Early Physics Results from CMS

F. Ronga (ETH Zurich)
on behalf of the Swiss CMS community

CHIPP annual plenary meeting – August 23 2010

Outline

- Swiss contributions to CMS
- Operations and Performance of the CMS detector
  - **electrons, jets, MET, b-tagging**
- First results from CMS
  - **QCD Physics**
  - **B Physics**
  - **EWK Physics**
  - **“Exotica”**
  - **Supersymmetry**

With an emphasis on areas contributed to by Swiss institutions

Switzerland & CMS

The Swiss CMS community

ETH Zurich

G.Dissertori, **C.Grab**, **F.Pauss**, B.Betev, Ch.Casella, S.Cittolin, M.Dittmar, A.Hervé, D.Luckey, W.Lustermann, P.Meridiani, F.Moortgat, F.Nessi-Tedaldi, L.Pape, A.Rizzi, F.Ronga, L.Sala, M.-C.Sawley, A.Thea, K.Theofilatos, D.Treille, J.Weng, P. Bortignon, L.Caminada (also PSI), Z.Chen, J.Eugster, C.Marchica (also PSI), P.Milenovic, C.Nägeli (also PSI), P.Nef, T.Punz, A.-K.Sanchez, B.Stieger, M.Weber, L.Wehrli, D.Da Silva Calafiori, L.Djambazov, M.Dröge, G.Faber, H.P.von Gunten, U.Horisberger, C.Haller, O.Holme, W.Kästli, U.Röser, S.Zelepoukine

PSI Villigen

R.Horisberger, Q.Ingram, W.Bertl, K.Deiters, W.Erdmann, D.Feichtinger, H.-C.Kästli, D.Kotlinski, U.Langenegger, D.Renker, T.Rohe, A.Starodumov, F.Meier, J.Sibille, B.Meier, S.Streuli

University of Zurich

C.Amsler, V.Chiochia, E.Aguiló, S.De Visscher, P.Otiougova, C.Regenfus, P.Robmann, A.Schmidt, H.Snoek, J.Storey, C.Favaro, M.Ivova Rikova, A.Jaeger, B.Millan Mejias, T.Rommerskirchen, D.Tsirigkas, L.Wilke (also PSI), J.Rochet, S.Steiner

44	Physicists
22	PhD students
15	Engineers/Technicians
81	Total

The Swiss CMS community

ETH Zurich

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University of Zurich

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Talks at CHIPP workshop next week

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Analysis activities: overview

N.B. Only listing activities linked to ICHEP results

- QCD [ETH,UZH]
  - **p_t and η of charged hadrons (0.9 and 2.36 TeV)**
  - **Inclusive Jet Spectrum**
  - **Hadronic event shapes** — M. Weber, ICHEP poster
- B (c) Physics [ETH, PSI, UZH]
  - **J/ψ production**
  - **Beauty production with muons**
  - **Inclusive b-jet production** — L. Caminada, ICHEP talk
- EWK [ETH,UZH]
  - **Inclusive W and Z production**
- "Exotica" [ETH]
  - **Heavy Stable Charged Particles**
- Supersymmetry [ETH, UZH]
  - **di- and multi-jet searches**
  - **dilepton searches**

Other contributions to Physics

- Coordination
  - **Physics coordinator**
    G. Dissertori (deputy) [ETH]
  - **E/gamma**
    P. Meridiani [ETH]
  - **b-tagging and vertexing**
    A. Rizzi [ETH]
  - **SUSY leptonic searches**
    F. Ronga [ETH]
  - **b-inclusive task force**
    V. Chiochia [UZH]
  - **b-tagging commissioning**
    A. Schmidt [UZH]
  - **Jet/MET DQM**
    J. Weng [ETH]

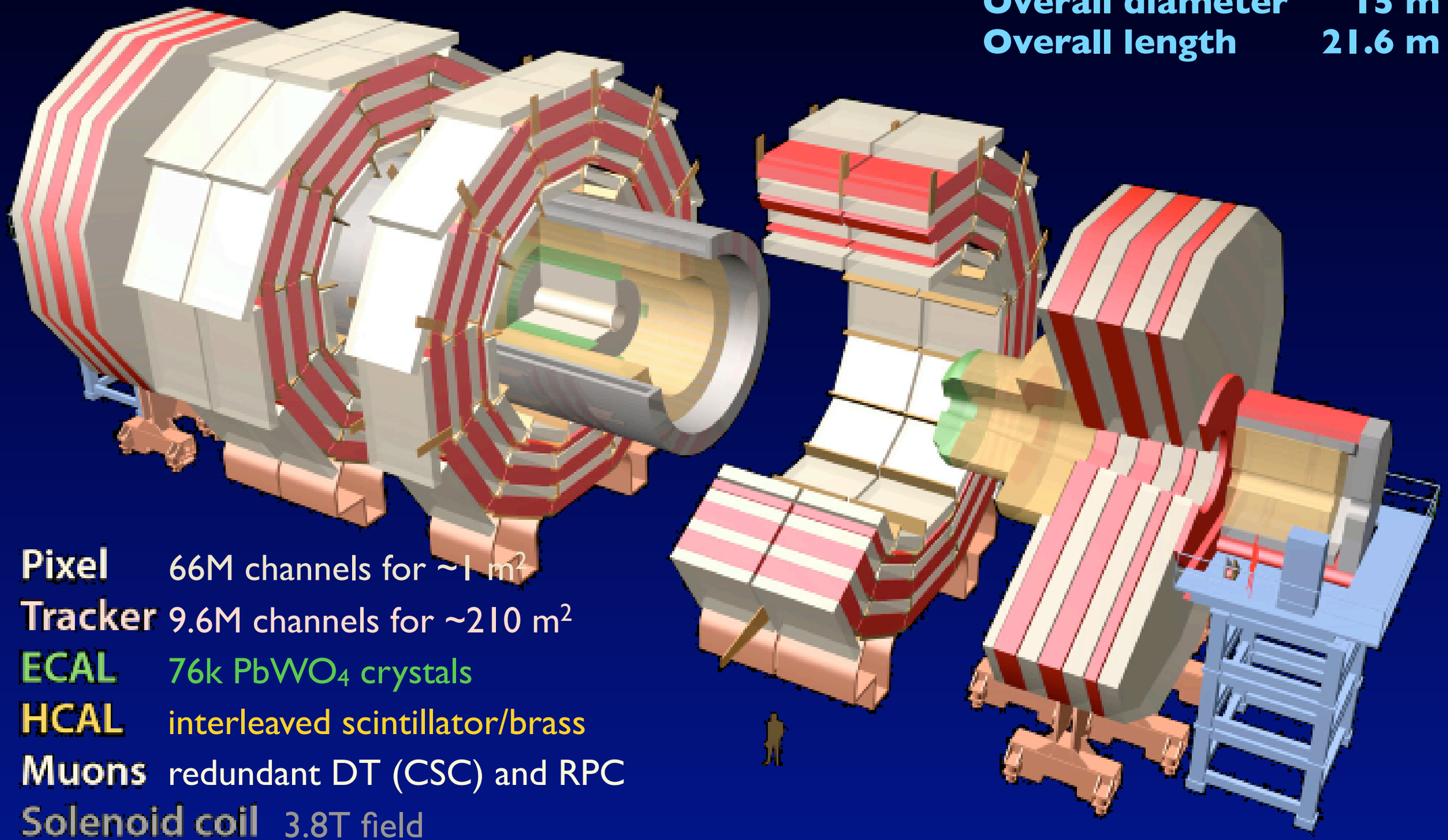
- Contributions to Physics "objects"
  - **Electrons and Photons [ETH]**
  - **Jets and missing energy [ETH]**
  - **b-tagging [ETH,UZH]**
  - **vertexing [ETH,PSI]**
  - **tracking [UZH]**
  - **tracker alignment [PSI,UZH]**
  - **ECAL calibration and cleaning [ETH]**

J. Weng ICHEP talk

CMS performance

The Compact Muon Solenoid

Total weight	**12500 t**
Overall diameter	**15 m**
Overall length	**21.6 m**

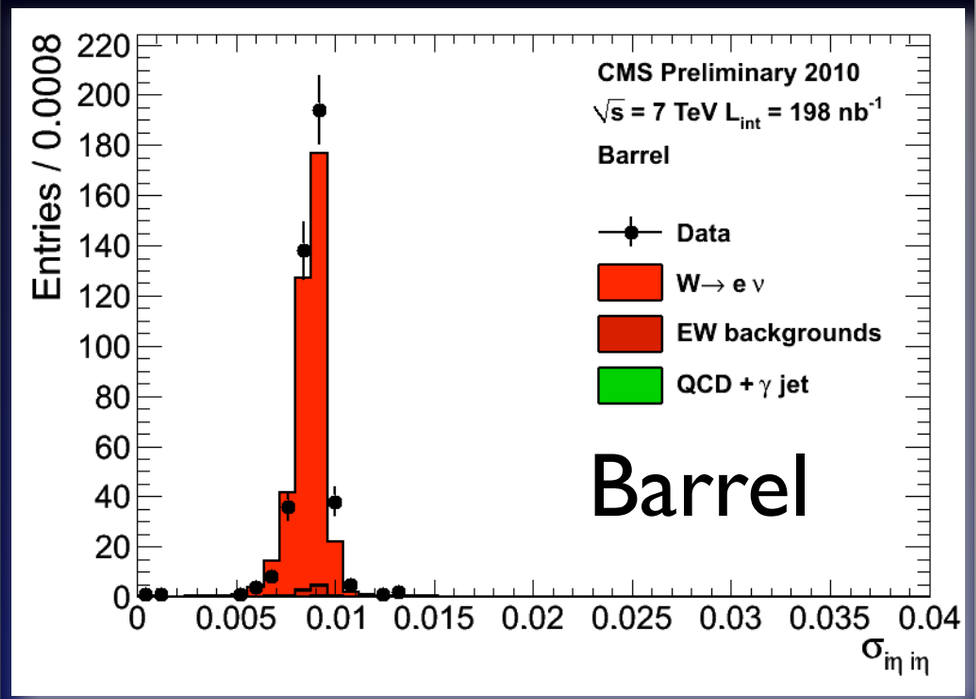


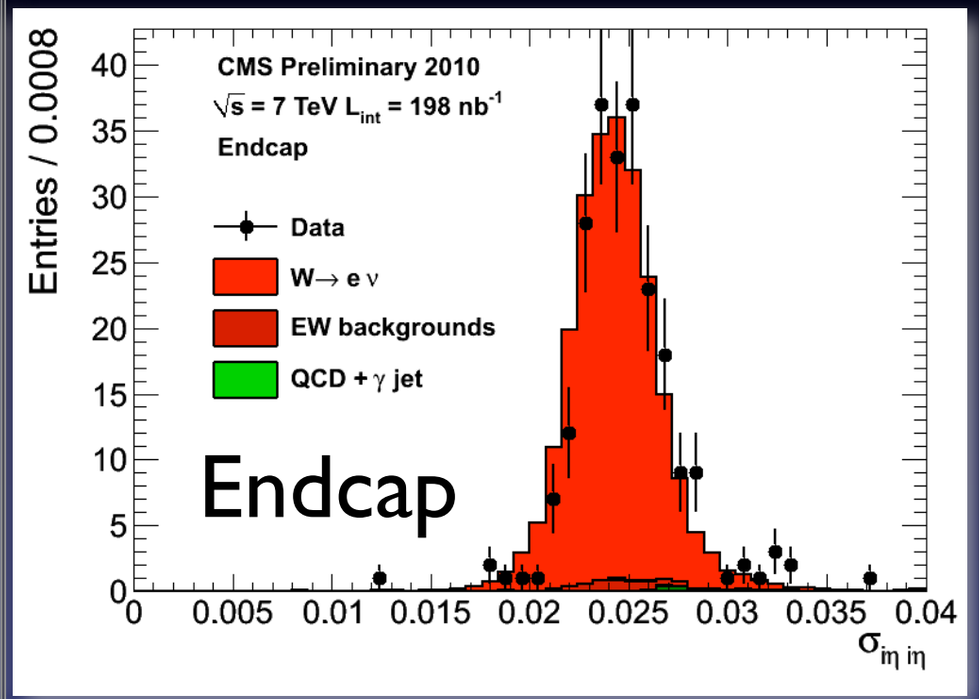
Pixel 66M channels for ~1 m^2
Tracker 9.6M channels for ~210 m^2
ECAL 76k $PbWO_4$ crystals
HCAL interleaved scintillator/brass
Muons redundant DT (CSC) and RPC
Solenoid coil 3.8T field

Electrons & photons [ETH]

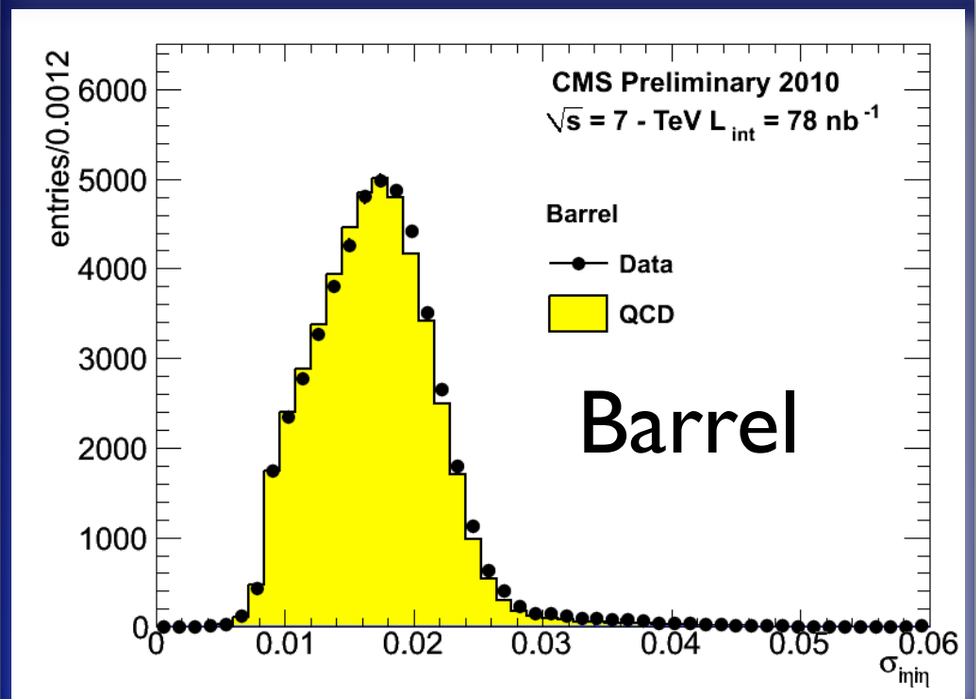
CMS DPS-2010/032

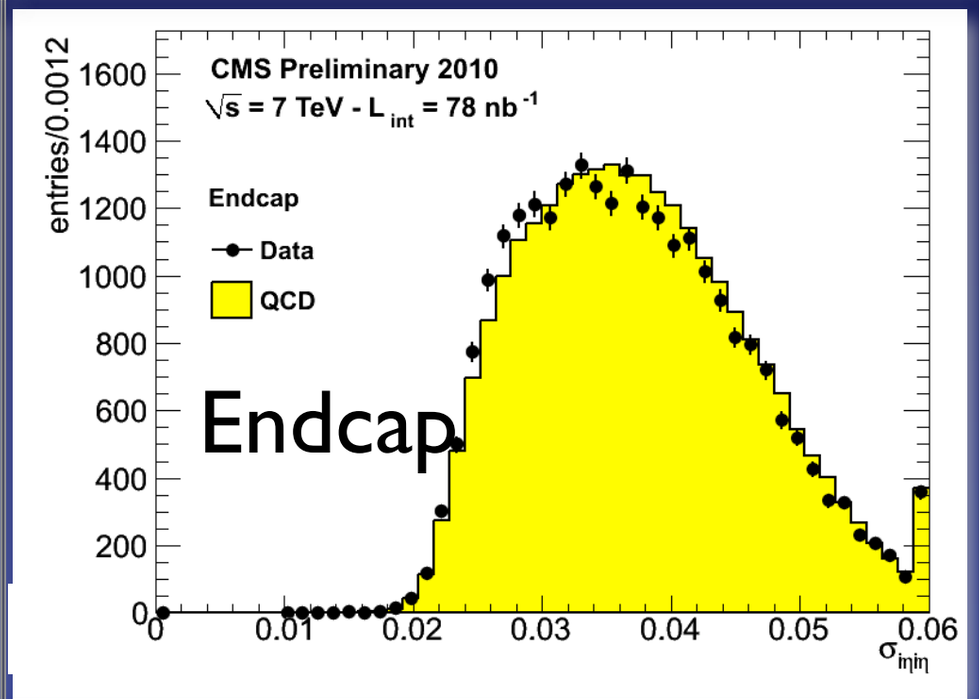
Signal-enriched





Background-enriched



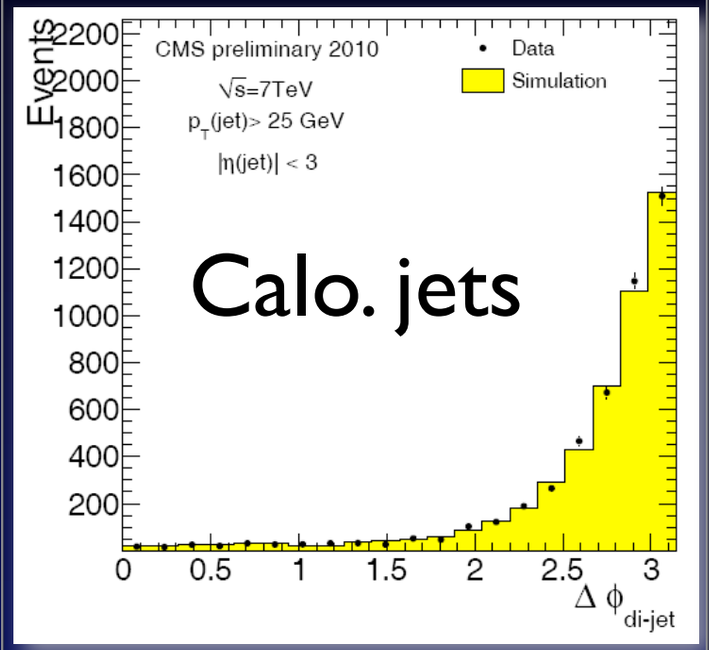


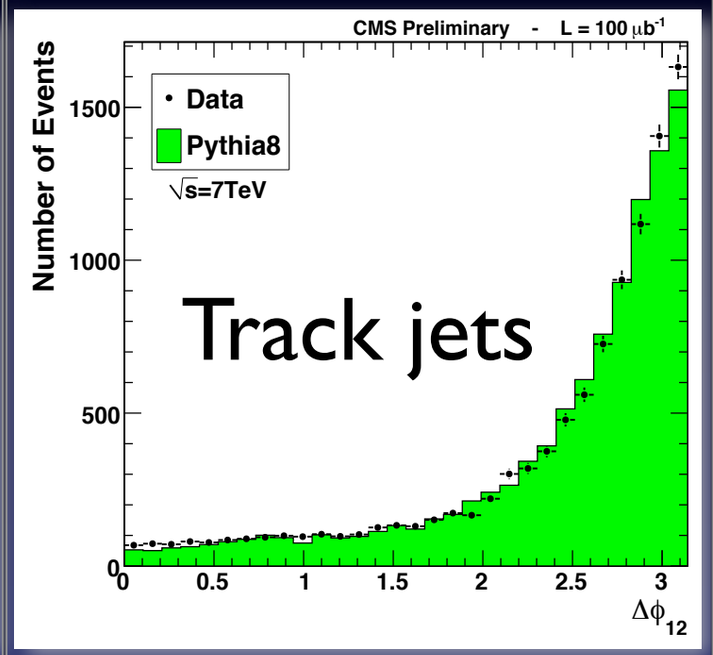
Shower shape variable (key electron identification variable)

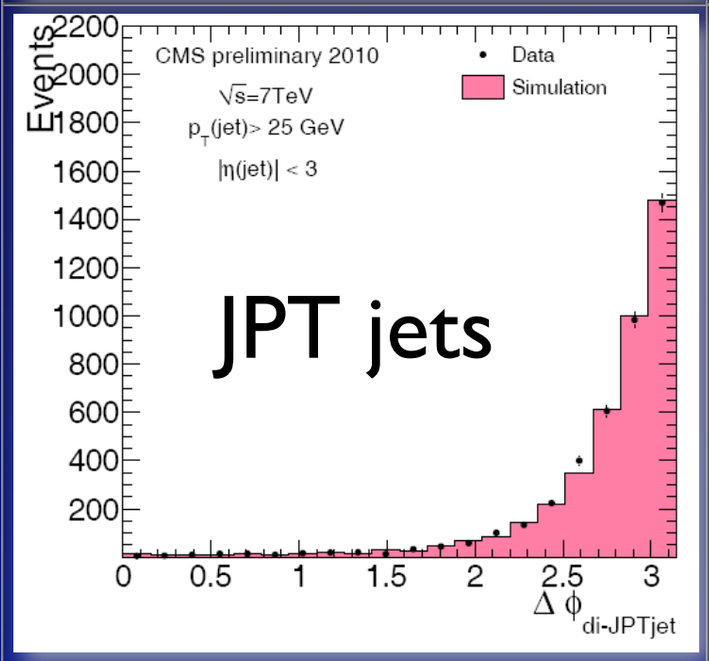
Jets [ETH]

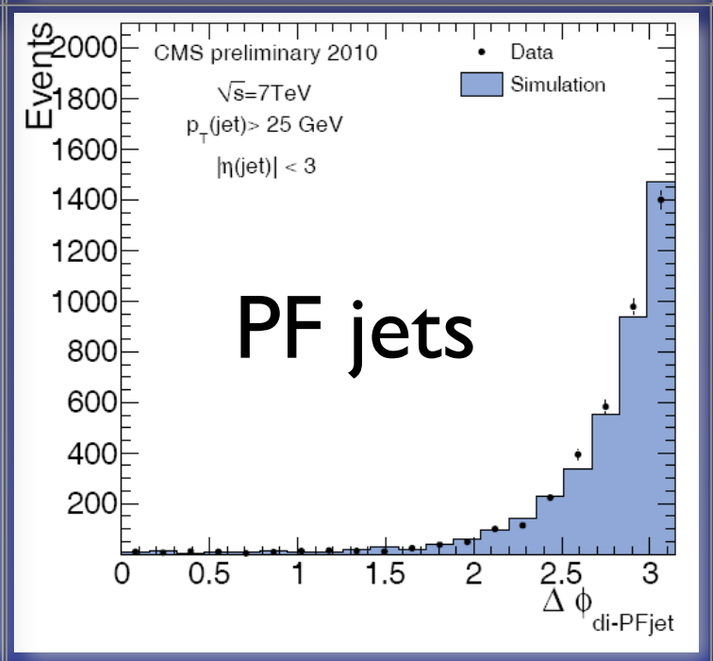
CMS PAS JME-10-003

- 4 types of jet reconstruction
  - **Calorimeter jets**
    - from calorimeter deposits only
  - **Track jets**
    - from tracks only
  - **Jet-plus-track jets**
    - subtract calorimeter response from CaloJet and replace with tracks
  - **Particle Flow (PF) jets**
    - cluster of particle flow objects: individual particle reconstruction by combining information from all sub-detectors
  - **Default clustering algo: anti-k_T with R=0.5**







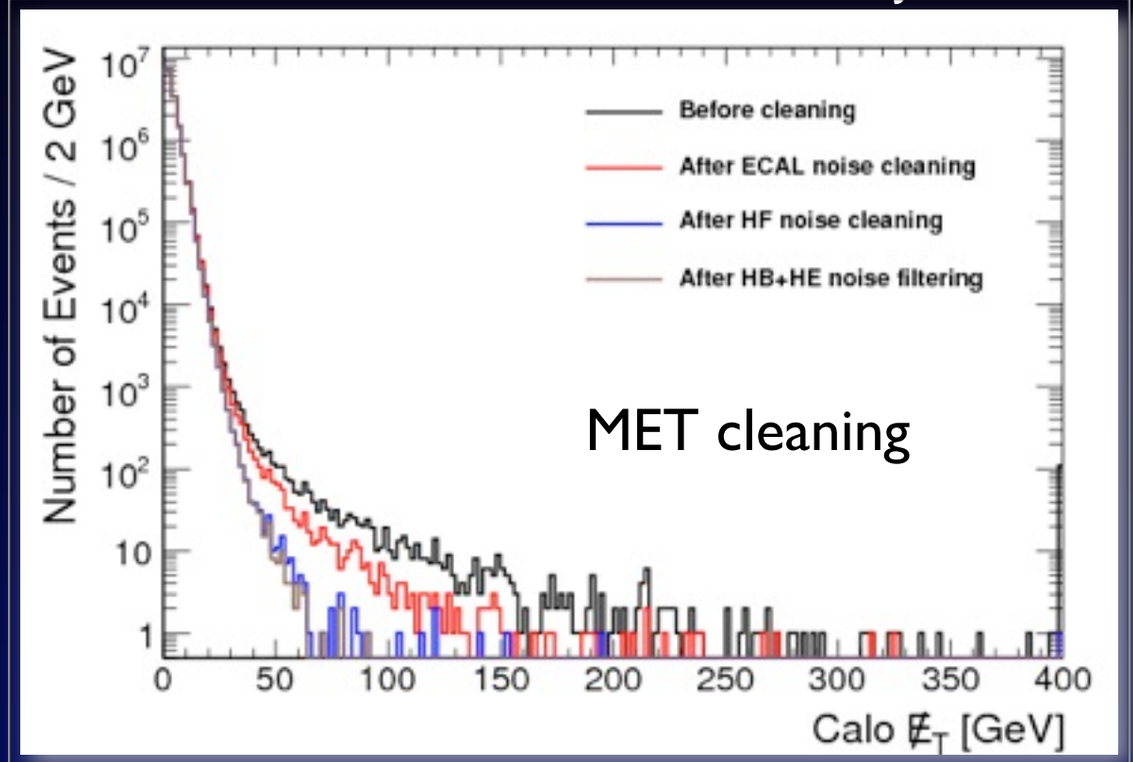


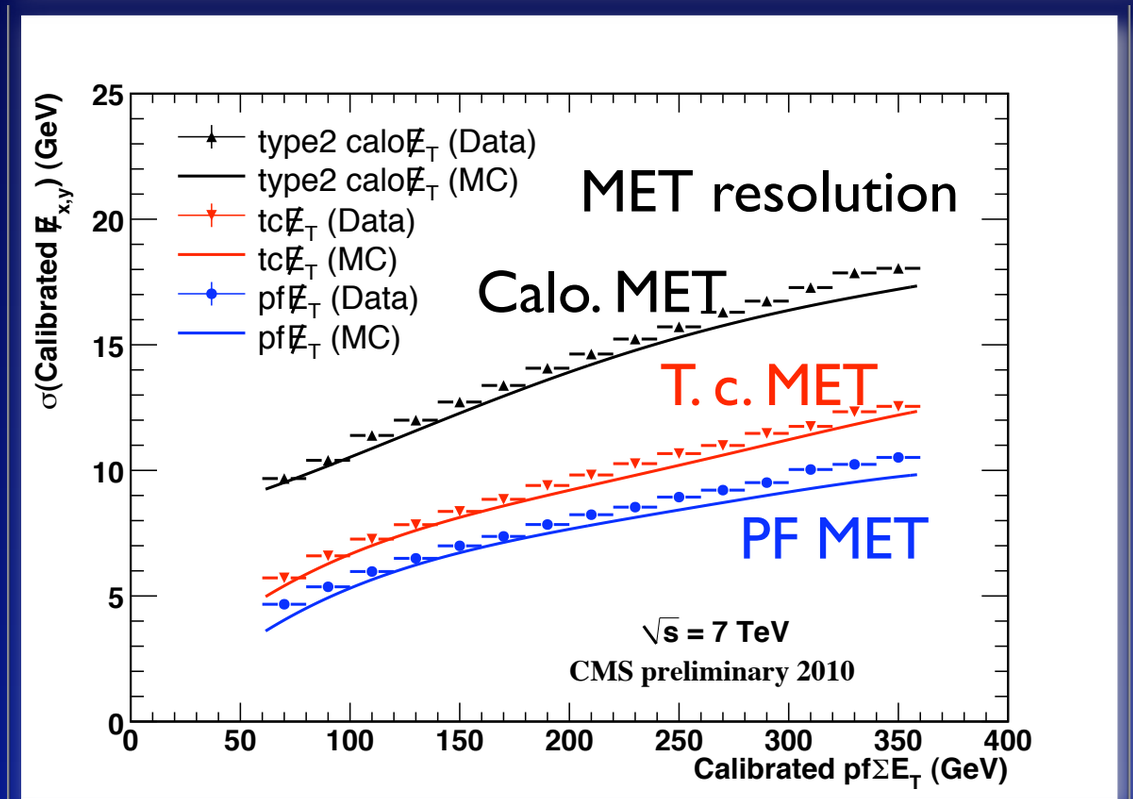
Δφ between two leading jets (used to select dijet sample)

Missing Transverse Energy [ETH]

CMS PAS JME-10-004

- Three types of MET
  - **roughly corresponding to calo. jet, JPT jet and PF jet reconstruction**
- No significant MET expected in minimum bias
  - **clean-up tails from noise**
    - crucial for many searches
    - very effective cleaning (tails compatible with MC)
- MET resolution vs PF $\Sigma(E_T)$
  - **much gain in combining sub-detector information**
    - as expected from MC

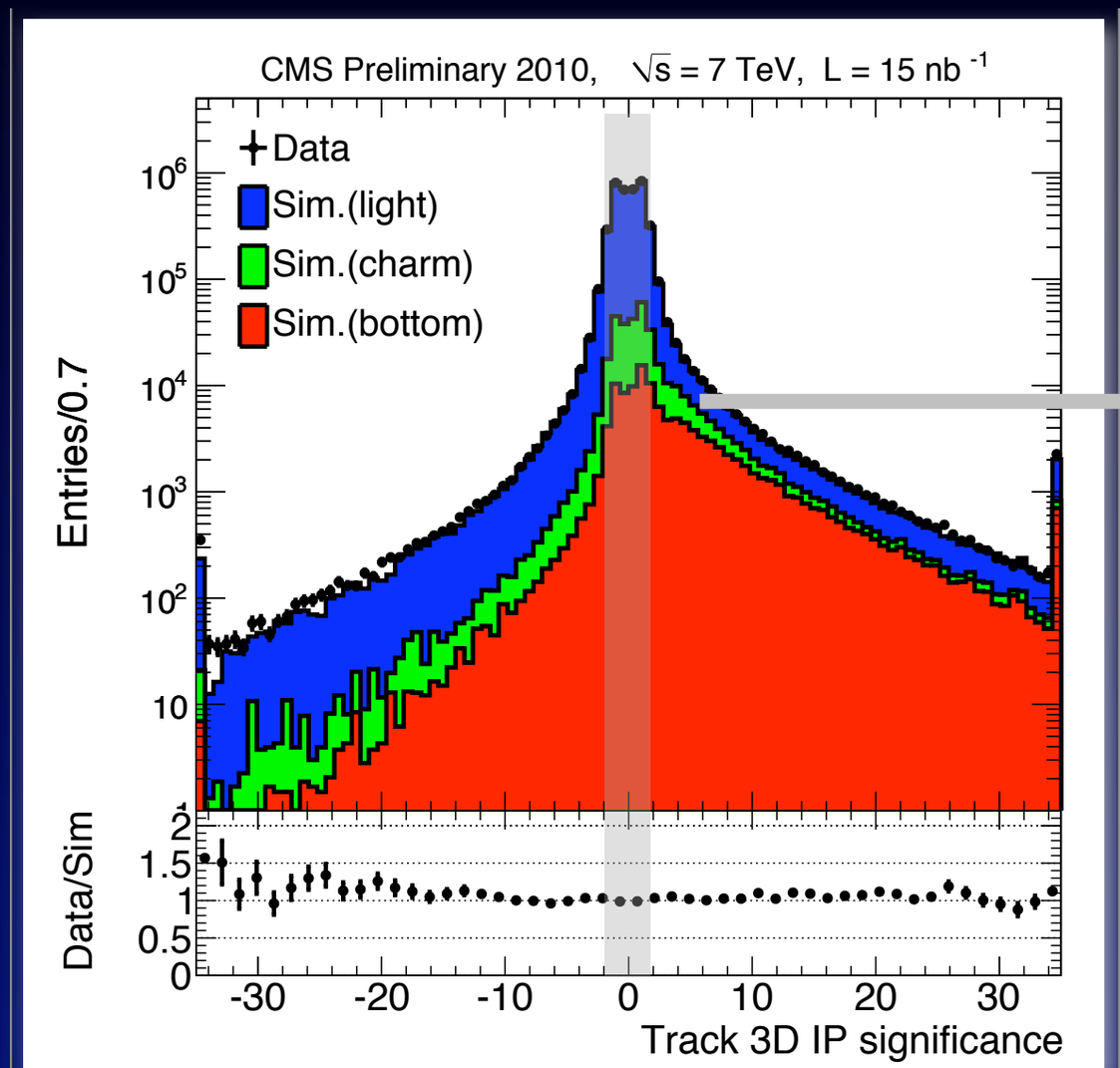


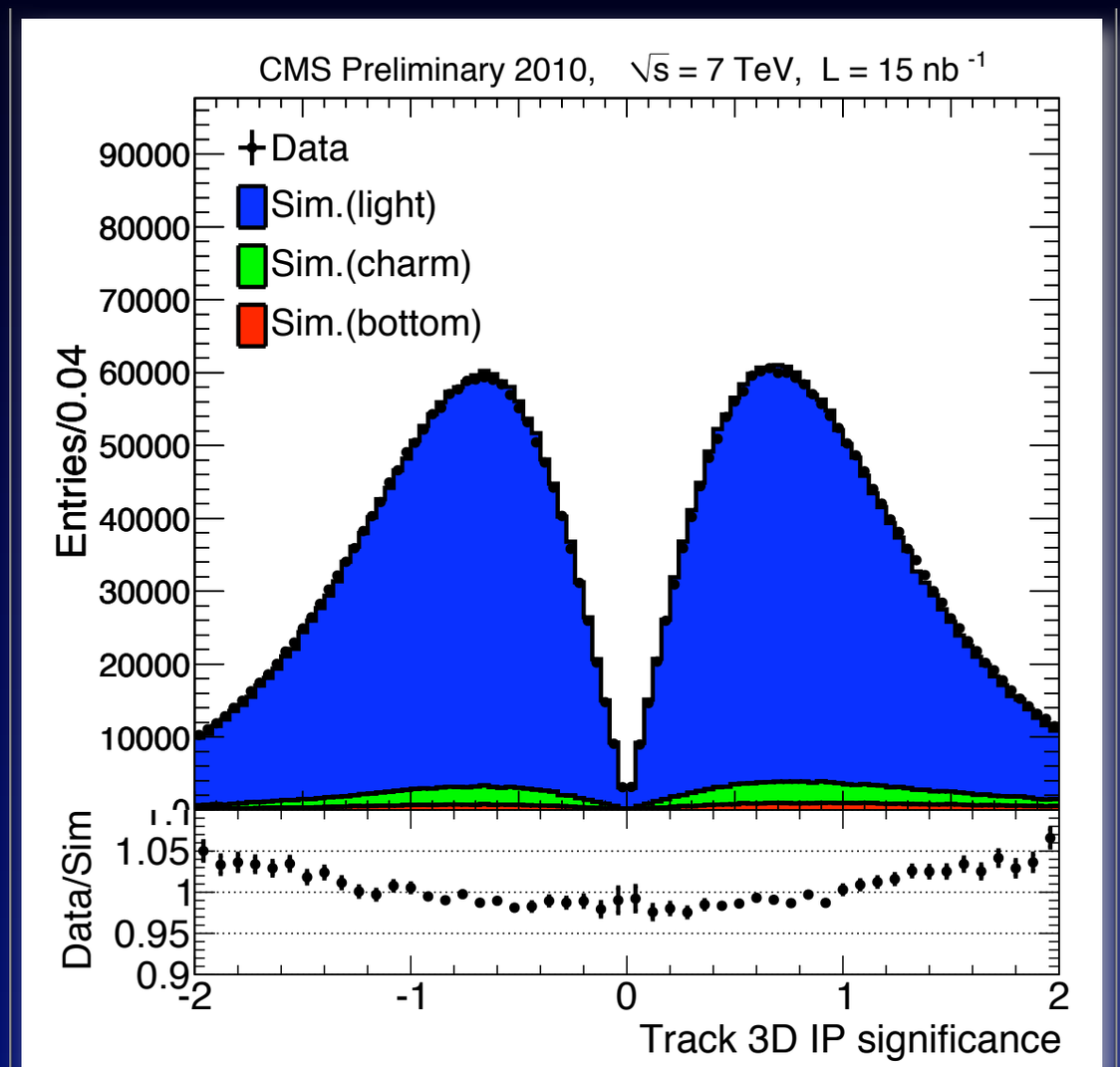


b-tagging [ETH,UZH]

Crucial for B Physics, top Physics, searches

CMS PAS BTV-10-001





3D impact parameter significance
Comparison between data and simulation

Same, linear & zoomed in central region
Symmetric for short lifetimes

➠ **Very good performance, well understood**

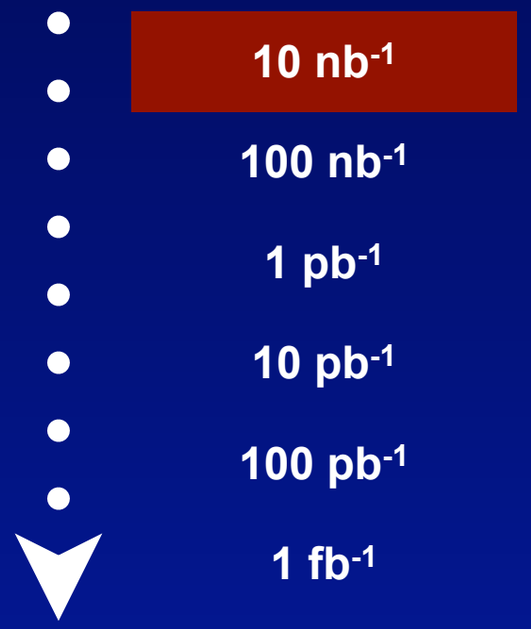
First results from CMS

Luminosity	(rough) Physics reach
10 nb^{-1}	QCD, Heavy flavour
100 nb^{-1}	W, Z
1 pb^{-1}	ttbar
10 pb^{-1}	Dijets, HSCP*,...
100 pb^{-1}	W', Z', low-mass SUSY
1 fb^{-1}	SUSY, MSSM Higgs

* Heavy Stable Charged Particles

QCD Physics

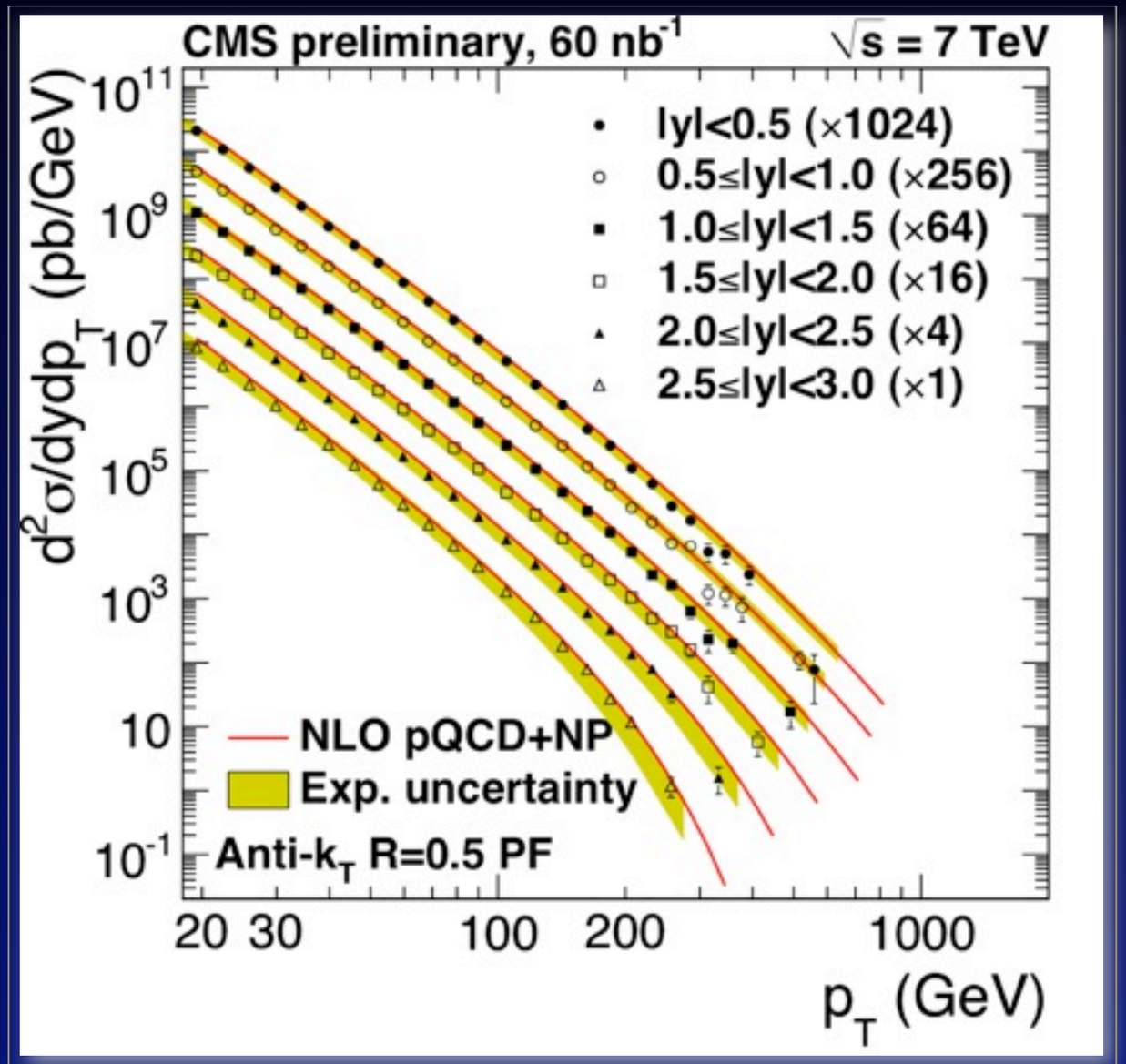
Tests of QCD at 7 TeV



Inclusive Jet cross-section

CMS PAS QCD-10-011

- Very high jet production at hadron colliders
  - **good agreement with NLO predictions at 1.96 TeV**
  - **measured at CMS with 3 jet types**
- Unfolding resolution effects
  - **using "ansatz" $f(p_t)$**
    - smeared with known jet resolutions
    - parameters of f determined by fit to data
- Good agreement with NLO
  - **in all jet reconstruction types**
  - **down to 20 GeV/c thanks to PF**



Inclusive jet cross-section

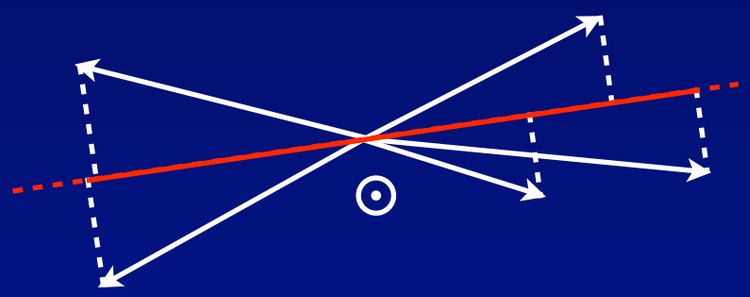
Hadronic Event Shapes

CMS PAS QCD-10-013

- Studying the energy flow in hadronic events
  - **Robust against detector effects**
    - Appropriate for early measurement of QCD event properties
  - **Can be computed in perturbative QCD**
  - **Distinguish models of multi-jet production (MC tuning)**

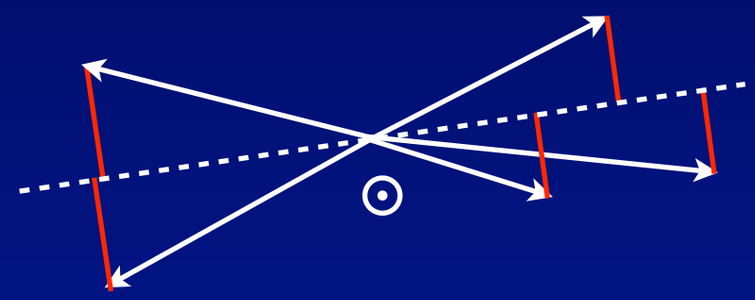
Central tranverse thrust

$$T_{\perp,\mathcal{C}} \equiv \max_{\vec{n}_T} \frac{\sum_{i\in\mathcal{C}} |\vec{p}_{\perp,i} \cdot \vec{n}_T|}{\sum_{i\in\mathcal{C}} p_{\perp,i}}$$



Central thrust minor

$$T_{m,\mathcal{C}} \equiv \frac{\sum_{i\in\mathcal{C}} |\vec{p}_{\perp,i} \times \vec{n}_{\mathrm{T},\mathcal{C}}|}{\sum_{i\in\mathcal{C}} p_{\perp,i}}.$$



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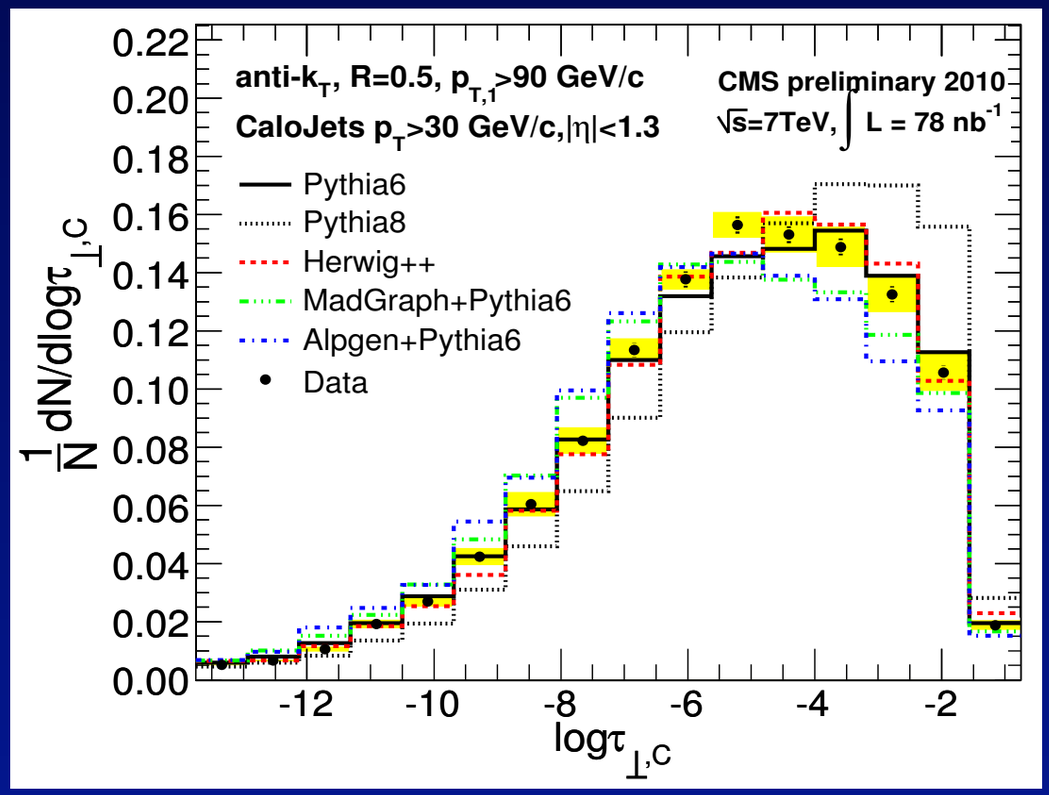
Central tranverse thrust ➠ $\tau_{\perp,c} \equiv 1 - T_{\perp,c}$



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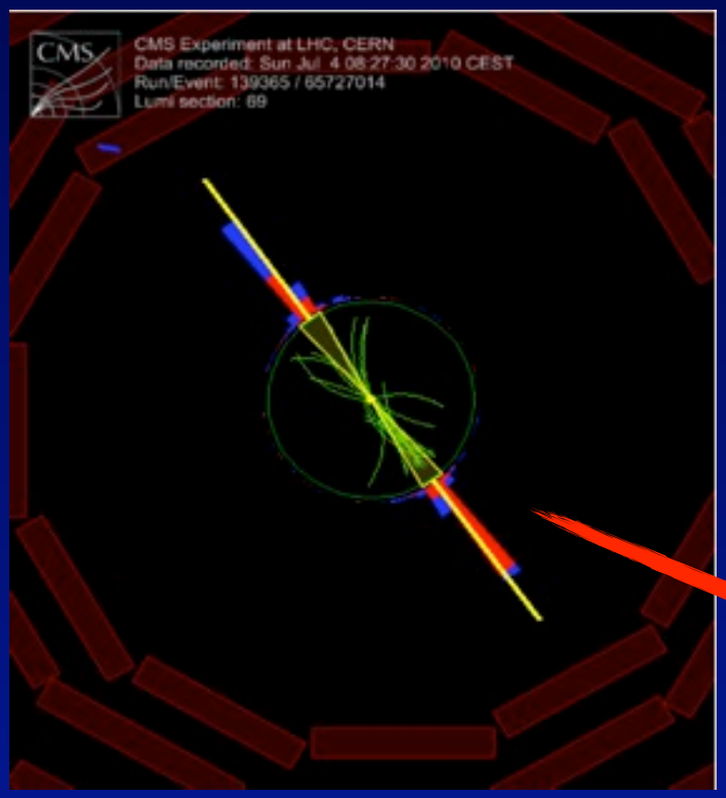

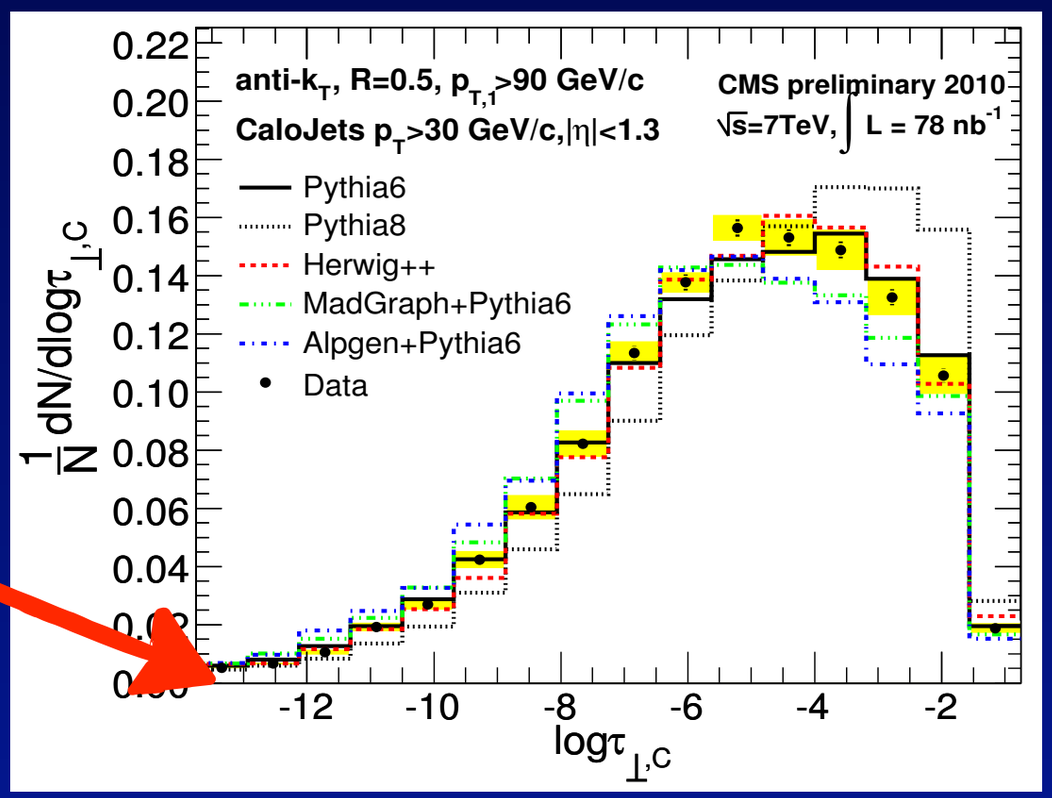

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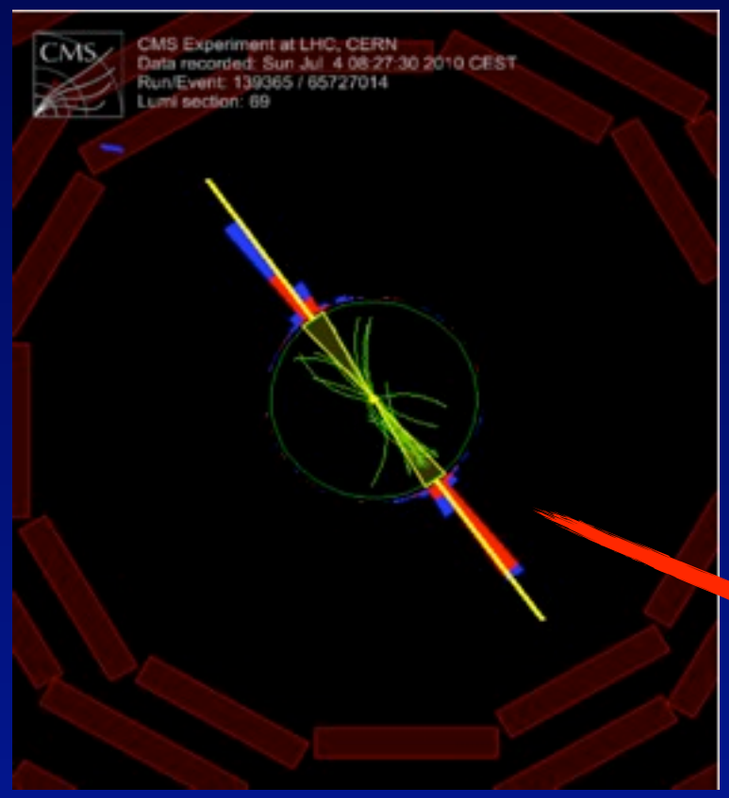
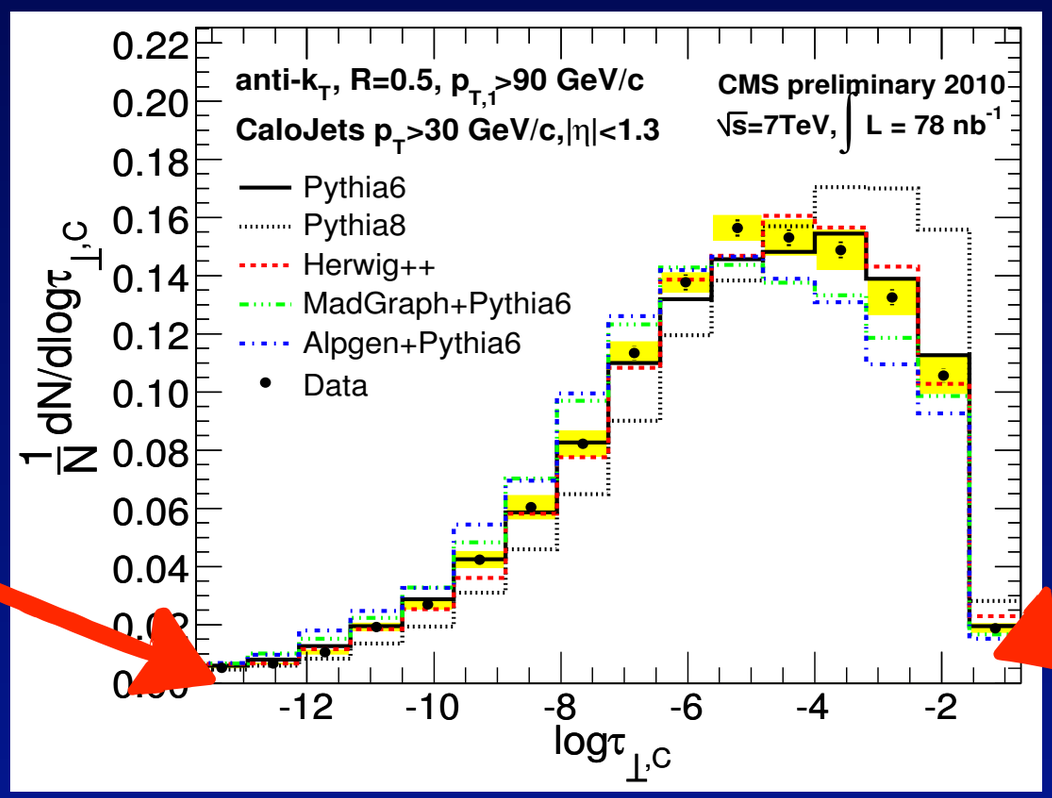
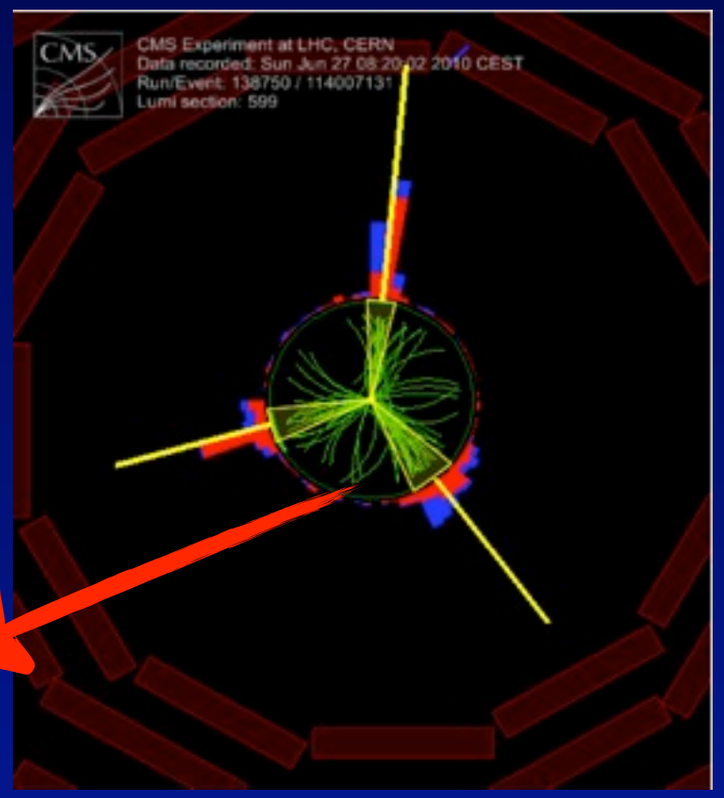
Central tranverse thrust $\Rightarrow \tau_{\perp,c} \equiv 1 - T_{\perp,c}$







Hadronic Event Shapes

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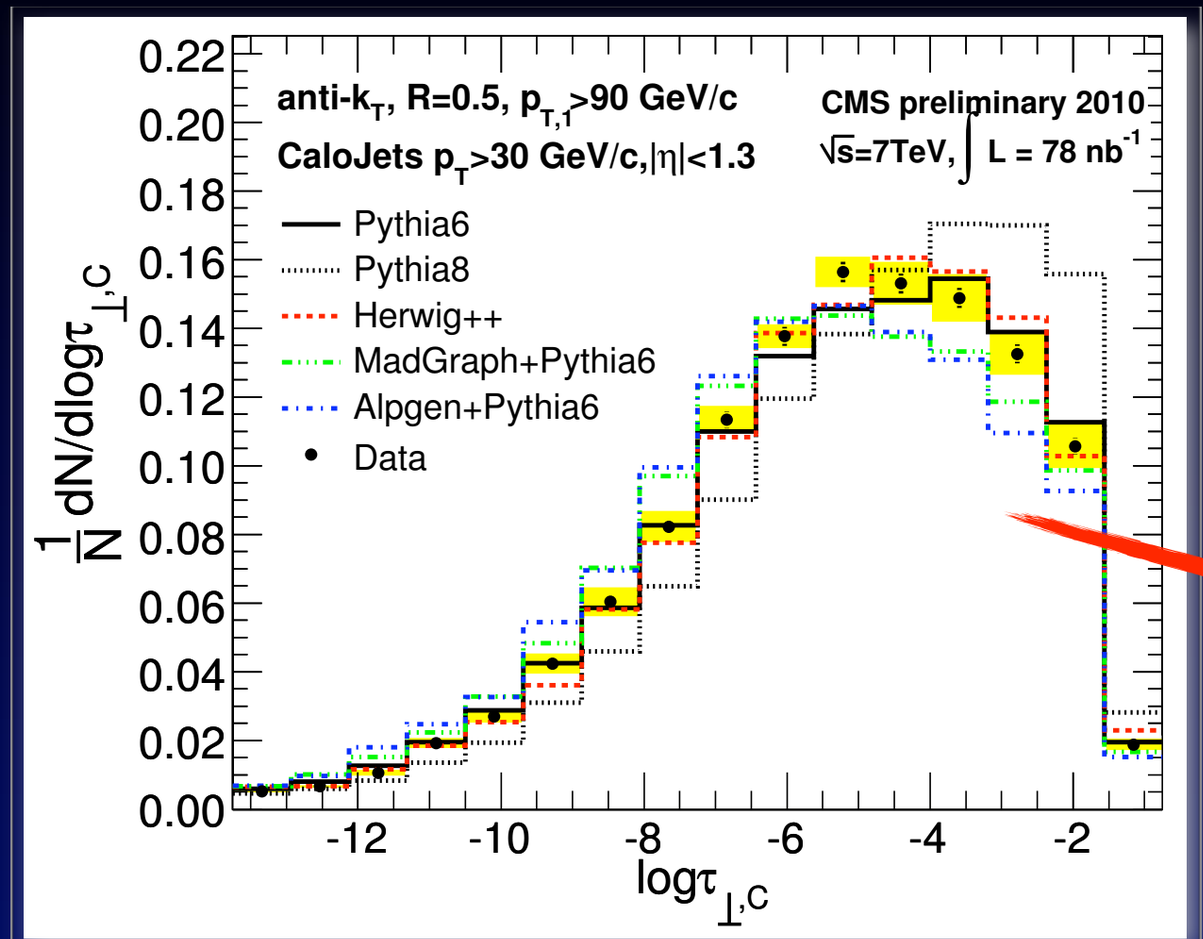
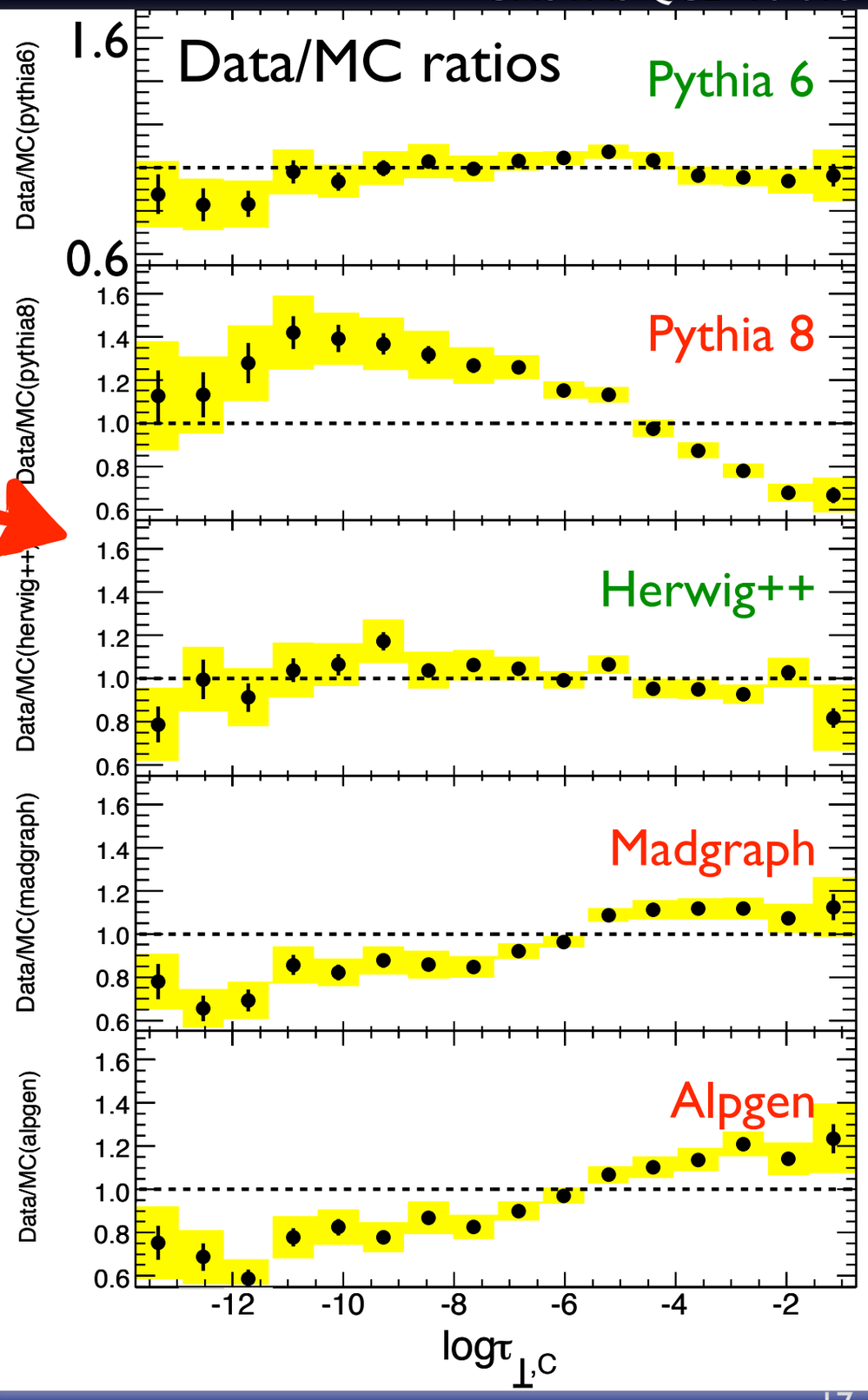




- Done for two p_T bins and different jet types (only one shown here, for central transverse thrust)

- **Pythia6 & Herwig++ compatible with data**
- **Alpgen and Madgraph overestimate fraction of back-to-back dijet events**
- **Pythia 8 underestimates it**

Beauty Physics

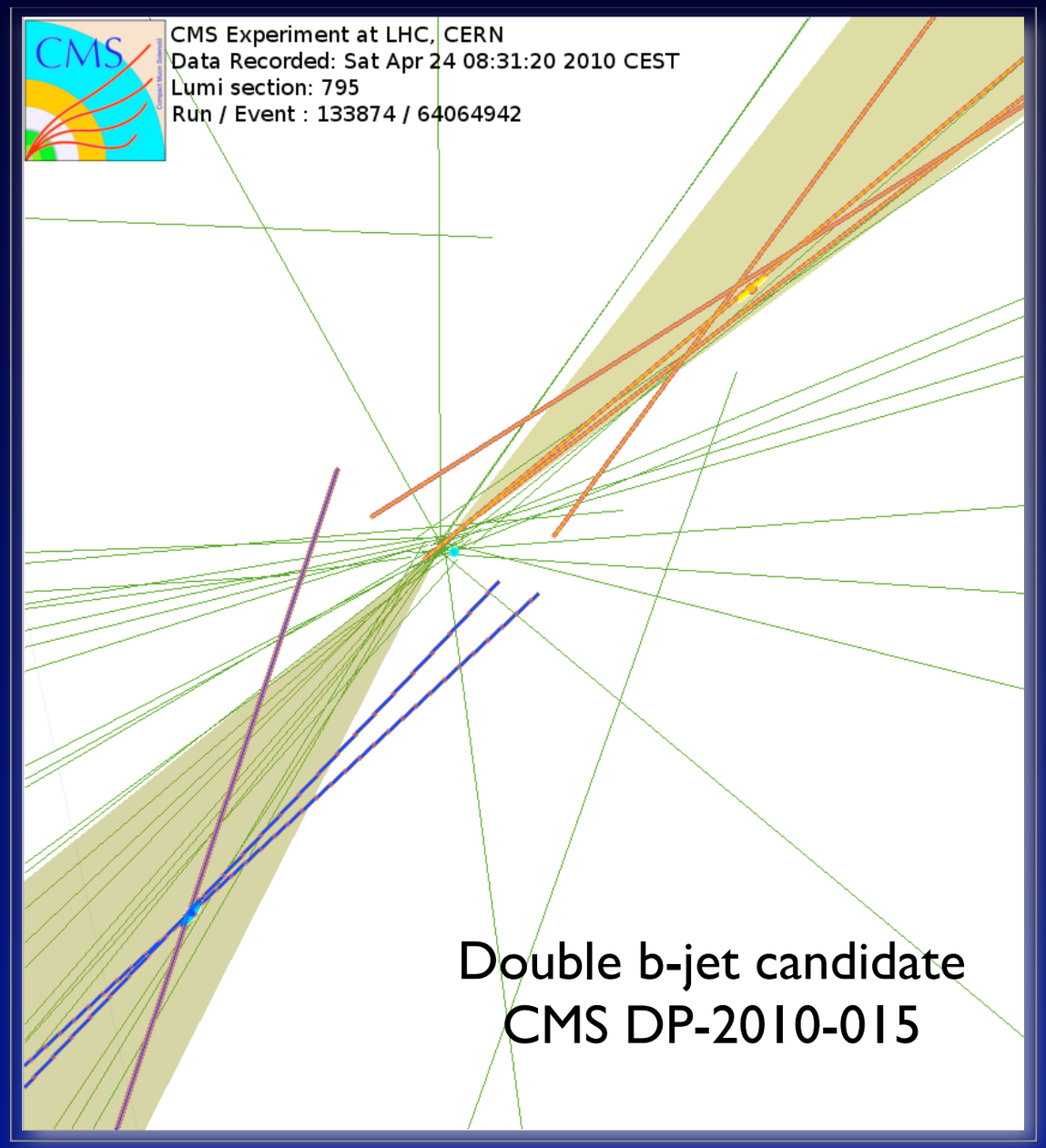
Further tests of QCD at 7 TeV

- **10 nb^{-1}**
- **100 nb^{-1}**
- **1 pb^{-1}**
- **10 pb^{-1}**
- **100 pb^{-1}**
- **1 fb^{-1}**

Beauty production cross-section

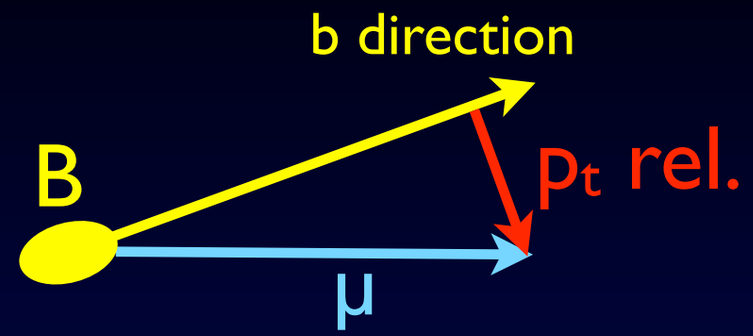
CMS PAS BPH-10-007
CMS PAS BPH-10-009

- bottom quark production
  - **can be (and has been) calculated in QCD (to NLO)**
    - but still sizeable theoretical uncertainties
  - **is abundant at LHC**
    - and represents an important background for many searches...
- Two independent methods
  - **using muon tagging**
  - **using b-tagging (secondary vertex)**
    - different systematic uncertainties
    - different phase space

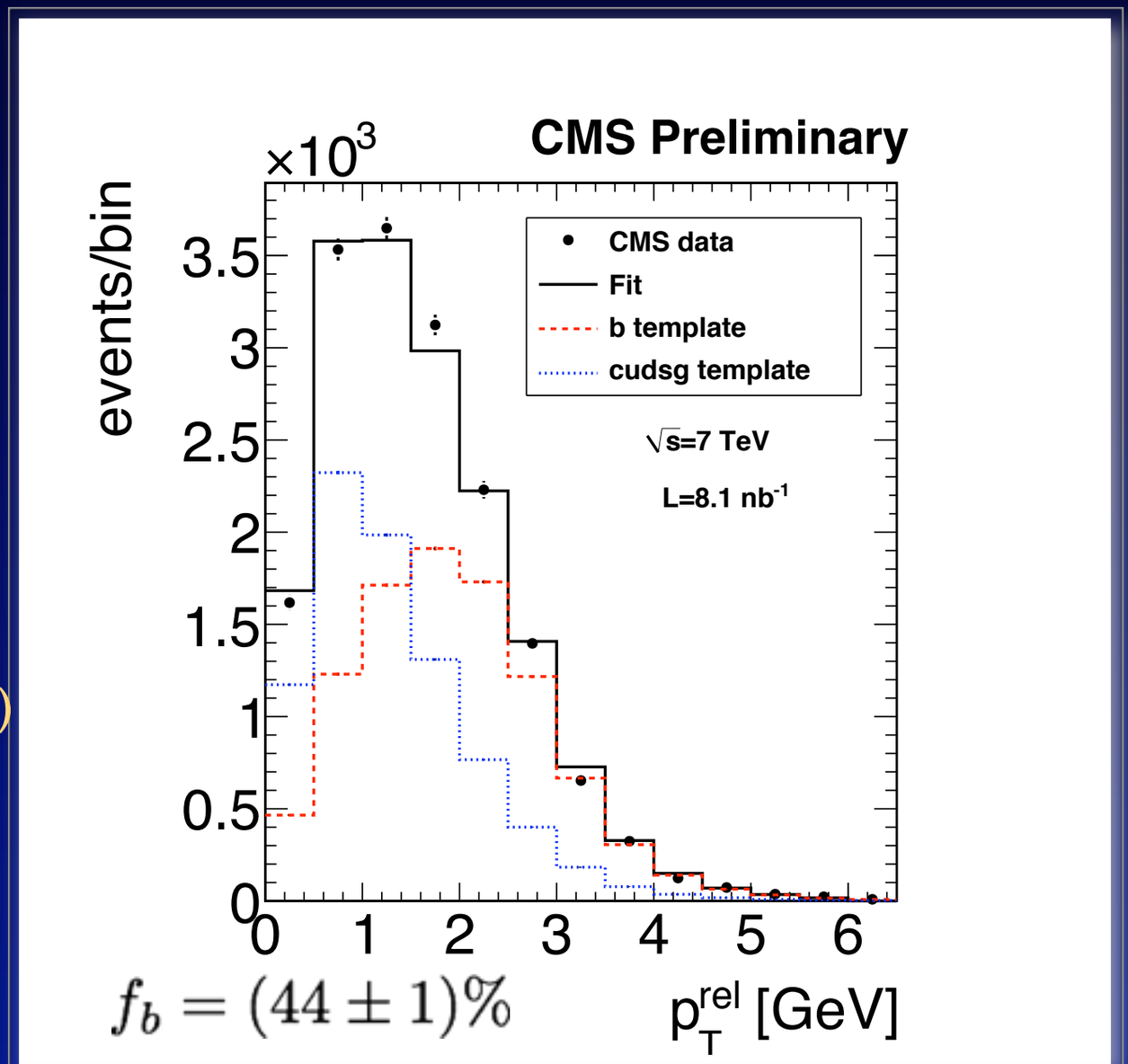


Open b production with muons

CMS PAS BPH-10-007



- Semi-leptonic decays to muons
  - **discriminate from background using relative muon p_t**
    - larger quark mass ⇒ higher p_t rel.
  - **b-jet only from tracks**
    - very good angular resolution (2-8%)
  - **binned maximum likelihood fit to p_t rel. distribution**
    - in bins of muon η and p_t
    - b and c templates from MC (b template validated in b-enriched data)
    - light quarks and gluons from mis-identified hadrons
    - returns fraction f_b of signal events in all selected events



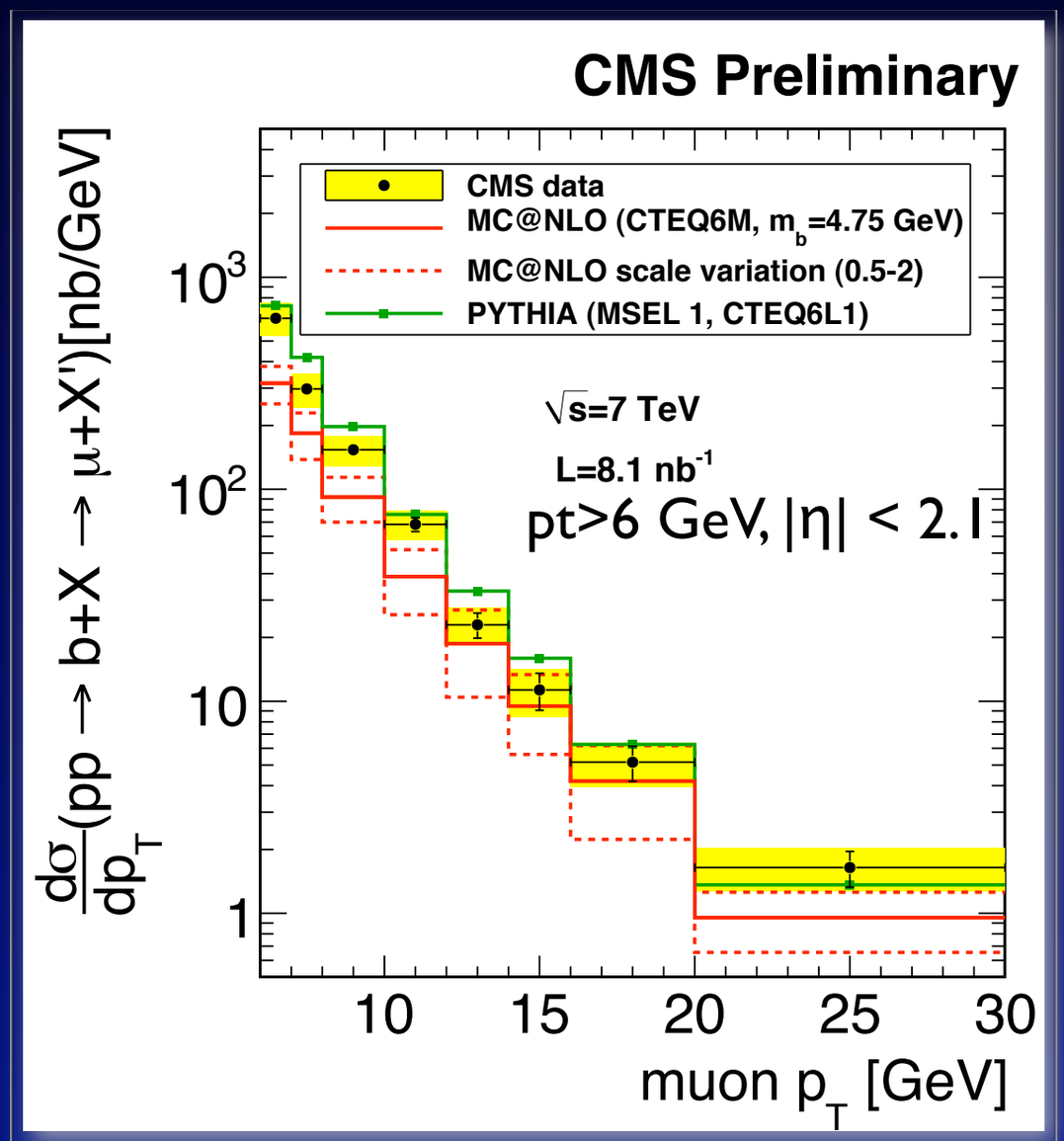
b cross-section with muons

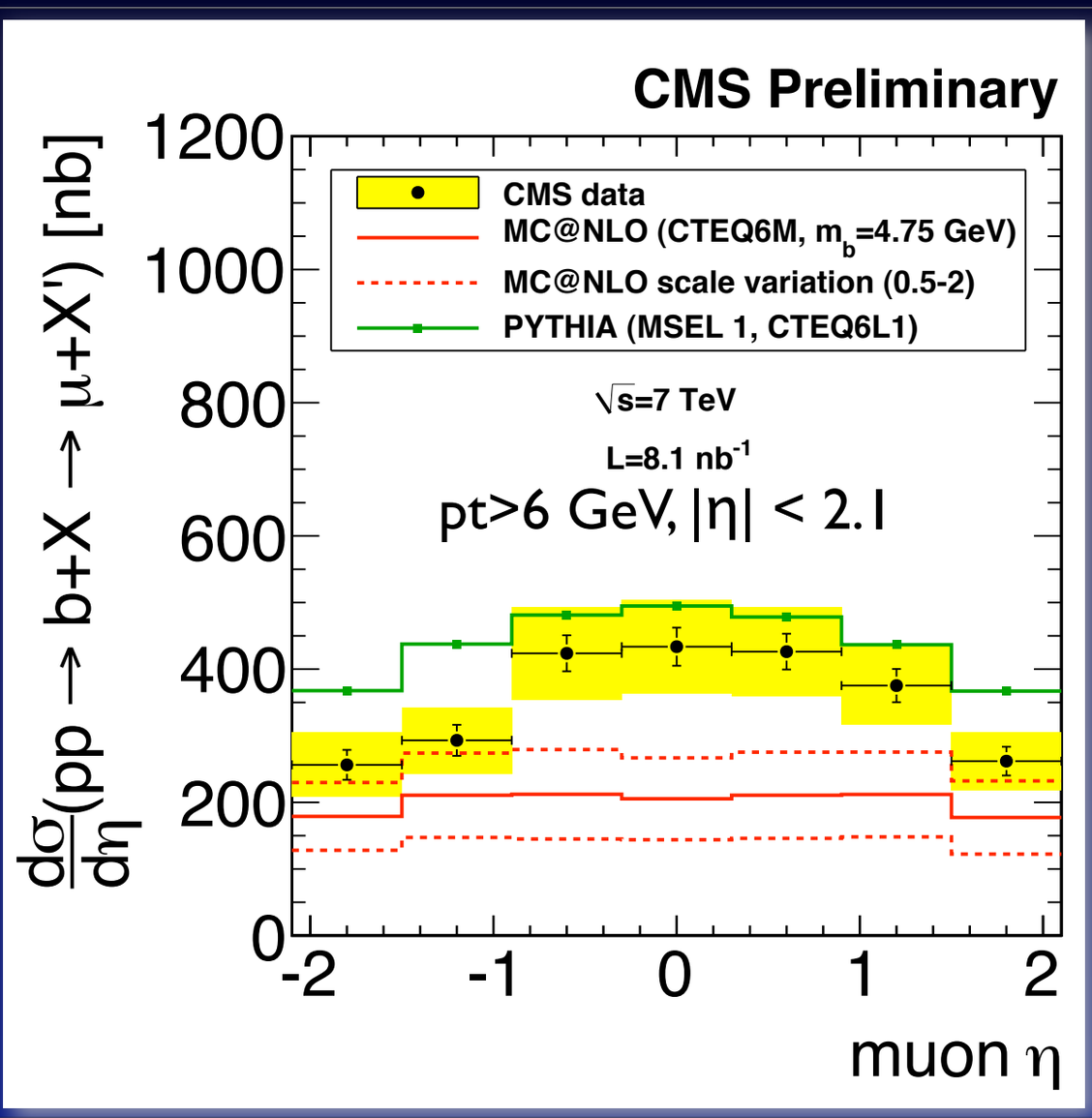
$$\sigma(pp \to b\bar{b} + X \to \mu + X') = \frac{f_b \times \#(\text{selected } \mu\text{s})}{\mathcal{L}\epsilon}$$

CMS PAS BPH-10-007

$\sigma_{measured}$ = (1.48±0.04$_{stat}$±0.22$_{syst}$±0.16$_{lumi}$) μb

$\sigma_{MC@NLO}$ = ($0.84^{-0.19}_{+0.36}$$_{scale}$±0.08$_{mb}$±0.04$_{pdf}$) μb





➠ **Higher cross-section in data than in MC@NLO (reasonable agreement at p_t>12 GeV/c)**

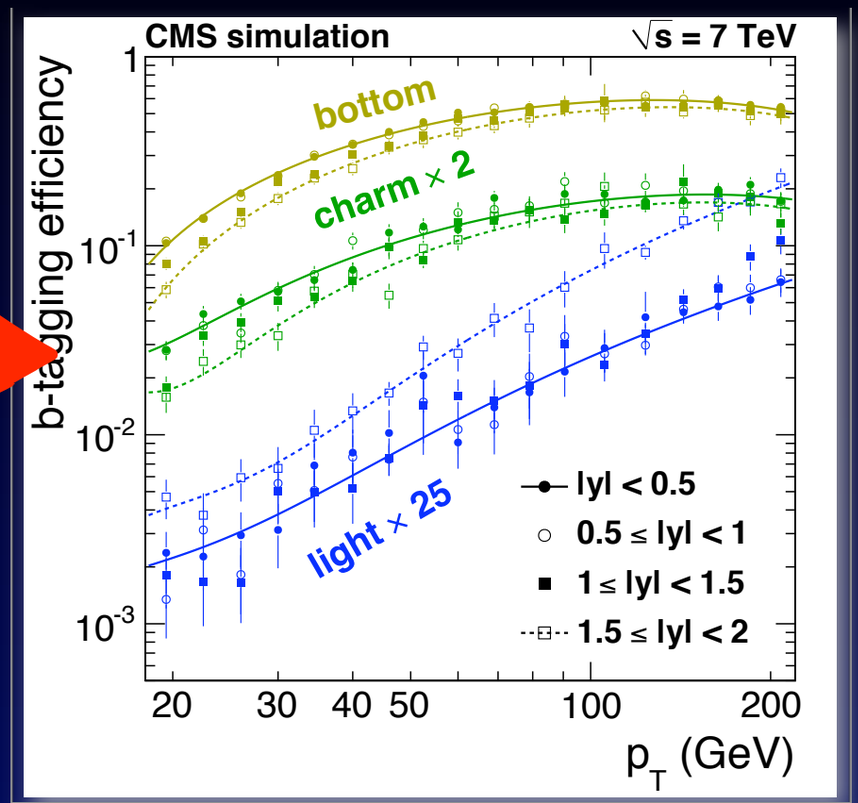
Inclusive b-jet production

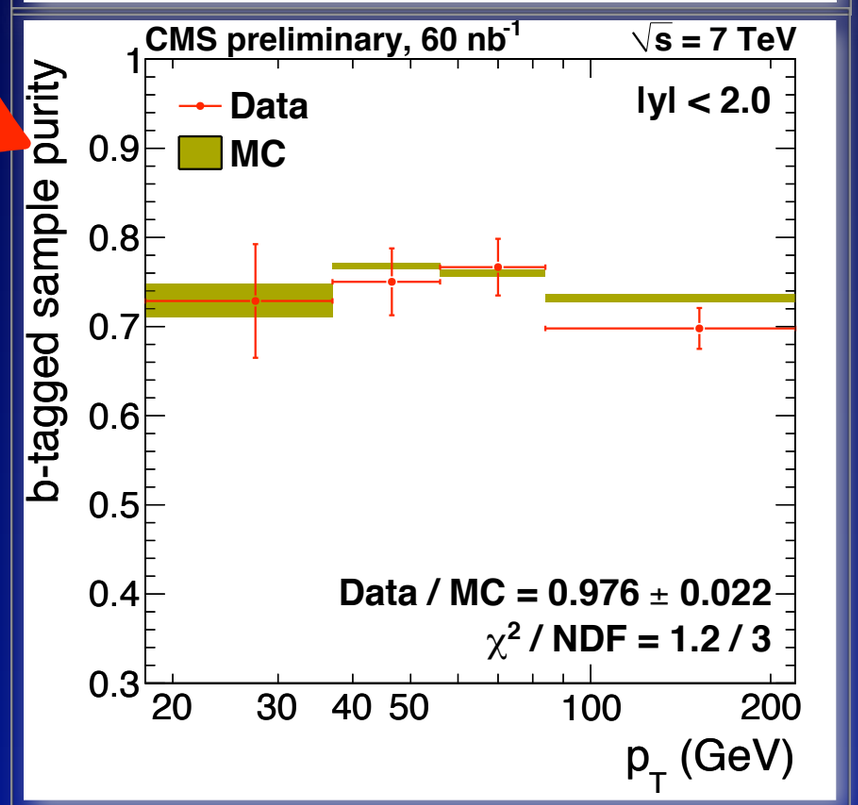
CMS PAS BPH-10-009

- using b-tagging to identify b-jets
  - **displaced vertex with at least 3 tracks**
  - **b-tagging efficiency ε_b from MC**
    - cross-checked with fit of p_t rel. distribution on muon-jet sub-sample
  - **b-tagged sample purity f_b from MC**
    - cross-checked with fit to vertex mass from data
    - light flavour mistag rate constrained from data
  - **Cross-section measurement:**

$$\frac{d^2\sigma_{\text{b-jets}}}{dp_t\,dy} = \frac{N_{\text{tagged}}\,f_b\,C_{\text{smear}}}{\epsilon_{\text{jet}}\,\epsilon_b\,\Delta p_t\,\Delta y\,\mathcal{L}}$$

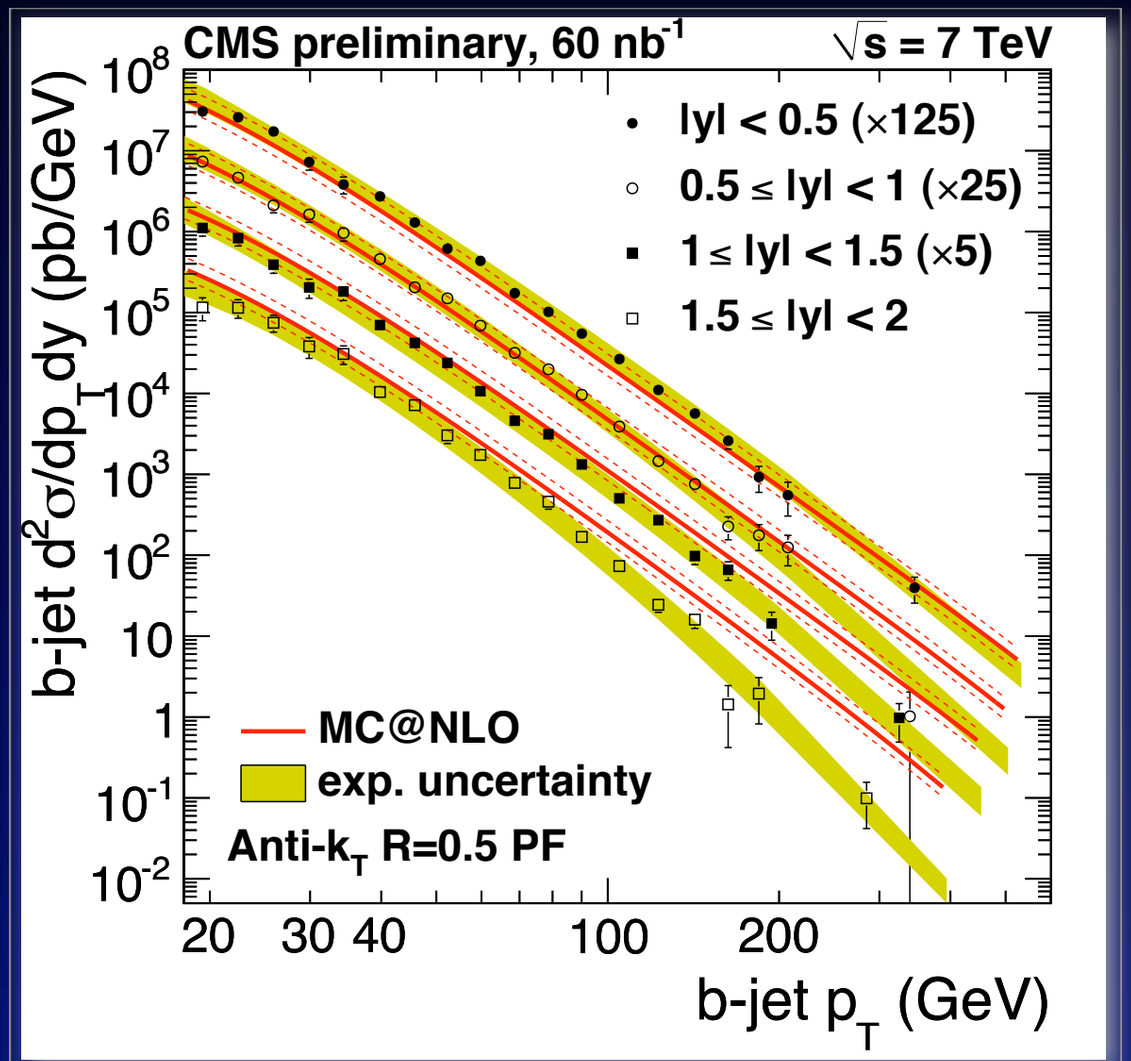
    - C_{smear}: unfolding correction (to particle level)
    - ε_{jet} jet reconstruction efficiency



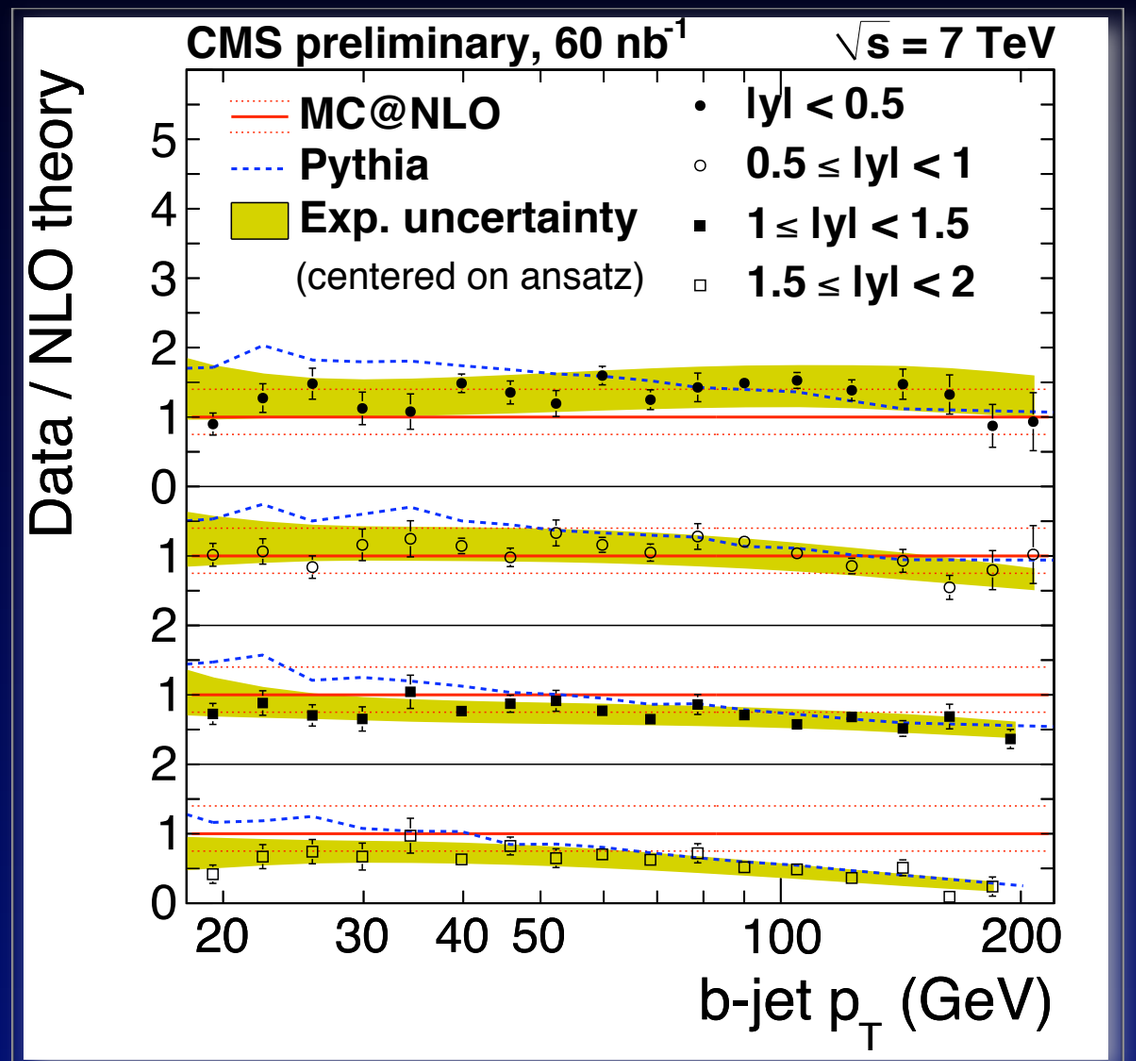


Inclusive b-jet cross-section

CMS PAS BPH-10-009



Data-MC comparison

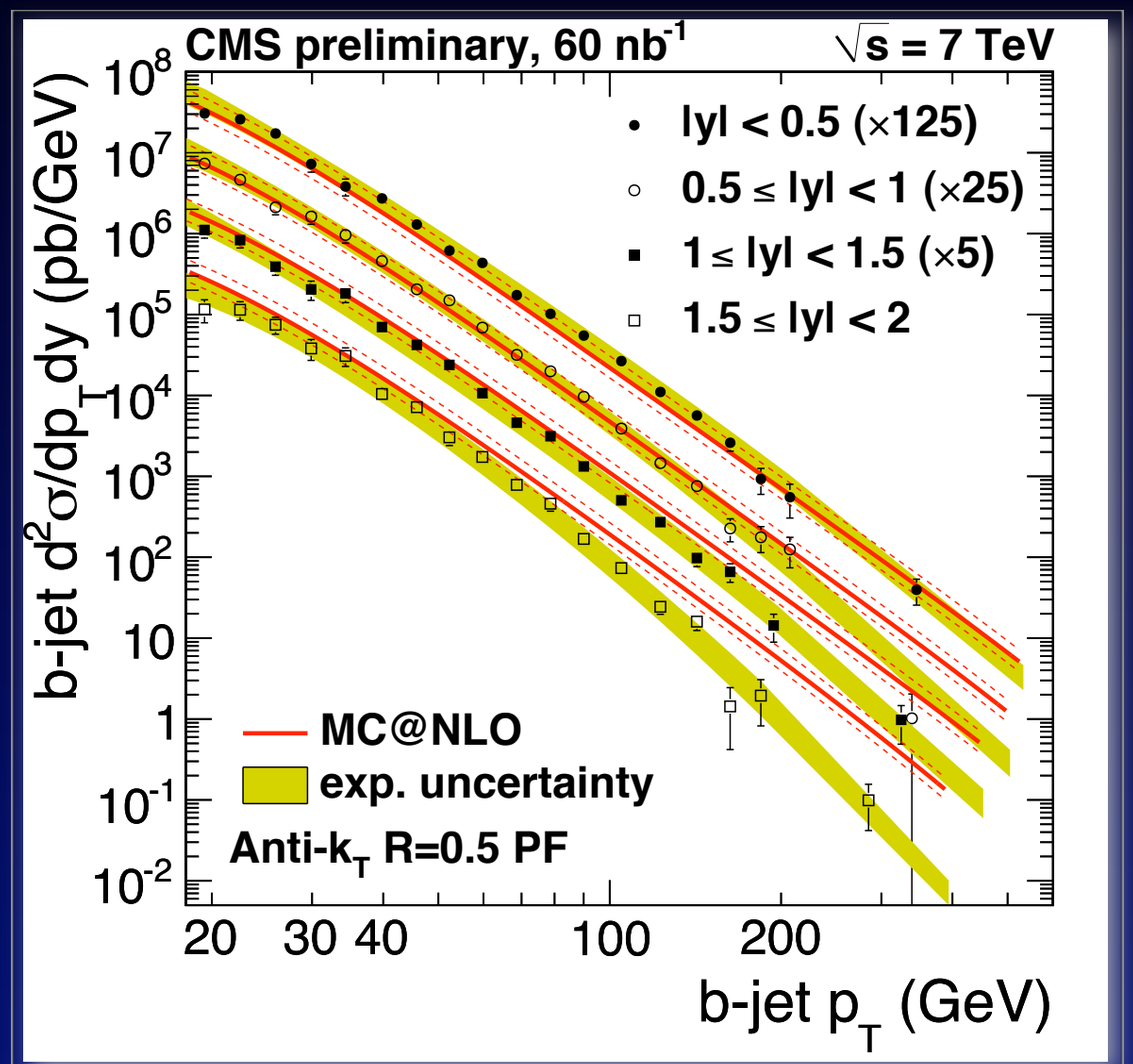


Data/MC ratios

➠ **Shape differences observed in MC@NLO (experimental & theoretical errors still large)**

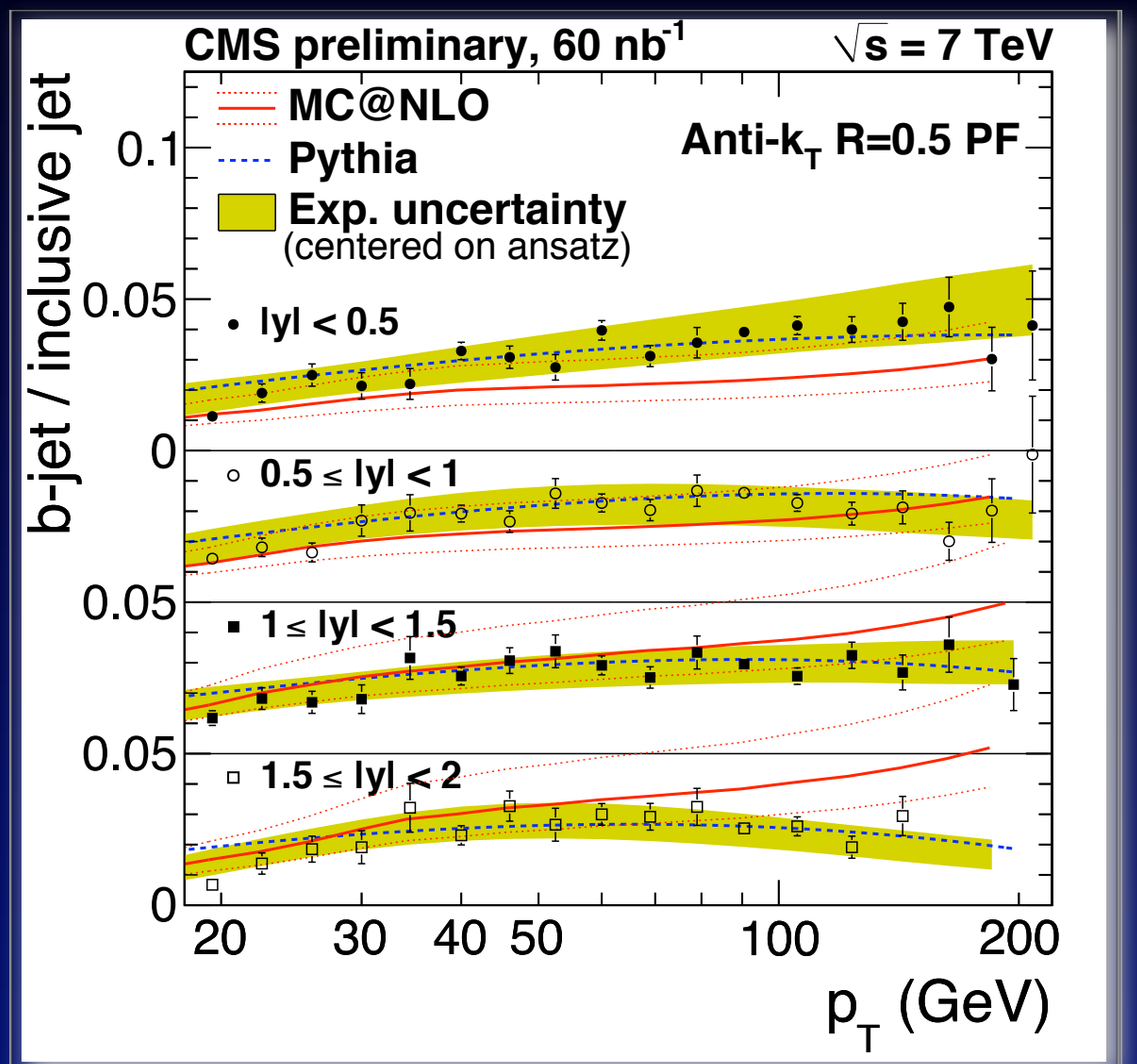
Inclusive b-jet cross-section

CMS PAS BPH-10-009



Data-MC comparison

Ratio to inclusive jet production



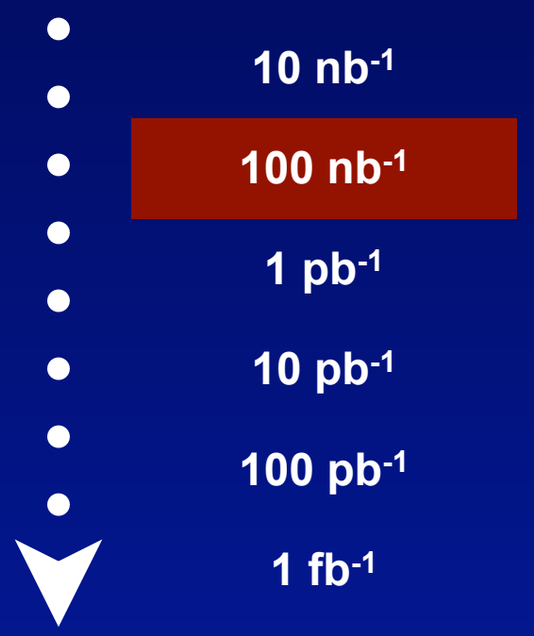
b-jet / inclusive jet ratio

➠ **Shape differences observed in MC@NLO (experimental & theoretical errors still large)**

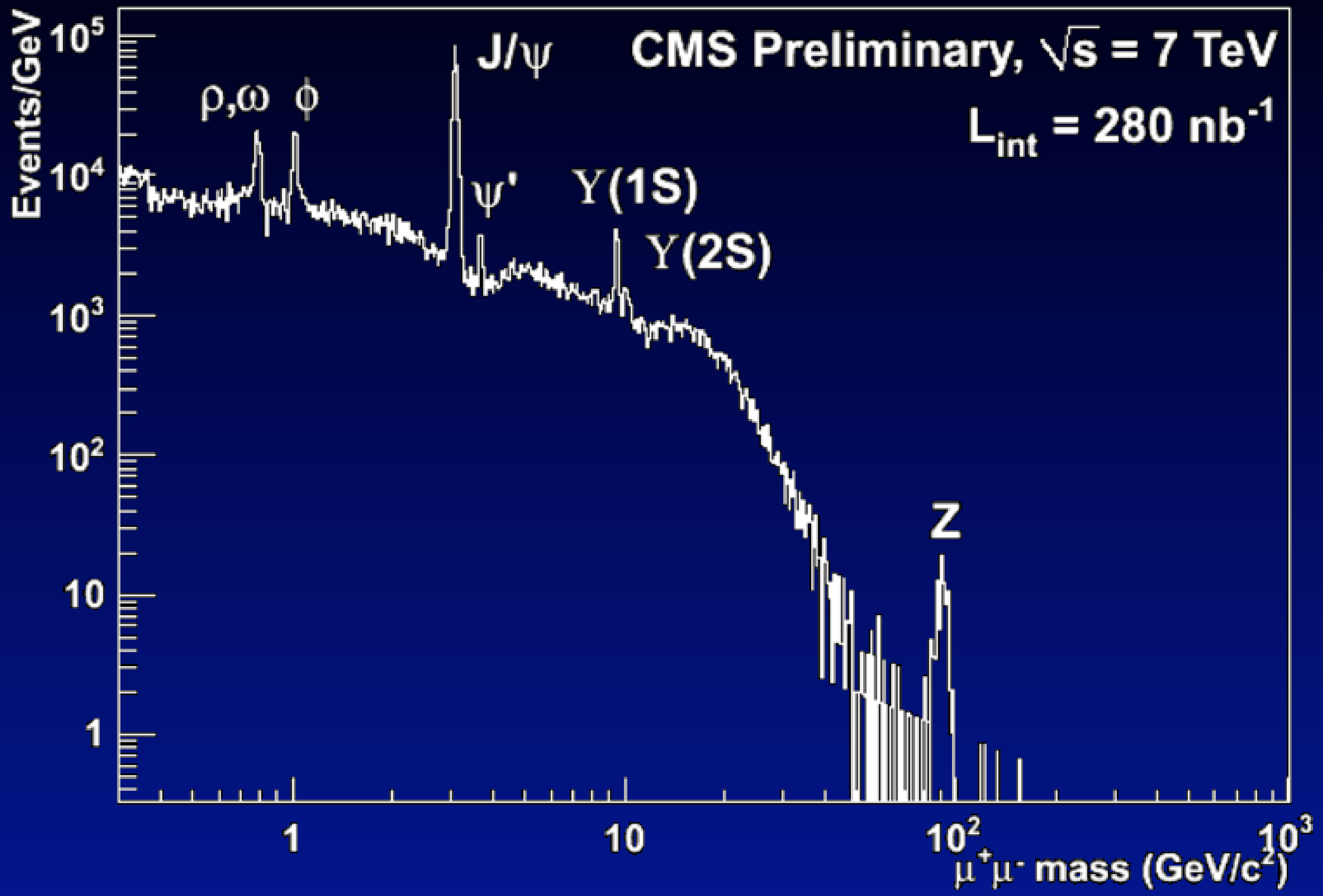
➠ **Very good agreement with Pythia**

Electroweak Physics

(Re)discovering the Standard Model at 7 TeV



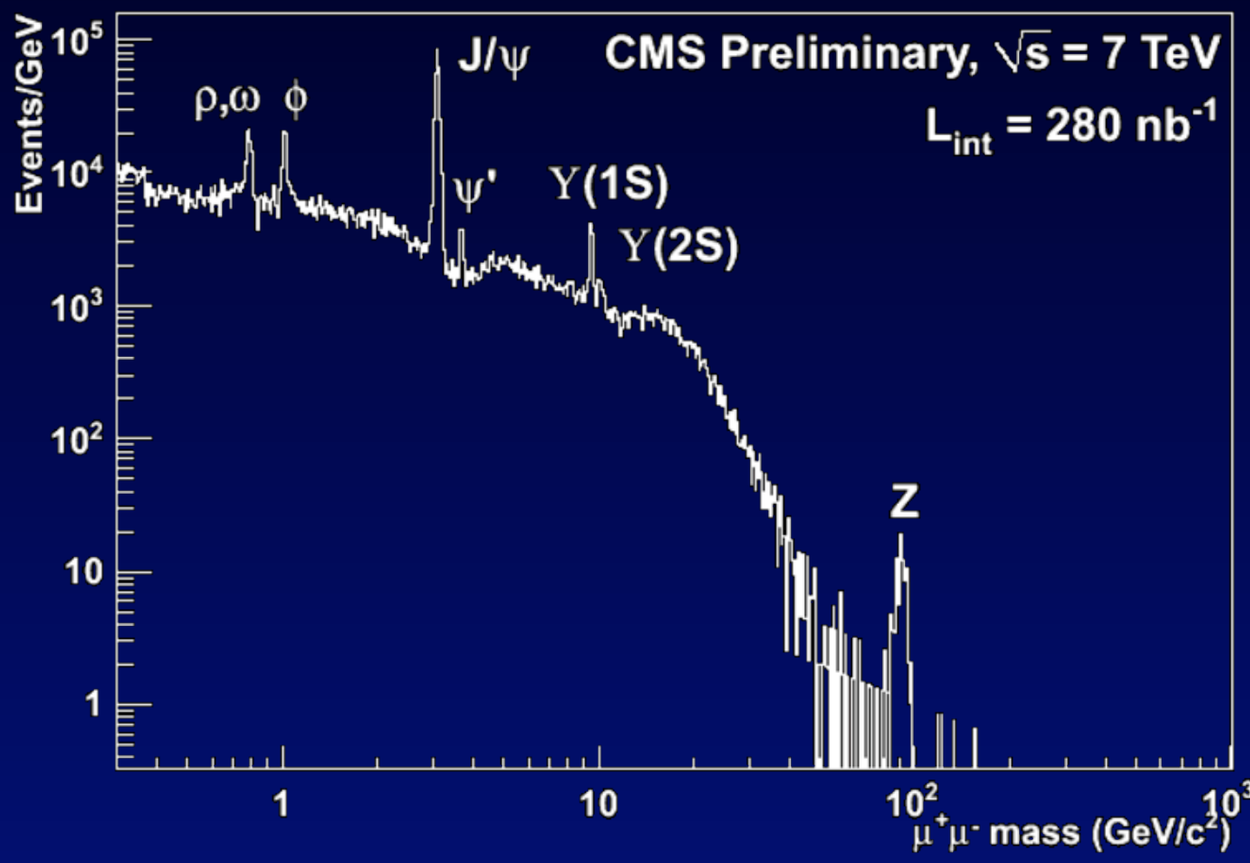
Prelude


Events/GeV
10^5
10^4
10^3
10^2
10
1
ρ,ω
φ
J/ψ
ψ'
Υ(1S)
Υ(2S)
Z
CMS Preliminary, √s = 7 TeV
L_{int} = 280 nb^{-1}
1
10
10^2
10^3
$\mu^+\mu^-$ mass (GeV/c^2)

Inclusive W and Z cross-sections

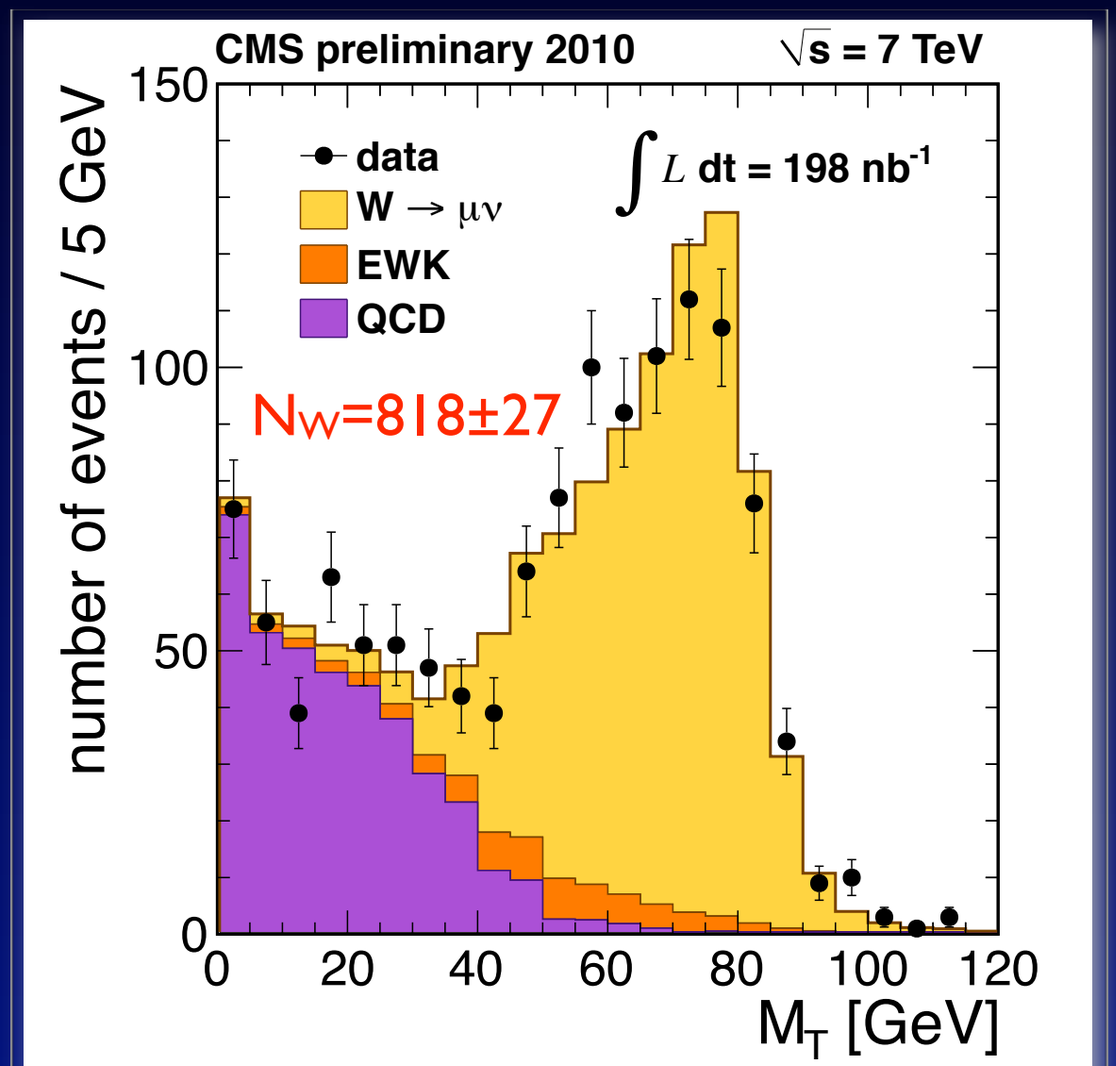
CMS PAS EWK-10-002

- First EWK measurement at the LHC
  - **well understood**
    - **benchmarks to study:**
      - parton distribution functions
      - detector effects
      - luminosity
      - analysis techniques
  - **... and background for searches**
- Production cross-section
  - **predicted at NLO and NNLO to few percent uncertainty**
    - possible luminosity monitor...

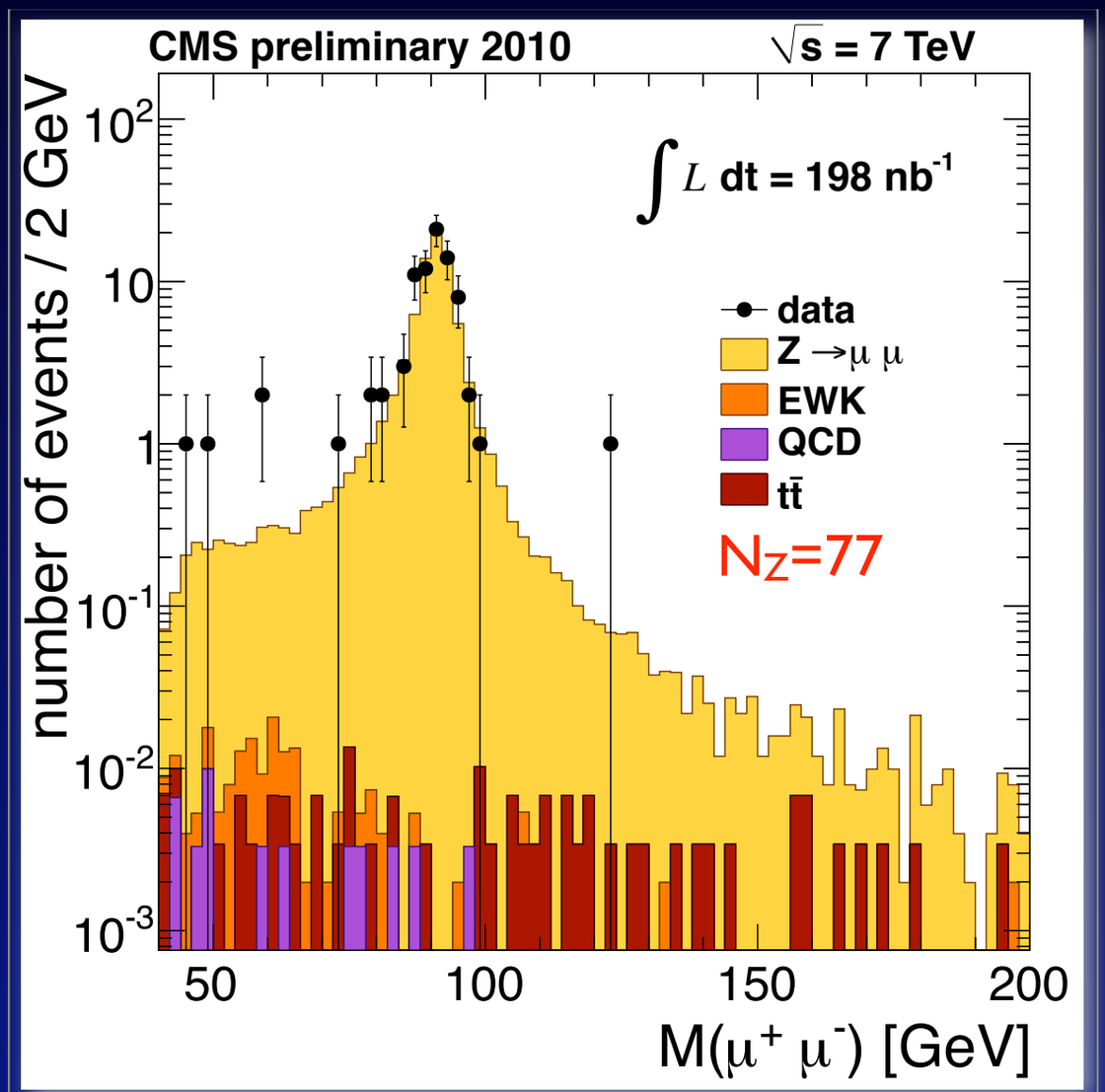


W and Z to muons

- **Good quality, isolated muons, pt > 20 GeV/c, |η| < 2.1 (2.4 for second μ in Z)**
- **Particle Flow missing energy to model neutrino**



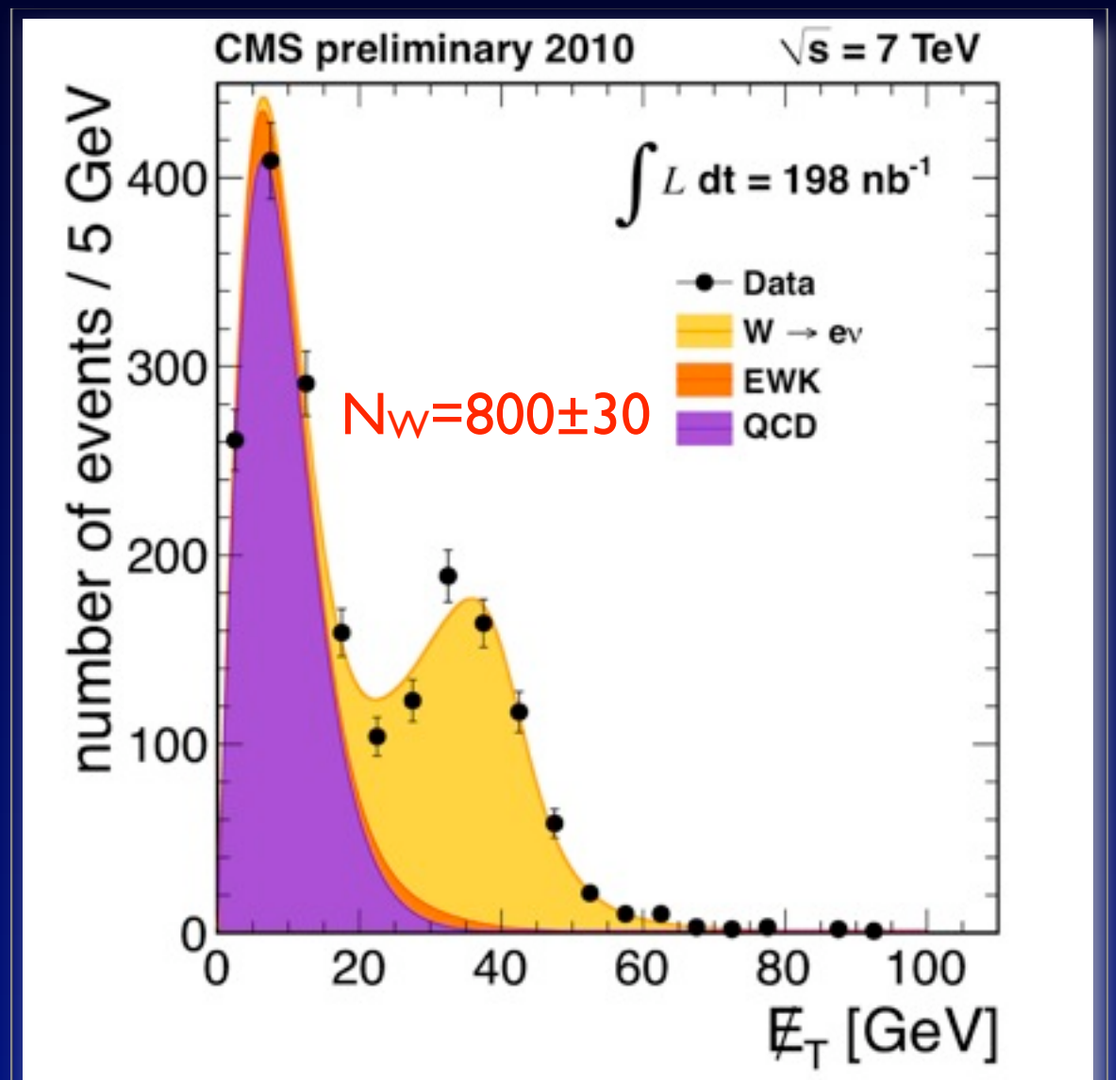
Yield from simultaneous fit to S+B M_T distribution
QCD from data, EWK and signal from MC



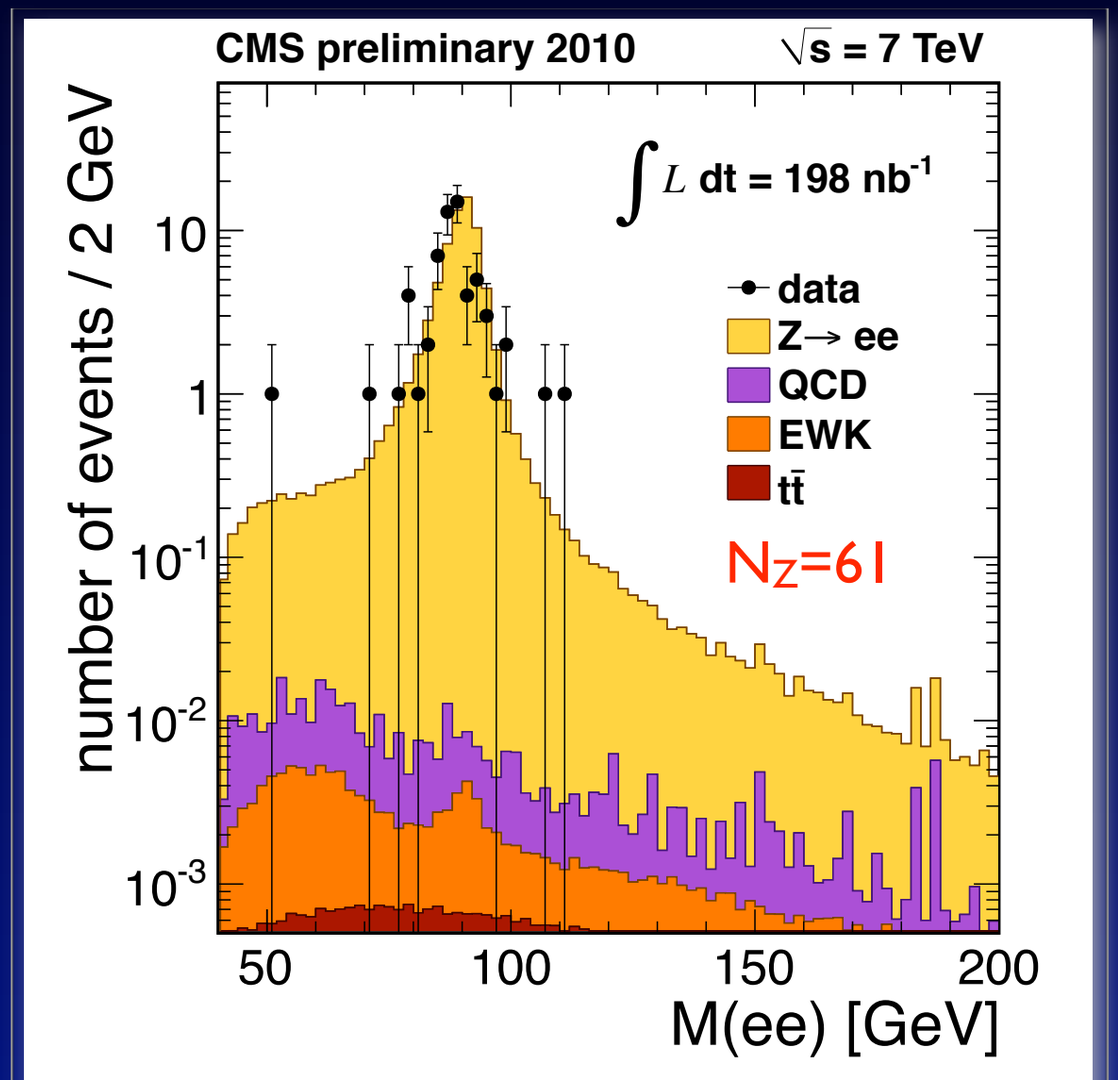
Yield from candidate event count.

W and Z to electrons

- **Good quality, isolated electron, pt > 20 GeV/c, $|\eta| \in [0,1.442] \cup [1.566,2.5]$**
- **Particle Flow missing energy to model neutrino**



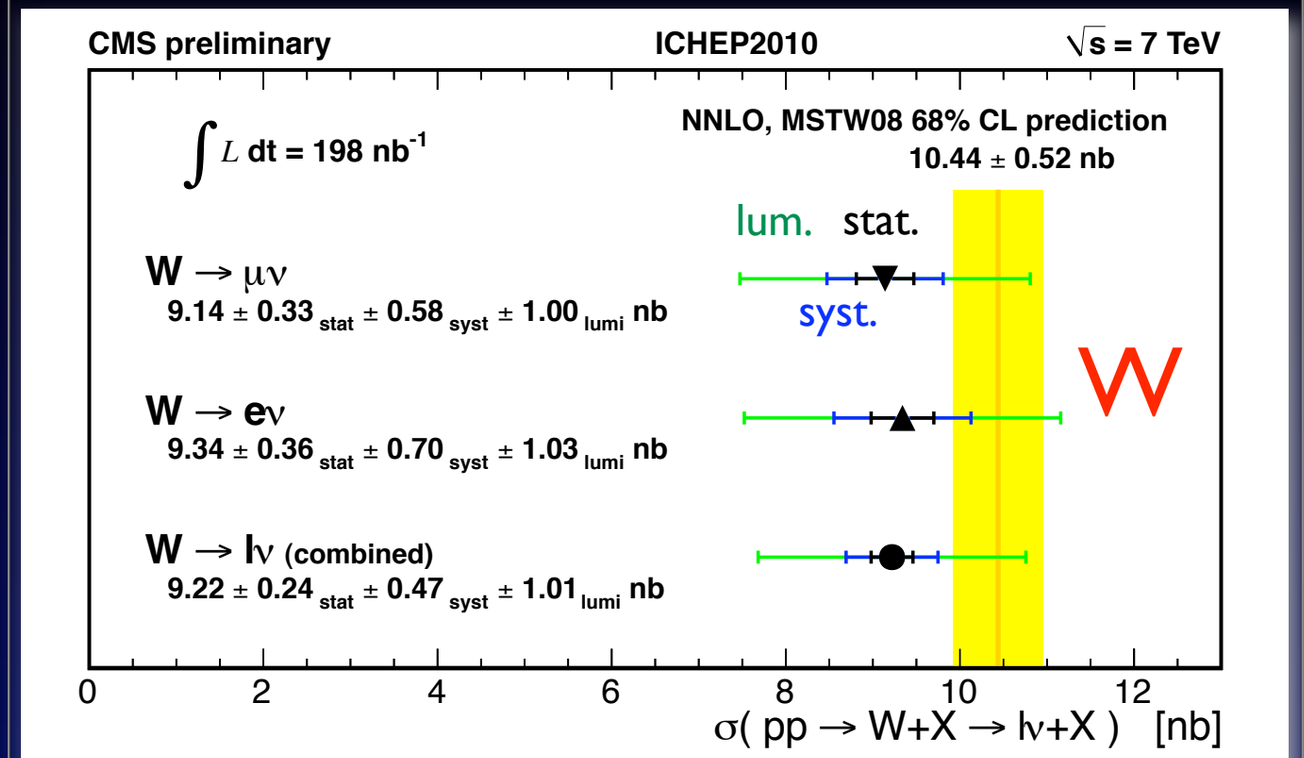
Yield from simultaneous fit to S+B MET distribution
QCD from data, EWK and signal from MC

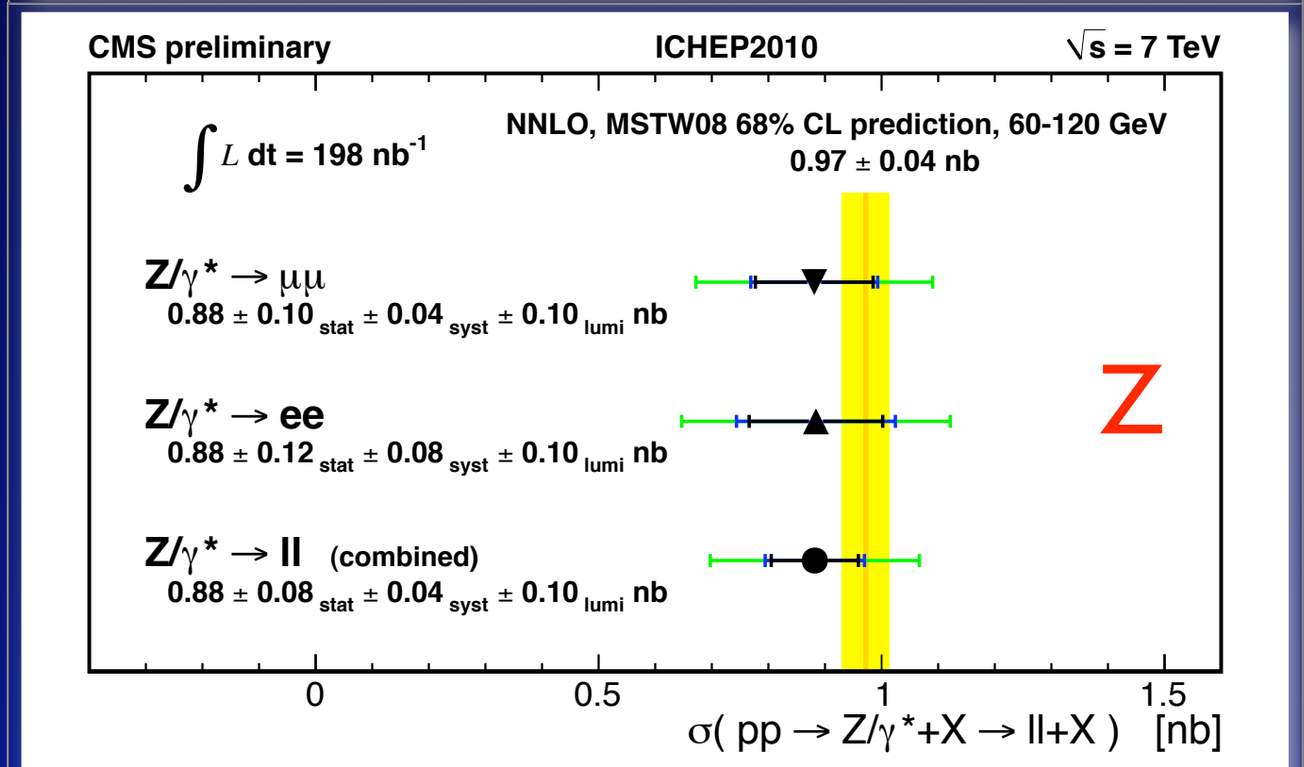


Yield from candidate event count.

Cross-section measurements

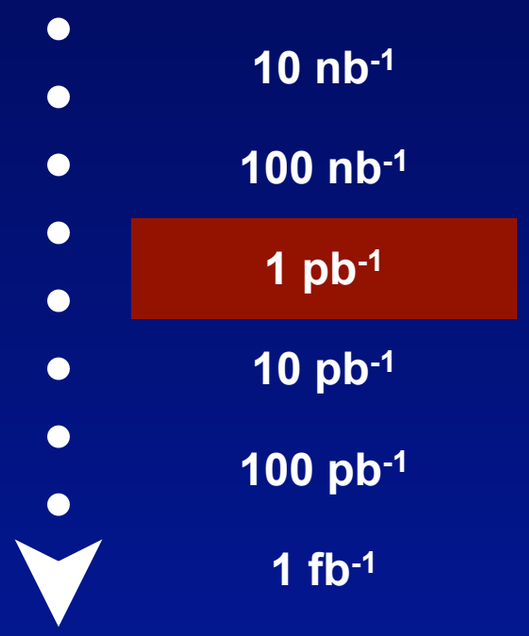
- Uncertainties
  - **Efficiencies and scales from Z events and recoil studies (photon+jets)**
  - **Background from cut inversion and control samples**
  - **PDFs from various PDF sets**
  - **Luminosity (11%) still dominant error**
- Results compatible with Standard Model expectation





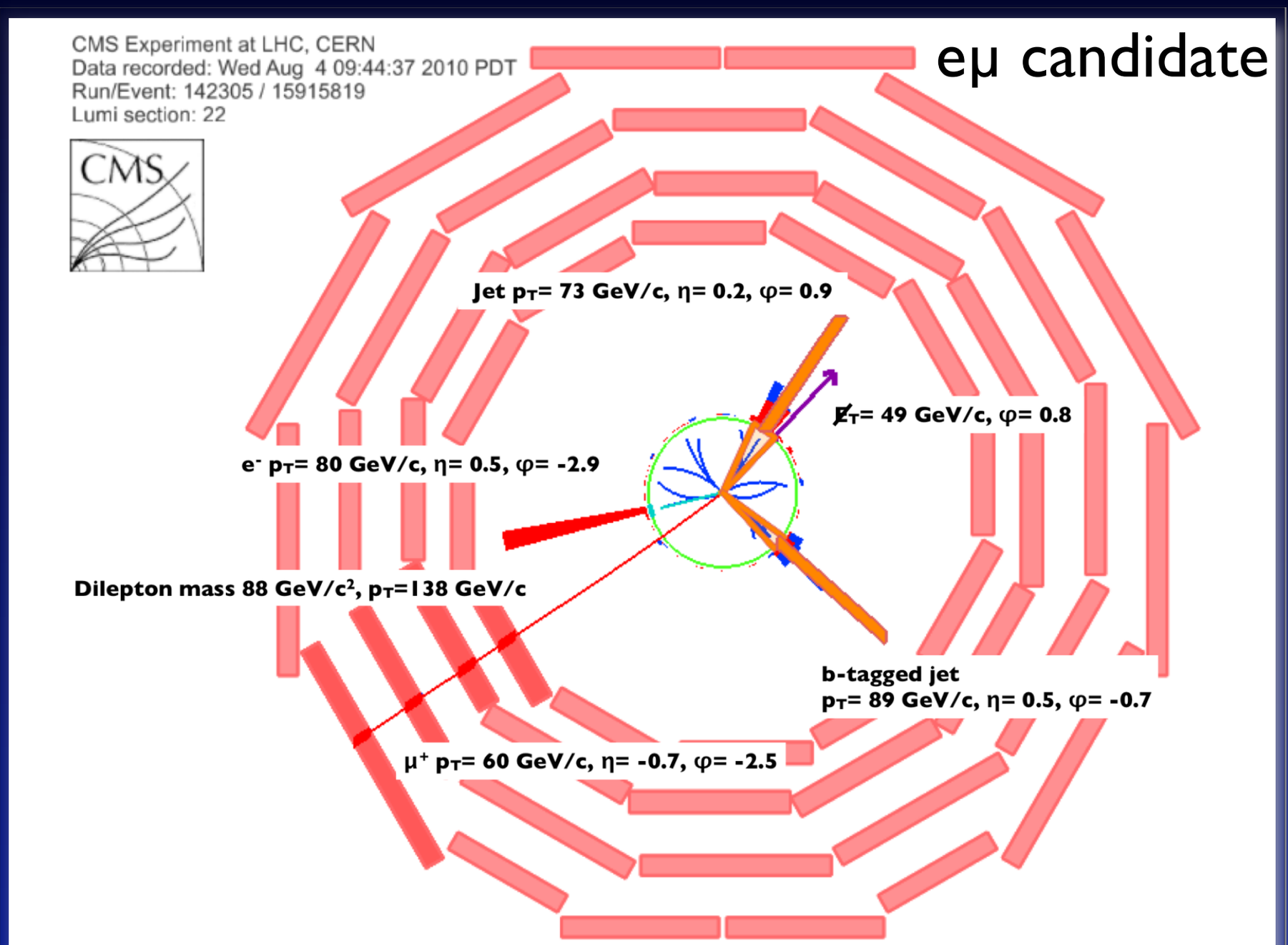
top Physics

en passant…



$t\bar{t}$ candidate events piling up

- Next important milestone
  - **background to searches: leptons, high jet multiplicity, missing energy**



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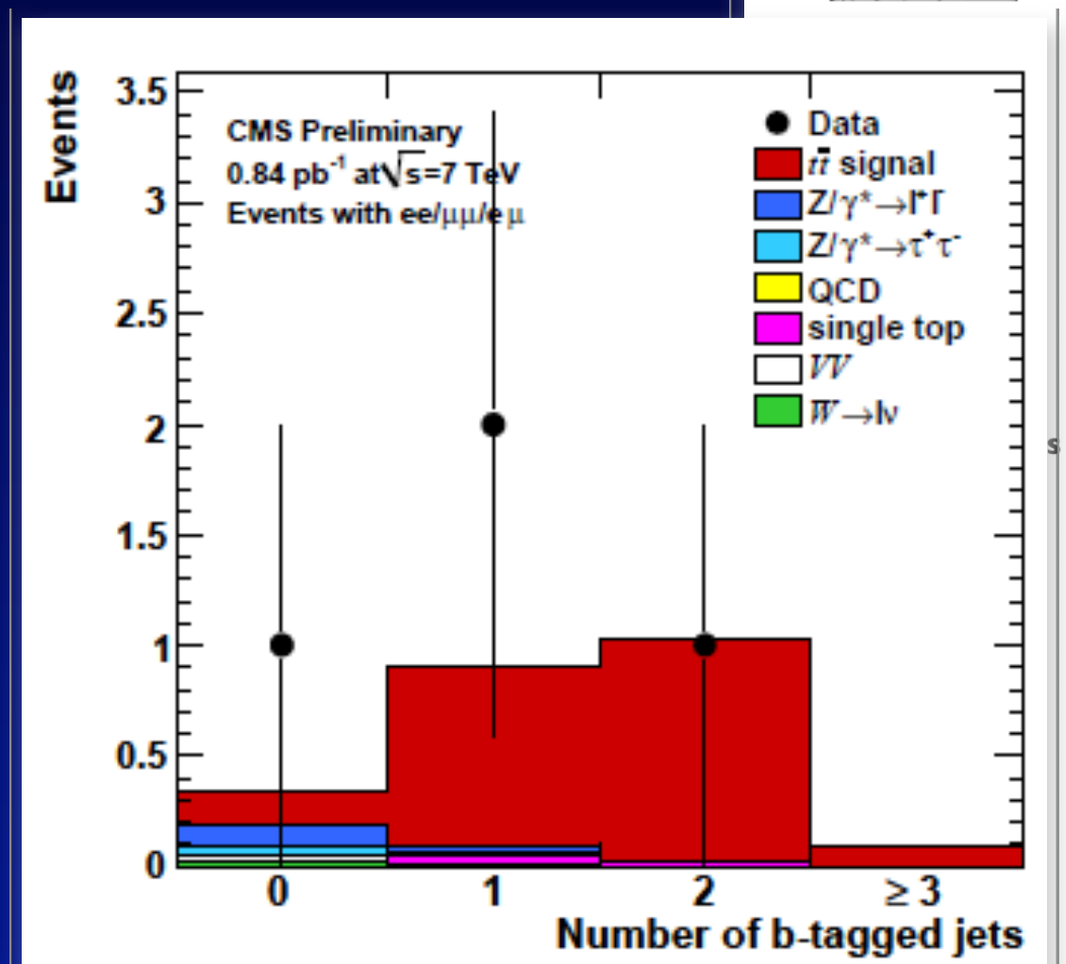
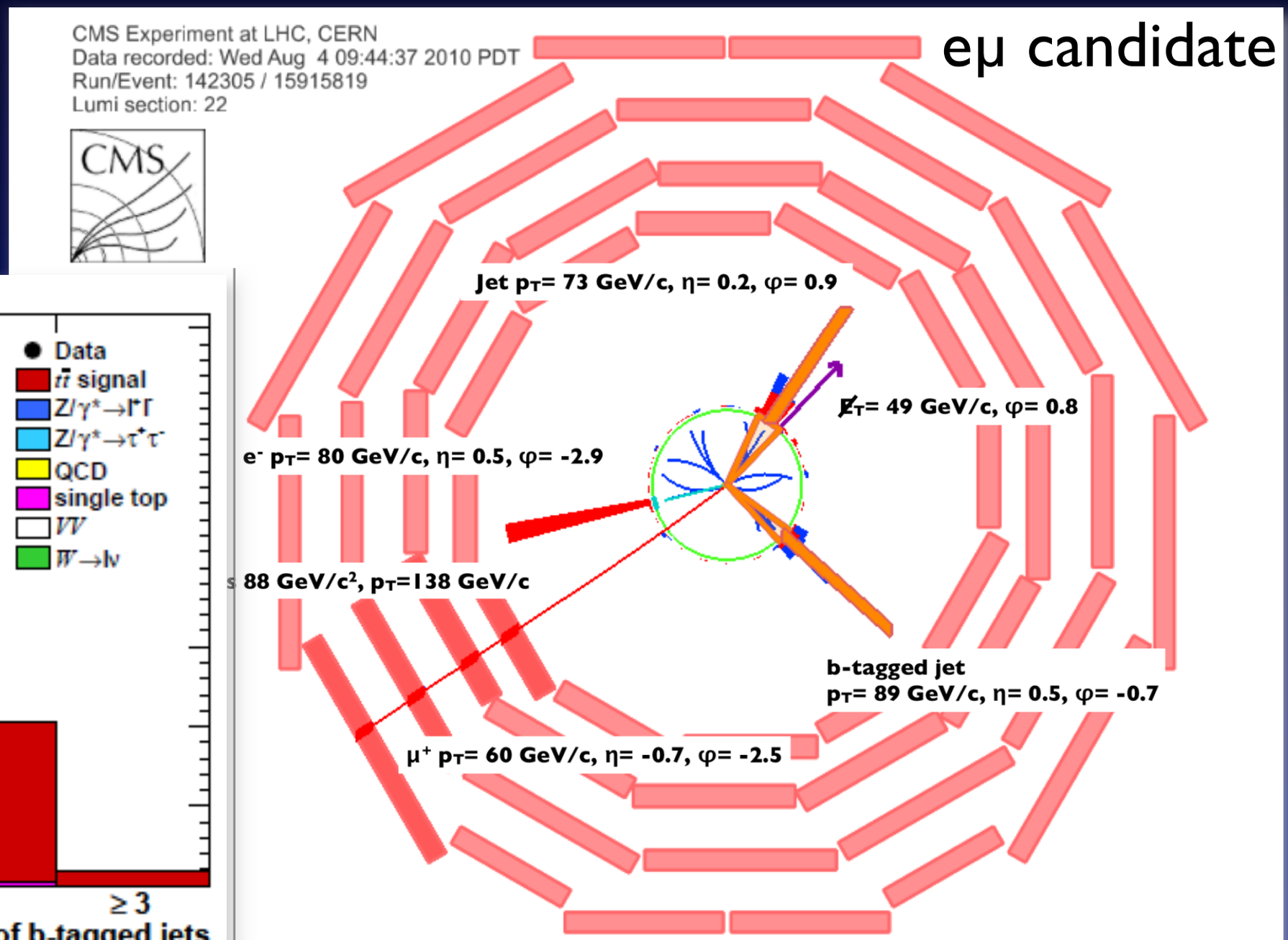
ee + eμ + μμ candidates

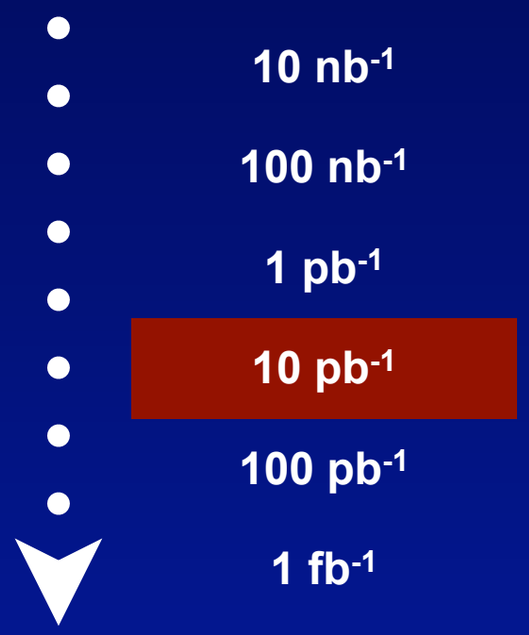


eμ candidate



“Exotic” Physics

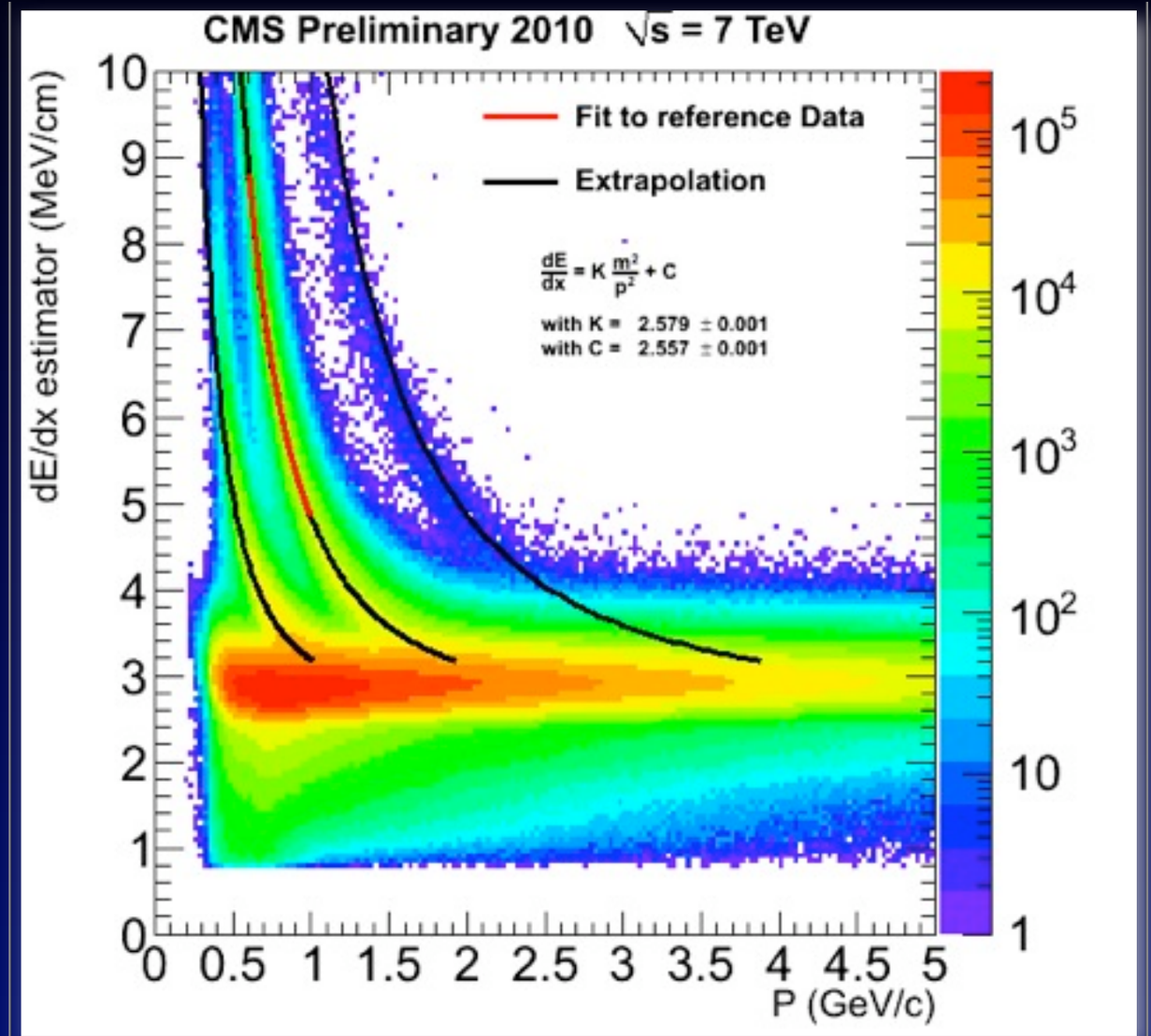
Challenging the Standard Model

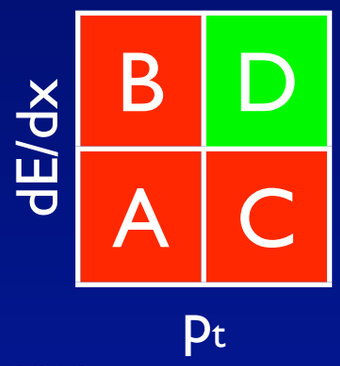


Heavy Stable Charged Particles

CMS PAS EXO-10-004

- Identify HSCP as it moves through the detector
  - **tracks with high p_t, high dE/dx**
    - "tracker-only" (silicon strip detector)
  - **additional selection: muon ID**
    - track+muon search
- Reconstruct mass from dE/dx
- Perform search
  - **counting experiment in masses 75-1200 GeV/c^2**
  - **data-driven prediction using side-bands**





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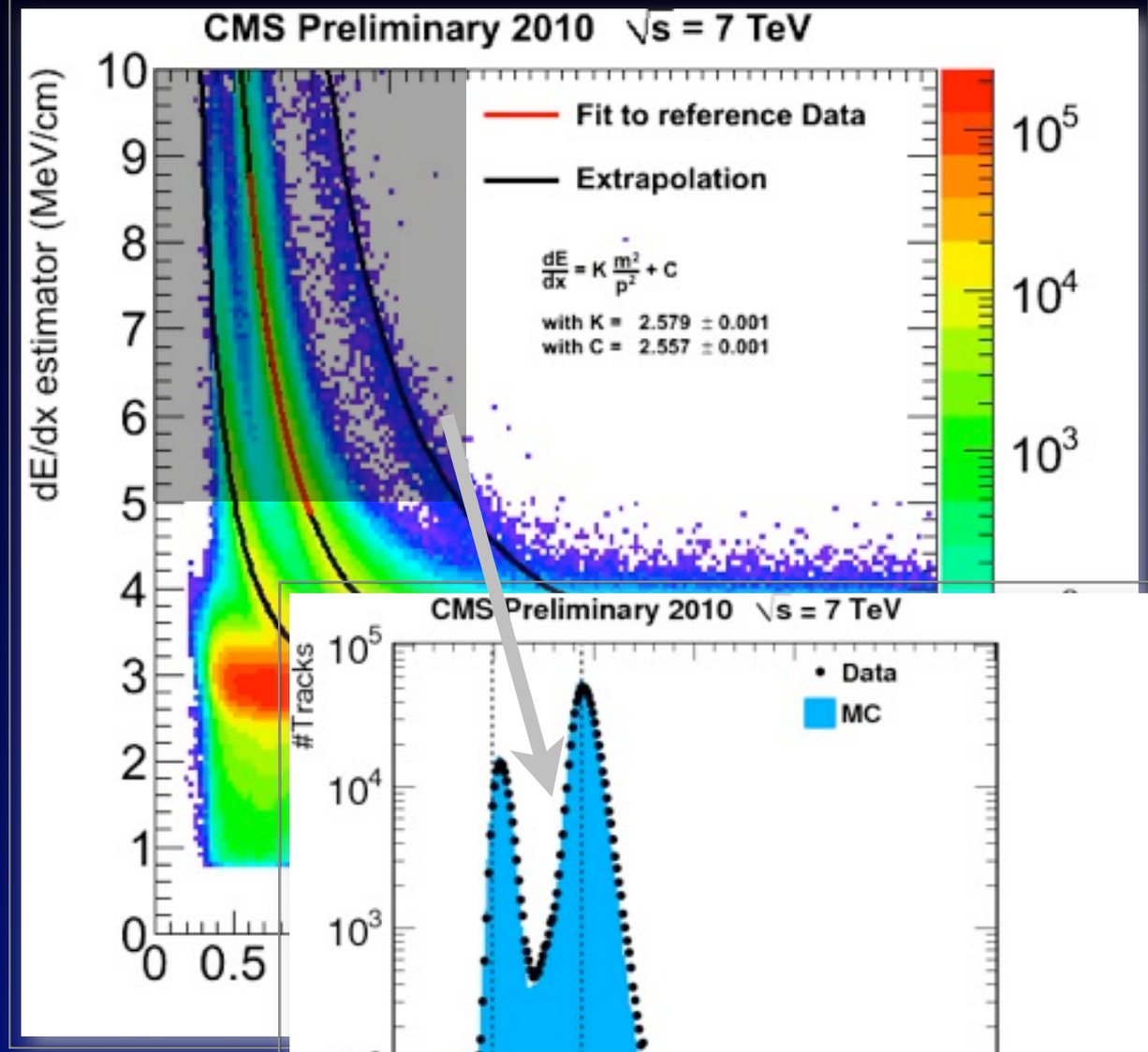
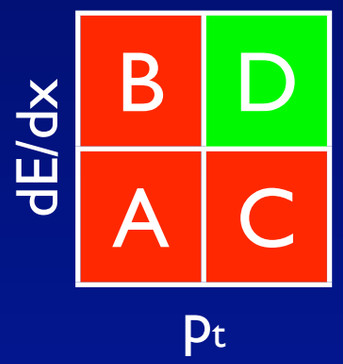
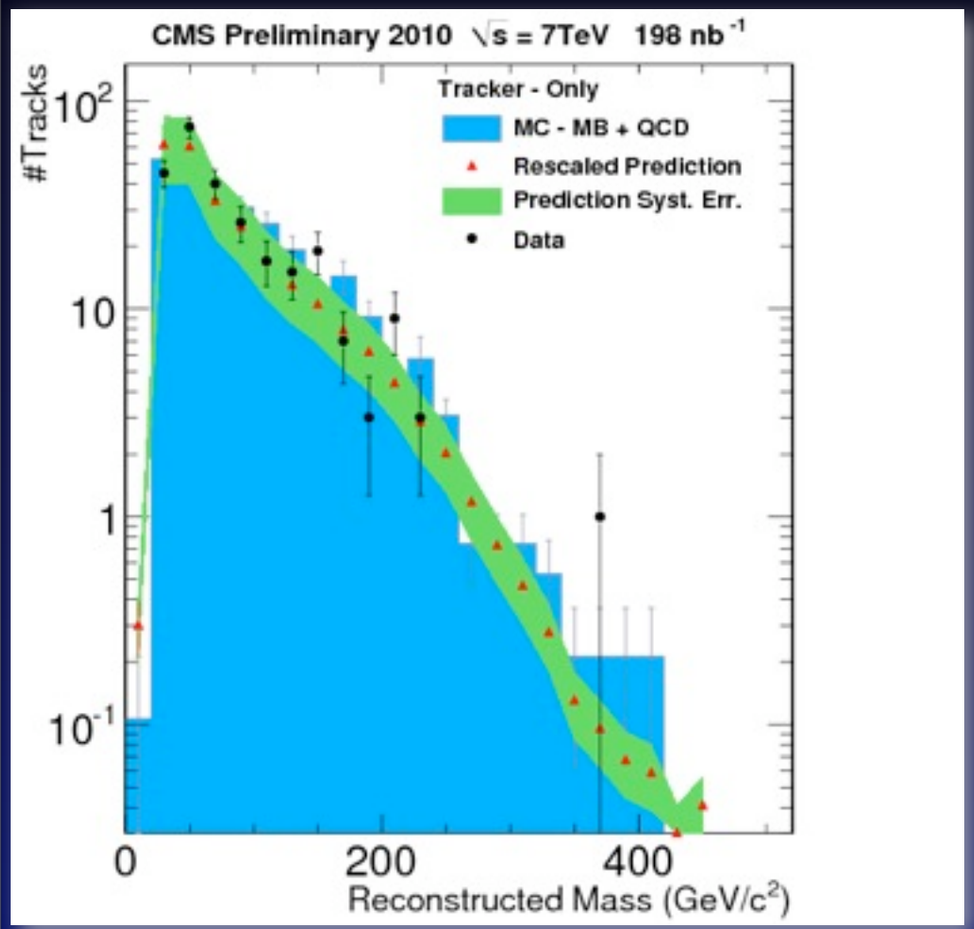
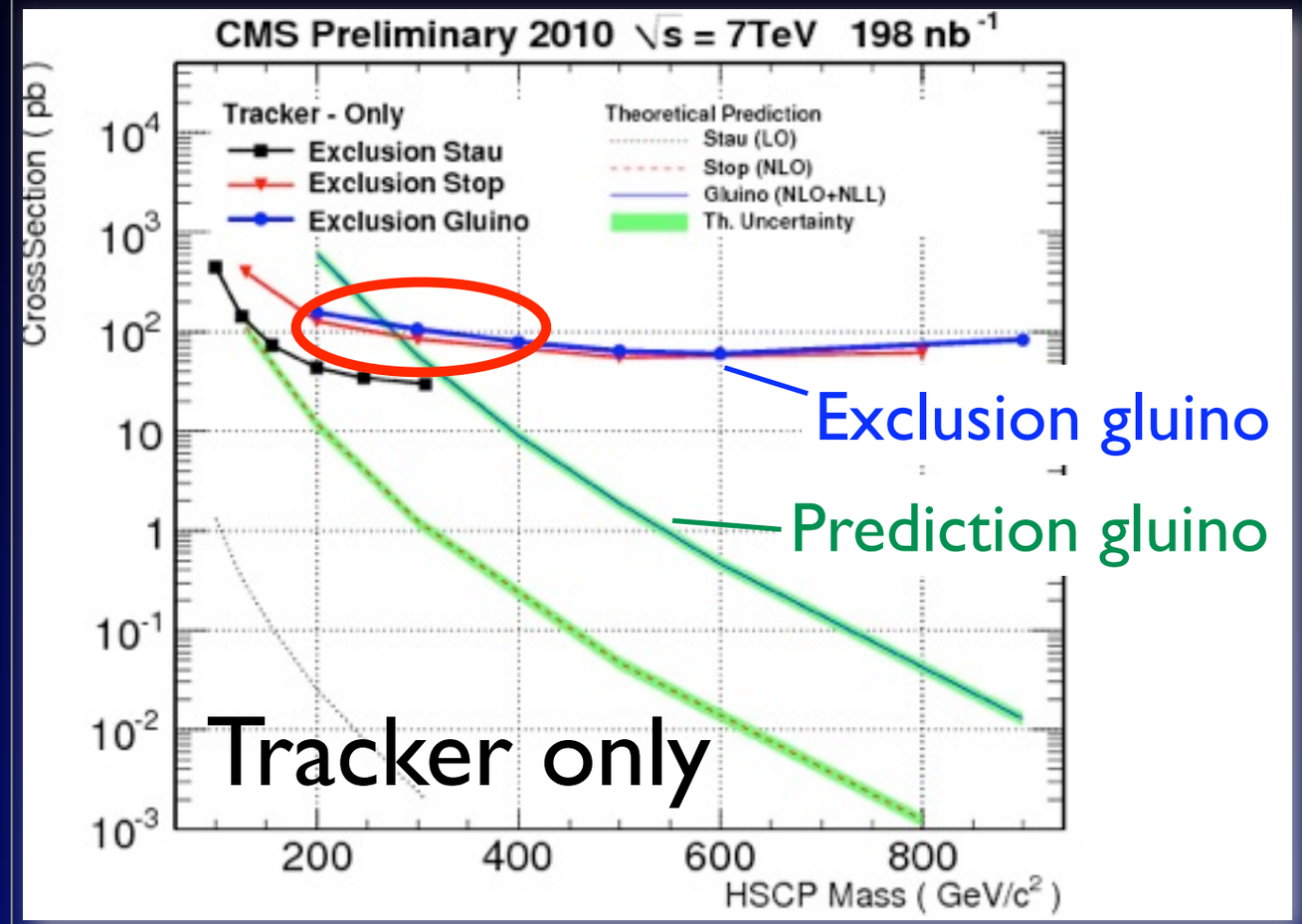




HSCP cross-section limits



Cross-check prediction in background-enhanced region (loose selection)

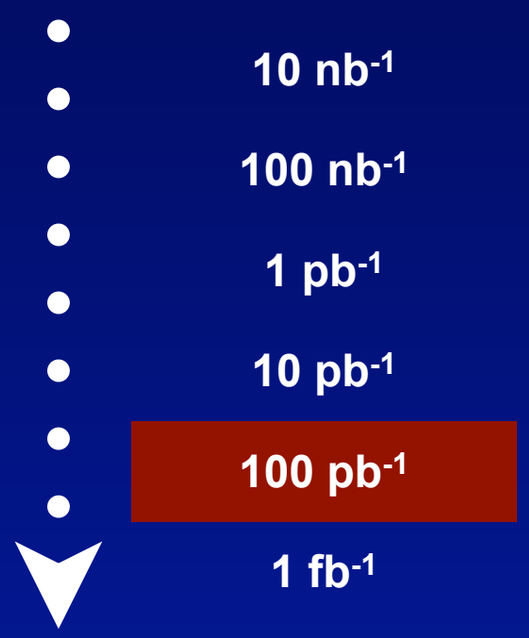


No event observed in signal region
➠ 95% CL upper limits

➠ **exclude $m_{gluino} < 271$ GeV/c^2 @ 95% CL (tracker-only)**
➠ **exclude $m_{gluino} < 284$ GeV/c^2 @ 95% CL(tracker+muon)**

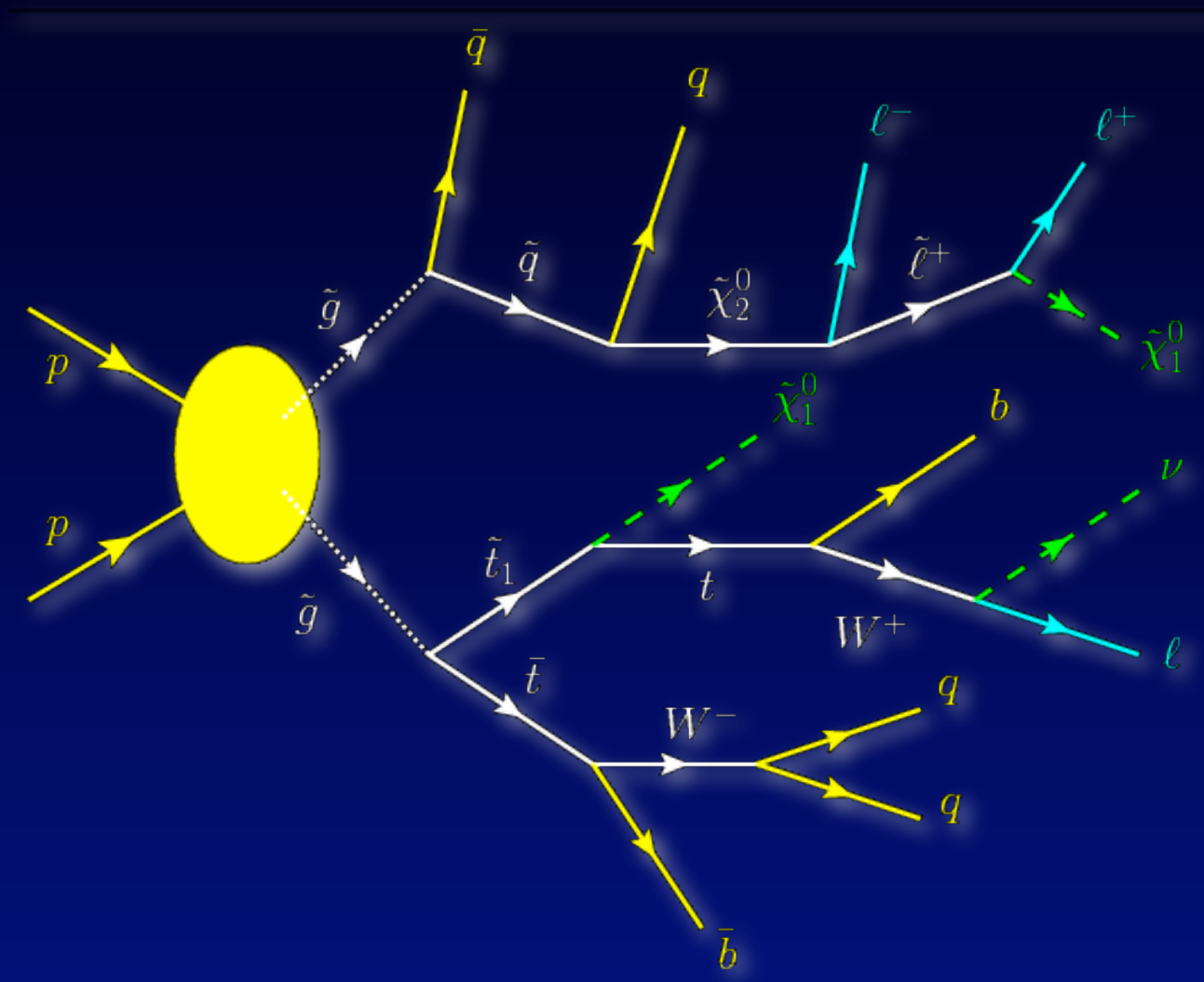
Supersymmetry

Challenging the Standard Model (bis repetita placent)



Searching for Supersymmetry

- SUSY Event topology
  - **low-p_t leptons**
  - **high jet multiplicity**
  - **large energy release (H_T)**
  - **missing energy**
- SUSY searches at CMS
  - **"all hadronic" (jets+MET)**
  - **leptonic (1,2,≥3 leptons+jets +MET)**
- Current emphasis (L<10/pb)
  - **validation of data-driven background extraction methods**



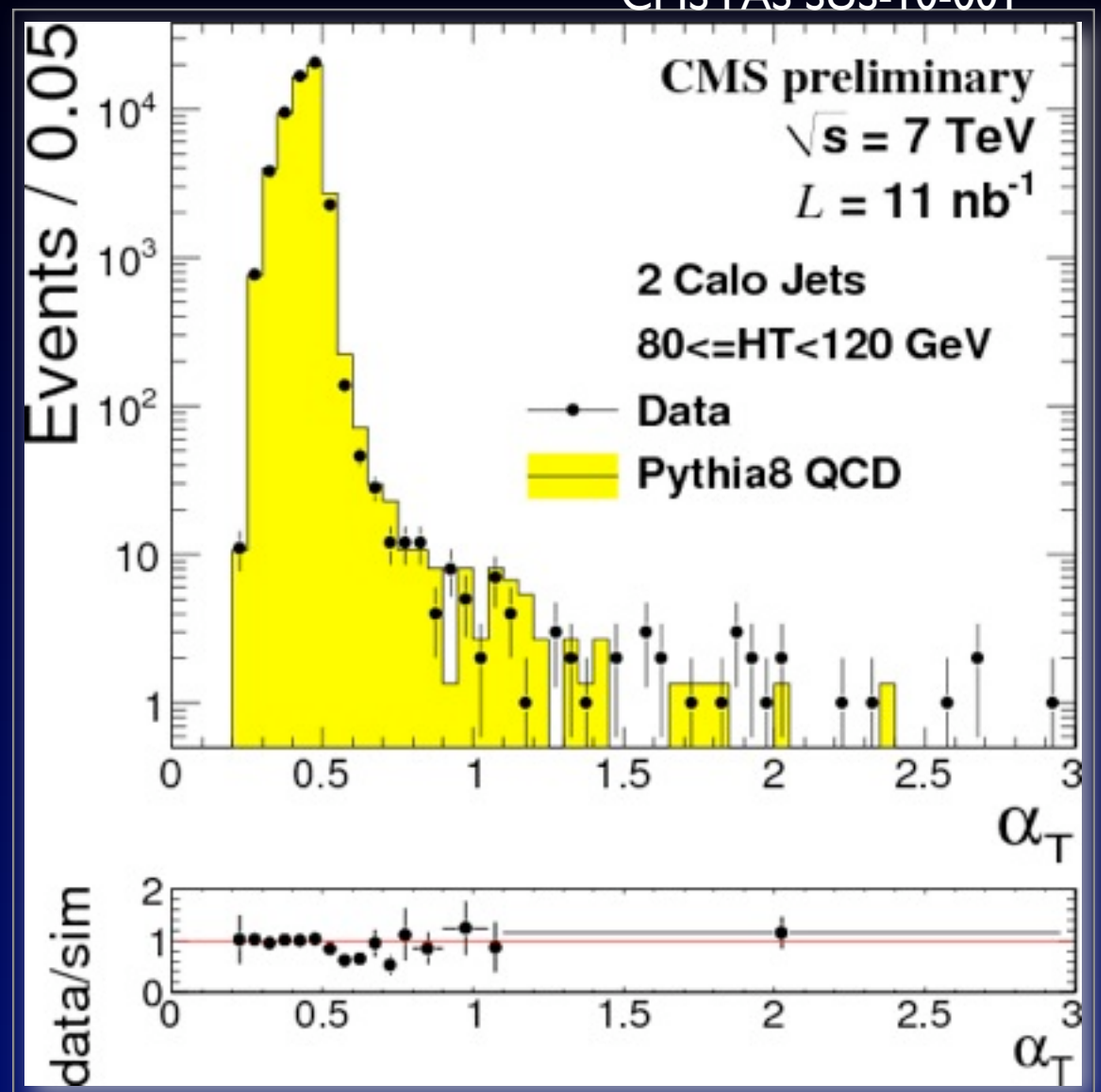
Hadronic searches

- Exclusive n-jet searches (n≥2)
  - **Suppress QCD with**

$$\alpha_T \equiv \frac{p_{T,2}}{M_T} = \frac{\sqrt{p_{T,2}/p_{T,1}}}{\sqrt{2(1-\cos\Delta\phi)}}$$

    - α_T=0.5 for perfectly balanced di-jet event
      α_T<0.5 if one jet mis-measured
  - **Steep fall observed in data**
    - Improves with H_T as expected
      - H_T = sum of jets p_T
  - **Use low-H_T distribution to estimate bkgd at high H_T**
    - normalise in high-η bin, since bkgd distribution flat in H_T, as verified in data
      - SUSY is more central

CMS PAS SUS-10-001



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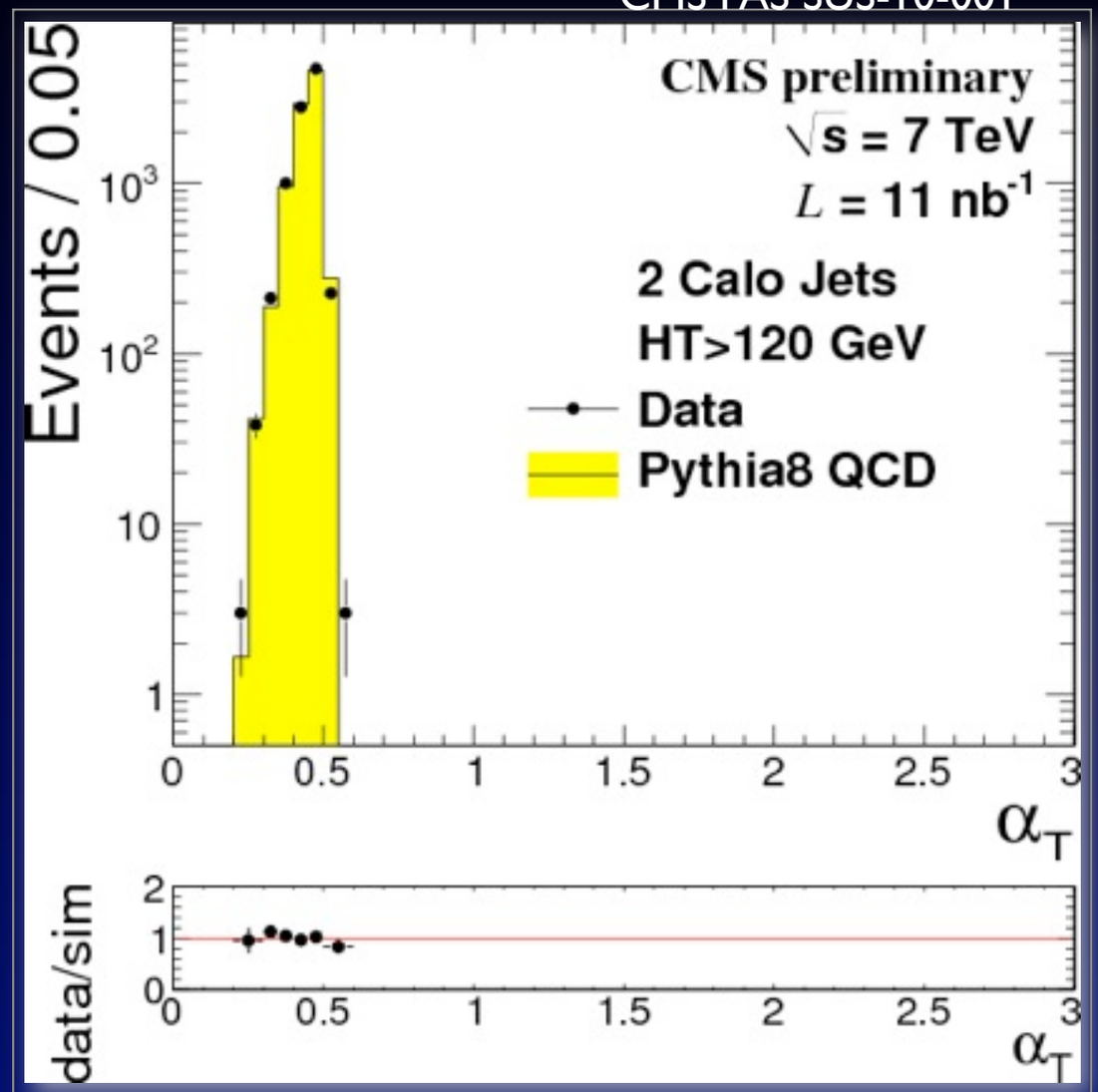

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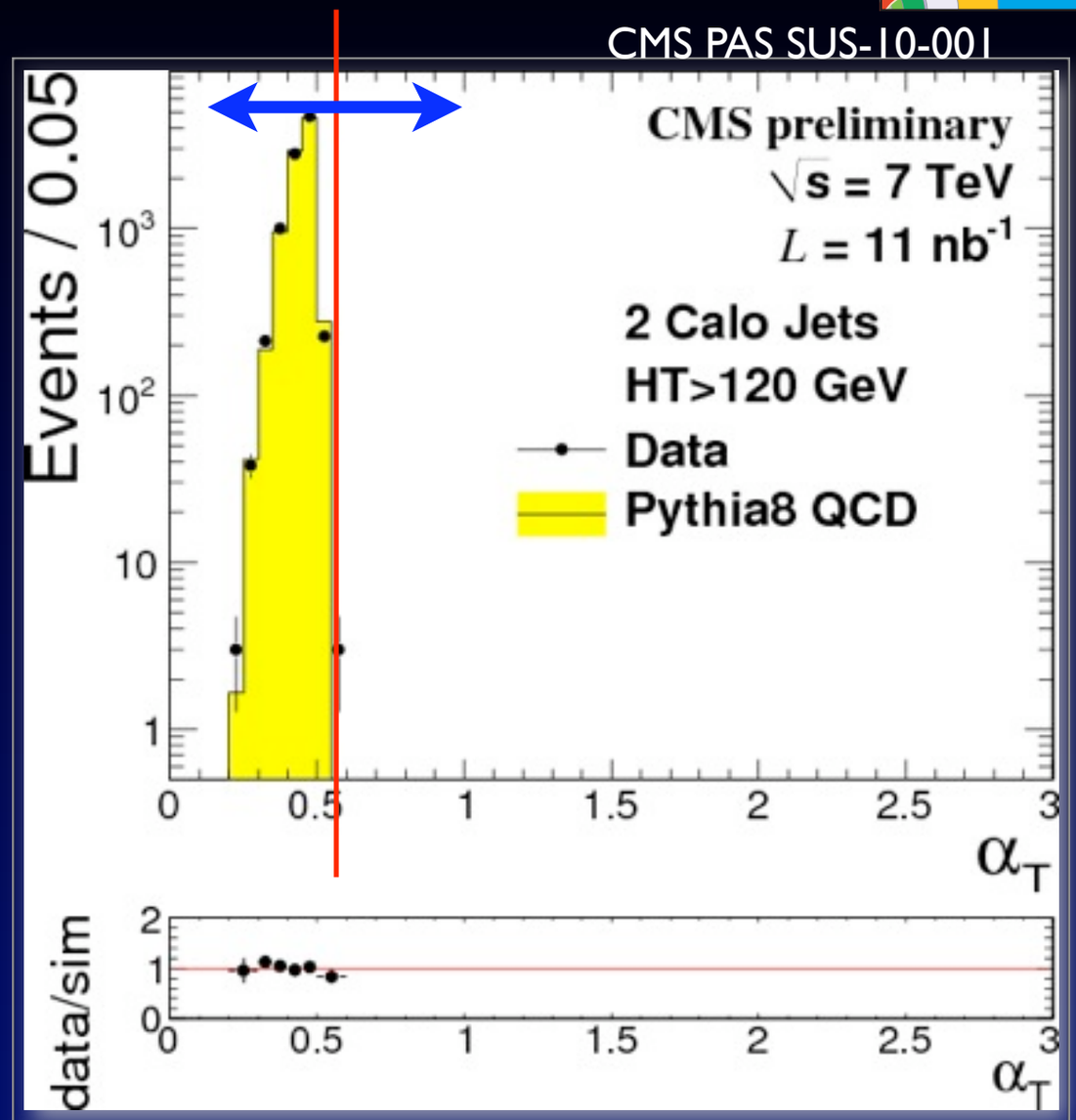

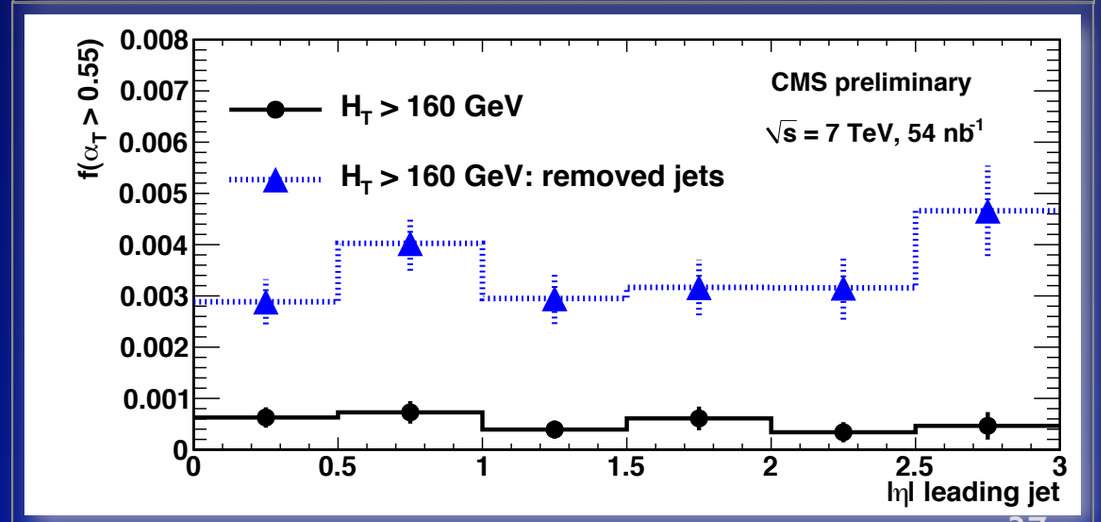

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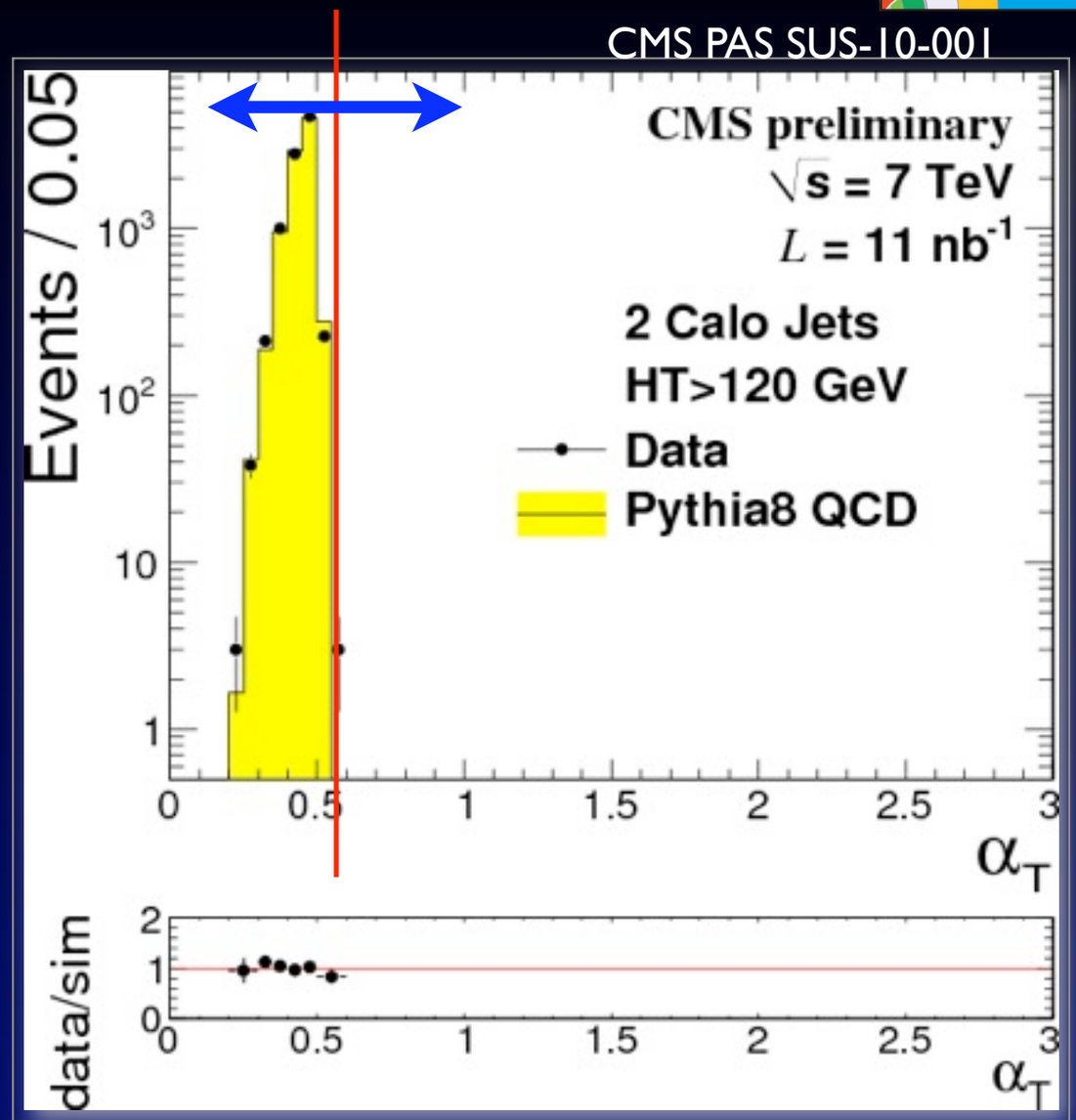
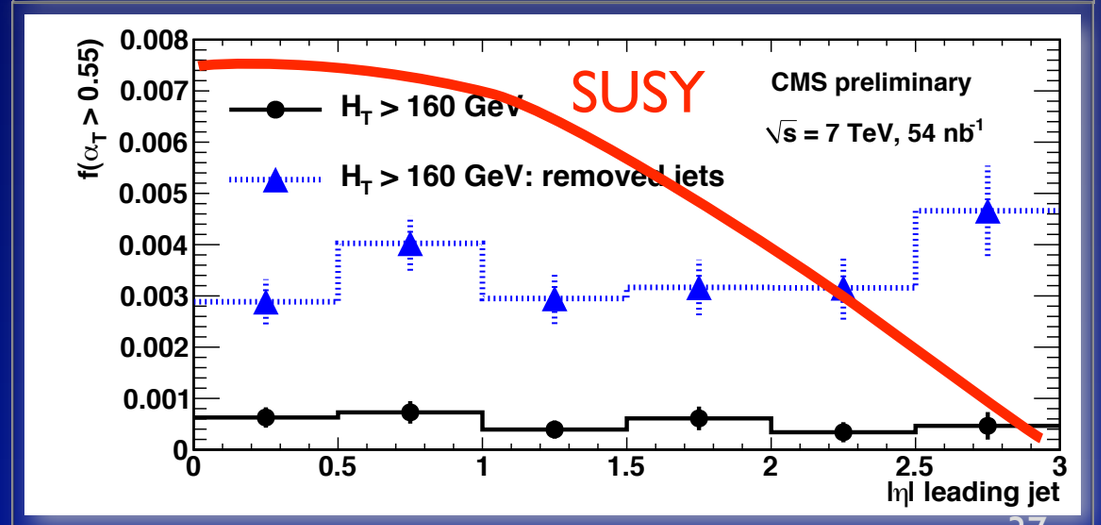


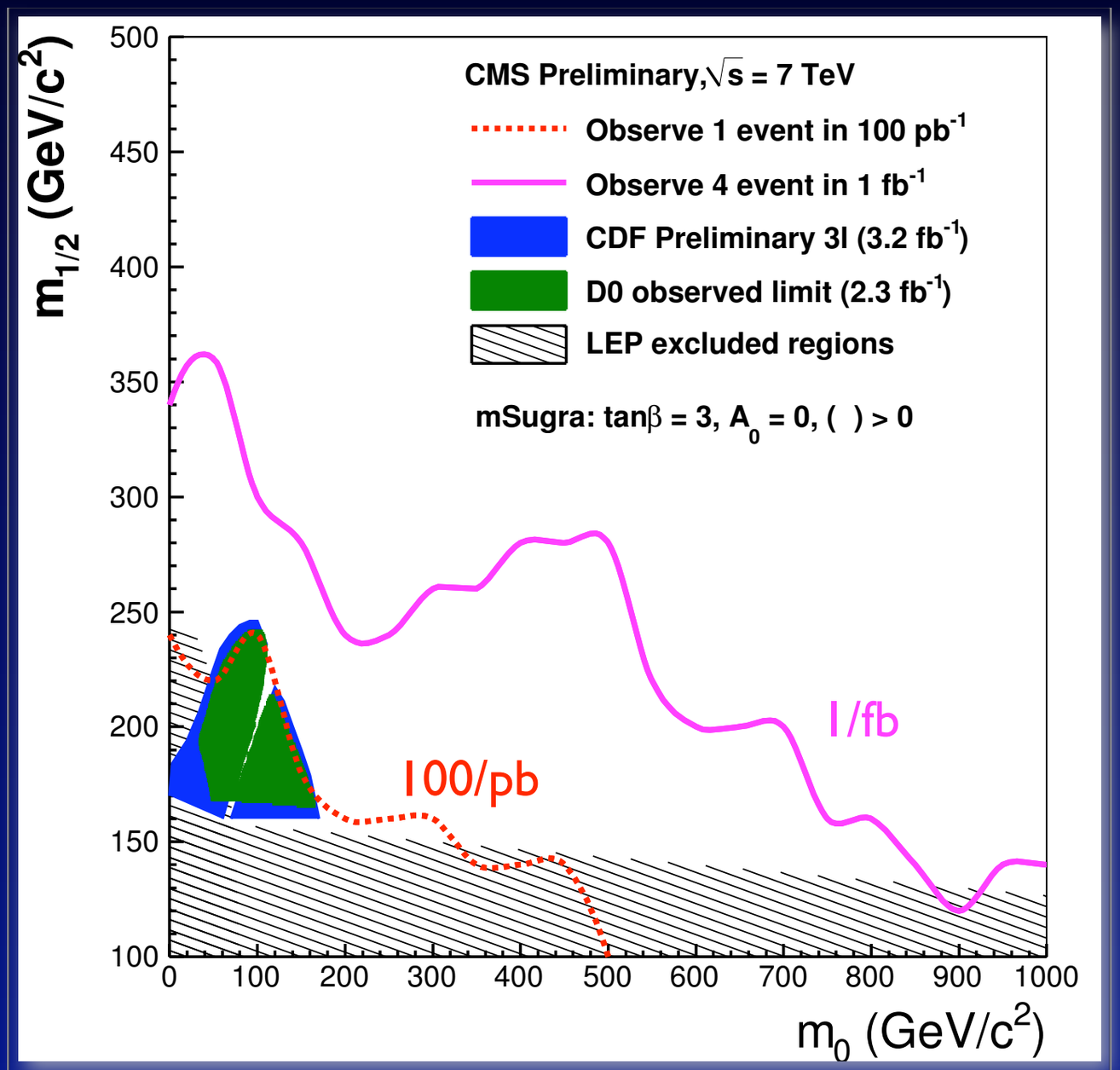


Same-sign dilepton searches

CMS NOTE-2010/008

- Event selection
  - **2 good and isolated same-sign leptons (ee,eμ,μμ)**
  - **≥3 jets, H_T > 200 GeV**
  - **missing energy**
- Very clean signature
  - **only SM background: $W^{\pm}W^{\pm}$**
  - **dominated by "fake" leptons, mainly from top**
  - **current emphasis (L < 50/pb) on controlling fake rates**
  - **$t\bar{t}$ studies as a first stage**

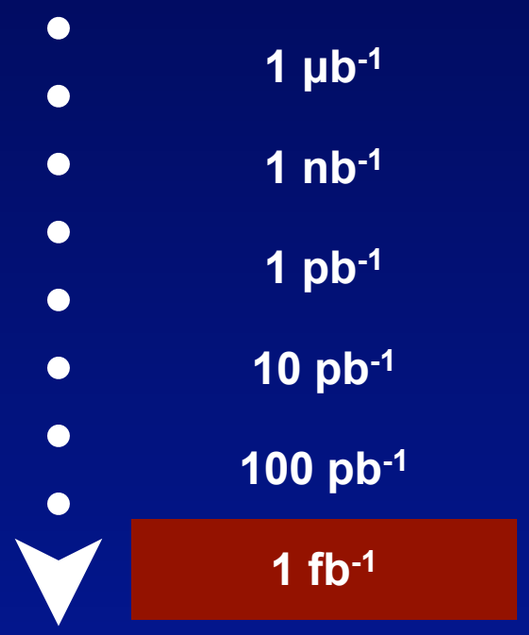
95% CL limits, mSugra



Outlook

What next?

- B Physics
  - **b-jet correlations**
  - **(rare) B_s decays, B_c, Λ_b**
- QCD and EWK Physics
  - **event shapes with higher p_t bins, MC tuning**
  - **W and Z boson p_t spectrum ➠ constraints on PDFs and MC models**
  - **on the way to H→WW, H→ττ**
- Exotic Physics
  - **tighten constraints on HSCP**
- Supersymmetry (and top on the way)
  - **add b-tagging to enhance signal**
  - **SS and OS dileptons (through SUSY Z channel)**



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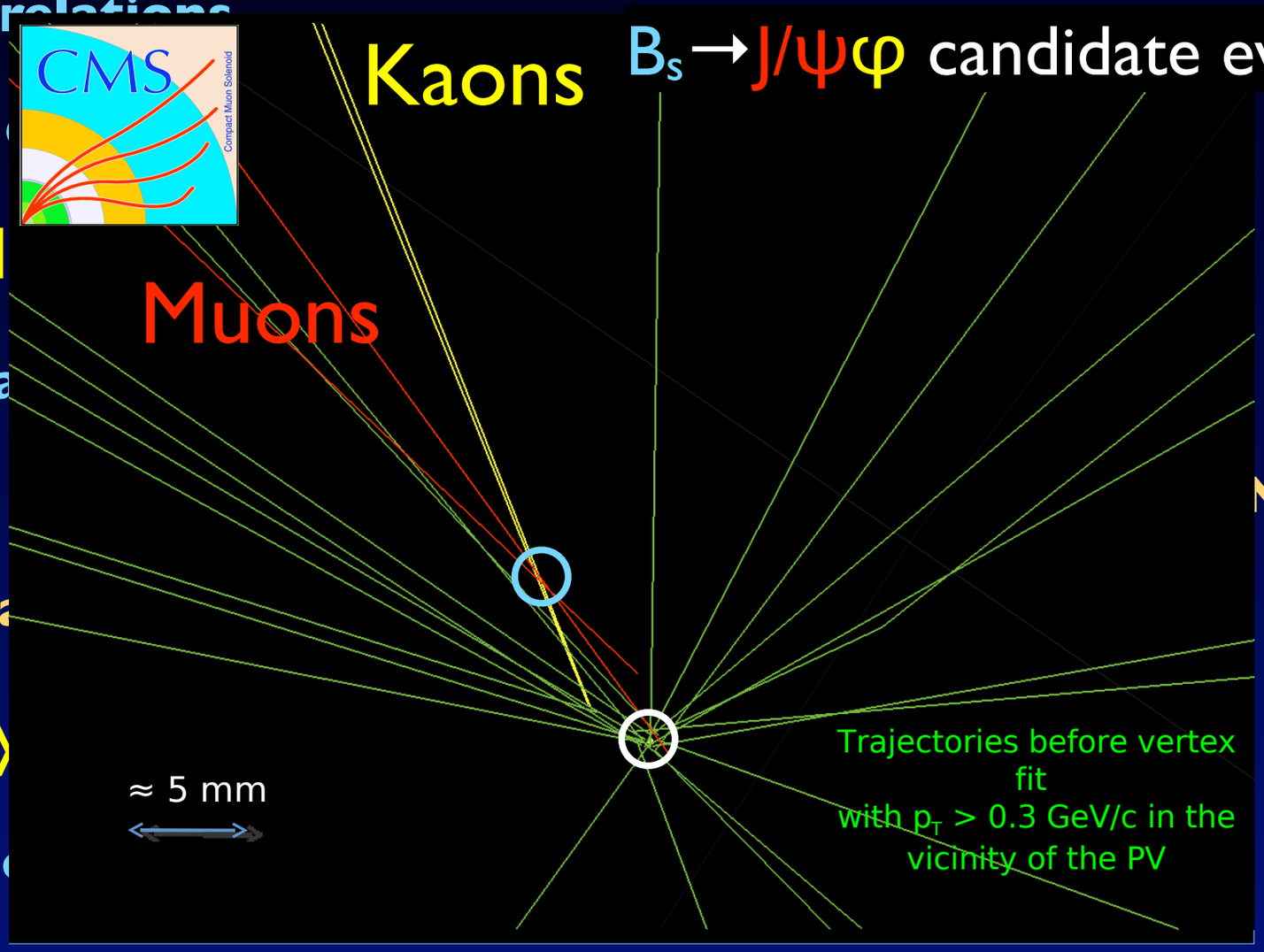

- 1 μb^{-1}
- 1 nb^{-1}
- 1 pb^{-1}
- 10 pb^{-1}
- 100 pb^{-1}
- 1 fb^{-1}

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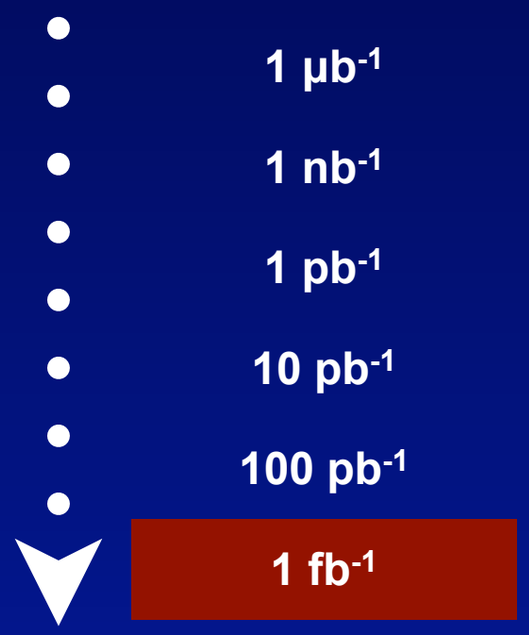

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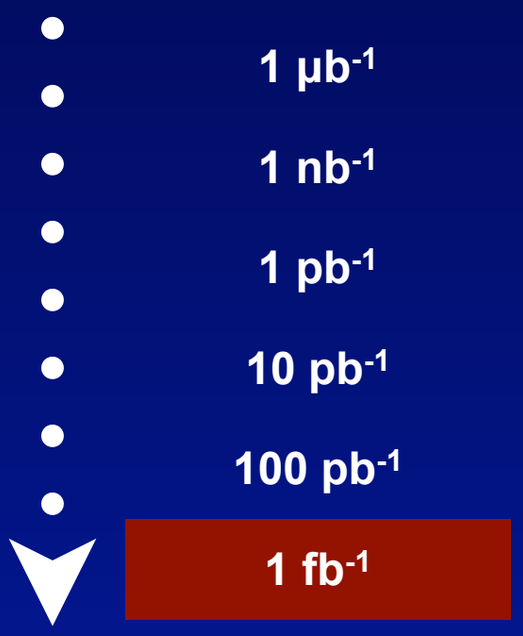
Entering the *discovery realm*



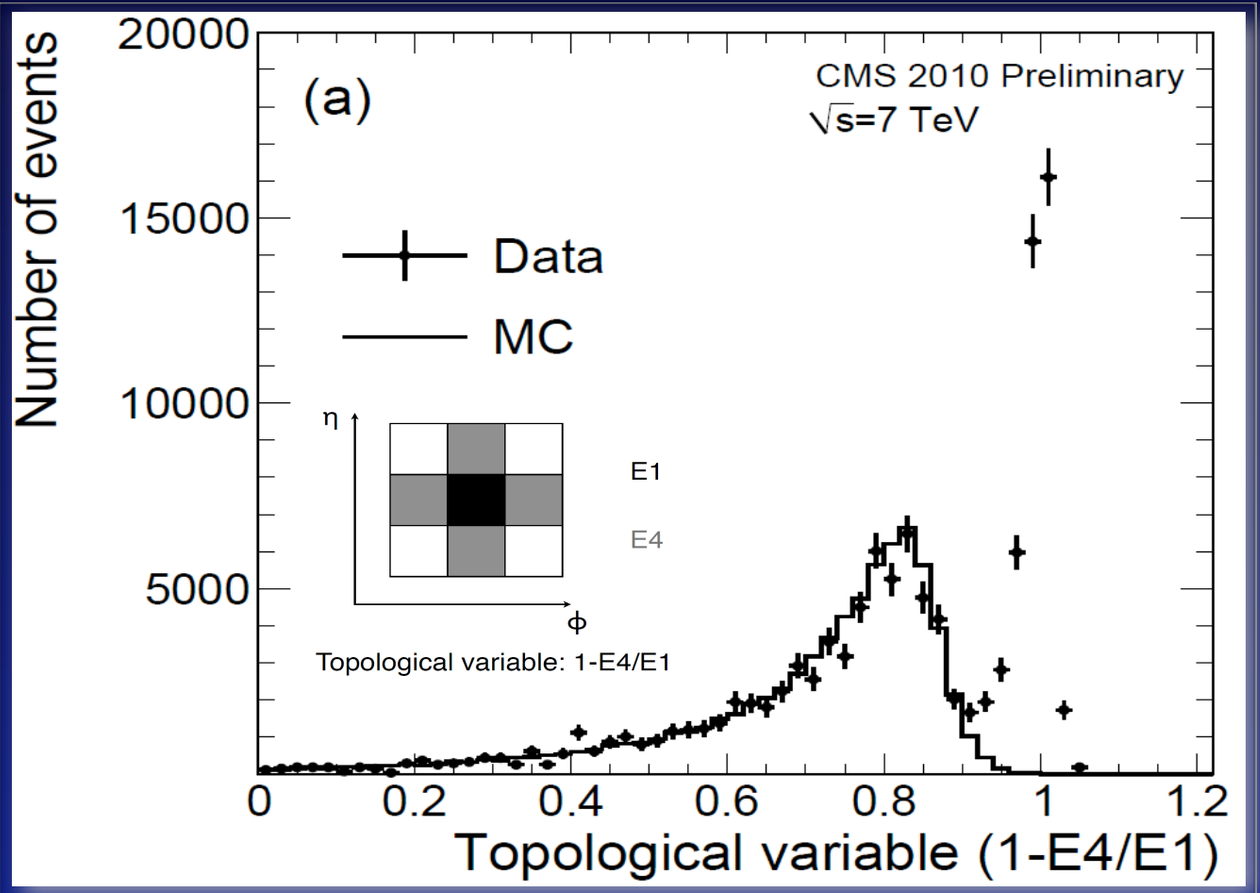
Summary

- Strong involvement of Swiss institutes in CMS Physics
  - **many contributions to conference results (more to come...)**
  - **coordination at various levels**
- CMS already has rich harvest of results
  - **precision tests of QCD**
  - **(re-)discovery of Standard Model (at 7 TeV!)**
  - **challenges to the Standard Model**
- More to come soon!
  - **hope for a very rich first LHC run**
  - **and more at the CHIPP workshop next week!**

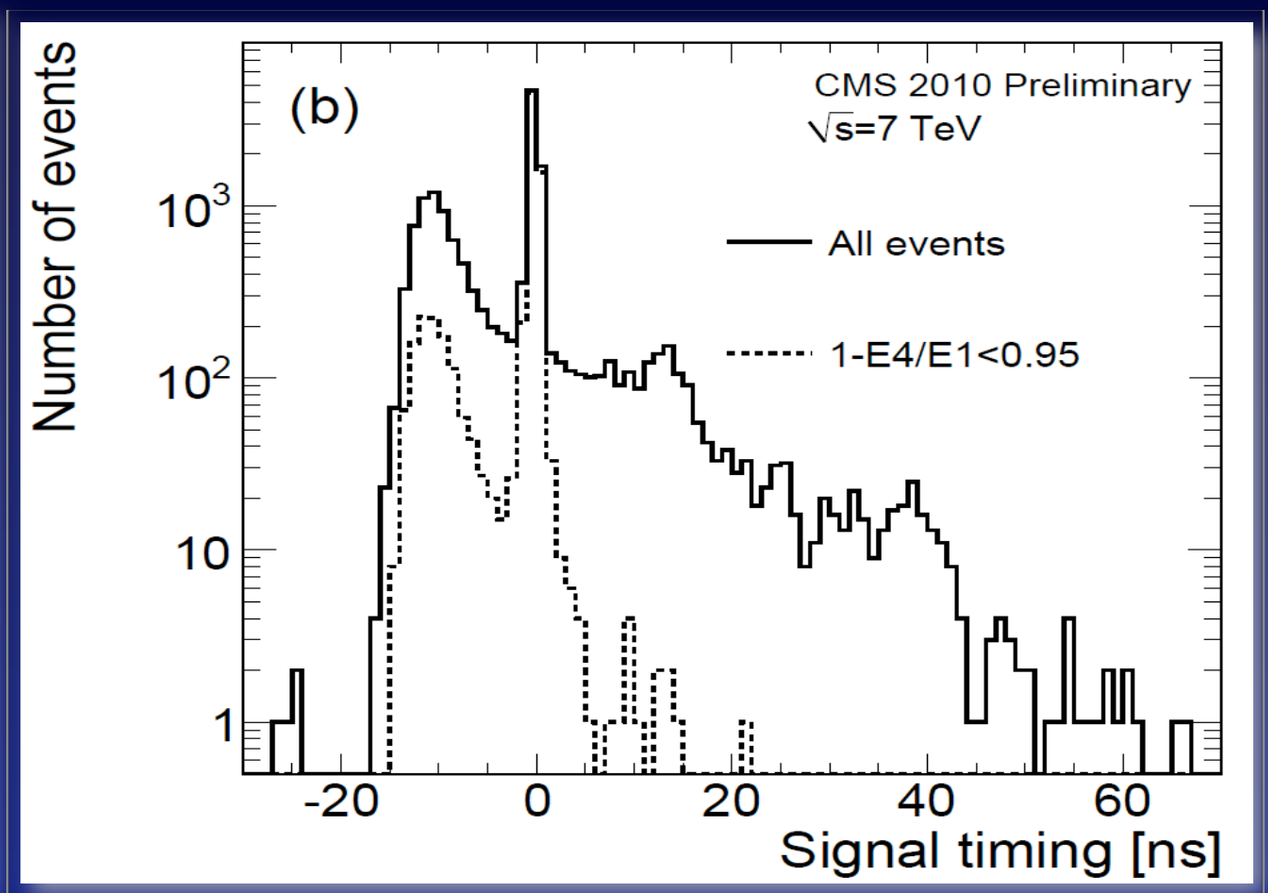
Backup

Anomalous ECAL signals

- Direct ionisation of read-out photodiode by highly ionising secondary particles
  - **removed by topological and timing cuts (signal shape discrimination also under investigation)**



Topological distribution of energy



Anomalous signals are out of time

R-hadrons

http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/Conferences/2005/MoriondQCD05_Kraan.pdf

R-parity conserved, stable $\tilde{g}$ hadronizes to **R–hadrons**

- R-mesons: $R = \tilde{g}q\bar{q}, (\tilde{q}\bar{q}) \rightarrow R^+, R^-, R^0$
- R-baryons: $R = \tilde{g}qqq, (\tilde{q}qq) \rightarrow R^{++}, R^+, R^-, R^0$
- R-gluinoballs: $R = \tilde{g}g \rightarrow R^0$

Gluino R-hadron production at LHC:

- $pp \rightarrow \tilde{g}\tilde{g}$
- $pp \rightarrow \tilde{g}\tilde{q} \rightarrow \tilde{g}\tilde{g}q$
- $pp \rightarrow \tilde{q}\tilde{q} \rightarrow \tilde{g}\tilde{g}qq$

NB1: heavy hadrons also predicted in theories with leptoquarks, extra dimenstions, GUT...

NB2: Stable gluinos at LHC mass ranges not excluded by accelerator experiments or cosmology

Aafke Kraan, March 2005, La Thuile – p.5/22