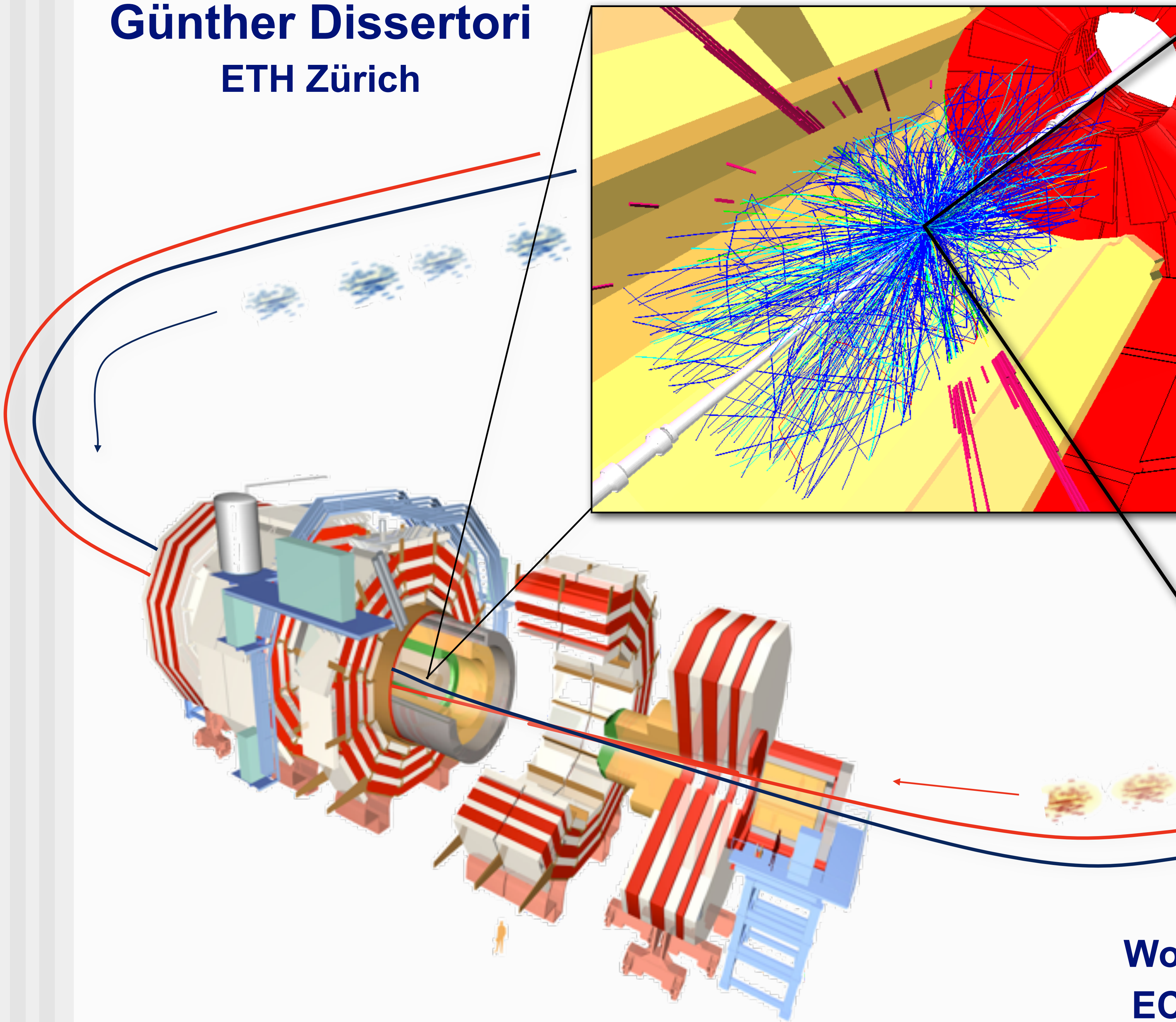
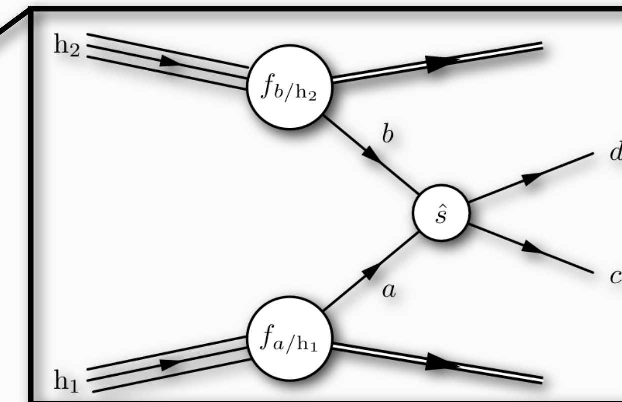
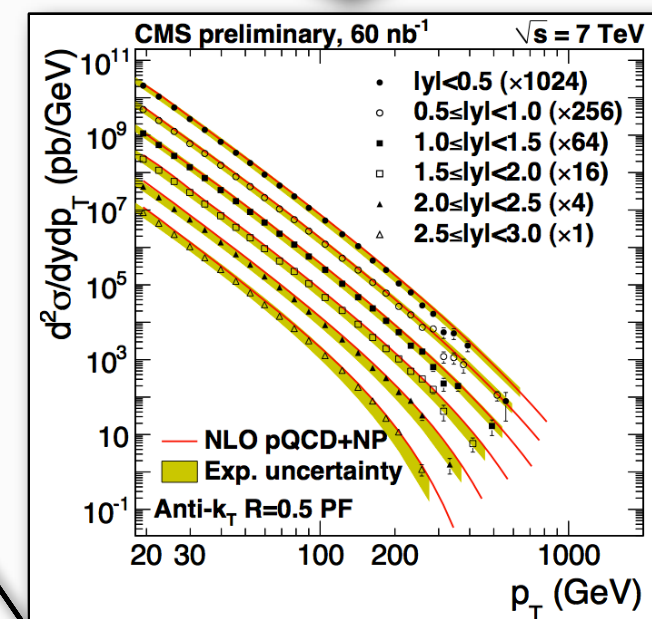
QCD Results from CMS

Günther Dissertori

ETH Zürich





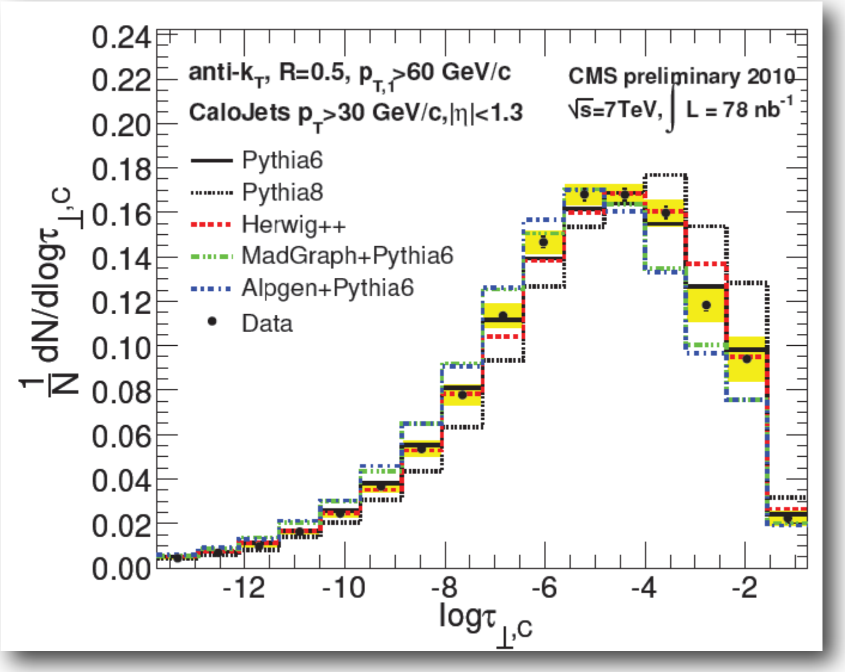


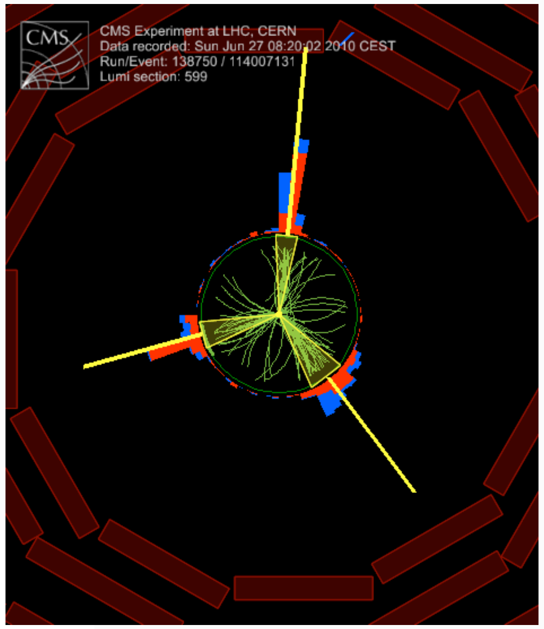
Workshop: QCD at the LHC

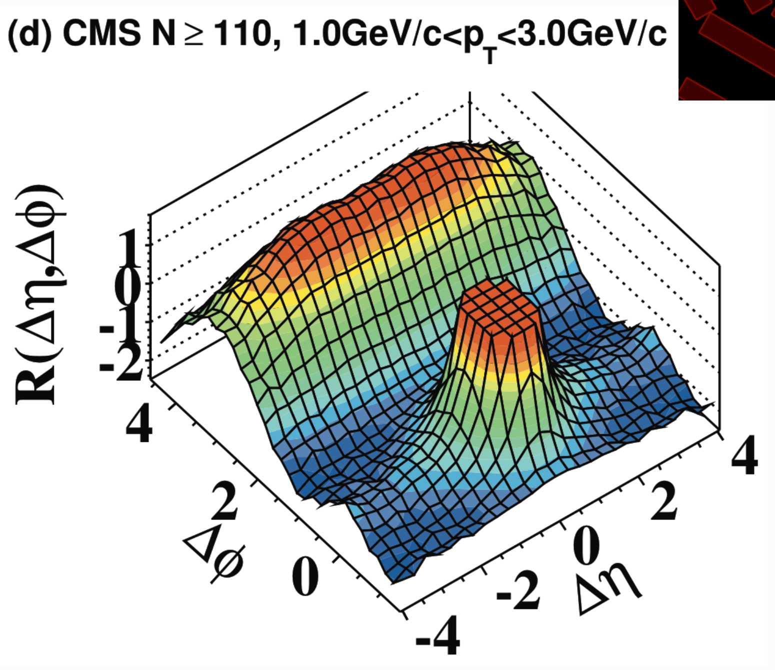
ECT*, Trento, Sep 27, 2010

Outline

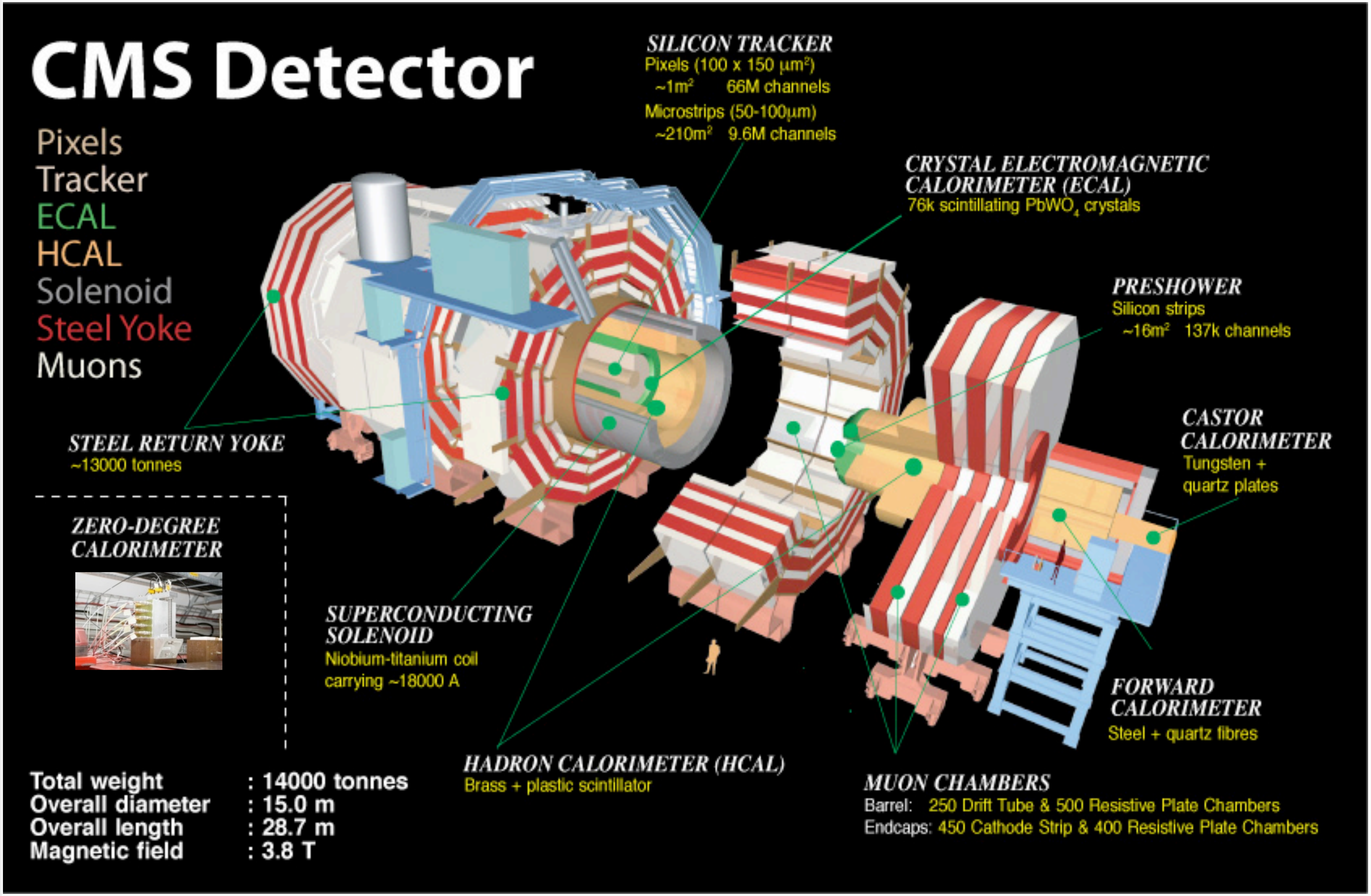
- Introduction
  - CMS operations
  - Ingredients (Jets, Pflow, ...)
- High-p_T Jet Physics
  - Incl jet cross section
  - Di-jet observables
  - Multi-jet studies
  - W+jets
  - Jet structure
- Forward/Diffractive results
- Low(er)-p_T Physics
  - Underlying Event studies
  - Particle Production in MB events
  - Particle correlations
- Conclusions







The CMS Detector



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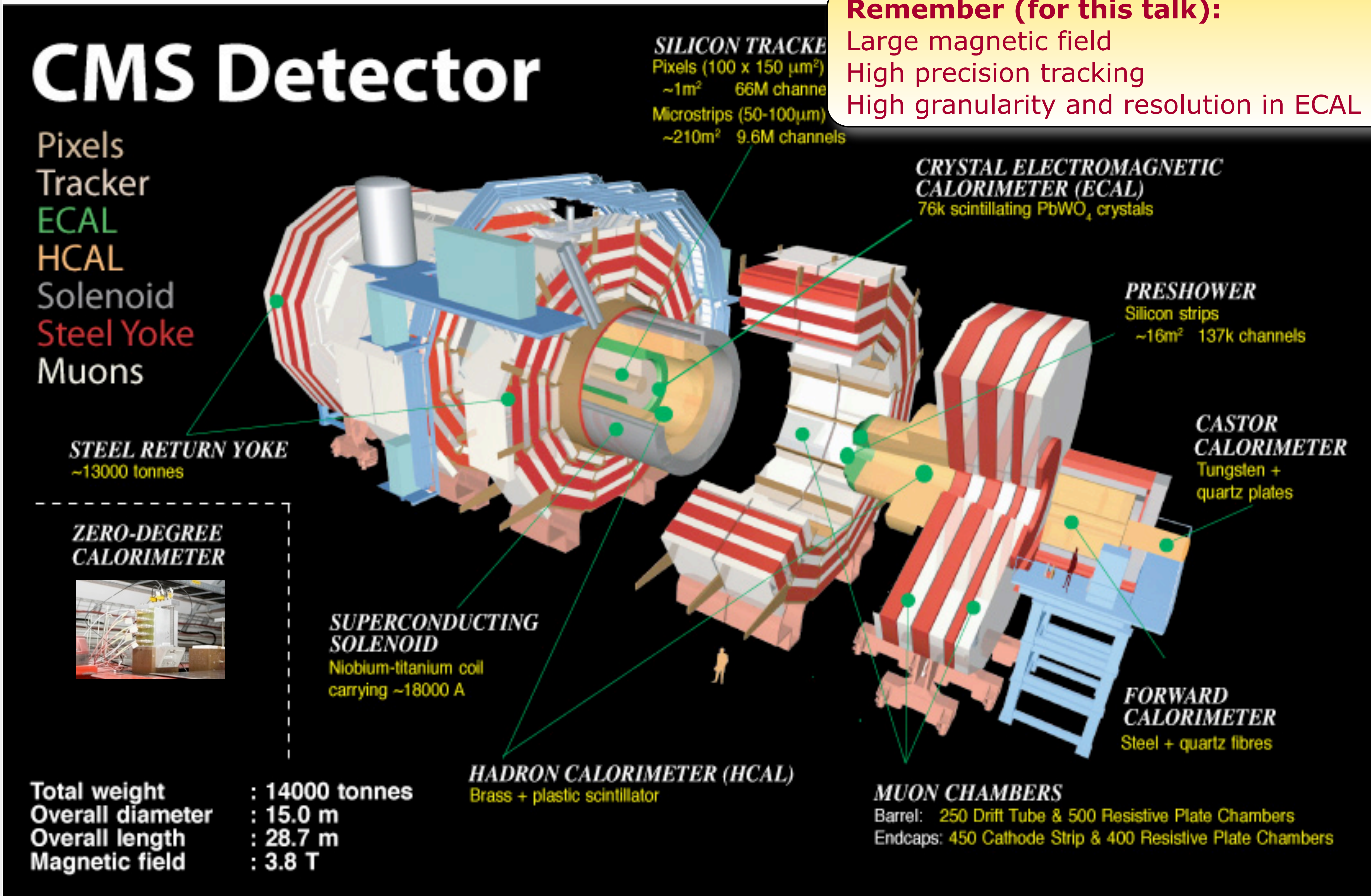
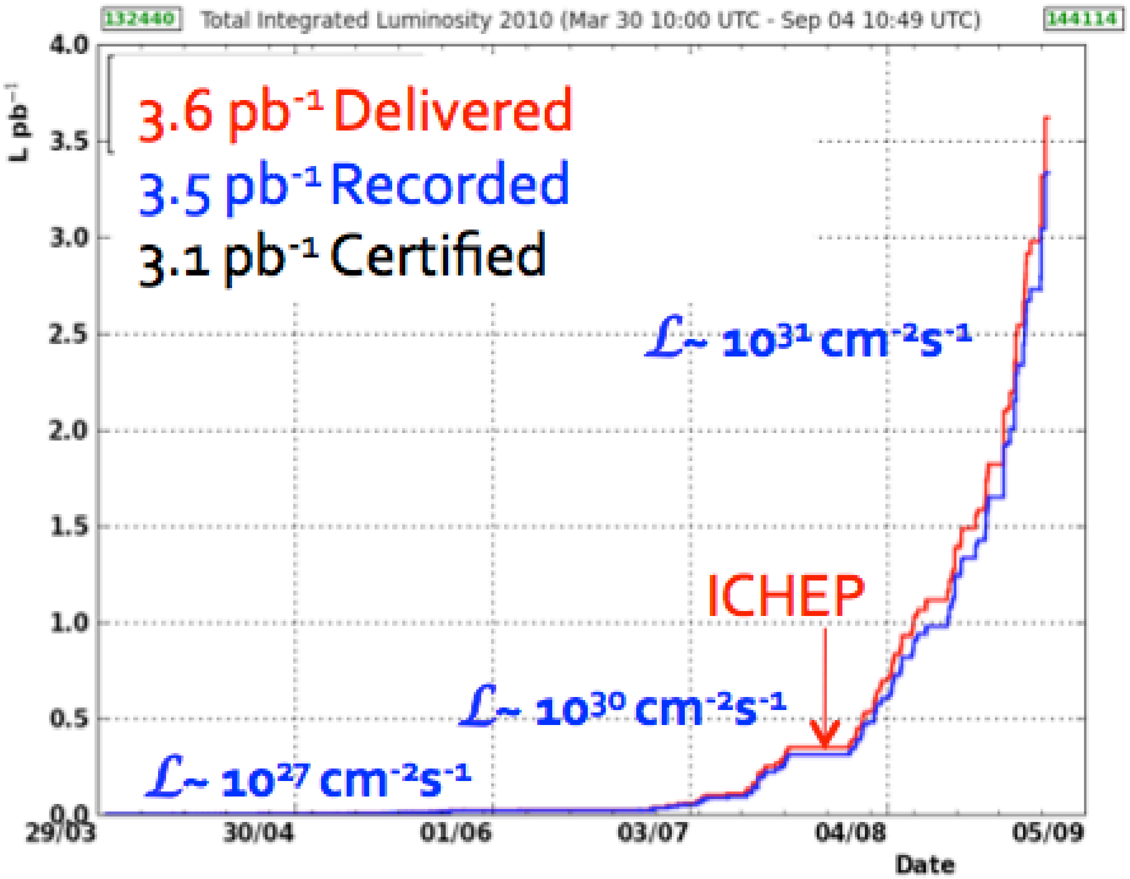
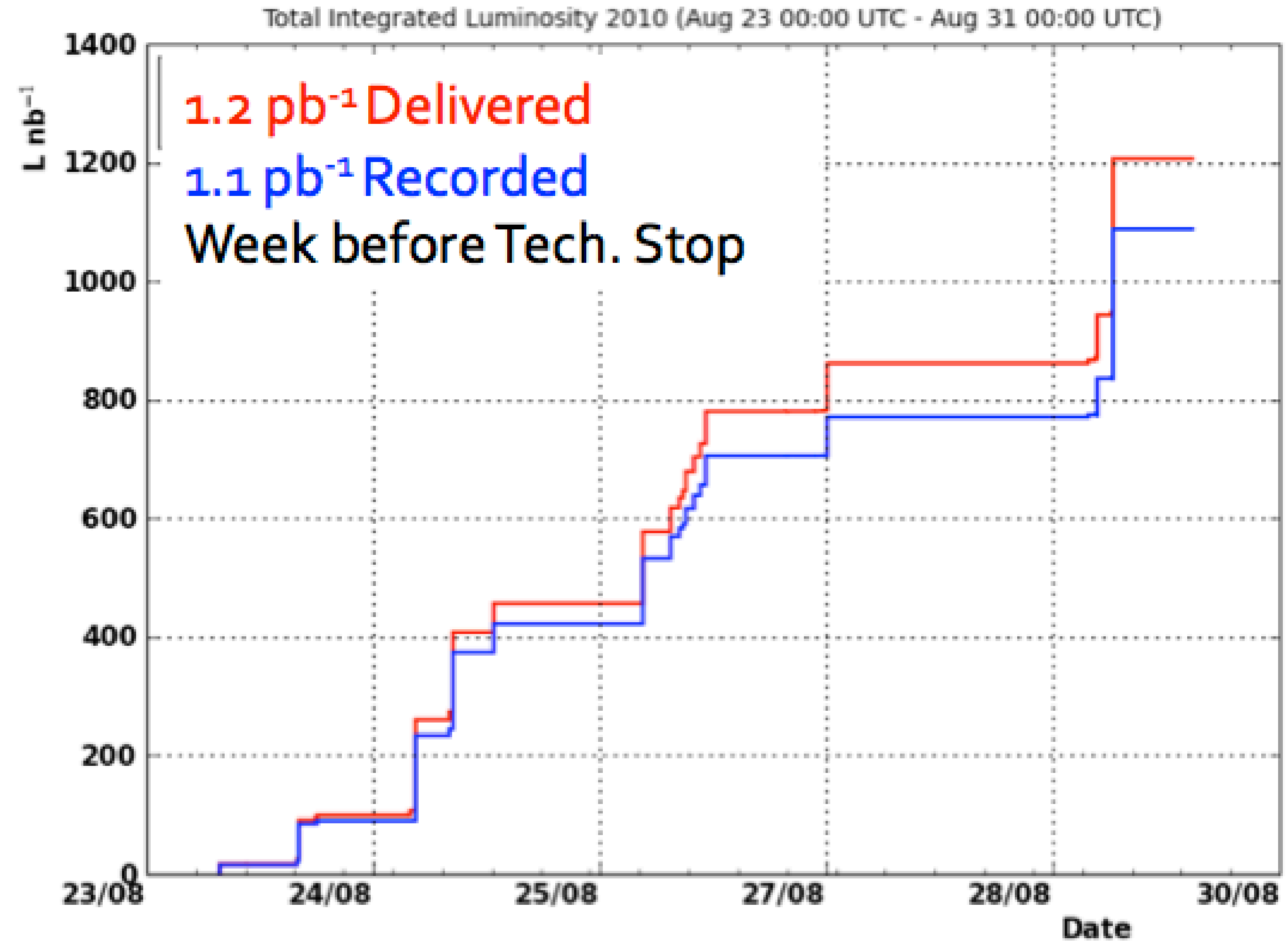


Remember (for this talk):
Large magnetic field
High precision tracking
High granularity and resolution in ECAL

Lumi: Delivered and Recorded



- Excellent performance for more than 4 orders of magnitude increase in $\mathcal{L}$
  - Highest luminosity to date at CMS $\mathcal{L}=1.07\times10^{31}\,cm^{-2}s^{-1}$



- Efficiency over 90% this year
  - Recently > 96% at high $\mathcal{L}$
  - Certified ("perfect") > 85% of all
- Short $\int\mathcal{L}dt$ doubling times:
  - New conditions mean new issues

As of Aug 31 Technical Stop

slide by J. Incandela

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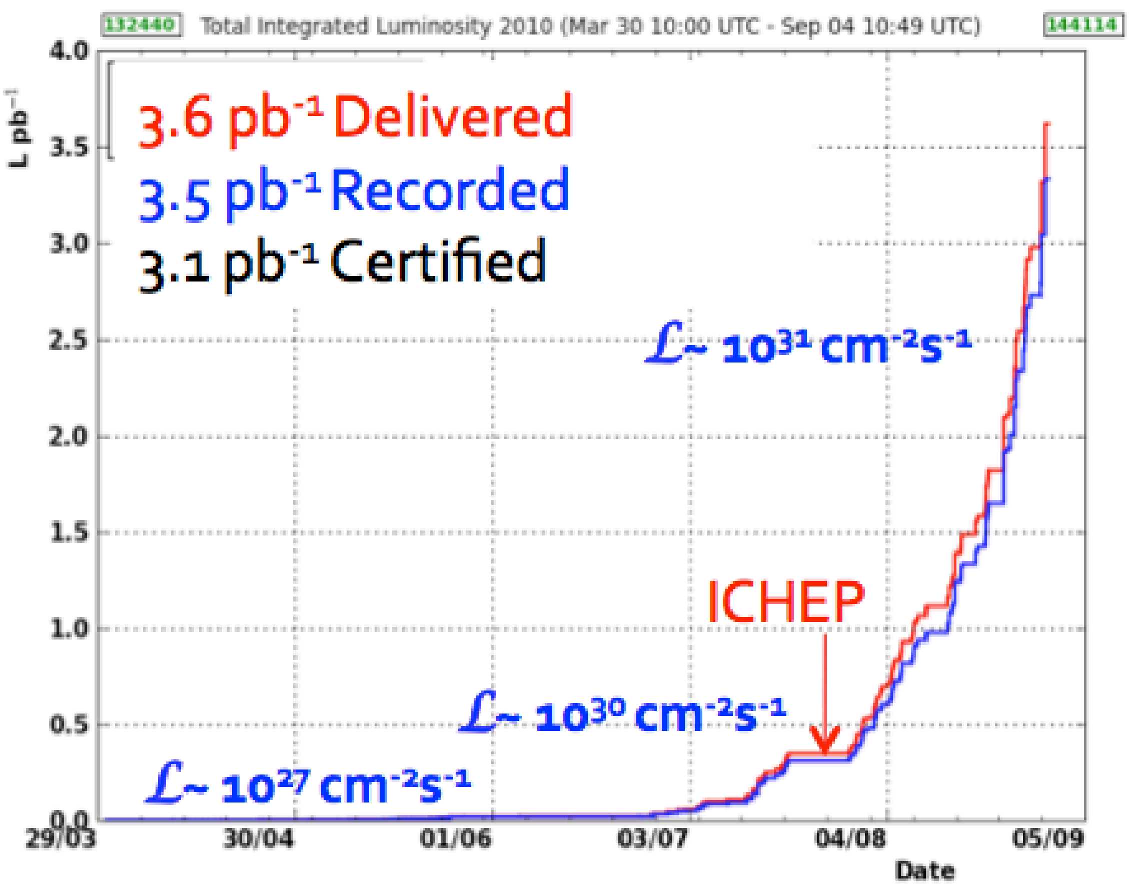

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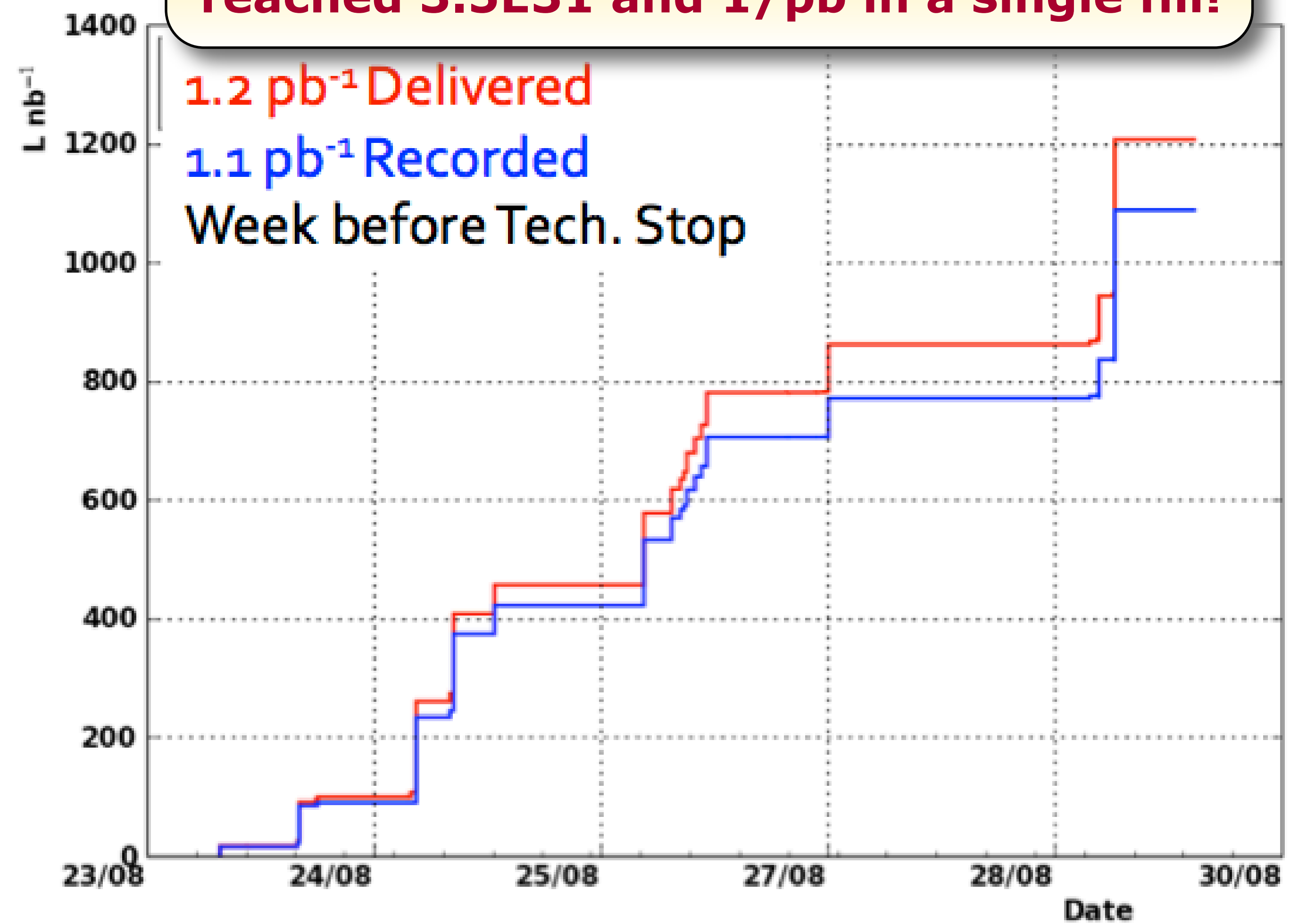
Hot off the press: Saturday-Sunday: reached 3.5E31 and 1/pb in a single fill!



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**As of Aug 31 Technical Stop*

slide by J. Incandela

The ingredients for the preparation of our today's menu:

Tracking
Jet Reconstruction

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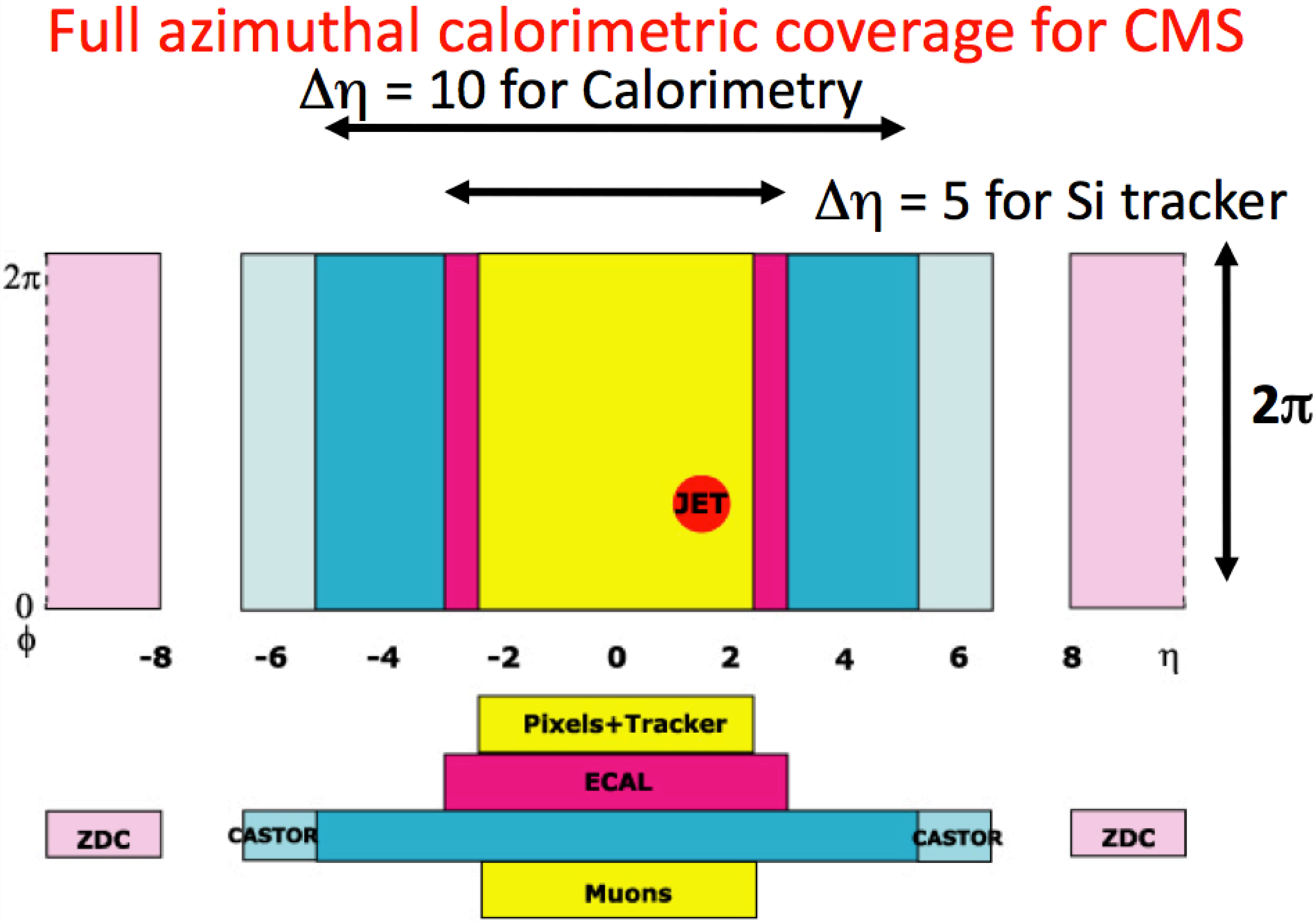
Tracking
Jet Reconstruction

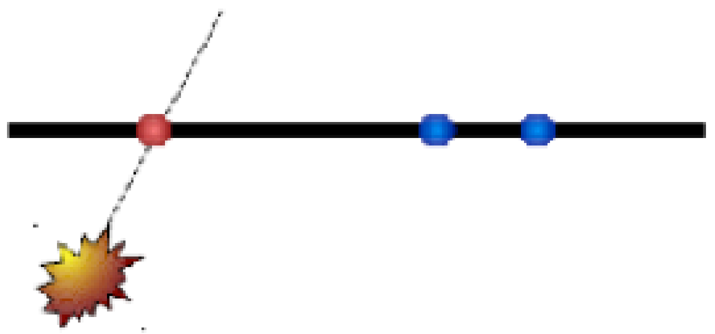
Observed so far:
Excellent performance in Physics Object Reconstruction
(Tracks, Electrons, Photons, Muons, Jets, MET, Particle Flow)

The CMS coverage

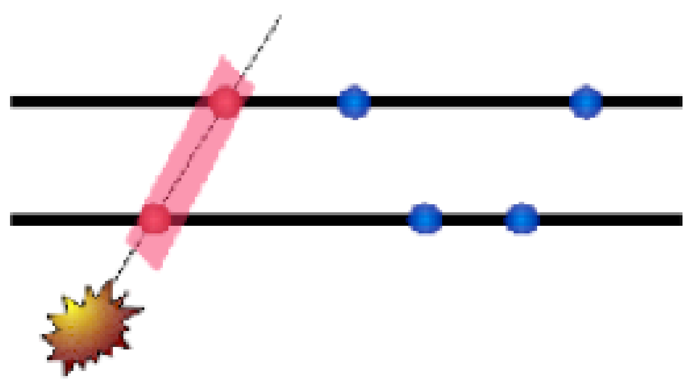


slide by S. Salur

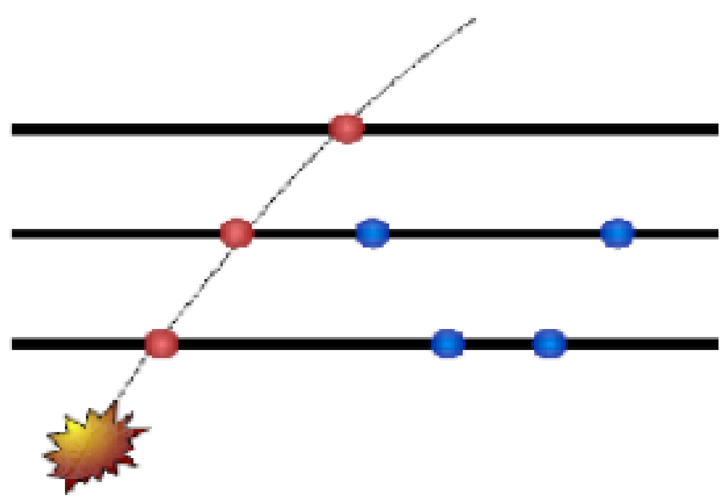
Track finding/counting down to low p_T



- Pixel hit counting (1 hit)
  - Using the primary vertex, calculate η for each cluster
  - Immune to detector mis-alignment, simplest
  - $p_T > 30$ MeV/c, $|\eta| < 2$



- Tracklets (2 hits)
  - Form hit pairs, calculate η
  - Data-driven background subtraction
  - $p_T > 50$ MeV/c, $|\eta| < 2$



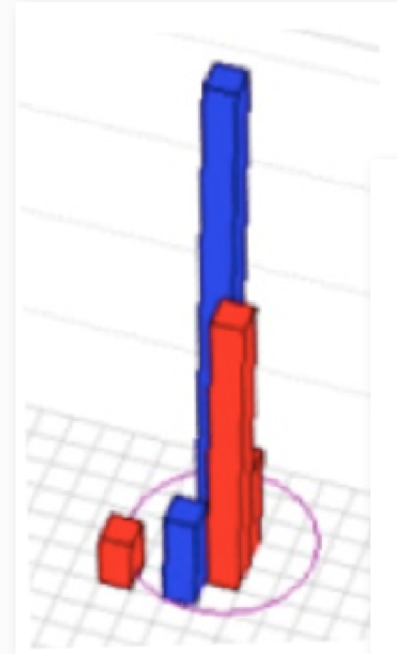
- Full tracks
  - Use all pixel and strip hits, provide η and p_T
  - Sensitive, most complex
  - $p_T > 100$ MeV/c, $|\eta| < 2.4$

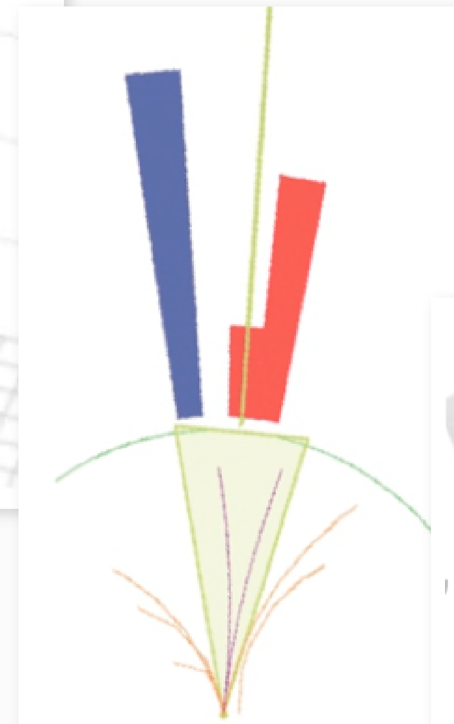
Measure η and p_T of charged hadrons with the silicon tracker

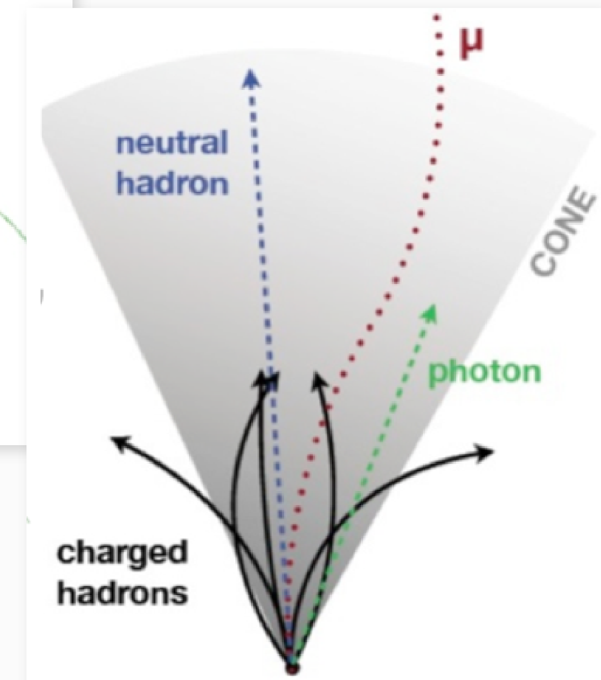
slide by F. Sikler

Jet Reconstruction

- CalorimeterJet (calojet)
  - from energy depositions grouped HCAL & ECAL
- Jet Plus Tracks (JPT)
  - Calorimeters jets corrected with tracker momentum
- Particle Flow Jets (PFJ):
  - Reconstructed particles using information from all sub-detectors; separate calibration per particle type
- TrackJets
  - from tracks only







- Jet Algorithms:
  - Default for p+p collisions is anti-K_T with R = 0.5
  - Also implemented: K_T, SiSCone

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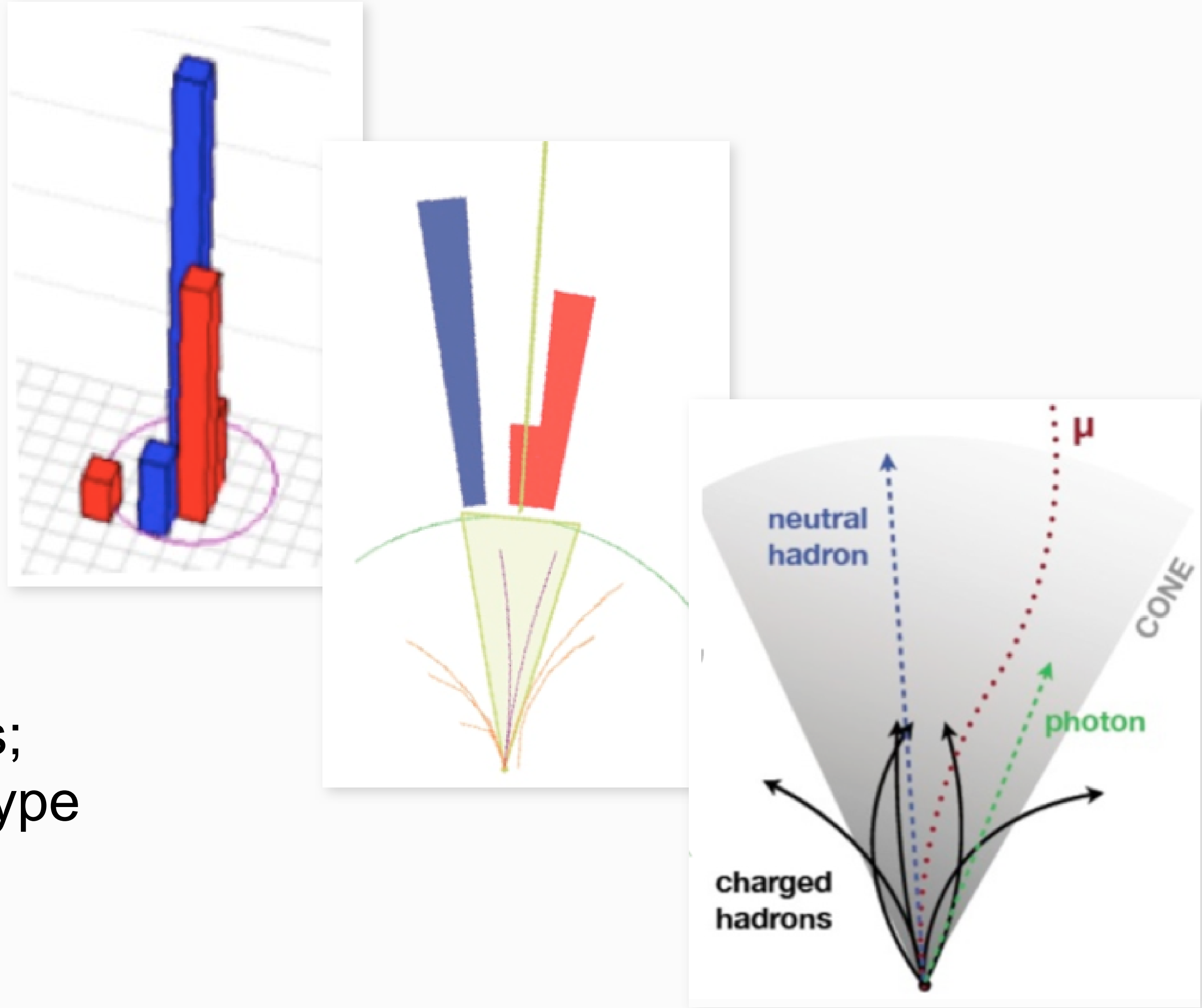

- Jet Algorithms:
  - Default for p+p collisions is anti-K_T with R = 0.5
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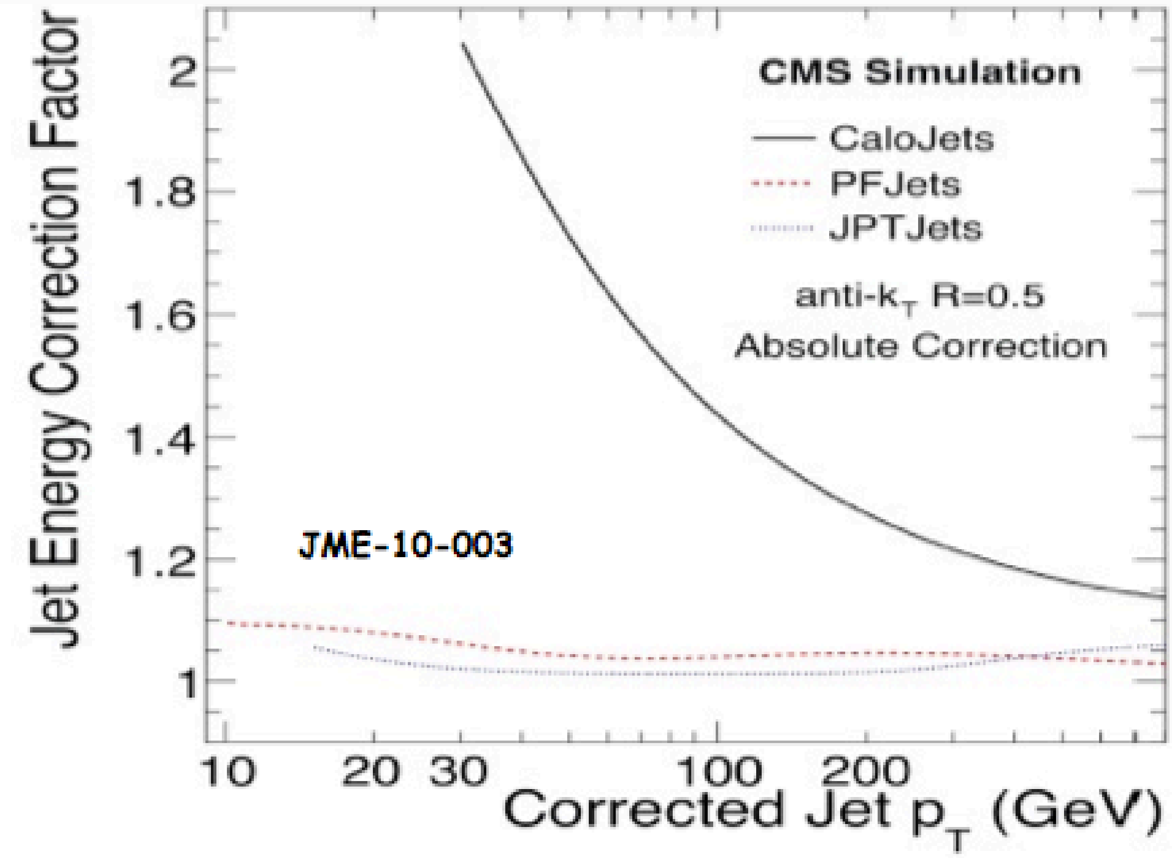
Using different inputs allows CMS to study and constrain experimental systematics for good understanding of jet identification, resolutions and energy scale

Jet Energy Corrections (JEC)

- Two Strategies: MC-truth JEC and In-situ JEC
- Majority of CMS physics analyses currently use MC-truth JEC
  - MC corrections are derived from PYTHIA QCD dijet MC events
- In-situ JEC sub-corrections will replace MC-truth corrections when available
  - indeed, with latest statistics accumulated we start to move in this direction



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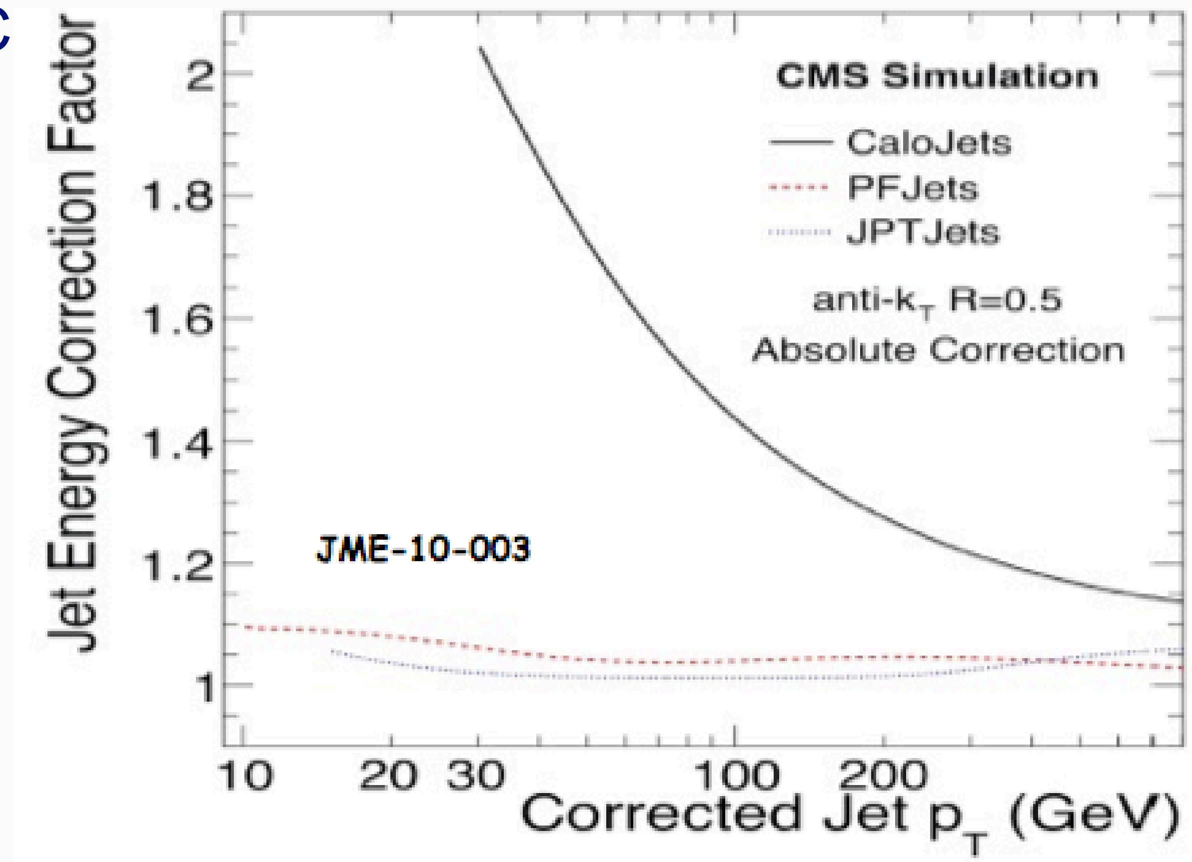
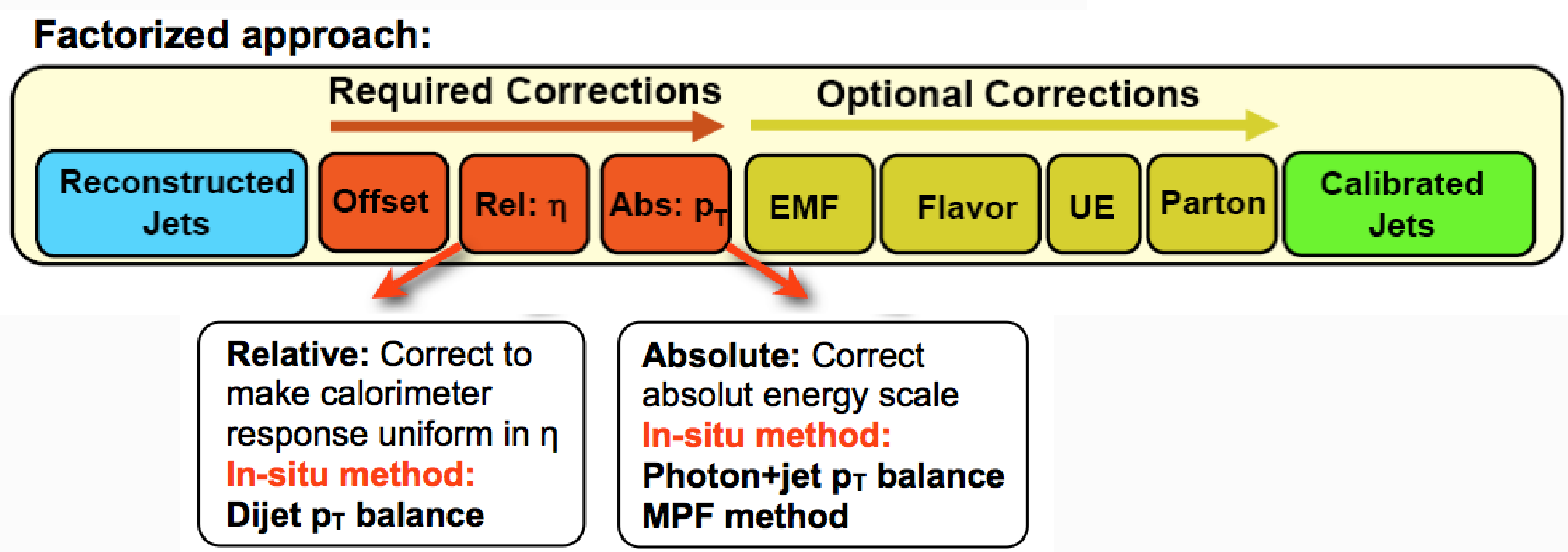
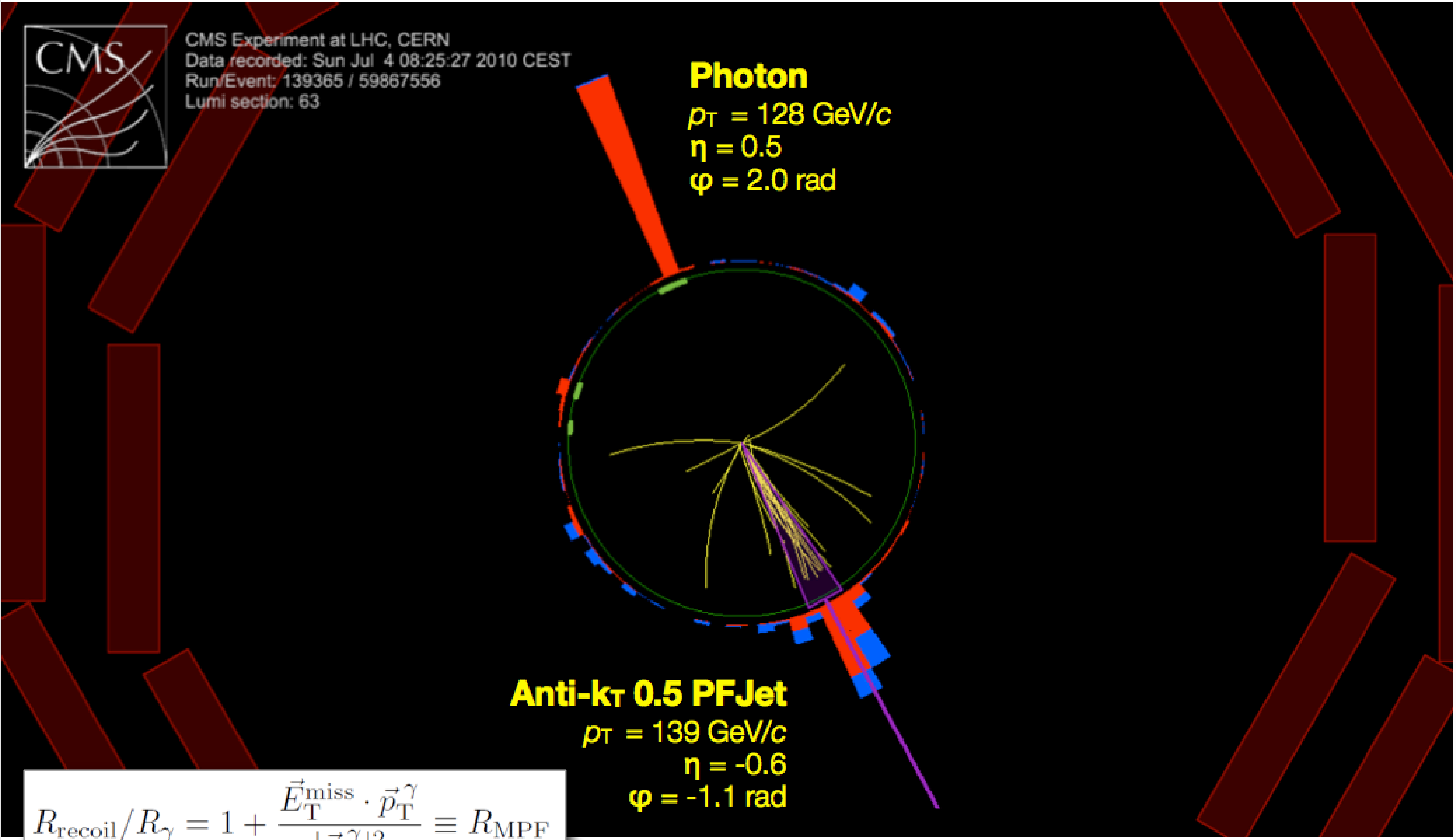




Photon+Jet Balance

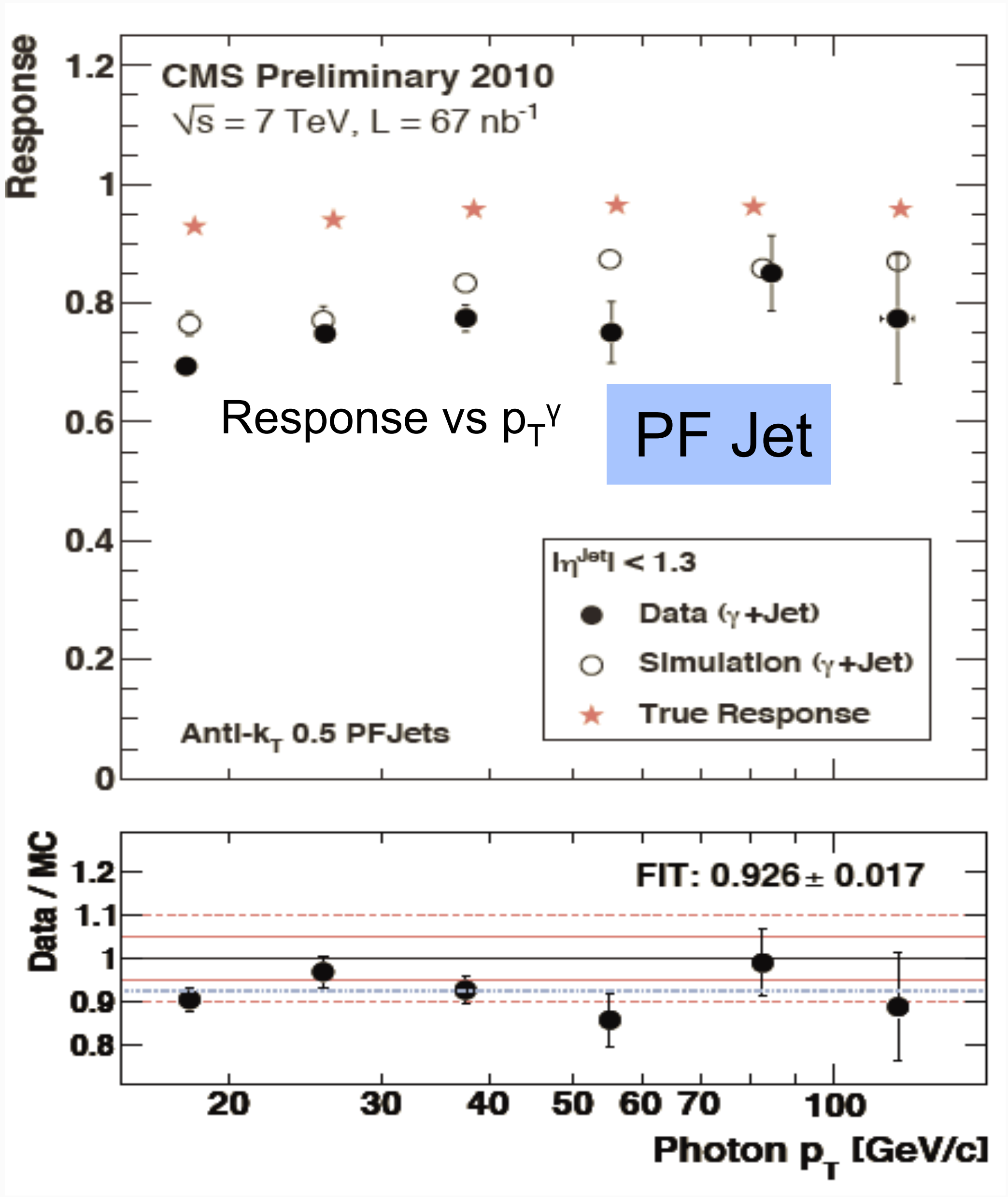


$$R_{\rm recoil}/R_\gamma = 1 + \frac{\vec{E}_{\rm T}^{\rm miss}\cdot\vec{p}_{\rm T}^{\,\gamma}}{|\vec{p}_{\rm T}^{\,\gamma}|^2} \equiv R_{\rm MPF}$$

Absolute JEC: photon+jet balance

JME-10-003

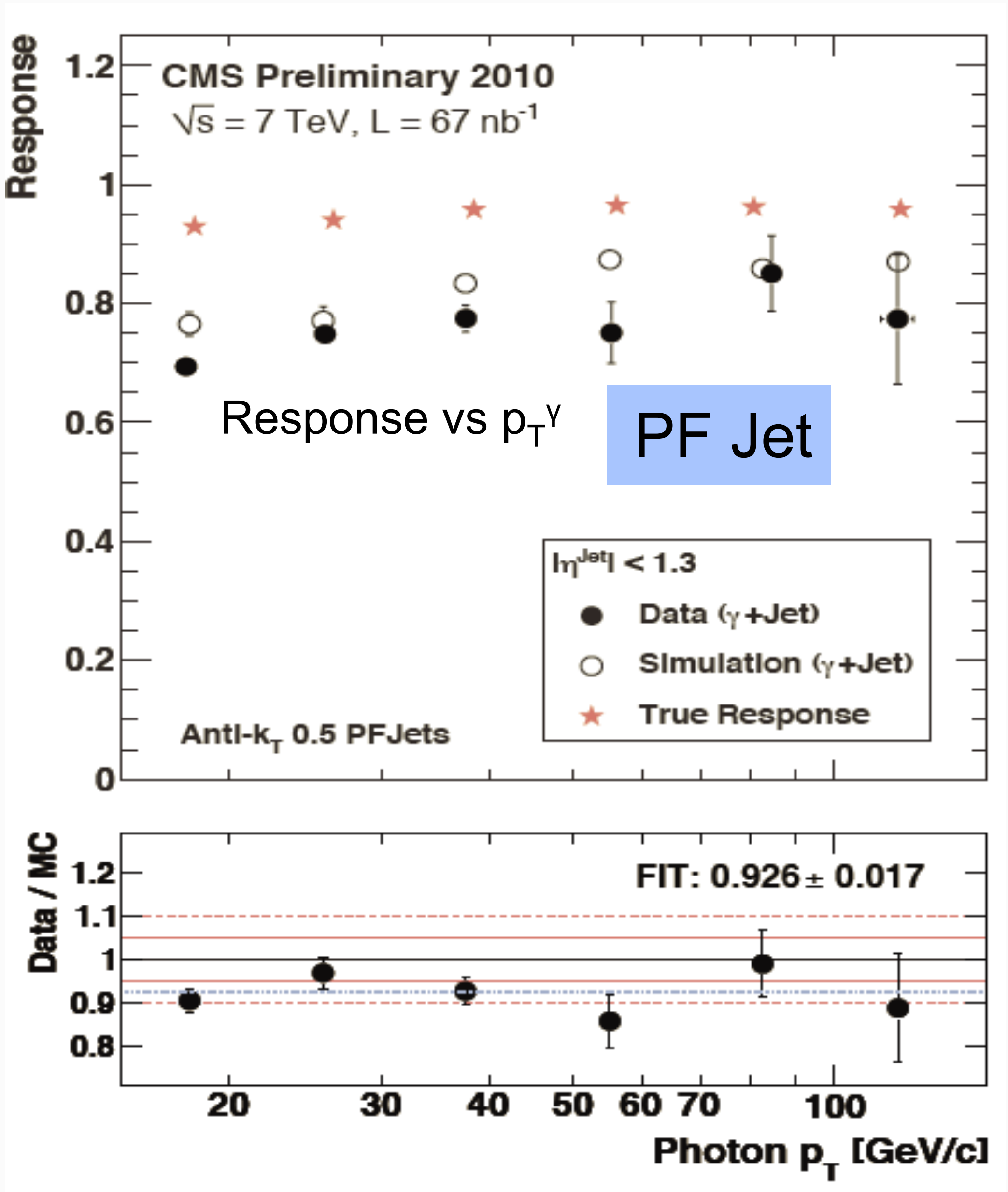
Photon+jet balance: Bias due to soft veto on second jet

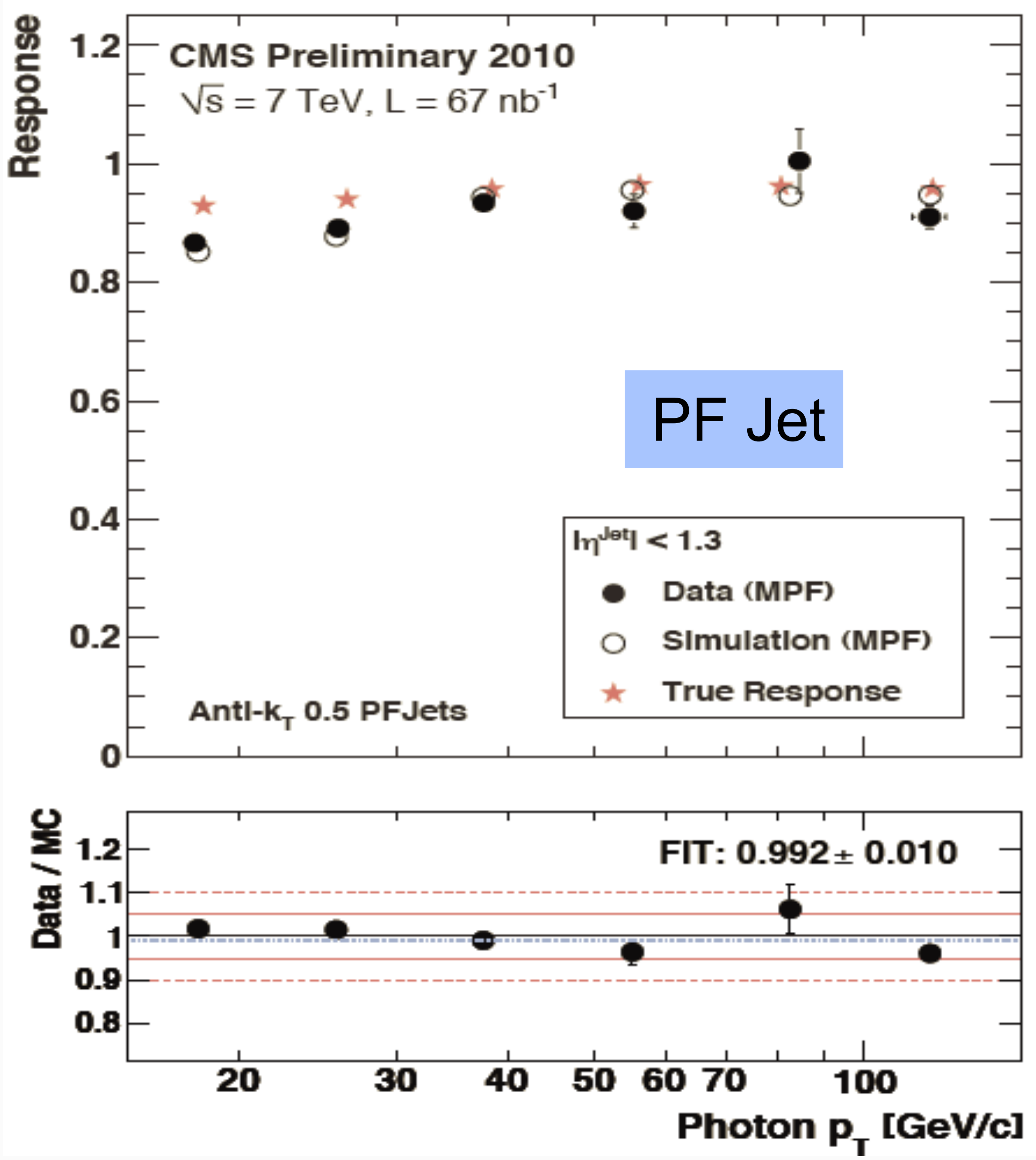


Absolute JEC: photon+jet balance

JME-10-003

Photon+jet balance: Bias due to soft veto on second jet → Missing-E_T projection fraction method (**MPF**, from D0) uses MET to measure the balance and is less sensitive to QCD radiation





=> Mostly good agreement when same method applied to MC and Data

=> Ongoing studies indicate **5%** (JPT,PF) and **10%** (CALO) **JEC uncertainty** as conservative

Jet p_T resolutions

JME-10-003

Extracted from Pythia QCD sample **(MC)** and Dijet Asymmetry method **(In Situ)**

Define pT asymmetry of the two leading jets in back-to-back dijet events: $A = \frac{p_T^{jet1} - p_T^{jet2}}{p_T^{jet1} + p_T^{jet2}}$

For approximately equal value of the jet p_T's: $\frac{\sigma(p_T)}{p_T} = \sqrt{2}\ \sigma_A$

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ETH Institute for Particle Physics

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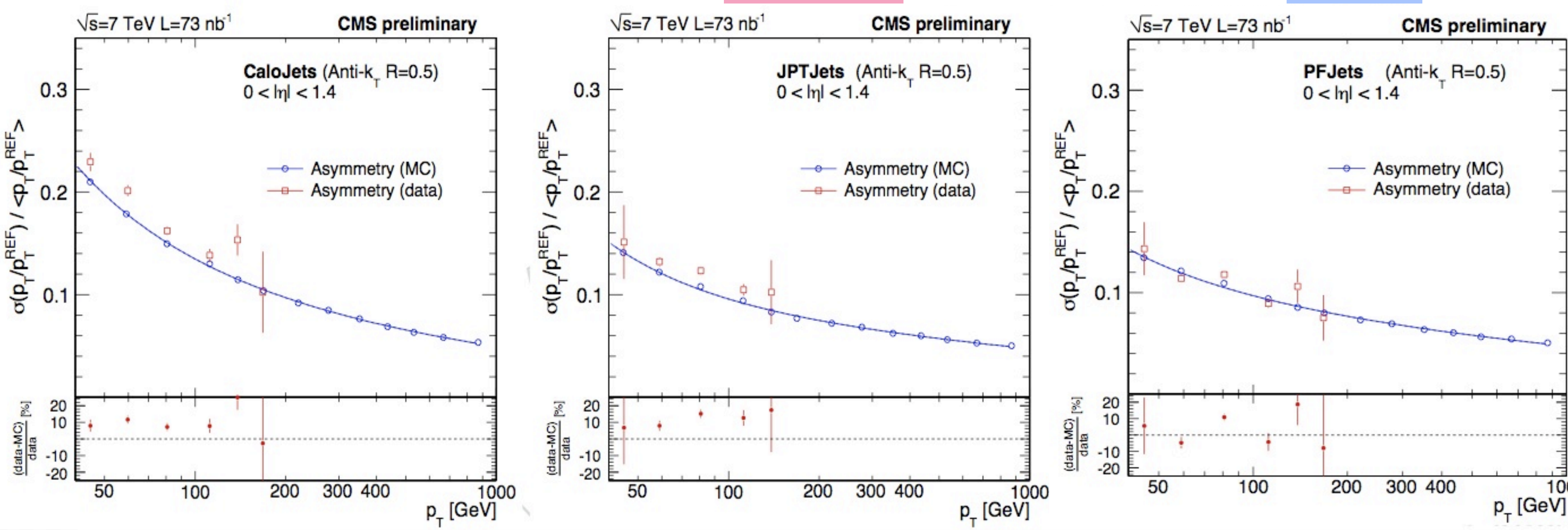
Calo Jet | JPT Jet | PF Jet



Full chain of Dijet Asymmetry method applied to data and MC to extract jet p_T resolutions

=> Observed data/MC agreement within a priori **~10% uncertainty**

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JME-10-003

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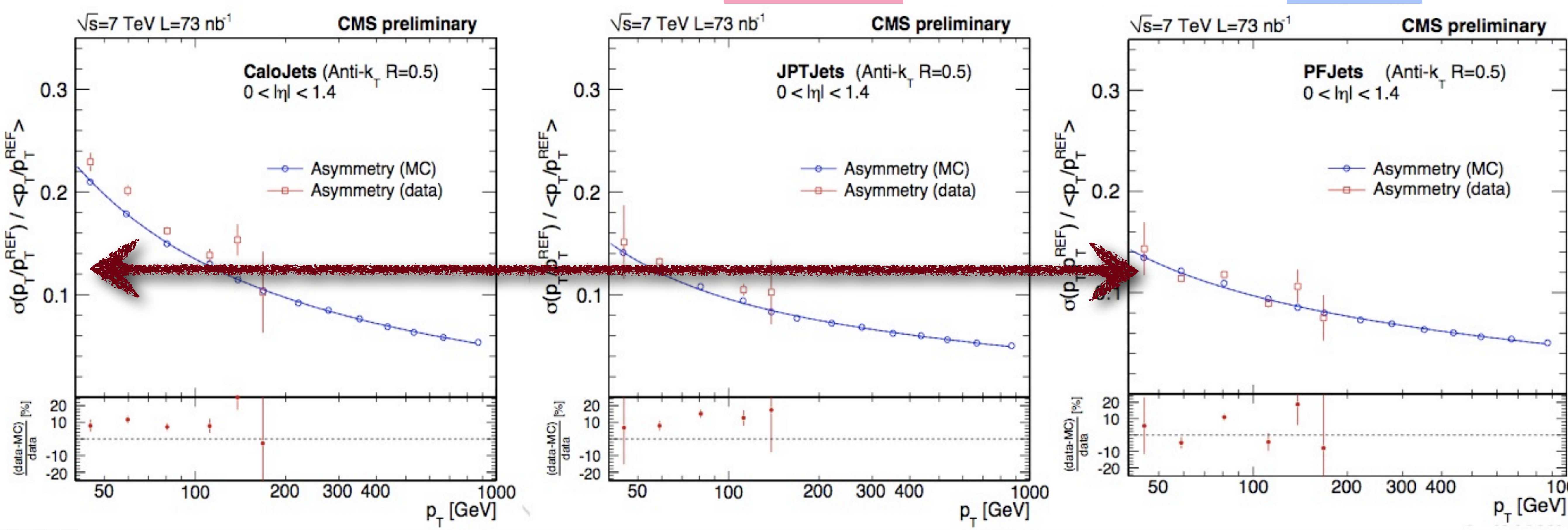
Calo Jet

JPT Jet

PF Jet



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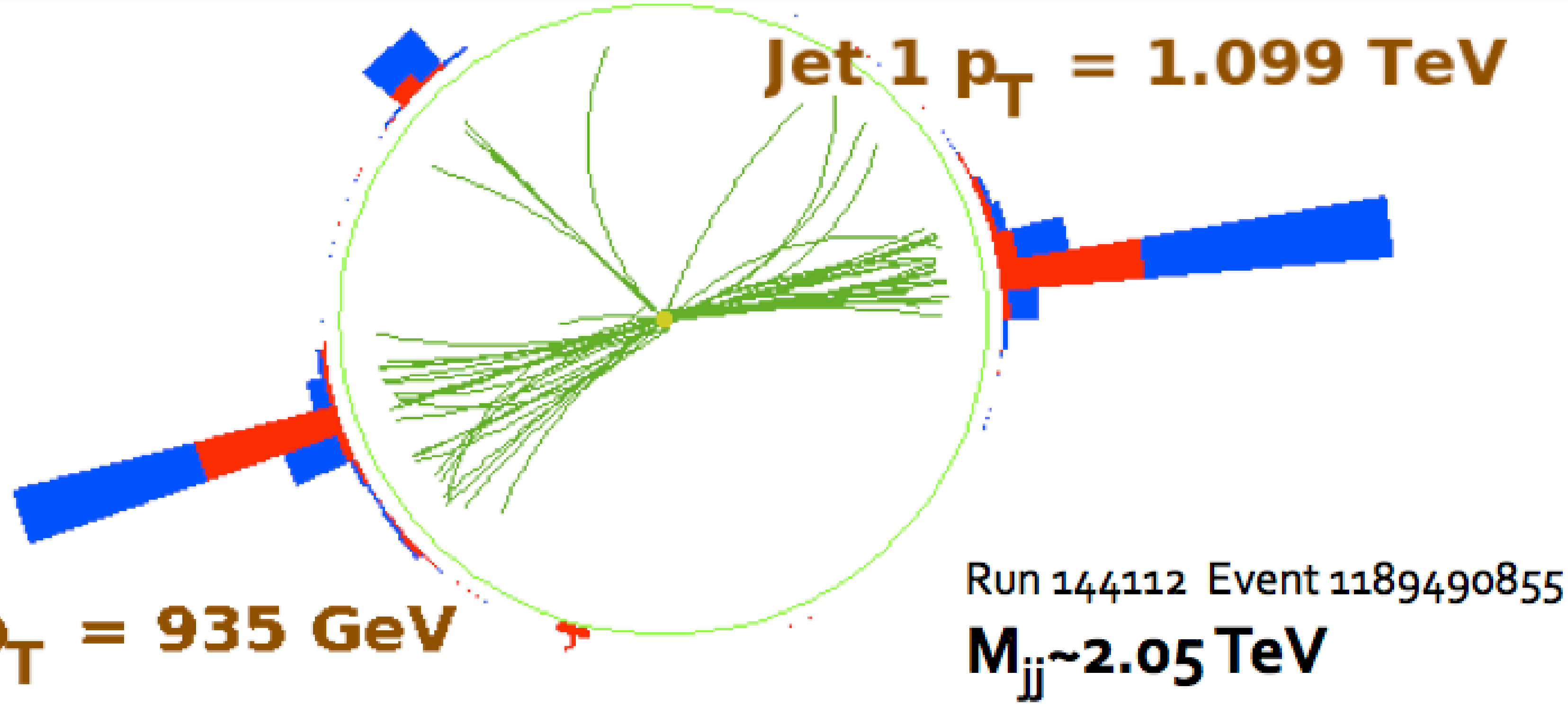
High-p_T Jet Physics

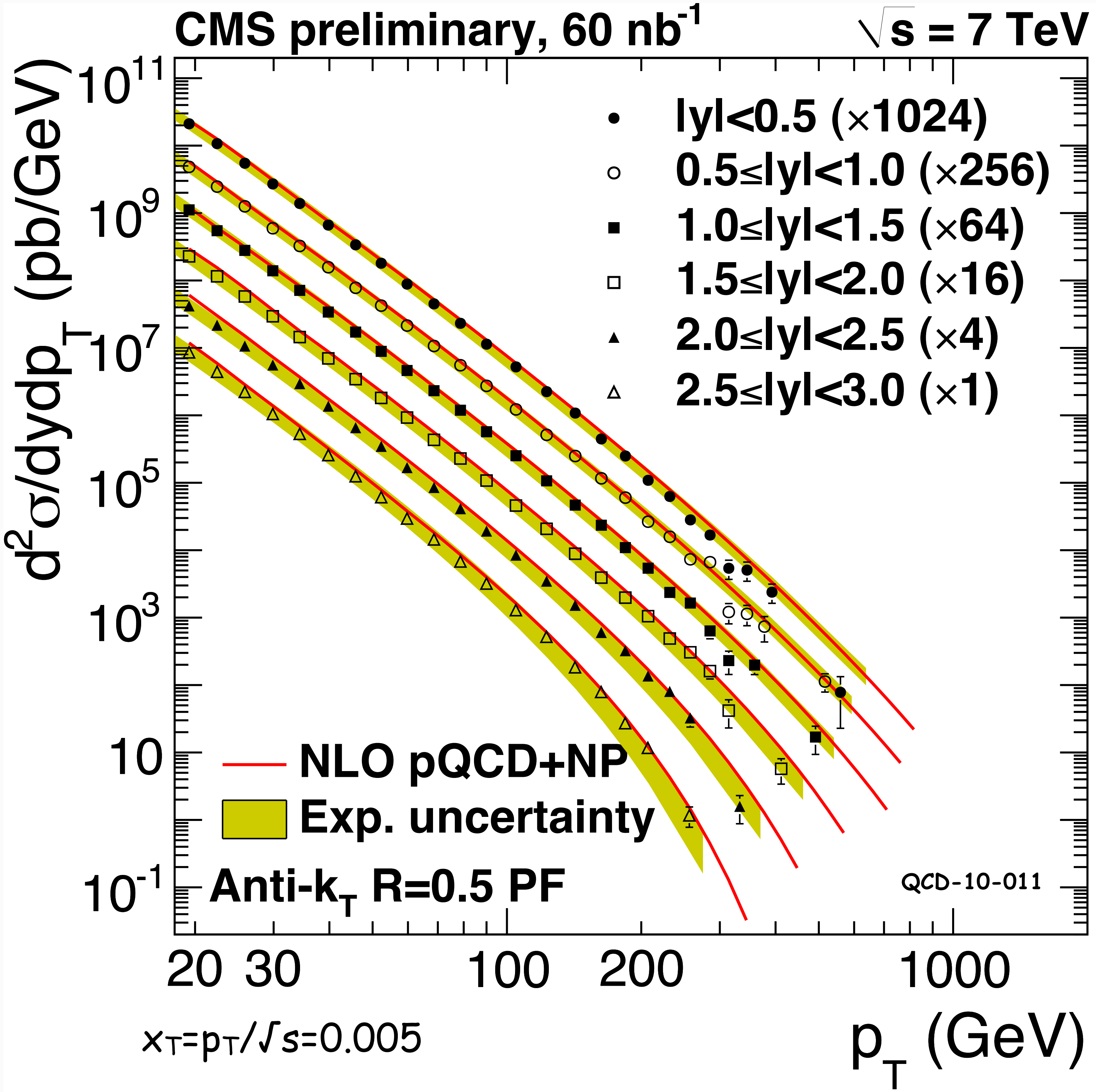


A high mass dijet event satisfying $\Delta\eta < 1.3$

Current highest mass dijet pair: ~2.7 TeV in 3.1 pb^{-1} of data

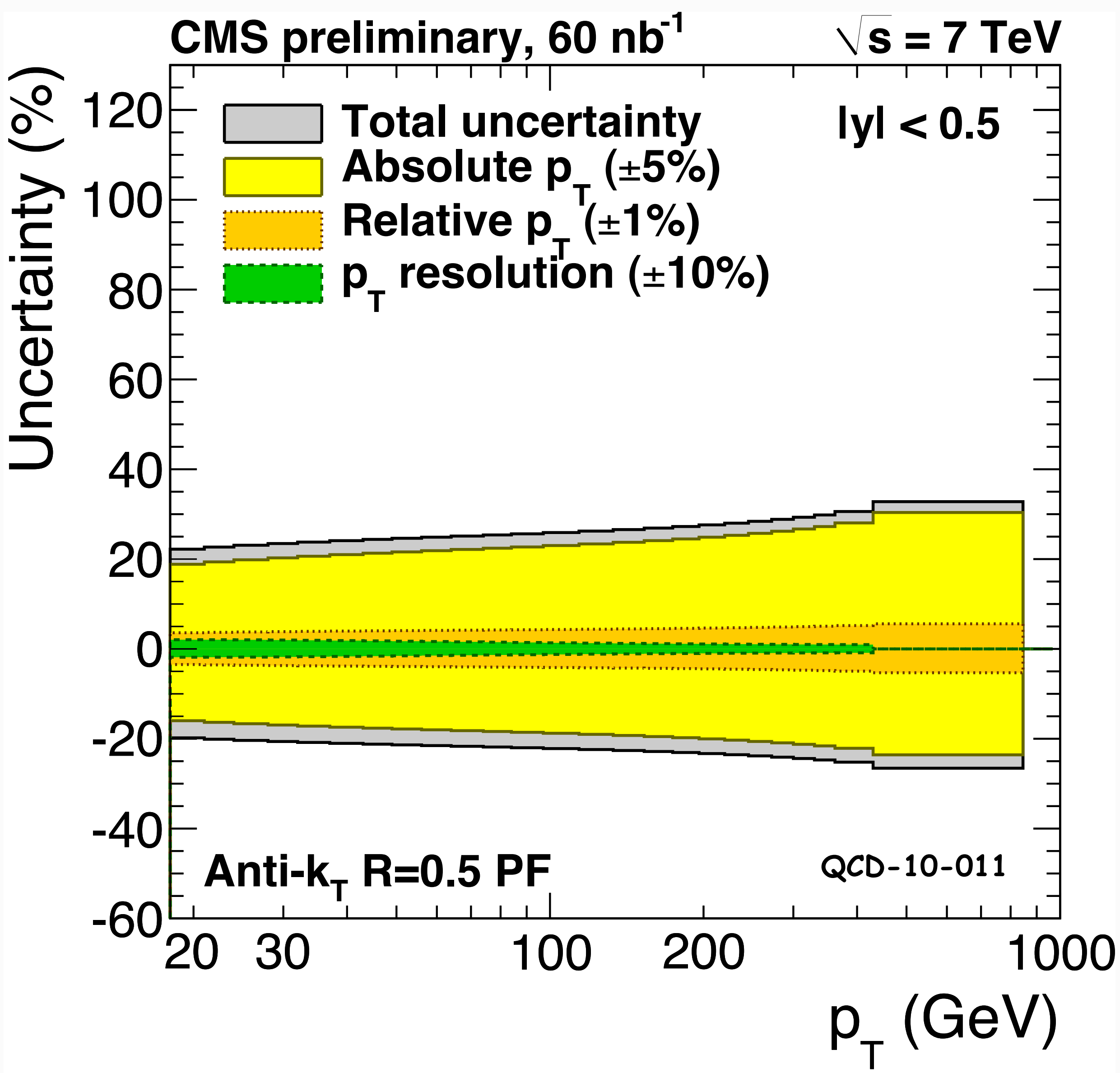
Inclusive jet cross section

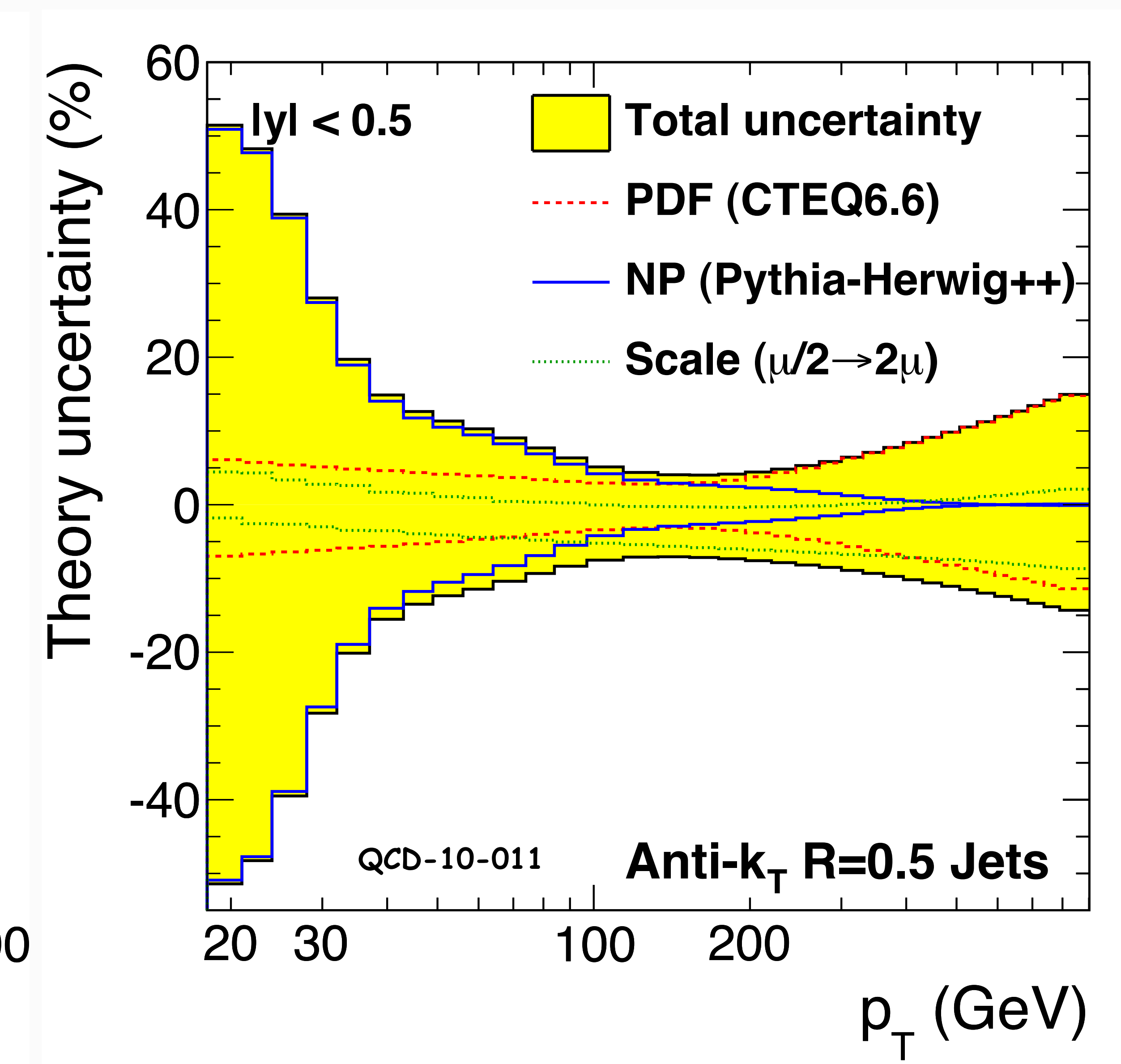
- Inclusive jet p_T spectra are in **good agreement with NLO** theory for all reconstruction types
- Extending to very low p_T thanks to novel reconstruction methods (Particle Flow)
- Low p_T reach limited from theory side by non-perturbative corrections
- Extending the high-p_T reach beyond Tevatron's
- Large rapidity coverage up to |y|<3



Inclusive jet cross section

- Main systematics for inclusive jet cross section, as for most other jet analyses: jet energy scale (5-10%), jet resolutions (10%) and luminosity (11%)
- Many analyses use ratio measurements to normalize out JEC and/or luminosity
- From theory side dominant systematics are parton distributions (PDF), non-perturbative corrections (NP) and factorization/renormalization scales ($\mu_{R,F}$)

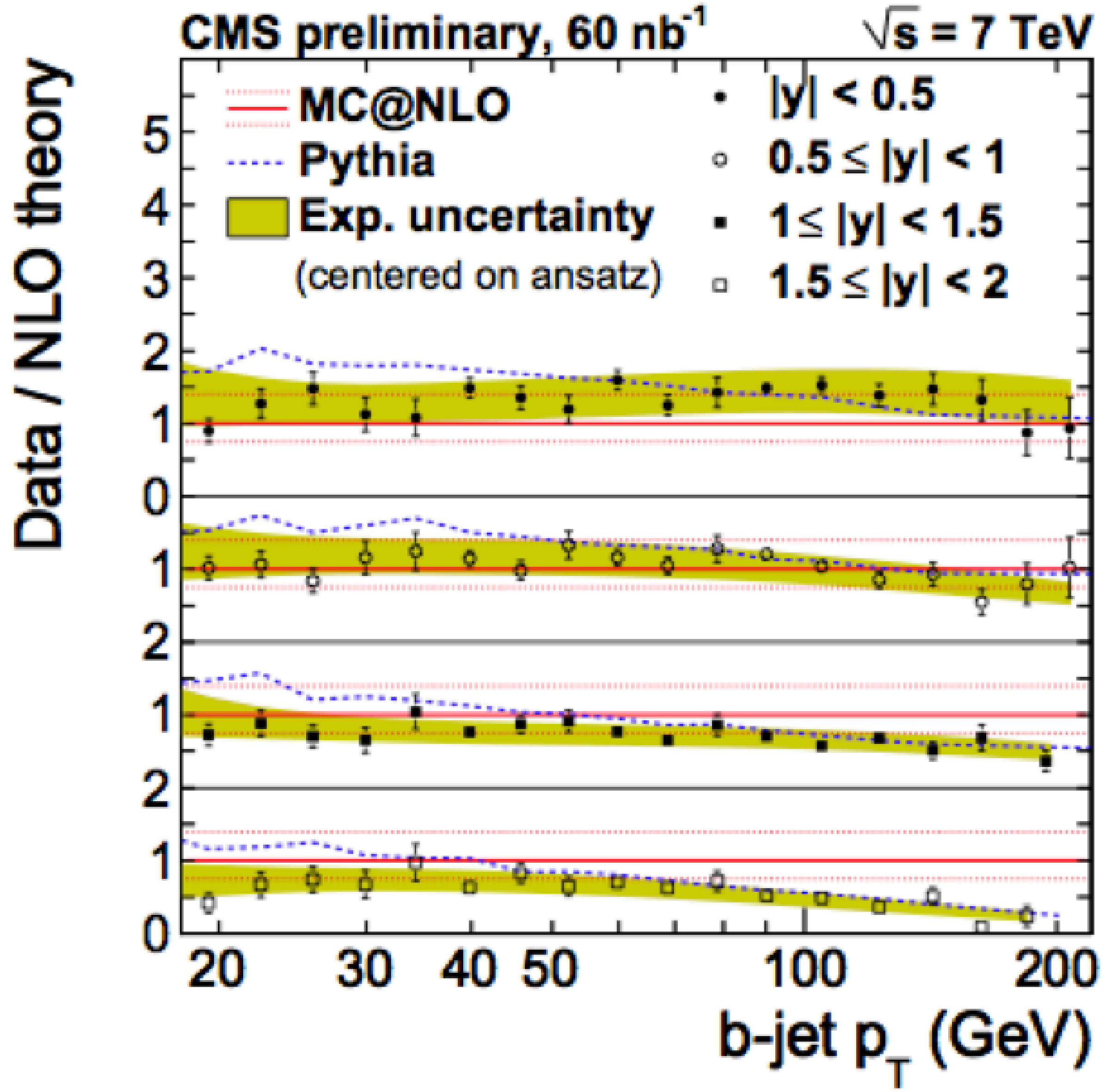




Inclusive b-jet production

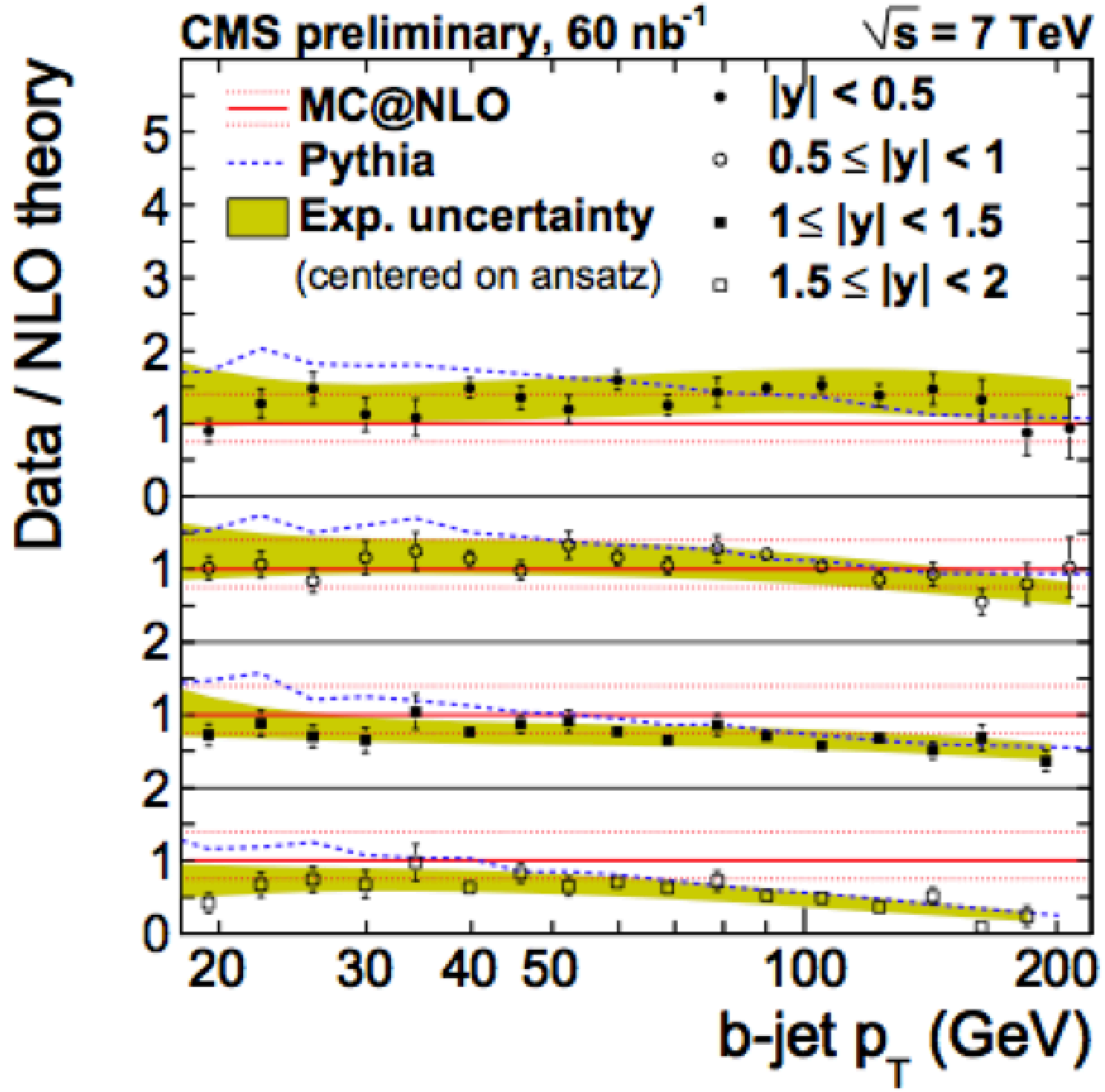
BPH-10-009

- b-jet xsec

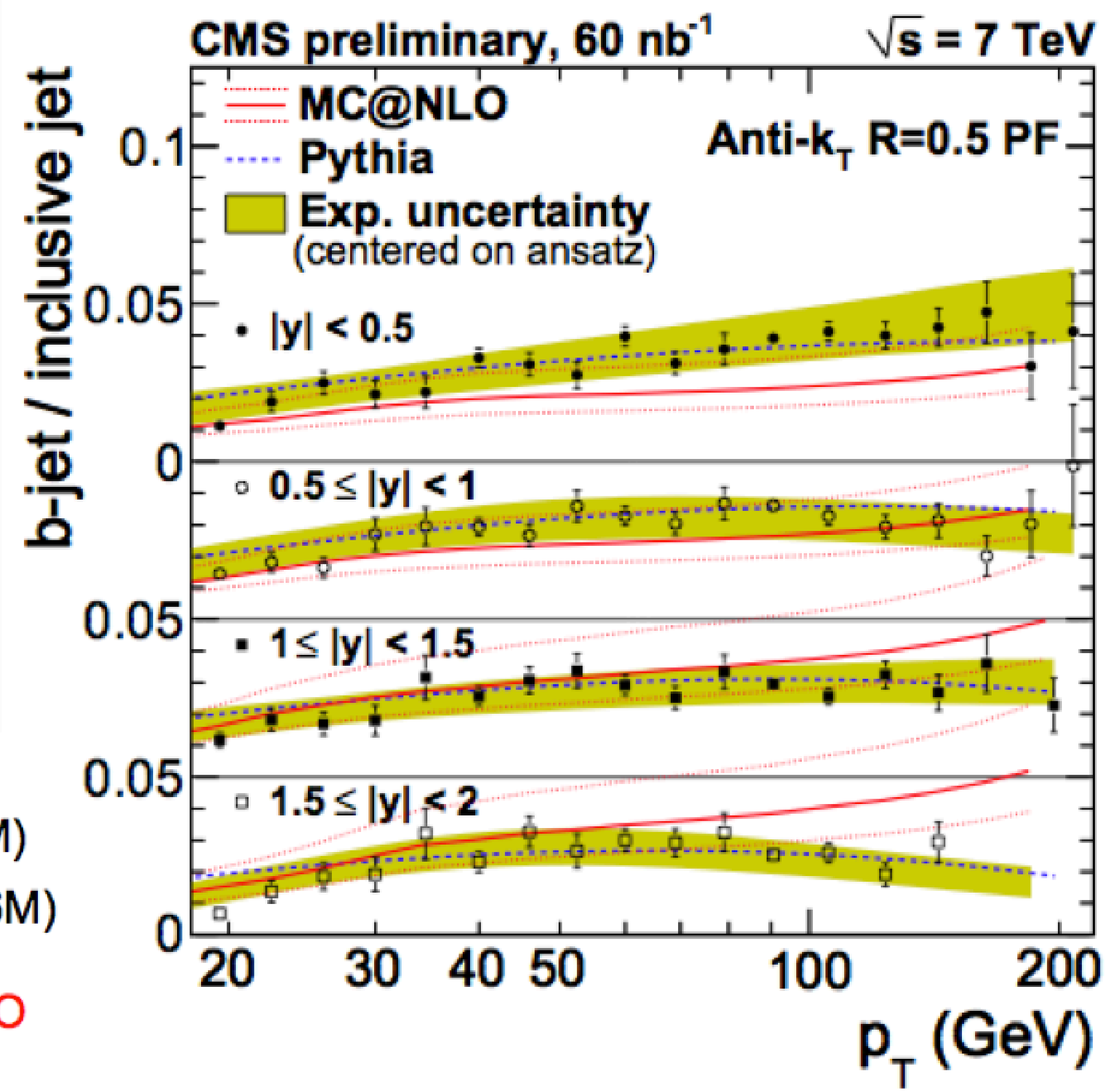


Inclusive b-jet production

- ❑ b-jet xsec



- ❑ Ratio to inclusive → partial syst cancellation
  - b-tag efficiency syst.~ 20%
  - JES b-jets VS LF jets ~1%



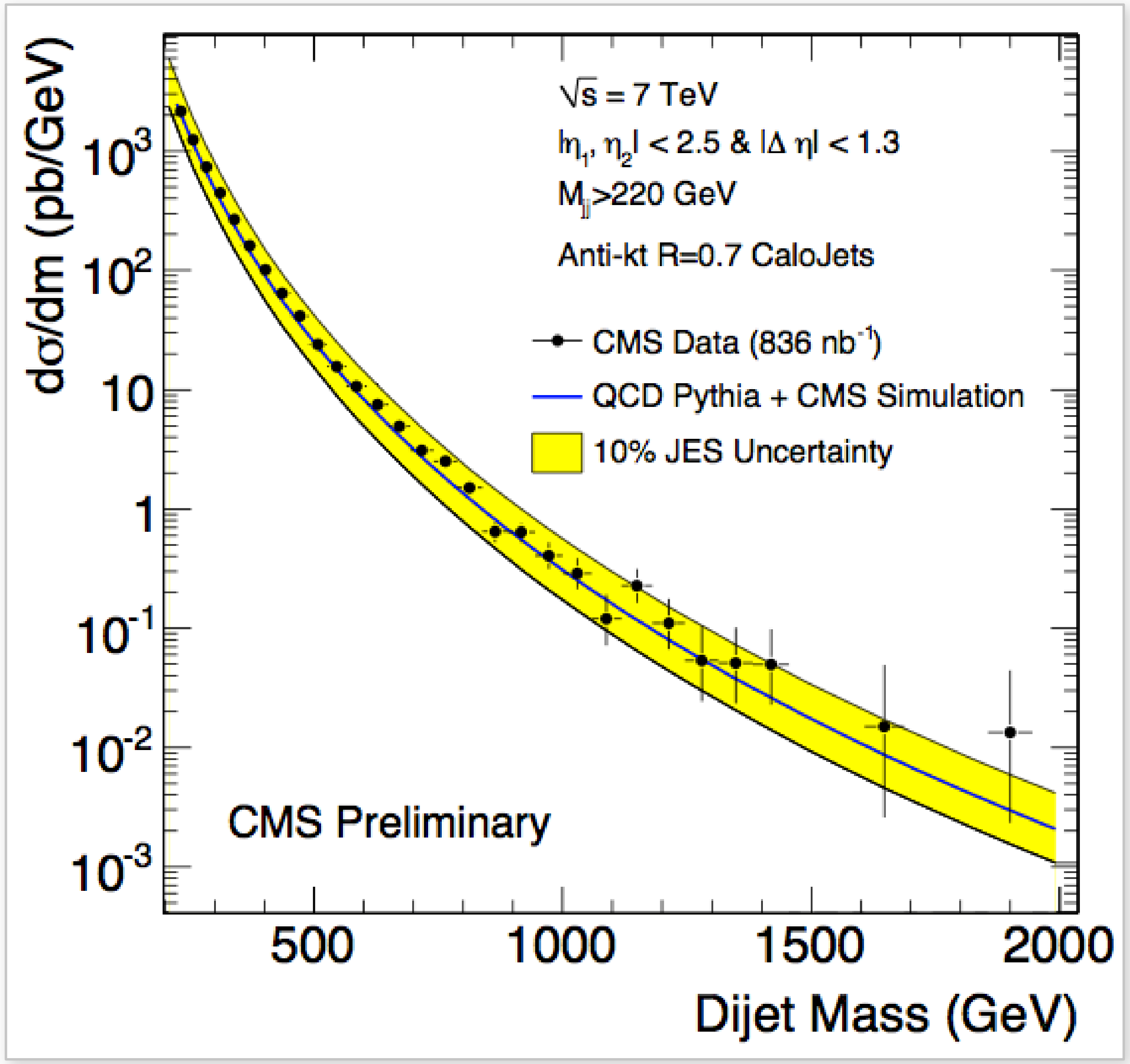
- ❑ Comparison to theory:
  - b-jets from MC@NLO (CTEQ6M)
  - inclusive jets from NLO (CTEQ6M)

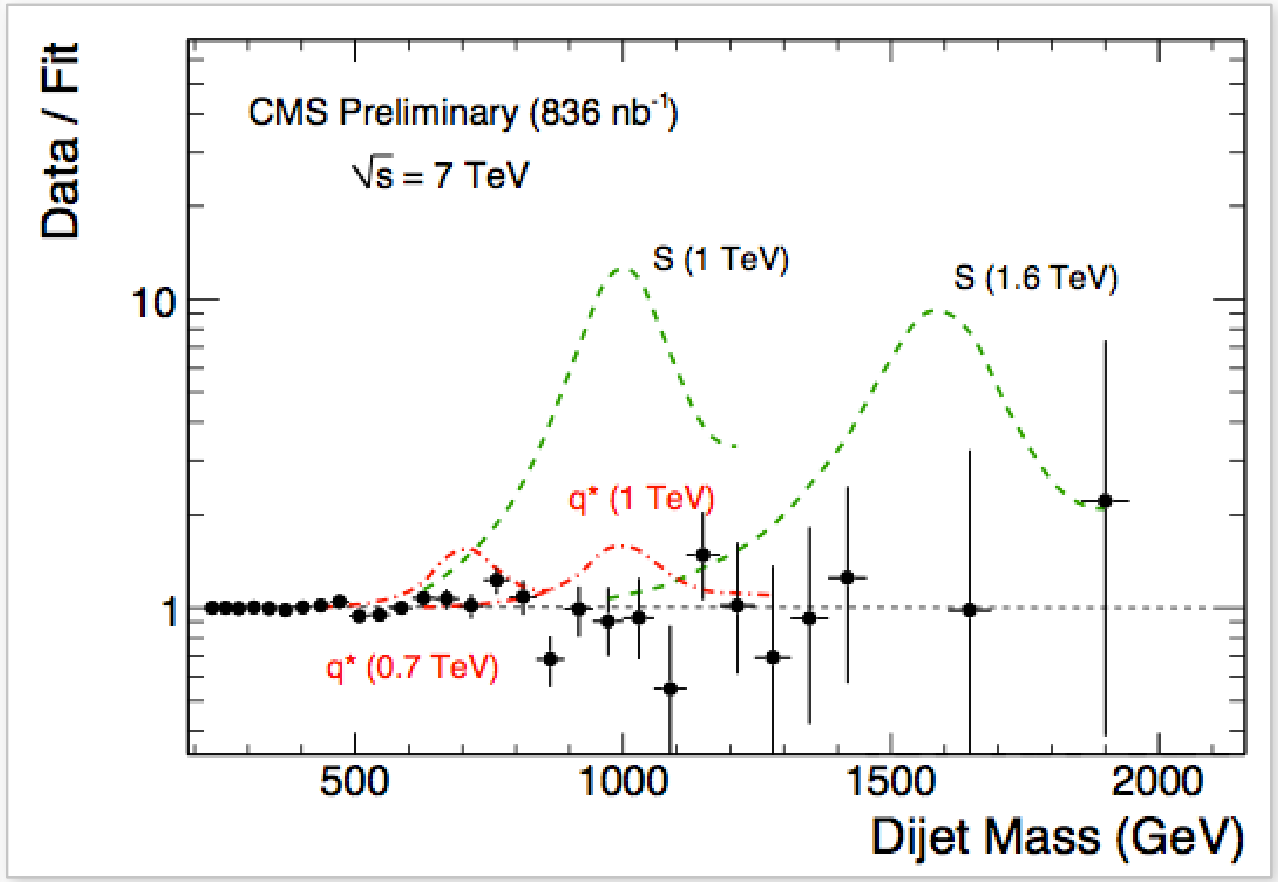
→ reasonable agreement with NLO **but different p_T, η shapes**

Di-Jets

Di-Jet Mass Distribution

EXO-10-010





- Search for narrow resonances in di-jet final states.
  - Differential cross section for $|\eta_1,\eta_2|<2.5$ and $|\Delta\eta_{12}|<1.3$.
    - Sensitive to coupling of any new massive object to quarks and gluons.
  - 95% CL mass limits
    - String resonances >2.1TeV, Excited quarks >1.14TeV
    - Axigluons/Colorons >1.06TeV, E6 Diquarks>0.58 TeV.

How to reduce uncertainties?

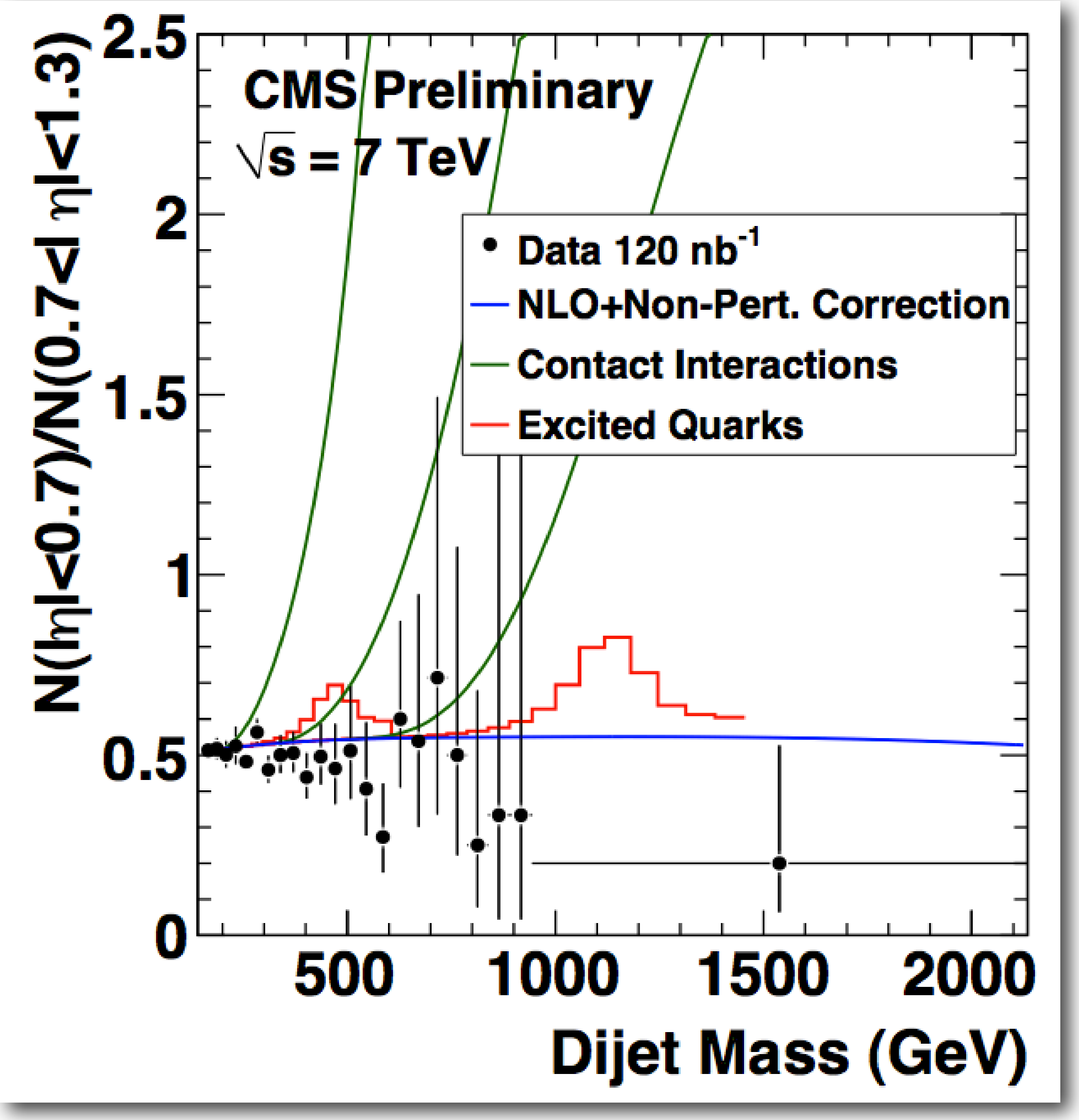
- Look at angular correlations as function of di-jet mass

Di-jet centrality ratio:

ratio of events where both jets are central, over those where both are "forward", as function of dijet mass.

New physics (at some large scale) is produced more centrally....

Soon updated limits based on larger statistics



CMS PAS EXO-10-002

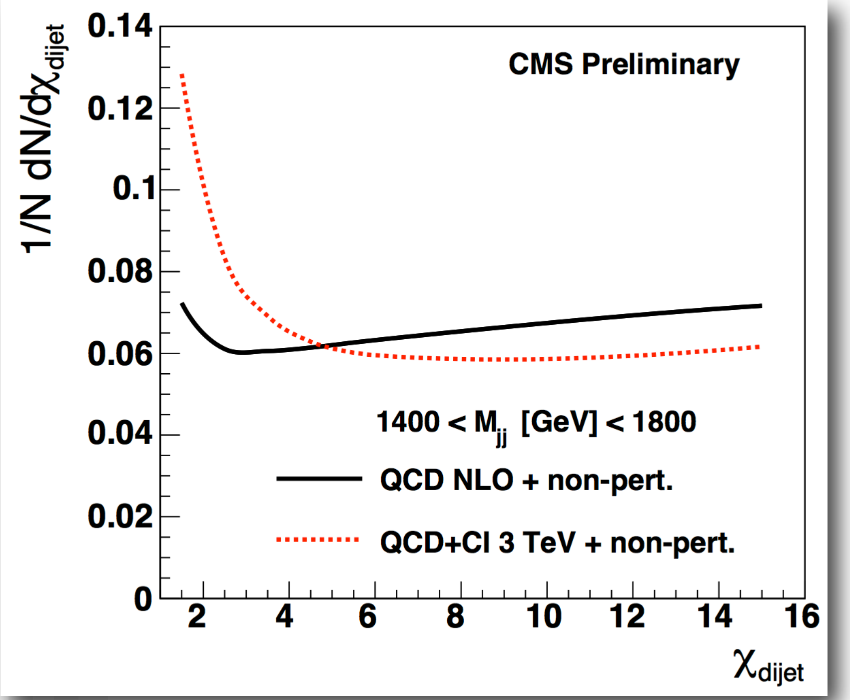
How to reduce uncertainties?

- Look at angular correlations as function of di-jet mass

$$\chi_{dijet} = \exp\left(\left|y_1 - y_2\right|\right)$$

probes parton scattering with light dependency on PDF

- flat for t-channel gluon exchange
- new physics → excess at low χ



- no lumi uncertainty
- very weak JES uncertainty
- Sensitivity up to Λ=3 TeV with few pb^{-1}; Tevatron limits Λ > 2.8-3 TeV

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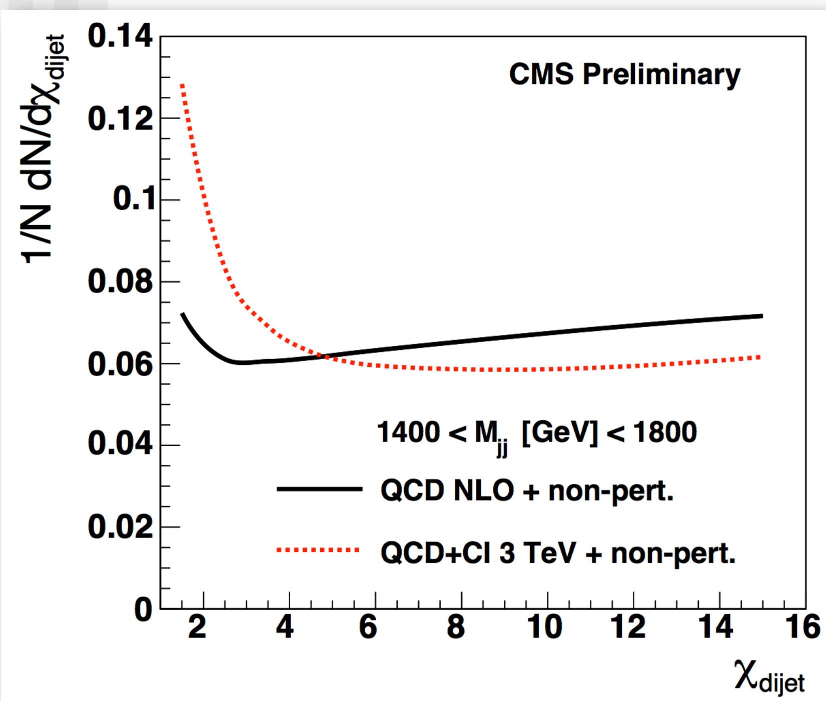
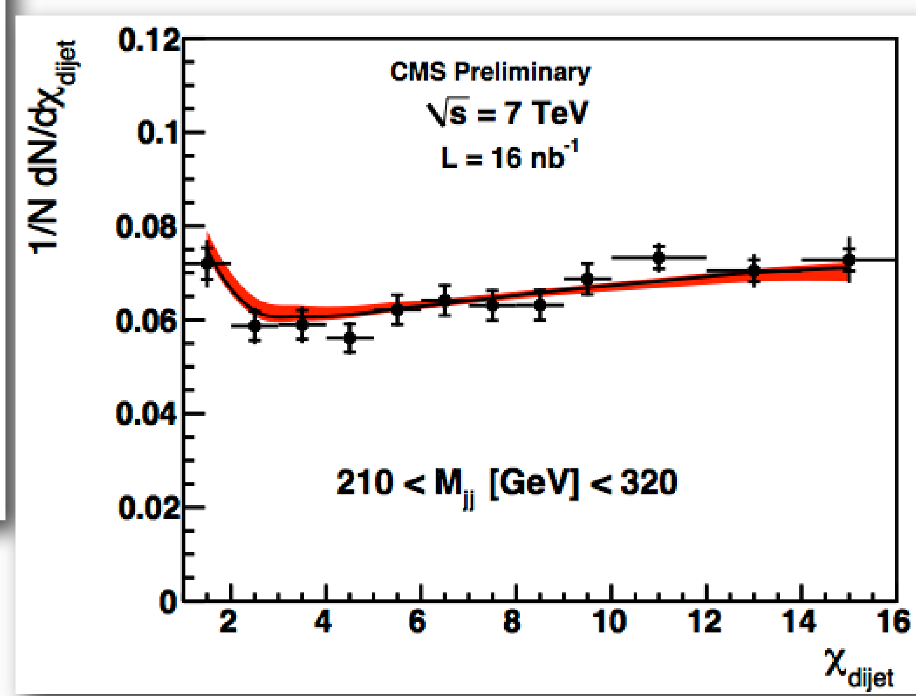
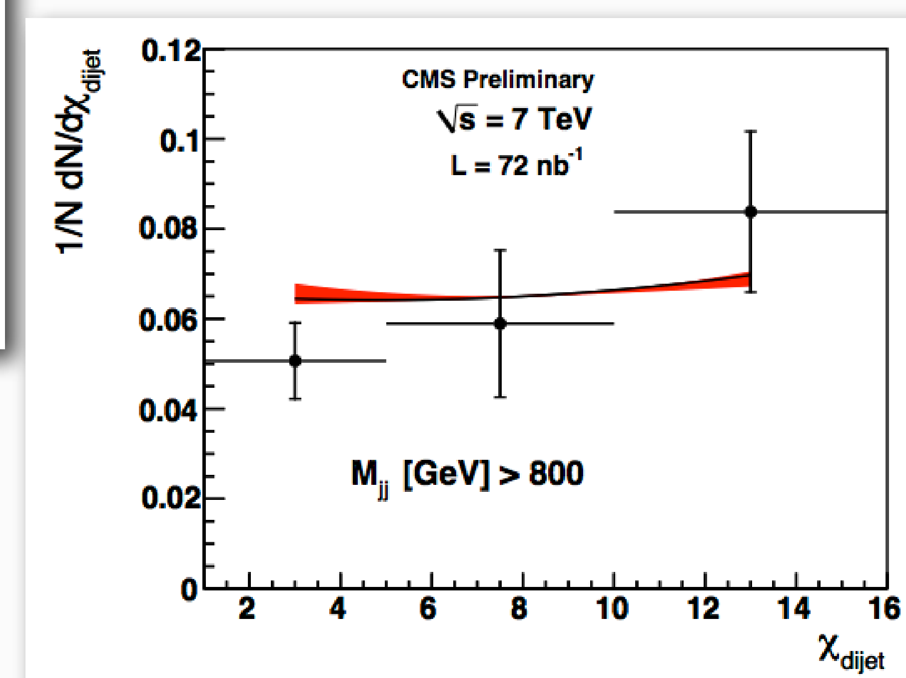




CMS PAS QCD-10-015



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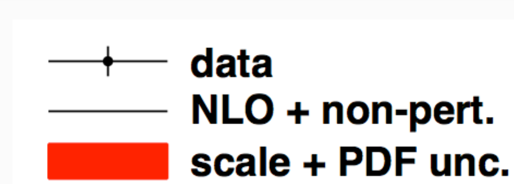


Correlations in Azimuth

- $\Delta\varphi_{dijet} = |\varphi_{jet1} - \varphi_{jet2}|$

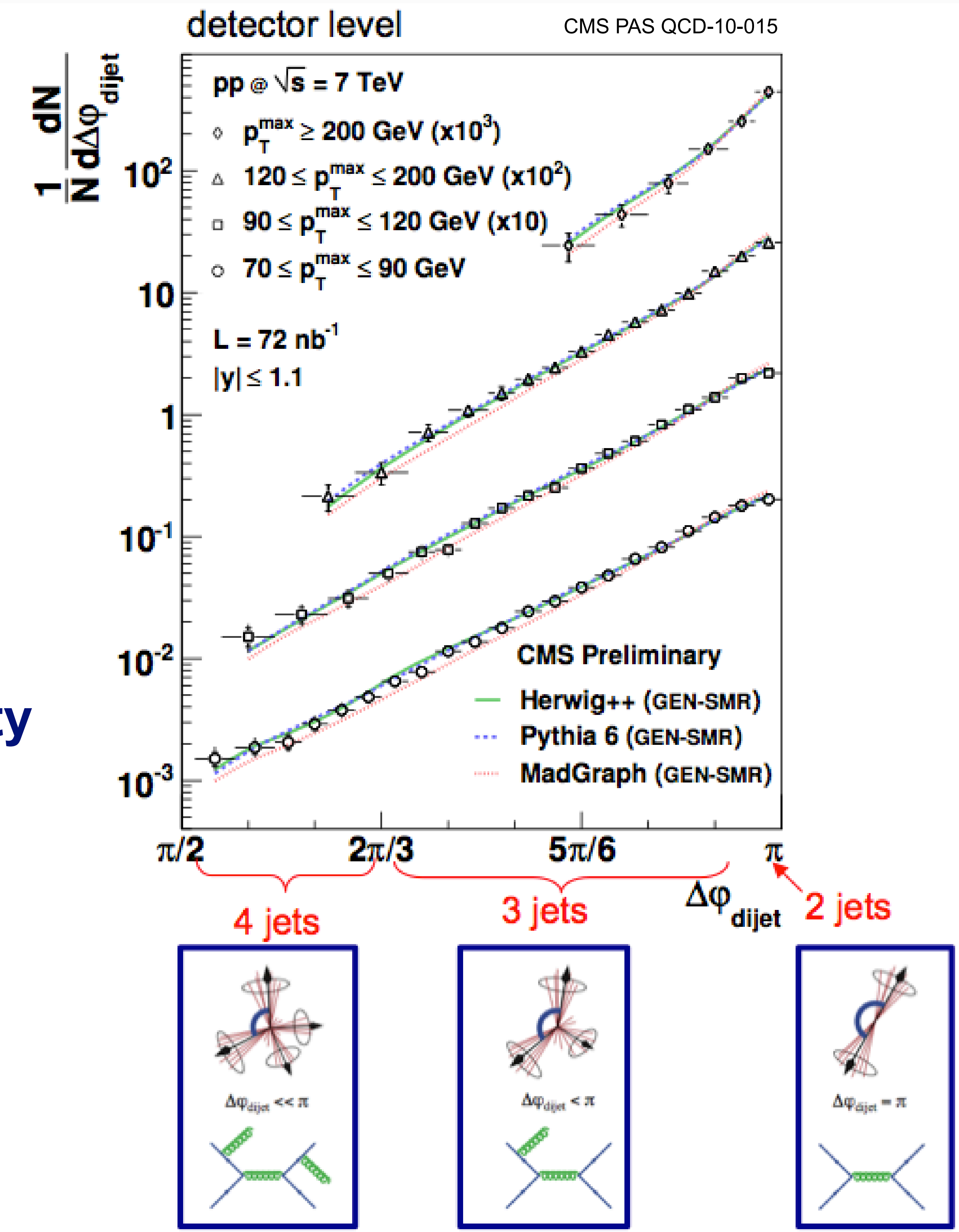
  sensitive to higher order QCD radiation effects

- Madgraph underestimates low $\Delta\phi$ (multi-jet) region

- High sensitivity to ISR, much less to FSR

- **Independent of luminosity**

- **Weakly dependent on Jet Energy Scale**



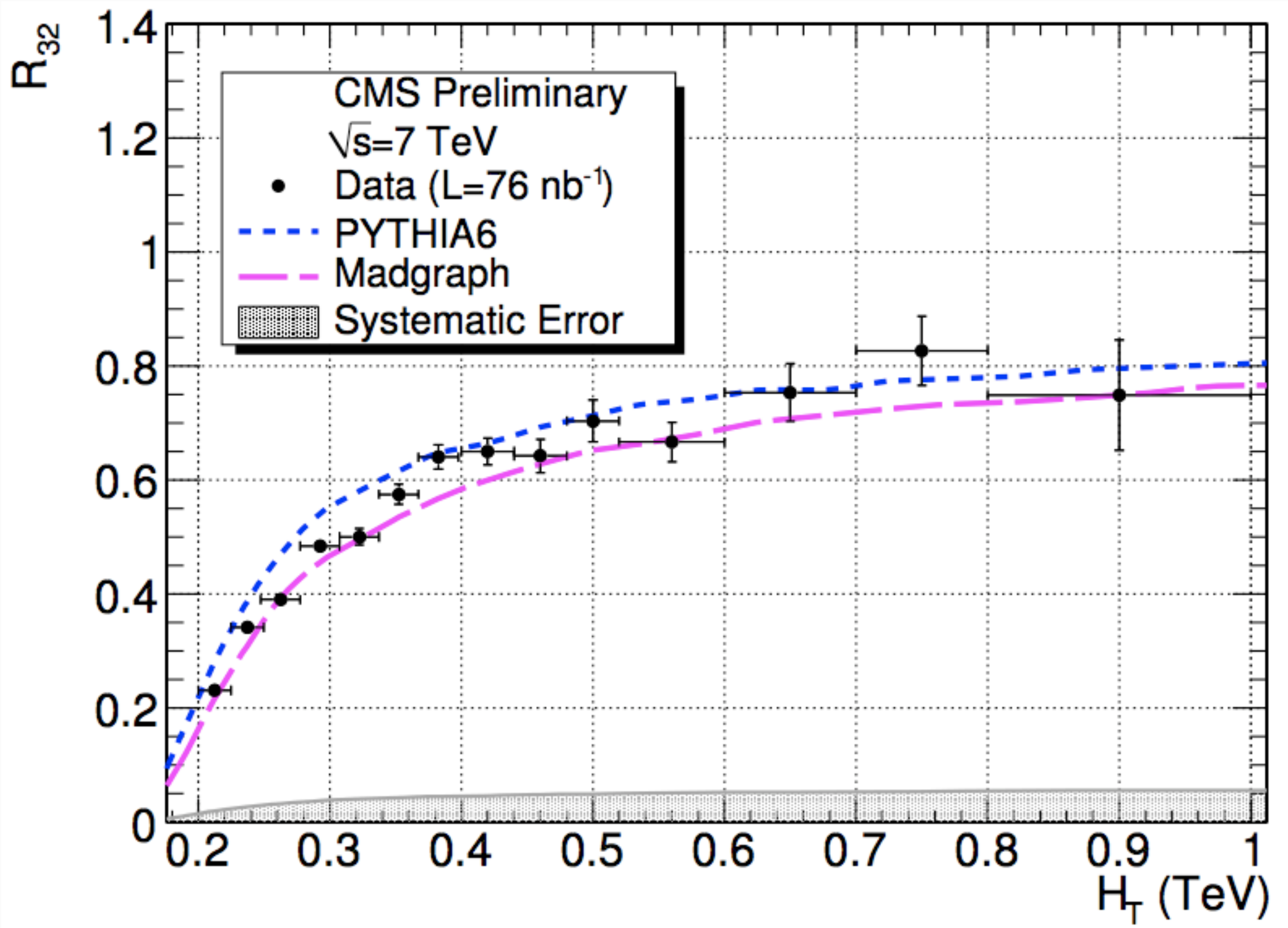
S. Bolognesi – ICHEP 2010

“Multi”-Jets

3/2-jet ratio

QCD-10-012

- Starting from inclusive and di- jets, more specific topologies focus on different aspects of theory; ratio measurements also reduce JEC and lumi uncertainty
- Ratio of inclusive 3-jet and inclusive 2-jet cross sections is a good example; $p_{T,jet} > 50$ GeV, $|y| < 2.5$, $R_{32} = (d\sigma_3/dH_T) / (d\sigma_2/dH_T)$
- Good agreement found with Pythia and Madgraph within uncertainties



Plateau sensitive to strong coupling;

extending up to highest H_T ever

Hadronic Event Shapes

CMS PAS QCD-10-013

- **Central transverse thrust**

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

Hadronic Event Shapes

CMS PAS QCD-10-013

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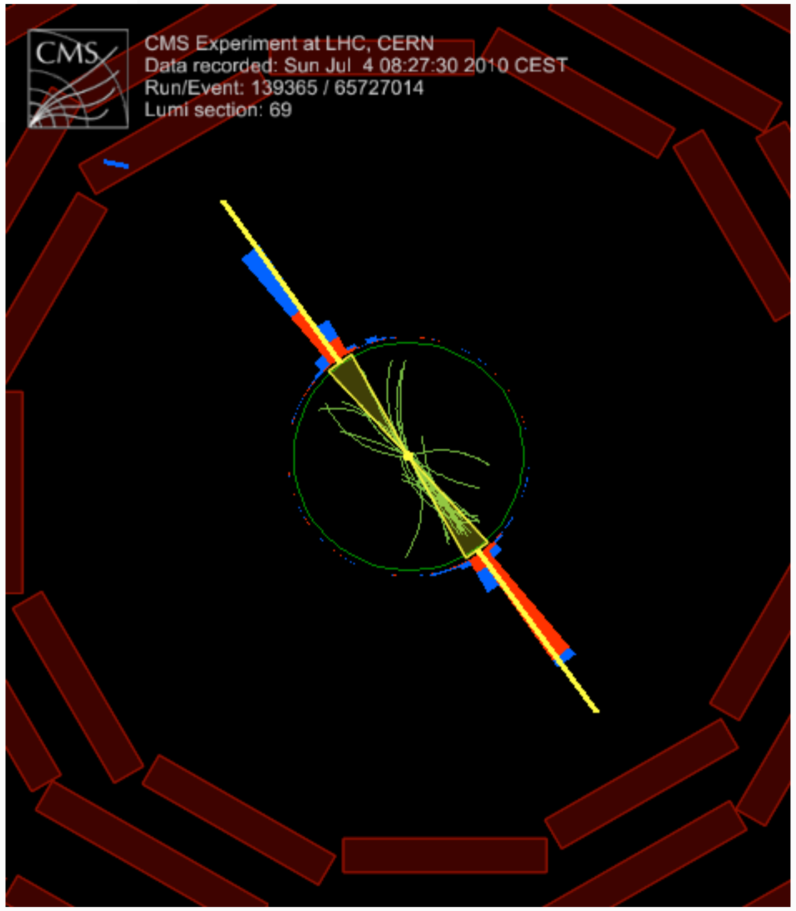

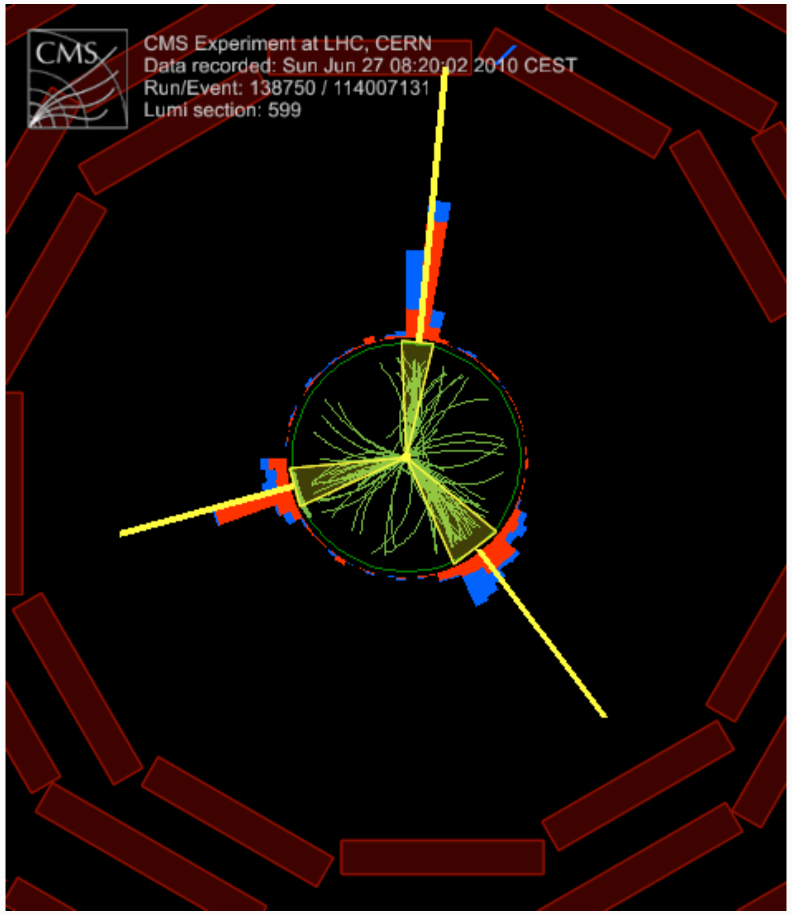

Hadronic Event Shapes

CMS PAS QCD-10-013

- **Central transverse thrust**

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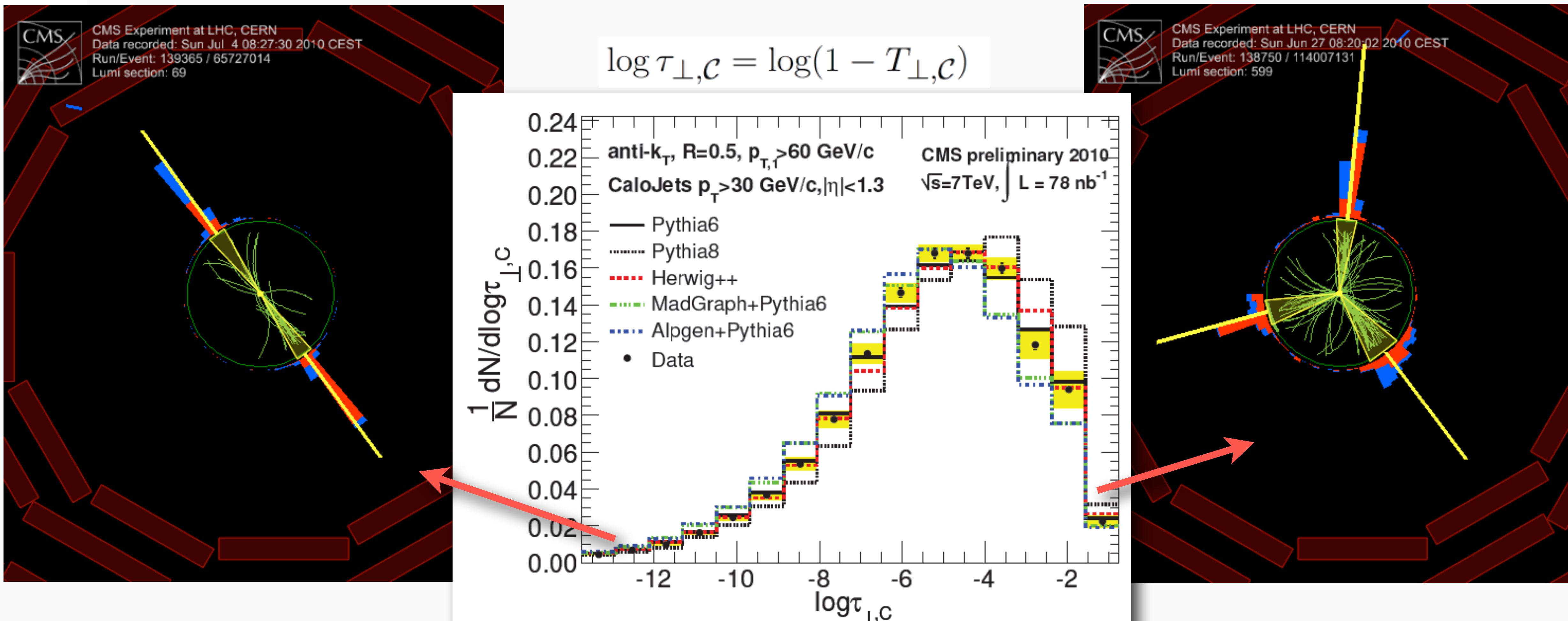
$$\log\tau_{\perp,\mathcal{C}} = \log(1 - T_{\perp,\mathcal{C}})$$



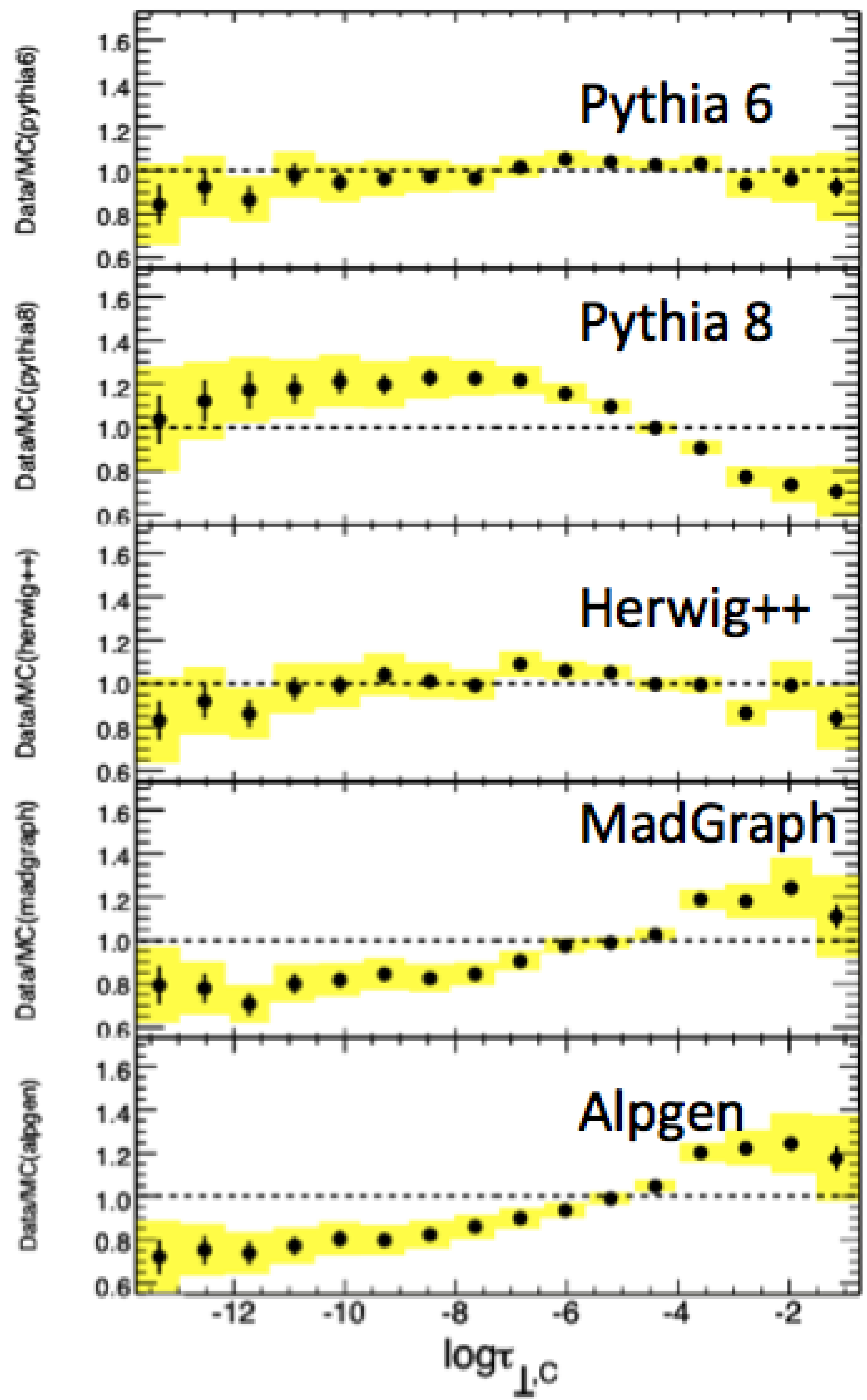
We use jet momenta as input; reduced sensitivity to UE; first measurement at LHC

- $p_T^{leading}$>60 GeV, $|\eta_{j1j2}|$<1.3, p_T>30 GeV, $|\eta|$<1.3,

→ JES dominant syst, JER and position resolution (±10%)

Sensitivity to multi-jet prod.

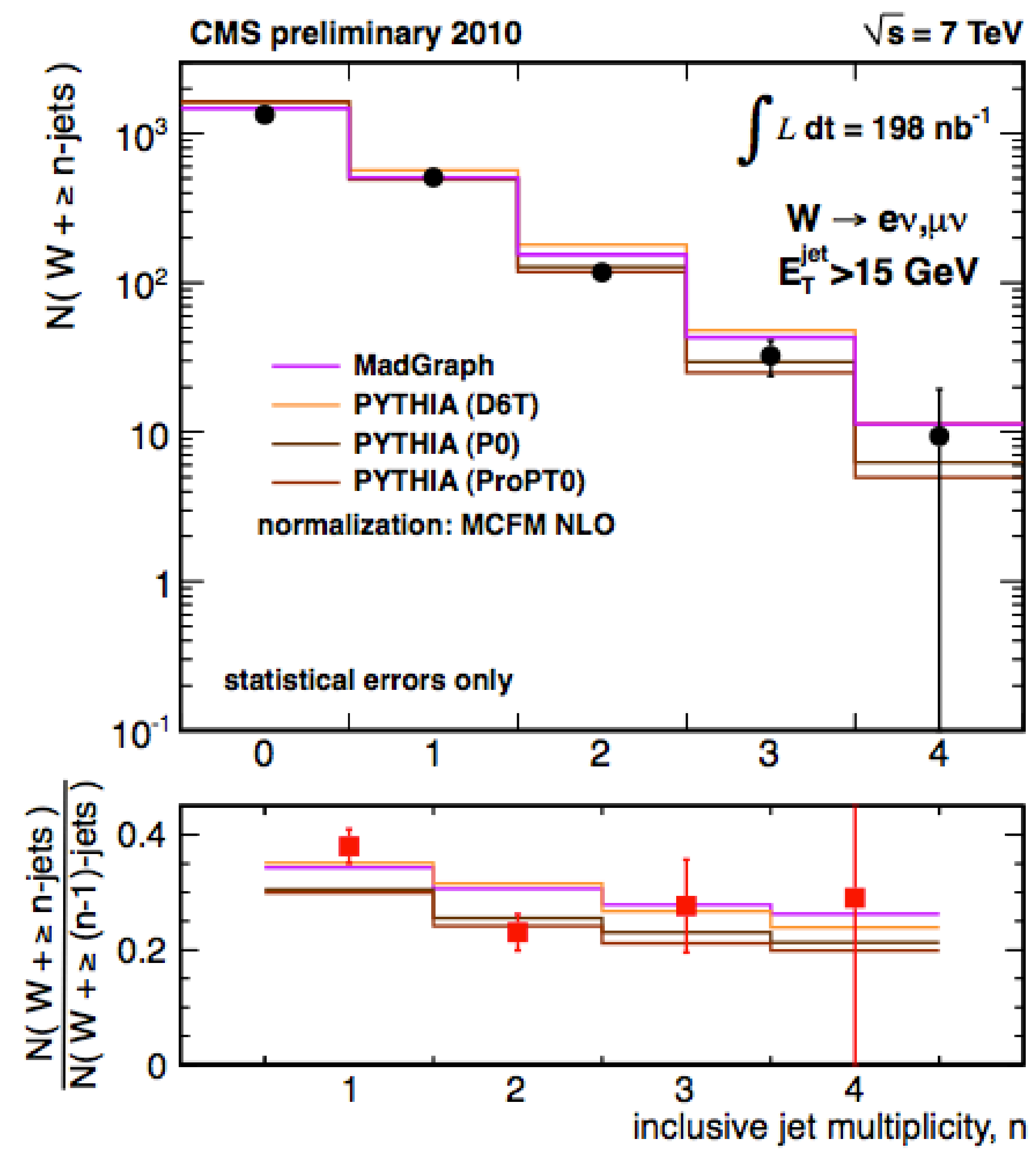
- Event shapes provide geometric information about energy flow in hadronic events
- Essential for tuning parton shower and non-perturbative components of Monte Carlo event generators
- Event shapes are robust against choice of jet reconstruction, as well as JEC and JER uncertainties



Pythia 6 and Herwig++ agree with data within uncertainties;
Alpgen and Madgraph overestimate fraction of back-to-back dijets,
and Pythia 8 underestimates it;
similar at all p_T

W+jet production : Jet Rates

- Yields shown for events with ≥ n jets
  - inclusive rates
- W signal extracted with a fit to the M_T distribution in each sample
  - statistical errors only
  - tt background sizable for n ≥ 3
- The use of Particle Flow jets allows to lower the jet E_T threshold to E_T > 15 GeV
- No big differences between PS (PYTHIA) and ME+PS(MadGraph)
  - But strong dependence on the MC tune

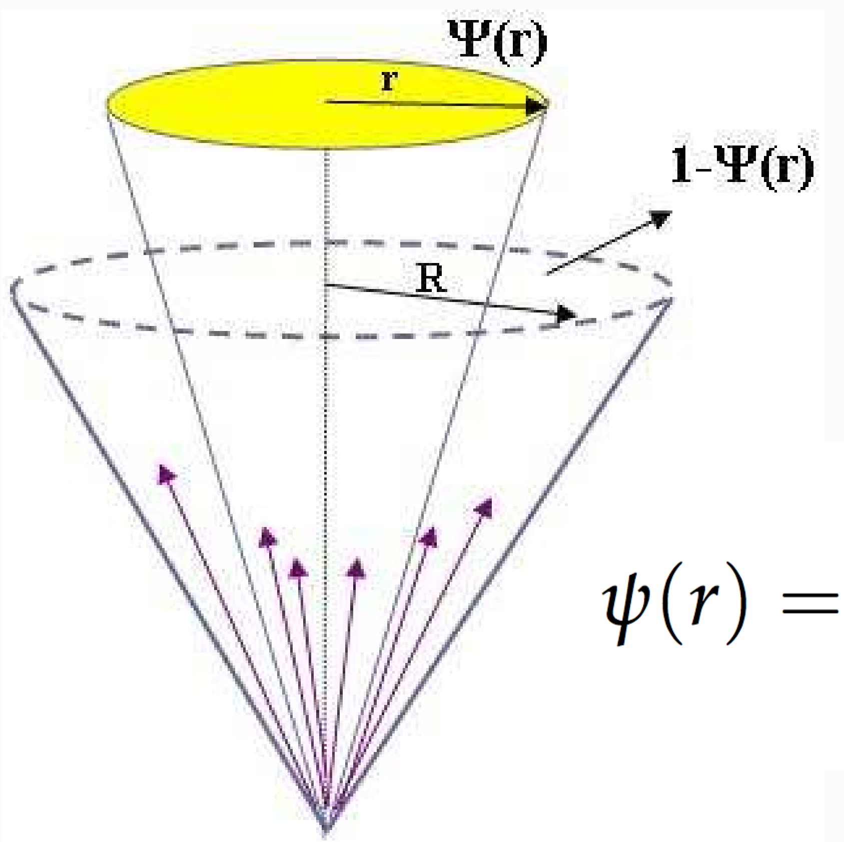


Jet-Structure

Jet transverse shapes

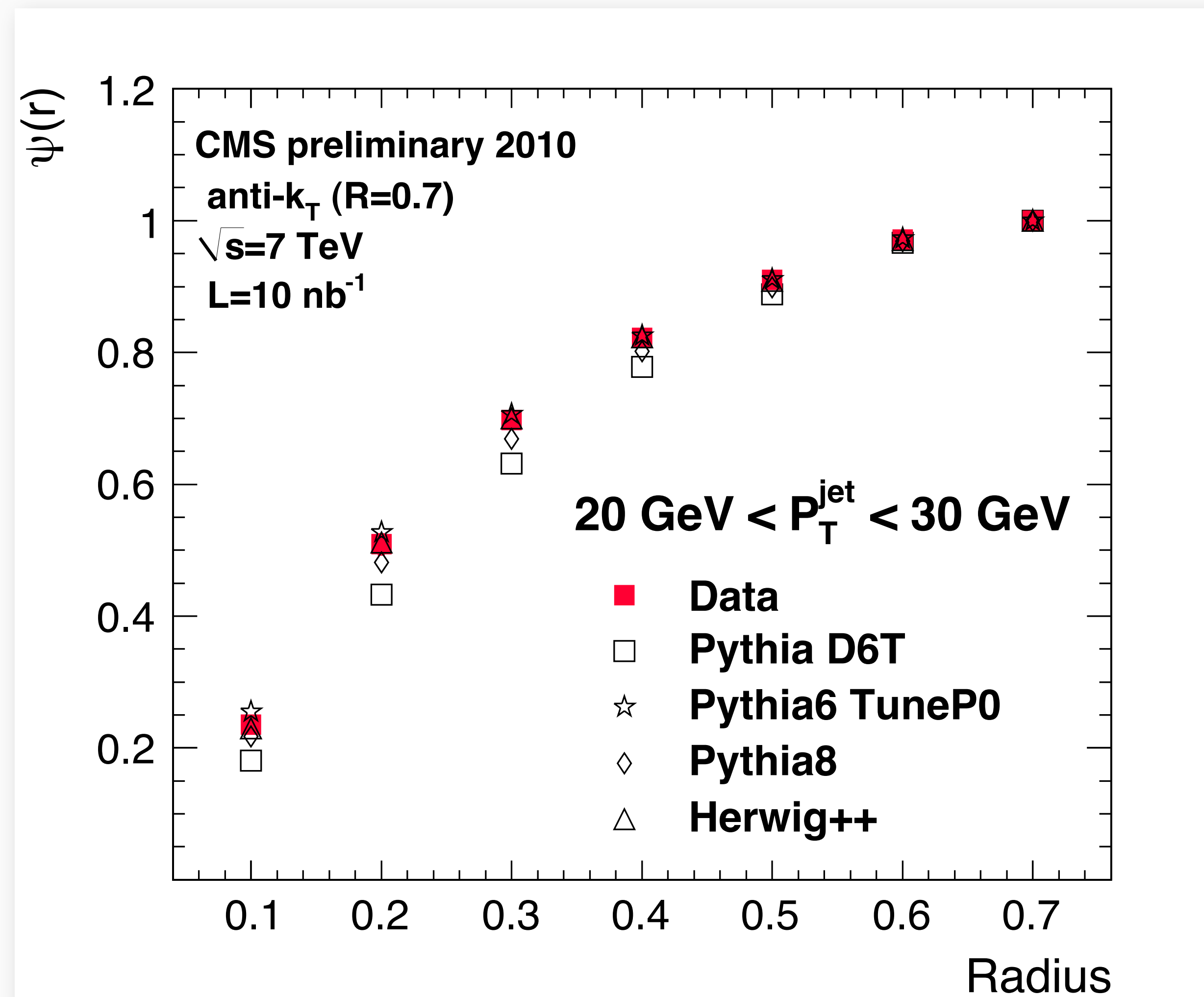
QCD-10-014

- Jet transverse shapes probe transition between hard pQCD and soft gluon radiation
- Phenomenological models motivated by QCD and tuned at e^+e^- colliders
- At hadron colliders underlying event is an important ingredient; models tuned at 2 TeV, but extrapolation to LHC uncertain
- Jet data dominated by gluon jets



$$\psi(r) = \frac{\sum_{r_i<r} p_{Ti}}{\sum_{r_i<R} p_{Ti}}$$

$$\langle \delta\phi^2 \rangle = \frac{\sum_{i\in \mathrm{jet}} (\phi_i - \phi_C)^2 \cdot p_{T,i}}{\sum_{i\in \mathrm{jet}} p_{T,i}}$$



Jet transverse shapes

QCD-10-014

ETH Institute for Particle Physics

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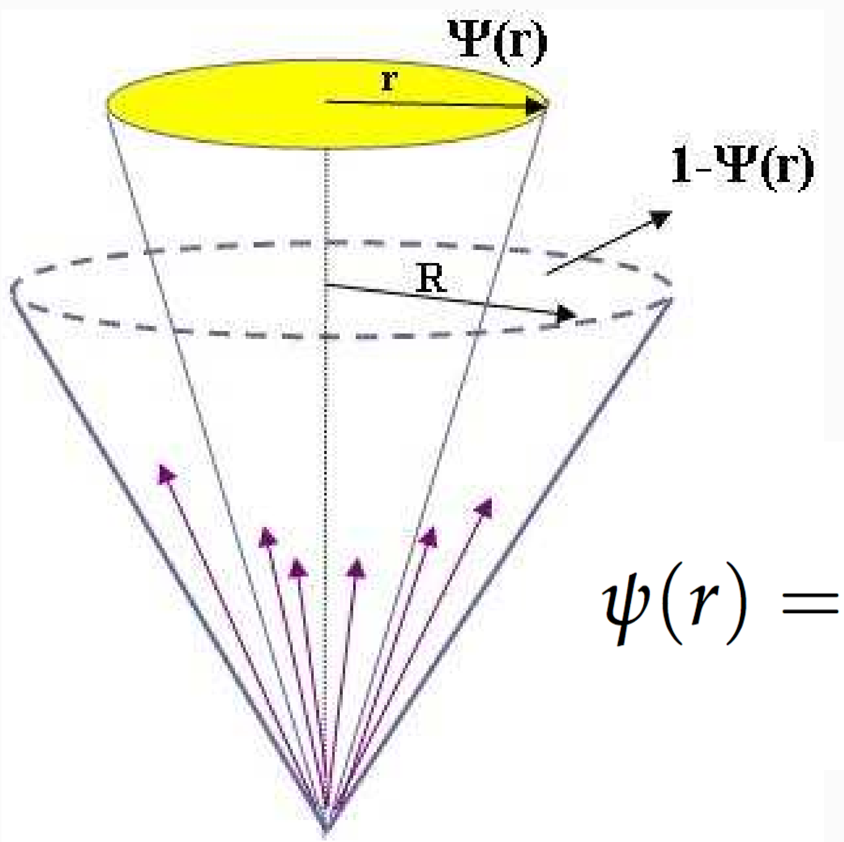

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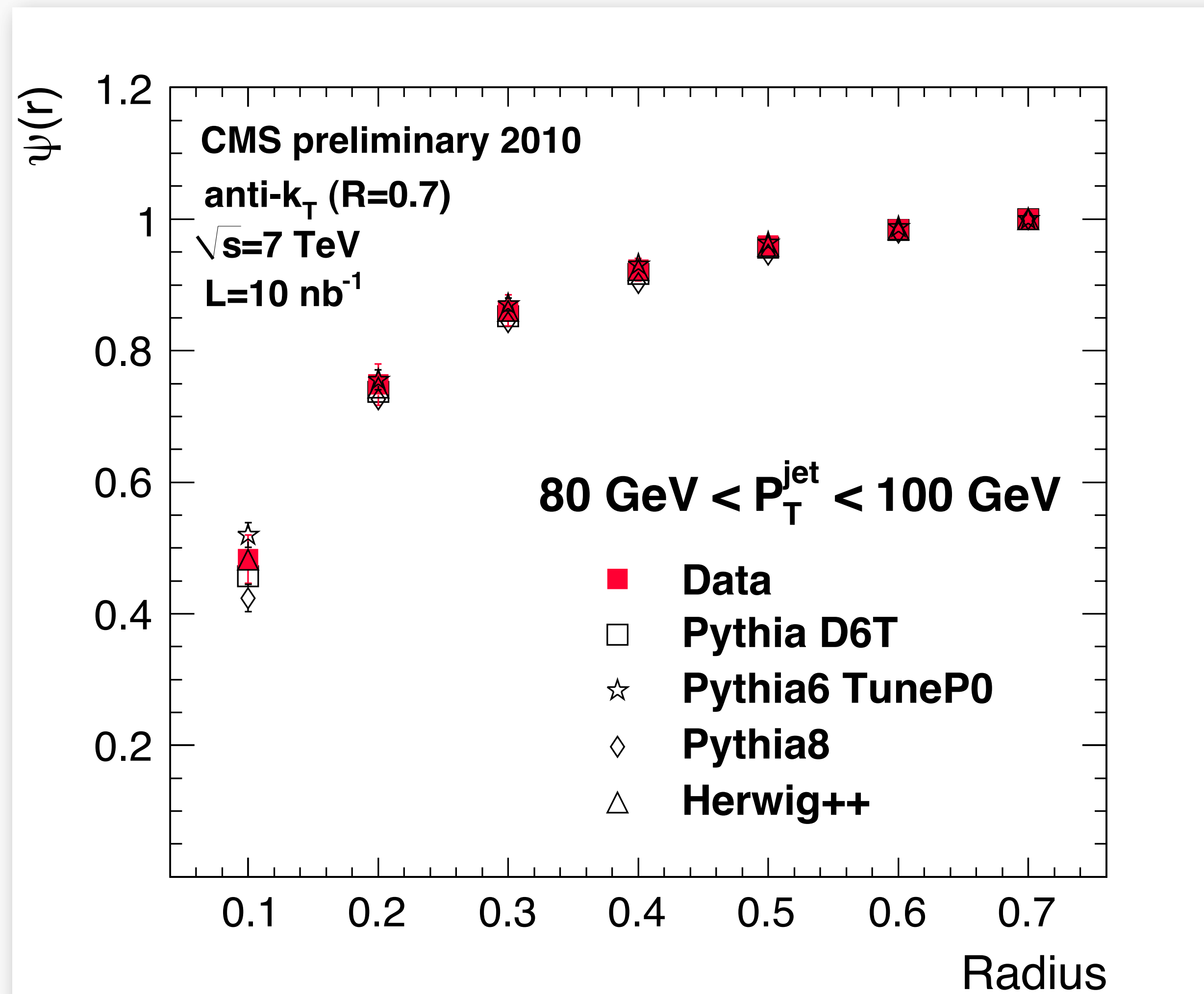
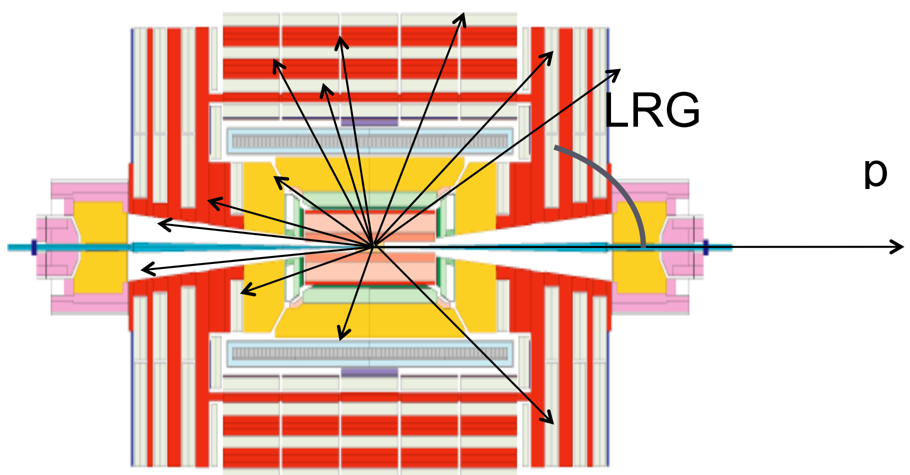
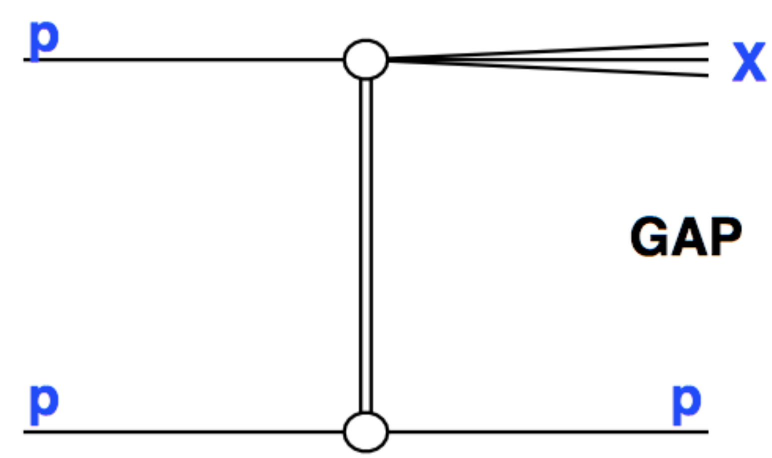
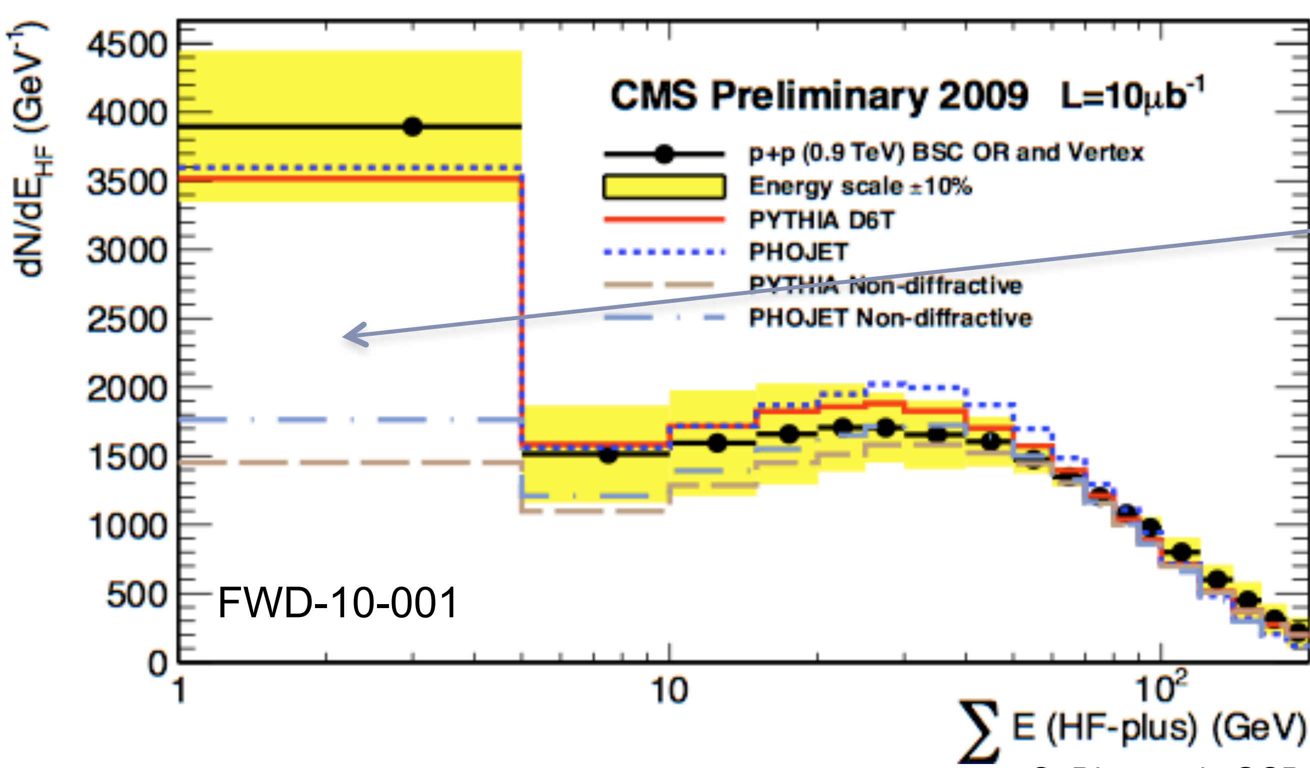


Forward Physics and Diffraction

Sketch of single-diffractive event:



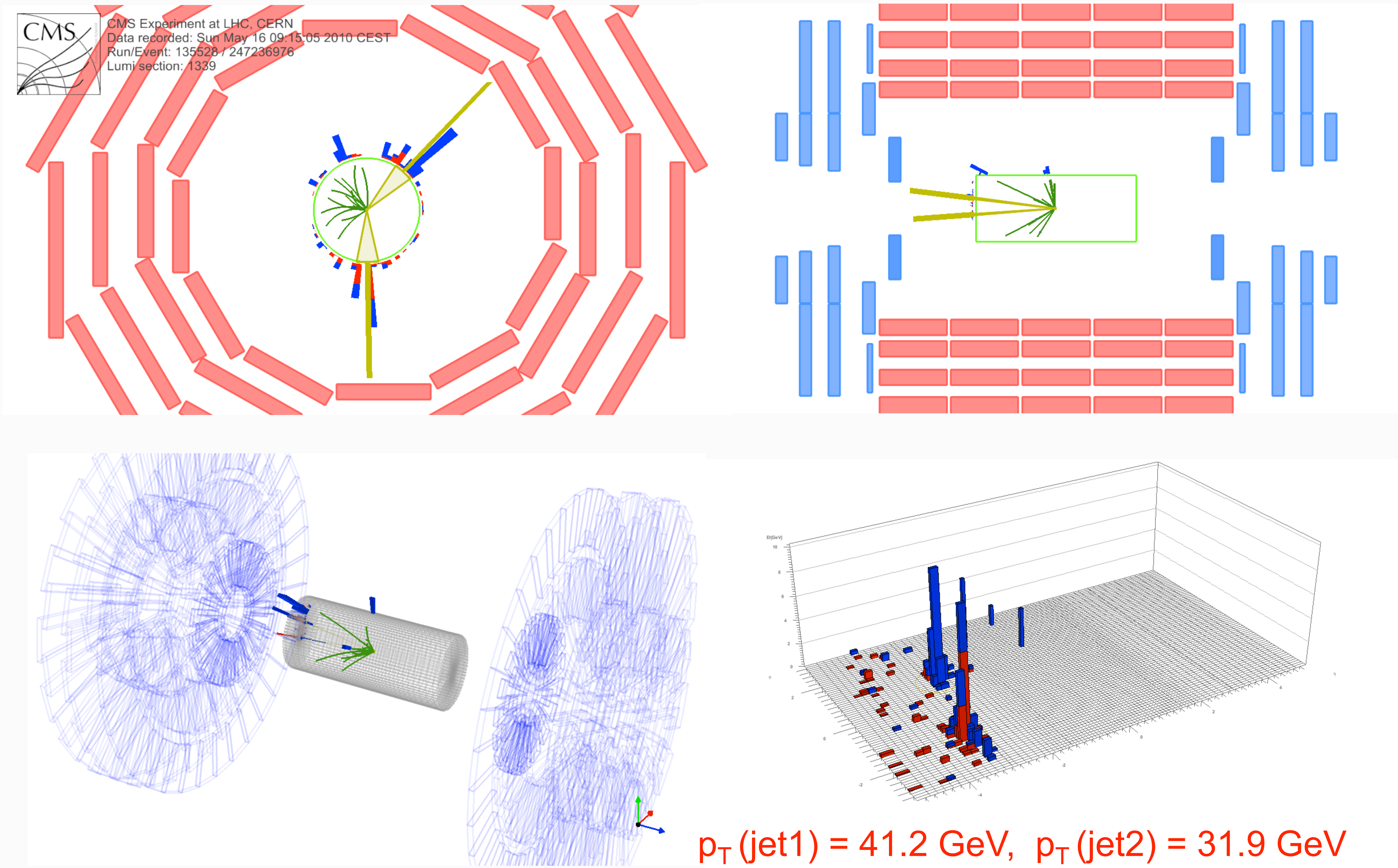




Σ E related to the momentum loss of the scattered proton. One expects a (diffractive) peak at low values of this variable ($\sigma \sim 1/\xi$).

N.B. All plots are uncorrected

Diffractive Di-Jet Candidate at 7 TeV



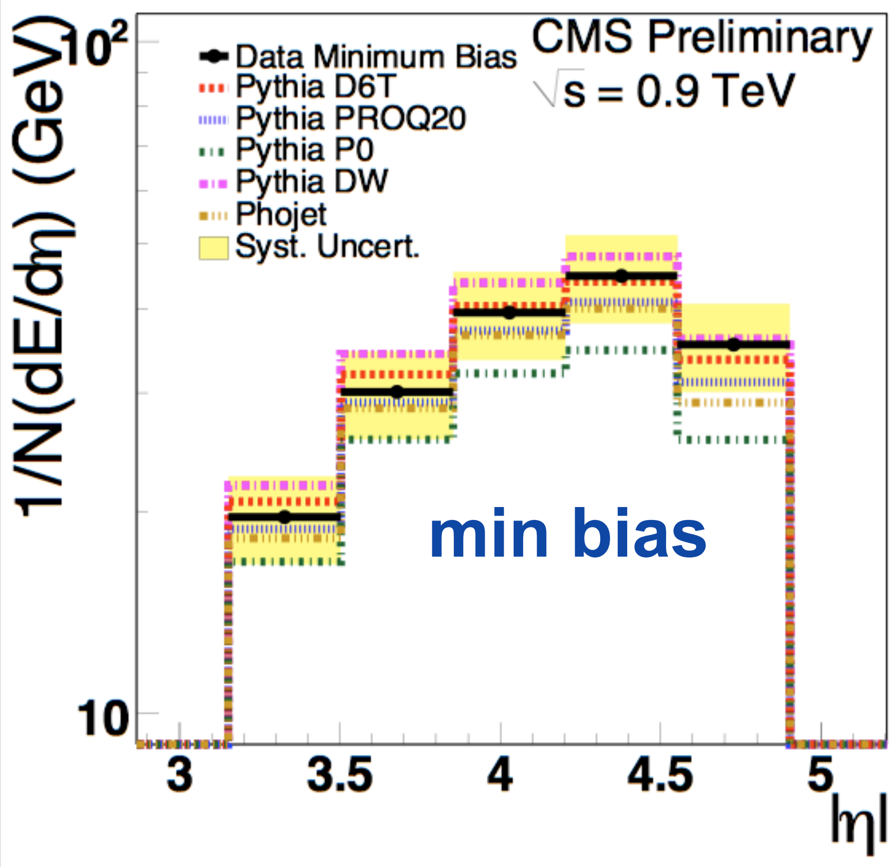
p_T (jet1) = 41.2 GeV, p_T (jet2) = 31.9 GeV

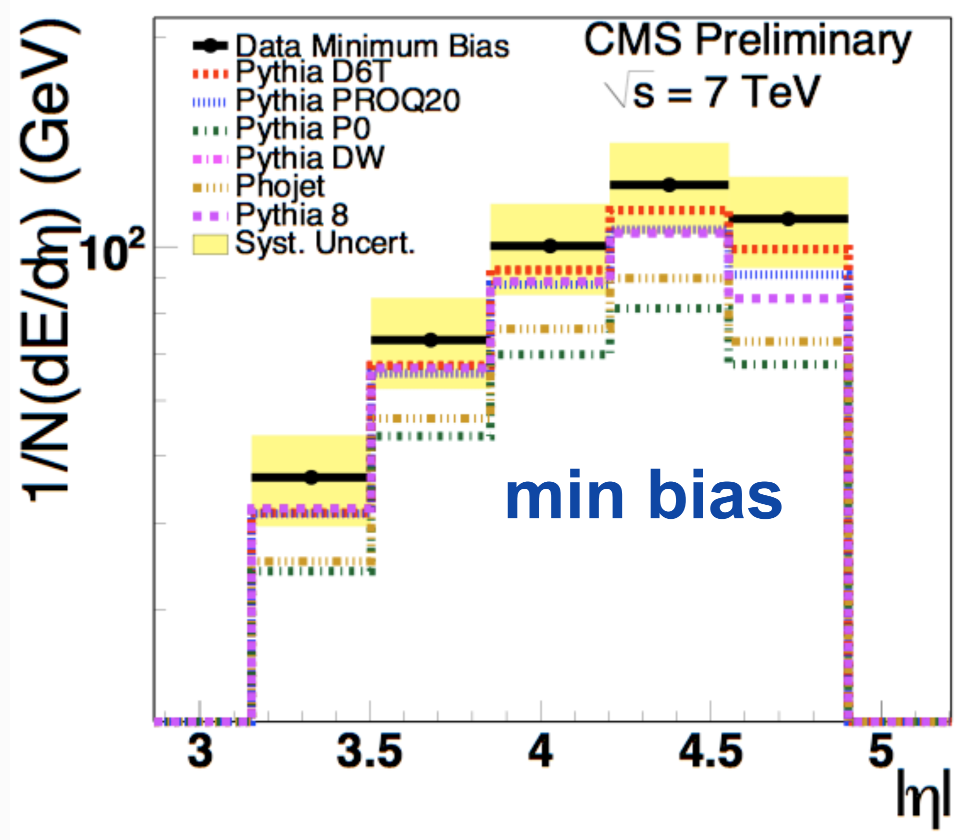
η (jet1) = -2.8, η (jet2) = -3.3

E(η < 3.0) > 1.5 GeV p_T(track) > 0.5 GeV

E(η ≥ 3.0) > 2.0 GeV

Measurement of forward energy flow



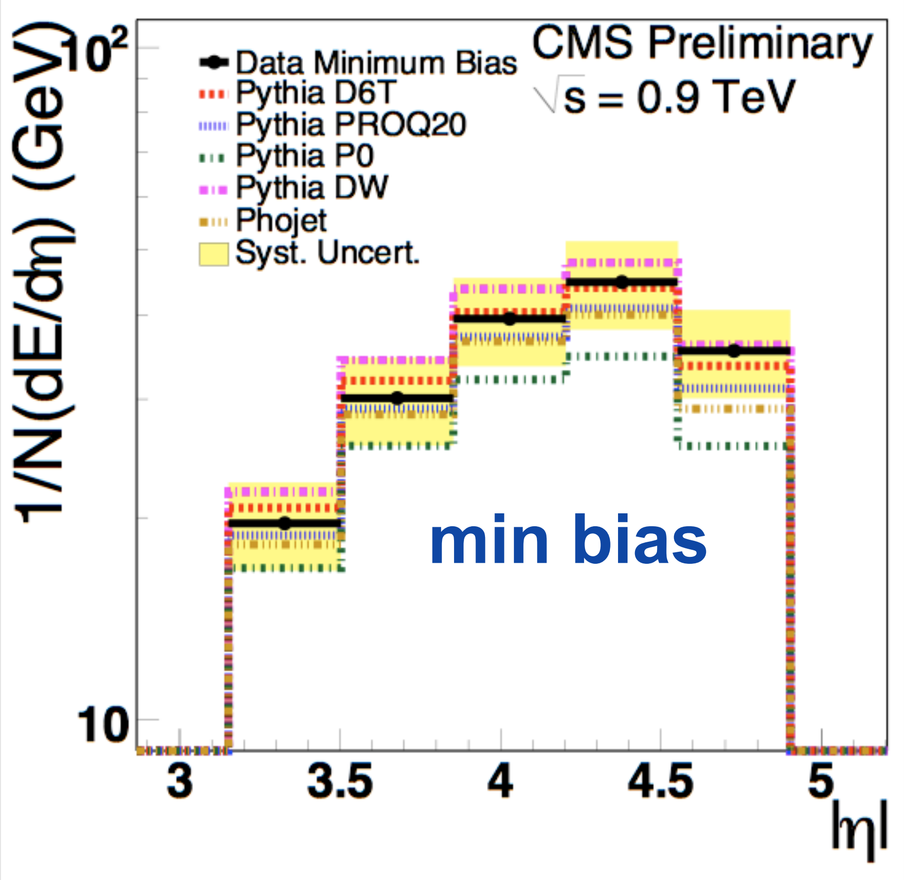


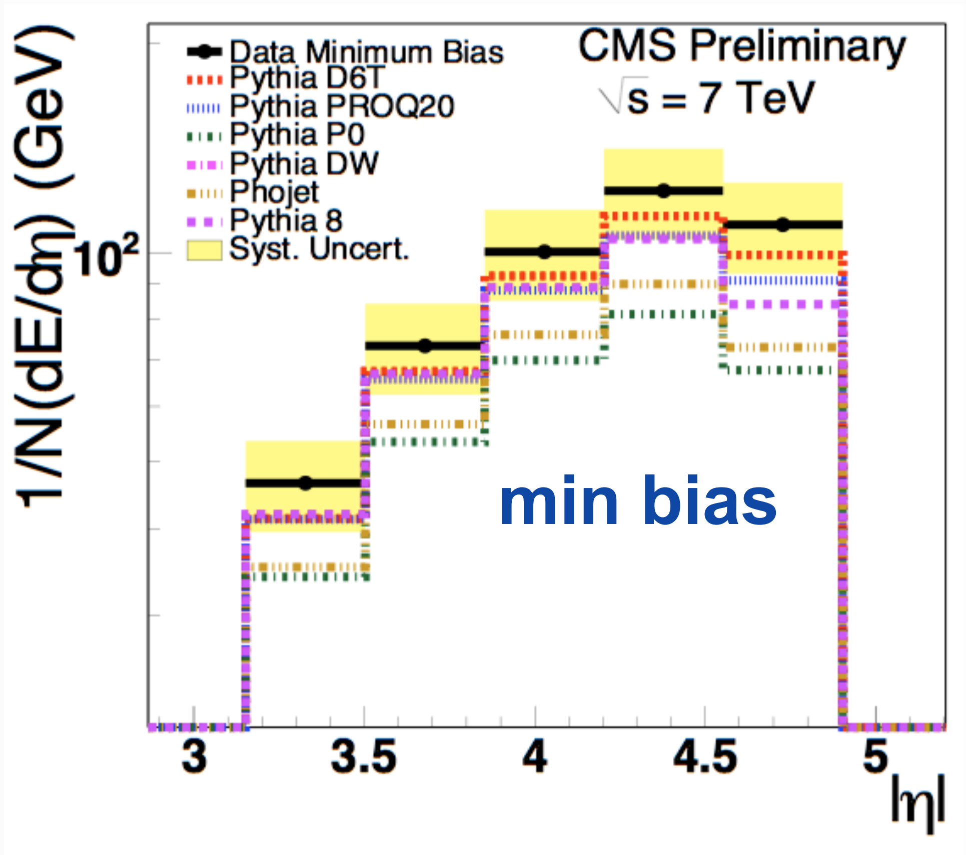
FWD-10-002

Forward Energy flow: sensitive to parton radiation and MPI

Energy flow increases from 0.9TeV to 7 TeV by factor ~ 3

Measurement of forward energy flow





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Energy flow in dijet events significantly larger than in minbias

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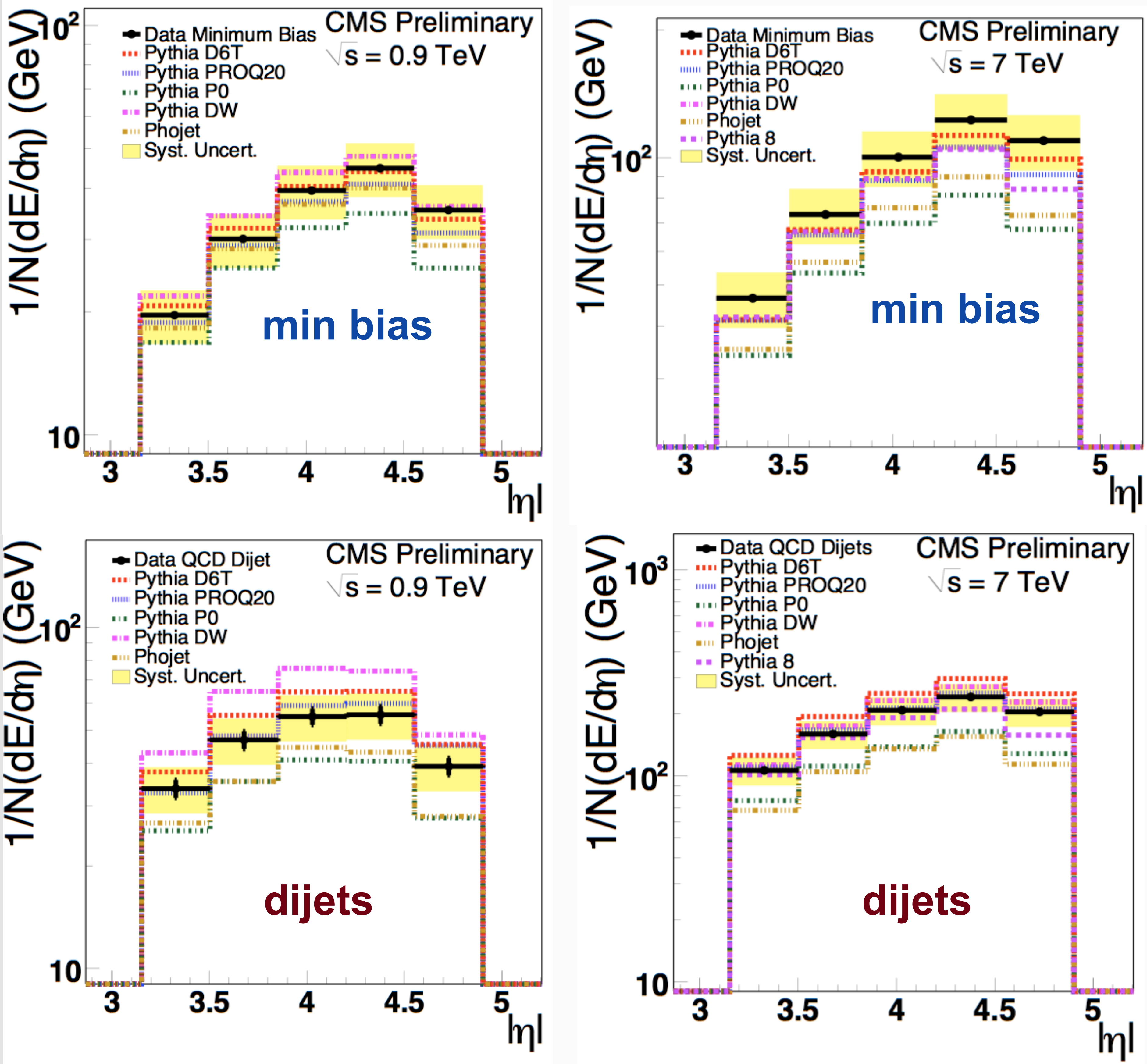
FWD-10-002



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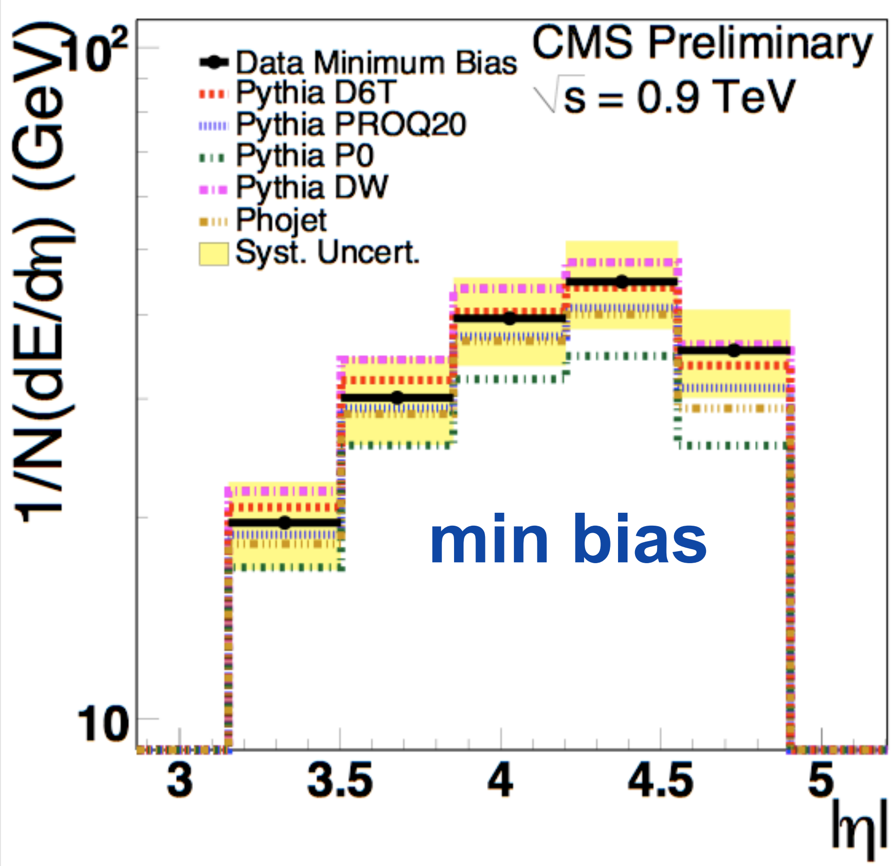
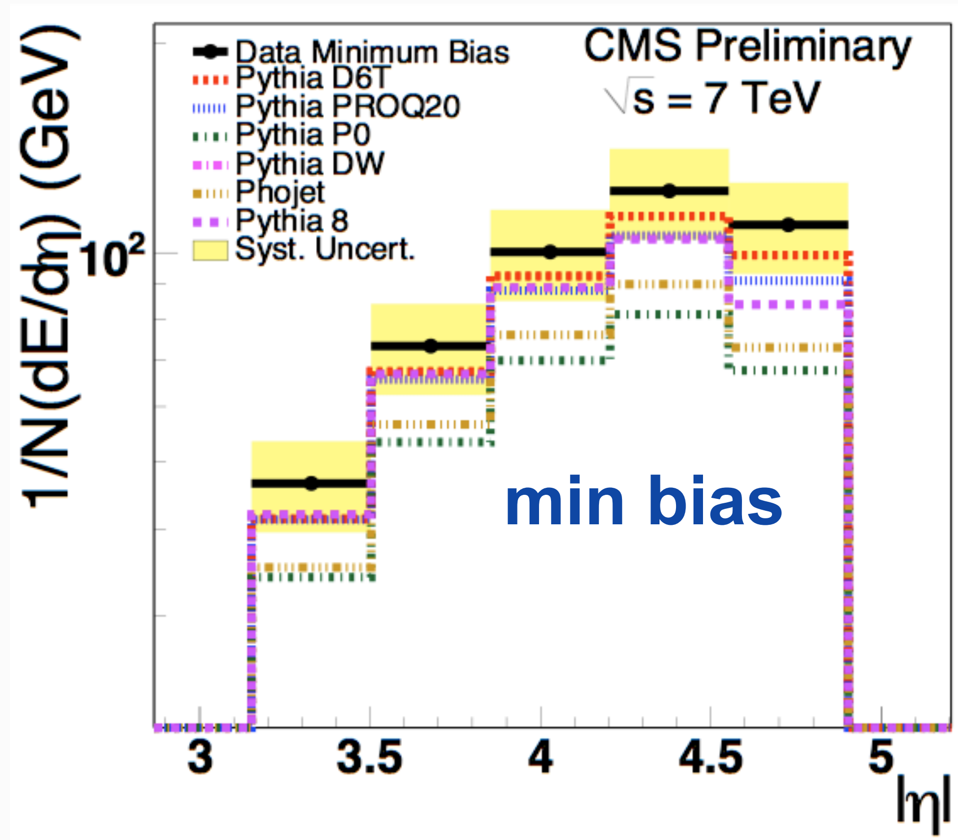
FWD-10-002





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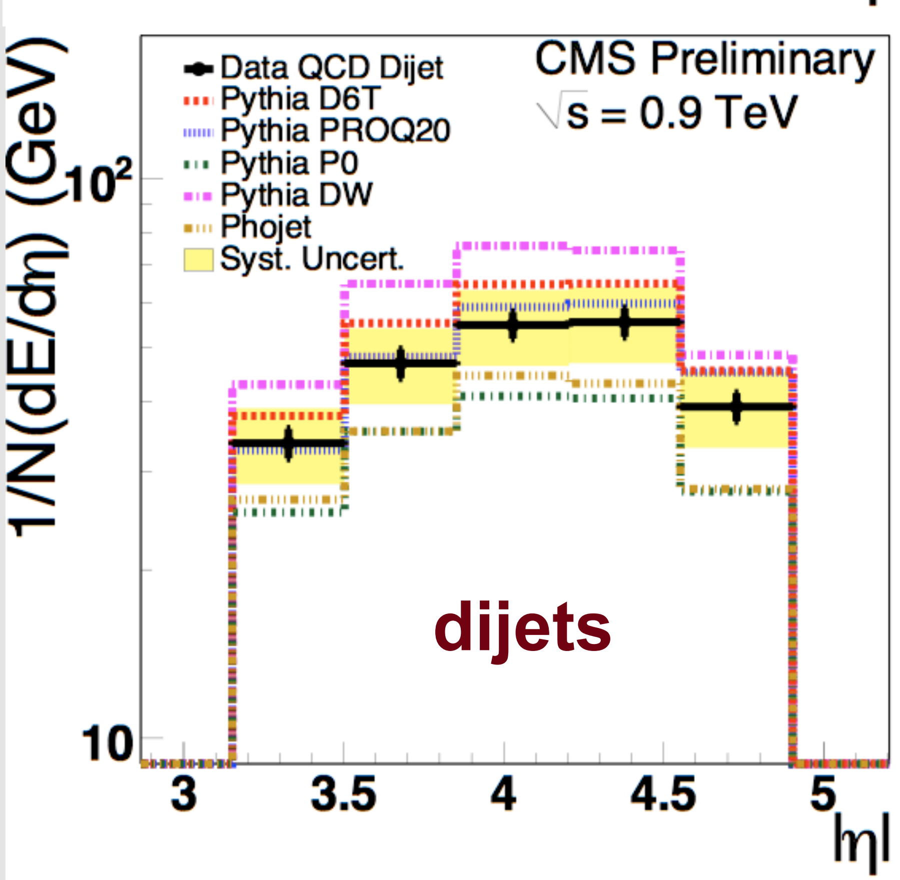
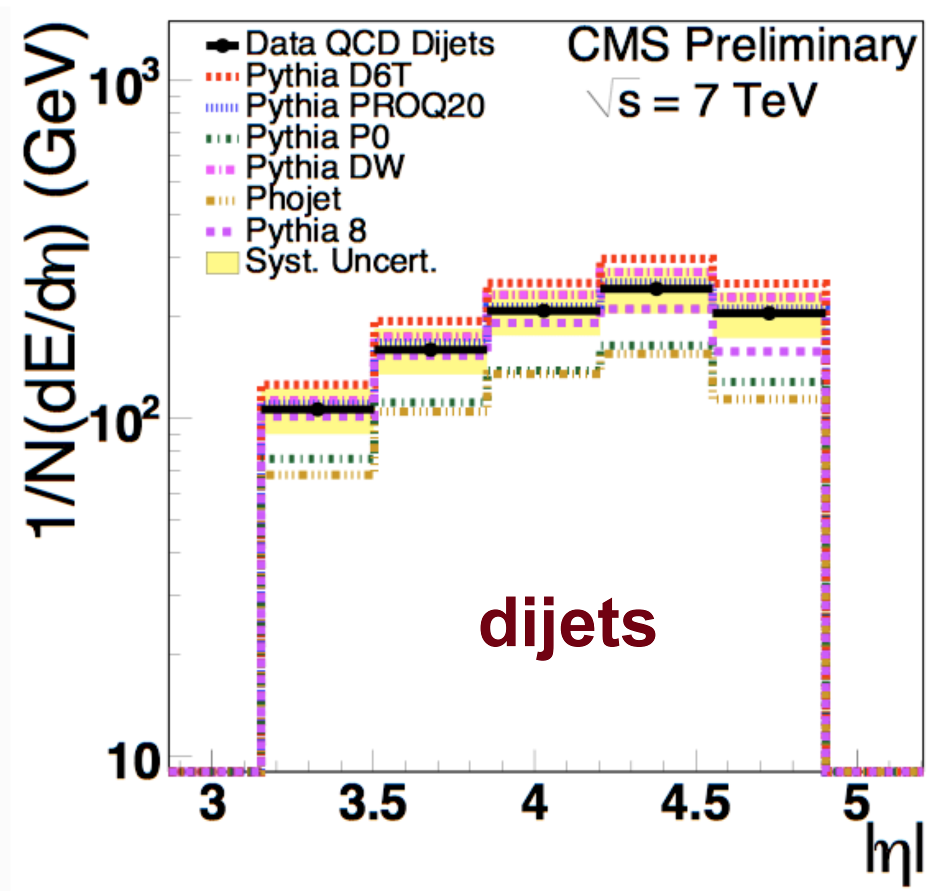




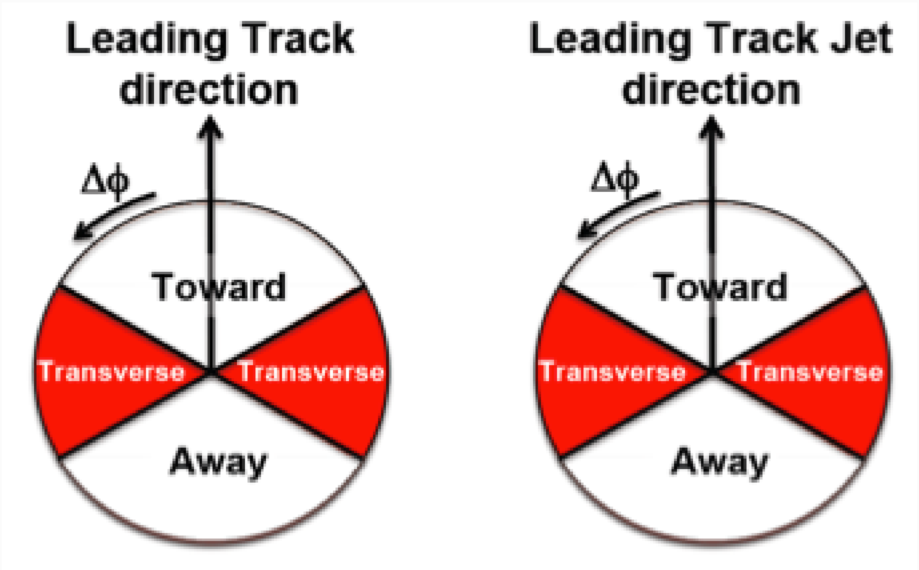
Energy flow in dijet events significantly larger than in minbias

See presentation by M. Velasco this week, for further discussion of forward and diffractive physics, and models/tunes

“Soft(er)” processes

Underlying Event Studies

Definitions



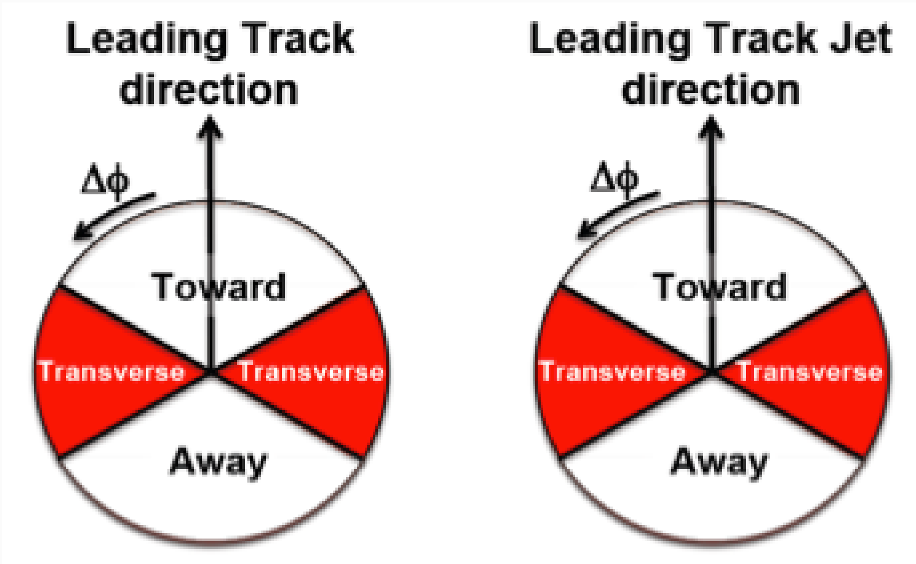
- Traditional approach (R. Field)
  - **Leading Track or Leading Track-Jet** define a direction in the phi plane
  - Track or Track-jet p_T provide an energy scale

Main observables, built from Tracks:

$d^2N_{ch}/d\eta d\Phi$ charged mult. density
$d^2Sum(PT)/d\eta d\Phi$ energy density

- Transverse region expected to be particularly sensitive to the UE

Definitions



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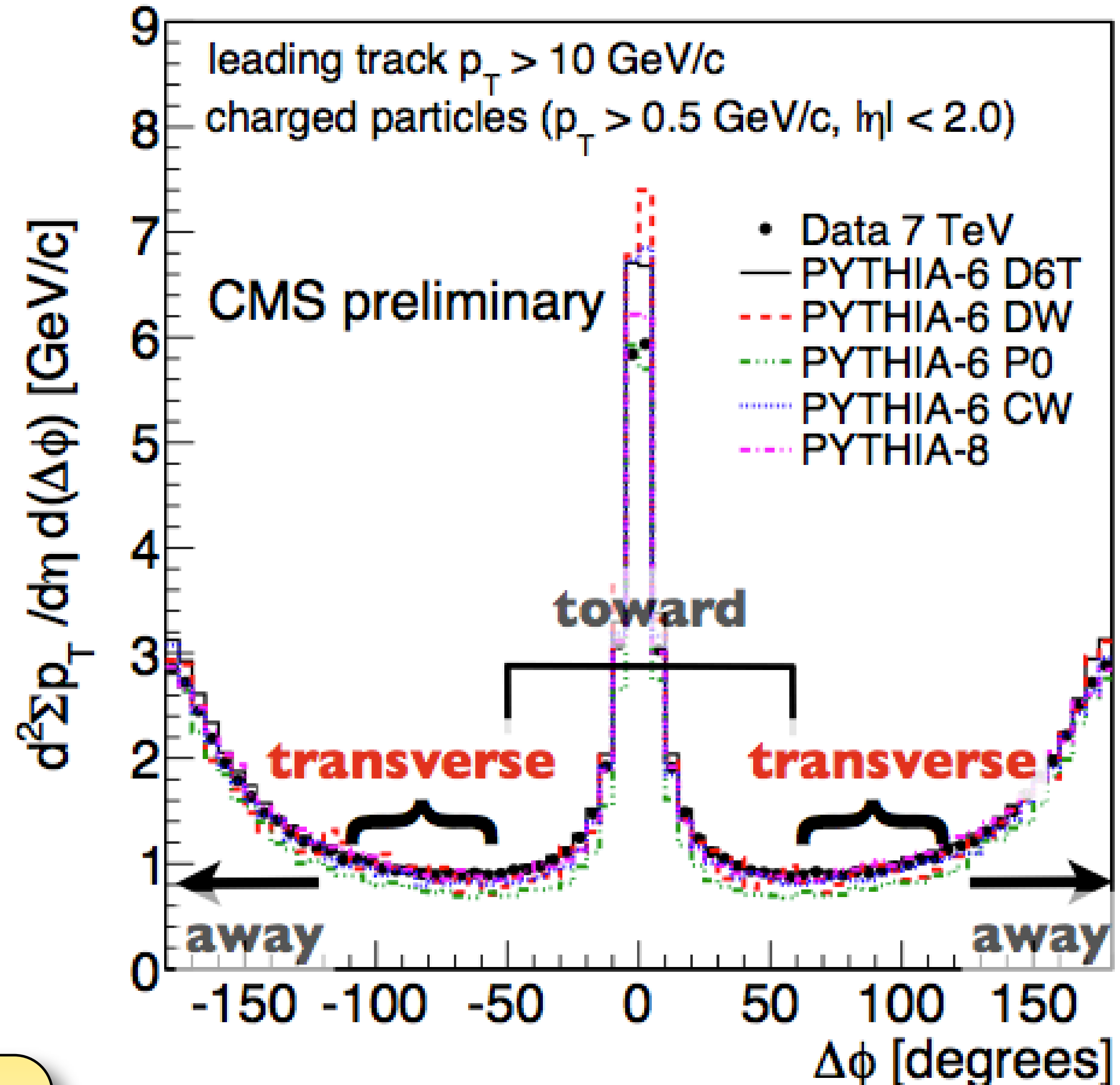
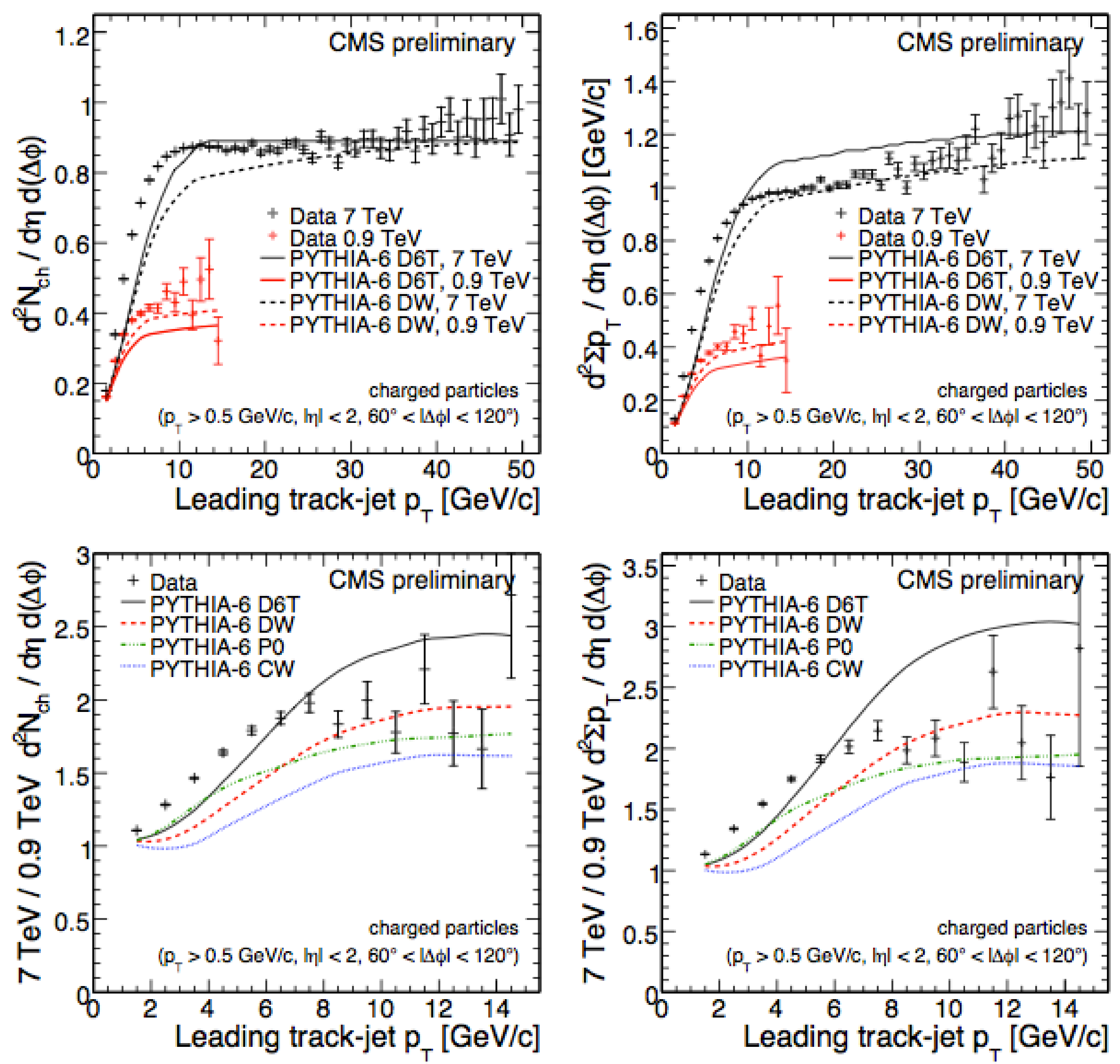


Note : so far data were not corrected for detector effects. Efforts in this direction under way

see QCD-10-001 and QCD-10-010

E_{cm} Dependence : Transverse Region

QCD-10-010



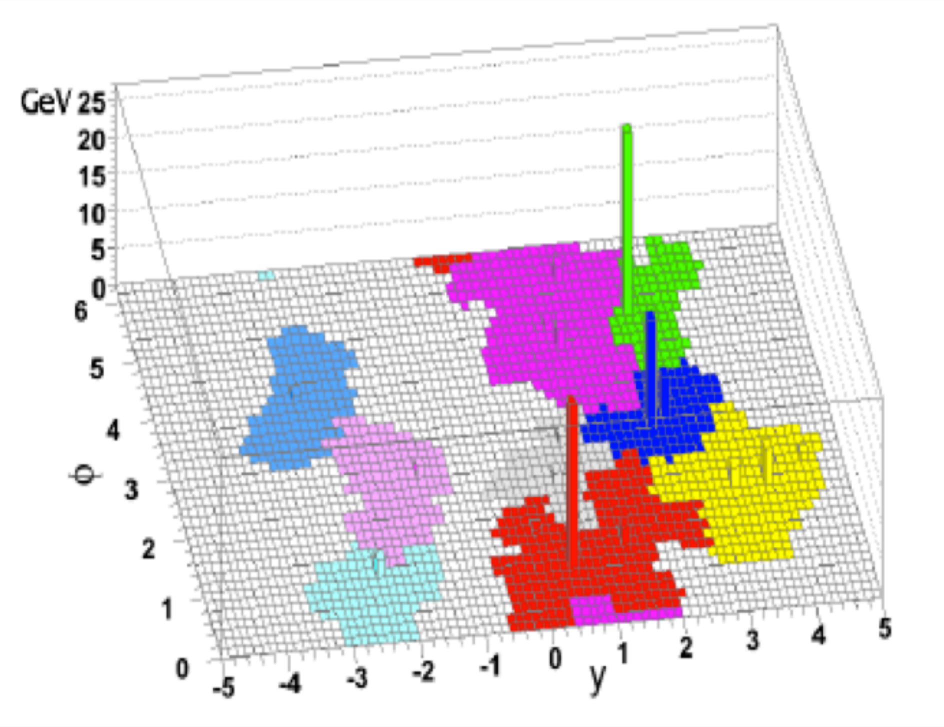
In general:
Poor description of the rise.

P0 has the worst shape.

D6T, with slower energy dependency of the p_T cut-off, overestimates the plateau regions

See presentation by Rick this week, regarding his new "amazing" Z1 tune !

Alternative approach to the UE

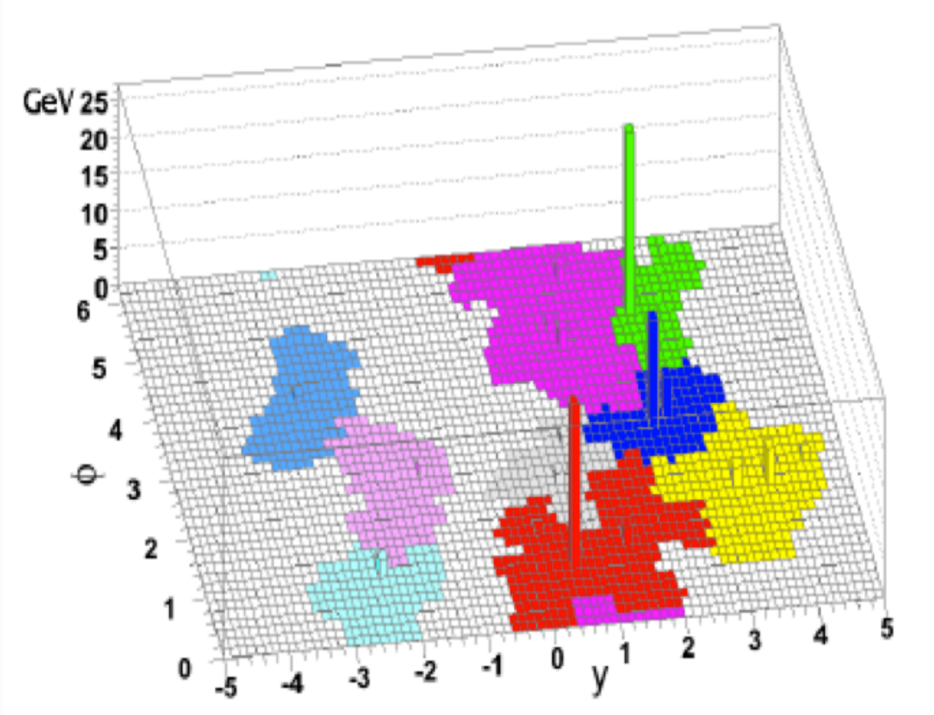


New Approach: Jet Area/Median

- Discussed in JHEP 04 (2010) 065 on generator level
- Median of pt/area of all jets in an event is a measure for UE activity → new observable ρ
- Supresses influence of hard objects
- Suitable for different event topologies

$$\rho' = \underset{j \in \text{physical jets}}{\text{median}} \left[\left\{ \frac{p_{Tj}}{A_j} \right\} \right] \cdot C \qquad C = \frac{\sum_{j \in \text{physical jets}} A_j}{A_{\text{tot}}}$$

Alternative approach to the UE



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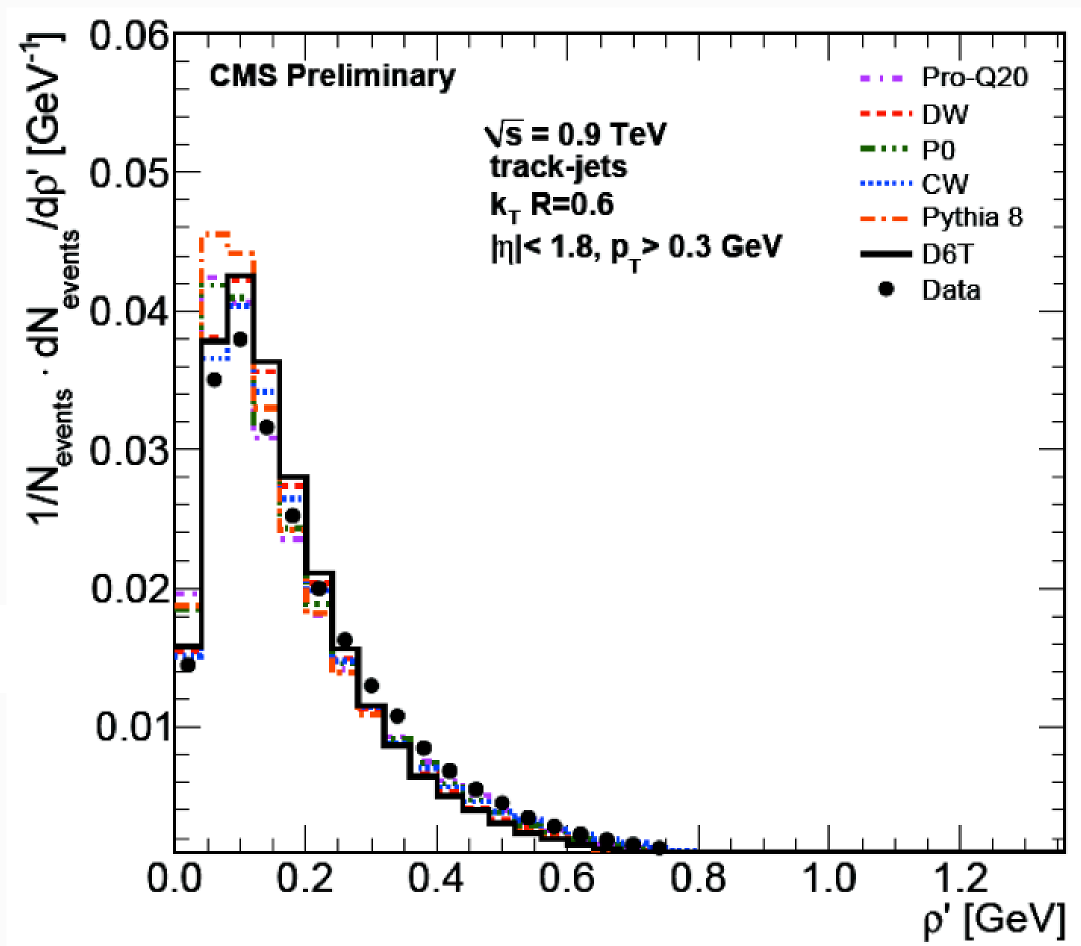
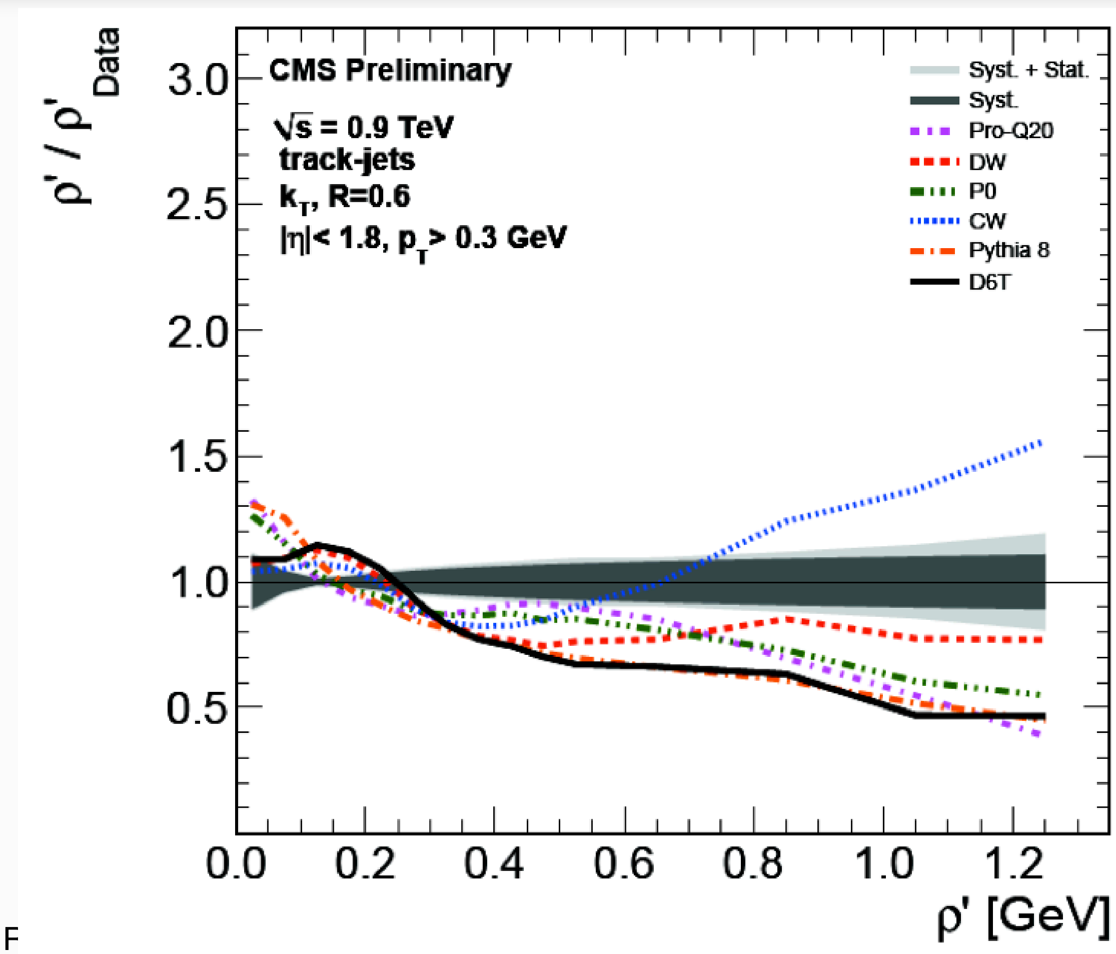




Particle Production (Multiplicities and Momentum distr.)

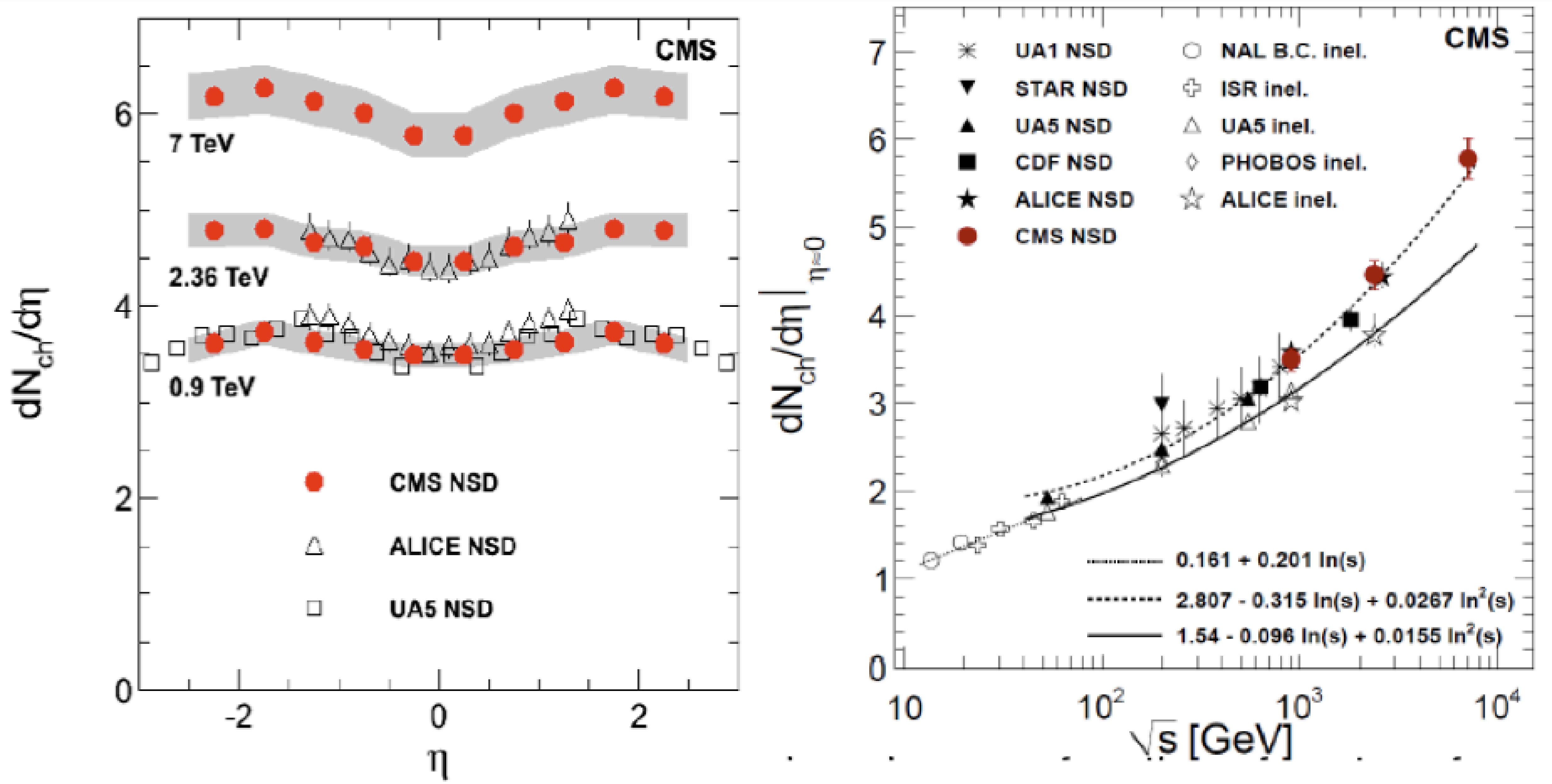
Min Bias and High-p_T

See also M. Velasco's presentation this week....

Pseudo-rap. density (NSD)

V. Khachatryan et al., JHEP 02 (2010) 041
V. Khachatryan et al., Phys. Rev. Lett. 105 (2010) 022002

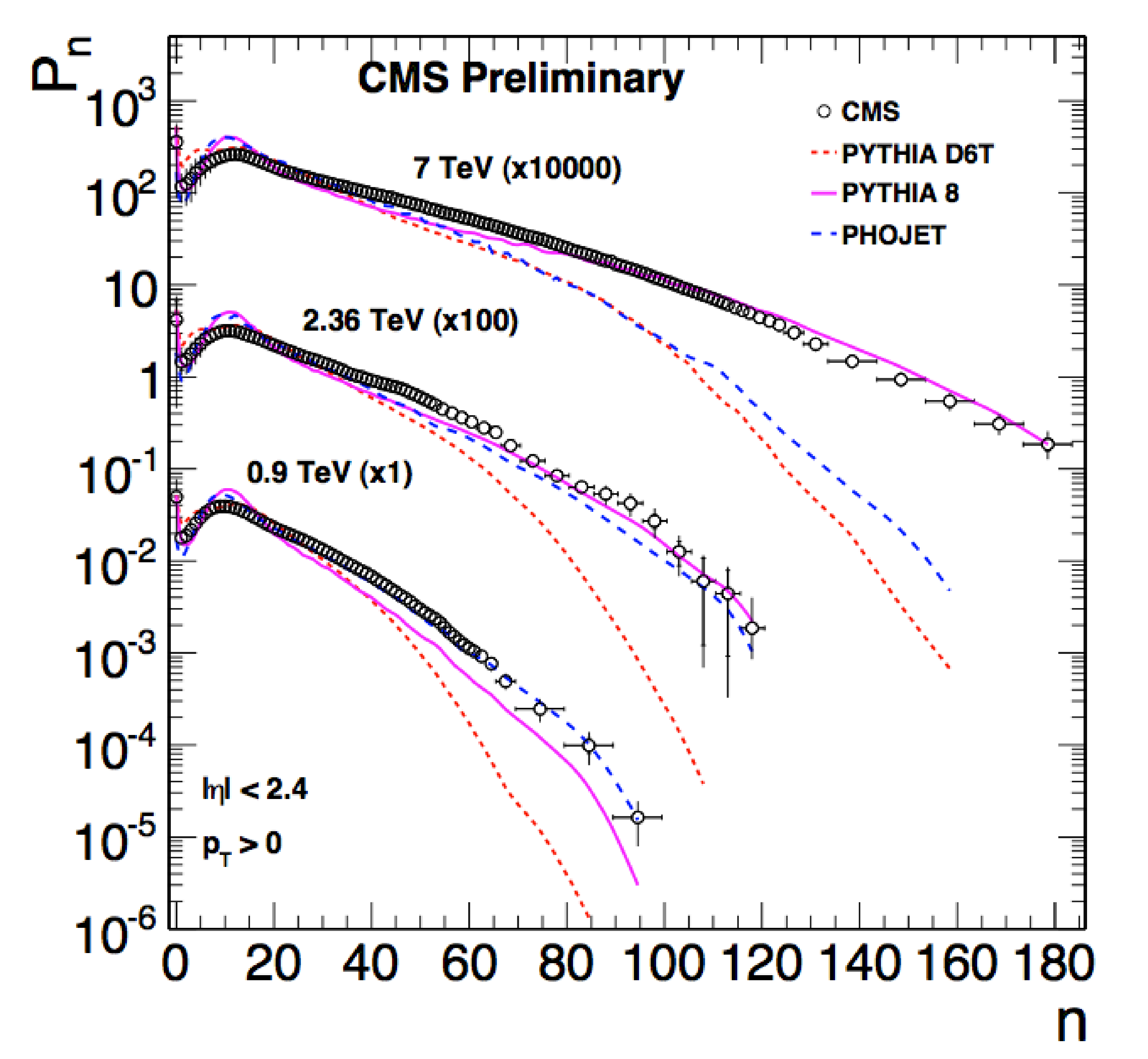
Minimum bias events
Non single-diffractive event selection (correction 6%→2.5% systematic error)
Really soft QCD (p_T tracks dow to 50MeV)



- Rise with √s :
  steeper than predicted by most MC models, with up to 40% difference

Charged particle multiplicities

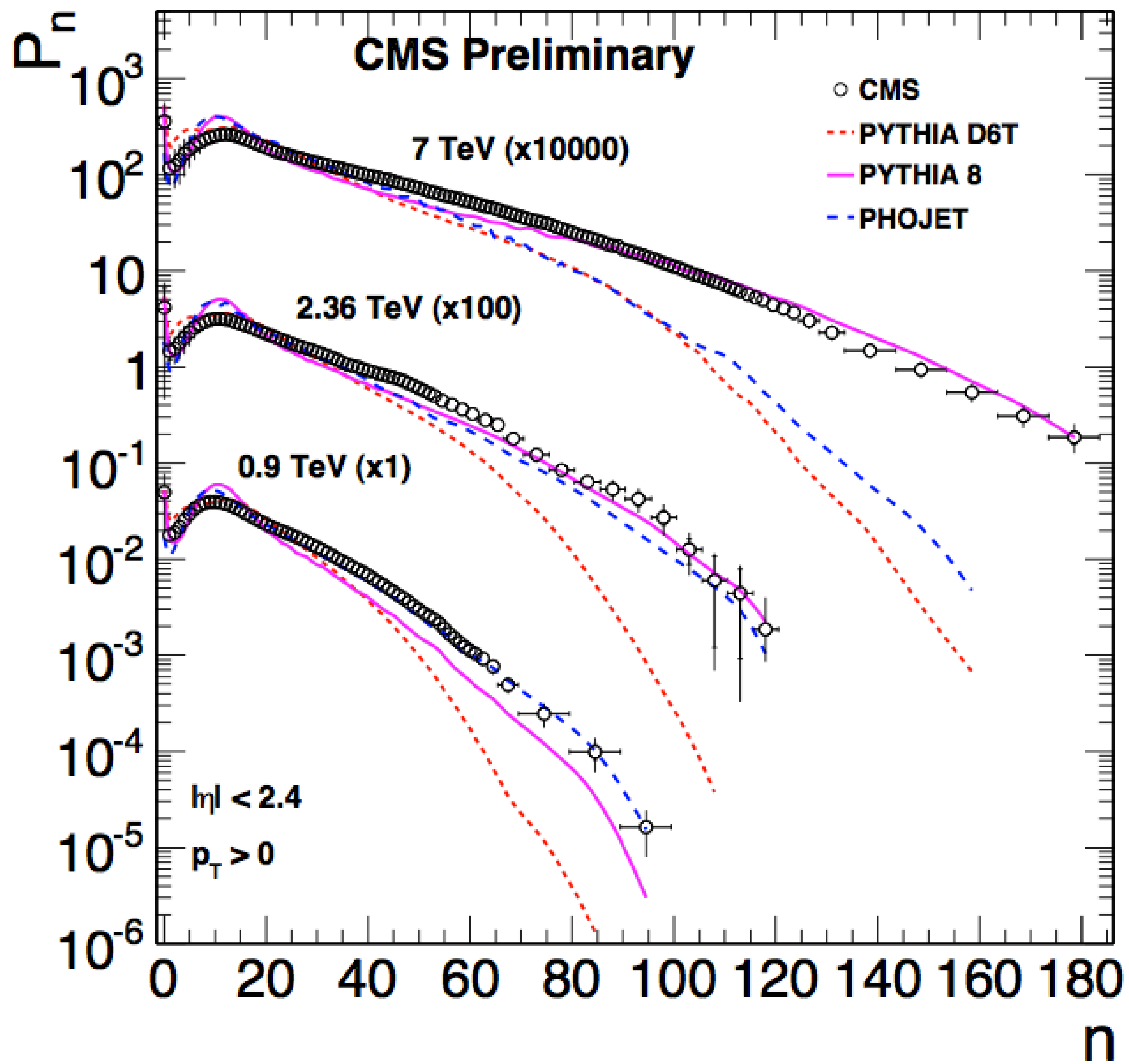
QCD-10-004



Unfolded up to primary hadron level
Extrapolated to p_T>0 (2% correction)
Normalization to NSD

Charged particle multiplicities

QCD-10-004

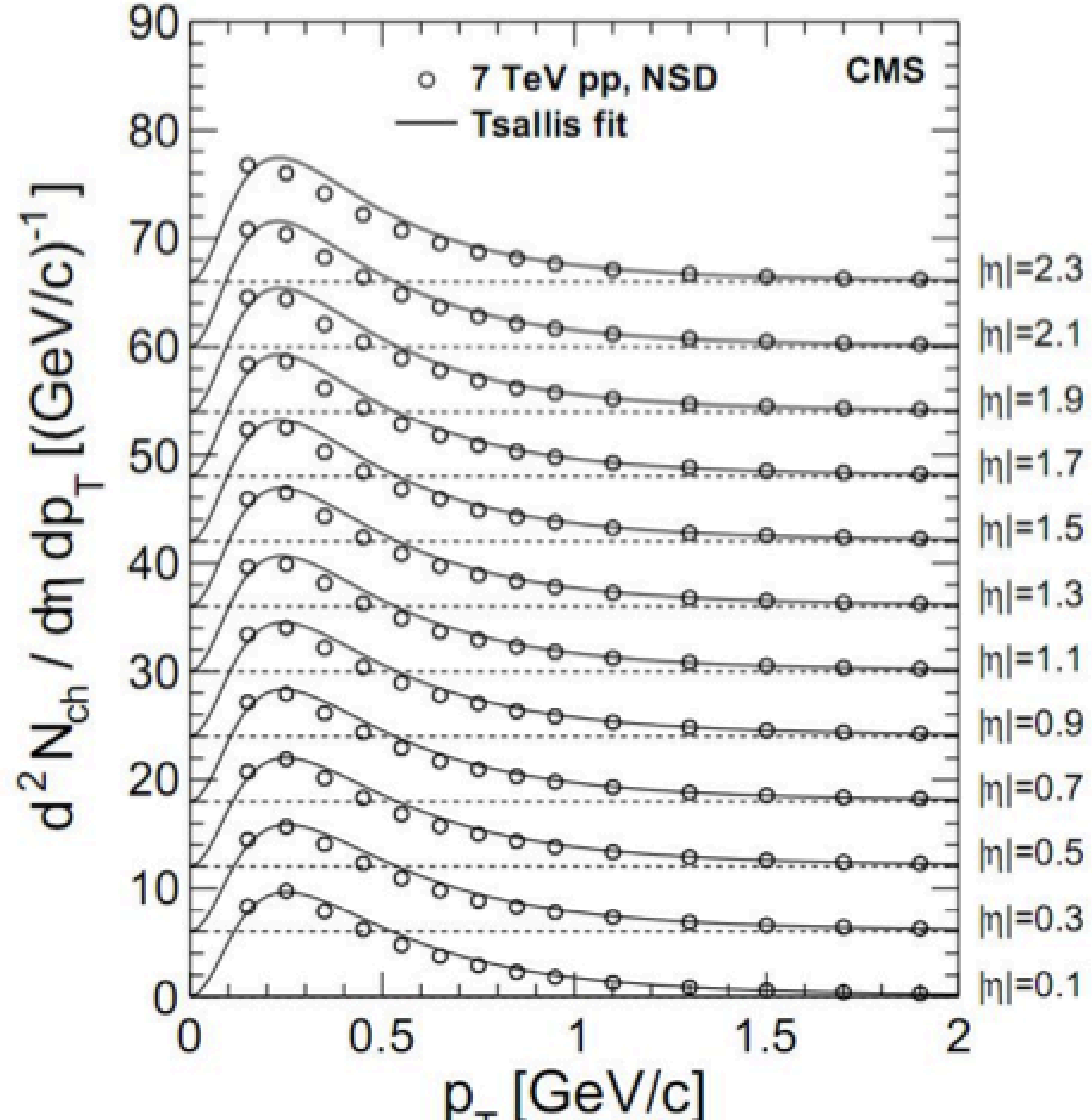


- shows need to improve (tuning of) models
- so far no model which is able to describe well, simultaneously, multiplicity and p_T distributions, over whole range and at diff. E_{cm}
- biggest discrepancies seen for p_T < 500 MeV

Unfolded up to primary hadron level
Extrapolated to p_T>0 (2% correction)
Normalization to NSD

Momentum Distributions

MinBias Trigger



Tsallis fit gives good description

$$E\frac{d^3N_{\rm ch}}{dp^3} = \frac{1}{2\pi p_T}\frac{E}{p}\frac{d^2N_{\rm ch}}{d\eta dp_T} = C(n,T,m)\frac{dN_{\rm ch}}{dy}\left(1+\frac{E_T}{nT}\right)^{-n}$$

V. Khachatryan et al., JHEP 02 (2010) 041
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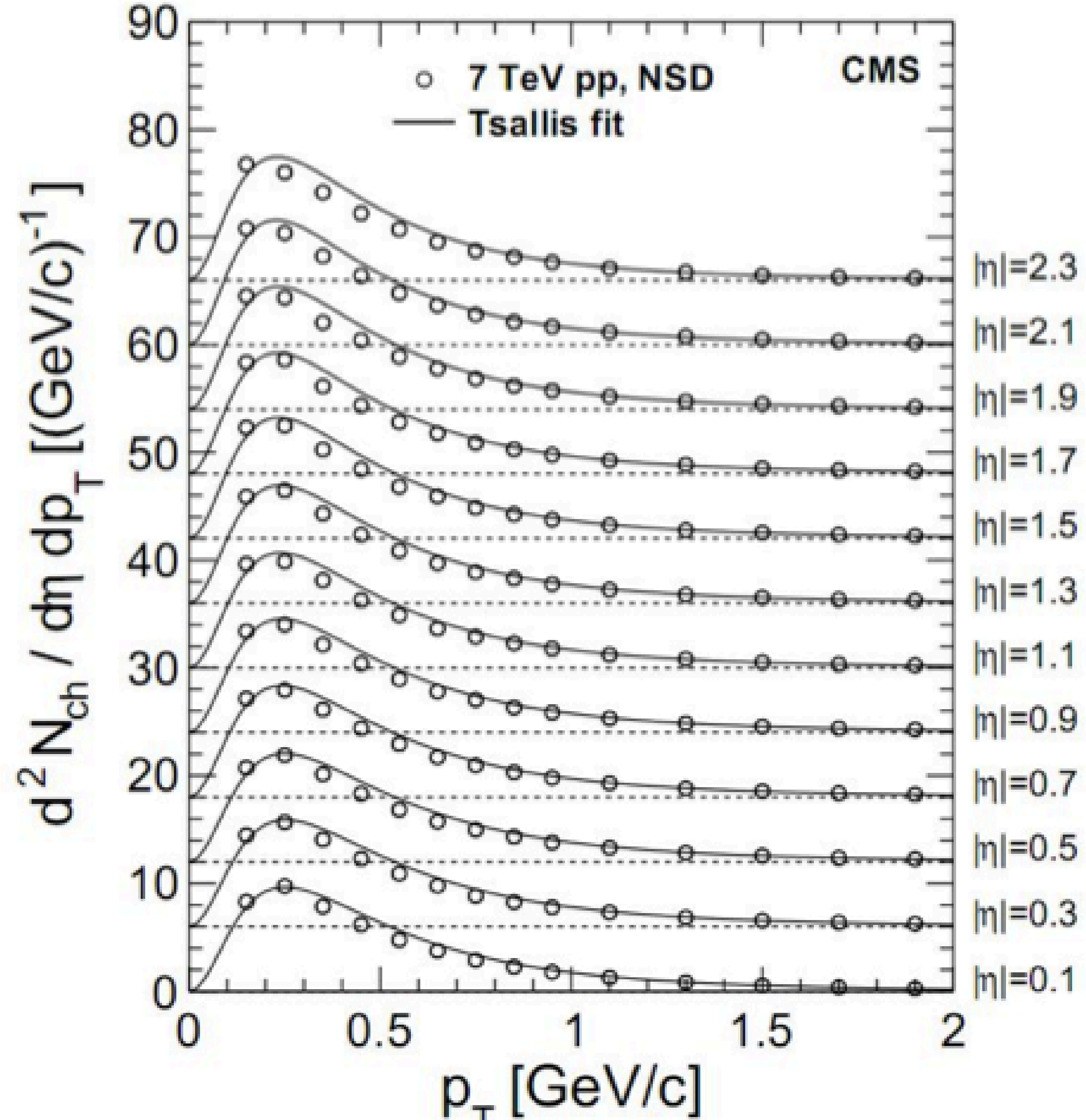

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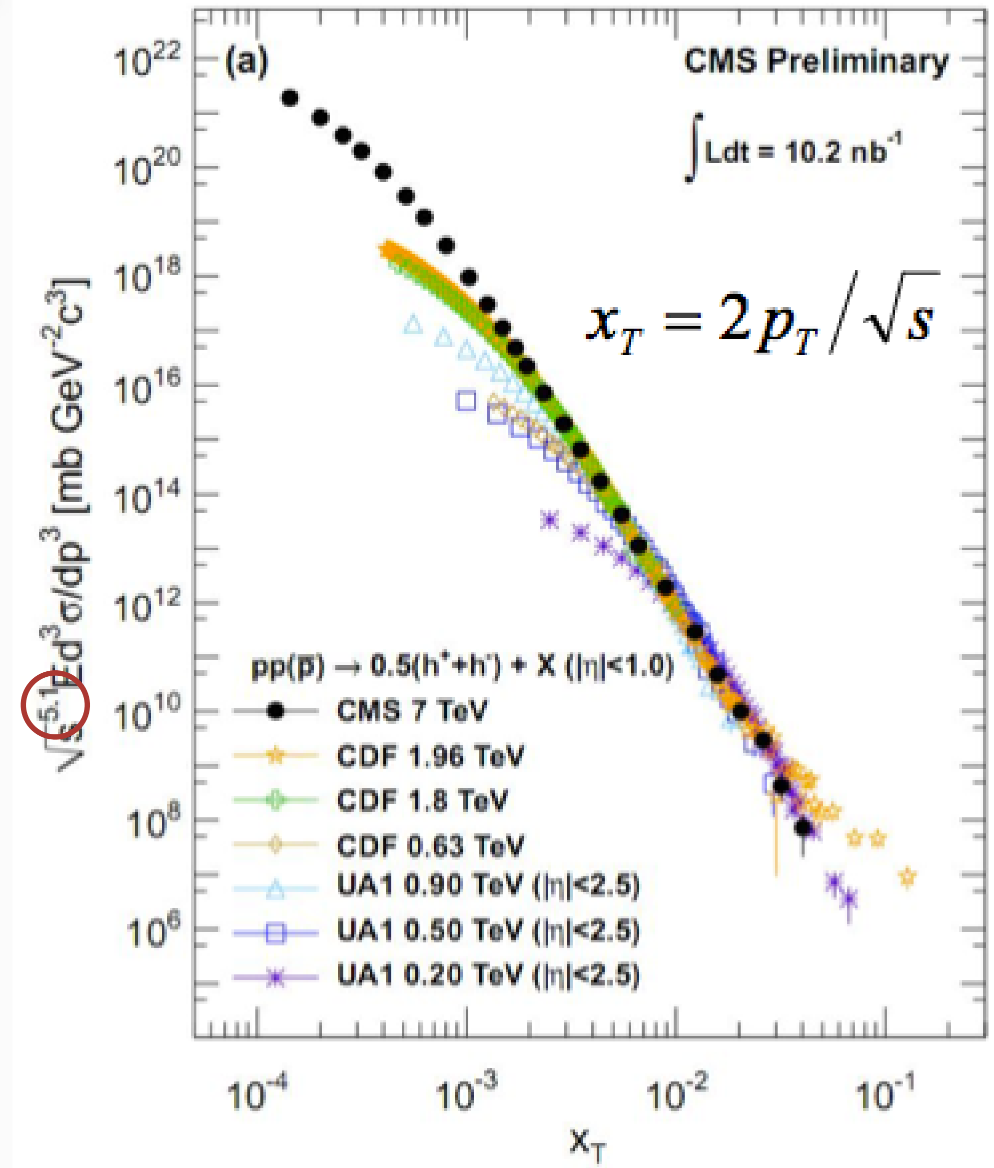
V. Khachatryan et al., JHEP 02 (2010) 041
V. Khachatryan et al., Phys. Rev. Lett. 105 (2010) 022002

Jet Trigger

QCD-10-008



Measured tracks up to 140 GeV/c

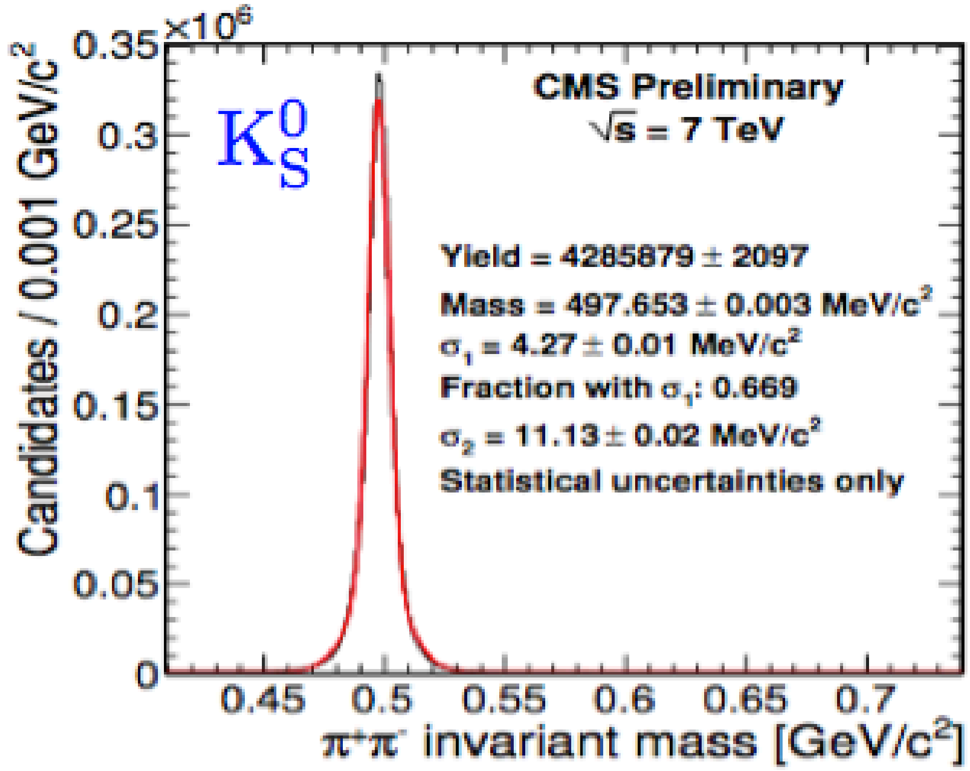
Expected power law scaling:

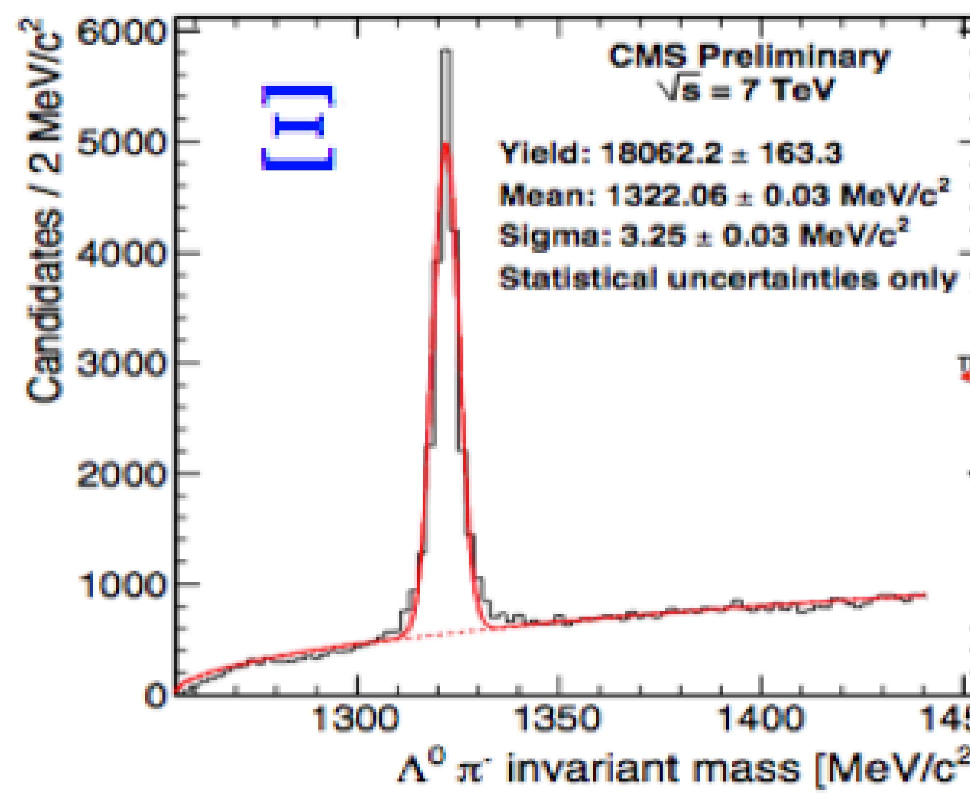
$$E\frac{d^3\sigma}{dp^3} = F(x_T)/\sqrt{s}^{\,n(x_T,\sqrt{s})}$$

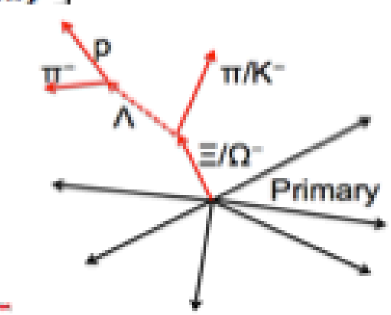
n≅5-6

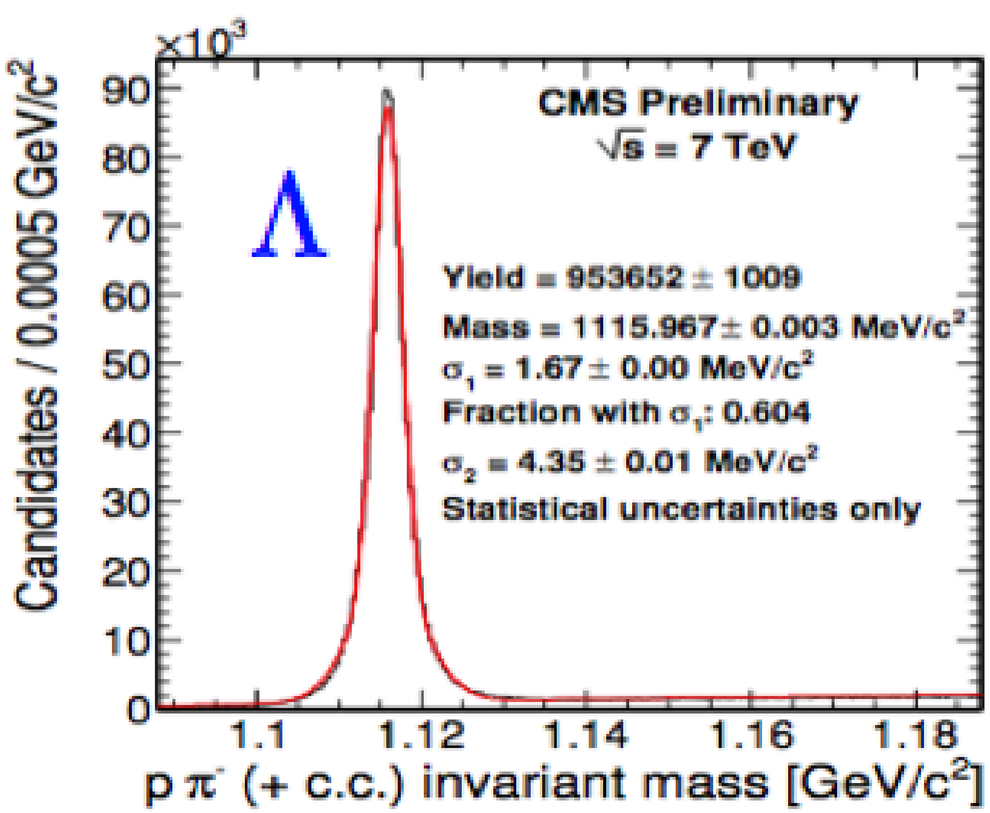
Strangeness Production

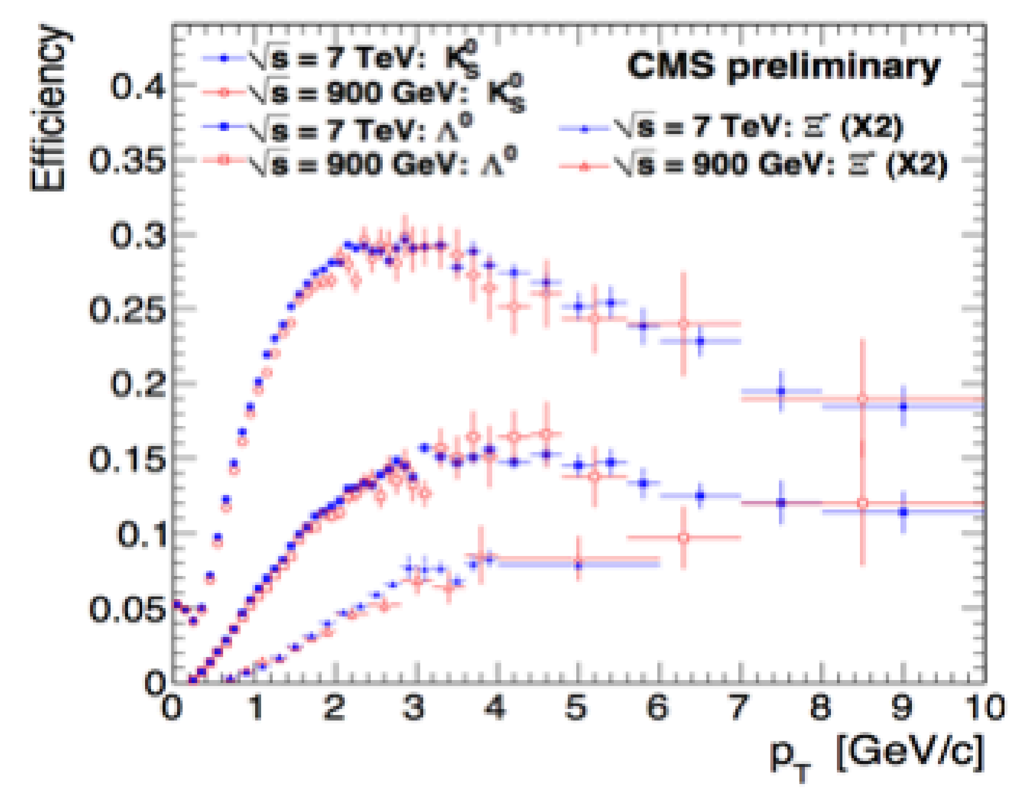
QCD-10-007





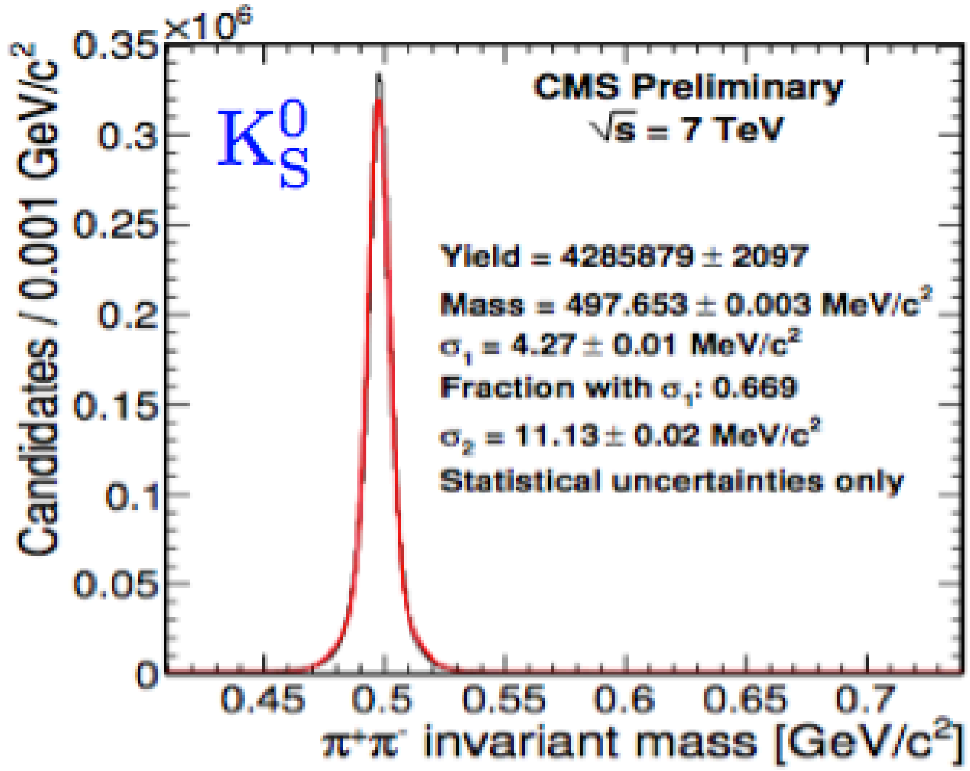


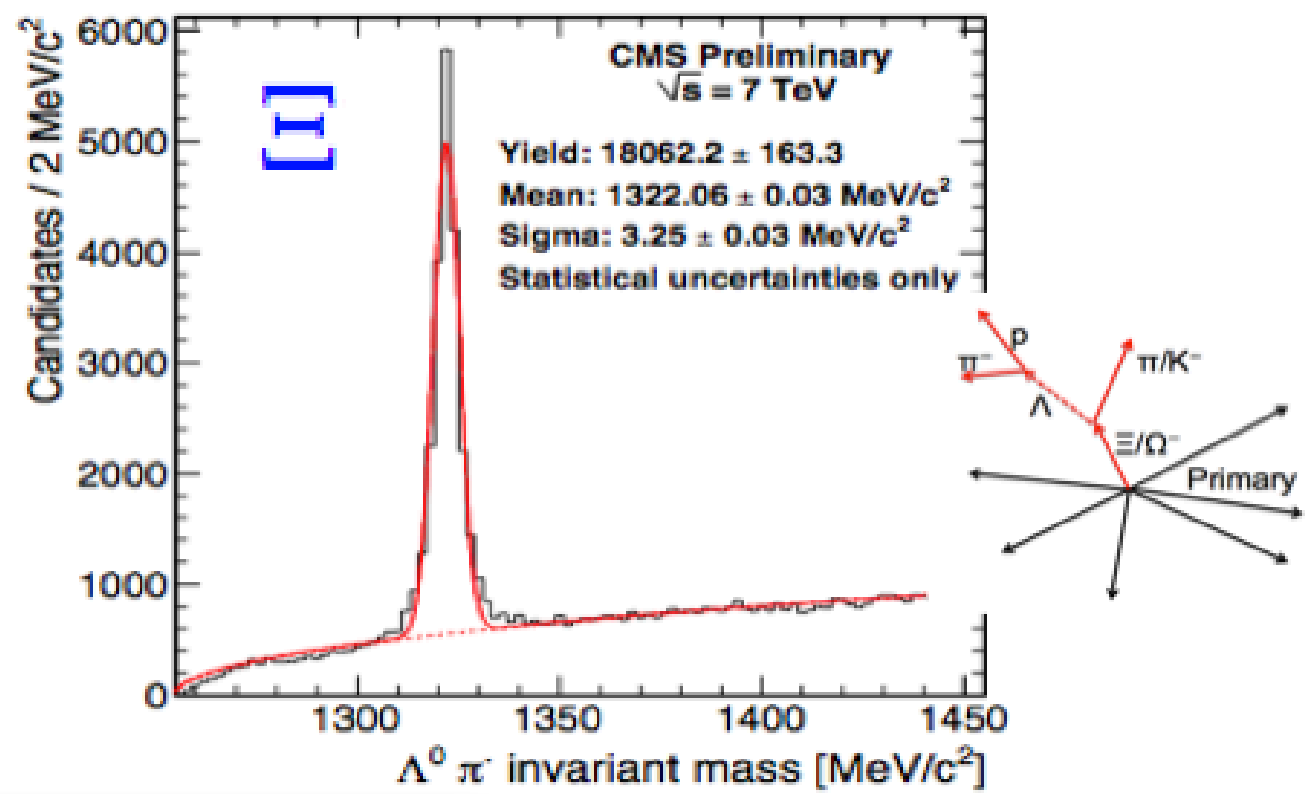




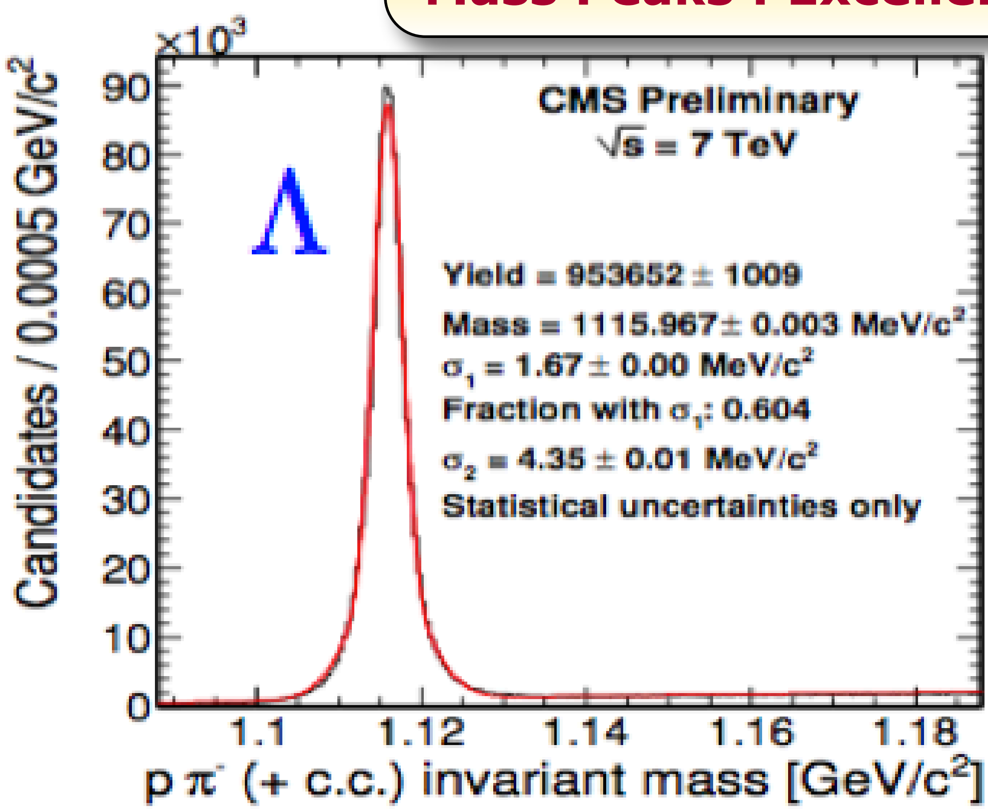
Strangeness Production

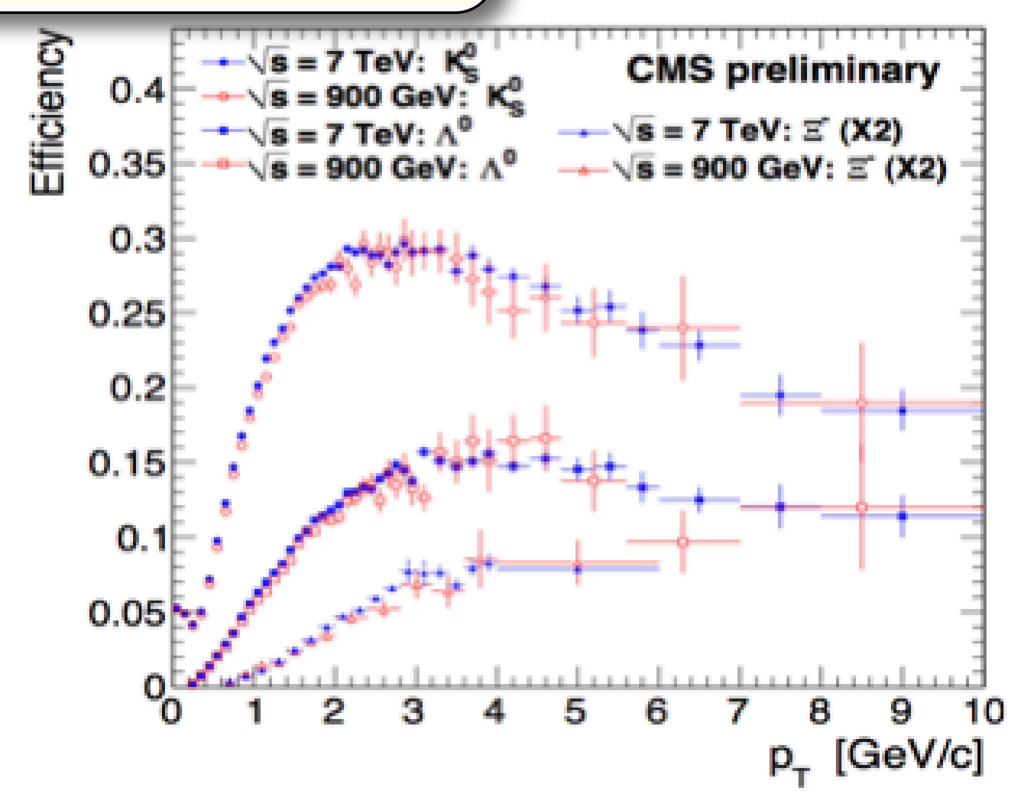
QCD-10-007





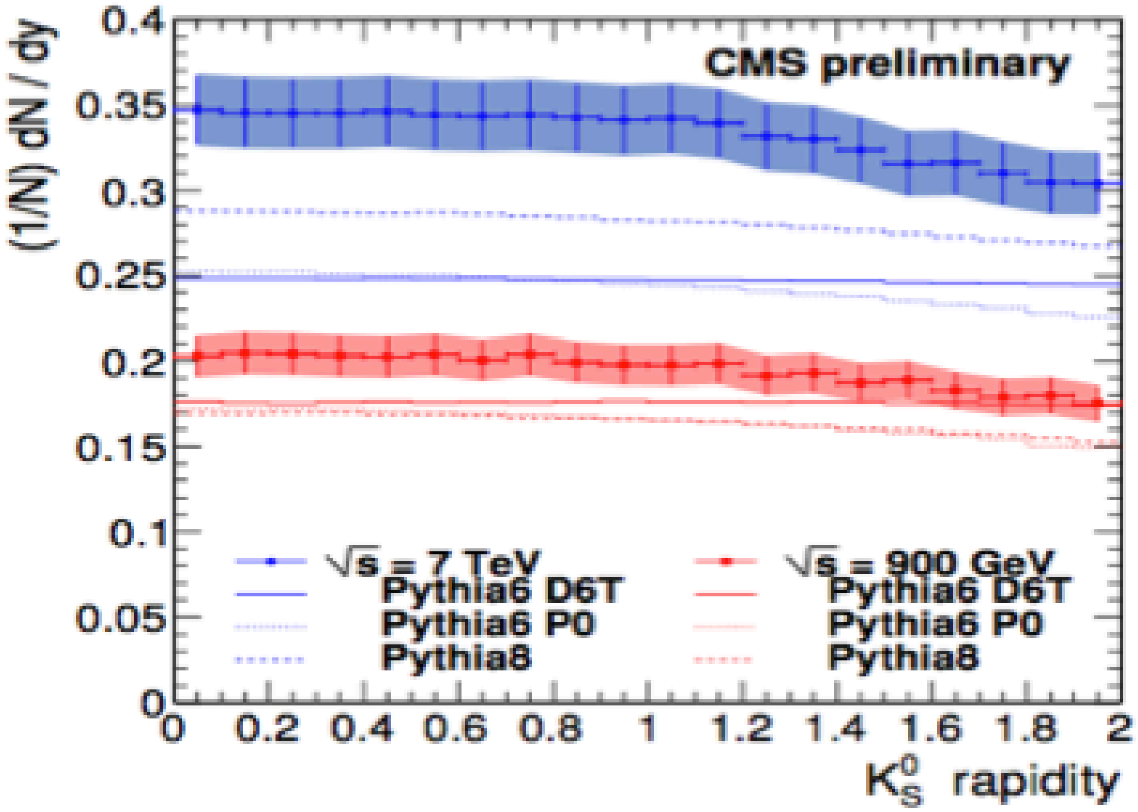
Mass Peaks : Excellent agreement with PDG!



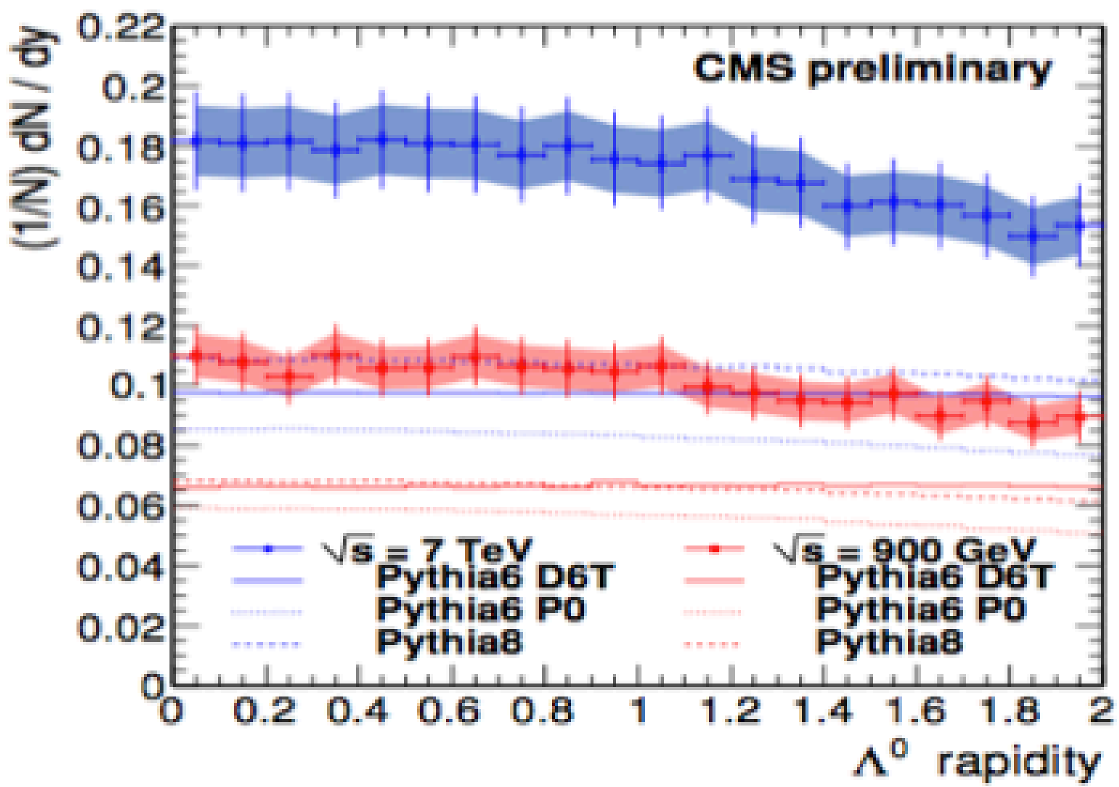


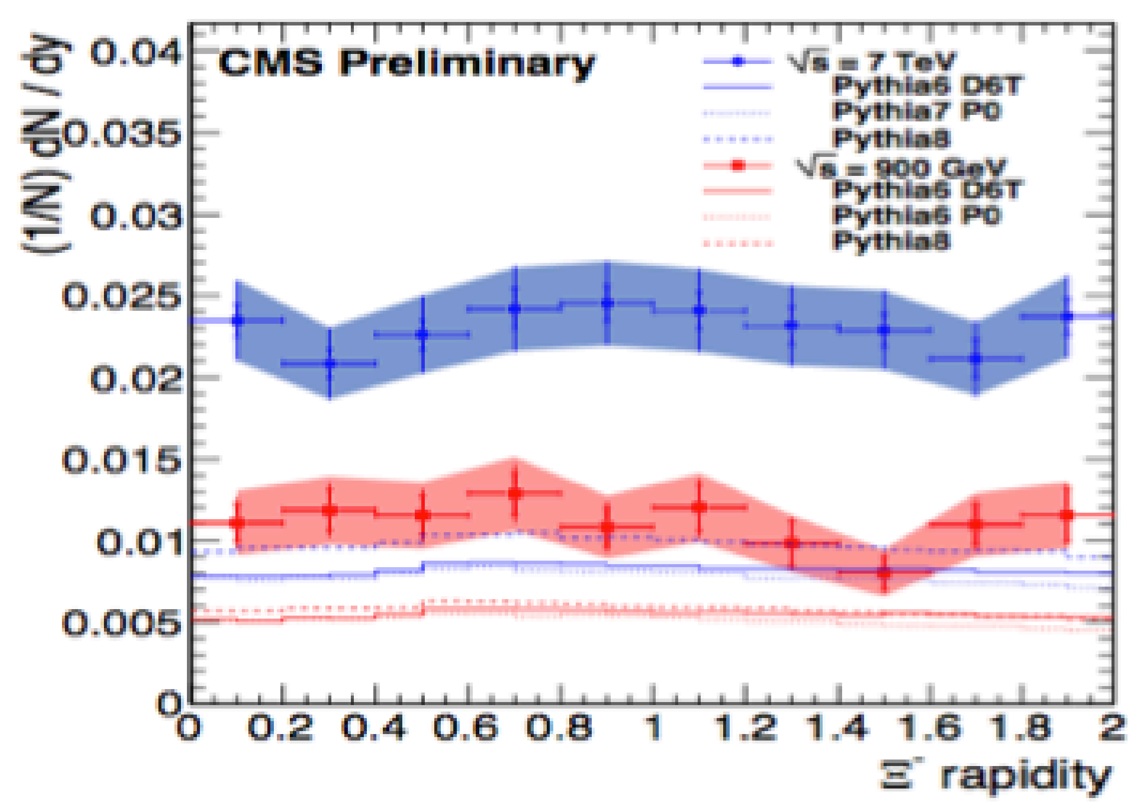
Comparison to generators

QCD-10-007



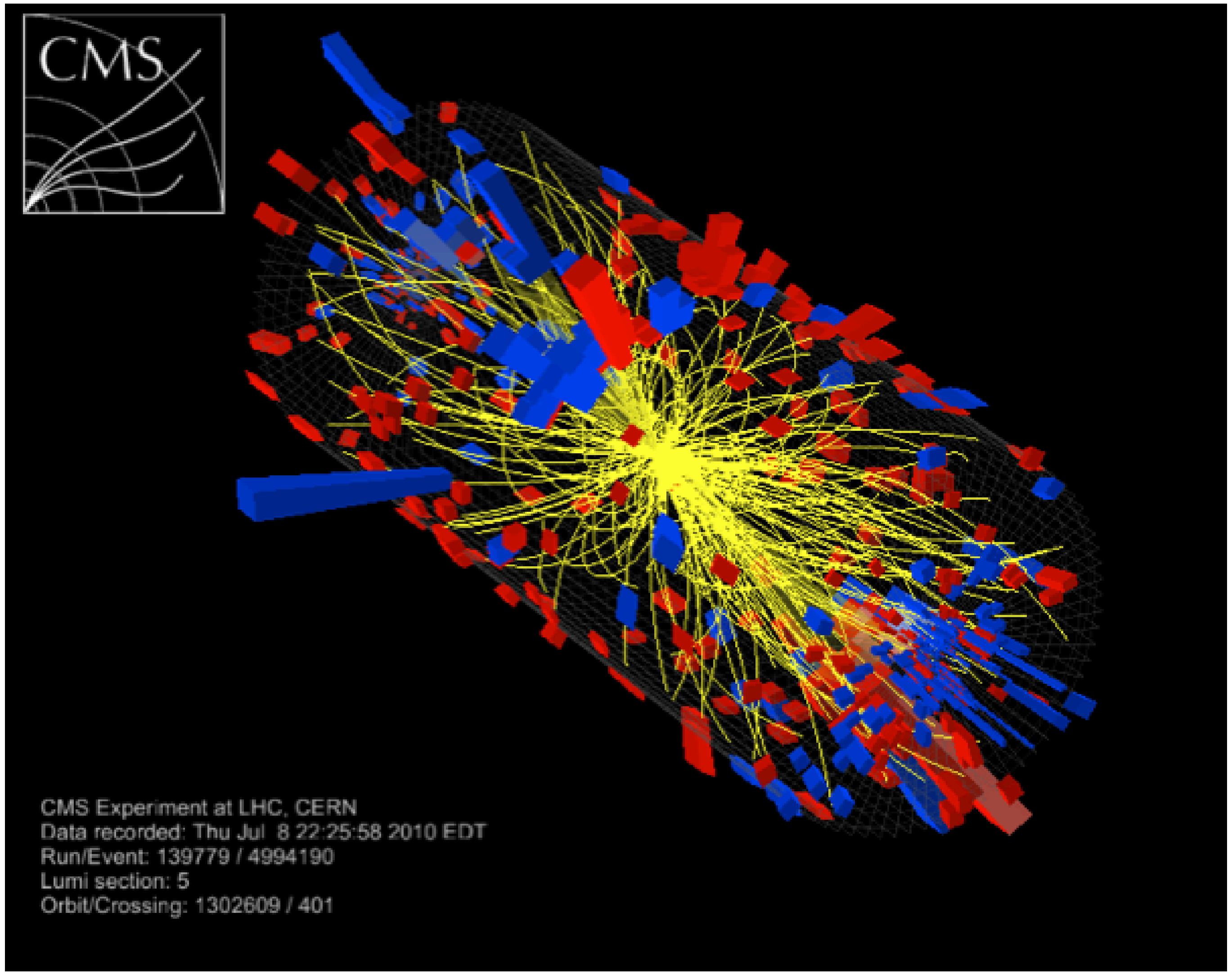
- **All generators underestimate the amount of Strange Particles produces at both 0.9 and 7 TeV**





slide by M. Velasco

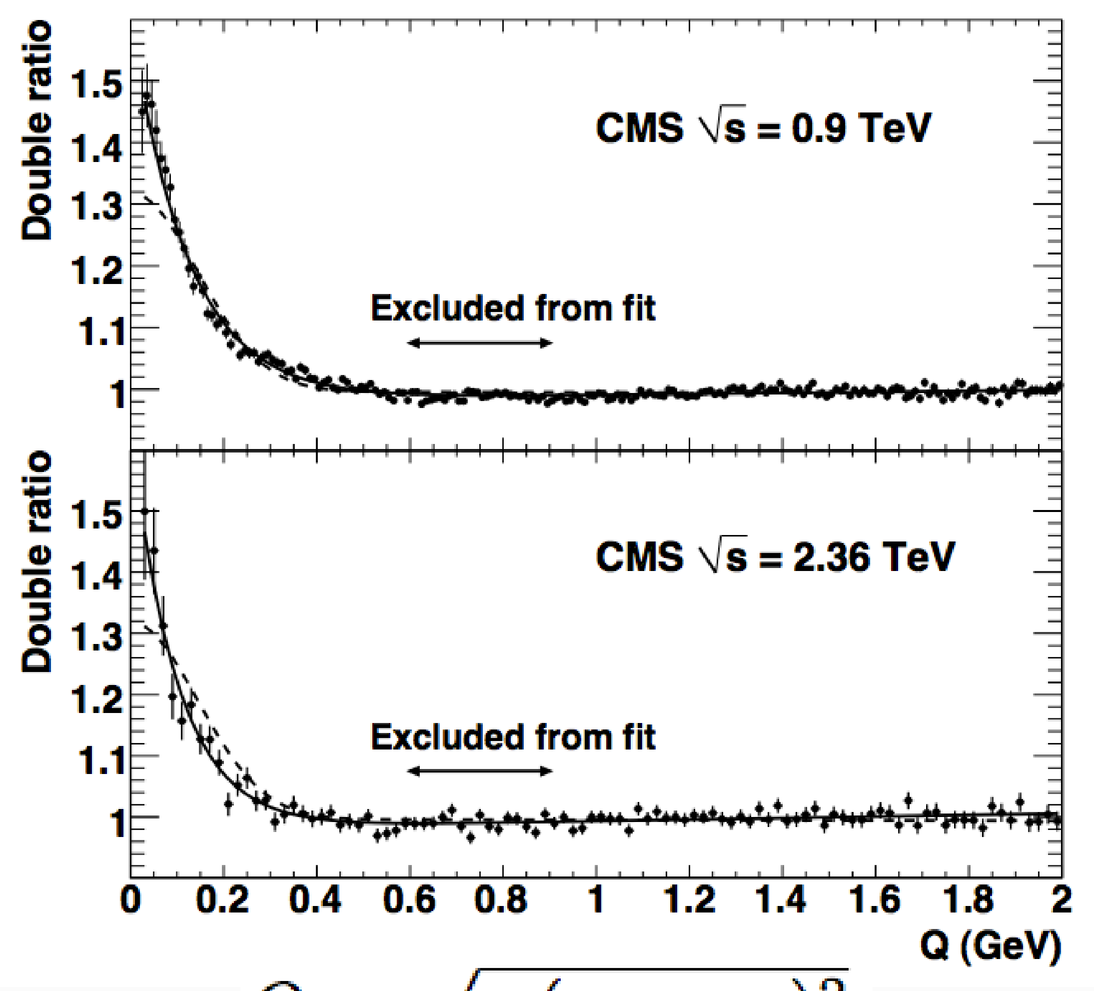
Two-Particle Correlations



Bose-Einstein correlations

PRL 105 (2010) 032001

- Correlations between identical bosons (here pions)
- Difficulty: construction of a BEC-free ref.-sample
- Exponential fit *exp(-Qr)* to enhancement at low Q, fits our data better than Gaussian



$$Q = \sqrt{-(p_1 - p_2)^2}$$

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PRL 105 (2010) 032001

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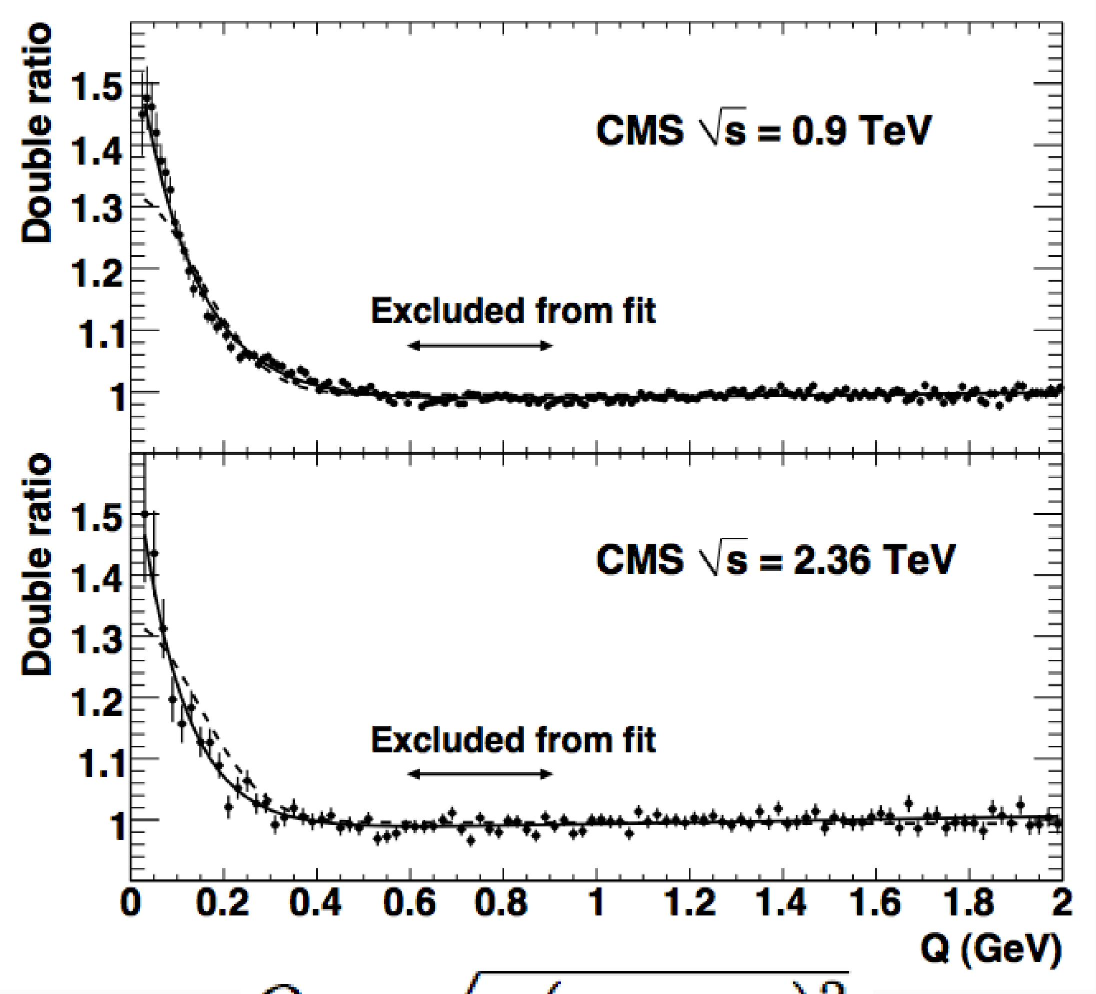
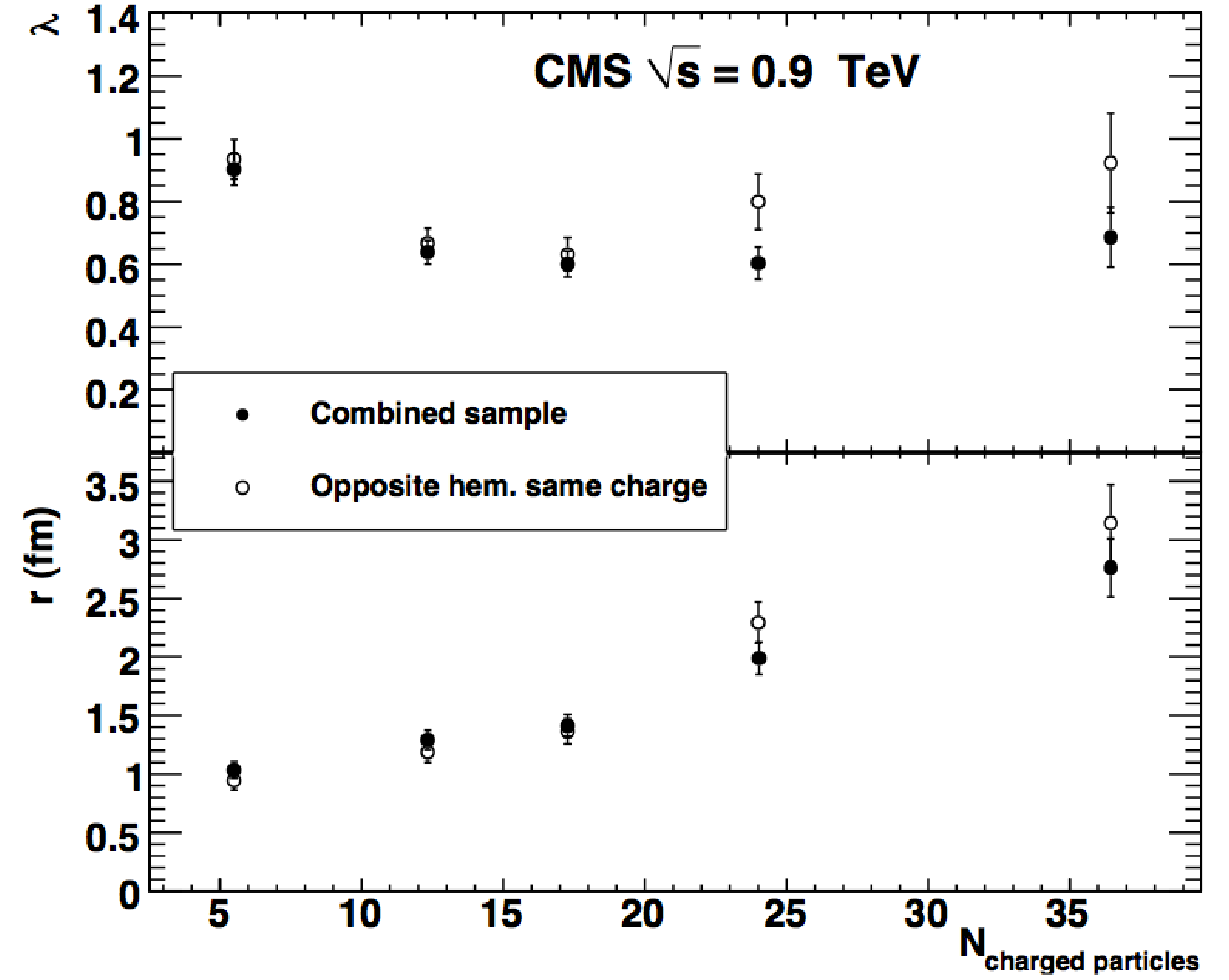
- Difficulty: construction of a BEC-free ref.-sample
- Exponential fit *exp(-Qr)* to enhancement at low Q, fits our data better than Gaussian



$$Q = \sqrt{-(p_1 - p_2)^2}$$

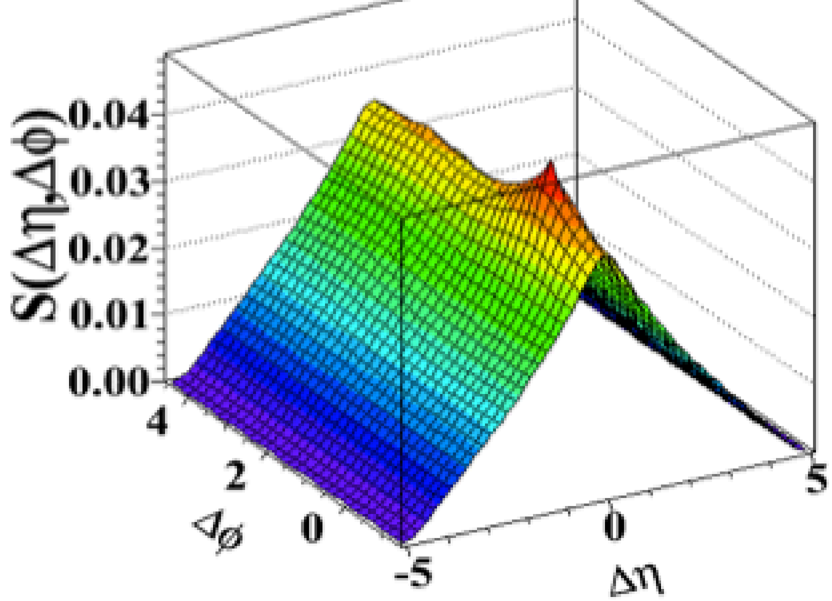


Interesting: size of emission region increases with multiplicity (also seen in prev. experiments)

Angular Correlations: Definitions

Signal distribution:

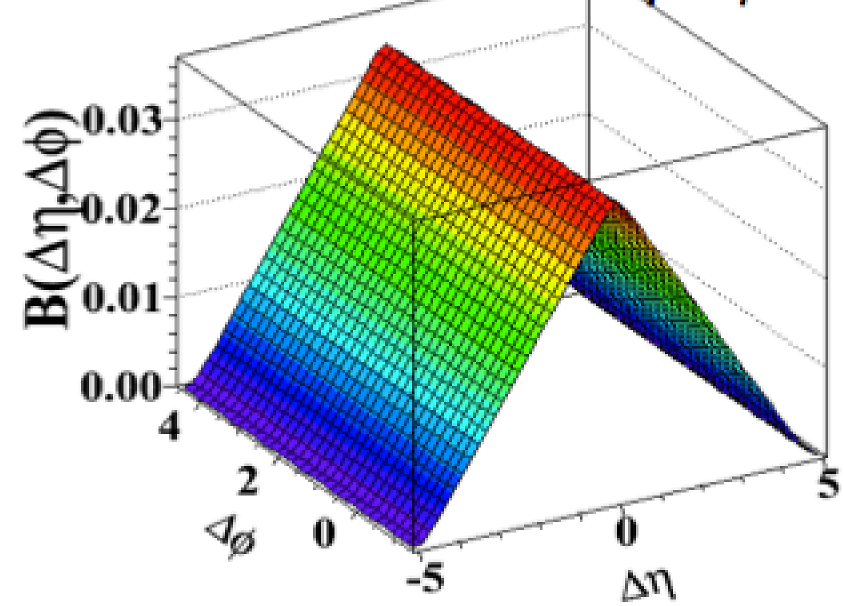
$$S_N(\Delta\eta,\Delta\varphi) = \frac{1}{N(N-1)}\frac{d^2N^{signal}}{d\Delta\eta d\Delta\varphi}$$



Same event pairs

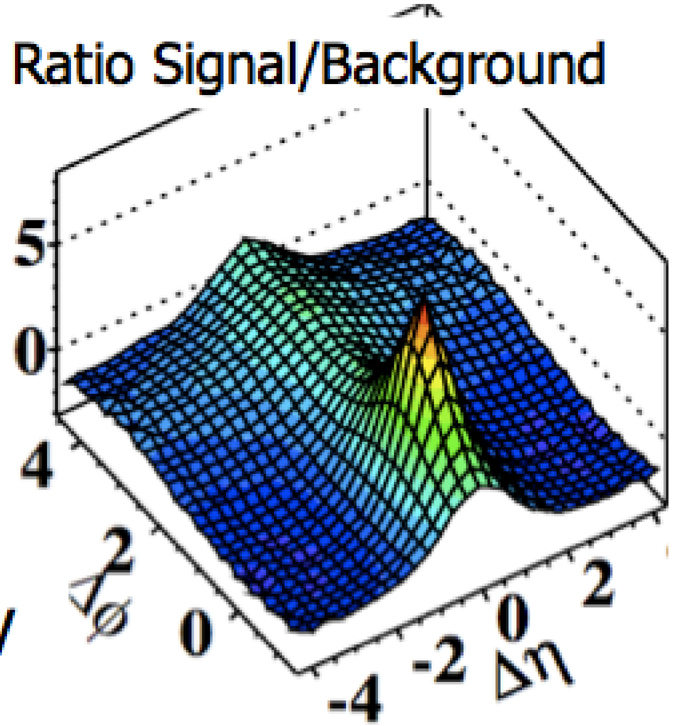
Background distribution:

$$B_N(\Delta\eta,\Delta\varphi) = \frac{1}{N^2}\frac{d^2N^{bkg}}{d\Delta\eta d\Delta\varphi}$$



Mixed event pairs

Ratio Signal/Background



$$R(\Delta\eta,\Delta\varphi) = \left\langle (N-1)\left(\frac{S_N(\Delta\eta,\Delta\varphi)}{B_N(\Delta\eta,\Delta\varphi)} - 1\right)\right\rangle_N$$

$$\Delta\eta = \eta_1 - \eta_2$$

$$\Delta\varphi = \varphi_1 - \varphi_2$$

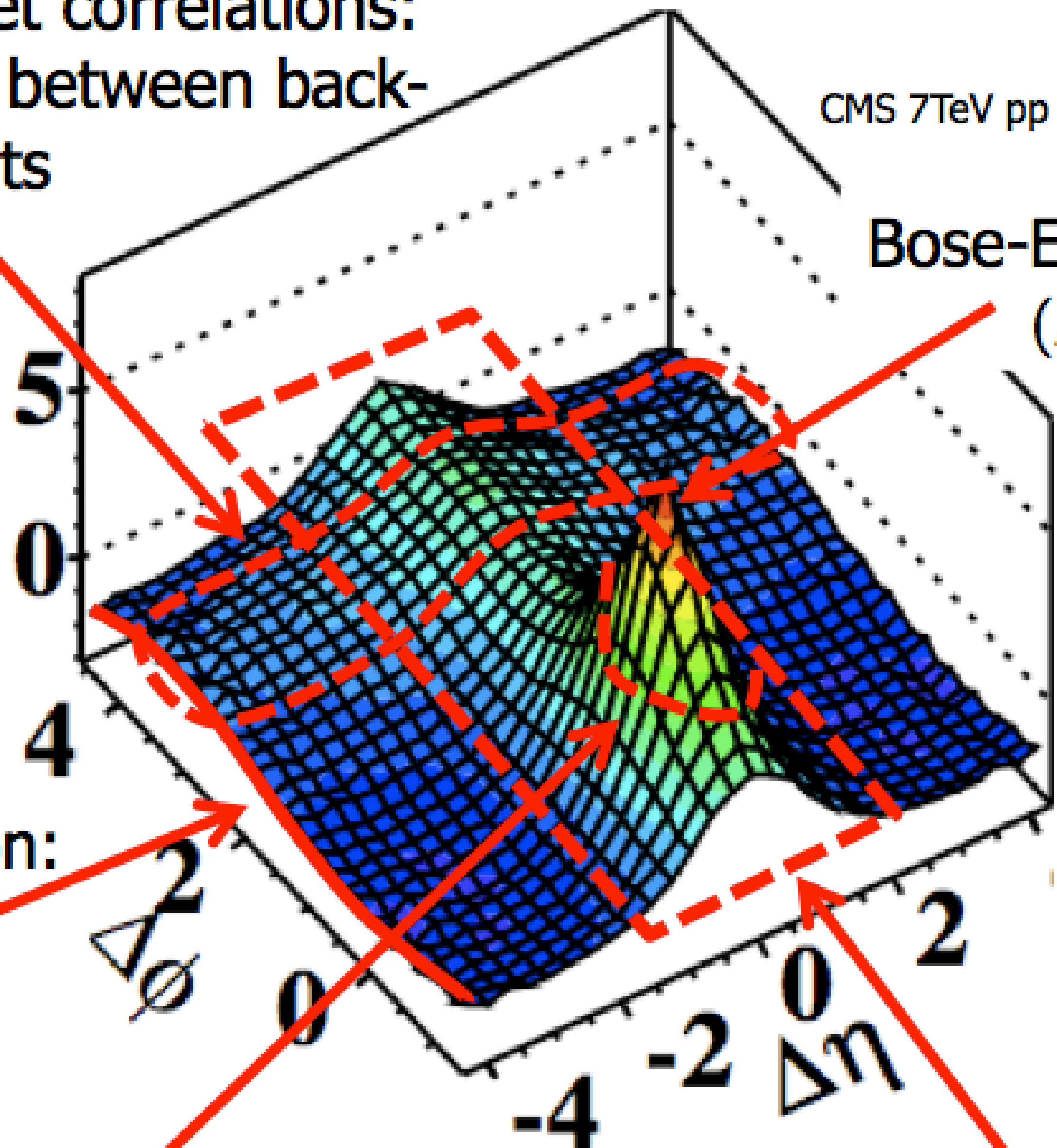
CMS pp 7TeV

p_T-inclusive two-particle angular correlations in min bias collisions

see G. Roland's talk at CERN seminar, 21.9.2010

Angular Correlation Functions

"Away-side" ($\Delta\phi \sim \pi$) jet correlations: Correlation of particles between back-to-back jets



Bose-Einstein correlations: ($\Delta\phi$,$\Delta\eta$) ~ (0,0)

Momentum conservation: ~ -cos($\Delta\phi$)

"Near-side" ($\Delta\phi \sim 0$) jet peak: Correlation of particles within a single jet

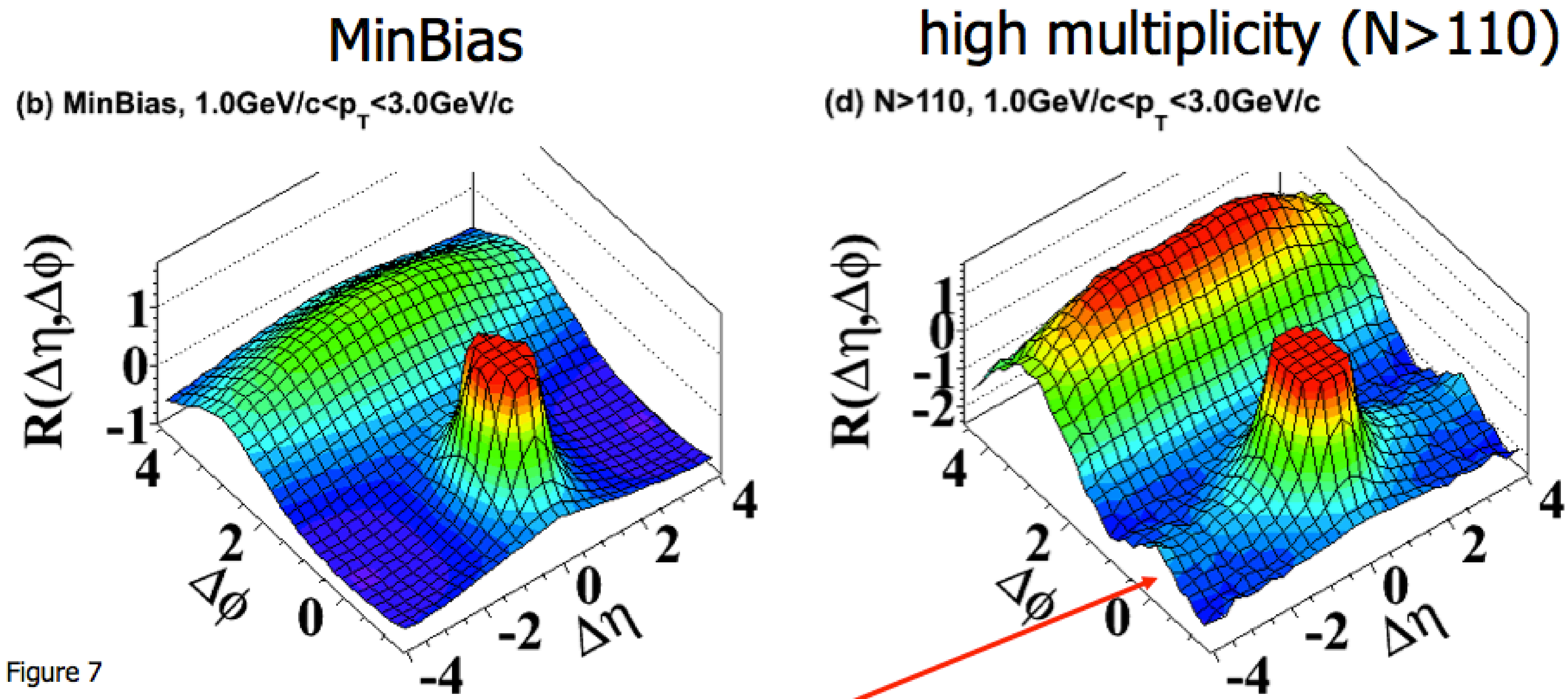
Short-range correlations ($\Delta\eta < 2$): Resonances, string fragmentation, "clusters"

see G. Roland's talk at CERN seminar, 21.9.2010

Results for MB and High-Mult. Triggers

CMS Collab.. arXiv:1009.4122, accept. for publ. in JHEP!

Intermediate p_T: 1-3 GeV/c



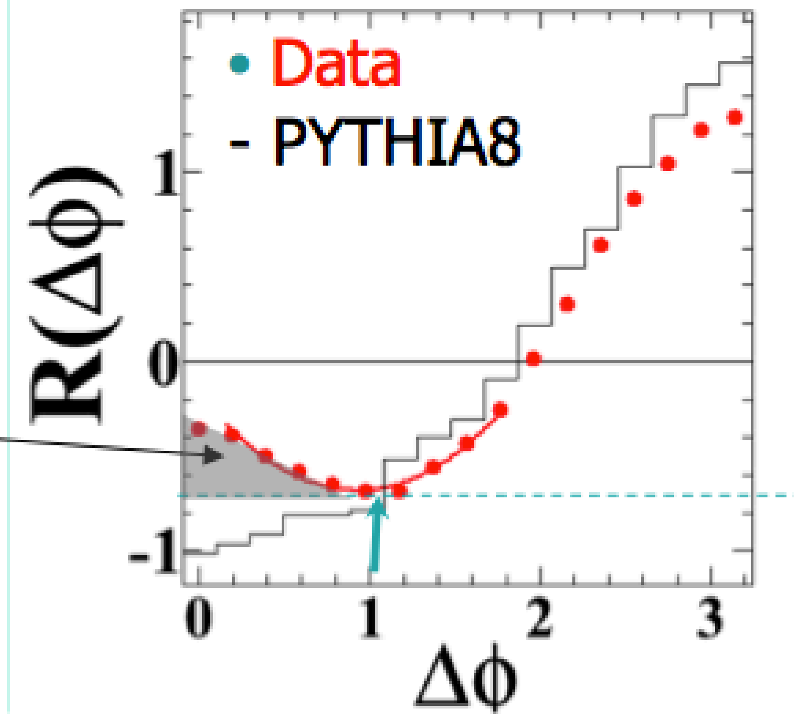
Pronounced structure at large δη around δφ ~ 0 !

see G. Roland's talk at CERN seminar, 21.9.2010

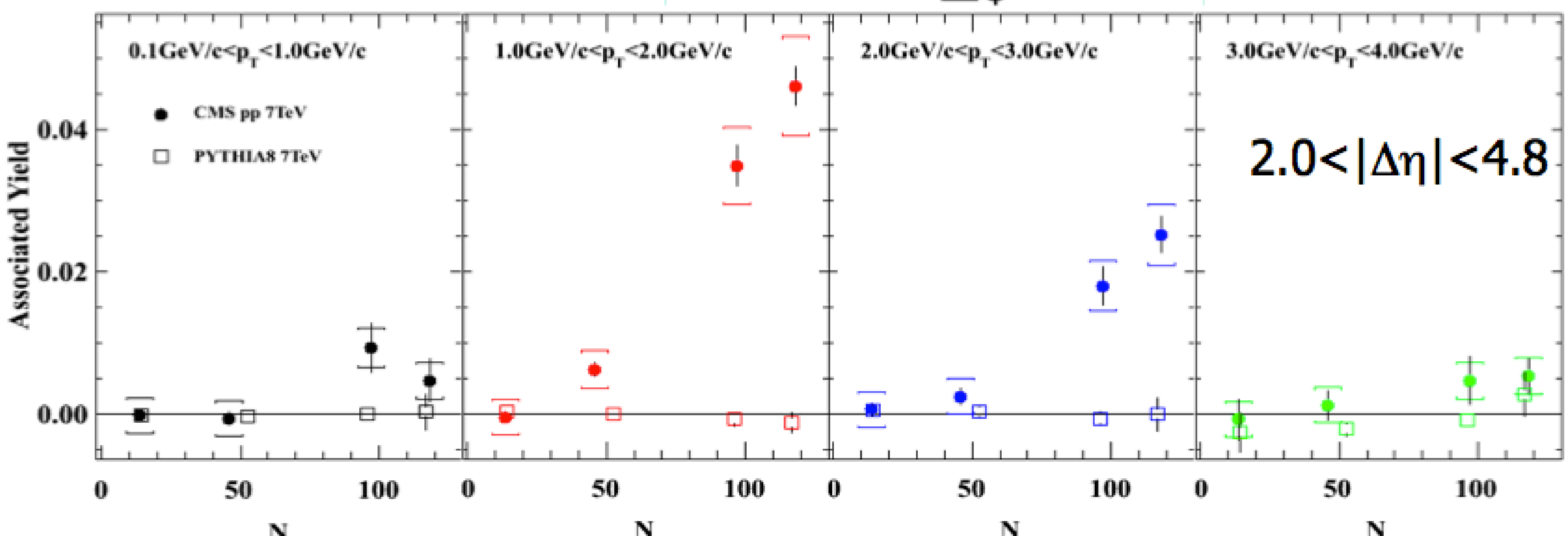
Multiplicity and p_T dependence

Zero Yield At Minimum (ZYAM)

Associated yield:
correlated multiplicity per particle



N>110
$2.0<|\Delta\eta|<4.8$
$1GeV/c<p_T<2GeV/c$



Associated yield grows with increasing multiplicity

see G. Roland's talk at CERN seminar, 21.9.2010

Conclusions on this observation

- Observation of long-range, near-side correlations in high multiplicity events
  - Signal grows with event multiplicity
  - Effect is maximal in the $1 < p_T < 3$ GeV/c range
- Long-range, near-side correlation is not seen in low multiplicity events and generators, but resembles effects seen in heavy-ion collisions at high energies
- Very extensive systematic checks performed
  - we are confident in the measurement as such
- This is a subtle effect in a complex environment – careful work is needed to establish physical origin
- **See G. Veres' talk (and dedicated discussion session) this week!**

Conclusions

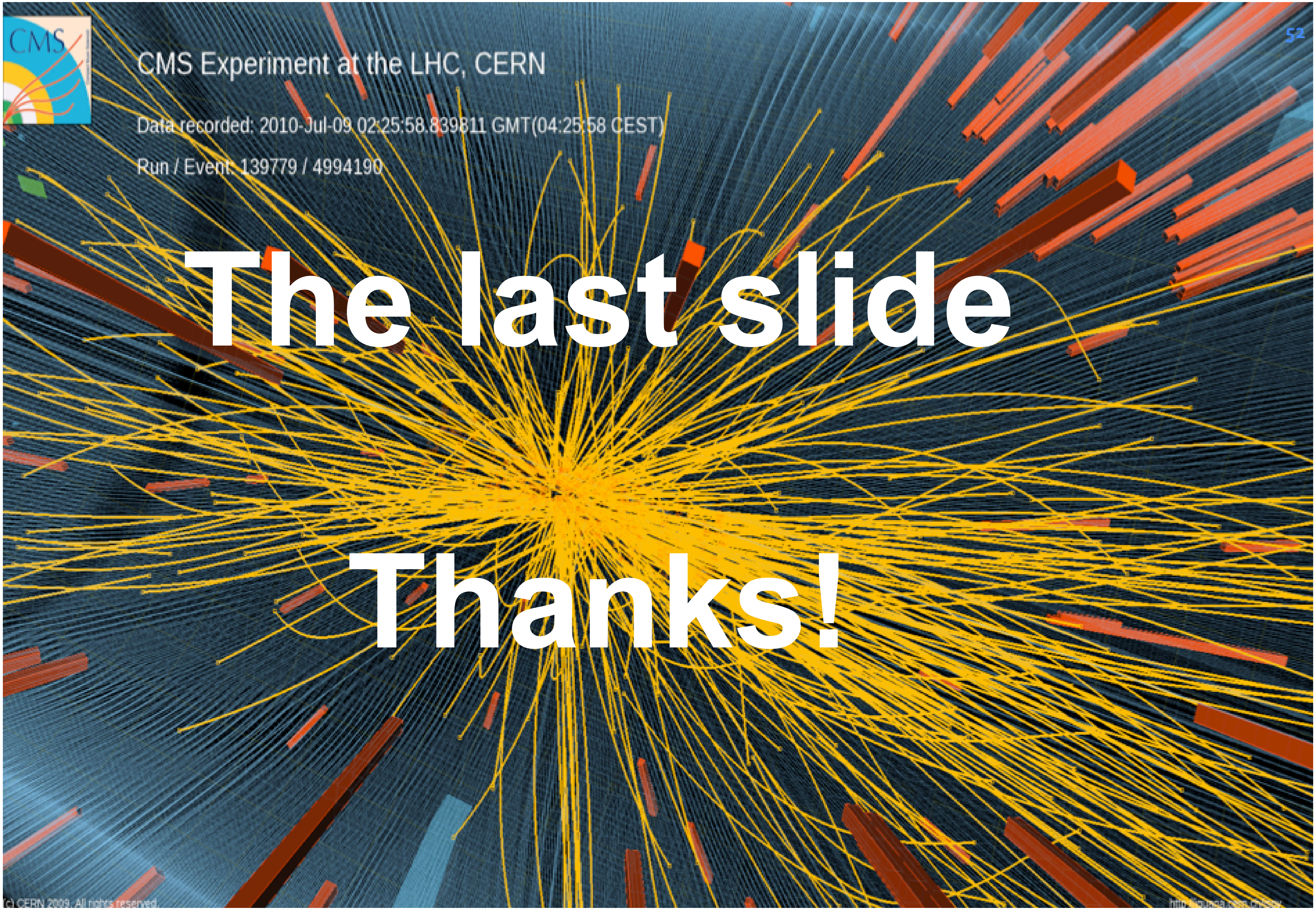
Summary

- The CMS experiment at the LHC performs extremely well
- Less than 6 months after start-up at 7 TeV, with 3 pb^{-1} in hand
  - there is already an amazing plethora of results
- QCD studies progressing well
  - on all fronts (high and low-pt)
- Currently
  - efforts towards unfolding/correction procedures (preparing high-and low-p_T results corrected for detector effects)
  - working on measurements based on common (with other exps) definitions, eg. regarding event selection
  - studies of DPI and MPI effects
  - and trying to understand better the first real surprise we had....

Some References

Gateway to collection of all CMS Results:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

- QCD-09-010 Charged hadrons @ 0.9/2.36 TeV [pub.]
- QCD-10-006 Charged hadrons @ 7 TeV [pub.]
- QCD-10-004 Charged particle multiplicities
- QCD-10-003 Bose-Einstein Correlations [pub.]
- QCD-10-001 Underlying Event @ 0.9TeV [pub.]
- QCD-10-010 Underlying Event @ 7 TeV
- QCD-10-005 Underlying Event from JetArea/Median
- QCD-10-002 Observation of Long-Range, Near-Side Angular Correlations [pub.]
- QCD-10-007 Strangeness production
- QCD-10-011 Inclusive Jets
- QCD-10-012 3-to-2 jet ratio
- QCD-10-013 Event shapes
- QCD-10-014 Jet transverse structure
- QCD-10-015 Dijet azimuthal decorrelations
- QCD-10-008 Charged hadron Pt spectra
- FWD-10-001 Observation of Diffraction
- FWD-10-002 Forward Energy Flow
- BPH-10-009 Incl. b-jet production
- EXO-10-010 Di-Jet Resonance
- EXO-10-002 Di-Jet Centrality Ratio


CMS Experiment at the LHC, CERN
Data recorded: 2010-Jul-09 02:25:58.839811 GMT(04:25:58 CEST)
Run / Event: 139779 / 4994190
The last slide
Thanks!
(c) CERN 2009. All rights reserved.

Thanks to...

- Input taken from (talks by)
  - Joe Incandela
  - Nick van Remortel
  - Mikko Voutilainen
  - S. Salur
  - F. Sikler
  - J. Weng
  - M. Velasco
  - G. Roland
  - H. Jung
- Thanks for feedback by G. Veres, F. Sikler, H. Jung

Further Material

Collecting events

- Events are collected from a combination of Minimum Bias and jet triggers
- So far: jets at trigger level not corrected for jet response, based on calorimeter information only
- In most cases, the low p_T results are limited to run periods with negligible pile-up (10 nb^{-1}), while high p_T results can use maximum luminosity with small offset systematics

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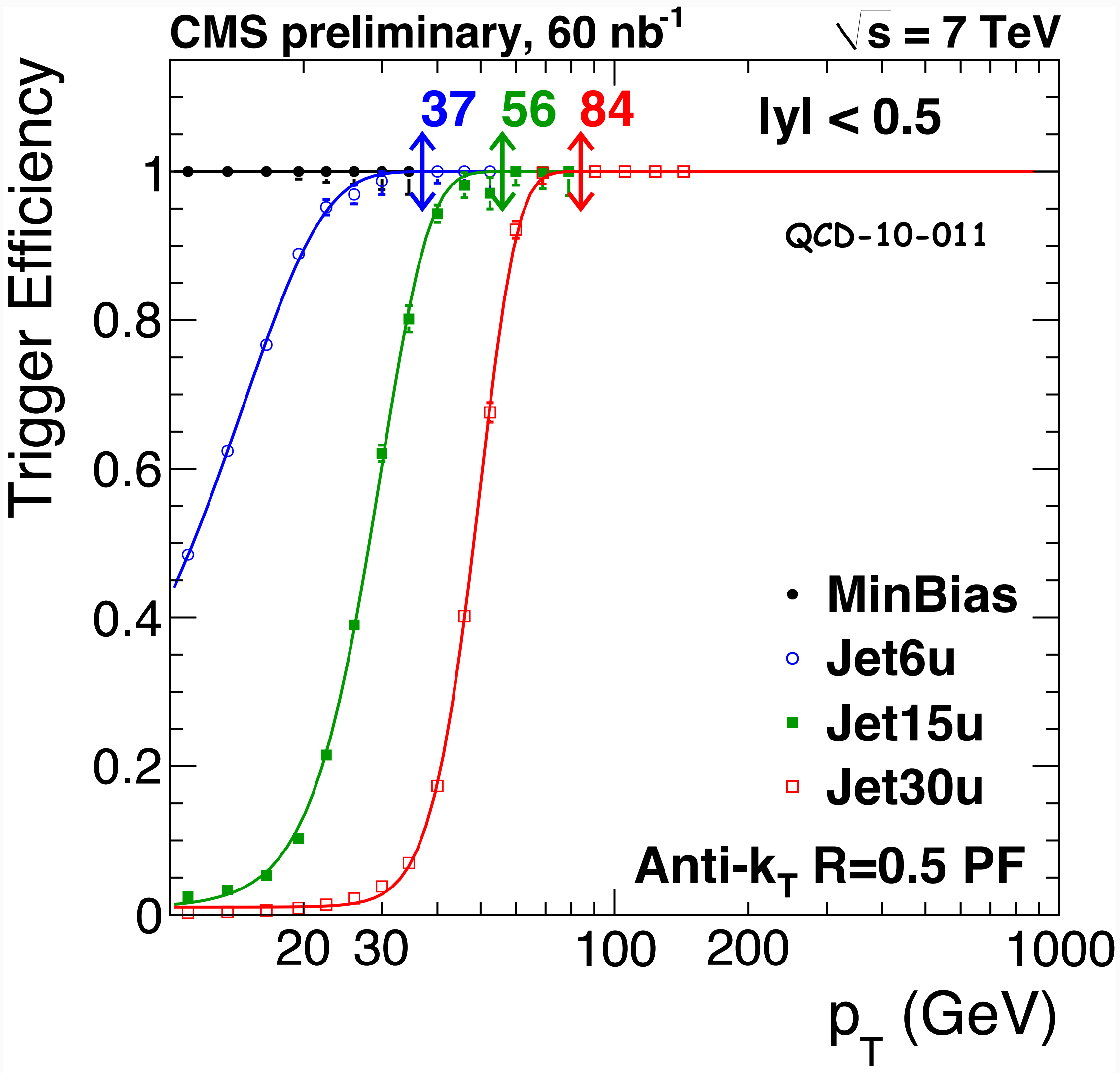
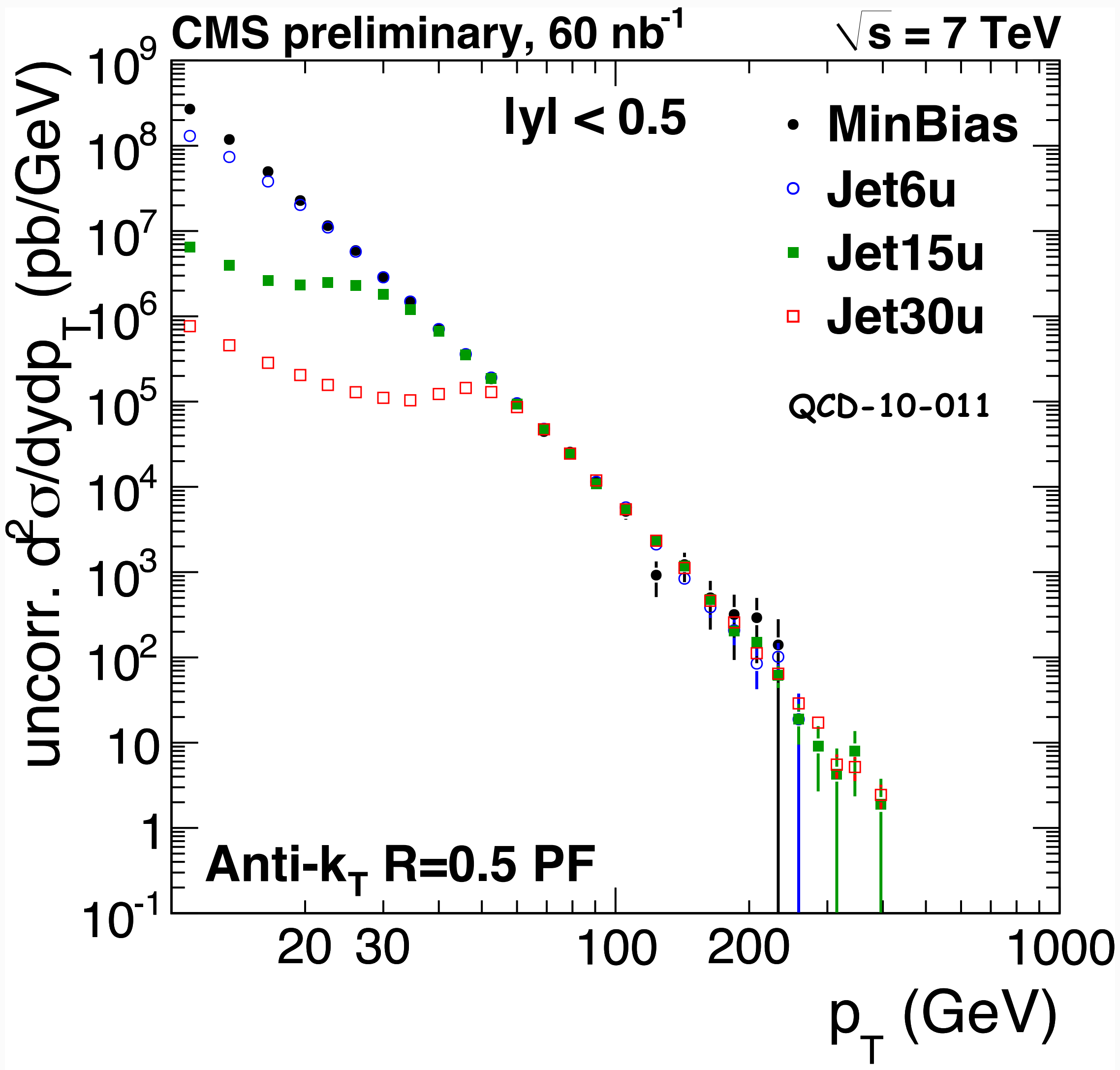
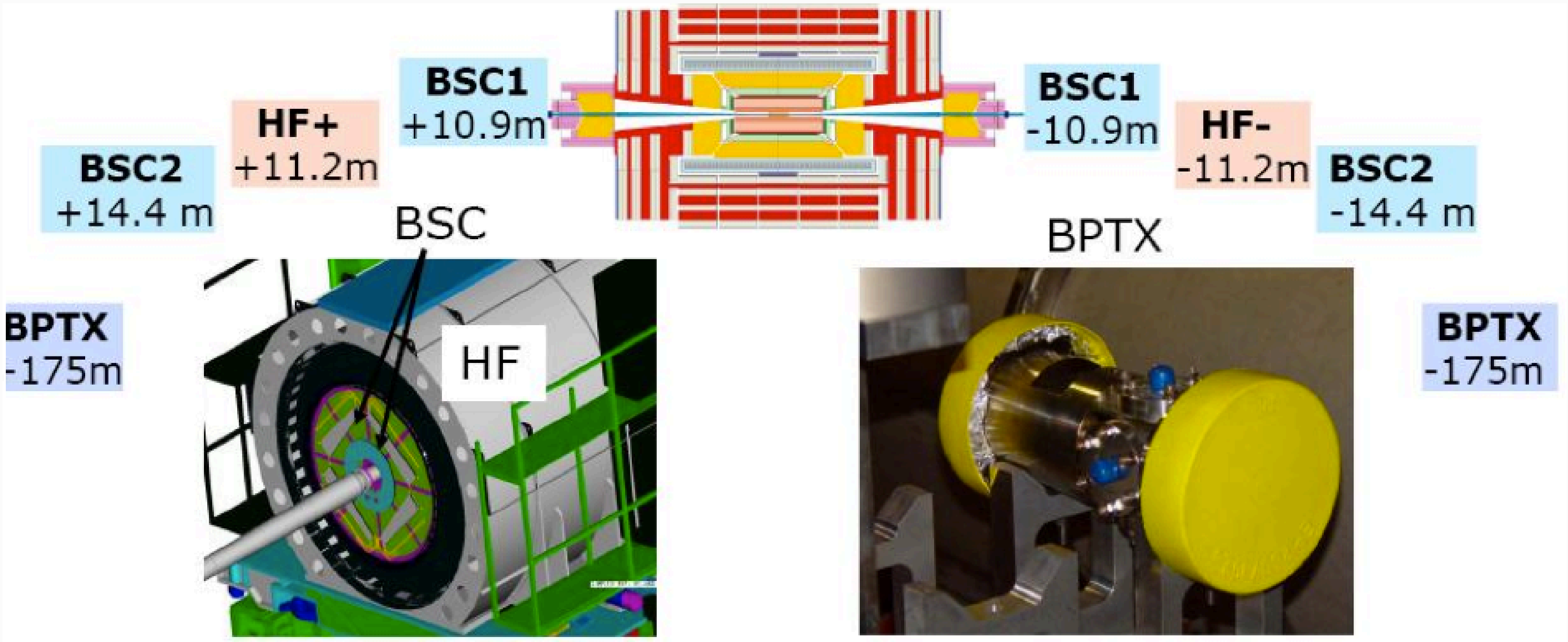


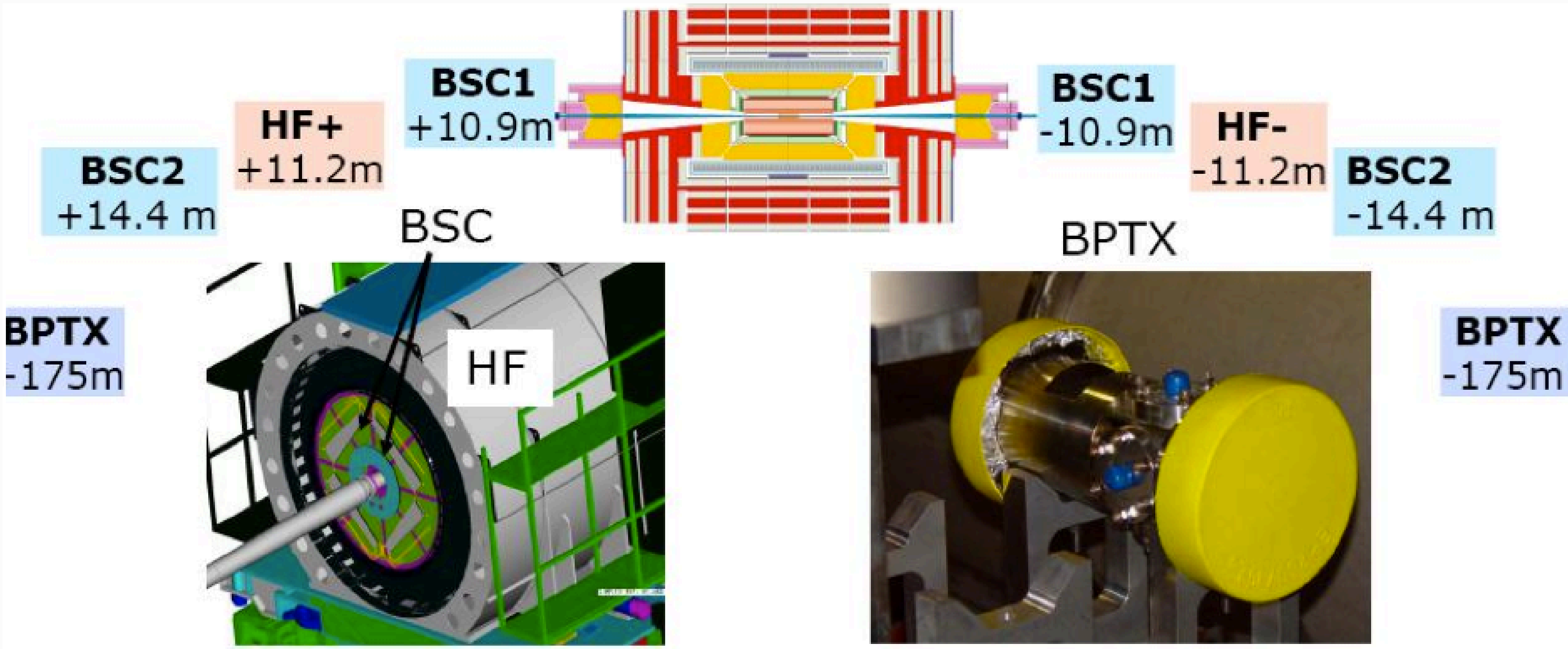


Minimum Bias Trigger



- **Trigger** :
  - any hit in the beam scintillator counters (BSC) AND
  - filled bunch passing the beam pickups (BPTX)
- **Offline event selection :**
  - 3 GeV in both sides of the HF
  - rejection of the beam halo using BSC timing
  - beam induced background rejection (pixel cluster shapes)
  - at least a reconstructed vertex near the collision point

Minimum Bias Trigger



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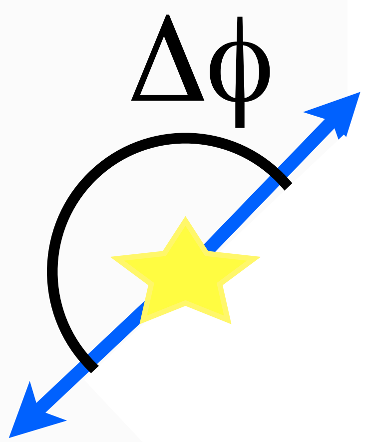
  - at least a reconstructed vertex near the collision point

Sample composition at 7 TeV

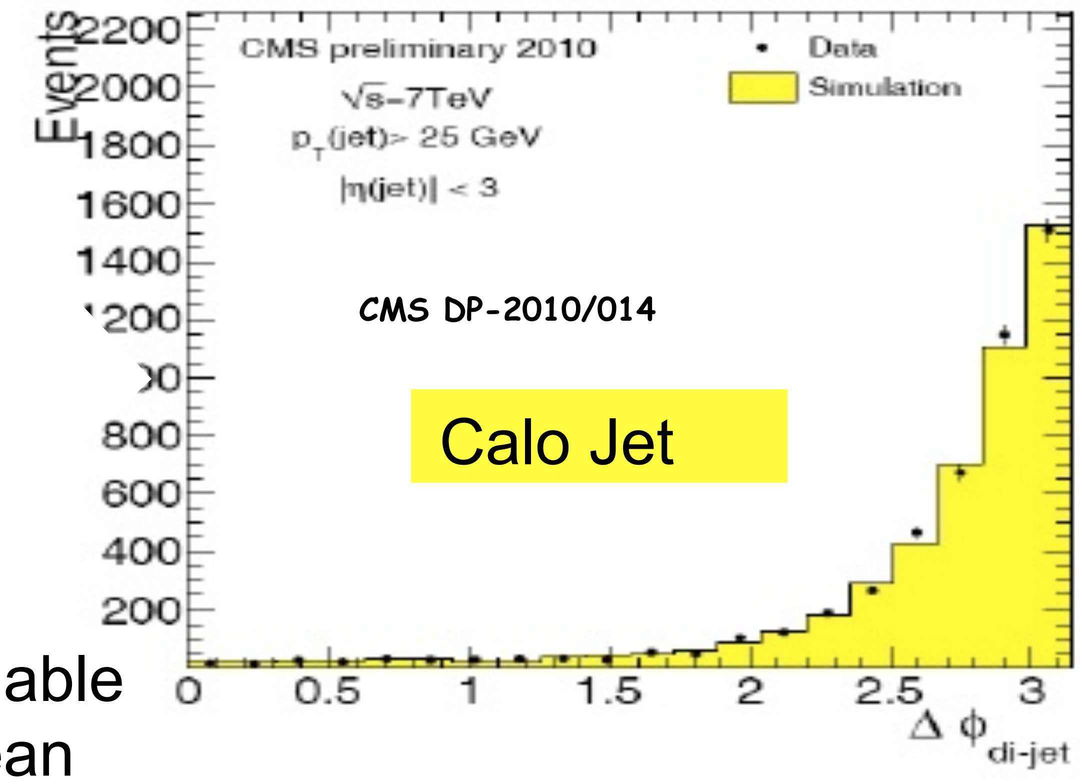
Proces	Fraction	Efficiency
SD	19.2%	26.7%
NSD	80.8%	86.3%

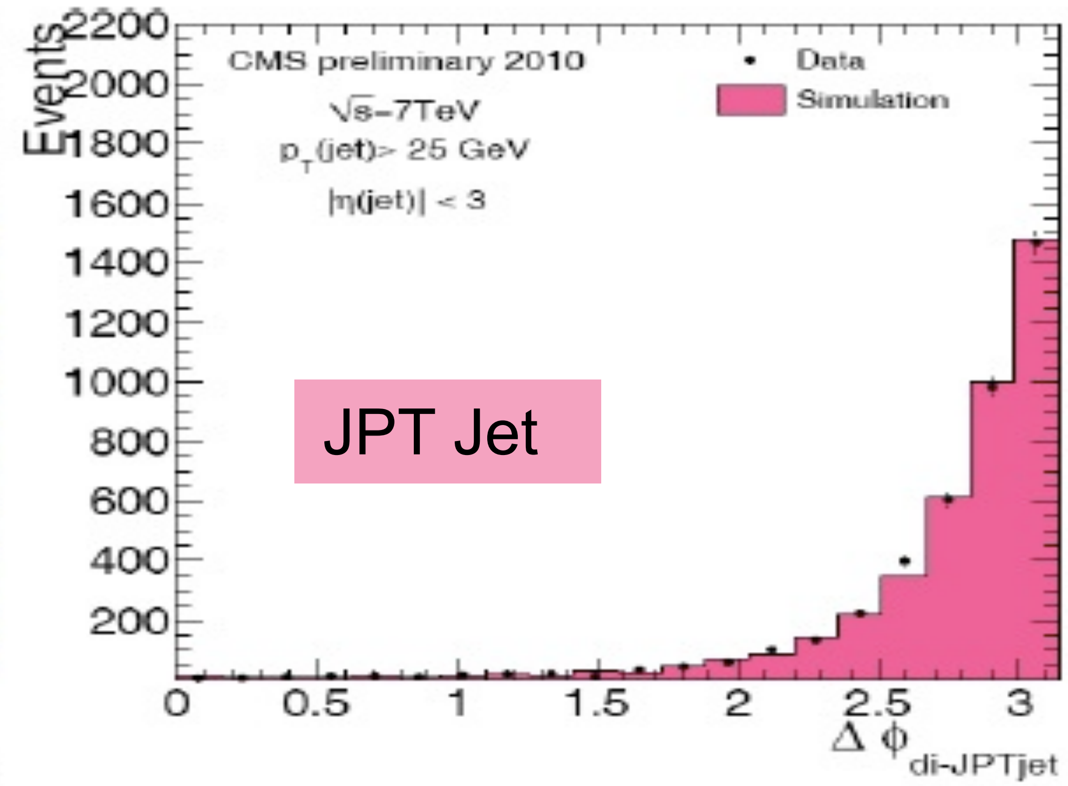
Pythia definitions

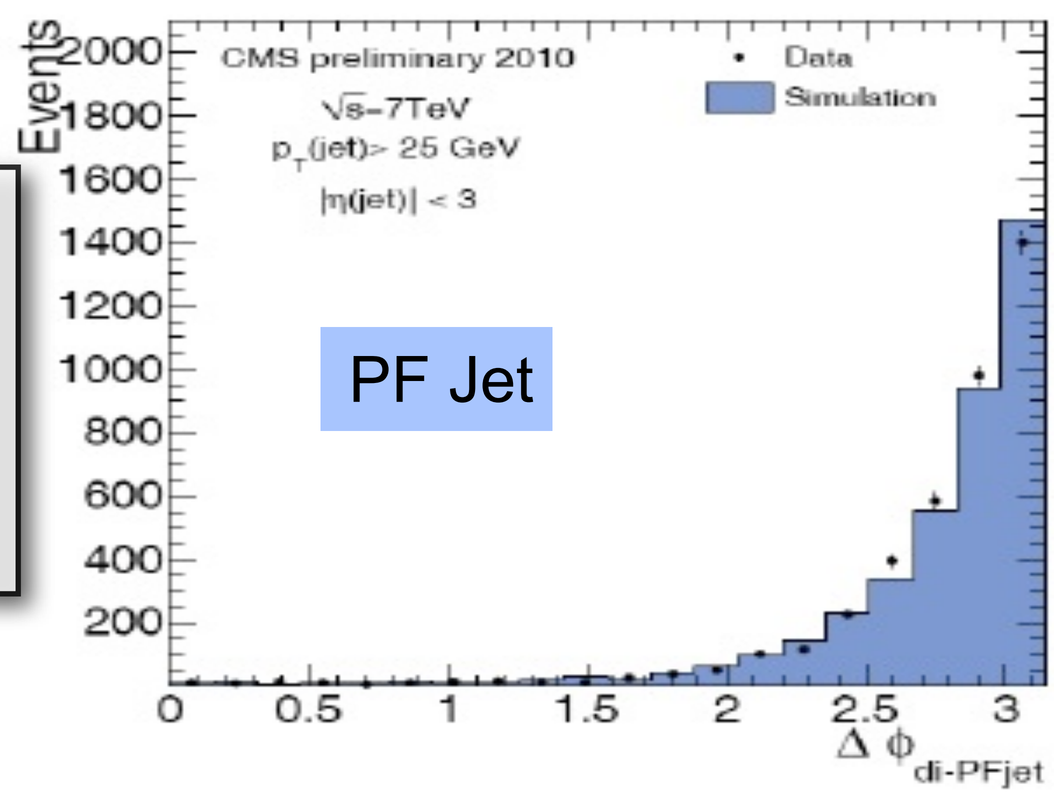
Jet performance: Di-jet examples

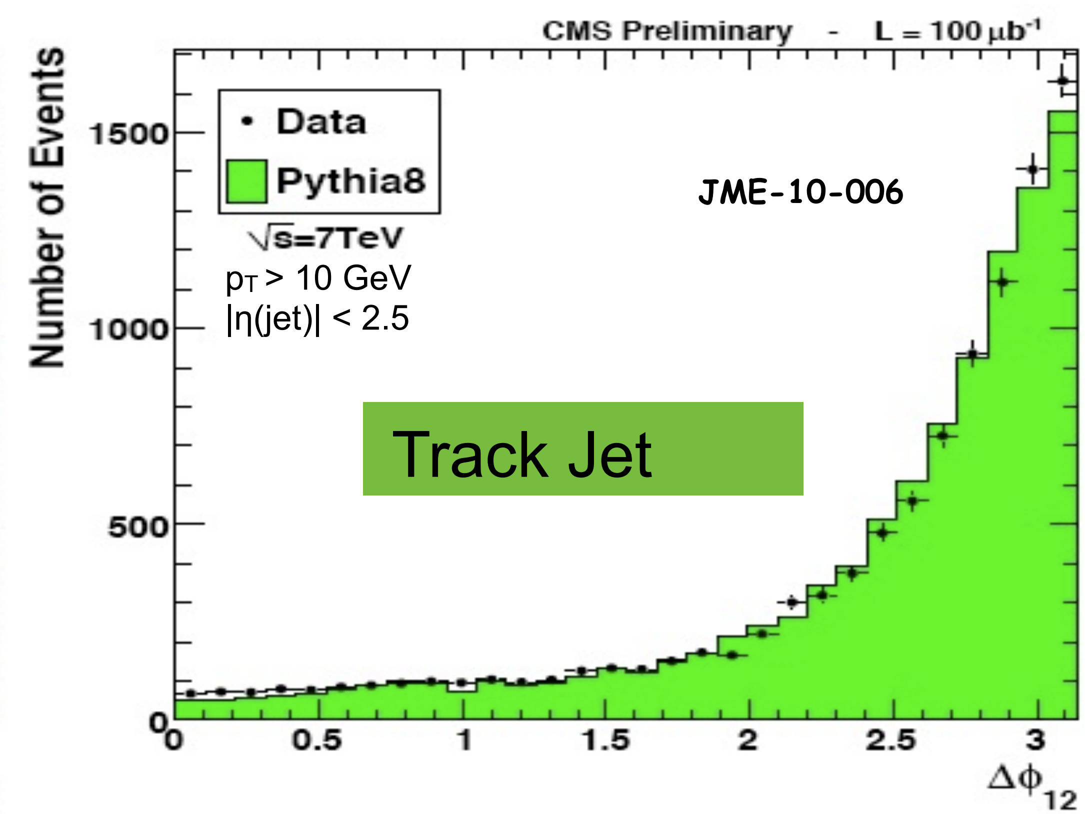


Important variable to select a clean dijet sample





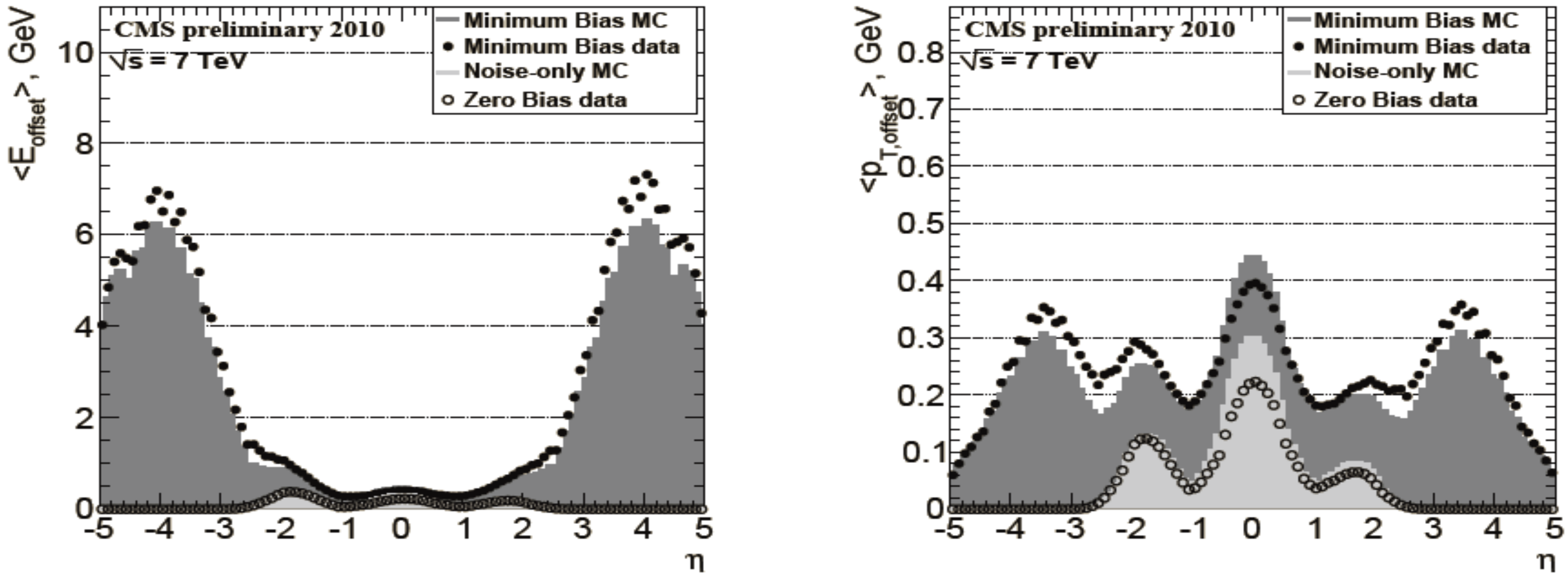




=> Good agreement for all jet types between data and MC

Backup: Offset correction

Slide by J. Weng, ICHEP

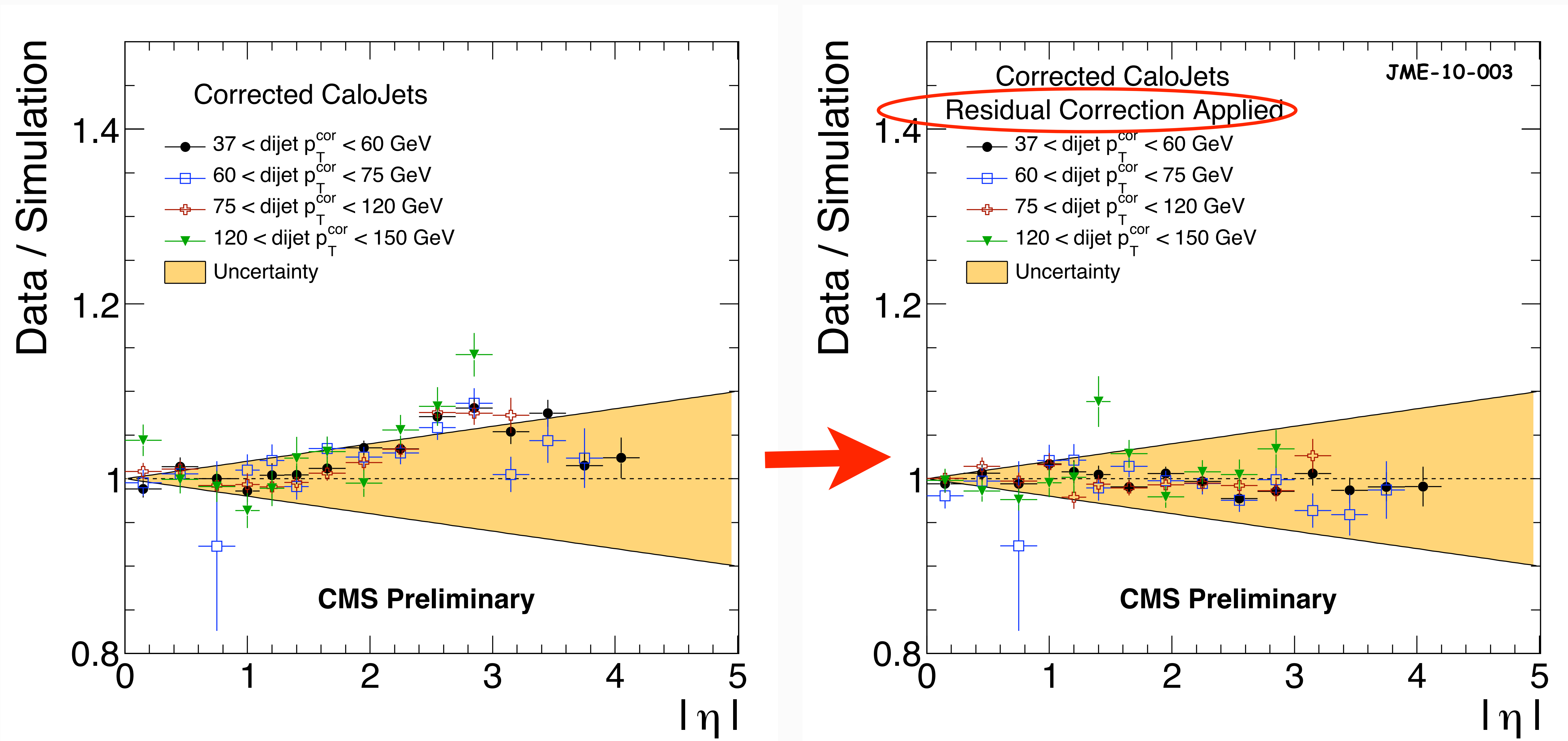


- Offset from noise:
  - is below 400 (300) MeV in energy (p_T).
  - Simulation gives good description of noise in data.
- Offset from one pile-up event:
  - Up to 7 GeV in energy, but stays below 350 MeV in p_T
  - Pythia Minimum Bias (D6T tune) gives decent description of PU
- Probability of pile-up in 2010 data typically ~50% (was ~10% in earlier plots)

=> Total average offset contribution to jet p_T is small in the current data.
=> No offset correction is applied in the standard JEC chain.

Jet corrections: relative η

- Response rapidity dependence is extracted from dijet asymmetry
- Residual correction is applied for inclusive jets, other studies are covered by the systematic uncertainty band of **2% times unit of rapidity**

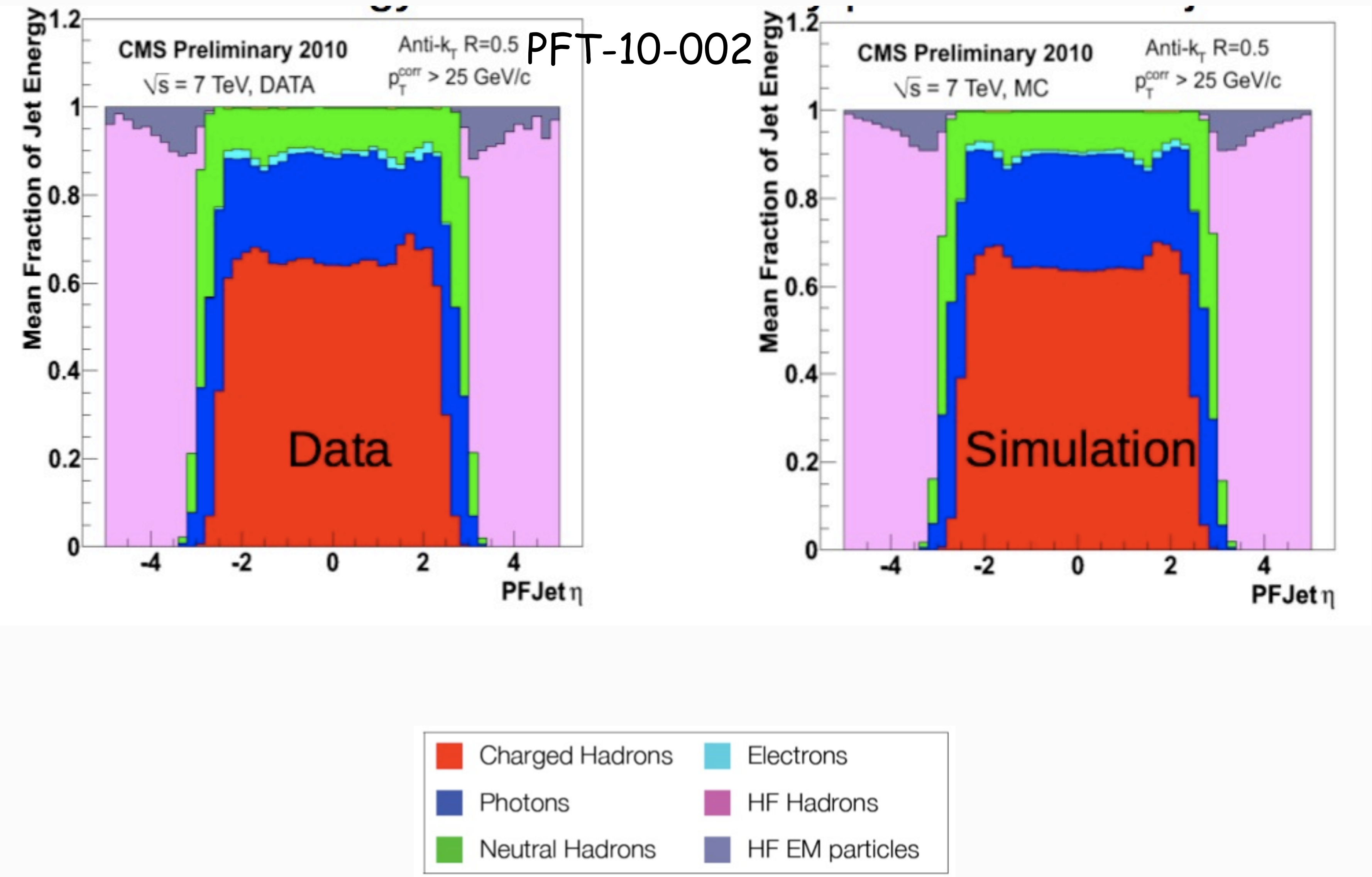


Backup : Absolute JES

- A-priori estimate of JEC uncertainty in barrel 5% for tracking-based jets (JPT, PFJets, track jets), 10% for CaloJets

- Constraints from test beam, jet composition studies and "first principles" (single pion response, π^0 mass peak, tracker resonances)

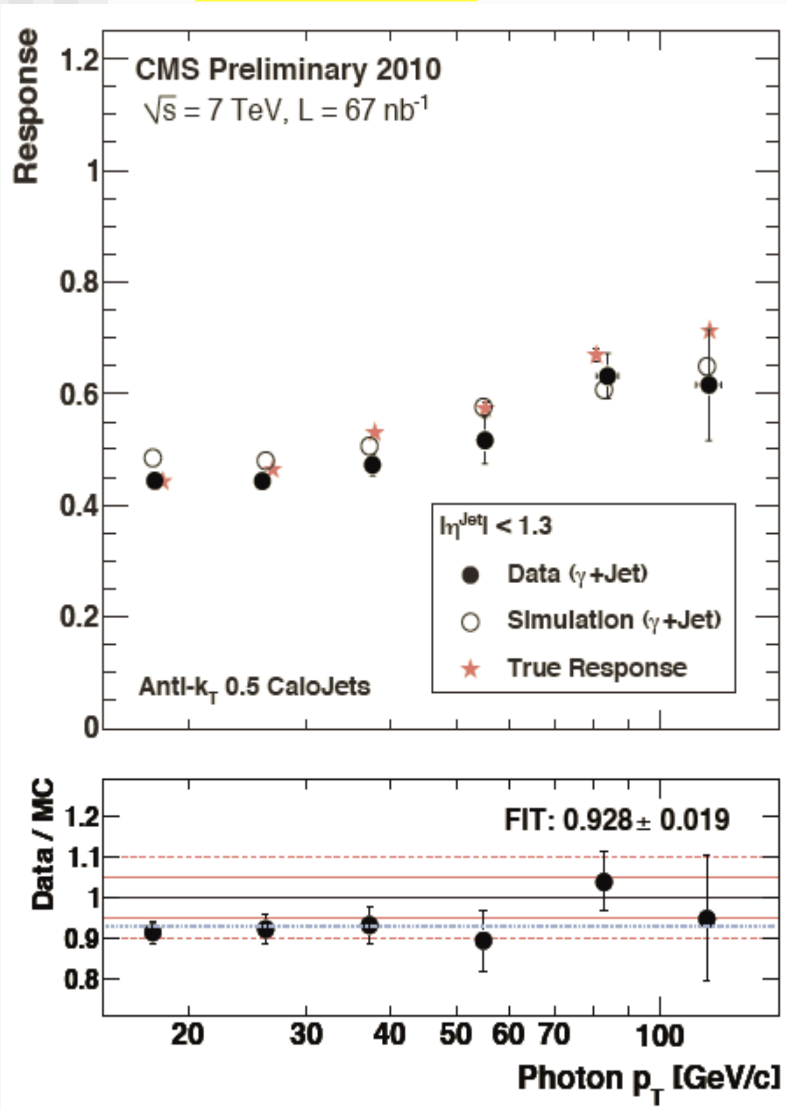
- Direct evidence from Missing-ET projection fraction method (MPF) supports **5%/10% JEC uncertainty** as conservative



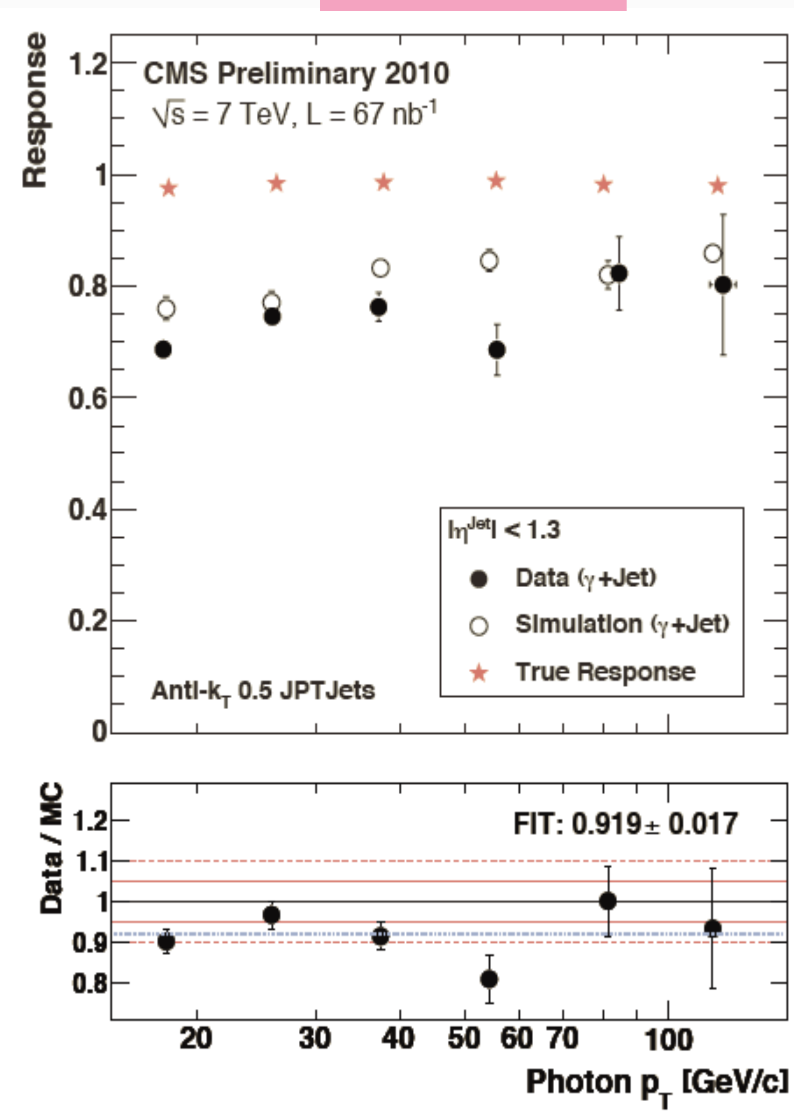
Backup: Absolute JEC

Balance "Response" versus p_T^{γ}

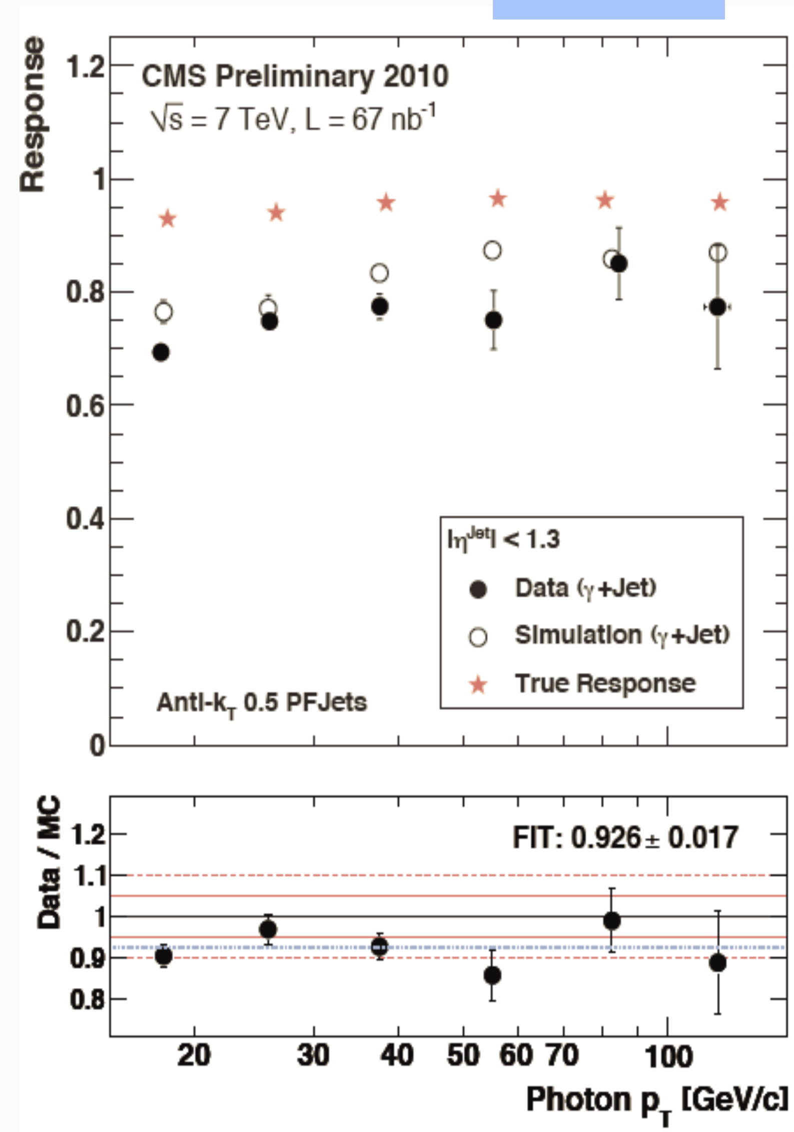
Calo Jet



JPT Jet



PF Jet



- Measured "response" is lower than MC-truth response
  - Loose second jet veto ($p_T^{2nd} < 0.5\ p_T^{\gamma}$) violates photon-jet p_T balancing and produces downward bias in the measurement.
- Reasonable data/MC agreement when the same p_T balance method is applied to data and simulation
- Pileup test in backups: ~no change with PV=1 cut

Backup: MPF

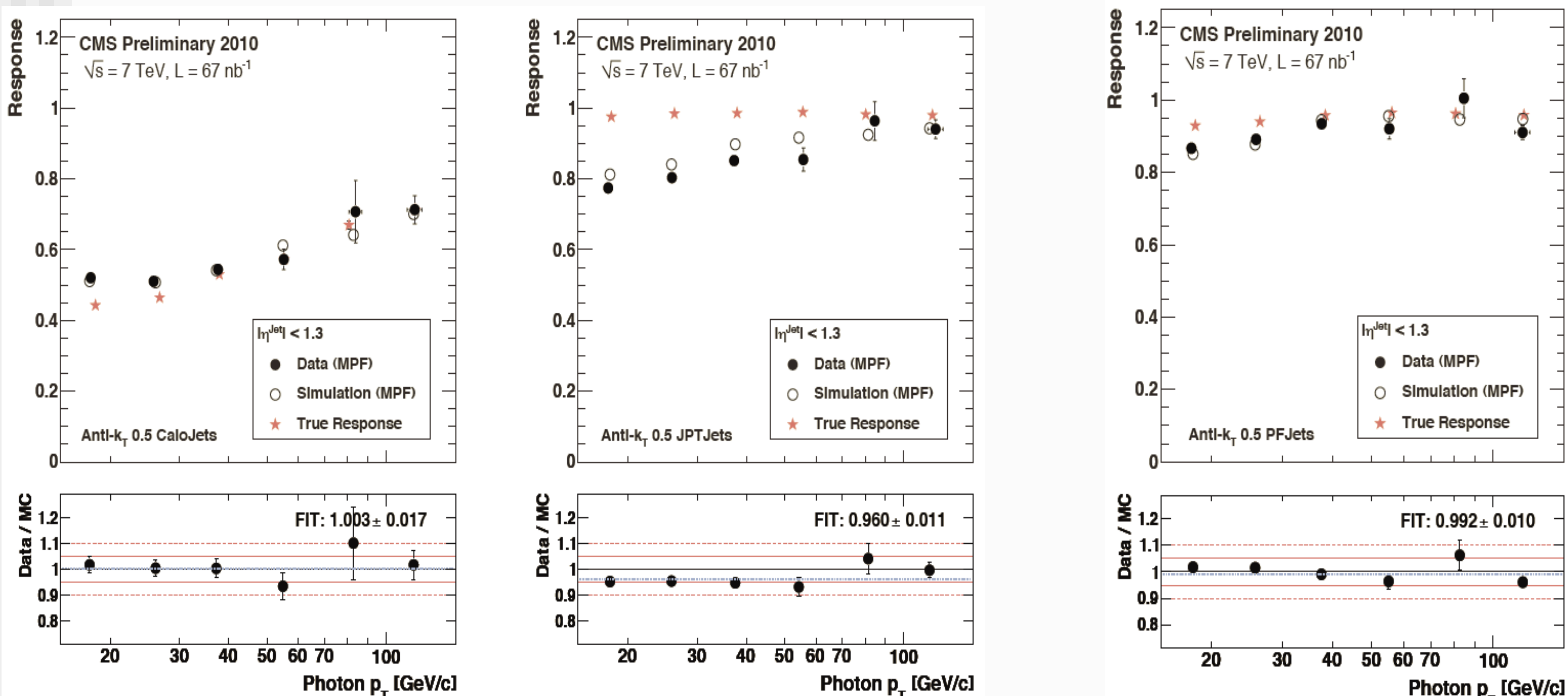
- Basics of MPF (Missing Momentum Fraction; AN-2010/218)
  - Ideally: $\vec{p}_T^{\,\gamma} + \vec{p}_T^{\,\rm recoil} = \vec{0}$
  - Add in the detector: $R_\gamma \vec{p}_T^{\,\gamma} + R_{\rm recoil}\vec{p}_T^{\,\rm recoil} = -\vec{E}_T^{\rm miss}$
  - Solving: $R_{\rm recoil}/R_\gamma = 1 + \dfrac{\vec{E}_T^{\rm miss}\cdot\vec{p}_T^{\,\gamma}}{|\vec{p}_T^{\,\gamma}|^2} \equiv R_{\rm MPF}$
  - R_{MPF} is assigned as the response of the recoil jet
- Advantage of MPF: Low sensitivity to extra radiation
  - Smaller error bars: Widths of distributions are narrower thanks to less fluctuations from the impact of extra radiation
  - Smaller bias wrt MC-truth than p_T^{jet}/p_T^{γ} for current very loose cuts on extra radiation
  - Helps to fully exploit the accuracy of PF method
- MPF method demonstrates the accuracy of JES for different types of jets more clearly than γ-jet balancing method does

Backup: Absolute MPF

Slide by J. Weng, ICHEP

MPF "Response" versus p_T^γ

Calo Jet | JPT Jet | PF Jet



- Measured "response" is closer to MC-truth response than for p_T balance
- Good data/MC agreement when the same MPF method is applied to data and simulation.

Unfolding

- Inclusive jet cross section uses **ansatz** unfolding to get to the particle level
- Phenomenological power law motivated by parton model (Feynman/Field/Fox), extended at the Tevatron, and updated at CMS for low p_T and b-jets

$$f(p_T) = N_0 p_T^{-\alpha} \underbrace{\left(1 - \frac{2 p_T \cosh(y_{\min})}{\sqrt{s}}\right)^{\beta}}_{\text{high } p_T} \underbrace{\exp(-\gamma/p_T)}_{\text{low } p_T \text{ and b-jets}}$$

new

$$C_{\text{smear}}(p_T) = \frac{f(p_T)}{F(p_T)}, \qquad F(p_T) = \int_{x=0}^{x=\infty} f(x) g(p_T - x) dx,$$

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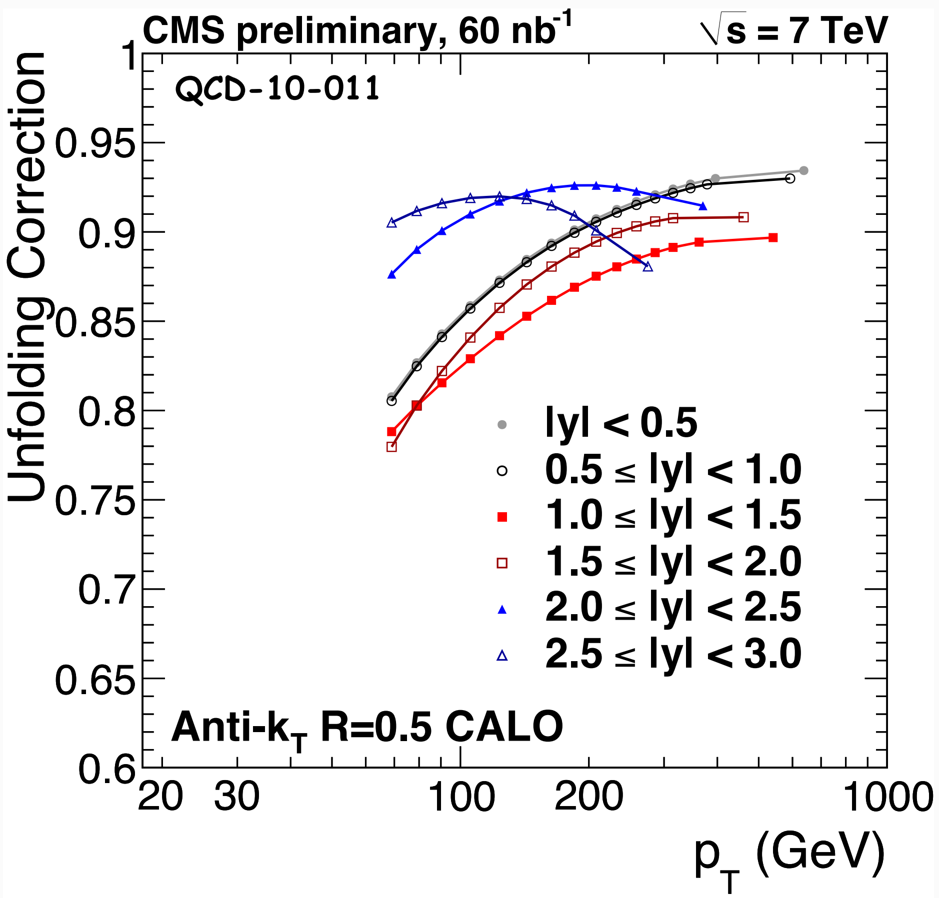
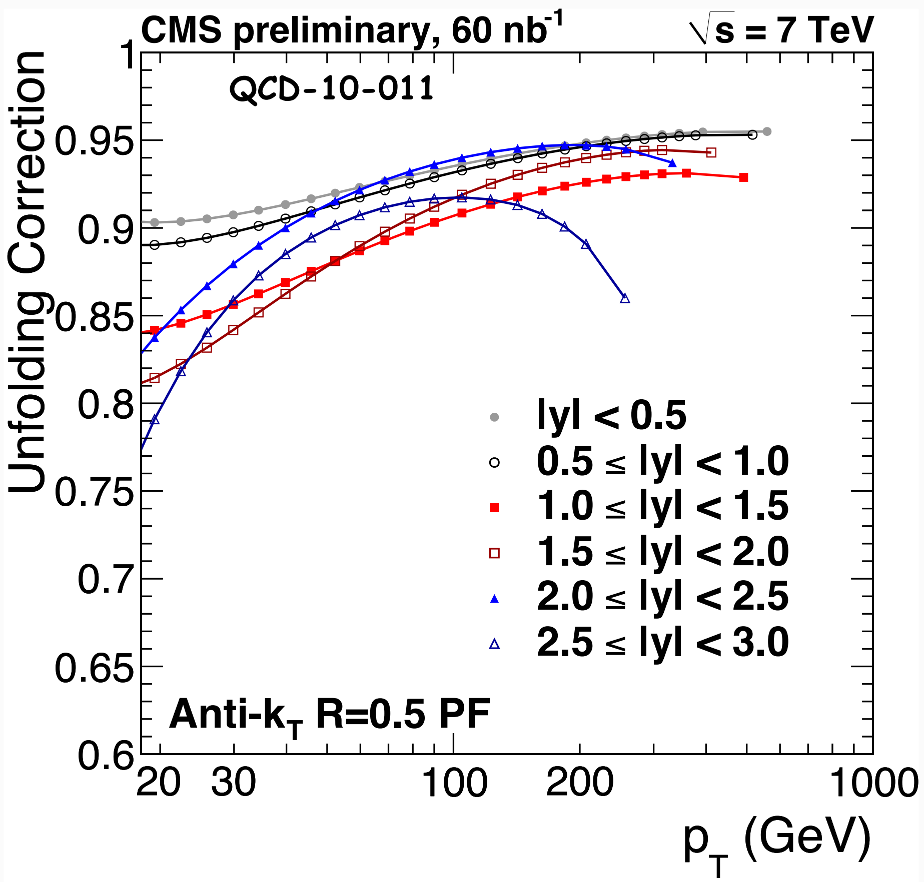
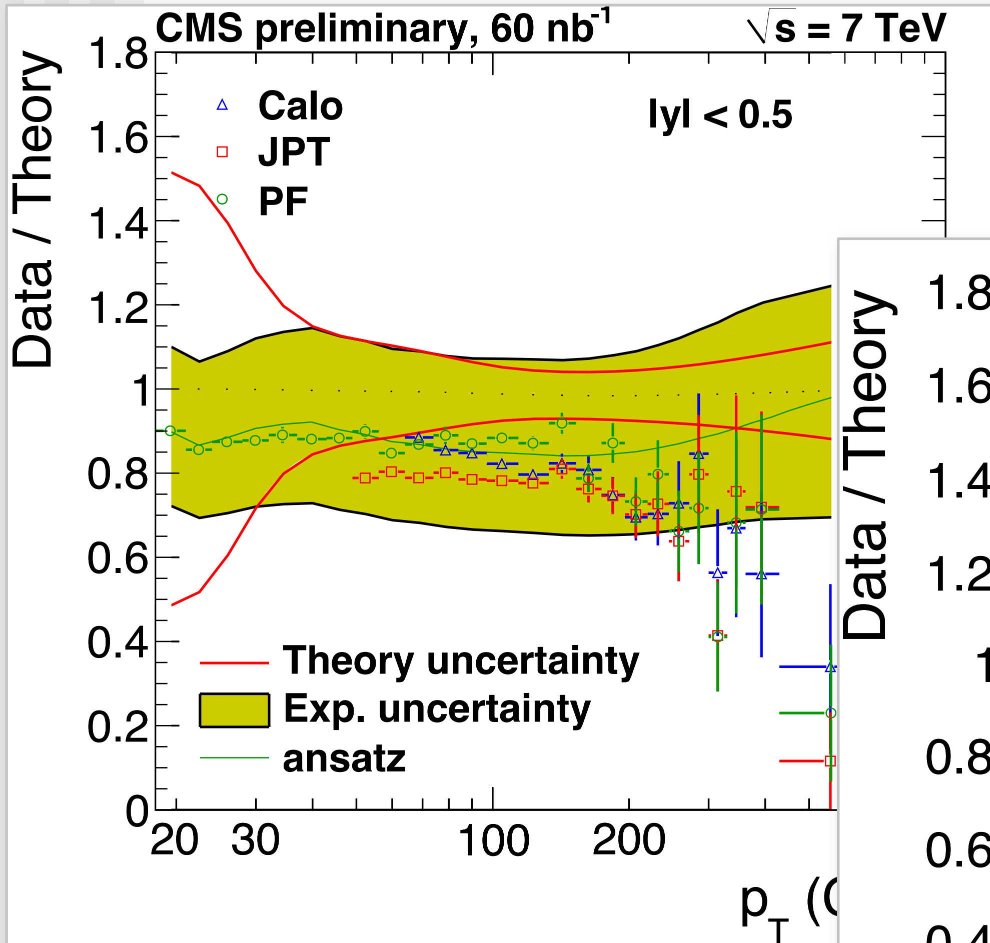
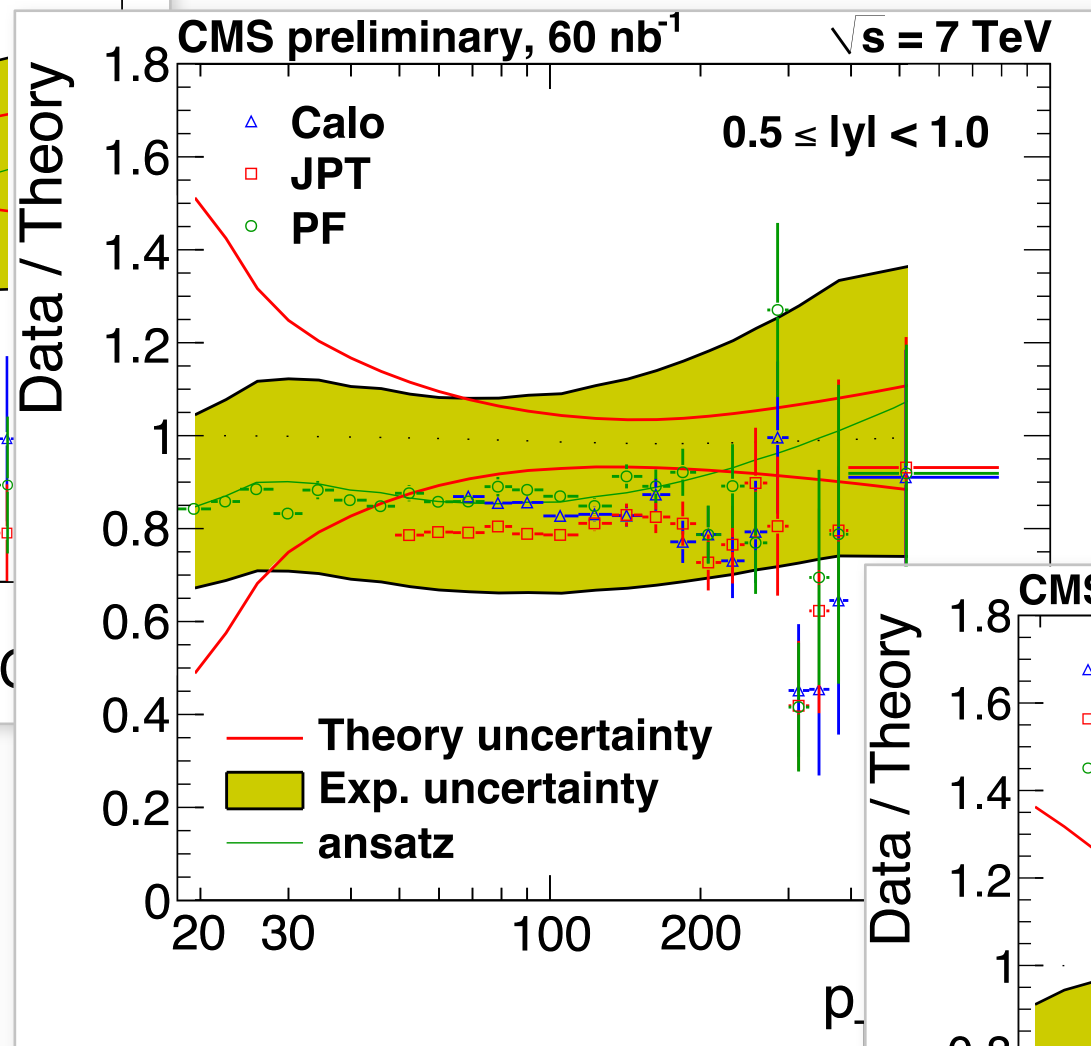


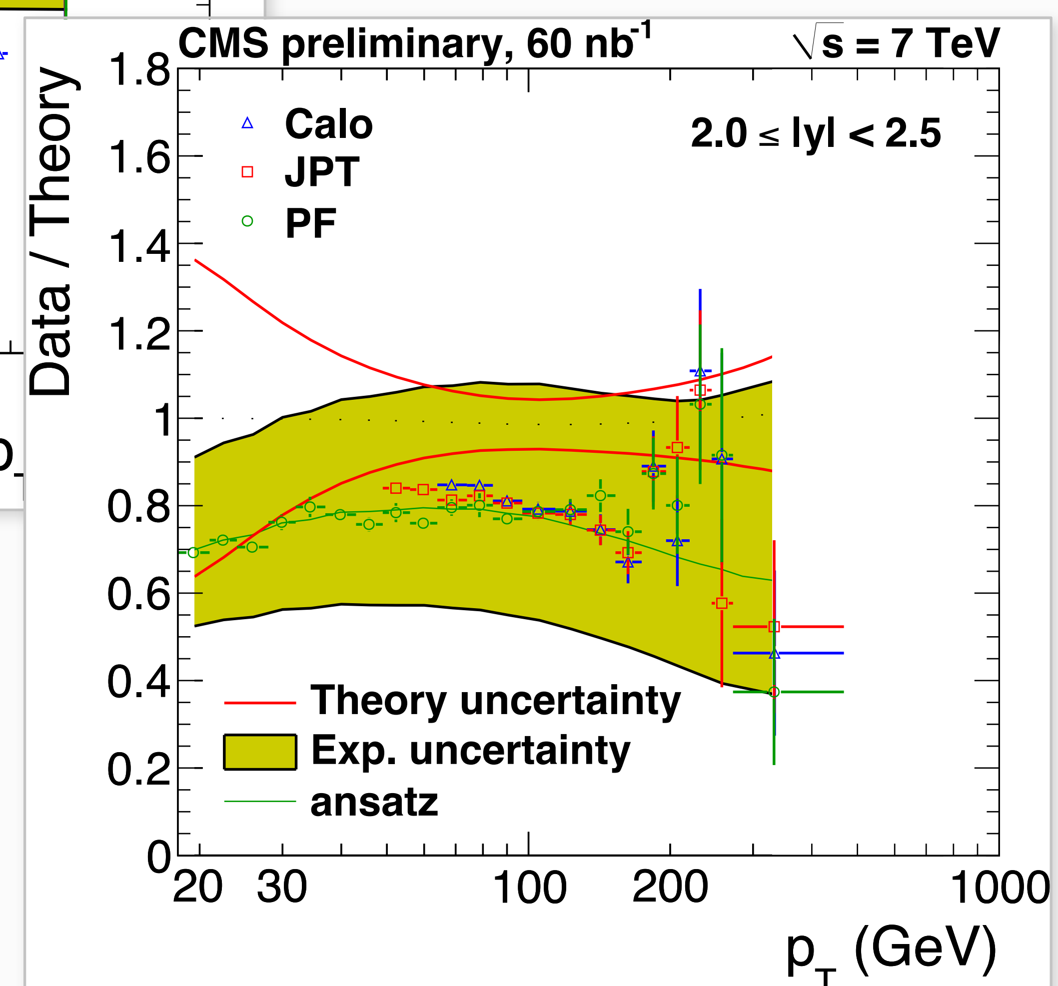


Inclusive jet cross section

QCD-10-011

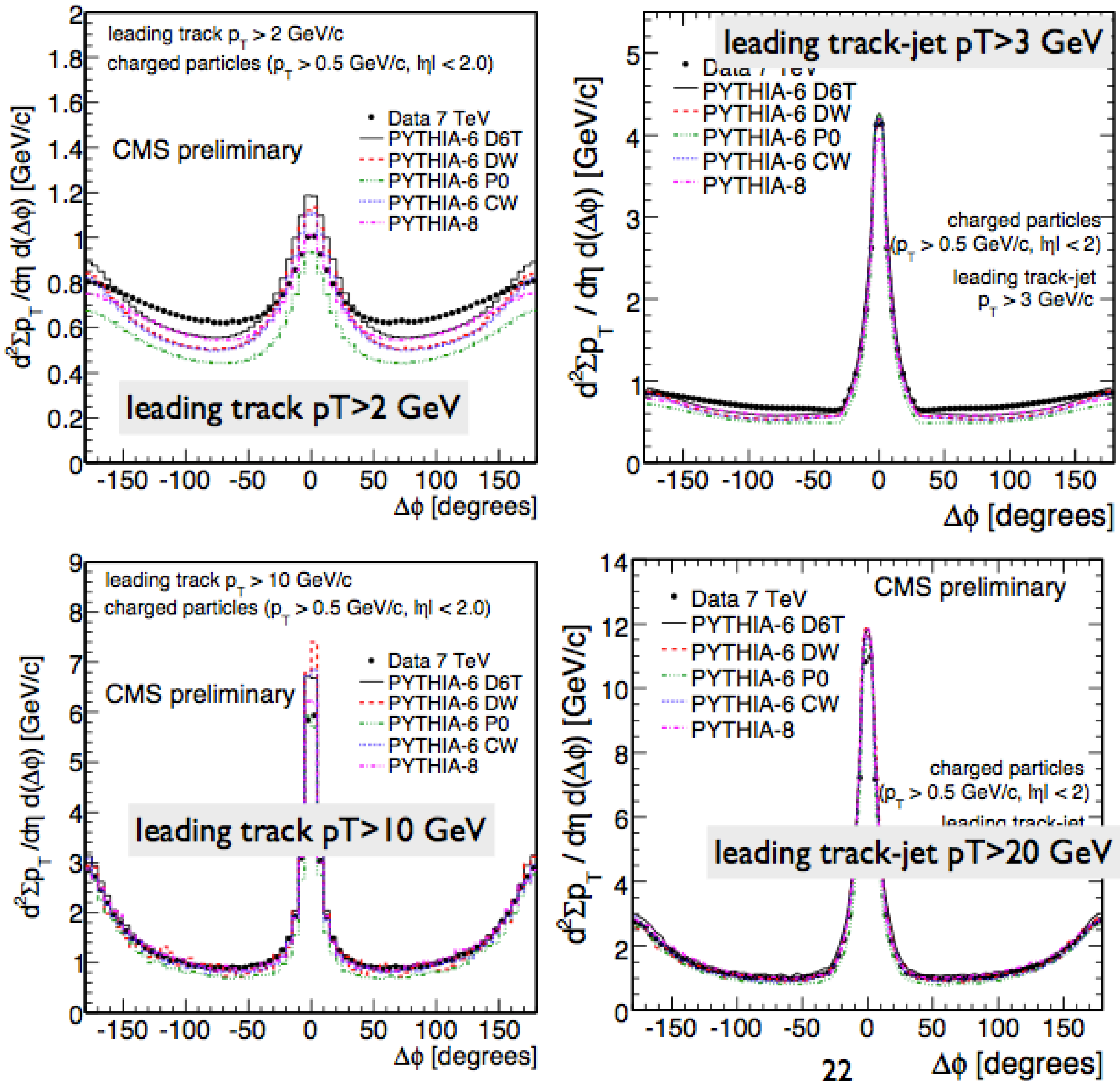






- Systematic uncertainty is centered around PF ansatz

Results at 7 TeV



see QCD-10-001 and QCD-10-010

low scale:

tow → P8 best fit

DW, CW, D6T 10-20% off

P0 significantly off

trans → all tunes below data

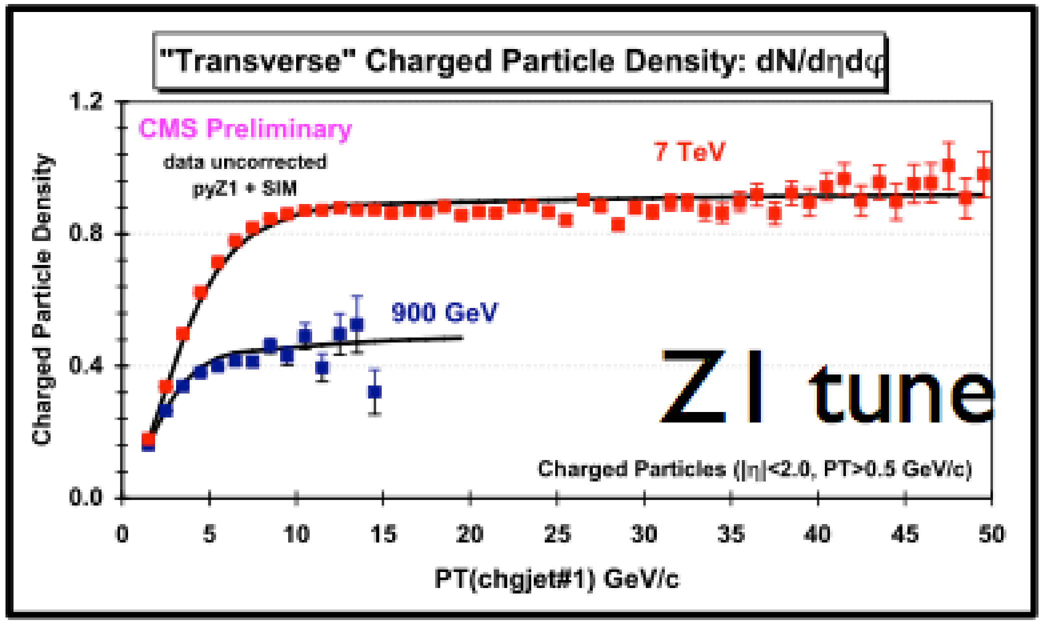
high scale:

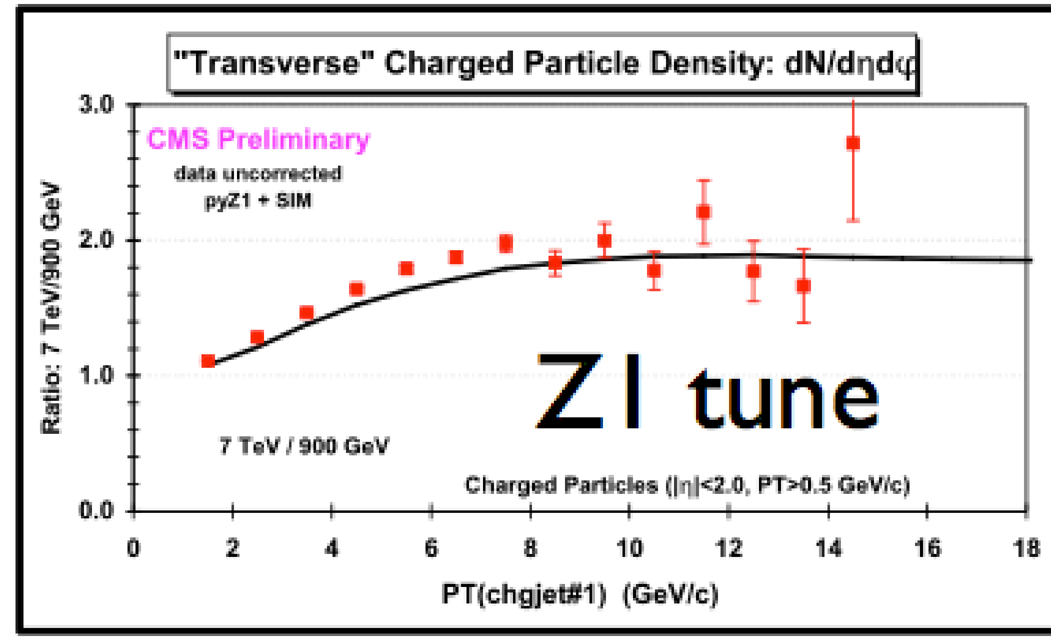
the agreement increase in all the regions

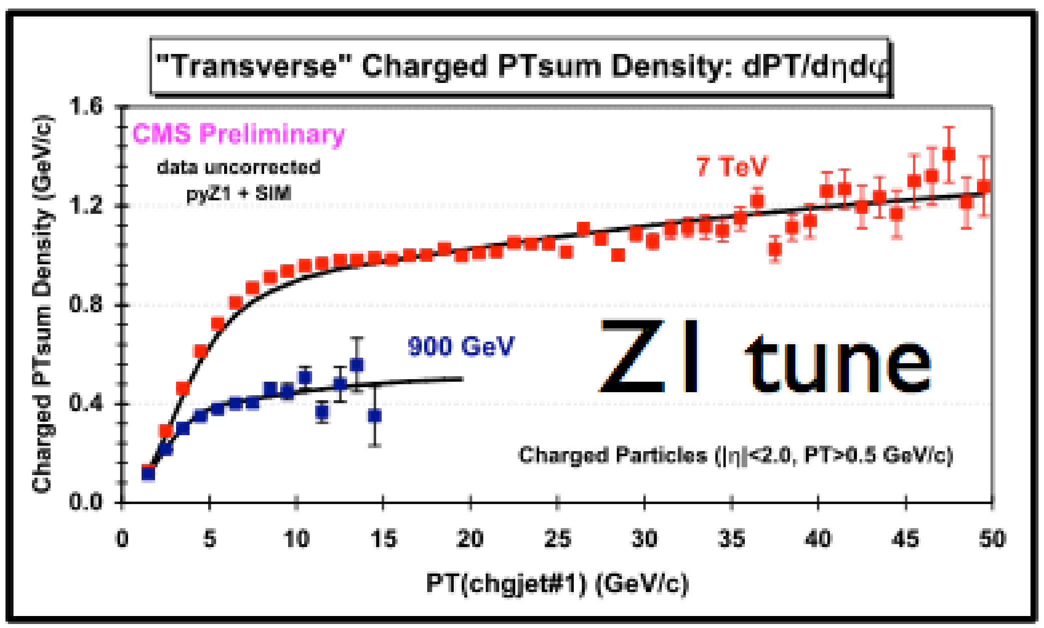
tow → P0 seems provide better fragmentation model for high z

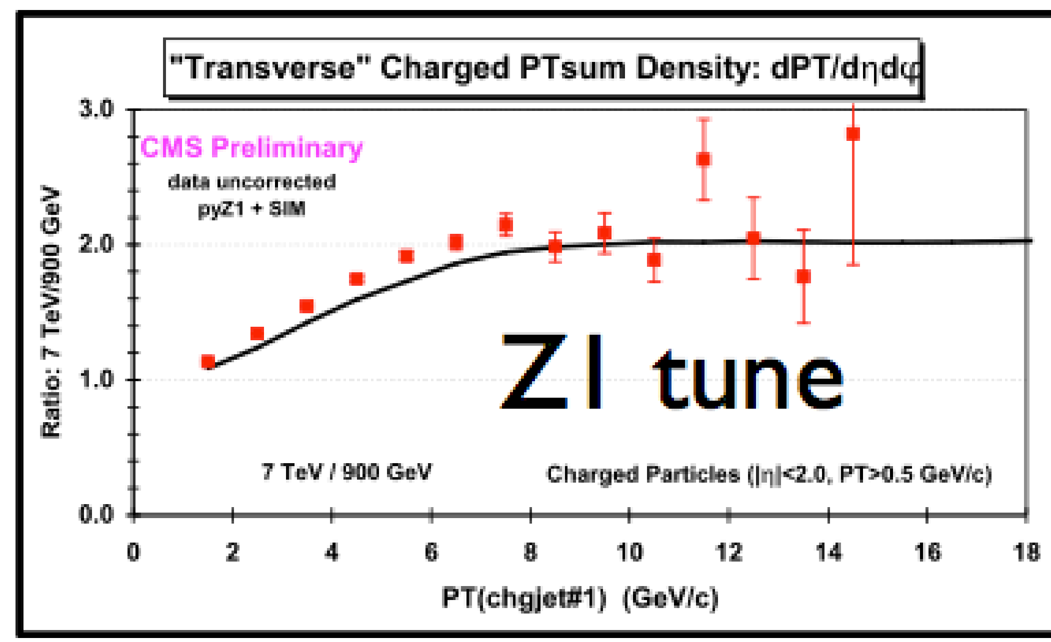
Note : so far data were not corrected for detector effects.
Efforts in this direction under way

However: recent news from Rick...









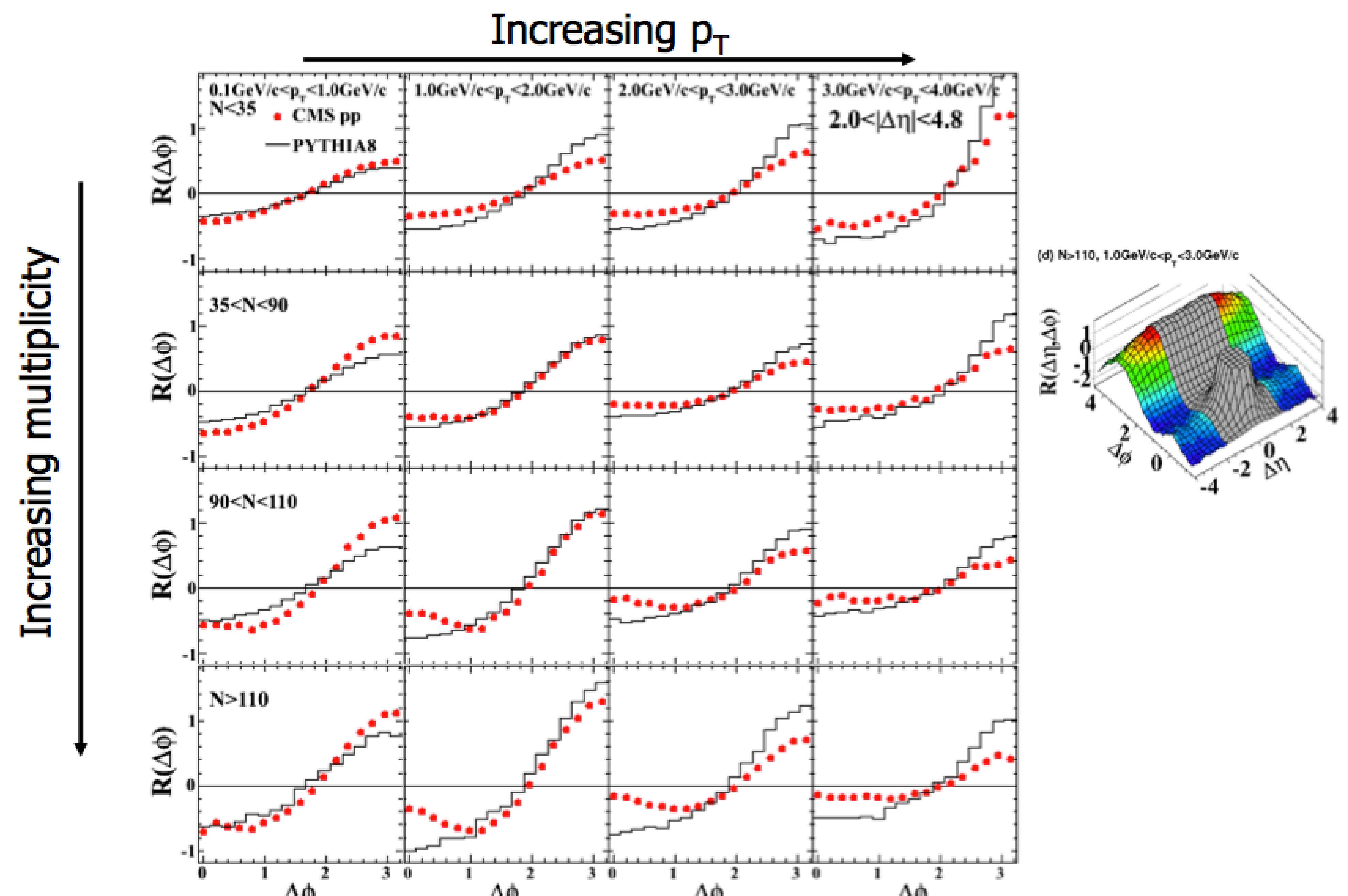
pT-ordered shower
new MPI model
color reconnection from MinBias

Tune Z1 (CTEQ5L)
PARP(82) = 1.932
PARP(90) = 0.275
PARP(77) = 1.016
PARP(78) = 0.538

To quote Rick : "amazing..."

In general good description of diff. distributions (multiplicities).
See discussions this week....

Multiplicity and pT dependence



"Ridge" maximal for highest multiplicity and $1 < p_T < 3$ GeV/c

CERN Seminar September 21 2010 19

see G. Roland's talk at CERN seminar, 21.9.2010