Beam-Hjet breakup tagging: RHIC Run22 tests

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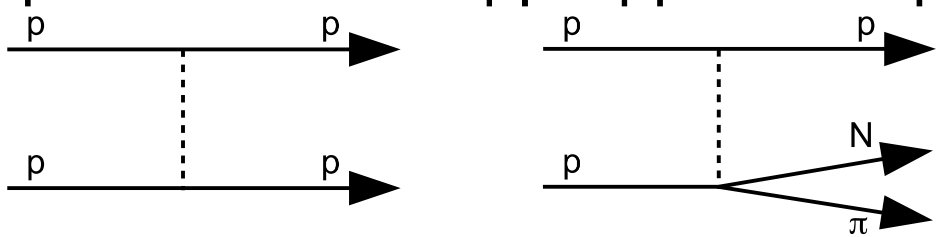
mtg. 11.05.22

- Motivation:
  ^{3}He absolute polarimetry, breakup tagging
- Tests @ RHIC:
  Hjet & ZDCs @ IP12
- Some results:
  ZDC signals & rates, beam correlation,
  beam-target correlation
- Tests @ future RHIC runs:
  ZDC improvements, DAQ improvements

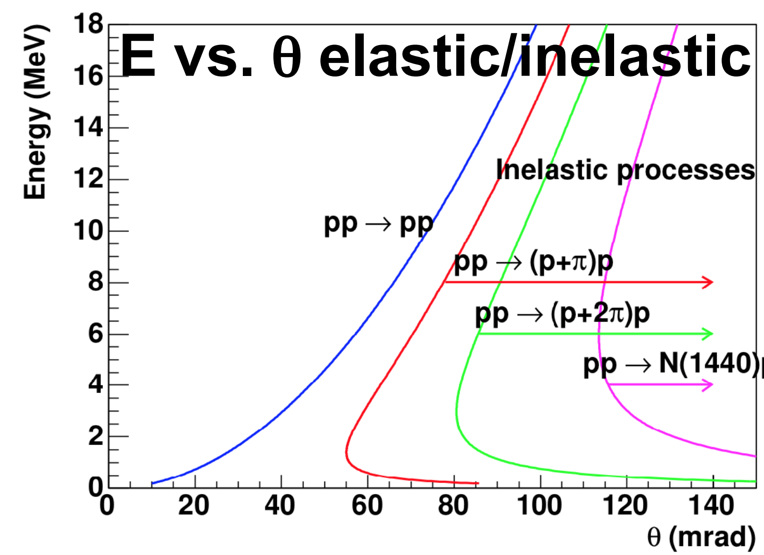
Motivation: ^{3}He breakup tagging

- Absolute polarimetry requires elastic scattering
- Proton polarim.: elastic pp→pp versus pp→pX



- Lowest lying p breakup state is p→Nπ,

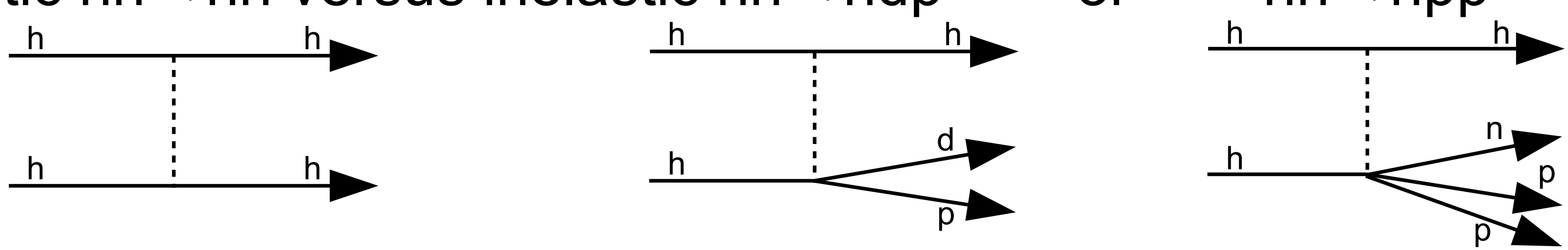
  $\Delta m = m_\pi \sim 140$ MeV



- Hjet detectors have E,θ resolution sufficient to separate elastic/inelastic

- ^{3}He≡h polarim.:

  elastic hh→hh versus inelastic hh→hdp or hh→npp



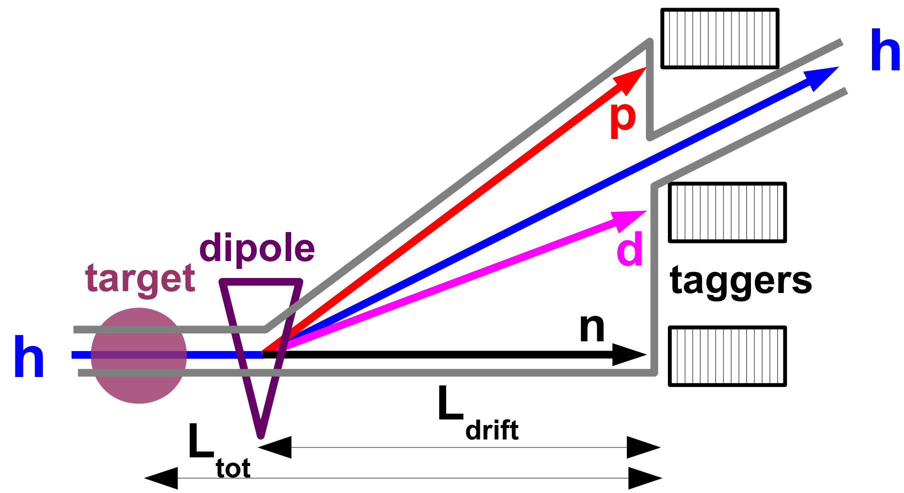
$\Delta m = 5.5$ MeV $\Delta m = 7.7$ MeV

- Hjet detectors lack E,θ resolution to distinguish few MeV Δm

Can we directly tag ^{3}He breakup fragments?

Tagging ^{3}He (≡h) breakup @ EIC

- Implementation @ EIC might look like:

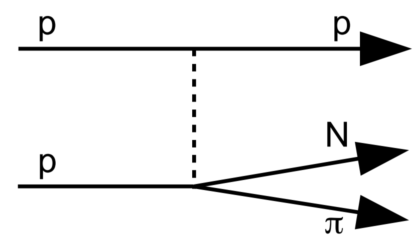


- Require arrangement:
  polarized target → some dipole → drift space → taggers
  (details extra slide)

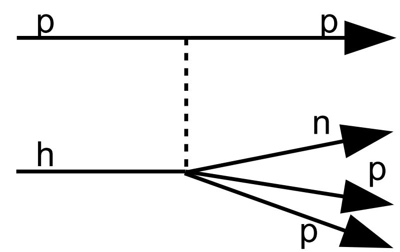
- Looking for a home:
  Ongoing discussion w/ EIC Hadron Storage Ring planners
  Zhengqiao running simulations

Beam breakup tag test @ RHIC: setup

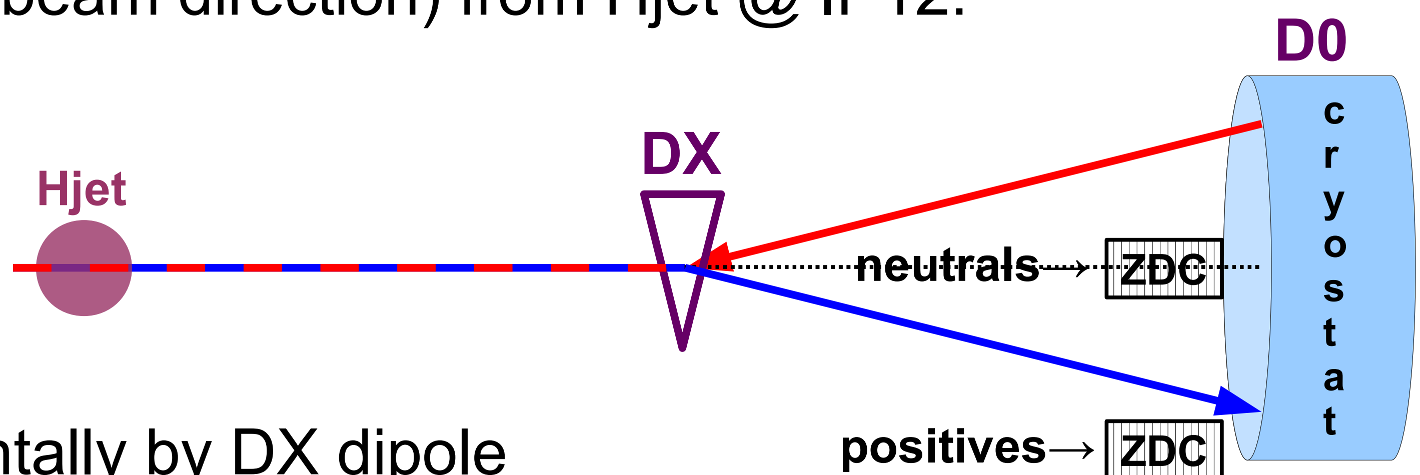
- Can test with
  - proton beam on Hjet proton target:



  - ^{3}He beam, Hjet proton target:



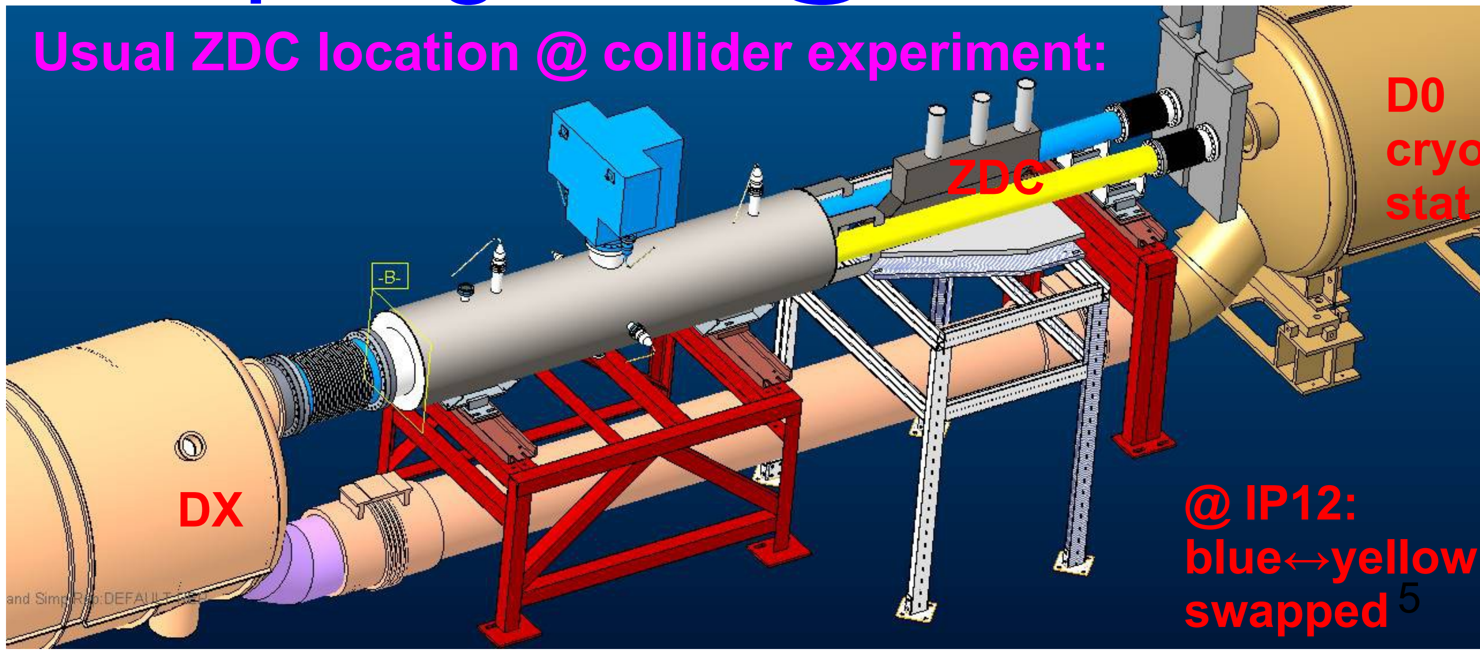
- Downstream (Blue beam direction) from Hjet @ IP12:



- Beams bent horizontally by DX dipole
- Space for taggers up to ~19 m → cryostat
- Beam fragments swept out of beam:
  - neutrals @ 0° (usual ZDC location collider expts.)
  - positives $p<p_{beam}$ may leave beampipe before cryostat

Beam breakup tag test @ RHIC: setup

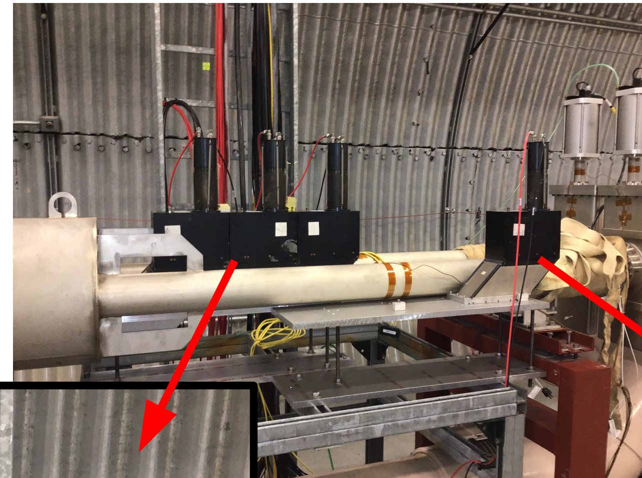
- Old drawing setup @
  IP2 (BRAHMS)
  IP6 (STAR)
  IP10 (PHOBOS)



- PHOBOS ZDCs installed @ IP12 November 2021
- neutrals: 3 ZCD modules between beam pipes (usual config.)
- positives : 1 module outside Blue b.p.
  (other modules missing PMTs)

Beam breakup tag test @ RHIC: setup

- Give some **labels** to the modules, **n**eutrals & **p**ositives:

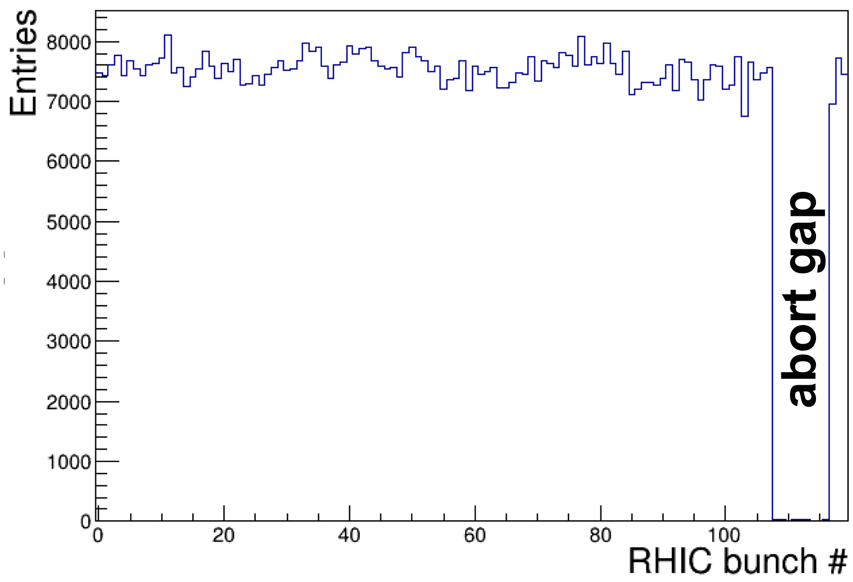


- 1st look with beam: no signals from **nC** ☹
  not clear why; PMT? need to check cables...
- Least important module, little energy in rear

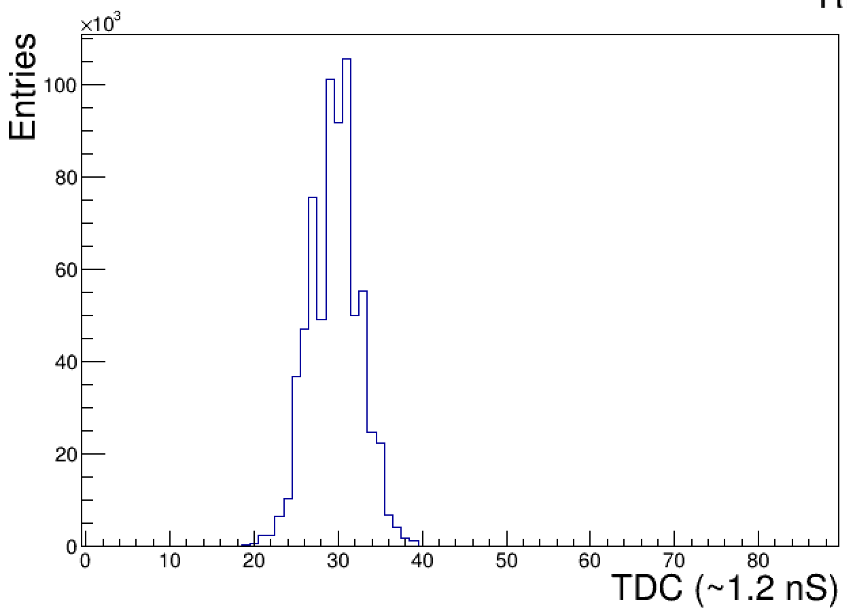
Breakup tag test @ RHIC: signals

- Outputs of ZDCs plugged into spare channels in pC polarimeter readout, measure hit times, energies, rates

- RHIC bunch distribution of hits follows RHIC bunch pattern, w/ 9 bunch 'abort gap'
- Normally 111-119, shifted earlier by 3
  - pC readout timed for pC polarim. ~50m downstream of ZDCs
  - cables ZDCs→readout shorter



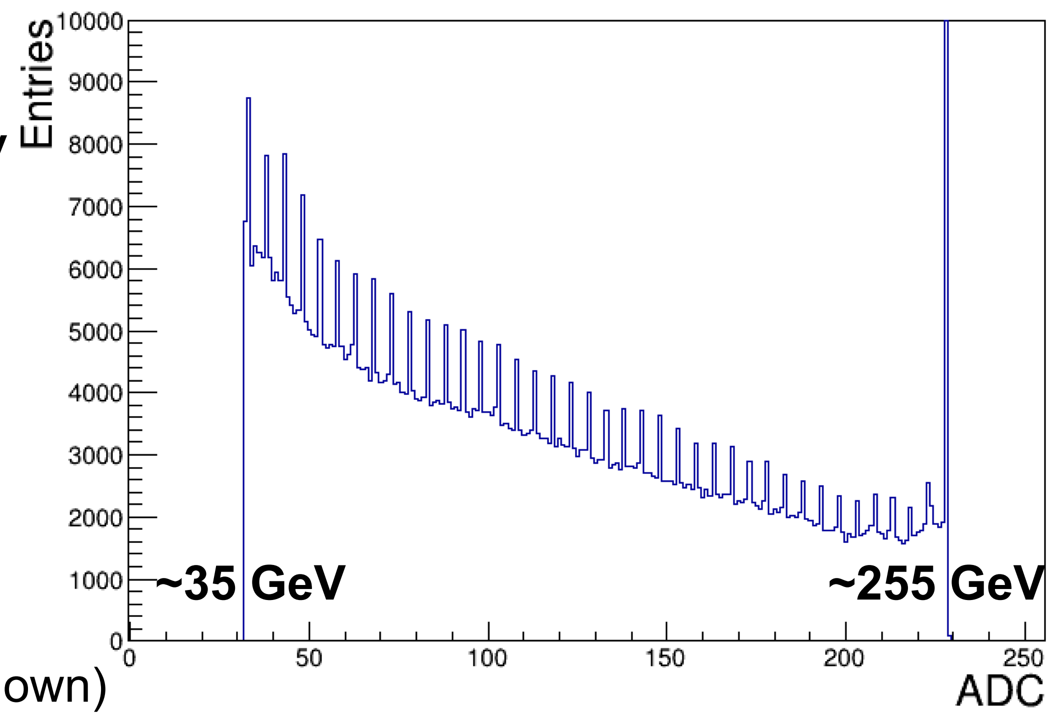
- TDC distribution consistent with RHIC bunch length



ZDC signals correlated with RHIC p-beam

Breakup tag test @ RHIC: signals

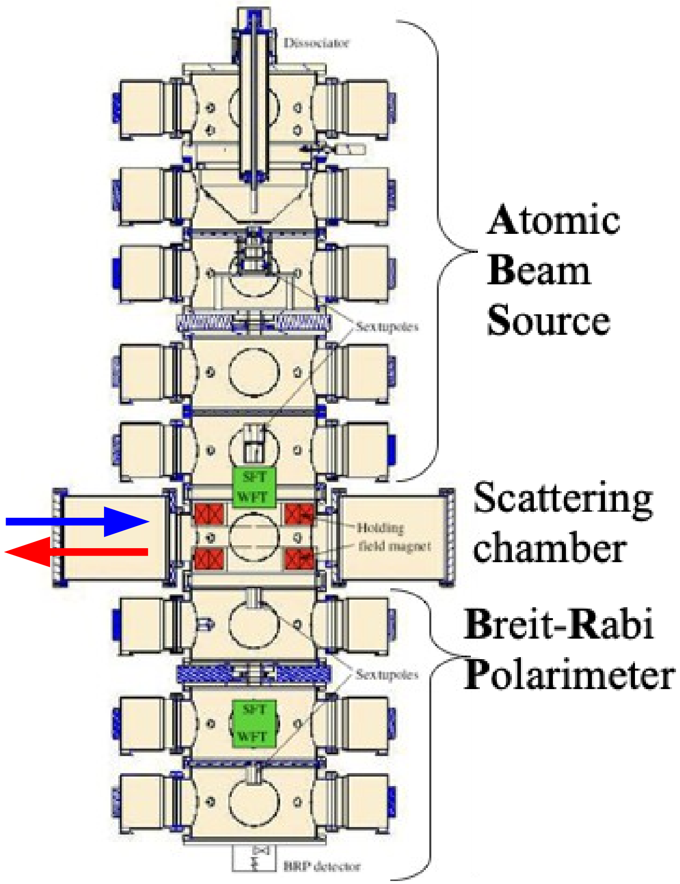
- PMT HV raised until endpoint clear in ADC saturation peak (255-baseline) ~ $E_{p\text{-beam}}$ = 255 GeV
- Trig. threshold ~35 GeV
- Peak structure every ~5 bins some WFD artifact (???)
- Featureless distribution i.e. no neutron peak (expected for pp → Xn)
- Similar for all 3 ZDC modules (nA shown)



Rates @ nominal proton current, Hjet density:

- nA ~ 70 kHz
- nB ~ 33 kHz
- pC ~ 22 kHz
- nA.or.nB ~ 80 kHz
- nA.and.nB ~ 24 kHz ← cleanest neutron selection
- nA.and.nB.and.pC ~ 8.5 kHz

Hjet target

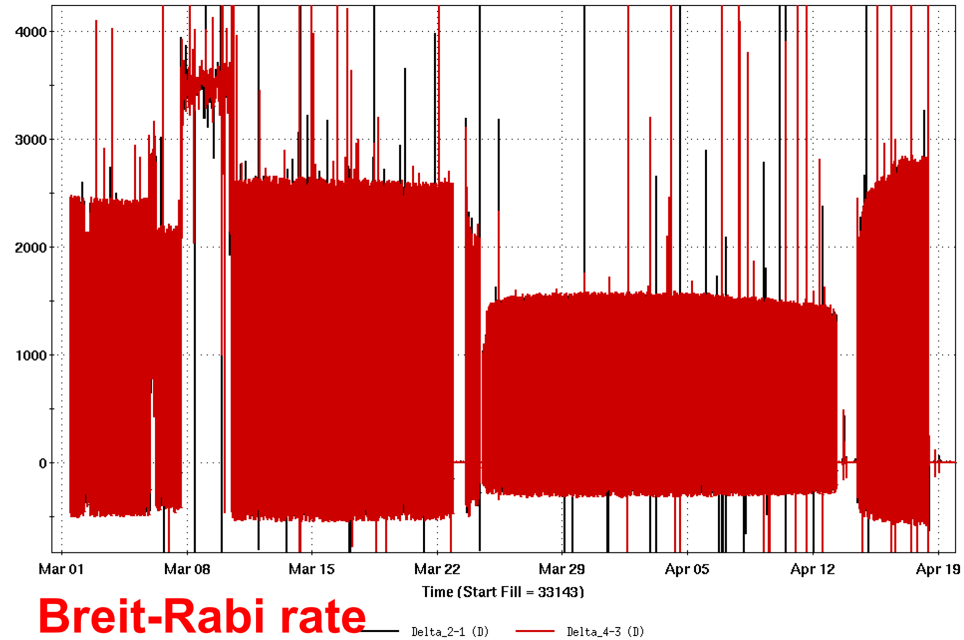


- A shutter can close off
  atomic beam → scattering chamber
  Hjet target density → 0

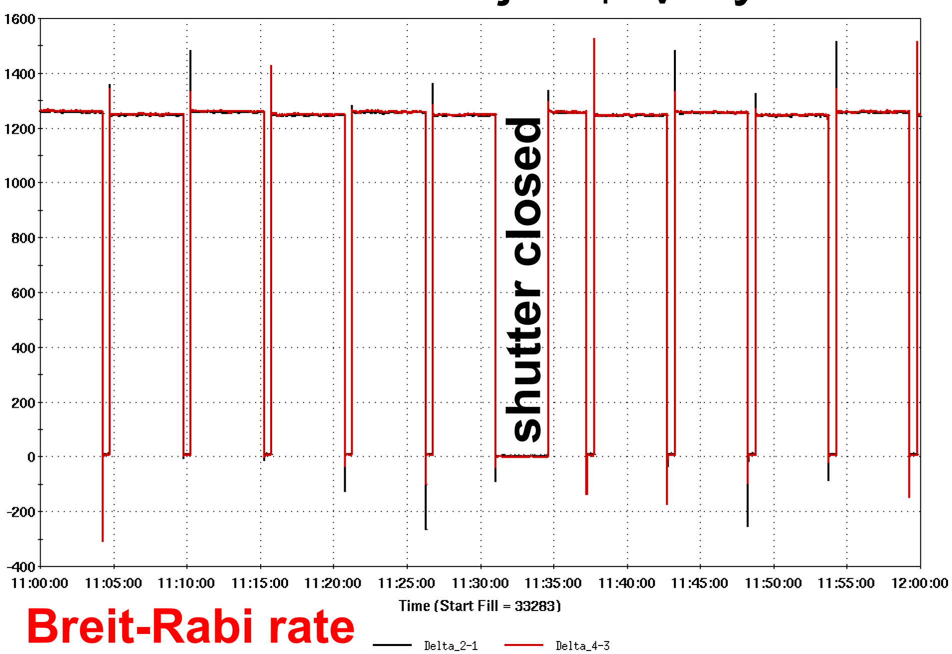
- Rate from Breit-Rabi polarim.
  $\propto$ Hjet target density

Hjet target density

- Hjet target density fairly constant over RHIC run
- Few weeks near end ~50% nominal
- Last days repaired, nominal



- During 50% period:
  - shutter closed few minutes
    (thanks A. Zelenski)
  - took several measurements
    before/during/after shutter closed
- Normal 5 min Hjet ↑/↓ cycle visible

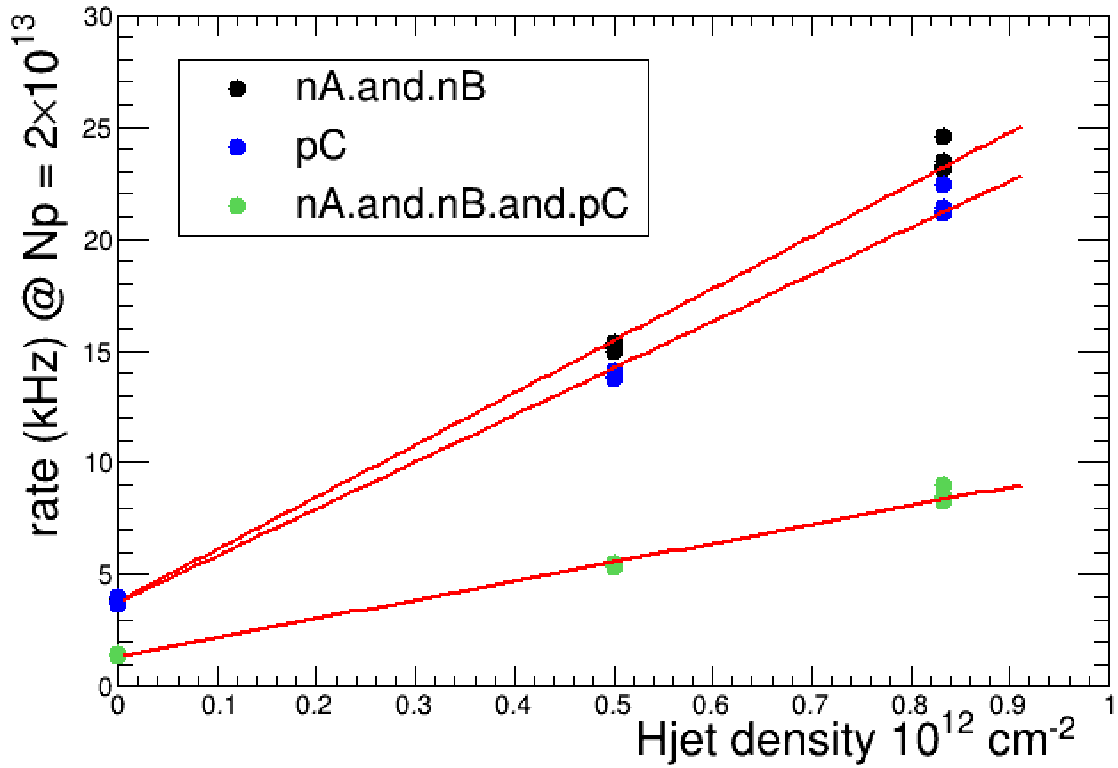


- Several more measurements after
  Hjet repaired, density ~83%

- Nominal Hjet density ~ 10^{12} cm^{-2}
  (A. Zelenski)

Rate vs. Hjet target density

- Beam backgrounds & beam-target rates ∝ proton beam current
  ⇒ normalize rates to nominal $N_p = 2\times10^{13}$ (few % variation data sets)
- Normalized rates vs target density:

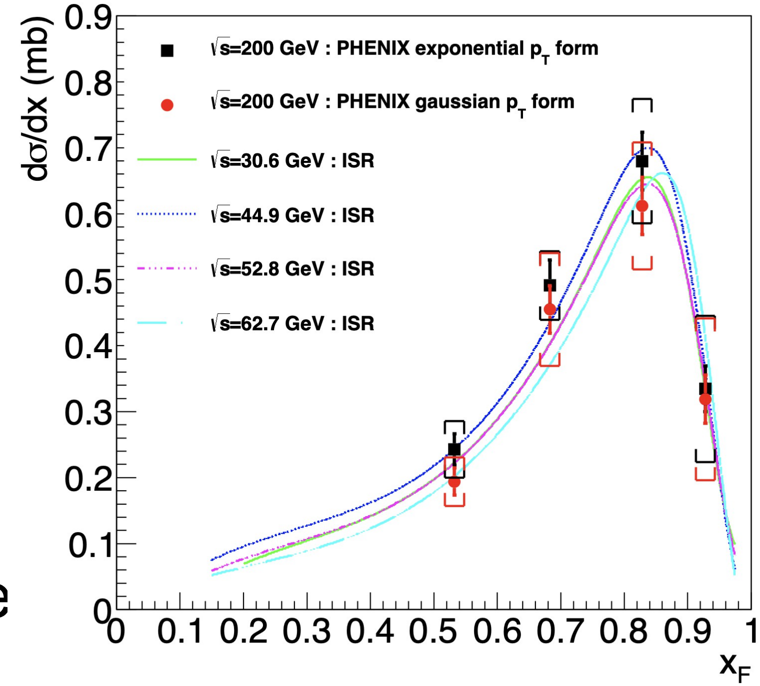


Luminosity
- RHIC $N_p = 2\times10^{13}$
- density = 10^{12} cm^{-2}
- L = 2000 mb^{-1} sec^{-1}

- Beam background @ zero density
- Beam-target signal linear in target density:
  ZDC signals correlated with beam-target interactions
- Slope ∝ cross section; e.g.: nA,nB coincidence $\sigma \approx 12$ mb

Neutron cross sections

- PHENIX had identical ZDC geometry
  (but better instrumented ZDCs, more later)
- Publication pp→Xn, $\sqrt{s}$ = 200 GeV
  Phys.Rev.D 88 (2013) 3, 032006
- Neutron cross section ~0.3 mb
- > order magnitude less than
  our coincidence @ $\sqrt{s}$ = 22 GeV
- We probably have a lot of beam-target
  backgrounds, e.g. scraping in beampipe

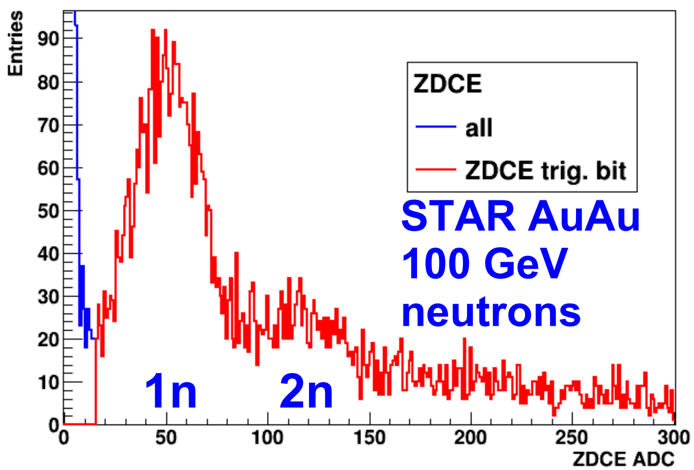


- Hjet elastic cross section @ low-|t| (recoil in detector acceptance)
  ~ 0.2-0.3 mb
- Measured (PHENIX) & observed (here) neutron cross sections
  up to order magnitude larger: purely hadronic
- |t| range Hjet recoils is Coulomb-Nulclear Interference (CNI) region
  additional factor α_{EM} in cross sections
- (Hjet recoil + breakup neutron) small fraction of
  purely hadronic breakup neutrons

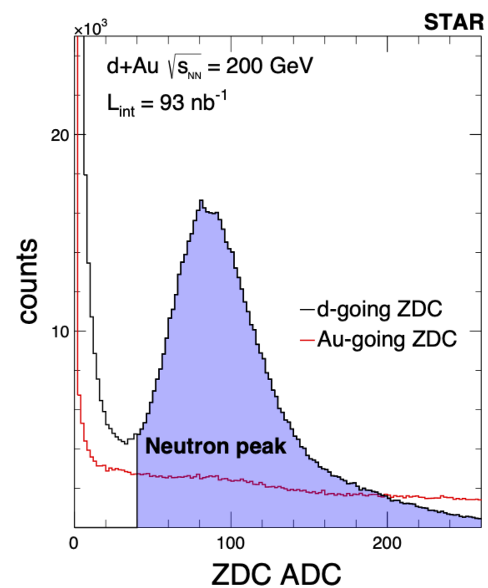
Next RHIC runs

- This year's RHIC run was highly problematic
- Heroic efforts of RHIC staff: physics goals achieved
- But no time left for planned ^{3}He beam tests
- Next (last) RHIC runs, all √s = 200 GeV: 2023&2025 AuAu 200
  2024 pp & pAu

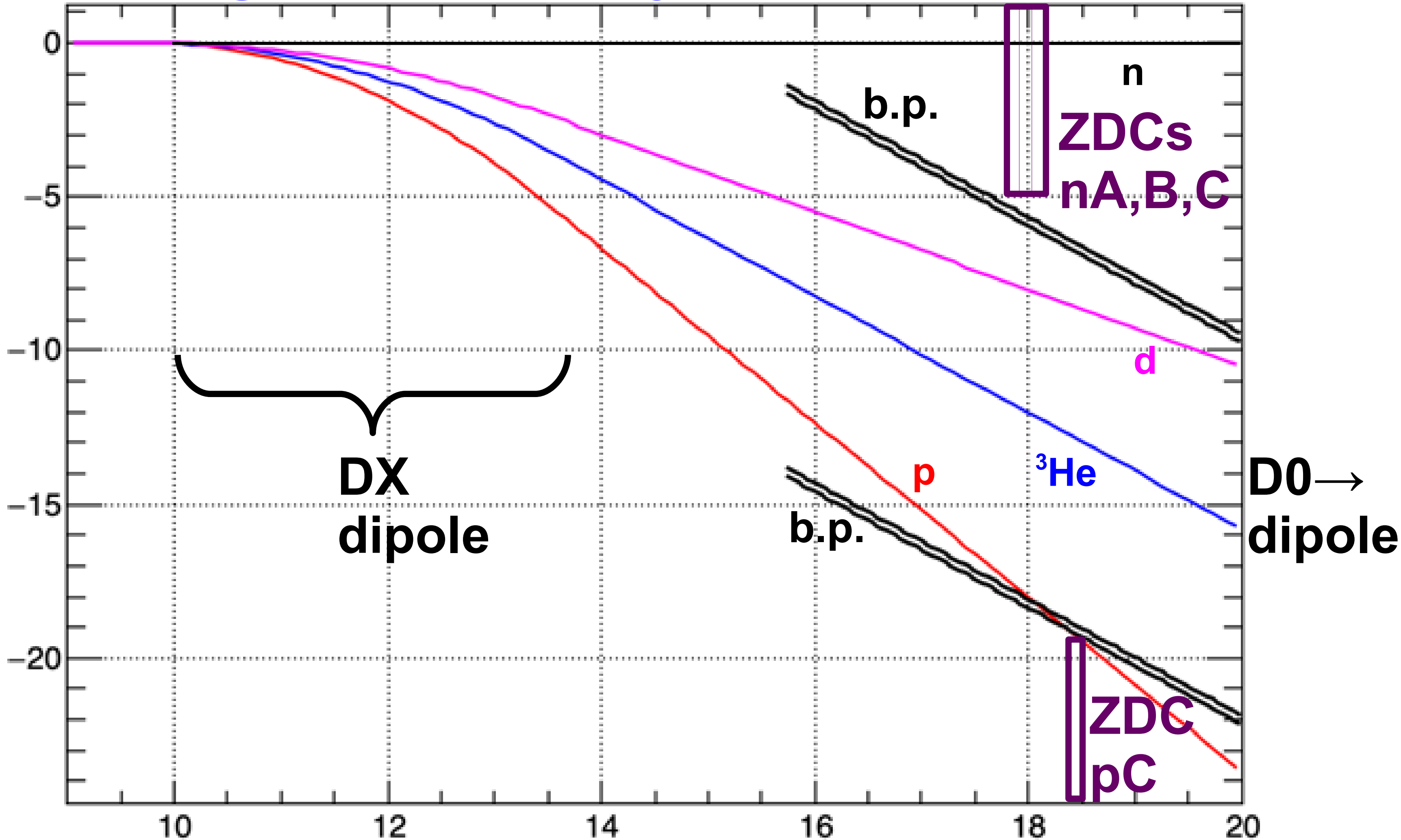
- In AuAu runs:
  single neutron peak from
  Au breakup, calibrate ZDCs



- Hopefully can have
  ^{3}He test runs
- Light ions, very clean
  single neutron peak
  here from dAu:
- Count neutrons
- And further study
  ^{3}He breakup ↘



^{3}He fragment trajectories DX→D0

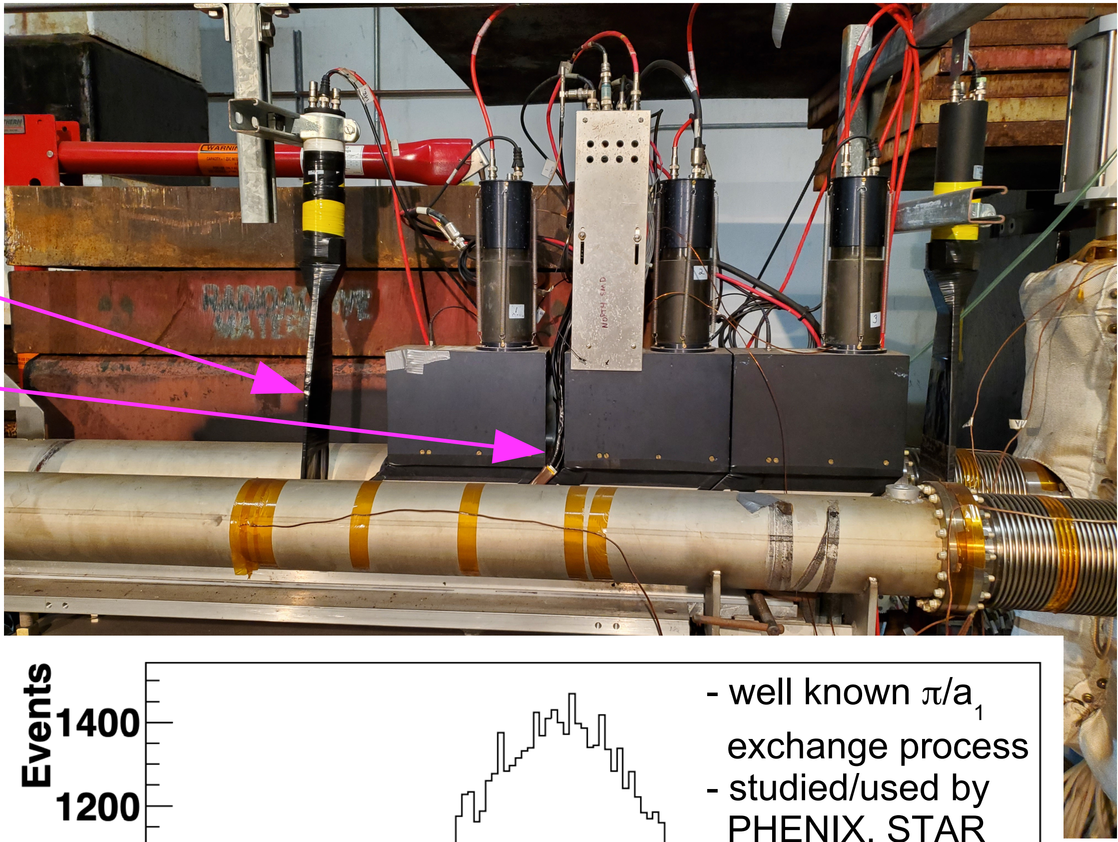


Beam ^{3}He (rigidity R=1) and fragments @ rest in beam frame:

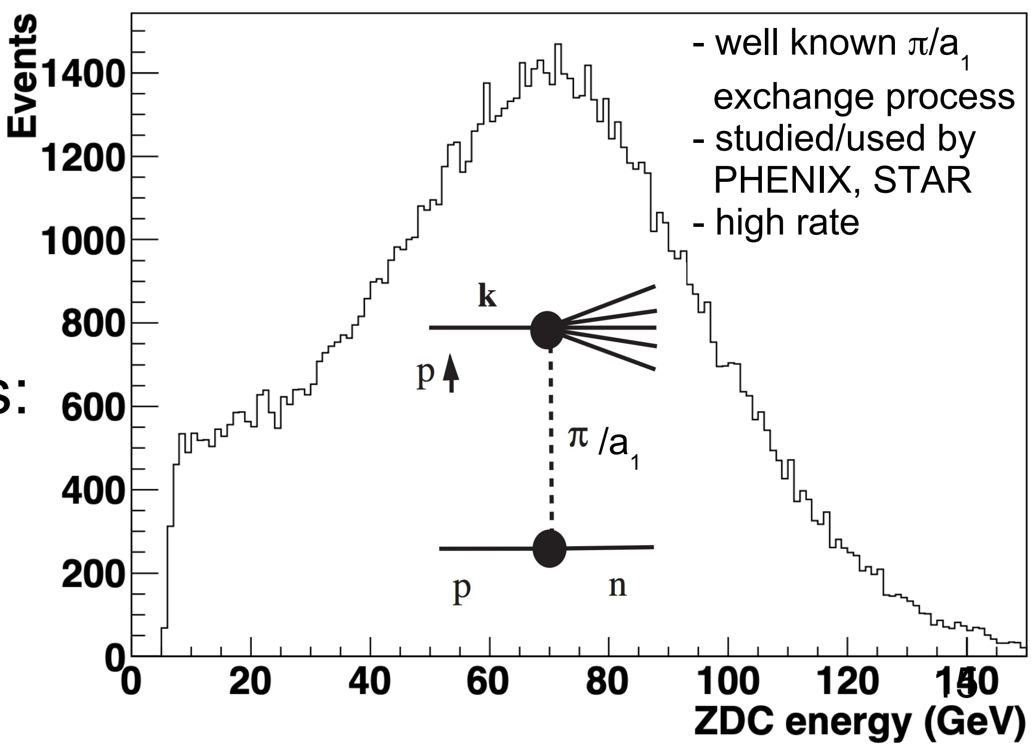
- neutrons (R=∞) exit b.p. ~cleanly
- deuterons (R=4/3) exit b.p. in D0 dipole, not detectable
- protons (R=2/3) exit b.p. at shallow angle, showering
  barely scrape outer ZDC module

ZDC improvements

- Our ZDCs are 'bare' calorimeters
- PHENIX had more (scintillators):
  - veto counter in front
  - hodoscope between 1st & 2nd modules



- Used to clean neutron signal:
  - reject veto hits: preshowers
  - require energy in hodoscope: reject EM showers
- Resulted in nice $E_{neutron}$ spectrum, similar to expectations:



- Could add same info for our ZDCs:
  - 2 small scintillation counters ~ 10 cm × 15-20 cm
  - Cables & HV already there

DAQ

- Ultimate study:
  correlate breakup tags w/ Hjet recoil protons
- Need taggers & Hjet in same data flow (DAQ)
- Rate problem: Hjet recoil channels ~10 Hz
  ZDC channels 10's kHz
  ZDC will rapidly fill buffers

Mitigation:

- Hjet recoil chans. read out full wave form, ~ 80 points
  For ZDC chans. read out only waveform amplitude, time?
- Can we trigger ZDC chans. only when an Hjet recoil hit?

These are questions for DAQ expert A. Poblaguev...

Summary

In RHIC Run22:

- We observed proton beam breakup in Hjet target interactions

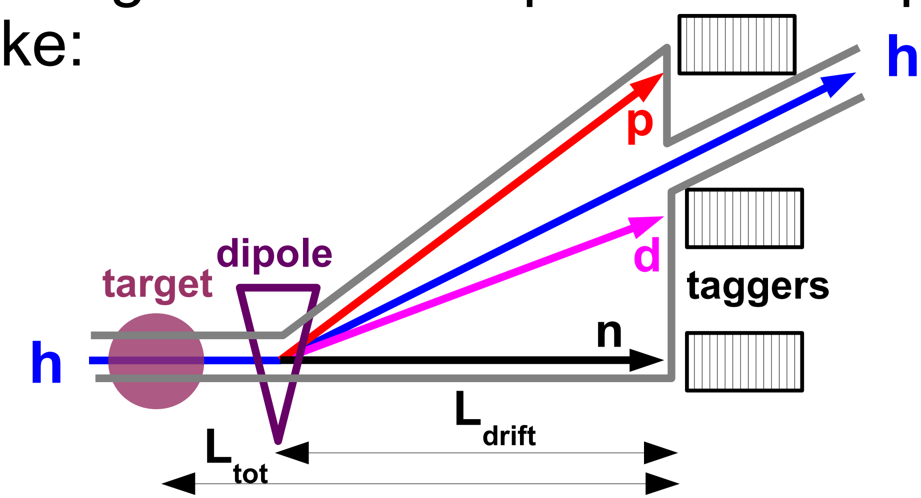
AHEAD

- Improve tagging:
  - Replace PMT?
  - ZDC + scintillators
  - readout in Hjet DAQ?
- Future RHIC runs:
  - AuAu or light ion run, calibrate ZDCs w/ single-n peak
  - ^{3}He (or d), measure light ion breakup

Extras

Tagging ^{3}He (≡h) breakup @ EIC

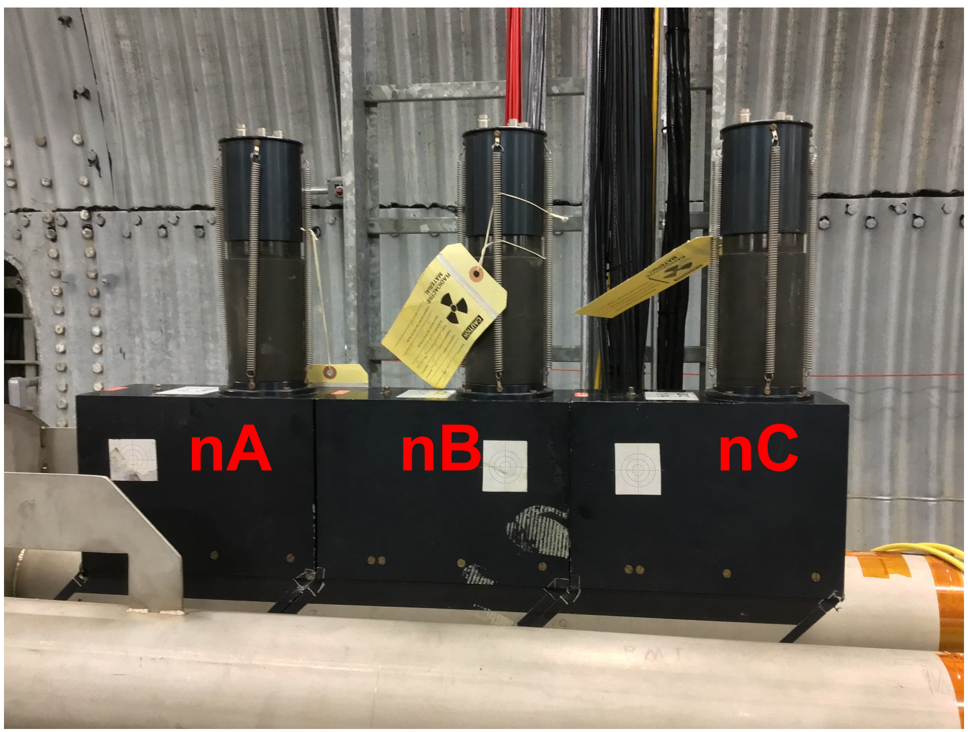
- At breakup threshold, fragments travel colinearly with beam; fraction of beam rigidity R_h: $R_d = 4/3R_h$; $R_p = 2/3R_h$; $R_n = \infty$
- Dipole single bend approx., beam bent by θ_h: $\theta_d = ¾\theta_h$; $\theta_p = 3/2\theta_h$; $\theta_n = 0$
- <u>Require:</u> arrangement target → some dipole → drift space → taggers might look like:



- <u>Require:</u> drift space L_{drift} long enough to get fragments out of beampipe vacuum and into taggers
- Fragments from breakup @ threshold define 0° point in taggers; breakup above threshold spread around this point
- <u>Require:</u> total target→tagger distance L_{tot} as small as possible, maximize tagger angular acceptance

ZDC modules

- W-Cherenkov fibers
- Each module
  1.7 interaction lengths



C. Adler et al. / Nuclear Instruments and Methods in Physics Research A 470 (2001) 488–499

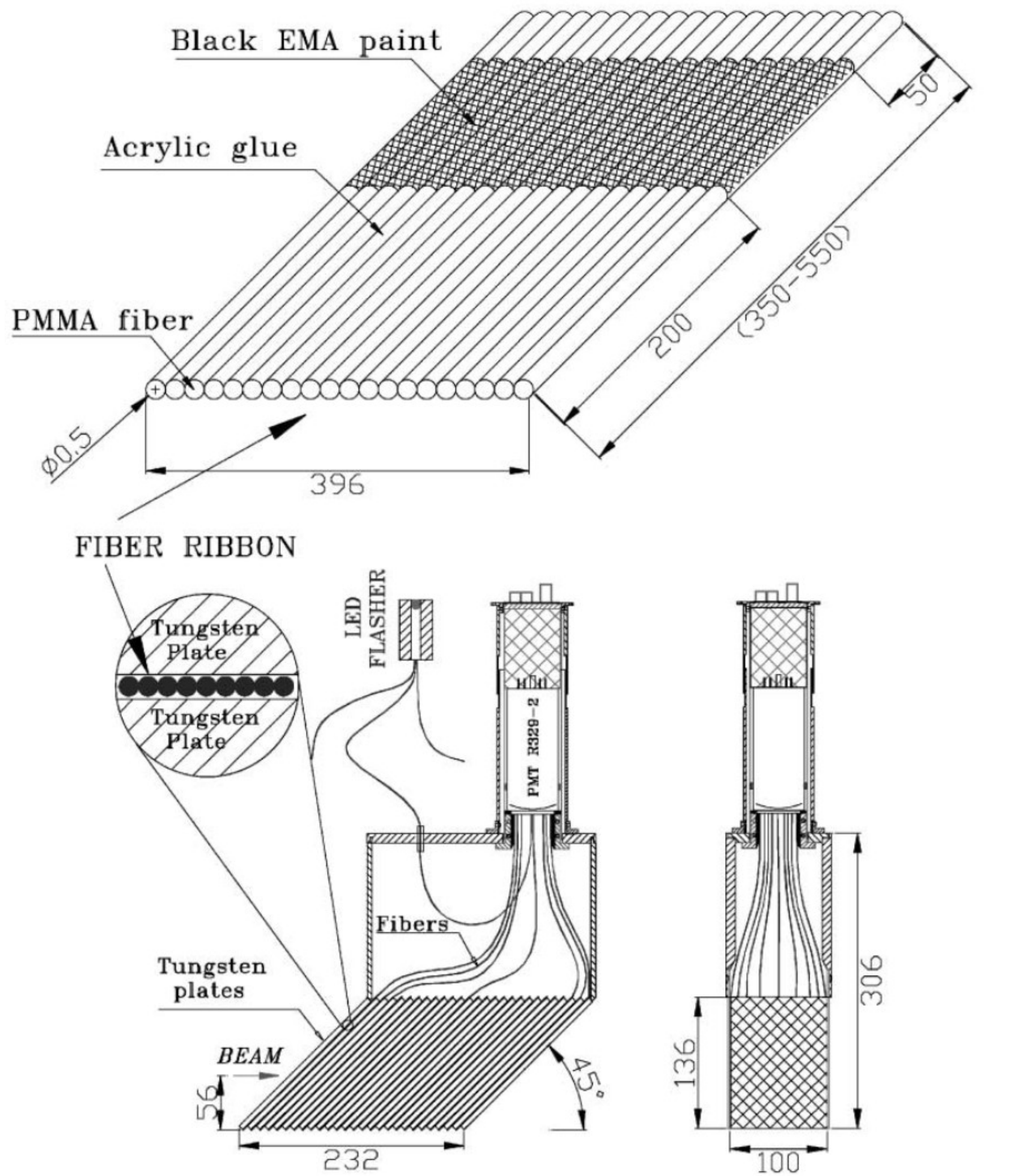


Fig. 5. Mechanical design of the production tungsten modules. Dimensions shown are in mm.