Advancing Nuclear Physics: New Horizons with Fixed-Target Proton-Nucleus Experiments at Intermediate Energies

Workshop summary

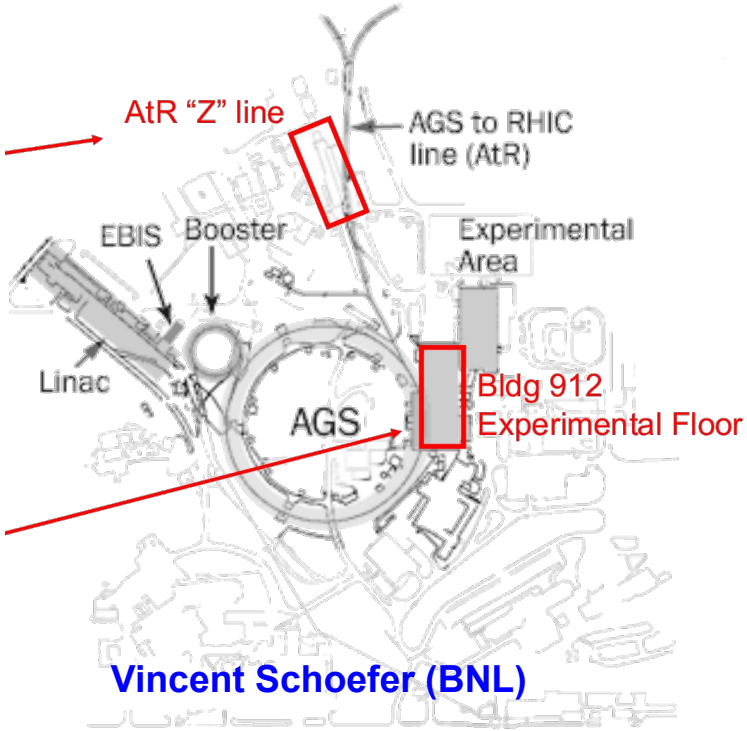
Christine Nattrass takes full responsibility for these slides

Two possible beamlines

Z line: More limited options but faster and cheaper
Rapid beam only
Tight space

Building 912: Up to four beam lines and could be ideal, but requires more construction and more expensive

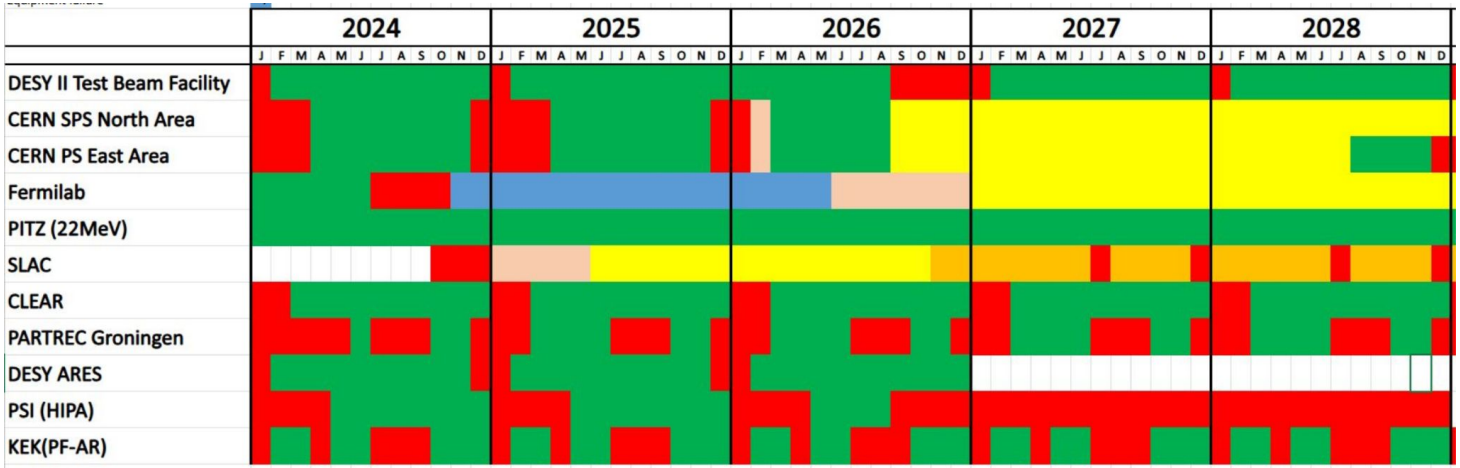
All facilities could run simultaneously



Great Hadron Drought of 2026+

Oskar Hartbrich

- We are entering a true drought in hadron beam facilities starting 2026
- Even if all facilities come back on time, they will be seriously overbooked
- EPIC's estimate for test beam needs based on survey of subsystems for European Particle Physics Strategy Update: *86 weeks in 3 years*
- **A (hadron) beam test facility at BNL would be a significant reduction of risk for ePIC**



Green→Good
Not green→Bad

Detailed sketch of facility!

The Ideal Beam Test Facility - Beams

- Mixed hadrons: 1GeV up to full AGS storage energy
  - Interesting for PID, calorimeters
  - Tracking detectors prefer highest momentum to minimize multiple scattering
- Electron enriched absorber configuration
- Muon configuration (beam stop)
  - Wide area muon beams are very useful for calorimeter calibration + parasitic running
- Variable beam focusing system
  - Including collimators for rate adjustment
- He/Vacuum tubes for precision low energy beams?
- Support from beamline experts

OAK RIDGE National Laboratory

The Ideal Beam Test Facility - Equipment

- Trigger scintillators
- Differential Cherenkov system for clean hadron selection?
- Dedicated pixel telescope?
  - Several systems available at FTBF, CERN beam tests
- Dedicated timing sensor test bench?
  - FTBF has “permanent” setup with timing reference MCP-PMT and 8+ very fast oscilloscope channels
- Easy access to beam + environmental conditions logging
- Cabinets full of (tested!) NIM modules :-)
  - Or just a few CAEN N1081-style programmable NIM logic modules?
- Access to standard electronics (a la CERN EPOOL)
  - Access to technician for simple soldering, machine shop work…

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The Ideal Beam Test Facility - Area

- Crane + operators, solid ground
- Moving stages of various sizes/weight limits
  - Remote operation from counting house
- Gas system integration: gas lines in/out of beam area, N + CDA available?
- Low impedance ground bars **everywhere**

- Counting house with network connectivity and signal/power feedthroughs to beam area
  - Full remote access

- Staging area in same hall
  - Fast turnover between beam times
  - Can receive parasitic muon beams? “Sequential” beam areas with beam stop?

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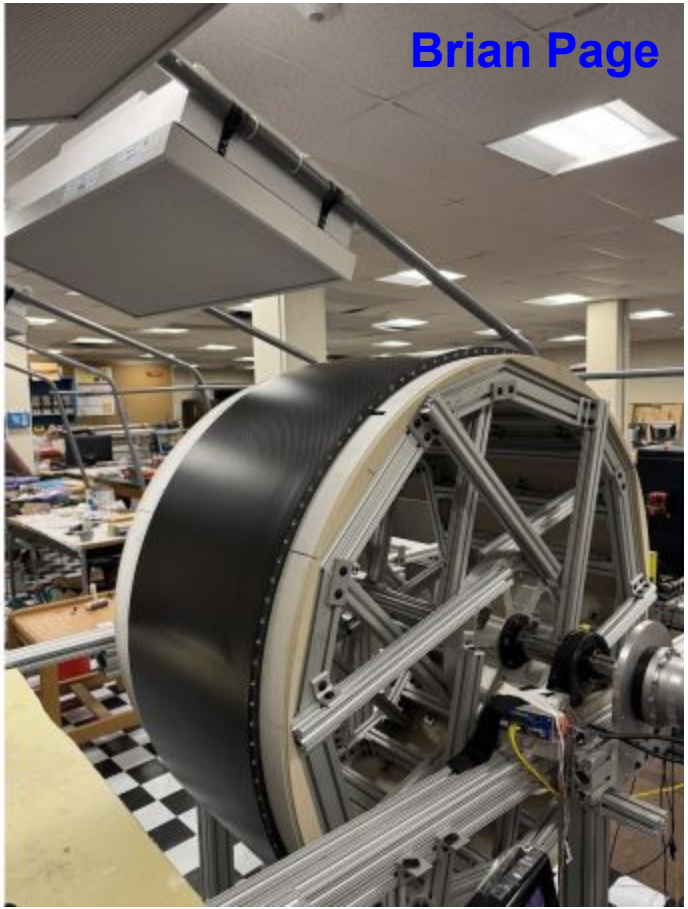
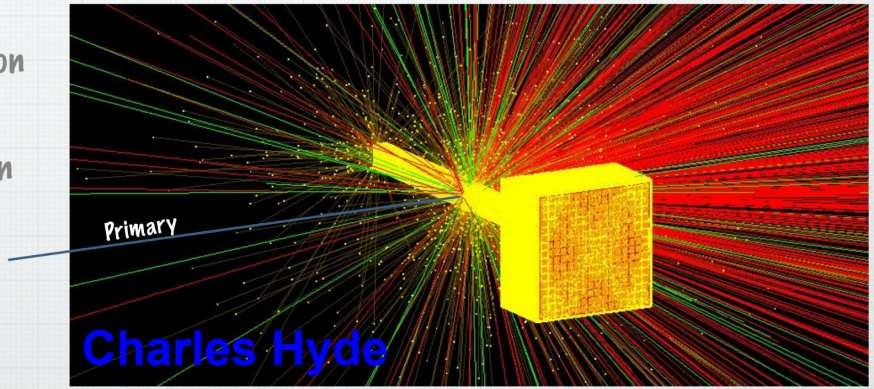
Oskar Hartbrich



MiniDIRC Cherenkov from Primary Ion and secondary δ-rays

- Primary Z=90 ion at P=100 GeV/u.
- δ-ray production ~ Z^2



Relativistic Ion Test Beams possibly unique in world?

We need a test beam facility at the AGS to mitigate risk and reduce contingency at the EIC.

AGS is an essential test bench for development of polarized sources and beams

- We have of order a decade to develop the polarization technology that is essential for EIC science. This includes:
  - polarized ion sources (^{2}H, ^{3}He, ^{6}Li and ^{7}Li)
  - polarimeters
  - spin manipulation in AGS and RHIC using solenoids and snakes
- We require maximum stable polarization and collision luminosity at the IP.
- The AGS is a local to EIC, is an integral element of the EIC accelerator and should be made available after RHIC operations cease.

Richard Milner

We need polarized beam development at the AGS for the EIC.

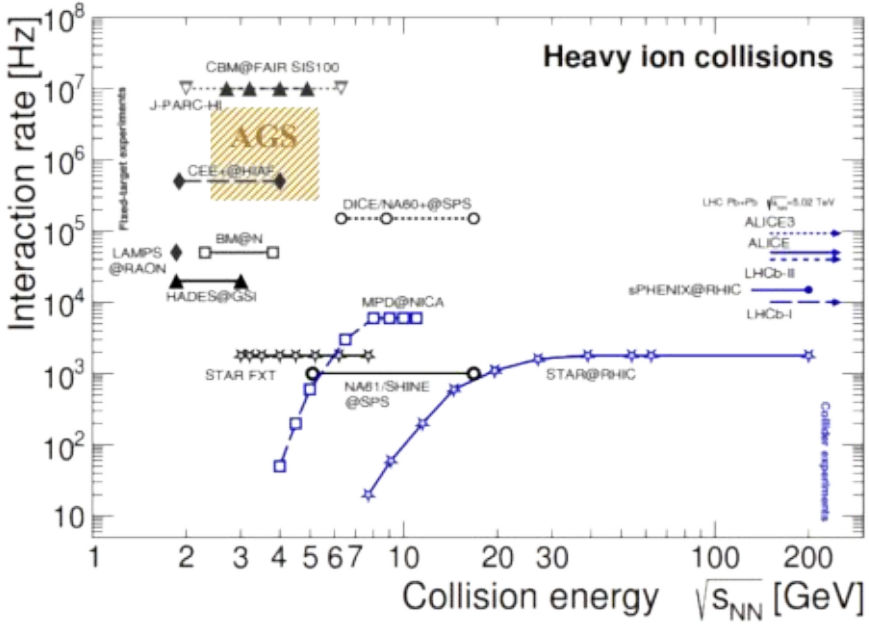
Fixed target experiments

Yasuyuki: The easy measurements have been done. “If you want to do a new heavy ion experiment at the AGS energy, you need to promise a new and very significant results that justify the cost and the effort”
Abhay: It must be unique. Need to keep the cost low.

What is NOT unique?

Experimental Landscape for High Facilities

Adapted from T. Galatyuk NPA (2019) 982



New Generation HI Experiments @AGS: complementary to CBM and/or aggressive timeline

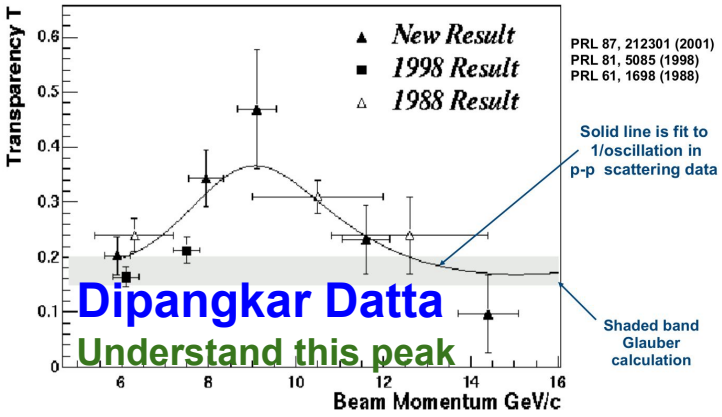
- Fixed target machines
  - Factor 100+ higher interaction rates
- CBM at SIS 100 @ GSI
  - Similar range as AGS
  - Similar interaction rate
  - Multipurpose experiment CBM
  - Timeline:

    CBM installation to start 2026
    SIS 100 commissioning at 2.7 GeV starts 2028
    Full performance 2030+
- DiCE at SPS @ CERN
  - Higher range up to 17 GeV
  - Dedicated dimuon/charm experiment
  - Timeline

    Proposal submitted 2025
    Projected installation 2029
    First physics 2030

Axel Drees

The enhancement observed in BNL (p,2p) experiment could be due to nuclear filtering of the oscillations in the cross section

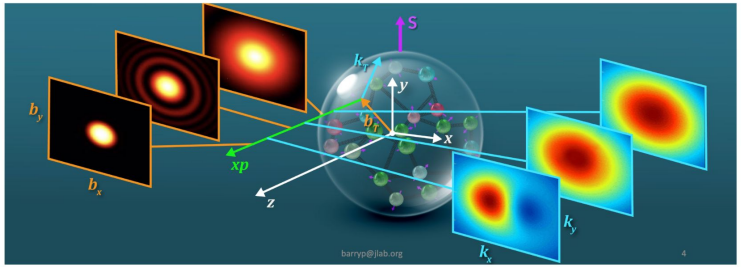


Dipangkar Datta

Understand this peak

Some context Review of TMDs & Factorization

3D structures of hadrons

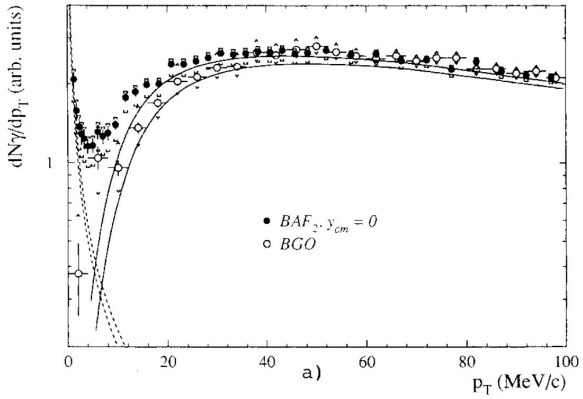


Leonard Gamberg

Transverse momentum distributions with polarized beams

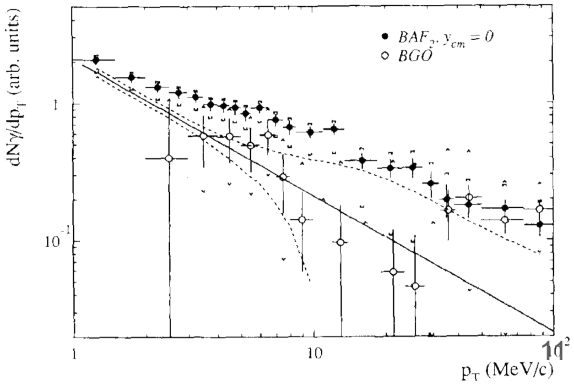
Axel Drees

Low momentum photons



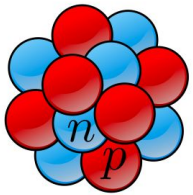
Direct Photons:

bremsstrahlung signal (consistent with Low's Theorem) + possible enhancement (hadronization?)



Hongkai Liu

What kind of new physics we can probe?



Features of ion beam:

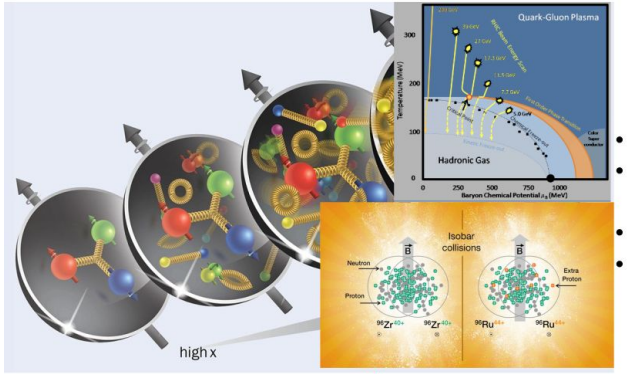
1. Carrying significant of baryon and electric charges
2. Low energy
3. Massive

} Soft emission of light bosons, not highly boosted

New bosons couple to baryon or electric charge

Target: a new light gauge boson that is long-lived and couples to baryon or electric charge

Baryon Junction at AGS?



Zhangbu Xu
Kent State University
BNL

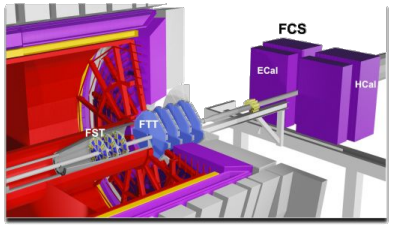
- baryon number carrier
- Three experimental approaches at RHIC (3+1)
- Other experimental results at FXT
- Future with AGS proton beam?

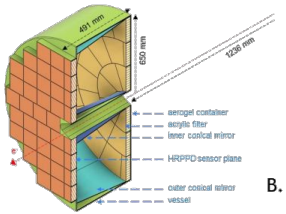
Zhangbu Xu

New Horizon of FXT at AGS 07/2025

Center for Nuclear Research | KENT STATE | Brookhaven National Laboratory | U.S. DEPARTMENT OF ENERGY | Office of Science

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





B. Page's talk

Kong Tu

Highlights:

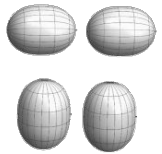
- Repurpose and reuse relatively new STAR forward detector system (both Tracking and Calorimeter)
- Expedite pfRICH (backward RICH) detector (or beam test prototype) in ePIC for PID (HRPPD has Timing)
- Low-cost in principle, and the detector has large acceptance with full tracking+PID+calorimetry

System scan at low energy?

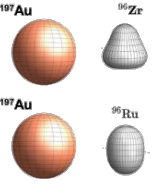
Jiangyong Jia

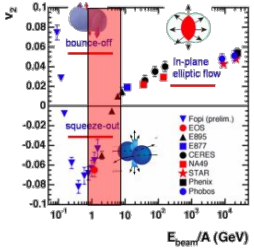
erturb the initial condition and observe the final-state responses, potentially with a large lever arm to probe the dynamics at similar volume. AGS is a unique facility for this

Stopping and expansion dynamics depend on orientation



Isobar collisions, either switch beam or the target





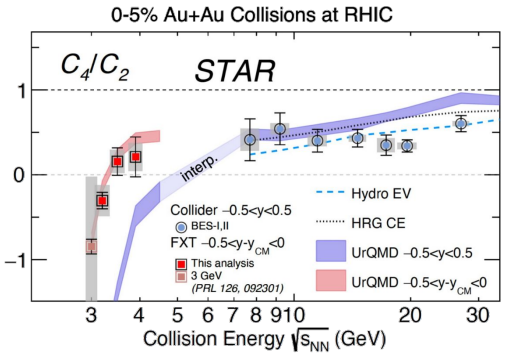
isobars	A	isobars	A	isobars	A	isobars	A	isobars	A	isobars
Ar, S	80	Se, Kr	106	Pd, Cd	124	Sn, Te, Xe	148	Nd, Sm	174	Yb, Hf
Ca, Ar	84	Kr, Sr, Mo	108	Pd, Cd	126	Te, Xe	150	Nd, Sm	176	Yb, Lu, Hf
Ca, Ti	86	Kr, Sr	110	Pd, Cd	128	Te, Xe	152	Sm, Gd	180	Hf, W
Ca, Ti	87	Rb, Sr	112	Cd, Sn	130	Te, Xe, Ba	154	Sm, Gd	184	W, Os
i, V, Cr	92	Zr, Nb, Mo	113	Cd, In	132	Xe, Ba	156	Gd,Dy	186	W, Os
Cr, Fe	94	Zr, Mo	114	Cd, Sn	134	Xe, Ba	158	Gd,Dy	187	Re, Os
Ni, Zn	96	Zr, Mo, Ru	115	In, Sn	136	Xe, Ba, Ce	160	Gd,Dy	190	Os, Pt
Zn, Ge	98	Mo, Ru	116	Cd, Sn	138	Ba, La, Ce	162	Dy,Er	192	Os, Pt
Ge, Se	100	Mo, Ru	120	Sn, Te	142	Ce, Nd	164	Dy,Er	196	Pt, Hg
Ge, Se	102	Ru, Pd	122	Sn, Te	144	Nd, Sm	168	Er,Yb	198	Pt, Hg
Se, Kr	104	Ru, Pd	123	Sb, Te	146	Nd, Sm	170	Er,Yb	204	Hg, Pb

$$R_{\mathcal{O}} \equiv \frac{\mathcal{O}_{X+X}}{\mathcal{O}_{Y+Y}} \approx 1 + c_1\Delta\beta_2^2 + c_2\Delta\beta_3^2 + c_3\Delta R_0 + c_4\Delta a$$

Dynamics is a strong function of $\sqrt{s}$, need collisions of the same isobar pairs at a few $\sqrt{s}$

AGS covers the range where the dynamics change the most

Results: Search for the Critical Point



Zachary Sweger (STAR, QM2025)

STAR: arXiv:2504.00817

HRG CE: P. B Munzinger et al, NPA 1008, 122141 (2021)
Hydro: V. Vovchenko et al, PRC 105, 014904 (2022)

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New BES-II data (FXT mode)

- ☐ New FXT data at 3.2, 3.5, 3.9 GeV out.
- ☐ Measurements done with half rapidity due to acceptance limitations
- ☐ Consistent with hadronic transport model UrQMD

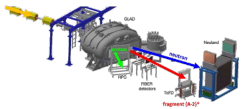
Ashish Pandav

Future

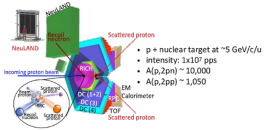
- 2N SRC precision era: High statistics + resolution + fully exclusive experiments
- Systematic studies for most neutron-rich nuclei
- Spectroscopy through (bound and unbound) fragment final state
- Search for 3-nucleon SRCs (inverse + normal kinematics)

Julian Kahlbow

R³B at FAIR



HADES at GSI



AGS?

- high intensity
- high energy/momentum transfer
- large angle (p,2p) measurement with backward recoil detection

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The Ideal Beam Test Facility - A Full Slice of ePIC

- ATLAS and CMS famously have (had?) full slices of their detectors in combined beam tests at SPS
  - Not sure how successful that was, but planning beam area to fit cannot hurt…

Can also serve as a detector!

Oskar Hartbrich

Physics Goals of the FXT Program

The Onset of Deconfinement:
- High p_T suppression
- N_{CQ} scaling of Elliptic Flow
- Strangeness Enhancement

Compressibility ➔ First Order Phase Transition
- Directed flow
- Tilt angle of the HBT source
- The Volume of the HBT source
- The width of the pion rapidity distributions
- The zero crossing of the elliptic flow (~6 AGeV)
- Volume measures from Coulomb Potential

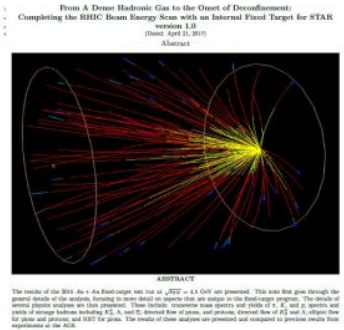
Criticality:
- Higher moments
- Particle Ratio Fluctuations

Chirality:
- Dilepton studies

Hypernuclei: ➔ Lifetime of the hypertriton

No measurements in this energy range

What a STAR FXT Program will not do:
- Omega's
- Charm
- Doubly Hyper nuclei
- p+p scan
- p+A scan
- peripheral collisions
- > 200 Million event per energy
- > two weeks of beam time


From A Dense Hadronic Gas to the Onset of Deconfinement:
Completing the RHIC Beam Energy Scan with an Internal Fixed Target for STAR
version 1.0
(Dated: April 21, 2017)
Abstract

ABSTRACT

Daniel Cebra

Some themes

- Multiple experiments leverage wide range of collision systems, energies
- Most proposals mentioned here could work with a large acceptance tracking detector with PID capabilities
- Perhaps some of this could be done with EIC prototype detectors?

NASA Has Identified High Energy Measurements as a Critical Need

- The *International Biophysics Collaboration* (IBC) considers studies relevant to space radiation protection, ion therapy, and other biophysics applications.

- Within IBC, a *Cross Section Working Group* was formed to assess and prioritize the needs for new measurements.

- The working group identified light nucleus production from heavy ion (Z = 2-26) induced reactions, with beam energies from 5-50 GeV, on targets of interest (C, Al, Fe) measurements as a key decadal need.
  https://doi.org/10.3389/fphy.2020.565954

This sounds a lot like a job for the mini-DIRC

Daniel Cebra

What is unique?

Flexibility in systems! Many proposals here.

Polarized beams! But unclear now what beams might be available. No ideas presented here capitalize on that!

Where do we go from here?

Position paper

- The case for a test beam

The case for polarized source development

- Prospectives for a physics program