Eccentricity and v2 in proton-proton collisions at the LHC

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1106.4356 [hep-ph] (Quark Matter proceedings)

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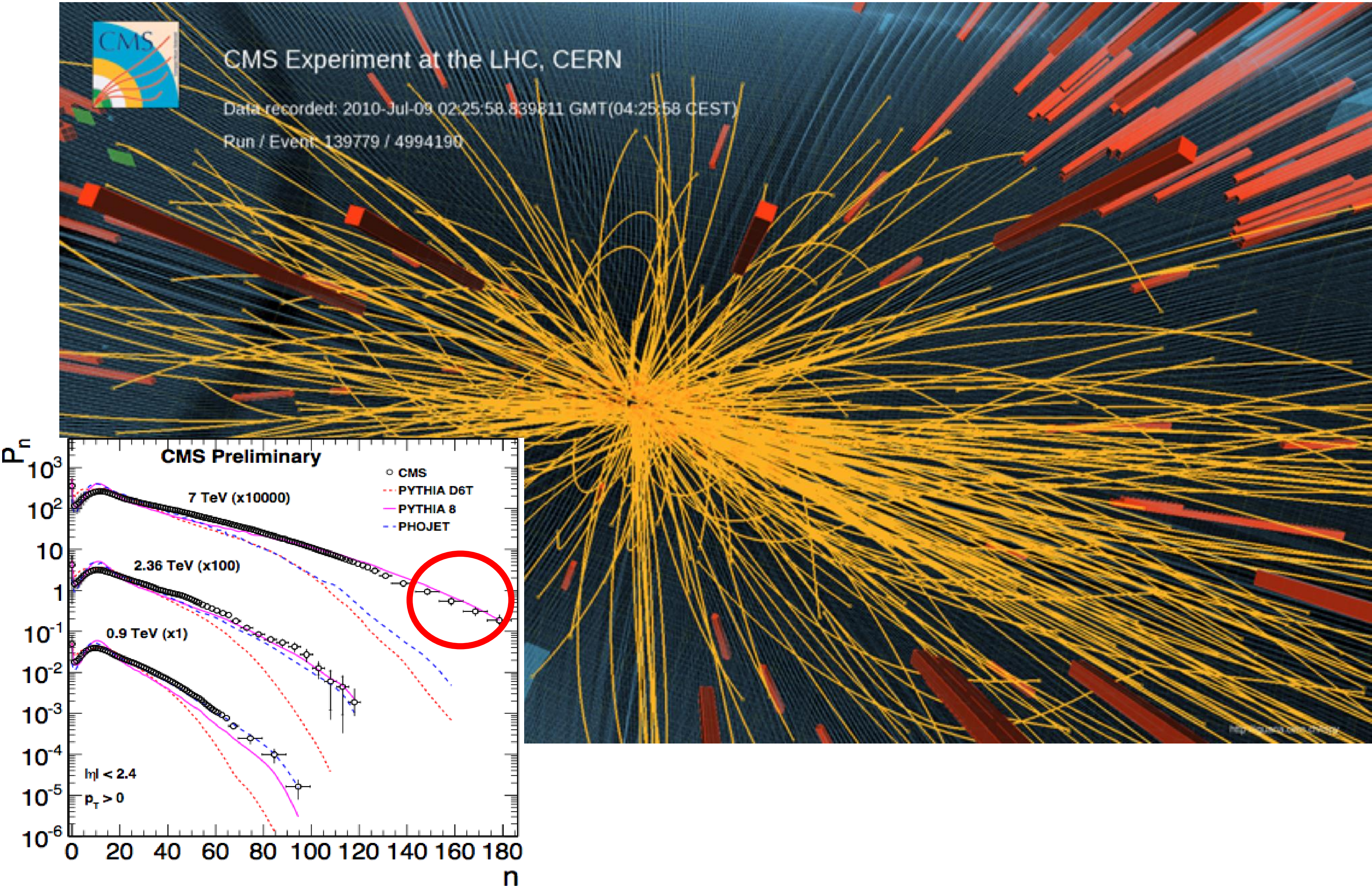
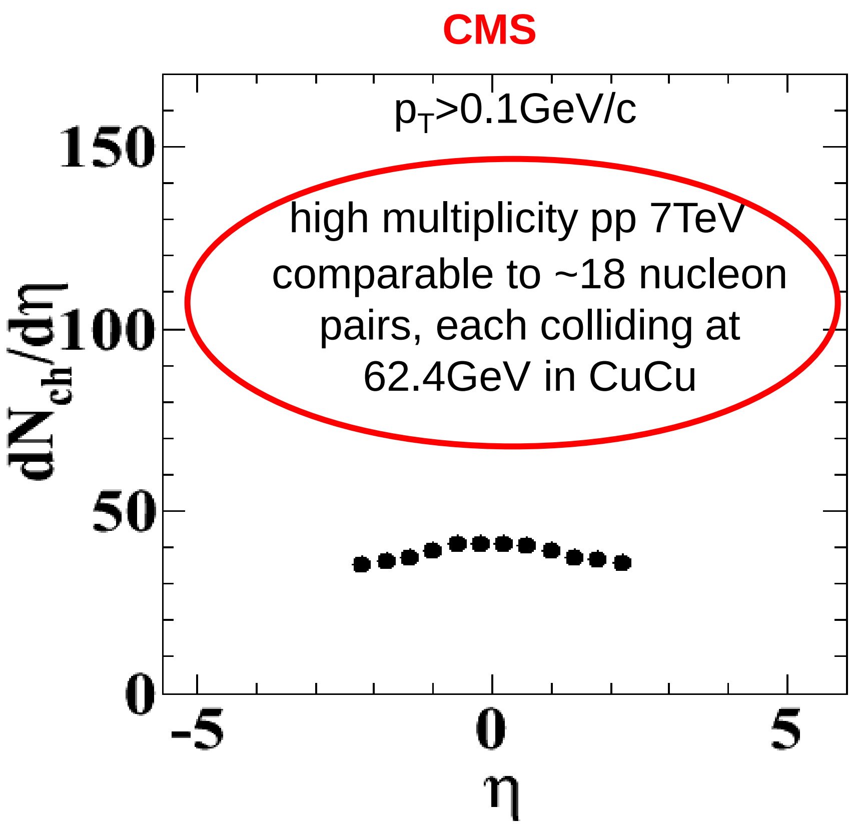
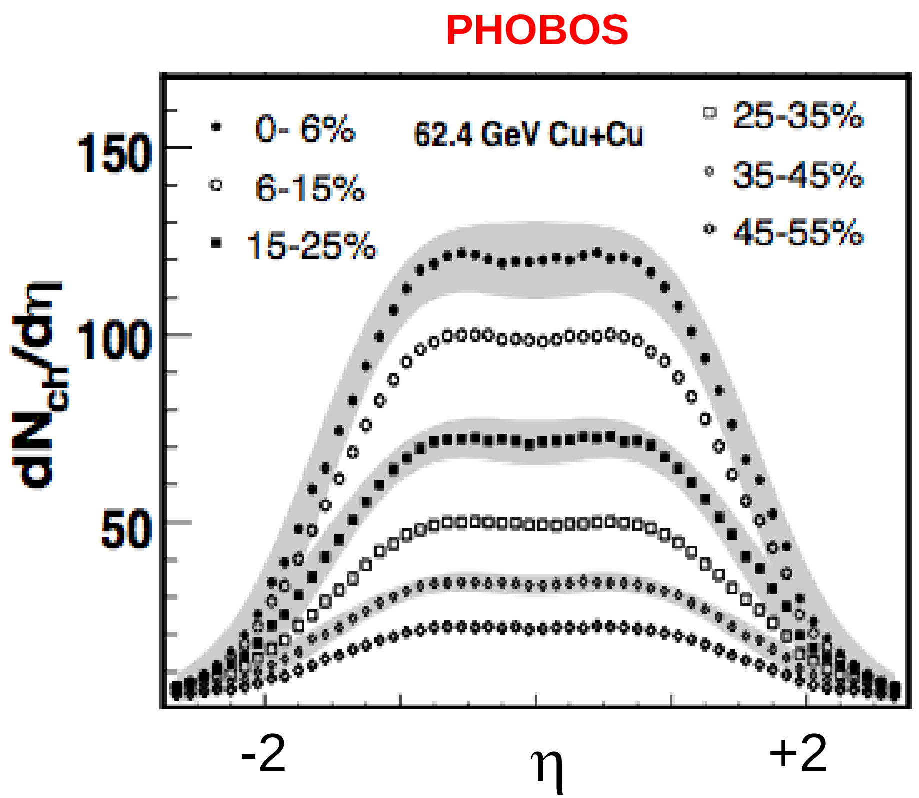
High-multiplicity pp events at the LHC



Like an AA collision !

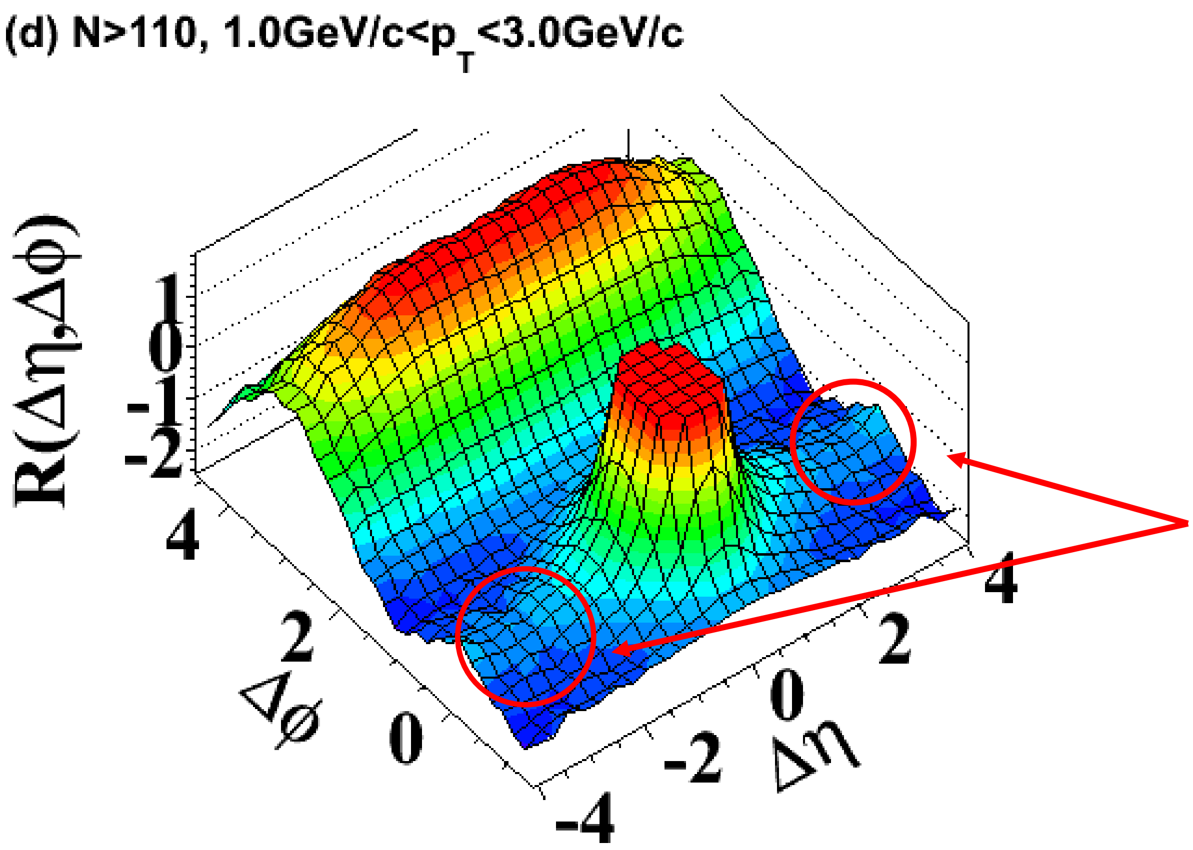




Phenomena usually discussed in the context of nucleus collisions may be observed in proton collisions !

Ridge in pp

CMS Collaboration, arXiv:1009.4122

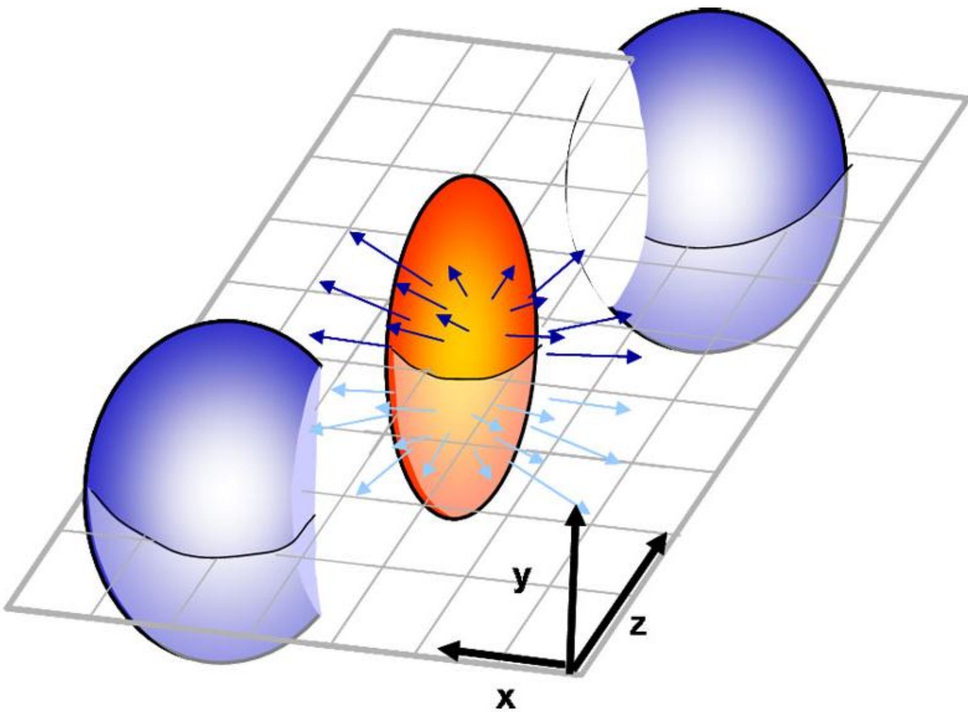


near-side, long-range rapidity correlation

First unexpected result in pp at the LHC !

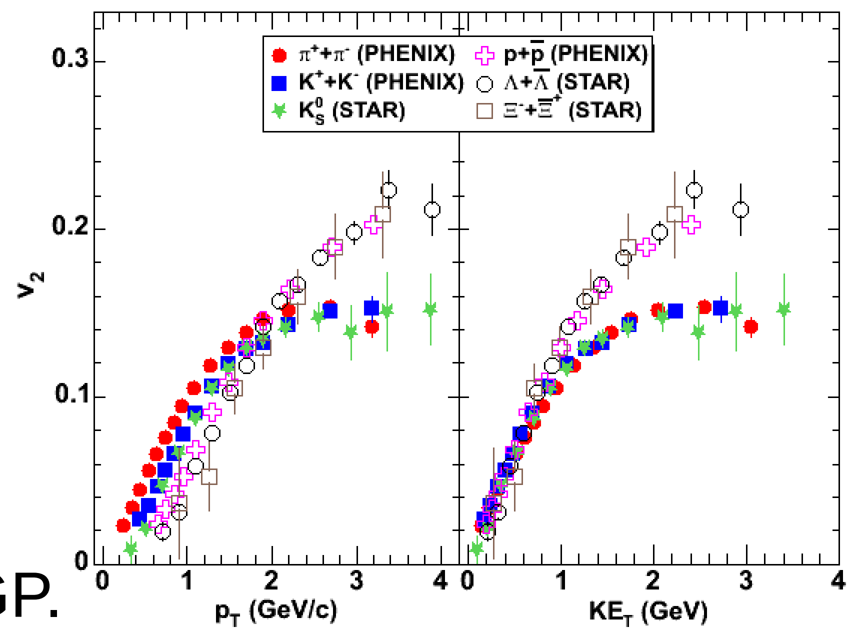
Possible collective effects in pp?

Elliptic flow v2



$$\frac{dN}{d\phi} \propto 1 + 2v_2 \cos 2\phi$$

$v_2 \propto \epsilon$ eccentricity



Hallmark of collective expansion, widely seen as a signal of the QGP.

Elliptic flow in pp : previous attempts

Fixed distribution (Woods-Saxon, Hard Sphere, Gaussian….)

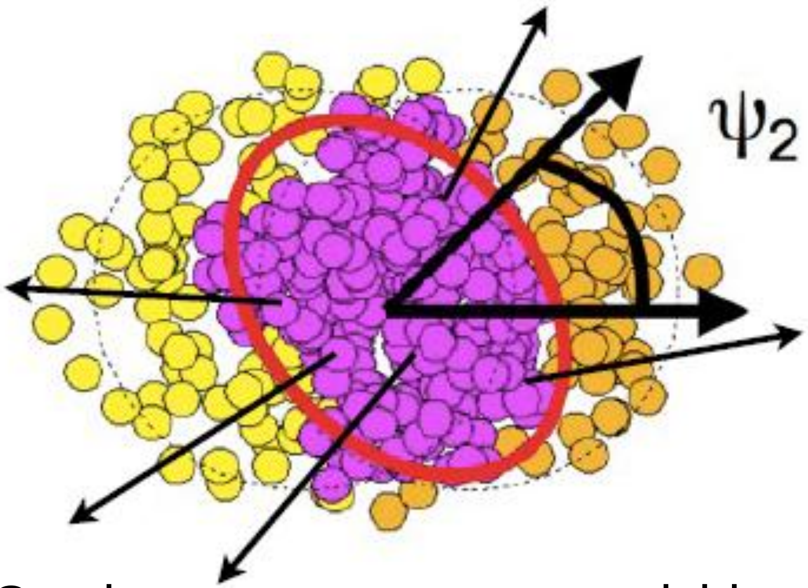
Luzum,Romatschke 0901.4588
Prasad, Roy, Chattopadhyay 0910.4844
d'Enterria, et al. 0910.3029
Bozek 0911.2392
Ortona, Denicol, Mota, Kodama, 0911.5158

Random distribution (Flux tube model, Hot spot model)

Bautista, Cunqueiro, de Deus, Pajares 0905.3058
Pierog, Porteboeuf, Karpenko, Werner, 1005.4526
Casalderrey-Solana, Wiedemann 0911.4400

Participant eccentricity

Event plane may be different from the reaction plane.



$$\epsilon_{\rm part} = \frac{\sqrt{(\sigma_y^2-\sigma_x^2)^2+4\sigma_{xy}^2}}{\sigma_y^2+\sigma_x^2}$$

Can be nonzero even at vanishing impact parameter due to fluctuations.

Important because high-multiplicity pp events mostly come from central collisions.

AA → fluctuation of nucleons
pp → fluctuation of small-x gluons

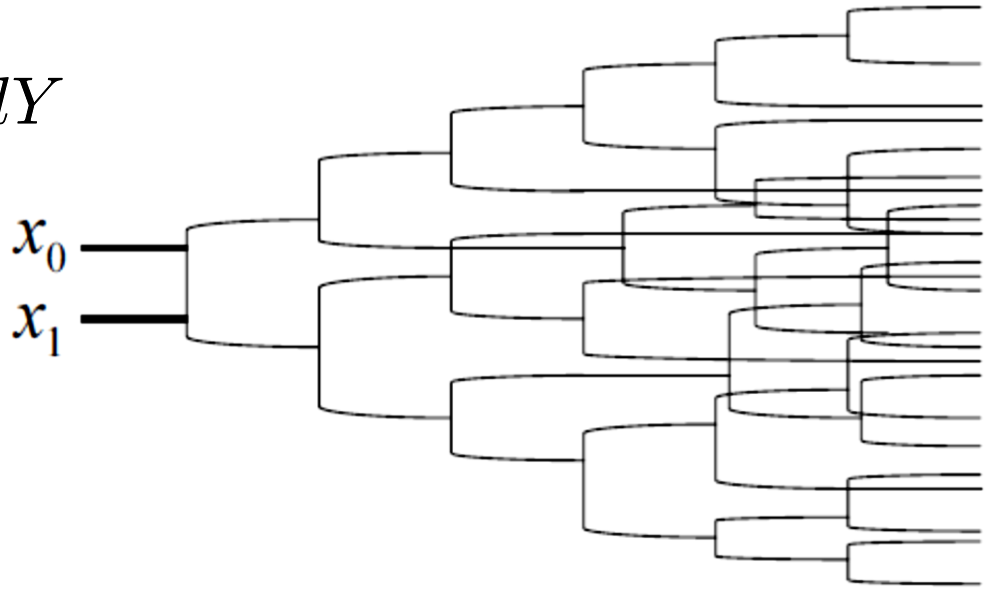
QCD dipole model

Mueller (1994~)

Coordinate space formulation of the BFKL equation

Probability of gluon (dipole) splitting

$$dP = \bar{\alpha}_s \frac{(\vec{x}-\vec{y})^2}{(\vec{x}-\vec{z})^2(\vec{z}-\vec{y})^2} d^2\vec{z}dY$$



→ Very strong fluctuation in the gluon multiplicity

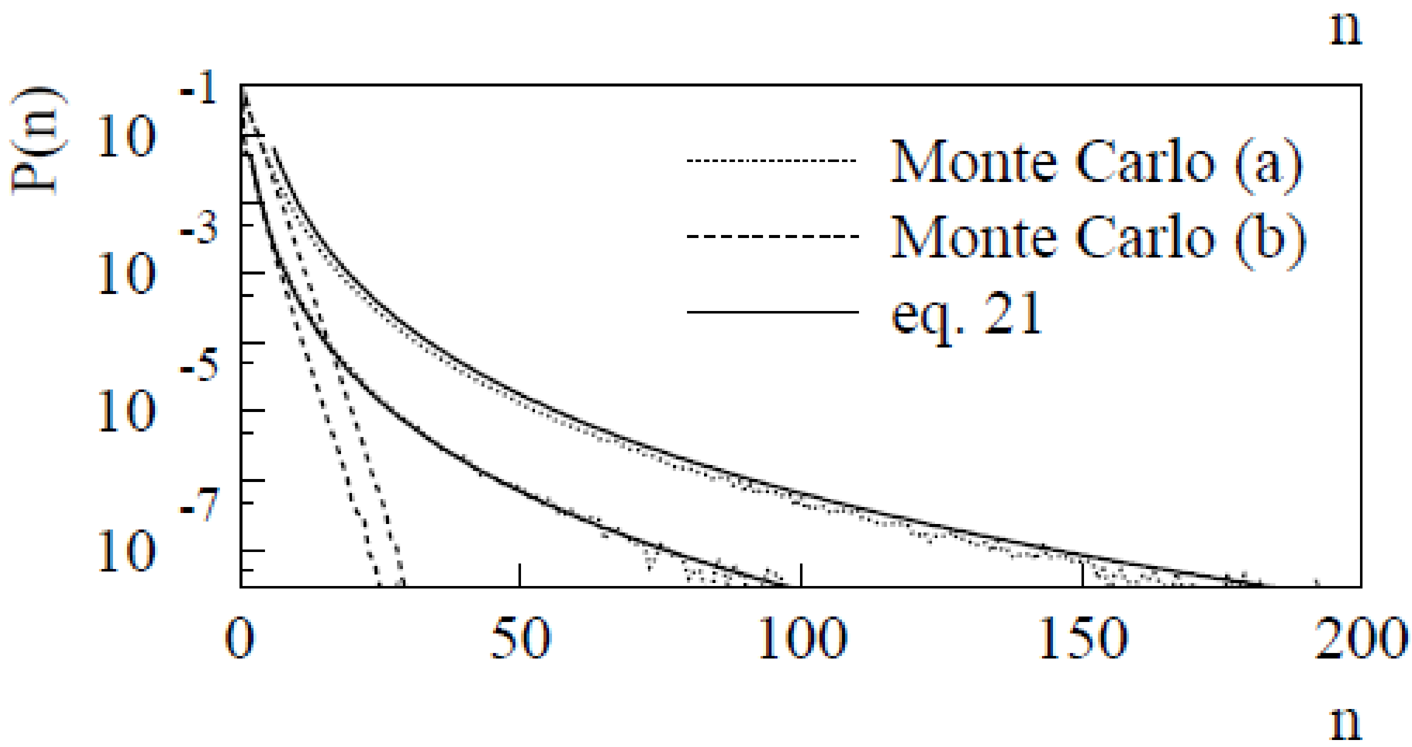
→ Very strong correlation in impact parameter space

Salam (1995)
YH, Mueller (2007)
Avsar, YH (2008)

Gluon number fluctuation

Probability distribution of the number of gluons in the dipole model

Salam (1995)



DIPSY

Full-fledged Monte Carlo event generator for pp based on the dipole model.

Flensburg, Gustafson, Lonnblad, arXiv:1103.4321
extension of Avsar, Gustafson, Lonnblad (2005~)

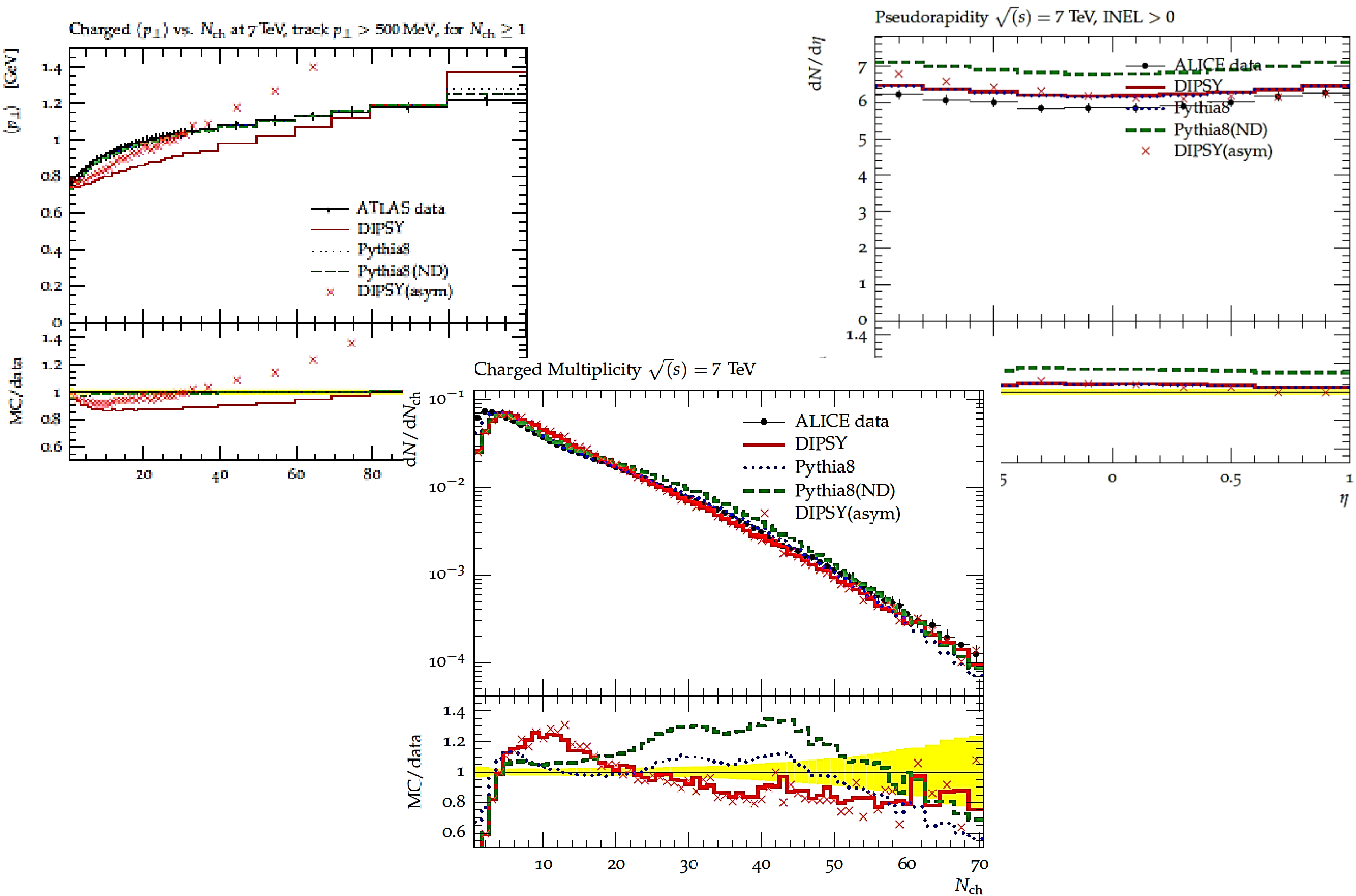
"Lund gang"

Featuring:

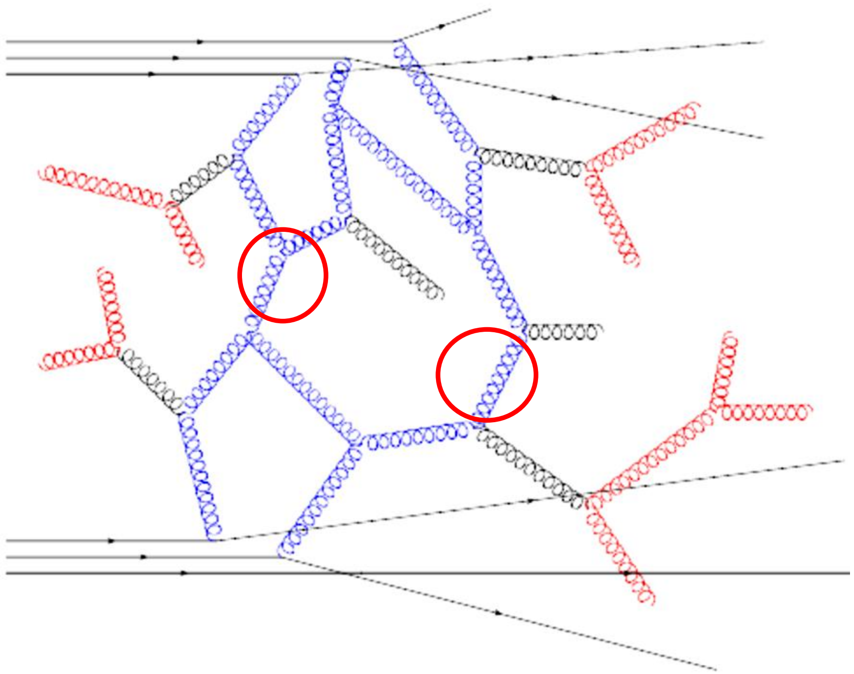
BFKL
Running coupling (NLO)
Energy conservation ($\mathrm{N}^n\mathrm{LO}$)
Saturation effects
Confinement effects
Multiple scattering,
Underlying events,
Parton shower (ARIADNE)
Hadronization (Pythia)

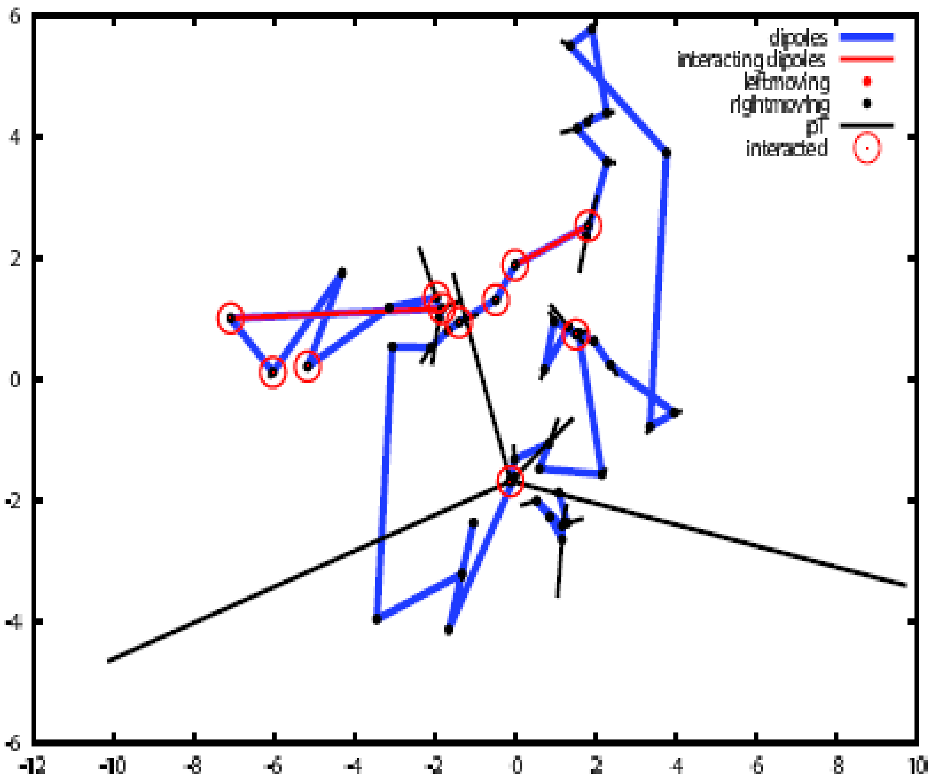
Energy dependence is a prediction. No ad hoc retuning of parameters at different energies.

Some sample results from DIPSY @7TeV



Deconstructing high-multiplicity events





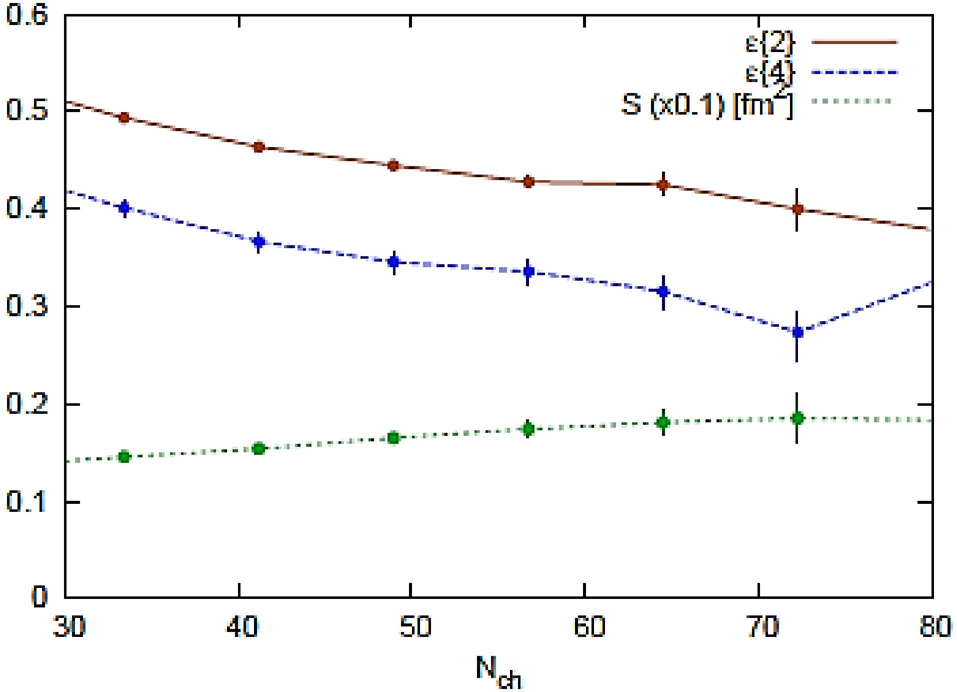
High-multiplicity pp events

= Upward fluctuation in the gluon number in proton’s w.f.

\+ Multiple (more than 10) parton-parton interactions

Eccentricity in pp at 7 TeV

Shape of the area occupied by the "liberated" gluons.



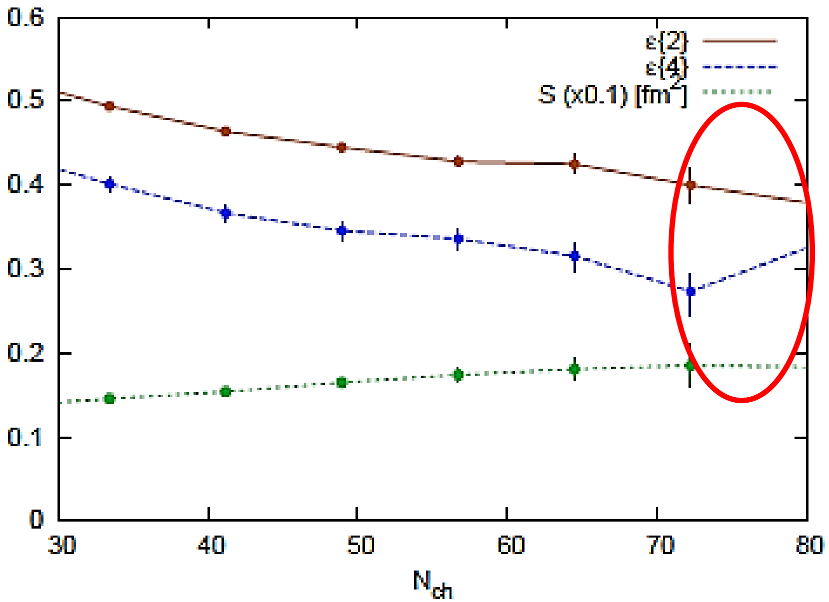
$$(|\eta| < 0.9)$$

$$\epsilon_{\mathrm{part}} = \frac{\sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4\sigma_{xy}^2}}{\sigma_y^2 + \sigma_x^2}$$

$$\epsilon\{2\} = \sqrt{\langle \epsilon_{\mathrm{part}}^2 \rangle}$$

$$\epsilon\{4\} = \left(2\langle \epsilon_{\mathrm{part}}^2 \rangle^2 - \langle \epsilon_{\mathrm{part}}^4 \rangle\right)^{\frac{1}{4}}$$

Comparison with Pb-Pb



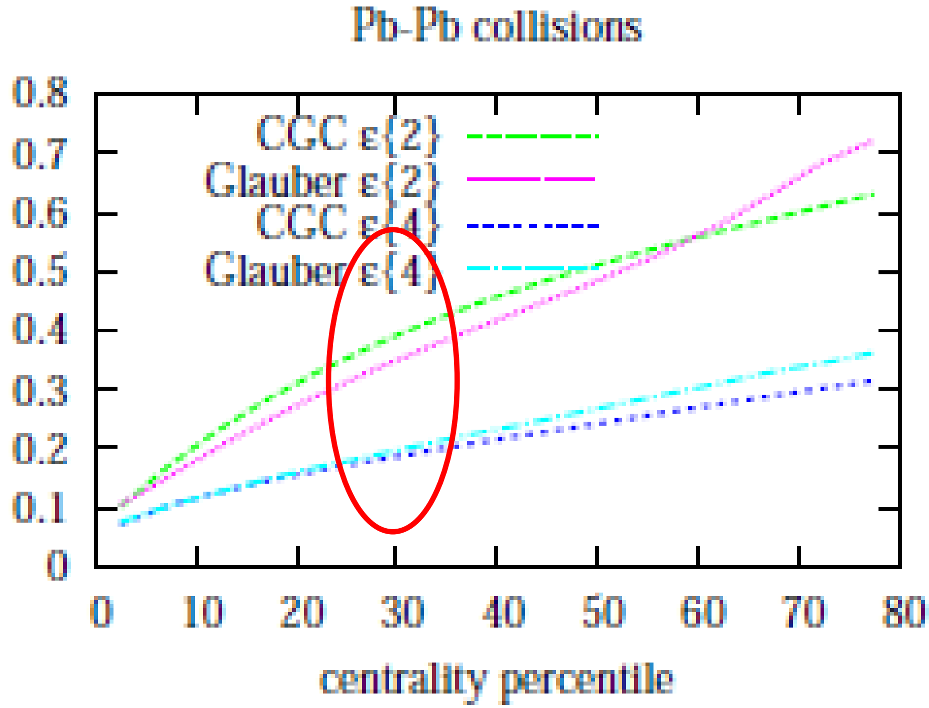


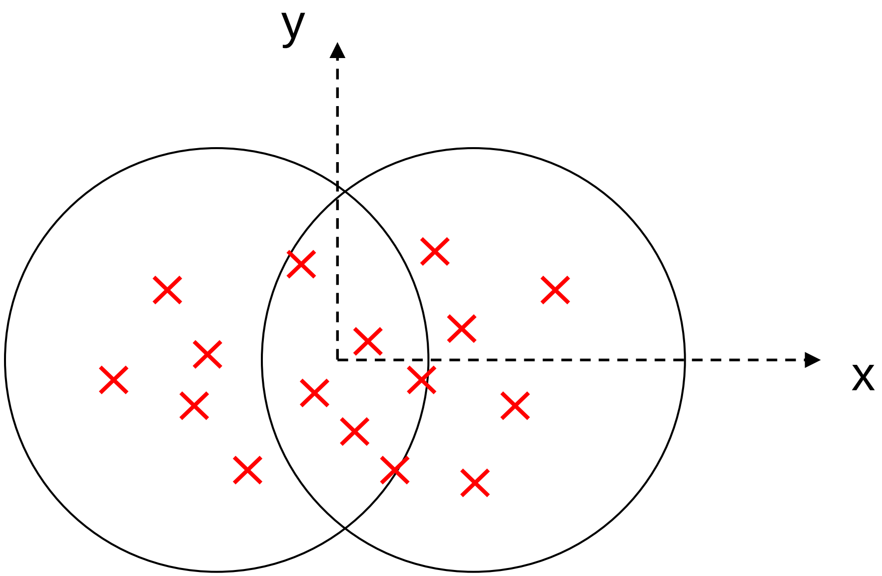
Figure by M. Luzum

Comparable to 30% central Pb-Pb collisions

Nature of eccentricity in pp

Conventional definition of the eccentricity at fixed b

$$\epsilon_s = \frac{\sigma_y^2 - \sigma_x^2}{\sigma_y^2 + \sigma_x^2}$$ is negative !



Nominal "overlapping region" is a poor guide in pp.

$$\epsilon \rightarrow v_2$$

Empirical relation between the eccentricity and v2.

Drescher, Dumitru, Gombeaud, Ollitrault. (2007)

$$v_2\{2\} = \epsilon\{2\} \left(\frac{v_2}{\epsilon}\right)_{hydro} \frac{1}{1 + \frac{\lambda}{K_0} \frac{\langle S \rangle}{dN/d\eta}}$$

$\sim \frac{1}{\text{(density)}}$

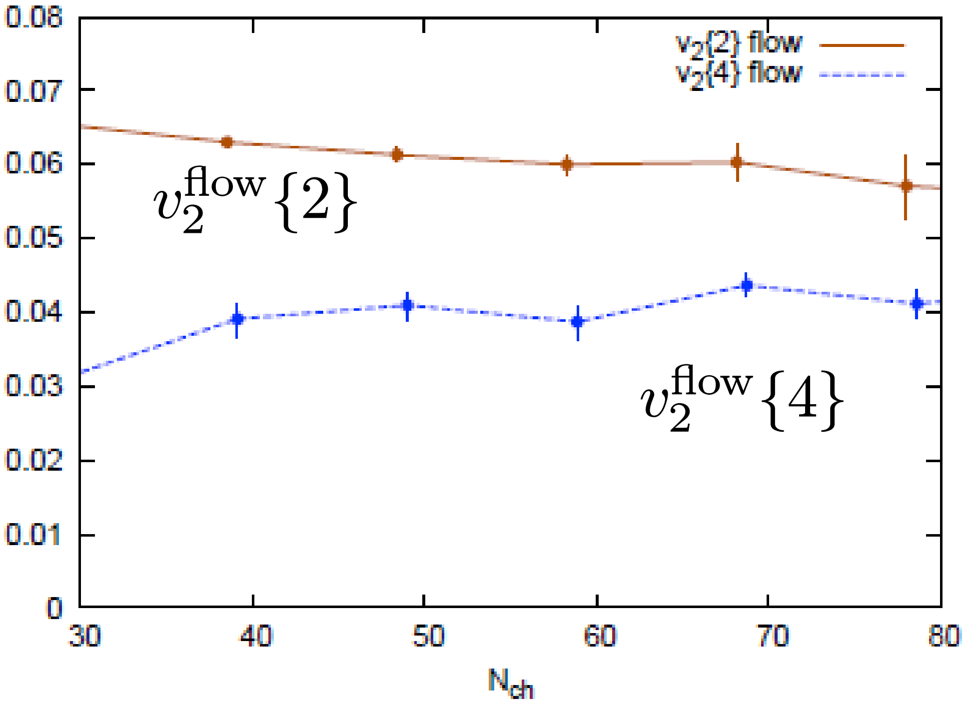
taking care of incomplete equilibration

$$(v_2\{2\})^2 = \left(\frac{v_2}{\epsilon}\right)^2_{hydro} \left\langle \frac{\epsilon^2_{part}}{(1 + \frac{\lambda}{K_0} \frac{S}{dN/d\eta})^2} \right\rangle$$

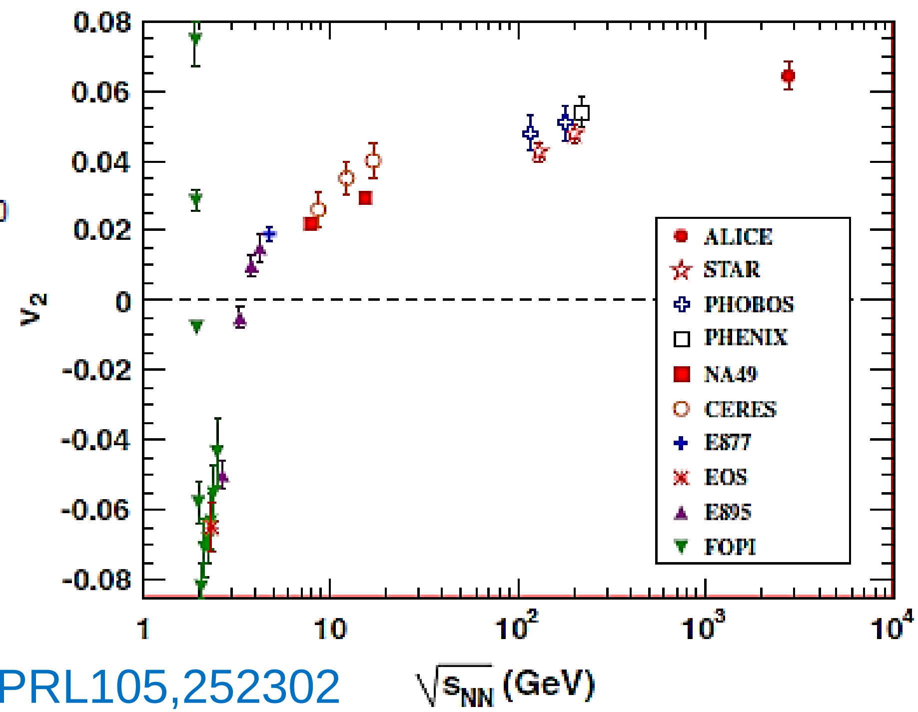
…and a similar relation between $\epsilon\{4\}$ and $v_2\{4\}$

In order to obtain large v2, a single event has to be both elliptic in shape and have high density.

Elliptic flow at 7 TeV



~ 6%
comparable to
AA at LHC, RHIC



Aamodt et al, PRL105,252302

“Nonflow” effect

v2 from n-particle angular correlation

$$v_2^2\{2\} = \langle \{\cos(2(\phi_i - \phi_j))\} \rangle ,$$
$$v_2^4\{4\} = 2(v_2\{2\})^4 - \langle \{\cos(2(\phi_i + \phi_j - \phi_k - \phi_l))\} \rangle$$

$$(v_2\{n\})^n = v_2^n + \delta_n$$

“flow” “nonflow”

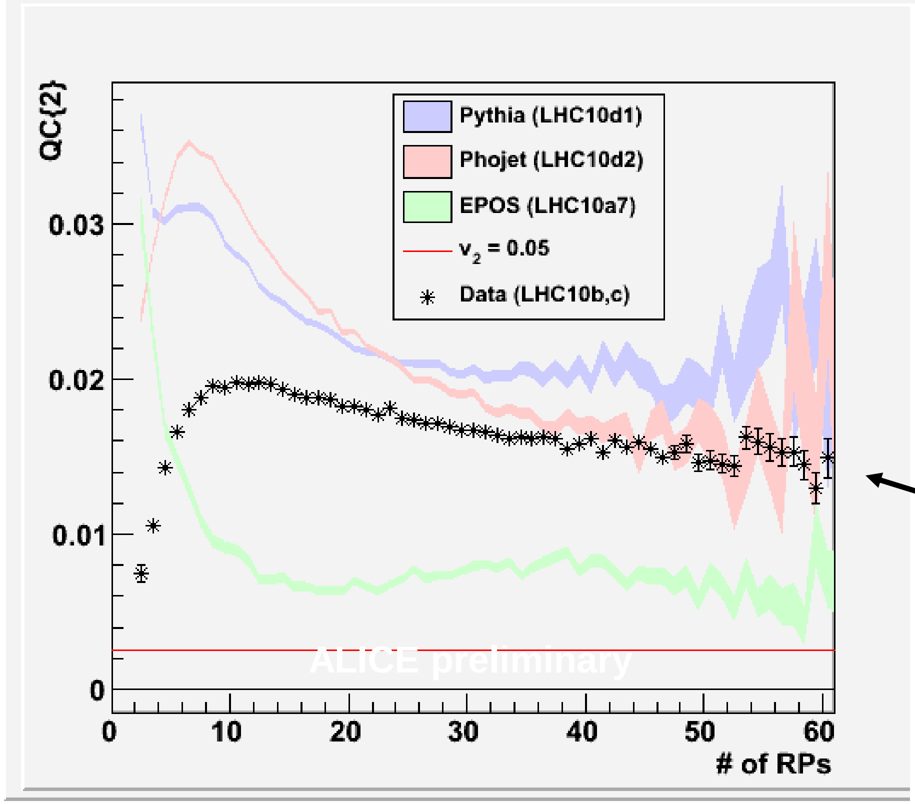
jets, hard scattering,
resonance decay,
BFKL evolution,
color connection, etc.

In AA, it is relatively innocuous $\delta_n \sim \left(\frac{1}{N_{ch}}\right)^{n-1}$

In pp, it could be very large…

ALICE data for $v_2\{2\}$

Bilandzic, talk at QCHS IX; AIP Conf. Proc. (2011)



$$\langle \cos 2\phi_{ij} \rangle = v_2^2 + \delta_2$$

"flow" "nonflow"

$$\sqrt{\langle \cos 2\phi_{ij} \rangle} \approx 0.14$$

Large nonflow contribution

dominate over the flow contribution…. $v_2^{\text{flow}}\{2\} \approx 0.06$

→ Necessary to go to higher cumulants.

$v_2\{4\}$ ALICE data vs. DIPSY

Avsar et al., 1106.4356 [hep-ph]

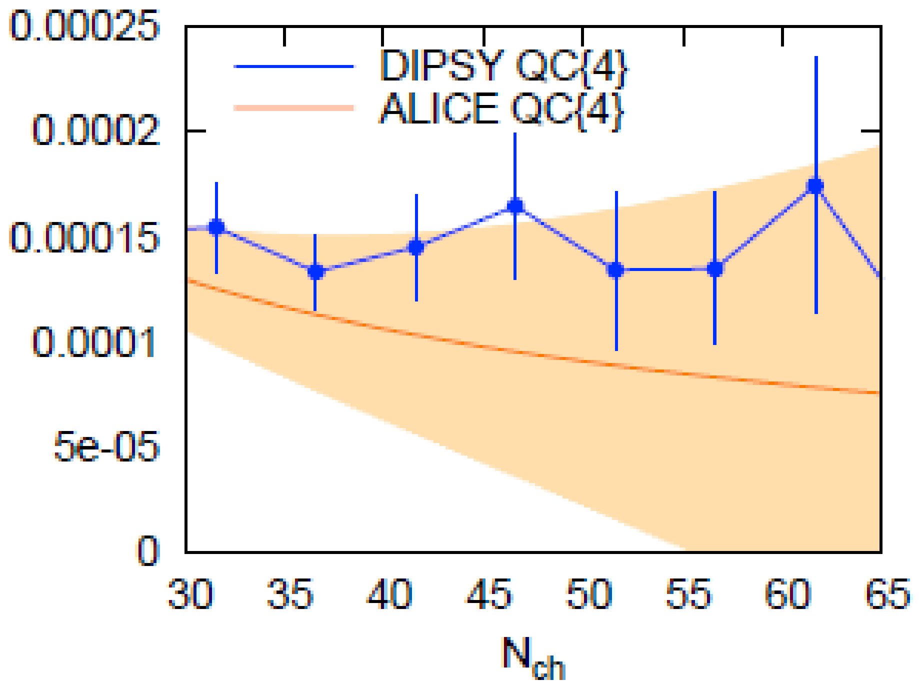
$(v_2\{4\})^4$ negative in the data and in MCs (no flow)

$(v_2^{\text{flow}}\{4\})^4$

$$\sim (\epsilon\{4\})^4 = 2\langle\epsilon_{\text{part}}^2\rangle^2 - \langle\epsilon_{\text{part}}^4\rangle$$

positive in the flow scenario

$-(v_2\{4\})^4$



Sign change at large Nch → Possible signature of flow.

Conclusions

- DIPSY can simulate high-multiplicity pp events with proper QCD dynamics in the transverse plane.
- Eccentricity is 30%, comparable to semi-central Pb collisions.
- Challenging to distinguish flow from non-flow correlations. We suggest to look for the sign change of (v2{4})^4.
- Extension to AA → talk by C. Flensburg.