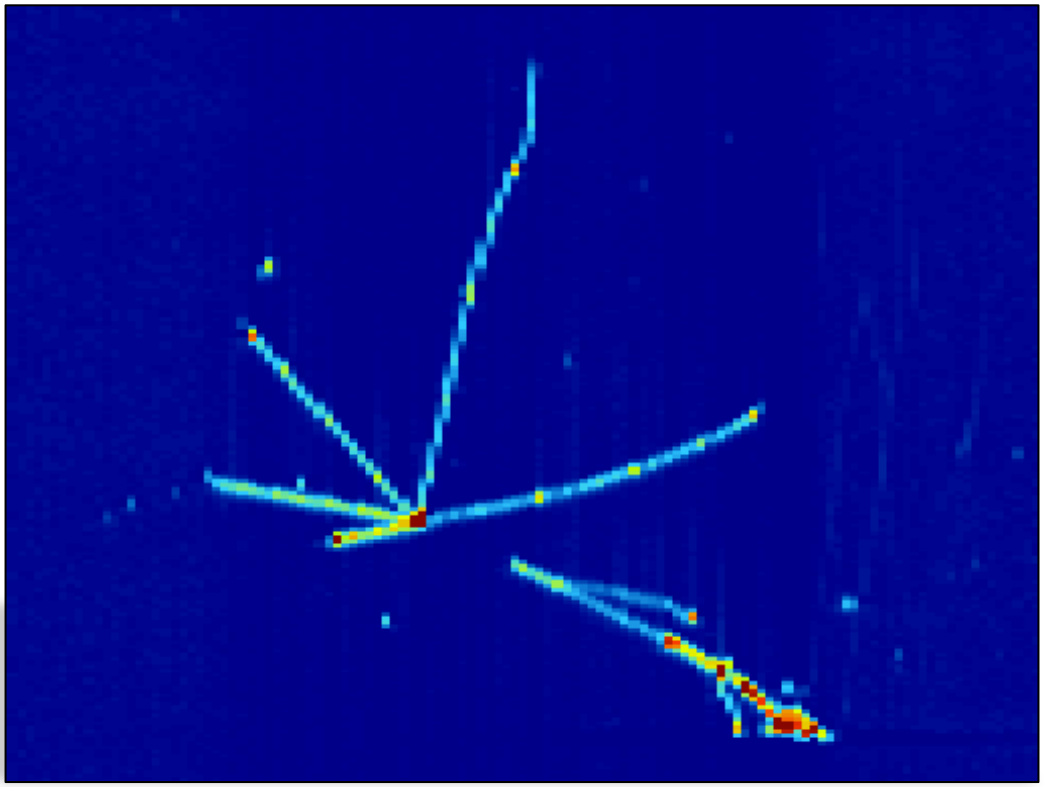
Antiproton Annihilation on Argon Nuclei in LArIAT



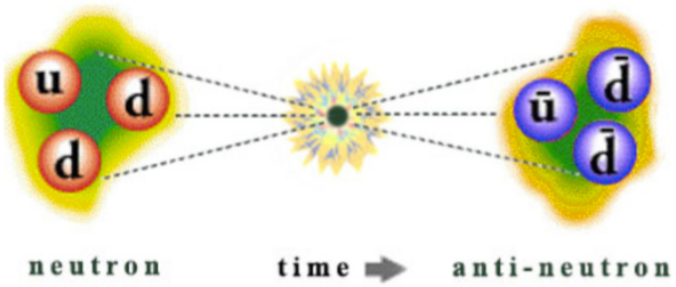
William Foreman, University of Chicago

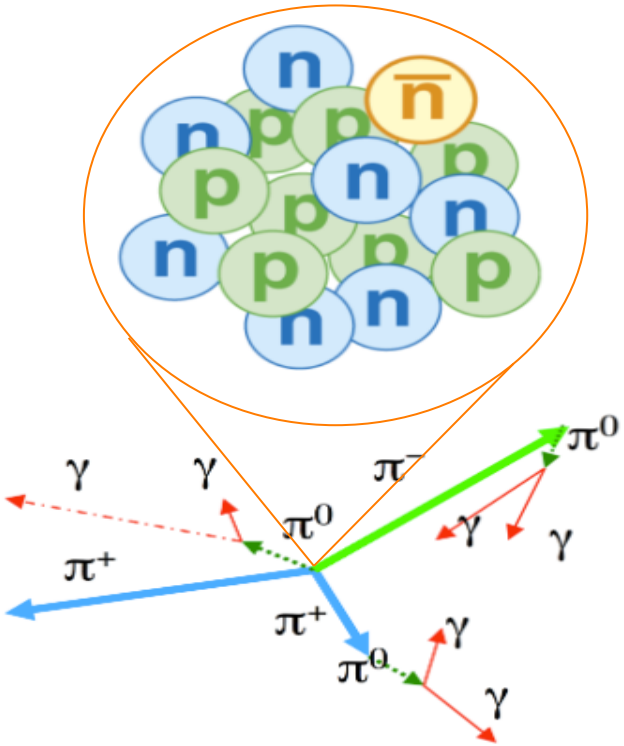
On Behalf of the LArIAT Collaboration

DPF 2017 – Fermilab

Wednesday, August 2, 2017

Motivation: Neutron-Antineutron Oscillation





- Feature of many BSM theories
- For *bound* neutrons, signature is decay products from subsequent annihilation of oscillated neutron with a neighboring nucleon

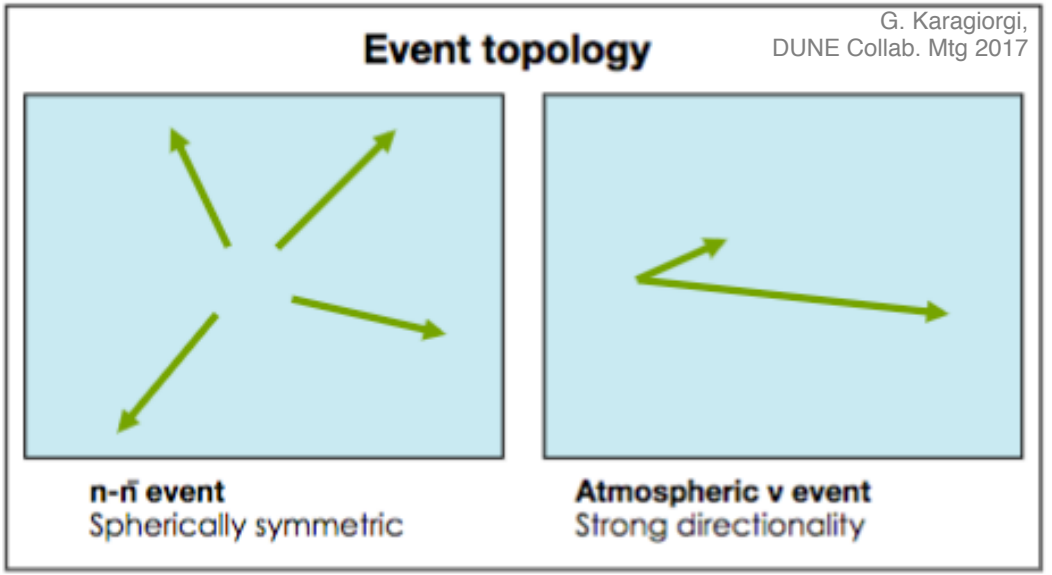
$$\tau_{\mathrm{bound}} = R \cdot \tau^2_{\mathrm{free}}$$

$\bar{n}+p$		$\bar{n}+n$	
$\pi^+\pi^0$	1%	$\pi^+\pi^-$	2%
$\pi^+2\pi^0$	8%	$2\pi^0$	1.5%
$\pi^+3\pi^0$	10%	$\pi^+\pi^-\pi^0$	6.5%
$2\pi^+\pi^-\pi^0$	22%	$\pi^+\pi^-2\pi^0$	11%
$2\pi^+\pi^-2\pi^0$	36%	$\pi^+\pi^-3\pi^0$	28%
$2\pi^+\pi^-2\omega$	16%	$2\pi^+2\pi^-$	7%
$3\pi^+2\pi^-\pi^0$	7%	$2\pi^+2\pi^-\pi^0$	24%
		$\pi^+\pi^-\omega$	10%
		$2\pi^+2\pi^-2\pi^0$	10%

arXiv:1109.4227, Super-K Neutron-Antineutron Oscillation Search (2015)

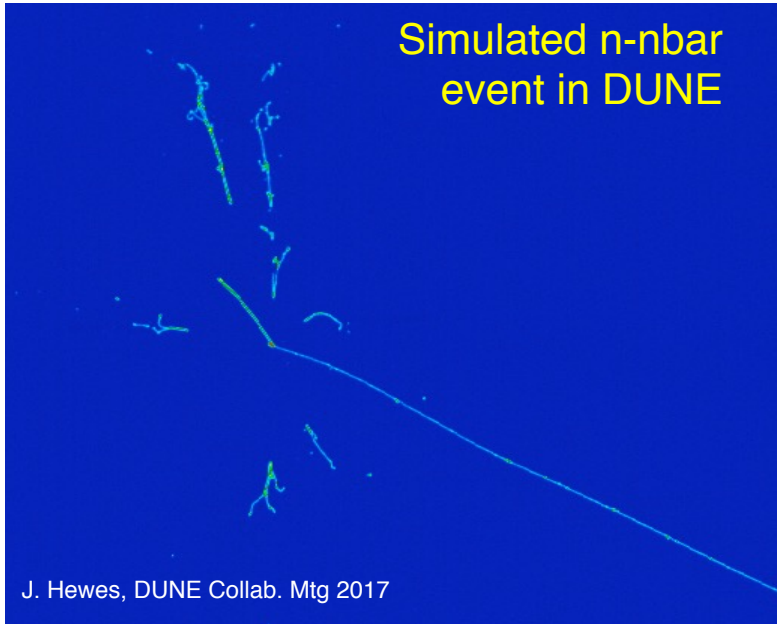
Search for n-nbar in a LArTPC

- **Star-like topology** & **final state energy ($E_f \sim 2m_pc^2$)** distinguishes from primary background

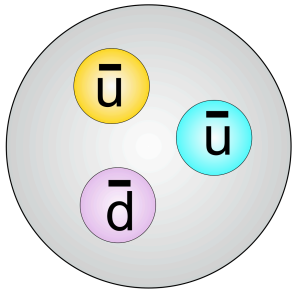


- DUNE expected to set τ (free) limit of ~1.7×10^9 s at 90% CL over 10yrs, a **x5** improvement on existing limit by Super-K of 2.7×10^8 s

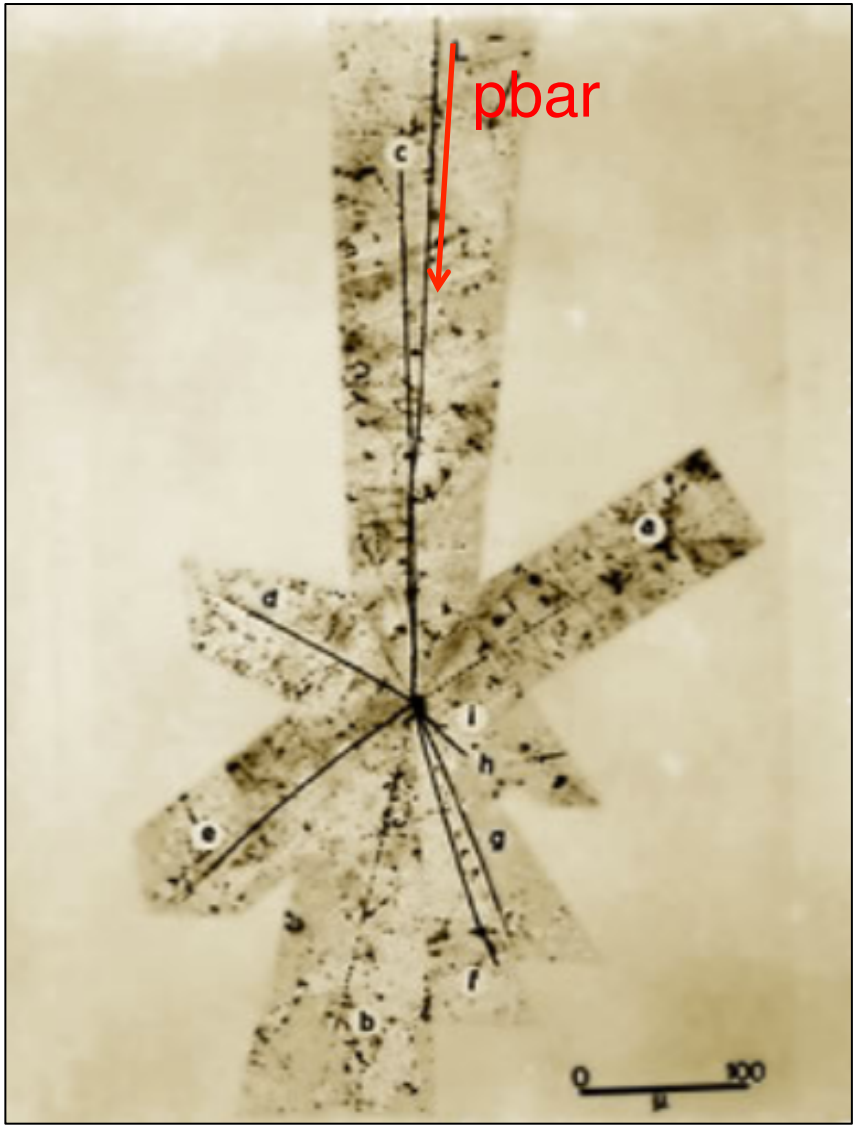
  See poster by Georgia Karagiorgi, and talk on 8/3 by Joshua Barrow!



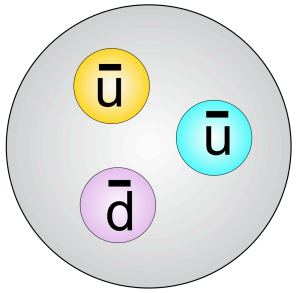
Antiproton Annihilation



Annihilation star first observed in photographic emulsion experiment in 1955 at UC Berkeley
(Chamberlain, Segrè, Wiegand, Ypsilantis, Goldhaber)



Antiproton Annihilation



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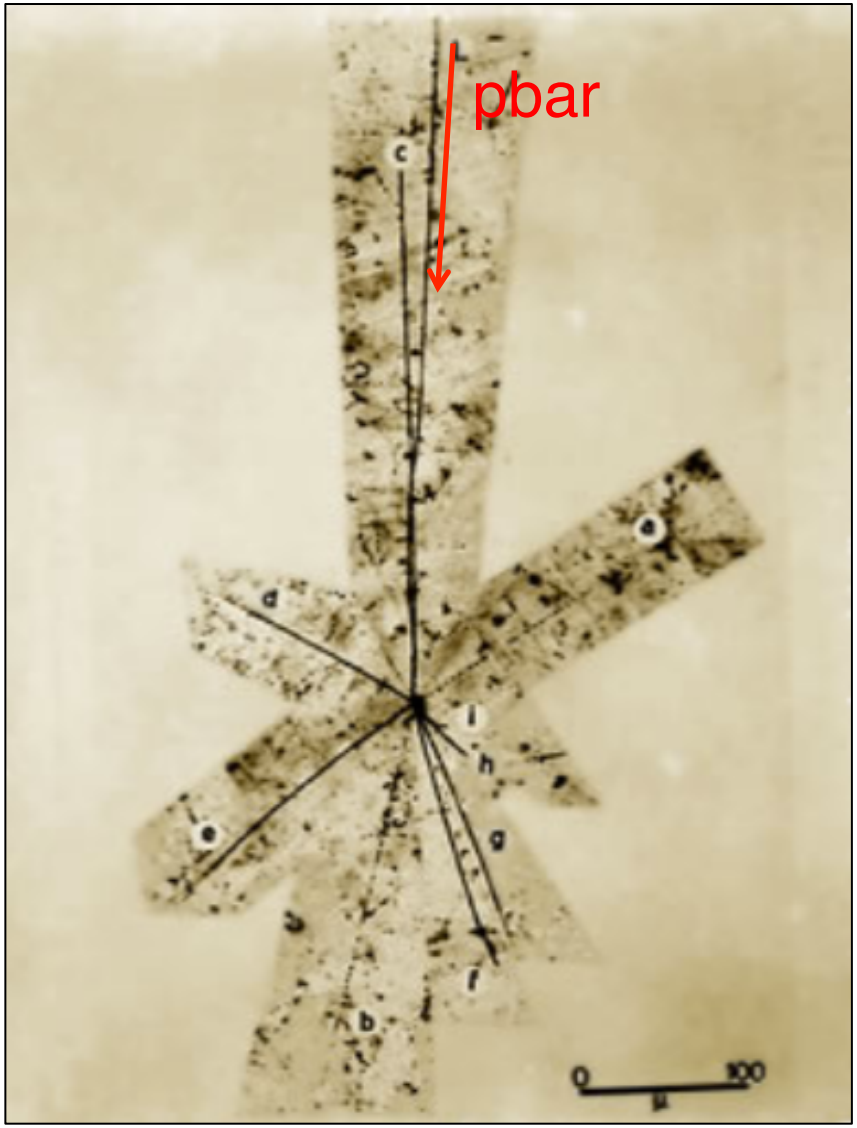
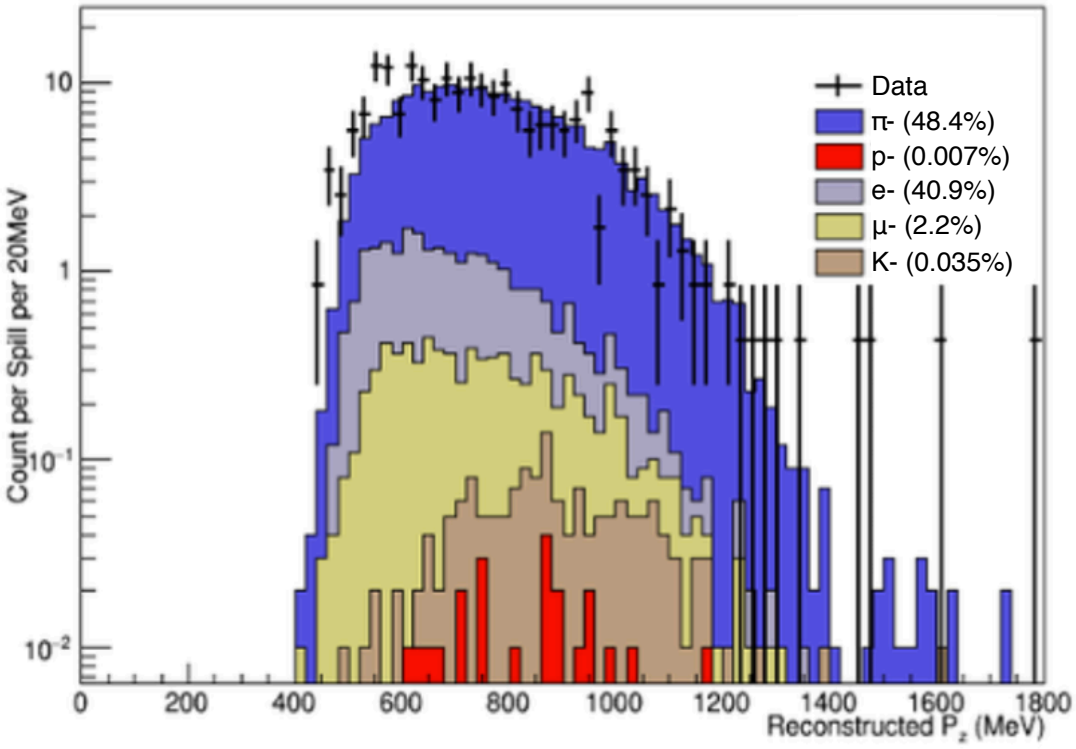
Mixed reviews in the press…

"New Atom Particle Found; Termed a Negative Proton"
New York Times

"Grim New Find at UC."
Berkeley Gazette



Antiprotons in LArIAT



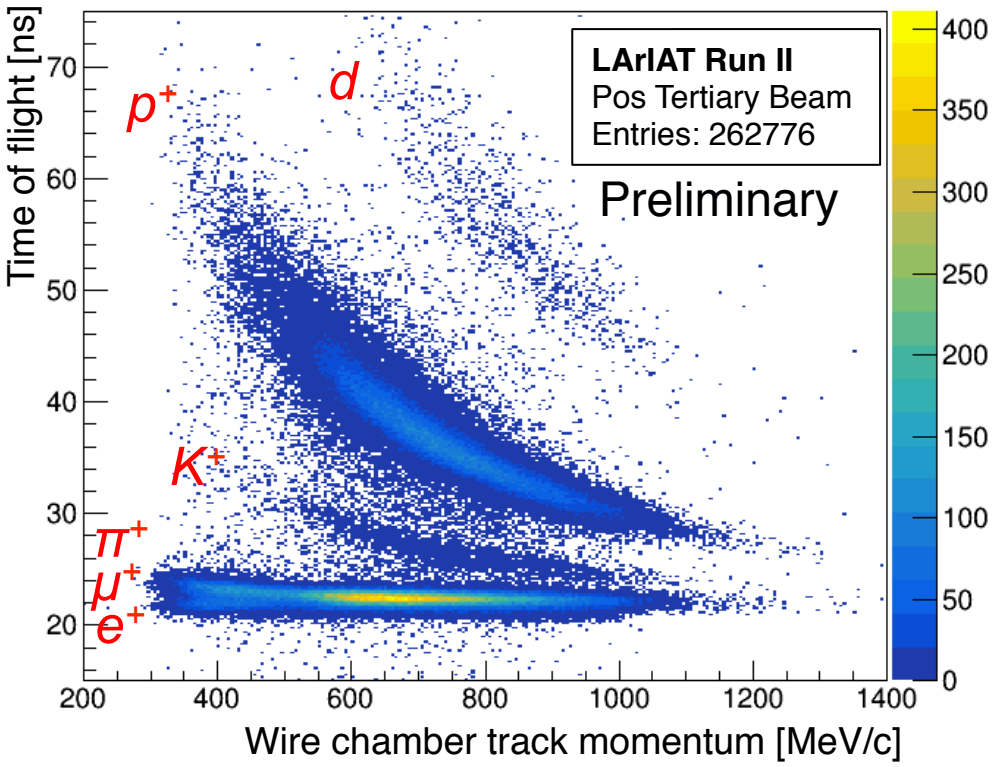
Lariat Negative Beamline Composition (MC + Data) -100A, 64 GeV pions

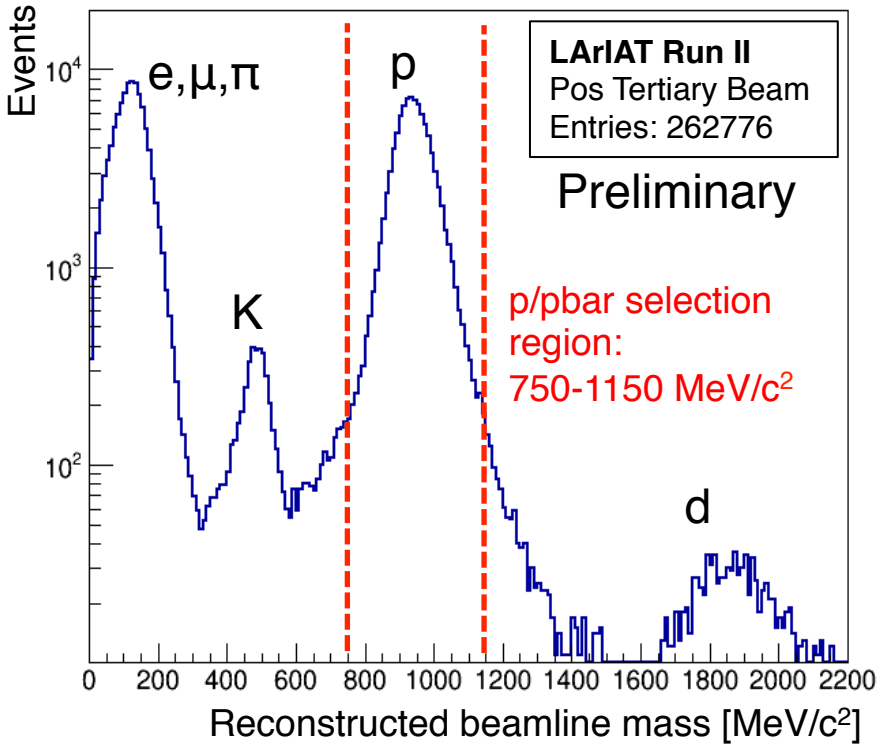
- Antiproton annihilation *at rest* is our best proxy to n-nbar signals in data
- LArIAT produces some pbars in our tertiary beamline (~0.007%!), which can stop and annihilate with surface Ar nucleons
- **A sample of pbar-Ar events in LArAT will:**
  - **Provide a test-bed for n-nbar reco algs over LArTPC data**
  - **Help constrain nuclear models used to simulate n-nbar final states**

Selecting Antiprotons in the LArIAT Beamline

Beamline Mass Calibration with Protons

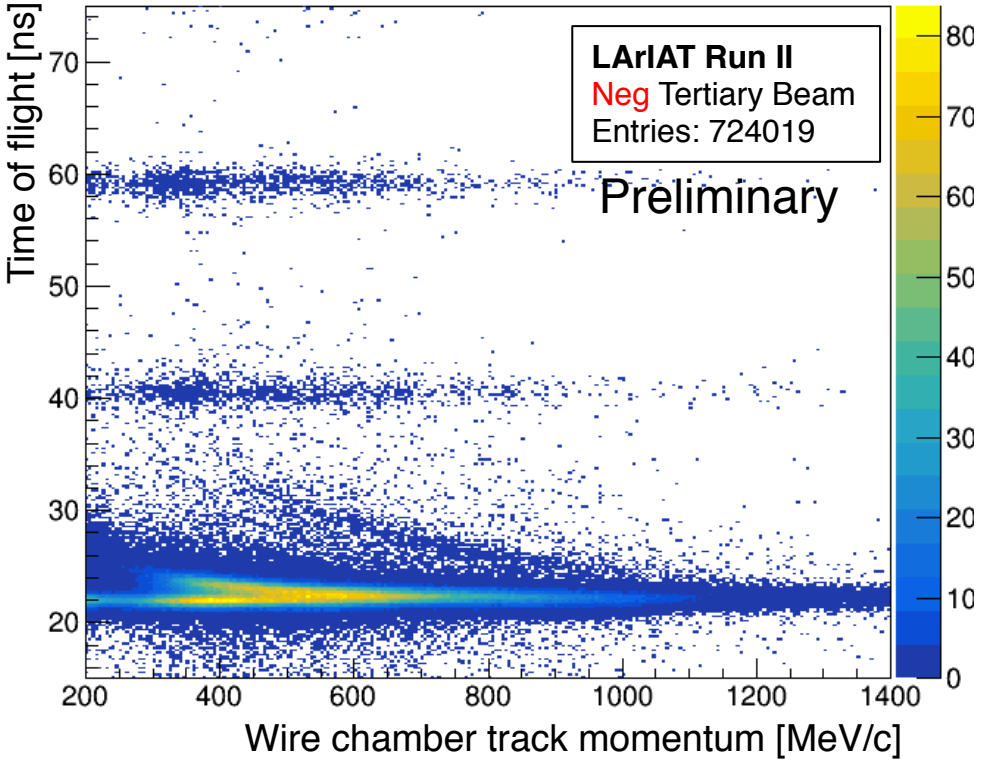
$$m = P_z \sqrt{\left(\frac{c \cdot \Delta T}{L}\right)^2 - 1}$$

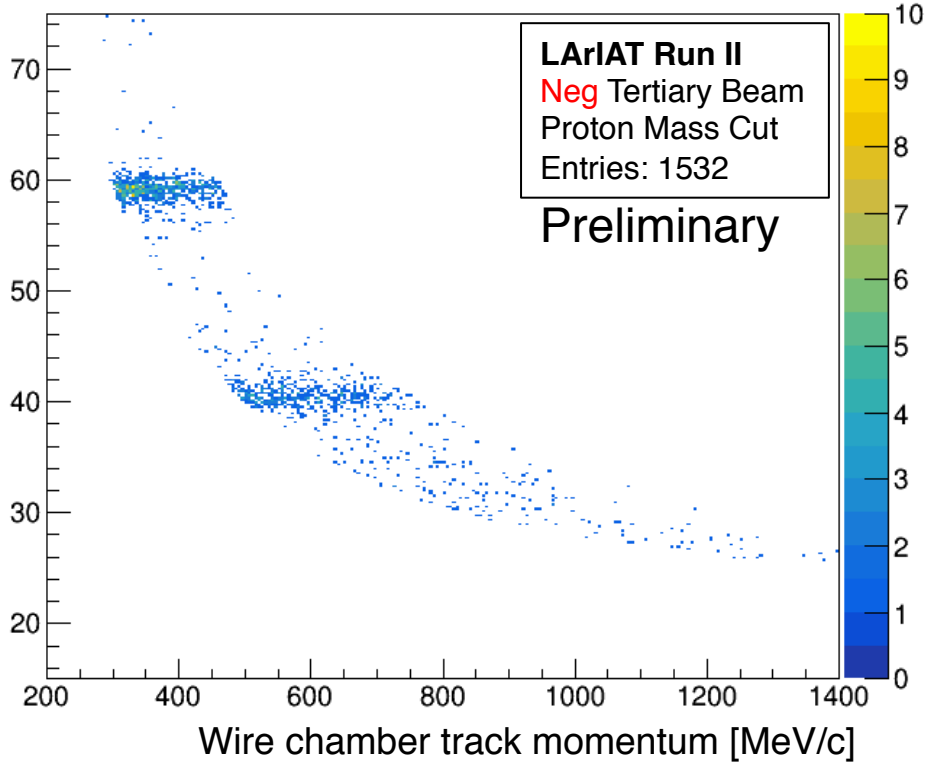




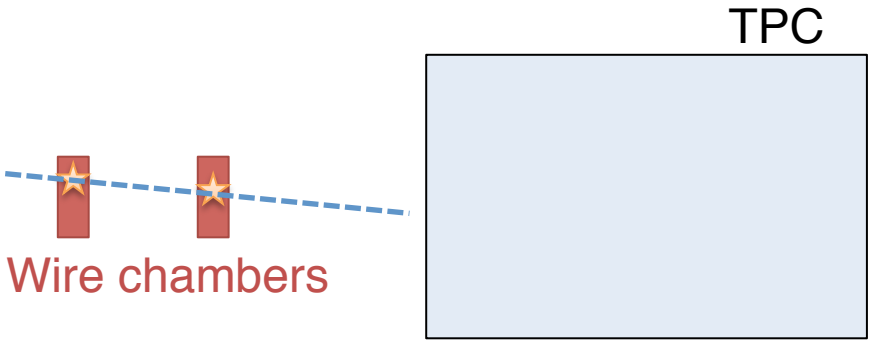
Looking for Antiprotons in Negative Beam

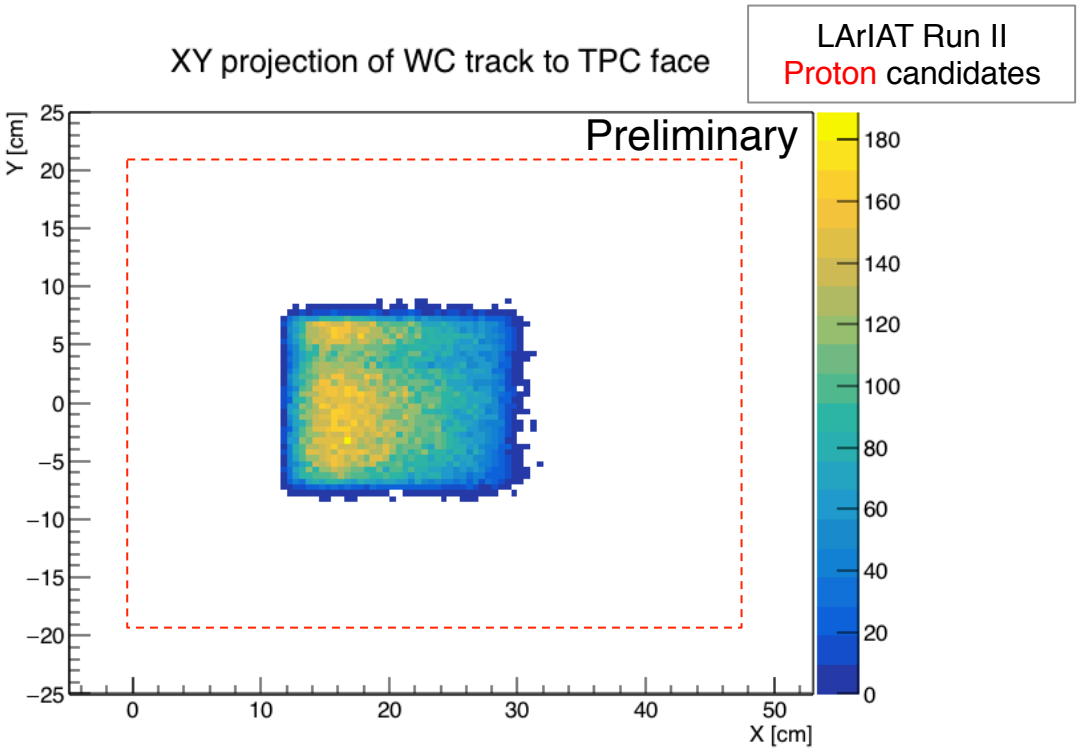
All Run II negative beam data → Selecting events in proton mass range





Wire Chamber Track Matching





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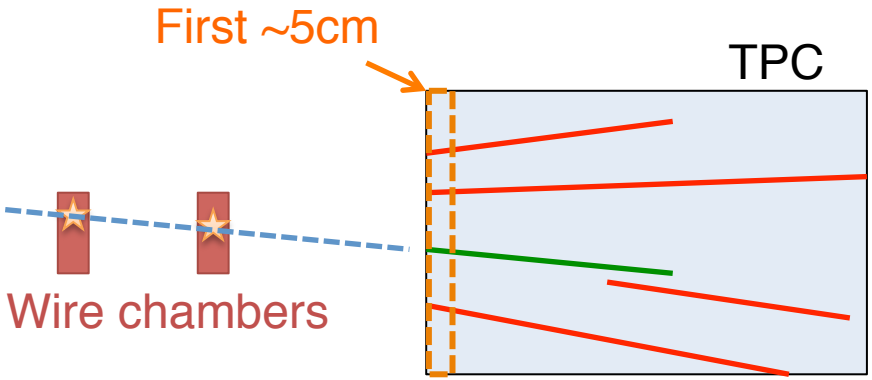
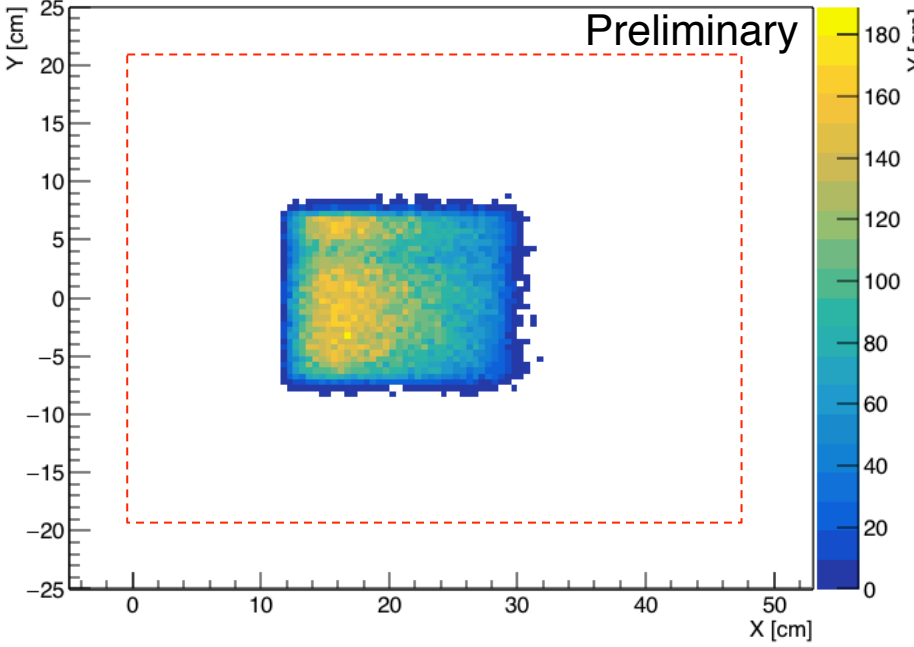
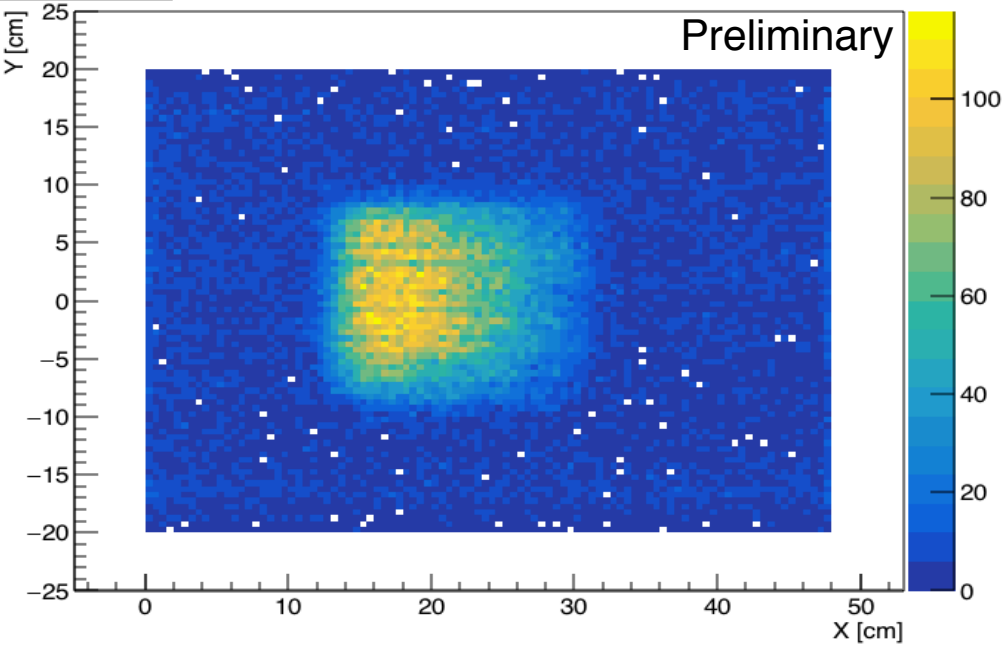


LArIAT Run II
Proton candidates

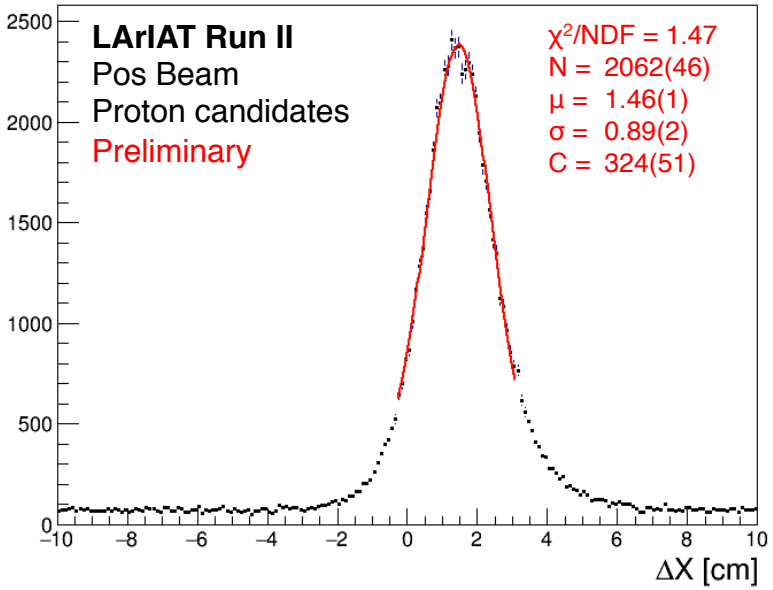
XY projection of WC track to TPC face

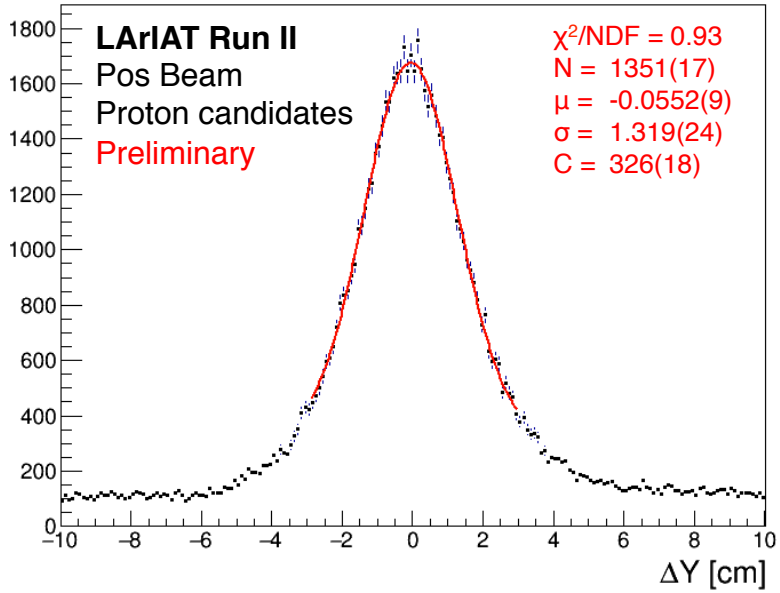


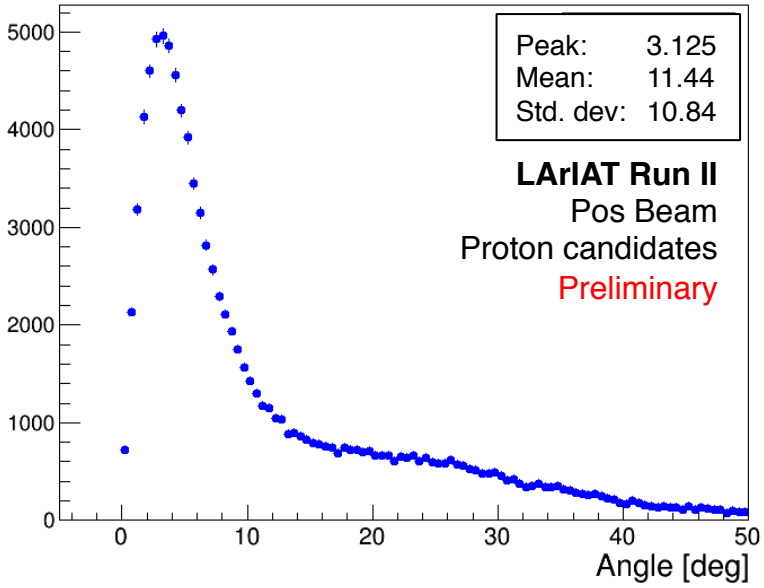
XY point of 'entering' TPC track



Wire Chamber Track Matching







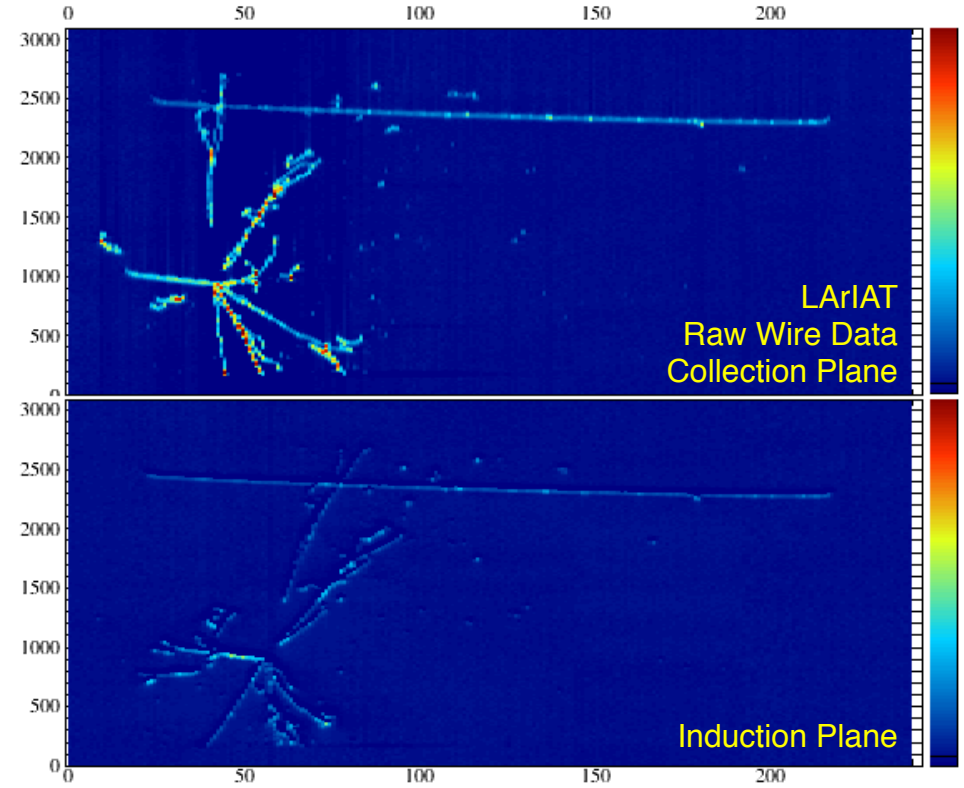
- Good matching seen in proton sample
- Currently optimizing selection cuts

Event Selection Breakdown

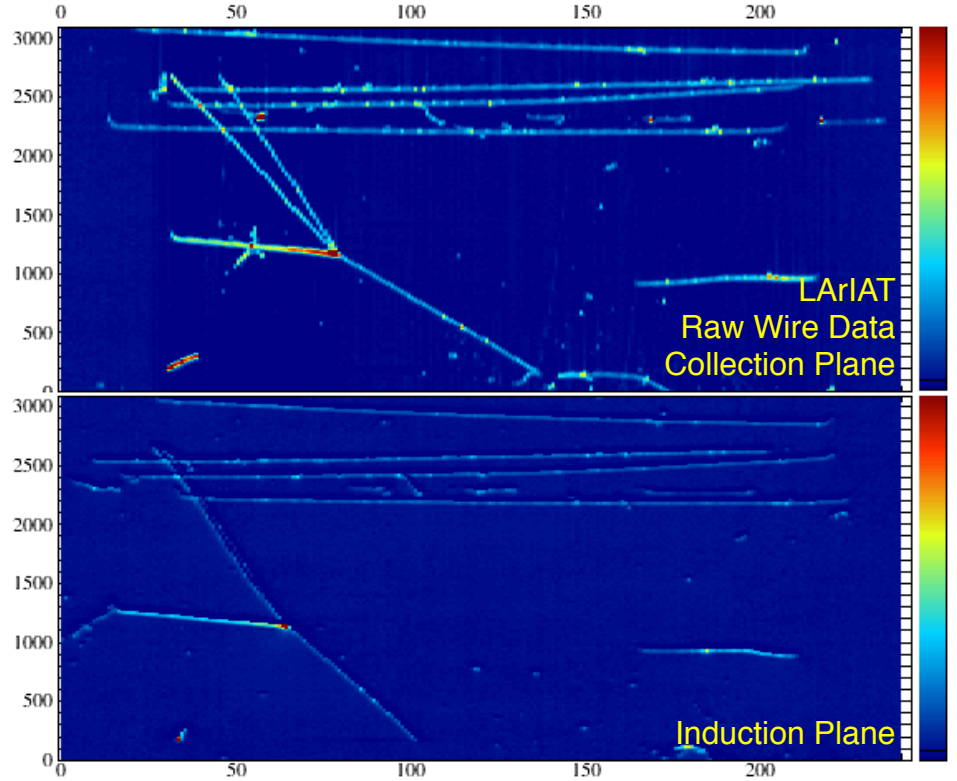
Event cuts	Run 1 Neg	Run 2 Neg	Run 3 Neg
Total events	430,792	5,330,568	1,442,706
Beam event w/ TPC info 1.2s < T < 5.5s RawDigits size > 0	81,103	1,518,837	725,503
1 TOF & 1 Pz 15ns < TOF < 75ns 200 MeV/c < Pz < 1400 MeV/c	36,692	724,019	378,232
Proton mass cut 700-1300 MeV/c^2	273	1,532	523
Identifiable pbar events (by eye)	~2	~50	~50
Golden *stopping pbar* events (by eye)	~1	~15	~15
WC-to-TPC match α < 20 deg -3cm < dx < 6cm -6cm < dy < 6cm Reject thru-going MaxMatched = 3	These by-eye steps to be replaced by WC-to-TPC matching, etc…		

Antiproton Candidate Event Examples

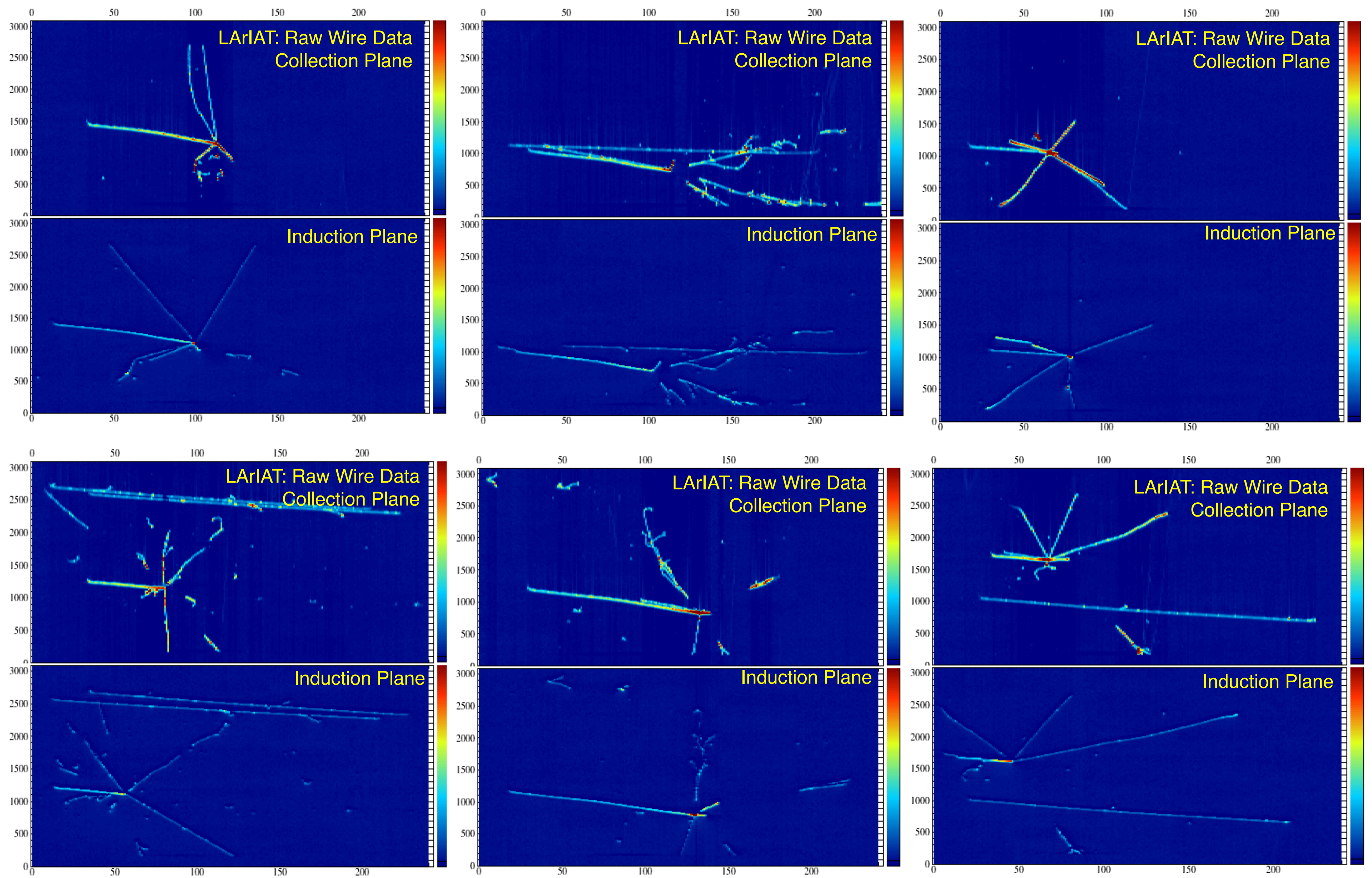
Annihilation in-flight



Annihilation at rest



A Few More…


LArIAT: Raw Wire Data
Collection Plane
Induction Plane
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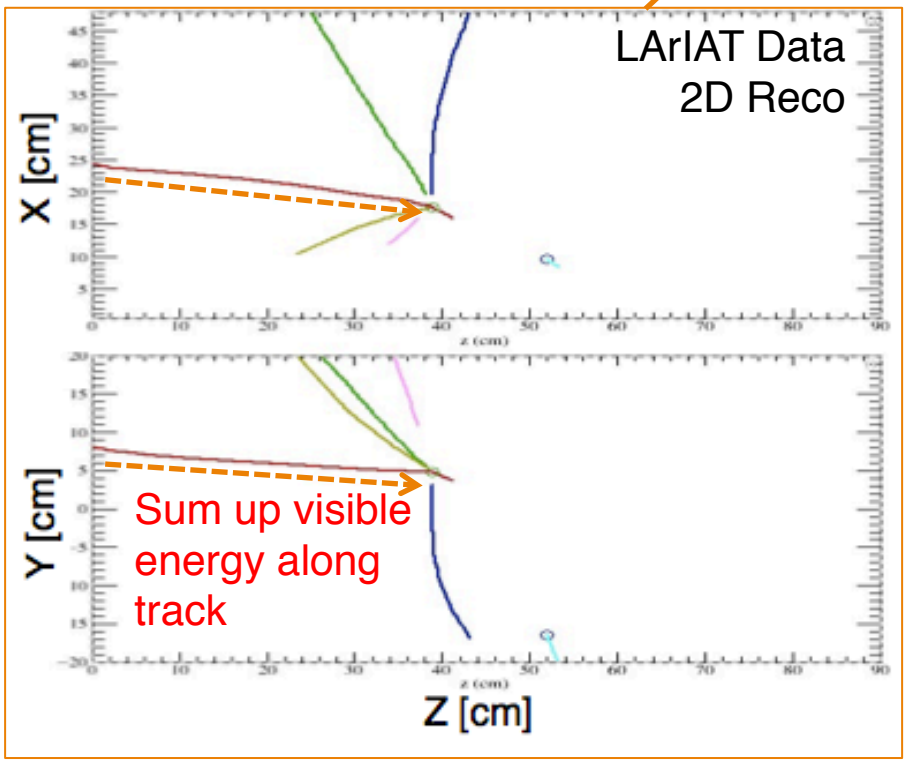
Collection Plane
Induction Plane

Next steps

Stage 1: Event Selection
- Beam mass cut (done)
- WC track matching (in prog.)
- dE/dx

Stage 2: Energy at annihilation

Stage 3: Final state reconstruction



Anticipated results:
- Charged pion multiplicity
- MIP vs. EM-like ratio of deposition
- Visible final-state energy

Take-Aways

- **LArIAT has observed ~O(100) antiproton annihilations in LAr for the first time!**
  - ~30 of these come to rest before annihilating

- Now beginning work on reconstructing these events in the TPC – stay tuned!

Thanks!

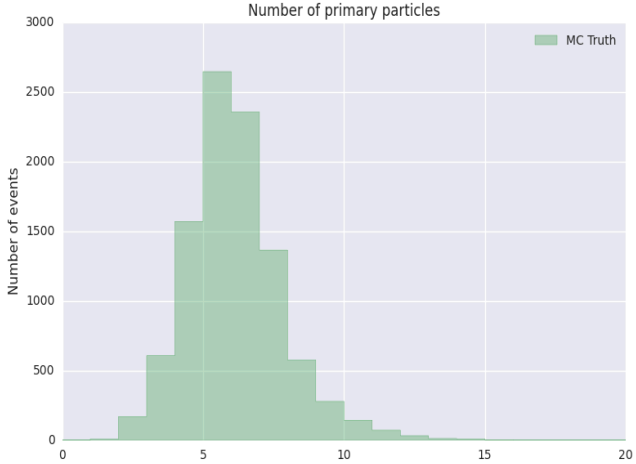
Backup

Anticipated deliverables

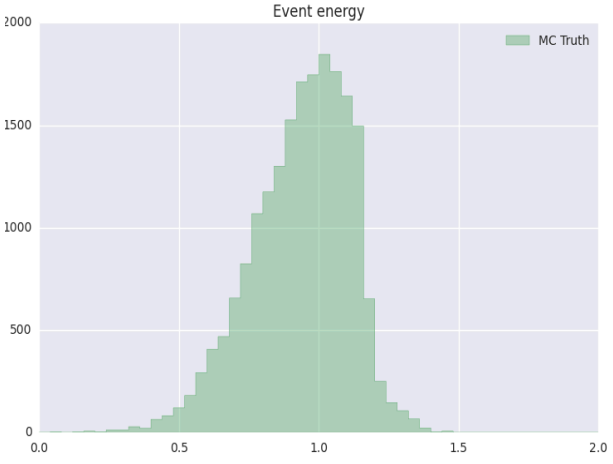
- ❑ Charged pion multiplicities
- ❑ Neutral pion multiplicities
  - ➢ challenging due to topology of $\pi^0 \rightarrow 2\gamma$ showers
- ❑ Total visible energy
  - ➢ MIP-like vs. EM-like total deposition

MC Truth n-nbar topology in ^{40}Ar

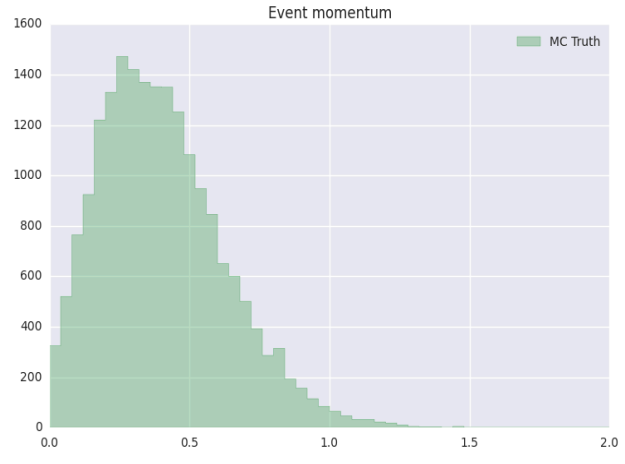
J. Hewes, G. Karagiorgi, K. Terao @ DUNE Collab Mtg '17



Num. of primary particles



Event Energy



Event Momentum

Systematic Uncertainty Budget in Signal Efficiency in Super-Kamiokande N-Nbar Search

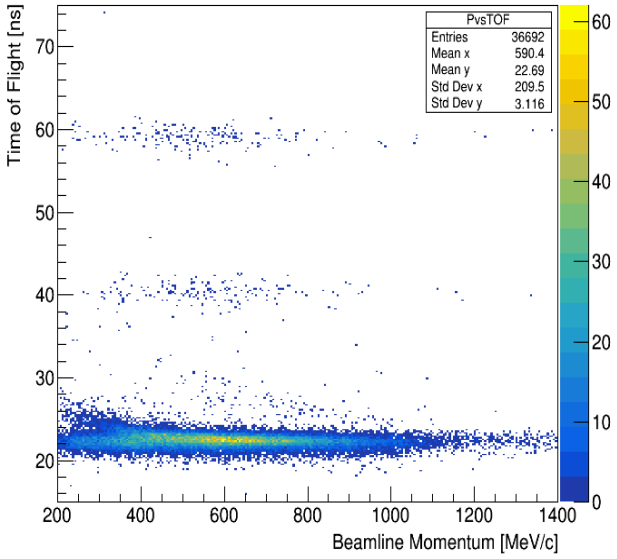
Signal efficiency

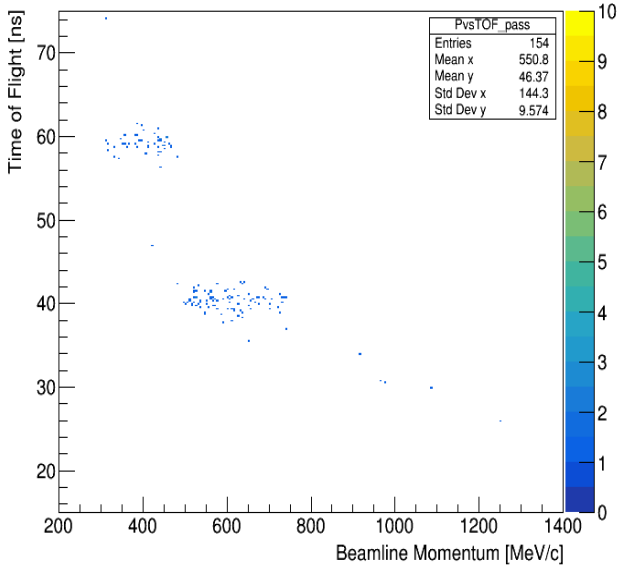
Sources	Uncertainty (%)
Fermi momentum of nucleons	6.2
Branching ratio of $\bar{n}$+nucleons	4.6
π propagation modeling	6.1
π-nucleon cross section in the nucleus	20.0
Energy scale	1.7
Asymmetry of detector gain	0.4
Cherenkov ring finding	2.2
Total	22.9

arXiv:1109.4227, Super-K Neutron-Antineutron Oscillation Search (2015)

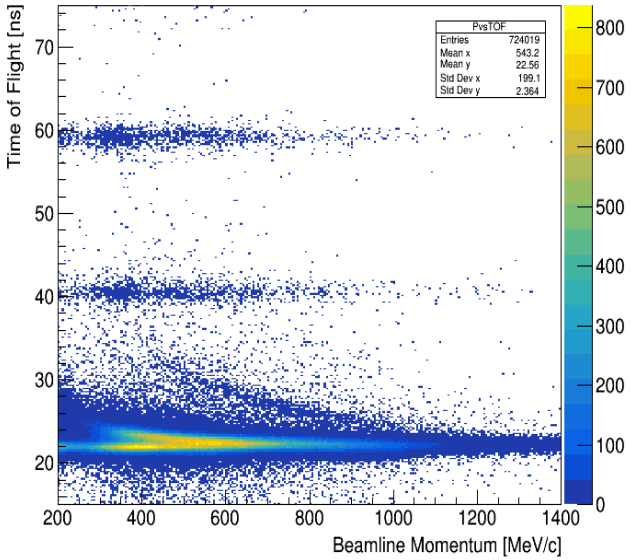
Beamline Selection Plots (Neg Beam)

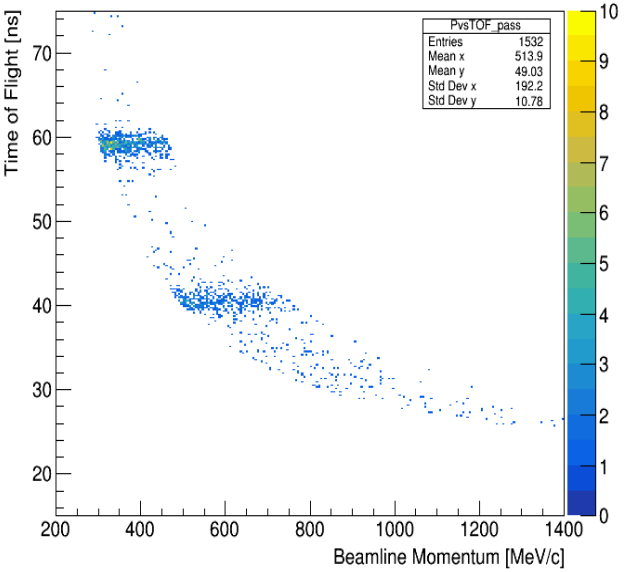
Run I





Run II





Run IIA