An idea for an AGS fixed-target experiment

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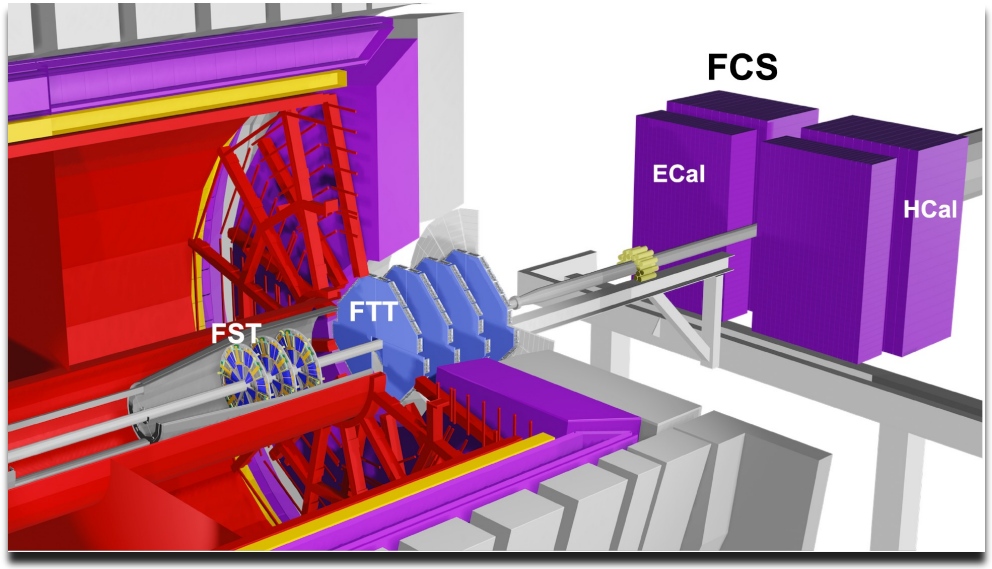
Thanks to discussions with Alexander Kiselev, Zhangbu Xu, and many others.

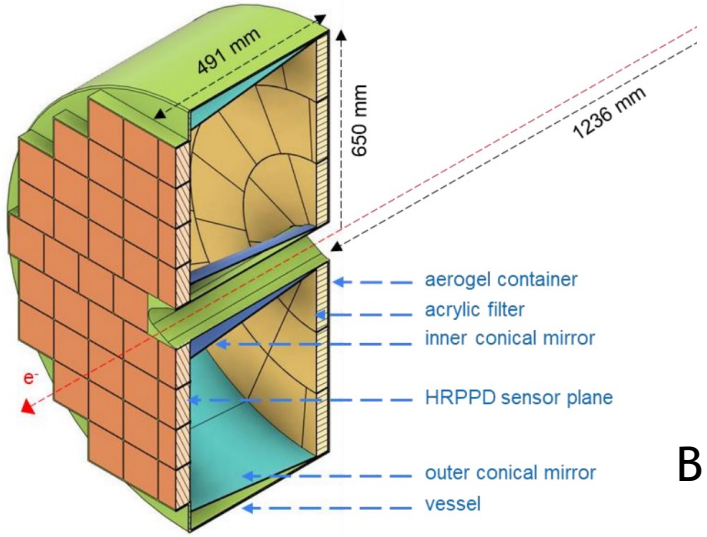
Context of this talk

What I was told:

- There is a finite possibility of refurbishing the AGS experimental hall for test beam facility and/or potentially even physics.
- Brainstorming and ideas are welcomed.
- Money is a problem as always, so don’t be crazy.
- Proton (up to ~23-25 GeV) and ion beams, with hadron polarization.

Proposal – the SPiRiT (Star forward and ePIC pfRICH experimenT)



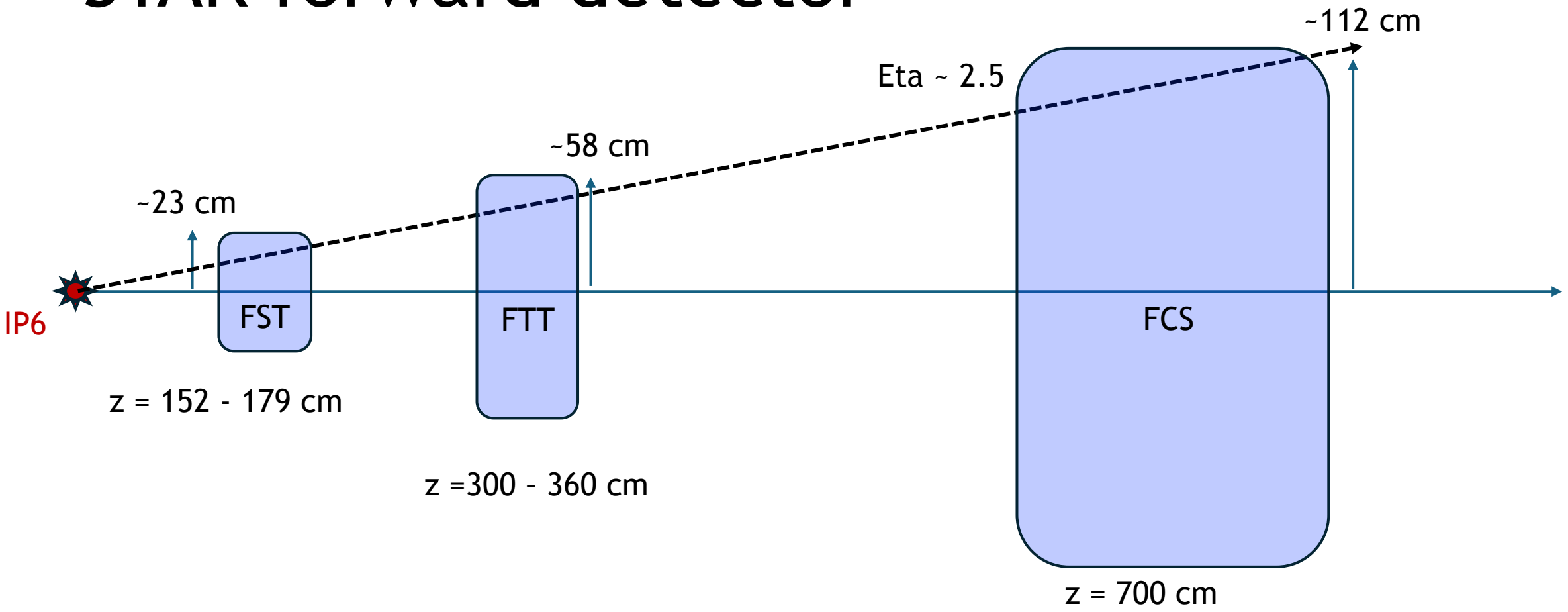


B. Page's talk

Highlights:

- Repurpose and reuse relatively new STAR forward detector system (both Tracking and Calorimeter)
- Expedite pfRICH (backward RICH) detector (or beam test prototype) in ePIC for PID (HRPPD has Timing)
- Low-cost in principle, and the detector has large acceptance with full tracking+PID+calorimetry

STAR forward detector



- STAR forward detector system covers ~ pseudorapidity 2.5 – 4.

STAR forward detector

spatial resolution of ~30, 100-150 um, respectively

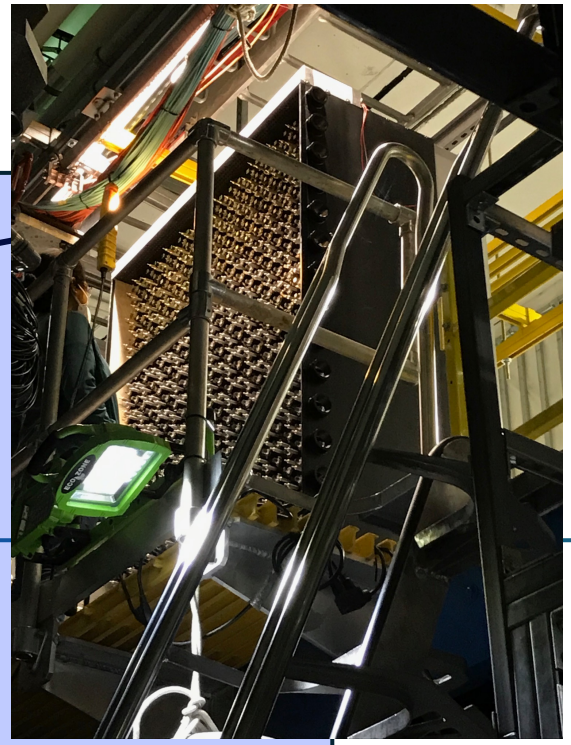
3 layers of Silicon

4 layers of sTGC
(Small-strip Thin Gap Chamber)

Eta ~ 2.5

~23 cm

IP6



Forward Tracking System

	Requirement	Motivation
Momentum Resolution	< 30%	A+A goals
Tracking Efficiency	> 80% @ 100 tracks / event	A+A goals
Charge Separation	–	p+p / p+A goals

Forward Calorimeter System

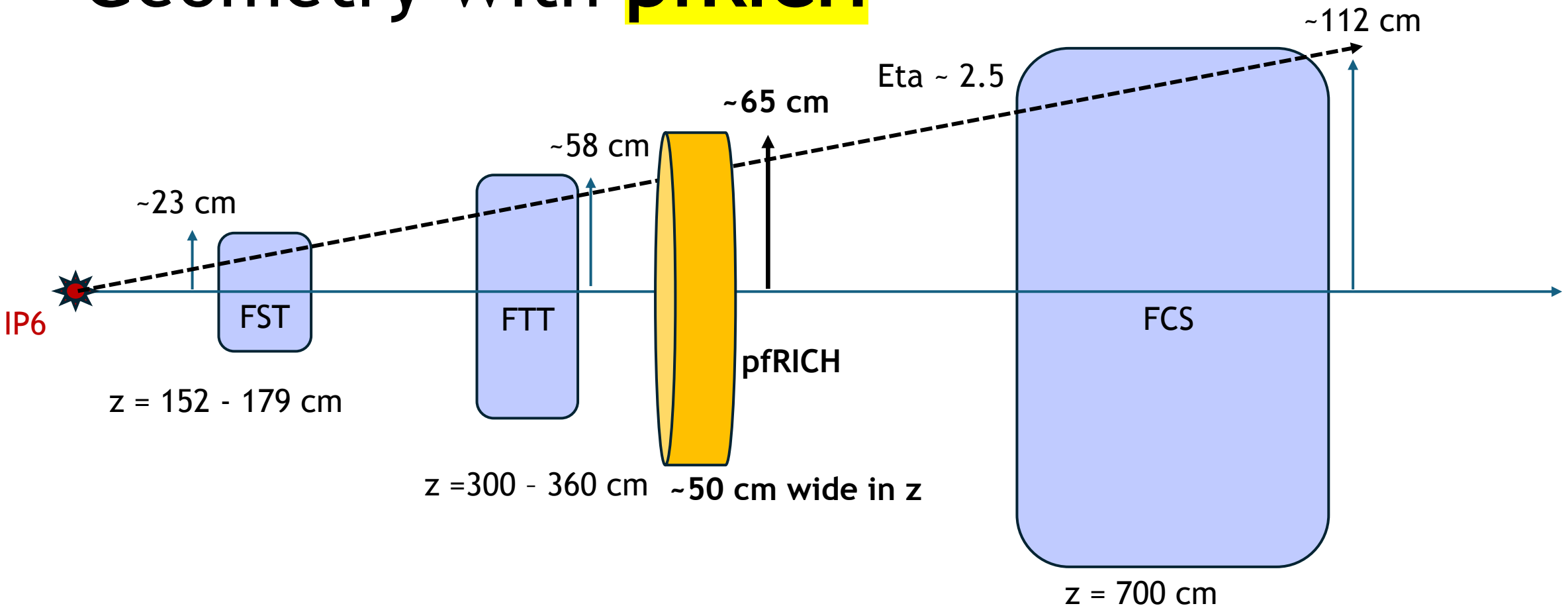
Detector	Resolution p+p and p+A	Resolution A+A
ECal	$\sim 10\%/\sqrt{E}$	$\sim 20\%/\sqrt{E}$
HCal	$\sim 50\%/\sqrt{E} + 10\%$	–

ECal and HCal, both ECal and HCal are split into two halves, inside (north) and outside (south) of the ring, totaling 1496 channels and 520 channels, respectively.

- STAR forward detector system covers ~ pseudorapidity 2.5 – 4.

See B. Page's talk for details on pfRICH

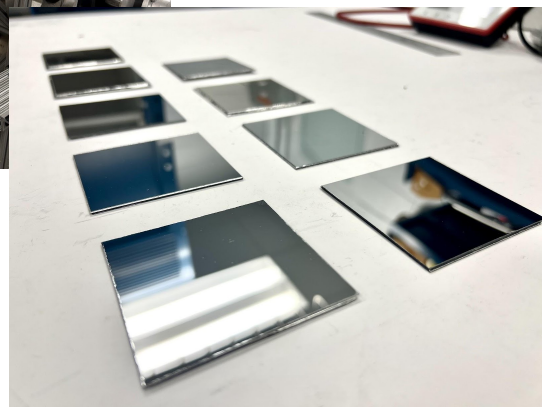
Geometry with pfRICH

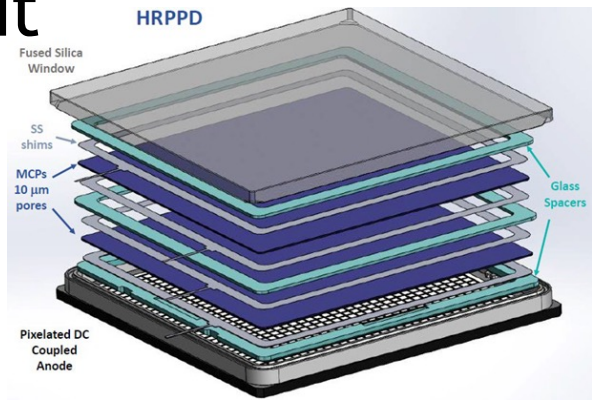


- STAR forward detector system covers ~ pseudorapidity 2.5 – 4.
- pfRICH designs to detect up to 7 GeV with 3 sigma pi/K separation.

Timeline on the pfRICH

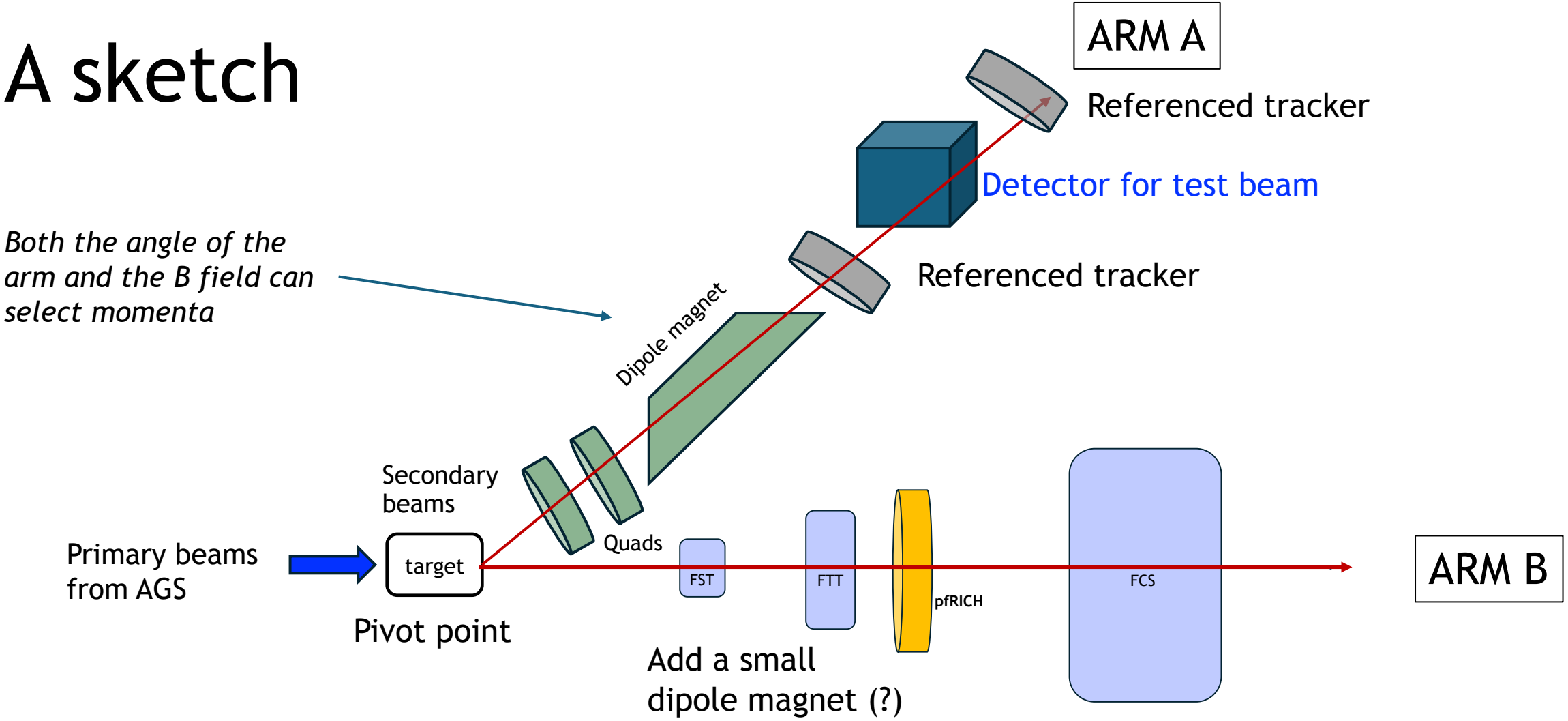
- We have a prototype vessel at SBU
- We have mirrors made in house at SBU
- We have a few QA stations setup at BNL, JLab, INFN, Temple, Yale, etc for HRPPD and Aerogel.
- A full-scale pfRICH may take up to 3 years due to production time for HRPPD, readout electronics, etc.





The bottom line: it can be done on a time scale of <= 3 years, instead of 10+ years

A sketch



We can switch between A (test beam setup) or B (physics) or A+B (physics) on a movable platform

Some remarks

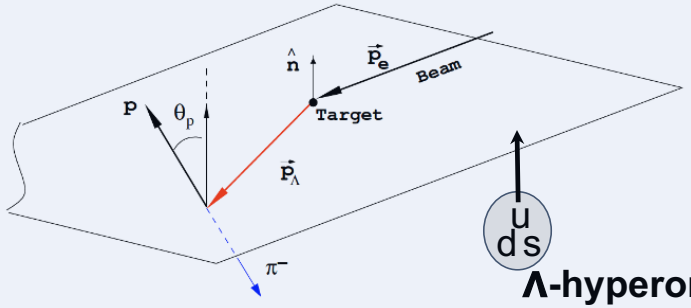
- A setup that can accommodate both beam test and physics would be ideal – quick switch on a rotational platform (?) or even do/use both at the same time!
- Some beam test may benefit just from primary beams
- Some physics programs may be possible with a SPiRiT like setup. (later)
- Dipole and Quads magnets (1-2) needed from RHIC.
- …

1 physics case –Transverse Λ polarization

- There is an unresolved puzzle about **Λ polarization since 1976.** Large transverse Λ polarization was observed in unpolarized hadron collisions (e.g., *p*Be). However, no $\bar{\Lambda}$ was observed.

Production plane

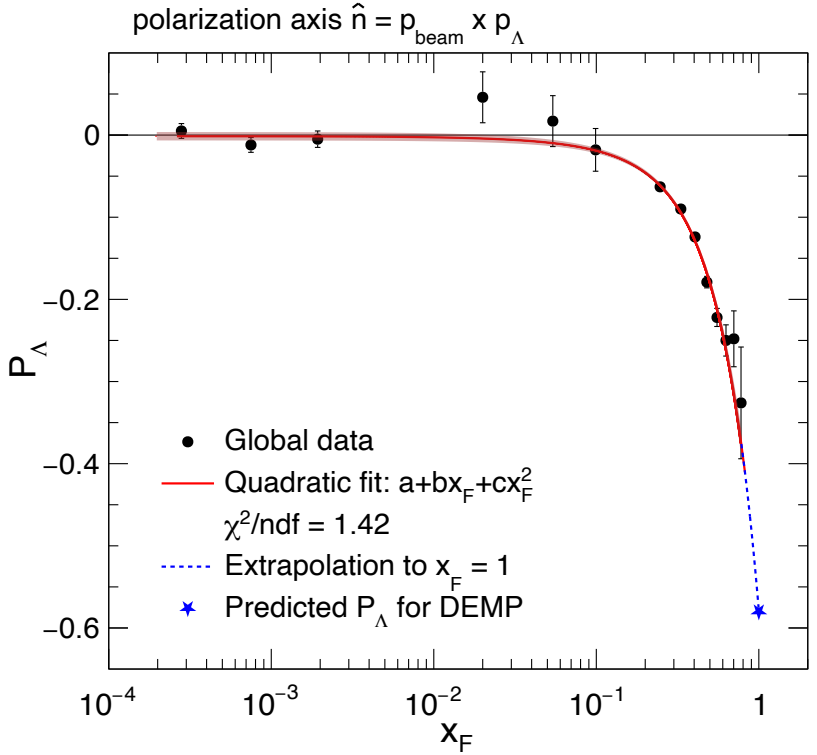
Example: HERMES experiment of ep deep inelastic scattering (DIS).



Λ-hyperon

Λ^0-polarization has been observed in p+p, NC/CC DIS, e+e, p+A, and AA* collisions.

* only in heavy-ion AA collisions, people think it's of different origin.



Strong dependent on xF

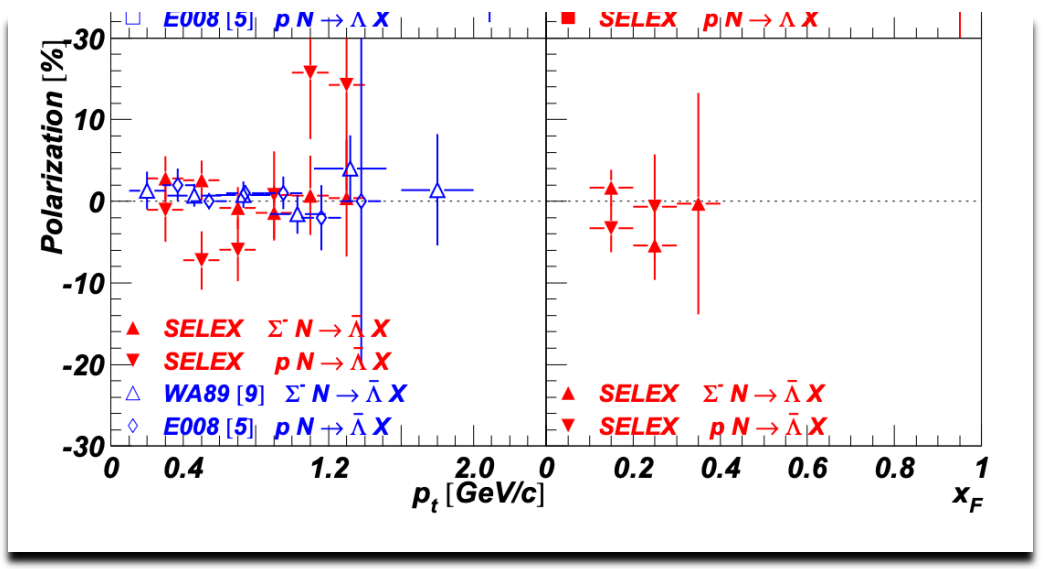
Phys. Rev. C 109 (2024) 5, 055205

Explanations are almost too many to summarize

- Lund semi-classical fragmentation model, finite pT lambdas infers orbital angular momentum (ssbar) and s quark spin needs to balance that. The higher the pT, the larger the effect.
- Thomas precession mechanism – a semi-classical recombination model.
- Single-pion exchange.
- Interference from resonances decay.
- TMD polarizing Fragmentation Functions (more modern framework).

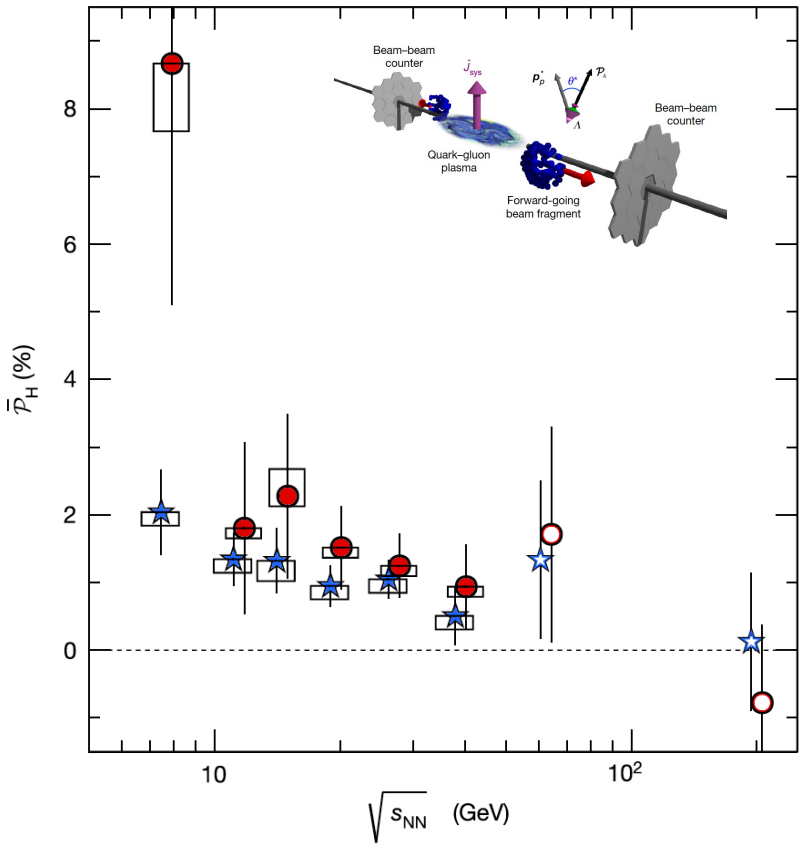
$\bar{\Lambda}$ polarization – always consistent with zero

Experiment/System	Anti-Λ Polarization
NOMAD (νμ CC DIS)	≈ 0
HERA-B (pA collisions)	≈ 0
WA89 (Σ^- beam)	≈ 0
SELEX (Σ^- & p beams)	≈ 0
HERMES (photoproduction)	≈ 0
… probably more from COMPASS and Jlab	

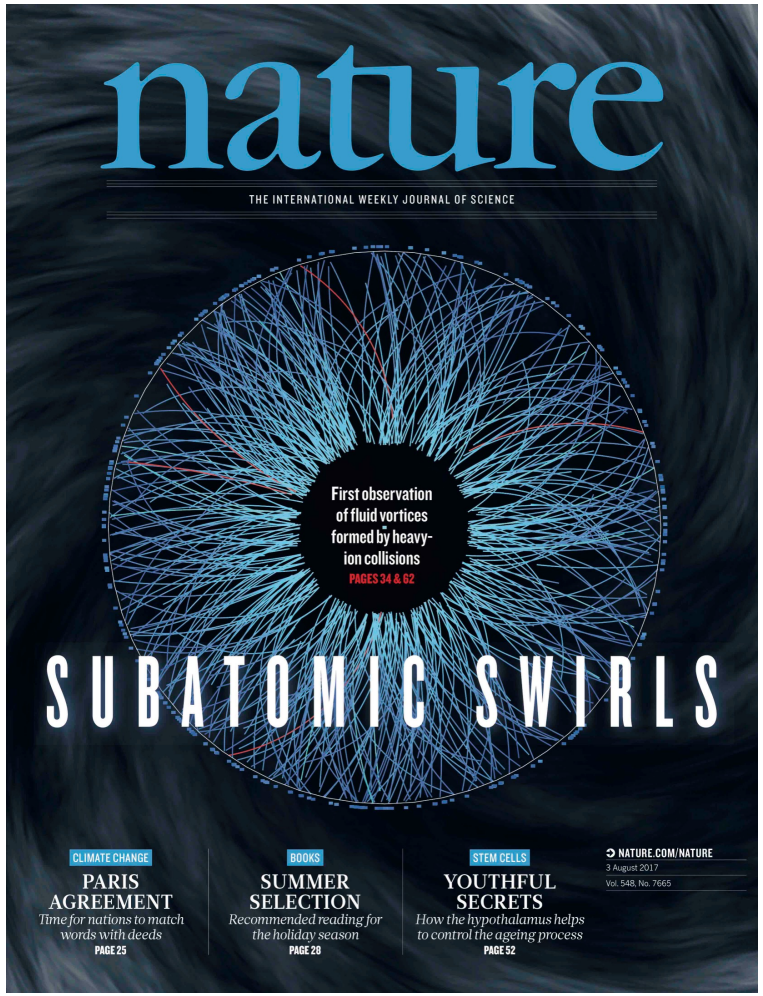


However, precision was never great, and can be consistent with a 5% signal as well

Relevance to HI physics - vorticity



AA – seem to be the only system that is understood by using “vorticity”



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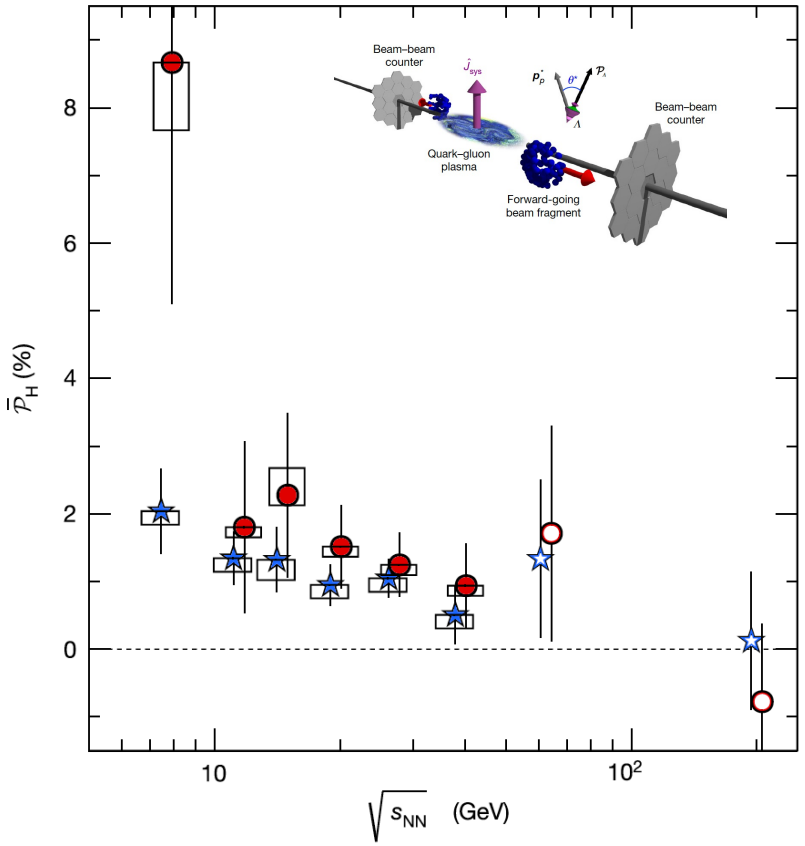

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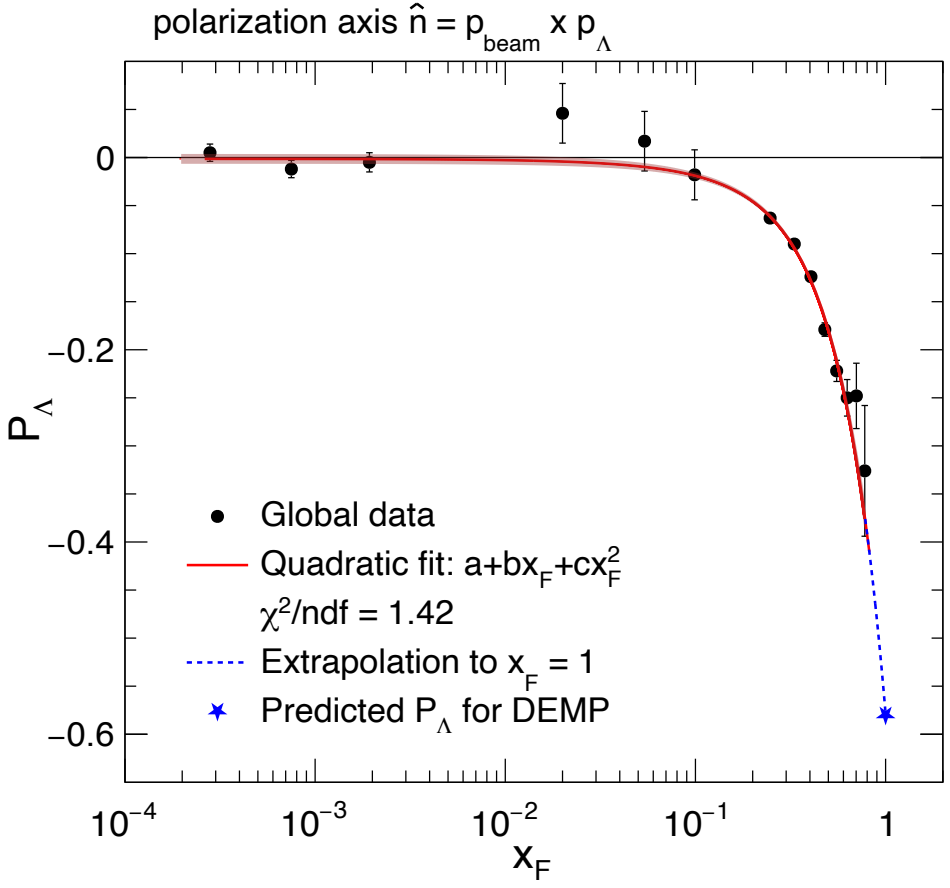

pp,pA,ep, nu-p, ee, or any system one can think of – a 50-year puzzle

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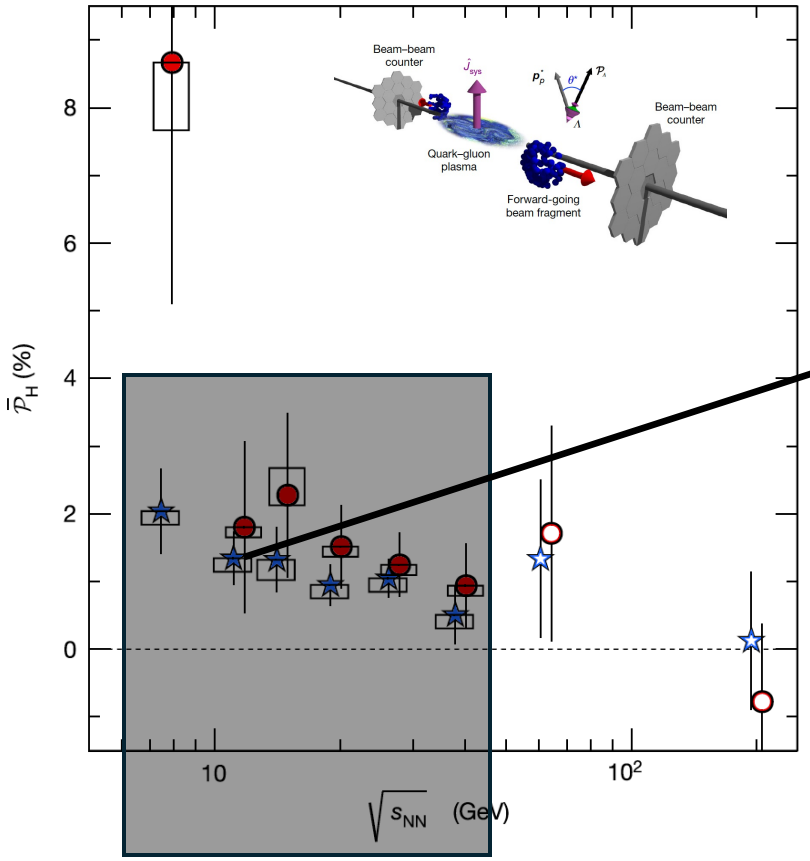

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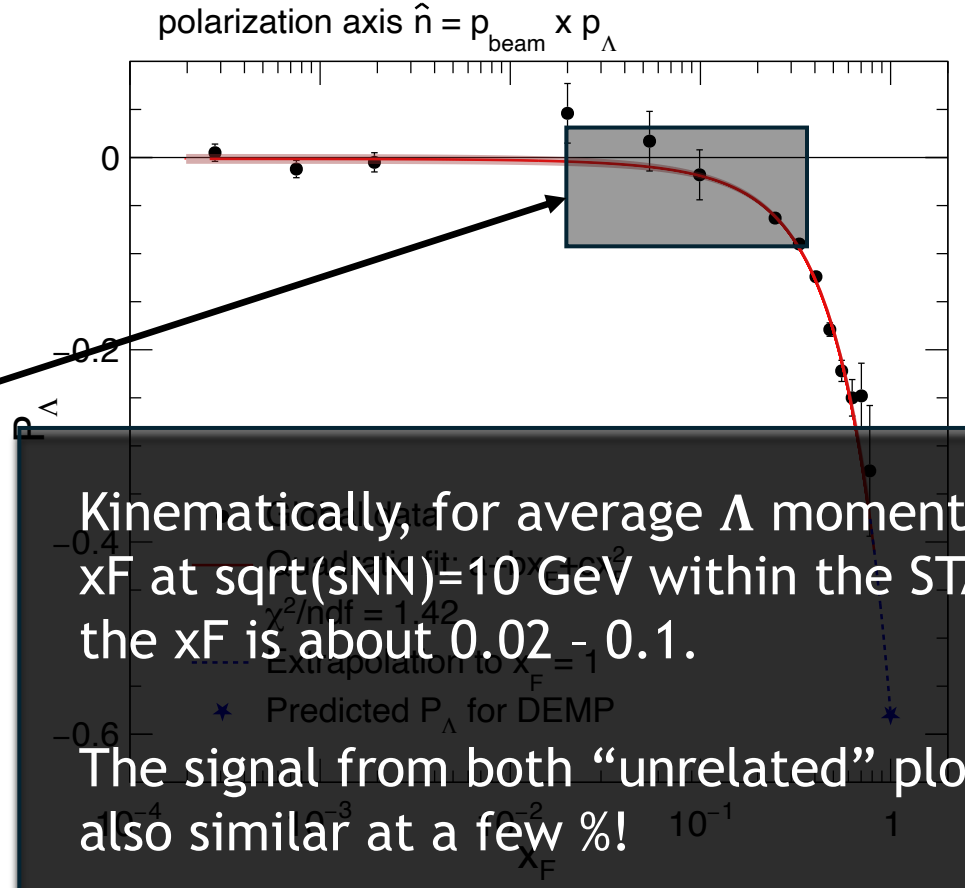


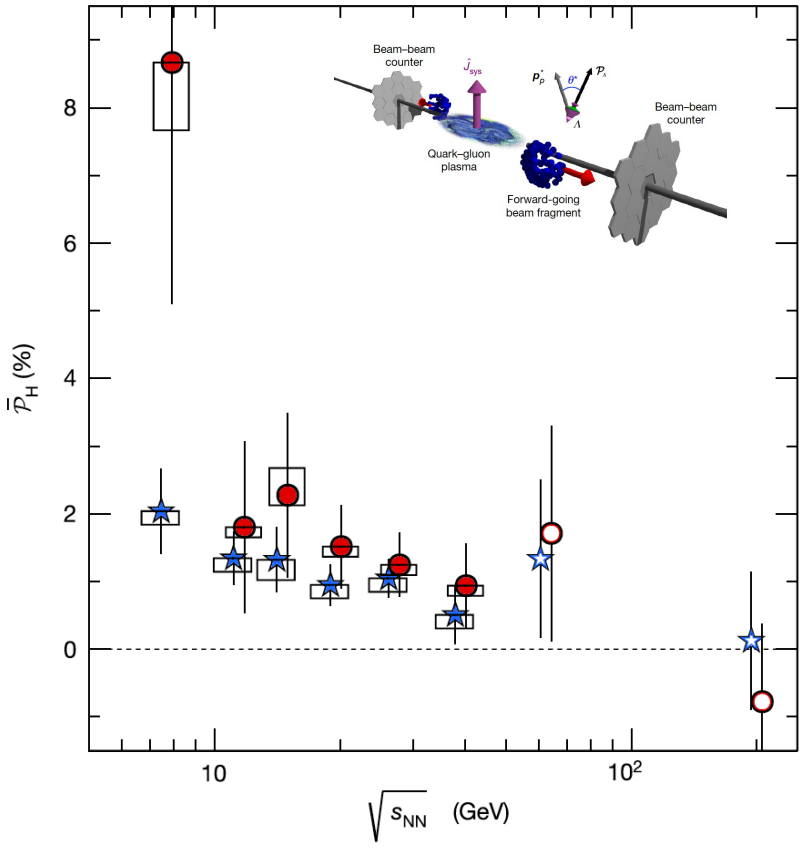
Kinematically, for average Λ momenta, the xF at sqrt(sNN)=10 GeV within the STAR TPC, the xF is about 0.02 – 0.1.

The signal from both “unrelated” plots is also similar at a few %!

Can this be a coincidence?

pp, pA, AA, nucleon-nucleon or any system one can think of – a 50-year puzzle

On the surface: they are measured very differently



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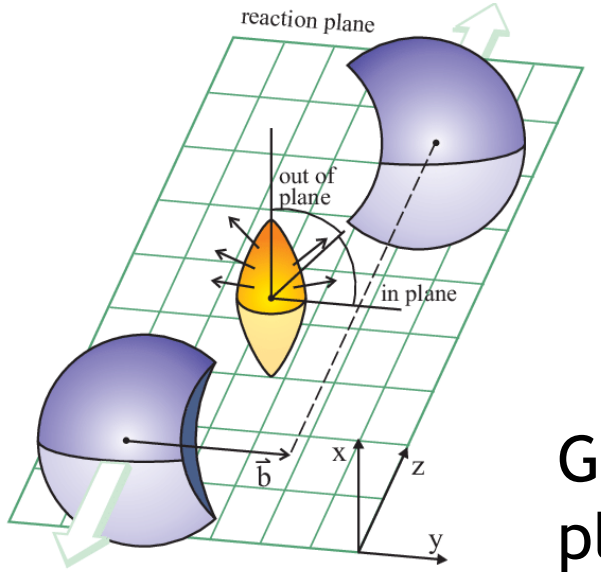
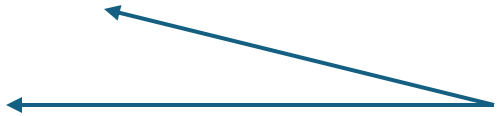


Global direction = event plane/reaction plane

For non-HI measurements, its production plane.

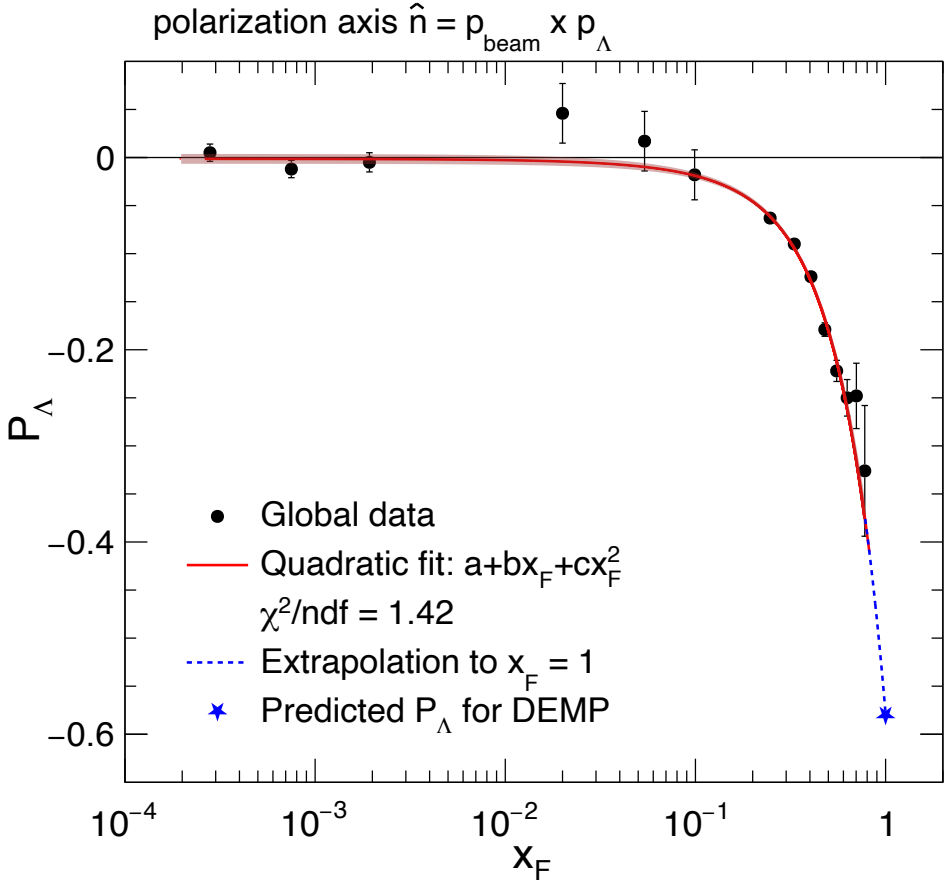
P_Lambda - Λ momentum



P_beam

Production plane = P_Lambda x P_beam

Global direction = production plane



pp,pA,ep, nu-p, ee, or any system one can think of – a 50-year puzzle

In heavy-ion collisions, are these two directions independent?

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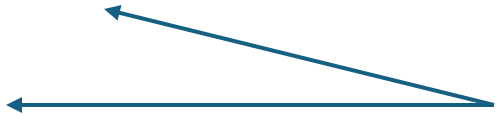

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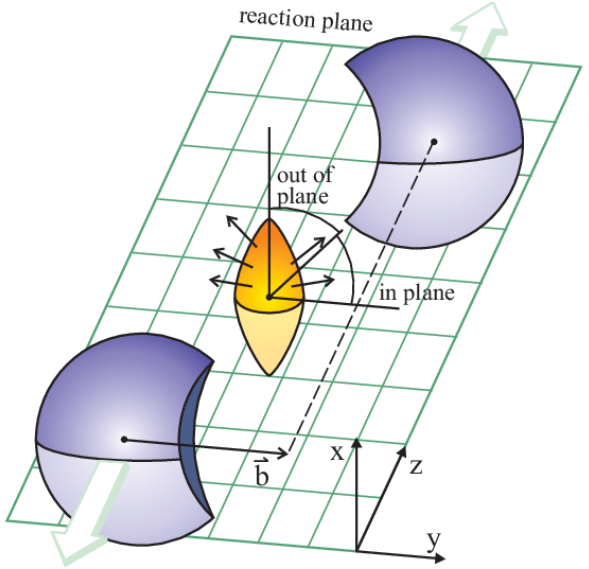

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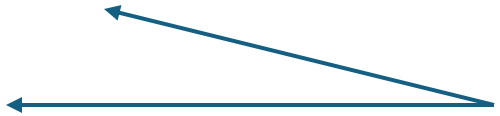

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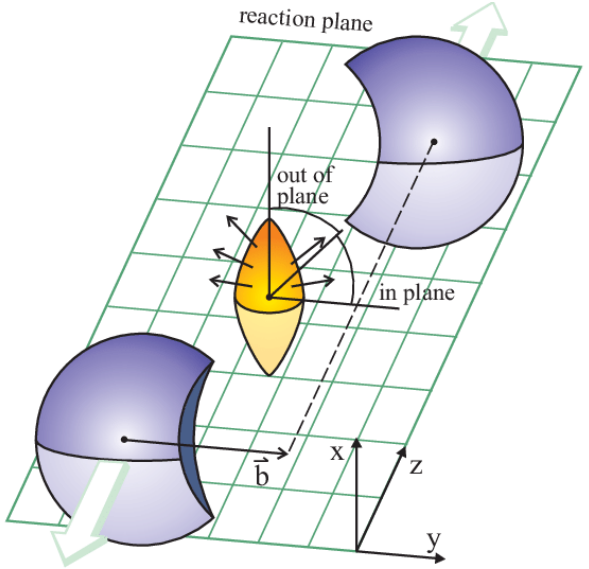
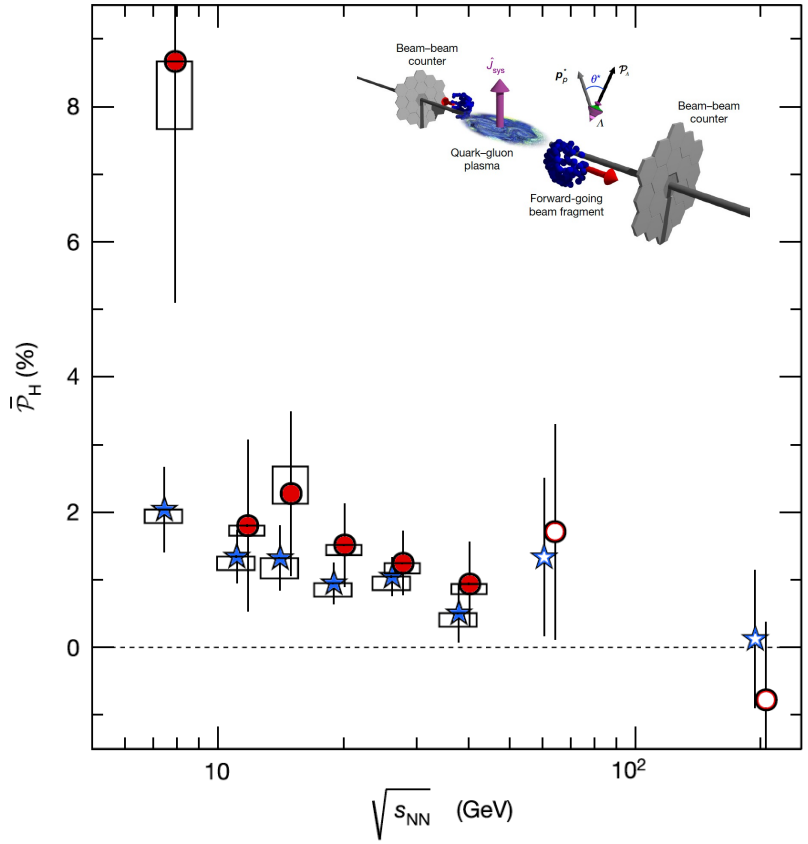


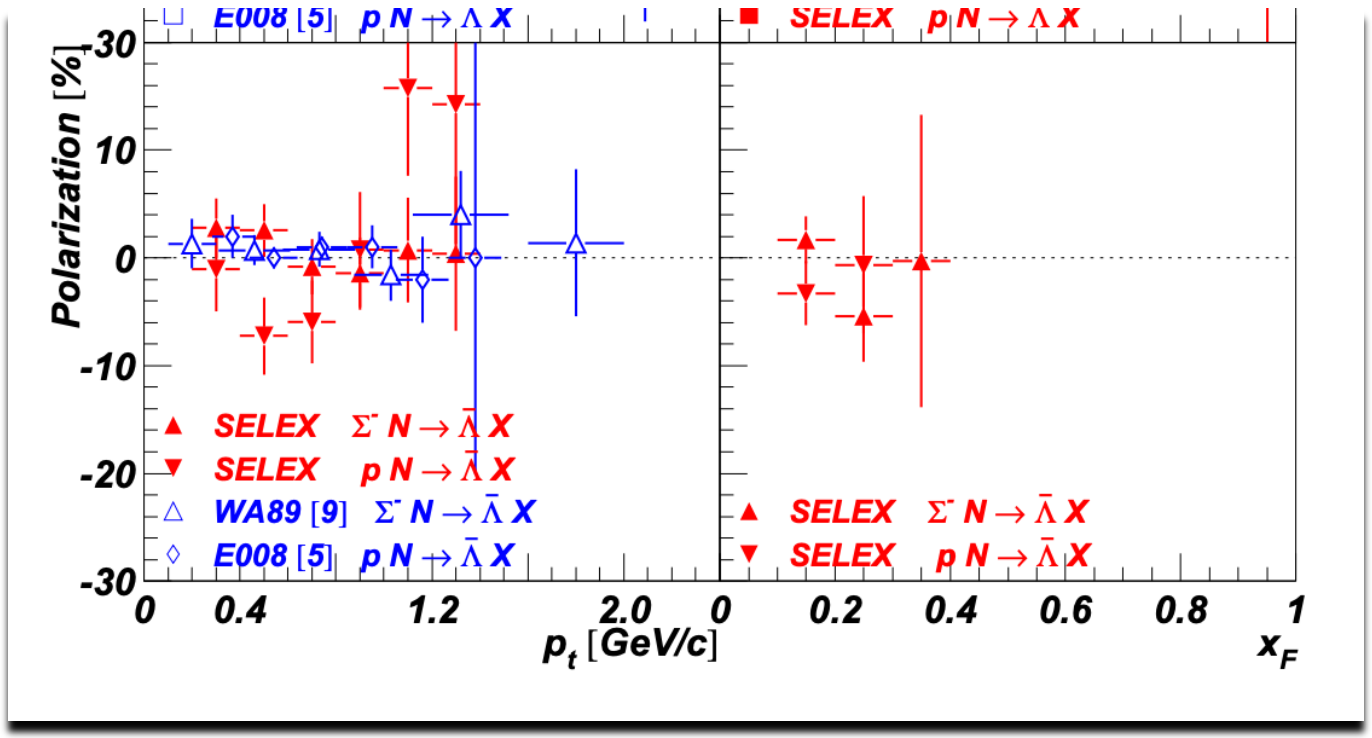
Global direction = event plane/reaction plane

No, HI collisions produce huge (directed, elliptic, etc) flow.

Λ momentum is influenced by the flow.

The strongest defense was $\bar{\Lambda}$





Only the vorticity effect can produce $\bar{\Lambda}$ polarization

(*Because we `KNOW` production plane mechanism $\bar{\Lambda}$ polarization is zero*)

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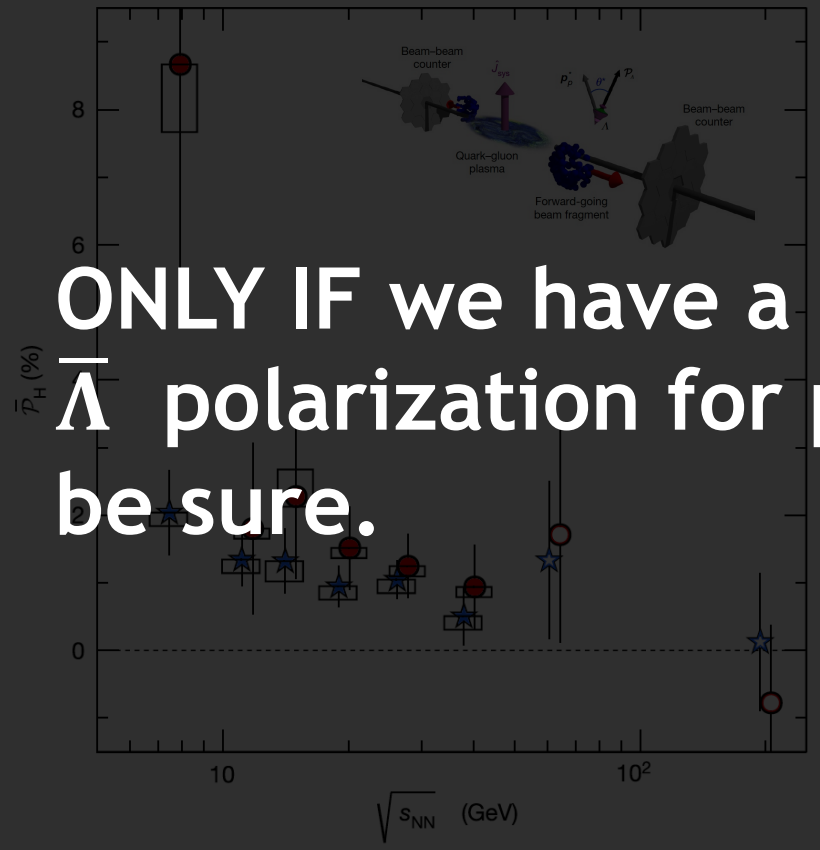
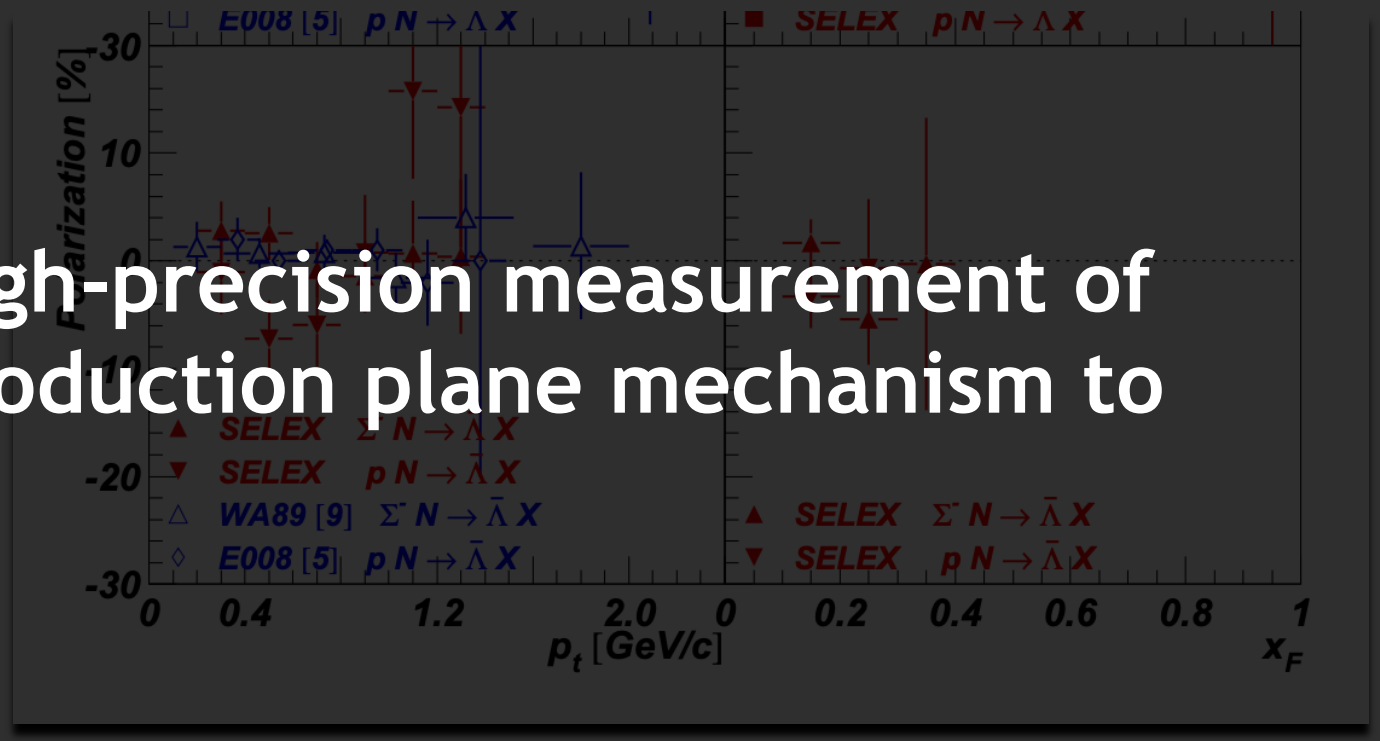
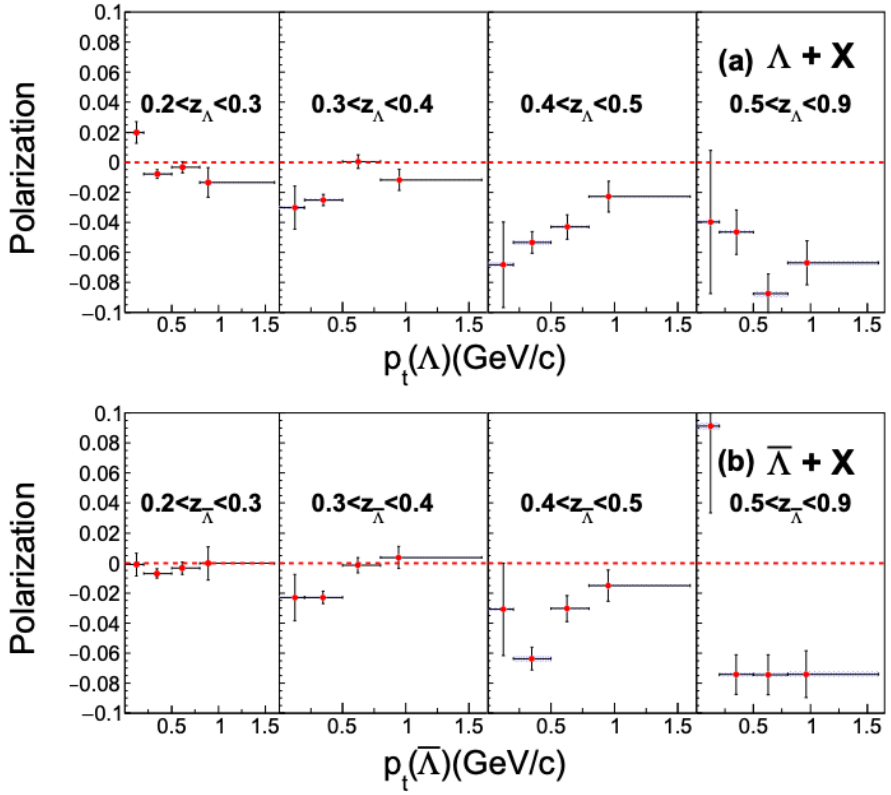




ONLY IF we have a high-precision measurement of $\bar{\Lambda}$ polarization for production plane mechanism to be sure.

Only the vorticity effect can produce $\bar{\Lambda}$ polarization
(*Because we `KNOW` production plane mechanism $\bar{\Lambda}$ polarization is zero*)

Another interesting result - $\bar{\Lambda}$ polarization in ee or jet does have a signal



Belle, 2018

Ps: STAR has seen something similar in jet

we obtain sensitivity to the flavor dependence of the observed polarization. Strong flavor dependences are seen in the $\Lambda(\bar{\Lambda})h^{\pm}X$ measurements. Our results suggest positive polarization for u ($\bar{u}$) quark fragmentation to a Λ ($\bar{\Lambda}$) and negative polarization for s ($\bar{s}$) quark fragmentation to a Λ ($\bar{\Lambda}$). A conclusive understanding needs more dedicated studies with theoretical calculations. Furthermore, we attempt to separate the contributions for directly-produced Λ particles from light quarks and those from

So why not in hadronic scattering? FF should be universal? Was it statistics or different effect?

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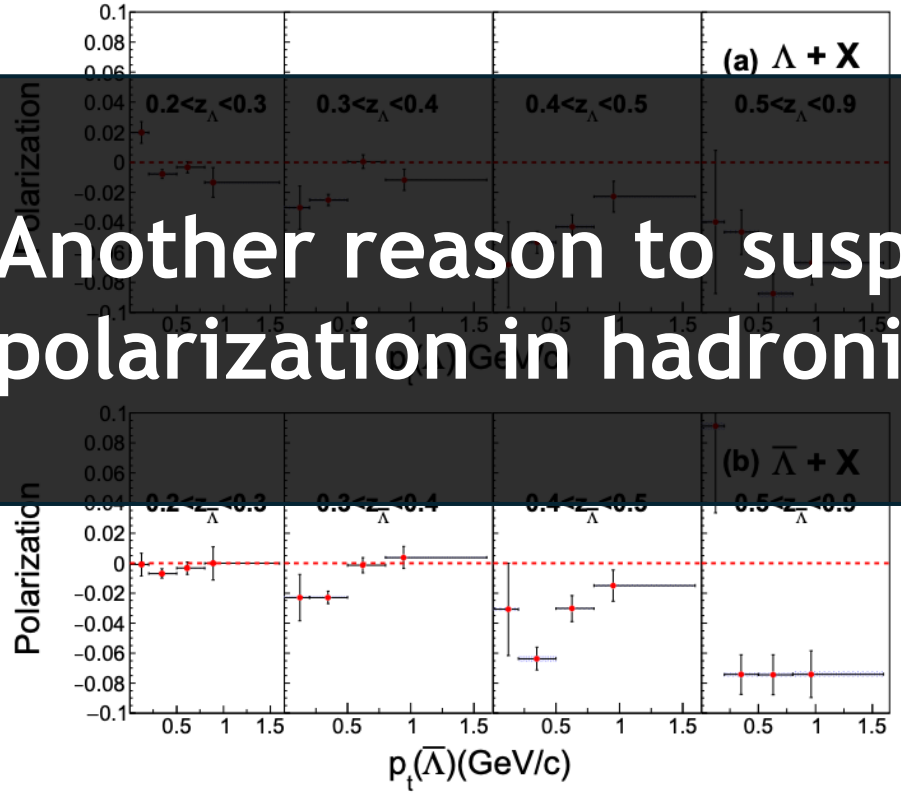

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Another reason to suspect a signal from $\bar{\Lambda}$ polarization in hadronic scattering.

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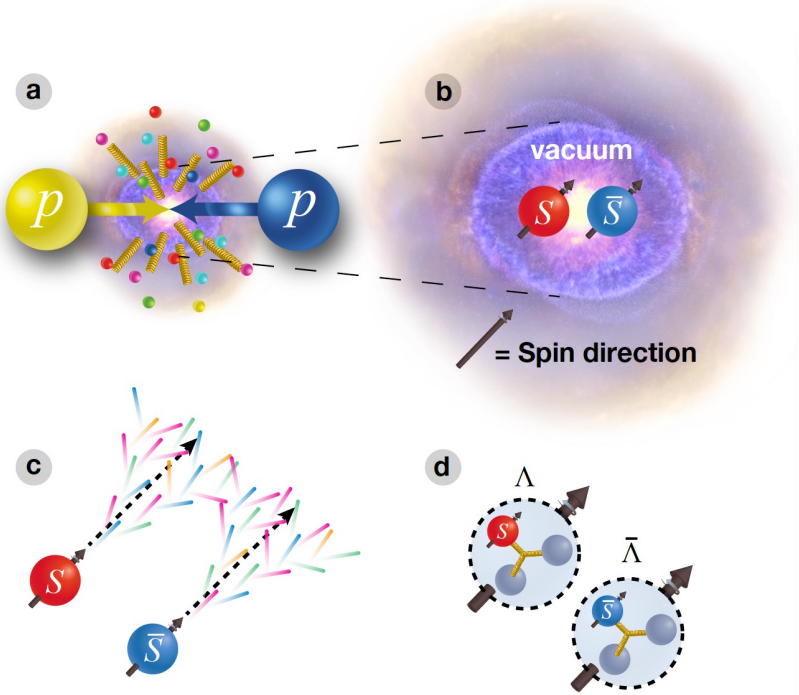
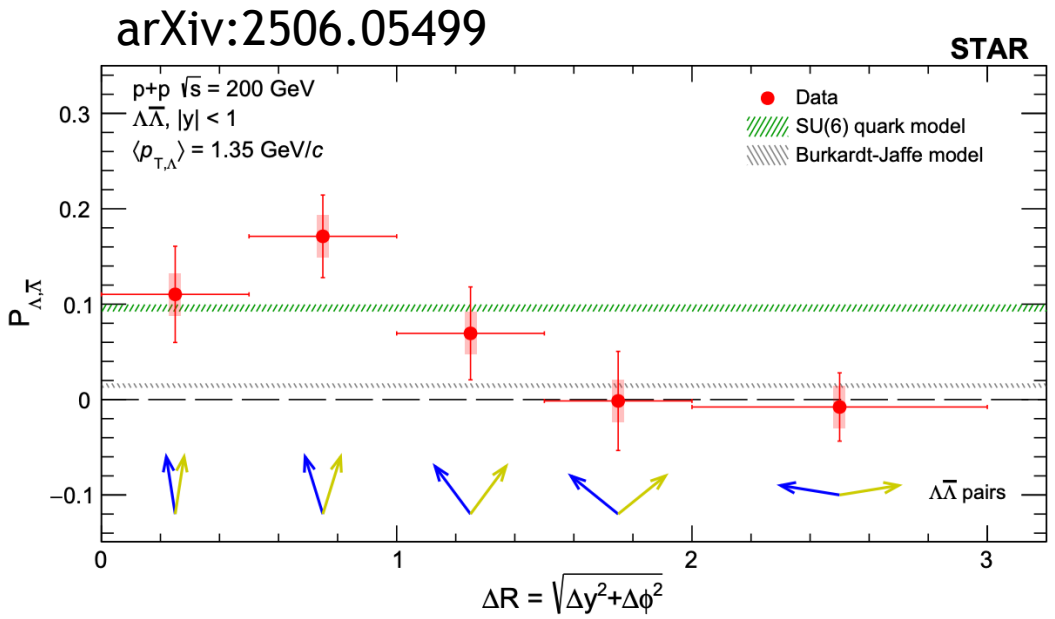
New results from STAR spin correlation

Sensitive to vacuum condensate and spin entanglement





- A new source of Λ polarization that is NOT production plane mechanism.
- **$\Lambda\bar{\Lambda}$ spin correlation** consistent with 100% spin triplet state – experimental evidence of the quantum entangled pairs of s and sbar quarks in the vacuum

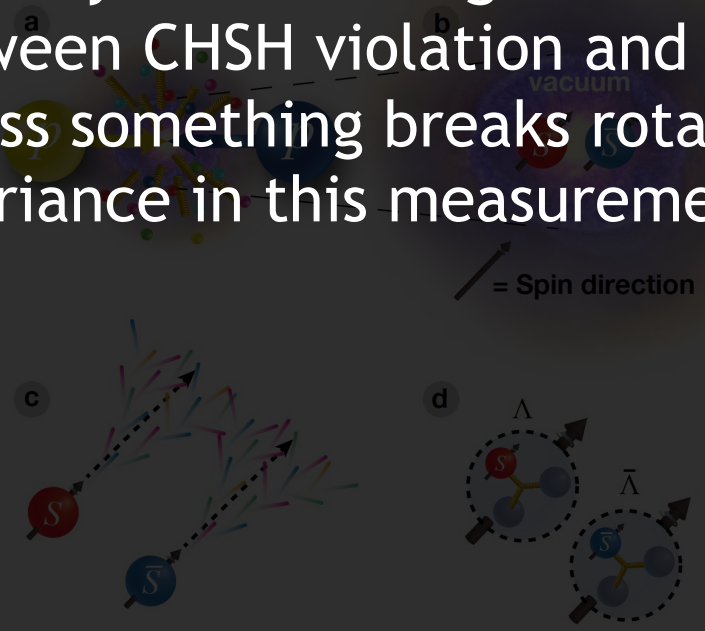
How does this help us?

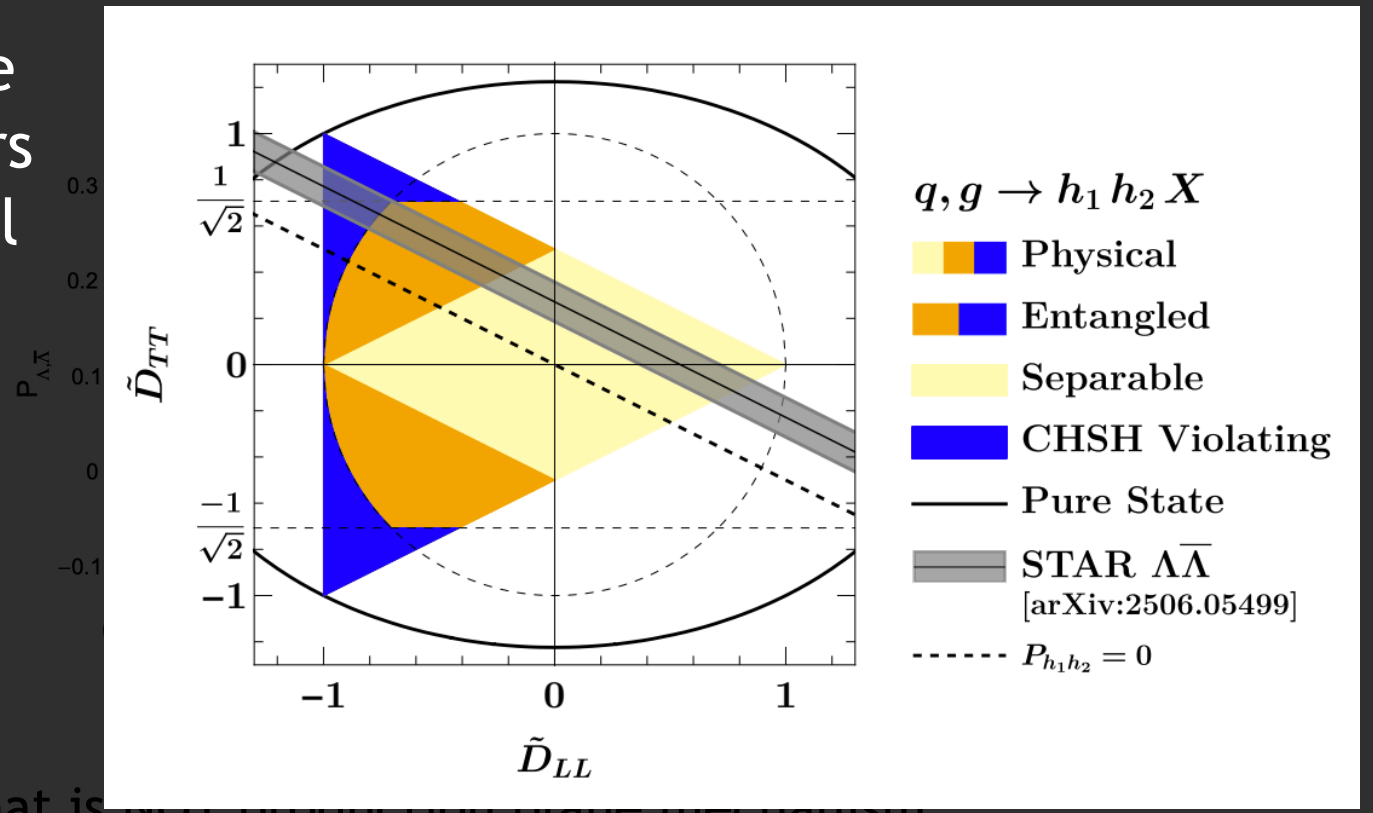
New results from STAR spin correlation

Proposal using spin correlation to study quantum effect in hadronization

Sensitive to vacuum condensate and spin entanglement

But they can't distinguish the case between CHSH violation and others unless something breaks rotational invariance in this measurement.





https://arxiv.org/pdf/2503.22607

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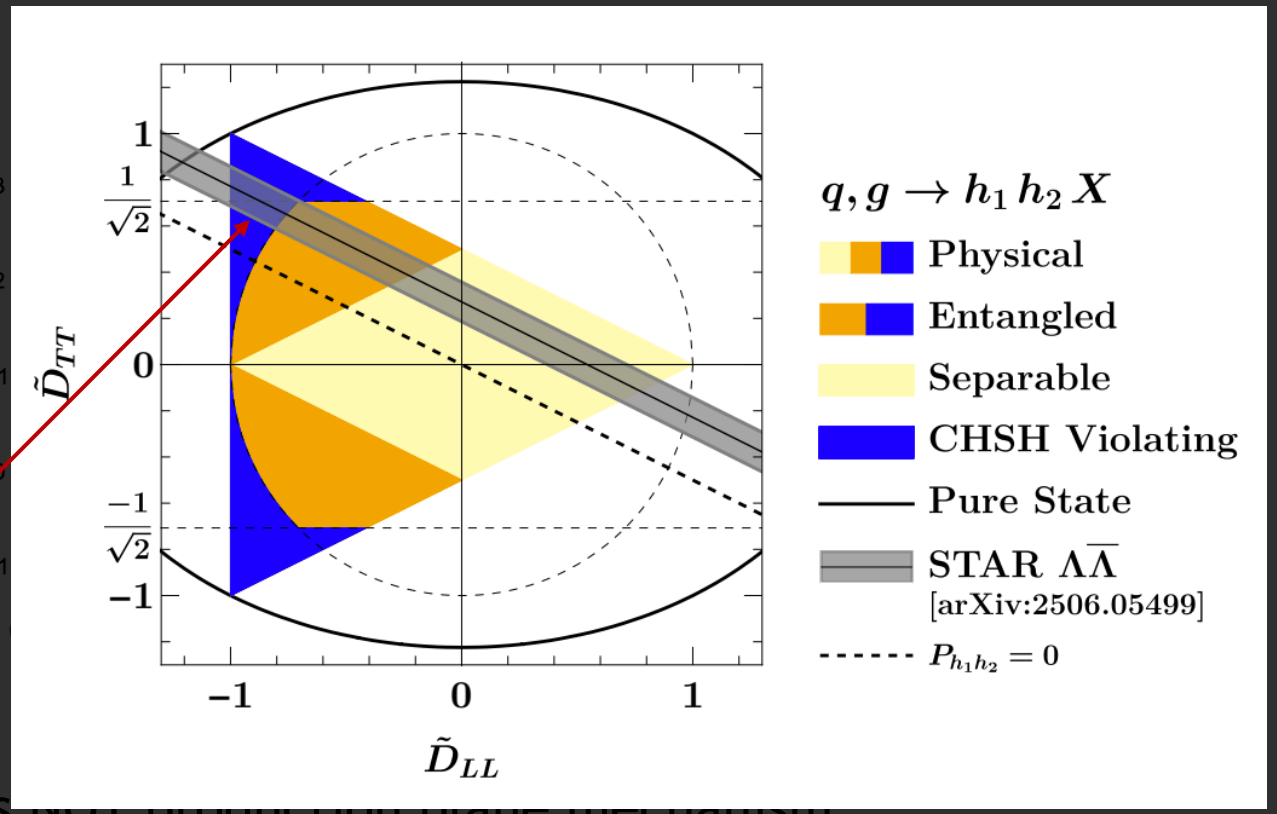
But they can't distinguish the case between CHSH violation and others unless something breaks rotational invariance in this measurement.

Lower energy collisions will produce "production plane" polarization or polarized beam(!), which is a global effect that may help them separate these cases



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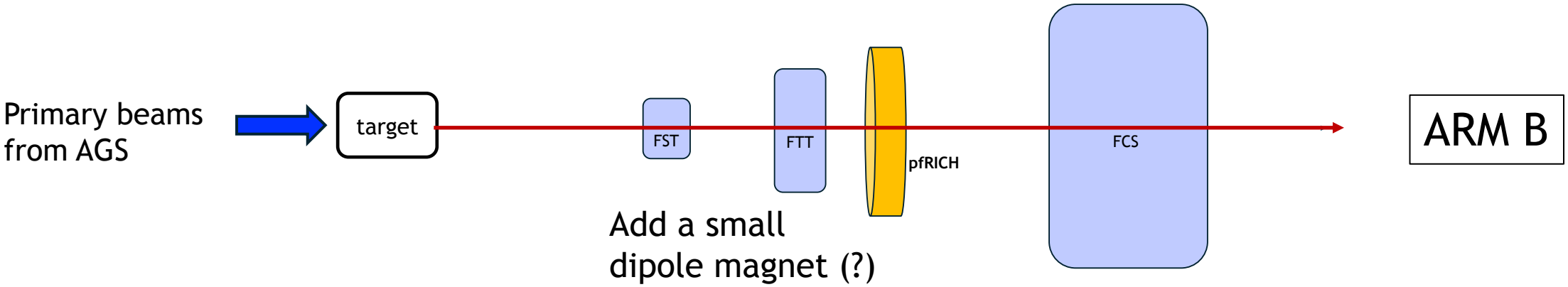
High statistics $\overline{\Lambda}$ and $\Lambda\overline{\Lambda}$ polarization in polarized fixed target experiment may shine new lights

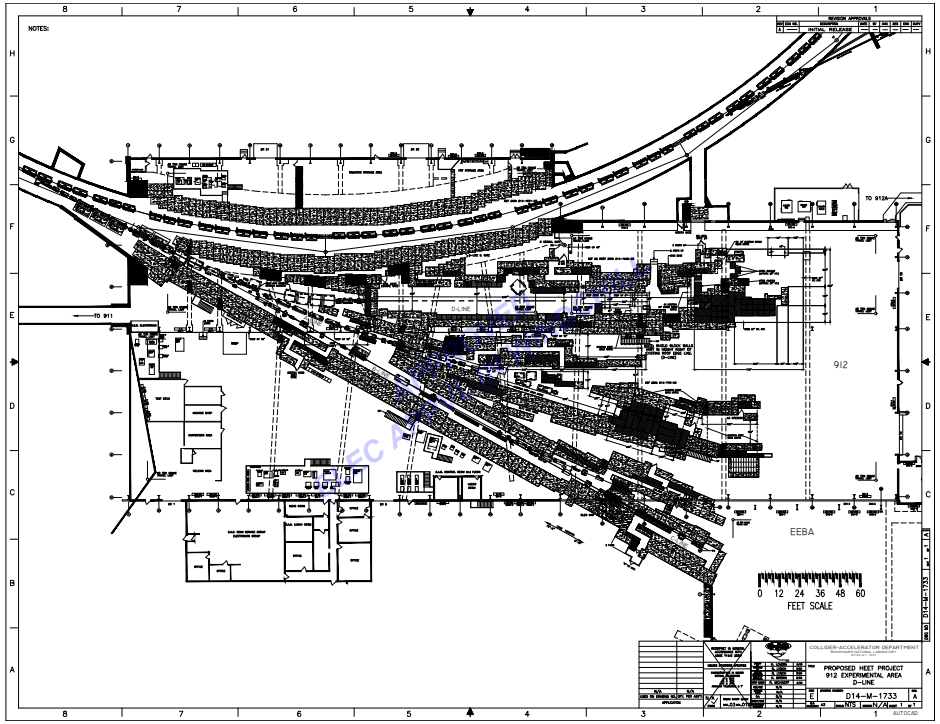
(A unique opportunity that I don't see elsewhere.)



This will be an ideal(?) experiment for forward (large xF) anti-lambda or $\Lambda\overline{\Lambda}$ polarization measurement

Summary

- Proposal of the **SPiRiT** experiment
- A sketch of a possible AGS experiment for both test beam and physics.
- Transverse Λ polarization remains a puzzle, where low energy $\bar{\Lambda}$ **polarization and $\Lambda\bar{\Lambda}$** spin correlations may shine new lights. They have relevance to HI physics, spin physics, and nonperturbative QCD in hadronization.
- Realistically, challenges are:
  - Money
  - Person power and how to not take existing resources
  - …



Thank you