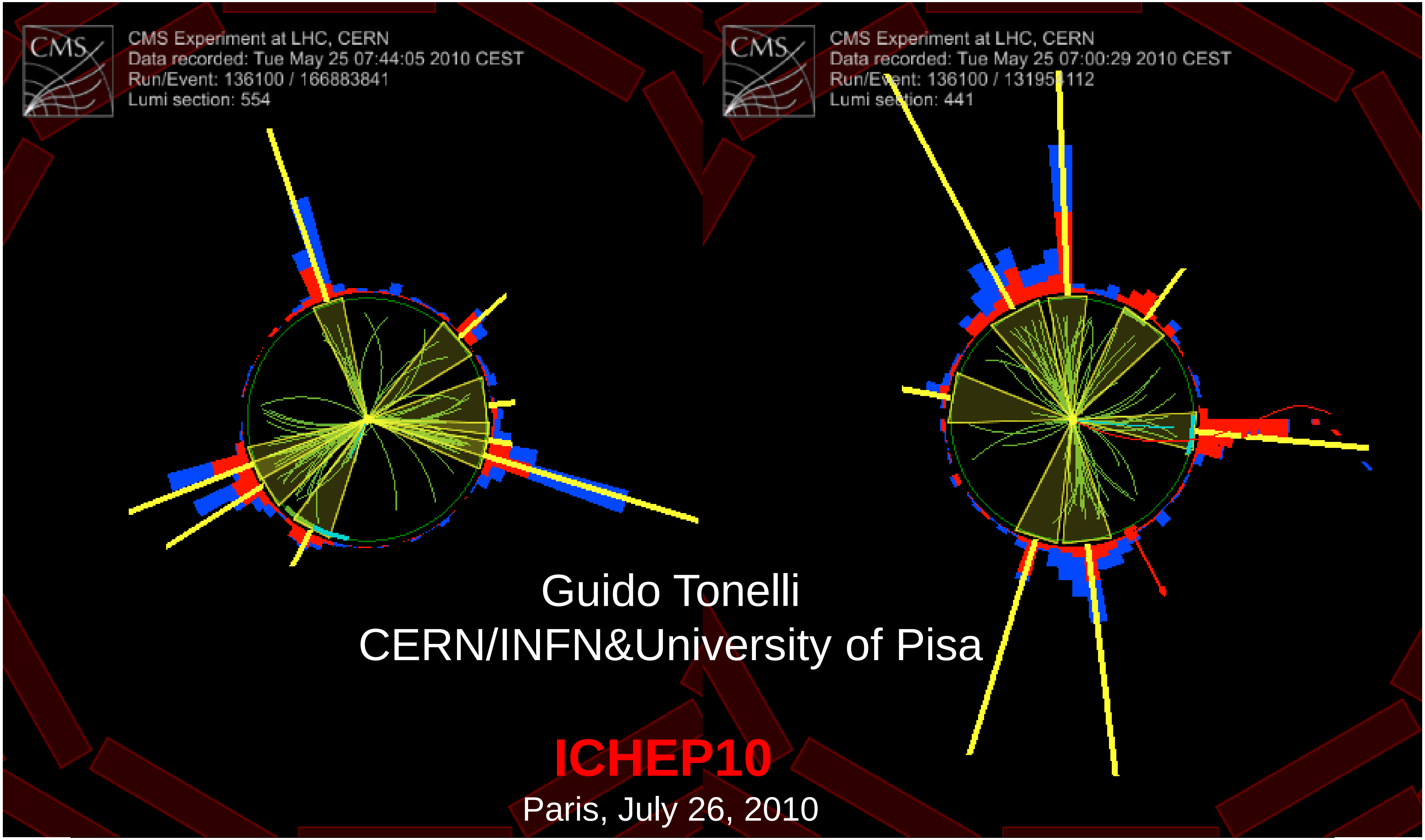
The CMS Experiment: Status and Highlights

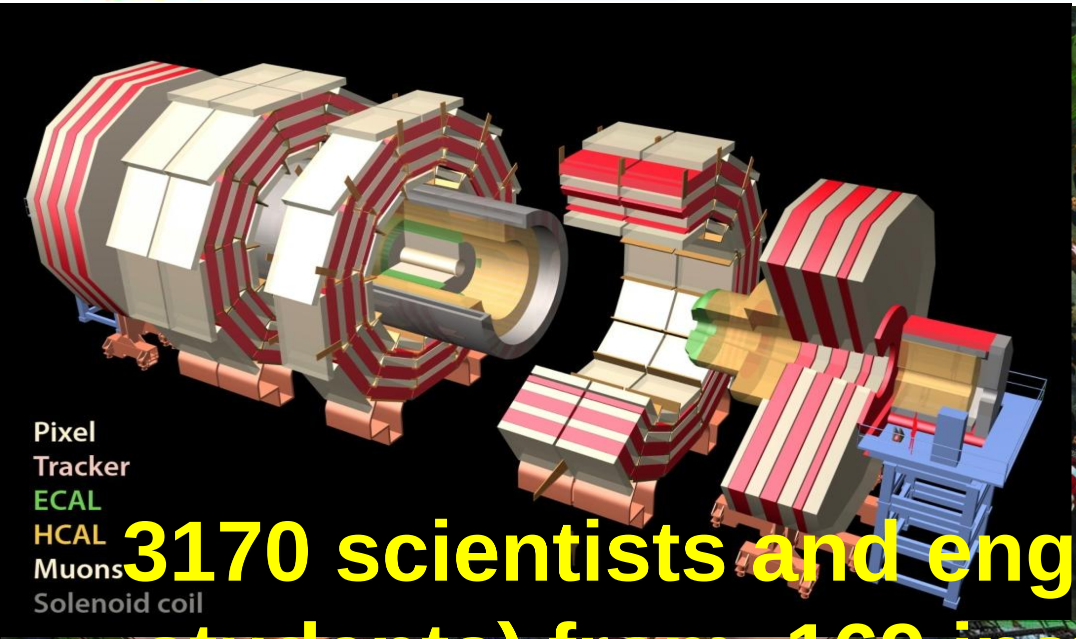


Guido Tonelli
CERN/INFN&University of Pisa

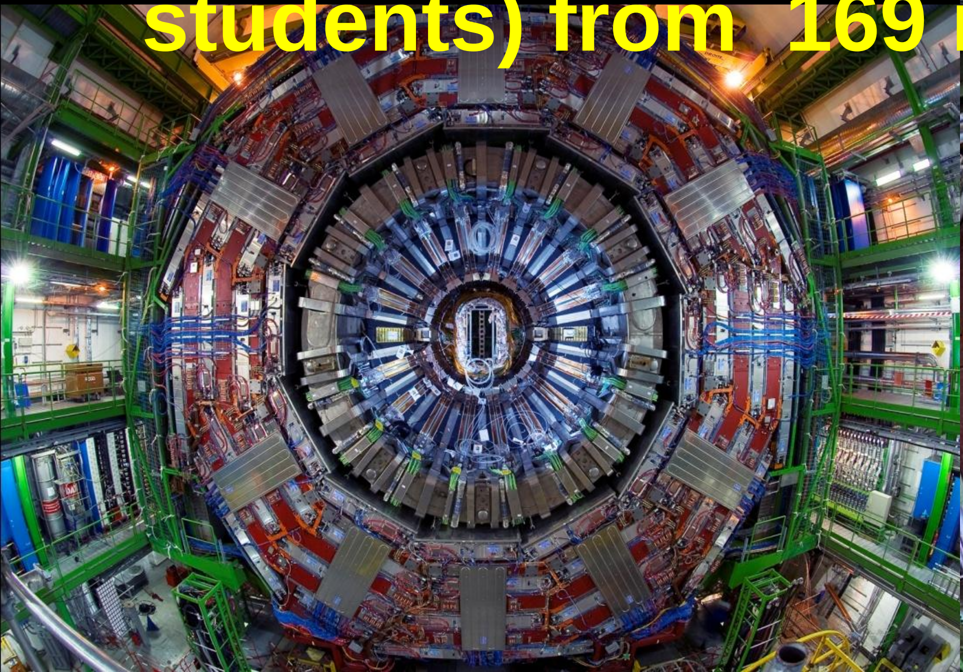
ICHEP10

Paris, July 26, 2010

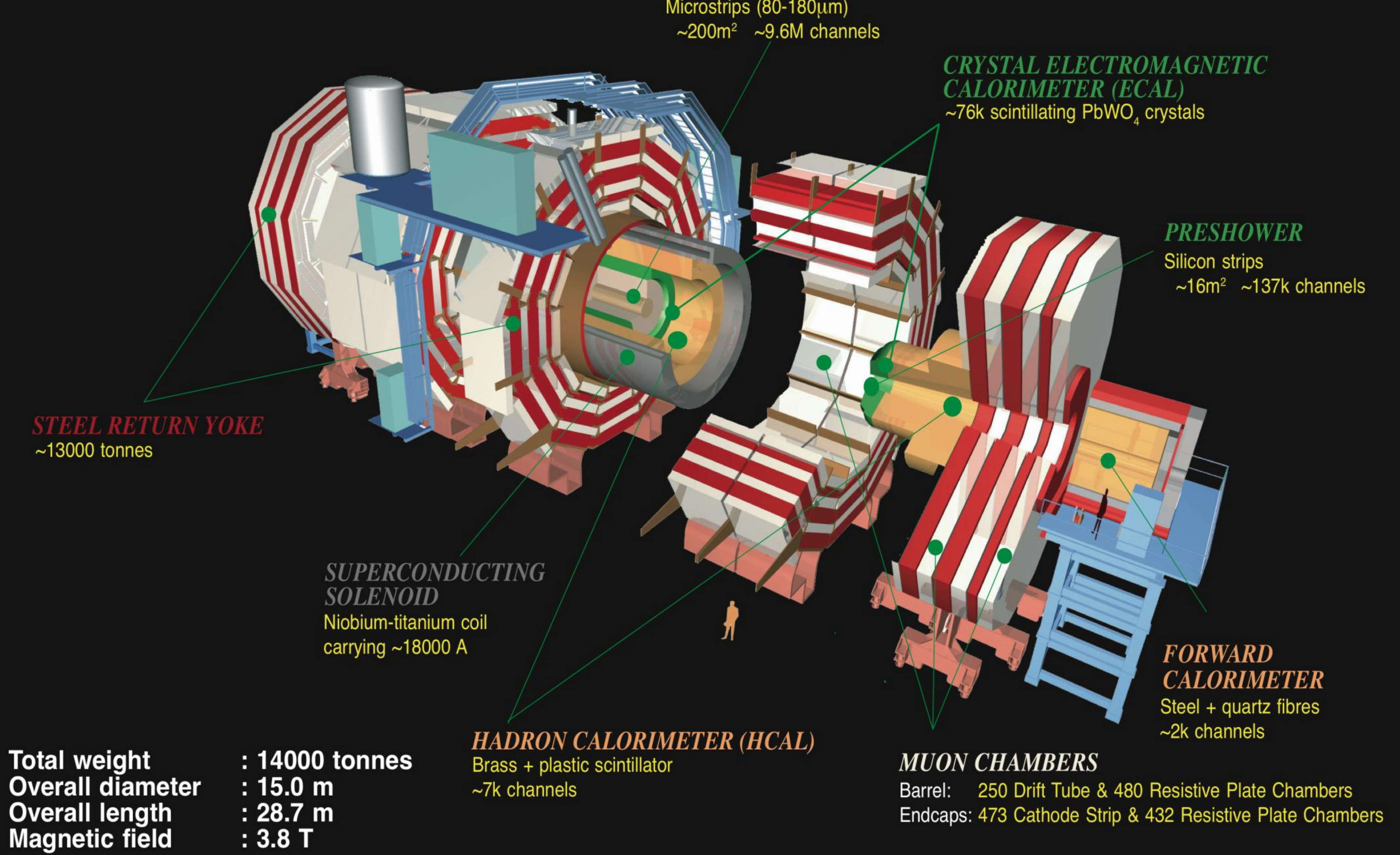
The CMS Collaboration



3170 scientists and engineers (including ~800 students) from 169 institutes in 39 countries

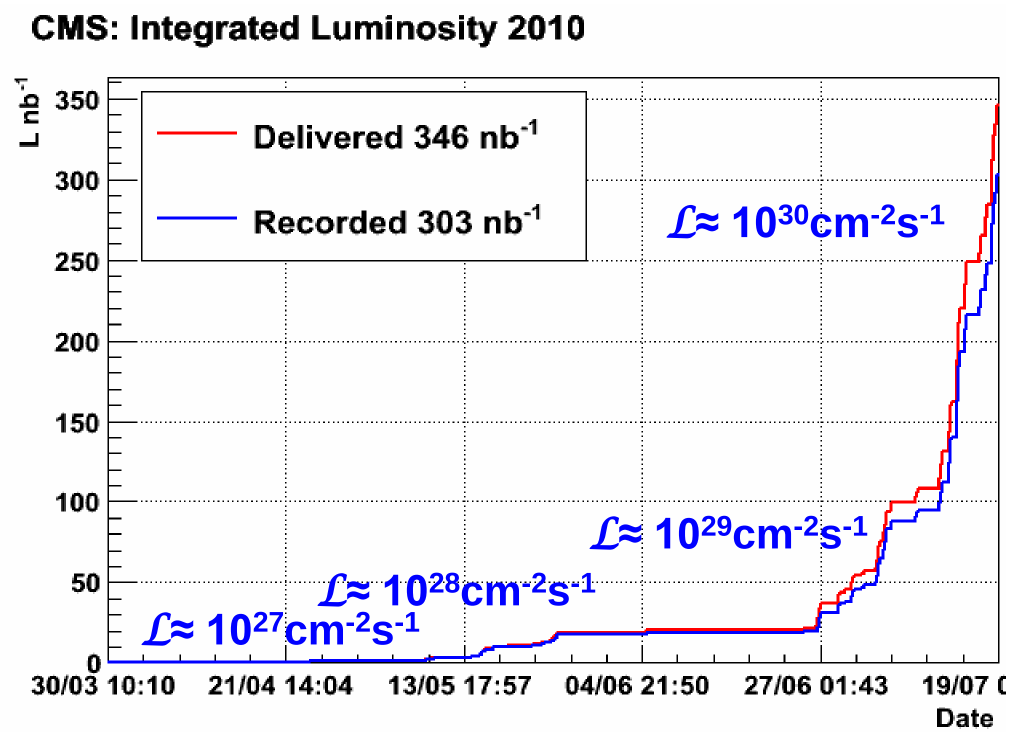


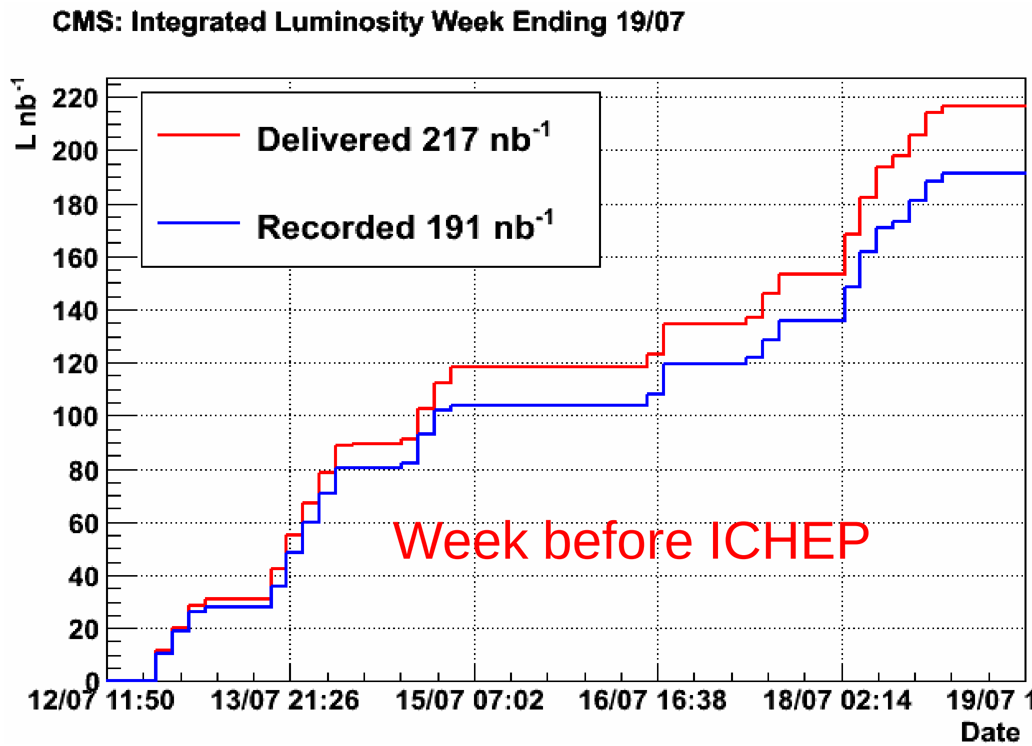
CMS Detector



7 TeV operations since March 30

About **346nb^{-1}** delivered by LHC and **~303nb^{-1}** of data collected by CMS. Overall data taking efficiency **~88%**.

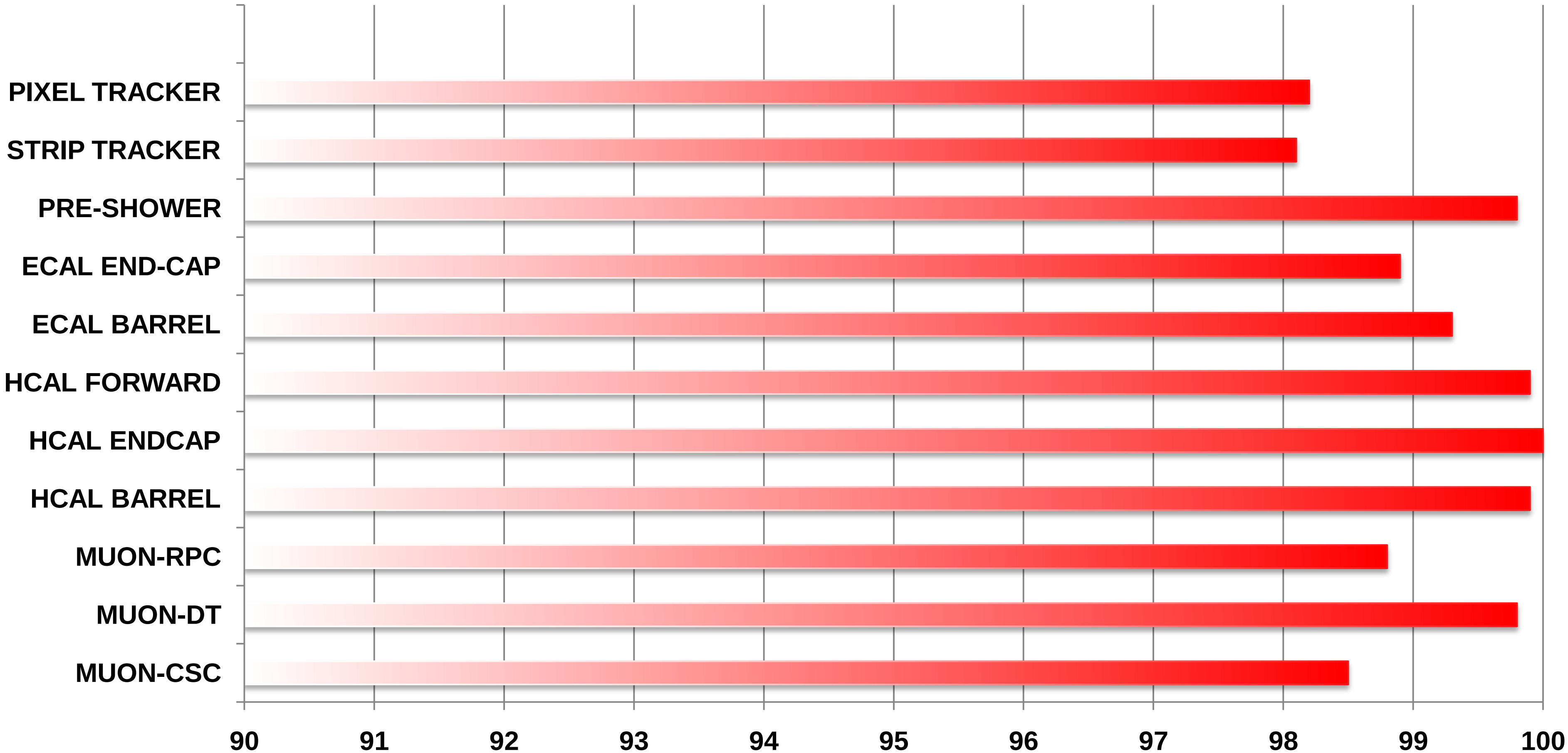




Good performance of CMS in coping with the 3 orders of magnitude increase in instantaneous luminosity. Additional challenge: most of the luminosity used for ICHEP results delivered in the last week(s).

281nb^{-1} good data for muon based analyses; 254 nb^{-1} validated for any analysis.

Sub-detectors operational status

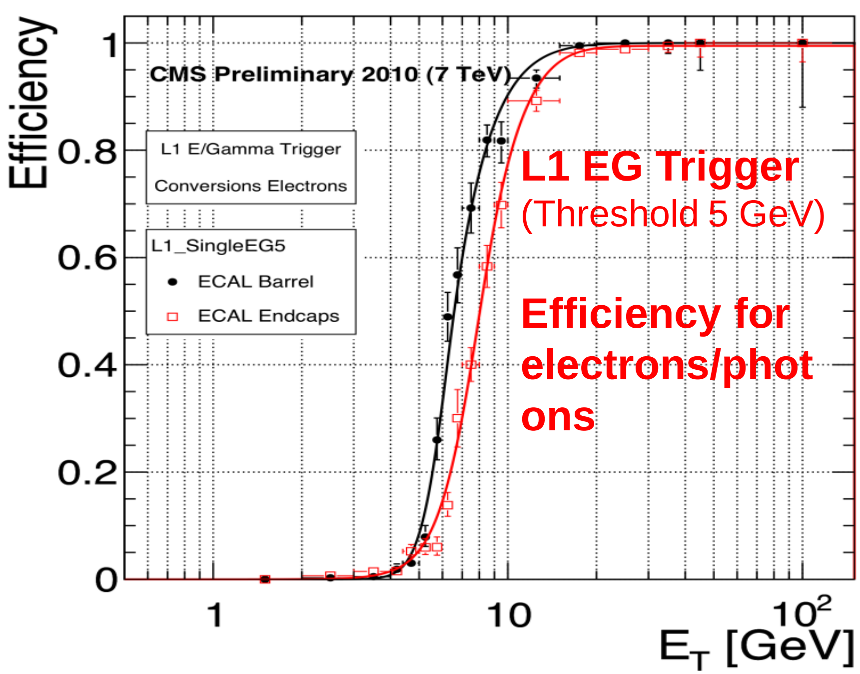


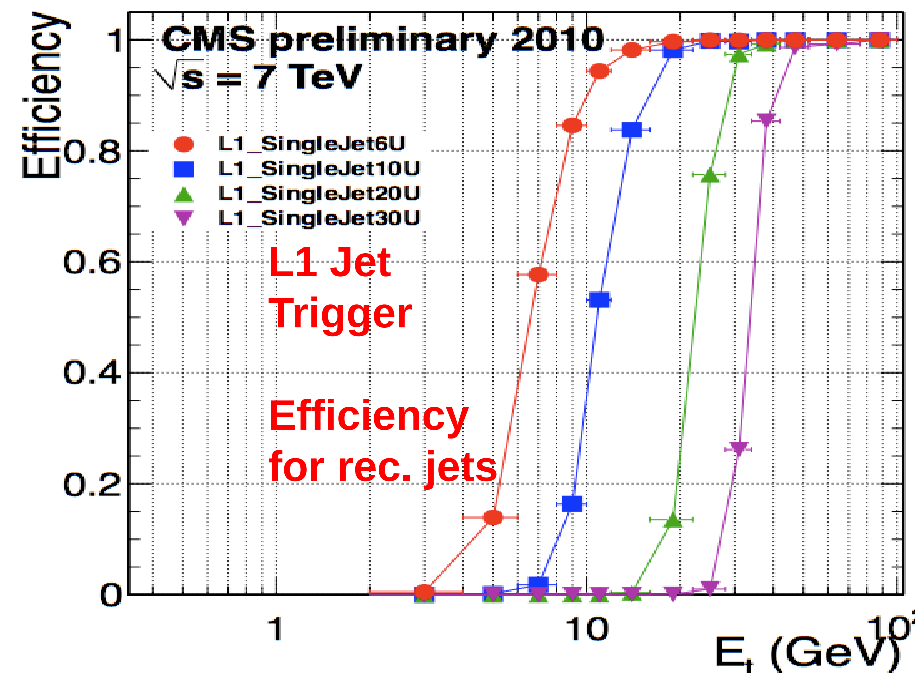
	MUON-CSC	MUON-DT	MUON-RPC	HCAL BARREL	HCAL ENDCAP	HCAL FORWARD	ECAL BARREL	ECAL END-CAP	PRE-SHOWER	STRIP TRACKER	PIXEL TRACKER	
Series1	98.5	99.8	98.8	99.9	100	99.9	99.3	98.9	99.8	98.1	98.2	

DAQ & L1 and HLT Triggers

- **L1/DAQ**
  - **L1 ~ 45kHz; Event size at DAQ 500 kB/evt (**after compression in HLT for StreamA **~250kB); 200-400Hz of data to storage.**
  - Timing has precision of 1 ns or better

- **All L1 triggers have high efficiency and sharp turn-on curves**

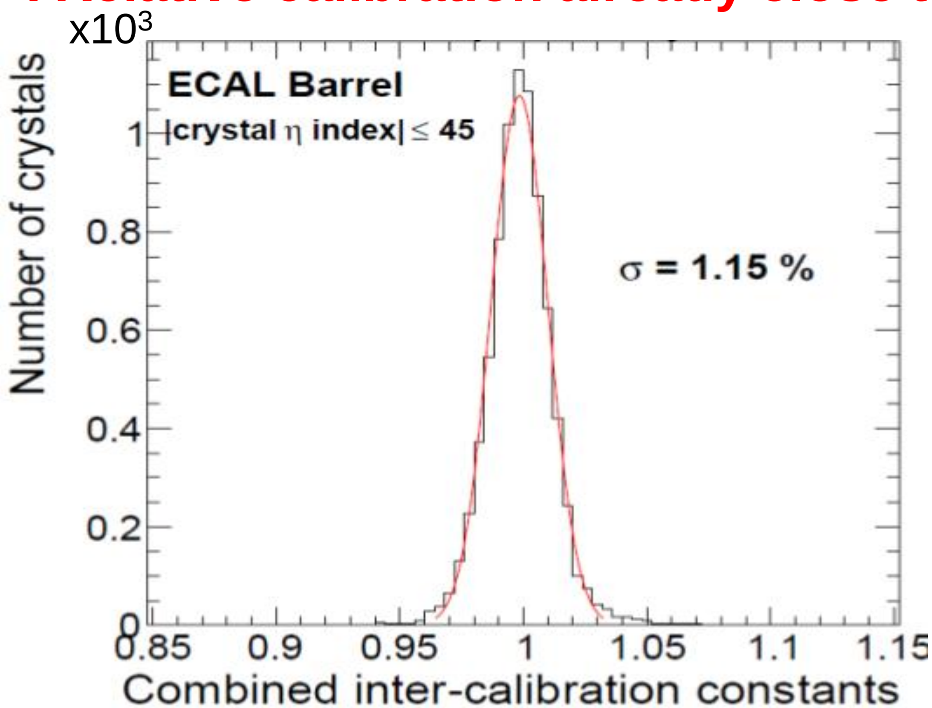


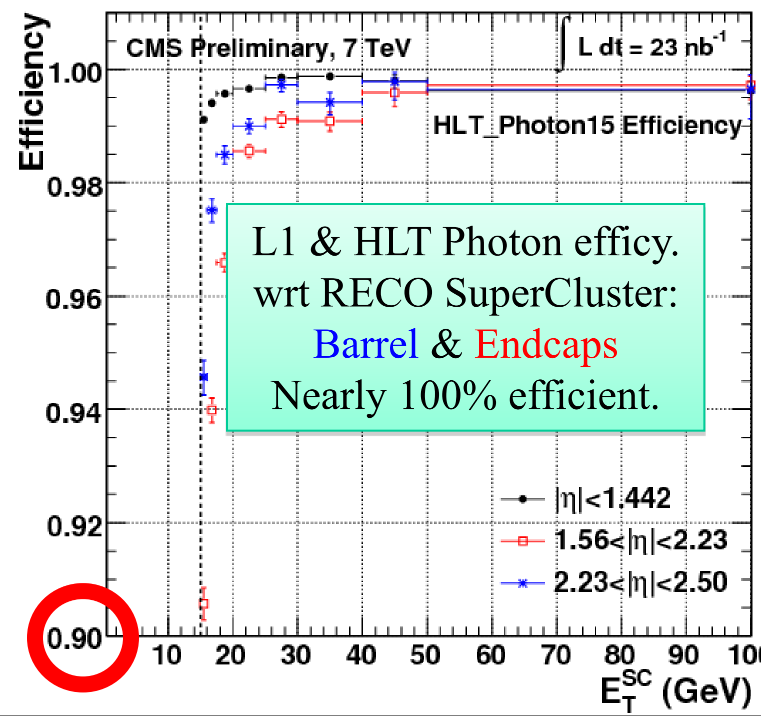


L1+ HLT Triggers

- **Successfully deployed HLT menus for 2-4-8x10^{29}cm^{-2}s^{-1} and 1.6x10^{30}cm^{-2}s^{-1}**. Each one has a factor 2 of safety margin. Very smooth running throughout. In preparation/validation **HLT menus for 10^{31}-10^{32}**.
- Processing time per event to **~50 ms/ev at a lumi of ~10^{30} cm^{-2}s^{-1}**
- (Farm Capacity ~100ms/evt at L1 rate of 50kHz)

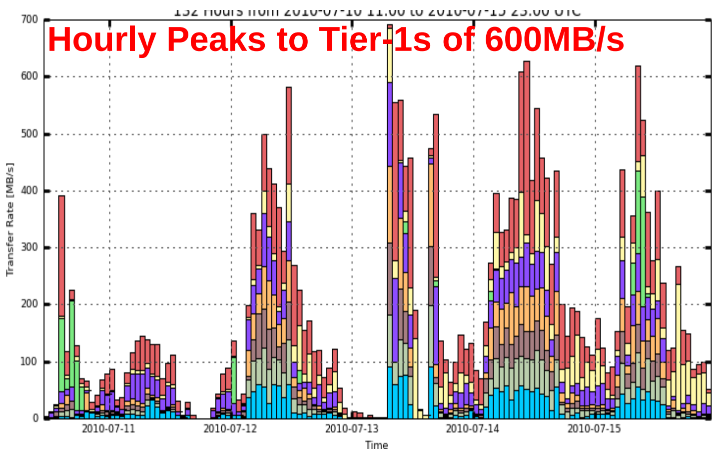
Special stream to collect π^os for the calibration of ECAL: >100 π^os/crystalxday @10^{30}. Relative calibration already close to 1%. Goal is 0.5% (>10pb^{-1})

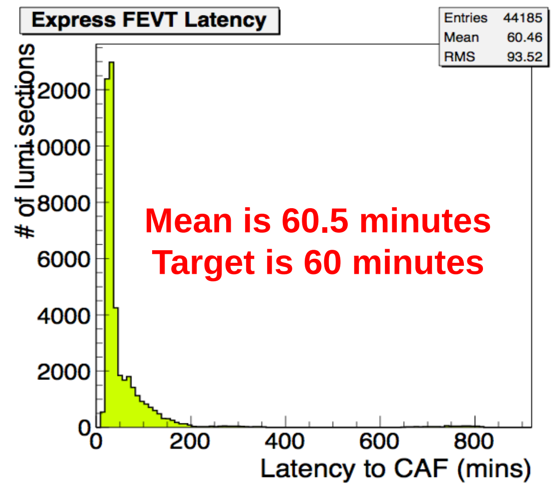


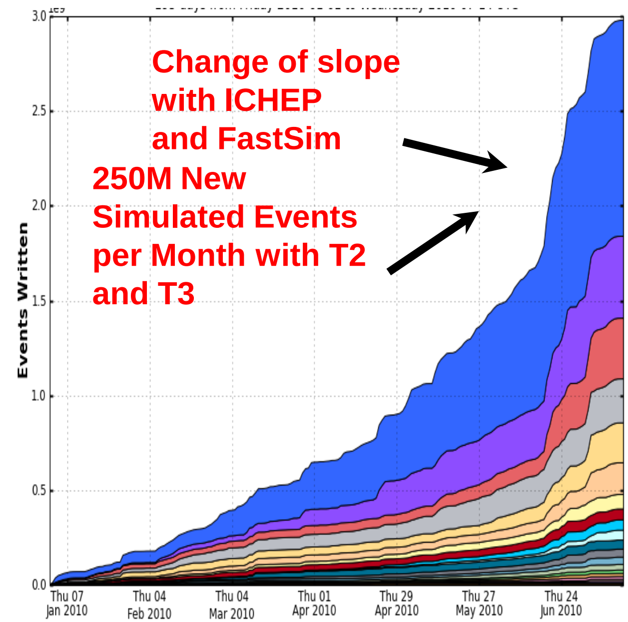


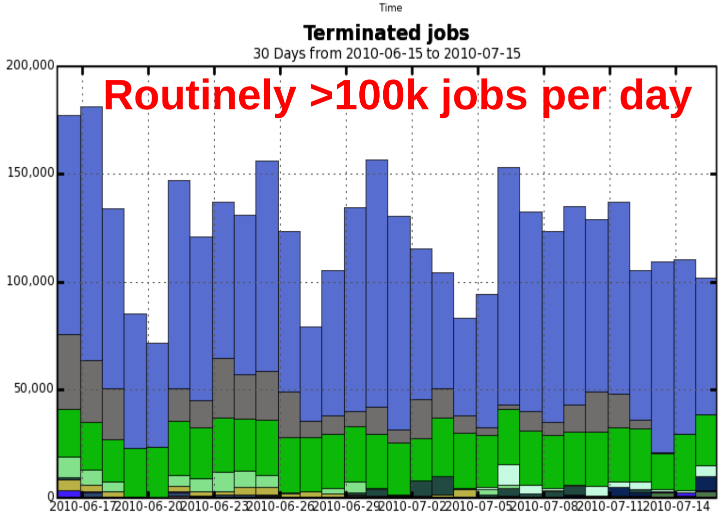
Data Processing, Transfer and Analysis Activities

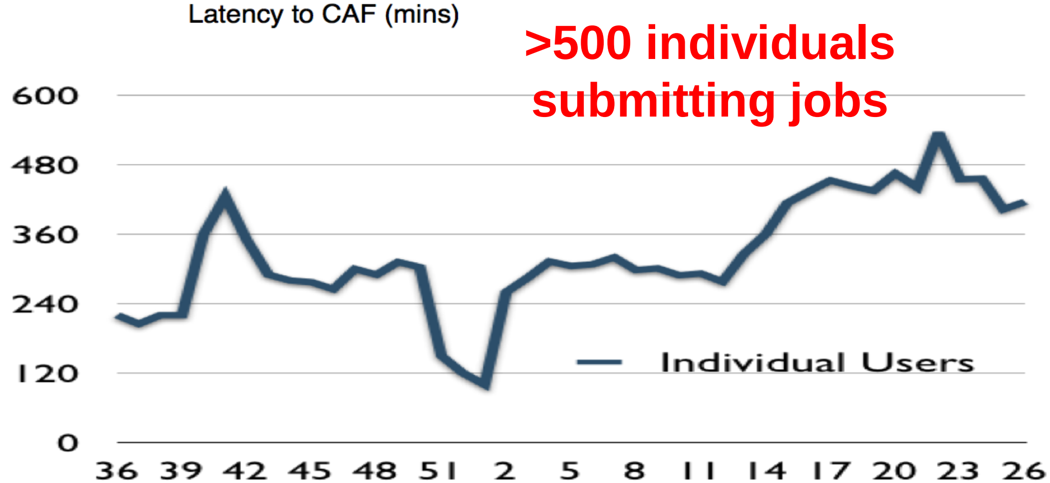
Excellent experience so far: the whole offline and computing organization + GRID infrastructure performing very well.



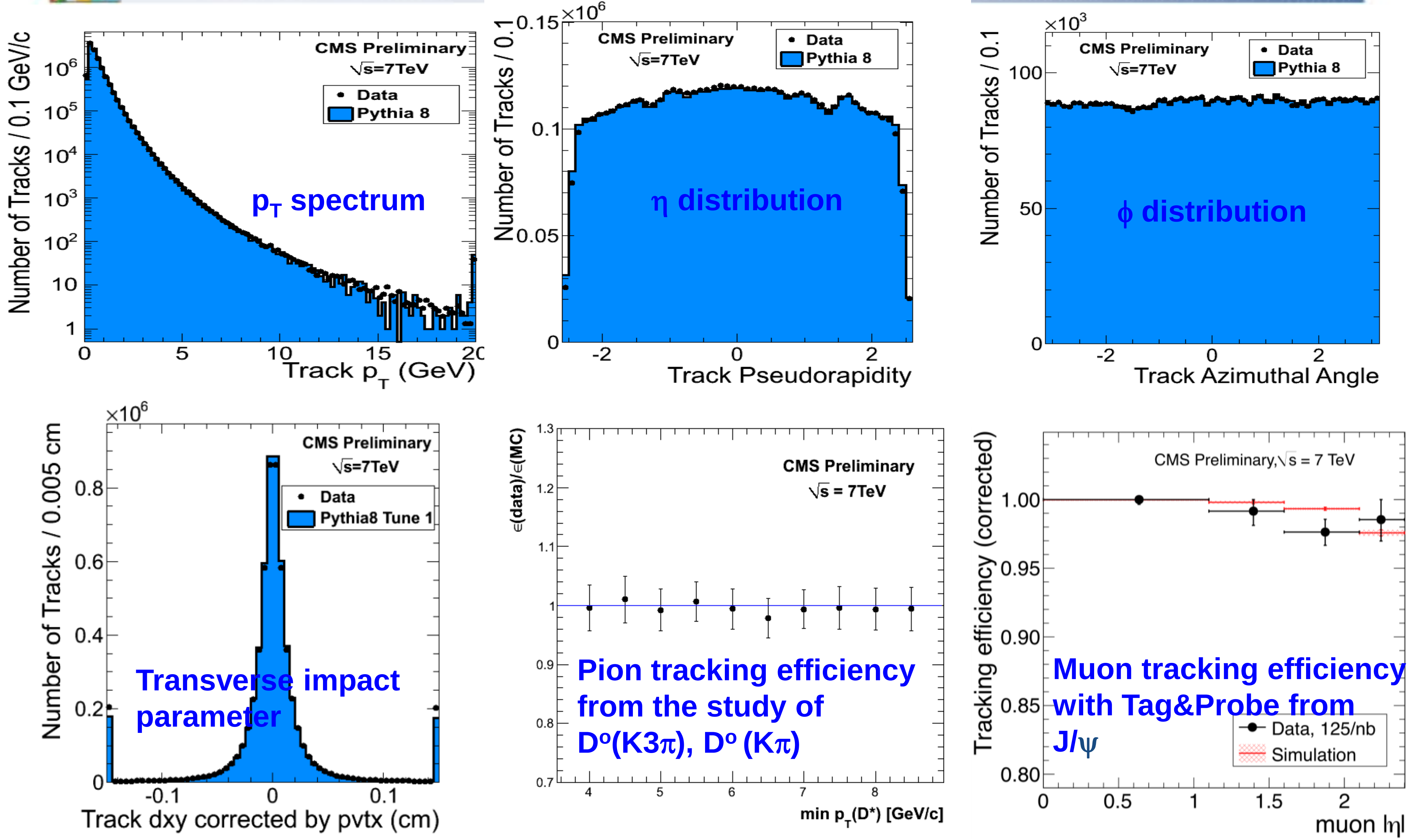






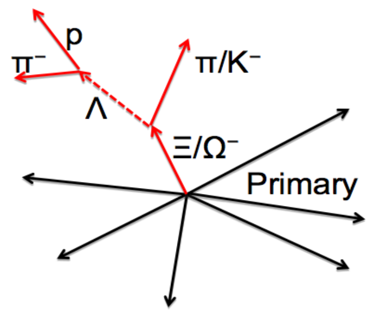


Understanding the Tracker Performance

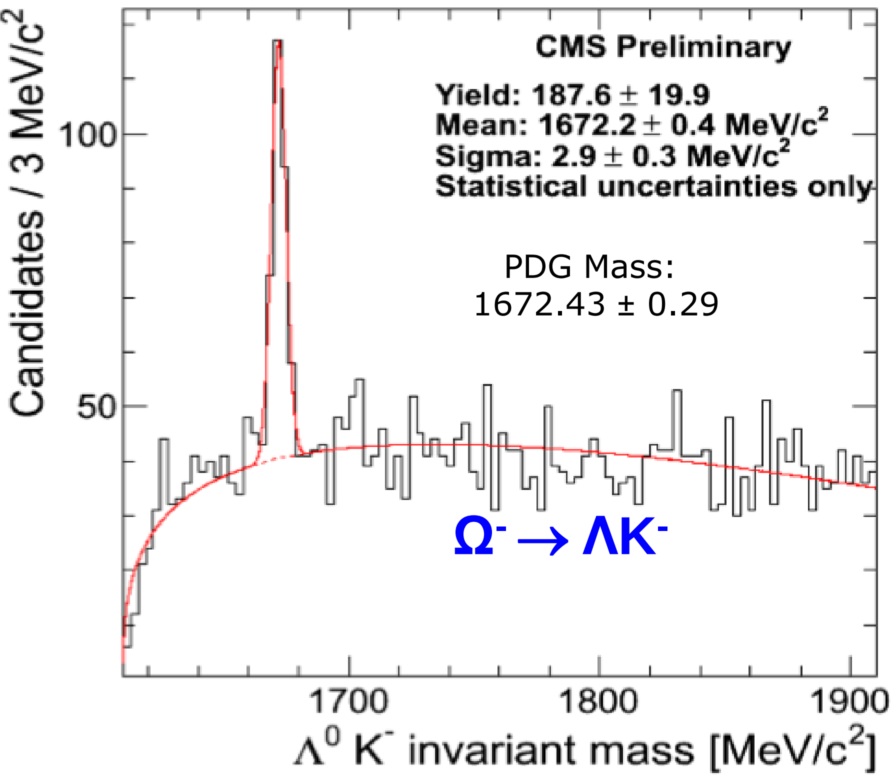


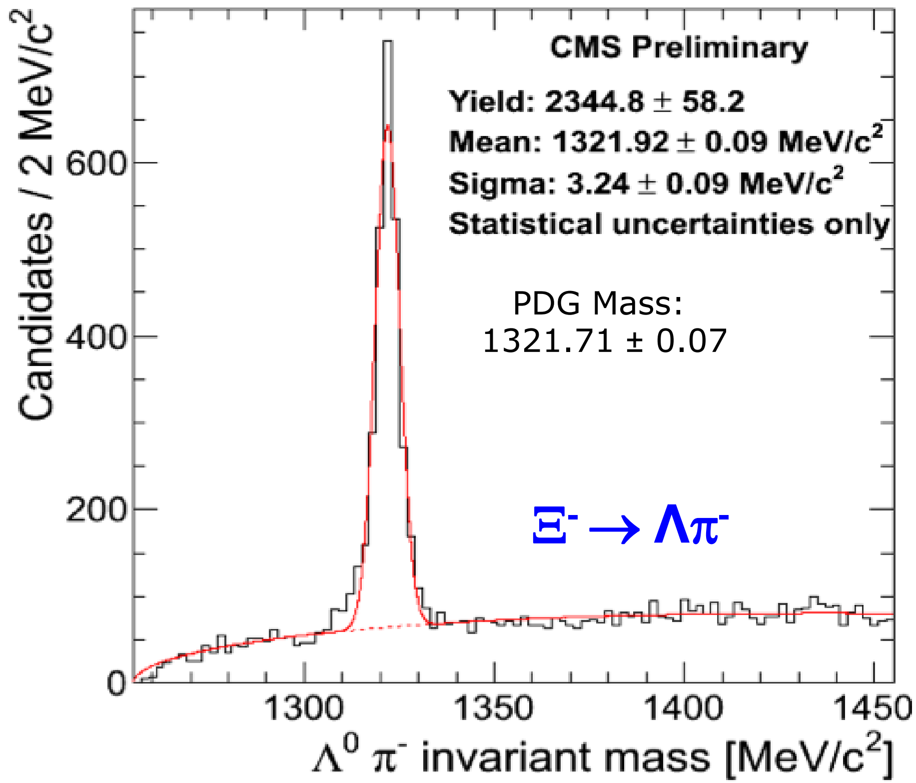
Low mass resonances

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



Invariant mass distribution for different combinations ($\Omega^\pm \to \Lambda K^\pm$ or $\Xi^\pm \to \Lambda\pi^\pm$) fit to a common vertex.



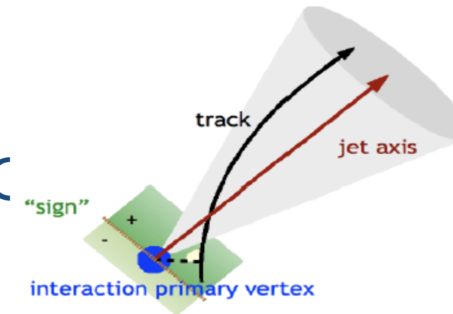


b-tagging

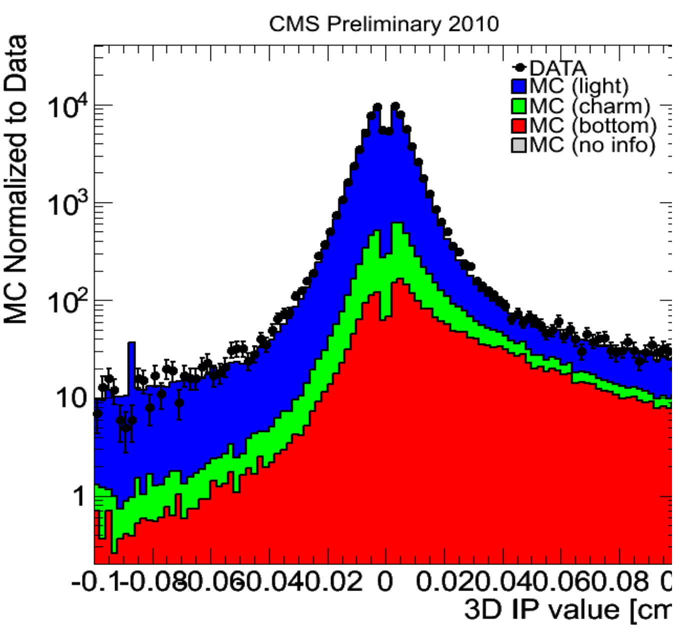
Several different b-tagging algorithms fully validated: a) Track counting b) Secondary vertex tagger c) Jet probability d) Lepton taggers.

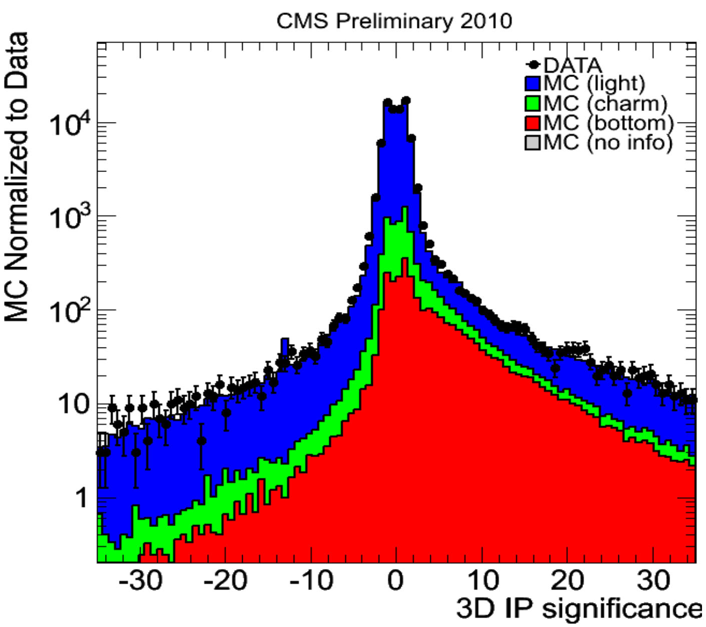
High efficiency taggers used in the first studies.

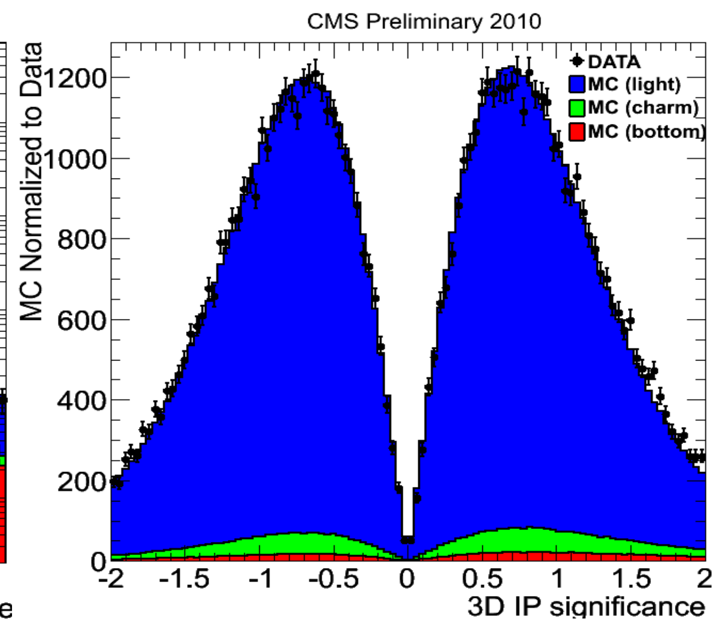
3D impact parameter value and significance (+zoom into all tracks with Pt>1GeV belonging to jets with p_T > 40 G 1.5 (*PFlow Jets anti-k_T R=0.5)*.



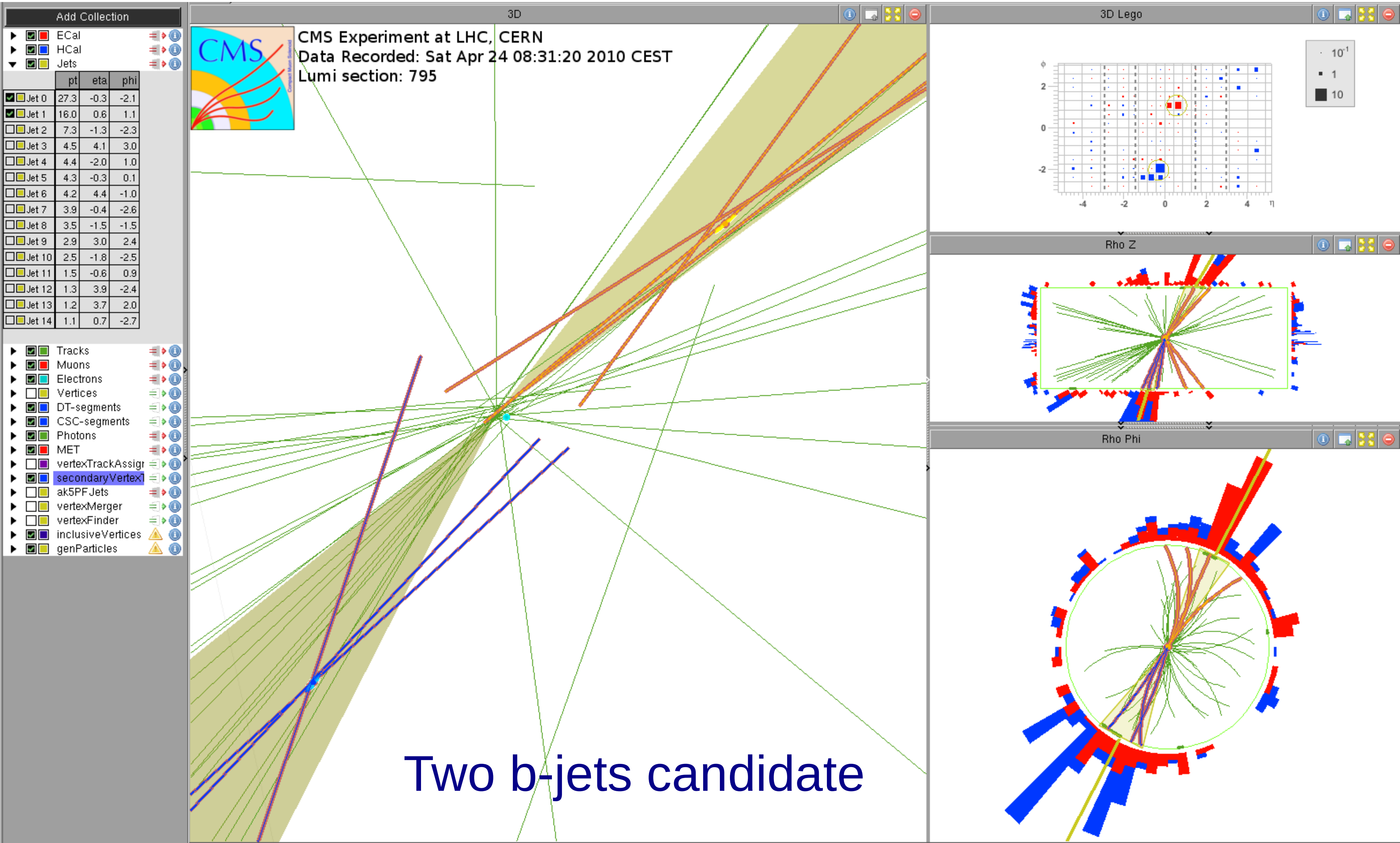
Excellent alignment and general tracking performance





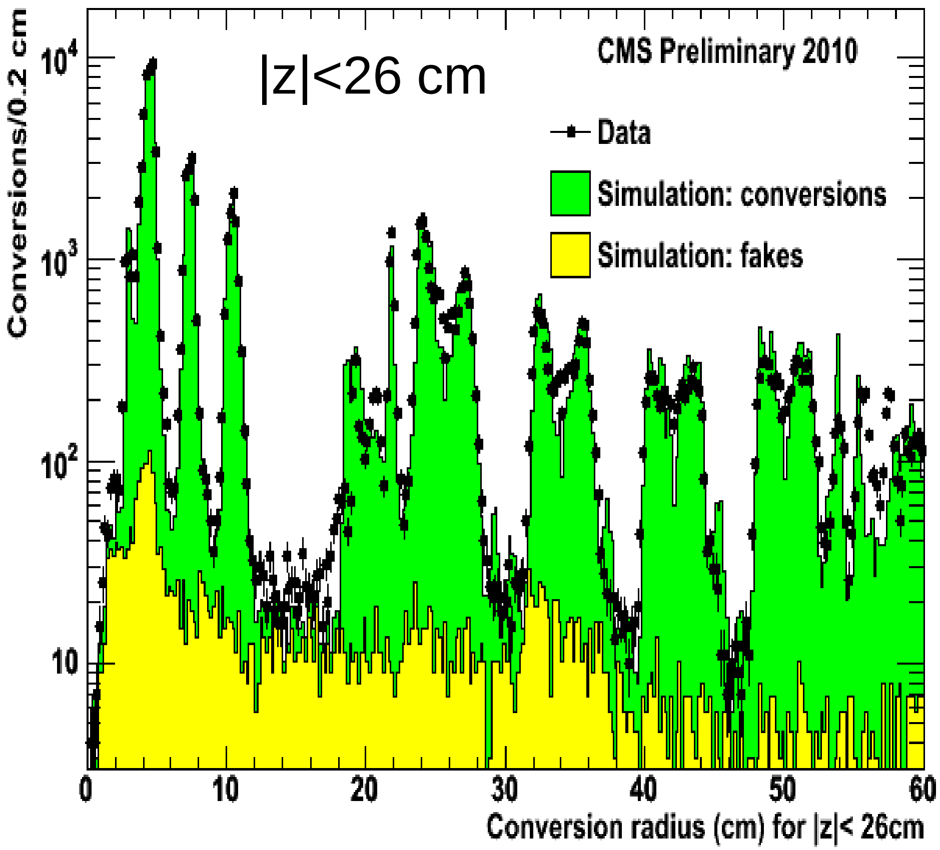


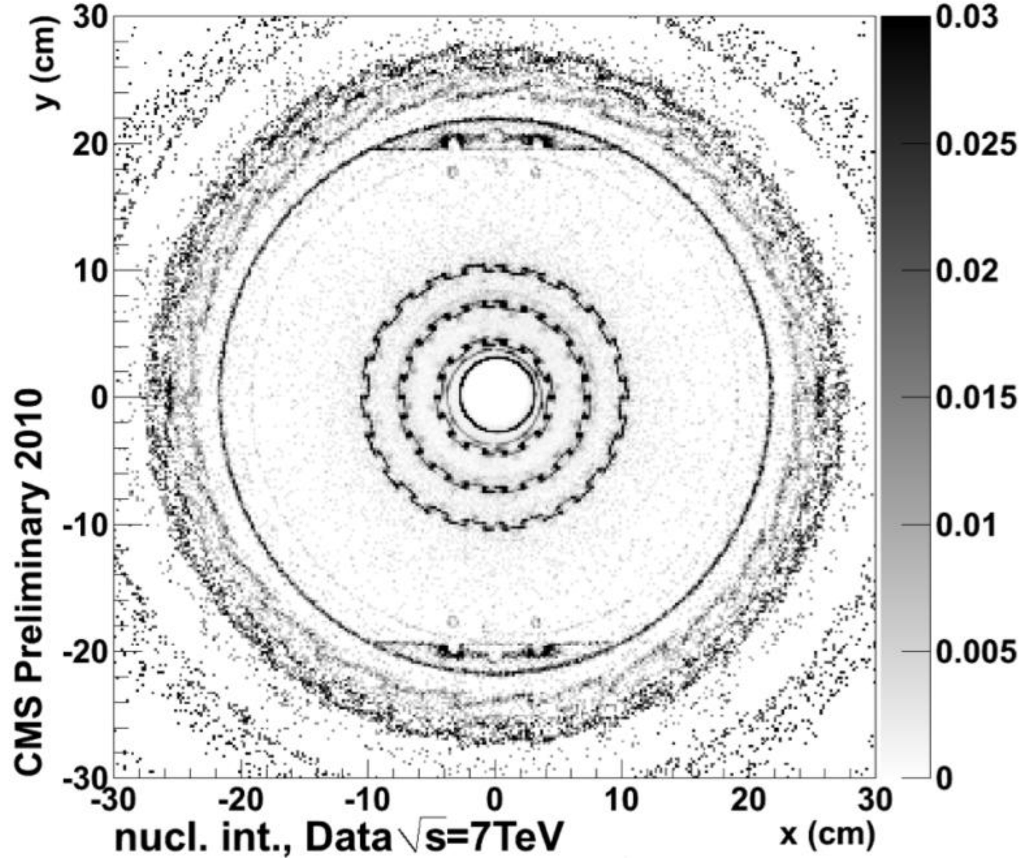
b-tagging at work



Two b-jets candidate

Progress in the study of the tracker material

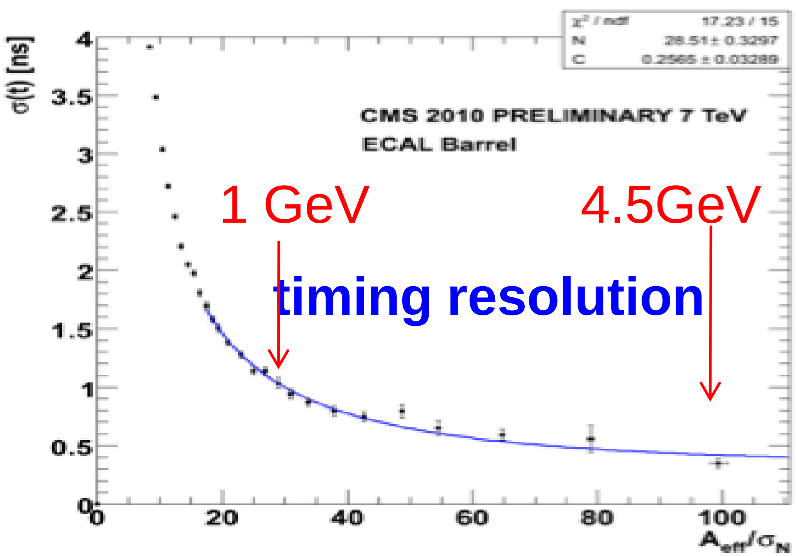


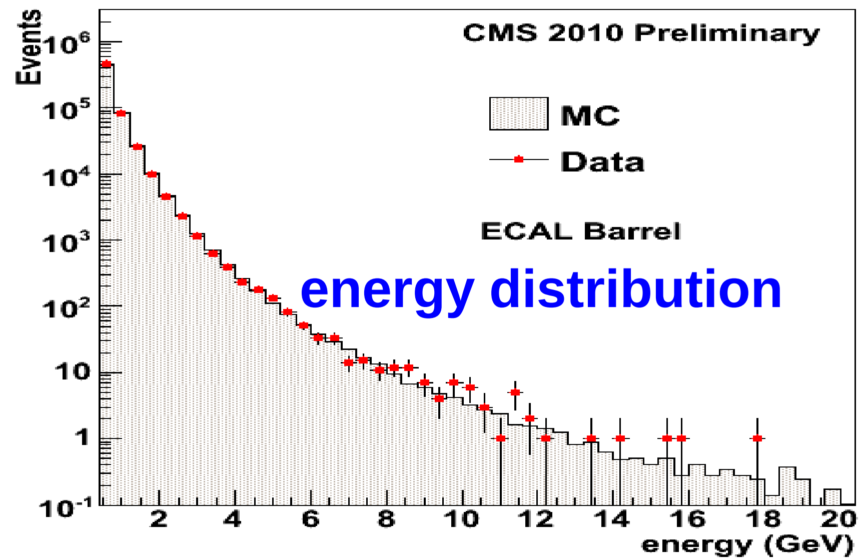


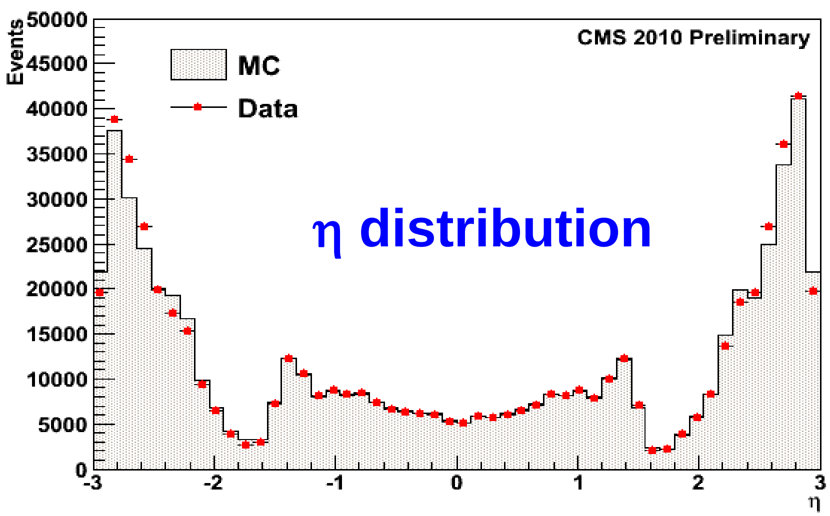
A complex activity is ongoing using many different, complementary methods: conversions, nuclear interactions, multiple scattering etc+ check of the energy loss and of the momentum scale using low mass resonances.

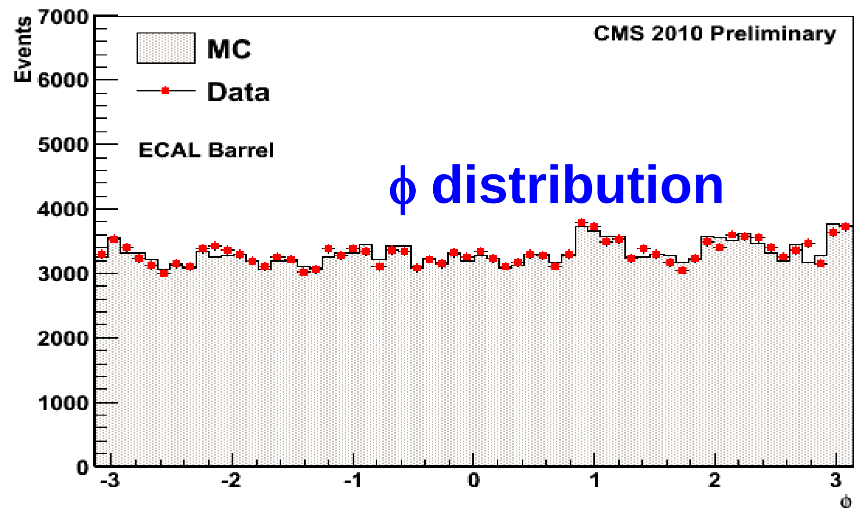
Material uncertainty today better than 10%→Systematics uncertainties on physics quantities related to material budget <1% .

ECAL clusters (electrons and photons)



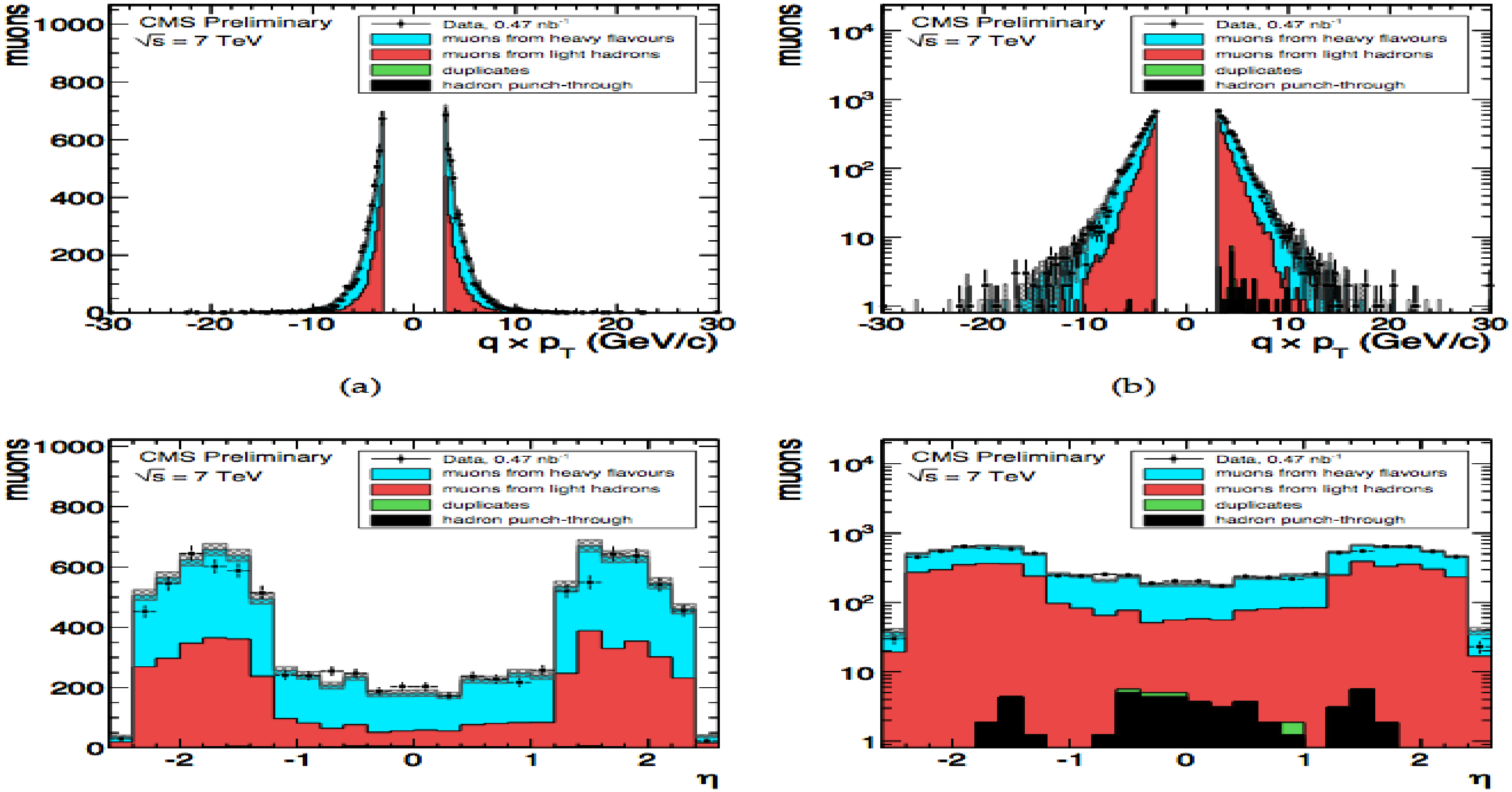






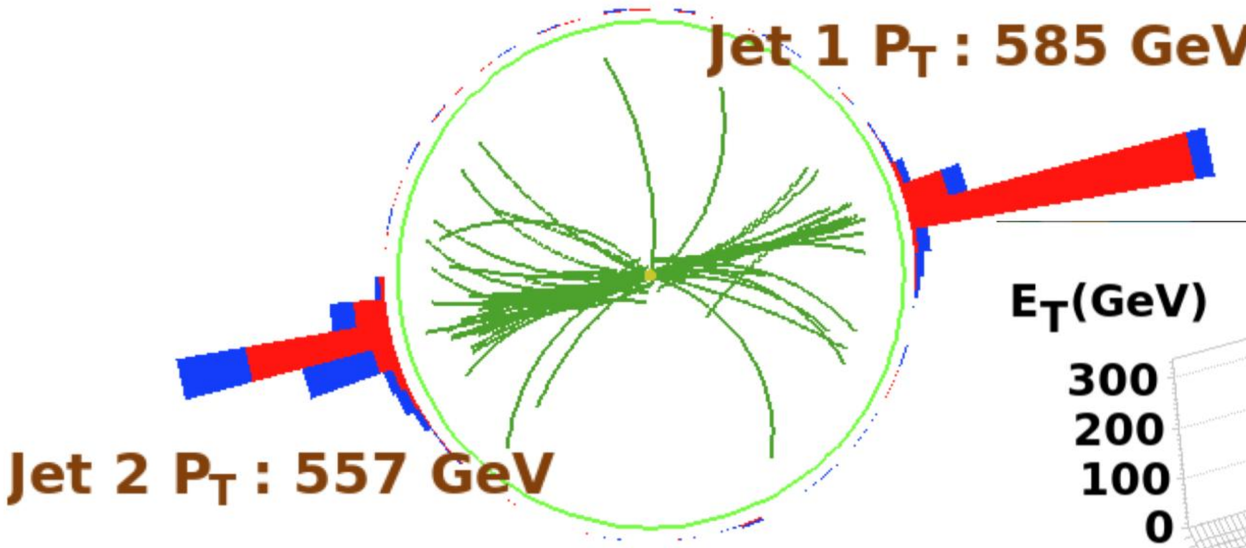
Muons

Muons identification efficiencies and kinematic variables have been studied in detail using minimum bias events and dimuon resonances.

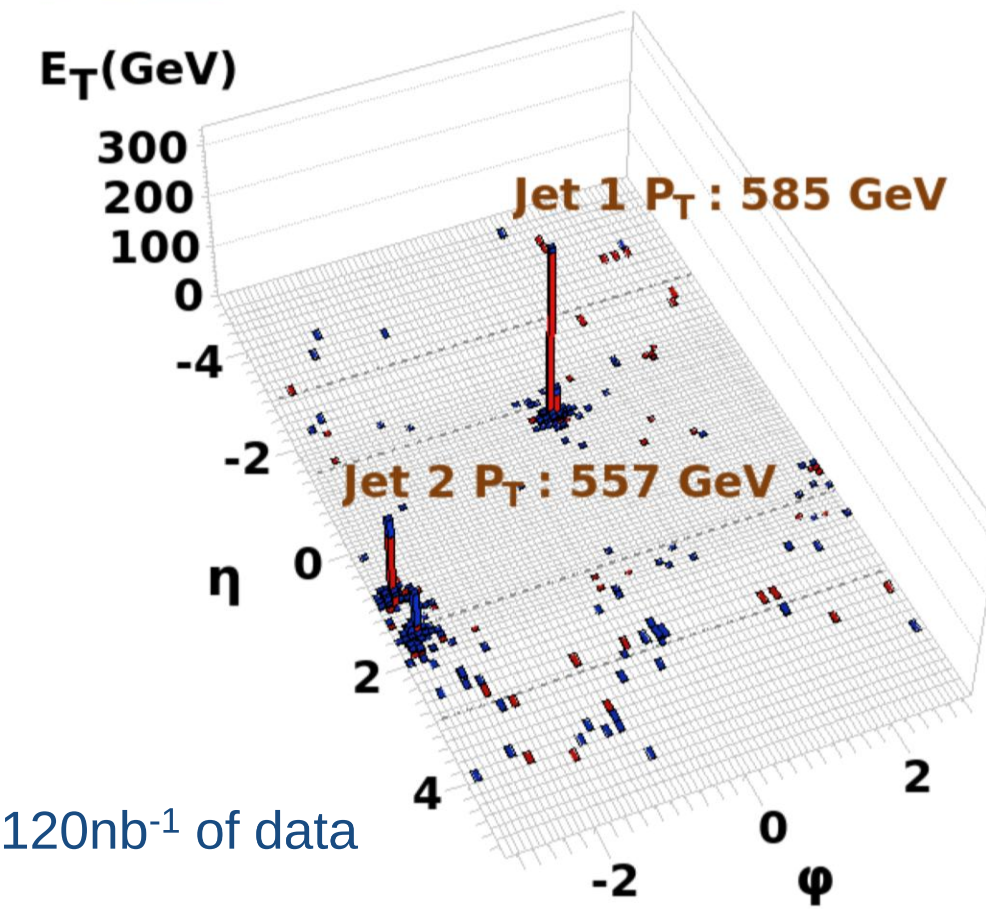


Distributions dominated by light hadron decay (red); excellent agreement with MC prediction including heavy flavor decays (blue); small fraction of punch-through (black) and fakes (green).

Jets and Missing E_T



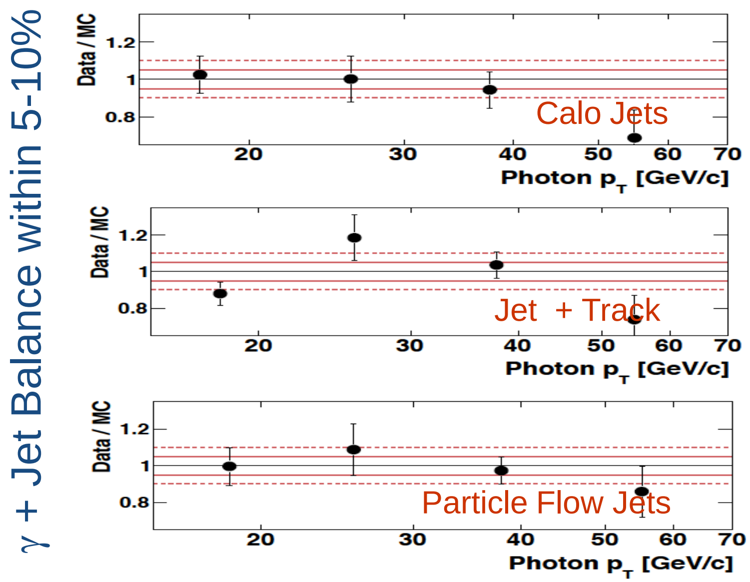
Run : 138919
Event : 32253996
Dijet Mass : 2.130 TeV

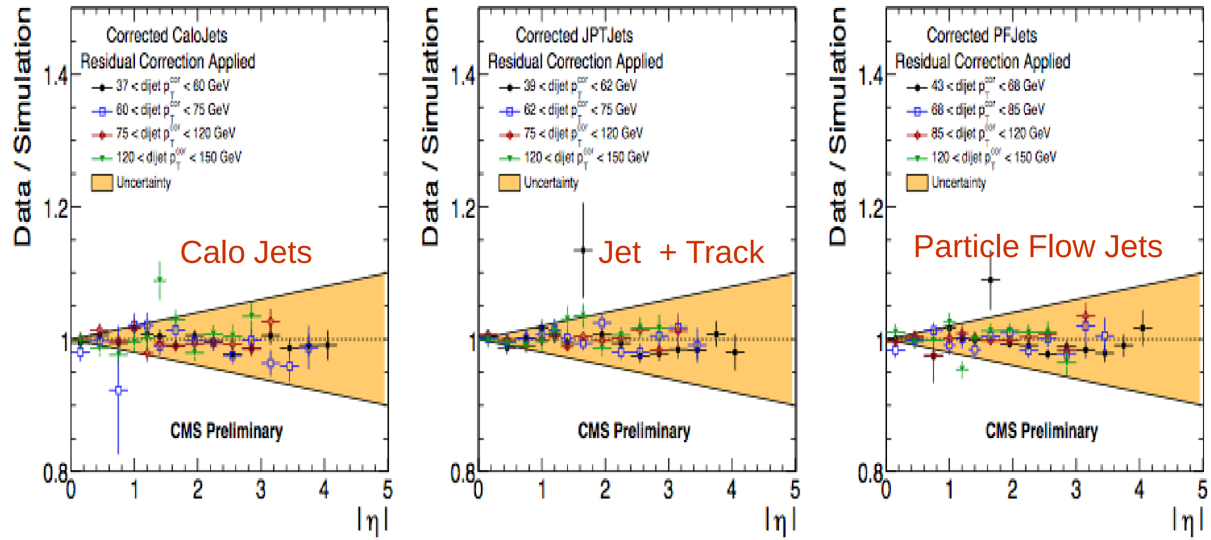


The highest mass dijet event in the first 120nb^{-1} of data

Jet Energy Correction

- Jets reconstructed with anti-k_T R=0.5 algorithms.
- Three different approaches: Purely Calorimetric, Jet+Tracks, Particle Flow Jets
- Jet Energy Correction performed using MC vs data on single particle response, dijet p_T balance, photon+jet balance.

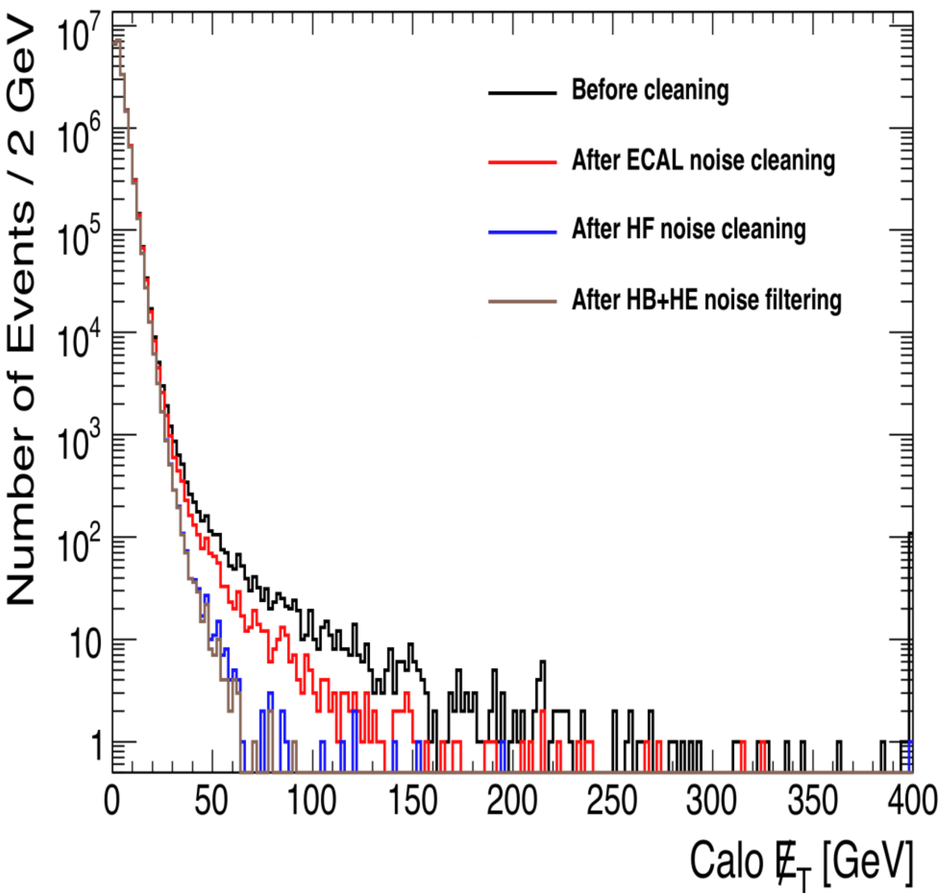


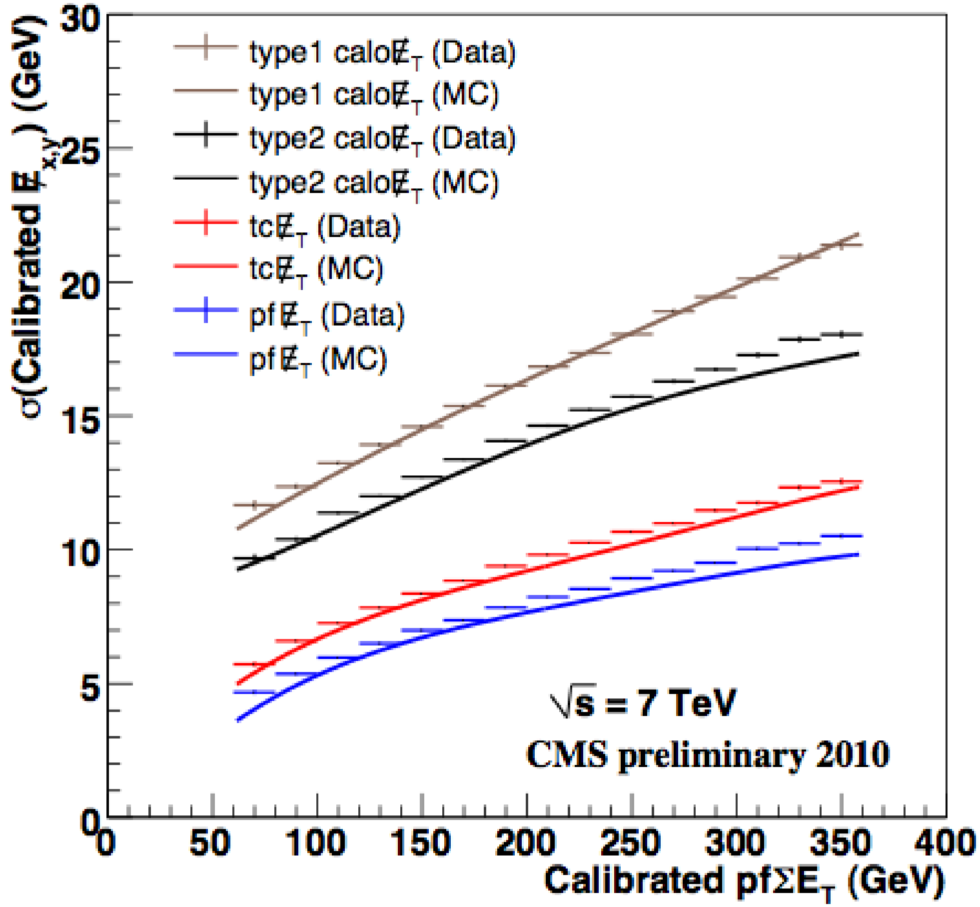


Current physics analysis use a 10% (5%) JEC uncertainties for CALO jets (JPT and PFjets), with an additional 2% uncertainty per unit rapidity.

Our measurements show that this assumption can be considered conservative.

Progress in MET



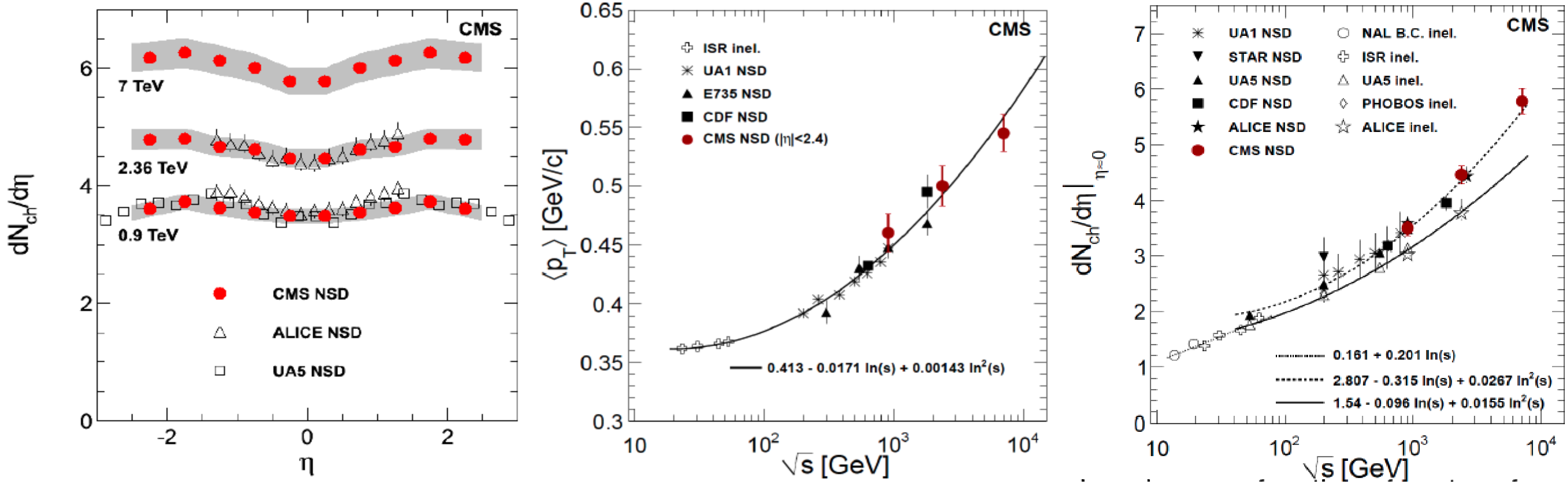


Excellent resolution and small non-gaussian tails. Understanding all sources of erratic noise is very important for cleaning the distributions. MET ready for physics.

Charged Hadrons

"Transverse Momentum and Pseudorapidity Distributions of Charged Hadrons in pp Collisions at √s=7TeV" Phys. Rev. Lett. 105, 2010.

- Minimum bias events
- Non single-diffractive event selection (correction 6%→2.5% systematic error)
- Really soft QCD (p_T tracks dow to 50MeV)



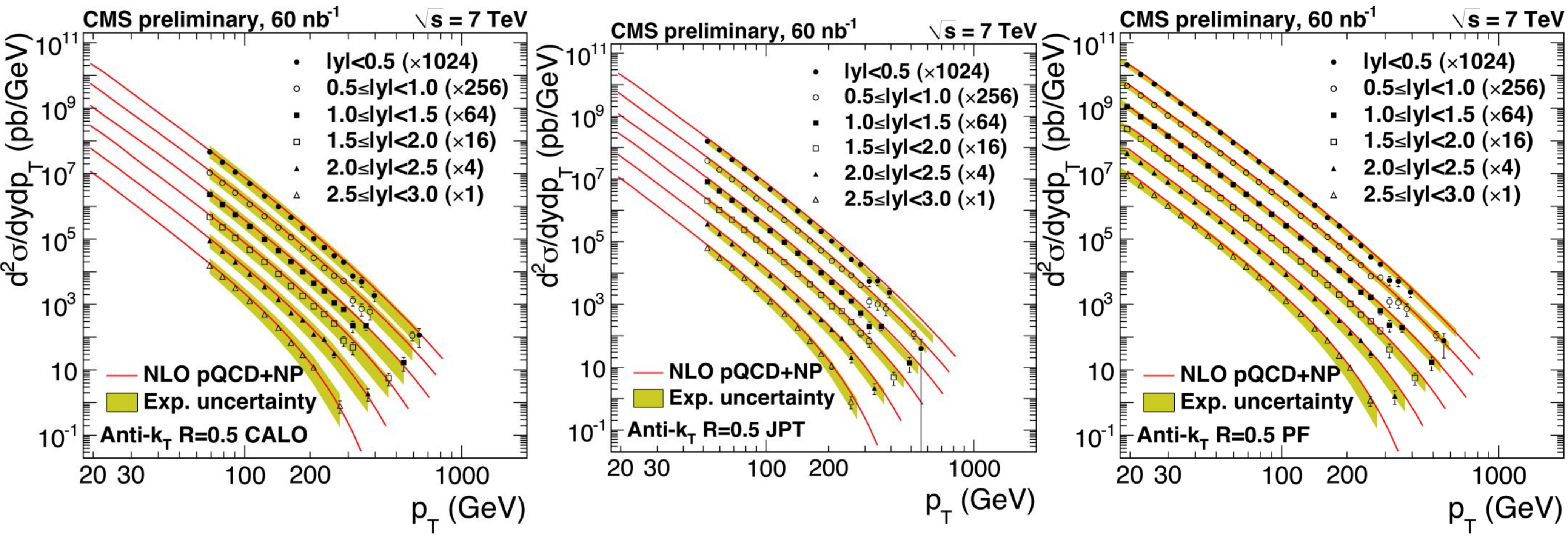
Rise of the particle density in data stronger than in model predictions. Careful tuning effort of the MC generators ongoing. Marginal impact on high p_T physics.

Inclusive jet cross section

Inclusive jet p_T spectra have ben produced for all three jet approaches used in CMS.

All results are in good agreement with NLO theory.

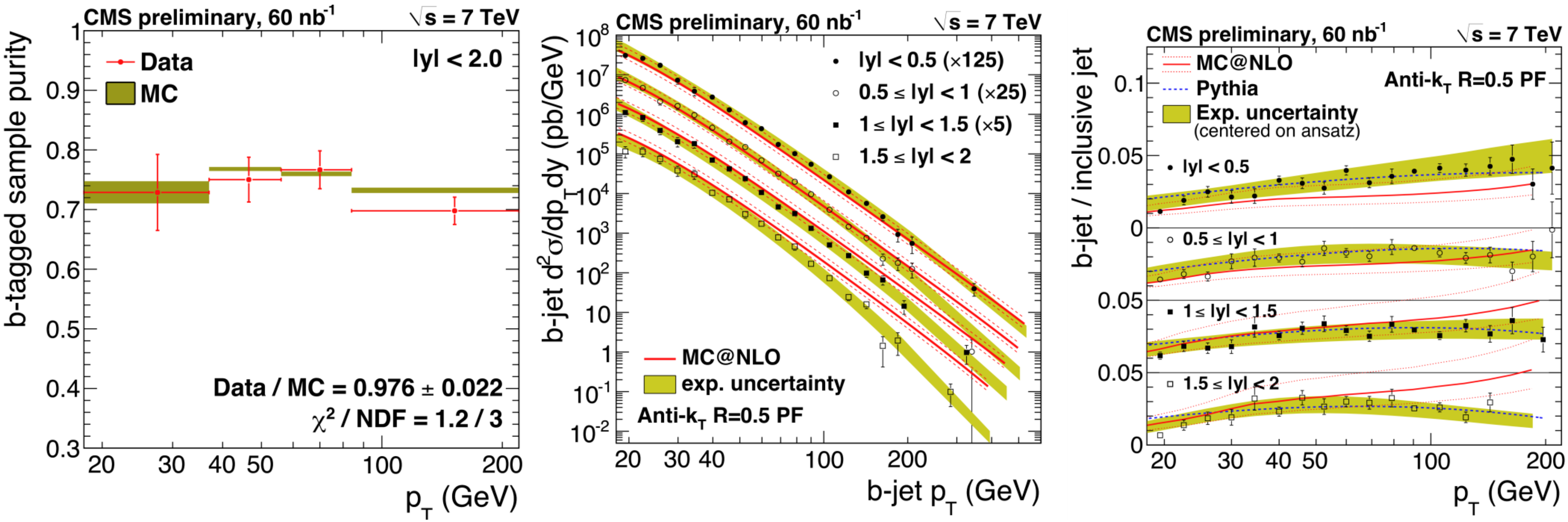
With the new Particle Flow approach the distributions can be extended to a low p_T value of 18 GeV.



Inclusive b-jet cross section

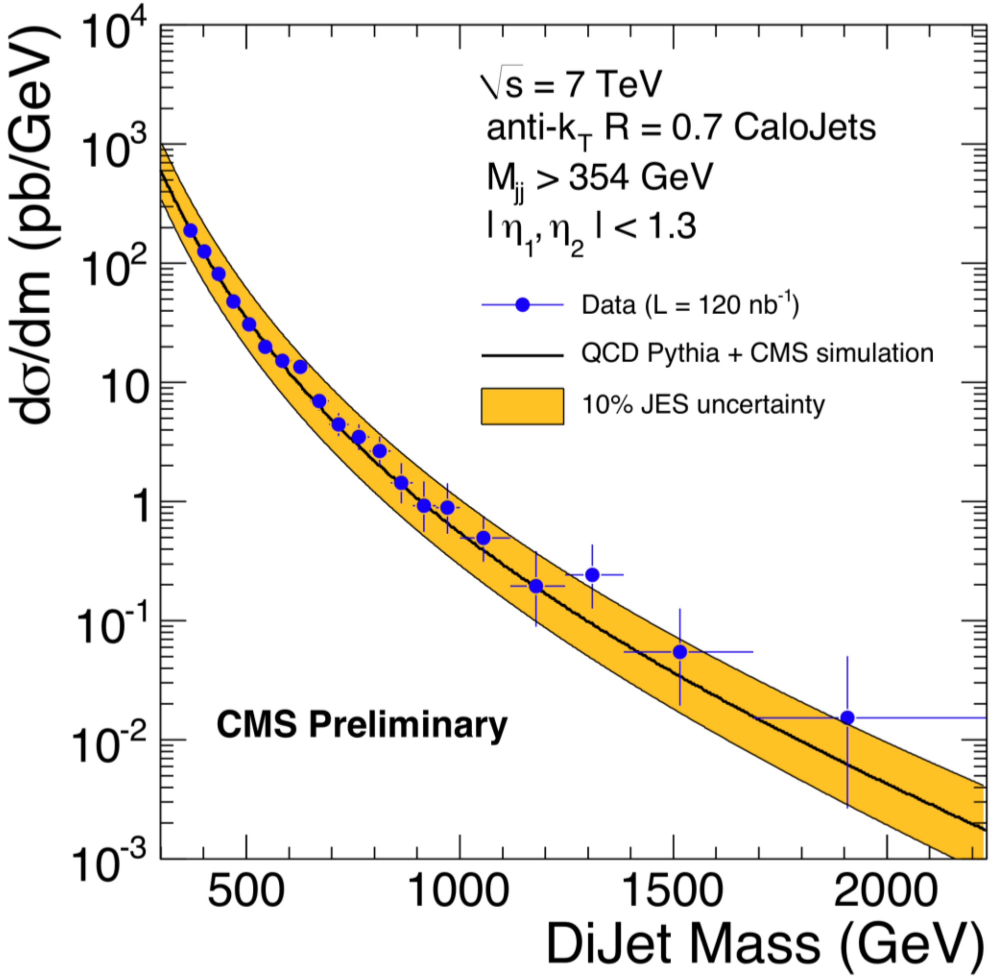
Important test of our capability to master the b-tagging tools (in this case the High Purity version of the Secondary Vertex Tagger).
The b-tagged purity of the sample has been extracted from the fit to the mass of the secondary vertex with templates. The b-tagging efficiency from a fit to the muon p_{Trel} variable using templates. Mistag rate from negative tails of the distributions.The ratio of the b-inclusive to the jet-inclusive to cancel out common systematic uncertainties.

Reasonable agreement with NLO but discrepancies in η and p_T shapes.

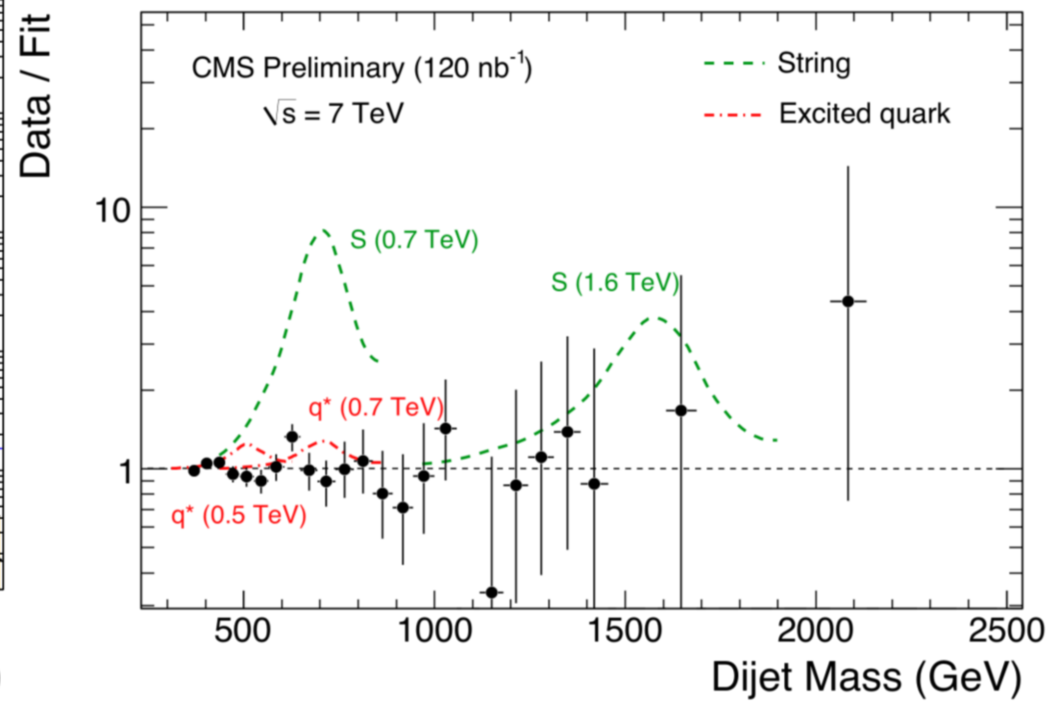


Search for narrow resonances in di-jet final states.

We have measured in 120nb^{-1} of data the dijet mass differential cross section for centrally produced jets $|\eta_1, \eta_2|<1.3$. The distribution is sensitive to the coupling of any new massive object from New Physics to quarks and gluons.



As appetizer of what will be soon possible: 85% exclusion limits for String resonances with mass <1.67TeV; excited quarks< 0.59TeV; axigluons <0.52TeV

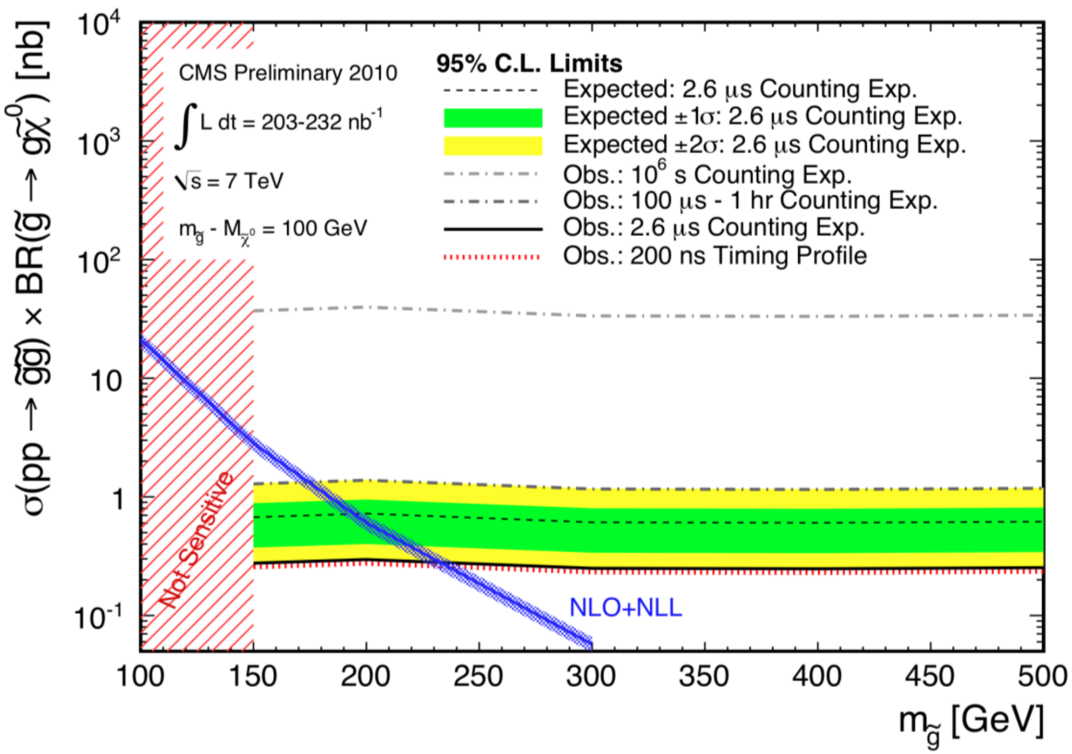


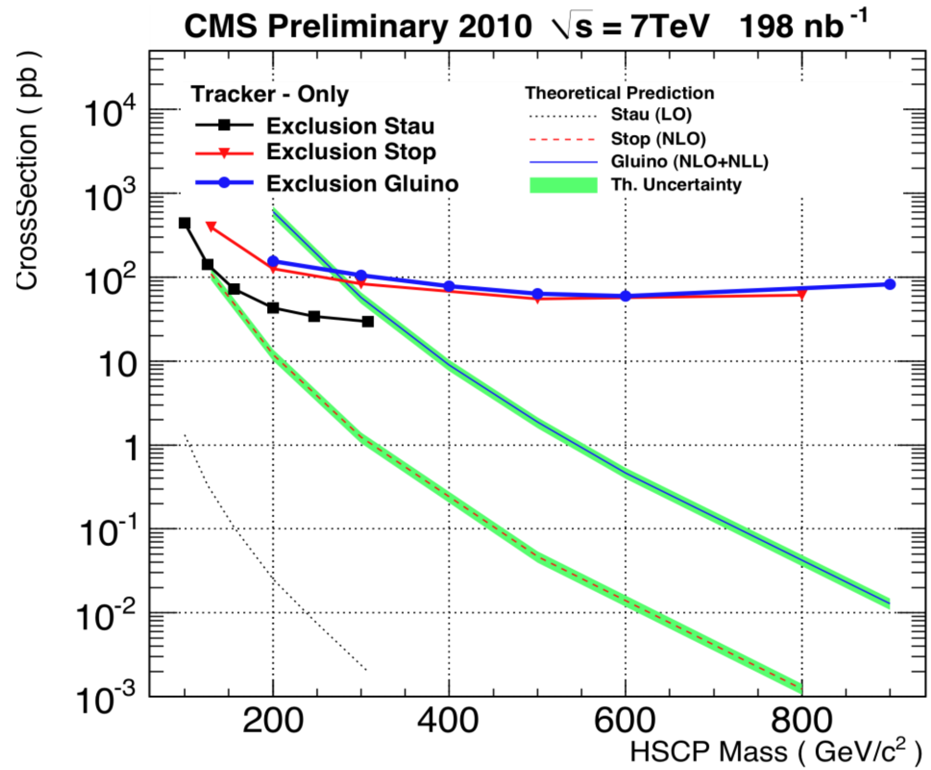
Stopped gluinos and Heavy Stable Charged Particles.

We search for long living particles decaying in the detector after the end of each LHC fills (special trigger to record important release of energy in “no beam condition”) and for heavy particles releasing anomalous signals in CMS while traversing the tracking system (high momentum, highly ionizing “muons”).

Gluino masses are excluded <229GeV (τ=200ns) and <225GeV (τ=2.6μs).

Limits on gluinos from HSCP analysis at 271 and 284 GeV (with muon id).

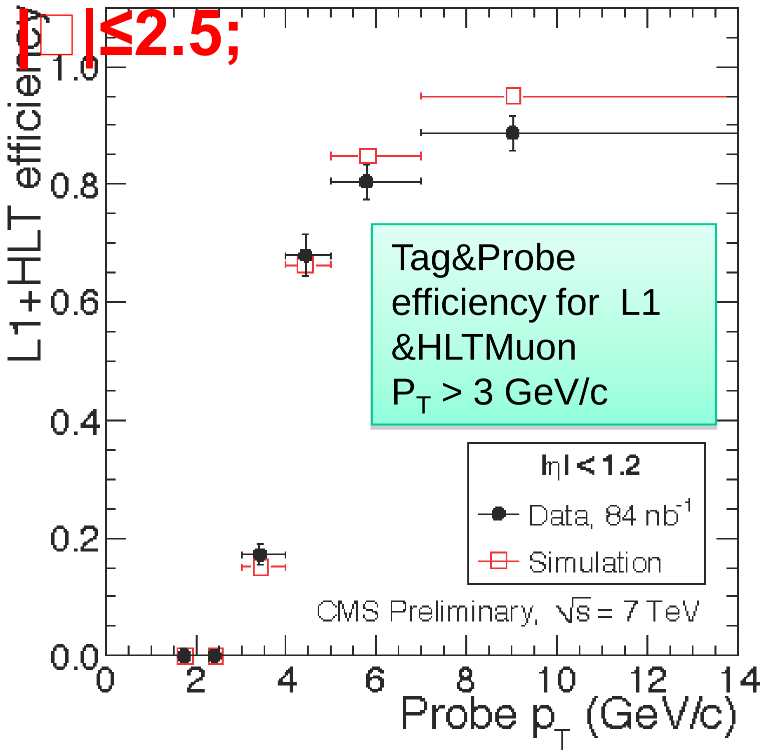


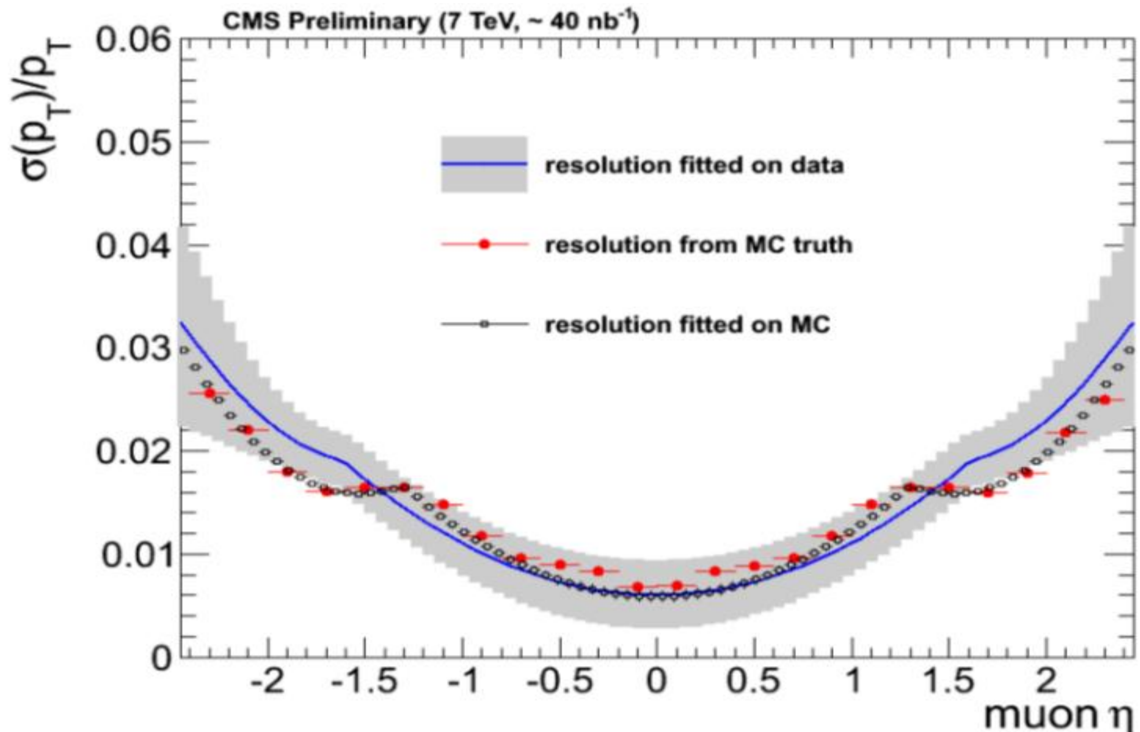


CMS features for J/ψ, Υ, Z…. and friends

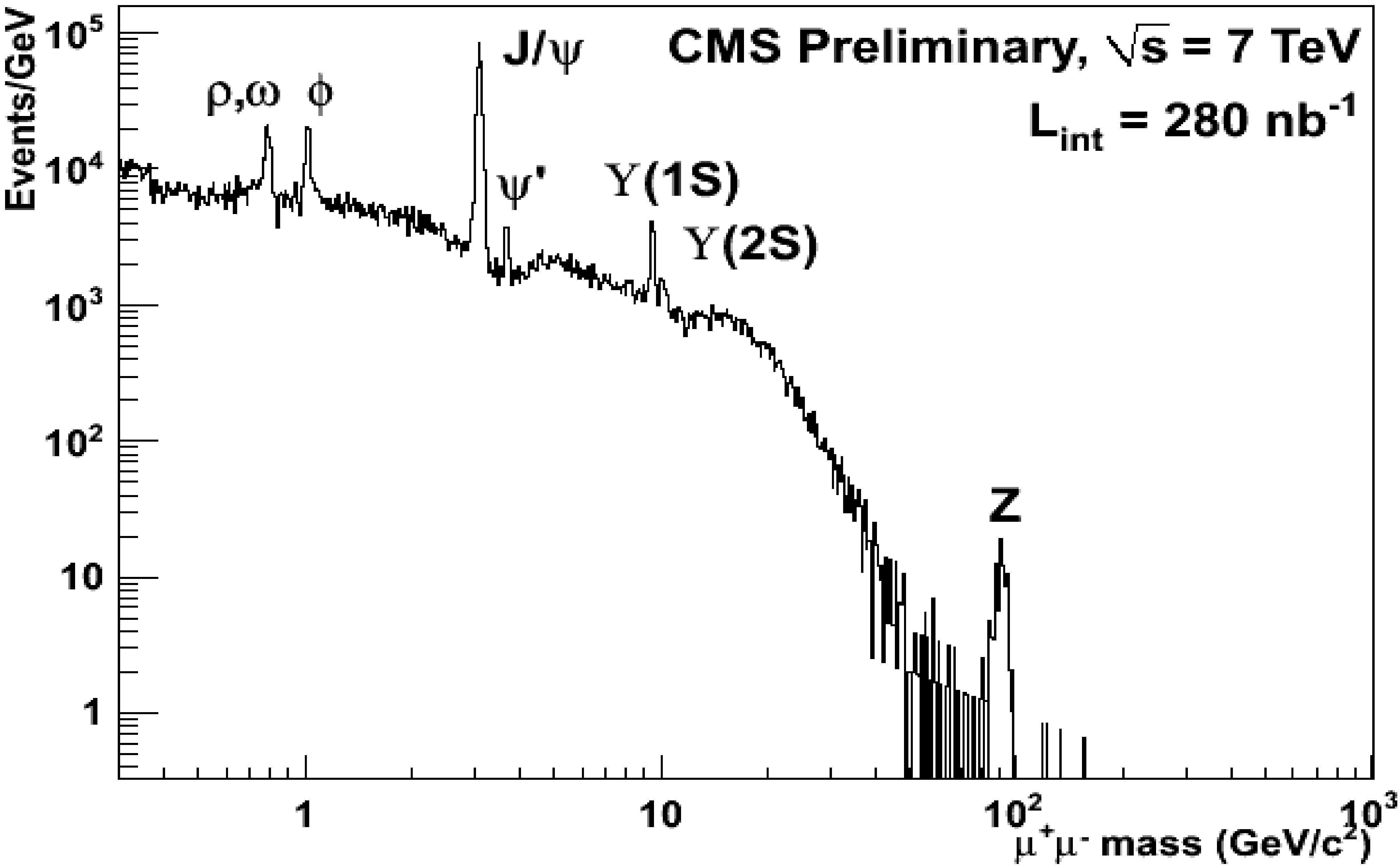
A) great flexibility of the trigger system of CMS. Two algorithms deployed: 1) HLT Mu3, is a single muon trigger using very loose L1 muon trigger primitives+ simple p_T cut of 3 GeV/c on the associated track. 2) L1 Double Muon Open: two muons at the hardware level, without any further processing (pt<4GeV in <1.4 |□|<2.4). **50k J/ψ per pb^{-1} down to 0 p_T in the forward.**

B) Excellent momentum resolution ≤1% for |□|≤0.7; ≤3% for |□|≤2.5;



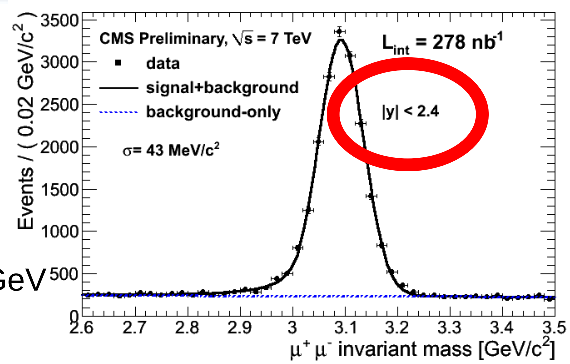


Here is the Compact Muon Solenoid

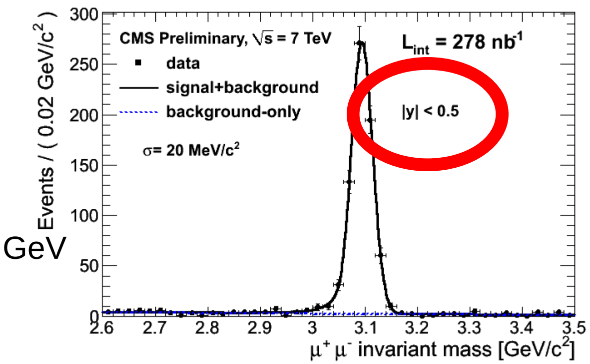


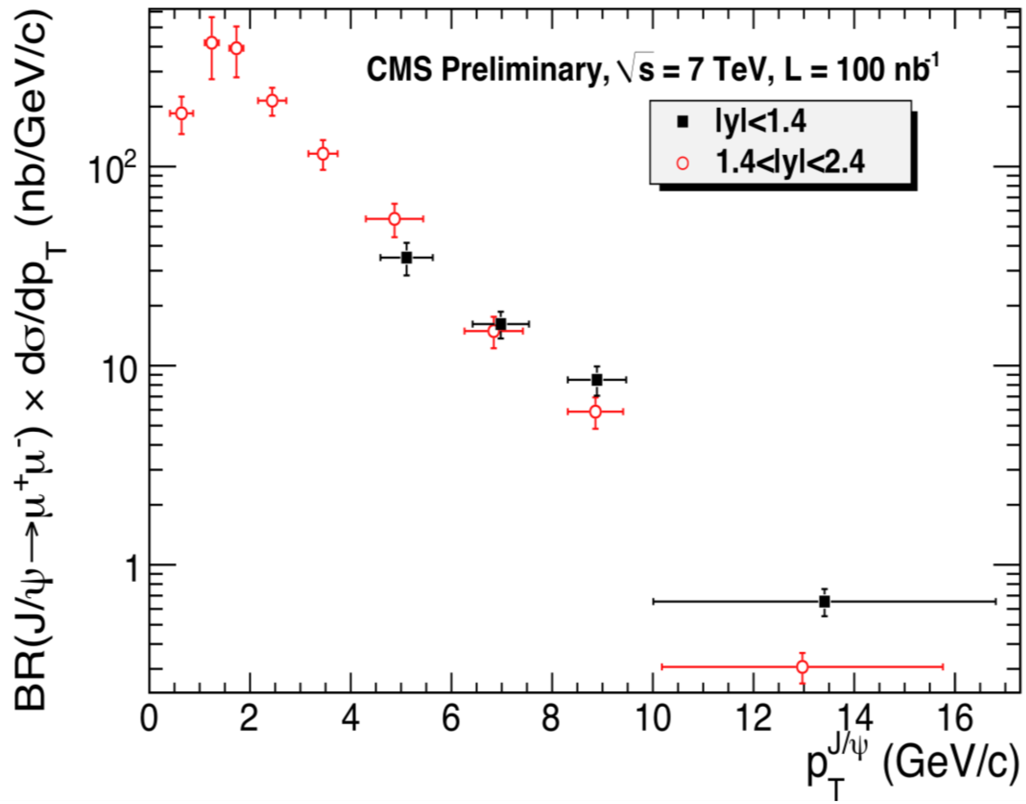
$J/\psi \to \mu^+\mu^-$ differential and total cross section

Signal events: 17156 ± 569
Sigma: 43.3 ± 0.5 (stat.) MeV
M_0 : 3.0927 ± 0.0005 (stat.) GeV
S/B= 6.4 ; χ^2/ndof = 1.7



Signal events: 710 ± 29
Sigma: 20.3 ± 0.7 (stat.) MeV
M_0 : 3.0945 ± 0.0008 (stat.) GeV
S/B= 64 ; χ^2/ndof = 1.1





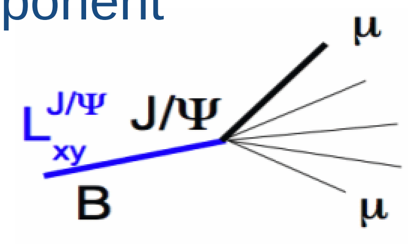
Differential cross section as a function of pT for the two different rapidity intervals and in the null polarization scenario. The total cross section for inclusive J/ψ production in the di-muon decay channel is

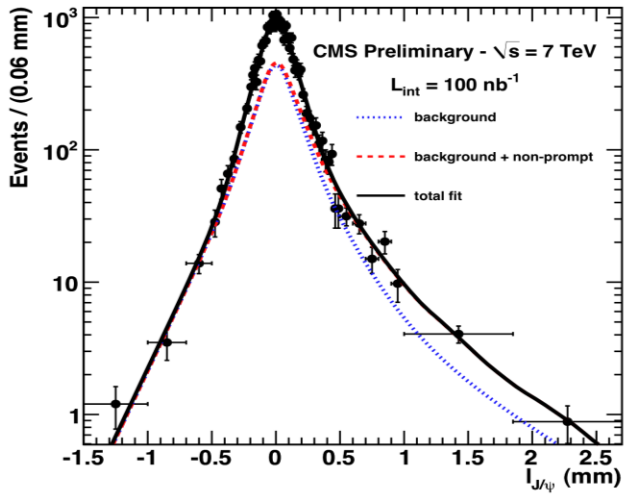
$BR(J/\psi \to \mu^+\mu^-) \cdot \sigma(pp \to J/\psi + X) = (289.1 \pm 16.7(stat) \pm 60.1(syst))$ nb

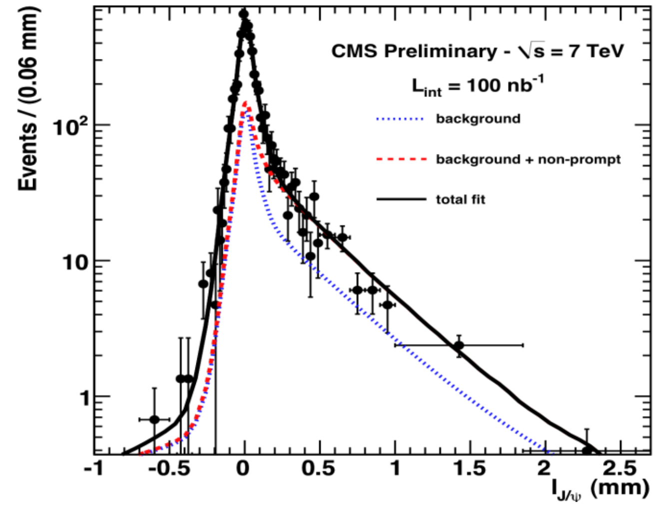
($4 \leq p_T \leq 30$GeV/c and $|y| < 2.4$; the systematic uncertainty is dominated by the statistical precision of the muon efficiency determination from data).

Fraction of $J/\psi \to \mu^+\mu^-$ from B Hadron decays

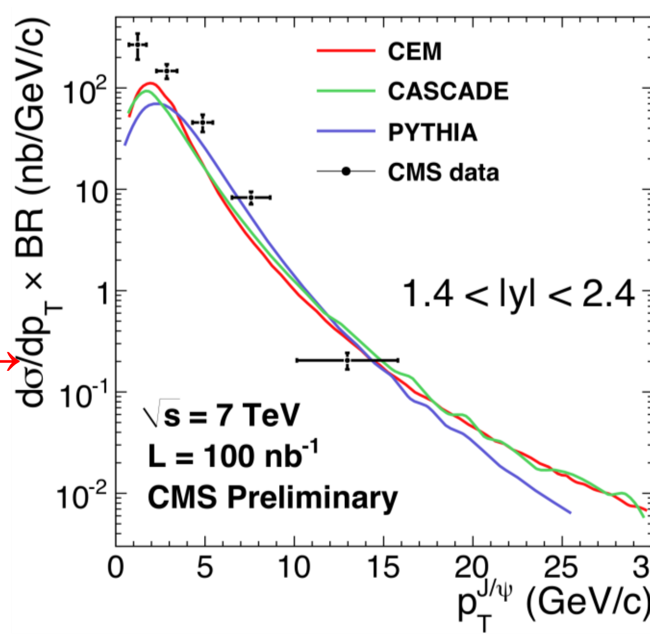
Traditional approach: the B transverse decay length used to separate the prompt from the non-prompt component

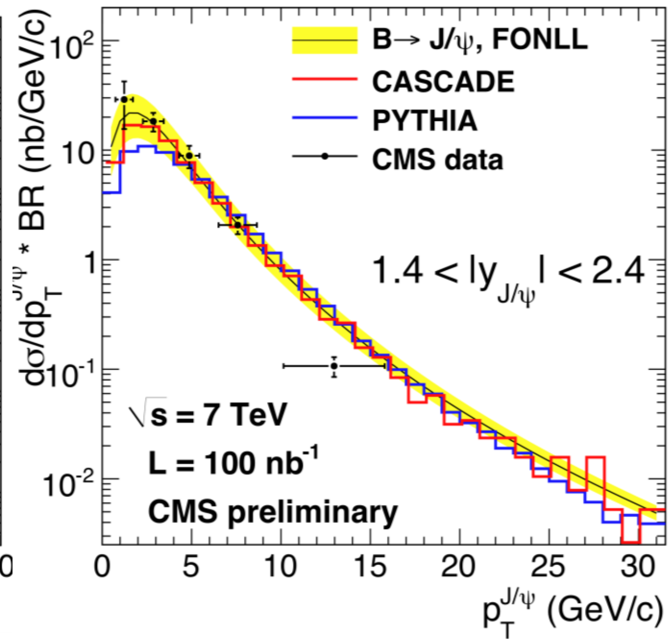






and to measure the prompt (non-prompt) differential cross section.



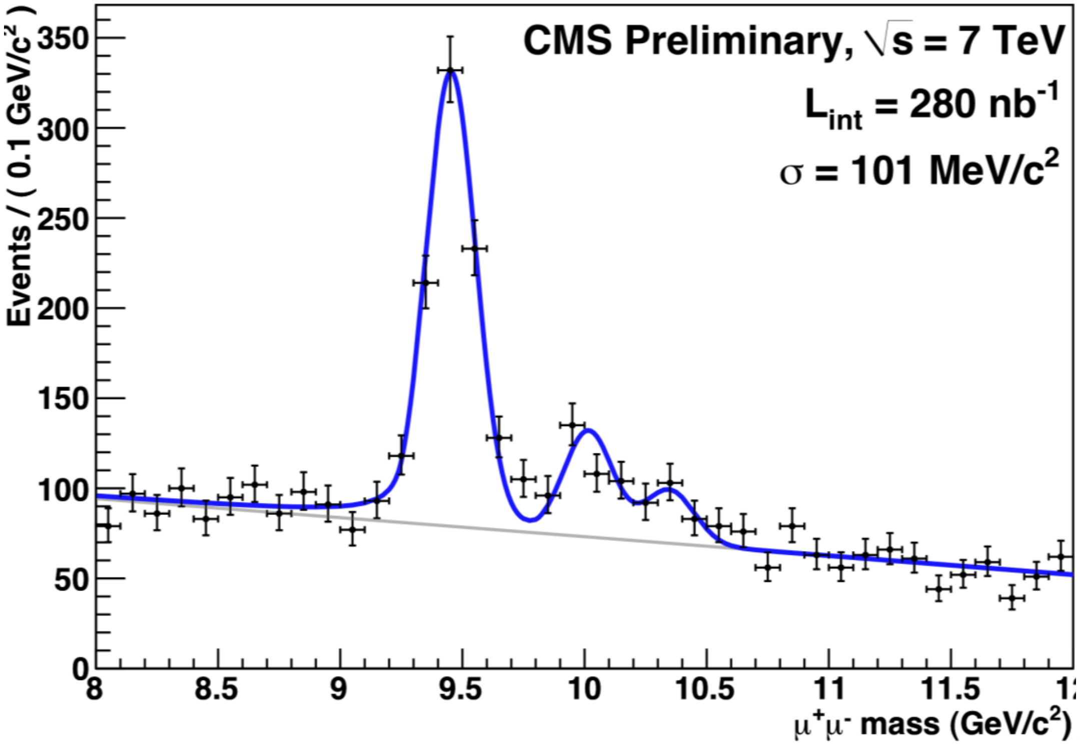


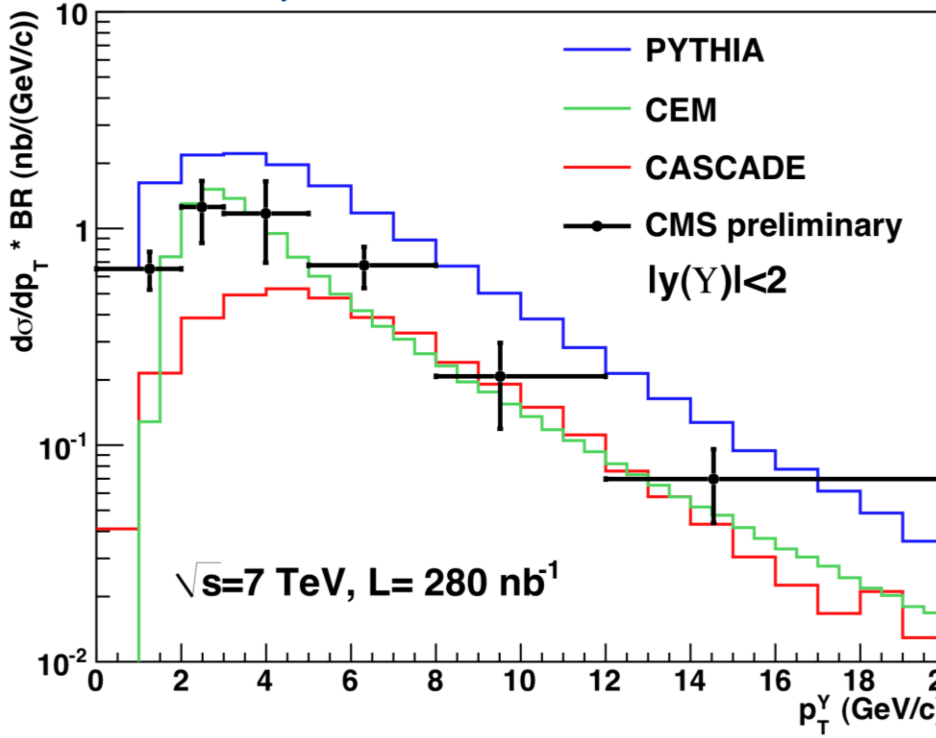
Non prompt cross section:

$BR(J/\psi \to \mu^+\mu^-) \cdot \sigma(pp \to bX \to J/\psi X') = (56.1 \pm 5.5(stat) \pm 7.2(syst))$ nb

(p_T>4GeV/c and |y| <2.4

Υ(1s, 2s and 3s)→$\mu^+\mu^-$





The Υ family is there and with enough statistics we will be able to resolve well the Υ2s from the Υ3s (we have measured 67MeV resolution for |y| <0.7). Meanwhile we have measured the Υ(1s) cross sectionxBR in dimuons and the corresponding differential cross section.

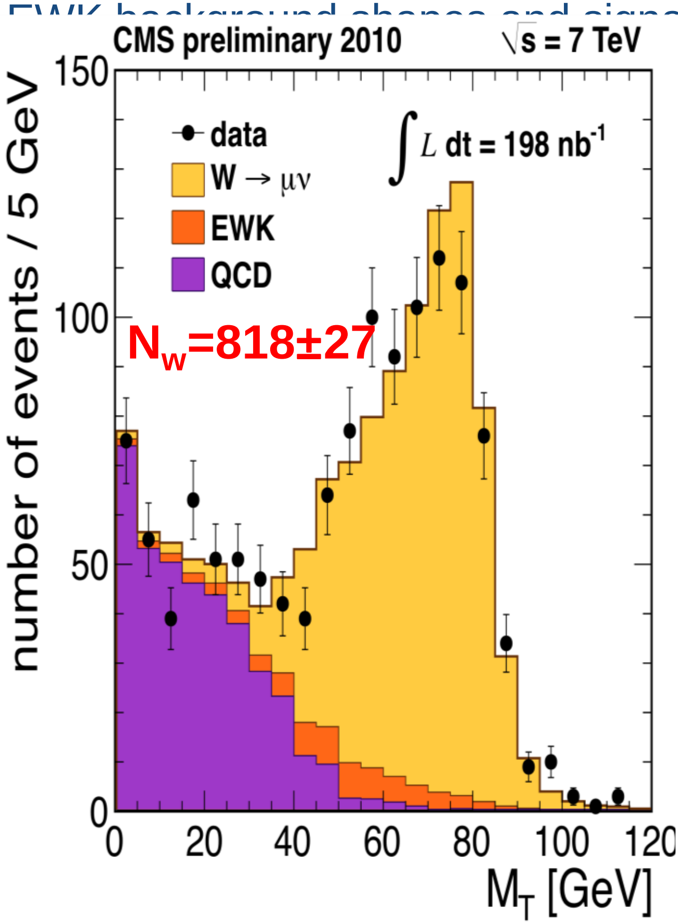
$\sigma(pp \rightarrow \Upsilon(1S)X) \cdot B(\Upsilon(1S) \rightarrow \mu^+ \mu^-) = (8.3 \pm 0.5 \pm 0.9 \pm 1.0)$nb

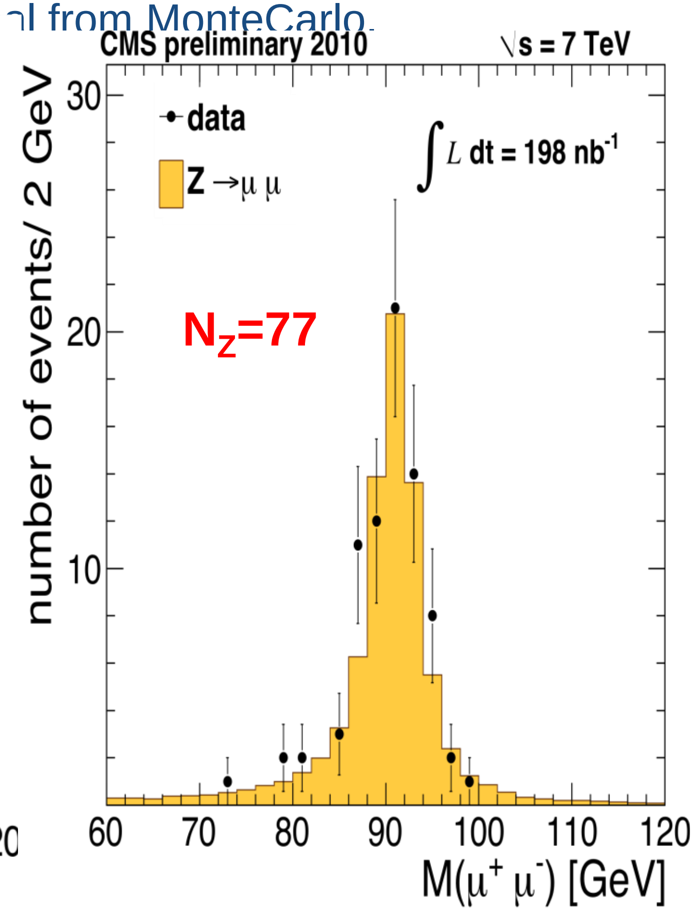
(Assuming no polarization and integrated over |y| <2.0)

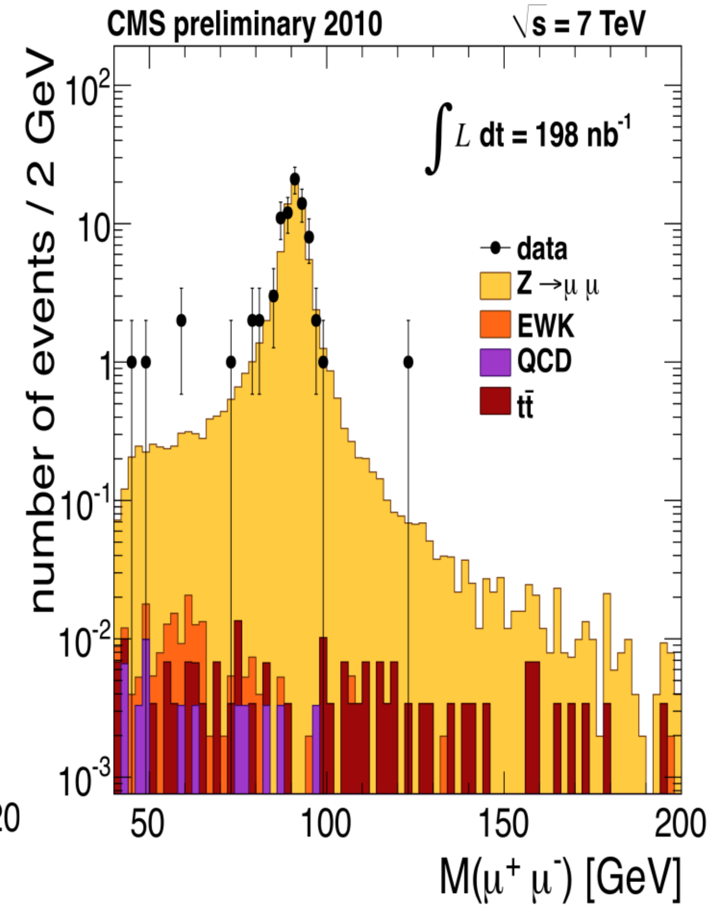
Extraction of the W± (Z°)→μ±{ (⌠+⌠-) yield signal

Trigger HLT path: μ+X(p_T>9GeV/c) |□|<2.

Good quality muon track (hits in pixels, strip tracker, muon system and □²/dof <10). For the W: relative isolation ≤0.15 in a cone of □R<0.3 around the muon. For the Z: looser quality criteria on the second muon, opposite charge and |□|<2.4; both muons isolated, p_T>20GeV and invariant mass 60<m_{mm}<120GeV/c^2. Simultaneous fits to backgrounds and signal contributions. QCD background shapes obtained using data. EWK background shapes and signal from MonteCarlo.

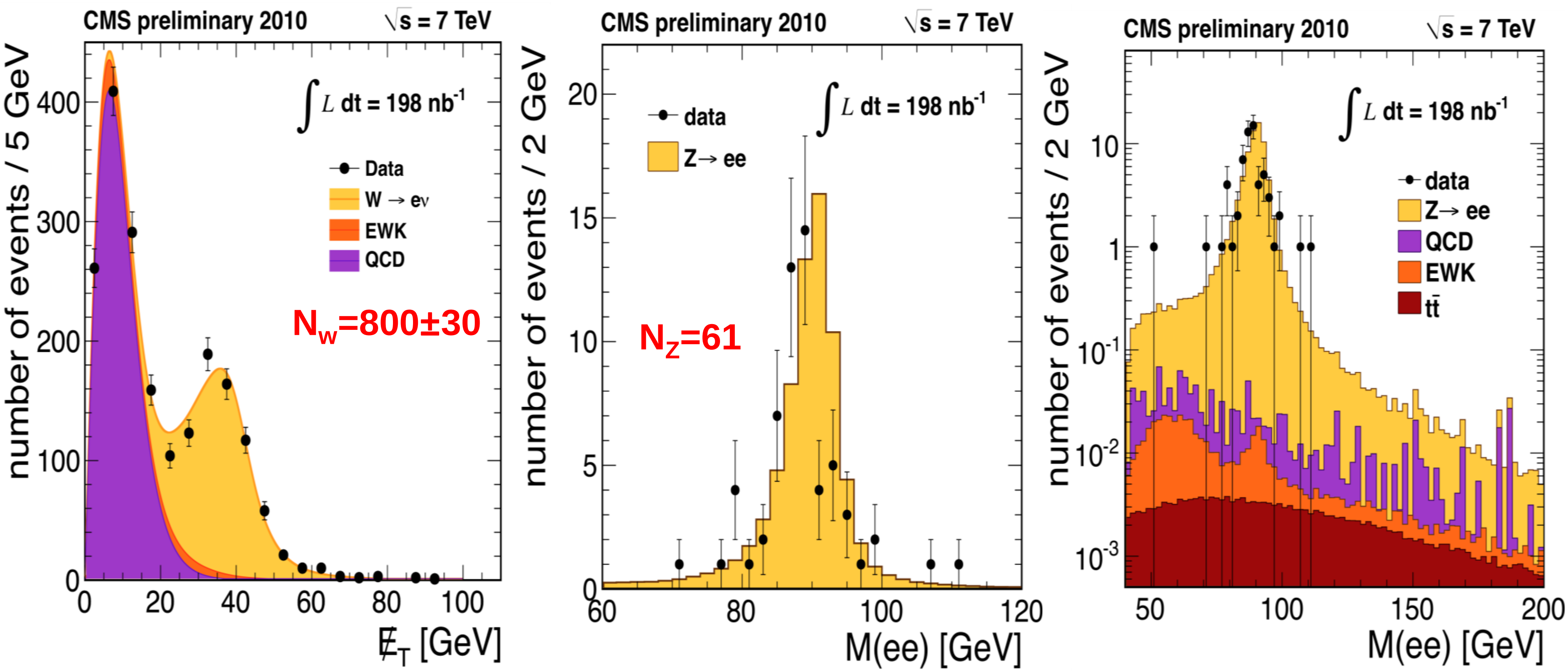




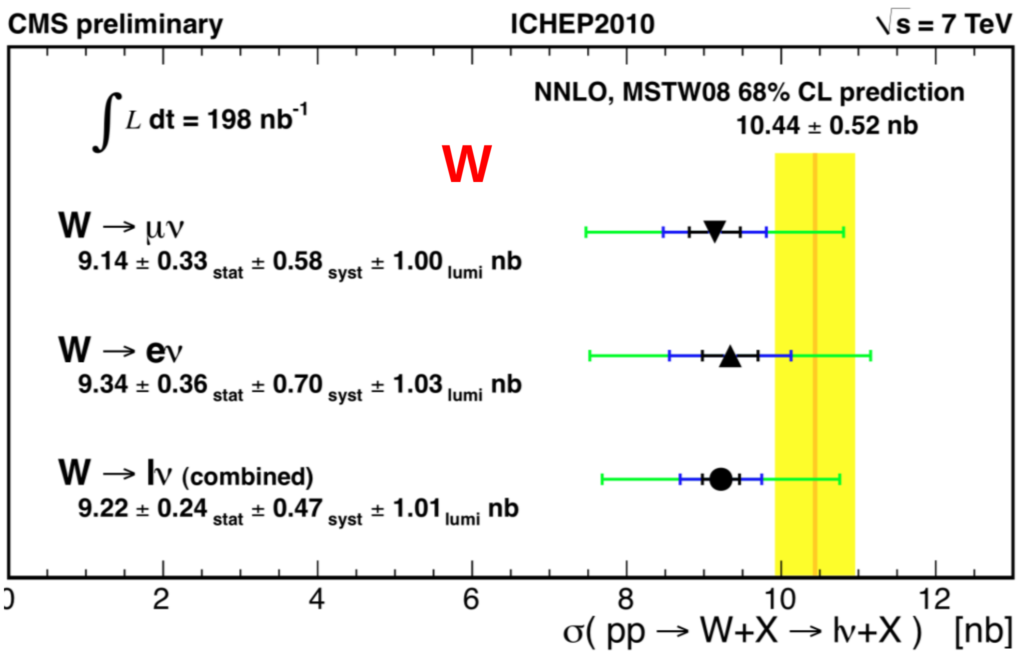


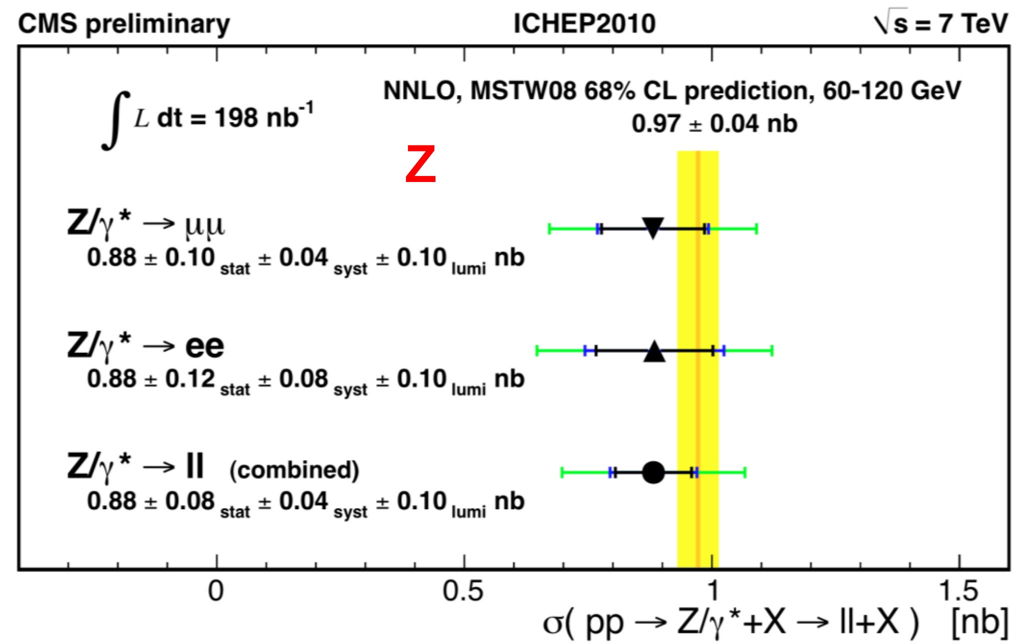
Extraction of the $W^{\pm}$ (Z^{o})→$e^{\pm}\nu$ ($e^{+}e^{-}$) yield signal

Trigger HLT path: $e/\gamma+X$ (E_T > 15 GeV). p_T>20GeV; 0<|□|<1.4; 1.566<|□|<2.5. Electron identification: ECAL clusters are required to match a track + requirements on shower shape variables in ECAL, HCAL.
Tight algorithm (75% efficiency) is used for W while a looser algorithm (90% efficiency) is used for the Z.
Yield of W bosons determined using simultaneous fits to background and signal contributions.QCD backgrour shapes obtained using data, electroweak background and signal shapes from Monte Carlo simulation

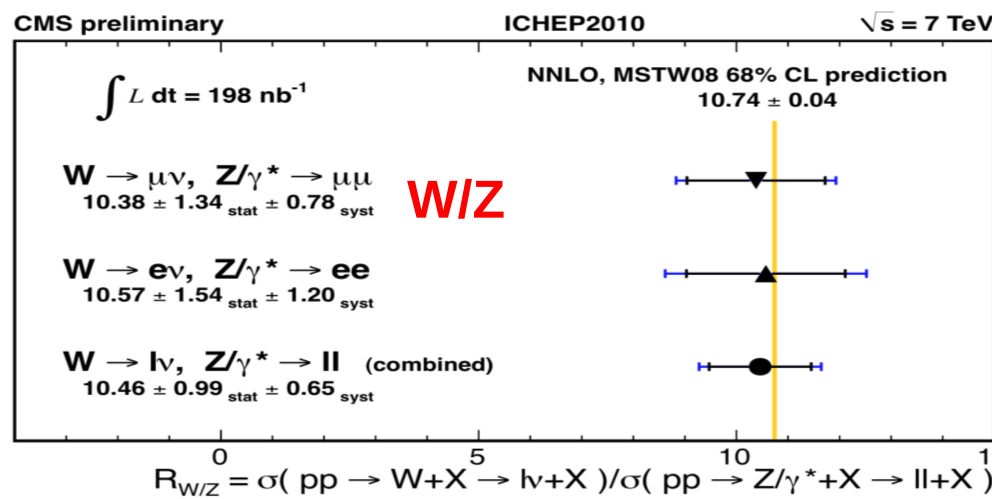


Results

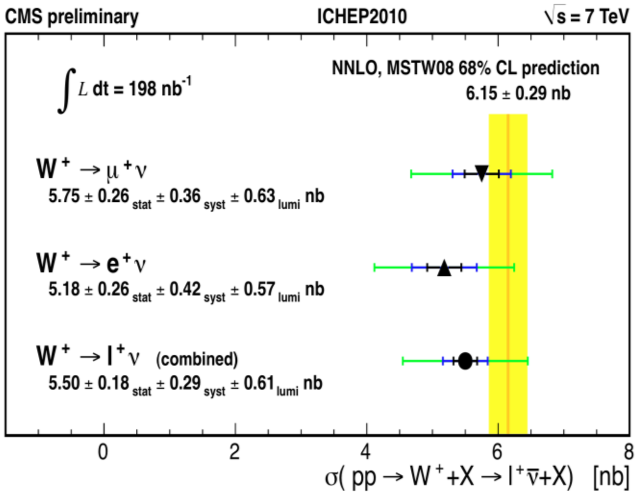


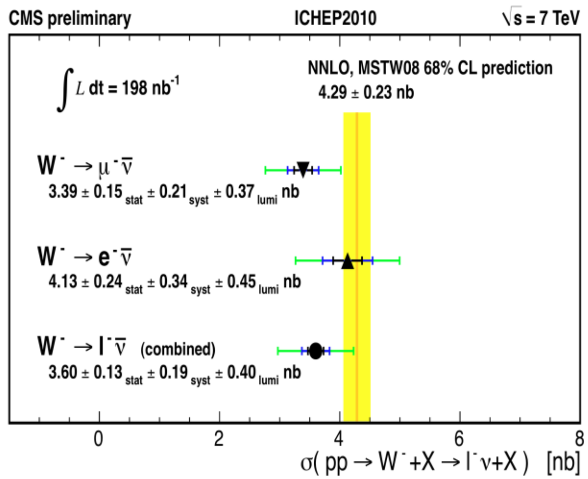


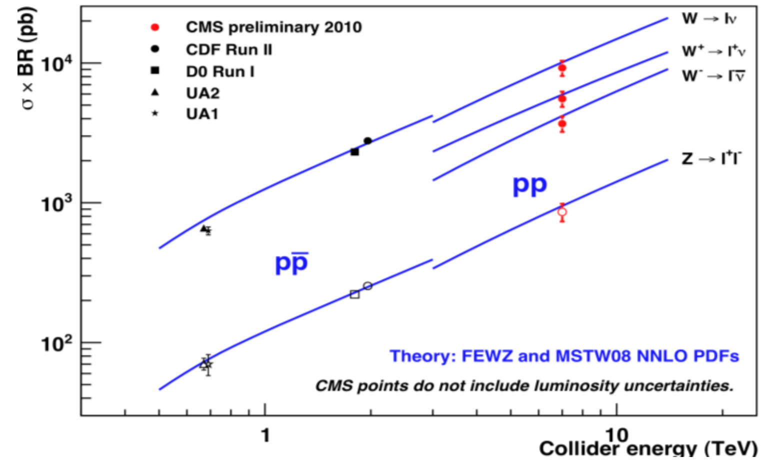
Notice: ~all major components of the measurements (efficiency, background, systematic errors etc) are carefully evaluated using data driven methods.

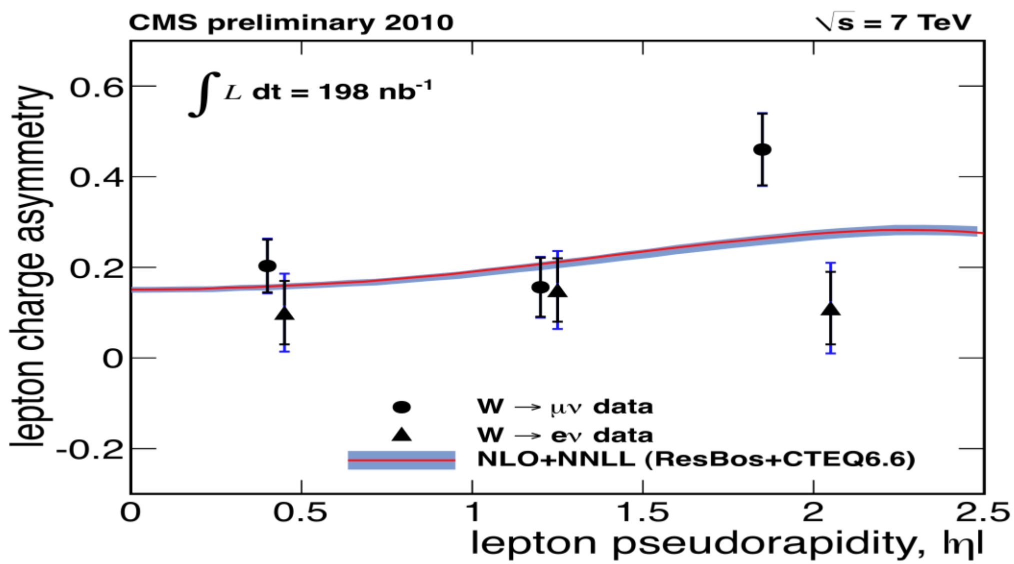


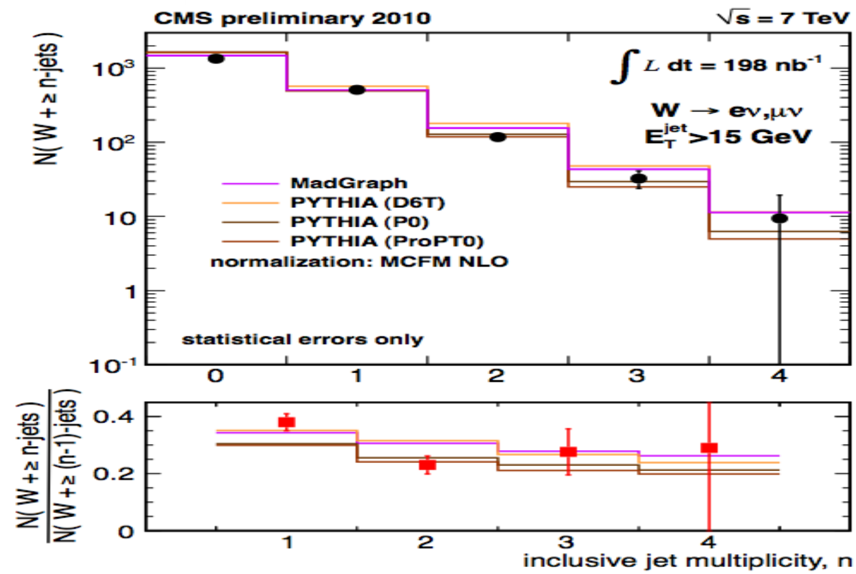
W+,W-, charge asymmetry and W+jets











and then we deploy everything for hunting the top

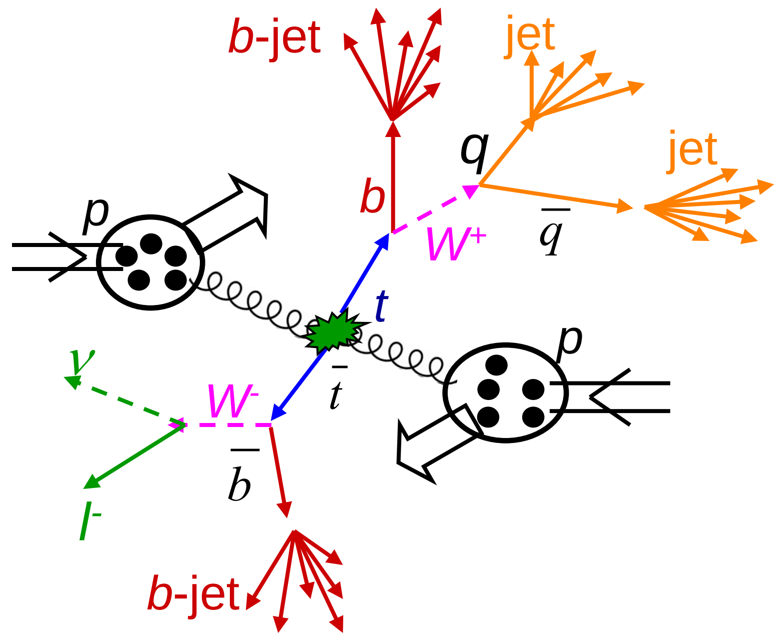
Lepton+Jets loose selection

- Triggers: μ+X (p_T > 9 GeV/c) or e/γ+X (E_T > 15 GeV)
  - Ask for exactly 1 prompt, isolated electron (muon) of good quality

Detected energy around the lepton

$$\text{Rel.isol.} = \frac{\overbrace{\sum_{R<0.3} p_T^{\text{track}} + \sum_{R<0.3} p_T^{\text{ECAL}} + \sum_{R<0.3} p_T^{\text{HCAL}}}^{\text{Detected energy around the lepton}}}{p_T(\text{lepton})}$$

- Rel.isol. < 10%(e), 5%(μ) due to larger backgrounds
- p_T(e) > 30 GeV/c, $|\eta_e|$ < 2.4
- $p_T(\mu)$ > 20 GeV/c, $|\eta_\mu|$ < 2.1
- No initial MET cut or b-tagging selection.

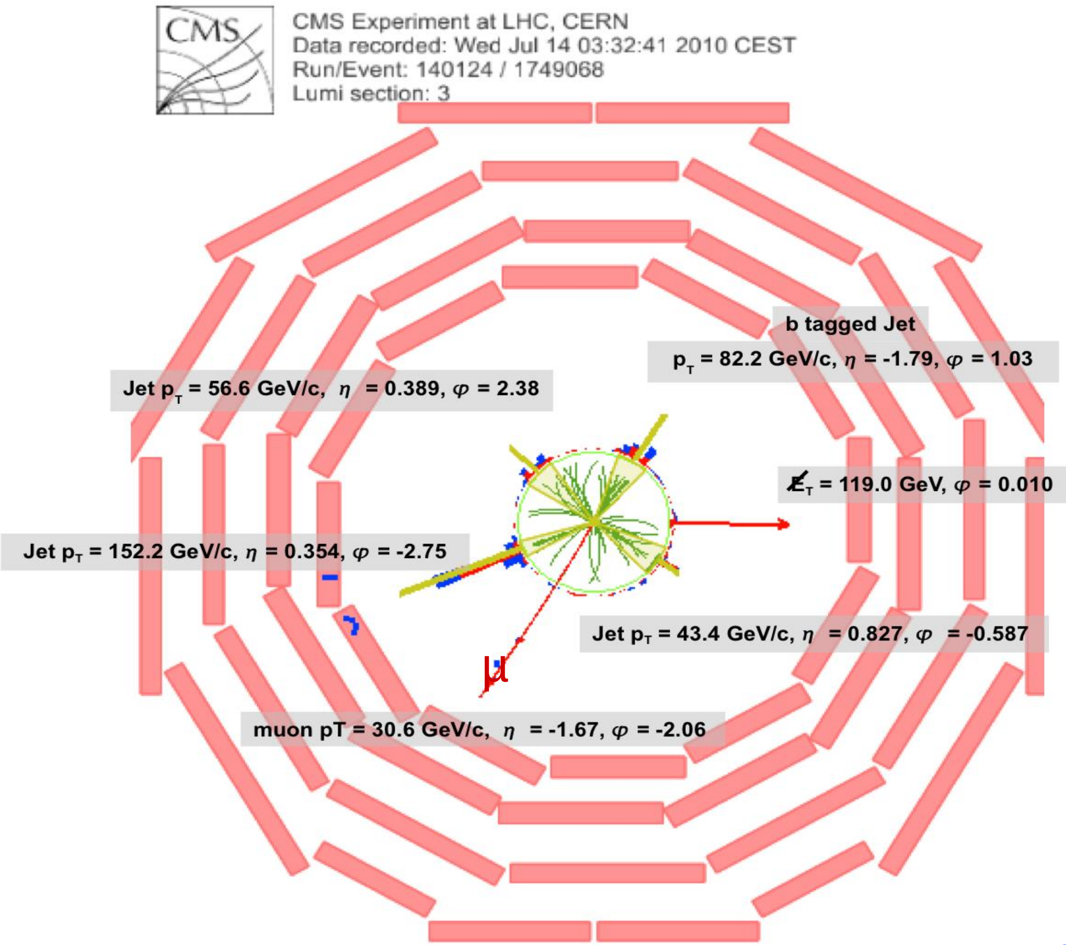


Count additional jets

- anti-k_T jets, R = 0.5
- using calorimeter info
- $|\eta|$ < 2.4, p_T > 30 GeV/c

≥ 4 jets is typical for ttbar

μ+Jets candidate event on July 14



Event passes all cuts of full selection

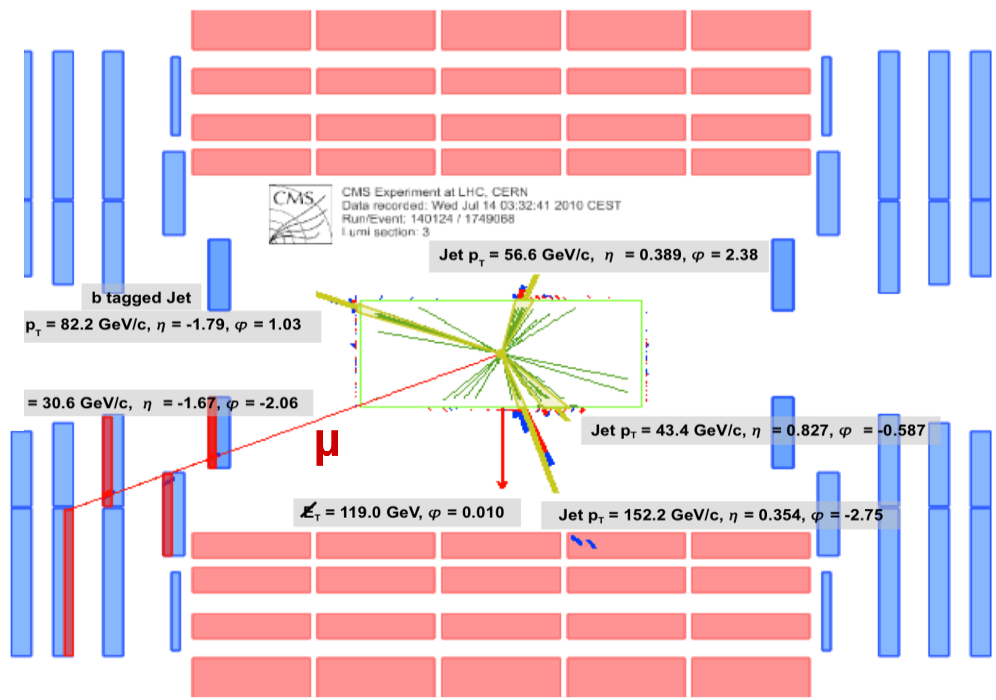
1 high-momentum muon

significant MET > 100

$m_T(W)$ = 104 GeV/c^2

4 high-p_T jets,

one of which with good *b*-tag



reconst. top mass around 210 GeV/c^2

masses of 2 untagged jets (3 possible comb.): 104, 105, 151 GeV/c^2

e+Jets candidate event on July 18

Event passes all cuts:

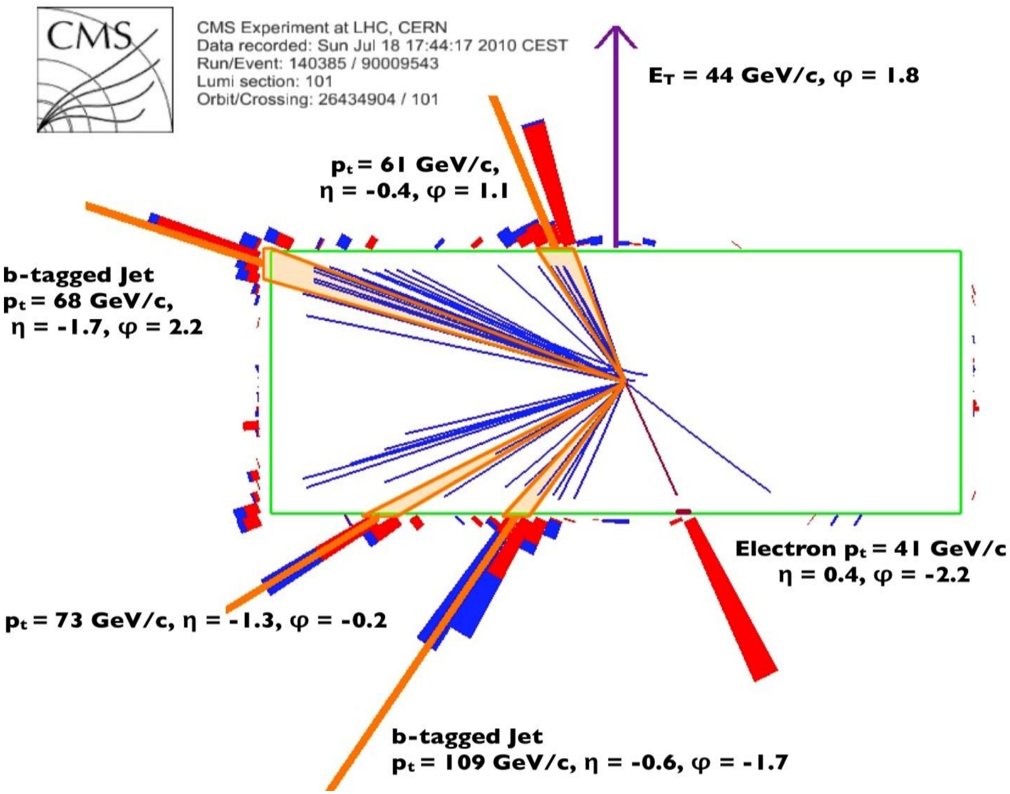
1 high-momentum electron

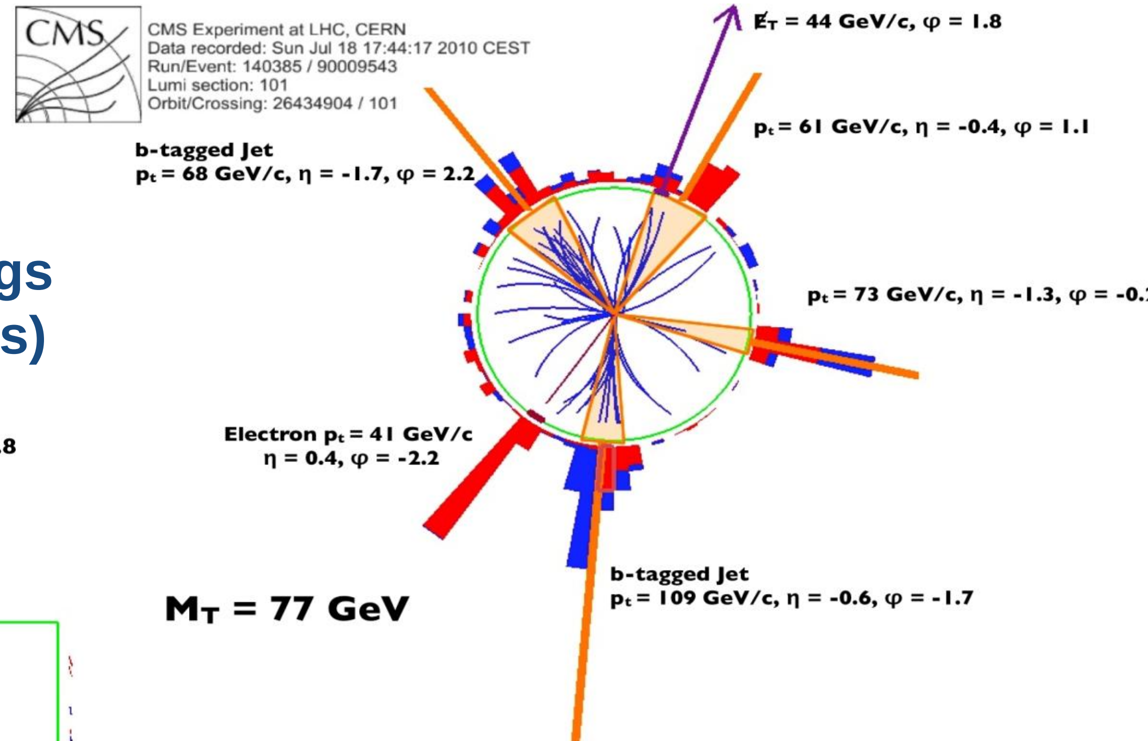
significant MET ≈ 44 GeV

4 high-p_T jets,

two of which with good/clear *b*-tags

(with reconstructed 2ndary vertices)





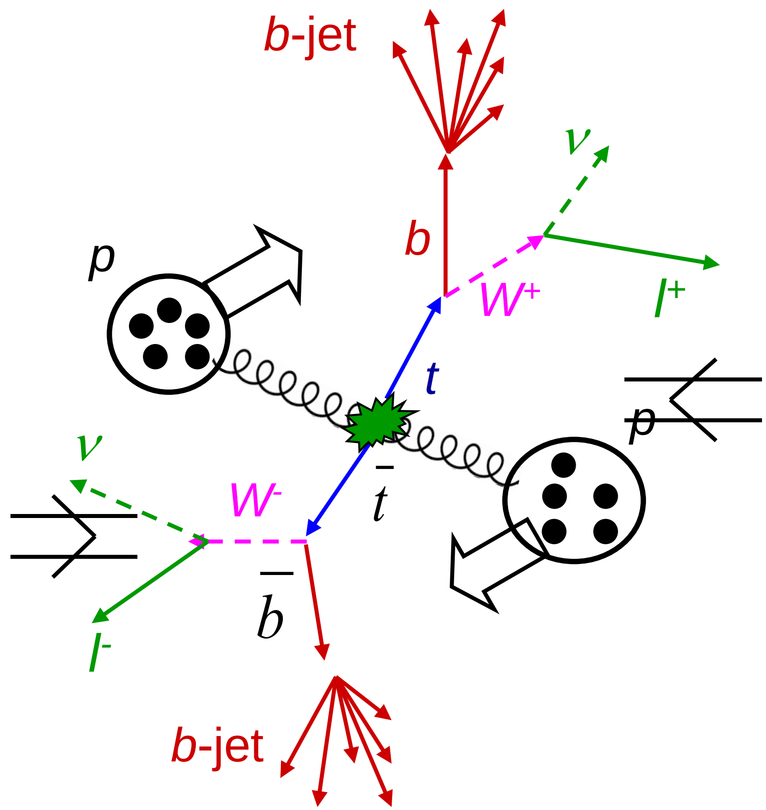
m_T(W) ≈ 77 GeV/c^2

Mass of 2 untagged jets ≈ 102 GeV/c^2

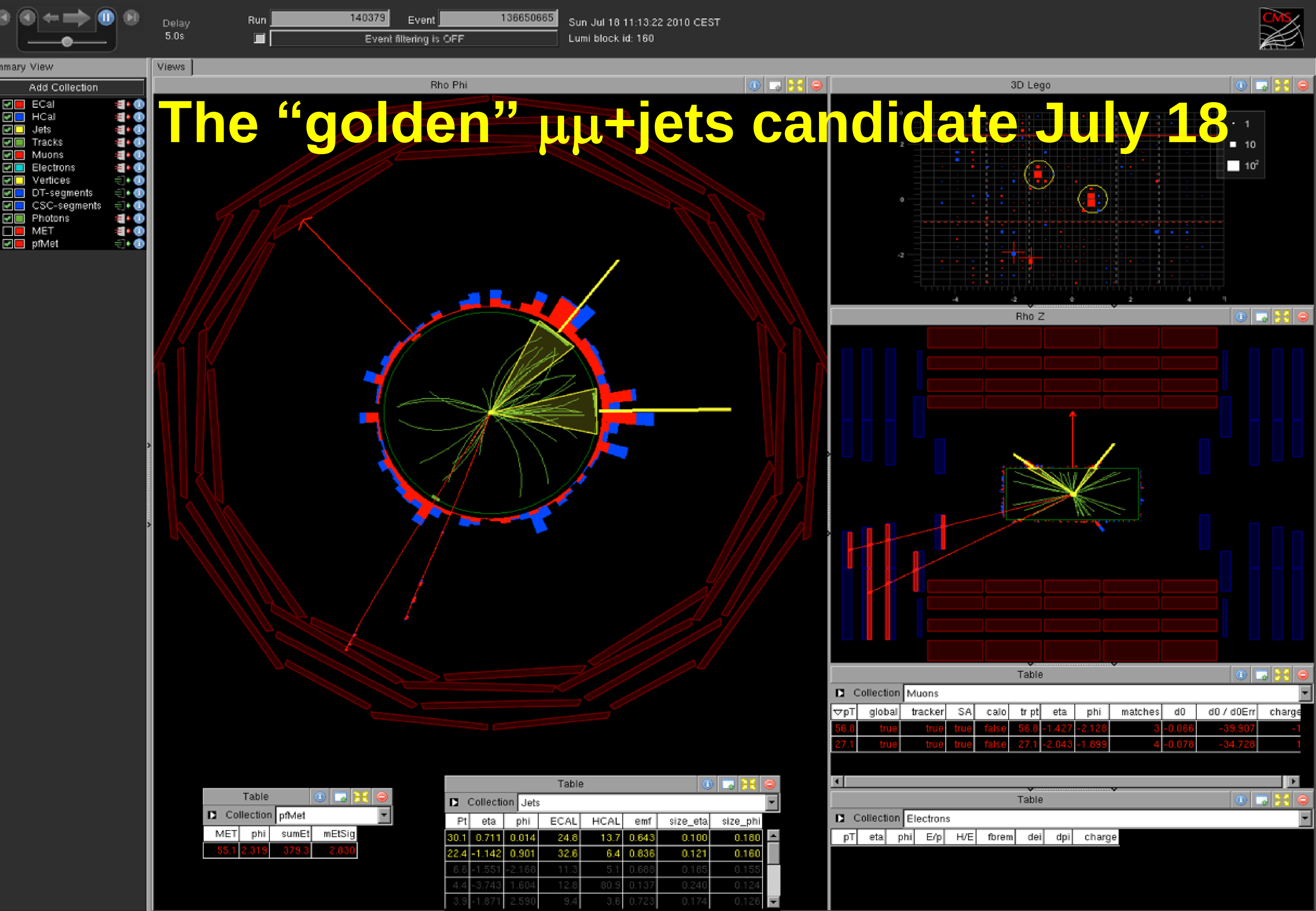
m(jjj) ≈ 208, 232 GeV/c^2
(for the two 3-jet combinations)

Dileptonic channels: *ee*, *μμ*, *eμ* + *X*

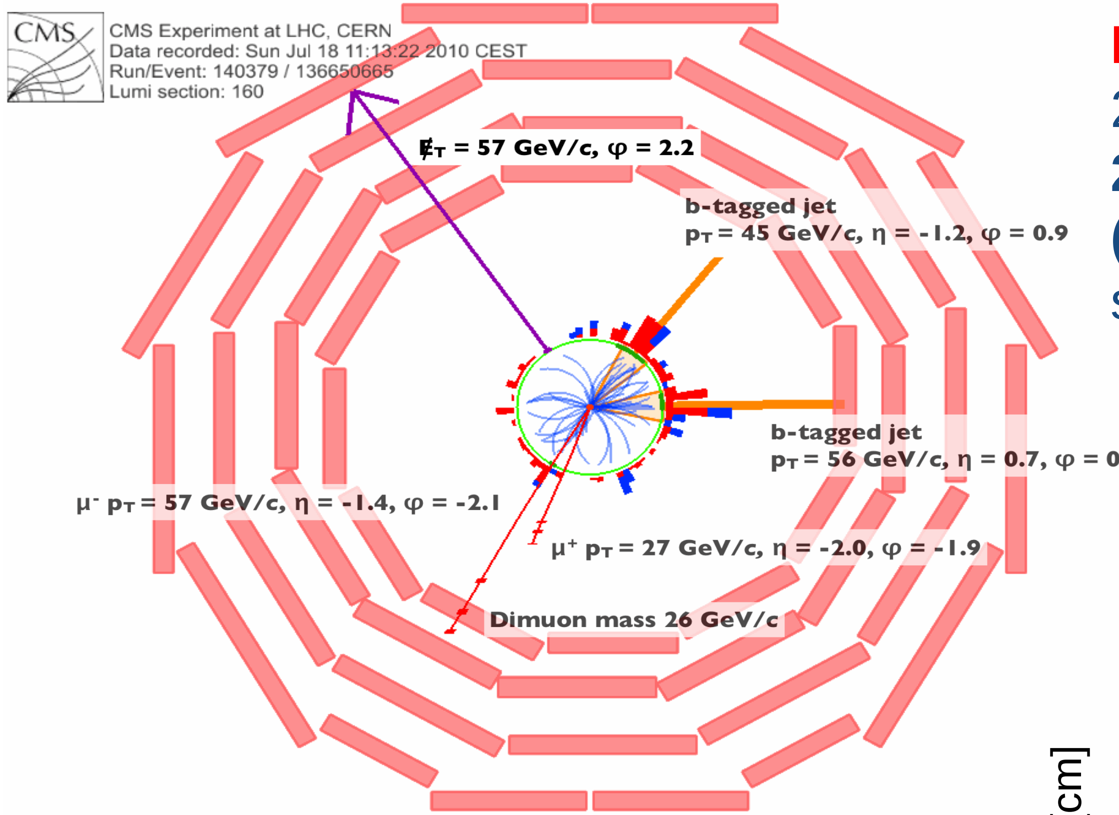
- Triggers: μ+X (p_T > 9 GeV/c) or e/γ+X (E_T > 15 GeV)
- 2 isolated, prompt, oppositely charged leptons (l = e,μ) of good quality
  - p_T(l) > 20 GeV/c
  - $|\eta_\mu| < 2.5$, $|\eta_e| < 2.4$
  - Relative isolation <15%.
- Missing transverse energy (MET)
  - using calorimeter⊕tracking
  - MET > 30 (20) GeV (in $e\mu$+X)
- Z-boson veto:
  - $76 < M_{ee,\mu\mu} < 106$ GeV/c^2
- Count additional jets:
  - anti-k_T jets, R = 0.5
  - using calorimeter⊕tracking info
  - $|\eta| < 2.4$, p_T > 30 GeV/c
  - ≥ 2 jets typical for ttbar



The “golden” μμ+jets candidate July 18



μμ +Jets Candidate Event



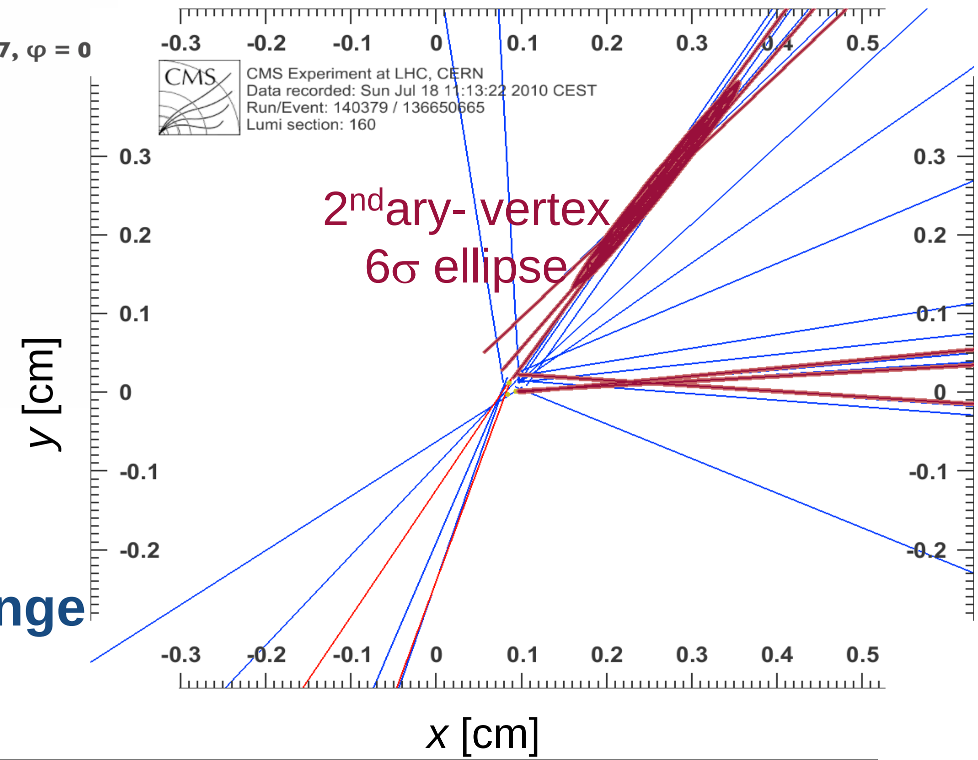
m(μμ) = 26 GeV/c^2

Event passes all cuts of full selection:

2 muons with opposite charge

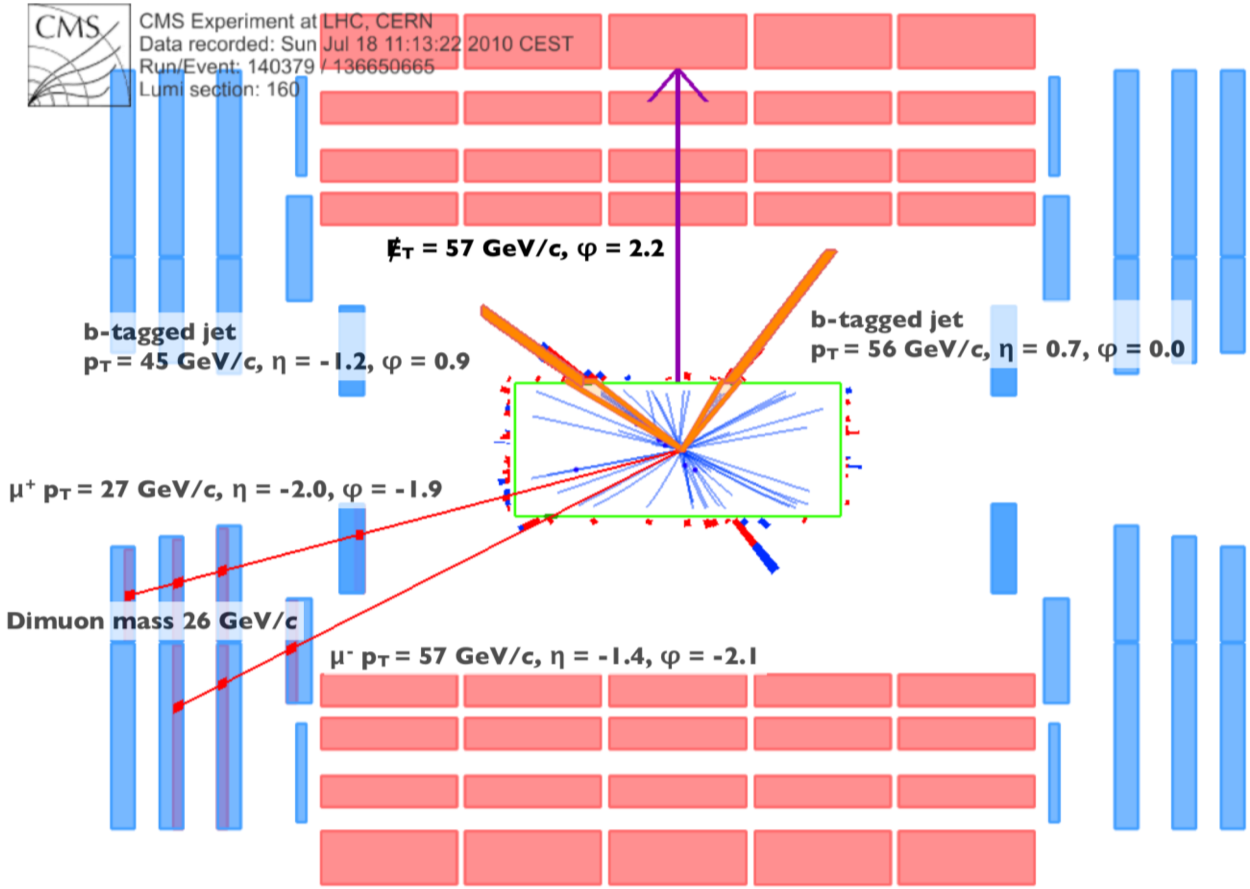
2 jets, both w/ good/clear *b*-tags (and secondary vertices!)

significant MET (>50 GeV)



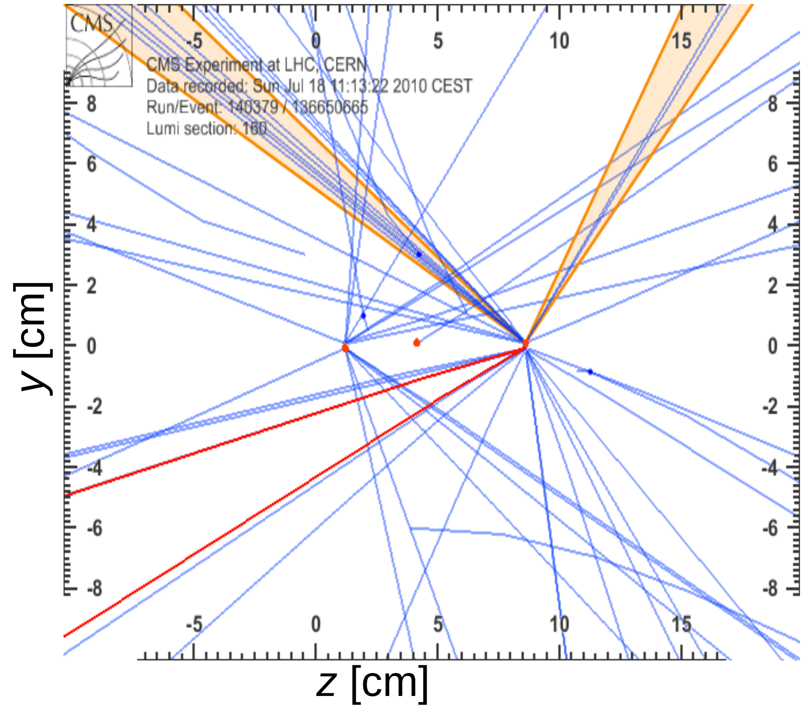
Preliminarily reconstr. mass is in the range 160–220 GeV/c^2 (consistent with m_{top})

μμ +Jets Candidate … cont'd



Multiple primary vertices → multiple *pp* collisions ("pile-up")

Jets & muons originate from same primary vertex

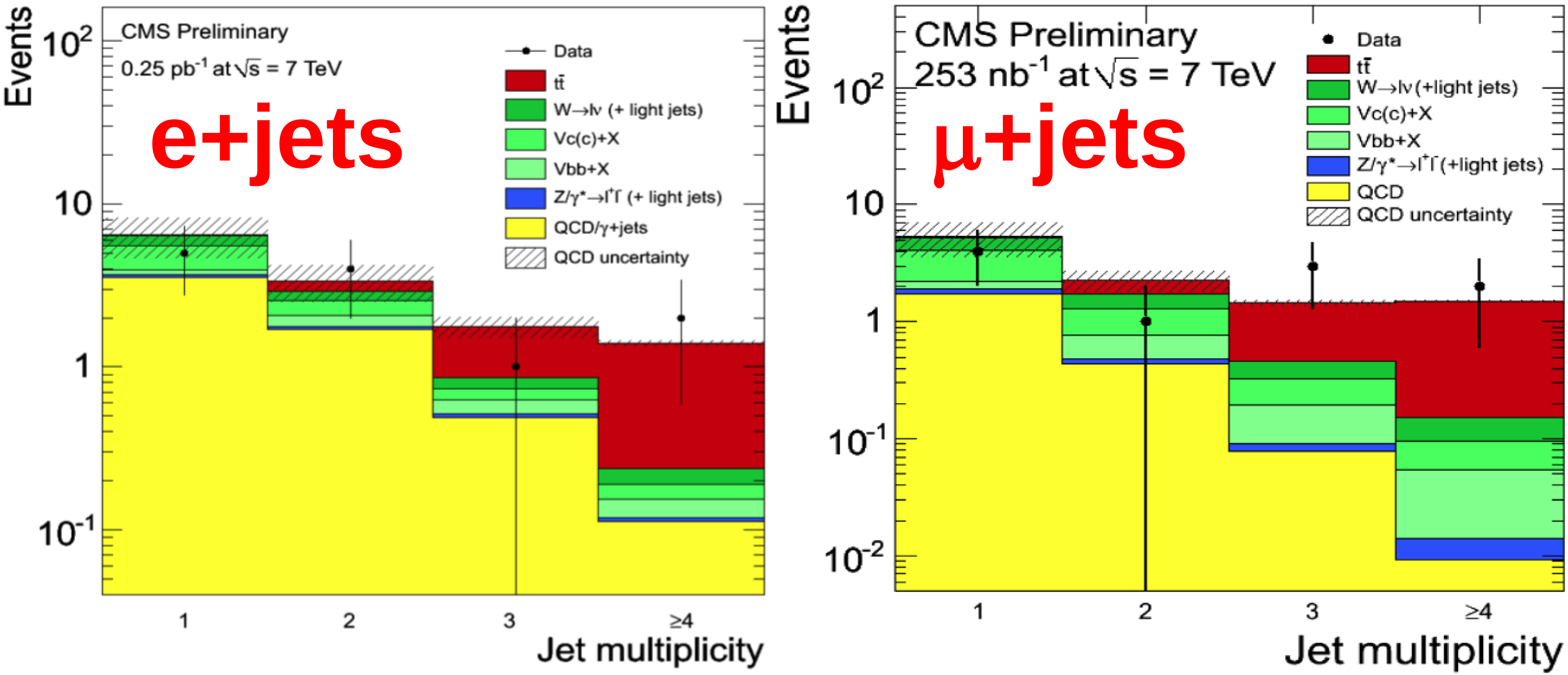


Very clean candidate sitting in a region where we expect very little background!

Where are we today?

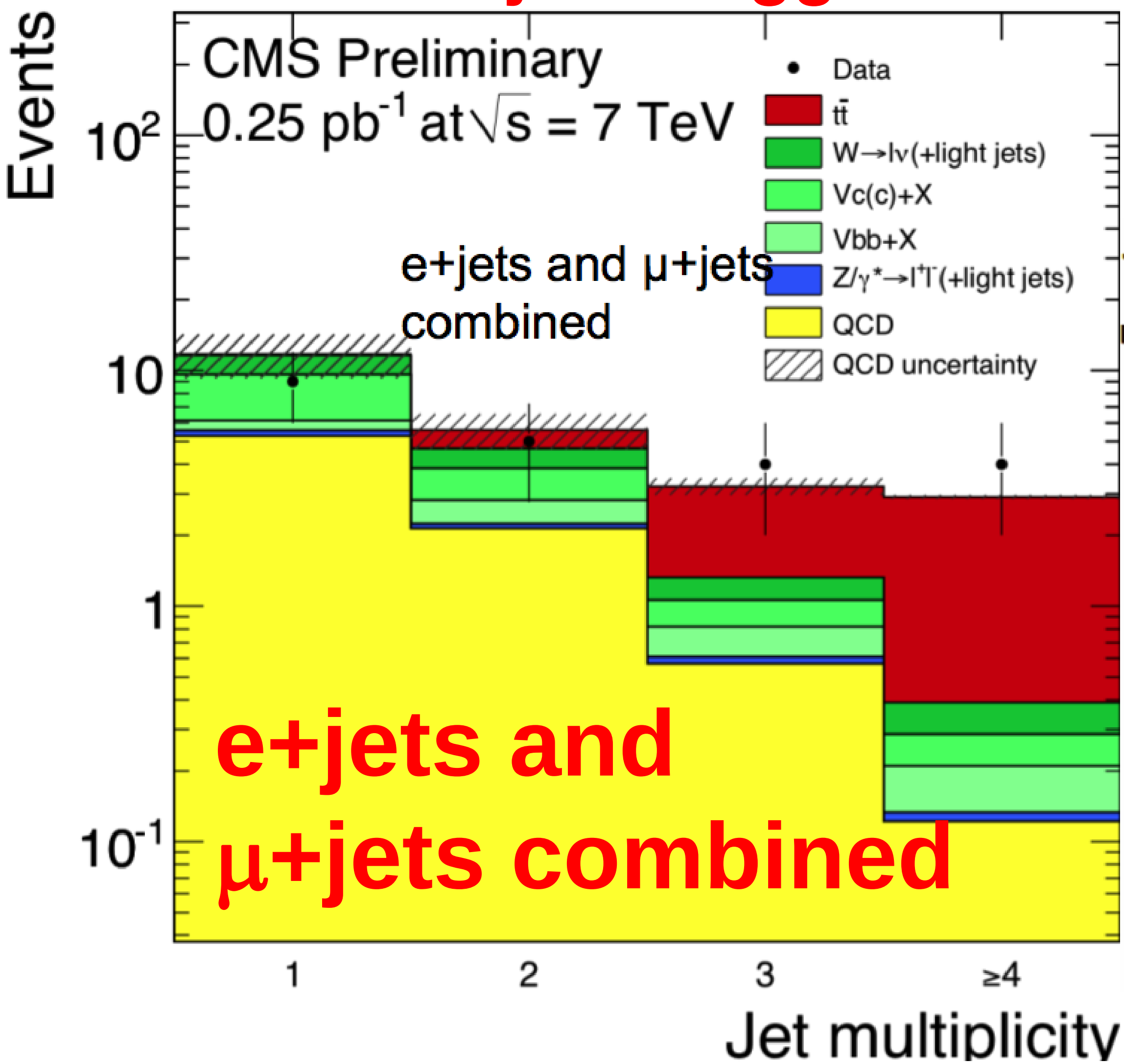
Going through the full statistics collected so far and **requiring at least 1 jet b-tagged** (simple secondary vertex tagger with ≥2 tracks)

WARNING: All following plots are“out of the box”, i.e. no syst., no data-driven background estimation, yields from sim. etc etc.

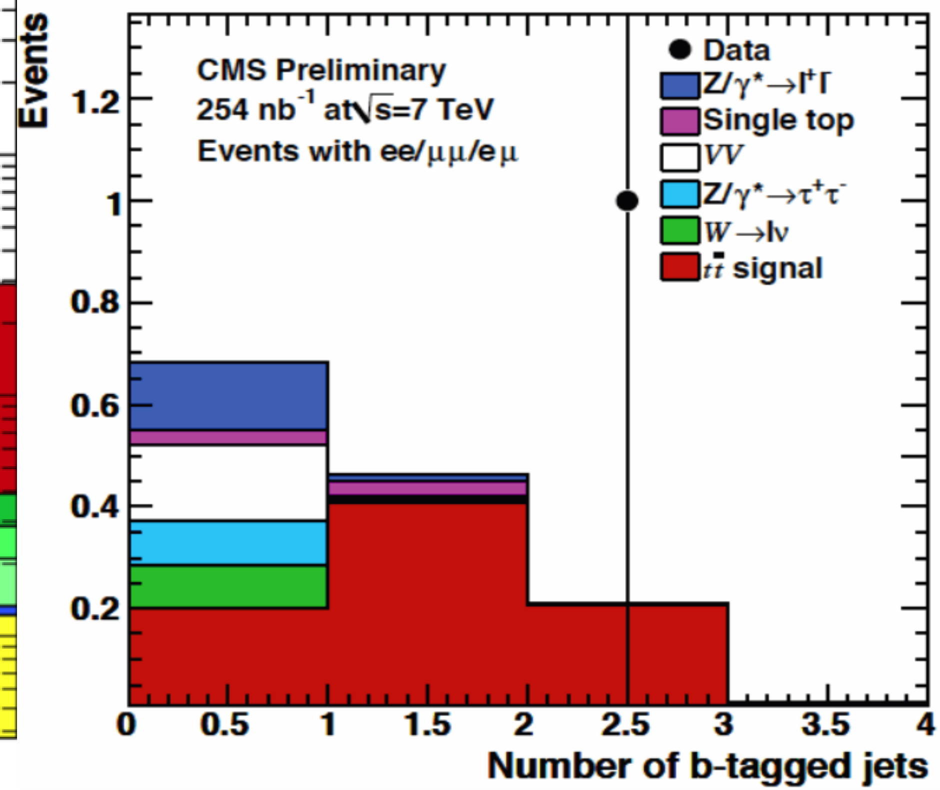


The signal region is getting populated

At least 1jet b-tagged



ee+jets/μe+jets/ μμ+jets



Conclusion

We are at the Top……

…..and it is just the beginning.

Many thanks

to you for the attention,

to the organizing committees for the perfect organization of this ICHEP10,

to the LHC teams for the excellent start-up of the first physics run at 7 TeV,

to the operations team of CMS (P5, online and offline, computing, validation, dqm etc) for having been so focused in taking high quality data up to the last available minute,

to the previous Spokespersons and the whole management at large of CMS

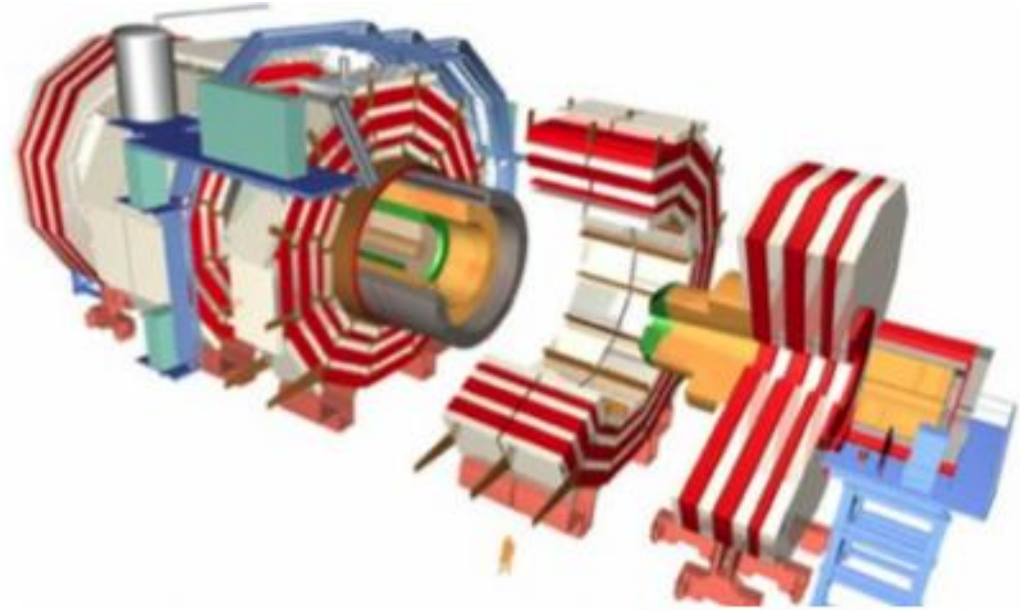
to the thousands of people that participated in the fantastic adventure of designing, building, installing and commissioning the CMS detector and its software and computing infrastructure.

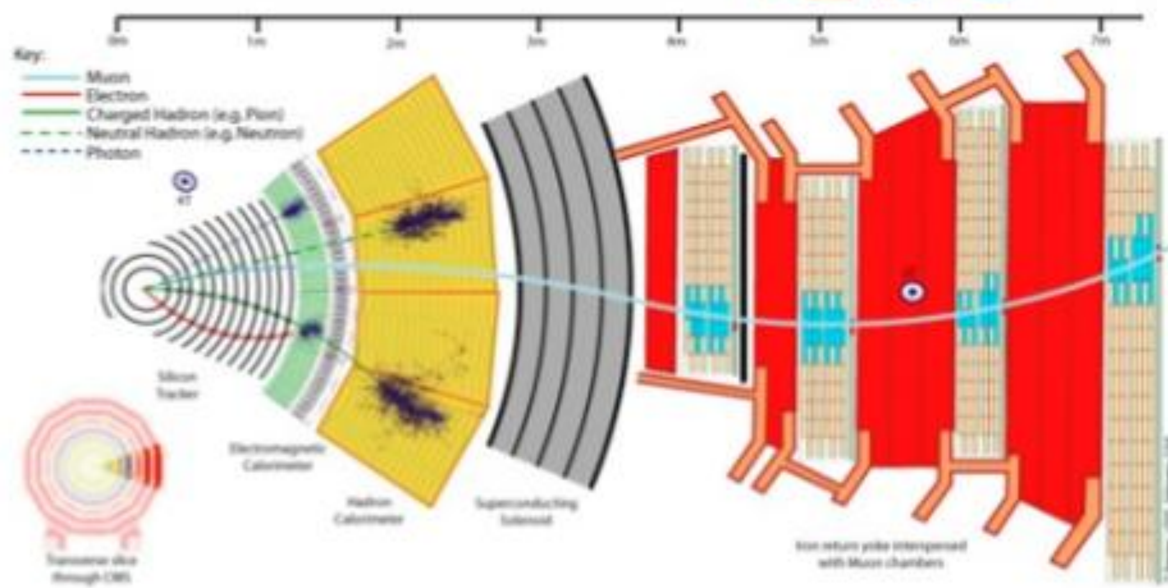
to the hundreds of young (and not so young) colleagues that spent many sleepless nights in the last weeks to produce these results,

Back-up slides

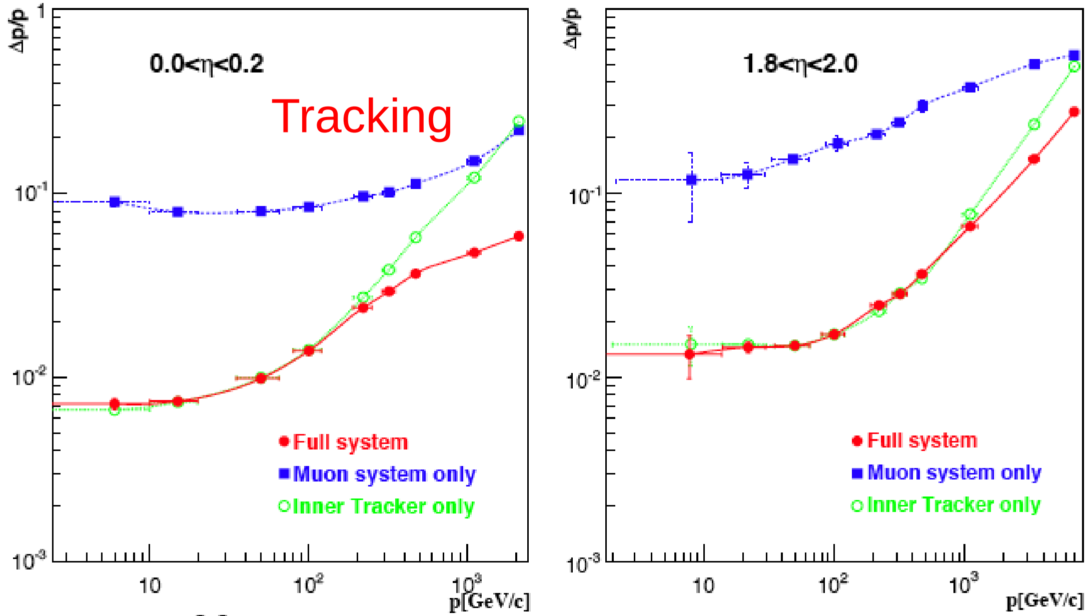
CMS detector

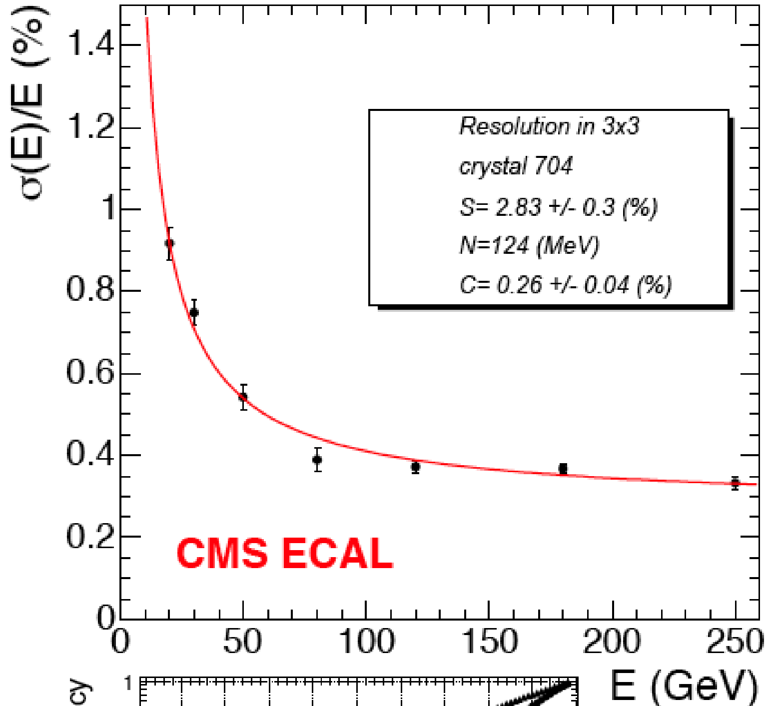
- Tracking, ECAL and HCAL all embedded inside 3.8 T solenoid magnet
- Muon chambers outside magnet, interleaved with iron return yoke
- Precise silicon pixel and silicon strip tracking system at $|\eta| < 2.4$
- Fine-grained (Moliere radius ~2 cm) lead tungstate crystal ECAL at $|\eta| < 3.0$
- Barrel+end cap HCAL coverage up to $|\eta| < 3$, hadronic forward up to $|\eta| < 5$

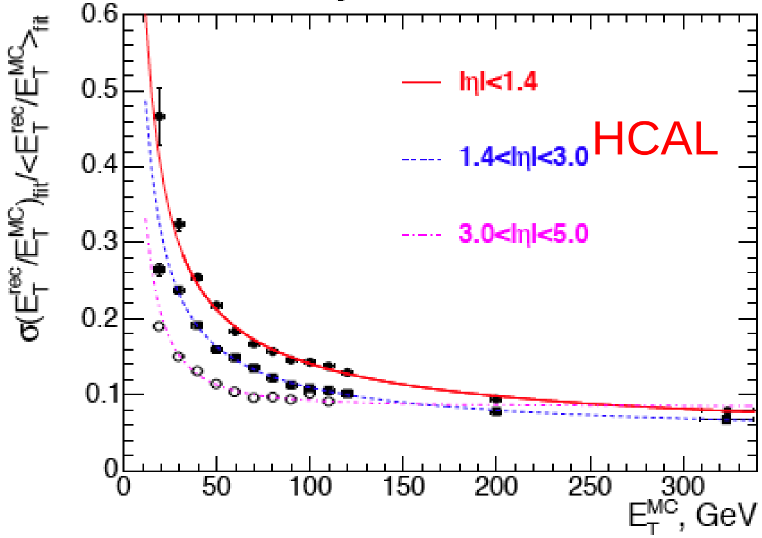


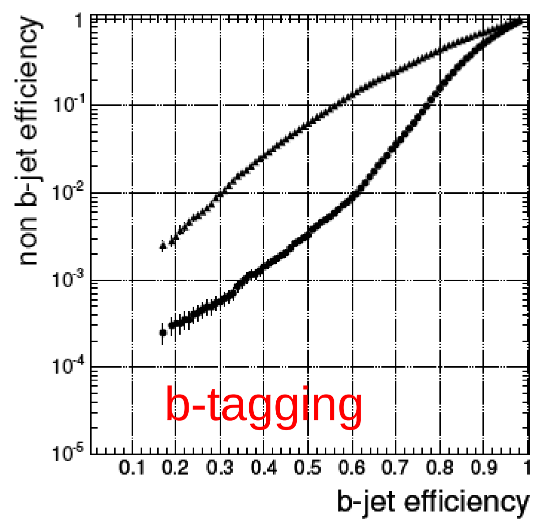


Performance of CMS in a nutshell

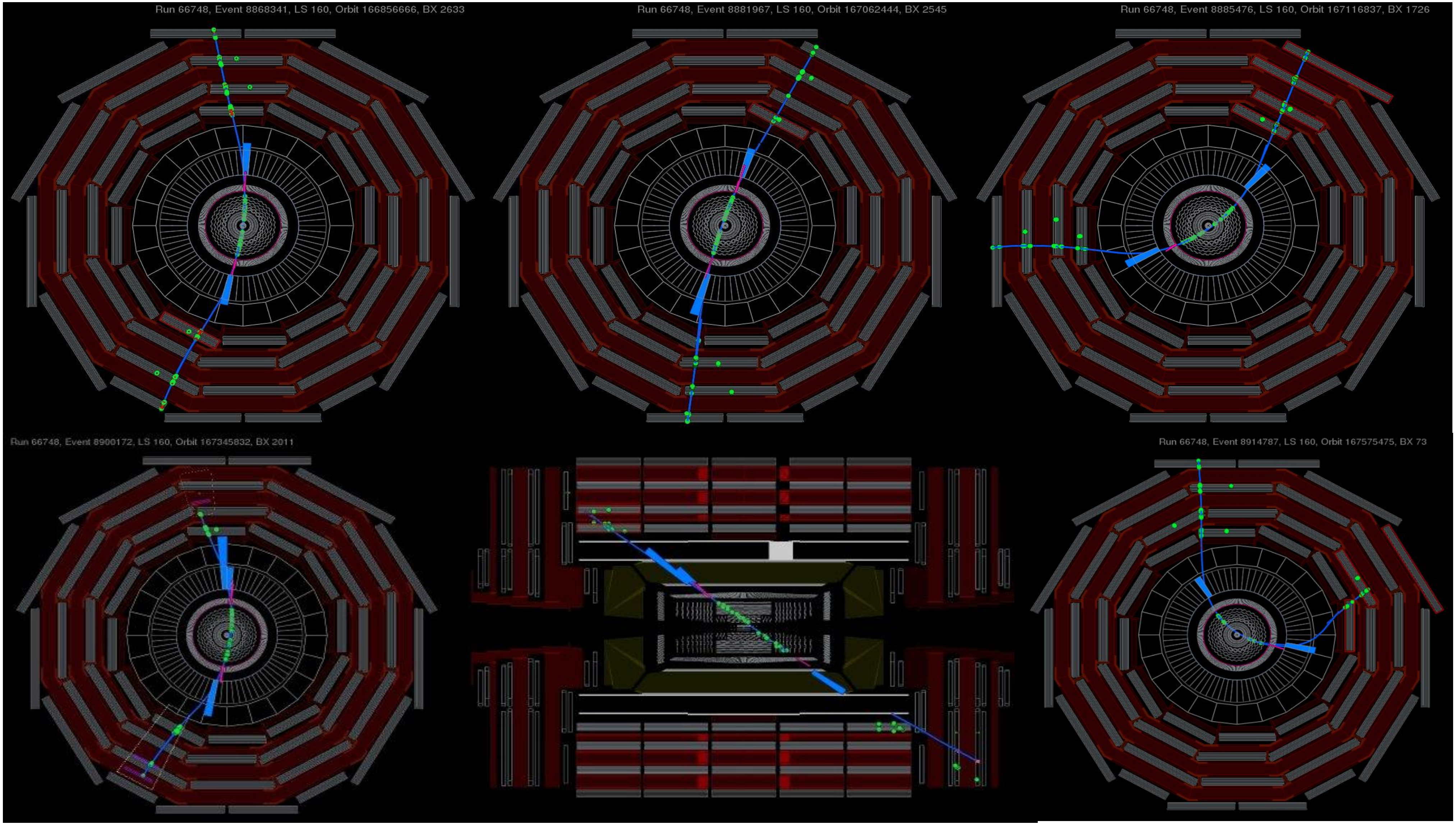




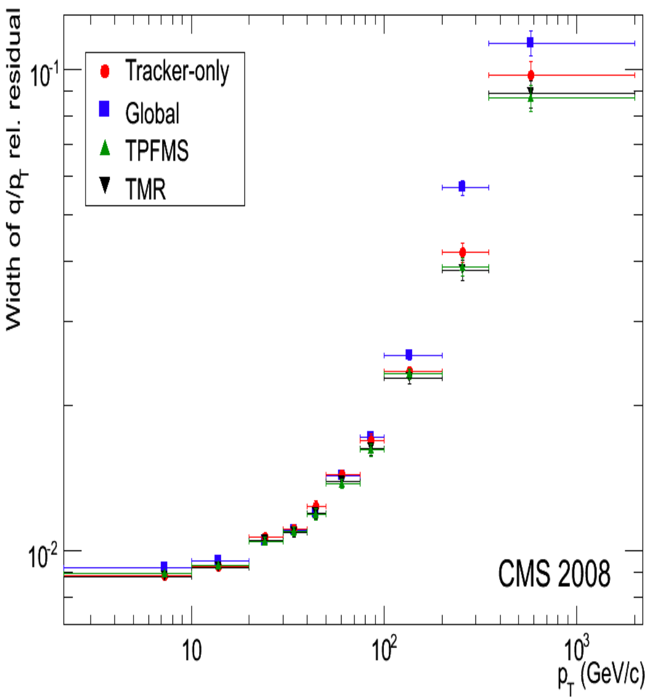




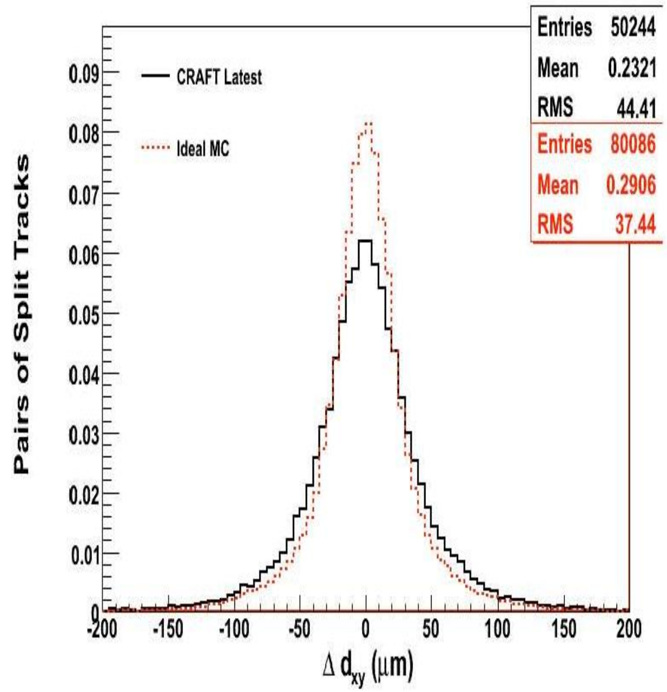
Before collisions >10^9 cosmics recorded



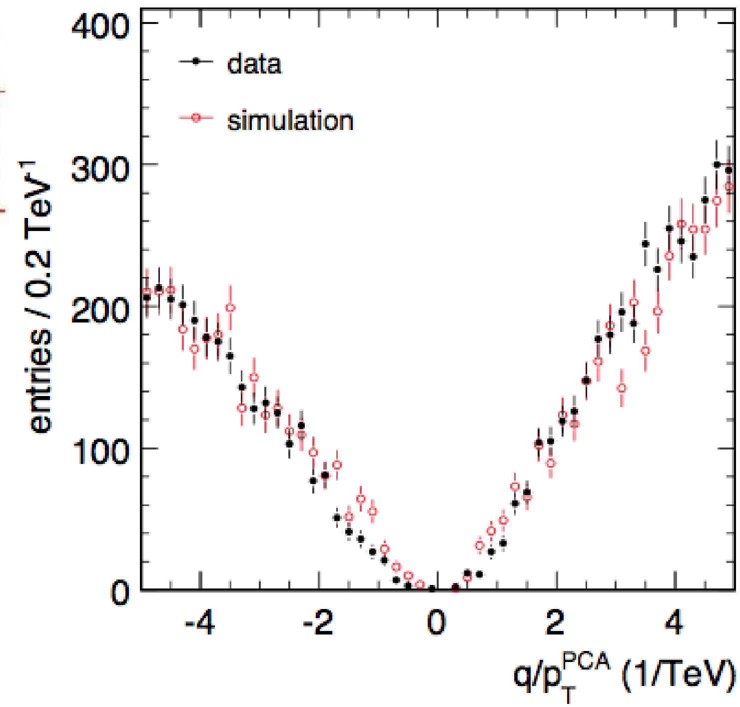
Detailed understanding of detector performance



Momentum resolution vs p_T with 2-leg muons.



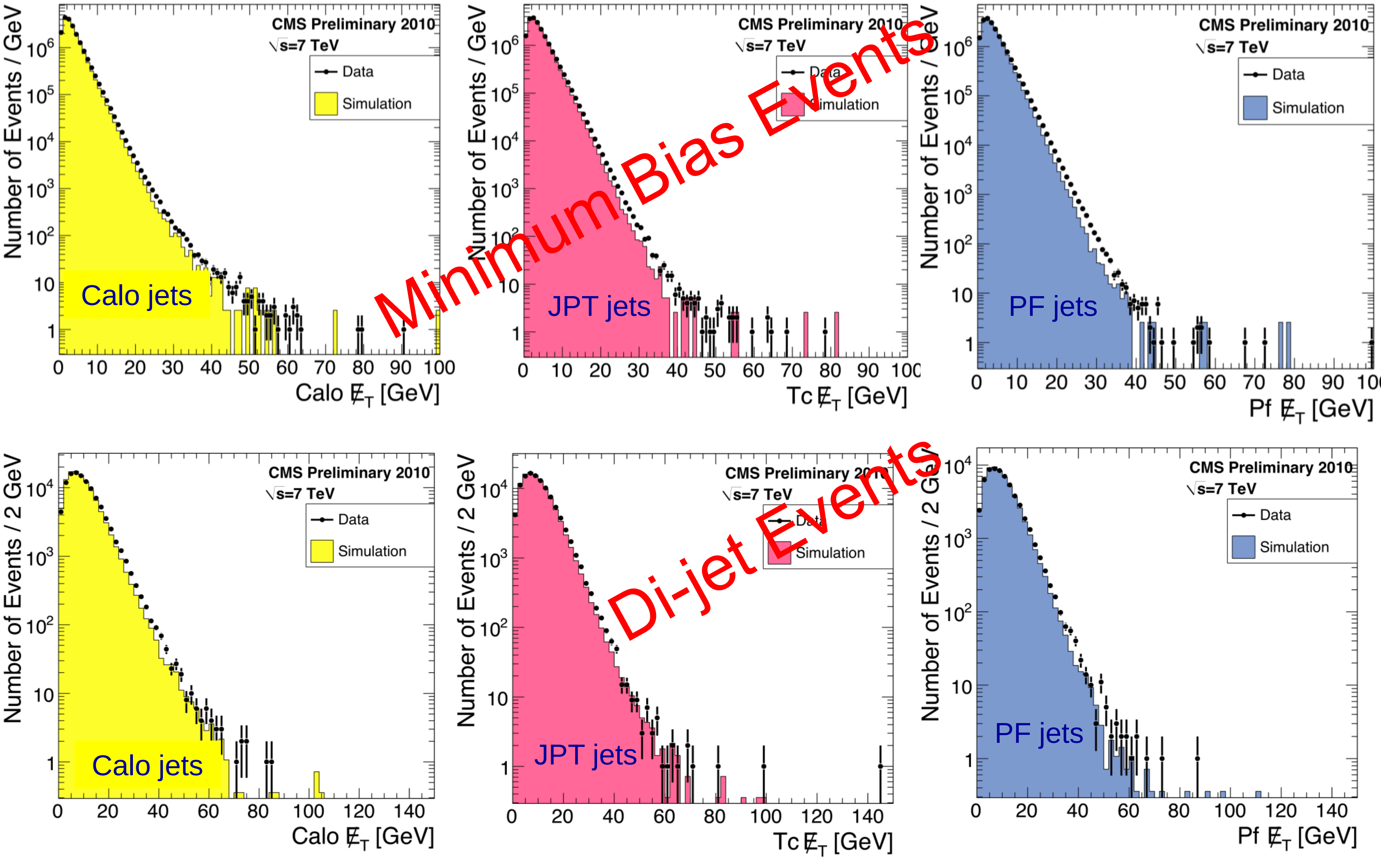
Distance of minimal approach with split tracks.



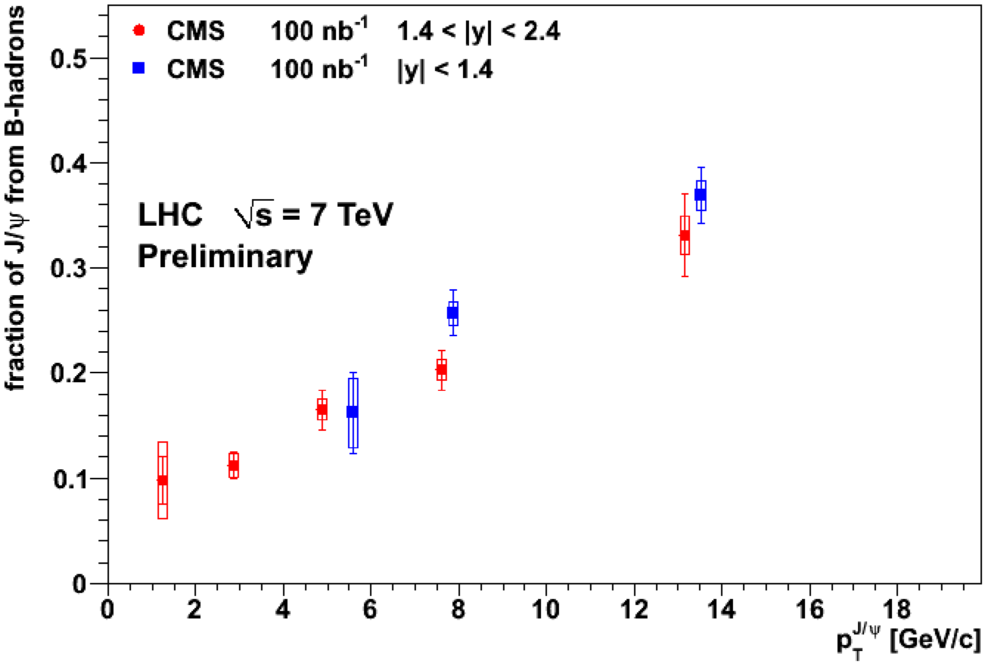
Excellent control of the momentum scale.

Good understanding of alignment and magnetic field; good description of the detector. Most of the tracker aligned at what was expected after $10pb^{-1}$ of collision data. Performance not too far from ideal.

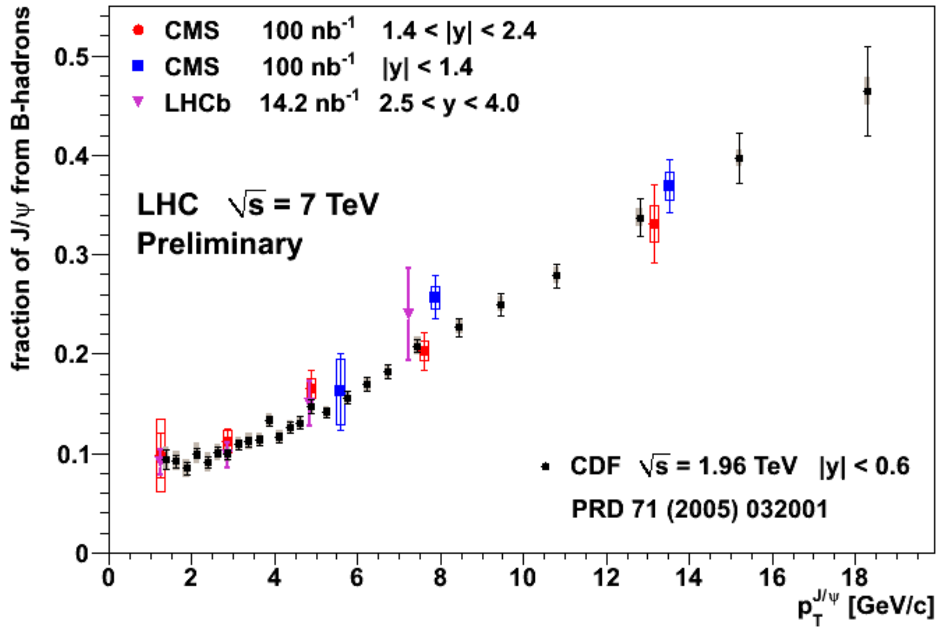
Missing Transverse Energy



Fraction of J/ψ from B hadron vs p_T



CMS data

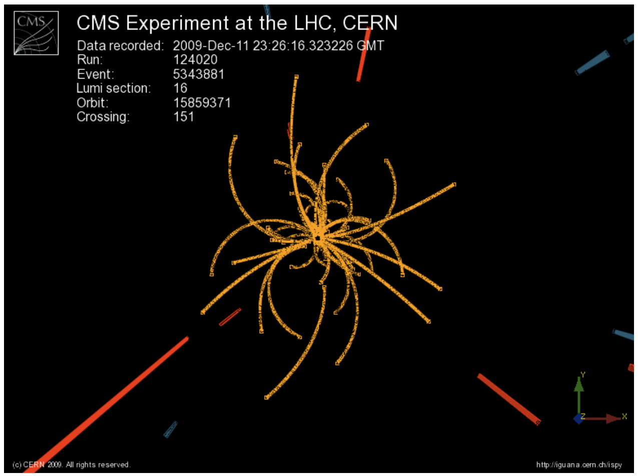


LHC and CDF data

Anomalous Signals in Calorimeters

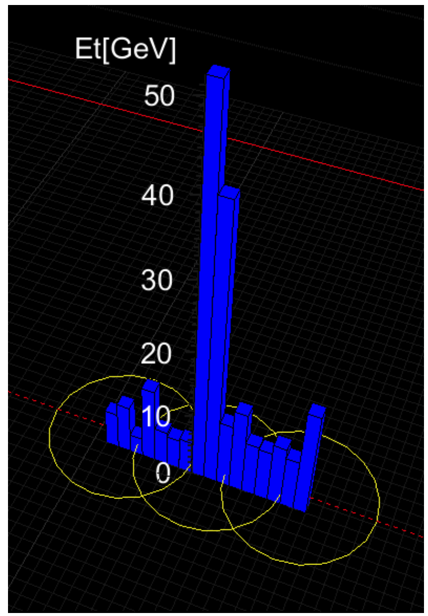
In collision data we observe some anomalous signals in ECAL and HCAL
Now reproduced in simulation.

ECAL



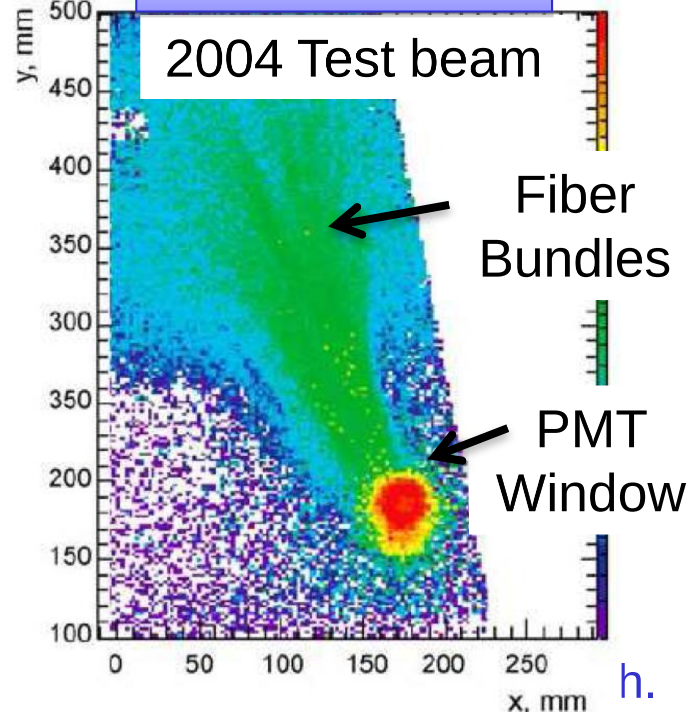
- Appear mostly in a single crystal
- In time with collisions but with wider time-spread (also occur in cosmics at a much lower rate)
- Caused mostly by deposits in APDs by highly ionising secondary particles.

HCAL: HB,HE



- Appear in 1-72 channels
- Random, low rate,
~ 10-20 Hz (E>20 GeV)
- Caused by ion feedback, noise & discharges in HPDs

HCAL: HF



h.

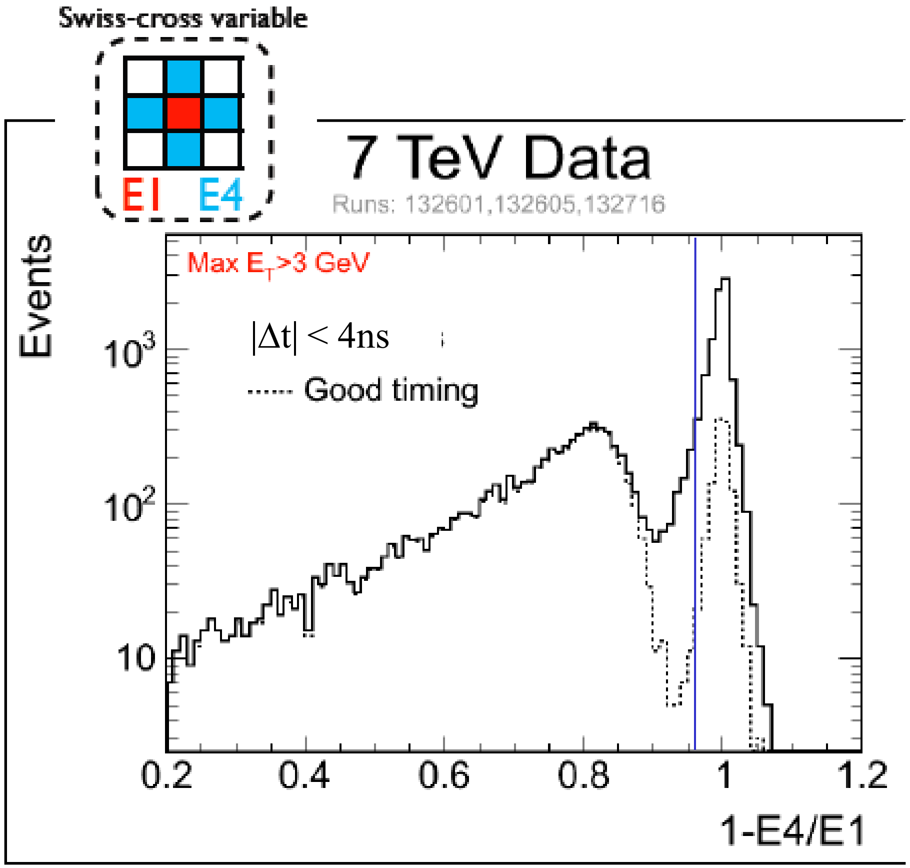
- In time with collisions
- Caused by C^{v} light by particles going through PMT glass

Identification of EB Anomalous Deposits

Tagging by topology:

At the cluster level the anomalous deposits tend to be in a single isolated crystal, while for good deposits energy is typically shared between neighbouring crystals.

Flag: k_{weird}

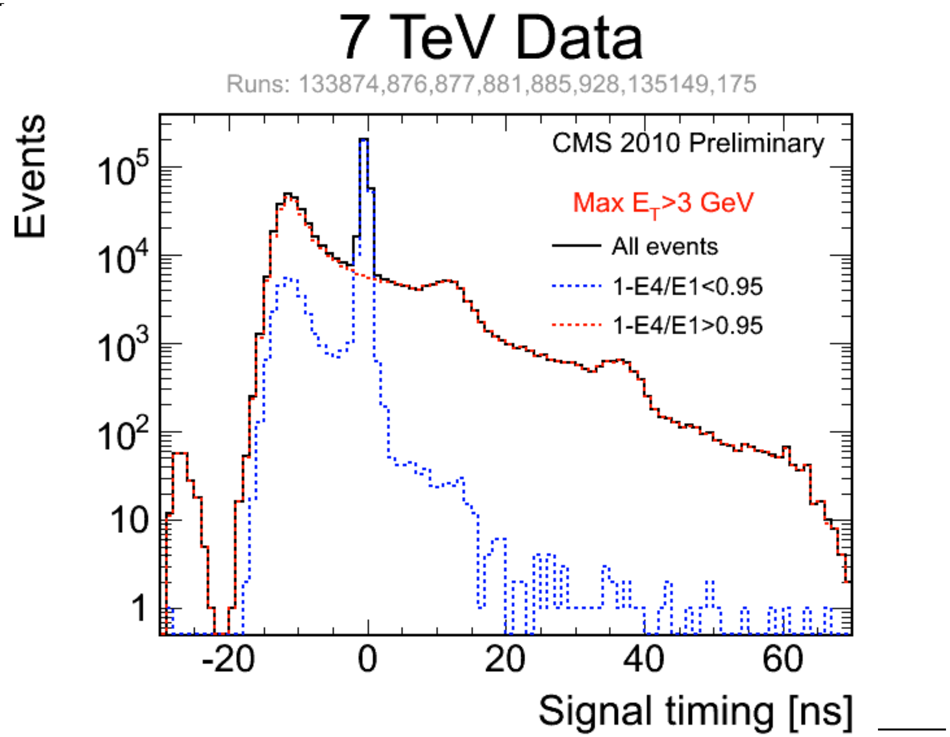


Tagging using timing:.

1) The anomalous signals tend to be out of time and have a much wider spread around the good timing.

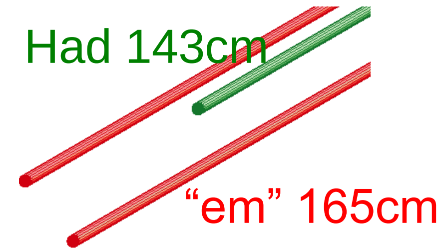
2) The anomalous signal's rise time is faster

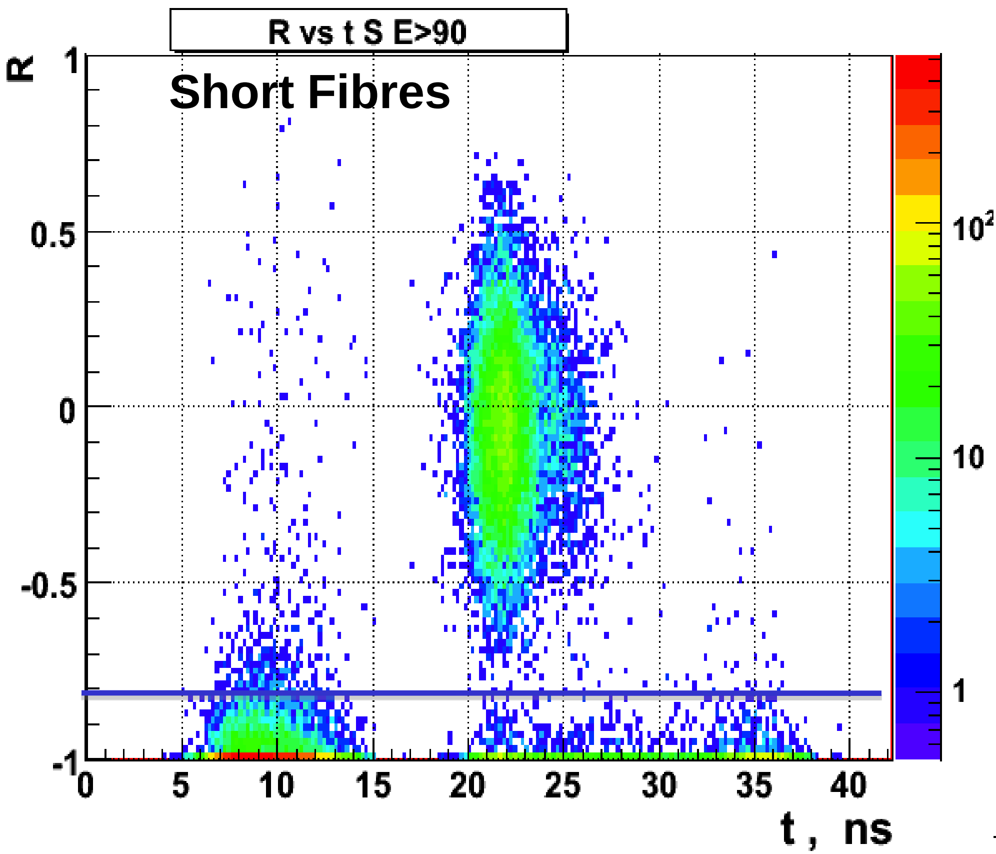
Flags: $k_{out\ of\ time}$, χ^2

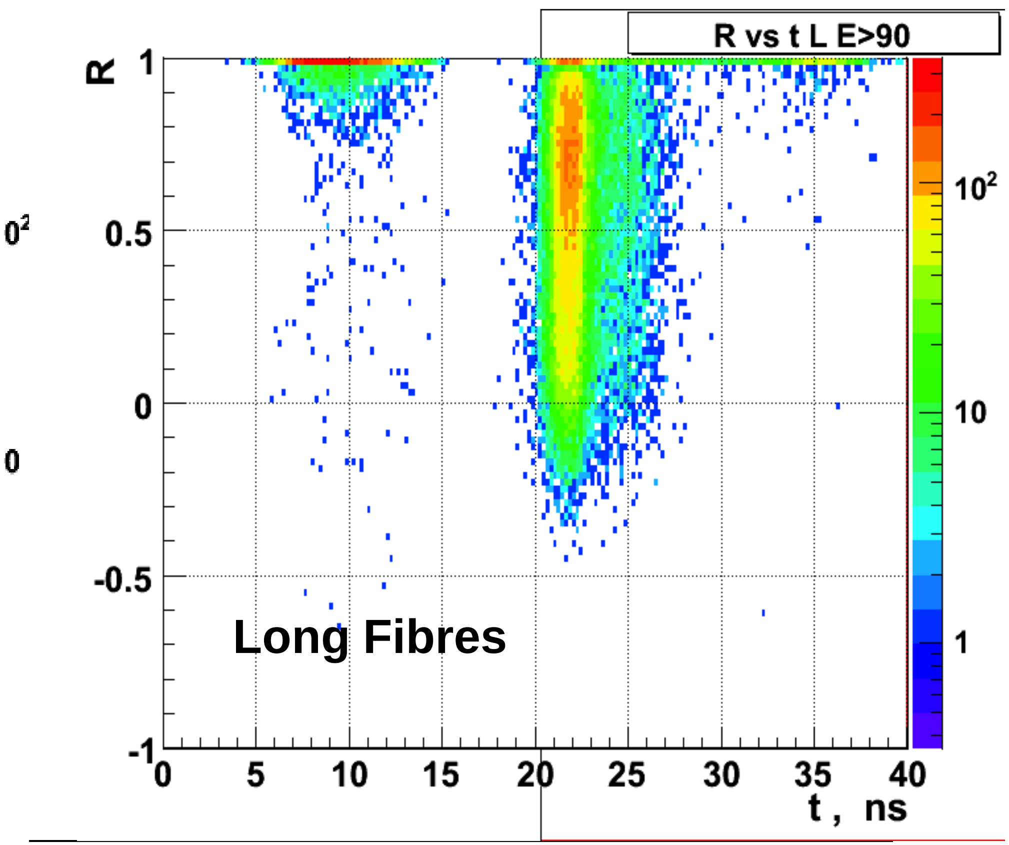


HF: Topological Criterion v/s Timing

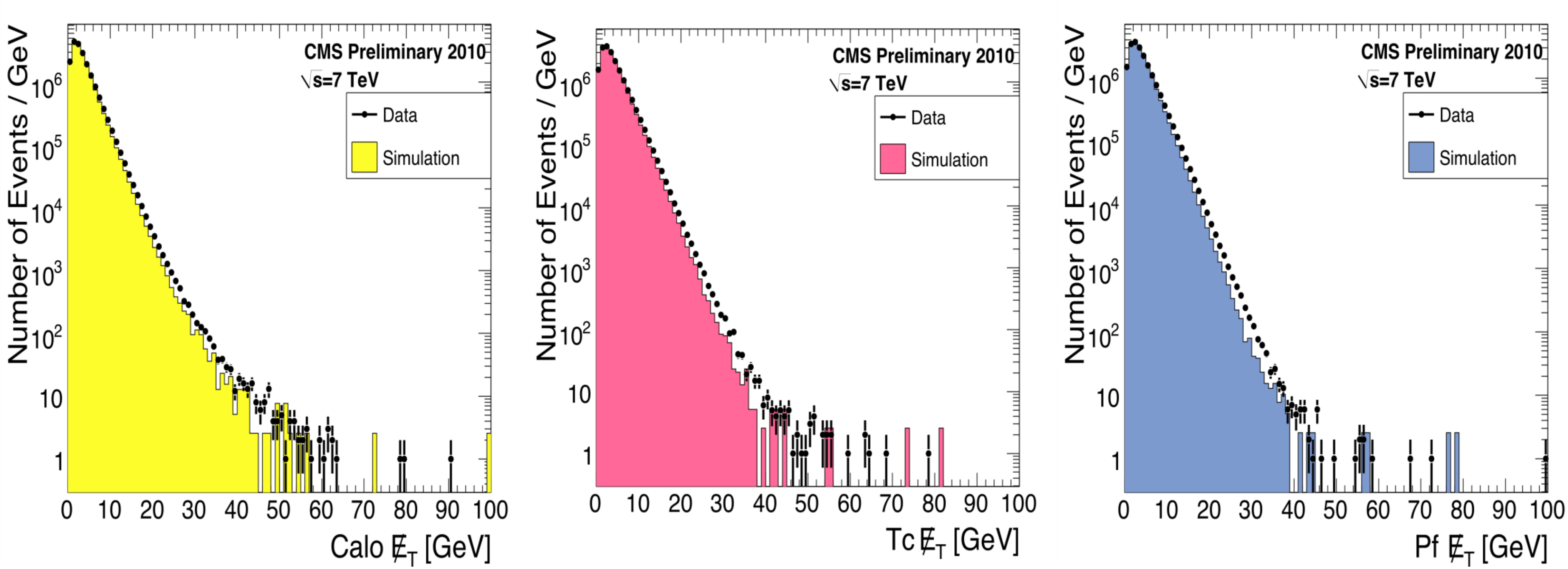
Long fibers: extend for the full length of HF
Short fibers: start at a depth of 22cm from the front of HF
HF PMT hits can be identified based on the energy sharing between the Long and Short fibers using a cut on $R = (E_L-E_S)/(E_L+E_S)$ and timing information.







Current Status of MET Cleaning



Distributions exponential over 5-6 orders of magnitude

Scan of events in the high tail show no entries from potential ECAL anomalous deposits. There are a few HF ones, look to be easily identifiable and algorithms against these are being developed. Though more work is still needed.