Gluon brehmsstrahlung and flow assymmetry in pA Collisions

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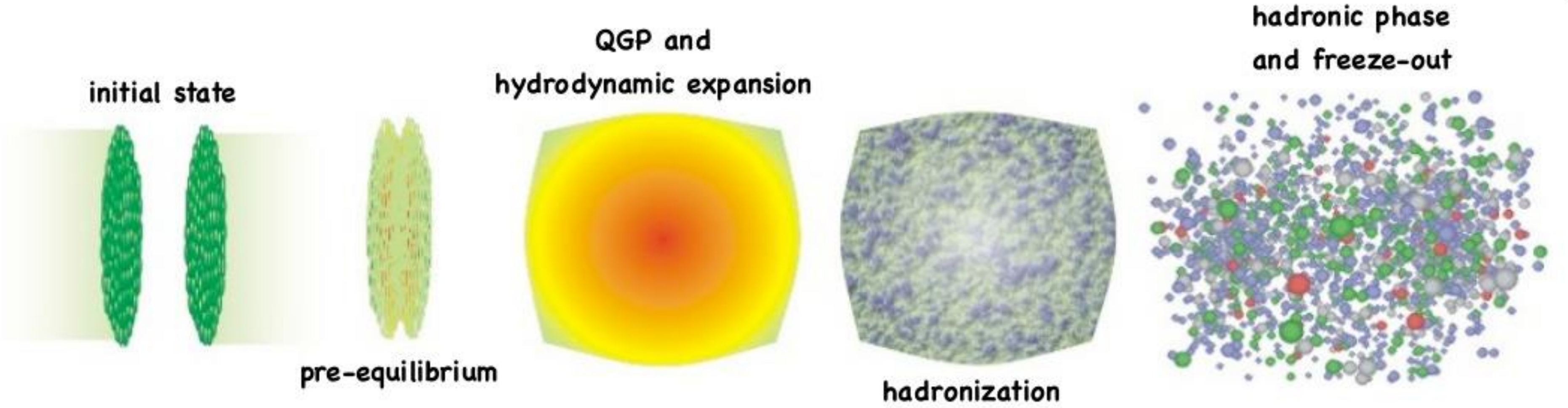
On the basis of our earlier work:
M. Gyulassy, P.L. I. Vitev, T.S. Bíró
Phys. Rev. D90 (2014) 054025. hep-ph/1405.7825

Zimanyi Winter School, Budapest, Hungary
6 December 2016

Standard Model of Heavy Ion Collisions:



Phases:

--- Initial condition: pre-equilibrium state

--- Hydrodynamical evolution
perfect fluid, viscous fluid, EOS

--- Hadronization mechanism
phase transition, coalescence/recombin.,
Cooper-Frye, incl. viscous corrections

--- Hadronic afterburner
hadronic interactions, final state effects

Questions, problems:

PDF, proton shape, color oscil.
Gluon saturation, shadowing
Space-time fluctuations
EOS properties, finite size eff.
Relativ. viscous hydrodynamics
Confinement-deconfinement
Order of phase transition
Mesoscopic system, size effects
Freeze-out characteristics
Dense hadronic matter
Resonance decays, …

Standard Model of Heavy Ion Collisions:

Question: What is the smallest size, where
this Standard Model (and hydro) remains valid?

What about if specific data display a good agreement between
periferic AA collisions
average pA collisions
high multiplicity pp collisions ??
……. (even smaller system) ???

Could we find consistent description and/or a new approach,
beyond the usual hydrodynamical description ?

Let us see the experimental data and explore the opportunities!

Proton-antiproton collisions at FERMILAB, √s = 1.8 TeV

VOLUME 67, NUMBER 12 PHYSICAL REVIEW LETTERS 16 SEPTEMBER 1991

Transverse Baryon Flow as Possible Evidence for a Quark-Gluon-Plasma Phase

Péter Lévai[a] and Berndt Müller
Department of Physics, Duke University, Durham, North Carolina 27706

(Received 13 March 1991)

In order to investigate the coupling between the collective flow of nucleons and pions in hot pion-dominated hadronic matter, we calculate the pion-nucleon drag coefficient in linearized transport theory. We find that the characteristic time for flow equalization is longer than the time scale of the expansion of a hadronic fireball created in high-energy collisions. The analysis of transverse-momentum data from $p+\bar{p}$ collisions at $\sqrt{s}=1.8$ TeV reveals the same flow velocity for mesons and antinucleons. We argue that this may be evidence for the formation of a quark-gluon plasma in these collisions.

PACS numbers: 25.70.Np, 12.38.Mh, 13.85.Hd

Rather general arguments indicate that the state of high energy density temporarily formed in ultrarelativistic central collisions of nuclei, and possibly even of single hadrons, exhibits approximate local thermal equilibrium and thus can be characterized by a temperature. This scenario is generally supported by the observation that transverse-momentum spectra of emitted particles fall exponentially at high p_T. It has often been speculated that a collective outward flow may develop during the expansion and final breakup of the high-density state [1]. The presence of a collective flow would be manifest in a nonthermal shape of the transverse-momentum spectrum. Because the flow velocity is superimposed with the random thermal motion, this effect grows with the mass of the emitted particles, and should be most clearly visible in baryon spectra. So far, experimental evidence for the existence of transverse flow at center-of-mass energies far above 1 GeV/u has been inconclusive [2,3], in contrast to collisions below this energy [4].

Gerber, Leutwyler, and Goity [5] recently showed that the expansion of a dense pion gas, as is formed in the central rapidity region after a highly relativistic nuclear collision, must lead to a rapid transverse flow. Gavin [6] pointed out that the expansion is even so rapid that the

viation from local thermal equilibrium is not too severe. We will now calculate δ and θ from first principles.

We assume that the evolution of the phase-space distribution functions $f_i(x,p)$, $i=\pi,N$, of pions and nucleons in the dense hadronic phase is described by the relativistic Boltzmann equation:

$$p^\nu \partial_\nu f_i(x,p) = \sum_j \mathcal{C}_{ij}(x,p) . \qquad (3)$$

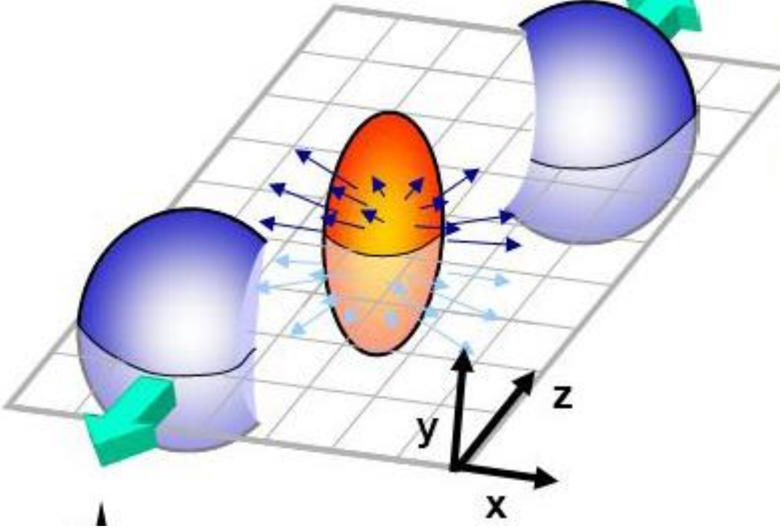
Here $\mathcal{C}_{ij}$ are the collision terms, which can be calculated from the known cross section for collisions between particles of type i and type j. In order to make contact with collective variables, such as the local flow velocity u^μ, it is useful to consider the momentum-space-integrated form of Eq. (3), introducing the energy-momentum tensor $T_i^{\mu\nu}$. Dissipative terms can then be expressed as the failure of the energy-momentum tensor to be locally conserved for each fluid component separately:

$$\partial_\nu T_i^{\mu\nu} = \mathcal{S}_i^\mu \equiv \sum_j \int d\Gamma_p\, p^\mu \mathcal{C}_{ij}(x,p) , \qquad (4)$$

where $d\Gamma_p = d^3p/(2\pi)^3 p^0$ is the invariant volume element in momentum space and $\mathcal{S}_i^\mu$ is the covariant dissipation four-vector.

Hidrodynamical analysis of π, K, p data (P. Lévai, B. Müller PRL, '91)

2016 – Latest experimental results at RHIC and LHC: azimuthal particle distributions and anisotropic flow



Spatial anisotropy

→ eccentriticies

2: ellipticity
3: triangularity
4: quadracity
5: pentacity

$$\varepsilon_n = \frac{\sqrt{\langle r^n \cos(n\phi)\rangle^2 + \langle r^n \sin(n\phi)\rangle^2}}{\langle r^n \rangle}$$

→ Investigating peripheral AA collisions

→ Overlap region is asymmetric in space,
almond shape (or more complicated)

→ Spatial anisotropy generates
momentum anisotropy,
this is „pressure induced” → EOS

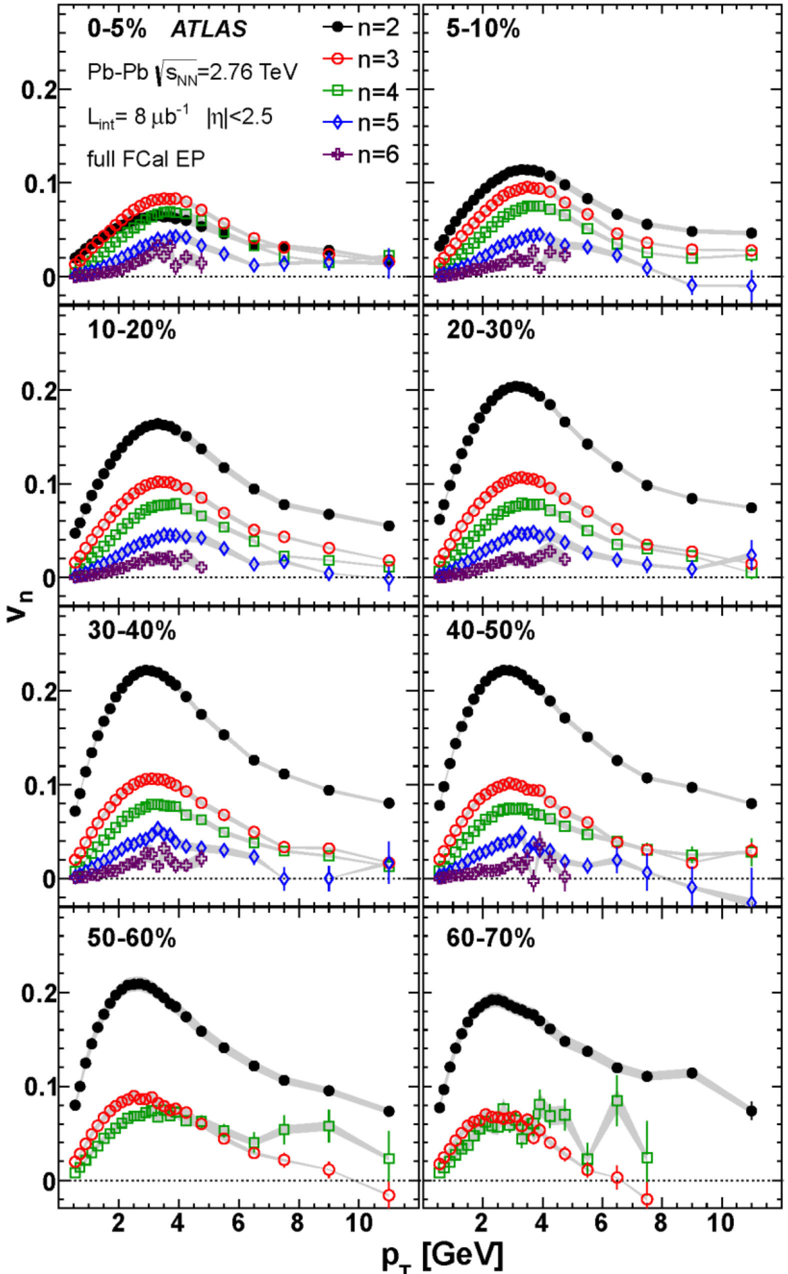
→ Fourier decomposition of
the azimuthal particle distibutions
leads to the harmonic flow components

⍰

$$\frac{dN}{d\phi} = \frac{N}{2\pi}\ (1 + \sum_n 2\, \mathrm{v}_n\, (\cos(n\quad))\ )$$

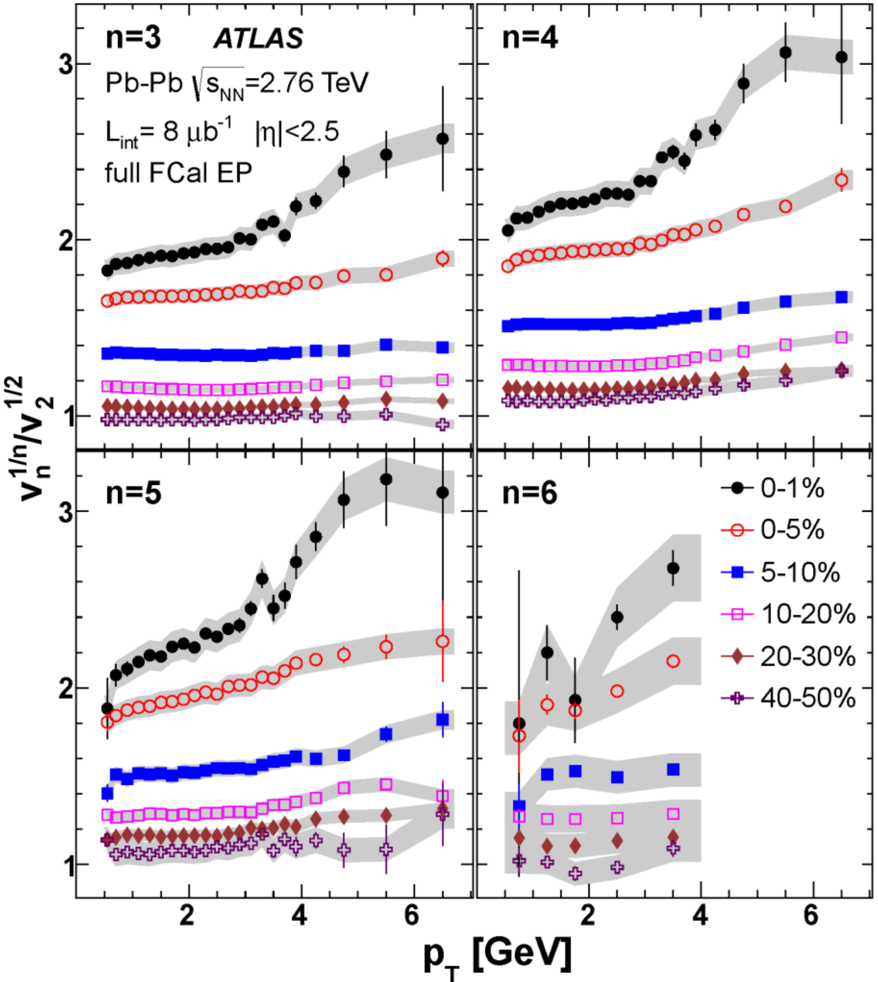
v1: directed flow; v2: elliptic flow; v3: …

Experimental results on v_n: PbPb, $\sqrt{s}$= 2.76 ATeV ATLAS



PRC86 (2012) 014907, ArXiv: 1203.3087

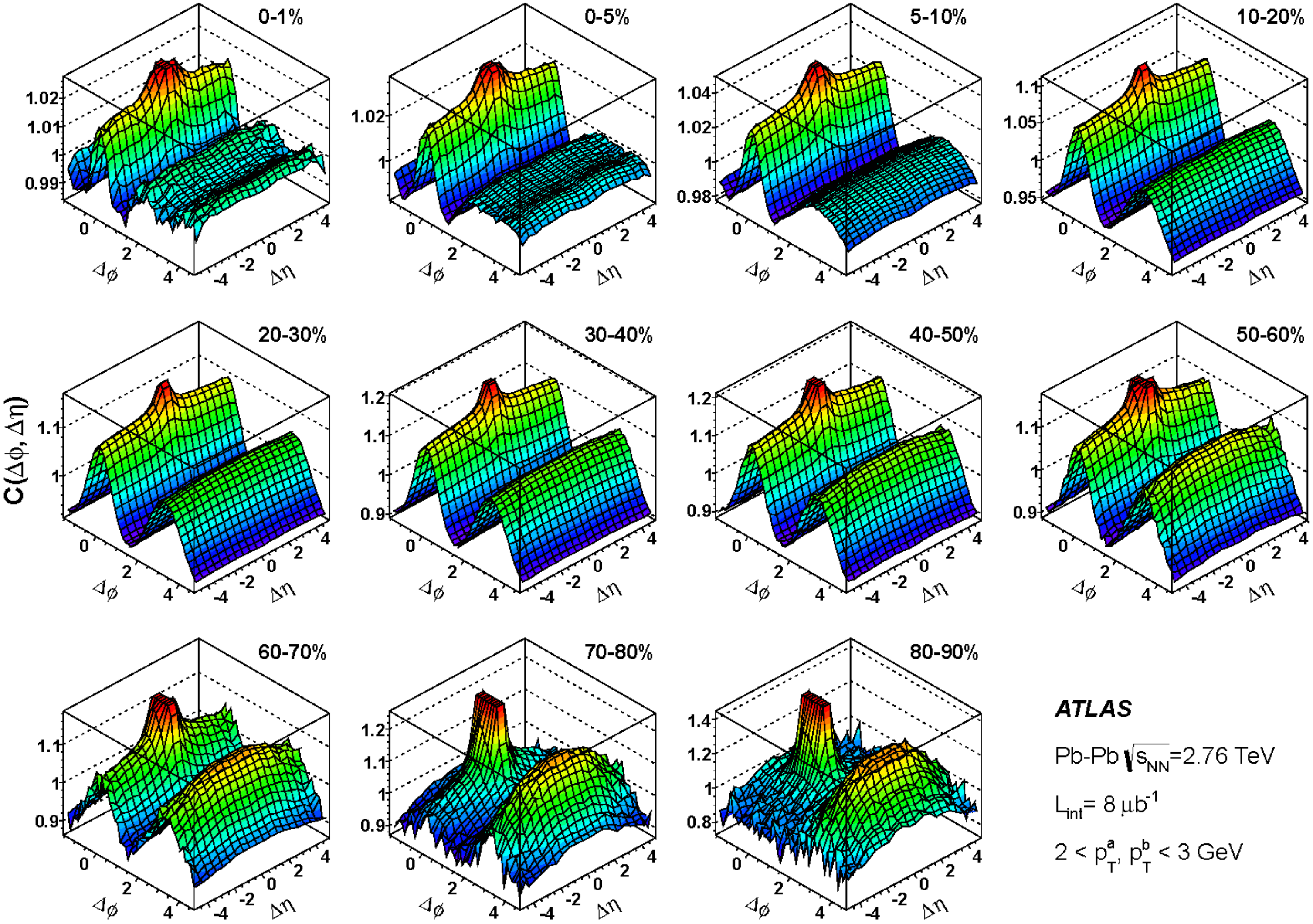
v_2, v_3, v_4, v_5 and v_6 at different centralities and the scaling $(v_n)^{1/n}$ for central and peripheral collisions



Experimental results on v_n: PbPb, $\sqrt{s}$= 2.76 ATeV ATLAS

PRC86 (2012) 014907, ArXiv: 1203.3087

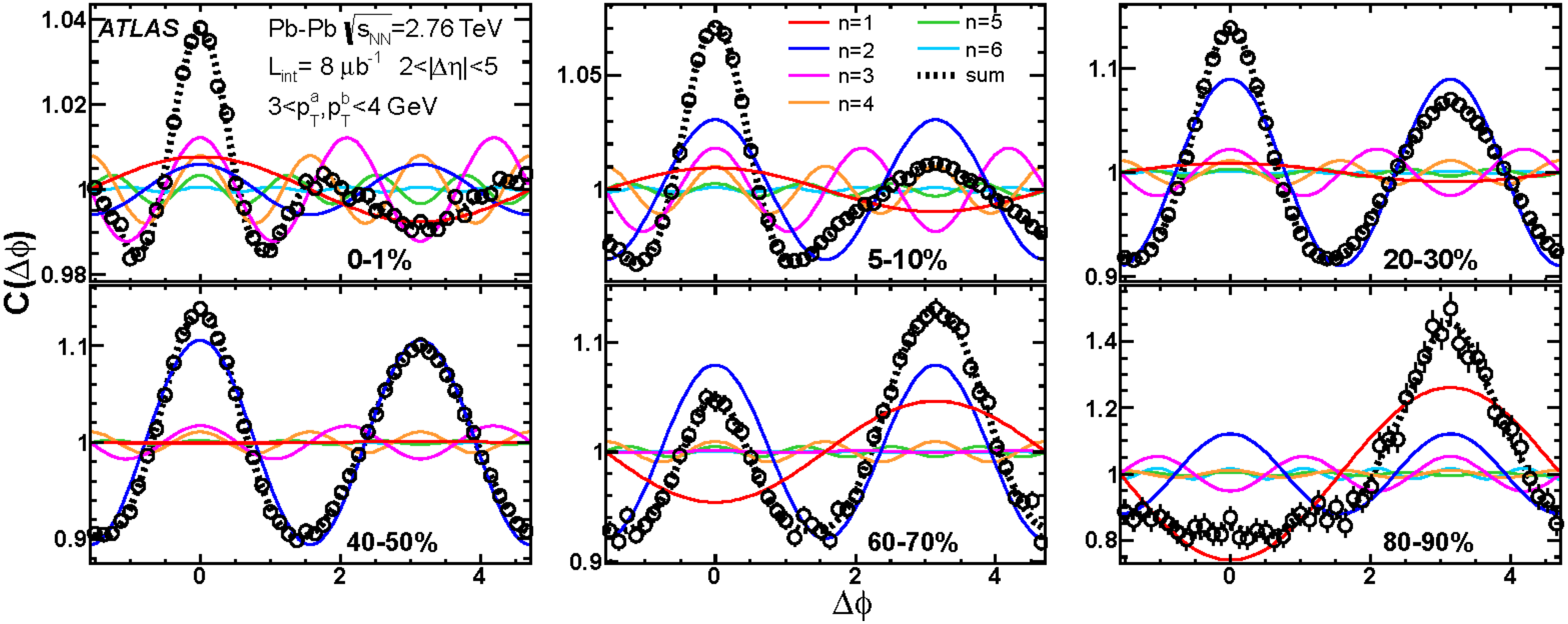
Long range correlations and ridge in PbPb at different centralities



Experimental results on v_n: PbPb, √s= 2.76 ATeV ATLAS

PRC86 (2012) 014907, ArXiv: 1203.3087

Superposition of flow harmonics v_1, v_2, v_3, v_4, v_5 and v_6 at different centralities



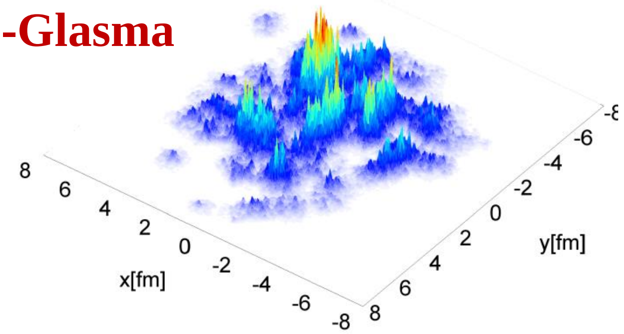
Bye-bye shock-wave and gluonic Cherenkov radiation !

Különböző elméleti modellek – illeszkedve a NIC Standard Modelljébe
Kezdeti feltételek – Energia sűrűség profilok AuAu-nál RHIC energián

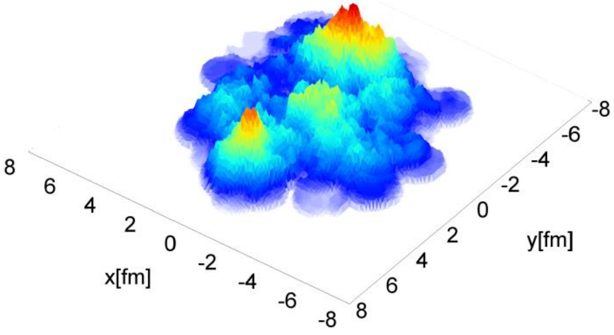
B. Schenke, P. Tribedy, R. Venugopalan, PRL108 (2012) 252301, PRC86 (2012) 034908.

[Glasma → hidro : τ(switch) ≈ $1/Q_s$ = 0.2 – 0.4 fm/c]

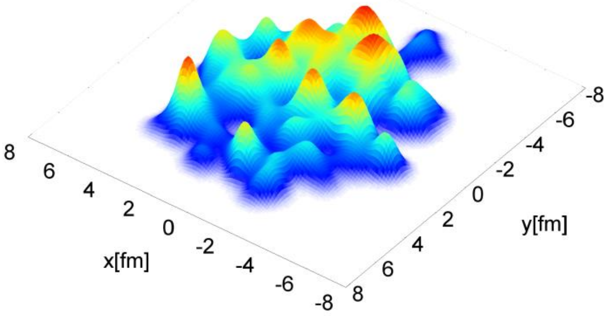
IP-Glasma



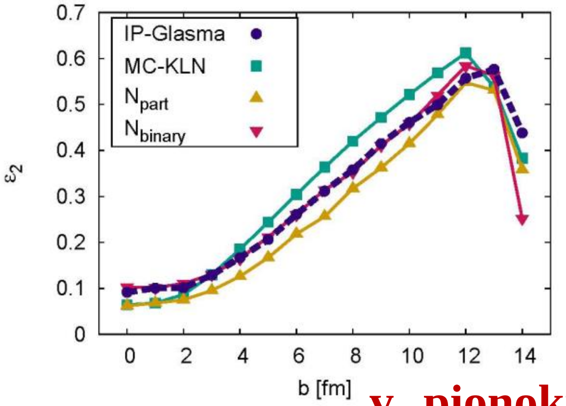
MC-KLN



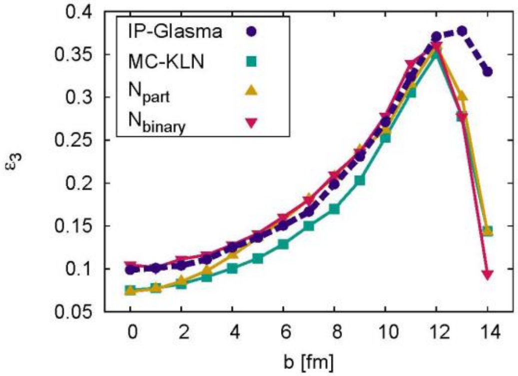
MC-Glauber



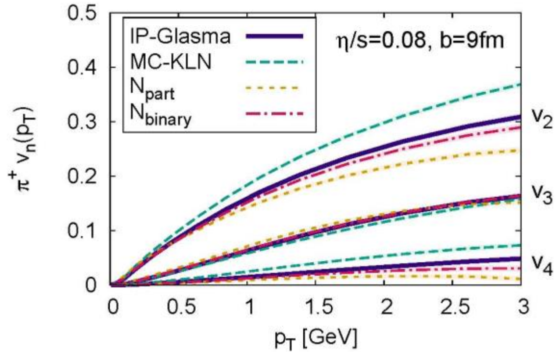
ε_2 : elliptikus



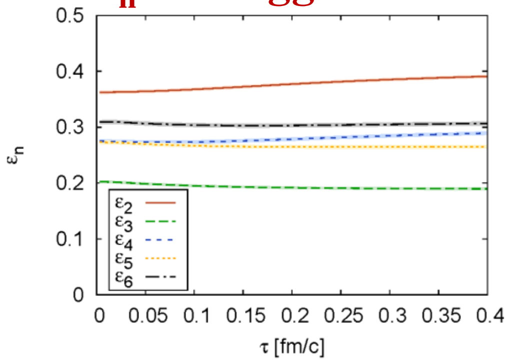
ε_3 : trianguláris



v_n pionokra



ε_n időfüggése



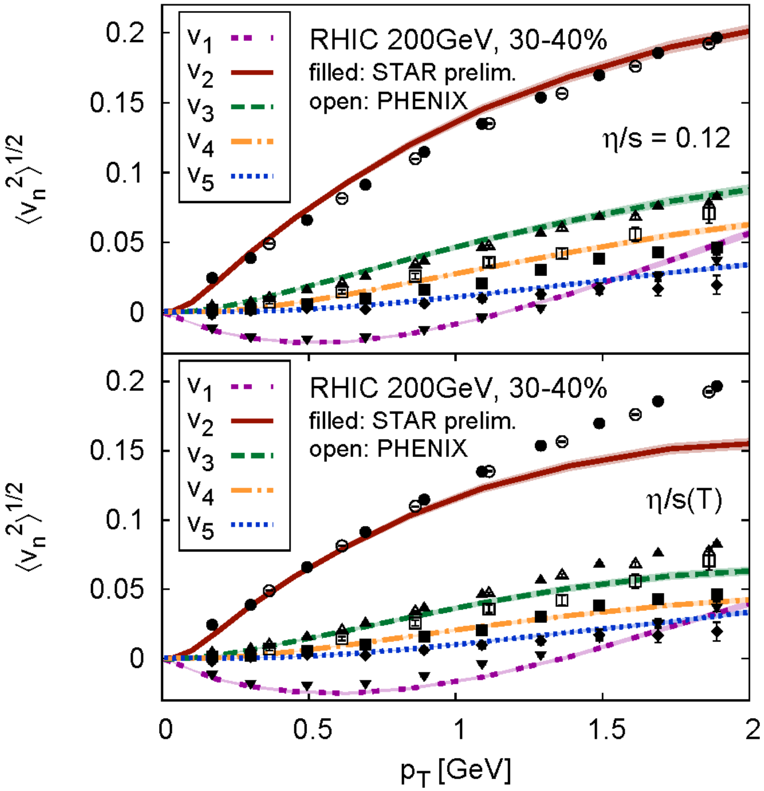
„… az ε_n értékek változása nagyon gyenge az első 0.4 fm/c alatt. Ezután pedig minden ε_n érték csökkenni fog, amint a rendszer részecskéiből álló sokaság egyre izotrópabb lesz.” (*Schenke et al,*

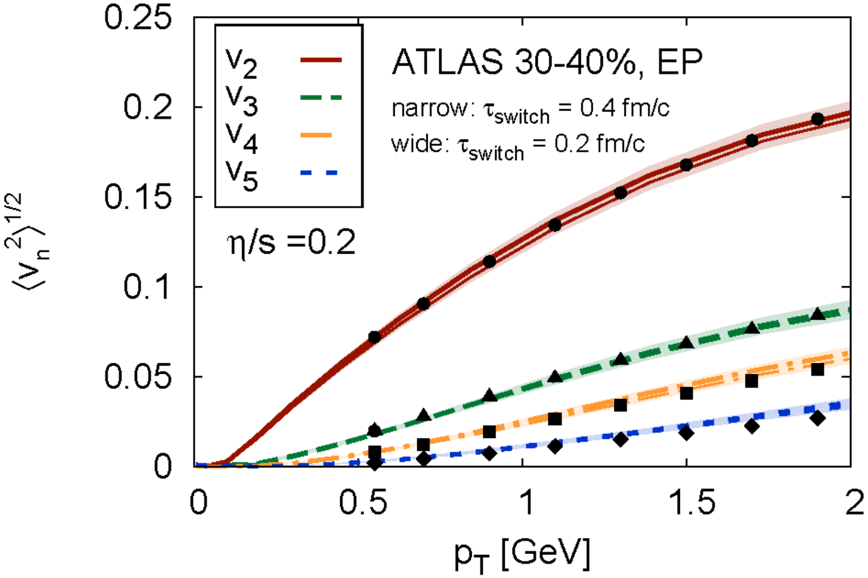
Akkor mikor jönnek létre a v_n értékek ?

Theoretical investigations, following the Standard Model of HIC
Sensitivity of the harmonic flow components on η/s and the time evolutin

C. Gale, S. Jeon, B. Schenke, P. Tribedy, R. Venugopalan, PRL109 (2013) 012302.

IP-Glasma + MUSIC hydro   [Glasma → hydro : τ(switch) ≈ $1/Q_s$ = 0.2 – 0.4 fm/c]





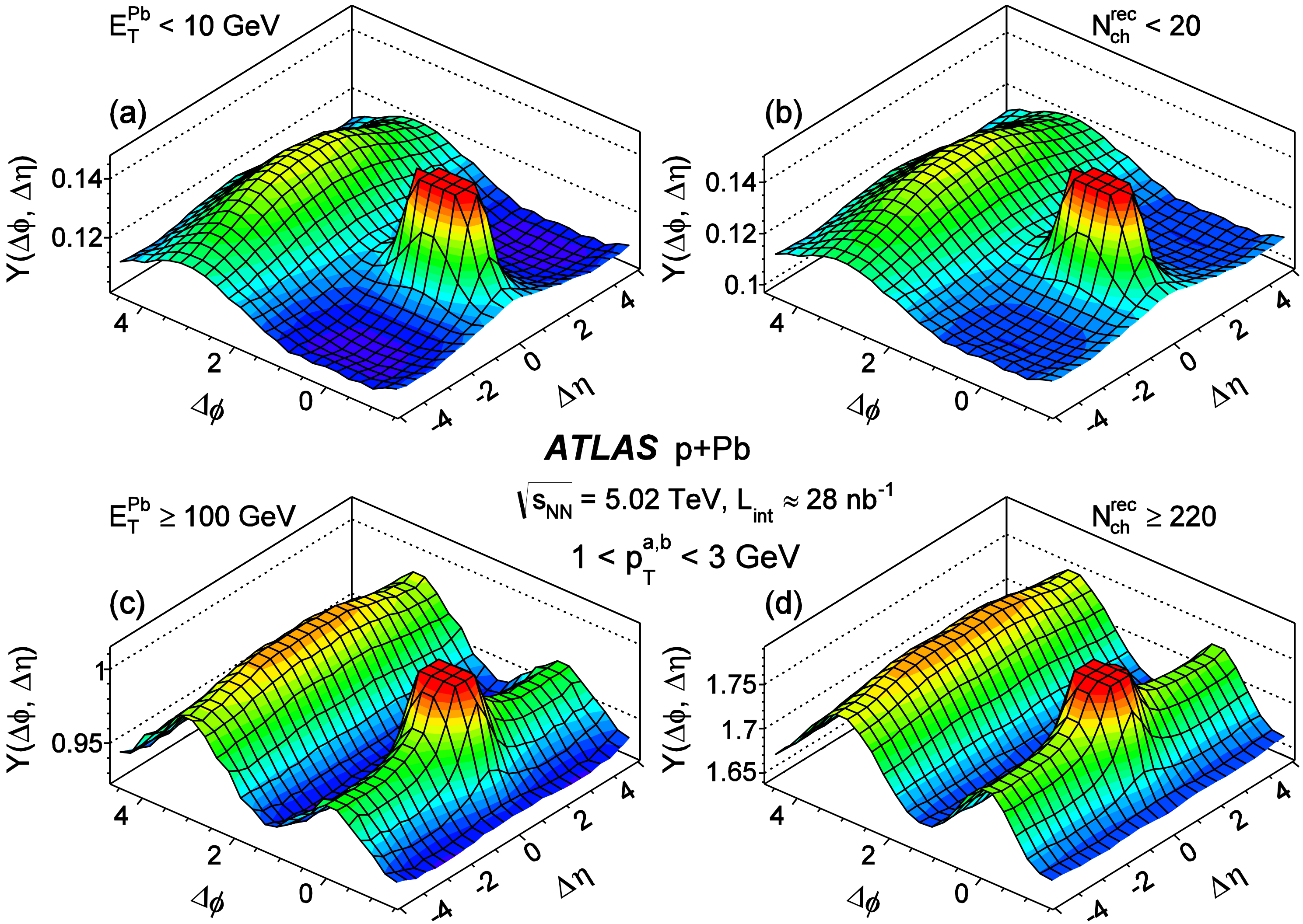
Weak sensitivity of v_n on the switching time τ between IP-Glasma state and hydrodynamics at LHC energy

Middle size sensitivity of v_n on the viscosity η/s at RHIC energy

Experimental results on v_n: pPb, $\sqrt{s}$= 5.02 TeV from ATLAS

PRC90 (2014) 044906 (Oct 2014), Arxiv: 1409.1792

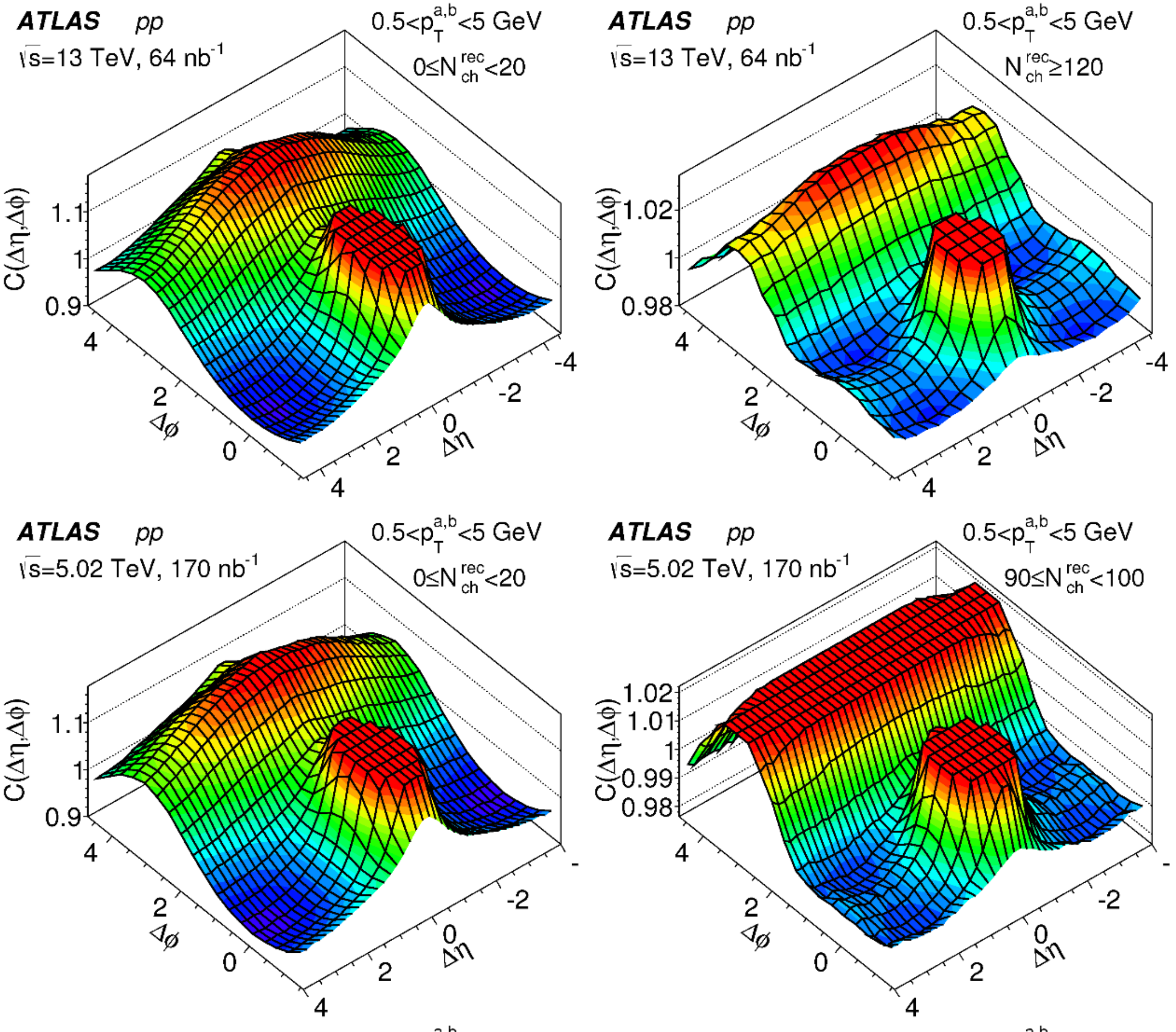
Long range correlations and ridge in pPb at small and large multiplicities



Latest experimental results on v_n: pp, $\sqrt{s}$= 5, 13 TeV from ATLAS

ArXiv: 1609.06213

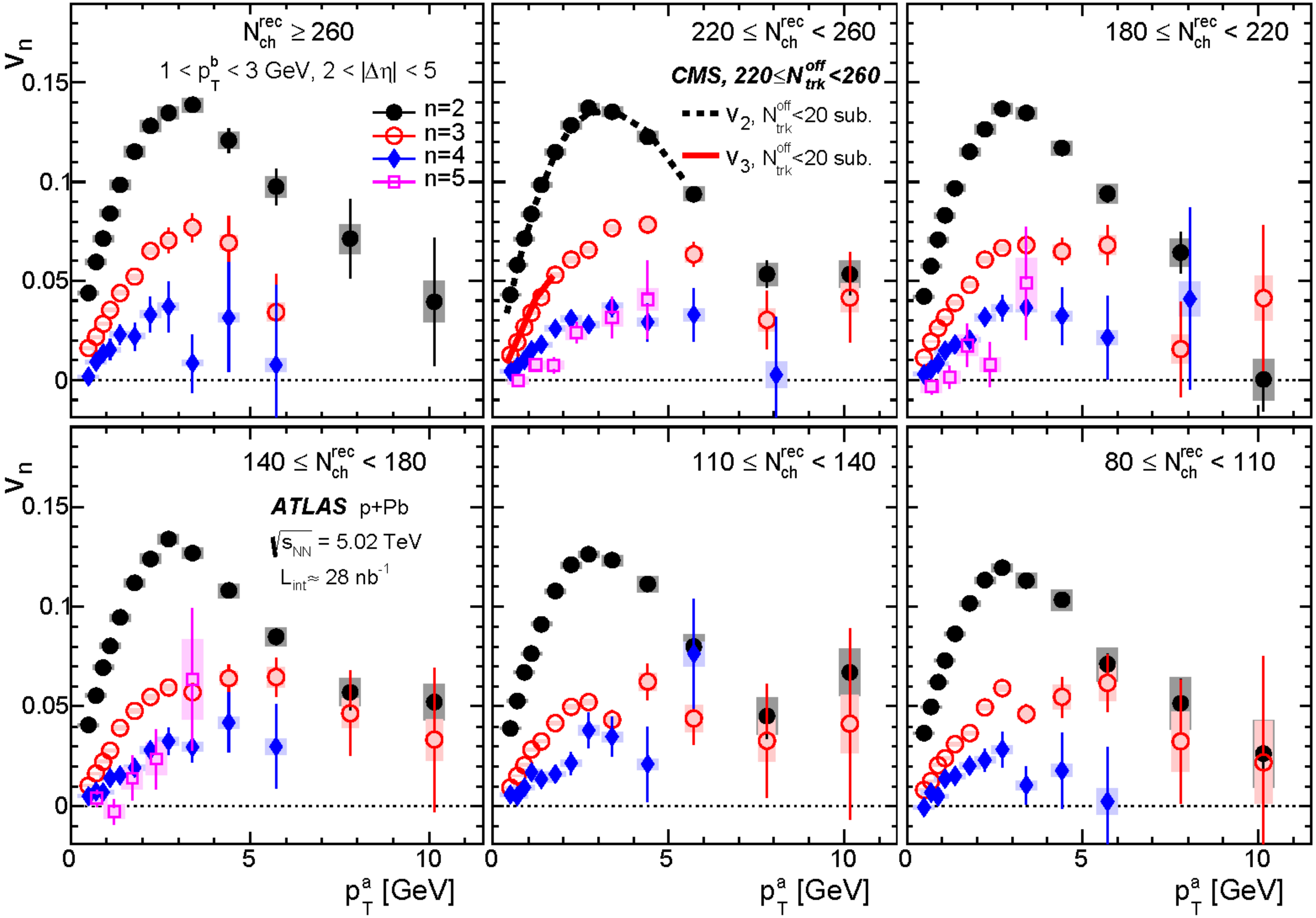
Long range correlations and ridge in pp at large multiplicities !!



Experimental results on v_n: pPb, $\sqrt{s}$= 5.02 TeV from ATLAS

PRC90 (2014) 044906, Arxiv: 1409.1792

v_2, v_3, v_4 and v_5 in pPb at different (high) multiplicities

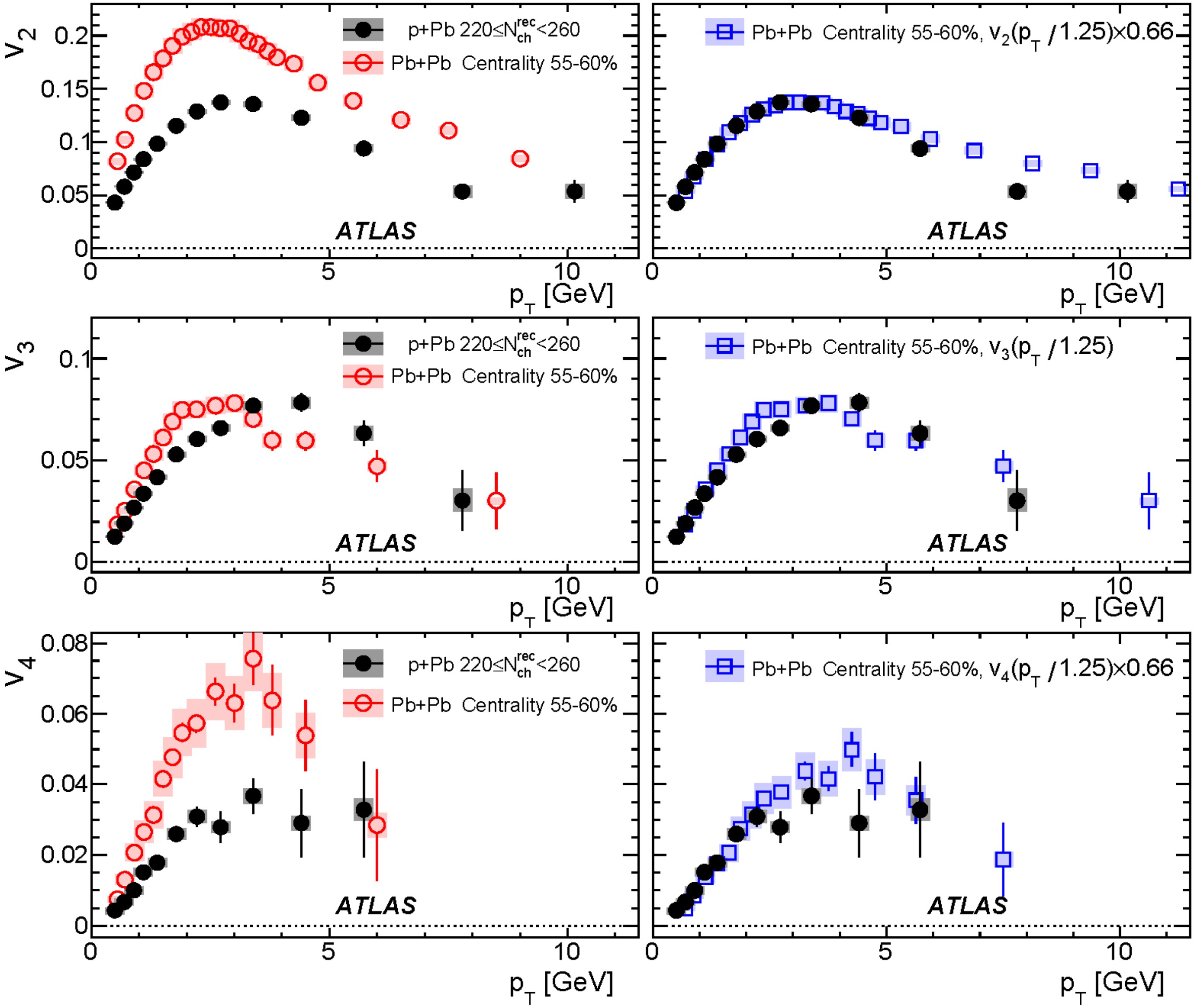


For v_n ATLAS and CMS results overlap

Experimental results on v_n: pPb, $\sqrt{s}$= 5.02 TeV from ATLAS

PRC90 (2014) 044906, Arxiv: 1409.1792

v_2, v_3 and v_4 in pPb and in peripheral PbPb at fix multiplicity window



Magic factors:

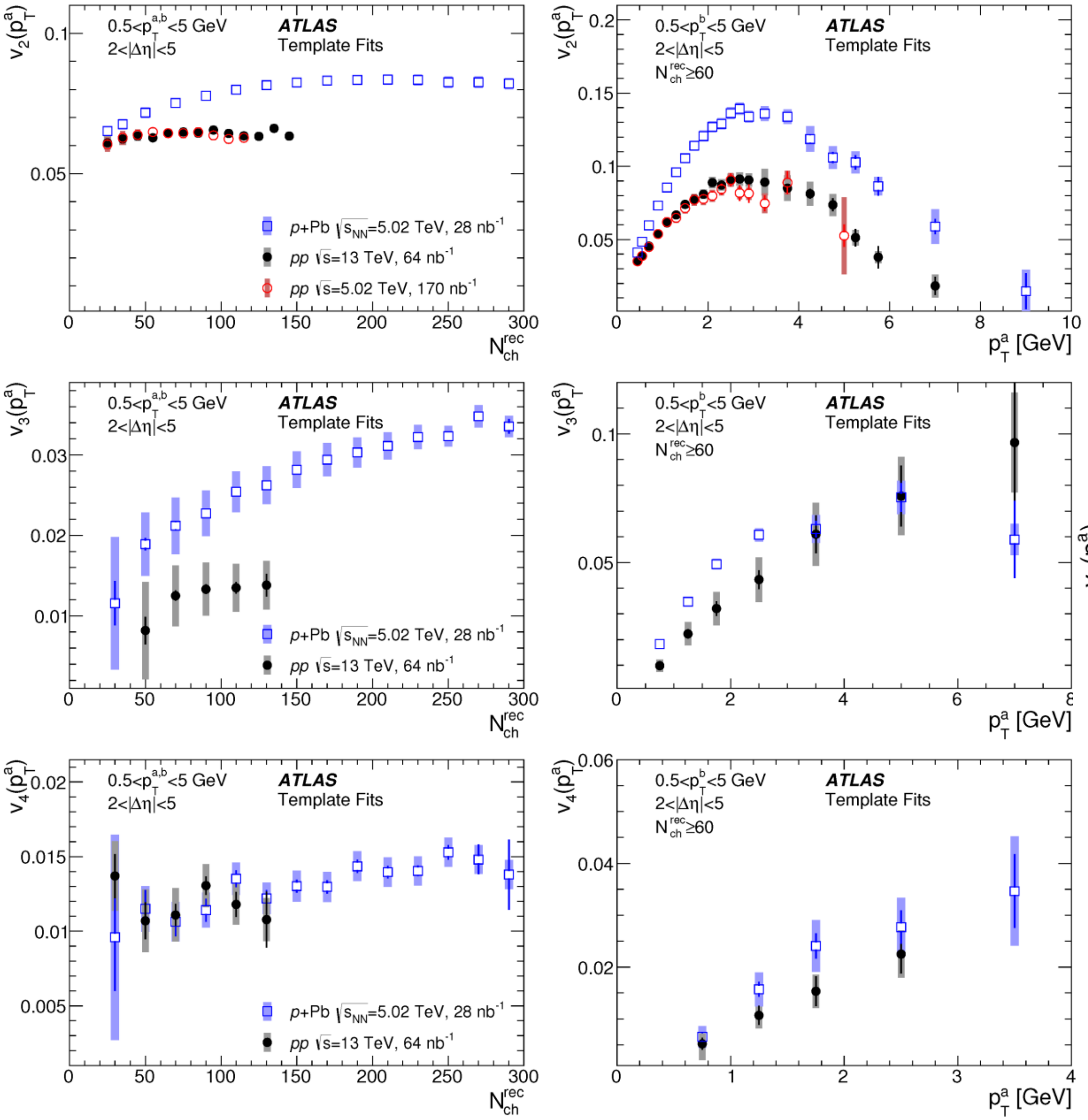
0.66 x $v_n(p_T/1.25)$

Explanation ?!

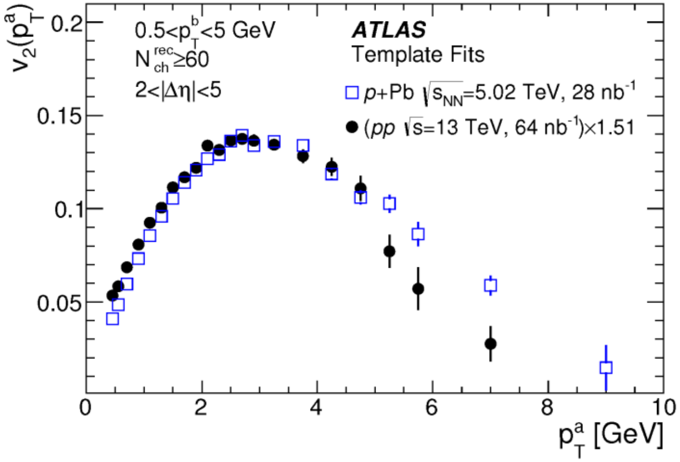
Latest experimental results on v_n: pp, $\sqrt{s}$= 5, 13 TeV from ATLAS

ArXiv: 1609.06213

v_2, v_3 and v_4 in pp, pPb at low & high multiplicities



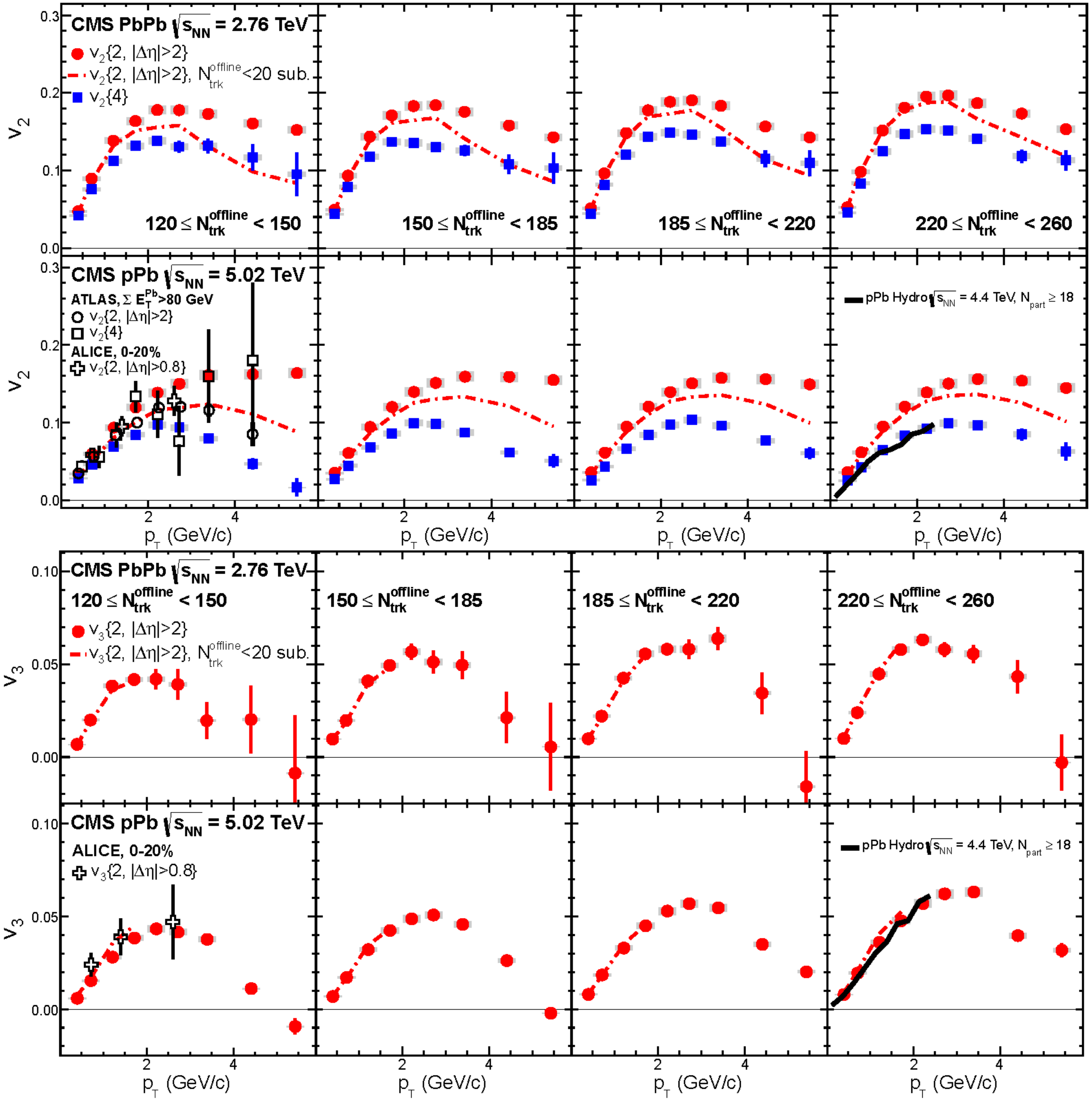
For v_2
pPb and pp results
Overlap with
Magic factor x 1.51



Experimental results on v_n: pPb, $\sqrt{s}$= 5.02 TeV from CMS

PLB724 (2013) 213., Arxiv: 1305.0609

$v_2\{2\}$ and $v_3\{2\}$ in pPb and peripheral PbPb in fix-multiplicity windows

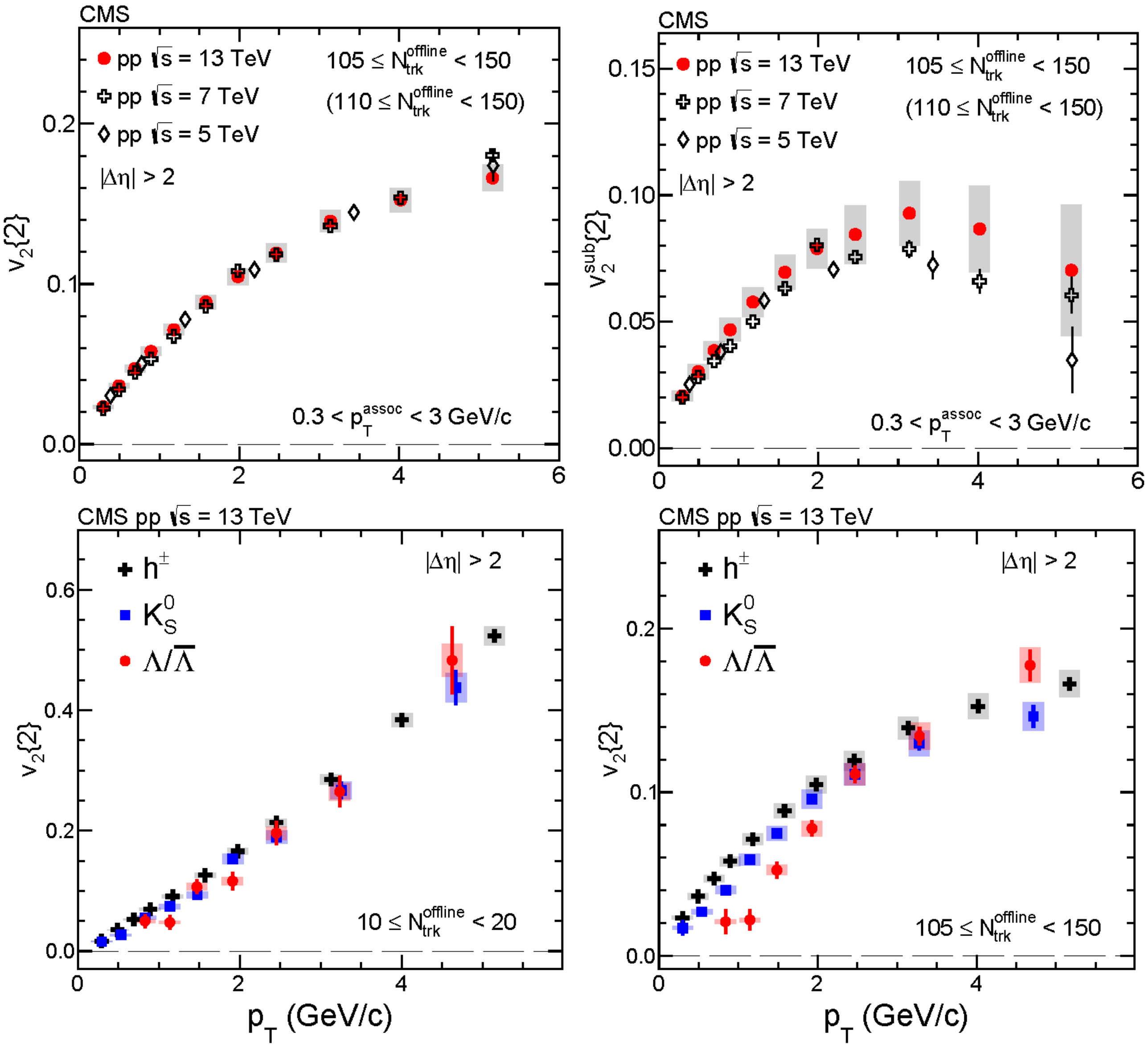


For $v_2\{2\}$, $v_3\{2\}$, $v_2\{4\}$ CMS, ALICE and ATLAS results overlap

Latest experimental results on v_n: pp, $\sqrt{s}$= 5,7,13 TeV from CMS

Arxiv: 1606.06198

$v_2\{2\}$ in pp in high-multiplicity windows

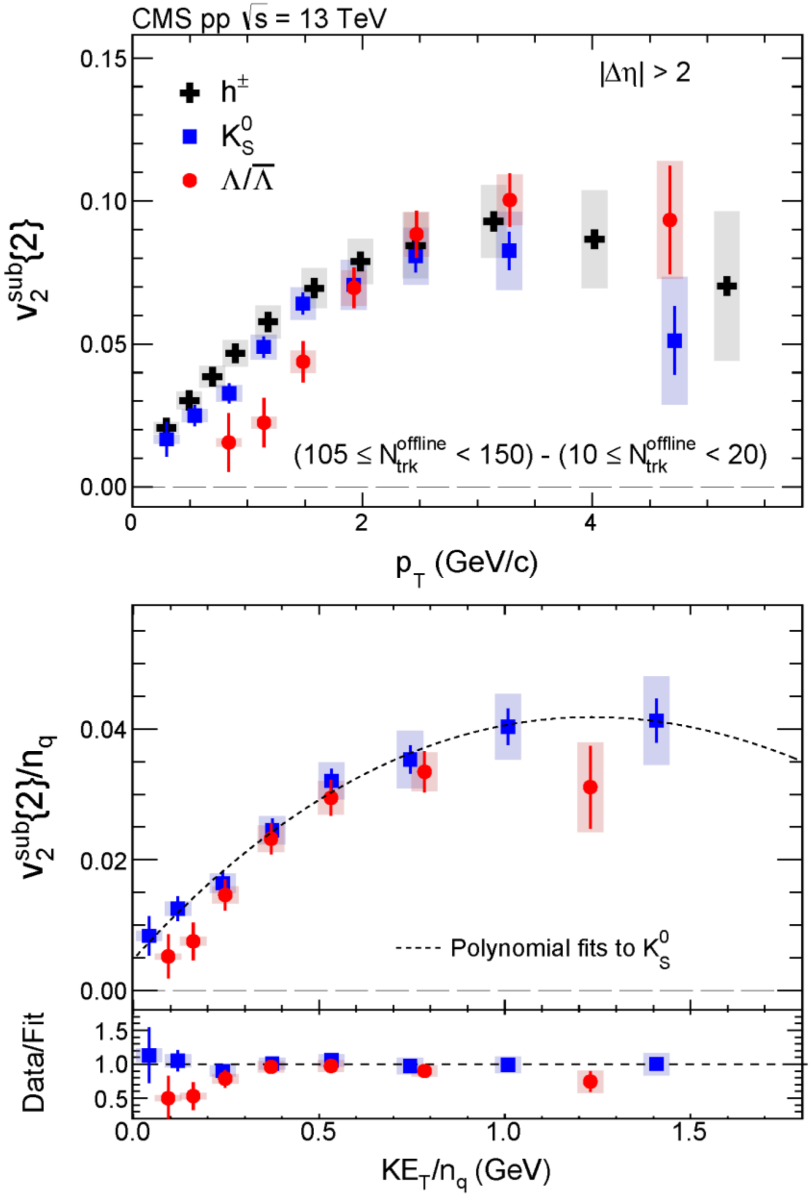


Flavour and
Mass dependence
in the CMS results

Latest experimental results on v_n: pp, $\sqrt{s}$= 13 TeV from CMS

Arxiv: 1606.06198

$v_2\{2\}$ in pp in high-multiplicity windows



Flavour and mass dependence in the CMS results for pp collision

Nq-scaling ????

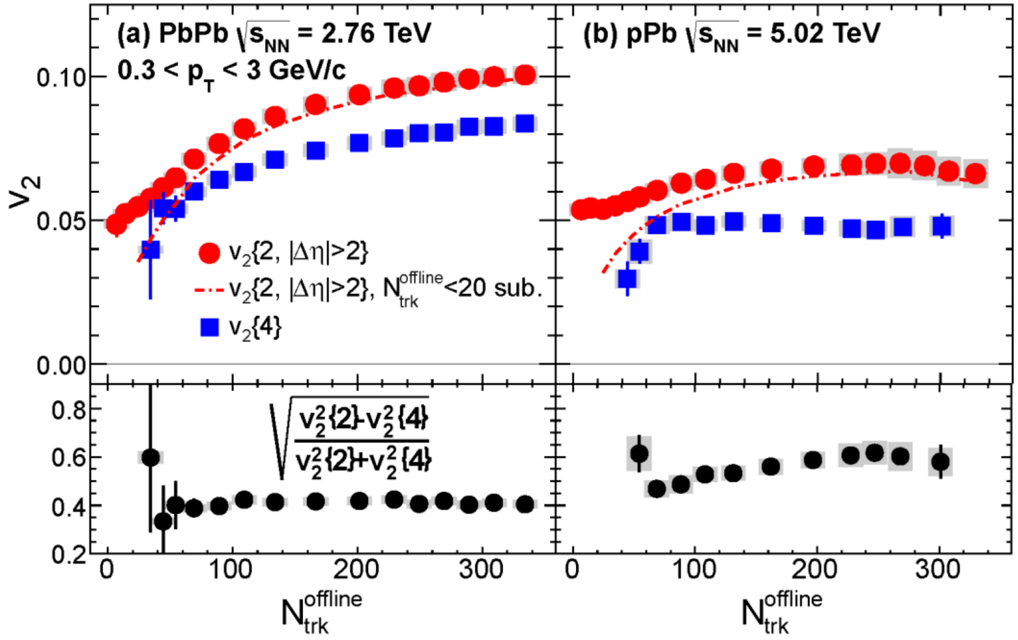
R.C. Hwa, C.B. Yang, PRC 2011: Ridge in pp collision at 7 TeV

Investigate proton/pion ratio!!!

Experimental results on v_n: pPb, $\sqrt{s}$= 5.02 TeV from CMS

PLB724 (2013) 213., Arxiv: 1305.0609

$v_2\{2\}$ and $v_3\{2\}$ in pPb and peripheral PbPb at fix multiplicity window



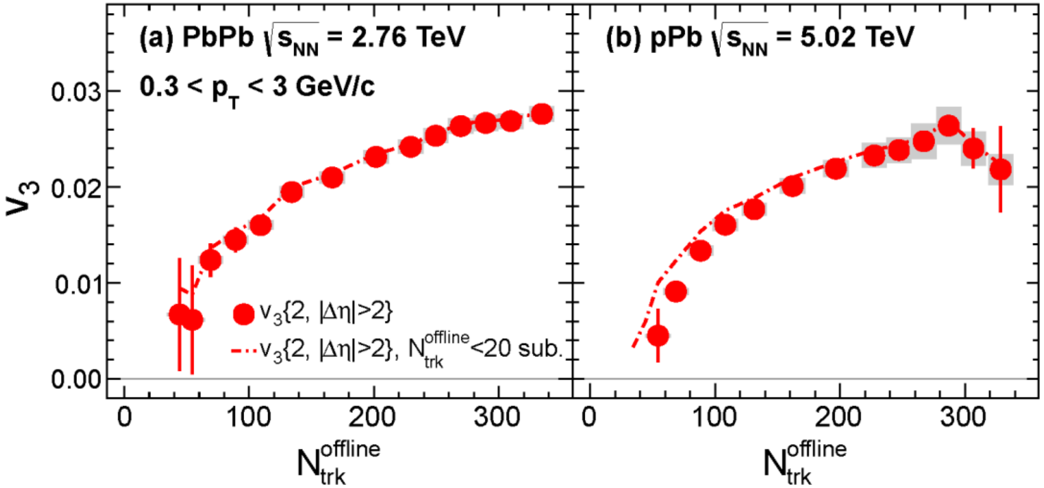
Fluctuations:

40 % in PbPb

50-60 % in pPb

residual nonflow correlations from back-to-back jets

Similar to RHIC results !

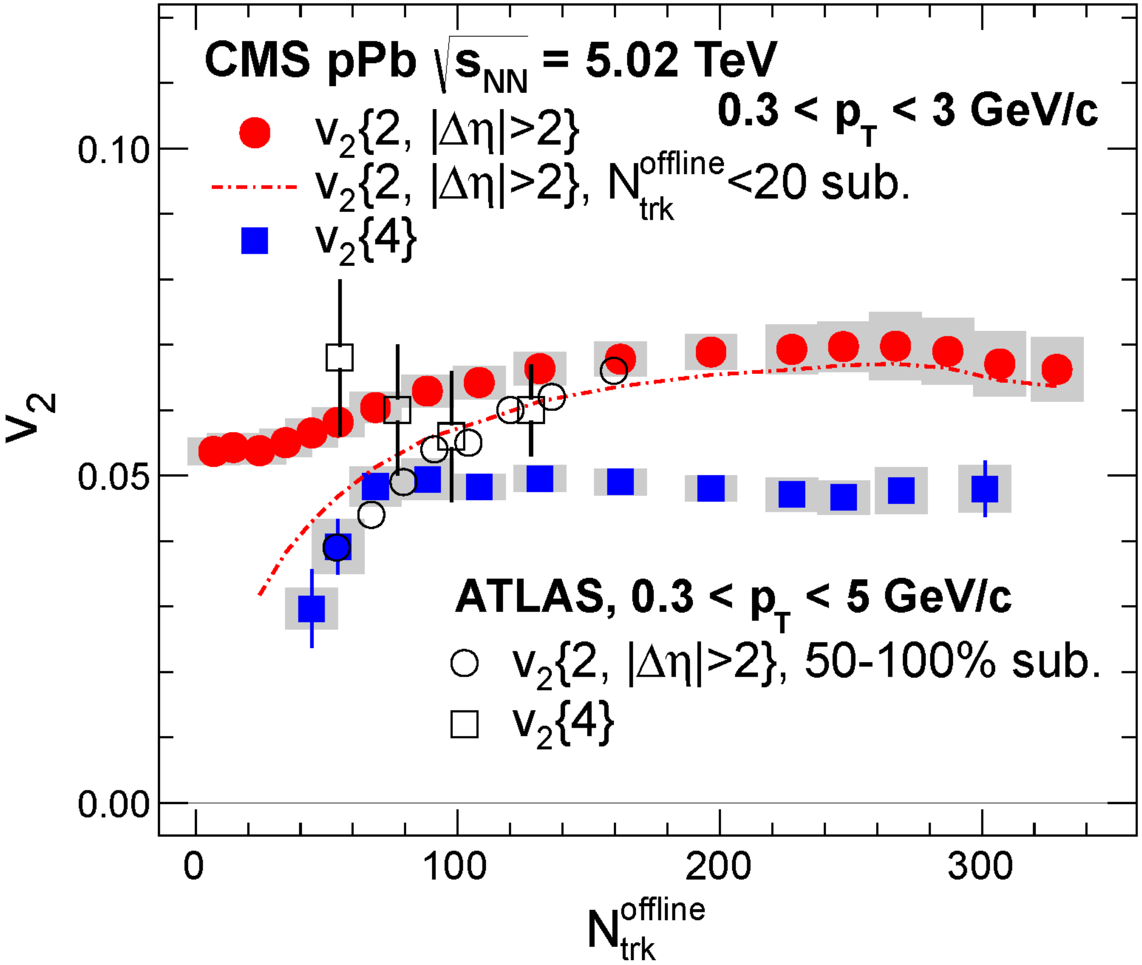


$v_3\{2\}$ are just the same in pPb and PbPb as the function of N_{trk} at longe range , $|\Delta\eta| > 2$!

Experimental results on v_n: pPb, √s= 5.02 TeV from CMS

PLB724 (2013) 213., Arxiv: 1305.0609

$v_2\{2\}$ and $v_2\{4\}$ in pPb and peripheral PbPb at fix multiplicity window



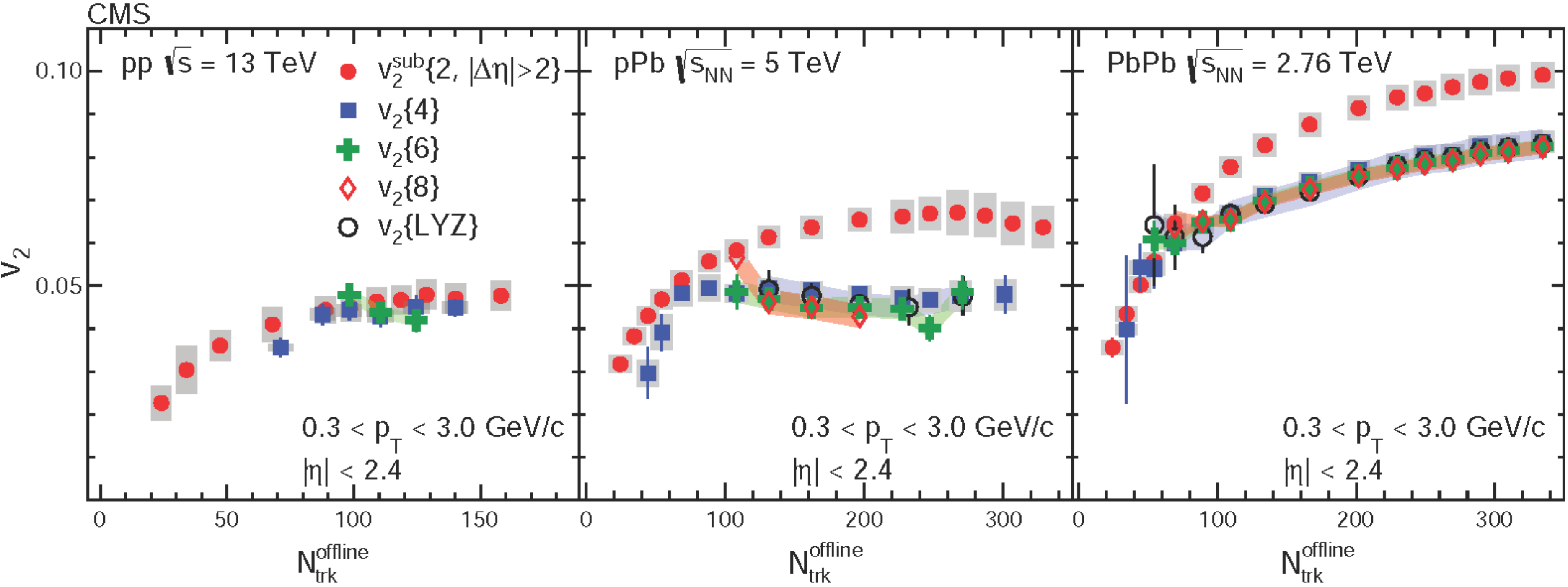
CMS and ATLAS data on $v_2\{2\}$ slightly differ, but not very much. (sligthly diff. windows)

ATLAS also claims the presence of large fluctuations in pPb collisions

Latest experimental results on v_n: pp, pPb, PbPb at $\sqrt{s}$= 13, 5, 2.76 ATeV from CMS

Arxiv: 1606.06198

Analyzing $v_2\{N\}$ in pp, pPb and PbPb



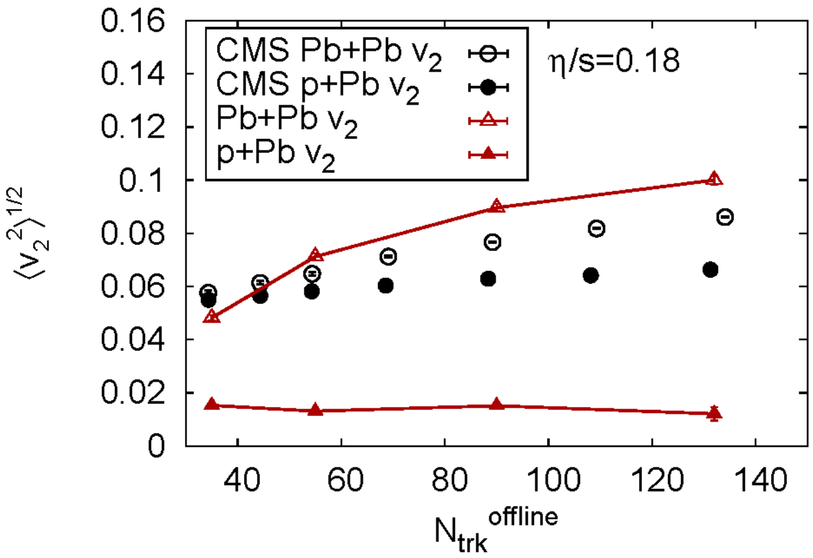
CMS: Fluctuations are larger in pp than in pPb and PbPb !!!!

Interesting measure for defining collectivity !

Theoretical investigations, following the Standard Model of HIC for pPb Sensitivity of the harmonic flow components on η/s and the time evolutin

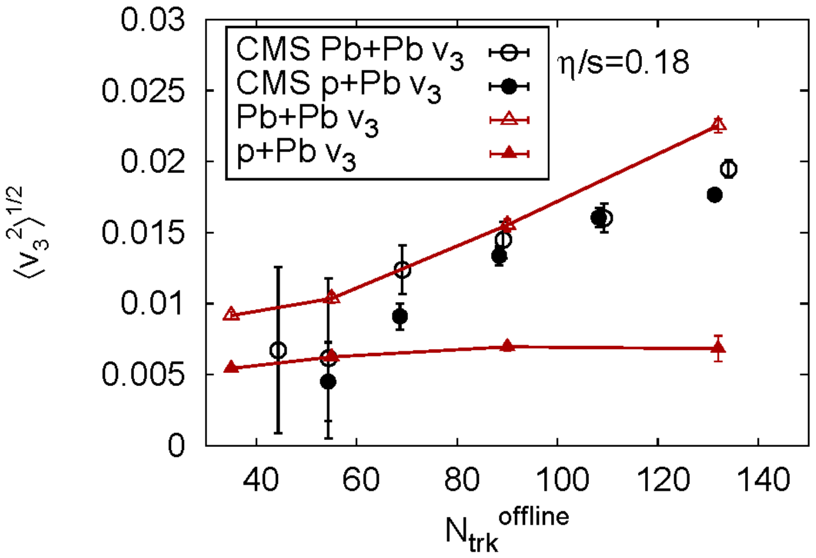
B. Schenke, R. Venugopalan, PRL113 (2014) 102301, Arxiv: 1405.3605

IP-Glasma + MUSIC hydro [Glasma → hydro : τ(switch) ≈ 1/Q_s = 0.2 – 0.4 fm/c]



CMS data and theory for v_2

PbPb results can be reproduced pPb data are underestimated by IP-Glasma+ MUSIC model at LHC energy



CMS data and theory for v_3

PbPb results can be reproduced pPb data are underestimated by IP-Glasma+ MUSIC model at LHC energy

„… possible breakdown of the hydrodynamical paradigm , when (it is) extended to very small systems.”

Recent data indicates strong similarities for anisotrop flow components in pPb collisions and peripheral PbPb collisions at the same multiplicity windows.

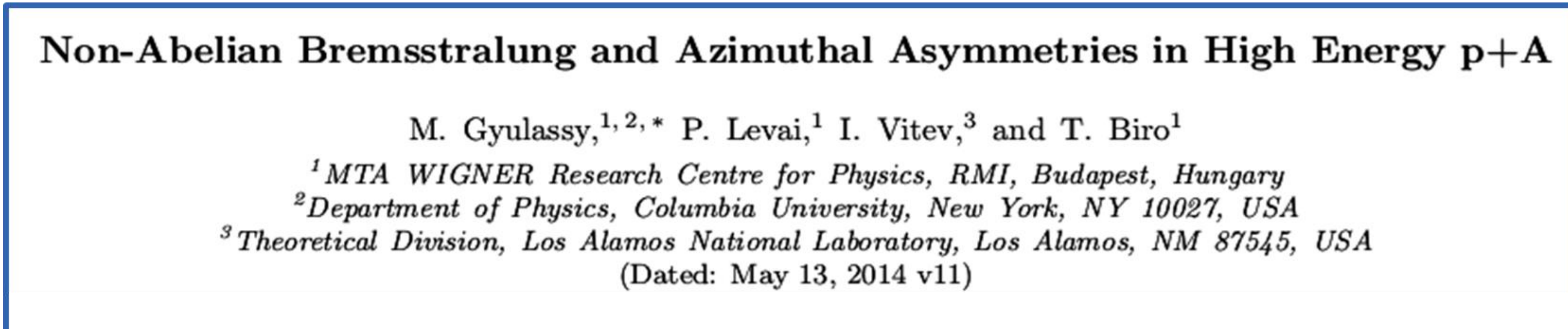
First conclusion: hydrodynamical behaviour in pPb at LHC energies
But:

- Fluctuation contributions seems to be large
- Hybrid model (IP Glasma + MUSIC) does not work for pPb,
  although it was working for PbPb collisions.

Our suggestion:

- Non-abelian beam jet bremsstrahlung
- Projectile beam jet form Color Scintillation Antenna (CSA)
- Bremsstrahlung from CSA clusters and arrays
  - Analitic calculations on the basis of GLV approximation
  - Including GLVB into HIJING for numerical calculations

Phys. Rev. D90 (2014) 054025. hep-ph/1805.7825



Non-Abelian Bremsstralung and Azimuthal Asymmetries in High Energy p+A

M. Gyulassy,[1, 2, *] P. Levai,[1] I. Vitev,[3] and T. Biro[1]

[1] *MTA WIGNER Research Centre for Physics, RMI, Budapest, Hungary*
[2] *Department of Physics, Columbia University, New York, NY 10027, USA*
[3] *Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA*
(Dated: May 13, 2014 v11)

II. FIRST ORDER IN OPACITY (GB) BREMSSTRAHLUNG AND AZIMUTHAL ASYMMETRIES v_n

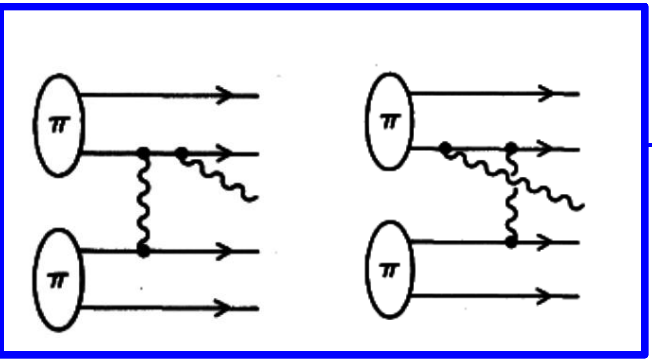
The above puzzles with BES and $D+Au$ at RHIC and with $p+Pb$ at LHC and models proposed so far motivate us to consider simpler more basic perturbative QCD sources of azimuthal asymmetries.The well known non-abelian bremstralung Gunion-Bertsch (GB) formula[29] for the soft gluon radiation single inclusive distribution is

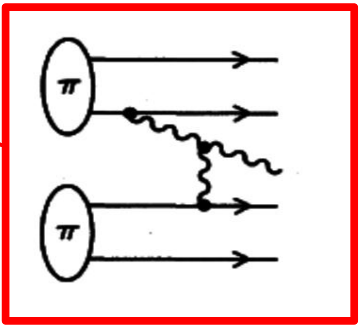
Color Dipole Form factor

$$\frac{dN_g^{(1)}}{d\eta d^2\mathbf{k}d^2\mathbf{q}} \equiv f(\eta,\mathbf{k},\mathbf{q})$$

$$= \frac{C_R\alpha_s}{\pi^2k^2}\frac{\mu^2}{(\mathbf{q}^2+\mu^2)}\frac{P_\eta}{(\mathbf{k}-\mathbf{q})^2+\mu^2}$$

$$\equiv \frac{F\cdot P}{A_{kq}-\cos(\phi-\psi)}$$





Gluon Bremsstrahlung peaks in transverse direction near net momentum transfer $\vec{Q}$ = (Q, ψ) that also defined reaction Event Plane (EP)

Basic Non-Abelian feature: uniform *rapidity "ridge"* (unlike in QED)

Also peaks in beam direction 1/k^2 (as in QED)

ϕ is the azimuthal angle of $\mathbf{k}$ and ψ is the azimuthal angle of $\mathbf{q}$ and abreviations

$$A \equiv A_{kq} \equiv (k^2+q^2+\mu^2)/(2k\,q) \geq 1$$

$$F \equiv F_{kq} \equiv \frac{C_R\alpha_s}{\pi^2k^2}\frac{\mu^2}{(\mathbf{q}^2+\mu^2)}\frac{1}{2kq}P_\eta$$

Kinematic rapidity envelope

$$P_\eta \equiv (1-e^{Y_T-\eta})^{n_f}(1-e^{\eta-Y_P})^{n_f} \quad ,$$

$$\begin{aligned} v_n(k,q,\psi)f_0(k,q) &\equiv \int\frac{d\phi}{2\pi}\cos(n\phi)f(\eta,k,\phi,q,\psi) \\ &= F\int\frac{d\phi}{2\pi}\frac{\cos(n\phi)}{A-\cos(\phi-\psi)} \\ &= \cos(n\psi)\,F\int\frac{d\phi}{2\pi}\frac{\cos(n\phi)}{A-\cos(\phi)} \quad . \end{aligned}$$

$f_0 \equiv \int d\phi f = \int d\phi\ d^7N/d\eta dk^2 d\phi dq^2 d\psi$ is the ϕ integrated single gluon inclusive

$$dN/d\eta dk^2 = F_{kq}P_\eta/(A_{kq}^2-1)^{1/2}$$

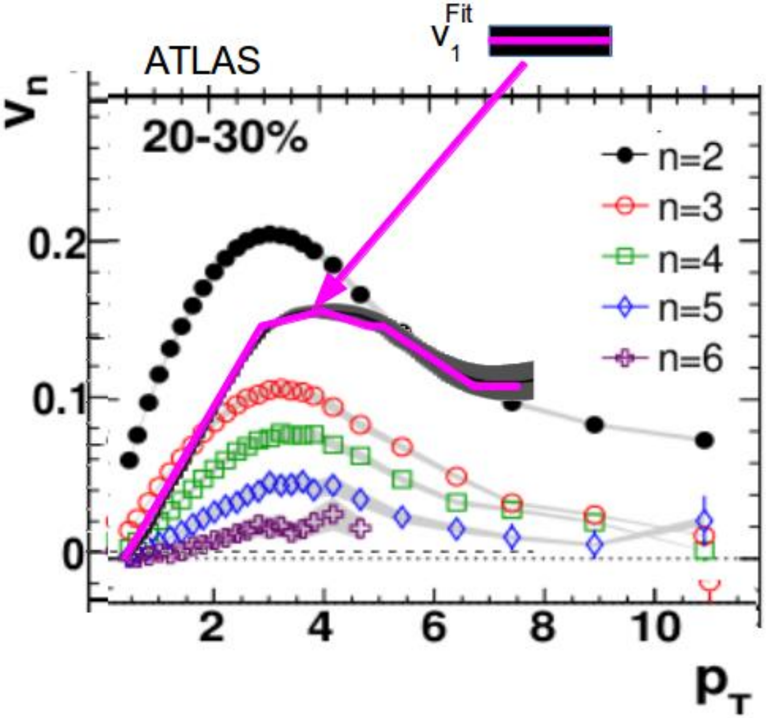
A single GB color antenna has analytic v_n:

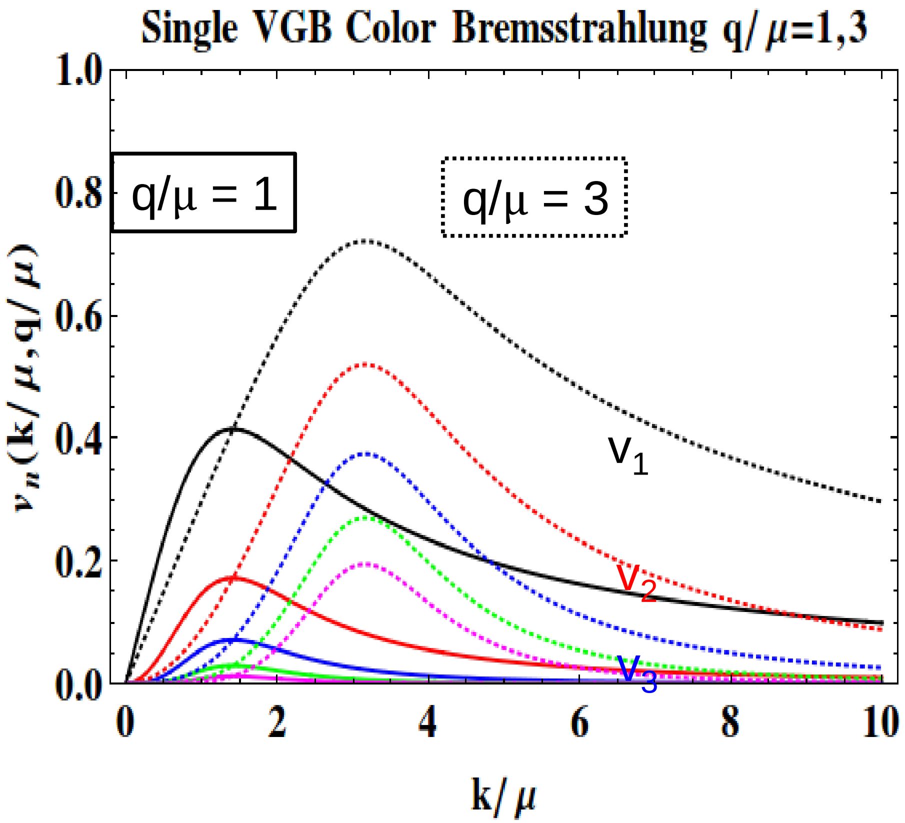
$$A_{kq} \equiv (k^2+q^2+\mu^2)/(2k\,q) \ge 1$$

$$\begin{aligned} v_1^{GB}(k,q,\psi) &= \cos[\psi](A_{kq}-\sqrt{A_{kq}^2-1}) \\ \lim_{\mu\to 0} v_1^{GB}(k,q,0) &= (k/q)\,\theta(q-k) \\ v_n^{GB}(k,q,\psi) &= \cos[n\psi]\,(v_1^{GB}(k,q,0))^n \\ \lim_{\mu\to 0} v_n^{GB}(k,q,0) &= (k/q)^n\,\theta(q-k)\ . \end{aligned}$$

Perfect $\mathbf{v_n^{1/n} = v_1}$ Scaling

Two particle v_n from ATLAS

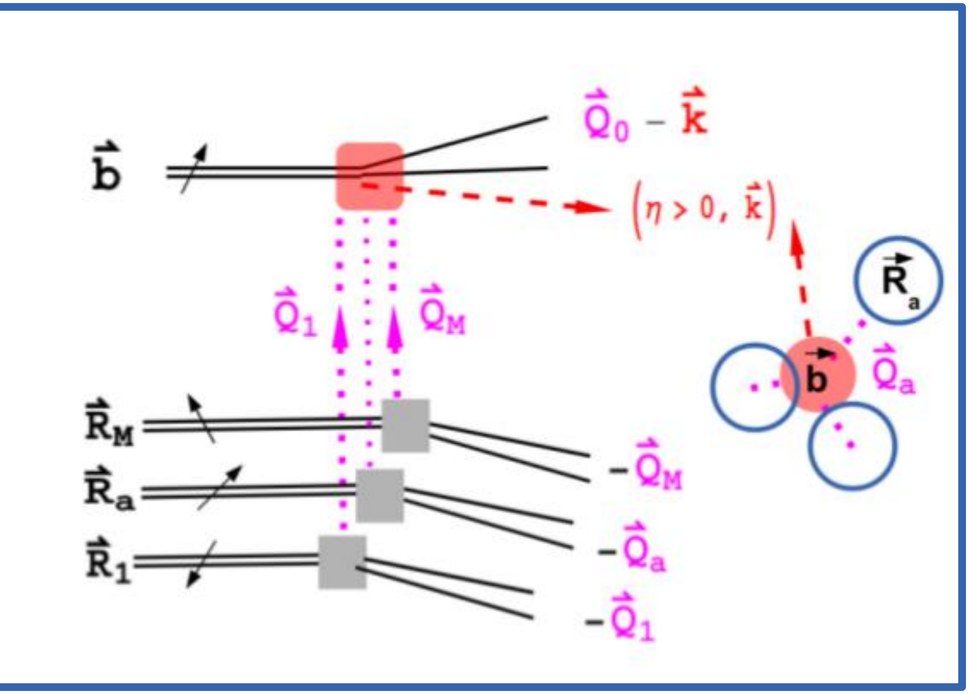




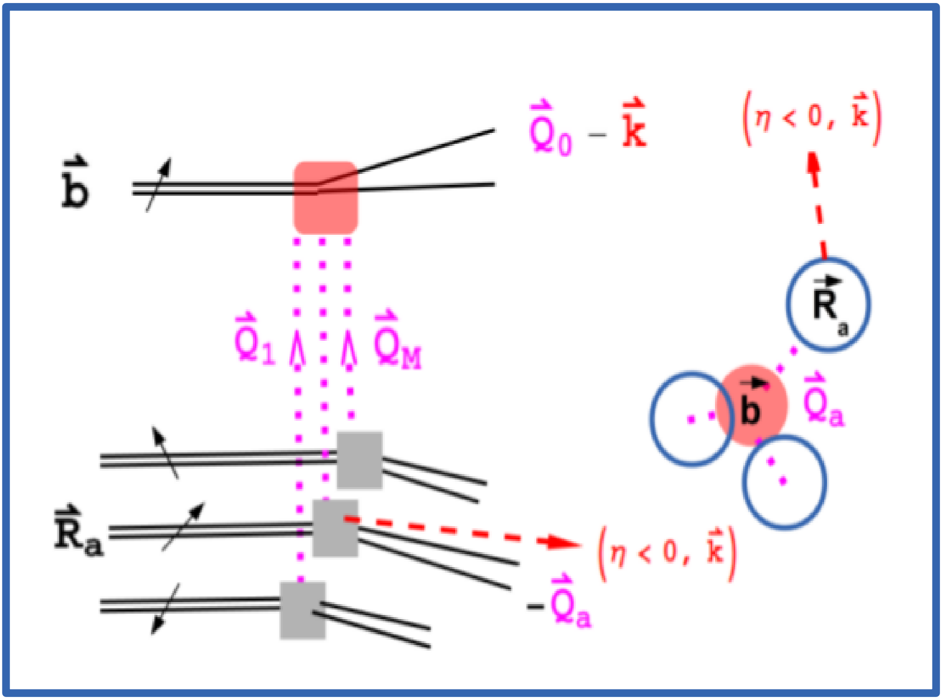
Note intrinsic huge even and odd v_n peaking near $\mu \sim Q_{sat}$

Combined projectile and target participants soft recoil Bremsstrahlung

Projectile Beam Jet Brems.



Participant Recoil Target Beam Jets Brems.



Target dipoles act coherently if transverse separation cannot be resolved

$$R_{ij} \lesssim d(k) = \frac{c}{k}$$

$1 \leq M \leq N$ coherent target clusters varies with gluon resolution scale k

If $i \in I_a$ and $j \in I_a$ as well as $j \in I_b$, then j is added to I_a if its $\langle d_{ij} \rangle_{i \in I_a} < \langle d_{ij} \rangle_{i \in I_b}$

Vitev → all order in opacity multiple scattering VGB generalization of GB Brems.

$$dN^{VGB}_{coh}(\mathbf{k}) = \sum_{n=1}^{\infty} \int d^2\mathbf{Q}\, P^{el}_n(\mathbf{Q})\, dN^{GB}(\mathbf{k},\mathbf{Q})$$

$$P^{el}_n(\mathbf{Q}) \;=\; \exp[-\chi]\frac{\chi^n}{n!} \int \left\{ \prod_{j=1}^{n} \frac{d^2\mathbf{q}_j}{\sigma_{el}} \frac{d\sigma_{el}}{d^2\mathbf{q}_j} \right\} \times \delta^2(\mathbf{Q} - (\mathbf{q}_1 + \cdots + \mathbf{q}_n))$$

Cumulative momentum transfer from n coherent scatterings

At n=Nth order in opacity with M coherent target clusters that can resolved by k Projectile plus Target bremsstrahlung sums to

$$\begin{aligned} dN^{M,N} &= dN^{N}_{P}(\eta,\mathbf{k}_1;\mathbf{Q}_P) + dN^{M,N}_{T}(\eta,\mathbf{k}_1;\{\mathbf{Q}_a\}) \\ &= \sum_{a=0}^{M} \frac{B_{1a}}{(\mathbf{k}_1 + \mathbf{Q}_a)^2 + \mu_a^2}\;, \end{aligned}$$

$$B_{ia} \equiv F_{k_i,Q_a}\, P_a(\eta_i)$$

$$\mathbf{Q}_0 \equiv -\mathbf{Q}_P = -\sum\nolimits_a \mathbf{Q}_a$$

2 glue Brems in independent emission approx.

$$dN^{N,M}_2(\mathbf{k}_1,\mathbf{k}_2) \;=\; \sum_{a=0}^{M}\sum_{b=0}^{M} \frac{B_{1a}}{A_{1a} - \cos(\phi_1 + \psi_a)} \frac{B_{2b}}{A_{2b} - \cos(\phi_2 + \psi_b)}$$

Two gluon relative Cos(n (φ1 – φ2)) analytic azimuthal harmonics CSA color antennas

$$f_n^{N,M}(k_1,k_2) \equiv \int_{-\pi}^{\pi} d\Phi \int_{-\pi}^{\pi} d\Delta\phi \cos(n\Delta\phi) dN_2^{N,M}(k_1,\Phi+\Delta\phi/2,k_2,\Phi-\Delta\phi/2)$$

$$=\sum_{a,b=0}^{M} B_{1a}B_{2b}\int_{-\pi}^{\pi} d\Phi' \frac{1}{A_{1a}-\cos(\Phi')}\int_{-\pi}^{\pi} d\Delta\phi \frac{\cos(n\Delta\phi)}{A_{2b}-\cos((\Phi'+\psi_b-\psi_a)-\Delta\phi)}$$

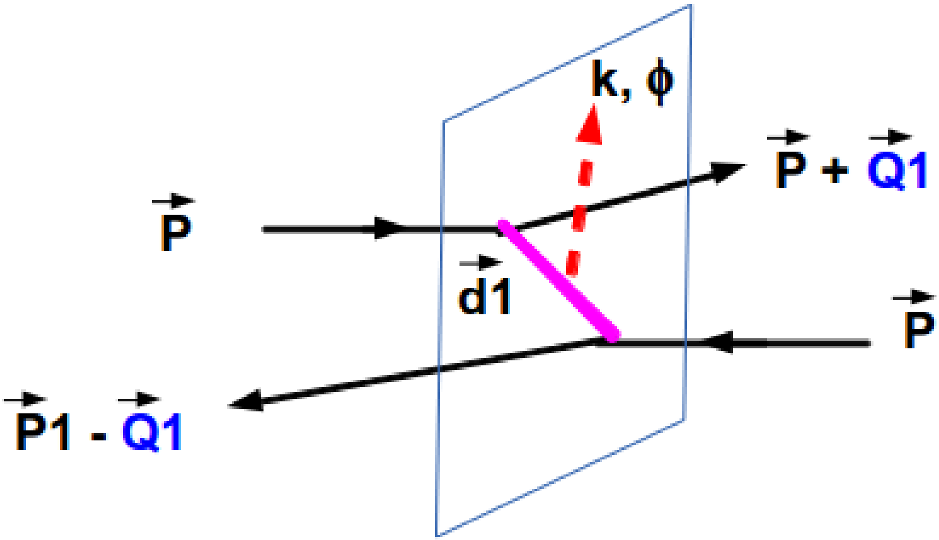
$$=\sum_{a,b=0}^{M} B_{1a}B_{2b}\, f_{0,1,a}\, f_{0,2,b} \boxed{(v_1^{GB}(k_1,Q_a)v_1^{GB}(k_2,Q_b))^n \cos(n(\psi_b-\psi_a))}$$

$$f_{n,1,a} = \int_{-\pi}^{\pi} d\Phi \frac{\cos(n\Phi)}{A_{1a}-\cos(\Phi)} = (v_1^{GB}(k_1,Q_a))^n f_{0,1,a} = \frac{\left(A_{k_1,Q_a}-\sqrt{A^2_{k_1,Q_a}-1}\right)^n}{\sqrt{A^2_{k_1,Q_a}-1)}}$$

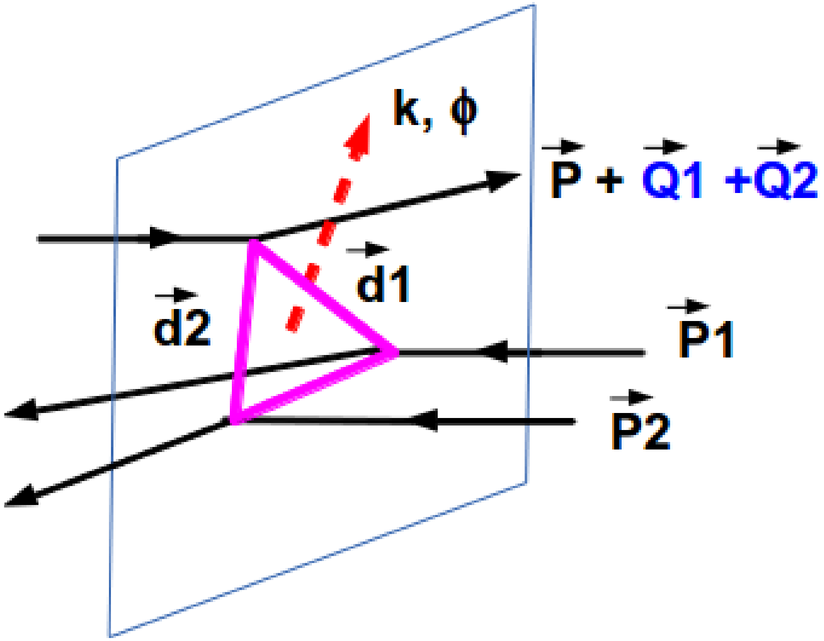
$$\boxed{v_n^{M,N}\{2\}[k_1,k_2] \equiv= \langle\cos(n(\phi_1-\phi_2))\rangle_{k_1,k_2} = \frac{\langle f_n^{M,N}(k_1,k_2)\rangle}{\langle f_0^{M,N}(k_1,k_2)\rangle}}$$

$$\langle\cdots\rangle = \int \left\{\prod_{a=0}^{M} d\mathbf{Q}_a\right\}\delta(\sum_{a=0}^{M}\mathbf{Q}_a)\sum_{m_1,\cdots,m_M}\delta(N-\sum_{a=1}^{M}m_a)\, p^{M,N}_{\{m_j\}}\, P^{el}_{m_1}(\mathbf{Q}_1)\cdots P^{el}_{m_1}(\mathbf{Q}_M)$$

Classical Color Field Produced by 2 or 3 Interfering dipole currents



Two BG dipole antenna array



Three BG dipole antenna array

Produce only n=2,4,6, ...

Produce all n=1, 2, 3, 4, ...

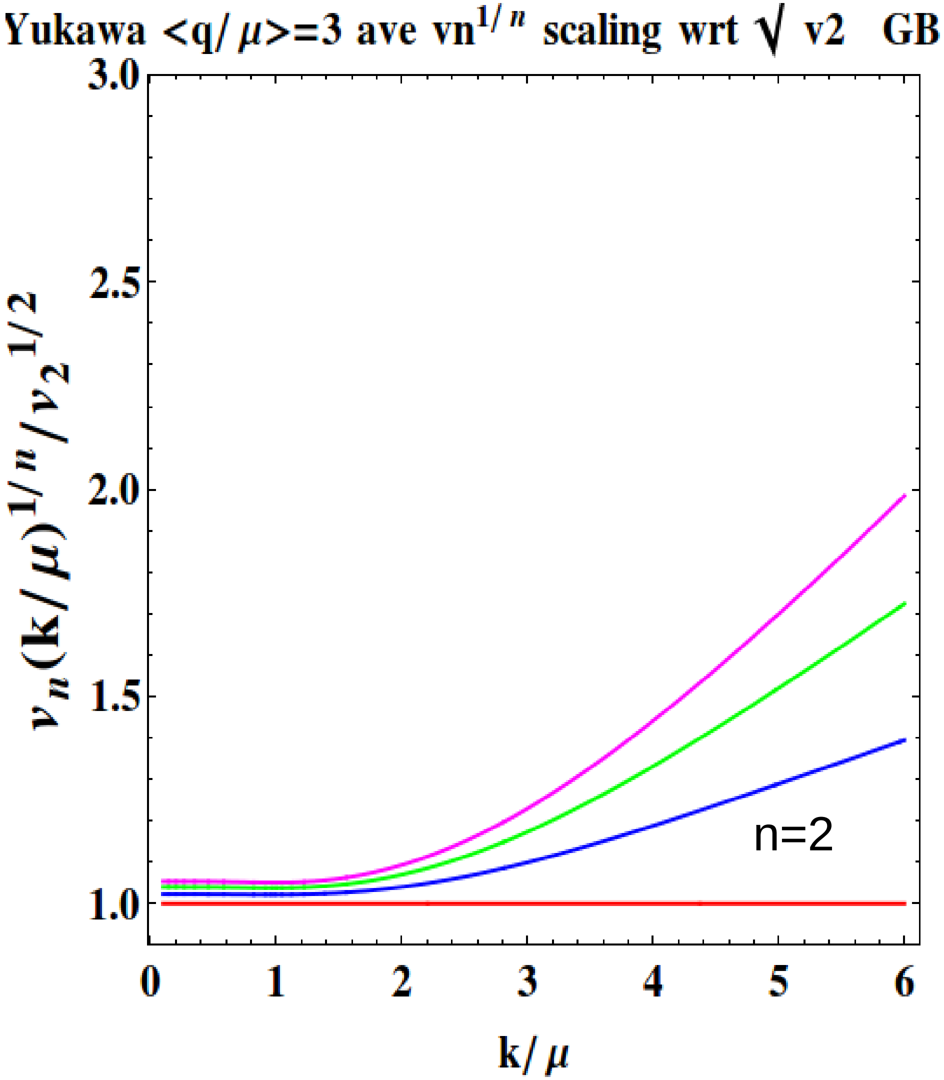
Numerical calculations for pp, pA and AA collisions:
HIJING model with radiating dipole antennas

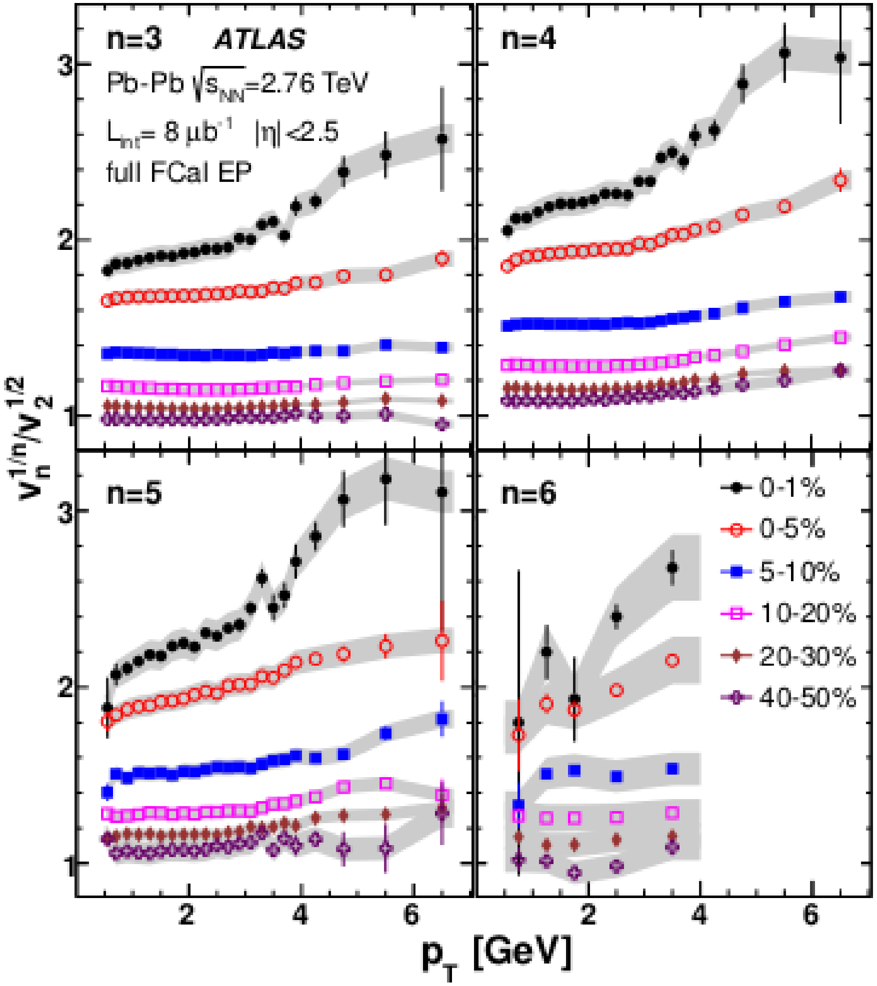
Fixed q GB pQCD Bremsstrahlung harmonics scale perfectly via 1/n power law

$$[v_n^{GB}(k,q,0)]^{1/n} \;=\; [v_m^{GB}(k,q,0)]^{1/m}$$

For Yukawa averaged ⟨q/μ⟩ =√M,

GB 1/n scaling hold for k < √M and breaks down for k > √M





Recent data indicates strong similarities for anisotrop flow components
in pPb collisions and peripheral PbPb collisions at the same multiplicity windows.

Realistic IC + hydrodynamical evolution does not work for pPb at LHC energies
Fluctuation contributions seems to be large

Suggestion-1: GLVB model with fluctuating non-abelian beam jet bremsstrahlung
Projectile beam jet form Color Scintillation Antenna (CSA)
Gluon bremsstrahlung from CSA clusters and arrays → HIJING
GLVB, Phys. Rev. D90 (2014) 054025; 1405.7825; 1407.7306

Suggestion-2: CGC with color charge fluctuations
„collectivity" from multi-particle correlation
non-trivial coherence patterns associated as initial state effects
L. McLerran, V.V. Skokov, A. Dumitru,
arXiv: 1407. 2651; PLB743 (2015) 134; PRD91 (2015) 074006;

Suggestion-3: BFKL Pomeron with gluon interference, two-gluon correlations
E. Levin, A. H. Rezaeian, PRD84 (2011) 034031
R.L. Ray, PRD90 (2014) 054013

Need more data and better undestanding of experimental data on fluctuation !!!
J. Y. Ollitrault, A. Poskanzer, (on cumulants) PLB742 (2015) 290

Summary:

1. Latest experimental data display
   a) Strong similarity of flow harmonics in pA and periferal AA collisions
      Beam-size independence ! (Depends on multiplicity!)
   b) dAu/AuAu and pPb/PbPb comparisons are very similar
      Beam energy independence

These are bad news !

2. „Perfect Fluidity" is „Sufficient" (with suitable initial conditions) to fit data
   and hydro is working well for AA collisions
   but seems to fail for pA at the same multiplicitiesto reproduce v_n

Perfect Fluidity may not be „Necessary"

3. New theoretical suggestions appeared for pA collisions (influence on AA ??):
   GLVB with fluctuating non-abelian jet bremsstrahlung and CSA
   CGC with color charge fluctuations and multi-particle correlations
   BFKL Pomeron with gluon interference, two-gluon correlations

4. GLVB: Work in progress is to implement anisotropic bremsstrahlung into
   HIJING in order to compute pA/AA results comparable to data

5. Need more data and better understanding of exp. data on/with fluctuation !!!
   (e.g. proton/pion ratio in high multiplicity pp collisions)