Very forward jets in pp and pA collisions at CMS

Pierre Van Mechelen
on behalf of the CMS Collaboration

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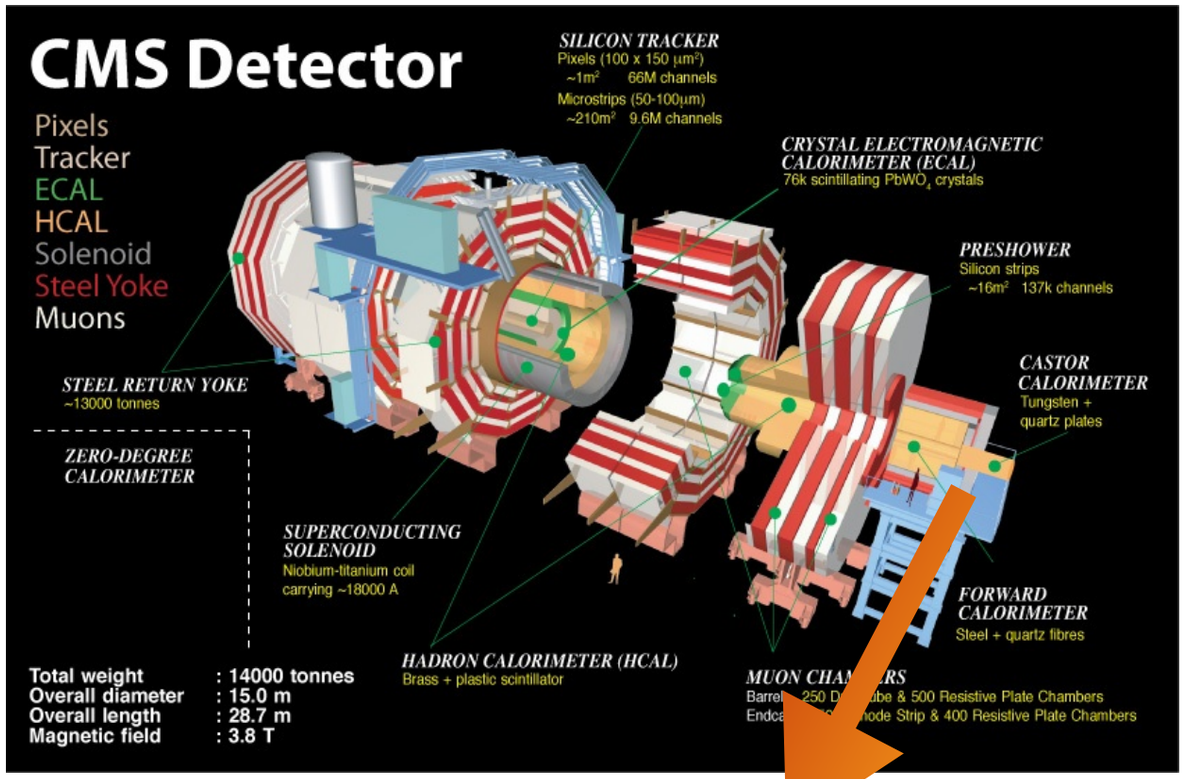
Outline

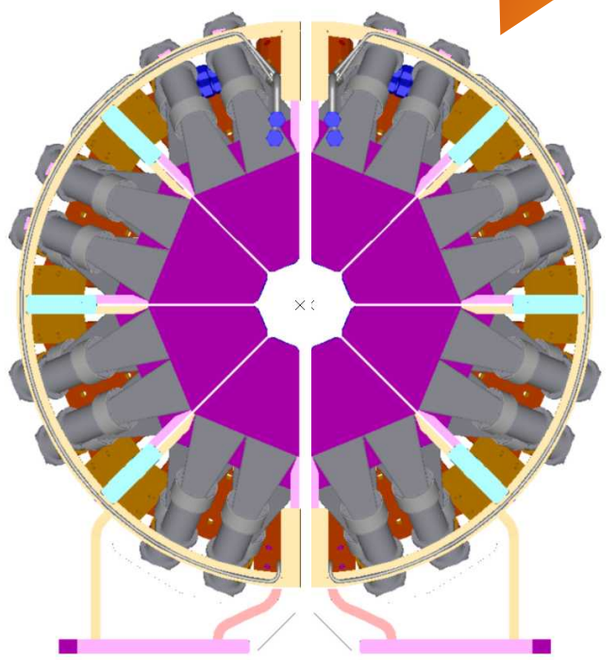
- A few words on CASTOR and very forward jet reconstruction in CMS…
- Measurement of the very forward inclusive jet cross section in pp collisions at $\sqrt{s}$ = 13 TeV
- Very forward inclusive jet cross sections in p+Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

The CASTOR calorimeter

Very forward energy measurement

- Extends the coverage in forward direction to $-6.6 < \eta < -5.2$
- 14.37m from the interaction point
- Octagonal cylinder with inner radius 3.7 cm, outer radius 14 cm and total depth 10.5 Λ_I
- Signal collection through Čerenkov photons transmitted to PMTs through air core light guides
- W absorber and quartz plates sandwich, with 45° inclination with respect to the beam axis
- Electromagnetic and hadronic sections
- 16-fold segmentation in φ, 14-fold segmentation in z, **no segmentation in η**
- Has been taking pp, pA and AA data in 2010, 2011, 2013, 2015, and 2016

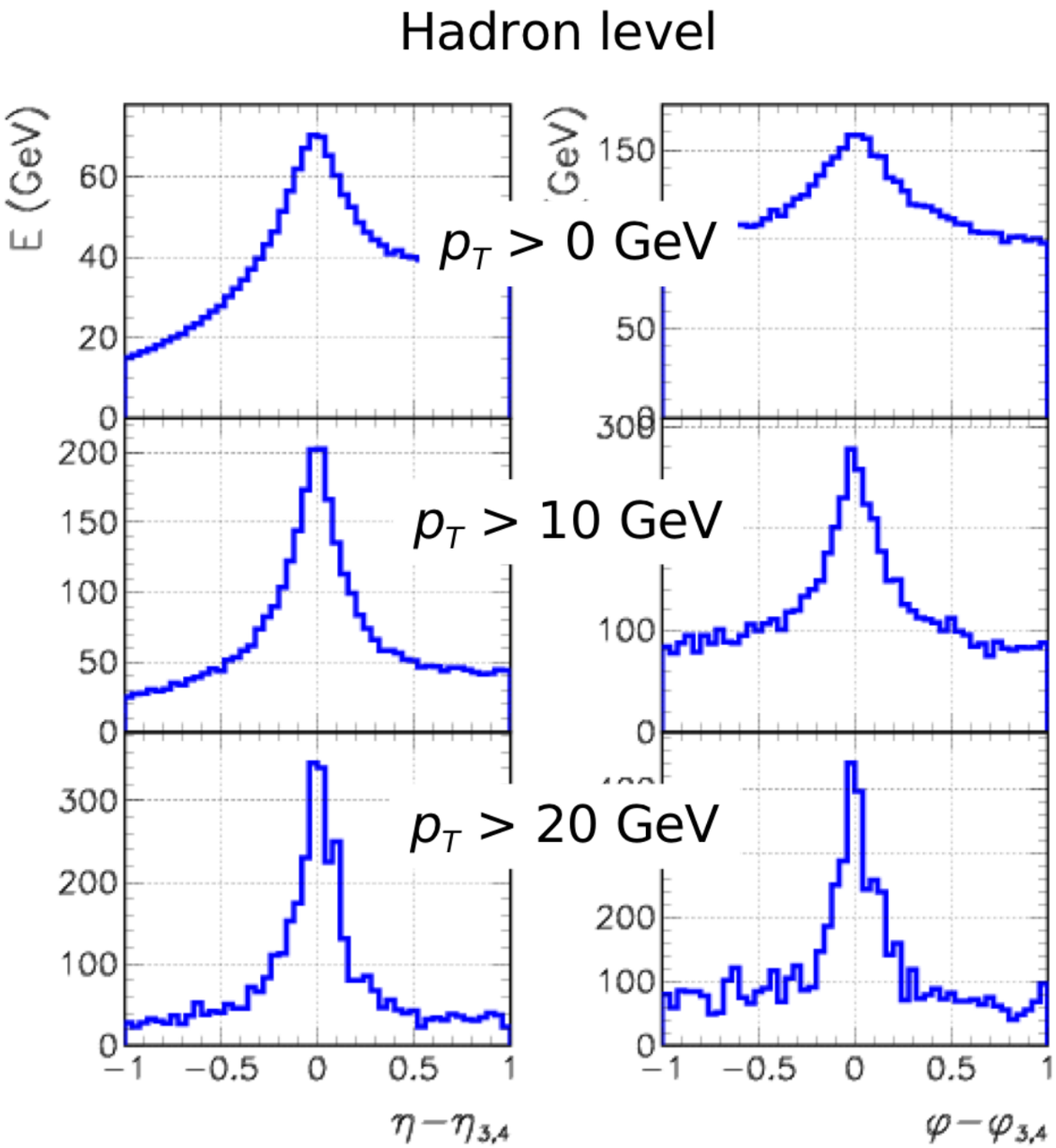


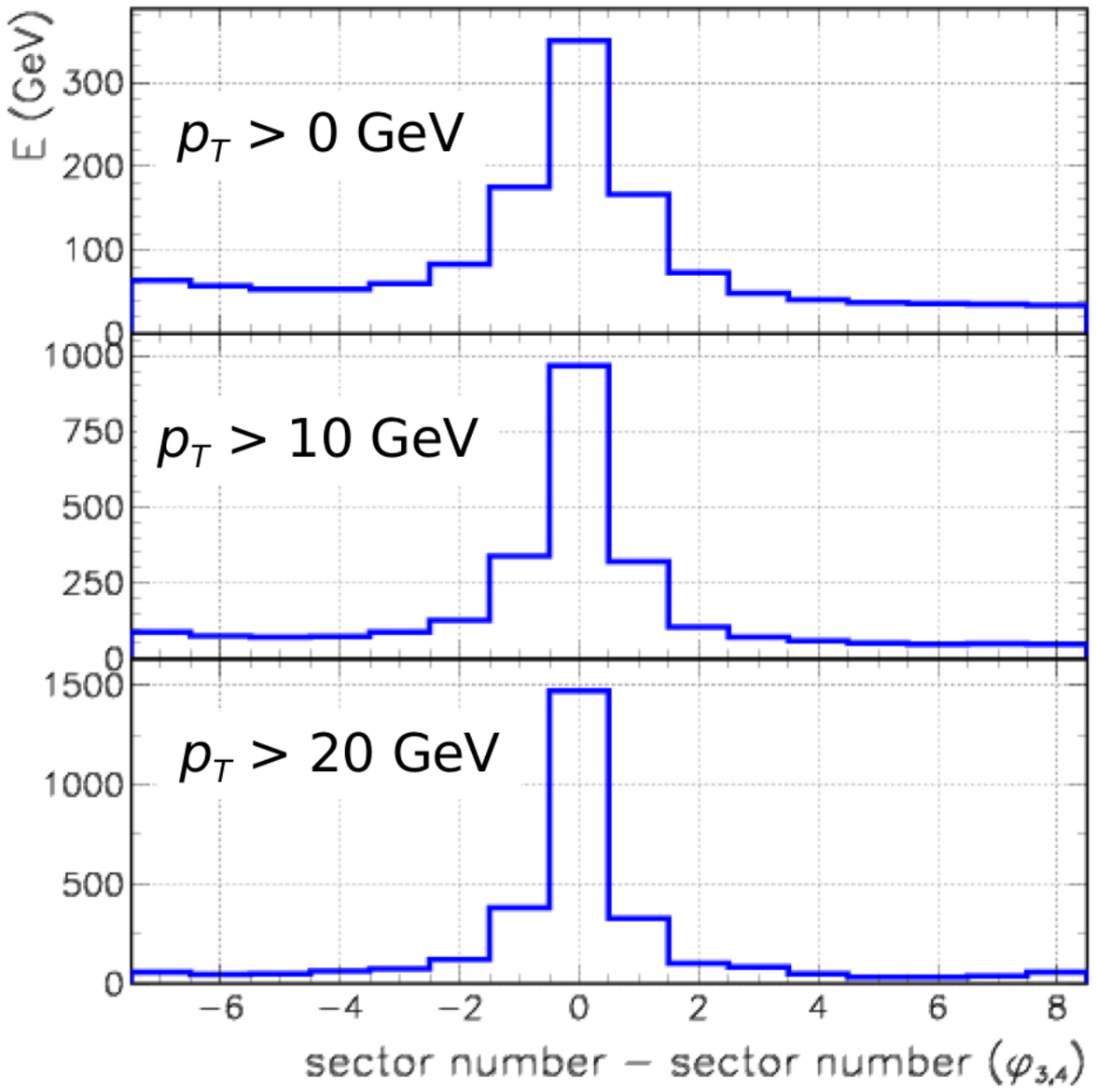


Forward jet kinematics

PYTHIA6 generator level study for pp collisions at √s = 7 TeV

- Detector signature: Jet profiles

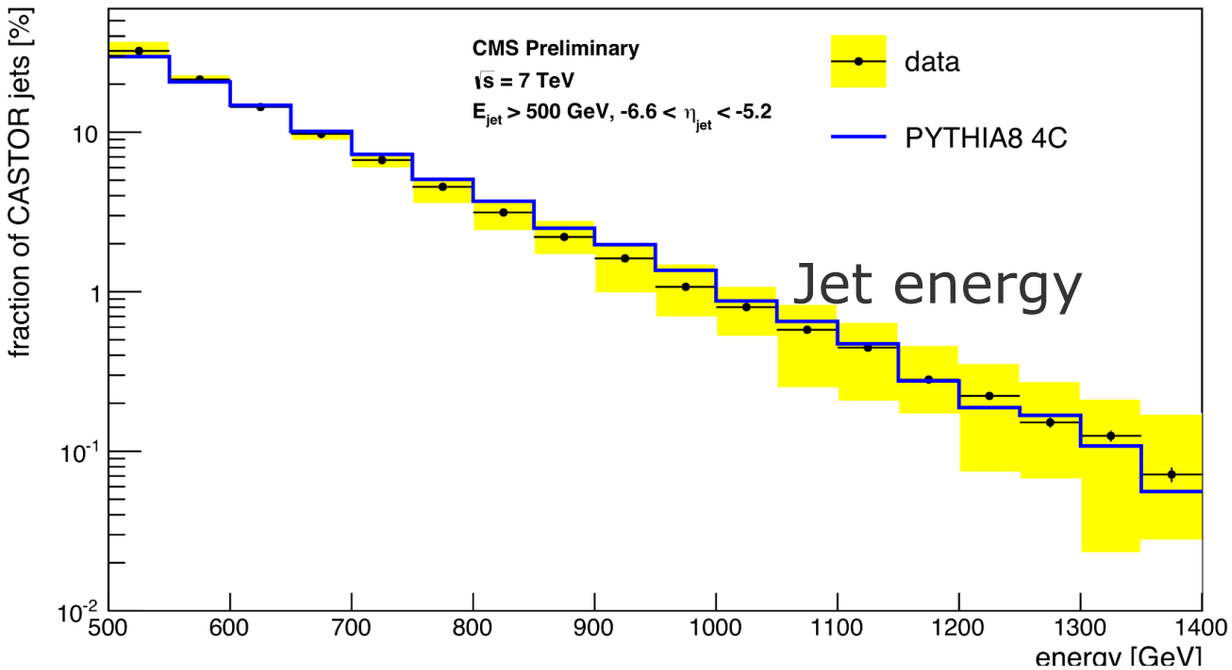


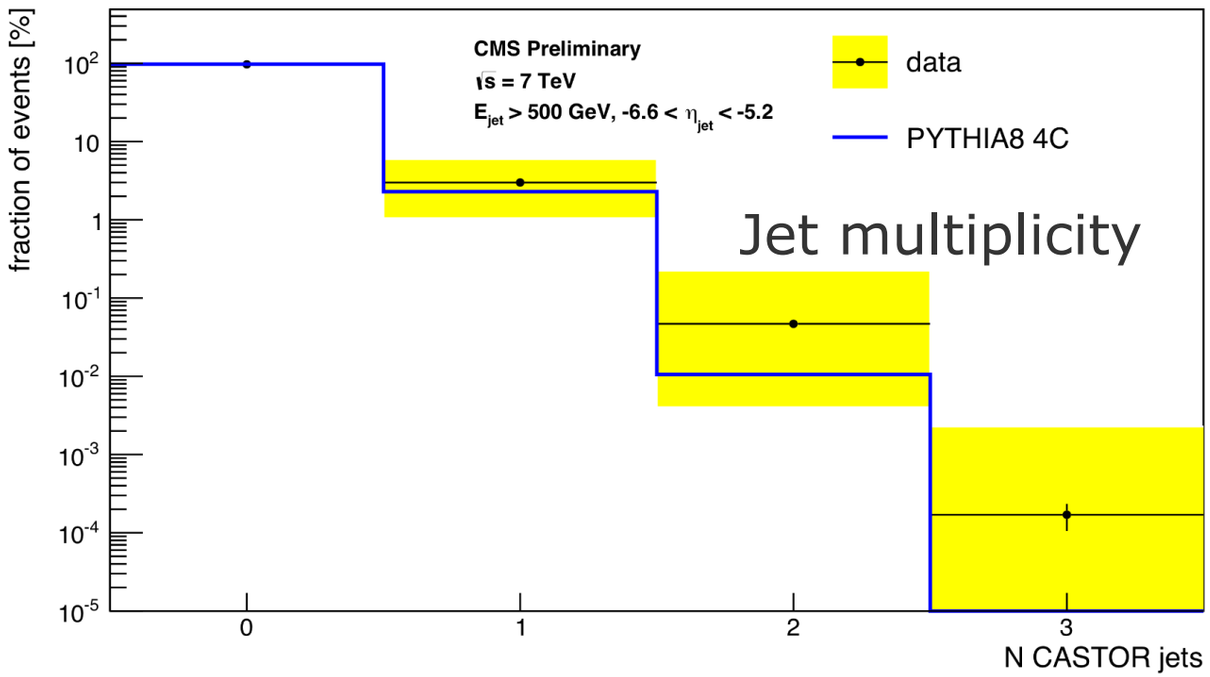


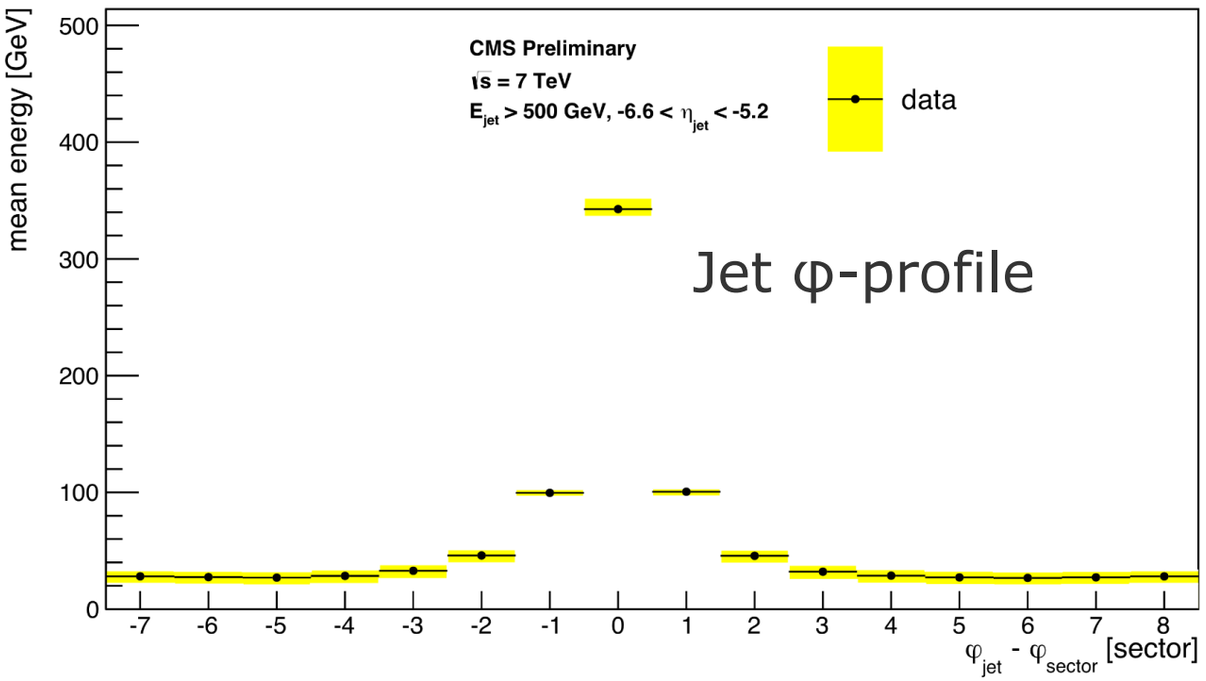
First look at jets in CASTOR

From 2010, low pile-up data

- Minimum-bias trigger
- Anti-k_T (R=0.5) track-jet (jet made of charged particles only)
  - require p_T > 1 GeV, $|\eta|$ < 2
- Anti-k_T (R=0.7) jet clustering in CASTOR
  - require E > 0.5 TeV
- All plots normalized to unity







CMS DP-2014/022

Measurement of the very forward inclusive jet cross section in pp collisions at $\sqrt{s}$ = 13 TeV

CMS-PAS-FSQ-16-003

Forward jets in pp

Why?

- Powerful benchmark for QCD model predictions

$$x = \frac{p_T\, e^{-\eta}}{\sqrt{s}}$$

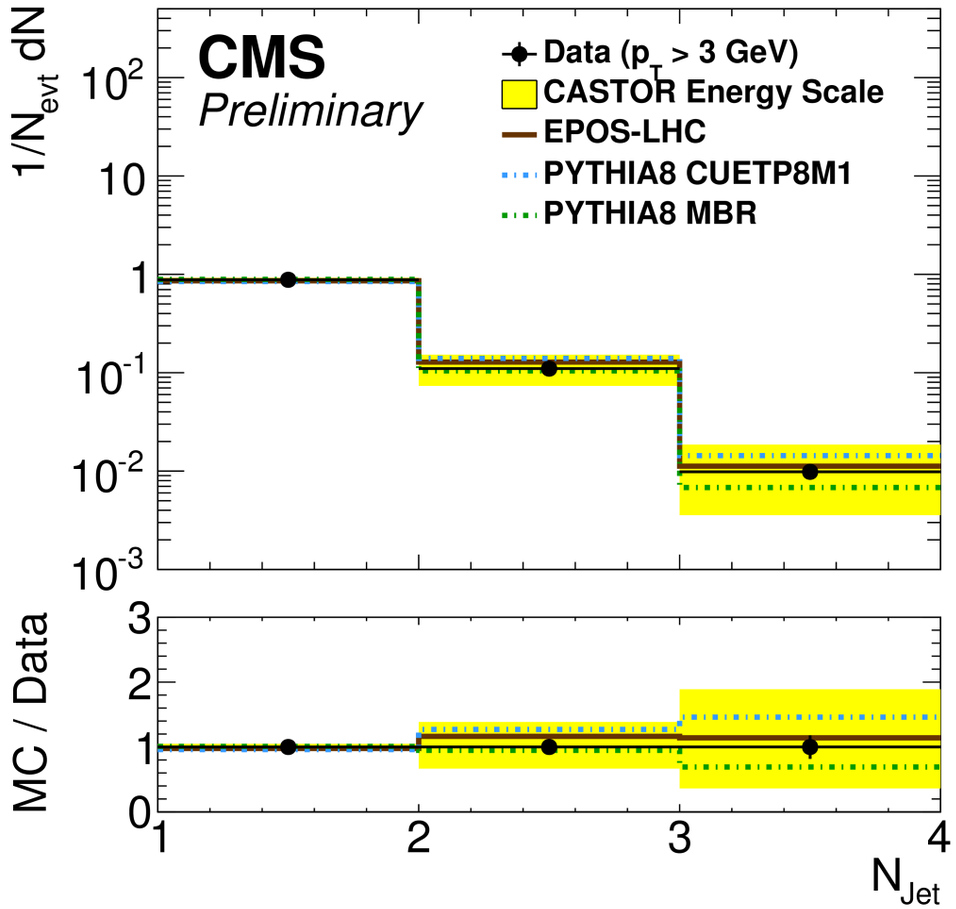
→ forward, low p_T jets give access to low x

- Sensitive to parton evolution dynamics (DGLAP/BFKL/CCFM)
- Possibly sensitive to parton saturation (nonlinear evolution)?

What?

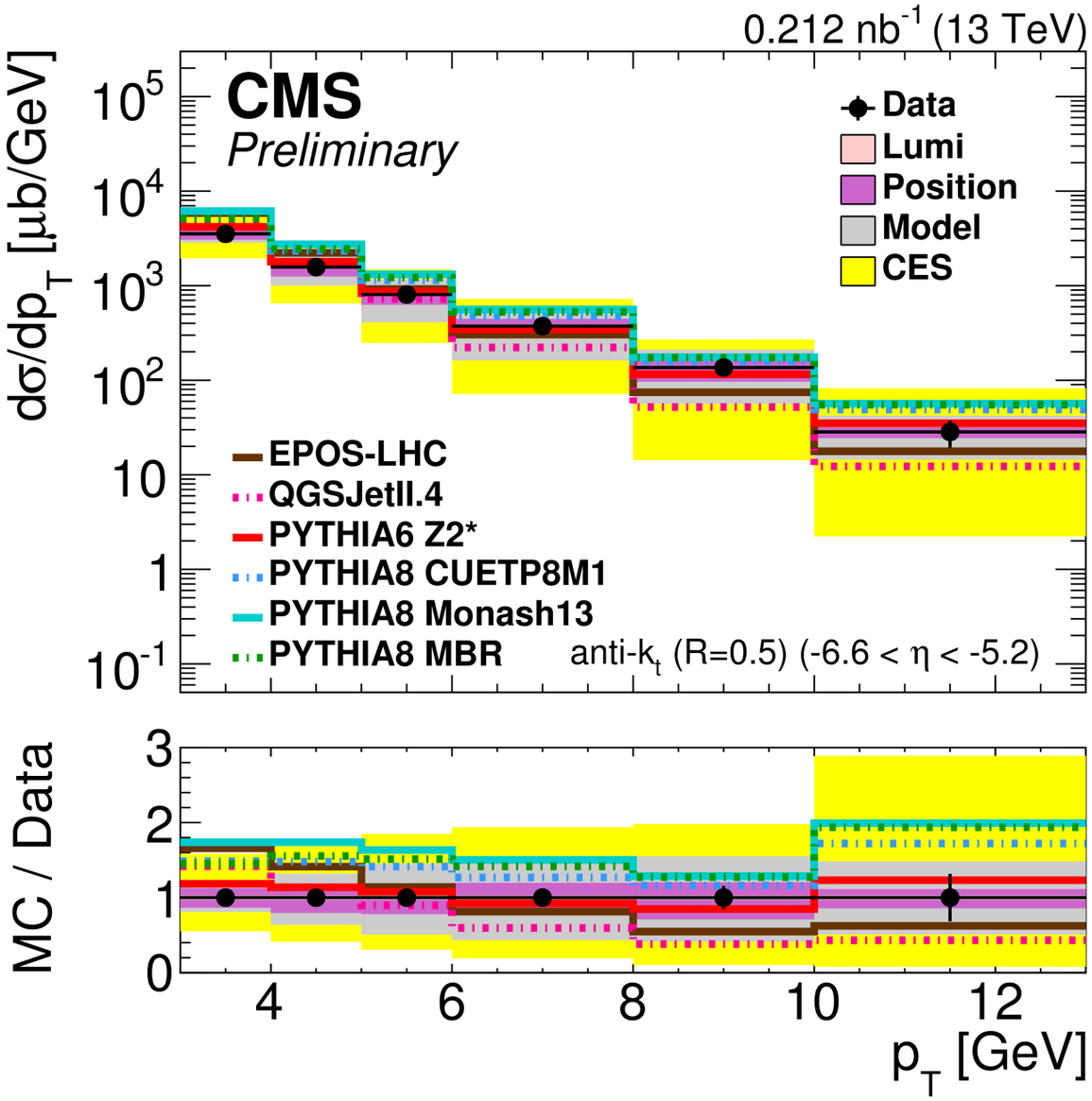
- Fully corrected inclusive jet cross sections and jet yields normalized to number of visible jets as function of jet p_T
  - anti-k_T jets with $R = 0.5$
  - $-6.6 < \eta < -5.2$
  - p_T unfolded from $E \cdot \cosh \eta$, with $\eta = -5.9$
- Energy scale uncertainty yields the dominant systematic uncertainty

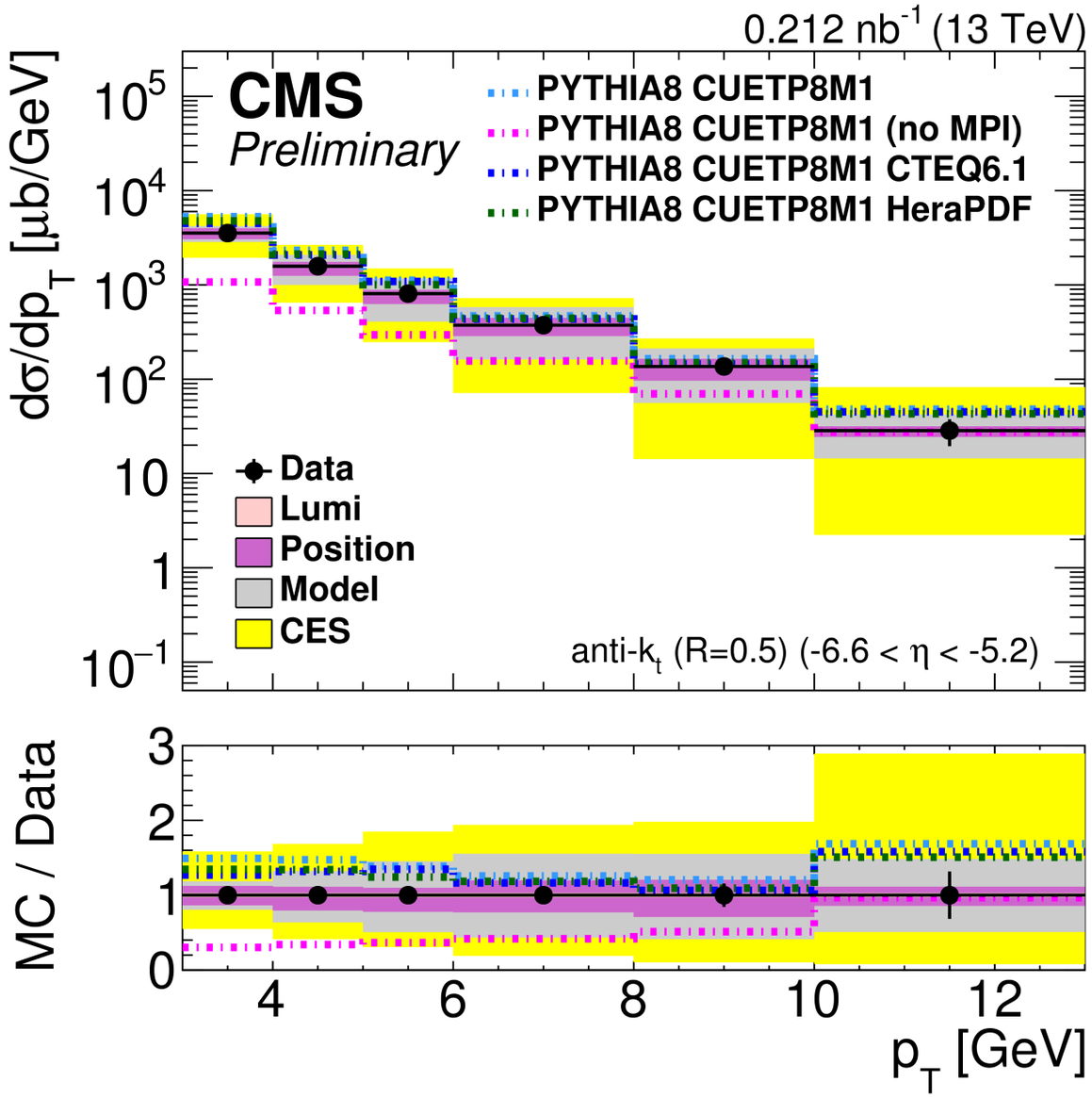
DETECTOR LEVEL JET MULTIPLICITY



Forward jets in pp

CROSS SECTION

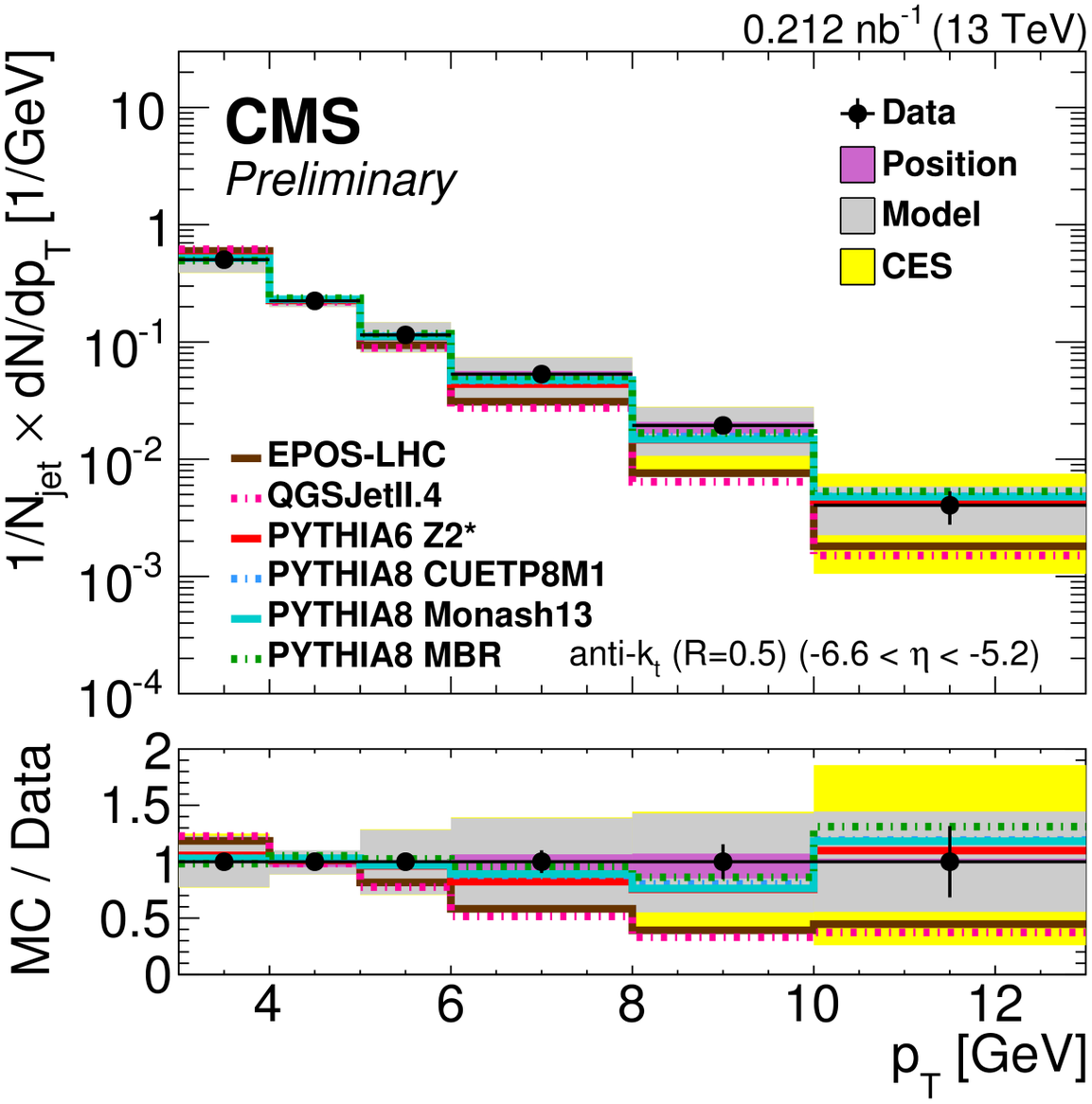


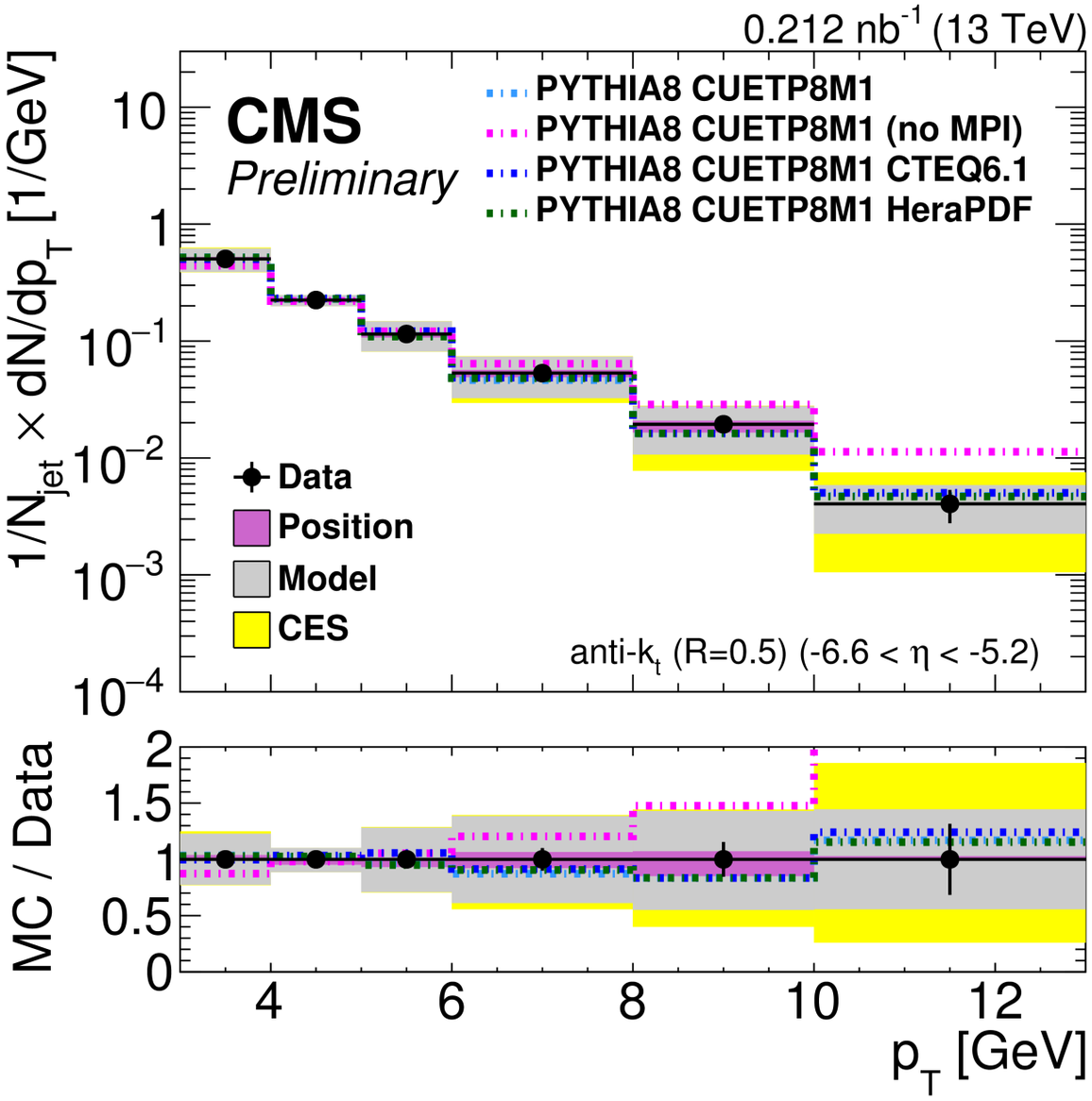


- All models are compatible with data within uncertainties
- Weak dependence on underlying PDF
- Large sensitivity to MPI modelling

Forward jets in pp

JET YIELD





- Smaller energy scale uncertainty when the jet yield is normalized by the number of visible jets
- EPOS and QGSJet are a bit softer than the data indicate

Very forward inclusive jet cross sections in p+Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

CMS-PAS-FSQ-17-001

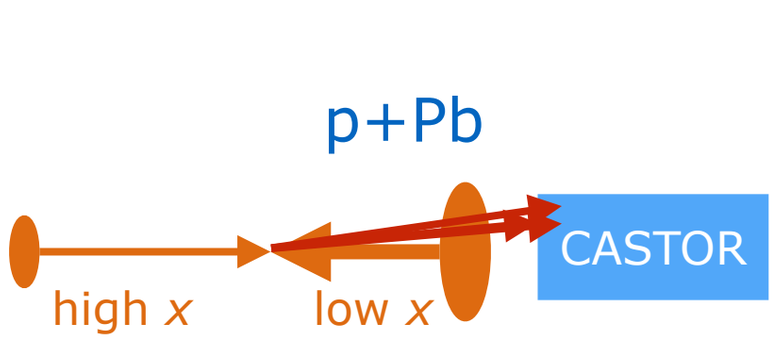
Forward jets in p+Pb/Pb+p

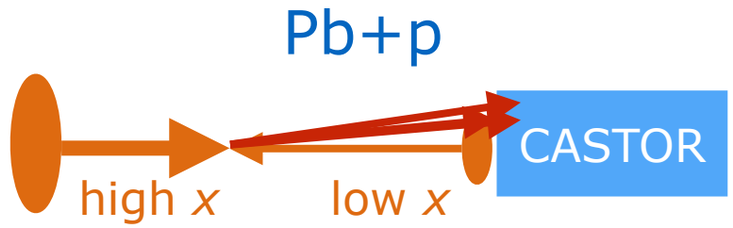
Why?

- Enhanced saturation (and nuclear) effects in collisions with heavy ions
- Saturation scale in collisions with ions more perturbative with respect to saturation scale in proton collisions

What?

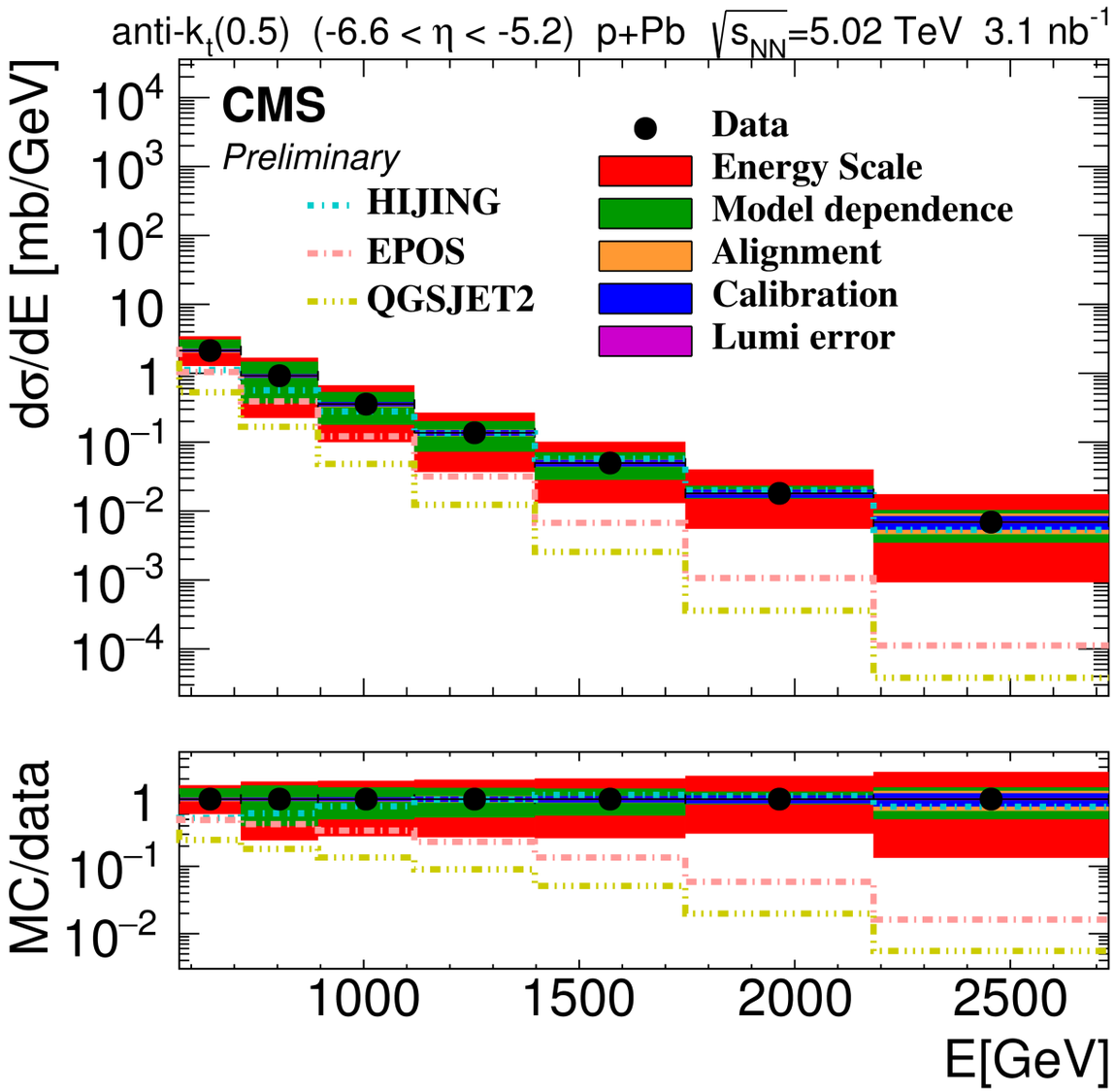
- Fully corrected inclusive jet cross sections in p+Pb (proton towards CASTOR) and Pb+p (ion towards CASTOR) as function of jet energy
  - double-sided event selection to suppress photon-induced and diffractive interactions
  - anti-k_T jets with $R = 0.5$
  - $-6.6 < \eta < -5.2$
- Ratio of p+Pb/Pb+p cross section as function of energy
- Dominant systematic uncertainty:
  - energy scale for absolute cross section
  - model dependence for cross section ratio

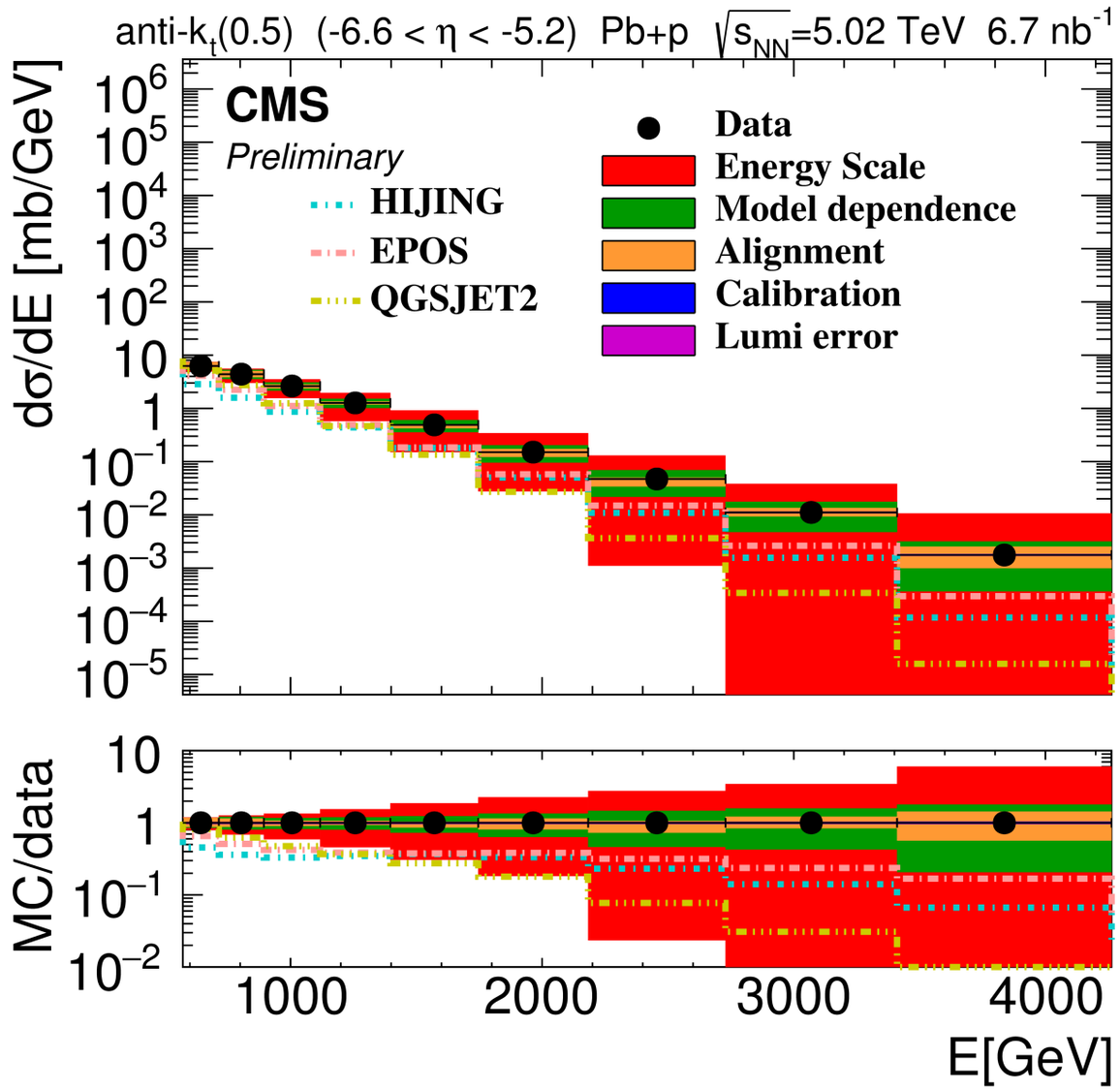




Forward jets in p+Pb/Pb+p

CROSS SECTION FOR p+Pb and Pb+p — LAB frame



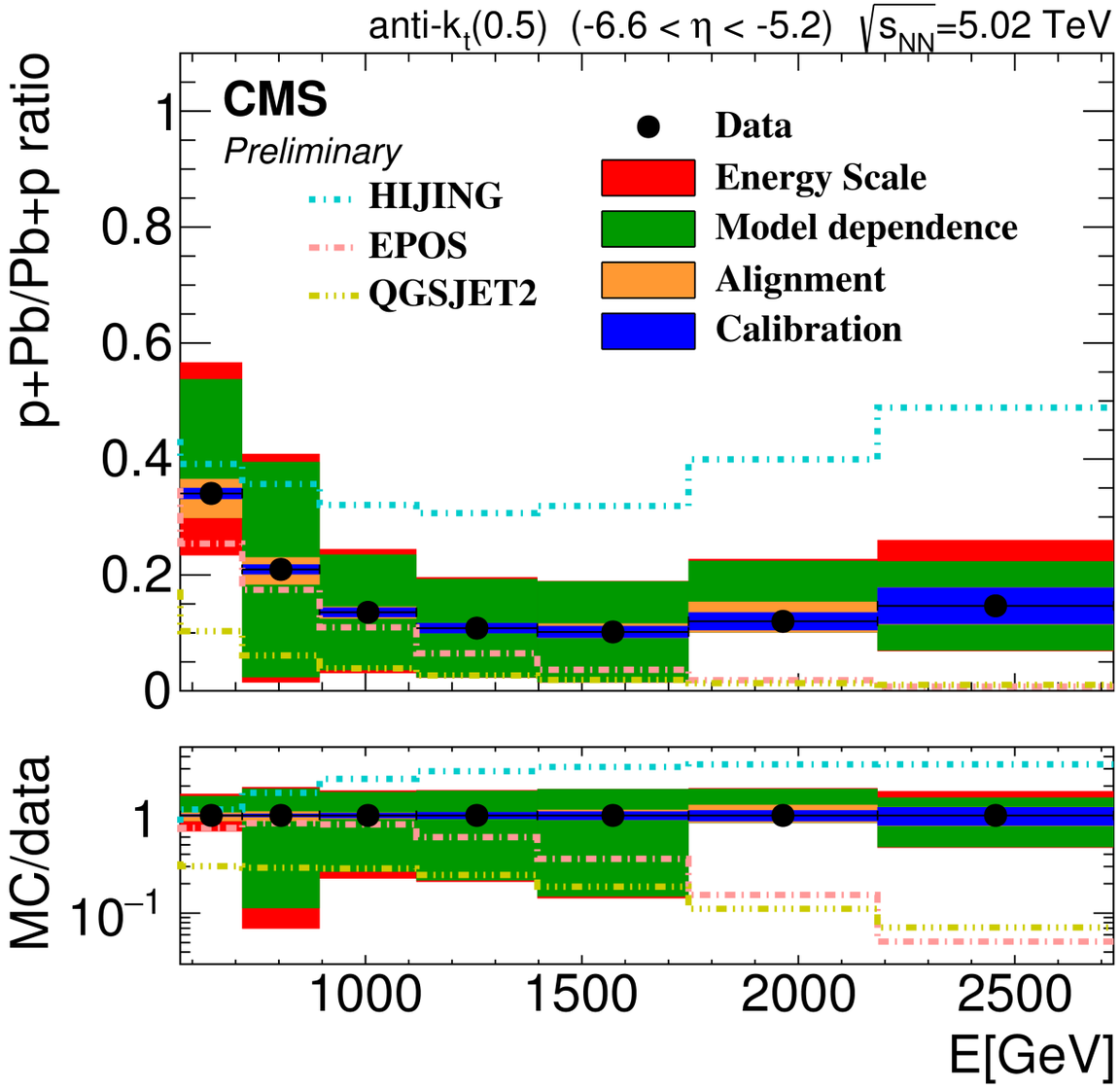


- p+Pb: HIJING describes data well; EPOS and QGSJet2 underestimate the cross section → hard component in data and HIJING?
- Pb+p: models underestimate low-energy tail, but are within large uncertainty at high energy → ion debris?

Forward jets in p+Pb/Pb+p

CROSS SECTION RATIO p+Pb/Pb+p

LAB frame



- Saturation expected in p+Pb, but not in Pb+p
  → depletion at low energy?
- Caveat: asymmetric beams lead to different boost factors and different acceptance windows
- Cancellation of energy scale uncertainty allows for better discrimination between data and models

Summary

- Measurements of **jets in the very forward region** (-6.6 < η < -5.2) at CMS are a reality!
- Major challenge: energy scale uncertainty
  → inventive procedures for cancelation of uncertainties are being developed

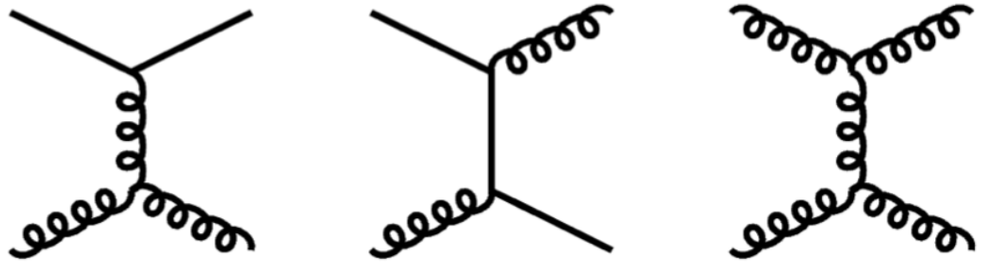
- Current results on forward jets are highly sensitive to Underlying UE tuning; weak depedence on PDF
- No clear sign for saturation yet (p+Pb results need to be further interpreted)

Backup

Forward jet kinematics

PYTHIA6 generator level study for pp collisions at √s = 7 TeV

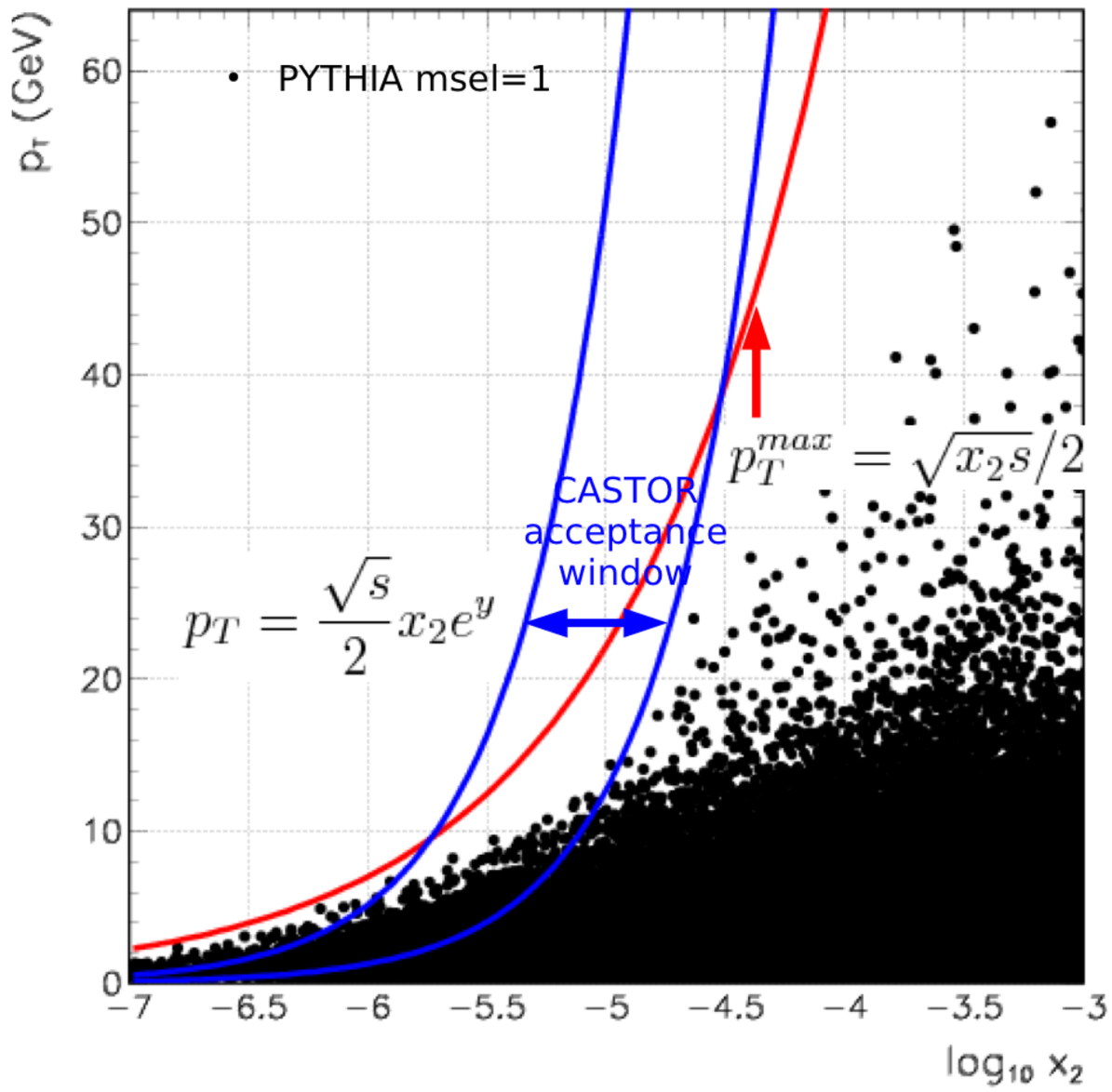
- MSEL=1: jets from *t*-channel exchange processes



qg → qg gg → gg

- Basic kinematics from "hard" subprocess

$$p_T^{max} \sim M/2$$
$$M^2 = x_1 x_2 s$$
$$y = \frac{1}{2} \ln x_1/x_2$$



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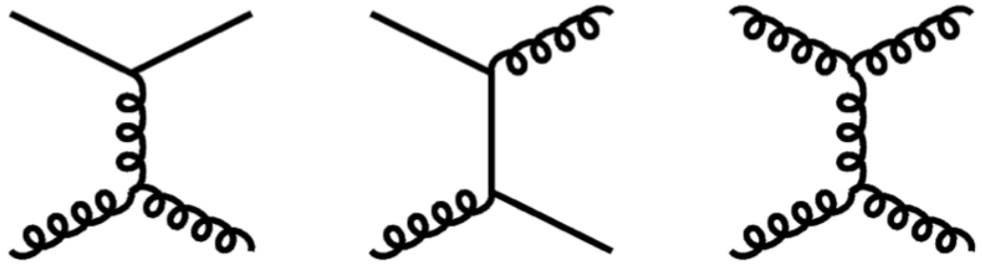

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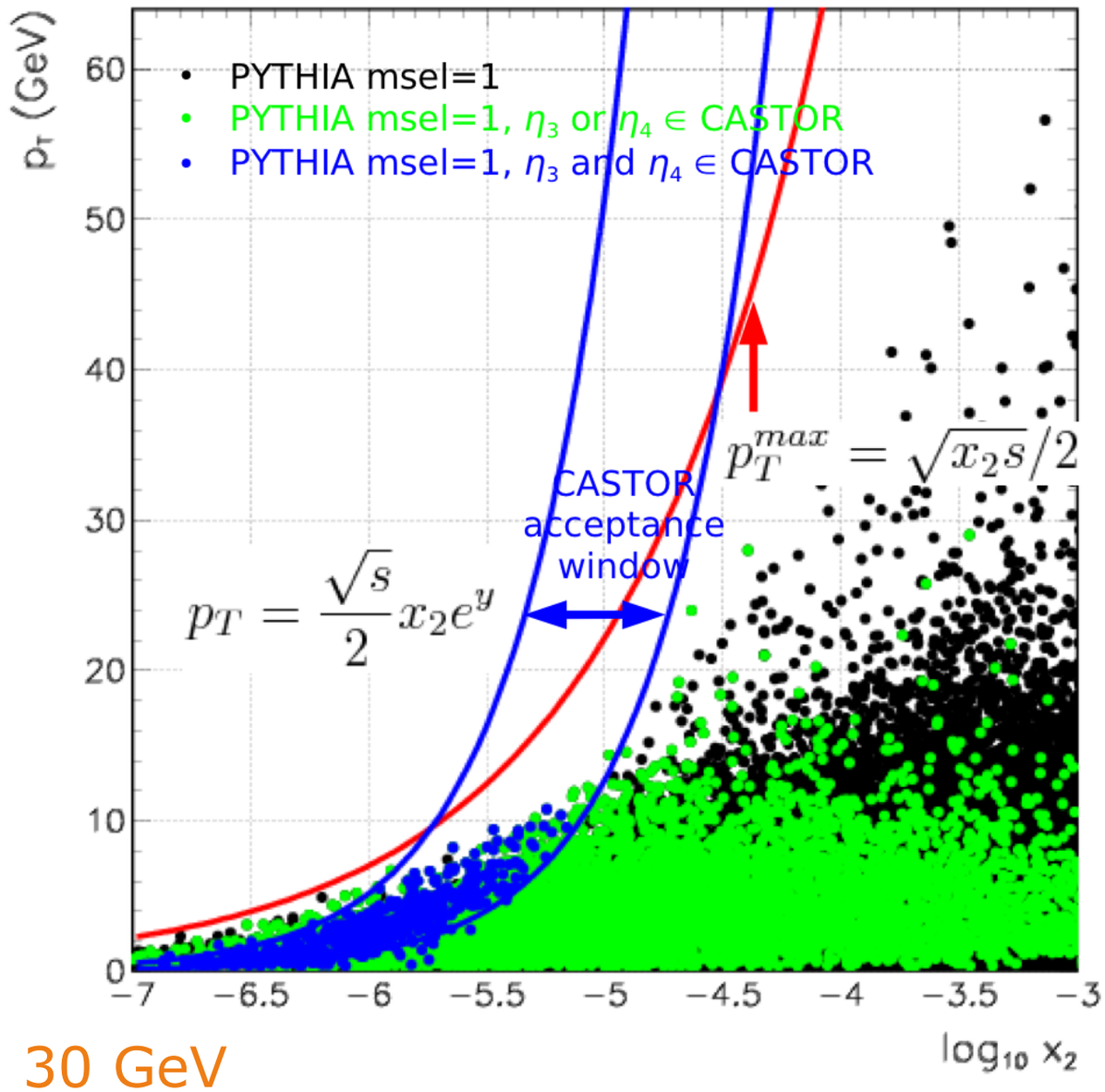
- Basic kinematics from "hard" subprocess

$$p_T^{max} \sim M/2$$
$$M^2 = x_1 x_2 s$$
$$y = \frac{1}{2} \ln x_1/x_2$$

- Caveat: not all jets come from hard subprocess with *y* in CASTOR (due to jet opening angle)



→ Maximum p_T for jets in CASTOR ~ 30 GeV

→ Reach in *x*-Bjorken down to 10^{-6}