Stony Brook University

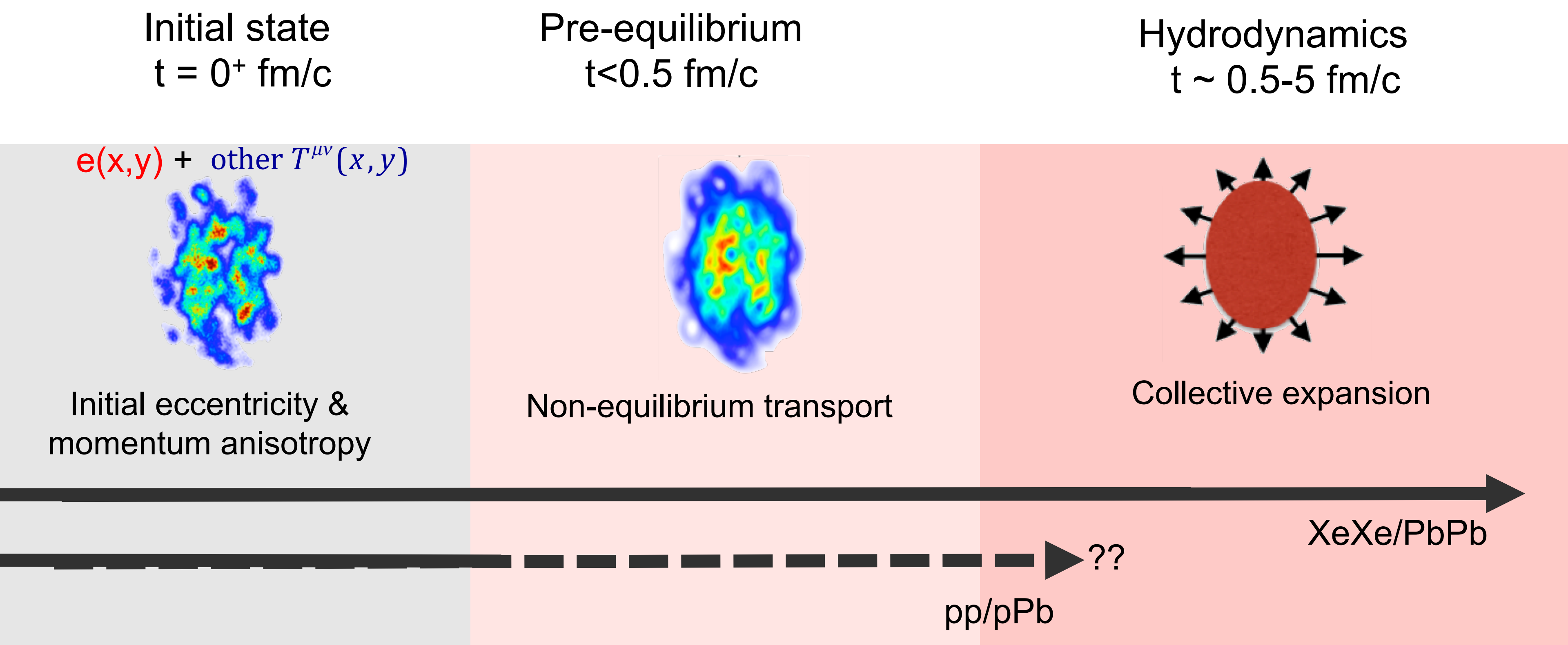
Overview of ATLAS results

Jiangyong Jia for the ATLAS Collaboration

Stony Brook University

ATLAS EXPERIMENT

Initial state and emergence of collectivity

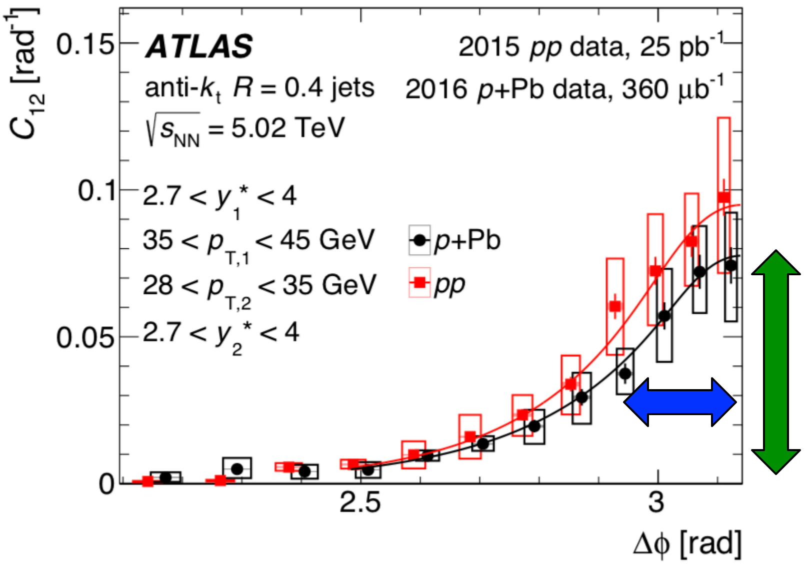


- Initial state
  - Forward dijets in pPb
  - γ production in pPb
  - W/Z production in PbPb
  - Light-by-light in PbPb
- Collectivity in small system
  - Photo-nuclear ridge
  - Z ridge
  - heavy flavor ridge
  - Multi-particle correlations
- Collectivity in large system
  - High-order flow fluctuations
  - Role of centrality fluctuations
  - v_n-p_T correlations

Forward dijet Δϕ correlation in pp, pPb

nucl-ex/1901.10440

$$C(\Delta\phi) = \frac{1}{N_1}\frac{dN_{12}}{d\Delta\phi}$$ Per leading-jet normalized



Dijet Δϕ with leading jet in $2.7<y_1^*<4$

Scan $-4<y_2^*<4$ ➔ Probe $10^{-4}<x_A<10^{-3}$

Extract the RMS width $\frac{Width_{pPb}}{Width_{pp}}$

Extract the integral yield $\frac{Yield_{pPb}}{Yield_{pp}}$

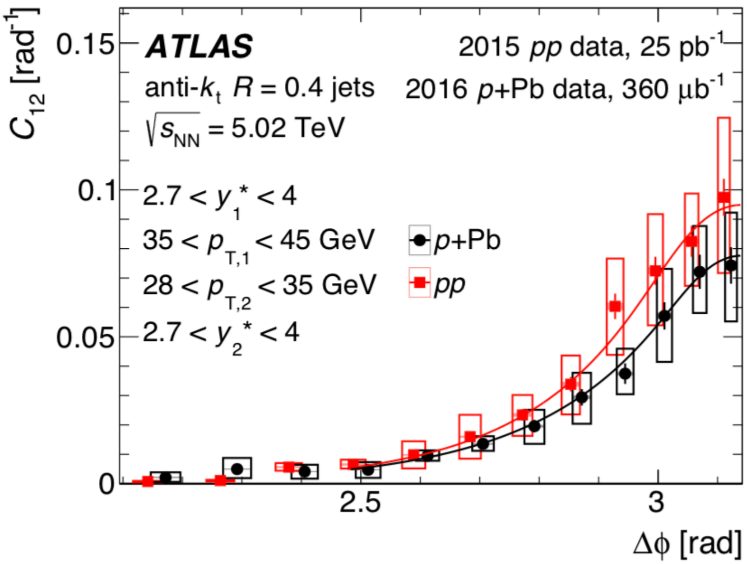
Quantify nuclear effect with the ratio pPb/pp

Sensitive to nPDF and saturation

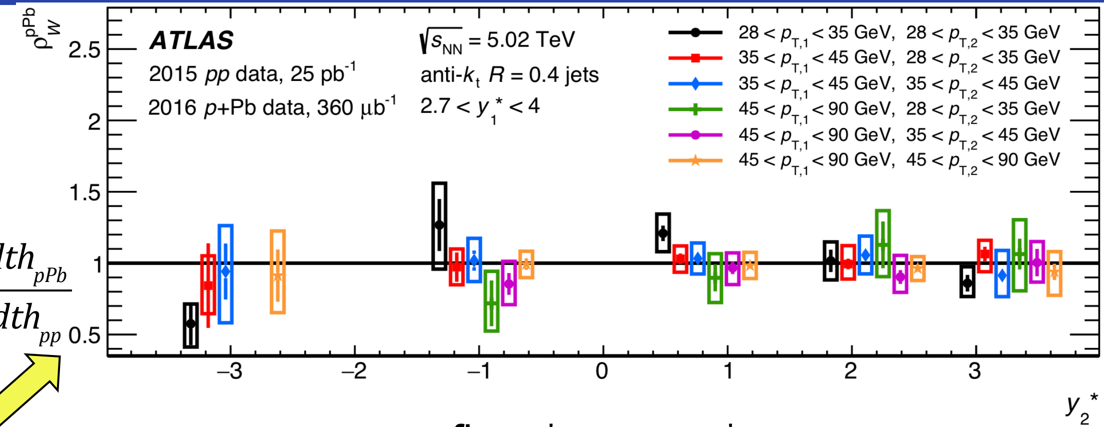
Forward dijet Δϕ correlation in pp, pPb

nucl-ex/1901.10440

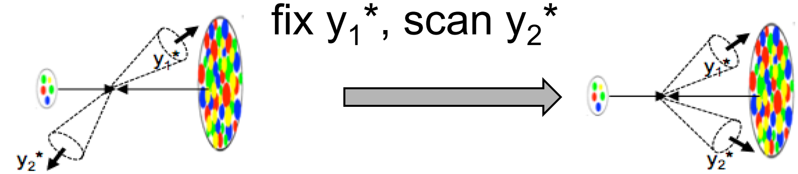
$$C(\Delta\phi) = \frac{1}{N_1}\frac{dN_{12}}{d\Delta\phi}$$



$$\frac{Width_{pPb}}{Width_{pp}}$$



fix y_1^*, scan y_2^*



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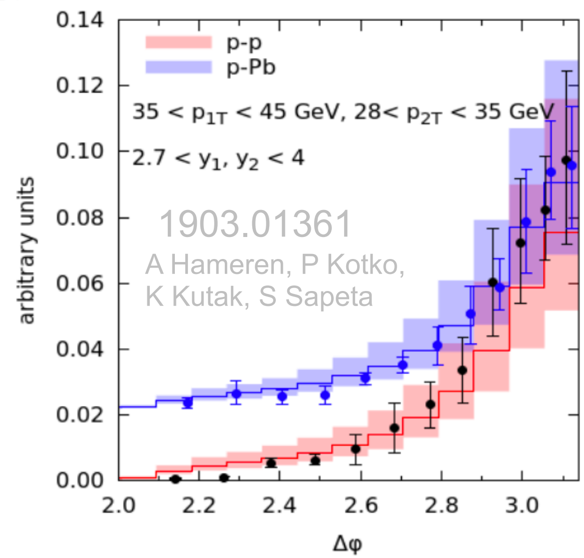

Sensitive to nPDF and saturation

No change in width,require interplay between saturation & Sudakov effects?

Dennis Perepelitsa Wed 14:00

Forward dijet Δϕ correlation in pp, pPb

nucl-ex/1901.10440

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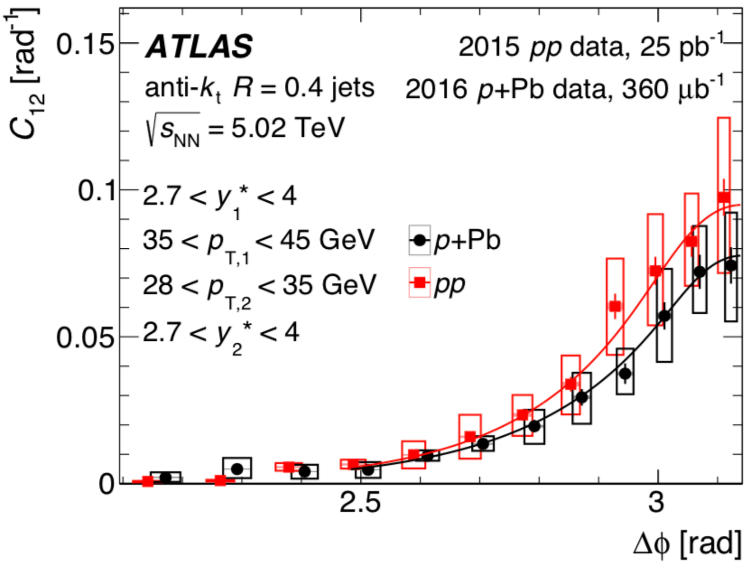
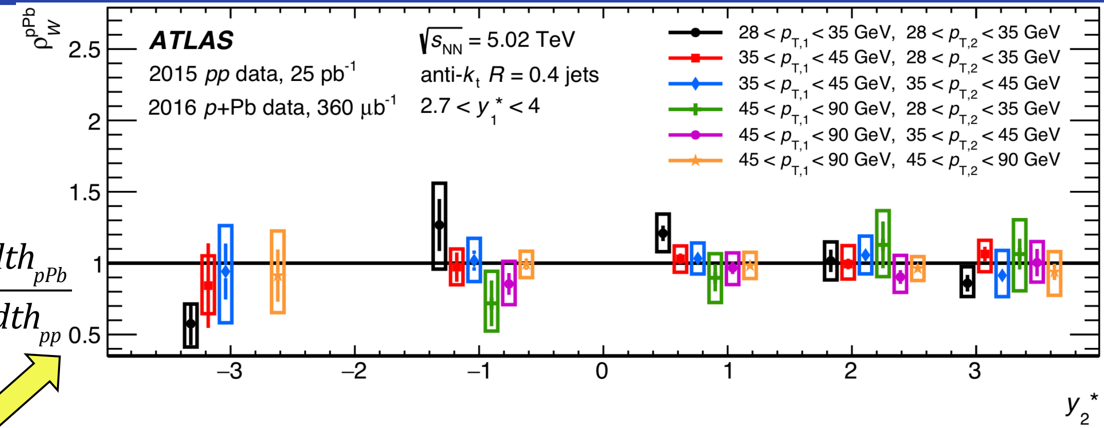
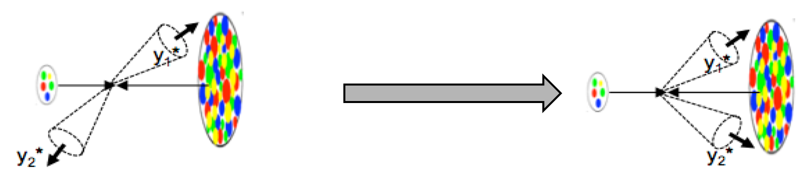
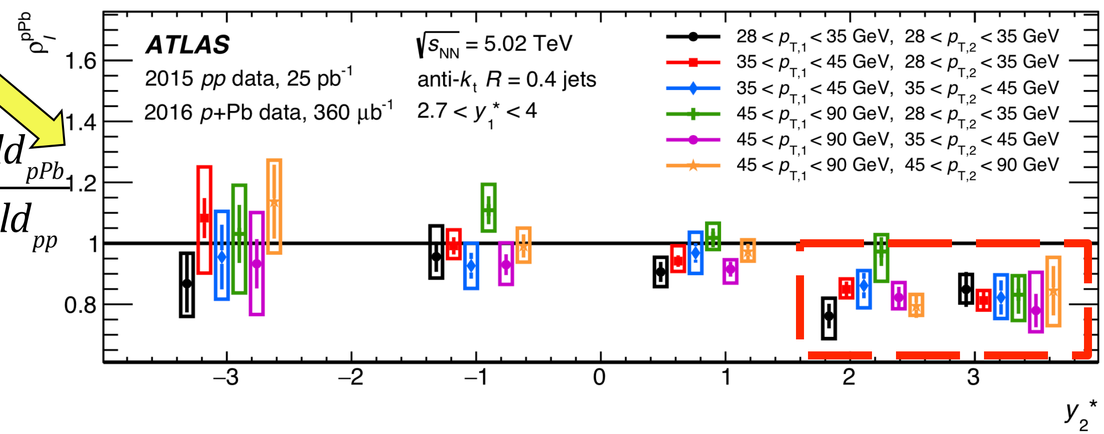








Dijet Δϕ with leading jet in $2.7<y_1^*<4$

Scan $-4<y_2^*<4$ ➔ Probe $10^{-4}<x_A<10^{-3}$

Sensitive to nPDF and saturation

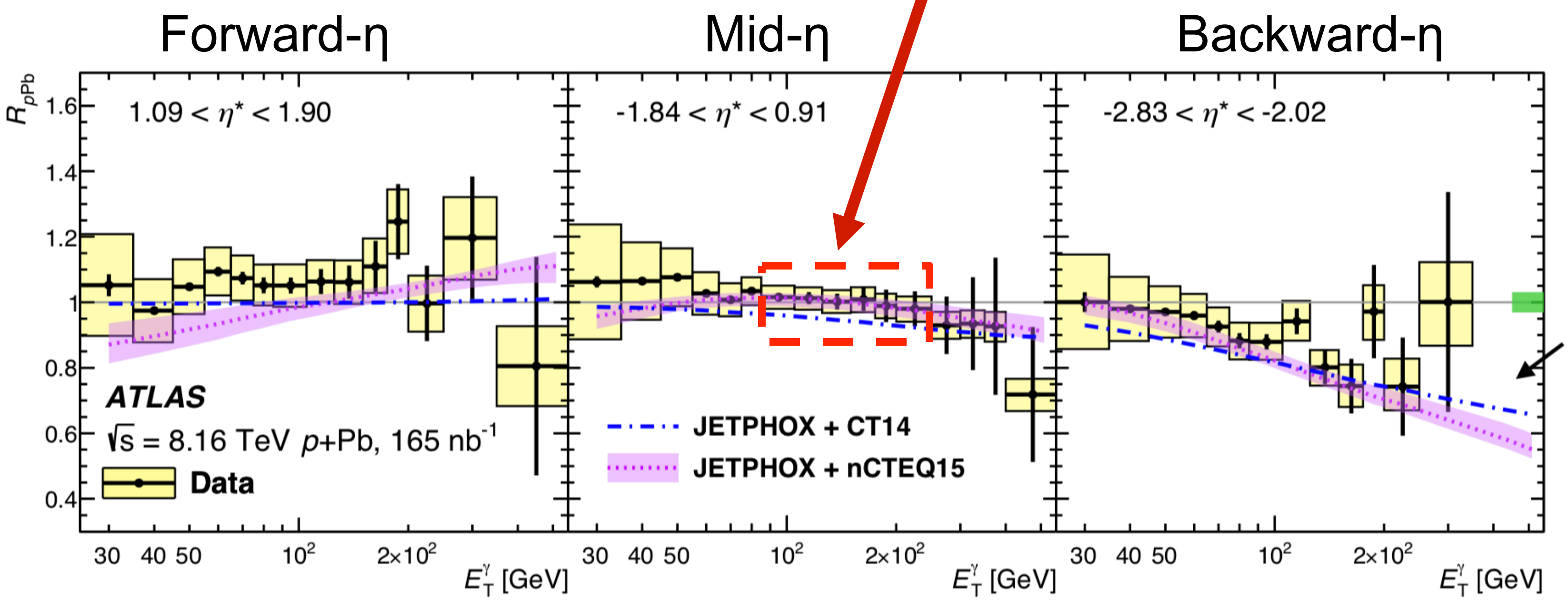
No change in width, 20% reduction in yield for Forward-Forward dijets

Dennis Perepelitsa Wed 14:00

nPDF: prompt photon R_{pPb}

nucl-ex/1903.02209

anti-shadow region favors nPDF (nCTEQ15)

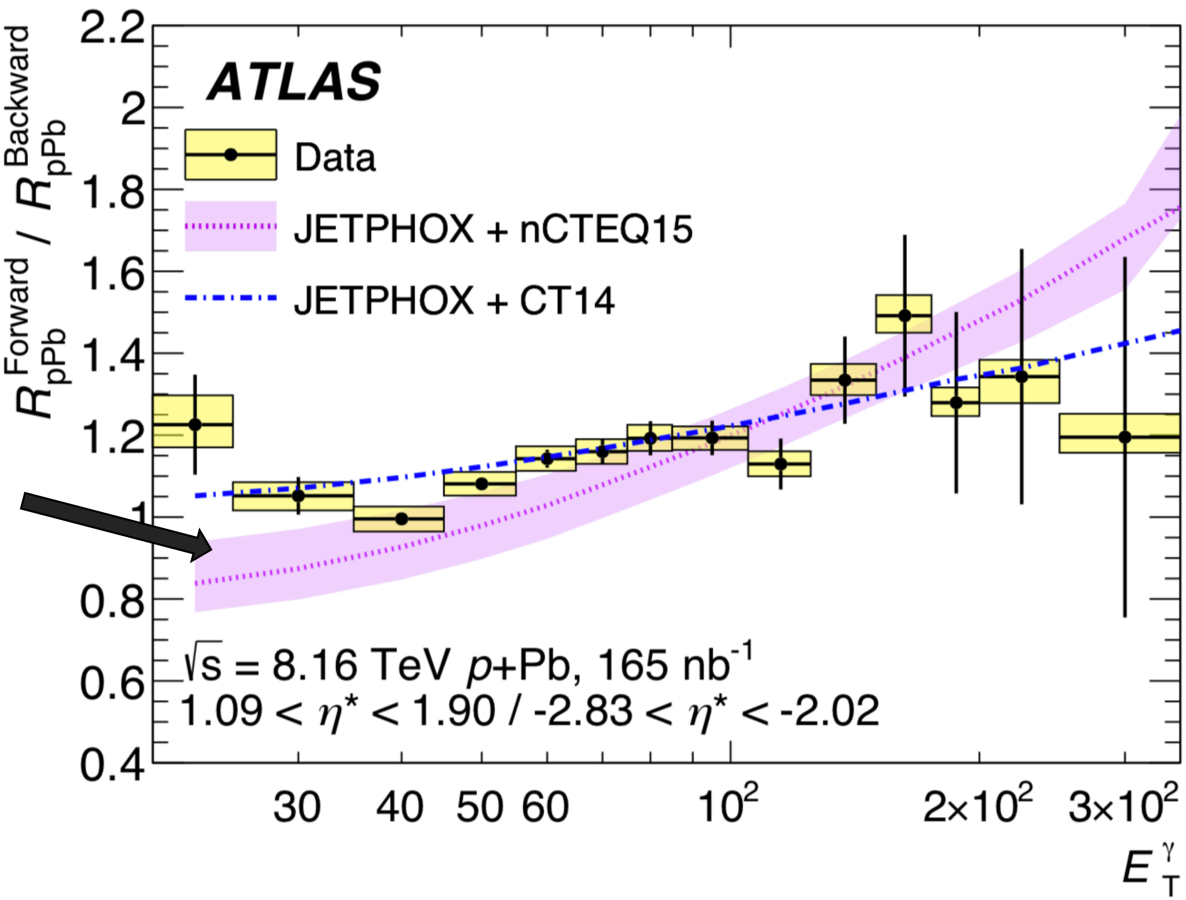


note: R_{pPb} < 1 just from isospin effects

Data overall close to "free nucleon PDF" (CT14)

nPDF: forward / backward R_{pPb} ratio

nucl-ex/1903.02209 cancel most systematic uncertainties with FB ratio

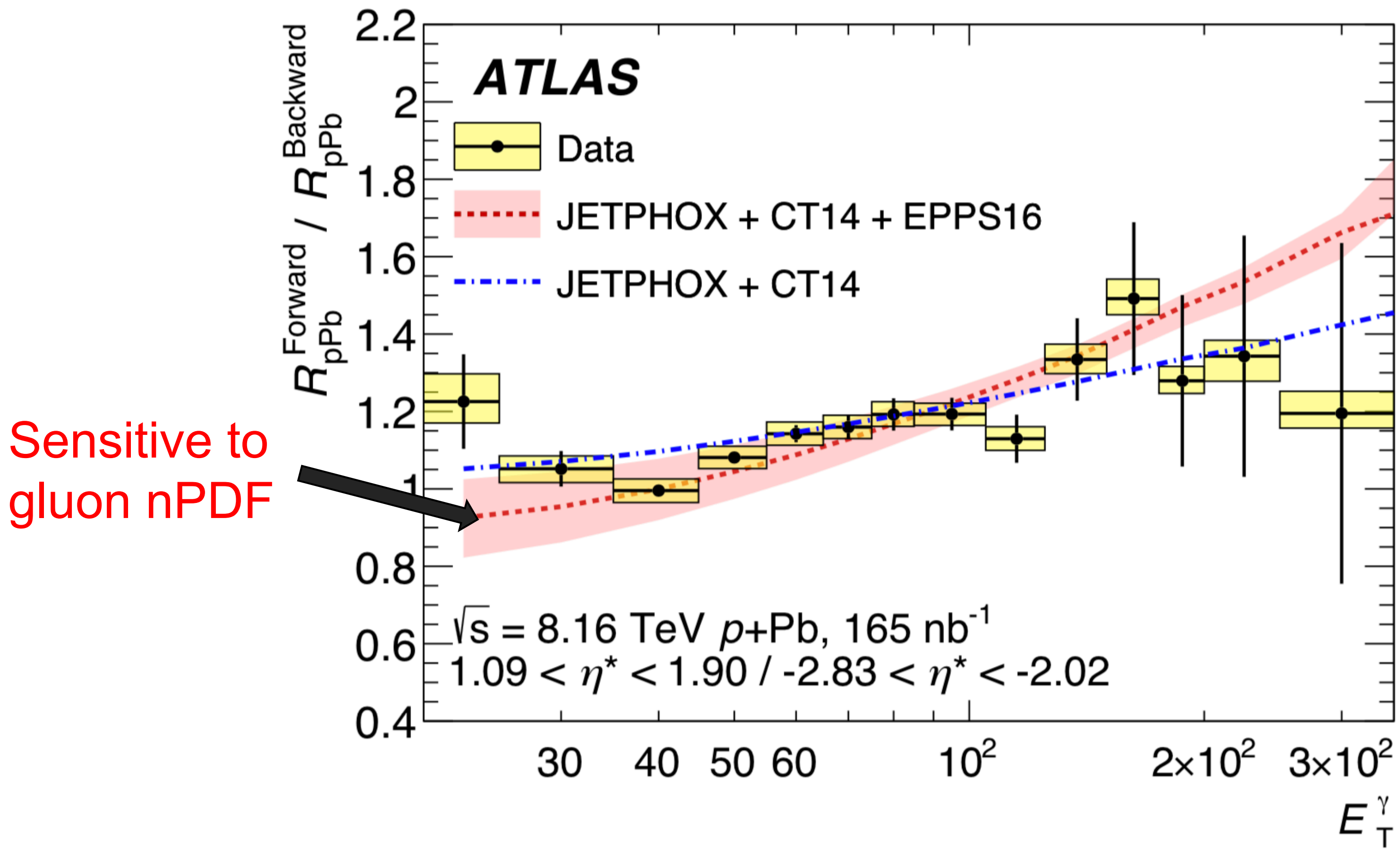


Sensitive to gluon nPDF

- Data almost compatible with free nucleon PDFs
- Modifications closer to EPPS16 than nCTEQ15

nPDF: forward / backward R_{pPb} ratio

nucl-ex/1903.02209 cancel most systematic uncertainties with FB ratio

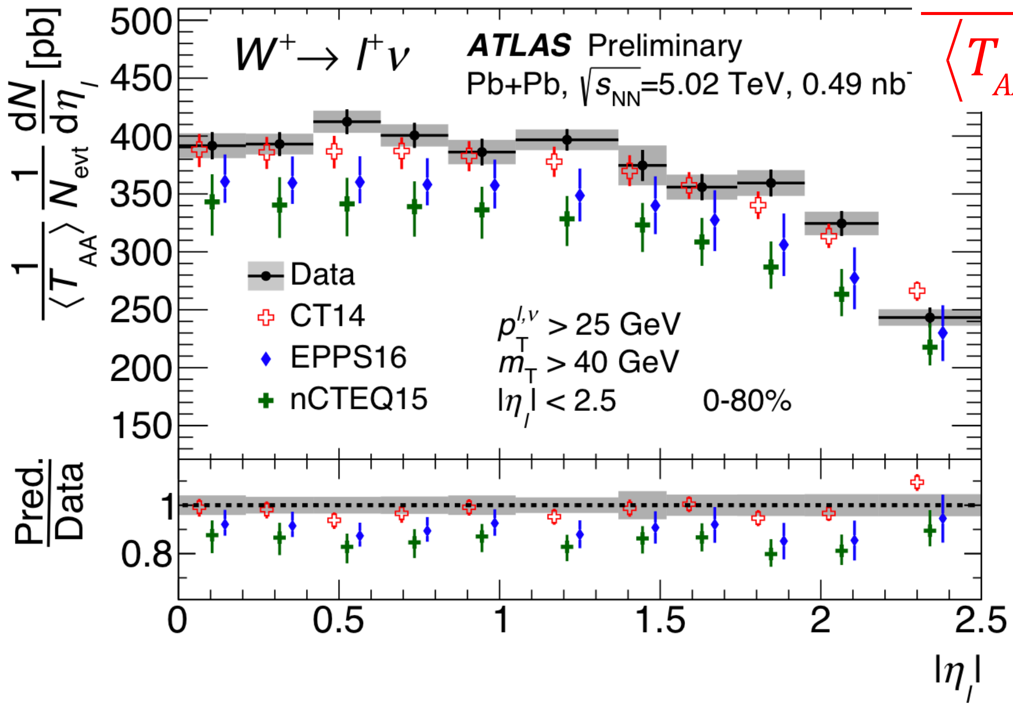


- Data almost compatible with free nucleon PDFs
- Modifications closer to EPPS16 than nCTEQ15

new

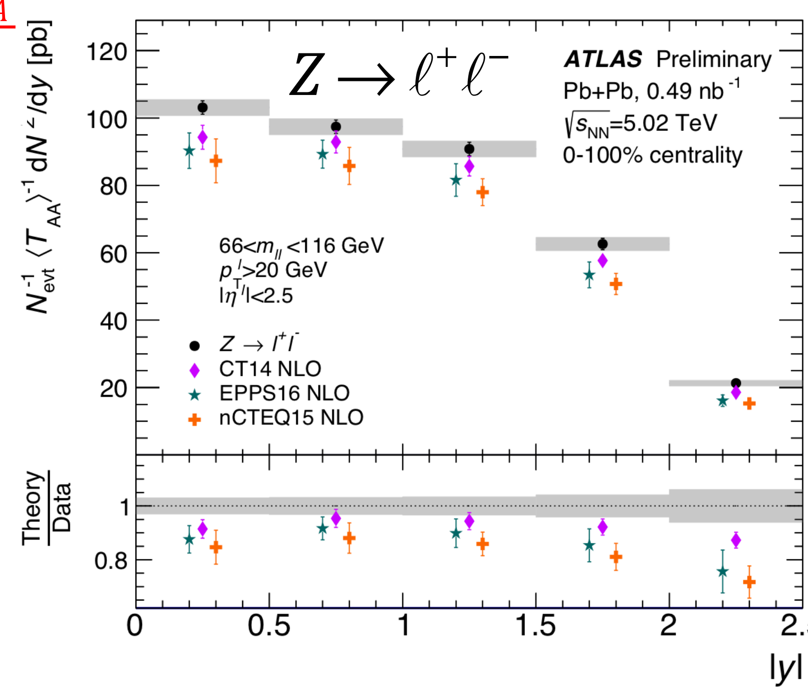
nPDF: W/Z boson in PbPb

HION-2018-25



$\frac{Yield_{AA}}{\langle T_{AA}\rangle}$

CONF-2019-024

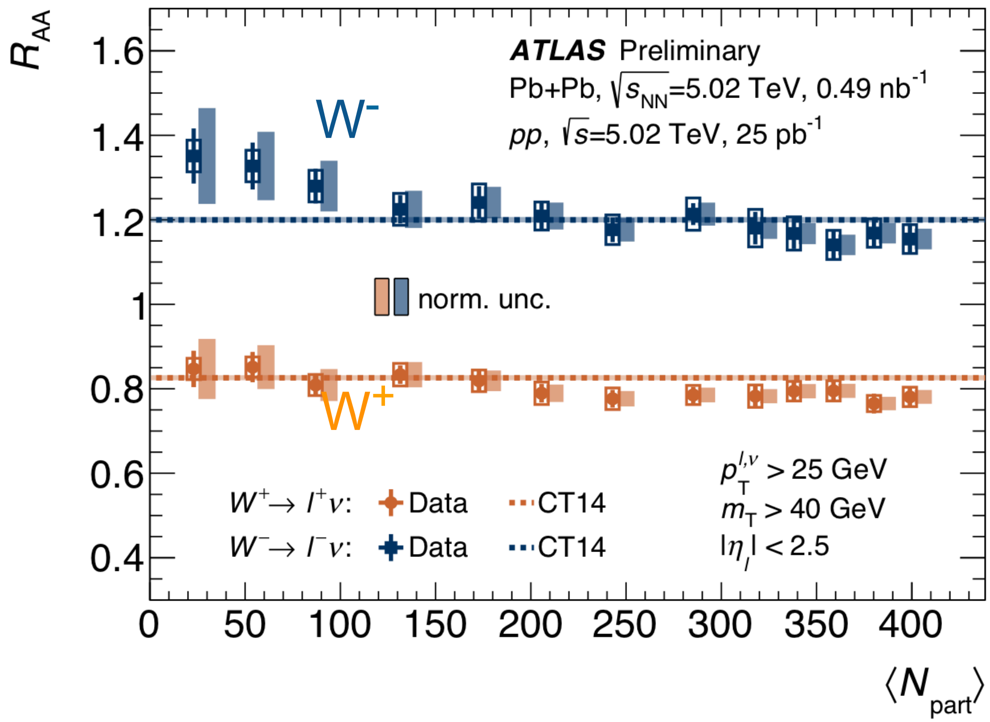


Minbias W, Z yield vs |η| or |y| normalized by T_{AA}

- Data almost compatible with free nucleon PDF+isospin
- Systematically higher than the nPDF models

Centrality dependence

HION-2018-25



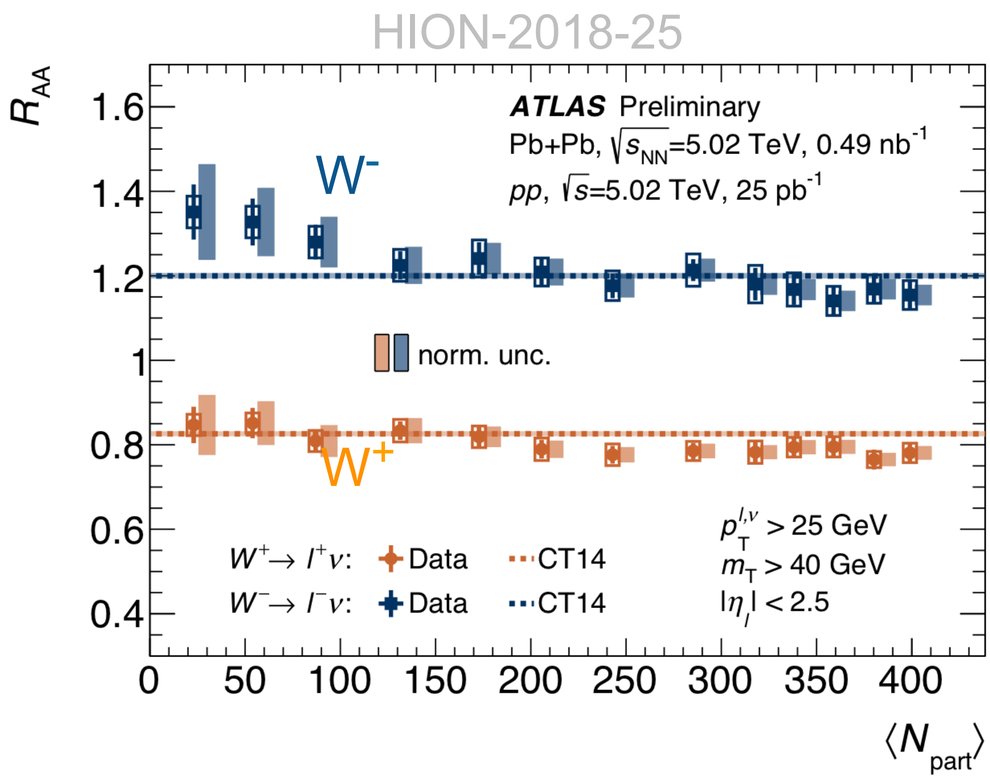
$$R_{AA} = \frac{Yield_{AA}}{\langle T_{AA} \rangle \sigma_{PP}}$$

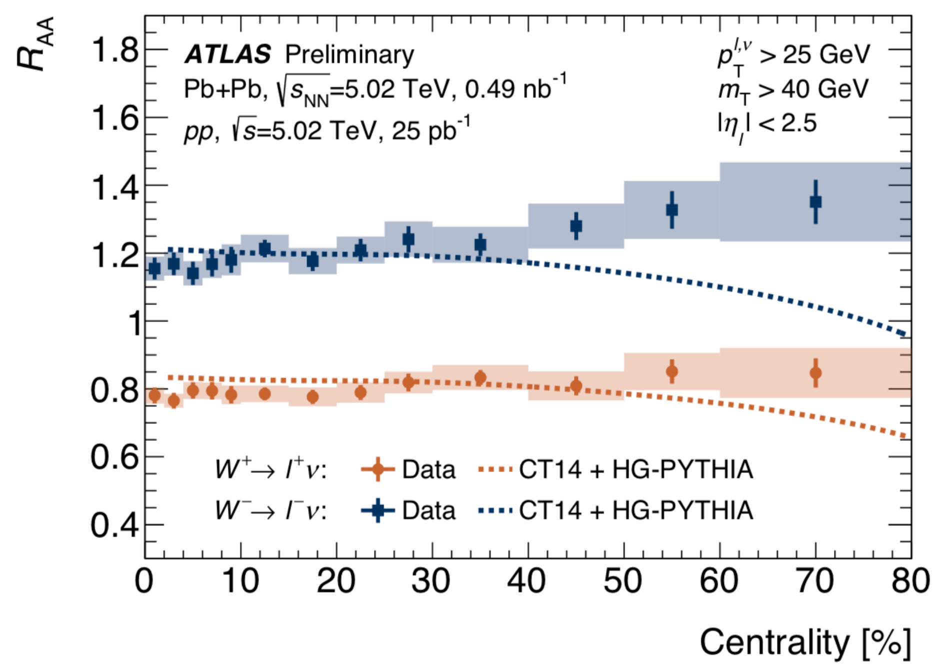
R_{AA} based on pp data and TGlauber v2.4

- Difference between W^+ and W^- due to expected isospin effects.
  - Glauber model describe W/Z production baseline within 10-15% (CT14)
- Data systematically increases toward low N_{part} wrt glauber baseline
  - Not explained by neutron skin or TGlauber v2.4 vs v3.2

new

Centrality dependence





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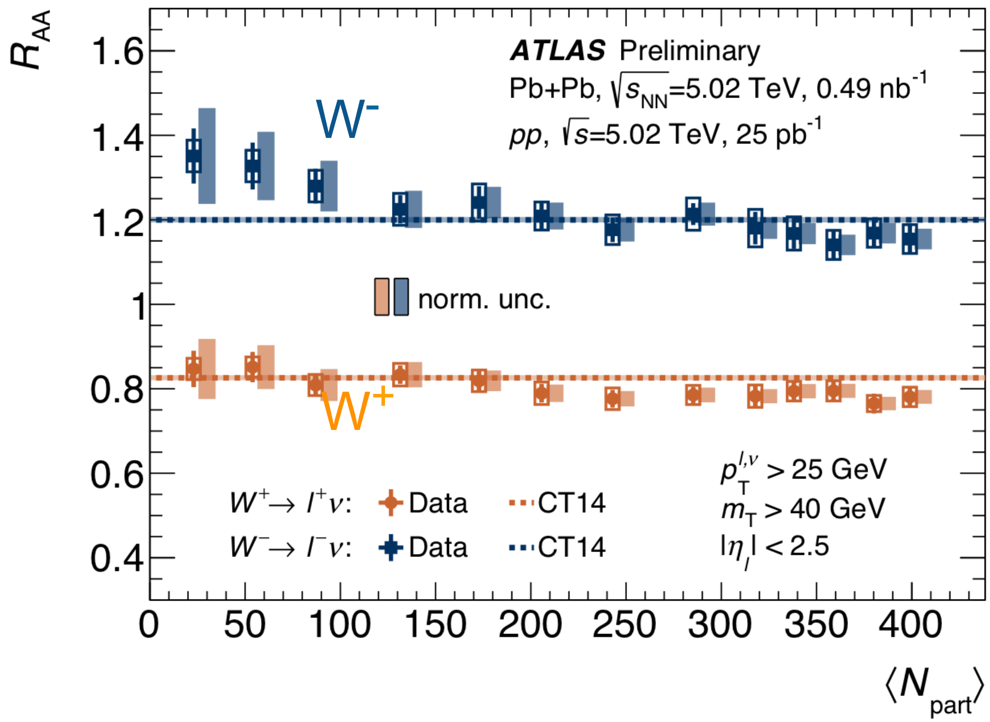
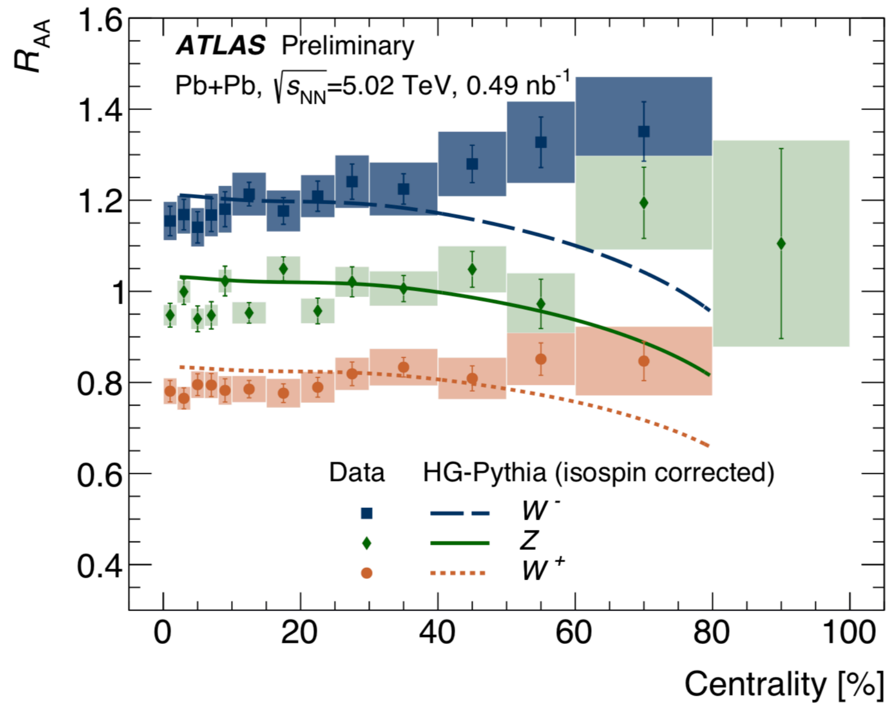
- Opposite to centrality selection bias for hadrons via HG-PYTHIA

new

Centrality dependence

HION-2018-25





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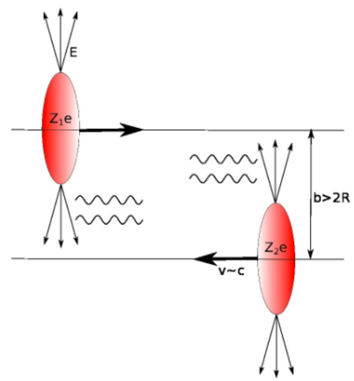
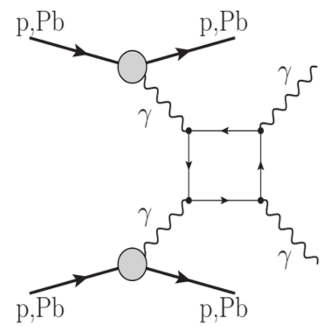
- Data systematically increases toward low N_{part} wrt glauber baseline
  - Not explained by neutron skin or TGlauber v2.4 vs v3.2
- Opposite to centrality selection bias for hadrons via HG-PYTHIA
  - Consistent between Z and W

Room for impact-parameter dependent nPDF effect?

Mirta Dumancic Tue 14:20

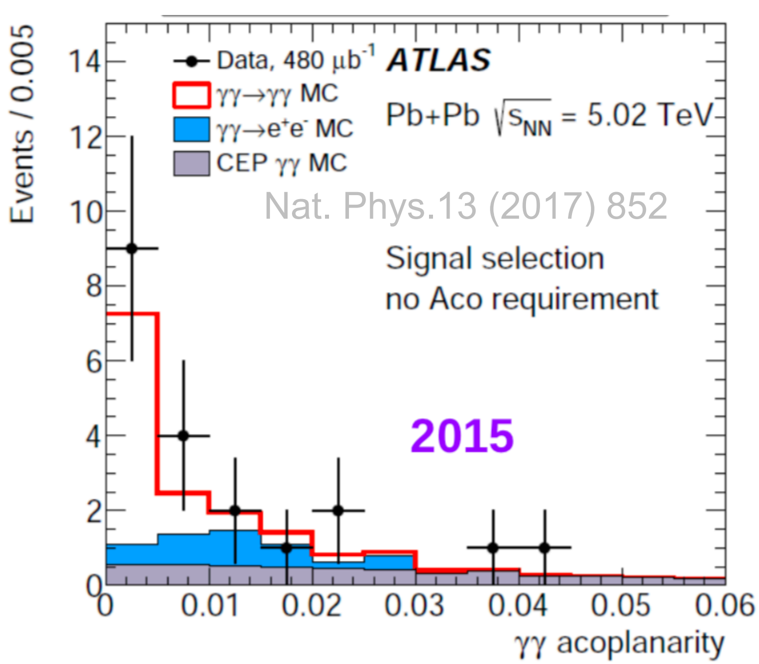
Observation of light-by-light scattering in UPC Pb+Pb

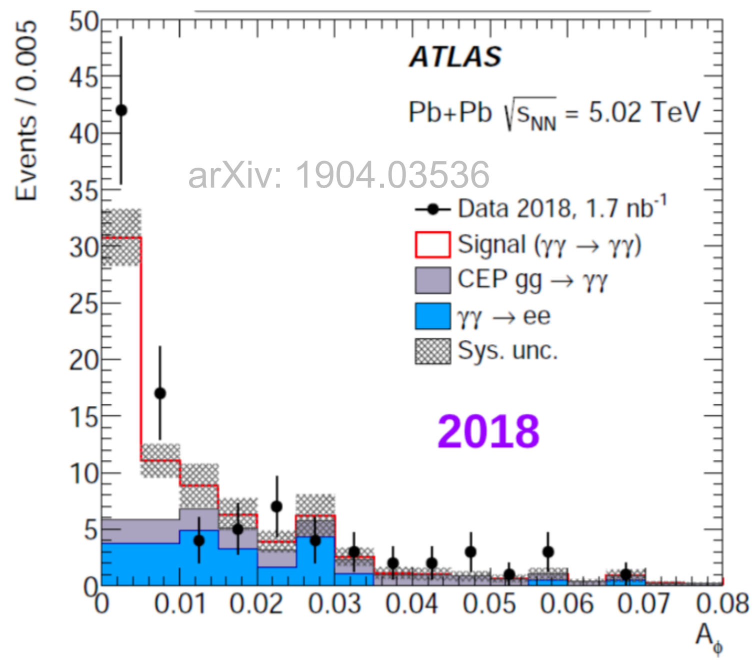




$\gamma\gamma \to \gamma\gamma$

Selection:
E_T>3 GeV, |η|<2.37, $m_{\gamma\gamma}$ > 6 GeV
Aco = (1-Δϕ/π)<0.01; no tracks

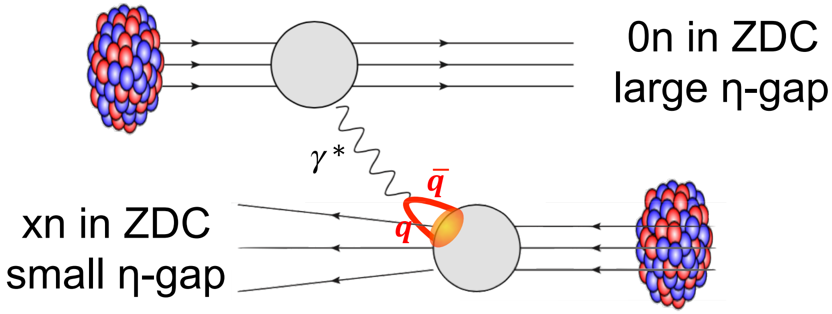


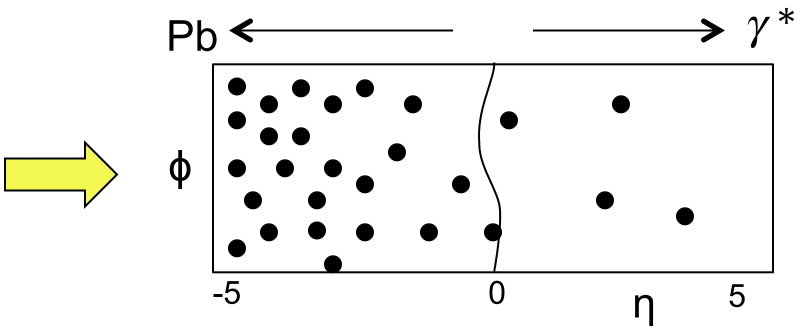


2015: 13 events, 4.4 σ significance

2018: 59 events, 8.2 σ observation

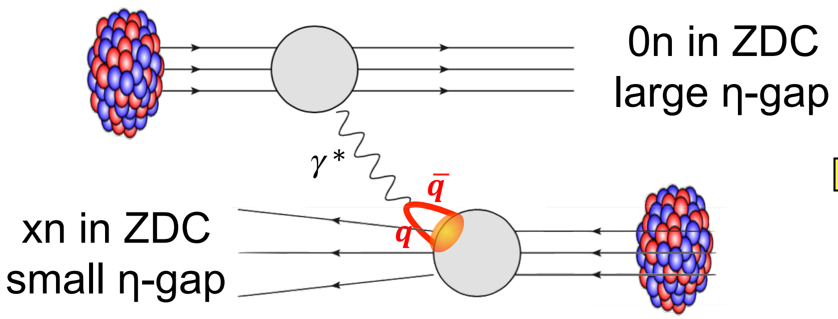
γ*+Pb collision in 5.02 TeV Pb+Pb

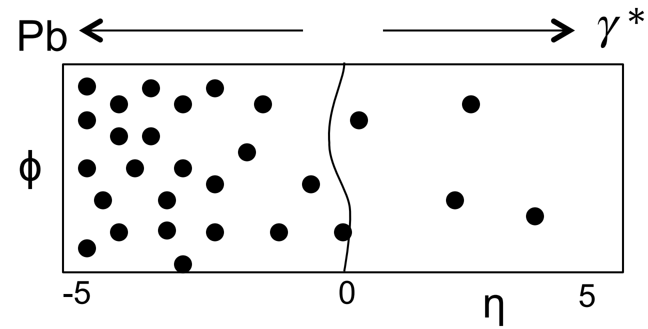




Mostly meson+Pb like but at low √s

γ*+Pb collision in 5.02 TeV Pb+Pb





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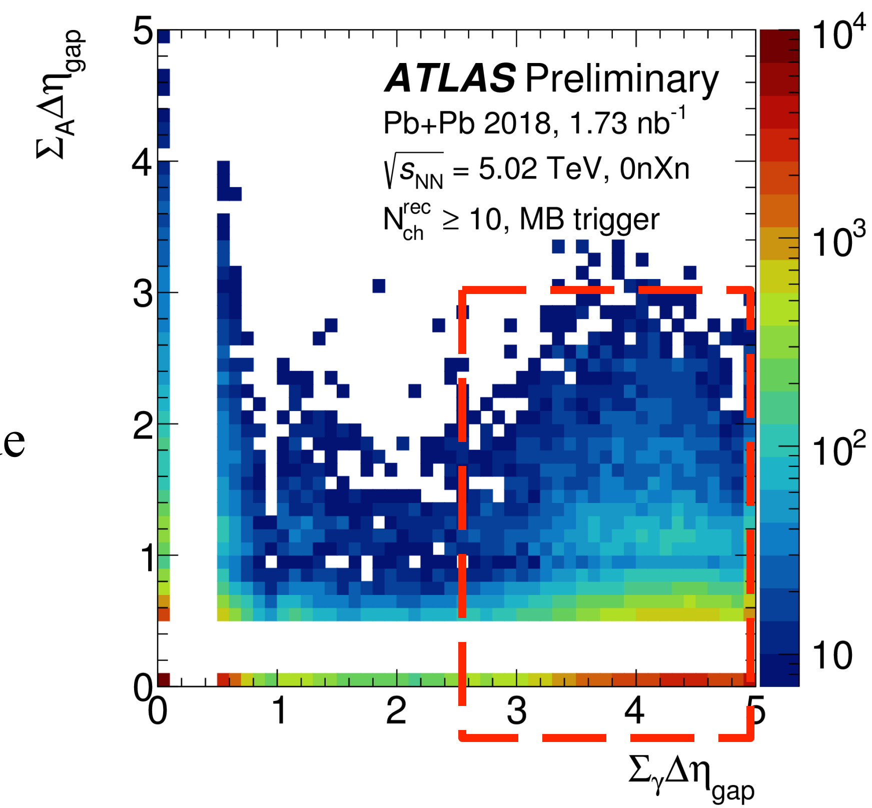


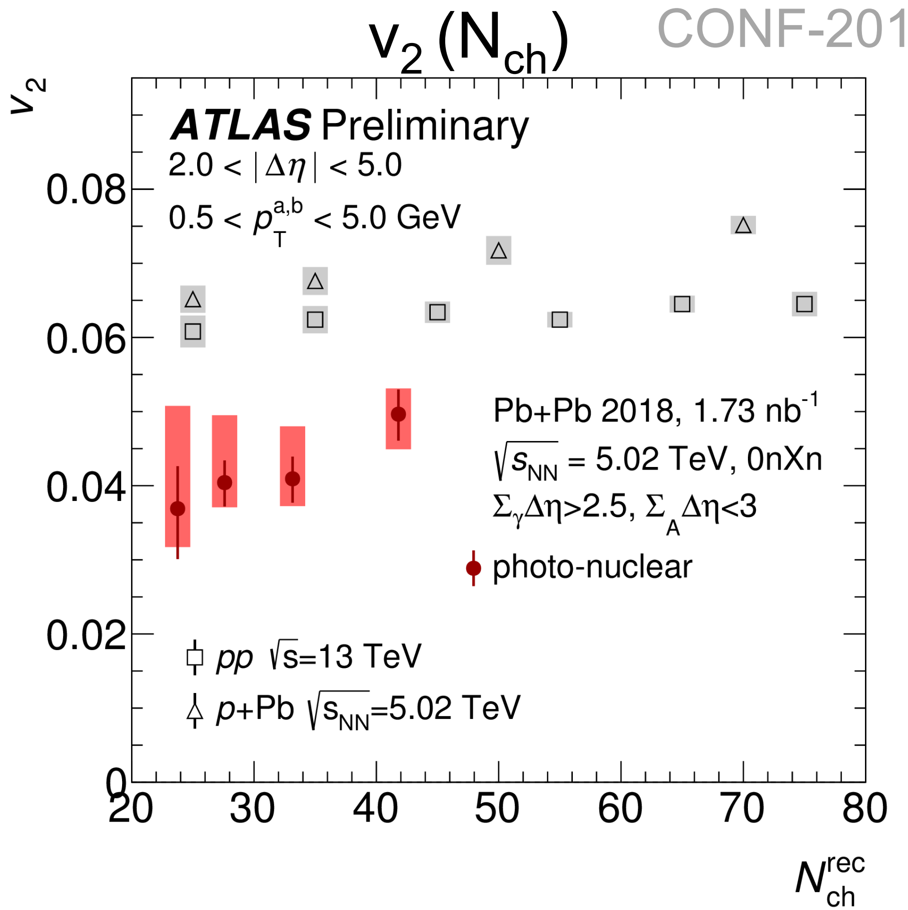
- Photo-nuclear events selected via:
  - Large gap and 0 neutrons on photon-side
  - Small gap and >0 neutrons on Pb-side

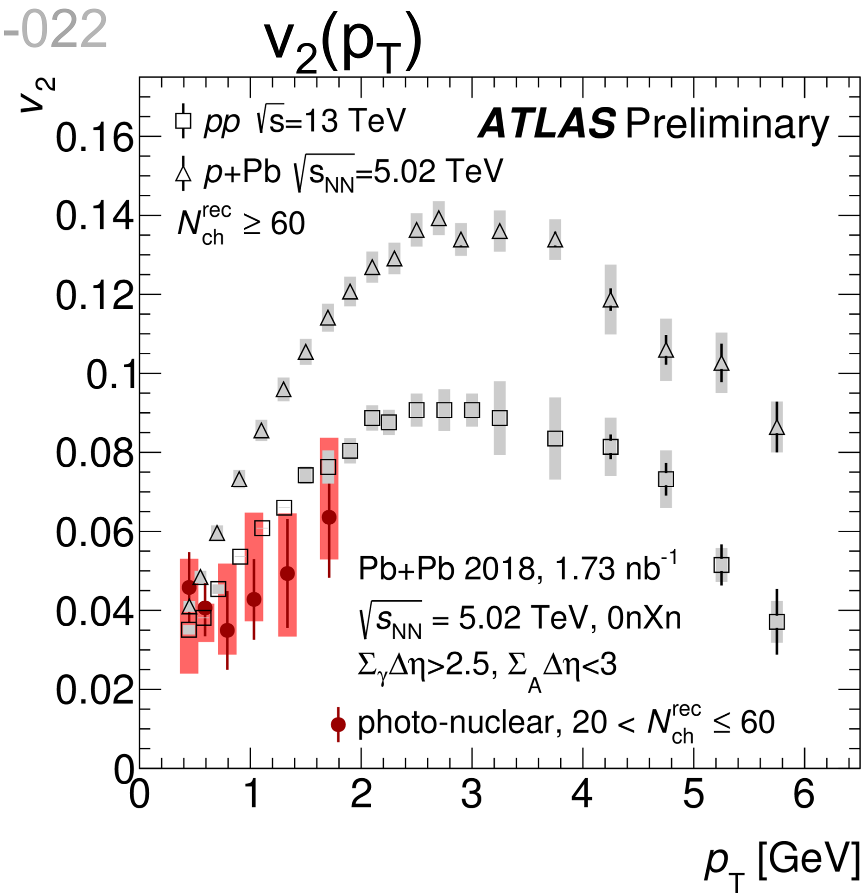
Blair Seidlitz wed 15:00

new

γ*+Pb collision in 5.02 TeV Pb+Pb

CONF-2019-022





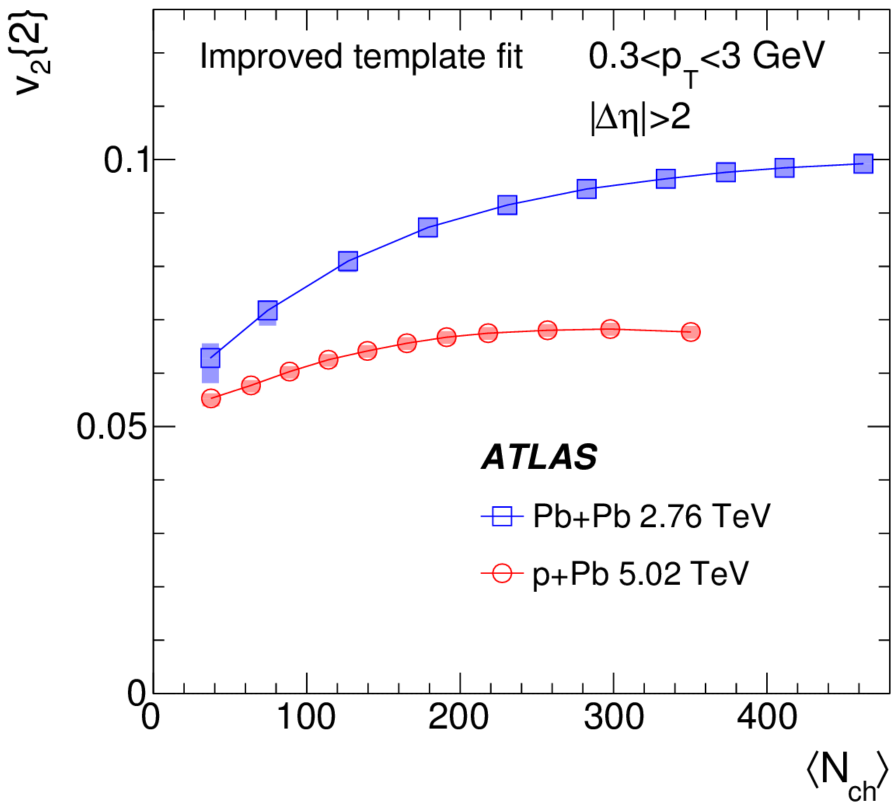
- Observed significant v_2, but smaller than pPb and pp
  - With a similar N_{ch}- and p_T-dependence trends

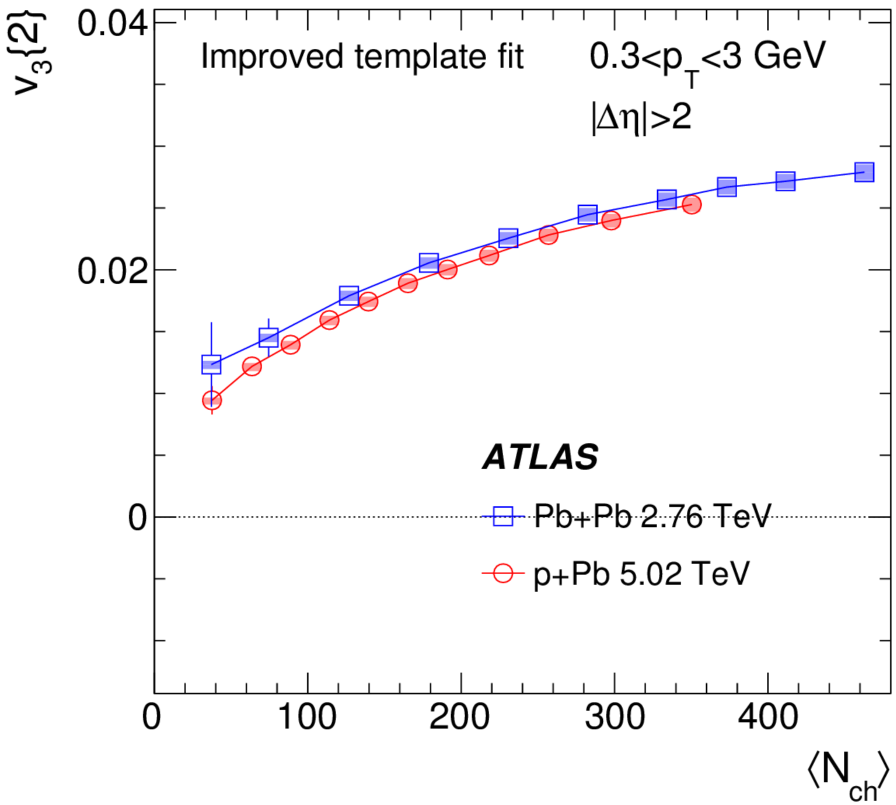
How this relates to v_2 studies at low √s, e.g at RHIC?

Blair Seidlitz wed 15:00

Summary of charged v_2,v_3 from small systems

arXiv:1609.06213, 1807.02012



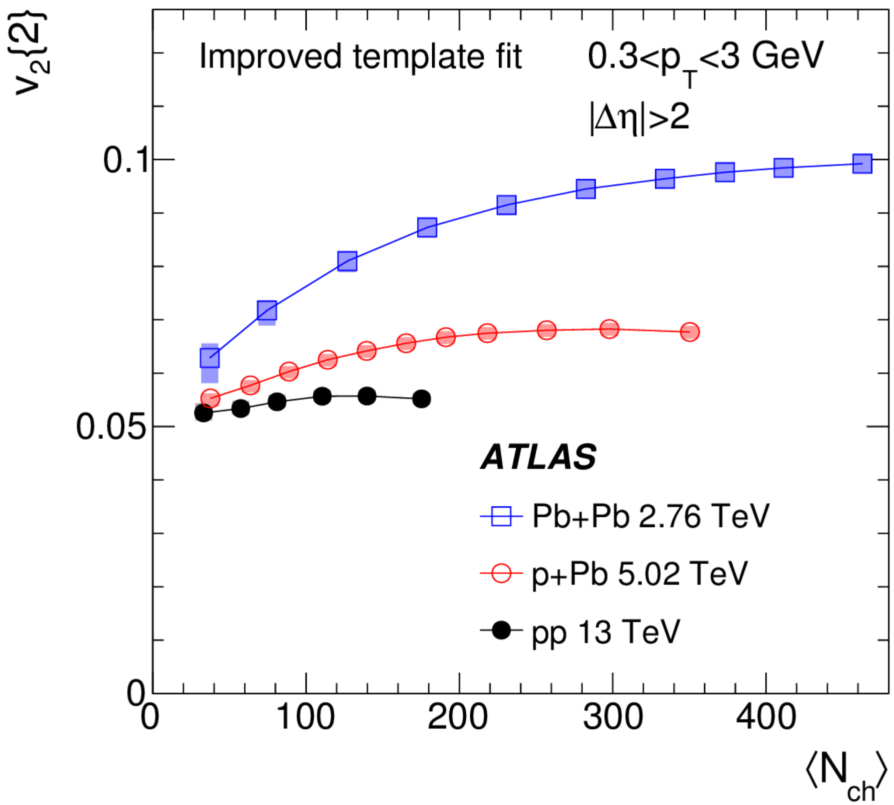


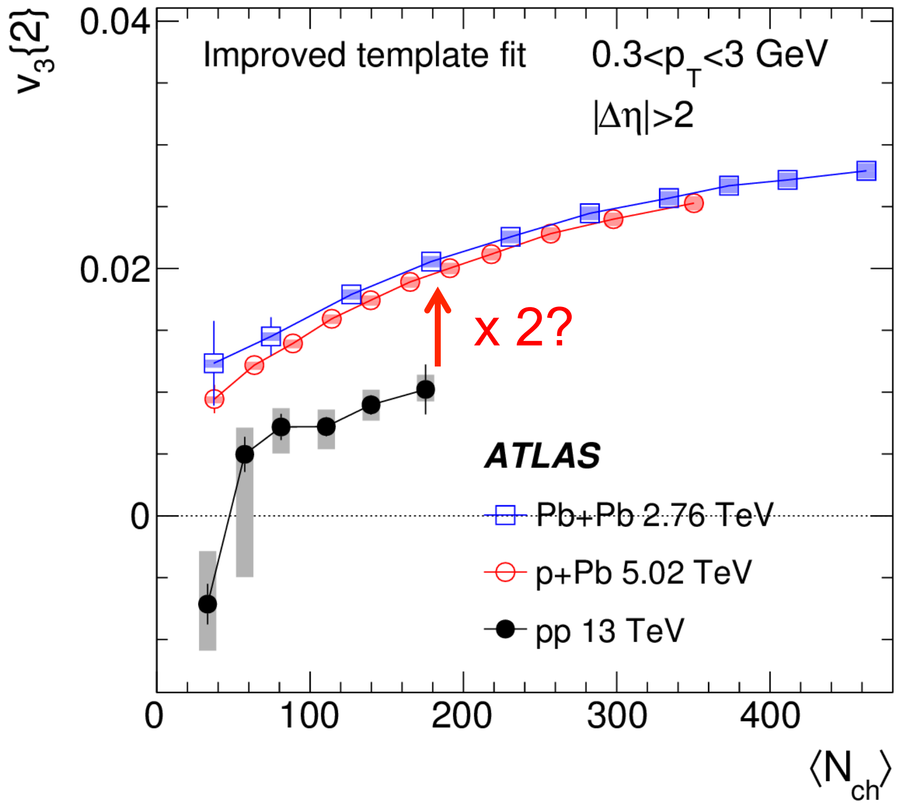
v_2 hierarchy reflects the average geometry effects

v_3, driven by fluctuations, follows a common Nch scaling

Summary of charged v_2,v_3 from small systems

arXiv:1609.06213, 1807.02012





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pp lower by x2 at same N_{ch}?

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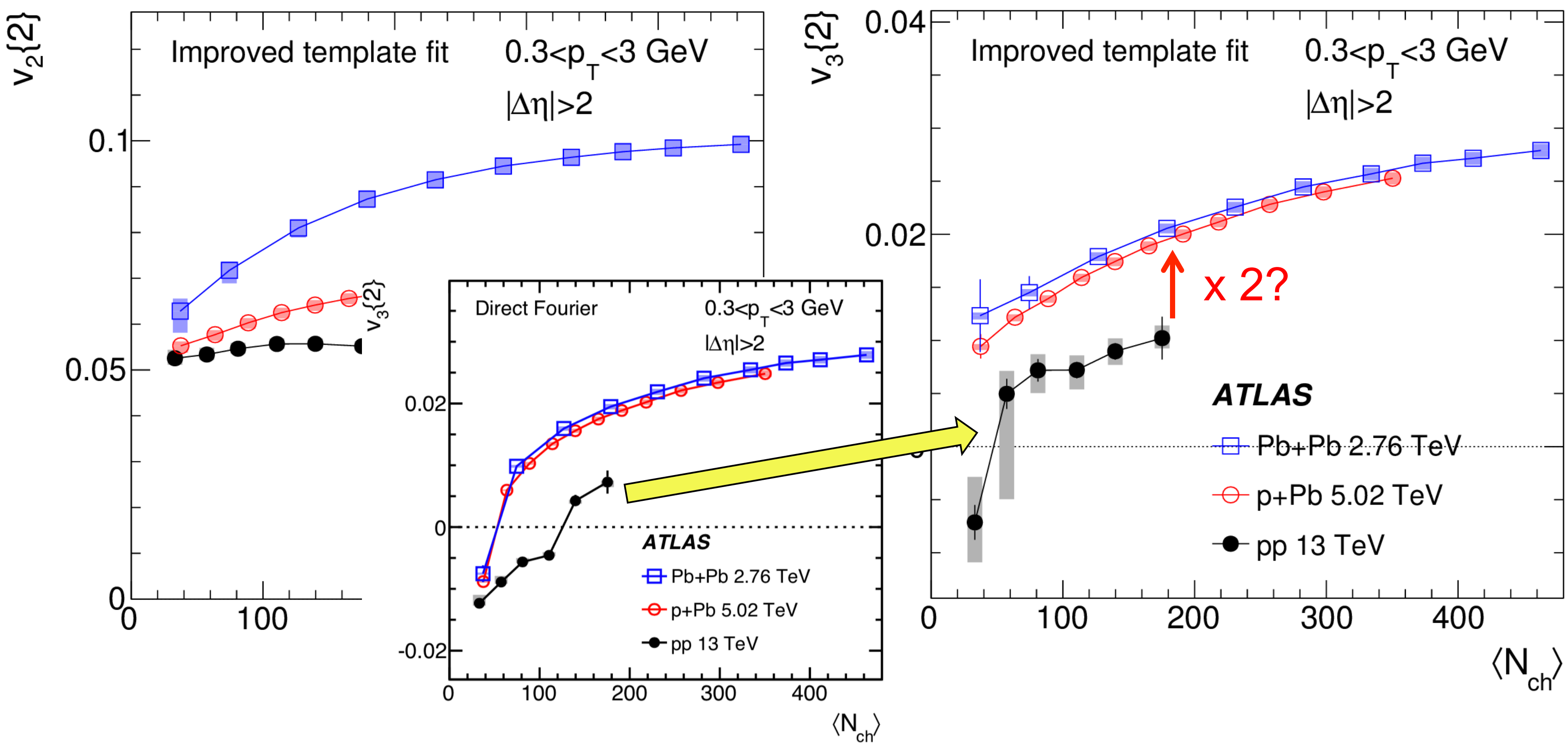


v_2 hierarchy reflects the average geometry effects

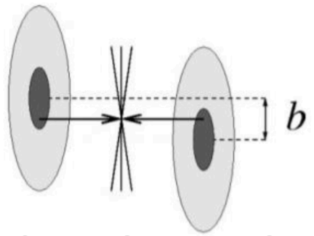
v_3, driven by fluctuations, follows a common Nch scaling

pp lower by x2 at same N_{ch}?

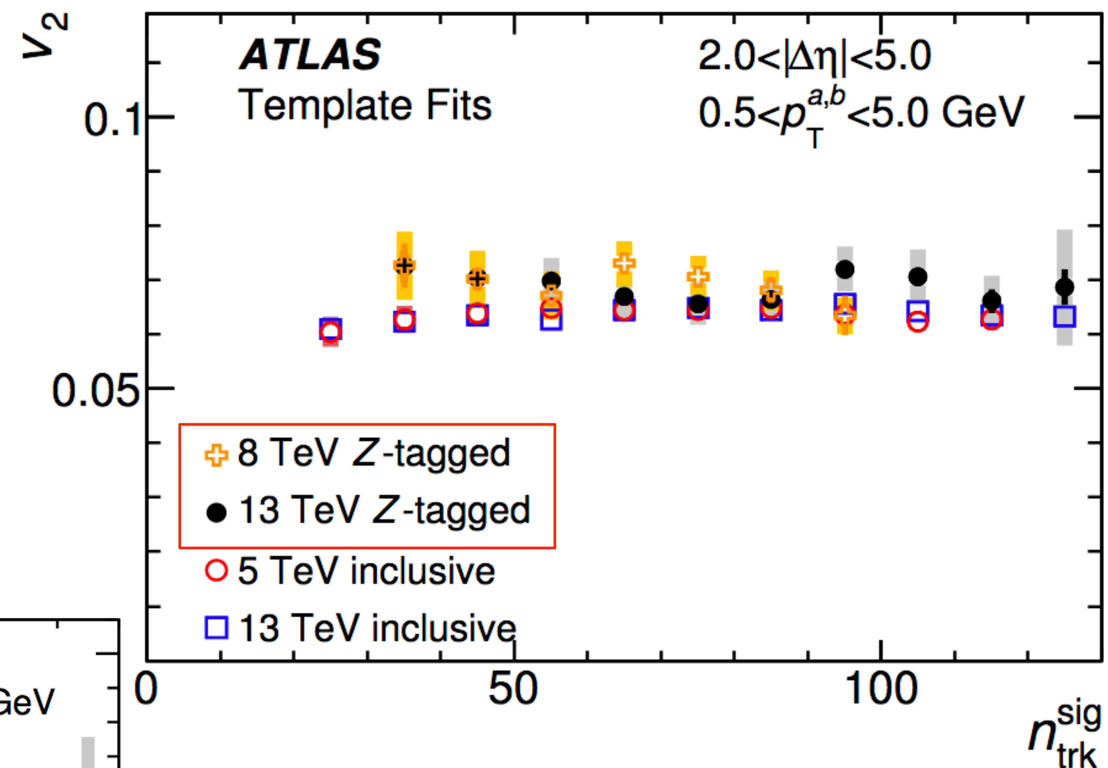
new v_2 in Z-boson-tagged pp events at 8/13 TeV

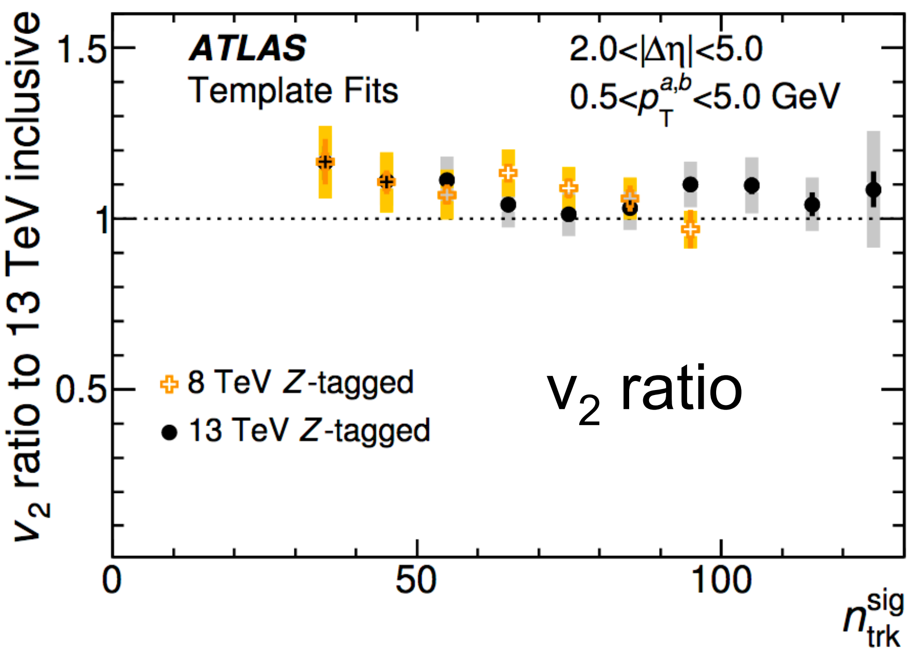
nucl-ex/1906.08290

Large Q^2-process select pp events with smaller impact parameter



L. Frankfurt, M. Strikman, C. Weiss
Phys. Rev. D 69, 114010 (2004)





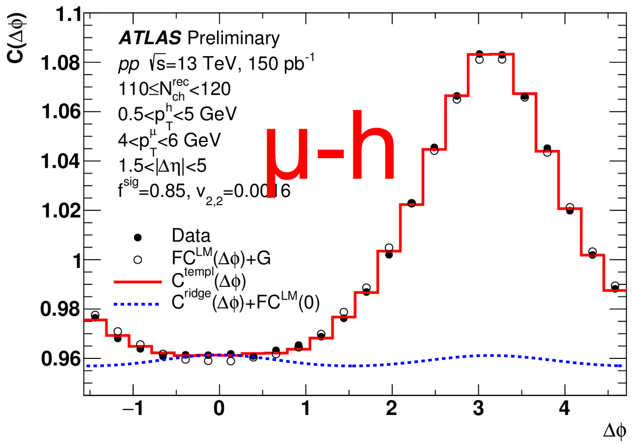
The *pp*-v_2 in Z-tagged events shows only a slight increase if any

Kurt Hill Wed 14:20

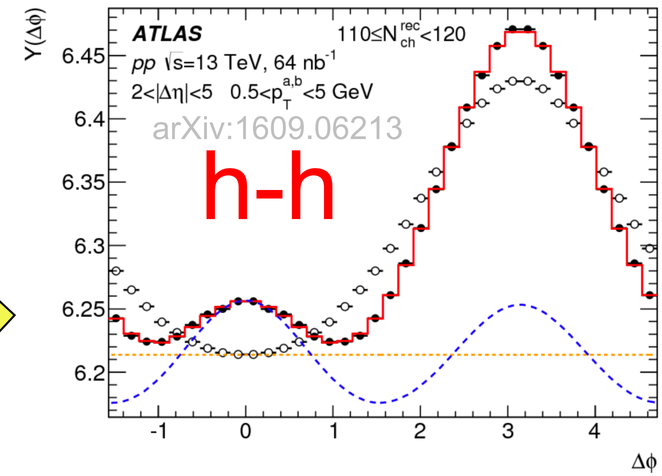
new

Heavy-flavor μ ridge in 13 TeV pp

- Correlation of 4-6 GeV muon from c & b decay with charged particles



$$v_2^{\mu} = \frac{v_{2,2}^{\mu-h}}{\sqrt{v_{2,2}^{h-h}}}$$



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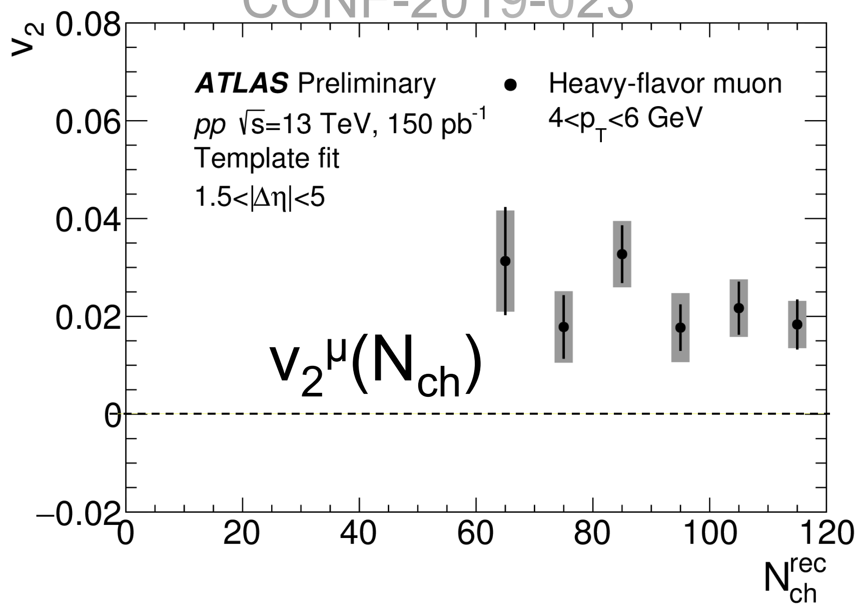
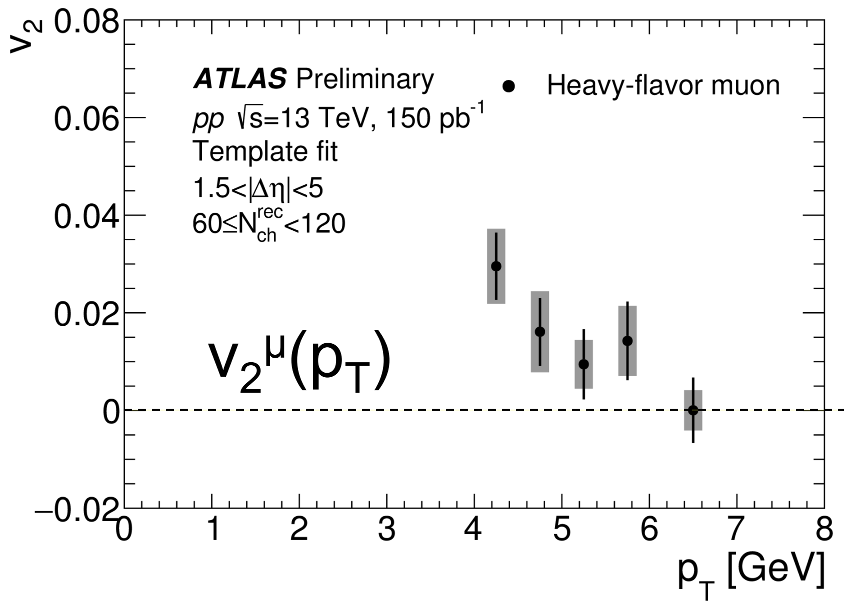




Kurt Hill Wed 14:20

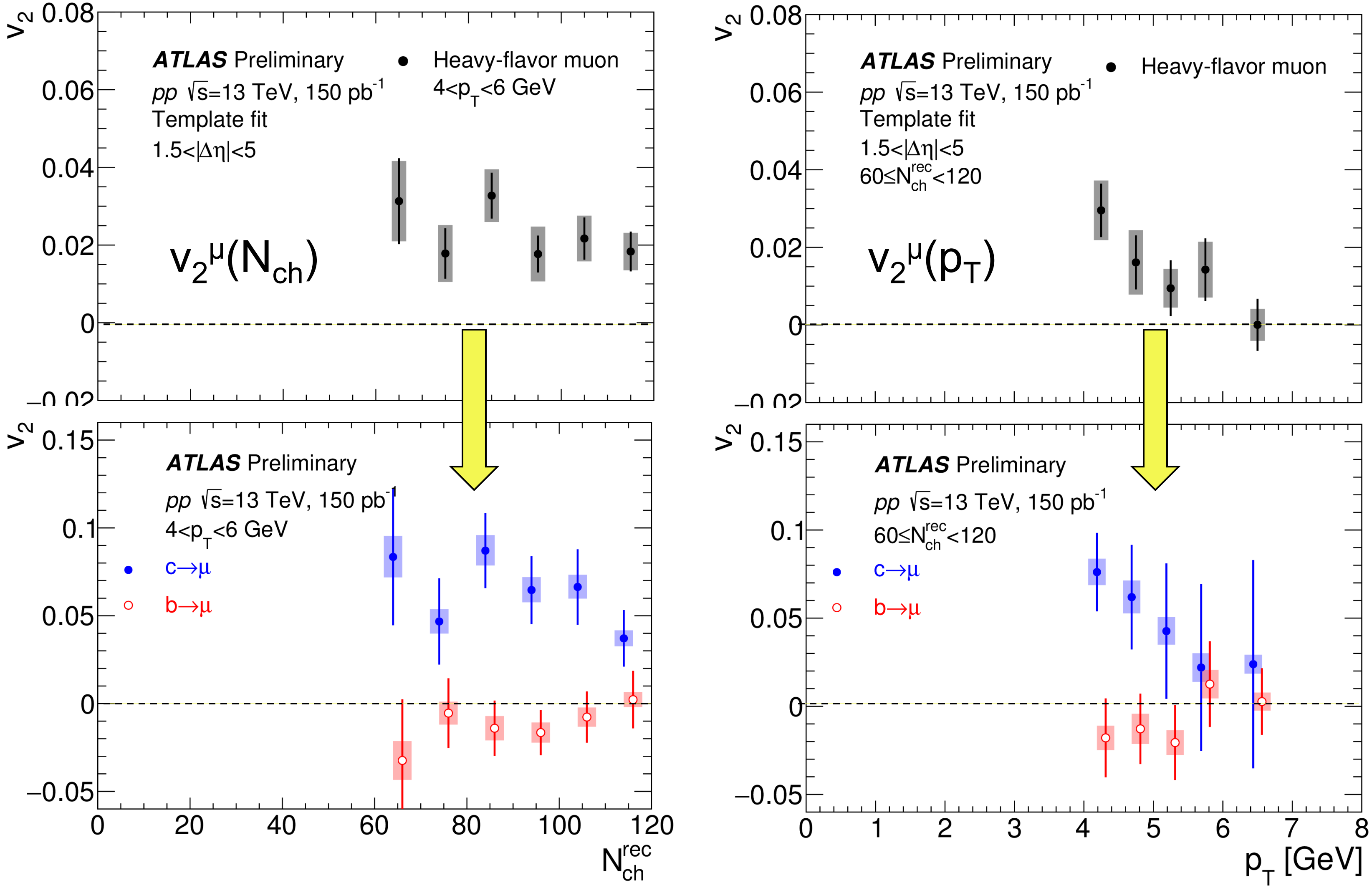
new

Heavy-flavor μ ridge in 13 TeV pp

Kurt Hill Wed 14:20

CONF-2019-023

- Separate charm and bottom contri. based on DCA distributions
  - Bottom fraction: 0.4 at 4 GeV and increase to 0.6 at 7 GeV.
- Bottom-μ v_2~0; charm-μ v_2 comparable to charged hadron in pp



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Kurt Hill Wed 14:20

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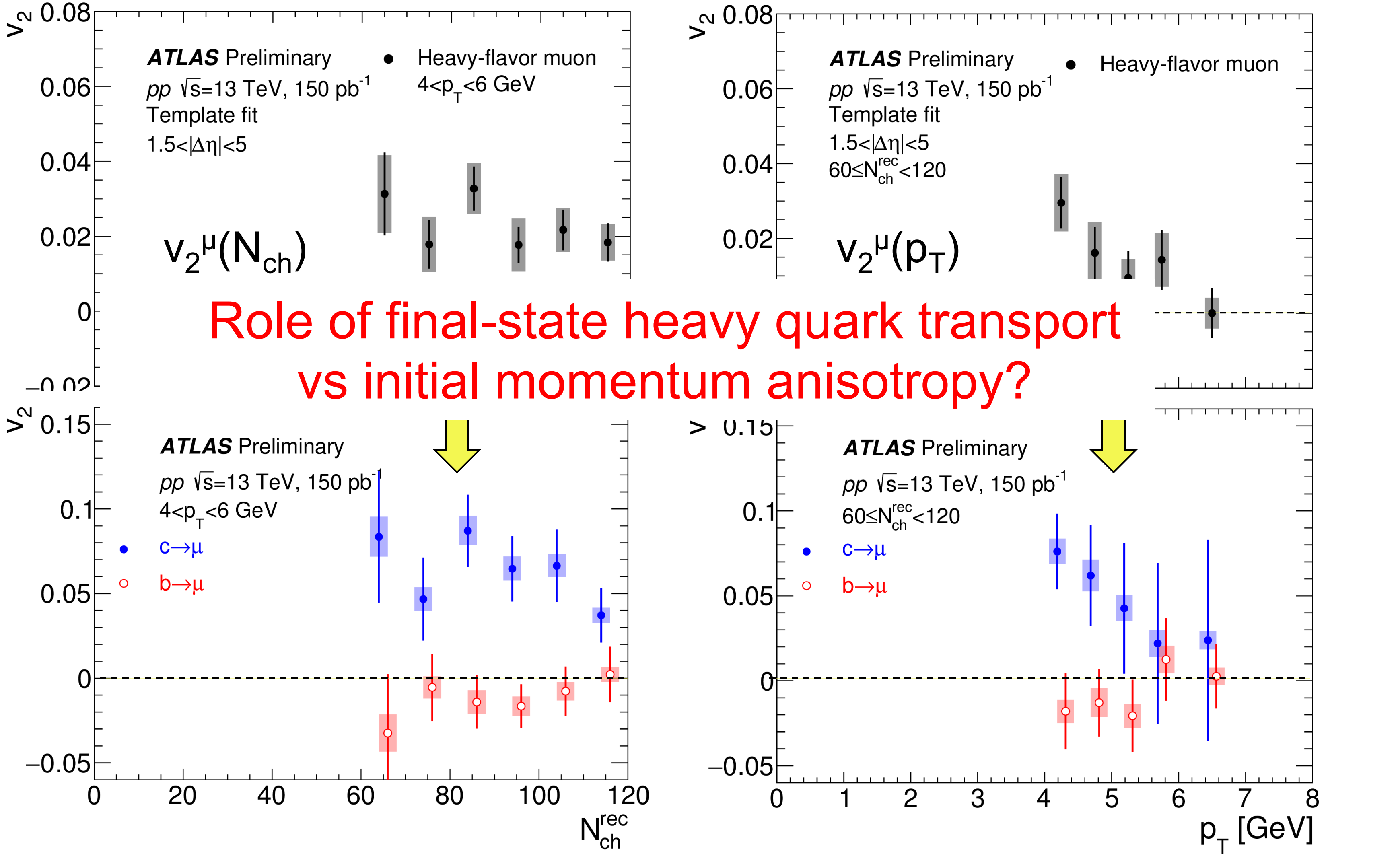


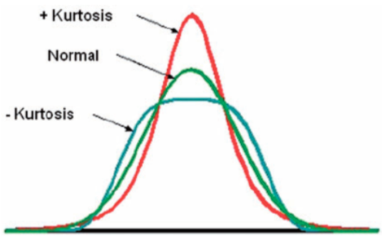
Role of final-state heavy quark transport vs initial momentum anisotropy?

Multi-particle correlations in small systems

- Four-particle cumulants probes $p(v_n)$

$$c_n\{4\} = \left\langle v_n^4 \right\rangle - 2\left\langle v_n^2 \right\rangle^2$$

"Kurtosis" of 2D $p(\mathbf{v}_n)$



- Four-particle symmetric cumulants probes $p(v_n, v_m)$

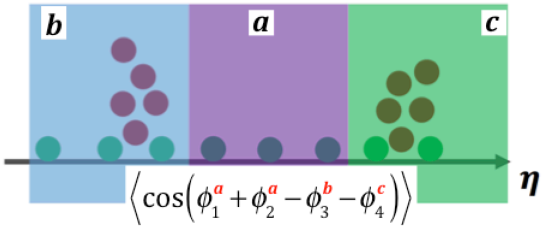
$$\mathrm{sc}_{n,m}\{4\} = \left\langle v_n^2 v_m^2 \right\rangle - \left\langle v_n^2 \right\rangle \left\langle v_m^2 \right\rangle$$

- Three-particle asymmetric cumulants

$\mathbf{v_4 \sim k v_2^2}$

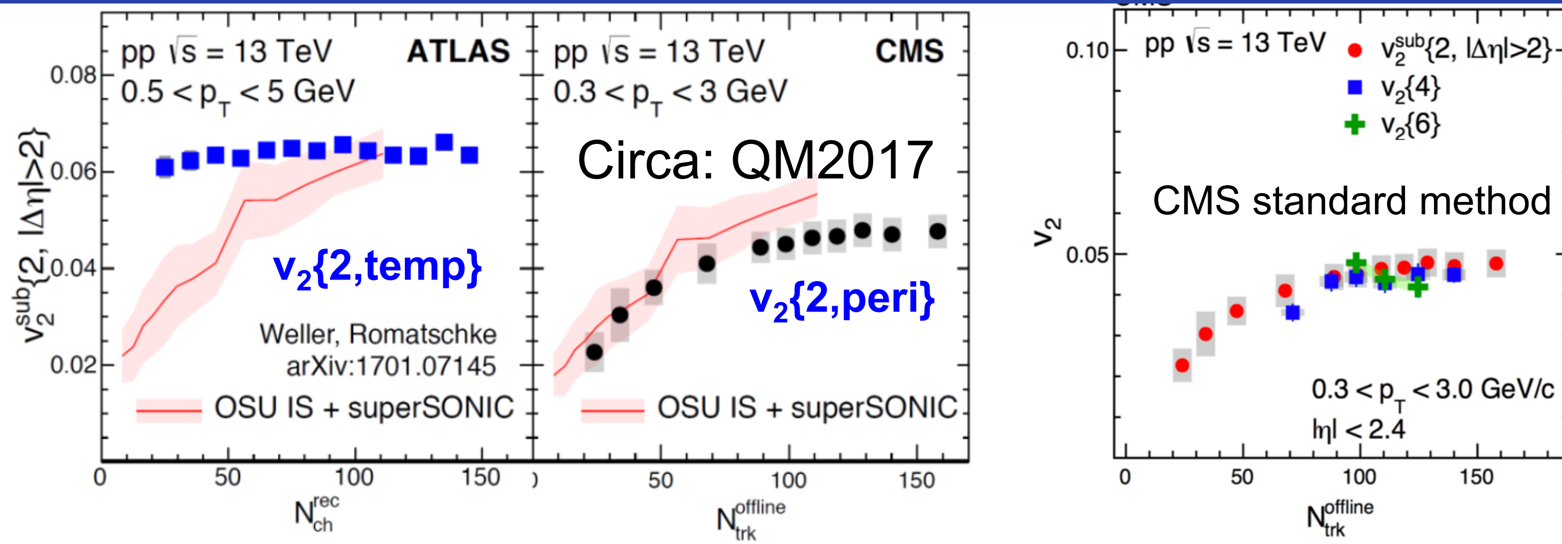
$$\mathrm{ac}_2\{3\} = \left\langle\left\langle \mathrm{e}^{\mathrm{i}(2\phi_1+2\phi_2-4\phi_3)} \right\rangle\right\rangle = \left\langle \boldsymbol{v}_2^2 \boldsymbol{v}_4^* \right\rangle \propto \left\langle v_2^4 \right\rangle$$

- Suppression of non-flow with η-subevent method



PRC96(2017) 034906 PRC97(2018) 024904

Collectivity toward low N_{ch} in pp?

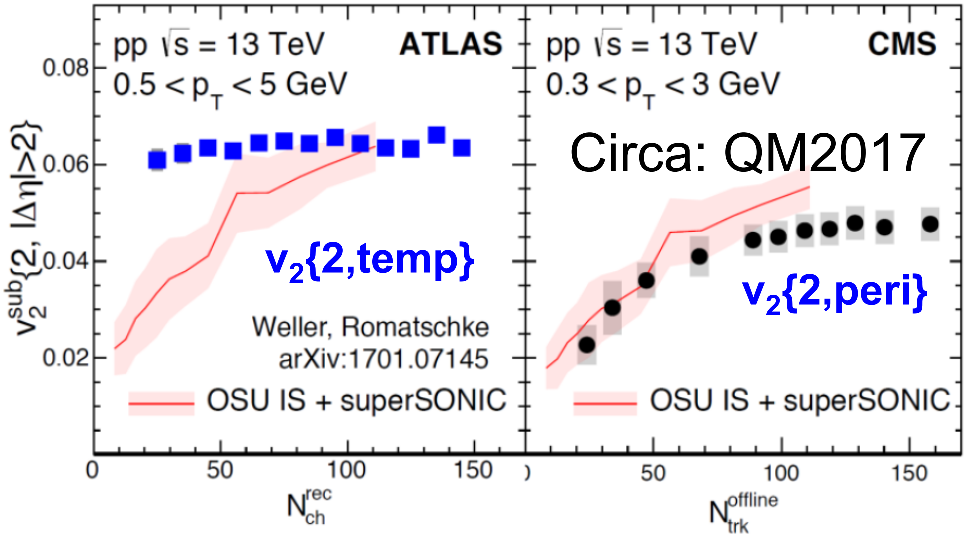


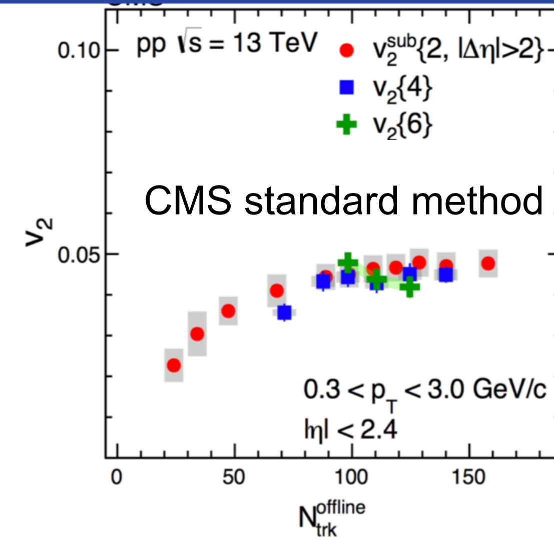
2PC $v_2(N_{ch})$ depends on non-flow sub

CMS $v_2\{4,std\} \approx v_2\{2,peri\}$

$v_2\{4,std\}$ affected by non-flow

Collectivity toward low N_{ch} in pp?



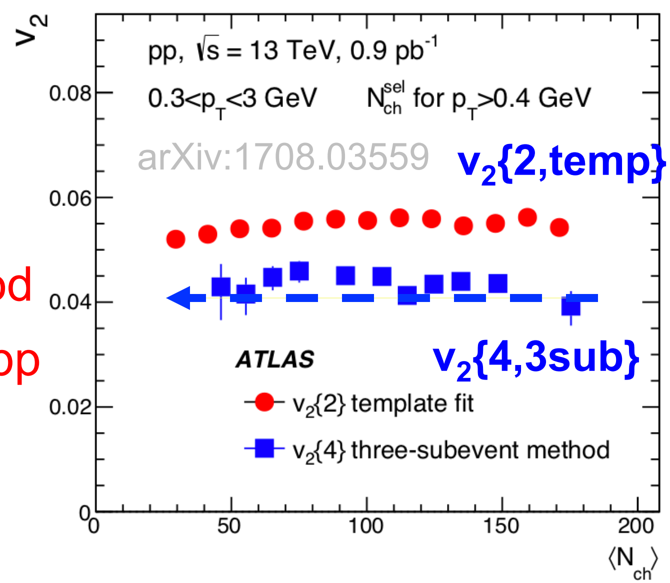


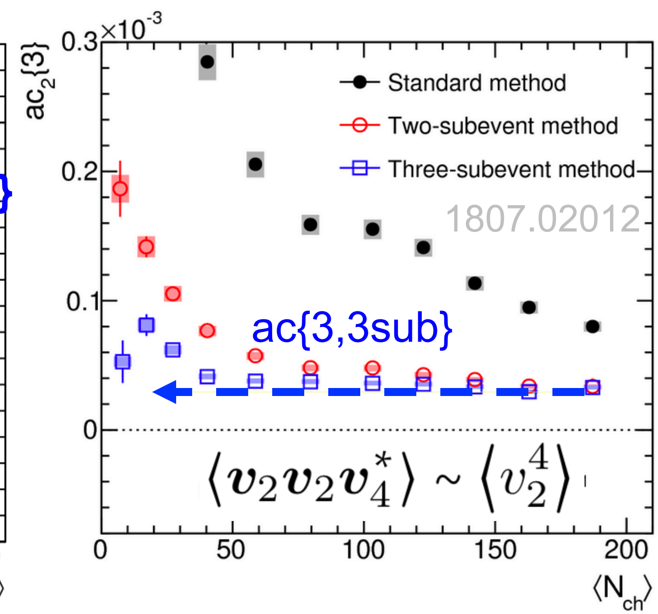
2PC $v_2(N_{ch})$ depends on non-flow sub

CMS $v_2\{4,std\} \approx v_2\{2,peri\}$

$v_2\{4,std\}$ affected by non-flow

Multi-particle correlations via three-subevent method support $v_2(N_{ch})$~const in pp

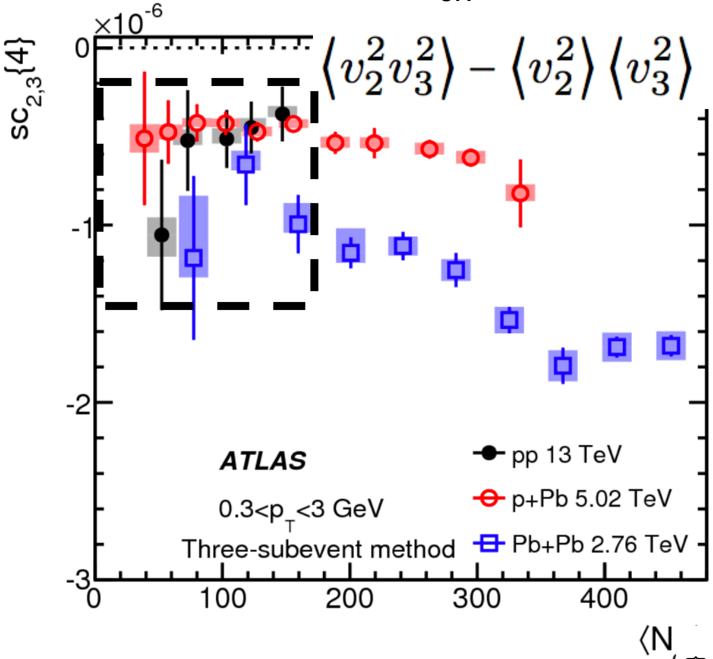




$$\langle v_2 v_2 v_4^* \rangle \sim \langle v_2^4 \rangle$$

Symmetric cumulants

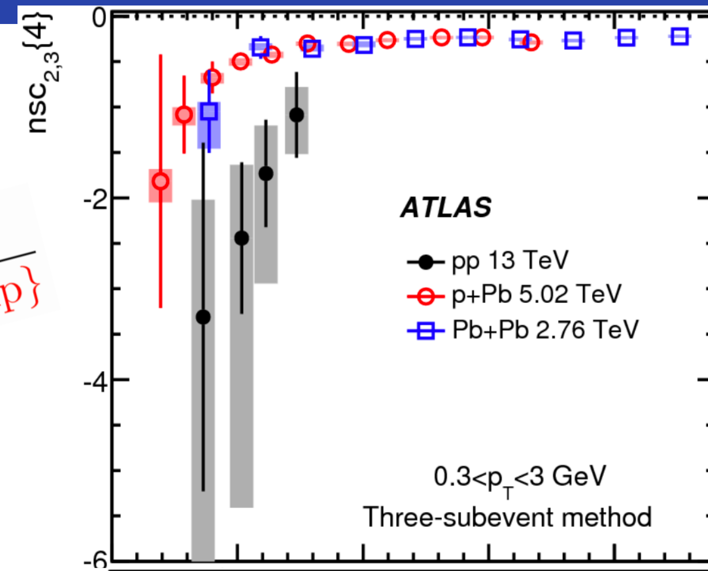
similar values among three systems over pp N_{ch} range,



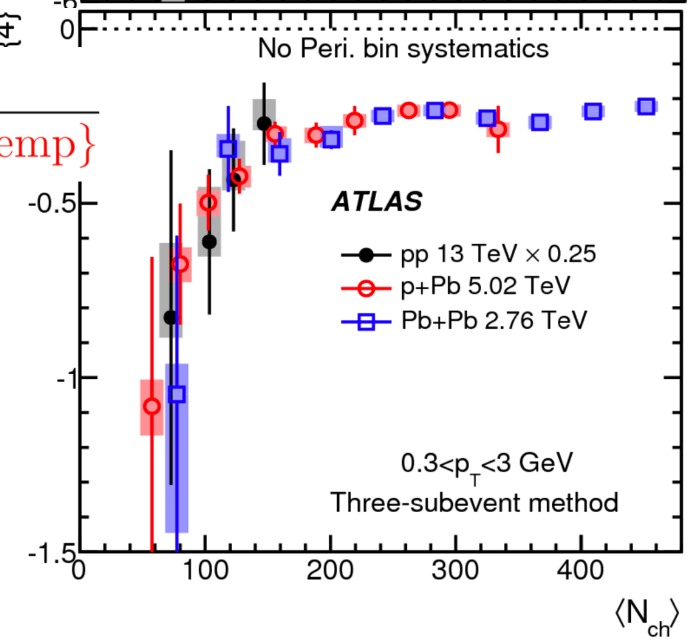
$$\langle v_2^2 v_3^2\rangle - \langle v_2^2\rangle\langle v_3^2\rangle$$

Expect scaling if $v_n^2\{2,\text{temp}\} = \langle v_n^2\rangle$

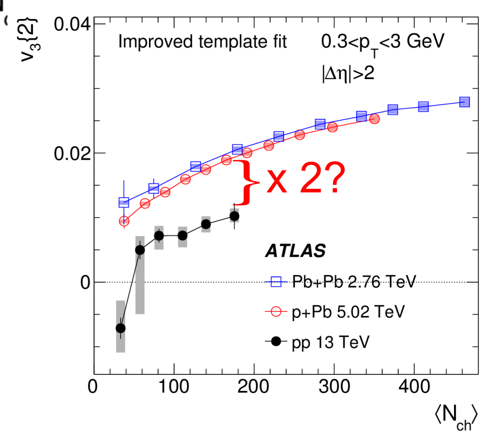
$$\frac{\langle v_2^2 v_3^2\rangle - \langle v_2^2\rangle\langle v_3^2\rangle}{v_2^2\{2,\text{temp}\}\,v_3^2\{2,\text{temp}\}}$$



$$\frac{\langle v_2^2 v_3^2\rangle - \langle v_2^2\rangle\langle v_3^2\rangle}{v_2^2\{2,\text{temp}\}\,(2v_3)^2\{2,\text{temp}\}}$$



arXiv:1807.02012

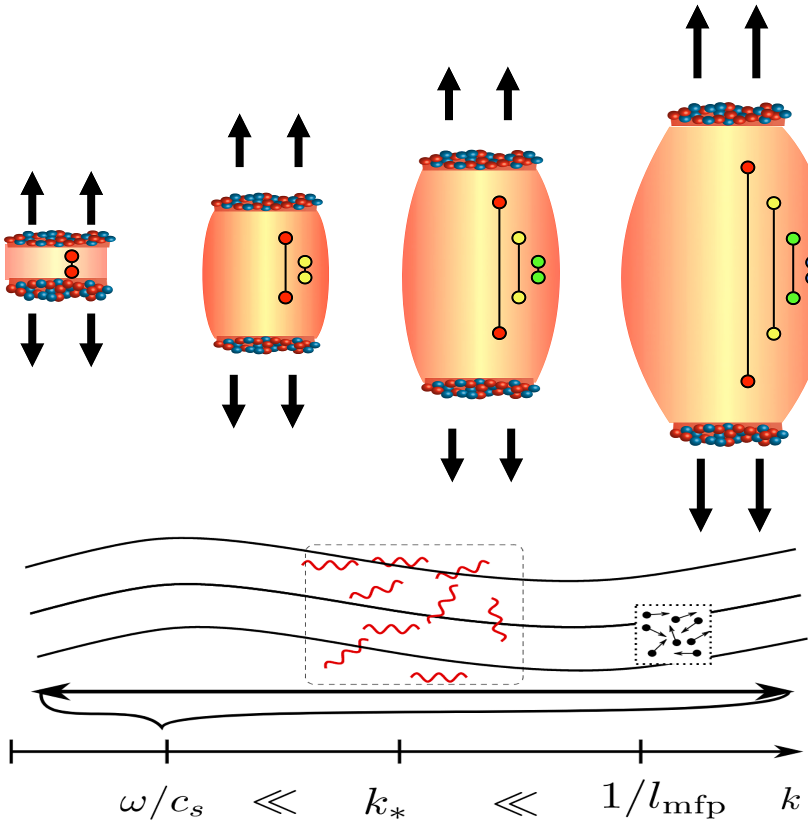


Scaling behavior of normalized SC(2,3) suggests x2 underestimation of v_3 in pp

Collectivity in large system

Fluctuations in heavy-ion collisions

- Fluctuations ←→ space-time dynamics of QGP
- Can arise at any time with varying length scale



Y. Akamatsu, A. Mazeliauskas, D.Teaney 1606.07742

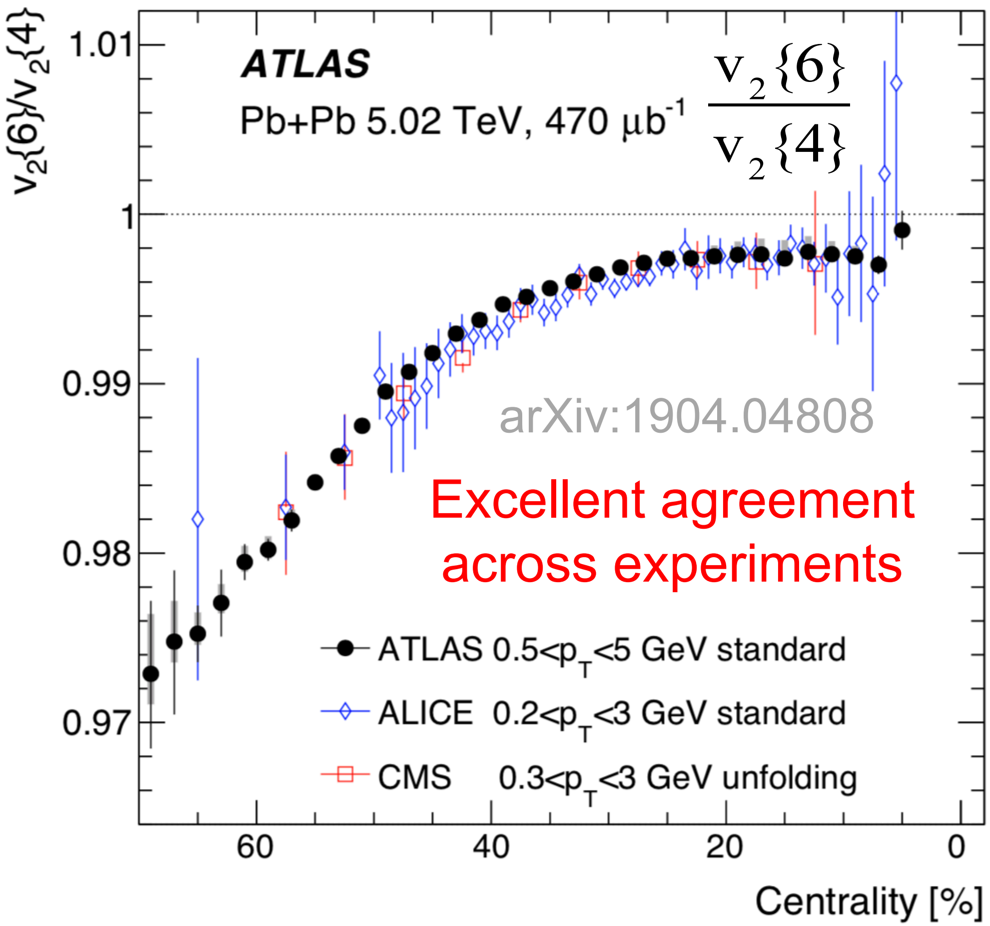
Initial state fluctuation
Hydro fluctuation
Critical fluctuation
…
Non-hydro modes
Jet quenching,
HBT
Resonance decays,
…

Experimental tool: Multi-particle correlations

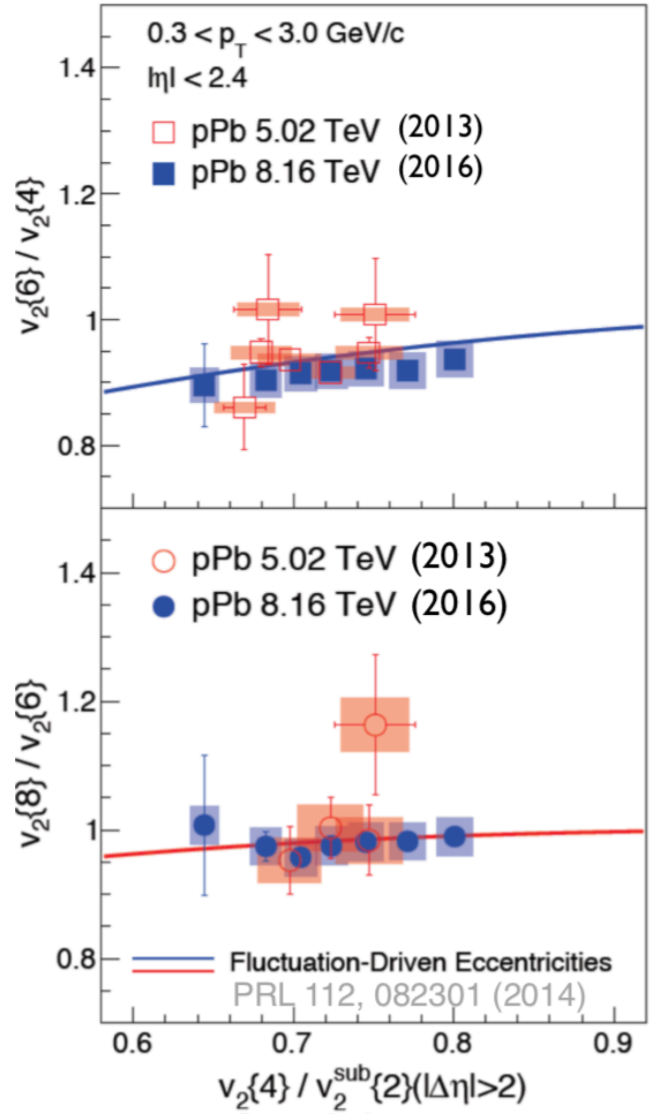
Current paradigm

$$\frac{v_2\{4\}}{v_2\{2\}} = \frac{\varepsilon_2\{4\}}{\varepsilon_2\{2\}} \qquad \frac{v_2\{6\}}{v_2\{4\}} = \frac{\varepsilon_2\{6\}}{\varepsilon_2\{4\}} \qquad \frac{v_2\{8\}}{v_2\{6\}} = \frac{\varepsilon_2\{8\}}{\varepsilon_2\{6\}}$$

Fine splitting of v_2 reflects that of ε_2

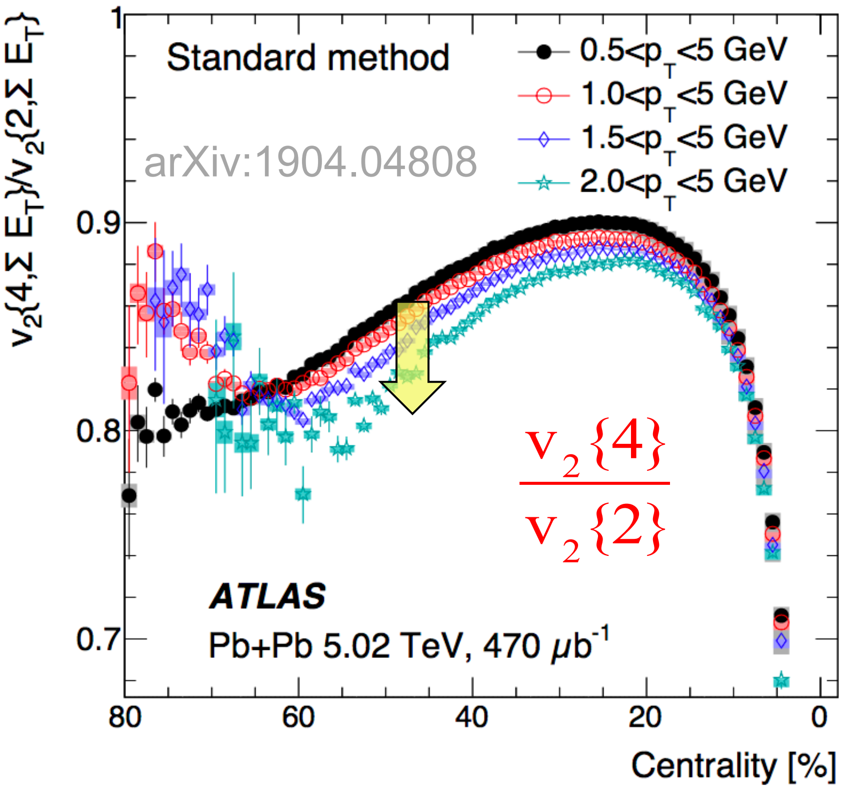


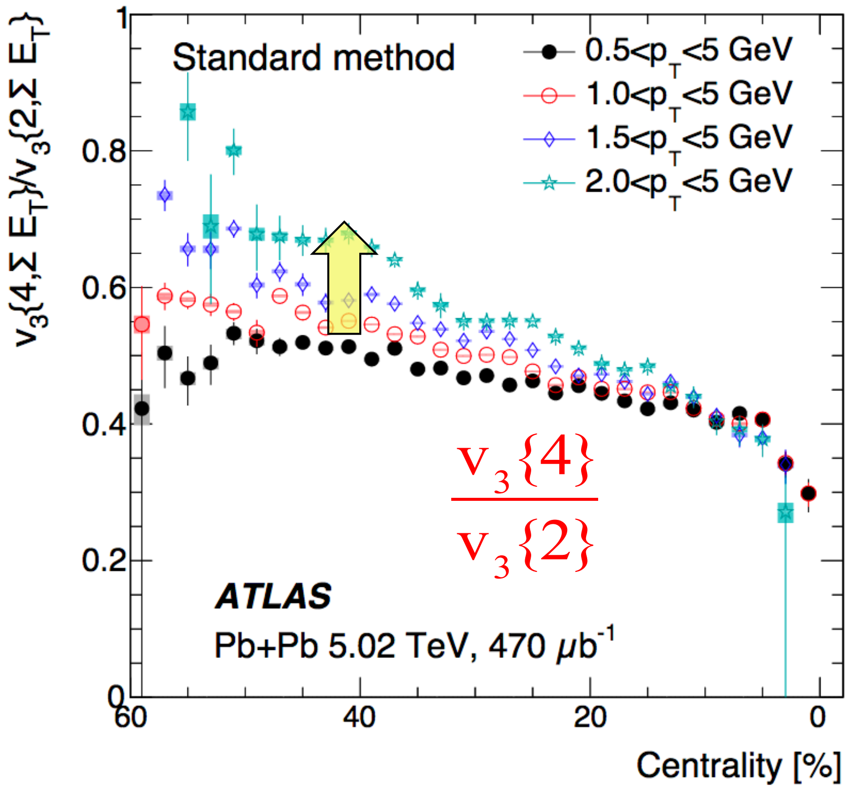
Used to argue evidence for geometry response in pPb



Do we see only geometry response?

Flow fluctuations: p_T dependence

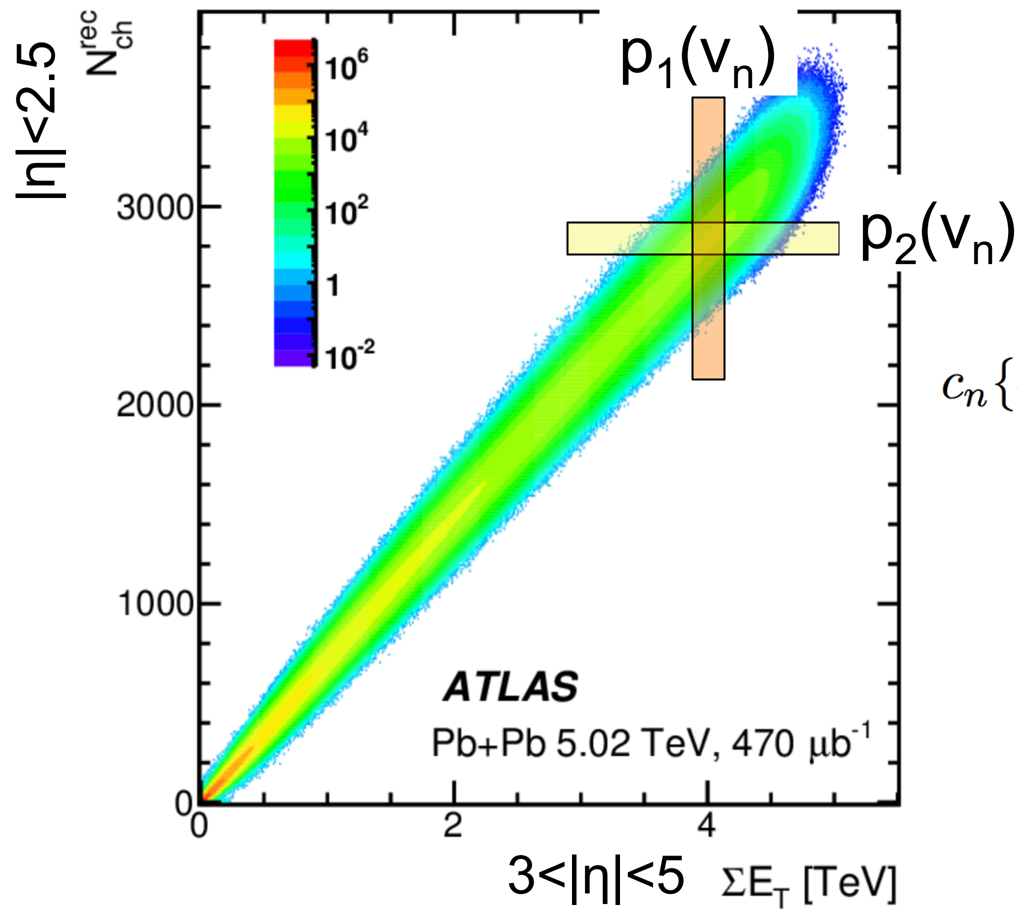




- Clear p_T dependence in cumulant ratios ➔ $\frac{v_2\{4\}}{v_2\{2\}} \neq \frac{\varepsilon_2\{4\}}{\varepsilon_2\{2\}}$
- Opposite trend: $v_2\{4\}/v_2\{2\}$ decreases with p_T, $v_3\{4\}/v_3\{2\}$ increases with p_T

Other dynamical flow fluctuations from initial and final state?

How centrality fluctuation affects flow fluctuation



$$c_n\{4\} = \langle v_n^4 \rangle - 2\langle v_n^2 \rangle^2$$

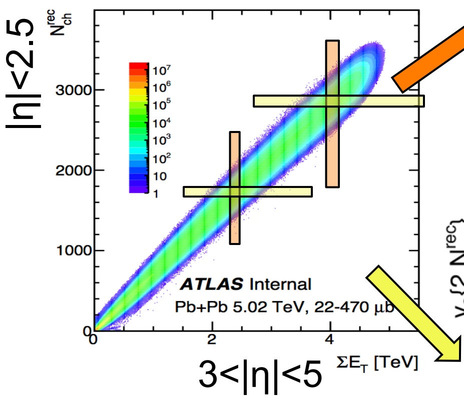
$$p(v_n | N) = \sum_{\text{cent}_{\text{true}}} p(v_n | \text{cent}_{\text{true}}) \otimes p(\text{cent}_{\text{true}} | N)$$

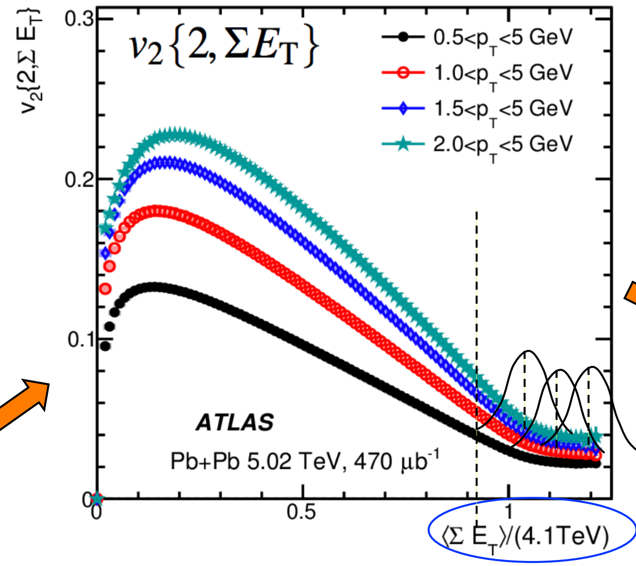
- Event ensemble selected for $p(v_n)$ depend on centrality definition
  - Even if $<E_T>$ and $<N_{ch}>$ are same, $p_1(v_n)$ and $p_2(v_n)$ could still be different

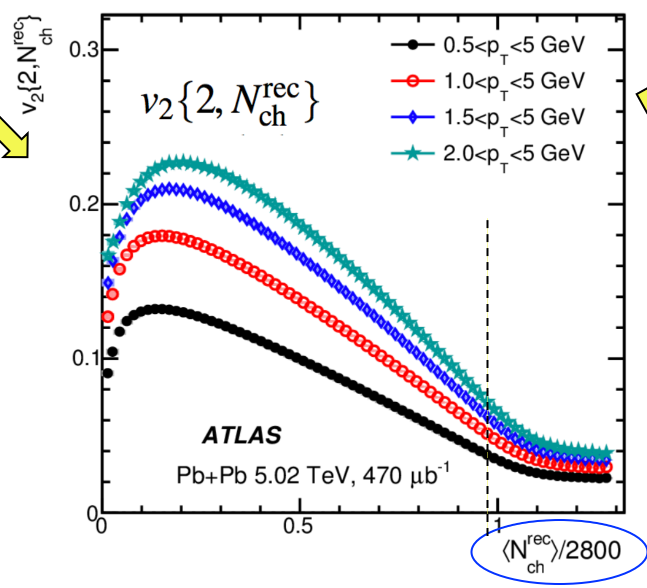
Centrality fluct. and v_2-slope in ultra-central collisions

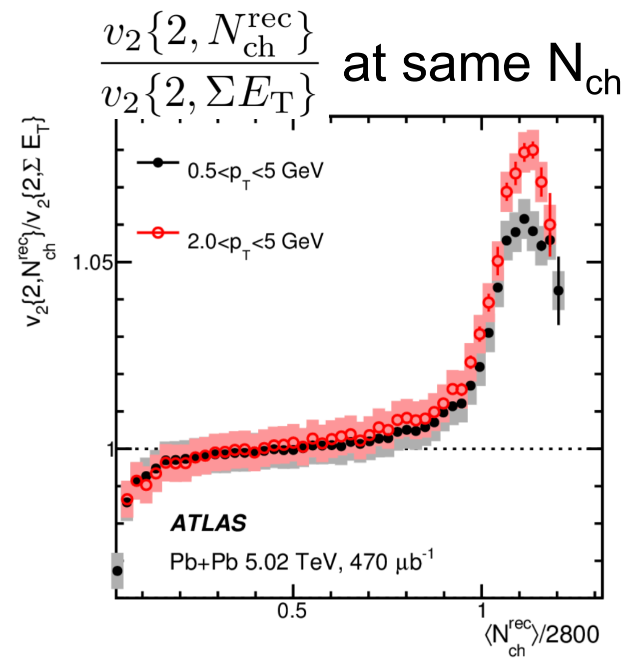
arXiv:1904.04808

arXiv:1803.01812





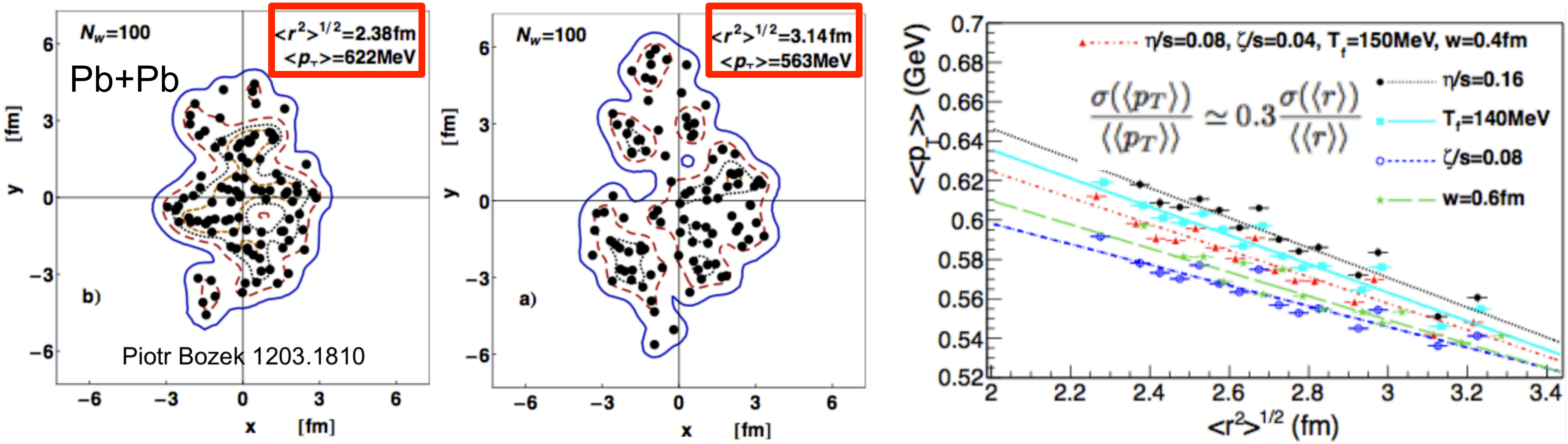




Larger centrality fluctuation for N_{ch}-bin(mid-η) than for E_T-bin(forward-η)

Also implies significant centrality decorrelation along η

v_n-p_T correlation in fixed centrality



$$\frac{\sigma(\langle p_T \rangle)}{\langle\langle p_T \rangle\rangle} \simeq 0.3 \frac{\sigma(\langle r \rangle)}{\langle\langle r \rangle\rangle}$$

Fluctuation of radial size correlates with radial flow and harmonic flow

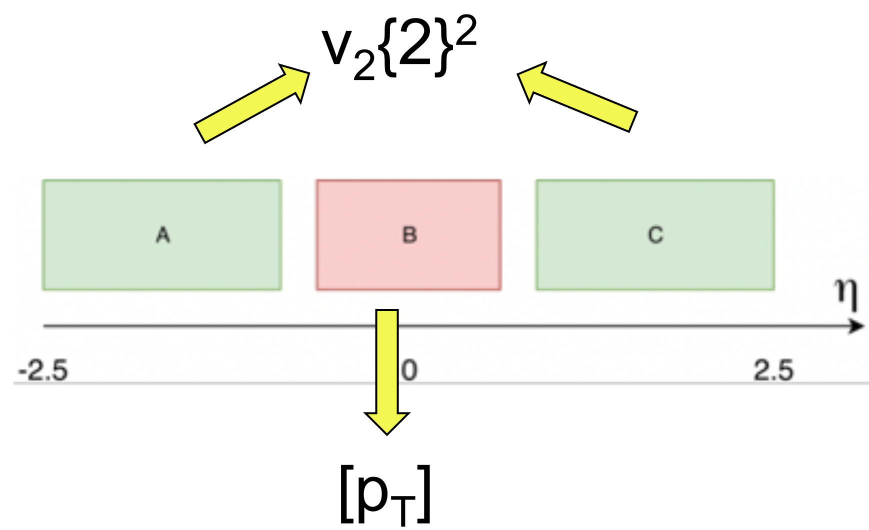
Resulting radial flow and harmonic flow also correlates

Mazeliauskas,Teany arXiv:1509.07492

v_n-p_T correlation is accessed via a three-particle cumulant

$$R = \frac{cov(v_n\{2\}^2, [p_T])}{\sqrt{var(v_n\{2\}^2)}\sqrt{var([p_T])}}$$

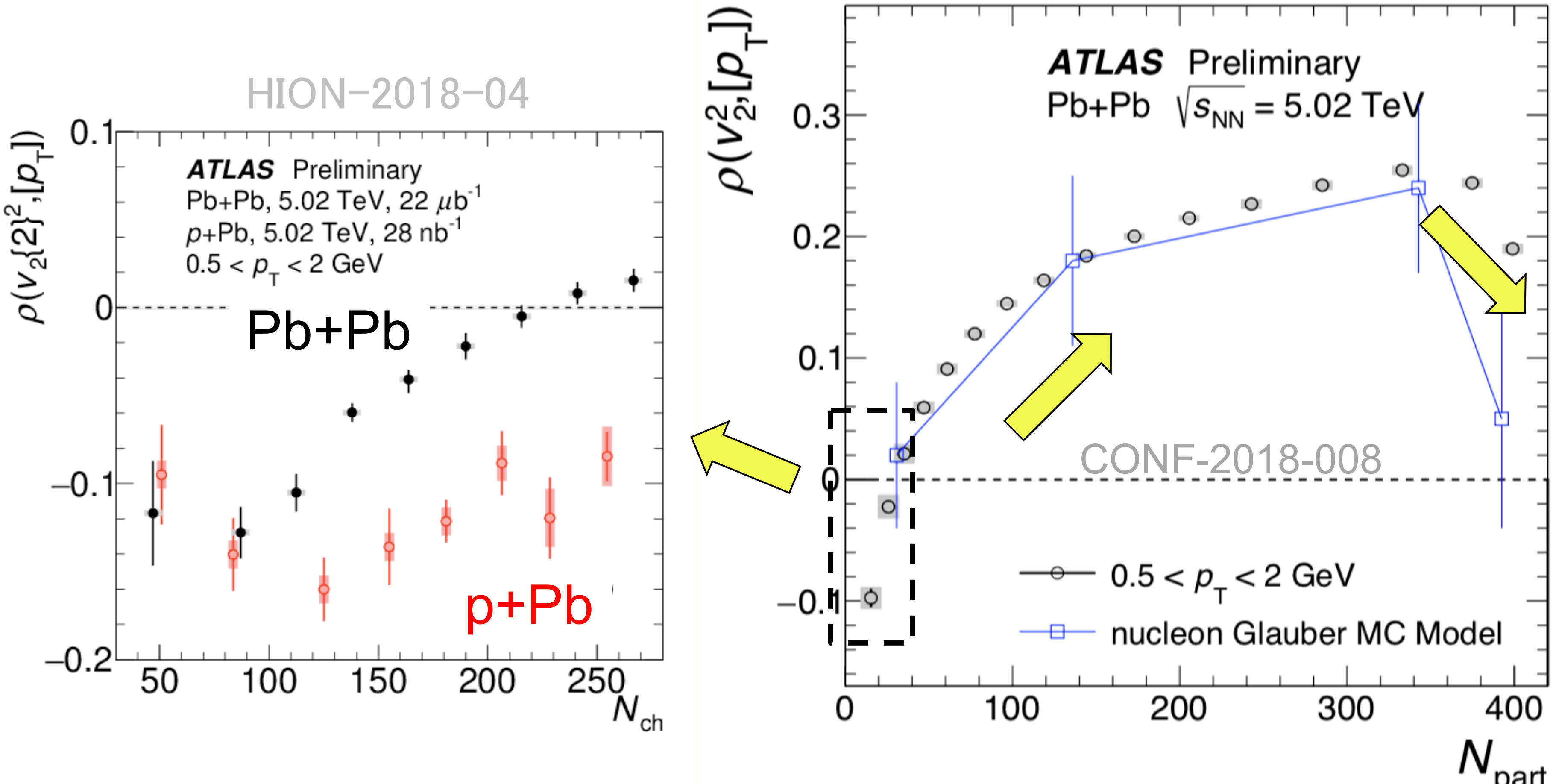
P. Bożek, PR C93 (2016) 044908



Klaudia Burka Poster

v_n-p_T correlation

Correlation increases toward central and decreases in central region
➔agrees with hydro calculation based on nucleon glauber model

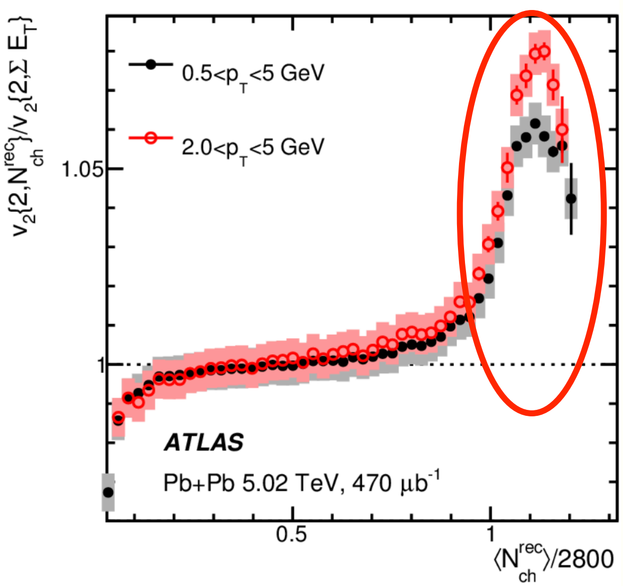


Anti-correlation in low N_{ch} region of PbPb and pPb! (not reflect ε_2^2<p_T>)
➔sensitive to the minimum size-scale driving the flow.

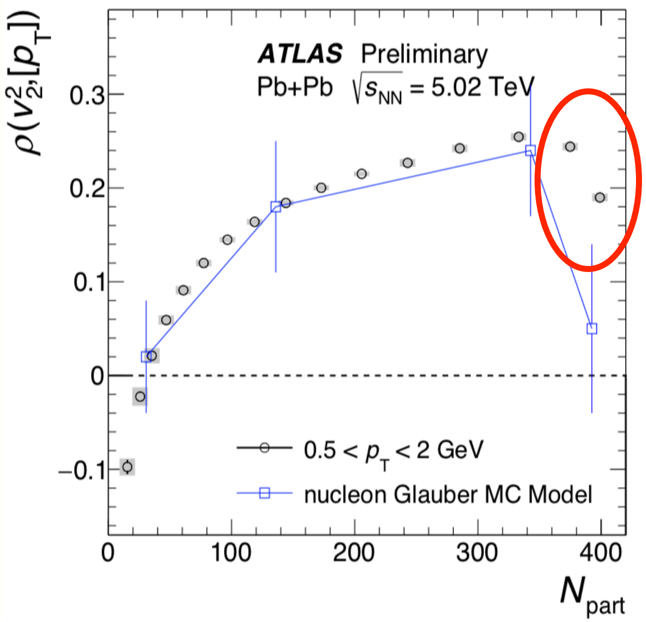
Centrality/size fluctuation in central collision

Modification of dynamic fluctuations in ultra-central collisions seen in several observables

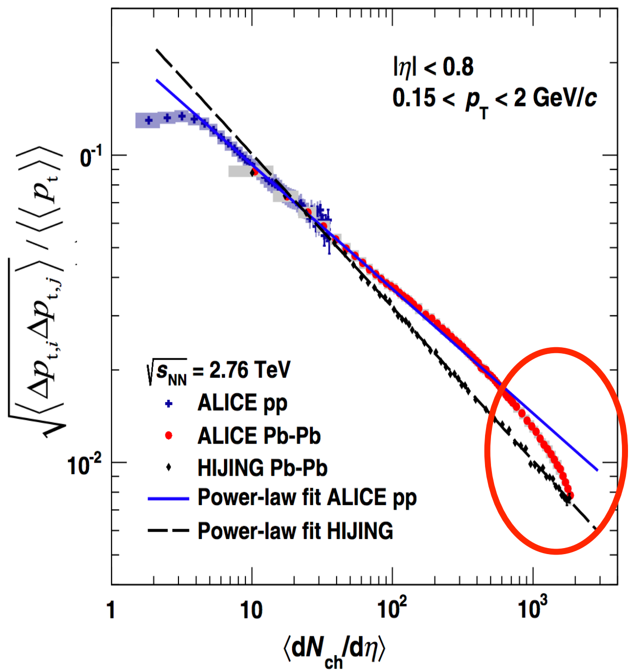
v_2^2 fluctuation



v_2^2<p_T> correlation



<p_T> fluctuation



Provide a way to study the nature of centrality and its fluctuation

➔Small systems: stronger centrality fluctuation & centrality decorrelations expected!

Summary

- New results by ATLAS will be presented in 5 talks and 1 posters
- Study of initial state and collectivity in PbPb, pPb and pp systems.
- Provides:
  - New information on the initial state of pPb and PbPb
    Glauber baseline describes W/Z within ~10-15%, leaving small room for nPDF effects.
  - New insights on the nature of collectivity in small systems
    First measurement of heavy-flavor muon v_2 from c/b in pp, and hadron v_2 in γ^*Pb.
    Evidence for $v_2(N_{ch})$~const in pp via multi-particle correlations
  - Improved understanding of flow/centrality fluctuation in large system
    Eccentricity is not the only source of flow fluctuation, importance of centrality fluctuation

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

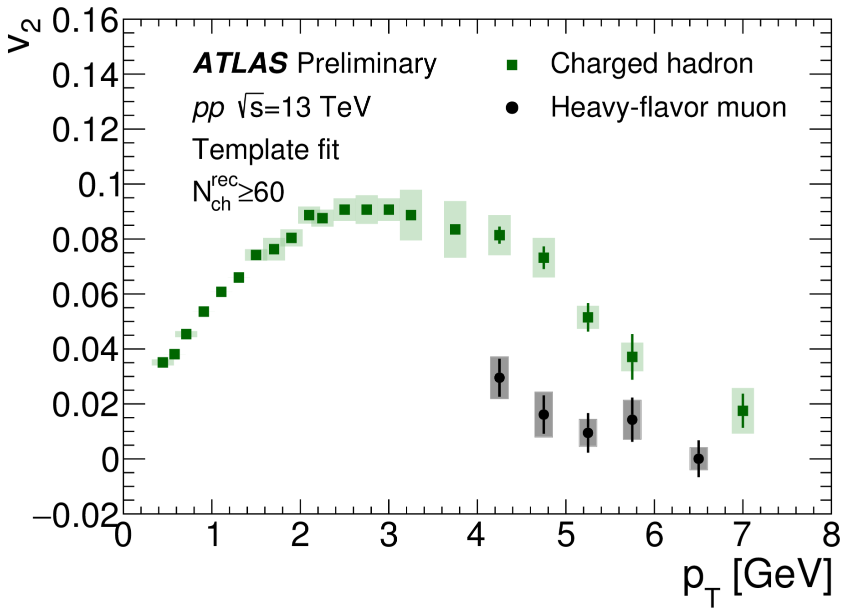
ATLAS Presentations

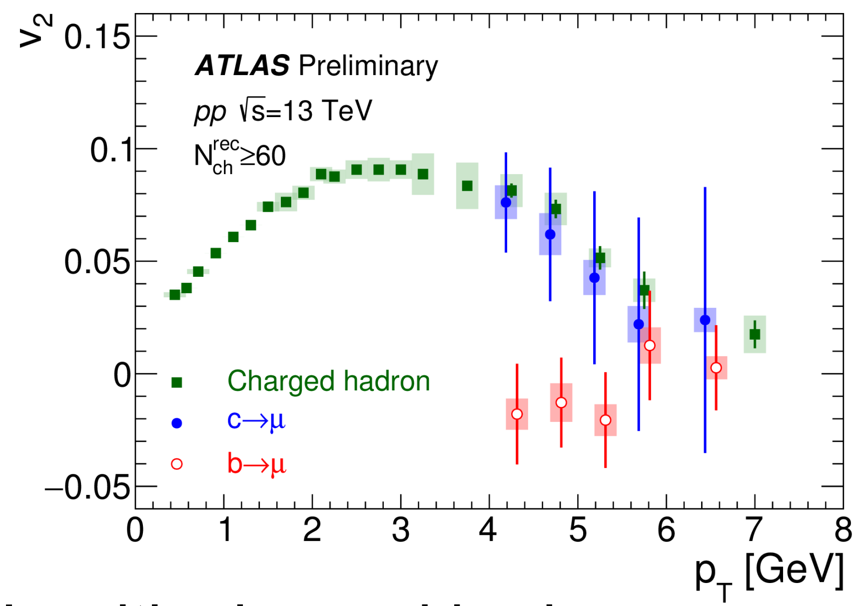
- Dennis Perepelitsa ***Jet and photon probes of small and large systems in ATLAS***
- Mirta Dumancic: ***Heavy electroweak boson production in Pb+Pb collisions with ATLAS***
- Kurt Hill: ***ATLAS measurements of azimuthal anisotropy of heavy flavor hadrons in Pb+Pb, p+Pb and pp collisions***
- Blair Seidlitz: ***Recent ATLAS results on correlations in small collisions systems and photon-induced processes in ultra-peripheral Pb+Pb collisions at 5.02 TeV***
- Arabinda Behera: ***ATLAS results on flow and flow fluctuations in heavy ion collisions***

- Klaudia Burka Poster: ***v_n--p_T correlations in 5.02 TeV Pb+Pb and p+Pb collisions with the ATLAS detector***

Heavy-flavor muon v_2 vs charged hadron v_2

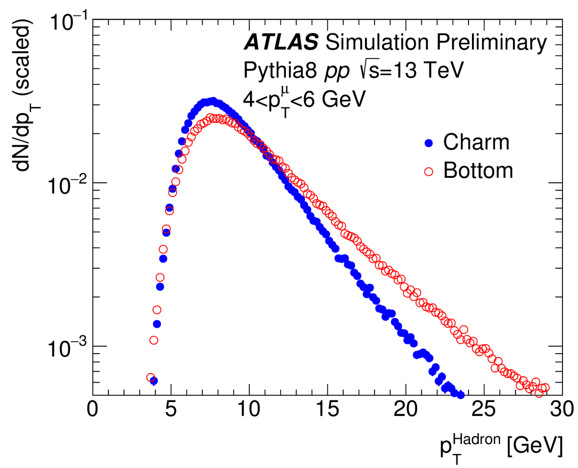
CONF-2019-023

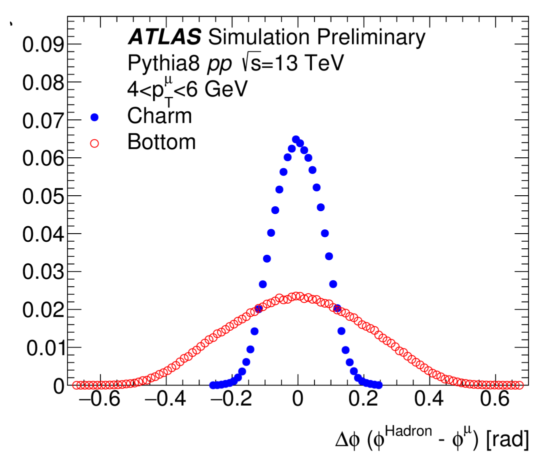




Charm muon v_2 comparable with charged hadron v_2

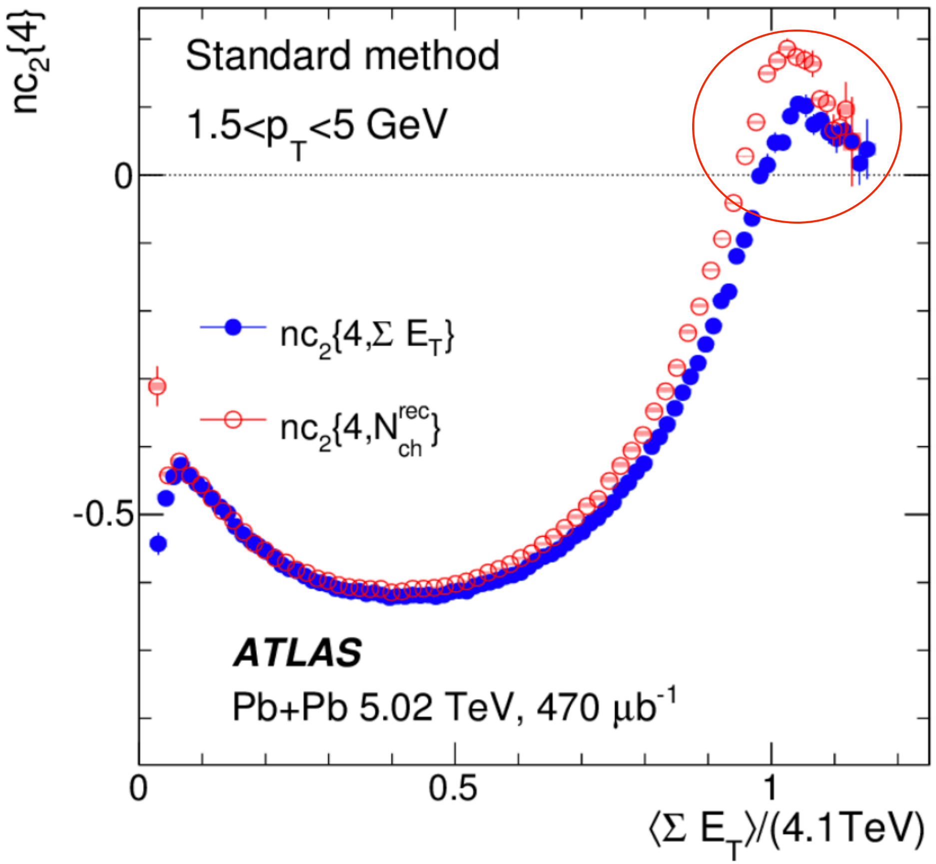
Also charm muon at p_T=4-6 GeV comes mainly from charm hadrons around 7 GeV. The $\Delta\phi$ smearing from decay also play a role





Kurt Hill Wed 1a

Centrality fluctuation & higher-order cumulants



Arabinda Behera
Tues. 2b

$$\mathrm{nc}_2\{4\} = \frac{\left\langle v_2^4 \right\rangle - 2\left\langle v_2^2 \right\rangle^2}{\left\langle v_2^2 \right\rangle^2} = -\left(\frac{v_2\{4\}}{v_2\{2\}}\right)^4$$

$nc_2\{4,N_{ch}^{rec}\}$ ($<\Sigma E_T>$) obtained by map N_{ch}^{rec} to corresponding $<\Sigma E_T>$

- Sign-change in UCC, reach max then decrease to zero.
- Difference between $nc_2\{4,\Sigma E_T\}$ & $nc_2\{4,N_{ch}^{rec}\}$ is largest in UCC, but also persist to mid-central.

Centrality fluctuation influences $c_n\{4\}$ over a broad centrality range!