Forward Physics and Soft QCD results

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on behalf of ALICE, ATLAS and CMS collaborations

LHC

Motivations

Soft and Forward QCD measurements

cross sections and diffraction

particles (flow, shape, id and correlations)

The role played by Multiple Parton Interactions

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The role played by Multiple Parton Interactions

LHC, multi-TeV age

Why interested in QCD while we look for new phenomena ?

LHC physics -> mainly **large cross-section phenomena** (QCD)

-> used for “Physics” and Detectors commissioning

QCD is a successful theory, heavily tested in past experiment and predictive for higher energy. Needed to be verified at any new energy

Asymptotic freedom, factorization and evolution are the instruments we use to analyze QCD processes at colliders

Perturbative QCD is an excellent description of the strong interaction at large Q^2 (in an ideal asymptotic freedom regime) but it is also needed to understand low Q^2 (soft phenomena), in the **non-perturbative regime**, surrounding all LHC production

+ LHC bring non-perturbative phenomena to relatively large Qs^2 (~ 1 GeV^2), large enough to be studied experimentally

+ Experimental guidance is of interest for improving phenomenological application of QCD to the soft sector

LHC, multi-TeV age

LHC is a proton-proton collider (up to 14 TeV)
mainly gluon-gluon interactions

Huge phase space for the final state:
high jet multiplicity expected

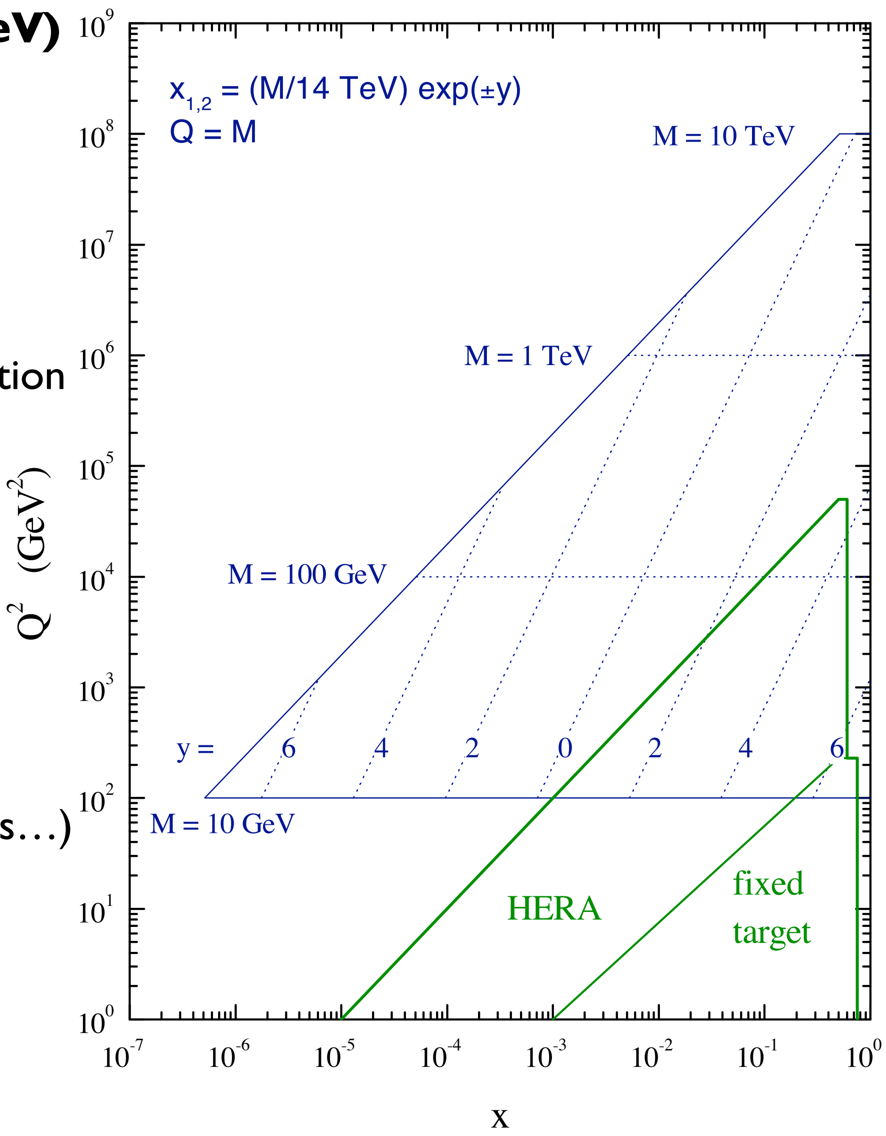
LHC extends the kinematical region from previous experiment (new info for proton structure and interaction dynamics)

10^{34} luminosity -> **high pile-up**
Pile-up is mainly generic p-p interactions ->
soft interactions

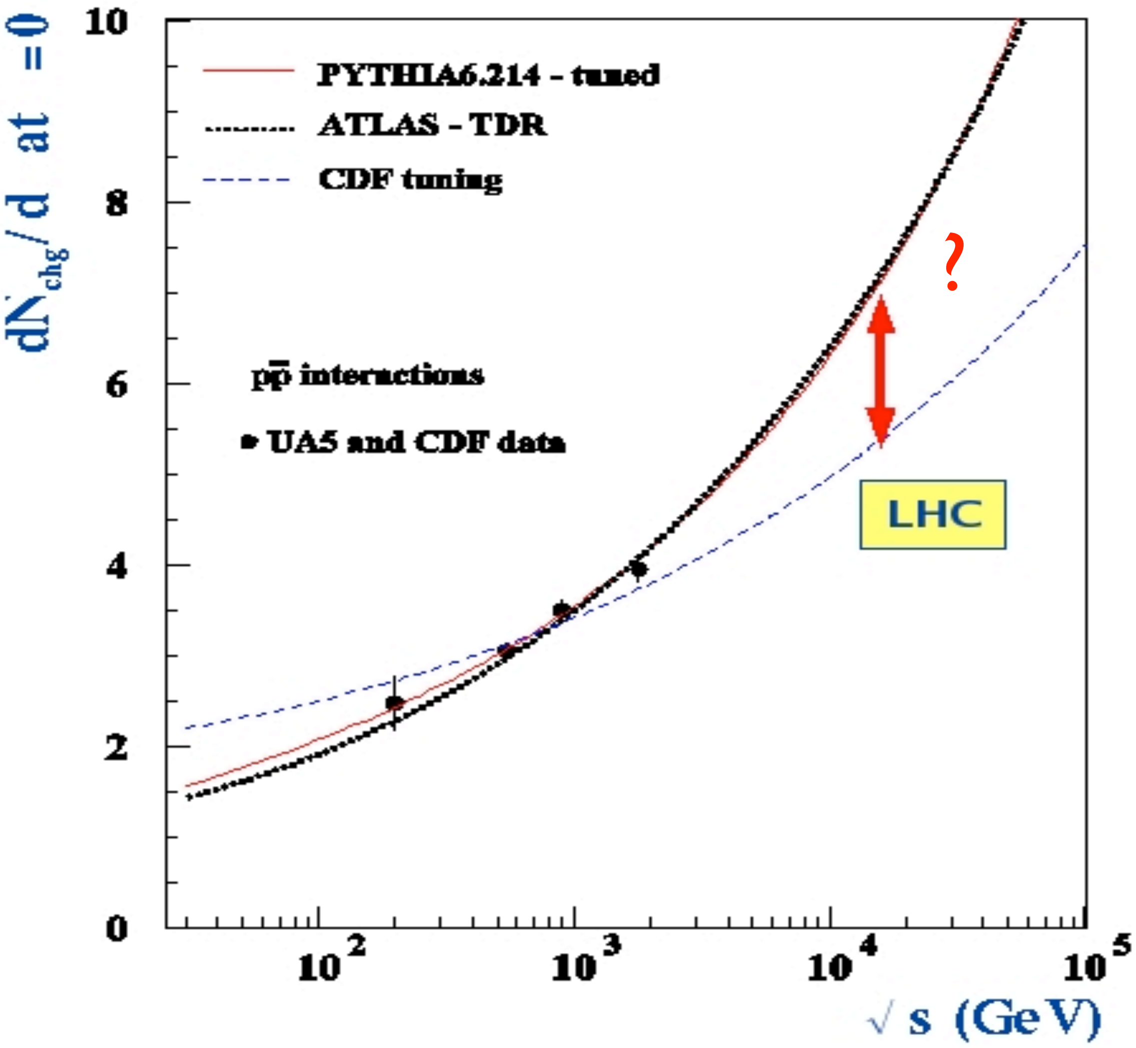
A robust modeling activity is needed
from Low and High pT phenomena:
+ strong dynamics at TeV (pQCD, PDFs, α_S, new physics…)
+ soft dynamics (Multiplicities, Underlying Event, non-perturbative effects, Multiple Interactions)

why?
+ optimal interaction description
+ background definition
+ clear signal for any old and new physics

LHC parton kinematics



Monte Carlo Models



Why modeling is so important ?

+ Monte Carlo models prove our ignorance

+ Our knowledge is $\sqrt{S}$-dependent: predictive models at SpS or Tevatron, diverge if extrapolated to higher energy

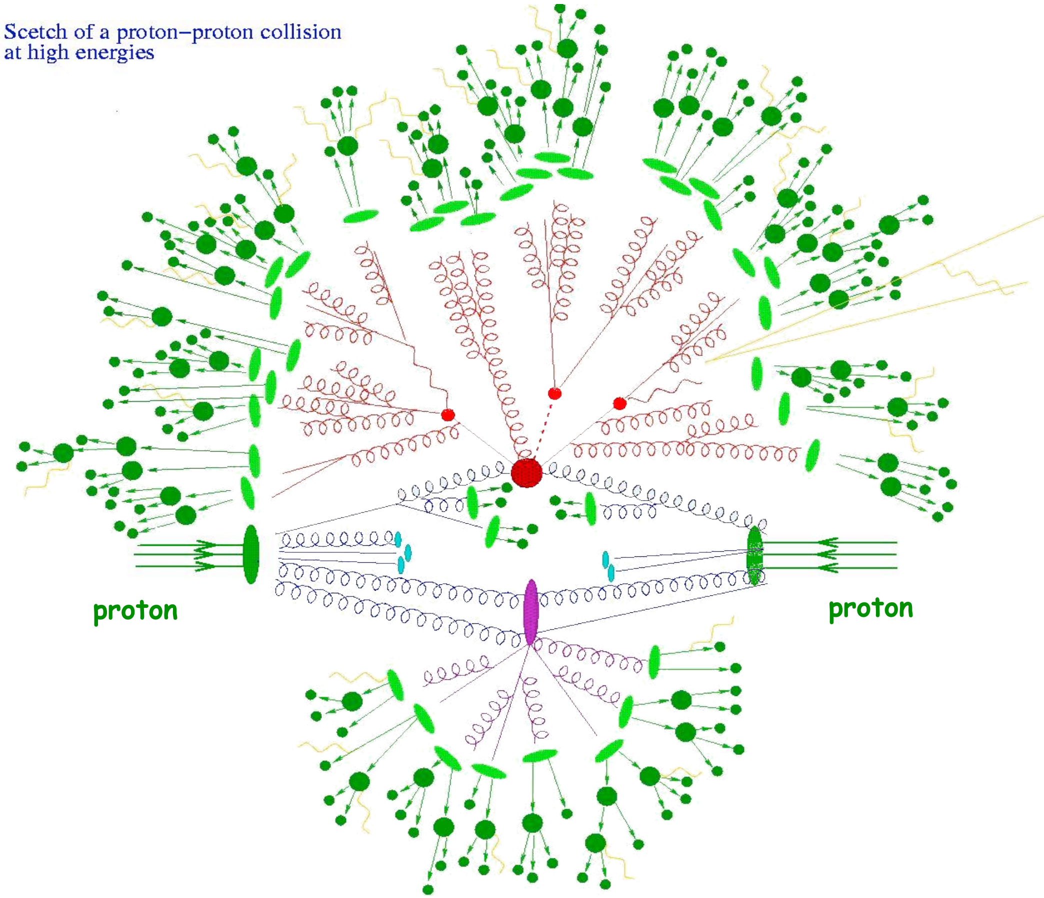
+ In addition **models depend on observables** (is there a universal tune?)

+ Lot of work is ongoing

How ?
+ experimentally, for instance, from basic observables based on soft and hard reactions

+ new calculations and tools like Rivet/Professor

Structure of the p-p interaction



Main Interaction

Radiation (ISR/FSR)

Jet

Fragmentation/
Hadronization

Mutiple Interactions
(MPI)

Beam Remnant

Phenomenological framework

The goal is to test SM (in)consistency

For each process expected at LHC:

Event rates (absolute, relative, differential)
Stat vs syst errors, backgrounds from data or MC?
Resolution, Energy Scale, Signal Significance

$$\sigma_{\mathrm{meas}} = \frac{N_{\mathrm{obs}} - N_{\mathrm{bkg}}}{\varepsilon \quad L}$$

Proton-Proton Luminosity uncertainty ~ 5% ? Do better?

Experimental issues : Triggers, reconstruction, isolation cuts, low-p_T jets (jet veto)

Theoretical issues : p_T distributions at NLO + resummation; differential calculations for detectable acceptance.

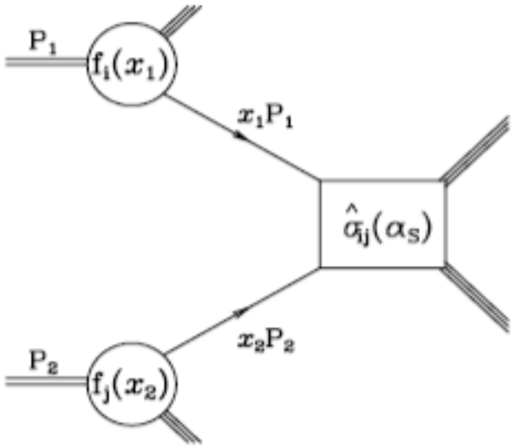
$$\sigma_{\mathrm{theo}} = PDF(x_1, x_2, Q^2) \otimes \hat{\sigma}_{\mathrm{hard}}$$

constrain, define uncertainties

HO calculations, implement in MC

Goal : test SM (in)consistency : $\sigma_{\mathrm{exp}} \pm \Delta_{\mathrm{exp}} \stackrel{?}{=} \sigma_{\mathrm{SM}} \pm \Delta_{\mathrm{th}}$

Phenomenological framework



How understand QCD processes ?
We need accurate **normalization and kinematical distributions**

we still can use tools from pQCD given
infrared-safe observables and factorizable quantities (where IR divergences can be reabsorbed in a np factor)

high interaction energy -> one can resolve partons from the sea -> **pQCD**

how ? factorization theorem

$$\frac{d\sigma}{dX} = \sum_{j,k}\int_{\hat{X}} f_j(x_1,Q_i)\, f_k(x_2,Q_i)\, \frac{d\hat{\sigma}_{jk}(Q_i,Q_f)}{d\hat{X}}\, F(\hat{X}\rightarrow X;Q_i,Q_f)$$

PDF (parton distribution functions):
Sum of all initial states leading, at the Q-scale, to p_j = xP(proton)

Transition from the partonic final state to the **final state** hadrons (hadronization, fragmentation, jet definition...)

Phenomenological framework

low-x and forward physics is a perfect benchmark to investigate
IR physics and test perturbative and non-perturbative models

1. Where is the energy going?

Note: *only linearized Sphericity is IR safe*

Sum(pT) densities, event shapes, mini-jet rates, ctrl&fwd energy flow, energy correlations… ≈ sensitive to pQCD + pMPI

2. How many tracks is it divided onto?

N_{tracks}, dN_{tracks}/dp_T, Associated track densities, track correlations…
≈ sensitive to hadronization + soft MPI

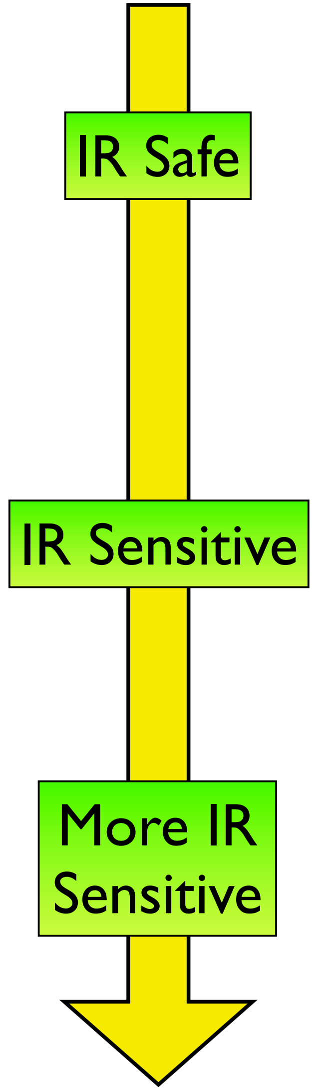
3. Are there gaps in it?

Created by diffraction (and color reconnections?). Destroyed by UE.

4. What kind of tracks?

Strangeness per track, baryons per track, baryon asymmetry, …
hadron-hadron correlations ≈ sensitive to details of hadronization

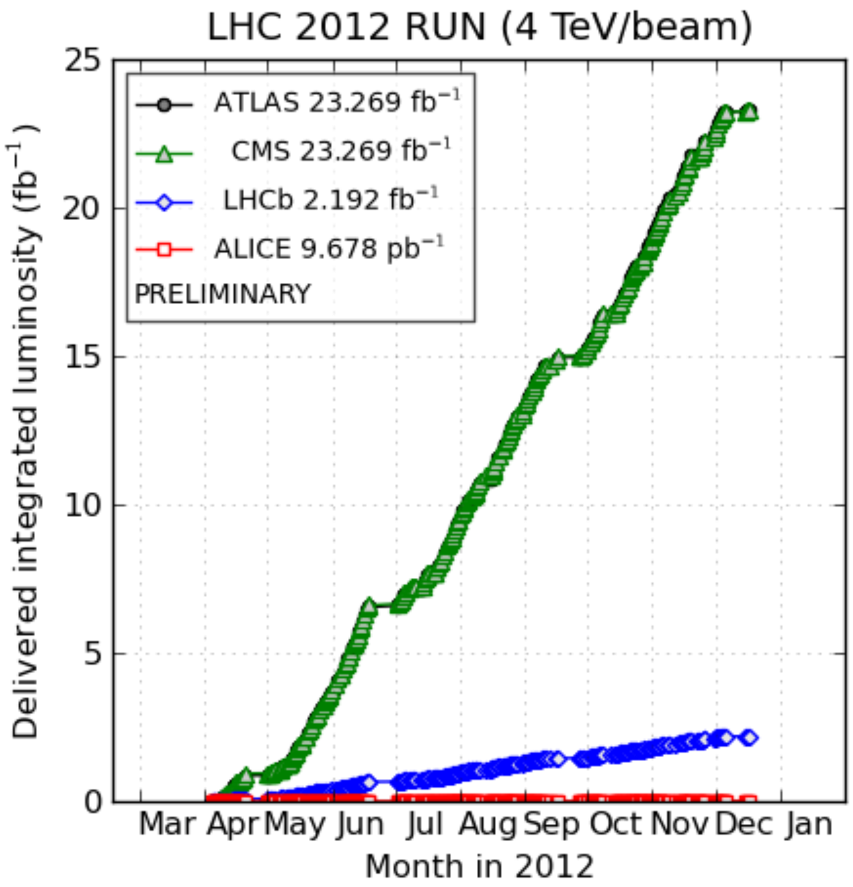
+ collective effects (+Quarkonium sensitive to color reconnections?)



curtesy of P. Skands

Experimental framework

LHC



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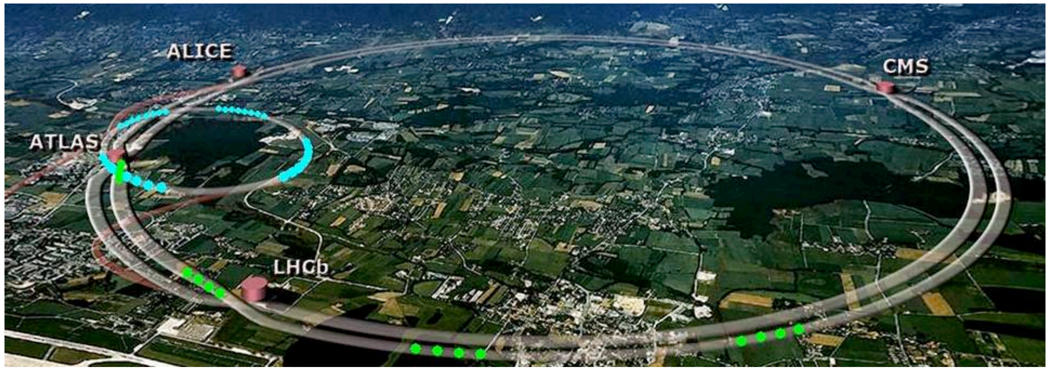
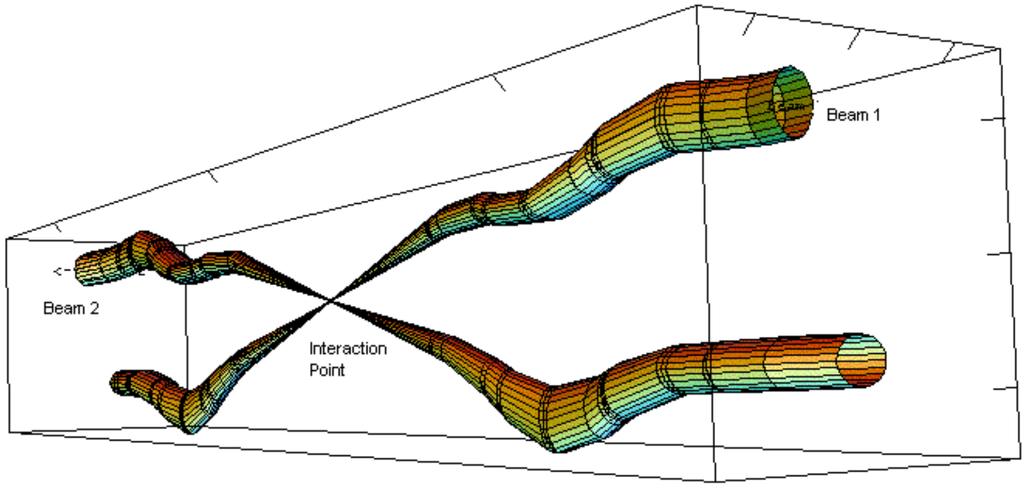
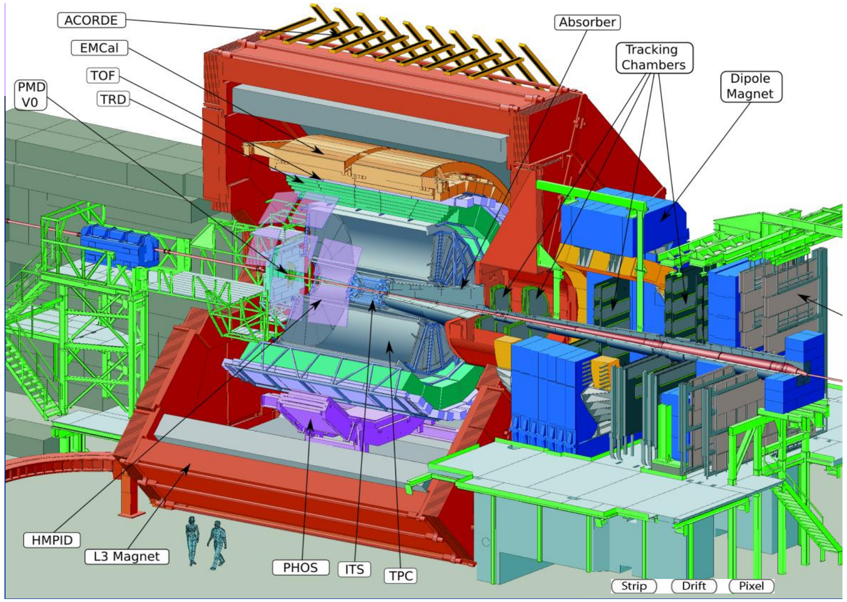


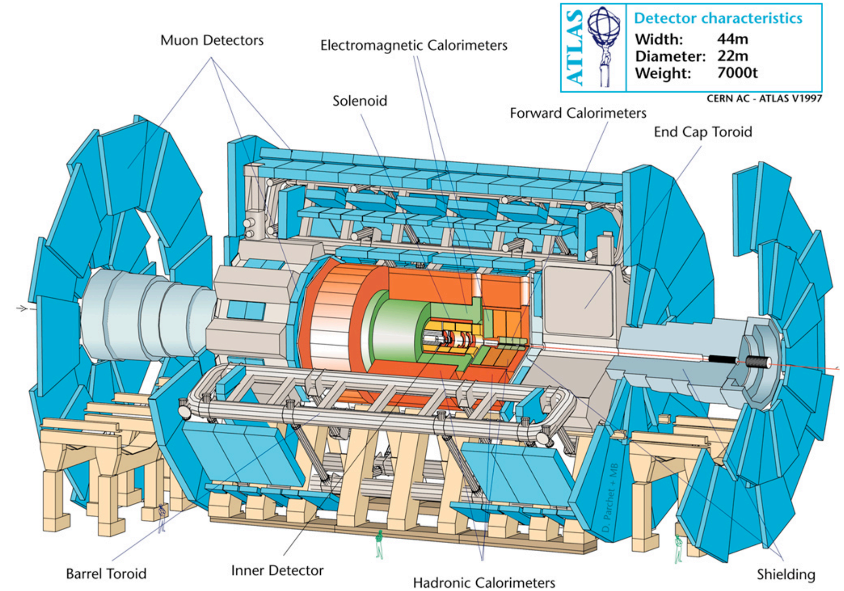


Relative beam sizes around IP1 (Atlas) in collision

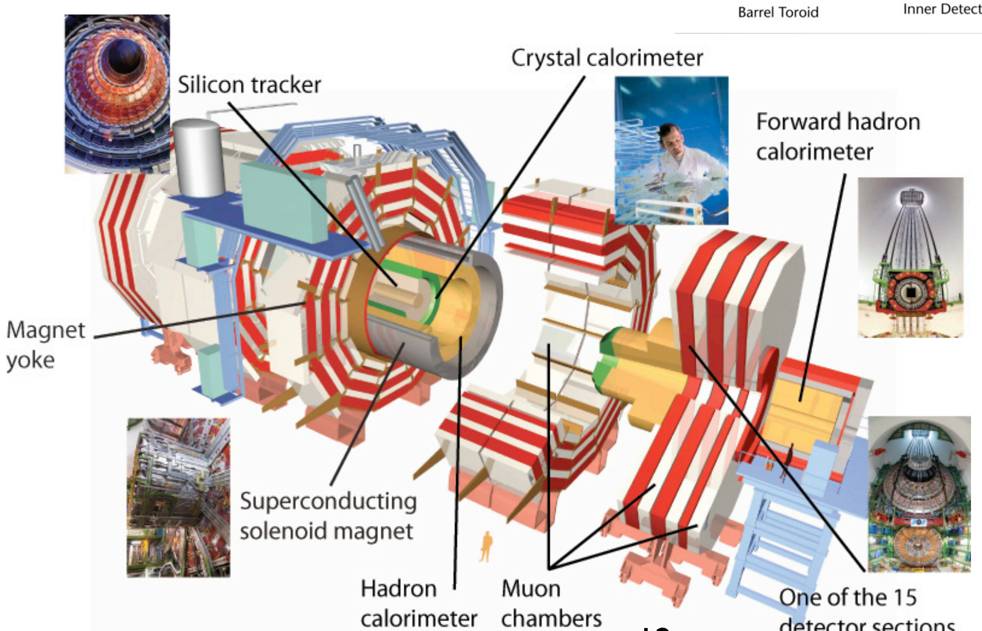
Experimental framework



ALICE



ATLAS



CMS

LHC

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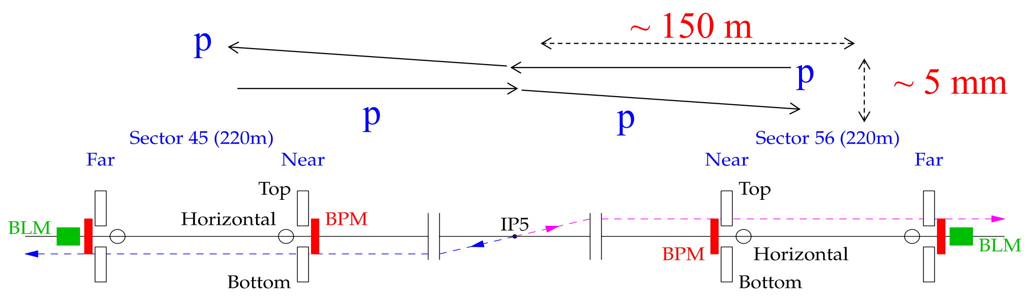
cross sections and diffraction

particles (flow, shape, id and correlations)

The role played by Multiple Parton Interactions

Total pp cross section

2 protons very forward dedicated experiment (or detectors) - RP, TOTEM...

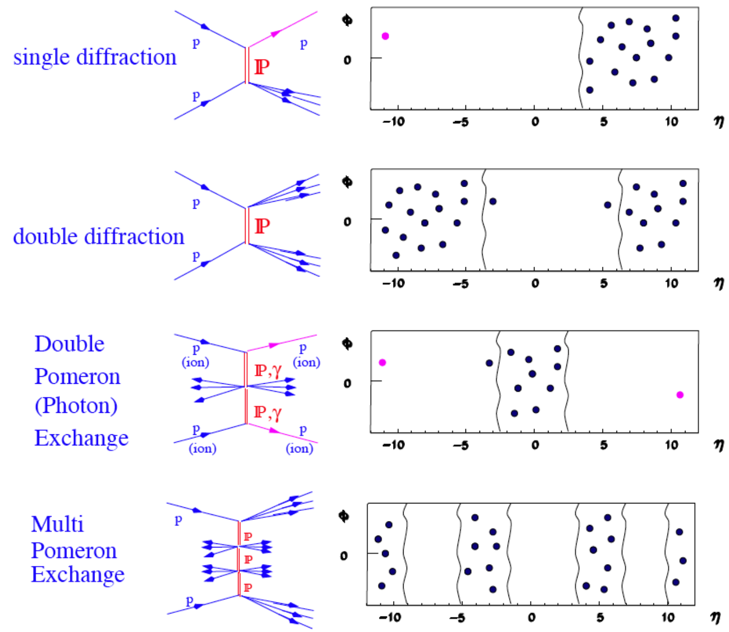


$$\sigma_{TOT} = \sigma_{elastic} + \sigma_{inelastic}$$

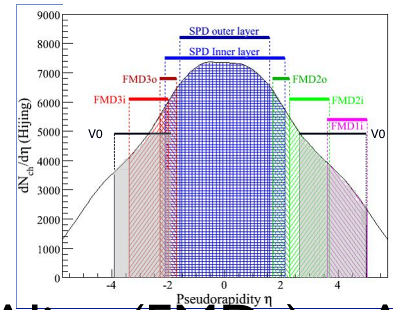
$$= \sigma_{non\text{-}diffractive} + \sigma_{diffractive}$$

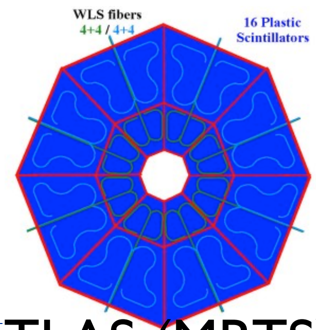
$$= \sigma_{SD} + \sigma_{DD} + \sigma_{CD}$$

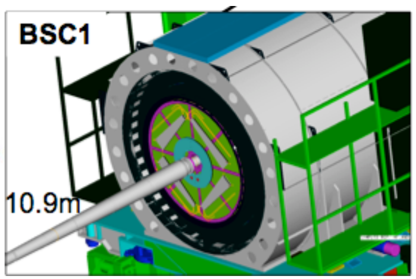
GAP-topologies



indirect (PileUp distributions / optical theorem) or direct ways (Minimum Bias Trigger)





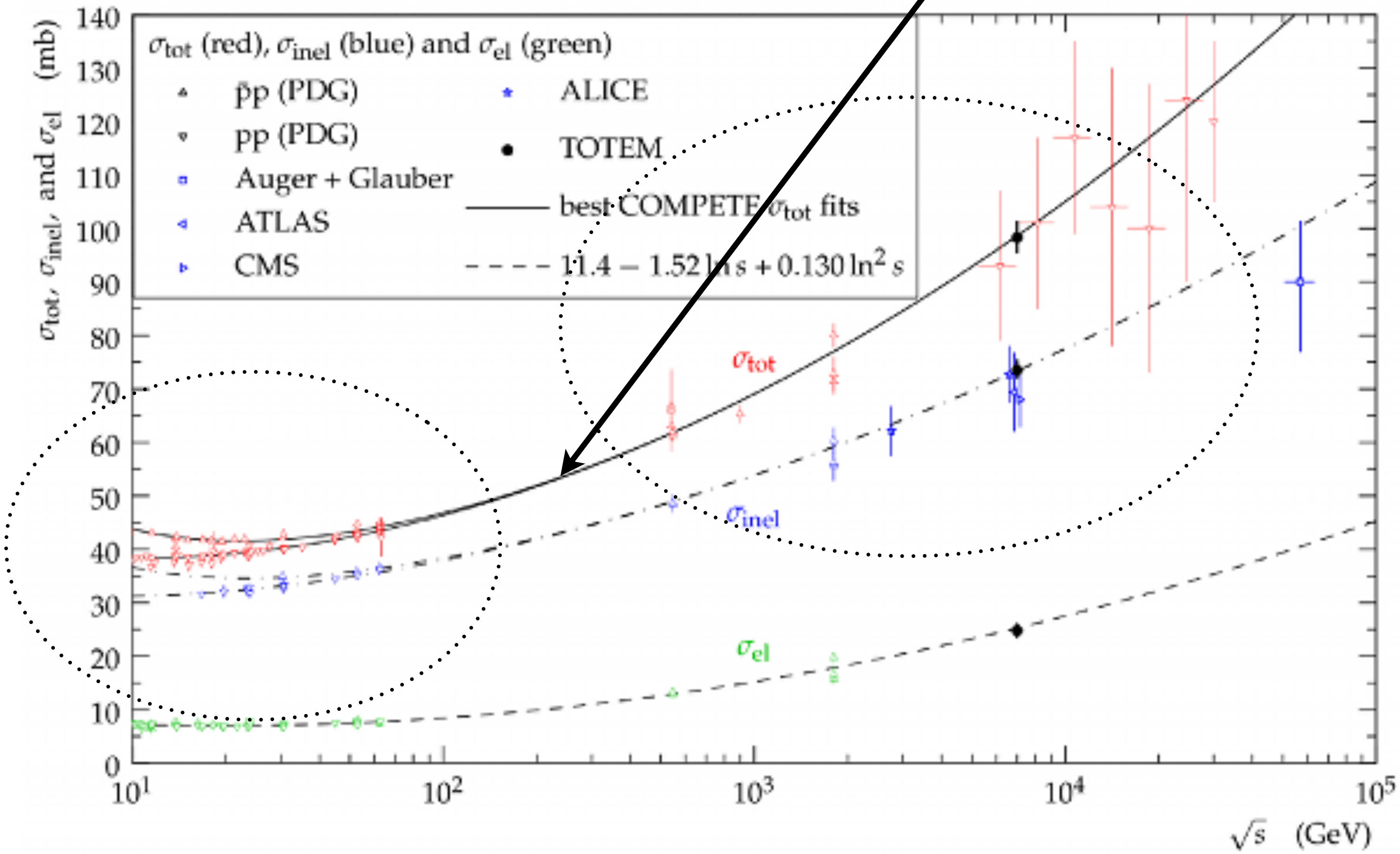


Alice (FMDs) ATLAS (MBTS) CMS (BSC+...)

Total pp cross section

$\sigma_{TOT}(S) = c + S^{-1/2} + \gamma \ln^2(s)$

(best fit from COMPETE coll.)



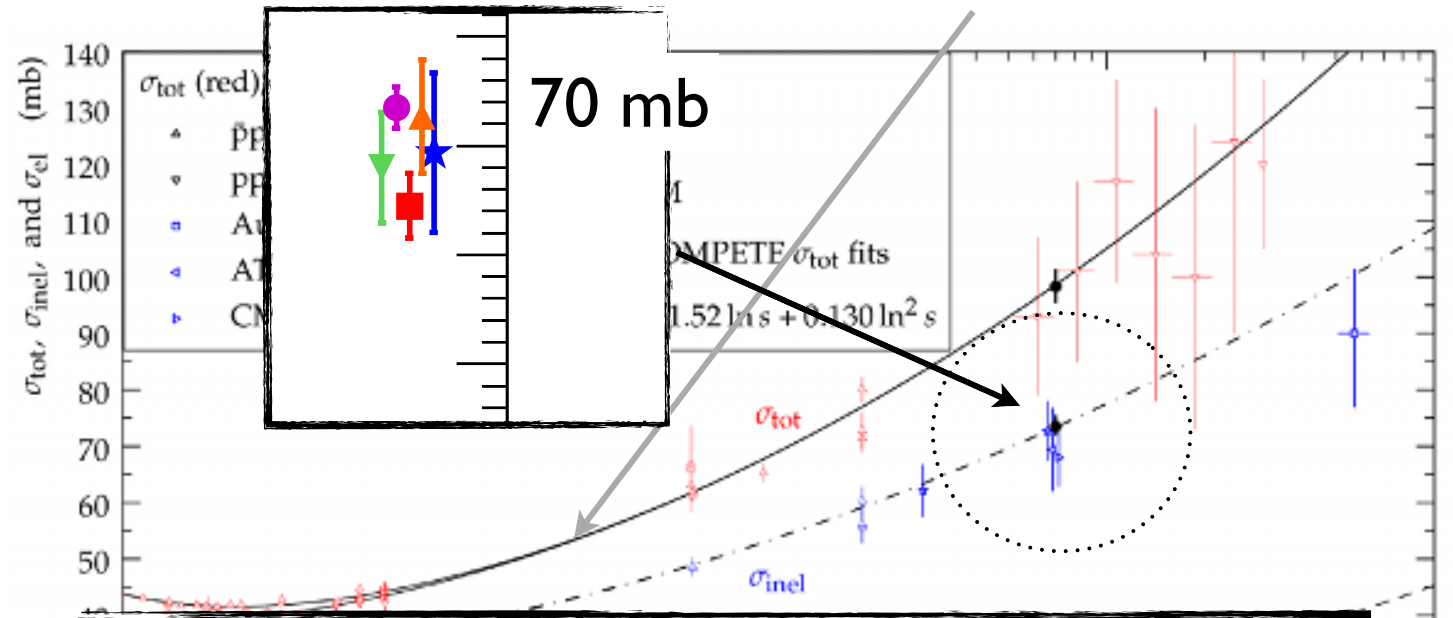
$\sigma_{TOT}(S) \propto S^{-1/2}$ (Regge)

$\sigma_{TOT}(S) \propto S^{\varepsilon} + \ln(S) + \ln^2(s)$

(Pomeron exchange)

Total pp cross section

$\sigma_{TOT}(S) = c + S^{-1/2} + \gamma \ln^2(s)$
(best fit from COMPETE coll.)



σ_{INEL} - Measurements are well in agreement between each others and with different methodology:

Alice - J.Phys.G G38 (2011) 124044
ATLAS - Nature Commun. 2 (2011) 463
CMS - PLB 722 (2013) 5
CMS (PileUp counting)- PLB 722 (2013) 5

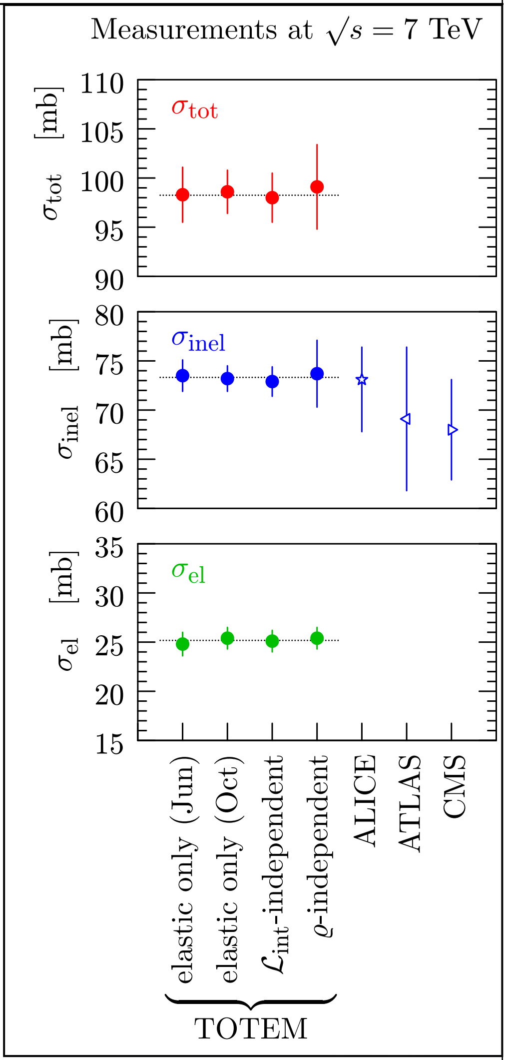
σ_{TOT}(S ... (S) + $\ln^2$(s)
(Pomeron exchange)

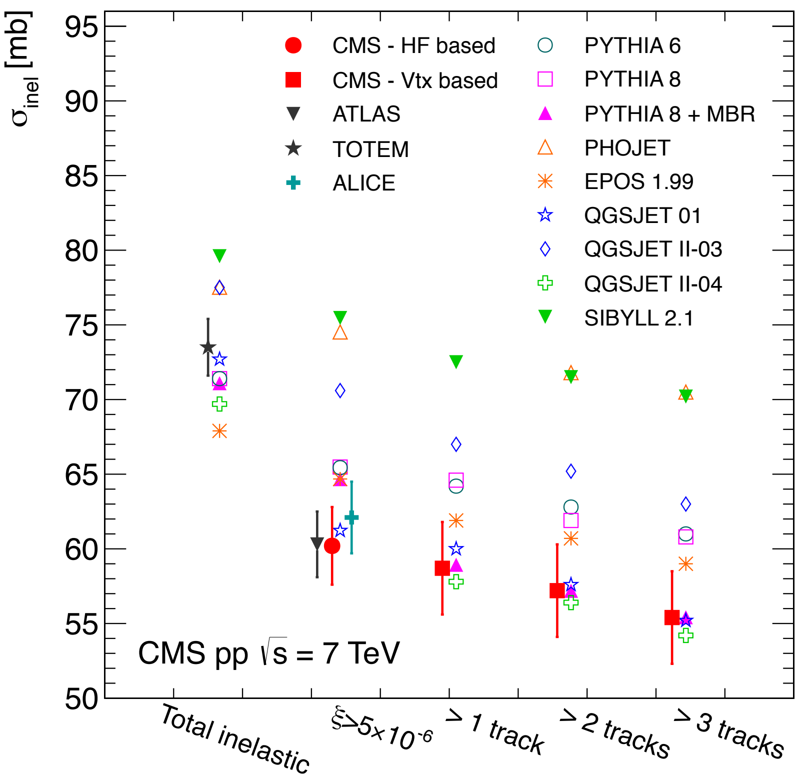
Total pp cross section

$\sigma_{TOT}(8\ \text{TeV})^{\text{TOTEM (OT)}} = 101.7 \mp 2.9$ mb
$\sigma_{TOT}(8\ \text{TeV})^{\text{COMEPTE}} = 101 \mp 5$ mb [confirms $\sim\ln^2(s)$]
($\sigma_{TOT}(8\ \text{TeV})^{\text{2-pomeron}} = 125 \mp 5$ mb)

$\sigma_{INELASTIC}(\xi>5{*}10^{-6})^{\text{ALICE}} = 62.1 \mp 1.0$ (syst) ∓ 2.2 (lumi) mb
$\sigma_{INELASTIC}(\xi>5{*}10^{-6})^{\text{ATLAS}} = 60.3 \mp 0.05$ (stat) ∓ 0.5 (syst) ∓ 2.1 (lumi) mb
$\sigma_{INELASTIC}(\xi>5{*}10^{-6})^{\text{CMS}} = 60.2 \mp 0.2$ (stat) ∓ 1.1 (syst) ∓ 2.4 (lumi) mb

Experimental results well in agreement within each others





+ PHOJET and SIBYLL overestimate σinel

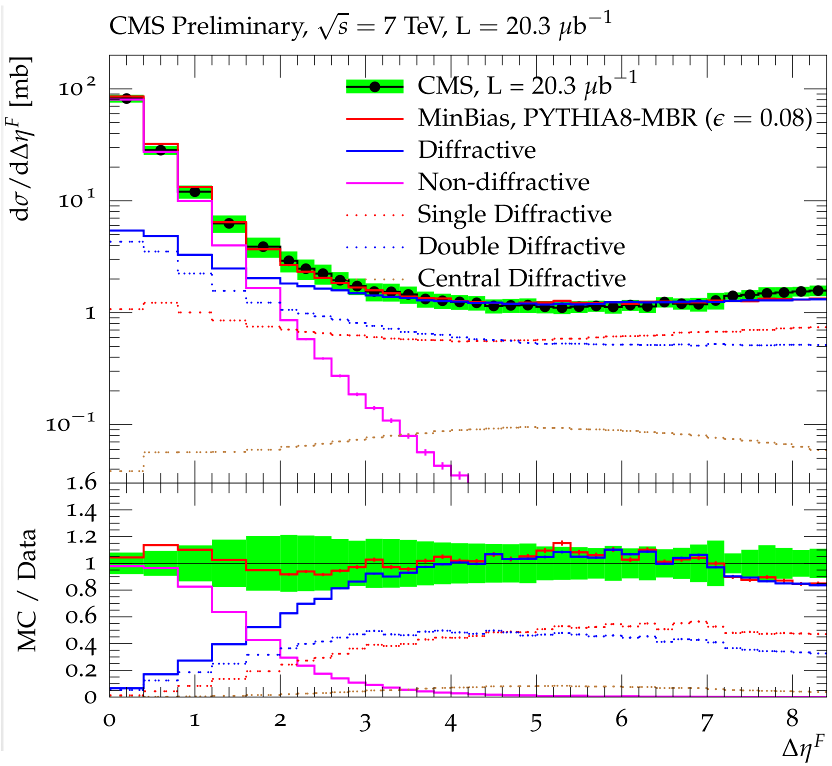
+ EPOS, QGSJET II-03, PYTHIA 6, and PYTHIA 8 about 10% above the data

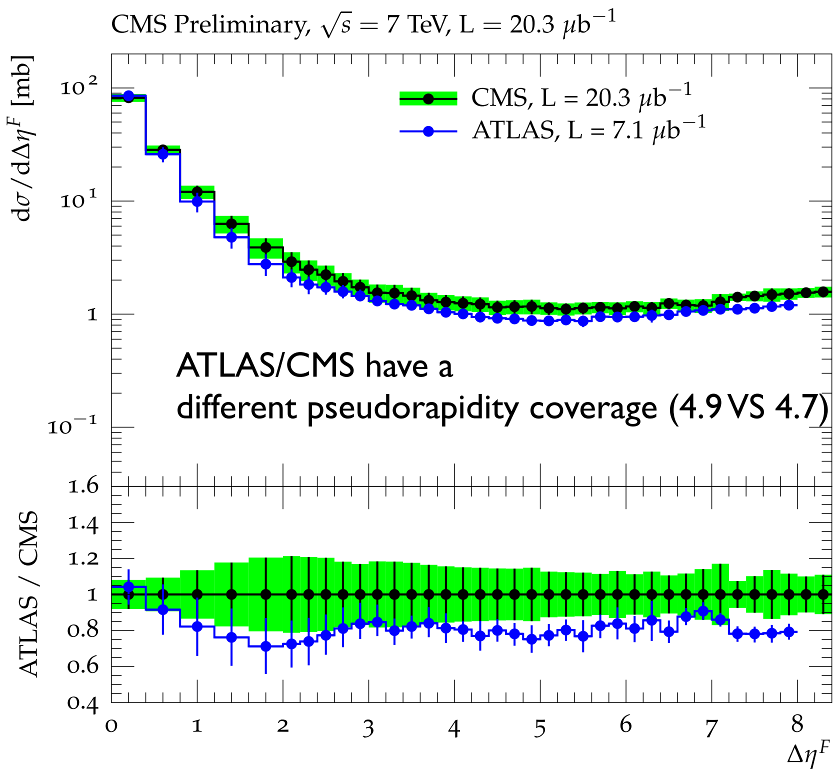
+ QGSJET 01, QGSJET II-04 agree well with the measurements

+ PYTHIA 8+MBR agrees well with the track-based measurements, but overestimates the prediction for σinel for $\xi > 5\times10^{-6}$

All models agree broadly with the relative dependence of the cross section on the criteria used to define the final states.

Total pp cross section - GAPs cross section



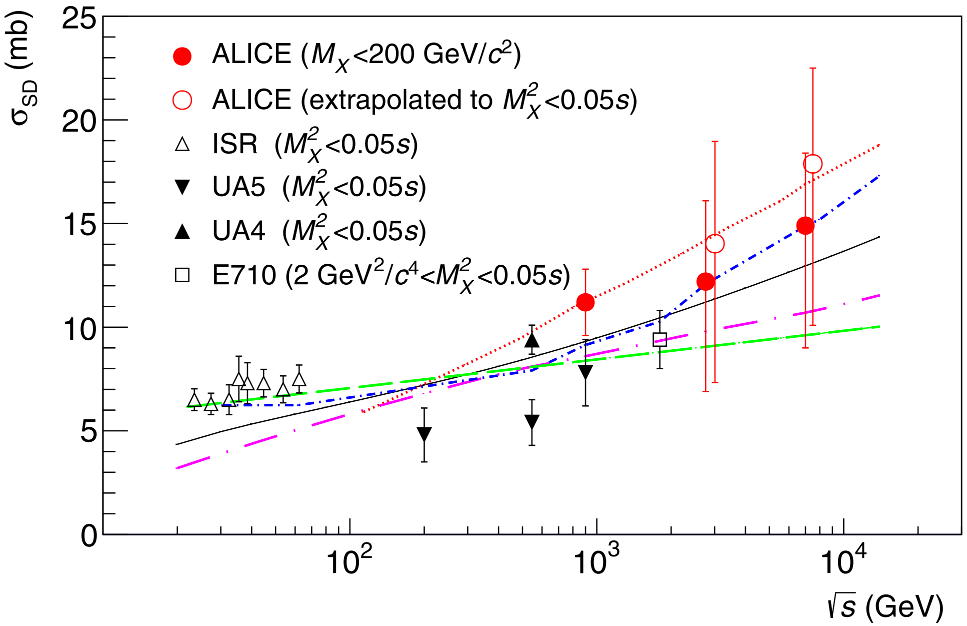


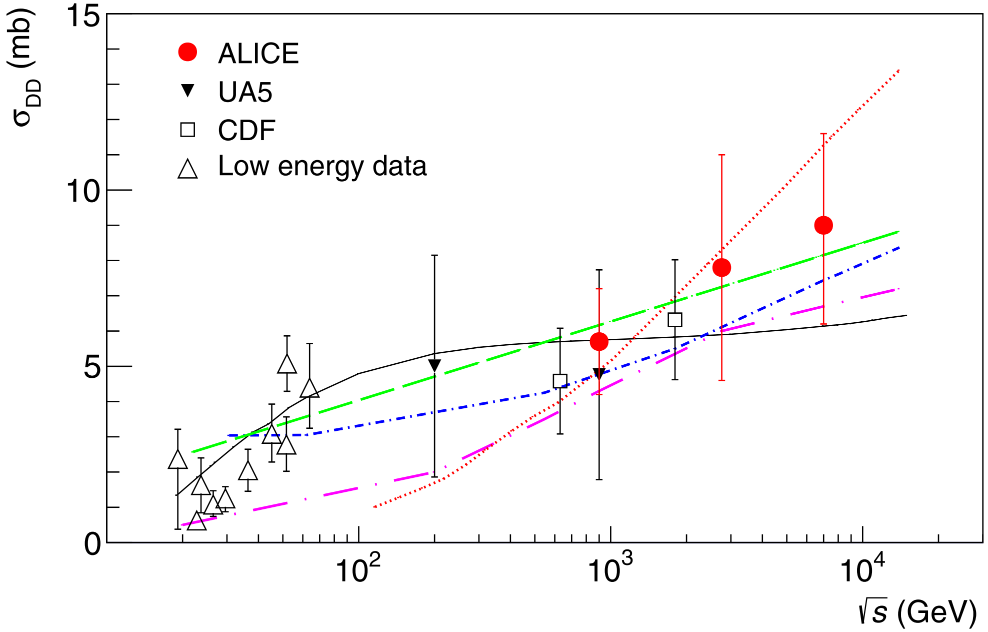
The size of the pseudorapidity gap is directly related to the diffractively dissociated system (in the whole mass range) - larger GAP -> higher contribution

$\Delta\eta$F = largest empty pseudorapidity interval, from edge of detector
non-diffractive events dominate at small gaps
diffractive plateau observed for large gaps

CMS Coll., PAS FSQ-12-005
ATLAS Coll., EPJ C72 (2012) 1926

Total pp cross section - Diffraction





Experimentally is not possible to distinguish pomeron exchange from secondary-reggeons, the separation of these processes is model dependent

Experimental measurements based on large gaps, compared with different model (triple reggeon, QGSJET II, N=4SYM...)

Good agreement on a wide energy range with the model based on Gribov's Regge calculus (Eur. Phys. J. C67 (2010) 397) - continuous black line

Almost constant SD fraction with energy $\sigma_{SD}/\sigma_{Inel} \simeq 0.2$

[consistency: good agreement at 900 GeV with previous measurements]

Eur.Phys.J. C73 (2013) 2456

LHC

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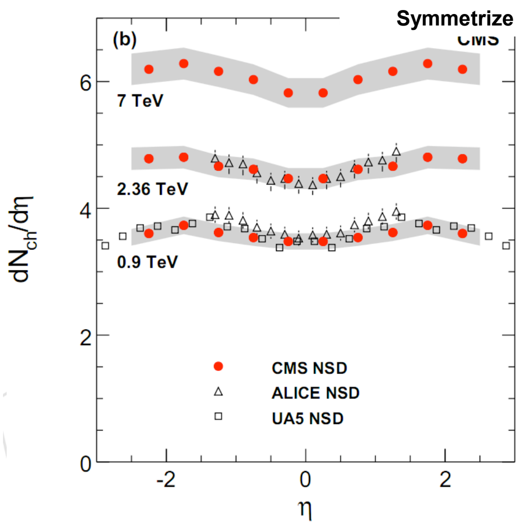
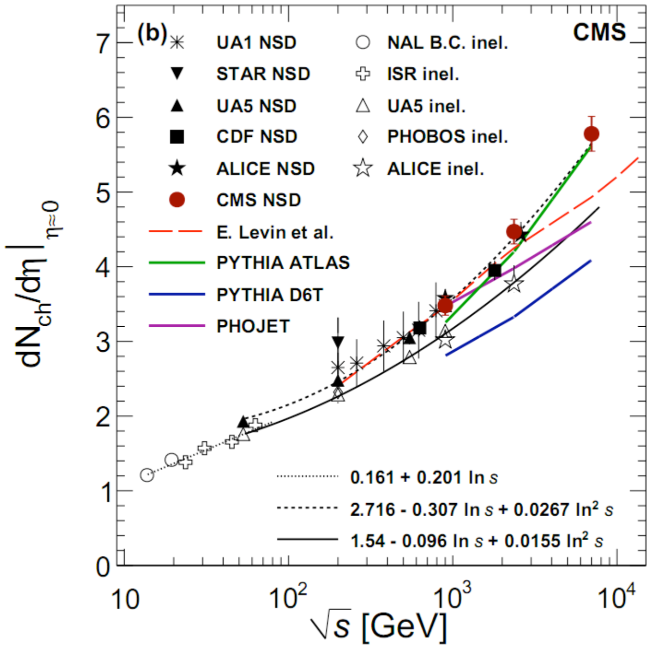
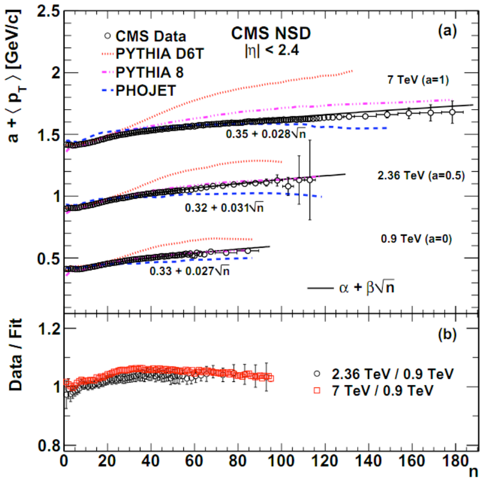
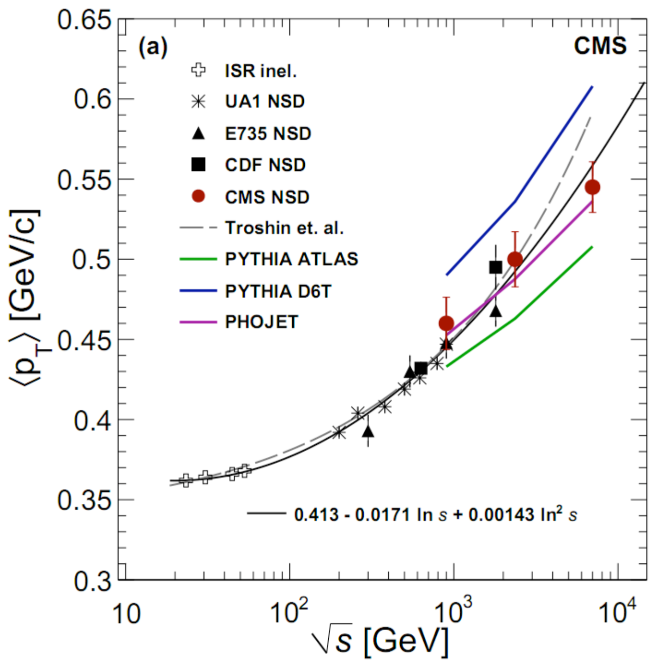
The role played by Multiple Parton Interactions

Pseudorapidity and pT distribution







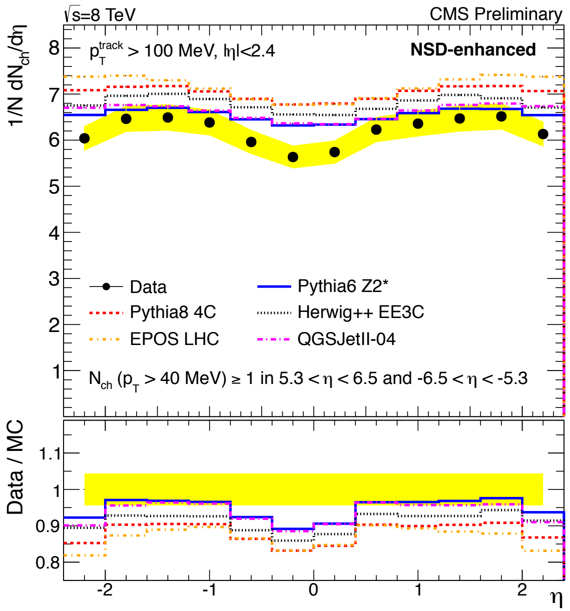


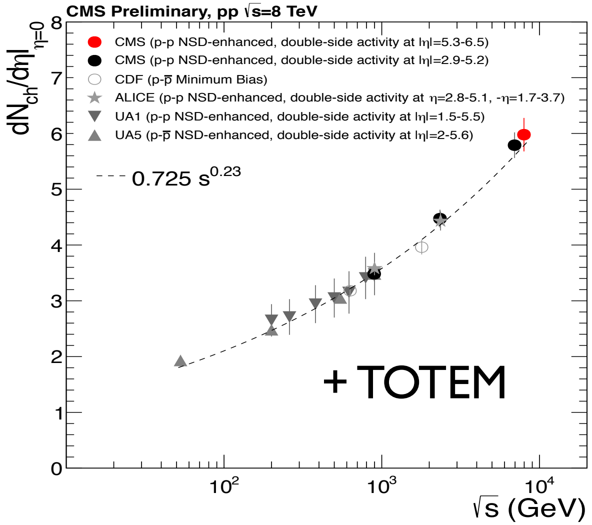
Most event generators are not able to describe simultaneously both energy evolution in $\rho(0)$ and $\langle p_T \rangle$

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

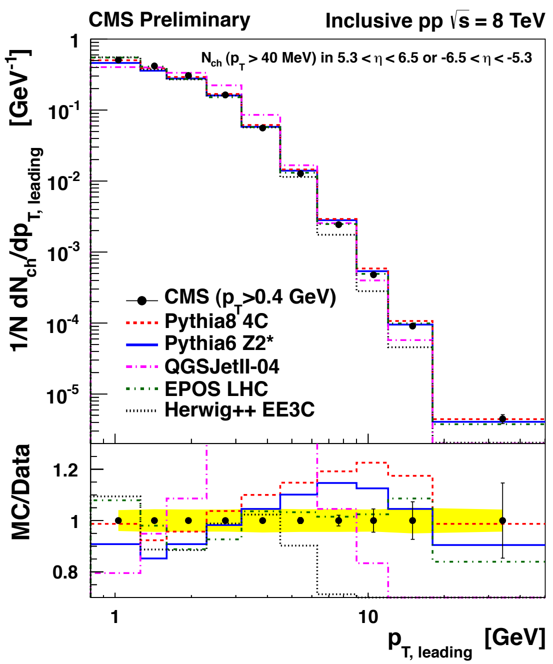
JHEP 02 (2010) 041
Phys. Rev. Lett. 105 (2010) 022002

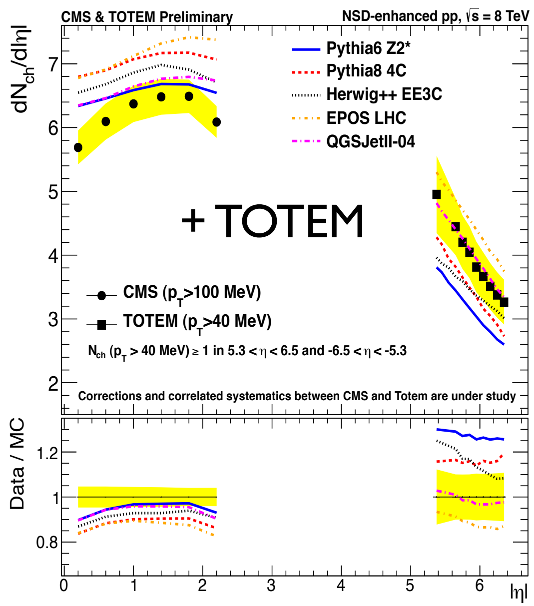
Pseudorapidity and pT distribution





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 energy independent for soft processes

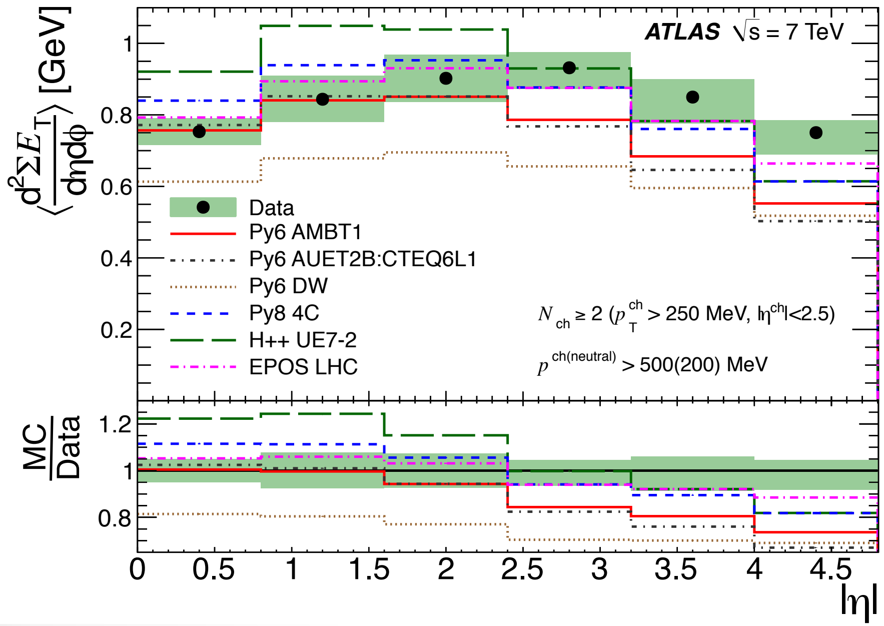
for hard scale the rise is due to

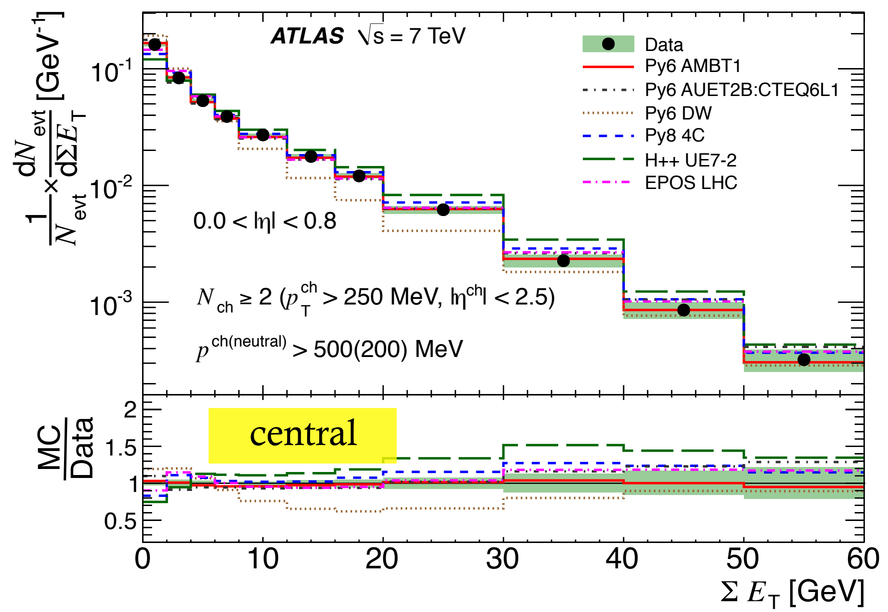
- production of jets in hard scatters
- and **MPI**

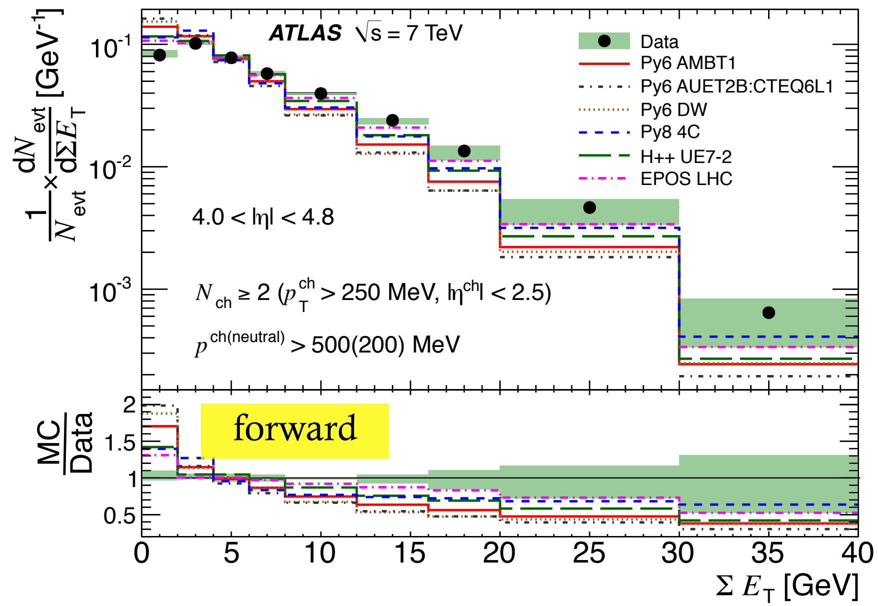
Z-generation pythia, tuned on MPI observables, does the best job in central region but fails forward

CMS PAS FSQ-12-026

Transverse Energy Flow







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

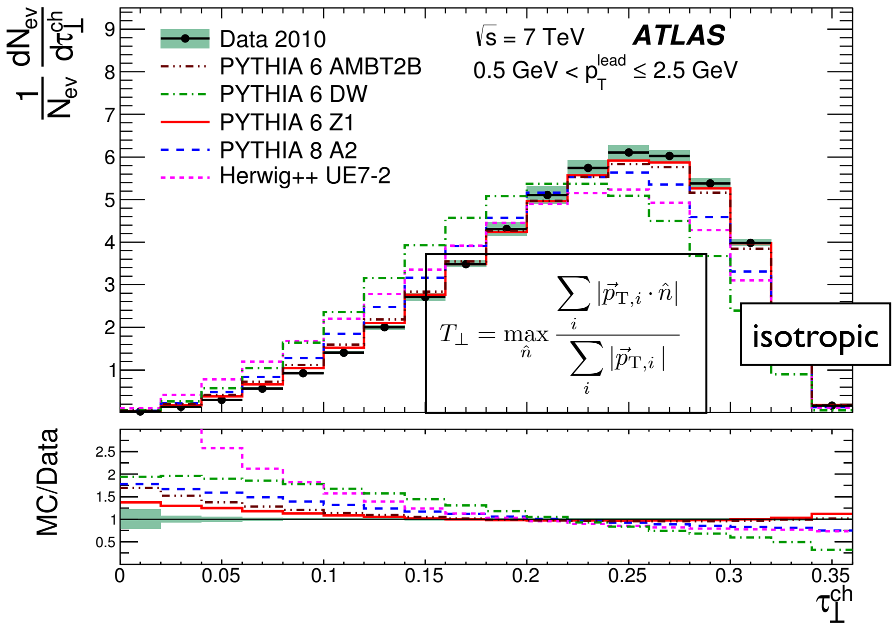
MCs underestimate the forward activity

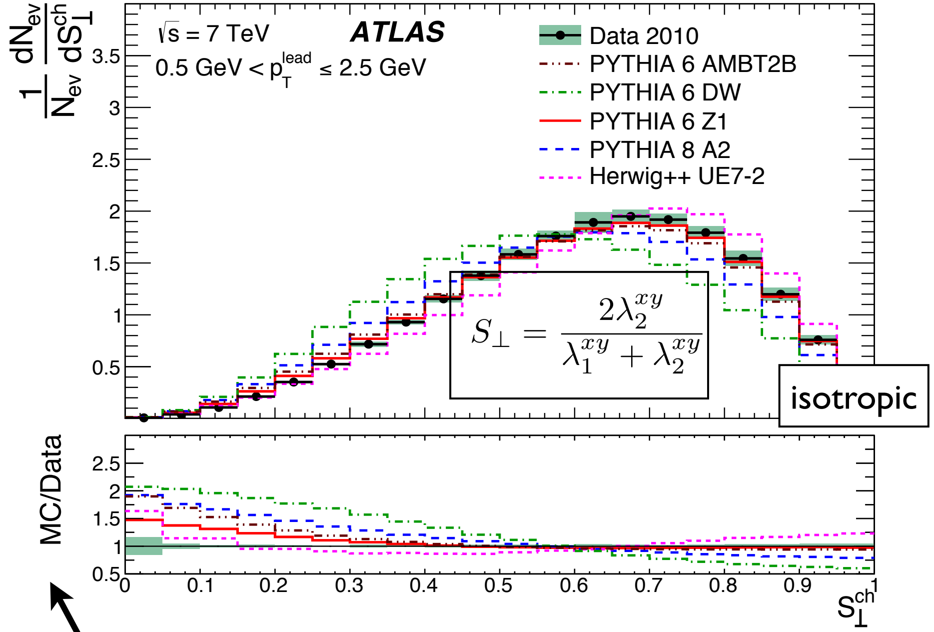
sensitivity to diffractive component is small

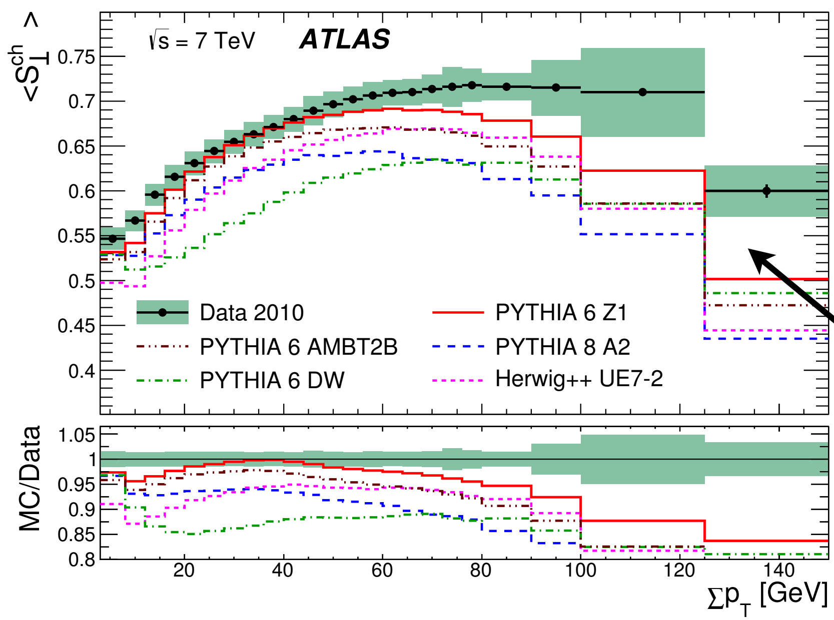
sensitivity to choice of proton PDFs and Underlying Event tune is observed

ATLAS, JHEP 11 (2012) 033

Event Shapes







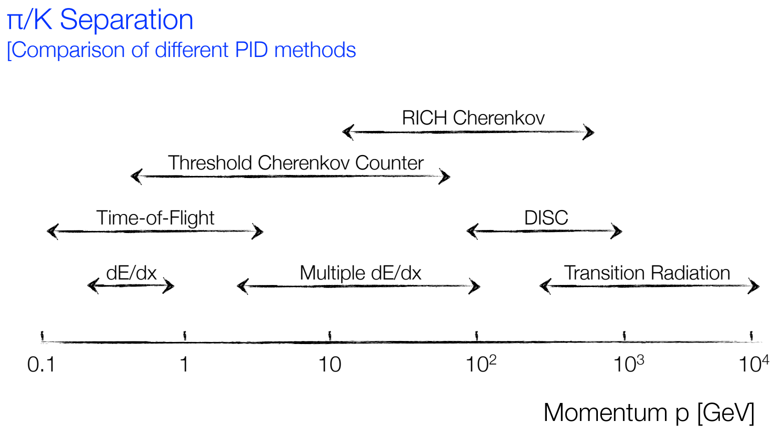
prevalence of spherical events with a soft pTlead selection

Z-generation Pythia Tune provide the best description

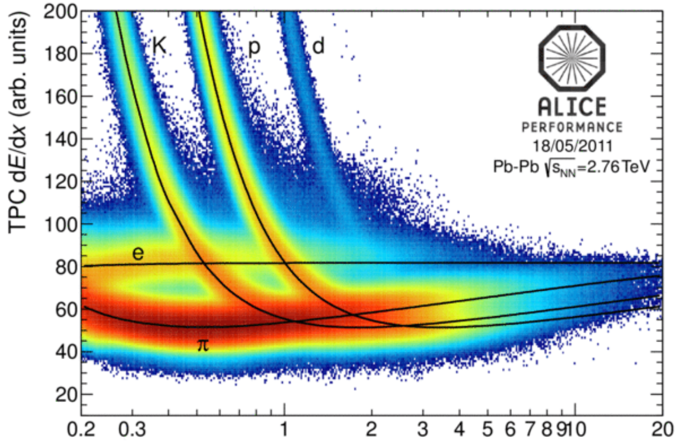
all MCs fail in reproducing shapes at high pTsum (same for high multiplicity events)

ATLAS, arXiv:1207.6915v4

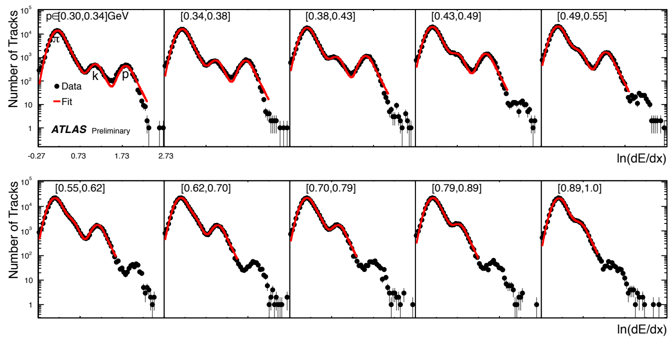
Particle production and identification



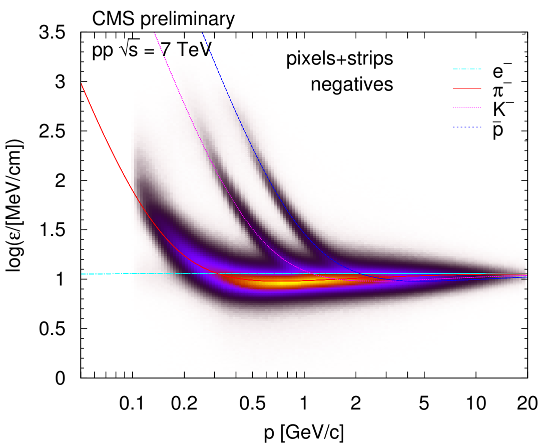
Particle identification is performed in different ways, depending on the peculiarity of the single detectors, estimators are build based on dE/dx, TOF, Secondary Vertex...



TIS+TPC+HMPID+TRD

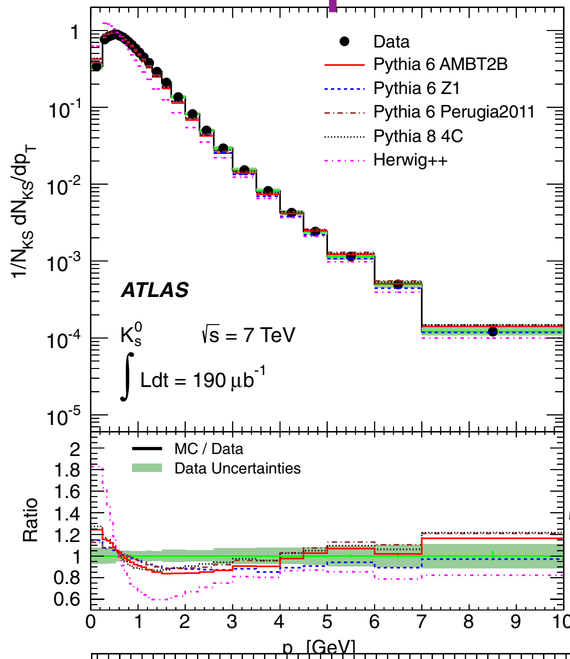


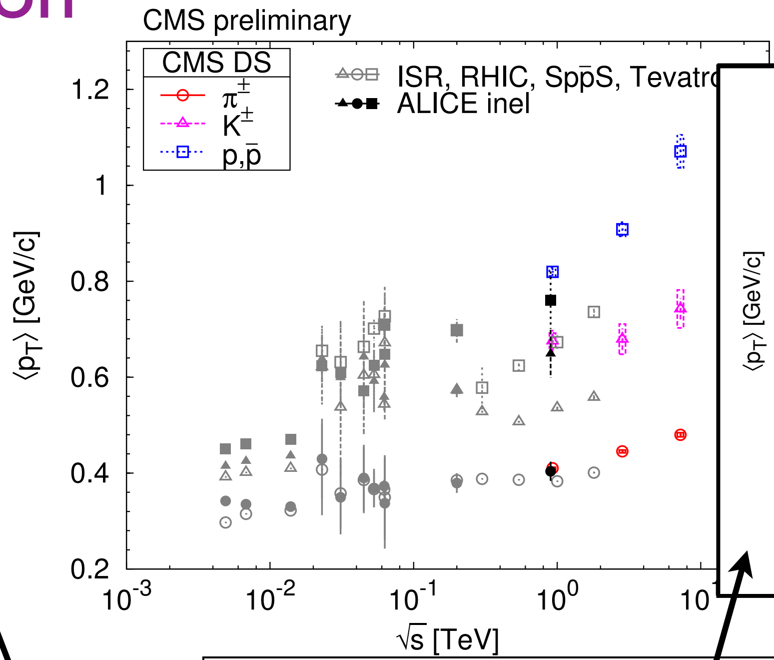
TRT+PIXEL +CALORIMETER

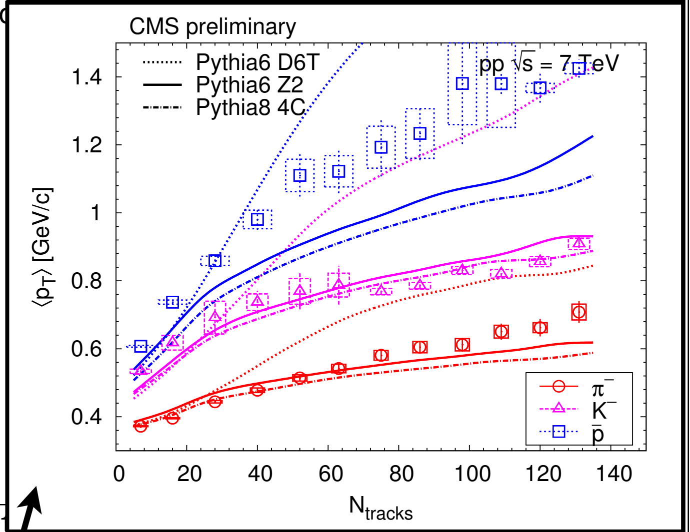


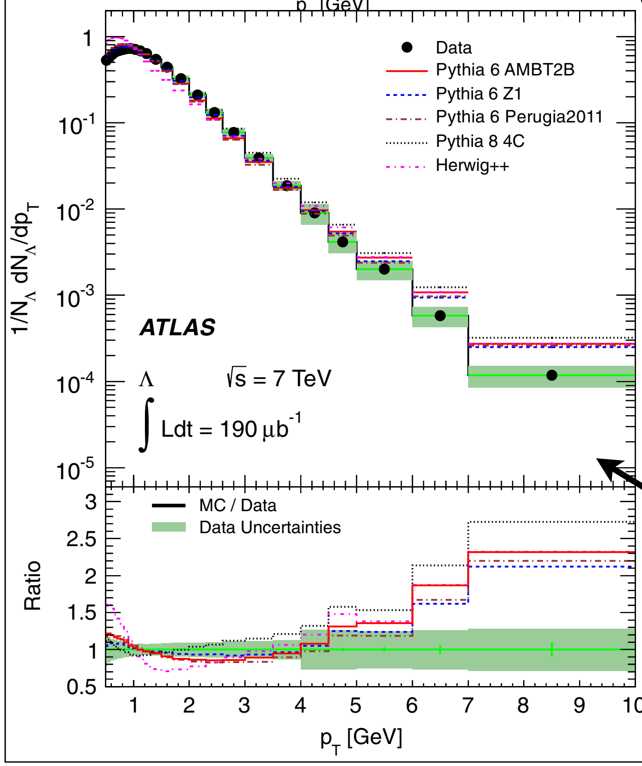
SILICON TARCKER

Particle production









Identified from displaced vertex (ATLAS); dE/dx in silicon (CMS)

Particle production seems strongly correlated with multiplicity rather than $\sqrt{S}$

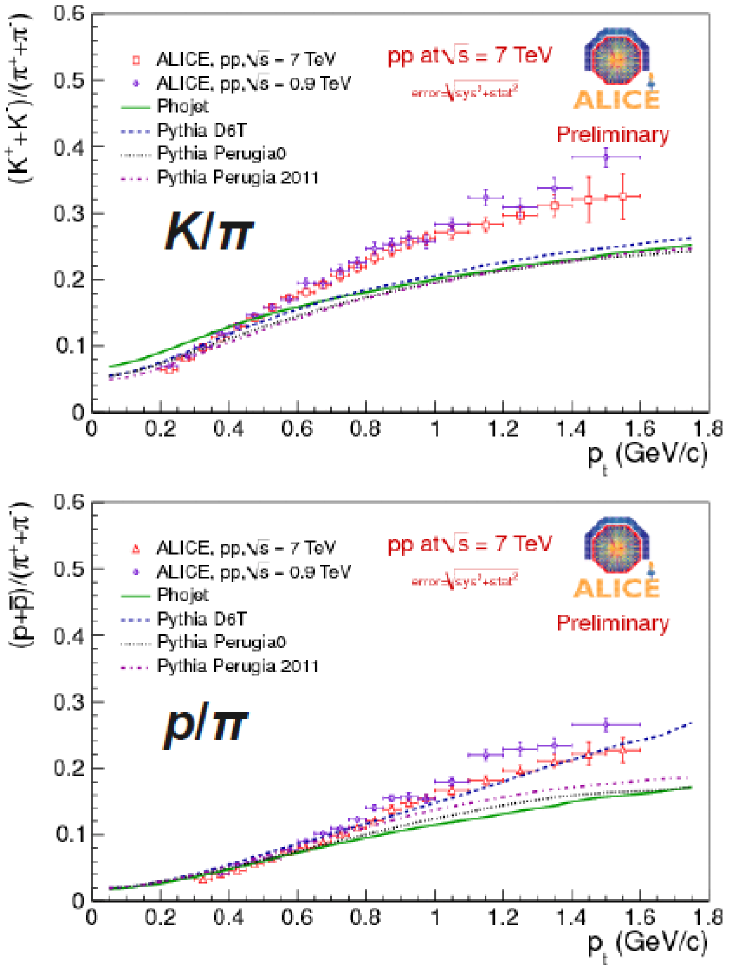
TeV scale -> dynamics of particle production constrained by the amount of initial parton energy

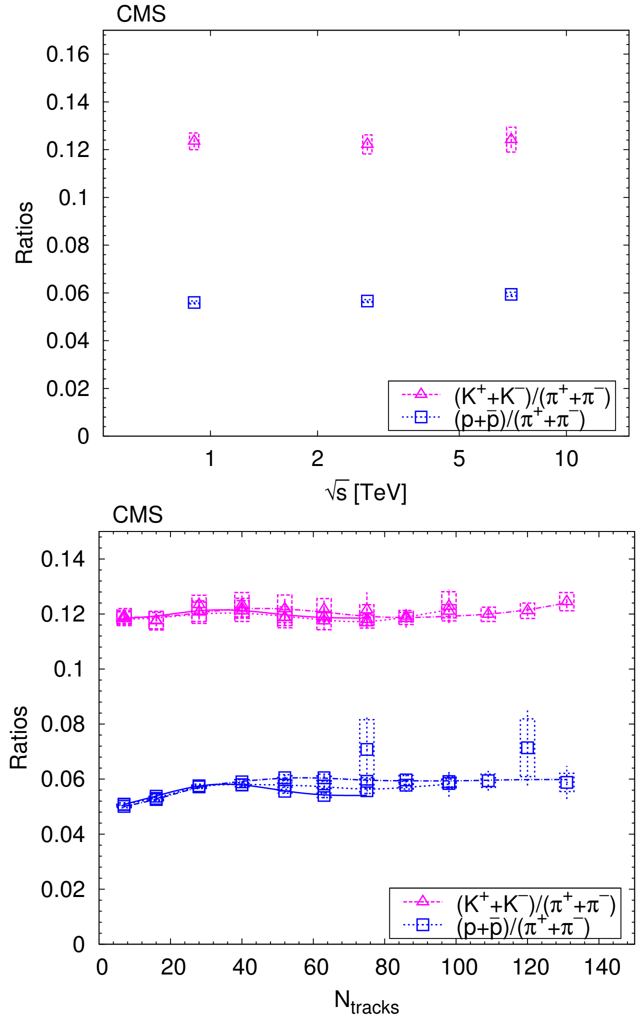
Strange particle agrees with PYTHIA distributions to 5% - best with Pythia Z-generation

Difficulty in describing Λ data at high-pT

Eur.Phys.J. C71 (2011) 1655 (ALICE)
PHYSICAL REVIEW D 85, 012001 (2012) (ATLAS)
arXiv:1207.4724 (CMS)

Particle production - ratios





Momentum dependence

Comparison with pythia *Perugia tunes* shows nice agreement with kaons and overestimation for pions

Particle ratios plots generally challenge MC

√S and multiplicity dependence:

K/π and p/π are flat with values 0.13 and 0.06-0.07

Opposite charge ratios – Flat, around 0.97-0.98 for pions; compatible with 1 for kaons - not shown here

Eur. Phys. J. C 72 (2012) 2164

2-particles correlations

SIGNAL:

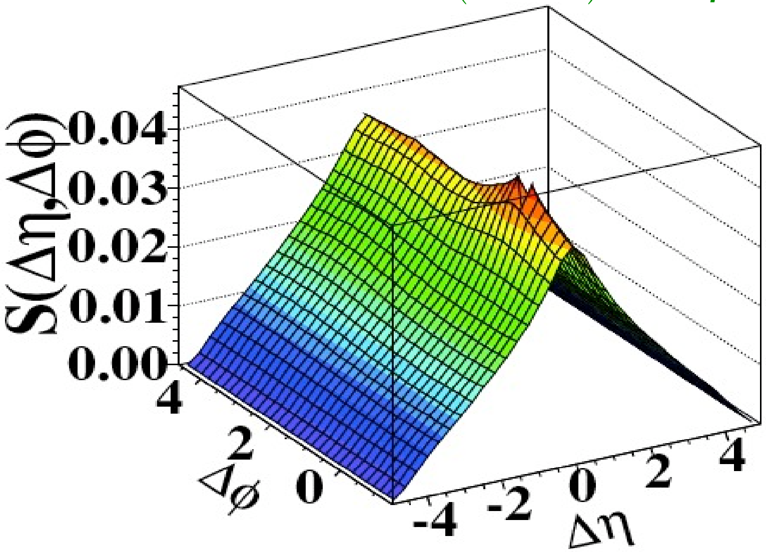
correlated and uncorrelated pairs from same event

$$S(\Delta\eta,\Delta\phi)=\frac{1}{N(N-1)}\frac{d^2N}{d\Delta\eta\Delta\phi}$$

BACKGROUND:

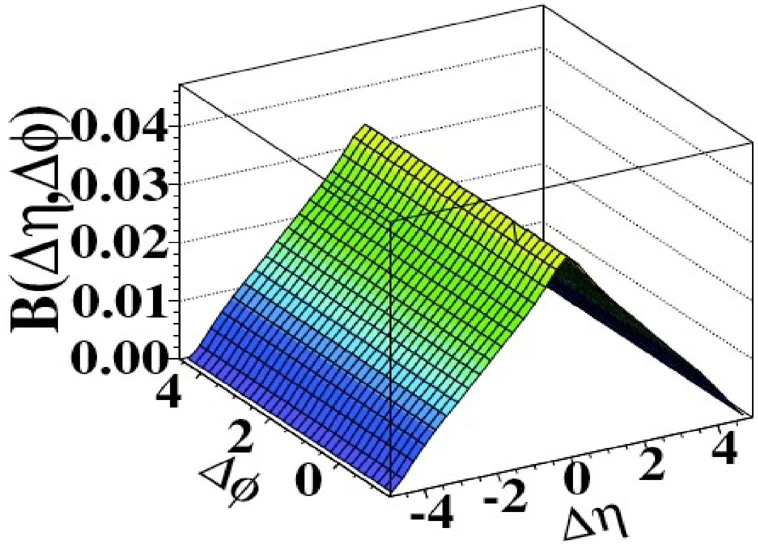
uncorrelated pairs from 2 events mixing

$$B(\Delta\eta,\Delta\phi)=\frac{1}{N^2}\frac{d^2N}{d\Delta\eta\Delta\phi}$$



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

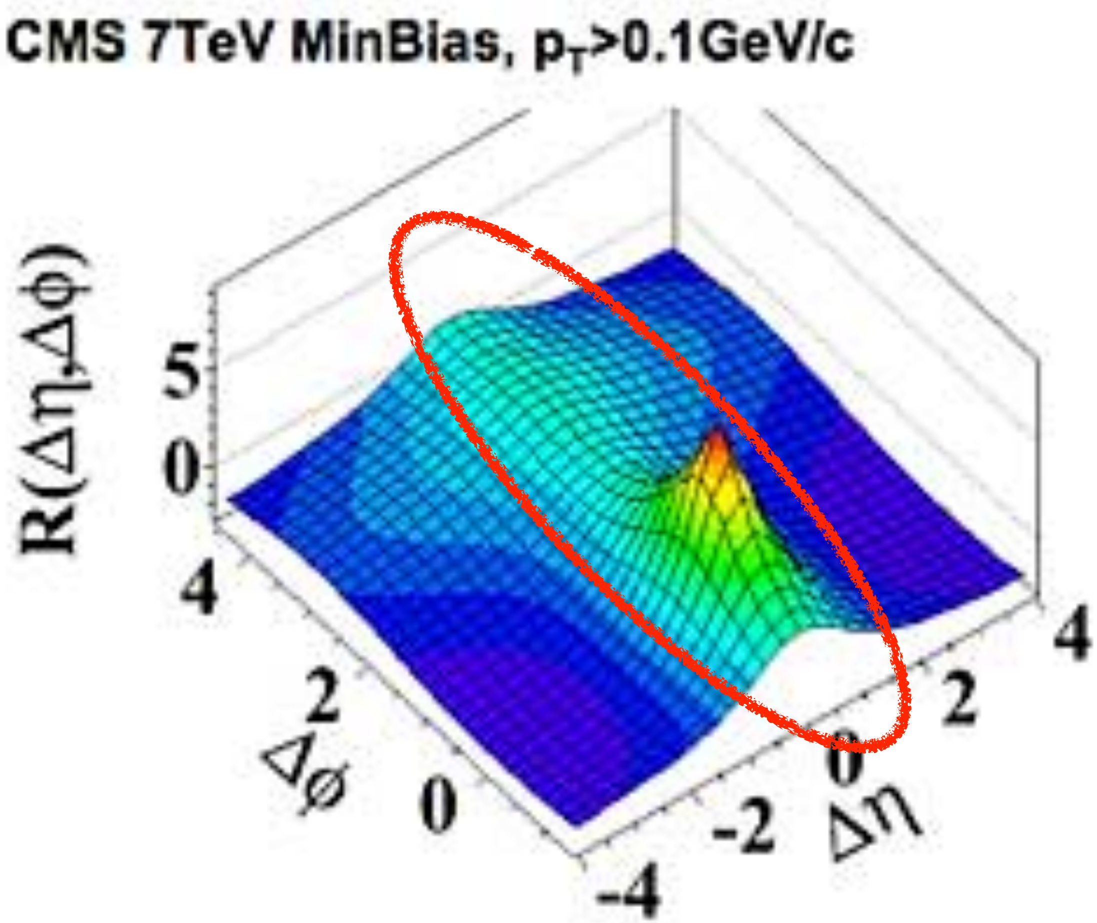
$$\Delta\phi=\phi_1-\phi_2$$



2-particles correlations are defined as

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

2-particles correlations



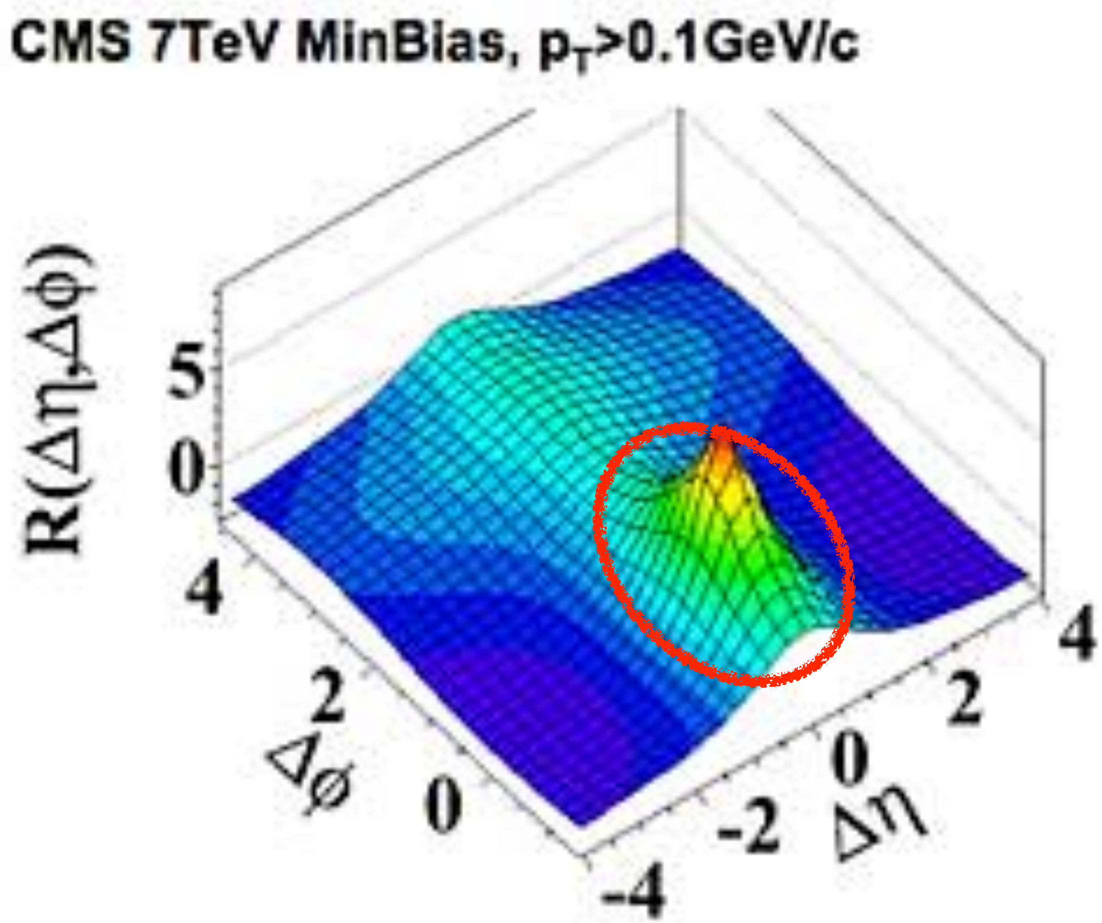
Gaussian ridge @ |Δη|<2 from cluster fragmentation (short-range)

Near-side peak @ Δη,ΔΦ~0 from near-side "jet"/higher pT clusters (+BE)

Broad ridge @ ΔΦ~π from Away-side "jet"/ lower pT clusters

Cos(ΔΦ) modulation from Momentum conservation

2-particles correlations



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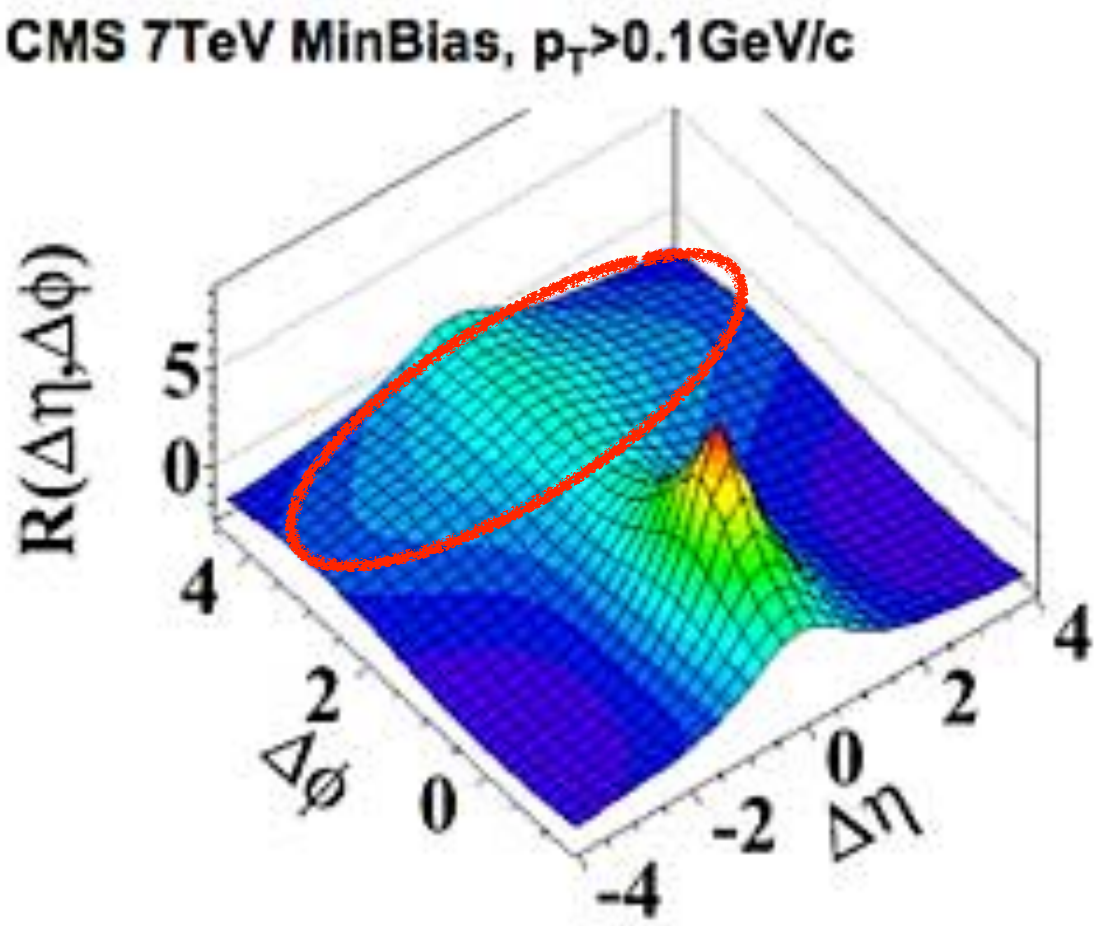

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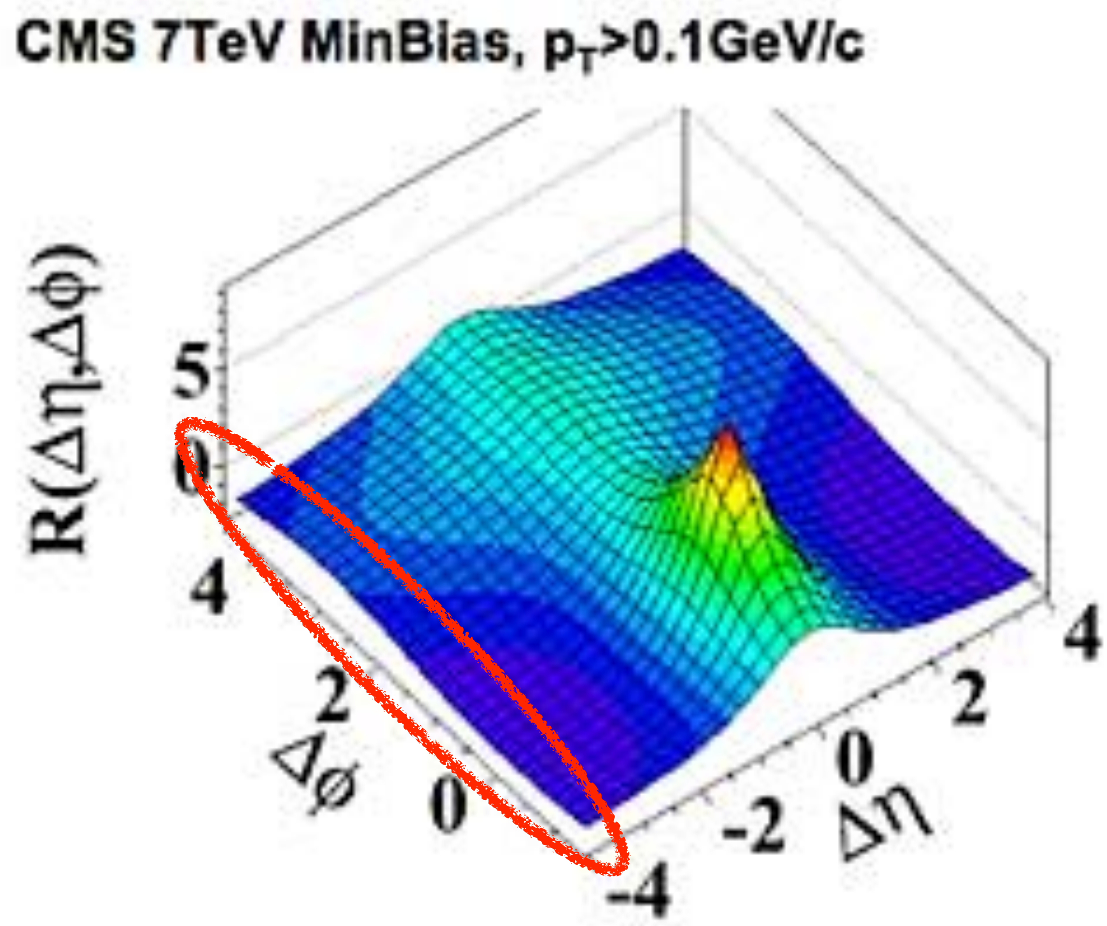
2-particles correlations



Gaussian ridge @ $|\Delta\eta|<2$ from cluster fragmentation (short-range)

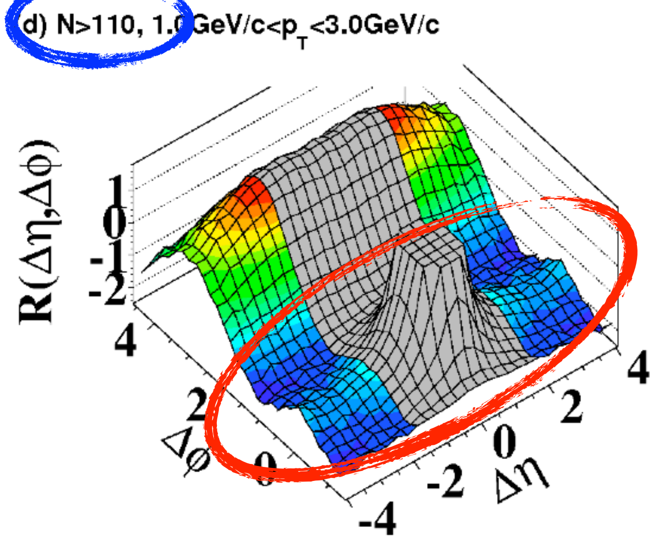
Near-side peak @ $\Delta\eta,\Delta\Phi \sim 0$ from near-side "jet"/higher pT clusters (+BE)

Broad ridge @ $\Delta\Phi \sim \pi$ from Away-side "jet"/ lower pT clusters

Cos($\Delta\Phi$) modulation from Momentum conservation

2-particles correlations

Long range:
Project 2 < |Δη| < 4.8 onto Δφ:



Ridge most pronounced for high multiplicity events and at 1 < p_T < 3 GeV.

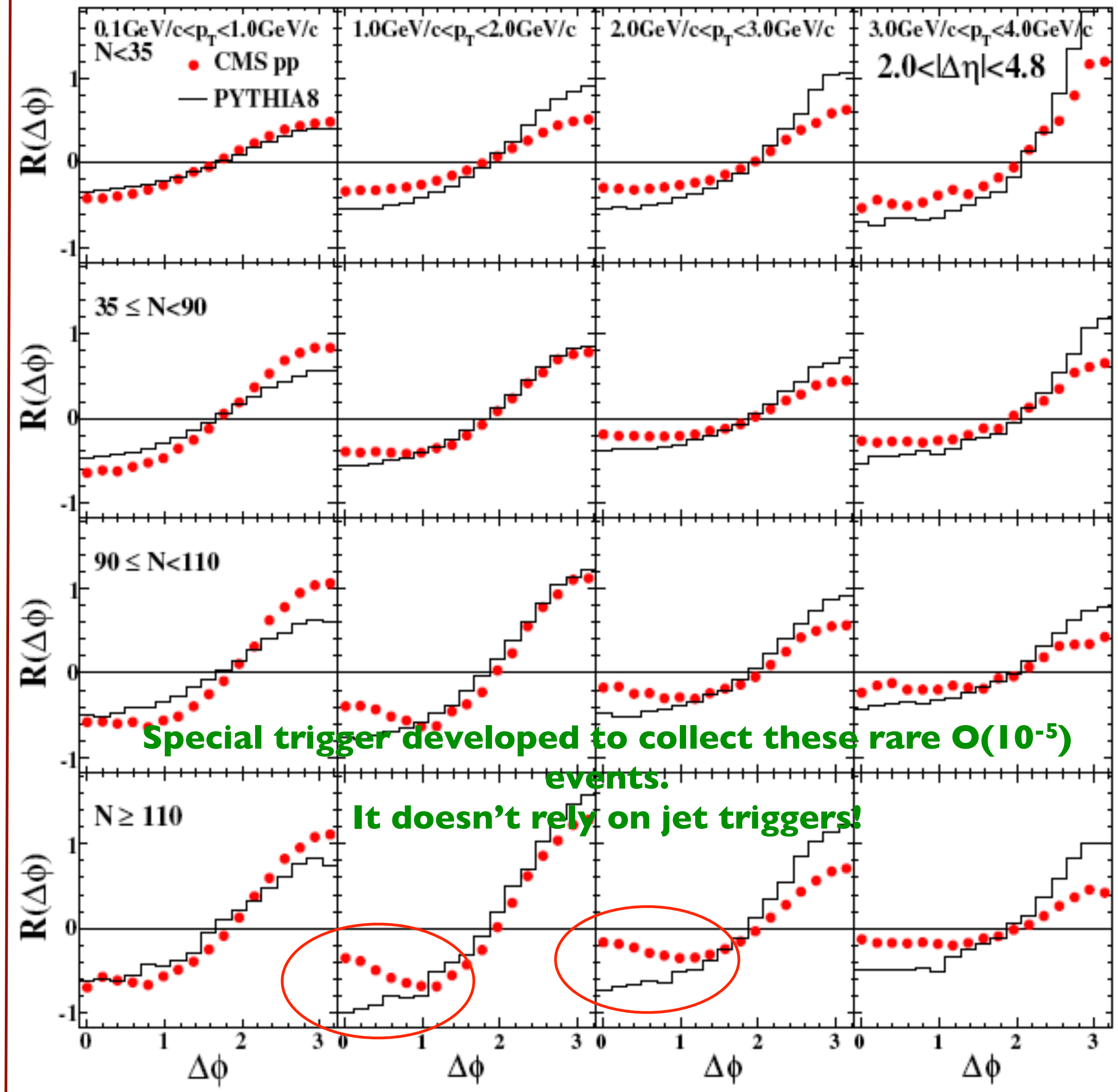
No ridge seen in tested MC models (Pythia 8, Pythia6, Herwig++, etc.)

Several interpretations proposed for this HI-like effect in pp interactions.

Possible role of Multiple Parton Interactions **[S. Alderweireldt, P.Mechelen arXiv:1203.2048]**

Increasing p_T

Increasing multiplicity

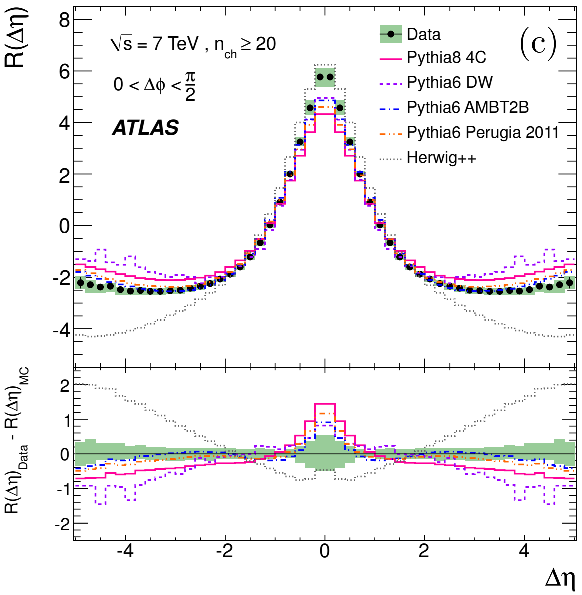


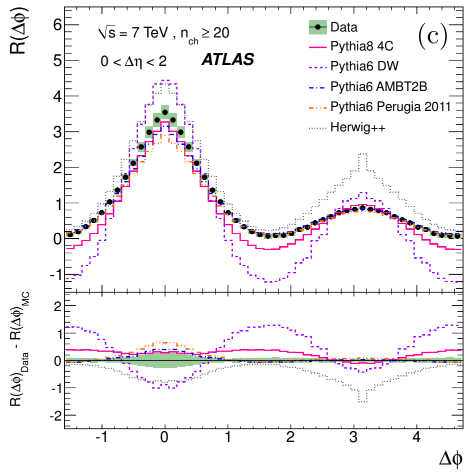
Special trigger developed to collect these rare O(10^{-5}) events.
It doesn't rely on jet triggers!

JHEP 1009:091,2010 **[CMS PAS QCD-10-002]**

correlations - the structure of QCD field

2 particle correlations





Overall shape description but difficult to reproduce the strength of the correlations (P6- AMBT2B and P8-4C provide the best description)

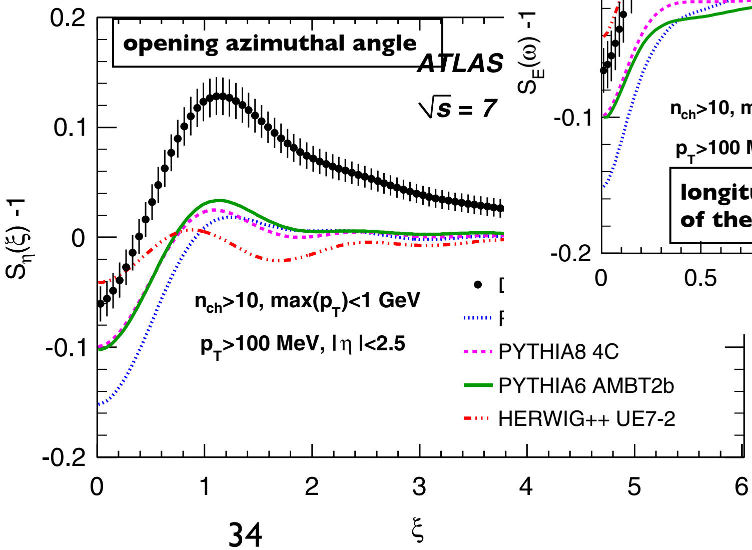
Phenomenology of soft particle production needs further improvement (tuning of diffraction, hadronization, MPI's or beyond....)

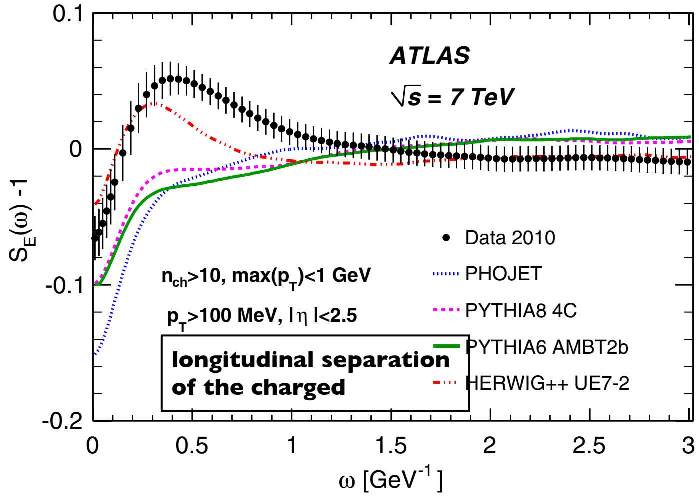
Azimuthal ordering of charged hadrons

MC models employing the standard Lund string fragmentation roughly reproduce the data

Overestimation of correlations in the low-pT depleted sample (maximally sensitive to UE)

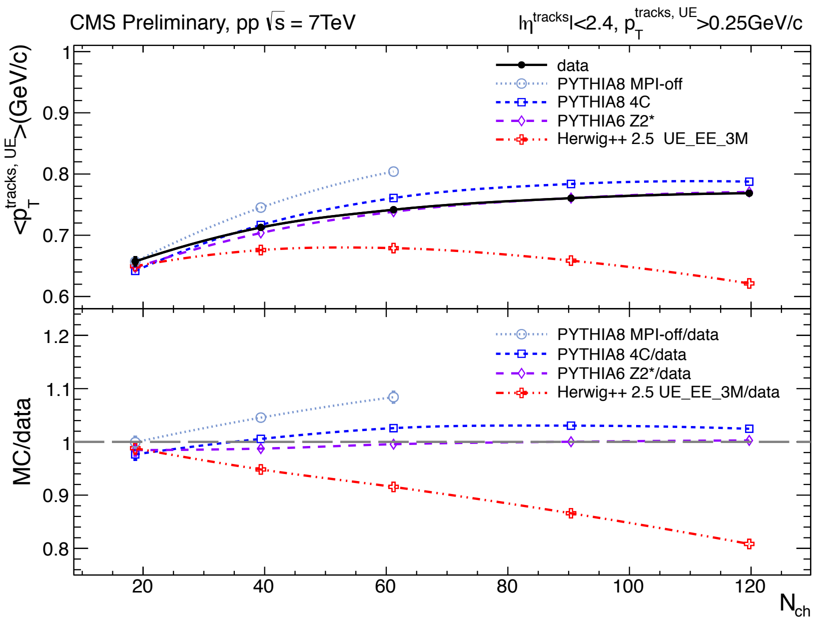
Indication of a fragmenting helixlike ordered gluon chains ?

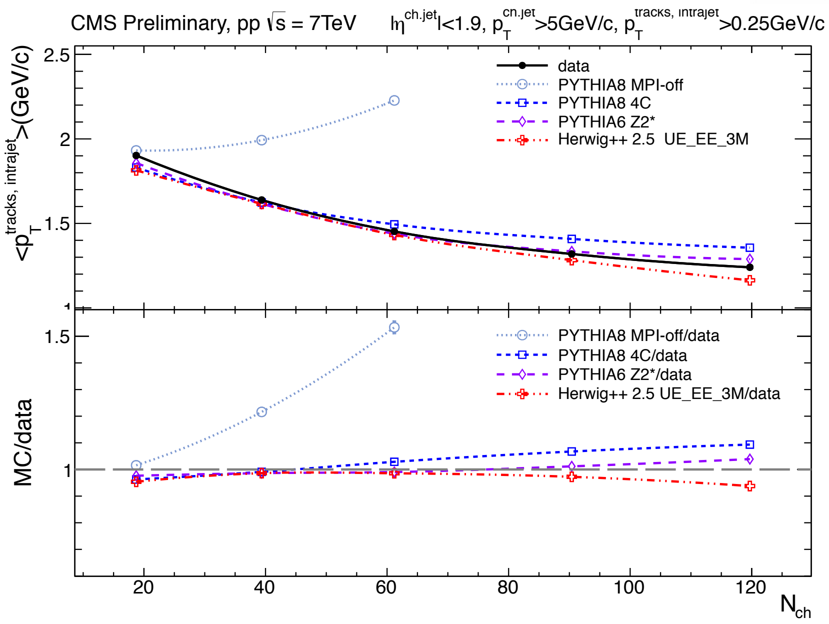


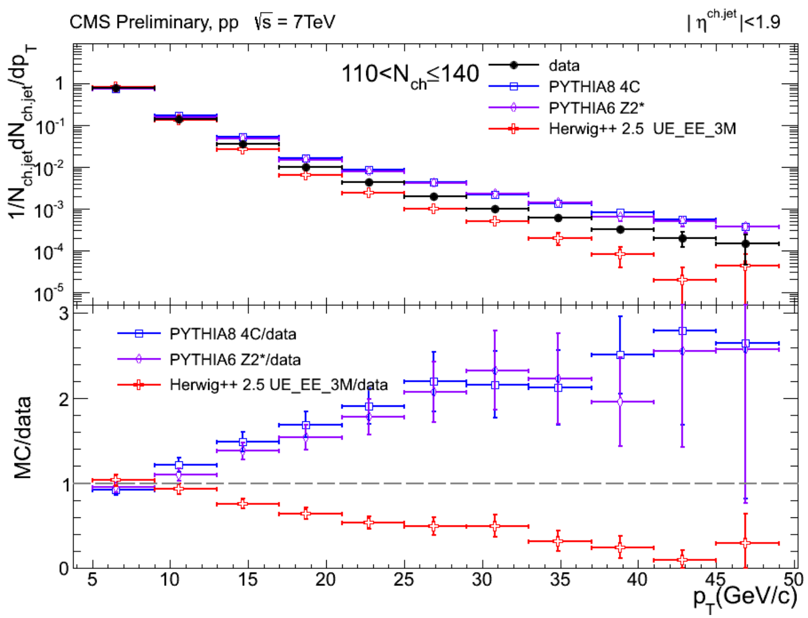


JHEP 1205 (2012) 157
PRD 86, 052005 (2012)

charged energy in/out track-jet definition







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

underlying activity is underestimated by HERWIG (more softer particles than Pythia)

for high-multiplicity events, PYTHIA predicts higher jet rates and harder pT spectra whereas HERWIG shows the opposite trend

CMS-PAS-FSQ-12-022

LHC

Motivations

Soft and Forward QCD measurements

cross sections and diffraction

particles (flow, shape, id and correlations)

Multiple Parton Interactions

soft pT

+ multiplicities
+ <pT> energy evolution
+ energy flow and shapes
+ scaling violation
+ correlations

hard pT

+ background processes to new physics searches
+ proton structure and understanding the dynamics of the hadronic interaction

strong indication of the role played by MPI

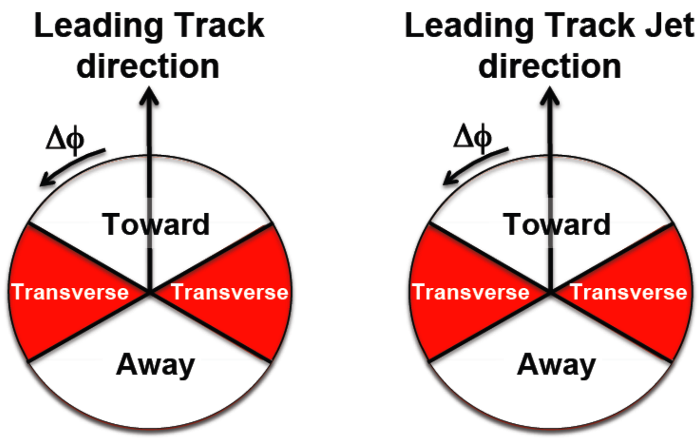
LHC research program:

soft MPI -> Underlying Event (low luminosity)

hard MPI -> direct measurement (high luminosity)

(not discussed here)

Underlying Event at CMS



Traditional approach (R. Field)

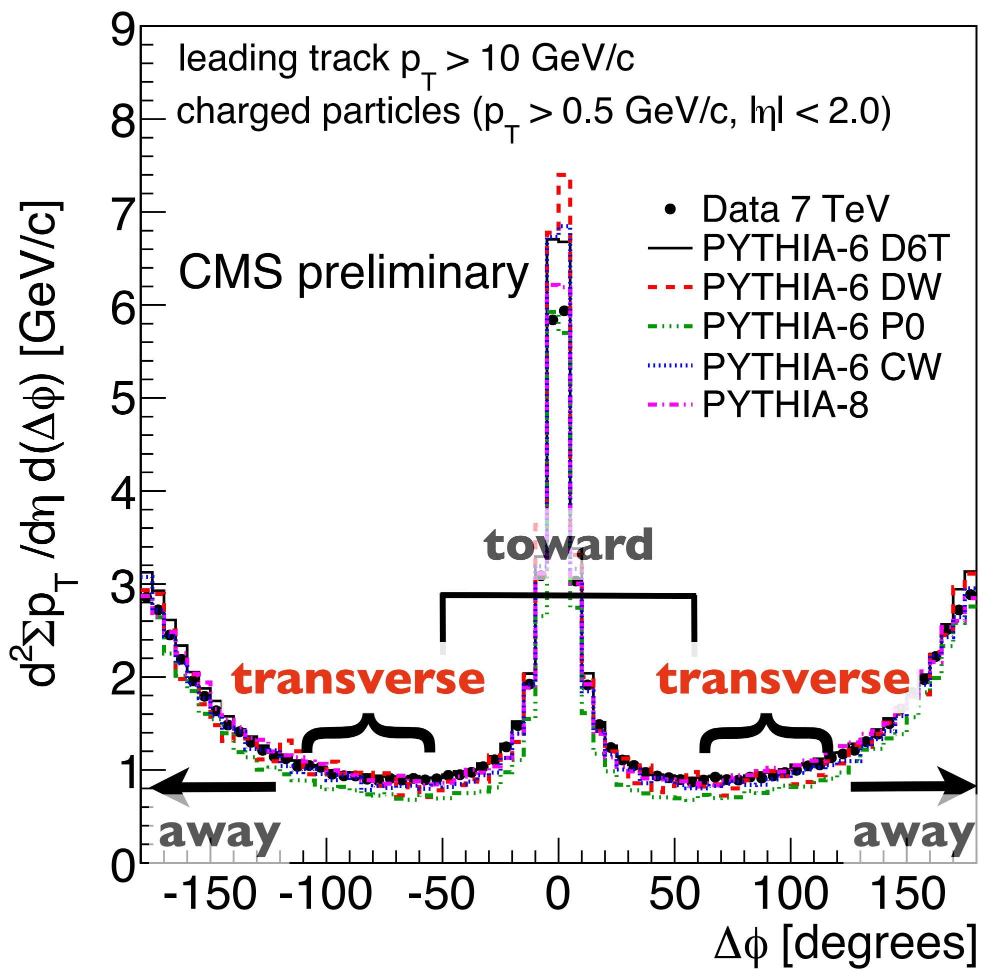
Leading Track or Leading Track-Jet define a direction in the phi plane

Track or Track-jet pT provide 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

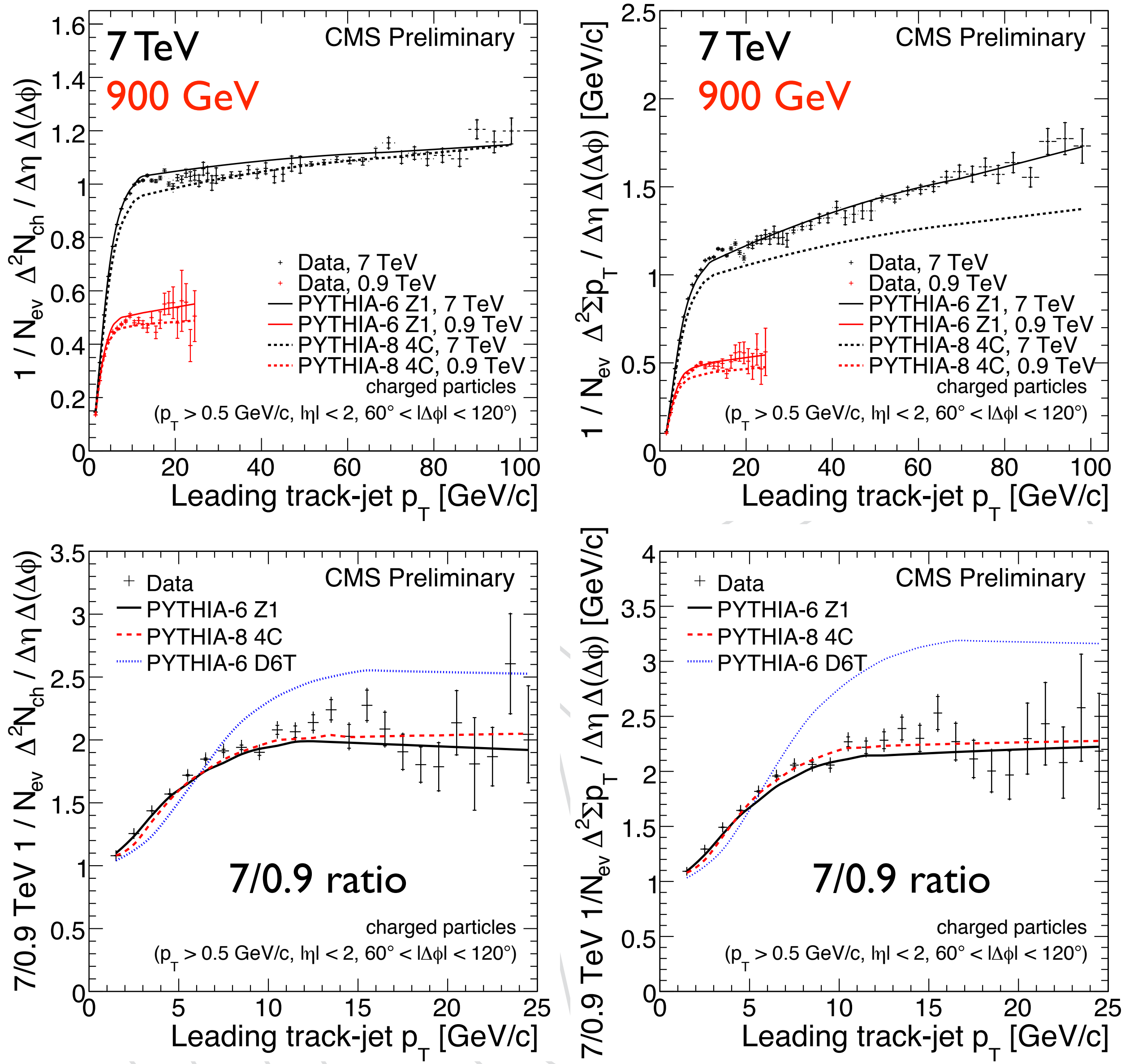


900 GeV - Eur.Phys.J.C70:555-572,2010
7 TeV - JHEP09 (2011) 109

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



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

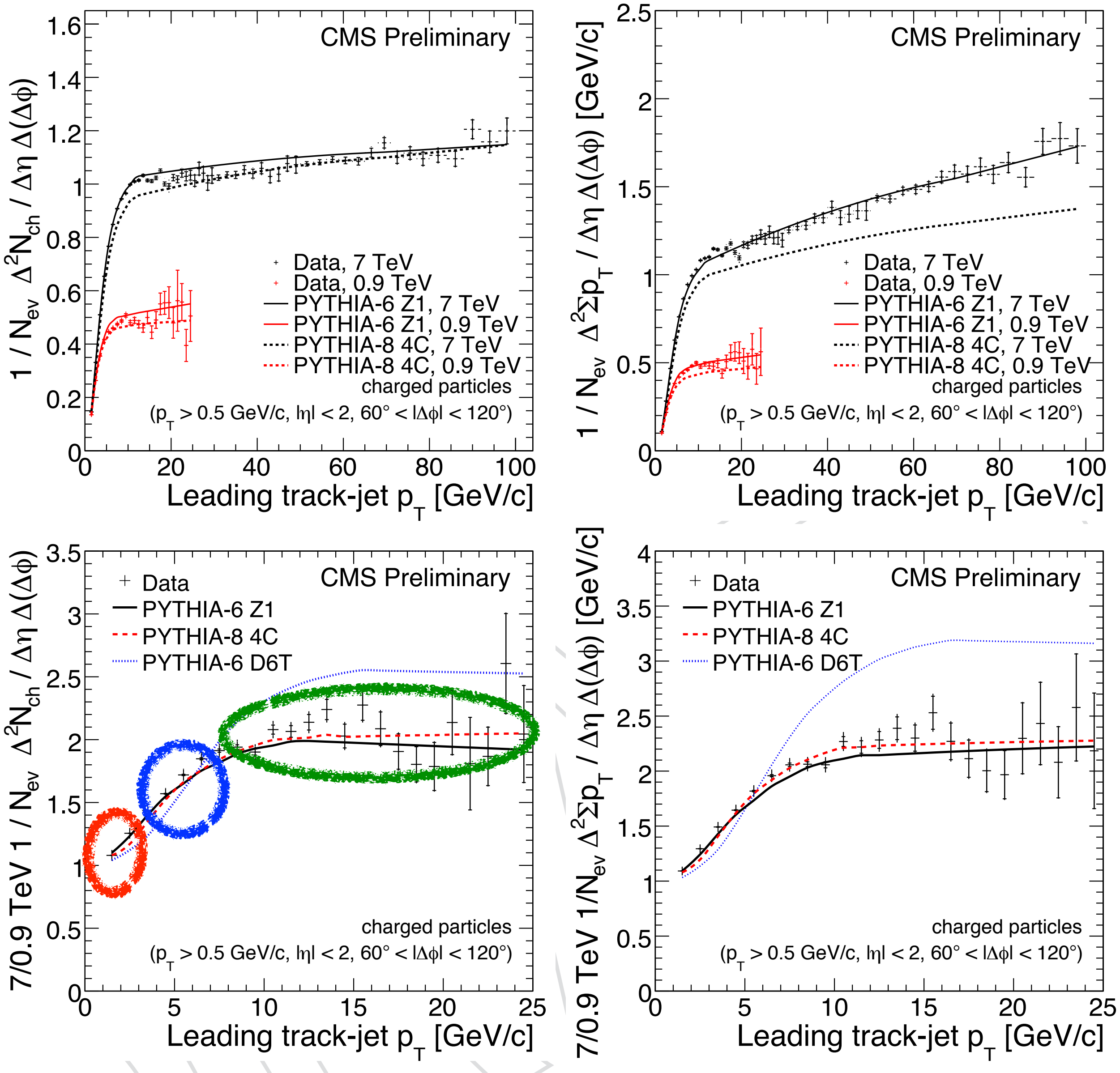
Plateau region with ~constant charged density and slow increase of pT_sum in a sturation regime

Increase of the activity with √S corroborates MPI model...

JHEP09 (2011) 109

The transverse region - jet events

corroborates MPI model...



soft

periferal collision
~independent on $\sqrt{s}$

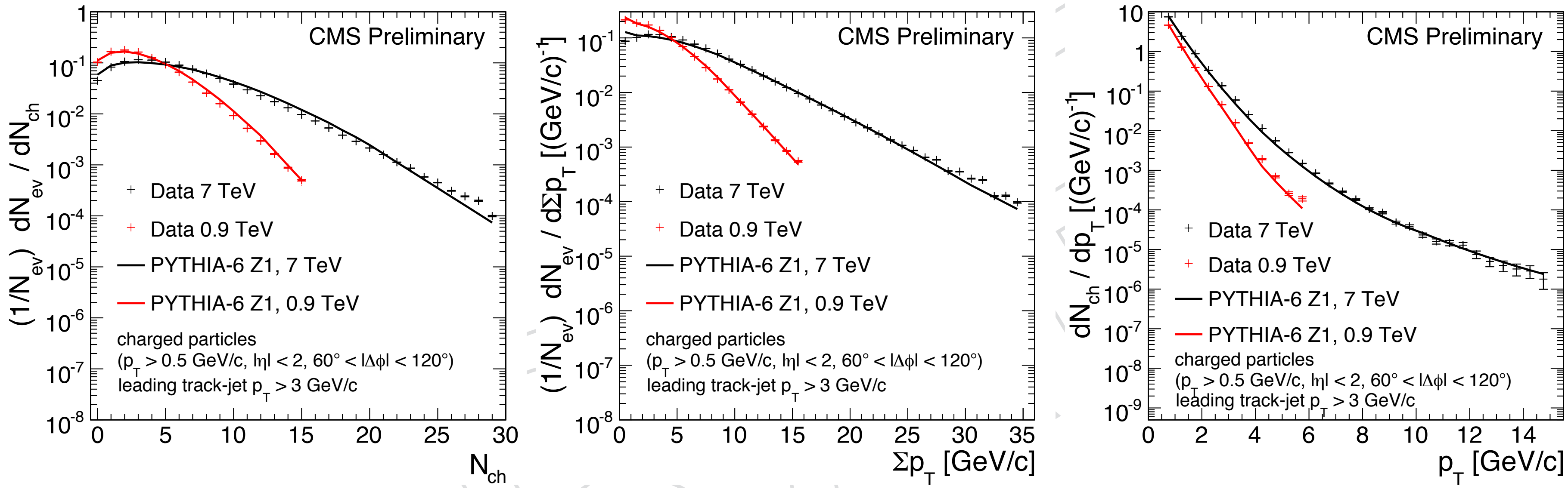
semi-soft

mix of central and peripheral collisions (increasing behaviour)

hard

mainly central collisions.
The ratio reflects the ratio of the sizes of the central, high parton density regions for the two $\sqrt{s}$ domains

The transverse region - jet events cumulative in the transverse region



Strong growth of the activity observed for a **fixed event energy scale (3 GeV)**

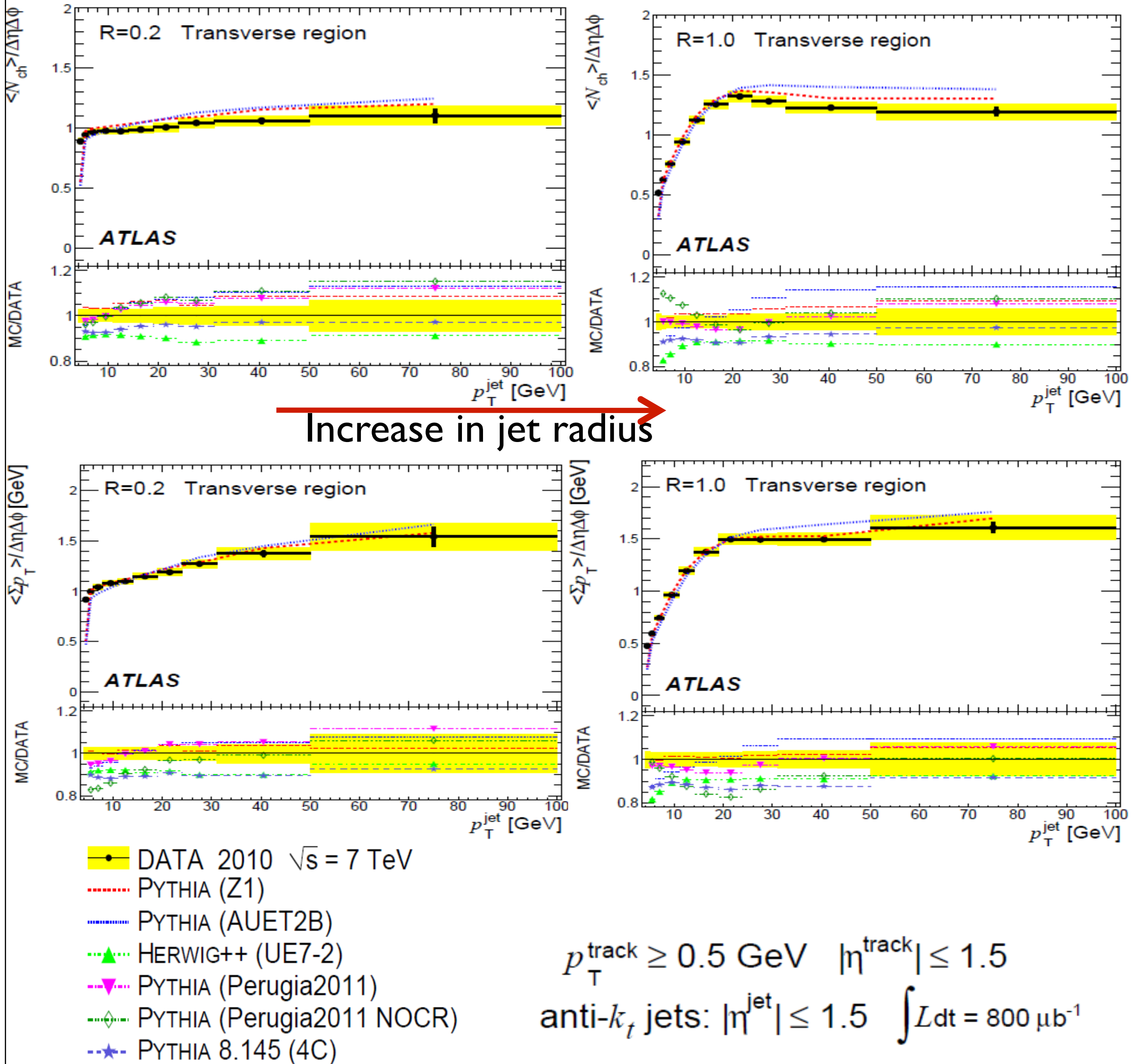
+ hard component in the UE, with p_T spectrum extending to 10 GeV

Several PYTHIA tunes have been compared

(Models differ in the implementation of radiation, fragmentation, color reconnection and multiple parton interactions, in particular in the $\sqrt{s}$ dependence of the amount of MPI activity)

+ Very good descriptions of most distributions at $\sqrt{s}$ = 7 TeV and of the $\sqrt{s}$ dependence from 0.9 to 7 TeV is provided by the Z1 tune.
+ Tunes adopting CTEQ6L may need a smoother increase of the pT-cut-off with increasing energy with respect to CTEQ5L tunes.

The transverse region - jet events

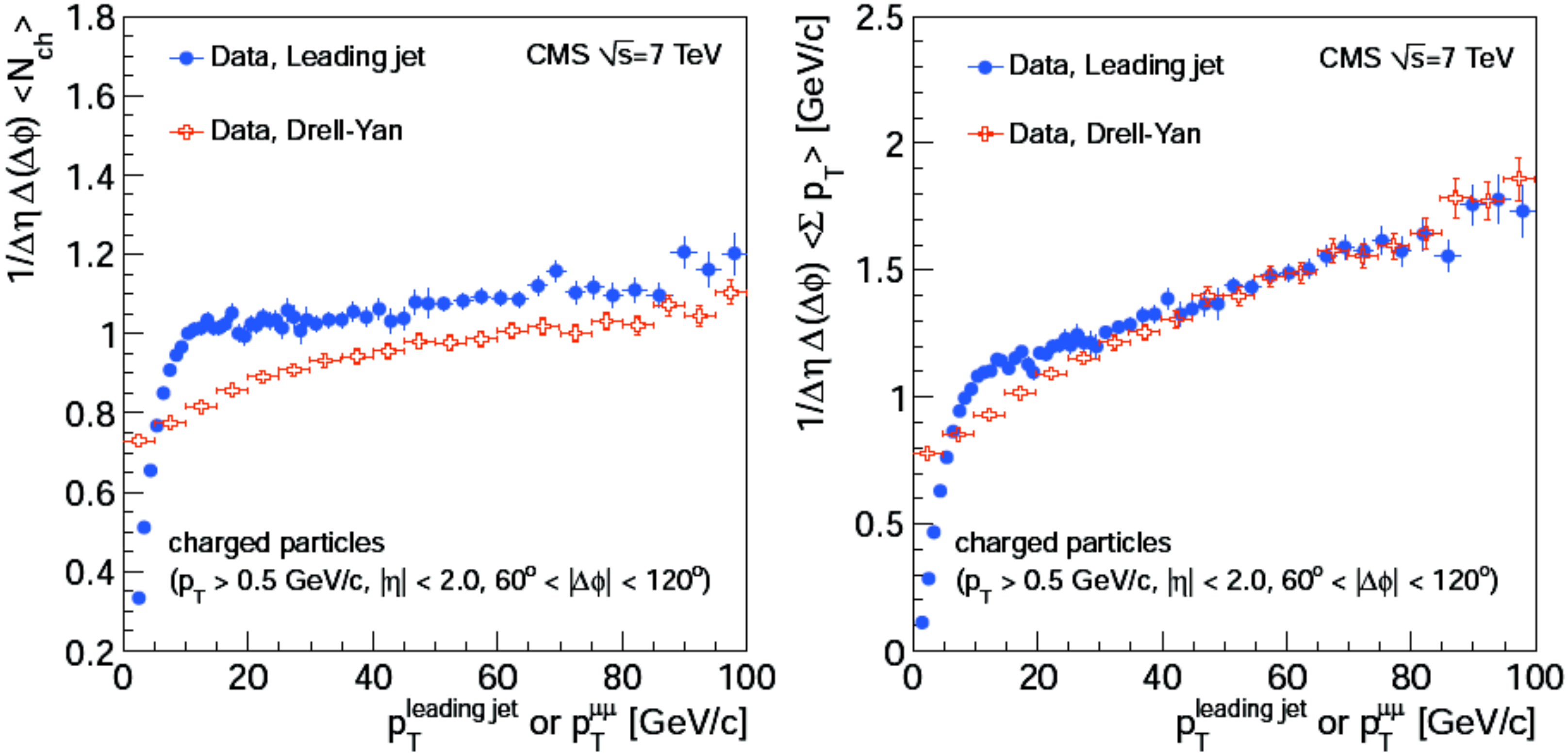


Anti-kT jets, radius: 0.2 to 1.0
Study UE in regions transverse to jets, as a function of $p_T^{\ jet}$

both the multiplicity and the scalar sum of the transverse momenta vary significantly with R while the average charged-particle transverse momentum depends minimally

PRD 86 (2012) 072004

The transverse region - Drell-Yan events



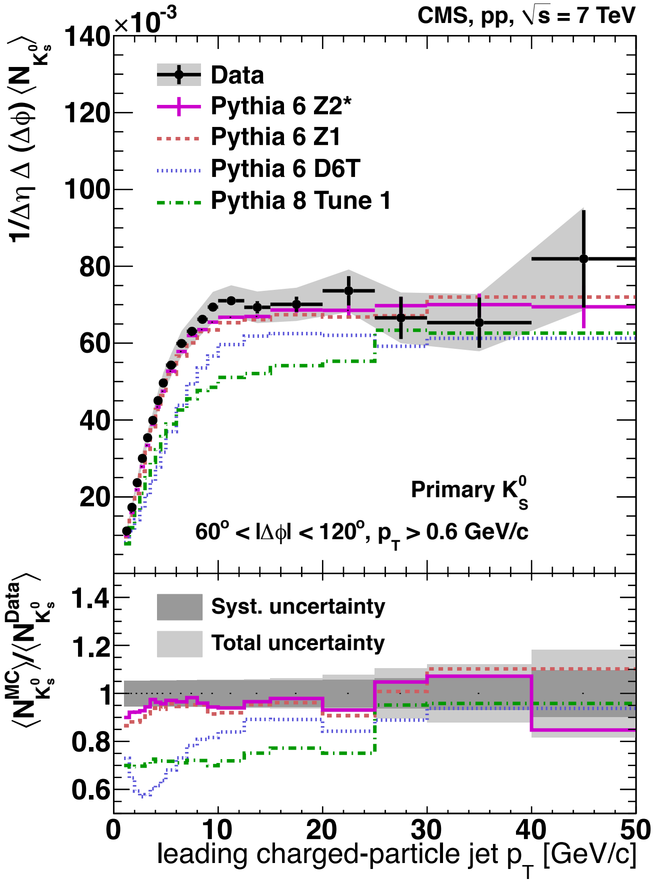
+ **Hard energy scale (81 < $M_{\mu\mu}$ < 101 GeV/c^2)**: no sharply rising part only the slow growth due to the ISR

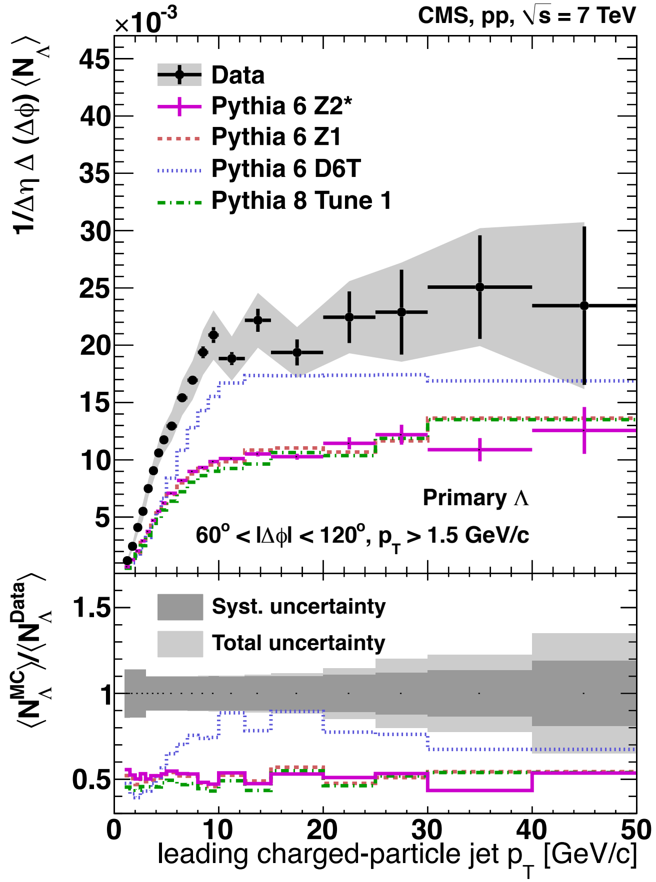
+ For $p_T^{\mu\mu}$ and leading $p_T^{\text{leading jet}}$ > 10 GeV/c DY events have a smaller particle density with a harder p_T due to the presence of **only ISR initiated by quarks**

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

hep-ex:1204.1411

The transverse region - identified particles





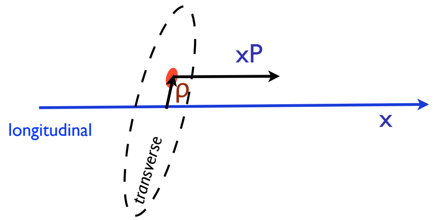
Same pattern observed for standard UE measurement, compatible with the IP interpretation

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

Transverse activity interpretation

M. Strikman et al. - "Transverse nucleon structure and diagnostics of hard parton-parton processes at LHC"



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

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

gluon transverse size decreases with increasing x

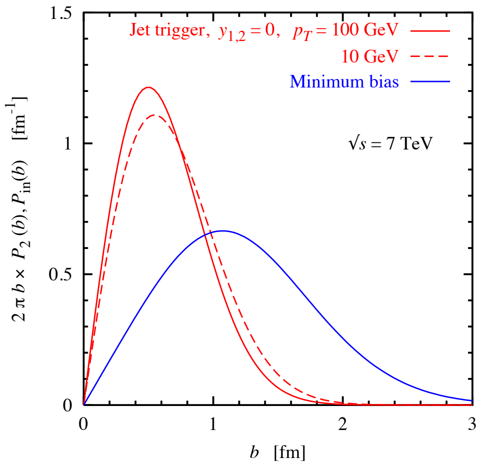
transverse size of large x partons is smaller than the transverse range of soft interactions

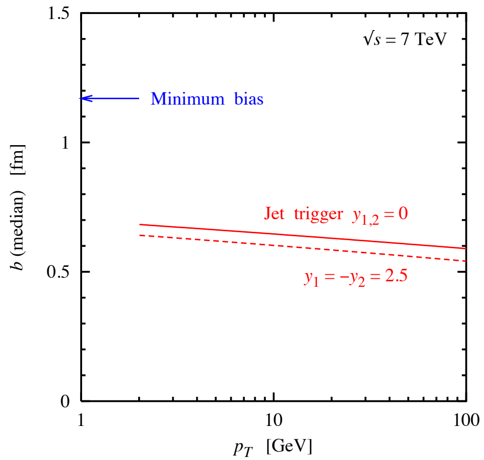
helpful to explain:

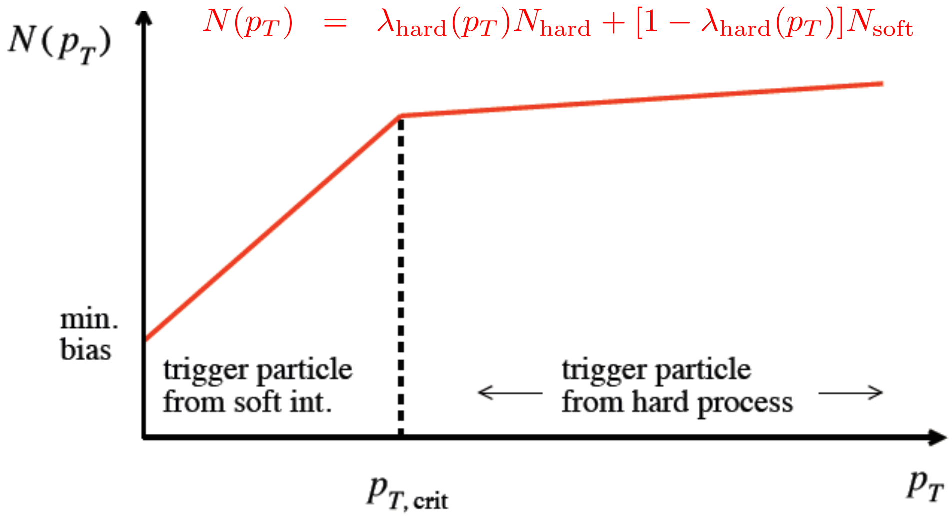
+ general UE feature

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

2 scale picture







[Phys. Rev. D83 (2011) 054012]

Energy Flow in the Forward Region

measurements relies on the energy flow in the hadron forward calorimeter (3.15<η<4.9) in the presence of events triggered by a more central activity (MinBias, di-jets...)

Test of central-forward correlation

$$E_{FLOW}(dijet) = \frac{1}{N_{dijet}} \frac{\Delta E}{\Delta \eta}(dijet)$$

$$E_{FLOW}(minbias) = \frac{1}{N_{minbias}} \frac{\Delta E}{\Delta \eta}(minbias)$$

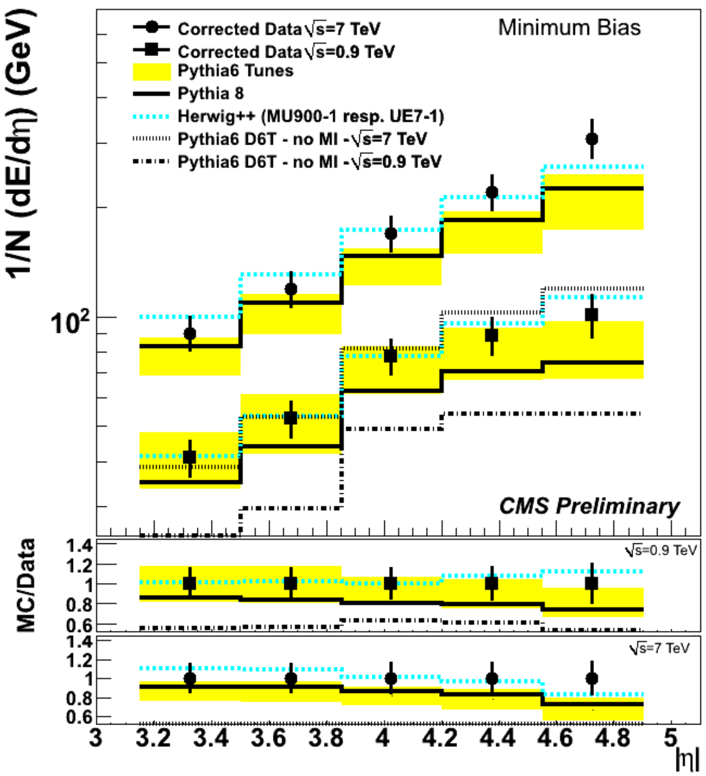
Studied Distributions

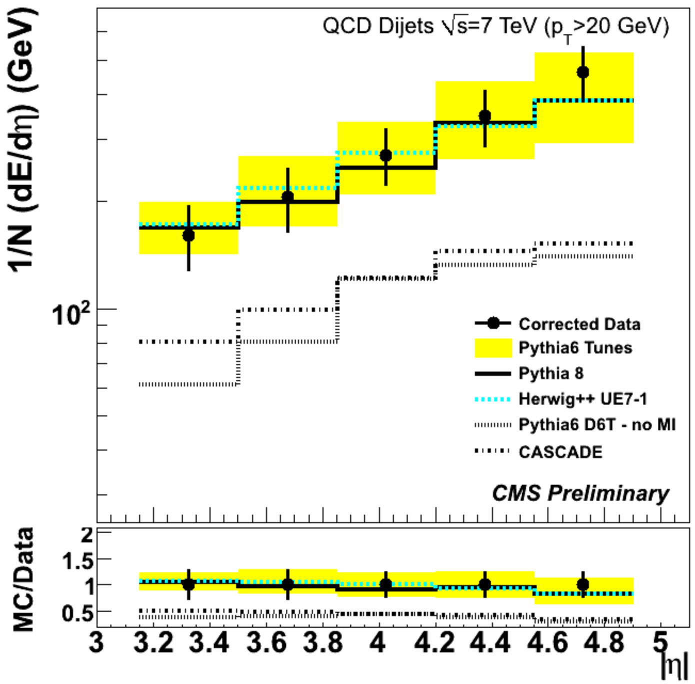
Two different $\sqrt{s}$ studied: 0.9 and 7 TeV

Di-jet sample is defined by pT>8 GeV at 0.9 TeV (20 GeV at 7 TeV) and $|\eta|<2.5$ and $|\Delta\varphi(j1,j2)-\pi|<1$

MinBias: at least one charged particle in both forward and backward regions (NSD)

Energy Flow in the Forward Region





Cascade Kt-factorization based MC, without MPI

Compared to other UE measurements, slightly different conclusions for what concerns the agreement of the MC models & tunes

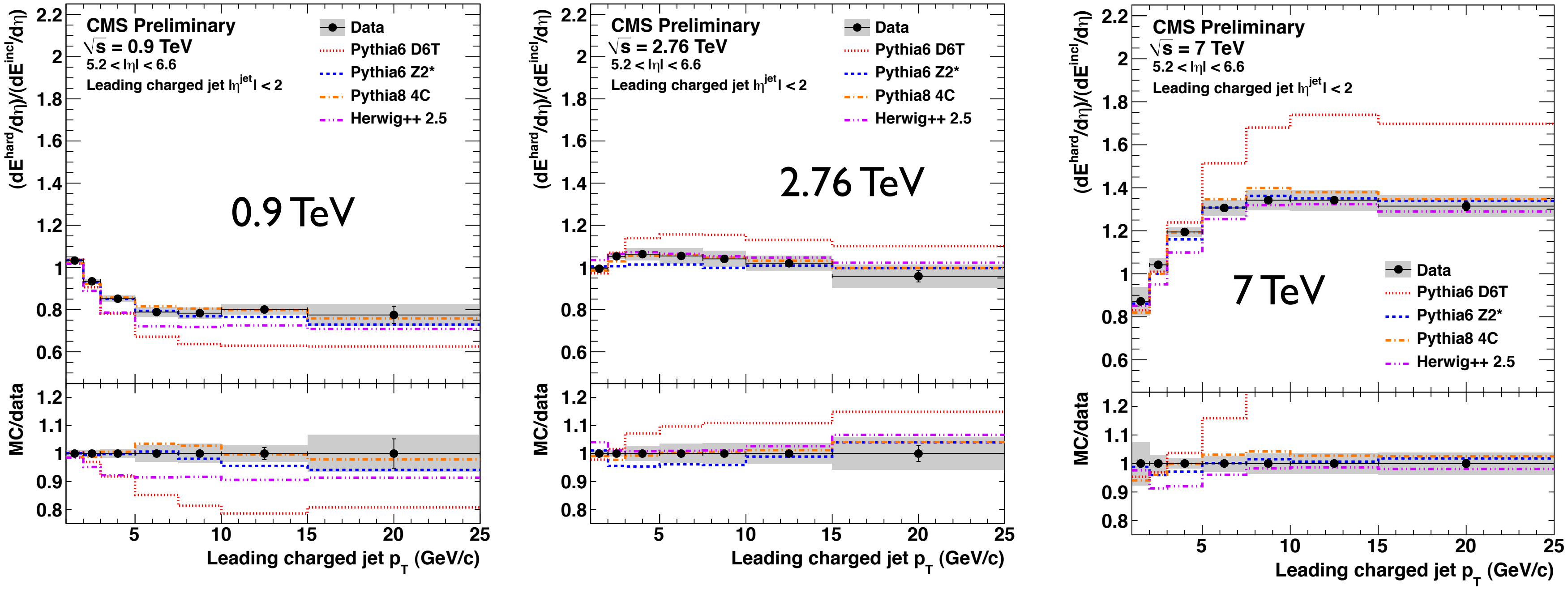
Energy Flow increases with the scale (MB vs di-jet) & √s:
Effect attributed mainly to MPI

Pattern very similar with respect to the traditional UE measurement from both a quantitative and qualitative point of view

Energy flow also increases with η (close to the beam remnant)

JHEP 1111 (2011) 148, Erratum-ibid. 1202 (2012) 055

Energy Flow in the Very Forward Region



Energy deposited in CASTOR ($5.1 < \eta < 6.6$) for events with a charged particle jet in the central region $|\eta|<2$, as a function of charged particle transverse momentum pT (normalized to the average energy in inclusive events)

> pT evolution of observable changes trend with $\sqrt{s}$ (decreasing at low $\sqrt{s}$, increasing at high $\sqrt{s}$)
> Post LHC models adopting pT-ordered showers are favored by data (agreement within 5-10%)
> Good agreement also for EPOS, QGSJET01, QGSJETII, SIBYLL 2.1 (within 20%)

JHEP 1304 (2013) 072

Many, many, many additional results and details can be found in:

ALICE

https://twiki.cern.ch/twiki/bin/view/ALICEpublic/ALICEPublicResults

ATLAS

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults

CMS

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsFSQ

Conclusions

QCD is a successful theory, tested in past experiments and largely predictive
Next LHC run, with increased pile-up, will be challenging for precision QCD

Impressive number of analyses related to soft QCD have been performed on collected data and are still ongoing on 8 TeV samples:

+ Large agreement and complementarity between the experiments
+ Important constraints for perturbative (and non-) models

Description of cross section and diffraction processes is increased, in both genuine-Reggeon and Pythia-MBR approach. Hadronization and fragmentation have been deeply tested.

Several indications from "solid" Minimum Bias observables tend to identify a strategic role played by the Multiple Parton Interactions into the dynamics of the hadronic interactions
Well-known (multiplicities, scaling, pT evolution, shapes...) and unexpected phenomena (correlations, multi-hard scattering...) seems to be intimately related to Multiple Interactions

Even if there are still difficulties (e.g. in describing high-multiplicity event activity) actual models (taking into account pT-ordered shower, color reconnection, MPI rescattering, MBR, helixlike fragmentation...) give a good description for the LHC physics