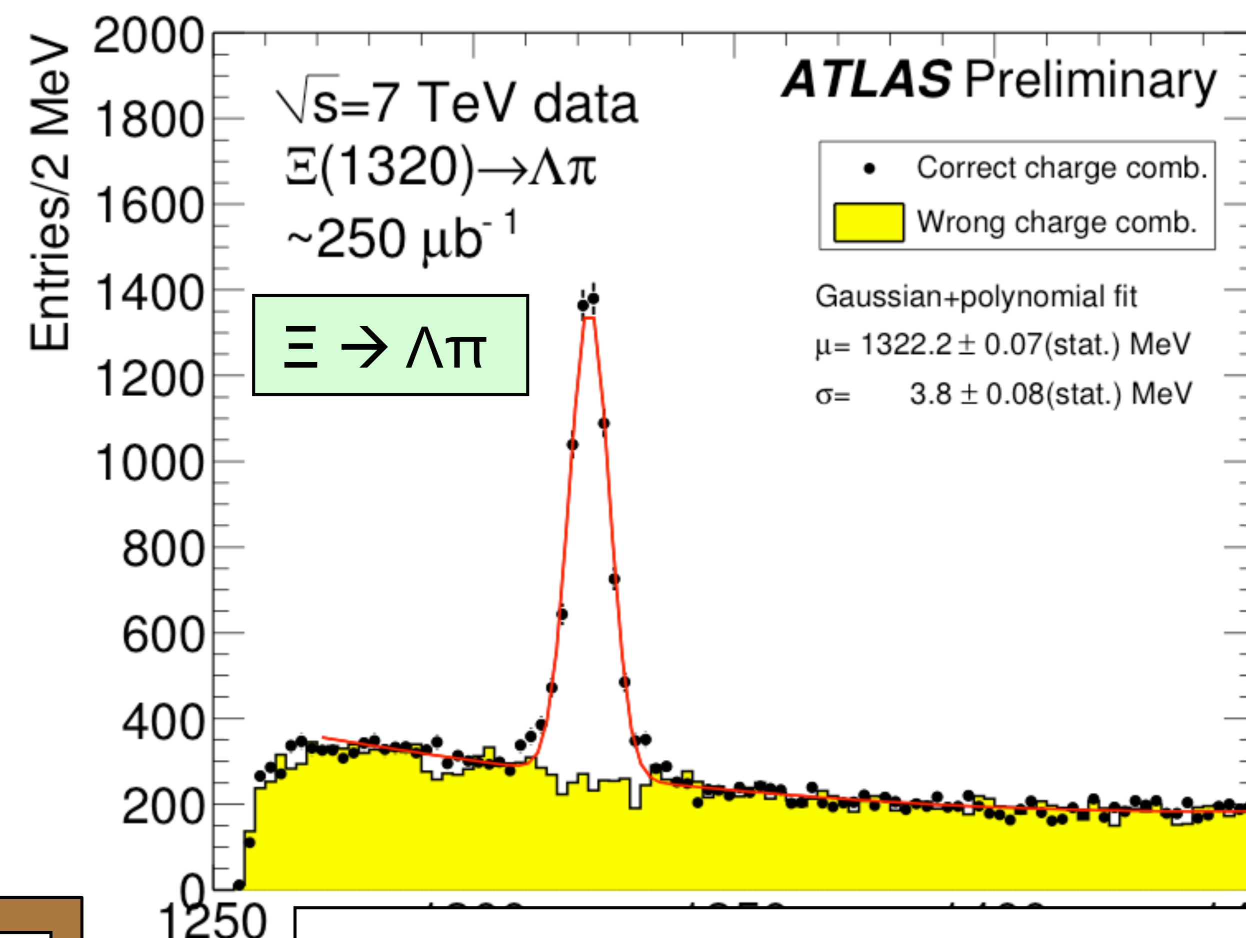


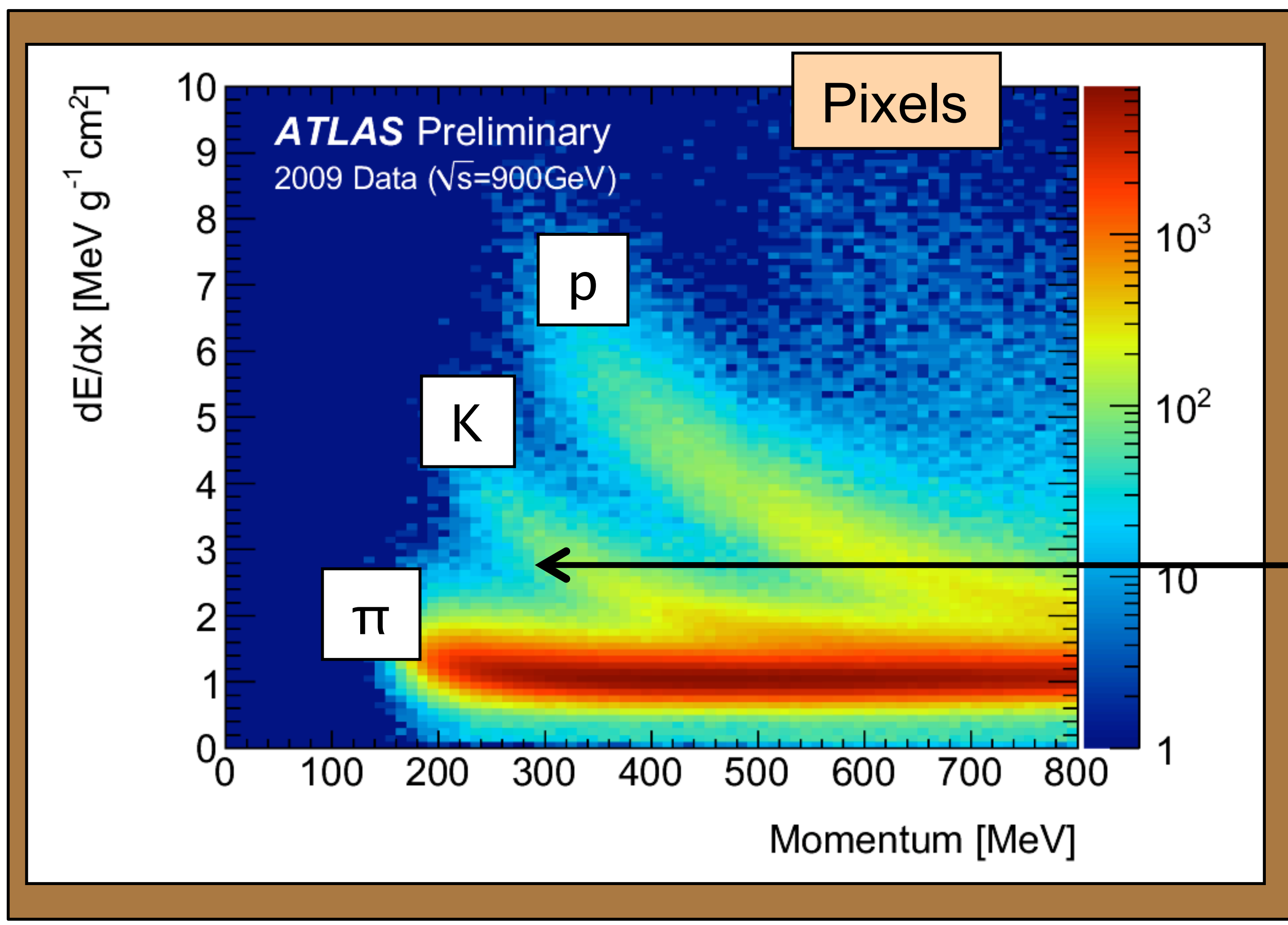


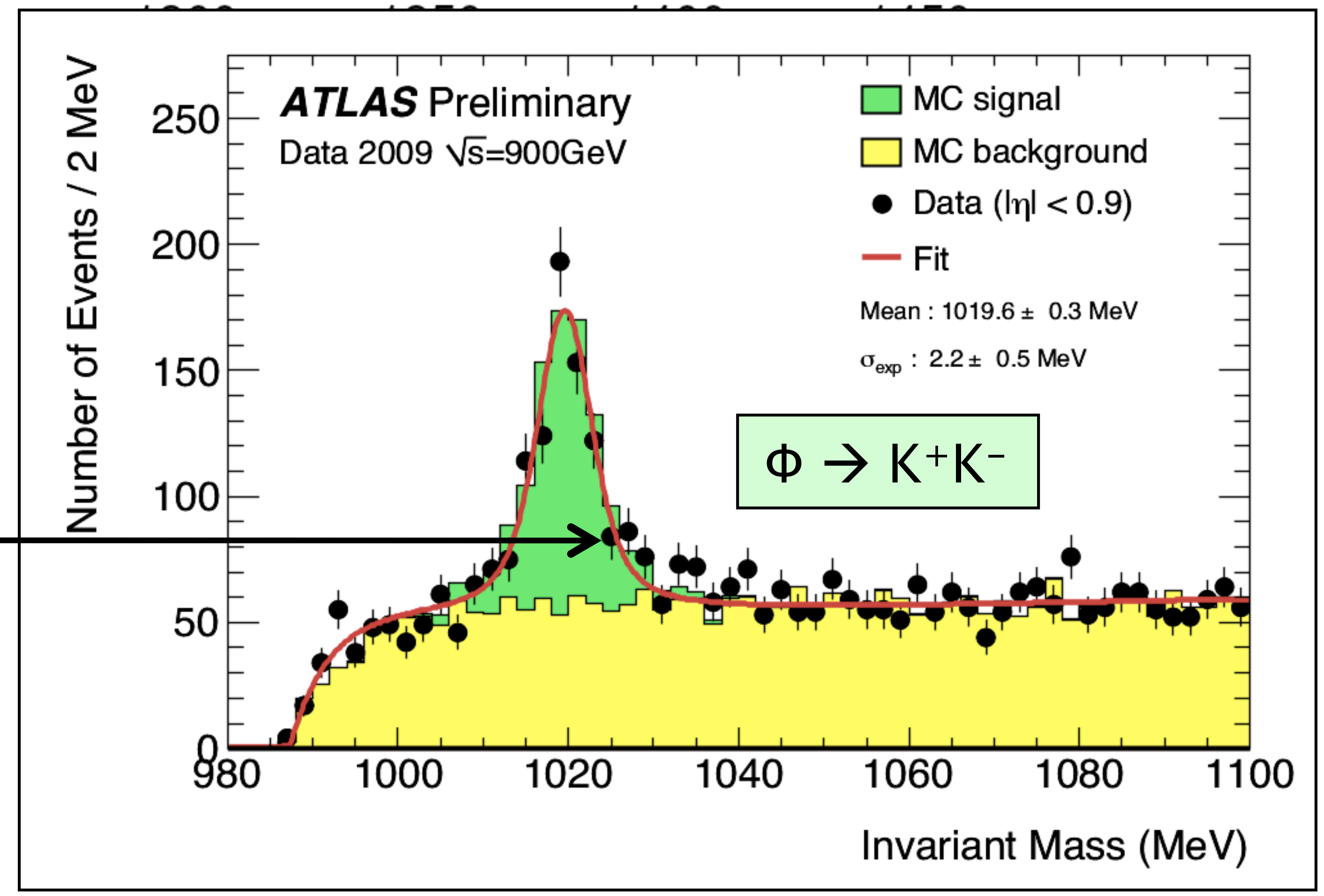
- Goal is to map ID material to better than 5% (using several methods)
- Reconstruction efficiency for Dalitz decays used to constrain beam-pipe thickness (in turn used as reference to estimate material in other layers)

ATLAS Tracker Performance

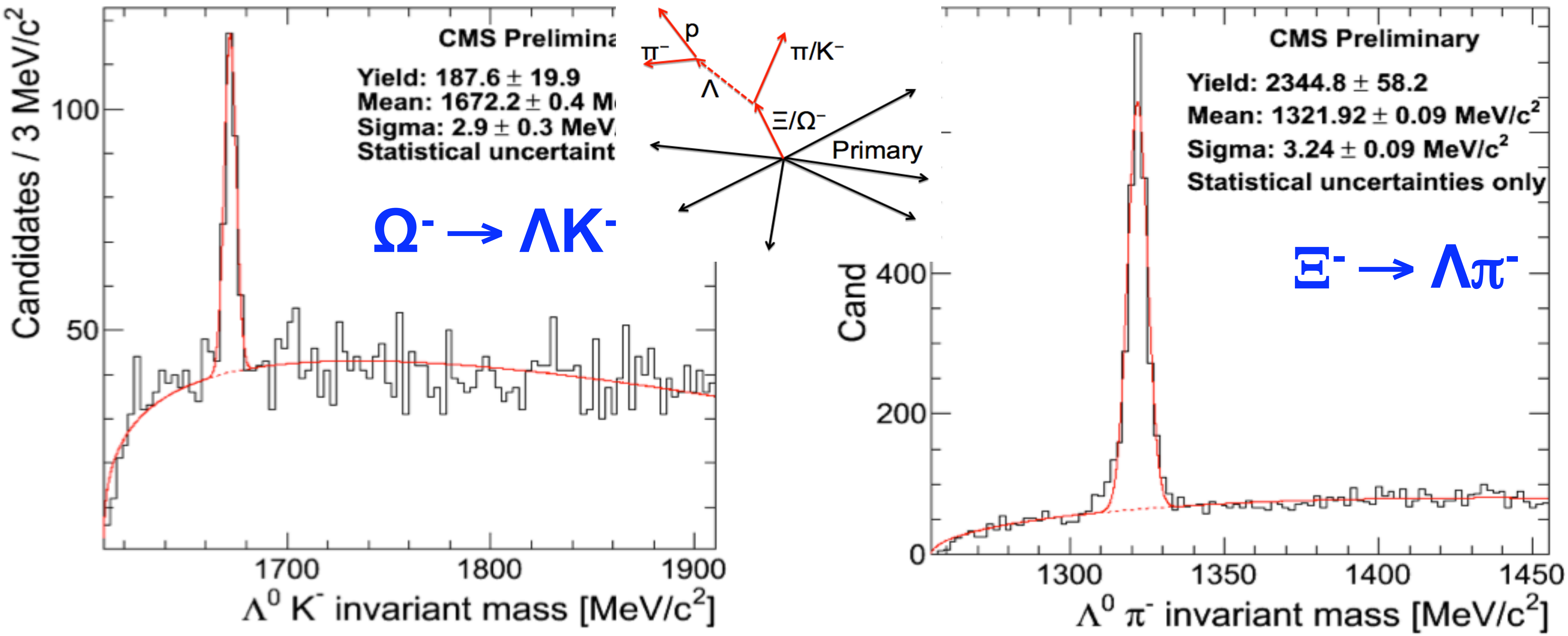








Low Mass Resonances



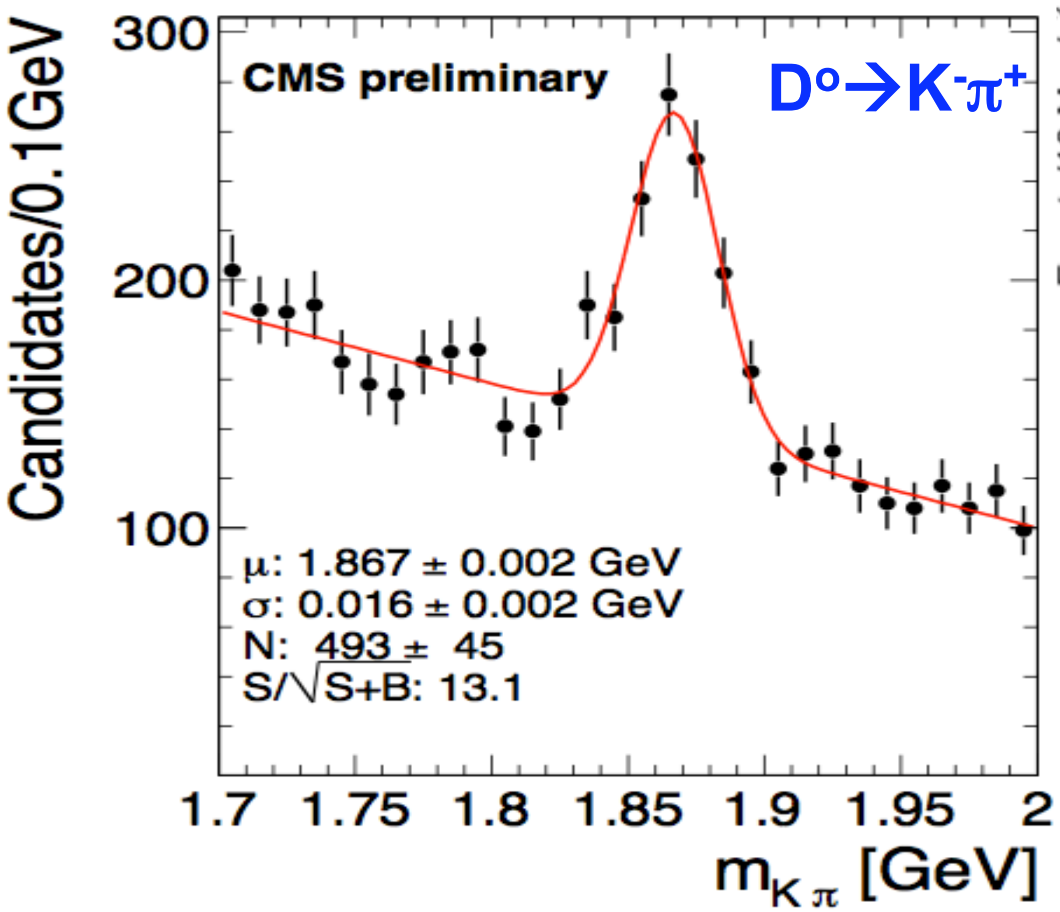
$\Omega^{\pm} \rightarrow \Lambda K^{\pm}$

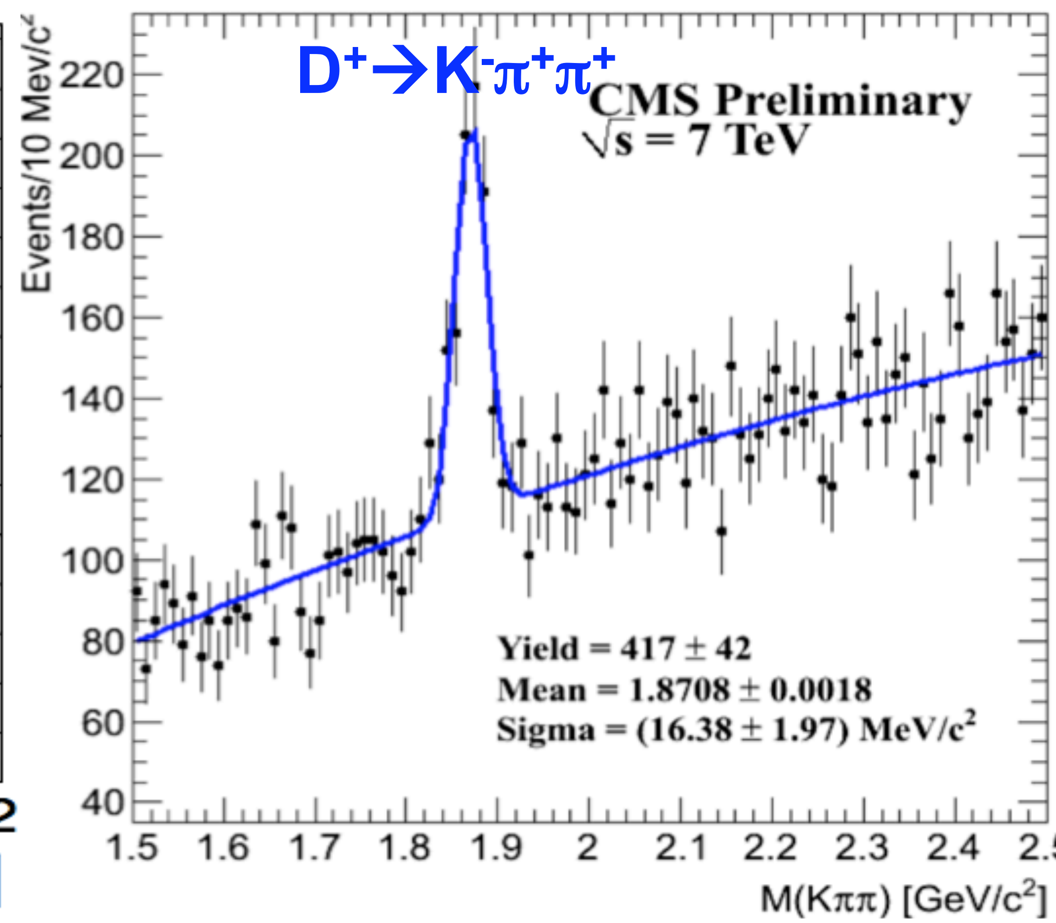
- ΛK^- or anti-ΛK^+
- combinations fit to a common vertex

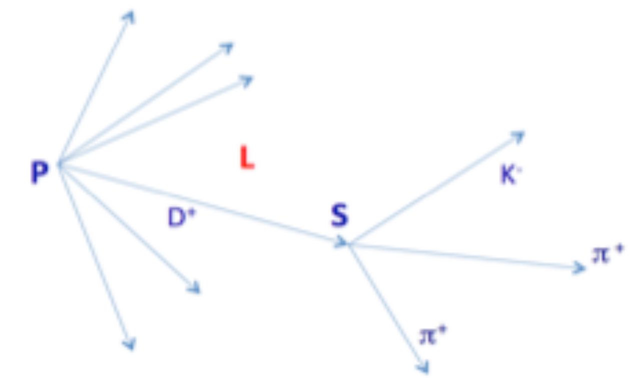
$\Xi^{\pm} \rightarrow \Lambda \pi^{\pm}$

- tracks displaced from primary vertex ($d_{3D} > 3\sigma$)
- Common displaced vertex ($L_{3D} > 10\sigma$)

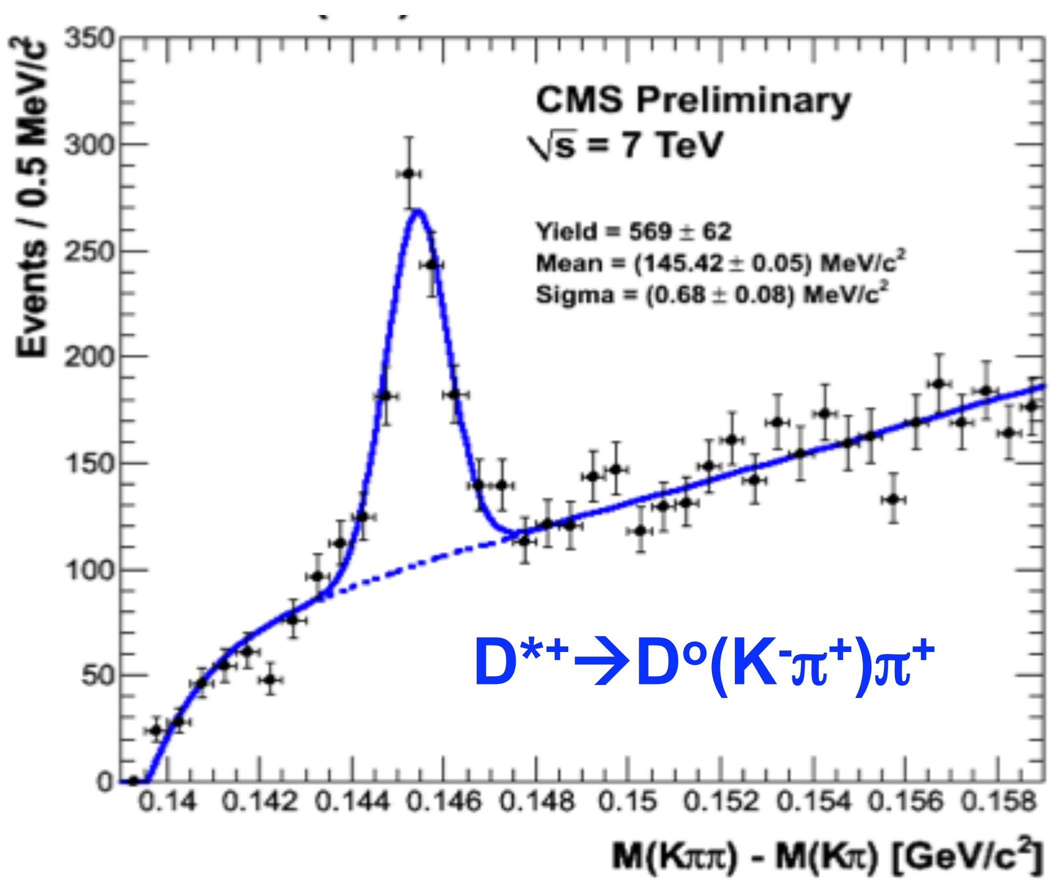
Reconstruction of Charm Mesons

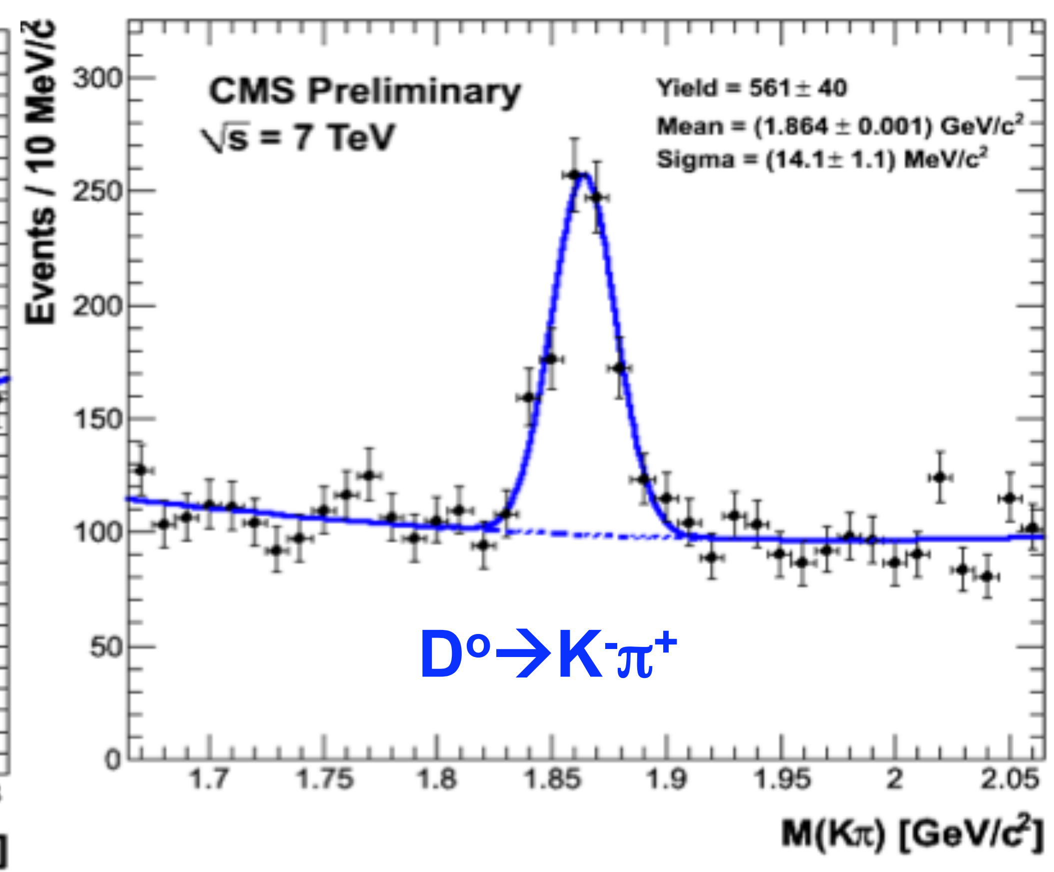






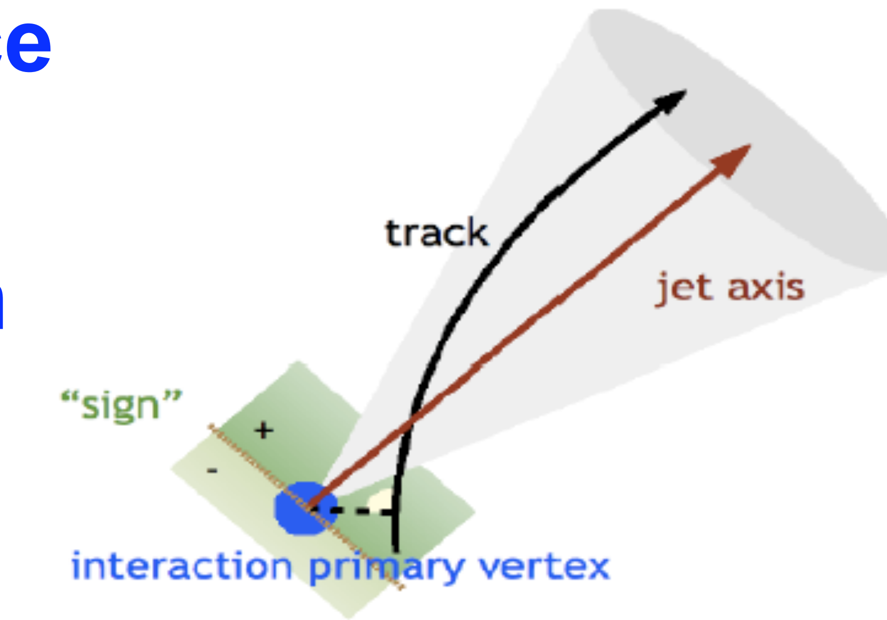
- Ongoing studies:
  - *momentum scale corrections and fine tuning the material description at few % level*;
  - *Material description photon conv., nuclear interactions, multiple scattering, energy loss*
  - Track reconstr. efficiency
  - *Ratios of rates $D^o \rightarrow K\pi$ / $D^o \rightarrow K\pi\pi\pi$ (+ other methods)*

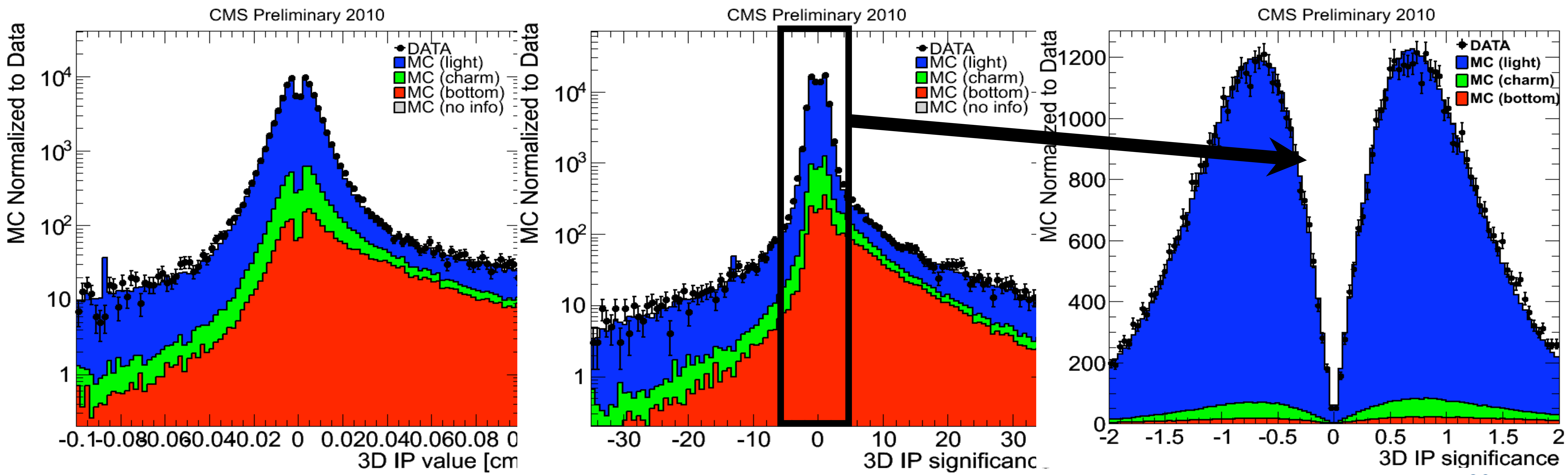




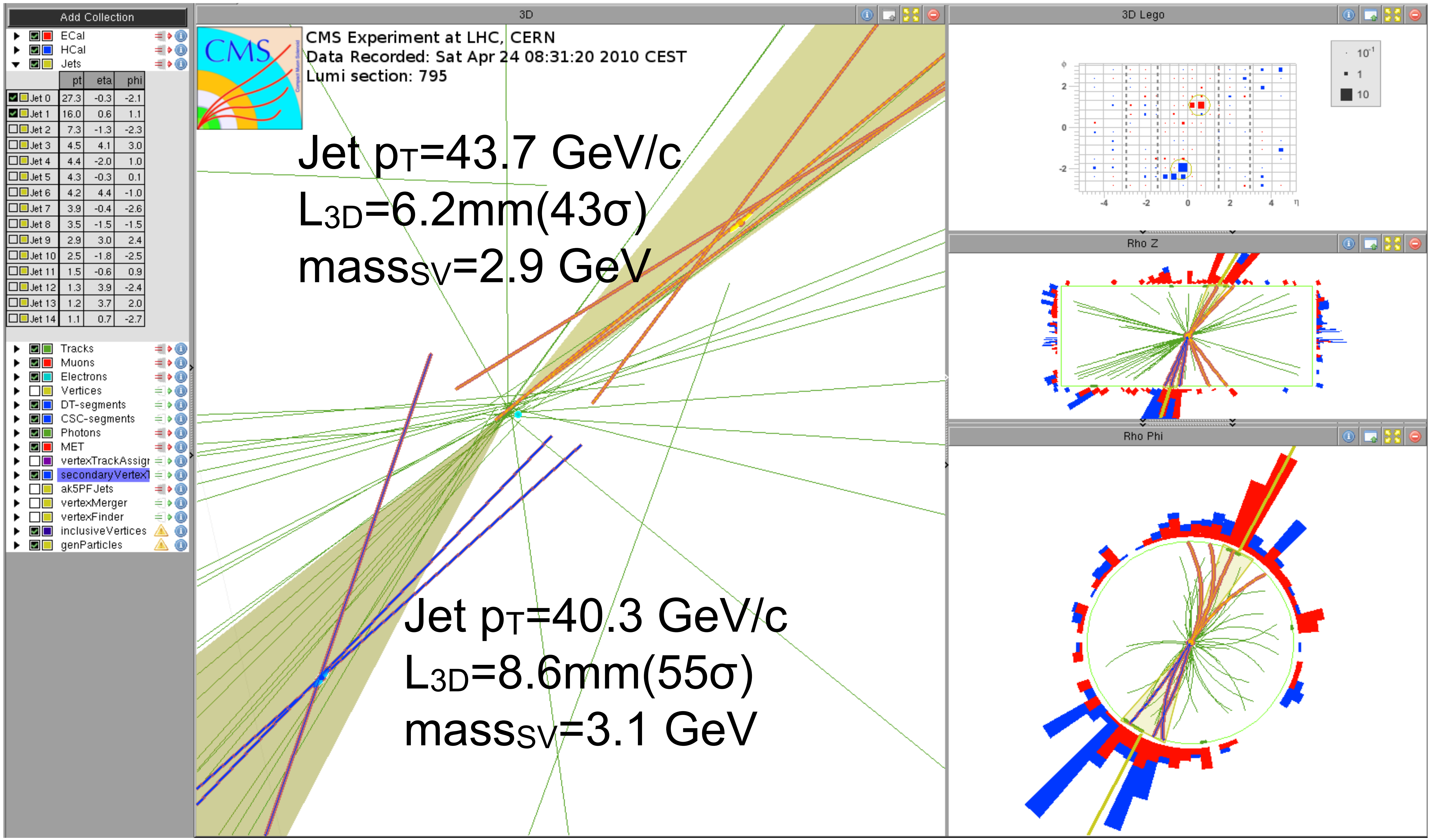
B Tagging

- **3D Impact parameter value and significance**
- **Selection:**
  - tracks with Pt>1GeV belonging to jets with p_T > 40 GeV and $|\eta|$ < 1.5 (*PFlow Jets anti-k_T R=0.5).*

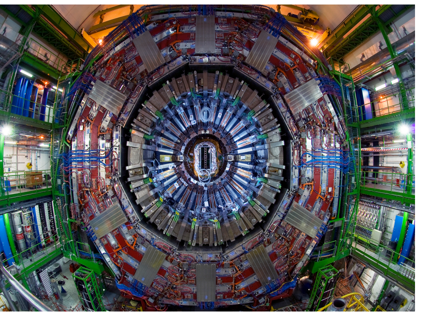


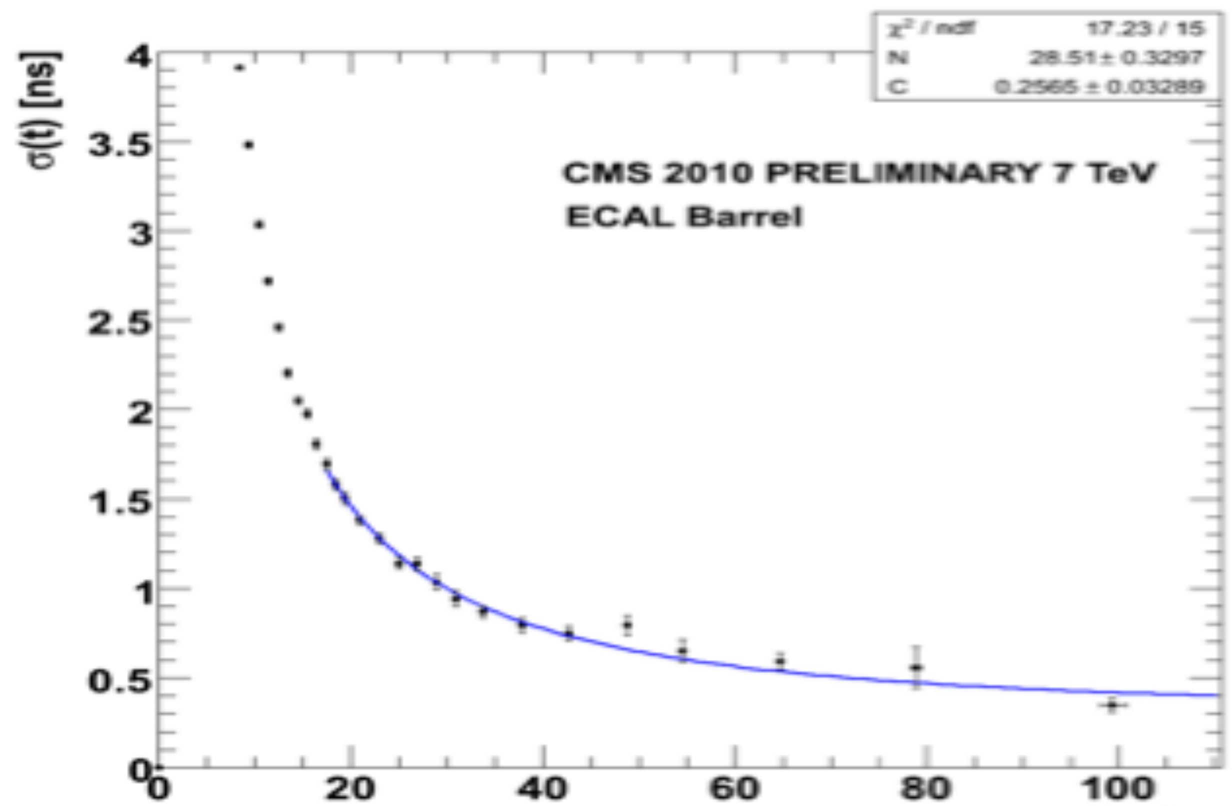


Two Tagged b-jets Candidate

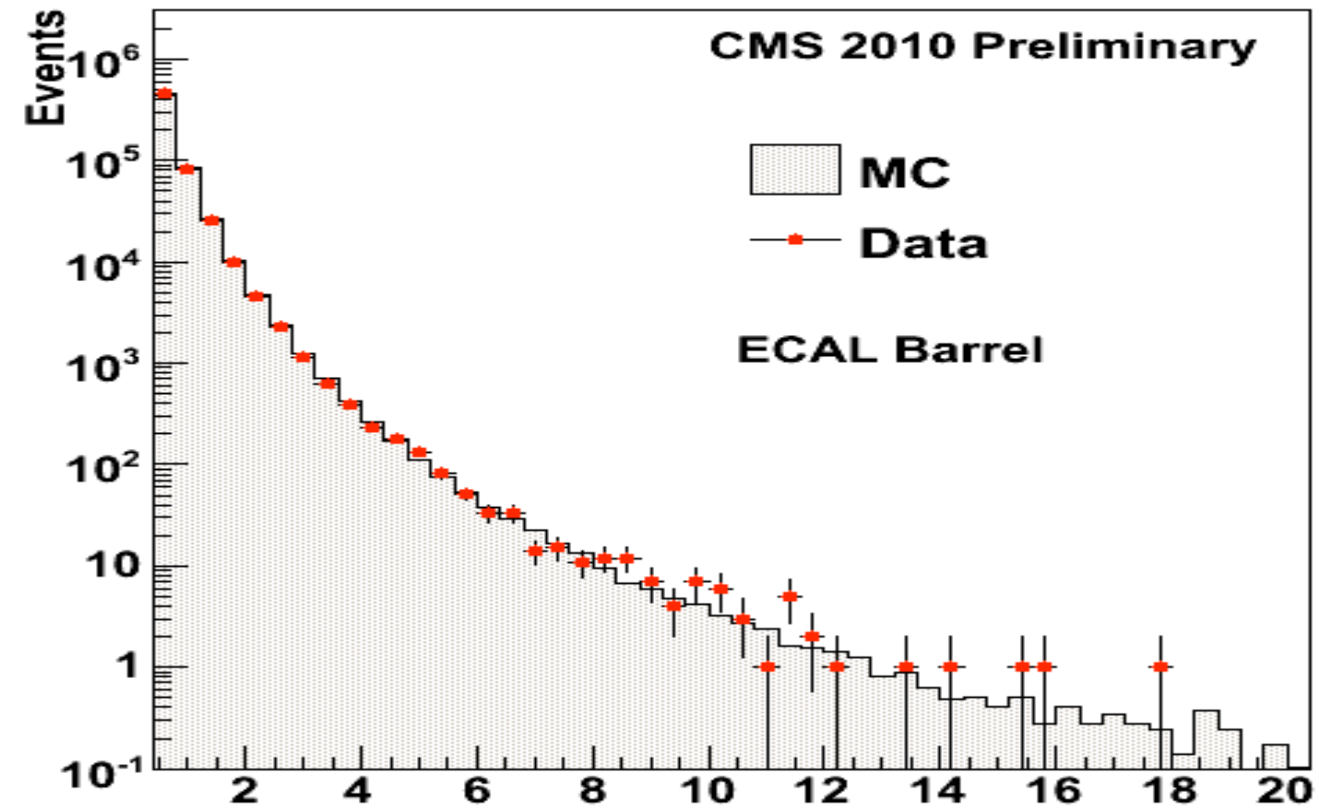


ECAL Clusters (e & γ)

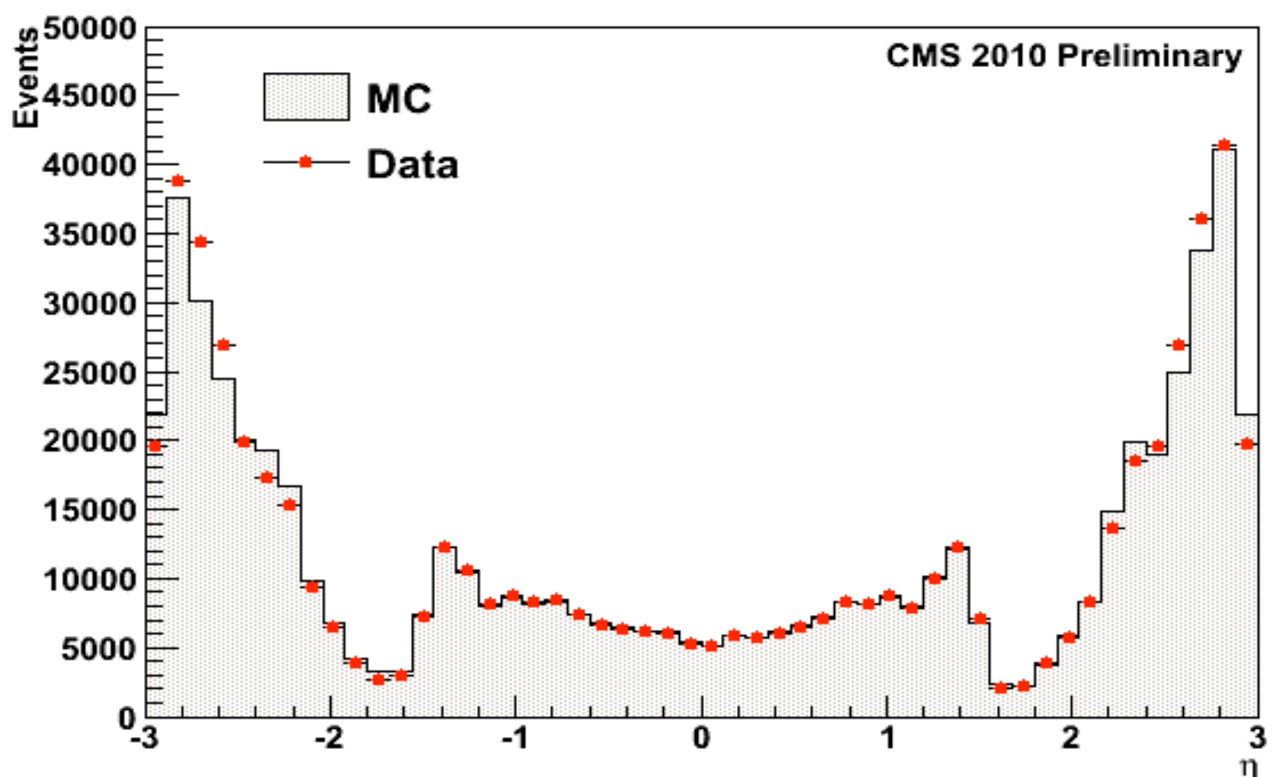




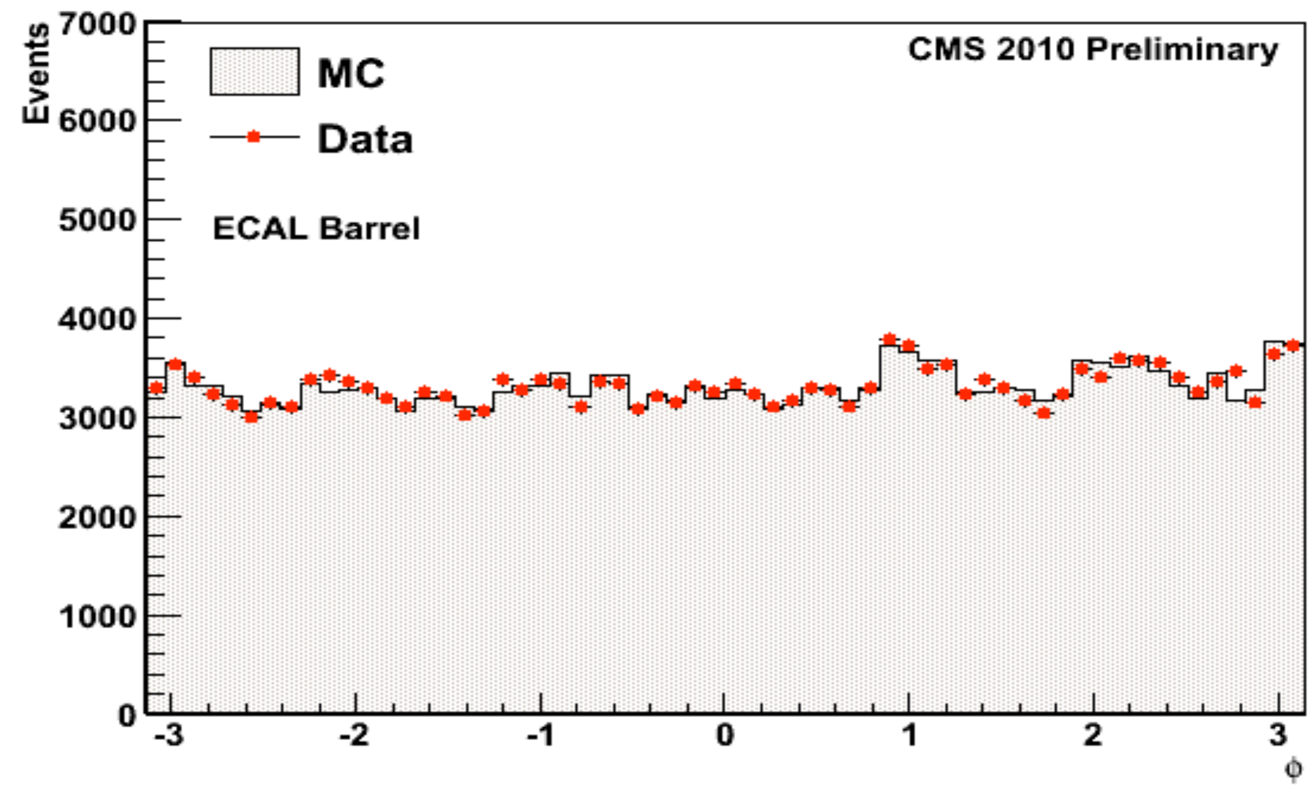
timing resolution



energy distribution

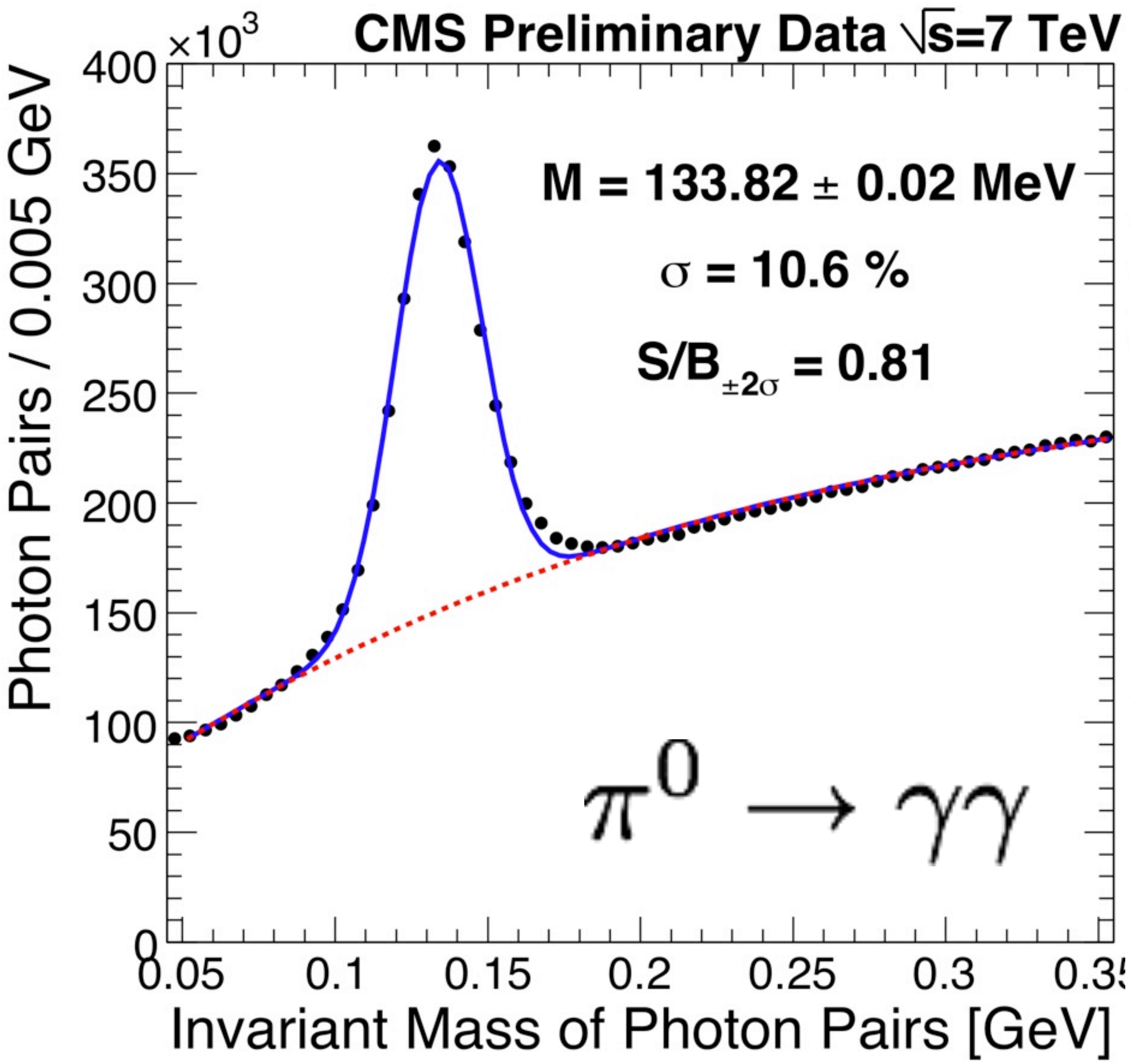


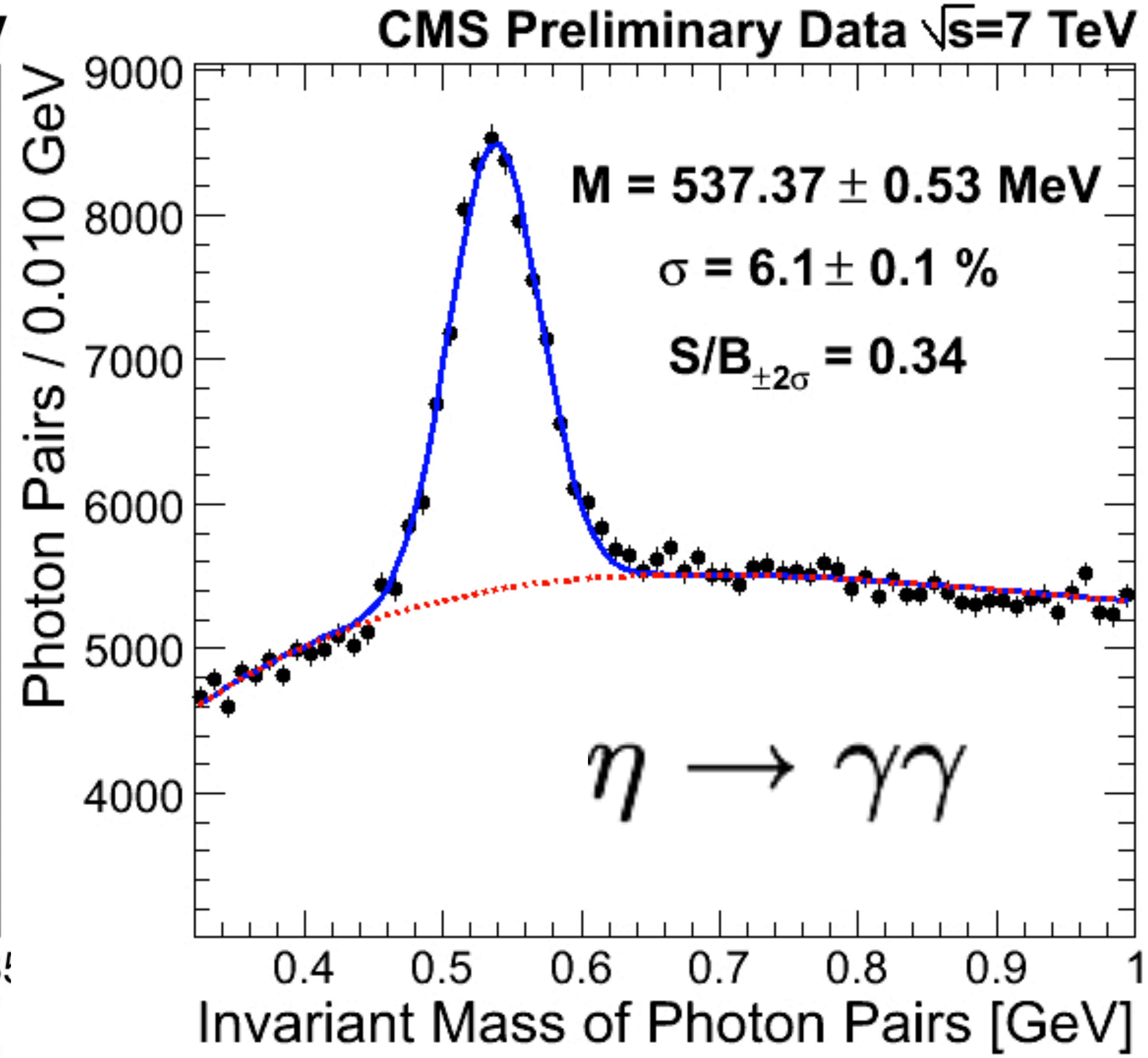
η distribution



φ distribution

ECAL Calibration





Agreement on energy scale at ~1% level (width well modeled)

π^0 and η samples to improve further calibration and monitoring

JET Reconstruction

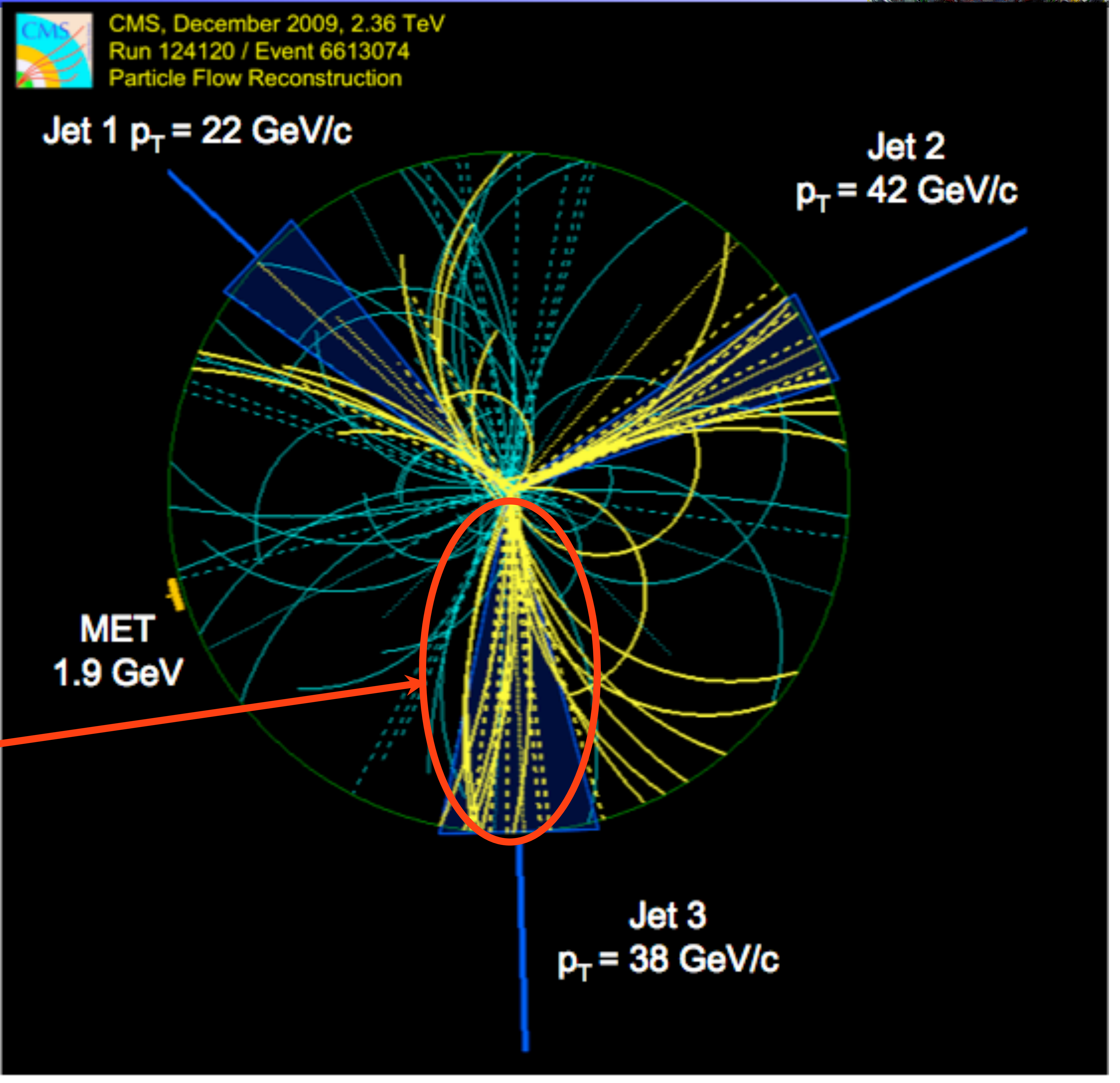
•Three different Jet Reconstruction methods:

•Calorimeter Jets:
Based on calorimeter tower

•Jet-plus-tracks Jets
a posteriori corrections to calorimeter using tracks

•Particle flow Jets
a priori use of tracks and calorimeter
Identify charged hadrons, photons, electrons, neutral hadrons

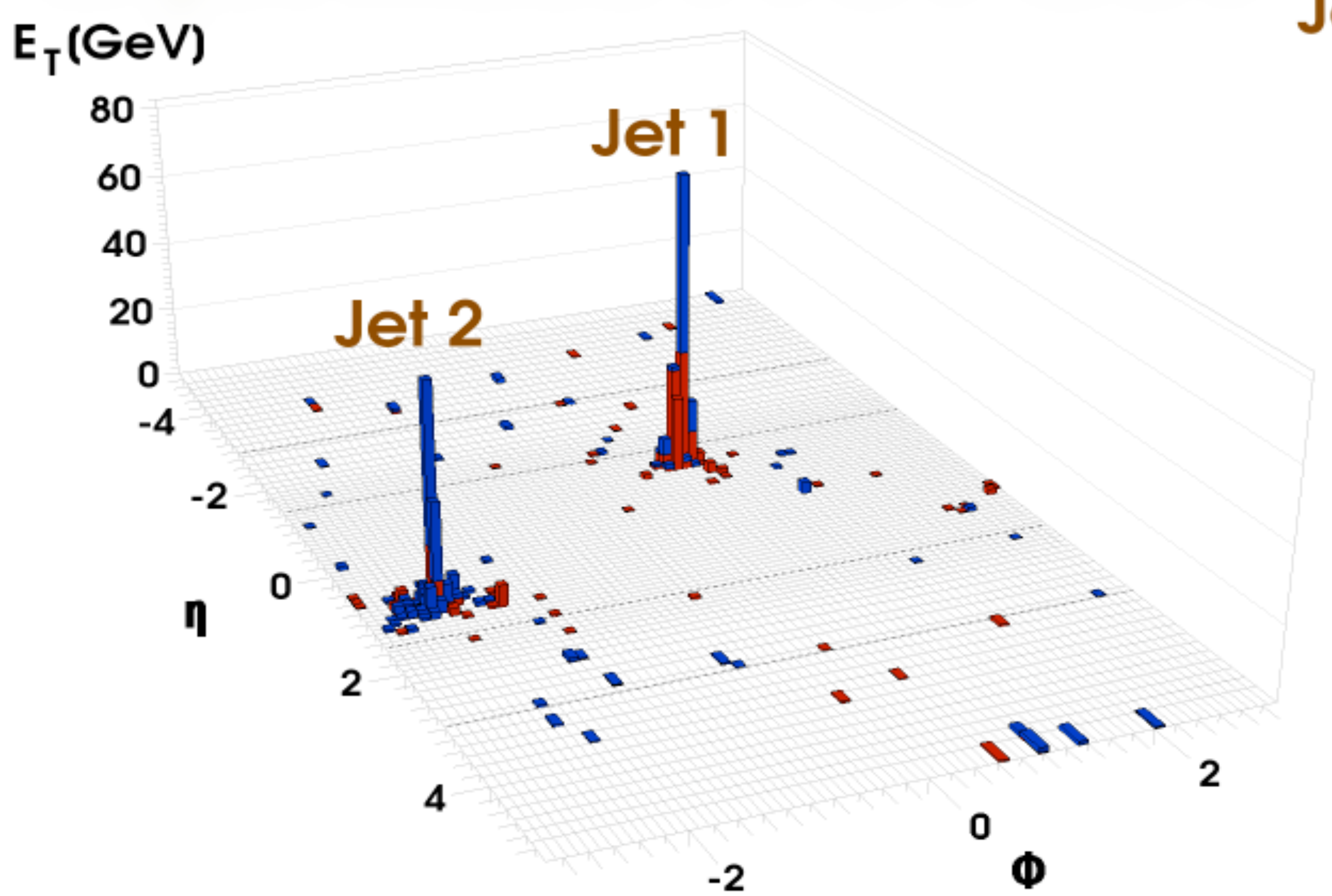
Default Jet Algorithm:
Anti-kT, R=0.5

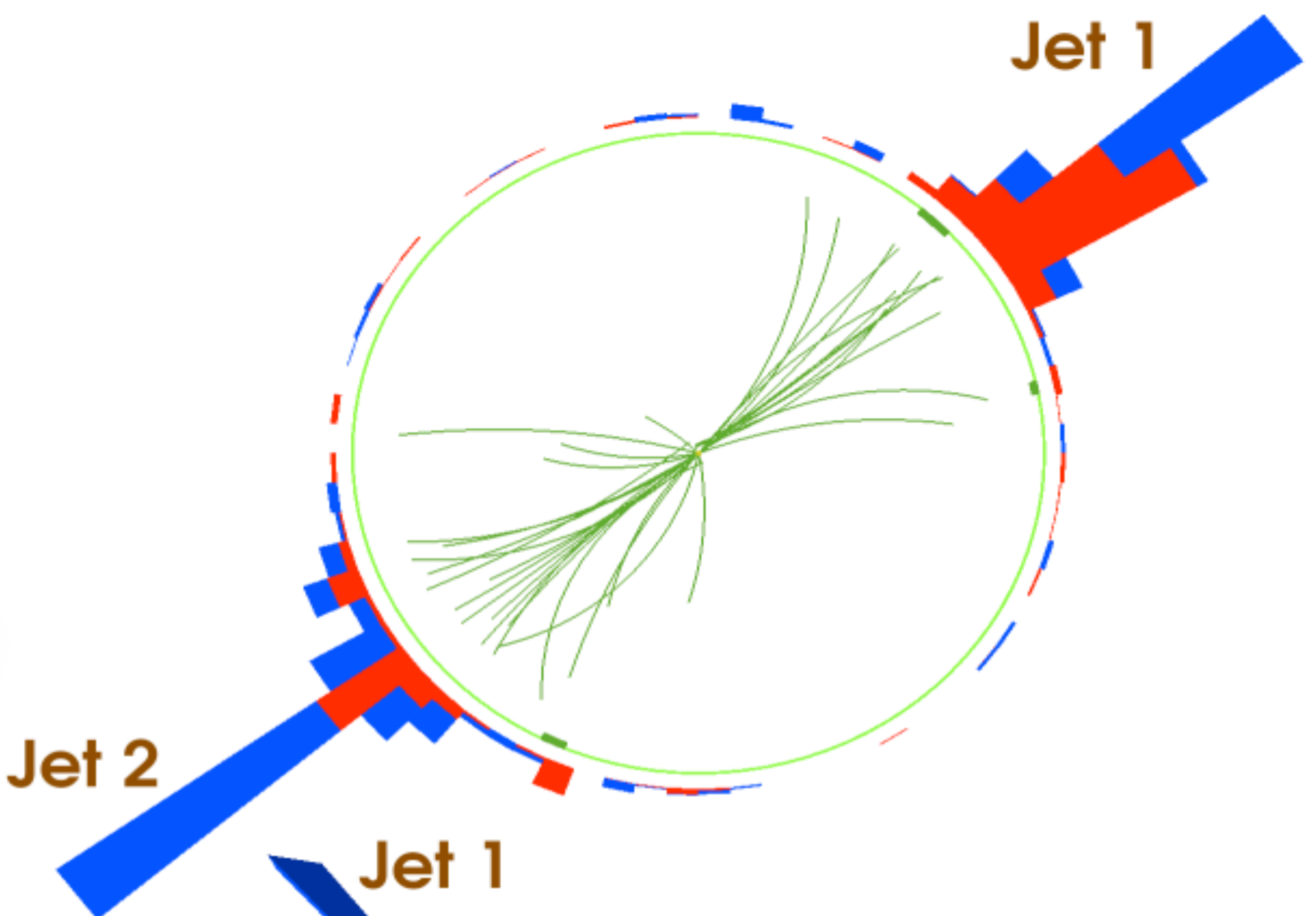


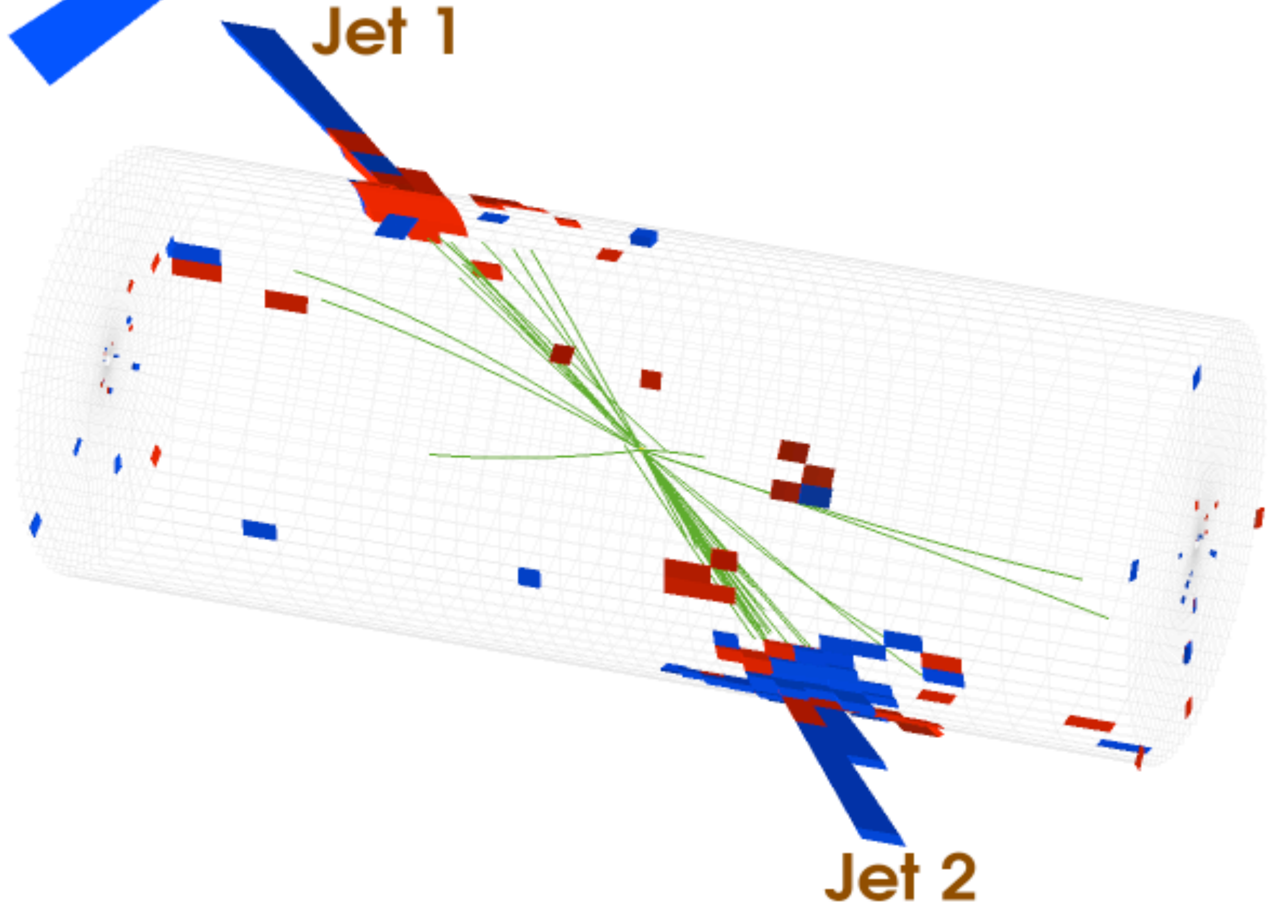
Di-jet Candidate Events

CMS Experiment at LHC, CERN
Run 133450 Event 16358963
Lumi section: 285
Sat Apr 17 2010, 12:25:05 CEST

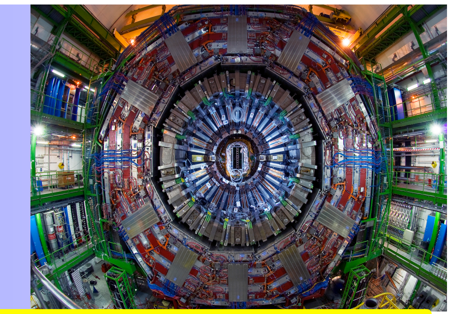
Jet 1 p_T : 253 GeV
Jet 2 p_T : 244 GeV
Dijet mass : 764 GeV

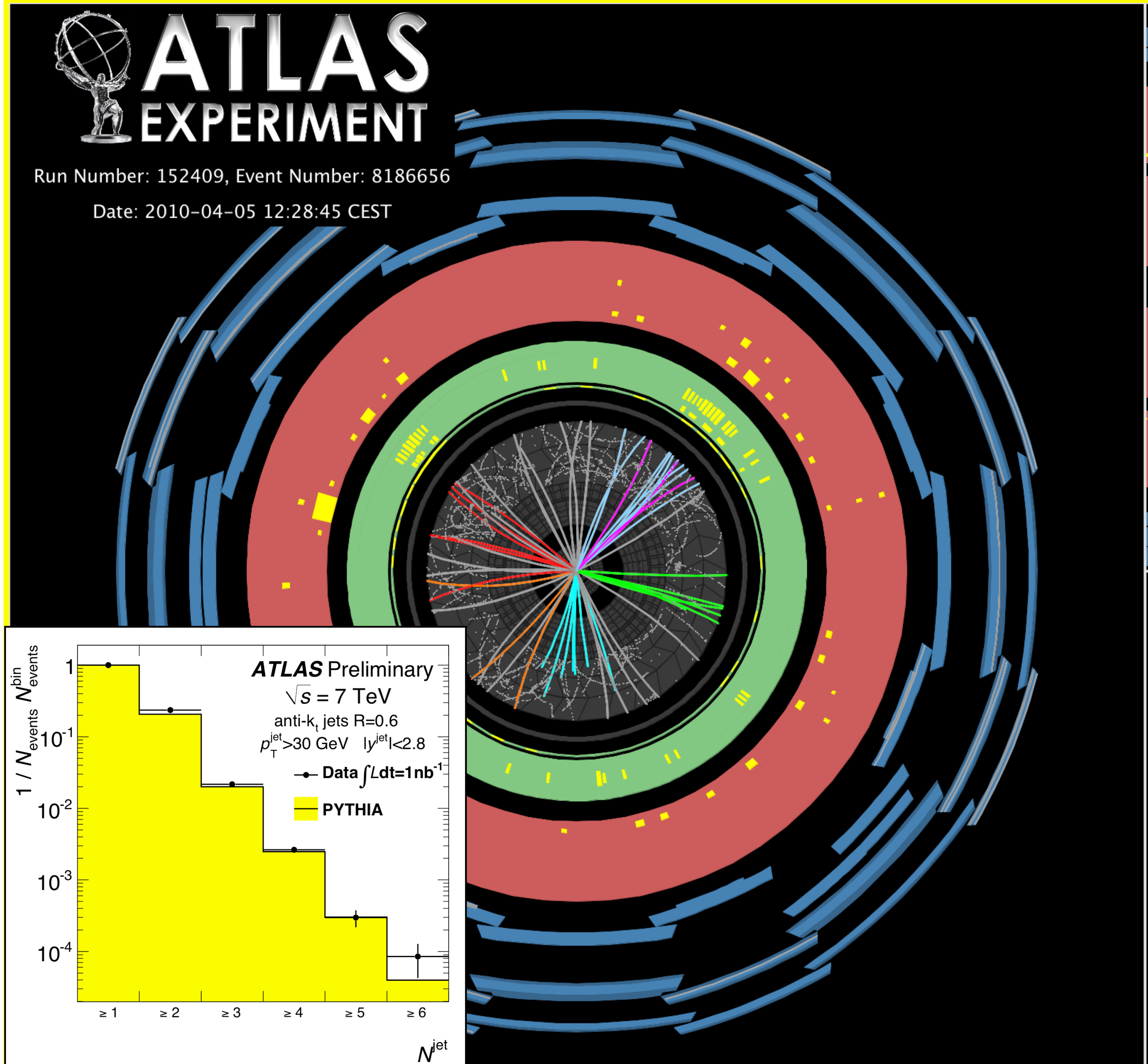


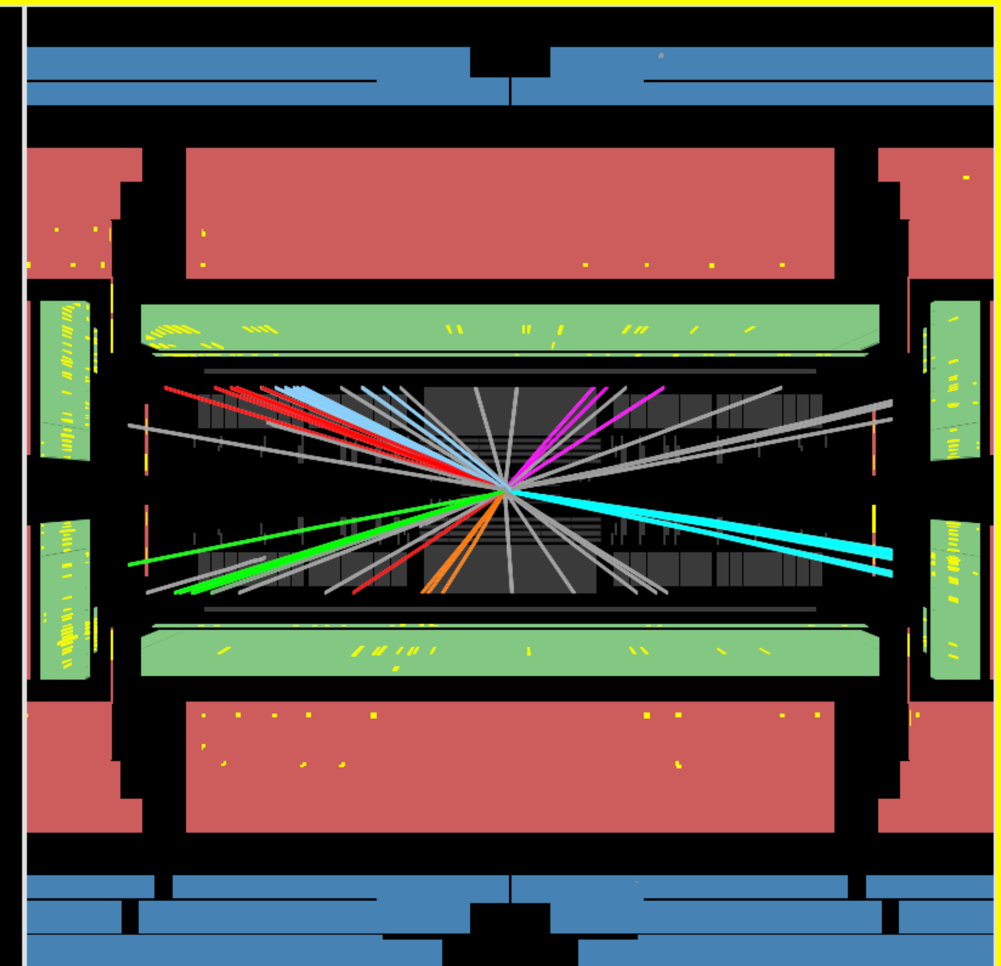


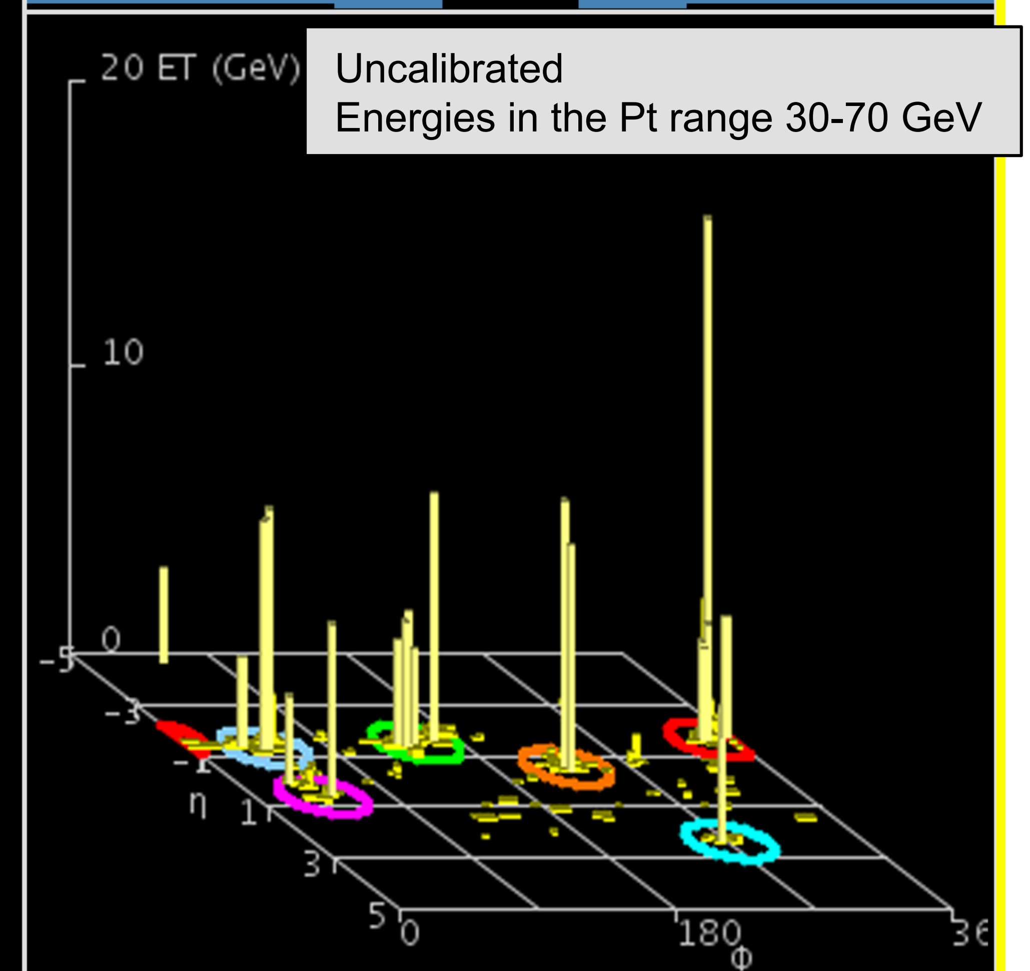


Jets in ATLAS





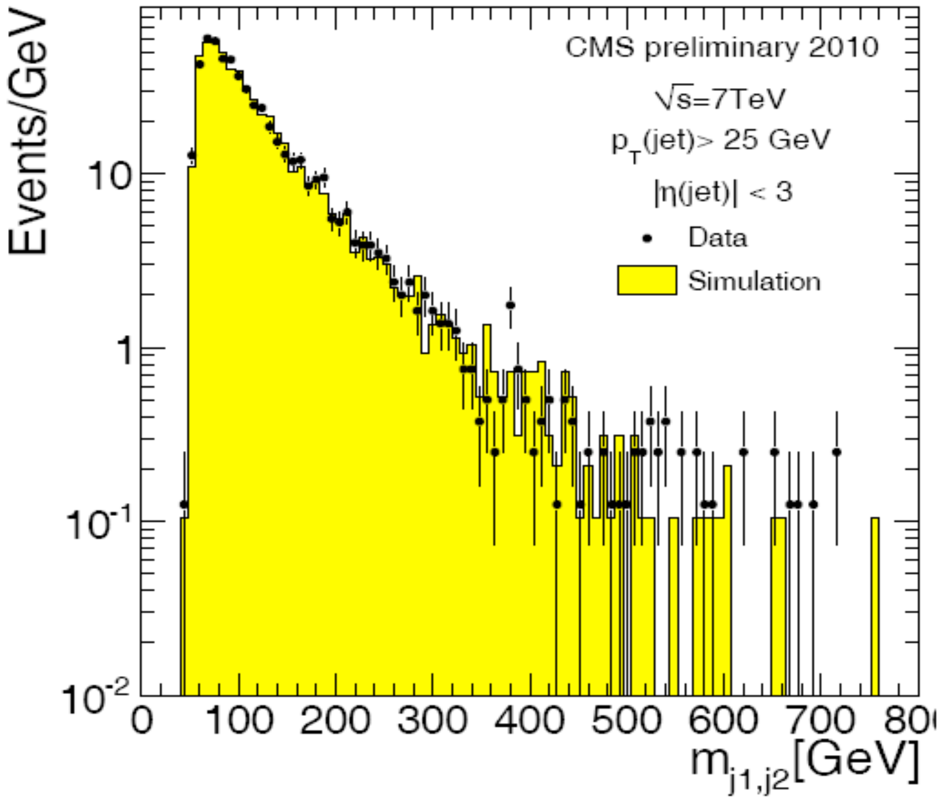


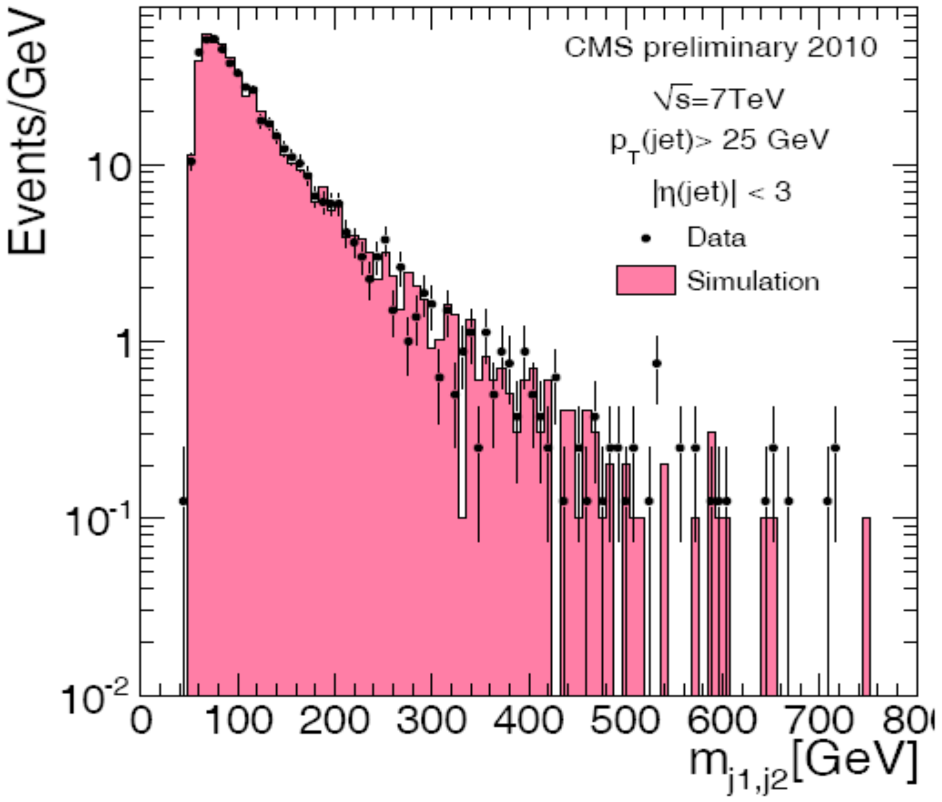


6 Jet Event in 7 TeV Collisions

CMS Dijet Distributions

- Jets reconstructed with the anti-k_T R=0.5 algorithm
- Dijet selection : Jet Pt > 25 GeV, $\Delta\Phi > 2.1$, $|\eta| < 3$
- Loose ID cuts on number of components
- Three different approaches: pure calorimetric, track corrected calo and particle flow.





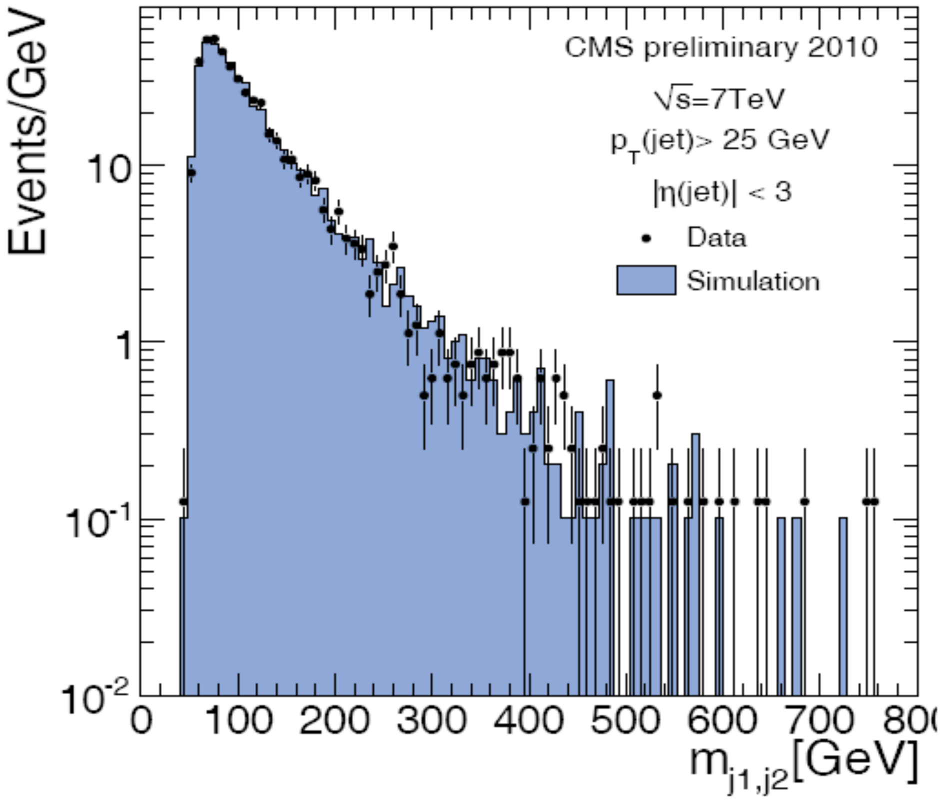
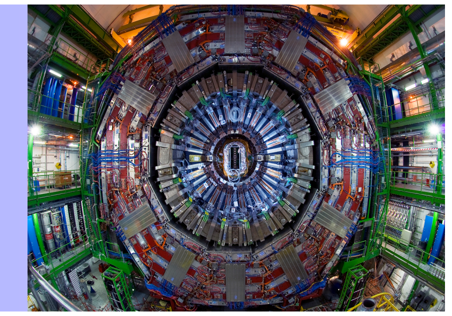


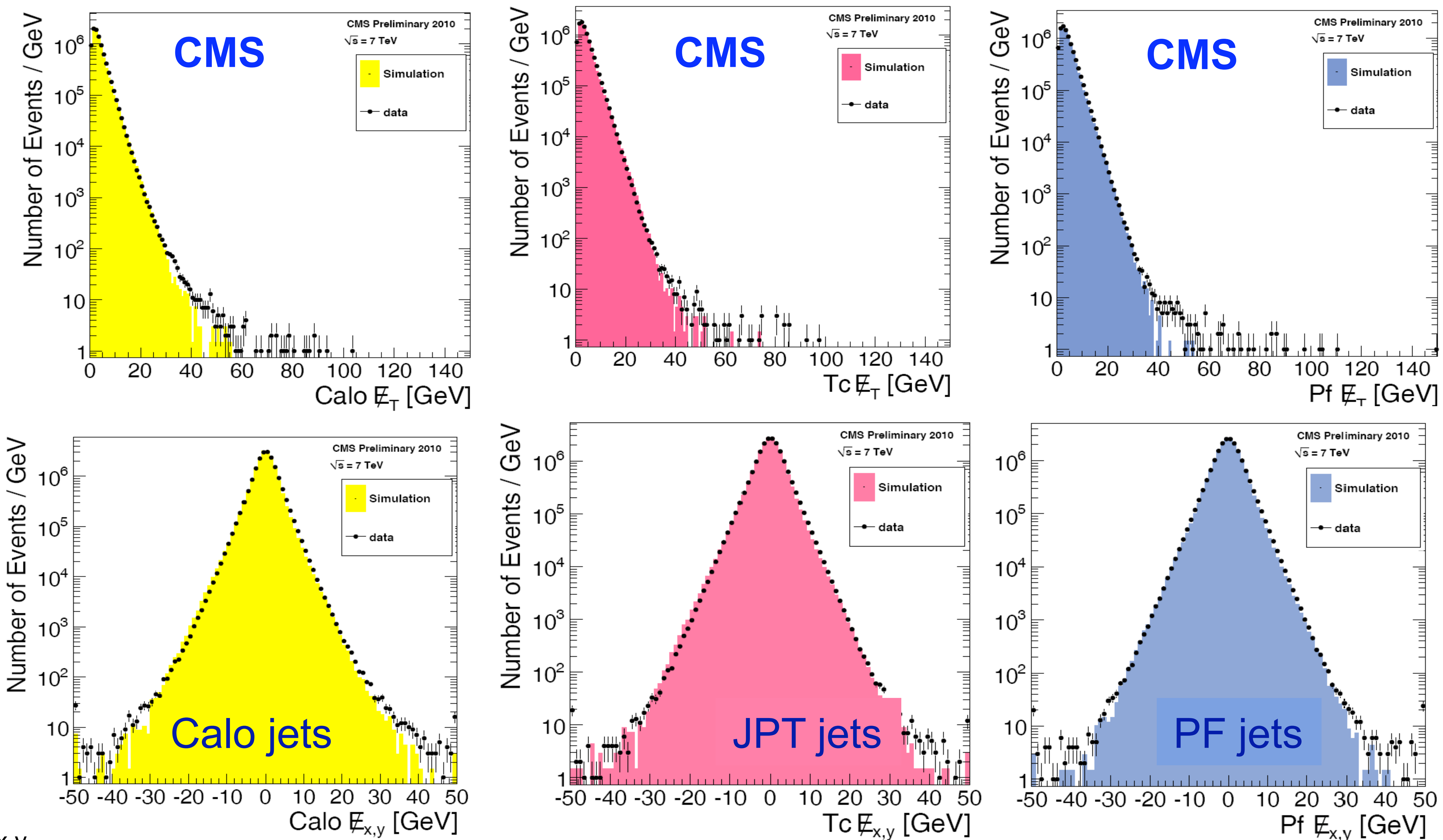
Figure: Data vs MC: Di jet mass $m_{j1,j2}$ for Calorimeter Jets, JPT jets, PFjets.

Missing Transverse Energy (MET)



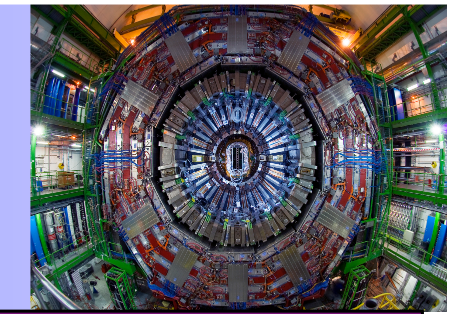
MET

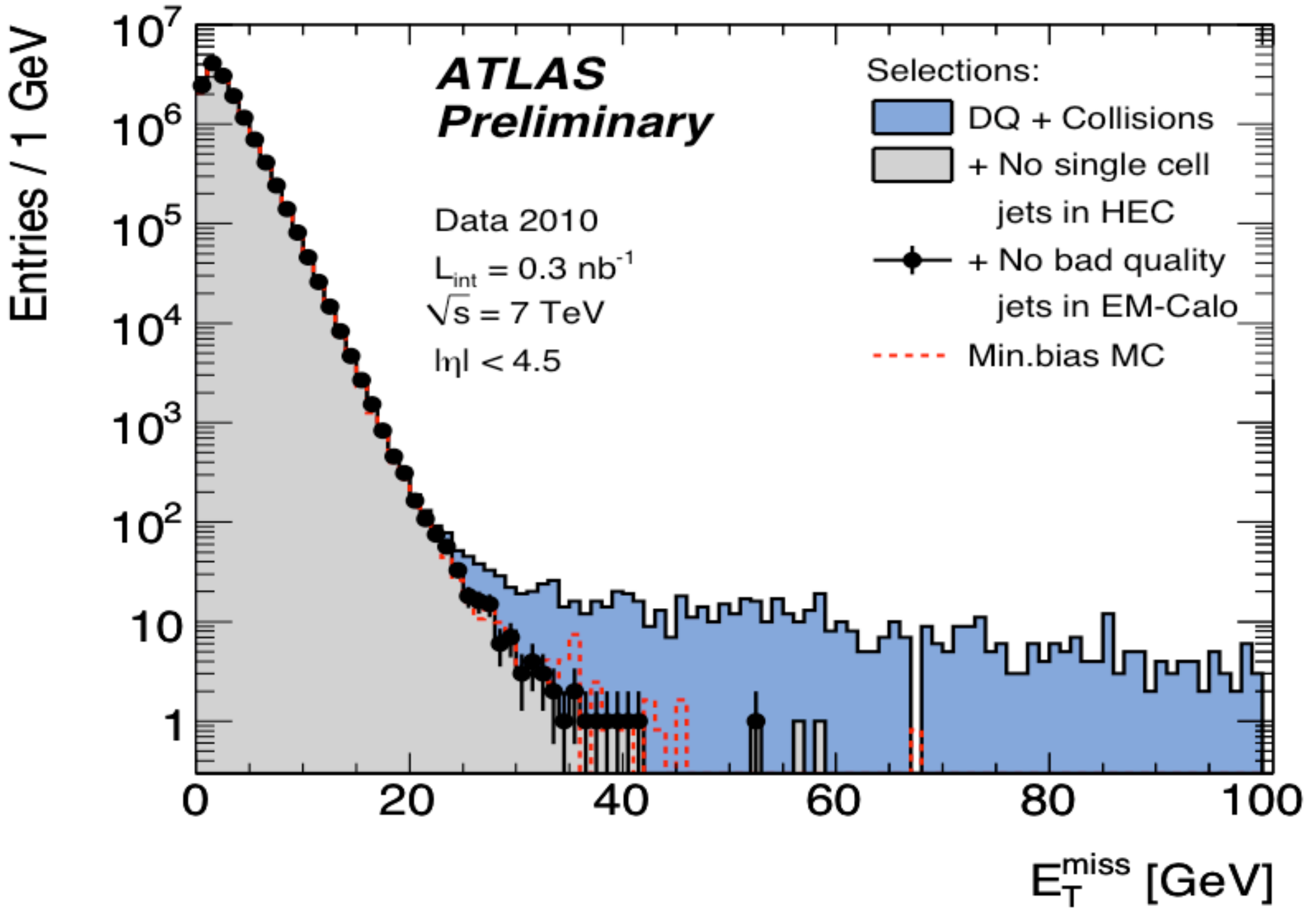
$MET_{x,y}$

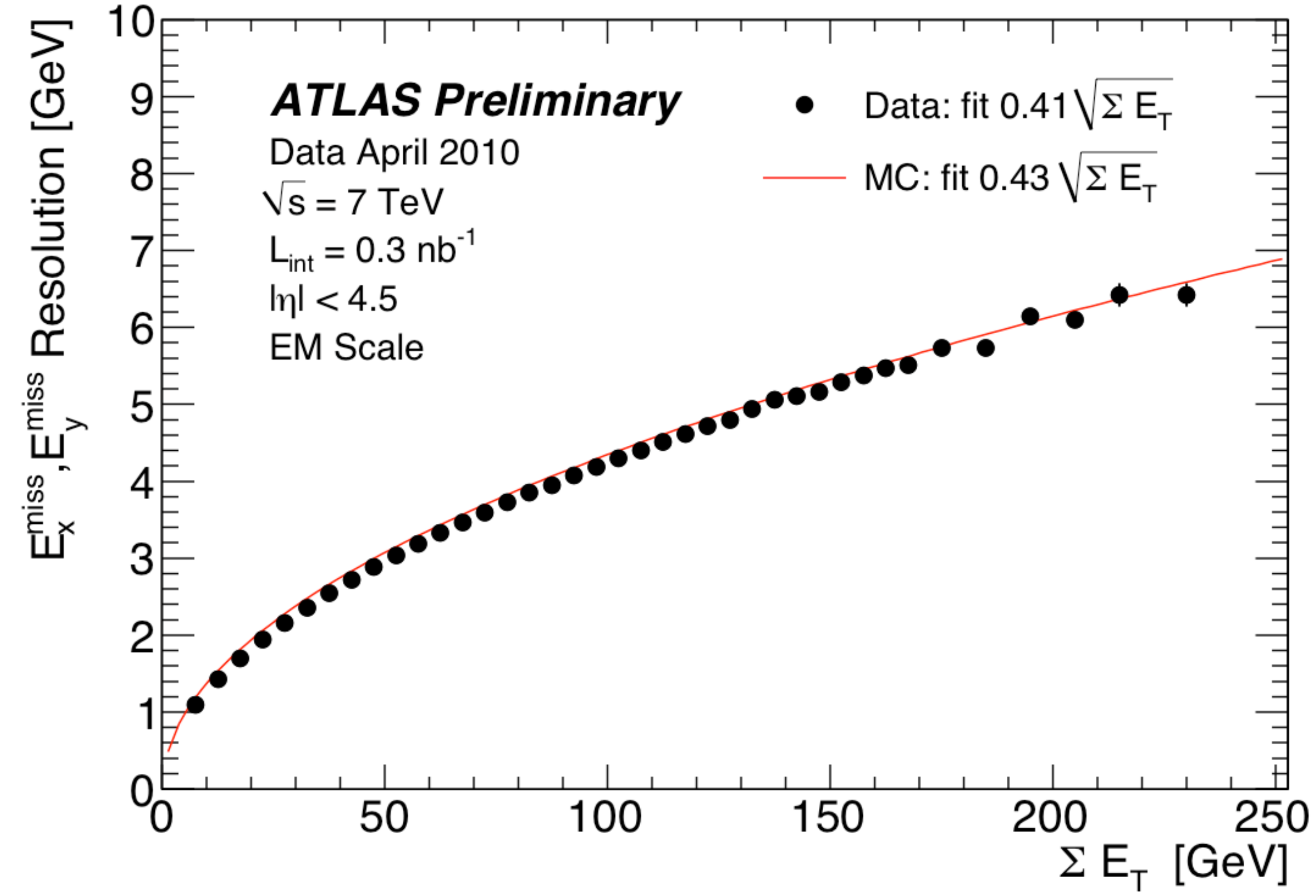


- **MB studies - monitoring of core and tails (noise dominated)**
- **Good agreement with MC over many orders of magnitude**
- **Continuous improvement of MET tails**

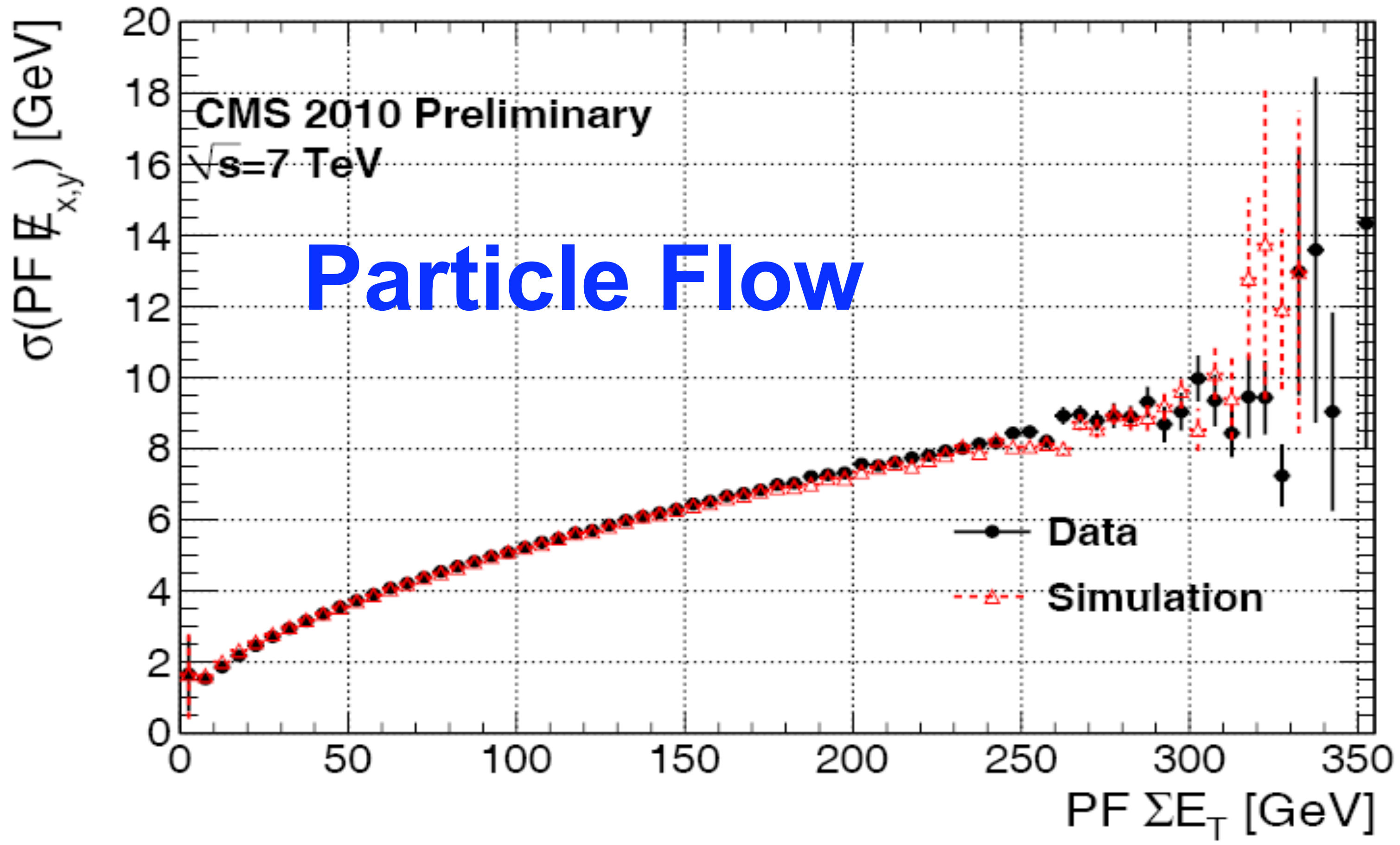
MET Resolutions



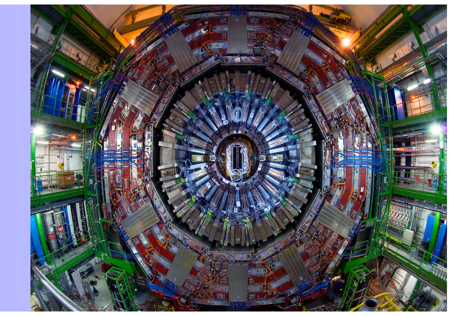


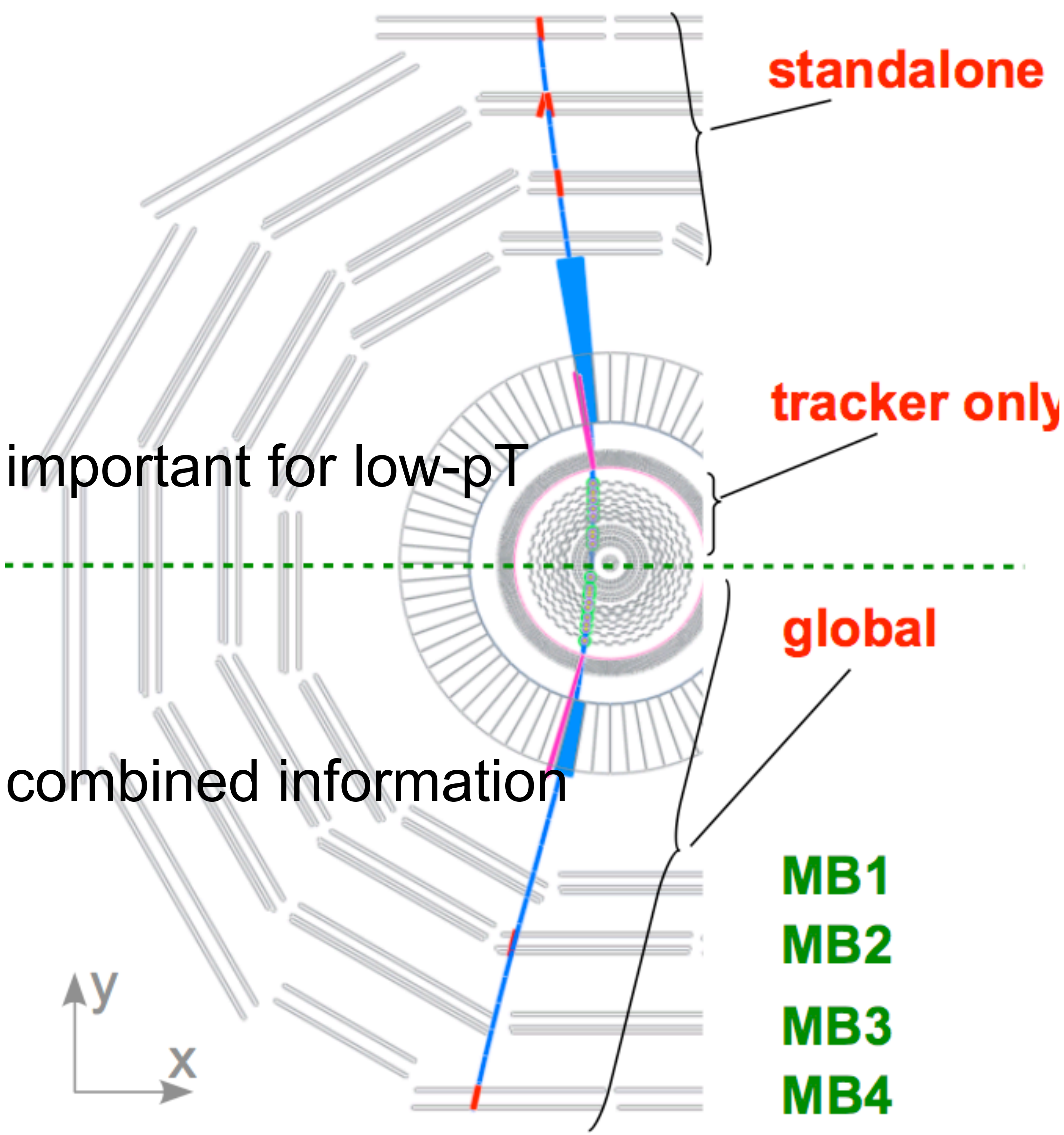


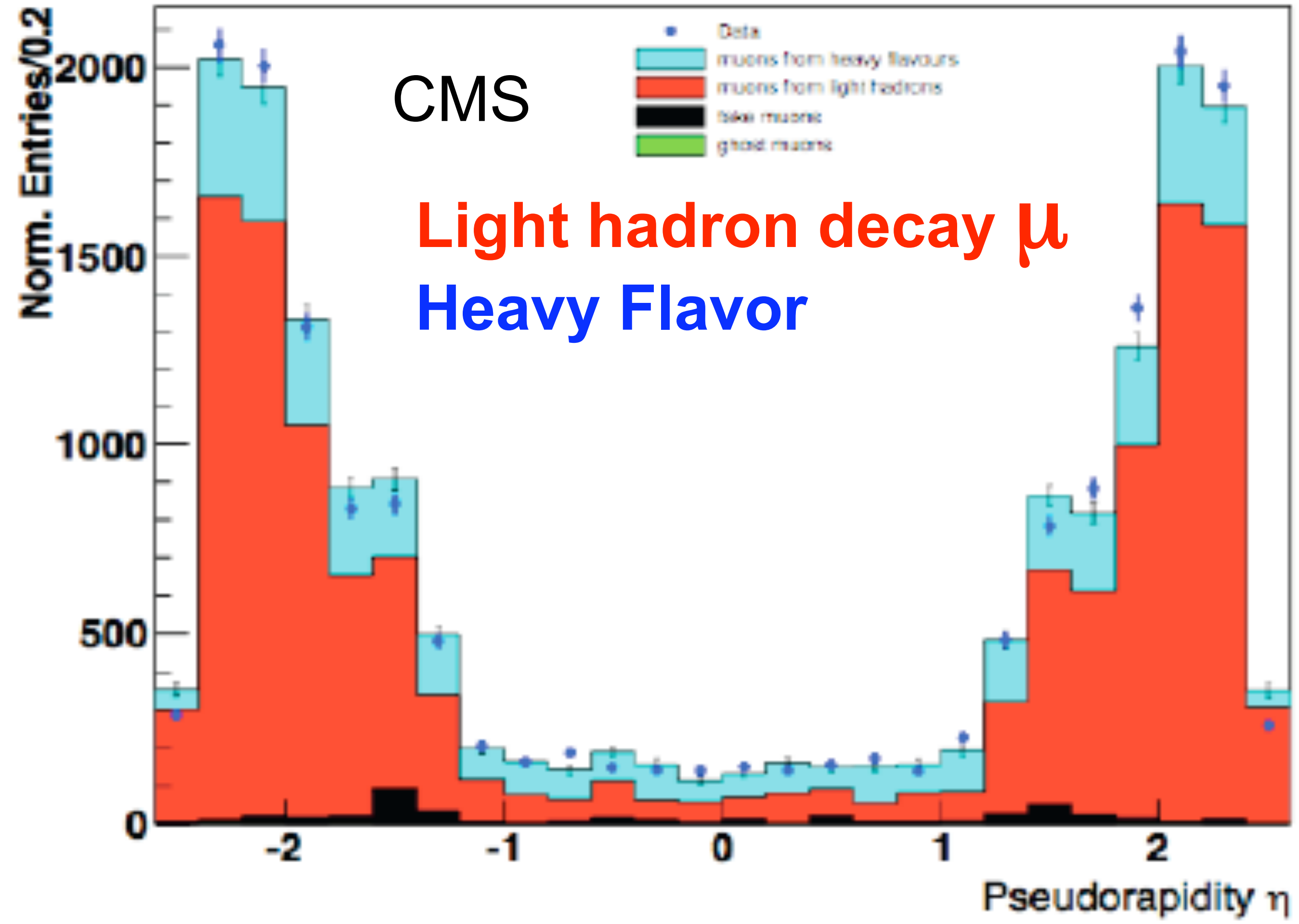
- E_T^{Miss} sensitive to calorimeter performance: noise, dead cells, cracks, mis-calibrations, beam backgrounds

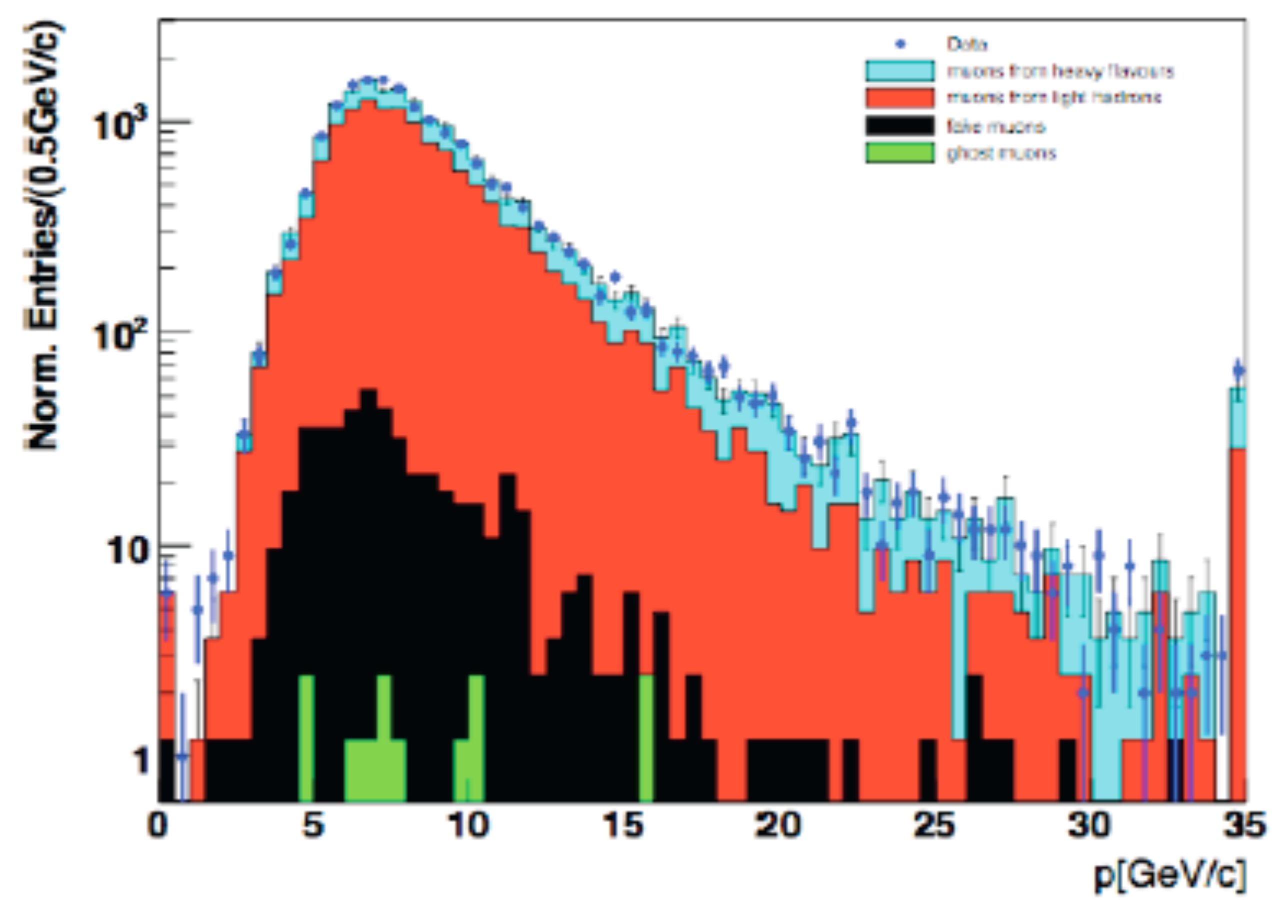


MUON Reconstruction

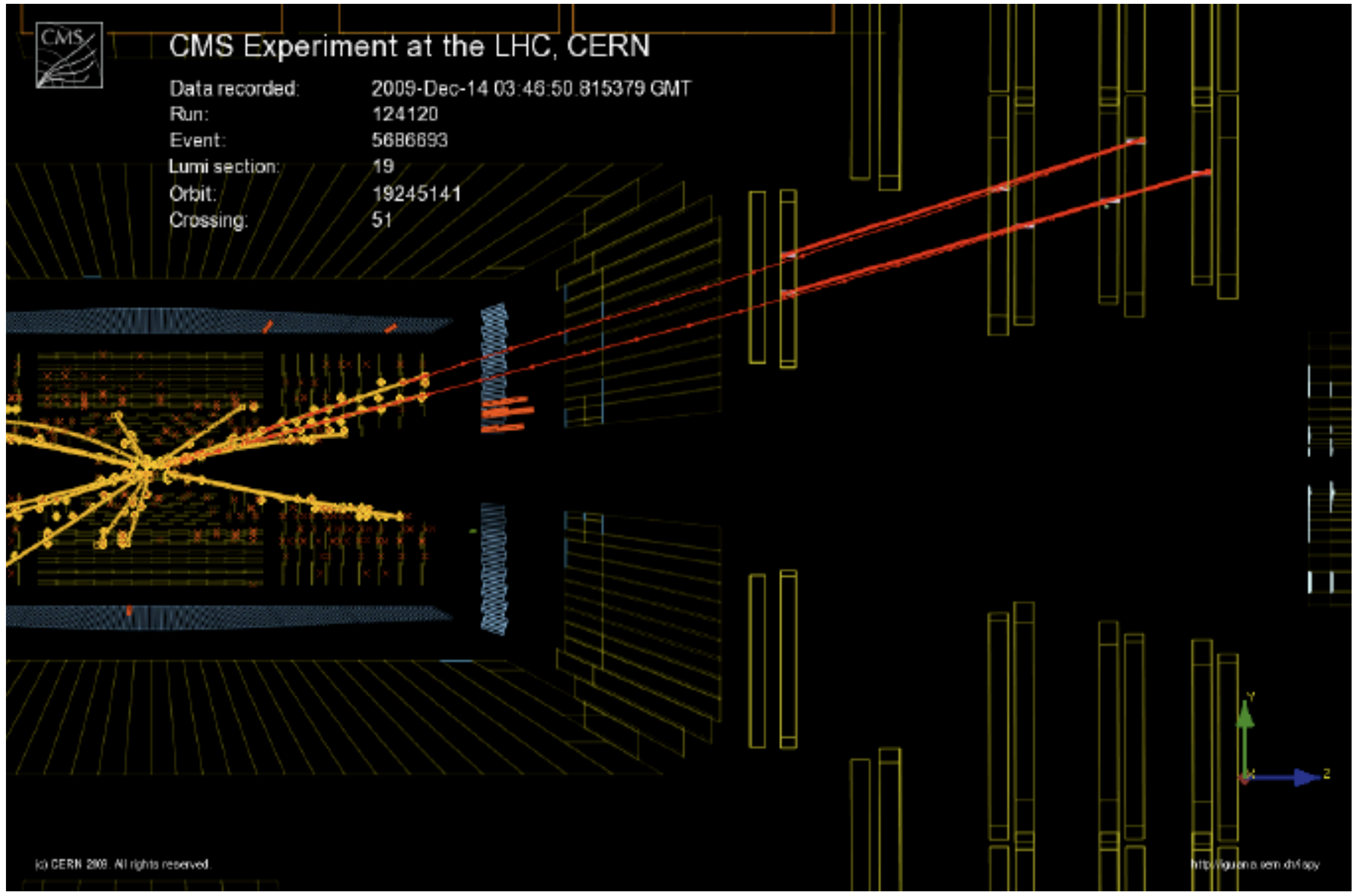


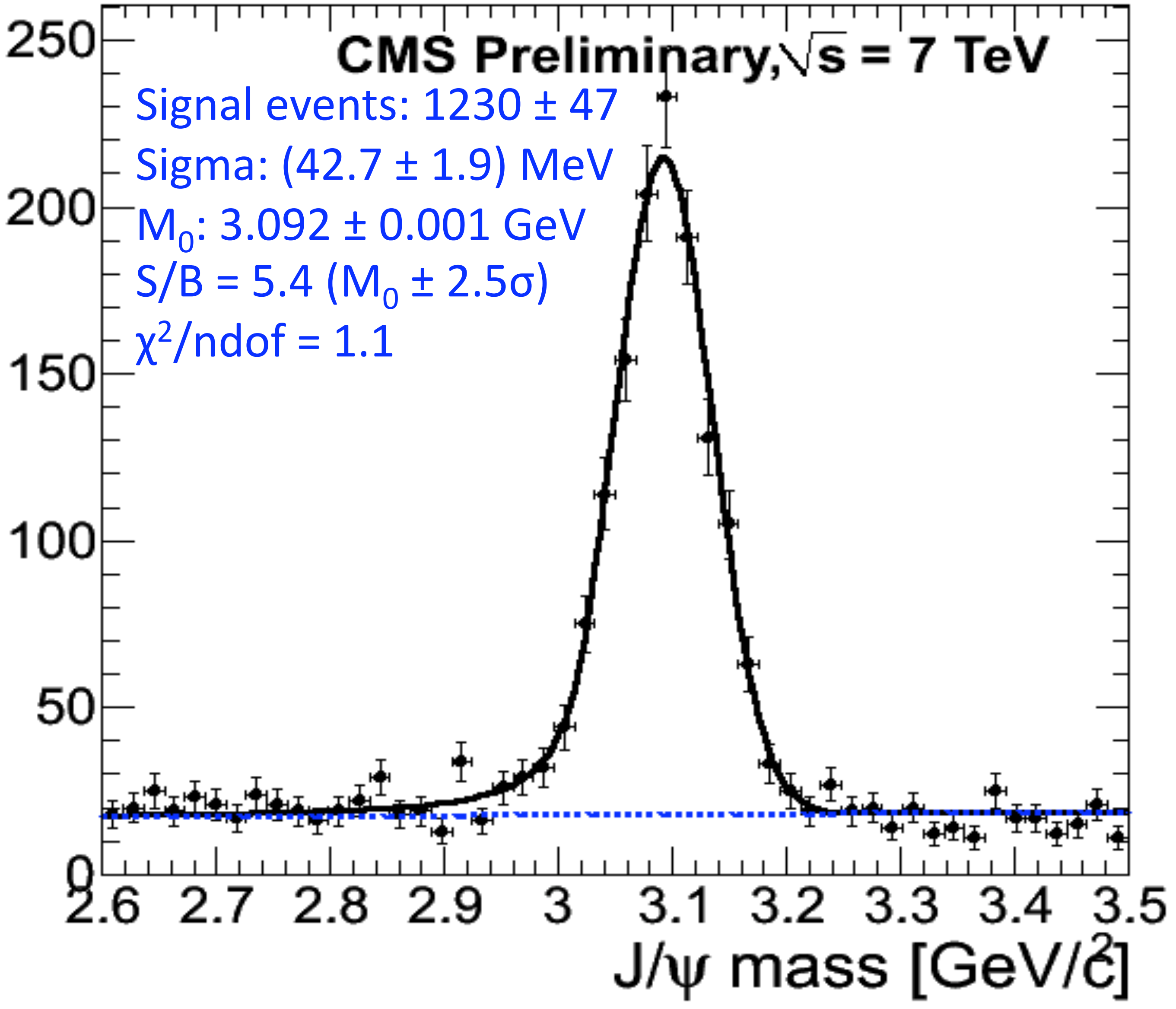






J/ψ→μ+μ- Reconstruction





Excellent signal for :

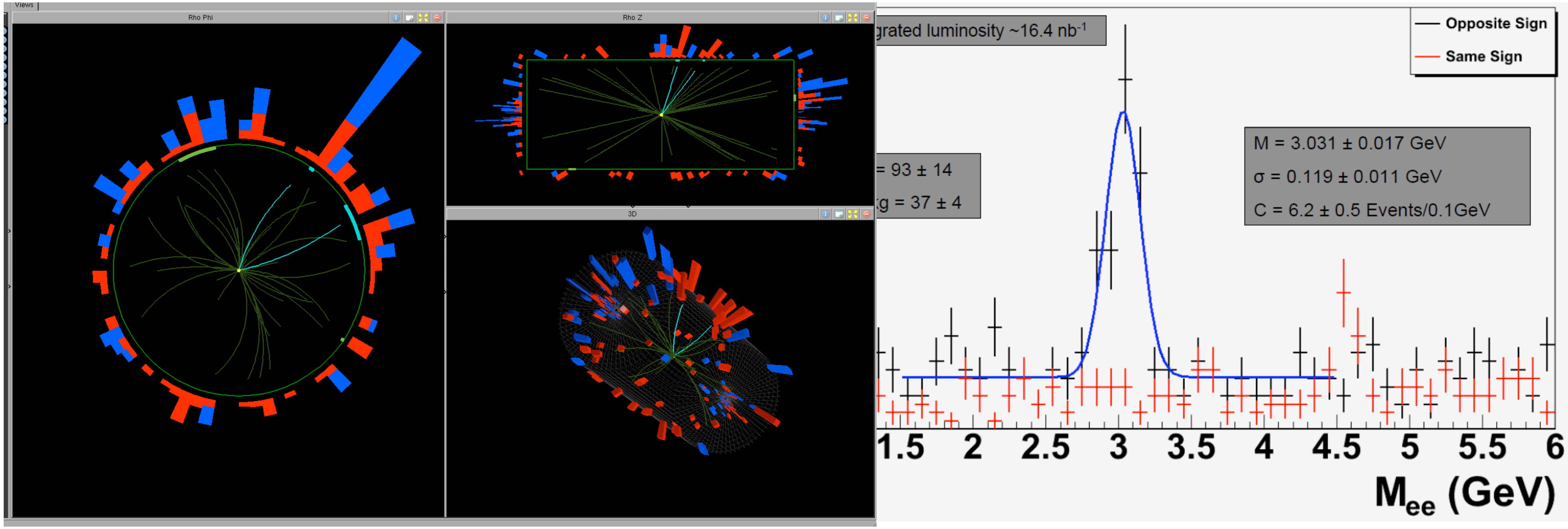
Calibration - momentum scale, reconstruction efficiency

Physics - J/ψ production properties, B->J/ψ X reconstruction, lifetime measurements

J/ψ→ e⁺e⁻ Reconstruction

Event Selection: loose electron requirements

More difficult: larger backgrounds; tighter selections; reduced signal

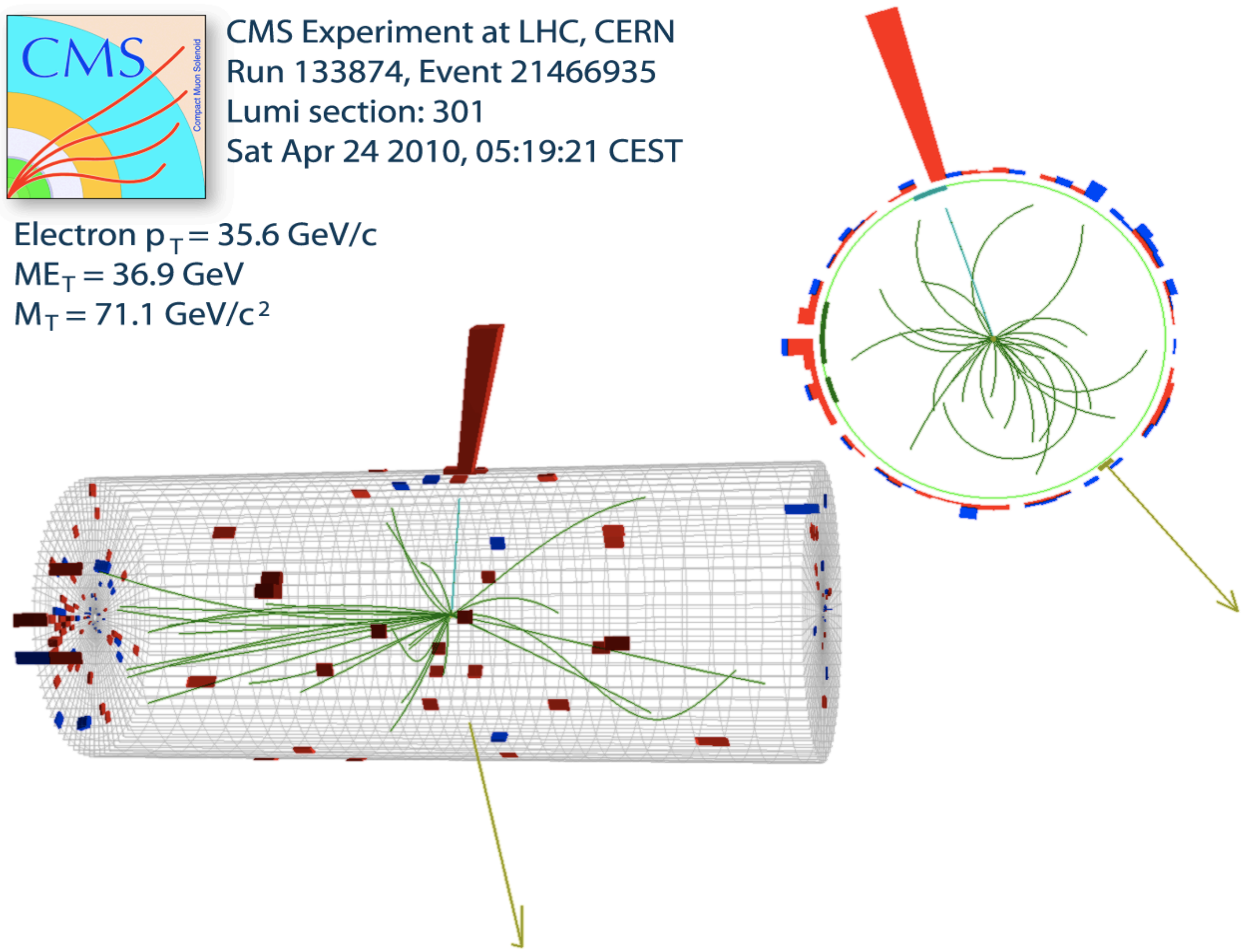


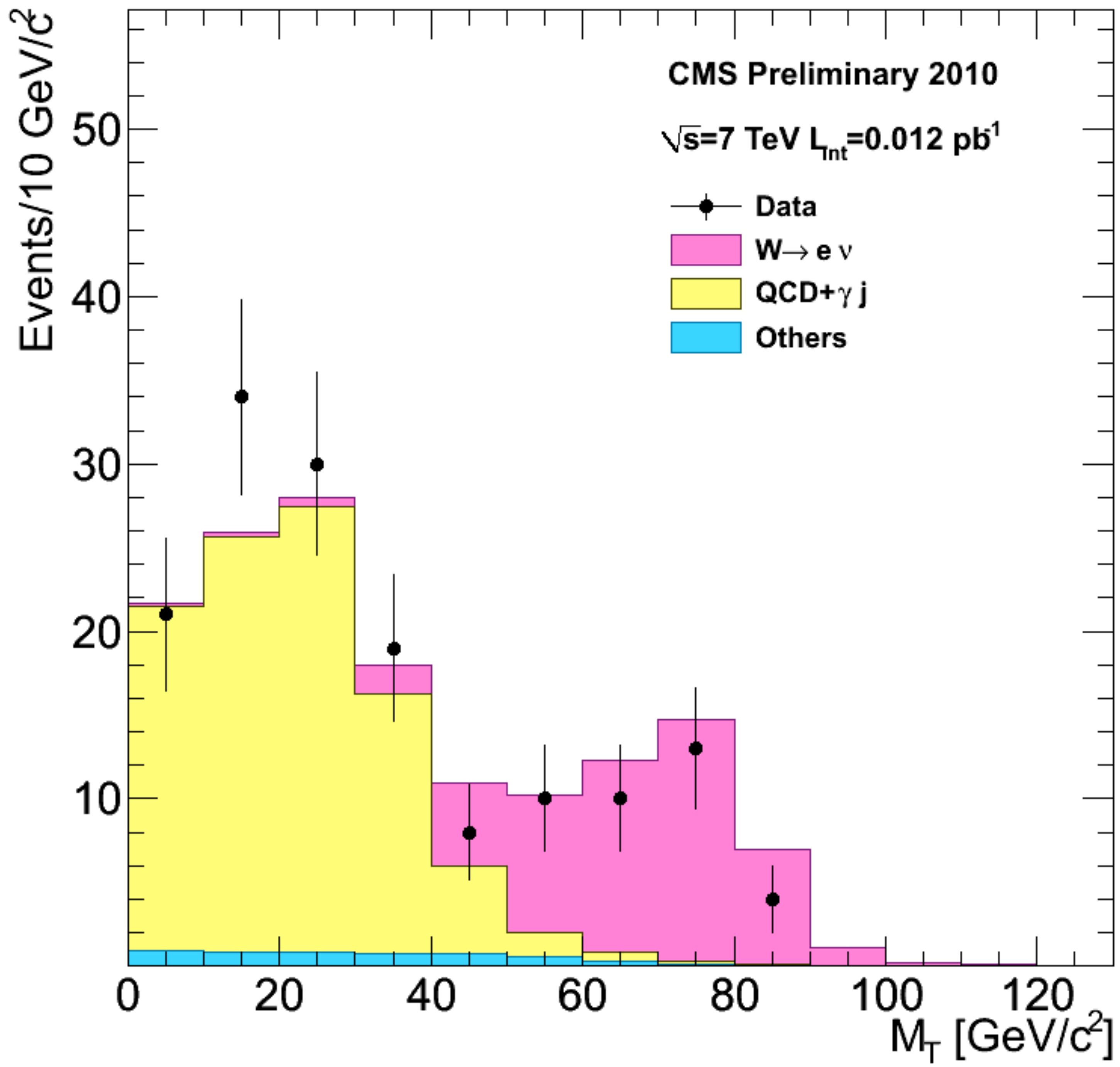
~93 events

$W^{\pm} \rightarrow e^{\pm}\nu$ Candidate Events

Event Selection: Basic Electron ID, no MET

MC cross sections: normalized to 12nb-1 integrated luminosity





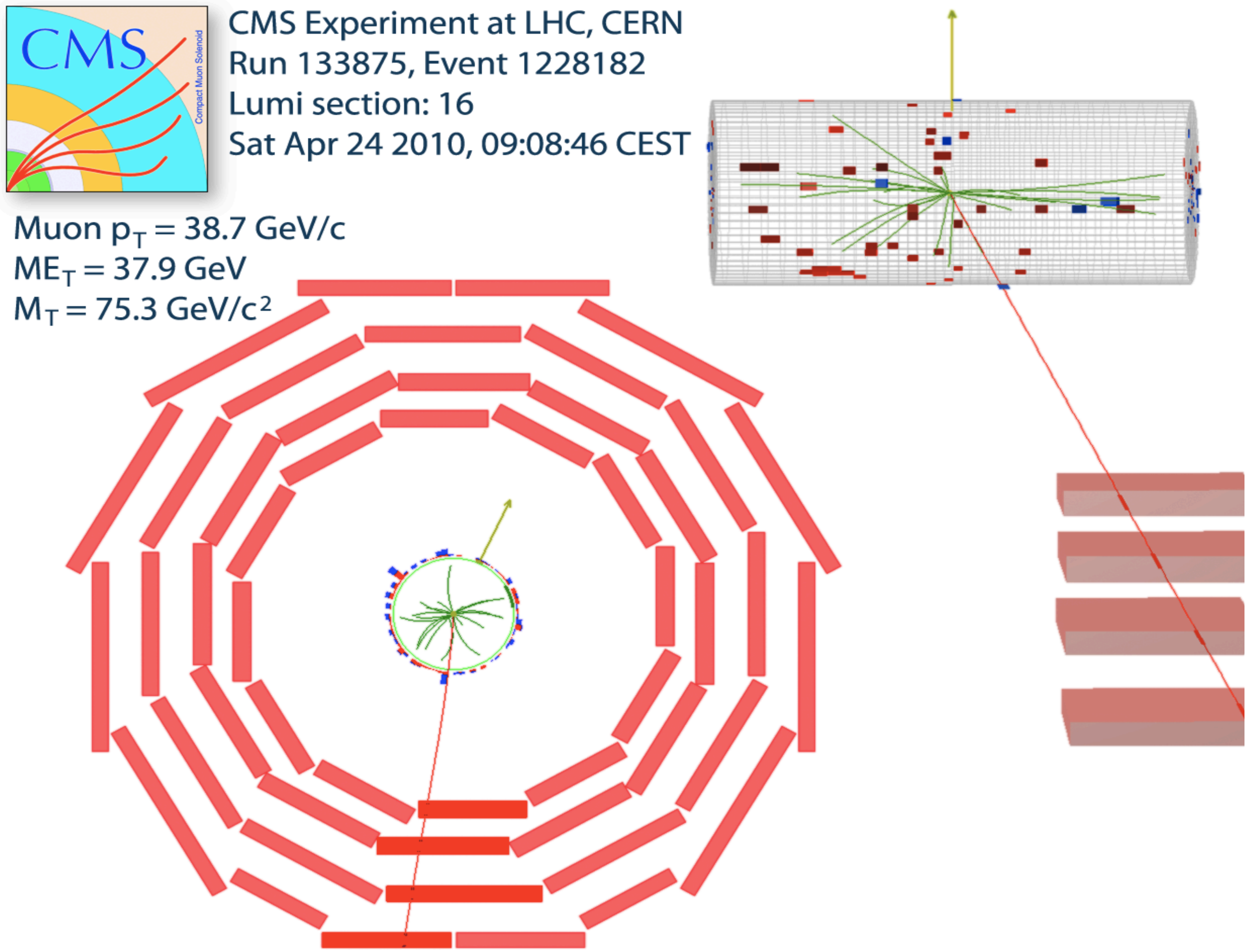
Candidate events inspected in detail for: timing, lepton reconstruction quality, event topology

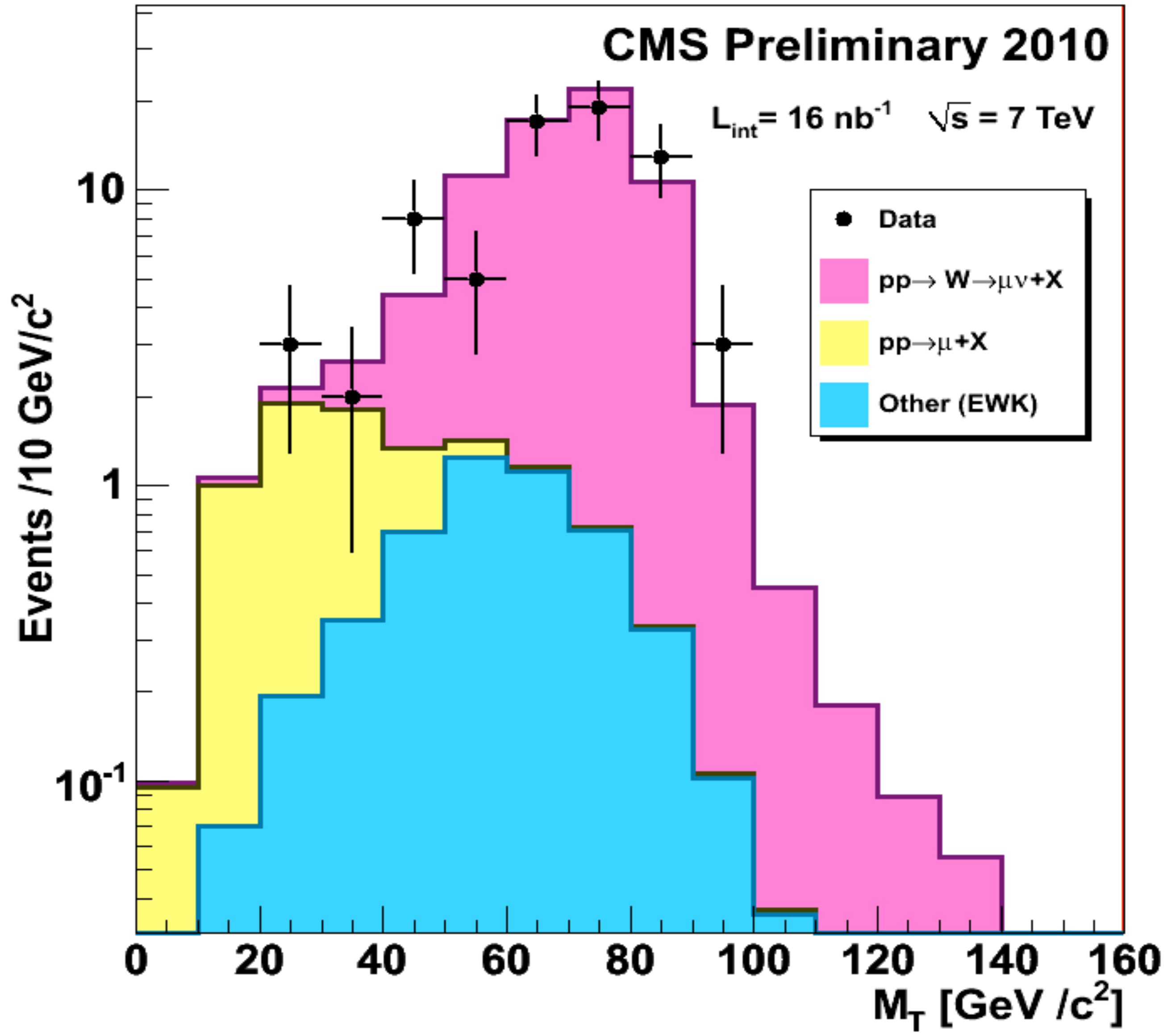
37 W candidate events w/ M_T > 50 GeV

$W^{\pm} \to \mu^{\pm}\nu$ Candidate Events

Event Selection: Muon ID (Global+Tracker Mu), $|\eta| < 2.1$, Pt, Isolation

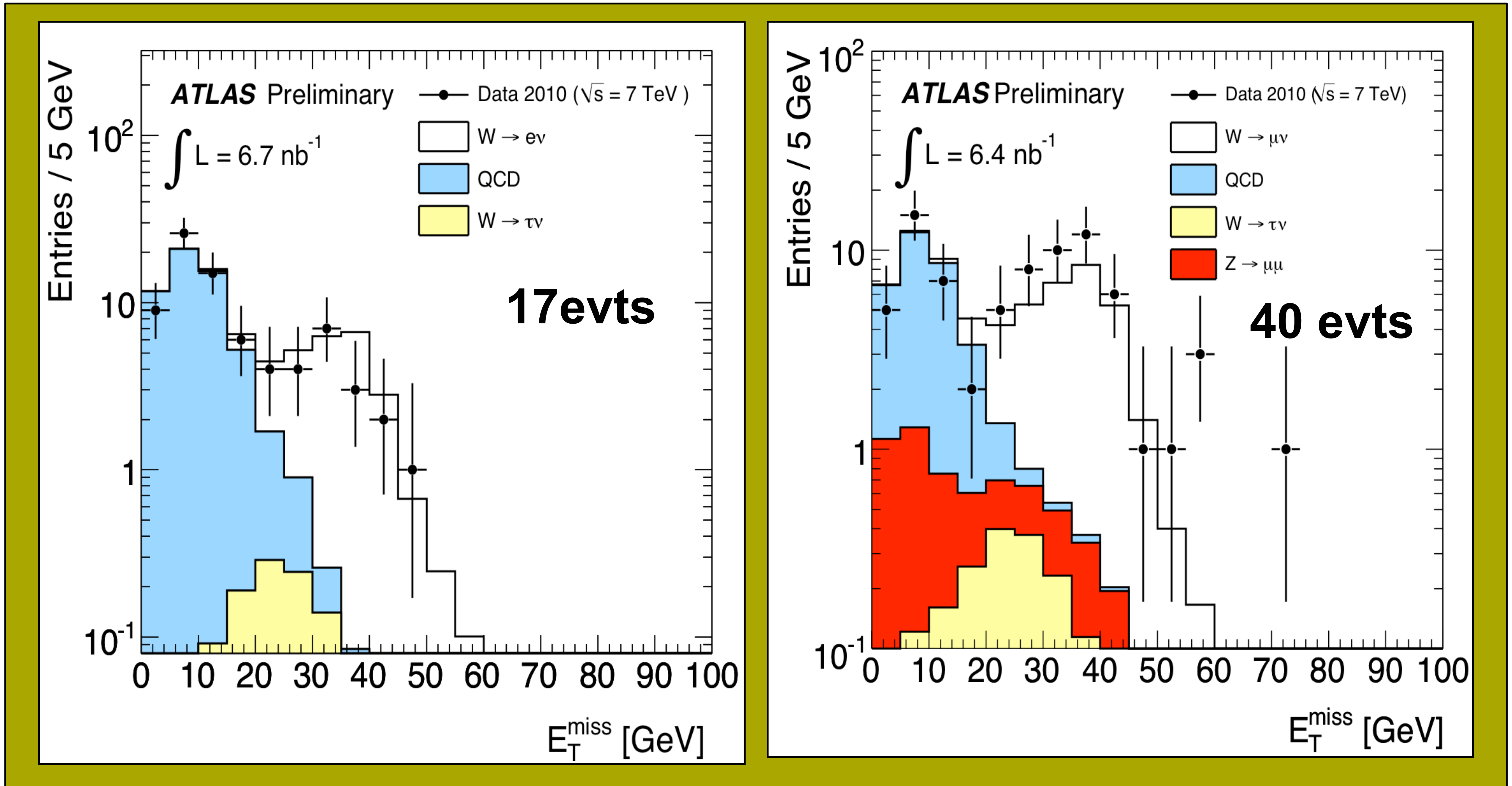
MC cross sections: normalized to 16nb-1 integrated luminosity





57 W candidate events w/ M_T > 50 GeV

ATLAS W Candidates



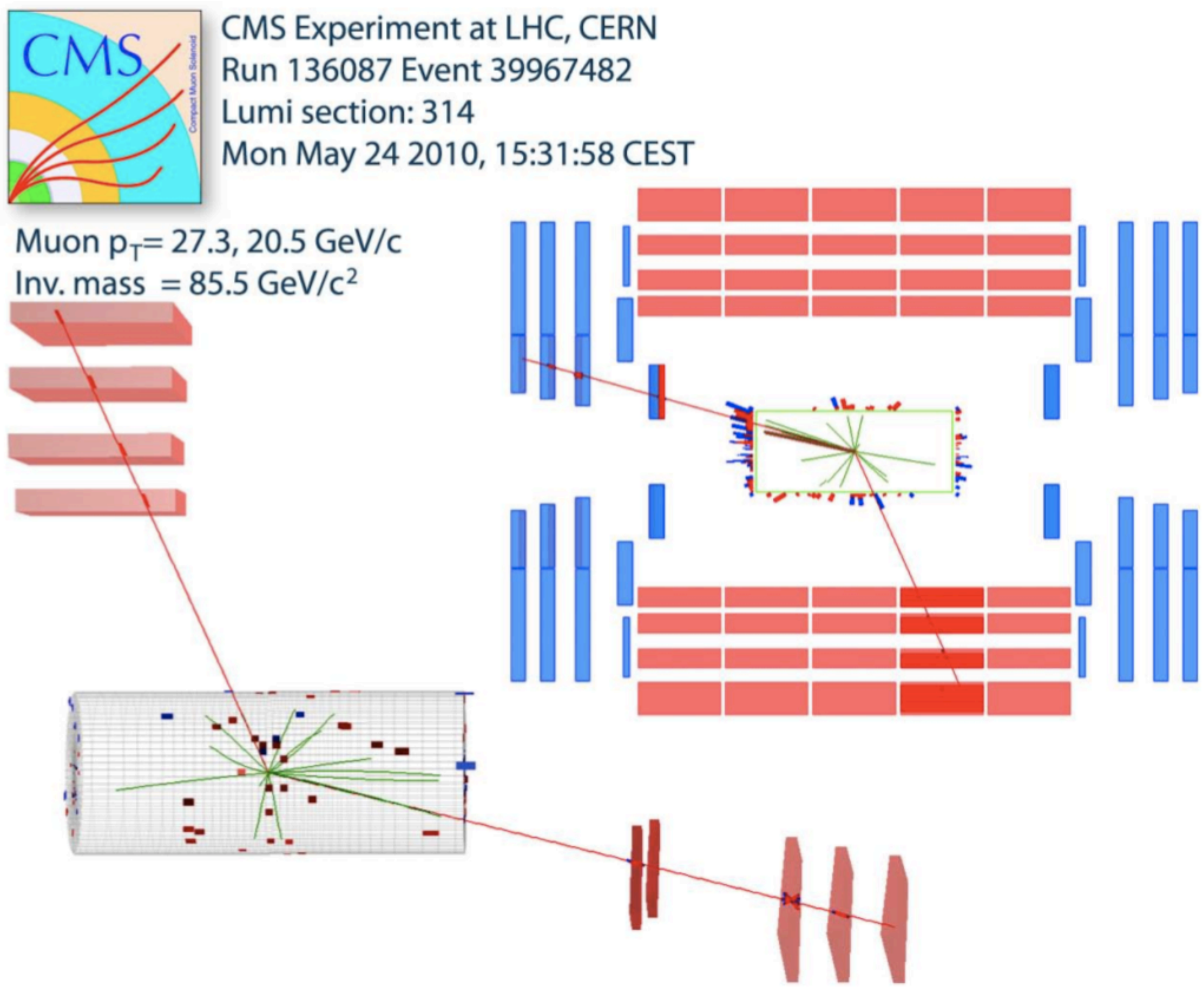
After all cuts but E_T^{miss} and m_T

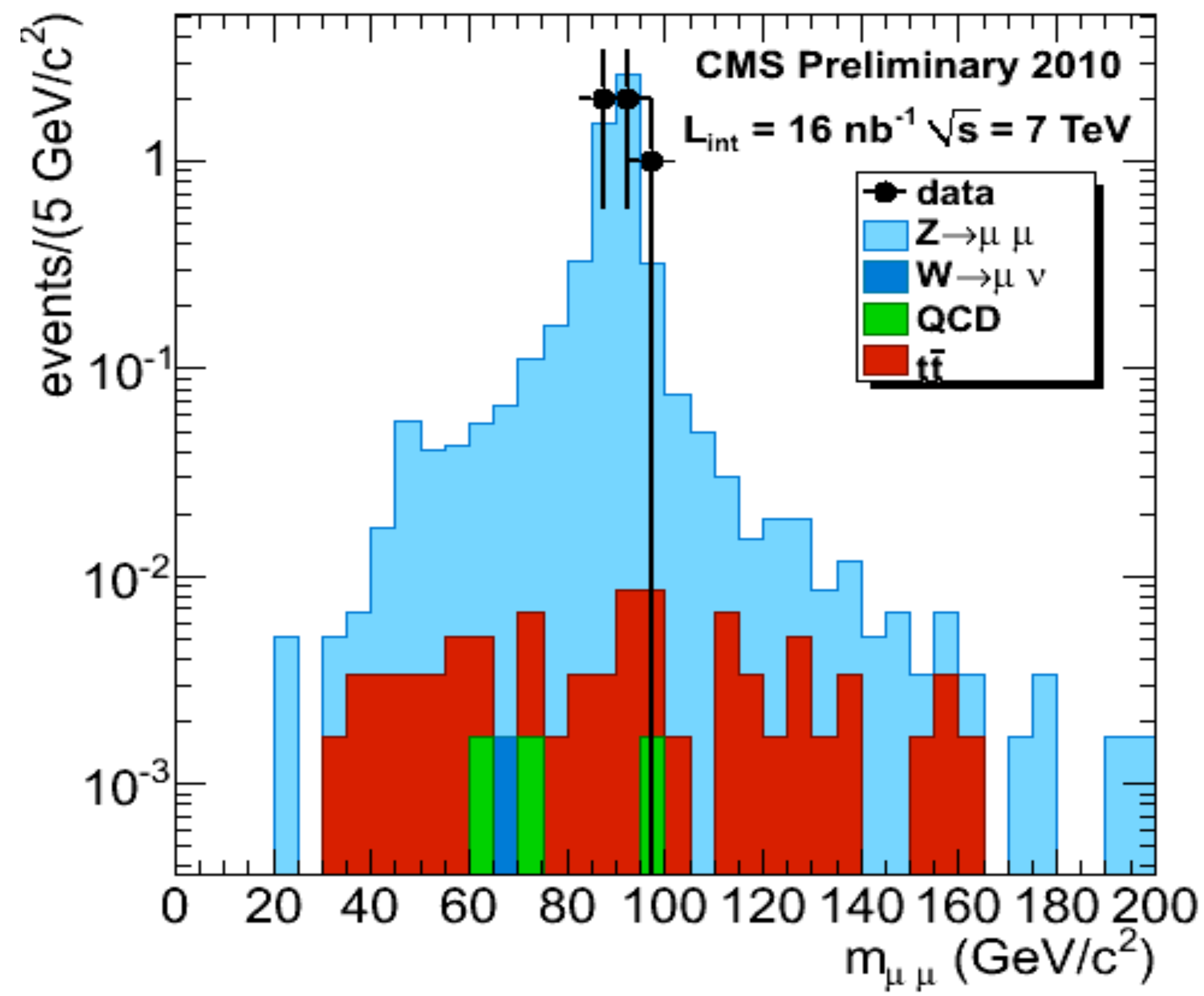
- **Ongoing detail inspection:**
  - **Reconstruction quality**
  - **Event topology**
  - **Timing**

Z->$\mu^+\mu^-$ Candidate Events

Event Selection: Loose Pt, Isolation and Muon id selection(Global +Tracker Mu), $|\eta| < 2.1$

MC cross sections: normalized to 16nb-1 integrated luminosity



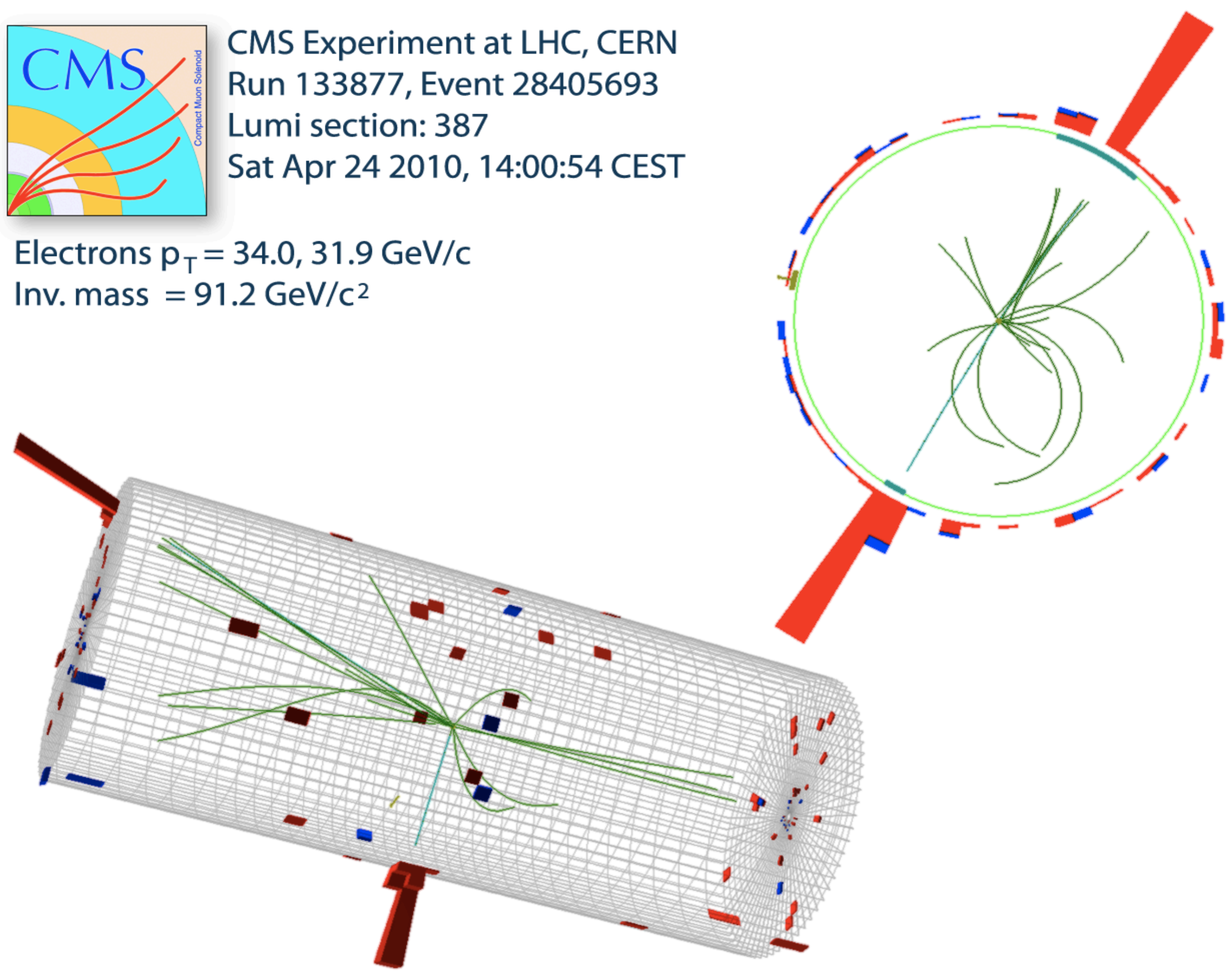


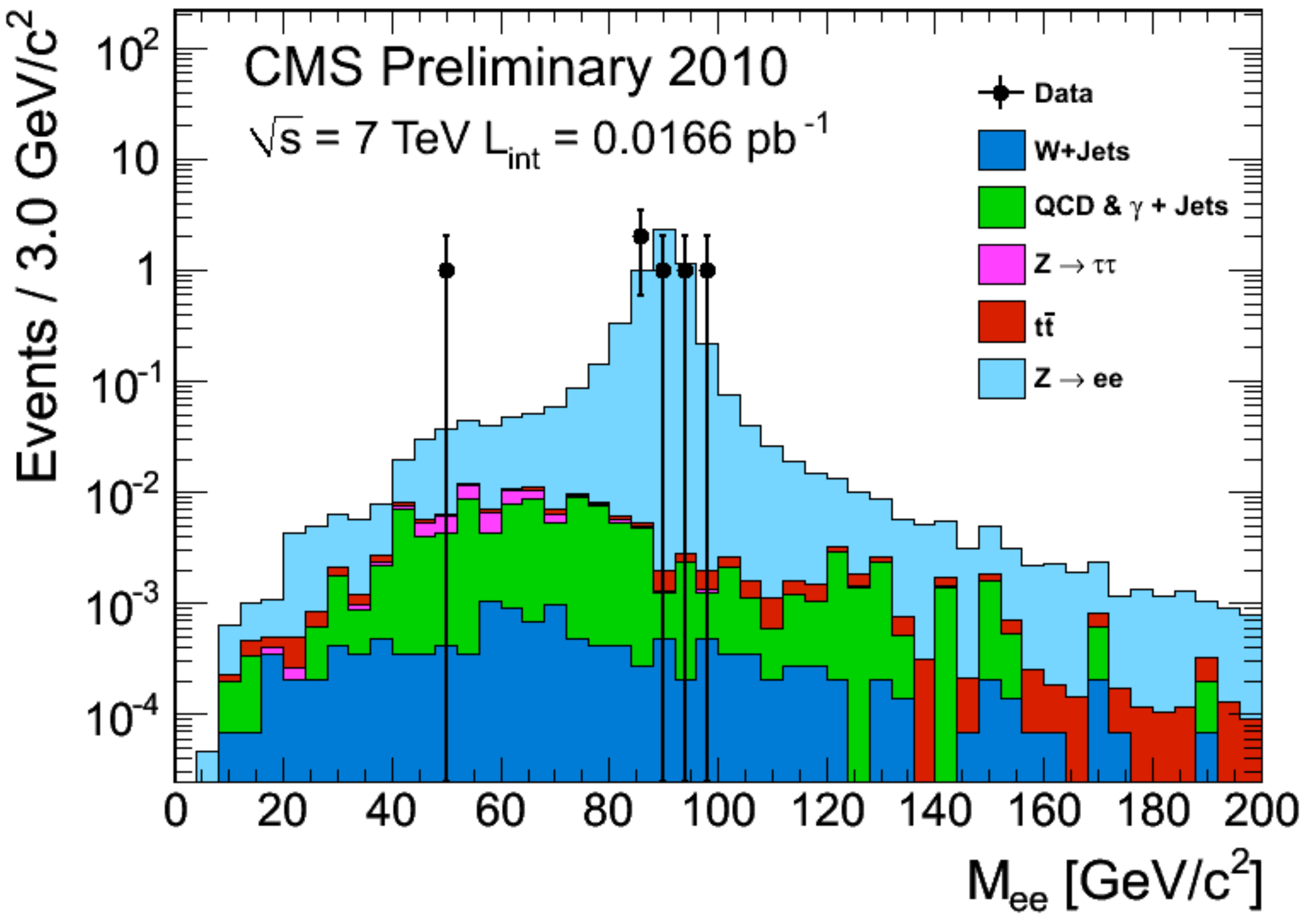
3 Z ->$\mu^+\mu^-$ candidate events

$Z \to e^+e^-$ Candidate Events

Event Selection: Two super-clusters with Et>20GeV

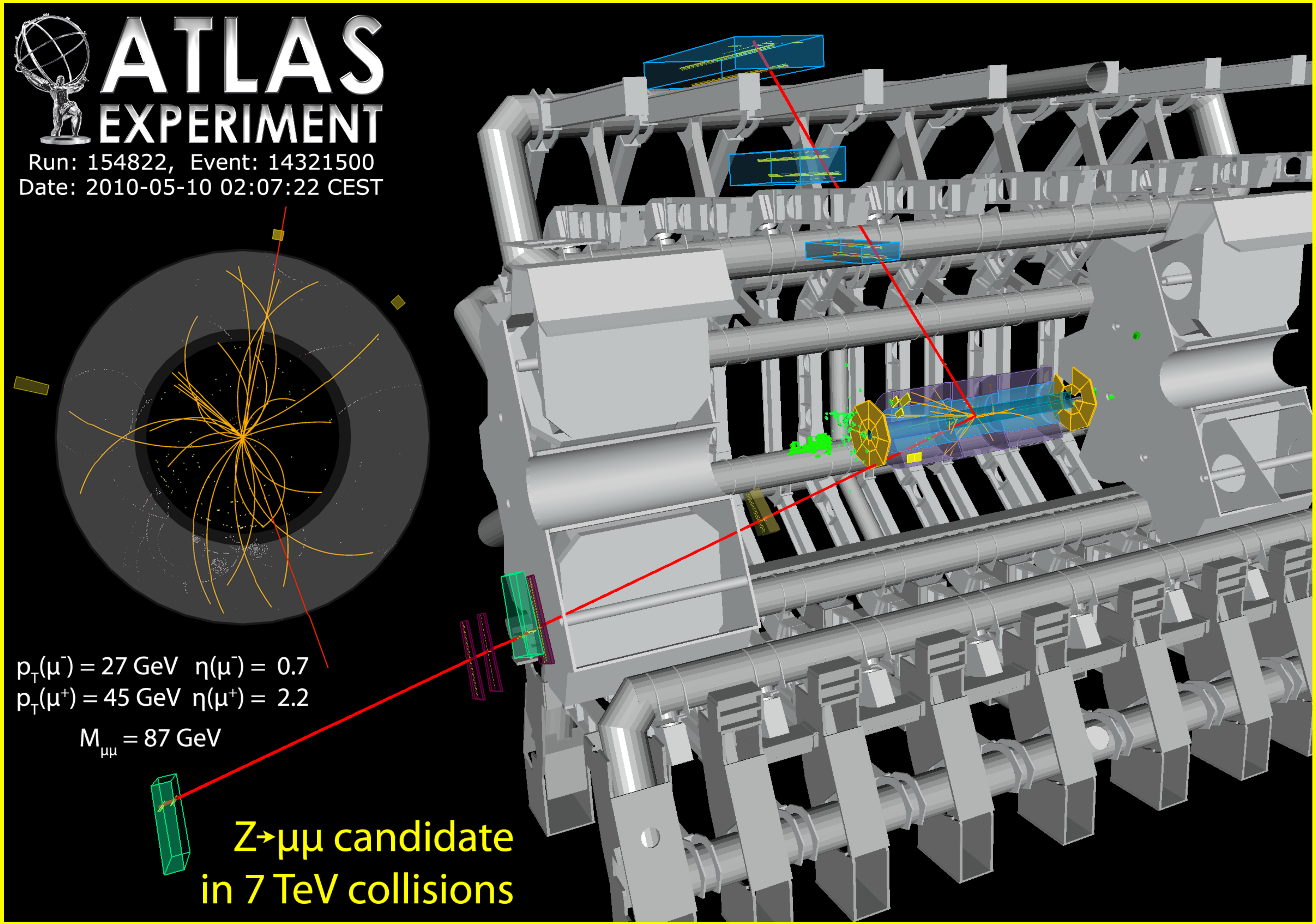
MC cross sections: normalized to 17nb^{-1} integrated luminosity





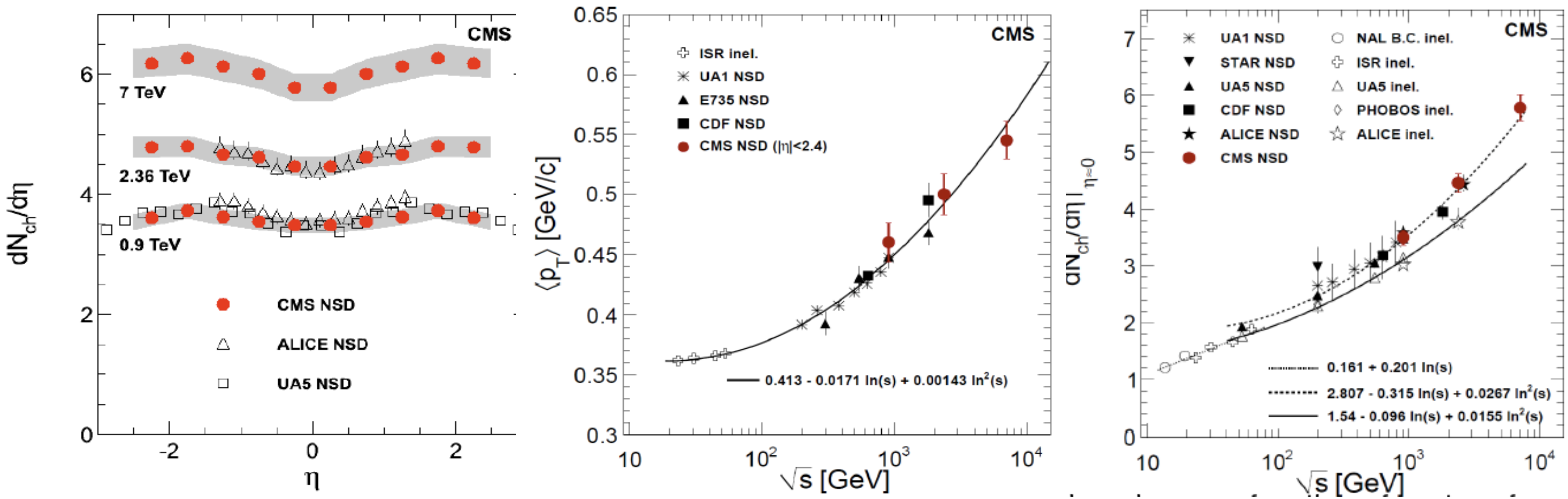
5 $Z \to e^+e^-$ candidate events

ATLAS Z candidate



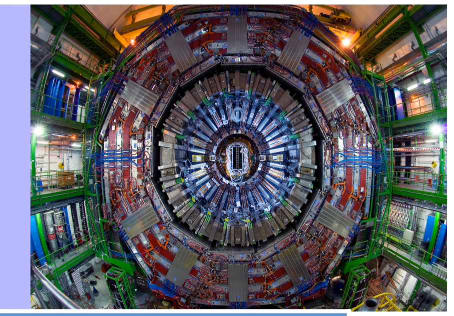
First CMS Publication @7TeV

"Transverse Momentum and Pseudorapidity Distributions of Charged Hadrons in pp Collisions at √s=7TeV" arXiv:1005.3299 in PRL on 18 Jun 2010



- Rise of the particle density at (2.36) 7 TeV steeper than model predictions
- Need for ongoing tuning of MC generators

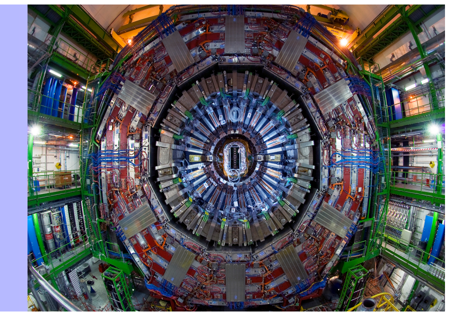
First Physics Run 2010-2011



Integrated L	SM Object	SM Use	Search Strategy
mb^{-1} (1)	UE, MB	Tune MC	
μb^{-1} (10^3)	Jets, Heavy flavor	Align. dE/dx Calib, trigger valid, MET c, b tag leptons	
nb^{-1} (10^6)	W Z	Cross section, charge Mass scale, resolution	**We are here!**
1 pb^{-1} (10^9)	Top pairs	Leptons + J + true MET	Dijet & HSCP exceed Tevatron
10 pb^{-1}			Dijet M > 2 TeV, LQ exceed Tevatron
100 pb^{-1} (2010)			M > TeV W' , Z', ED New range for SUSY
1000 pb^{-1} (2011) (10^{12})			SUSY – TeV mass scale Higgs @ 95% CL, (140,190) GeV, BH, Technicolor

PLAN: Rediscovering the Standard Model, followed by precision measurements…
Then launch searches, starting with strongly produced final states.

Conclusions



- **Rapid Commissioning of the LHC and Experiments with Beams and Increased Luminosity**
- ***Thank you to the LHC Team for Excellent Performance and Operation for Physics!***
- **LHC's leaps in energy and luminosity present enormous exploration opportunities**
- **Rediscovery of the Standard Model underway with First LHC Publications**
- **Excitement of Discoveries is arriving!**
- I would like to thank G.Tonelli, F. Gianotti, A. de Roeck, D. Green and others for material

END of presentation