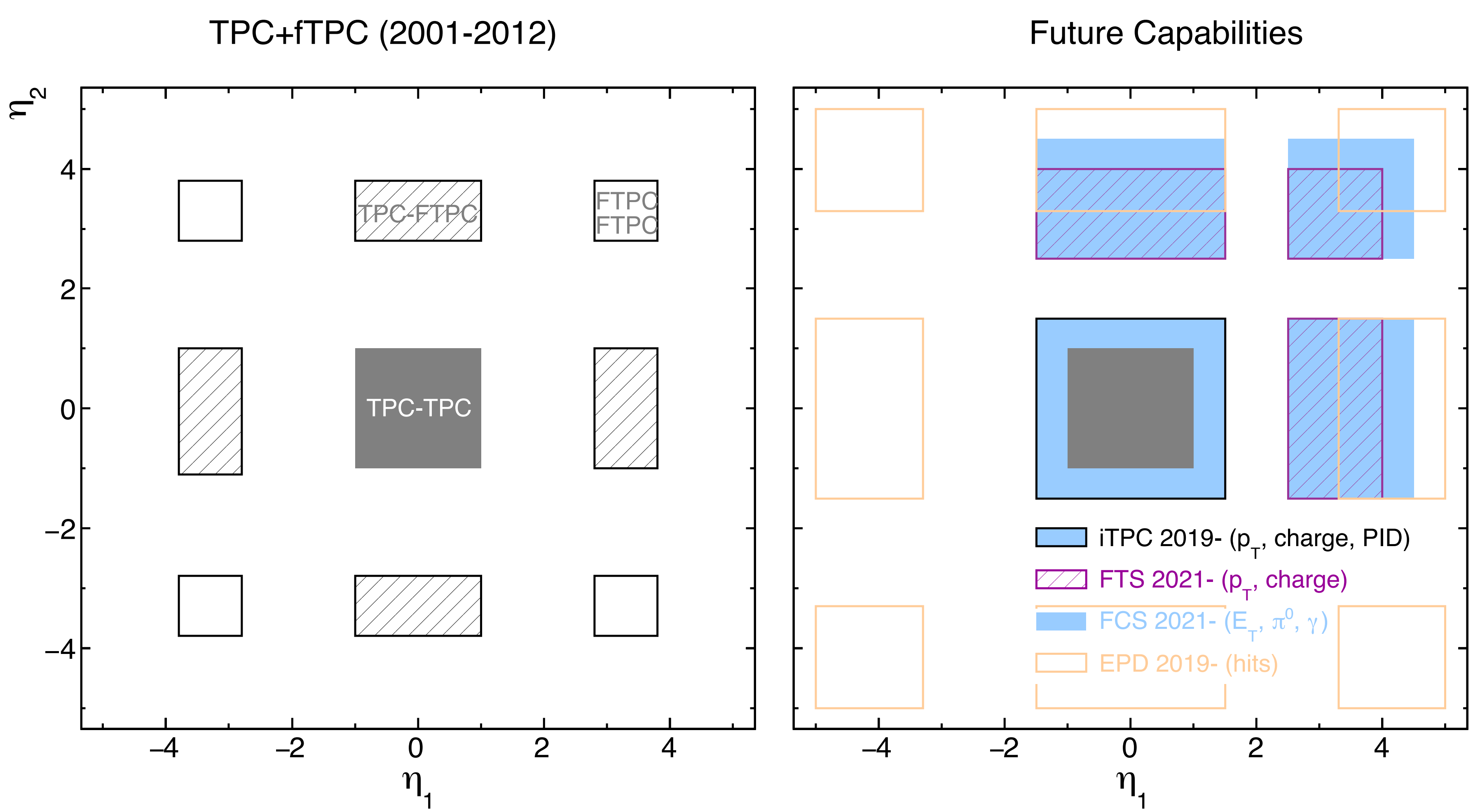
Heavy Ion physics possibilities with fSTAR

Prithwish Tribedy

BROOKHAVEN NATIONAL LABORATORY

RSC meeting for forward upgrade, BNL, 2017



Physics interests

Our Goal : Measurements of global observables in **heavy ion collisions** over **wide** range of **rapidity** at **RHIC**

Major interests :

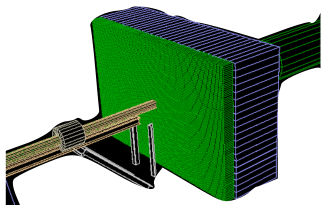
- Constraining longitudinal structure of the Initial stages of HICs
- Constraining the temperature dependence of shear viscosity

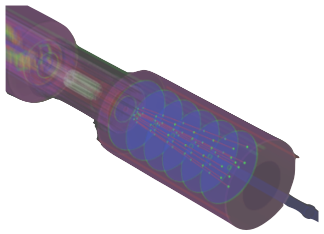
Other interests :

- Event-shape-engineering
- Chiral Magnetic Effect

Detectors	**Acceptance**
Forward Calorimeter **(FCS)**	$-2.5 > \eta > -4.2$, E_T (photons, hadrons)
Forward Tracking System **(FTS)**	$-2.5 > \eta > -4.2$, p_T (charged particles)

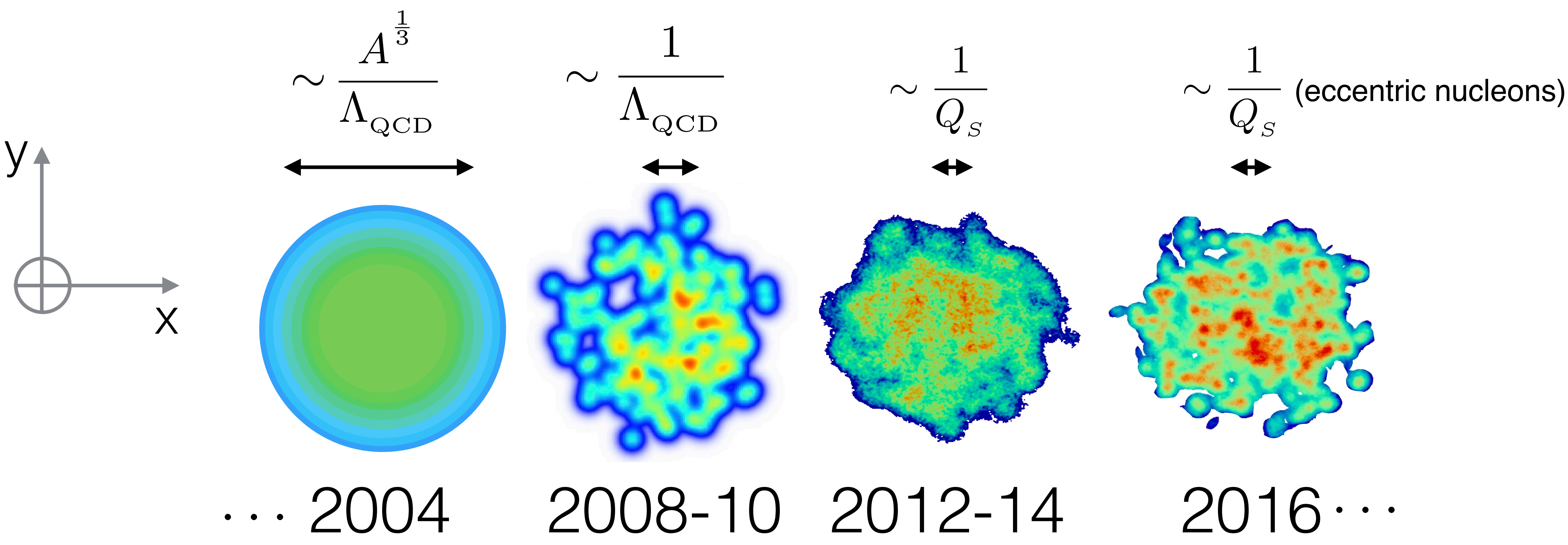
fSTAR





Initial state of HICs

Over a decade we have learned a great deal about the transverse structures of the initial state of Heavy Ion collisions



Initial state geometry and fluctuations

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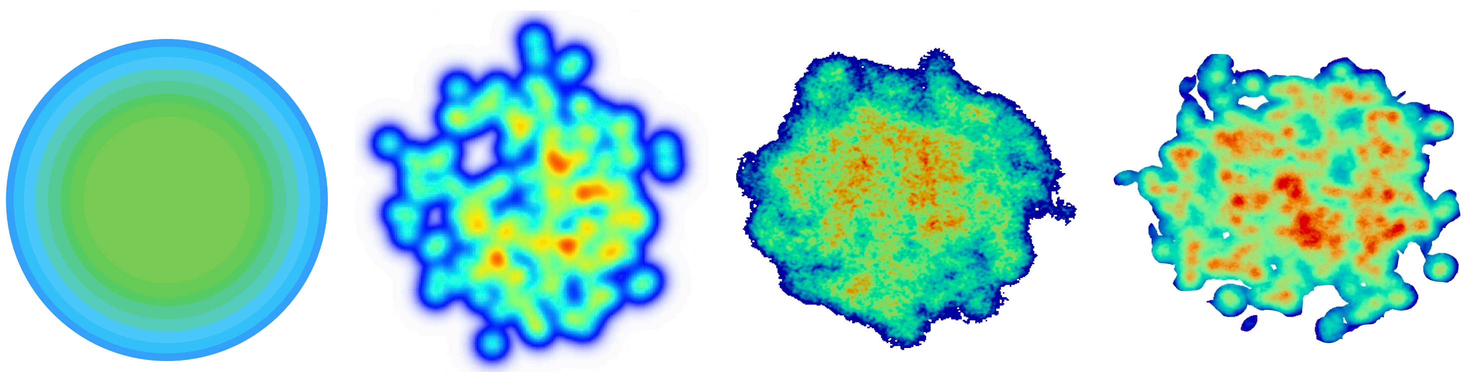
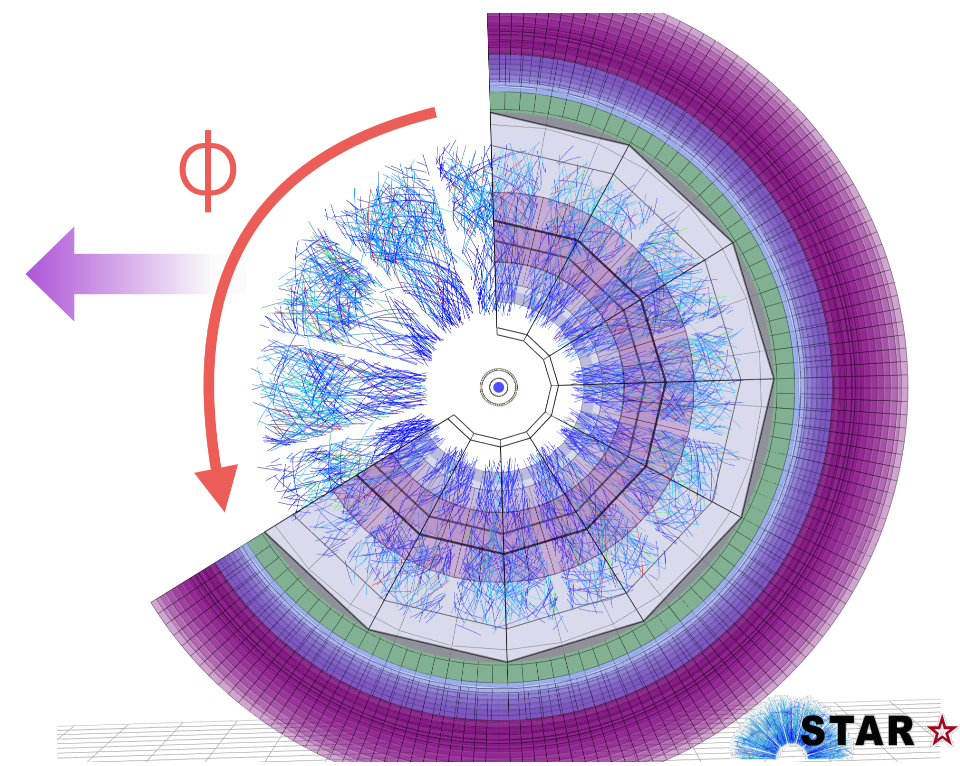


$\cdots$ 2004 2008-10 2012-14 2016 $\cdots$



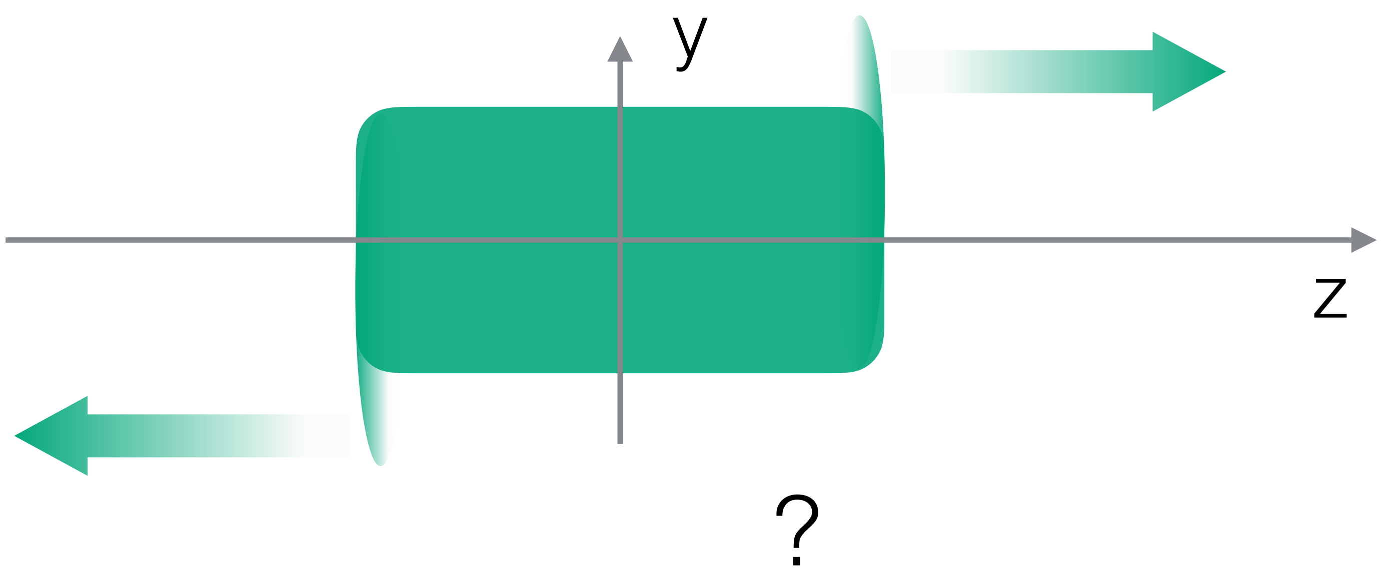
Precision measurements of anisotropy in the transverse ch-hadron spectra + theory

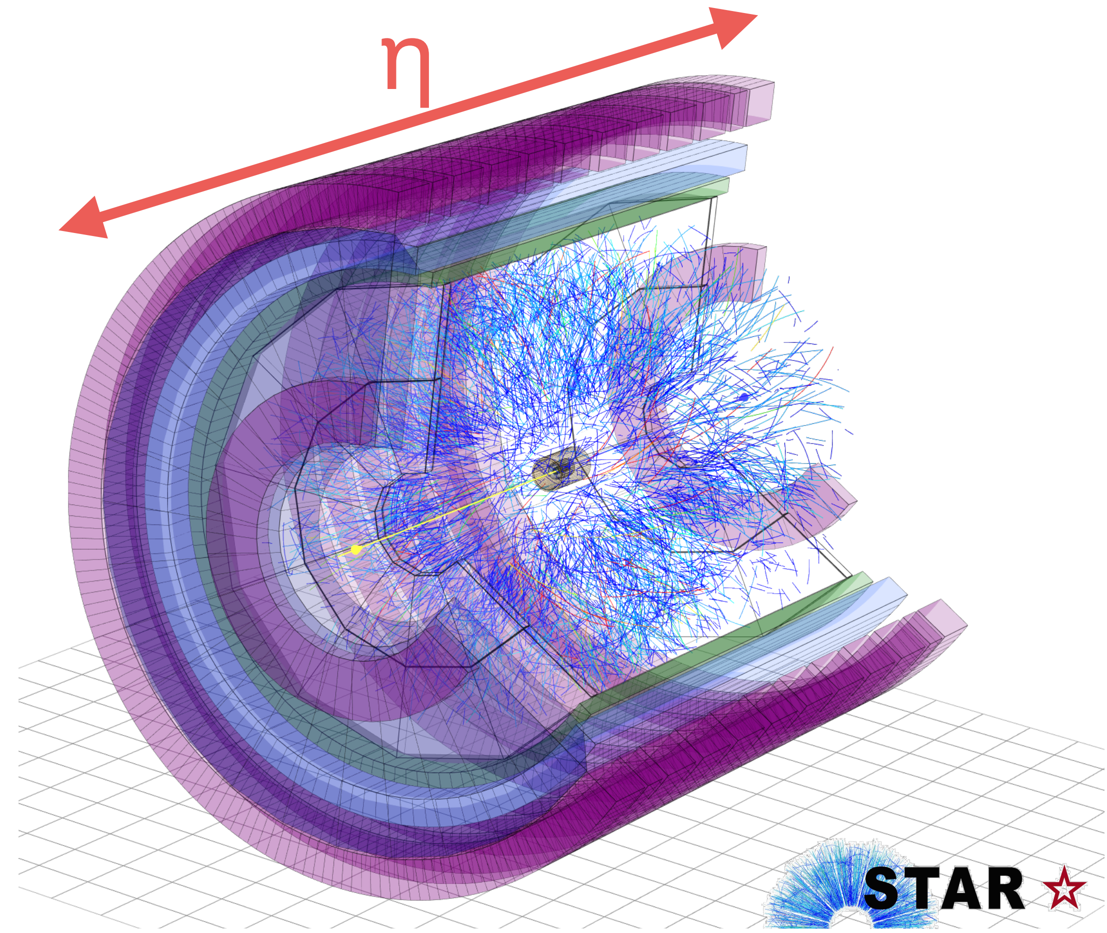
$$\frac{dN}{d\phi} \propto 1 + 2v_1 \cos(\phi) + 2v_2 \cos(2\phi) + 2v_3 \cos(3\phi) + 2v_4 \cos(4\phi) + \cdots$$

Flow harmonics

Longitudinal structures of the initial state of HICs

The longitudinal structure of heavy ion collisions is largely unexplored





Most theoretical simulations assume boost invariance of initial state

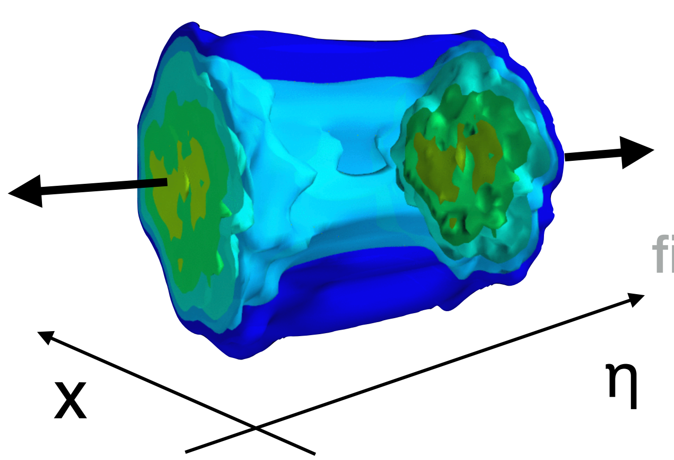


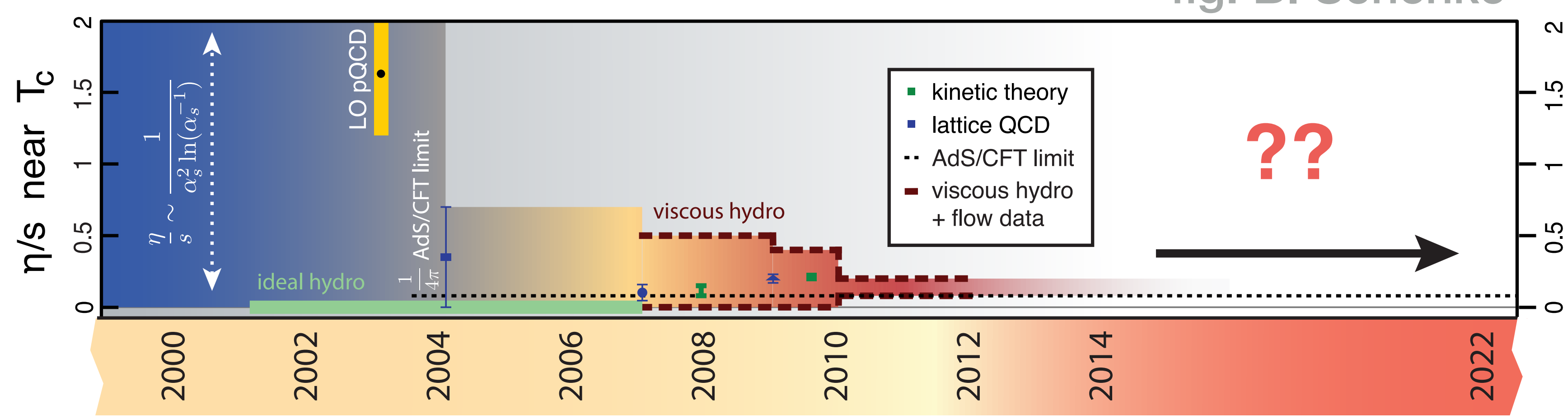
fig: B. Schenke

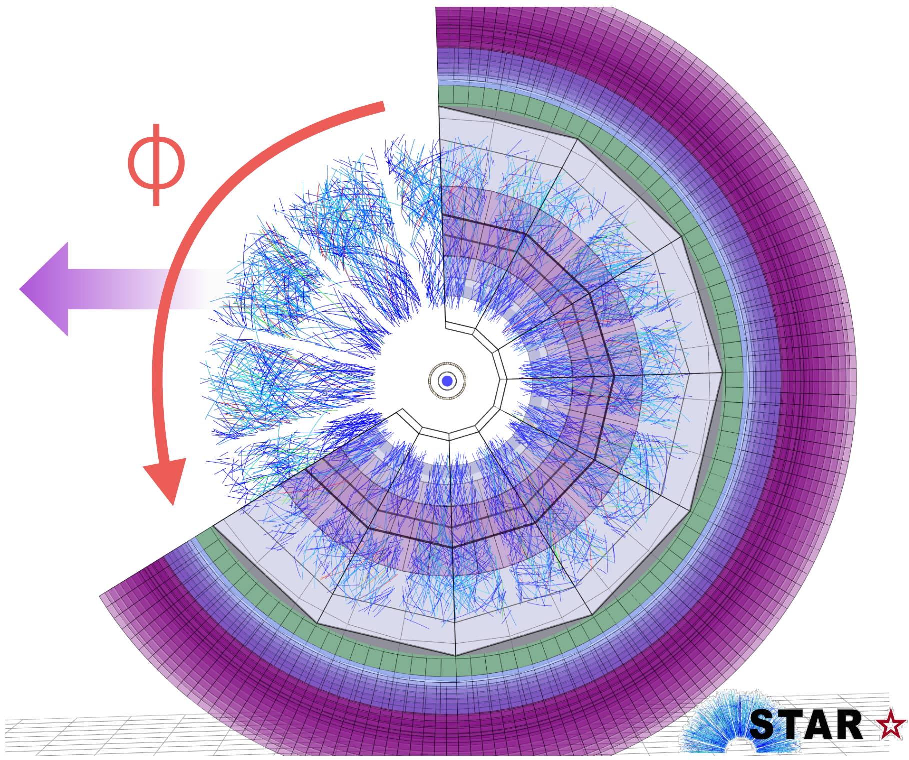
Can we lean about the longitudinal structure of HICs in the final phase of RHIC ?

Transport properties of matter formed in HICs

We have made precision measurements of the shear viscosity to entropy density ratio η/s of the matter formed in HICs

fig: B. Schenke





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viscous damping

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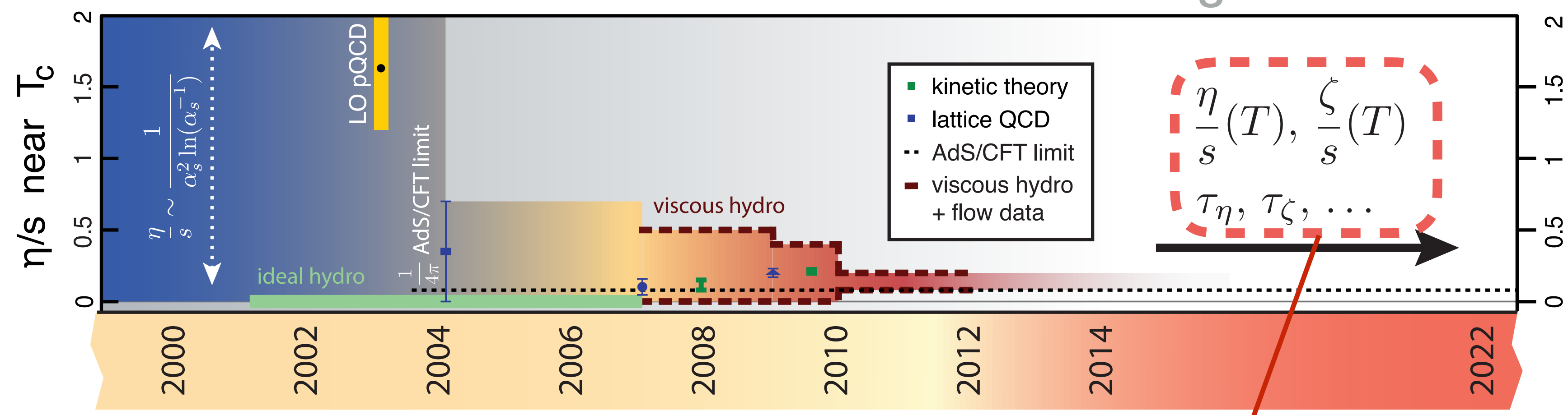

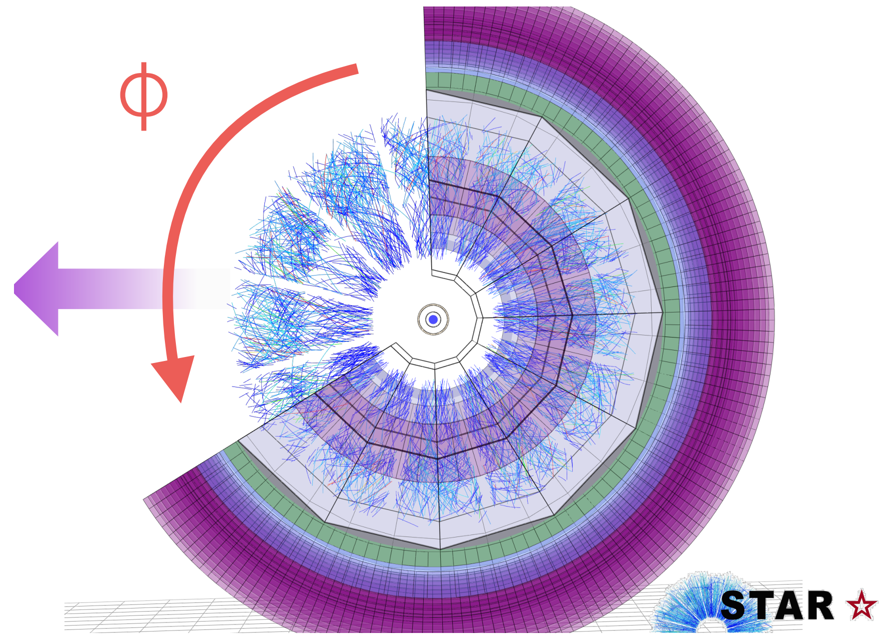

"…temperature dependence will be more tightly constrained by upcoming measurements…"

Page 22, The 2015 LONG RANGE PLAN for NUCLEAR SCIENCE

Can we map out the temperature dependence profile of transport parameters ?

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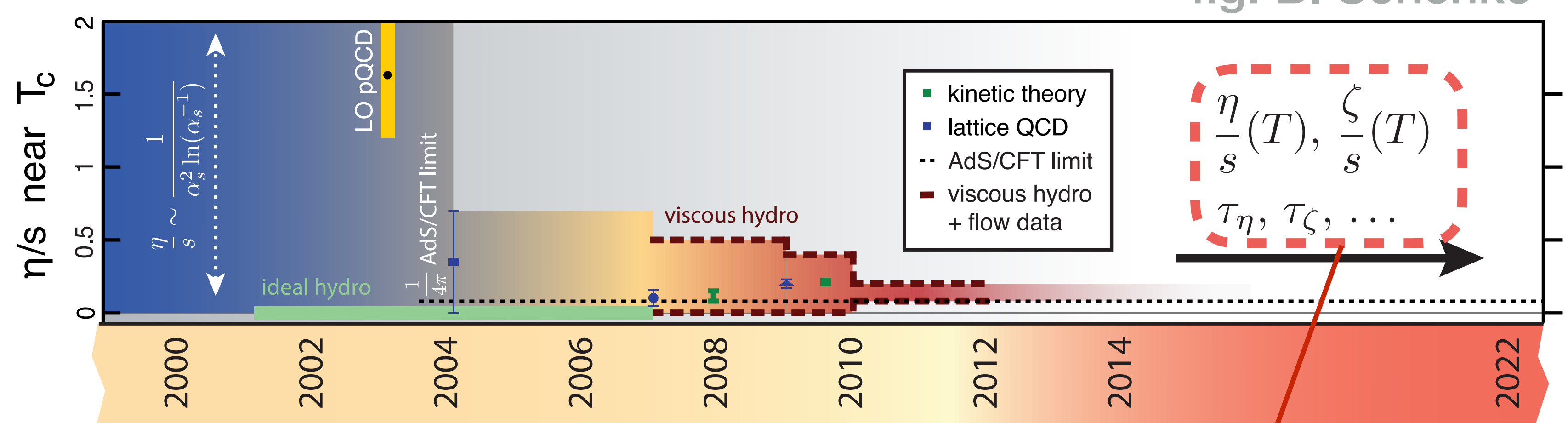

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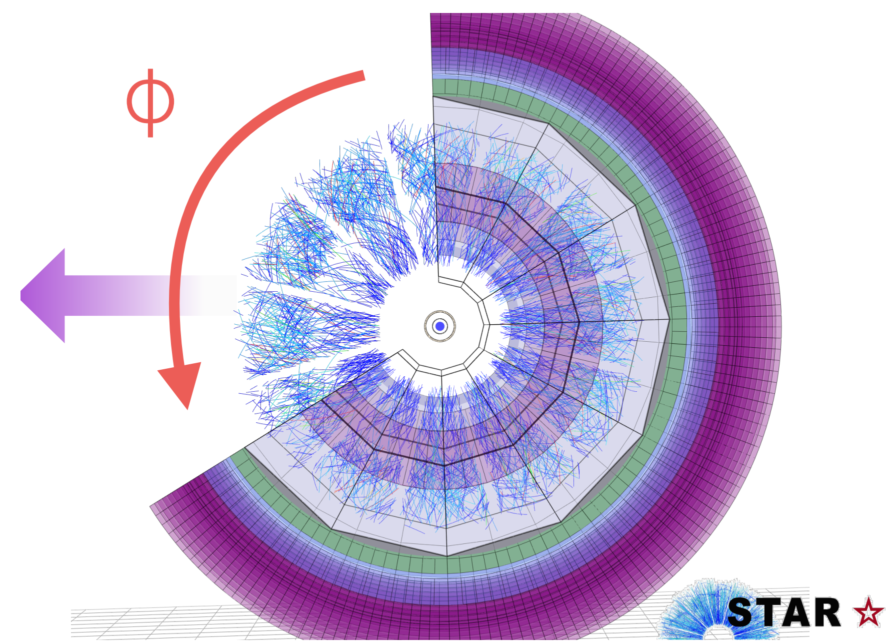
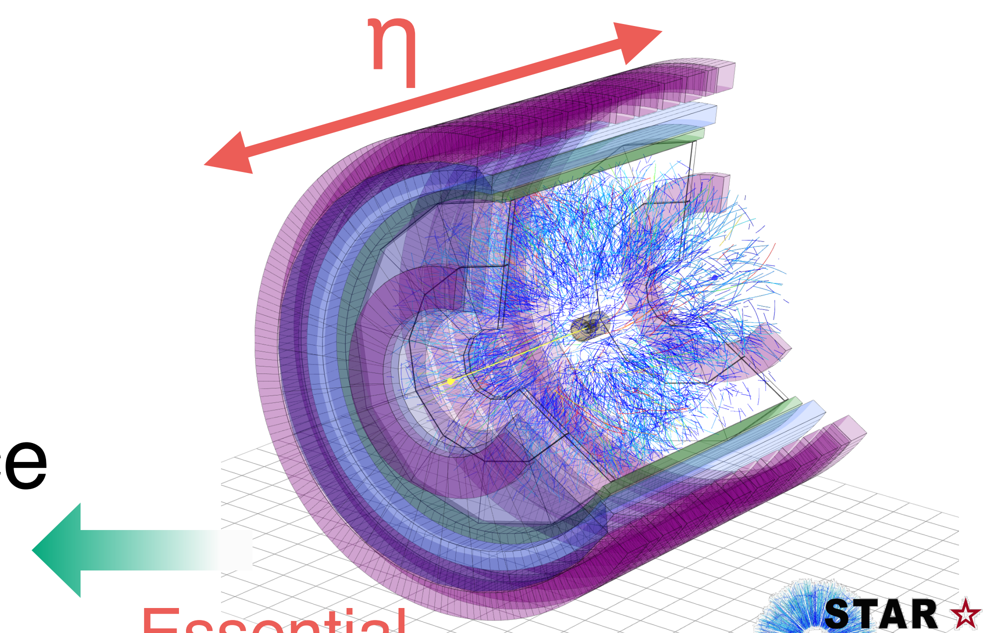




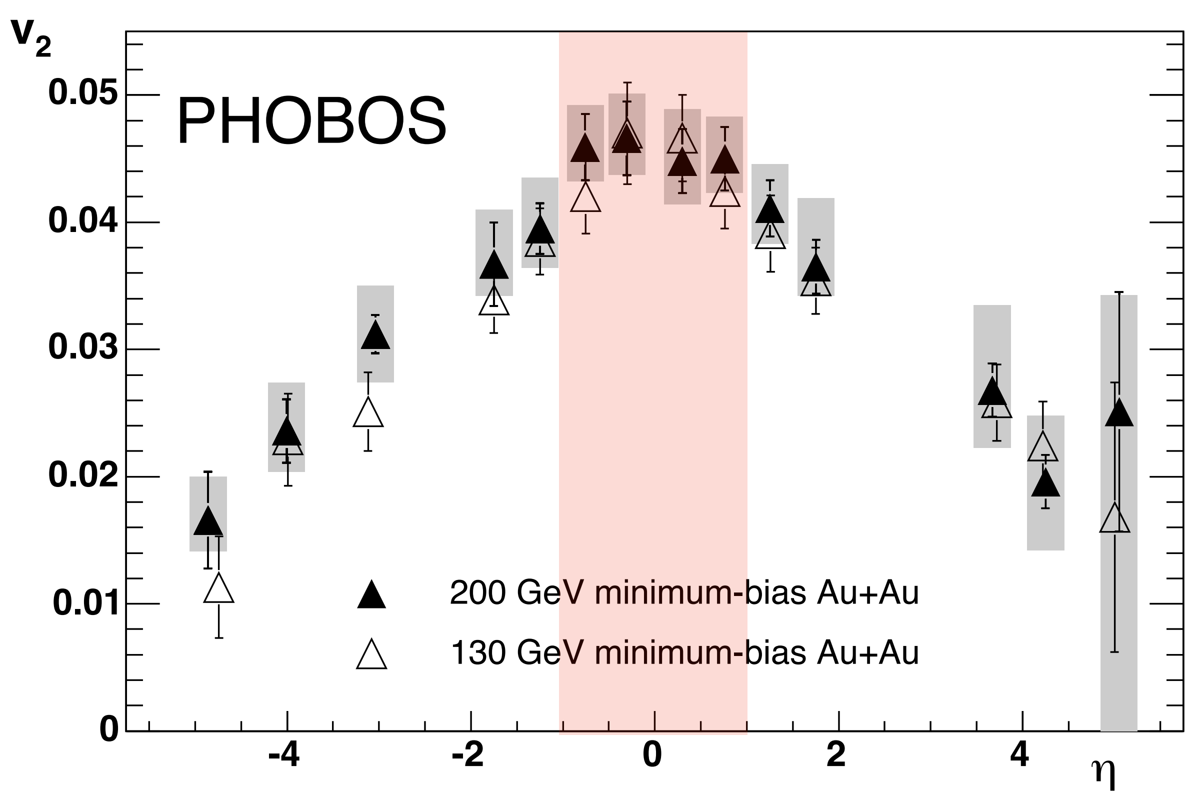
Can we map out the temperature dependence profile of transport parameters ?

Essential

Existing measurements at forward rapidity

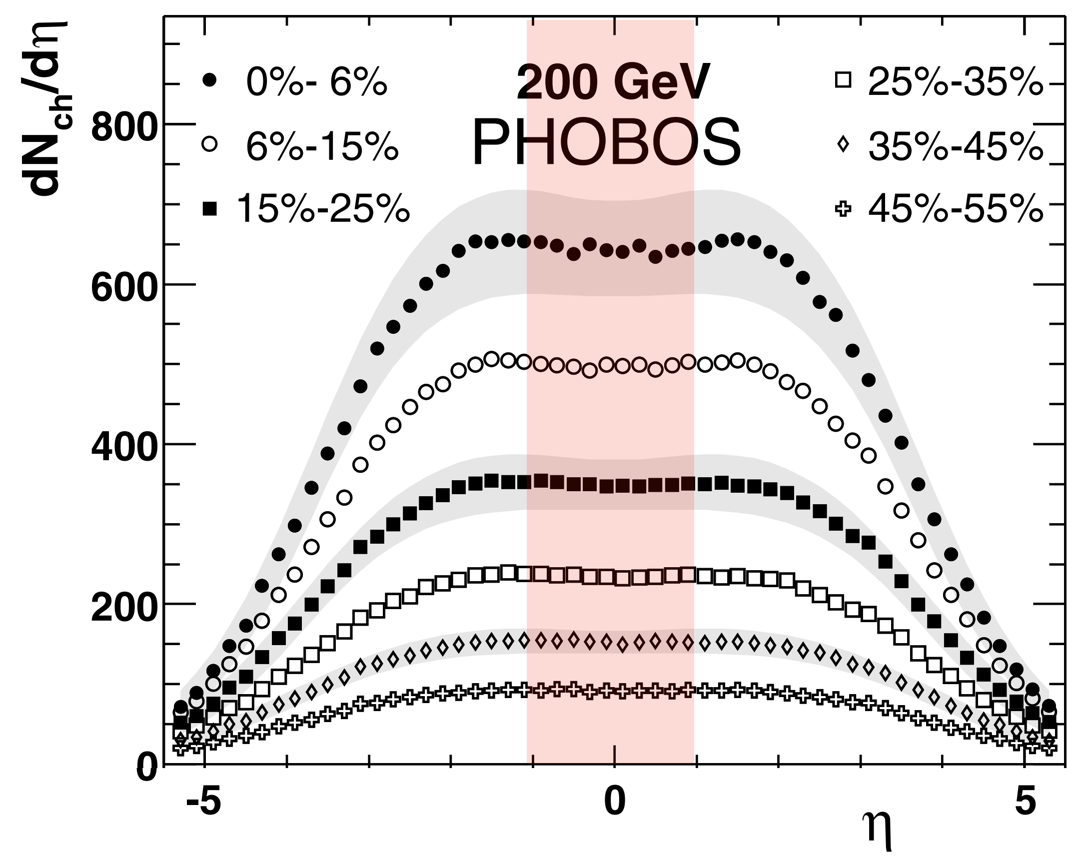
Limited previous measurements exist at forward rapidity at RHIC

Phys Rev C 72, 051901(R) (2005)



Charged hadrons flow

Phys. Rev. Lett. 91, 052303 (2003)



Charged hadrons multiplicity

No data on higher order flow harmonics (v_3, v_4, v_5)& rapidity density correlations/fluctuations $\left\langle \frac{dN}{dY_1}\frac{dN}{dY_2} \right\rangle$?

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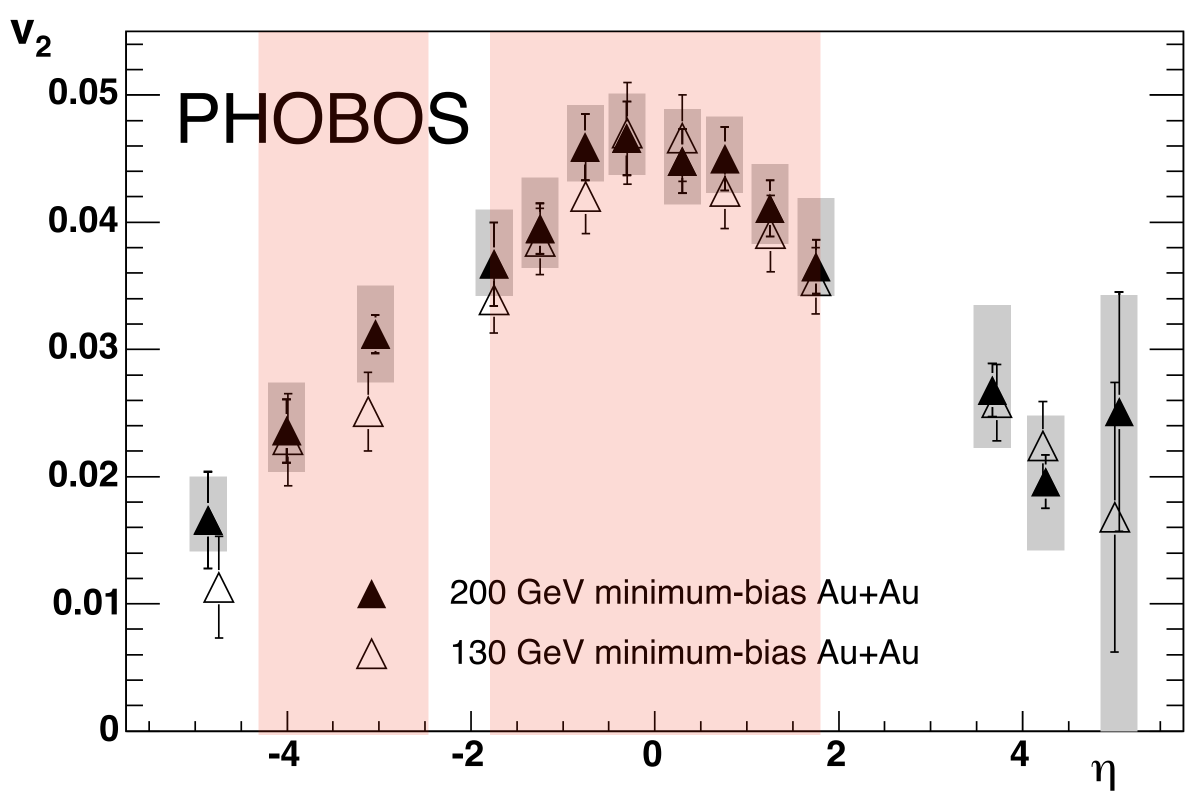

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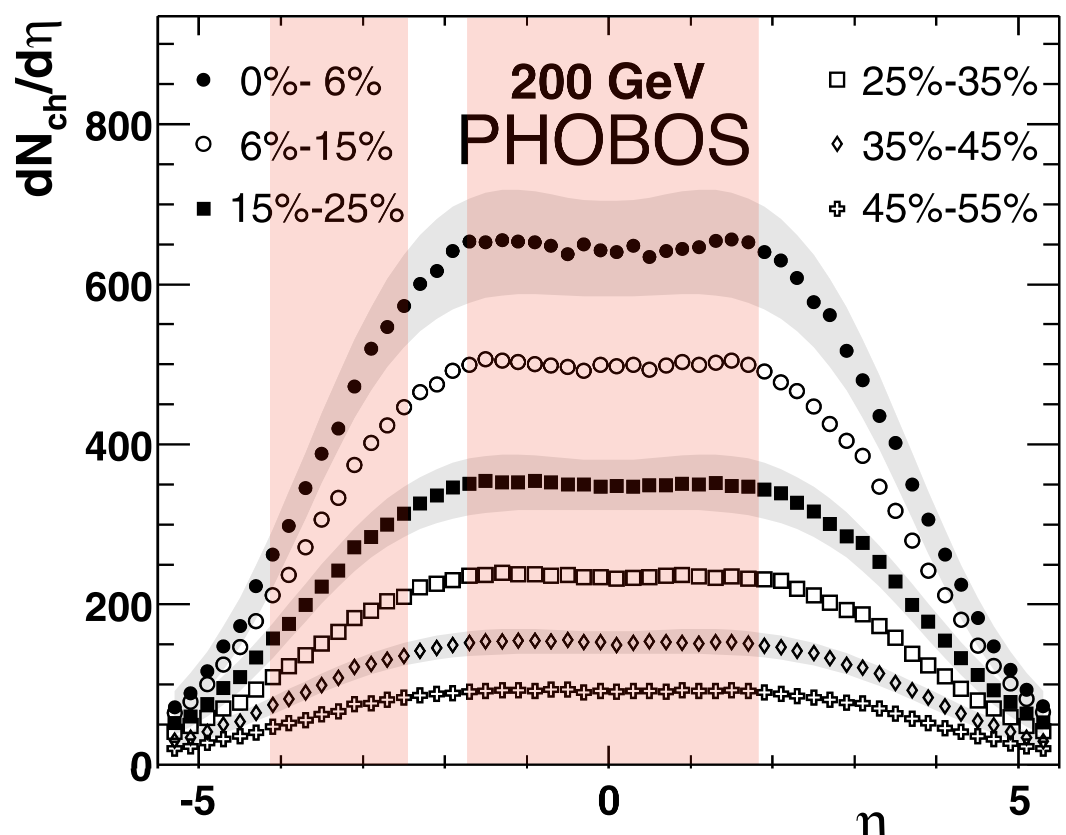

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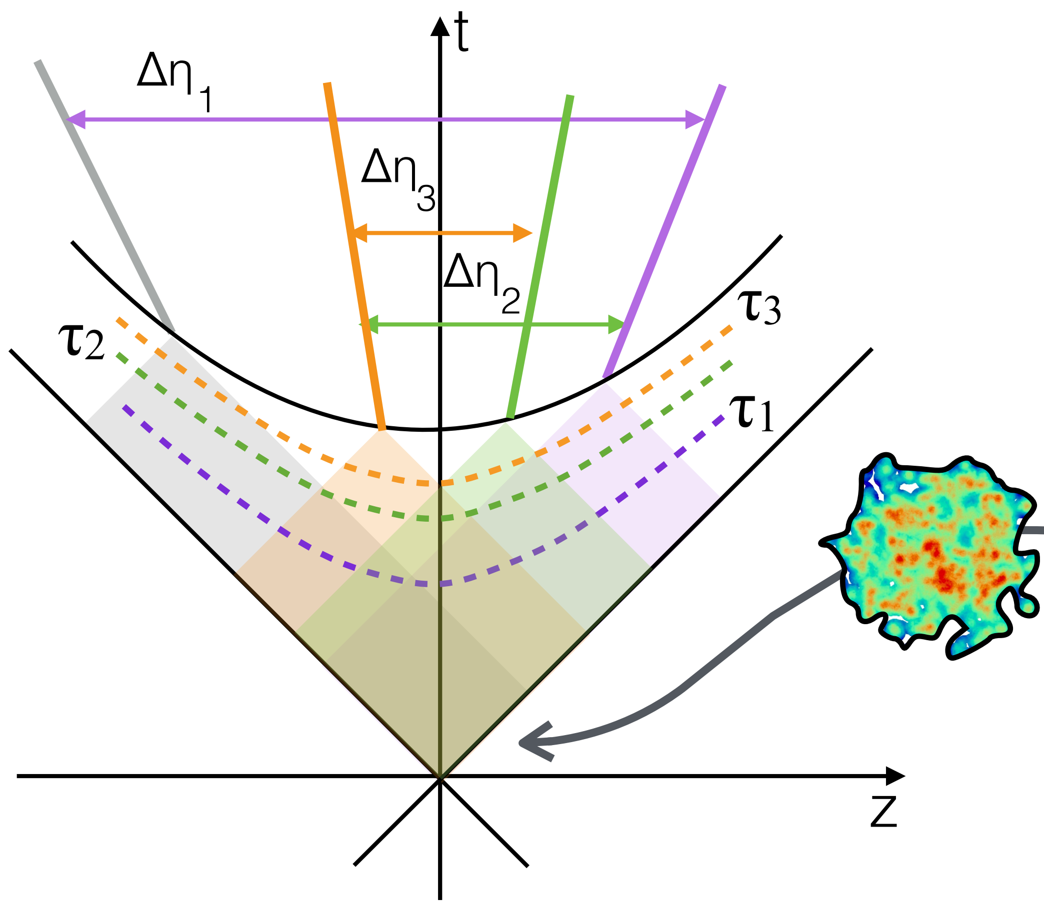
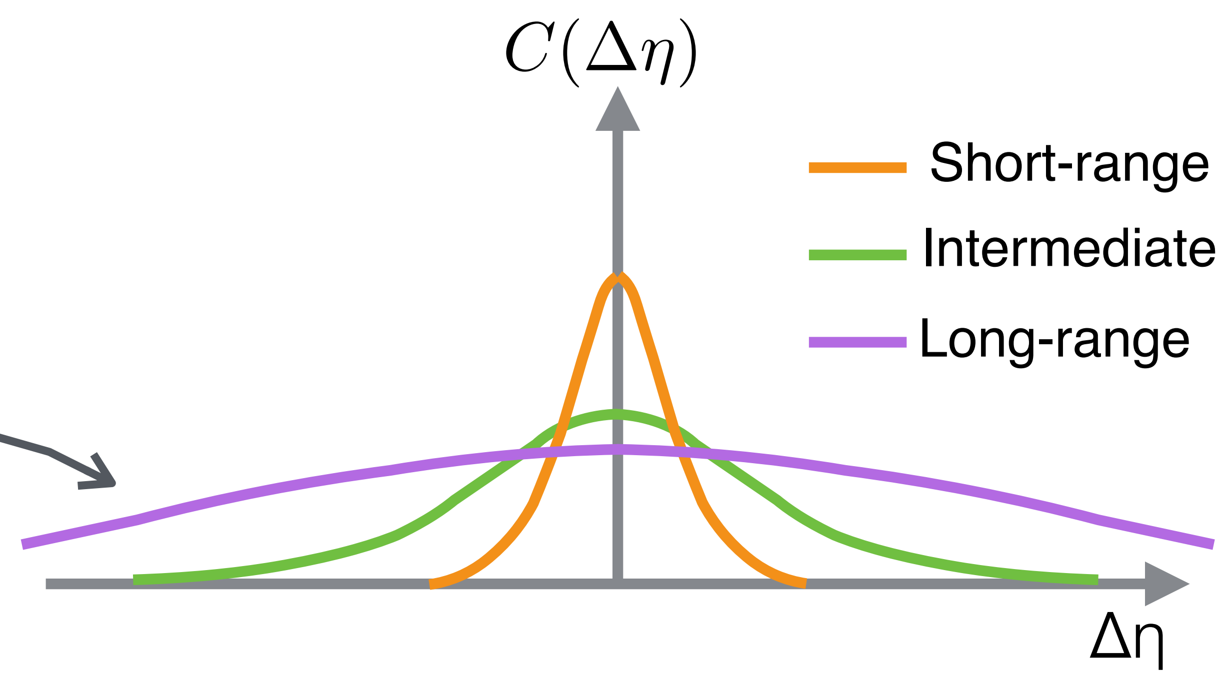
Why do we need wider window of rapidity ?

Dynamics of early time spread over wide range of rapidity





System produced in heavy ion collisions have lifetime of ~10 fm
Causality limits signals from different τ to spread at different Δη

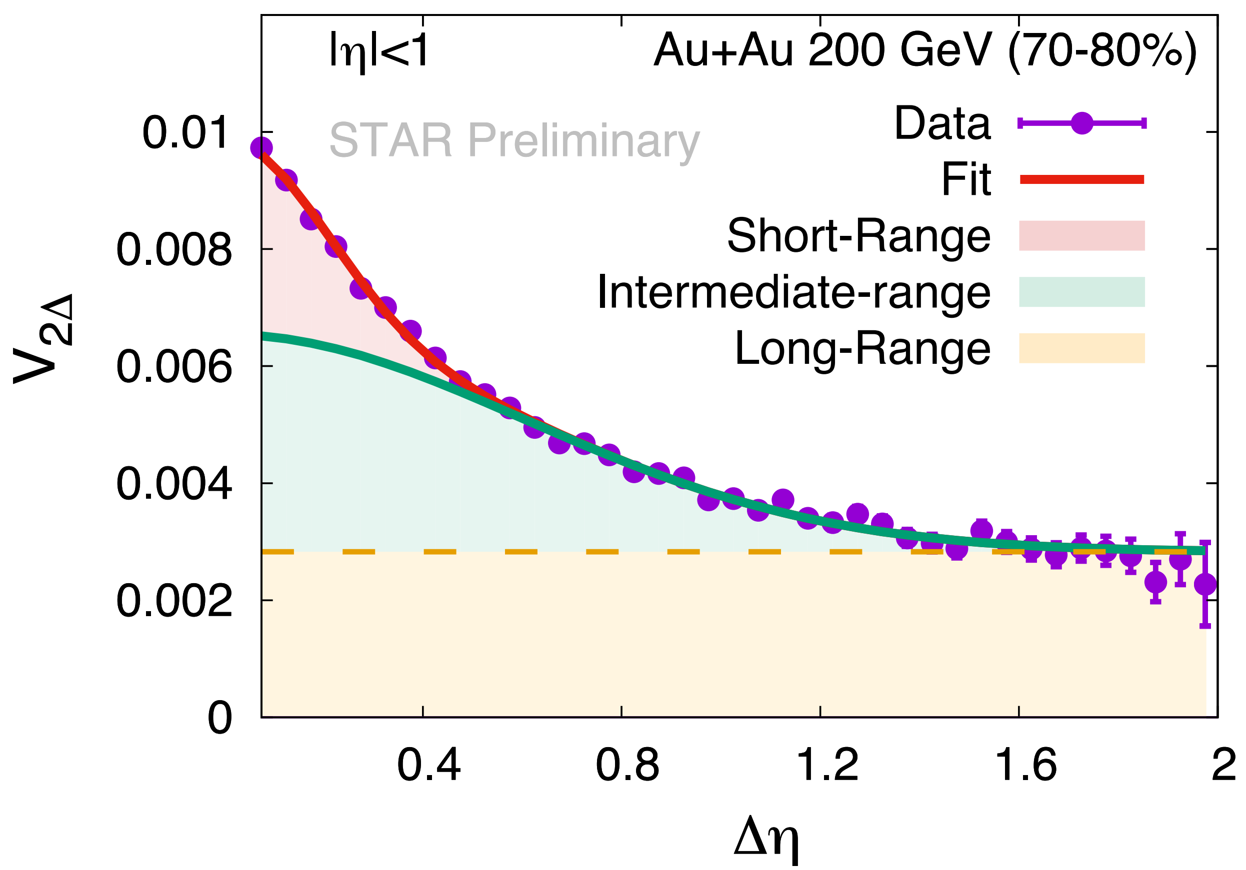
Different rapidity window → physics at different times

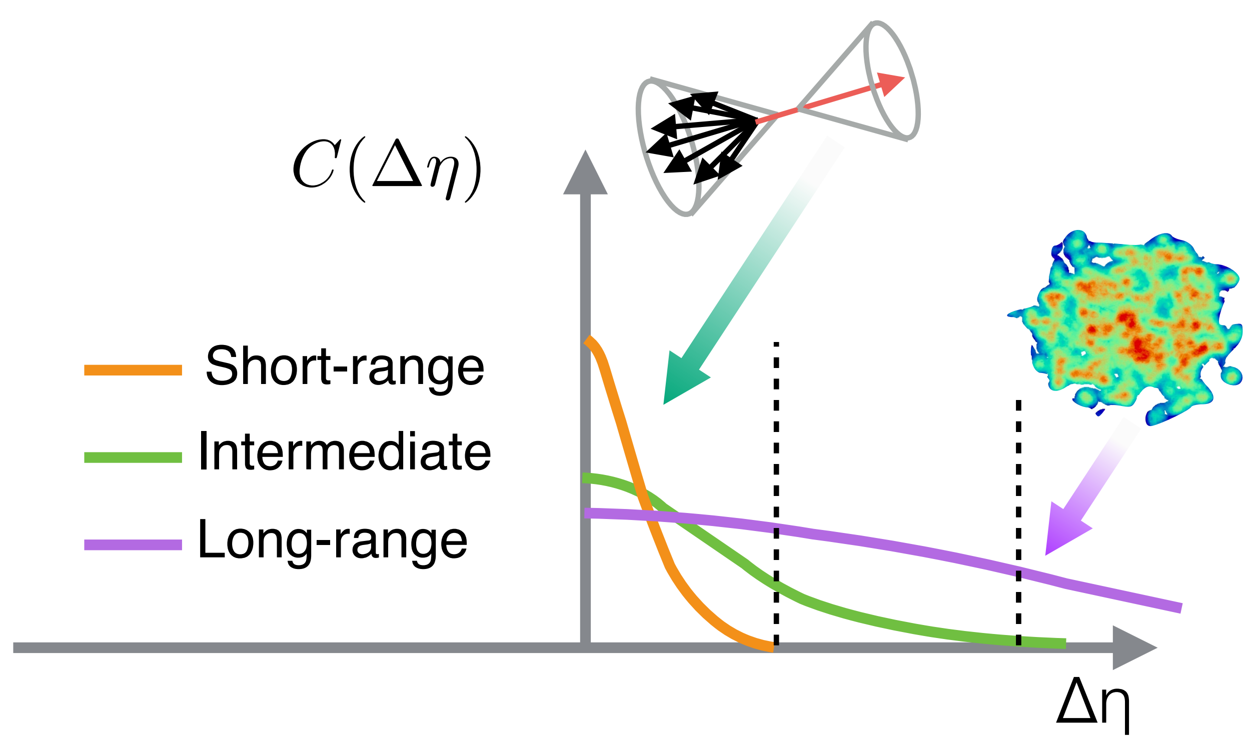
Why do we need wider window of rapidity ?

Flow like correlations are early time long-range → large Δη

Background comes from Jets & non-flow → small Δη

$$V_{2\Delta} = \langle \cos(2(\phi_1(\eta_1) - \phi_2(\eta_2))) \rangle$$





Precise extraction of flow (azimuthal correlations) requires measurements over wide window of rapidity

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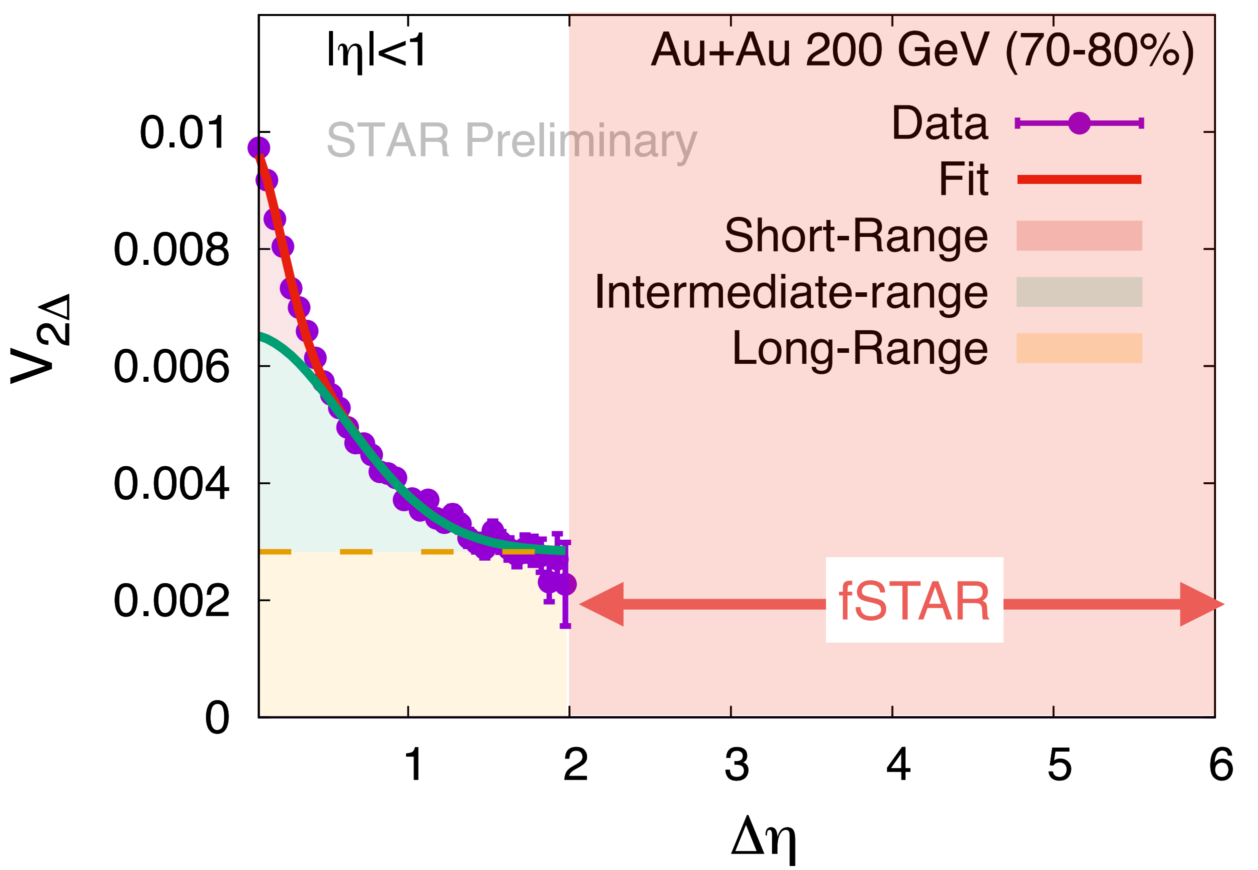

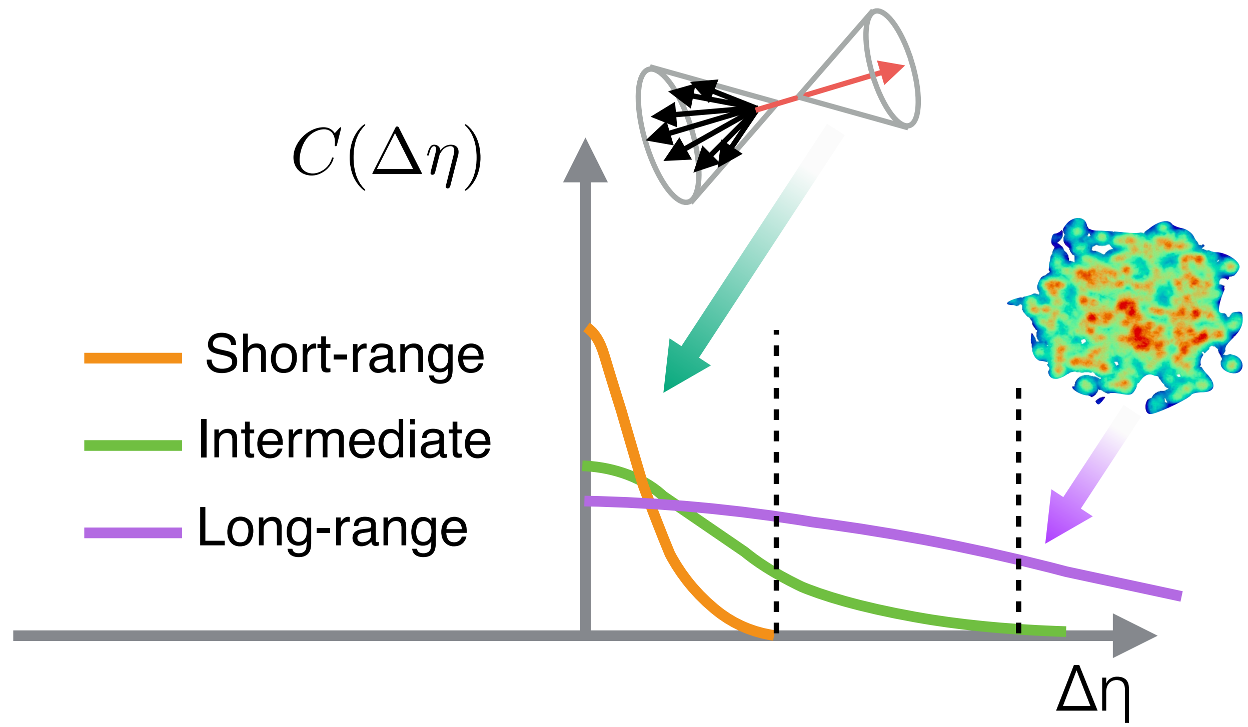

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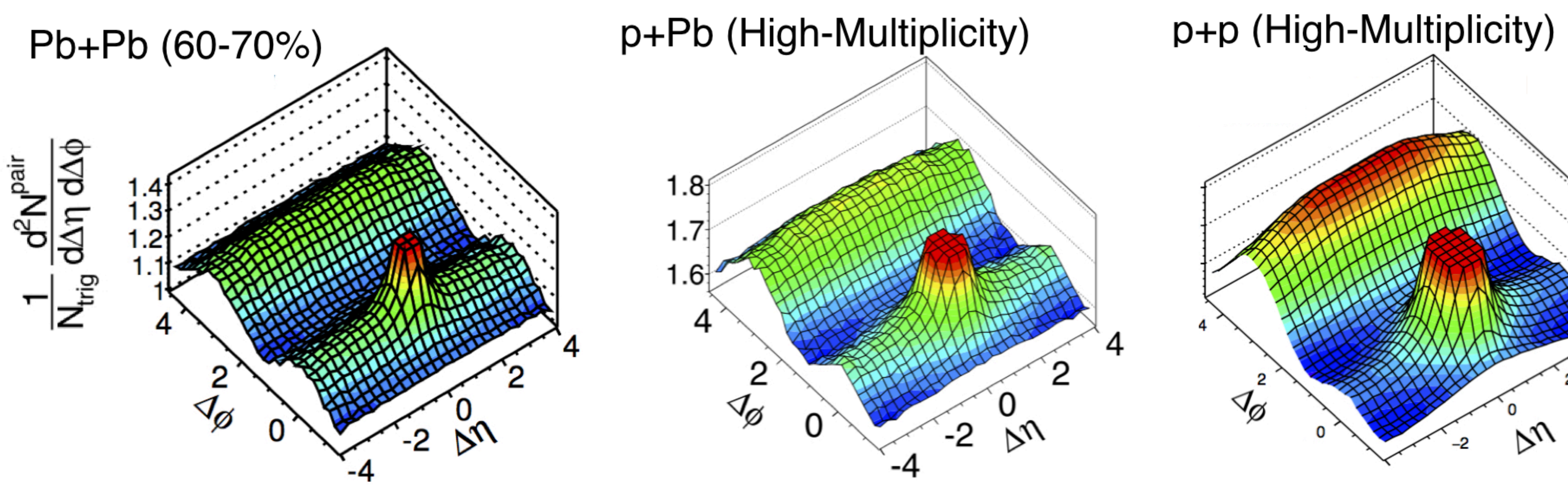
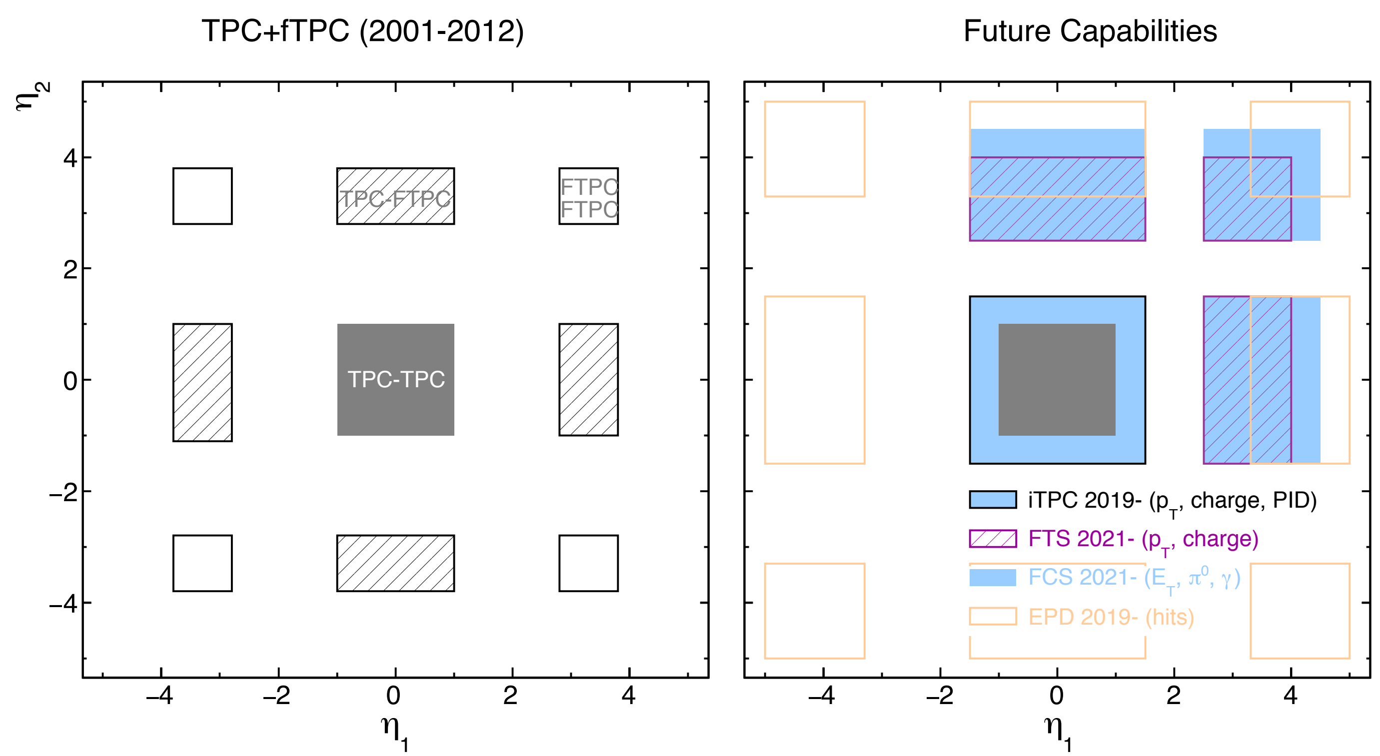
Why do we need wider window of rapidity ?

High multiplicity events in small collision systems and HICs



Long-range two particle correlations are of primary interest for small collisions system

Unique opportunity with fSTAR

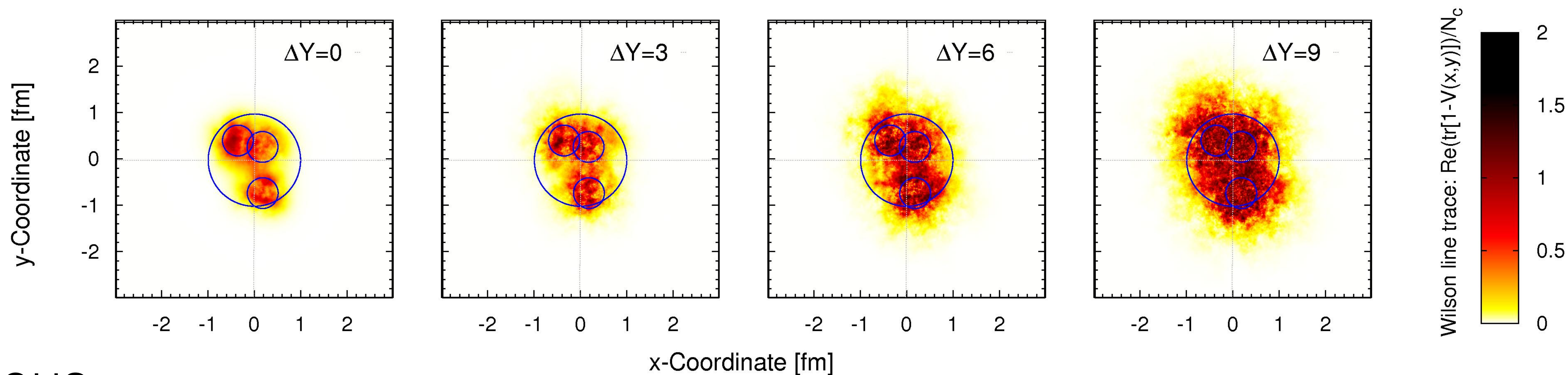


Rapidity provides ways to vary Bjorken x

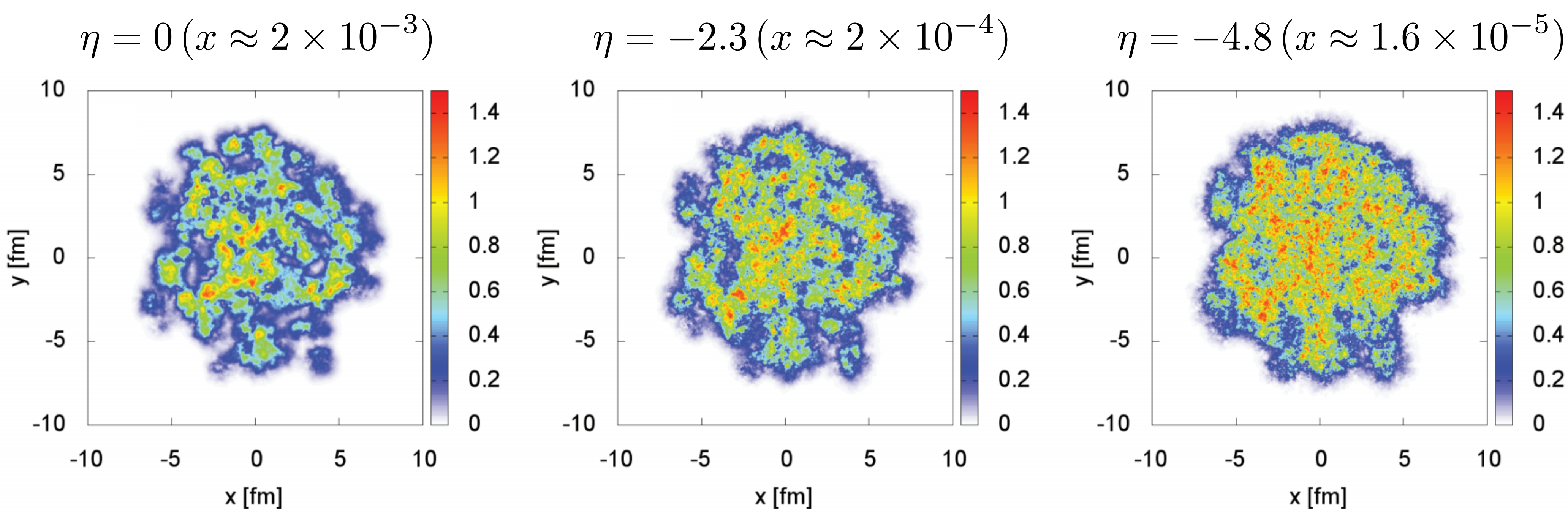
Proton

small x →

Schenke, Schlichting 1407.8458



Nucleus

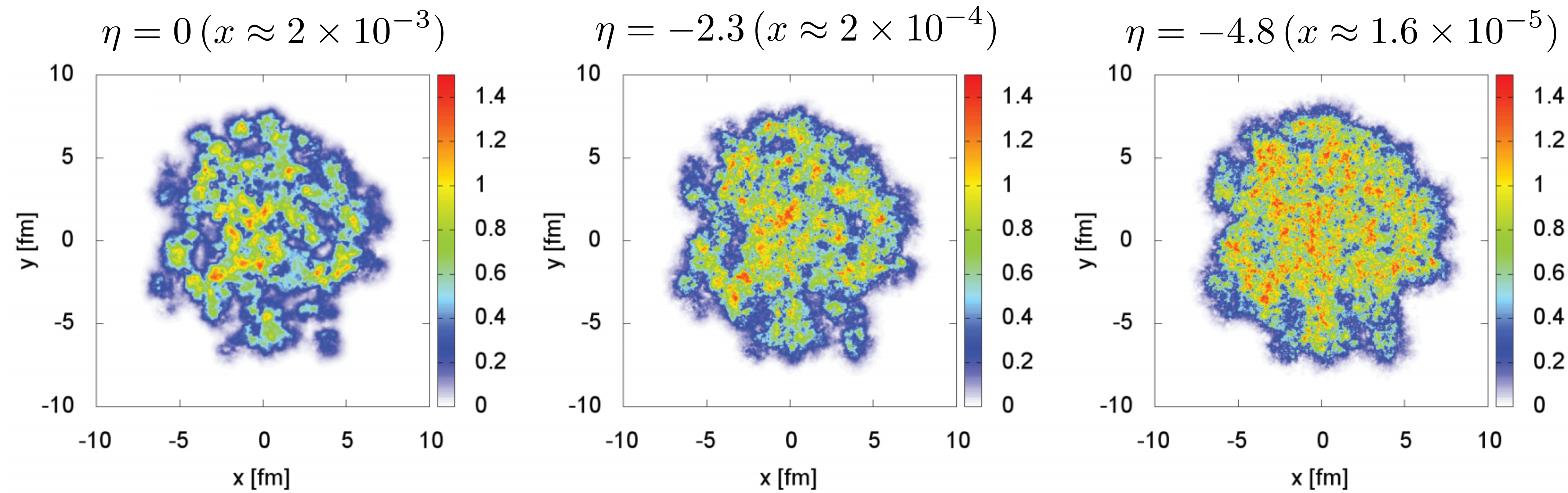


Gluon density inside protons and nuclei changes with x (rapidity)

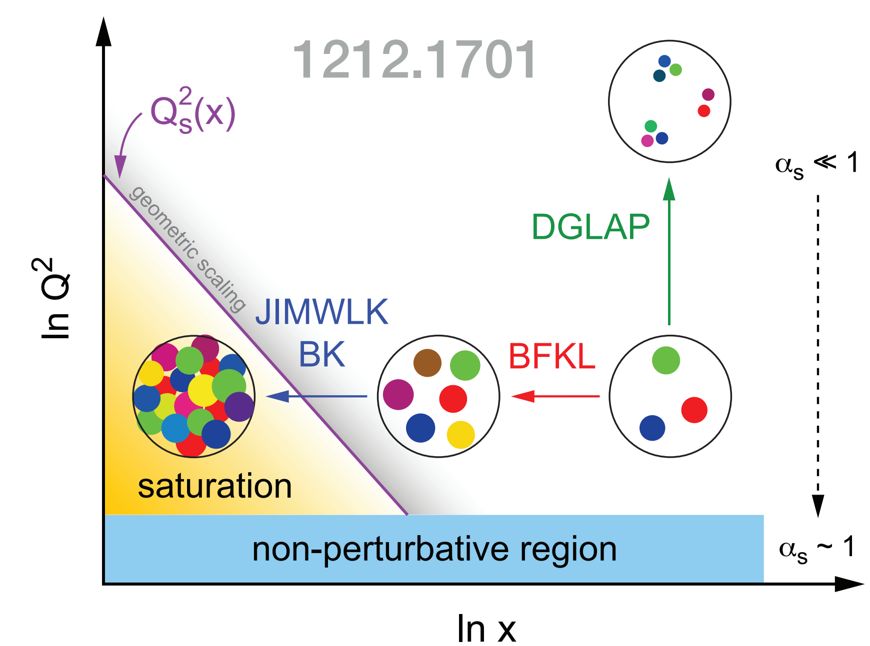
Testing ground for QCD evolution equations (BK, JIMWLK)

Rapidity provides ways to vary Bjorken x

fig : Schenke, Schlichting 1605.07158



Rapidity evolutions → predictions of non-linear regime of High energy QCD effective theory (CGC)

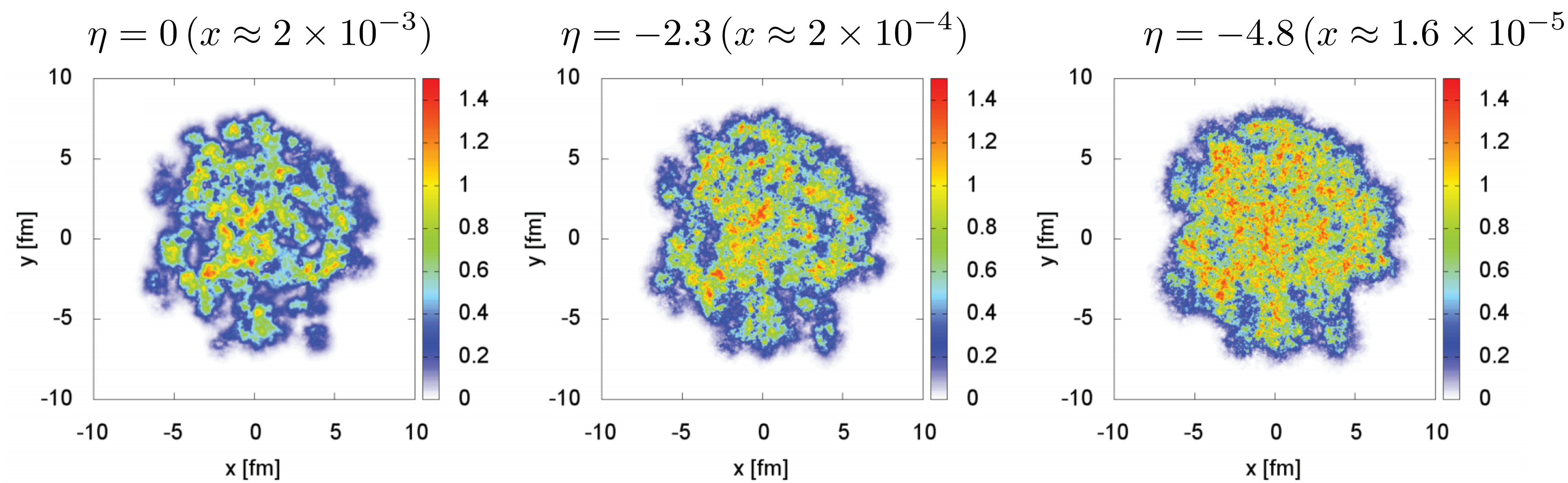


LHC data provide constrains for BK, JIMWLK, RHIC data will provide test

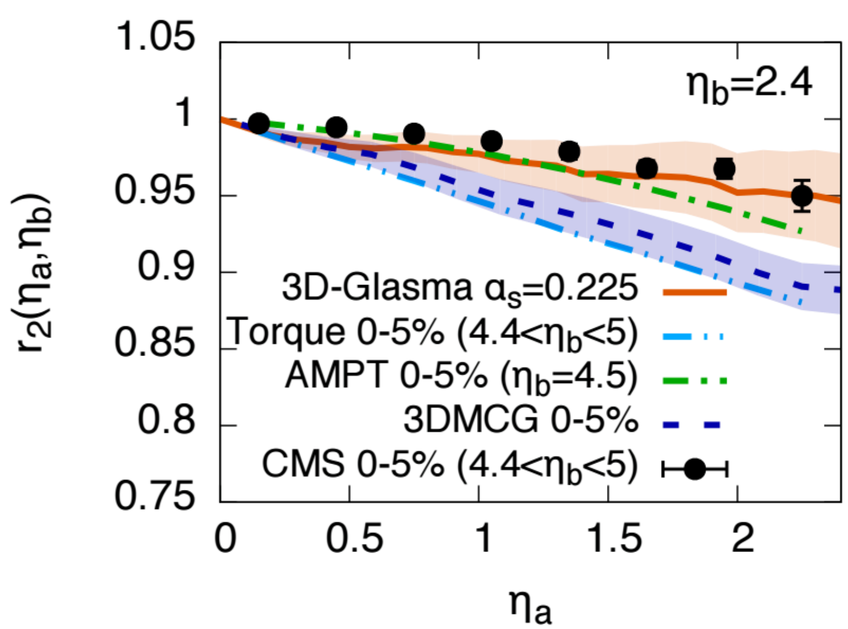
Constraining gluon density inside nuclei → smooth transition to EIC physics

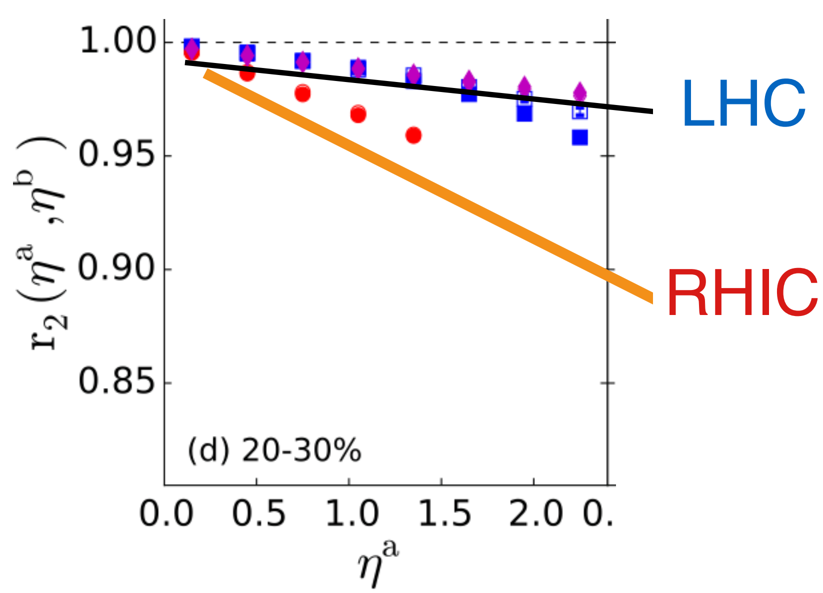
Why study at RHIC is important ?

fig : Schenke, Schlichting 1605.07158



Observables : $r_n(\eta^a, \eta^b) \equiv \frac{V_{n\Delta}(-\eta^a, \eta^b)}{V_{n\Delta}(\eta^a, \eta^b)}$ $\quad V_{n\Delta} = \langle \cos(n(\phi_1(\eta_1) - \phi_2(\eta_2))) \rangle$

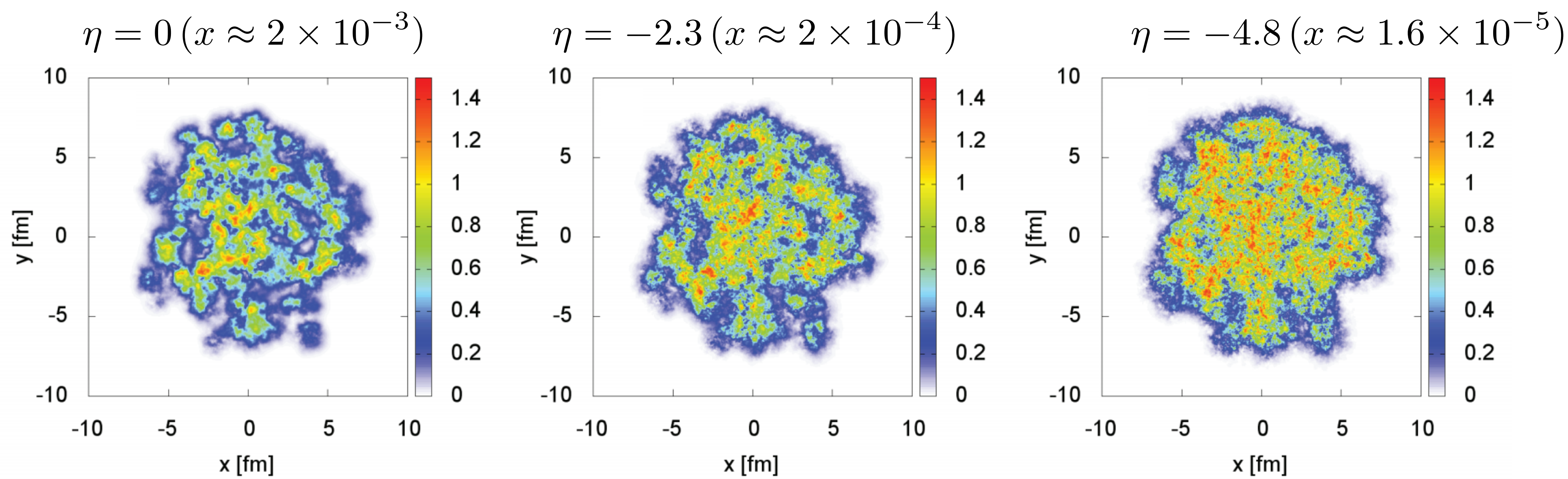




Stronger De-correlation predicted at RHIC than LHC

Very first attempt from STAR

fig : Schenke, Schlichting 1605.07158



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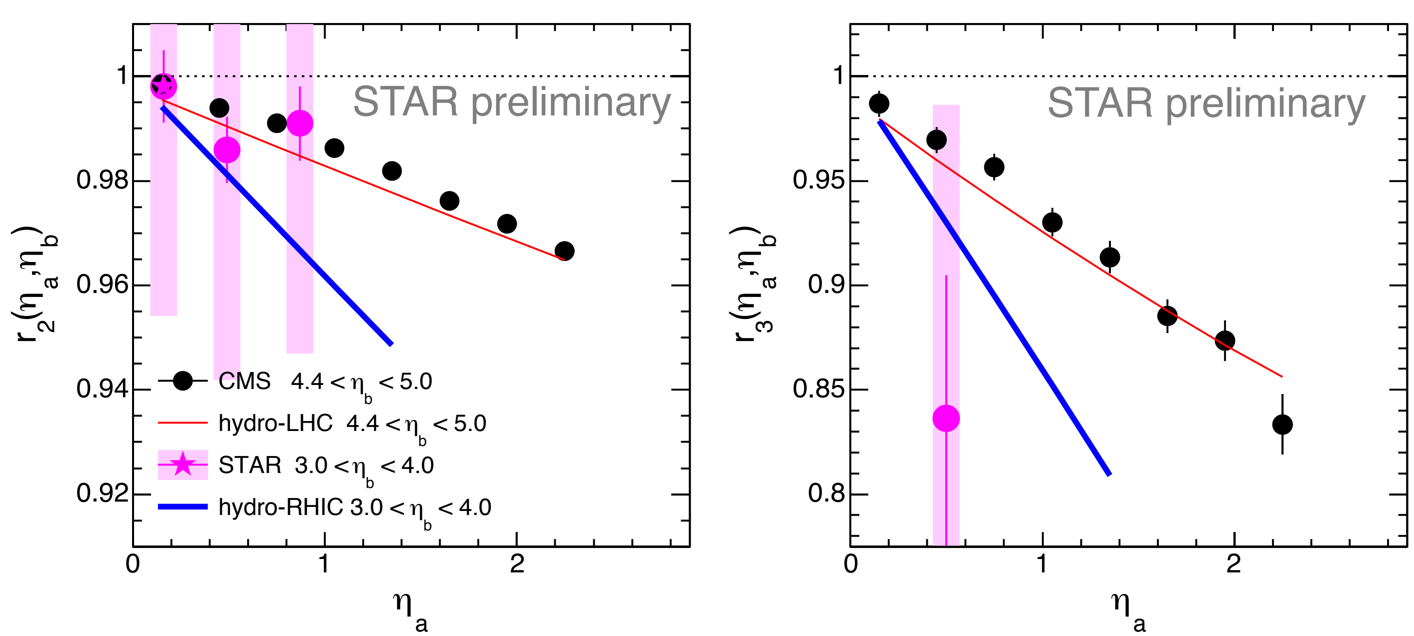


Current measurements with FTPC (3<η<4) have large uncertainties

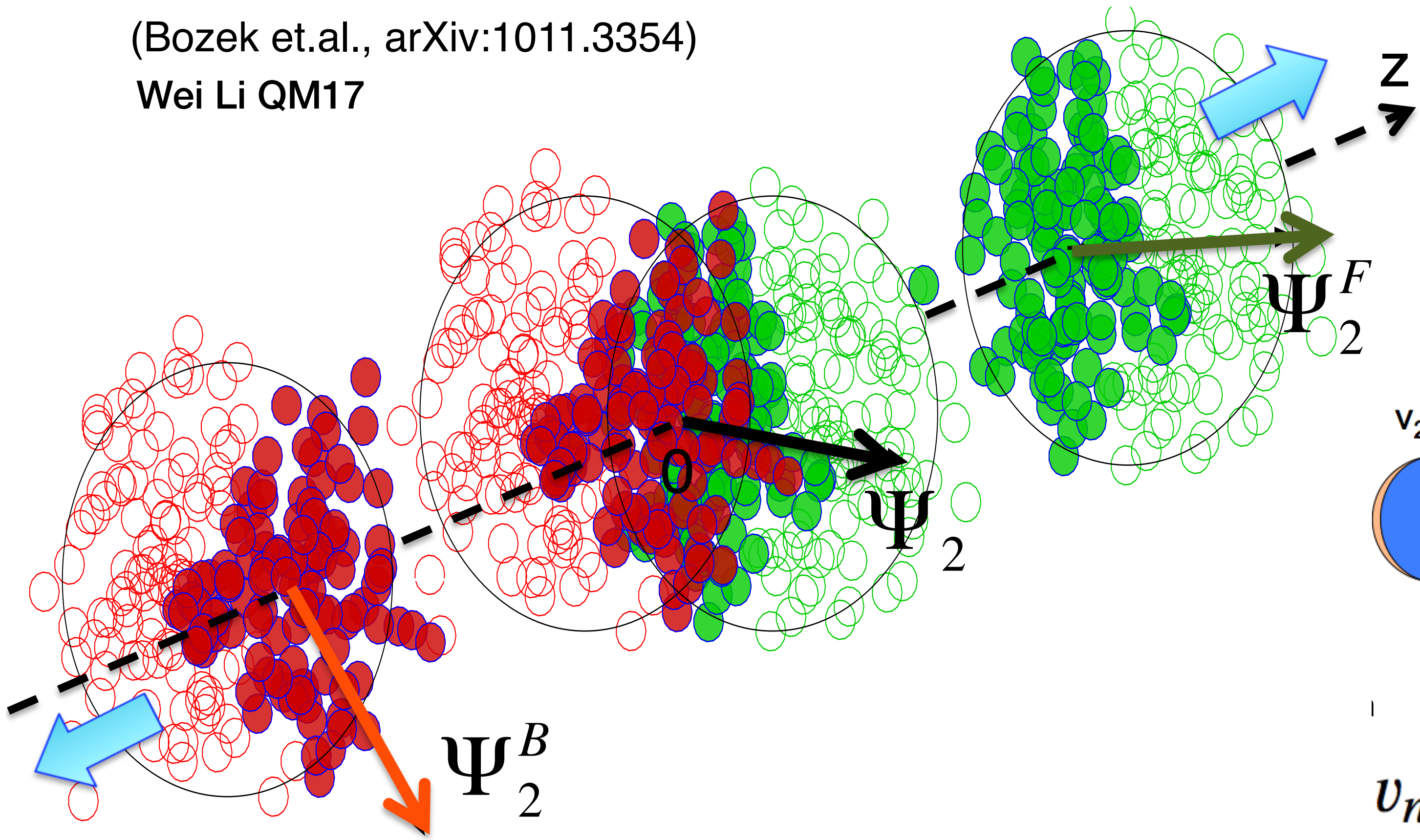
fSTAR will provide improved measurements

Why study at RHIC is important ?

Stronger breaking of **boost-invariance** →
due to longitudinal fluctuations at RHIC

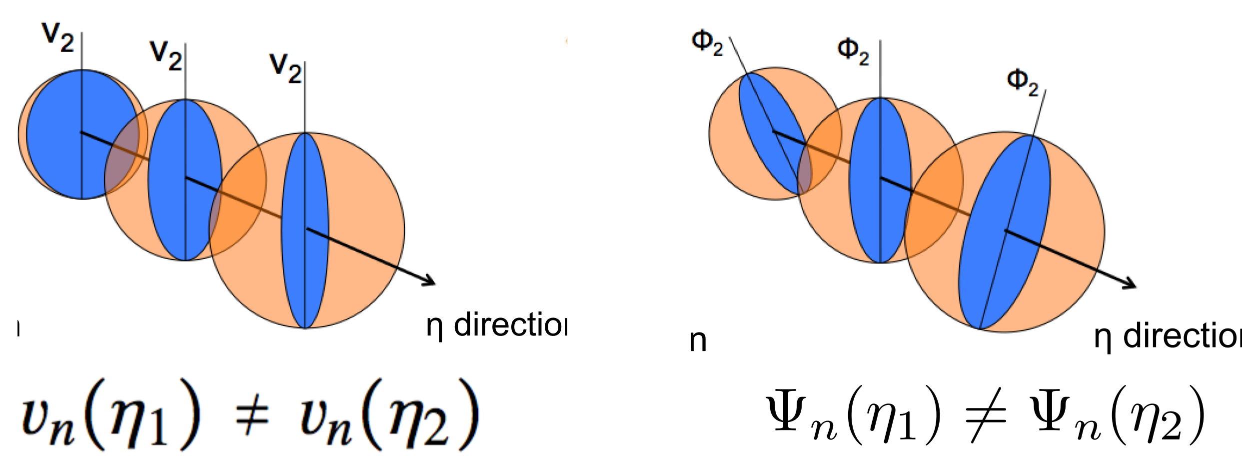
RHIC → lower energies & Y_{beam} nucleon scale fluctuations dominate

Forward and backward going participants determine the shape of participant zone



Because of **torque** and **twist** effects both magnitude of flow and direction change

Peng Huo QM17

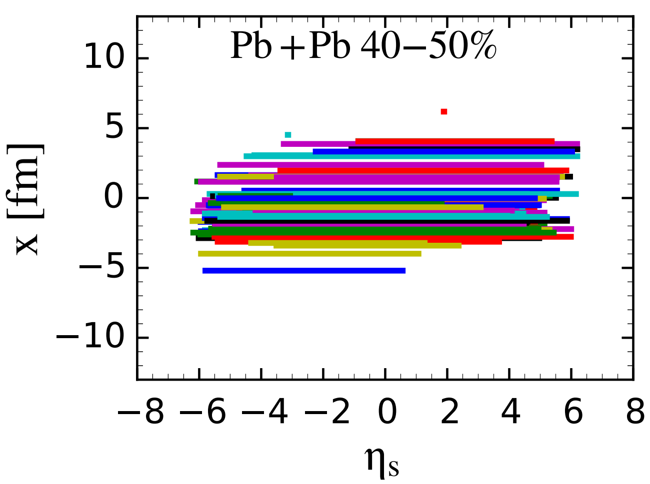


Initial state at low energy is poorly understood, RHIC is ideal

3D structure of Initial state physics

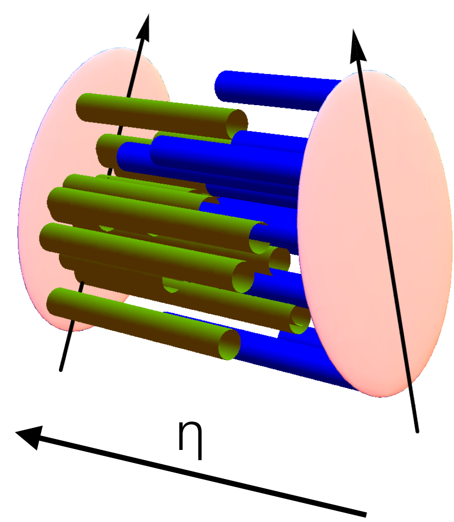
Several recent models have been proposed with different underlying dynamics for longitudinal structure of initial state of HICs

Longitudinal strings



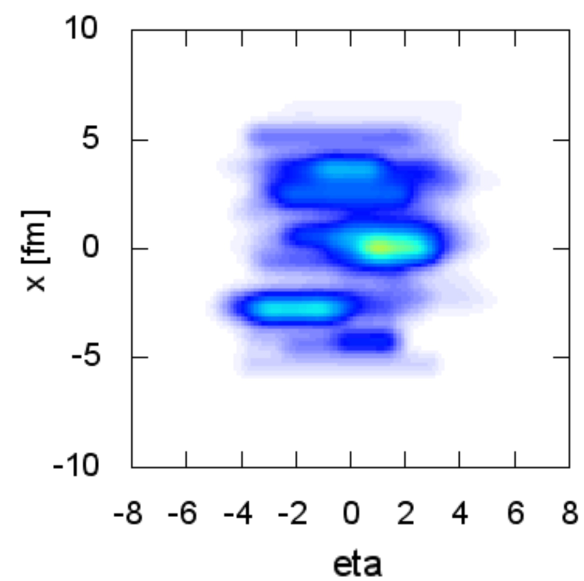
Pang, Petersen, Qin, Roy, Wang 1511.04131

Torqued fireball



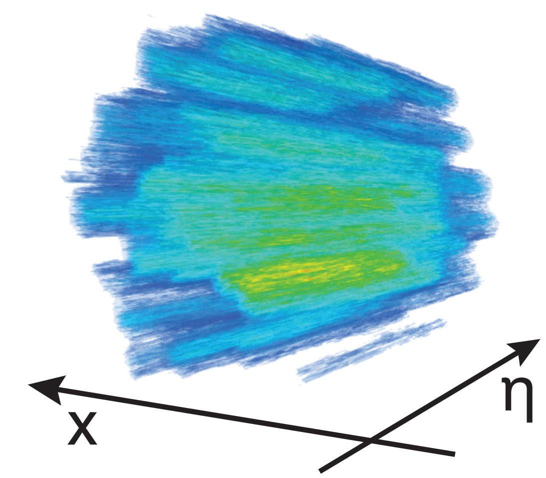
Bozek, Broniowski 1506.02817

3D-Glauber



Schenke, Monnai 1509.04103

3D-Glasma



Schenke, Schlichting 1605.07158

Can future measurement discriminate these models ?

What is the scale at which boost invariance is broken ?

3D structure of Initial state physics

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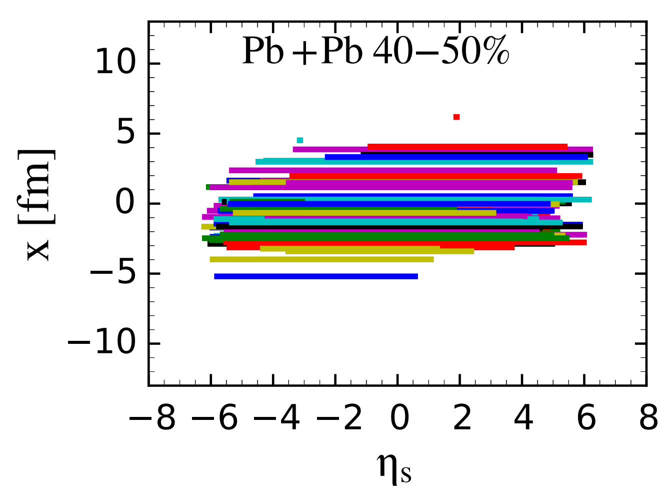
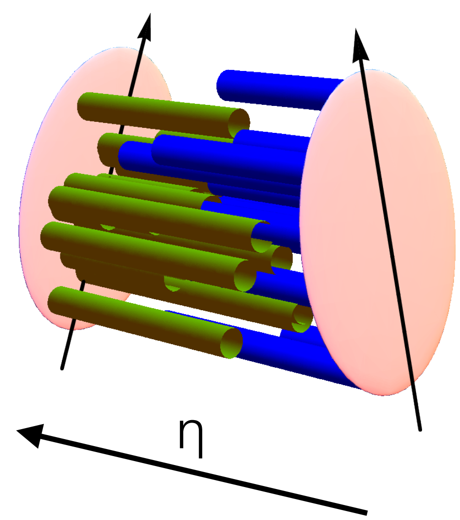
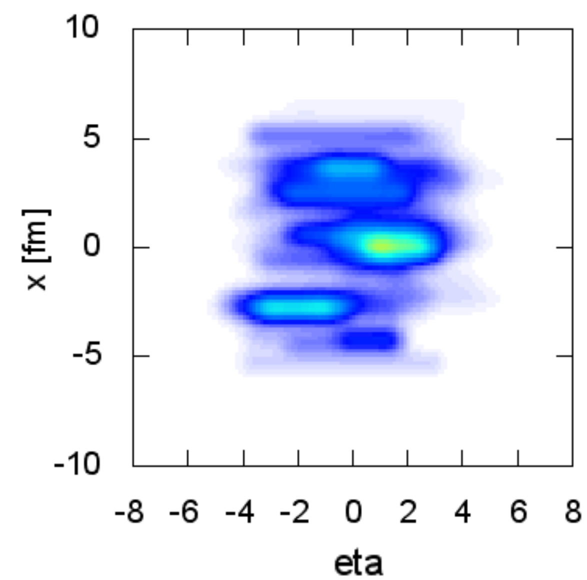
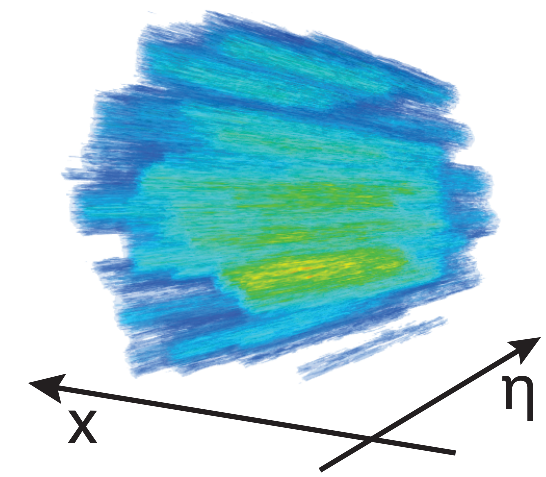
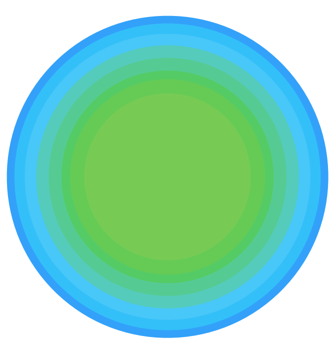
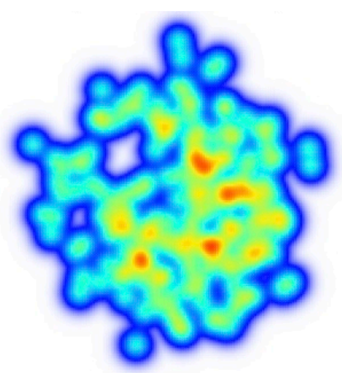
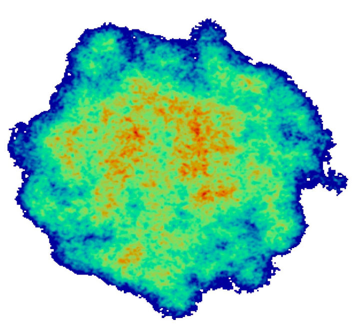
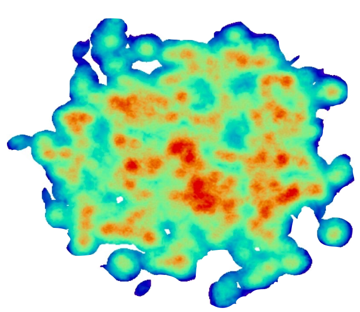








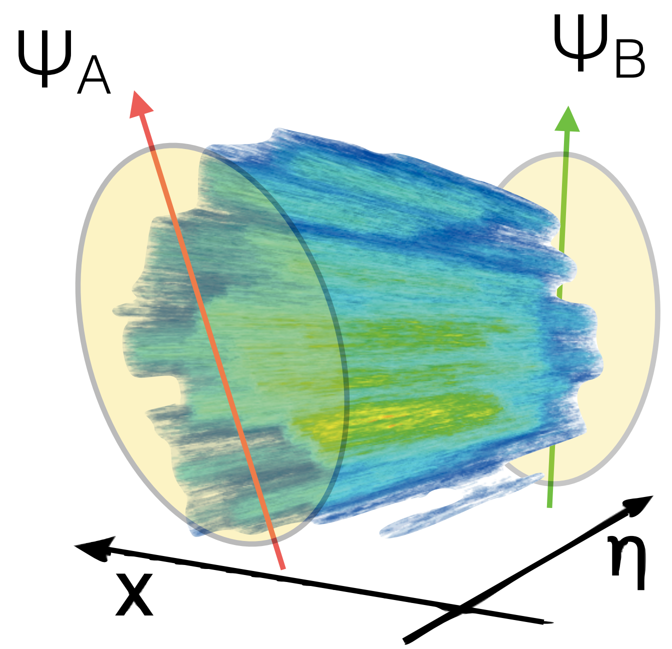
· · · 2004 2008-10 2012-14 2016 · · ·

Will history repeat itself ?

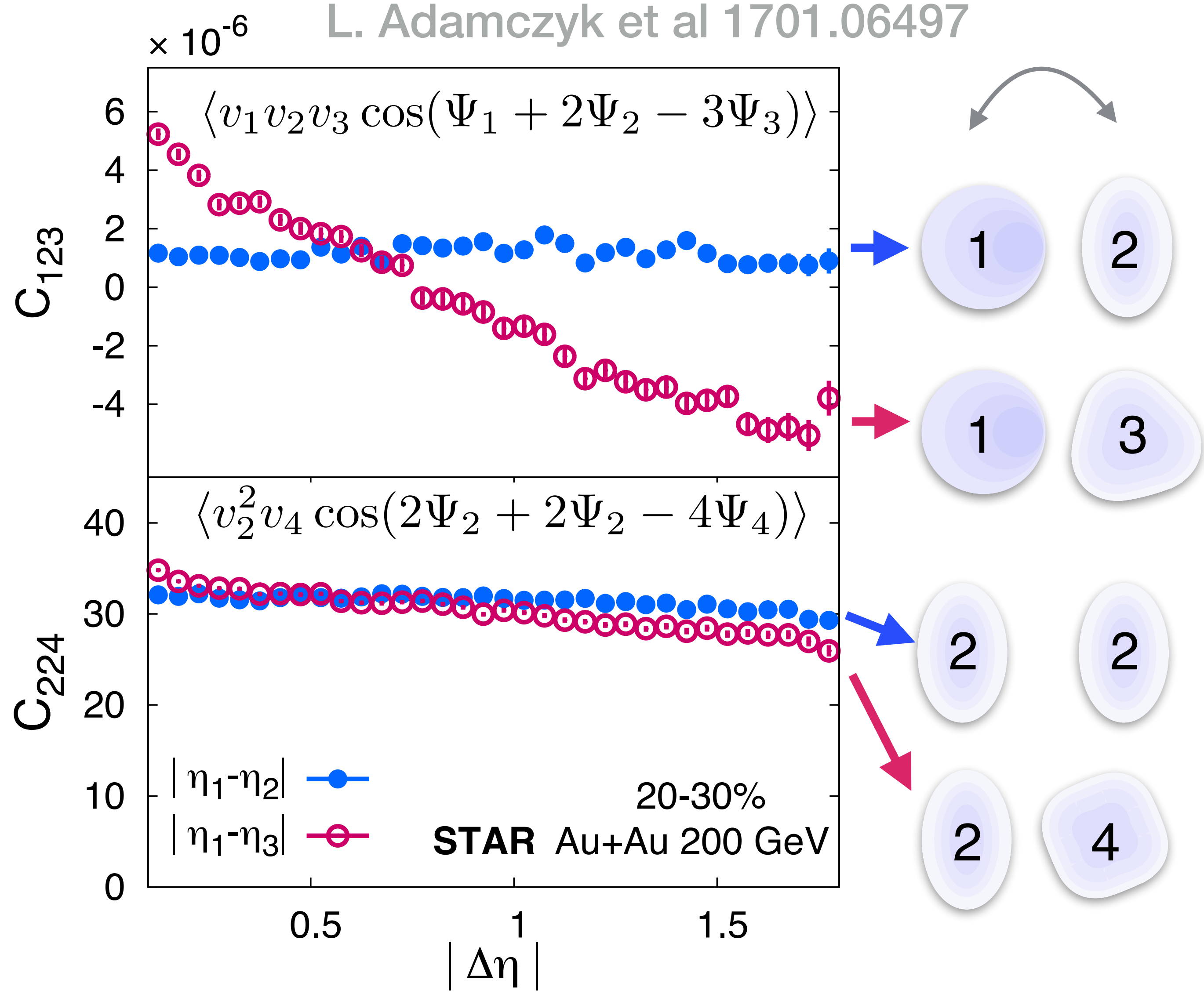
Very first attempt from STAR

Measurement from STAR with existing detectors :
Hints of longitudinal de-correlations

fig : 1605.07158



L. Adamczyk et al 1701.06497



Measurement using 300 M event with TPC → could go up to 1.8

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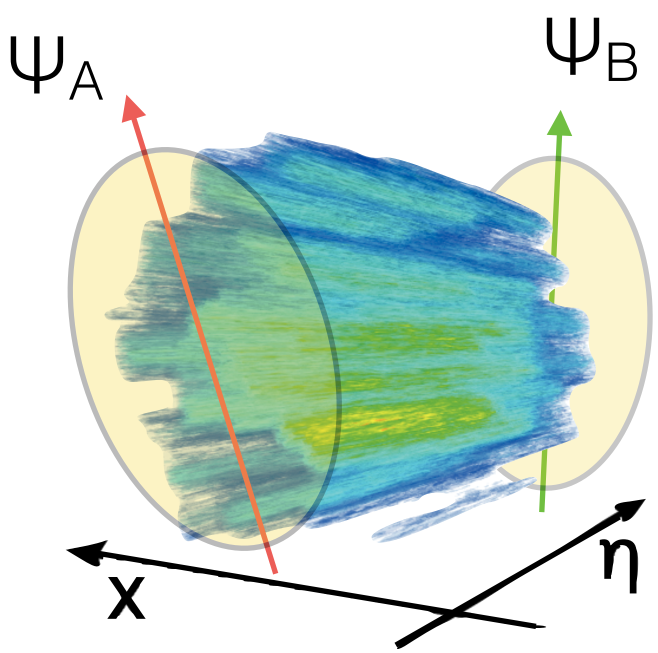

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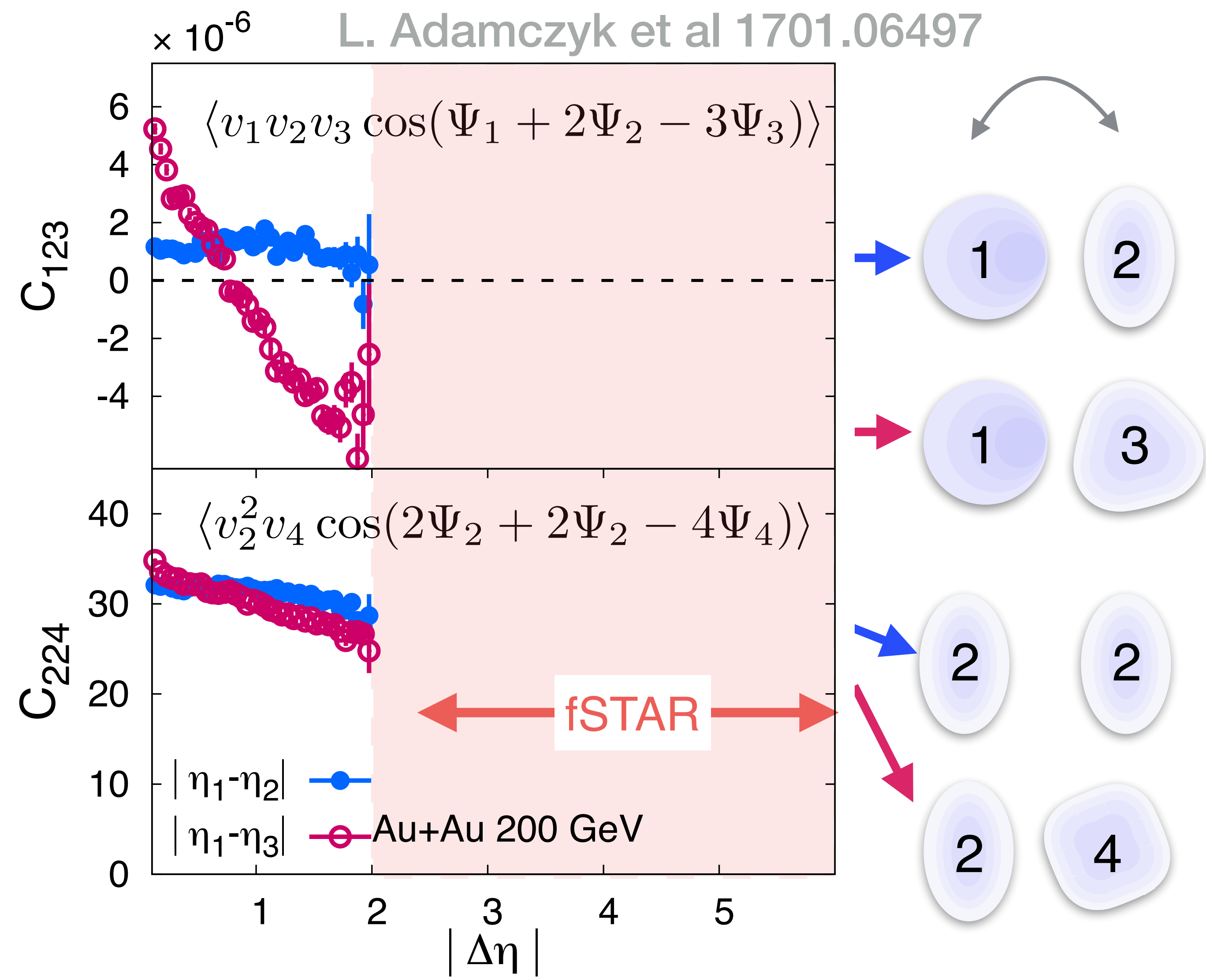


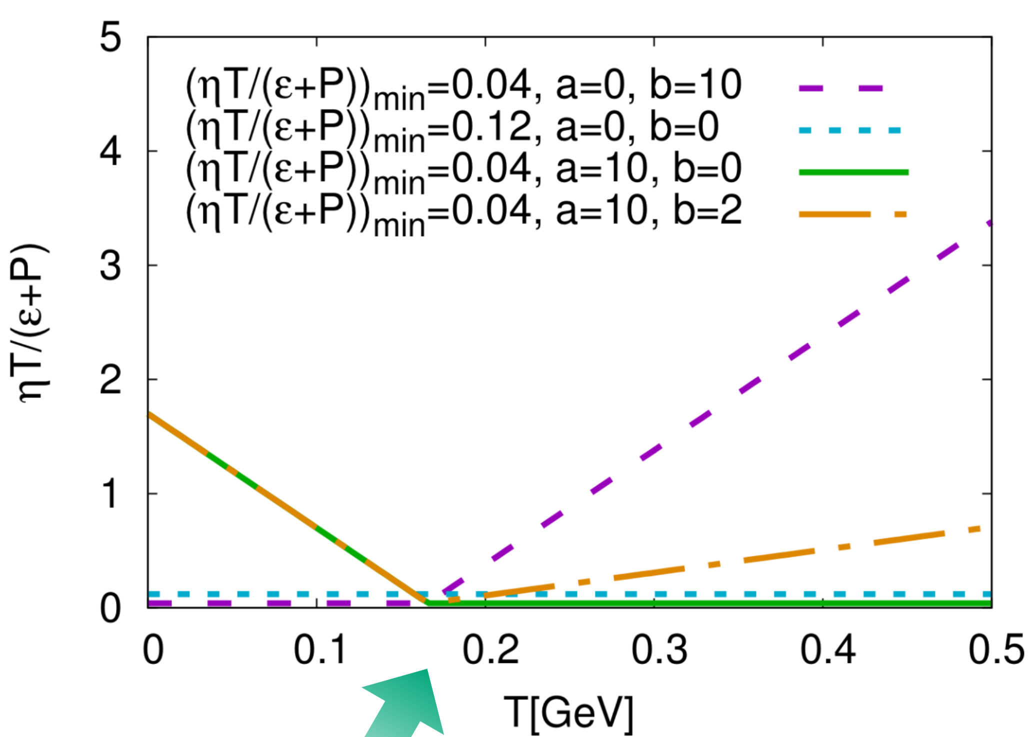
Measurement using 300 M event with TPC → could go up to 1.8

Wider Δη can probe this in more details

Constraining temperature dependence of η/s(T)

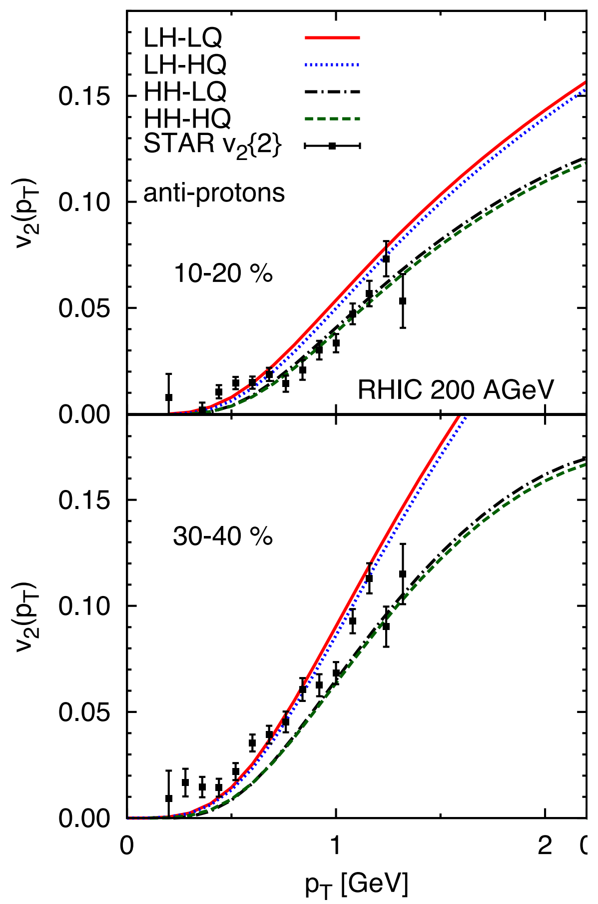
Viscosity has temperature dependence

Niemi et al 1203.2452

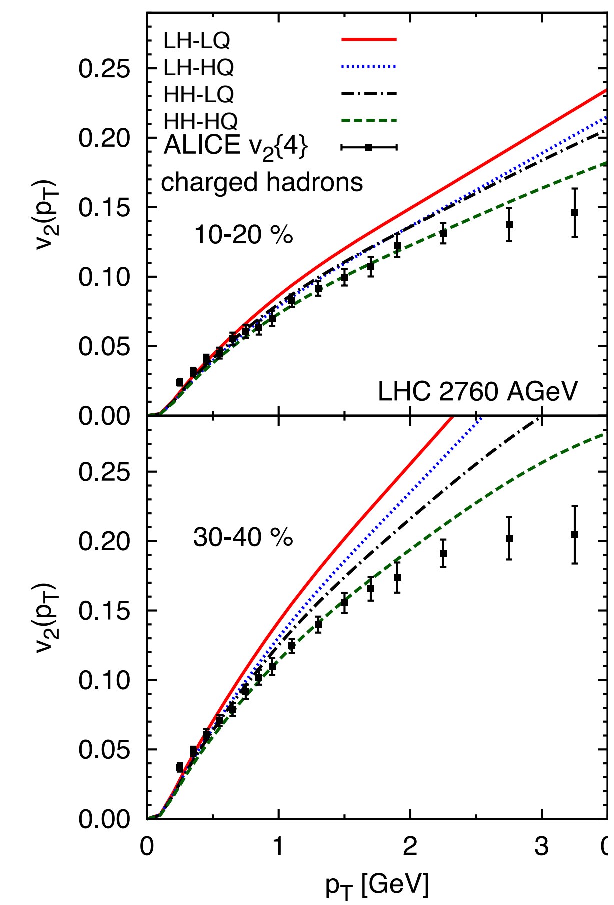


Region of perfect fluidity

RHIC $\eta/s(T \lesssim T_C)$



LHC $\eta/s(T > T_C)$

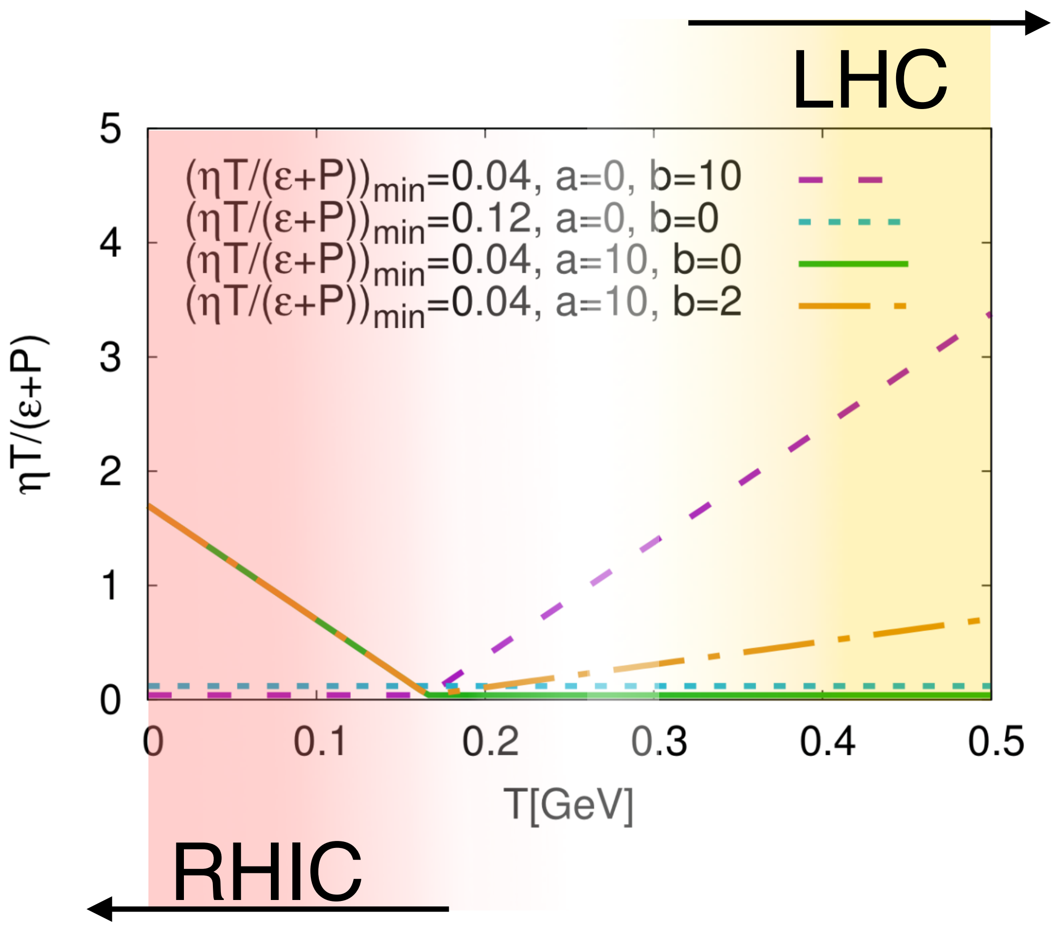


η/s (T) → can not be fully constrained by measurements at single energy

Constraining temperature dependence of η/s(T)

Viscosity has temperature dependence :

Niemi et al 1203.2452



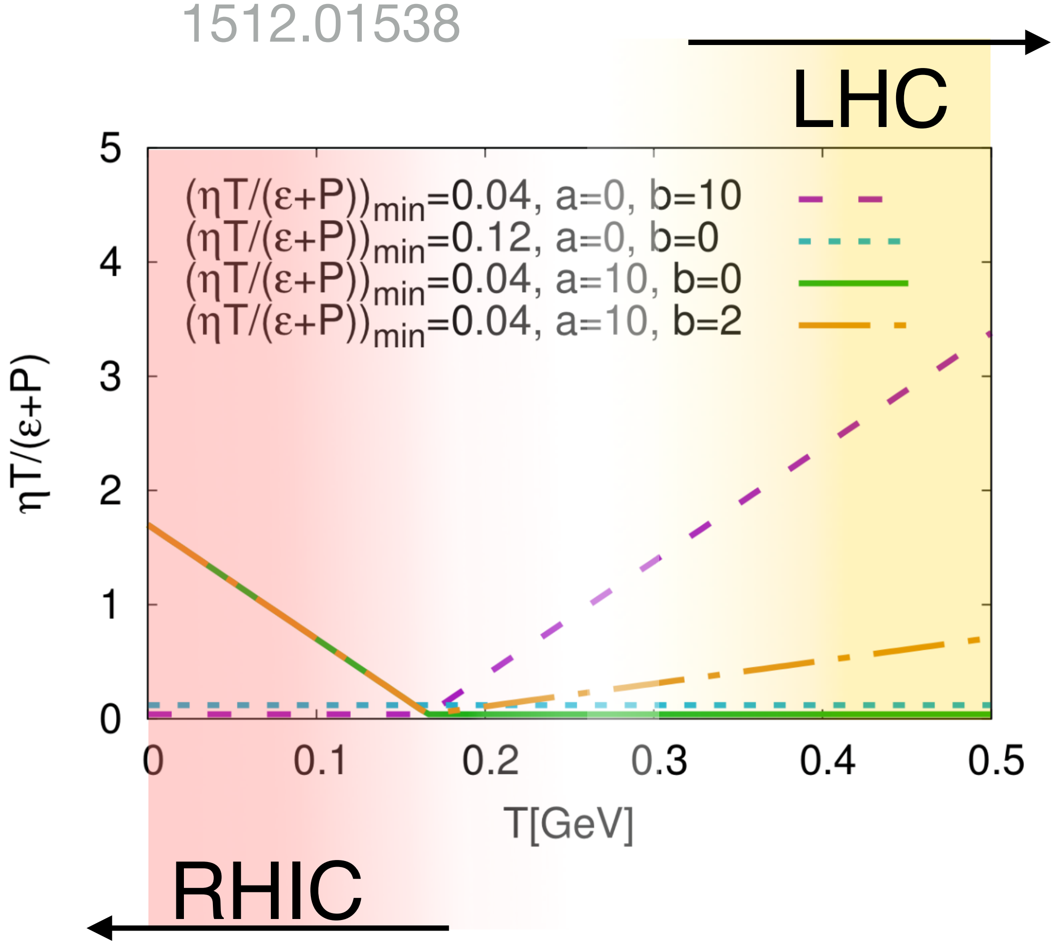
η/s (T) → can not be fully constrained by measurements at single energy

Constraining temperature dependence of η/s(T)

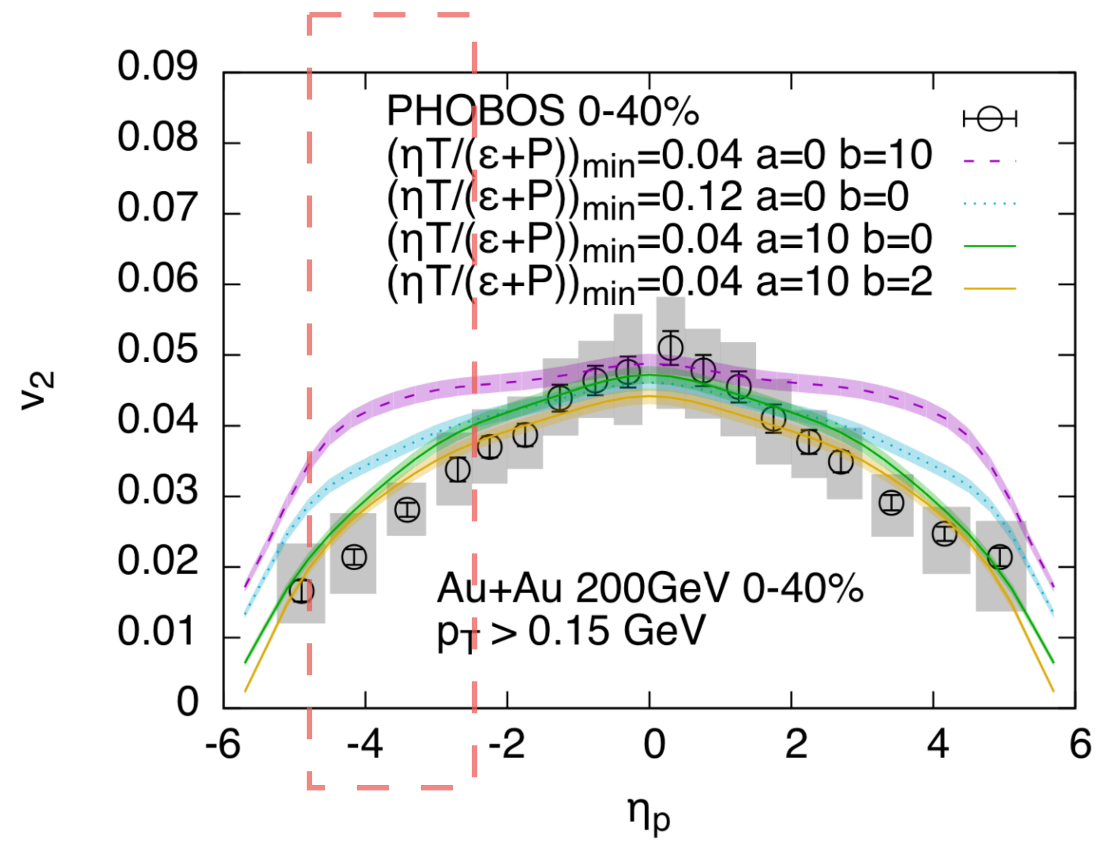
Viscosity has temperature dependence :

RHIC collisions can probe the region of perfect fluidity

Denicol *et al* 1512.01538



Denicol et al PhysRevLett.116.212301

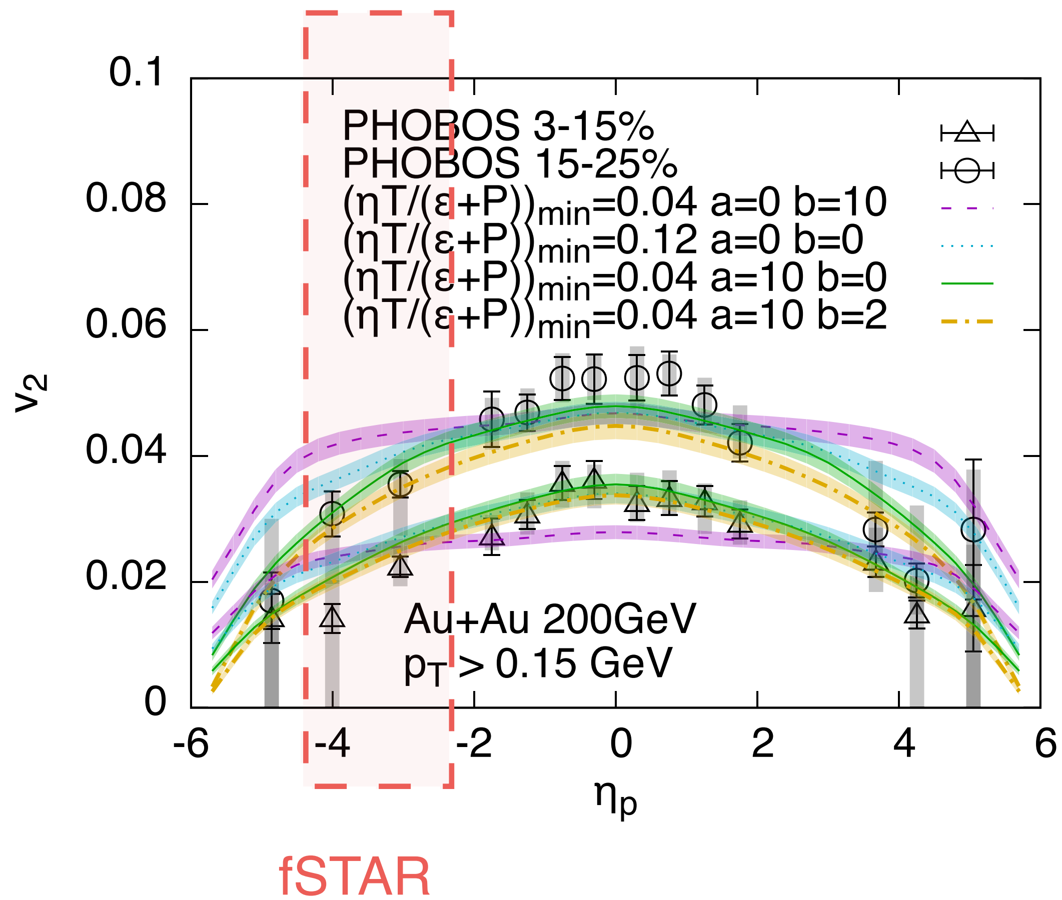


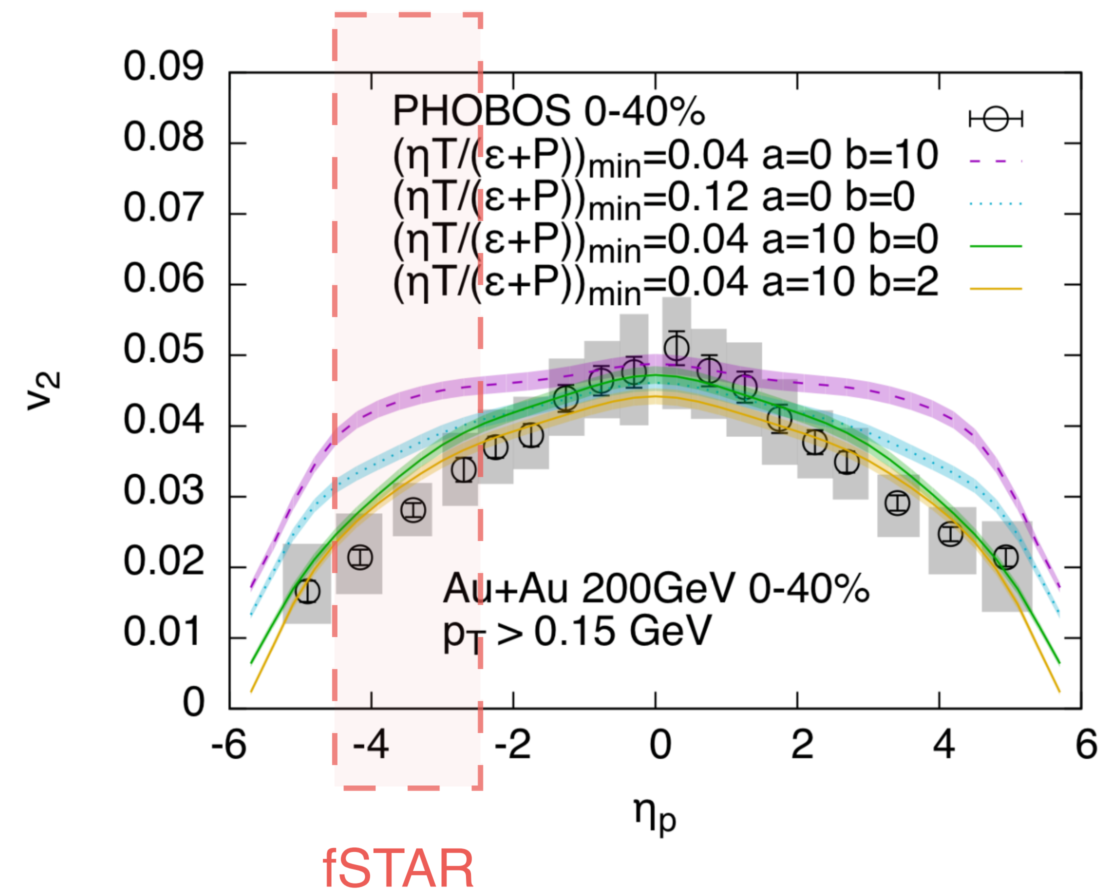
Measurements at RHIC can constrain η/s (T) over wide window of temperatures

Constraining temperature dependence of η/s(T)

Existing data has large uncertainties to constrain η/s (T)

Denicol et al PhysRevLett.116.212301





Measurements at RHIC can constrain η/s (T) over wide window of temperatures

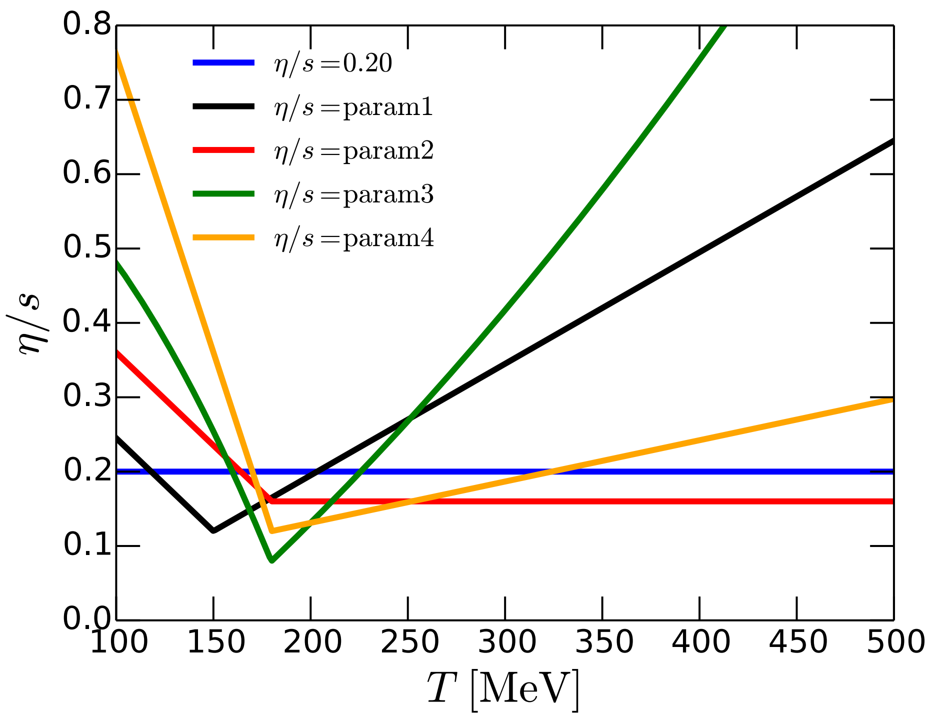
First attempt from STAR to constrain η/s (T)

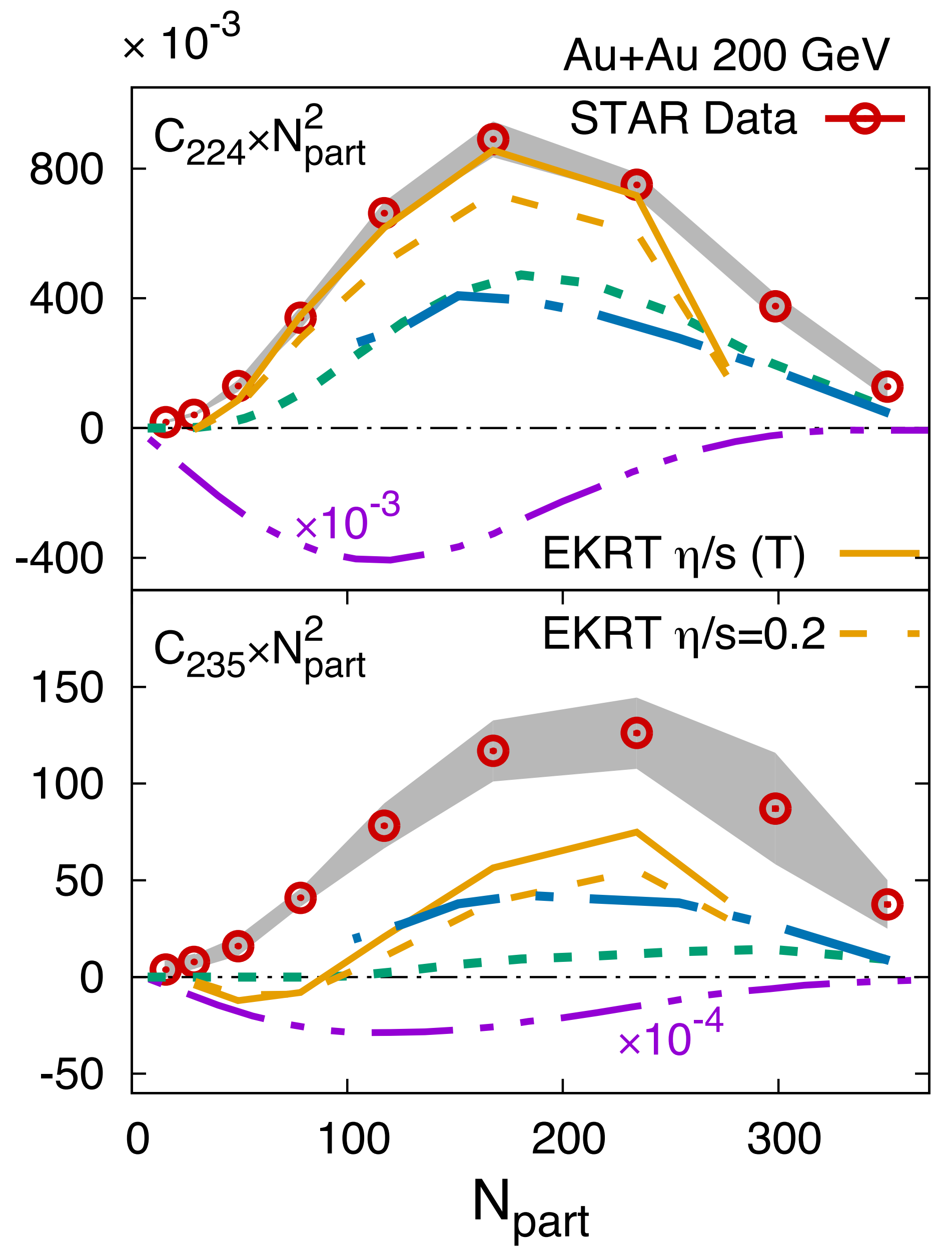
L. Adamczyk et al 1701.06497

Three particle correlation

$$C_{224} = \langle \cos(2\phi_1 + 2\phi_2 - 4\phi_3) \rangle$$
$$C_{235} = \langle \cos(2\phi_1 + 3\phi_2 - 5\phi_3) \rangle$$

Niemi *et al* 1505.02677

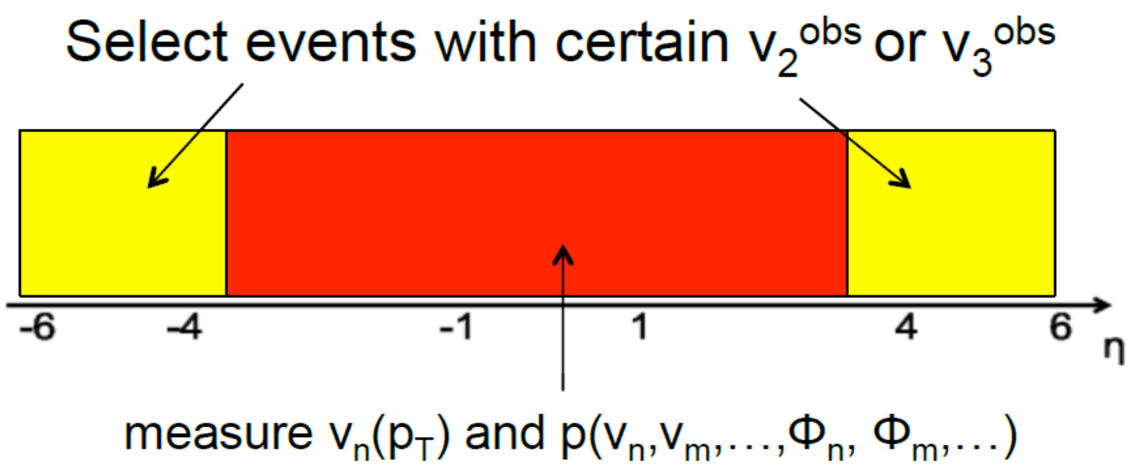


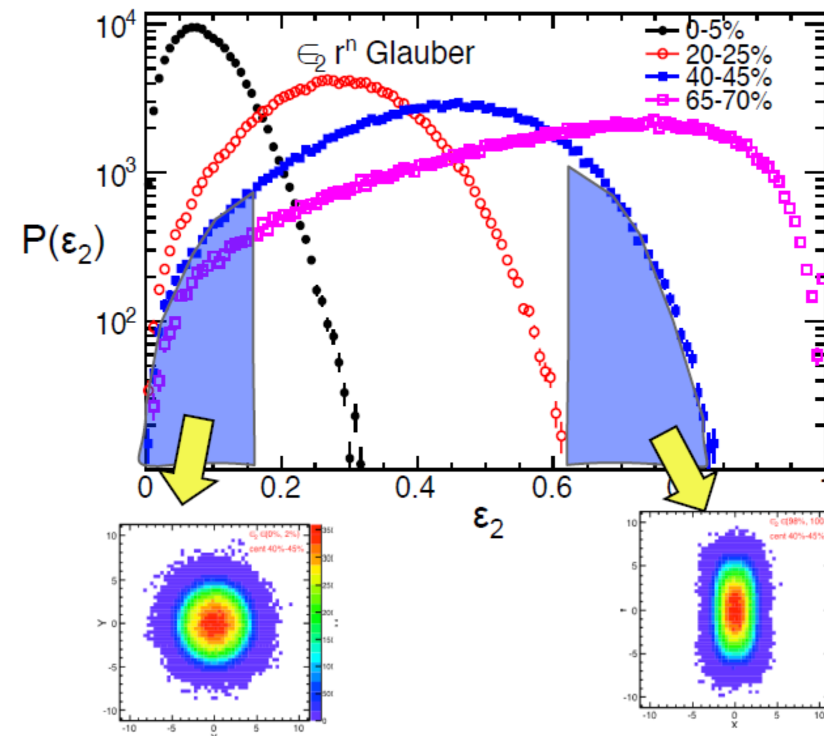


300 M event with TPC (-1<η<1) has been compared to different η/s(T), none explain data

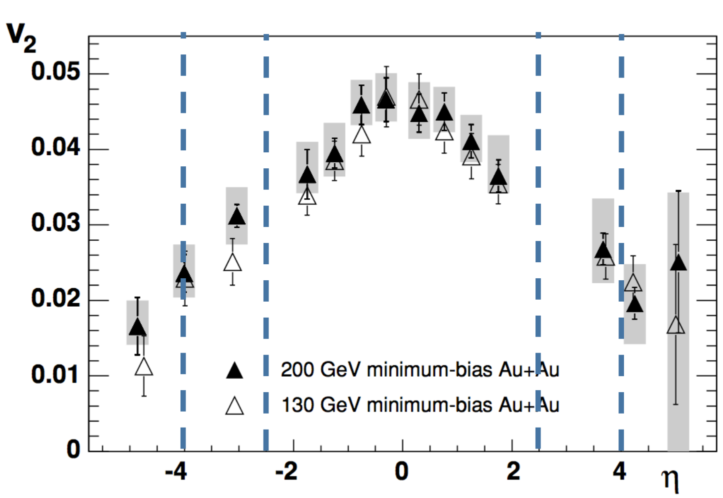
Rapidity dependent measurement seems to be essential

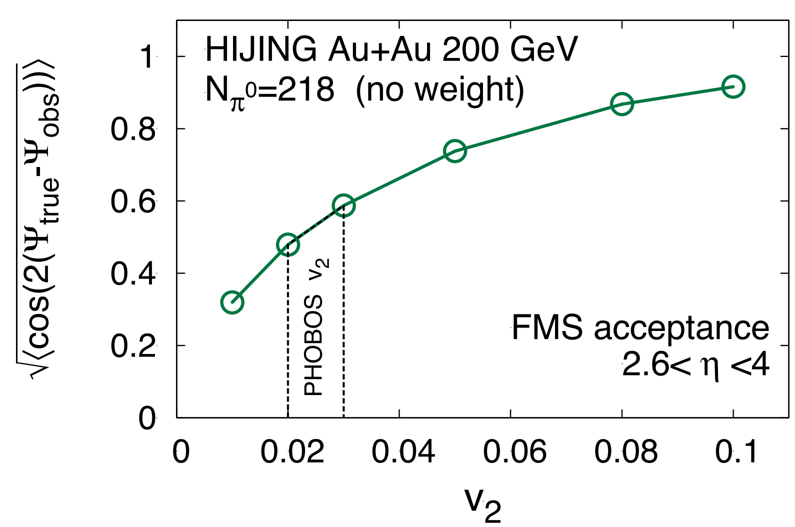
Other motivations : Event shape engineering

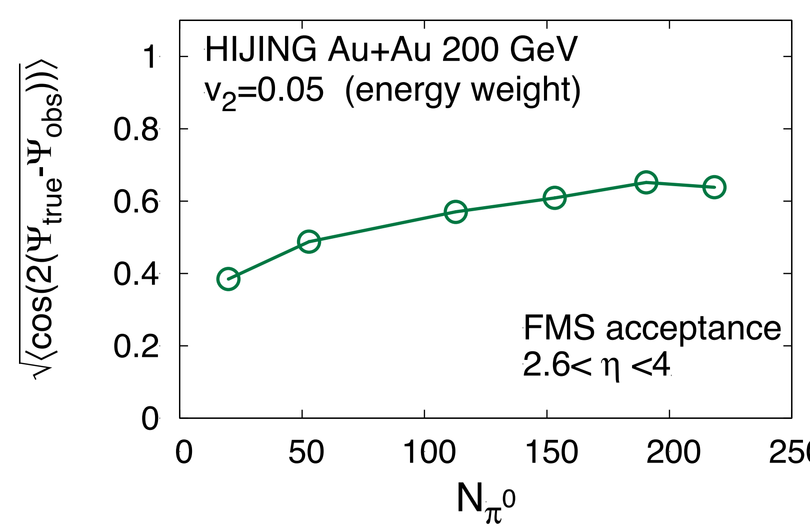




Charged hadrons

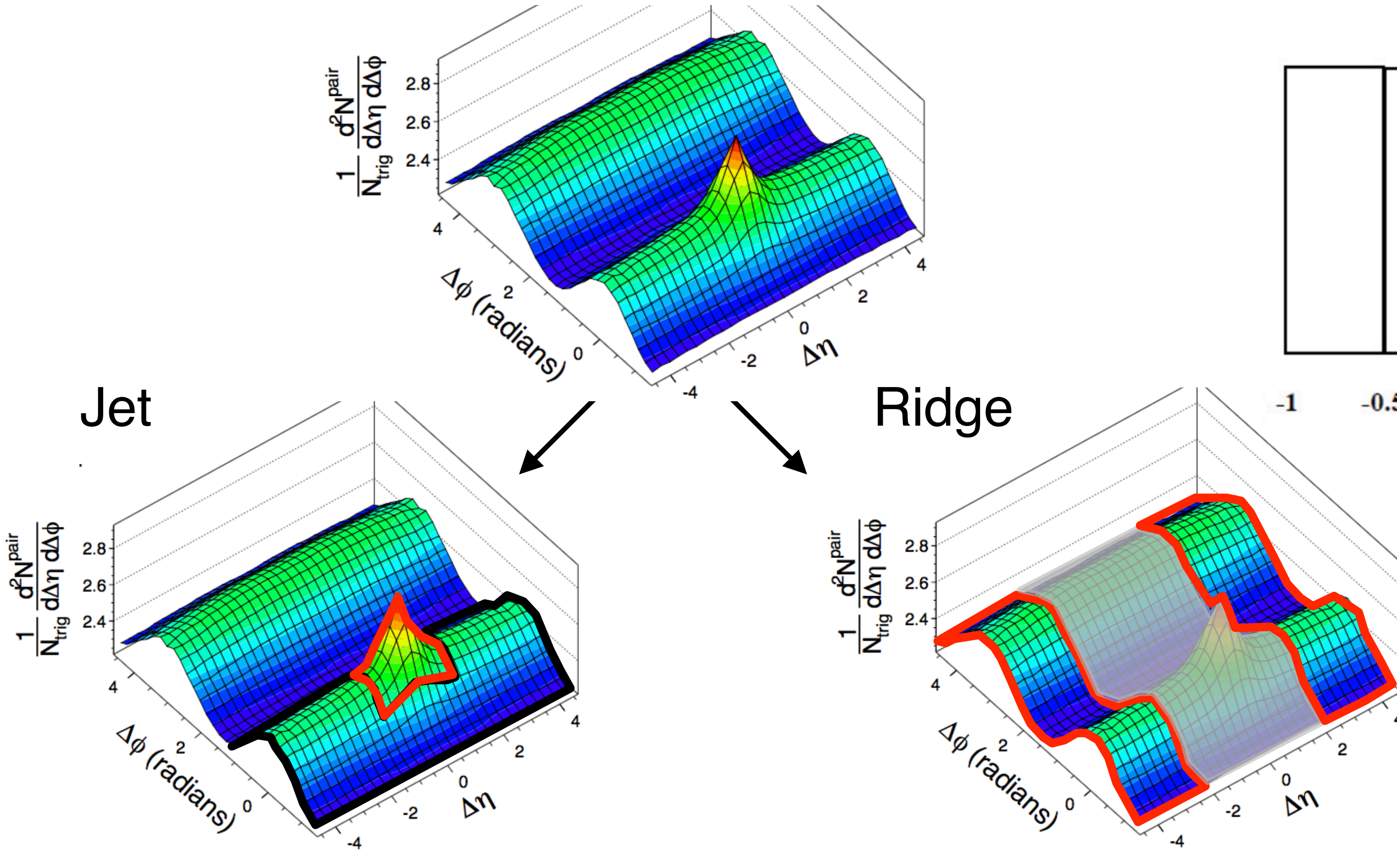


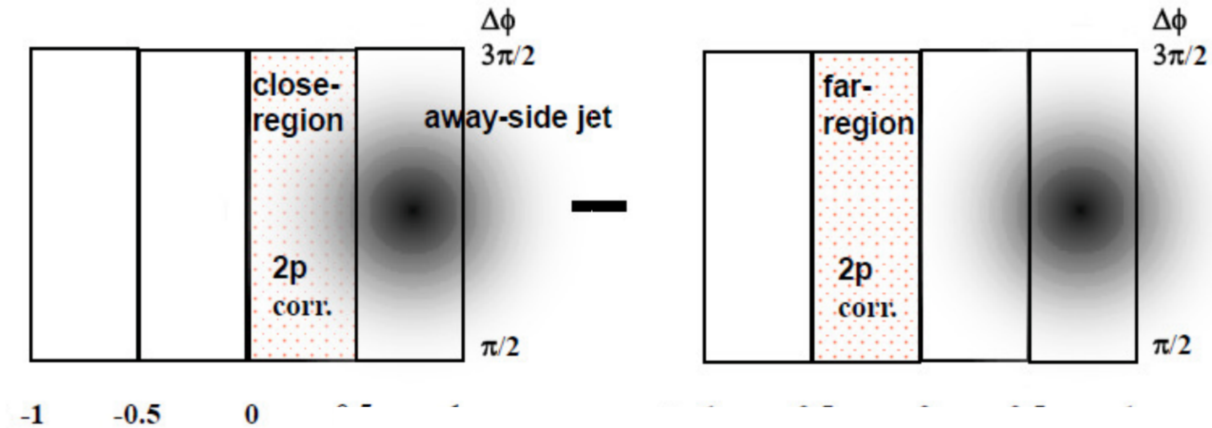




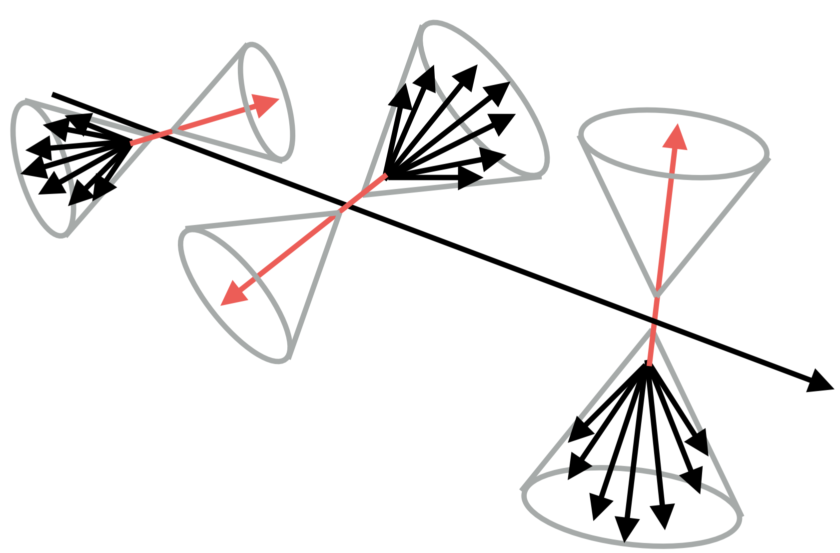
Feasibility studies with currently available FMS detector is underway, fSTAR will be ideal

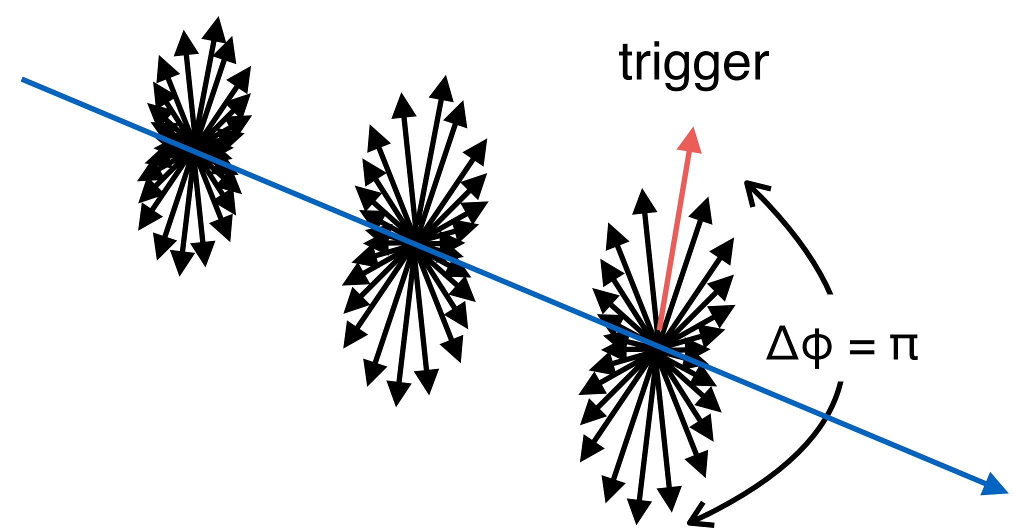
Other motivations : Jets background studies





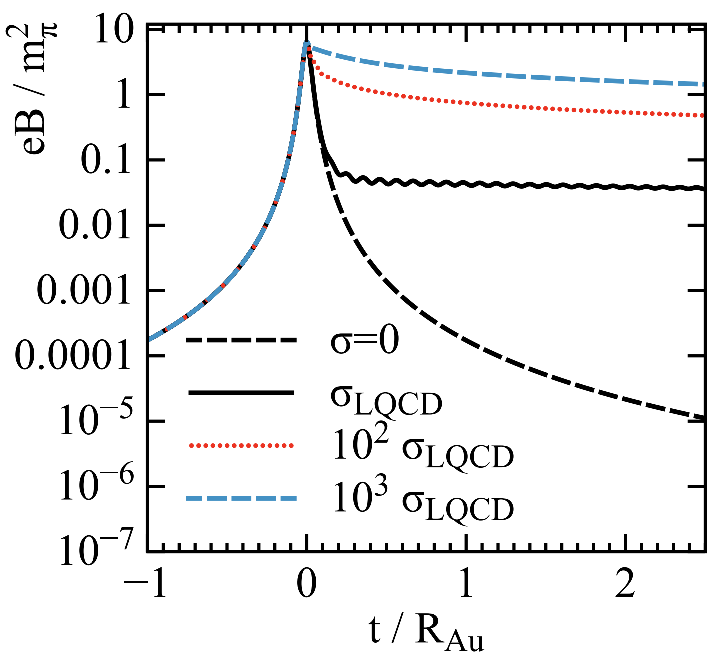
Use long range structure of ridge to subtract flow like background

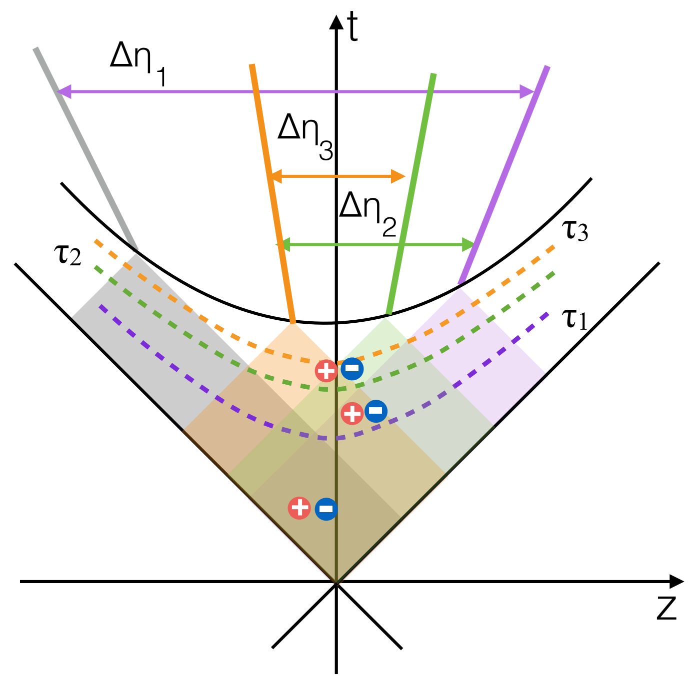




Other motivations : Chiral Magnetic Effect

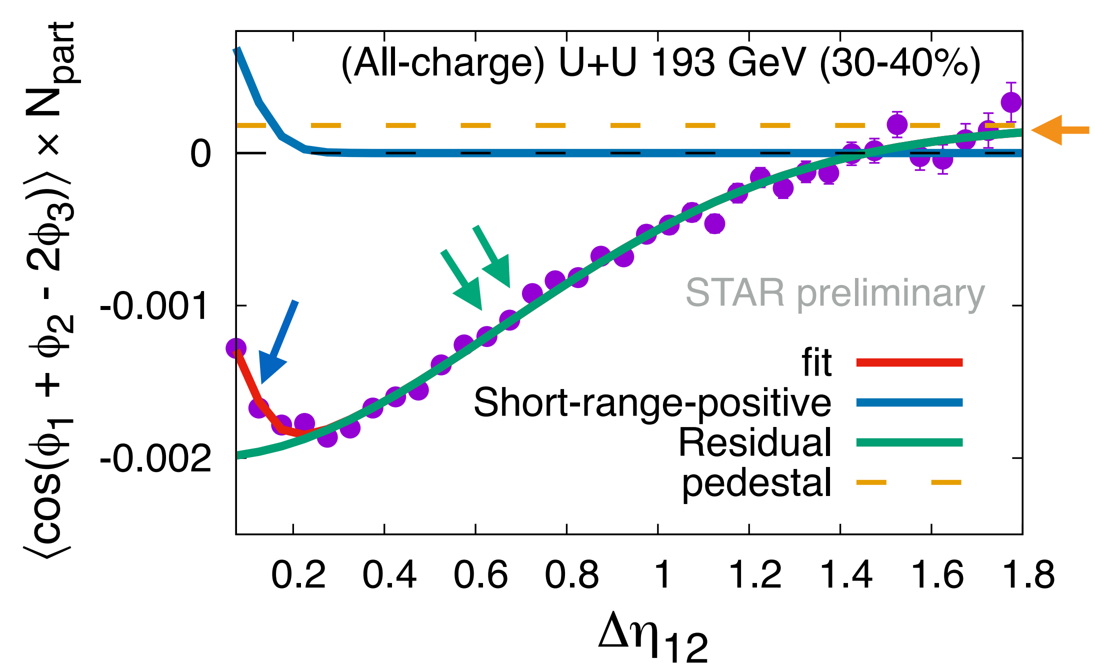
Magnetic field driven effects are early time phenomena





Many sources of backgrounds for CME are short range

P.Tribedy QM 2017



$$C_{112}(\Delta\eta_{12}) = A_{SR}\, e^{-(\Delta\eta)^2/2\sigma_{SR}^2} - A_V\, e^{-(\Delta\eta)^2/2\sigma_V^2} + A_R$$

Rapidity dependent three particle correlations is essential to remove background of CME → Unique opportunity with fSTAR

Summary

<table>
<tr><th colspan="2">Physics Measurements</th><th rowspan="2">Longitudinal decorrelation $C_n(\Delta\eta)$ $r_n(\eta_a,\eta_b)$</th><th rowspan="2">Temperature dependent transport $\eta/s(T)$, $\zeta/s(T)$</th><th rowspan="2">Mixed flow Harmonics correlation $C_{m,n,m+n}$</th><th rowspan="2">Ridge $V_{n\Delta}$</th><th rowspan="2">Event Shape and Jet-studies</th></tr>
<tr><th>Detectors</th><th>Acceptance</th></tr>
<tr><td>Forward Calorimeter (FCS)</td><td>$-2.5 > \eta > -4.2$, E_T (photons, hadrons)</td><td rowspan="2">One of these detectors necessary</td><td></td><td rowspan="2">One of these detectors necessary</td><td>Good to have</td><td rowspan="2">One of these detectors needed</td></tr>
<tr><td>Forward Tracking System (FTS)</td><td>$-2.5 > \eta > -4.2$, p_T (charged particles)</td><td>Important</td><td>Important</td></tr>
</table>

fSTAR upgrade at RHIC will provide unique opportunity to :

study the structure of the initial state that leads to **breaking of boost invariance** in heavy ion collisions and to explore of the transport properties of the hot and dense matter formed in heavy ion collisions near the region of perfect fluidity.

Backup