Measurements of nuclear parton distribution functions using dijets and forward jets at the CMS detector

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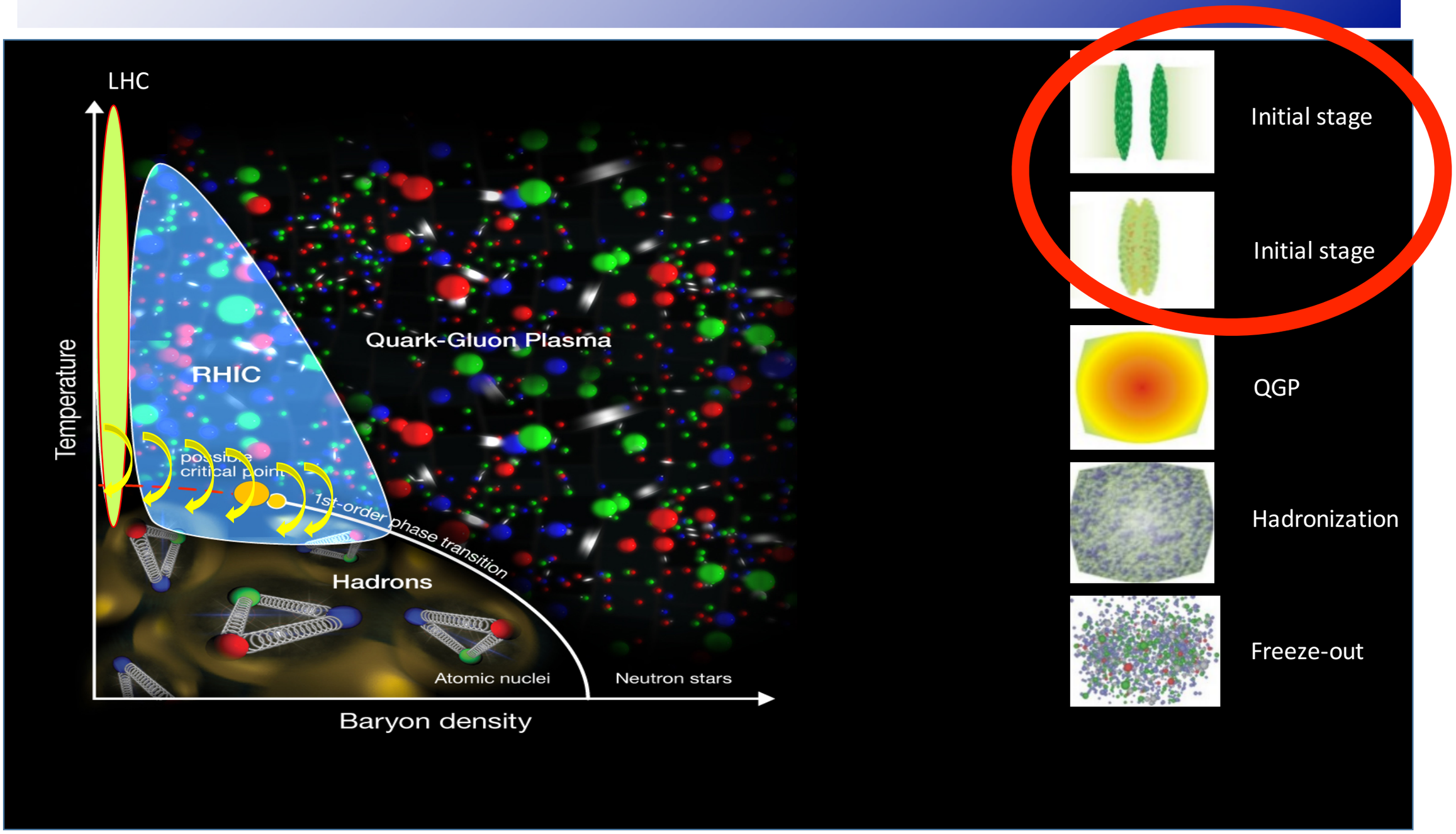
University of Kansas
For the CMS Collaboration

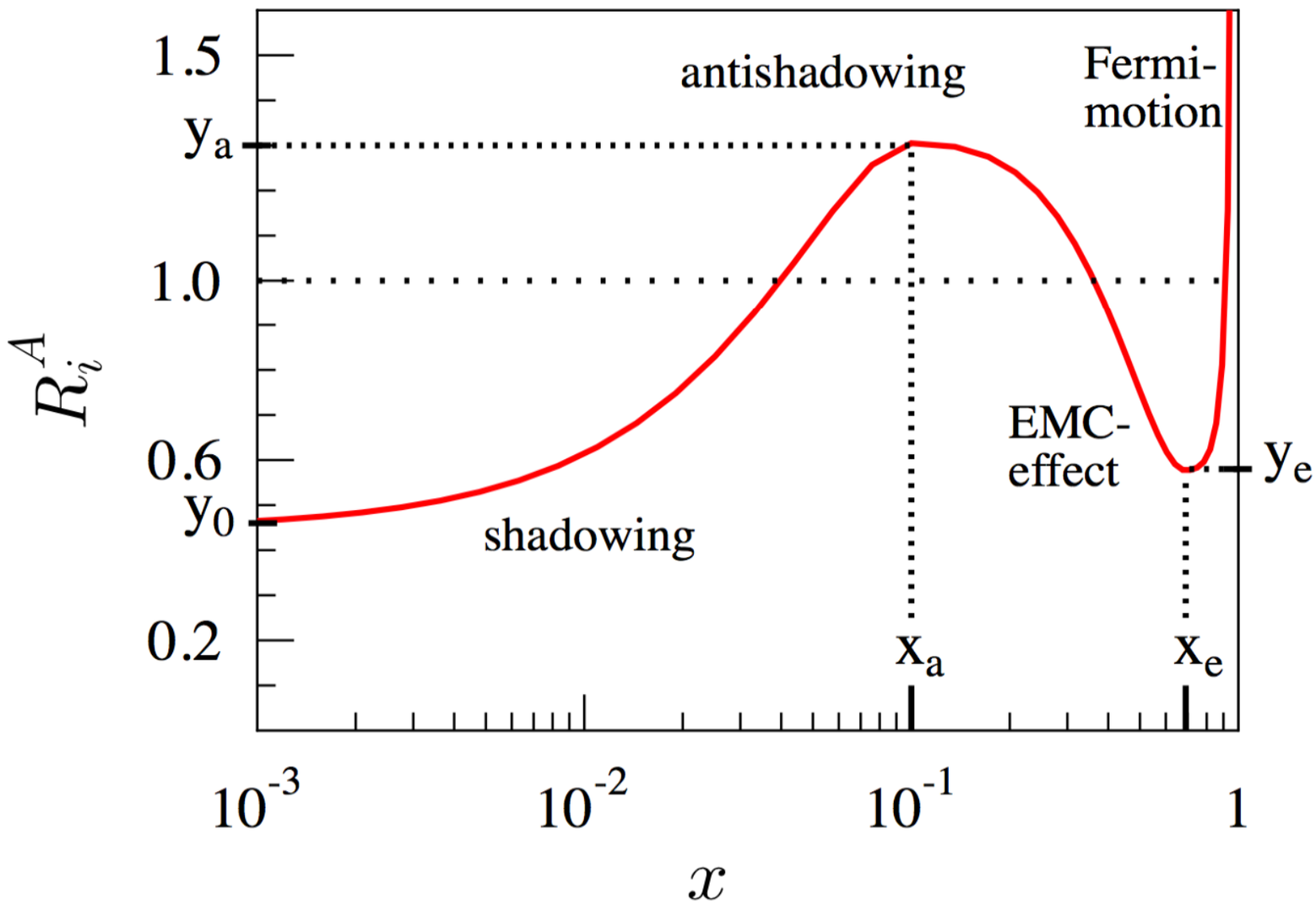
Quark Matter: International Conference on Relativistic Nucleus-Nucleus Collisions
Venice, Italy - 14 May 2018

Understanding the initial state



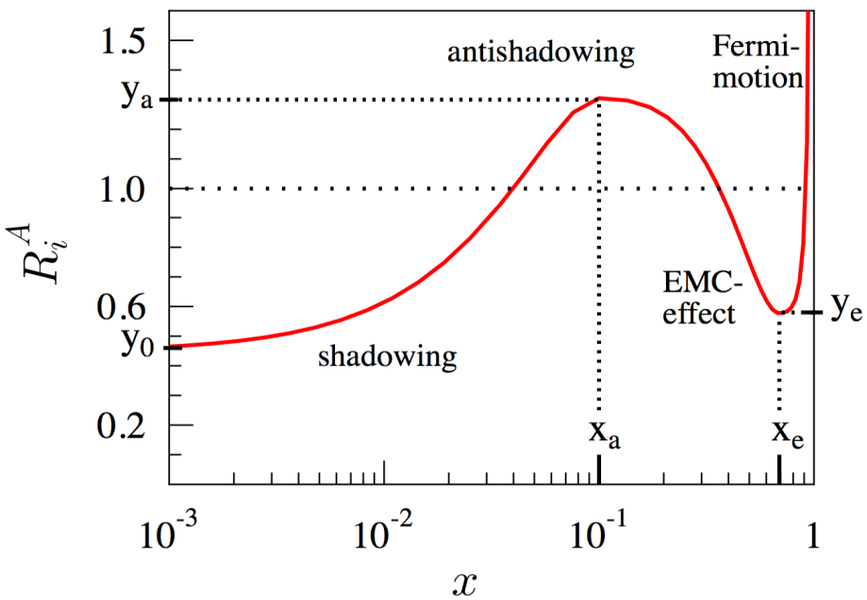
the nature of the initial state is one of the most important questions in high-energy nuclear physics

Nuclear effects



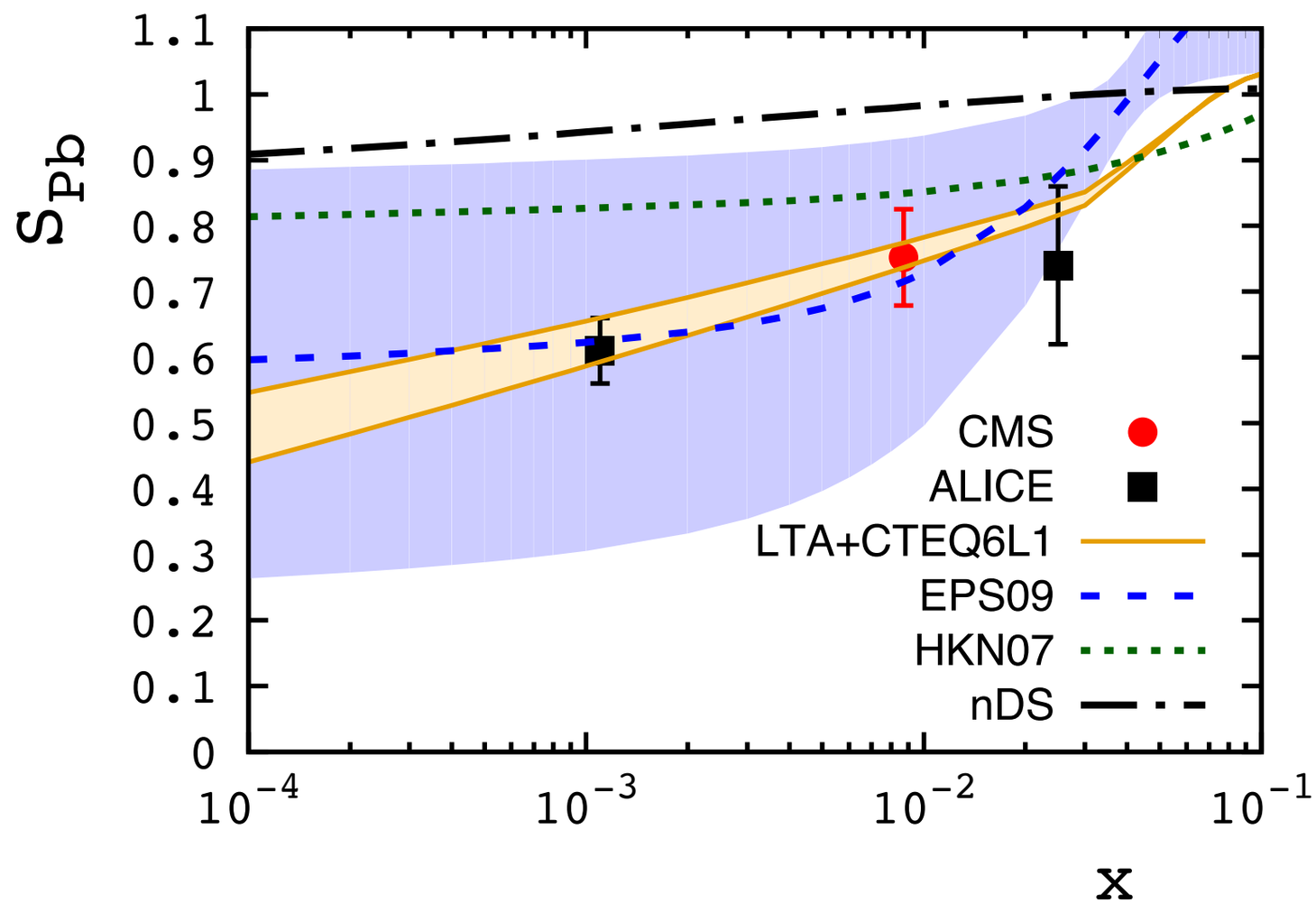
$$R = \frac{f_{i/A}}{A f_{i/p}} \approx \frac{\text{measured}}{\text{expected if no nuclear effects}}$$

Nuclear effects at **Low x**



Evidence of nuclear gluon effects in γPb interactions
D. Tapia Takaki
Quark Matter 2017

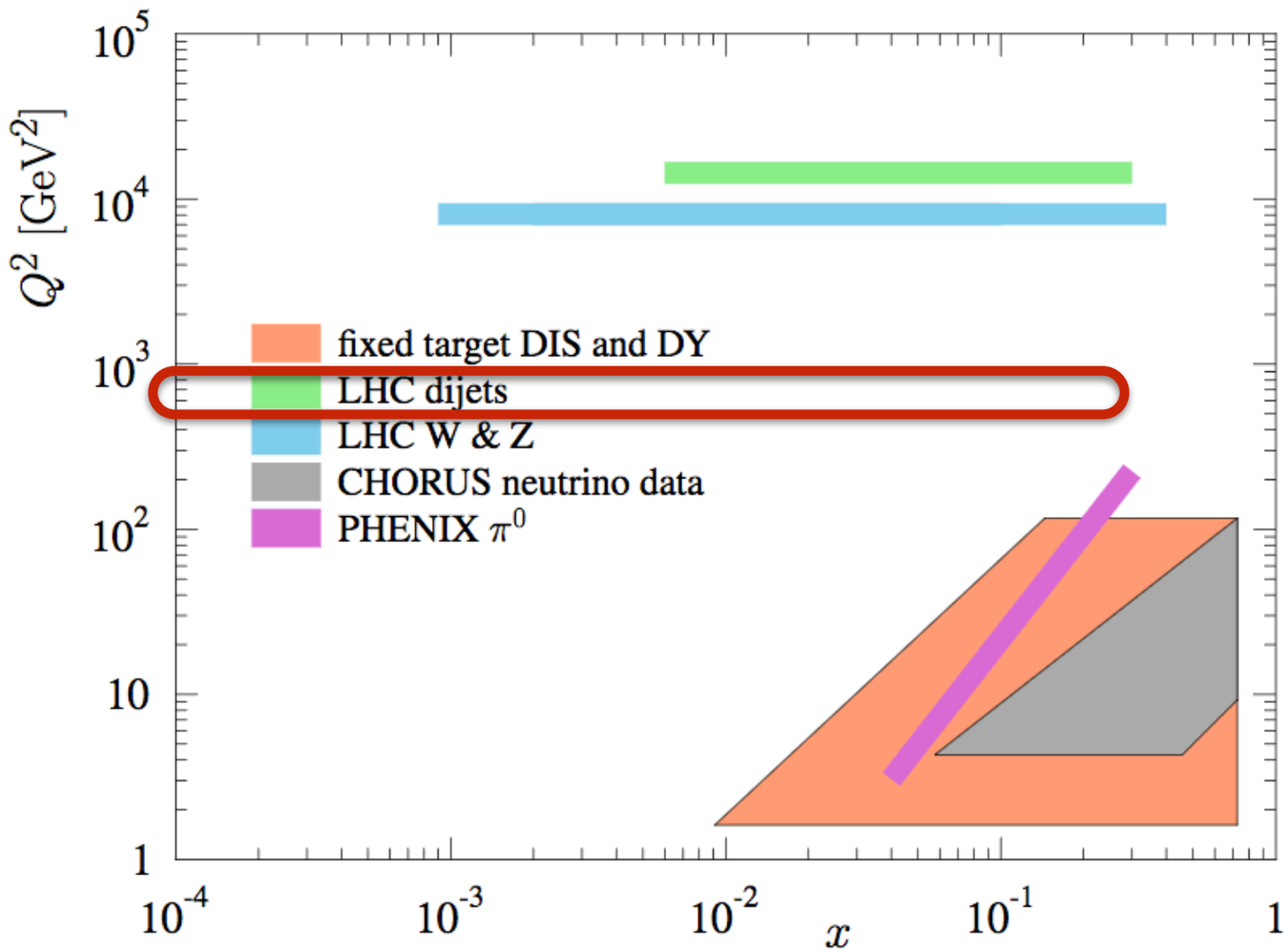
Coherent J/ψ photoproduction off Pb nuclei
By V. Guzey, et. al using Phys. Lett. B726 (2013) 290–295 and latest ALICE and CMS results



$$R = \frac{f_{i/A}}{A f_{i/p}} \approx \frac{\text{measured}}{\text{expected if no nuclear effects}}$$

High x - Nuclear gluon density

K.J. Eskola, et al. Eur. Phys. J. C (2017) 77: 163



CMS has a program to study initial state and nPDFs using a wide variety of processes

See talk by A. Stahl on nPDF studies using electroweak bosons in 8 TeV pPb

Constraining gluon distributions in nuclei using dijets

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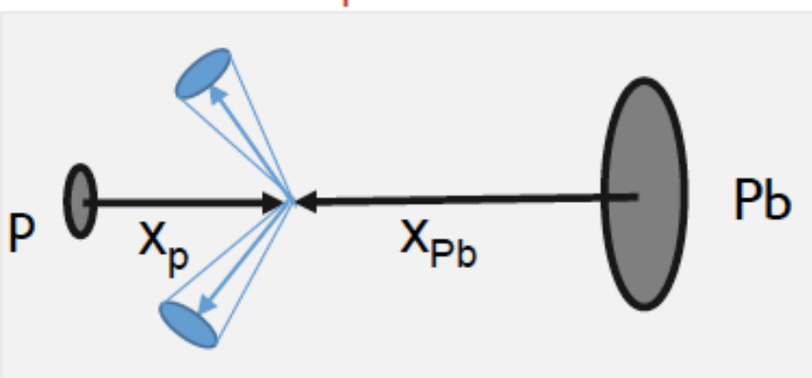
$$\eta_{dijet} = \frac{\eta_1 + \eta_2}{2}$$

Constraining gluon distributions in nuclei using dijets

$$\eta_{dijet} = \frac{\eta_1 + \eta_2}{2} \propto 0.5 \log\left(\frac{x_p}{x_{Pb}}\right) + \eta_{CM}$$

Constraining gluon distributions in nuclei using dijets

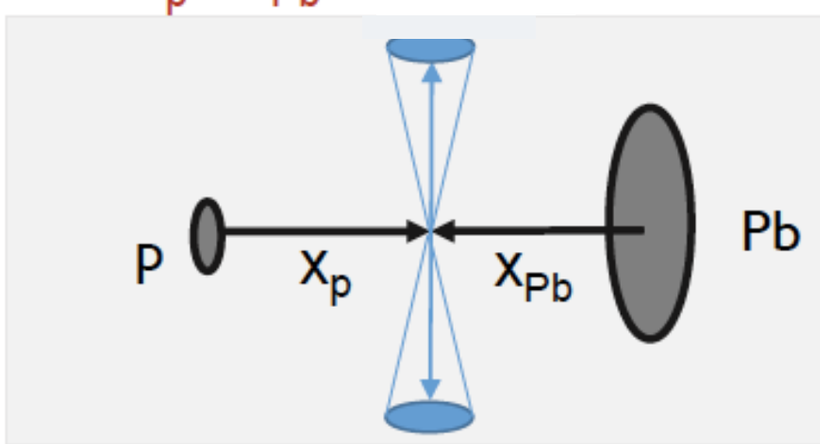
$x_p < x_{Pb}$



EMC

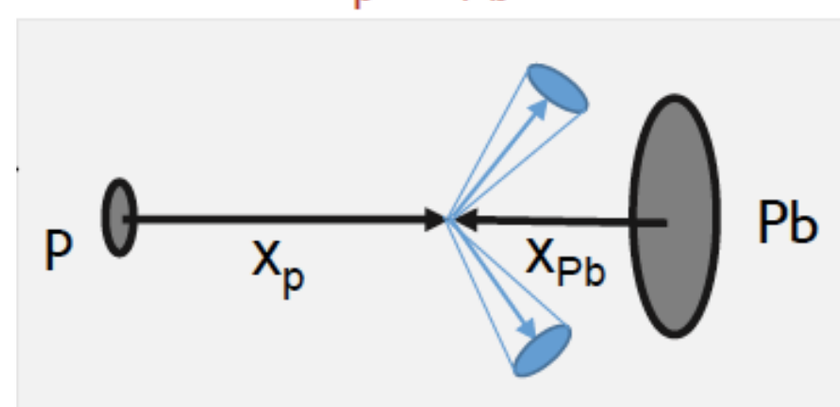
Anti-shadowing

$x_p \sim x_{Pb}$



Shadowing

$x_p > x_{Pb}$



Constraining gluon distributions in nuclei using dijets

$$\eta_{dijet} = \frac{\eta_1 + \eta_2}{2} \propto 0.5 \log\left(\frac{x_p}{x_{Pb}}\right) + \eta_{CM}$$

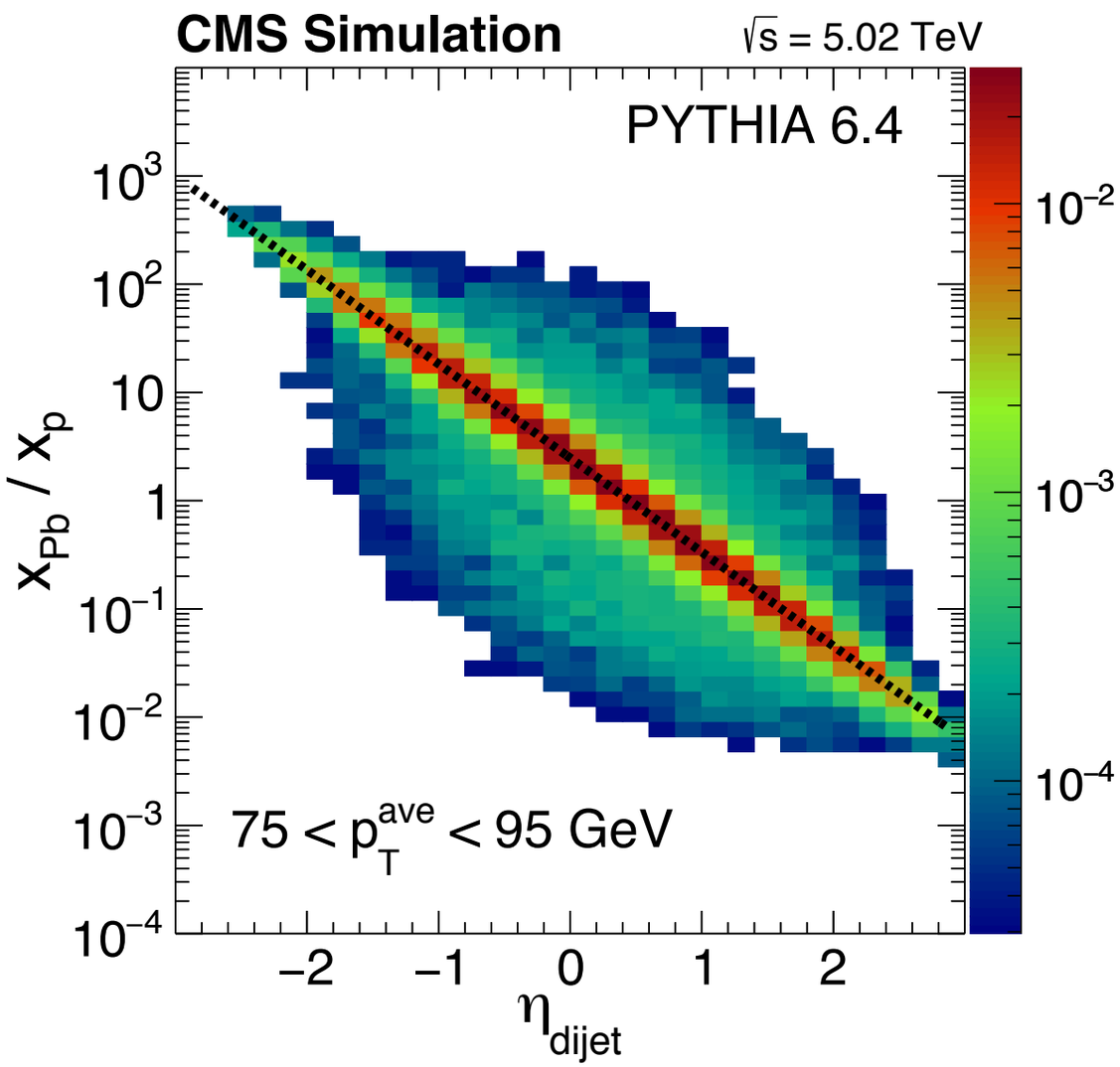
$$p_T^{ave} = \frac{p_{T,1} + p_{T,2}}{2} \propto Q$$

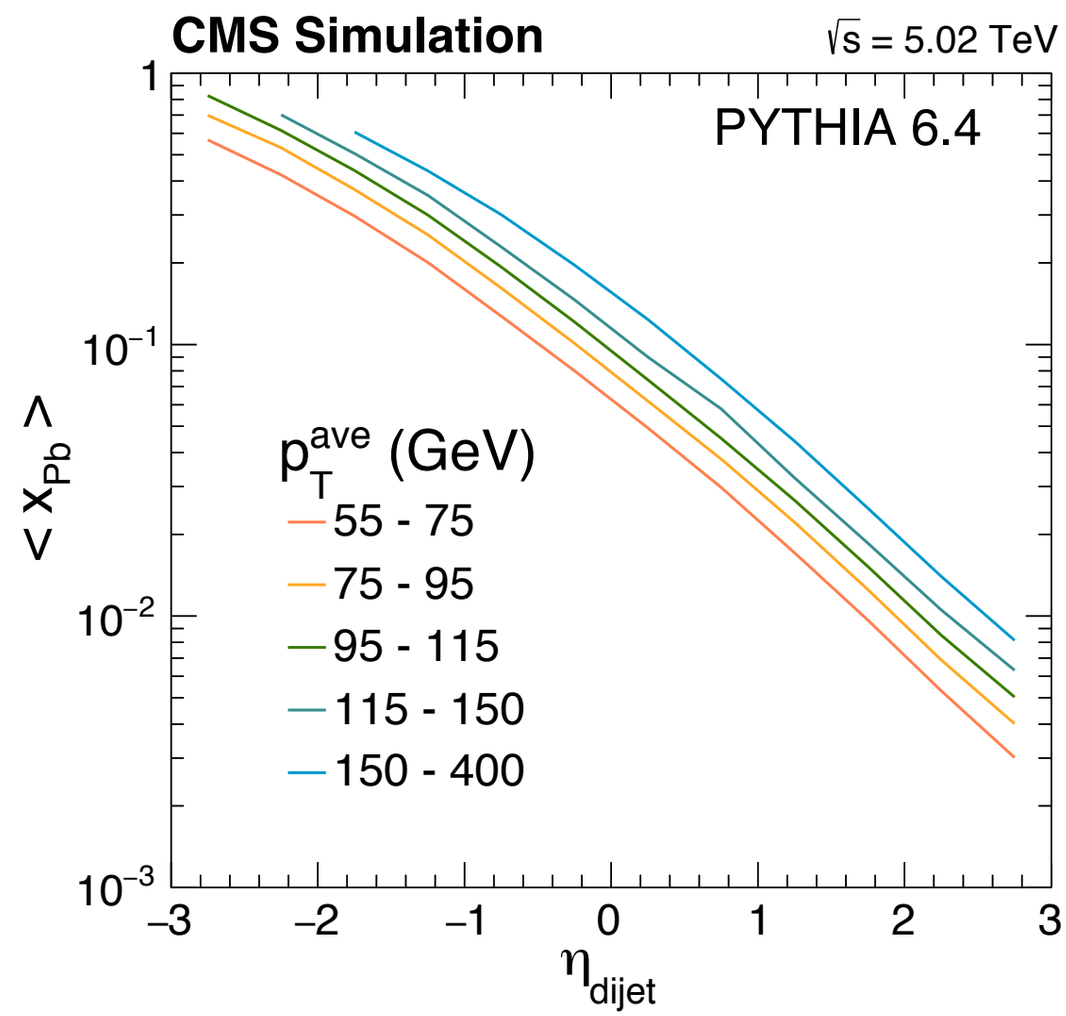
Constraining gluon distributions in nuclei using dijets

Dijet measurements in pPb collisions have been shown to be one of the most important tools for constraining the gluon nuclear parton distribution functions (PDFs) **at large Bjorken-x**

$$\eta_{\text{dijet}} = (\eta_1 + \eta_2)/2$$

$$p_{\text{T}}^{\text{ave}} = (p_{\text{T},1} + p_{\text{T},2})/2$$

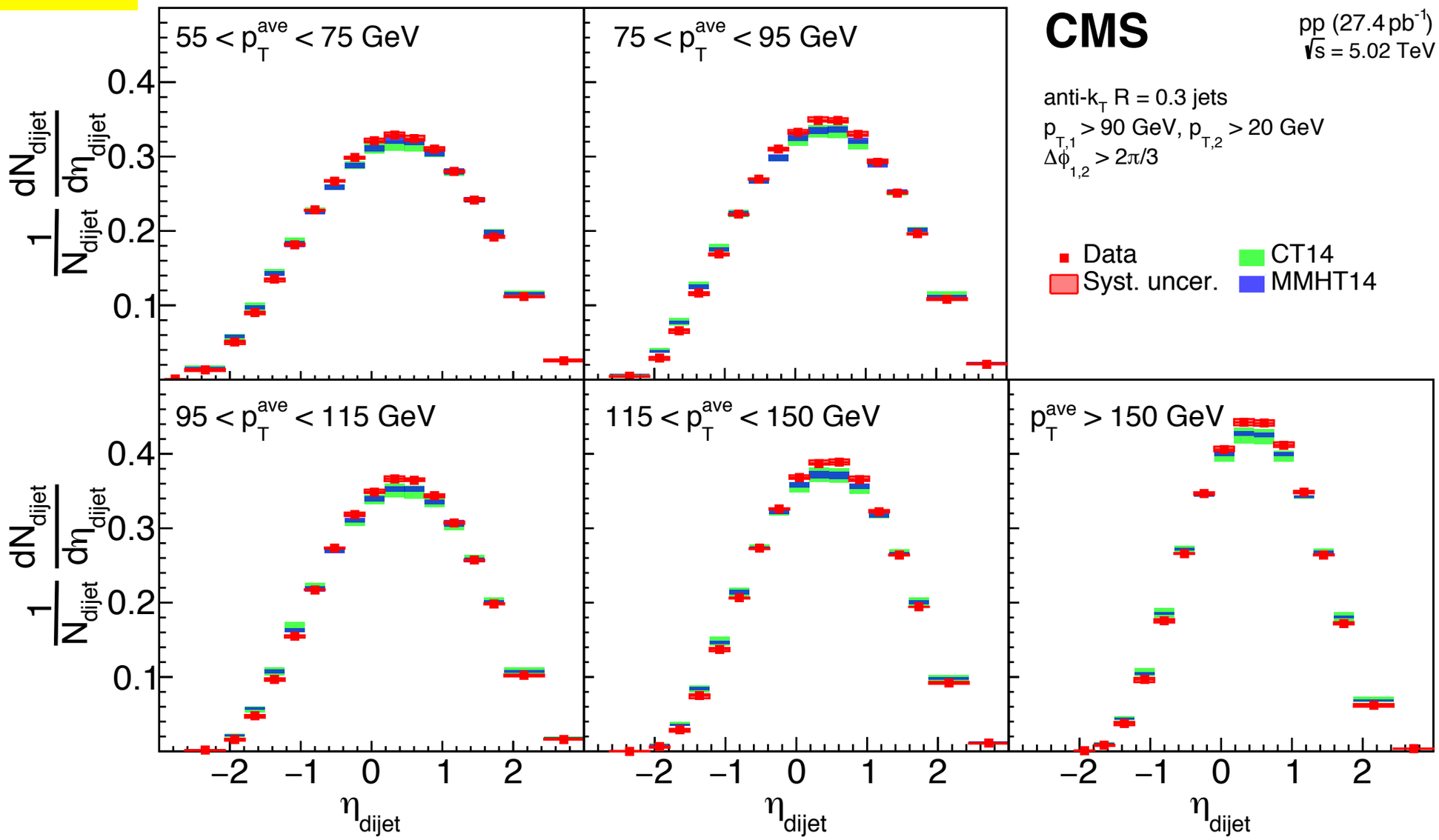




HIN-16-003

Constraining gluon distributions in nuclei using dijets

pp collisions at 5.02 TeV



Measurement as a function of dijet average transverse momentum in order to study the nuclear modifications of PDFs at **various factorization scales**

nPDF considered

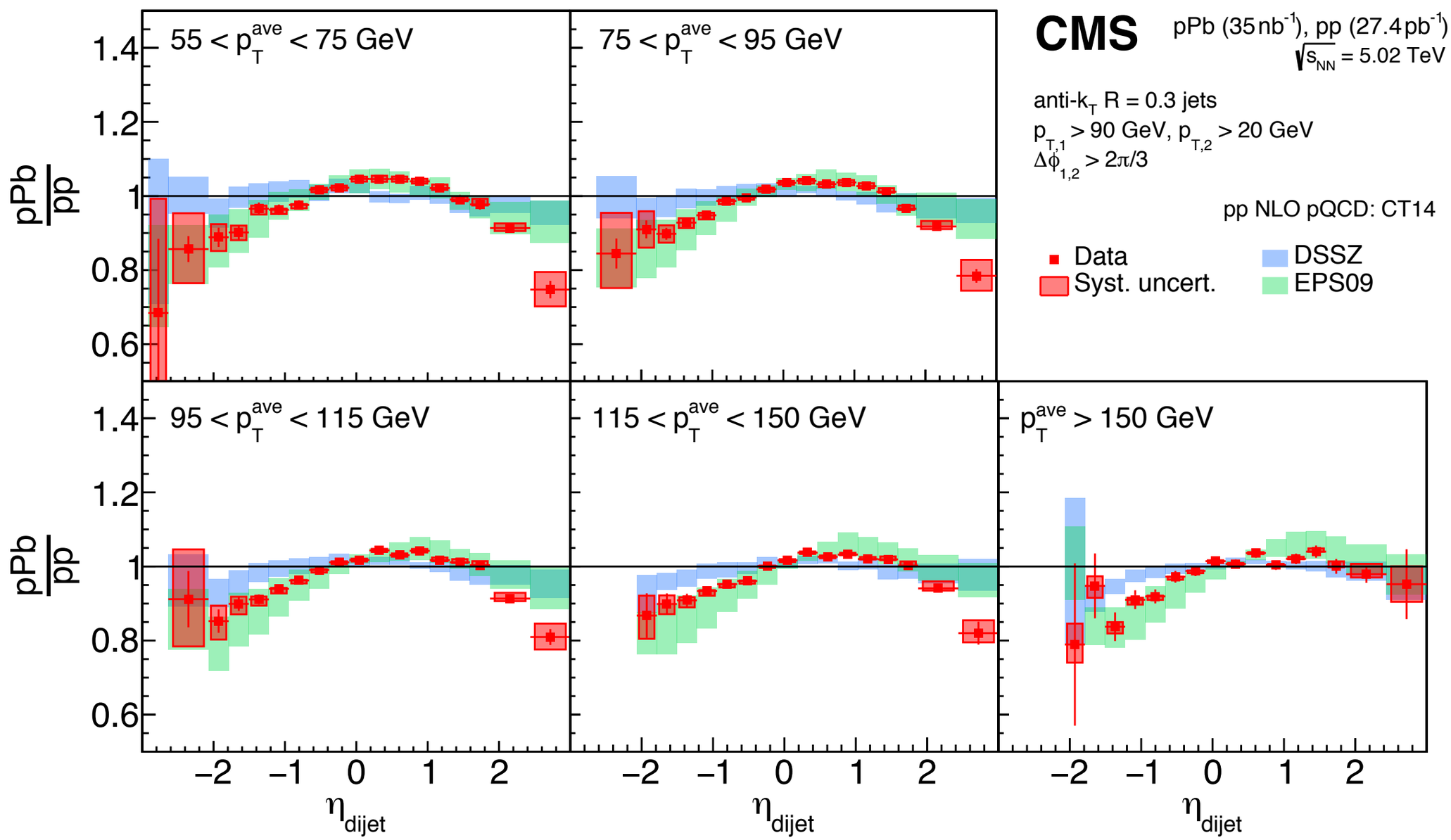
EPS09, nCTEQ15, EPPS16 are based on NLO pQCD using different parametrization and different datasets as input

EPPS16 uses LHC data from Z/W/dijets at 5 TeV pPb

DSSZ: "Benchmark" - No significant nuclear modification. It uses RHIC pion data (parton-to-pion fragmentation function)

Constraining gluon distributions in nuclei using dijets

pPb/pp ratio

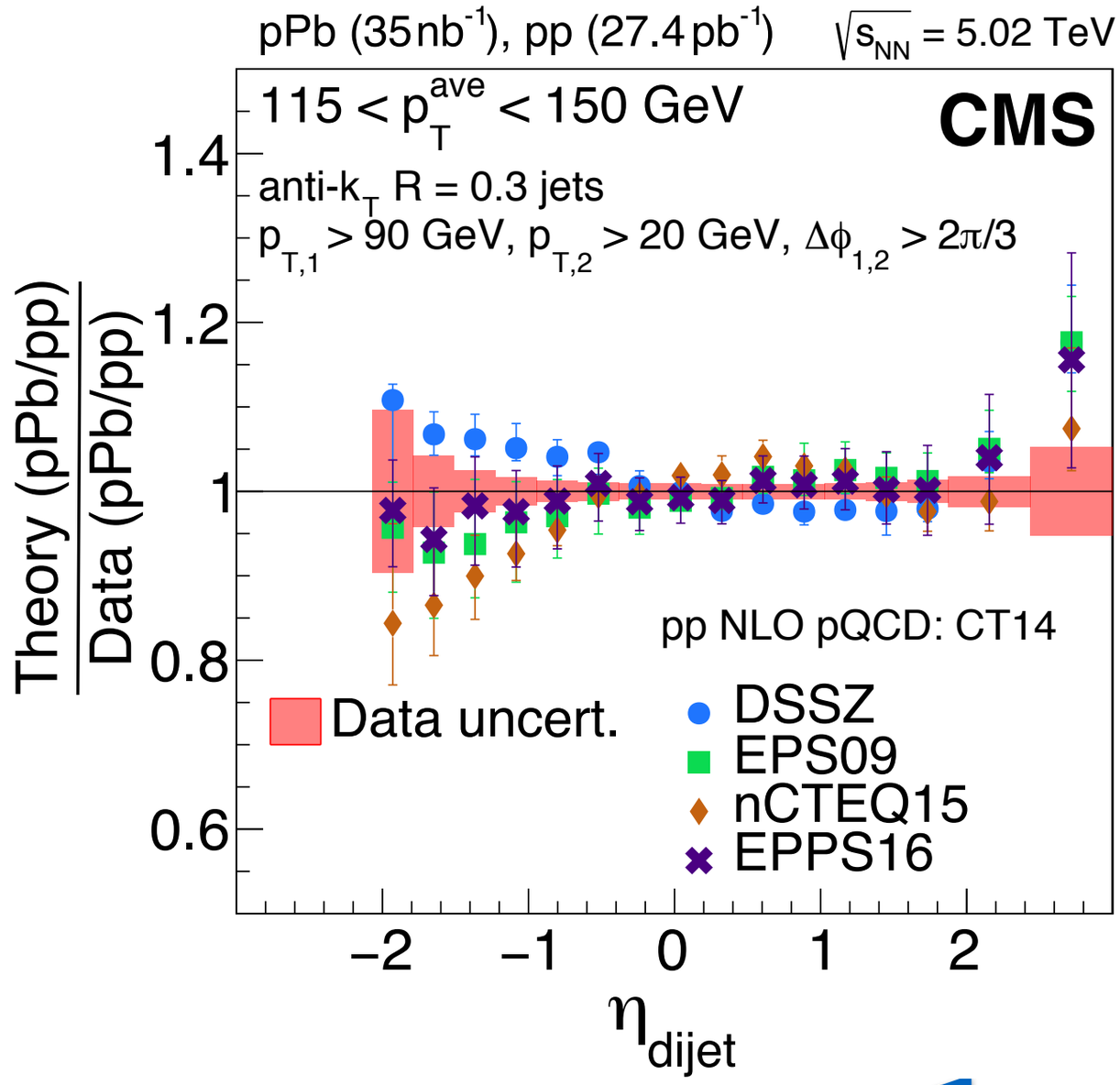


Comparing to **next-to-leading-order perturbative QCD predictions** obtained from both nucleon and nuclear PDFs

First evidence that the gluon PDF at large Bjorken x in lead ions is strongly suppressed

Data are incompatible with predictions using nucleon PDFs or using nPDFs **without large-x gluon suppression**.

Based on a statistical analysis, *the EPS09 nPDF provides the best overall agreement* with the data

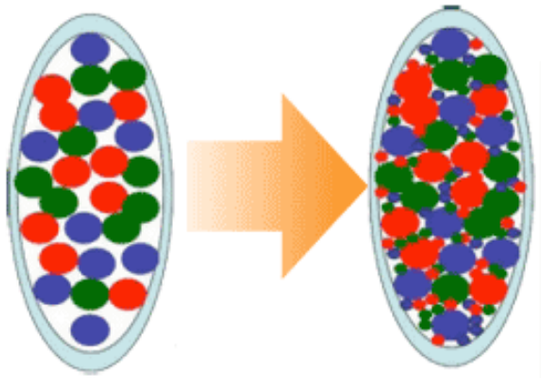


High x

Low x

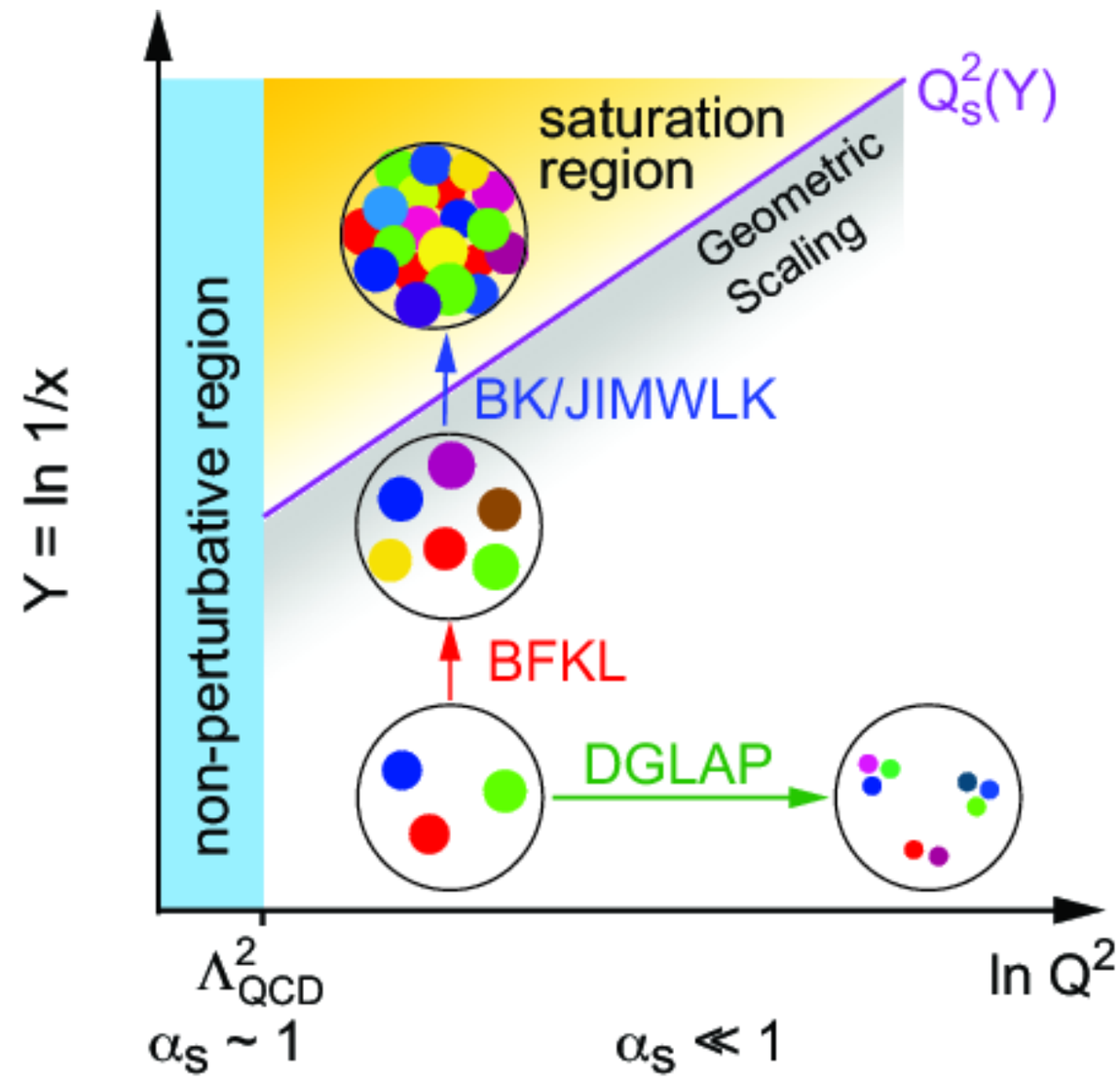
Searching for **gluon saturation** studying <u>inclusive very forward jet</u> cross sections in pPb collisions at 5.02 TeV

Searching for gluon saturation

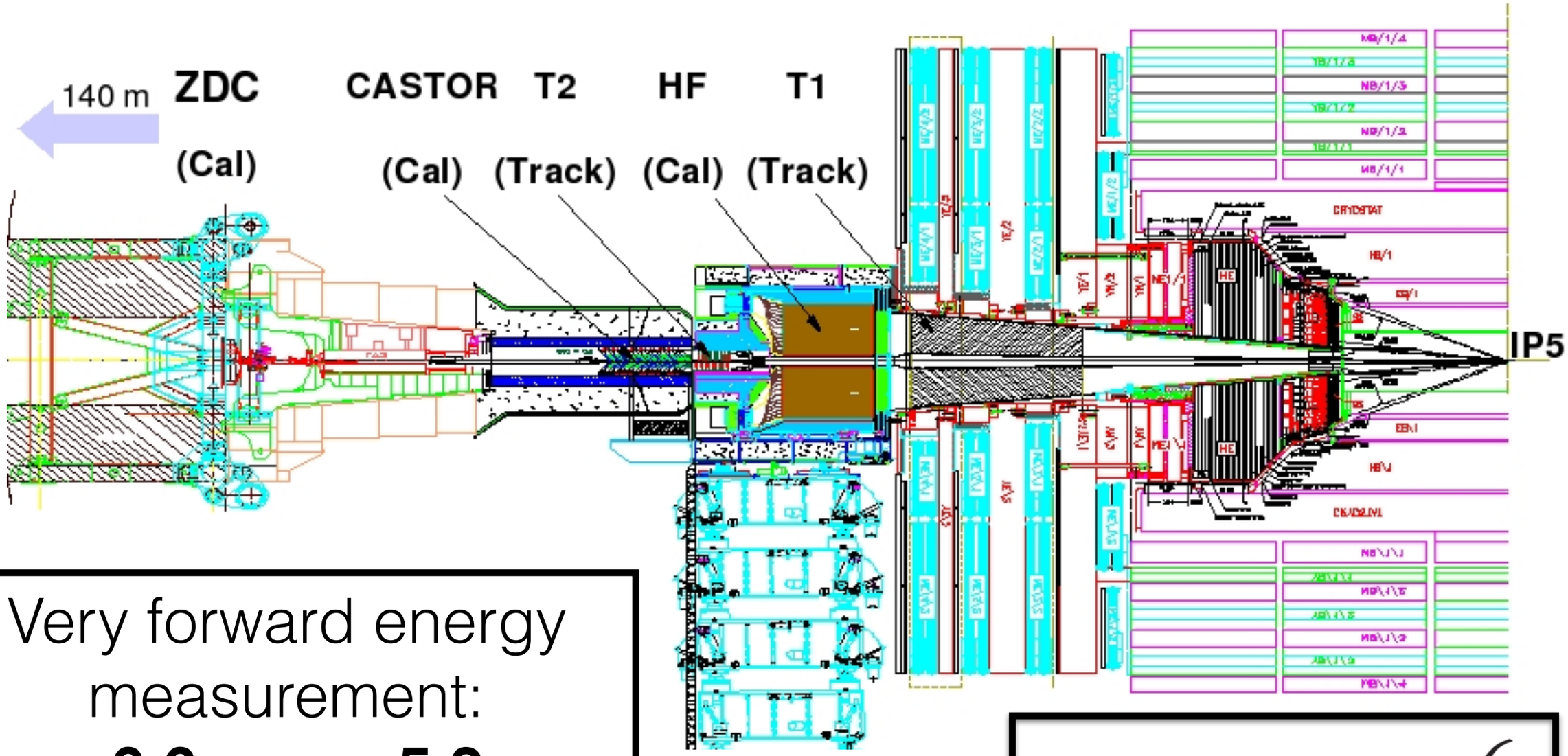


The forward region is particularly sensitive to gluon saturation

$$x \approx \frac{p_T}{\sqrt{s}} e^{\pm\eta}$$



Inclusive **very forward** jet cross sections in pPb collisions at 5.02 TeV



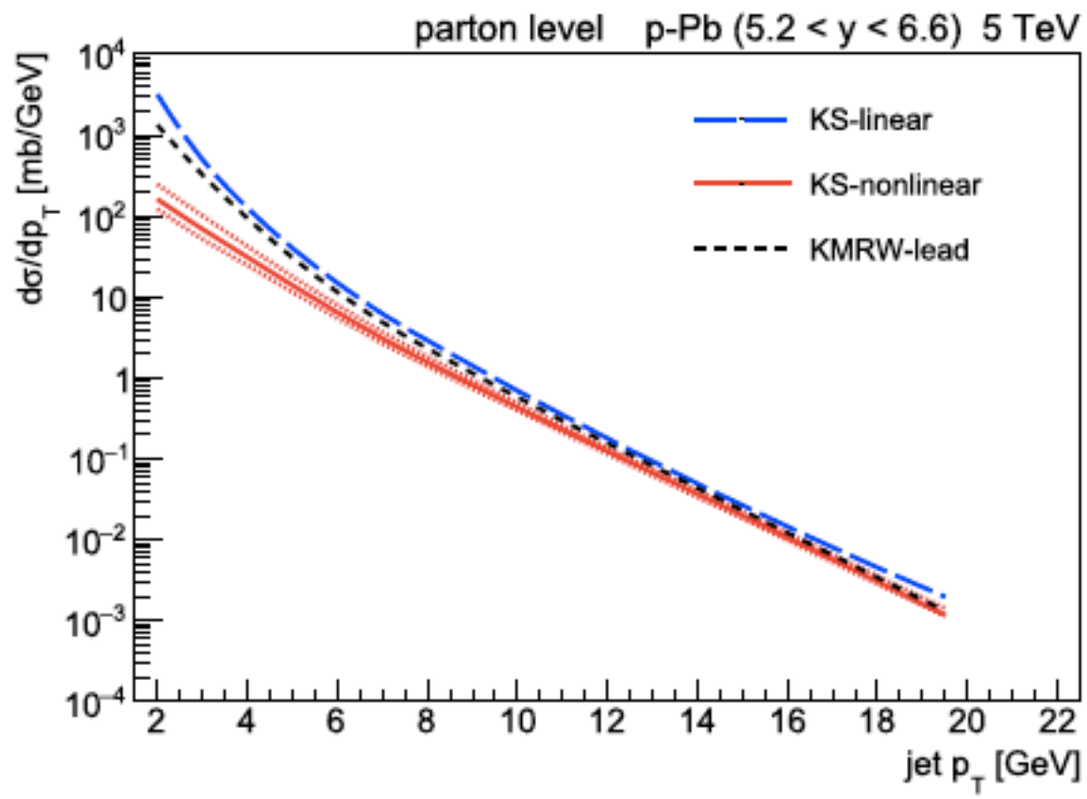
Very forward energy measurement:
-6.6 < η < -5.2

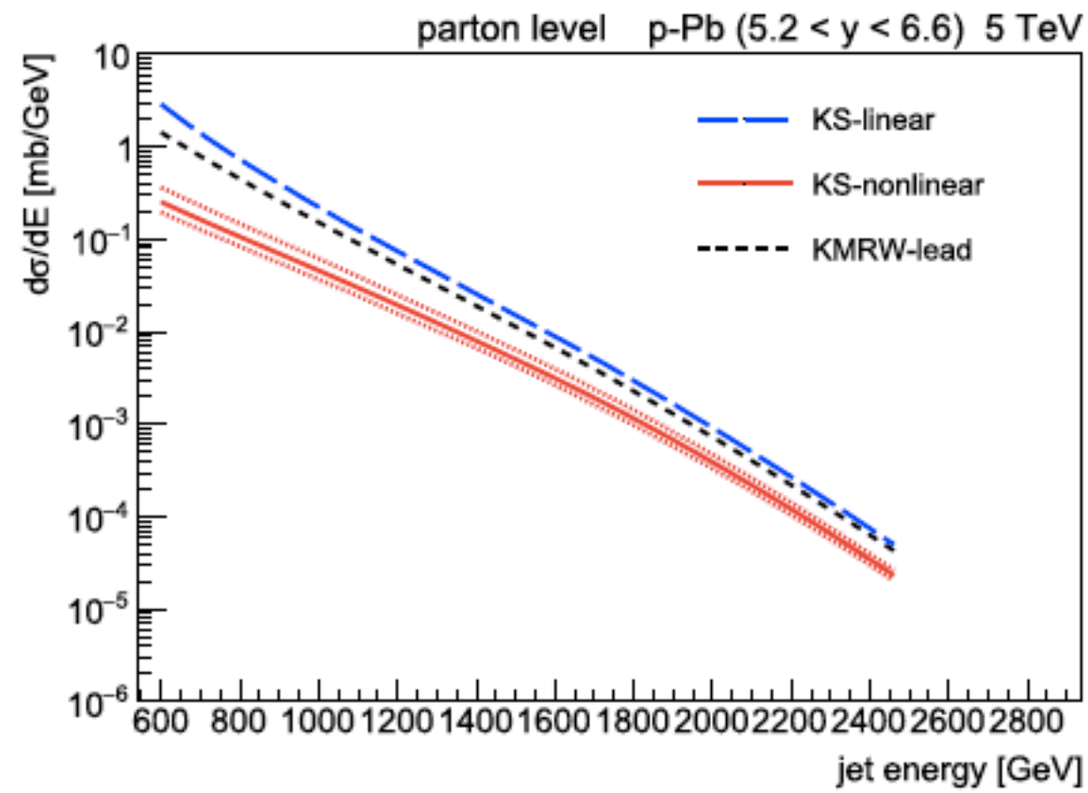
$$x \geq 10^{-6}$$

Inclusive **very forward** jet cross sections in pPb collisions at 5.02 TeV

$$x \geq 10^{-6}$$

M. Bury, et al.
Phys. Lett. B780 (2018) 185-190





KS-linear: *solution of the momentum space version of the extended BFKL equation*

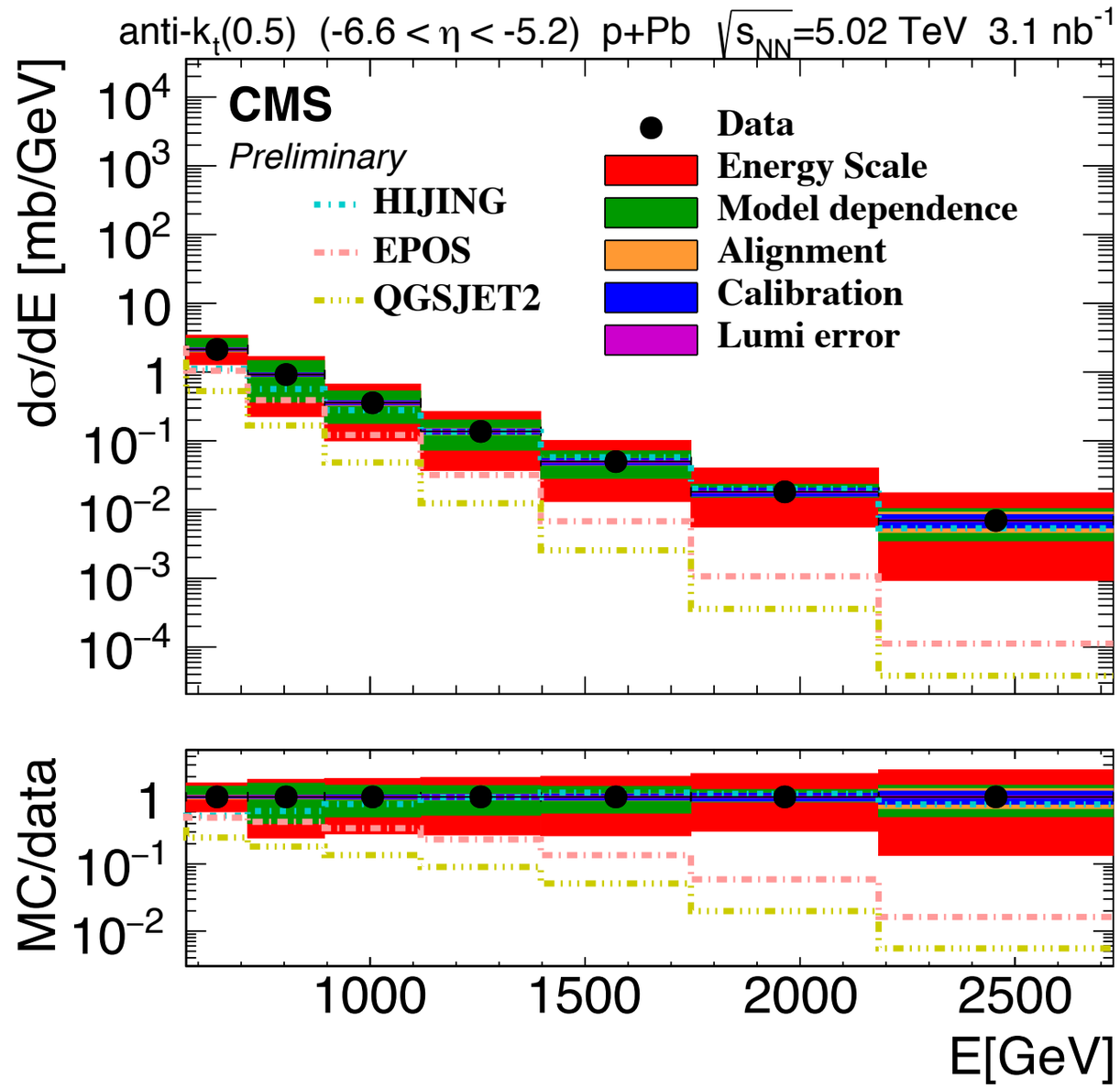
KS-nonlinear (gluon saturation): *solution of the momentum space version of the BK equation*

KMRW-lead: *gluon density obtained from a collinear gluon density and using nPDF*

Inclusive very forward jet cross sections in pPb collisions at 5.02 TeV

p+Pb: p —> CASTOR

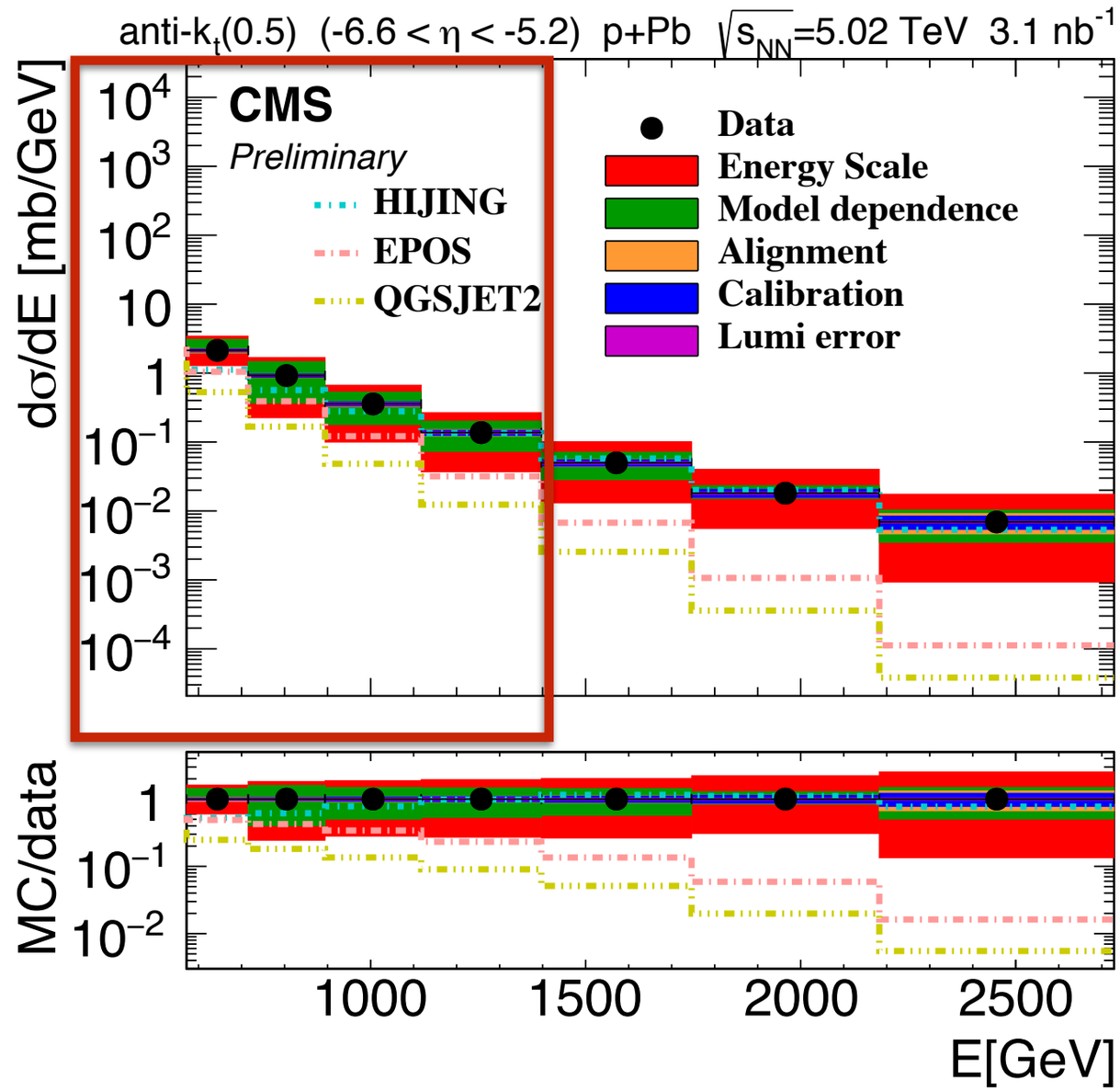
Data unfolded at particle level



HIJING describes best the data, favoring DGLAP parton showers with shadowing corrections. EPOS and QGSJETII prediction is too soft

Inclusive very forward jet cross sections in pPb collisions at 5.02 TeV

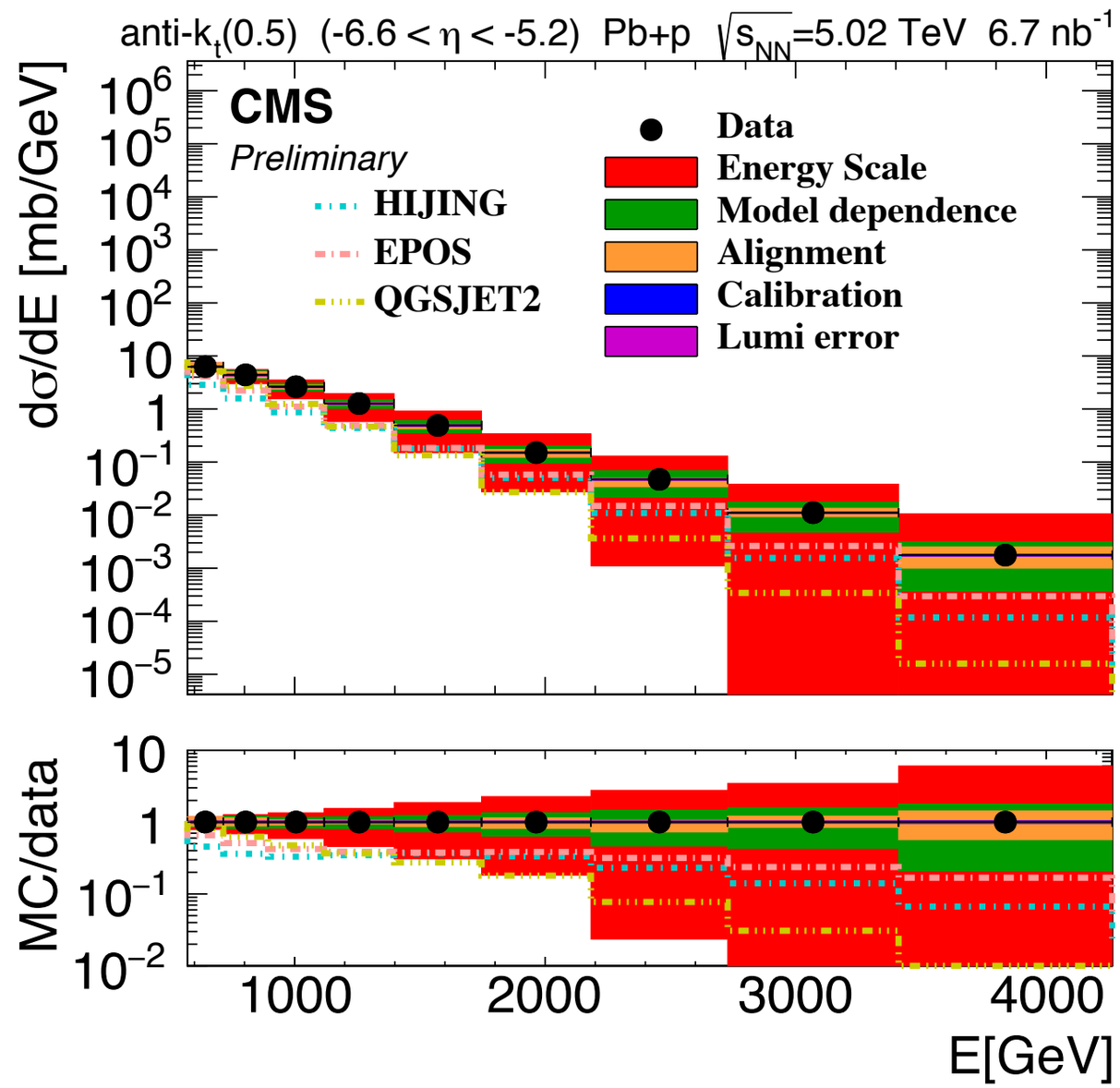
p+Pb: p —> CASTOR



The slope of the distribution is sensitive to nonlinear evolution, gluon saturation models, specially at low energies

Inclusive very forward jet cross sections in pPb collisions at 5.02 TeV

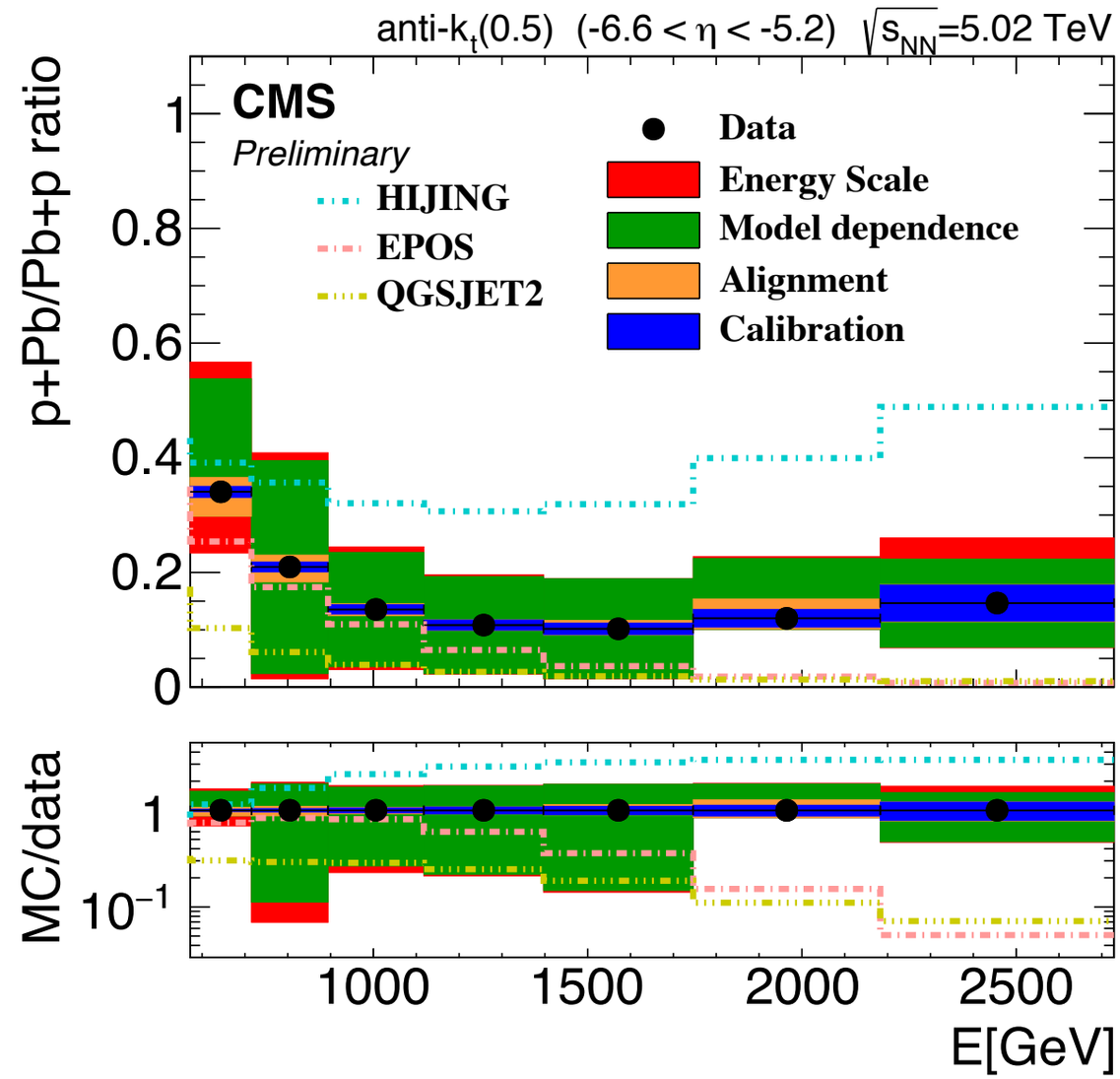
Pb+p: Pb —> CASTOR



Region affected by the ion remnants

EPOS-LHC and HIJING models describe the data reasonably well

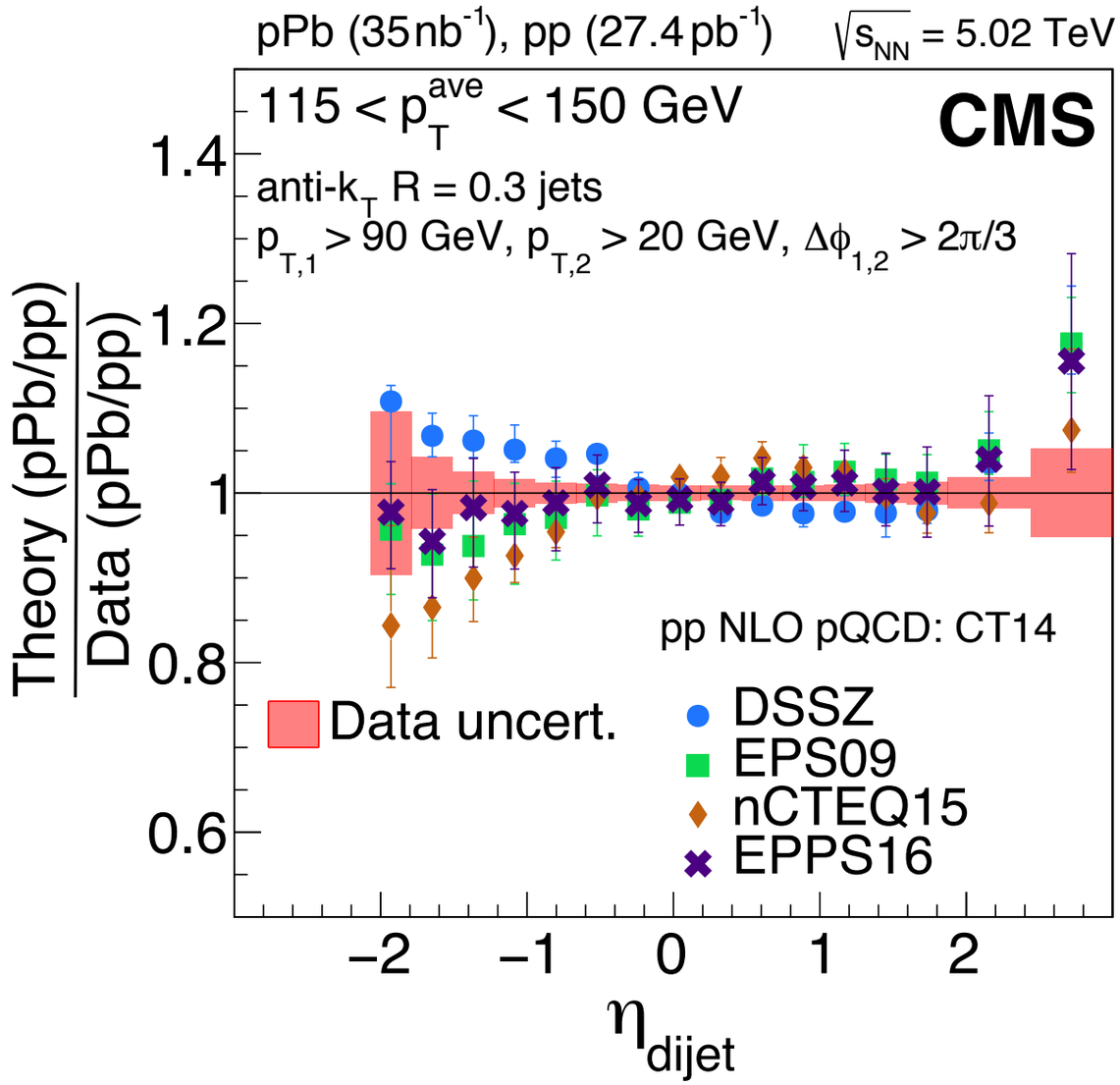
Inclusive very forward jet cross sections in pPb collisions at 5.02 TeV

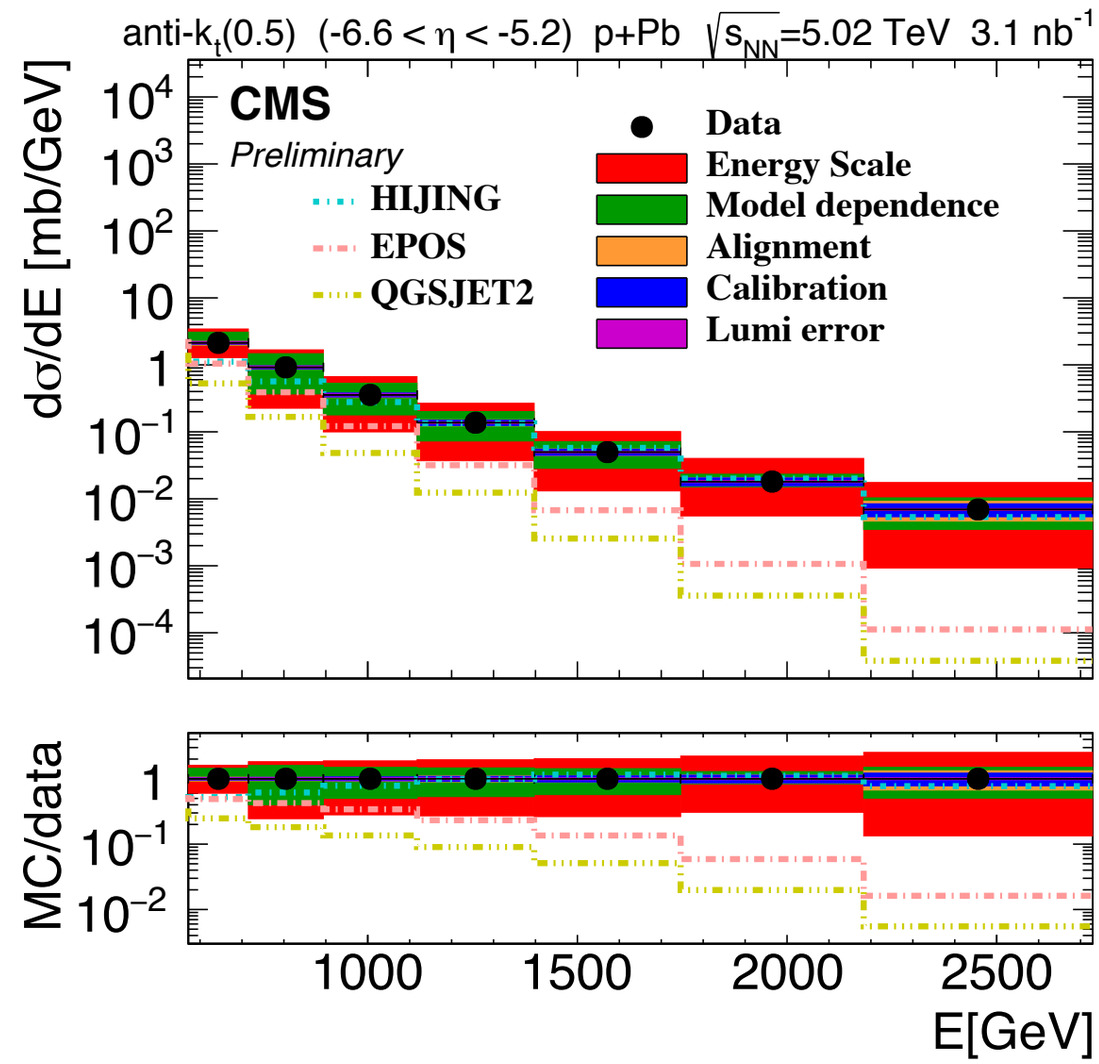


Energy scale uncertainty and luminosity cancel out

Model uncertainty is the largest, so useful for model development

Summary





Studying inclusive dijets in both pp and pPb. We found **first evidence** that the gluon PDF at **large Bjorken x** in lead ions is *strongly suppressed*

Studying very forward inclusive jets in pPb. We studied **previously unexplored x > 10^{-6}** kinematic region *sensitive to gluon saturation in the proton*

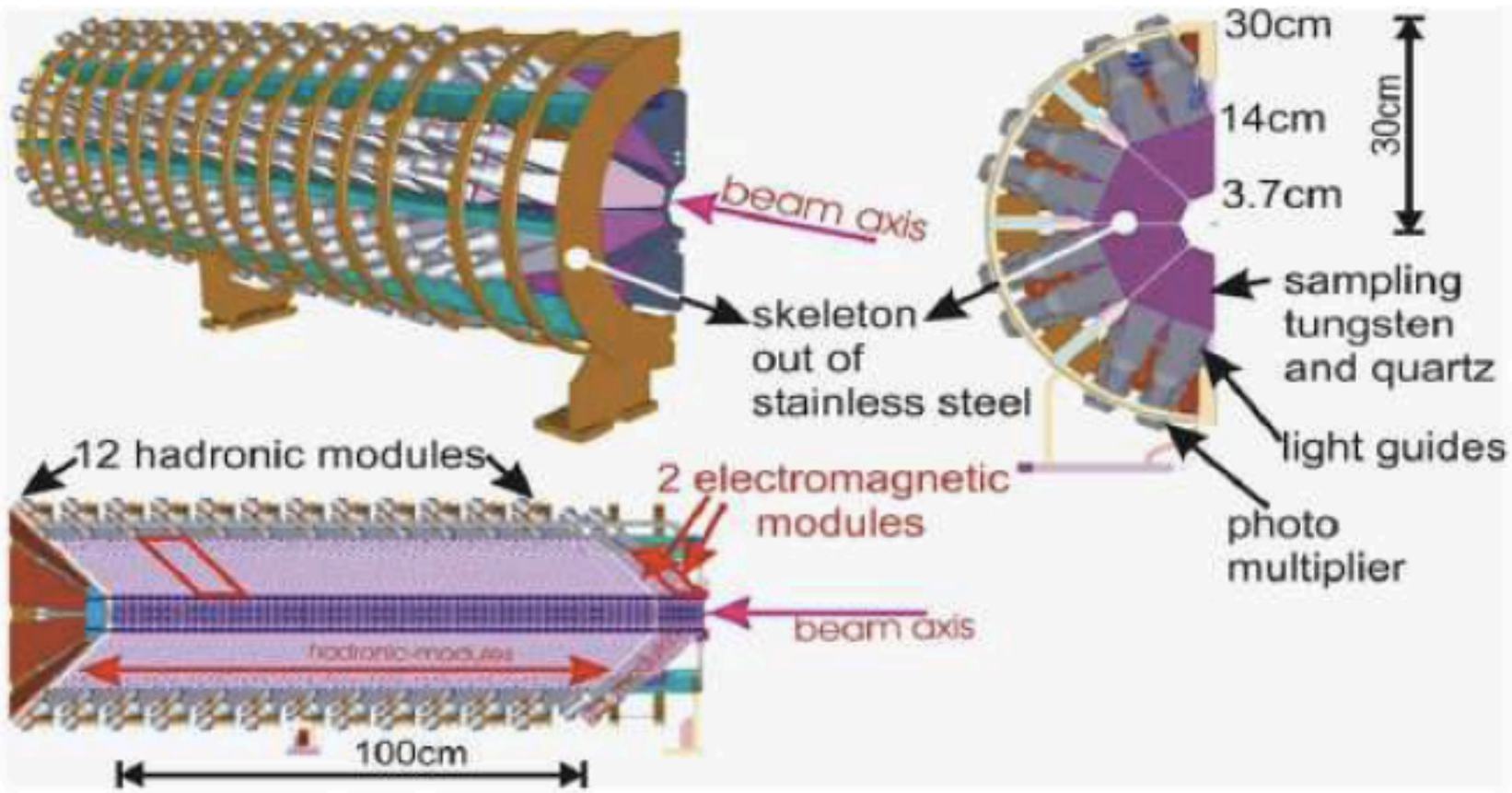
Additional slides

CASTOR

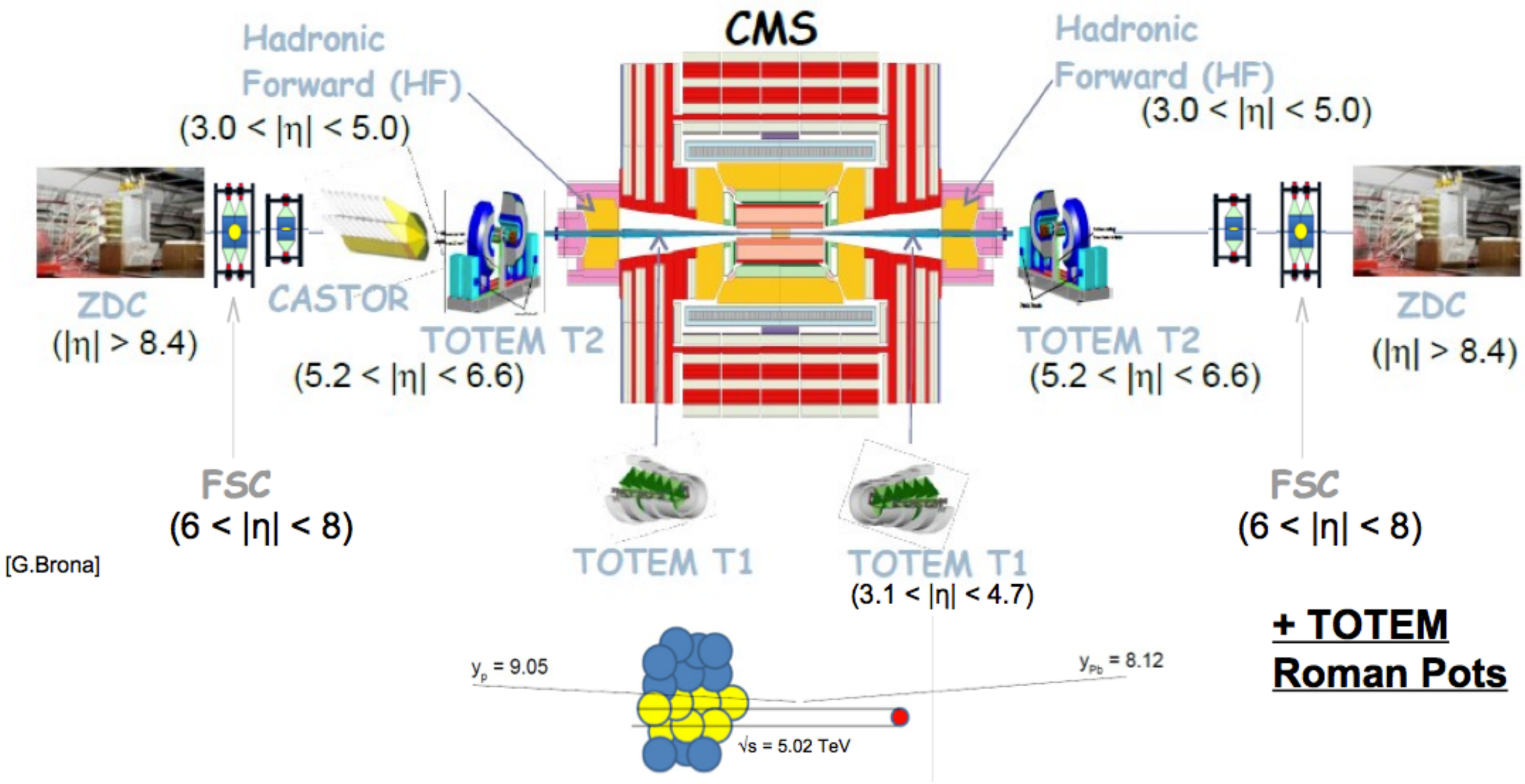
very forward energy measurement: $-6.6 < \eta < -5.2$

14-fold segmentation in z, 16-fold segmentation in ϕ,

no segmentation in η



CMS: Compact Muon Solenoid



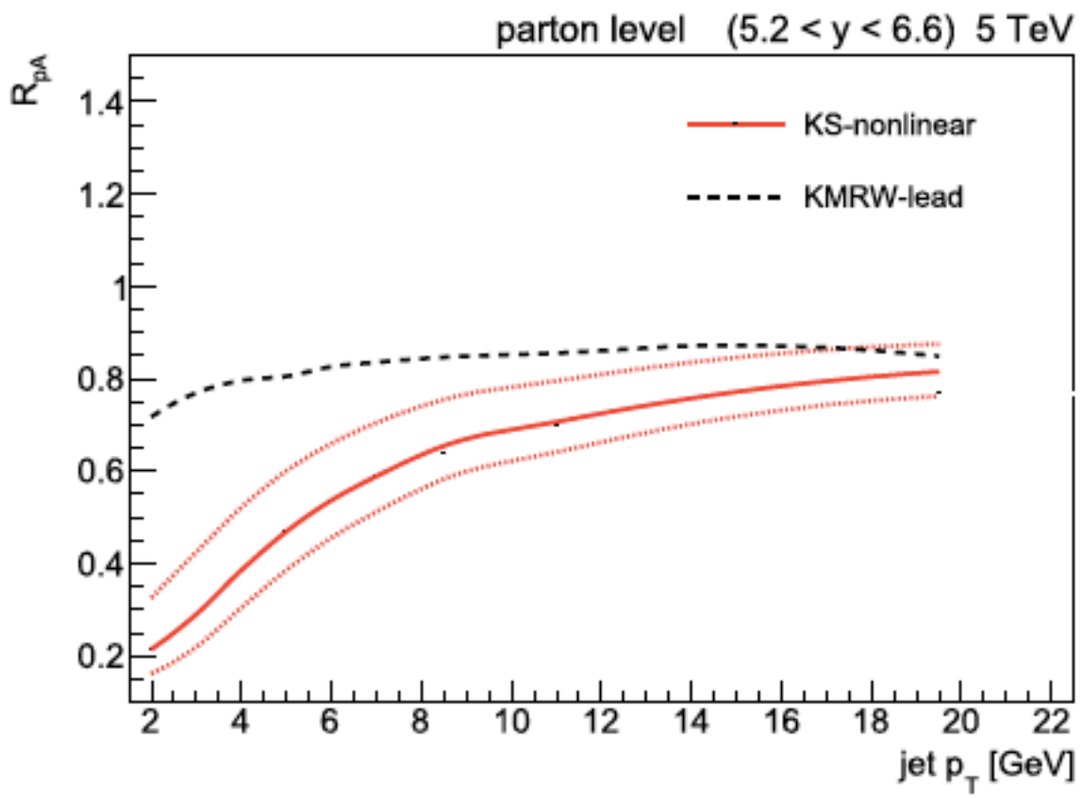
[G.Brona]

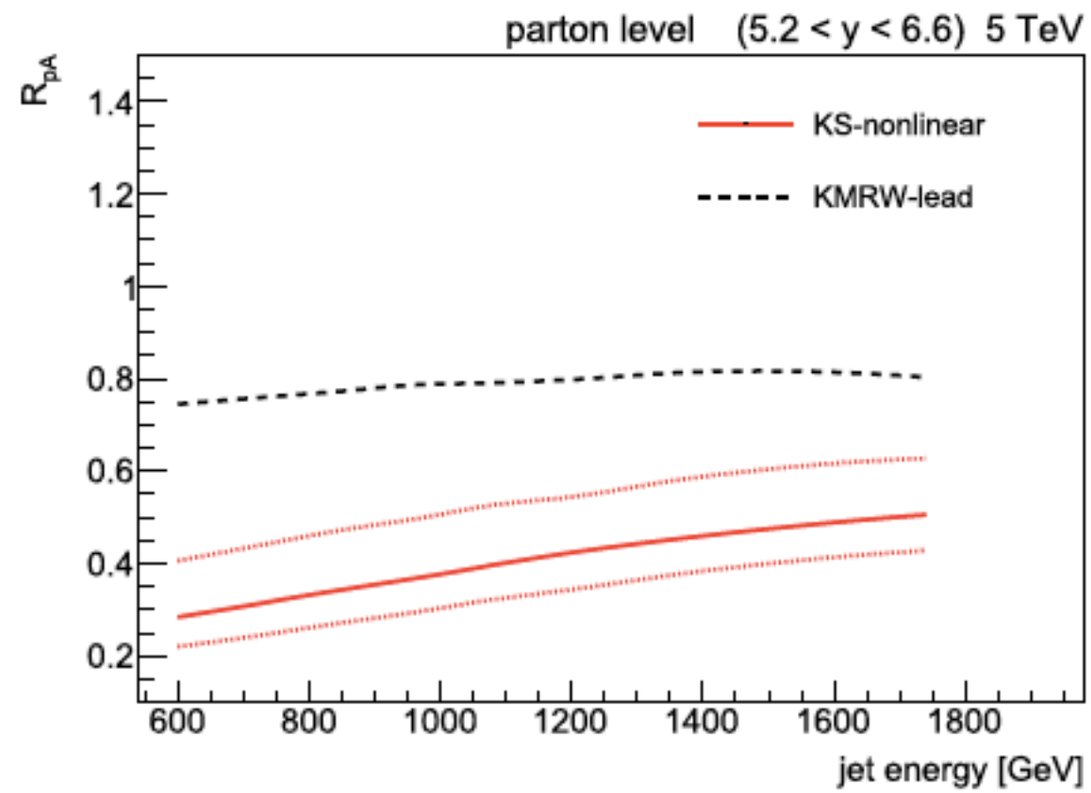
+ TOTEM Roman Pots

Inclusive **very forward** jet cross sections in pPb collisions at 5.02 TeV

$$R_{pA} = \frac{\sigma_{pPb}}{A\,\sigma_{pp}}$$

M. Bury, et al.
Phys. Lett. B780 (2018) 185-190





$$x \geq 10^{-6}$$

Constraining gluon distributions in nuclei using dijets