Multiple Parton Interactions

(where we are)

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Many thanks to: MPI@LHC forum
Special thanks to: Paolo Bartalini, Daniele Treleani, Sergio Scopetta

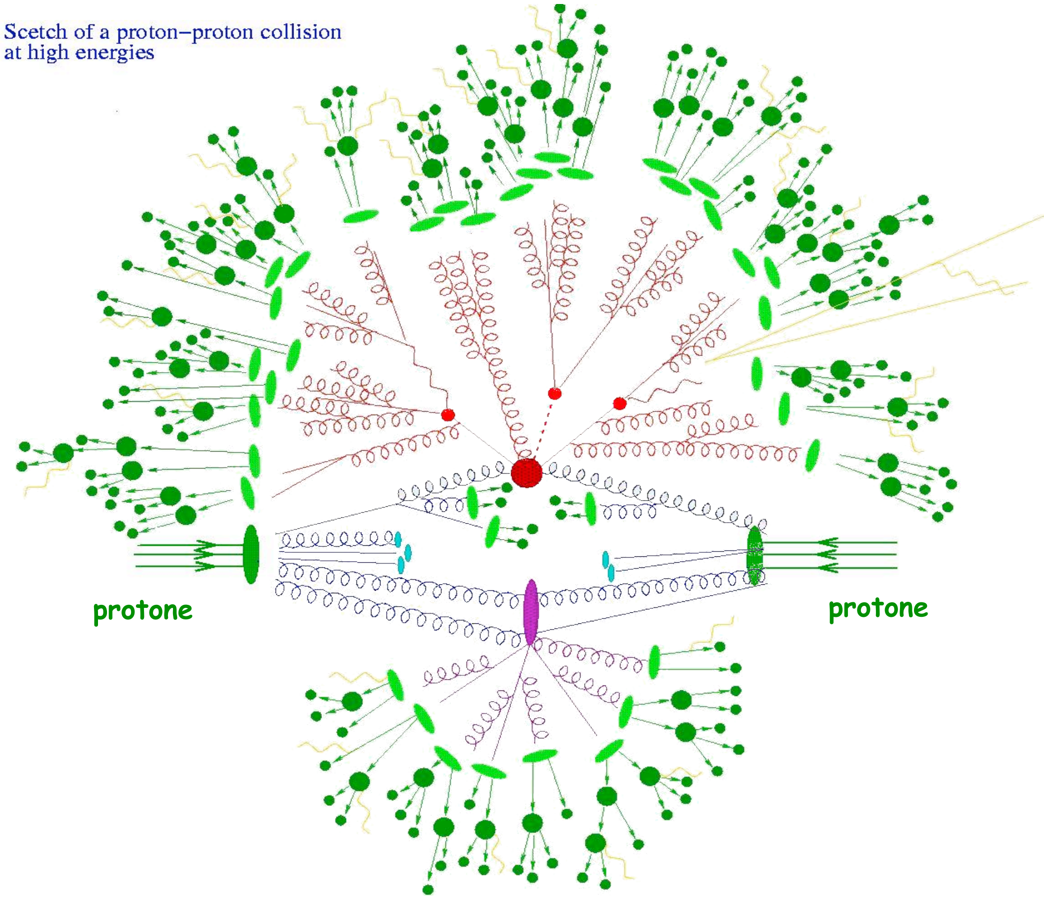
1. Motivations for MPI

Phenomenology/Characterization:

2. Soft-MPI
3. Hard-MPI (Double Parton Scattering)
4. Correlations

Conclusions/Highlights

Section 1 - Structure of the p-p interaction



Main Interaction

Radiation (ISR/FSR)

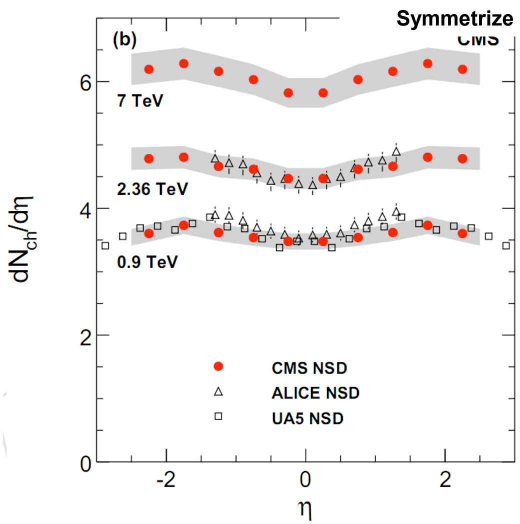
Jet

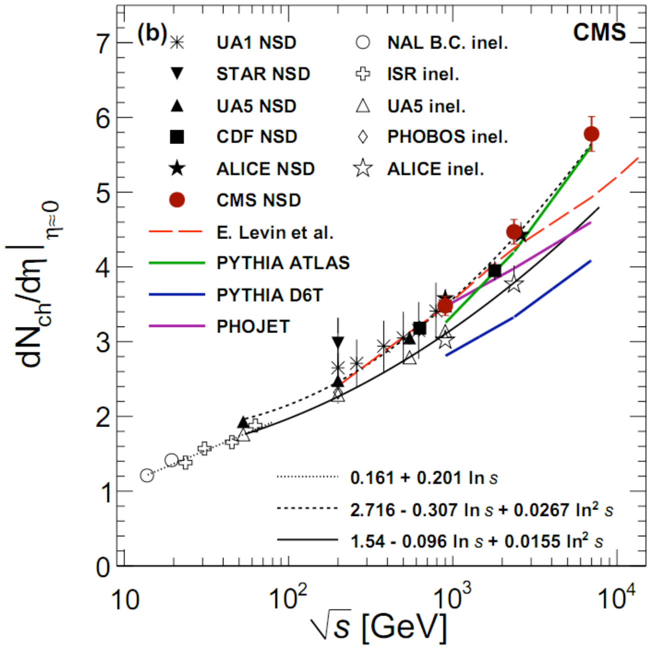
Fragmentation/ Hadronization

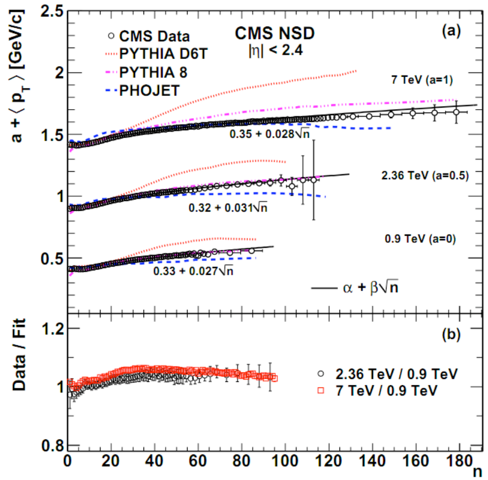
Mutiple Interactions (MPI)

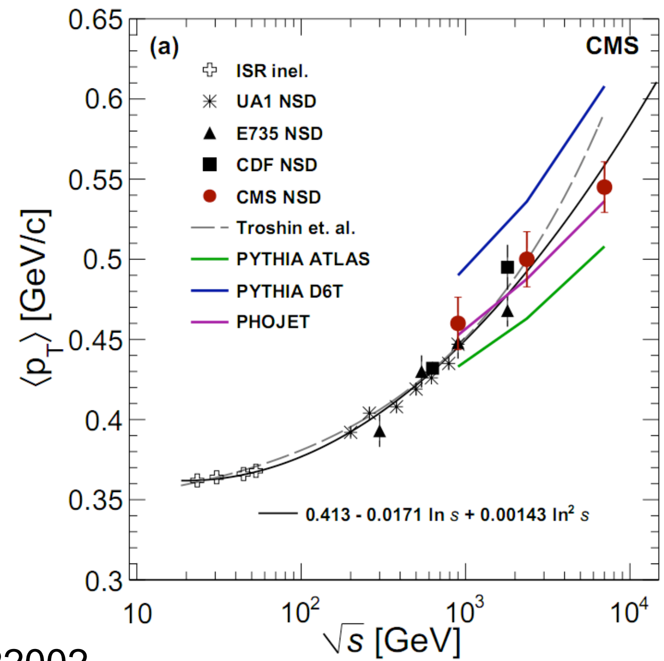
Beam Remnant

Pseudorapidity and pT distribution









JHEP 02 (2010) 041
Phys. Rev. Lett. 105 (2010) 022002

Most models are not able to describe simultaneously both energy evolution in $\rho(0)$ and $<p_T>$

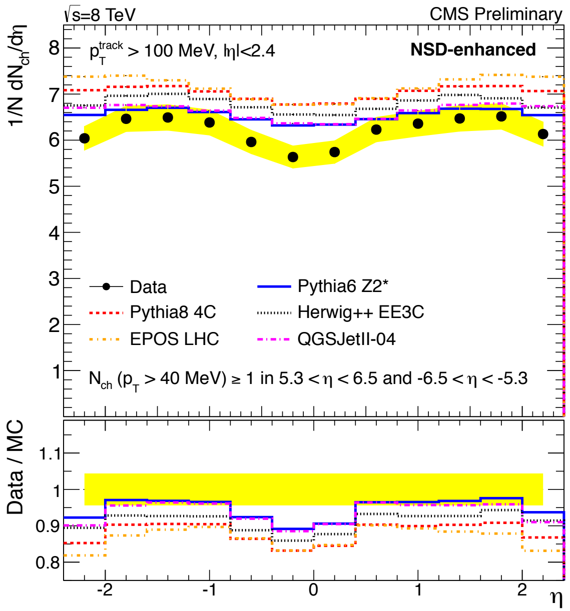
Why do these quantities rise and why faster than ln(s) ?

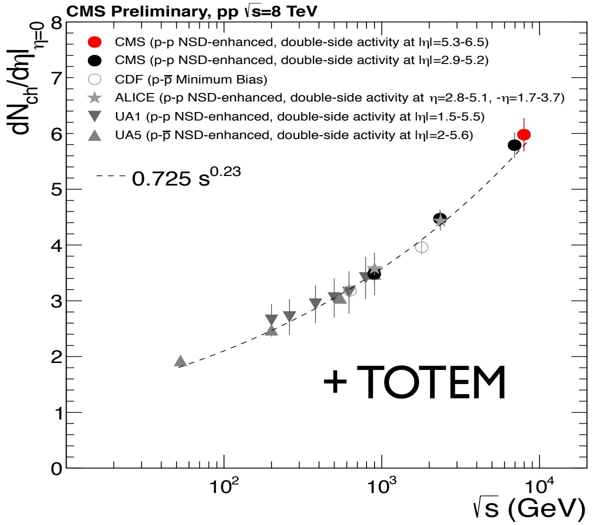
Solution: Multiple Parton Interactions
[T. Sjöstrand et al. PRD 36 (1987) 2019]

Introduce IP correlations in MPI
Turn off of the cross section at P_T cut-off

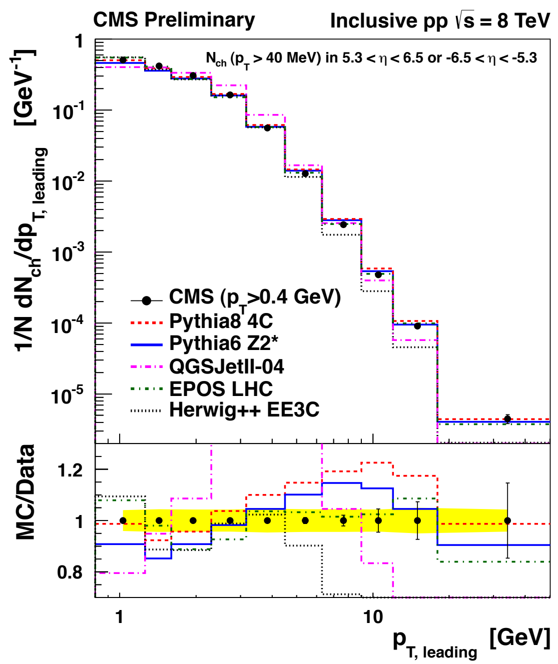
$$< N_{MPI} > = \sigma_{parton-parton} / \sigma_{proton-proton}$$

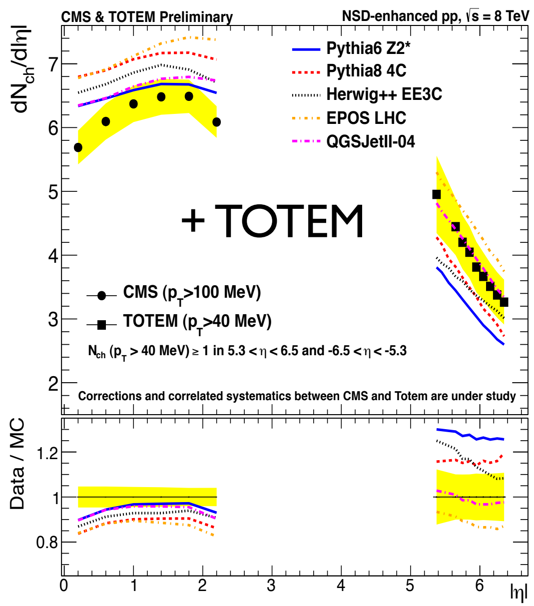
Pseudorapidity and pT distribution





8 TeV - NSD Enhanced





QCD radiation violates Feynman scaling at high energies

But, even when assuming Feynman scaling, the possibility of creating more strings in **MPI** gives rise of ρ(0) stronger than ln(s)

< p_T> is expected energy independent for soft processes

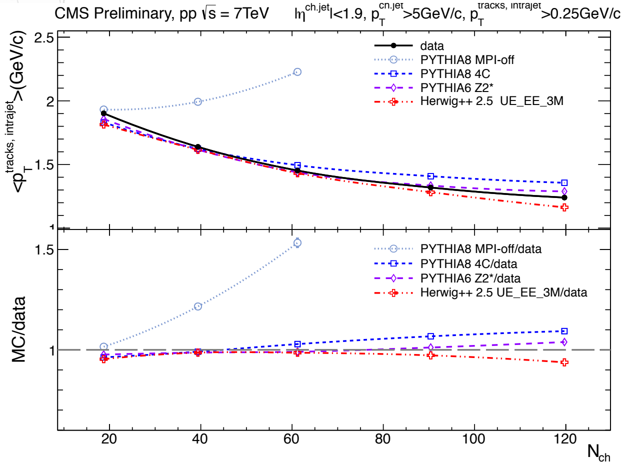
for hard scale the rise is due to

- production of jets in hard scatters
- and **MPI**

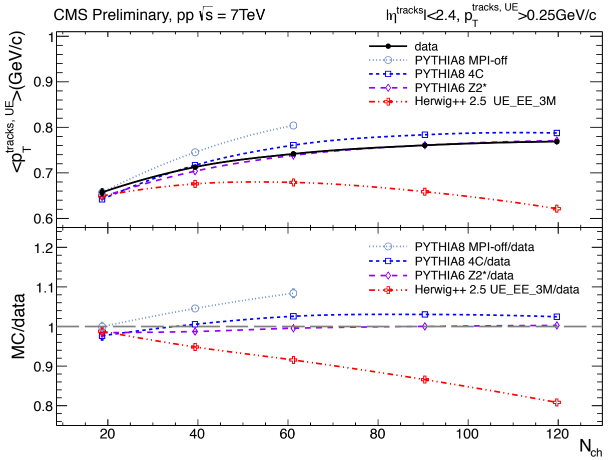
Models with MPI do the best job in central region (even if they ~fail forward)

CMS PAS FSQ-12-026

charged energy in/out track-jet definition

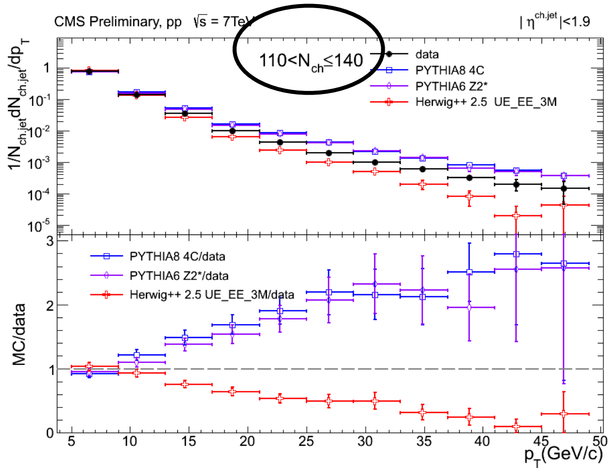


Intra-jet flow turns out to be very well described by pQCD MPI models, with MC slightly narrower at large N_{ch}.



After removing all intrajet particles from the event, the remaining particles are considered as belonging to the underlying event.

in high-multiplicity events, the model agreement is missing



good agreement with MPI prediction (especially Z-generation tunes) for charged inside and outside jet

what about high-multiplicities ?

CMS-PAS-FSQ-12-022

Transverse Sphericity

$$S_{\mathrm{T}} = \frac{2\lambda_2}{\lambda_2 + \lambda_1}$$

$$\mathbf{S_{xy}} = \frac{1}{\sum_j p_{\mathrm{T}j}} \sum_i \frac{1}{p_{\mathrm{T}i}} \begin{pmatrix} p_{x_i}^2 & p_{x_i} p_{y_i} \\ p_{y_i} p_{x_i} & p_{y_i}^2 \end{pmatrix}$$

$S_T \approx 0$ jetty events

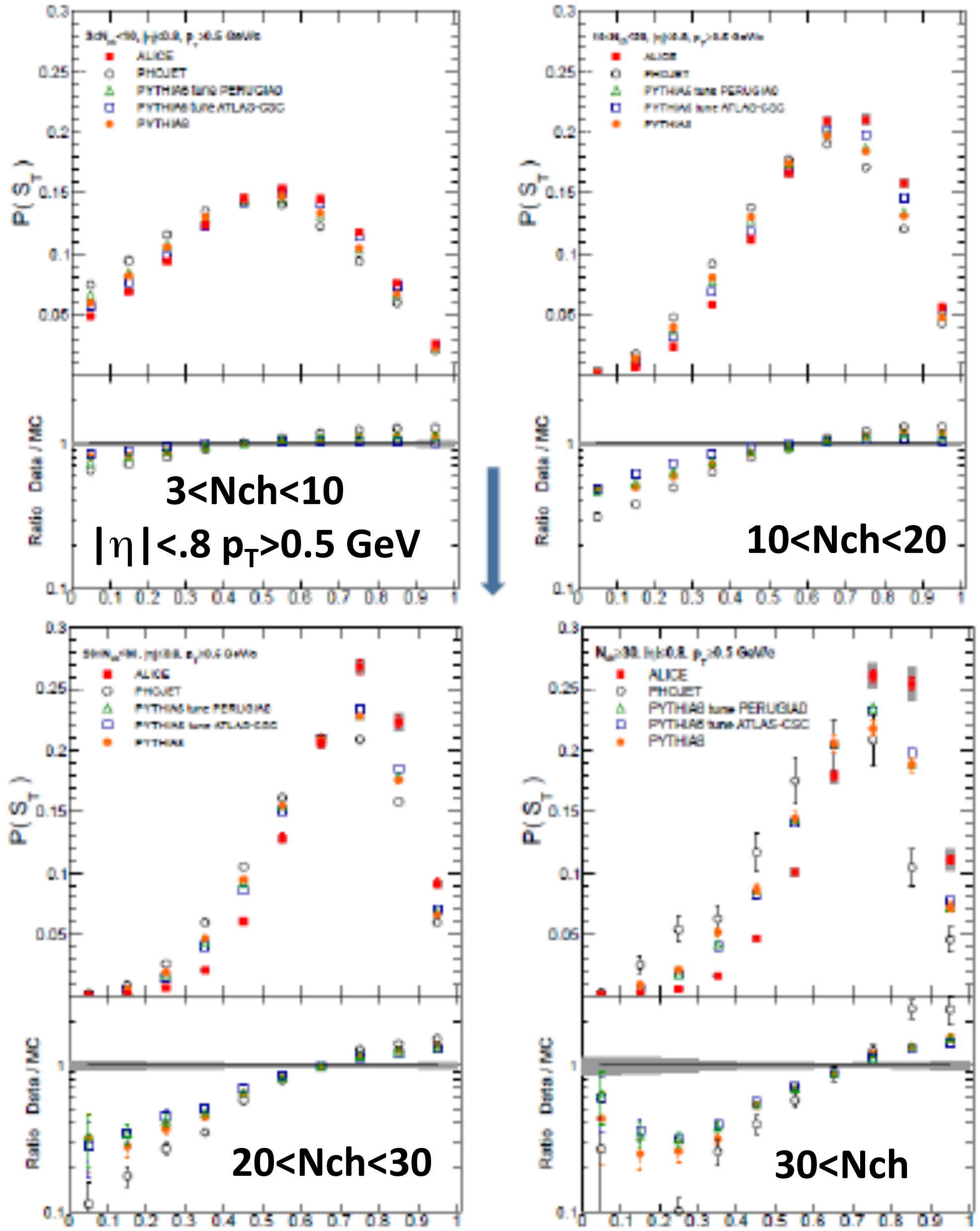
$S_T \approx 1$ isotropic events

Average Transverse Sphericity grows with N_{ch}, as expected.

The large multiplicity events are less "jetty" than expected: no model reproduces the ALICE observations for $N_{ch} > 30$

Large multiplicity: Sphericity correlated to N_{MPI} may provide additional handles to study large multiplicity features

[G.Paic, MPI@LHC 2013, Antwerpen]
See also arXiv:1404.2372



ALICE, Eur.Phys.J. C72 (2012) 2124

Section I - multiplicities

MPI model:

Energy evolution in $\rho(0)$ and $<p_T>$, KNO scaling violation, event shape...

Jet constituents...

High multiplicity events turn out to be less jetty than predicted, they can be regarded as the result of several MPI

This is also confirmed by the Transverse Sphericity analysis.

The high multiplicity events are not driven by the leading interaction, they are rather due to large MPI multiplicities ? Best data/model agreement if MPI+CR

not shown:

$dN_{ch}/d\eta$ shapes and <pT> vs Nch normalization favor implementation of color reconnections in MPI models

Barion/meson ratios vs p_T in pp interactions are know to scale with vs $\sqrt{s}$. A first look to their N_{ch} dependence in the context of pQCD MPI reveal sensitivity to color reconnections with qualitative flow-like patterns.

Section 1 - multiplicities

Energy evolution in ρ(0) and <p_T> as well as KNO violation, modeled by MPI

Several indications of the role played by MPI
focussed investigations needed

High multiplicity events turn out to be much less jetty than predicted by Pythia. In the context of the pQCD MPI models they can be regarded as the result of several MPI.

The MPI@LHC forum is a consequence of a series of WS
[Perugia 2008, Glasgow 2010, DESY 2011, CERN 2012, Antwerpen 2013, Krakow 2014] aiming to:

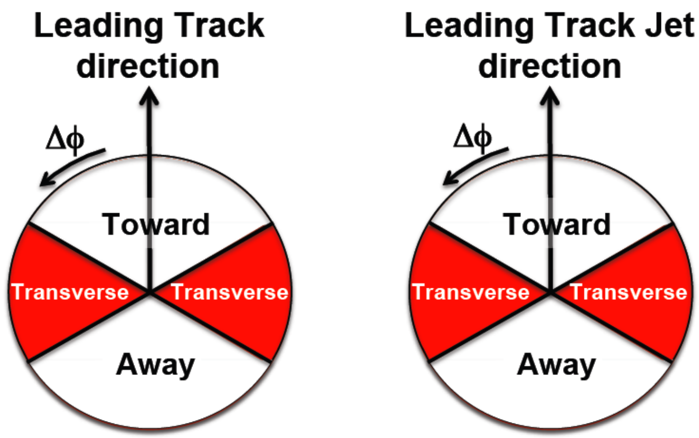
The high multiplicity events are not driven by the leading interaction, they are rather due to large MPI multiplicities (even more diluted in p-Pb collisions).

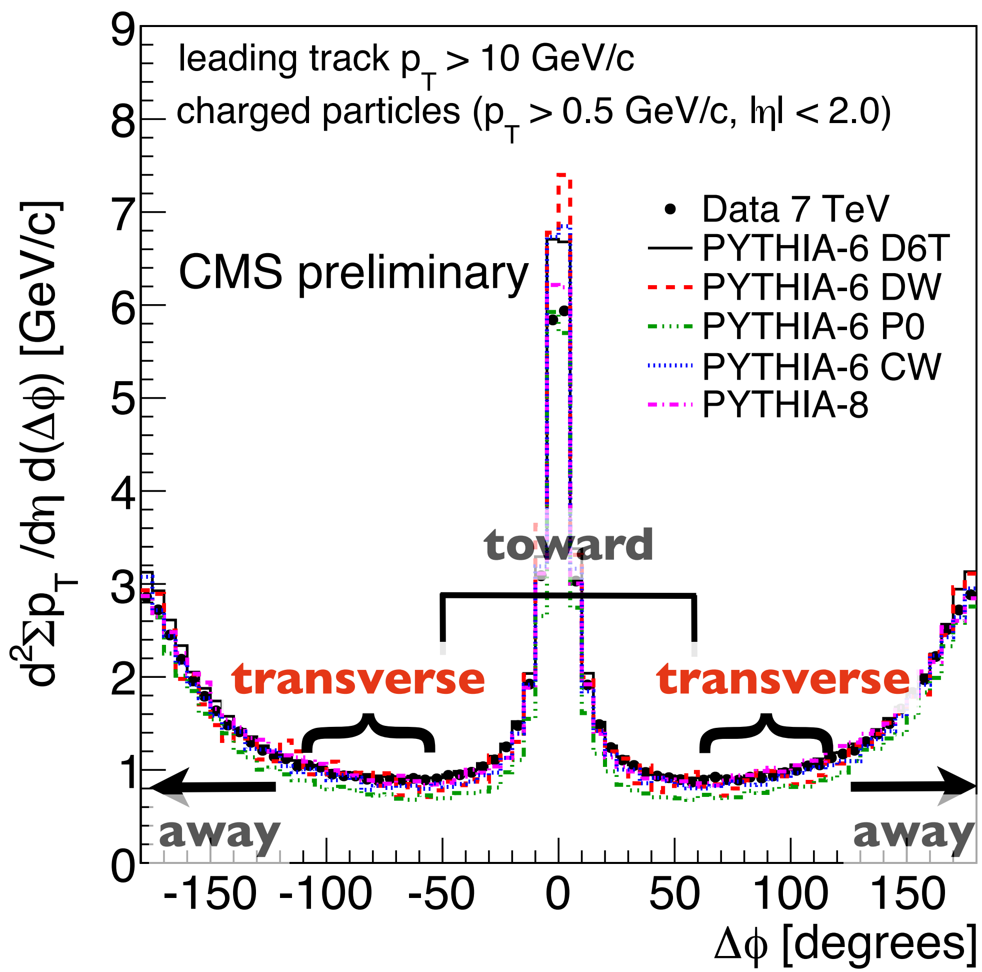
Bring Exp and Theo communities on the same topic
Setup a characterization program for LHC

favor implementation of color reconnections in MPI models

Soft MPI phenomenology → Underlying Event
Hard MPI phenomenology → Double Parton Scattering

Section 2 - Underlying Event





Traditional approach (R. Field)

Leading Track or Leading Track-Jet define a direction in the phi plane for the HS

Track or Track-jet pT provides an energy scale

Observables are built from tracks:

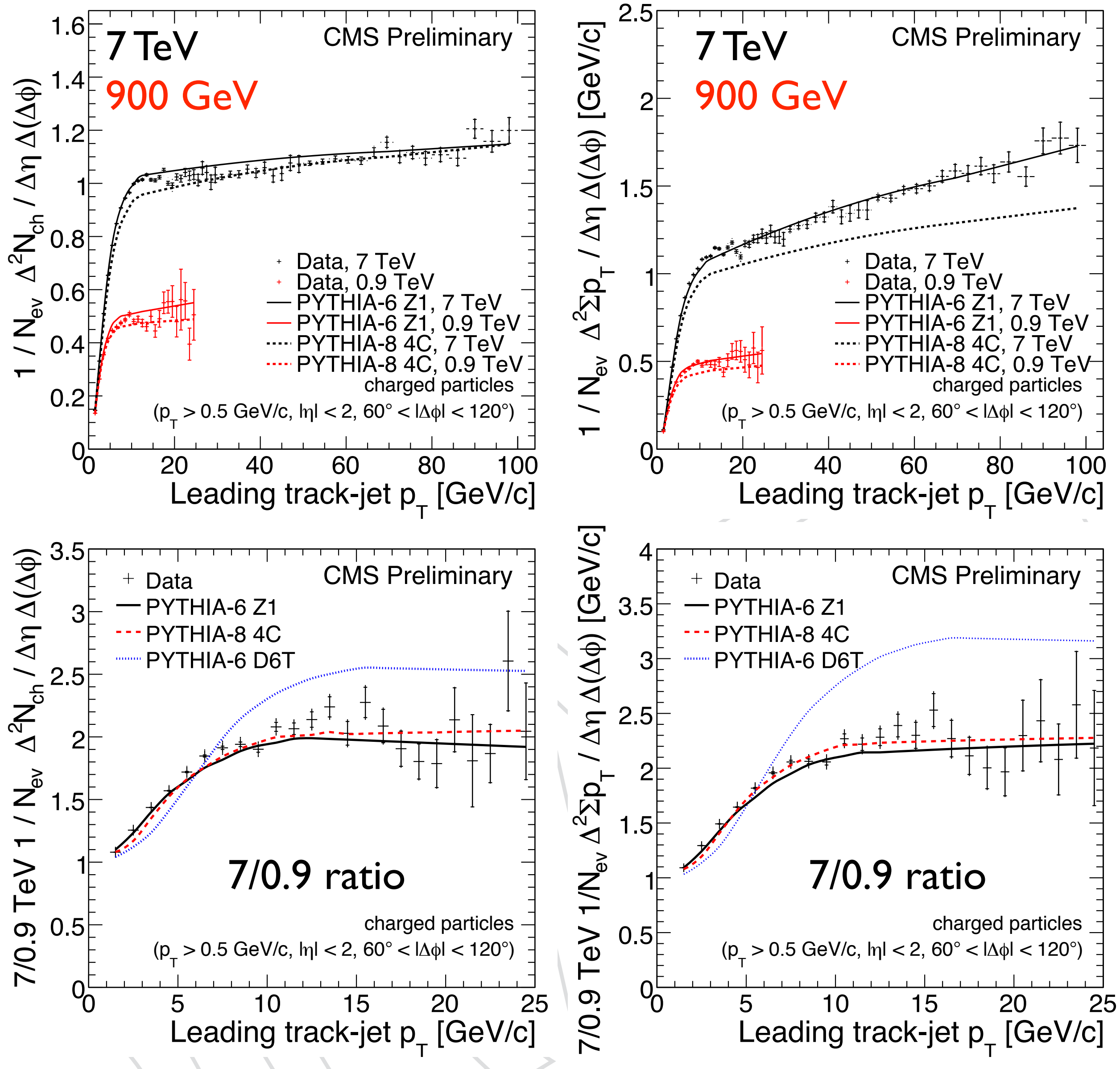
- **$d^2N_{ch}/d\eta d\phi$ -** multiplicity density
- **$d^2\Sigma p_T/d\eta d\phi$ -** energy density

900 GeV - Eur.Phys.J.C70:555-572,2010
7 TeV - JHEP09 (2011) 109

Observables can be defined using Δφ correlations relative to main activity

Transverse region is expected to be sensitive to the UE

The transverse region - jet events



1) **Fast rise** for pT< 8(4) GeV/c due to the increase of the MPI

2) **Plateau region** with ~constant charged density increasing pT_sum (radiation)

3) Increase of the activity with $\sqrt{S}$ → more MPI

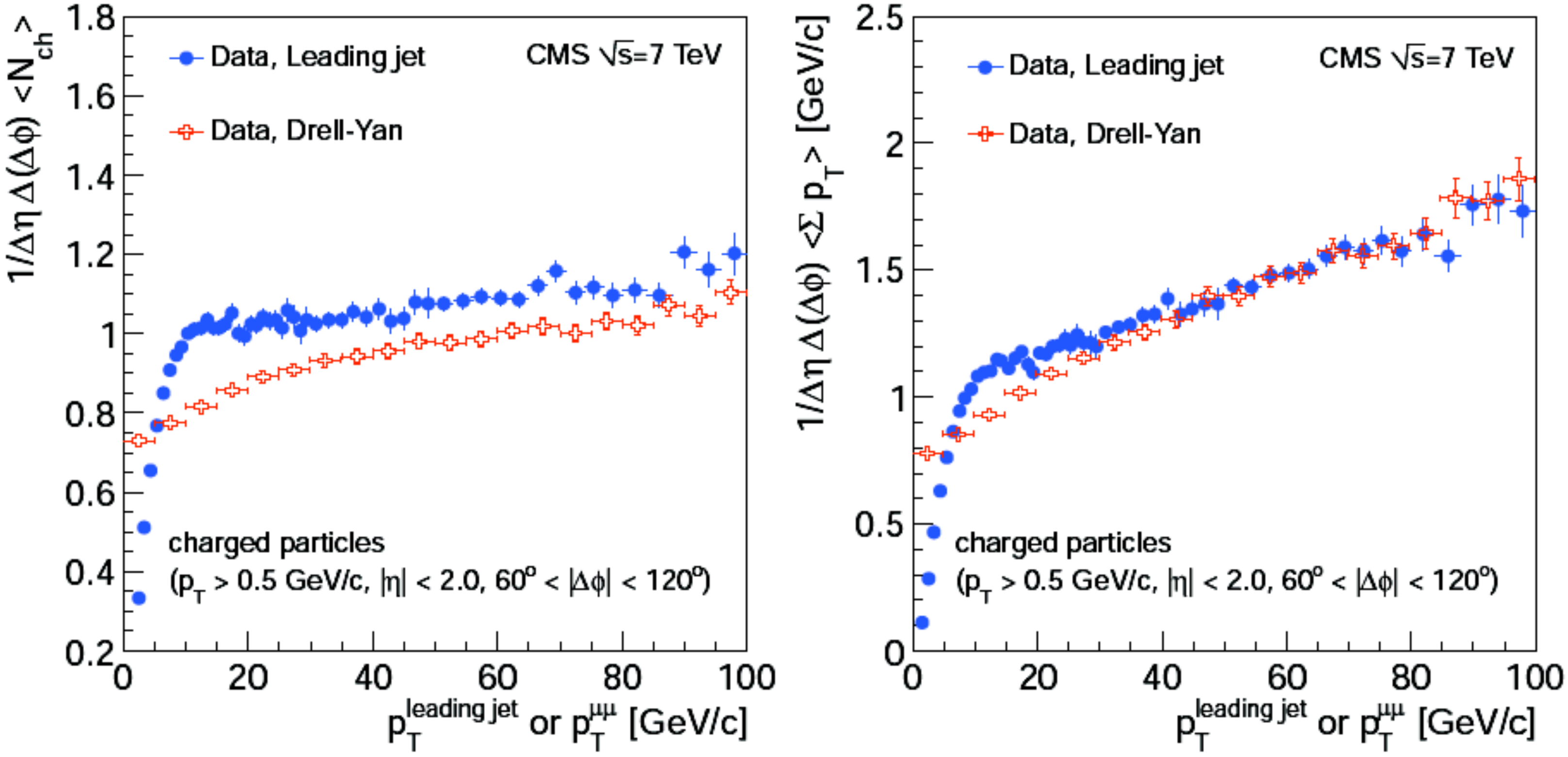
Interpretation:

Fast rise:
periferal collision
~independent on $\sqrt{s}$

Plateau:
mainly **central collisions**
The ratio reflects the different size of the central, high parton density regions for the two $\sqrt{s}$ domains

JHEP09 (2011) 109

The transverse region - Drell-Yan events



+ **Hard energy scale (81 < $M_{\mu\mu}$ < 101 GeV/c²)**: no fast rise

+ scale > 10 GeV/c DY events have a smaller particle density with a harder p_T due to the presence of **only ISR initiated by quarks**

+ Hadronic events have both initial and final state radiation predominantly initiated by gluons.

hep-ex:1204.1411

Section 2 - soft MPI

Two scale picture (rise at low p_T + plateau) in the case of **jet events**:

Interpretation: peripheral + central collisions (high p_T jets) hence large MPI multiplicity

Single scale picture (plateau) in the case of **DY**

Interpretation: DY events select more central collisions hence large MPI multiplicity.

MPI+GPDF analysis also explains UE(DY)/UE(jets)

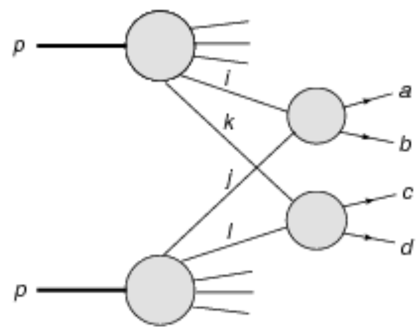
Connection to $<\rho^2>_g / <\rho^2>_q$

[see backup for a detailed interpretation based on transverse nucleon structure]

Section 3 - Double Parton Scattering

Double high P_T interactions observed 30 years ago by AFS, UA2 in 4jets topologies

20-10 years ago CDF and D0 used also 3jet + γ



$\sigma(A+B) = m * \sigma(A) * \sigma(B) / \sigma_{eff}$

(m = ½ for identical interactions, m = 1 otherwise) - $P(B|A) = P(B) * (\sigma_{Non\text{-}Diffractive}/\sigma_{eff})$

$$\sigma_{\text{eff}} = \frac{1}{\int d^2\beta F^2(\beta)}$$

naïve prediction: $\sigma_{eff} \approx 1/\pi R_{EM}^2 \approx 60$ mb (3÷6 times higher than data)

$\sigma_{eff} \approx$ (process,) scale and $\sqrt{s}$ independent [D. Treleani et al., very rich bibliography]

σ_{eff} mostly depends on geometry

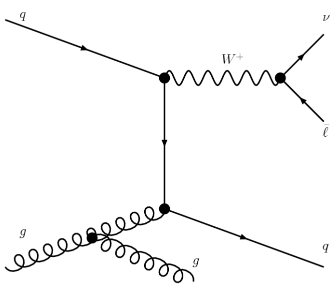
$\sigma_{eff} \approx 34$ mb considering 4 → 4 processes [M. Strikman et al.]

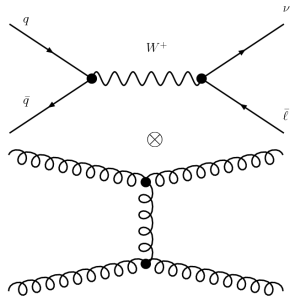
3 in 4 processes give significant contributions, rising with $x_{Bjorken}$ [B.Blok, MPI@LHC 2013]

Pythia 6 and Pythia 8: $\sigma_{eff} = \sigma_{Non\text{-}Diffractive} / \langle f_{impact} \rangle \sim 20\text{-}30$ mb

where $\langle f_{impact} \rangle$ [enhancement central/peripheral] is tune dependent → soft MPI tunes: $\sigma_{eff} \approx 20÷30$ mb

W+2j (CMS) - Double Parton Scattering



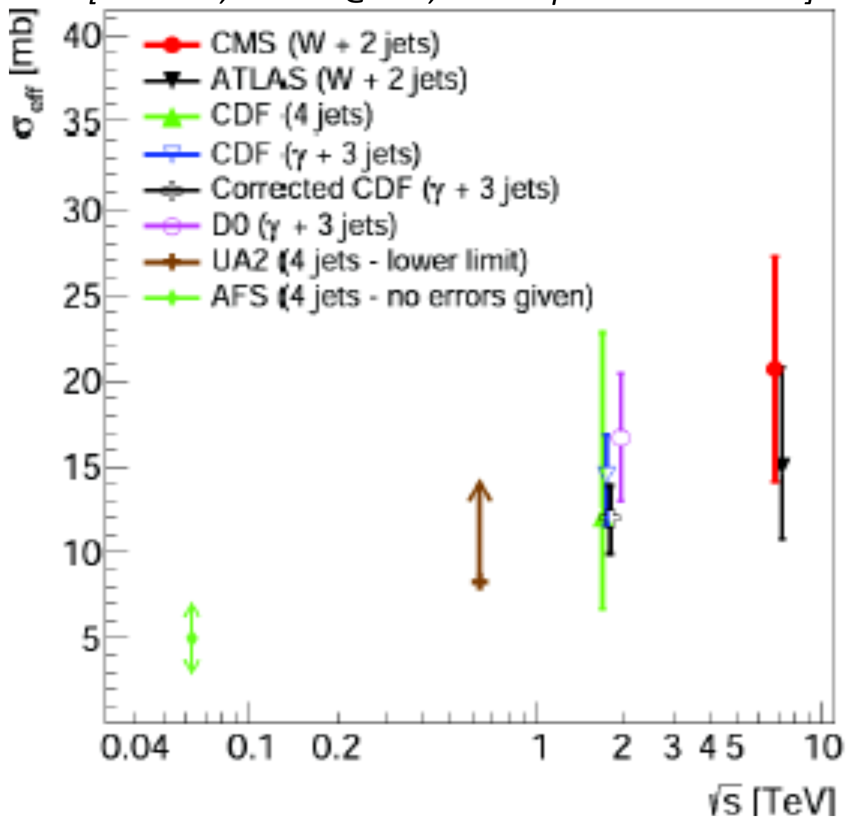


Measured di-jet x-section

Measured Ratio between W+2jets and W+0jets x-sections

$$\sigma_{\text{eff}} = \frac{R}{f_{\text{DPS}}} \cdot \sigma'_{2j}$$

[S.Bansal, 5th MPI@LHC, Antwerp December 2013]



arXiv:1312.5729.

measured $\sigma_{\text{eff}} \approx$ 10÷20 mb
(lower at Tevatron, higher from LHC)

from previous slide, prediction based on soft MPI tune is $\approx$ 20÷60 mb

DPS underestimated in the models tuned on Soft QCD phenomenology?

What are the relationships between "soft" and "hard" MPI measurements?
Which role for parton correlations ?

Introduction to Double Parton Scattering

hadronic:

σ_{DPS} (4jets@100 GeV) = ½ * (σ (2jets))^2/σ_{eff}= ½ * (1μb)^2/σ_{eff} = 5 10^{-5} μb = **50 pb**

apply extra 1% factor for each b-jet pair requirement

σ_{DPS} (2γ+2jets@20 GeV) = ½ * (σ (γ+jet))^2/σ_{eff} = ½ * (0.1μb)^2/σ_{eff} = 5 10^{-7} μb = **0.5 pb**

hadronic - incoming/future:

σ_{DPS} ($W^\pm \rightarrow \mu\nu, W^\pm \rightarrow \mu\nu$) = ½ * ($\sigma$ ($W^\pm \rightarrow \mu\nu$))^2/σ_{eff} = ½ * (20nb)^2/σ_{eff} = 2 10^{-5} nb = **20 f**b

half of which (10 fb) corresponds to same sign muons

σ_{DPS} ($Z \rightarrow \mu\mu, Z \rightarrow \mu\mu$) = ½ * ($\sigma$ ($Z \rightarrow \mu\mu$))^2/σ_{eff} = ½ * (2nb)^2/σ_{eff} = 2 10^{-7} nb = **0.2 fb**

heavy flavor final-state:

$\sigma^{J/\psi J/\psi}$ = 5.1 +- 1.0 (stat) +- 1.1 (syst) nb

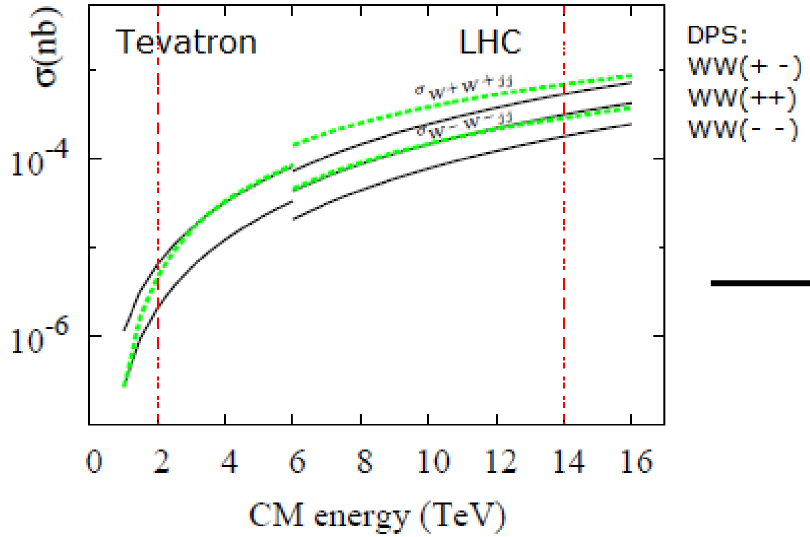
(20% higher than the SPS predictions. contribution from DPS? SPS contribution suppressed at large Δy)

heavy flavor final-state - incoming/future:

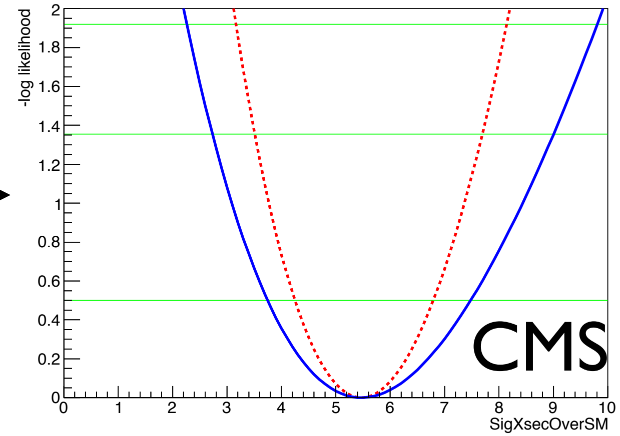
[W+prompt J/ψ - hint for DPS contribution higher than assumption]

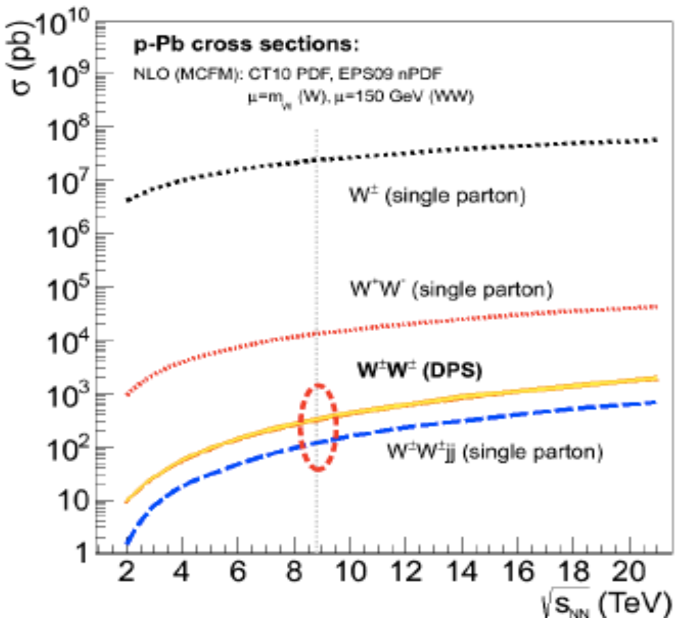
[Z+D - DPS higher than SPS]

same sign Ws - Double Parton Scattering



very low stat available from runI, only lower limit on σ_{eff}





p-Pb 8.8 TeV enhancement

DPS/SPS separation largely increased:

DPS~300 pb

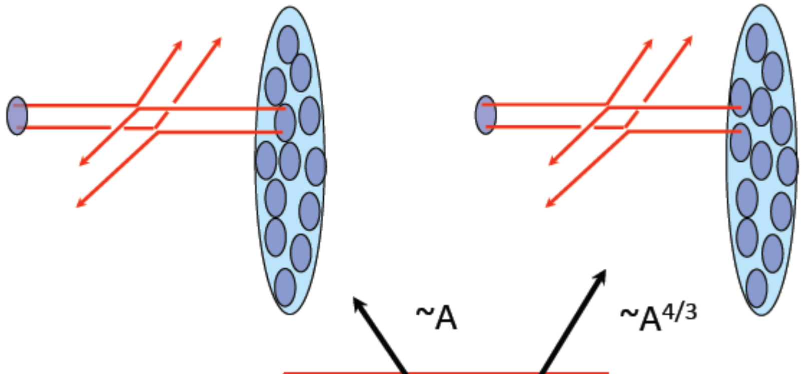
SPS~100 pb

$\sigma_{eff,pp}/\sigma_{eff,pA} \approx$ **600**

D'Enterria & Snigirev, arXiv:1211.0197.

p-N - Double Parton Scattering

[D.Treleani, MPI@LHC 2013, Antwerpen] - Arxiv:1309.6201



$$\sigma_D^A = \sigma_D^A\big|_1 + \sigma_D^A\big|_2$$

Additional information on σ_{eff} from MPI correlations are expected in p-N collisions

effects of longitudinal and transverse correlations are in fact different when a single nucleon or both target nucleons participate in the hard process.

The simplest case: W+2j in p-Pb:

+ interference term absent
+ strong anti-shadowing correction:
  1)proportional to MPI multiplicity and
  2)weakly depending on transverse correlation

experimentally easy to detect (using the lepton from W)

$$\sigma_D^{pA}(WJJ)\big|_1 = \frac{1}{\sigma_{eff}}\left[Z\sigma_S^{p[p]}(W)\sigma_S^{p[p]}(JJ) + (A-Z)\sigma_S^{p[n]}(W)\sigma_S^{p[n]}(JJ)\right]$$

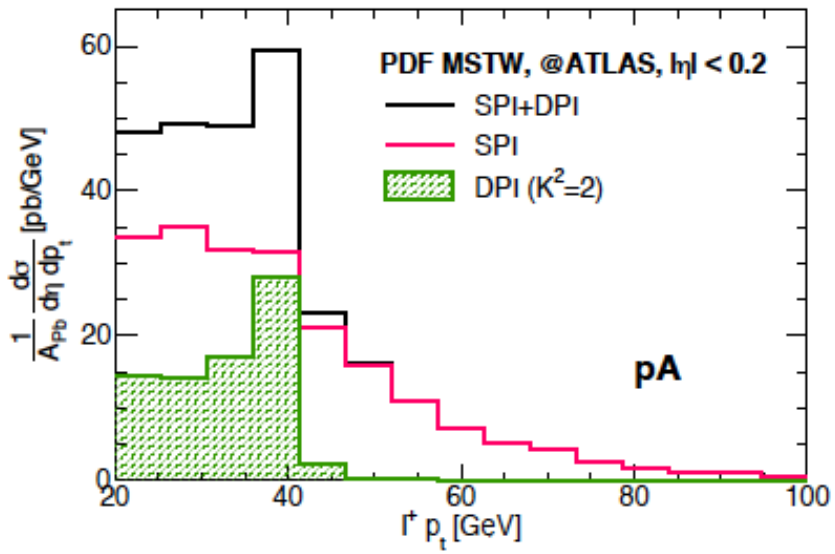
$$\sigma_D^{pA}(WJJ)\big|_2 = K\left[\frac{Z}{A}\sigma_S^{pp}(W) + \frac{A-Z}{A}\sigma_S^{pn}(W)\right]\sigma_S^{pp}(JJ) \times\left[\int T(B)^2 d^2B - 2\int \rho(B,z)^2 d^2B dz \times r_c \mathcal{C}_K\right]$$

short range nuclear correlation

anti-shadowing contribution

nuclear thickness function => growth as A$^{4/3}$

nuclear density => growth as A



Enhanced shoulder at ≈ 40 GeV in pA interactions

Section 3 - Double Hard Scattering

Corrected distributions for several DPS-sensitive observables
Achieved for 4jets, W+2jets, W+J/Ψ, Z+D, double J/Ψ, double open charm, other channels in progress.

Interpretation, consistency checks
In progress...still no direct DPS evidence. Large systematics on σ_{eff}, model dependency

More processes: study process dependency
In progress, precision of the measurements still doesn't allow to compare σ_{eff} in q-initiated and g-initiated processes, comparing with corresponding UE ratios.

Differential distributions
Requires more integrated luminosity: HL-LHC, i.e. FUTURE…

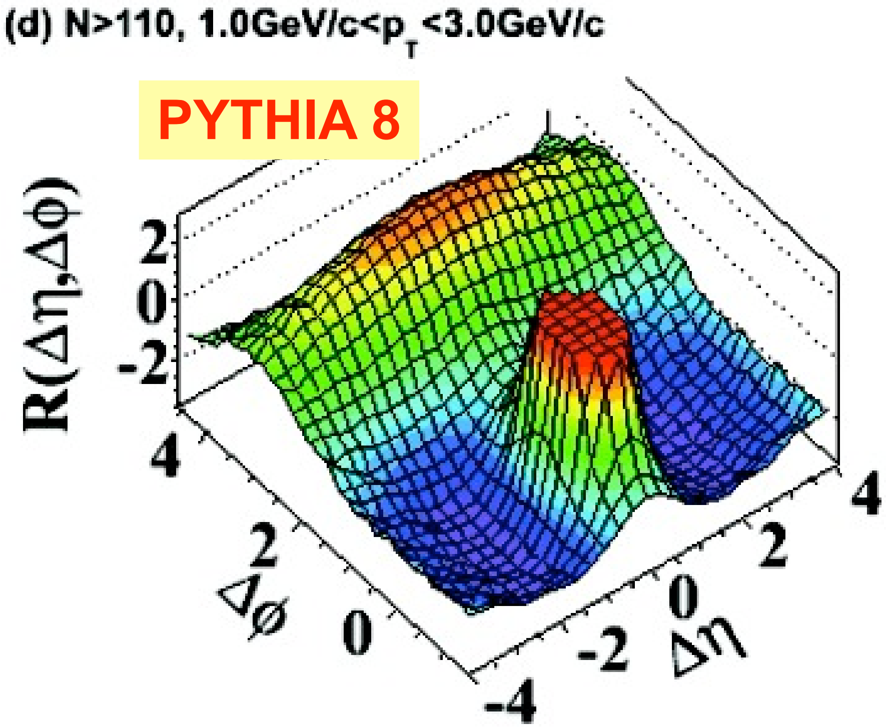
Extension of the DPS measurements to p-Pb
should proceed in parallel, for now we have some nice/promising TH predictions and feasibility studies

Sensitivity to parton correlations

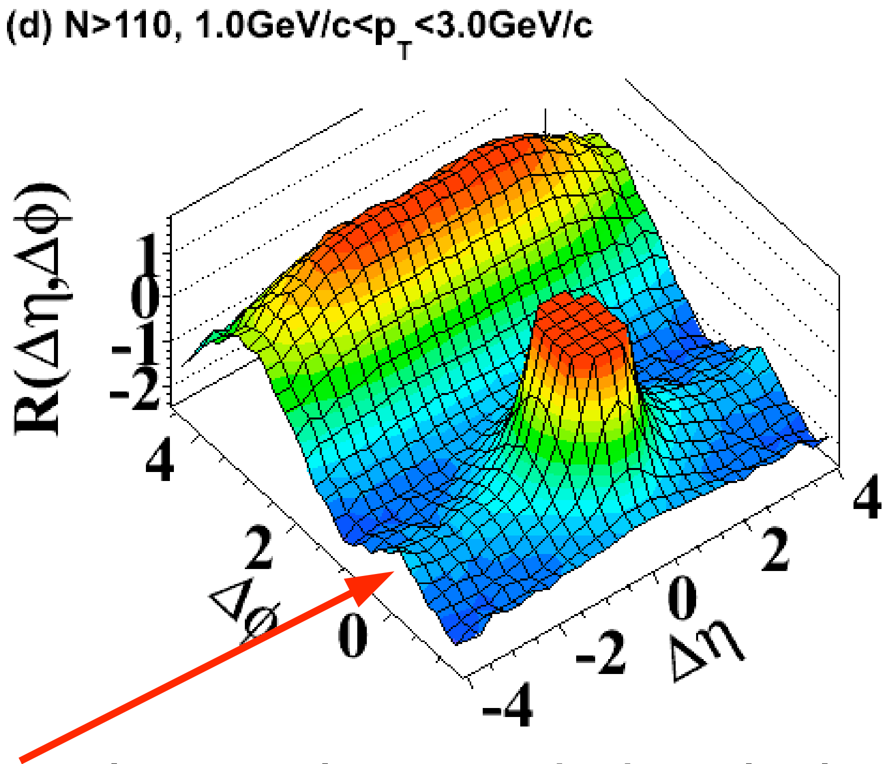
Section 4 - High multiplicity correlations

Intermediate pT : 1 < p_T < 3 GeV/c

High Multiplicity: N>110



High Multiplicity: N>110



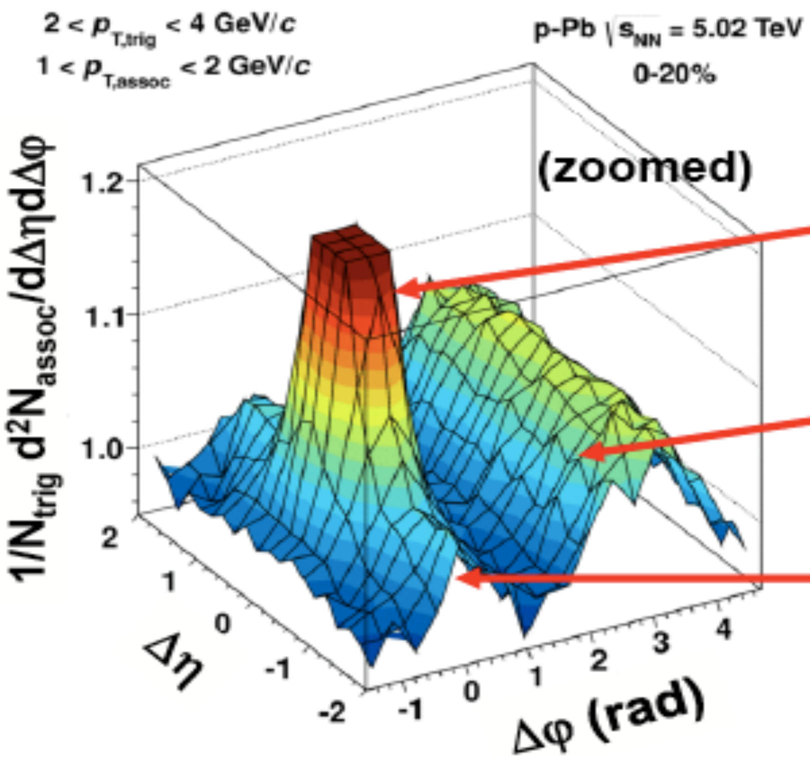
Observation of a Long-Range, Near-Side angular correlations at high multiplicity in pp events at intermediate pT (Ridge at $\Delta\phi \sim 0$)

not reproduced by actual models

High multiplicity correlations

A similar feature observed at RHIC (AuAu 200 GeV). Interpreted as **hot and dense matter** formed in relativistic heavy ion collisions

ALICE: reported same structure in p-Pb collisions (5.02 TeV)



$2 < p_{T,trig} < 4$ GeV/c
$1 < p_{T,assoc} < 2$ GeV/c
20% highest multiplicity

Near-side jet
($\Delta\varphi \sim 0$, $\Delta\eta \sim 0$)

Away-side jet
($\Delta\varphi \sim \pi$, elongated in $\Delta\eta$)

Near-side ridge
($\Delta\varphi \sim 0$, elongated in $\Delta\eta$)

Correlation profile for lower multiplicity (60-100%) is subtracted from the one for higher (20% highest)

Possible interpretations (elliptic flow a part)

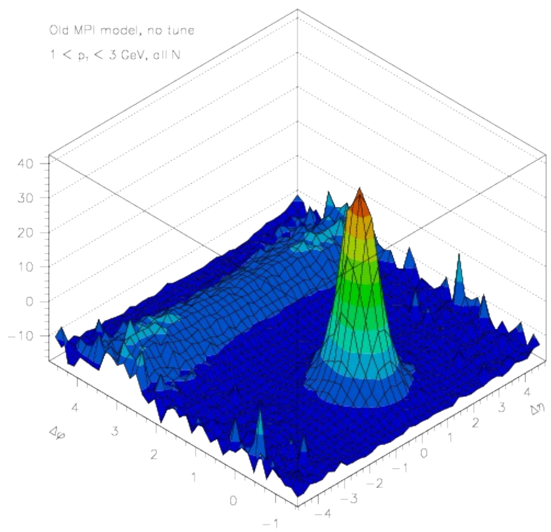
MPI model does not take into account angular momentum conservation

The number of MPI is regularized by the IP, but the azimuth of the scattering plane is chosen randomly for each MPI → no long-range near-side angular correlations in PYTHIA

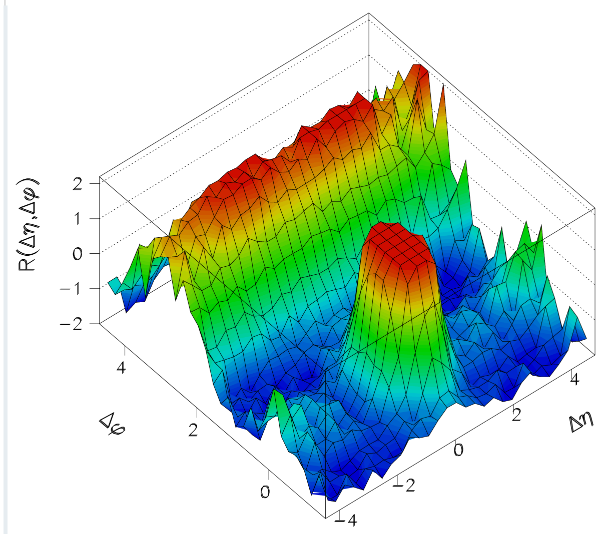
With a impact-parameter dependent smearing:

$$\phi_i = \phi_{hardest} + \mathrm{Gauss}(\mu = 0, \sigma = 1)\,\arctan(b_{avg}/b)$$

1 < pT < 3 GeV, all N



1 < pT < 3 GeV, N > 90



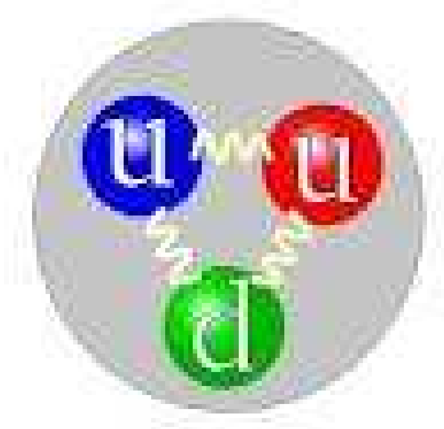
Such a correlation can be naturally explained in a physical picture based on the impact parameter between the protons

Warnings:
Azimuthal correlation of MPIs was studied experimentally at Tevatron but no evidence was observed

Correlation modeling in a Constituent Quark Model

S. Scopetta et al. - PRD 87, 114021 (2013)

- In a potential model, effective particles are strongly bound and correlated.
  No modifications of the model properties are necessary to describe correlations



- In this sense, CQM are a proper framework to describe DPCs **BUT** their predictions are reliable in the valence region, while LHC data, for the moment, are available only for much lower values of Bjorken x
- At very low x, due to the large population of partons, the role of correlations may be less relevant **BUT** there is no quantitative theoretical estimate available

Correlation modeling in a Constituent Quark Model

- In principle, correlations are there
- We are not alone in addressing this issue
  (see Markus' and almost all the other talks. Many published papers: Korotkikh and Snigirev (2004), Gaunt and Stirling (2010), Diehl and Schäfer (2011), Snigirev (2011), Blok et al. (2012), Schweitzer, Strikman and Weiss (2013)...)
- DPCs cannot be studied from first principles:
  dPDFs are non-perturbative quantities
- Our contribution: a quark model analysis as a possible useful tool

The Isgur-Karl model
IK is a suitable framework for a first CQM calculation of DPCs:

- IK is the prototype of any other CQM; low energy properties of the nucleon, such as the spectrum and the electromagnetic form factors at small momentum transfer are reproduced;
- Gross features of the standard PDFs are reproduced.

The model results correspond to a low momentum scale (hadronic scale, μ_o^2). There are only valence quarks: the scale has to be very low ($\mu_o \simeq$0.300 GeV according to NLO pQCD). Data are taken at a high momentum scale t. QCD evolution needed!

Correlation modeling in a Constituent Quark Model

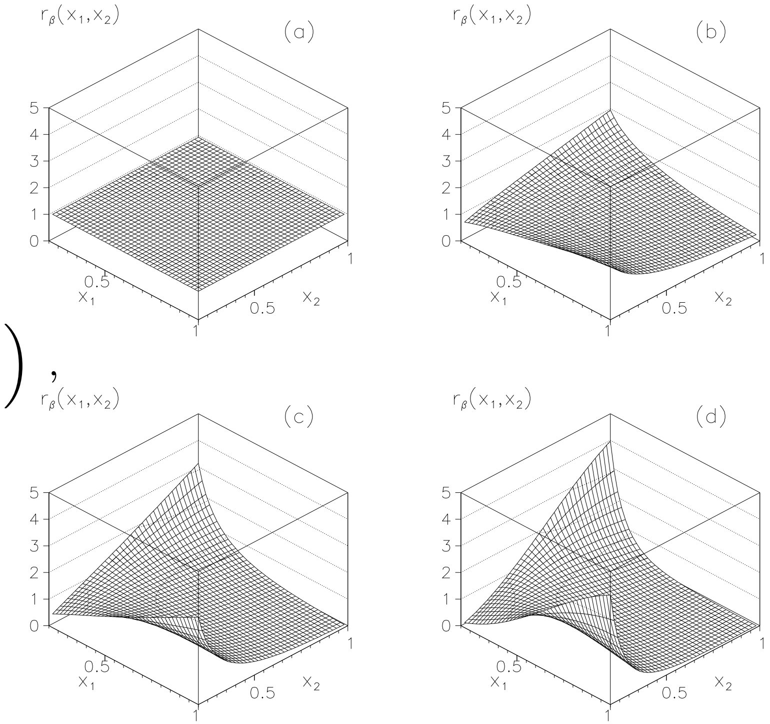
$$r_\beta(x_1,x_2) = \frac{2uu_\beta(x_1,x_2,k_\perp=0)}{u_\beta(x_1)u_\beta(x_2)}$$ where:

1) the dPDF depends on a parameter β:

$$uu_\beta(x_1,x_2,k_\perp=0) = 2\frac{(4-\beta)^{3/2}}{\pi^3\alpha^6}\int d\vec{k}_1 d\vec{k}_2$$
$$\times e^{-2(k_1^2+k_2^2+\beta\vec{k}_1\cdot\vec{k}_2)/\alpha^2}\,\delta\left(x_1-\frac{k_1^+}{P^+}\right)\delta\left(x_2-\frac{k_2^+}{P^+}\right),$$

2) the corresponding PDF is:

$$u_\beta(x_i) = 2\frac{(4-\beta)^{3/2}}{\pi^3\alpha^6}\int d\vec{k}_1 d\vec{k}_2$$
$$\times e^{-2(k_1^2+k_2^2+\beta\vec{k}_1\cdot\vec{k}_2)/\alpha^2}\,\delta\left(x_i-\frac{k_i^+}{P^+}\right),$$



a) $\beta=0$: uncorrelated scenario; b) $\beta=0.25$; c) $\beta=0.5$;
d) $\beta=1$: the correlated HO framework

Huge effect! May be the real situation is somewhere in between (a) and (d)...
We have to improve the model...

Recent developments using LF RHD (work in preparation)

* A covariant approach with on-shell constituents
* Correct support (important for QCD evolution)
* Proper framework for spin correlations and low-x model calculations

Section 4 - Correlations

Significant ridge structures are observed in high multiplicity pp ($\sqrt{s}$ = 2.76 and 7 TeV), p-Pb ($\sqrt{s_{NN}}$ = 5.02 TeV) and Pb-Pb ($\sqrt{s_{NN}}$ = 2.76 TeV) collisions

Pb-Pb: expected from the elliptic flow

p-Pb and pp observations still miss an agreed interpretation

Interpretation: Large multiplicities without pronounced jetty structures point to an important role played by Multiple Parton Interactions

Angular momentum conservation?
Color reconnections?
Multi-Phase Transport Model (AMPT) is successful relies on pQCD MPI for the description of the initial state
Explore the full potential ("3D correlations" from p-N collisions)

CQM:
Can one analyze dPDFs @ LHC kinematics (very low x, high momentum scale) within relativistic quark models (whose predictions are initially valid in the valence region) ?

[Tools: QCD evolution of dPDFs; inclusion of higher Fock space components in addition to the valence one]

soft&hard MPI - energy scale

Z(μμ)+Z(μμ)

≈ 0.1 fb

W(μν)+W(μν)

W(μν)+HF   Z(μμ)+HF

bb+jj   γ+3j

4j   W(μν)+jj   Z(μμ)+jj

Double J/Ψ   W(μν)+J/Ψ

Soft (Minimum Bias)   j+UE   W+UE   Z(μμ)+UE

≈ 100 mb

Scale of secondary scatter(s)

Scale of primary scatter

LHC measurements available

LHC measurements not yet available

Complement with p-A and A-A

Conclusions/Highlights

Multiple Parton Interactions have been introduced to solve the unitarity problem generated by the fast raise of the inclusive hard cross sections at small x

MPI are an instruments to probe proton matter distribution, understand the collision dynamics and define at the best a unexpected background to new physics search

Past experiments indicating Double Parton Scattering suggested the extension of the same perturbative picture to the soft regime, giving rise to the first implementation of the MPI processes in a pQCD Monte Carlo model (T.Sjöstrand and M.van Zijl). Such model turned out to be successful in reproducing the charged multiplicity distributions and Koba Nielsen Olesen (KNO) scaling violation

The critical kinematical regime of MPI may be identified by comparing the rate of double collisions with the rate of single collisions. When the two rates become comparable **multiple collisions are no longer a small perturbation and all multiple collisions become equally important**, while the production of hard partons becomes a common feature of the inelastic event.

Several observations don't have a straightforward interpretation with independent interactions, i.e. increasing <pT> vs Nch. A large amount of **colour reconnections** recover, but is this the correct interpretation? **Correlations ?** And, if so, what is the physics and what are the rules that govern colour reconnection? To what extent can colour reconnection affect observables like the meson/barion ratios that can be attributed to effects dealing with transport in dense matter?

Conclusions/Highlights

The status of the art of Multiple Parton Interactions needs to be reviewed in the light of the recent LHC measurements on both hard and soft MPI.

The MPI@LHC workshop, started in 2008 in Perugia, today at the 6th edition, is providing a common theo/exp platform for MPI understanding.

Hard-MPI measurement still don't provide a crystal clear DPS evidence.

Following the observation of long-range ridge-like structure in high multiplicity events, soft MPI measurements at the LHC focused on the detailed investigation of large multiplicity events (sphericity, jets...): these events are less jetty than predicted by the models.

What should be considered to be the most striking evidence of MPI via DPS?

And what are the features of large multiplicity production?

To what extent we can trust the general-purpose pQCD MPI models?

Explore scaling properties: observables in pp, pPb and PbPb driven by charged multiplicity?

What role is played by correlations ?

Higher Energies...higher luminosities...

1) DPS/SPS Heavy Flavors production is expected to increase with $\sqrt{S}$ (experimental challenging ?)

2) Rare productions with top and heavy bosons, unavoidable BGs to new physics searches

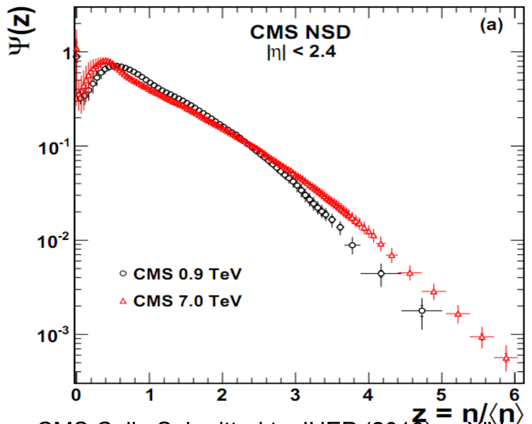
3) proton-Nuclei interactions, DPS enhanced, longitudinal correlations, help the 3D definition of σ_{eff}

backup

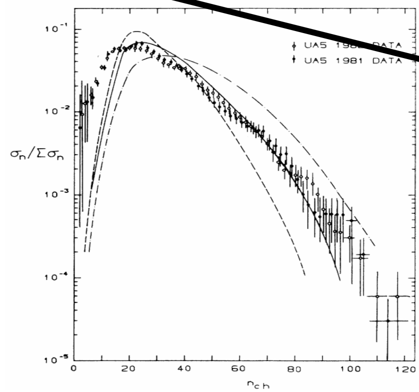
Multiplicities and KNO scaling

KNO (Koba-Nielsen-Olesen) Scaling is not a consequence of Feynman scaling, but of hadrons produced by the self-similar branching of a single string

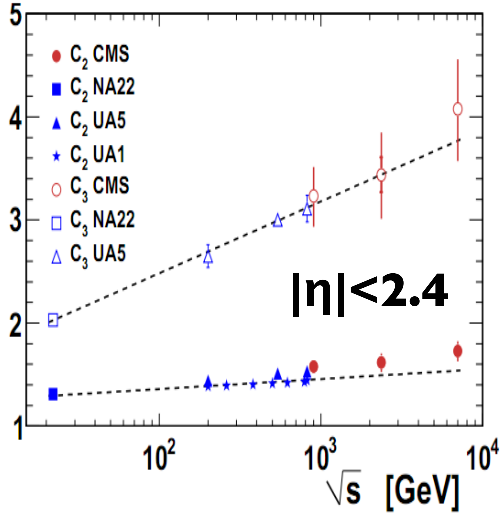
Strong KNO scaling violation in intermediate-range of pseudorapidity intervals is an **indication of MPI**

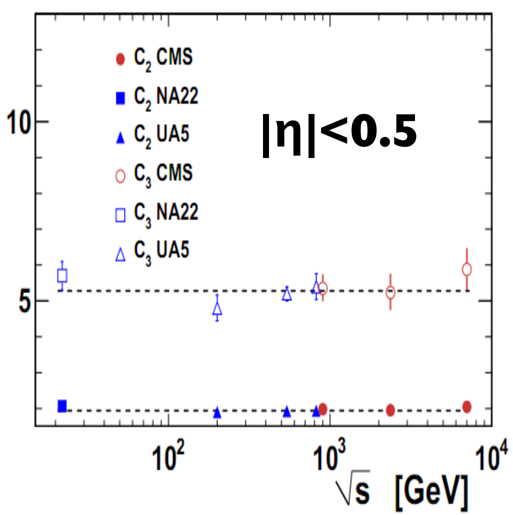


CMS Coll., Submitted to JHEP (2010), arXiv



Interpretation of UA5 540 GeV data: T. Sjostrand and M. van Zijl, Phys. Rev. D36(1987) 2019



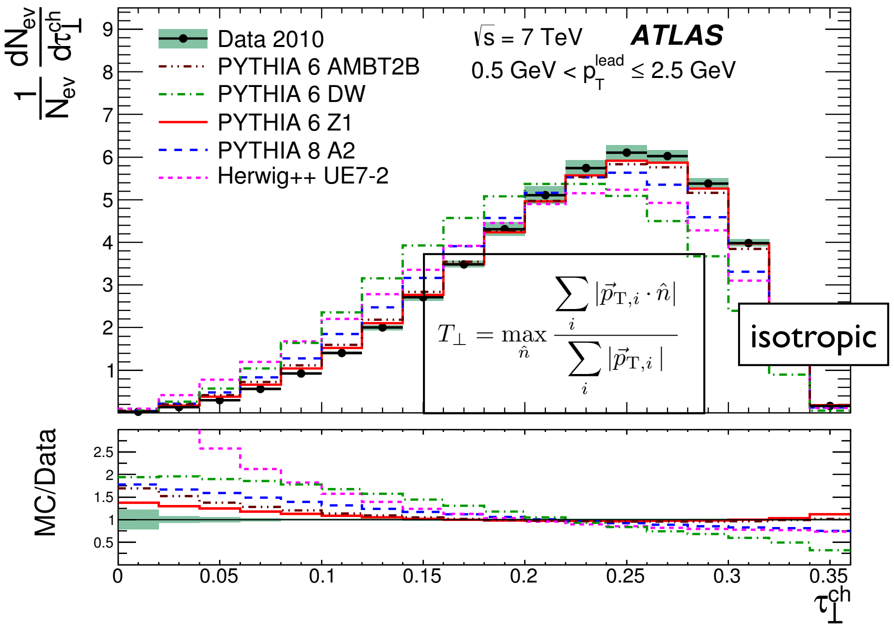


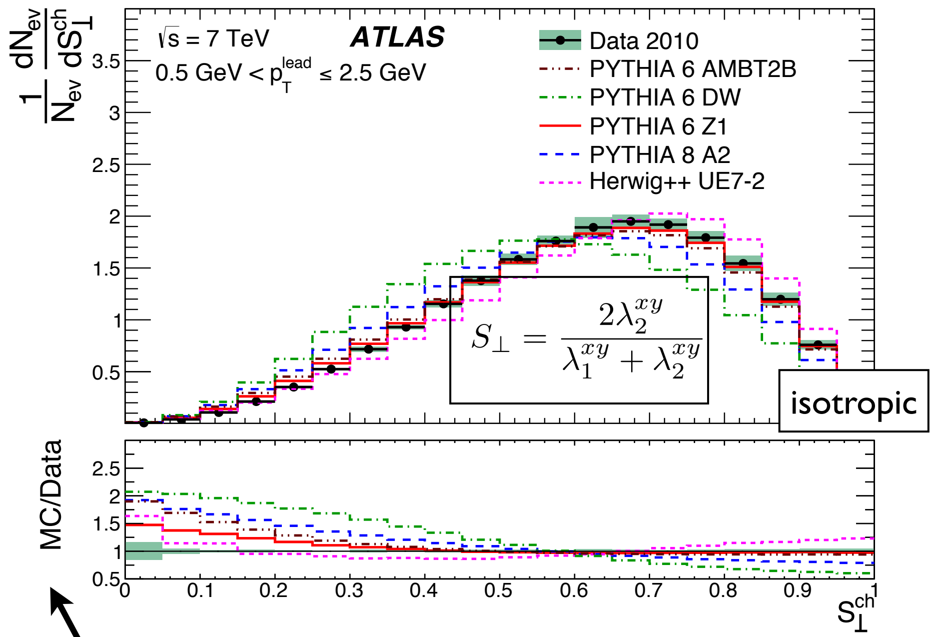
$$C_q = \frac{\langle n^q \rangle}{\langle n \rangle^q}$$

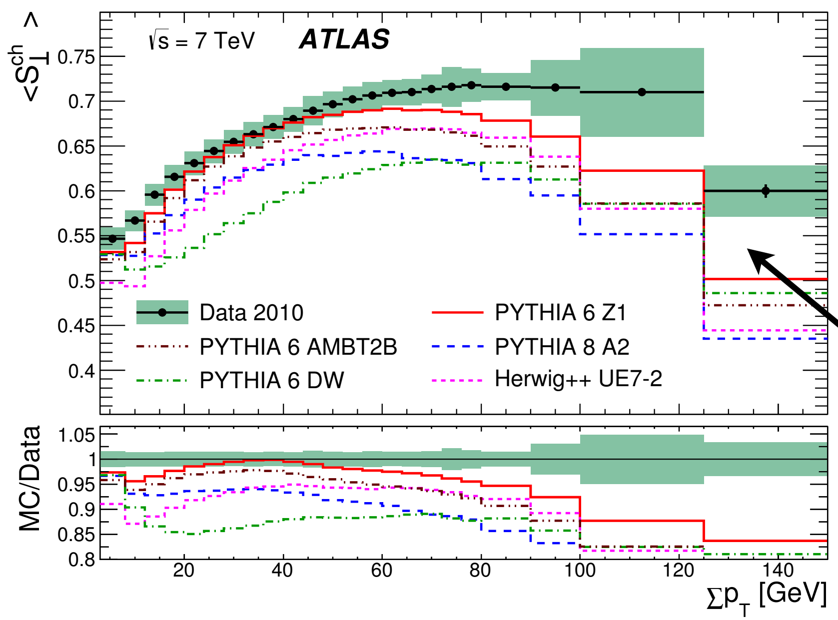
Increase with s indicates KNO scaling violation

KNO scaling holds for small rapidity intervals

Event Shapes







prevalence of spherical events with a soft pTlead selection

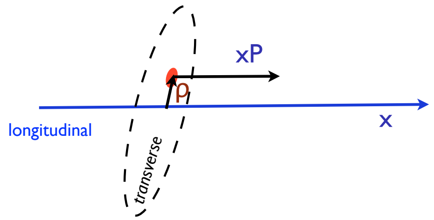
Z-generation Pythia Tune provide the best description

all models fail in reproducing shapes at high pTsum (and high multiplicity events - next slide)

ATLAS, arXiv:1207.6915v4

Transverse activity interpretation

M. Strikman et al. - "Transverse nucleon structure and diagnostics of hard parton-parton processes at LHC"
[Phys. Rev. D83 (2011) 054012]



$$\langle \rho^2 \rangle_g = \frac{\partial}{\partial t}\frac{G(x.t)}{G(x,0)}$$

$$\langle \rho^2 (x > 10^{-2} \rangle \ll R^2_{soft}$$

gluon transverse size decreases with increasing x

transverse size of large x partons is smaller than the transverse range of soft interactions

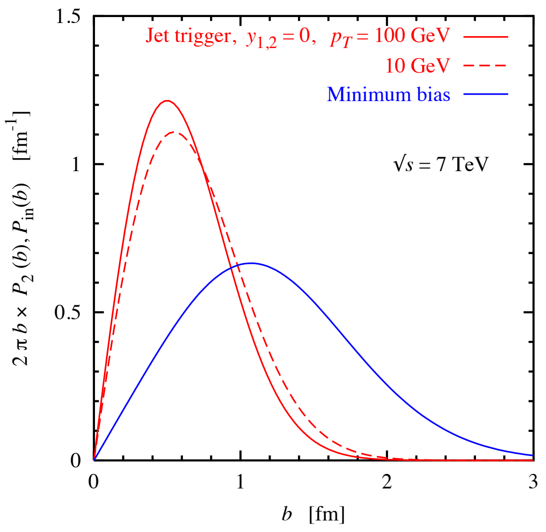
helpful to explain:

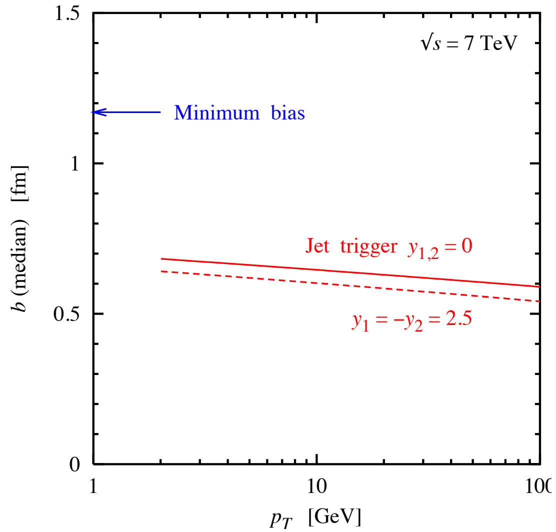
+ general UE feature

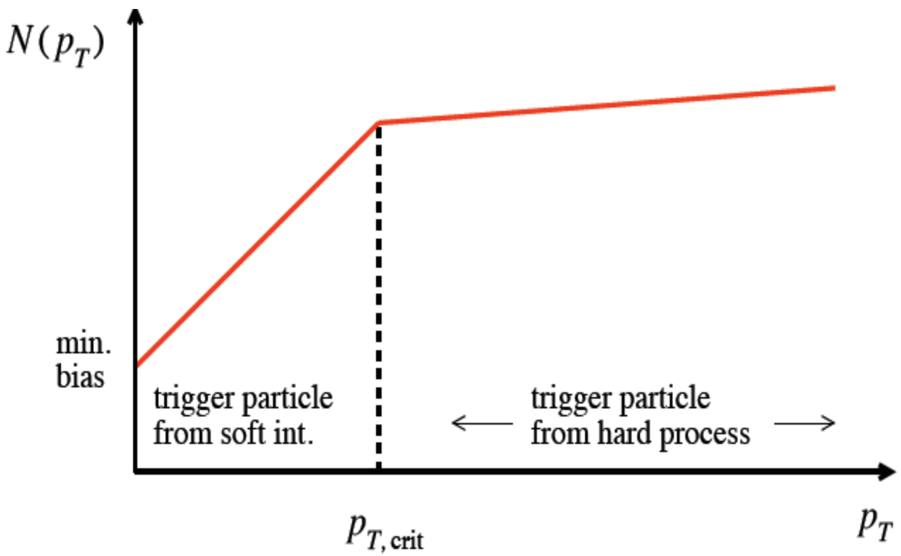
+ $<\rho^2>_g < <\rho^2>_q$
UE in DY < UE in Jets

2 scale picture

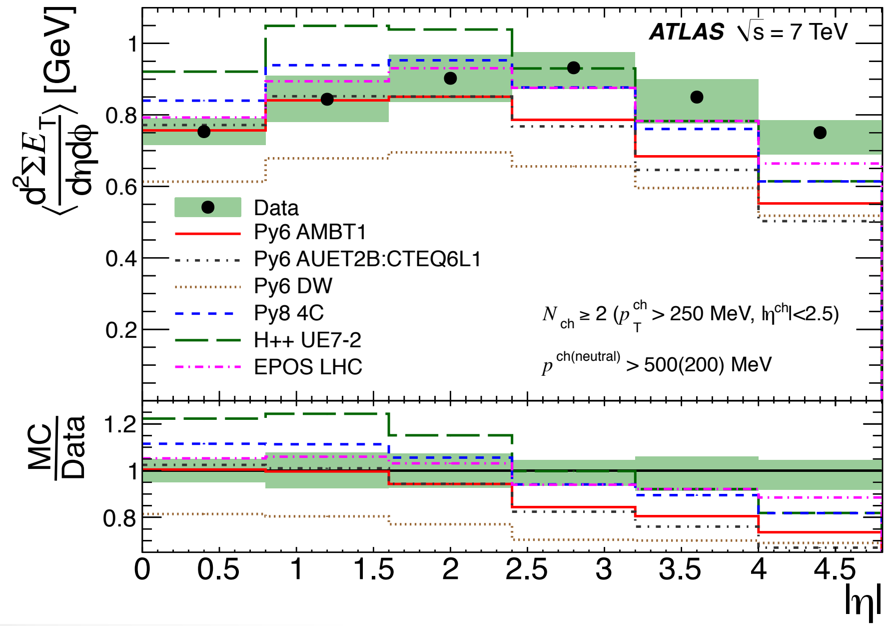
$$N(p_T) \;=\; \lambda_{\rm hard}(p_T)N_{\rm hard} + [1 - \lambda_{\rm hard}(p_T)]N_{\rm soft}$$

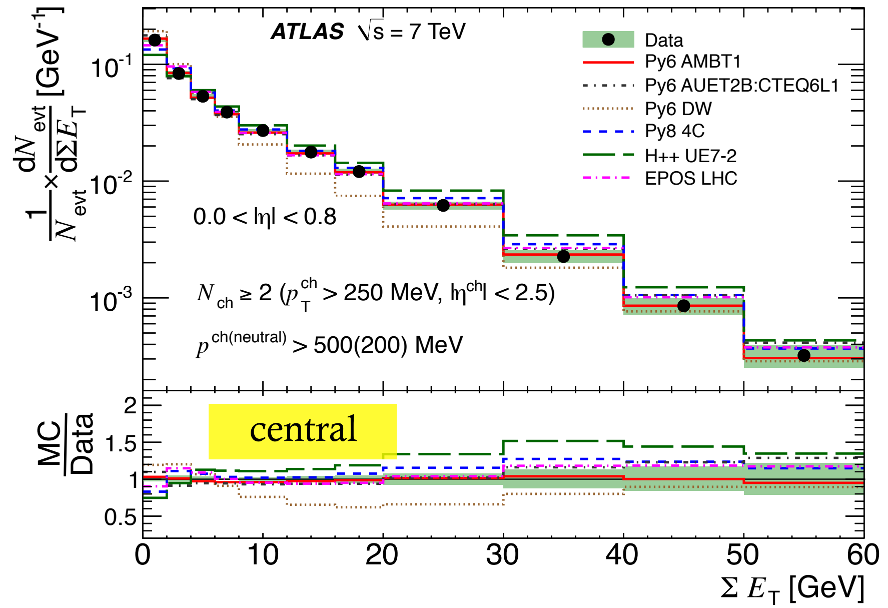


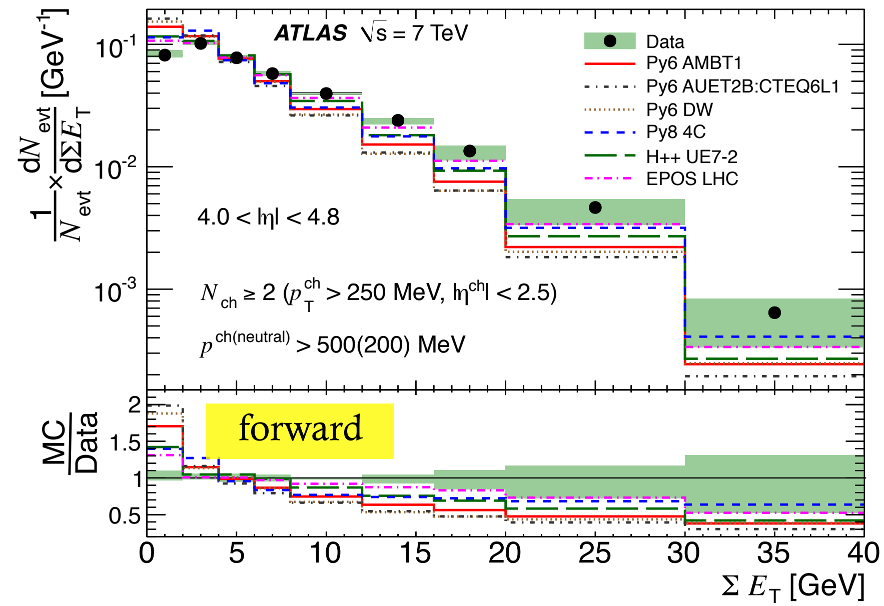




Transverse Energy Flow







charged and neutral components included (using the full acceptance of ATLAS calorimeter) important complementary measurement to charged particle distributions

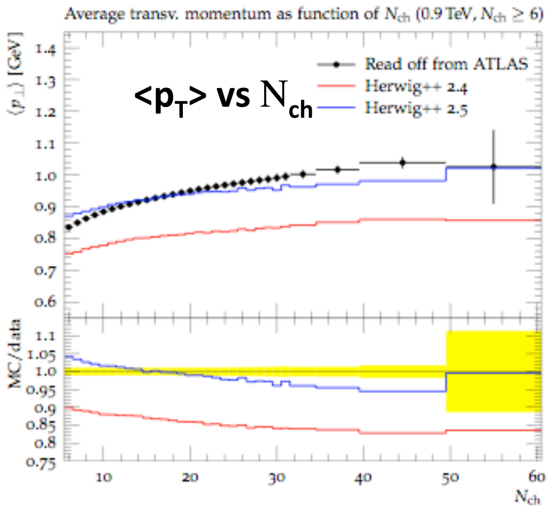
MCs underestimate the forward activity

sensitivity to diffractive component is small

sensitivity to choice of proton PDFs and Underlying Event tune is observed

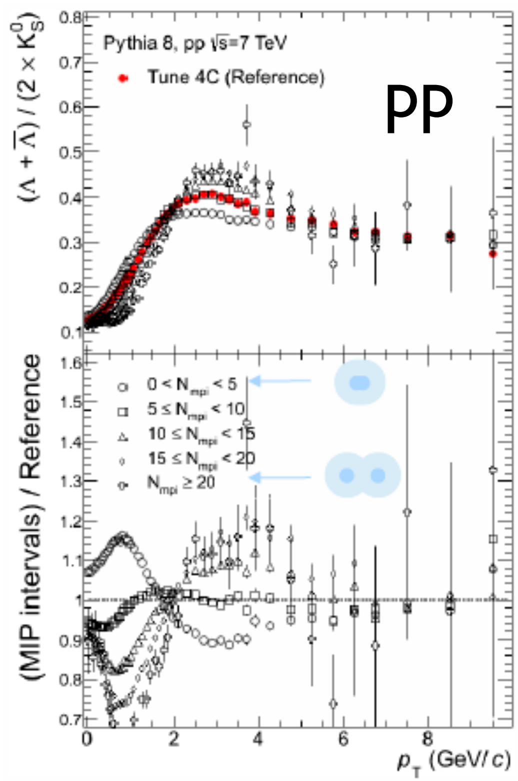
ATLAS, JHEP 11 (2012) 033

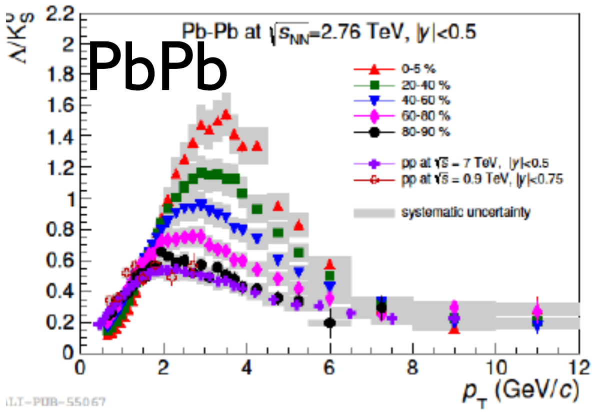
Color Reconnection



[M. Seymour, MPI@LHC 2013, Antwerpen]

Color reconnection unavoidable to describes the shapes of pseudo-rapidity and $\langle p_T \rangle$ vs N_{ch}.





flow-like patterns in pp

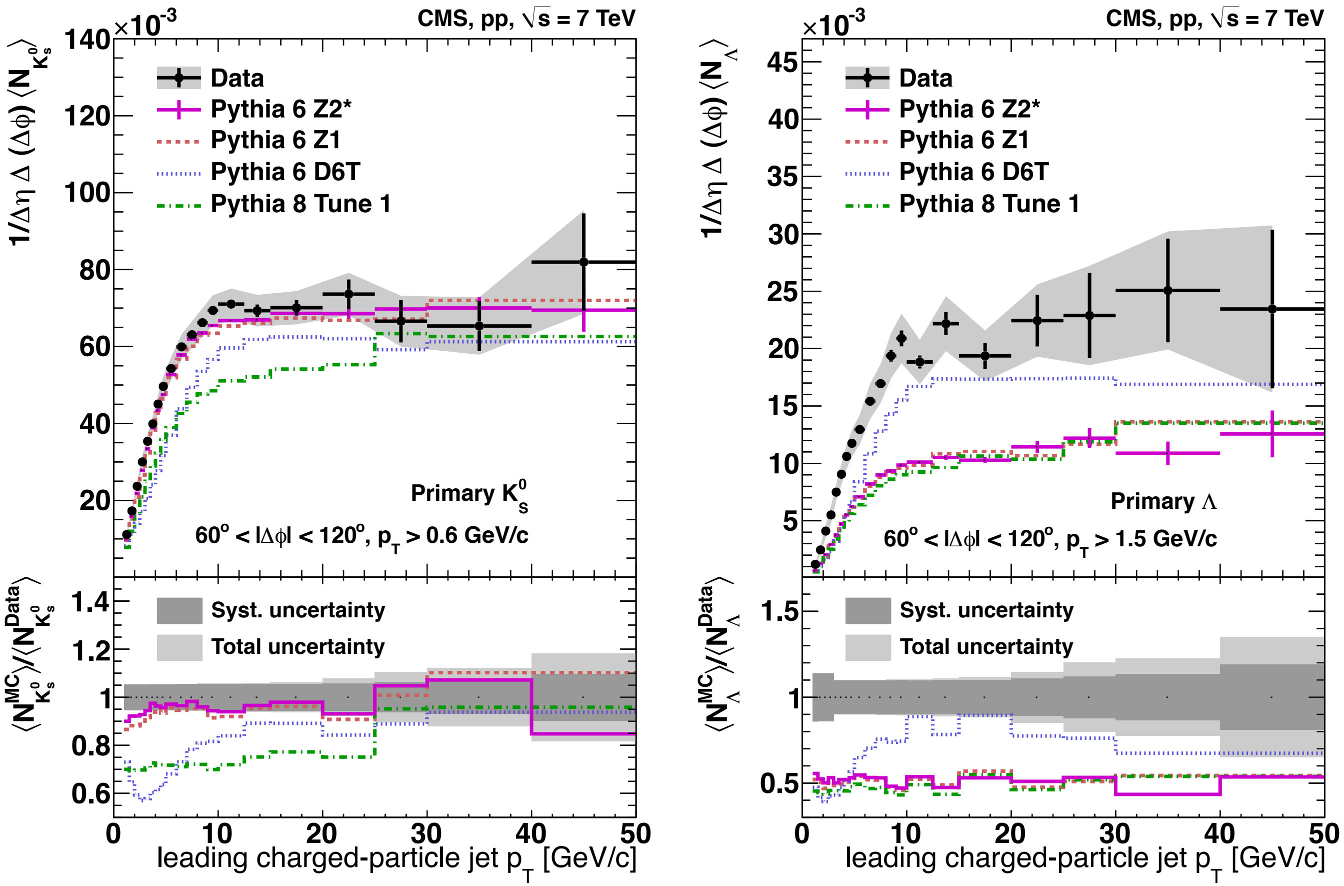
[G.Paic, MPI@LHC 2013, Antwerpen]
See also arXiv:1404.2372

pp interaction simulated with Pythia 8 Tune 4C don't know about flow

Λ/K_S^0 ratio in different N_{ch} ranges evolve as the Λ/K_S^0 ratio in different centrality ranges in Pb-Pb interactions (measured by ALICE)

Color reconnection matter. Flat shapes otherwise.

The transverse region - identified particles



Same pattern observed for standard UE measurement, compatible with the IP interpretation

PYTHIA underestimate the data by 15–30% for K_S mesons and by about 50% for Λ baryons

Deficit similar to that observed for the inclusive strange particle production in pp collisions

CERN-PH-EP-2013-086