Observation of the Antimatter Helium-4 Nucleus (Anti-α)

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for the STAR Collaboration

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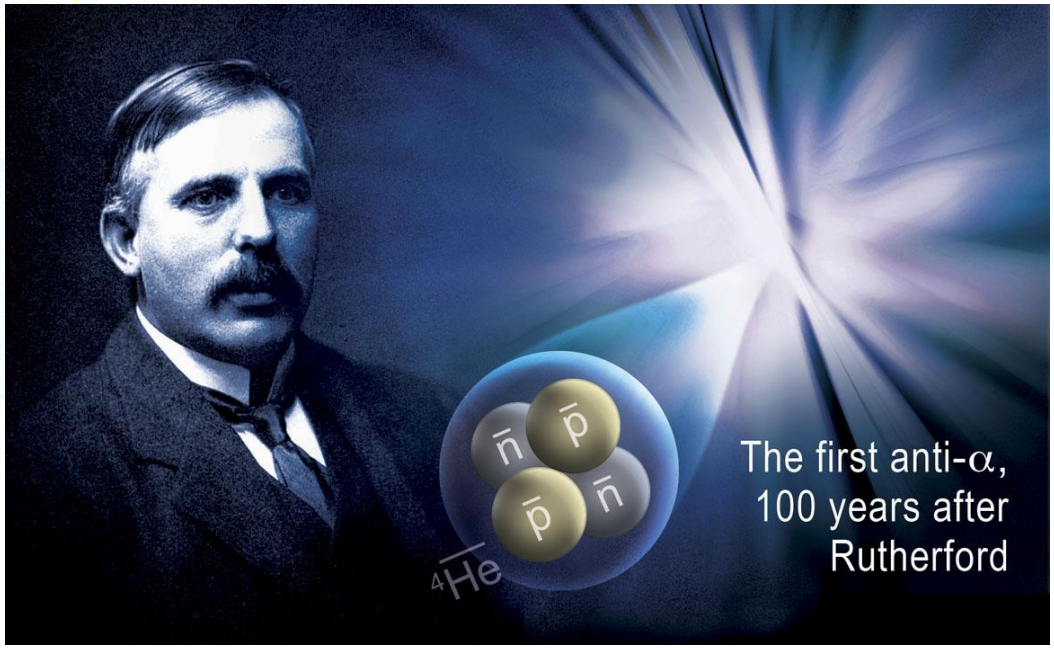
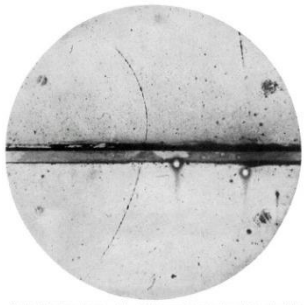
Outline

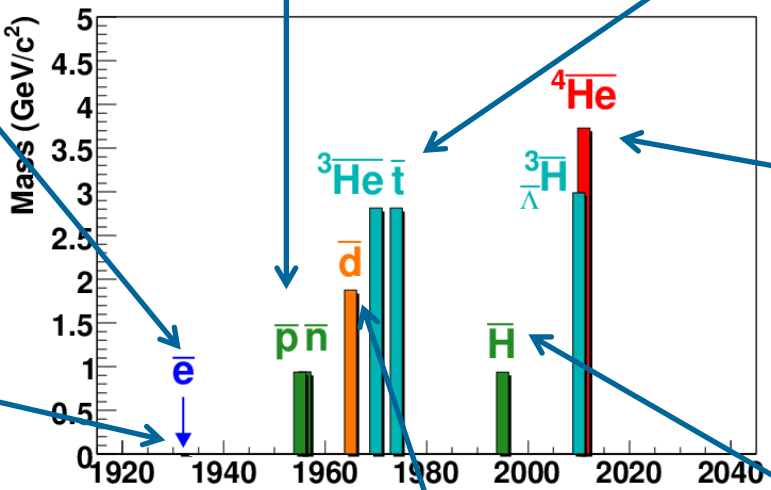


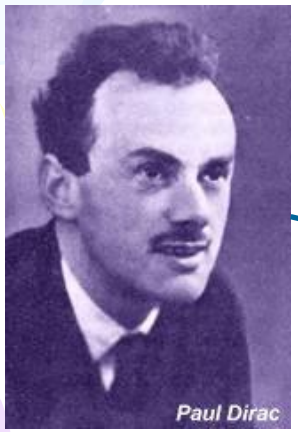
- History and motivation
- Identification and Anti-^{4}He counts
- Event display
- ^{4}He and anti-^{4}He yields

- DOI: 10.1038/nature10079
- arXiv: 1103.3312v2

History of Anti Matter Search

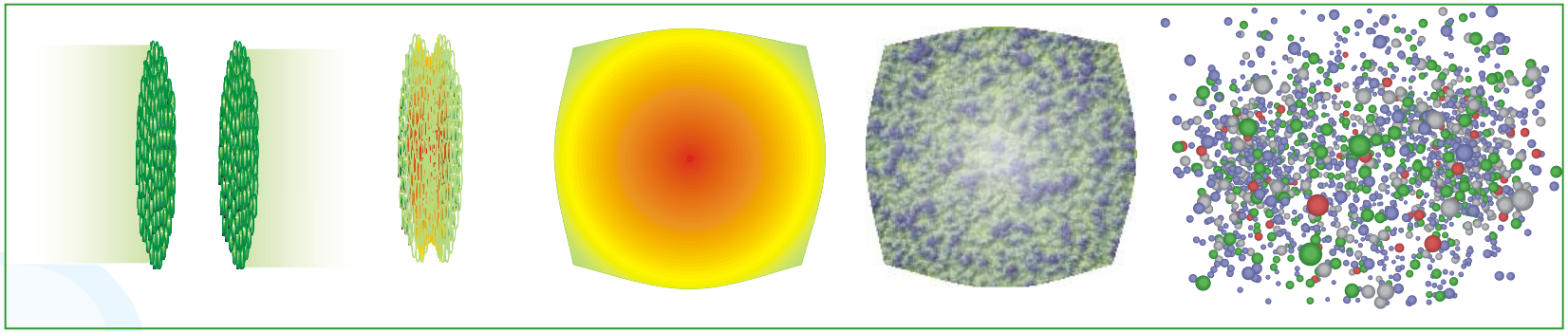




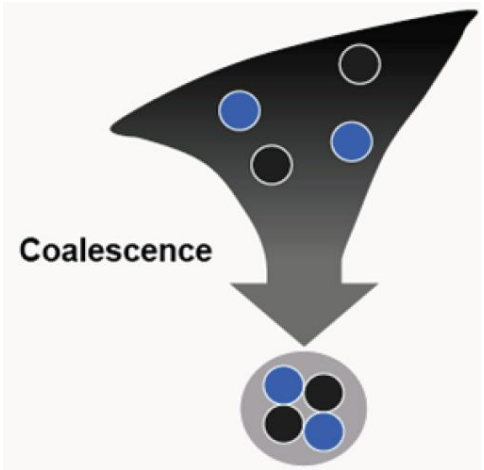


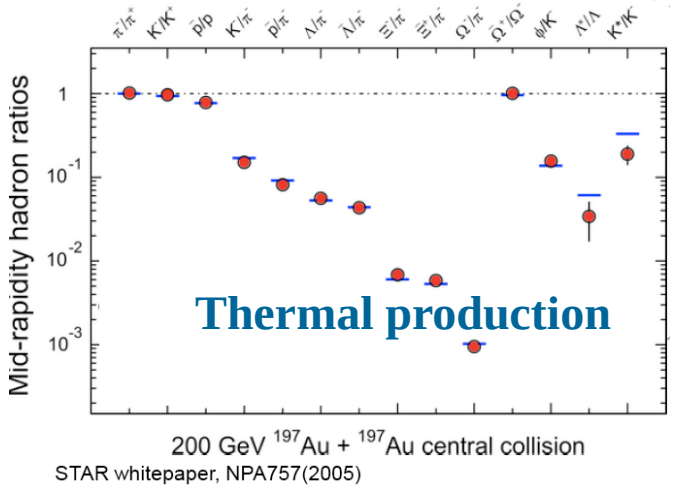
Dirac, P.A.M., The Quantum Theory of the Electron. Proc. Roy. Soc. Lond. A 117, 610 (1928).

Anti-^{4}He in High Energy Nuclear Collisions



- Controlled, repeatable "little bangs".
- Prove the existence (if any), providing a point of reference for future possible observations in cosmic radiation.





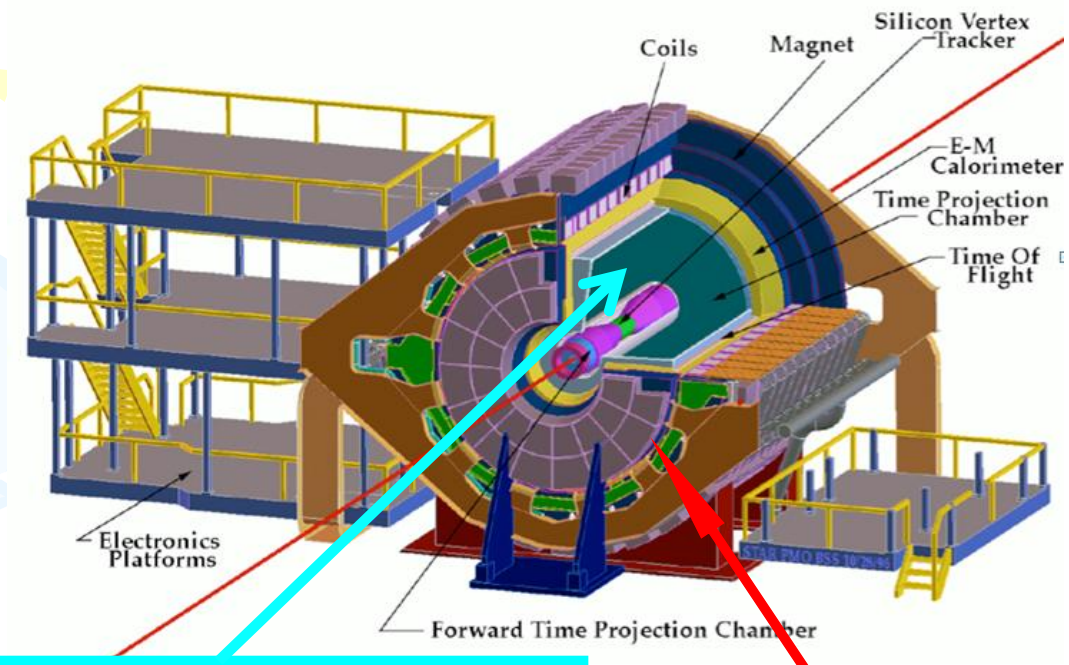
STAR whitepaper, NPA757(2005)

Sato, H. & Yazaki, K. Phys. Lett. B 98, 153-157 (1981)
Butler, S. T. & Perarson, C. A. Phys. Rev. Lett. 7, 69-71 (1961)

$$N_i = V g_i \int \frac{d^3p}{(2\pi)^3} \exp\left(-\frac{E_i}{T} + \frac{\mu_i}{T}\right)$$

- Study production mechanism.

STAR Detector & Dataset



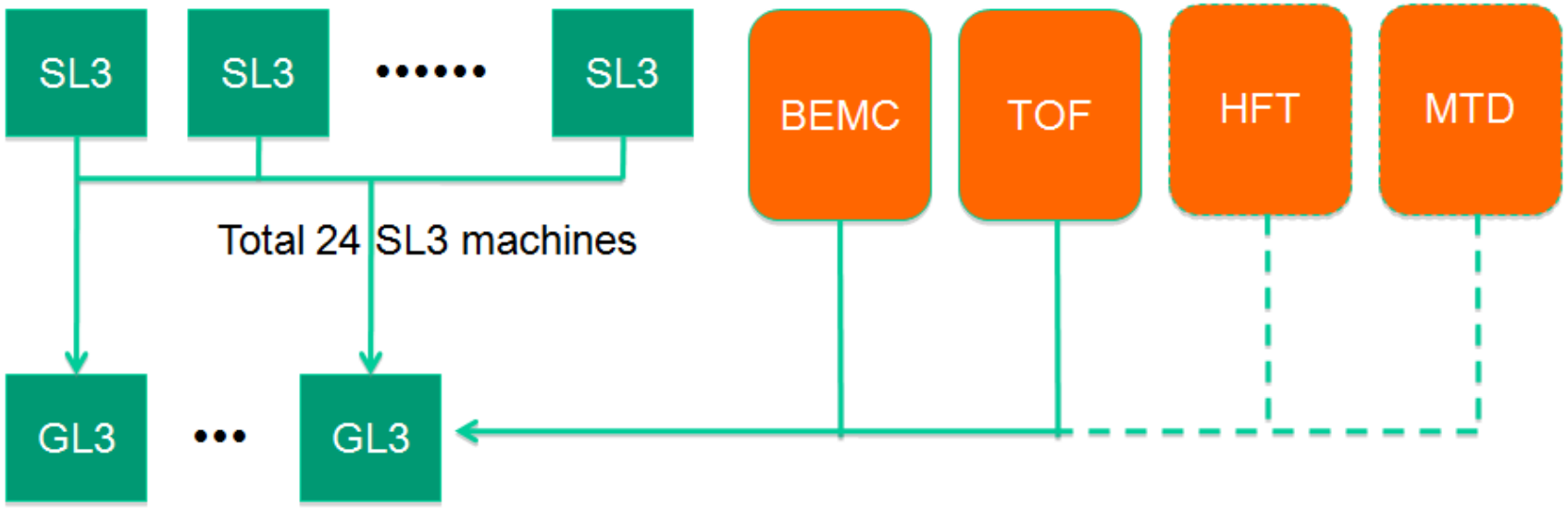
- taken in 2007
  - Au+Au 200GeV
- taken in 2010, online selected by High Level Trigger (HLT)
  - Au+Au 200GeV
  - Au+Au 62GeV
- ~one billion events together

Time Projection Chamber (TPC)
-Measures momentum (p) and energy loss per unit path length (dE/dx)

Time Of Flight (TOF)

High Level Trigger (HLT) -Selecting events with charge 2 tracks

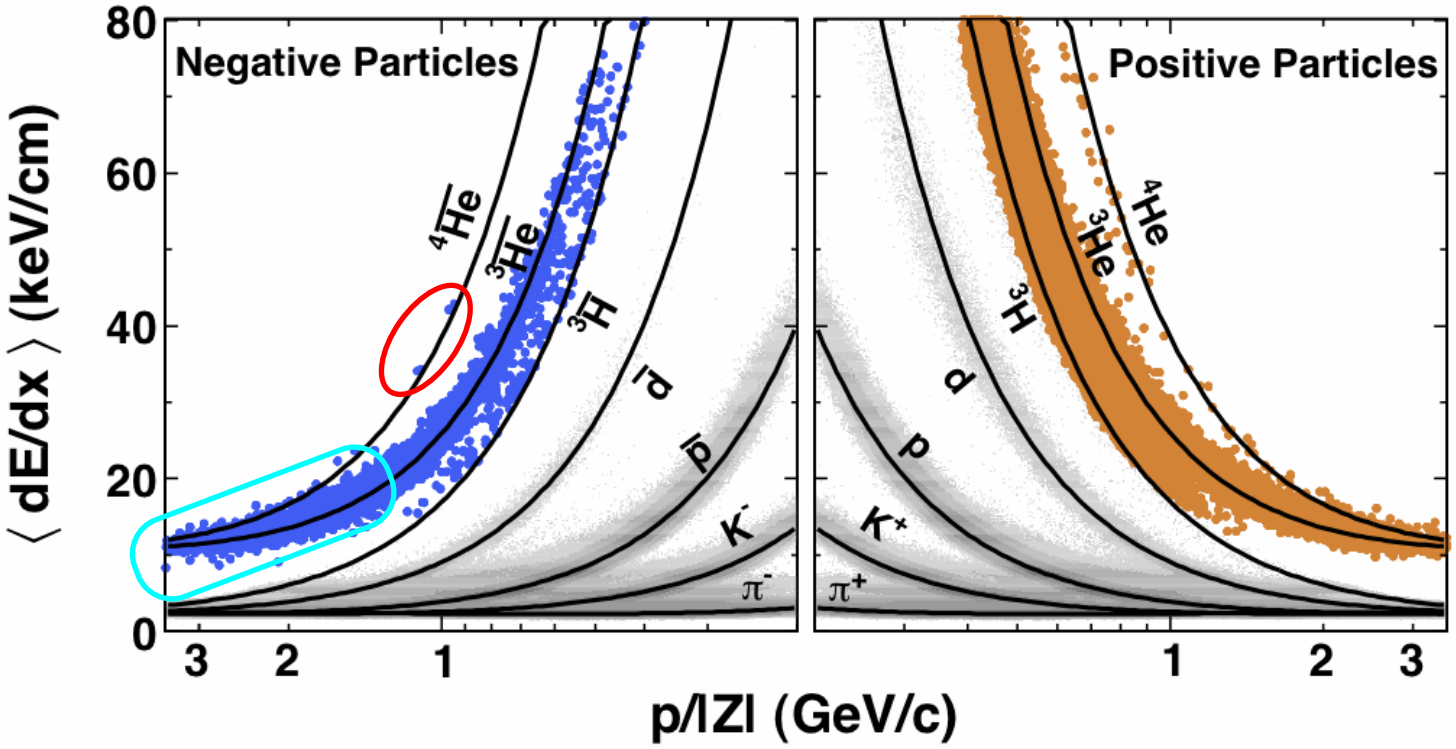
High Level Trigger



- Sector Level 3 (SL3) machines:
  - attached to 24 TPC sectors
  - data acquisition and hit reconstruction
  - tracking for HLT
- Global Level 3 (GL3)
  - event reconstruction
  - selecting events with charge 2 tracks
- ~70 % efficiency for charge 2 events within the selected ~1 % of all events

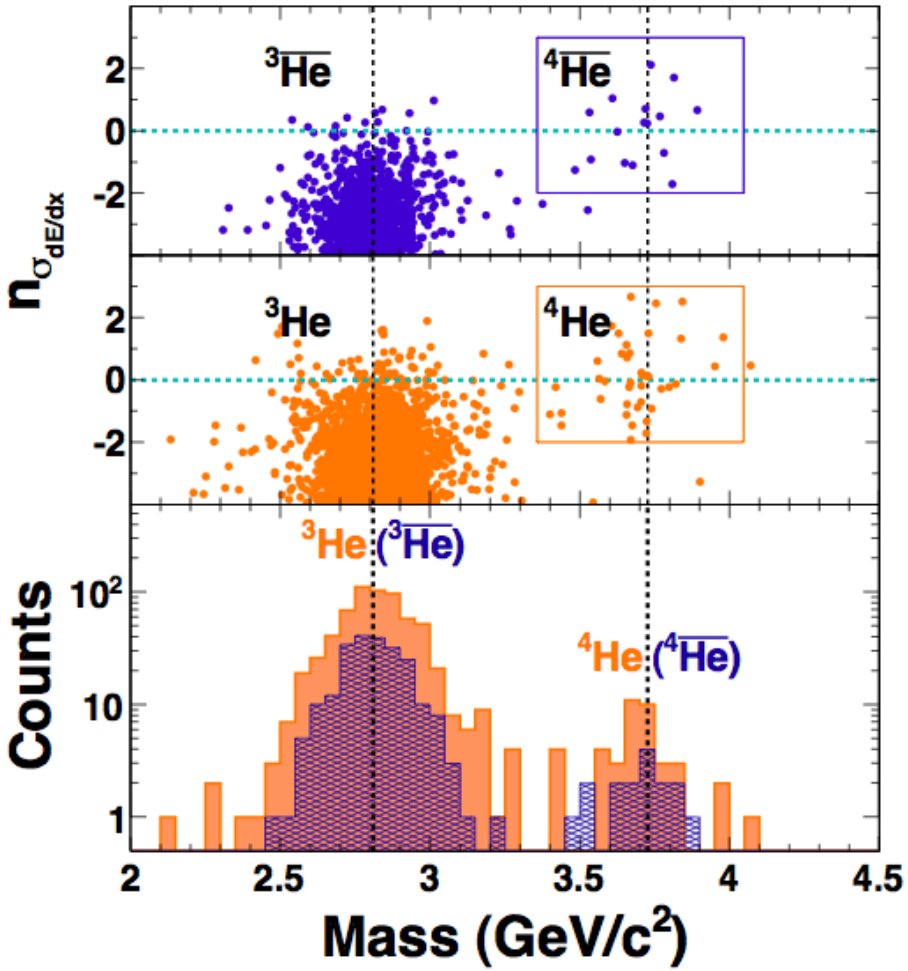
Ke, Hongwei J7.00007

Particle Identification by TPC dE/dx vs. p



2 anti-^{4}He's can be identified by dE/dx vs. p alone in 2007 and 2010 data respectively. At higher momentum anti-^{4}He and anti-^{3}He dE/dx merge together.

TOF and TPC Combined Particle Identification



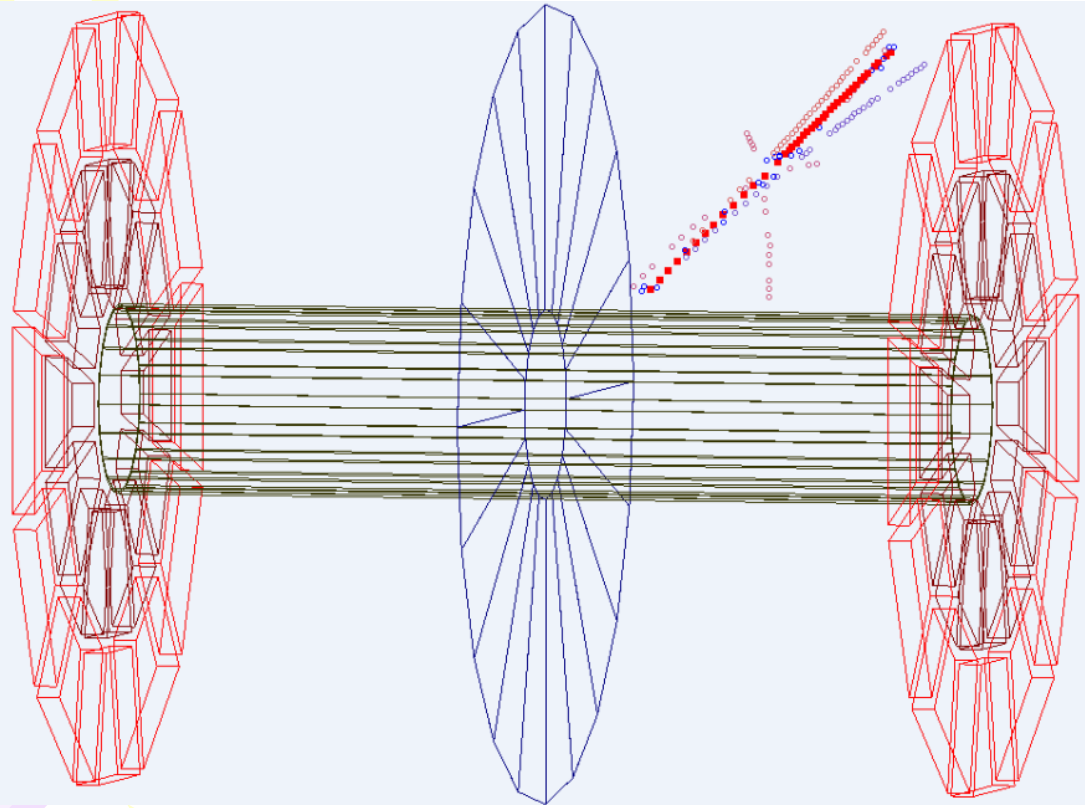
$n_{\sigma dE/dx} = \ln((dE/dx^{measured})/(dE/dx^{bichsel}))/\sigma$

Path length (L), Time of flight → β; β, Momentum p → mass

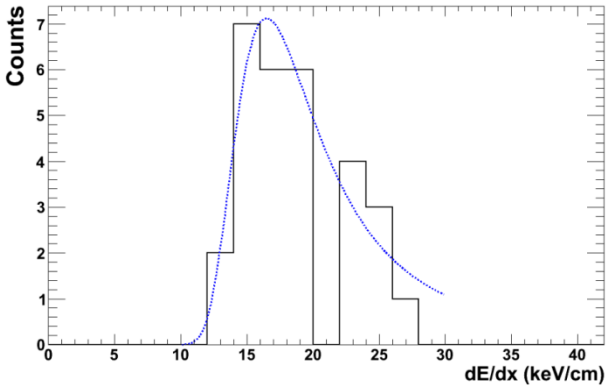
- 18 counts in total
- 15 from 200 GeV collisions in 2010
  - Background ~ 1.4
  - Probability of all misidentification ~ 10^{-11}
  - Significance > 6
- 1 from 62 GeV collisions in 2010
- 2 from 200 GeV collisions in 2007

Event Display

run ID	event ID	vertexZ	Ref Mult	nHits	nHitsdEdx	Rigidity (primary)	eta	phi	dca	path length	chi2	$n\sigma^4_{He}$	EMC Energy	tofLocalZ	tofLocalY	tot	tof	β	Mass
11073003	164108	-4.207	478	41	20	2.319	0.791	2.835	0.789	250.747	1.616	2.11	--	-0.916	-1.489	25.915	12.135	0.780	3.726



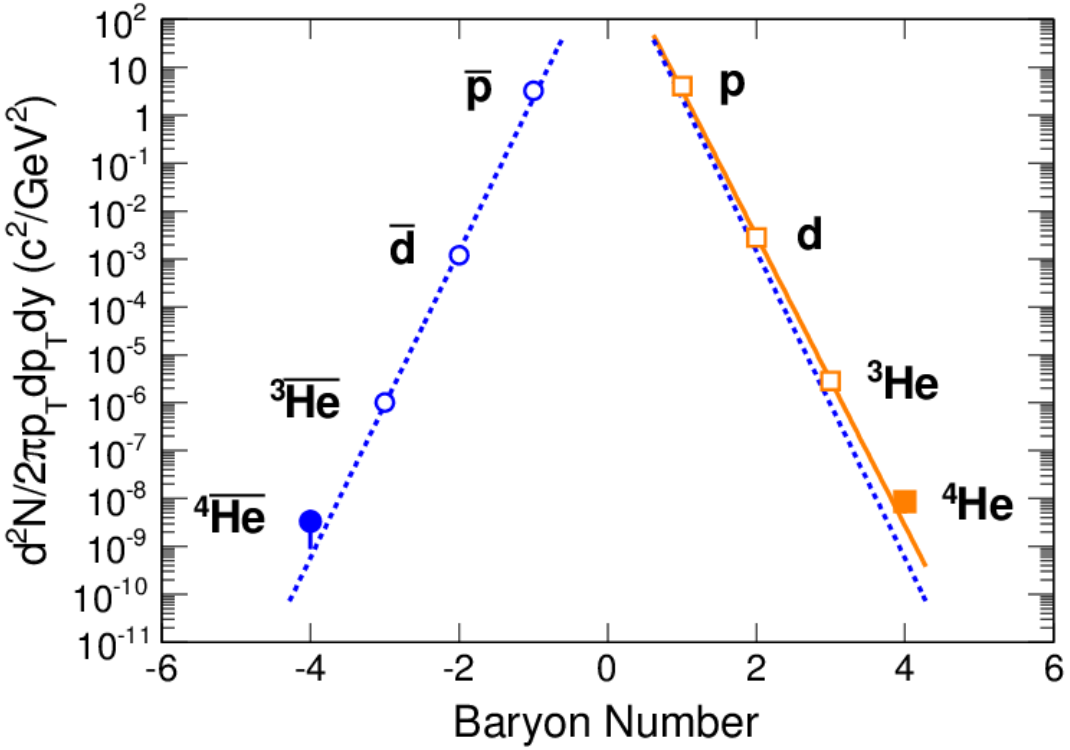
- All 18 candidates are visually inspected



Hit dE/dx

Invariant Yields

- 200 GeV Central (head on) collisions
- transverse momentum $(p_T)/A$: 0.75 ~ 1 GeV/c
- The exponential fit of the yields can be described by both coalescence and thermal models.
- Production rate reduces by a factor of 1.6×10^3 (1.1×10^3) for each additional antinucleon (nucleon) added to the antinucleus (nucleus).



- Next stable antinuclei are anti-^{6}Li and anti-^{6}He, with 10^{-6} yield of anti-^{4}He, thus anti-^{4}He may remain the heaviest stable antimatter in the foreseeable future.

Summary and Outlook

- Anti-^{4}He is produced in high energy nuclear collisions and STAR is able to identify them by dE/dx vs. p and mass from Time Of Flight.
- A total of 18 counts are observed in three data sets, with 6σ significance in 200 GeV Au+Au collisions in 2010 alone.
- ^{4}He and anti-^{4}He yields approximately follow the exponential trend, which is expected by both coalescence and thermal models.

Thank you!

Anti-^{4}He counts in different data sets

- 18 counts in total
  - 15 from Run 10 200 GeV Au+Au collisions
    - 5 minbias + 5 central with 1 tagged by both triggers
    - 6 from other triggers
  - 1 from Run 10 62 GeV Au+Au collisions
  - 2 from Run 7 200 GeV Au+Au collisions
- In Run 10 200 GeV Au+Au collisions

	Counts	**Background**	**Significance**
^{4}He	**26**	**3.5**	**7.6**
Anti-^{4}He	**15**	**1.4**	**6.5**

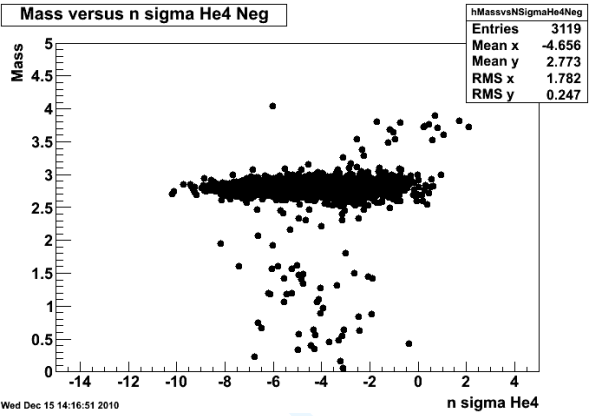
^{4}He and anti-^{4}He yields

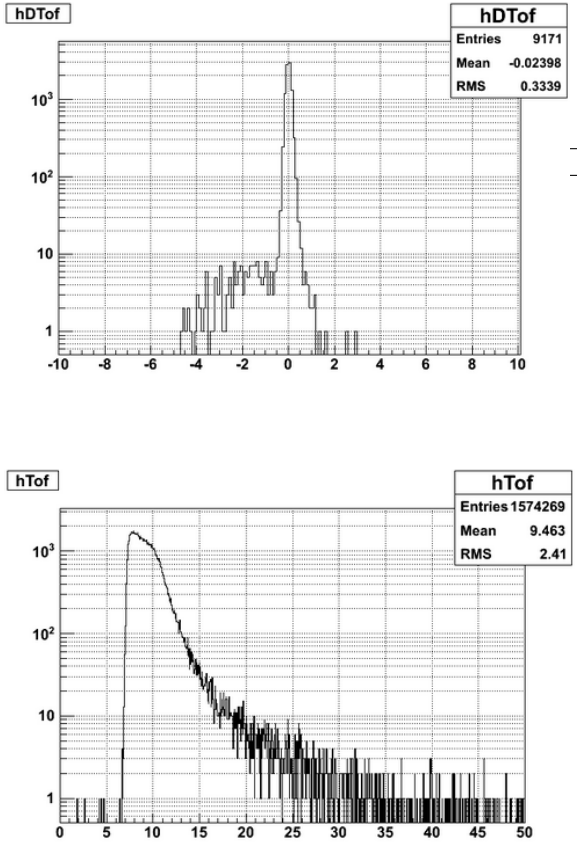
- Measure (anti-)^{4}He/(anti-)^{3}He ratio from Run 10 200 GeV Au+Au central HLT selected events
- Use (anti-)^{3}He $dN/(2\pi p_T dp_T d\eta)$ from old measurements to get (anti-)^{4}He yield
- p_T/A: 0.75 ~ 1 GeV/c
- α: 5 Anti α: 2
- He3: 953 Anti He3: 352
- α/primary He3 : 3.0 +- 1.3 (stat) + 0.5 - 0.3 (sys) e-3
- anti α/primary anti He3 : 3.2 +- 2.3 (stat) + 0.7 - 0.2 (sys) e-3
- α : 8.6 +- 3.8 (stat) + 0.9 - 2.8 (sys) e-9 (GeV/c)-2
- anti α : 3.3 +- 2.4 (stat) + 0.5 - 0.9 (sys) e-9 (GeV/c)-2

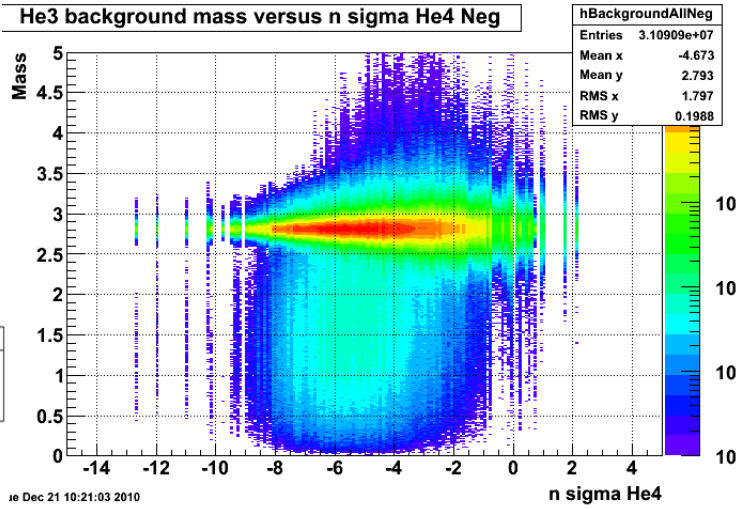
α and anti-α yields - systematic errors

- background (-6%)
- knock outs (-5%)
- absorption (+4%)
- TPC tracking efficiency for He3 old measurement(+- 10 %)
- a slight p_T difference between the (anti-)He3 yield data points we use (~2.47 GeV/c) and 2.625 GeV/c (-12 %)
- (anti) He3 feed down from (anti) hypertriton (+18%)

Background Estimation





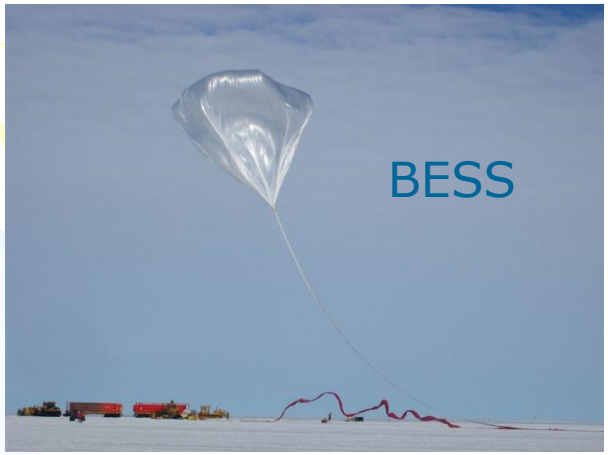


History

- In 1928, Dirac predicted the existence of negative energy states of electrons.
- In 1932, Anderson discovered positron in cosmic radiation.
- In 1955, antiproton and antineutron were observed at Bevatron, Berkly.
- In 1970 and 1974, anti-He3 and antitriton were discovered at Institute of High Energy Physics, Russia.
- In 1995, antihydrogen is produced at LEAR, CERN. PS210 collaboration.

- 简并度 Degeneracy

Anti-α in the Sky



PaMela

- Finger print of anti-star

AMS