ALICE overview

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Outline

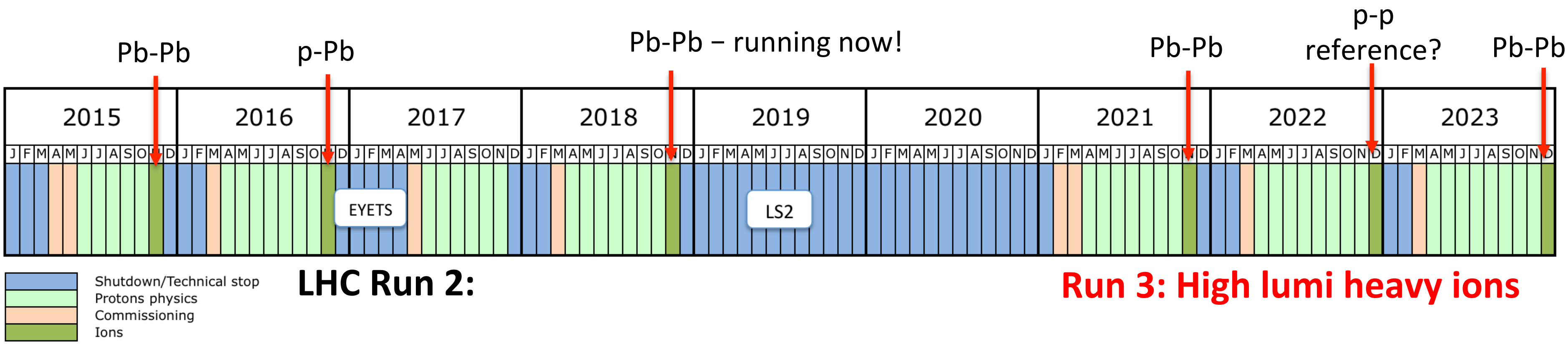
1. Enter high-luminosity era in heavy ion collisions

- particularly Finnish contribution

2. Analysis performed in Jyväskylä

- *very* limited view to ALICE as a whole

High-luminosity HI starts 2021



ALICE goals: ALICE LoI: J. Phys. G: Nucl. Part. Phys. 41 (2014) 087001

1. Heavy quark measurements down to low-p_T
2. Thermal electromagnetic radiation
3. Light nuclei production in heavy-ion collisions

Three common features:

- Vertexing and particle identification needed
- Low signal/background.
- Cannot be triggered

=> need large minimum bias sample

Long Shutdown 2 (LS2) 2019 – 2020

Major upgrade in ALICE:

- New TPC Readout Chambers
- New Inner tracker
- New Muon Forward Tracker
- New Fast Interaction Trigger –detector (FIT)
- Online-Offline computing system, "O^2"

ALICE strategy in high-luminosity running:

When dedicated trigger is not possible:

- Speed up detectors and reduce data size, continuous readout
- Take heavy ion data with 50 kHz interaction rate

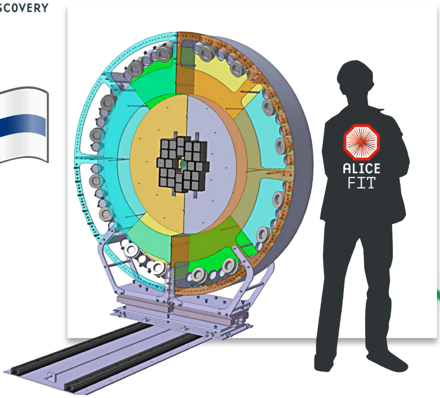
  => write all Pb+Pb at this high rate

  => 100 times larger MB data sample as compared to Run 1 & 2

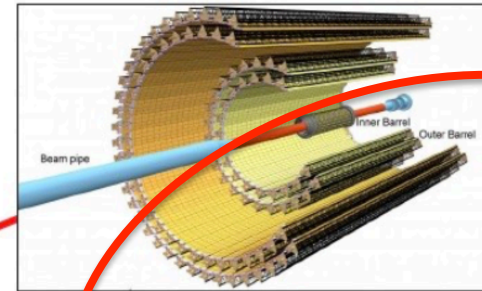
10/nb ~ 100 billion events + 3/nb low B-field (dielectron)

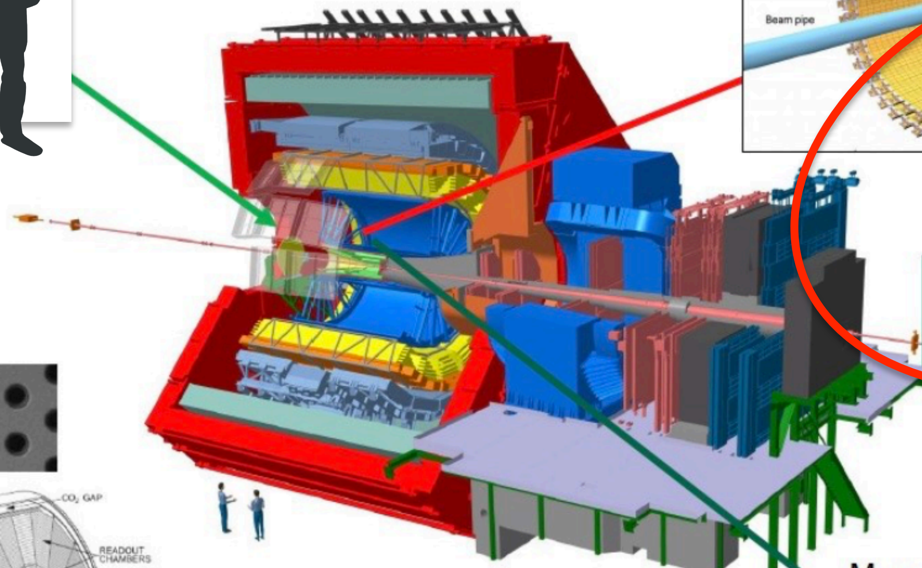
ALICE upgrade

New Fast Interaction Trigger (FIT)
Project leading and conseptual design from Finland. 24% (364 kCHF) core.



New Inner Tracking System (ITS)

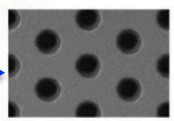


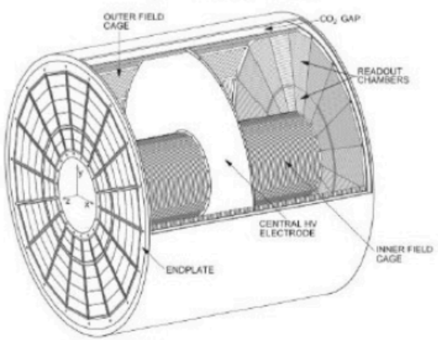


Both based on Monolithic Active Pixel Sensors (MAPS)

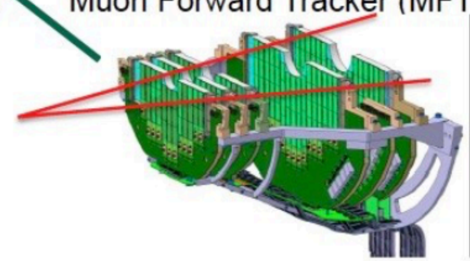
TPC with GEM based readout

QA of the GEM foils →





Muon Forward Tracker (MFT)



+ improved readout for TOF, ZDC, TRD, MUON ARM
+ new Central Trigger Processor
+ new DAQ/Offline architecture

Finland:

- provides 364 kCHF (approx 24%) core contribution to FIT
- more details: see Maciej's talk!

Main branches and personnel

1. Collective flow

2. Medium modifications of jets

- using two particle correlations or reconstructed jet

3. FIT

- design, construct, software, running, expert shifts, …

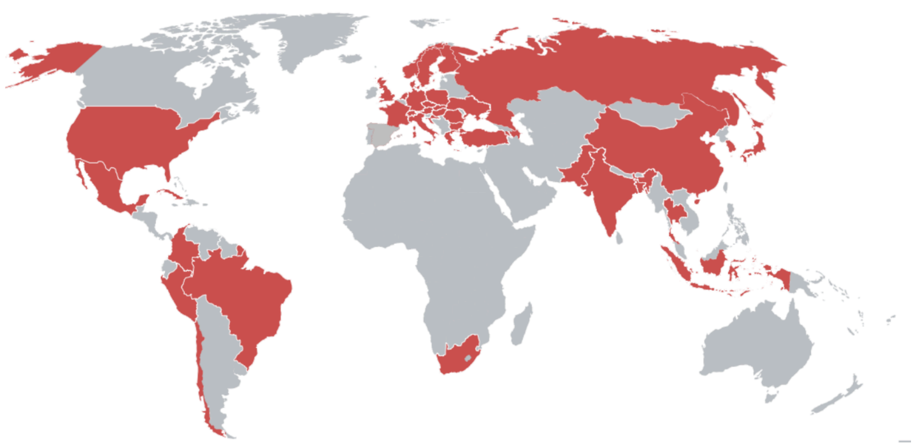
All-male panel broken!

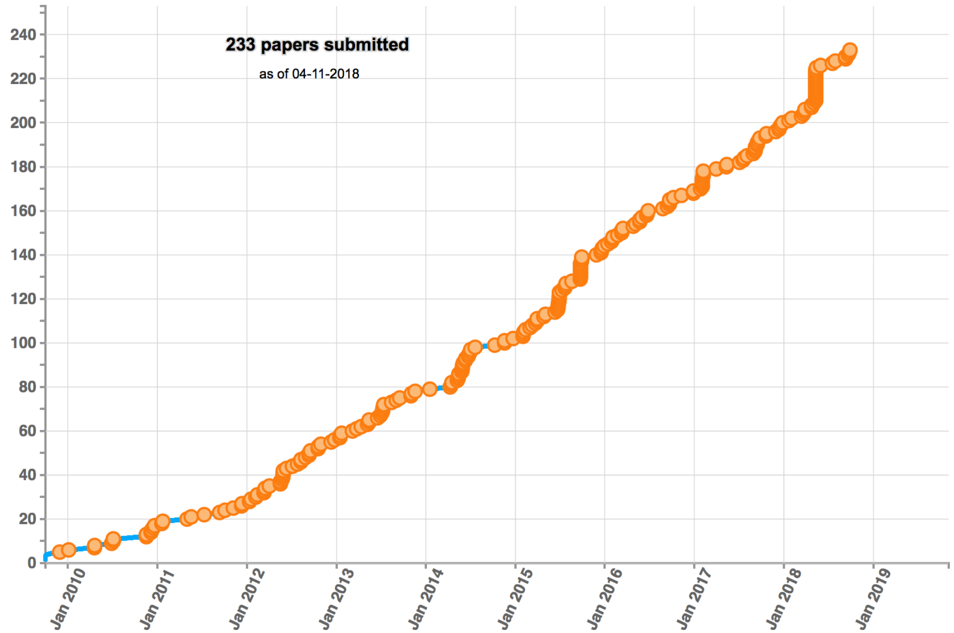
ALICE Collaboration

ALICE:

- 41 countries, 177 institutes, 1800 members
- 233 papers since 2010, i.e. order of 30 per year

What do we do here in Jyväskylä?





Analysis topics in Jyväskylä

UNIVERSITY OF JYVÄSKYLÄ

HELSINKI INSTITUTE OF PHYSICS

ALICE
A JOURNEY OF DISCOVERY

TODAY

Flow:

Non-linear decomposition and acoustic scaling
Jasper Parkkila (defense goal 2021)

Jets and two-particle correlations:

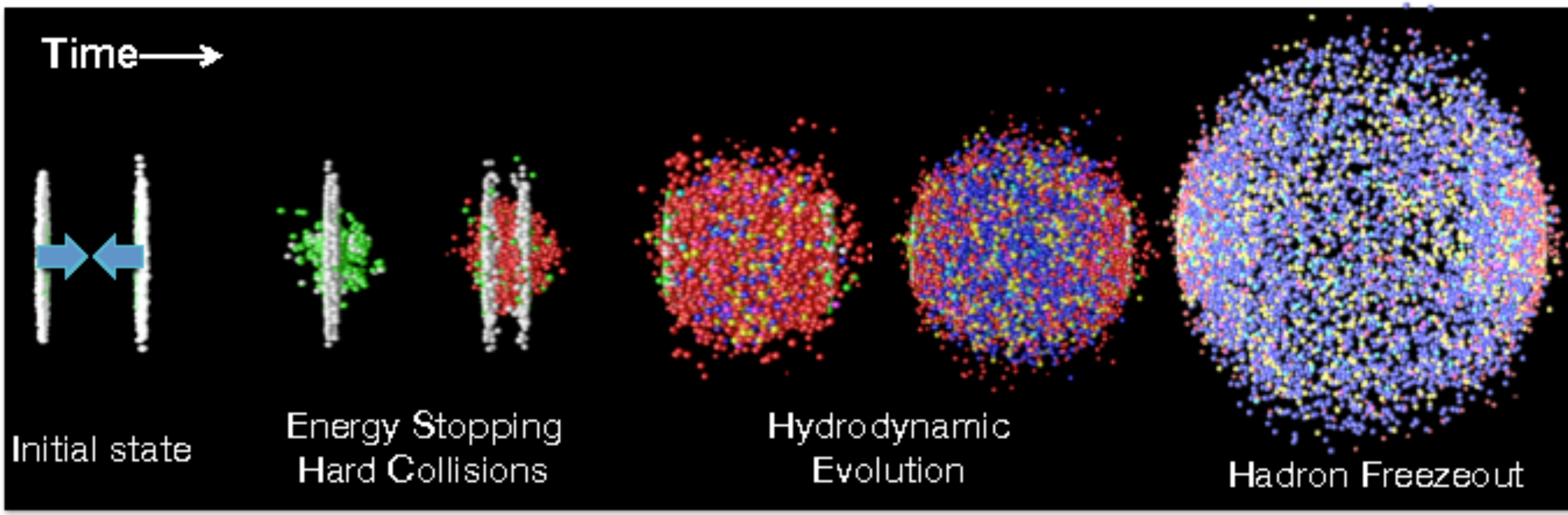
Jet shape modification in Pb+Pb collisions using two-particle correlations
Márton Vargyas (defense 30.11.2018)

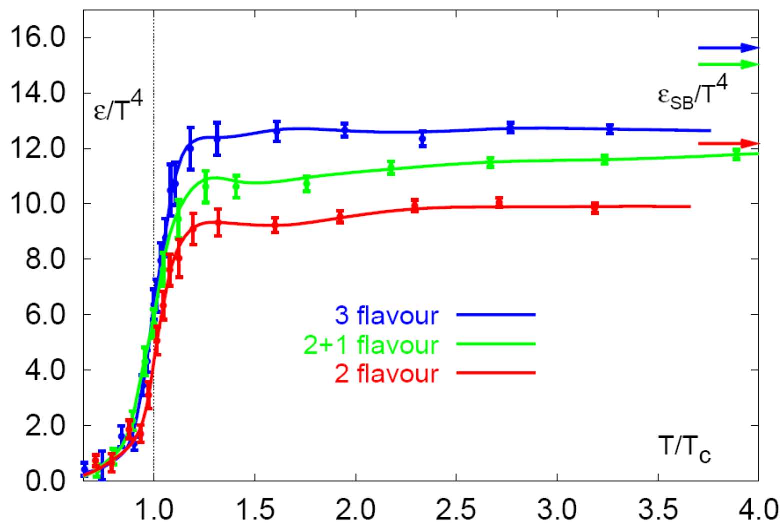
Jet fragmentation transverse momentum in p+Pb using two-particle correlations
Jussi Viinikainen (defense 15.12.2017)

Jet fragmentation transverse momentum in p+Pb using reconstructed jets
Tomas Snellman (defense expected summer 2019)

Di-jet mass modifications in Pb+Pb collisions
Oskari Saarimäki (defense goal 2022) – NEW

Heavy ion collisions





Bjorken estimate for energy density after primary interactions in LHC:

$$\varepsilon_{Bjorken} \sim \frac{\langle m_T \rangle}{\pi R_A^2 \tau_0} \frac{dN}{dy} = \frac{1}{A\tau_0} \frac{dE^{\text{measured}}}{dy}$$

$\sim$ 16 GeV/fm^3

Critical energy density ε_c~1 GeV/fm^3

Transport properties

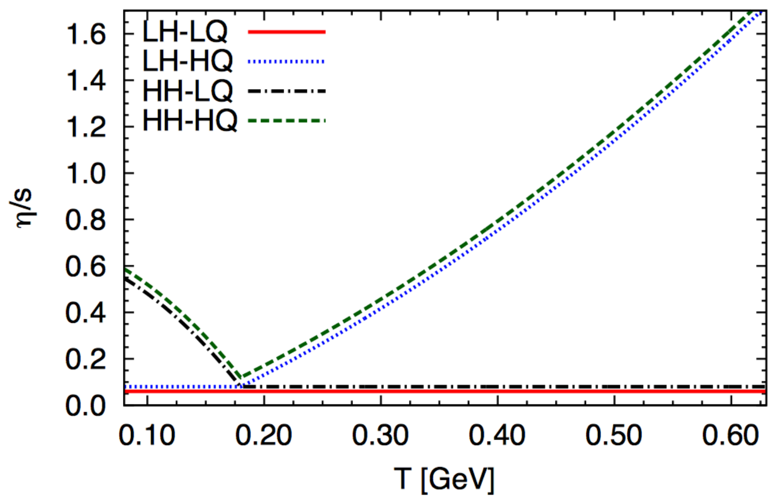
QGP established experimentally => properties, precision measurements

Lower bound of fluidity, shear viscosity to entropy ratio, in nature

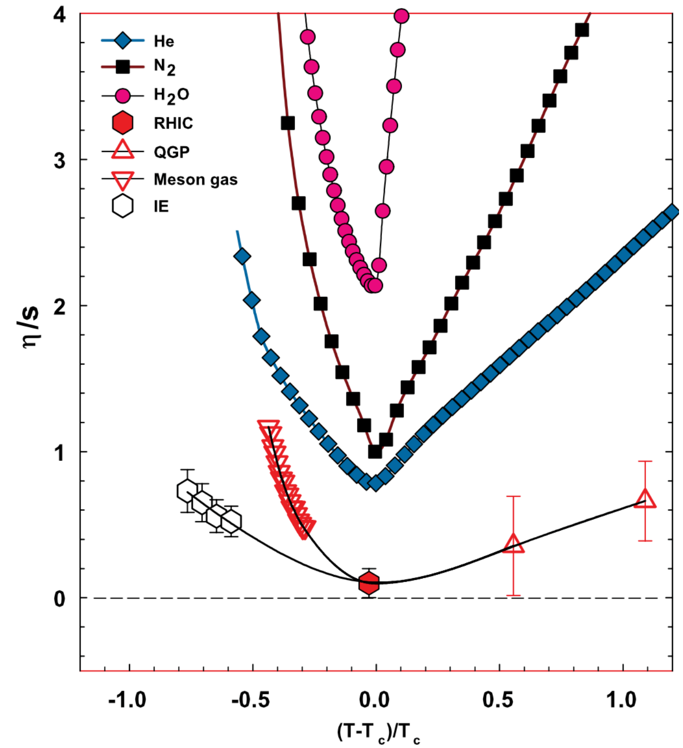
- uncertainty relation **Phys.Rev. D31 (1985) 53**
- string theory techniques **Phys. Rev. Lett. 94 (2005) 111601**

$$\frac{\eta}{s} \geq \frac{1}{4\pi} \approx 0.08$$

Temperature dependence?



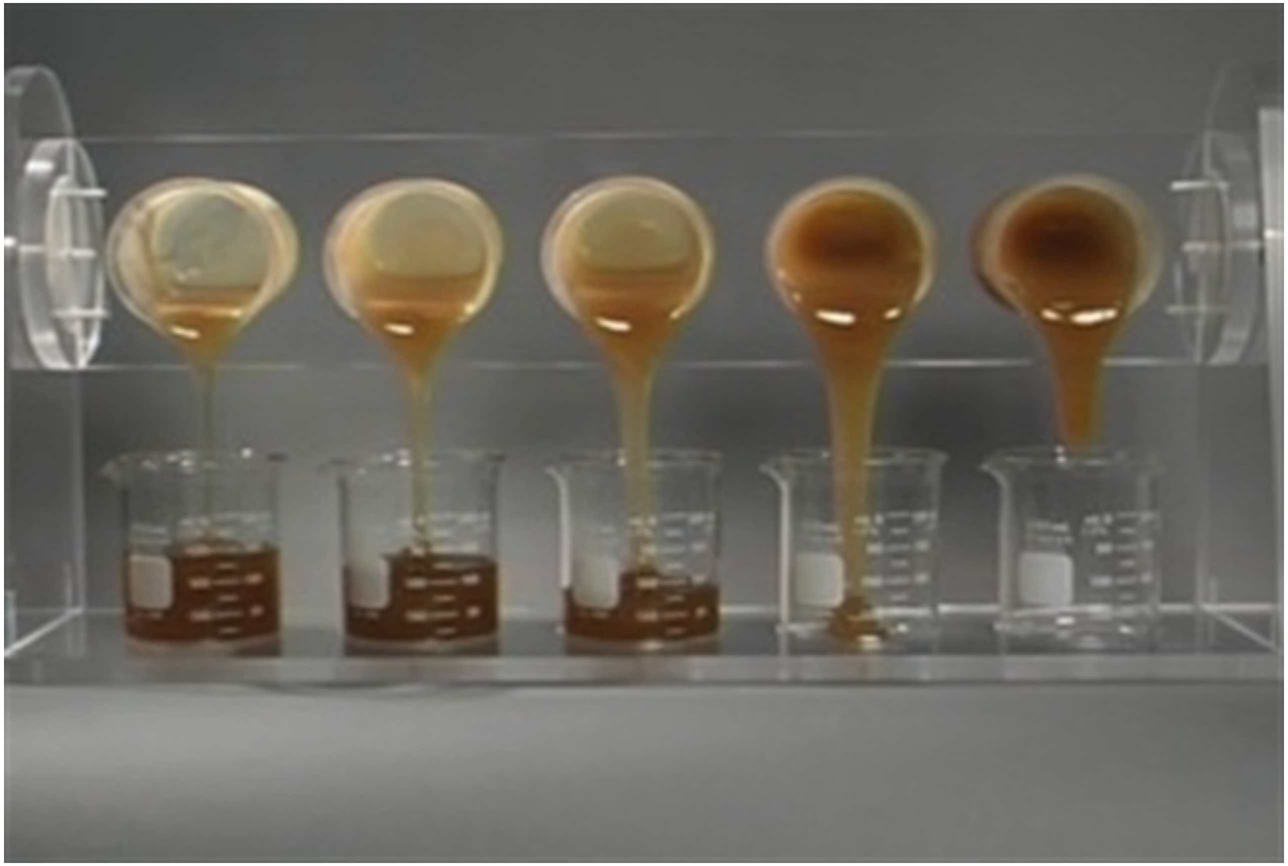
Phys.Rev.Lett. 97 (2006) 152303
Phys.Rev.Lett. 106 (2011) 212302



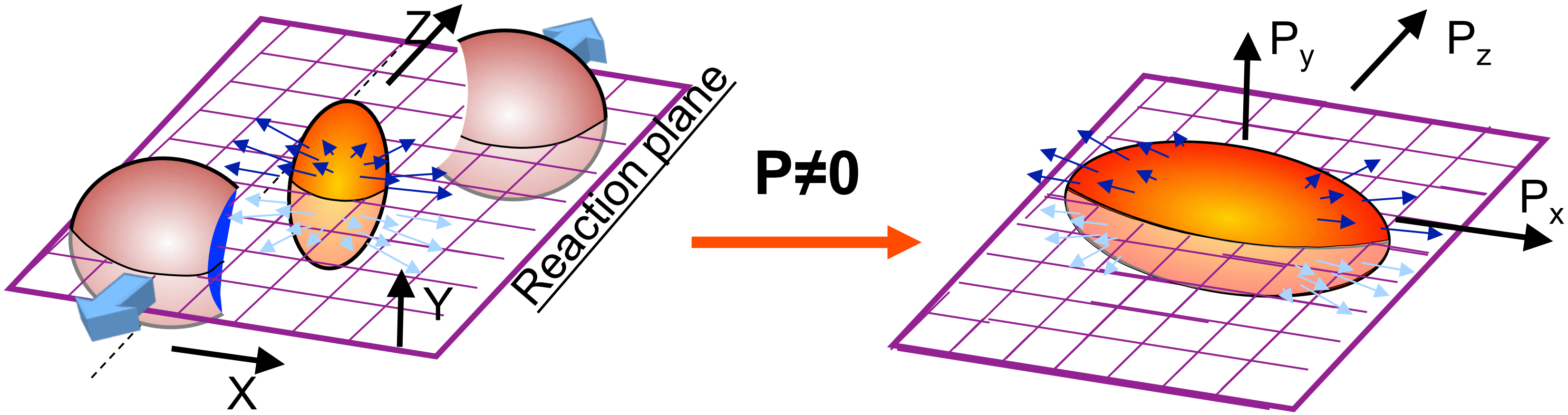
Phys.Rev.Lett. 98 (2007) 092301

Effect of viscosity

How to observe viscosity in heavy ion collisions?



Anisotropic flow

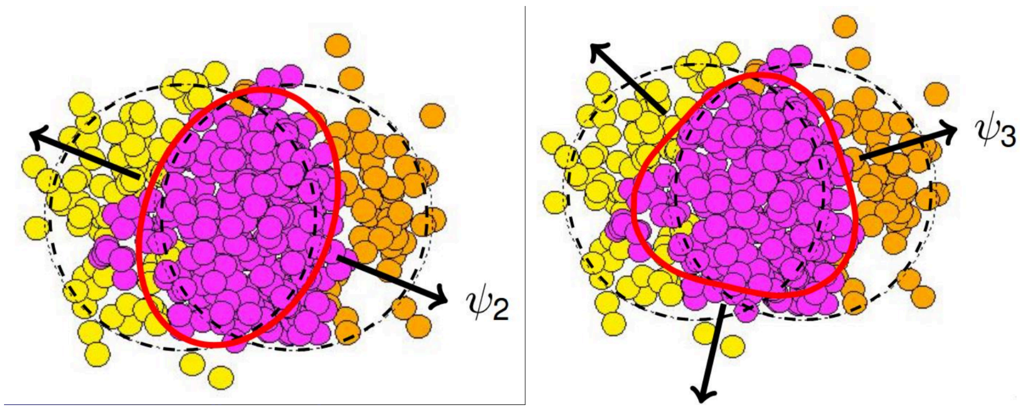


Collectivity: initial geometrical asymmetry turns asymmetric particle spectra

Fourier expansion in azimuth:

$$\frac{dN}{d\phi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos\left[n(\phi - \psi_n)\right]$$

“Flow coefficients”:
elliptic flow v_2, triangular flow v_3, …



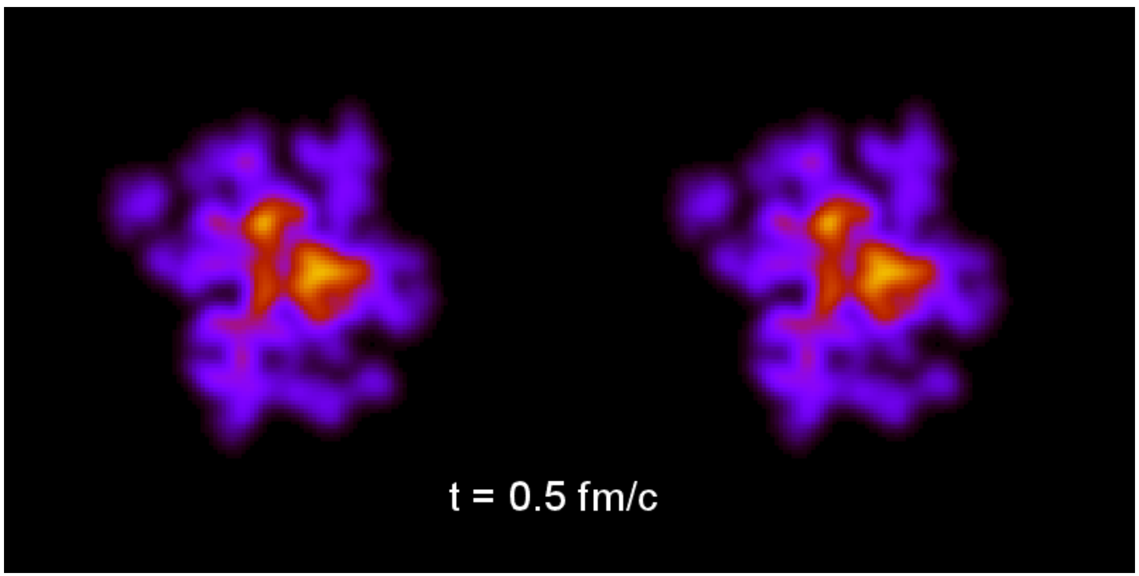
Elliptic flow ⇔ geometry
Triangular flow ⇔ fluctuations

FIT: Collision centrality!

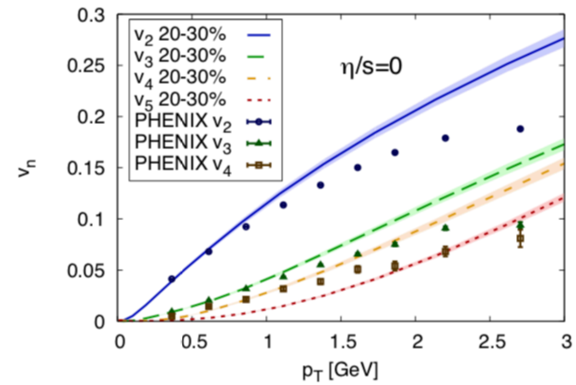
Effect of viscosity

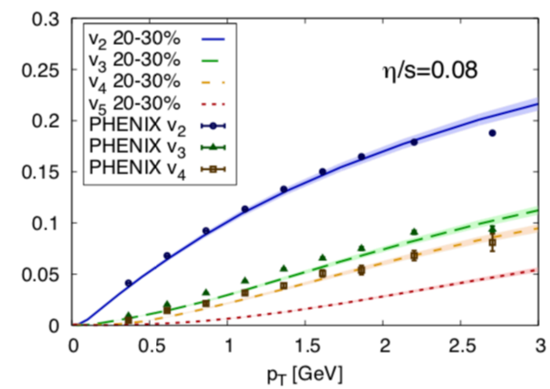
Simulation: Bjoern Schenke
results: Phys. Rev. C85 (2012) 024901

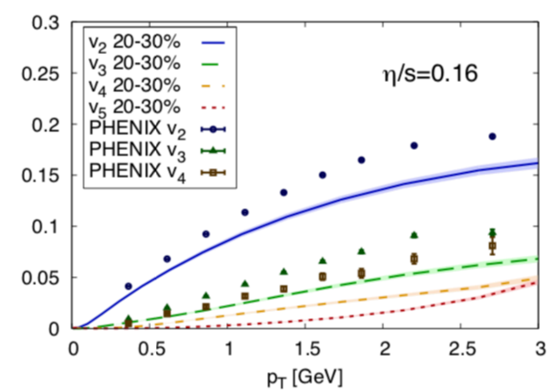
Viscosity damps finer structures in evolution
=> particularly higher flow harmonics v_n suppress



$\eta/s = 0$ $\eta/s > 0$

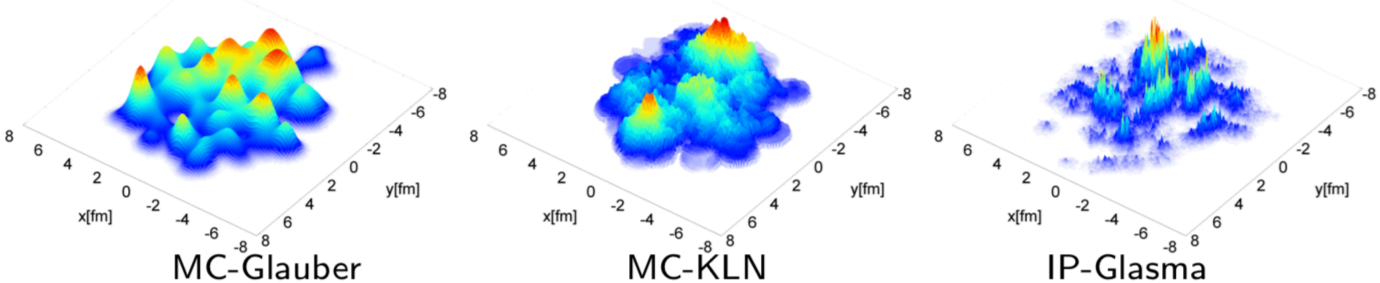




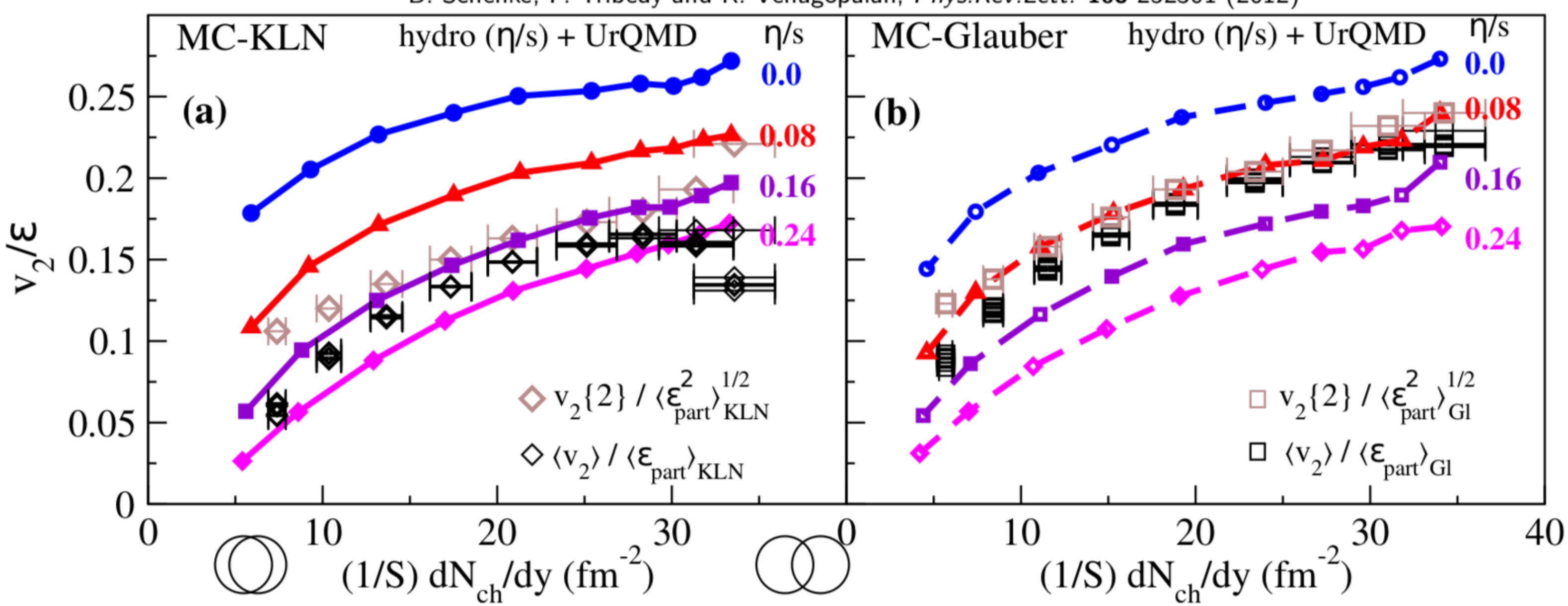


Initial state vs. evolution

Complication: different initial states favour different values of η/s
=> need more sensitive observables



B. Schenke, P. Tribedy and R. Venugopalan, *Phys.Rev.Lett.* **108** 252301 (2012)

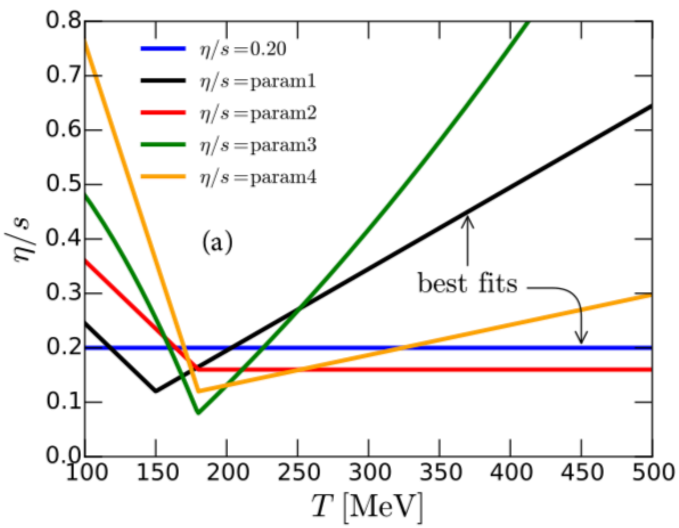


Symmetric cumulants

Correlations among flow harmonics

$$SC(m,n) \equiv \langle v_m v_n \rangle - \langle v_m \rangle \langle v_n \rangle$$

In hydrodynamical simulations:

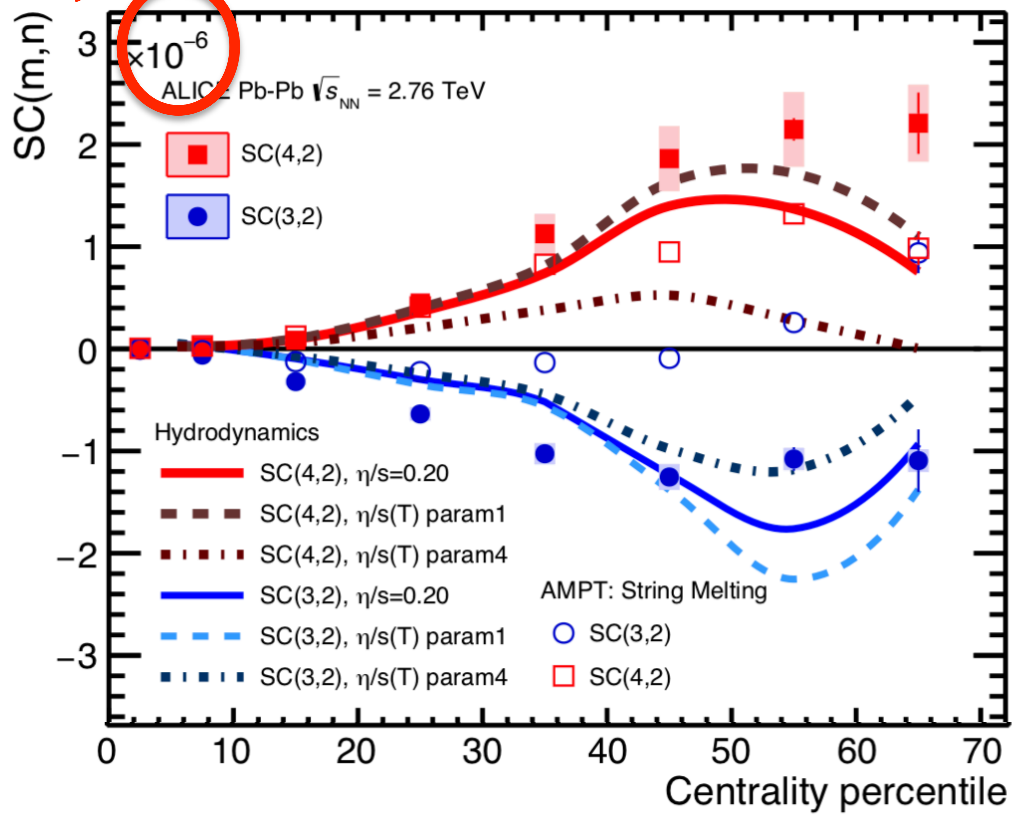


Phys. Rev. C93 (2016) no. 2, 024907

First time sensitivity to the temperature dependence of η/s!

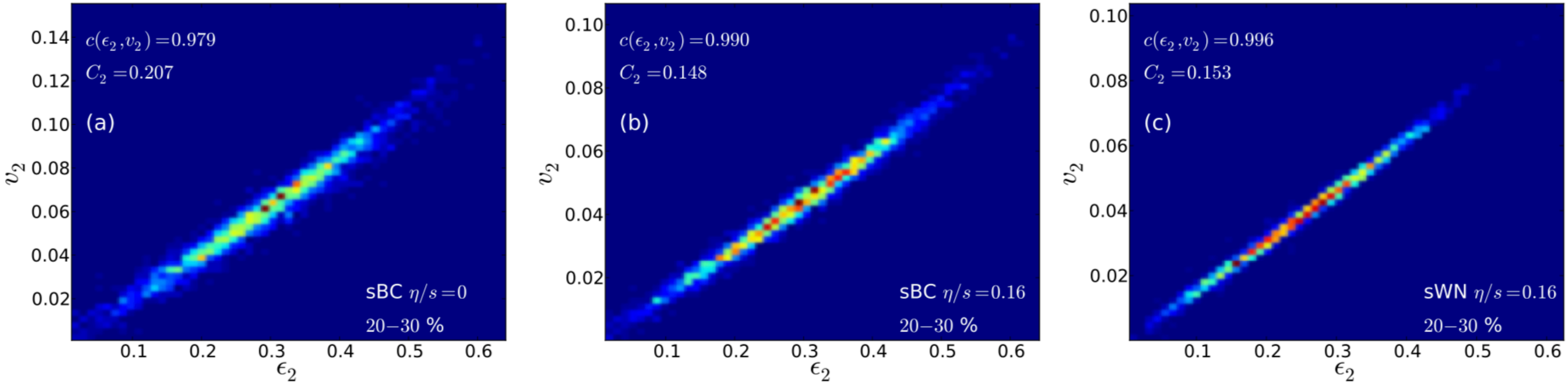
Precision!

Phys. Rev. Lett. 117 (2016) 182301



Non-linear decomposition

Hydrodynamics: **Phys. Rev. C87 (2013) no. 5, 054901**



Response of initial state eccentricity to flow is fairly linear for v_2 and v_3.
Non-linearity grows when moving to higher flow harmonics v_n, n > 3.

Decompose flow vector $V_n = v_n e^{in\psi_n}$ into linear (nL) and non-linear contributions:

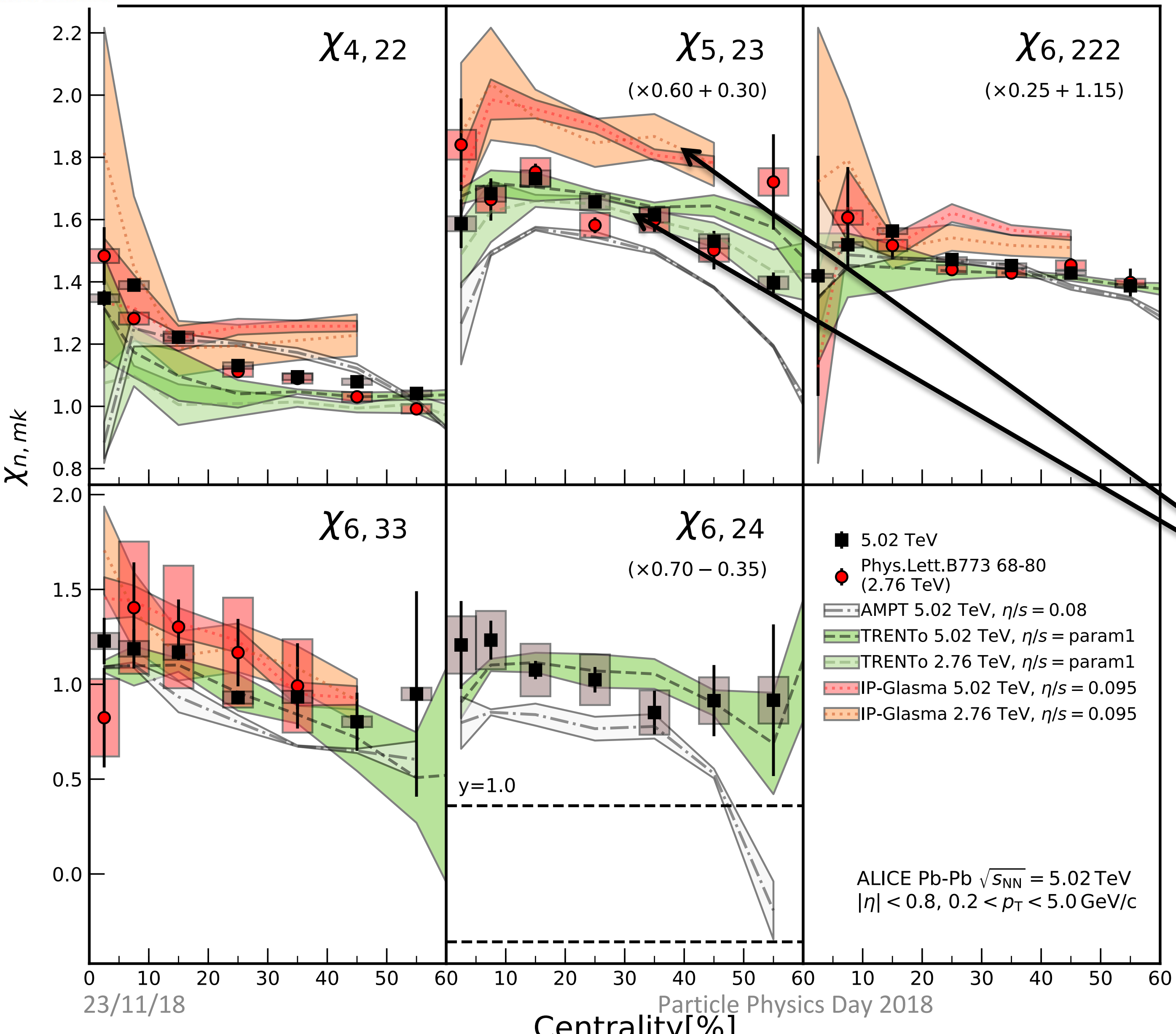
$$V_4 = V_{4L} + \chi_{4,22} V_2^2$$

Phys. Lett. B773 (2017) 68

$$V_5 = V_{5L} + \chi_{5,32} V_2 V_3$$

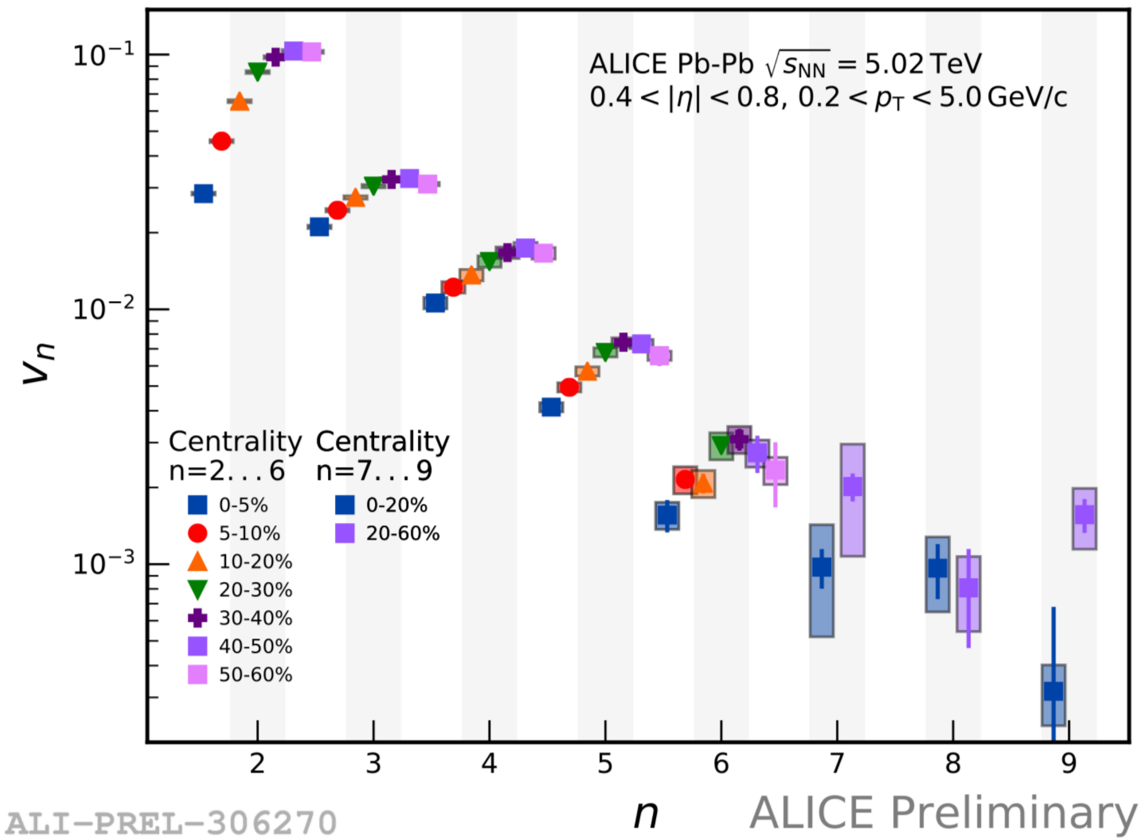
$$V_6 = V_{6L} + \chi_{6,222} V_2^3 + \chi_{6,33} V_3^2 + \chi_{6,24} V_2 V_{4L}$$

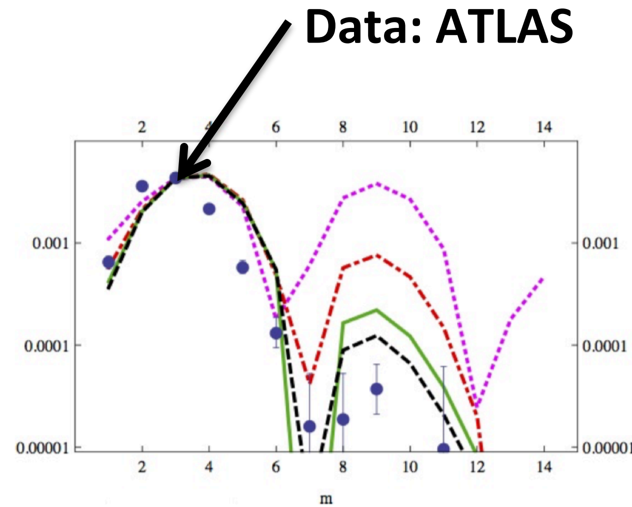
Non-linear decomposition



Sensitivity to initial state

Acoustic peak





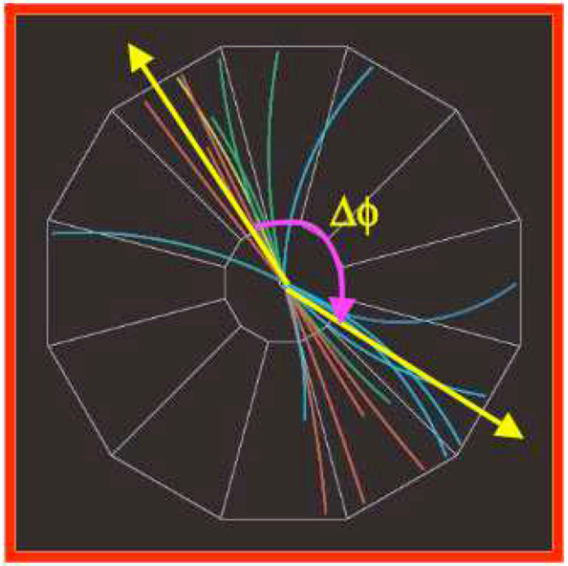
From top to bottom, $4\pi\eta/s = 0, 1, 1.68, 2$

E. Shuryak, arXiv:1710.03776 [hep-ph]

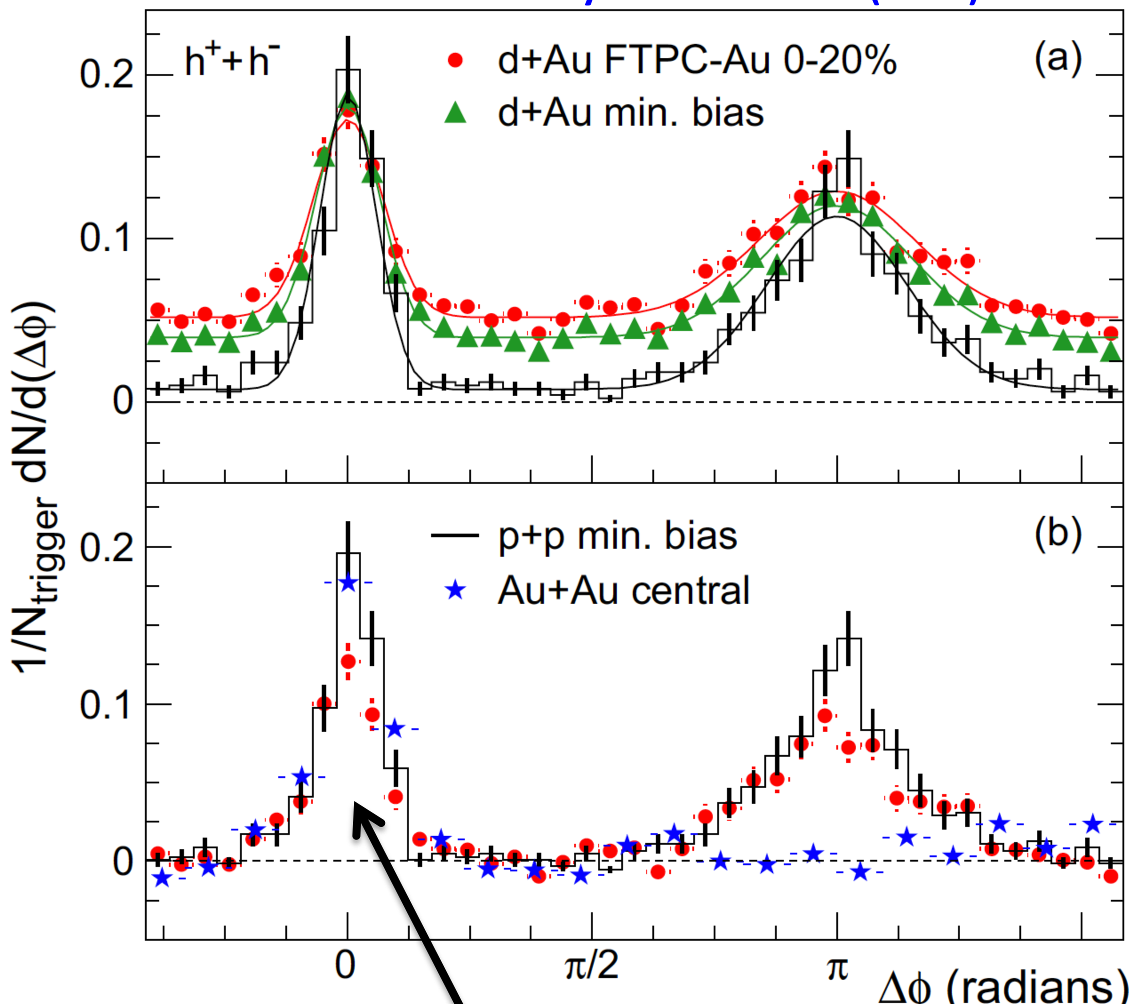
Theoretical model: $v_9 > v_8$ because initial state perturbations

Very statistics hungry analysis.

Modification of jets in Pb+Pb



Phys. Rev. Lett. 91 (2003) 072304



Classic observation by STAR: Away side jet associated yield is suppressed.

Next: study trigger jet at LHC

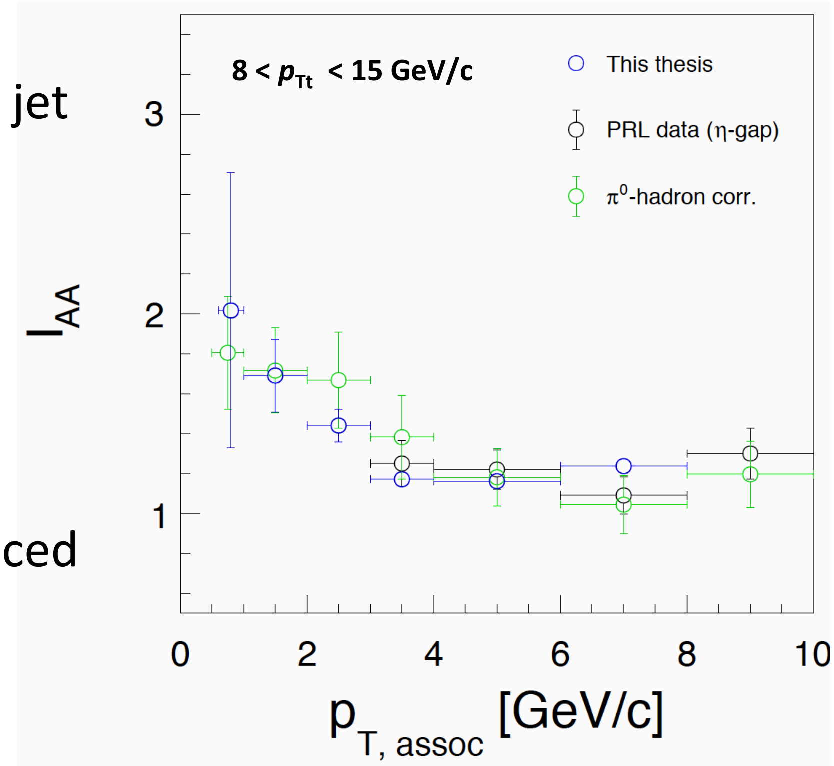
Near side jet, around trigger yield = integral of peak

Modification of yield in jet

Medium modification of yield associated with jet

$$I_{AA} = \frac{(\text{per trigger yield in PbPb})}{(\text{per trigger yield in pp})}$$

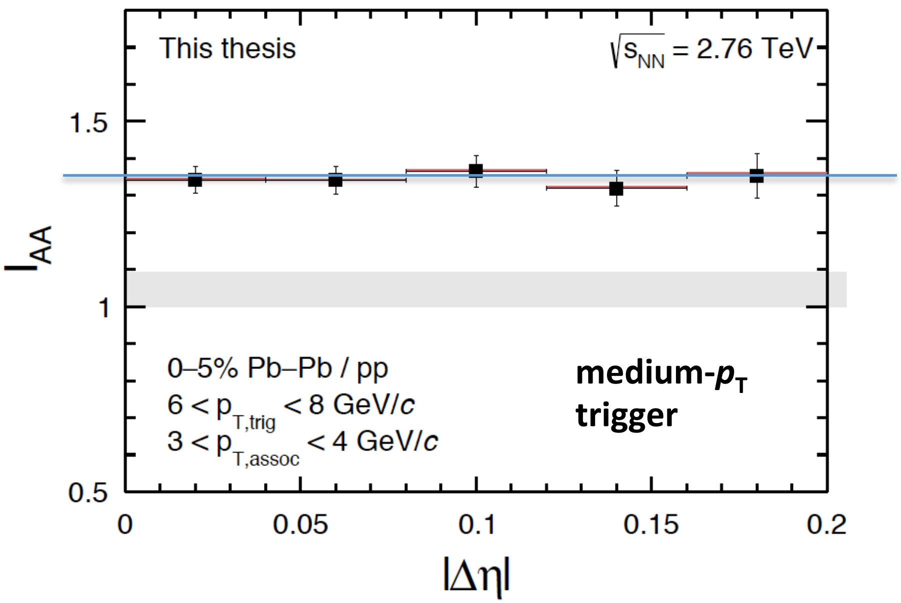
Physical implication:
Rise at low-pT gives evidence to medium induced radiation.

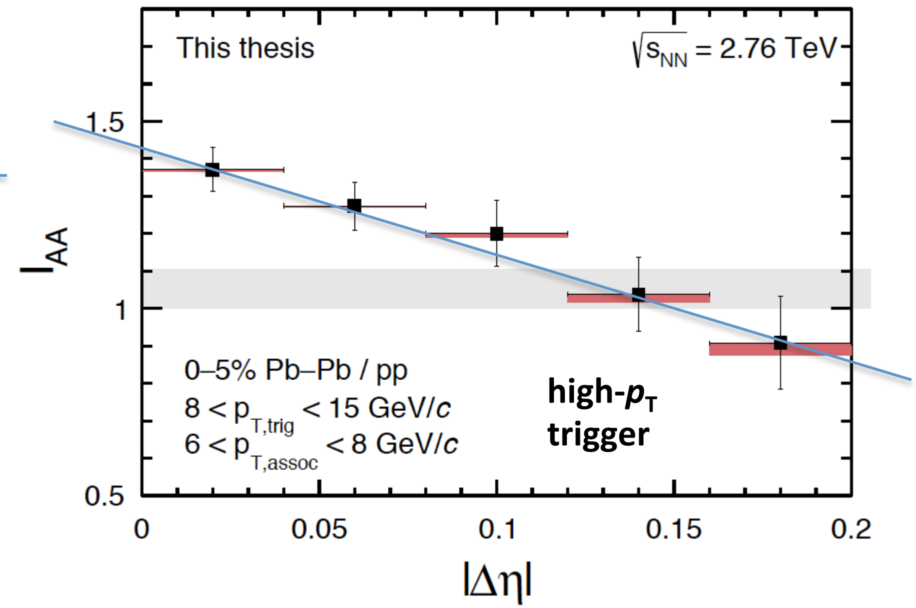


Phys. Rev. Lett. 108 (2012) 092301
Phys. Lett. B763 (2016) 238
Marton Vargyas, PhD-thesis

Jet narrowing in HI collisions

Márton Vargyas, PhD-thesis





Study the IAA as a function of $\Delta\eta$ ⇔ modification of jet shape in PbPb

Observation: dropping trend with high-p_T trigger and associated
=> hard jets are narrower in PbPb as compared to pp

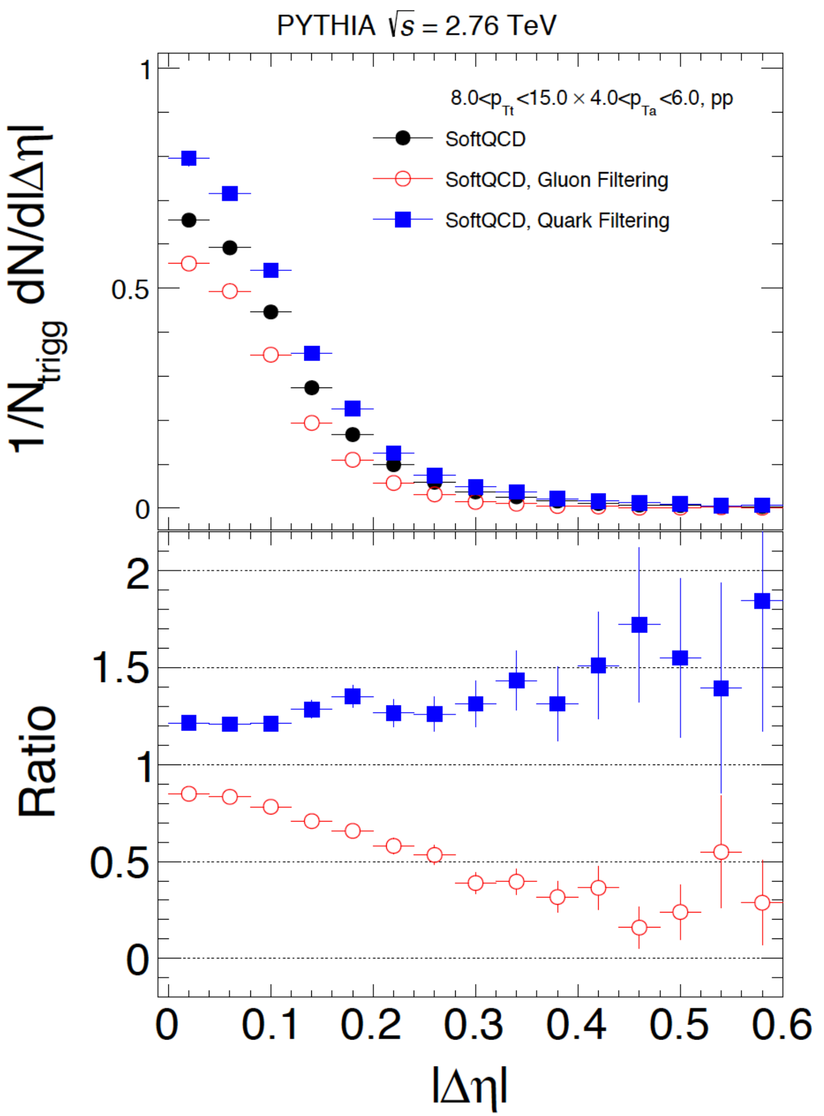
Interpretation: ”gluon filtering”?

Simple PYTHIA study:

- Form Δη-correlation function for quark and gluon initiated jets separately
- Make “I_{AA}” such that “quark” or “gluon” is divided by “all”
- Observe: narrowing (broadening), when gluons (quarks) are filtered out. (Quark jets known to be narrower.)
- Qualitatively similar behaviour

Enrichment of quark jets in PbPb?

Similar conclusion with jet reconstruction **JHEP 1810 (2018) 139**



Conclusions

- Long Shutdown 2 is very important upgrade to ALICE
- Run 3, starting 2021, provides high-luminosity in PbPb
- Large statistics at the LHC has enabled flow measurements with unprecedented accuracy

- Jyväskylä:
  - project leadership in Fast Interaction Trigger –detector
  - flow analysis
  - jets using both two-particle correlations and jet reconstruction

Backup

Lower bound of viscosity

Kinetic theory:

Danielewicz, Gyulassy, Phys.Rev. D31 (1985) 53
W. A. Zajc, talk in "Strings to Things" workshop, 2008

$$\eta \approx \frac{1}{3} n \langle p \rangle \lambda$$

Smallest meaningful mean free path from formation time

$$\lambda \geq \frac{1}{\langle p \rangle}$$

For relativistic bose-gas:

$$s = \frac{\varepsilon + P}{T} \sim \frac{4}{3}\frac{\varepsilon}{T} \sim \frac{4}{3}\frac{\pi^2}{30}\frac{\pi^2}{\zeta(3)}\left[g_B \frac{\zeta(3)}{\pi^2} T^3\right] \sim 3.6n$$

Together gives a lower bound for viscosity to entropy ratio

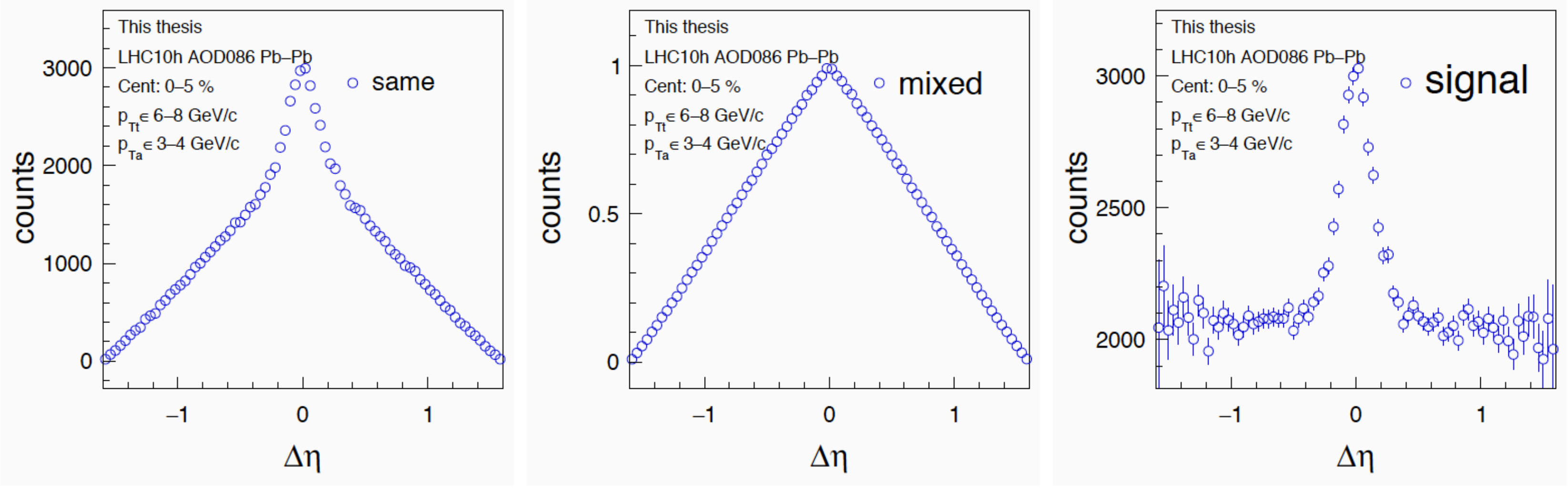
$$\eta \geq \frac{1}{3} \times \frac{s}{3.6} \quad \Rightarrow \quad \frac{\eta}{s} \geq 0.1 \approx 0.08 \approx \frac{1}{4\pi}$$

Note: not too strict constraints on underlying microscopic theory!

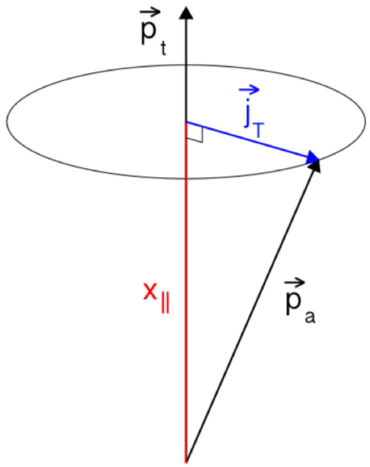
Jet associated yield

Treat finite acceptance with mixed event technique.
Fit generalized gaussian + constant to extract yield and describe combinatorial background.

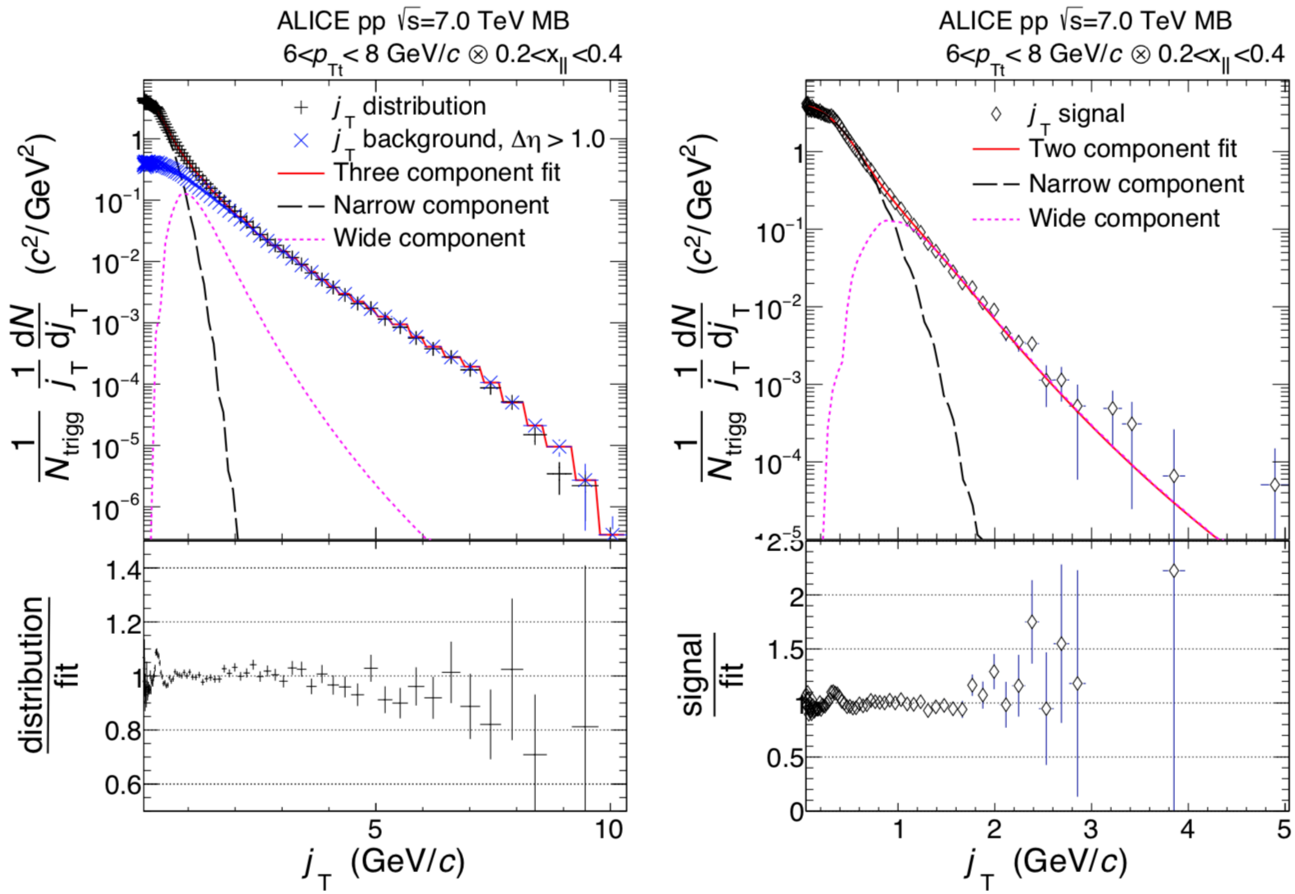
$$Y(\Delta\eta) = C_{\text{single}}(p_{\text{Ta}}) \frac{1}{N_{\text{trigg}}} \frac{\mathrm{d}N_{\text{same}}/\mathrm{d}\Delta\eta}{B \times \mathrm{d}N_{\text{mixed}}/\mathrm{d}\Delta\eta} = C_{\text{single}}(p_{\text{Ta}}) \frac{1}{N_{\text{trigg}}} \frac{\mathrm{d}N}{\mathrm{d}\Delta\eta}. \quad (28)$$



Jet transverse fragmentation momentum j_T in pPb – di-hadrons



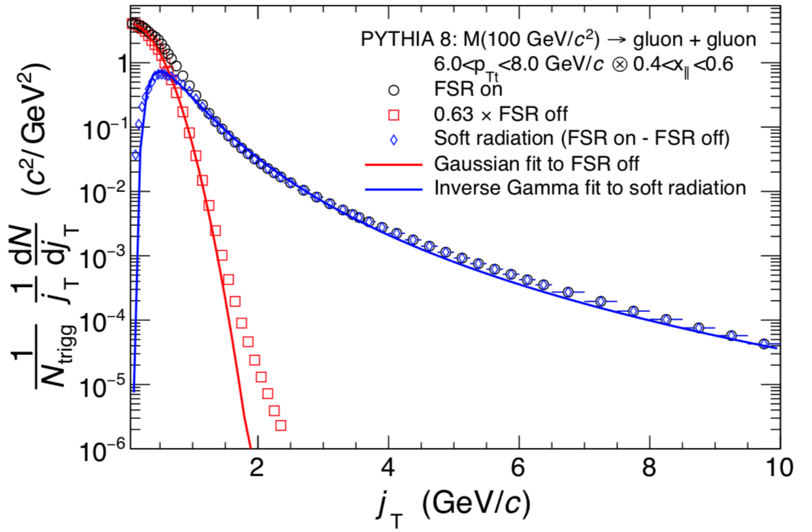
$$j_T = \frac{\left|\vec{p}_{T,\mathrm{trigg}} \times \vec{p}_{T,\mathrm{assoc}}\right|}{\left|\vec{p}_{T,\mathrm{trigg}}\right|}$$

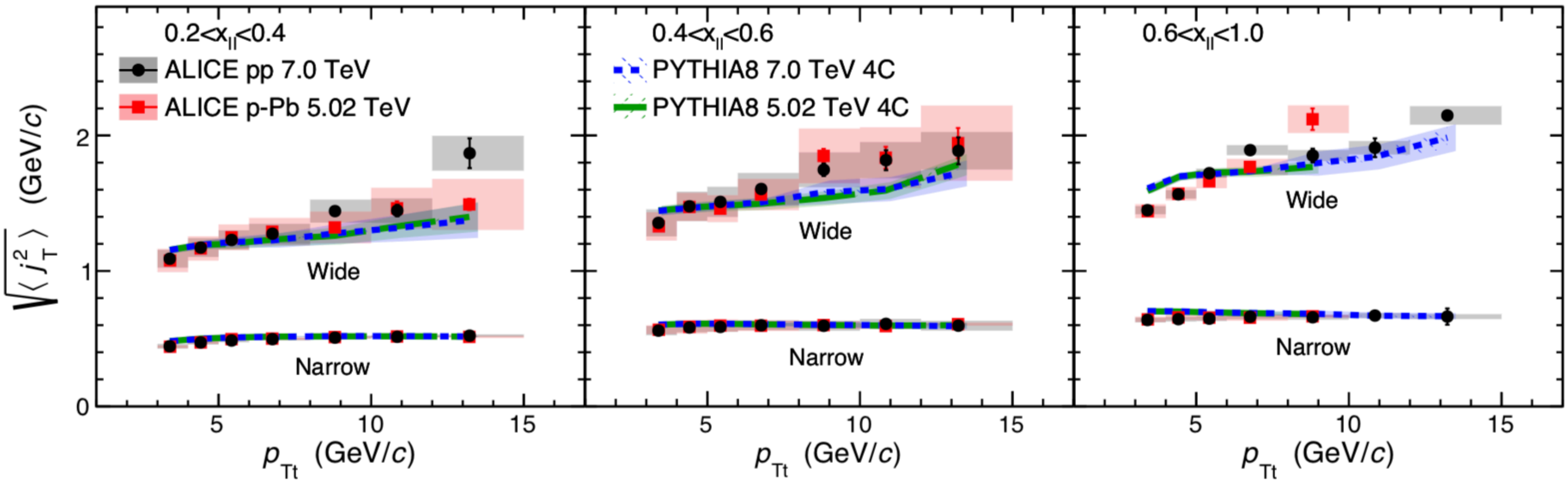


Clear narrow and wide components observed in j_T signal

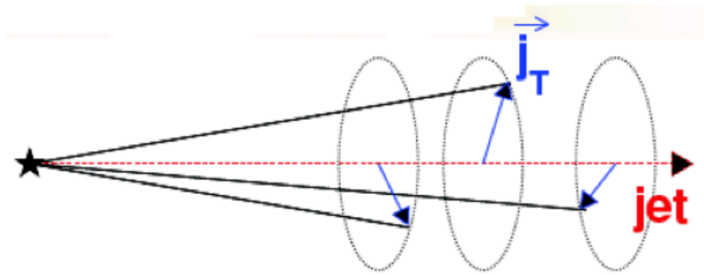
Jet transverse fragmentation momentum j_T in pPb – di-hadrons

- clear wide & narrow components
- PYTHIA based interpretation:
  - wide: soft QCD shower
  - narrow: non-perturbative hadronization

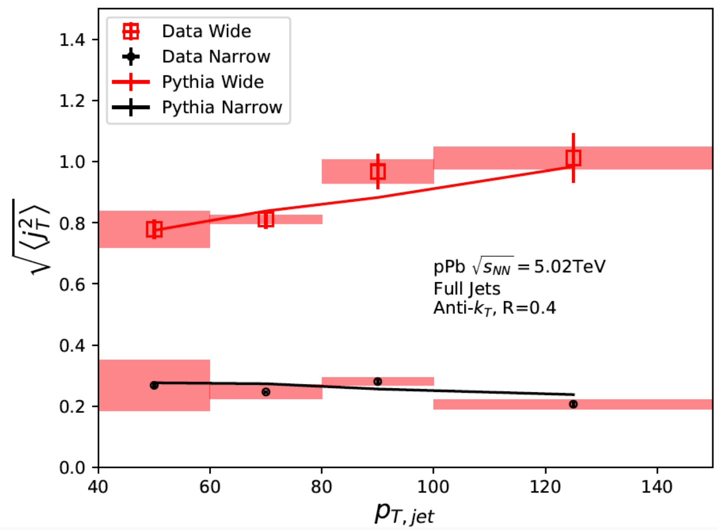


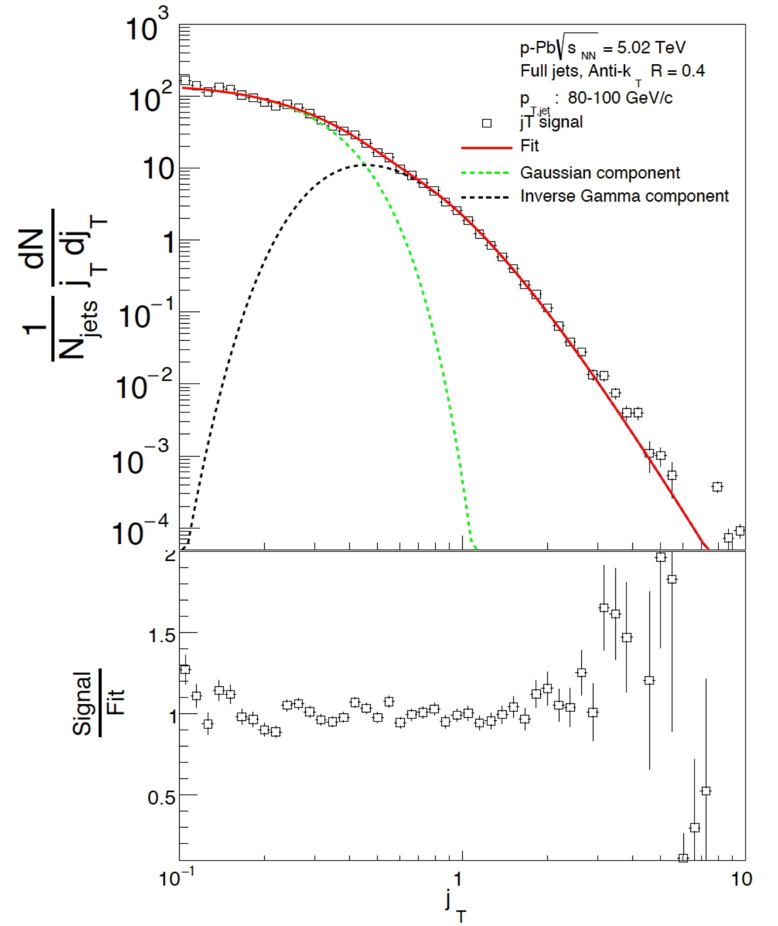


Jet transverse fragmentation momentum j_T in pPb – reconstructed jets



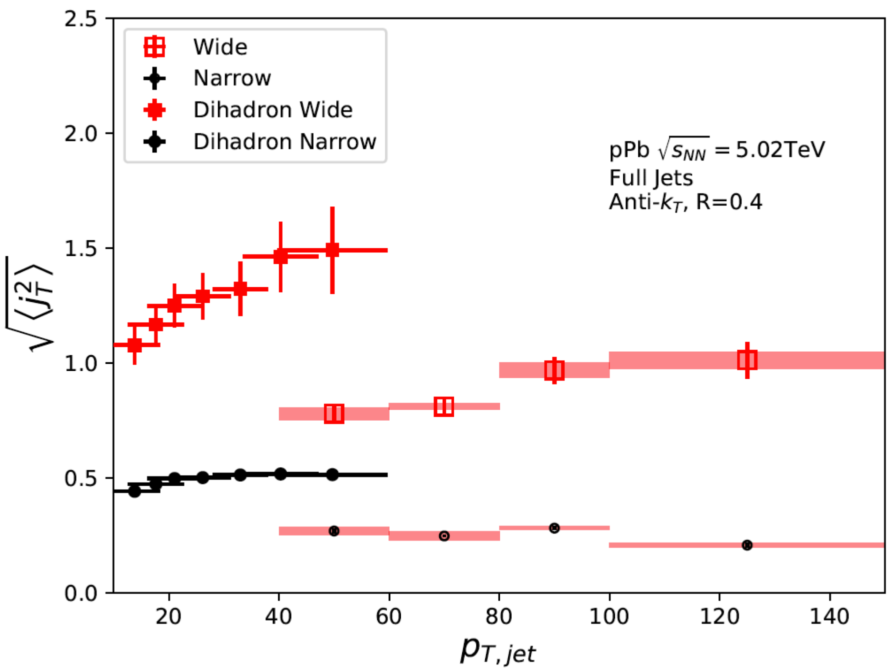
$$j_T = \frac{\left|\vec{p}_{T,\mathrm{jet}} \times \vec{p}_{T,\mathrm{track}}\right|}{\left|\vec{p}_{T,\mathrm{jet}}\right|}$$





The same observation using reconstructed jets

Compare di-hadron and jet j_T:



Jet results smaller, because:

- Jets have finite "radius" => $j_{T,max} \sim R\, p_{T,const}$
- Direction of the leading hadron deviates from jet axis
- Jet algorithm finds compact objects by definition

"Gluon filtering"

ALICE study with reconstructed jets: **JHEP 1810 (2018) 139**

Study jet angularity and p_T-dispersion in pp and in PbPb.

Data shows:
In PbPb, angularity distribution is more narrow but pTD-broder.

PYTHIA:
Kinematical collimation:
⬄ both angularity and pTD narrower

Enrichment of quark jets:
⬄ angularity narrower but pTD broader