TOF Physics at EIC

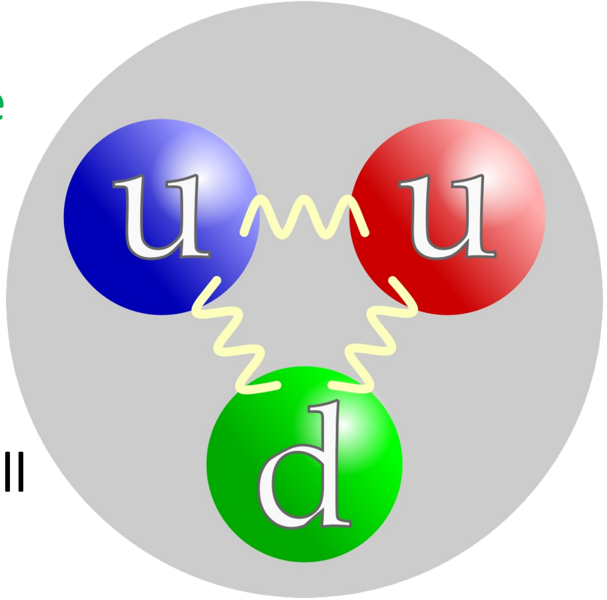
In YR and ALL proto-proposals
EIC is a non-perturbative QCD facility

Zhangbu Xu (BNL)

- Physics cases for EIC
  - Heavy-Flavor (Lambda_c and Ds, charm chemistry)
    https://agenda.infn.it/event/30932/contributions/171283/attachments/93246/127182/2022June30_EICnationalMeeting.pdf
  - SIDIS (hadron spectra, chemistry)
  - Vector meson diffractive production (Q^2 dependence of ϕ)
  - V u-channel exclusive back-scattering (exchange of three quarks) https://arxiv.org/pdf/2204.07915.pdf
  - Baryon Carrier (quark or a gluon junction)
- Complementarity of TOF and DIRC

https://en.wikipedia.org/wiki/Quark

Do gluons carry baryon number?



- Baryon Number: One of the most strictly conserved quantities in the Universe: energy, momentum, baryon number.
  Textbook says that each quark carries 1/3 of a baryon number, and **Gluons 0**. But it was never been convincingly proved!
  Most ignored and taken for granted fundamental conserved number carrier!

- Baryon Junction: nonperturbative configuration of gluons linked to all three valence quarks
  - Carries the baryon number (Regge Theory and LQCD)
  - Theorized to be an effective mechanism of stopping baryons in pp and AA

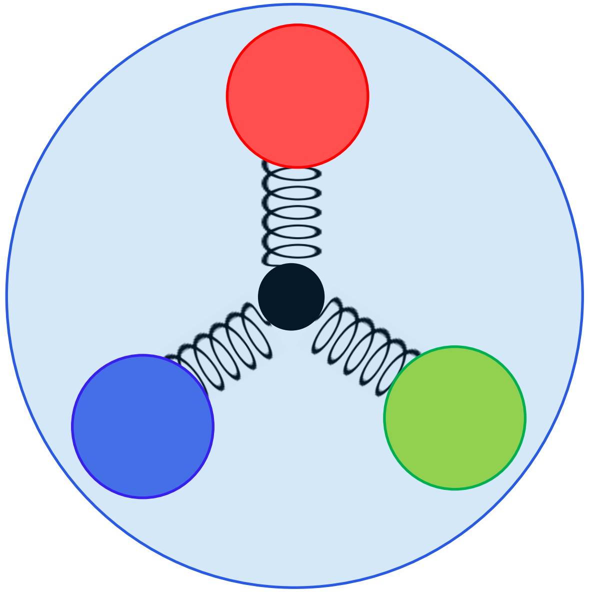
  D. Kharzeev, Physics Letters B **378**, 238-246 (1996)

- Many of the models used for heavy-ion collisions at RHIC (HIJING, AMPT, UrQMD) have implemented a nonperturbative baryon stopping mechanism

  V. Topor Pop, *et al,* Phys. Rev. C **70**, 064906 (2004)

  Zi-Wei Lin, *et al*, Phys. Rev. C **72**, 064901 (2005)

  M. Bleicher, *et al,* J.Phys.G **25,** 1859-1896 (1999)

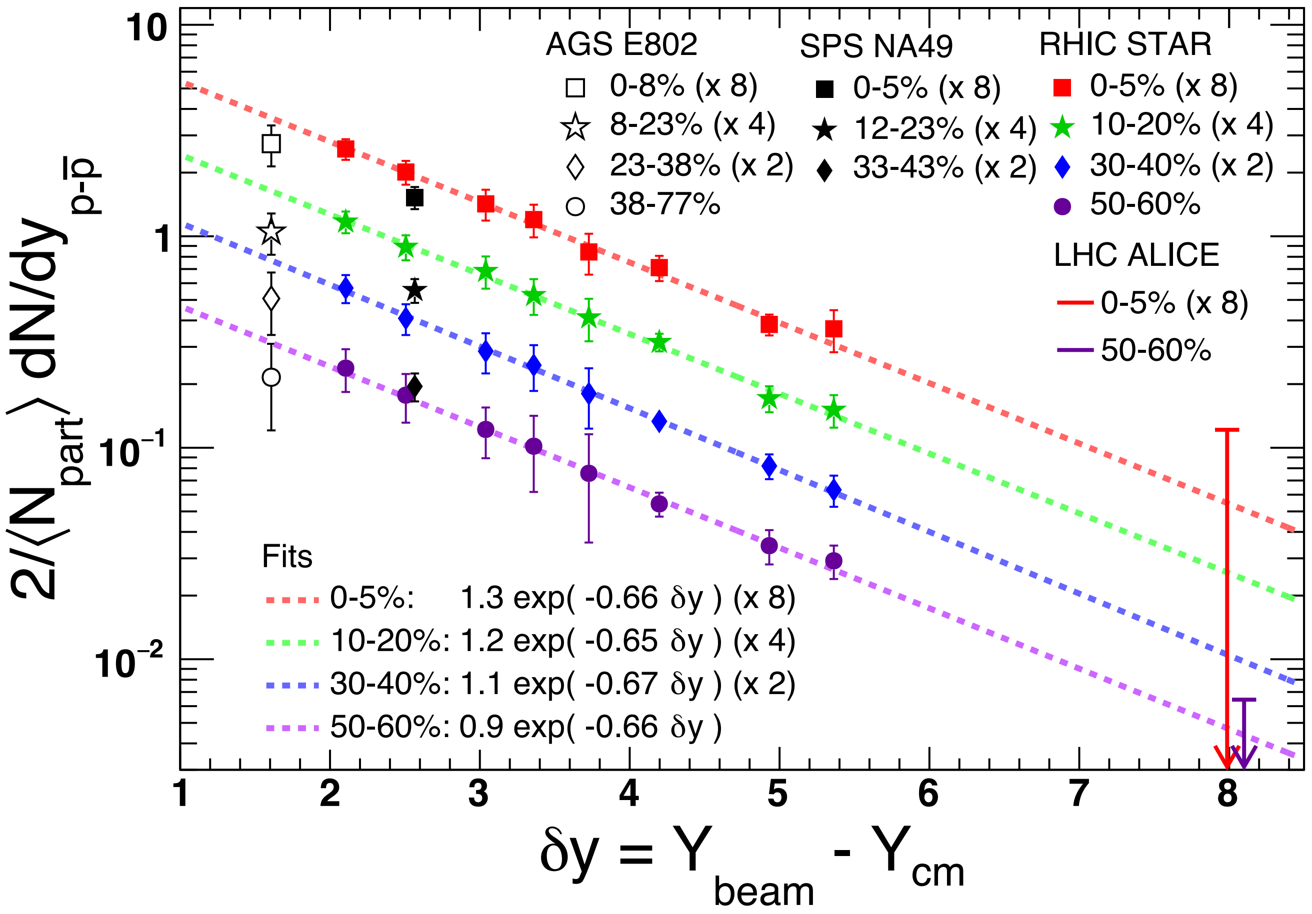


- But no signature of baryon junction has been cleanly identified in the experiment

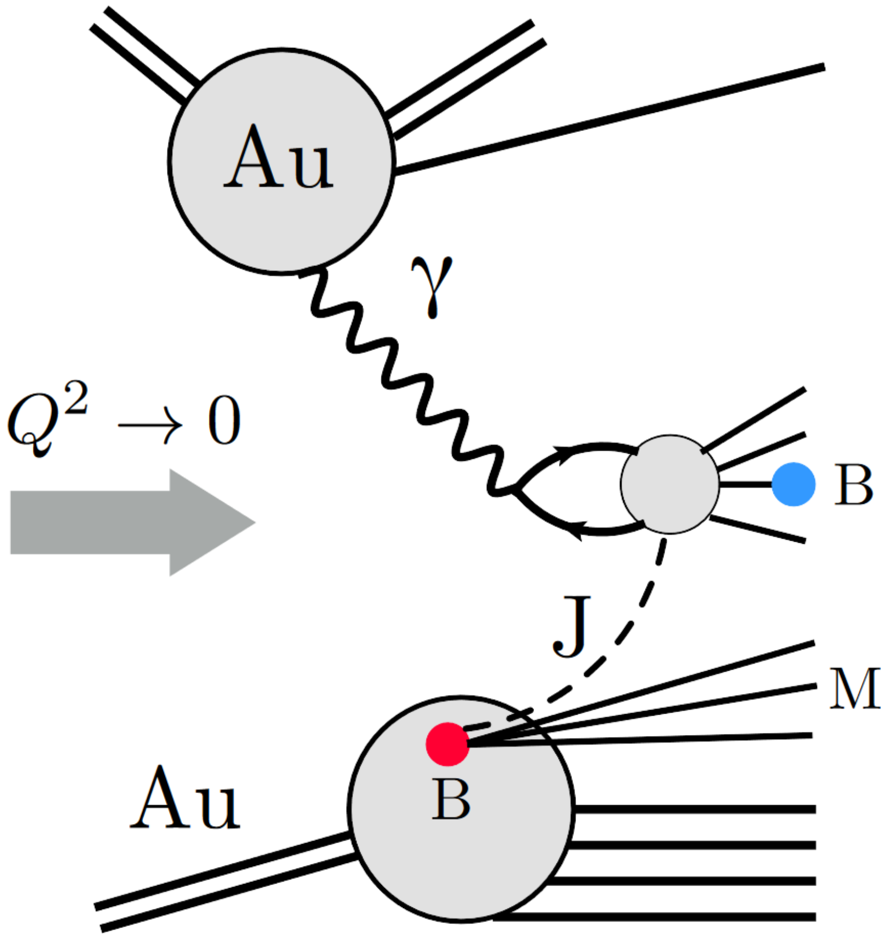
Best ways of probing baryon carrier

STAR, Phys. Rev. C **79** (2009) 34909; **96** (2017) 44904
JDB, NL, PT and XZB, arXiv:2205.05685

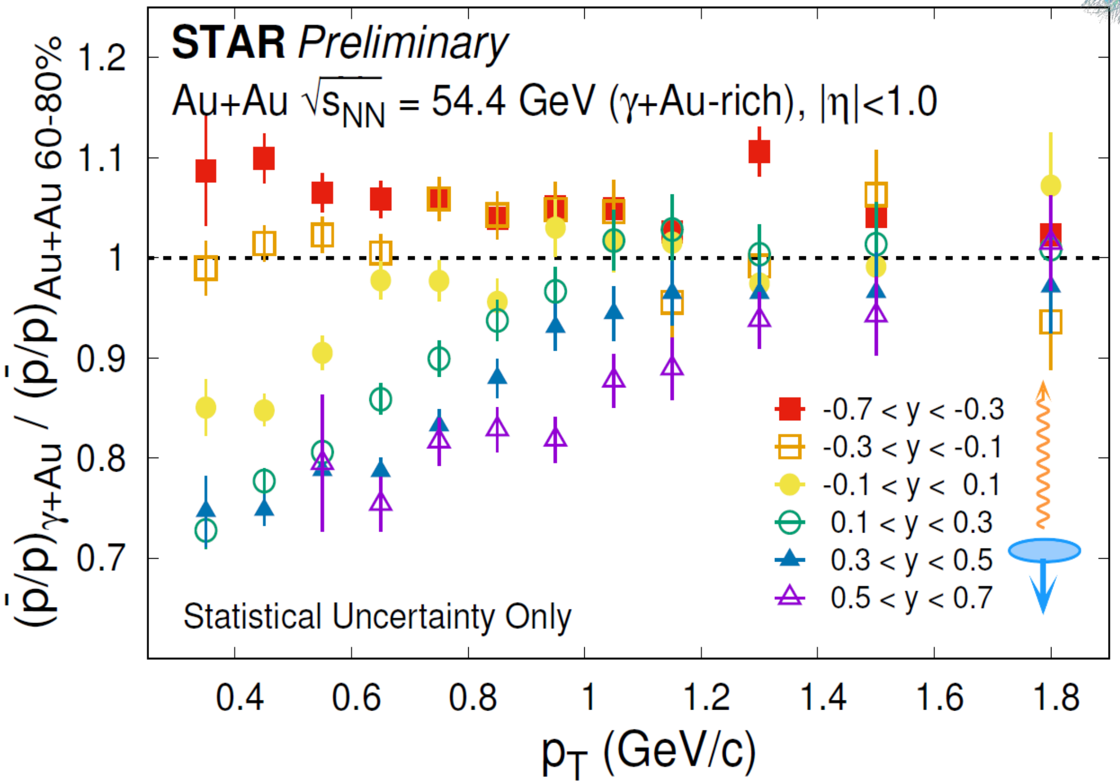
- Beam Energy Dependence of net baryon yields at midrapidity in A+A collisions
- Net Charge (quark) vs Net Baryon (gluon) at midrapidity in isobar collisions
- Rapidity asymmetry in γ+A (e+A)
  Regge theory predicts exp(-0.5*y)



Low p_T Baryon Enhancement in γA



J. D. Brandenburg *et al*, arXiv 2205.05685



- Double ratio: $\bar{p}/p < 1$ at lower p_T
  - Soft baryon stopping that is **stronger** in γA compared to peripheral AA
  - Ratio is smaller at higher rapidity (A-going side)

Baryon Junction Distribution Function (JDF)

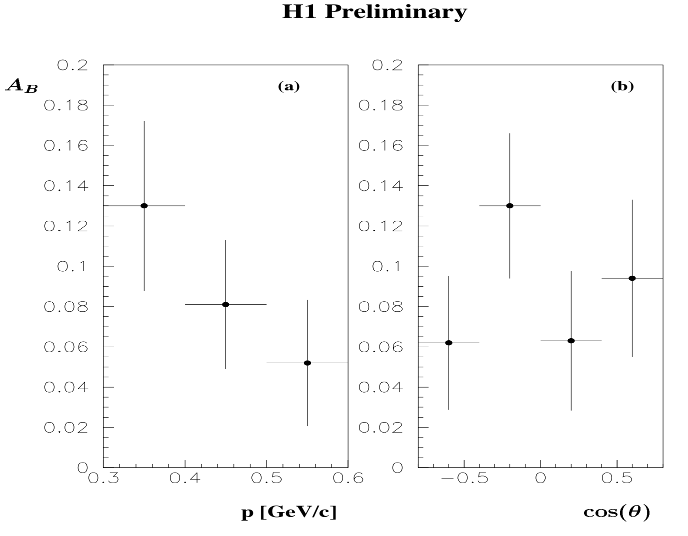
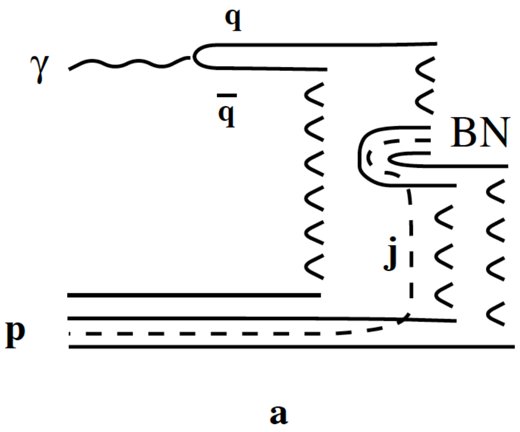


Figure 7: Baryon asymmetry as function of the proton momentum (a) and the polar angle (b).

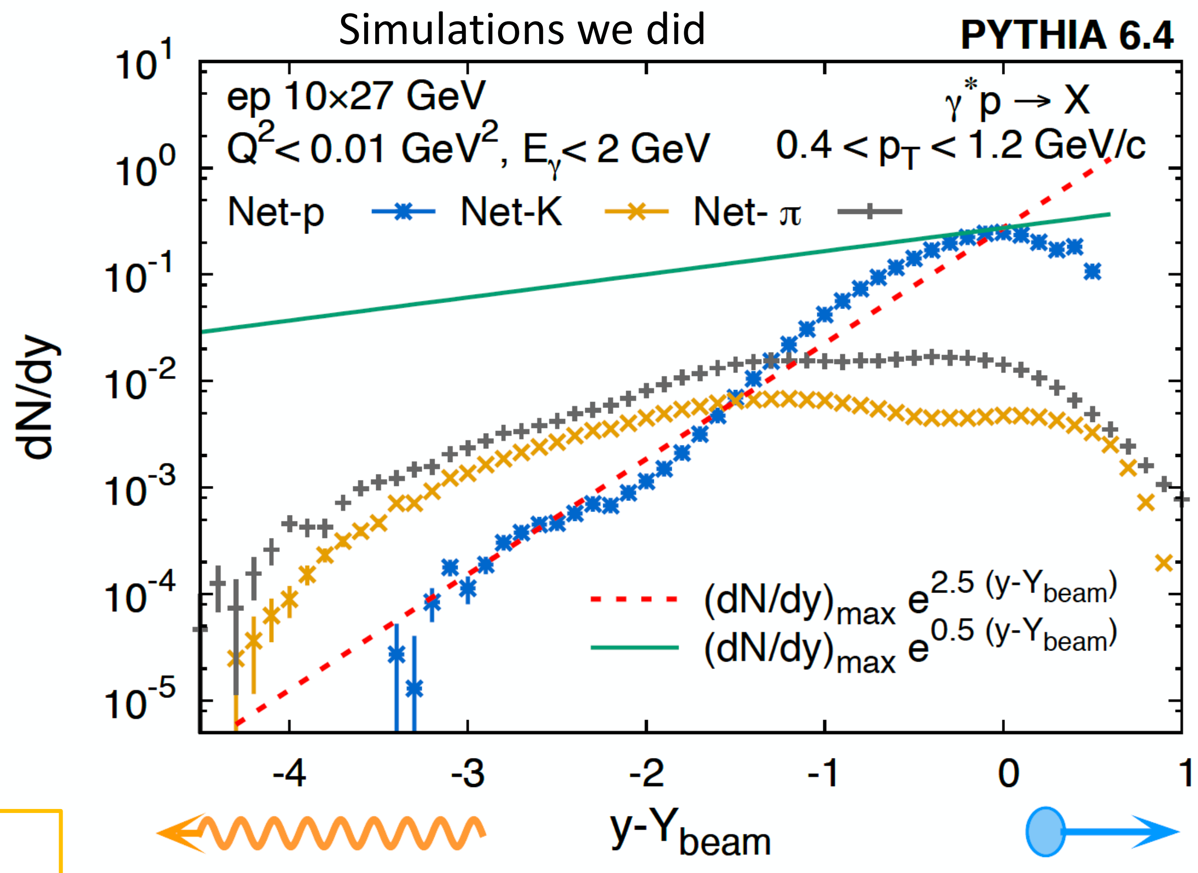


Our final result for the baryon asymmetry is

$$A_B = (8.0 \pm 1.0 \pm 2.5)\% .$$

Measurement of the Baryon-Antibaryon Asymmetry in Photoproduction at HERA

C. Adloff et al. (H1 Collaboration), ICHEP 1998



Baryon stopping at HERA: Evidence for gluonic mechanism

Boris Kopeliovich (Heidelberg, Max Planck Inst. and Dubna, JINR), Bogdan Povh (Heidelberg, Max Planck Inst.)

Published in: *Phys.Lett.B* 446 (1999) 321-325 • e-Print: hep-ph/9810530 [hep-ph]

Many theory papers cited this result even as late as 2008

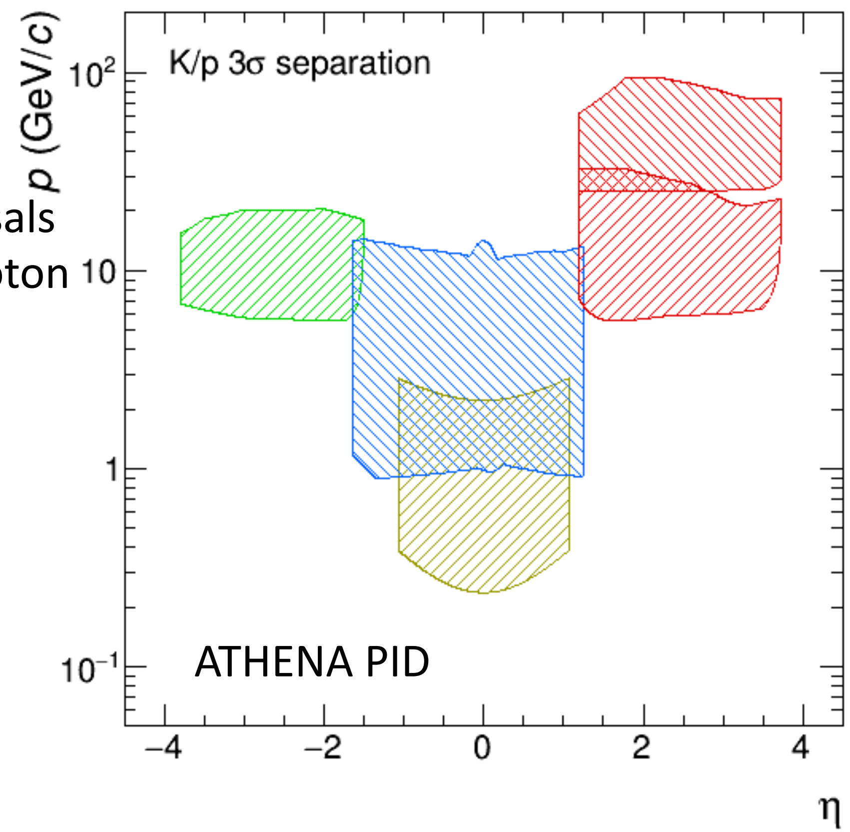
What is clear from STAR and other new measurements:
At HERA kinematics, A_B~=<1%, H1 is x10 too large
PYTHIA6.4 would predict almost 0%.
HERA is at wrong kinematics without good PID detector

EIC is the best to address this fundamental science at DAY 1 with TOF

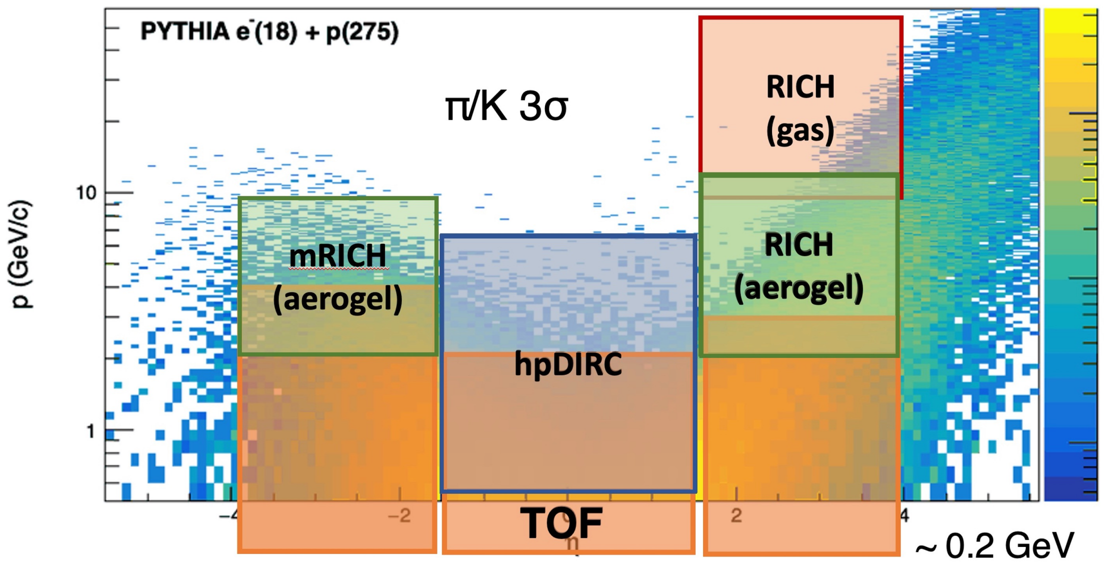
γ+A at EIC

Similar nucleus target rapidity, better kinematics control
Needs proton PID at low p_T over large rapidity range

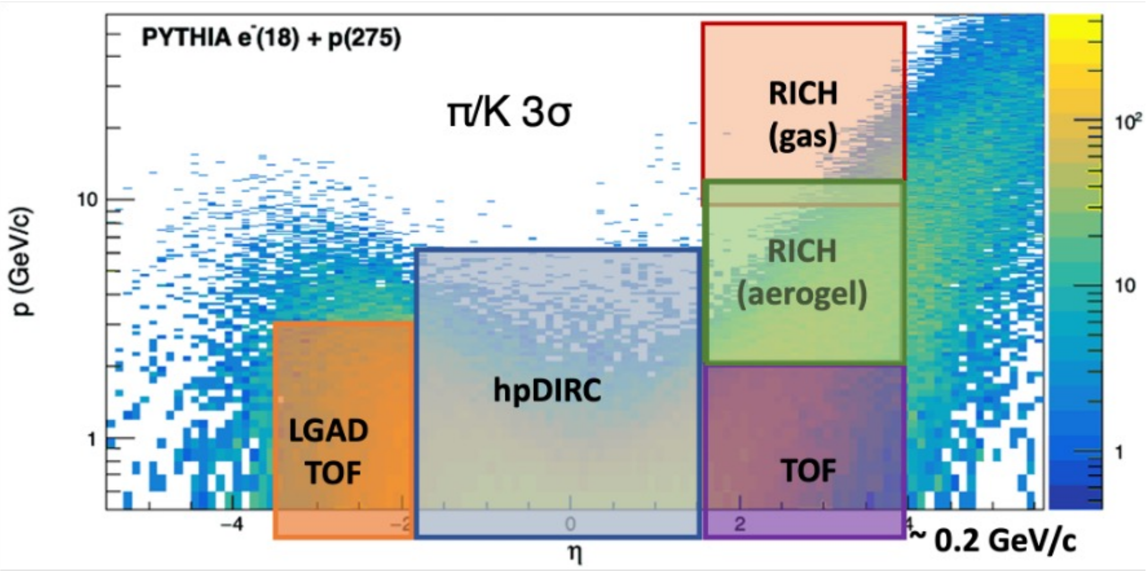
All three proposals have low-pT proton PID



ECCE



CORE



ACLGAD Sensor Design and Progress

Characterization of BNL and HPK AC-LGAD sensors with a 120 GeV proton beam

Ryan Heller, Christopher Madrid, Artur Apresyan, William K. Brooks, Wei Chen, Gabriele D'Amen, Gabriele Giacomini, Ikumi Goya, Kazuhiko Hara, Sayuka Kita, Sergey Los, Adam Molnar, Koji Nakamura, Cristián Peña, Claudio San Martín, Alessandro Tricoli, Tatsuki Ueda, Si Xie

We present measurements of AC-LGADs performed at the Fermilab's test beam facility using 120 GeV protons. We studied the performance of various strip and pad AC-LGAD sensors that were produced by BNL and HPK. The measurements are performed with our upgraded test beam setup that utilizes a high precision telescope tracker, and a simultaneous readout of up to 7 channels per sensor, which allows detailed studies of signal sharing characteristics. These measurements allow us to assess the differences in designs between different manufacturers, and optimize them based on experimental performance. We then study several reconstruction algorithms to optimize position and time resolutions that utilize the signal sharing properties of each sensor. We present a world's first demonstration of silicon sensors in a test beam that simultaneously achieve better than 6-10 micron position and 30 ps time resolution. This represents a substantial improvement to the spatial resolution than would be obtained with binary readout of sensors with similar pitch.

Subjects: **Instrumentation and Detectors (physics.ins-det)**
Cite as: arXiv:2201.07772 **[physics.ins-det]**

We present a world's first demonstration of silicon sensors in a test beam that simultaneously achieve better than 6-10 micron position and 30 ps time resolution.

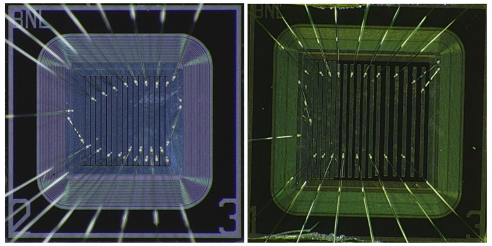


Figure 1: The BNL manufactured sensors tested at FNAL. BNL 2020 sensor (left) with 100 μm pitch and 20 μm gap sizes. BNL 2021 sensor (right) with three pitch variations 100 μm (narrow), 150 μm (medium), and 200 μm (wide).

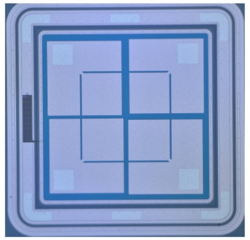


Figure 2: The HPK manufactured sensor tested at FNAL. The four-pad device with each pad of size 500×500 μm^2, and interpad gap sizes of 20, 30, 40, and 50 µm.

Various sensors with long strips by BNL

BNL long strips
1 cm x 500 um, 300 um gaps, W1
1 cm x 500 um, 200 um gaps, W2
1 cm x 500 um, 400 um gaps, W2
2.5 cm x 500 um, 300 um gaps, W1
2.5 cm x 500 um, 300 um gaps, W2
0.5 cm x 500 um, 300 um gaps, W1
0.5 cm x 500 um, 300 um gaps, W1
1 cm multipitch (100, 200, 300 um), 50% gap, W1

Other sensors
HPK 1 cm strips, 80 um pitch, Eb type 30 and 45 um metal
BNL 500 um pads, 4x4, squares 250 um metal
BNL 500 um pads, 4x4, circles 150 um diameter metal
BNL 2021 strips, 150 um pitch

FNAL Test Beam results presented by Chis Madrid on July 1, 2022

- **Large sensors will need to have a position dependent delay correction**
- **Even with non-uniformity we manage to get great results; was not clear it was possible a-priori**
- **Sensor length rather than sensor area matters for pulse shape variables**
- **For this large pitch and current resistivity two strip x-position reconstruction only available in gaps**
  Time resolution is uniform after time corrections for all sensors
- **All sensors satisfy time resolution < 50ps and position resolution < 30 microns**

- next: **HPK sensors focus on large area sensors**
- **Propose smallest metals, 500um pitch, vary length**
- **Fixed length and vary metal width**
- **Various metal sizes e.g. 50, 100, 150 um**
- **Study different pitches larger than 500 um by BNL**
- READOUT

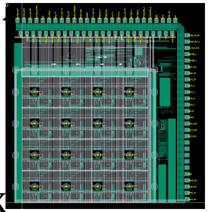
- **Redesign readout board with larger channel count and sensor area (Done by BNL)**
- Wire bond locations
- Tune readout board for larger sensors
- Double readout
- Study incident angle

ASIC designs and progresses

https://indico.bnl.gov/event/16144/
https://indico.bnl.gov/event/16330/

EICROC (IN2P3 France)

- **Based on Altiroc1/2 : ATLAS HGTD LGAD ASIC pro**
- EICROC0



  - 4x4 500 um pixels matrix
  - Sent to fabrication in march2022
  - Expected back early July
- Next Step:
- Profit from AIDA engineering run nov2022 to fabricate EICROC1
- EICROC1 : larger chip to study floorplanning and EIC DAQ
- Probably with variants of columns to study different low-power front-end and digitization
- Target 1 mW/ch
- May also put variants of EICROC0 to test with existing sensors and setup

Fast LGAD Read-out ASICs at SCIPP (UCSC)

- Testing performance of three different ASICs

Institution		Technology	Output	# of Chan	Funding	Specific Goals	Status
INFN Torino	FAST	110 nm CMOS	Discrim. & TDC!	20	INFN	Large Capacitance TDC	Testing
NALU Scientific	HPSoC*	65 nm CMOS	Waveform	5 (Prototype) > 81 (Final)	DoE SBIR	Digital back-end	Testing
Anadyne Inc	ASROC**	Si-Ge BiCMOS	Discrim.	16	DoE SBIR	Low Power	Simulations final Layout Board design

- Next year map out performance with sensors, various capacitance and power values.
  Want to verify the simulated performance advantages in power and signal-to-noise for the Si-Ge technology.

Timing ASIC for LGAD sensors based on a Constant Fraction Discriminator – FCFD0

Good performance for the first generation CFD-chip produced in TSMC 65nm technology node
-Precise measurements and calibrations of the chip on a bench, stable operations, low dead time
– Consistent with simulations: ~30 ps at 5fC, < 10 ps at 30 fC, with LGAD-like pulses
• Now moving on to testing with LGAD signals
• Development of the next version is starting, targeting specifically
AC-LGAD signals to achieve good timing and position resolutions

Bottomline is that ASIC designs from three teams are progressing and there is no show-stopper yet

Detector 1 and eRD112 Institution involvements

EIC Detector eRD112 involvements

Institution	Far-Forward (RP/B0)	TOF & Tracking	Detector Simulation	AC-LGAD Sensor	Frontend ASIC	Mechanical and Cooling	On/Off-detector Electronics	Others	Resources
BNL (A. Tricoli)	Yes	Yes		Yes	Testing		There is interest in the group to help wiht the overall architecture and off-detector electrinics, e.g. FELIX		2 scientists, 1 and 1/2 postdoc, 1 tech. There is interest from other people, i.e. another scientist and a professional
SCIPP/UCSC (B. Schumm)				We are tuning TCAD simulations to be used for sensor design and optimization. We are also performing extensive characterization studies of contemporary prototypes.	We are working with two private firms, under SBIR contracts, to develop two approaches to front-end readout, including CMOS and SiGe. These developments are geared towards improved temporal resolution and low power consumption		Waveform digitization is included in one of the ASIC projects		Ongoing part-time contributions from two faculty, three postdocs, two senior staff
LANL (X. Li)	Yes	Yes		Yes. We have established test bench in lab for AC-LGAD characterization. The studies include single sensor and telescope testing with a 90Sr source. We also plan to carry out irradiation tests at the LANL LANSCe facility and a research reactor in UT Austin.	Testing		We could help on the integration and testing.		2 scientists, 1 postdoc to work on this part time, 1 mechincal engineer could provide engineer support.
NCKU (Y. Yang)		Yes		Testing.		Yes			
ORNL (C.Loizides, F. Bock, K.Read, Oskar Hartbrich)			Yes, including access to computing resources	Testing and characterization. Electronics laboratory with test benches available.	Possible engineering support, with limited availability of experienced ASIC design engineer, depending on funding.	Yes, depending on funding.	Yes.		~3 (technical) scientists. Mechanical and electrical engineers available depending on support obtained/identified. Electronics laboratory with test equipment and testing space available.
Rice (W. Li, F. Geurts)		Yes	Yes	Yes. sensor testing and characterization			Yes. Specifically, we are interested in service hybrids (readout boards, power boards) leveraging expertise in CMS ETL		2 physicists and 1 postdoc plus part-time contributions from students
UIC (Z. Ye, O. Evdokimov)	Yes	Yes	Yes	TCAD simulation. Sensor characterization	Possible ASIC designer depending on funding. Testing (extensive experience with CMS ETROC)		off-detector readout electronics leveraging expertise in CMS ETL		part-time contributions from 2 physics faculties, 1 postdoc and 2 PhD students, possible engineering support from ASIC designer, eletronics engineer and mechanical technicians with funding

CMS DC-LGAD TOF Project involvements

- Sensor, bump-bonding: Kansas Univ, ORNL
- Frontend ASIC testing and production QA/QC: UIC
- Frontend electronics other than ASIC: Rice
- Mechanical structure: MIT
- HV and LV power system: Rice
- DAQ electronics: UIC

STAR Forward Silicon Tracker:

- Sensor and bump-bonding: UIC/FNAL
- Mechanics and cooling: NCKU and BNL
- FEE/DAQ: USTC/SDU/BNL/IU

hpDIRC vs ACLGAD TOF Coverage at low pt

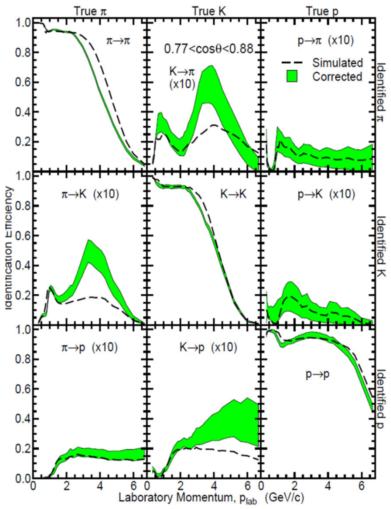
DIRC COUNTERS IN THRESHOLD MODE

Initial request: presentation about experience with DIRC threshold mode

Experience? I am not aware of any studies of DIRC performance
in threshold/veto mode from BaBar, Belle II, GlueX, or PANDA

Those experiments have/had dedicated lower-momentum PID systems
(dE/dx and/or TOF), published their DIRC PID studies for
positive ID, both particles above threshold

Example: BaBar charged hadron effi/mis-ID (2013),
DIRC contributes for wide momentum range but dE/dx from
vertex detector and drift chamber dominate at lower momentum,
no separate discussion of DIRC impact



BaBar Collaboration, J. P. Lees et al.,
Production of charged pions, kaons and protons
in e+e- annihilations into hadrons at sqrt{s} = 10.54 GeV
arXiv:1306.2895, Phys.Rev. D88 (2013) 032011,
doi:10.1103/PhysRevD.88.032011

Today: discuss special threshold mode features for hpDIRC,
examples from PANDA-based Geant simulation photon yield study

G. Kalicy, J. Schwiening • DIRC Threshold Mode • GD/I Meeting • July 7, 2022 2

It is clear from experts and past experiences, it is important to have complementary PID capabilities

do we need to have PID below 250MeV/c in the barrel? **???**