Rapporteur talk

GLOBAL VARIABLES AND CORRELATIONS

UNIVERSITÉ DE STRASBOURG

Boris HIPPOLYTE and Dirk RISCHKE

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Quark Matter 2012 | Washington D.C. | Saturday August the 18th

OUTLINE

- our first feelings about Quark Matter 2012 : great !
  - ➡ stunning developments from both theory and phenomenology sides
  - ➡ wealth of fresh top-quality measurements;
  - ➡ stimulating discussions triggered by interesting new ideas;

Current understanding of initial state conditions and fluctuations;

Experimental constraints from azimuthal anisotropy: v_2 and higher harmonics;

More details on elliptic flow using data from BES up to LHC energy;

Event shape Engineering (ESE);

Chemical freeze-out and hadrochemistry (baryons, mesons, strangeness);

Radial flow and kinetic freeze-out: spectra, freeze-out parameters, BES, LHC;

Annihilation + Nuclei and Hypernuclei + Exotic search (after HBT);

HBT/Femtoscopy: in pp, BES then RHIC and LHC

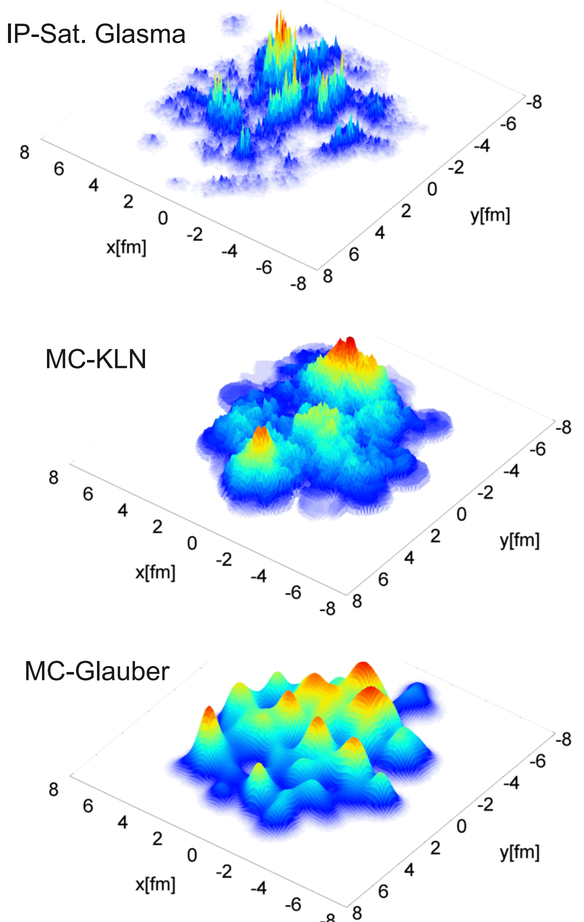
Net protons (higher moments), Net charge fluctuations

Chiral Magnetic Effect

INITIAL CONDITIONS AND FLUCTUATIONS...

- cross roads: state-of-the-art modeling of initial conditions meets extremely precise experimental measurements of fluctuations !

Initial energy density (arb. units)



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

Spectacularly good level of agreement:

Talk of B.Schenke: 3A

“real QM time” matching of EbyE $P(v_{n=2\text{-}4})$ vs. $v_{n=2\text{-}4}$ by ATLAS

Talk of J.Jia: 4A

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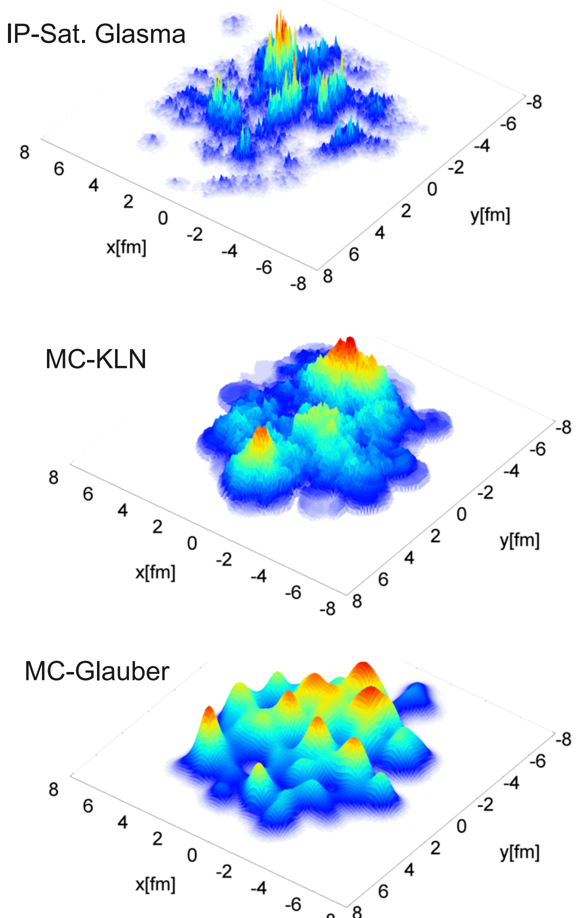

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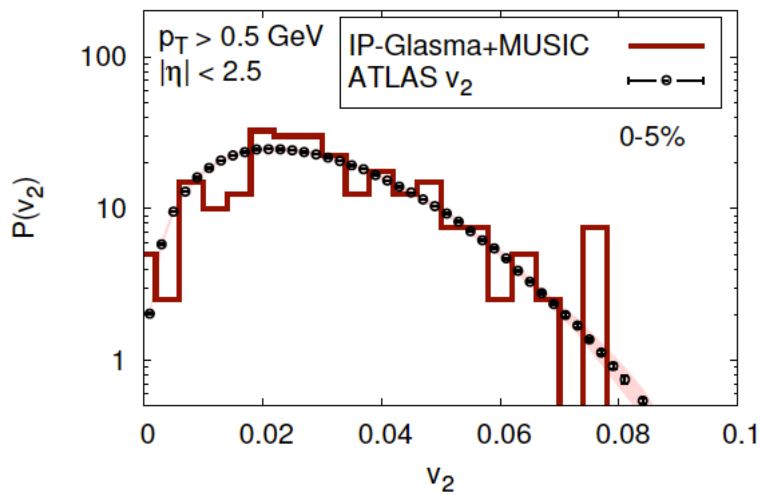

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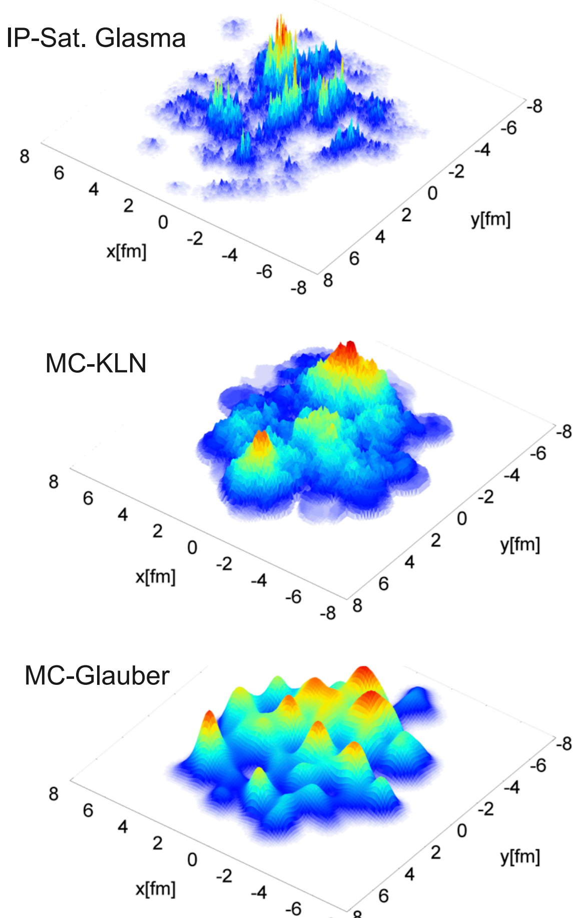

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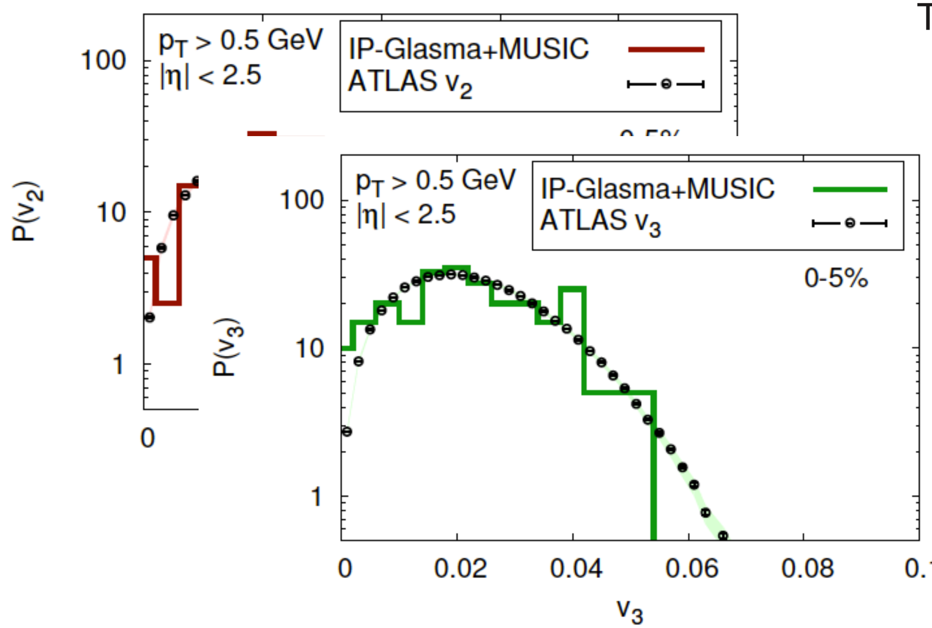

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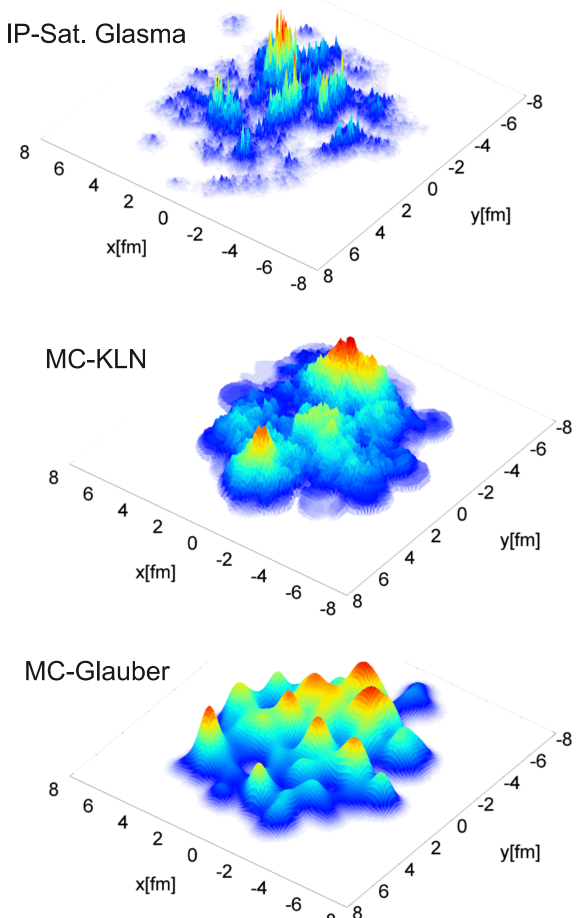

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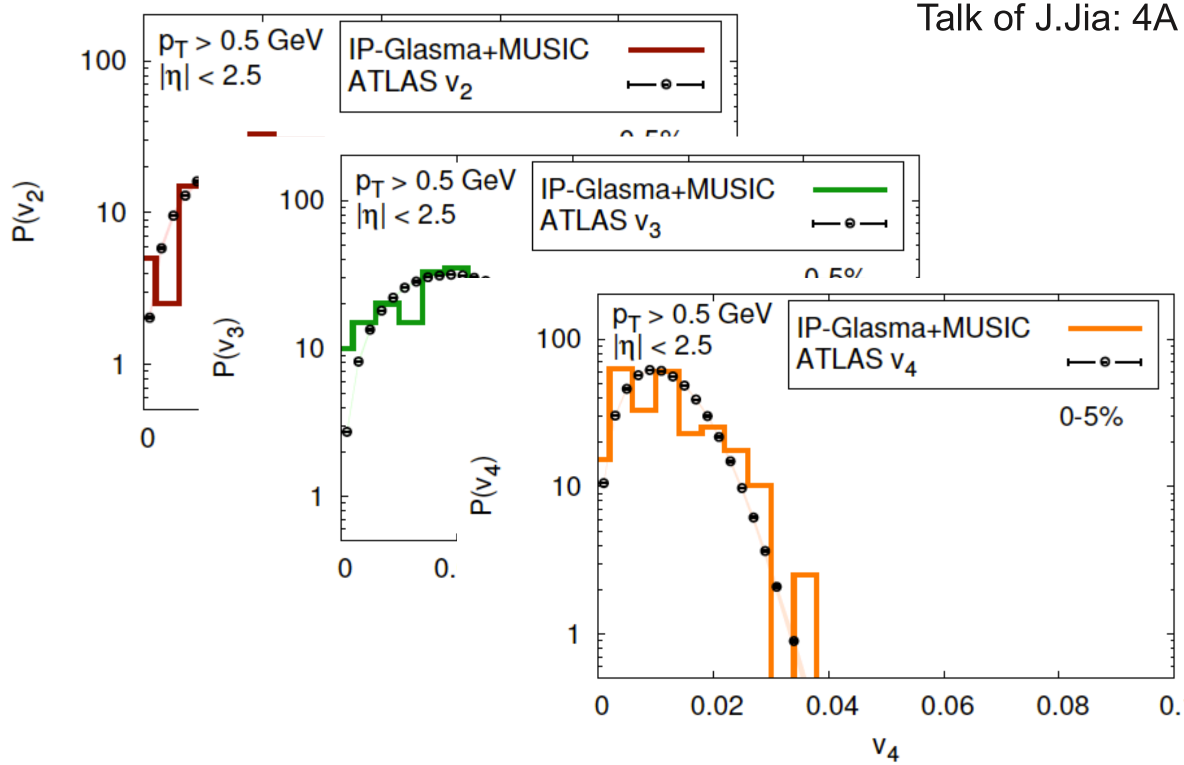

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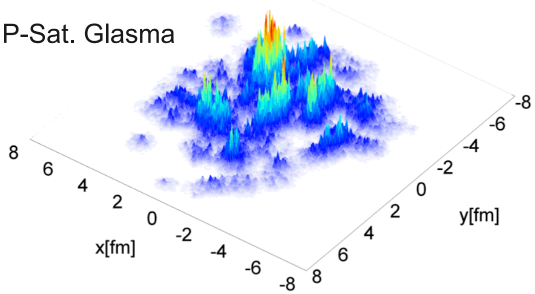
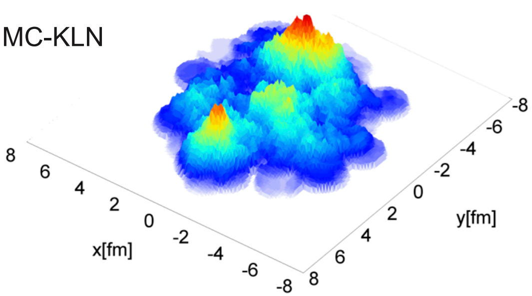
Initial energy density (arb. units)

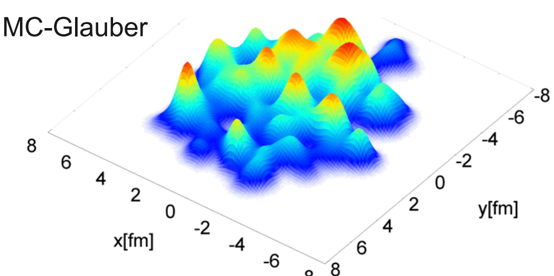
IP-Sat. Glasma



MC-KLN



MC-Glauber



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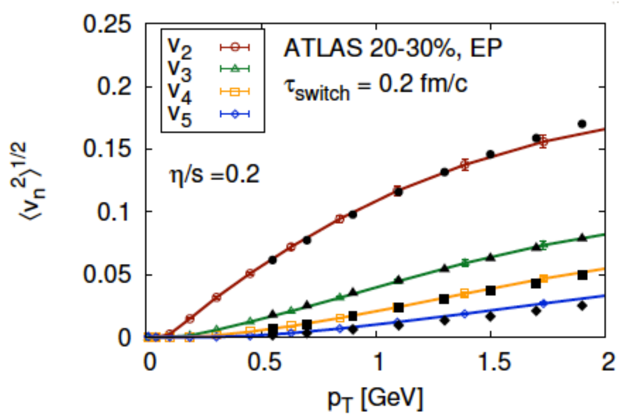
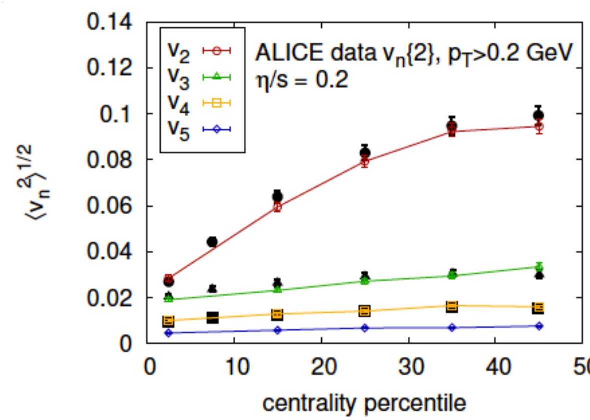
$\eta/s=0.2$ (using MUSIC hydro and matching ATLAS & ALICE v_n)





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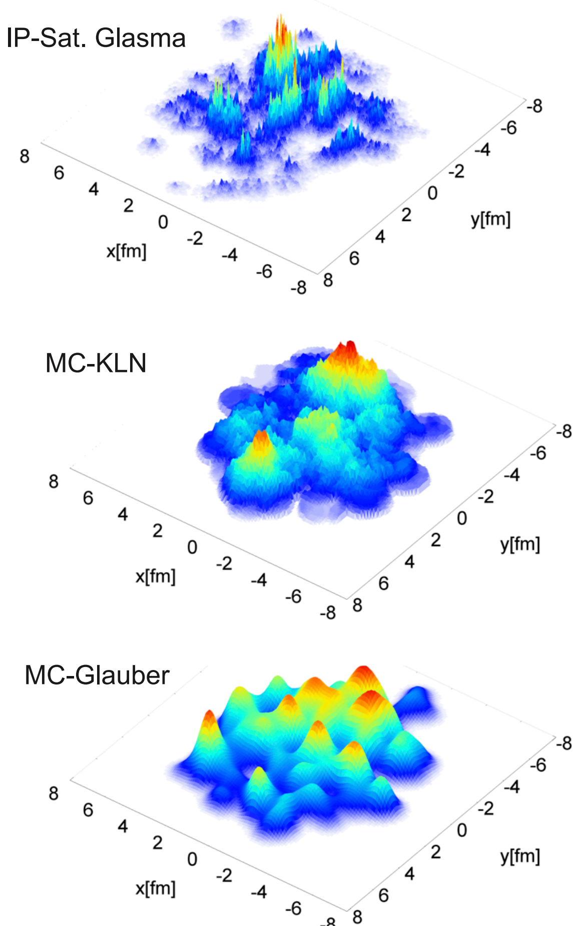

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$\eta/s=0.2$ (using MUSIC hydro and matching ATLAS & ALICE v_n)

Consistent results: shear viscosity / entropy density

quantification of syst. uncertainties when extracting η/s
"conservative" $0.07 \leq \eta/s \leq 0.43$

Talk of M.Luzum: 2A

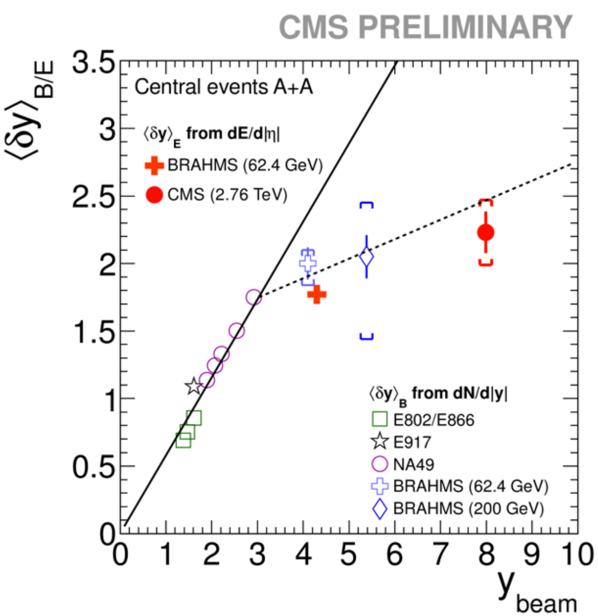
Additional and fresh constraints: from Ultra Central Collisions (2‰) by CMS: b<2 fm and $v_{n=2-6}\{2,\Delta\eta>2\}$

Talk of S.Tuo: 7D

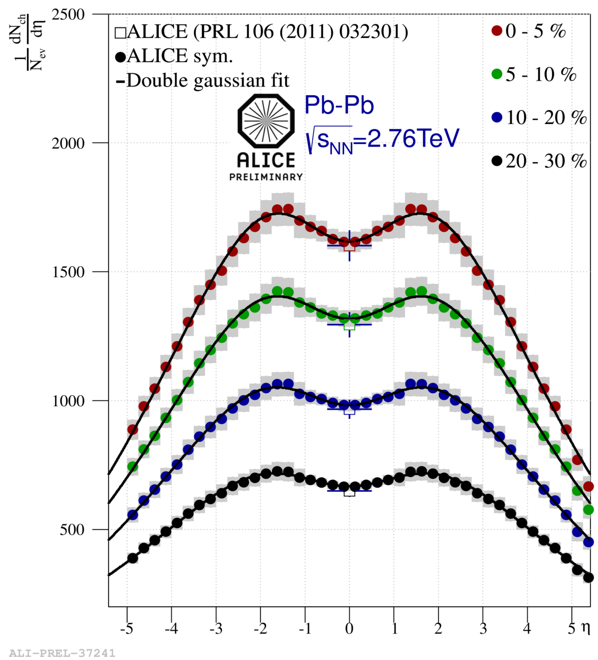
... MORE EXPERIMENTAL CONSTRAINTS...

- excitation function of nuclear stopping power;
- charge particle pseudorapidity density;
- transverse energy pseudorapidity density and excitation function;

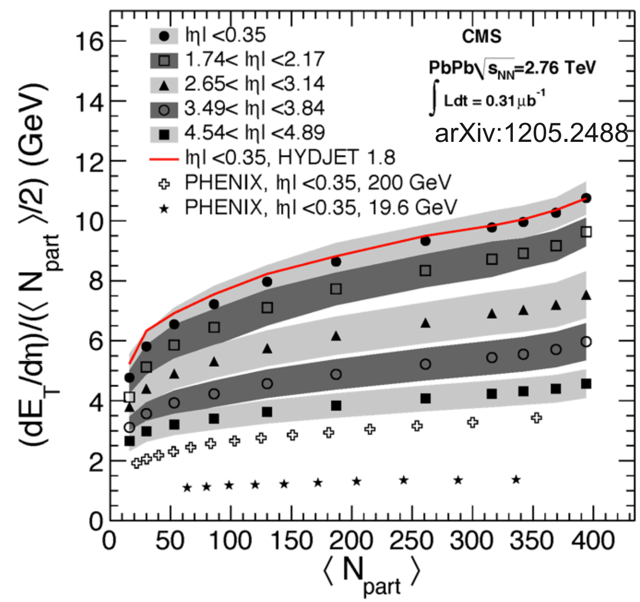
Talk of H.Wöhrmann: 3D



Talk of M.Guilbaud: 2A



Talk of M.Malek: 2A



Longitudinal constraints even if final state measurements...

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- excitation function of nuclear stopping power;
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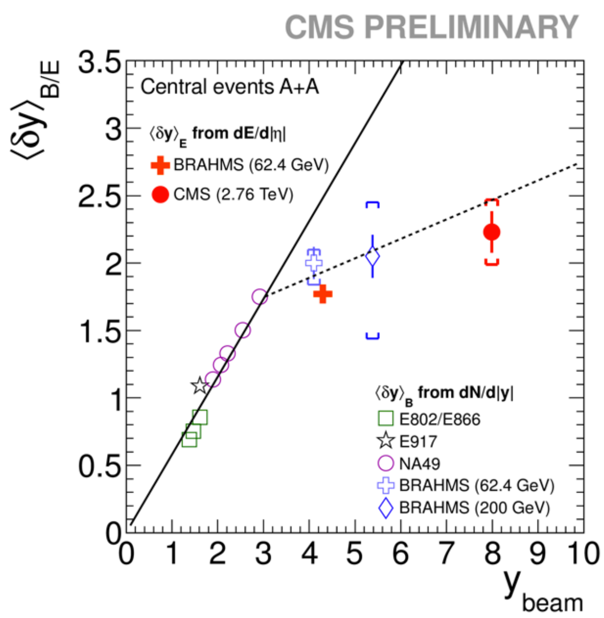

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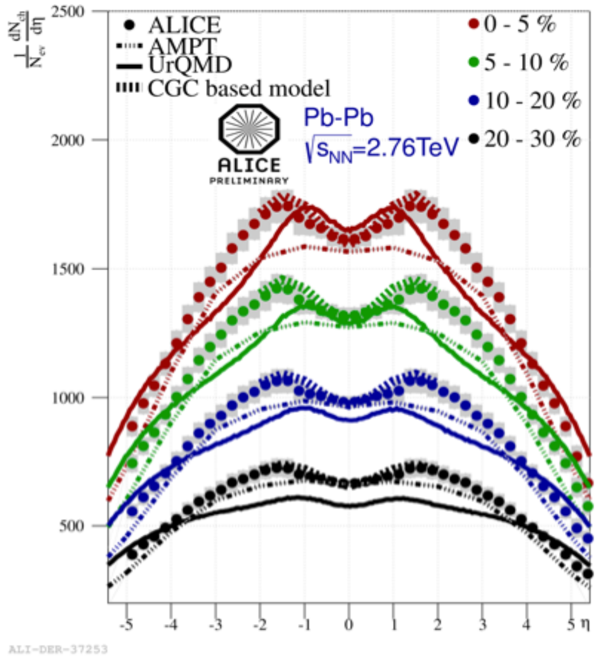

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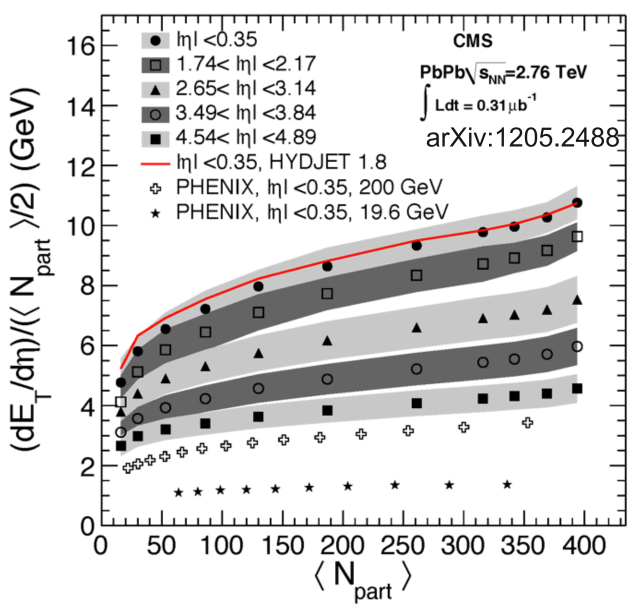

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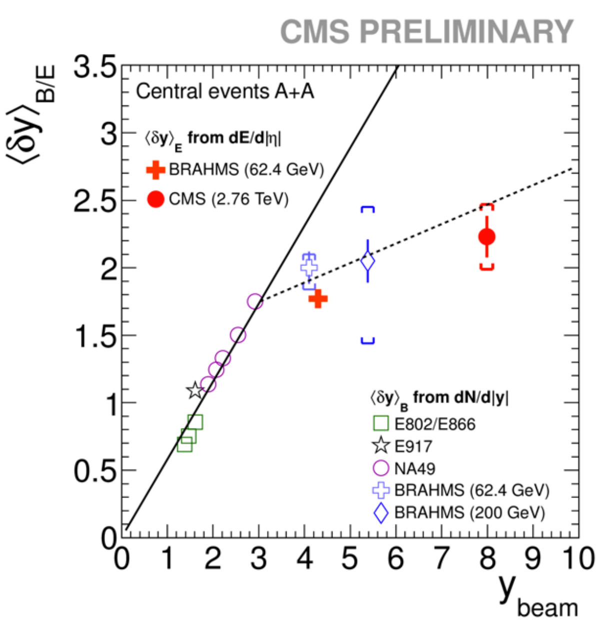

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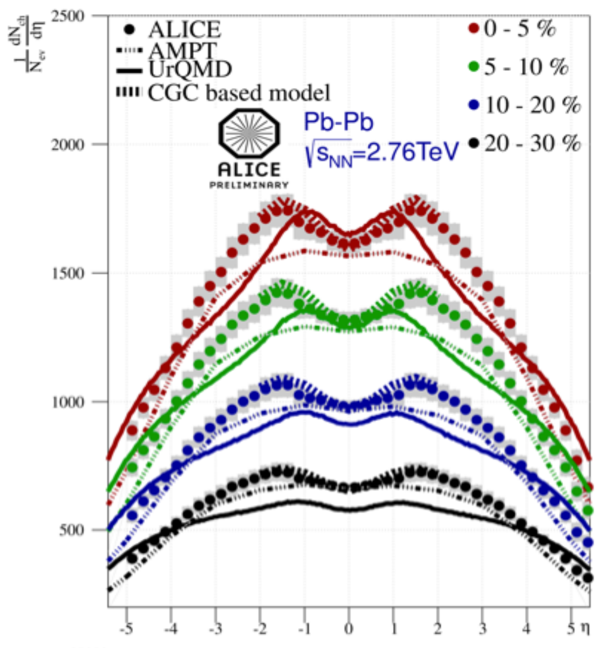
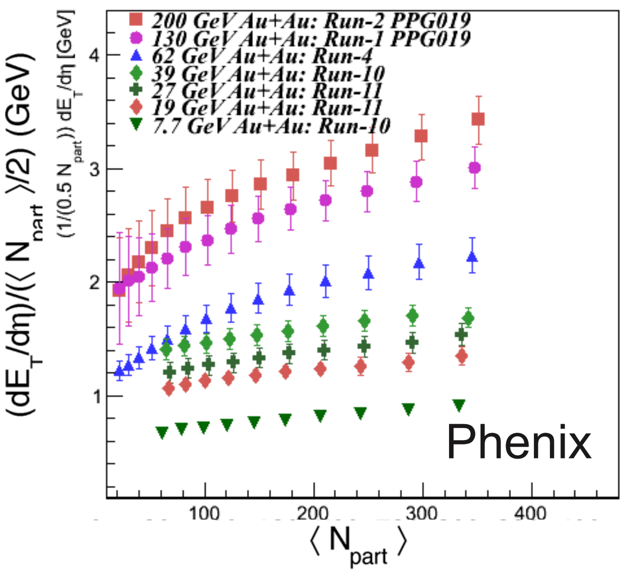


Talk of M.Malek: 2A

Talk of E.O'Brien: Plenary VA



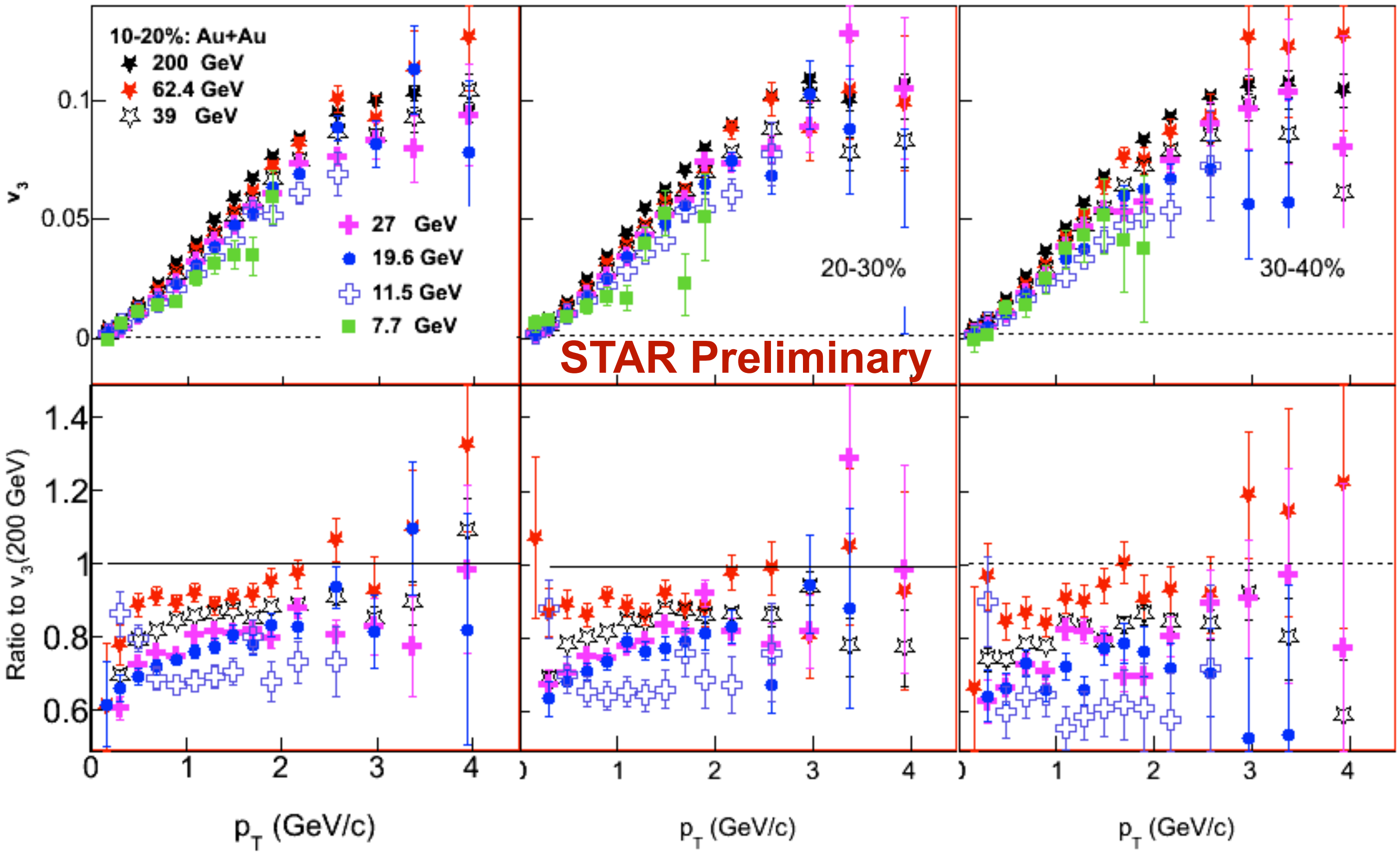
Longitudinal constraints even if final state measurements...

... ON FLUID-DYNAMICS: AZIMUTHAL ANISOTROPY

- starting from the Beam Energy Scan at RHIC

v_3

Talk of Y.Pandit: 1A



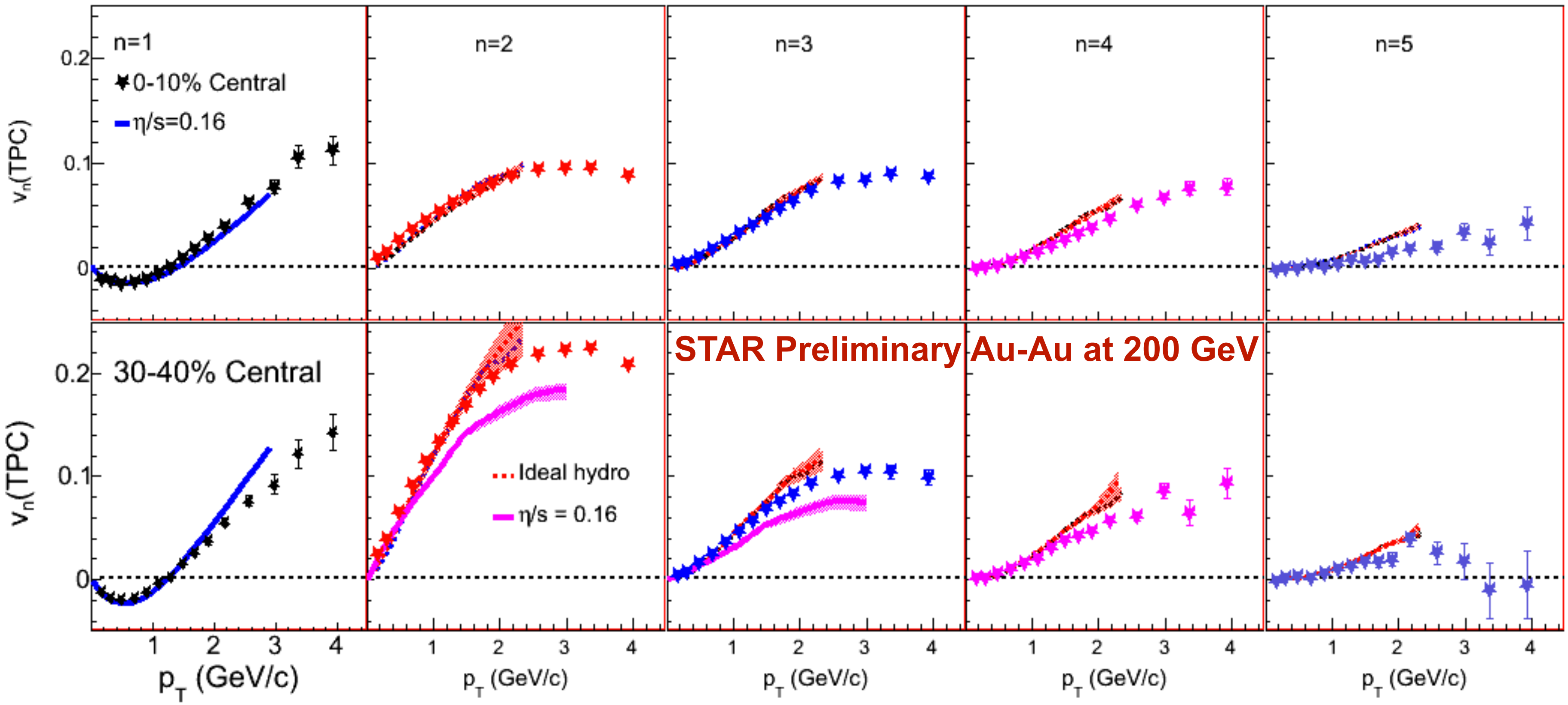
v_3 (p_T) from the BES systematically lower than 200 GeV values.

... ON FLUID-DYNAMICS: AZIMUTHAL ANISOTROPY

- to higher order harmonics at top RHIC energy ... $v_{n=1-5}$

Models by: (n=1) Retinskya *et al.*, PRL 108, 252302 (2012),
(n=2,3) Schenke *et al.*, PRL 106, 042301 (2011),
(n=2-5) Gardim *et al.*, arXiv: 1293.2882.

Talk of Y.Pandit: 1A



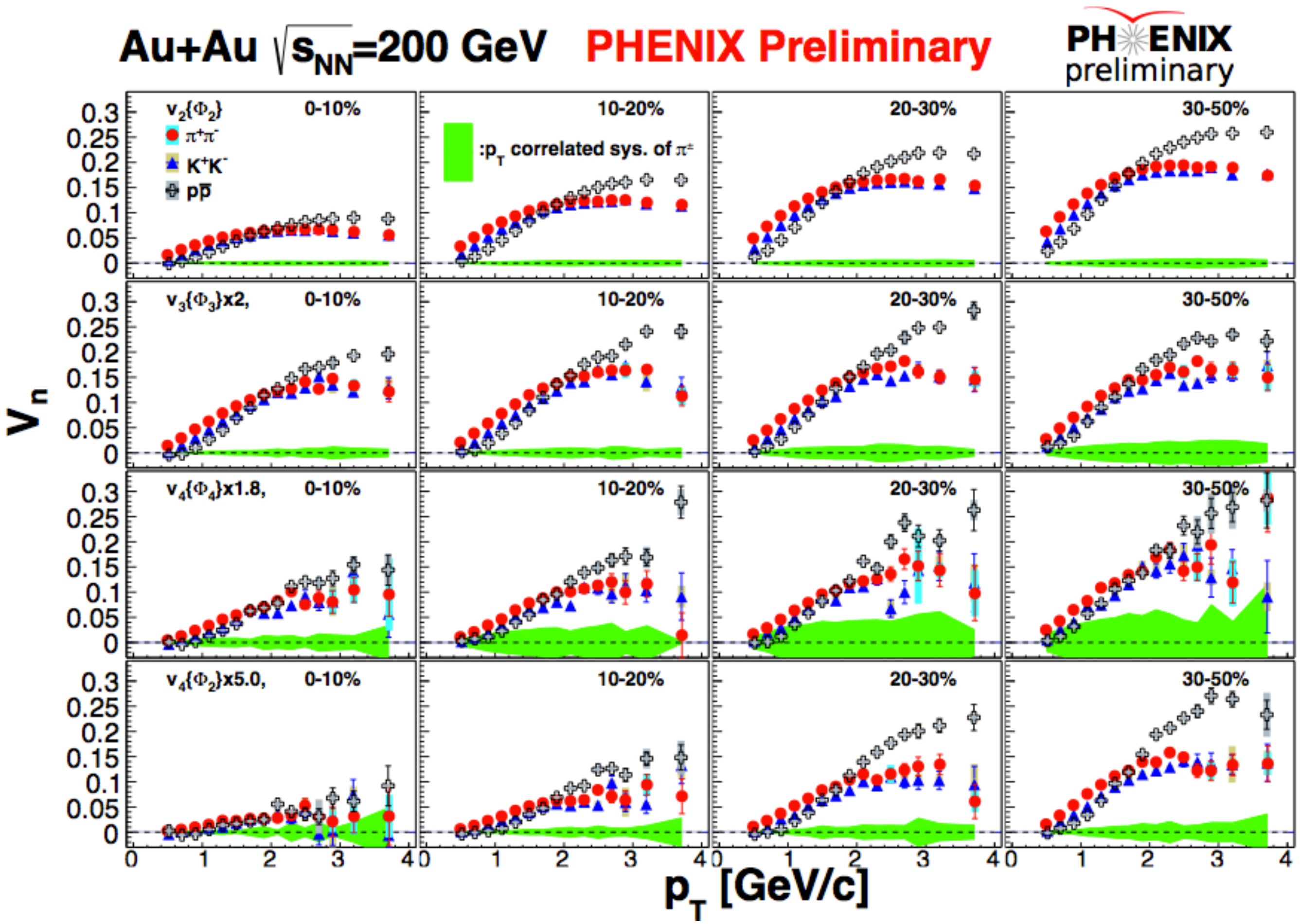
Low viscosity (η/s~0.16) is always favoured

... ON FLUID-DYNAMICS: AZIMUTHAL ANISOTROPY

- and even adding PID...

$v_{n=2-5}$

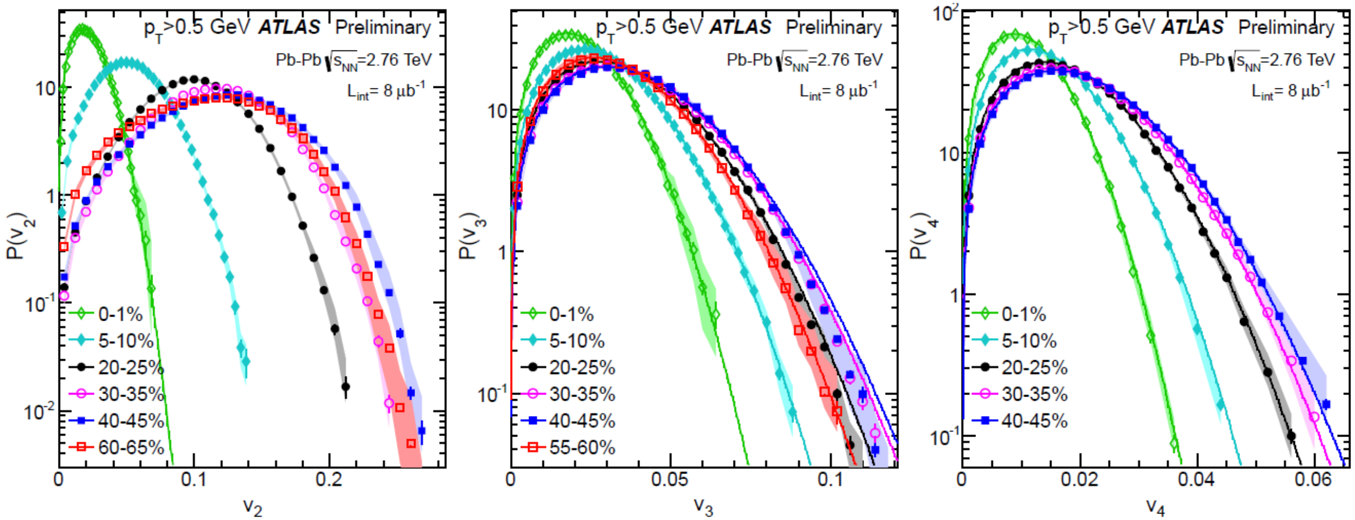
Talk of Y.Gu: 2A



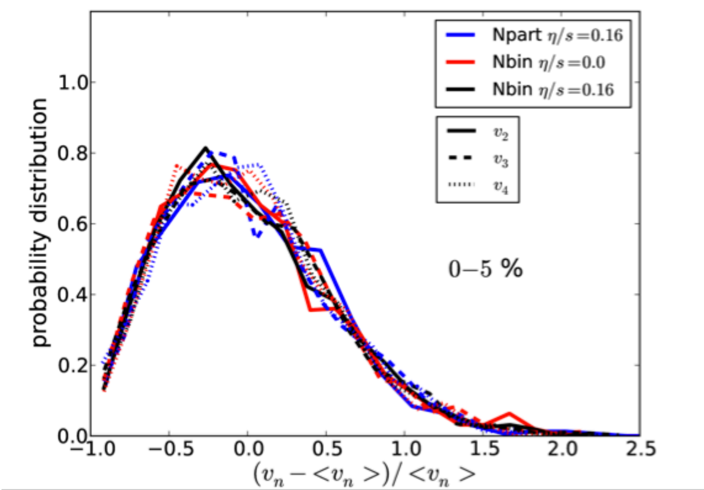
... ON FLUID-DYNAMICS: AZIMUTHAL ANISOTROPY

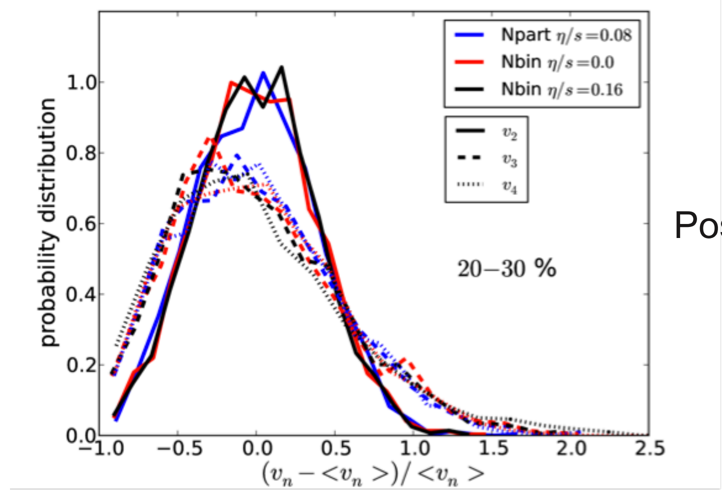
- then constraining further with LHC measurements

E-by-E v_n distributions



Talk of J.Jia: 4A





Poster of H.Niemi *et al.*: 248

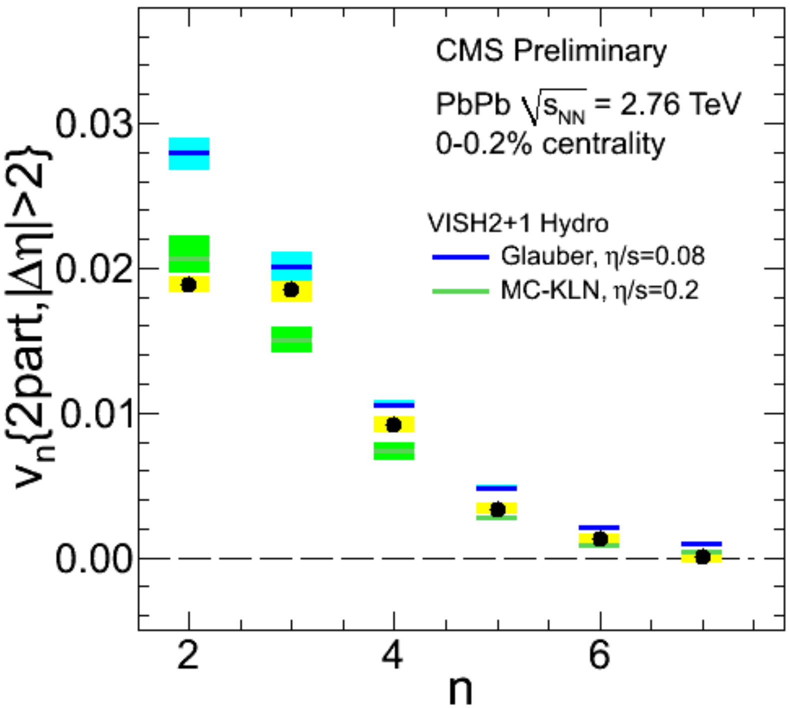
... ON FLUID-DYNAMICS: AZIMUTHAL ANISOTROPY

- up to Ultra Central Collisions (2‰) from CMS $v_{n=2\text{-}7}\{2\}$

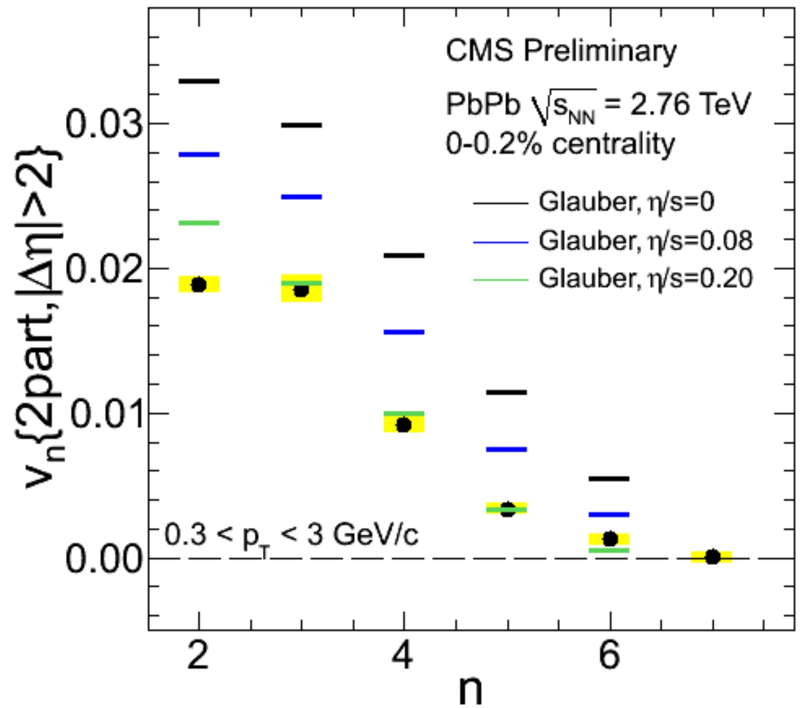
Talk of S.Tuo: 7D

Poster of W.Li: 242

Calculation by U.Heinz *et al.*



Calculation by M.Luzum *et al.*

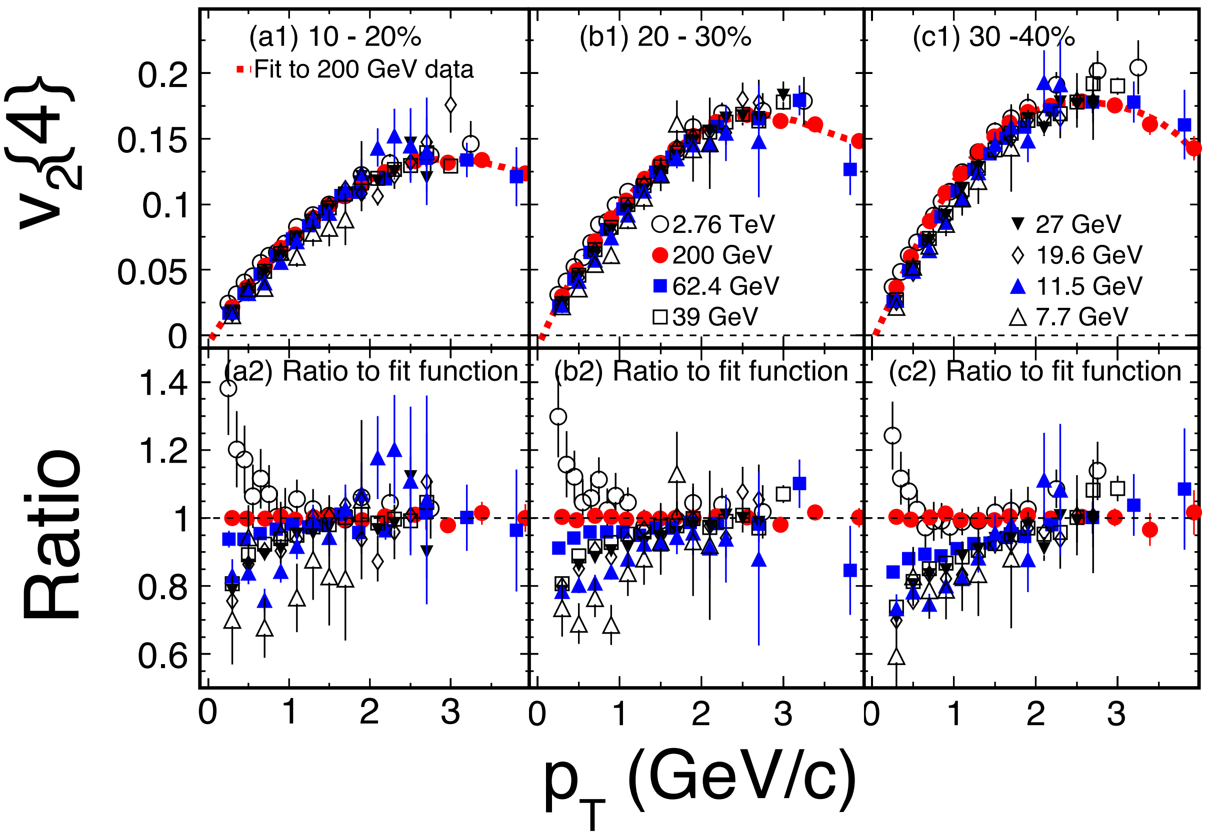


Would be interesting if IP-Glasma can also here reconcile v_2 and v_n with a single η/s...

... ON FLUID-DYNAMICS: AZIMUTHAL ANISOTROPY

- higher cumulants

Higher cumulants



Isolating non-flow and fluctuation contributions

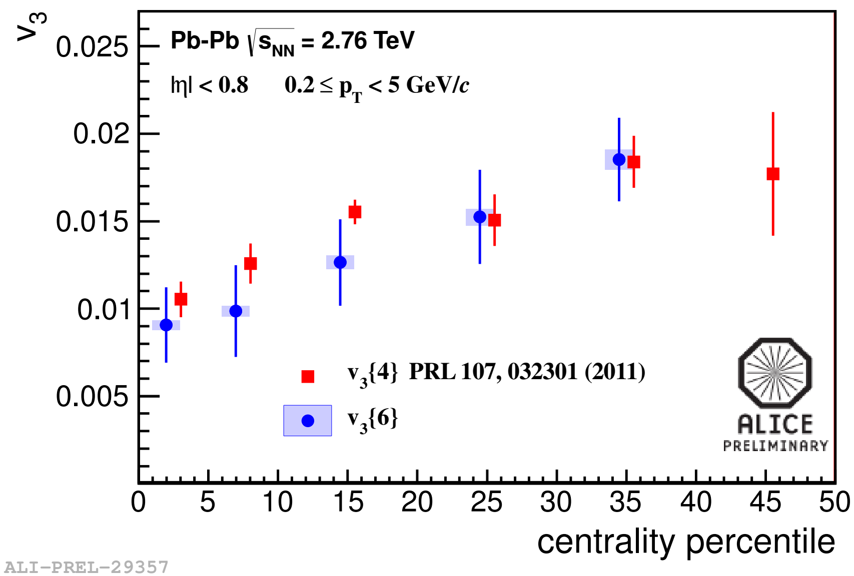
Talk of S.Shi: 6B

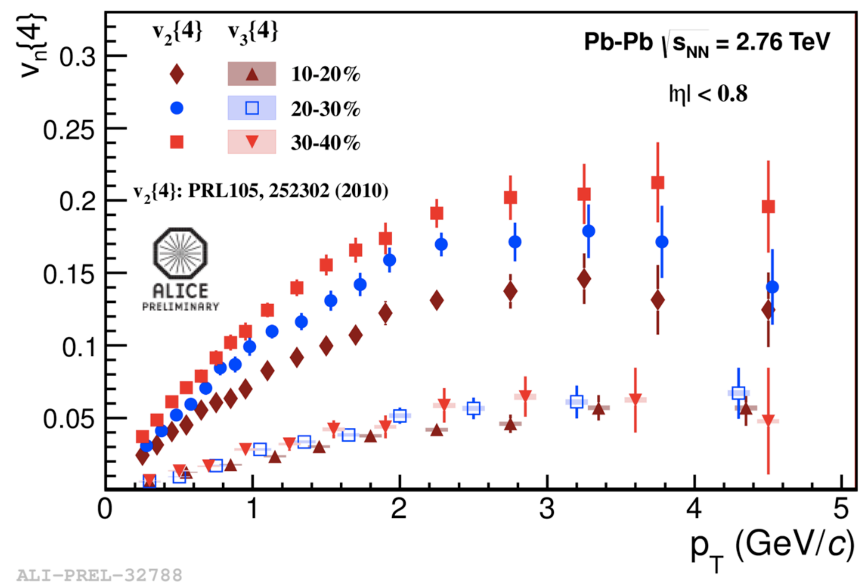
Note: Careful (w.r.t. radial flow) when drawing a comparison up to LHC energies...

... ON FLUID-DYNAMICS: AZIMUTHAL ANISOTROPY

- higher harmonics with higher cumulants

Higher harmonics with higher cumulants





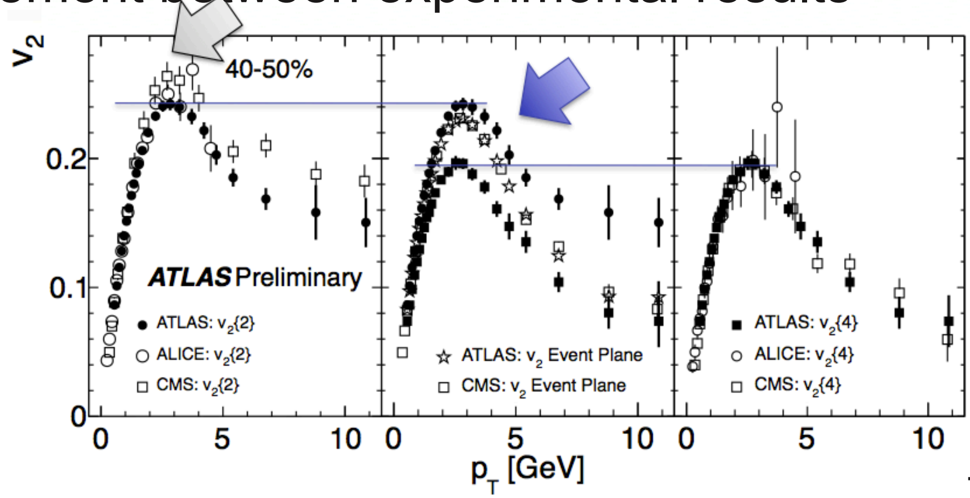
Talk of A.Bilandzic: 7D

Experimental fact: non-negligible 3rd moment when compared to 1st or 2nd

Strong centrality dependence of $v_2\{4\}$ but weak centrality dependence of $v_3\{4\}$

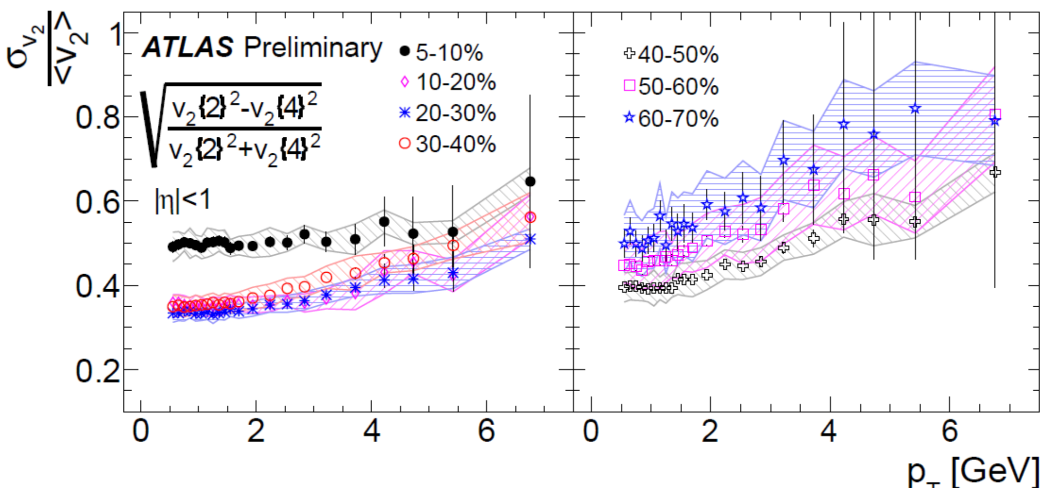
... ON FLUID-DYNAMICS: AZIMUTHAL ANISOTROPY

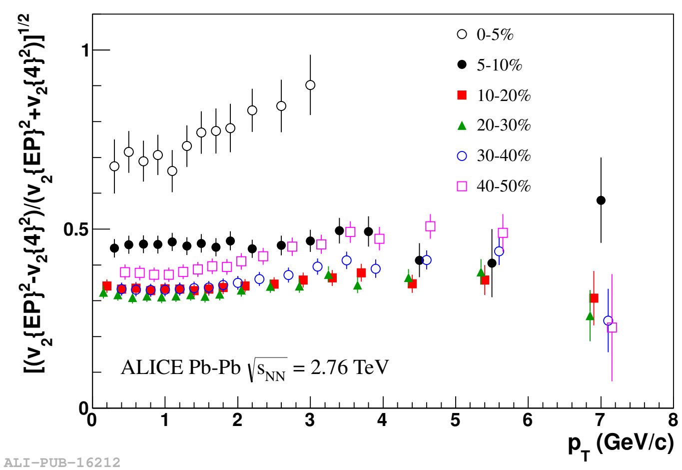
- excellent agreement between experimental results



Talk of T.Bold: 6D

Talk of A.Dobrin: 1C



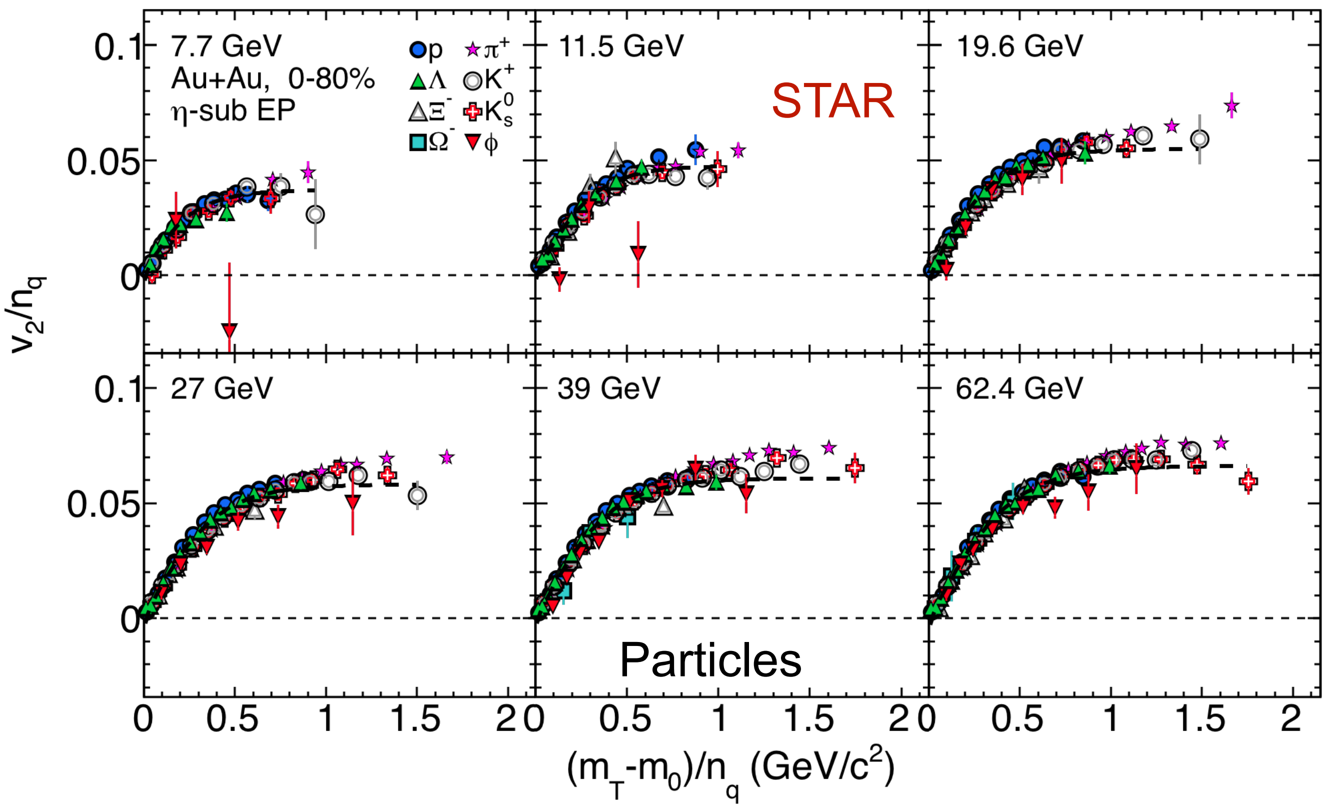


...with sometimes unexpected trends...

... ON FLUID-DYNAMICS: AZIMUTHAL ANISOTROPY

- v_2+PID ! probing hadron mass and constituent quark dependence

at RHIC



Talk of S.Shi: 6B

ϕ (2σ) !

ncq scaling appears to work

none !

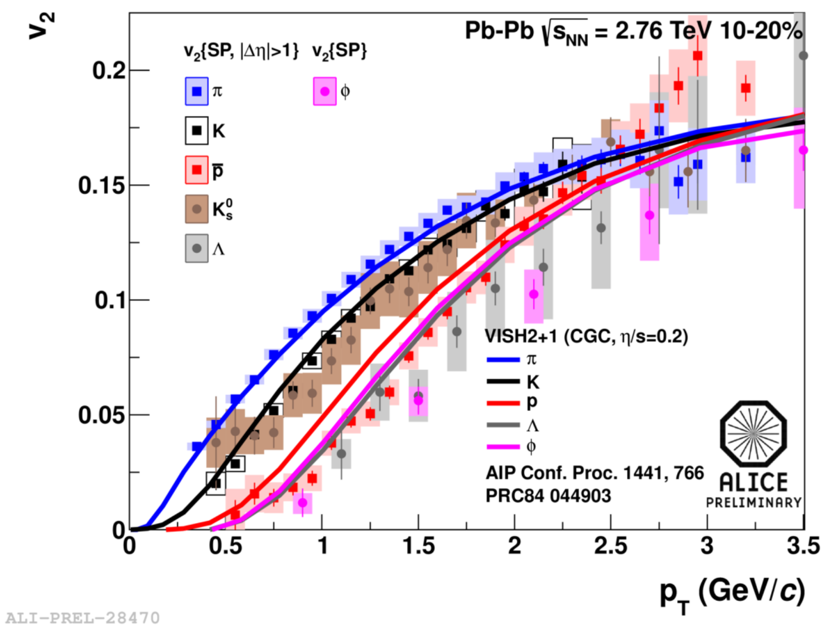
7.7 11.5 19.6 27 39 62.4 200 2760 GeV

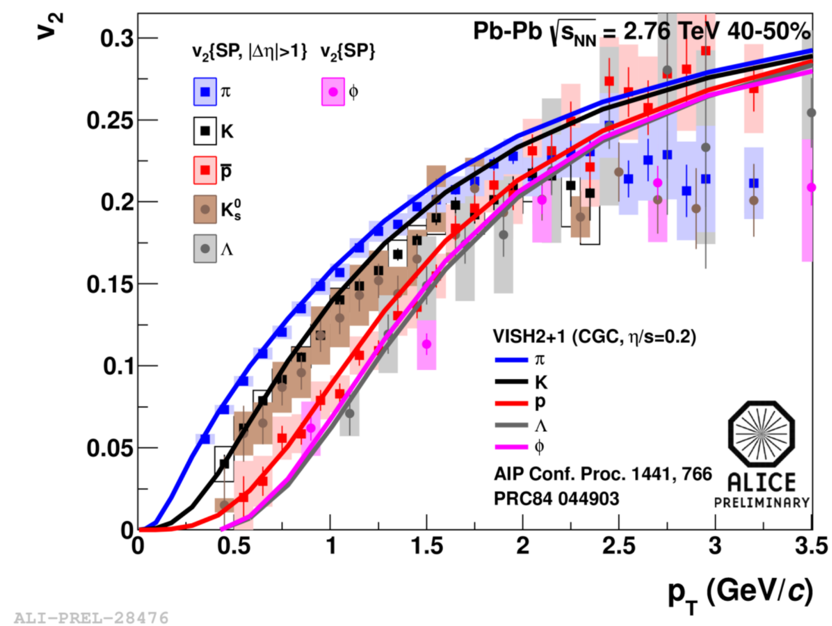
... ON FLUID-DYNAMICS: AZIMUTHAL ANISOTROPY

- v_2+PID ! probing hadron mass and constituent quark dependence

VISH2+1, talk by H.Song Plenary ID

at the LHC





Talk of F.Noferini: 6D

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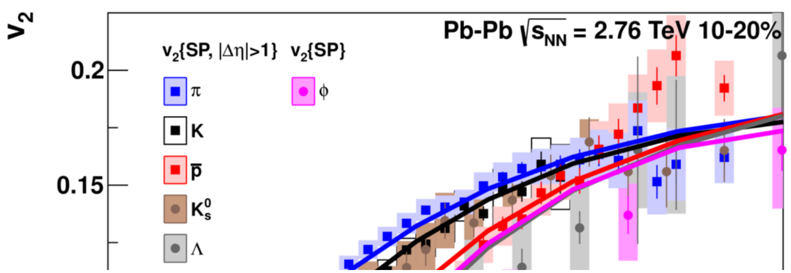
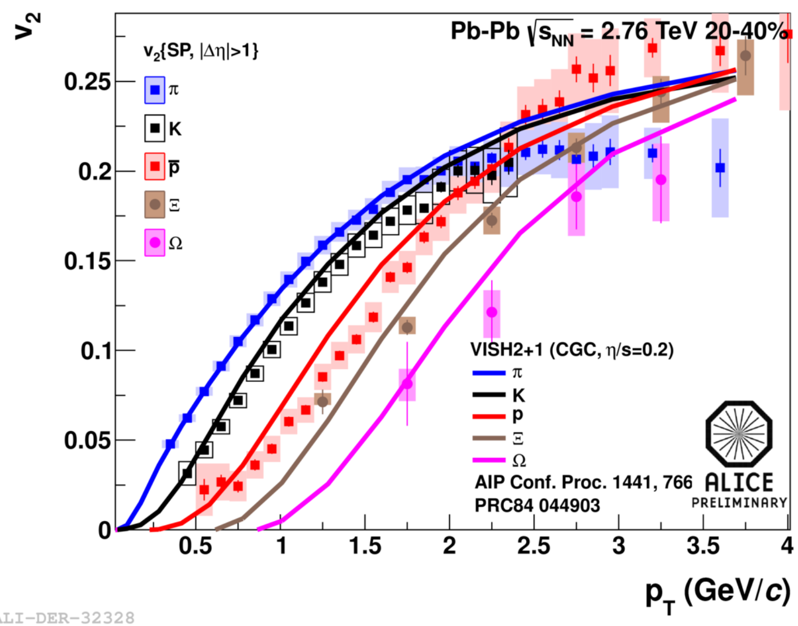
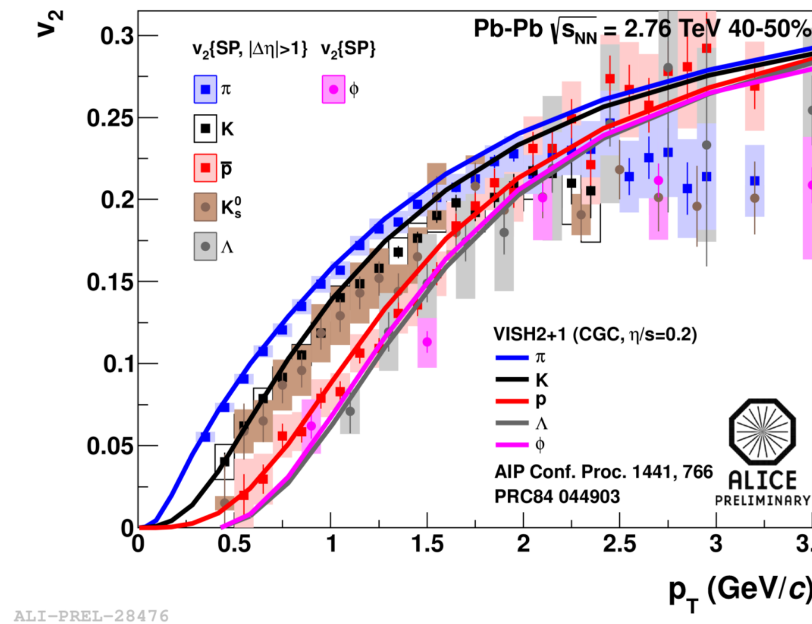






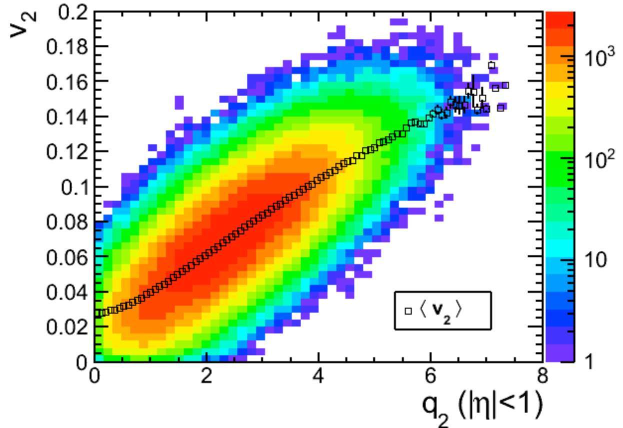
Talk of F.Noferini: 6D

Precise measurements from π to Ω leaving very little (no) room for ncq scaling at the LHC...

EVENT SHAPE ENGINEERING

Talk of S.Voloshin: Plenary IC

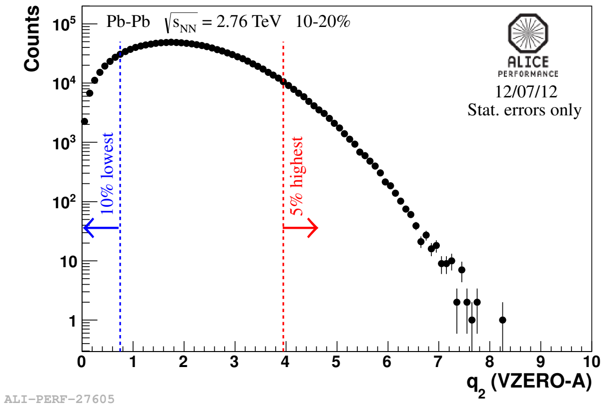
- Selection of azimuthally anisotropic events: length of flow vector, q_2



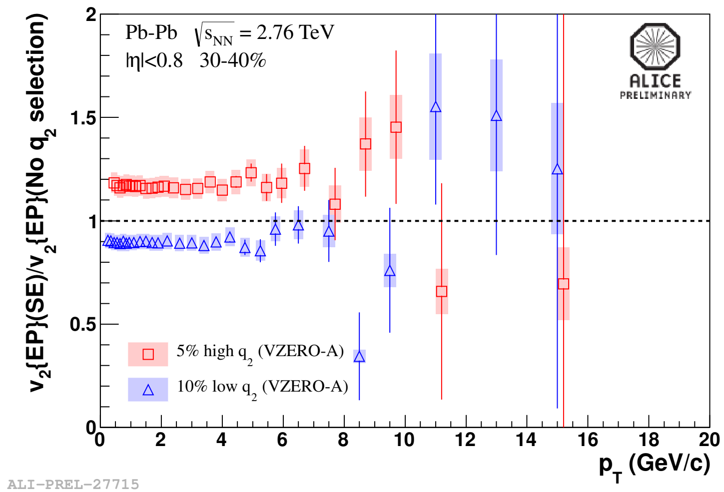
$$Q_{n,X} = \sum_{i=1}^{M} \cos(n\phi_i)$$

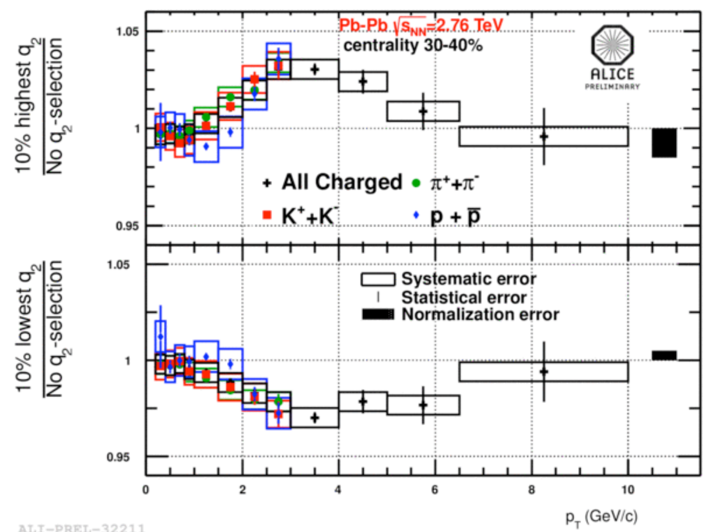
$$Q_{n,Y} = \sum_{i=1}^{M} \sin(n\phi_i)$$

$$q_n = Q_n/\sqrt{M}$$



Talk of A.Dobrin:1C





Talk of L.Milano: 5A

expected effect on v_2 and consequence on PID'ed transverse momentum spectra

STATE-OF-THE-ART SYSTEM EVOLUTION MODELING

- linking the wagons for a full description of the system evolution !

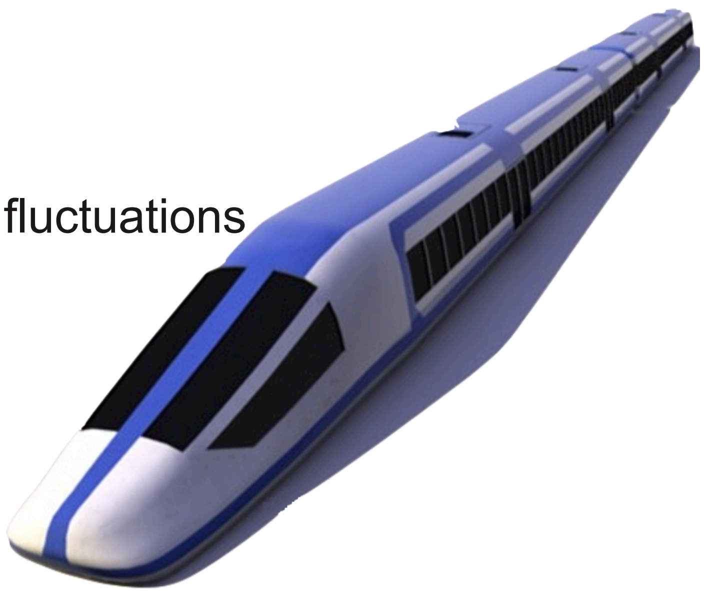
Talk of H.Petersen: Plenary VA

STATE-OF-THE-ART SYSTEM EVOLUTION MODELING

- linking the wagons for a full description of the system evolution !
  - state-of-the-art modeling of initial conditions;

Talk of H.Petersen: Plenary VA

initial fluctuations



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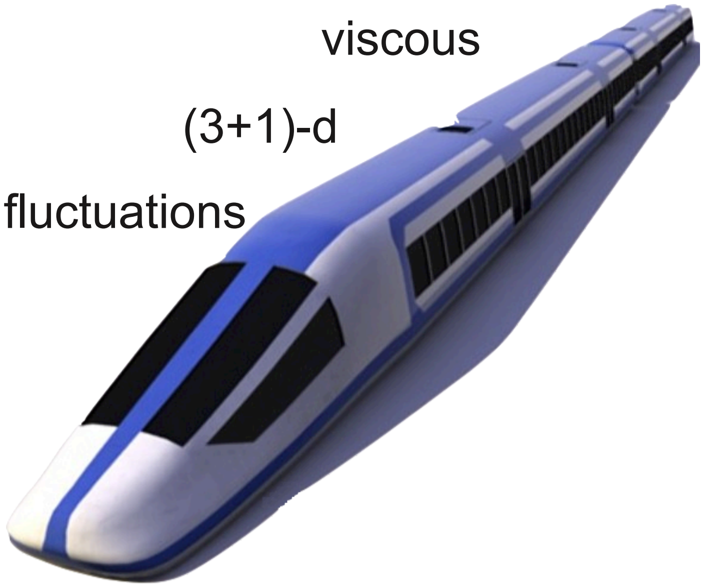

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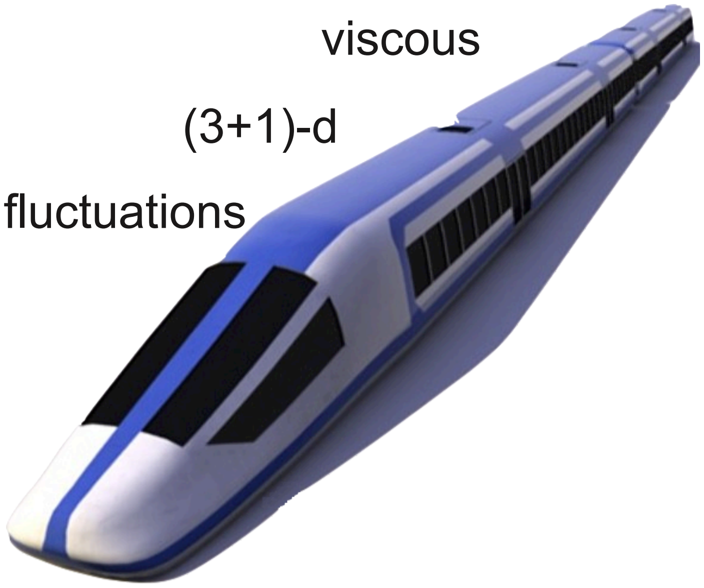
  - state-of-the-art modeling of initial conditions;
  - state-of-the-art hydrodynamics (3+1)d viscous;
  - state-of-the-art freeze-out: hadronic afterburner;

Talk of H.Petersen: Plenary VA



STATE-OF-THE-ART SYSTEM EVOLUTION MODELING

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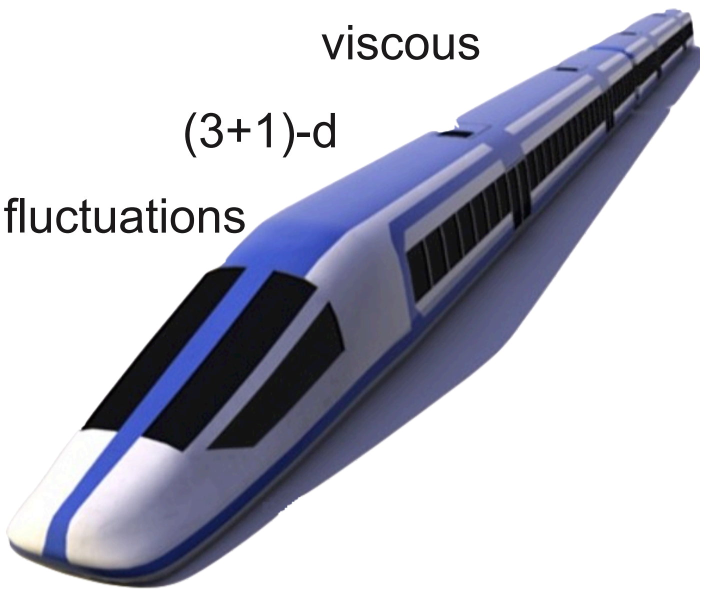

Compilation by J.-Y. Ollitrault: Plenary IC

Author/Presenter	QM2012	arXiv	initial fluctuations	3+1d	viscous	afterburner
Huichao Song	1D	1207.2396			✓	✓
Teaney/Yan	1A	1206.1905			✓	
Chun Shen	1A	1202.6620			✓	
Sangyong Jeon	2A		✓	✓	✓	✓
Matt Luzum	2A				✓	
Piotr Bozek	2C	1204.3580	✓	✓	✓	
Björn Schenke	3A	1109.6289	✓	✓	✓	
Dusling/Schaefer	3A	1109.5181			✓	
Chiho Nonaka	3A	1204.4795	✓	✓	✓	
Ryblewski/Florkowski	3D	1204.2624		✓		
Longgang Pang	4D	1205.5019	✓	✓		
Hannah Petersen	VA	1201.1881	✓	✓		✓
Fernando Gardim	6D	1111.6538	✓	✓		
Zhi Qiu	29	1208.1200	✓		✓	
Gardim/Grassi	52	1203.2882	✓	✓		
Katya Retinskaya	57	1203.0931			✓	
Hirano/Murase	255	1204.5814	✓	✓		✓
Holopainen/Huovinen	284	1207.7331	✓			
Asis Chaudhuri		1112.1166	✓		✓	
Iurii Karpenko		1204.5351		✓		✓
Yu-Liang Yan		1110.6704		✓		✓
Josh Vredevoogd		1202.1509		✓	✓	
Ron Soltz		1208.0897			✓	✓
Rafael Derradi de Souza		1110.5698	✓	✓		

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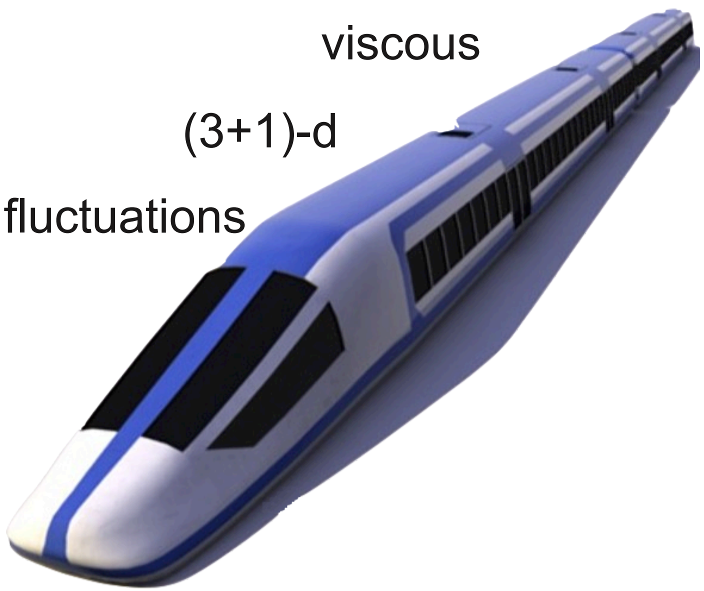

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Laszlo Csernai	23	1112.4287
Amaresh Jaiswal	48	1204.3779
Ioannis Bouras	80	1208.1039
Flörchinger/Wiedemann	97	1108.5535
Harri Niemi	248	
Mate Csanad	295	1205.5965
Gavin/Moschelli	296/354	1205.1218
Jaki Noronha-Hostler	304	
Pilar Staig	365	
Akihiro Monnai	388	1204.4713
Philipe Mota	615	

more...

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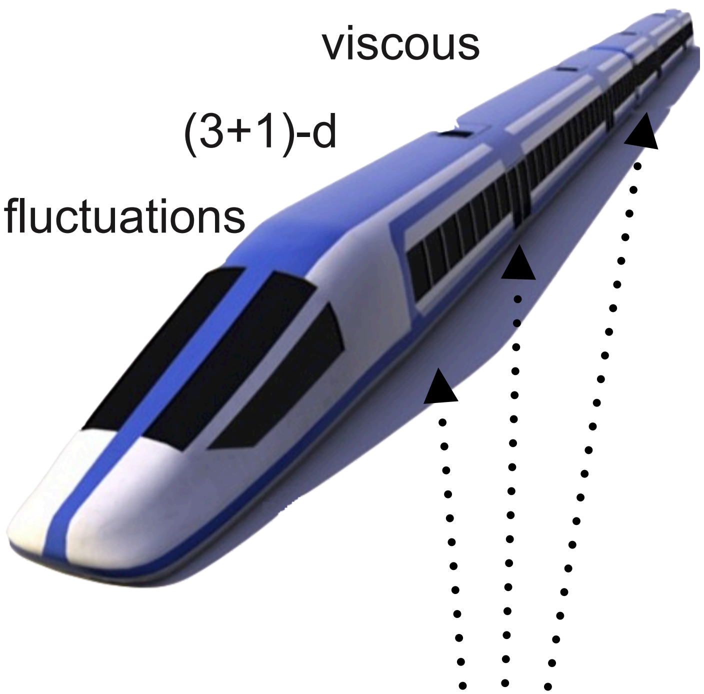

And control each interface !

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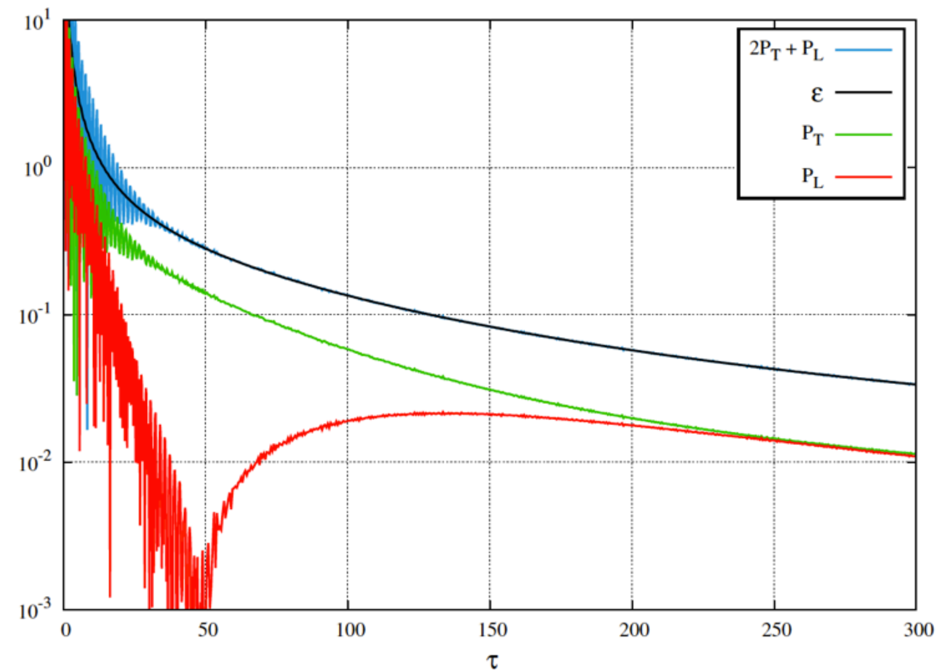
more...

INCLUDING QUANTUM FLUCTUATIONS

- so far: matching of classical **non-equilibrated** Yang-Mills solutions to viscous (i.e. **close to equilibrium**) fluid dynamics...
- What remains to be done:
- **Equilibration** of YM solutions including *quantum fluctuations* for longitudinally expanding scalar field

K.Dusling, T.Epelbaum, F.Gelis, R.Venugopalan arXiv:1206.3336

Talk of K.Dusling: Plenary IC
Talk of R.Venugopalan: 4D



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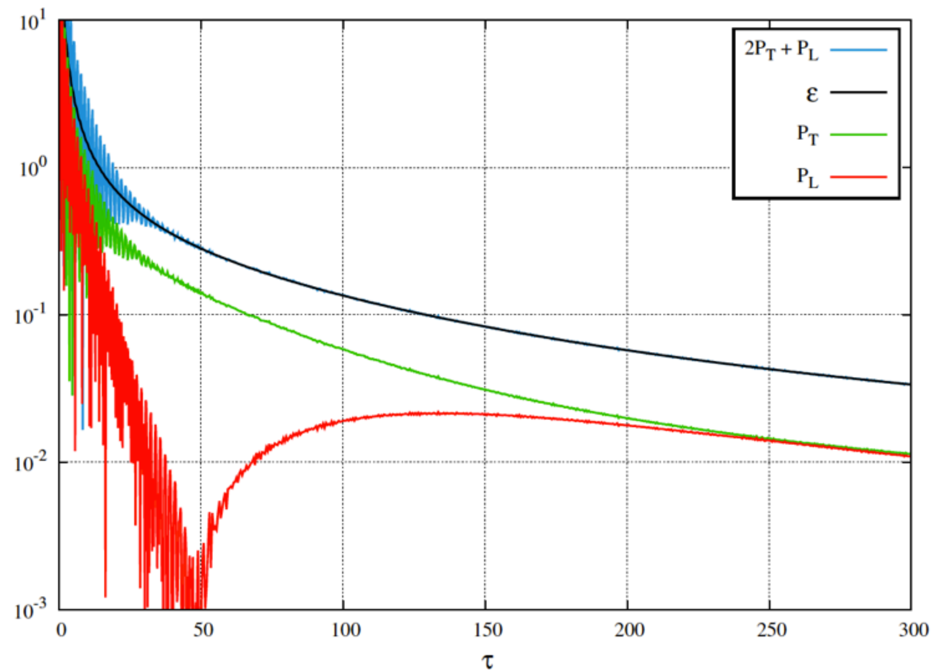


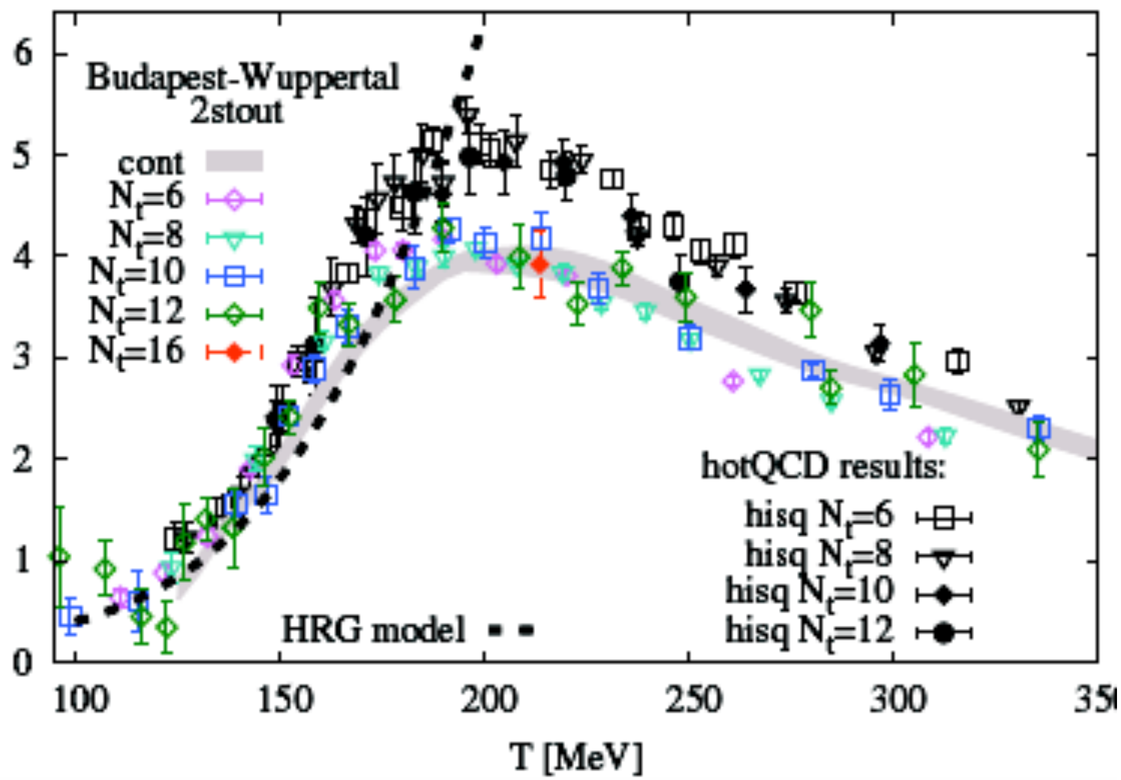
Matter equilibrates thermally much earlier than mechanically

Intermediate stage: Anisotropic hydrodynamics?

Talk of W.Florkowski: 3D

CONVERGING ON THE EOS

- T_c = 155 MeV, Budapest-Wuppertal and HotQCD agree
- Interaction measure:



QCD critical point ?

Talk of Y.Hidaka: 6B

No critical point outside a pion-condensed phase

Talk of R.Gavai: 6B

$T_E = 0.96\ T_c$, $m_E = 1.8\ T_E$

Talk of C.Ratti: 5B

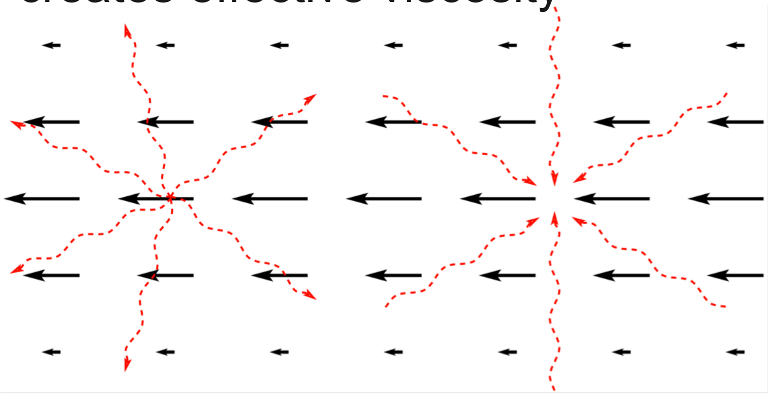
Talk of S.Borsanyi: VA

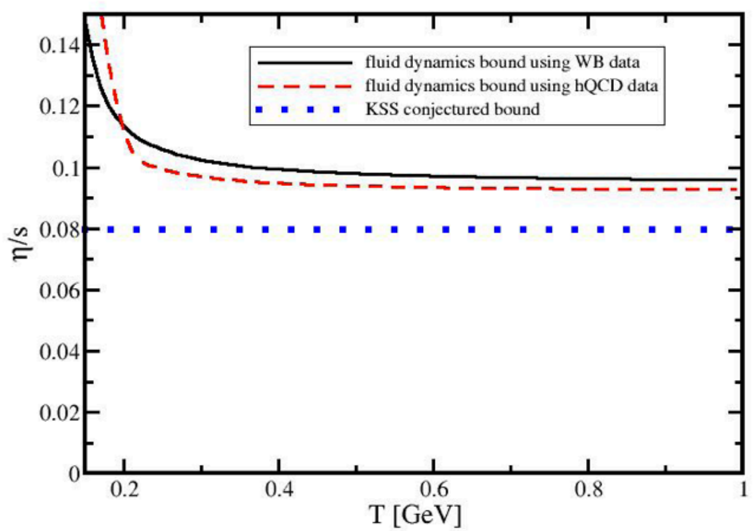
DETERMINING η/s AS A FUNCTION OF TEMPERATURE

Talk of P.Romatschke: 5D

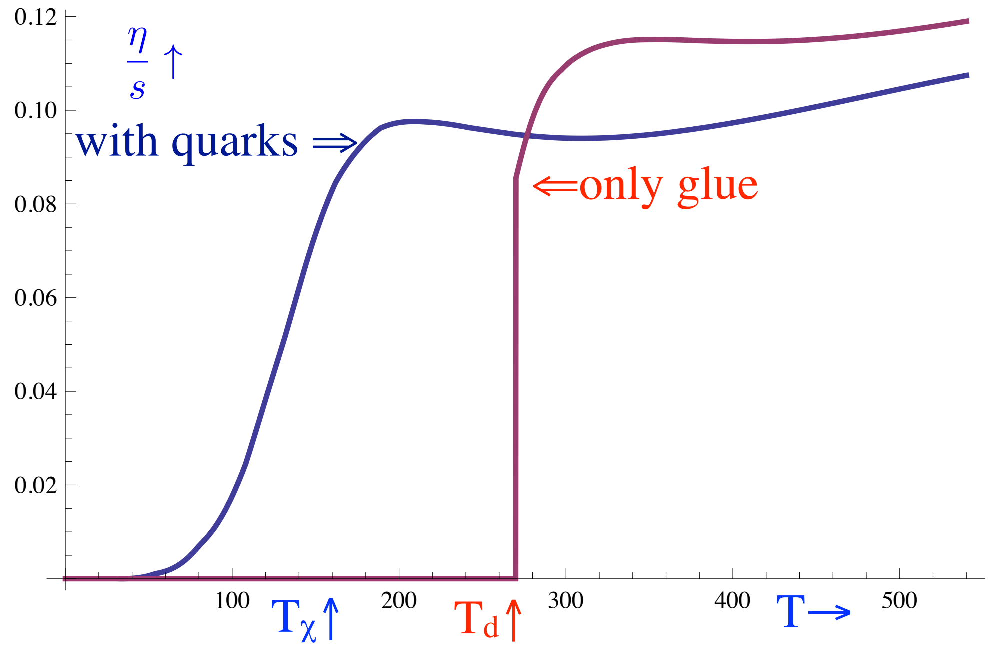
Talk of R.Pisarski: 5D

Scattering of sound waves creates effective viscosity





Matrix model for semi-QGP



TURNING FLUID INTO PARTICLES

- δf corrections to the single-particle distribution function:
  - Israel - Stewart: p^2, E^2, p E
  - Dusling, Moore,Teaney: $p^{1.38}$, PRC 81 (2010) 034907
  - Molnar: polynomial in p (poster #370)
  - Denicol: quadratic in p, polynomial in E (1A, Tue)

$$\delta f_{\mathbf{p}}^{(i)} = f_{0\mathbf{p}}^{(i)} \sum_{\ell=0}^{\infty} \sum_{n=0}^{\infty} \mathcal{H}_{i\mathbf{p}}^{(n\ell)} \rho_{i,n}^{\mu_1\cdots\mu_\ell} p_{i,\mu_1} \cdots p_{i,\mu_\ell} \qquad \mathcal{H}_{i\mathbf{p}}^{(n\ell)} \equiv \frac{W_i^{(\ell)}}{\ell!} \sum_{m=n}^{\infty} a_{mn}^{(\ell)i} P_{i\mathbf{p}}^{(m\ell)}(E_{\mathbf{p}})$$

$$\rho_{i,r}^{\mu_1\ldots\mu_\ell} \equiv \left\langle E_{i\mathbf{p}}^r p_i^{\langle\mu_1} \ldots p_i^{\mu_\ell\rangle} \right\rangle_\delta \qquad p_i^{\langle\mu_1} \cdots p_i^{\mu_m\rangle} \equiv \Delta_{\nu_1\cdots\nu_m}^{\mu_1\cdots\mu_m} p_i^{\nu_1} \cdots p_i^{\nu_m}$$

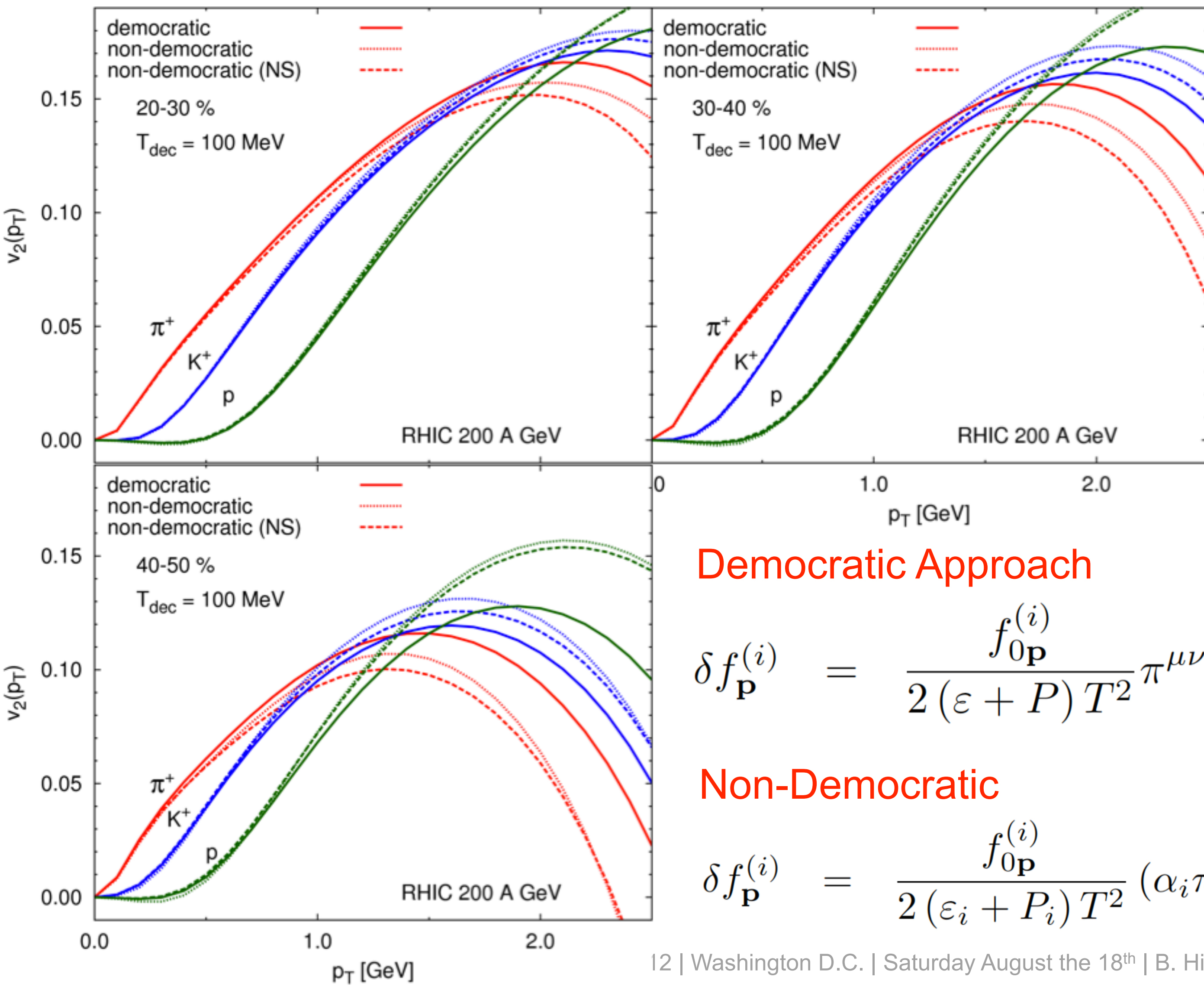
$$\langle \ldots \rangle_\delta = \int dP_i \; (\ldots)\, \delta f_{\mathbf{p}}^{(i)}$$

arXiv:1202.4551[nucl-th]

Systematic derivation of transient fluid dynamics from the Boltzmann equation via:
- power-counting in Knudsen and inverse Reynolds number
- ordering of microscopic time scales

➡ transport coefficients converge to values of Chapman-Enskog expansion when increasing n

FREEZE-OUT FOR MULTI-COMPONENT FLUIDS



Talk of G.Denicol: 1A

Democratic Approach

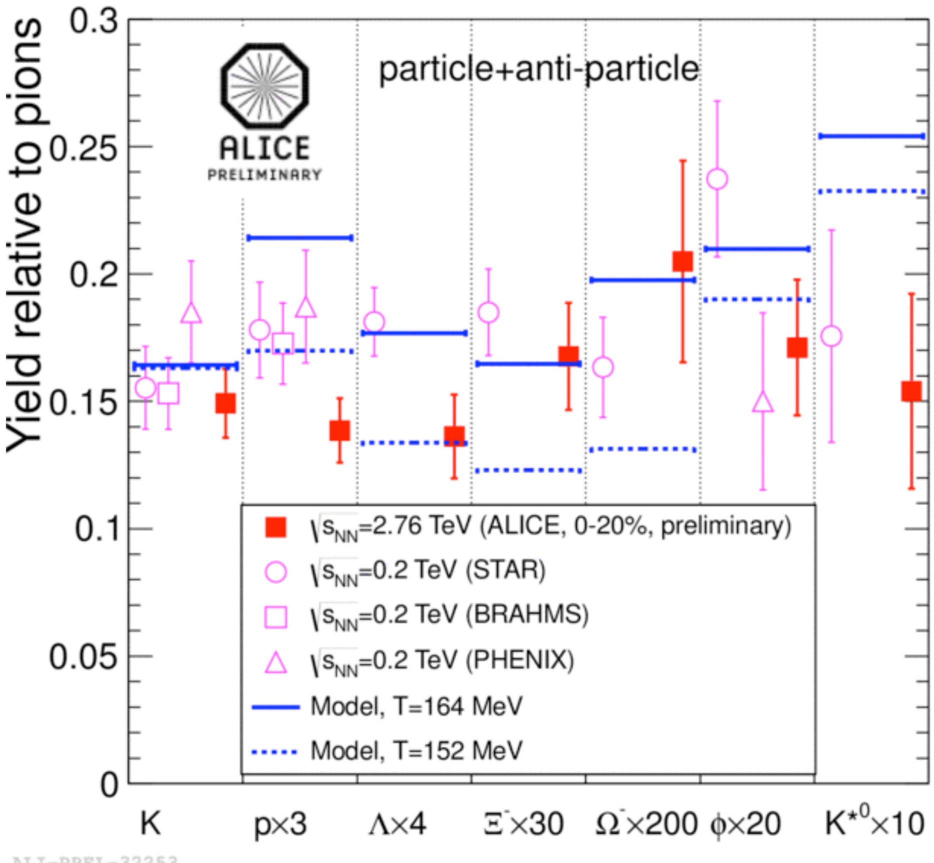
$$\delta f_{\mathbf{p}}^{(i)} = \frac{f_{0\mathbf{p}}^{(i)}}{2\left(\varepsilon + P\right)T^2}\pi^{\mu\nu}p_{i,\mu}p_{,i\nu}$$

Non-Democratic

$$\delta f_{\mathbf{p}}^{(i)} = \frac{f_{0\mathbf{p}}^{(i)}}{2\left(\varepsilon_i + P_i\right)T^2}\left(\alpha_i\pi^{\mu\nu} + \beta_i\sigma^{\mu\nu}\right)p_{i,\mu}p_{i,\nu}$$

CHEMICAL FREEZE-OUT FROM HADROCHEMISTRY

- between hydro and afterburners: T_{ch}



Talk of L.Milano: 5A

Some "tension" at the LHC for a statistical thermal description relying on T_{ch} only

Talk of P.Braun-Munzinger: 5A

Stressed the importance of corrections for feed-down and secondaries from interaction with material

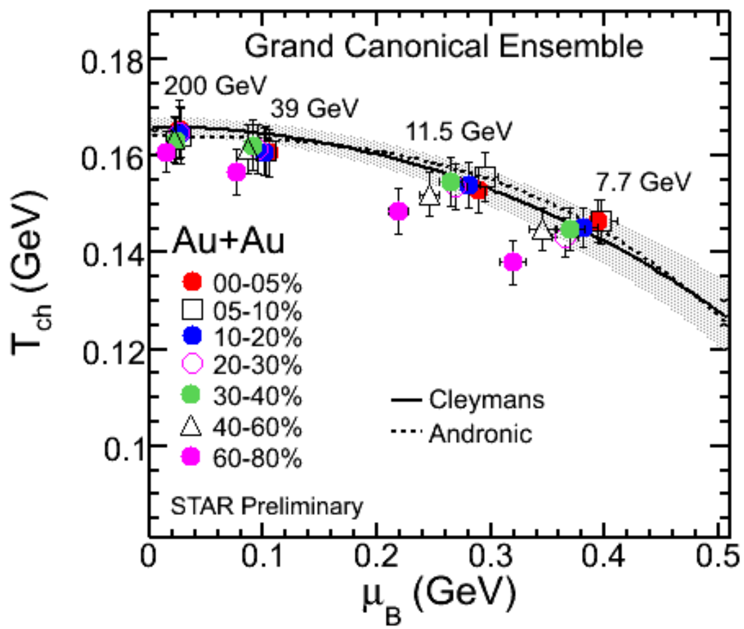
Poster of M.Petran: 319

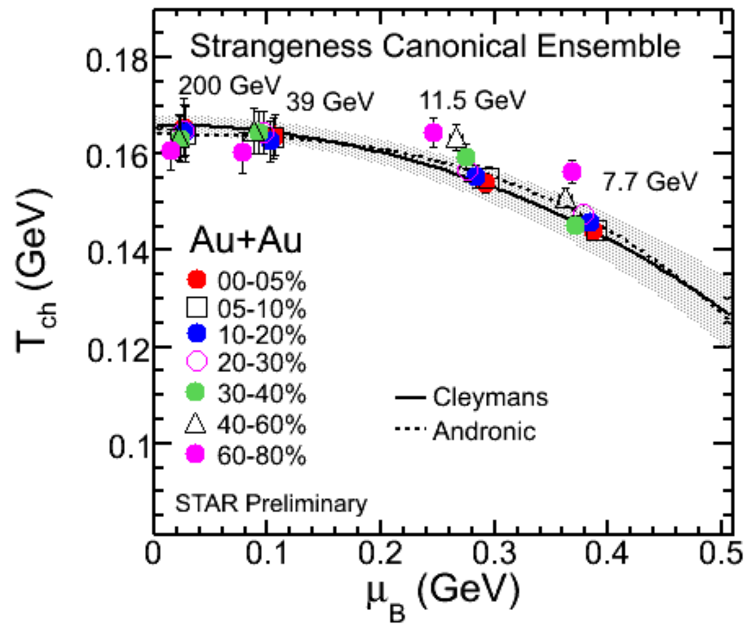
Underlined the importance of the charm contribution to strangeness production

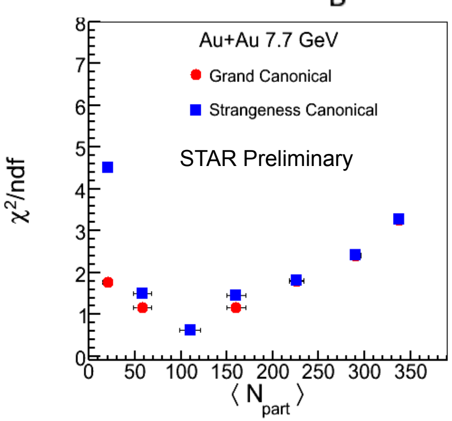
FURTHER CONSTRAINTS FROM HADROCHEMISTRY

- from BES at RHIC: T_{ch} vs. μ_B

talk of S.Das: 6B





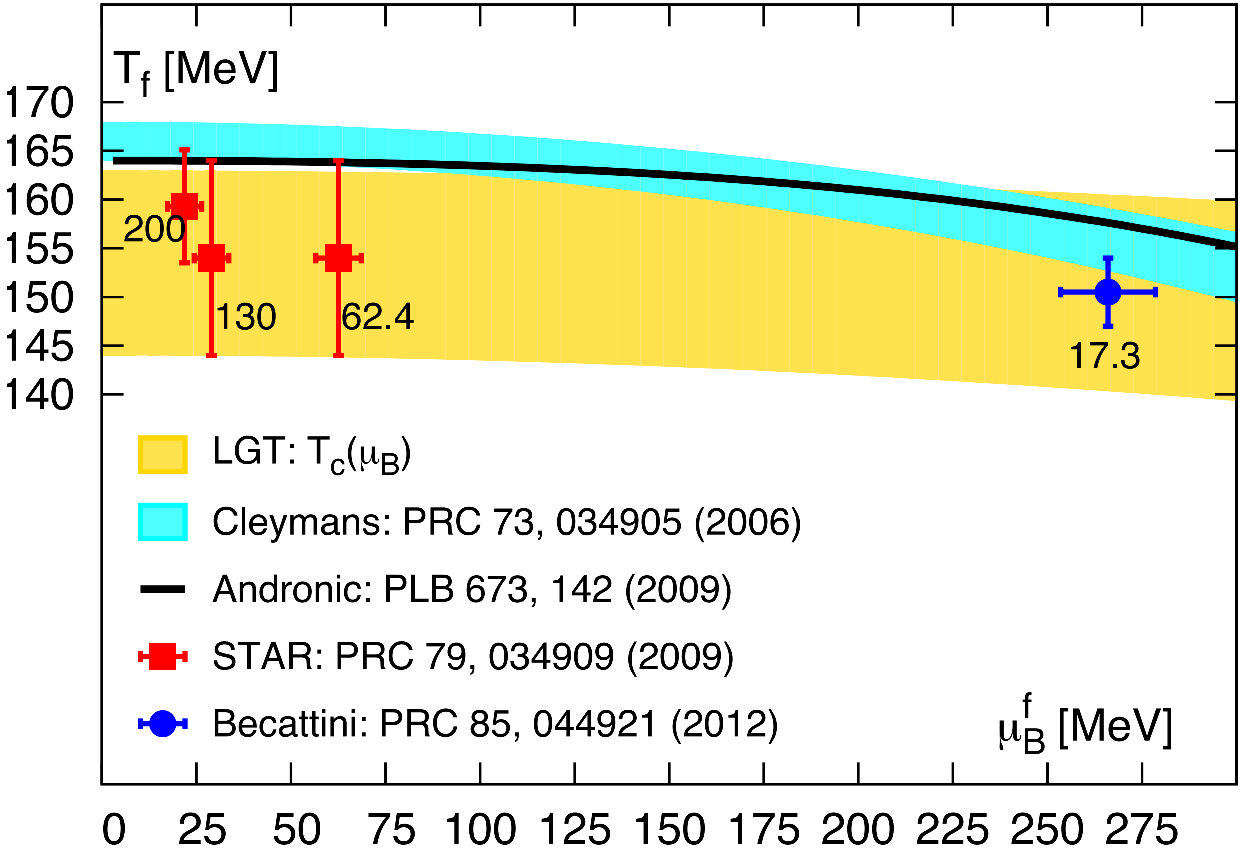


fits done with THERMUS, S.Wheaton et al., Comput. Phys. Commun.180:84-106, 2009

Observation of a centrality dependence of the freeze-out temperature vs. baryo chemical potential (beam energy)

COMPARISON WITH LQCD EXPECTATIONS

- Handles on chemical freeze-out, T_{ch}



Talk of V.Skokov: Plenary VA

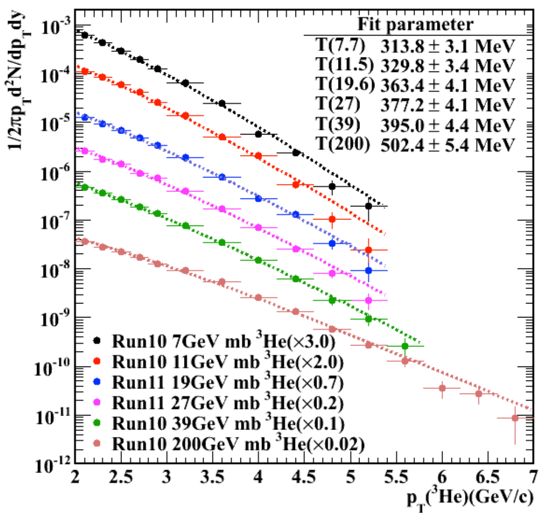
Talk of S.Das: 6B

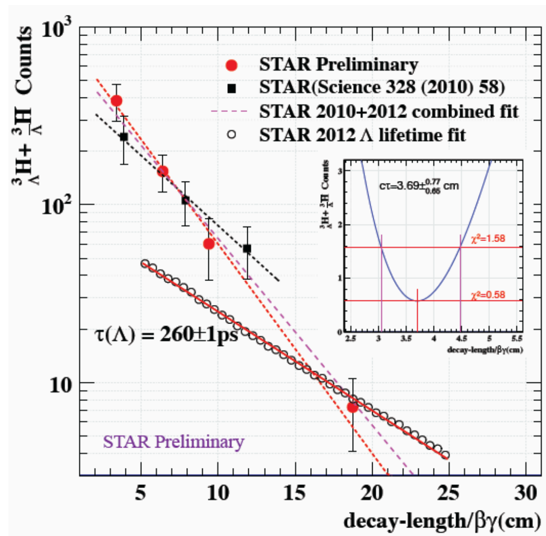
Talk of S.Mukherjee: 5B

Freeze-out is close to crossover line for energies from $\sqrt{s}$=200 GeV to $\sqrt{s}$=17.3 GeV

NUCLEI, HYPERNUCLEI AND EXOTICA

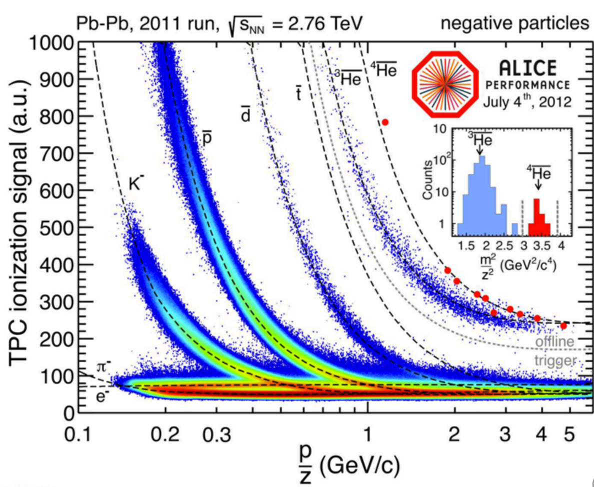
- both at RHIC and at the LHC

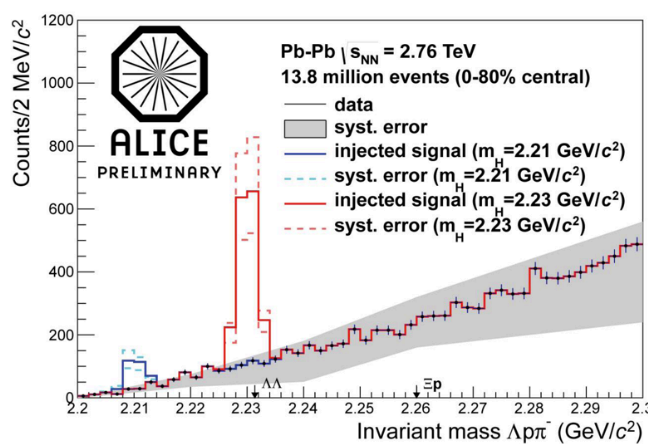




(anti-)Hypertriton spectra at RHIC, excitation function and lifetime !

Talk Y.Zhu: 5A



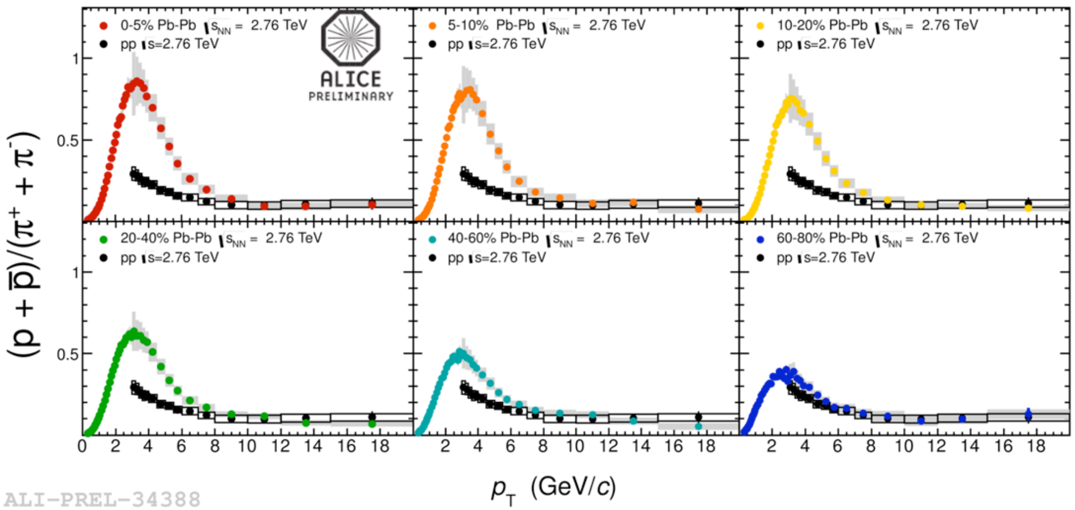


anti-Alpha and (anti-)Hypertriton measured at the LHC... no signal of H-dibaryon... yet !

Talk of B.Dönigus: 5A

INVESTIGATING THE RECOMBINATION SCENARIO

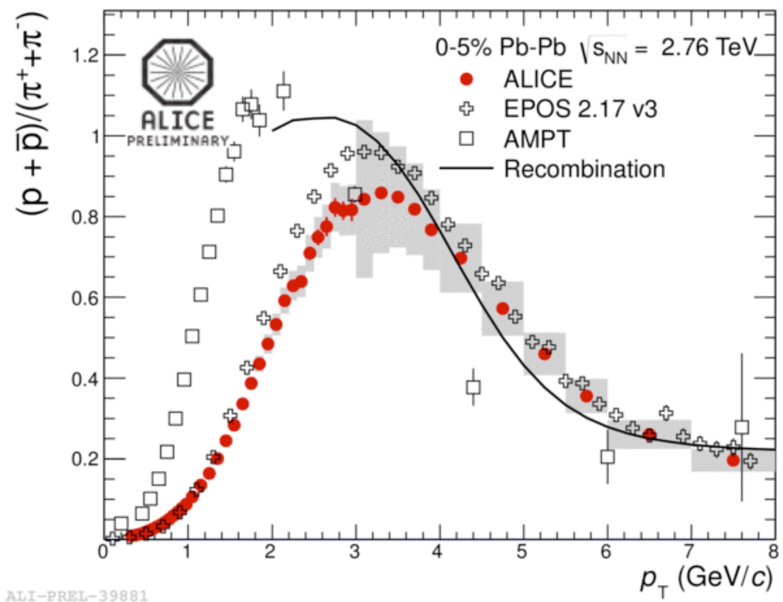
- Using baryon vs. meson production and p_T ratios at the LHC



At intermediate p_T, the enhancement of the baryon/ meson ratio seen at RHIC is still visible at the LHC

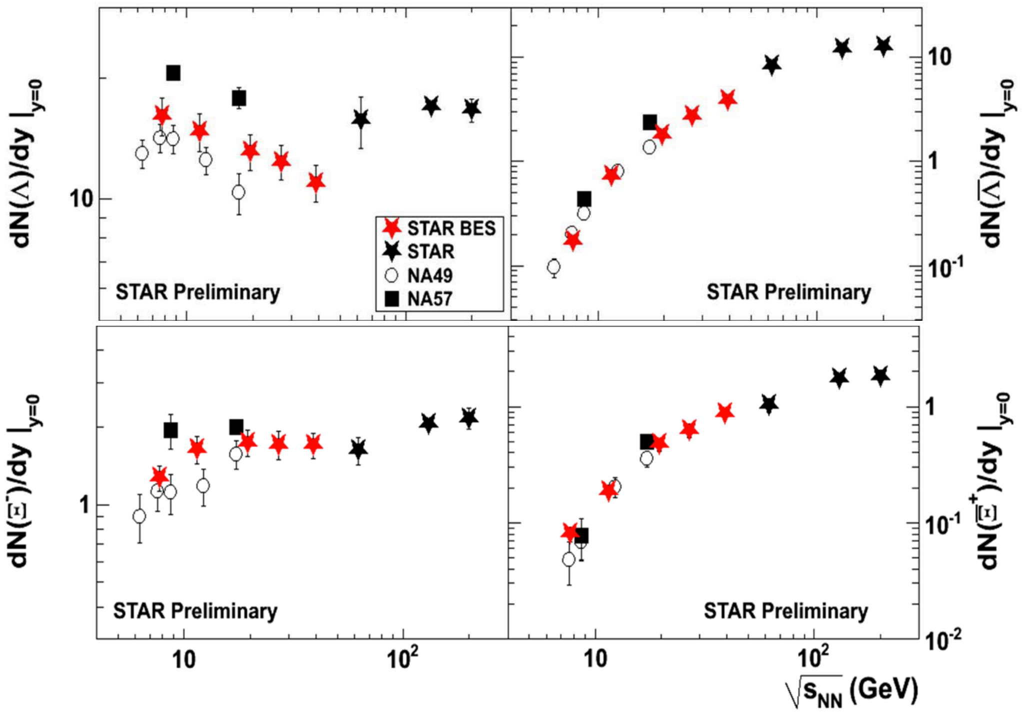
Talk of A.Ortiz: 5C

Several models using different hadronization mechanisms are compared...



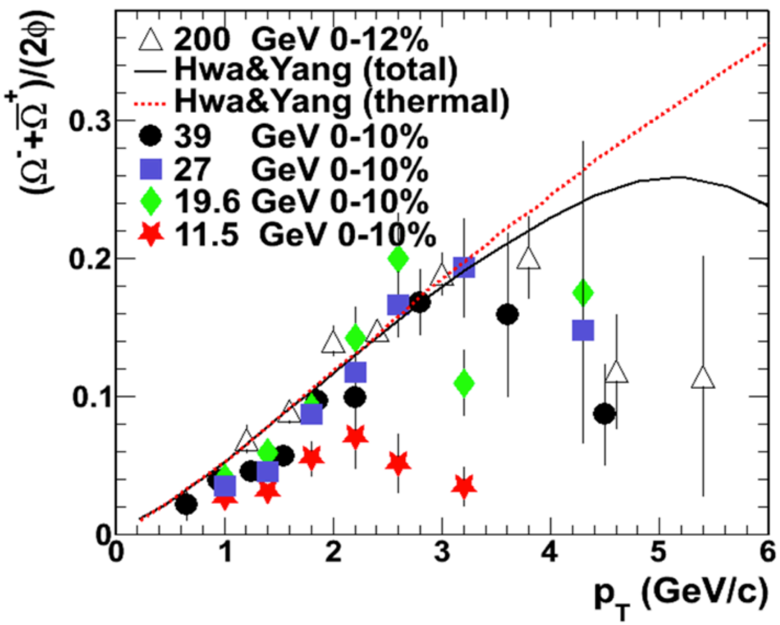
INVESTIGATING THE RECOMBINATION SCENARIO

- using strangeness production and the BES at RHIC



Detailed mapping of the hyperon excitation function and compared to SPS results

Talk of X.Zhang: 5A

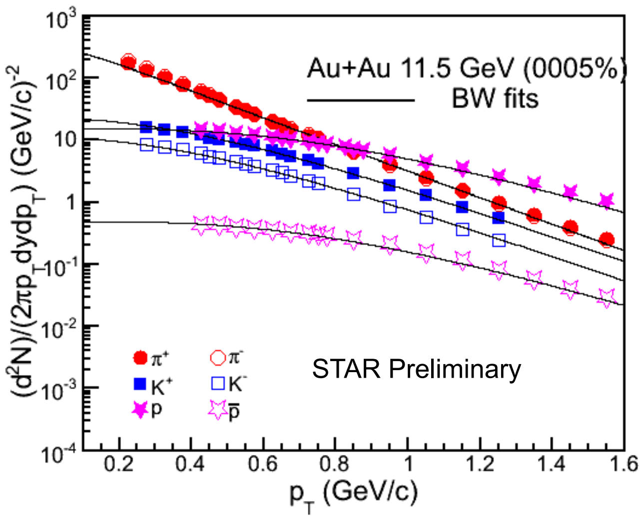


Incentive: identifying the possible onset of recombination via Ω/ϕ

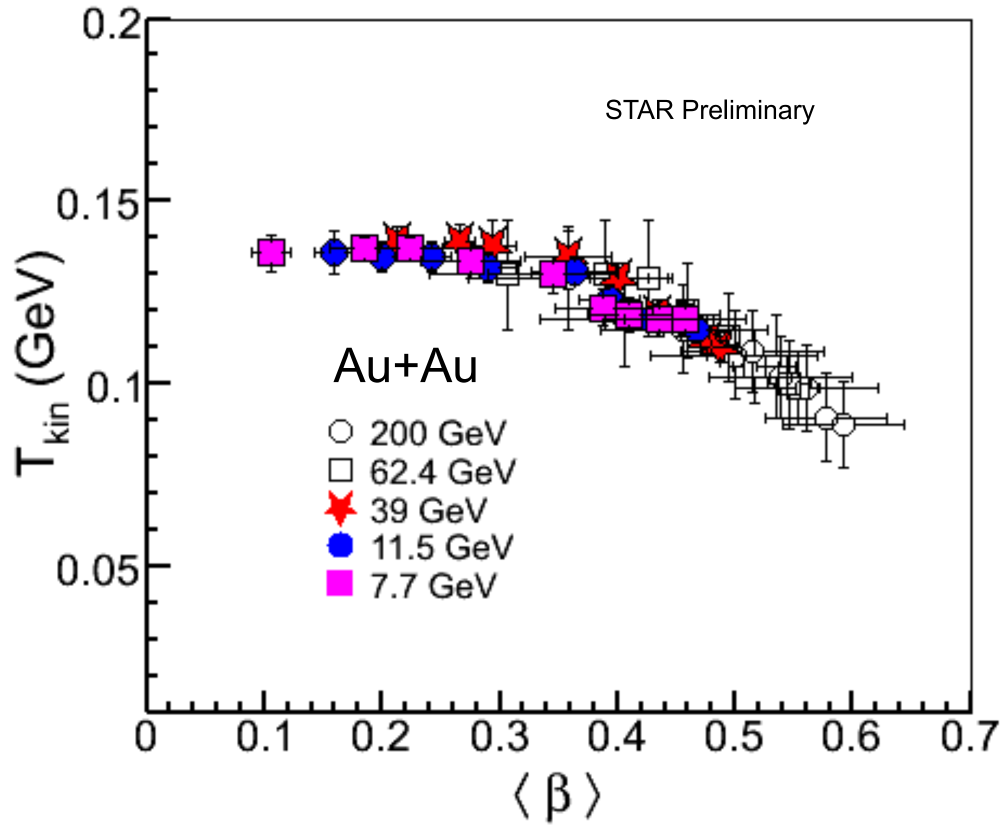
CONSTRAINTS FROM HADROCHEMISTRY

- Radial flow and kinetic freeze-out temperatureT_{kin}

Talk of S.Das: 6B



fits done with blast wave on charged π,K and p

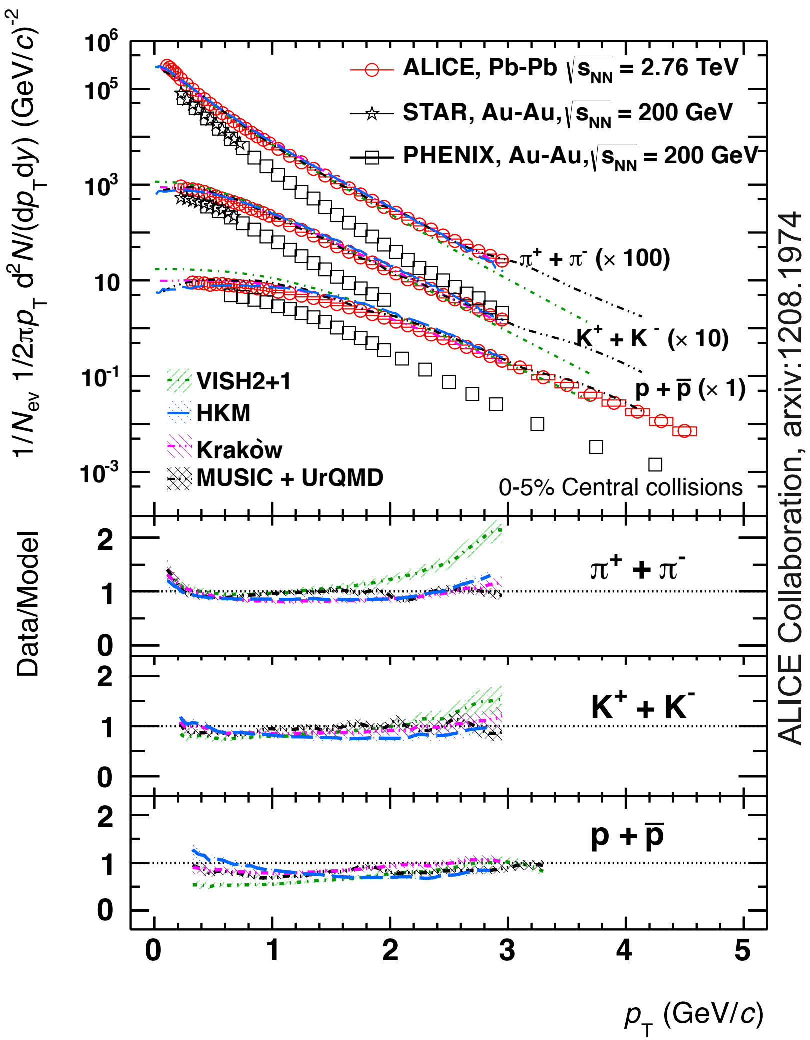


Radial flow increase from most peripheral collisions at $\sqrt{s_{NN}}$ = 7.7 GeV to most central Au-Au events at $\sqrt{s_{NN}}$ = 200 GeV

CONSTRAINTS FROM HADROCHEMISTRY

- Radial flow and kinetic freeze-out temperatureT_{kin}

Talk of L.Milano: 5A



Large radial flow: $<\beta_T>$ = 0.65 ± 0.02
(~10% higher w.r.t. RHIC)

Very good description of hydro(s)...

model comparison:
- VISH2+1 (Viscous hydro)
- HKM (Hydro+ UrQMD)
- Krakòw (viscous corr., lower the effective T_{ch})
- **MUSIC** (EbE 3+1D Hydro + UrQMD): 100 events

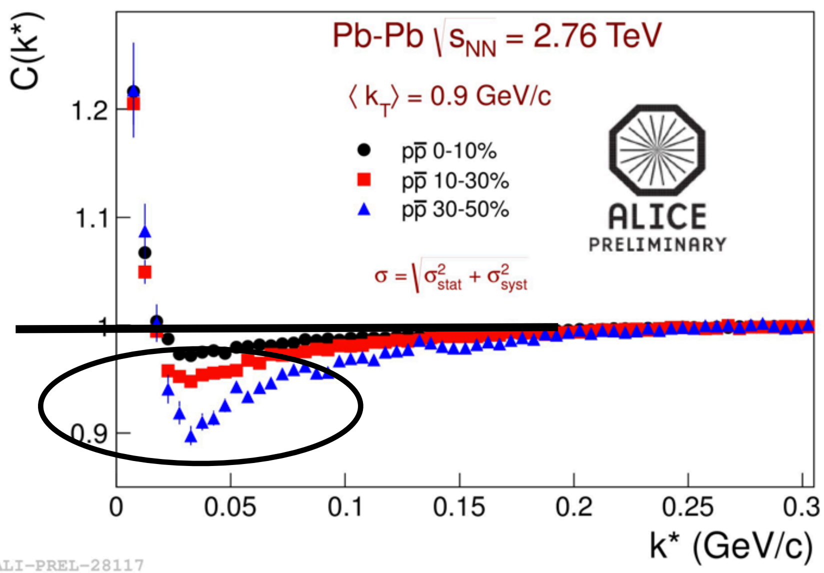
Any room for a ~30% drop of protons due to hadronic rescattering and annihilation ?

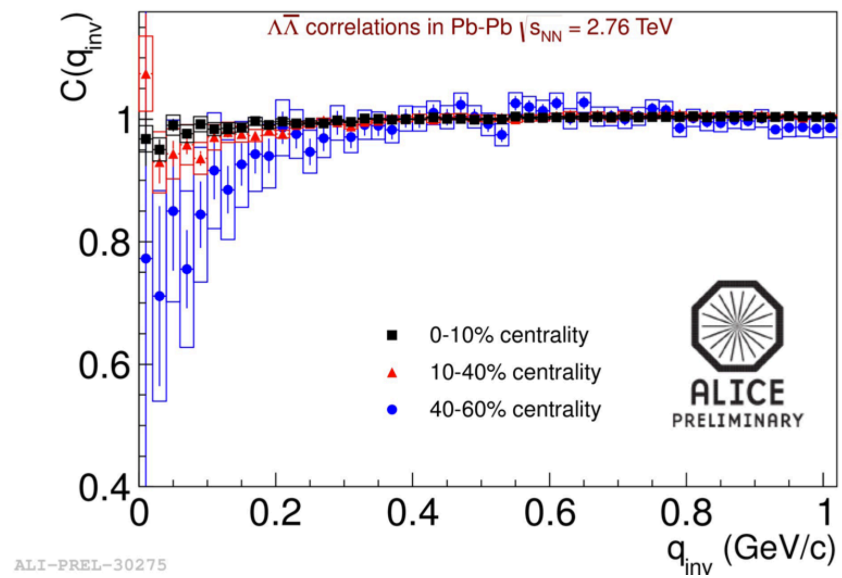
Evolution as a function of centrality and for hyperons

CONSTRAINTS FROM HADROCHEMISTRY

- proton and lambda femtoscopy

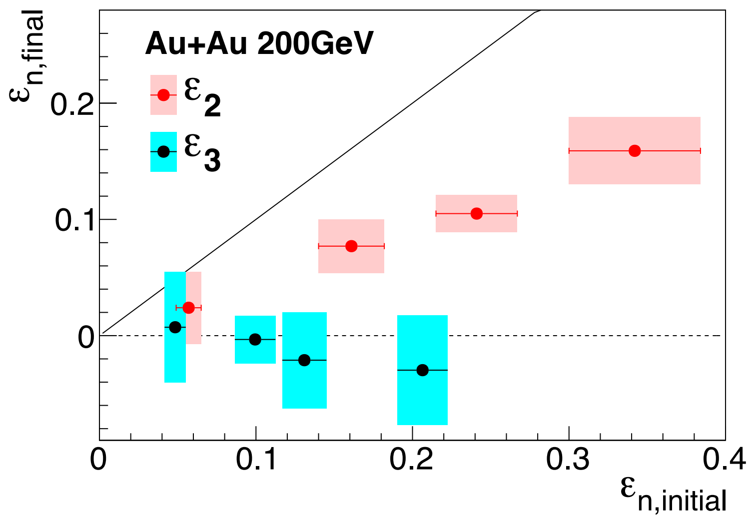
Talk of M. Szymański: 1C

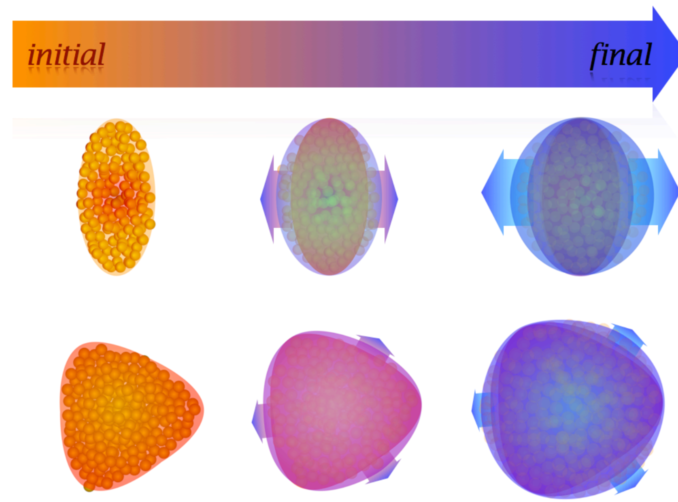




Final state rescattering proposed as explanation for low proton yield
Reflected in BB femtoscopic correlations

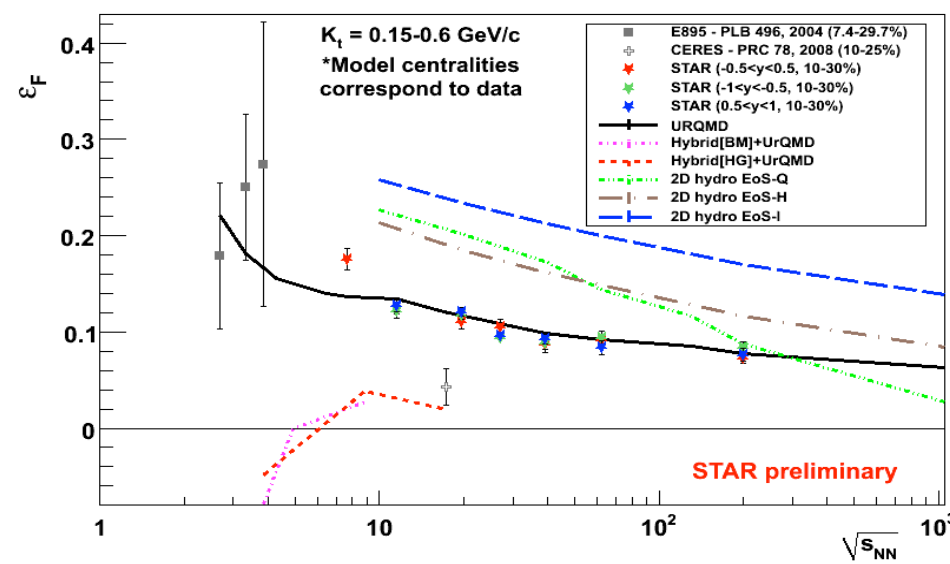
EVOLUTION WASHES OUT HIGHER HARMONIC ANISOTROPY





Talk of T. Niida: 1C

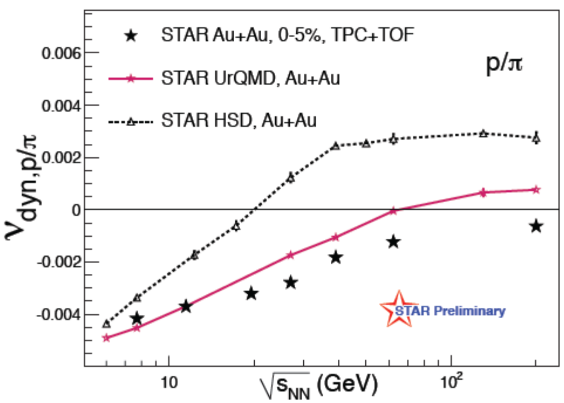
Excitation function for freeze-out eccentricity, ε_F

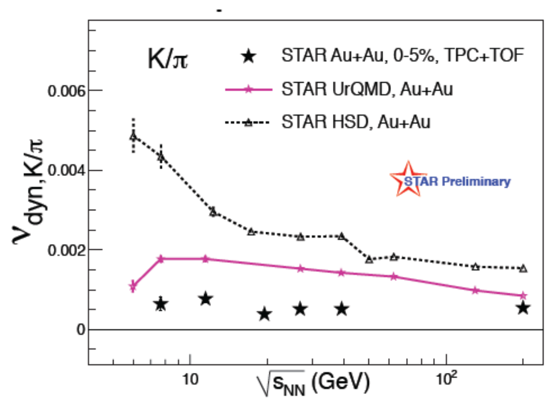


Excitation function of final eccentricity shows a monotonic behaviour

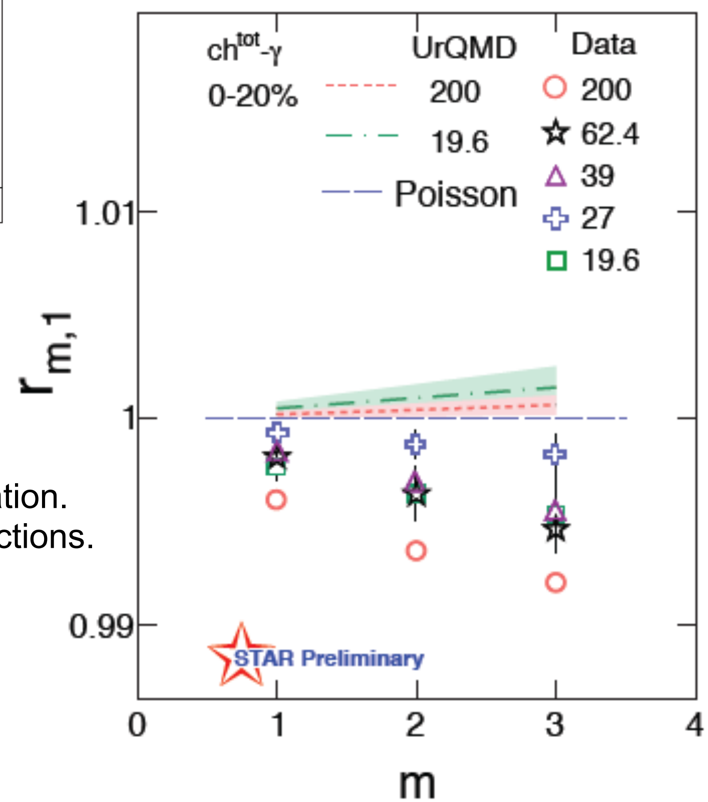
Talk of N. Shah: 1C

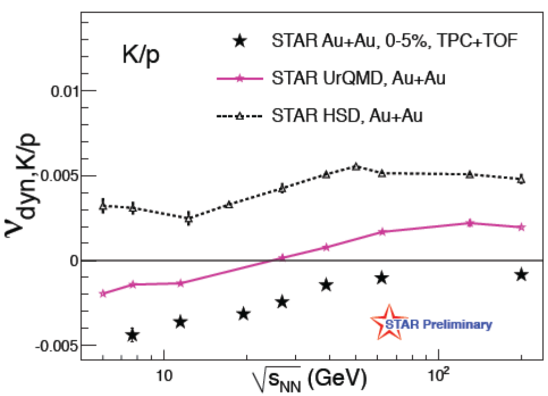
EXCITATION FUNCTION OF PARTICLE-RATIO FLUCTUATIONS





Talk of P. Tribedy: 2C





(measurement at mid-rapidity |η|<1)
Monotonic trend in the range of 7.7-200 GeV.
K/p and p/π are dominated by correlation.
Data are below hadronic model predictions.

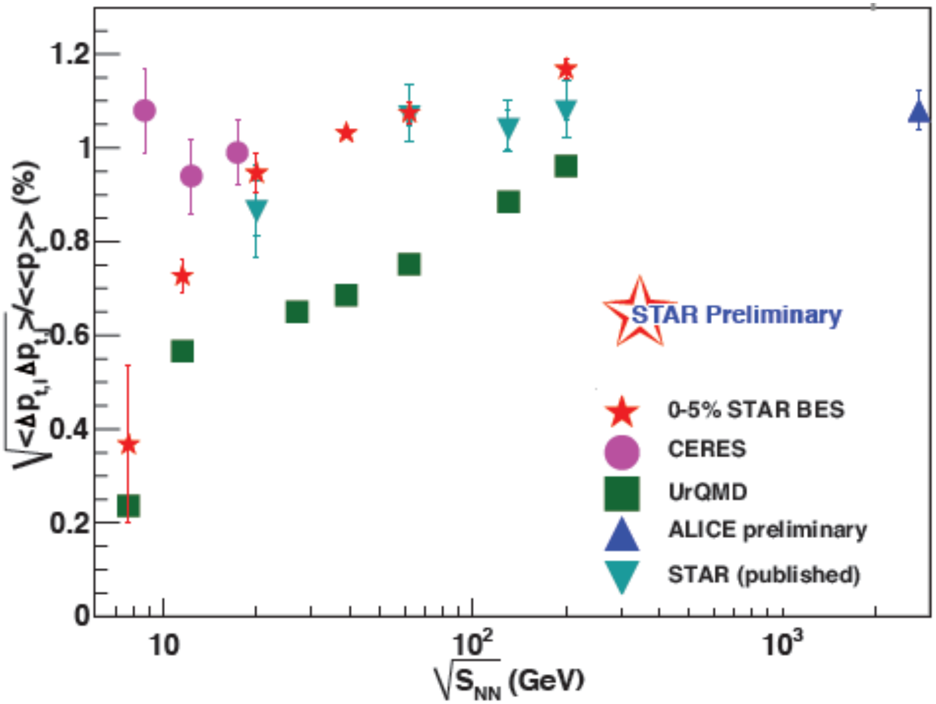
Charge-to-neutral correlations shows anti-correlation, in contrast to models

P_T-CORRELATIONS

- Correlation scaled with <<p_T>>

Talk of P. Tribedy: 2C

- Most central data points show monotonic decrease below 39 GeV.
- UrQMD reproduces trend, lies below data.
- Difference with CERES, e.g. acceptance is under investigation.



Poster of J.Novak: 263

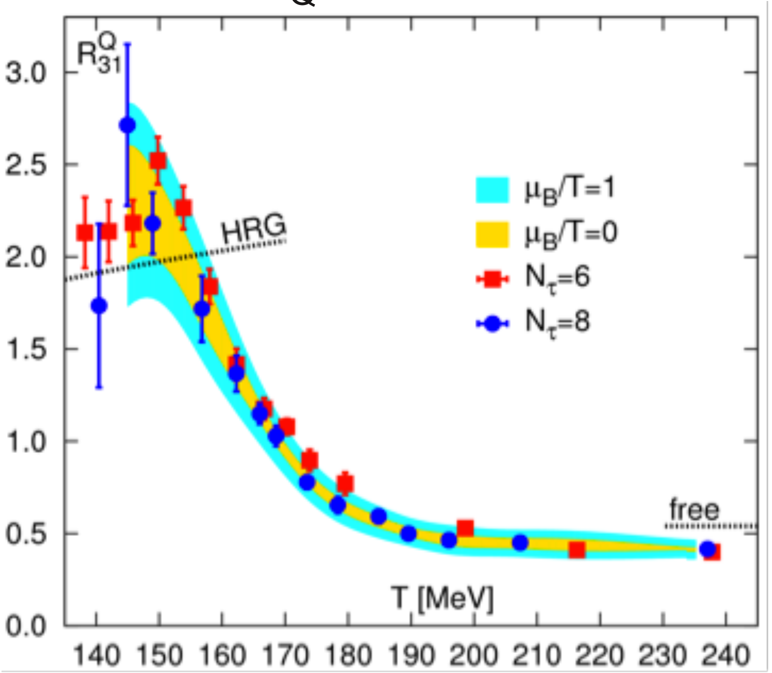
LATTICE QCD IS MOVING CLOSER TOWARDS EXPERIMENT

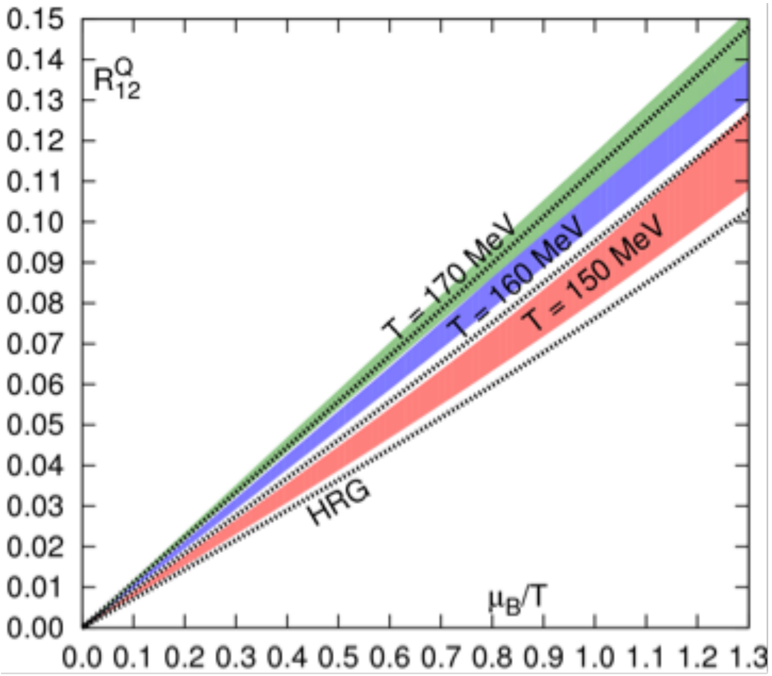
- Electric charge fluctuations

Talks of C. Schmitt and S.Mukherjee: 5B

$$R_{31}^{Q} = \frac{\langle(\delta N_Q)^3\rangle}{\langle N_Q\rangle}$$

$$R_{12}^{Q} = \frac{\langle N_Q\rangle}{\langle(\delta N_Q)^2\rangle}$$



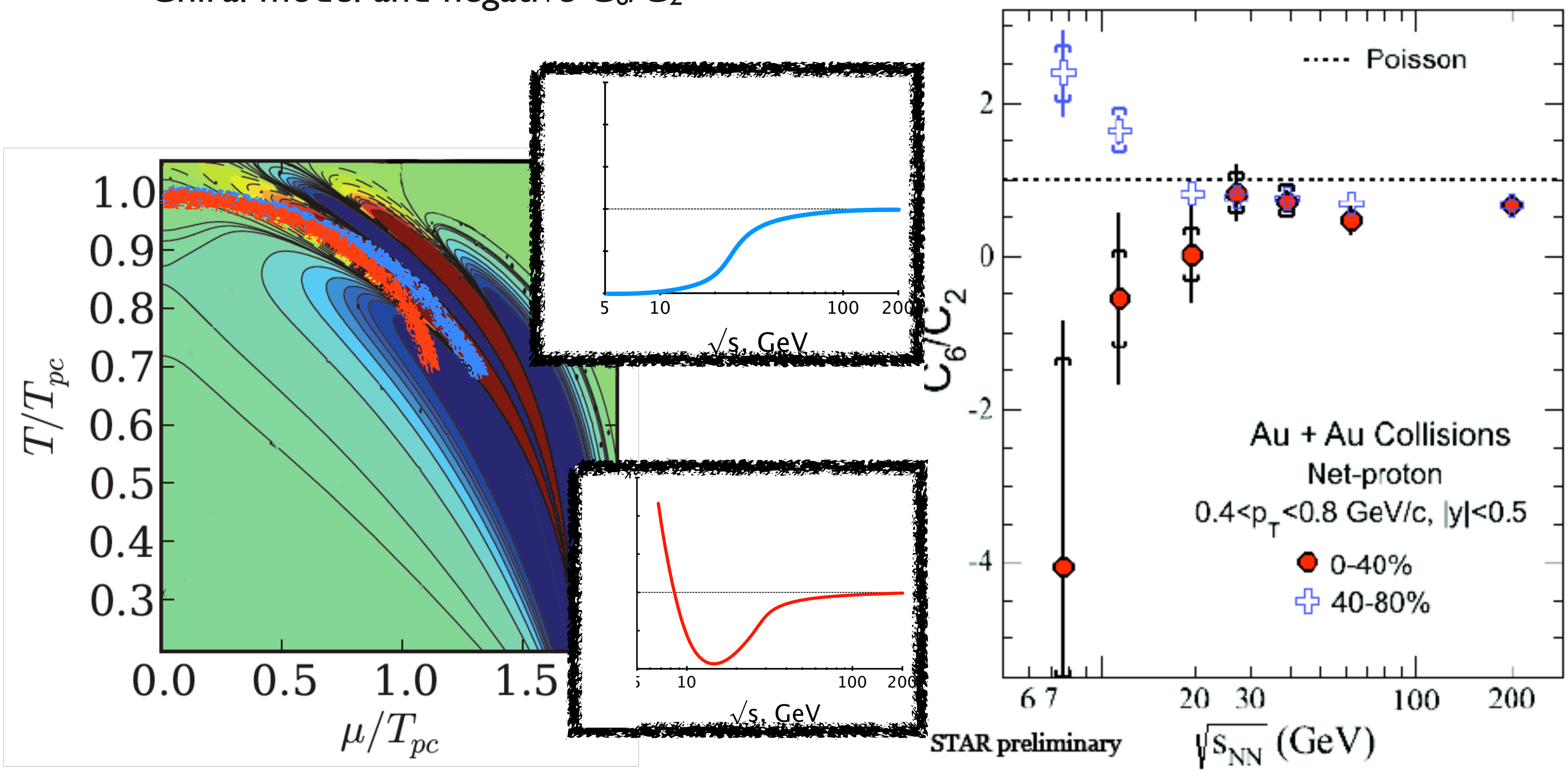


C_6/C_2 CORRELATION

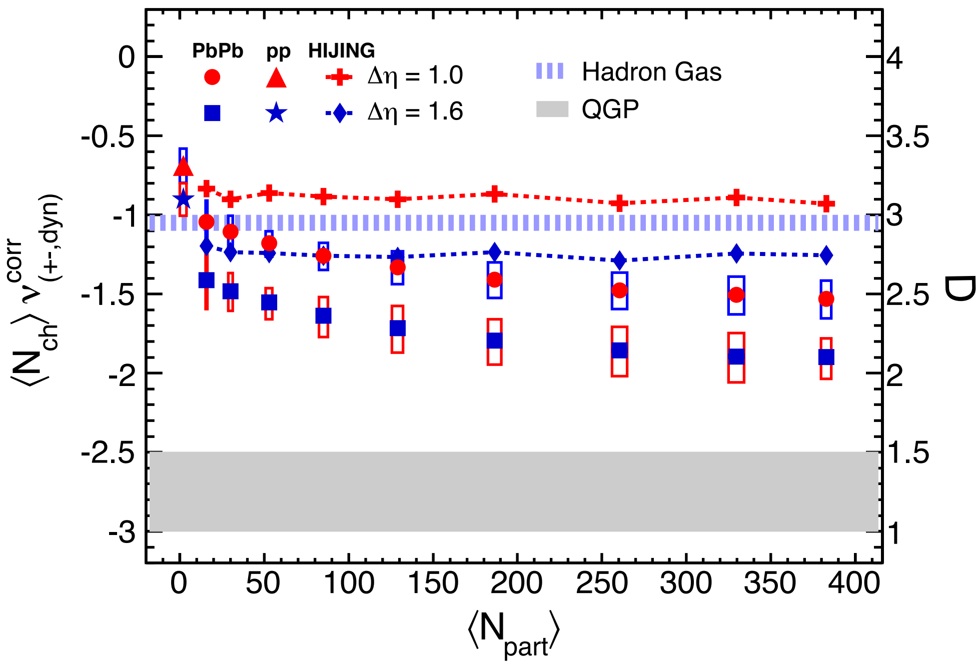
Talk of V.Skokov: Plenary VA

Chiral model and negative C_6/C_2

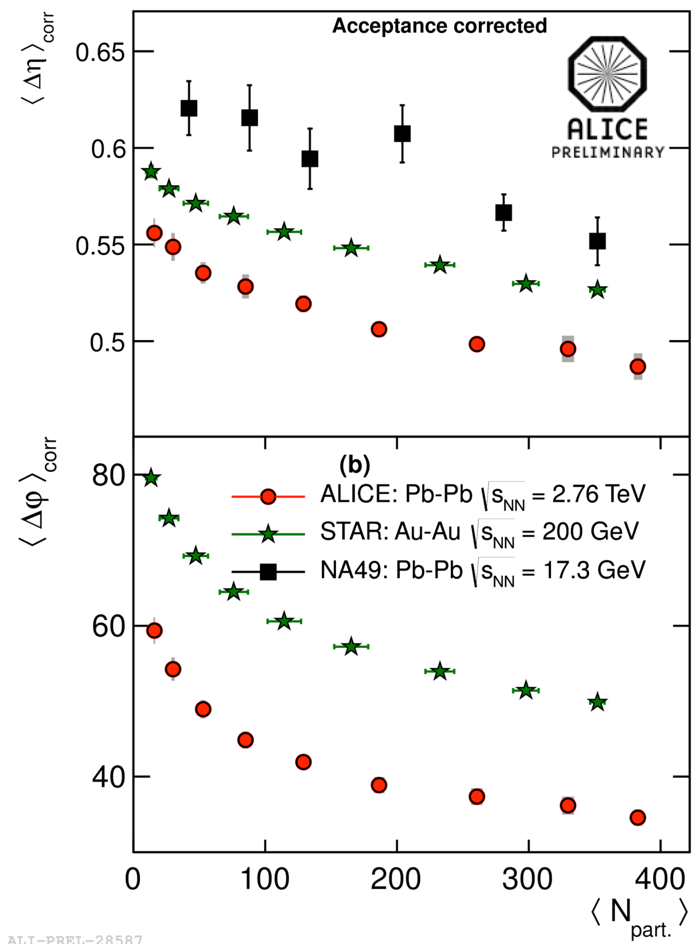
Talk of L.Chen: 2C



CHARGE FLUCTUATIONS, BALANCE FUNCTIONS



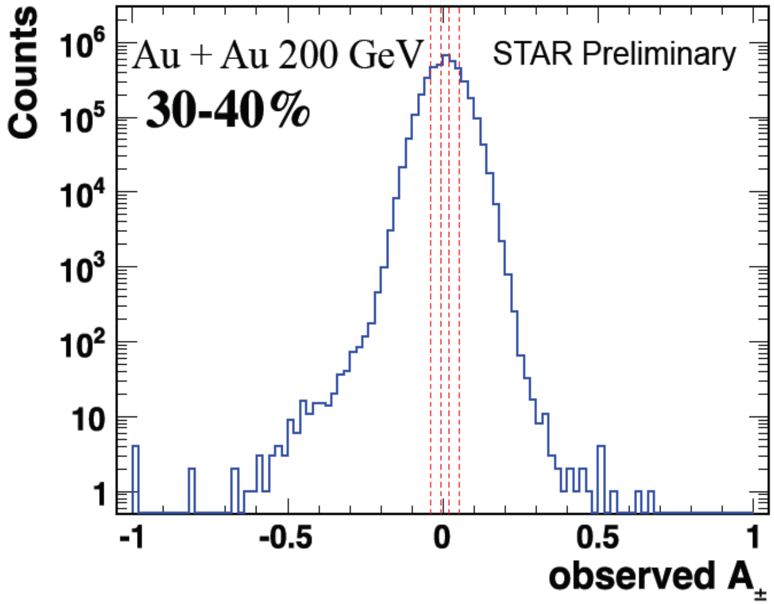
Talk of M.Weber: 2C



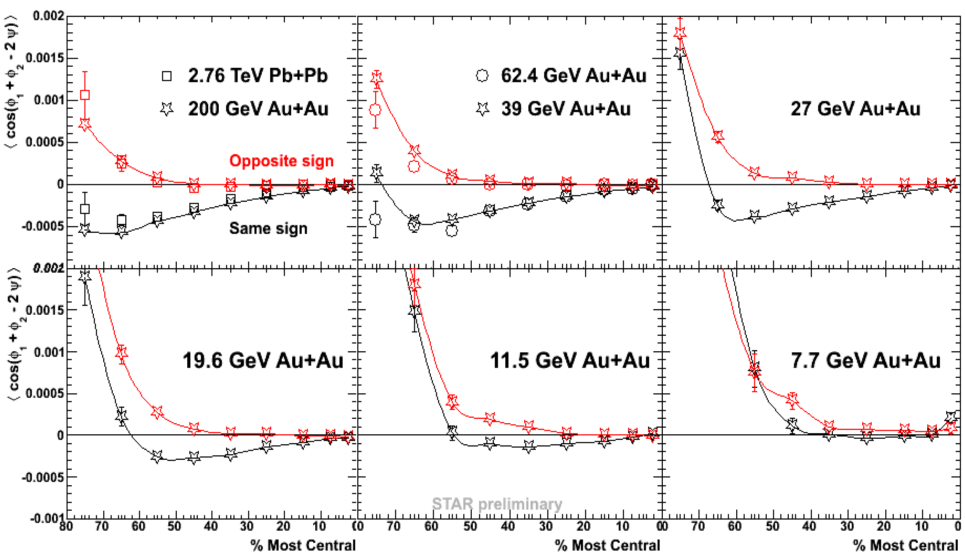
CHIRAL MAGNETIC EFFECT

Talk of G.Wang: Plenary IVB

Events with charge asymmetry $A_{\pm} = \frac{\overline{N}_{+} - \overline{N}_{-}}{\overline{N}_{+} + \overline{N}_{-}}$ exist

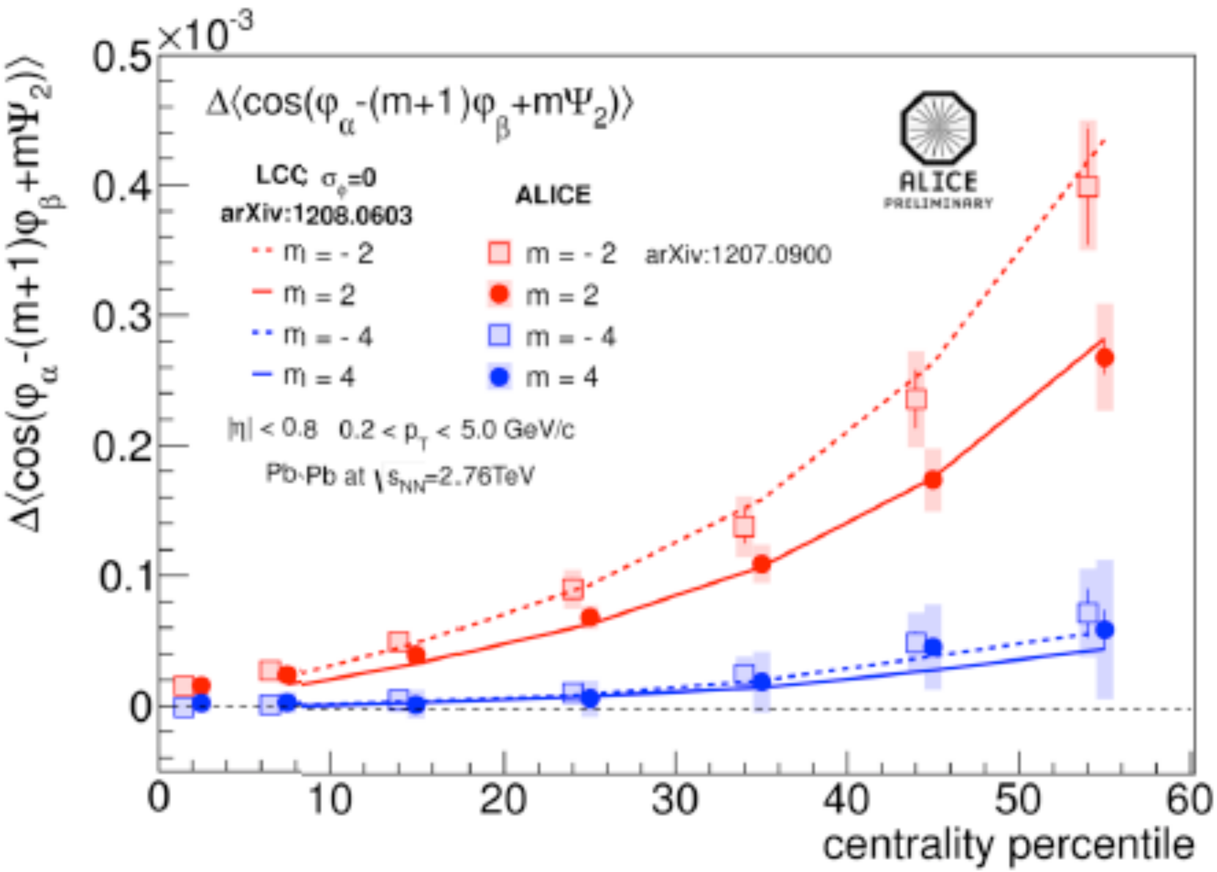


CME should appear in these events



CHIRAL MAGNETIC EFFECT

Talk of Y.Hori: 2C

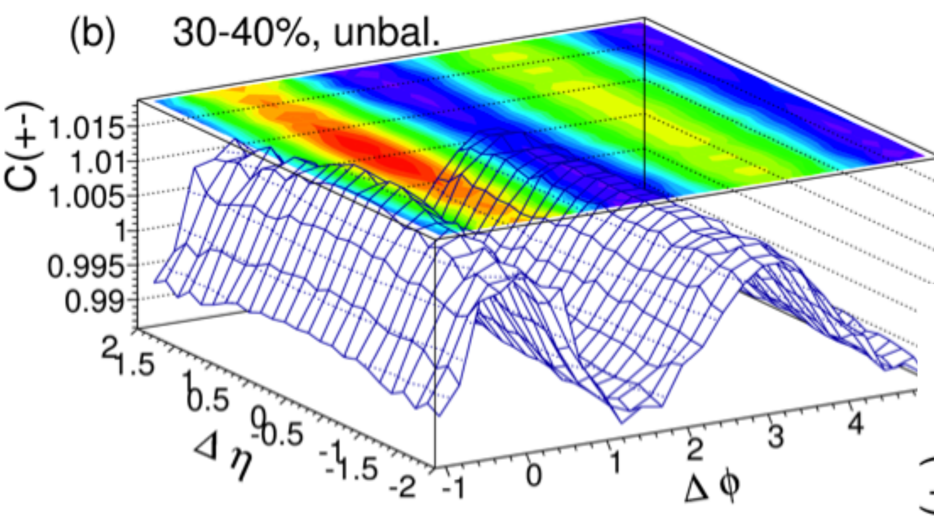


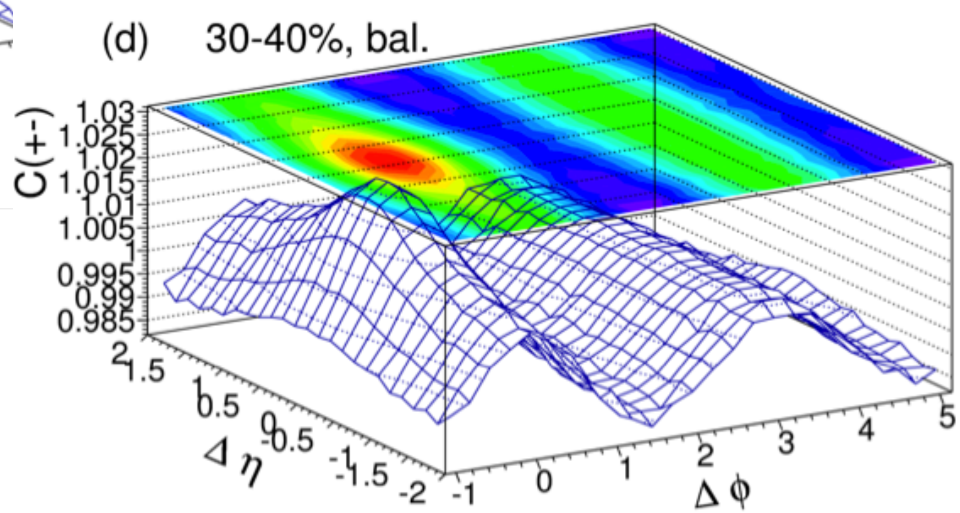
Models with local charge conservation can explain two-particle correlation function

EFFECT OF CHARGE CONSERVATION

- Fall-off of near-side ridge:

Talk of P.Bozek: 2C





MOVING TO THE FUTURE

- Very near future: scrutinize new measurements:
  - ➡ check consistency of experimental results
  - ➡ validity of models/descriptions from 7.7 GeV to 2.76 TeV
- Systematic studies for constraining initial conditions;
  - ➡ higher order flow harmonics and plane angles
  - ➡ fluctuations in ultra-central events
- Hydrodynamics with fluctuations:
  - ➡ relationship with transient fluid dynamics has to be clarified!

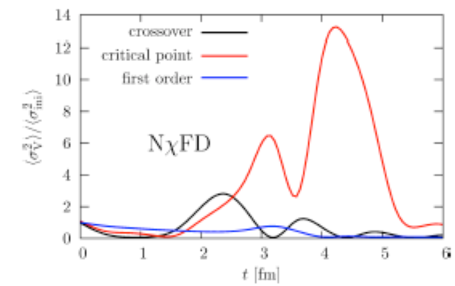
Talk of J.Kapusta: 6B
Talk of M.Stephanov: 6D

- Hydrodynamics with dynamical chiral fields

Talk of M.Nahrgang: 7B

- Details of determining chemical and thermal freeze-out parameters
- Chiral MHD to clarify Chiral Magnetic Effect

Event-by-event fluctuations



correlation length from $G(r) \propto \exp(-r/\xi)$