Fluid dynamical phenomena in QGP and its recent experimental signatures

The Critical Point and Onset of Deconfinement Conference - CPOD 2018
September 24 - 28, 2018

Laszlo P. Csernai,
University of Bergen &
Wuhan Univ. of Technology
24 September 2018

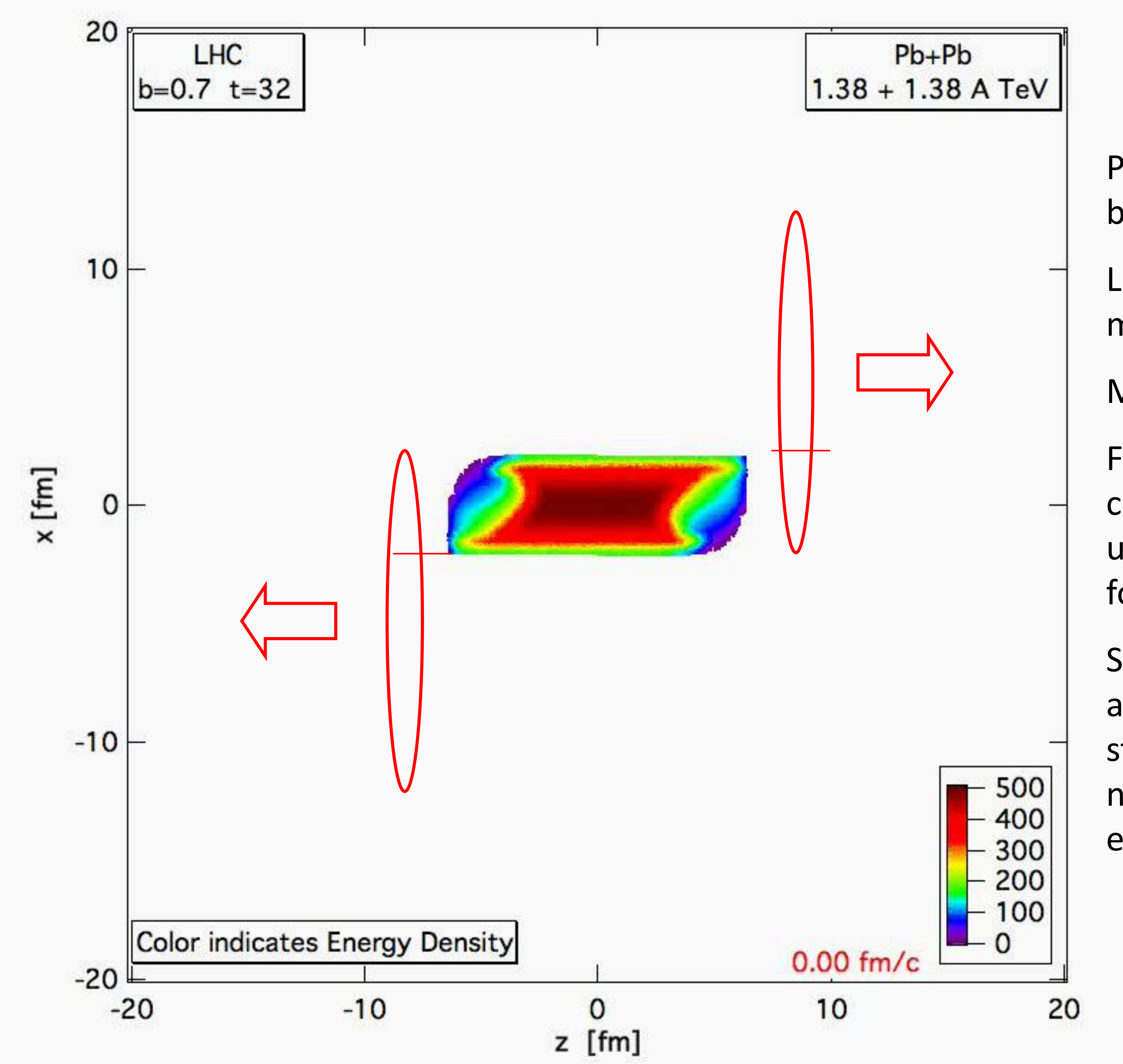
Dr. Yilong Xie, U. Bergen, > CUG, Wuhan

Prof. Dujuan Wang, CCNU, Wuhan

Prof. V.K. Magas, U. Barcelona

Prof. D.D. Strottman, Los Alamos NL

Prof. J.I. Kapusta, U. Minnesota, Minneapolis



PIC-hydro

Pb+Pb 1.38+1.38 A TeV, b= 70 % of b_max

Lagrangian fluid cells, moving, ~ 5 mill.

MIT Bag m. EoS

FO at T ~ 200 MeV, but calculated much longer, until pressure is zero for 90% of the cells.

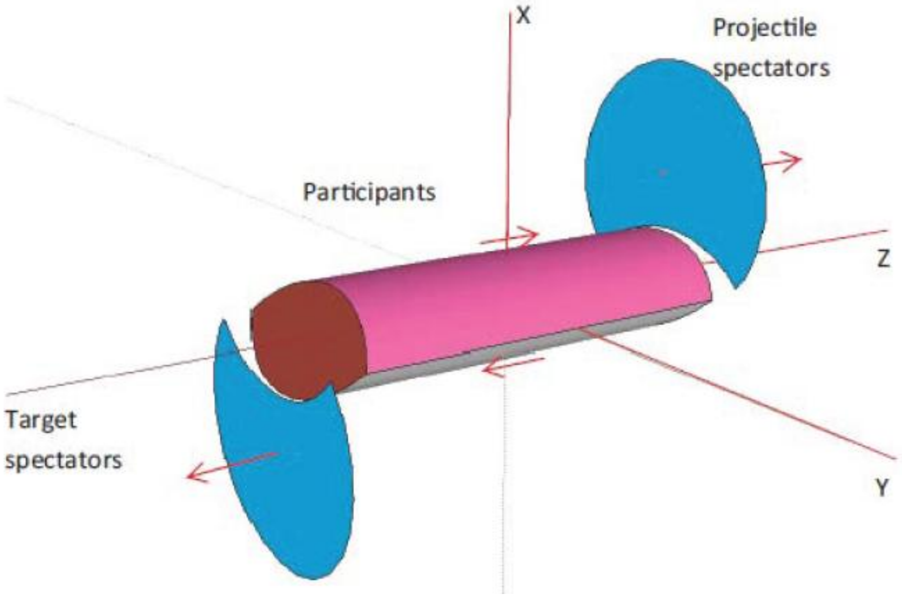
Structure and asymmetries of init. state are maintained in nearly perfect expansion.

IOP Publishing Journal of Physics G: Nuclear and Particle Physics
J. Phys. G: Nucl. Part. Phys. 41 (2014) 124001 (21pp) doi:10.1088/0954-3899/41/12/124001

Global collective flow in heavy ion reactions from the beginnings to the future

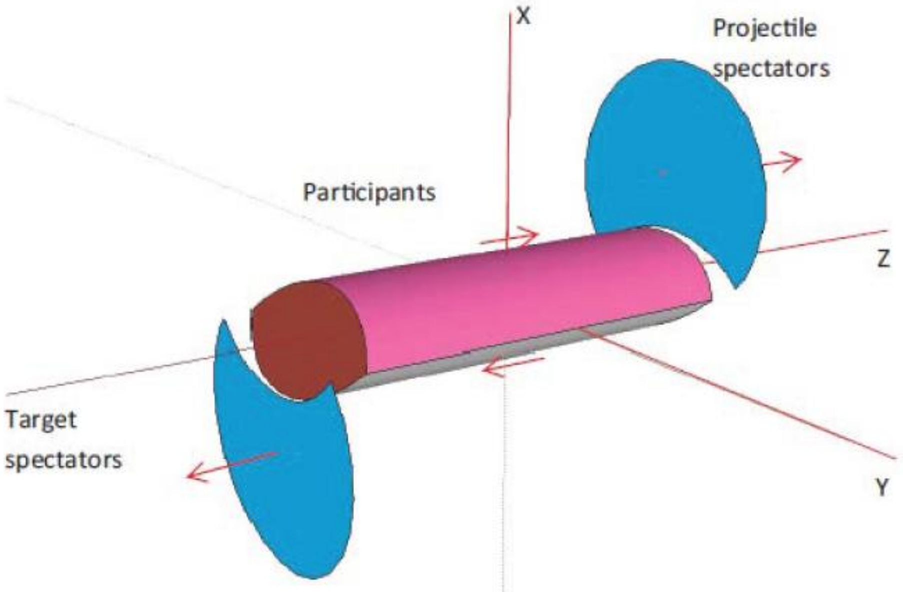
L P Csernai[1] and H Stöcker[2,3]

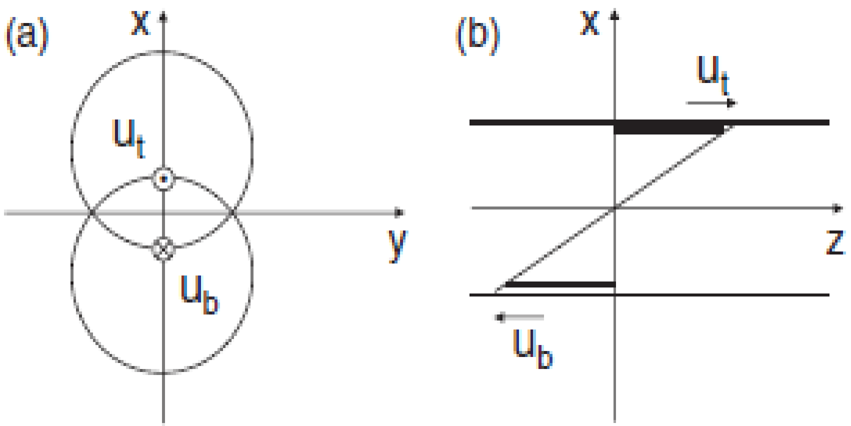
For a reconstructable series expansion we need a fixed coordinate system **x, y**, z, axes (reaction plane) and the **c.m.** – EbE.
Both global collective flow and fluctuations can be characterized in such reference frame.



Periheral Collisions - Initial State

- Peripheral reactions
- Shear ➔ vorticity ➔
- L: in -y direction



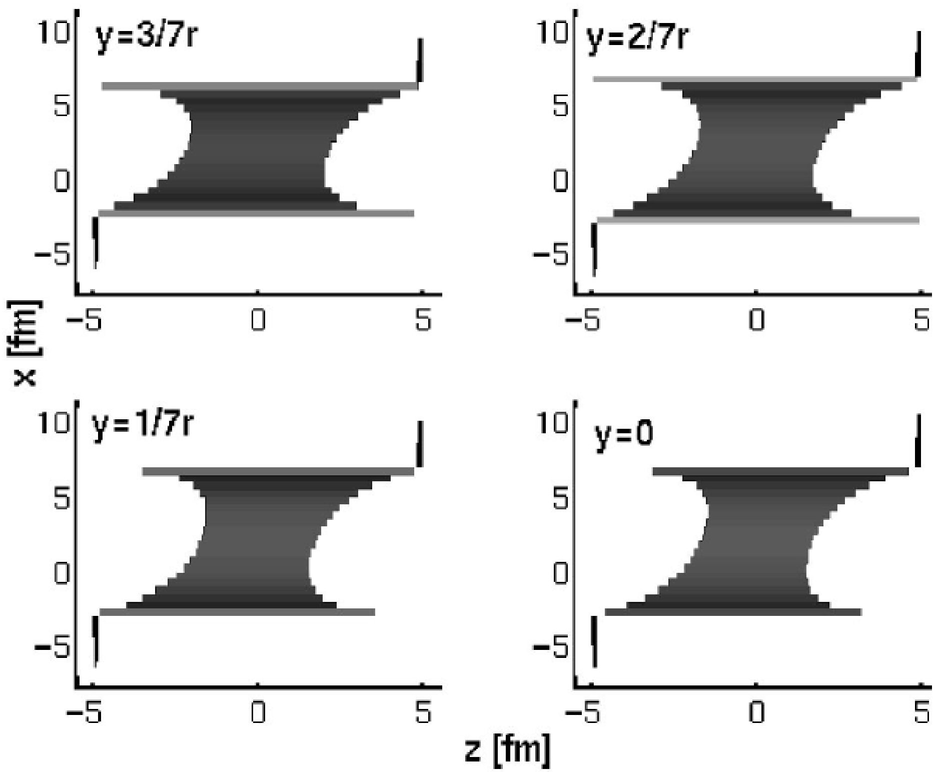


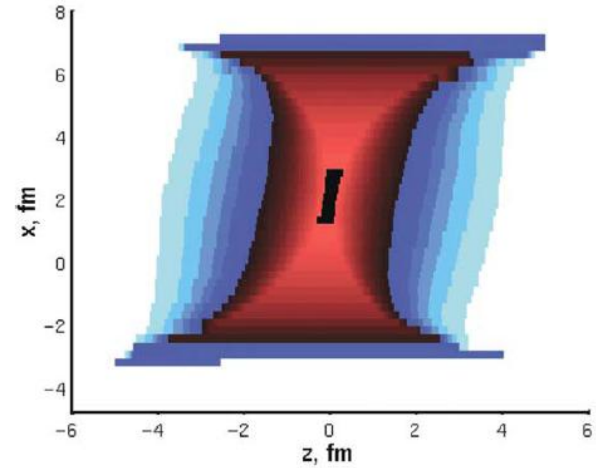
Hw P: L = ?

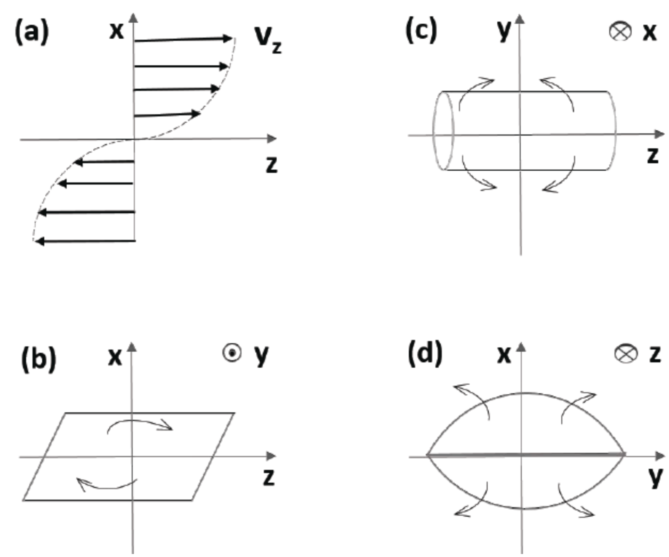
Initial State – Peripheral reactions

Magas, Csernai, Strottman **(2001), (2002)**

- Yang-Mills flux tube model for longitudinal streaks
- String tension is decreasing at the periphery
- Initial shear & vorticity is present



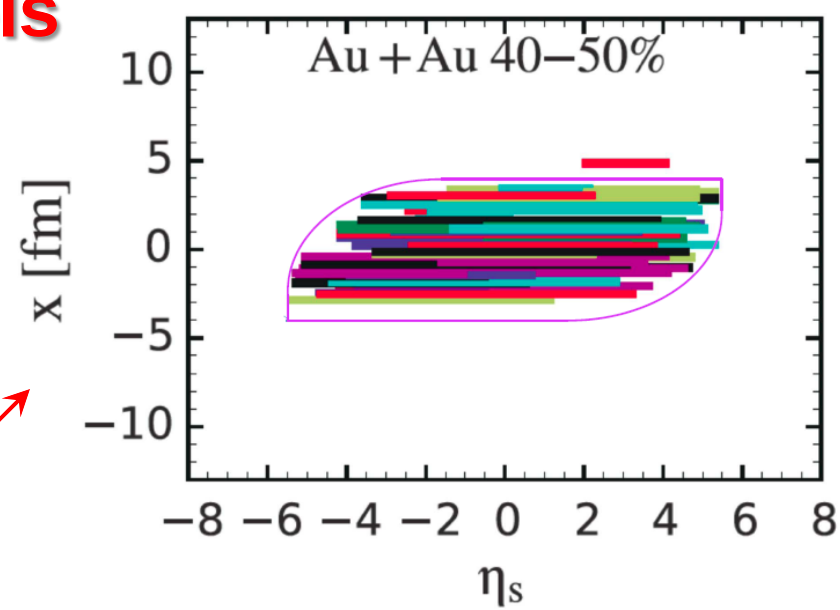




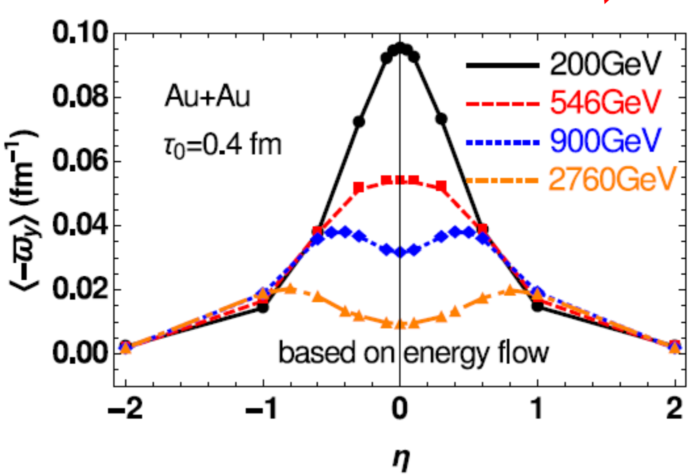
Present parton kinetic models - HIJING, AMPT, PACIAE

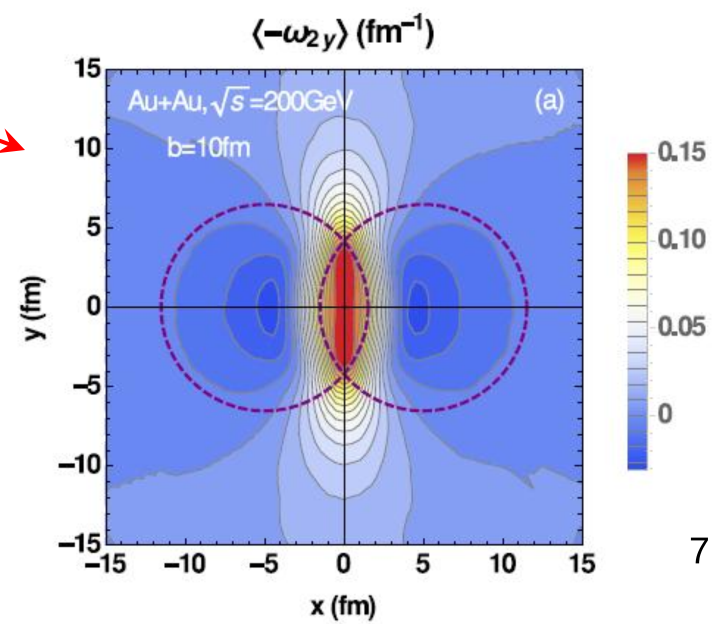
Different space-time configurations

[Long-Gang Pang, Hannah Petersen, Guang-You Qin, Victor Roy and Xin-Nian Wang, 27 September - 3 October **2015**, Kobe, Japan; and Long-Gang Pang, Hannah Petersen, Guang-You Qin, Victor Roy, Xin-Nian Wang, arXiv: **15**11.04131]

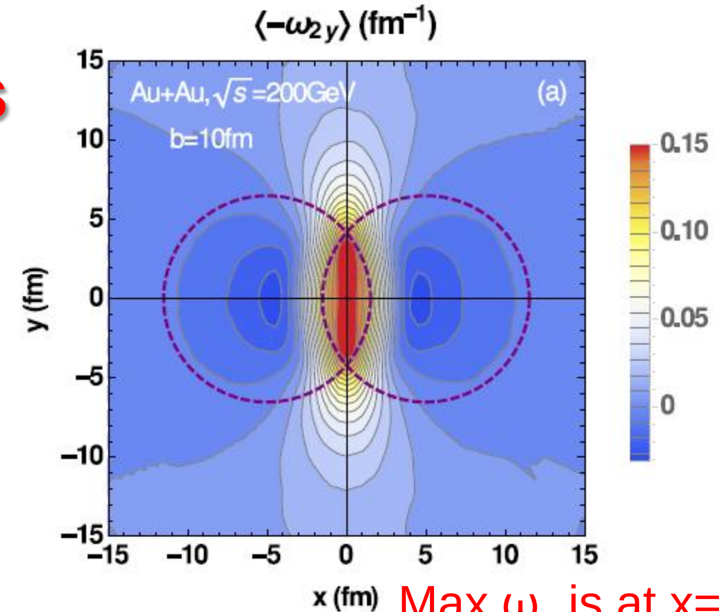


[Wei-Tian Deng, and Xu-Guang Huang, arXiv: **16**09.01801]





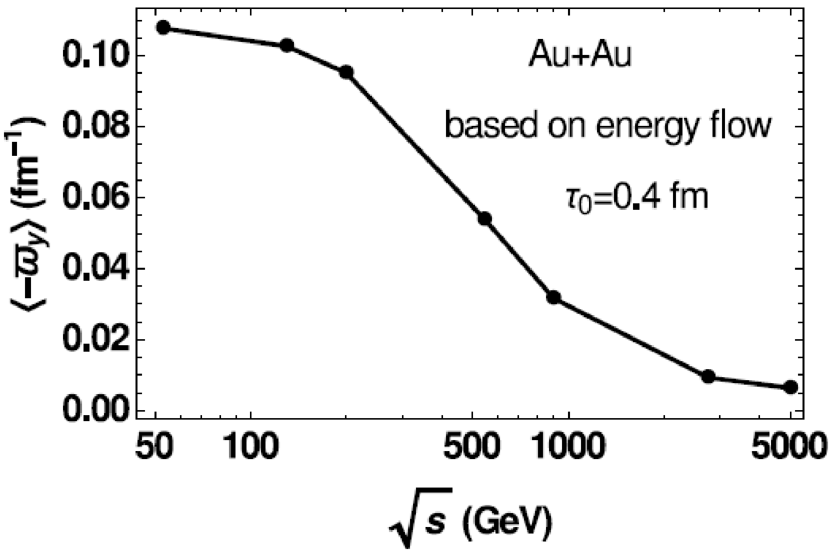
Present parton kinetic models - HIJING, AMPT, PATHIA

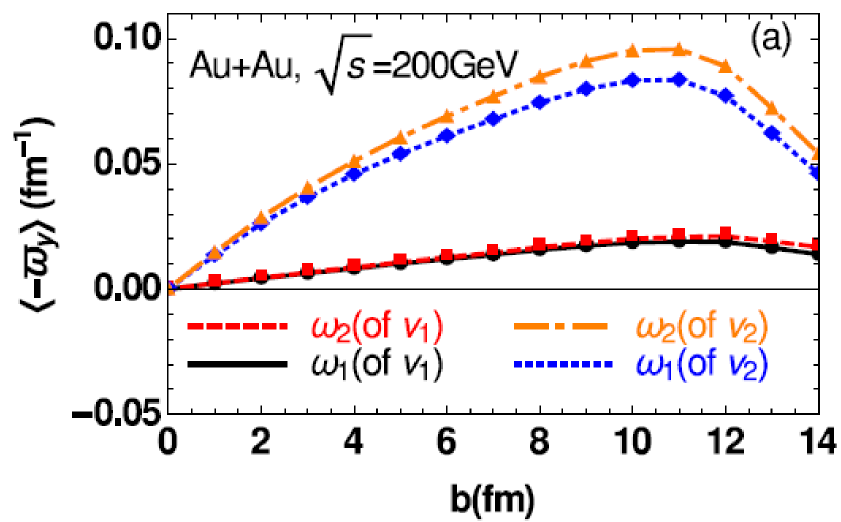


Max ω_y is at x=0 !!!

Different space-time configurations

[Wei-Tian Deng, and Xu-Guang Huang, Vorticity in heavy-ion collisions, Phys. Rev. C 93, 064907 (2016).]





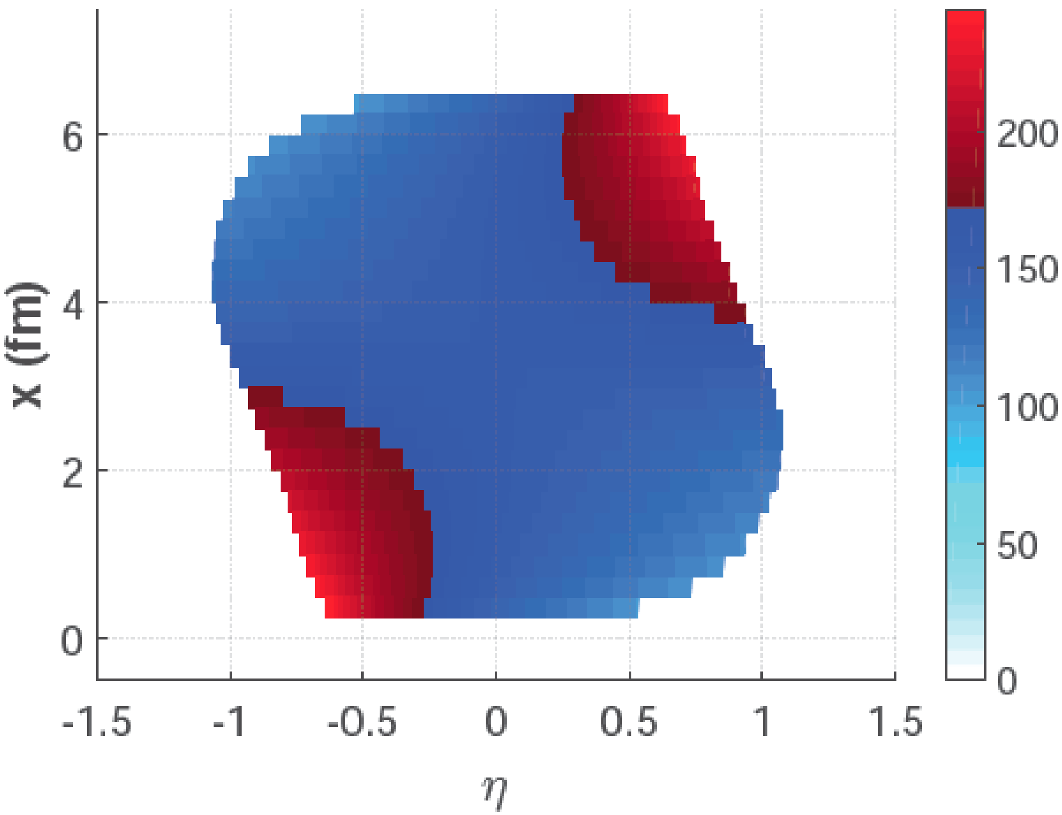
ε flow

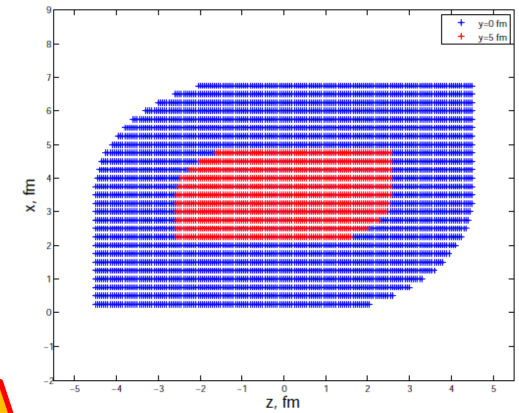
ρ flow

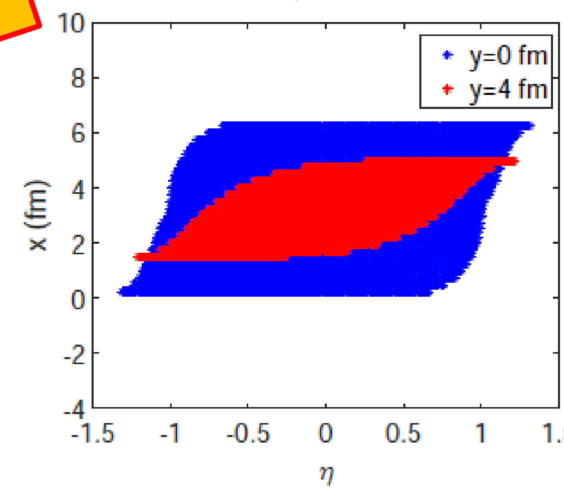
New I.S. in τ, η coordinates ➔ x,y,z,t

Thus for each streak, i, we can get the origin of the $\tau=\tau_0$ hyperbola, t_{i0} & z_{i0}.

Energy density GeV/fm^3
propagated to the c.m. hyperbola

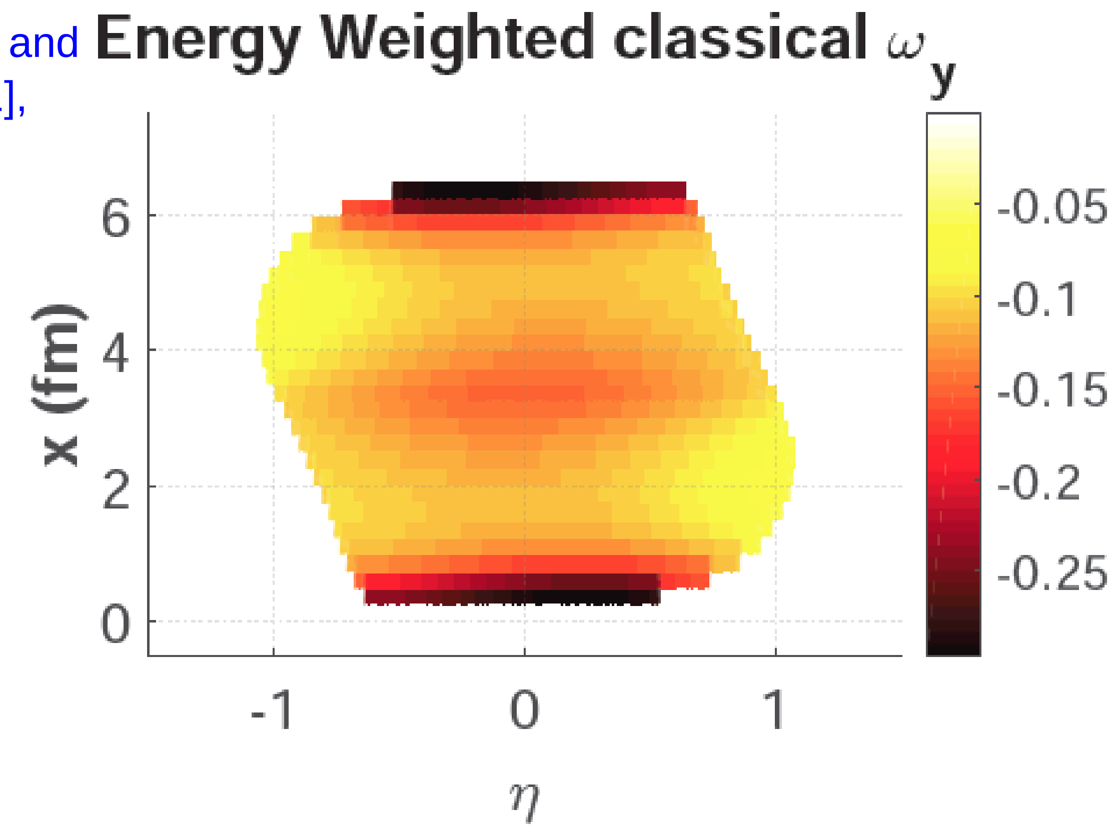






Consequences – vorticity (2018):

- Vorticity is max. at the edges, at high +/- X
- Consequence of the Bjorken type model
- Contradicts to AMPT and parton cascade results of [Wei-Tian Deng, and Xu-Guang Huang, arXiv: 1609.01801], where max. is at x=0.



V. K. Magas,[1,2] J. Gordillo,[1] D. Strottman,[3,4] Y. L. Xie,[3,5] and L. P. Csernai[3]

PHYSICAL REVIEW C **97**, 064903 (2018)

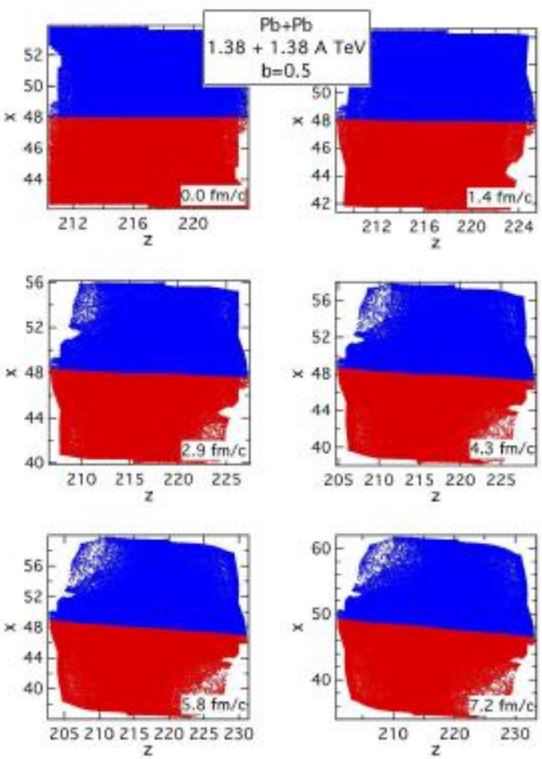
Shear & Turbulence → KHI

L.P. Csernai[1,2,3], D.D. Strottman[2,3], and Cs. Anderlik[4]

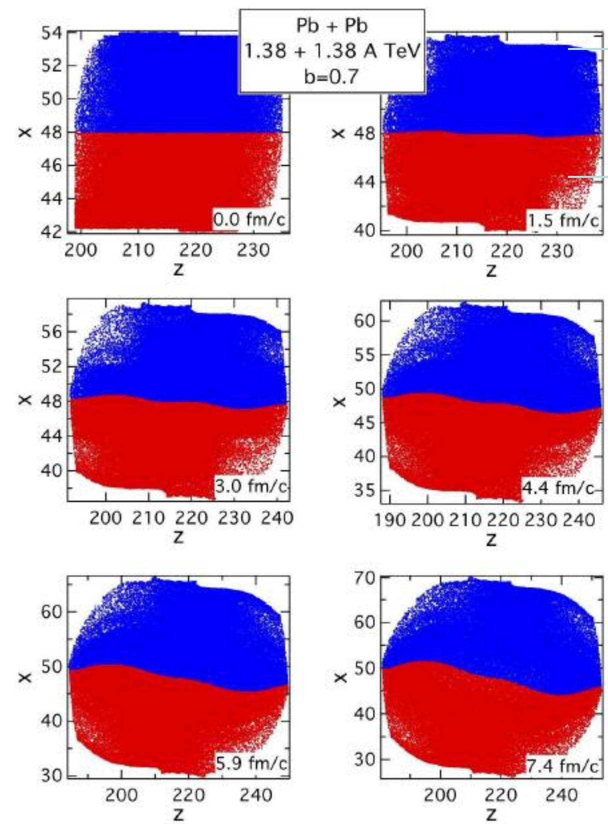
PHYSICAL REVIEW C **85**, 054901 (2012)

ROTATION – high η

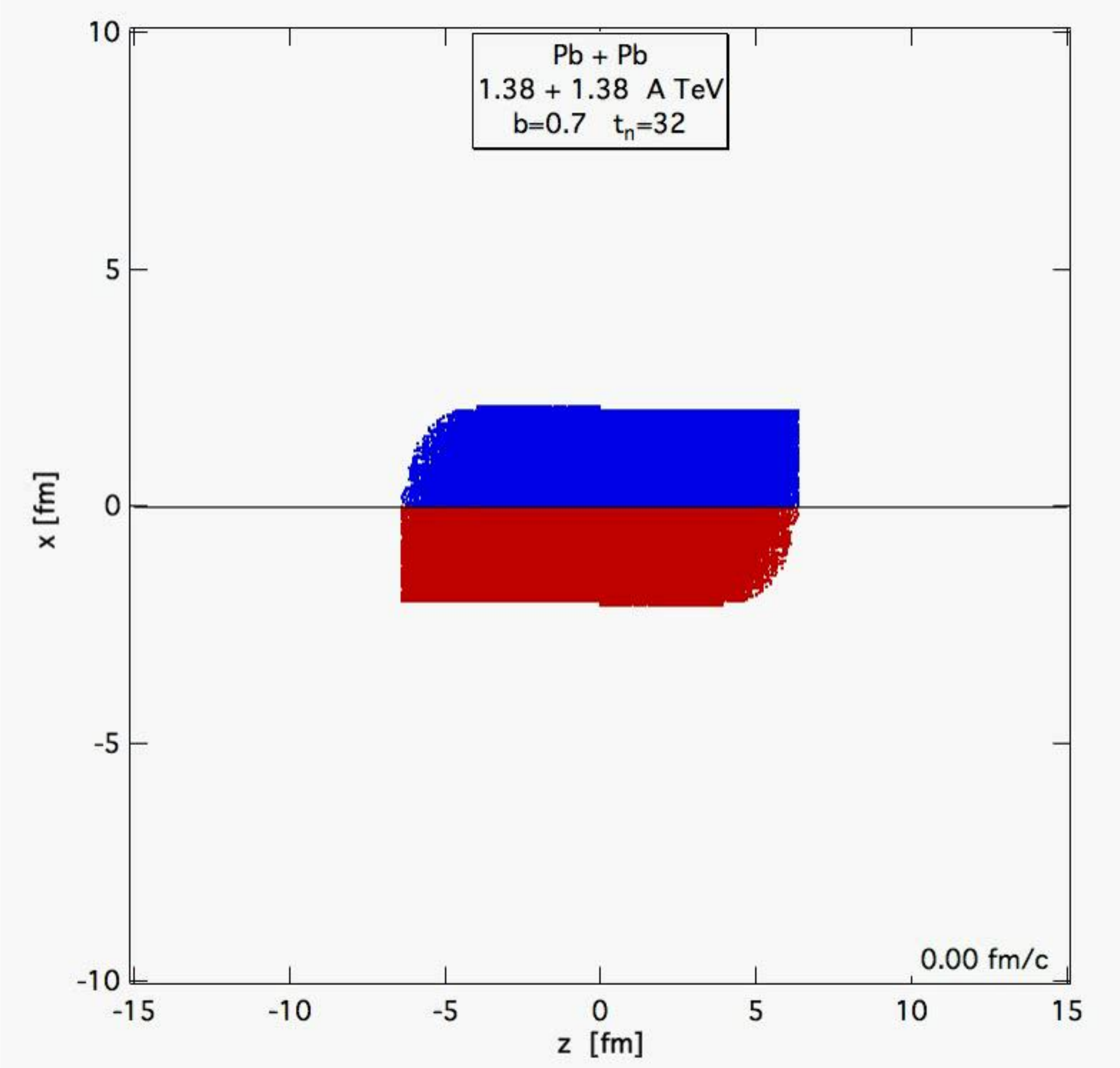
KHI– low η



KHI



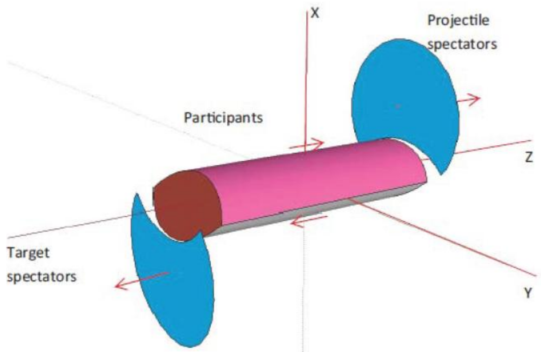
2.4 fm



Kelvin – Helmholtz Instability

PICR Hydro (2012)

Consequences – vorticity (2013):



- Will be similar to the **2001-2** I.S. in (t,z) coordinates
- More compact → vorticity may survive better
- The earlier results will remain qualitatively similar:

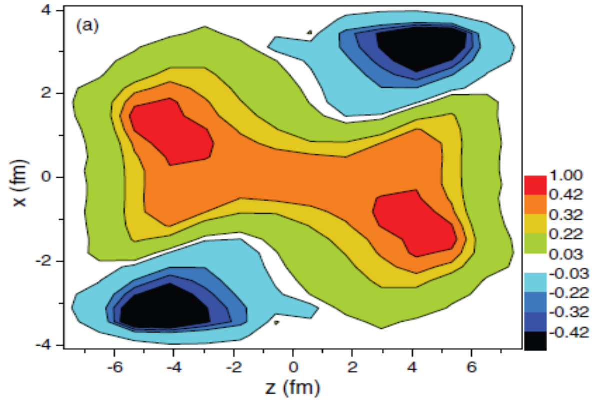


Fig. 3 The vorticity calculated in the reaction (xz) plane at t = 0.17 fm/c after the start of fluid dynamical evolution.

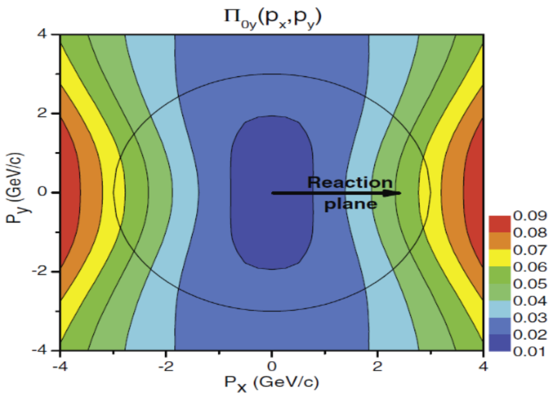


Fig. 4. The dominant y component of the observable polarization, $\Pi_0(\mathbf{p})$ in the Λ's rest frame.

The initial rotation can lead to observable **vorticity** (Fig. 3), and polarization (Fig. 4): Leading vorticity term.
The initial angular momentum can be transferred to the **polarization** at final state, via spin-orbit coupling or equipartition.

[L. P. Csernai, et al, PRC **87**, 034906 **(2013)**]
[F. Becattini, et al. PRC **88**, 034905 **(2013)**]

Consequences:

Based on Ref. [Becattini, **2013**], Λ polarization can be calculated as:

$$\mathbf{\Pi}(p) = \frac{\hbar\epsilon}{8m} \frac{\int dV n_F(x,p) (\nabla \times \beta)}{\int dV n_F(x,p)}$$

Vorticity, 1st

$$+ \frac{\hbar \mathbf{p}}{8m} \times \frac{\int dV n_F(x,p) (\partial_t \beta + \nabla \beta^0)}{\int dV n_F(x,p)} .$$

Expansion, 2nd

where $\beta^\mu(x) = [1/T(x)]u^\mu(x)$ is the inverse temperature four-vector field. Then thermal vorticity is $\omega = \nabla \times \beta$.

The polarization 3-vector in the rest frame of particle can be found by Lorentz-boosting the above four-vector:

$$\mathbf{\Pi}_0(p) = \mathbf{\Pi}(p) - \frac{\mathbf{p}}{p^0(p^0+m)} \mathbf{\Pi}(p) \cdot \mathbf{p} \ ,$$

[F. Becattini, L.P. Csernai, and D.J. Wang, Phys. Rev. C **88**, 034905 **(2013)**]

Y. L. Xie,[1] M. Bleicher,[2,3] H. Stöcker,[2,3] D. J. Wang,[4] and L. P. Csernai[1]

Λ polarization in peripheral collisions at moderately relativistic energies

Consequences:

PHYSICAL REVIEW C 94, 054907 (2016)

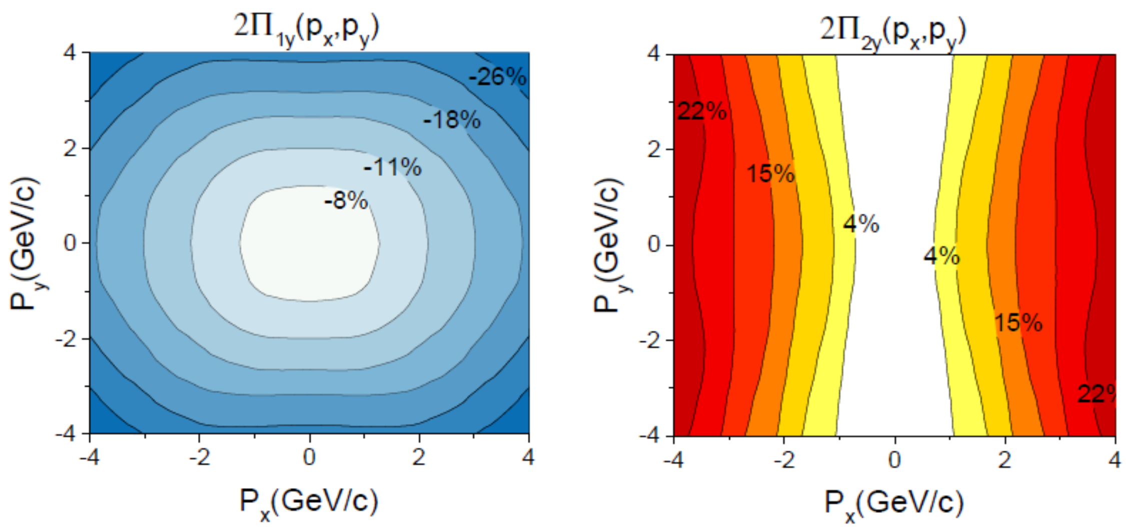


Fig. 6 The first (left) and second (right) term of the dominant *y* component of the Λ polarization for momentum vectors in the transverse plane at p_z = 0,for the FAIR U+U reaction at 8.0 GeV

- The *y* component is dominant, is up to ~20%, as we can compare it with x and z components later.
- 1st & 2nd terms are opposite direction. Result into a relatively smaller value of global polarization.

Consequences / c.m. !

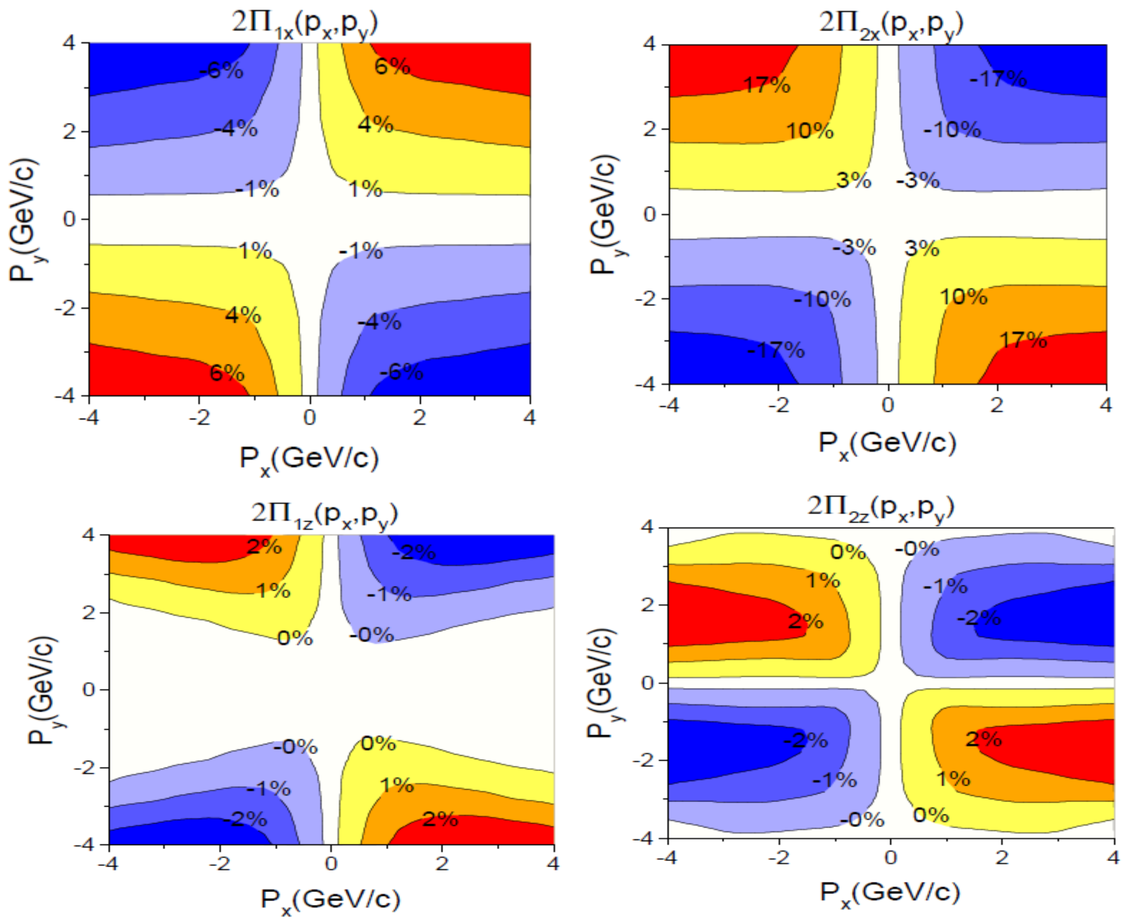
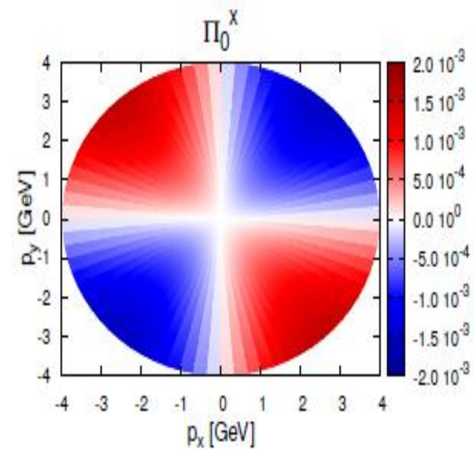


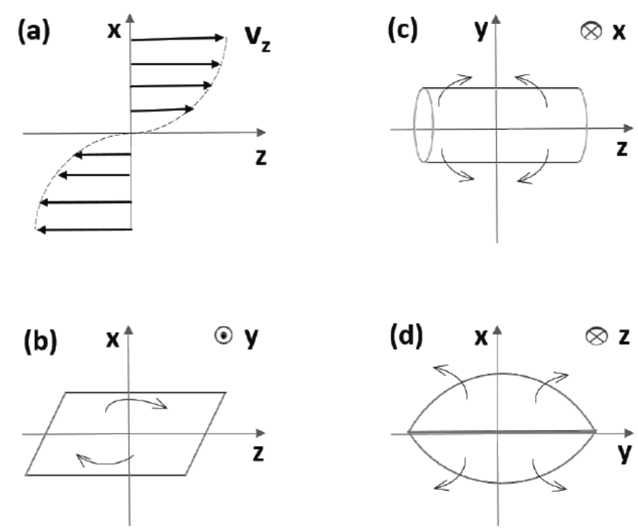
Fig. 7 The first (left) and second (right) terms of the x(up) and y(down) components of the Λ polarization for momentum vectors in the transverse plane at pz = 0,for the FAIR U+U reaction at 8.0 GeV

[Xie, Bleicher, Stoecker, Wang, Csernai, PRC **94**, 054907 (**2016**).]



[Becattini, et al., Eur. Phys. J. C 75, 406 (**2015**).]

1. Anti-symmetry



At the highest energies / Rel. Hydro.

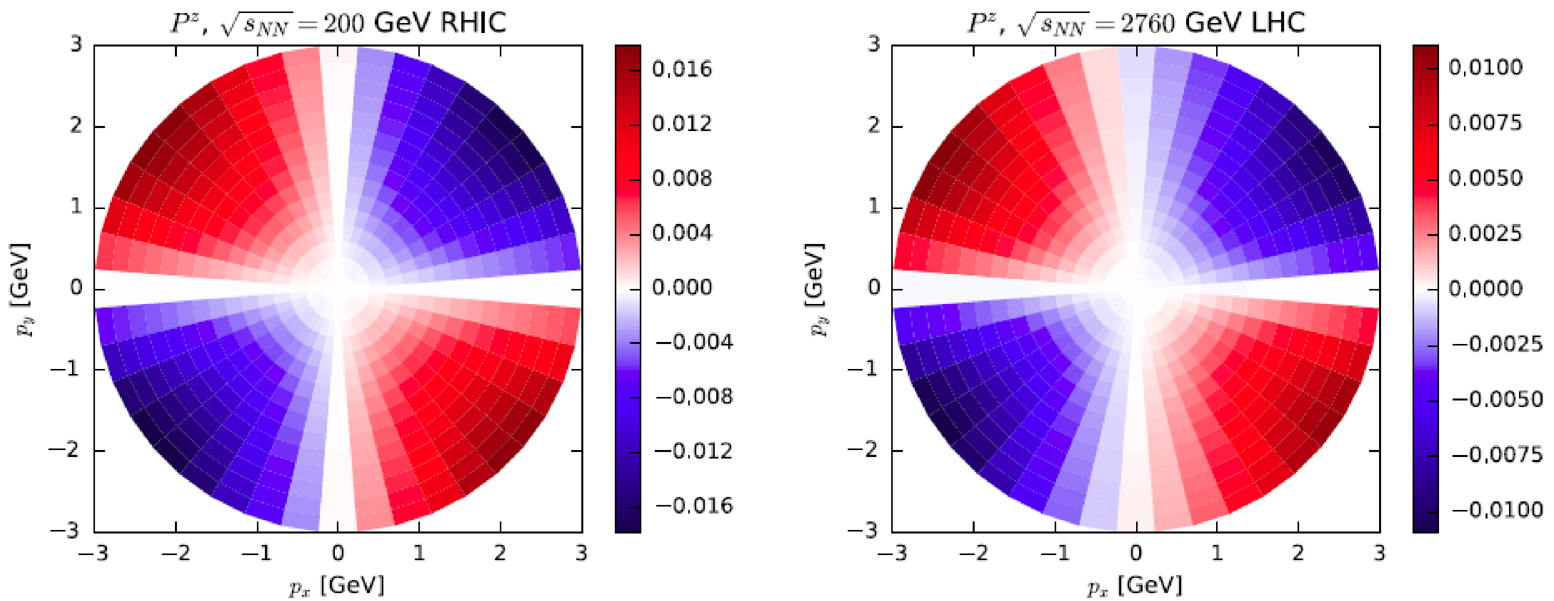
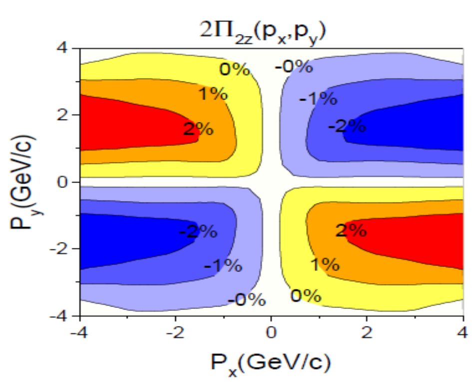


FIG. 2. Map of longitudinal component of polarization of midrapidity Λ from a hydrodynamic calculation corresponding to 20%–50% central Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV (left) and 20%–50% central Pb-Pb collisions at $\sqrt{s_{NN}} = 2760$ GeV (right).

F. Becattini and Iu. Karpenko
PHYSICAL REVIEW LETTERS **120,** 012302 (2018)



[Xie et al., PRC **94**, 054907 (**2016**)]

Polarization and EbE c.m. determination

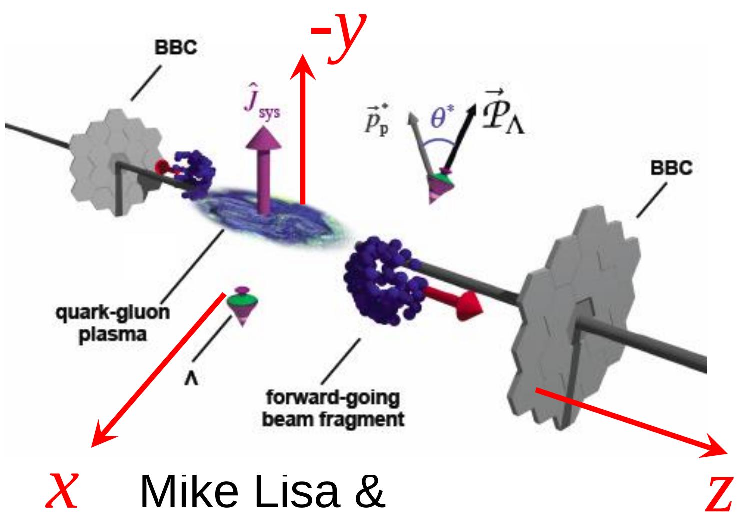
- Earlier EbE c.m. determination ➔ increased V_1 by a factor of 2 [Cs.,E.,M., (2012)].
- Now polarization in x and z directions is symmetric in **EbE c.m. frame**!!!

- ➔ integrated *x* & *z* polarizations vanish (except random fluct.)

- ➔ finding EbE c.m. is possible by
  - Minimizing integrated Π_x & Π_z
  - Maximizing integrated $-\Pi_y$

Observable consequences

[Yilong Xie, Dujuan Wang, and Laszlo P. Csernai[1]
PHYSICAL REVIEW C **95**, 031901(R) (2017)]



Mike Lisa & STAR:
Angular mom.→
Vorticity (**rot** v)→
Λ & anti- Λ
polarization

[Xie et al., PRC 94, 054907 (2016).]

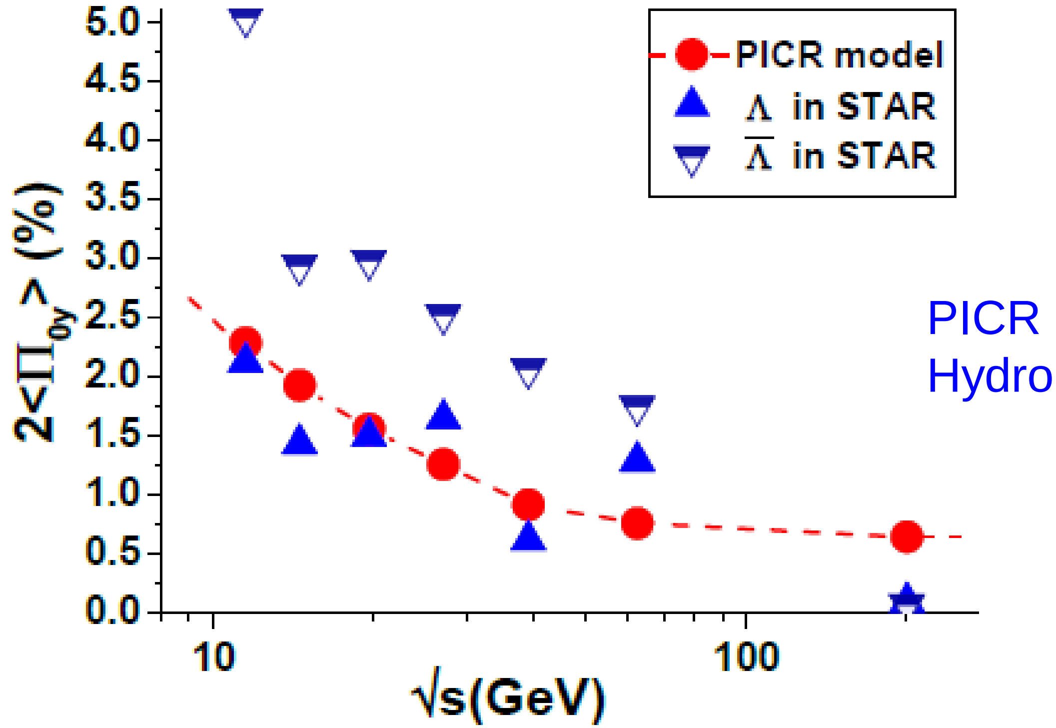
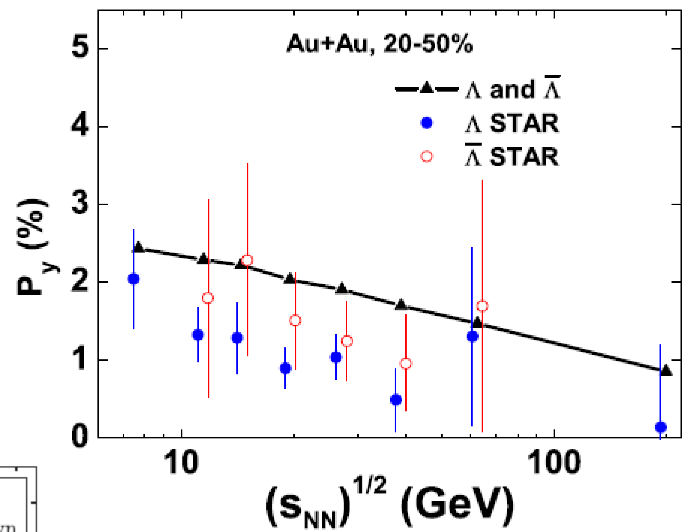


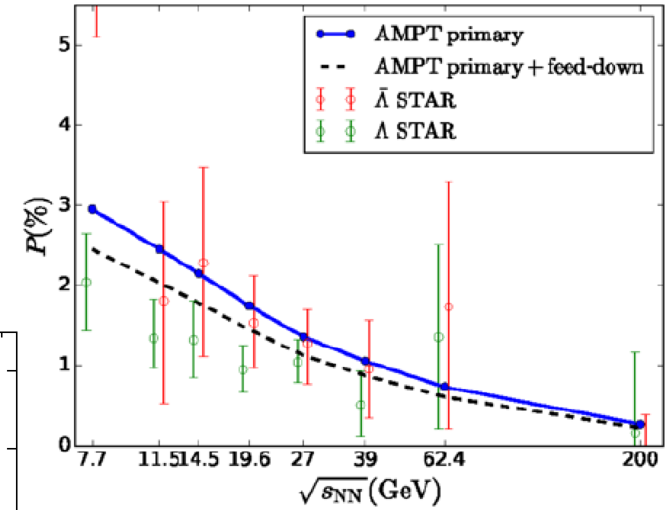
FIG. 4. (Color online) The global polarization, $2\langle\Pi_{0y}\rangle_p$, in our PICR hydro-model (red circle) and STAR BES experiments (green triangle), at energies $\sqrt{s}$ of 11.5GeV, 14.5GeV, 19.6GeV, 27GeV, 39GeV, 62.4GeV, and 200GeV. The red The experimental data were extracted from Ref[Mike Lisa], dropping the error bars.

Λ & Anti-Λ Polarization

AMPT



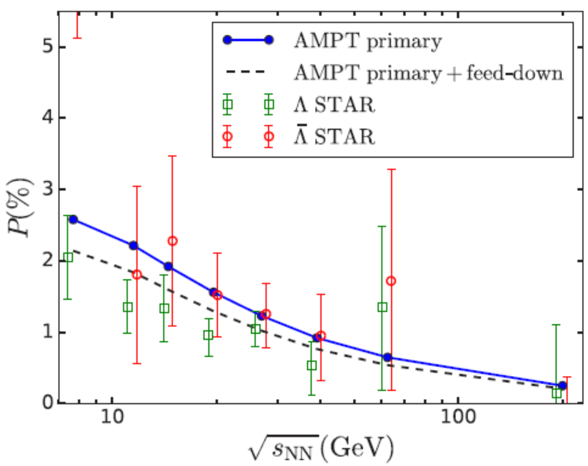
[Sun & Ko, PRC 96, 024906 (2017).]



[Li, Petersen, et al., NPA 967 (2017) 772.]

AMPT

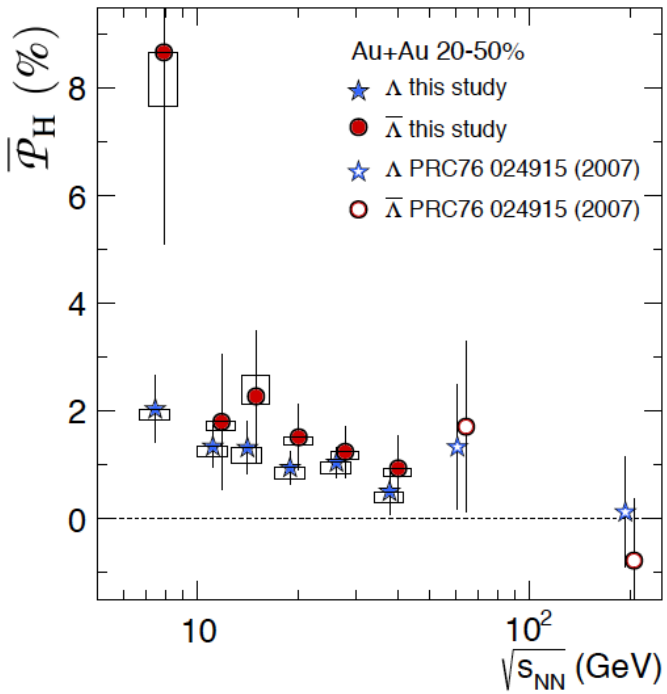
AMPT



[Li, Pang et al., PRC 96, 054908 (2017).]

Global Λ Polarization

$\Lambda \rightarrow p\pi$



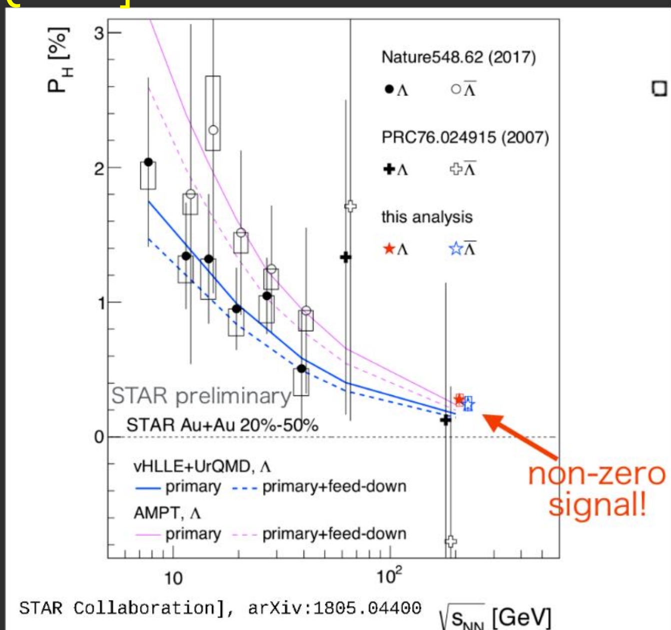
[Global Λ hyperon polarization in nuclear collisions, STAR Collaboration Nature Letters -548, 62 (2017).]

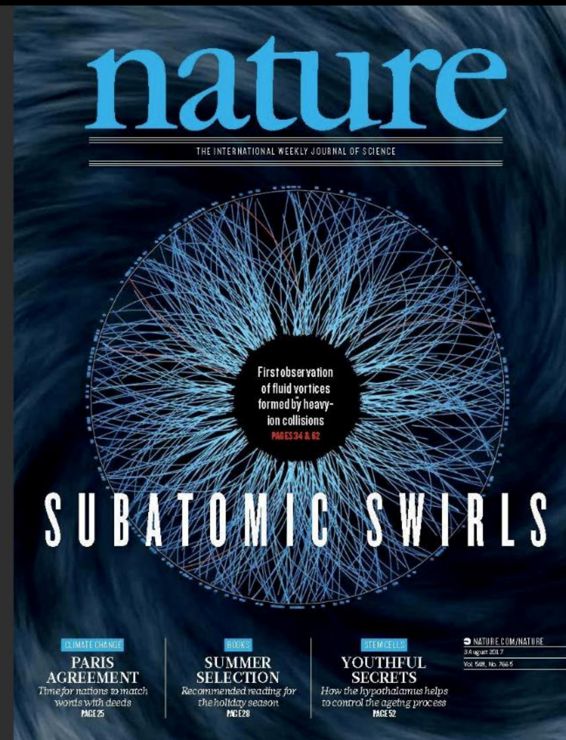
- Positive Λ signal → positive vorticity
- **First time non-zero signal observed!**
- $\bar{\Lambda}$ > Λ (?) → magnetic coupling
- First measurement on ϕ meson spin alignment

arXiv:1701.06657

[F. Becattini, QM18]

Polarization





Z. Ye, T. Niida, this conference

In agreement with most calculations using the formula

$$S^{\mu}(p) = \frac{1}{8m}\epsilon^{\mu\nu\rho\sigma}p_{\sigma}\frac{\int_{\Sigma} \mathrm{d}\Sigma_{\tau}p^{\tau}n_F(1-n_F)\partial_{\nu}\beta_{\rho}}{\int_{\Sigma} \mathrm{d}\Sigma_{\tau}p^{\tau}\, n_F}$$

L. Csernai, L. G. Pang, X. N. Wang, C. Ko, X. G. Wang, Q. Wang, X. L. Xia, J. Liao, A. Sorin, O. Teryaev, I. Karpenko, F.B.

I. Karpenko, Y. Xie this conference

One of the most important new results in last year:
Global Λ hyperon polarization in nucl. coll., Nature, August 2017

Sensitive measure of angular momentum, collective shear & vorticity in peripheral heavy ion collisions!

P_H is defined positive, but points in the –y direction !

How to measure?

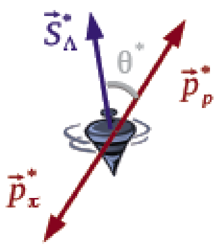
[T. Niida, QM18]

Parity-violating decay of hyperons

In case of Λ's decay, daughter proton is preferentially emitted in the direction of Λ's spin (opposite for anti-Λ)

$$\frac{dN}{d\Omega^*} = \frac{1}{4\pi}(1 + \alpha_H \mathbf{P}_H \cdot \mathbf{p}_p^*)$$

P_H: Λ polarization
p_p^*: proton momentum in Λ rest frame
α_H: Λ decay parameter
($\alpha_\Lambda = -\alpha_{\bar{\Lambda}} = 0.642 \pm 0.013$)

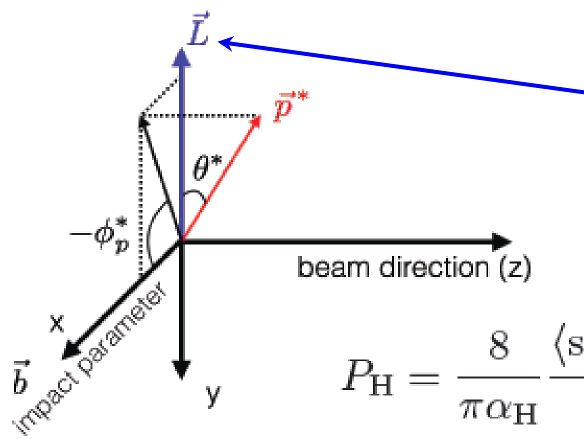


$$\Lambda \rightarrow p + \pi^-$$

(BR: 63.9%, cτ~7.9 cm)

Projection onto the transverse plane

- ★ Direction of the angular momentum is determined by the angle of spectator plane (spectators deflect outwards)
  - S. Voloshin and TN, PRC94.021901(R)(2016)
- ★ Flow analysis technique can be used for signal extraction
  - STAR, PRC76, 024915 (2007)



P_H is defined positive, but points in the –y direction !

$$P_H = \frac{8}{\pi \alpha_H} \frac{\langle \sin(\Psi_1 - \phi_p^*) \rangle}{\mathrm{Res}(\Psi_1)}$$

ϕ_p^*: ϕ of daughter proton in Λ rest frame
STAR, PRC76, 024915 (2007)

Question # 1

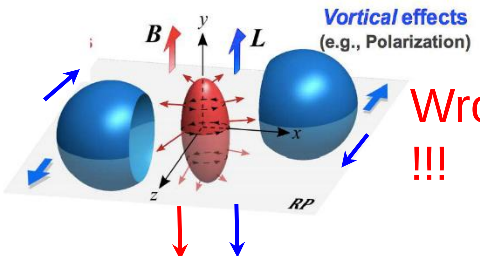
Dependence of polarization on the emission angle of the Λ

$$\mathbf{P}_{\Lambda}\,(p_x,p_y)$$

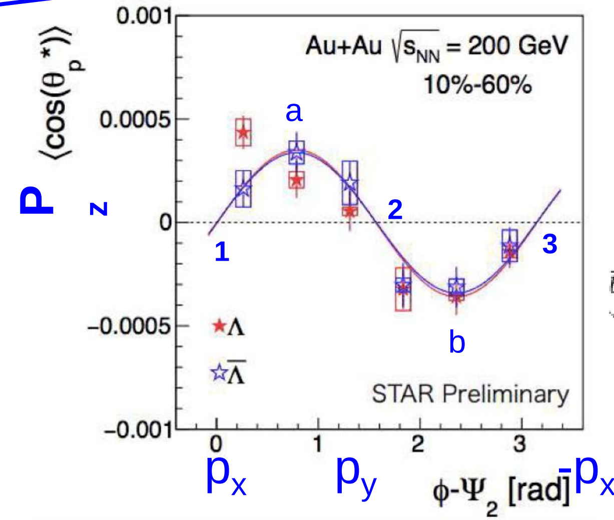
[Marco van Leeuwen, Summary QM18]

General convention:
Projectile is at + X
Projectile moves twrd + Z
Here NOT !!!

Vorticity

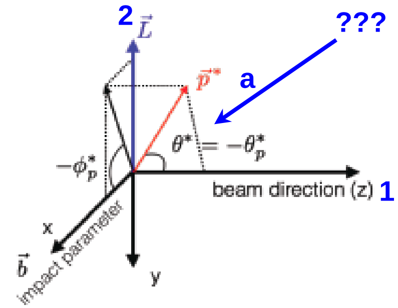


Wrong !!!

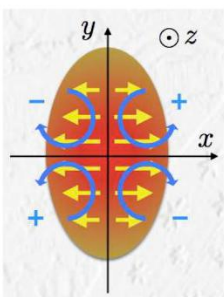


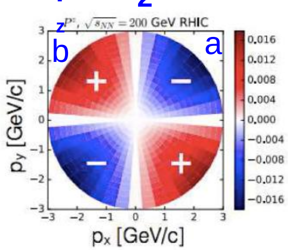
p_x p_y $-p_x$

$p_y=0$ $p_x=0$



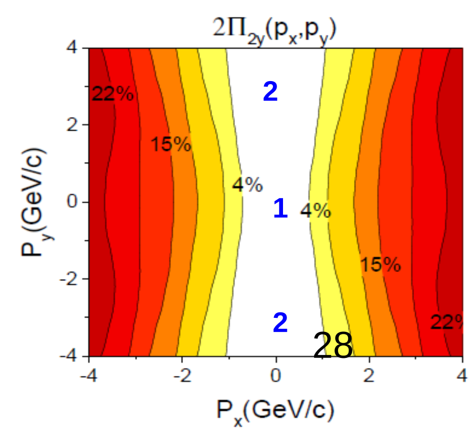
[STAR-arXiv-1805. 04400 & STAR- Zhenyu Ye, QM 18]





Clear effect seen: modulation of longitudinal spin alignment with angle to event plane

However: sign is opposite of expected!



$P_z(p_x,p_y)$ from elliptic flow vorticity

$P_z(p_x,p_y)$ no shear vorticity

$P_{2y}(p_x,p_y)$ /w shear & no vorticity

[Yilong Xie, UoB, QM18]

Polarization vector

$\beta^{\mu}(x) = [1/T(x)]u^{\mu}(x)$

In experiments, the polarization is measured in particle's rest frame---- Lorentz-boosting:

$$\mathbf{\Pi}_0(p) = \mathbf{\Pi}(p) - \frac{\mathbf{p}}{p^0(p^0+m)}\mathbf{\Pi}(p)\cdot\mathbf{p}\ ,$$

[F. Becattini, L.P. Csernai, and D.J. Wang, Phys. Rev. C **88**, 034905 (2013).]

Results: X and Z components

[Yilong Xie (U. Bergen) Quark Matter 2018
inv. talk.: *Global Λ polarization* …]

1. Small magnitude.
2. Anti-symmetric

P_z & P_x : no shear flow vorticity

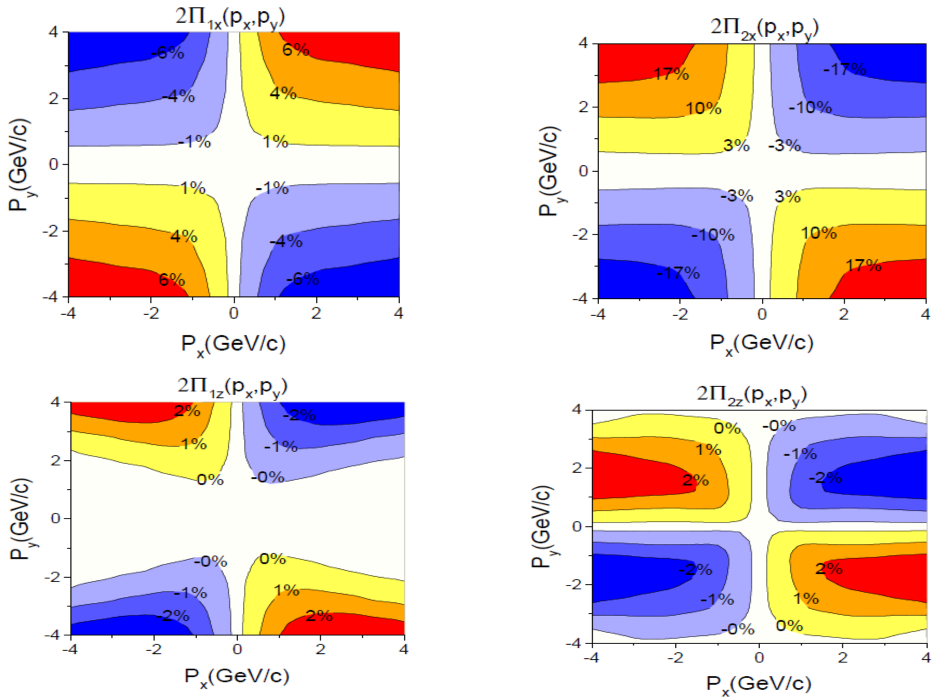
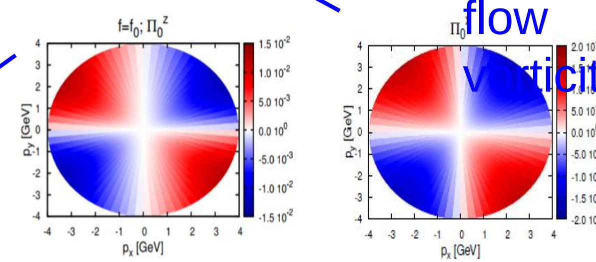


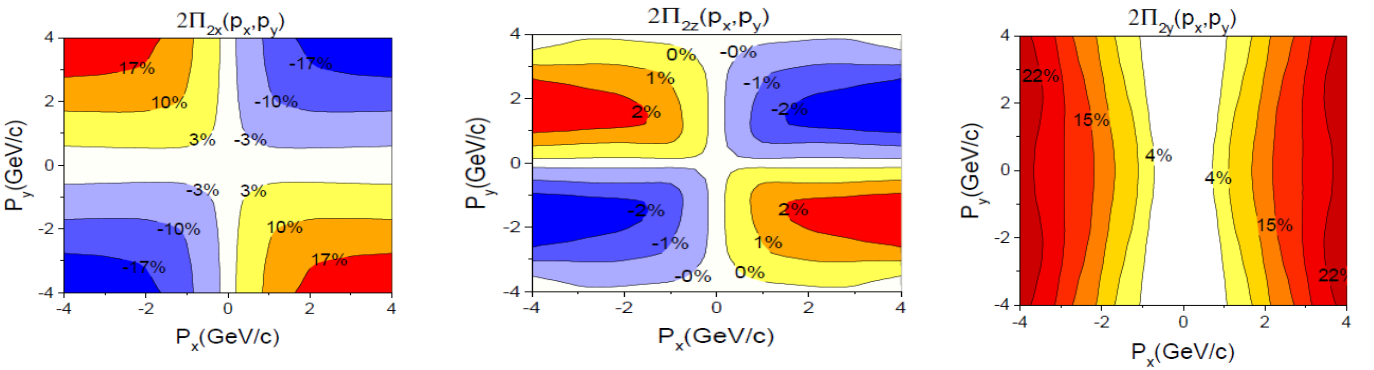
Fig. 7 The first (left) and second (right) terms of the x(up) and y(down) components of the Λ polarization for momentum vectors in the transverse plane at pz = 0,for the FAIR U+U reaction at 8.0 GeV



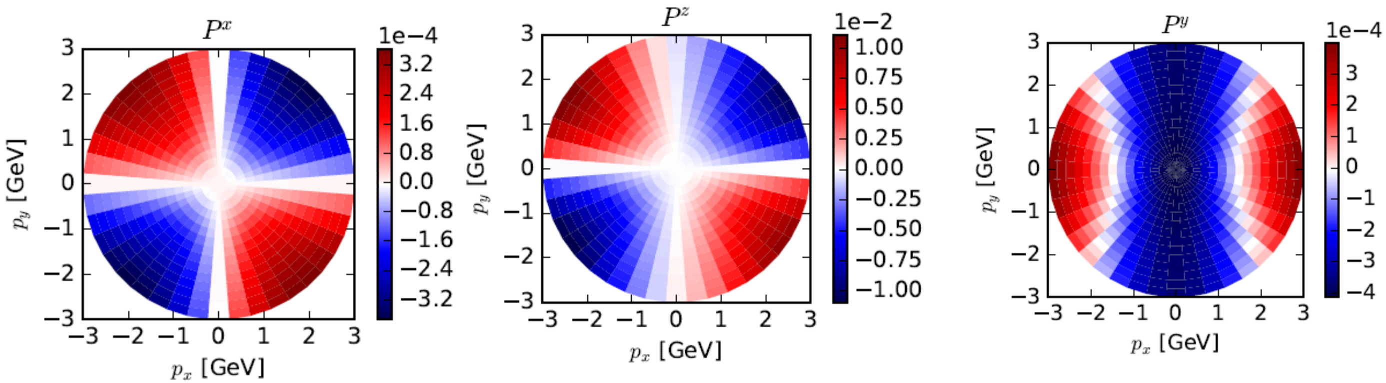
ECHO-QGP numerical code, implementing relativistic dissipative hydrodynamics in the causal Israel-Stewart framework in 3+1 dimensions with an initial Bjorken flow profile

[Becattini, et al., Eur. Phys. J. C 75, 406 (2015).]

Conclusion # 1



[Yilong Xie, talk QM18]
2: no shear vorticity



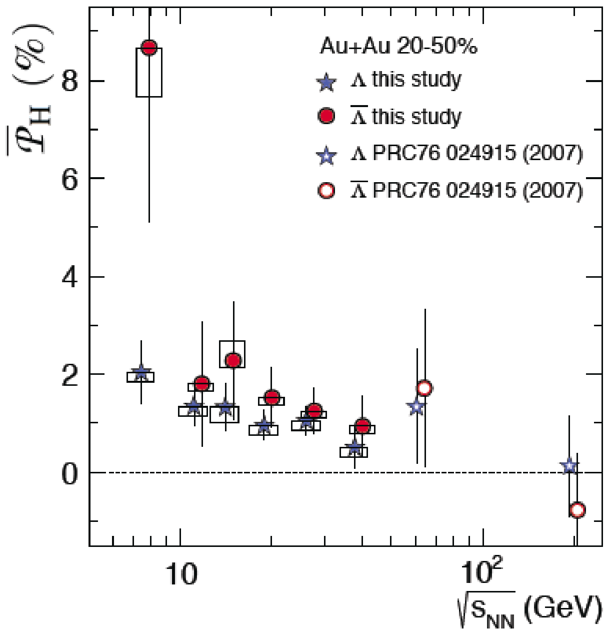
[I. Karpenko, talk QM18]
no initial shear
no NR vorticity

* Signature in theory is in agreement !!! (Magnitude is I.S. dependent)

* Exp. is a mix of P-s for X & Y and 1 & 2 components

Question # 2

What causes the difference of Λ and anti-Λ polarization ?



[STAR, Nature 548 (2017) 62.]

Λ & anti-Λ polarization measurement, BES: STAR Collaboration, Nature 548, 62 (2017)

Indication of larger polarization of anti-Λ-s (**?**)

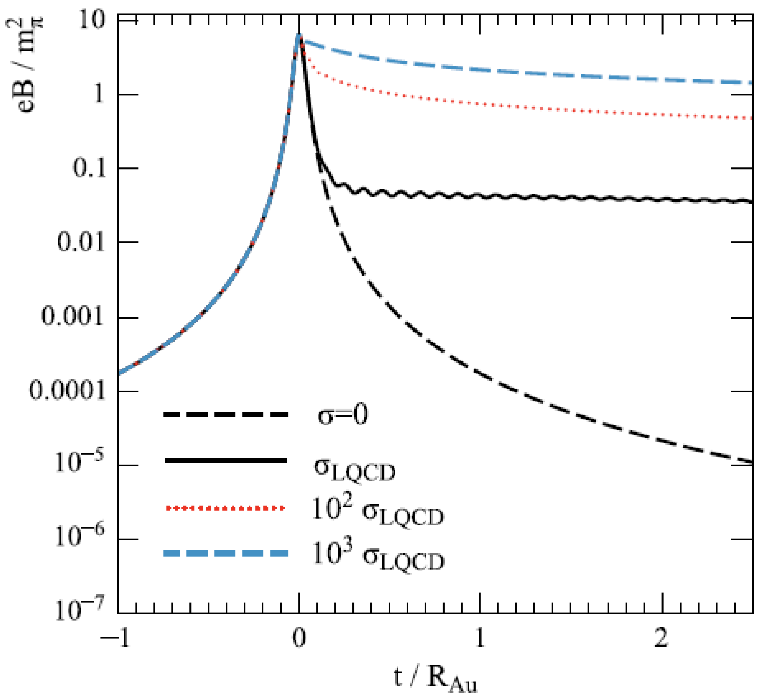
- Frequently attributed to magnetic effect caused the P & T spectators.

- Summarized by [Karpenko, talk QM18]:
  * Vorticity creates the average polarization.
  * The magnetic moment makes the Polarization splitting for Λ and anti-Λ
  * Question is there magnetic field at hadronization & freeze-out (**??**)

- Spectators are Lorentz contracted to $\Delta t = 2R_N/\gamma$

Frequently cited (!!!) :

L. McLerran, V. Skokov / Nuclear Physics A 929 (2014) 184–190



Magnetic field for **STATIC** medium with Ohmic conductivity.

The magnetic field lifetime in a collision

There is an internal current, j_{int}, generated in the medium.

"The characteristic time scale is defined by the external magnetic field and proportional to the thickness of the nucleus in the beam direction, i.e. tc~2R/ γ.For the top RHIC energy, tc ~ 0.2 fm/c.“

"These subtle [expansion] effects, however, cannot be taken into account in the present studies ... “

"The conducting medium in the collision is not formed immediately, because the quarks need time to be created from the glasma field. Nonetheless, to make our estimates of the conductivity effects as optimistic as possible we will consider that the conducting medium is formed immediately after the collision and **does not alter (!)** during the evolution."

V. VORONYUK *et al.*
PHYSICAL REVIEW C **83**, 054911 (2011)

The magnetic field lifetime in a collision **2**

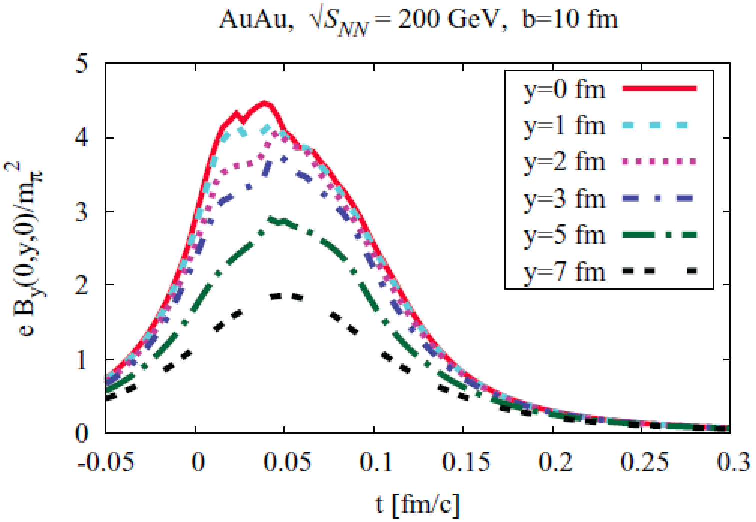


FIG. 6. (Color online) Time evolution of the magnetic field at the point y for the central overlap point $x = 0$.

[V. Voronyuk, V. D. Toneev, W. Cassing, E. L. Bratkovskaya, V. P. Konchakovski, S. A. Voloshin]

The magnetic field in the expanding medium is short lived, t ~ 0.15 fm/c at the initial moments, where quarks are not yet created.

The effect of this initial field is utterly negligible at the freeze out time of t_{FO} ~ 10 fm/c.

Dynamical hydro calculations assume that thermal, spin, and vorticity are equilibrated by the FO time. The spin-orbit interaction is assumed to be sufficiently strong (and equal) to achieve this equilibrium.

Competing strong spin-orbit interaction ⇔ Hypernuclei

- In all calculations **spin-orbit equilibration** is assumed, by freeze-out
- However, from initial vorticity it takes time to build up Λ polarization
- Spin-orbit interaction for Λ and anti-Λ is not the same
- This is indicated by spin-orbit splitting of Hypernuclei !

- Presented also at **Workshop on Chirality, Vorticity** …,Firenze, 19-22 March & **QM2018,** Lido di Venezia, 14-19 May, 2018 :
  - **L.P. Csernai**, Uo Bergen: Λ polarization in peripheral heavy ion collisions
  - **I. Vassiliev** for the FAIR/CBM Collaboration: Perspectives on strangeness physics with CBM experiment
  - **Tetyana Galatyuk**, TU Darmstadt / GSI: Future facilities for high μ_B physics
  - **Stefania Bufalino**, Politecnico and INFN Torino: Strangeness and nuclei production in nuclear collisions

Λ & Anti-Λ Coupling to Nucleons

Difference based on Hypernuclei:
1.0 – 1.5 MeV i.e. ~ 20% of nuclear binding energy !!!

~ 20 Λ-hypernuclei ($T_{1/2} = 10^{-10}$s) 1953-1995

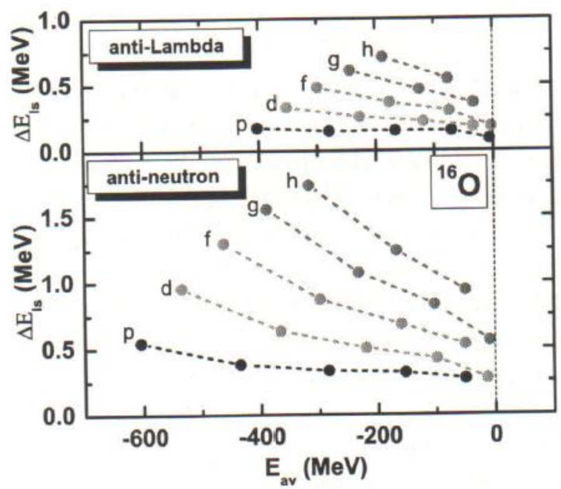


Fig. 2. Spin-orbit splitting $\epsilon_A(nl_{l-1/2}) - \epsilon_A(nl_{l+1/2})$ in the spectra of anti-Lambda and anti-neutron in ^{16}O versus the average energy of a pair of spin doublets. The vertical dashed line shows the continuum limit.

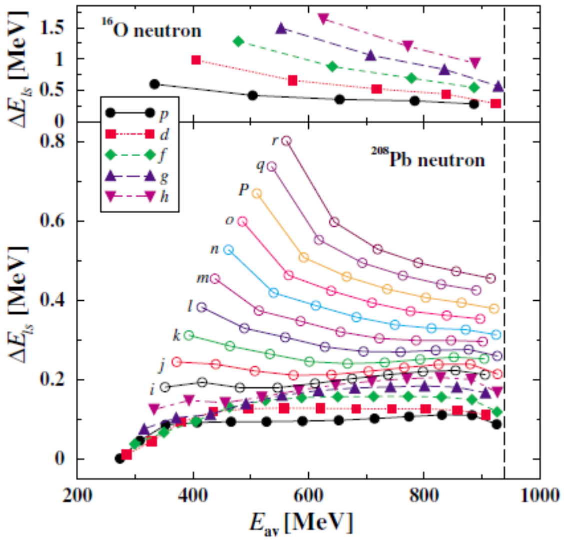


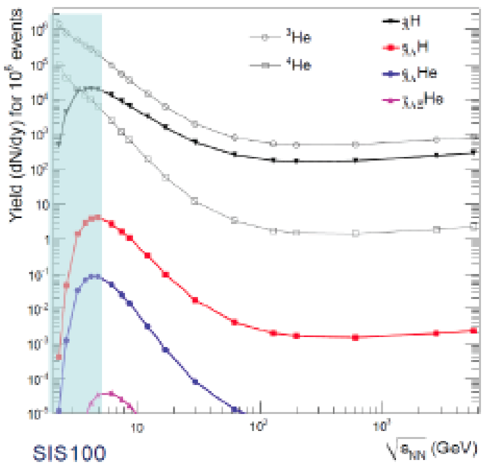
FIG. 2 (color online). Spin-orbit splitting $\epsilon_A(nl_{l-1/2}) - \epsilon_A(nl_{l+1/2})$ in antineutron spectra of ^{16}O and ^{208}Pb versus the average energy of a pair of spin doublets. The vertical dashed line shows the continuum limit.

[ZhouSG-etal-PhysRevLett.91(2003)262501]

[SongCY-etal-IJMPE19(2010)2538]

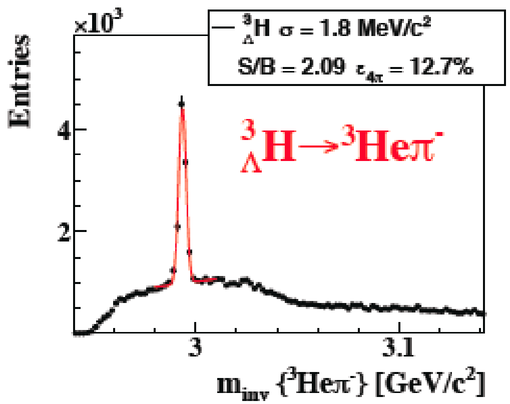
[Csernai, Chirality WS, 2018]

Hypernuclei production in A+A collisions

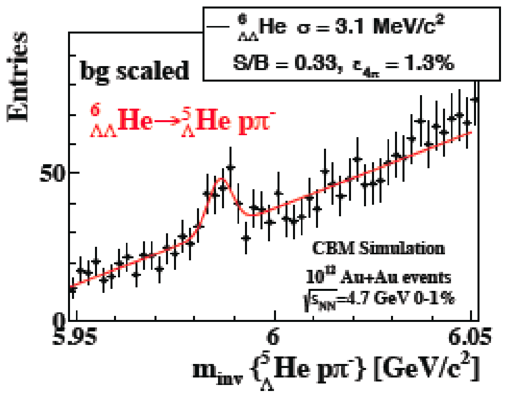


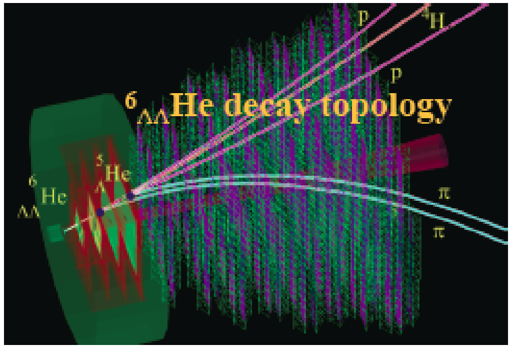
A. Andronic et al., Phys. Lett. B697 (2011) 203

5M mbias events Au+Au at 10AGeV/c
5 sec at 1MHz IR (1.8 k/sec)



Expected collection rate: ~60 $^6_{\Lambda\Lambda}$He in 1 week at 10MHz IR





- According to the current theoretical predictions CBM will be able to perform comprehensive study of hypernuclei, including:
  - precise measurements of lifetime;
  - excitation functions;
  - flow.
- It has a huge potential to register and investigate double Λ hypernuclei.

[Vassiliev, QM 2018]

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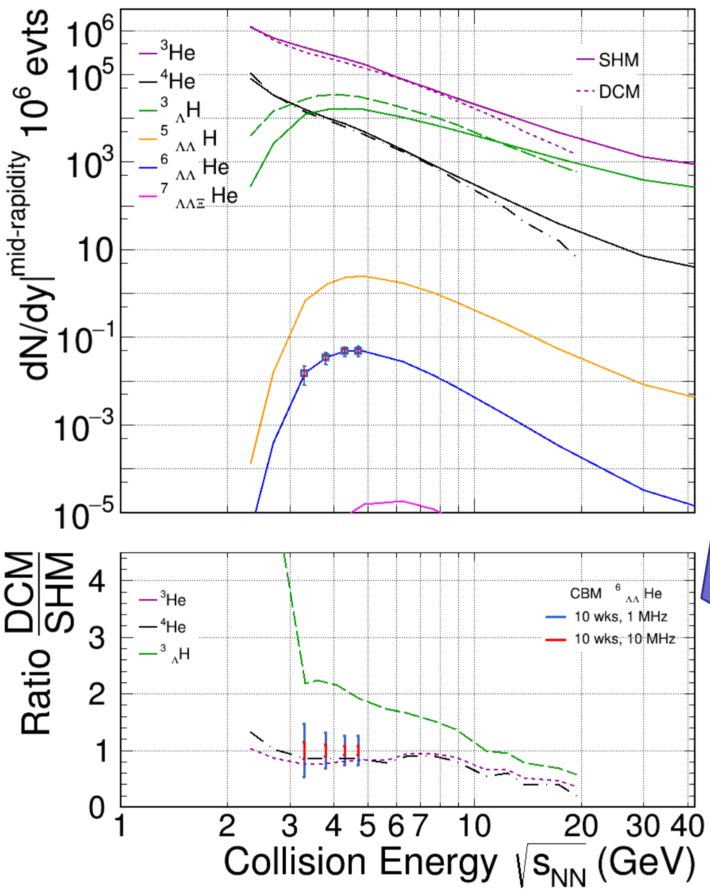
Nuclei and hyper-nuclei production



SHM: A. Andronic et al., Phys.Lett. B697 (2011)
DCM: J. Steinheimer et al., Phys.Lett. B714 (2012)

- How do nuclei and hyper-nuclei form?
  - Compact multi-quark states at the phase boundary?
  - Coalescence?
- What are their properties?
- Do YY bound states exist?

ALICE Collab., Phys. Lett. B 754 (2016) 360
STAR Collab., arXiv:1710.00436 [nucl-ex]
HAL CD Coll., arXiv:1709.00654 [hep-lat]

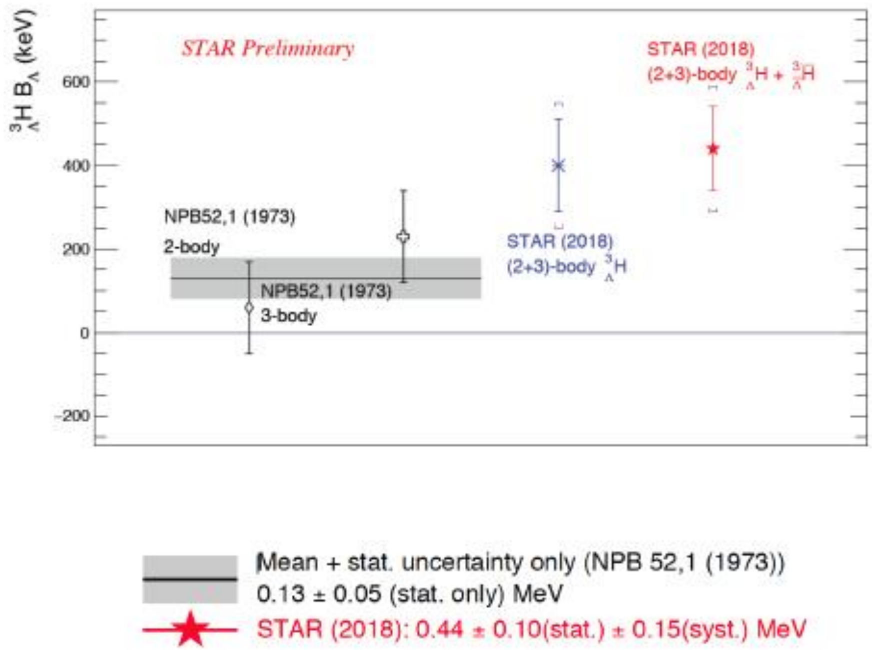
Precision measurement of spectra, life-time and flow pattern

CBM	$\sqrt{s_{NN}}$	Run time	ε %	R_{int}, MHz	Duty F %	Yield
$^3_\Lambda$H	4.7 GeV	1 wks	19	10	50	5.5×10^9
$^4_\Lambda$He	4.7 GeV	1 wks	15	10	50	2.7×10^8
$^6_{\Lambda\Lambda}$He	4.7 GeV	10 wks	1	10	50	146
MPD S2						
$^3_\Lambda$H	5 GeV	10 wks	1	0.5	100	9×10^4
$^4_\Lambda$He	5 GeV	10 wks	0.4	0.5	100	1×10^4

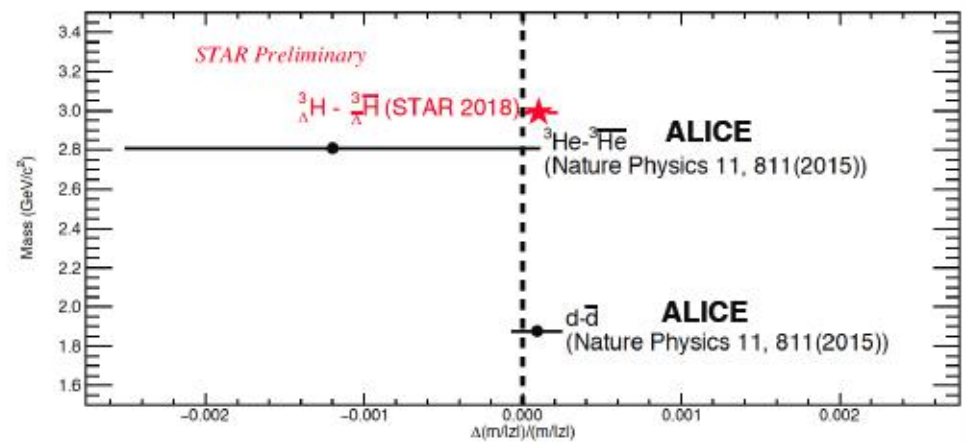
[Tetyana Galatyuk, QM 2018]

Hypertriton: news from STAR

Latest news



Mass difference measurement for hyper-matter confirms the result obtained with light nuclei and it is consistent with CPT prediction.



$$\Delta m = 2.8 \mathrm{Gev/c^2} \text{ between } {}^3_\Lambda H \text{ and } {}^3_\Lambda \bar{H}.$$

[Stefania Bufalino, QM 2018]

Λ spin interaction with external

$$H^{\omega}_{\rm spin} = -\frac{g_{\omega\Lambda}}{m_\Lambda}\beta\,\boldsymbol{S}\cdot\boldsymbol{B}_\omega - i\frac{g_{\omega\Lambda}}{4m_\Lambda^2}\boldsymbol{S}\cdot\boldsymbol{\nabla}\times\boldsymbol{E}_\omega - \frac{g_{\omega\Lambda}}{2m_\Lambda^2}\boldsymbol{S}\cdot\boldsymbol{E}_\omega\times\boldsymbol{p} \quad (3)$$

where $\beta = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$ is the usual Dirac 4x4 matrix.

[J. D. Bjorken and S. D. Drell, Relativistic Quantum Mechanics (McGraw-Hill, 1964)]

When acting on the spinors of Λ and anti-Λ they result in opposite signs whereas the second and third terms have the same sign.

The second and third terms contribute to the usual nuclear spin-orbit energy.

[L. P. Csernai, J. I. Kapusta, T. Welle, arXiv:1807.11521]

$$H^{\omega}_{\text{spin-orbit}} = \frac{g_{\omega\Lambda}}{2m_\Lambda^2}\frac{1}{r}\frac{\partial\omega_0}{\partial r}\boldsymbol{S}\cdot\boldsymbol{L}$$

Standard spin-orbit interaction

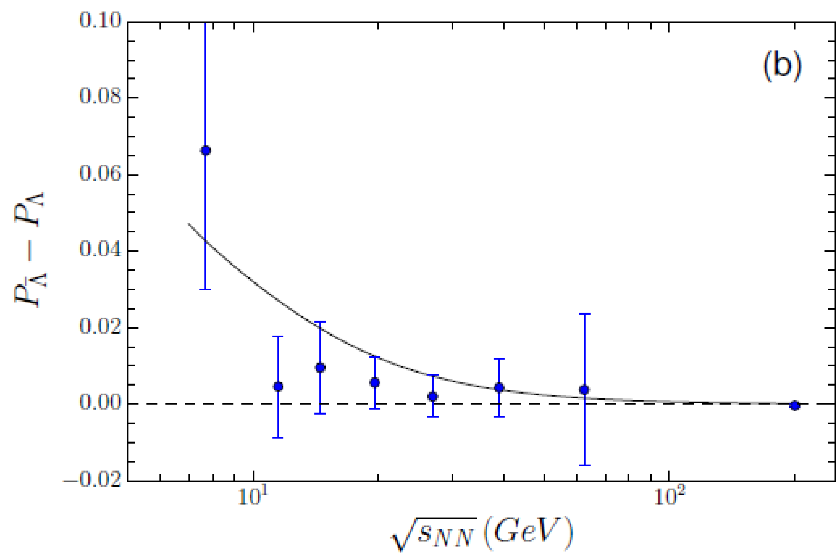
where $\boldsymbol{L} = \boldsymbol{r}\times\boldsymbol{p}$ is the orbital angular momentum.

Therefore we approximate [Serot & Walecka]

$$m_\omega^2\omega^\mu = \bar{g}_\omega J_{\rm B}^\mu \qquad \boldsymbol{J}_{\rm B} = n_{\rm B}(t)\boldsymbol{v}(\boldsymbol{x},t) \qquad \boldsymbol{v} = \left(\dot{\psi}_x(t)x + c_1 z/t, \dot{\psi}_y(t)y, z/t + c_3 x/t\right).$$

➔ $$\boldsymbol{B}_\omega = \frac{\bar{g}_\omega}{m_\omega^2}\left(\frac{\Delta c}{t}\right) n_{\rm B}(t)\,\hat{\boldsymbol{y}}$$

➔



Summary

- Collective flow is the most dominant collective feature of HI reactions.
- Peripheral reactions show shear, vorticity (turbulence) for small transport coefficients ➔ exp. Λ-Polarization
- I.S. is of utmost importance, it can be implemented in (*t, z*) and (τ, η) hydro codes
- Different components, *-y, x, z*, and momentum dependence do show the weight of different dynamical flow patterns.
- ➔ **Λ-Polarization is highly sensitive diagnostic tool**

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