Laszlo Csernai 70 Symposium

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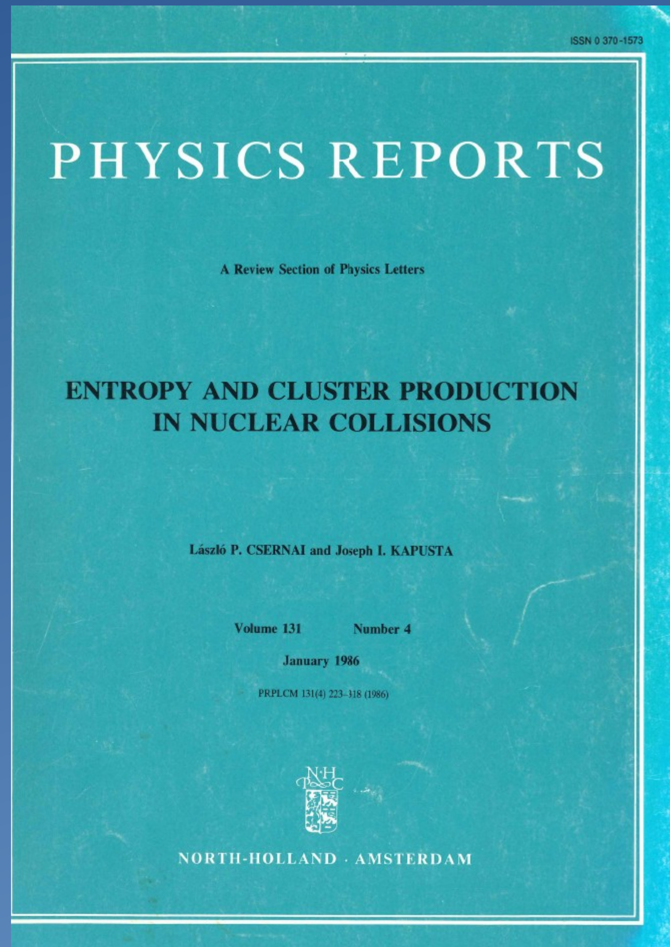
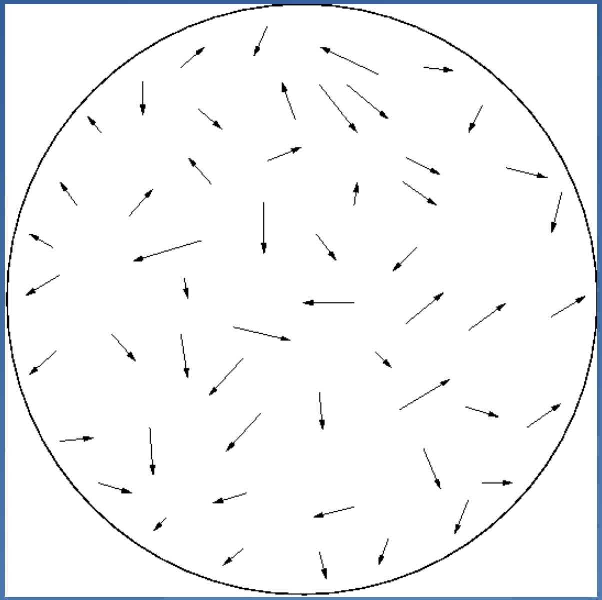
Coalescence and (anti-)deuteron production



Coalescence and (anti-)deuteron production

Deuterons and anti-deuterons formed through coalescence at the late stages of the collisions.

Imagine a number of neutrons and protons enclosed in a volume V:



A deuteron will be formed when a proton and a neutron are within a certain distance in momentum and configuration space.

It can be shown that this leads to:

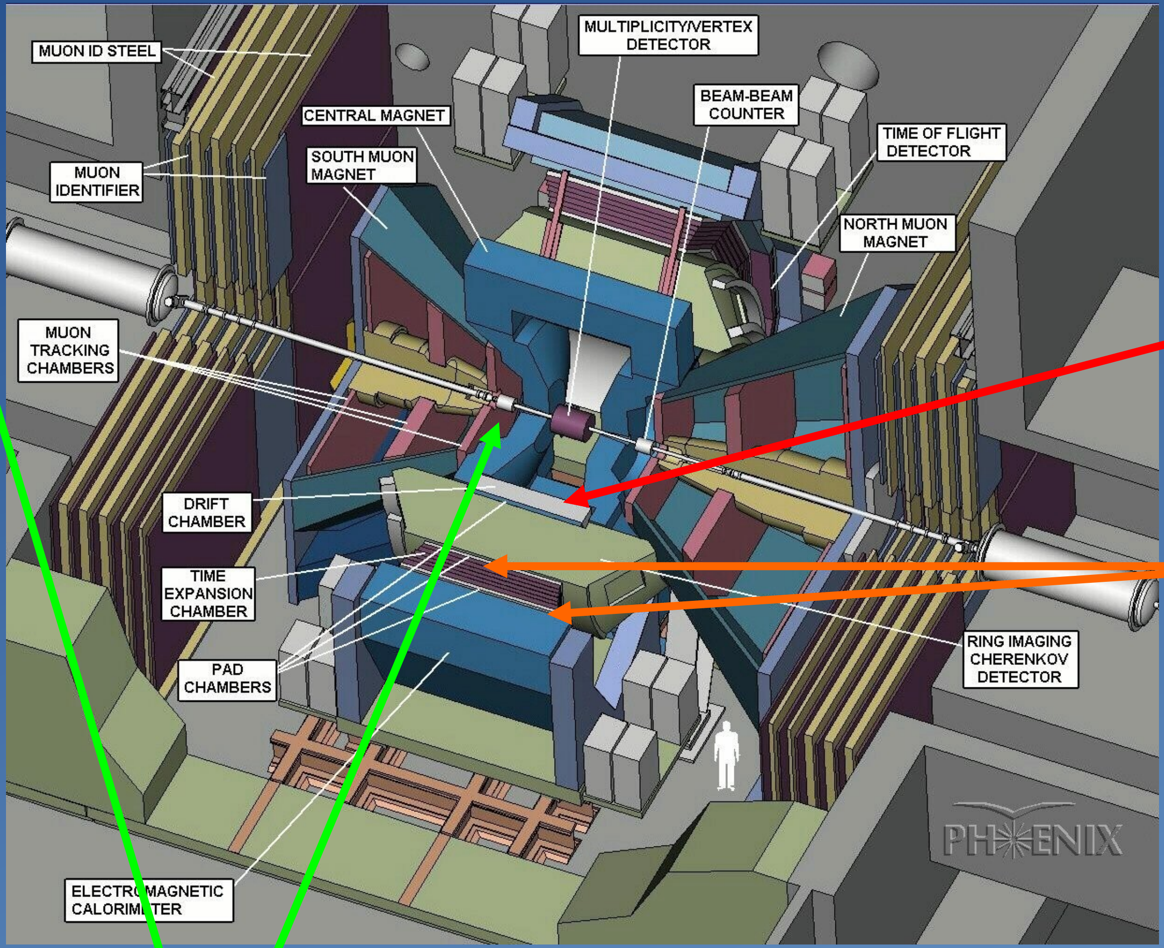
$$E_d \frac{d^3 N_d}{d^3 p_d}\bigg|_{p_d = 2p_p} = B_2 \left(E_p \frac{d^3 N_p}{d^3 p_p} \right)^2$$

where $p_d = 2p_p$ and B_2 is the coalescence parameter, $B_2 \propto 1/V$.

Assuming that n and p have similar d^3N/dp^3

A consequence of this is that one expects the ratio dbar/d $\approx$ (pbar/p)^2.

Coalescence and (anti-)deuteron production



Central tracking arms:

- Drift chamber
- Pad Chambers (2, or 3 layers)

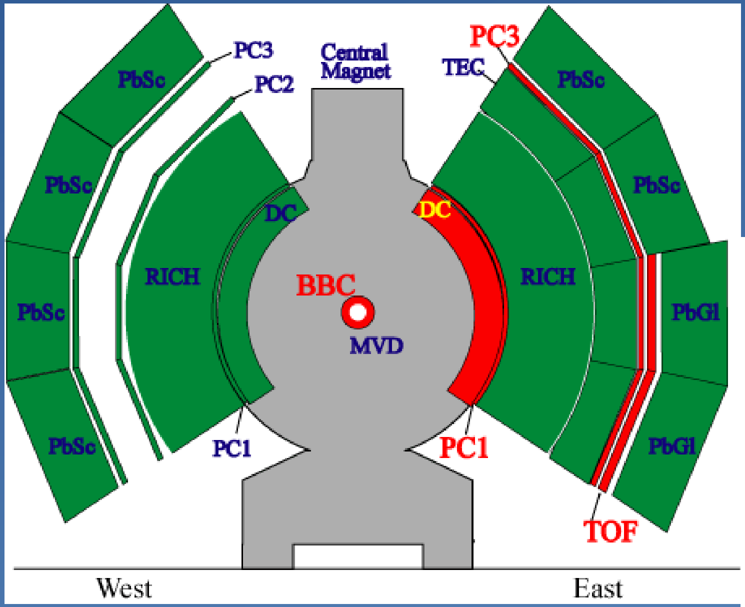
BBC – Beam-Beam Counters; charged ptcles in $3.0 \leq |\eta| \leq 3.9$

ZDC – Zero-Degree Calorimeter; neutral beam fragments

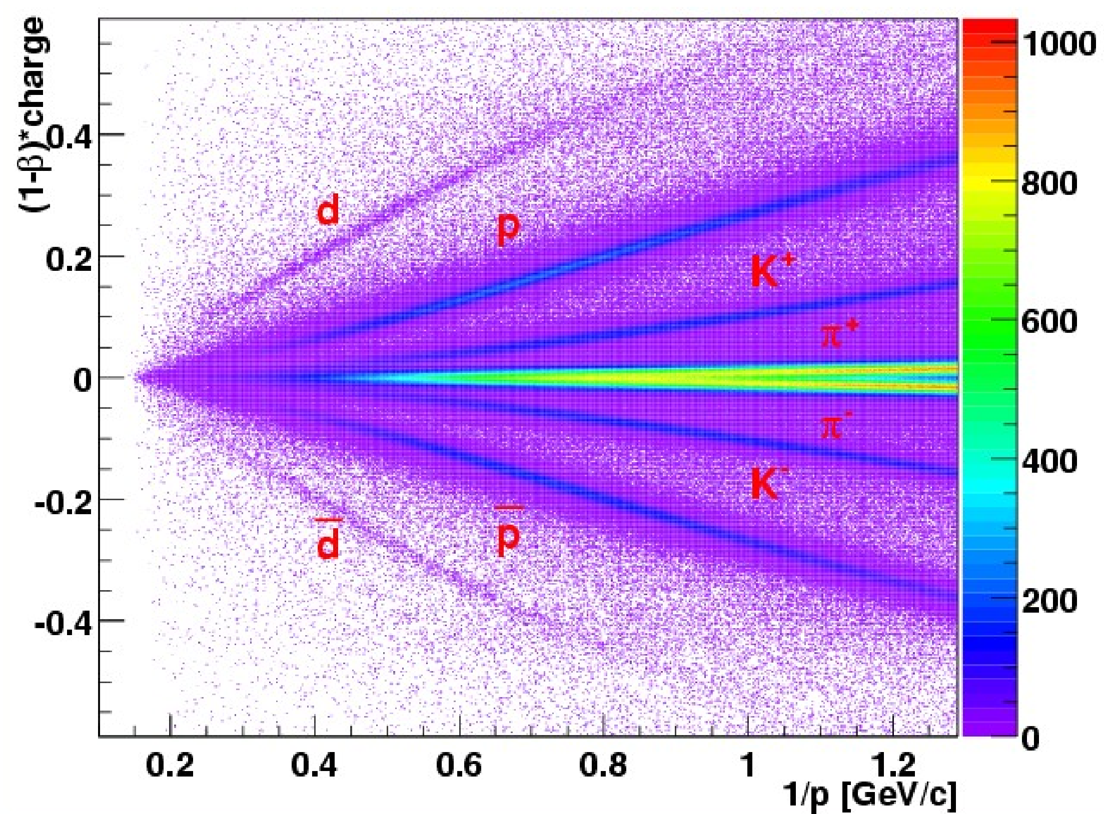
Used for triggering and centrality selection

Coalescence and (anti-)deuteron production

Experimental method: Use the central tracking arm in PHENIX,
Drift Chamber, Pad Chambers (2 layers), Time-of-Flight.
Preliminary PHENIX results from Run 2 at 200 GeV.

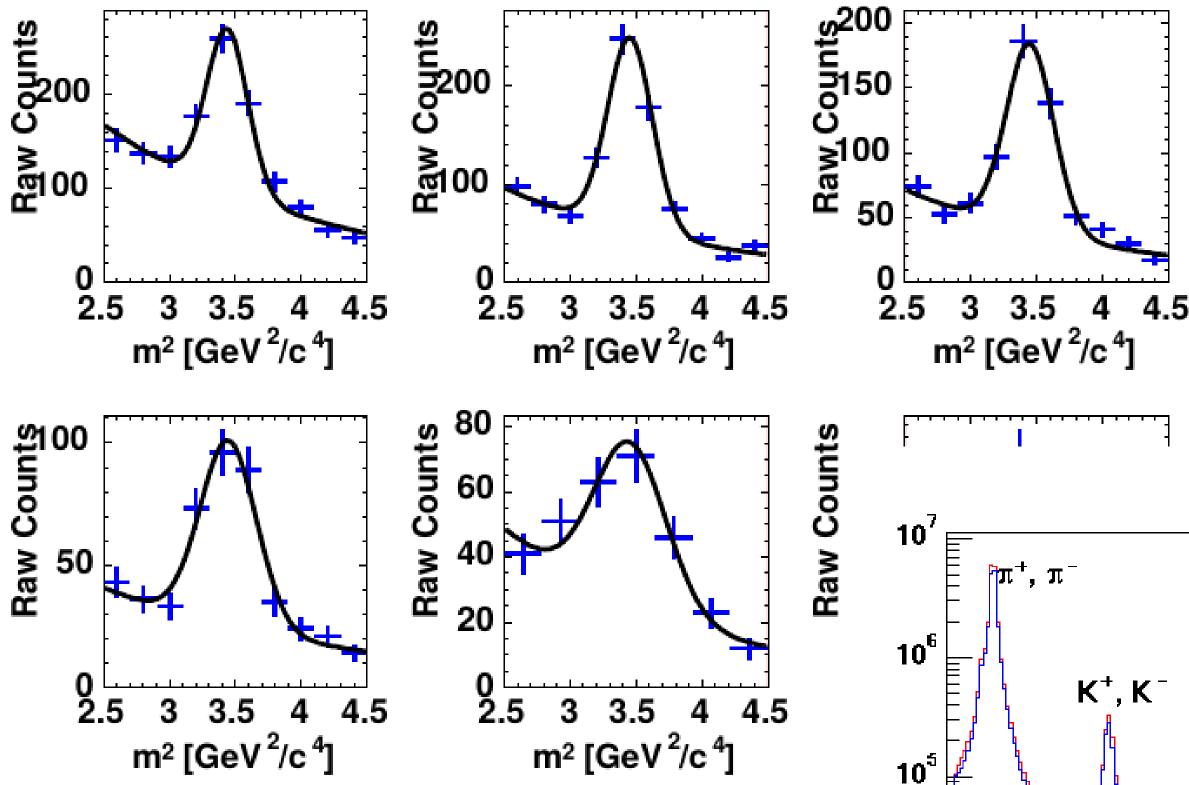


Combining the momentum information (from the deflection in the magnetic field) with the flight-time (from ToF):

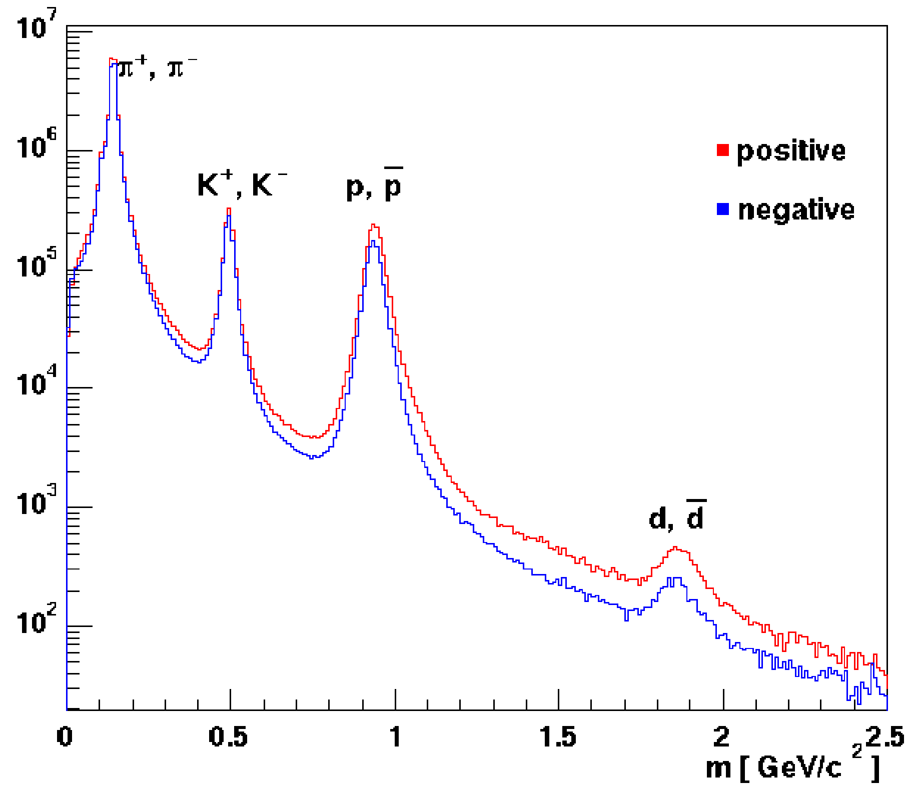


Bands of deuterons and anti-deuterons can be clearly seen

Coalescence and (anti-)deuteron production

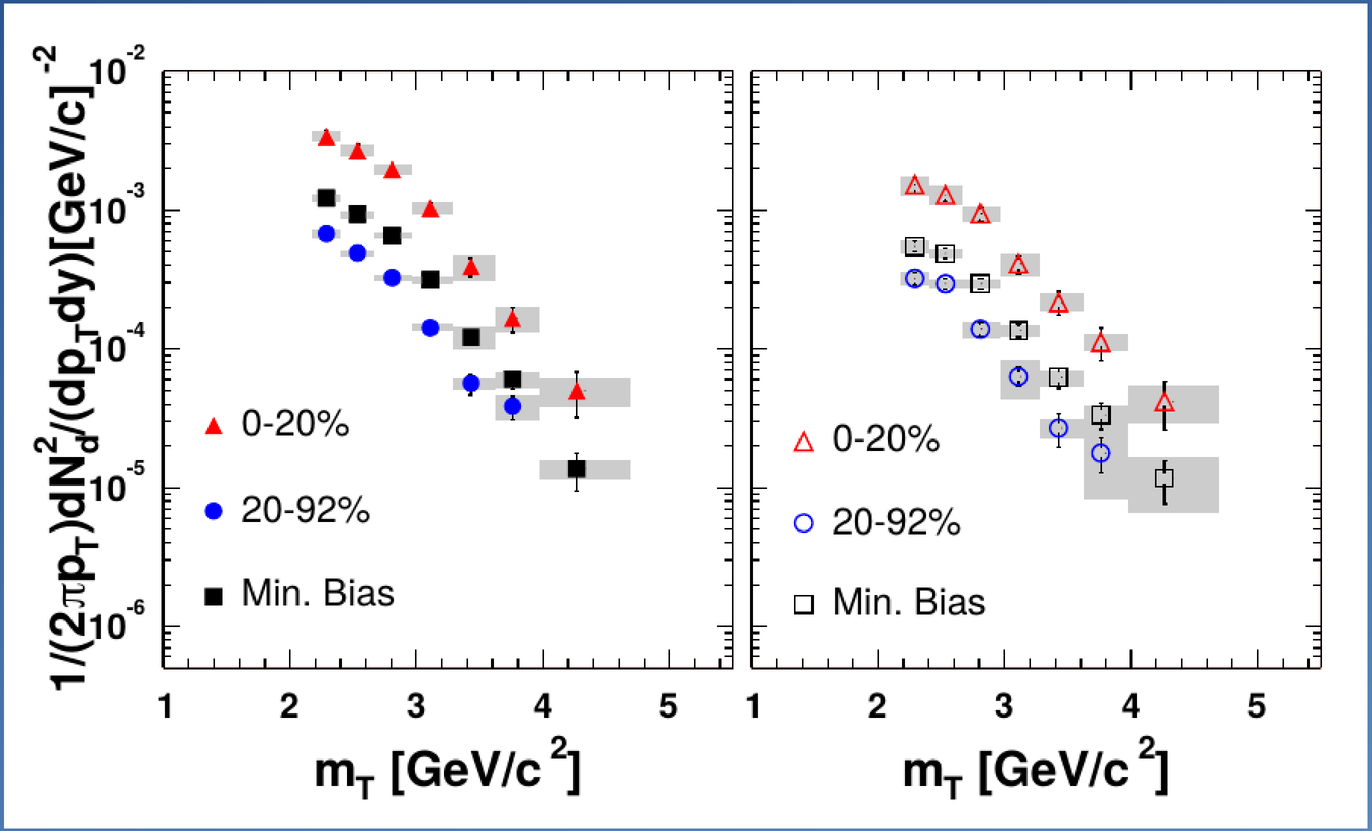


PHENIX Collaboration Phys. Rev. 94 (2005) 122302.



The yield is extracted by fitting the m^2 spectrum to a function for the signal (gaussian) + background ($1/x$ or e^{-x})

Coalescence and (anti-)deuteron production

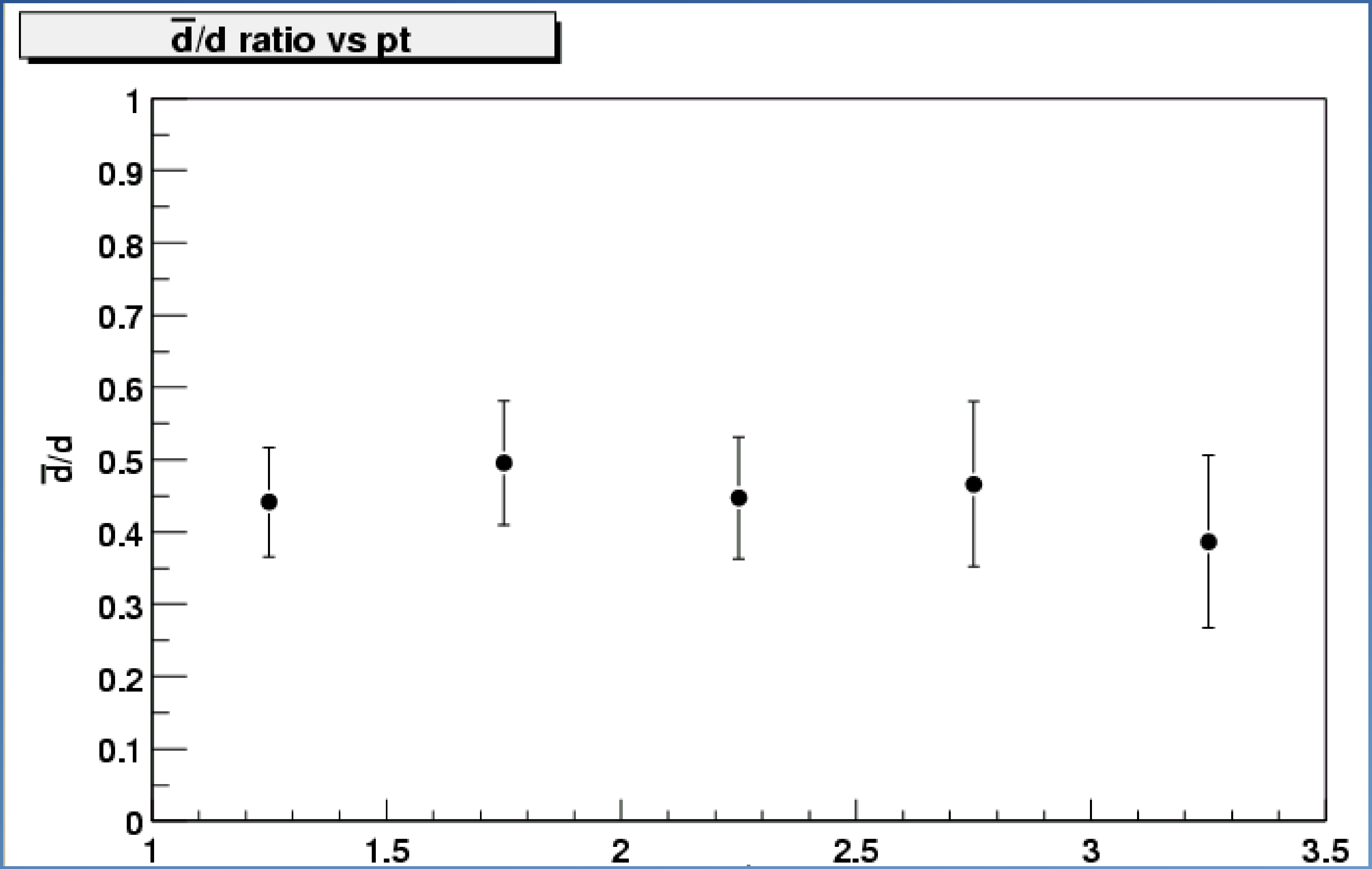


The spectrum has been fit to an exp. function in m_T, $\propto \exp(-m_T/T)$

The high inverse slopes T ~ 500 MeV result from coalescence and strong transverse expansion. Consistent with findings at AGS and SPS energies.

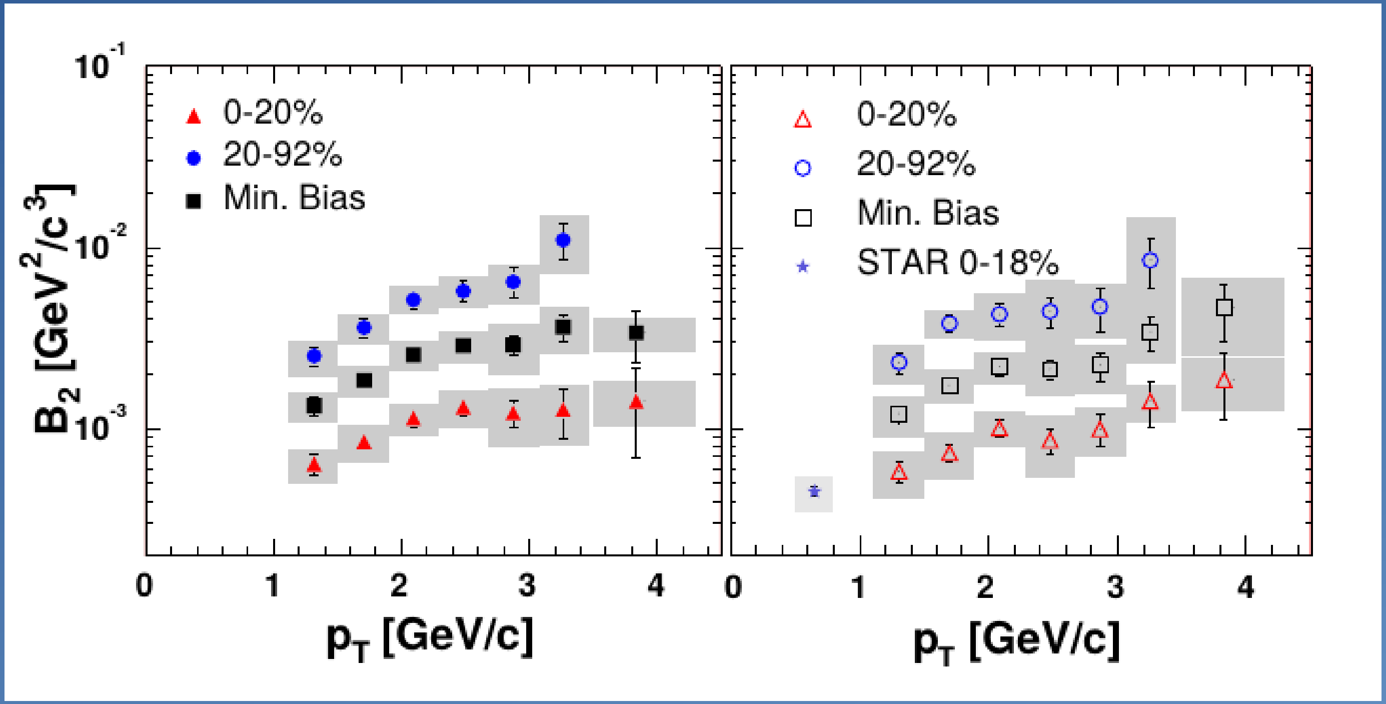
Coalescence and (anti-)deuteron production

As expected, the ration d/dbar is consistent with $(p/pbar)^2$.



Coalescence and (anti-)deuteron production

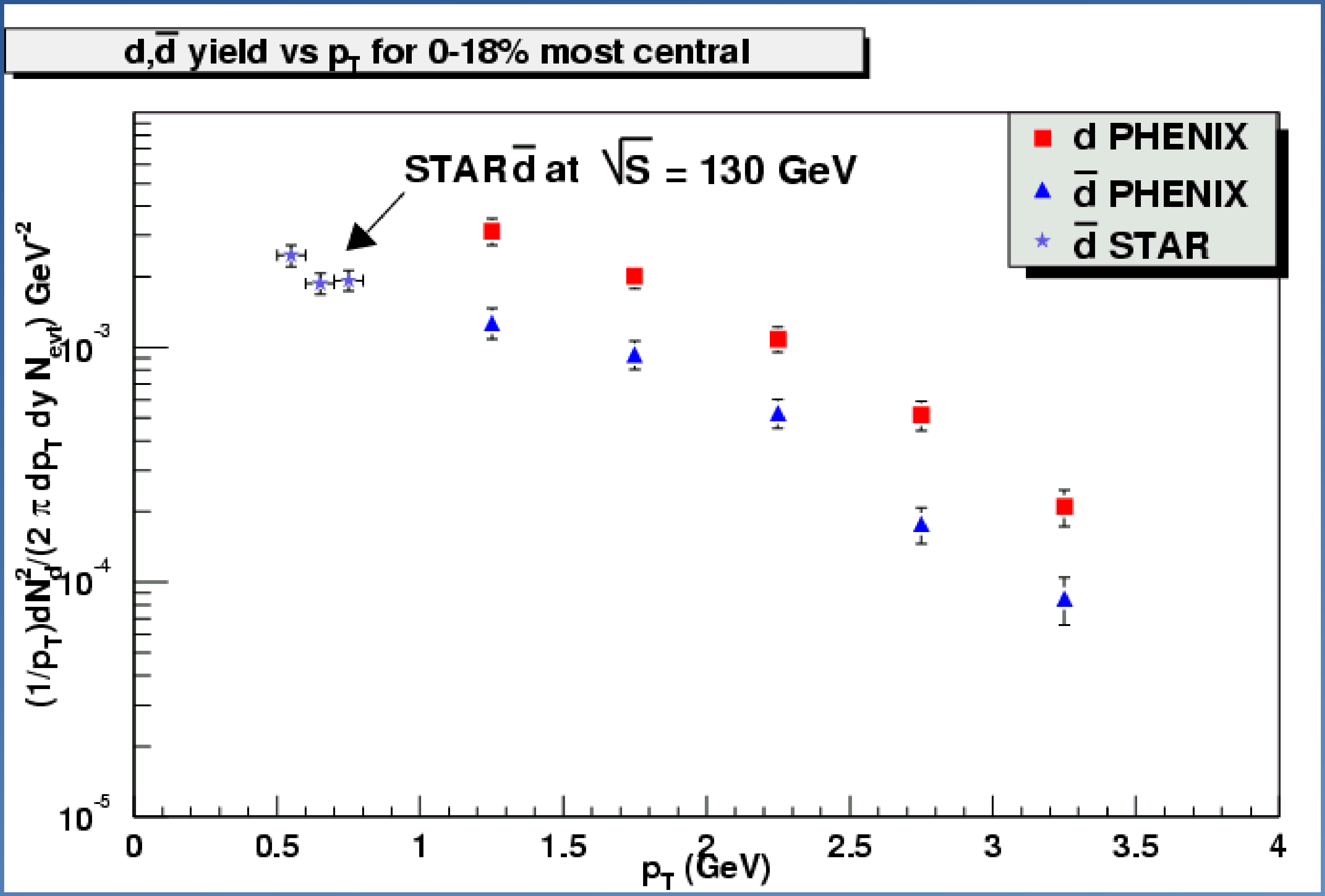
The coalescence parameter shows a depence on p_T. Not expected from a simple model, which does not include space-momentum correlations.



The variation with p_T is believed to be caused by radial flow.

Coalescence and (anti-)deuteron production

Comparison with STAR (at 130 GeV)



Only stat. errors shown; ≈20% systematic uncertainty in yield.

PHENIX data extends to much higher p_T than STAR and includes both d and dbar (STAR only dbar).

Coalescence and (anti-)deuteron production

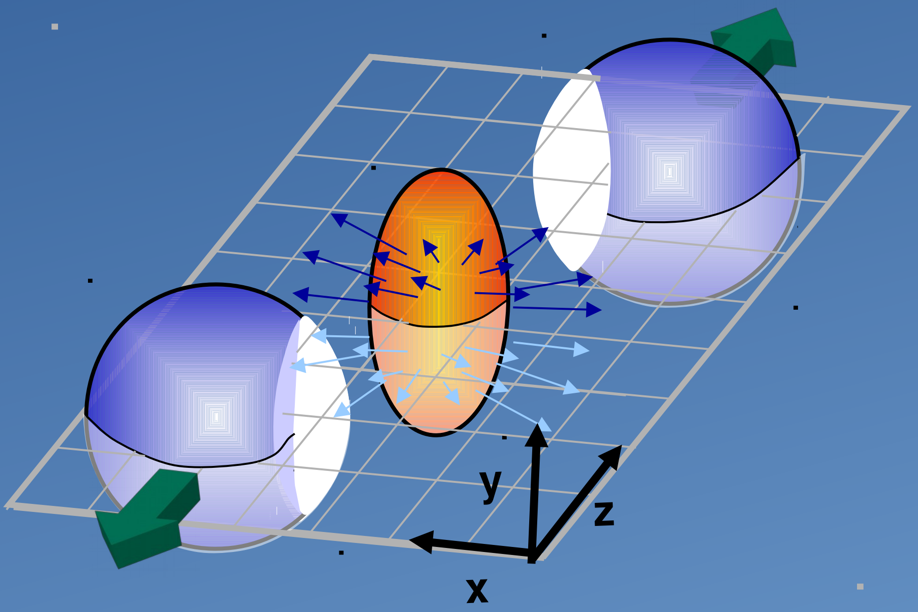
- The variation of B_2 with p_T indicates an expanding source.

- From the measurement a ratio n/nbar = 0.64 $\pm$ 0.04 can be extracted.

Λ-Polarization

In a non-central collision, the participant matter acquire angular momenta of $\sim 1000\hbar$ in a direction perpendiculat to the reaction plane.

Also strong magnetic fields, pointing along the same direction, are produced.



Particles produced in the participant region could be polarized from these effects:

spin-orbit interaction

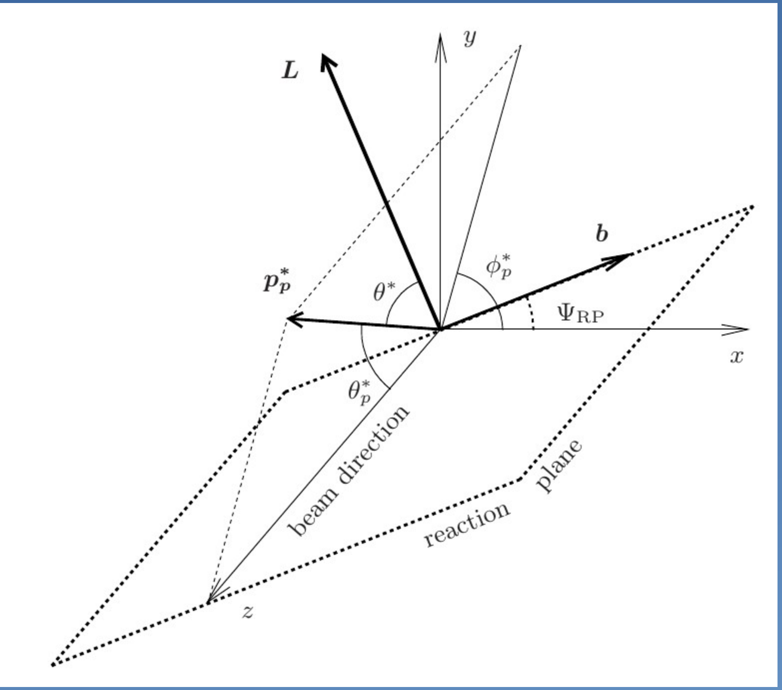
spin-B interactions.

Λ-Polarization

The interactions should affect all particles with spin, so why Λ?

Purely experimental reasons:

The decay $\Lambda \rightarrow p + \pi$ implies that the polarization will be reflected in the angular distribution of the protons.

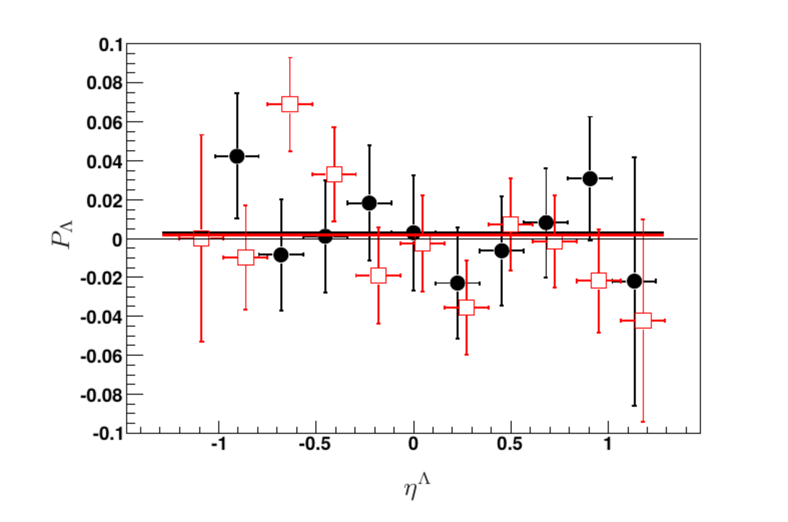


Λ-Polarization

Laszlo's prediction (from 2013): Spin-orbit effects ==> polarization of ~few % for Au+Au collisions at $\sqrt{s}$ = 200 GeV.

Magnetic field effects a factor ~10^{-4} lower.

Earlier results (2007) at $\sqrt{s}$ = 200 GeV had been rather pessimistic, no polarization observed.



STAR Collaboration:
Phys. Rev. C 76 (2007) 024915

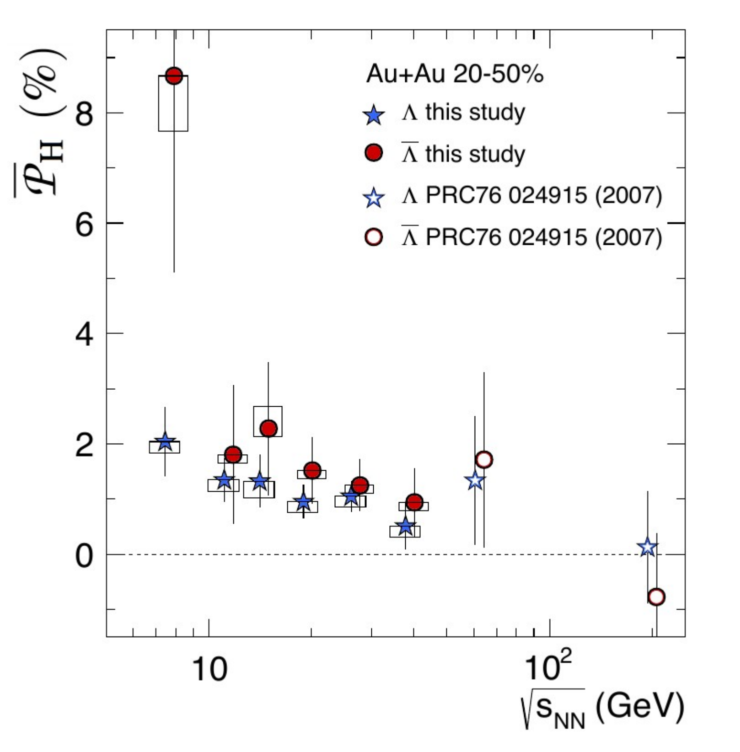
Λ-Polarization

However, following the RHIC beam energy scan, STAR claimed a major discovery:

“*we present the first measurement of an alignment between the angular momentum of a non-central collision and the spin of emitted particles, revealing that the fluid produced in heavy ion collisions is by far the most vortical system ever observed*.”

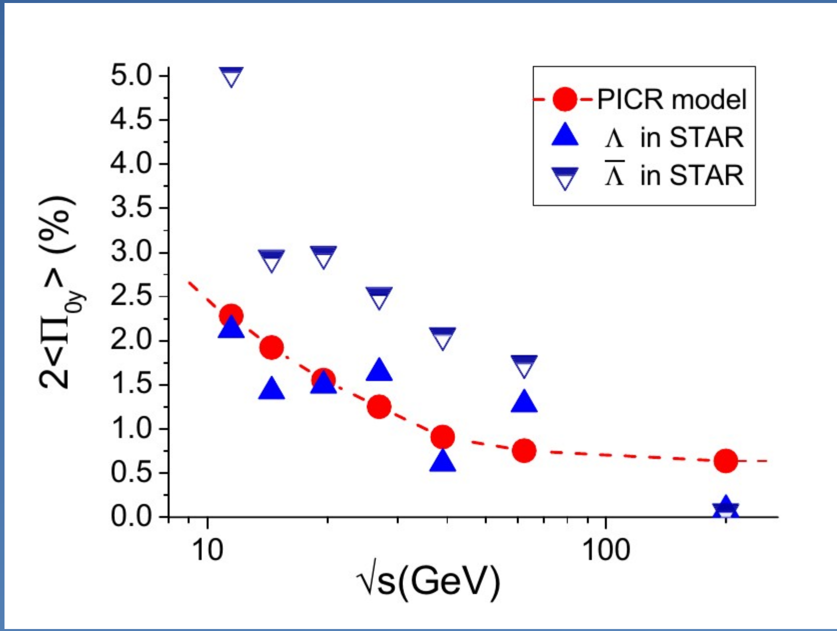
It turns out that there is decreasing trend with collision energy.

STAR Collaboration, Nature 548 (2017) 62



Λ-Polarization

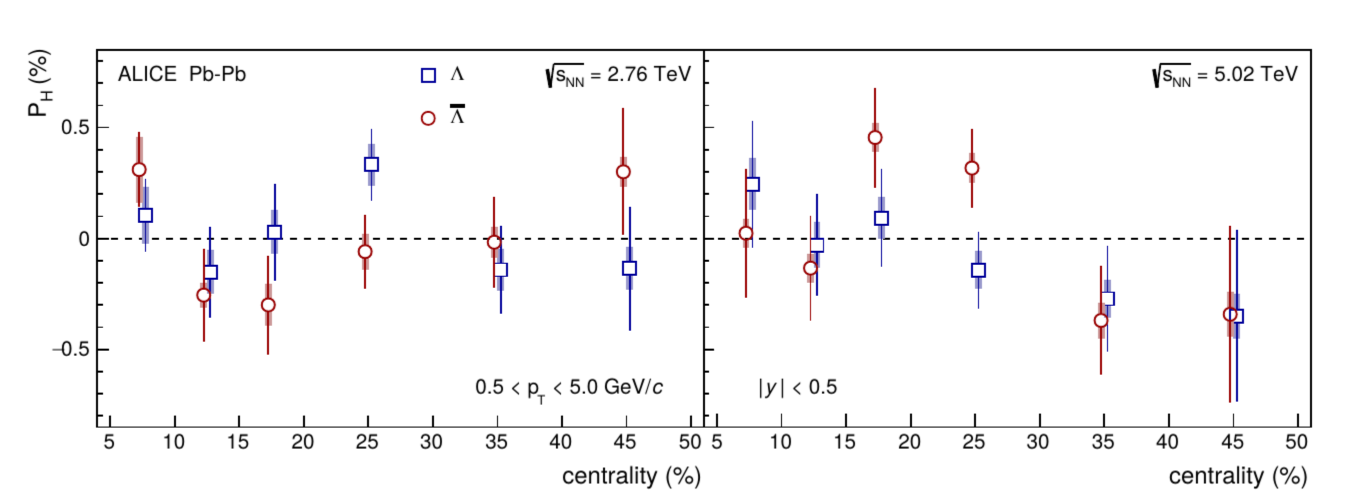
This energy dependence could, however, be reproduced in an update model by Laszlo and coworkers (Phys. Rev. C 95 (2017) 031901):



Au+Au Collisions at $\sqrt{s}$ = 200 GeV, 50% centrality.

Λ-Polarization

Only last week, ALICE presented the first results on this measurement at the LHC: ALICE Collaboration, arXiv:1909.01281 (3. September 2019):



For 15-50% centrality, combined $\Lambda/\bar{\Lambda}$, 2.76/5.05 TeV:

P = 0,01 ± 0.06(stat.) ±0.03 (syst.)%

Of course, not so fun to report a null result, but this was expected.

Λ-Polarization

Finally, what about the electromagnetic effects?

100 fold increas in statistics compared to the published result ==> 10 times lower statistical error.

Spin-orbit effects ↘ as $\sqrt{s}$ ↗.

The strength of B increases as γ (Lorentz factor of the beam) goes up (although the time duration of the pulse decreases by the same factor). ==>
A factor ~25 increase in B between RHIC and LHC.

Will these effects become visible with higher statistics at the LHC?

Note: The B-field should affect Λ and anti-Λ in the opposite way (μ_B of an anti-particle is -μ_B of the particle).

Travels with Laszlo in China - Great Wall

Travels with Laszlo in China - Summer Palace

Travels with Laszlo in China - Peking duck

Conclusions

Congratulations on your 70^{th} birthday, Laszlo!

Good luck for the future!