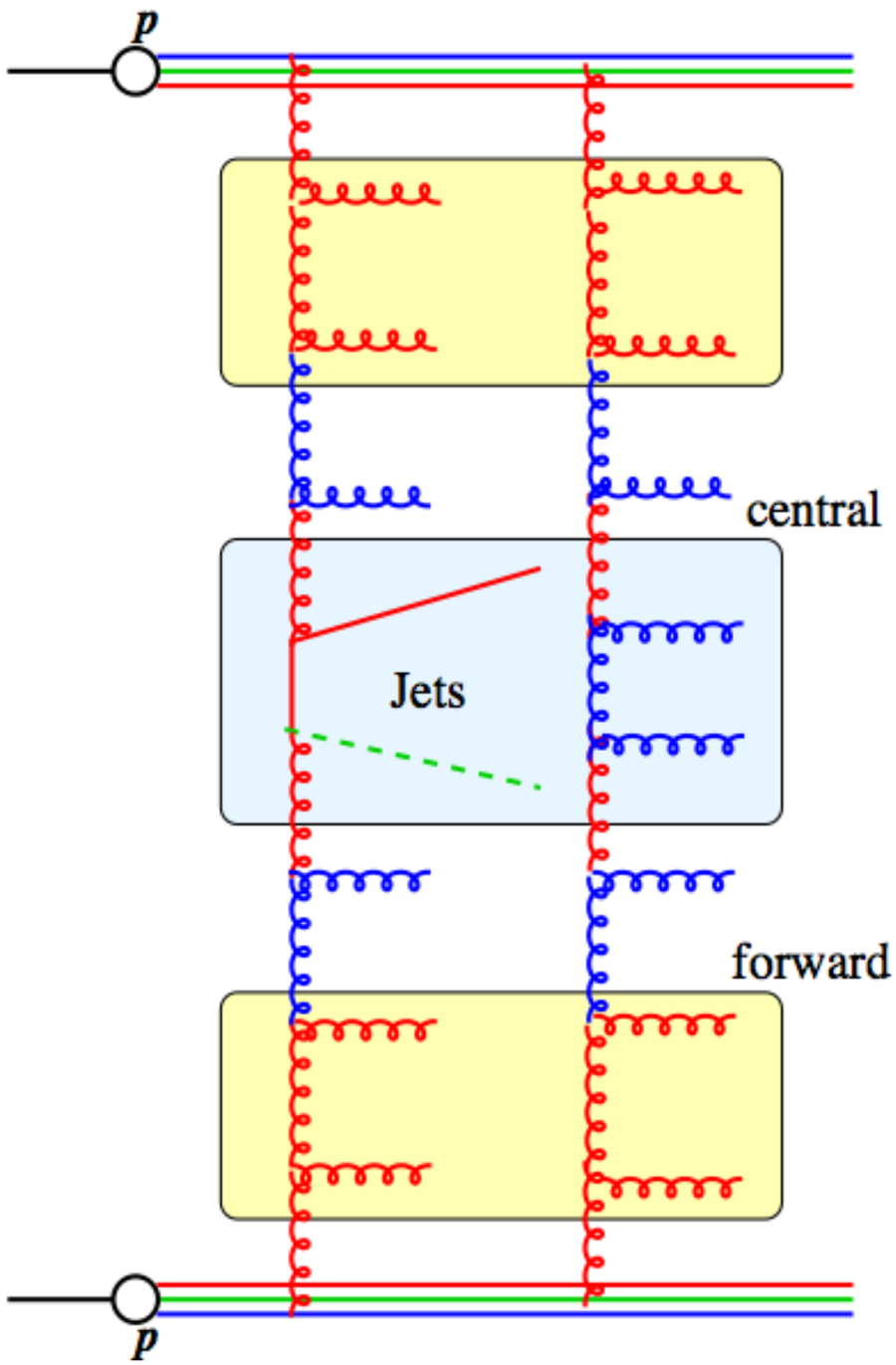
Measurements of forward energy flow and forward jet production with CMS

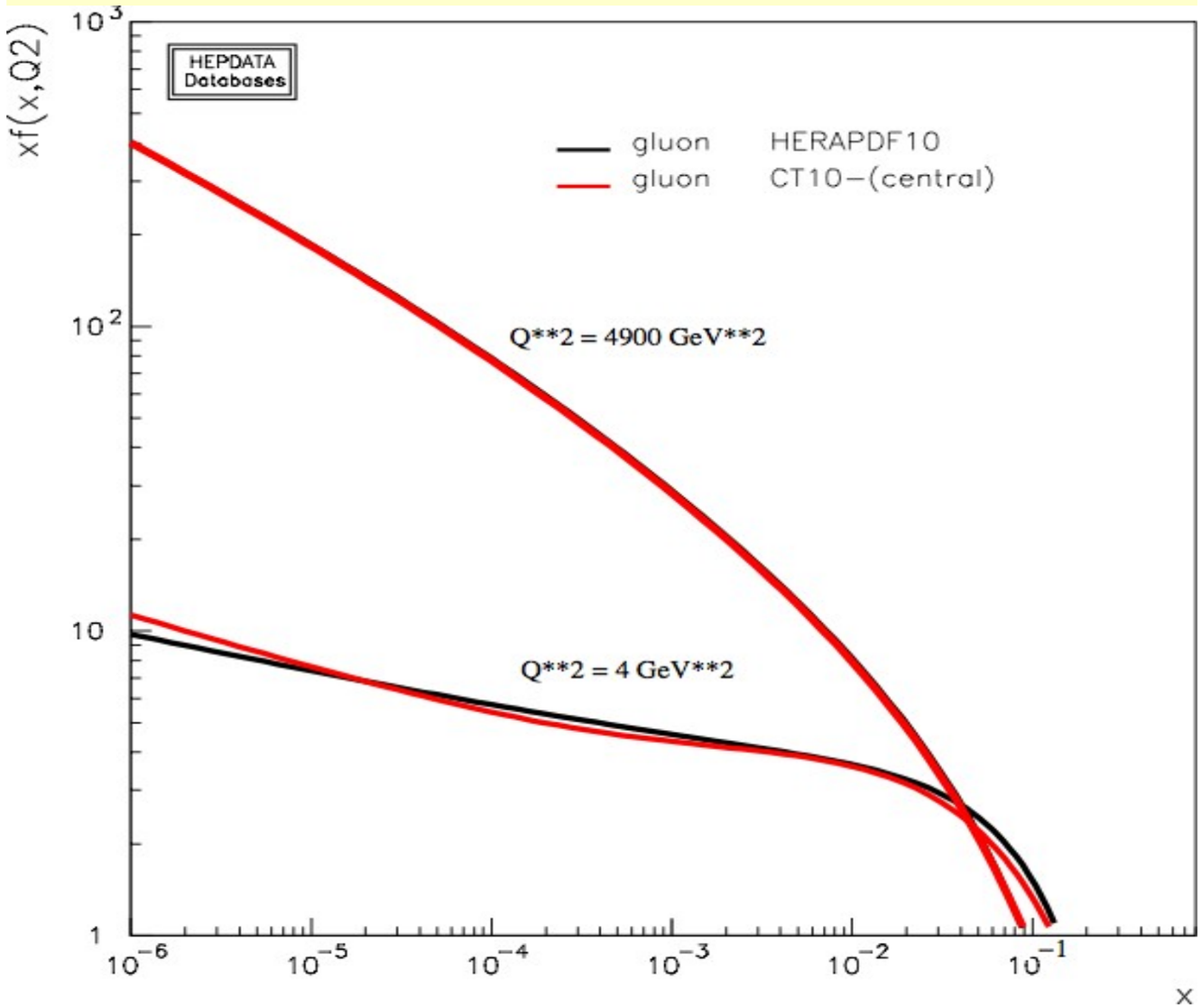
H. Jung (CERN, DESY)
on behalf of CMS

Why forward ?



accessible x values at $\sqrt{s}$ = 7 TeV

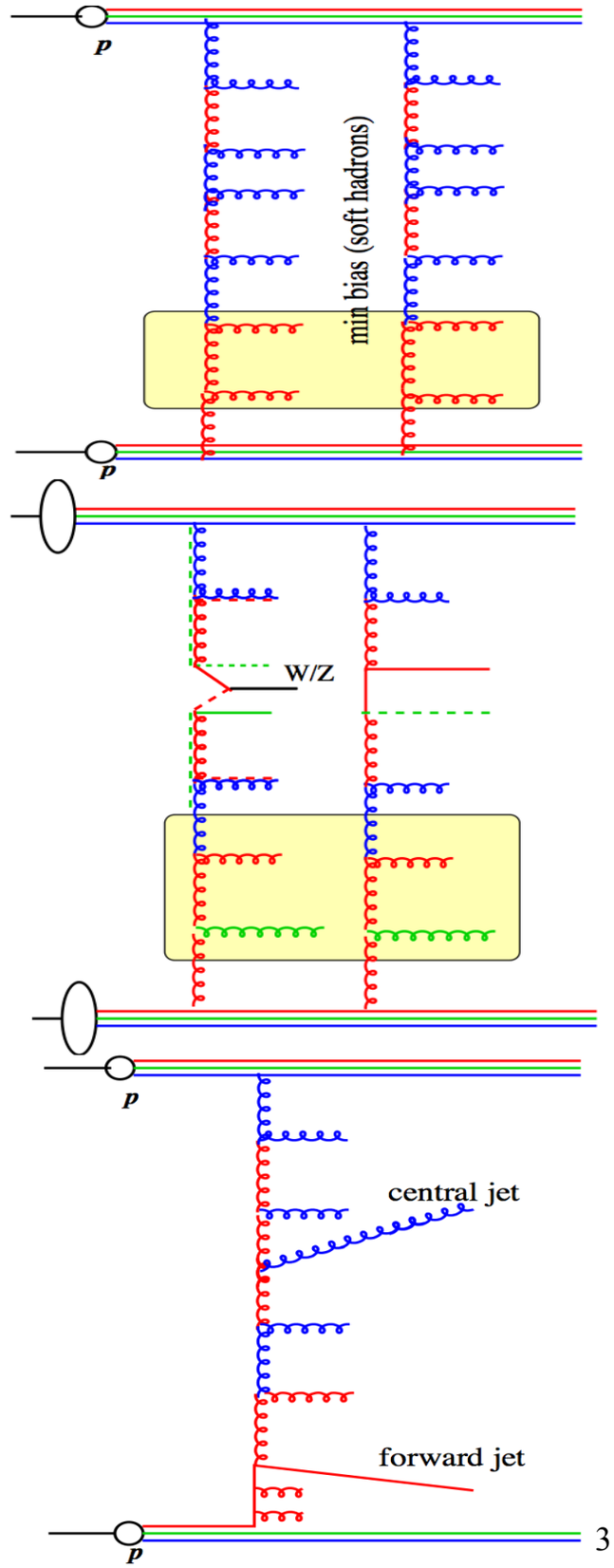
p_t	central (η=0)	forward (η=4)
2 GeV	$5\ 10^{-4}$	$2\ 10^{-2}$, $1\ 10^{-5}$
35 GeV	$1\ 10^{-2}$	0.4, $2\ 10^{-4}$



- study of small and large x !!!

Strategy for small x measurements

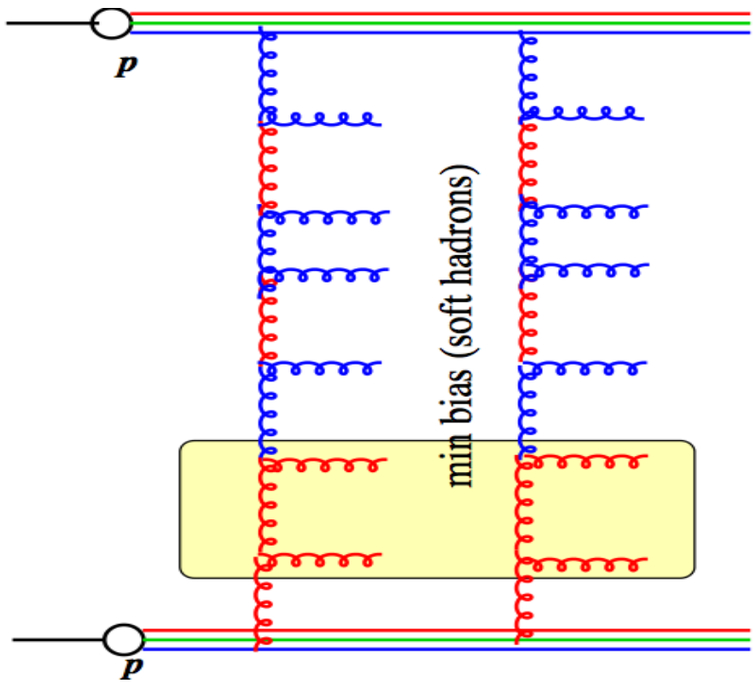
scale	central (activity)	forward (activity)
small	small	small: energy flow
larger	large: high p_t dijets	small: energy flow
large	large: W/Z	small: energy flow
large	–	large: high p_t jets
large	large: high p_t jet	large: high p_t jet



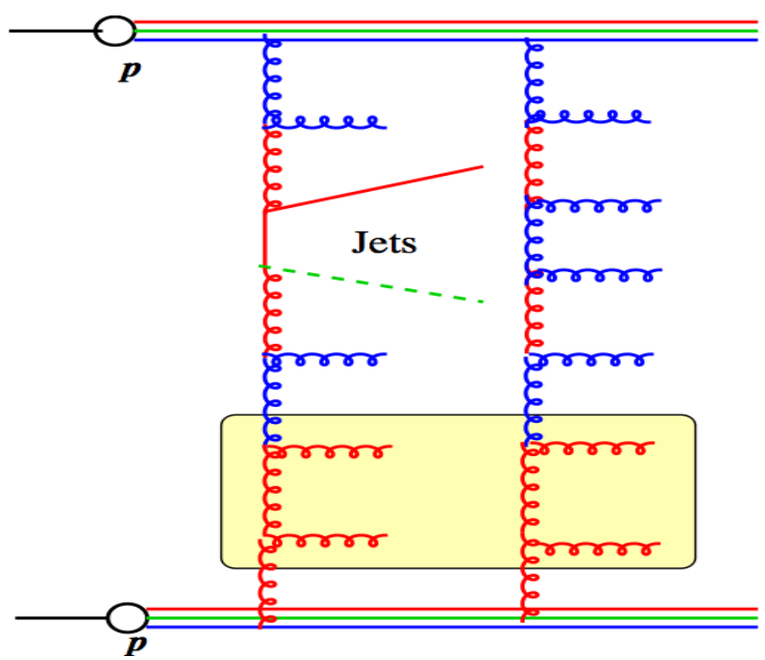
Energy flow measurements

- measurement of $\frac{1}{N}\frac{dE}{d\eta}$

- minimum bias events
  at $\sqrt{s}$ = 0.9 (7) TeV



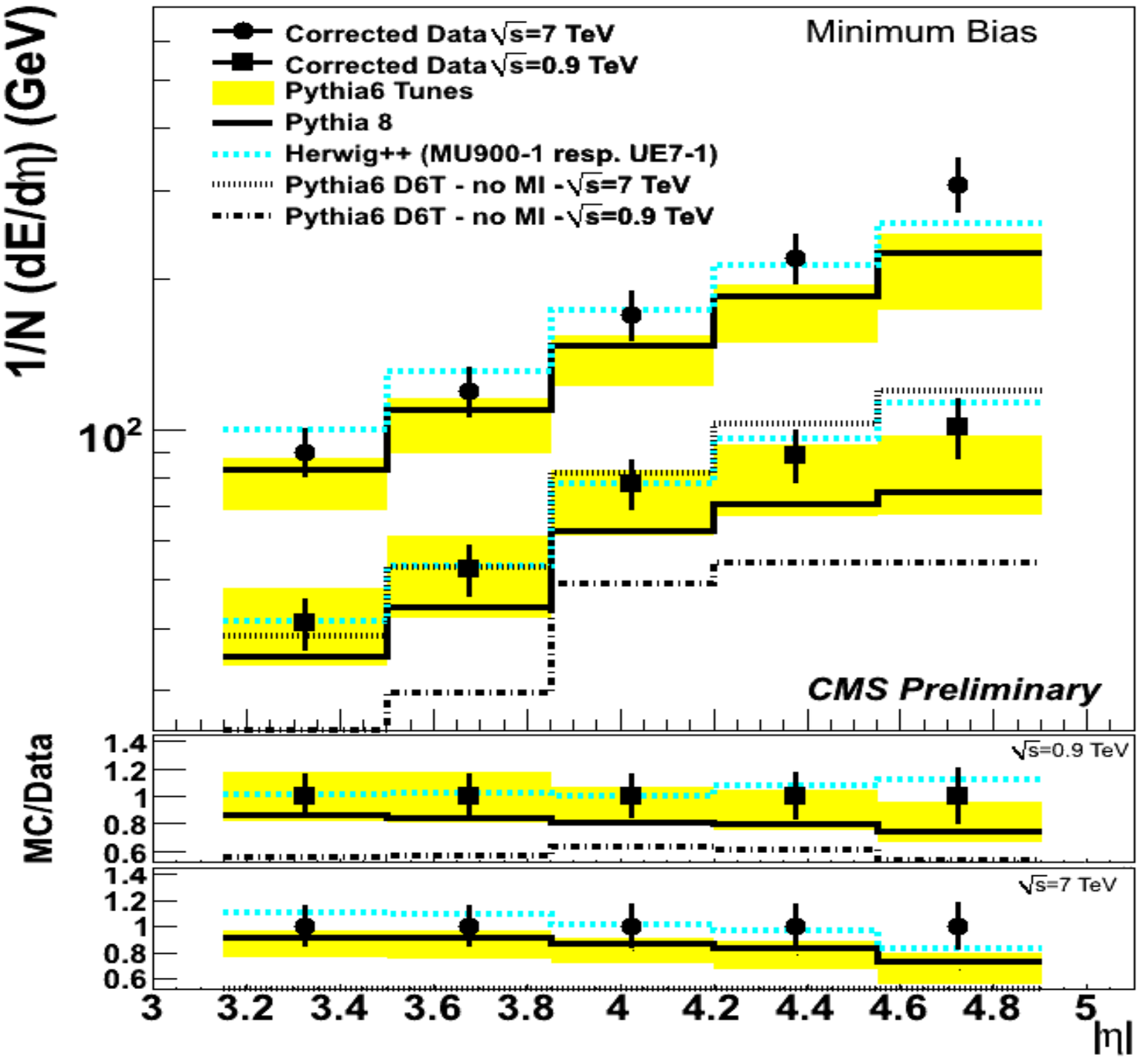
- central dijet events $|\eta|<2.5$,
  E_T > 8(20) GeV at $\sqrt{s}$ = 0.9 (7) TeV

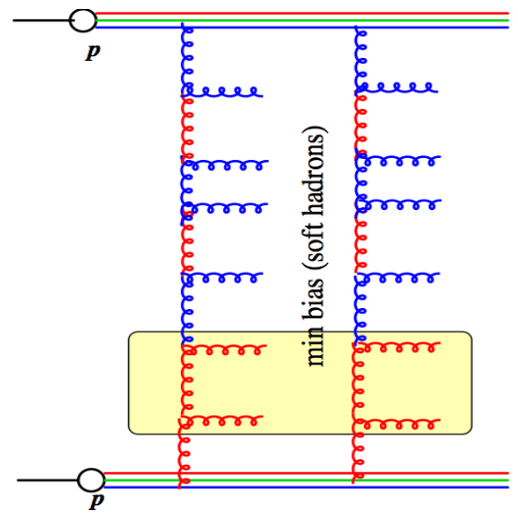


- trigger: charged particles in forward/backward region ($3.9 < |\eta| < 4.4$)
- systematics: energy scale uncertainty → 10 %
  - model uncertainty → 3 – 8 % minimum bias, → 4 – 18 % jets
  - total 11 – 14 % for minimum bias, 13 – 22 % for dijets

MinBias energy flow measurement

CMS-PAS-FWD-10-011

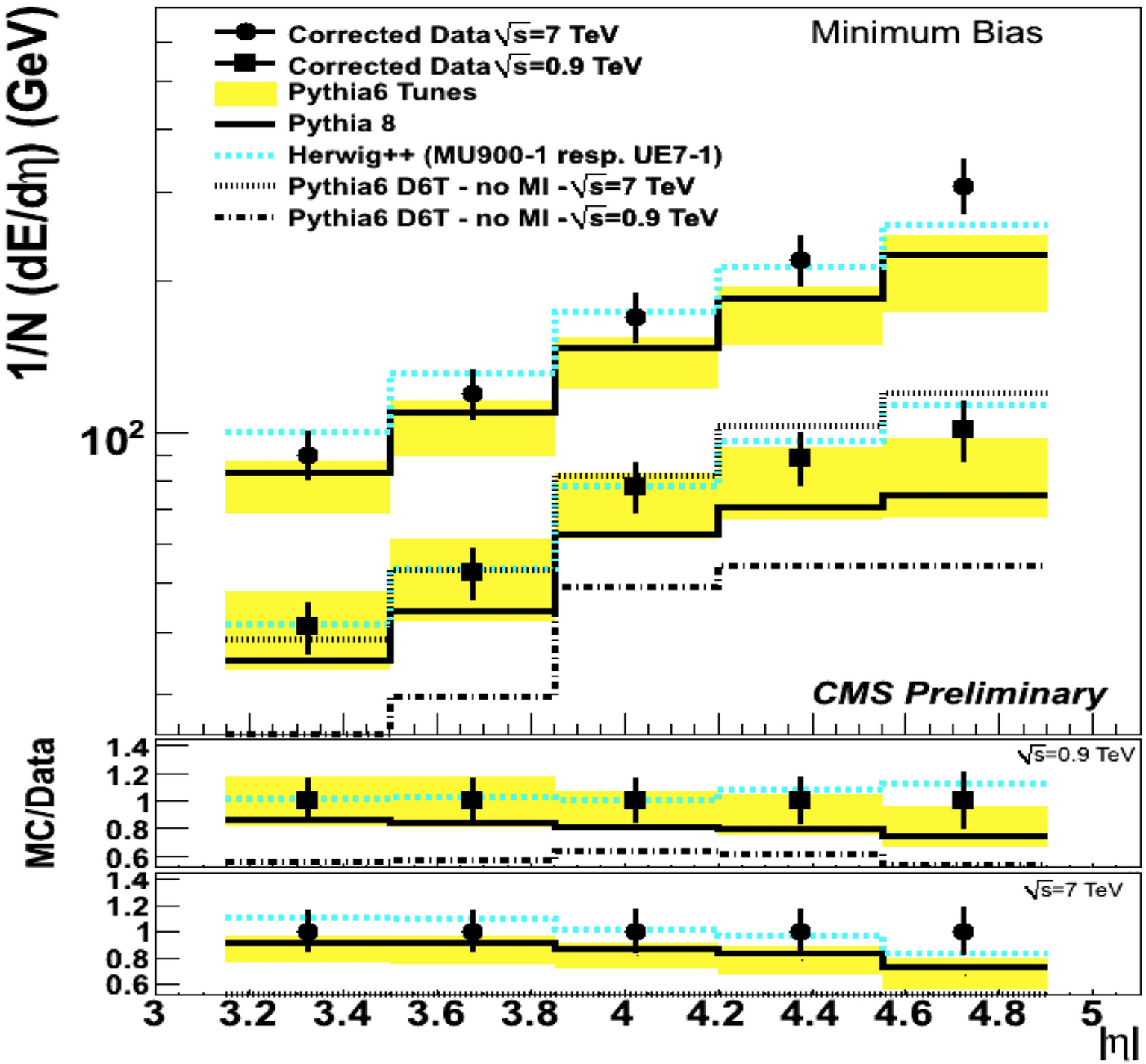


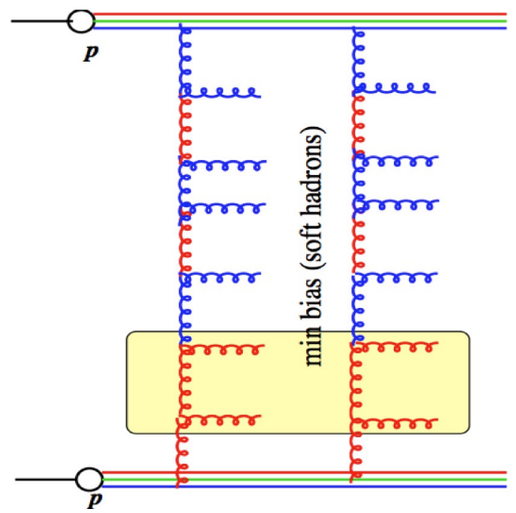


- energy flow measured at $\sqrt{s}$ =0.9 and 7 TeV
- rise with η corresponds to flat E_t-flow at $\sim 2.5\ (6)$ GeV
- change in E_t flow from $\sqrt{s}$ =0.9 and 7 TeV similar to change in N_{ch}
- at $\sqrt{s}$ =0.9 TeV similar to UA1 measurement.

MinBias energy flow measurement

CMS-PAS-FWD-10-011

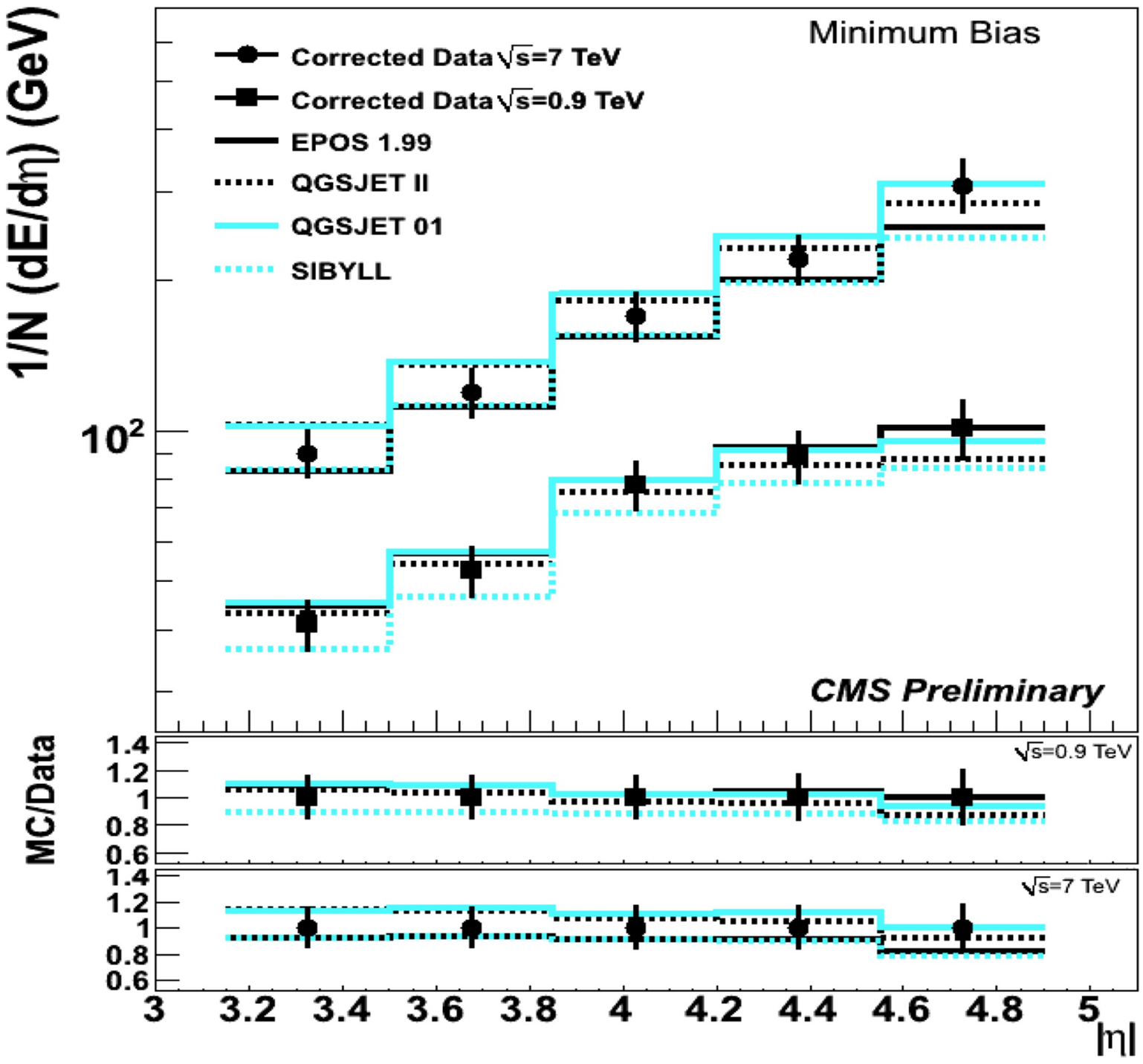




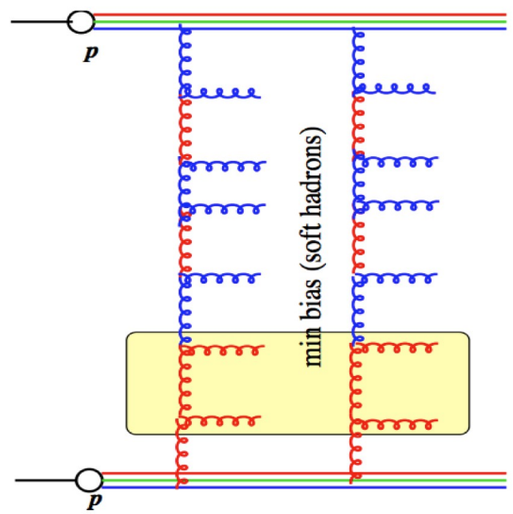
comparison to MC predictions:

- predictions w/o MI too low
- HERWIG
  - √s dependent tunes work
- PYTHIA
  - large spread between tunes
  - even LHC tunes do not work well

MinBias energy flow measurement



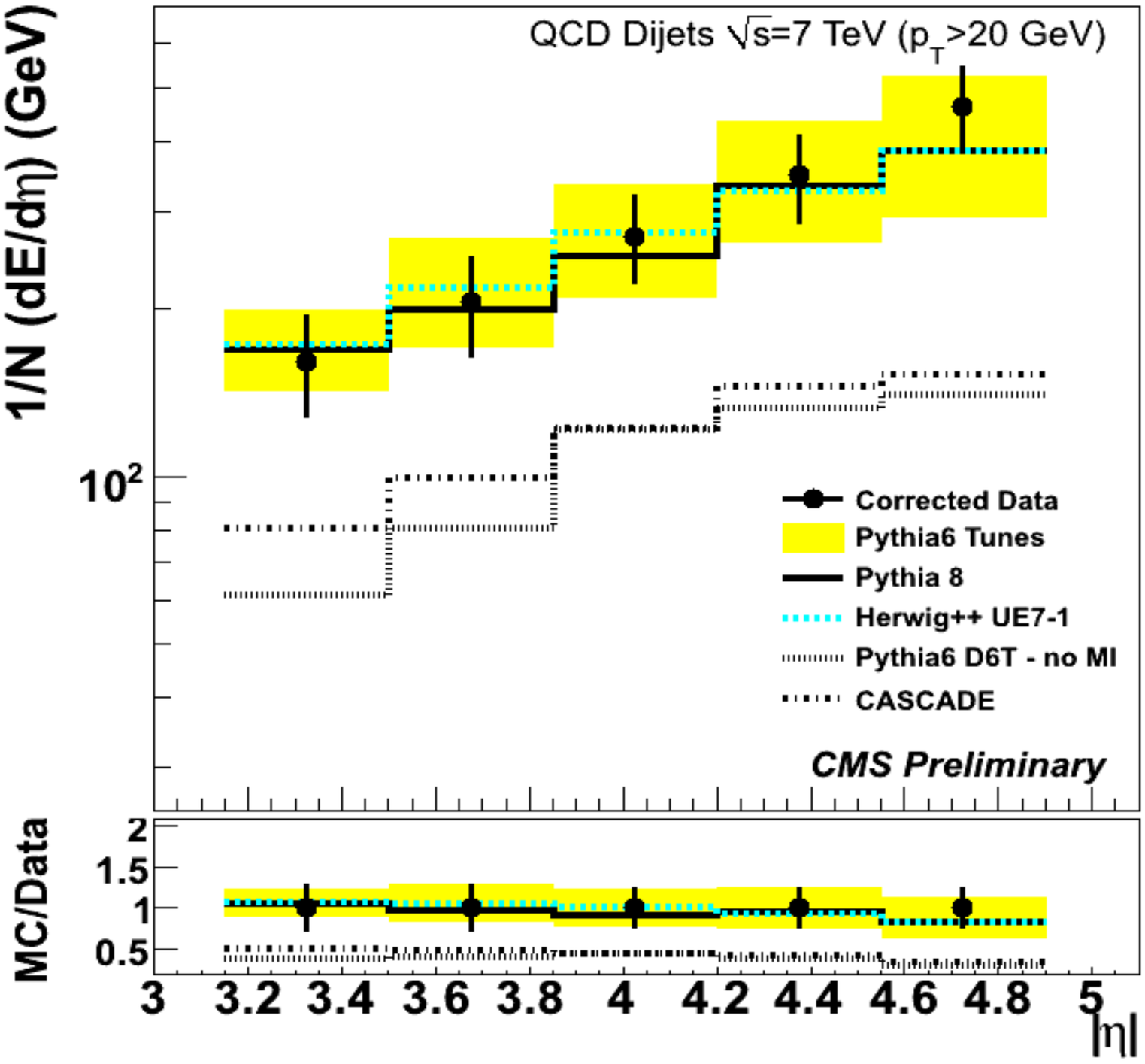
CMS-PAS-FWD-10-011



comparison to MC predictions:

- predictions w/o MI too low
- HERWIG
  - √s dependent tunes work
- PYTHIA
  - large spread between tunes
  - even LHC tunes do not work well
- Cosmic Ray generators
  - work pretty well w/o extra tuning !!!

Dijet energy flow measurement



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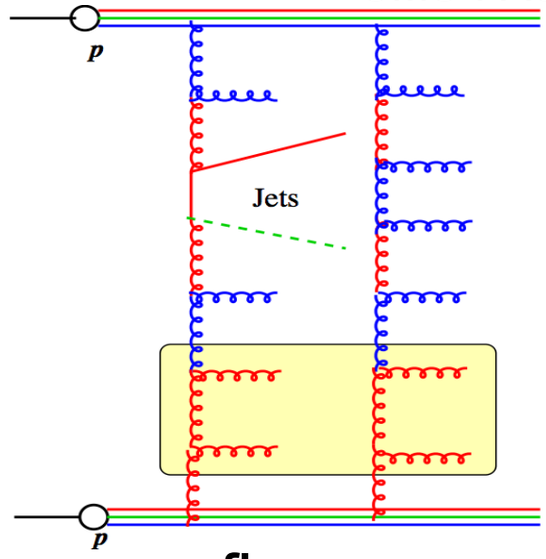
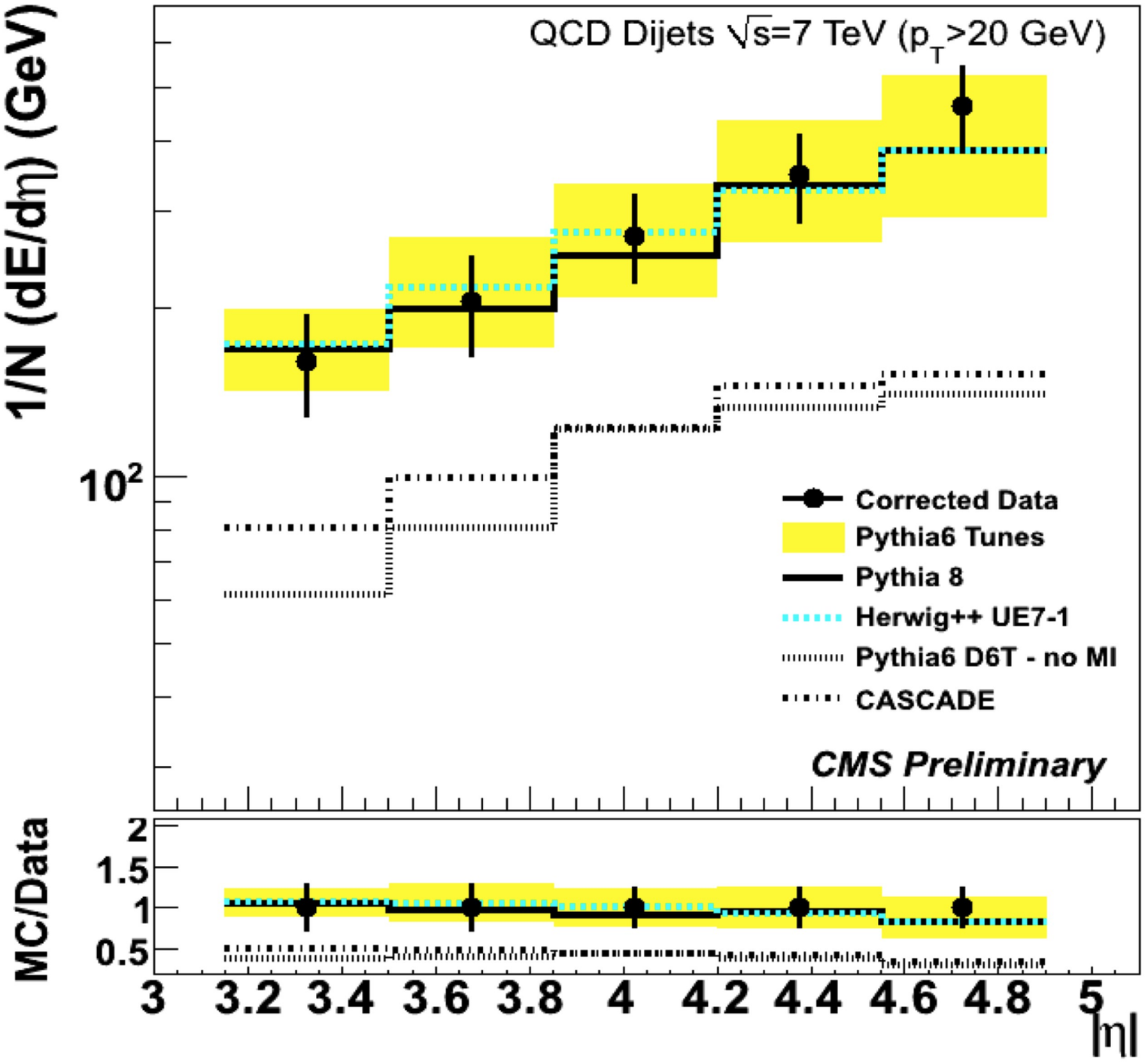


- energy flow measured at $\sqrt{s}$ = 7 TeV for dijets with p_t > 20 GeV
- rise with η corresponds to decreasing E_t-flow with $E_t \sim 11.5\ (9)$ GeV at $\eta \sim 3\ (5)$
- E_t - flow is much larger than observed at HERA (by factor of 3 - 5)

Dijet energy flow measurement



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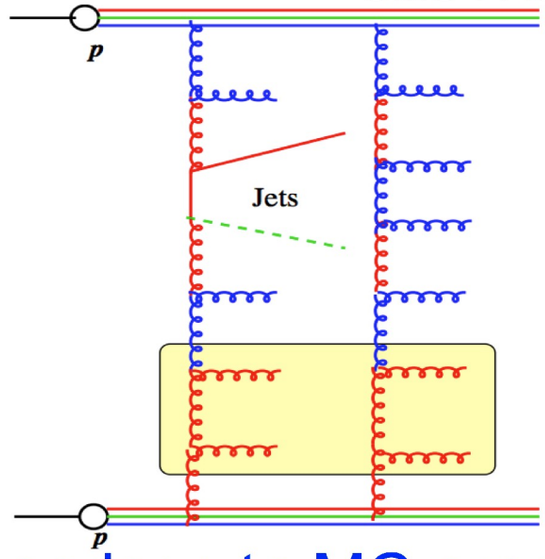
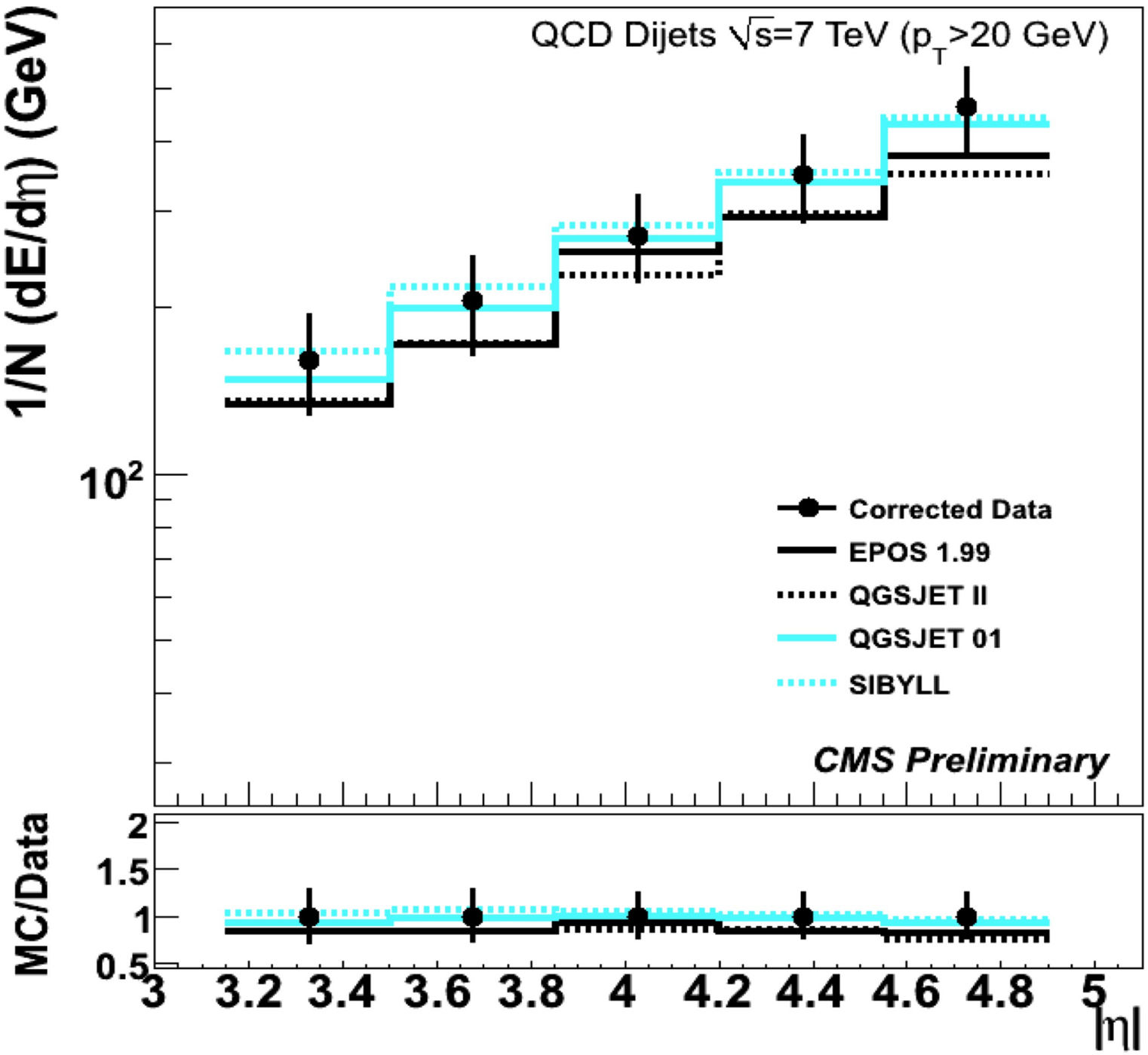


comparison to MC predictions:

- predictions w/o MI too low
- HERWIG
  - √s dependent tunes work
- PYTHIA
  - tunes cover data

Dijet energy flow measurement



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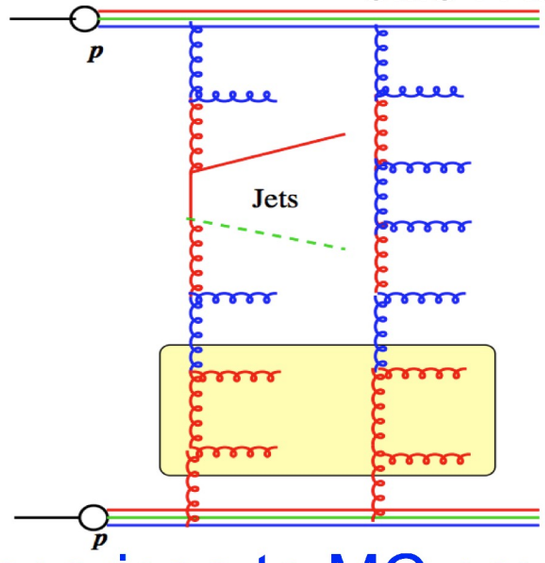
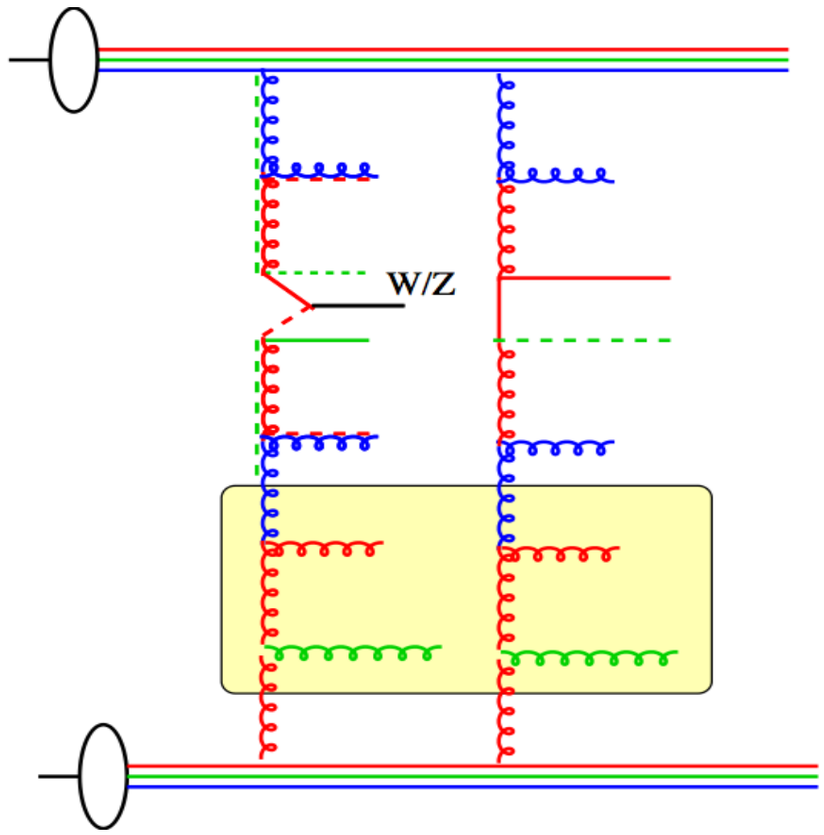


Comparison to MC predictions:

- Predictions w/o MI too low
- HERWIG
  - √s dependent tunes work
- PYTHIA
  - tunes cover data
- Cosmic Ray MCs
  - describe data

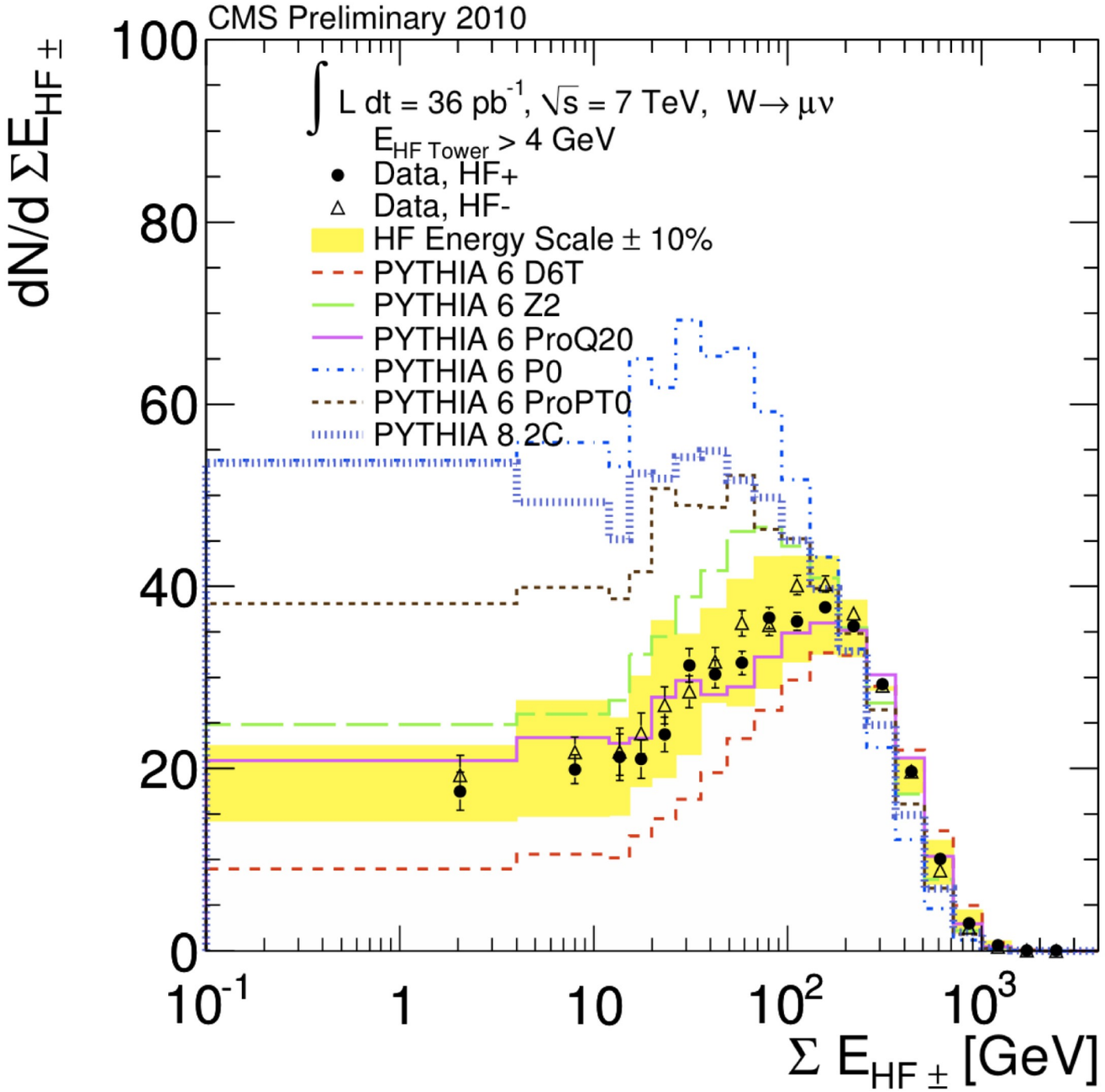
W/Z & forward energy measurement

- measure W/Z with lepton in $|\eta| < 1.4$

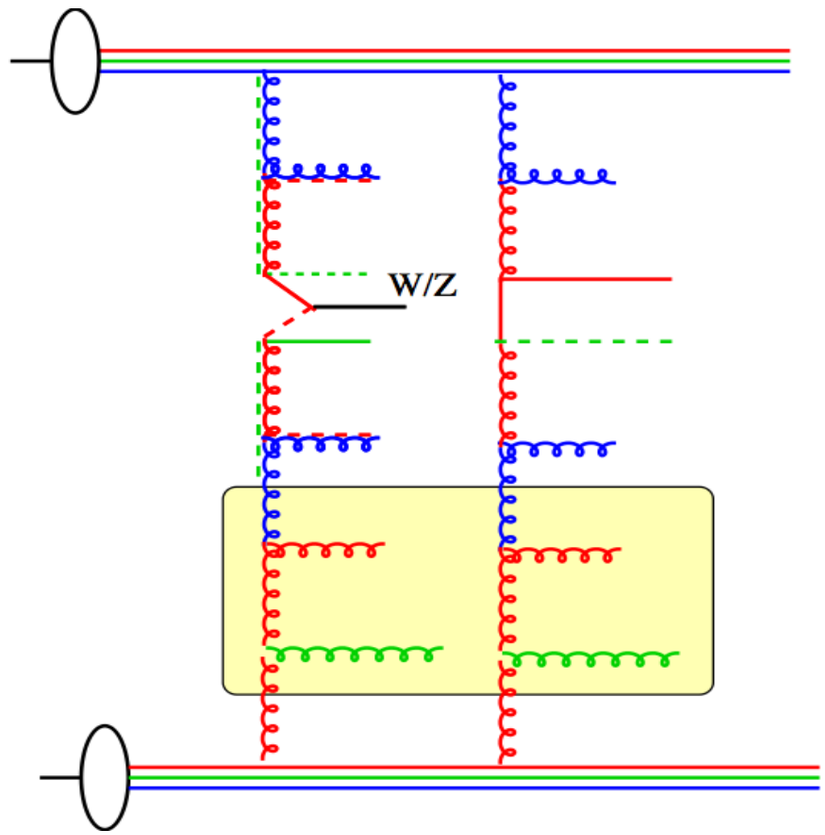


- correlations with central track multiplicity (not shown)
- measure energy in Hadronic Forward Calorimeter (HF) in $(3.0 < |\eta| < 4.9)$

W/Z Energy flow measurement



CMS-PAS-FWD-10-008

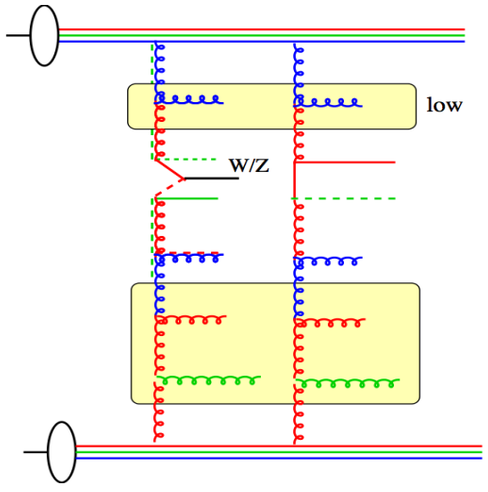


- energy distribution in fwd region sensitive to underlying event tunes
- large differences in small and large energy region

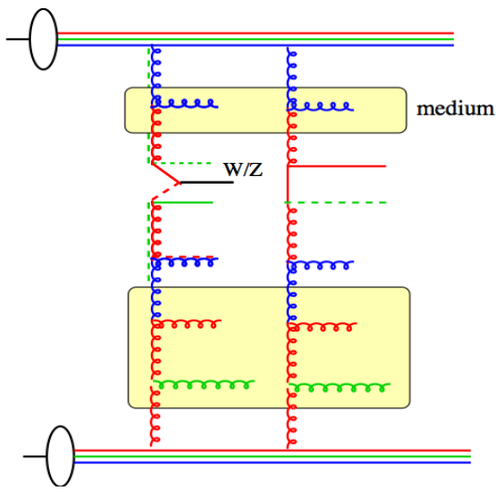
W/Z Energy flow measurement

CMS-PAS-FWD-10-008

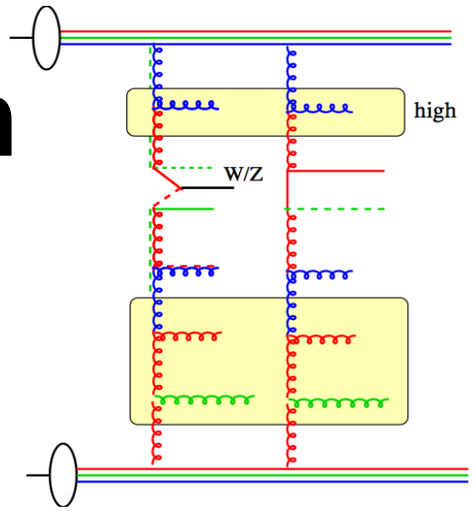
Correlation between forward and backward energy distribution



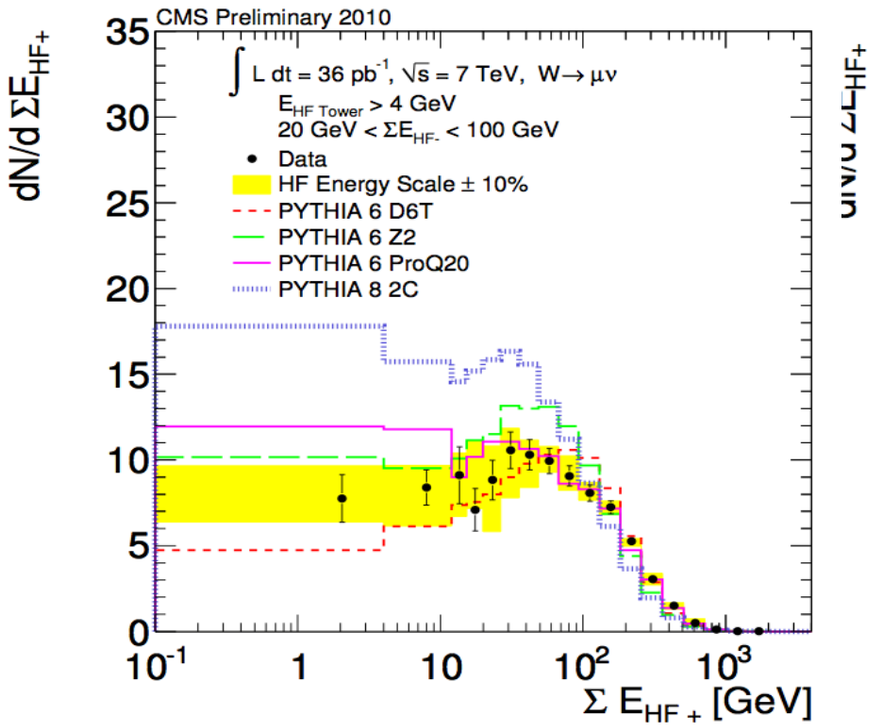
low

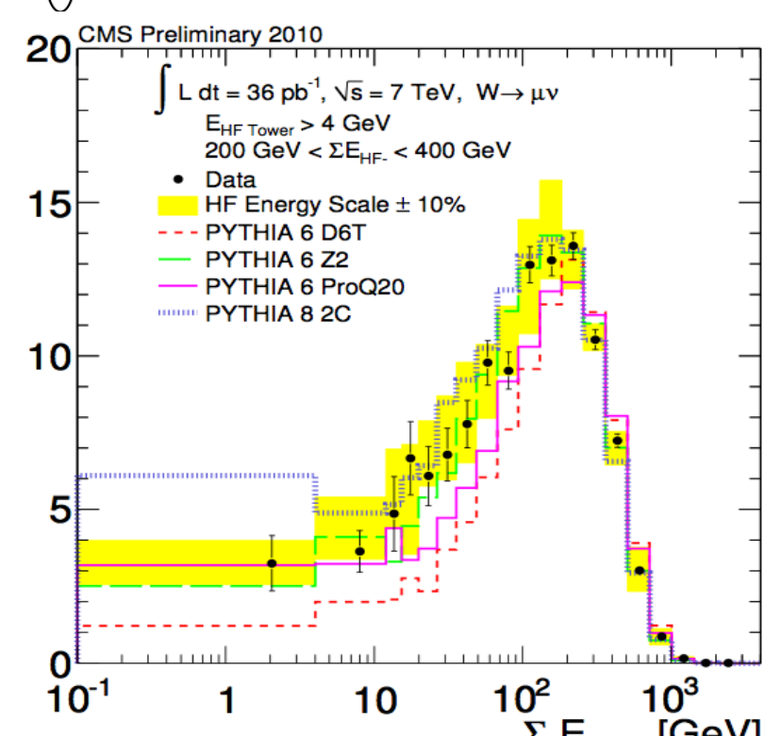


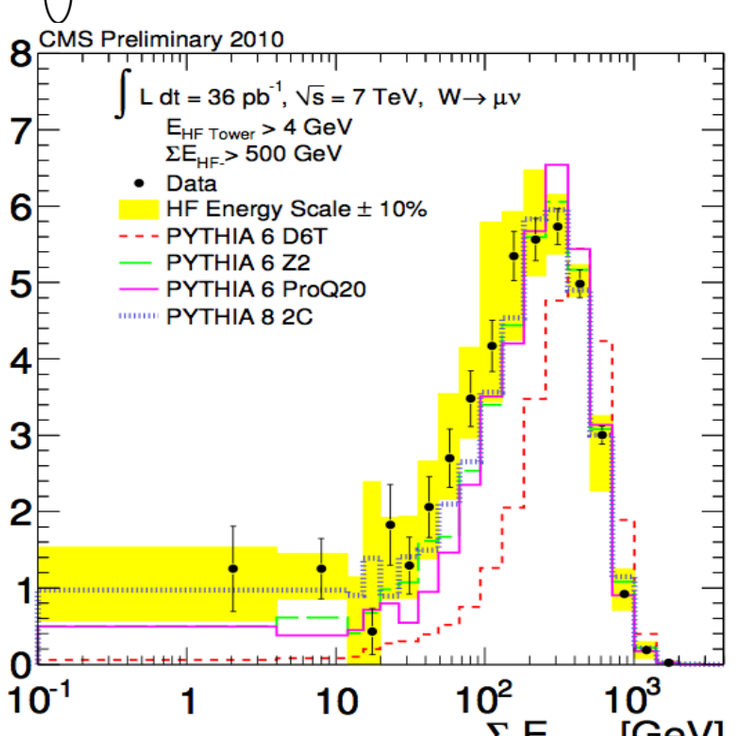
medium



high



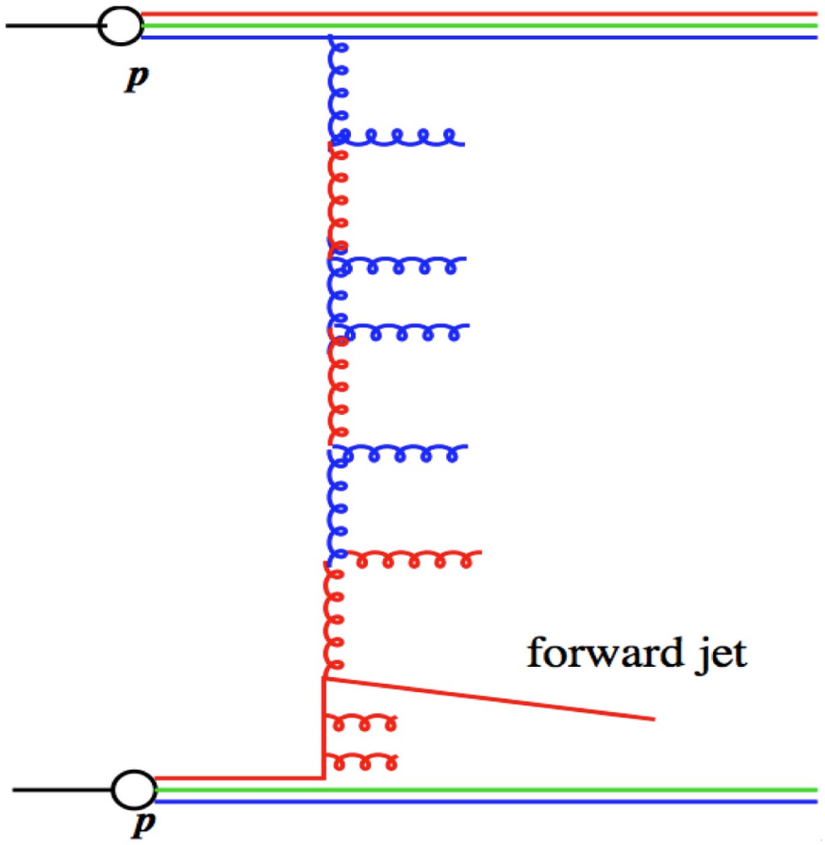




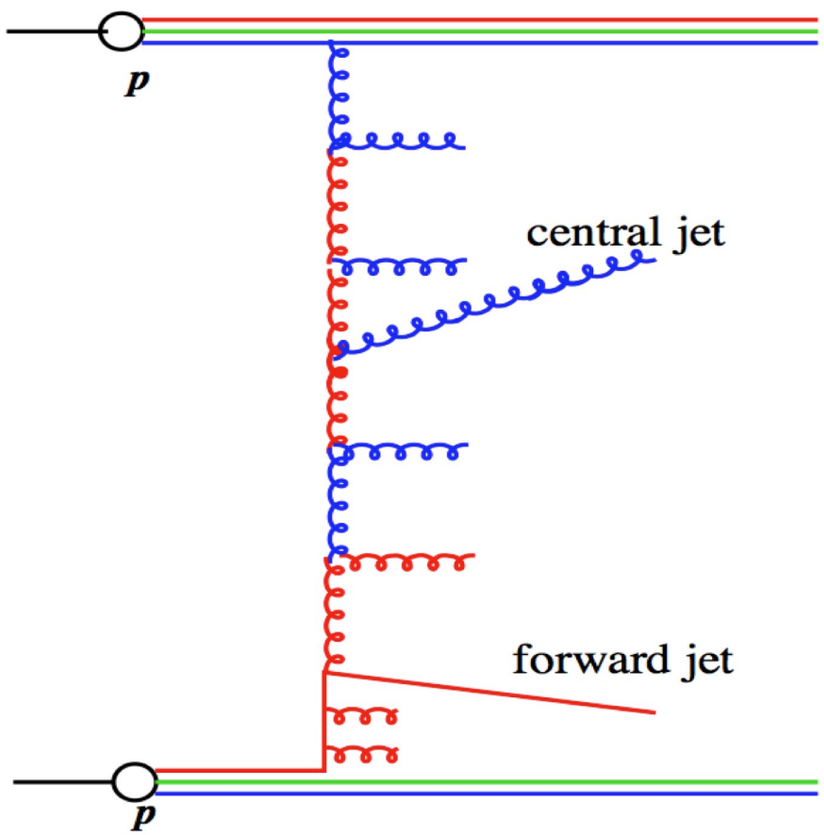
- energy distribution in forward/backward region strongly correlated
- energy spectra and correlations are not well modeled

Jets in forward region

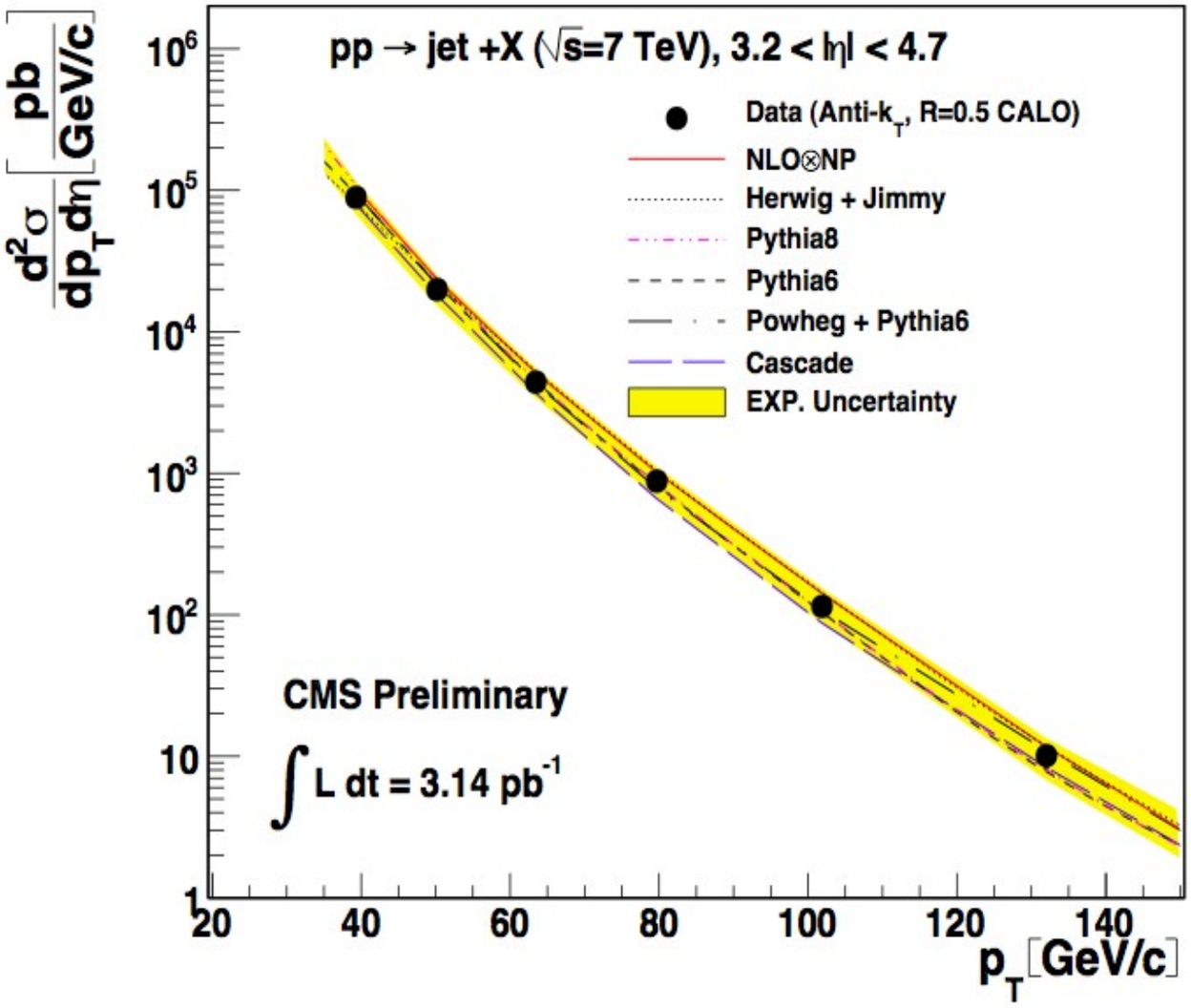
- inclusive forward jets
  - E_t > 35 GeV (anti-kt, R=0.5)
  - $3.2 < |\eta_f| < 4.7$



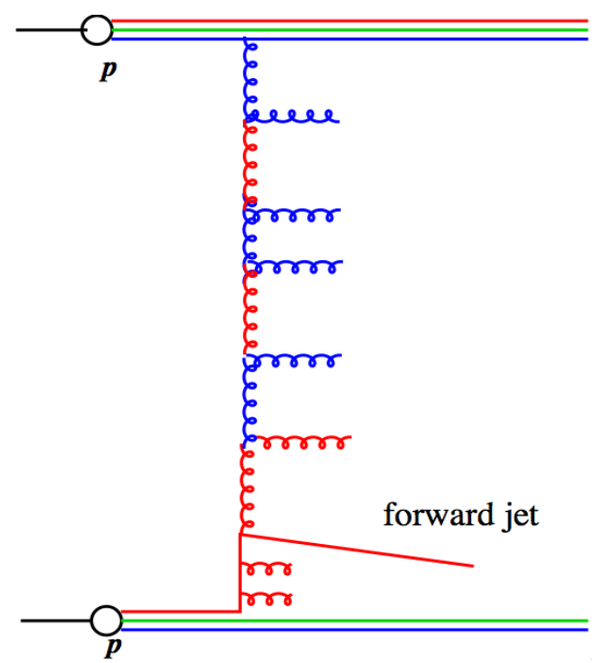
- associated forward & central jets
  - E_t > GeV (anti-kt, R=0.5)
  - $|\eta_c| < 2.8$ and $3.2 < |\eta_f| < 4.7$



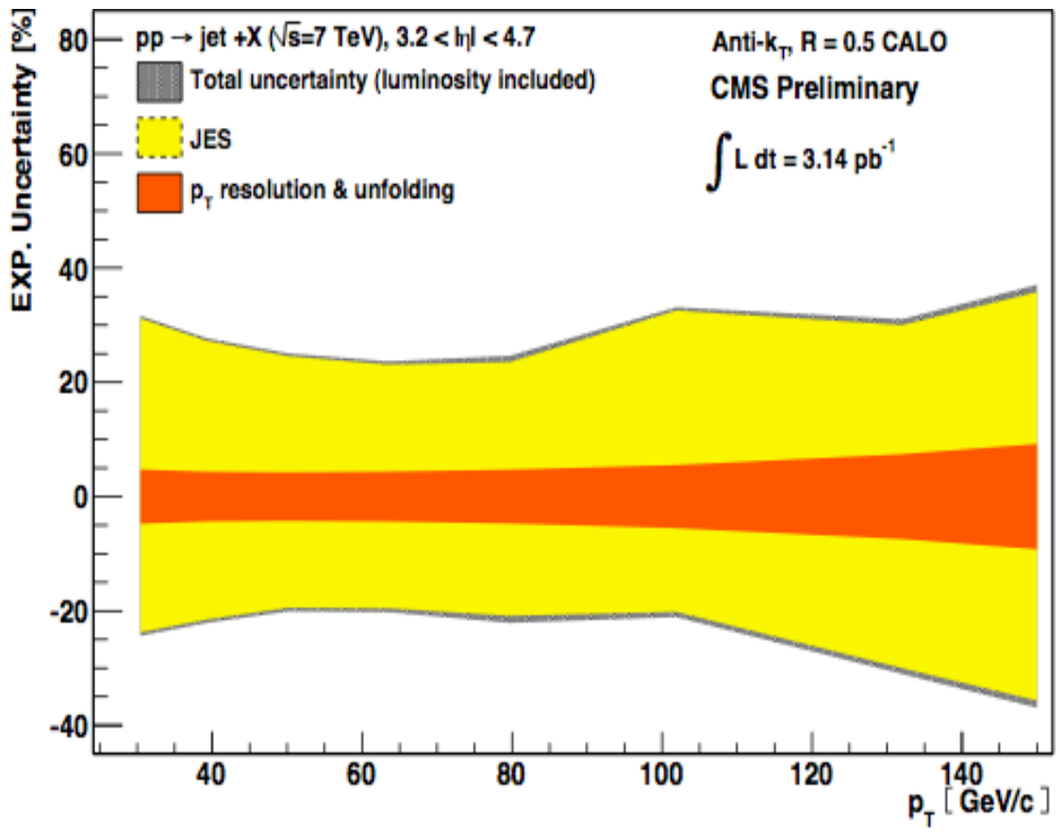
Inclusive forward jet measurement



CMS-PAS-FWD-10-003



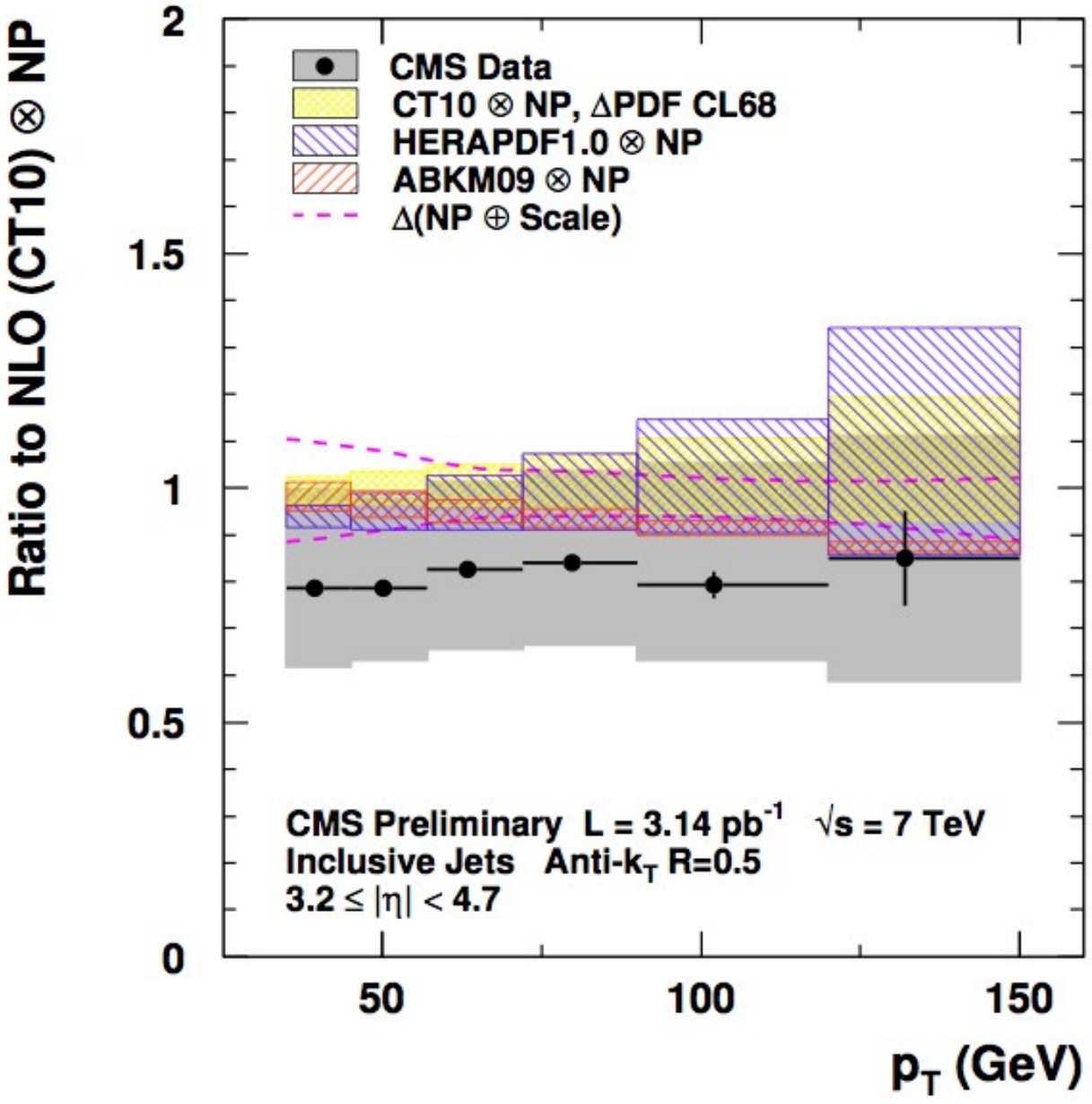
high energetic jets
$p_t \sim 150$ GeV
$\rightarrow E \sim 3000$ GeV



- jets measured in $3.4 < |\eta| < 4.7$
- largest systematic uncertainty: Jet energy scale
- all theory predictions agree with data within experimental uncertainties

Inclusive forward jet measurement

CERN-CMS-note 2011-004

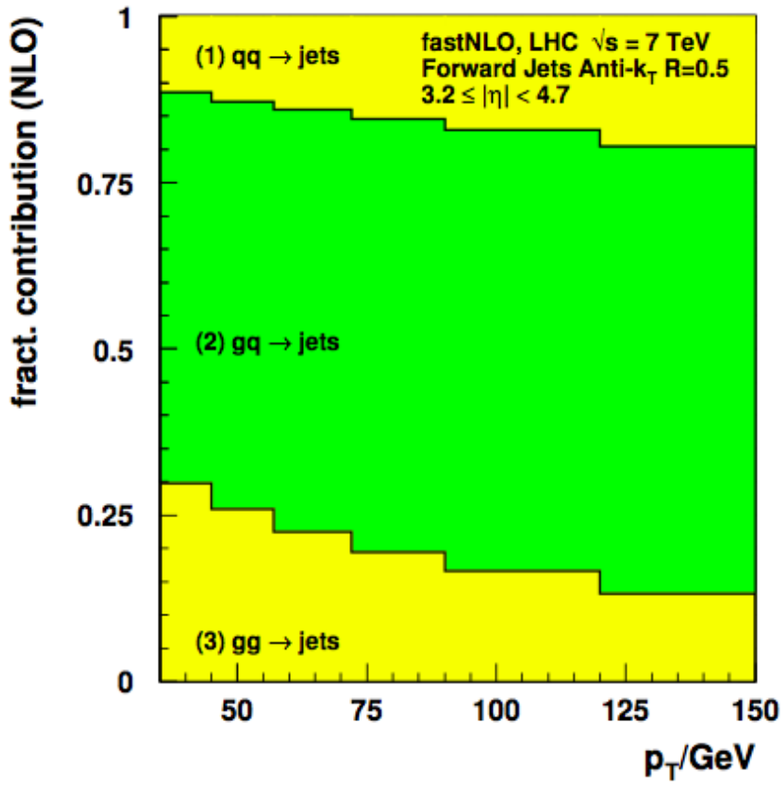


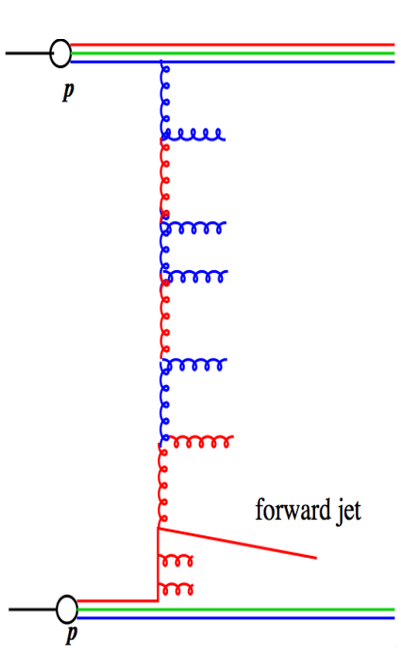
- non-perturbative corrections (NP)
  - hadronization & multiparton interactions
- scale: μ_f & μ_r varied by 2 independently

➔ ~ 10 %

- PDF uncertainties largest at large p_t coming from large x partons

  ~ 10 … 30 %





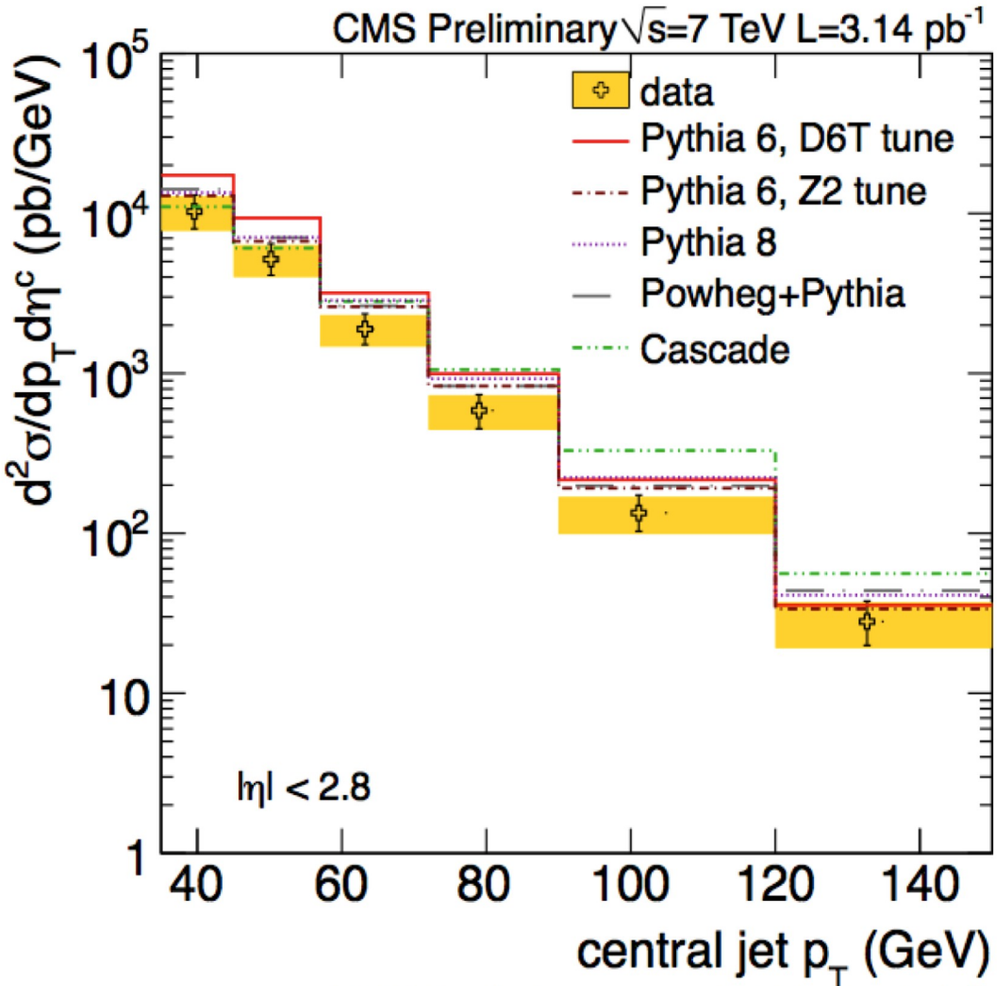
- forward jet measurement can constrain high x and low x parton distributions

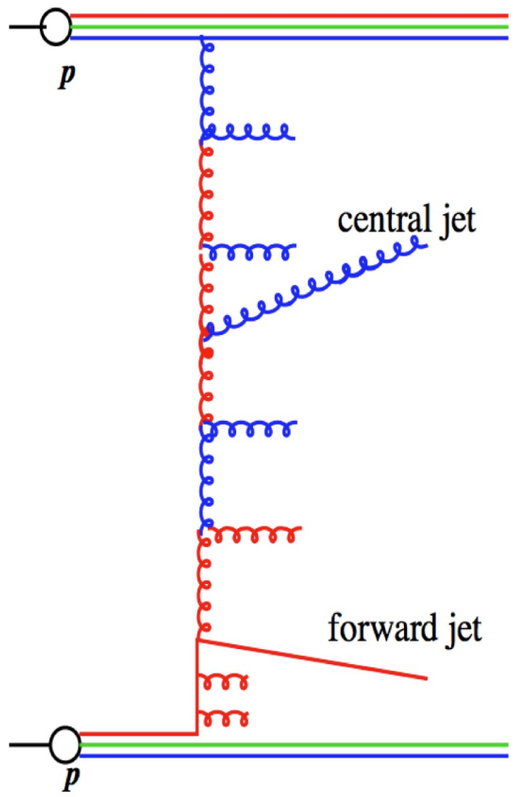
H. Jung, Measurements of forward energy flow and forward jet production with CMS, 23. July 2011, EPS2011

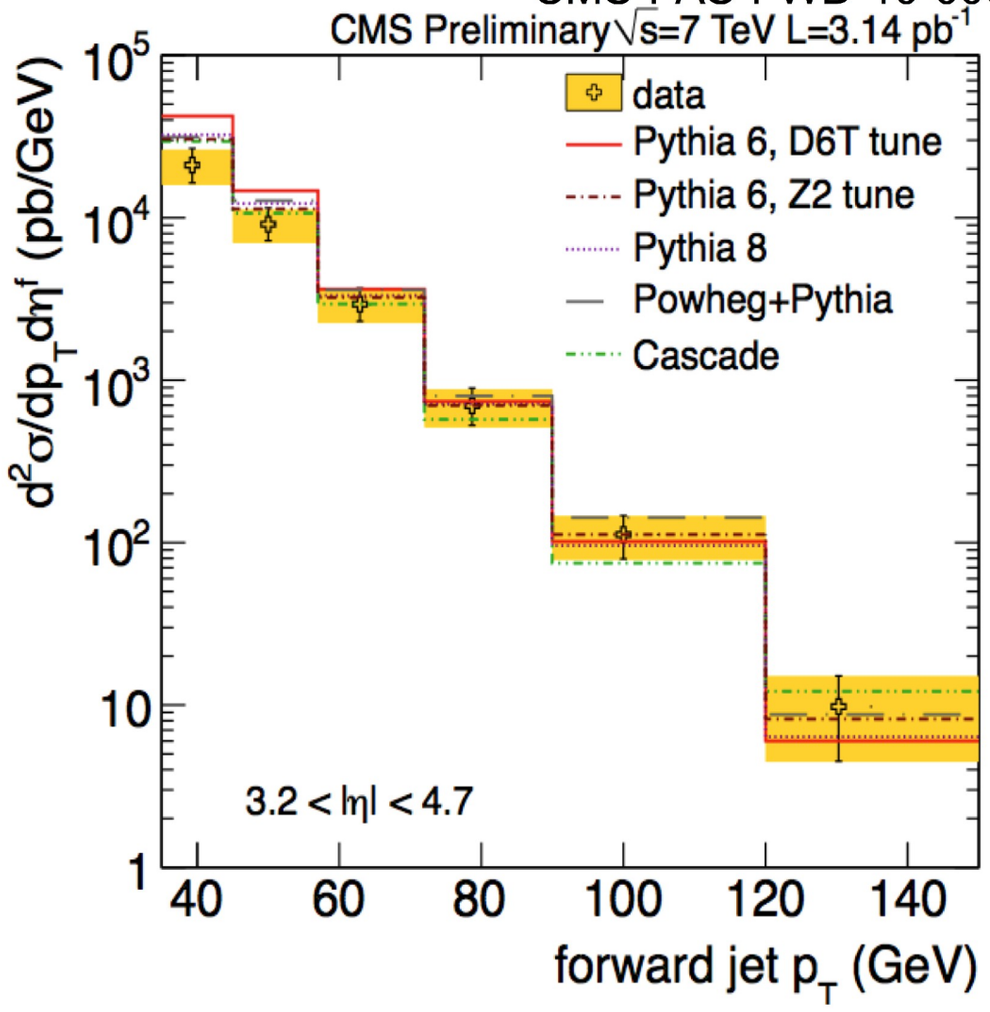
courtesy K. Rabbertz

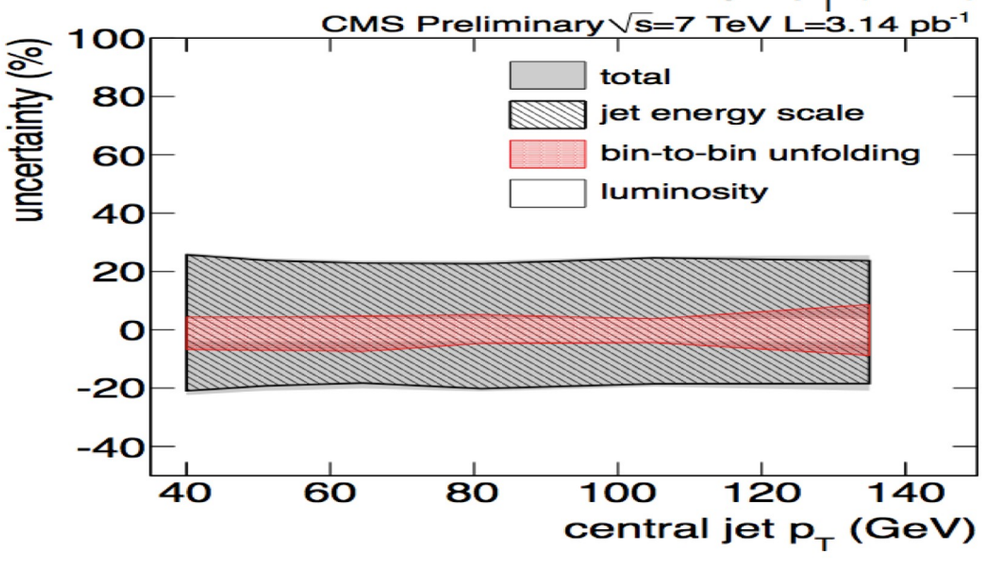
Forward and central jet measurement

CMS-PAS-FWD-10-006





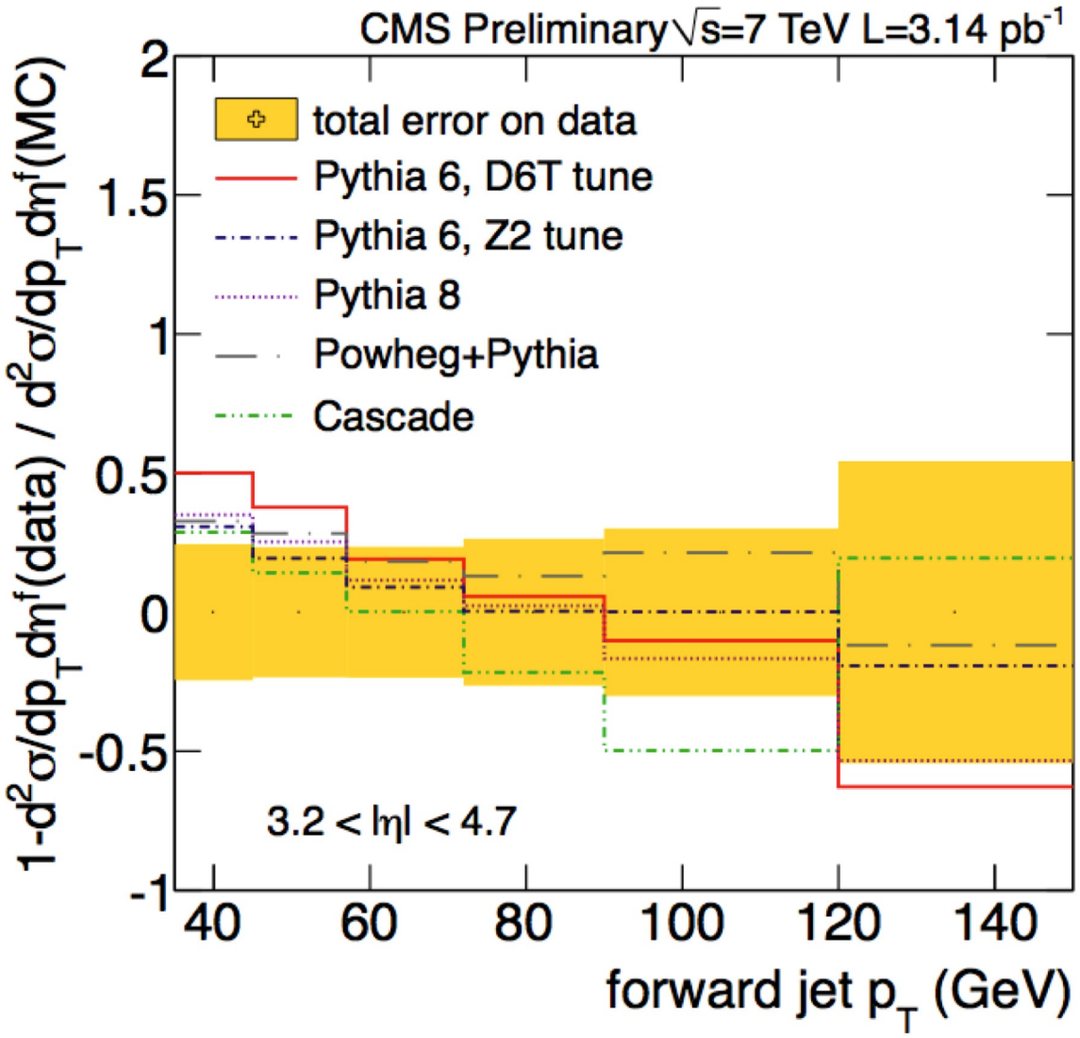


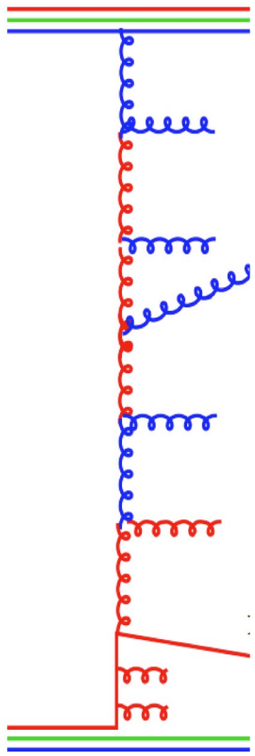


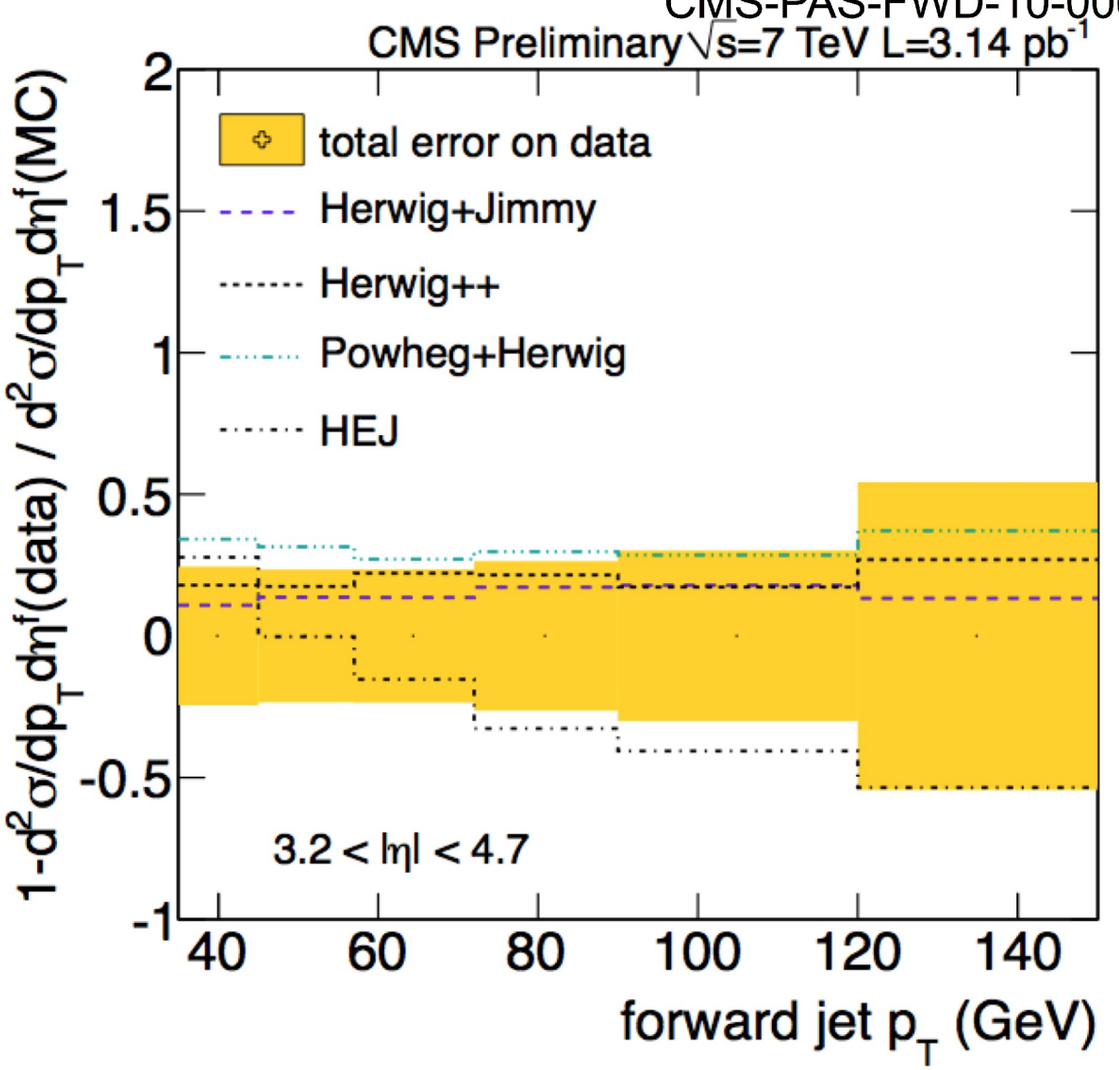
- associated central & forward jets measured with pt > 35 GeV
- largest uncertainty: Jet energy scale
- large spread in theory predictions

Forward and central jet measurement

CMS-PAS-FWD-10-006







- predictions from collinear approach:
- differences between PYTHIA - HERWIG
- differences also in POWHEG prediction using PYTHIA/HERWIG

- predictions from small x calculations
- HEJ(at parton level): within experimental uncertainties
- CASCADE: larger deviations to data

➔room for improvement

Conclusions

- first measurements from low to high pt in forward region
  - energy flow in minimum bias, dijet and W/Z events
    - continuation from measurements at low $\sqrt{s}$ in $p\bar{p}$ and HERA
  - inclusive forward jet and associated forward-central jet cross sections
    - test of small and high x PDFs as well as small x predictions
- inclusive measurements can be described (!) with
  - NLO, MC + PS + MPI and small x improved MCs
- correlations between central and forward region are challenge for theory !

LHC is small x QCD machine

- LHC can access lowest x values
  - for central W/Z production at

7 TeV: $x \sim 0.01$

14 TeV: $x \sim 0.005$

  - at forward rapidities ($\eta \sim 5$):

7 TeV $x \sim 6 \cdot 10^{-5}$

14 TeV $x \sim 3 \cdot 10^{-5}$

  - for central jets with $p_t > 20$ GeV

7 TeV : $x \sim 0.006$

14 TeV : $x \sim 0.003$

  - at forward rapidities ($\eta \sim 5$):

7 TeV: $x \sim 4 \cdot 10^{-5}$

14 TeV: $x \sim 2 \cdot 10^{-5}$

J. M. Campbell, J. W. Huston, and W. J. Stirling.
Hard Interactions of Quarks and Gluons: A Primer for LHC Physics.
Rept. Prog. Phys., 70:89, 2007.