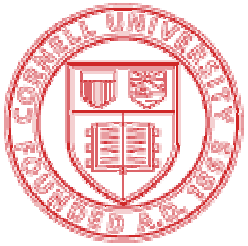


Cornell University
Floyd R. Newman Laboratory for
Elementary-Particle Physics

First Results from CMS

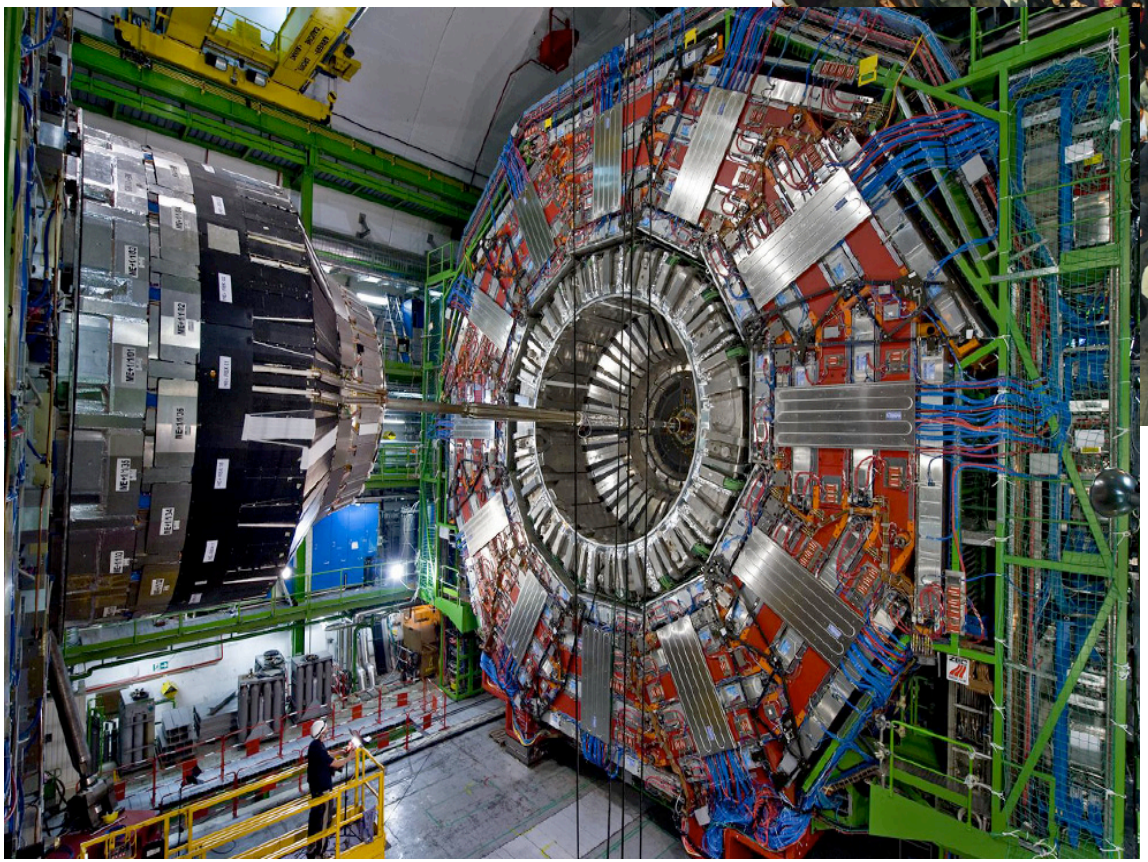
XXXVIII SLAC Summer Institute

"Neutrinos"

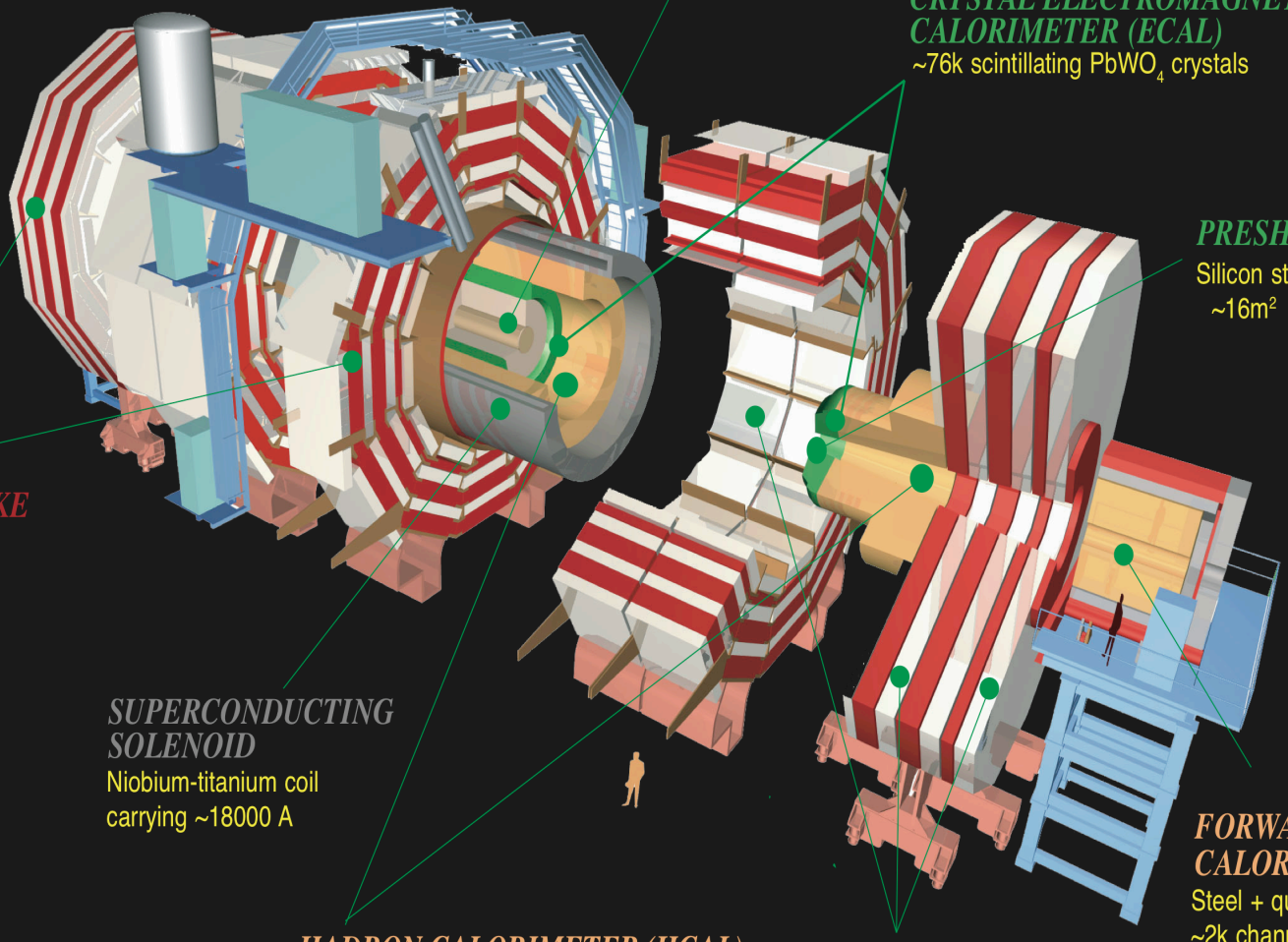
August 2nd, 2010

Julia Thom, Cornell University

The CMS collaboration:
3170 scientists and engineers (including 800 students) from 169 institutes and 39 countries



CMS Detector



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: 473 Cathode Strip & 432 Resistive Plate Chambers

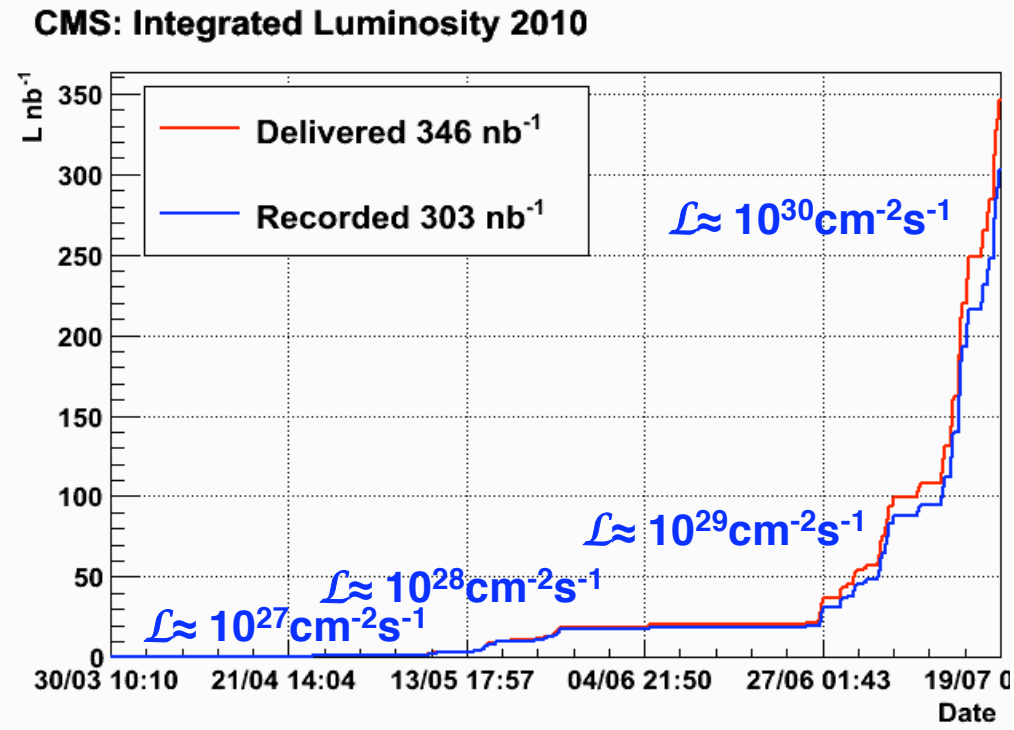
Total weight	**: 14000 tonnes**
Overall diameter	**: 15.0 m**
Overall length	**: 28.7 m**
Magnetic field	**: 3.8 T**

7 TeV operations since March 30th

346 nb^{-1} delivered by LHC

303 nb^{-1} collected by CMS (88% efficient)

- Most of the data taken in 2 last weeks
- Fast turnaround: 254 nb^{-1} validated for analysis



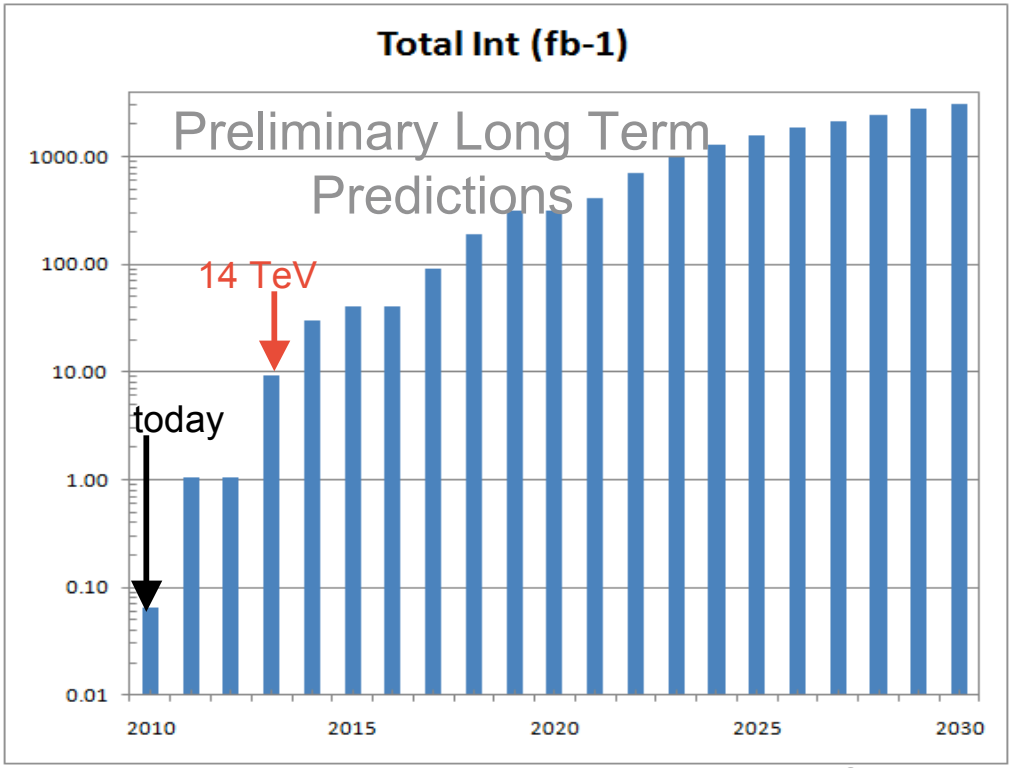
LHC operations: the future

Short term: at least 1 fb^{-1} delivered by end of 2011

- We have 0.03% so far
- Must reach $1x10^{32}cm^{-2}s^{-1}$ this year

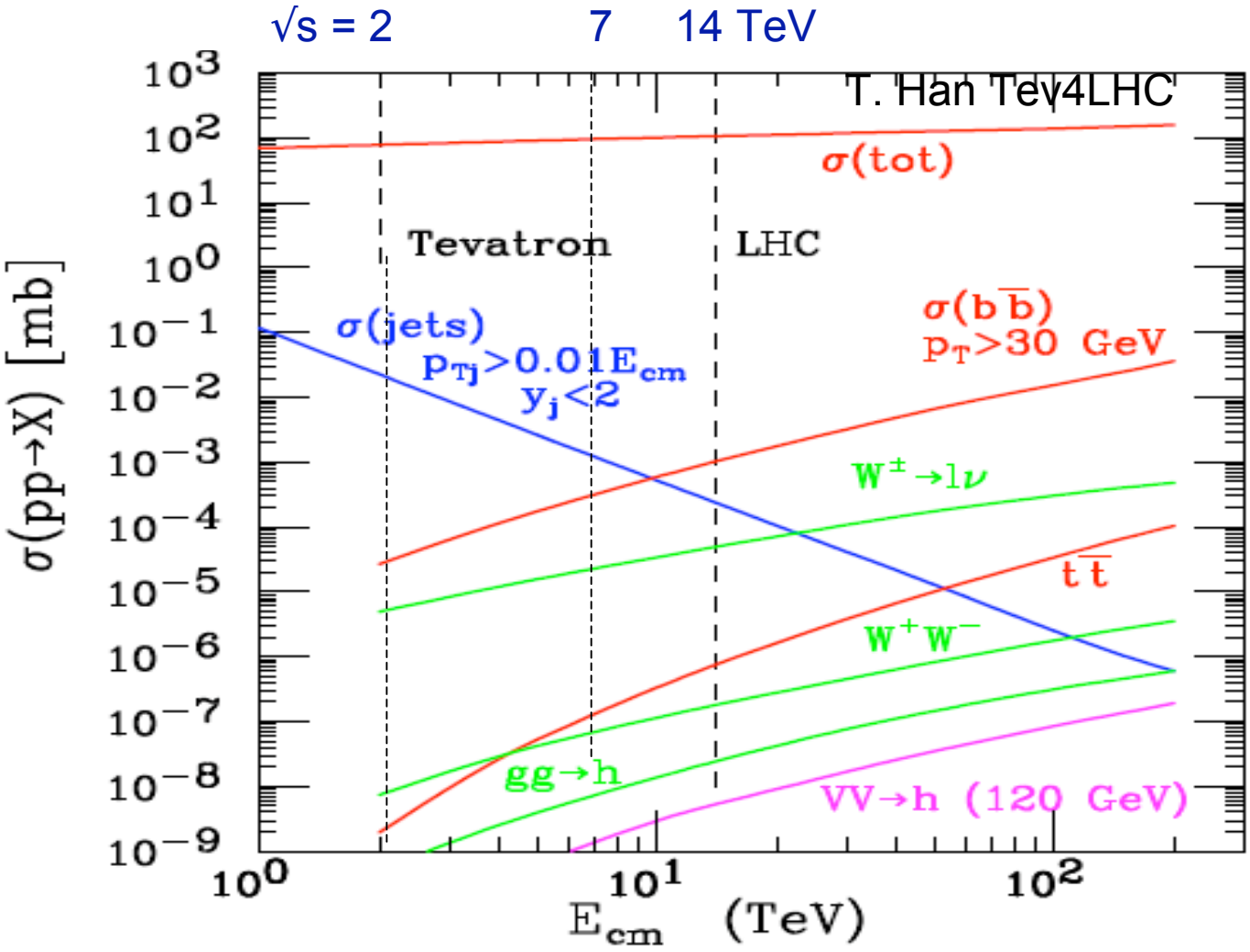
Longer Term: 3000 fb^{-1} collected by end of LHC life

- Must reach peak $1x10^{34}cm^{-2}s^{-1}$ during 2021-2030



From S.Meyers, ICHEP

Expected cross sections at 7 TeV

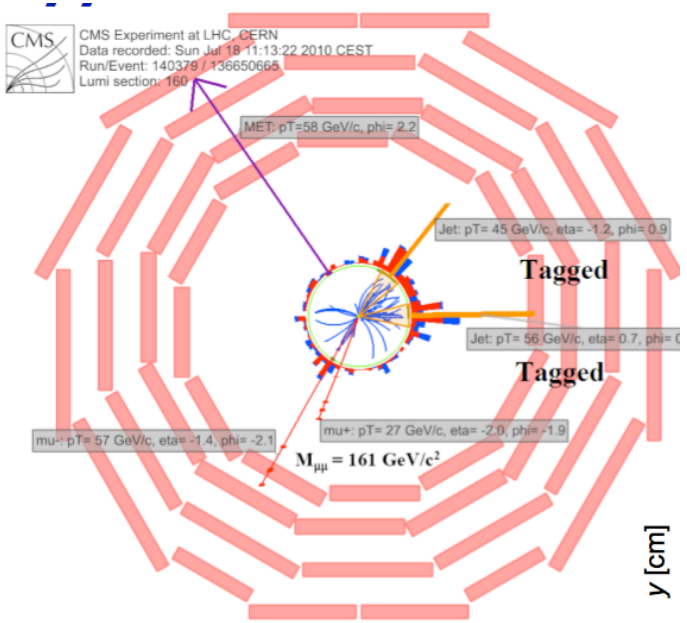


Outline of the talk

1. The basic objects, and CMS reconstruction performance with the early data
   - Tracks, Jets, b-tags
   - Missing energy "ME_T"
   - Muons, electrons and photons

2. Standard Candles and Early Physics results
   - Jet production
   - Early searches
   - J/ψ, Υ, W, Z
   - Top quarks

3. Outlook
   - Higgs
   - New Physics (NP): SUSY,..



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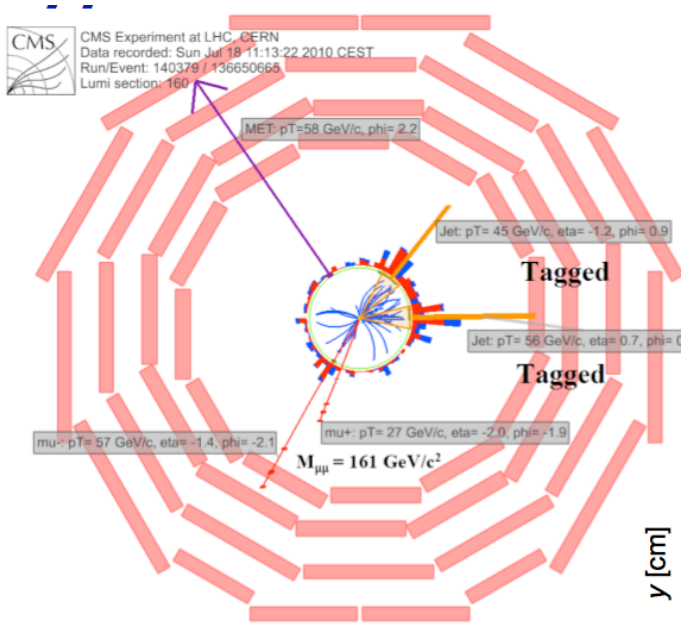
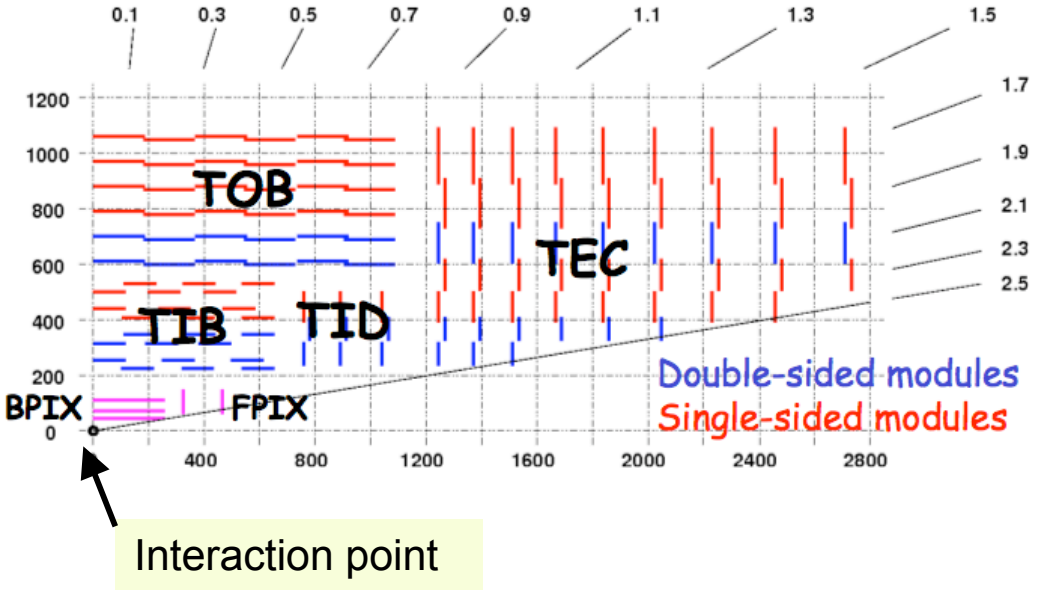


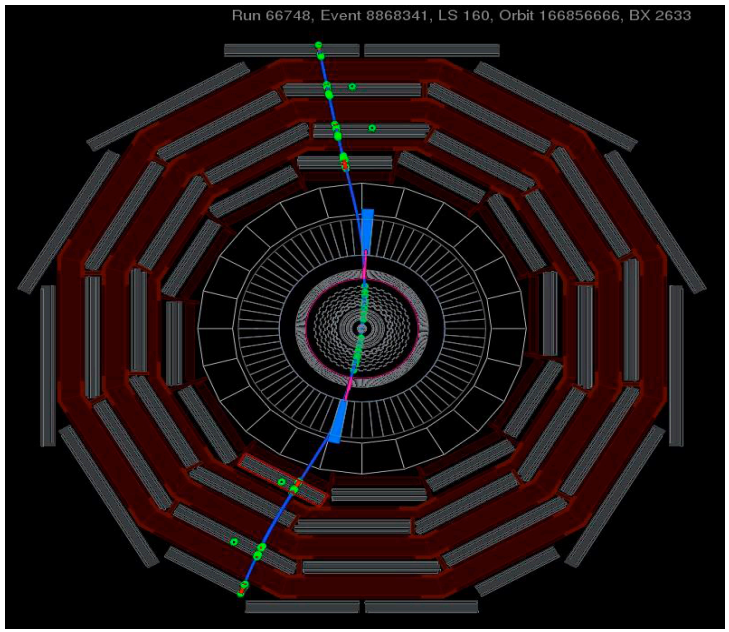
Tracks

- Central region of detector (r=2.4-110cm) instrumented with silicon strip and silicon pixel detectors for 3D tracking of charged particles
  - Coverage: pseudo-rapidity $|\eta|$=0 to 2.5

Side view of tracker quadrant:



Cosmic muon:

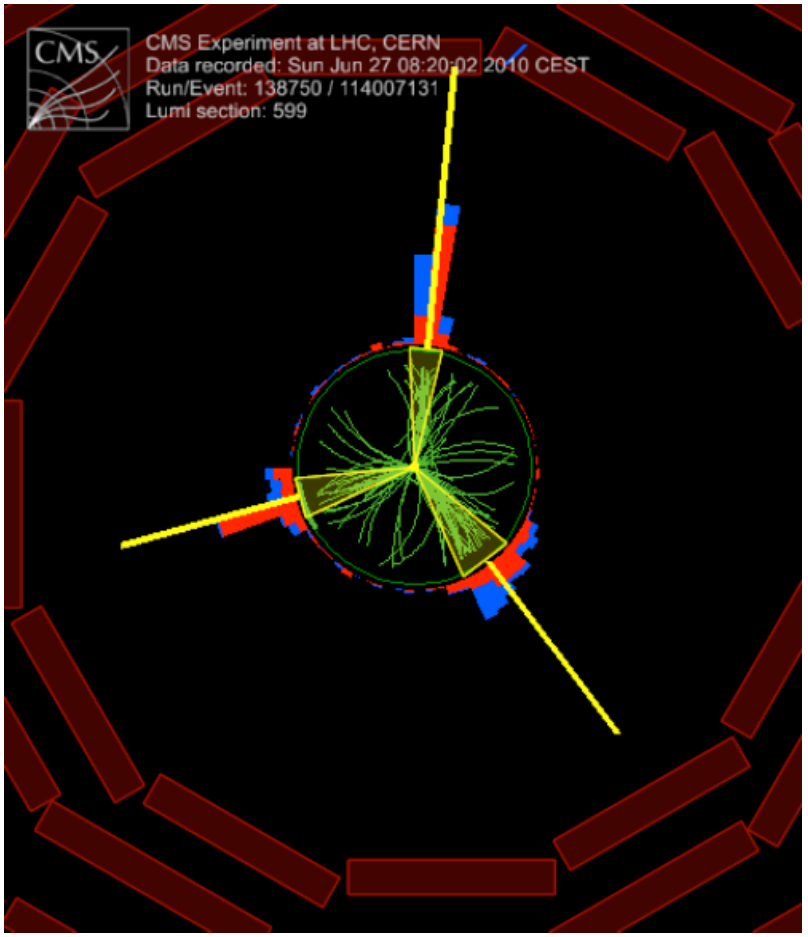


Jet reconstruction

Quarks and gluons initiate jet production, detected through had/em showers.

4 jet reconstruction algorithms:

1. Calorimeter only
2. Calorimeter, corrected using associated track measurements
3. Particle flow: reconstruct all particles using all sub-detectors prior to jet clustering
4. Track jets (independent)

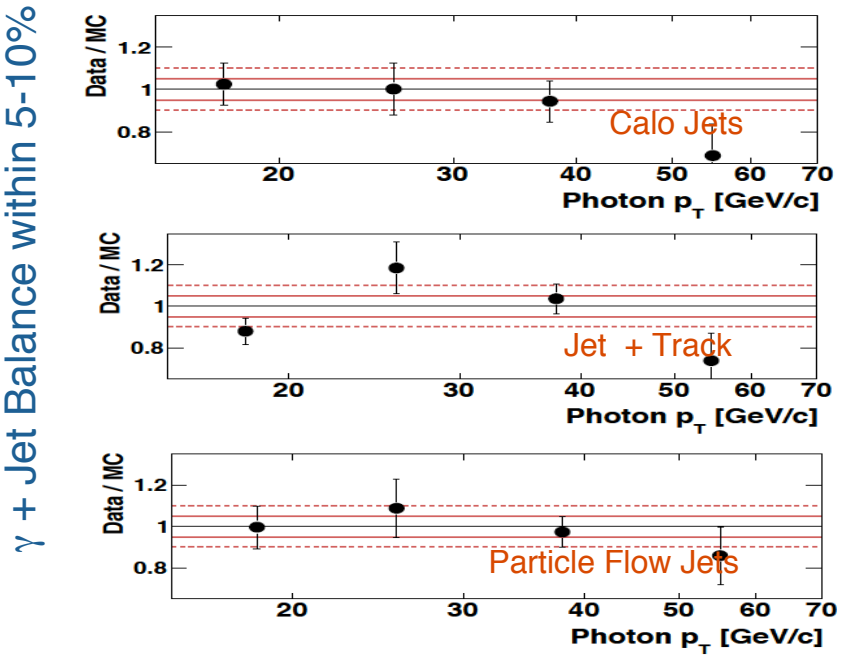


Jet Energy Calibration

Calorimeter response is non-linear and non-uniform, so observed energy needs to be corrected:

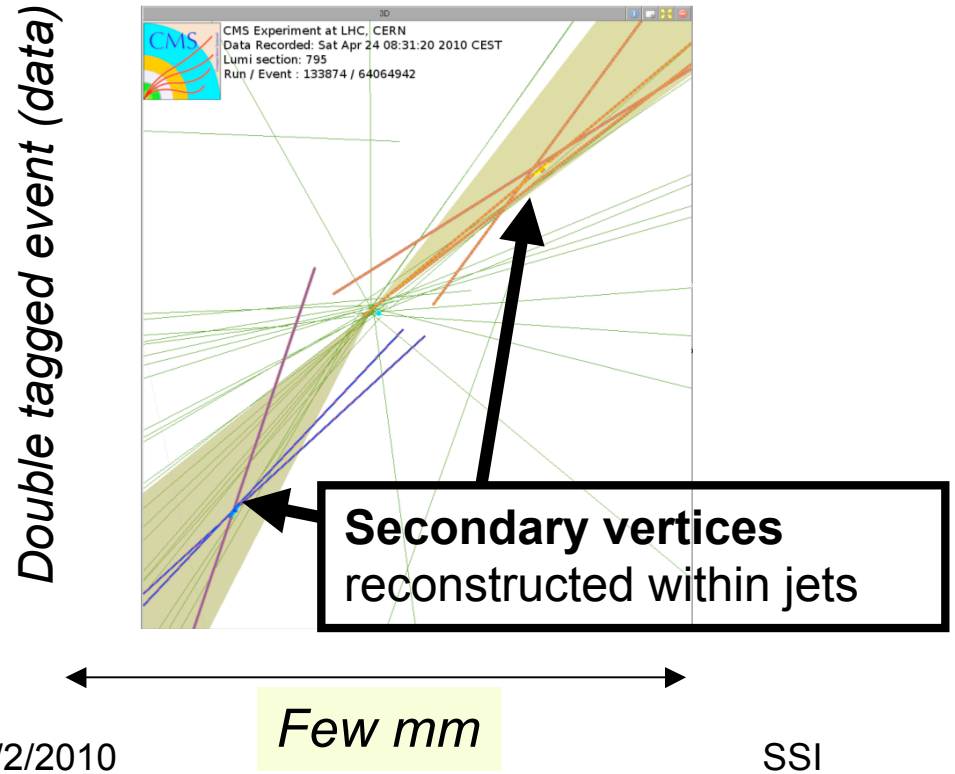
- depending on algorithm, jet p_T and η..: correction up to factor 2!
- Correction done using MC so far, but checked in data, e.g. with energy balance in γ+jet events

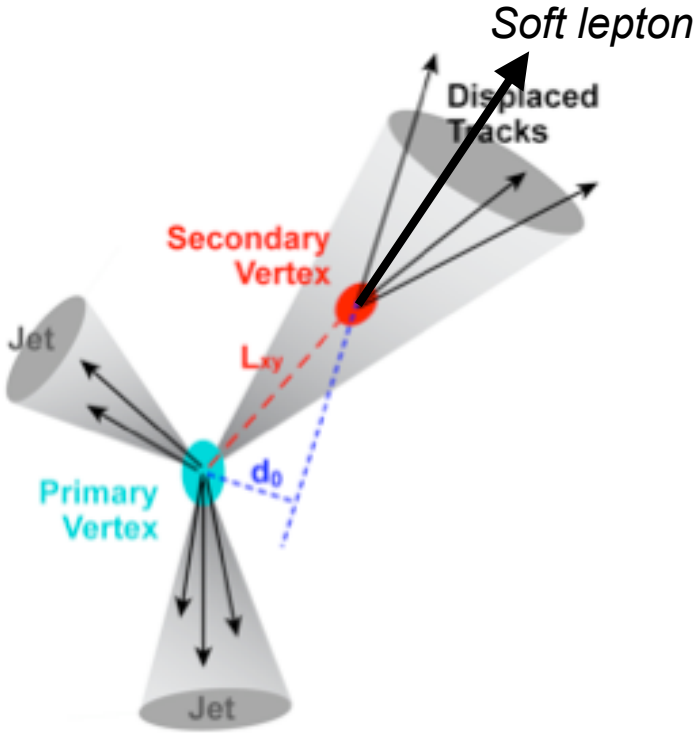
MC/data agree within ~5-10% (=systematic uncertainty for jet energy measurement)



B tagging of jets

- Identify jets originating from b quark by long lifetime of B hadrons *Discovered at SLAC/PEP!*
  - causes a decay vertex clearly separated from the interaction point
- Example algorithms:
  - Reconstruct secondary vertices based on track impact parameter
  - Select jets with leptons from semileptonic decay of B



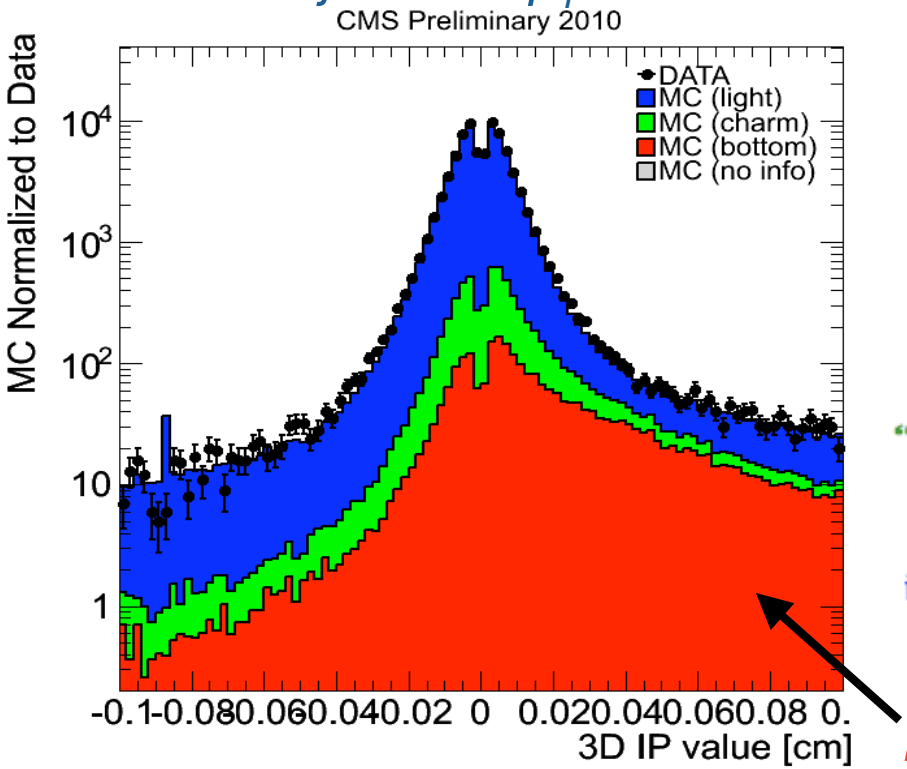


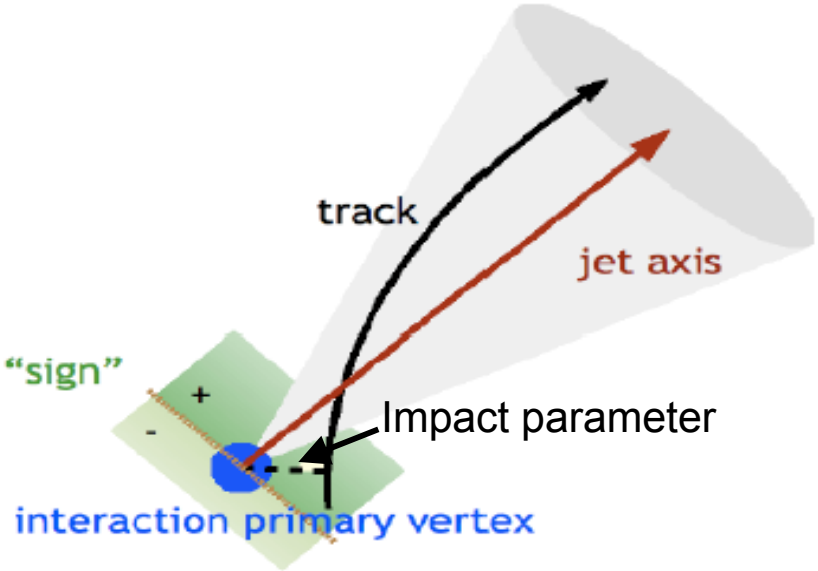
B tagging: 3D impact parameter

Measure the 3D impact parameter of tracks within jets:

- Large impact parameter value: track points to secondary vertex
- Need excellent alignment and general tracking performance

For tracks with p_T>1GeV belonging to central jets with p_T > 40 GeV:

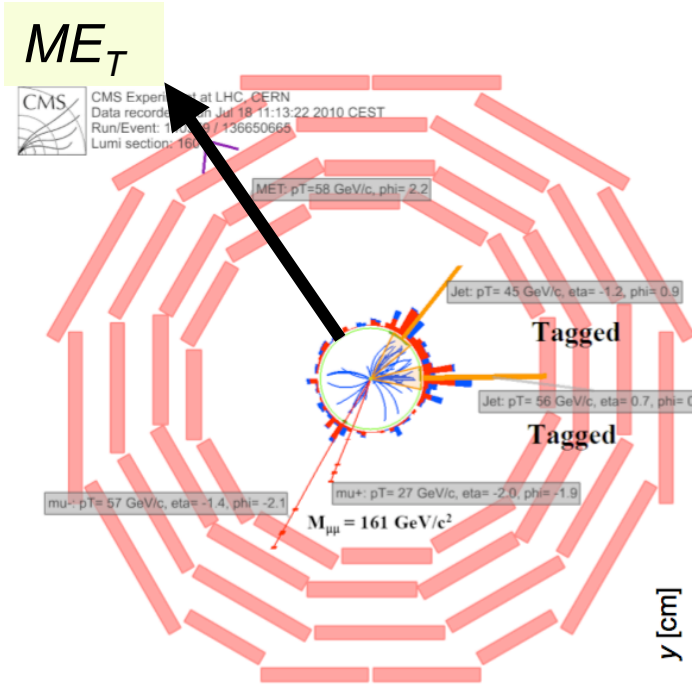




Long-lived b (and c)

Missing Transverse Energy ME_T

- Missing transverse momentum is defined as the apparent imbalance of the component of the momentum in the plane perpendicular to the beam direction
  - Note: we only have handle in transverse direction since "boost" of initial quark/gluon is unknown
- magnitude is referred to as missing transverse energy ME_T
- Allows for (indirect) detection of neutrinos, WIMPS,.. which cause imbalance in the transverse vector sum
  - E.g. most SUSY models predict ME_T>150 GeV



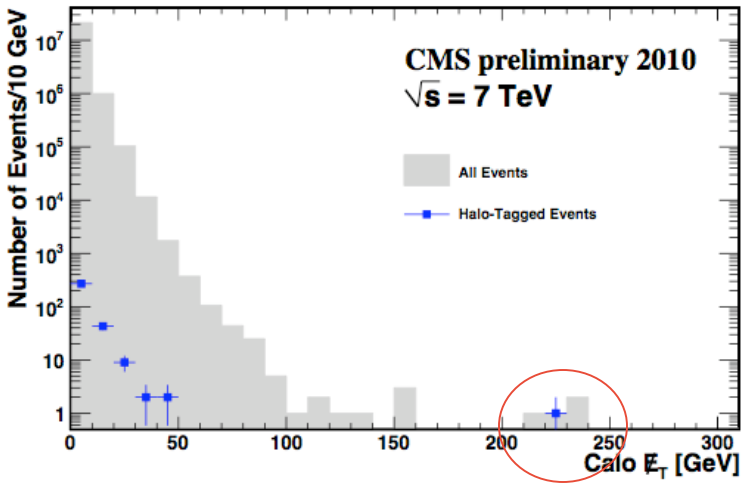
ME_T: Experimental Challenge

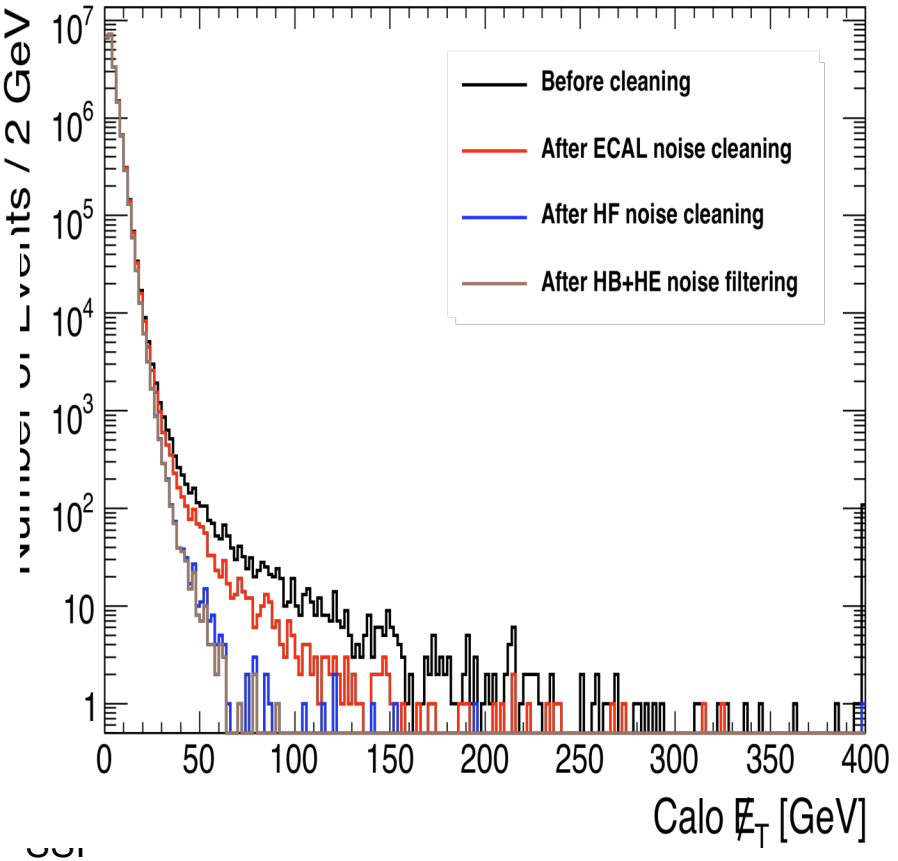
ME_T reconstruction with 3 algorithms: "calo ME_T", track-corrected ME_T, "Particle flow ME_T".

Reconstructed ME_T has to be cleaned of effects due to

- instrumental noise
- cosmics, beam halo,..

Beam halo tagged events at high ME_T:

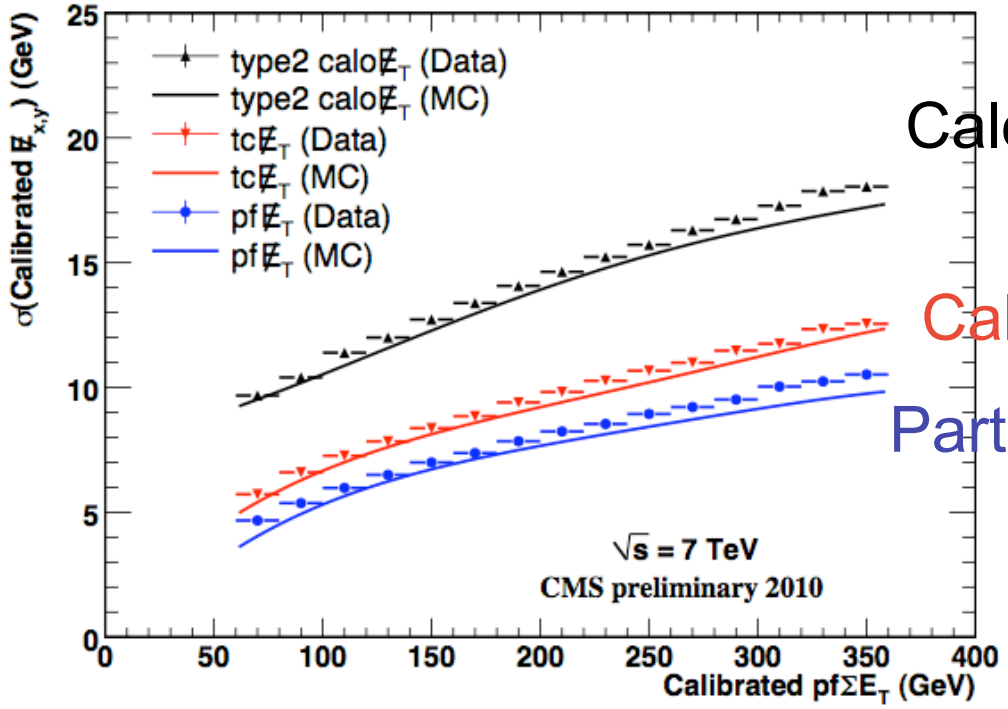




ME_T resolution

ME_T resolution due to noise, calorimeter response etc strongly depends on the associated sum of transverse energy, ΣE_T

Very good (5-10 %) ME_T resolution, esp. for particle flow and track-corrected ME_T, as measured in minimum-bias data



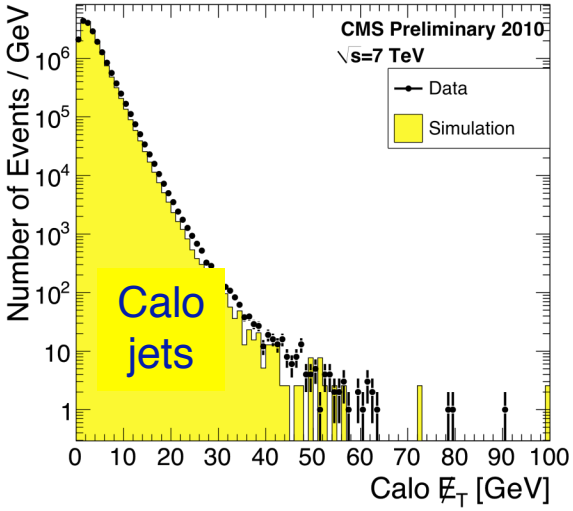
Calorimeter only

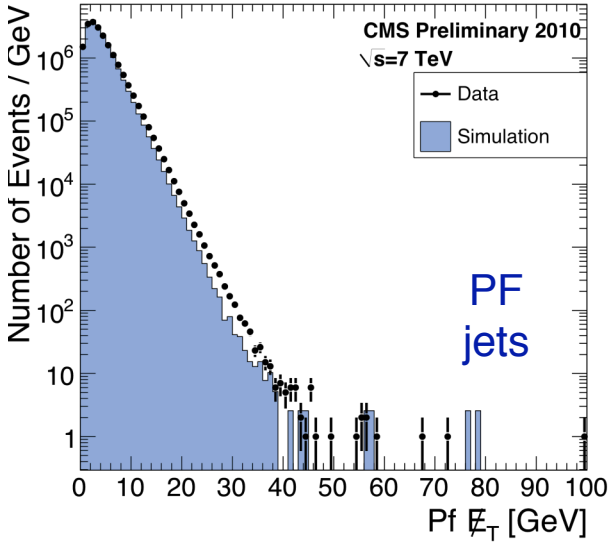
Calo+tracks

Particle flow

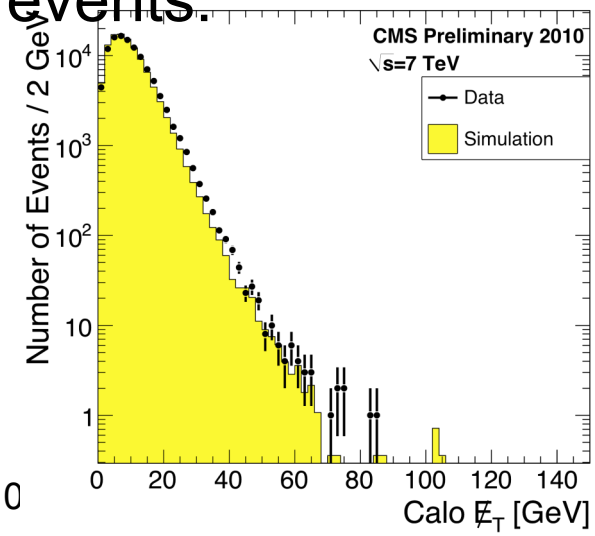
Simulation of ME_T over 7 orders of magnitude

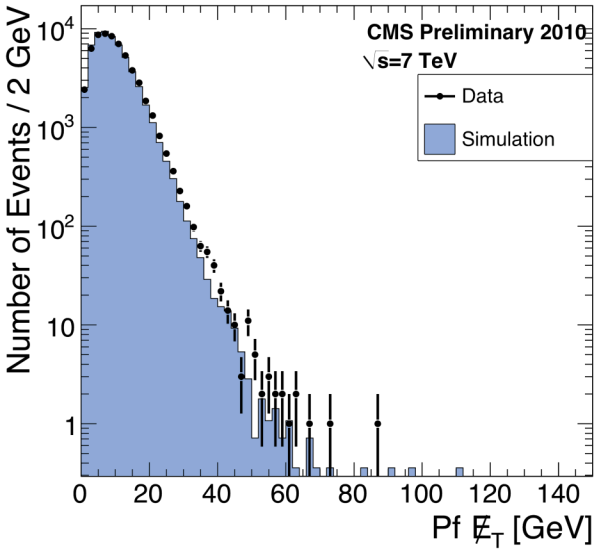
- Minimum Bias events:





- Di-jet events:

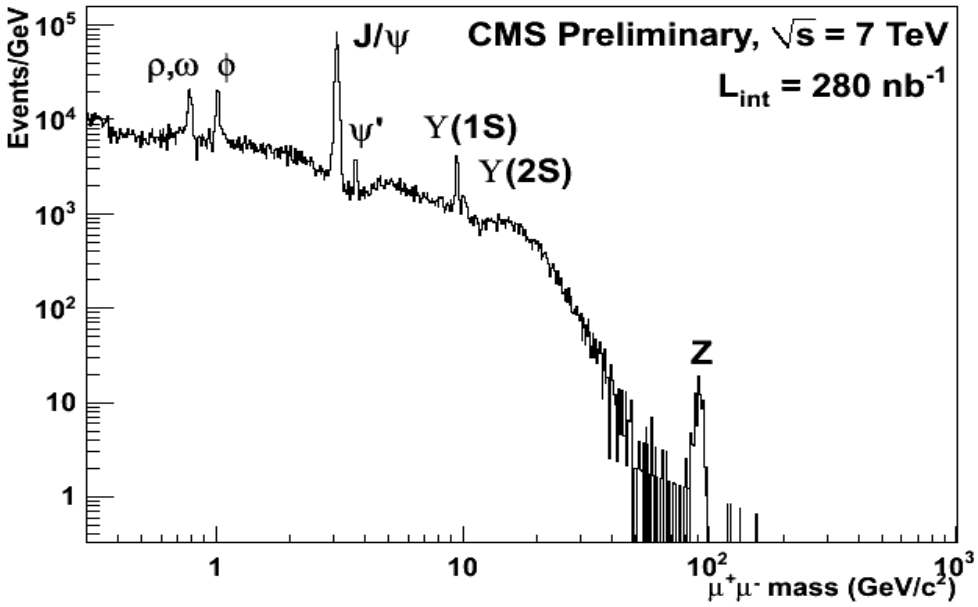


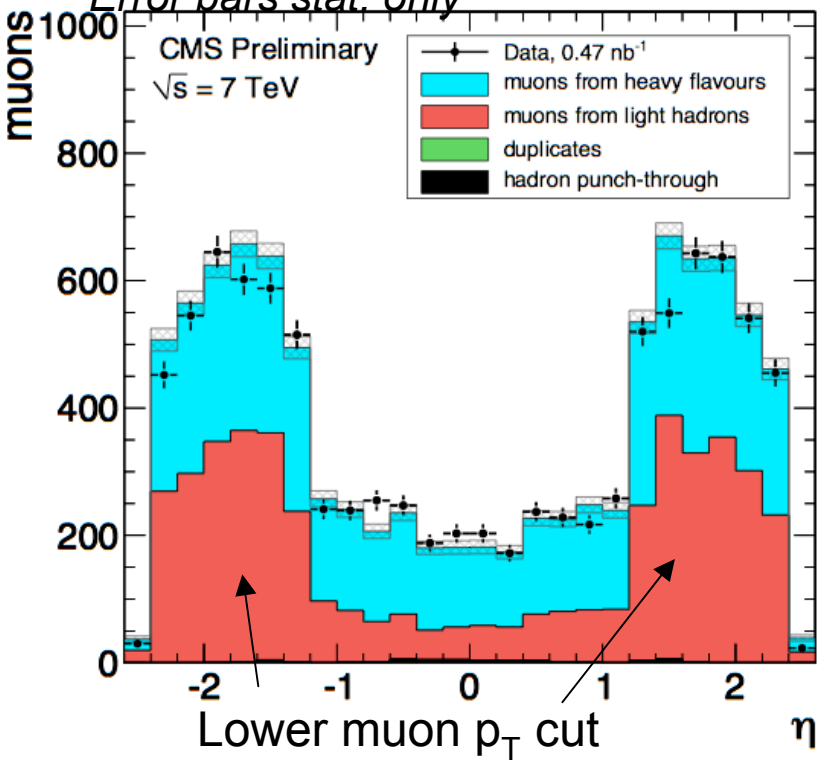


Muons: the "M" in CMS

- Hits in muon detectors, matched up with tracks
- CMS trigger flexible: can use very loose muon triggers
  - 50k J/ψ per pb^{-1} down to 0 p_T in forward direction!
- Muon identification studied using minimum bias events and dimuon resonances

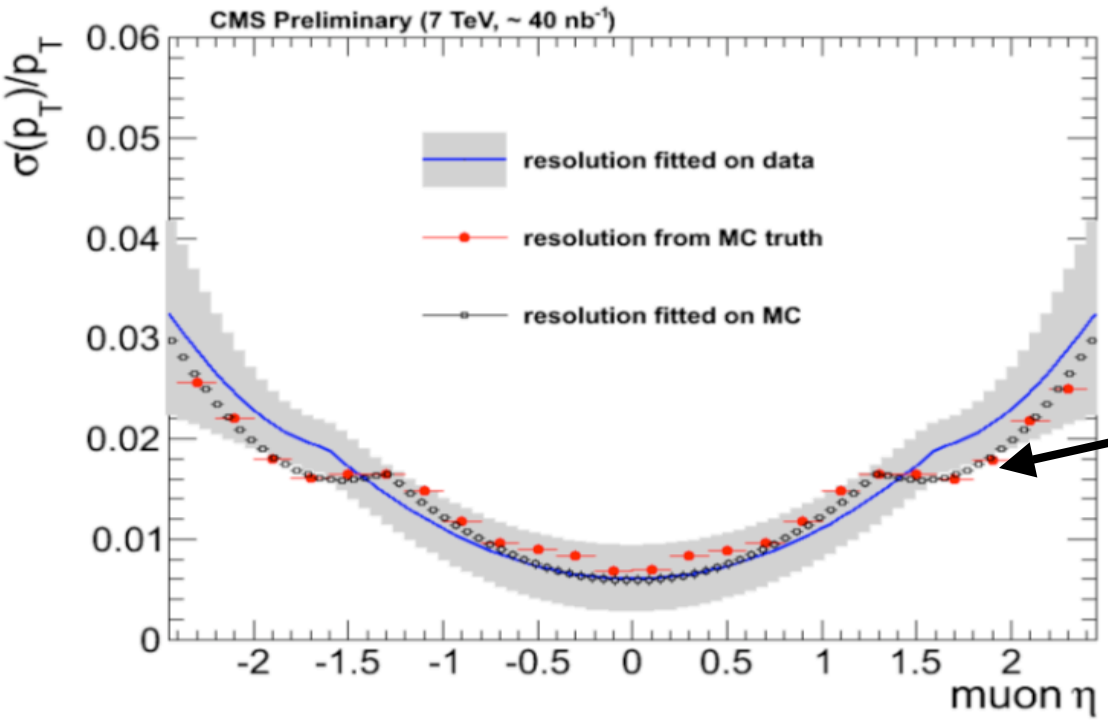
Min bias data, compared to simulation. Error bars stat. only





Muon momentum resolution

- Excellent momentum resolution ~1% for $|\eta|<0.7$, as determined by fits to the J/ψ line shape
- Uncertainty dominated by statistics, will improve with more data from Y resonance

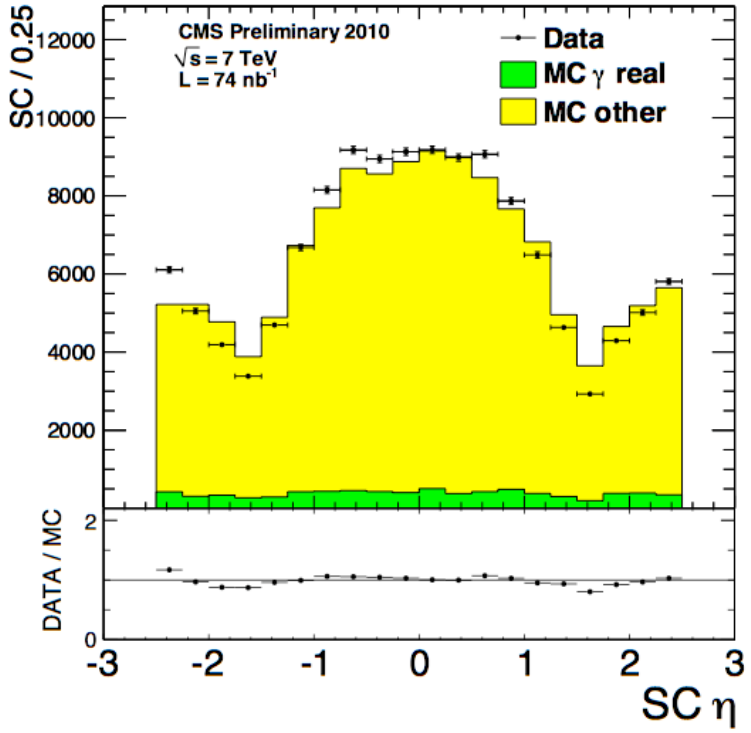


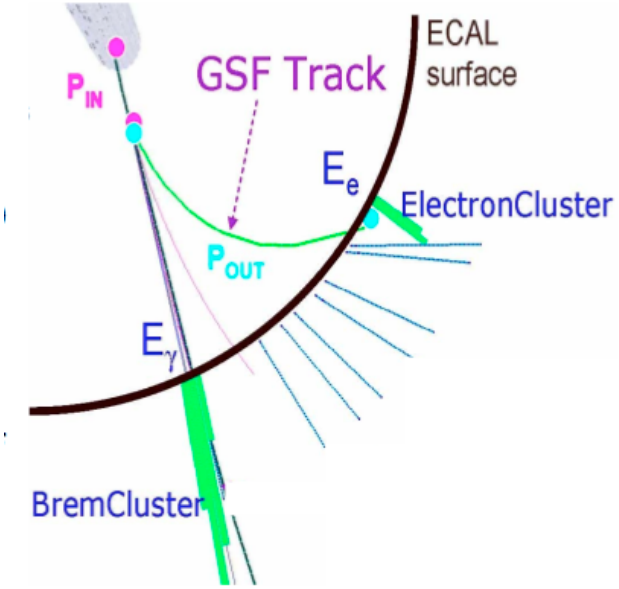
Barrel-endcap transition region

Electrons and Photons

- Reconstructed using ECAL clusters
  - Detector Material causes conversions and bremsstrahlung, energy flow spreads due to magnetic field
  - Superclusters formed to collect the total energy

Supercluster pseudorapidity,
Minimum Bias data

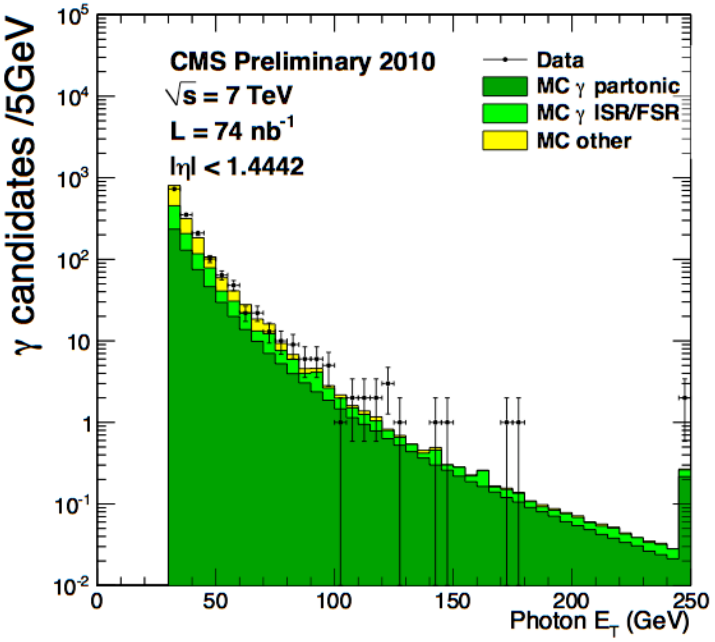




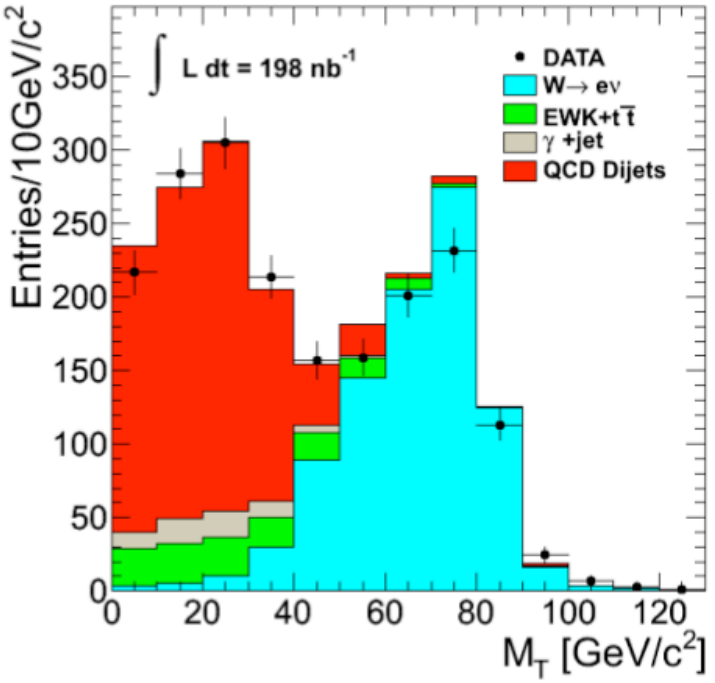
Electrons and Photons

- Photons selected using ECAL and tracking isolation
- Electrons selected using ECAL and track matching

Central photon candidates in Min.bias data

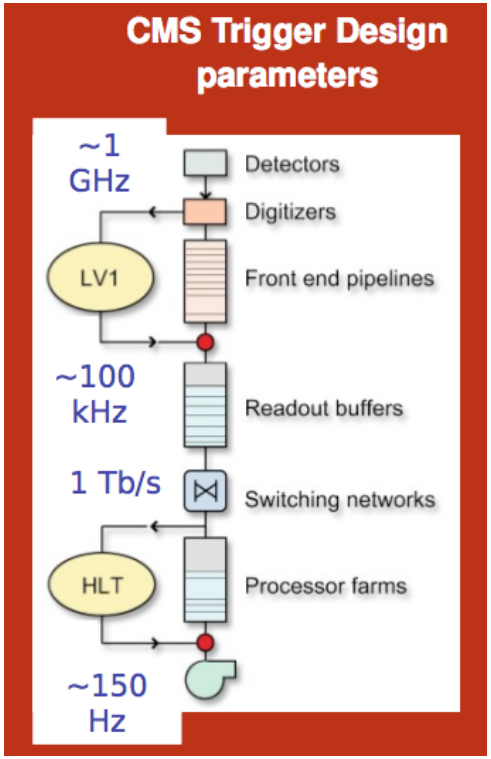


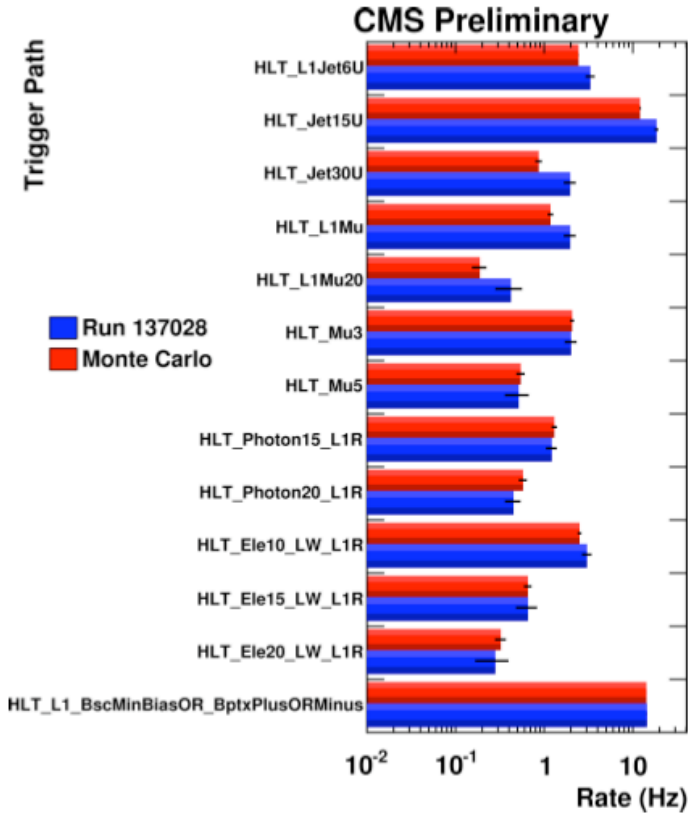
Electron candidates: reconstructed transverse mass



Triggers

- Reducing data stream with fast online decision
- Two levels: “L1” (hardware) and “HLT” (software)
- HLT trigger menu: 150 triggers (jet, ME_T, muon,..)
- Current total trigger processing time per event: <50 ms





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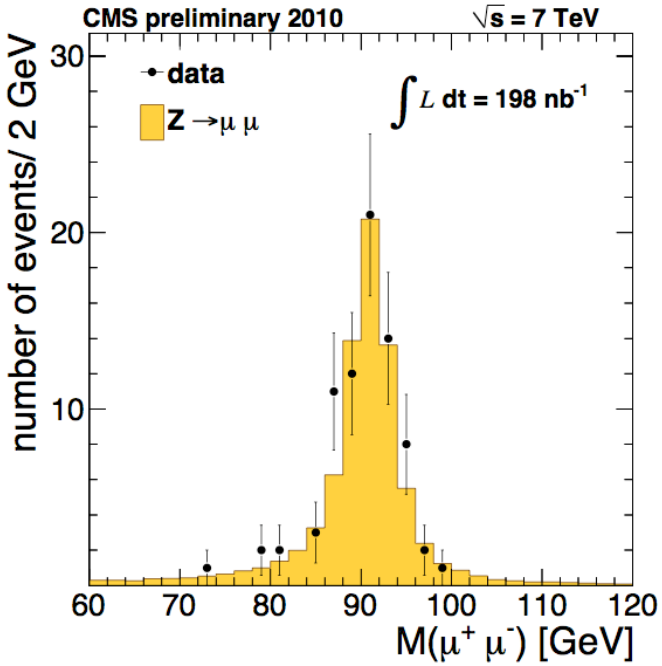
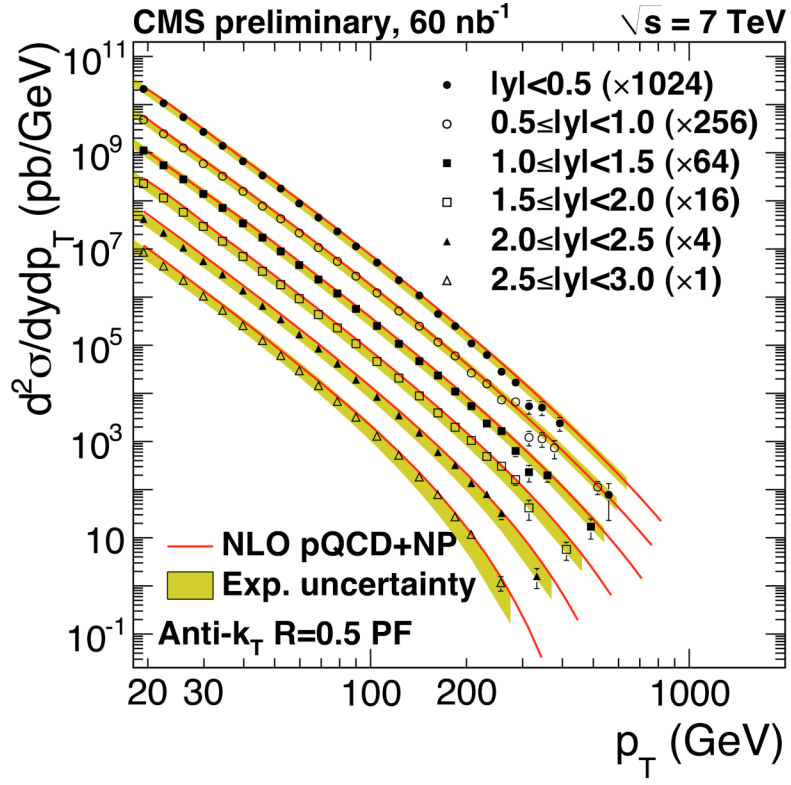


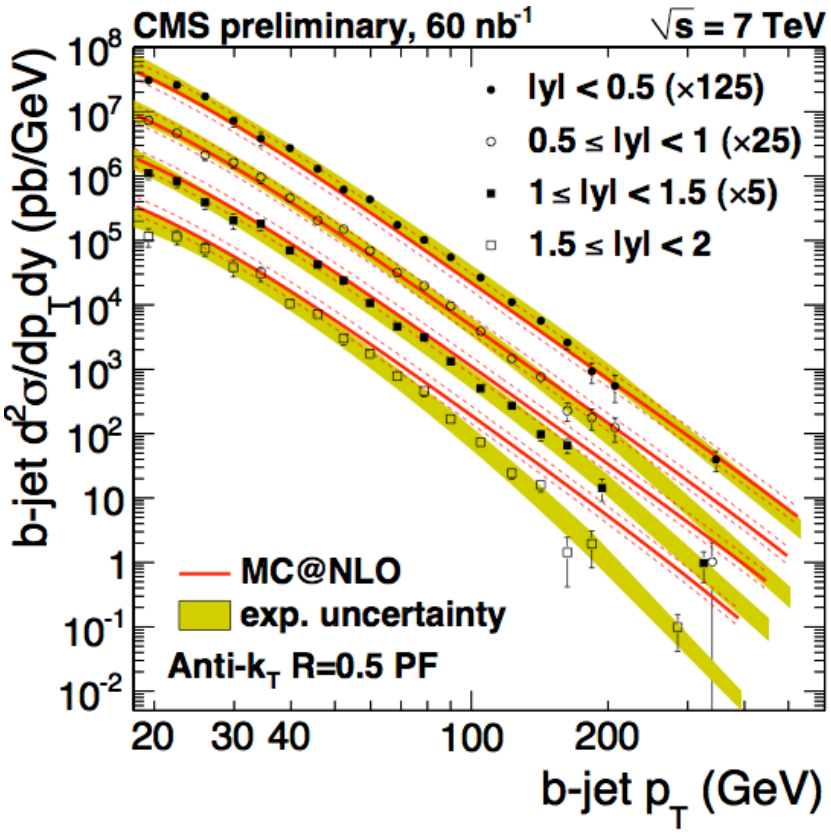
Inclusive jet cross section

- Basic measurement at hadron collider- very high rate of jet production
- Good test of jet reconstruction- see good agreement with NLO theory
- Jet p_T spectra produced for all jet rec. approaches
  - Extending distributions to low p_T using “Particle Flow”

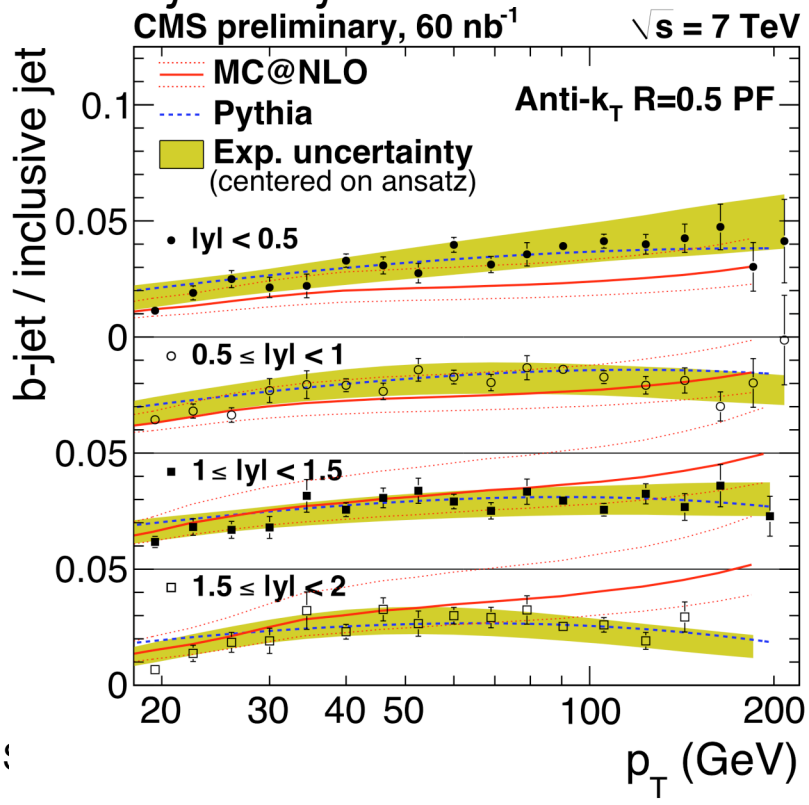


Incl. b-jet cross section

- Sizable theoretical uncertainties, interesting to verify results at high energy
  - Reasonable agreement with NLO
- important background to NP searches

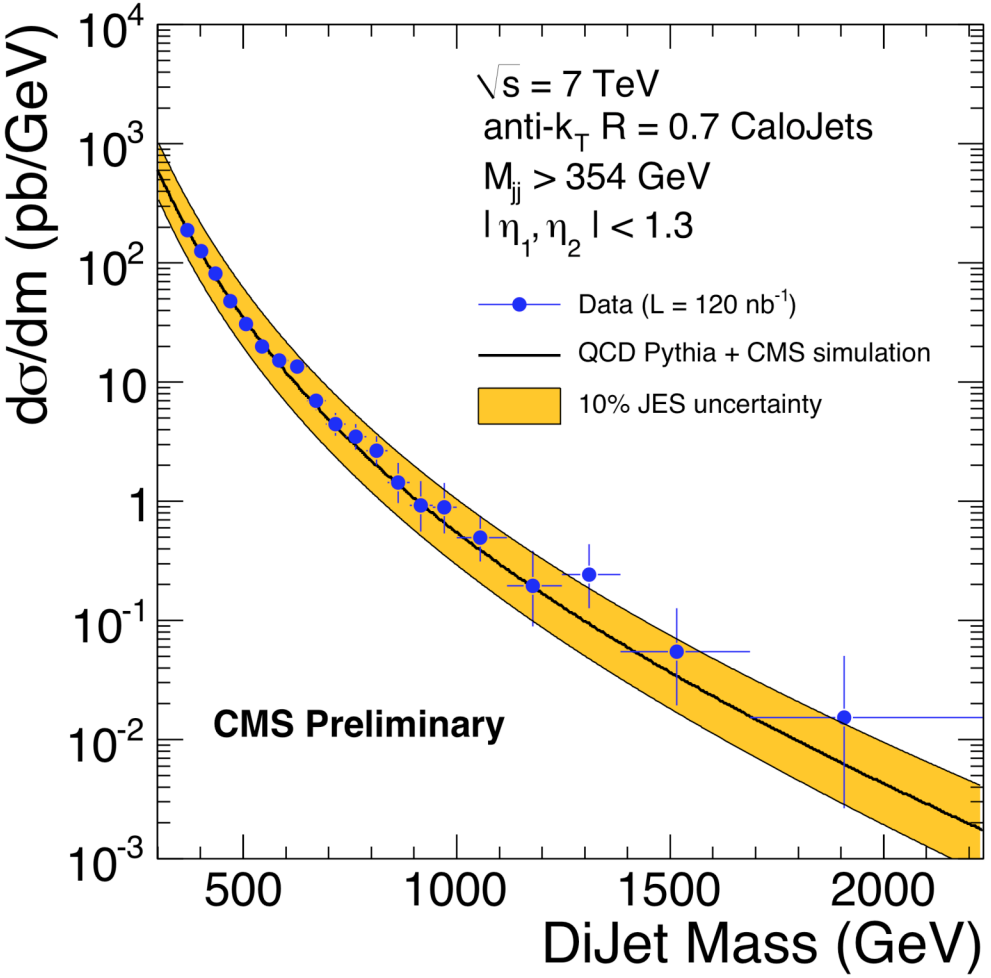


Common syst. cancel out in ratio B-jet/incl.jet:



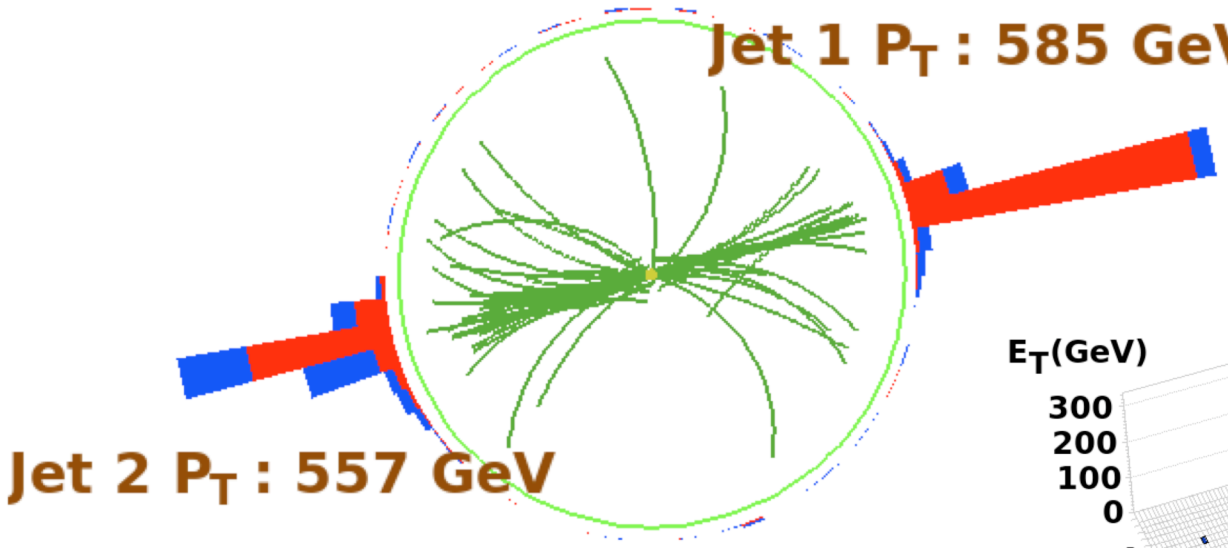
Search for narrow resonance in dijets

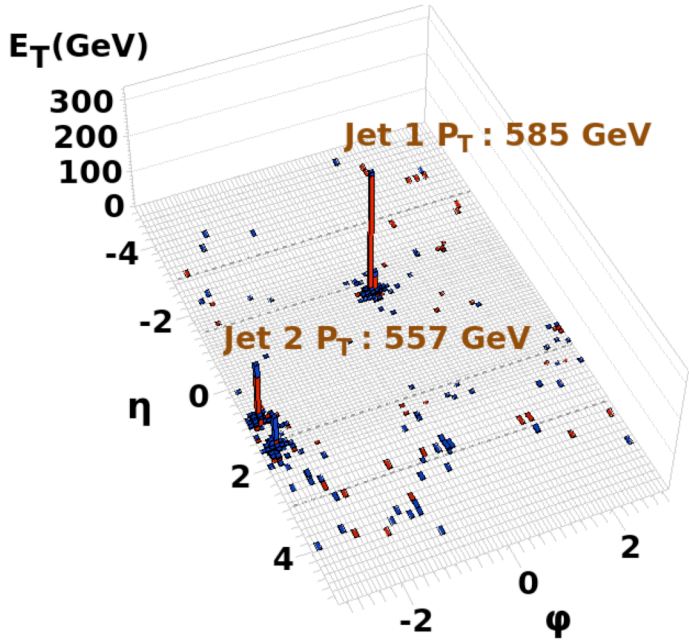
- Measure differential cross section for centrally produced jets
- Many NP models predict new massive objects coupling to q,g, resulting in resonances
- Starting to exclude certain NP ranges, e.g.
  - string resonances with m<1.6 TeV,
  - excited quark mass m<0.59 TeV
  - axigluon mass m<0.52 TeV



Starting to reach beyond Tevatron:

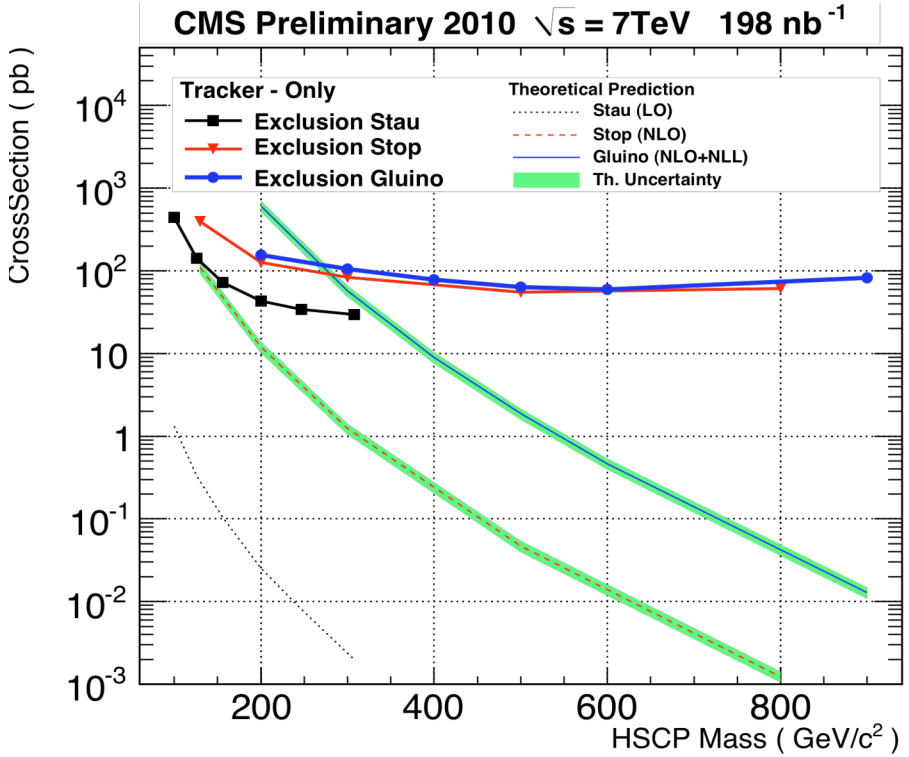
- Highest di-jet mass in first 120nb^{-1} of data: m_{jj}=2.13 TeV





Stopped Gluinos and Heavy Stable Charged Particles

- Search for long lived particles decaying in the detector after end of each LHC fill
  - No signal observed during search intervals, can be interpreted as exclusion limit on gluino masses: <229GeV (t=200ns) and <225GeV (t=2.6μs).
- Search for anomalous signals from heavy particles
  - Interpret in context of (quasi-)stable stau, gluino, scalar top as limits on cross section



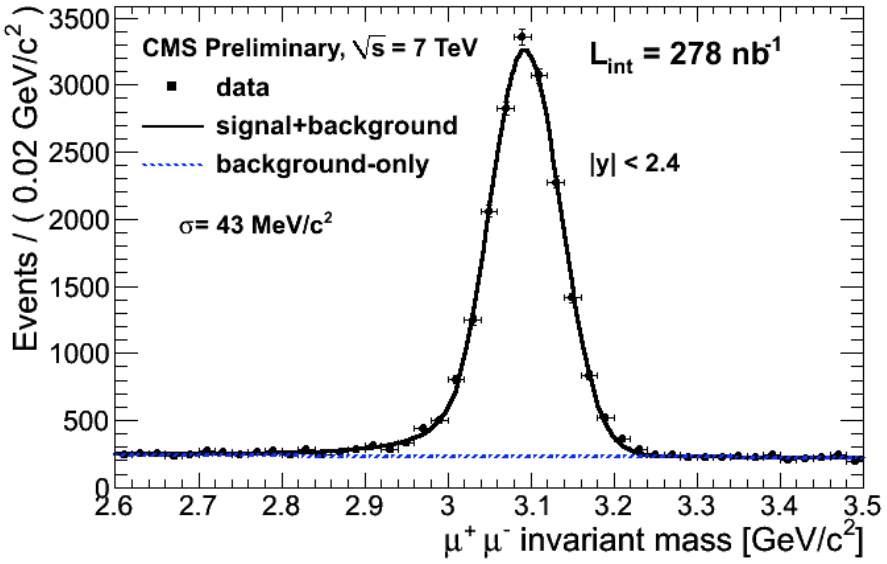
J/ψ→μ+μ- differential and total cross section

Total cross section for incl. J/ψ production in the di-muon decay channel ($4 \leq p_T \leq 30$GeV/c and $|y| < 2.4$):

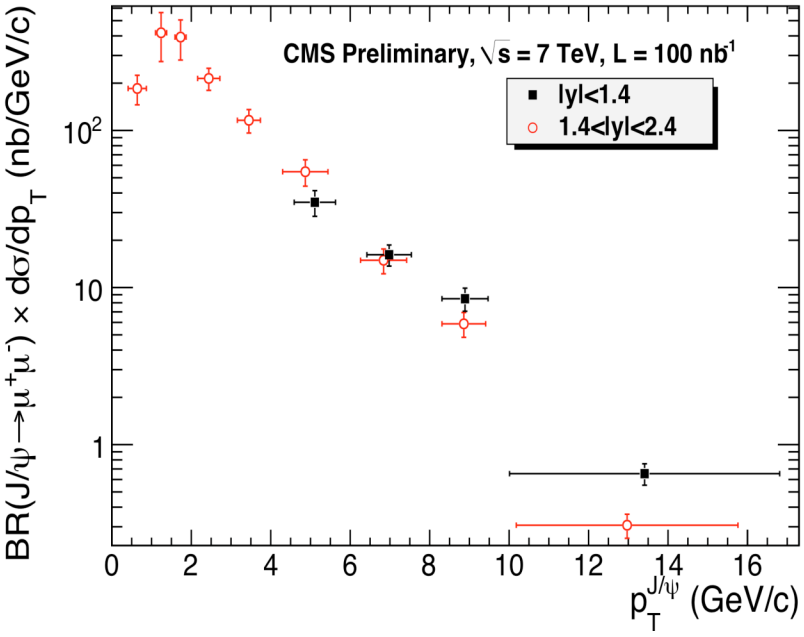
$BR(J/\psi \rightarrow \mu^+\mu^-) \cdot \sigma(pp \rightarrow J/\psi + X) =$
$(289.1 \pm 16.7(stat) \pm 60.1(syst))$ nb

– Syst. dominated by the stat. precision of the muon efficiency determination from data

17156 ± 569 signal events (central)



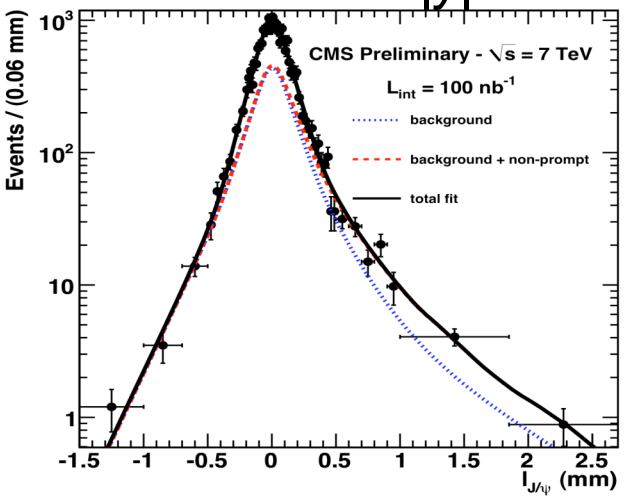
Differential cross section
(null polarization scenario)



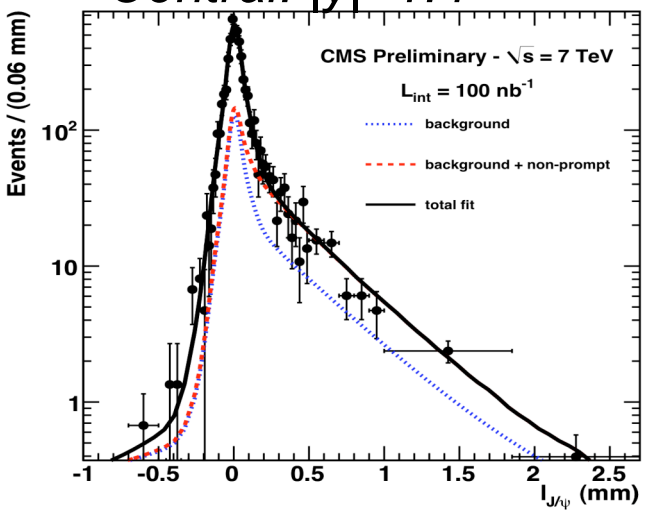
Fraction of J/Ψ from B Hadron decay

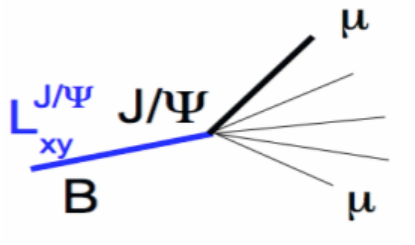
- Use transverse decay length to separate prompt from non-prompt component

Forward: 1.4<|y|<2.4

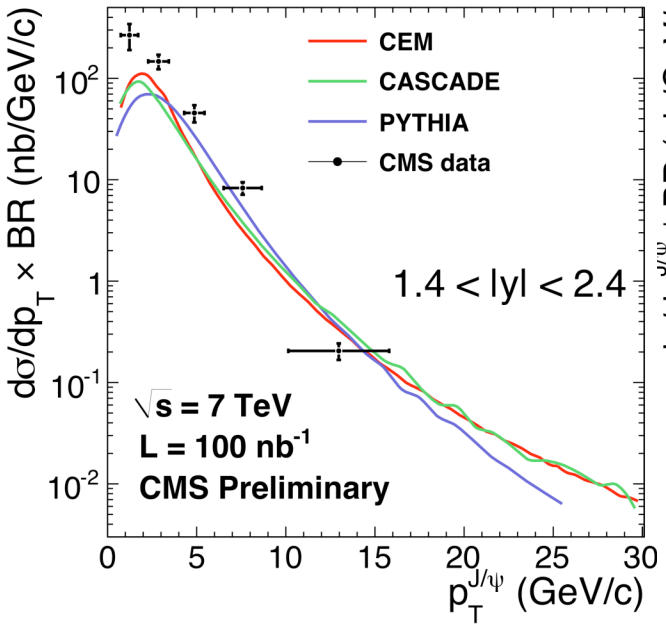


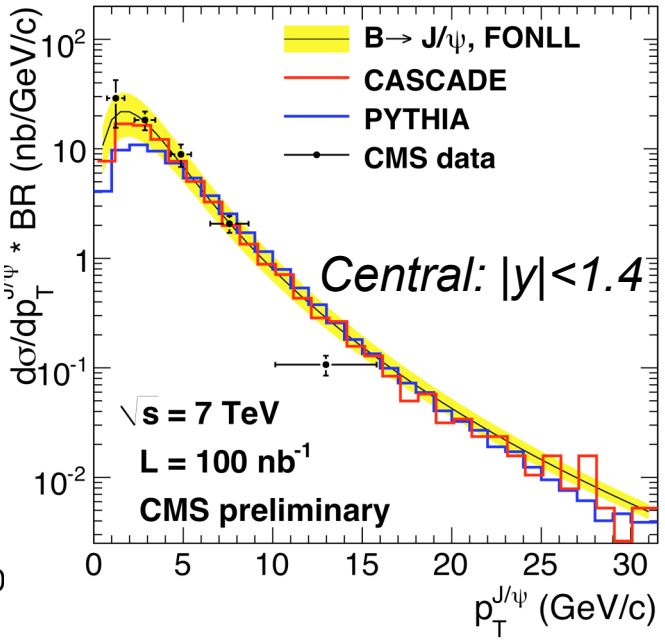
Central: |y|<1.4





Prompt diff. cross section:

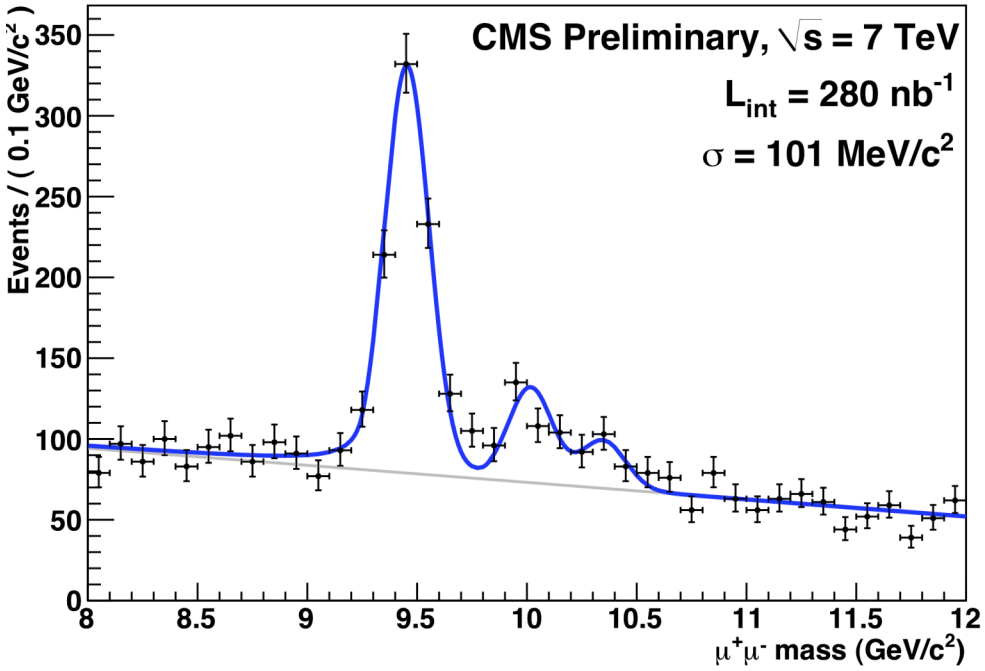


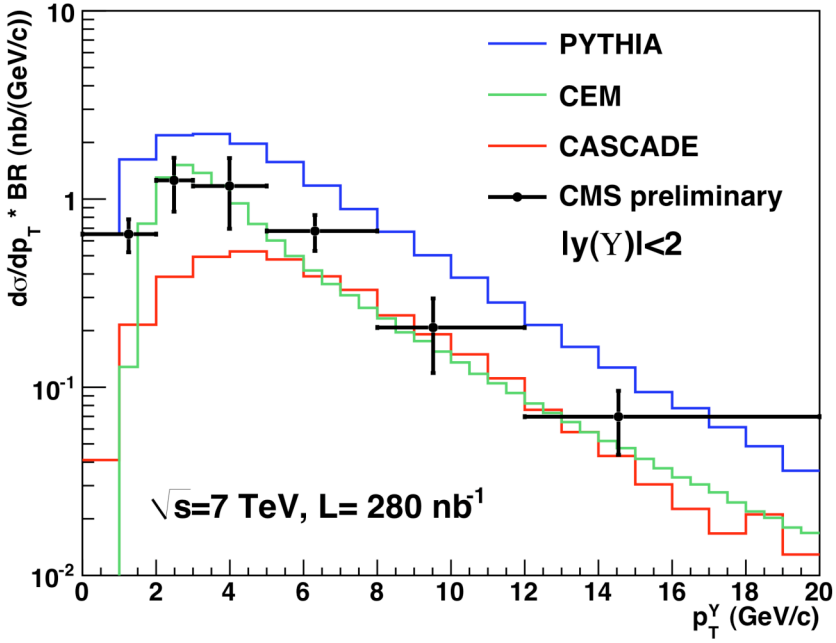


Υ(1s, 2s and 3s)→μ+μ-

measured the Υ(1s) cross section x BR in dimuons and the corresponding differential cross section

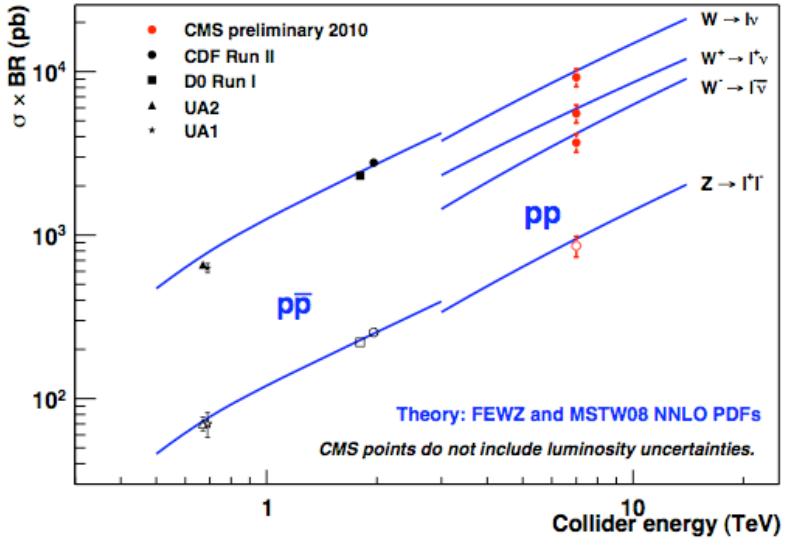
σ(pp →Υ(1S)X)·B(Υ(1S)→μ+ μ−)=(8.3±0.5±0.9±1.0)nb





W and Z production cross sections

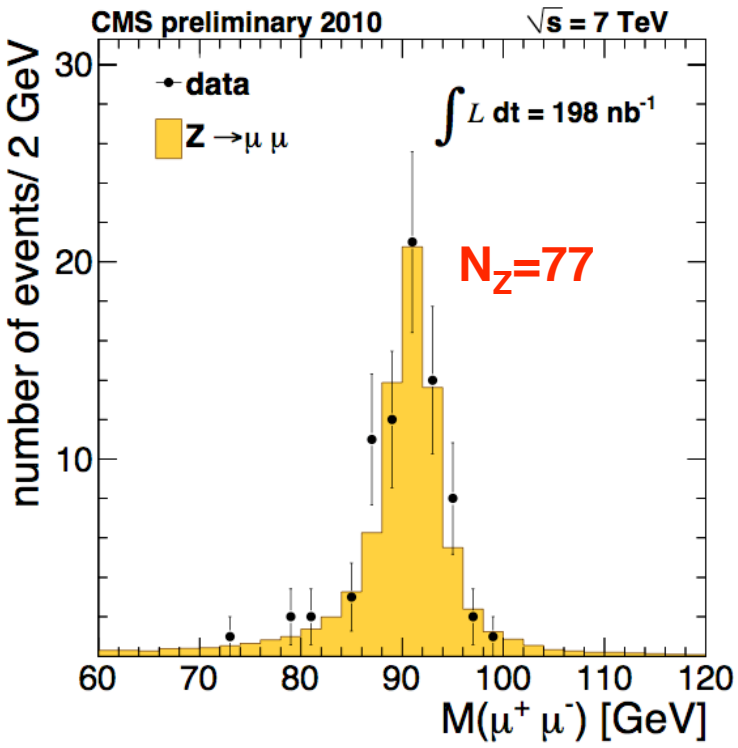
- Precision test for pert.QCD (NNLO) and proton PDFs
  - First ewk process in pp collisions at 7TeV!

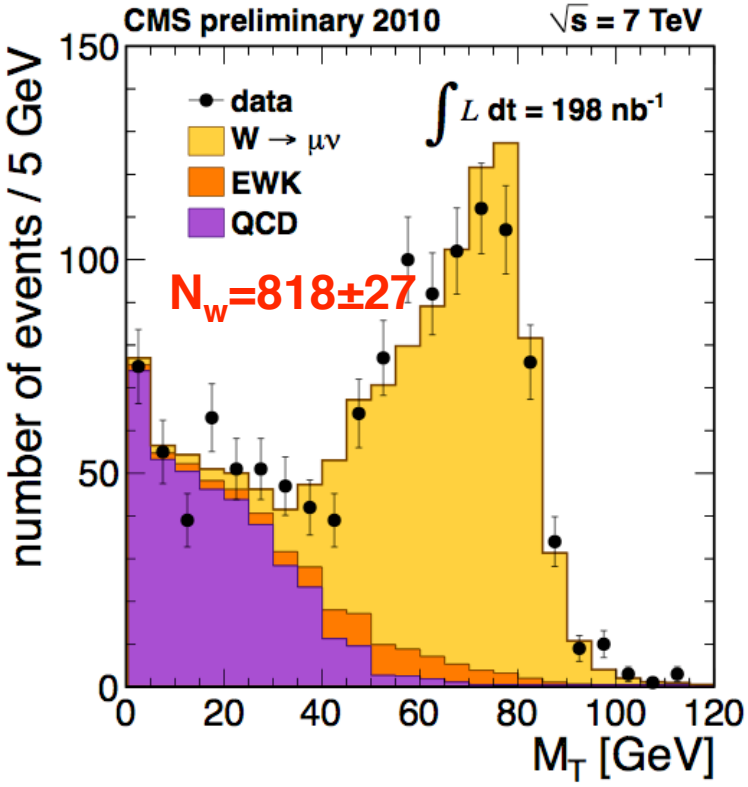


- Benchmark point for lepton reconstruction and identification, ME_T
- Important related measurements:
  - Ratio W/Z cross section; uncertainty on luminosity cancels
  - Forward backward asymmetry of lepton pairs sensitive to NP (e.g. extra neutral gauge bosons)
  - W+jets production: test of pert. QCD and one of most important background processes!

Extraction of the W(Z)→μν(μμ) signal

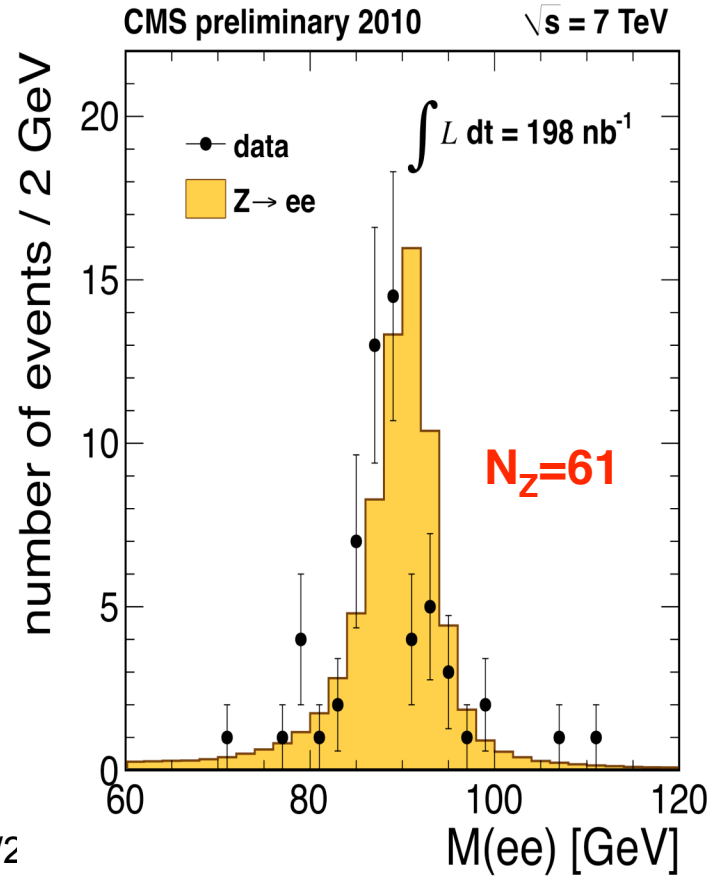
- Trigger HLT path: μ+X(p_T>9 GeV/c) |η|<2.
- QCD background shapes from data, others from MC

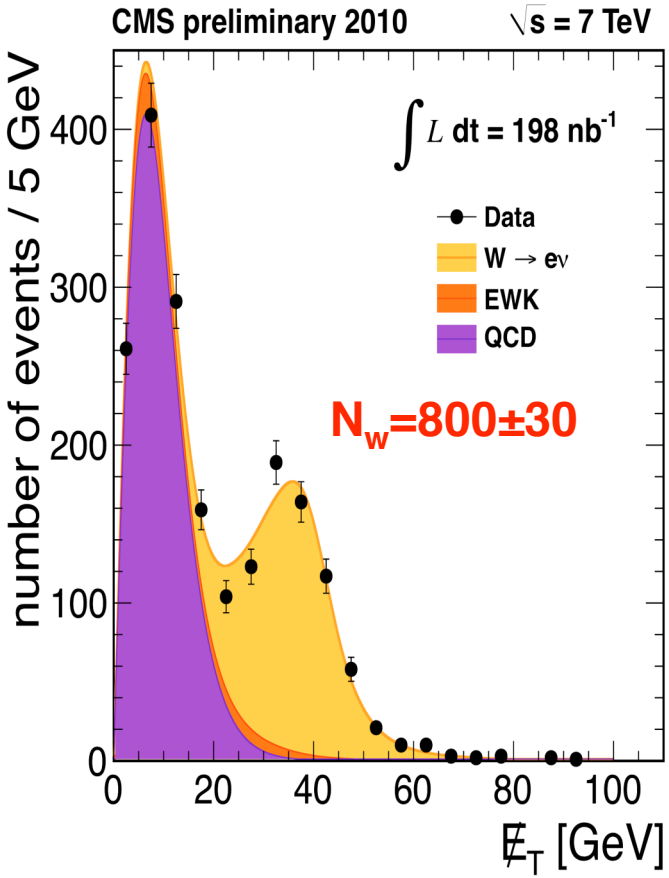




Extraction of the W(Z)→eν(ee) signal

- Trigger HLT path: e/γ+X(E_T>15 GeV/c)
- Yield of W bosons determined using simultaneous fits to background and signal contributions

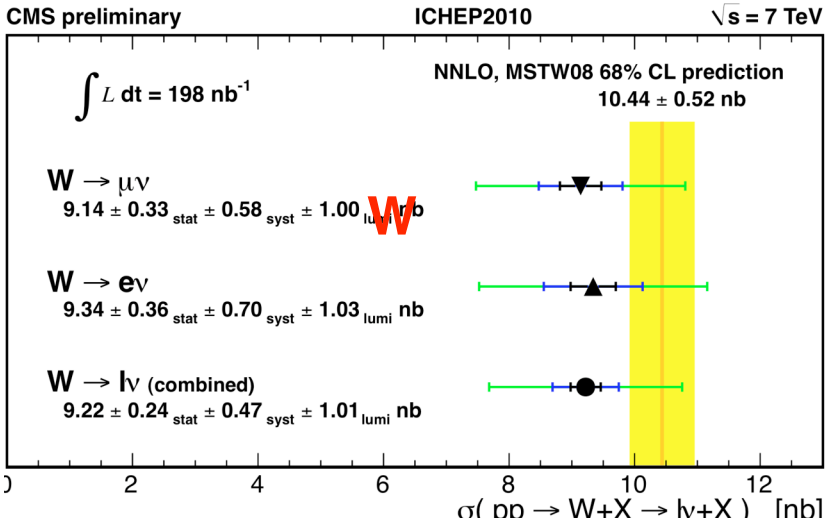


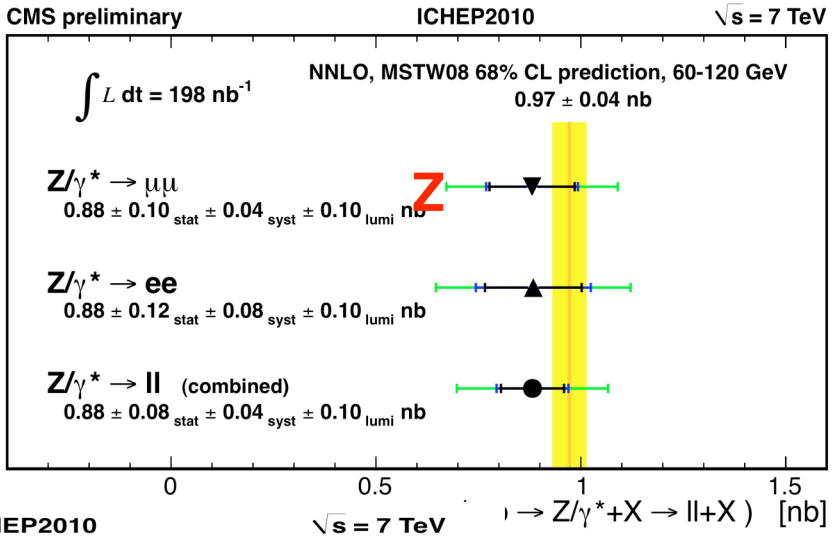


W and Z: cross section results

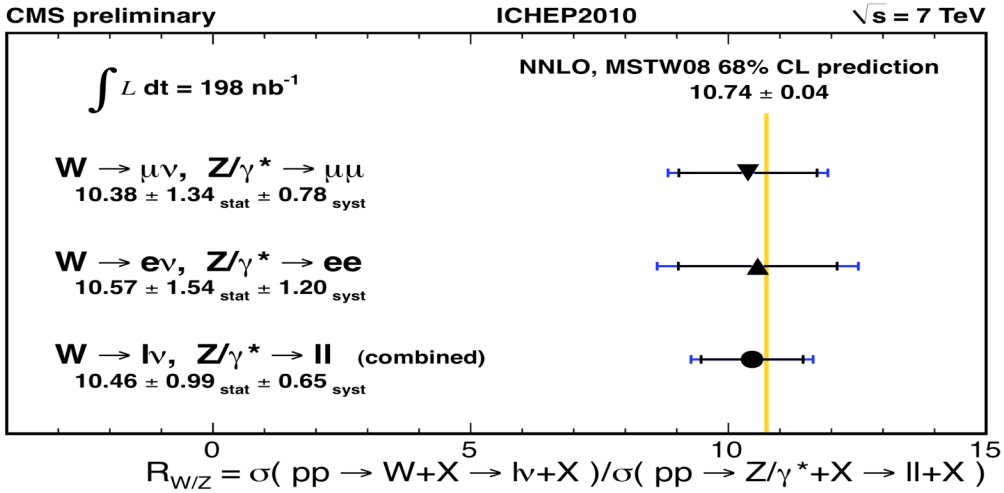
Important test of many analysis components:

- Lumi, e,μ efficiency, ME_T resolution, background systematics,…



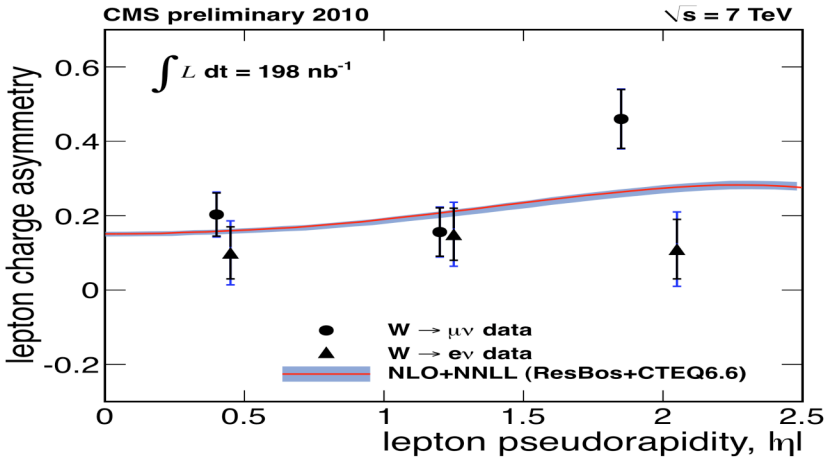


WZ ratio:

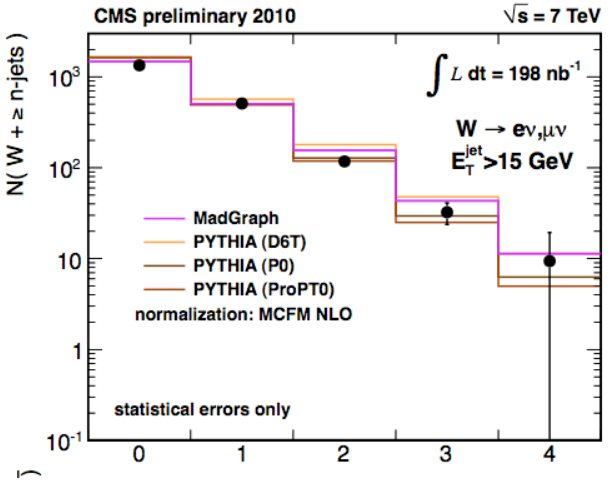


lepton charge asymmetry and W+jets

- W^+ and W^- produced at different rates in pp collisions
  - More u than d quarks
  - charge asymmetry measurement useful constraint for PDFs



- W + jets production:
  - important background to (single) top, Higgs, NP searches



Putting it all together: top quarks

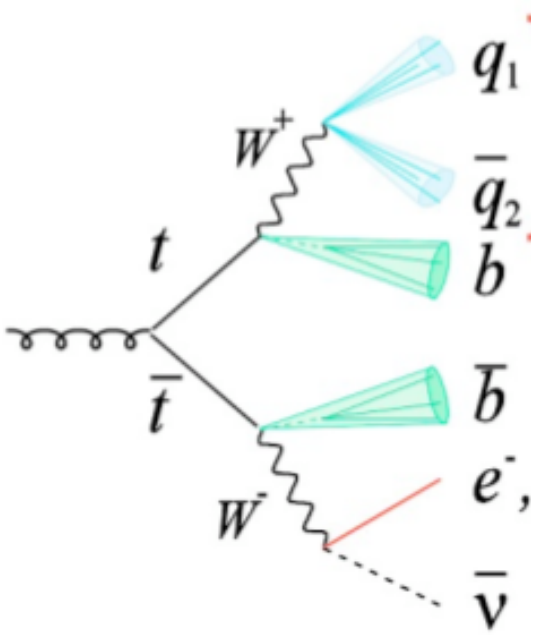
So far only produced at Tevatron, discovery in 1995

Top physics tests all aspects of the reconstruction: ME_T, leptons, jets, b-tagging.

Extremely interesting as place for NP discovery- massive X->tt, top decay,…

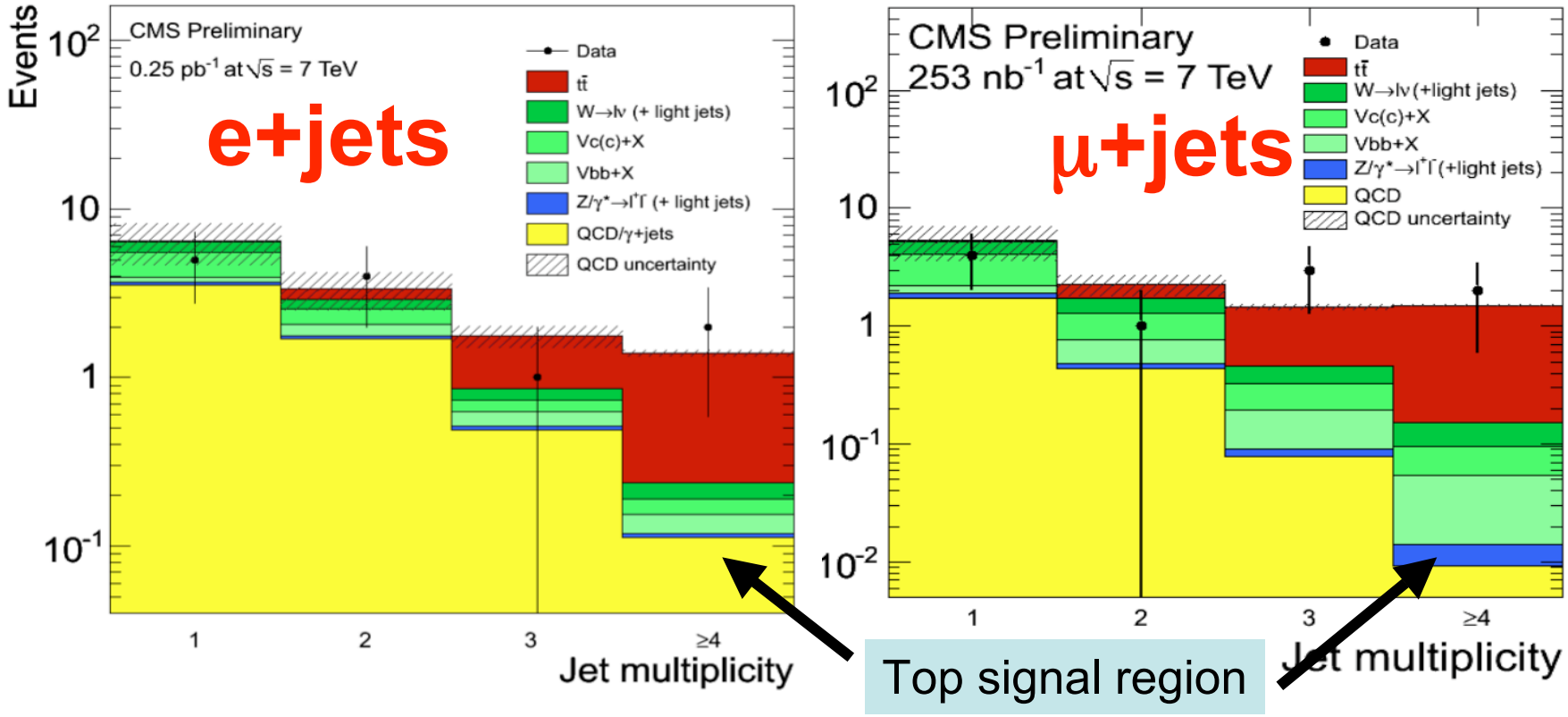
2 main channels:

- "lepton+jets": 4 jets (2 from b), and missing E_T from ν
  - BF=24/81, but significant background
- "dilepton": 2 jets and missing E_T from ν
  - Clean, but low stat. BF=4/81



lepton+jets channel

- Pretag event selection:
  - Exactly one good isolated and central muon (electron) with pT>20(30) GeV, at least 4 central jets pT>30 GeV , no MET requirement
- In the presence of at least 1 b-tagged jet to suppress background:

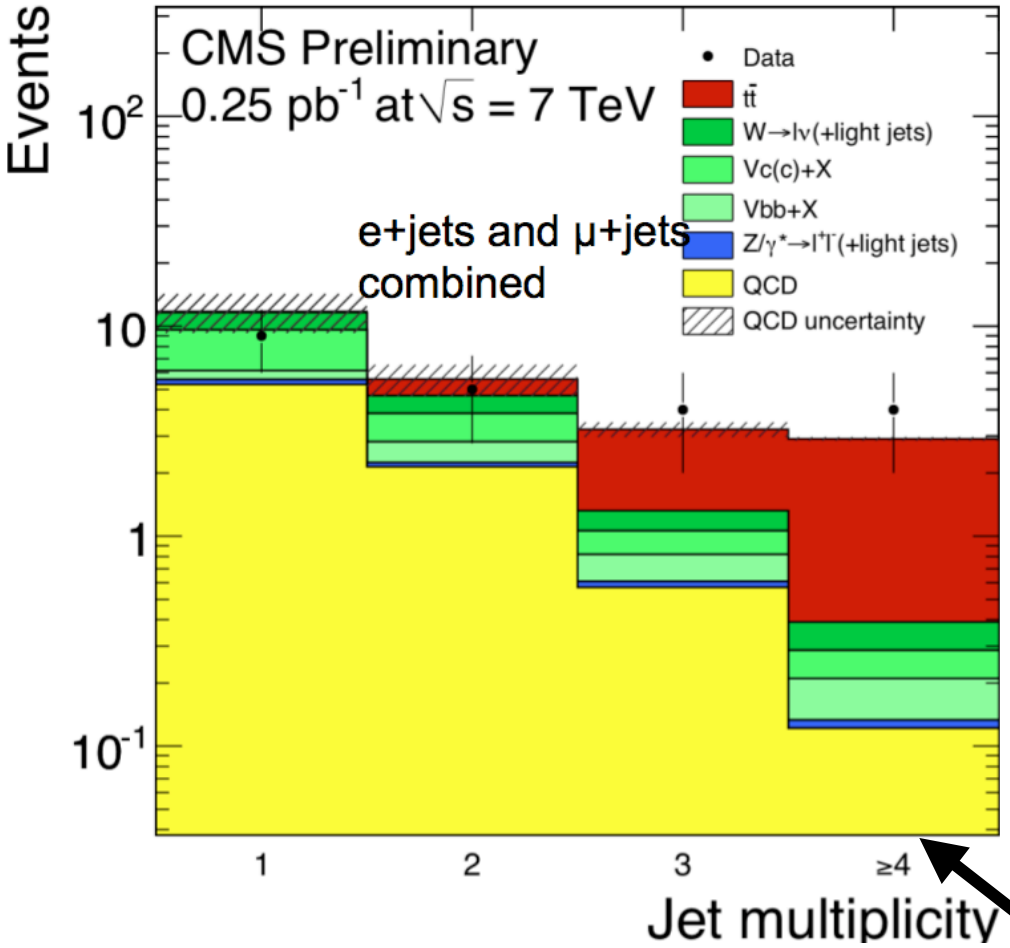


plots are“out of the box”, i.e. no syst., no data-driven background estimation, etc etc.

lepton+jets channel: combined

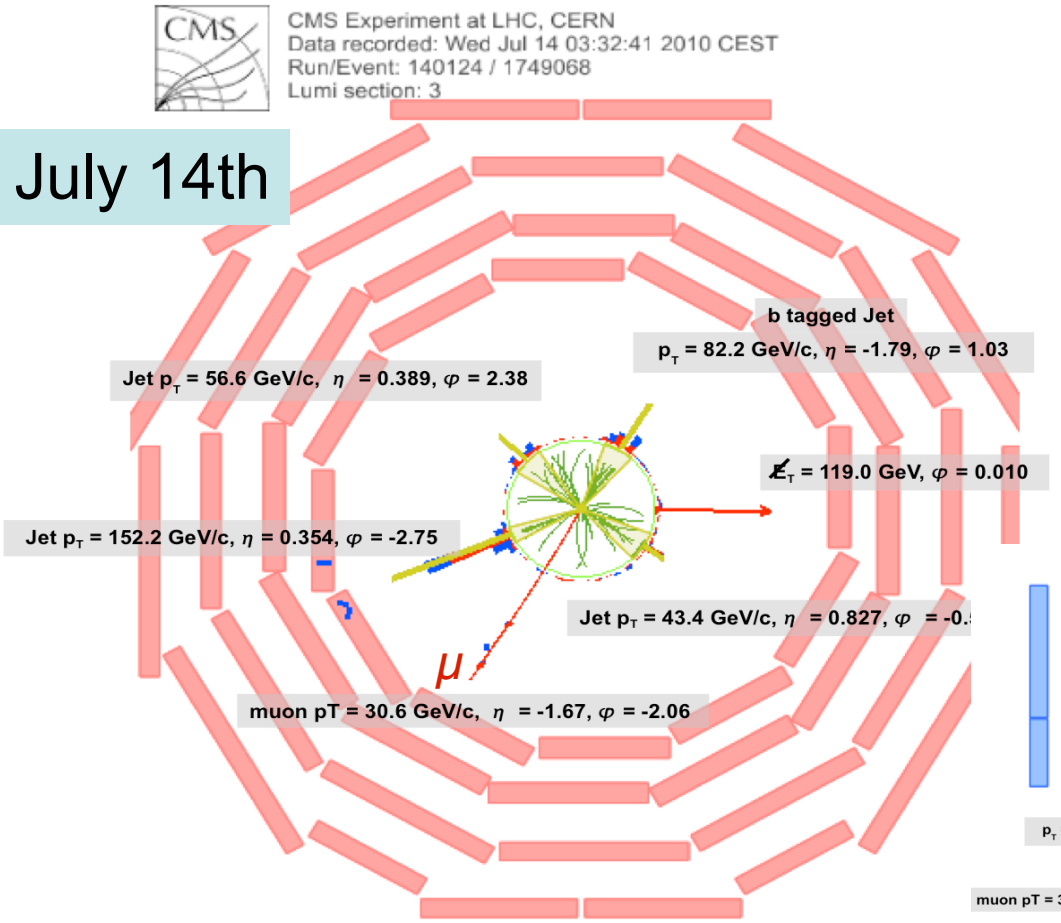
Observed: 4 events

Expected: 3.3 top events

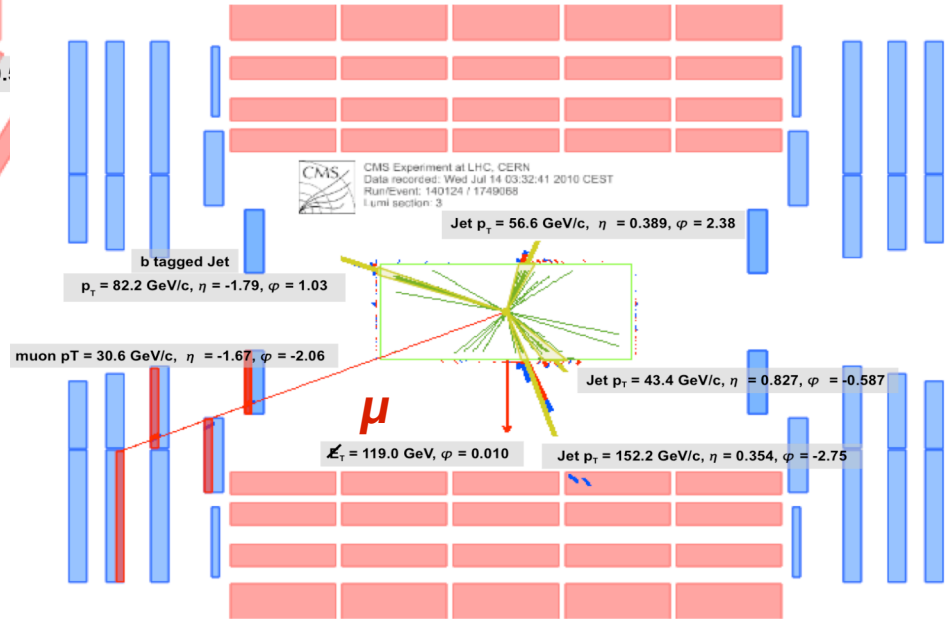


Top signal region

Event display of a “golden” μ+jets event



Event passes all selection cuts
1 high-momentum muon
significant MET > 100GeV
m_T(W) = 104 GeV/c^2
4 high-p_T jets,
one of which with good *b*-tag



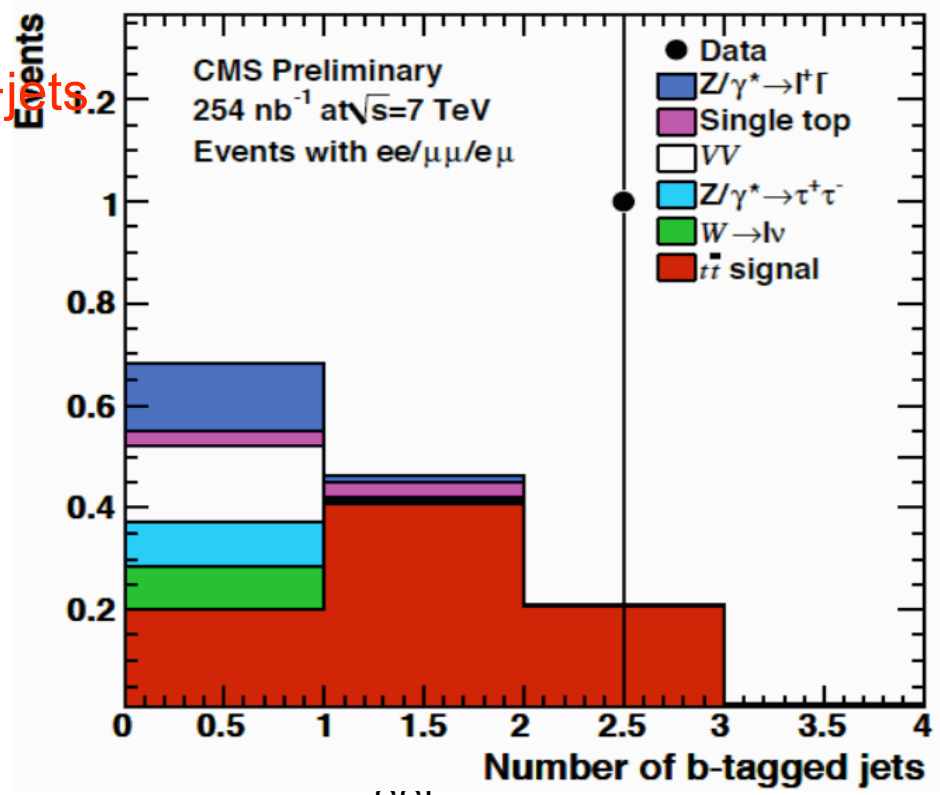
reconst. top mass around 210 GeV/c^2

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

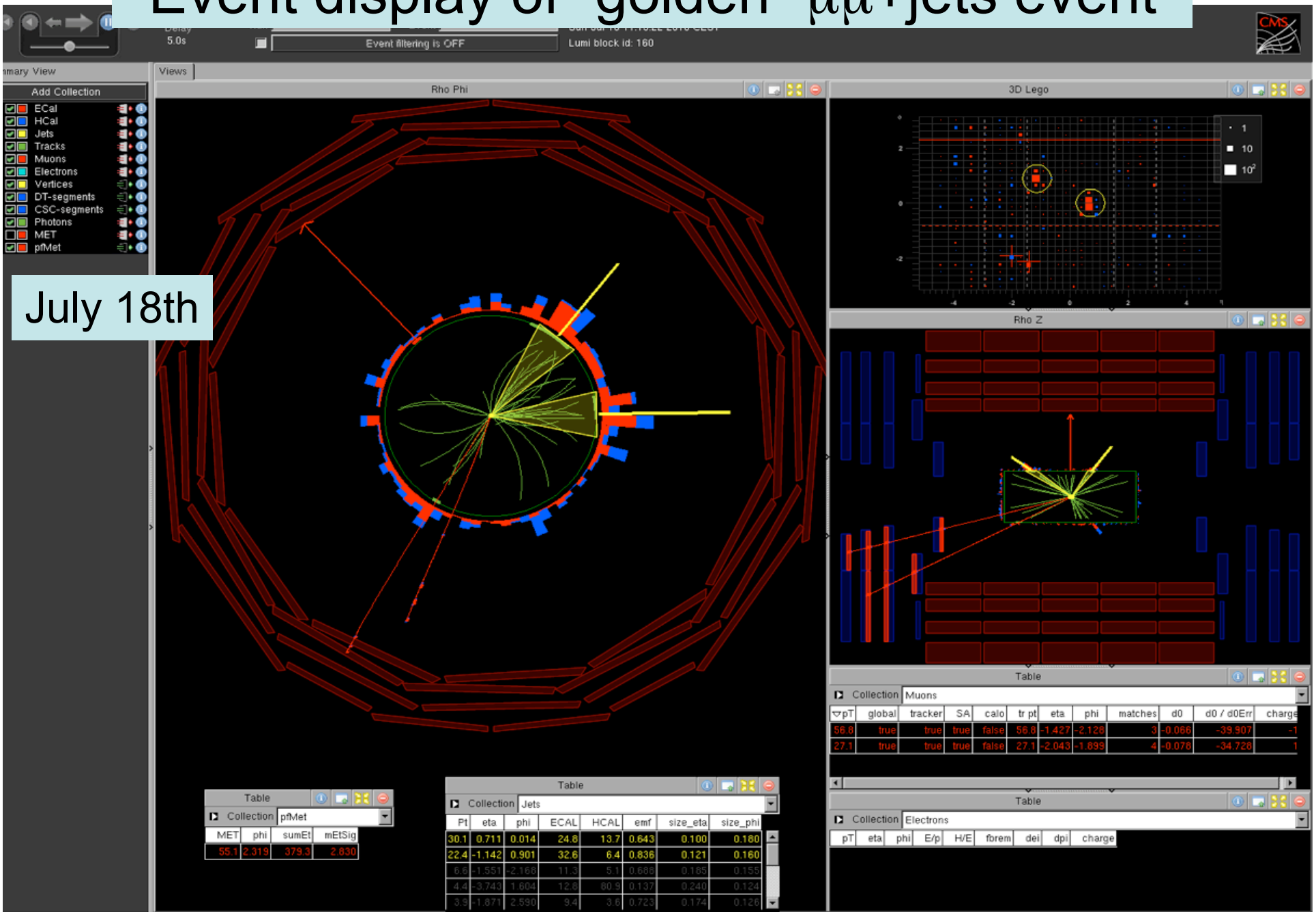
Dilepton Channel

- Event selection:
  - 2 isolated, prompt, oppositely charged, central muons or electrons p_T>20 GeV, ME_T>30 GeV, at least 2 central jets p_T>20 GeV, Z veto

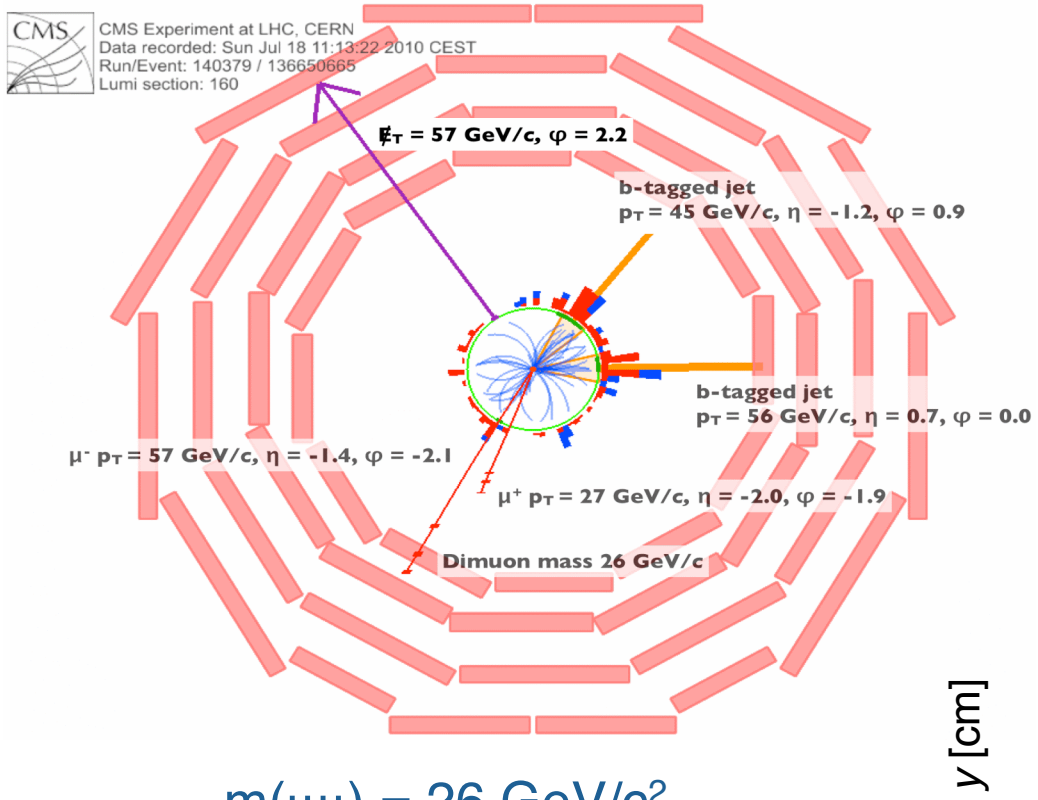
ee+jets/μe+jets/μμ+jets



Event display of “golden” μμ+jets event



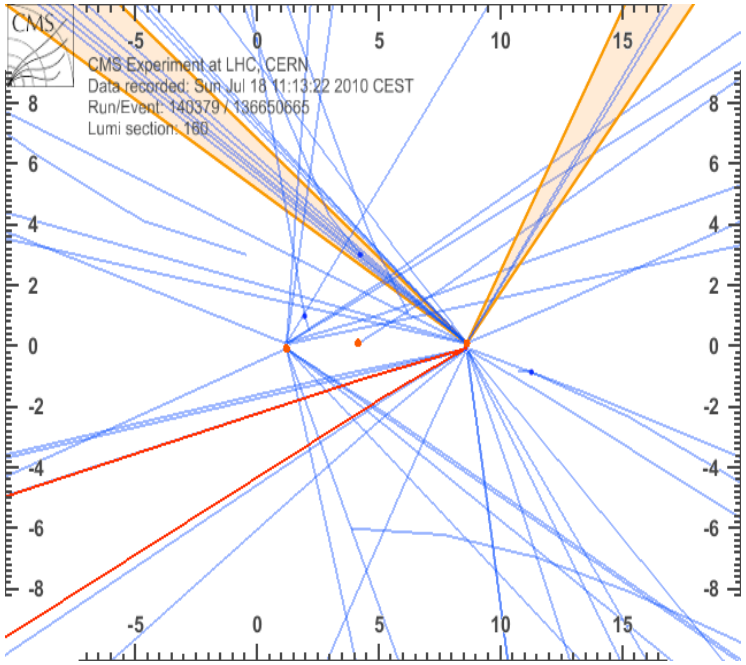
Golden μμ+jets event..cont'd



$m(\mu\mu) = 26\ GeV/c^2$

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

Jets & muons originate from same primary vertex



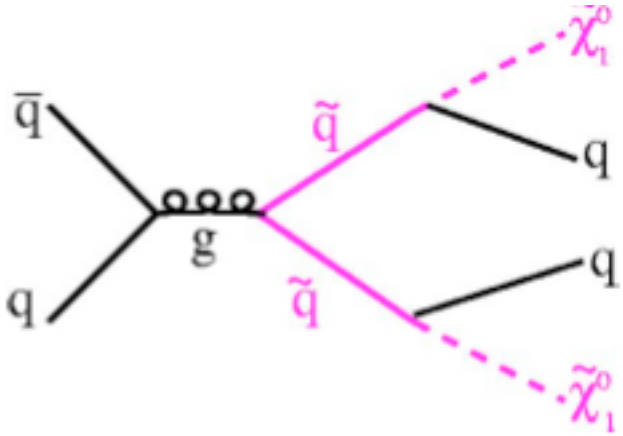
Preliminarily reconstr. mass is in the range 160–220 GeV/c^2 (consistent with m_{top})

Outline of the talk

1. The basic objects, and CMS reconstruction performance with the early data
   - Tracks, Jets, b-tags
   - missing energy “MET”
   - Muons, electrons and photons

2. Standard Candles and Early Physics results
   - W,Z
   - QCD processes
   - Top
   - Early searches

3. Outlook
   - Higgs
   - New Physics: SUSY,..

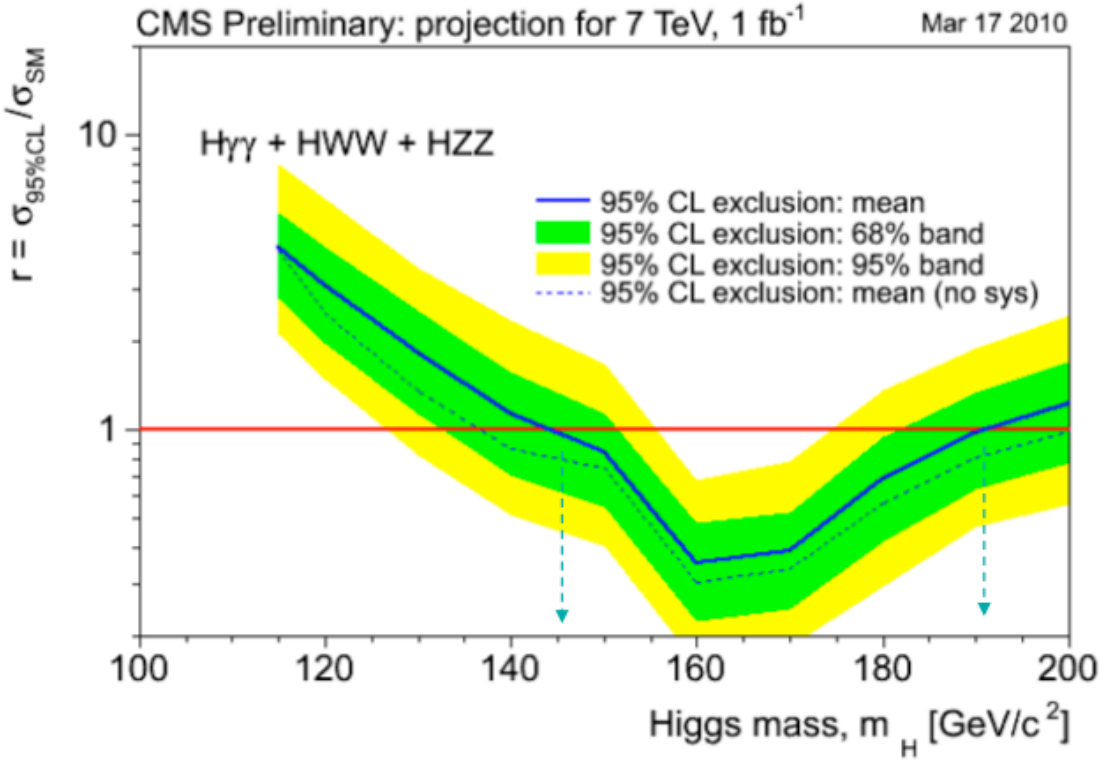


Outlook

- Higgs detection
  - SM H->$\gamma\gamma$, WW, ZZ
  - Higgs production associated with b or t quarks
- New Physics
  - SUSY, UED, LH,… detected in signatures with jets, leptons, photons and ME_T
    - ME_T from undetected lightest new particle, the dark matter candidate
  - Many other channels, e.g. resonances, W'Z',top,QCD sector, B_s…
- Have shown performance and calibration of the important ingredients for the CMS discovery program: jets, MET, leptons, btags

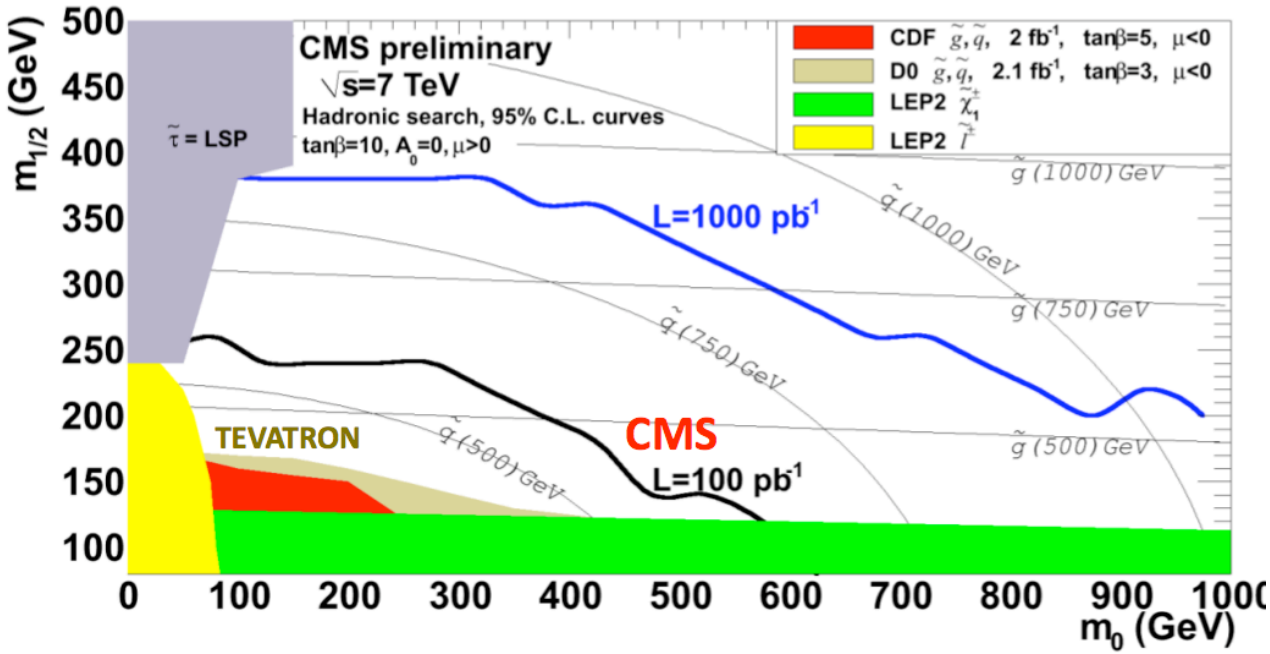
SM Higgs Prospects

- SM Higgs: combination of $\gamma\gamma$+WW+ZZ search channels
- With 7TeV,100pb^{-1} by Nov and 1fb^{-1} by end of 2011
  - expected 95% CL exclusion range: 145-190 GeV
  - Conservative estimate, based on $\gamma\gamma$+WW+ZZ channels only



Preparing for SUSY search

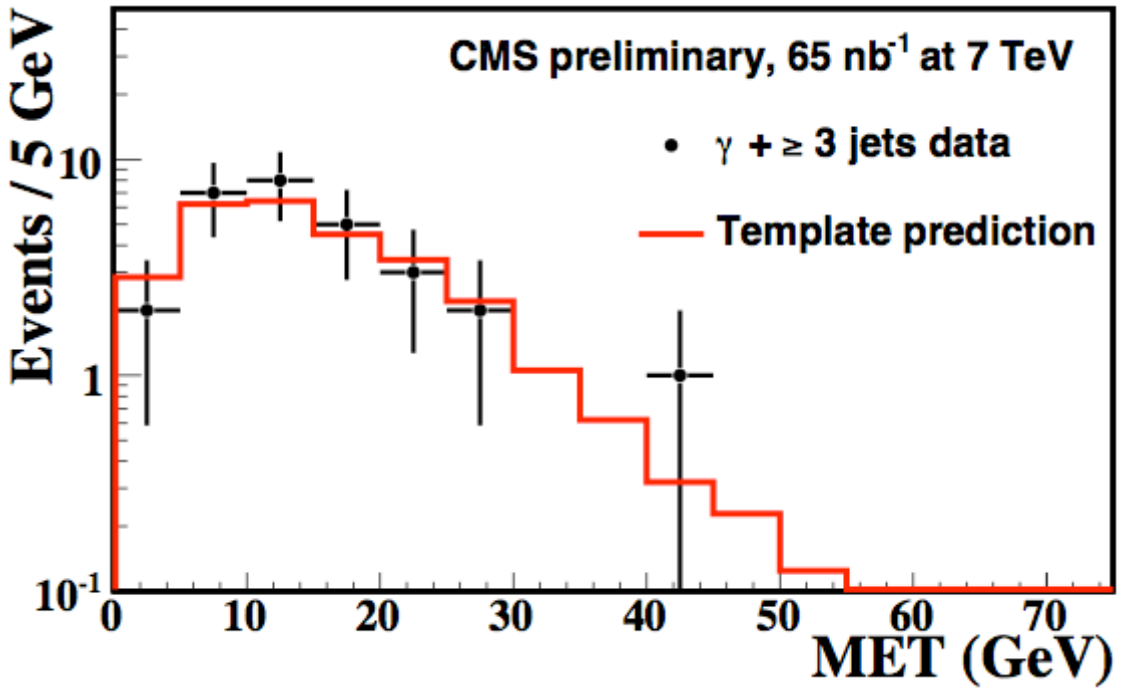
- Example: jets+ME_T signature ("hadronic search")
- Typically require ME_T>150 GeV
  - QCD multijet + mismeasured MET is not main background, but poorly known (and large) cross section needs to be estimated from data
- With current data set don't expect to have any sensitivity to SUSY, used for bkg testing



Example: ME_T shape prediction with templates

Form templates from data to model (true and fake) ME_T, using Jet and γ+jet triggers

- Test template prediction in region relevant for SUSY searches

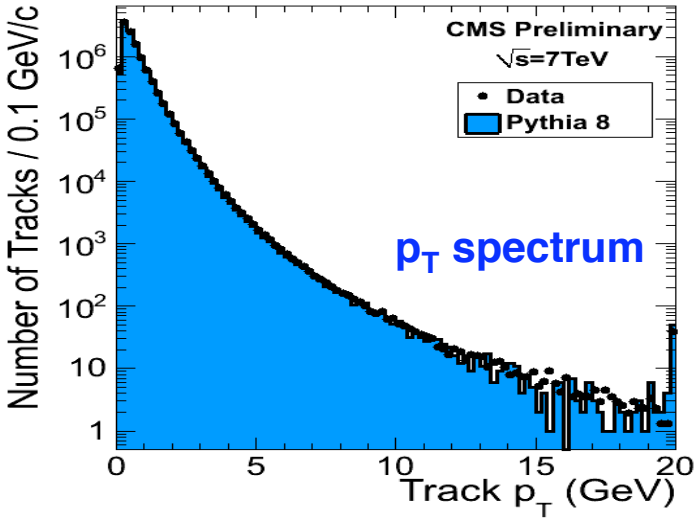


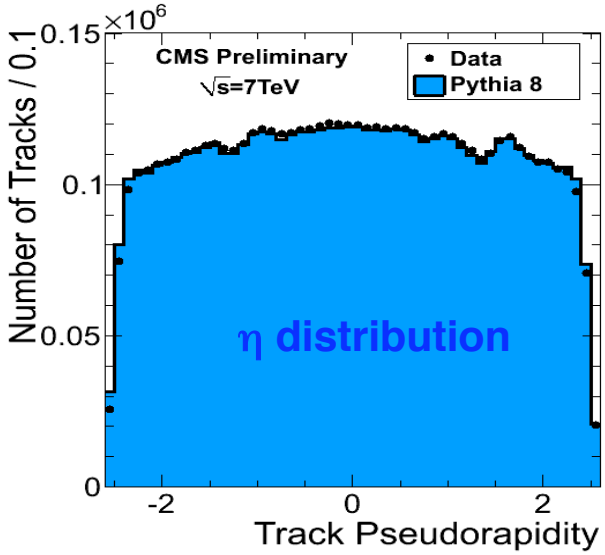
Summary

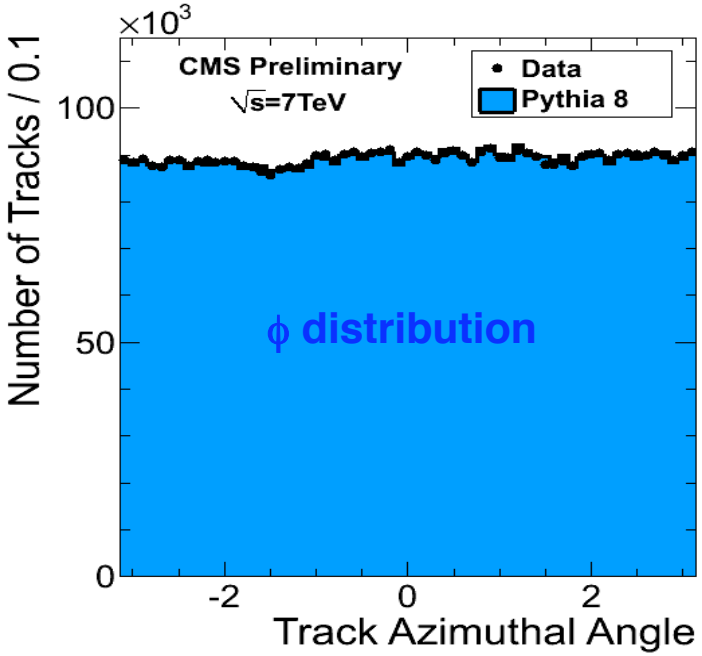
- CMS is taking and analyzing data at 7 TeV
  - 9 years after CMS construction began
  - Combined effort of thousands of people
- First results with up to 0.25pb^{-1} show good performance of all sub-detectors, good control over standard candle processes and the first European top quarks!
  - Impressive turn around- data was taken only few weeks ago
- Ready for our discovery program!

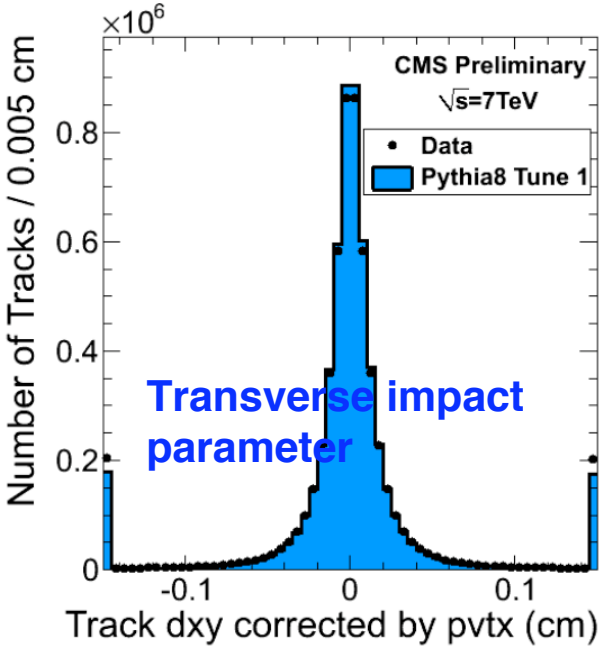
- Backup Material

Tracker Performance



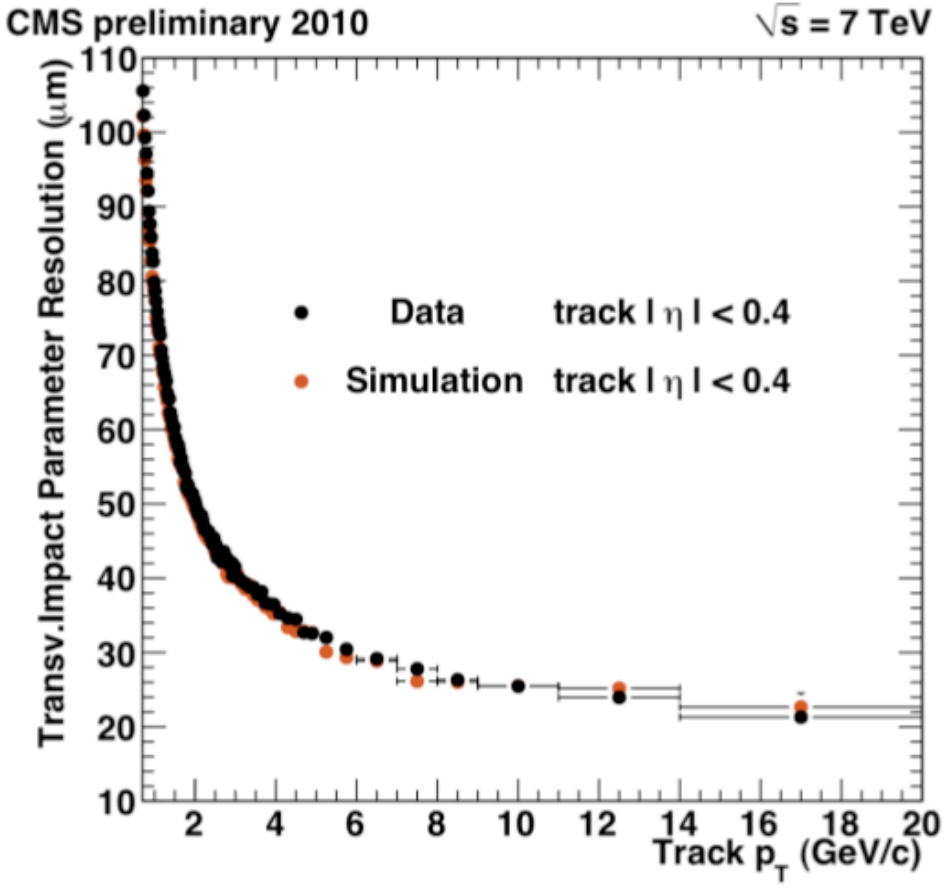






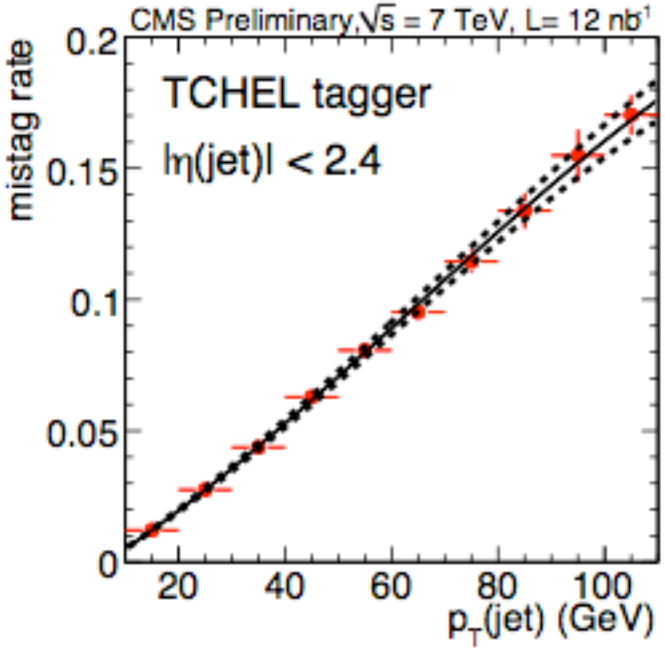
Impact parameter Resolution

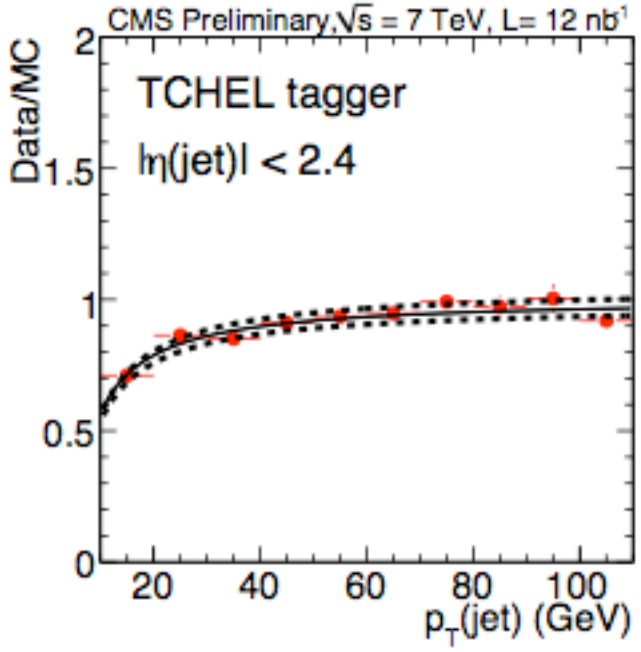
- Good agreement between data and MC for wide range of track p_T



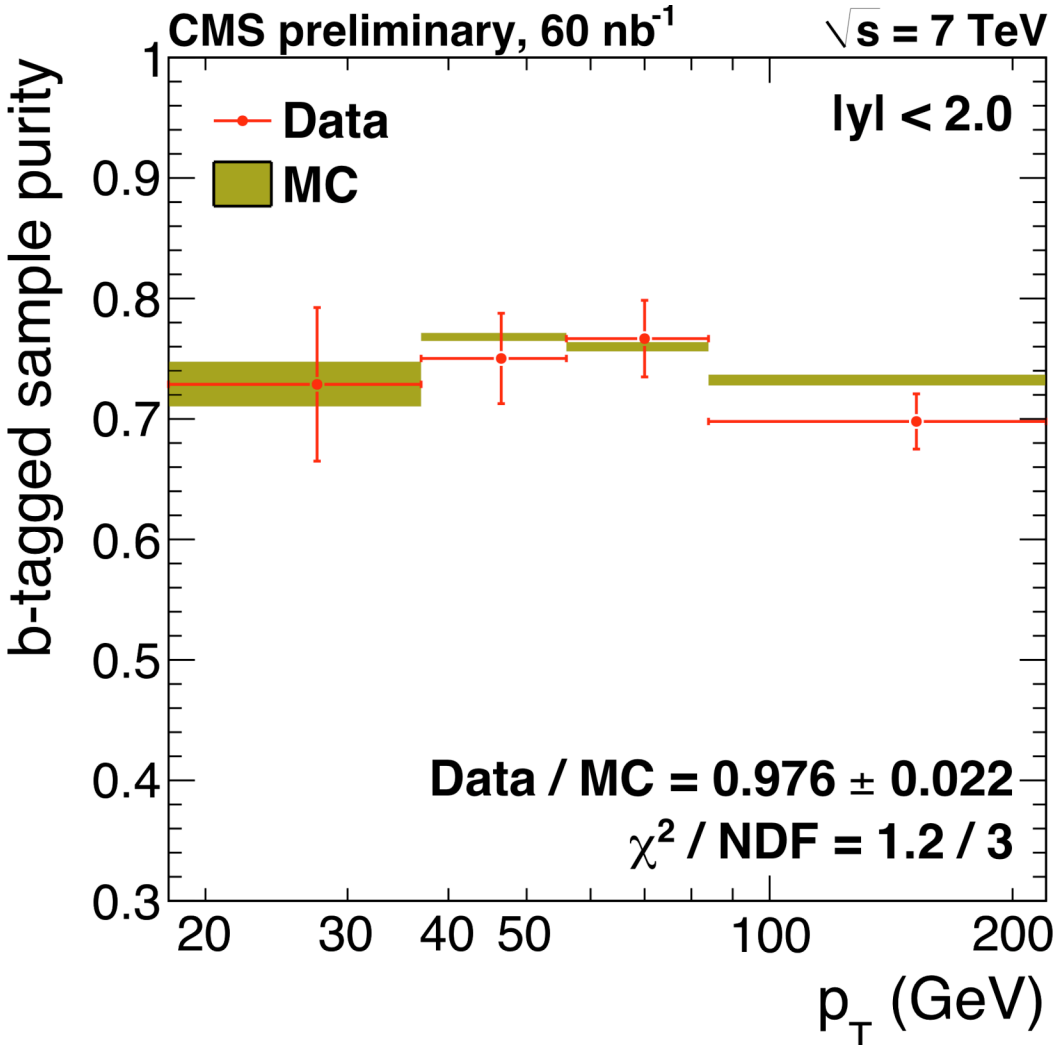
B tag performance: mistag

- Mistag rate estimated from data using “negative tags”
- Examine jets that have a secondary vertex reconstructed behind the IP
  - Indicates rate of misreconstructed b-jets



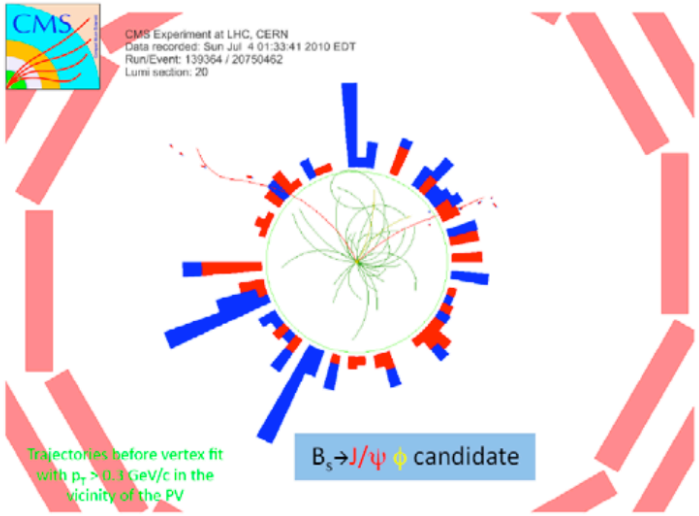


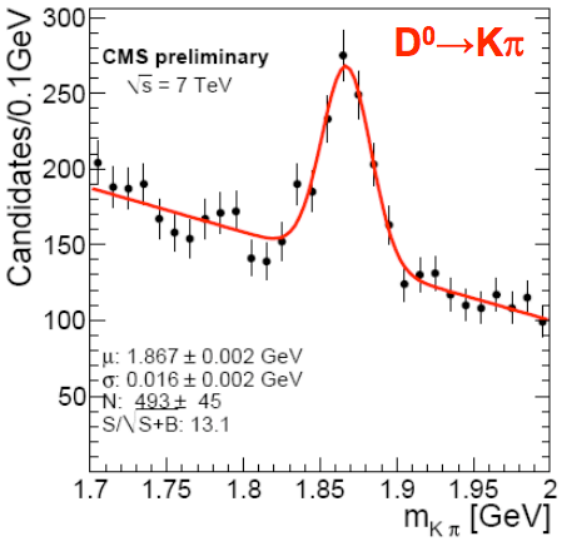
B-tag purity for incl b-jet study

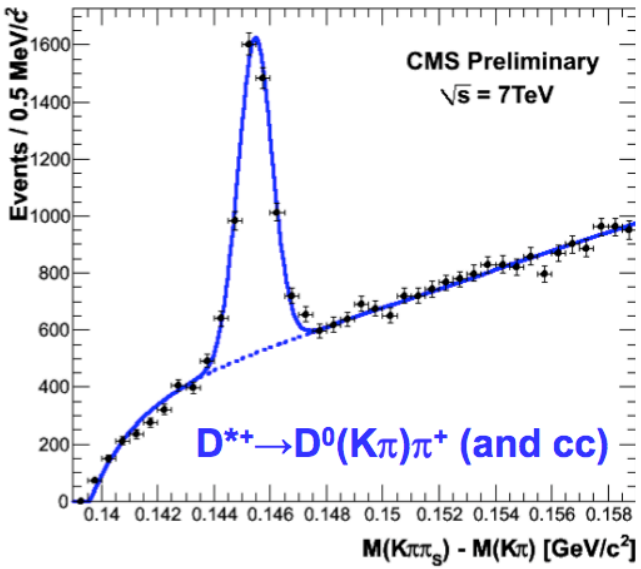


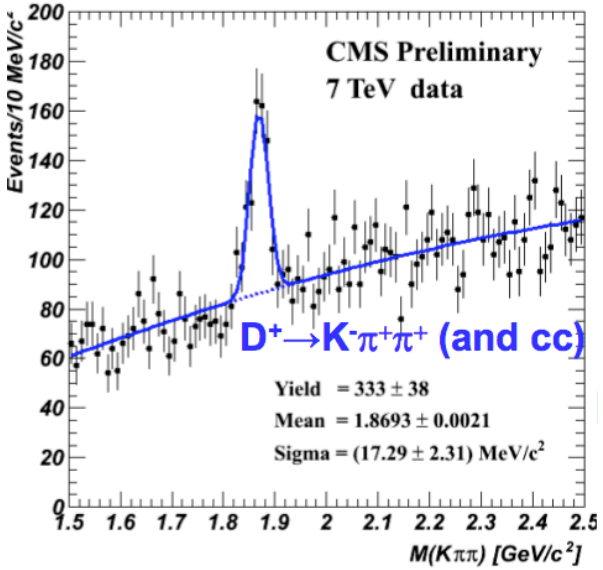
Exclusive B physics

- First candidates for $B_s \rightarrow J/\psi\ \phi$

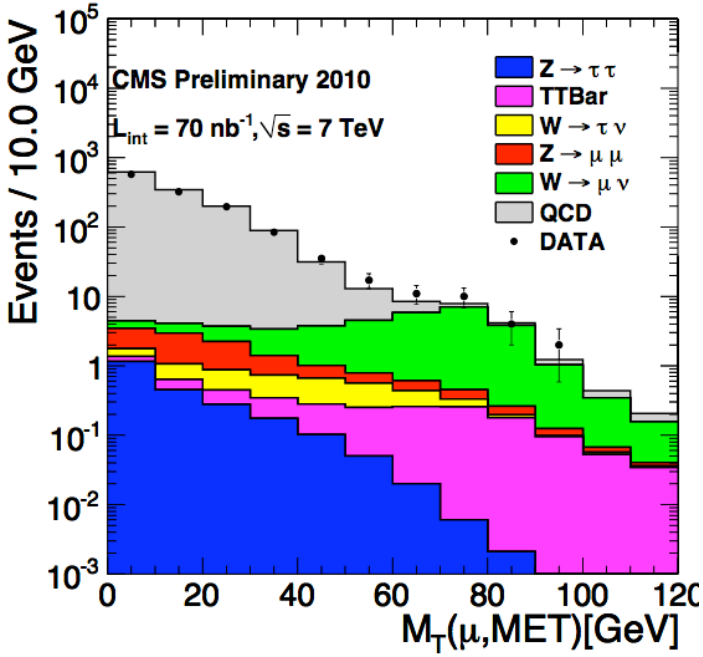


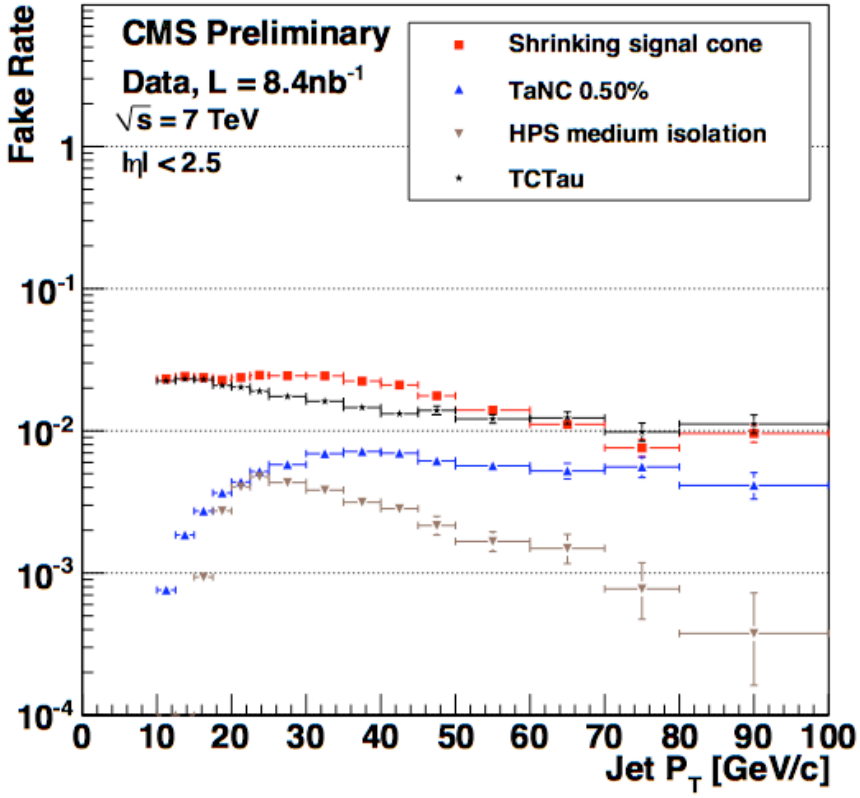




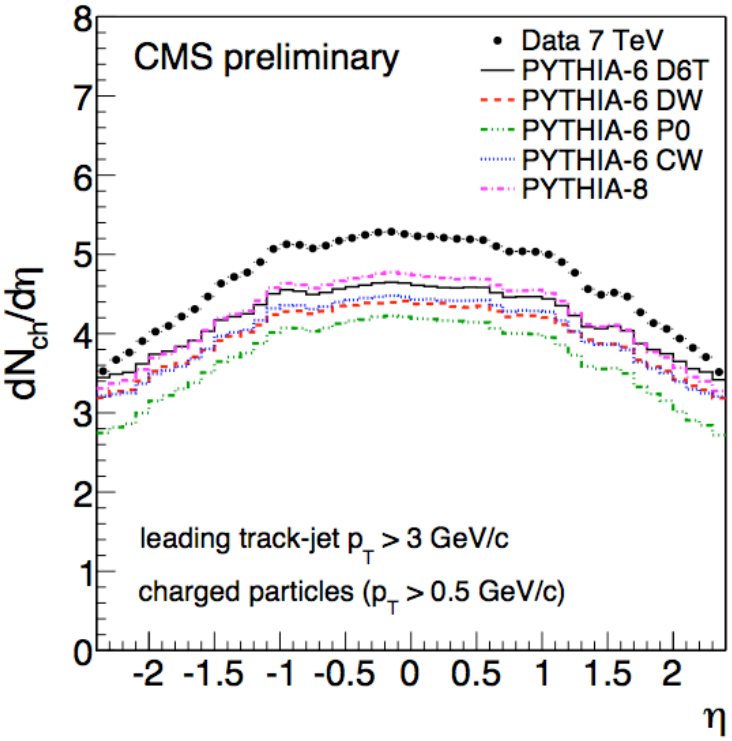


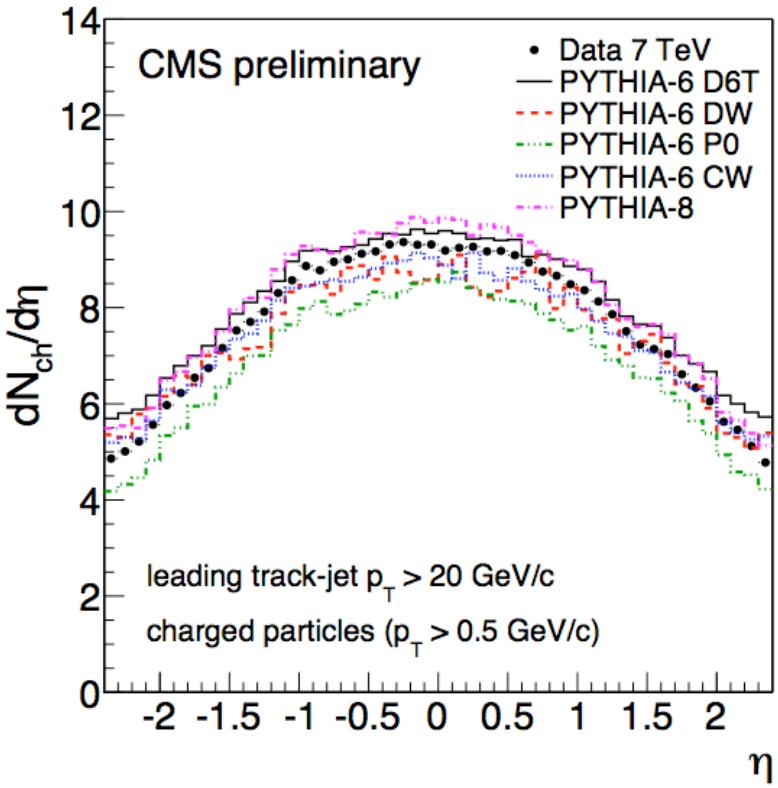
Tau identification





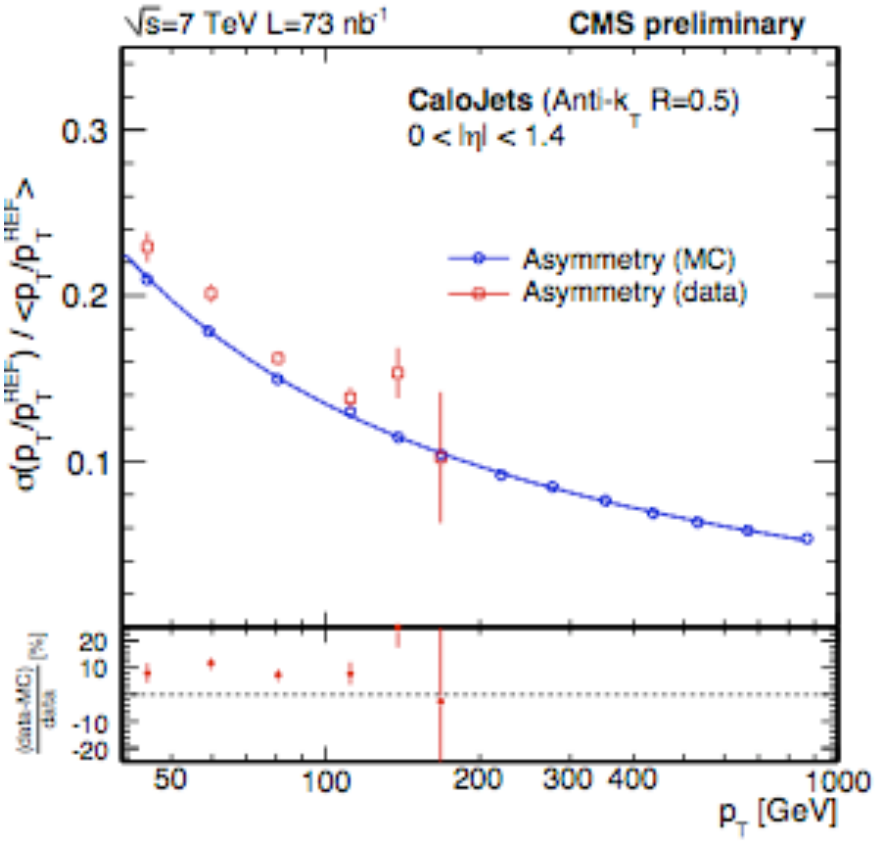
Charged track multiplicity





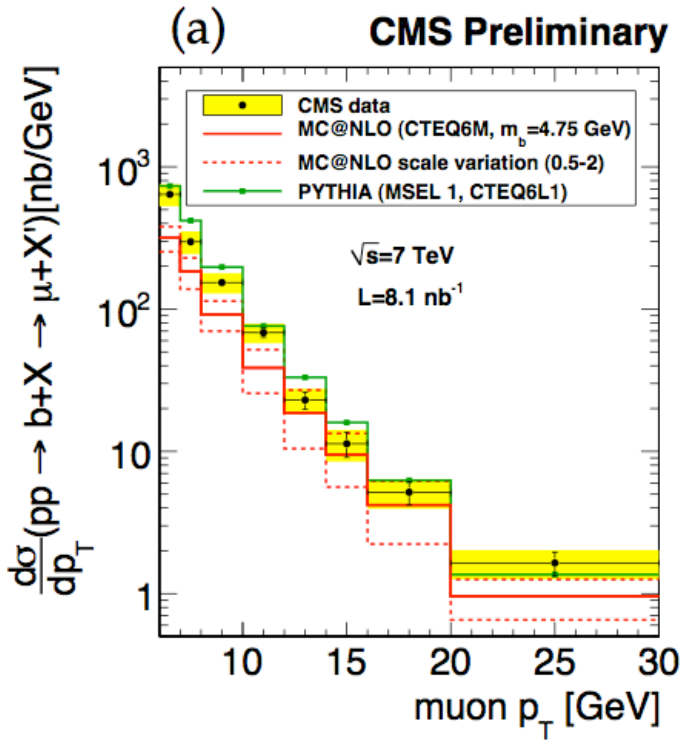
Jet p_T resolution

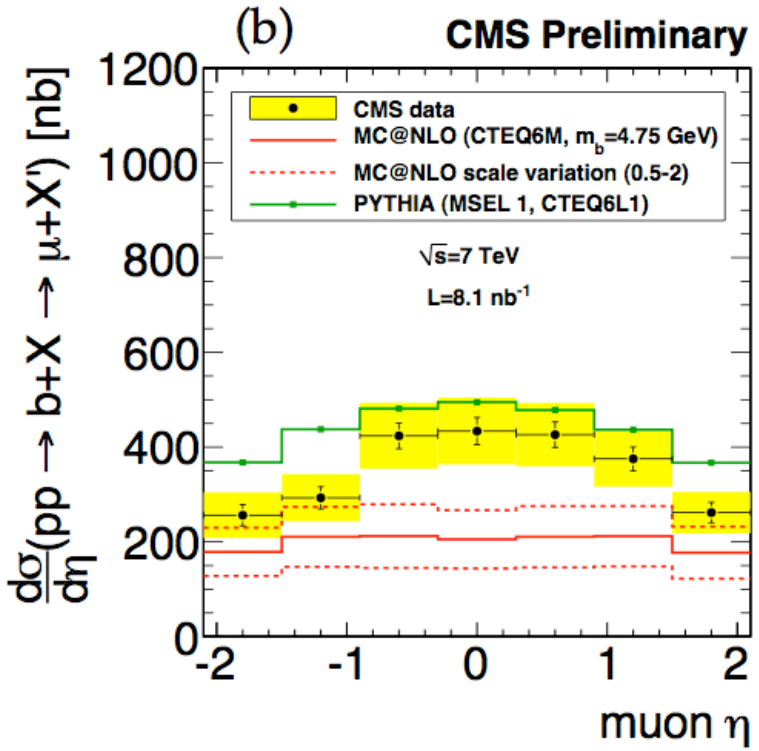
- Measure p_T asymmetry of the two leading jets in back-to-back dijet events



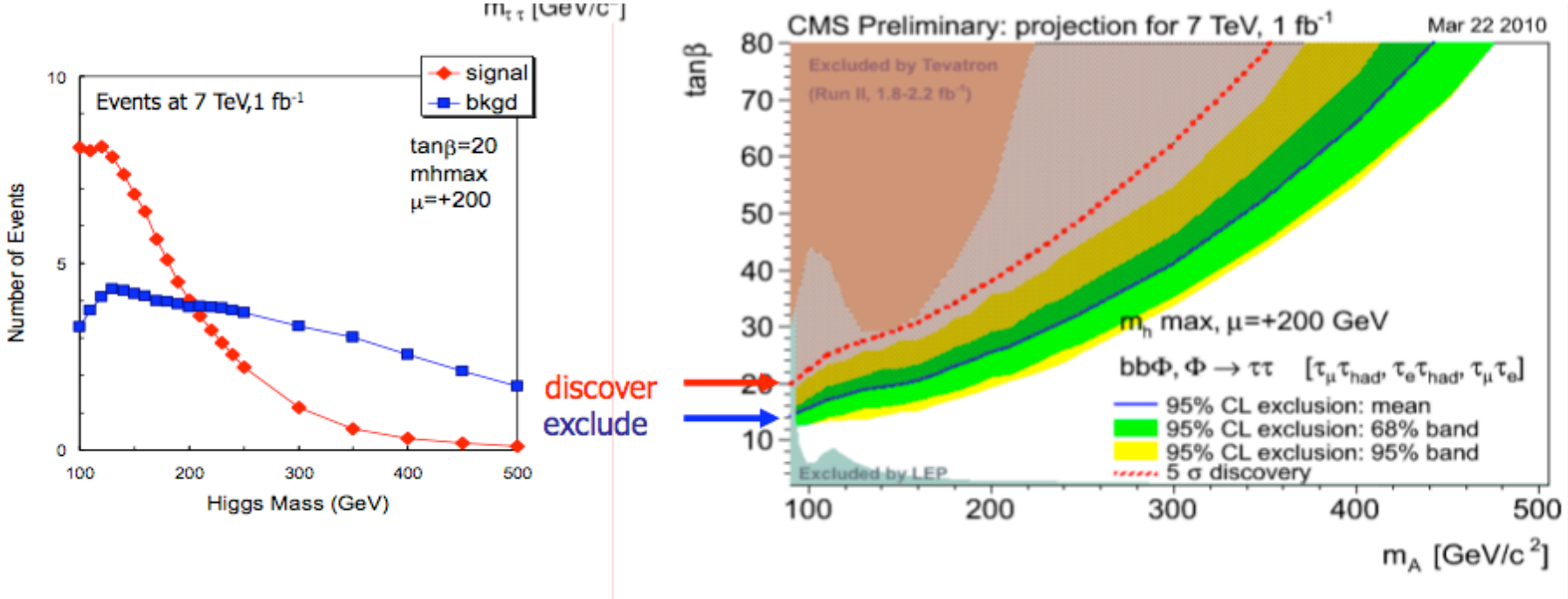
open b prod cross section

- Require presence of a muon from semileptonic B decay
- See discrepancy with MC@NLO in pseudorapidity distribution



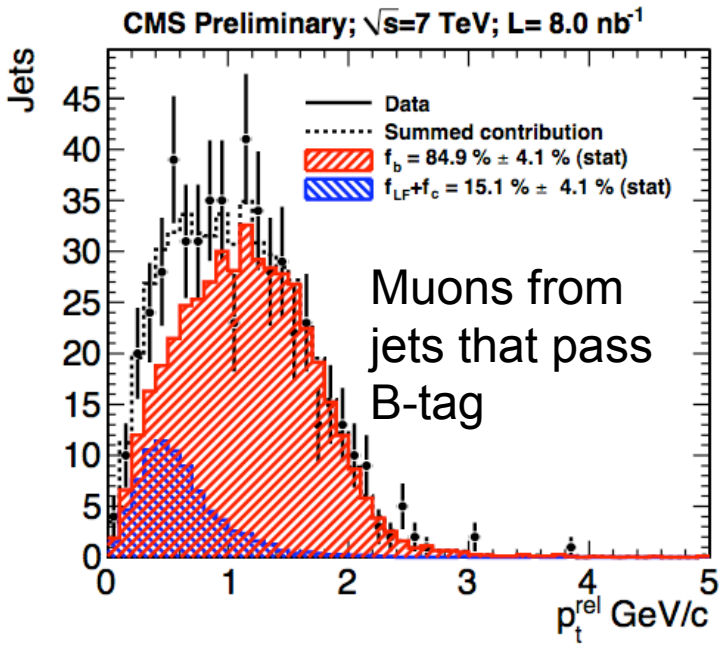


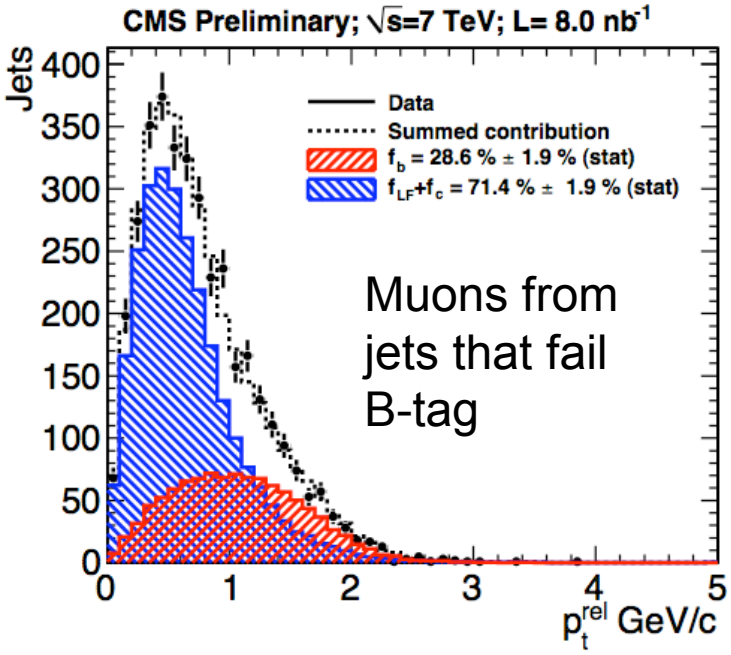
MSSM Higgs pp-->bbΦ, Φ-->ττ



B tag performance: efficiency

- efficiency is estimated from data using events with jets containing a muon
- Examine momentum of muon transverse to jet, p_t^{rel}
  - Muons from B have large p_t^{rel}
  - B fraction determined with template fits
  - Tagging efficiency calculated using b fraction and number of tagged





Trigger Performance

- Rates within 20% of expectation, smooth running and data delivery
- Optimal efficiency as measured with data

Example: Photon trigger
L1 & HLT Photon effiency wrt
RECO SuperCluster:
Barrel & Endcaps
nearly 100% efficient.