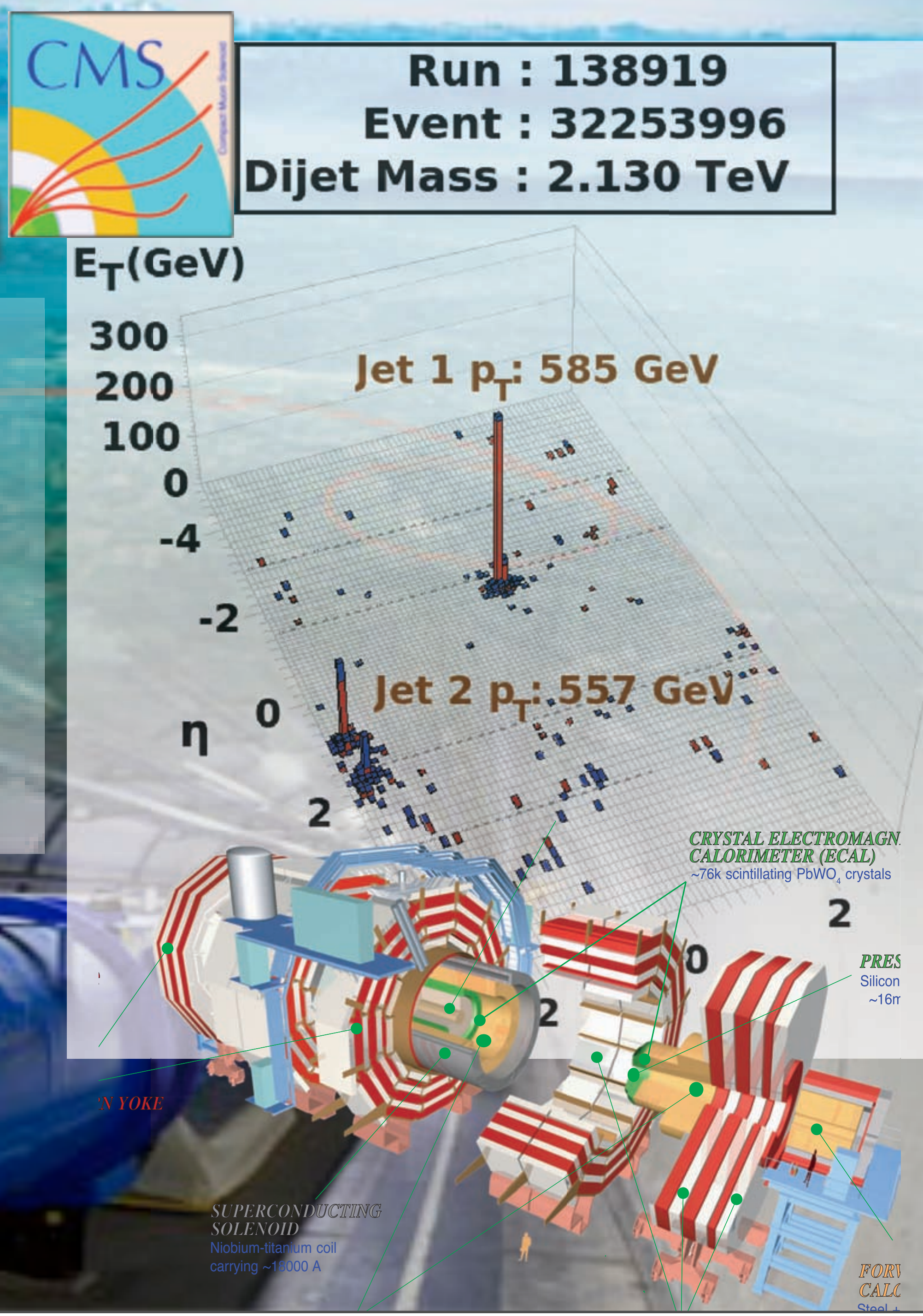
Recent Results from



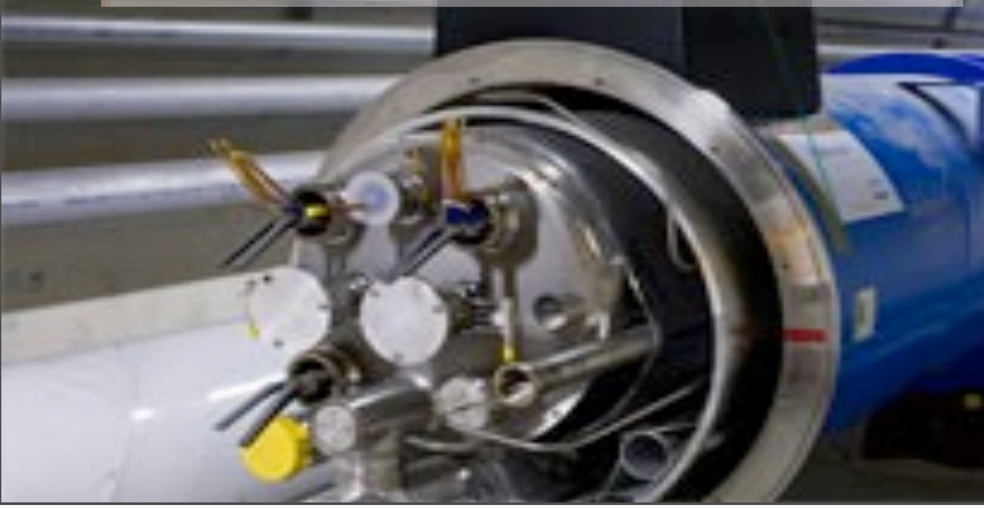
Greg Landsberg

BROWN UNIVERSITY

ATLAS Americas Meeting

U of Texas, Arlington

August 9, 2010



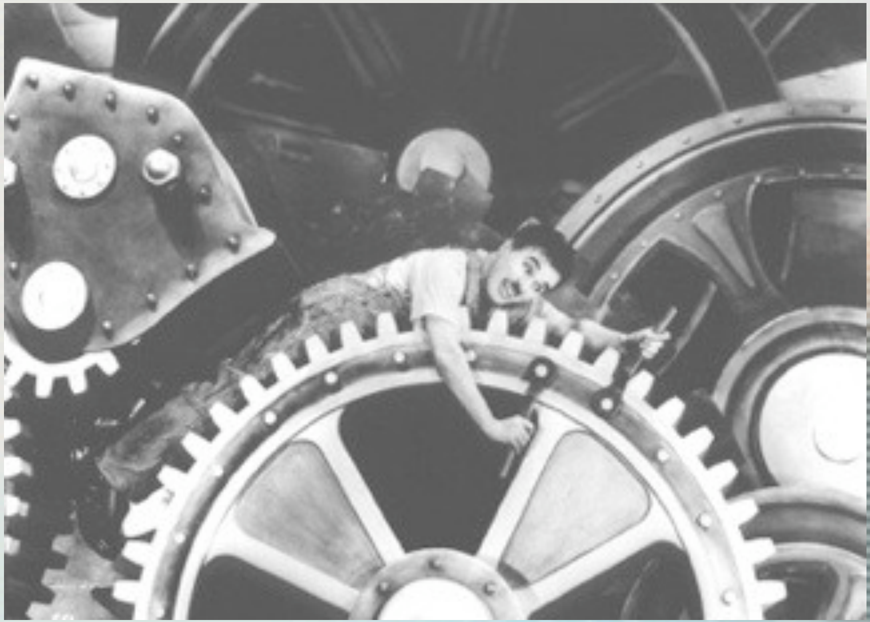
Outline

- CMS Performance
- Soft Physics at CMS
- Standard Model Measurements
- First Searches
- To the Top
- Conclusions

- Can’t cover all the 24 Physics Analyses Summaries available publicly and 21 more notes on detector performance - will just highlight the most recent (ICHEP) selected results
- Please refer to: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults for more details

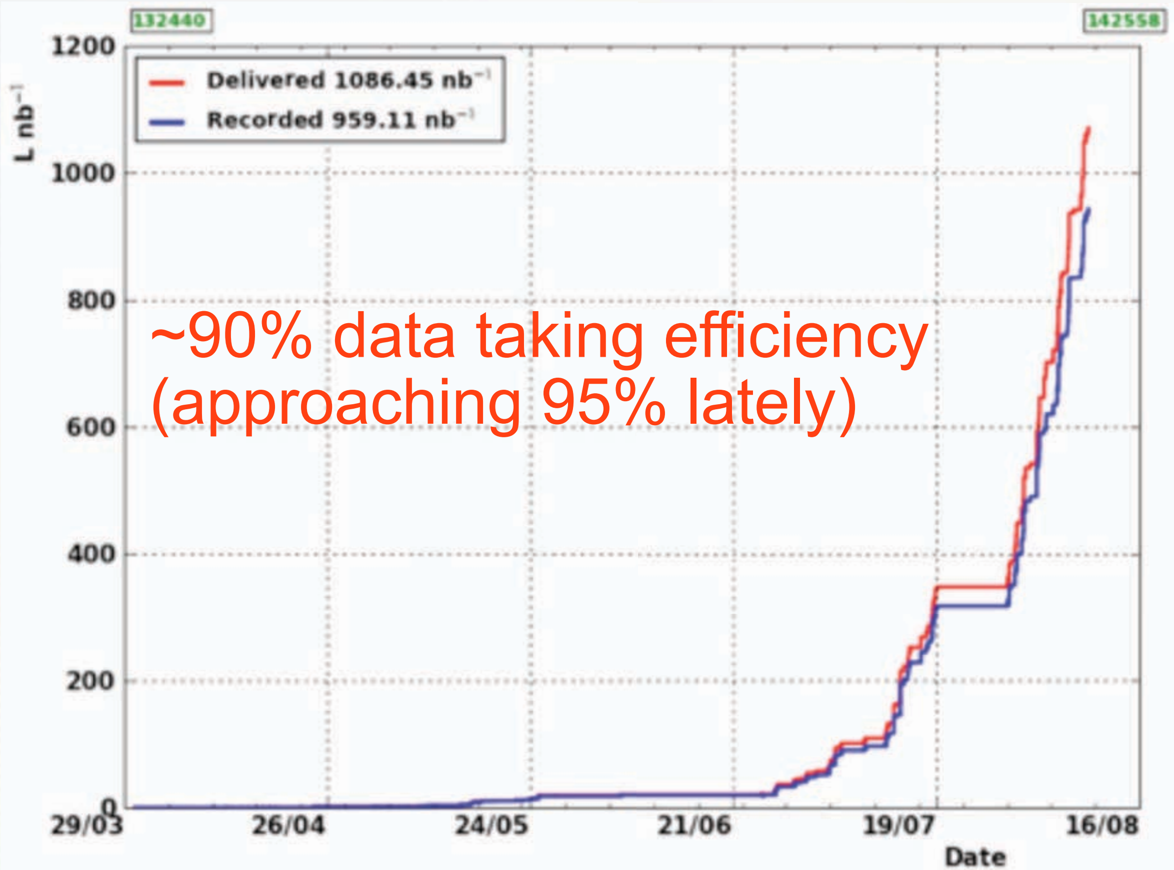
The Machine

The LHC

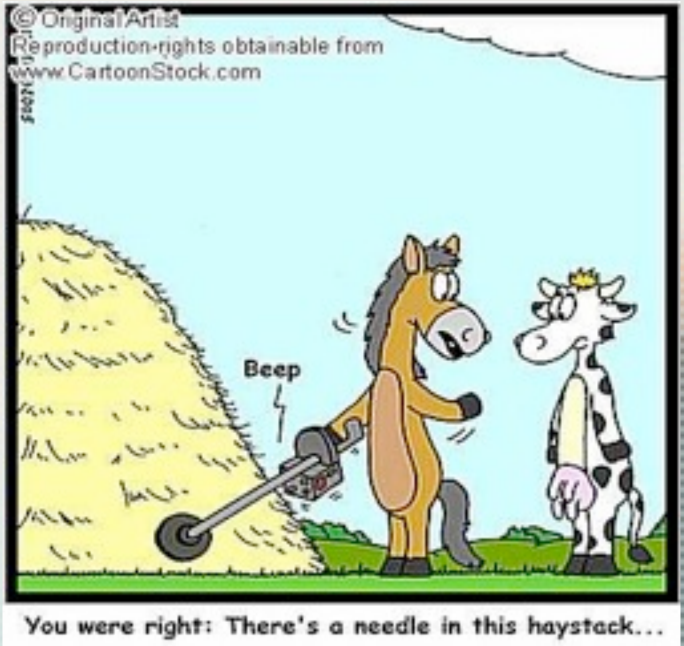


Thank You, the LHC!

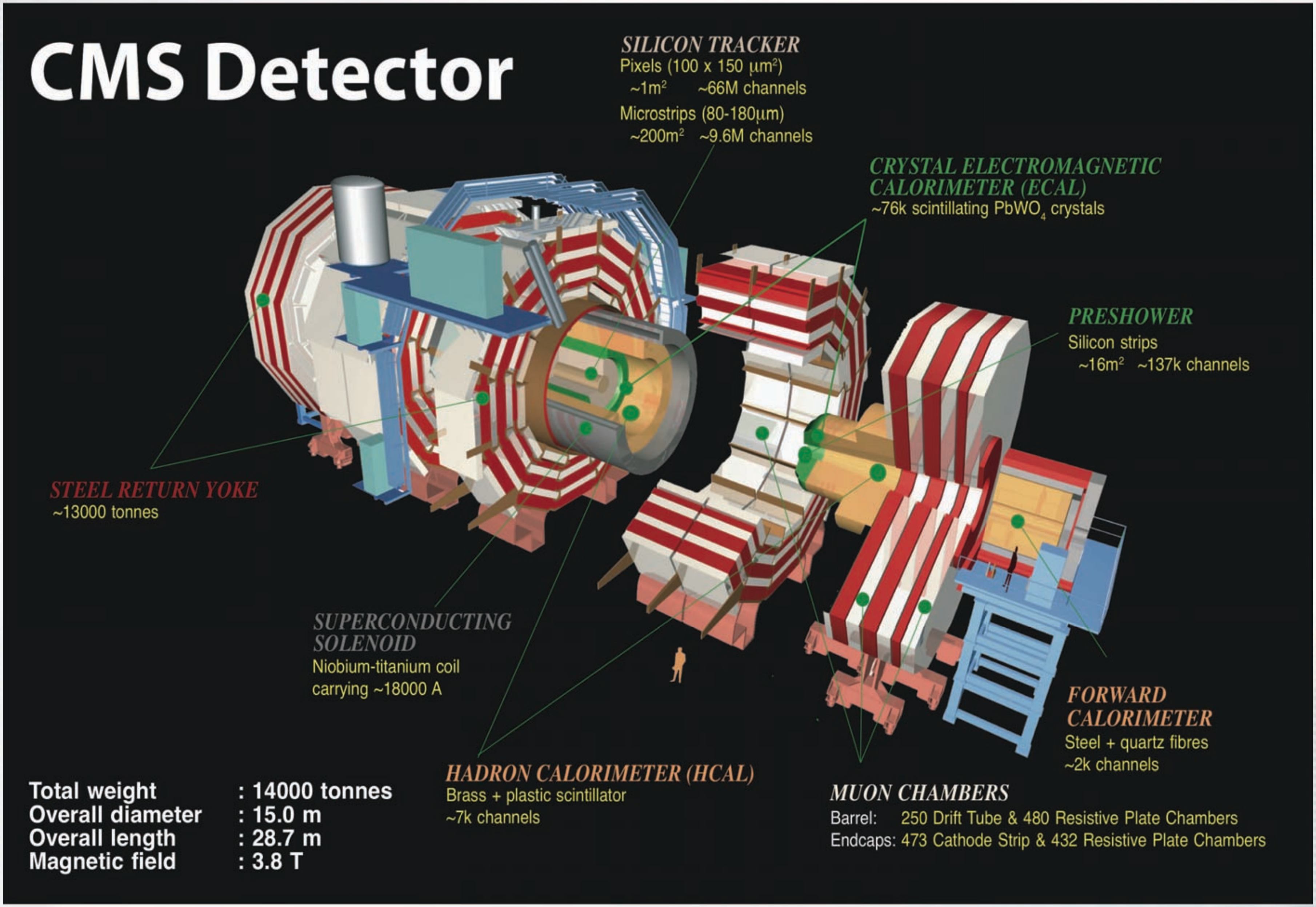
- Spectacular machine performance just before the ICHEP and in August
- Thank you for delivering the first inverse picobarn!
- Eagerly awaiting for 99 pb^{-1} more this year and another 900 pb^{-1} next year!



The Detector



Compact Muon Solenoid



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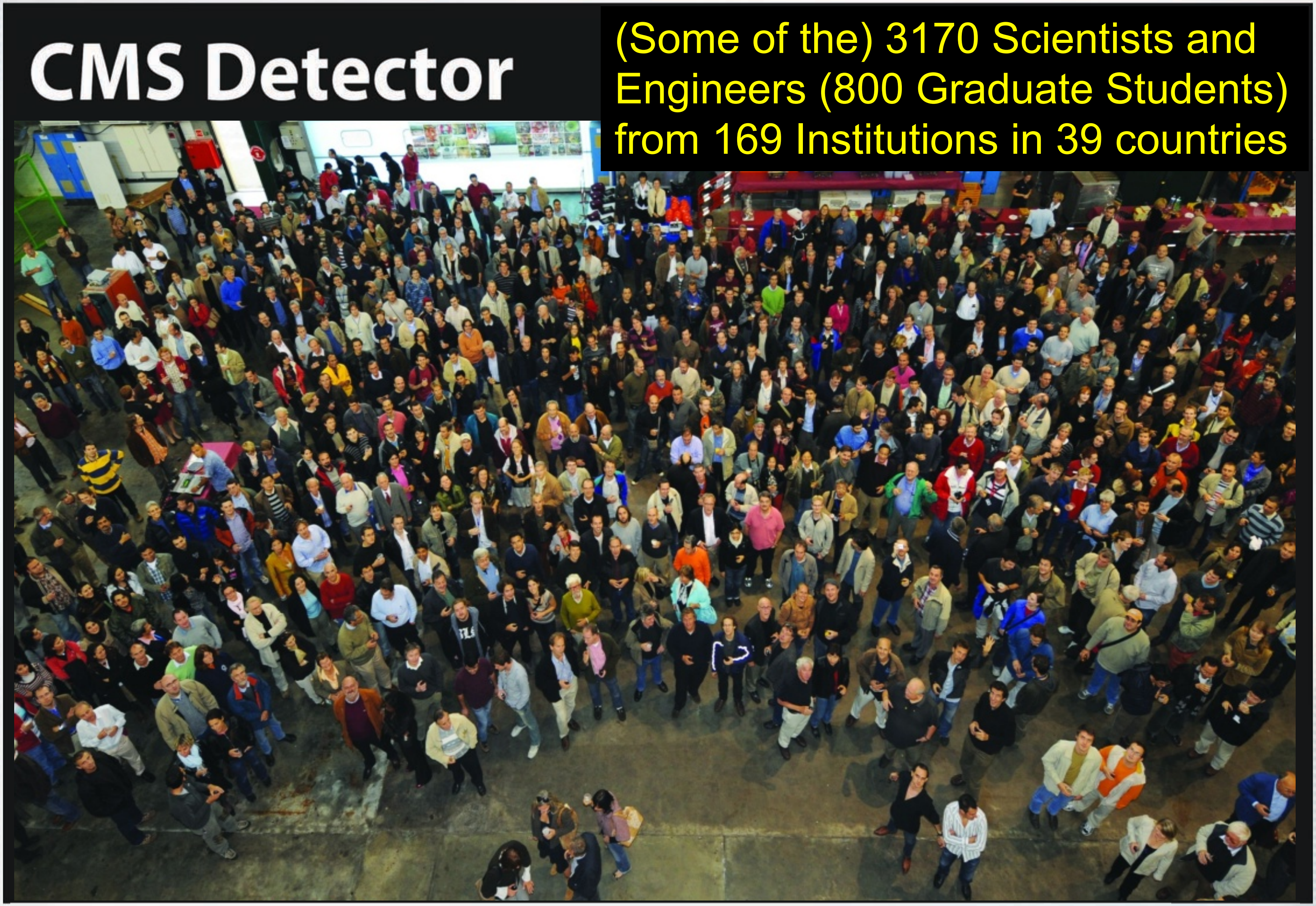
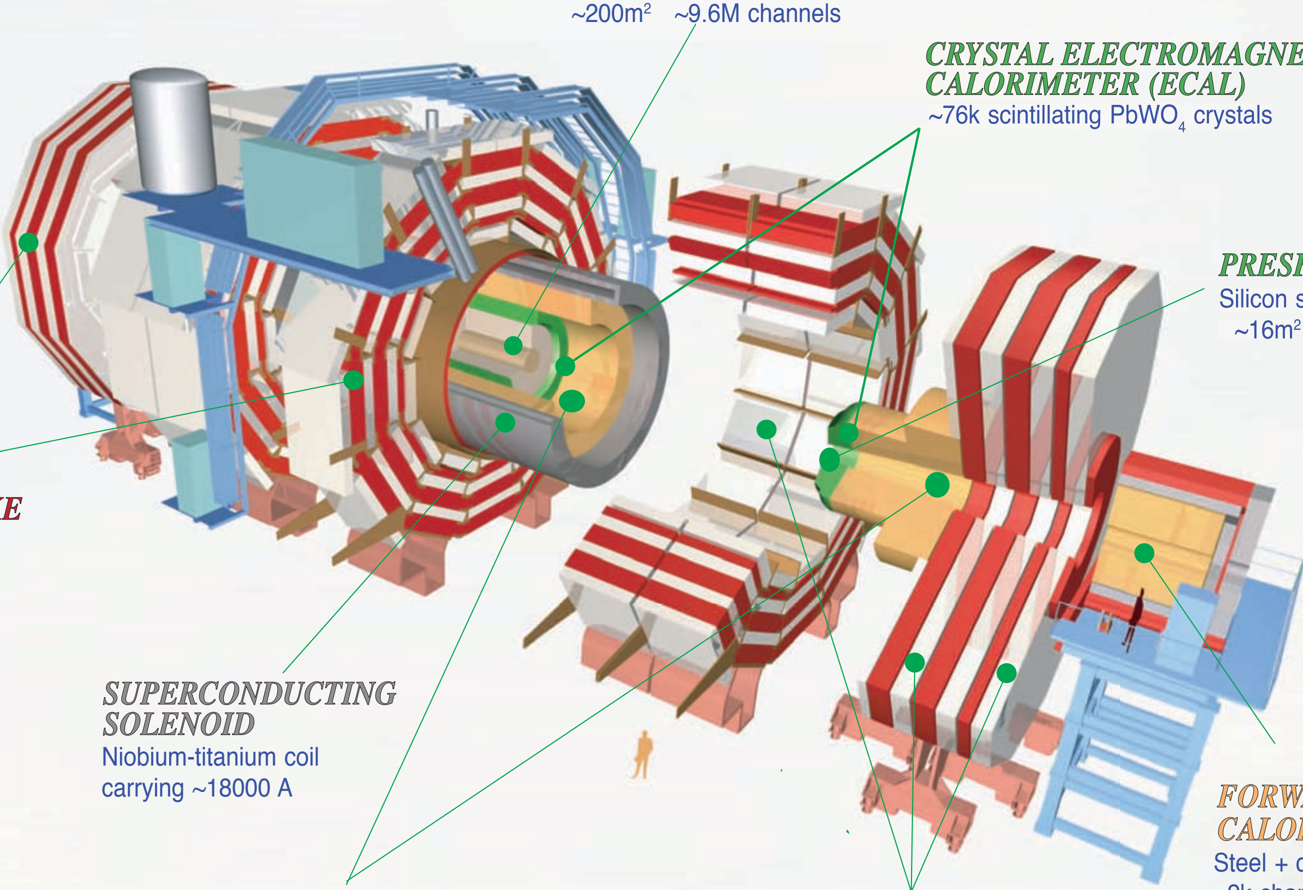


(Some of the) 3170 Scientists and Engineers (800 Graduate Students) from 169 Institutions in 39 countries

Understanding CMS: Tracker

CMS Detector

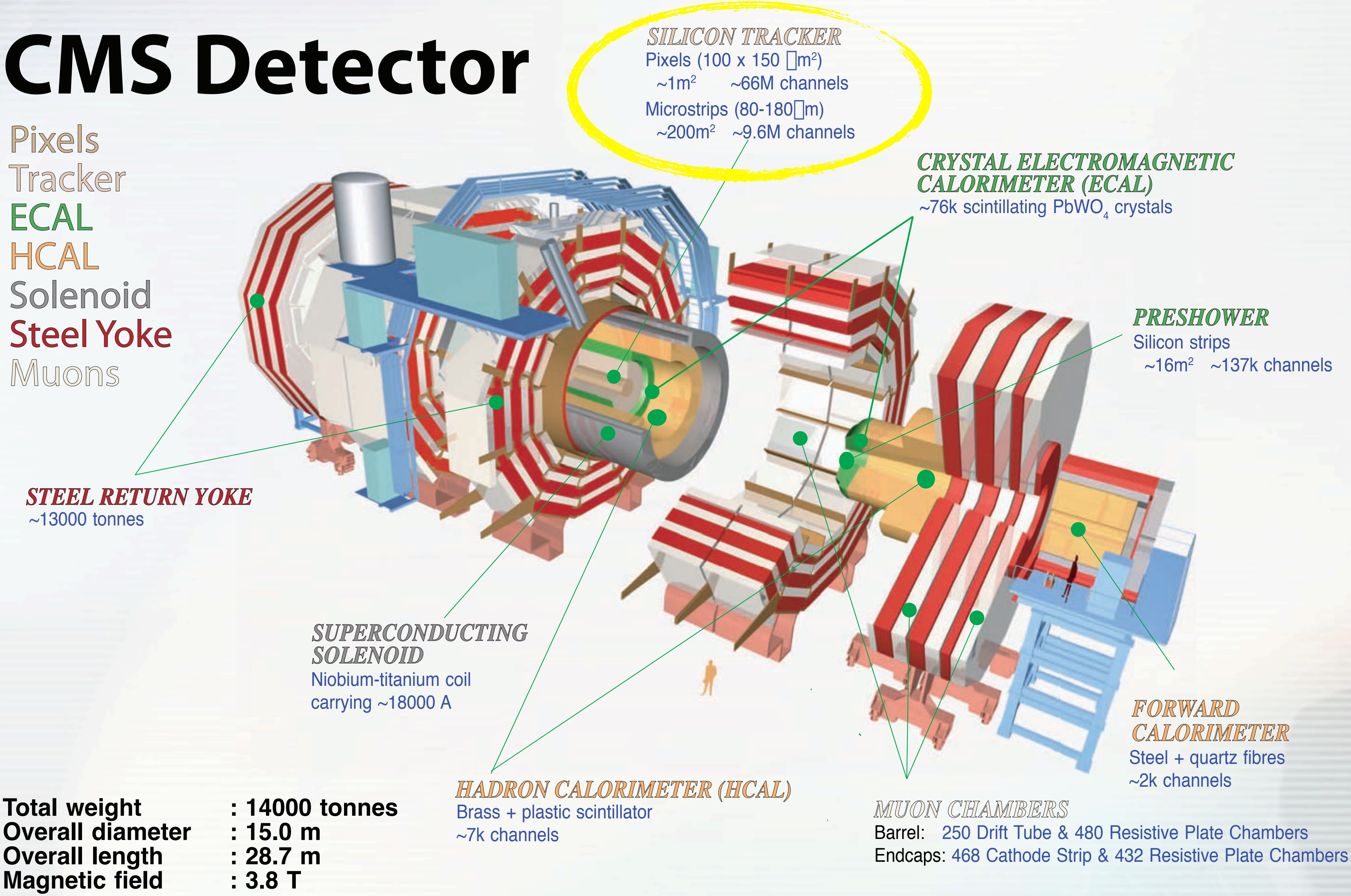
Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons



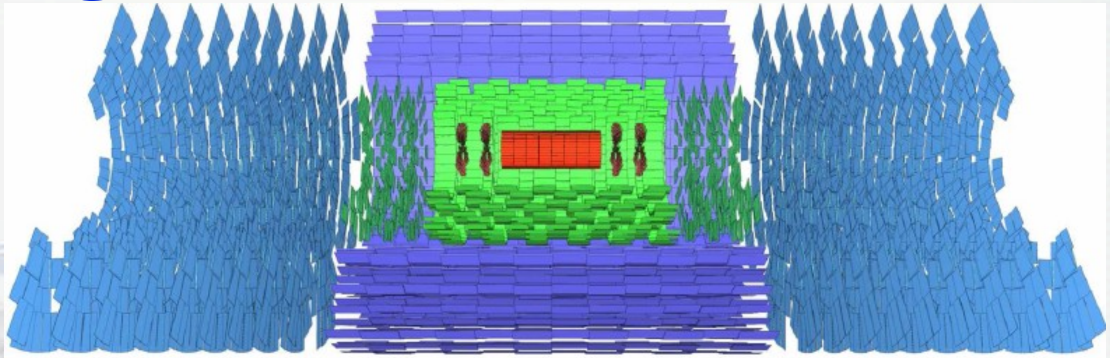
Total weight : **14000 tonnes**
Overall diameter : **15.0 m**
Overall length : **28.7 m**
Magnetic field : **3.8 T**

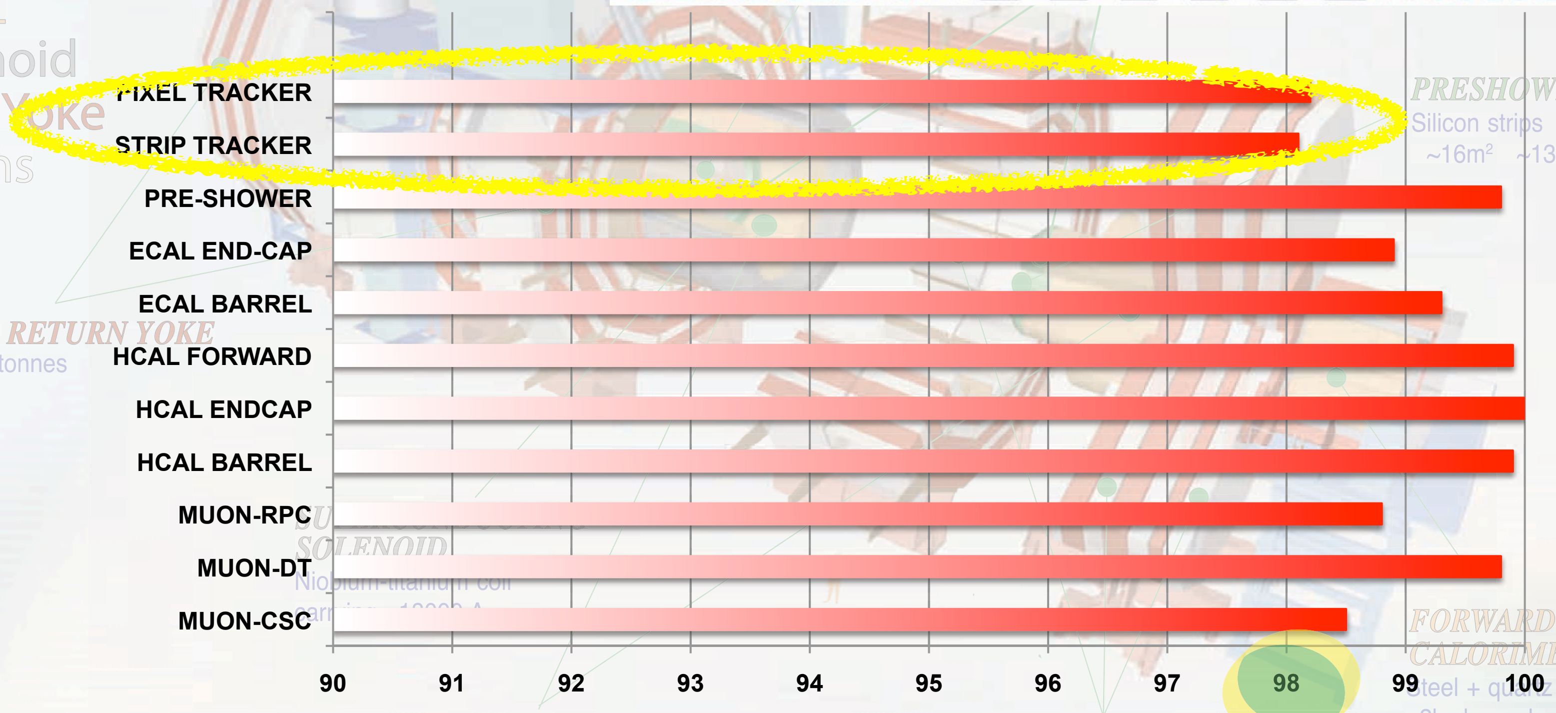
Monday, August 9, 2010

Understanding CMS: Tracker



Understanding CMS: Tracker

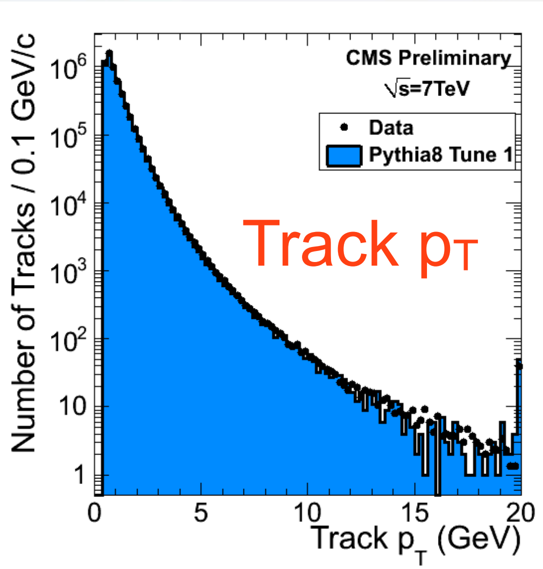


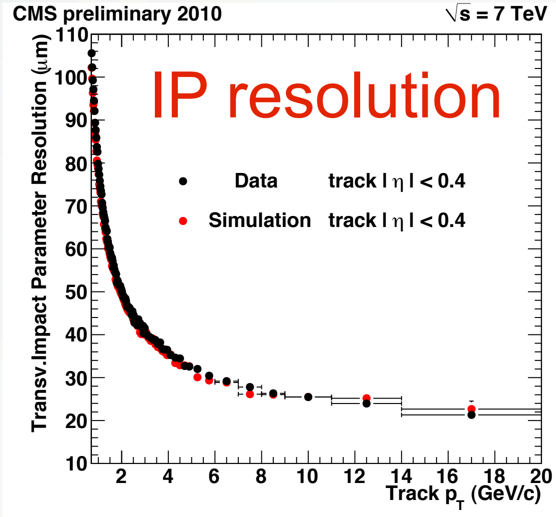


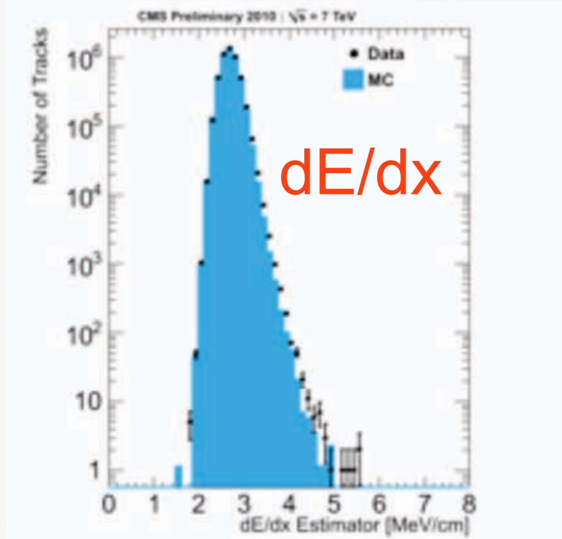
	MUON-CSC	MUON-DT	MUON-RPC	HCAL BARREL	HCAL ENDCAP	HCAL FORWARD	ECAL BARREL	ECAL END-CAP	PRE-SHOWER	STRIP TRACKER	PIXEL TRACKER
Series1	98.5	99.8	98.8	99.9	100	99.9	99.3	98.9	99.8	98.1	98.2

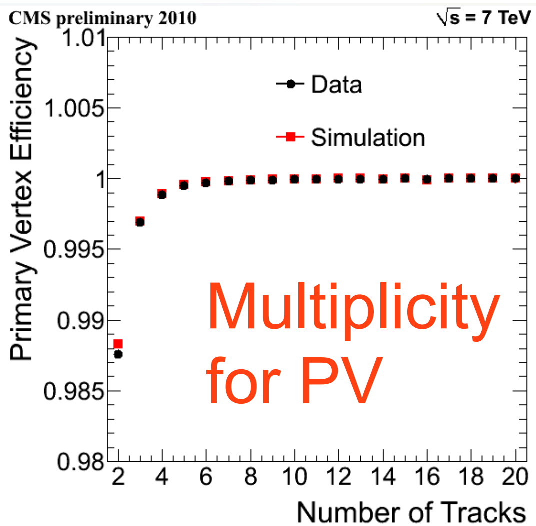
Tracker Performance

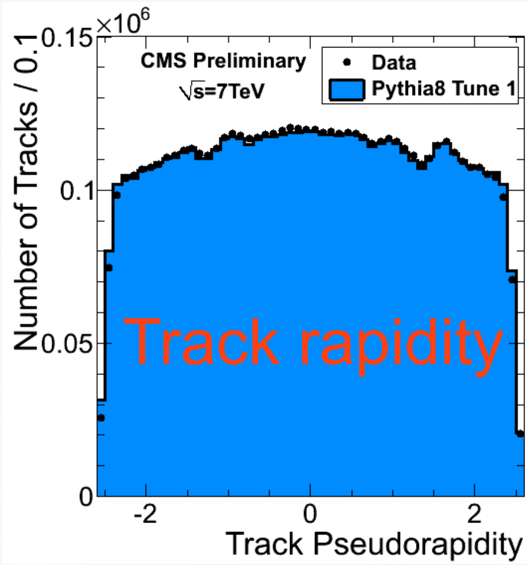
- 75 Million Channels, 200 m^2 of Silicon; >98% operational
- Remarkable agreement between the data and the simulations

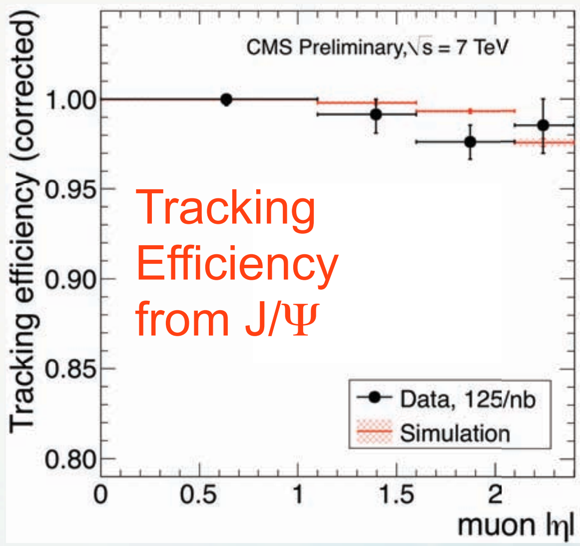






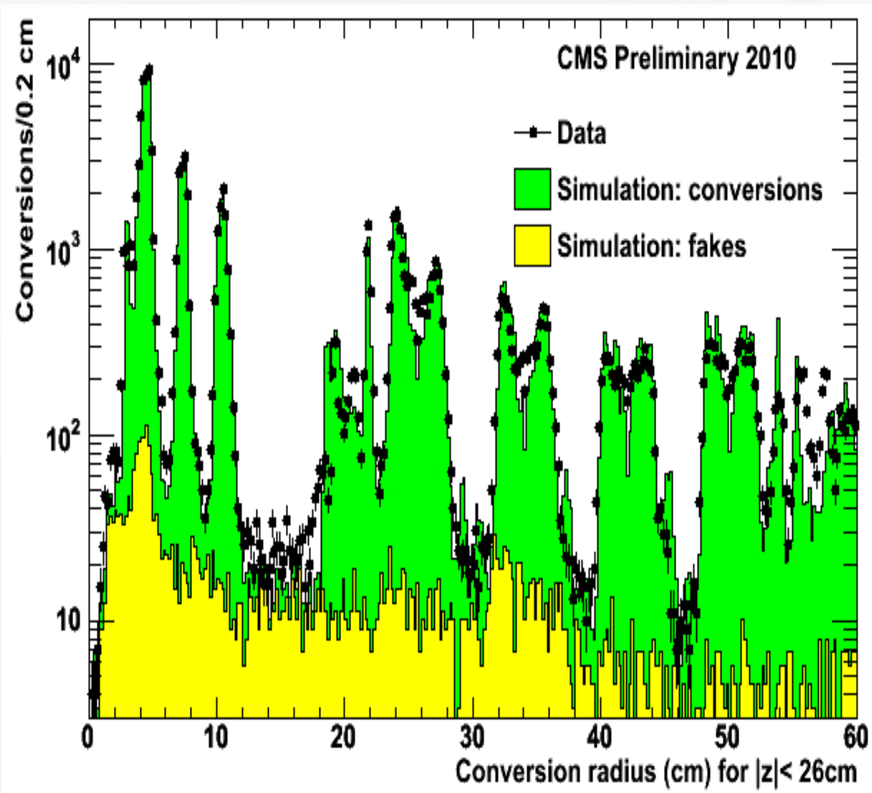


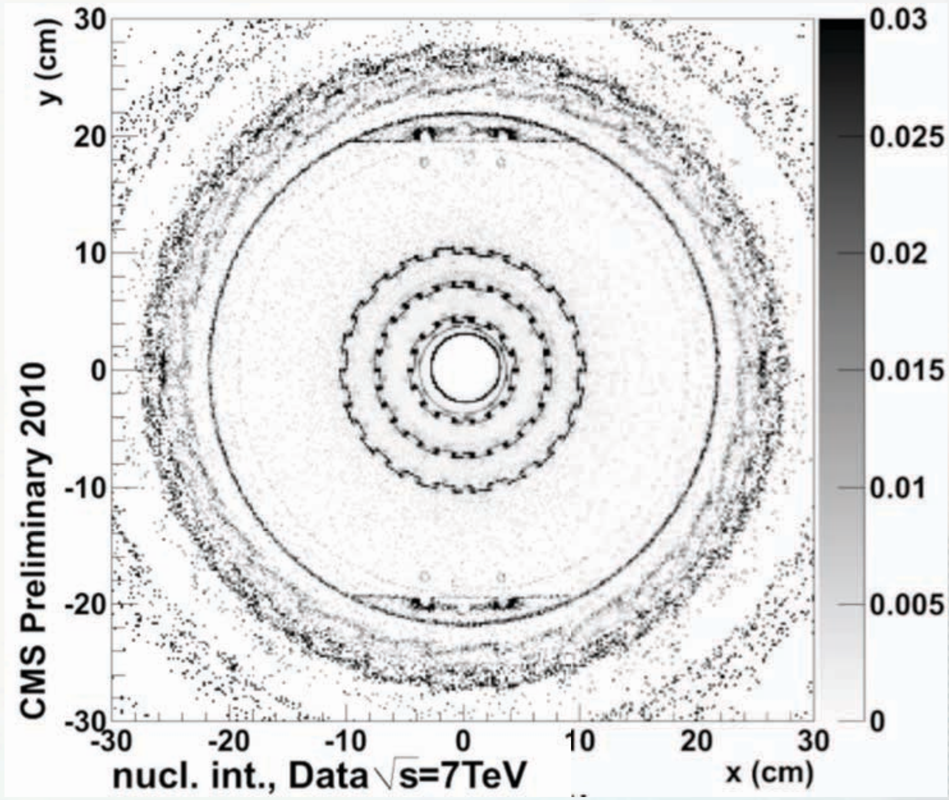




Understanding the Material

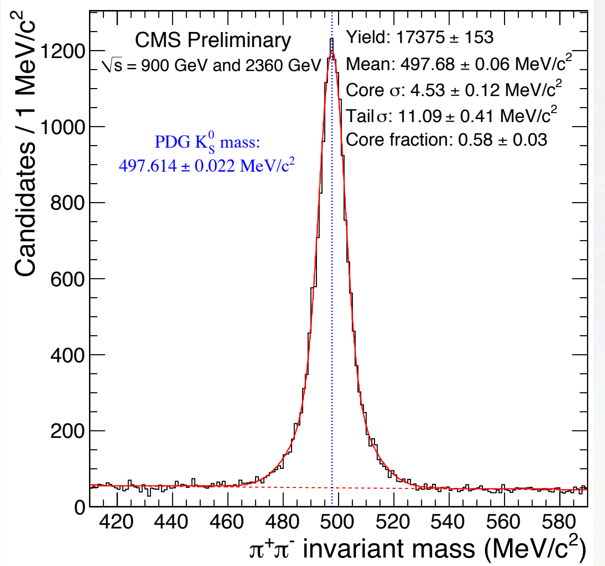
- X-Raying the detector with photon conversions and nuclear interactions
- Excellent agreement with the simulations
- Proper understanding of the material budget

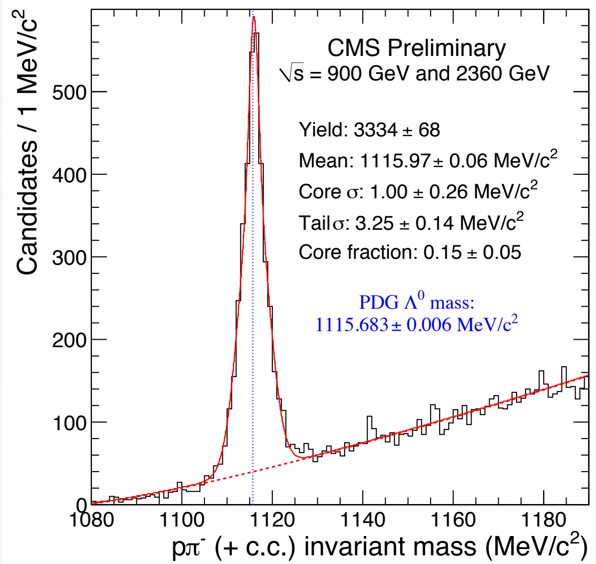


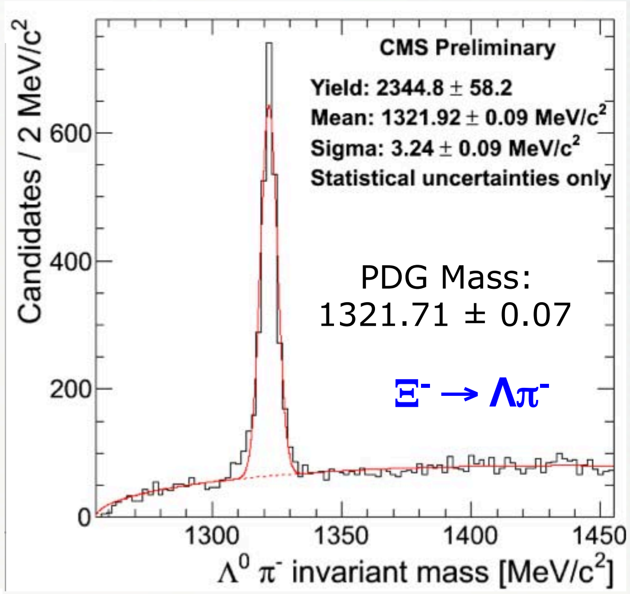


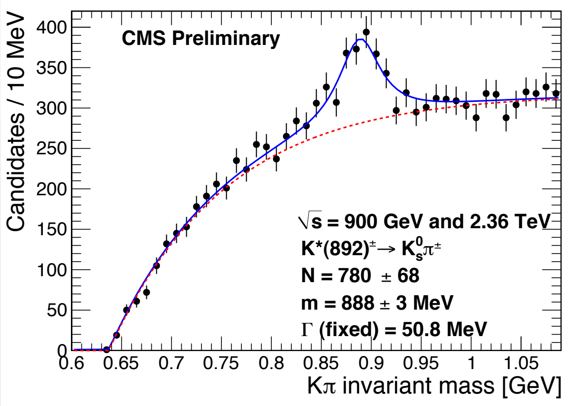
Low-Mass Resonances

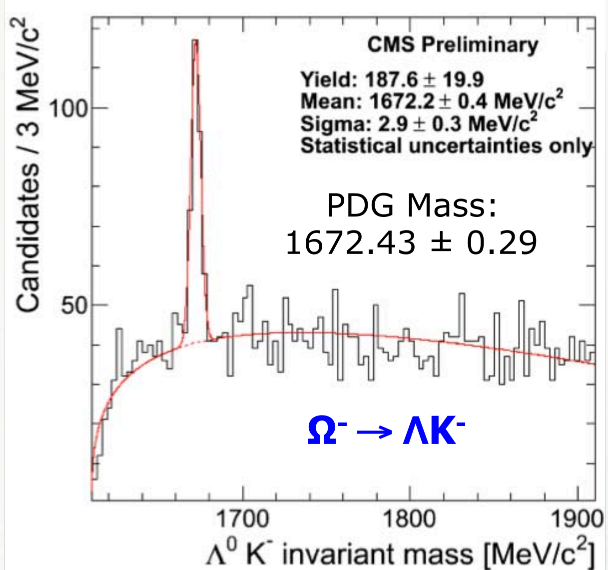
- Expected resolutions and masses for resonances

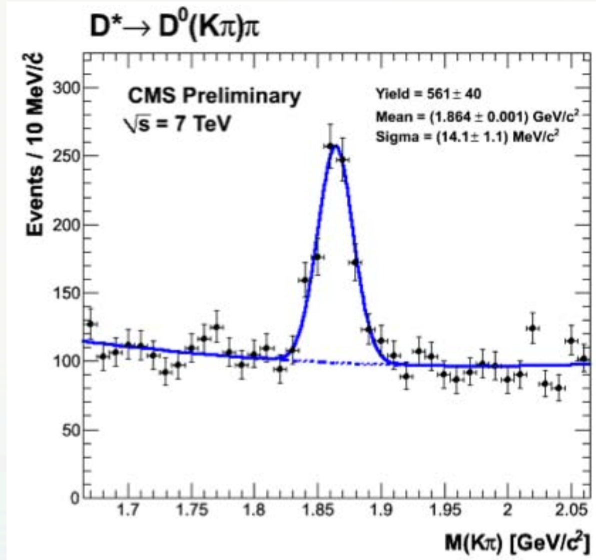






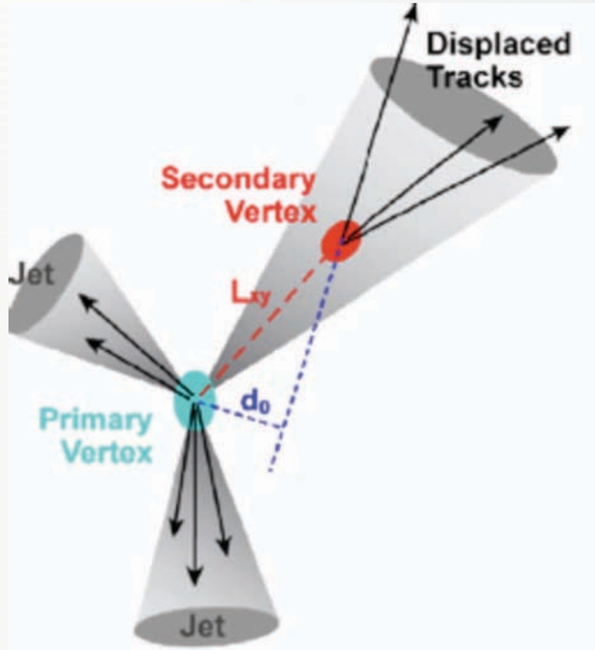


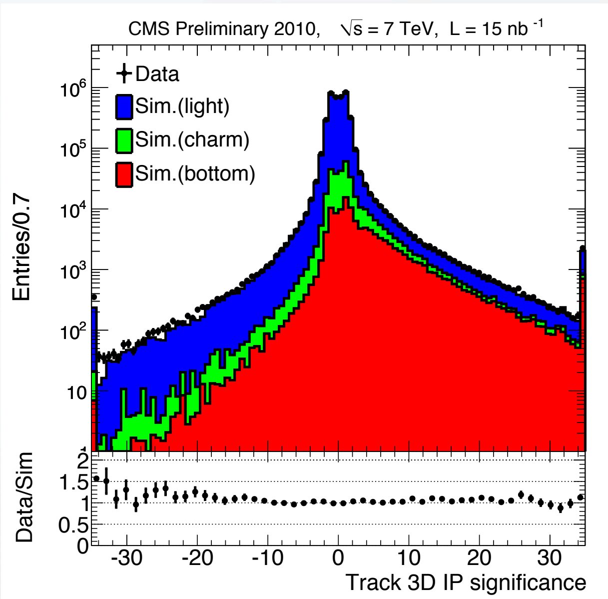


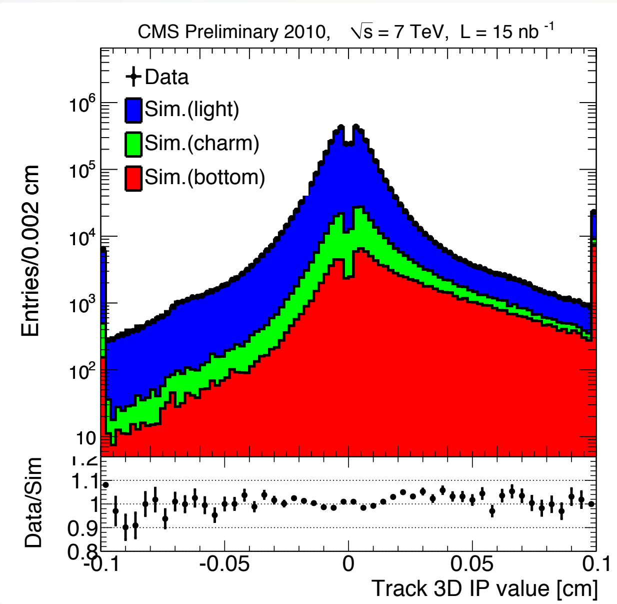


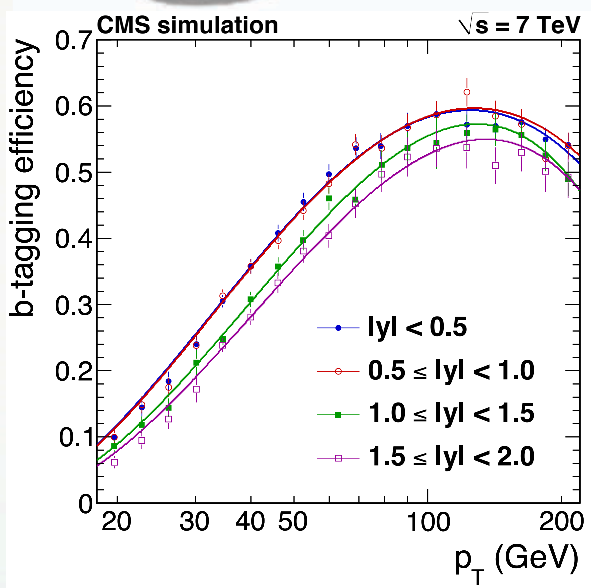
B-Tagging

- 3D impact parameters in jets with p_T > 40 GeV for tracks with p_T > 1 GeV
- Excellent agreement with simulations proves good tracker alignment









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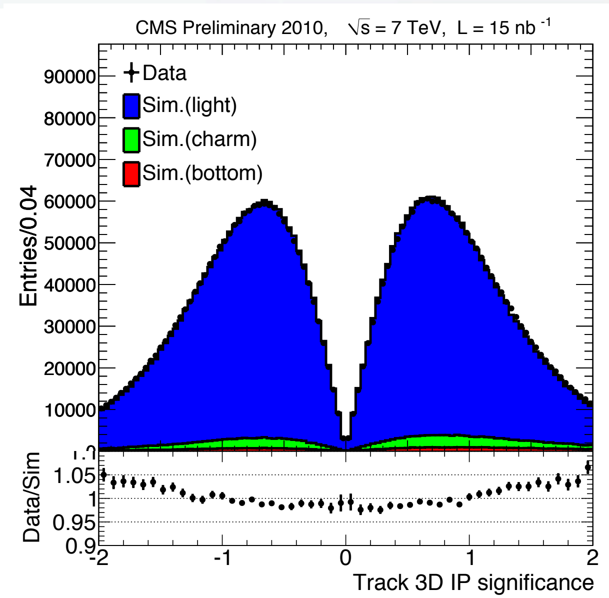
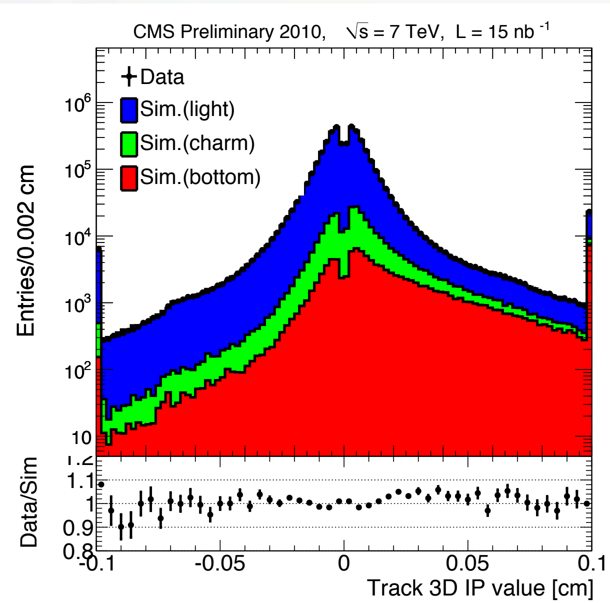
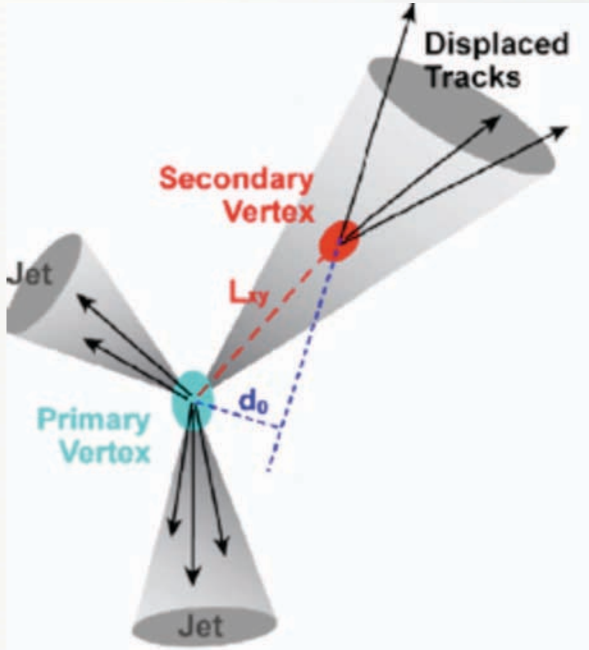
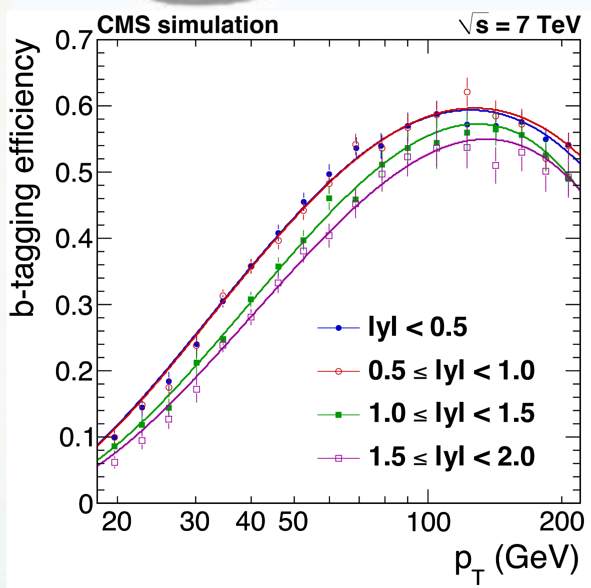
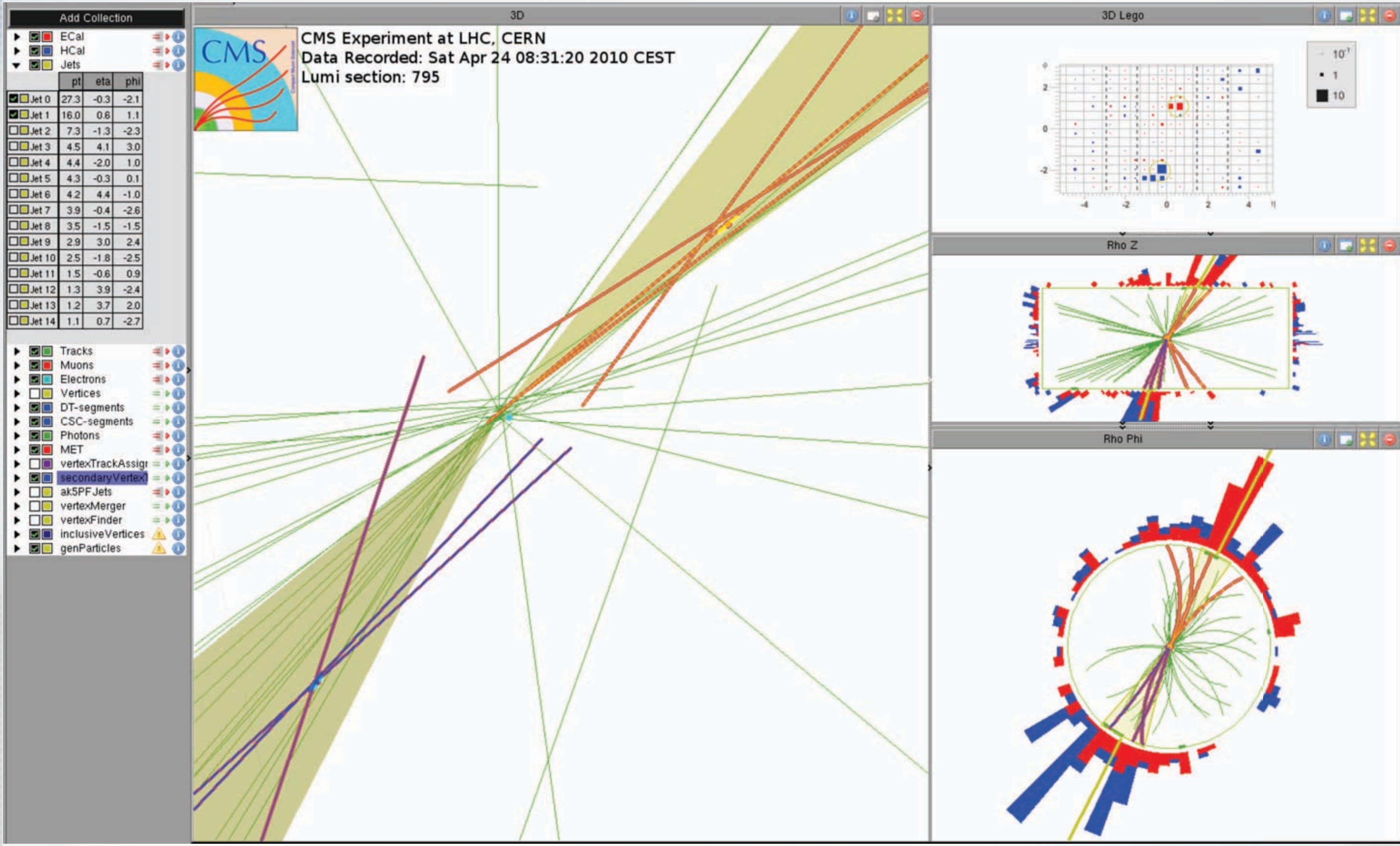








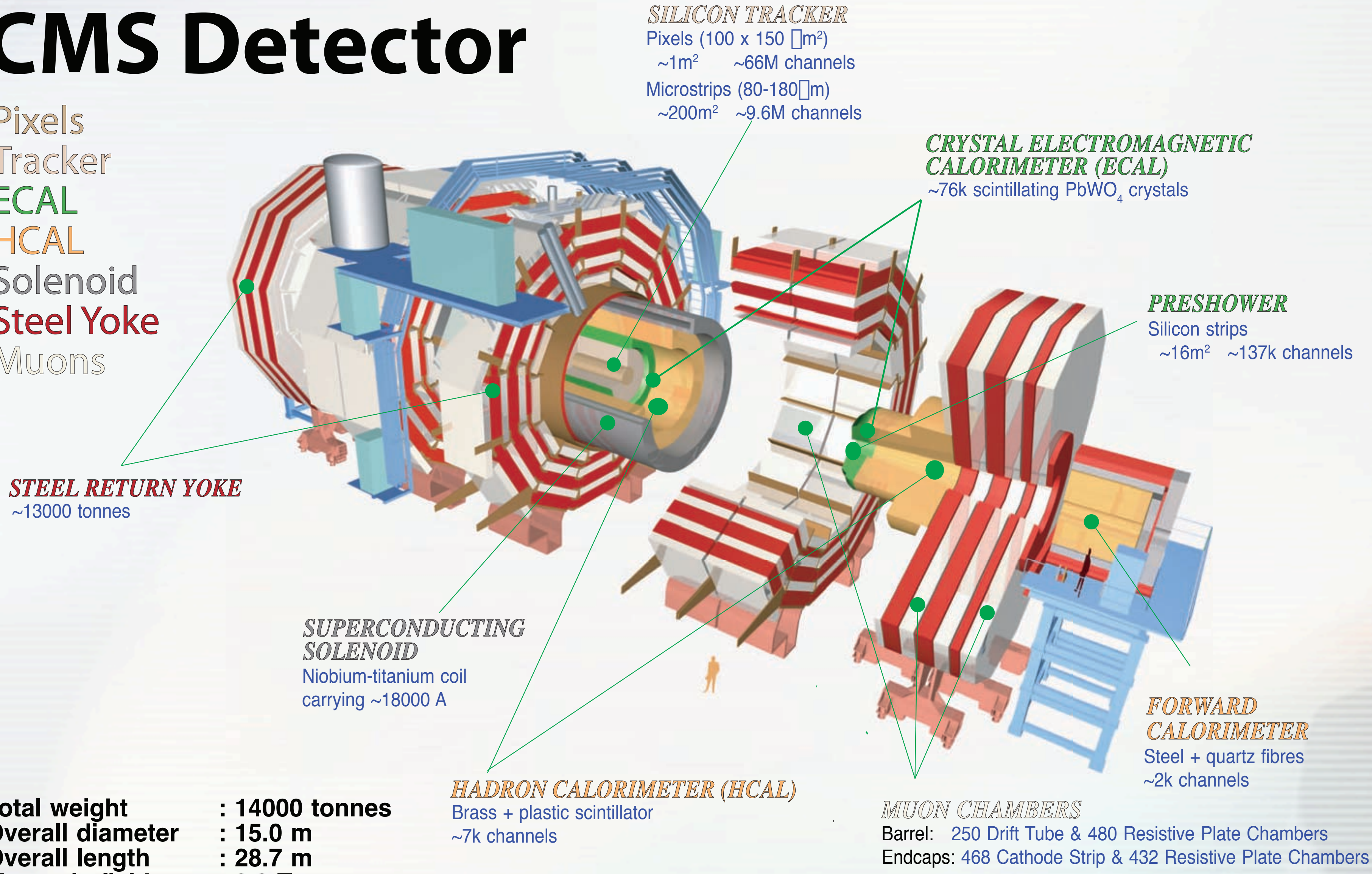
A $b\bar{b}$ Candidate



Understanding CMS: ECAL

CMS Detector

Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons



Total weight	**: 14000 tonnes**
Overall diameter	**: 15.0 m**
Overall length	**: 28.7 m**
Magnetic field	**: 3.8 T**

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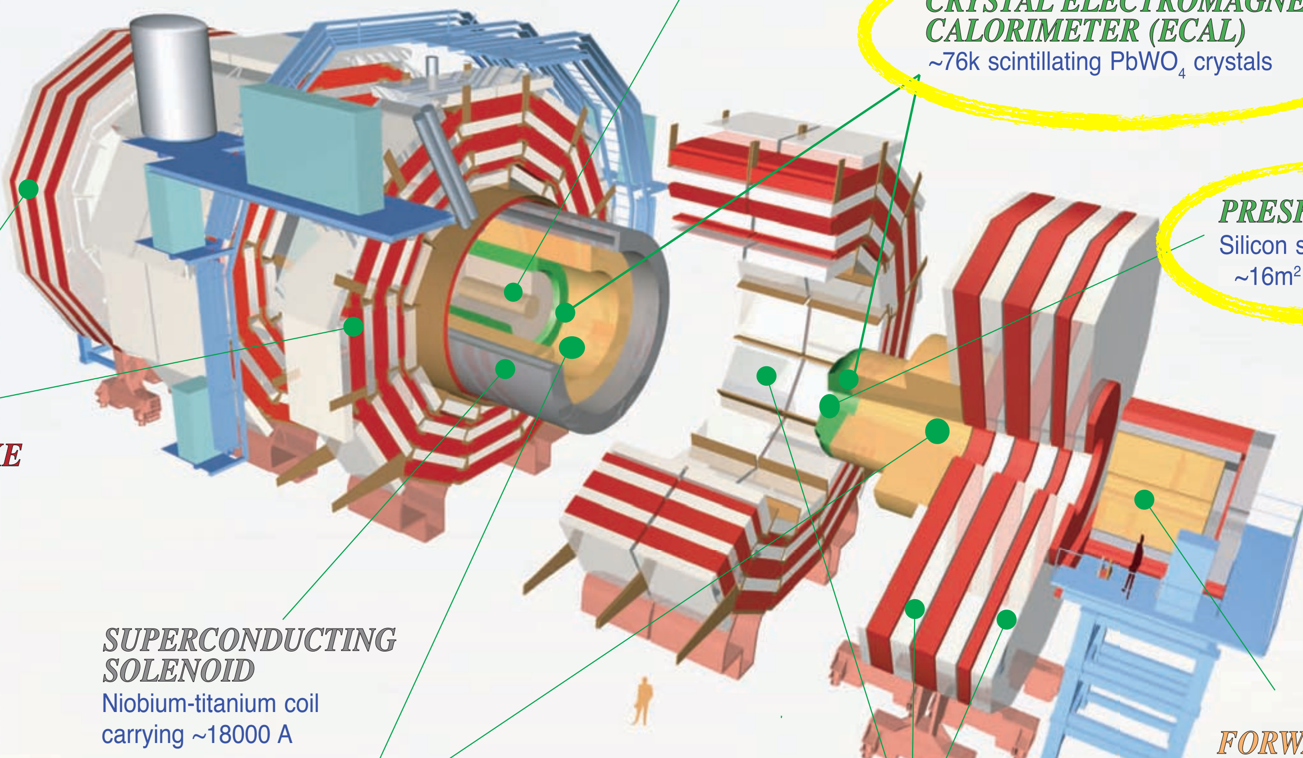

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Understanding CMS: ECAL

CMS Detector

Pixels
Tracker
ECAL
HCAL
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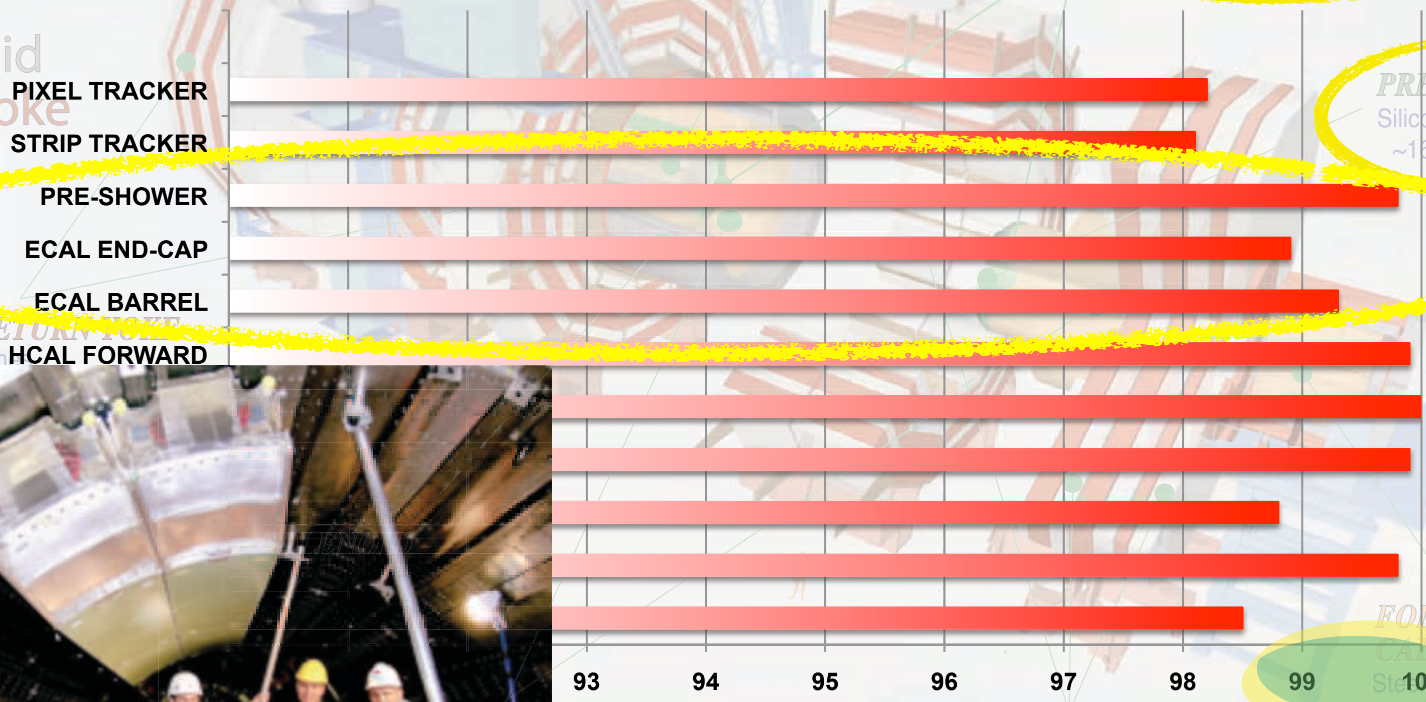
Steel Yoke
Muons

SILICON TRACKER
Pixels (100 x 150 μm²)
~1m² ~66M channels
Microstrips (80-180μm)
~200m² ~9.6M channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76k scintillating $PbWO_4$ crystals

PRESHOWER
Silicon strips
~16m² ~137k channels

STEEL RETURN YOKE
~13000 tonn



FORWARD CALORIMETER
Steel + quartz fibres
~2k channels

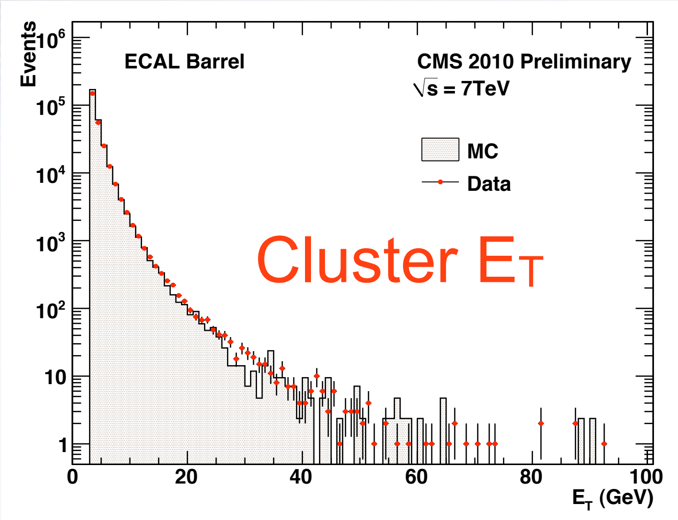
HADRON CALORIMETER (HCAL)

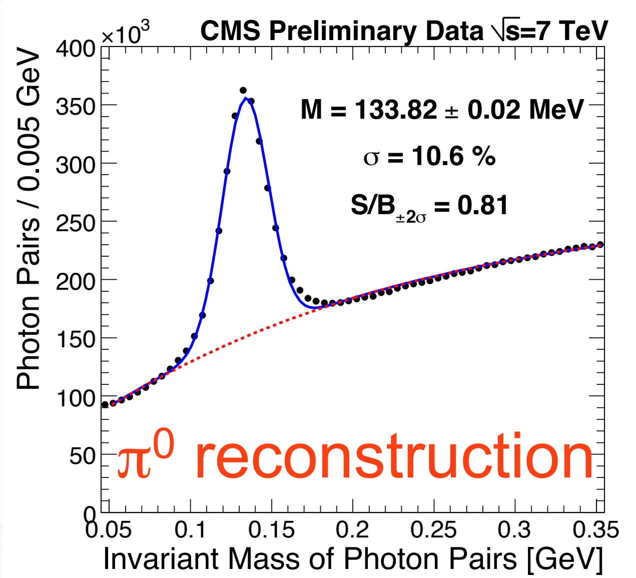
MUON CHAMBERS
250 Drift Tube & 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip & 432 Resistive Plate Chambers

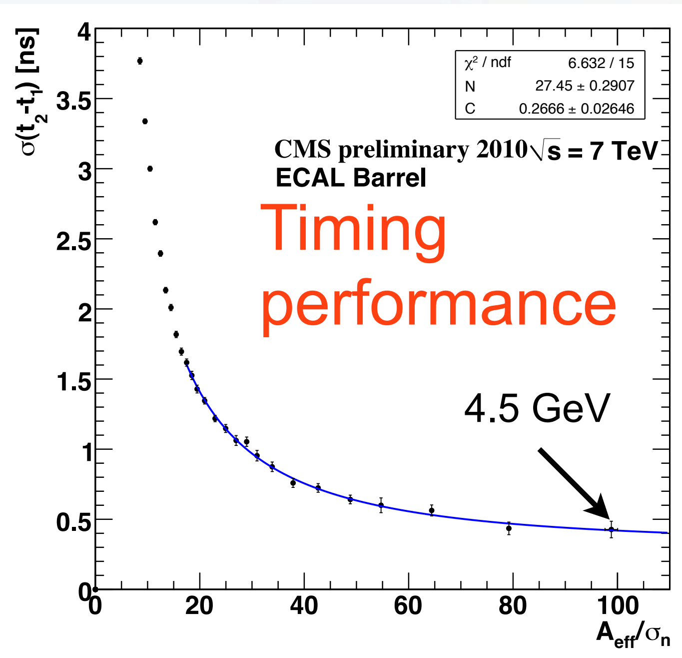
HCAL ENDCAP	HCAL FORWARD	ECAL BARREL	ECAL END-CAP	PRE-SHOWER	STRIP TRACKER	PIXEL TRACKER
100	99.9	99.3	98.9	99.8	98.1	98.2

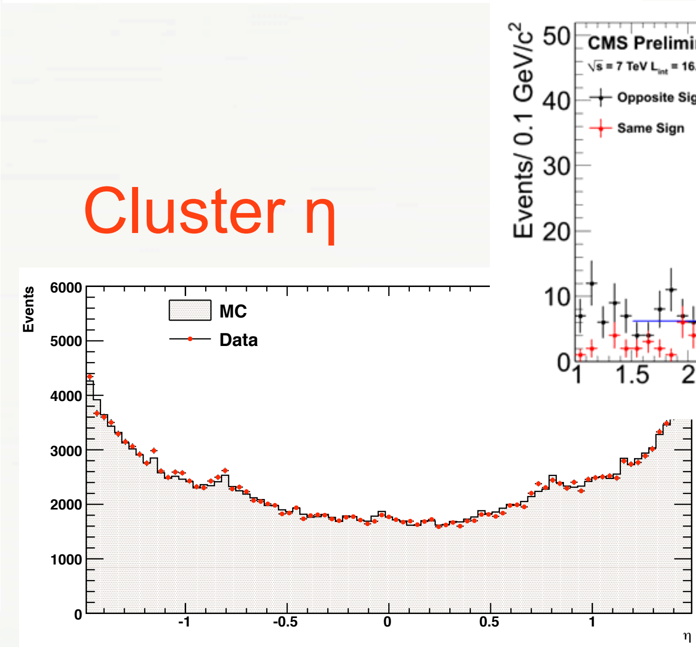
Monday, August 9, 2010

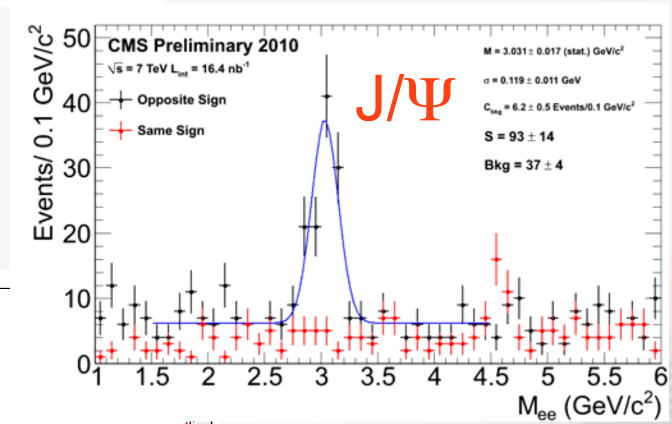
ECAL Performance











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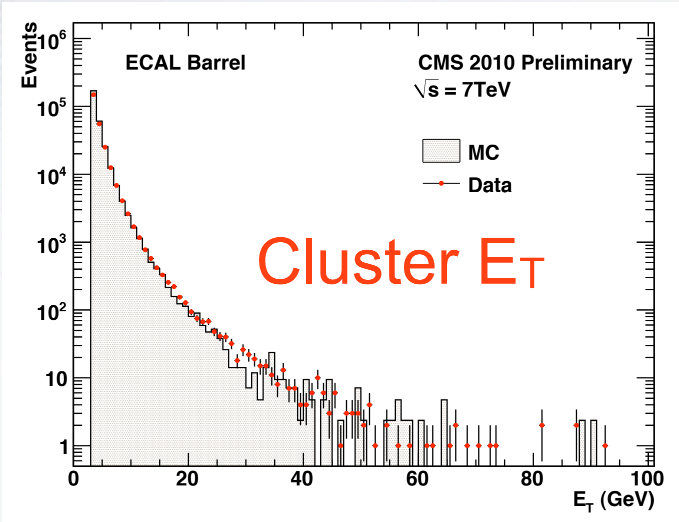

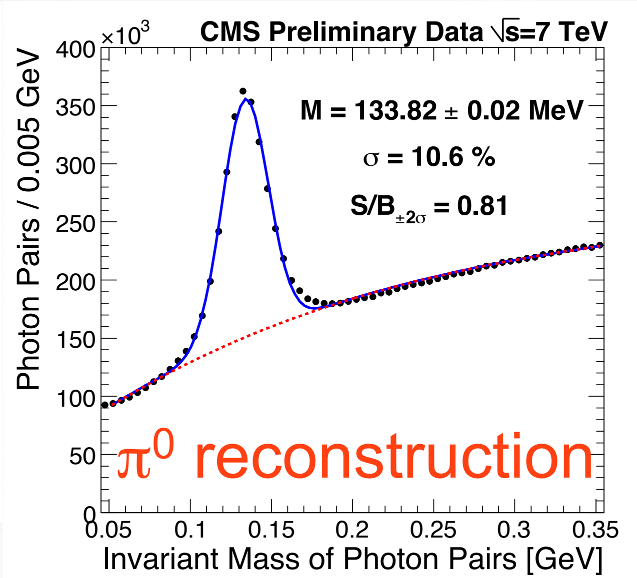

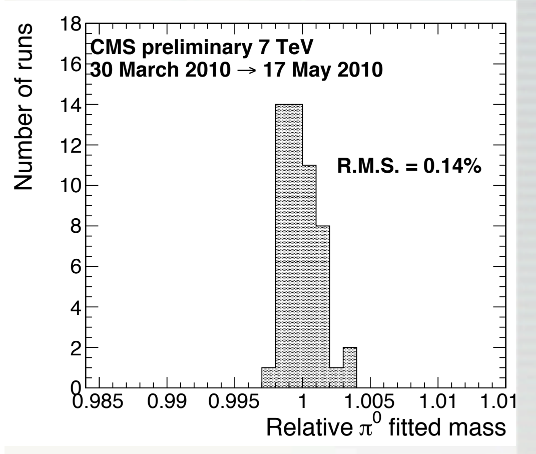

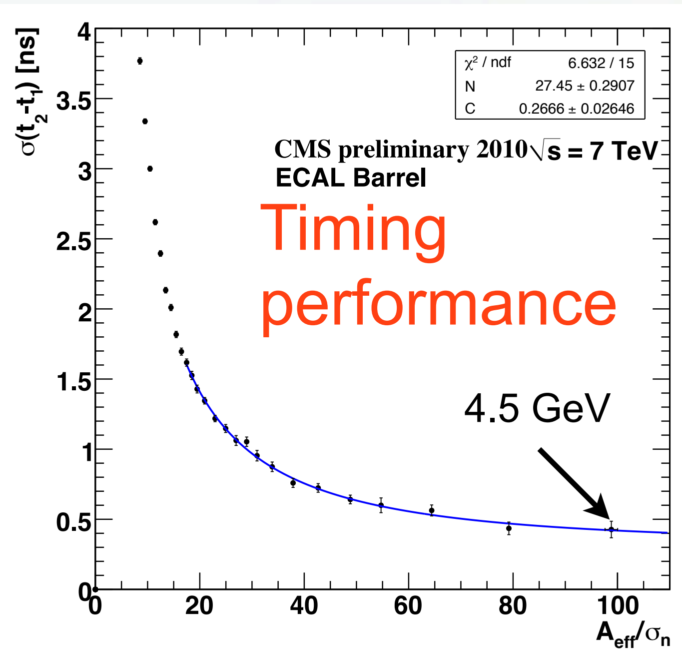

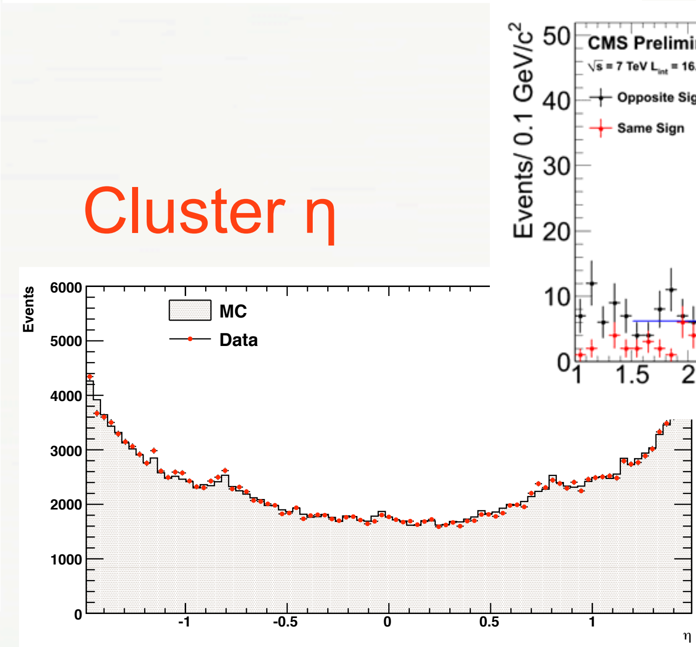

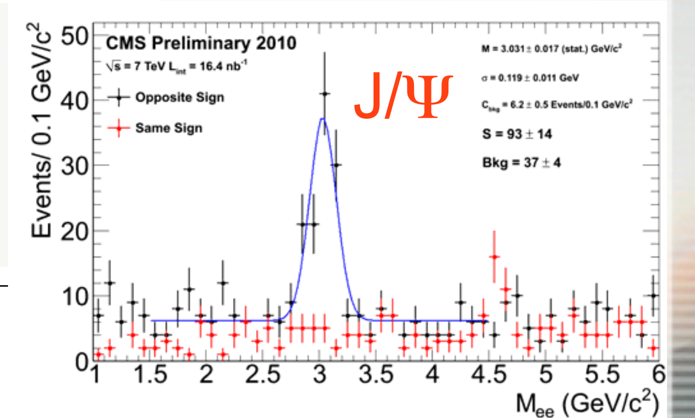

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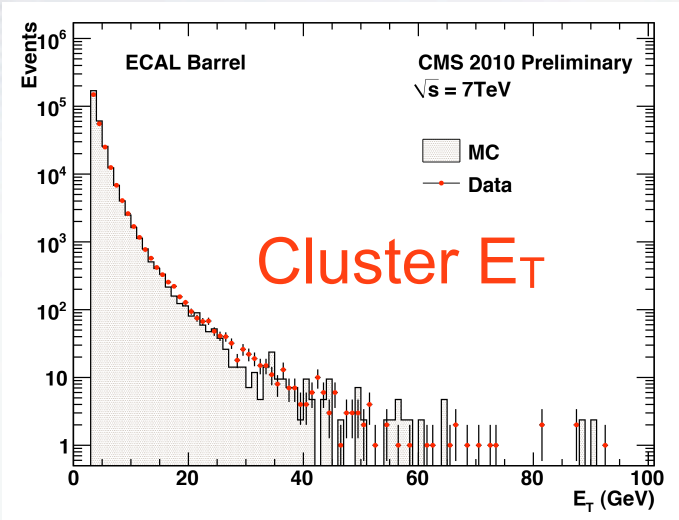

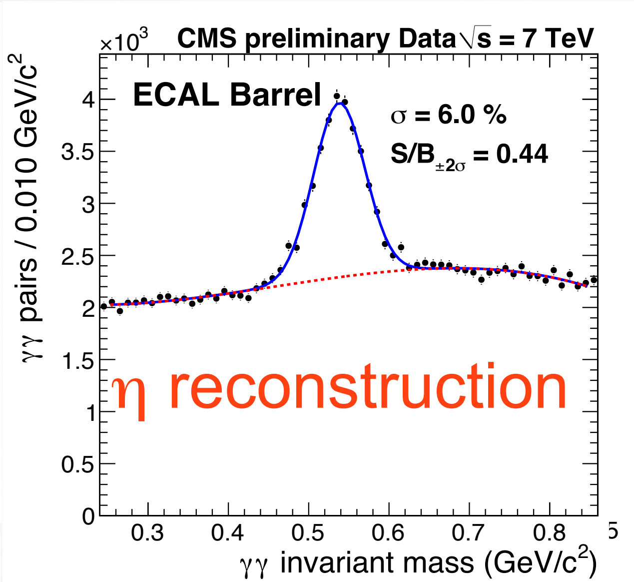

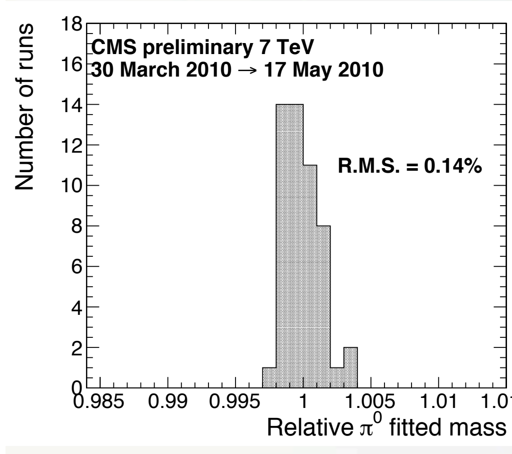

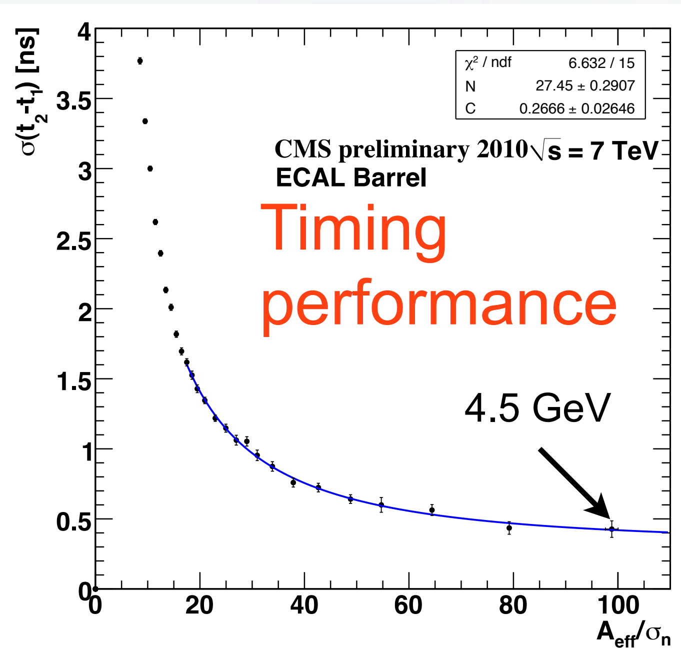

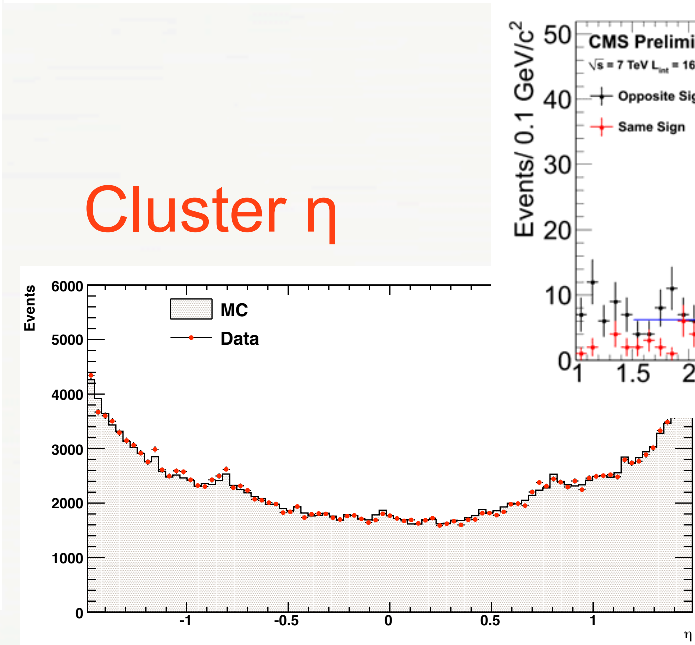

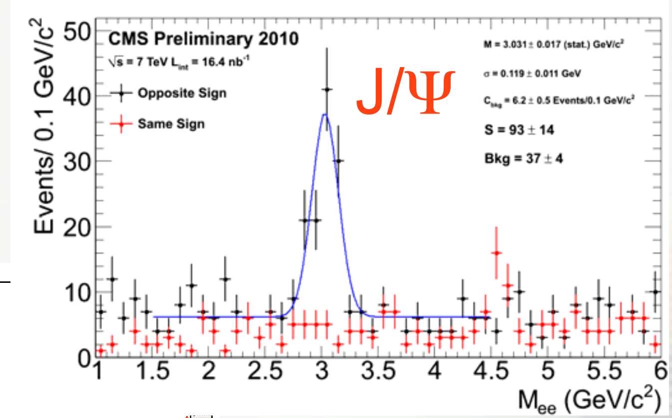

Understanding CMS: HCAL

CMS Detector

Pixels
Tracker
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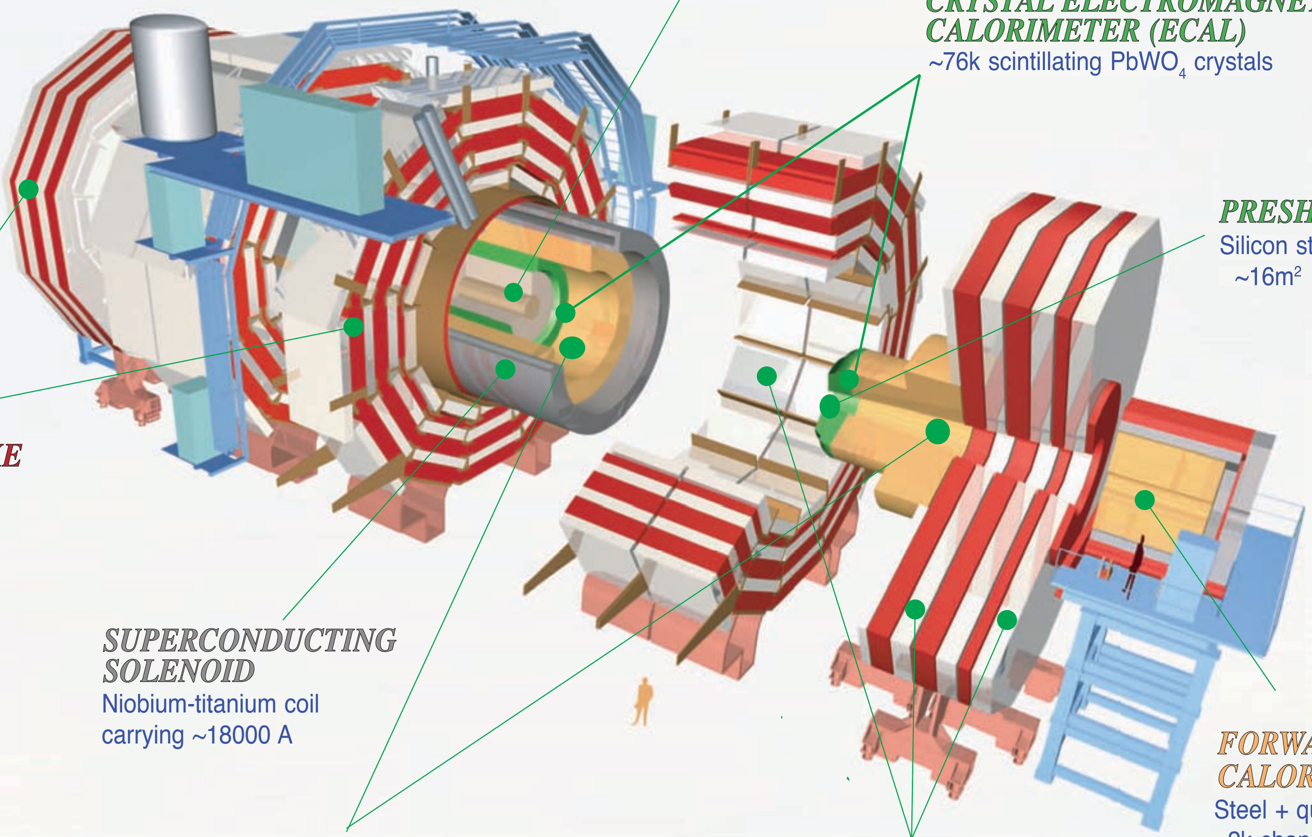

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Overall diameter : 15.0 m
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Understanding CMS: HCAL

CMS Detector

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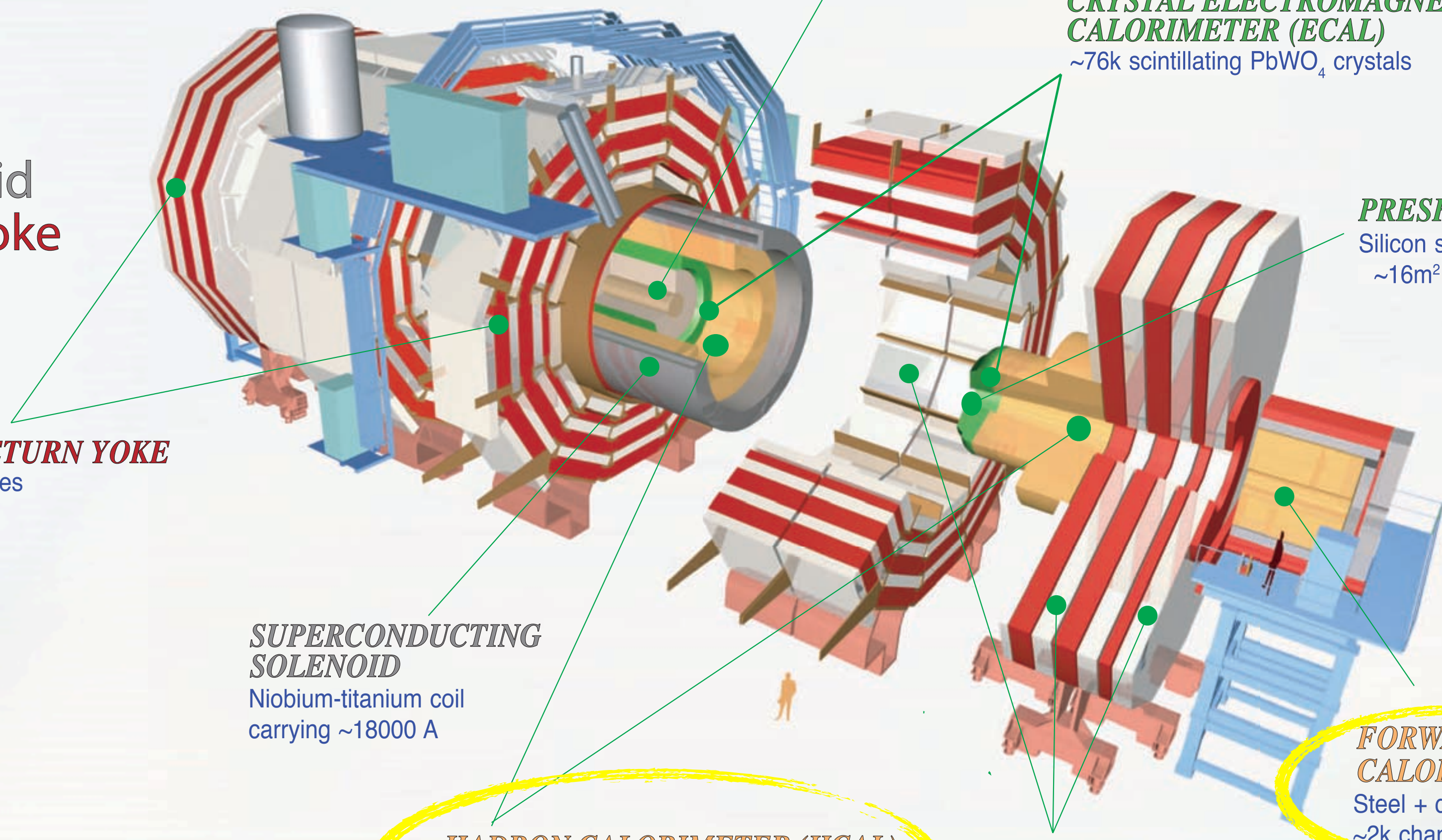

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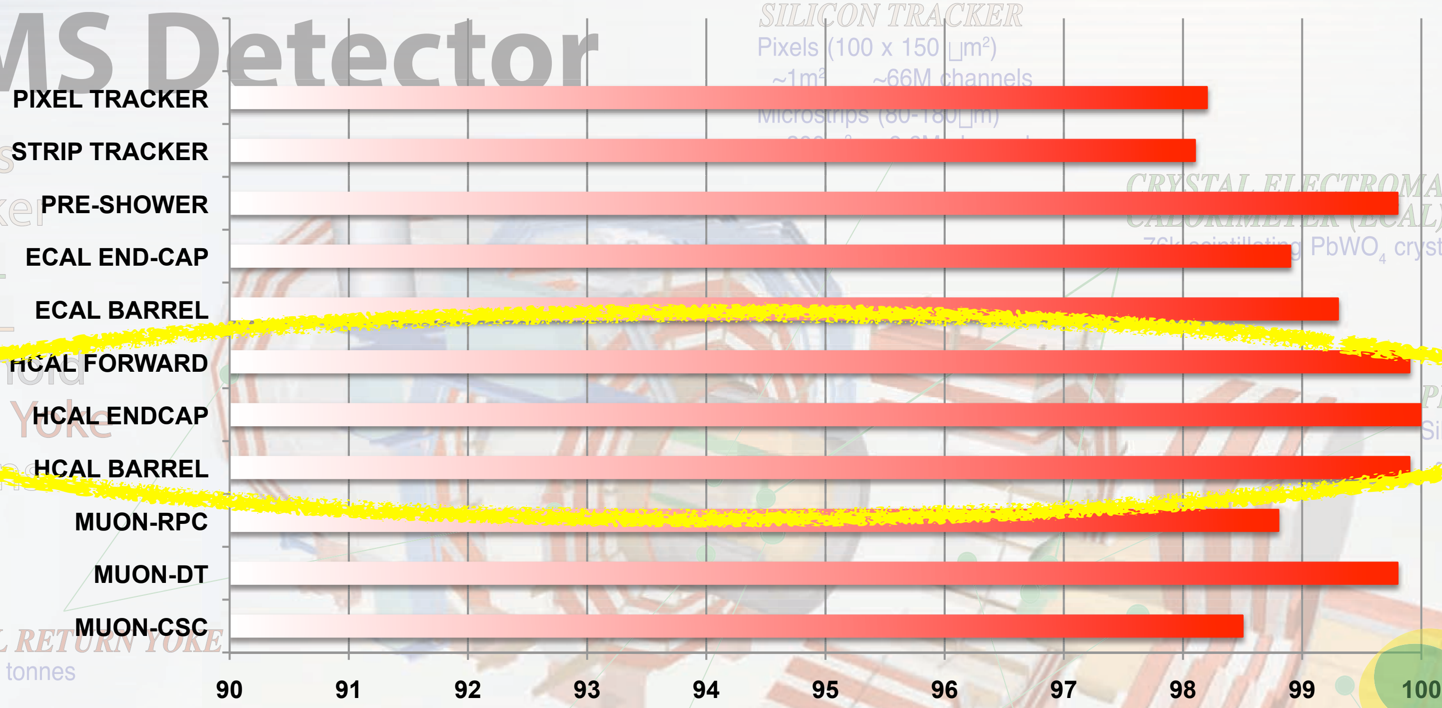
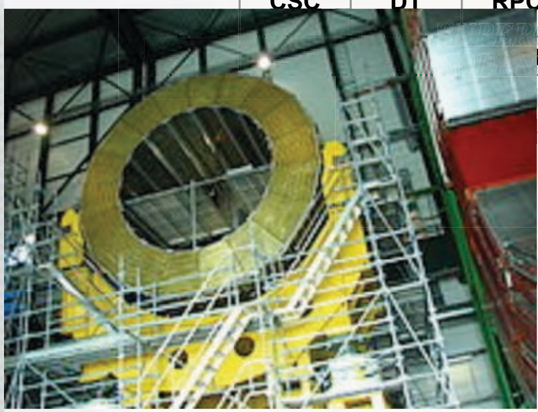
Understanding CMS: HCAL

CMS Detector



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



SILICON TRACKER
Pixels (100 x 150 μm²)
~1m² ~66M channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)

PRESHOWER
Silicon strips
~137k channels

STEEL RETURN YOKE
~13000 tonnes

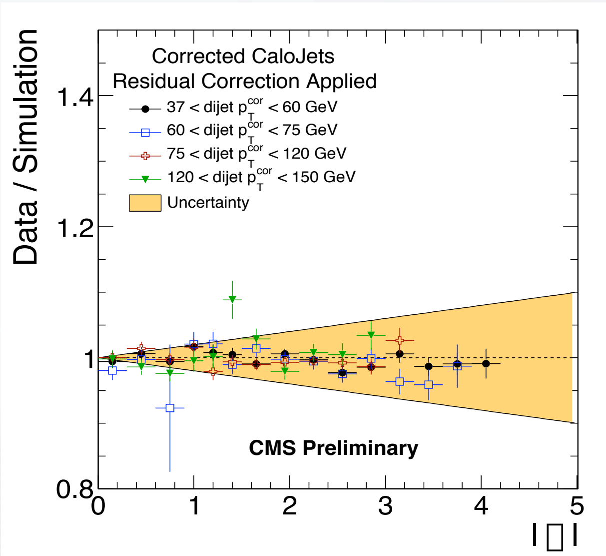
HADRON CALORIMETER (HCAL)
Brass + plastic scintillator
~7k channels

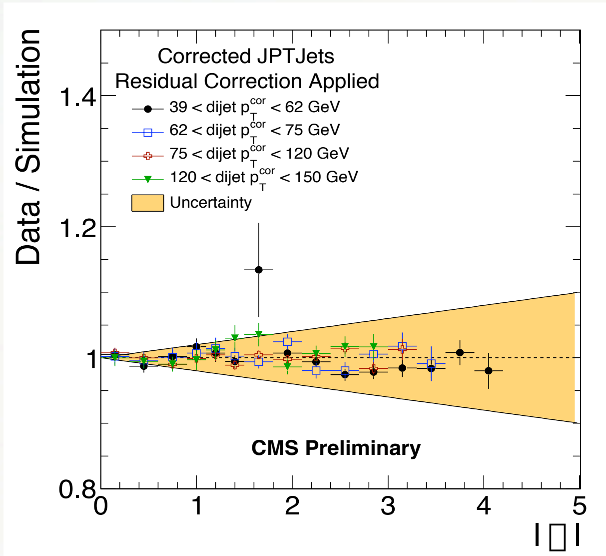
FORWARD CALORIMETER
Steel + quartz fibres
~2k channels

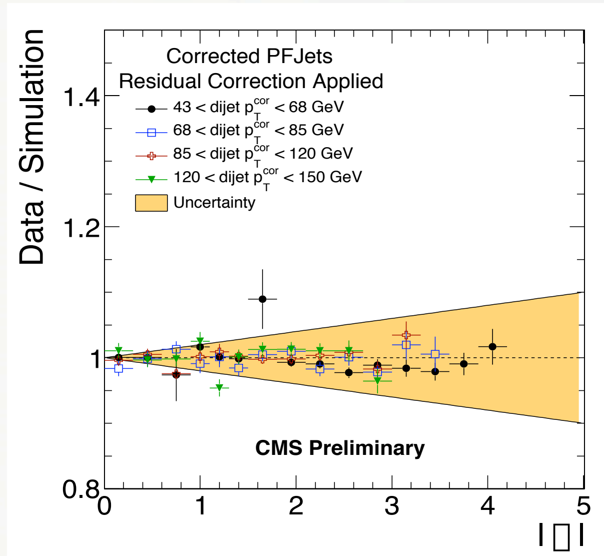
MUON CHAMBERS
Barrel: 250 Drift Tube & 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip & 432 Resistive Plate Chambers

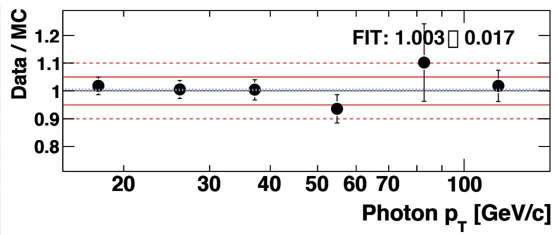
Jets at CMS

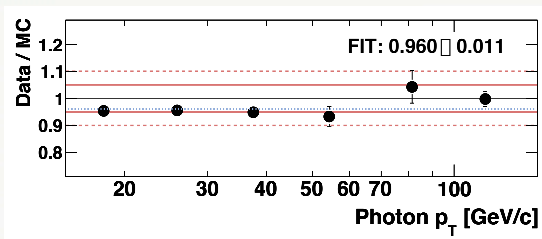
- Three types of algorithms have been commissioned: CaloJets, Jets-Plus-Tracks, Particle Flow Jets
- Good description of basic jet properties with the MC
- JES from MC has been shown to agree with data to 5% (JPT, PFJets) or 10% (CaloJets)

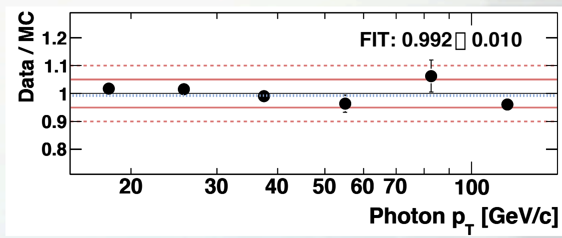






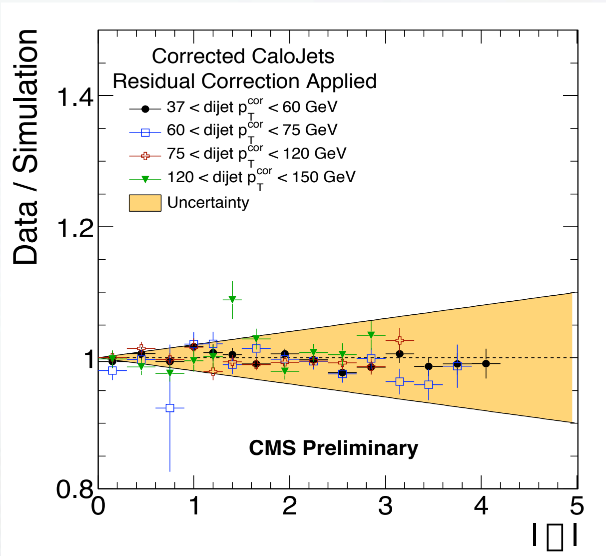


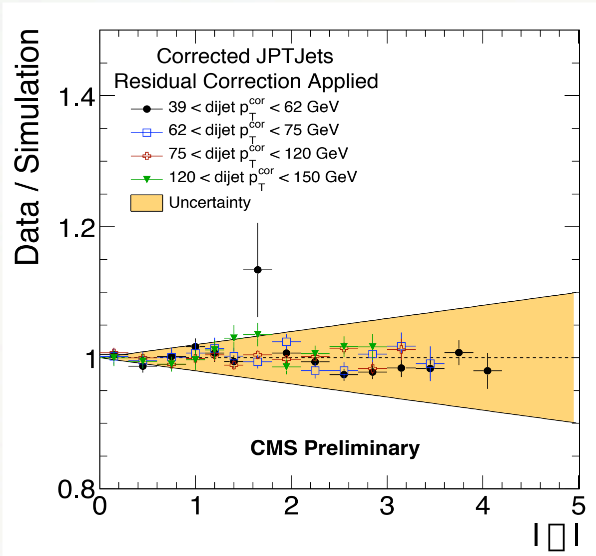


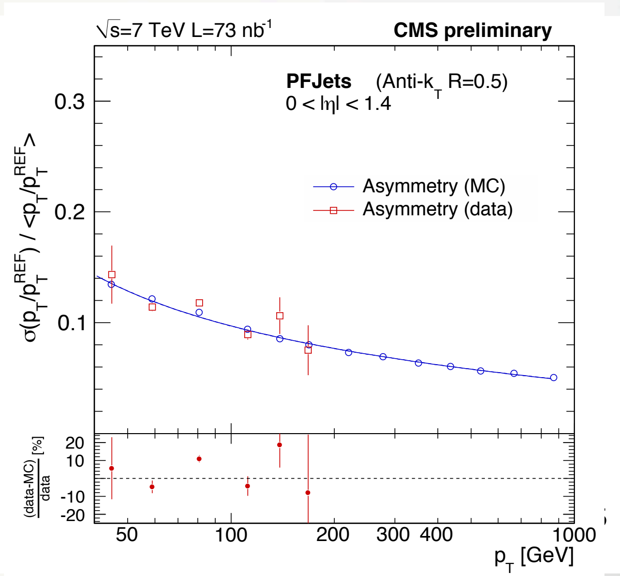


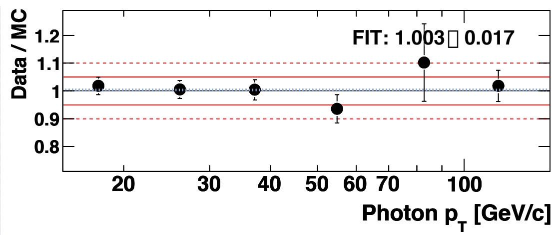
Jets at CMS

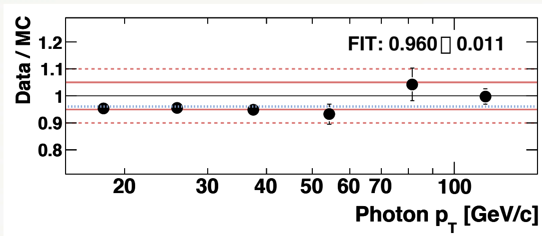
- Three types of algorithms have been commissioned: CaloJets, Jets-Plus-Tracks, Particle Flow Jets
- Good description of basic jet properties with the MC
- JES from MC has been shown to agree with data to 5% (JPT, PFJets) or 10% (CaloJets)

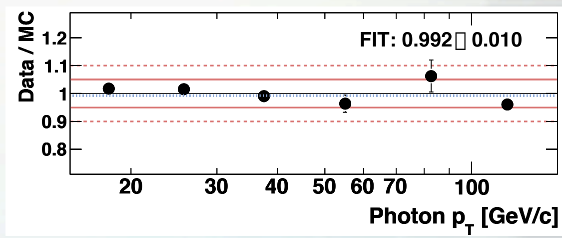






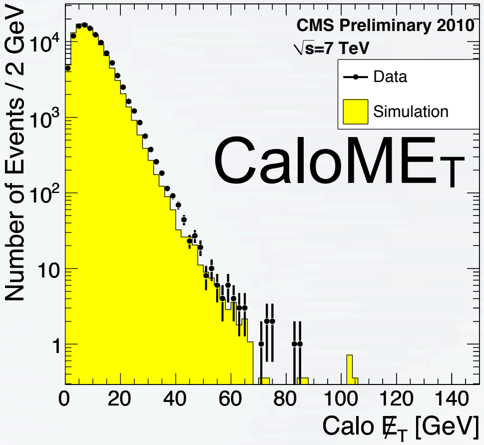


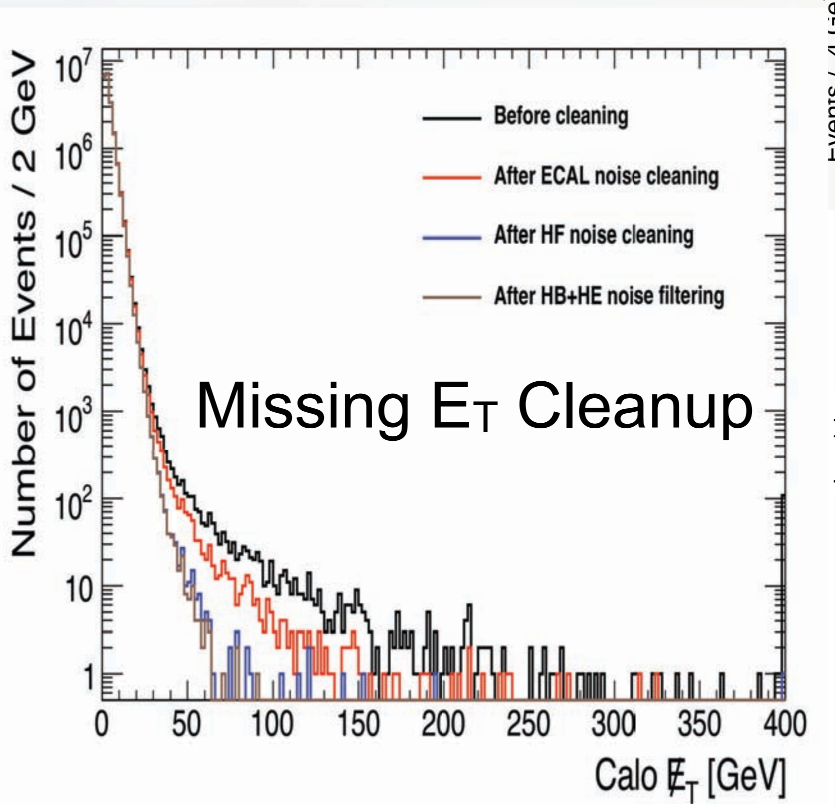


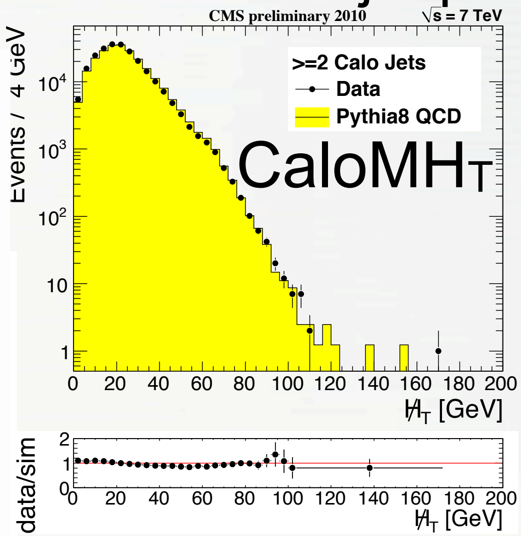


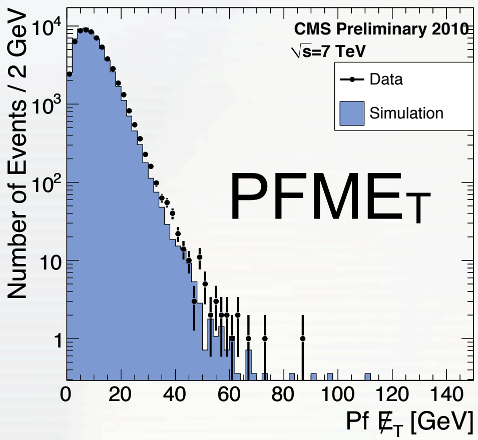
Missing E_T Commissioning

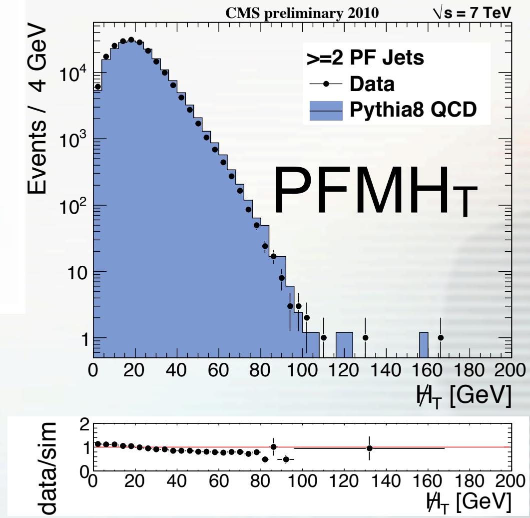
- Three types of ME_T, depending on jet algorithm and corresponding JES corrections (and additional unclustered energy corrections)
- Also three types of MH_T, defined as a negative vector sum of jet p_T











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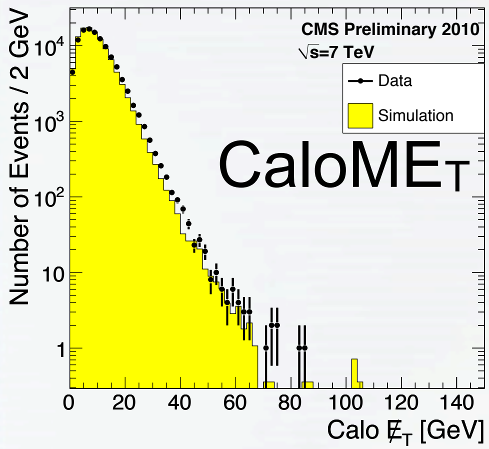
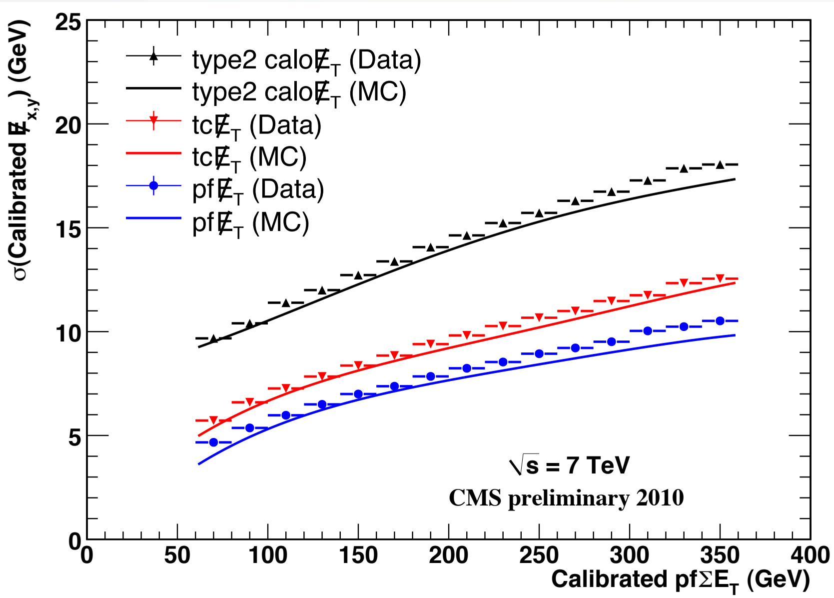
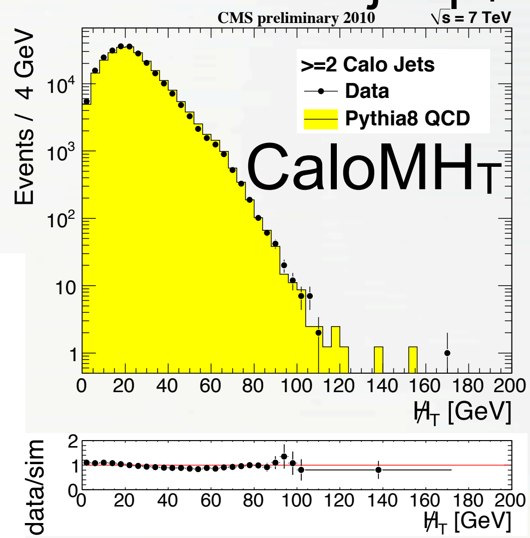
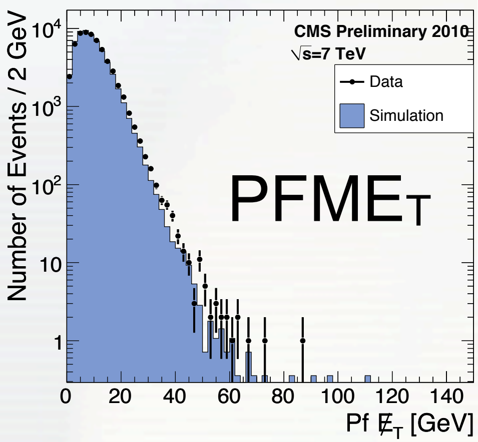
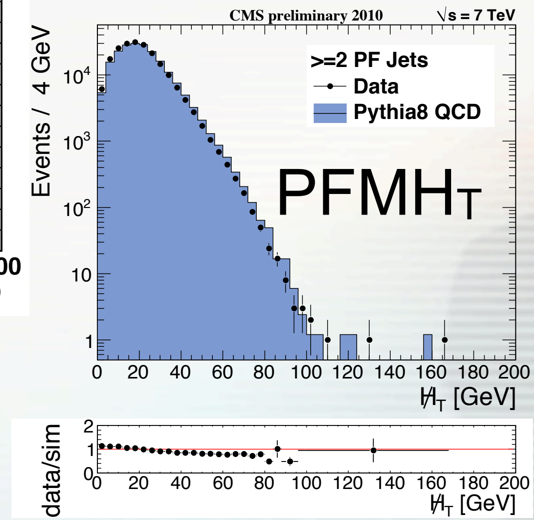


ME_T resolution as a function of scalar sum E_T for the three algorithms







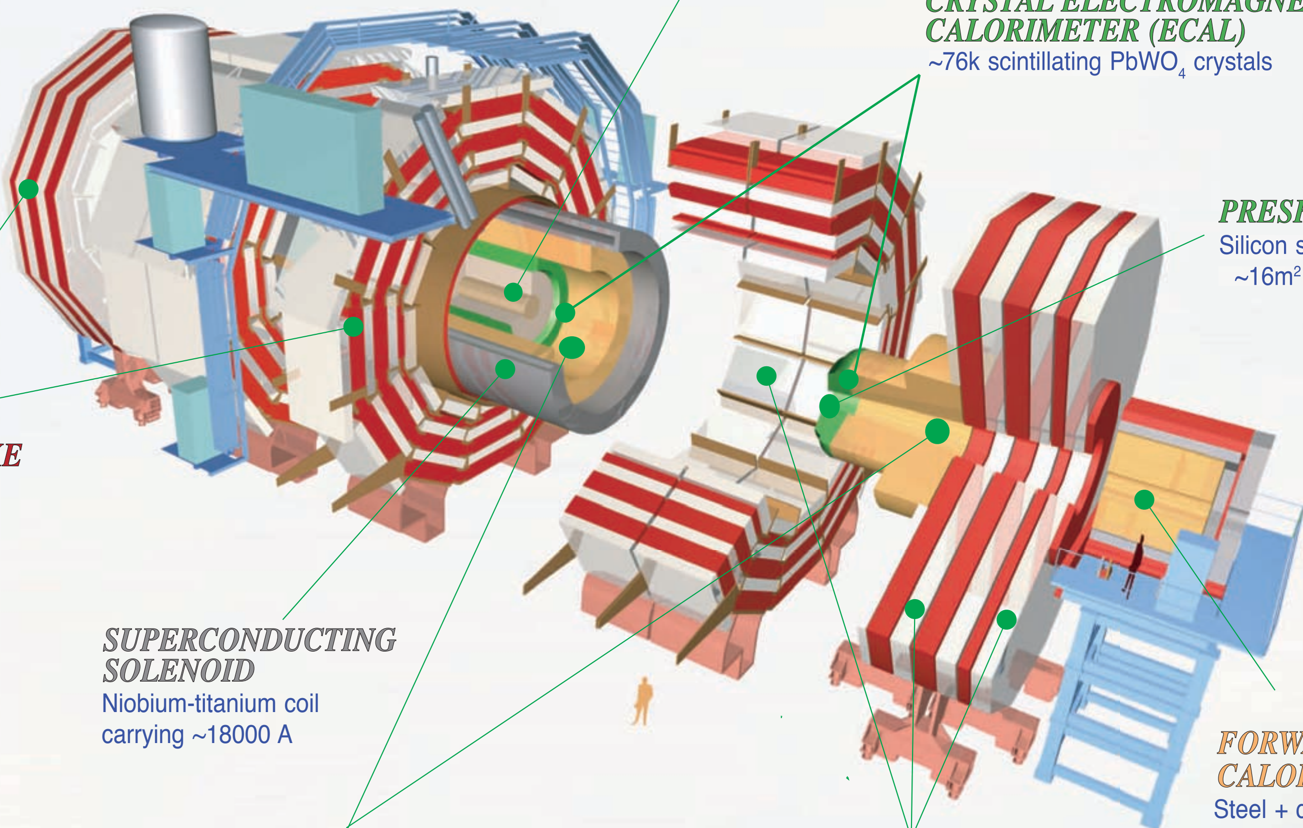


Good overall agreement with the MC (amazing as it is!)

Understanding CMS: Muons

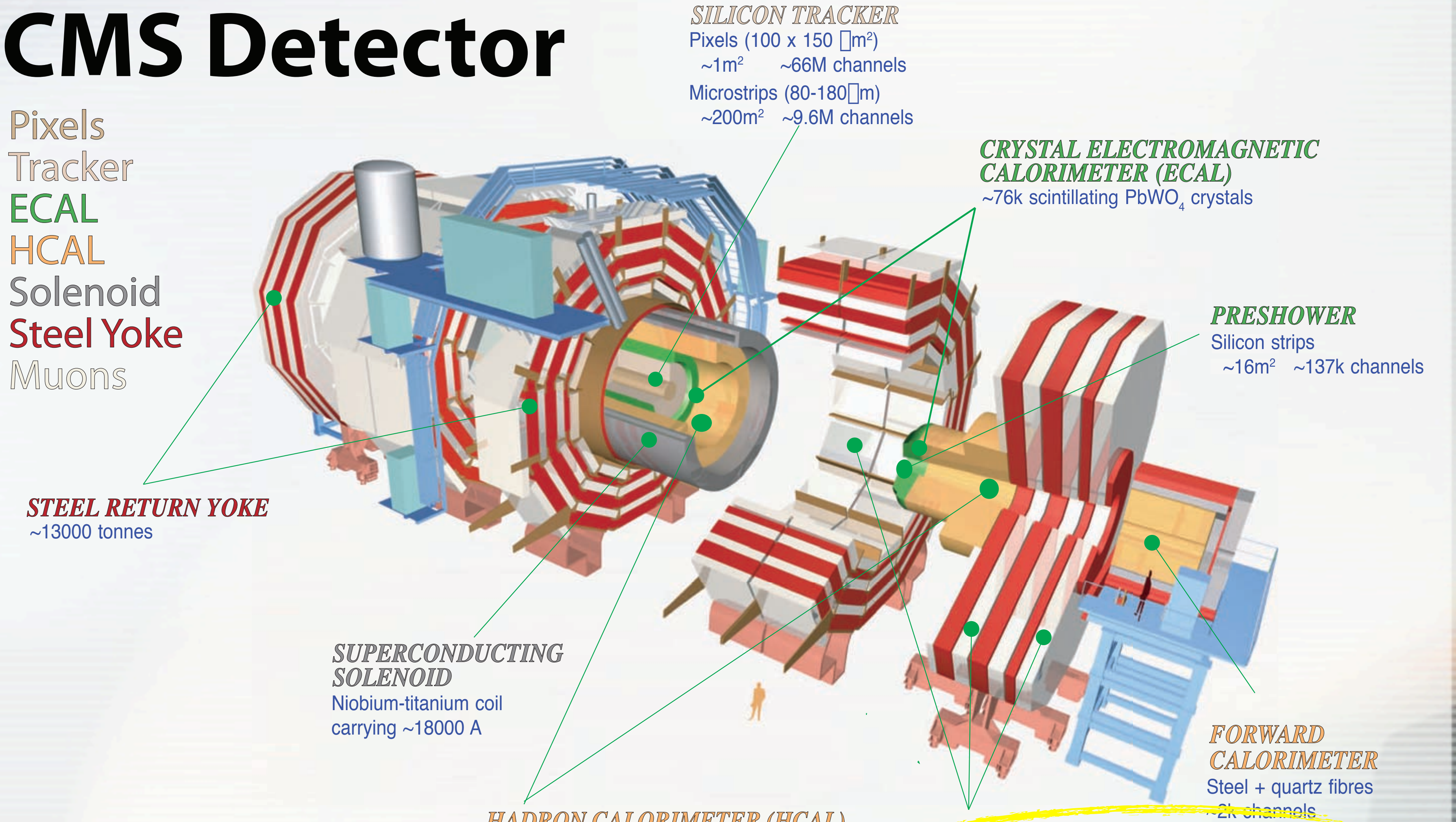
CMS Detector

Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons



Total weight : 14000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

Understanding CMS: Muons



Total weight	**: 14000 tonnes**
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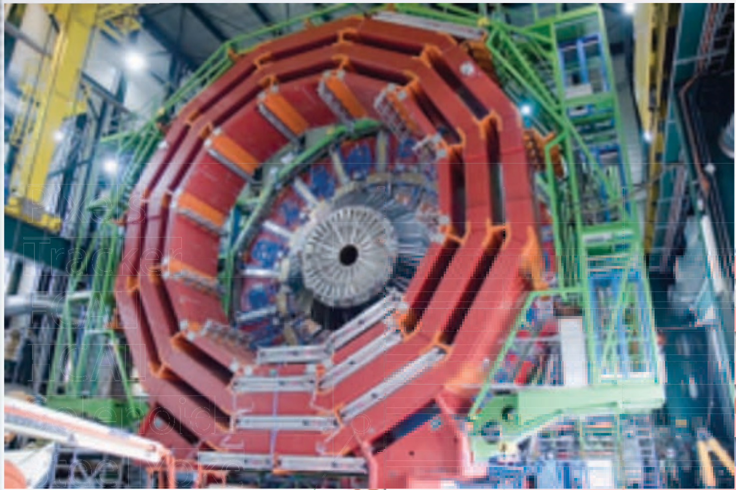
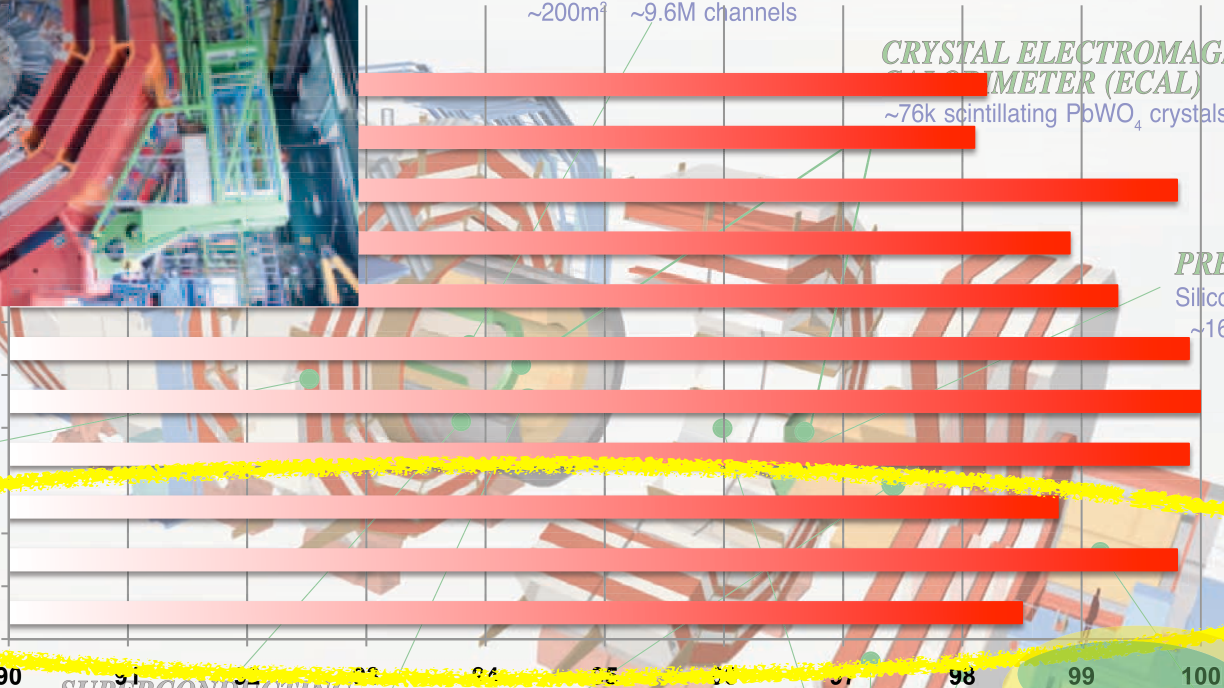
Understanding CMS: Muons





	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

SILICON TRACKER
Pixels (100 x 150 μm²) ~1m² ~66M channels
Microstrips (80-180μm) ~200m² ~9.6M channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76k scintillating $PbWO_4$ crystals

PRESHOWER
Silicon strips ~16m² ~137k channels

STEEL RETURN YOKE
~13000 tonnes

SUPERCONDUCTING SOLENOID
Niobium-titanium coil carrying ~18000 A

HADRON CALORIMETER (HCAL)
Brass + plastic scintillator ~7k channels

FORWARD CALORIMETER
Steel + quartz fibres ~2k channels

MUON CHAMBERS
Barrel: 250 Drift Tube & 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip & 432 Resistive Plate Chambers

Total weight : 14000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

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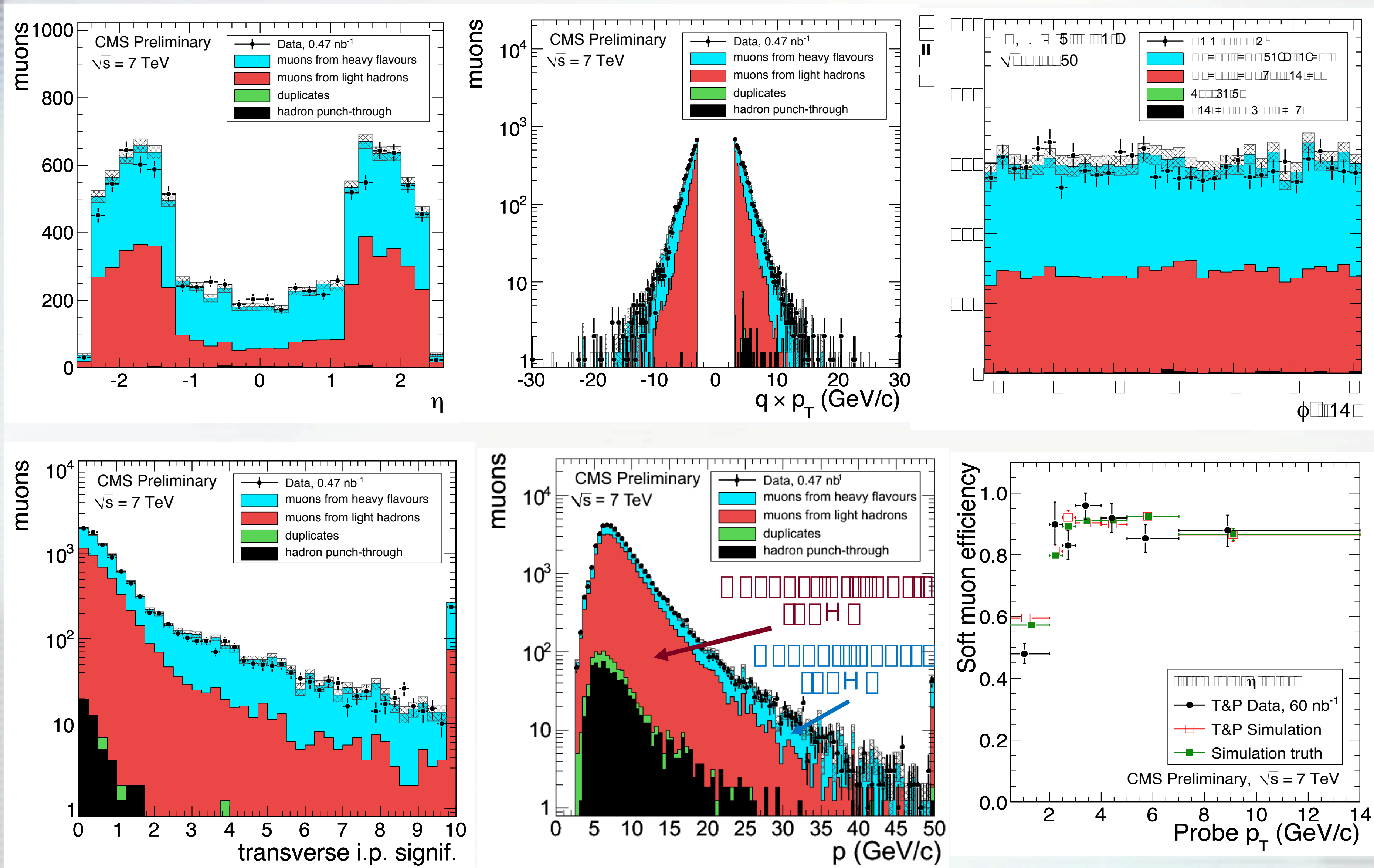
Muon is Our Second Name!



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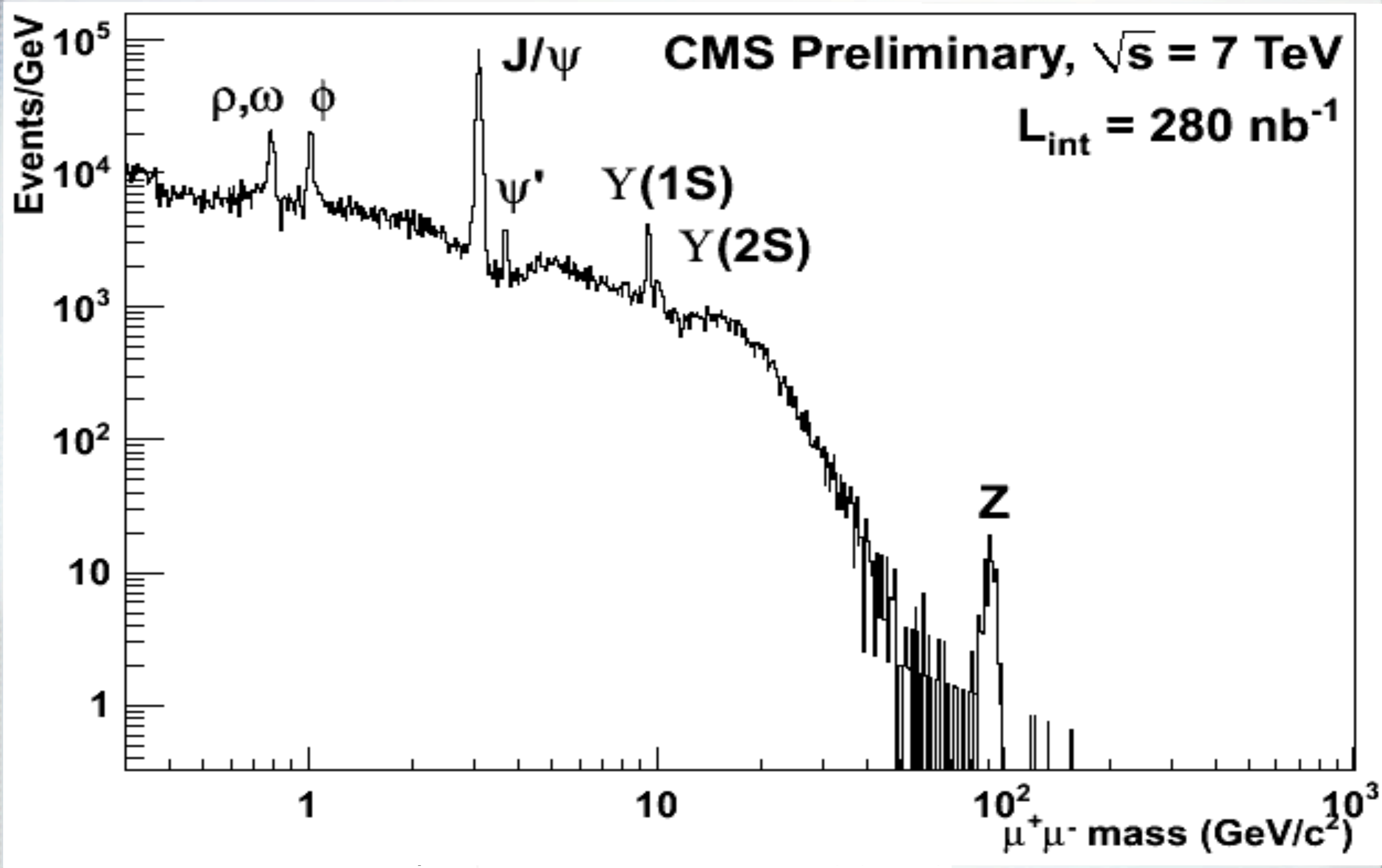
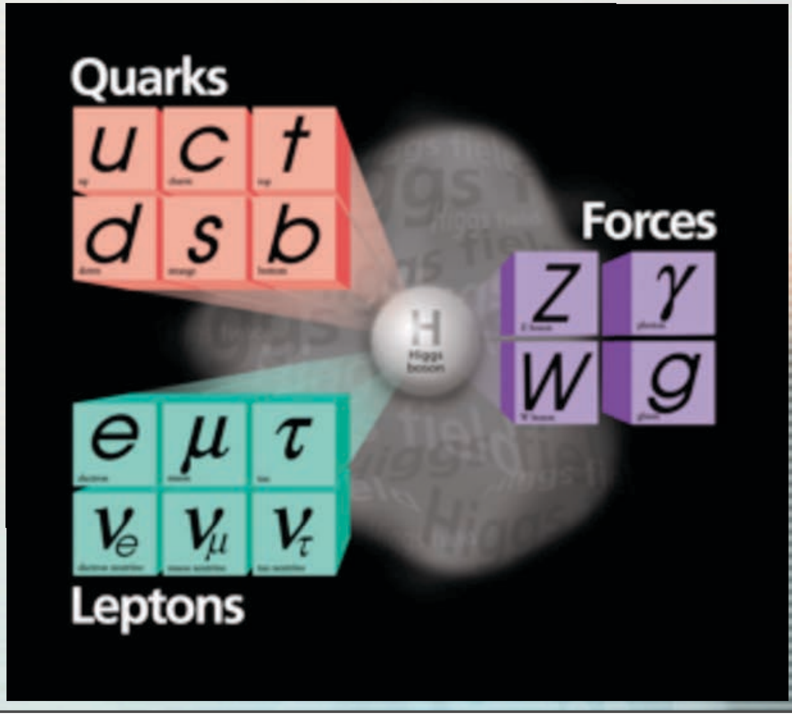
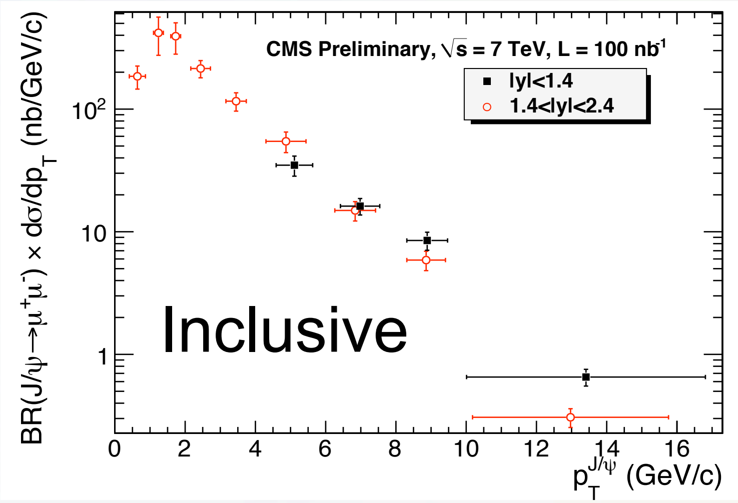


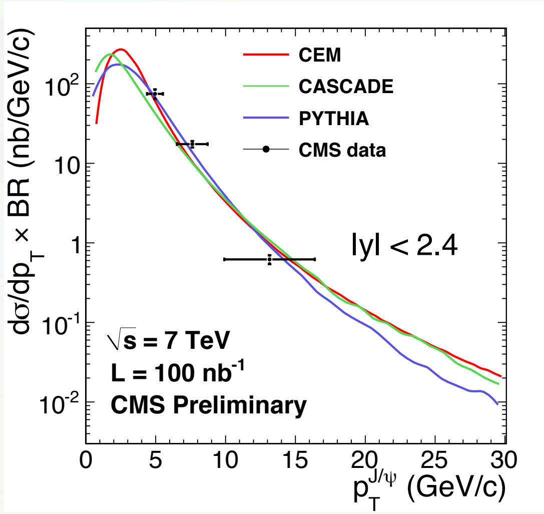
The Standard Model

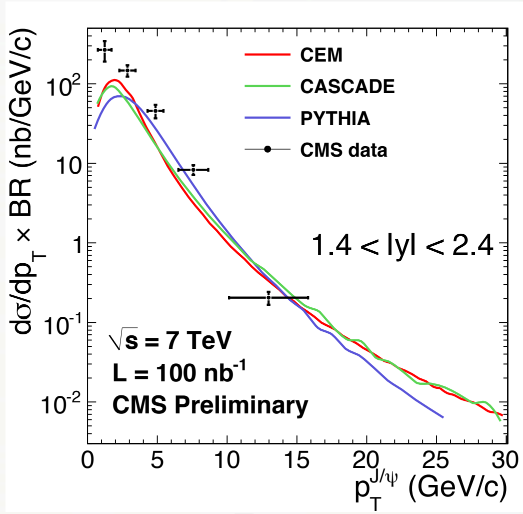


Charming Muon Solenoid

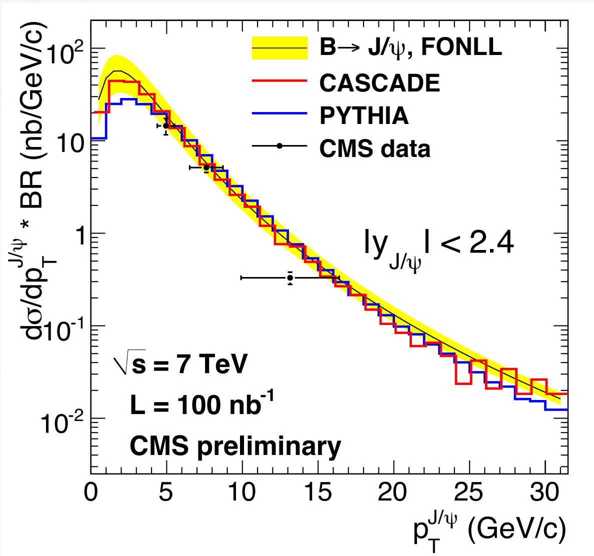
- Prompt and non-prompt J/Ψ production cross section in two rapidity ranges

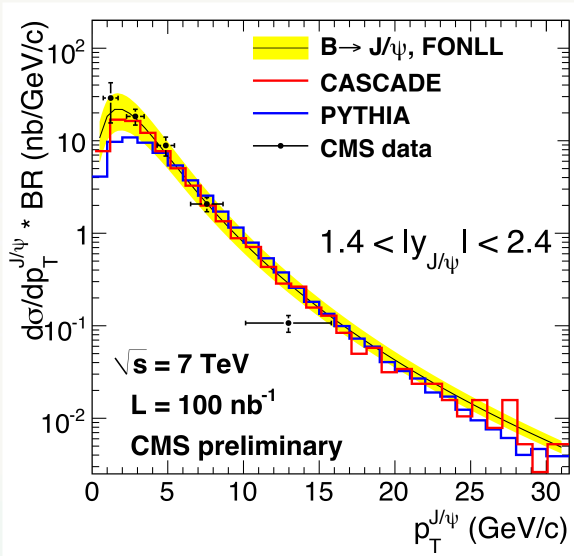






Prompt





Non-Prompt

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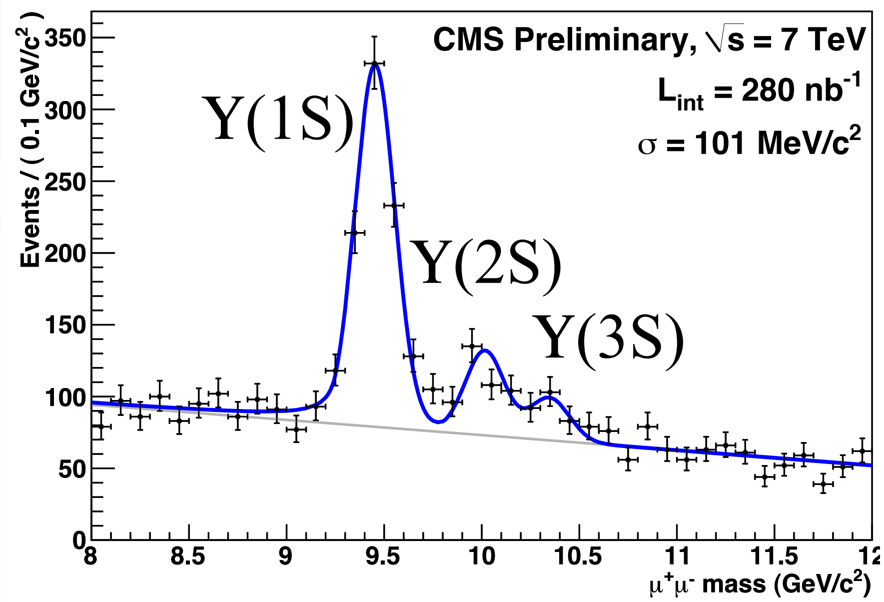
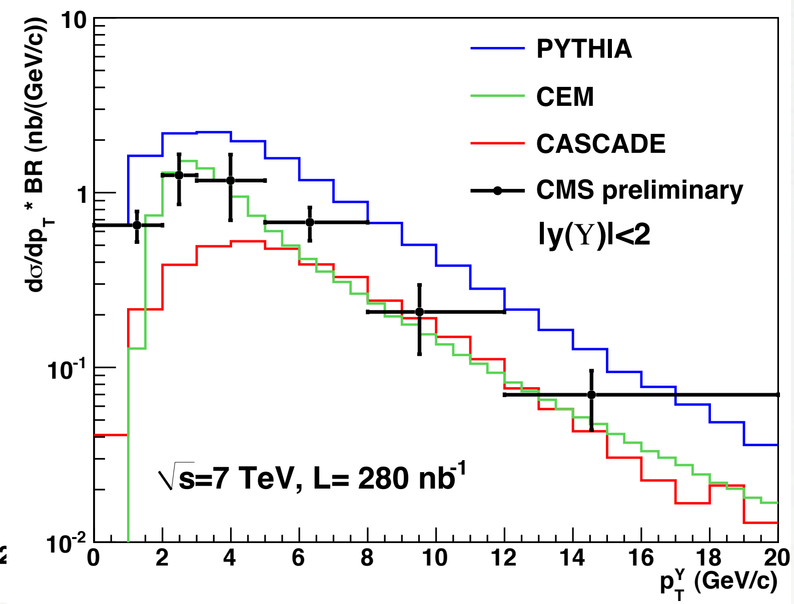
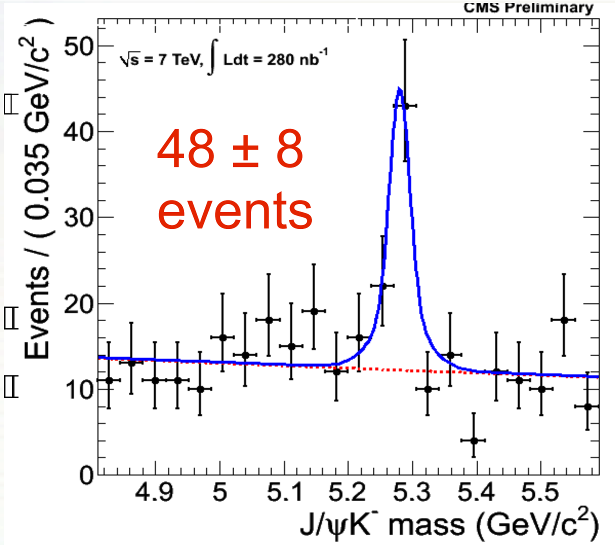
Beauty at CMS

- First measurements of beauty production



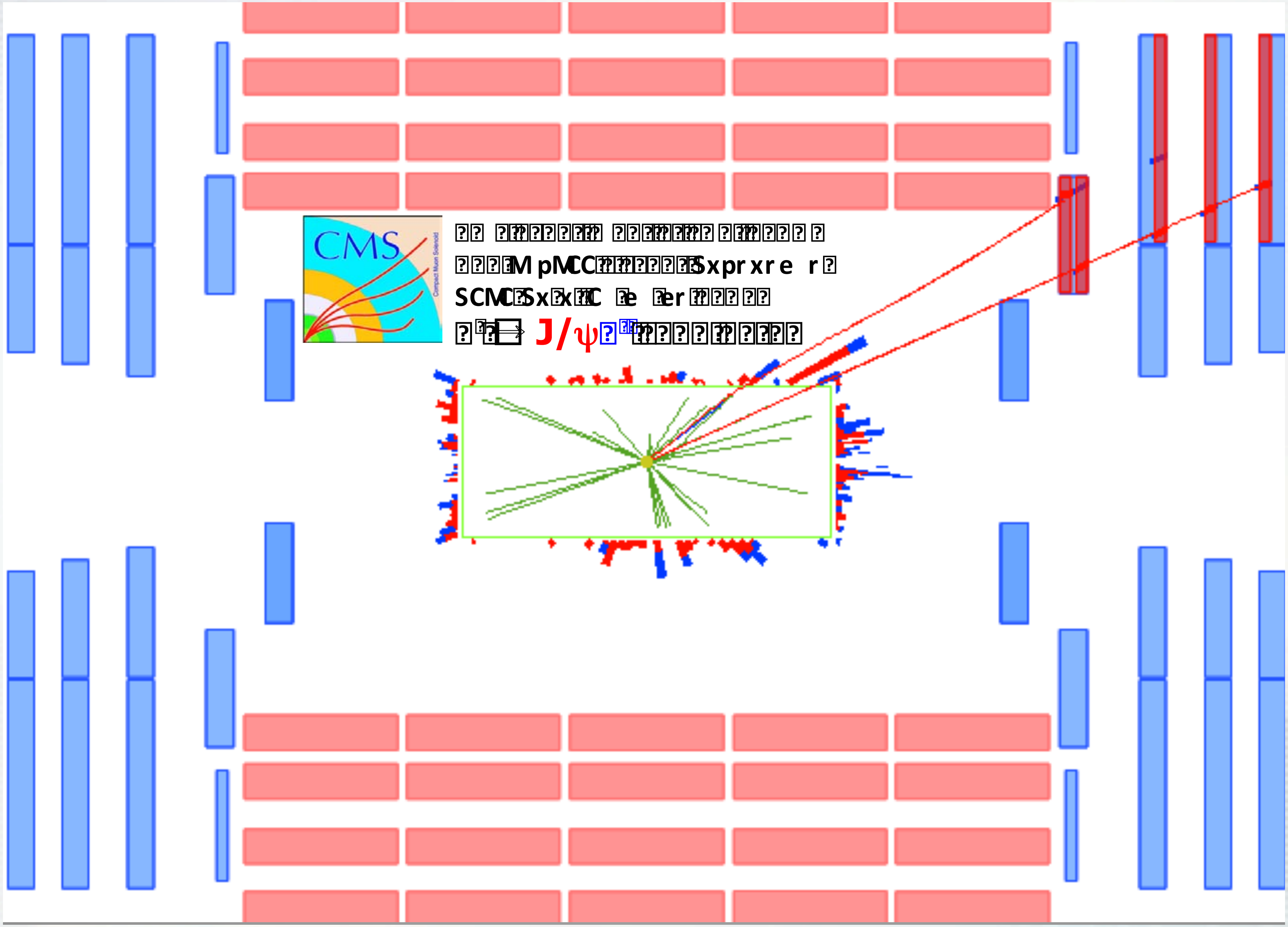




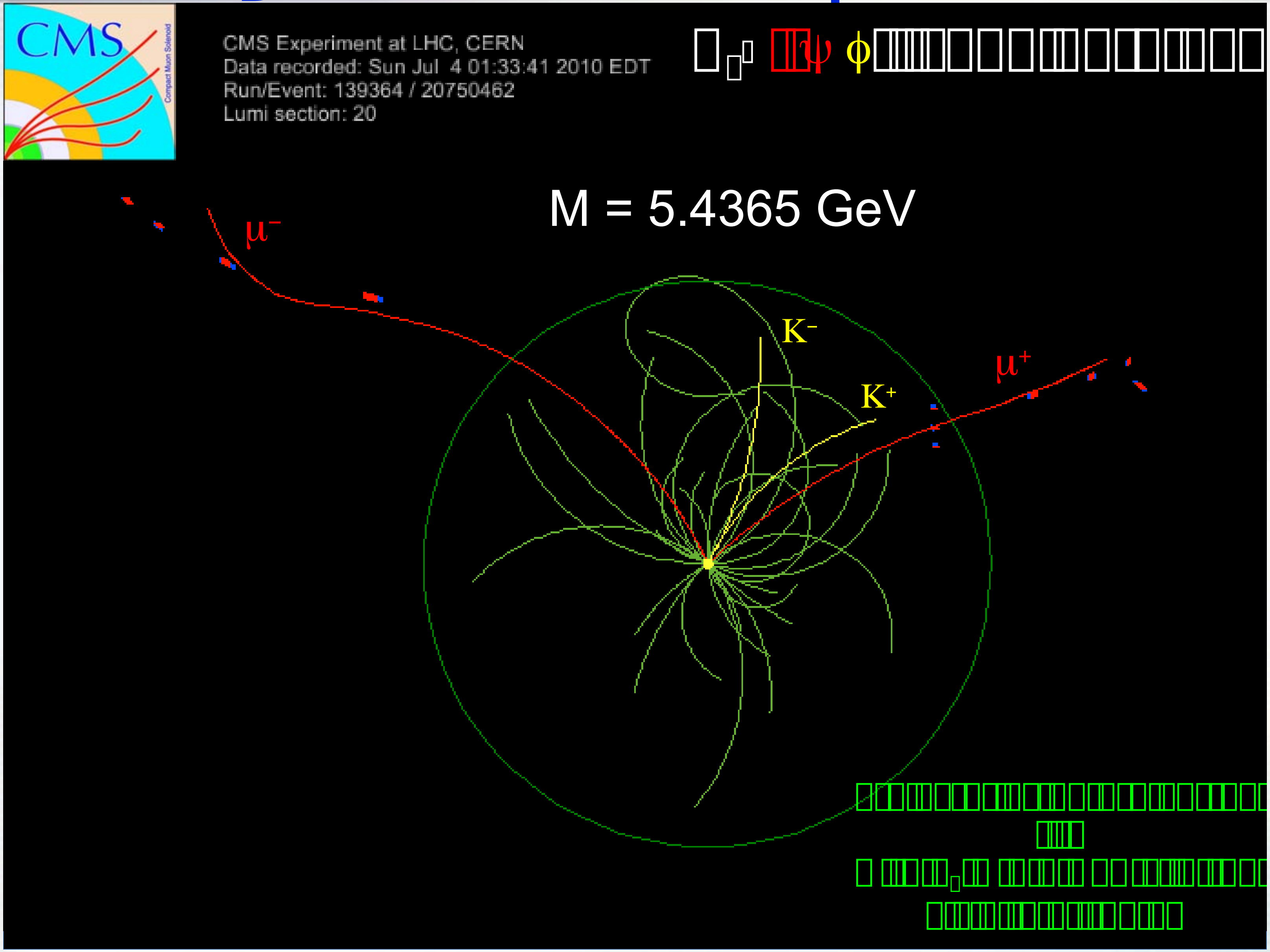
σ(pp →Υ(1S)X)·B(Υ(1S)→μ+ μ−)= (8.3 ± 0.5 ± 0.9 ± 1.0)nb

$B^{\pm} \rightarrow J/\Psi\ K^{\pm}$

$B \to J/\Psi K^-$ Candidate

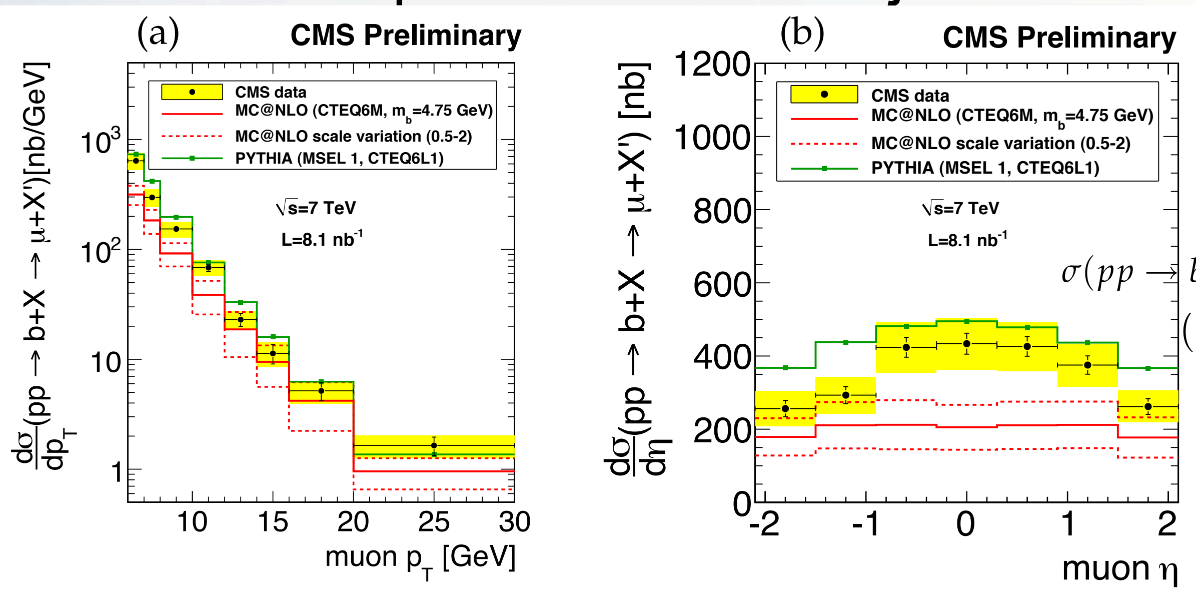


B-Physics: $B_s \to J/\Psi\phi$

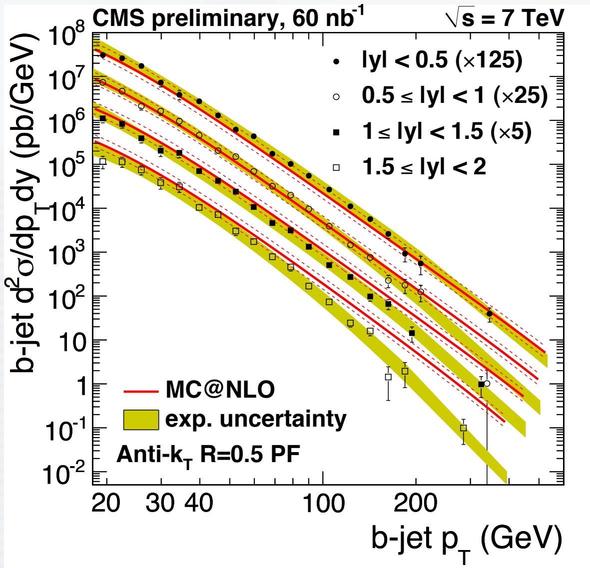


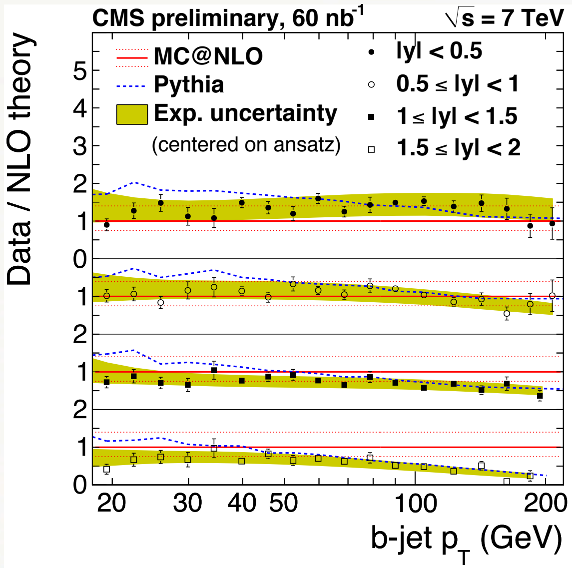
B-Physics: Cross Sections

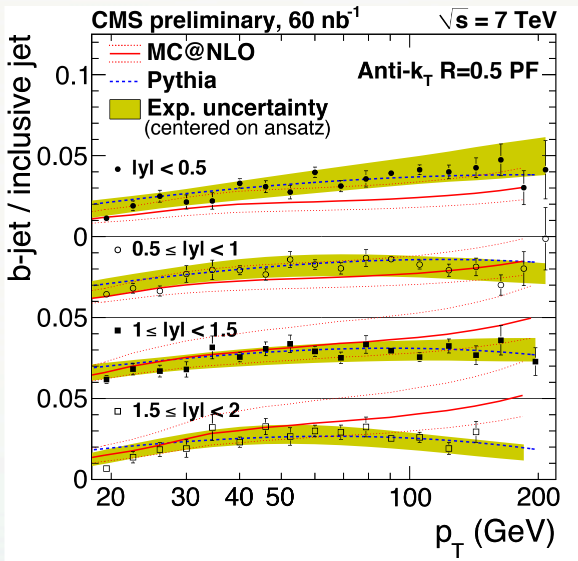
- Inclusive b-production and b-jet cross section measurements



$$\sigma(pp \to b + X \to \mu + X', p_{\perp}^{\mu} > 6\,\mathrm{GeV}, |\eta^{\mu}| < 2.1) =$$
$$(1.48 \pm 0.04_{\mathrm{stat}} \pm 0.22_{\mathrm{syst}} \pm 0.16_{\mathrm{lumi}})\ \mu\mathrm{b}$$

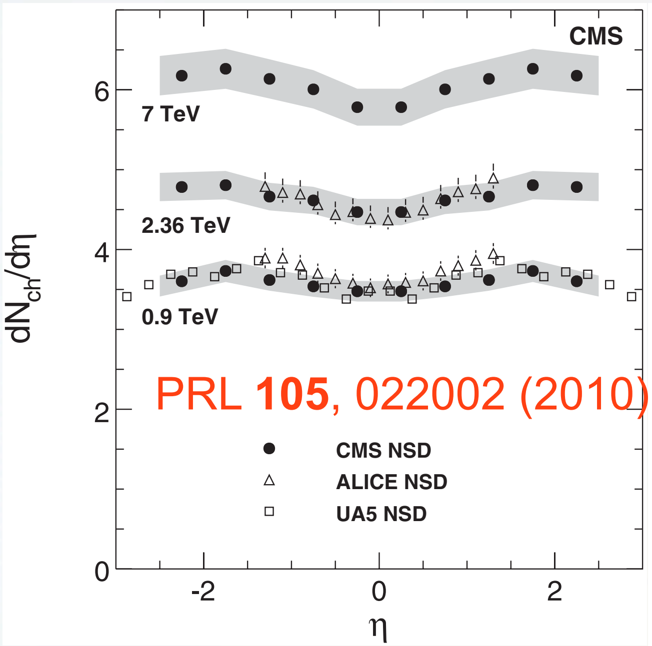




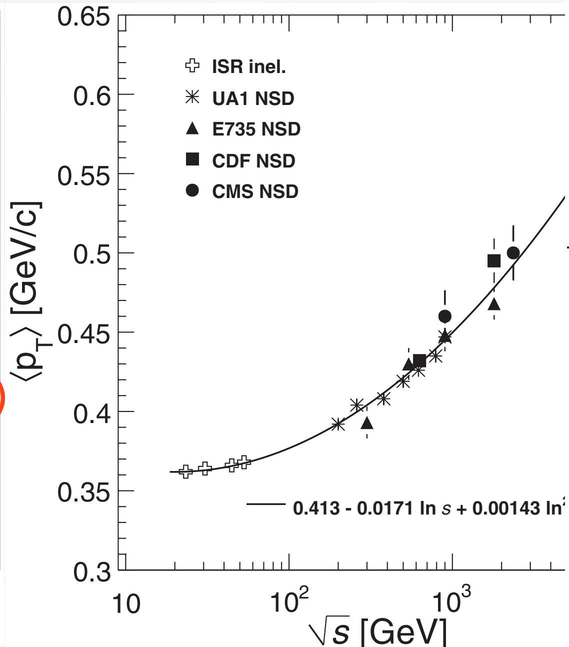


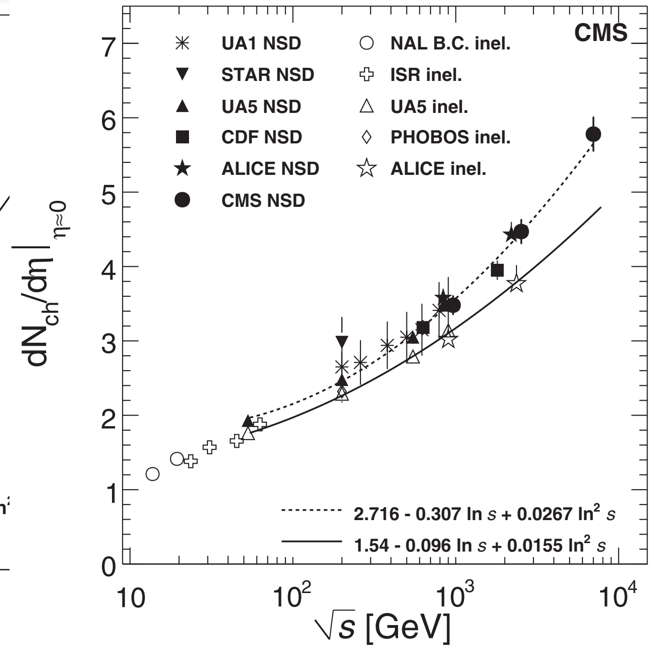
Soft QCD

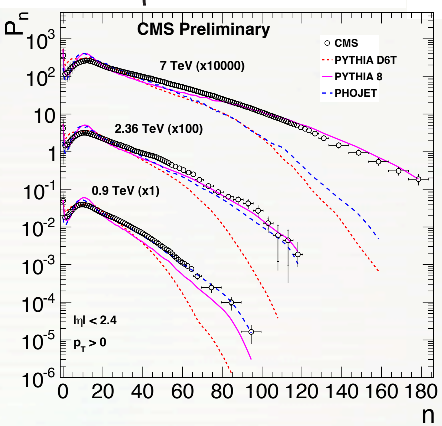
- Charged particle density in minimum-bias events increases faster with √s than the various tunes predict

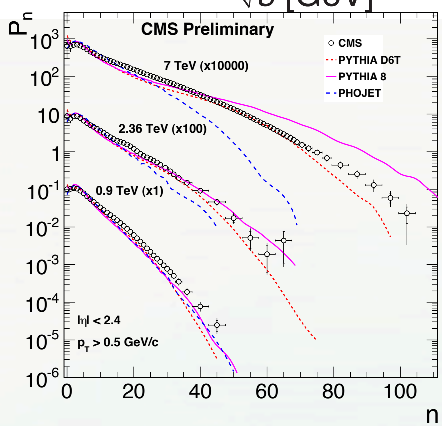


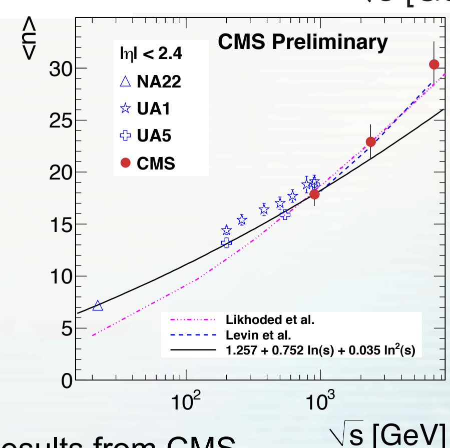
PRL **105**, 022002 (2010)











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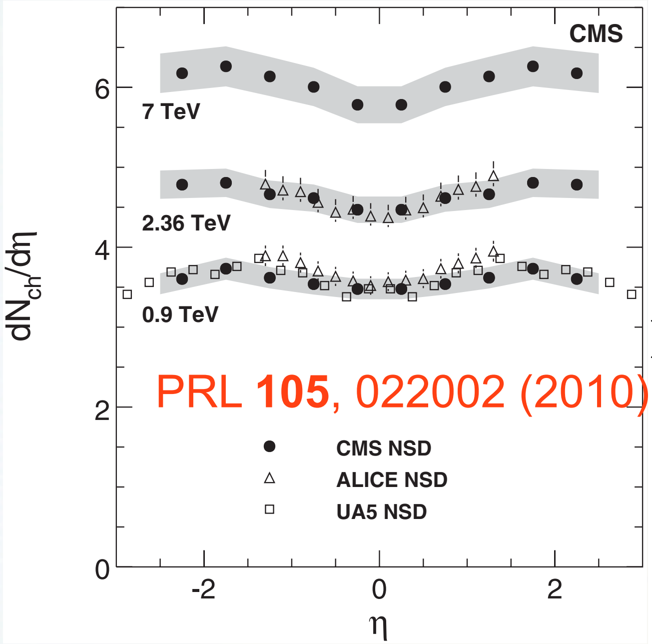

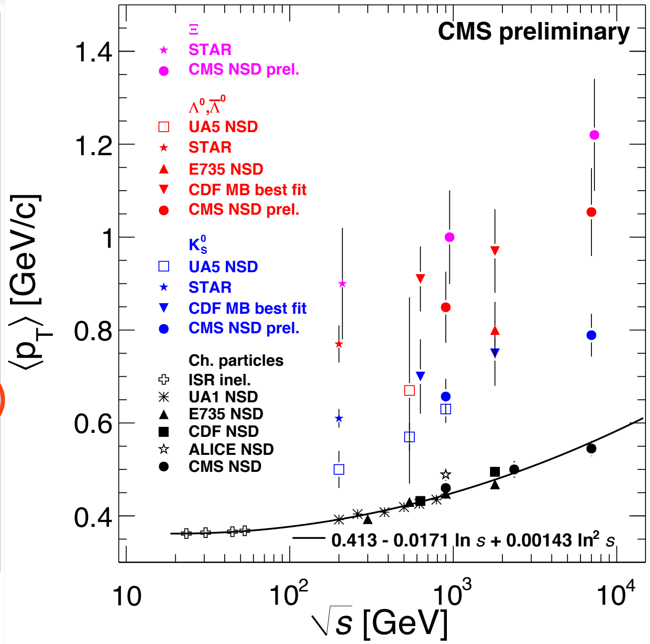

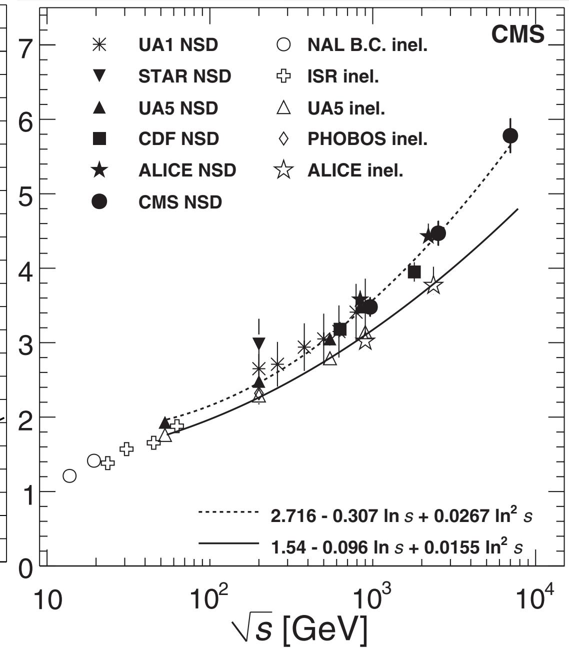

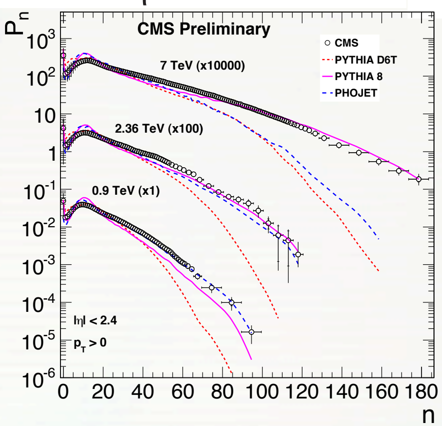

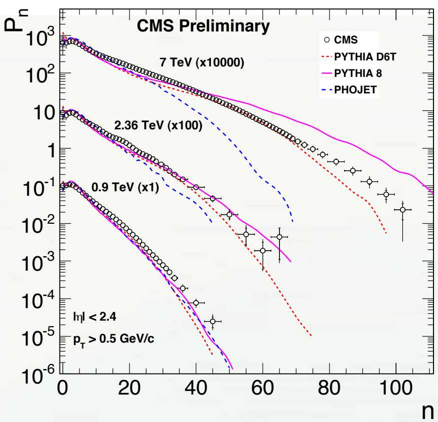

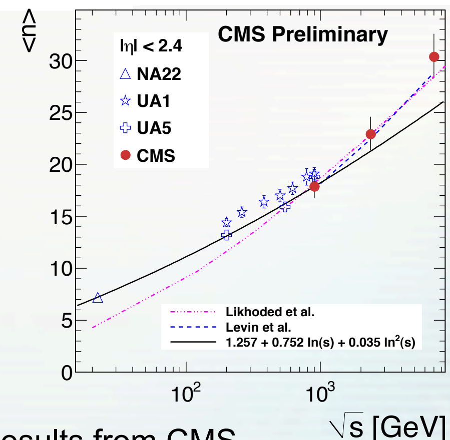

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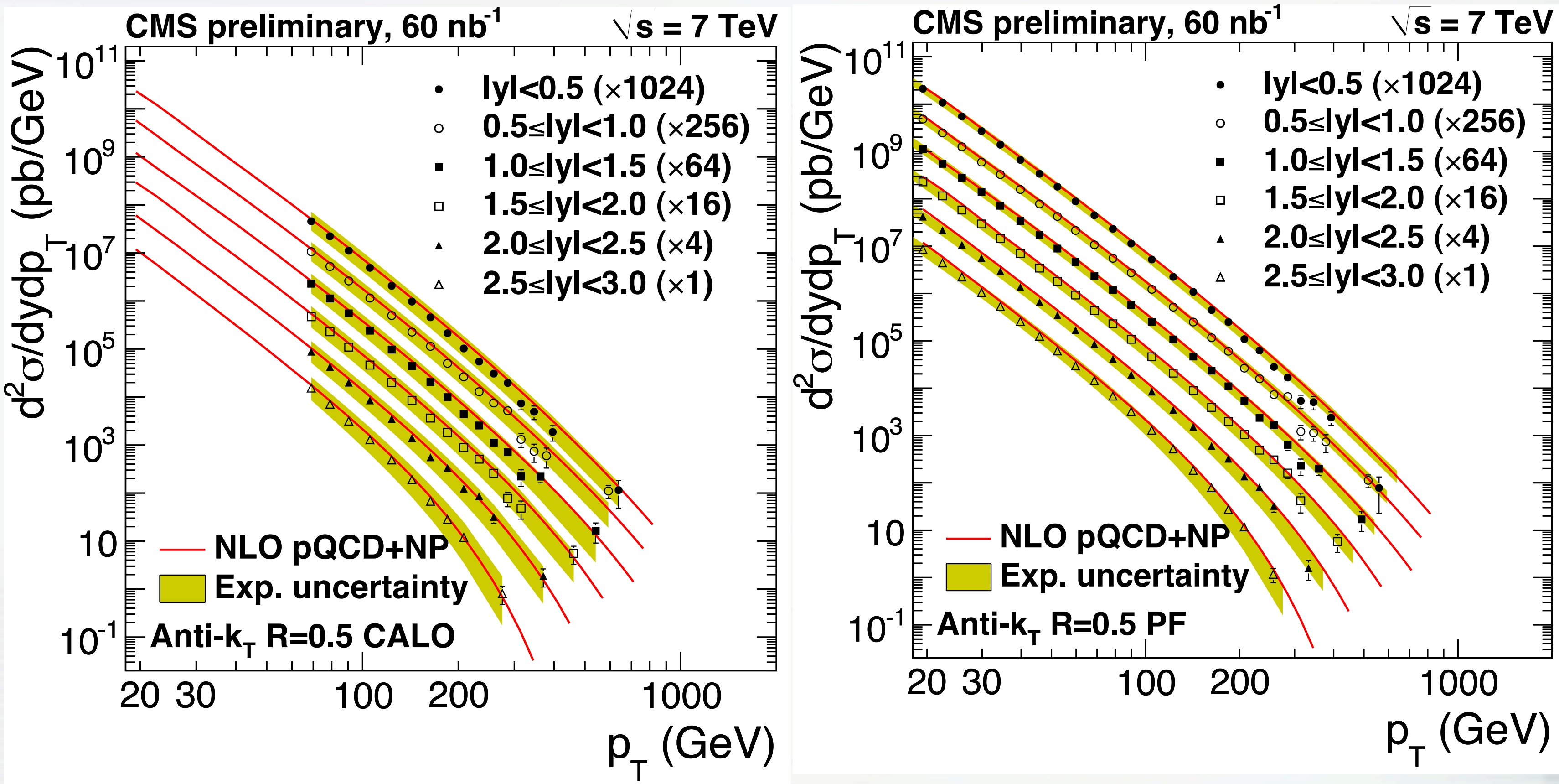
Hard QCD

- Inclusive jet cross sections agree well with the NLO pQCD predictions over 9 decades in range



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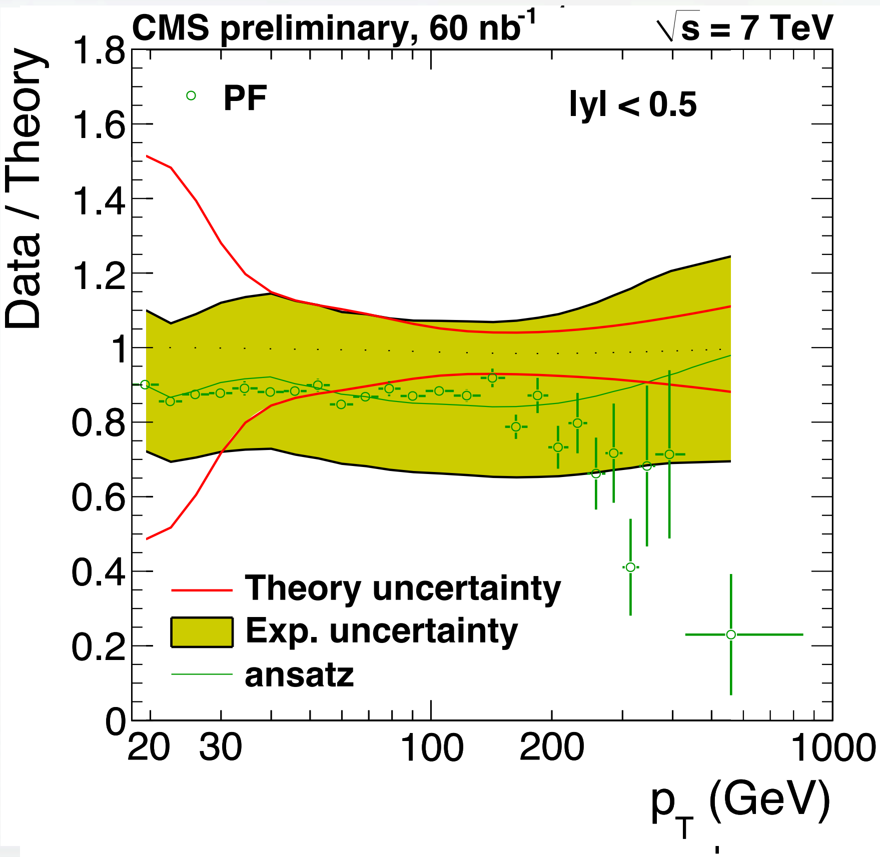

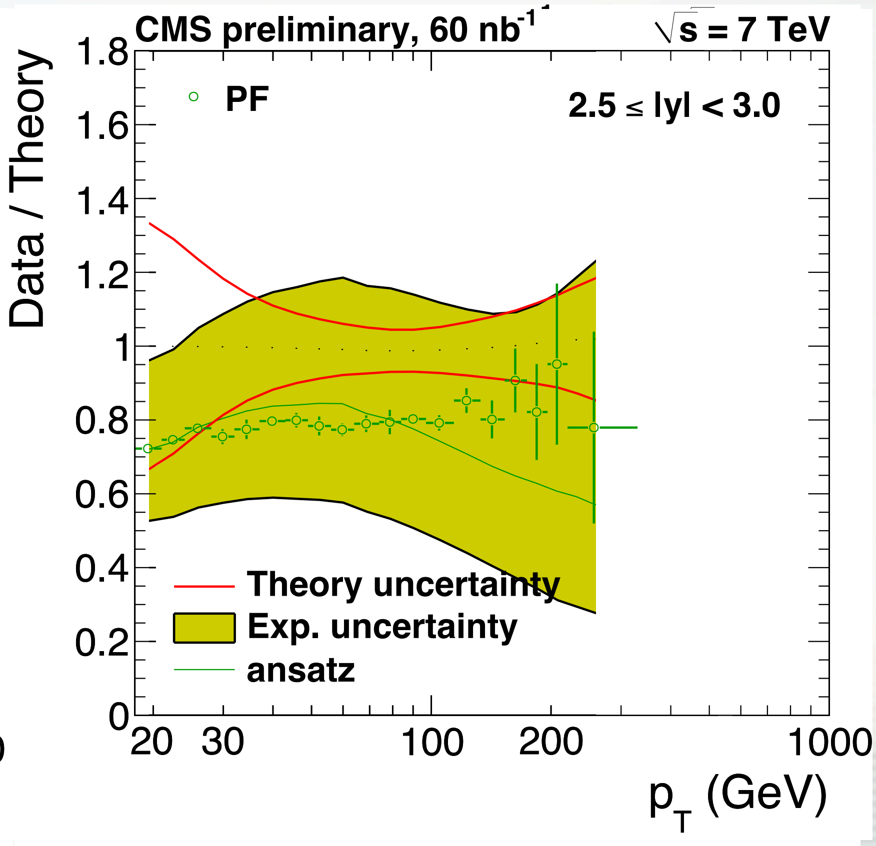

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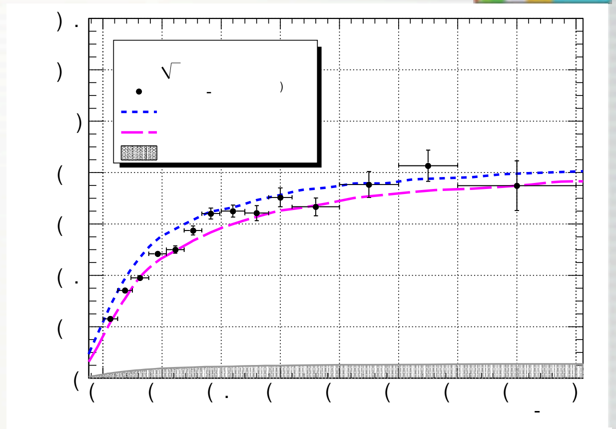
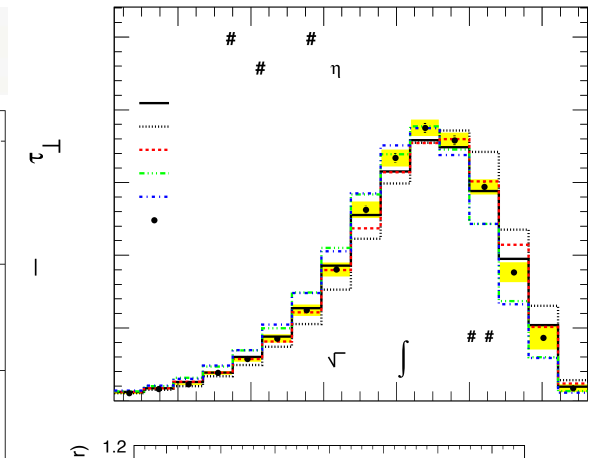
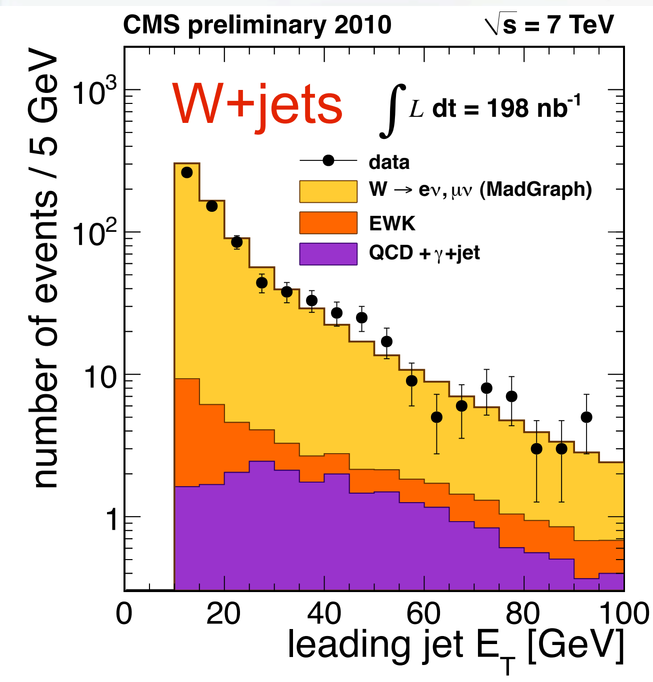
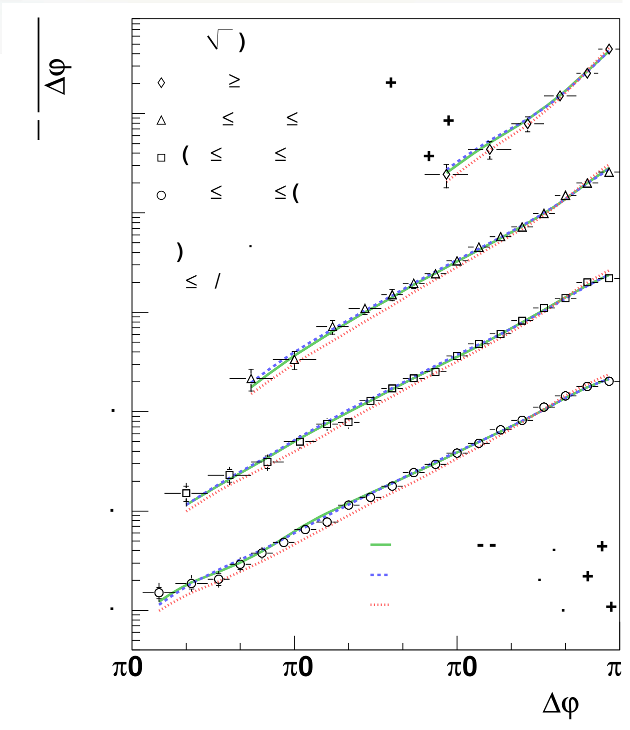
More Hard QCD

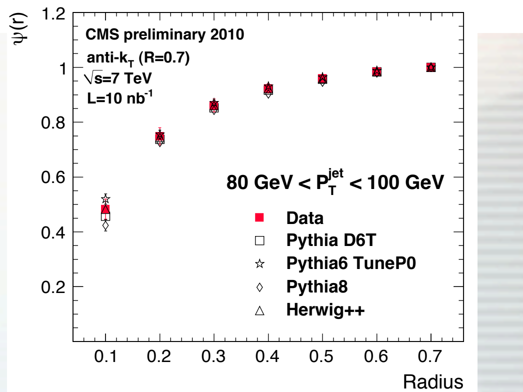
- Number of other measurements:
  - Azimuthal decorrelations
  - Ratio of 3 to 2 jets
  - W+jets
  - Jet shape, event shape
- Good agreement with NLO pQCD





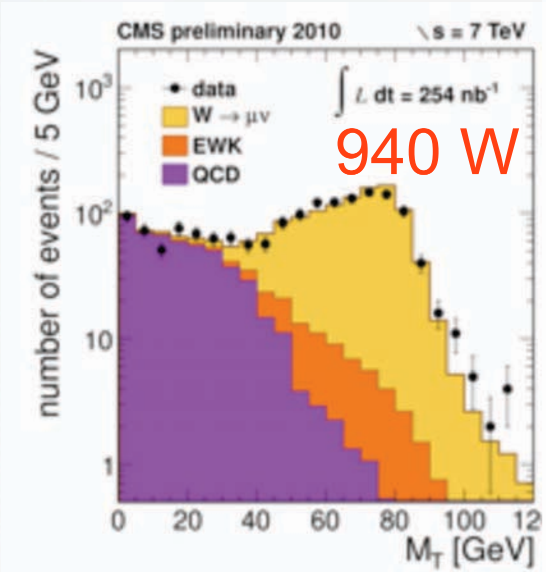


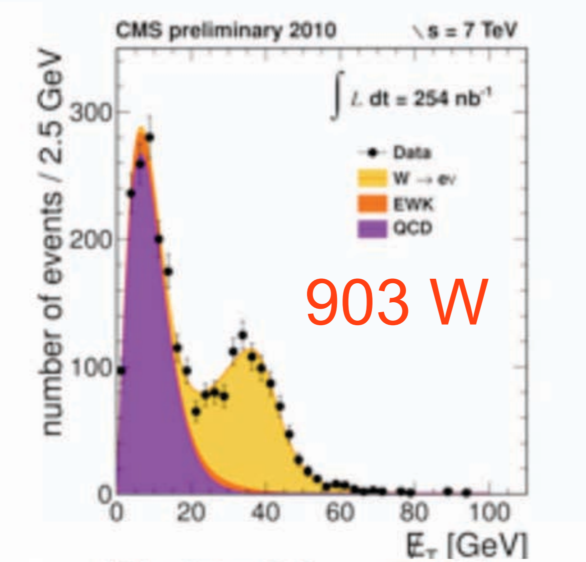


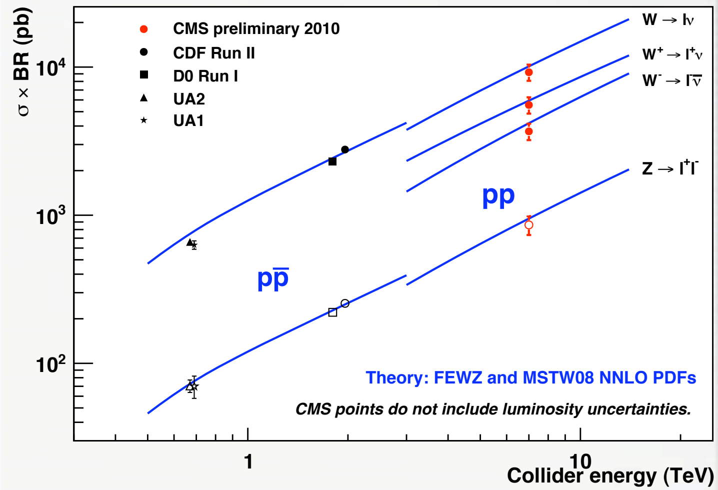


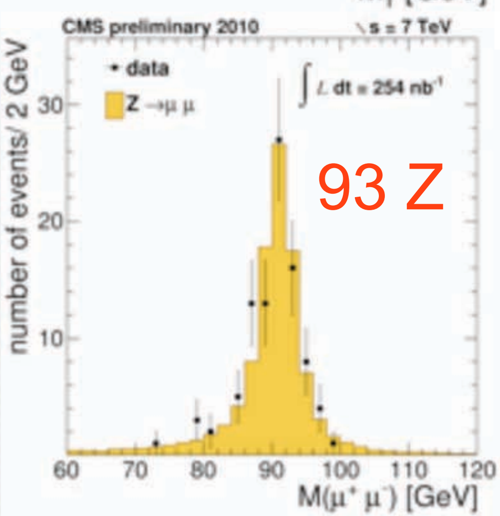
W/Z Physics

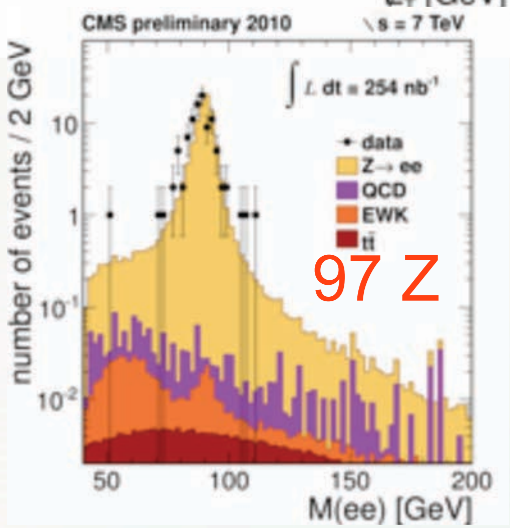
- Measurement of the W/Z cross section and asymmetry

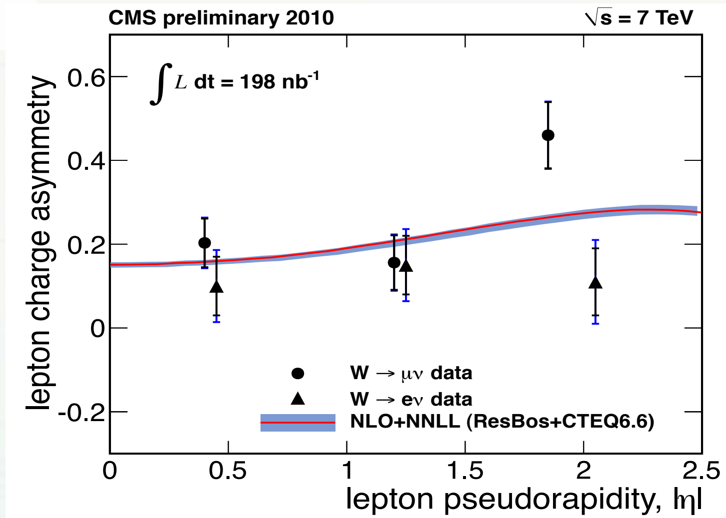






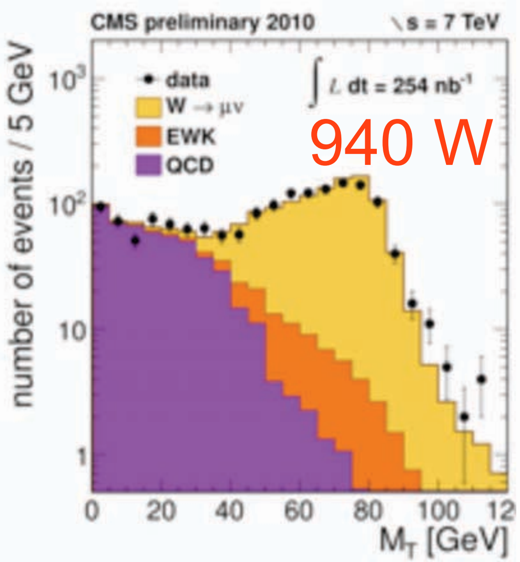


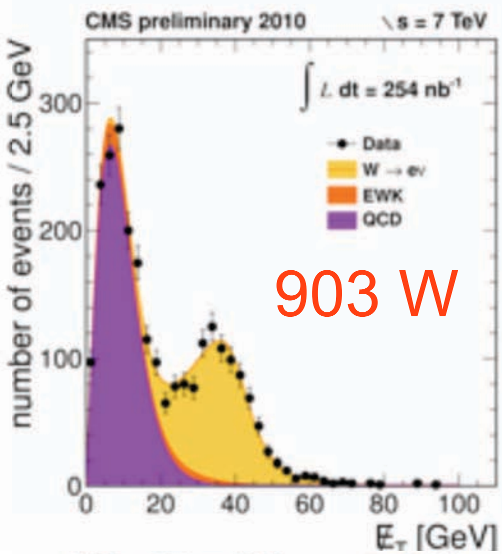


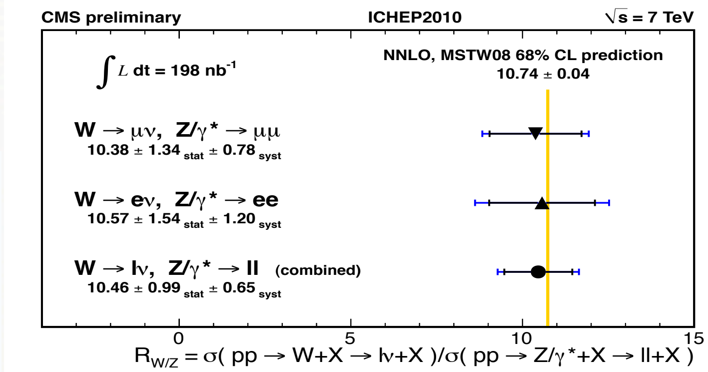


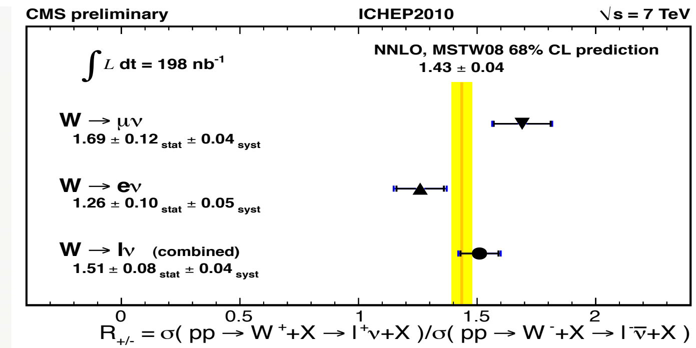
W/Z Physics

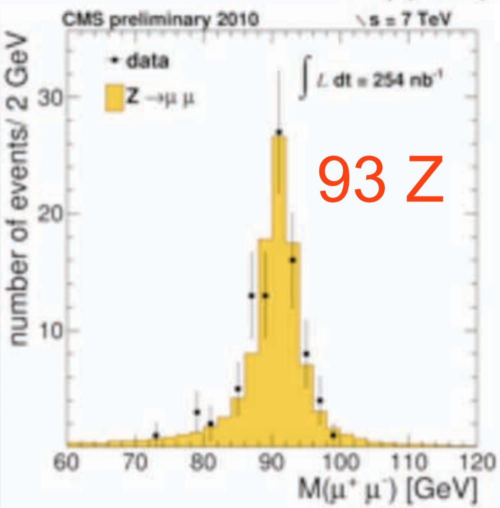
- Measurement of the W/Z cross section and asymmetry

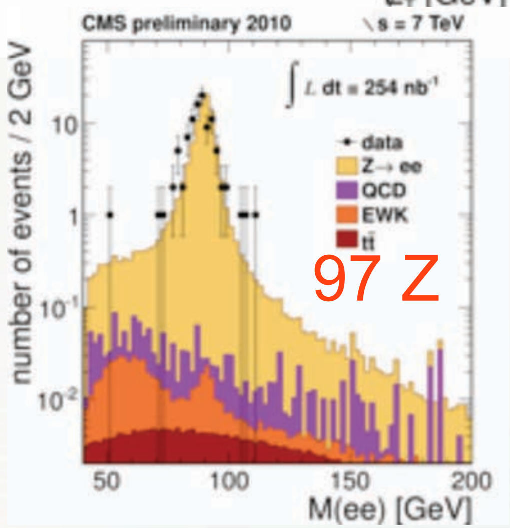


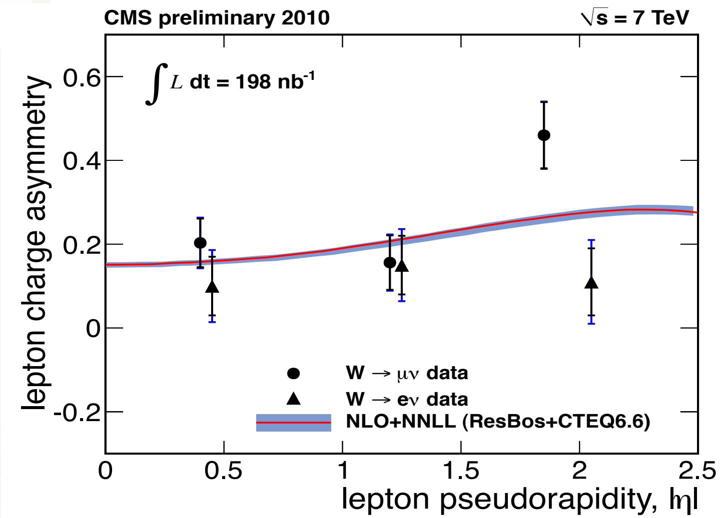












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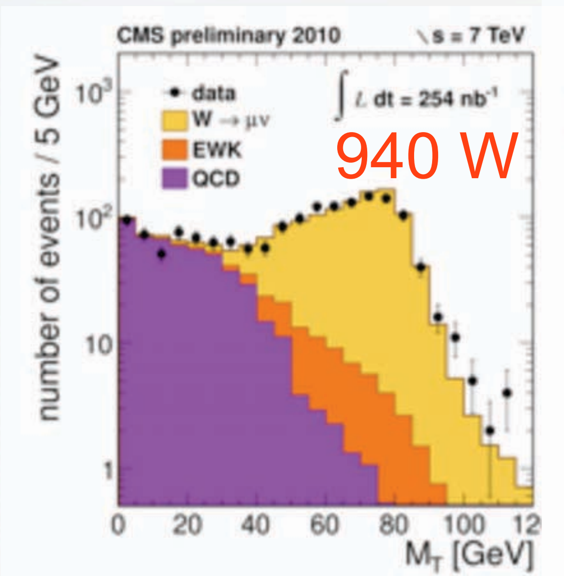
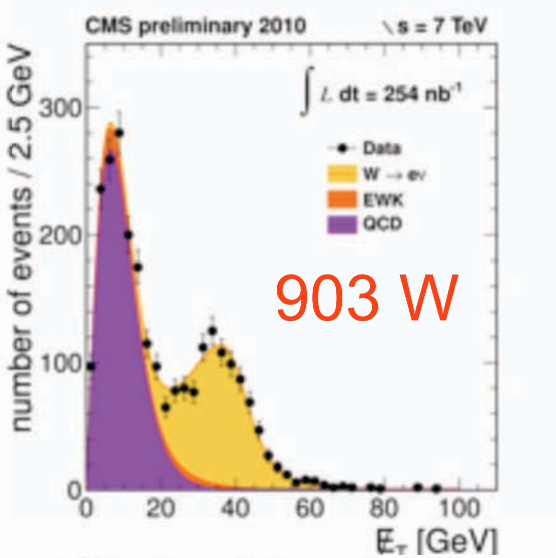
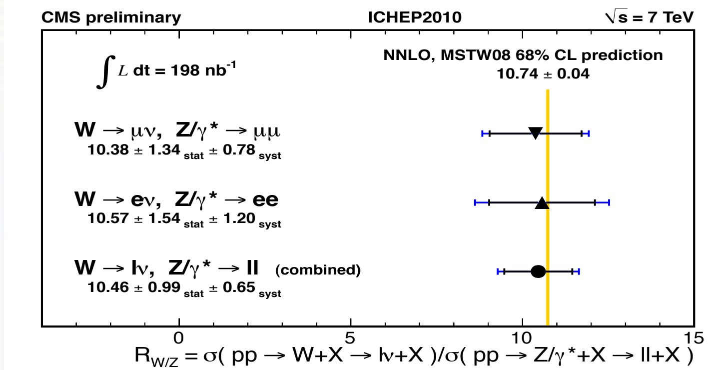
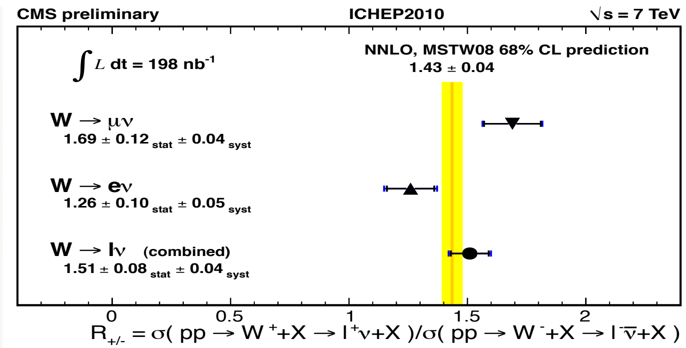
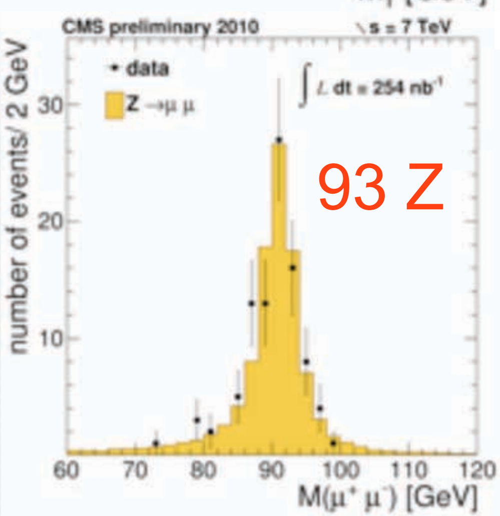
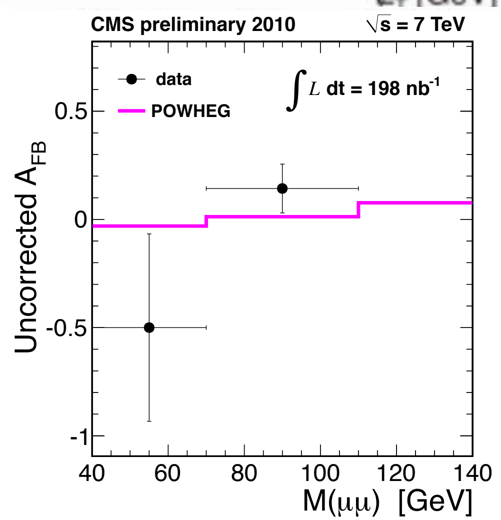


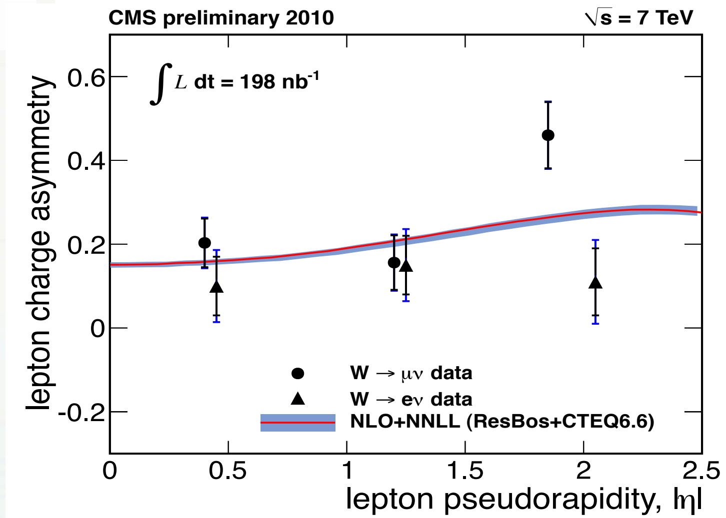






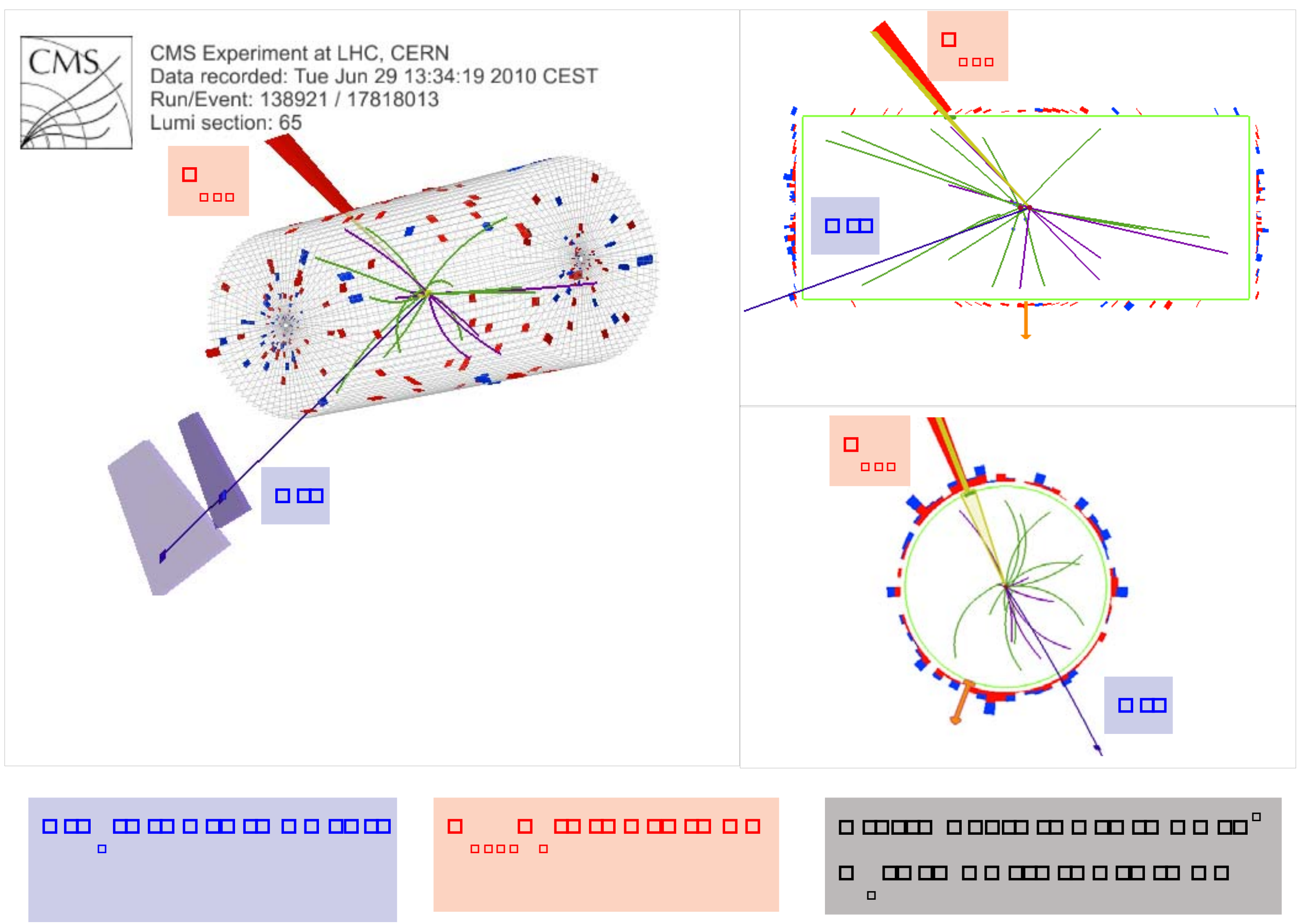


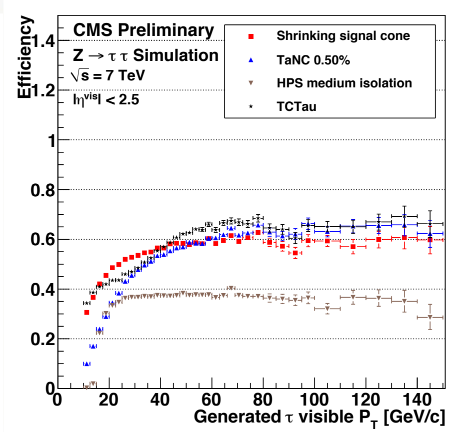


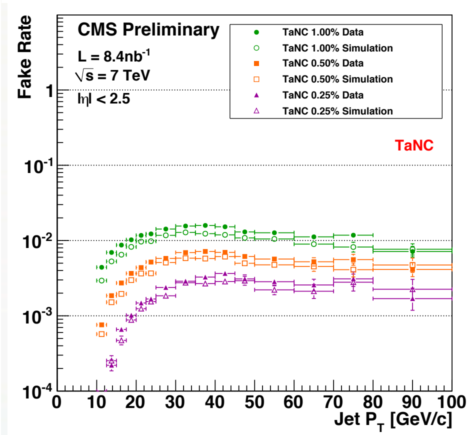


Z[ττ] Candidate

- Tau-reconstruction using particle flow techniques
- 10^{-2}-10^{-3} τ_h mistag rate with 60-40% efficiency







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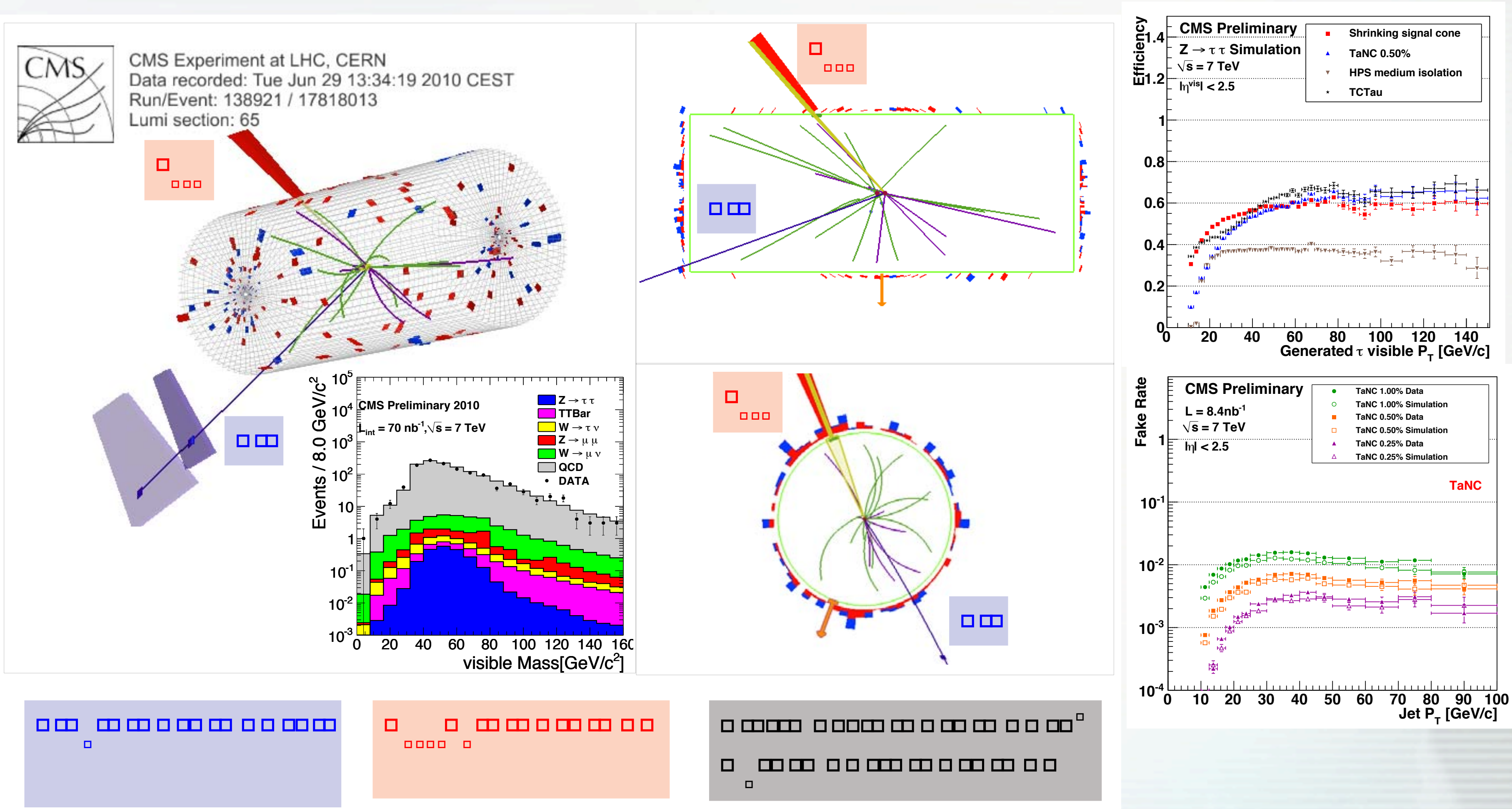
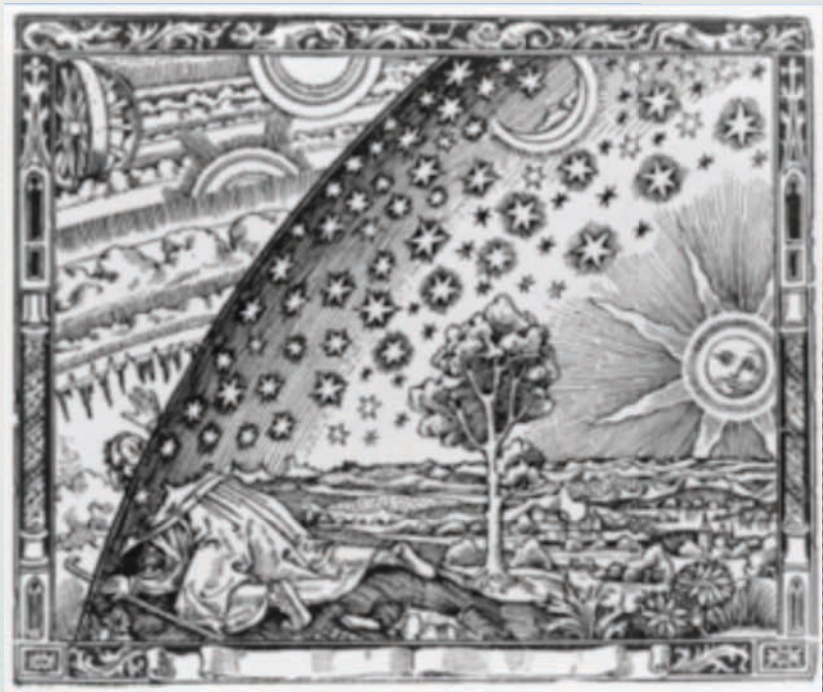


Beyond the Standard Model

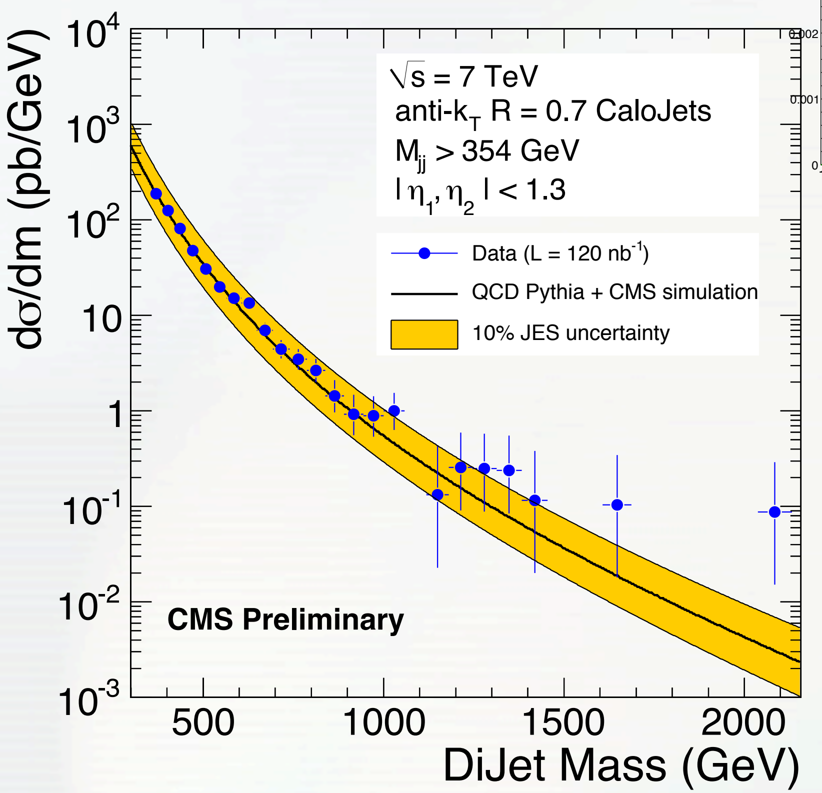


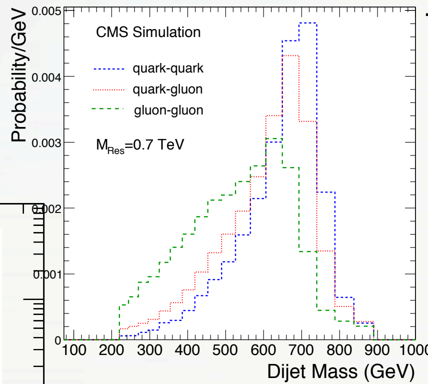
Searches in Dijets

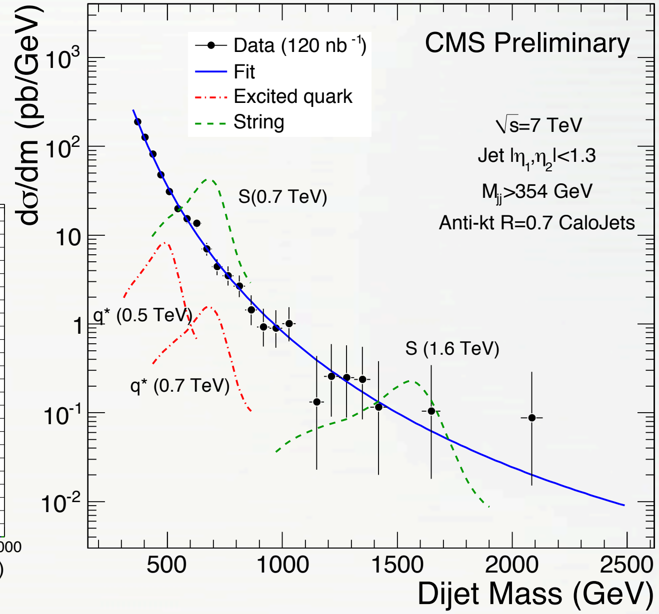
- Strong s-channel production of colored objects at high mass has huge advantage at the LHC w.r.t. the Tevatron, particularly in the gg-fusion channel
- Can exceed the Tevatron sensitivity even with a fraction of pb^{-1} of 7 TeV data
- Examples: generic compositeness, excited quarks, diquarks, colorons, axigluons, string resonances, etc.
- Weakly produced s-channel objects can also be probed, but with higher luminosity (W′/Z′, G_{KK}, etc.)
- Three ways of looking for these objects:
  - Bump search in the dijet spectrum;
  - Dijet centrality ratio, with fine mass binning;
  - Dijet angular distribution, with coarse mass binning
- At CMS we pursue all three type of searches

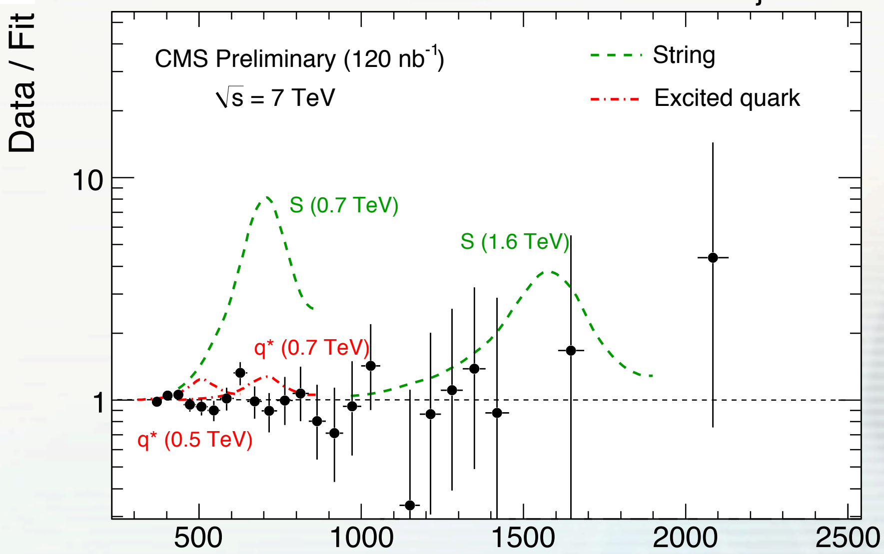
Dijet Bump Hunt

- Parameterize spectrum with a smooth, 3-parameter fit function and look for bumps; none found
- Proceed with setting limits, including systematics (10% JES uncertainty is the dominant effect)









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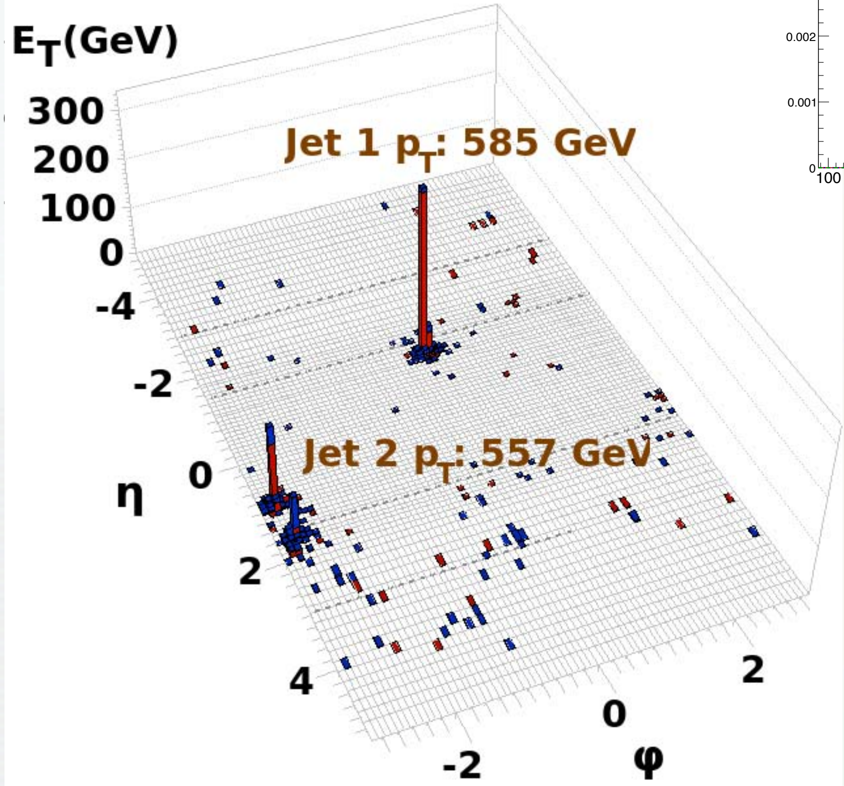
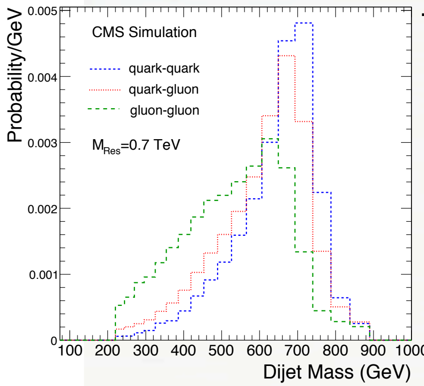
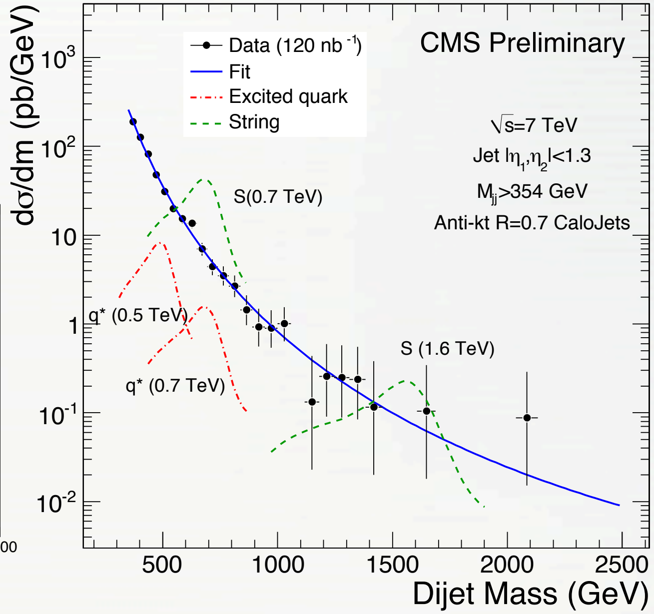
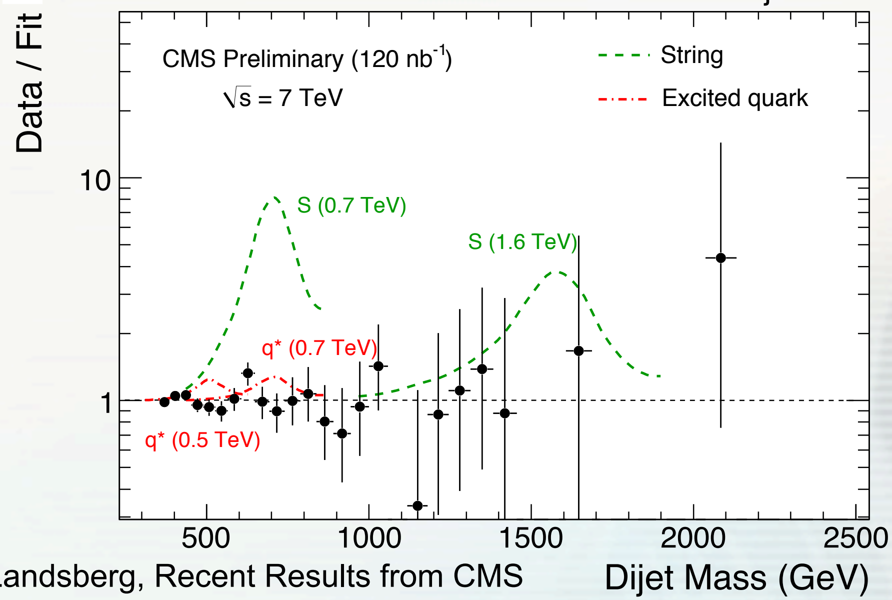
Run : 138919
Event : 32253996
Dijet Mass : 2.130 TeV



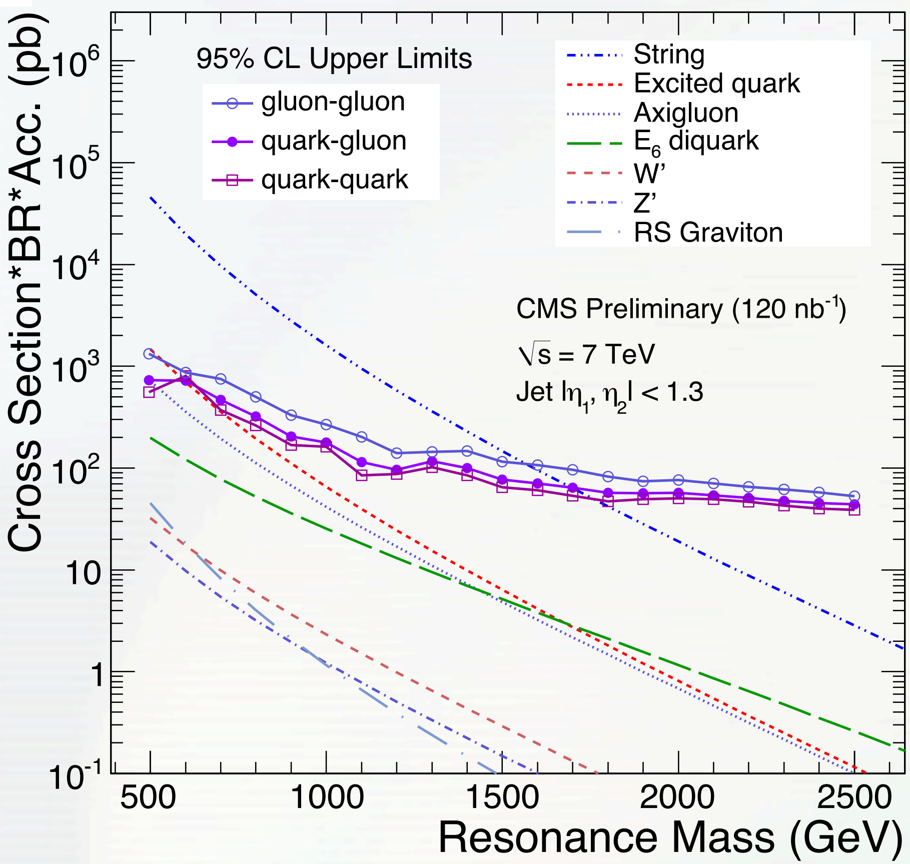


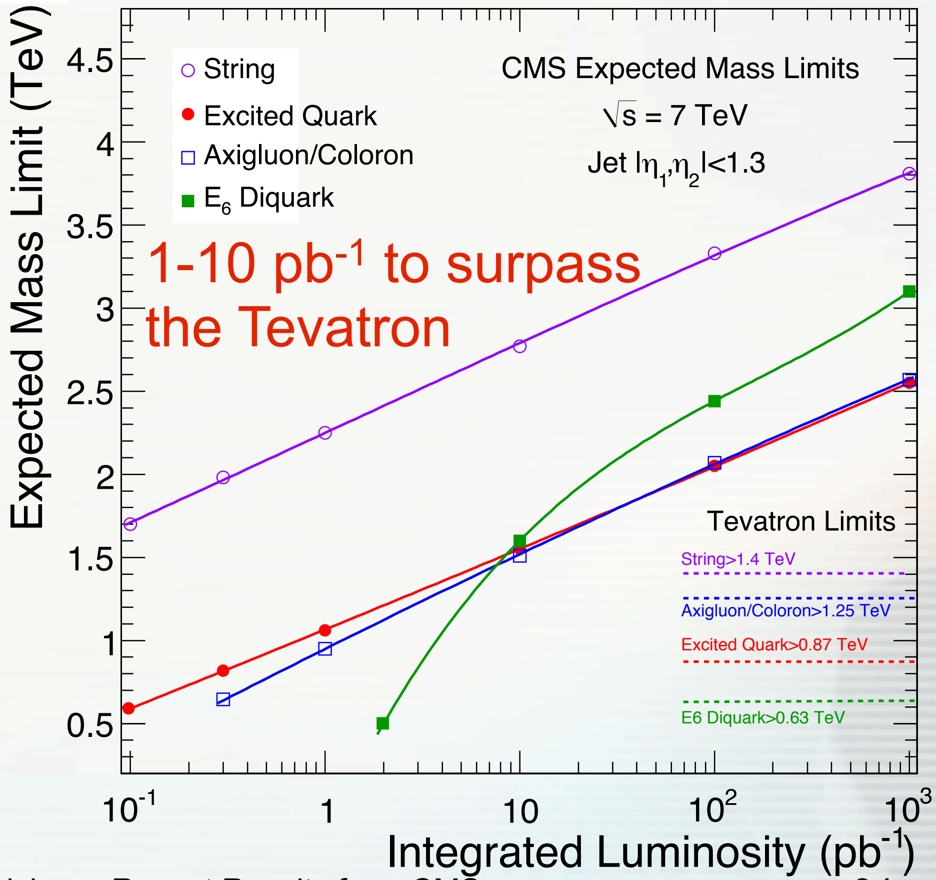




Dijet Resonance Limits

- Most stringent limits on string resonances (M < 1.67 TeV @95% CL)
  - Estimated Tevatron sensitivity is 1.4 TeV
- Limits on excited quarks: 0.59 TeV
  - Current Tevatron limit: 0.87 TeV



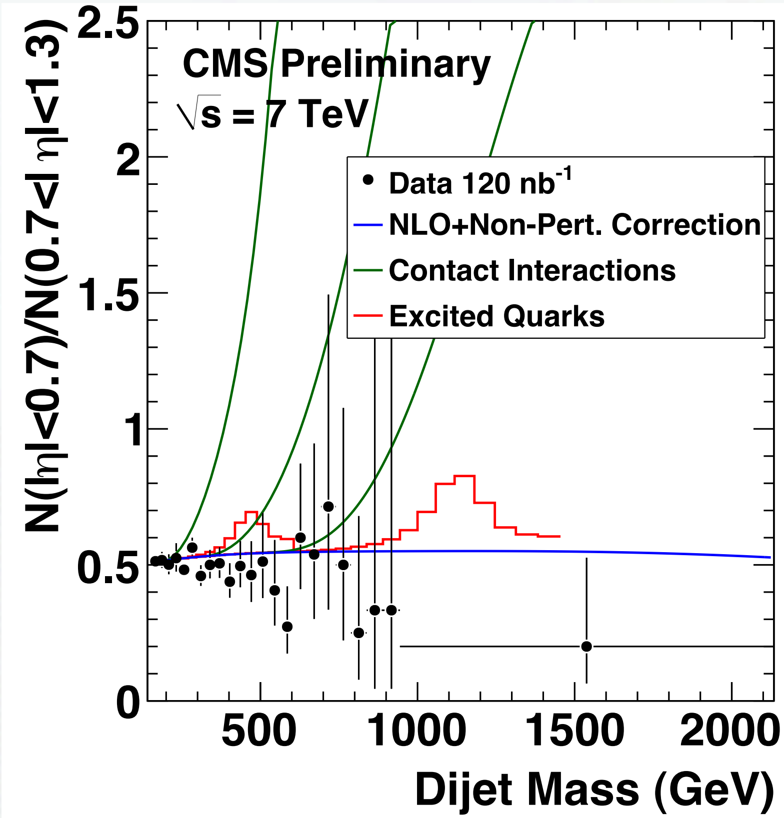


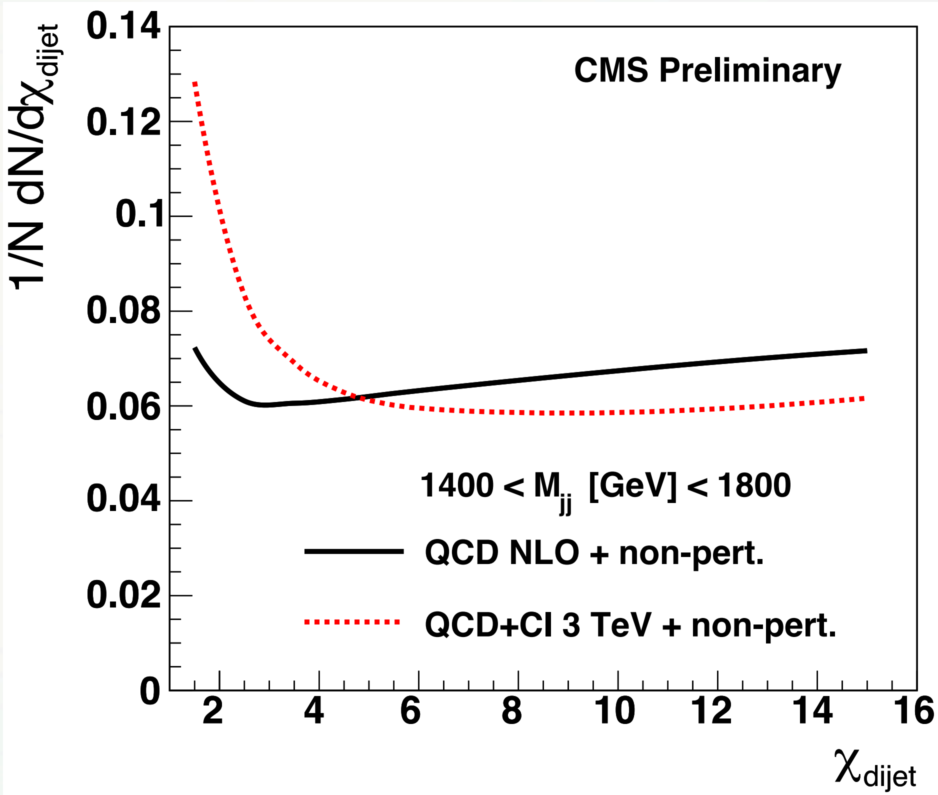
Dijet Angular Distributions

- Either use centrality, i.e. the ratio of the number of events with both jets within |η| < 0.7 to that with both jets within 0.7 < |η| < 1.3, or the χ variable

$$\chi = e^{2y^*} = \frac{1+\cos\theta^*}{1-\cos\theta^*}$$

- Complementarity of the two approaches: ratio uses coarse angular bins but fine mass bins; χ uses much finer angular info, but coarse mass bins





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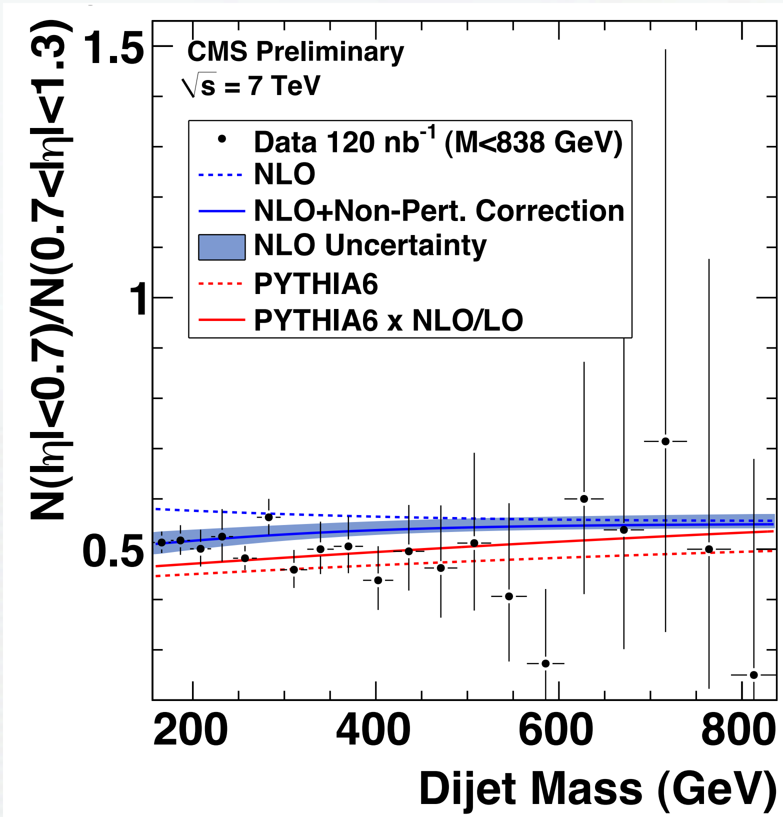

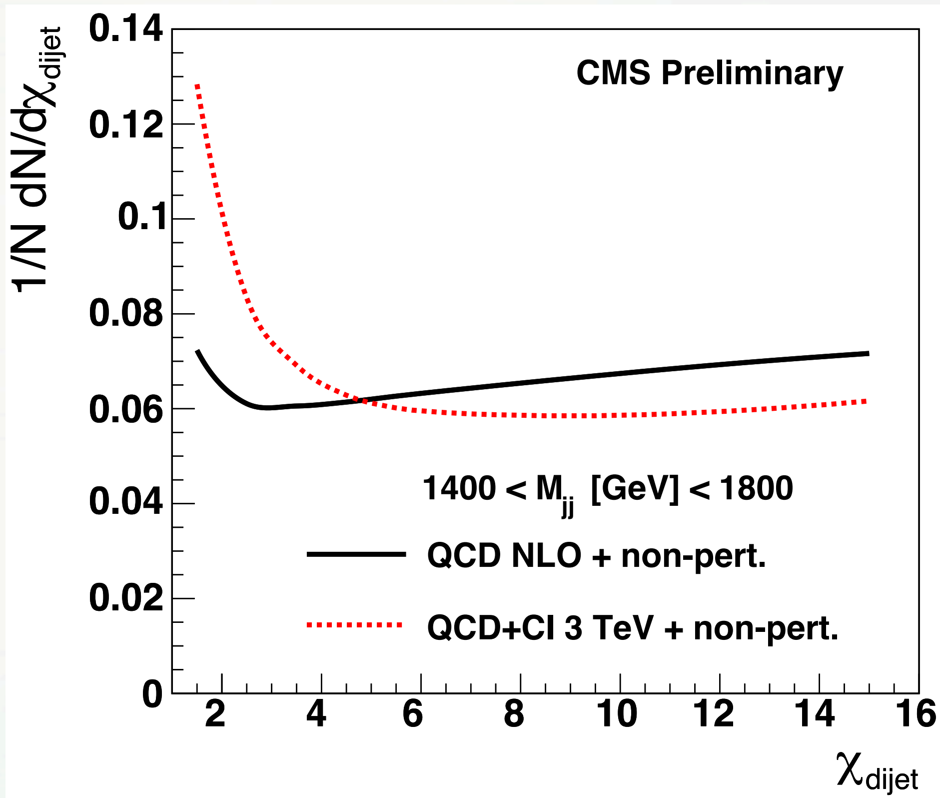

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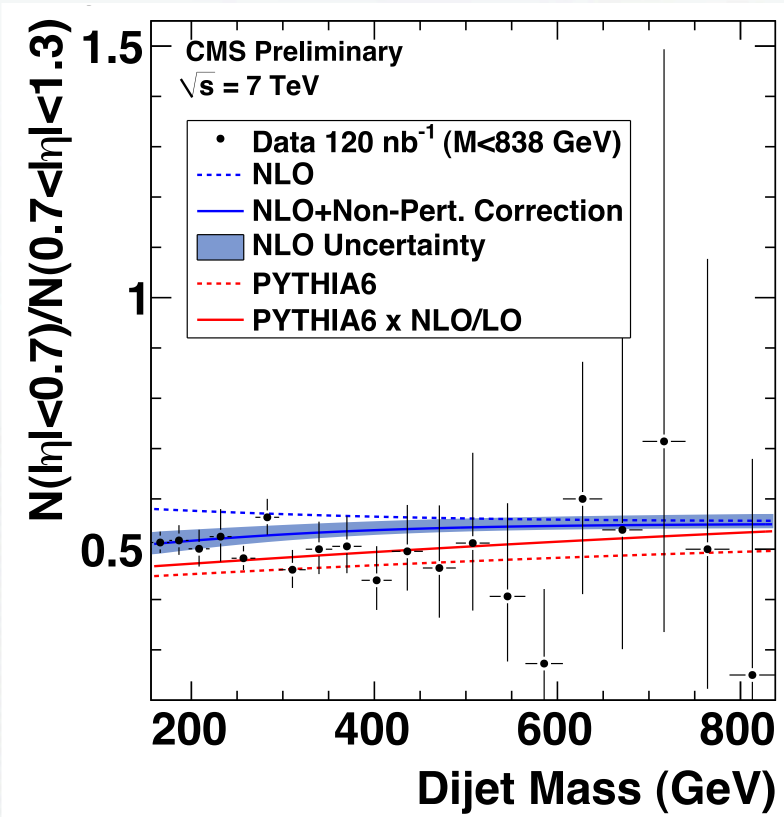

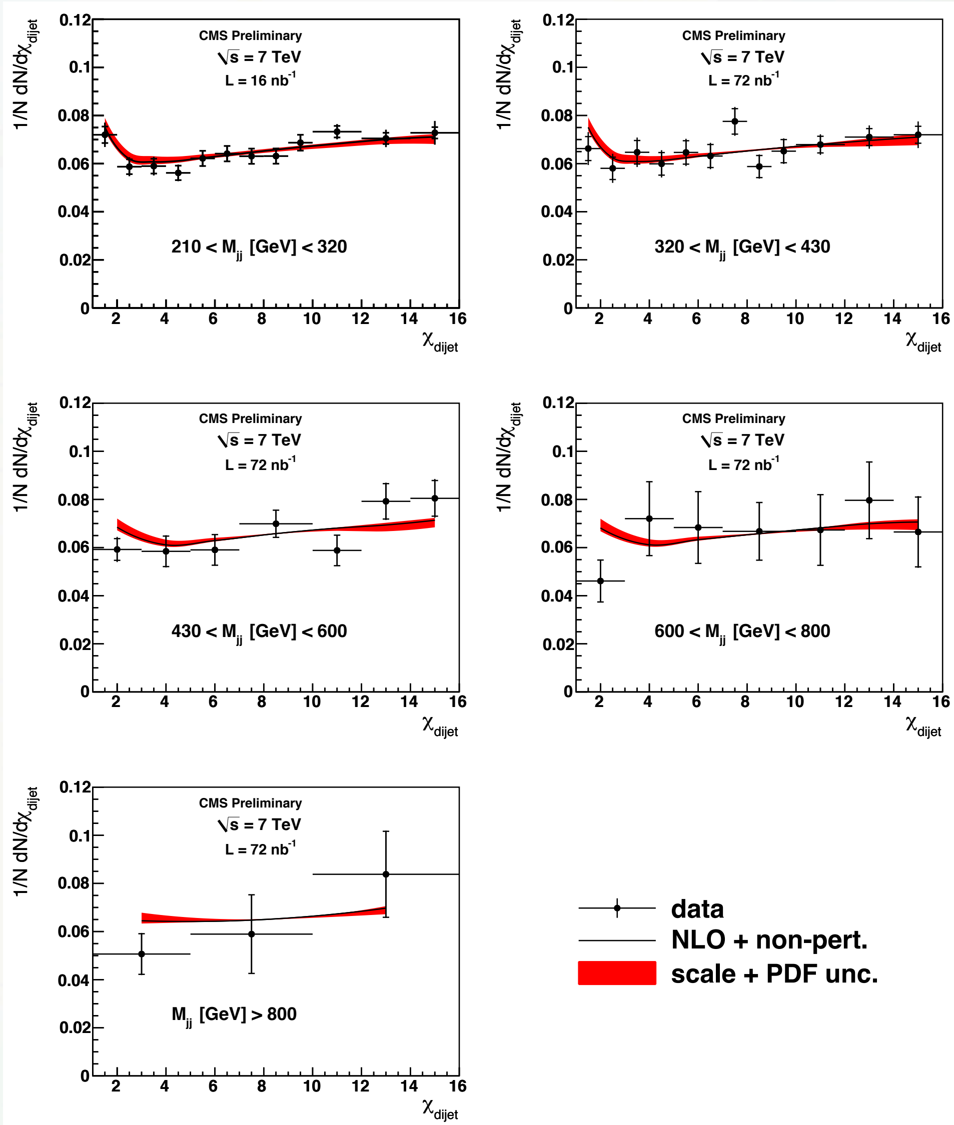

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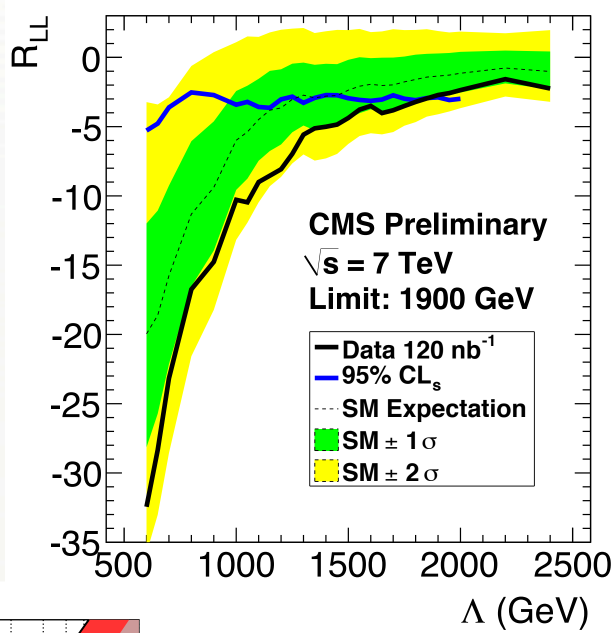
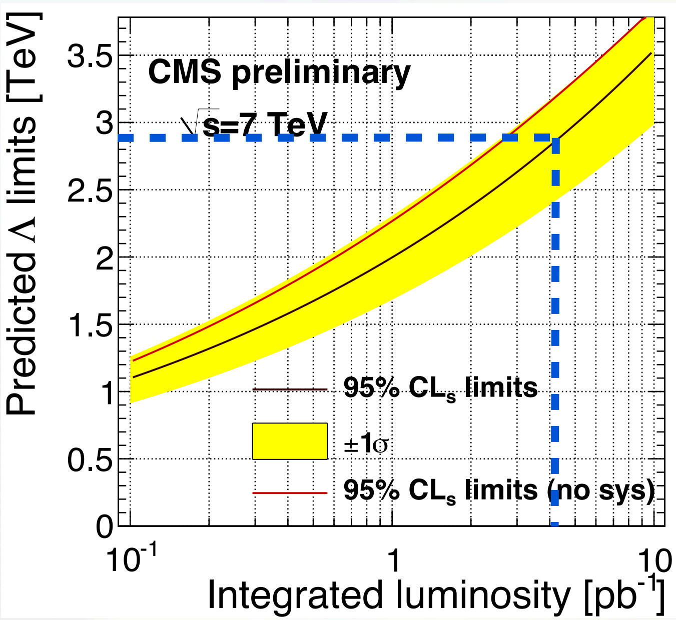
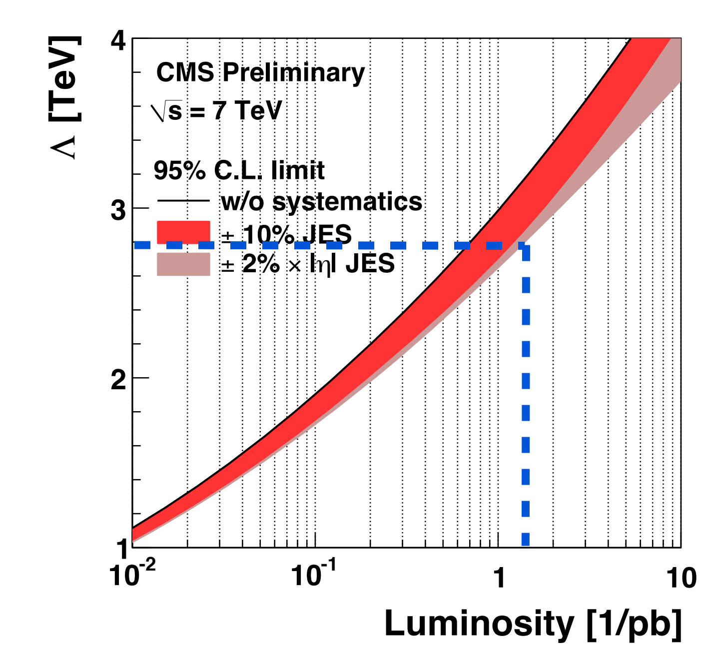
Limits on Compositeness

- Uses likelihood ratio technique with systematics incorporated in the likelihood function to set limits
  - Uncertainties dominated by JES
- Λ_{LL} > 1.9 TeV @ 95% CL (1.5 TeV expected) w/ 120 nb^{-1} of data







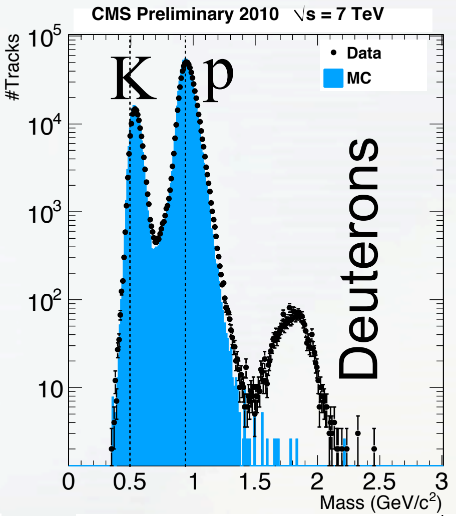
2-4 pb^{-1} is needed to exceed the Tevatron limit of 2.8 TeV

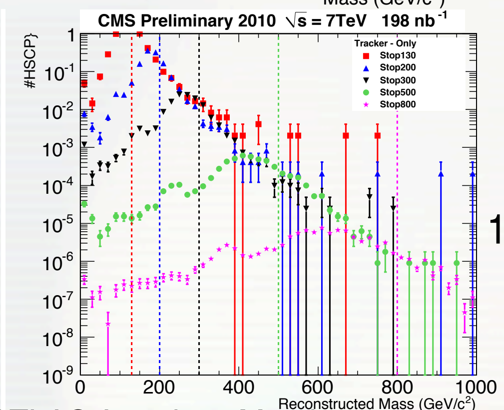
Search for Long-Lived Particles

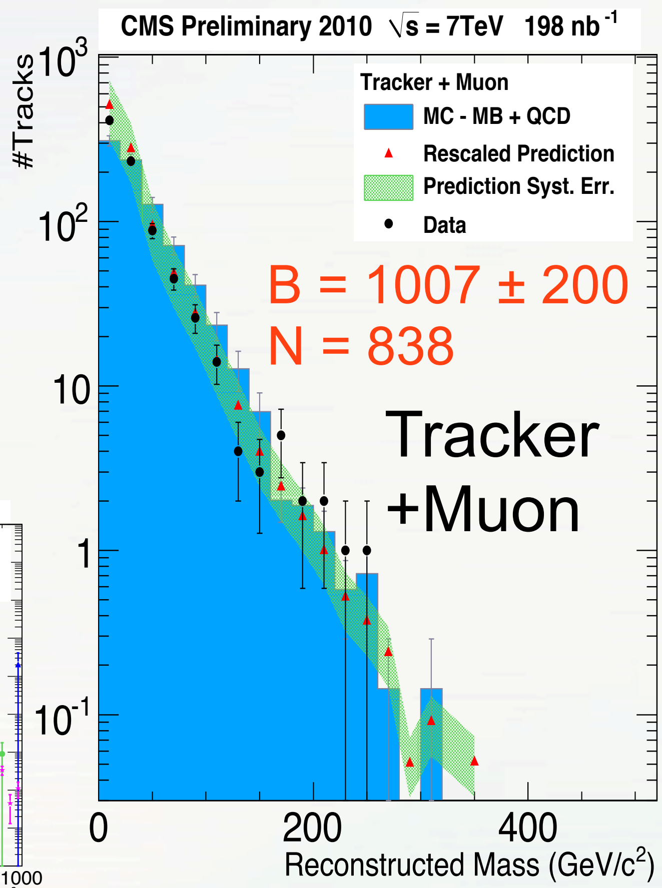
- Predicted in many extensions of the SM: SUSY, hidden valley, etc.
- Two type of searches pursued with early data:
  - Massive charged long-lived particles leaving highly ionizing tracks in the tracker (and the muon system)
  - Long-lived strongly interacting particles stopping in the detector and decaying out-of-time with the collisions
- Excellent dE/dx resolution of the CMS detector as well as thick calorimeters allow us to pursue these analyses very rapidly
- Complicated LHC beam structure with a number of gaps in the bunch sequence allows for a large coverage in terms of stopped particle lifetime

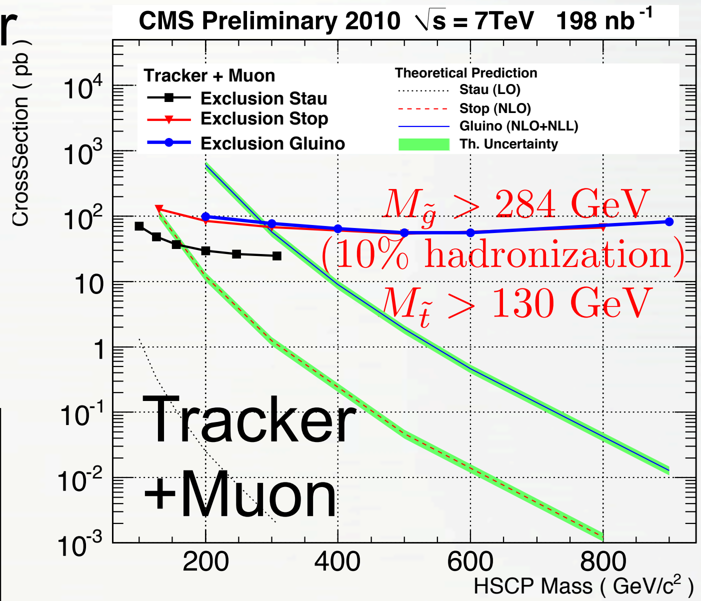
Heavy Stable Charged Particles

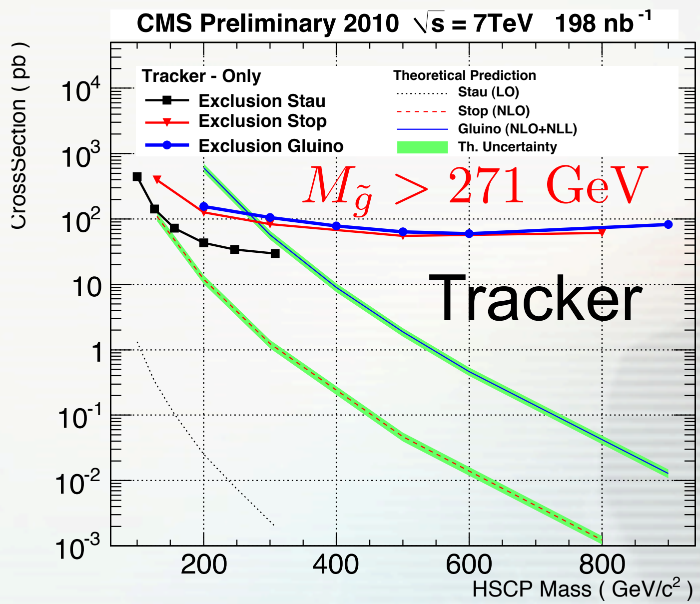
- Tracker-only (gluinos/stops) and tracker +muon (staus)analyses
- Background prediction is data-driven, based on low-momentum tracks
- Mass estimated from dE/dx and p





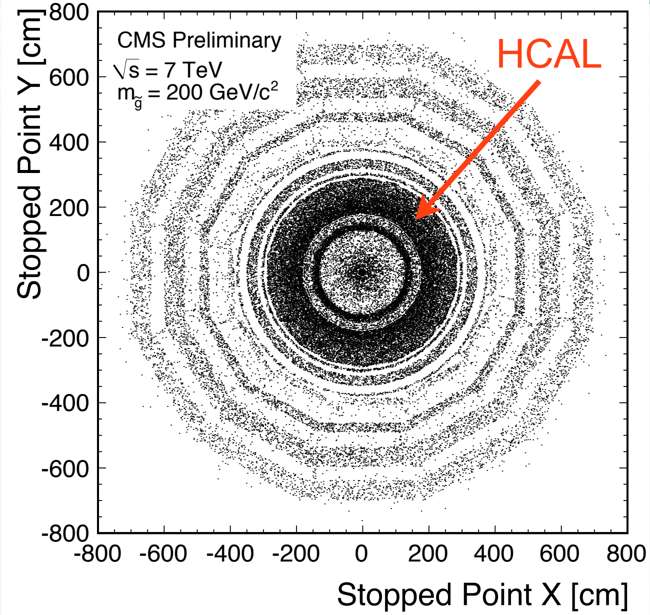


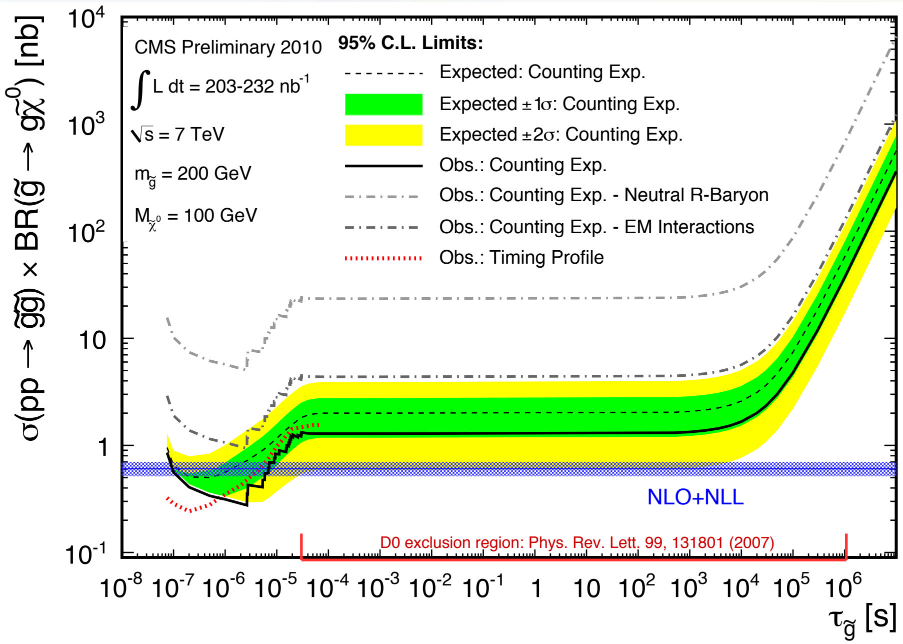


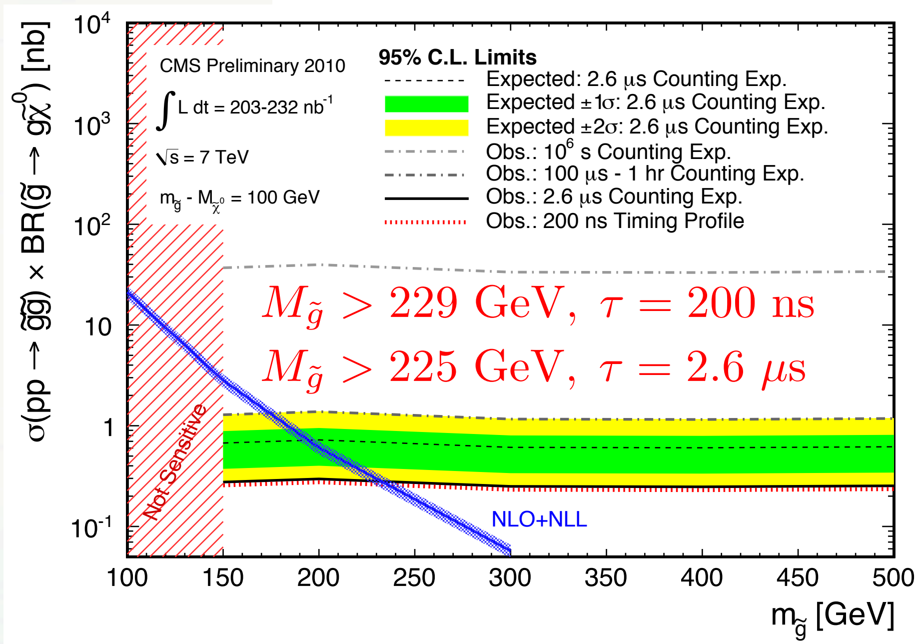


Stopped Gluinos

- Designed and commissioned special no-beam trigger using BPTX in anti-coincidence
- Routinely run after the end of the fill to get sensitivity to log lifetimes
- Already extends the Tevatron exclusion toward shorter lifetime!







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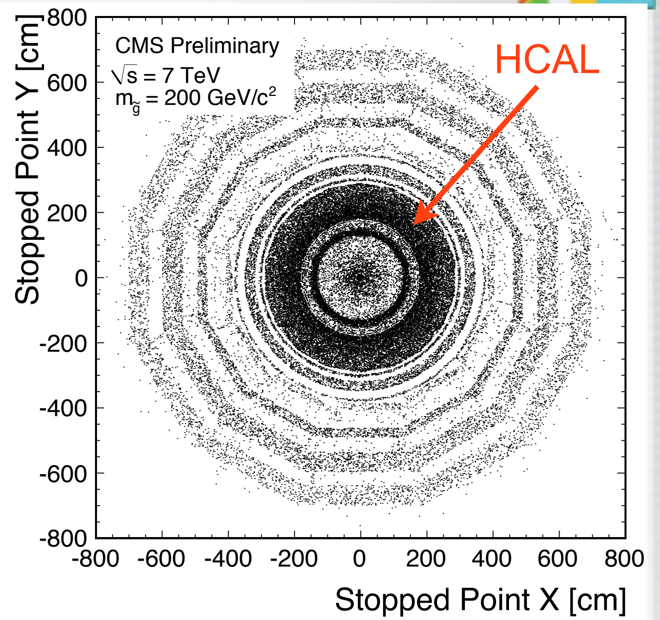
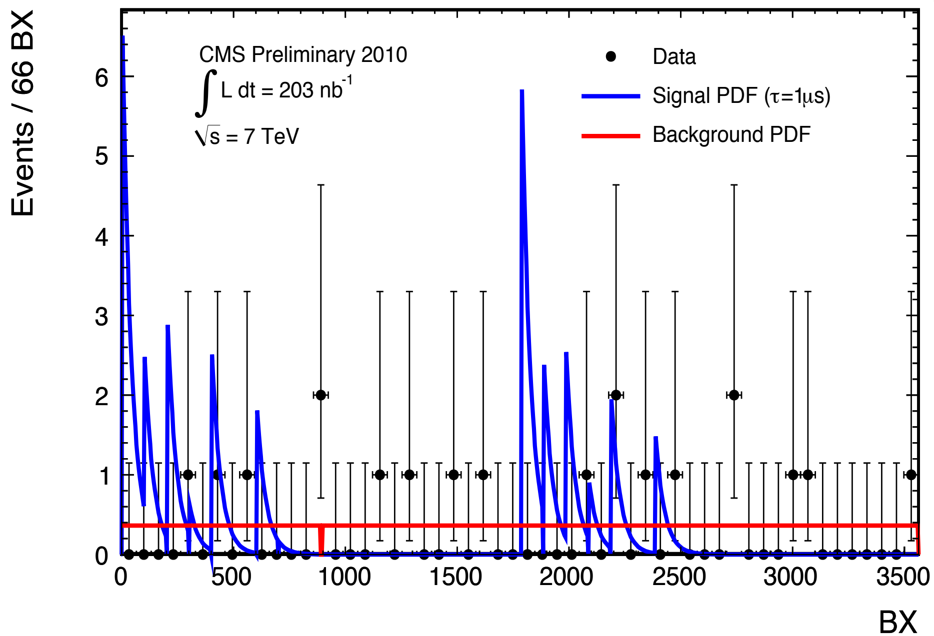
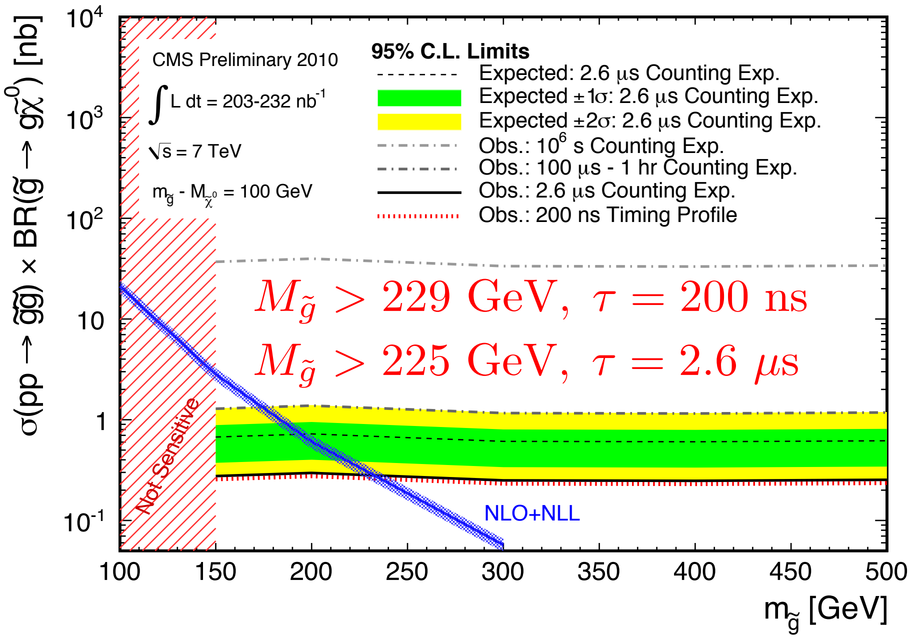
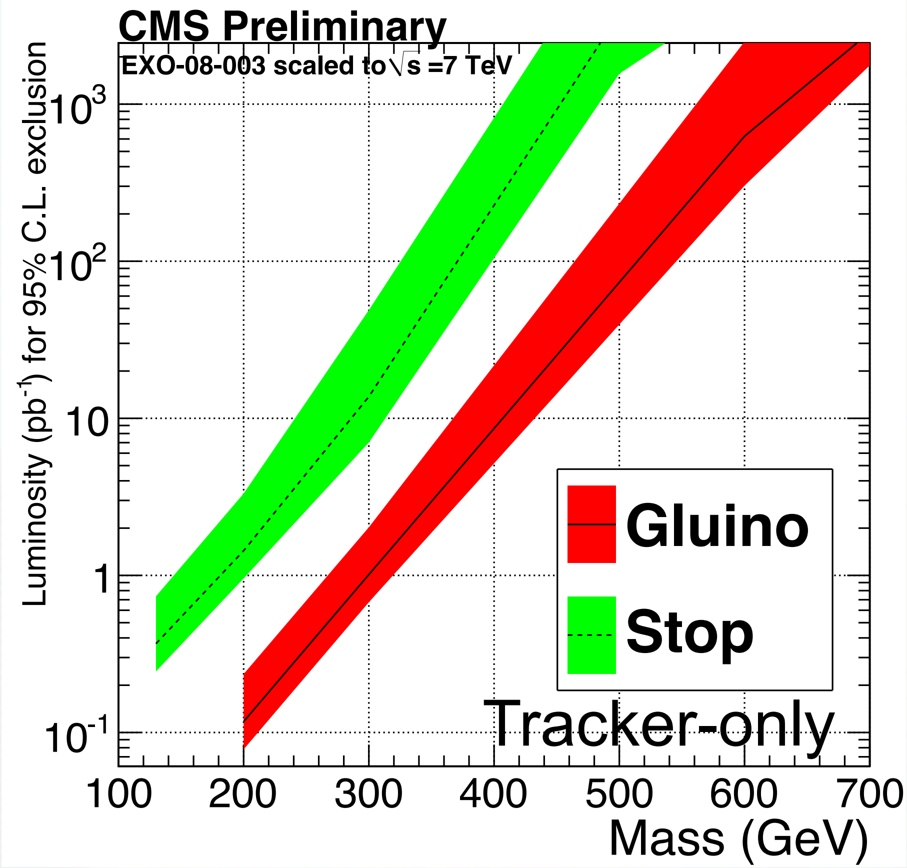


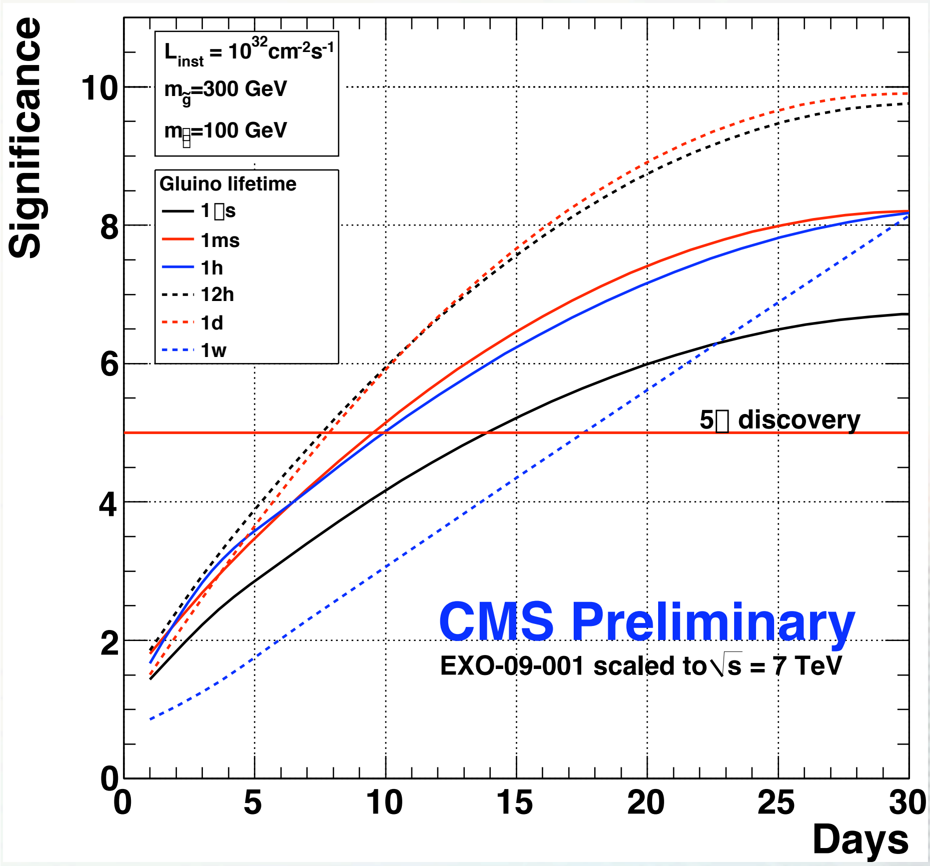




Future Sensitivity

- Very high potential for both analyses
- HSCP search should supersede the Tevatron limit on stop of 250 GeV and on gluinos of ~350 GeV with just 2-3 pb^{-1} of data
- Stopped gluino analysis already probes new territory and will expand it considerably with just days of high-luminosity running





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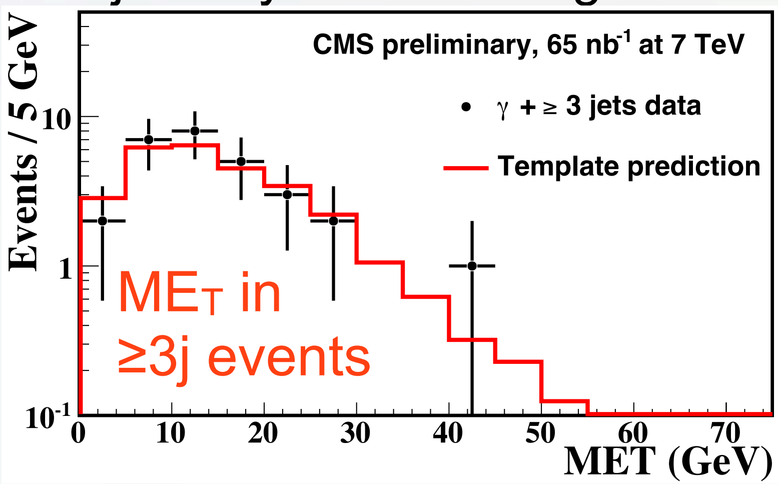
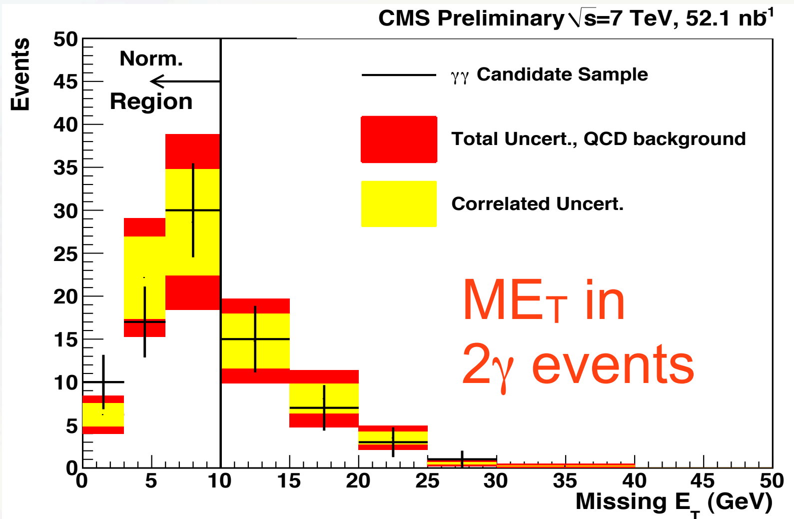
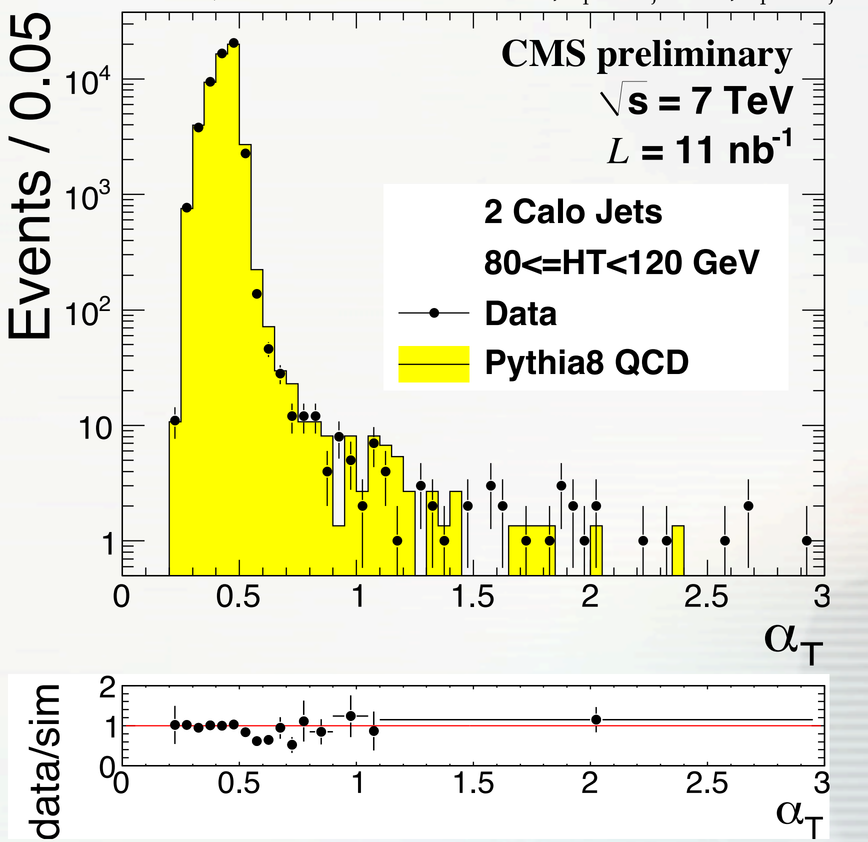
Toward SUSY Searches

- Searches for SUSY are gearing up and will be pursued with 10-100 pb^{-1}
- Current focus on ME_T commissioning and data-driven background estimates
- The jet-only search using α_T variable is promising as well





$$\alpha_T = \frac{1}{2}\frac{H_T - \Delta H_T}{\sqrt{H_T^2 - (MHT)^2}}. \quad H_T = \sum_{\text{jets } j} p_{Tj} \quad \Delta H_T = p_{T\text{pseudojet 1}} - p_{T\text{pseudojet 2}}$$



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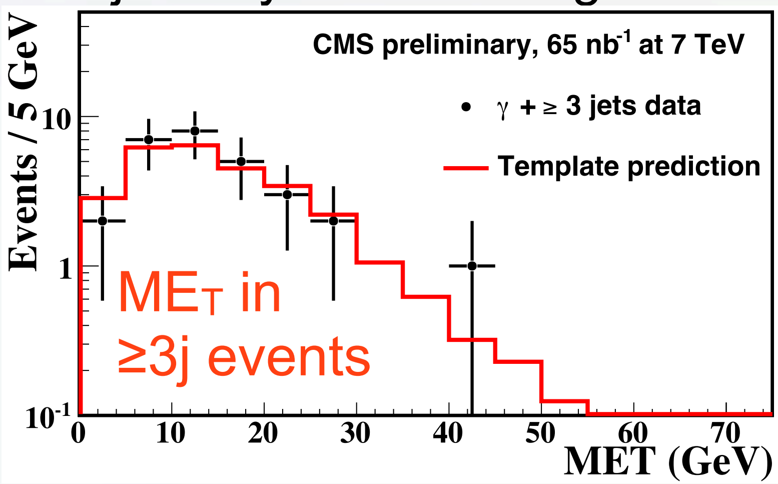

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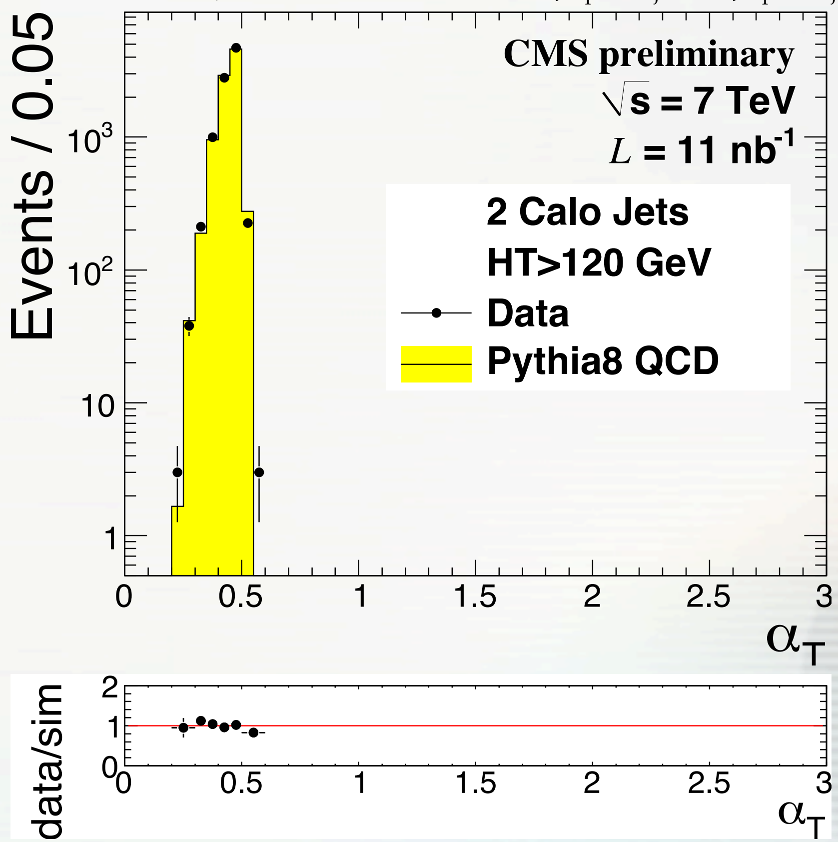

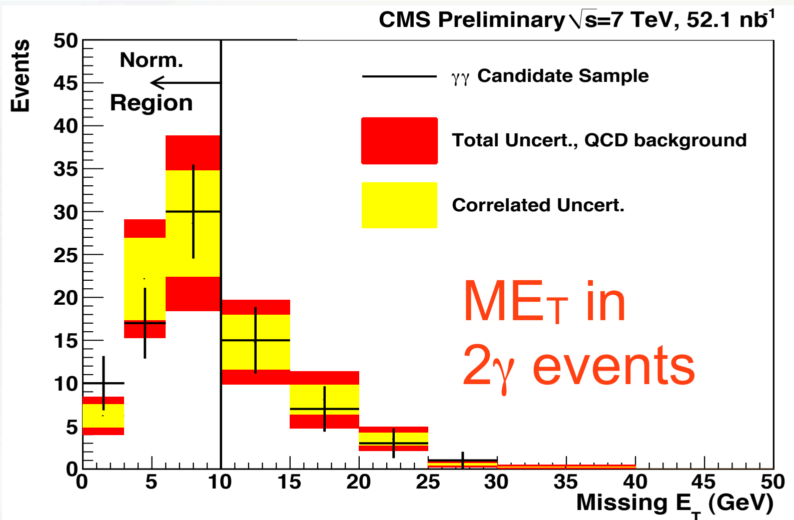

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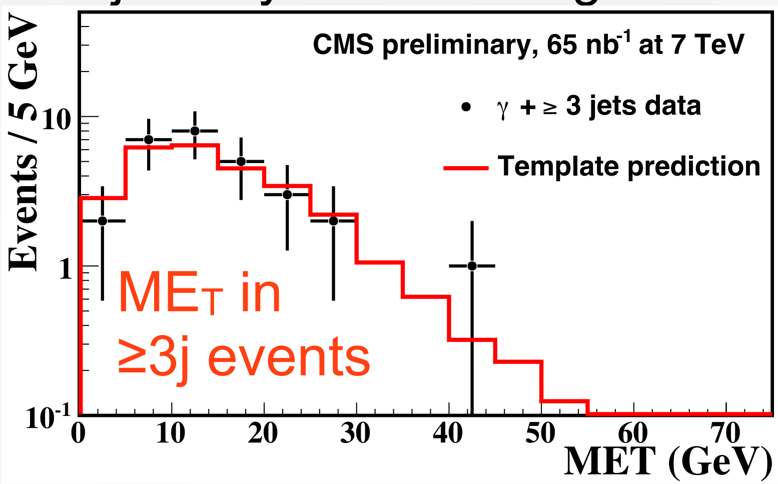
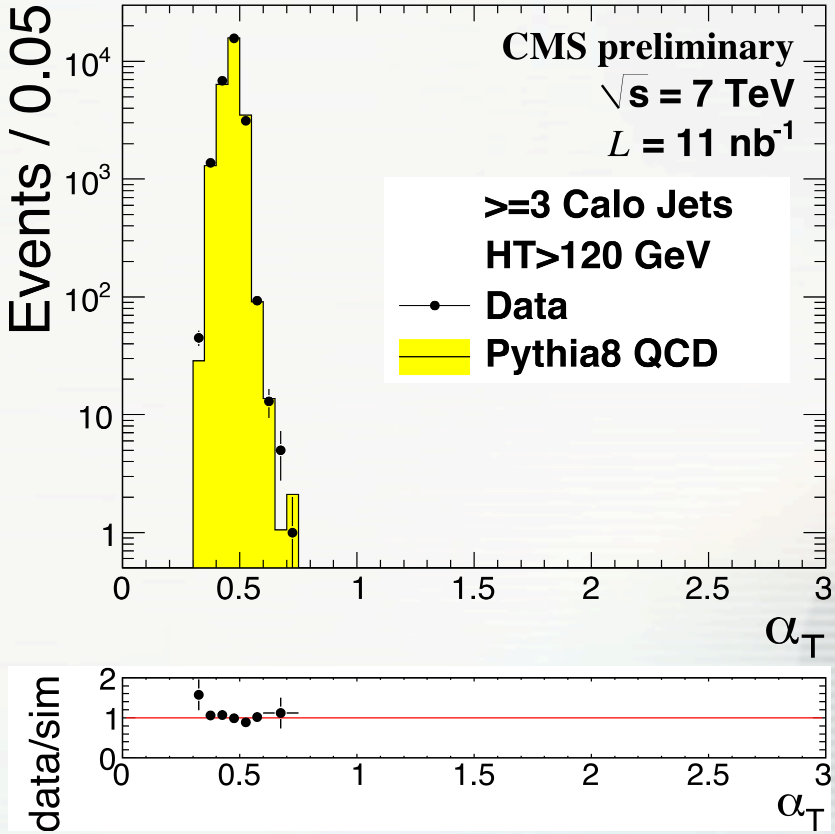
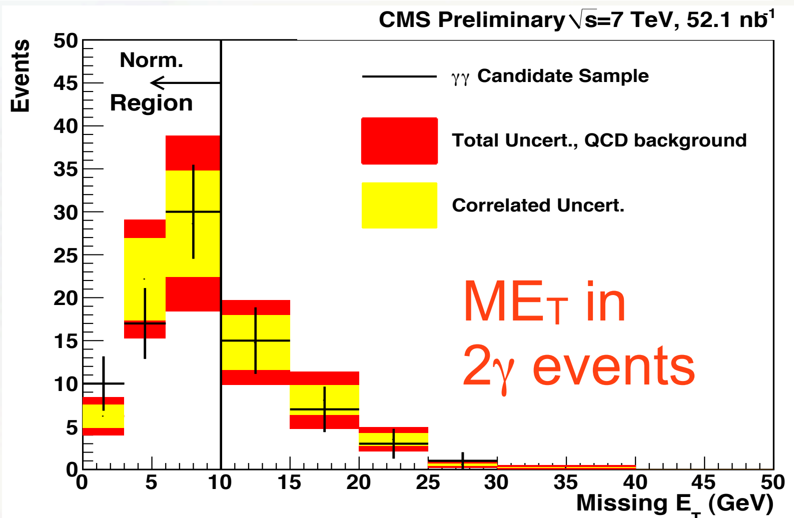


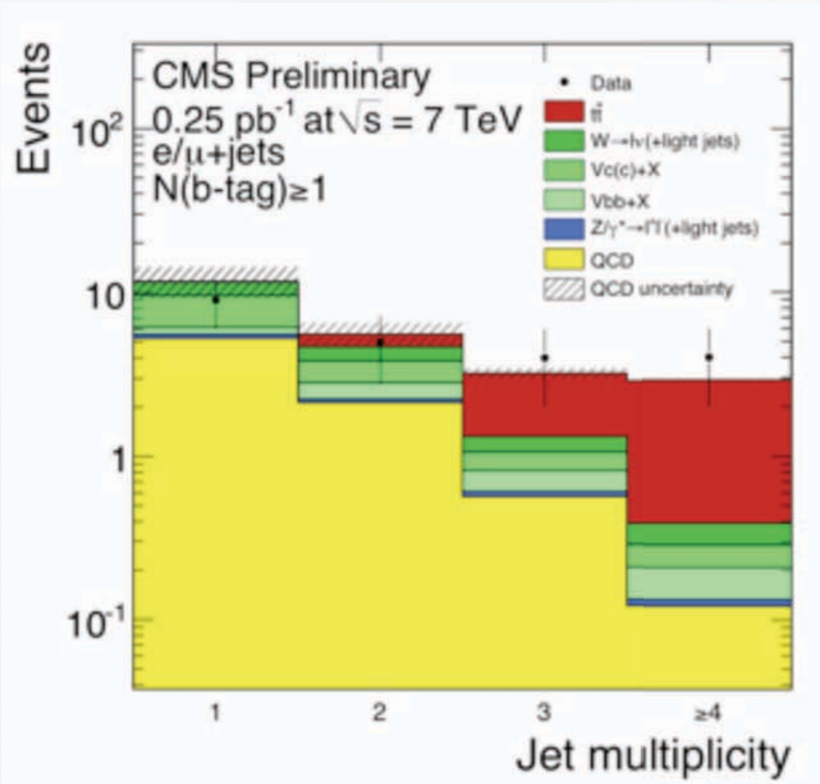
$$\alpha_T = \frac{1}{2}\frac{H_T - \Delta H_T}{\sqrt{H_T^2 - (MHT)^2}}. \qquad H_T = \sum_{\text{jets } j} p_{Tj} \qquad \Delta H_T = p_{T\text{pseudojet }1} - p_{T\text{pseudojet }2}$$

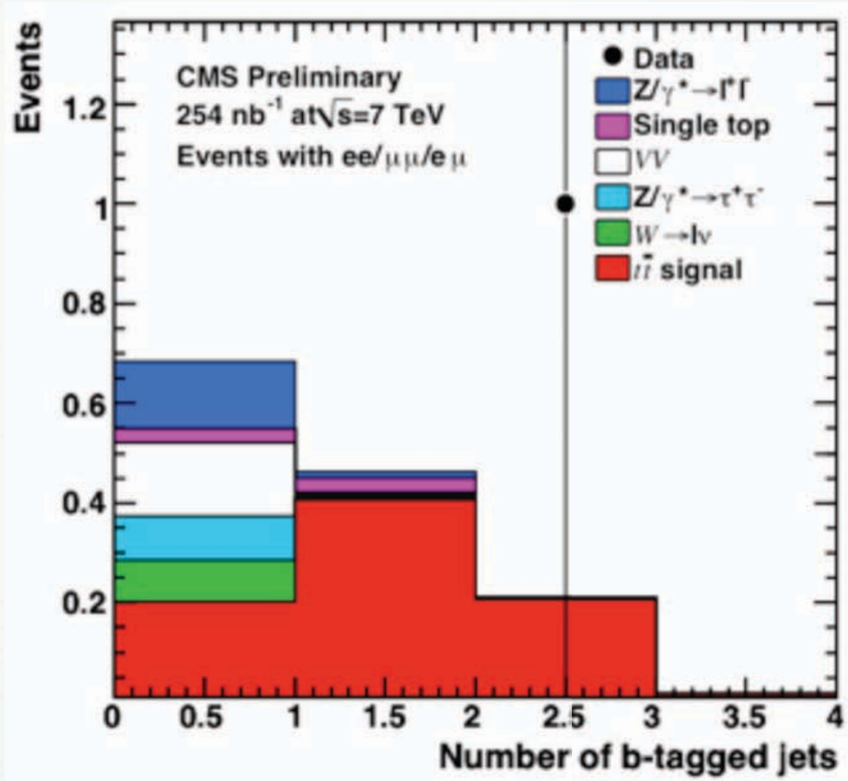




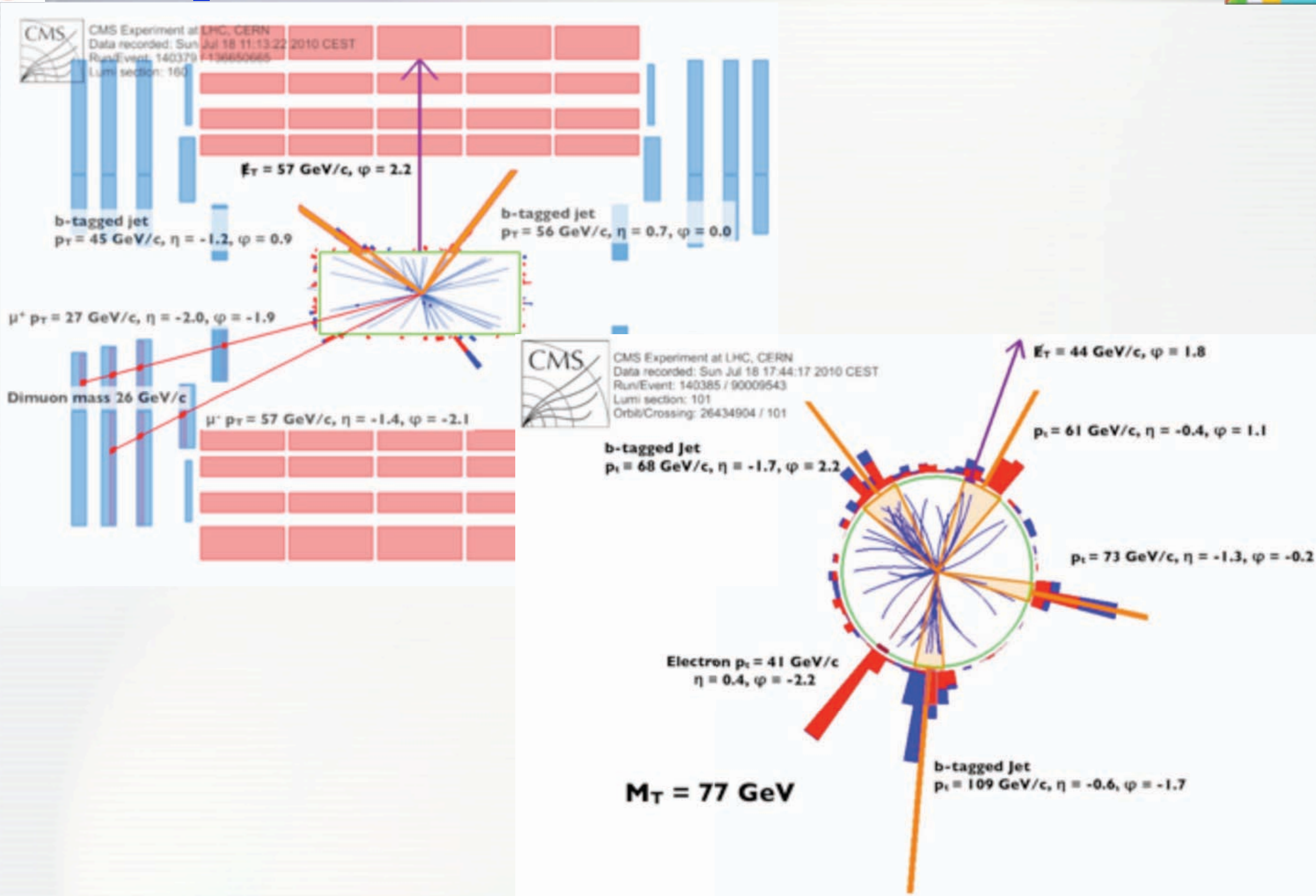
Topping it Off

- e/μ+jets channel: benefits from excellent b-tagging performance
- Dilepton channel - already low background, made negligible by addition of b-tagging
- Golden μμ candidate with 2 b-tags; top-like distribution in N_{jet} in the lepton+jets channel



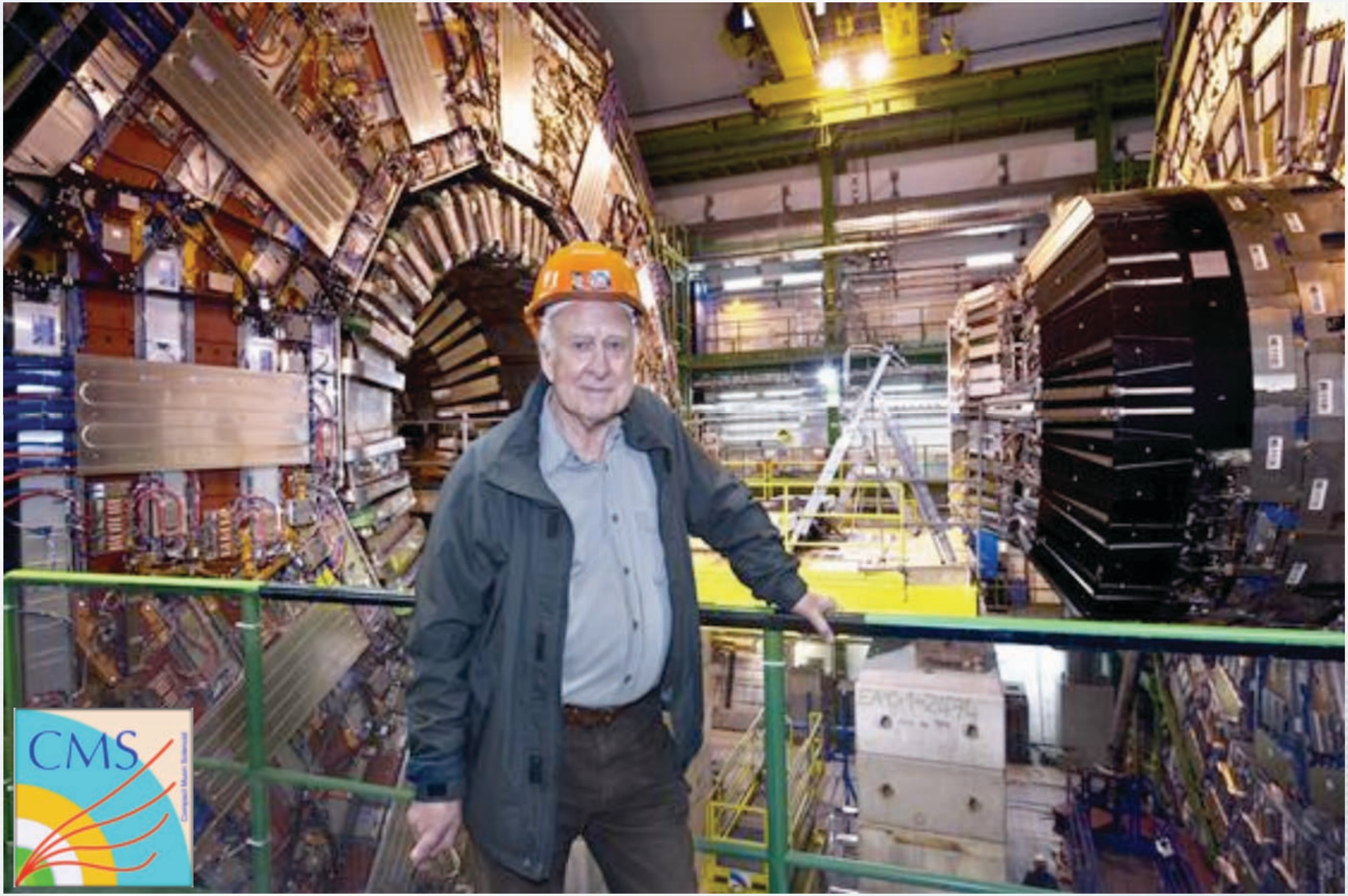


Top Candidates



Higgs at CMS

- An observation of (Peter) Higgs by the CMS Detector



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- Exciting discoveries can happen as early as this year, and by the end of the next year a lot of still uncharted territory will be mapped
- This is just the beginning: the LHC will deliver beautiful physics for the entire decade and we are there to catch it!

The Future is Bright!