Status Report of The CMS Experiment

Christos Leonidopoulos

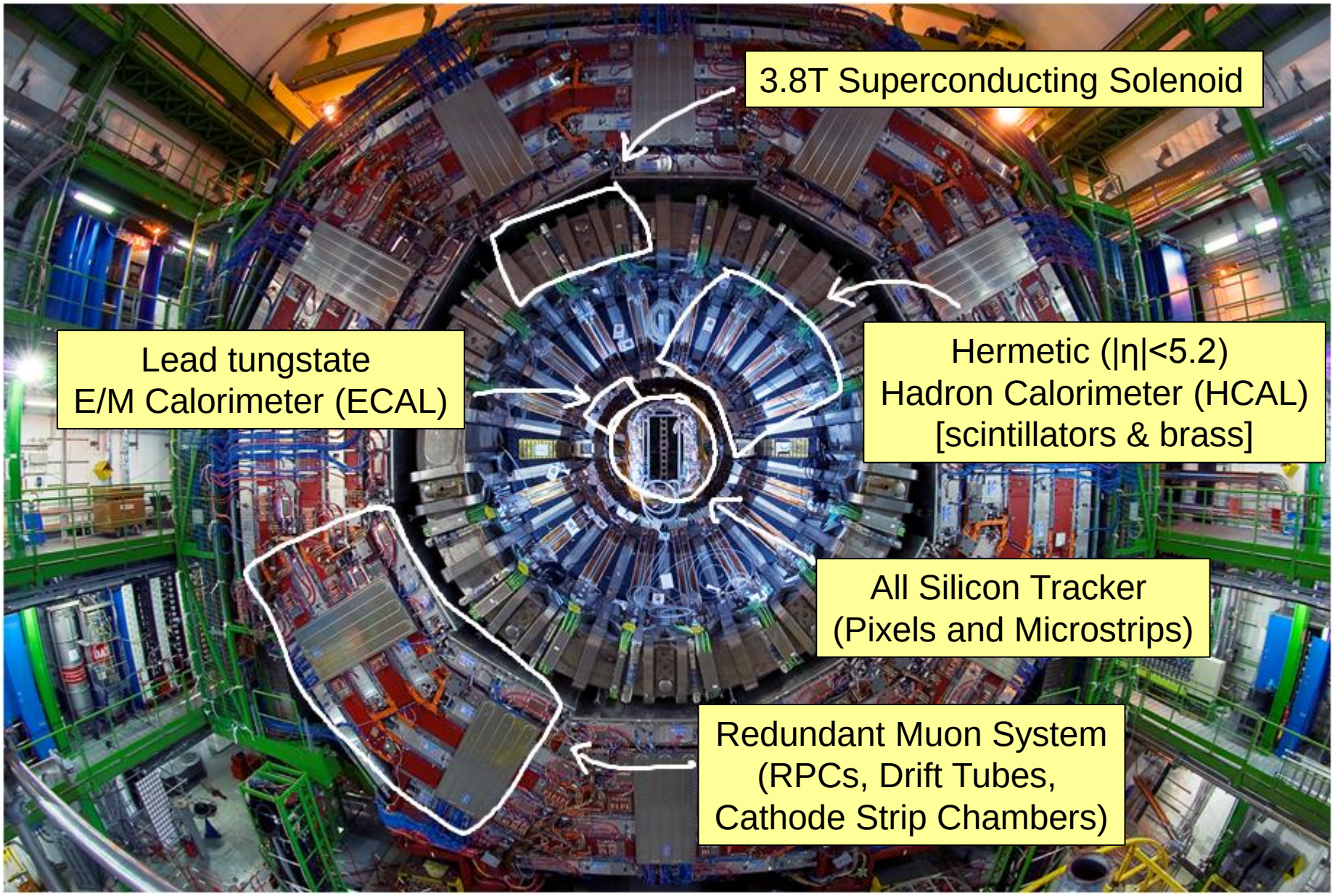
CERN-PH

on behalf of the CMS Collaboration

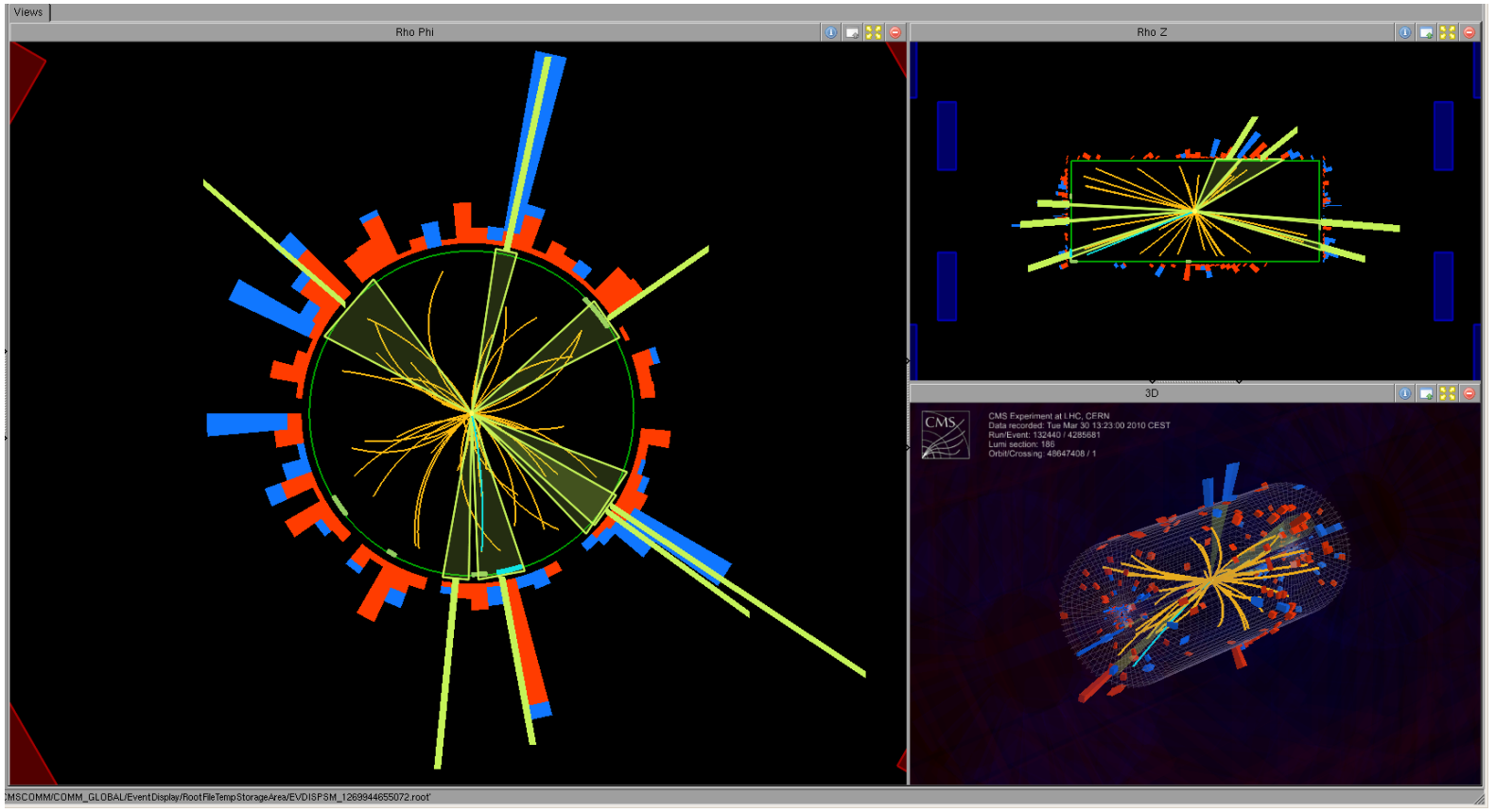
102nd LHCC Meeting, CERN

7 July 2010

Reminder: we went from this…

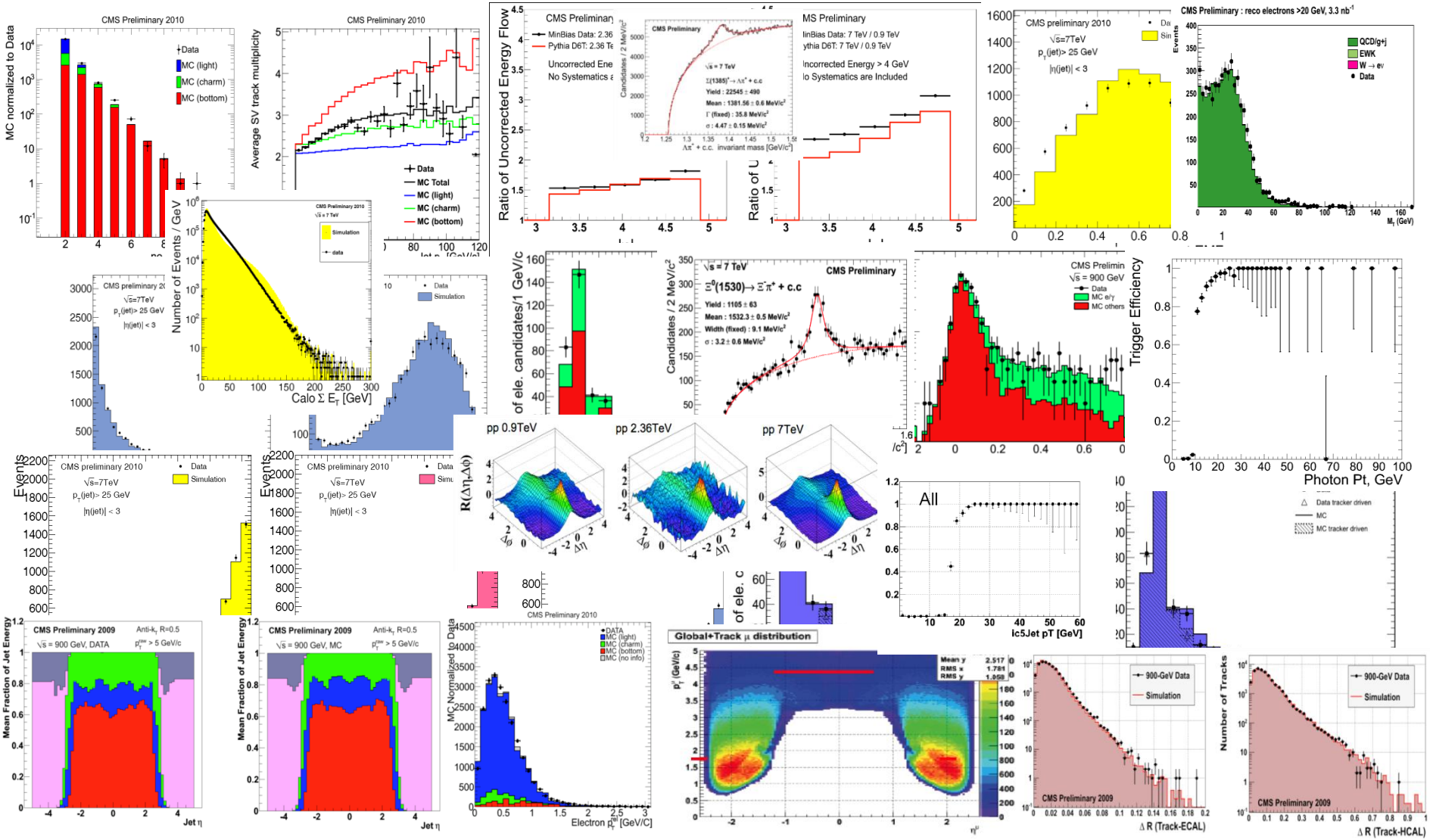


…to this



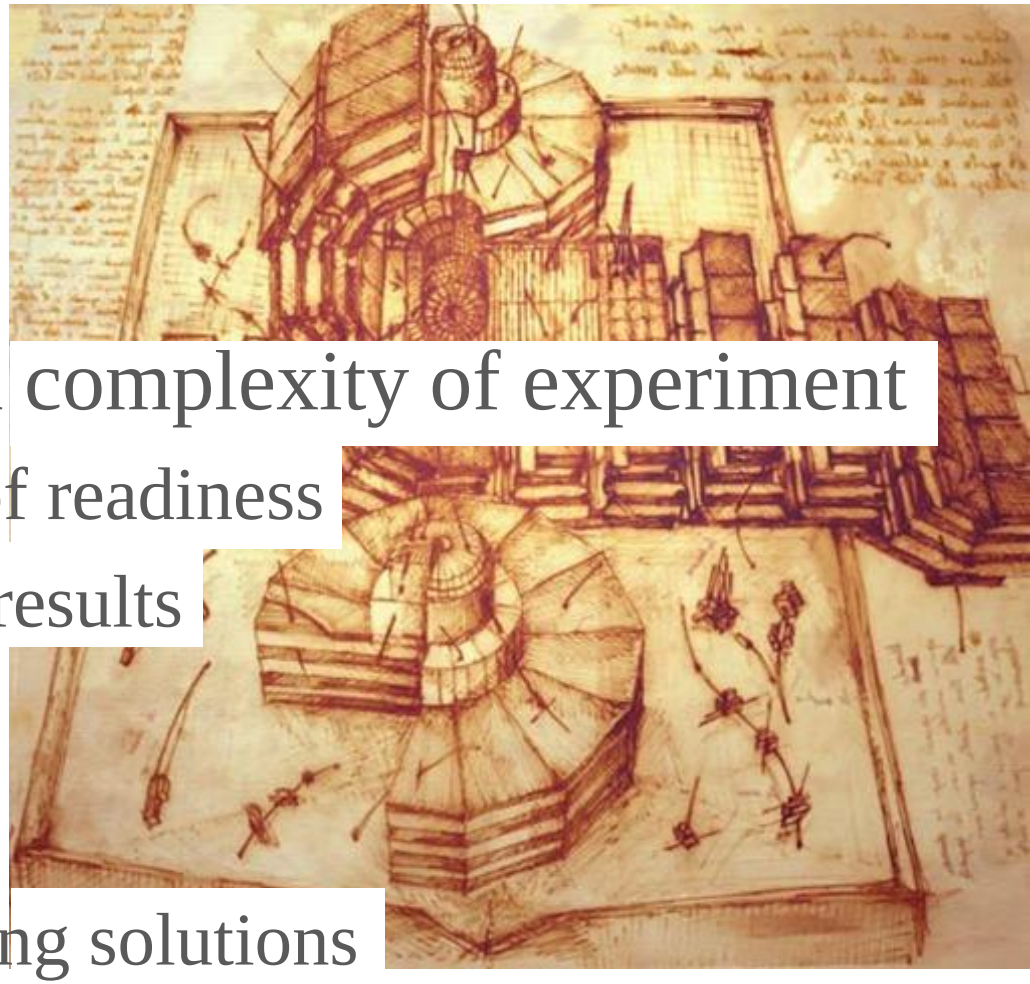
First 7 TeV collisions in CMS – 30 March 2010

…and this, just three months later



From data-taking to the plots

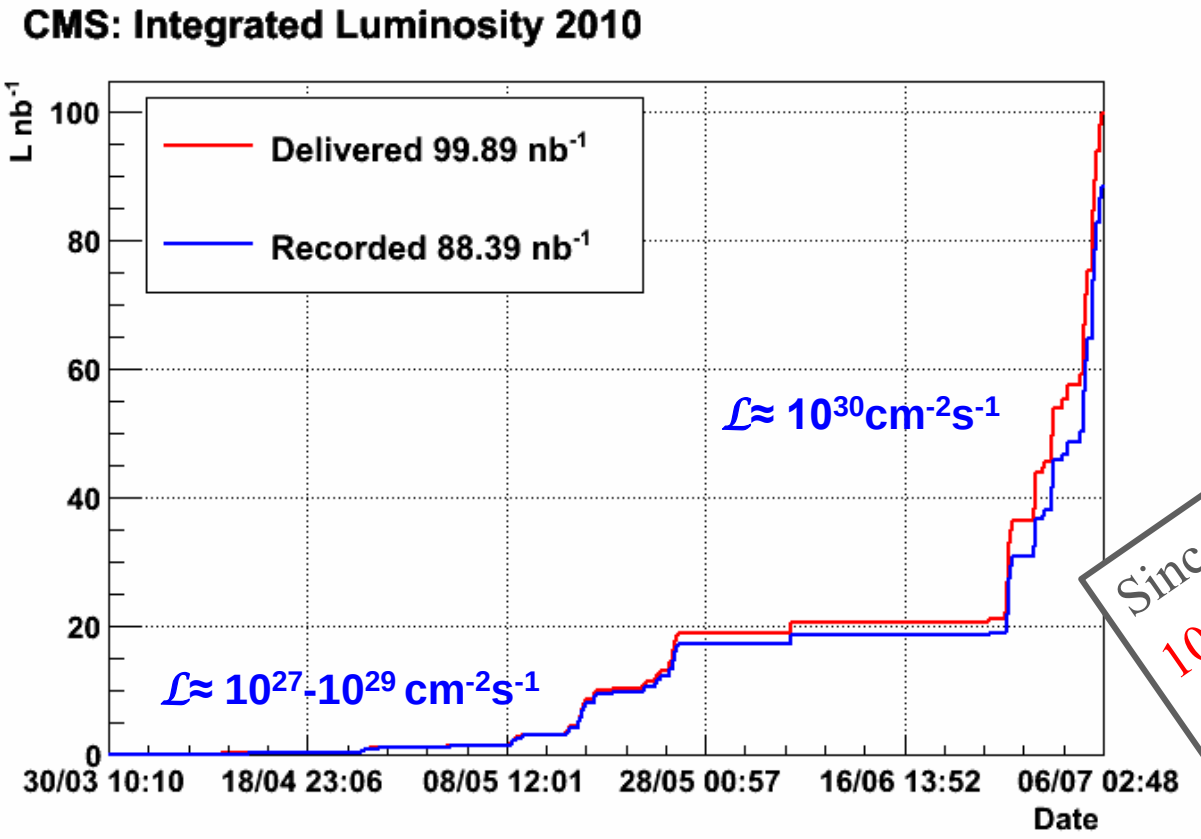
CMS is still in the commissioning phase



- Hard work, long hours
- Despite early phase and complexity of experiment
  - Unprecedented levels of readiness
  - Very encouraging first results
- But:
  - Always problems seeking solutions
  - Hardest part is ahead of us

Operations

Integrated luminosity

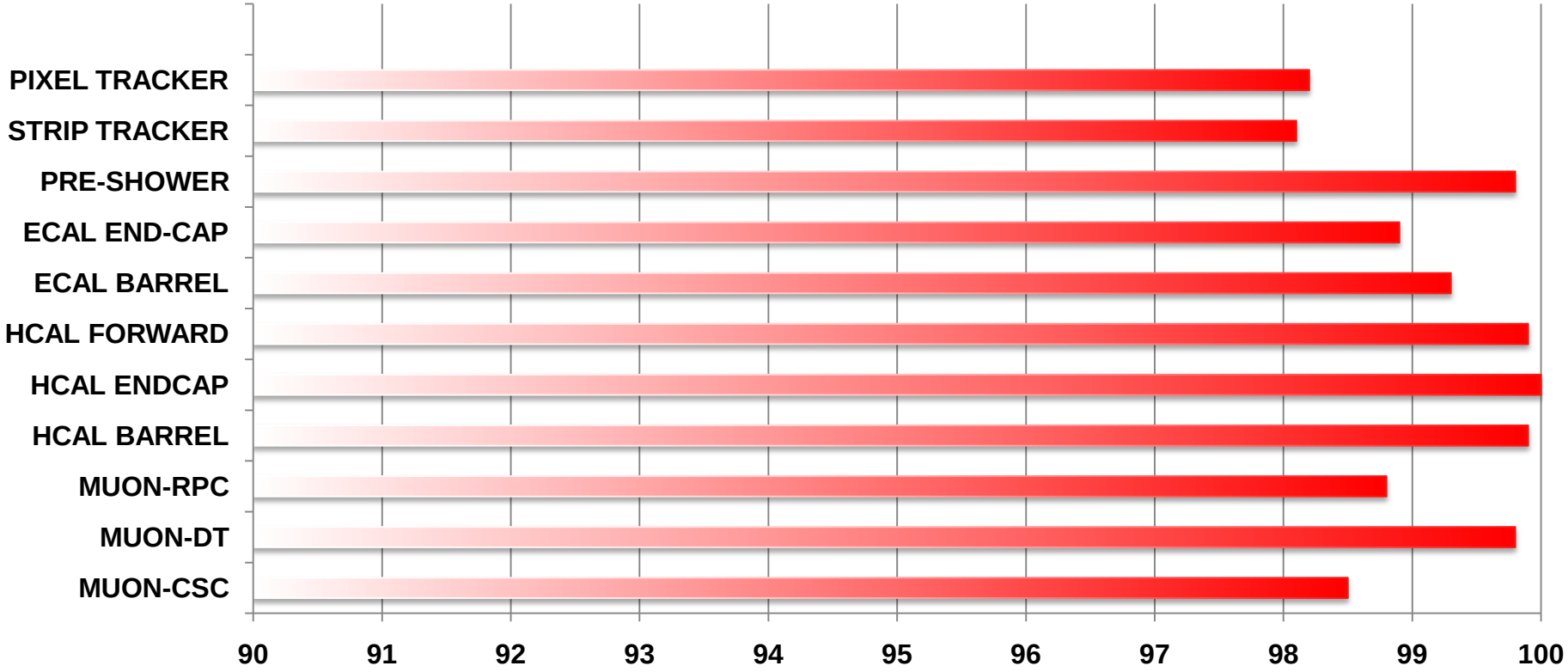


Since end of March (7 TeV):
100 nb^{-1} delivered (*)
88 nb^{-1} recorded (~88%)

(*) Stable beams only

- ~3/4 of data recorded arrived in last 10 days
- Working hard to integrate full datasets for ICHEP
- Most performance plots use only fraction of data

Subdetectors status



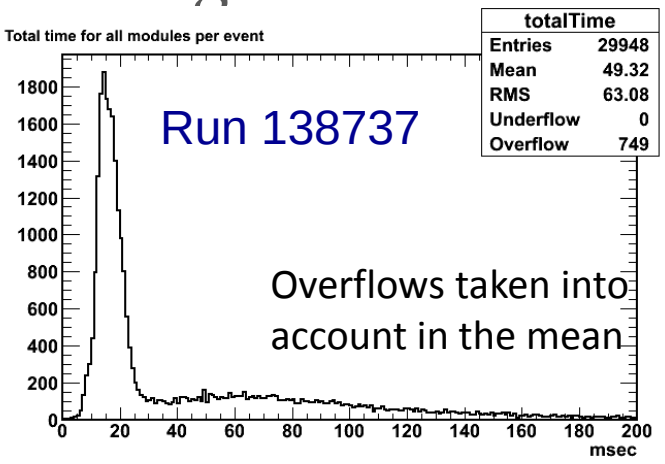
MUON-CSC	MUON-DT	MUON-RPC	HCAL BARREL	HCAL ENDCAP	HCAL FORWARD	ECAL BARREL	ECAL END-CAP	PRE-SHOWER	STRIP TRACKER	PIXEL TRACKER	
98.5	99.8	98.8	99.9	100	99.9	99.3	98.9	99.8	98.1	98.2	

Alignment/calibration status, dead/masked channels mirrored in MC

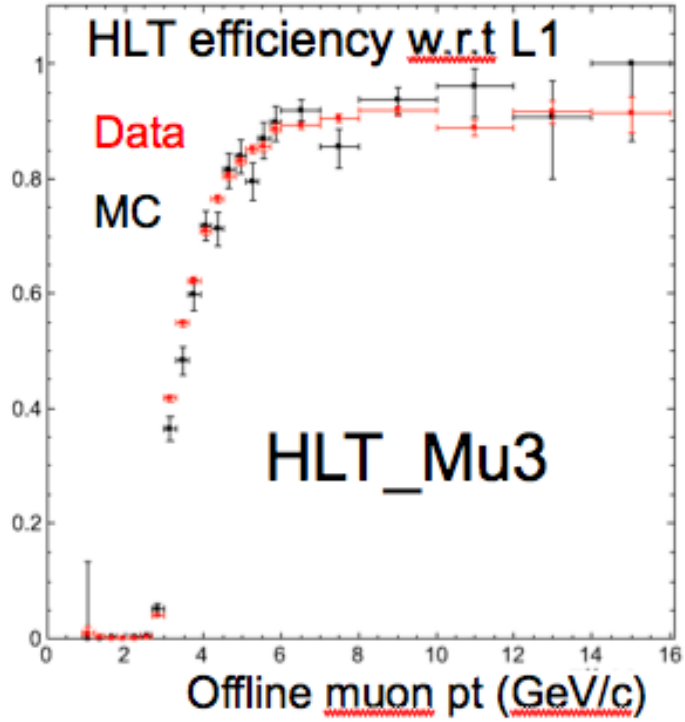
“The Trigger does not determine which Physics Model is Right. Only which Physics Model is Left.”

DAQ/Trigger

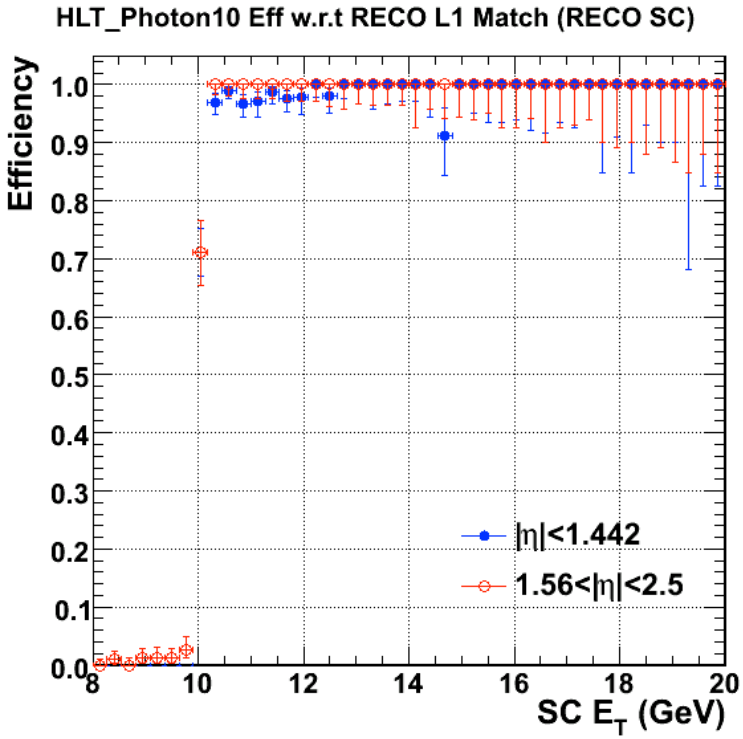
- L1/DAQ rate: 45 kHz, @<0.5 MB/evt
- High-Level Trigger: have successfully deployed online trigger menus spanning luminosities from 1E27 through 2E30
  - Very smooth running throughout (200-400 Hz)
- HLT CPU-performance: 49 ms/evt
  - Primary contributors: commissioning and early analysis triggers
  - Contingency: factor of 2
  - Constantly on watch list



Trigger Performance

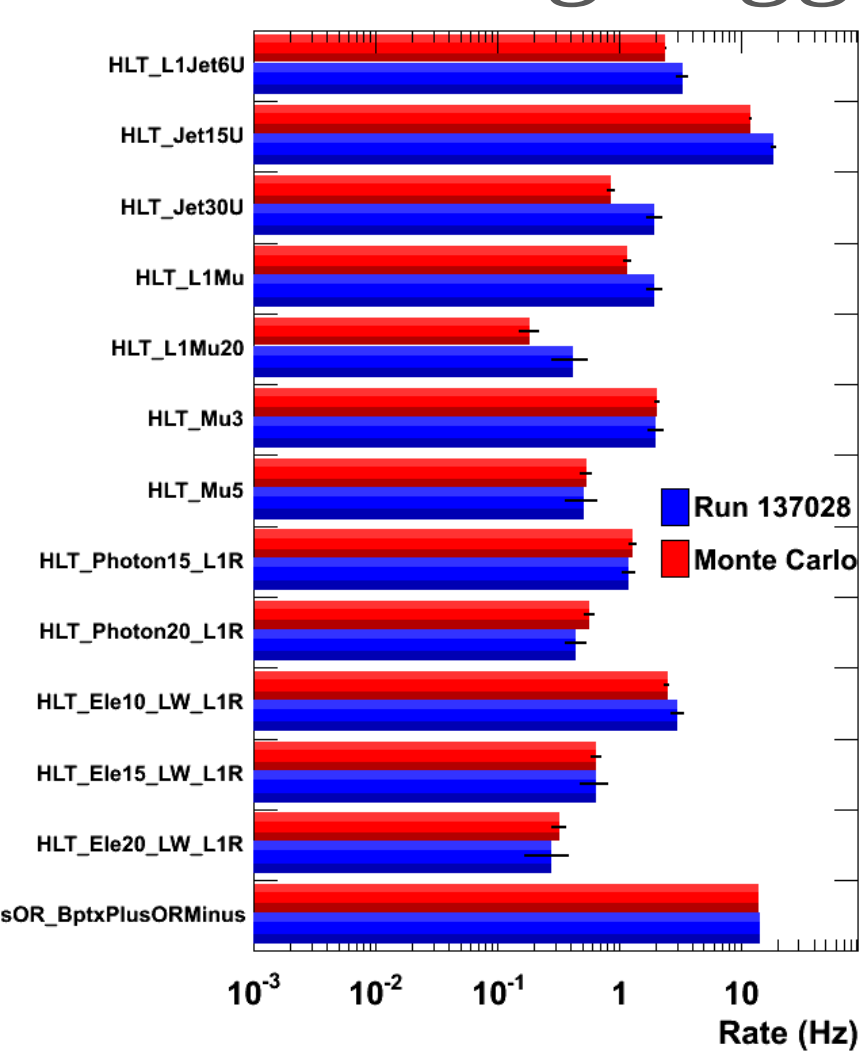


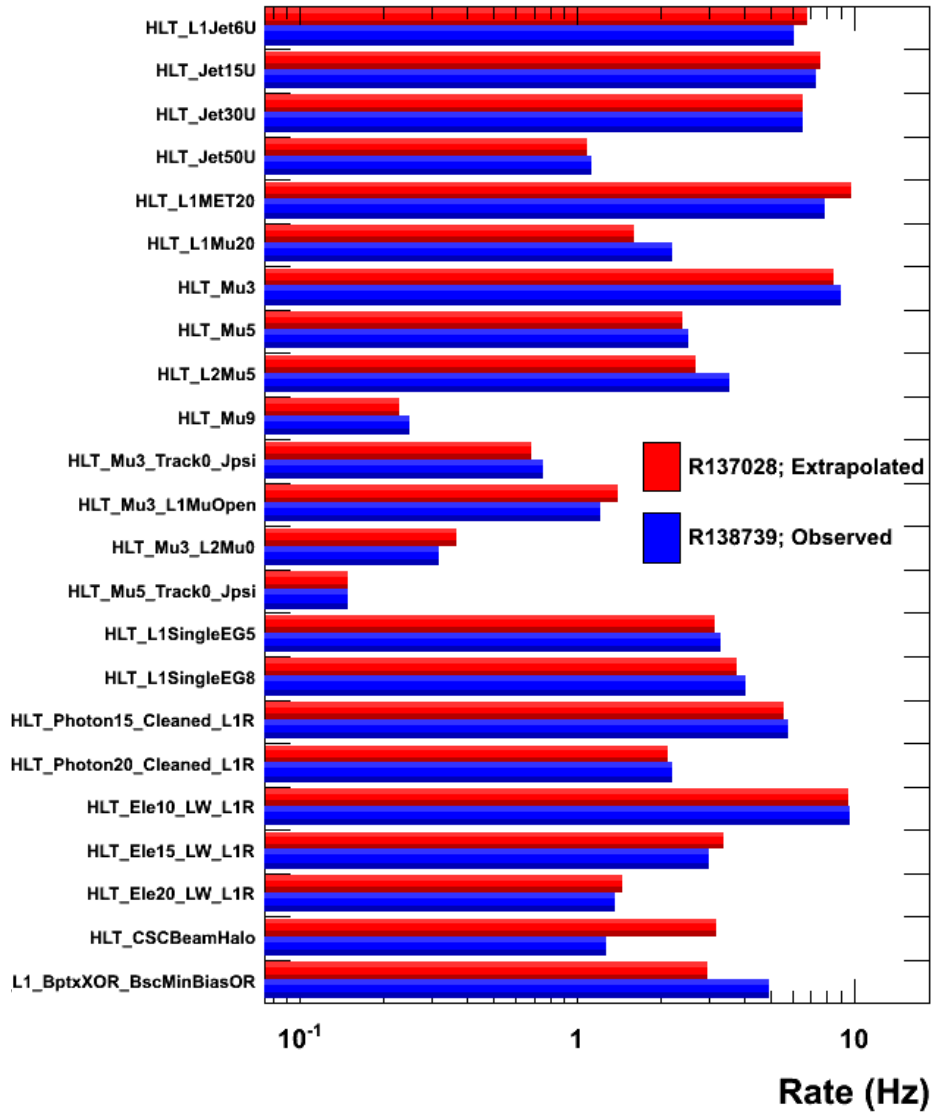
- HLT muon efficiency wrt L1
- L1 objects matched to offline objects
- ~90% efficiency at the plateau



- Photon efficiency wrt offline "super clusters"
- For barrel & endcaps
- Nearly 100% efficient

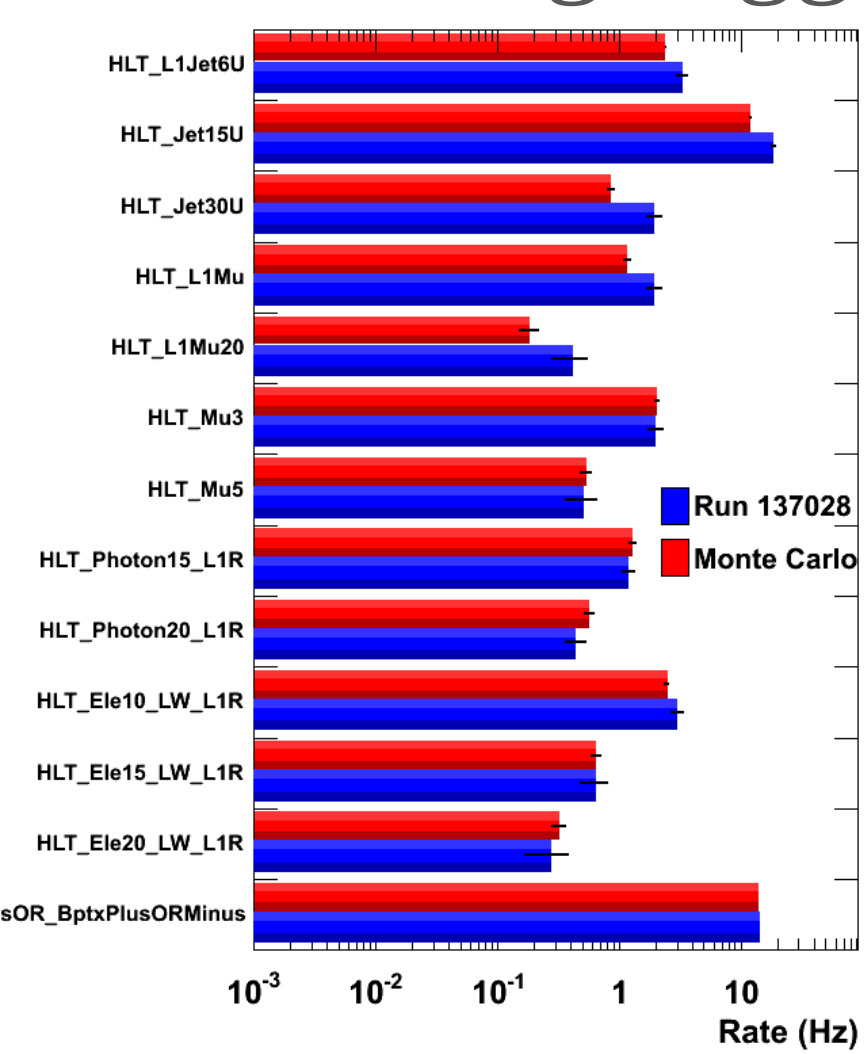
Predicting trigger rates: MC vs. data

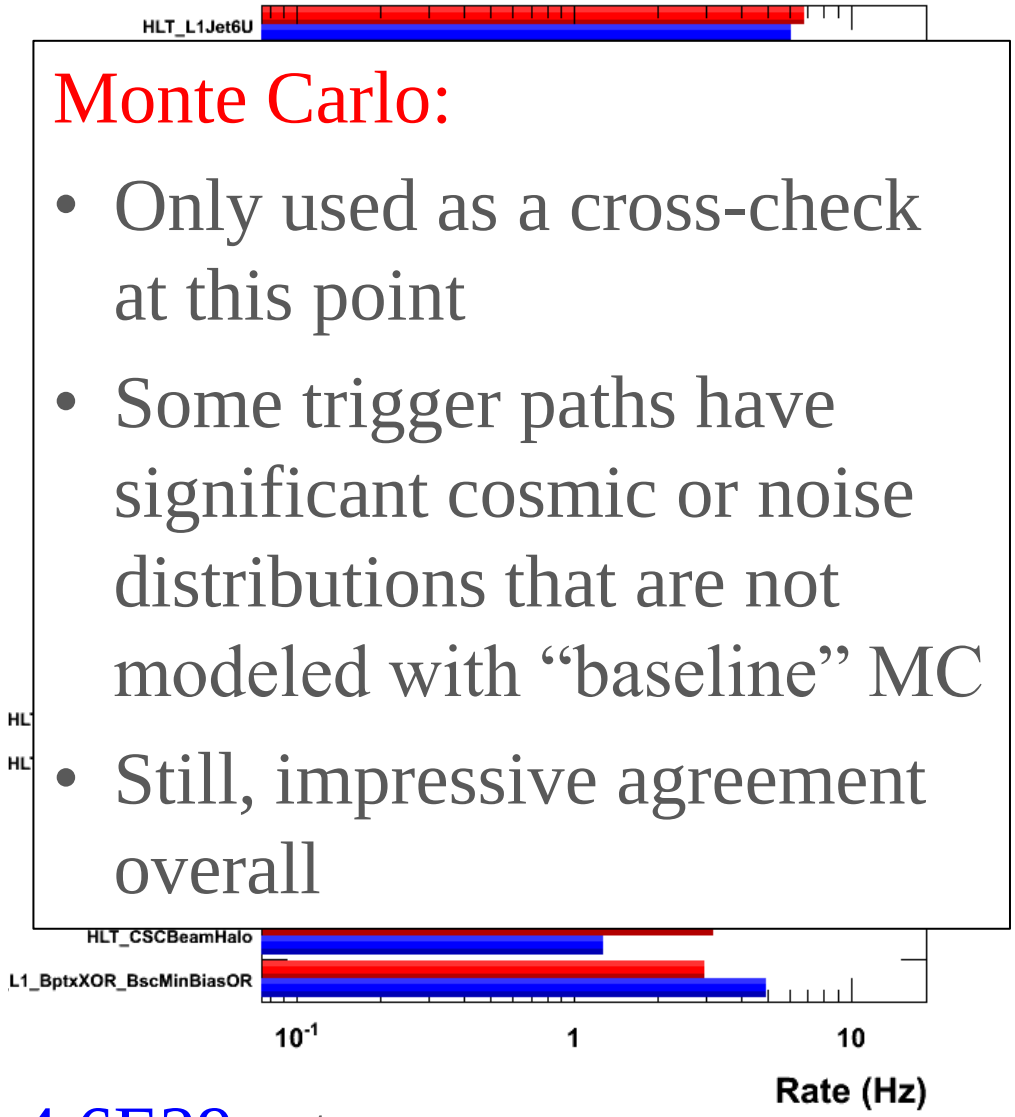




"Building trigger menus 101"

Predicting trigger rates: MC vs. data





Monte Carlo:

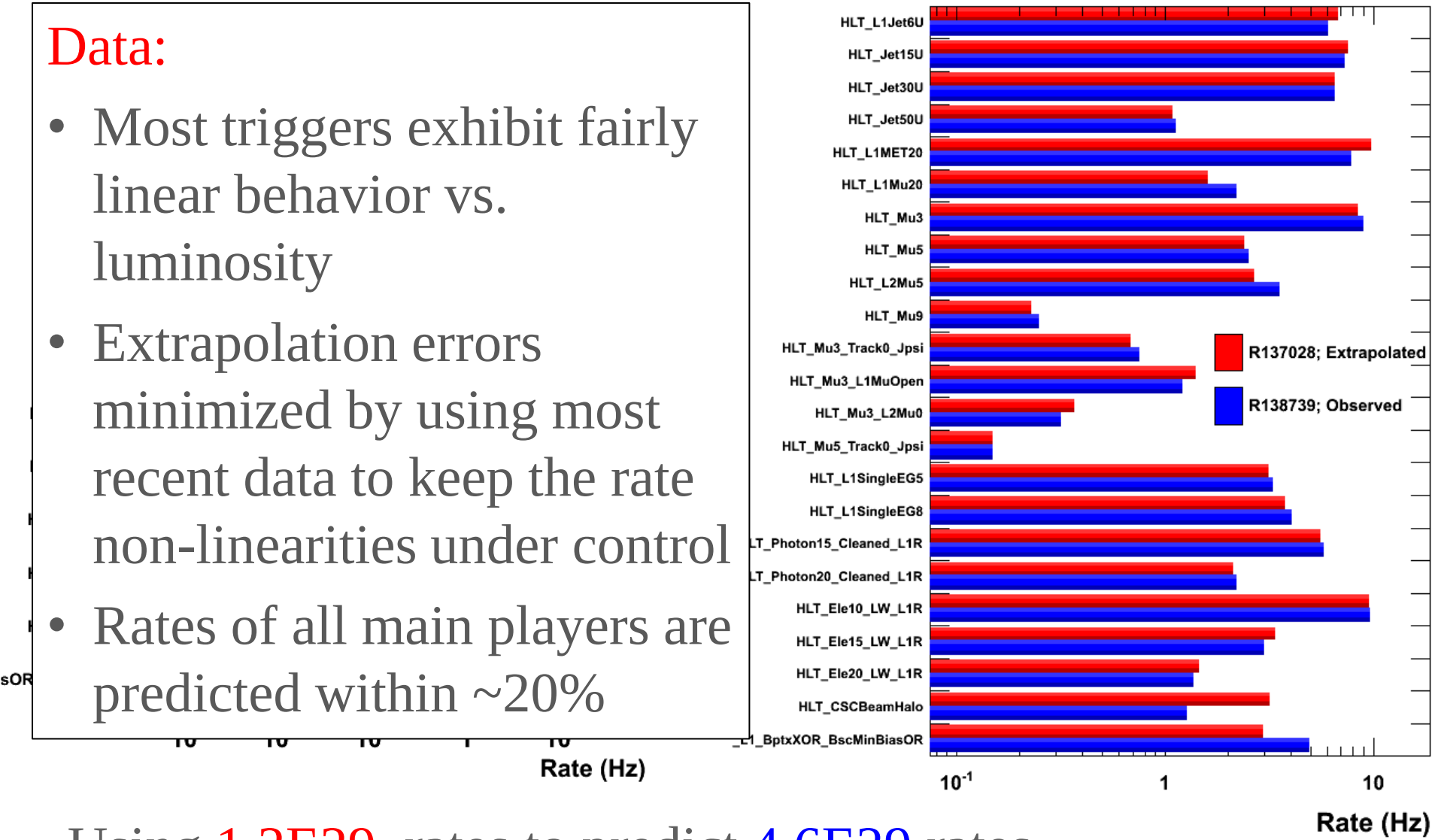
- Only used as a cross-check at this point
- Some trigger paths have significant cosmic or noise distributions that are not modeled with “baseline” MC
- Still, impressive agreement overall

Using MC to cross-check 4.6E29 rates

Predicting trigger rates: MC vs. data

Data:

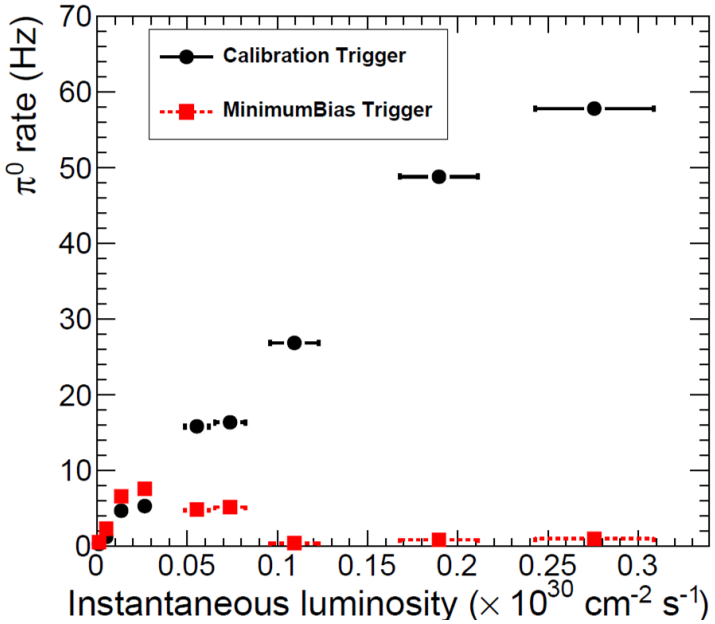
- Most triggers exhibit fairly linear behavior vs. luminosity
- Extrapolation errors minimized by using most recent data to keep the rate non-linearities under control
- Rates of all main players are predicted within ~20%



Using 1.2E29 rates to predict 4.6E29 rates

Calibration Trigger Streams

- Calibration triggers have access to full L1 rate, and they output small fraction of event



- Feature unique to CMS HLT
- Calibration starts online!

Calibration Trigger Streams

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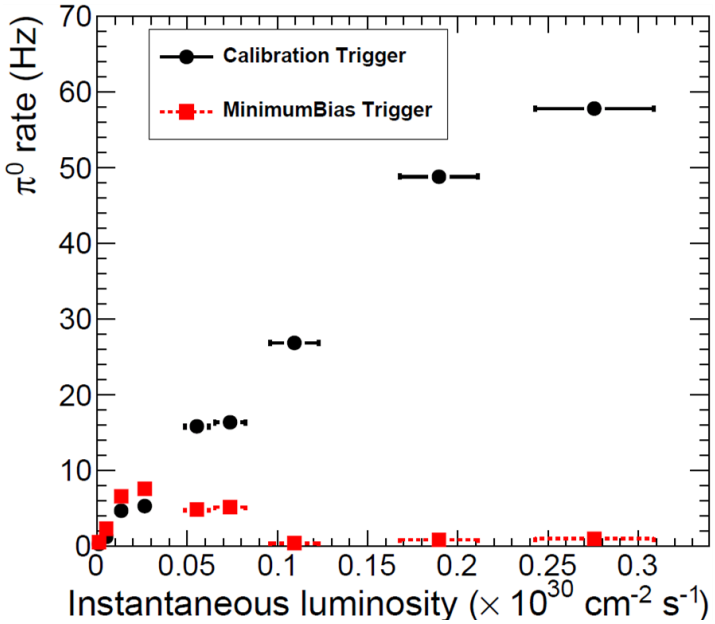
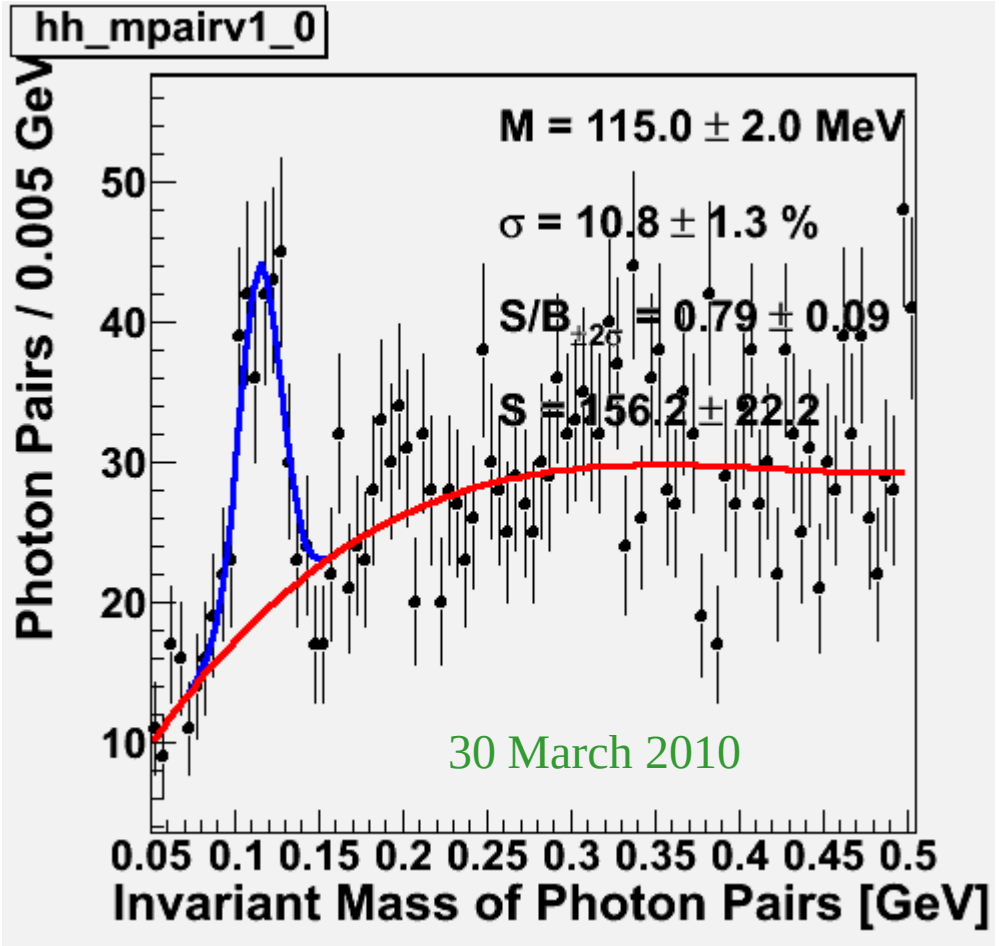
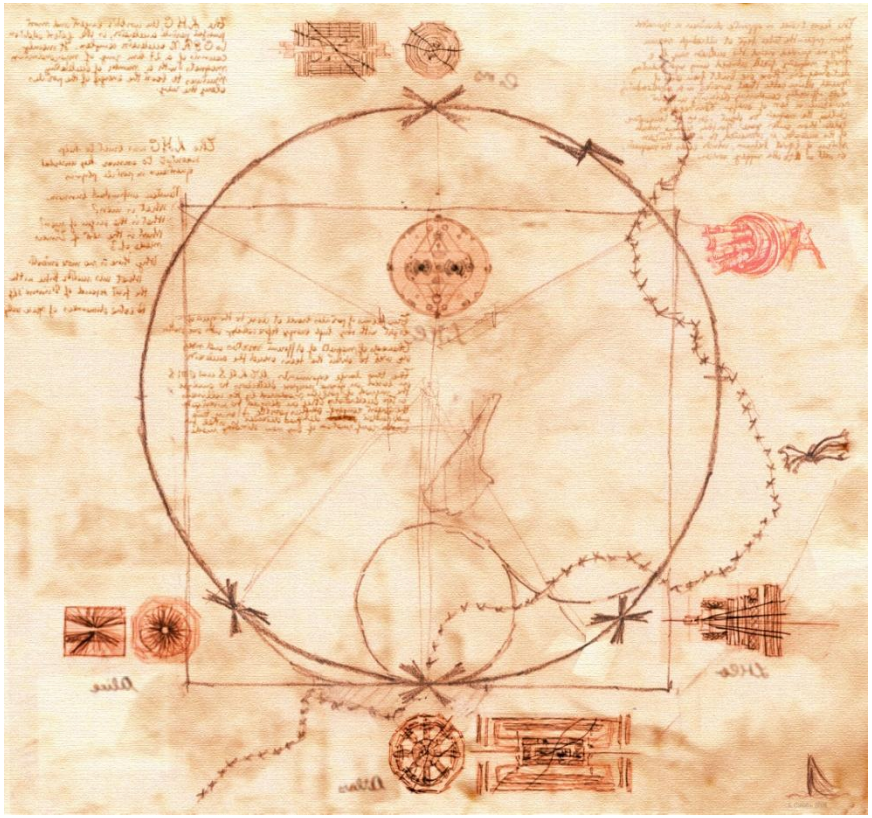


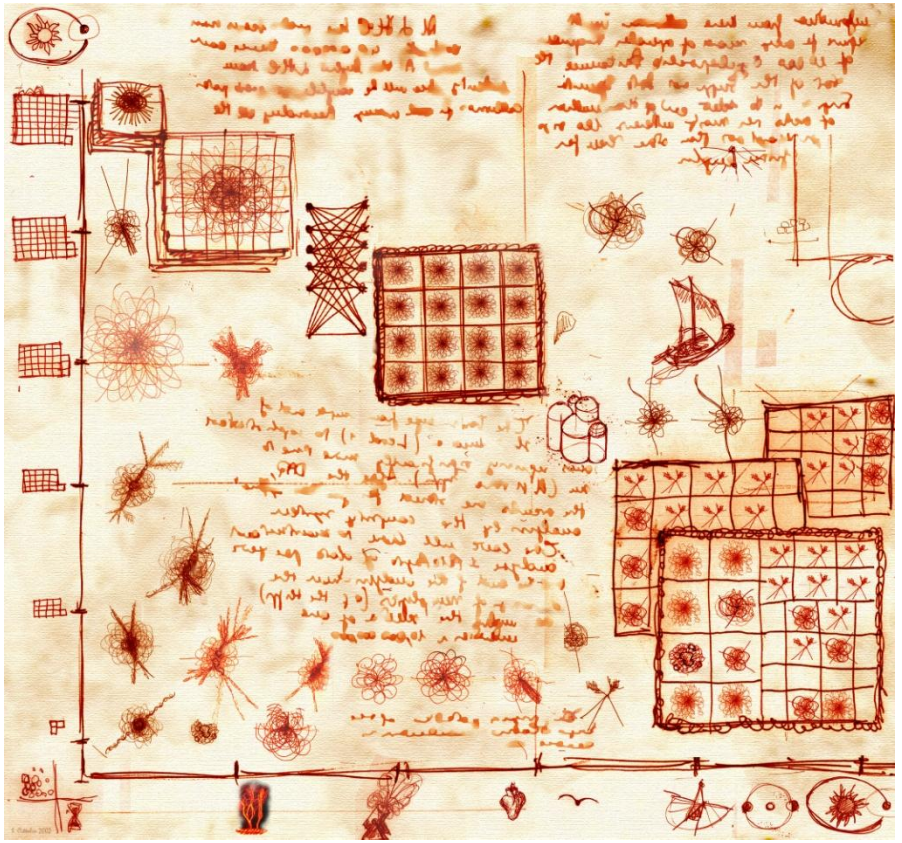


- π^0 peak reconstructed offline 200 seconds into 7 TeV run

LHC has delivered



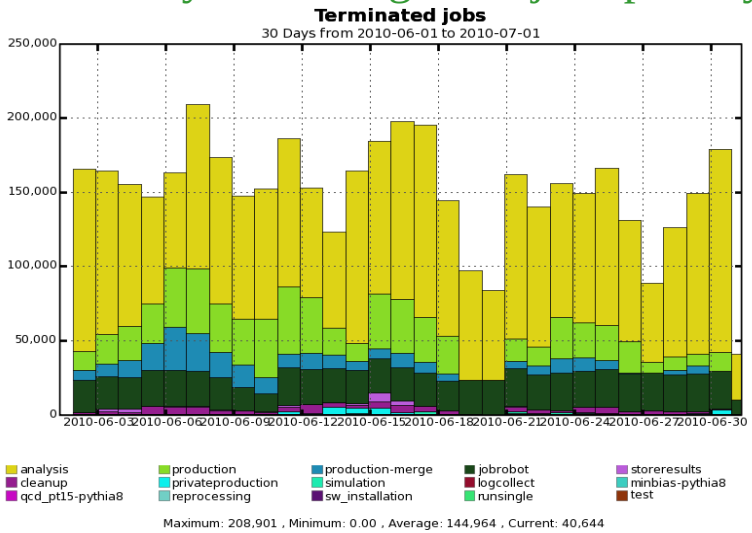
Trigger has accepted

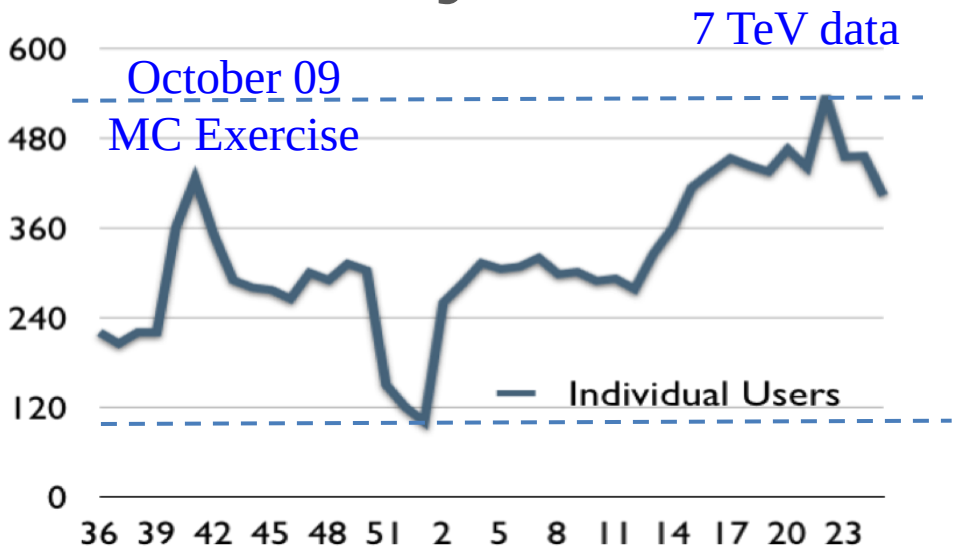


CMS will analyze

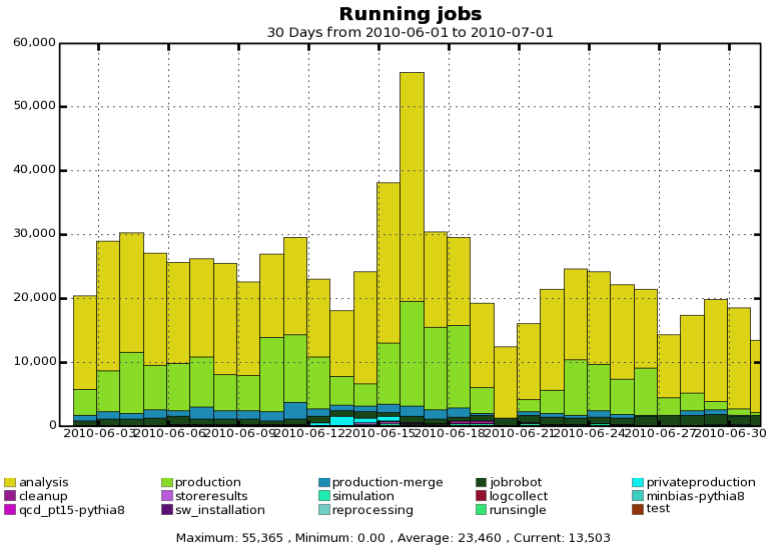
Analysis Activity

Routinely delivering 100k jobs per day





Winter Break



10-20k analysis jobs running on Tier-2s continuously every day of June

Physics production

3+1 CMS papers since May

1) **Measurement of the Underlying Event Activity in Proton-Proton Collisions at 0.9 TeV.**
By CMS Collaboration (Vardan Khachatryan *et al.*). Jun 2010. Temporary entry
e-Print: **arXiv:1006.2083** [hep-ex]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords
Abstract and Postscript and PDF from arXiv.org (mirrors: au br cn de es fr il in it jp kr ru tw uk za aps lanl)
Bookmarkable link to this information

2) **Measurement of the charge ratio of atmospheric muons with the CMS detector.**
By CMS Collaboration (V. Khachatryan *et al.*). May 2010. Temporary entry
e-Print: **arXiv:1005.5332** [hep-ex]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords
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Bookmarkable link to this information

3) **Transverse-momentum and pseudorapidity distributions of charged hadrons in pp collisions at sqrt(s) = 7 TeV.**
By CMS Collaboration (V. Khachatryan *et al.*) CSM-QCD-10-006, CERN-PH-EP-2010-009, FERMILAB-PUB-10-170-CMS, May 2010. 26pp.
Long author list - awaiting processing.
e-Print: **arXiv:1005.3299** [hep-ex]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 3 times
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Fermilab Library Server (fulltext available)
EXP CERN-LHC-CMS | Reaction Data (Durham)
Bookmarkable link to this information

4) **Measurement of Bose-Einstein correlations with first CMS data.**
By CMS Collaboration (Vardan Khachatryan *et al.*) CMS-QCD-10-003, CERN-PH-EP-2010-010, FERMILAB-PUB-10-171-CMS, May 2010. 24pp.
Long author list - awaiting processing.
e-Print: **arXiv:1005.3294** [hep-ex]

References | LaTeX(US) | LaTeX(EU) | Harvmac | BibTeX | Keywords | Cited 1 time
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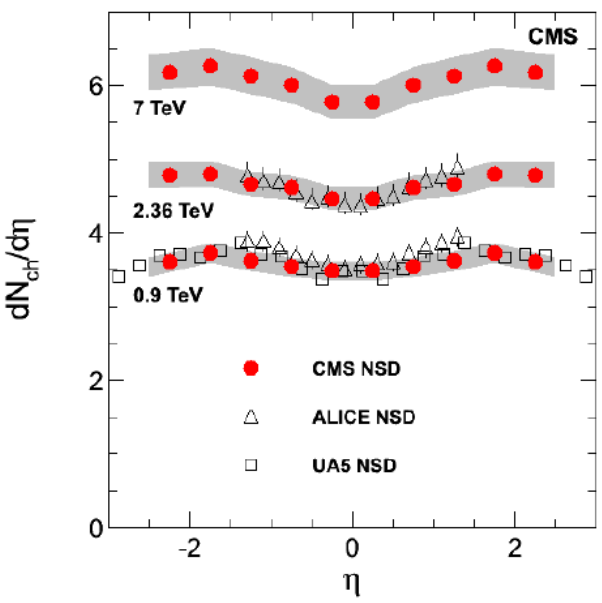
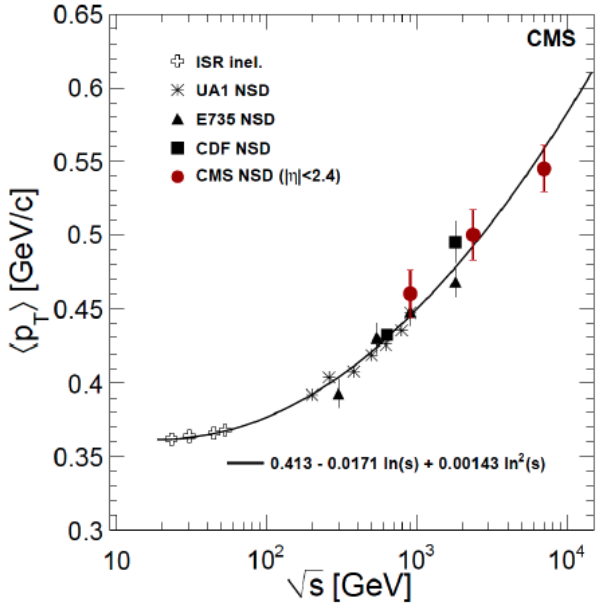
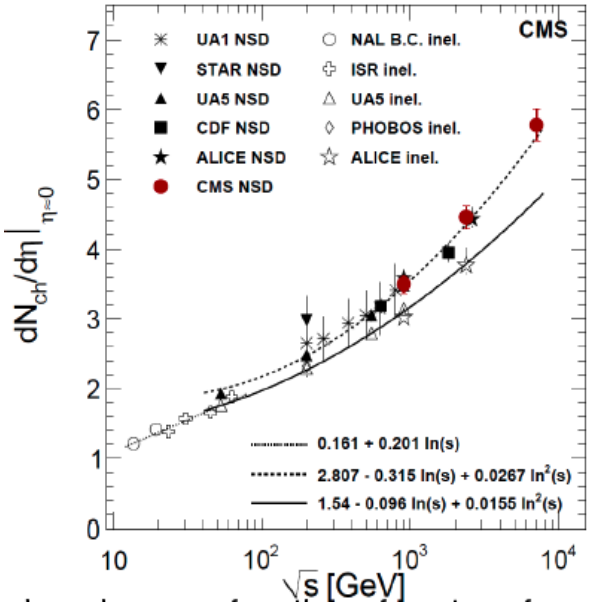
CMS paper at 7TeV

"Transverse Momentum and Pseudorapidity Distributions of Charged Hadrons in pp Collisions at √s=7TeV", submitted to PRL







- Rise of the particle density at (2.36) 7 TeV steeper than in models
- Careful tuning effort of the MC generators is ongoing

CMS paper at 7TeV

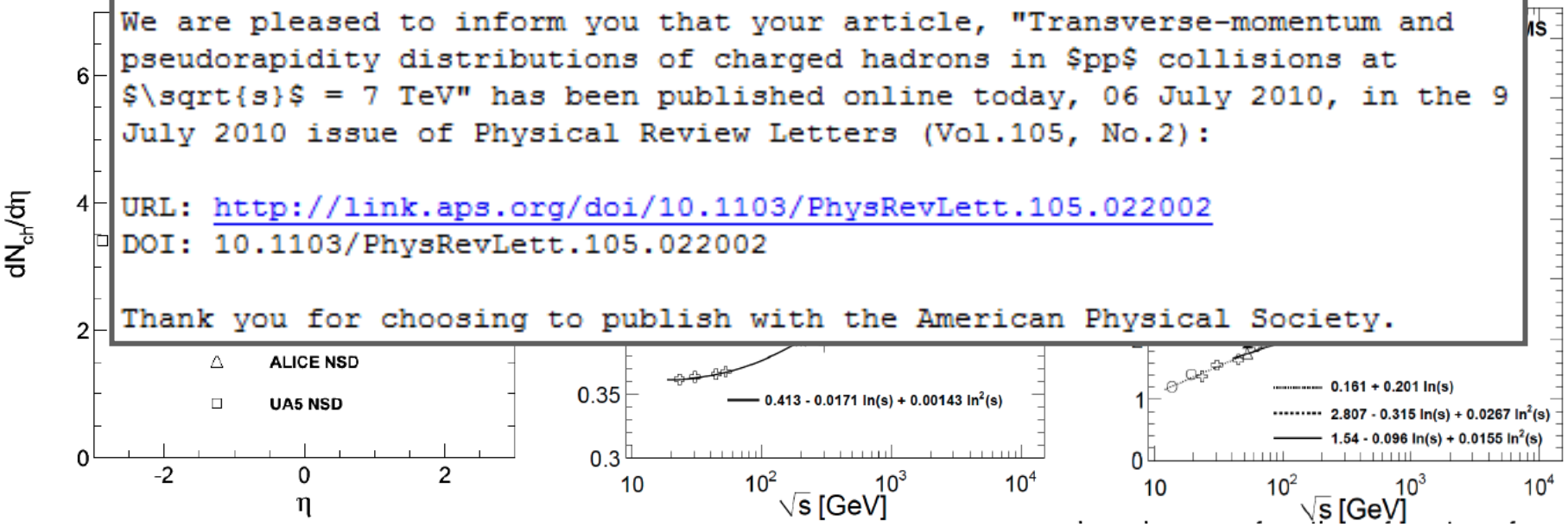
"Transverse Momentum and Pseudorapidity Distributions of Charged Hadrons in pp Collisions at √s=7TeV", submitted to PRL

Last night at ~midnight:

We are pleased to inform you that your article, "Transverse-momentum and pseudorapidity distributions of charged hadrons in pp collisions at $\sqrt{s}$ = 7 TeV" has been published online today, 06 July 2010, in the 9 July 2010 issue of Physical Review Letters (Vol.105, No.2):

URL: http://link.aps.org/doi/10.1103/PhysRevLett.105.022002
DOI: 10.1103/PhysRevLett.105.022002

Thank you for choosing to publish with the American Physical Society.



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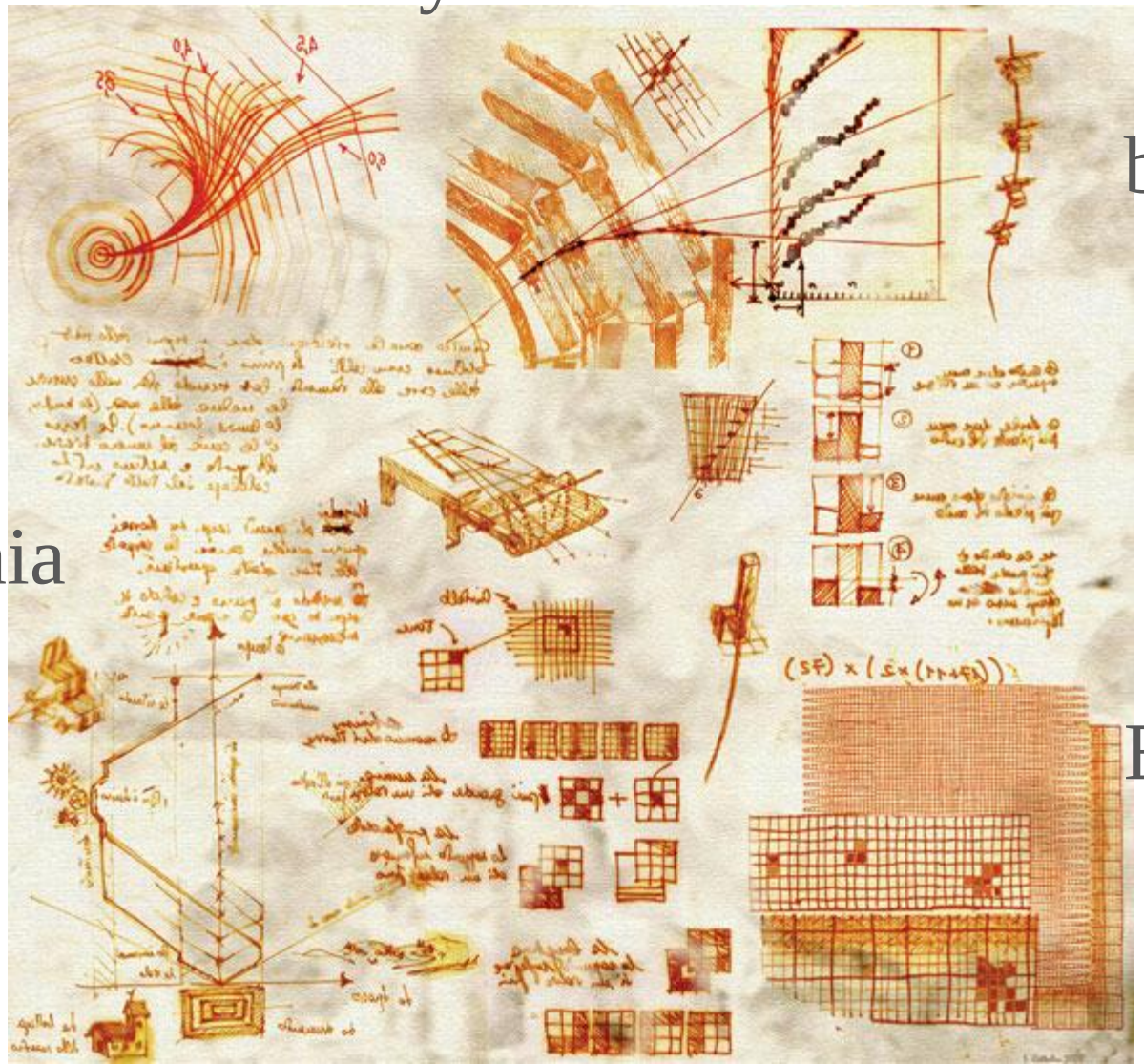
Detector & Physics Performance

Calorimetry

Jets

Tracking



b-tagging

Muon
EWK/Onia

Electron
EWK/Onia

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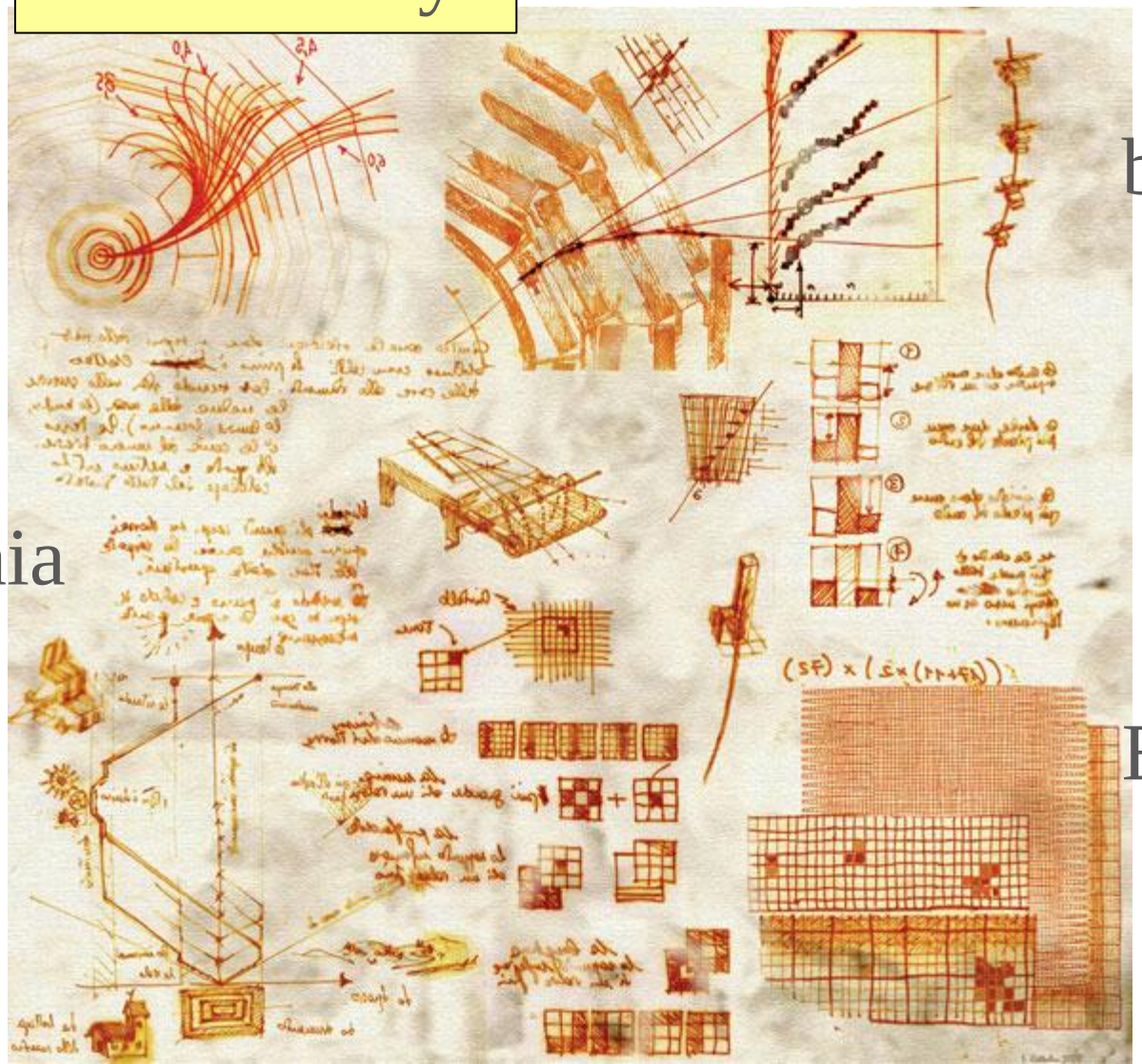
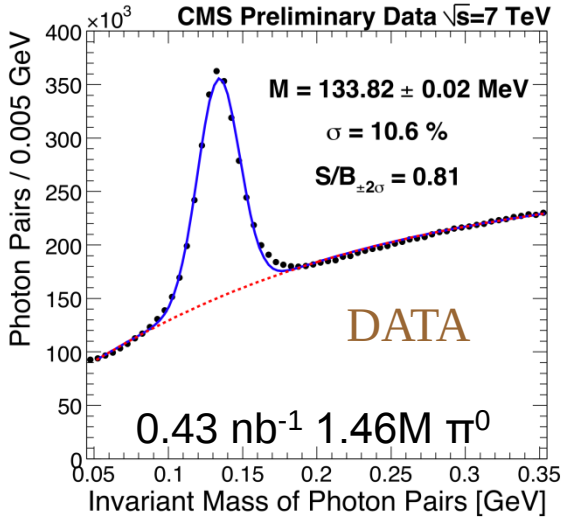


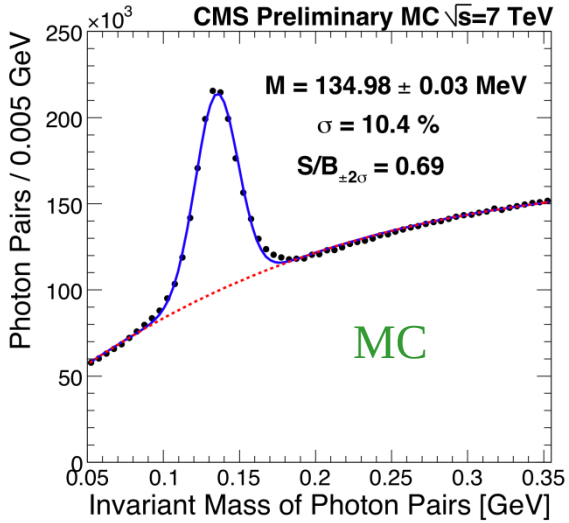
Calorimetry: π^0 and $\eta \rightarrow \gamma\gamma$

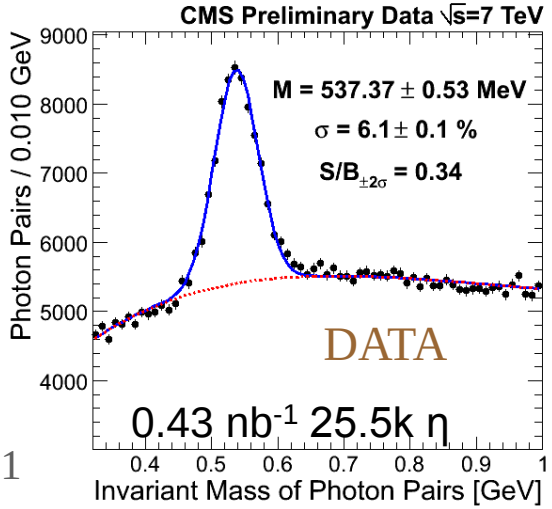
MC based correction applied according to cluster η and energy

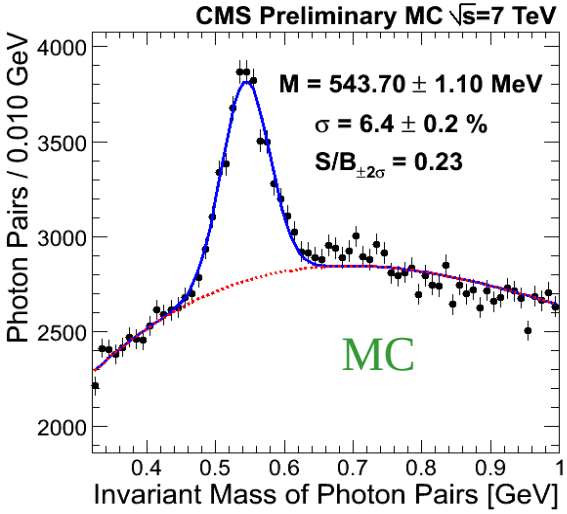
1.46M of $\pi^0 \rightarrow \gamma\gamma$
$P_T(\gamma) > 0.4$ GeV,
$P_T(\text{pair}) > 1$ GeV

25.5K $\eta \rightarrow \gamma\gamma$
$P_T(\gamma) > 0.5$ GeV,
$P_T(\text{pair}) > 2.5$ GeV



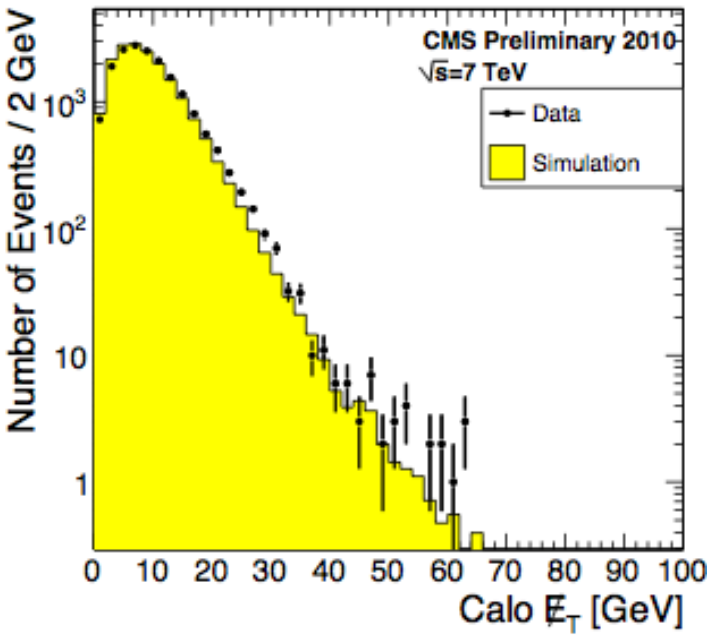






- Statistics refer to < 0.5 nb^{-1}
- Very useful tool to intercalibrate the crystals
- Good agreement in width and Signal/Background ratio
- Masses agree with expectations to within 1%

Calorimetry: Missing E_T



Calorimetric MET (GeV)

- *Jets reconstructed with the anti-k_T R=0.5 algorithm*
- *Dijet selection : Jet P_T > 25 GeV, $\Delta\varphi$ > 2.1, $|\eta|$ < 3*
- *Loose ID cuts on number of components and neutral/charged* energy fraction

Detector & Physics Performance

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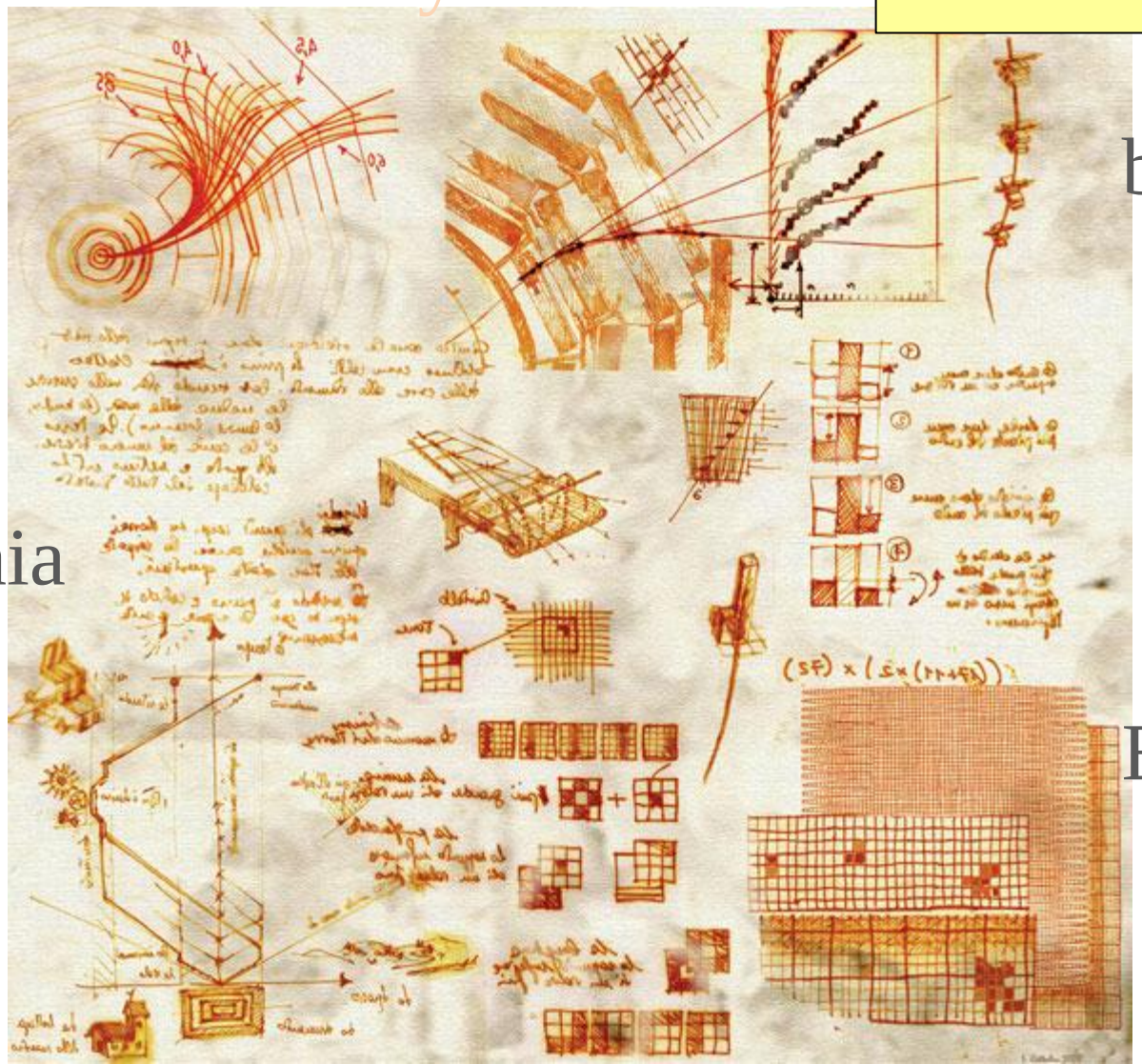
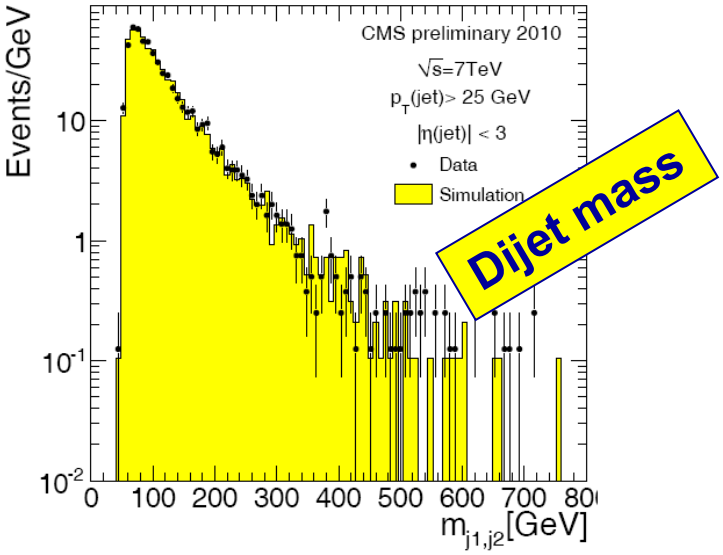
b-tagging

Muon
EWK/Onia

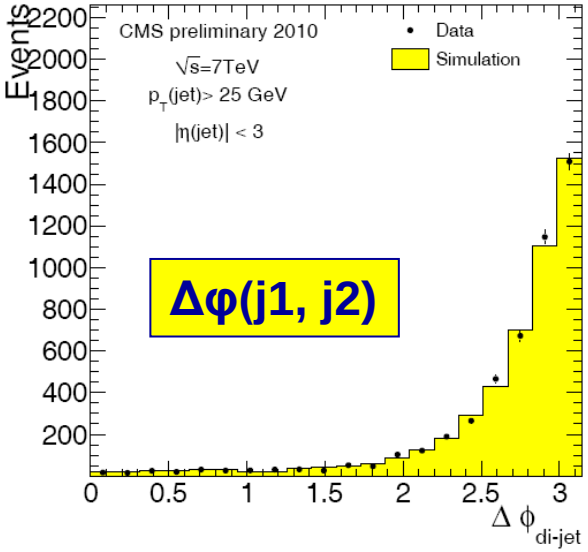
Electron
EWK/Onia



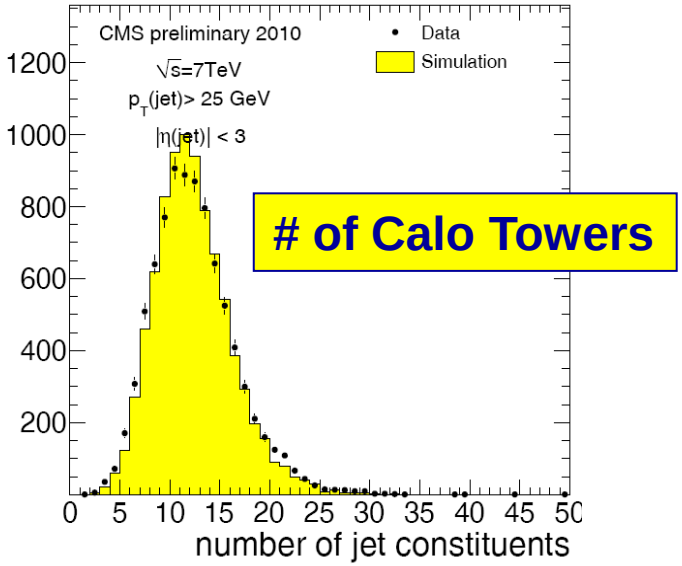
Calorimetric di-jet events



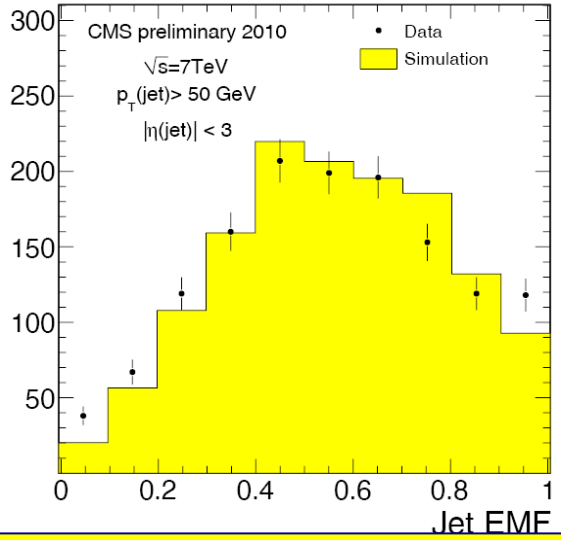
Dijet mass



Δφ(j1, j2)



# of Calo Towers



Fraction of EM energy in Calo-Jets

Detector & Physics Performance

Calorimetry

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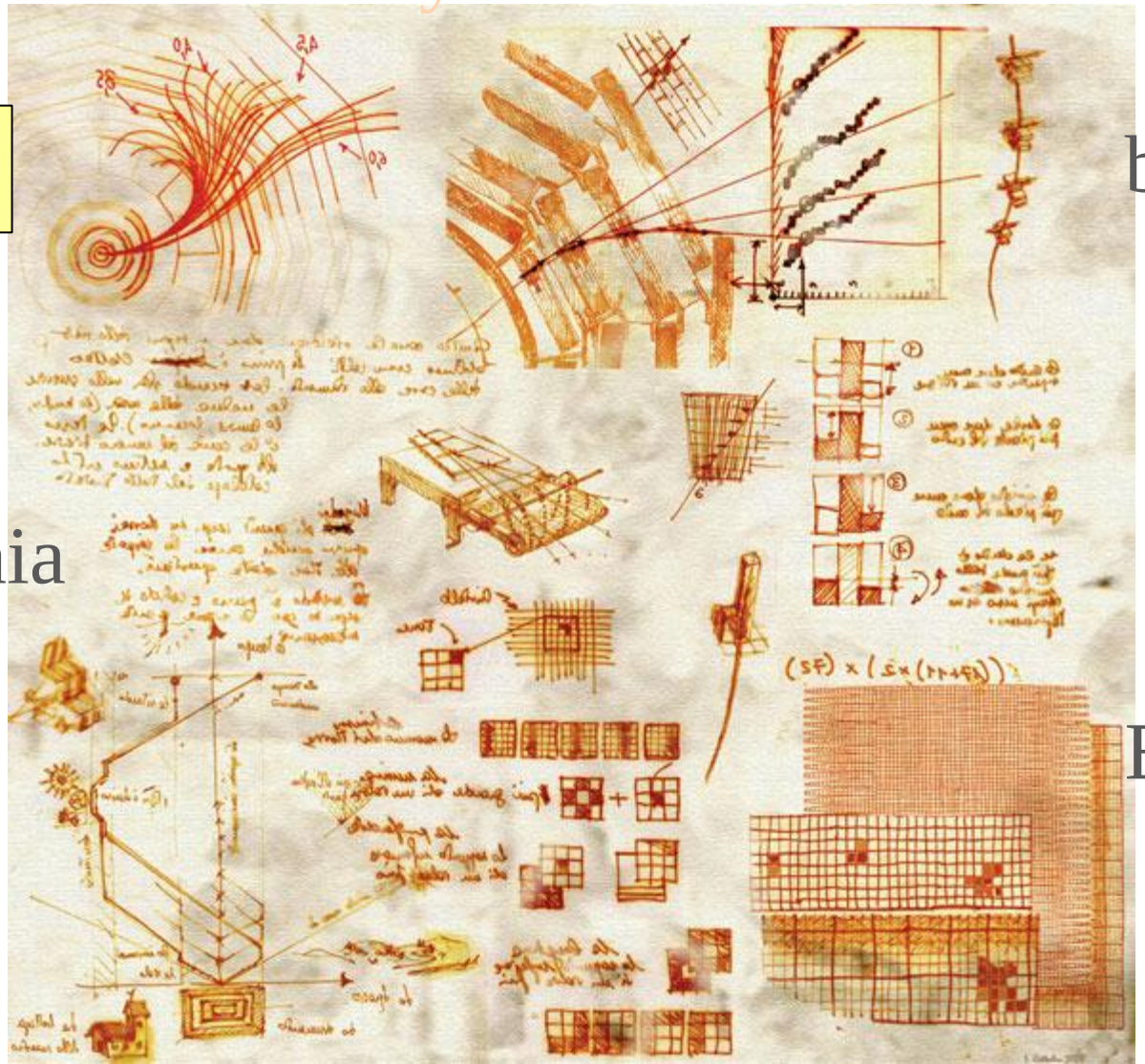
Tracking



b-tagging

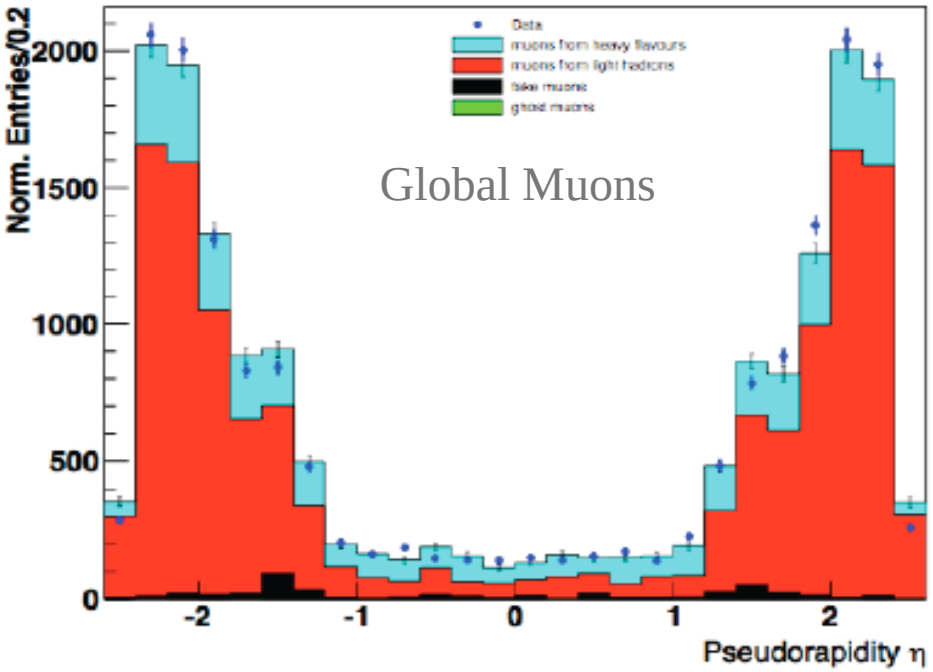
Muon
EWK/Onia

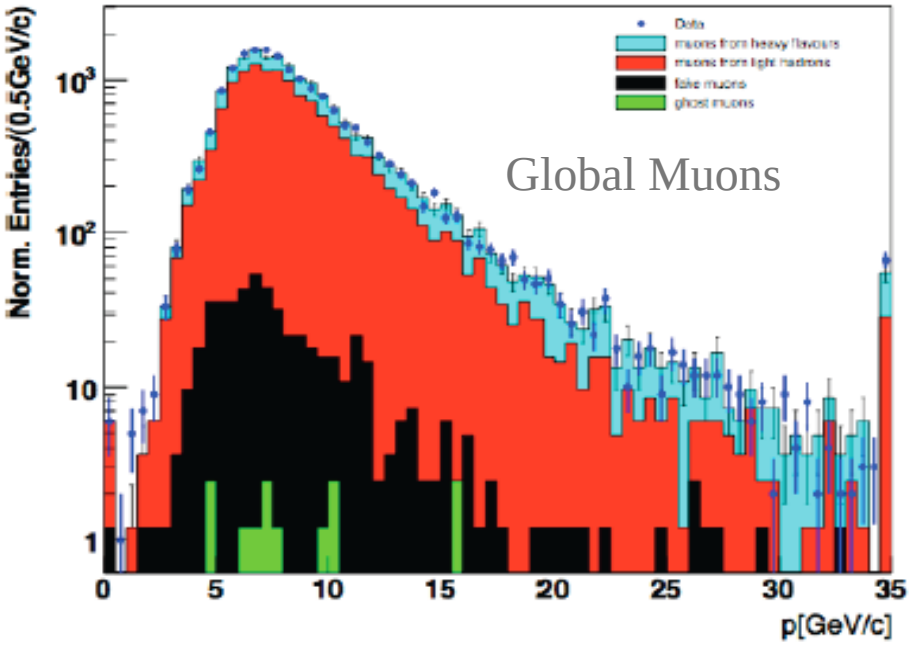
Electron
EWK/Onia

Tracking distributions

Muon distributions

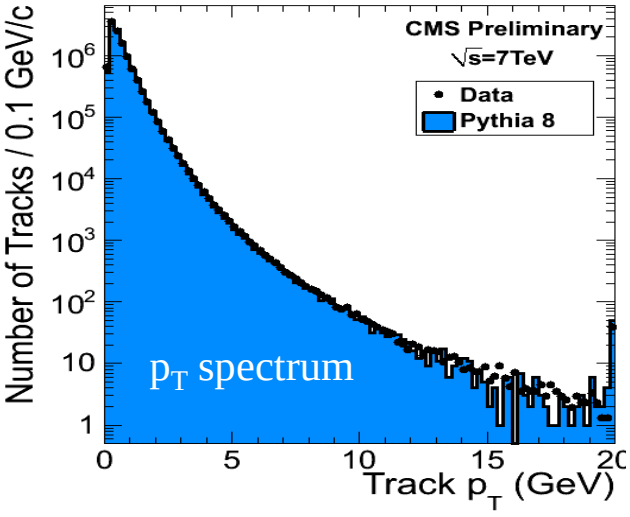
"Global Muons": matched tracks from Muon system and Tracker

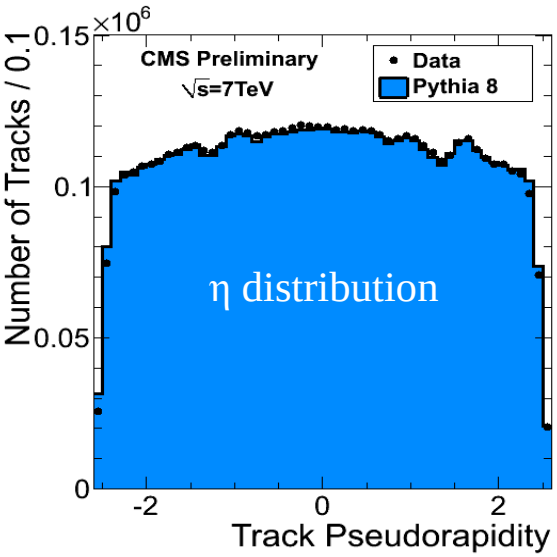


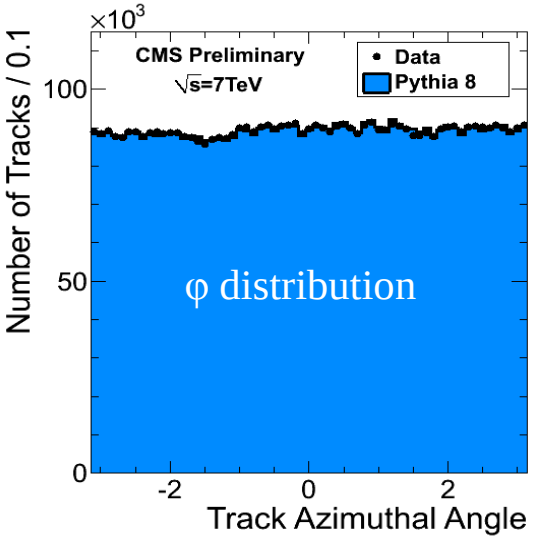


- η and p_T distributions dominated by light hadron decay muons (red)
- good agreement with MC prediction, including
  - heavy flavor decays (blue)
  - punch-through (black)
  - fakes (green)

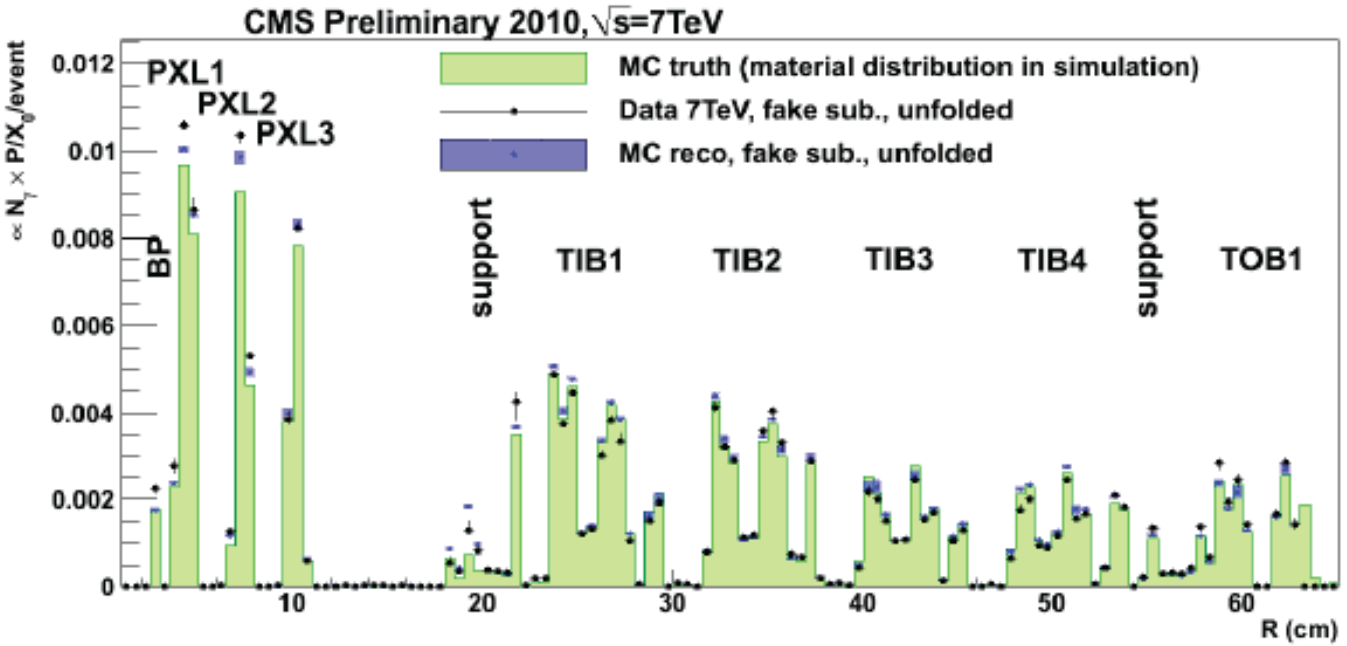
Tracking distributions





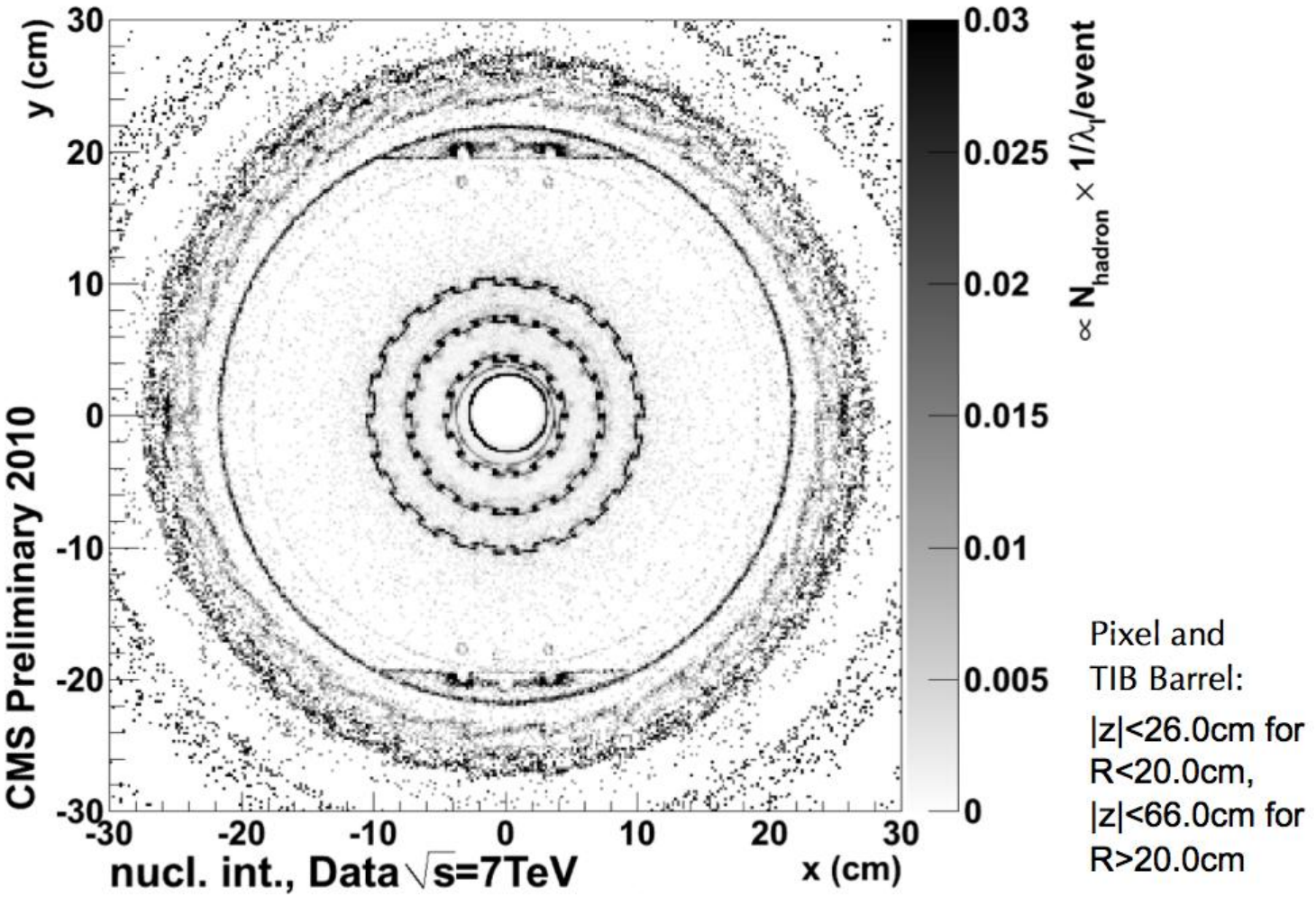


Tracker Material Budget



Distribution of nuclear interactions
in the tracker as a function of radial length

Tomography

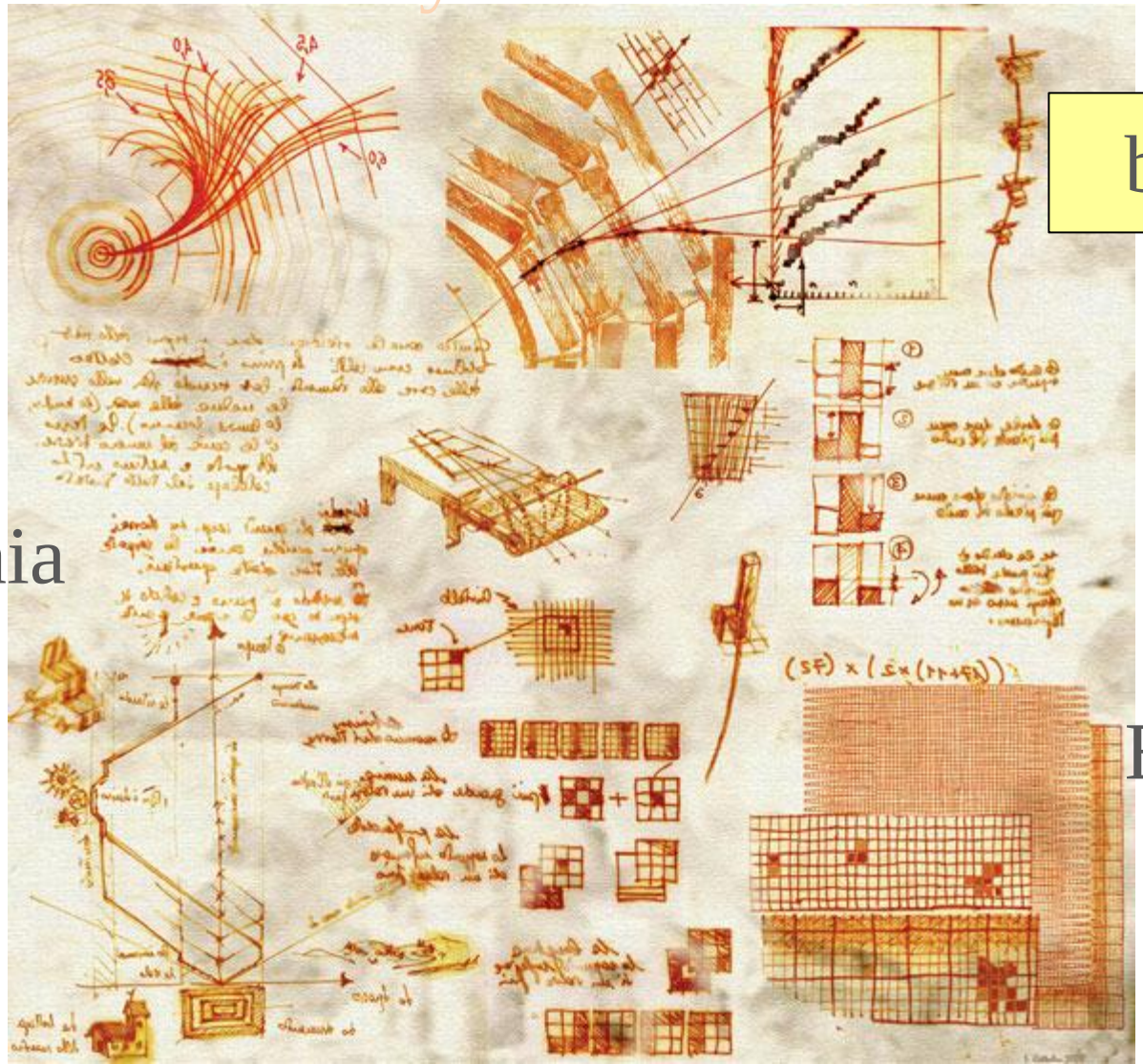

CMS Preliminary 2010
nucl. int., Data $\sqrt{s}$=7TeV
y (cm)
x (cm)
30
20
10
0
-10
-20
-30
-30
-20
-10
0
10
20
30
0.03
0.025
0.02
0.015
0.01
0.005
0
$\propto N_{hadron} \times 1/\lambda_I$/event
Pixel and
TIB Barrel:
|z|<26.0cm for
R<20.0cm,
|z|<66.0cm for
R>20.0cm

Detector & Physics Performance

Calorimetry

Jets

Tracking



b-tagging

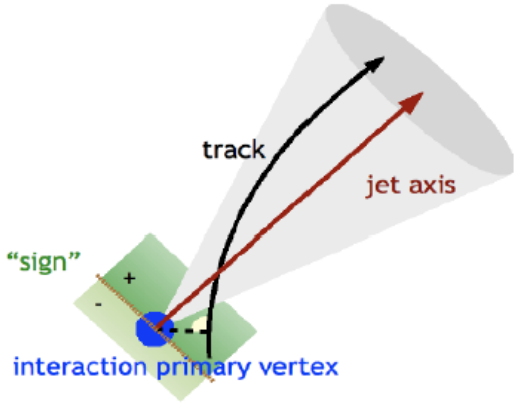
Muon
EWK/Onia

Electron
EWK/Onia

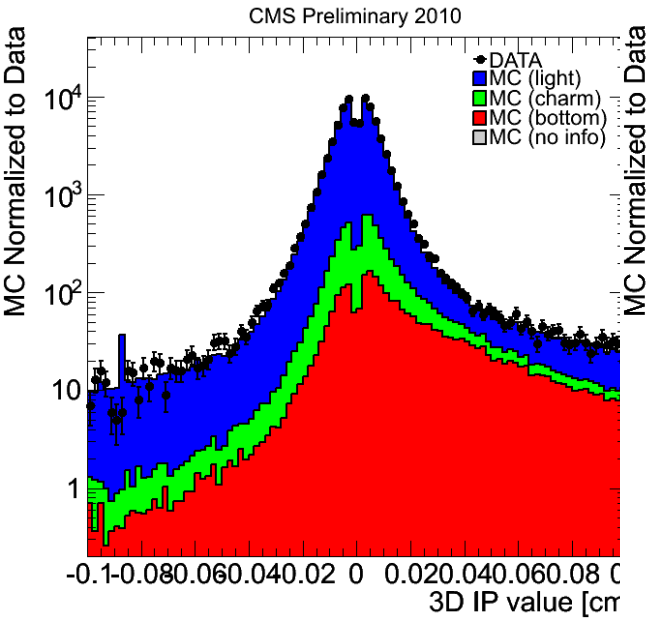
b-tagging 3D IP significance

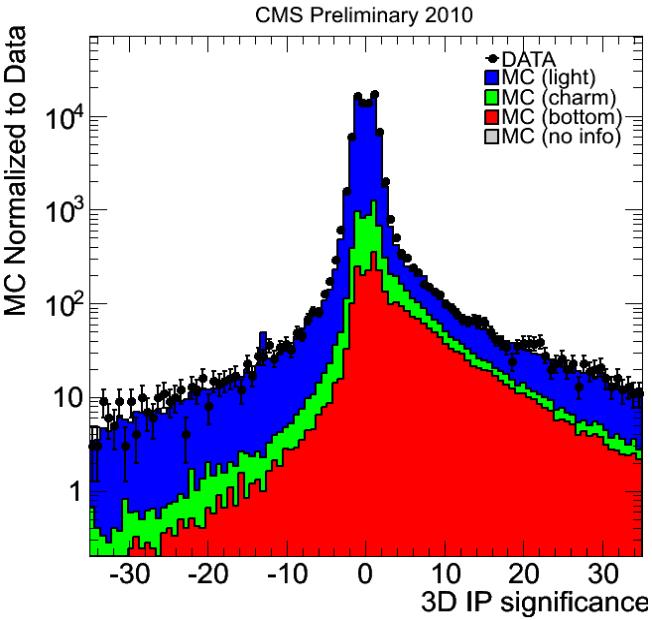
3D impact parameter value and significance

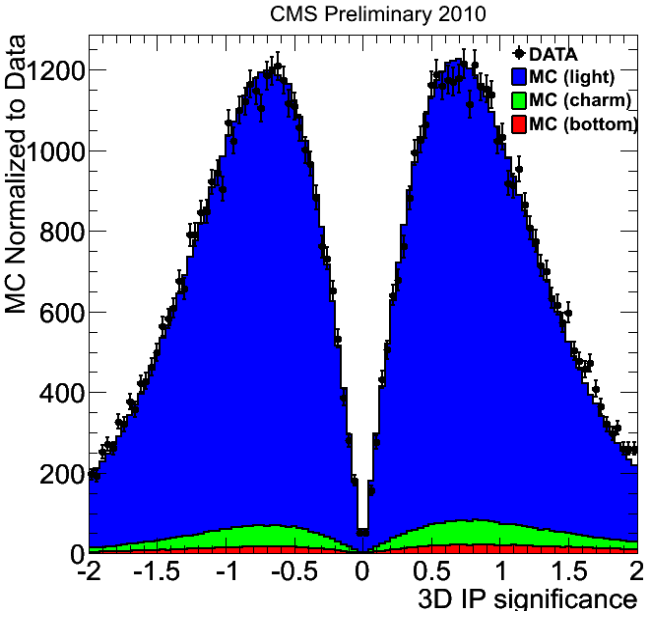
all tracks with p_T> 1GeV belonging to jets with p_T > 40 GeV and $|\eta| < 1.5$ - PFlow Jets anti-k_T R=0.5)



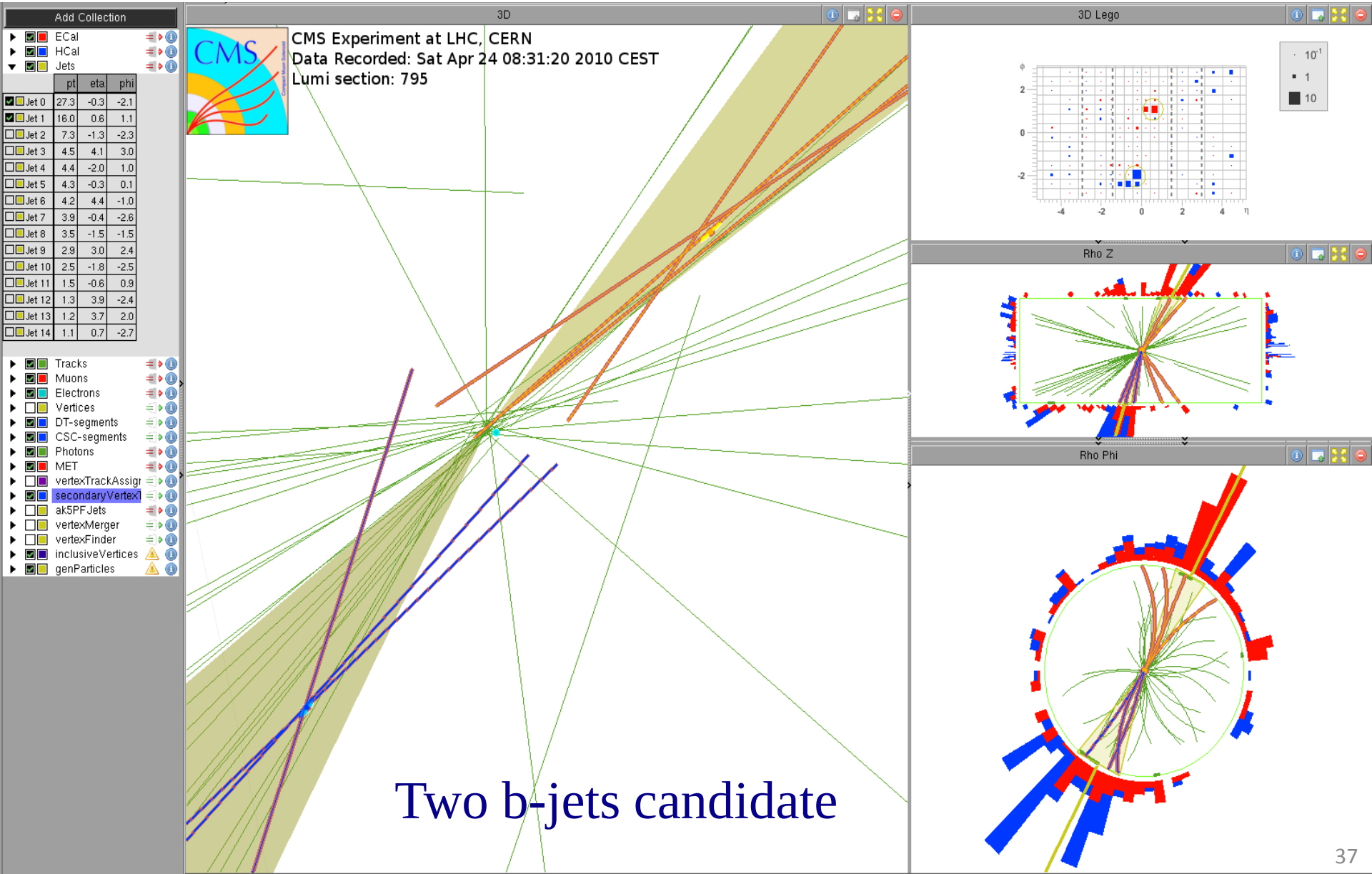
Excellent alignment and general tracking performance

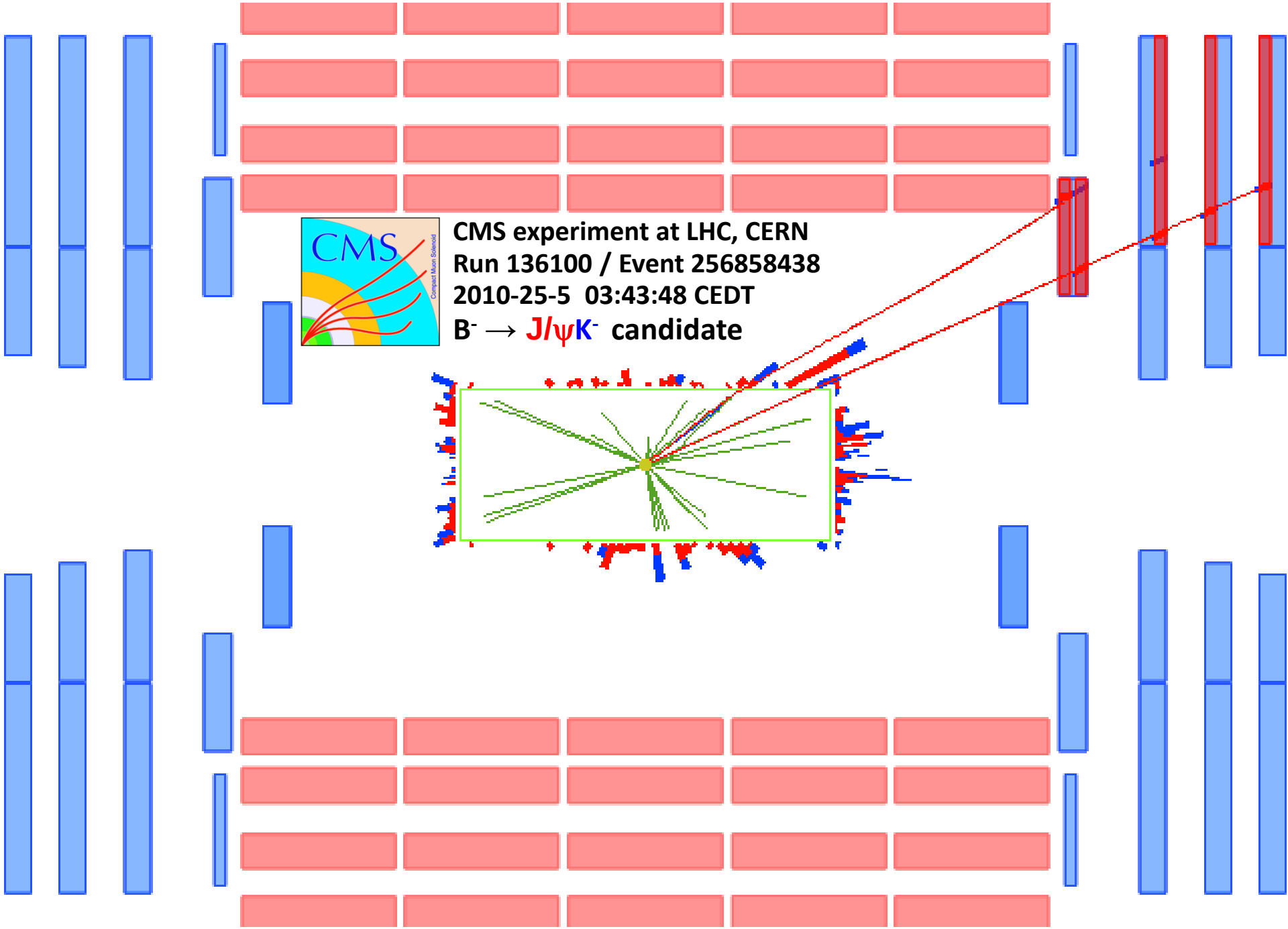


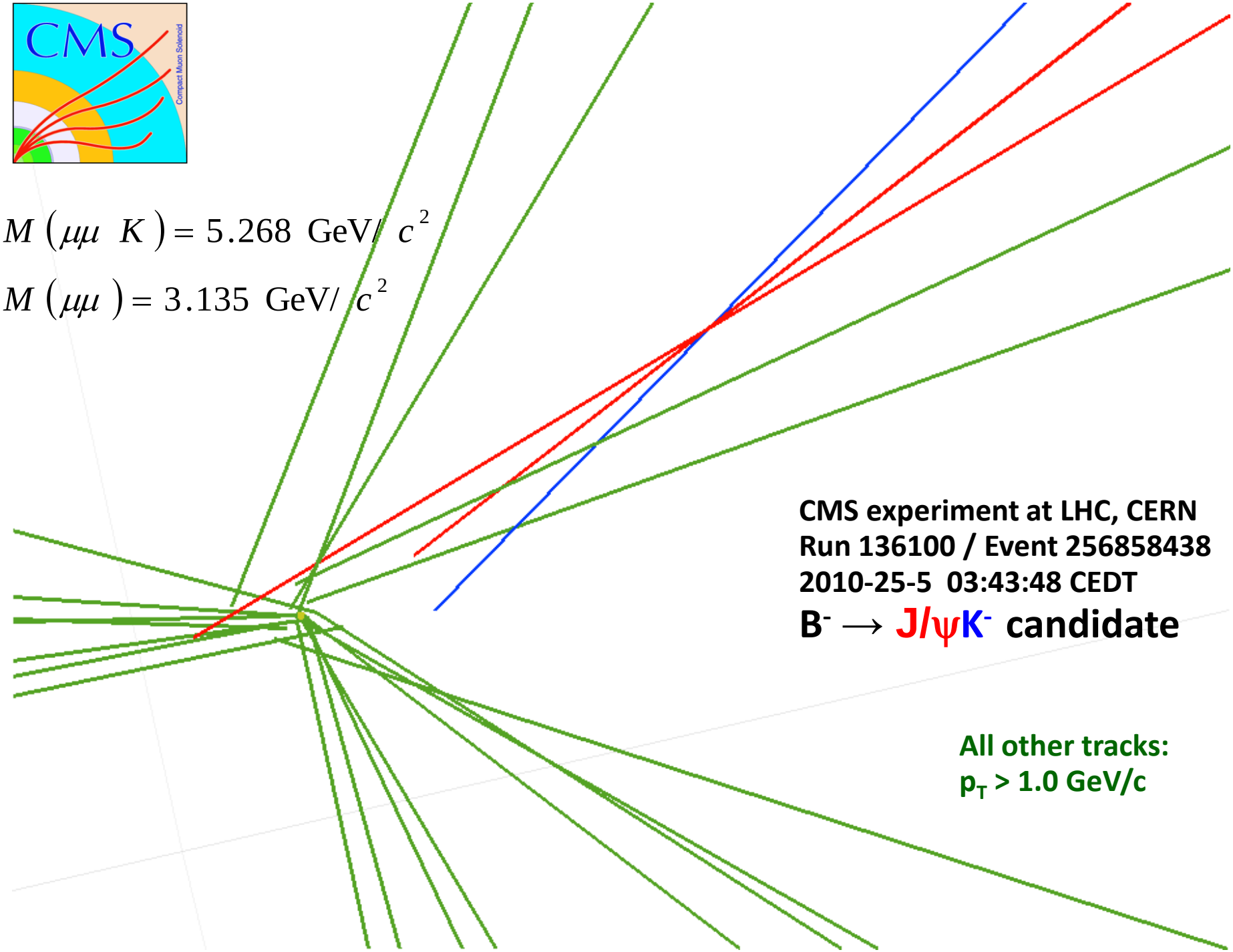




b-tagging example




CMS
Compact Muon Solenoid
CMS experiment at LHC, CERN
Run 136100 / Event 256858438
2010-25-5 03:43:48 CEDT
B⁻ → J/ψK⁻ candidate

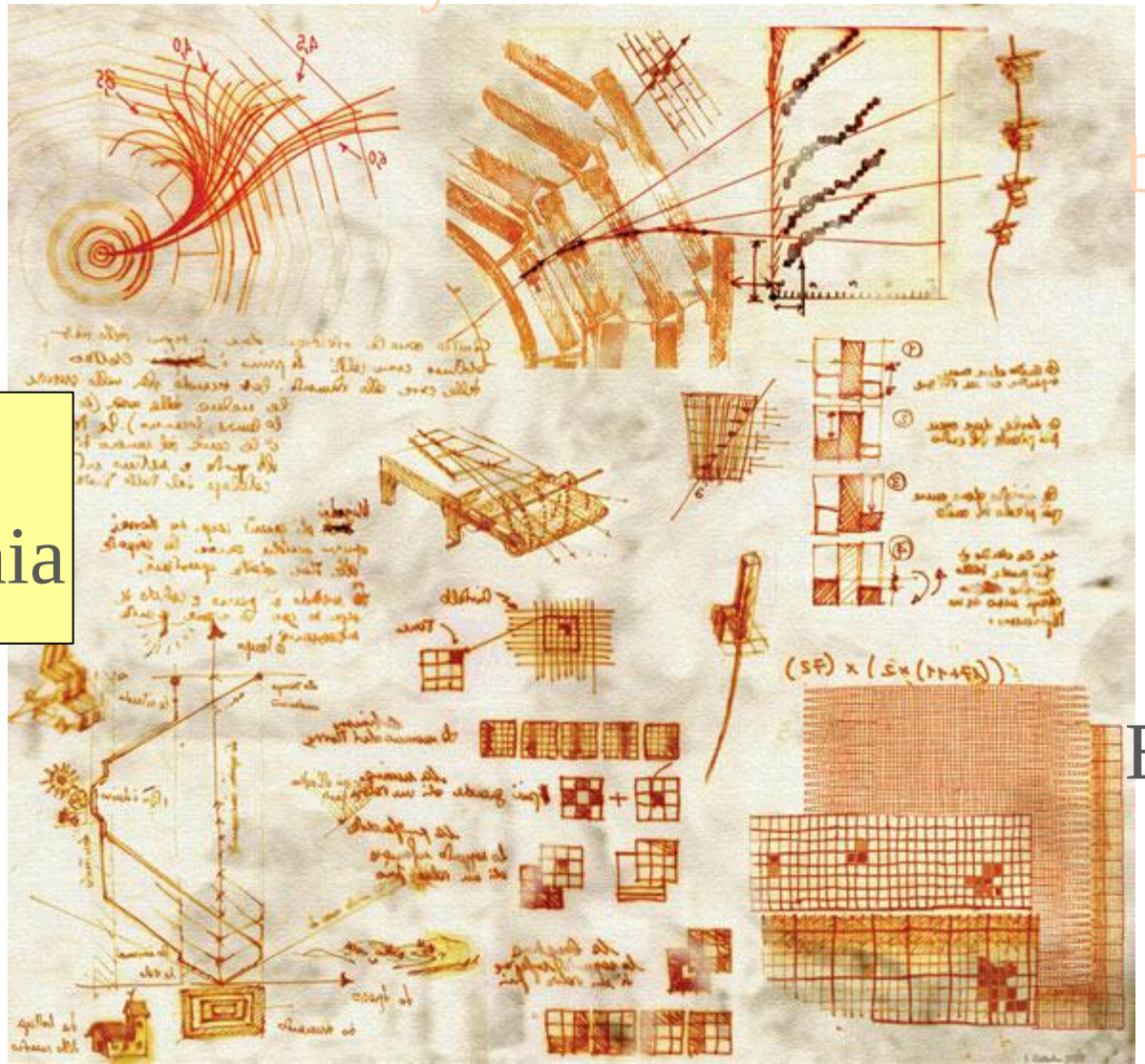

CMS
Compact Muon Solenoid
$M(\mu\mu K) = 5.268\ \text{GeV}/c^2$
$M(\mu\mu) = 3.135\ \text{GeV}/c^2$
CMS experiment at LHC, CERN
Run 136100 / Event 256858438
2010-25-5 03:43:48 CEDT
$B^- \rightarrow J/\psi K^-$ candidate
All other tracks:
$p_T > 1.0$ GeV/c

Detector & Physics Performance

Calorimetry

Jets

Tracking

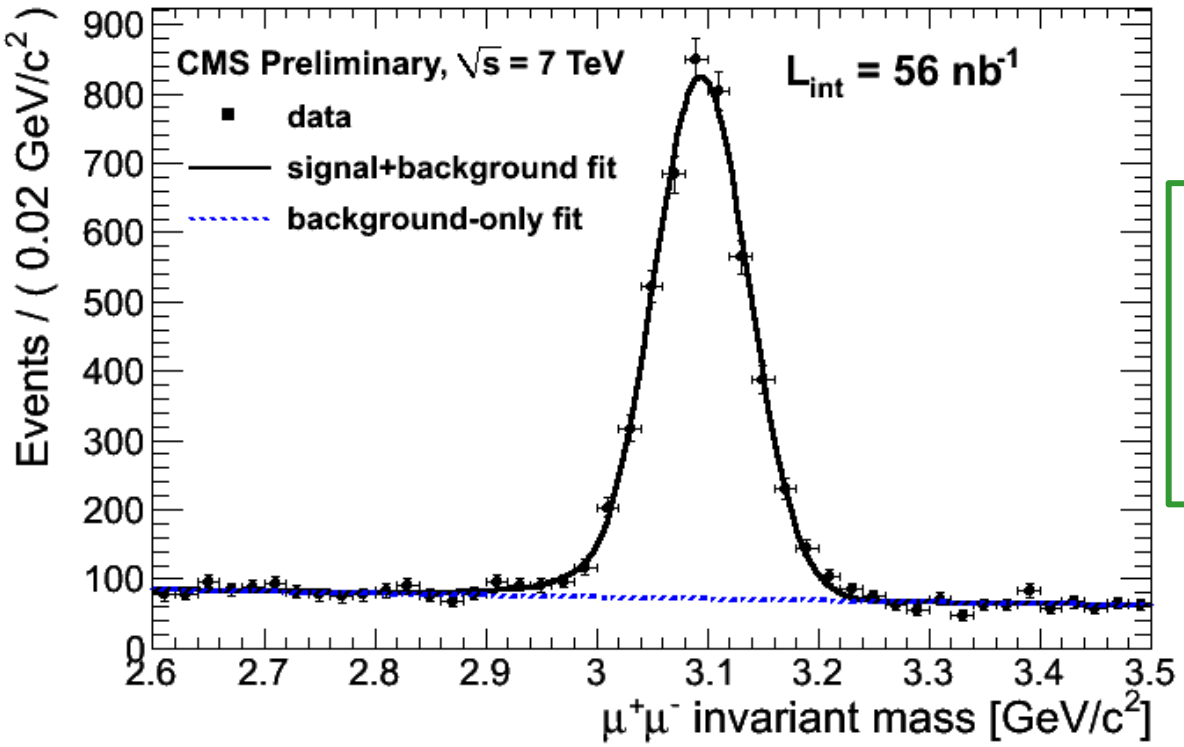


b-tagging

Muon
EWK/Onia

Electron
EWK/Onia

$J/\psi \rightarrow \mu^+\mu^-$



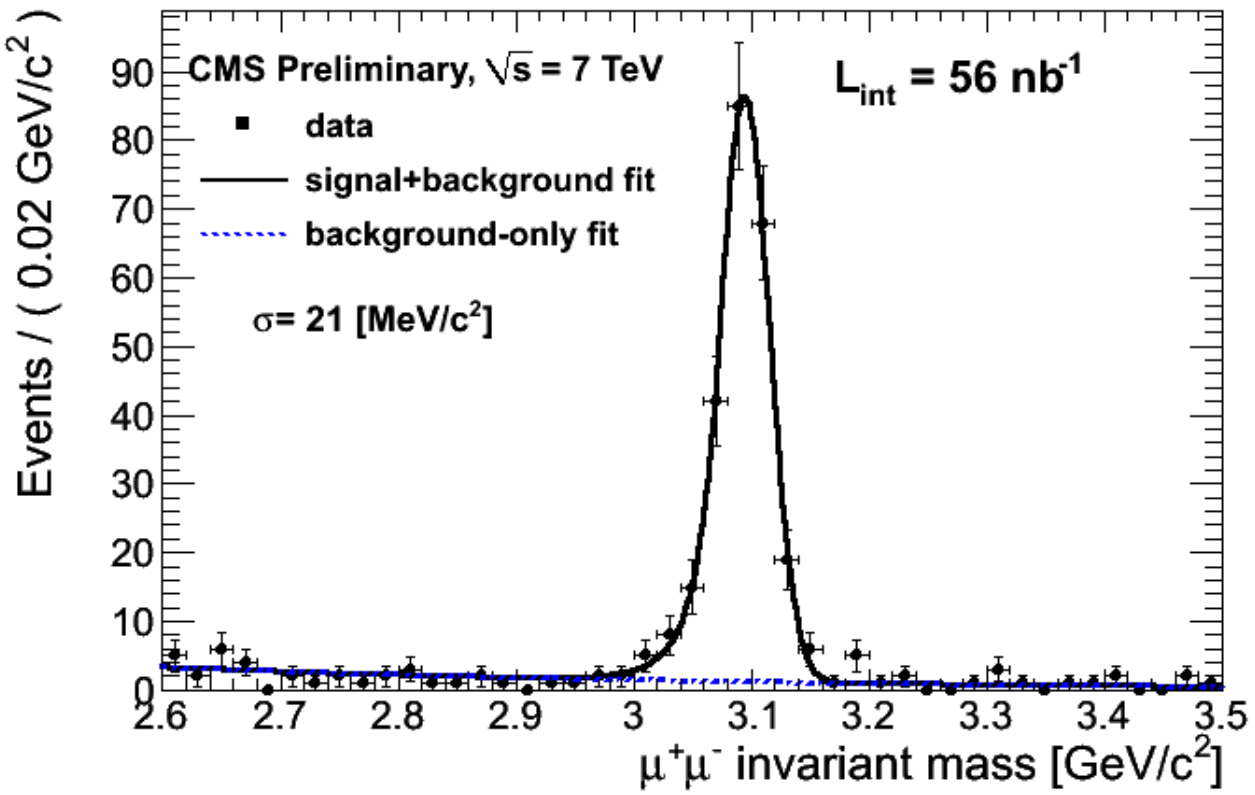
56 nb^{-1}

Signal events: 4150 ± 222
Sigma: 43.1 ± 1.9 (stat.) MeV
M_0 : 3.094 ± 0.001 (stat.) GeV
S/B= 5.2
$\chi^2/N_{dof} = 1.0$

Ongoing studies:

- Momentum scale corrections by studying mass as a function of η, p_T (material budget)
- Efficiency studies with tag-n-probe
- Flight distance with determination of prompt and $b \rightarrow J/\psi + X$ terms

$J/\psi \rightarrow \mu^+\mu^-$: The Best Of

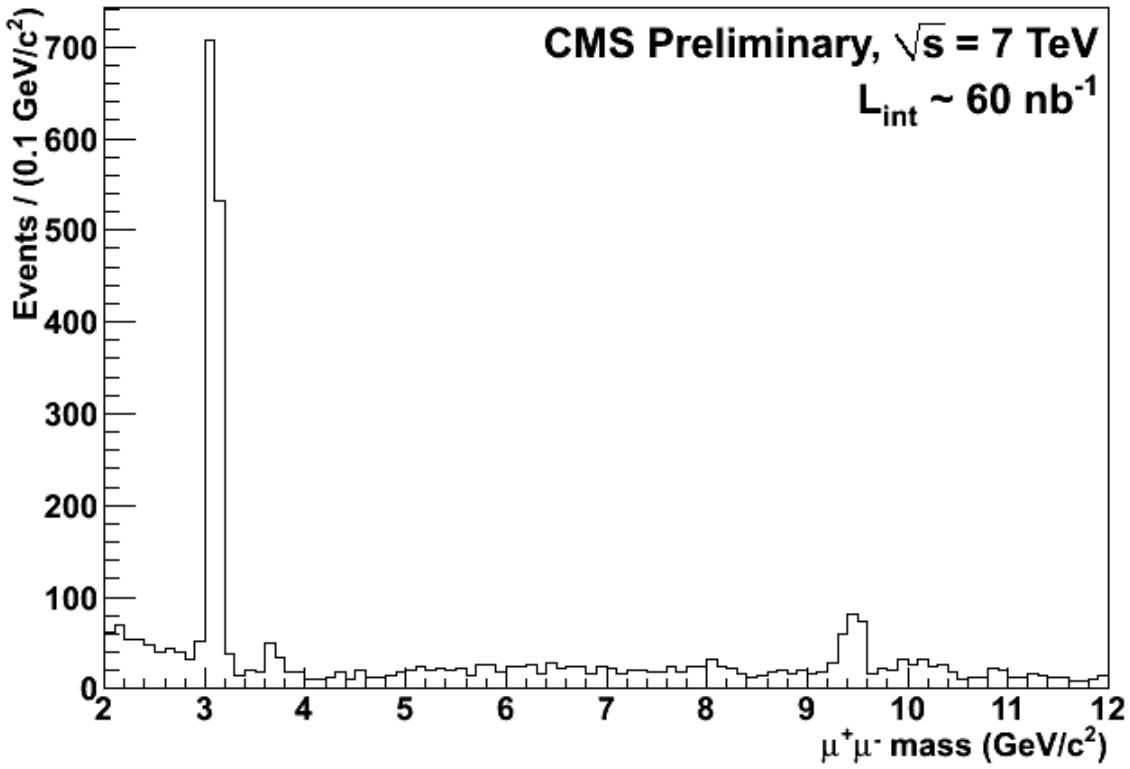


56 nb^{-1}

Selection of central (barrel), high-quality dimuons:

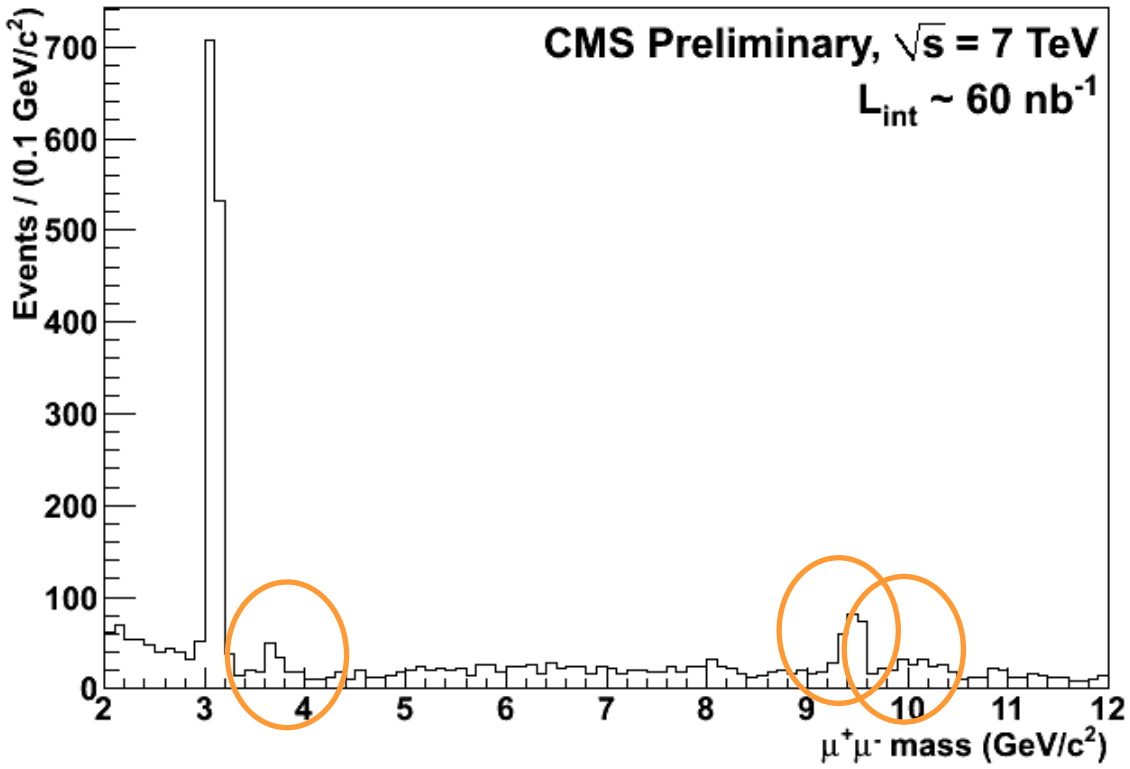
- Resolution: 43.1 MeV → 21.0 MeV

$J/\psi \rightarrow \mu^+\mu^-$ and friends



60 nb^{-1}

$J/\psi \rightarrow \mu^+\mu^-$ and friends

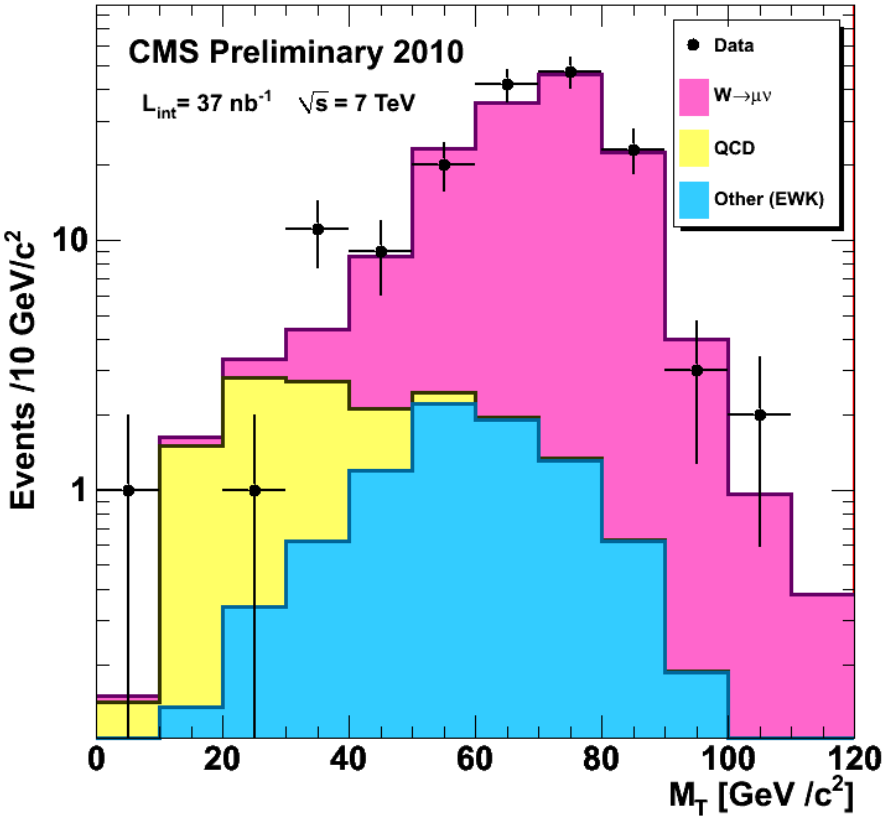


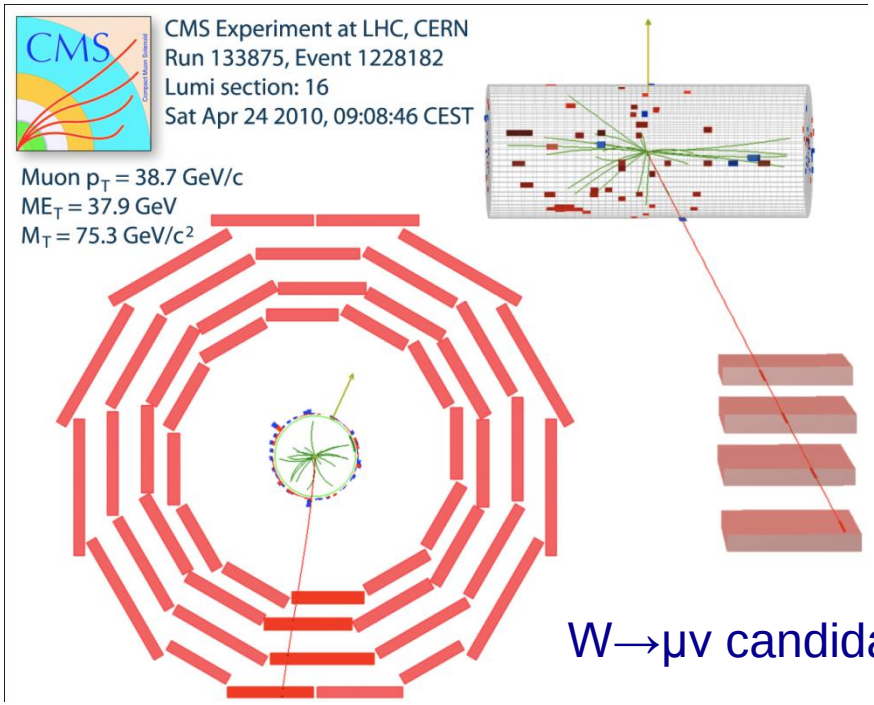
60 nb^{-1}

Not enough statistics to disentangle all resonances (yet)

W →μ ν observation

- Event selection:
  - Muon id cuts
  - Isolation, p_T and MET cuts
- Monte Carlo: Event count normalized to integrated luminosity





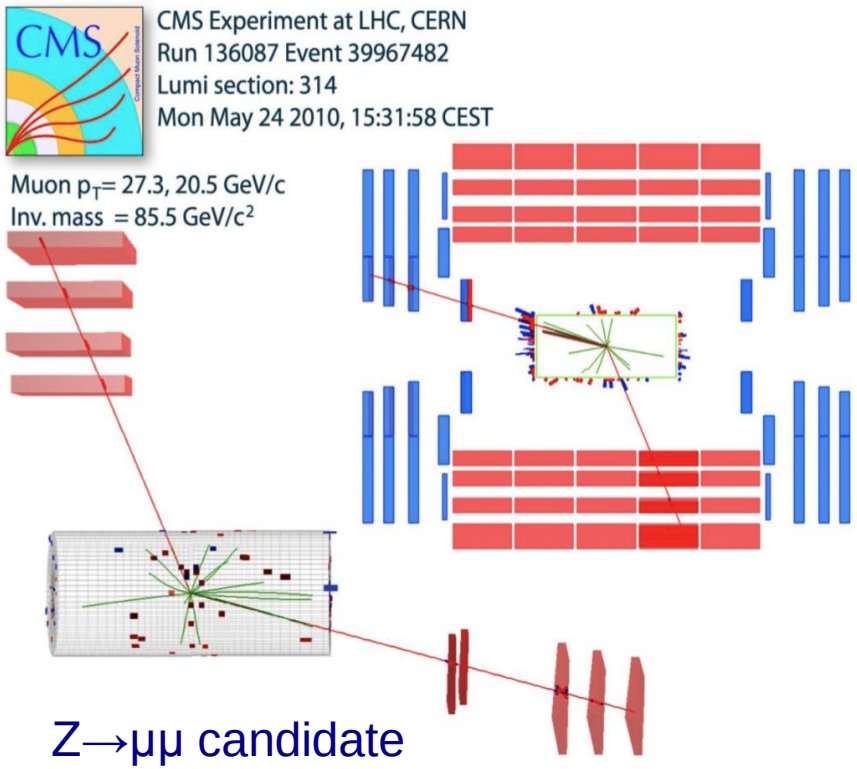
W→μν candidate

# of candidate (M_T > 50 GeV) = 137
# of expected signal (M_T > 50 GeV) = 128
# of expected background (M_T > 50 GeV) = 7

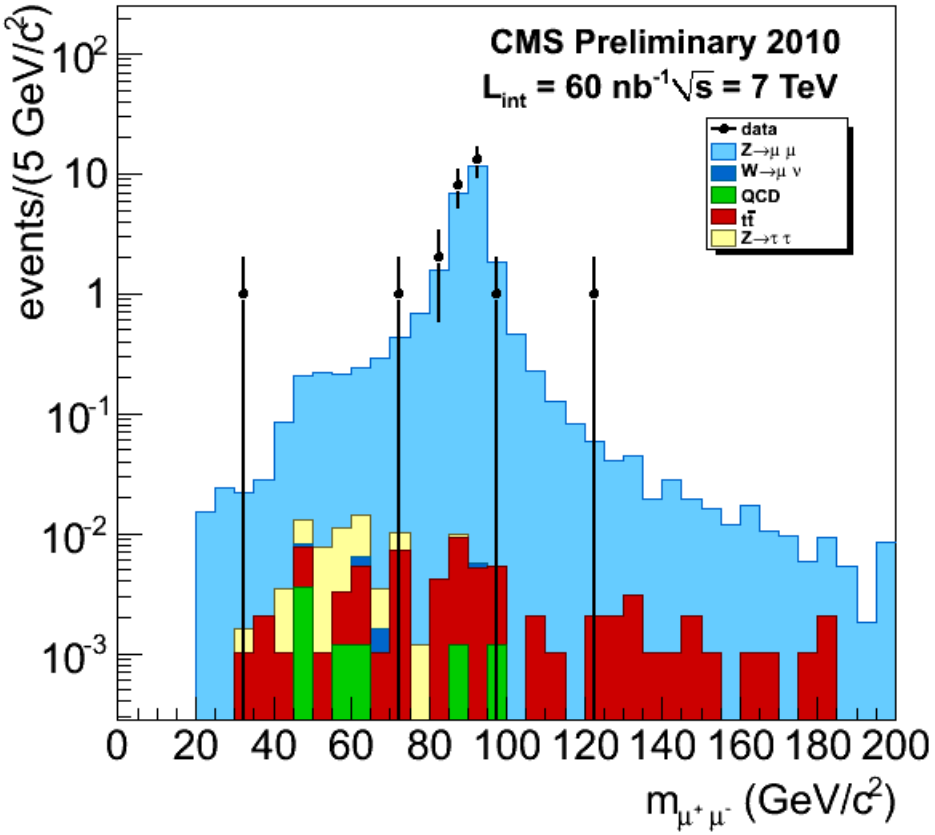
37 nb^{-1}

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

- Event selection:
  - Muon id cuts
  - Loose isolation, p_T cuts
- Monte Carlo: Event count normalized to integrated luminosity



Z→μμ candidate



#of candidate = 25
#of expected signal = 24.7
#of expected background = 0.08

60 nb^{-1}

Detector & Physics Performance

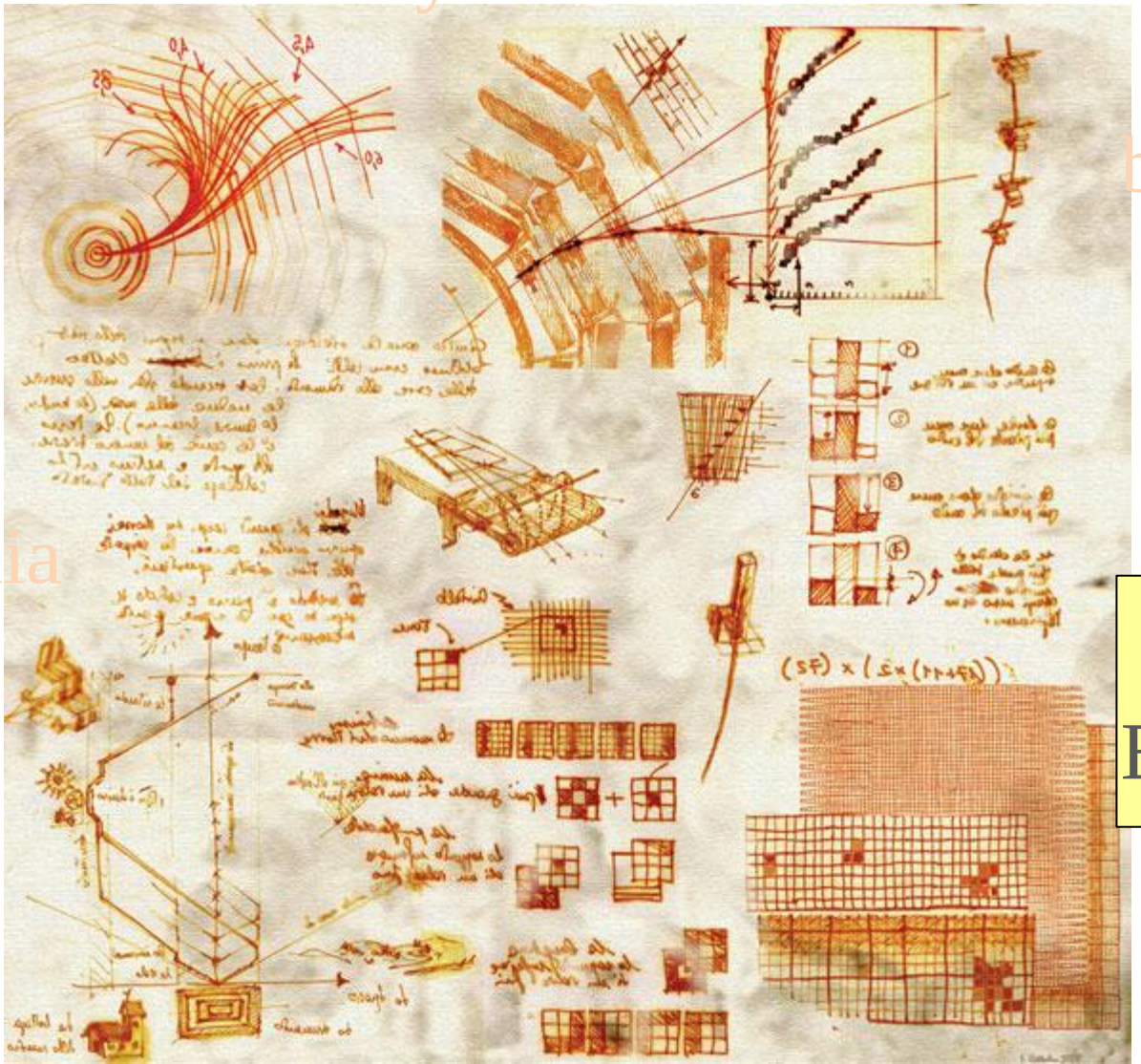
Calorimetry

Jets

Tracking

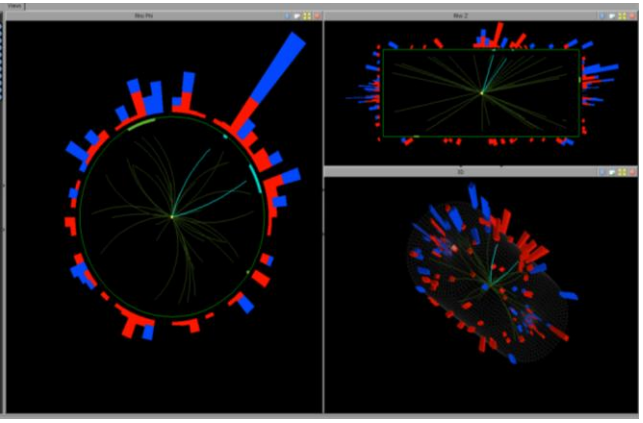
b-tagging

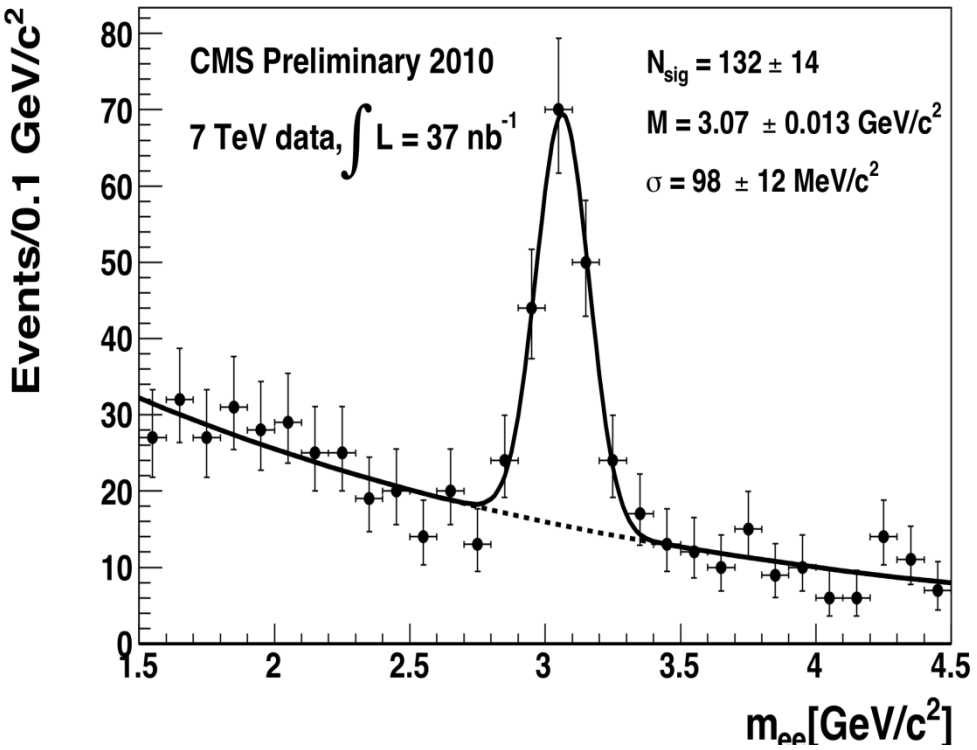
Muon
EWK/Onia



Electron
EWK/Onia

$J/\psi \rightarrow e^+e^-$





37 nb^{-1}

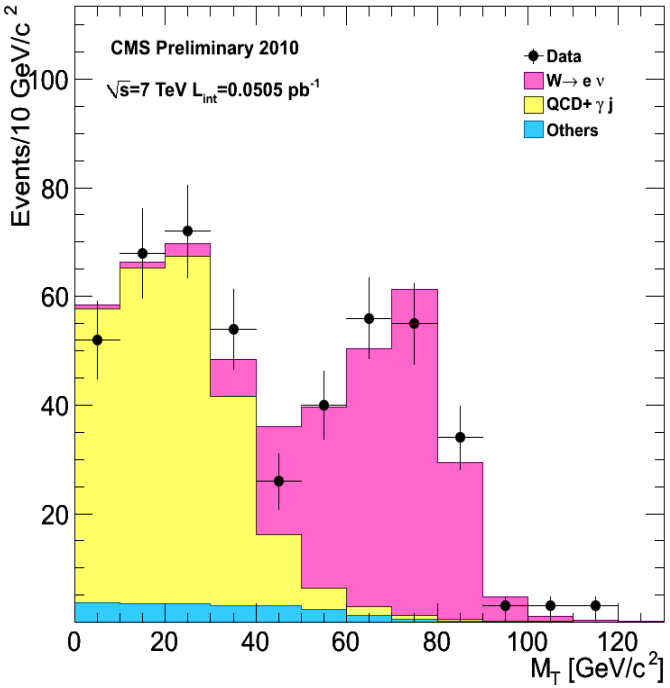
Signal events: 132 ± 14
Sigma: 98 ± 12 (stat.) MeV
M_0 : 3.070± 0.013 (stat.) GeV

- Higher background, tighter selection compared to muon channel
- Challenging analysis, Particle-Flow selection crucial
- Very promising preliminary results, signal clearly established

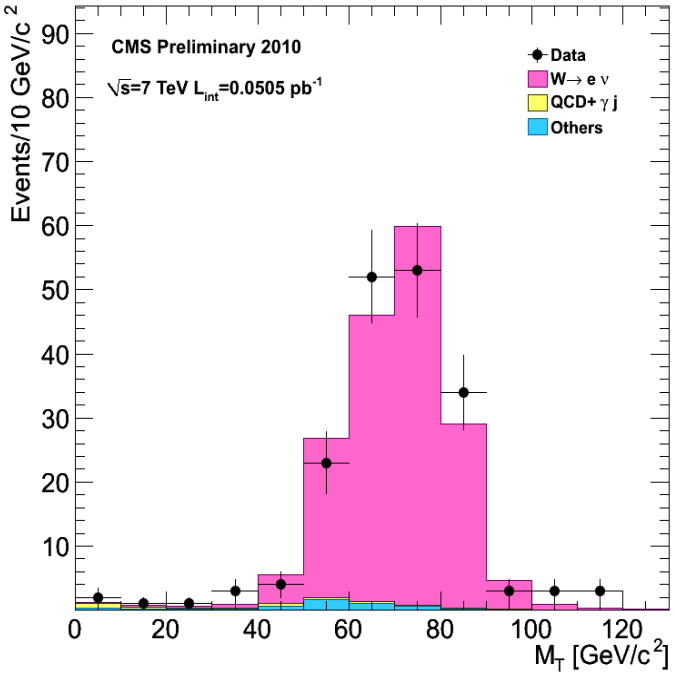
W →e ν observation

Two event selections:

- Basic electron ID, no MET cuts
- More advanced electron ID, cuts on E_T, MET, ΣE_T



196 candidates with $M_T > 50$ GeV
MC: Sig =176, Bkg =11

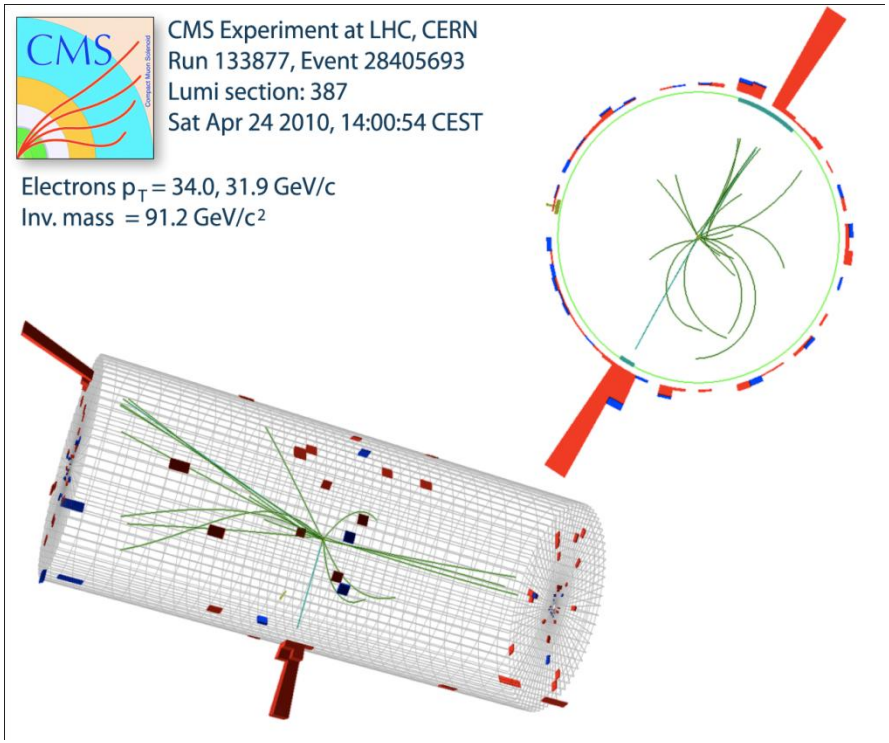


173 candidates with $M_T > 50$ GeV
MC: Sig=163, Bkg=5

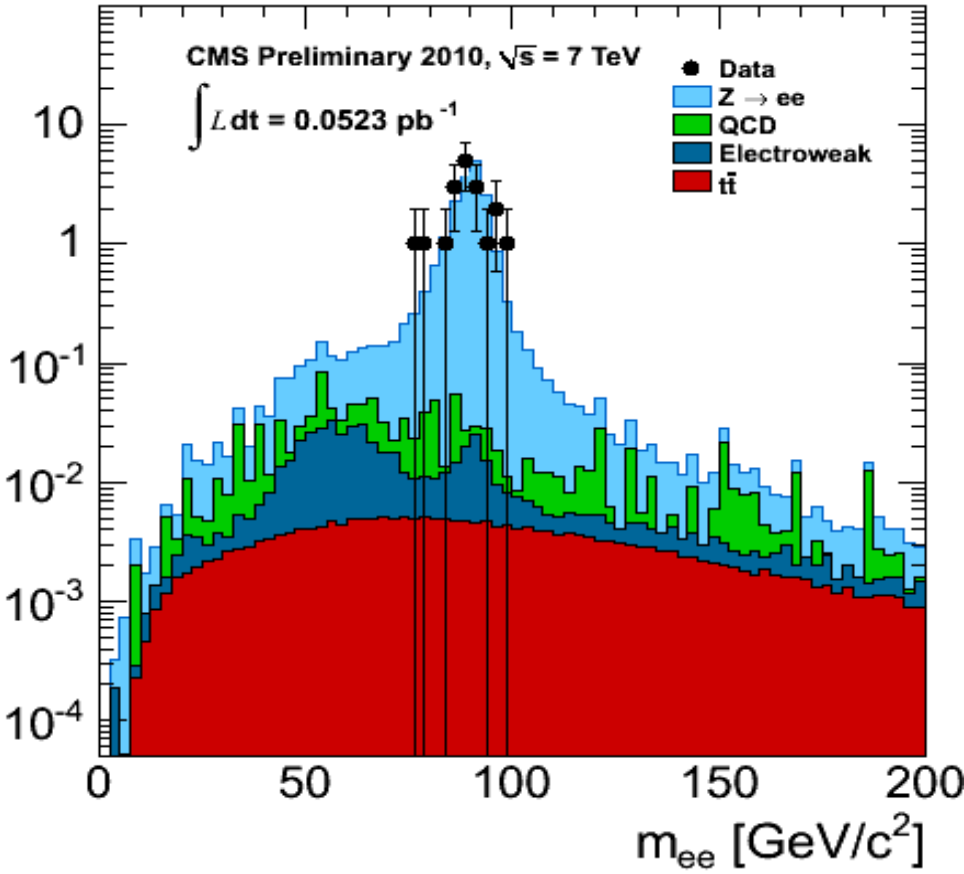
51 nb^{-1}

$Z \rightarrow e^+e^-$ observation

- Event selection:
  - Two electrons with $E_T > 20$ GeV
- Monte Carlo: Event count normalized to integrated luminosity



Z→ee candidate



#of candidate = 18
#of expected signal = 19
#of expected background = 0.8

52 nb^{-1}

Summary

7 TeV collisions: a very exciting run!

- The CMS detector is working according to design
  - First performance results are very encouraging
  - Its behavior can be reproduced in Monte Carlo simulation
  - Our level of understanding for this early commissioning phase is very advanced

- The "rediscovery" of the SM has begun
- We are setting the grounds for challenging it as early as the end of 2010

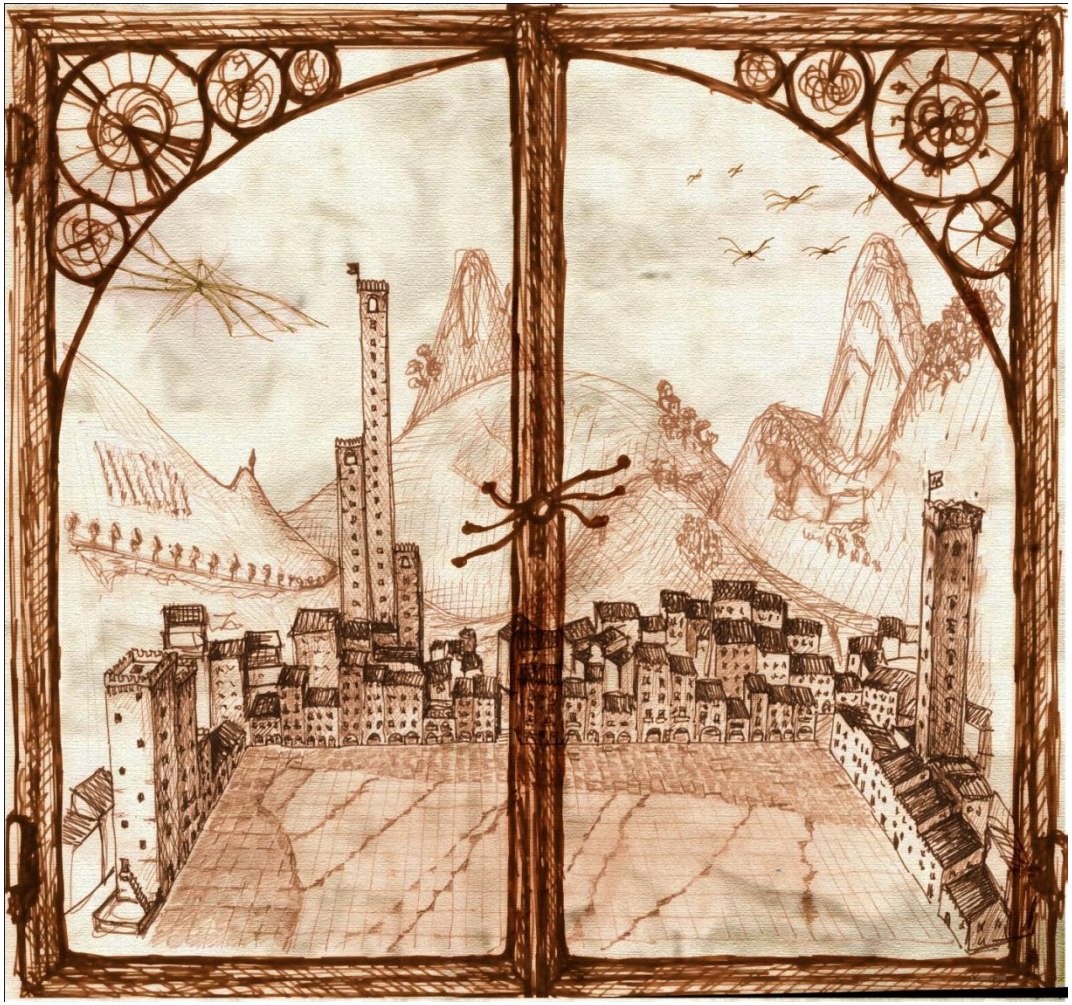
Epilogue

- The technology of the LHC accelerator and experiments is unprecedented

- Massive amount of work and preparation invested in building and commissioning hardware & software
- But: we do not forget that the real challenges are still ahead (for all of us)

- We should consider this truly exciting period as the beginning of a marathon

The Beginning of The Journey

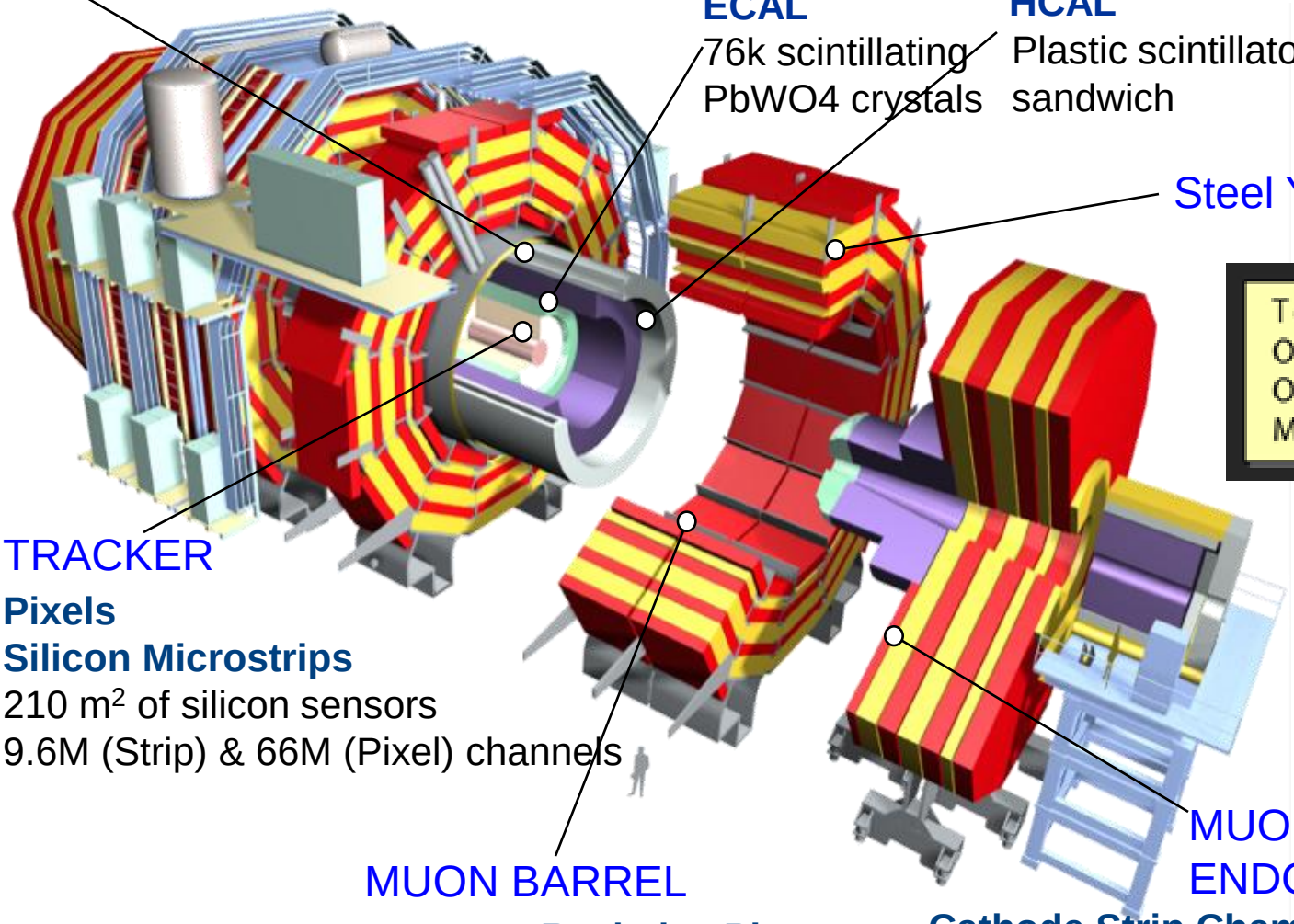


Credit for "Da Vinci" drawings: Sergio Cittolin

Credit for material used in this talk: LHC, CMS

Backup

The CMS Detector



Superconducting Coil, 4 Tesla

CALORIMETERS

ECAL
76k scintillating PbWO4 crystals

HCAL
Plastic scintillator/brass sandwich

Steel YOKE

Total weight : 12500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

TRACKER

Pixels

Silicon Microstrips
210 m^2 of silicon sensors
9.6M (Strip) & 66M (Pixel) channels

MUON BARREL

Drift Tube Chambers (DT)

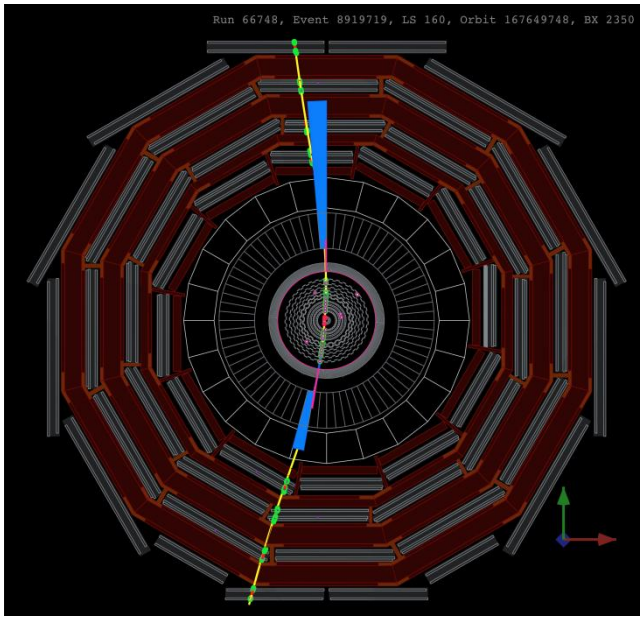
Resistive Plate Chambers (RPC)

MUON ENDCAPS

Cathode Strip Chambers (CSC)
Resistive Plate Chambers (RPC)

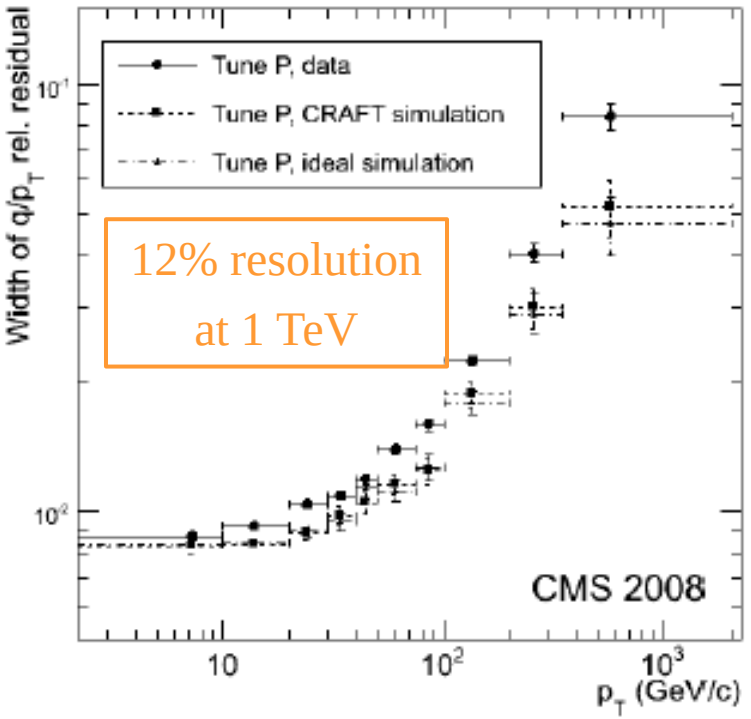
Muon p_T resolution with cosmics

1B events of (mostly muon) cosmic events collected make muons the best understood reconstructed object in CMS



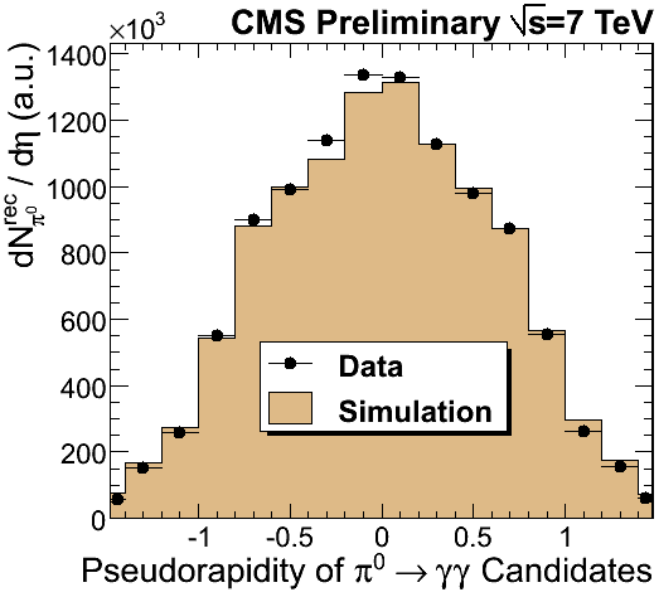
$$R(q/p_T) = \frac{(q/p_T)^{\text{upper}} - (q/p_T)^{\text{lower}}}{\sqrt{2}(q/p_T)^{\text{lower}}}$$

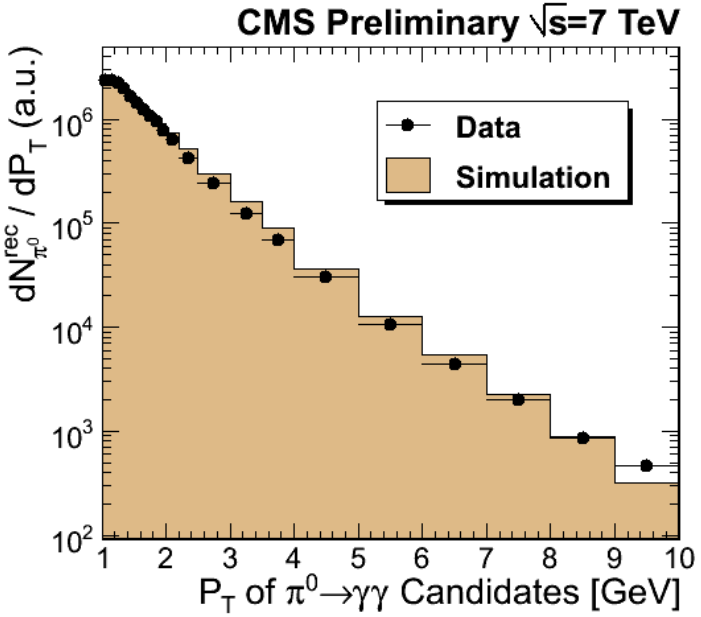
Compare muon p_T in upper, lower detector halves to evaluate resolution



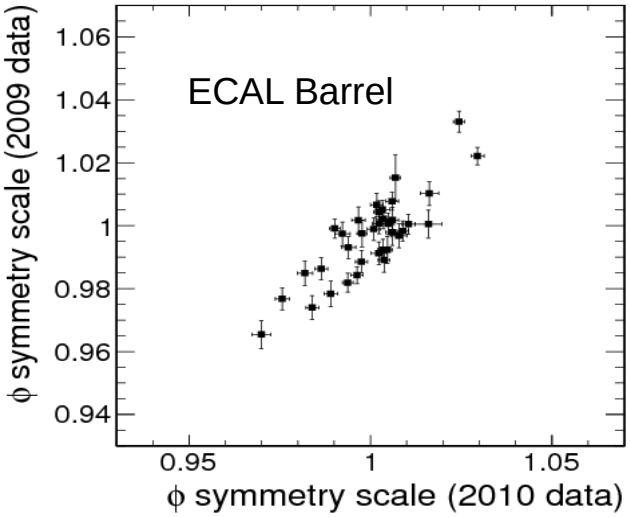
π^0s and ECAL calibration

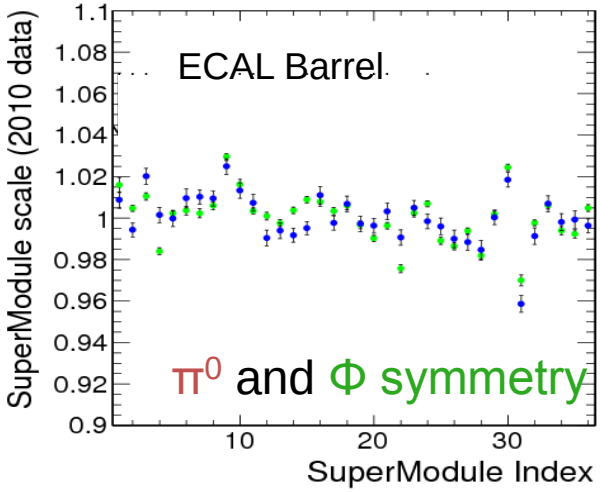
$\pi^0 \rightarrow \gamma\gamma$
η, Φ distributions





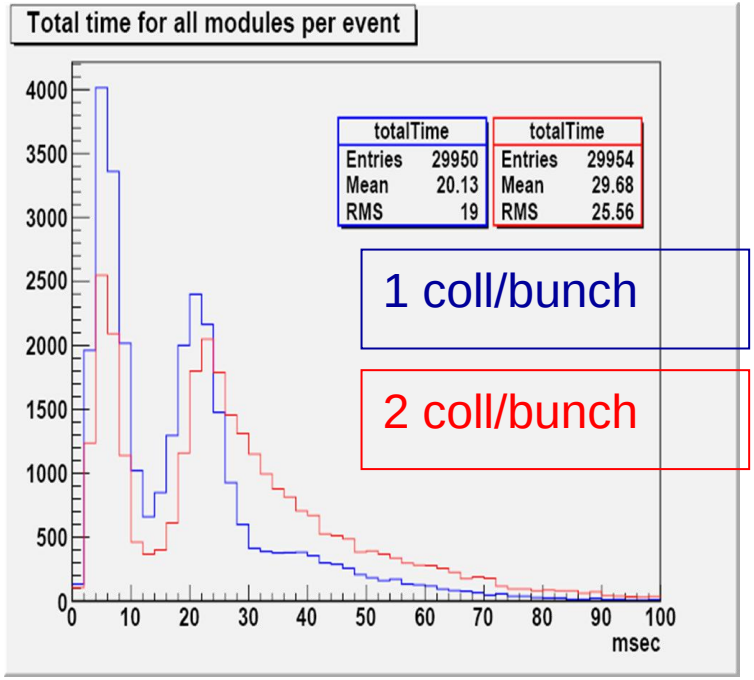
Relative calibration
precision ~ 2%
target ~ 0.5% at 10pb^{-1}





HLT: CPU performance & pile-up

- First look at impact of pileup on CPU-performance



- Have deployed “multiple-vertex” trigger to facilitate pile-up studies with real data

$J/\psi \rightarrow \mu^+\mu^-$

- Run range: 132440-139370
- Common selection:
  - No scraping
  - Tracker Muons of opposite charge
  - Pixel layers >= 2
  - Tracker hits >= 12
  - Tracker chi2 < 3
  - Mu pT > 2.5
  - Mu segments >=2
  - Matched L1DoubleMuOpen
  - vertex Prob > 0.05

Run 136100, Event 256858438

- Measured Parameters:

$M(\mu\mu K) = 5.268\ \text{GeV}/c^2$

$M(\mu\mu) = 3.135\ \text{GeV}/c^2$

$p_T(B) = 18.6\ \text{GeV}/c$

$p_T(\mu^+) = 10.1\ \text{GeV}/c$

$p_T(\mu^-) = 3.4\ \text{GeV}/c$

$p_T(K^-) = 5.3\ \text{GeV}/c$

$\text{Prob}(\chi^2) = 0.844$

$L_{xy} = 1.93\ \text{mm}$

$\sigma(L_{xy}) = 0.11\ \text{mm}$

$L_{xy}/\sigma(L_{xy}) = 18$

3-trk vertex that is displaced from the PV by 2mm (18σ).

Our background is dominated by real J/ψ