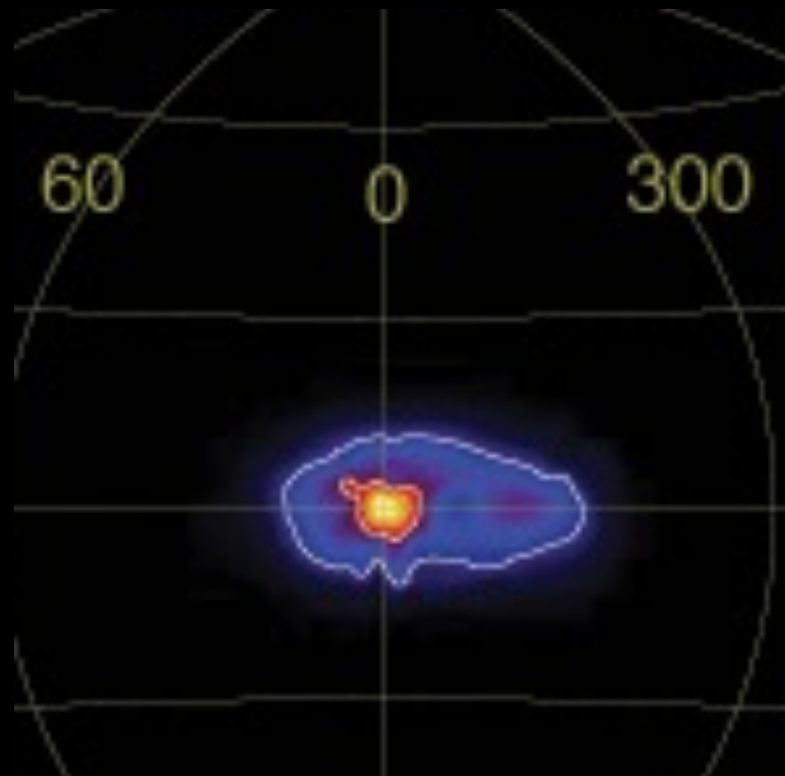
Observation of the antimatter helium4 nucleus

STAR ☆

Aihong Tang

Why Antimatter ?

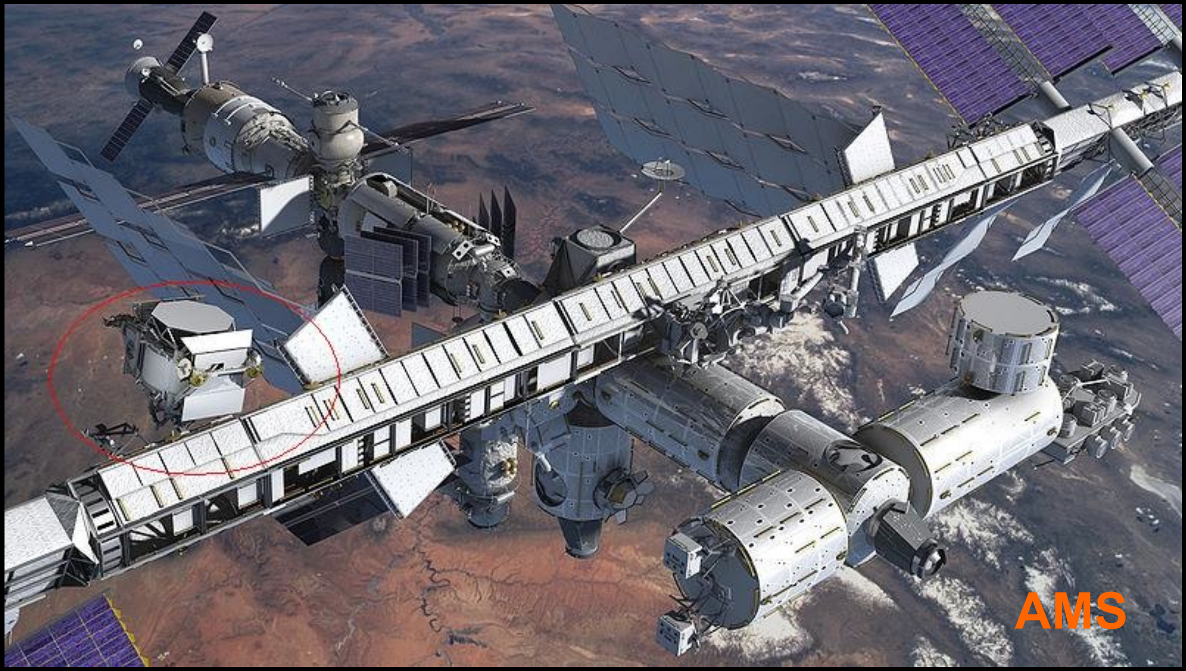
Nature 451, 159 (2008)



Clue to the matter anti-matter asymmetry.

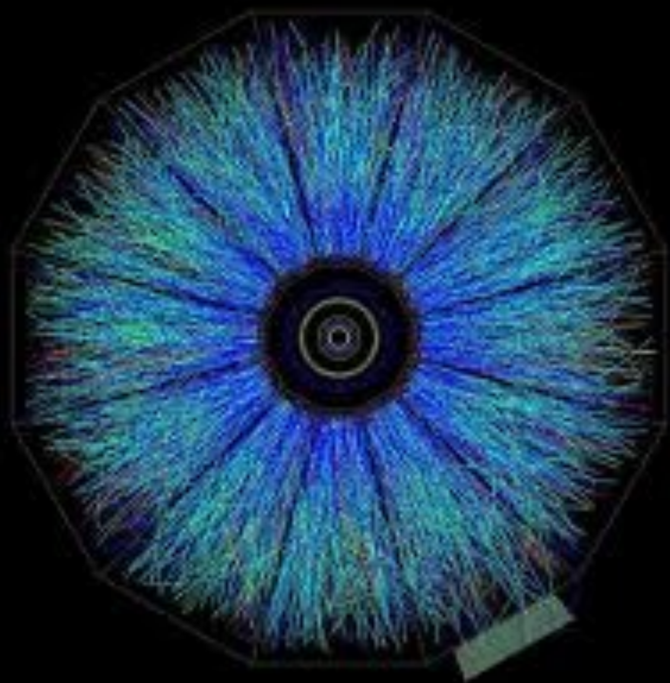
Antimatter matters !

Why Antihelium 4 (anti-α) ?



Finger print of anti-star !

Why High-energy Nuclear Collisions ?



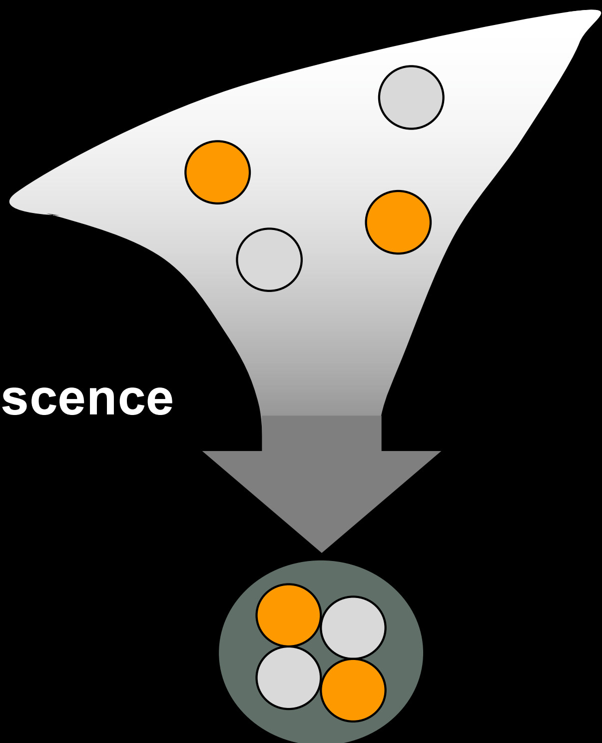
• Sweet spot between elementary particle collisions and Big Bang for anti-nuclei production.

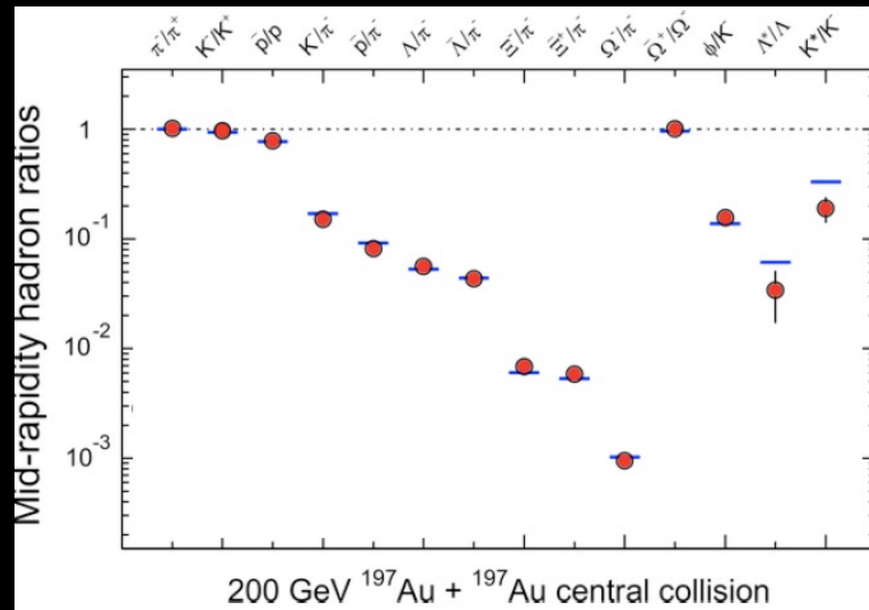
• Controlled, repeatable "little bangs". Active production instead of "passive" searches.

• Prove the existence (if any), provide a point of reference for future observations in cosmic radiation.

Production Mechanisms

Coalescence





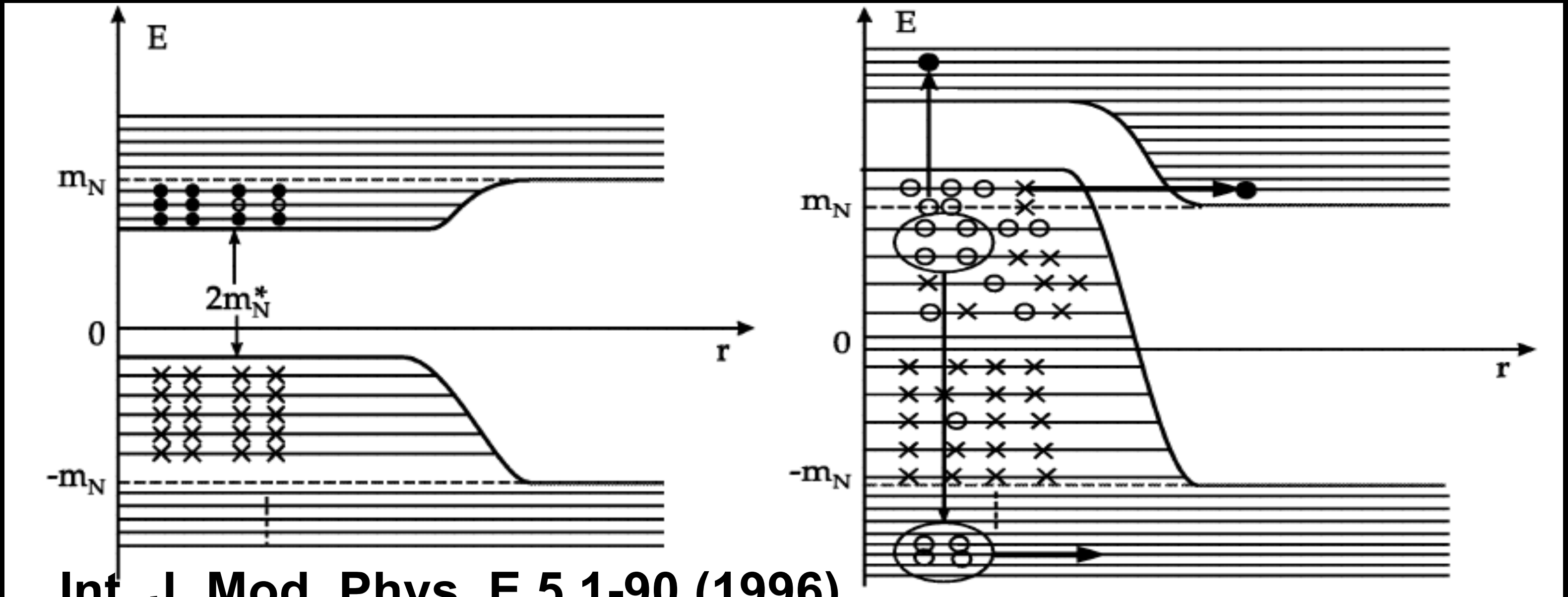
STAR whitepaper, NPA757(2005)

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

Thermal production

- **Relativistic Heavy Ion collisions :**
  - ✓ **High antibaryon density**
  - ✓ **High temperature**
- **Favorable environment for both production mechanisms.**

Production Mechanisms

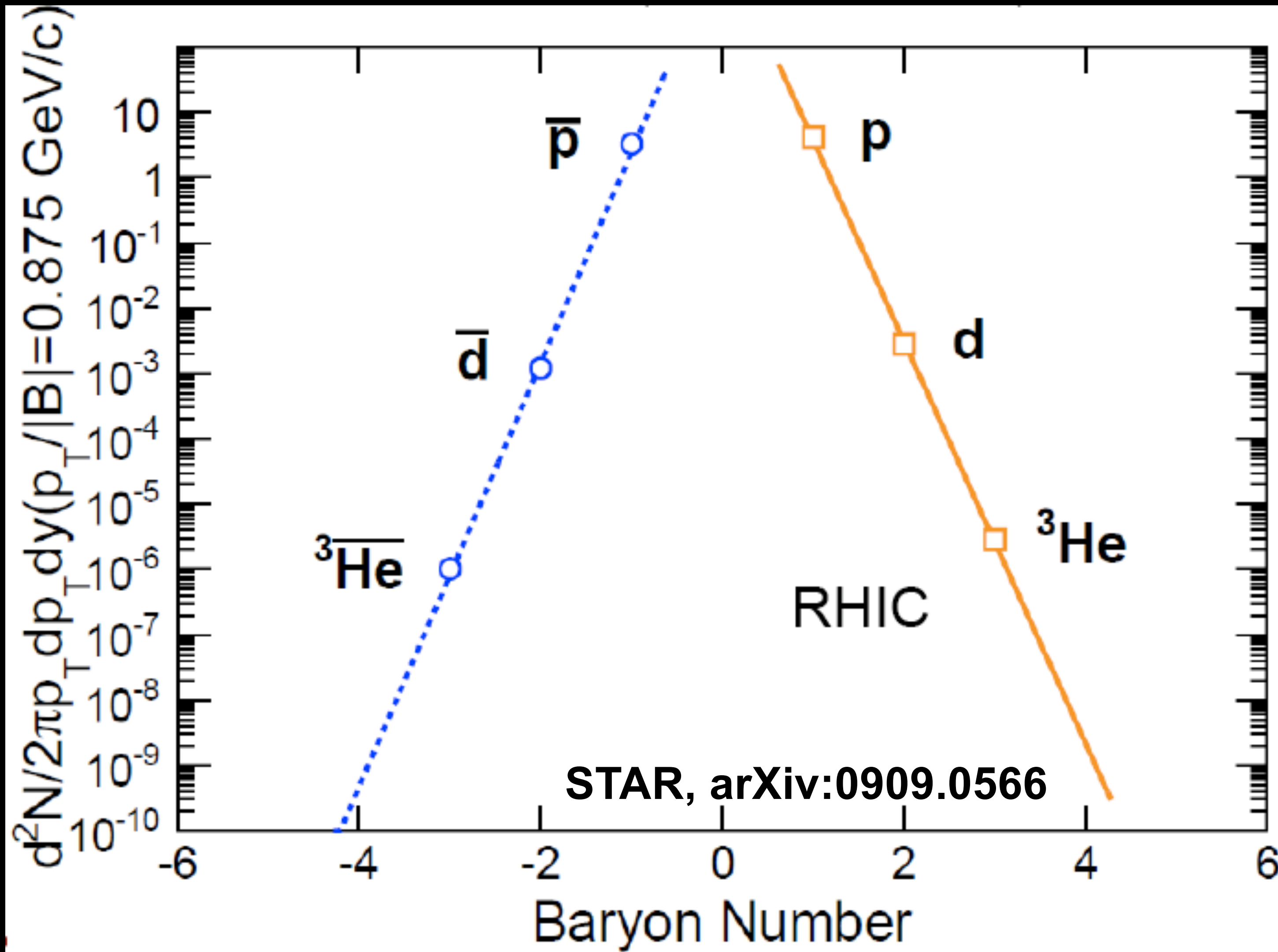


Int. J. Mod. Phys. E 5 1-90 (1996)

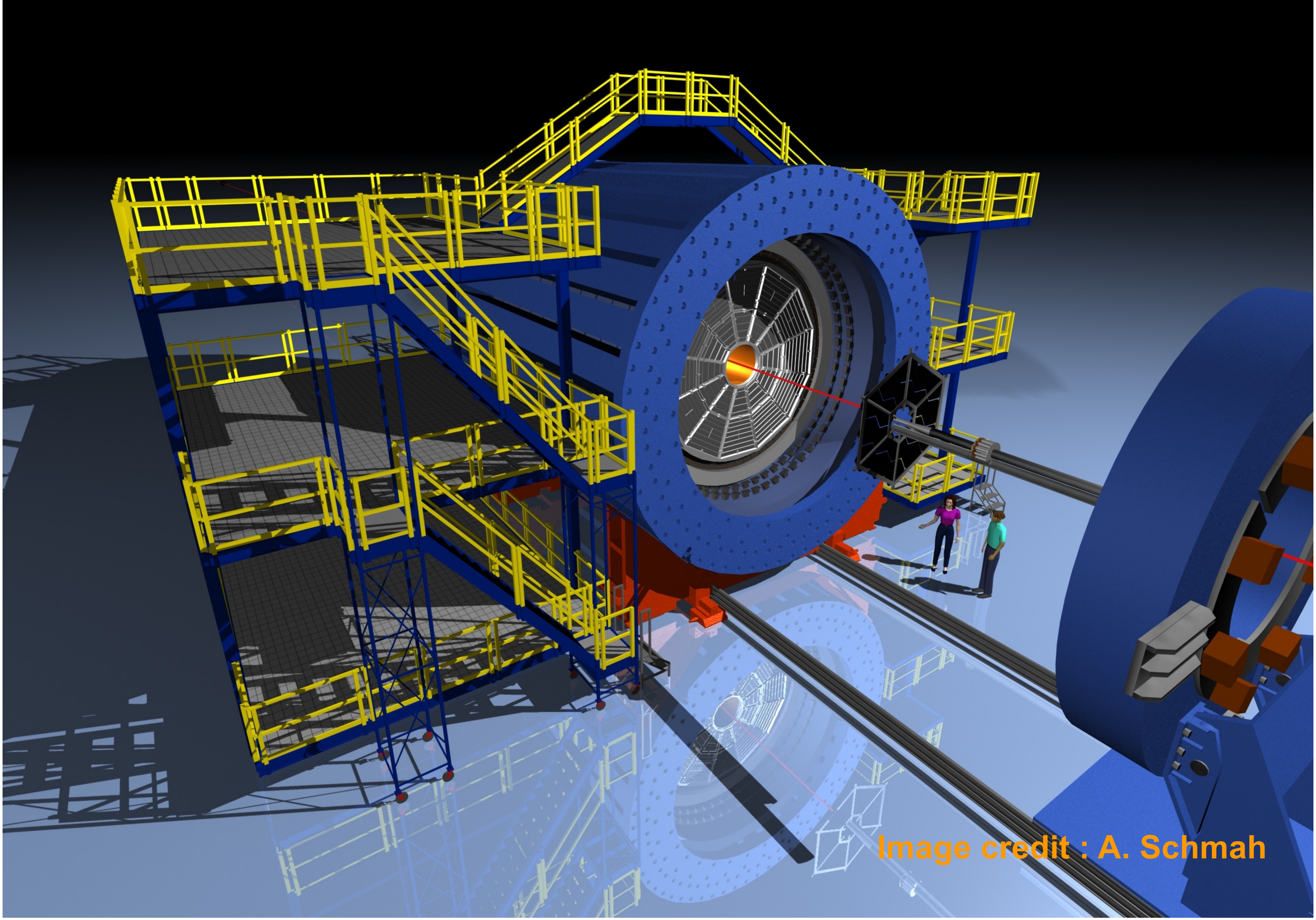
Idea from Walter Greiner: correlations are present in vacuum, allowing antinucleus like anti-α to be directly excited from the vacuum. Rate could be much larger than low value predicted by statistical coalescence.

Could be exciting but no evidence so far.

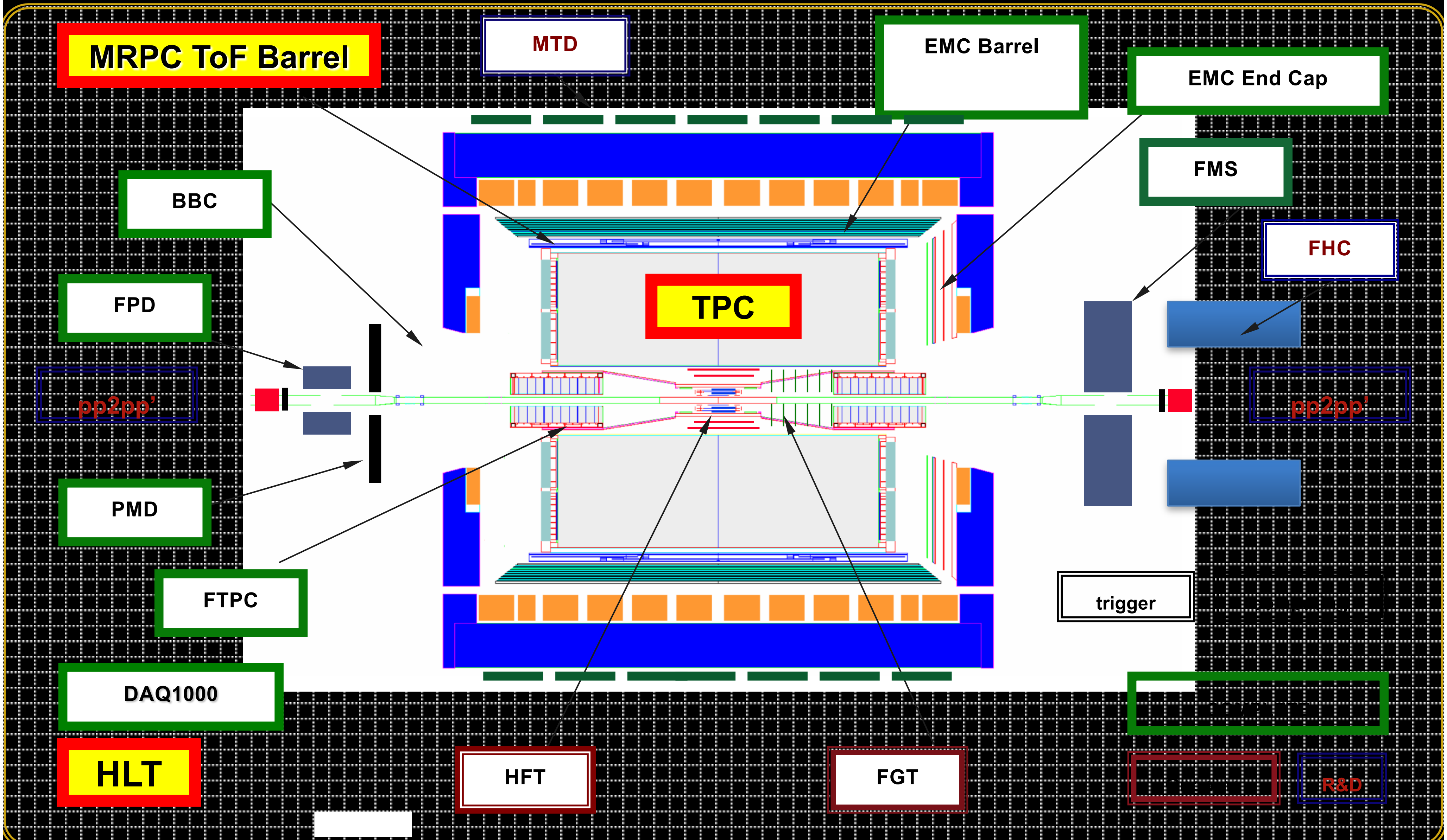
It is a challenging job



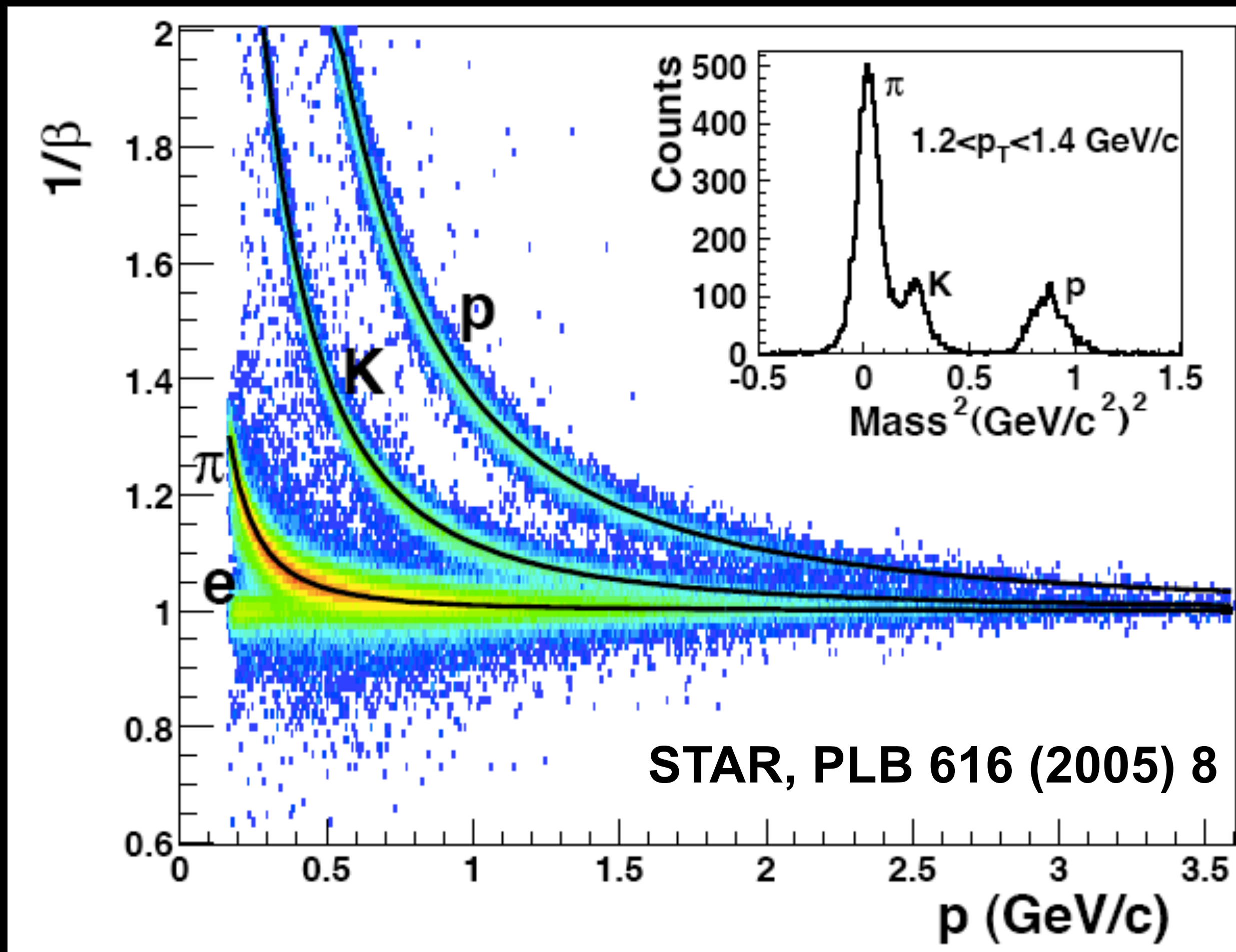
STAR Setup



Key Components for this Search

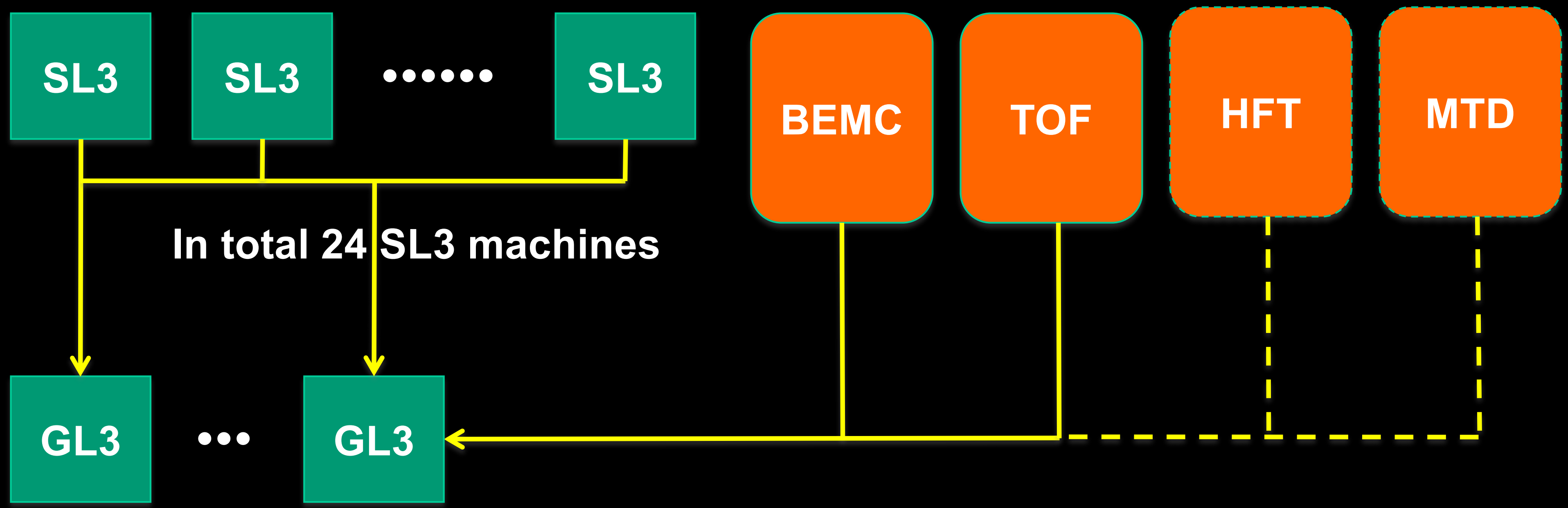


PID : TPC + TOF



TPC and TOF combined provide clean particle identification.

STAR's High Level online tracking Trigger (HLT)



- Sector tracking (SL3) in DAQ machines (24 in total, each for a TPC sector).
- Information from subsystems (SL3 and others) are sent to Global L3 machines (GL3) where an event is assembled and a trigger decision is made.

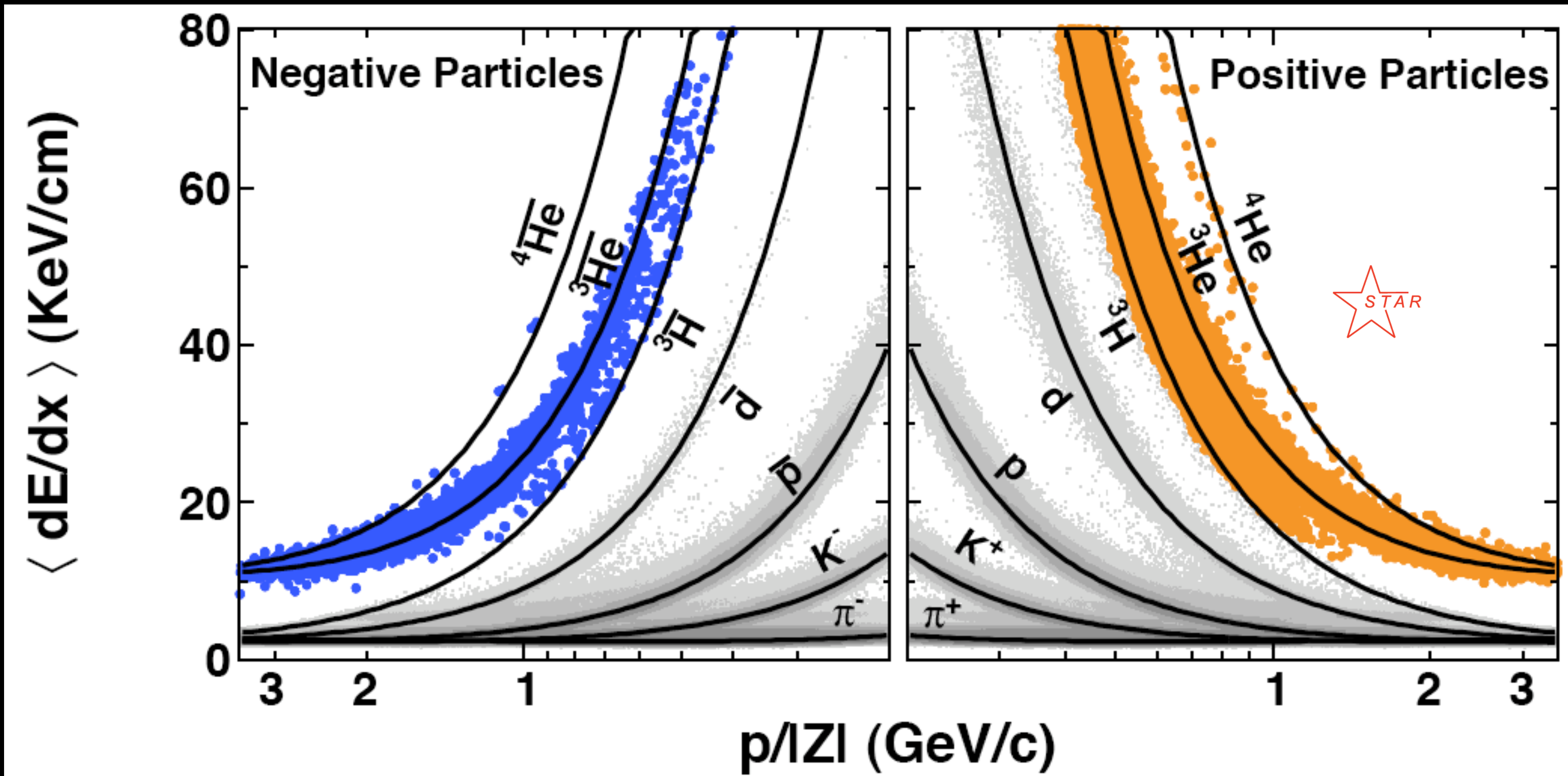
Fast physics output with HLT

Data Sample

- 360 million minimum bias (MB) collisions, 270 million central collisions and 170 million high tower calorimeter events at 200 GeV in 2010.
- 70 million MB events at 200 GeV in 2007.
- 170 million MB events at 62 GeV in 2010.

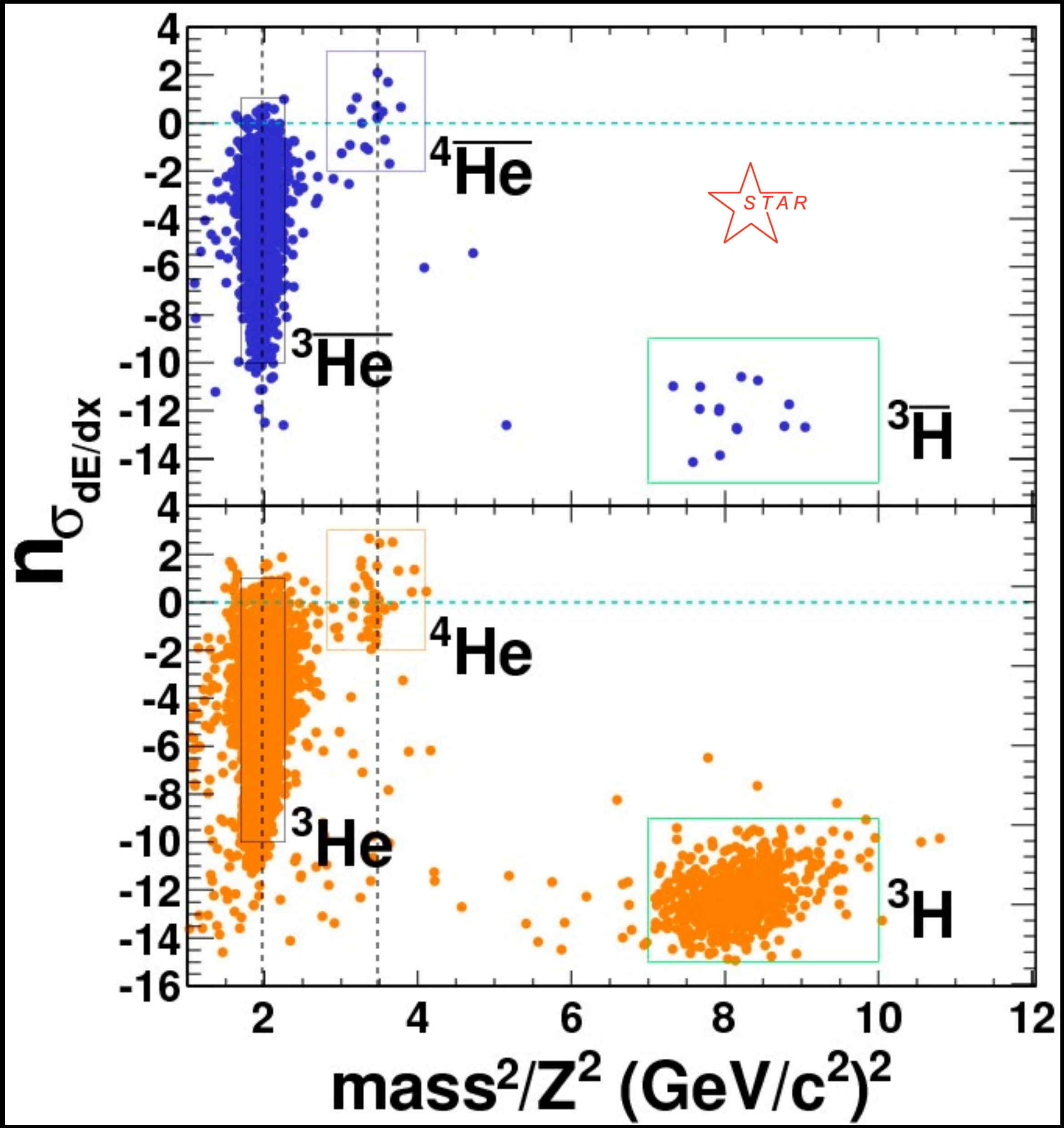
In total one billion AuAu events sampled

dE/dx vs Rigidity

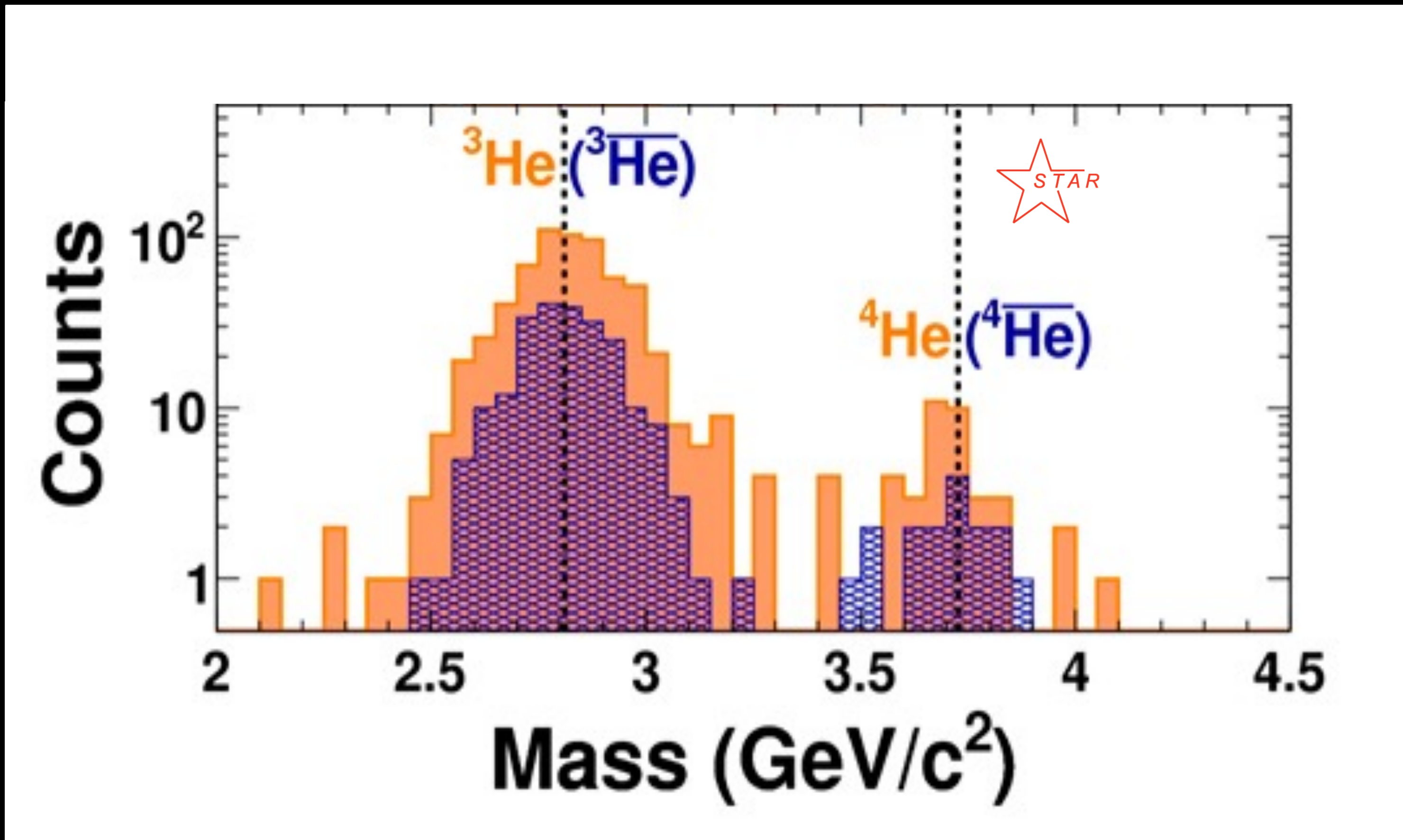


HLT has processing power to do rudimentary event reconstruction in real time, allowing events with a *|Z|* = 2 track to be tagged and fast-tracked via the normal offline calibration & reconstruction chain.

Combined PID (TPC+TOF)



Combined PID (TPC+TOF)



Very clean identification after search of > half-trillion tracks from almost one billion gold-gold collisions.

In total 18 counts observed.

Quality Assurance

Anti-α track qualities and event figs

http://www.star.bnl.gov/protected/lfspectra/xueliang/Web/Run10HLTAntiHe4/note/evtdisplay/evtdisplay.htm

Observation…-4 nucleus   Index of /pr…iAlphaPaper   HLT review ,… experiment   STAR Online Web Server   HLT Online Monitoring

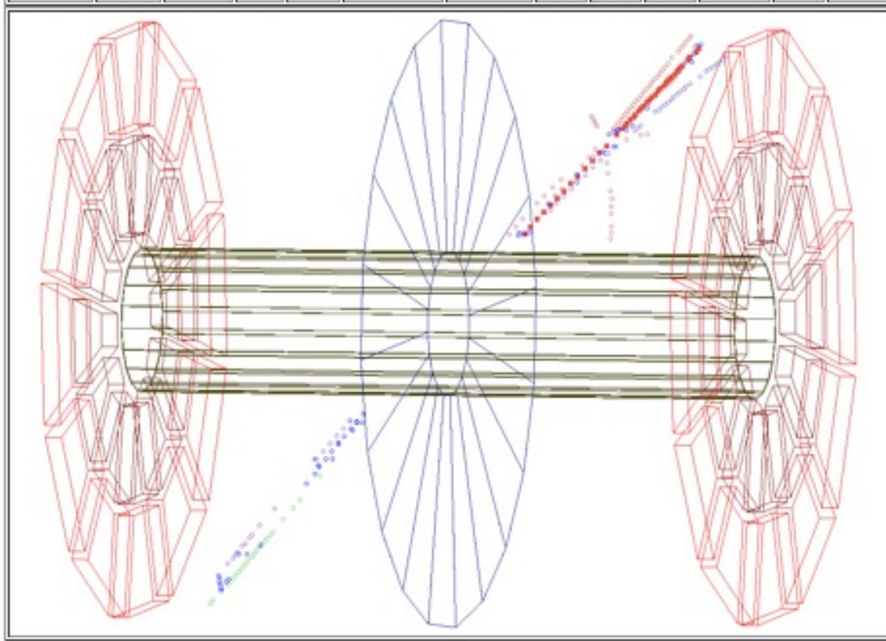
Anti-α track qualities and event figs

Anti-α information:

- Run10 200GeV Au+Au collisions

1. First anti-α candidate track qualities.

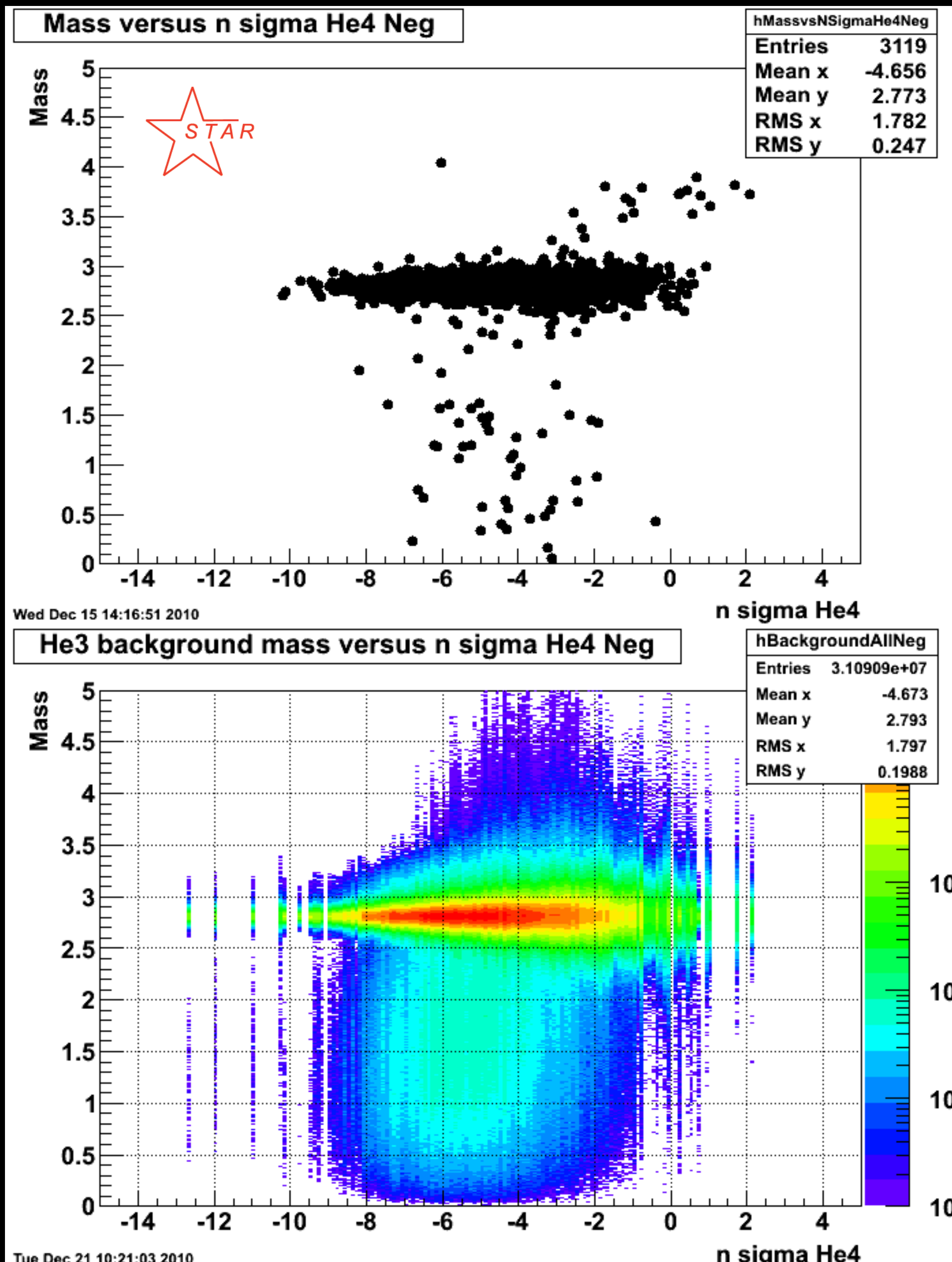
run ID	event ID	vertexZ	Ref Mult	nHits	nHitsdEdx	Rigidity (primary)	eta	phi	dca	path length	chi2	$n\sigma^4_{He}$	EMC Energy	tofLocalZ	tofLocalY	tot	tof	β	Mass
11073003	164108	-4.207	478	41	20	2.319	0.791	2.835	0.789	250.747	1.616	2.11	--	-0.916	-1.489	25.915	12.135	0.780	3.726



STAR Preliminary

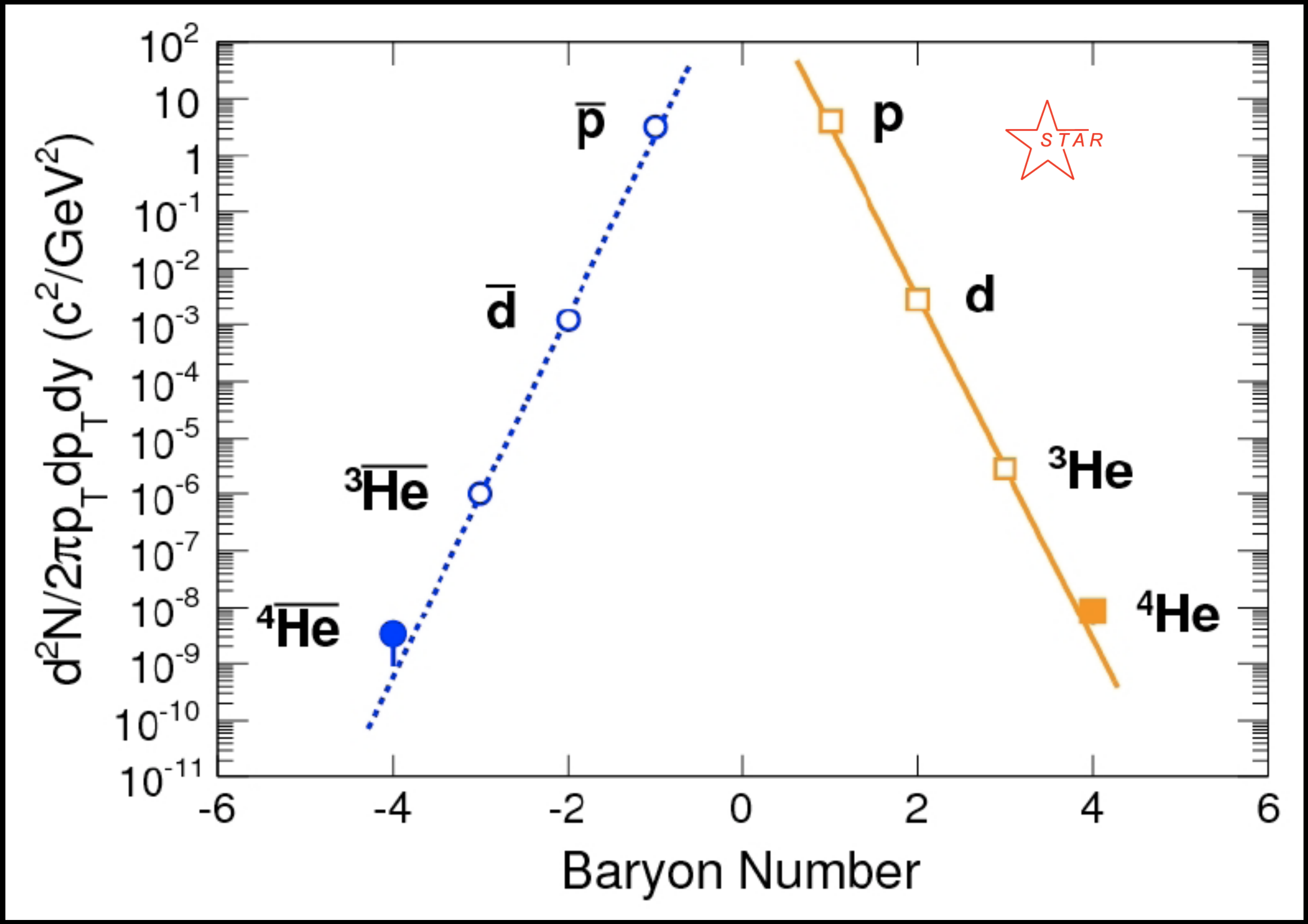
2. Second anti-α candidate track qualities.

Background Estimation



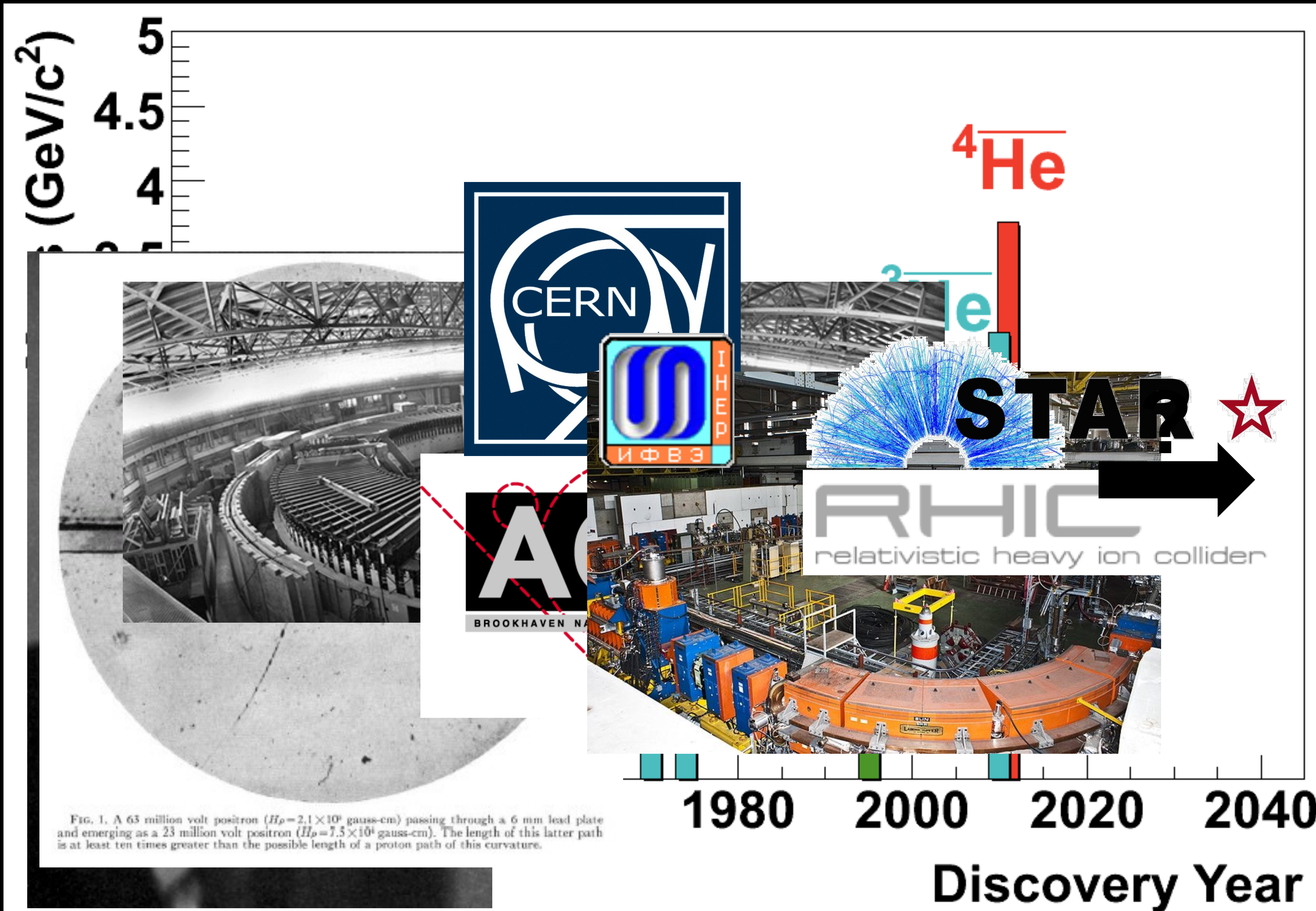
- Background contributes 1.4 counts of the 15 total counts from AuAu collisions at 200 GeV in 2010. Probability of misidentification at 10^{-11} level.

Reduction Factor

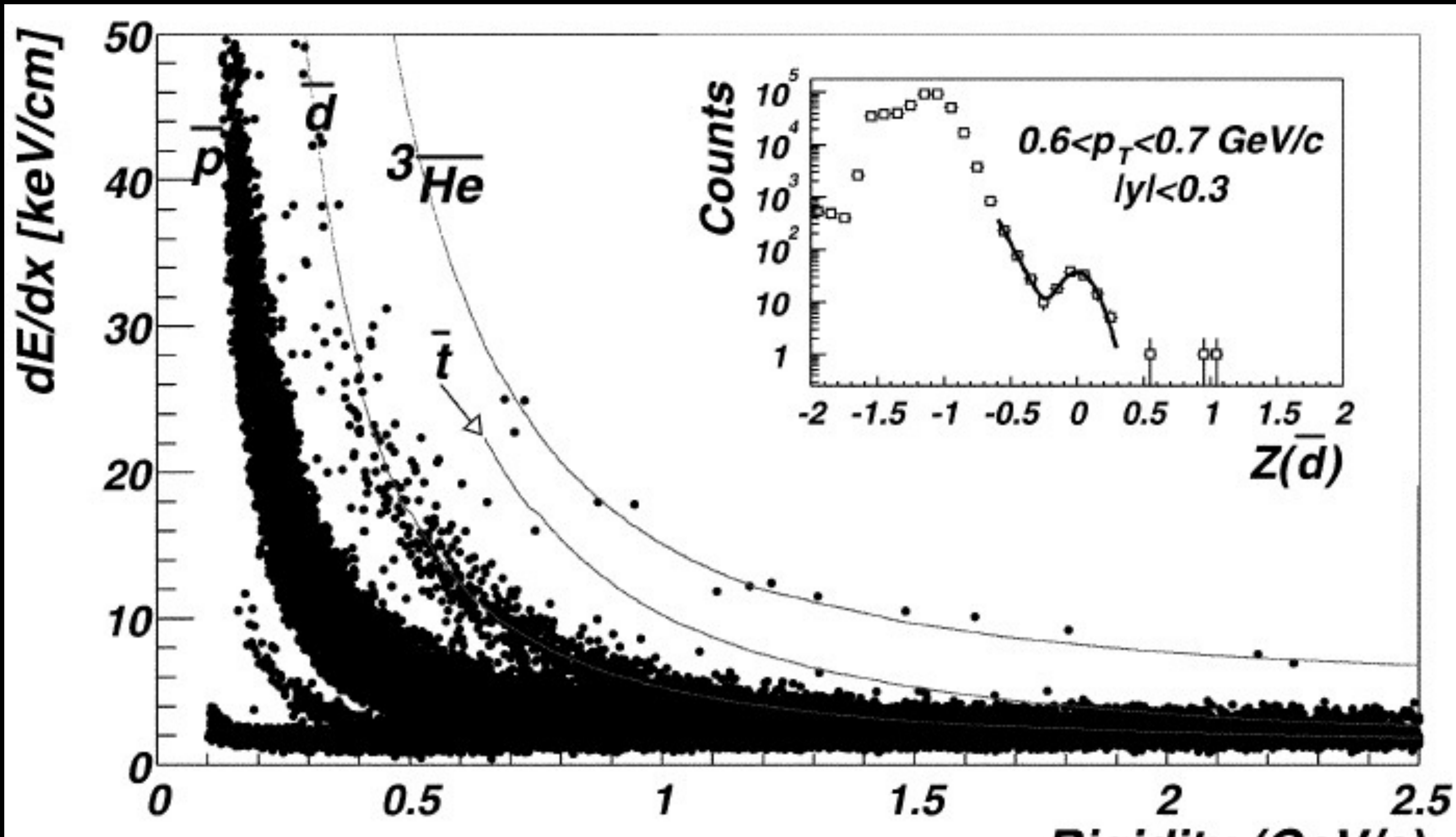


• Production rate reduces by a factor of $1.6x10^3$ ($1.1x10^3$) for each additional antinucleon (nucleon) added to the antinucleus (nucleus).

Race for the Heaviest



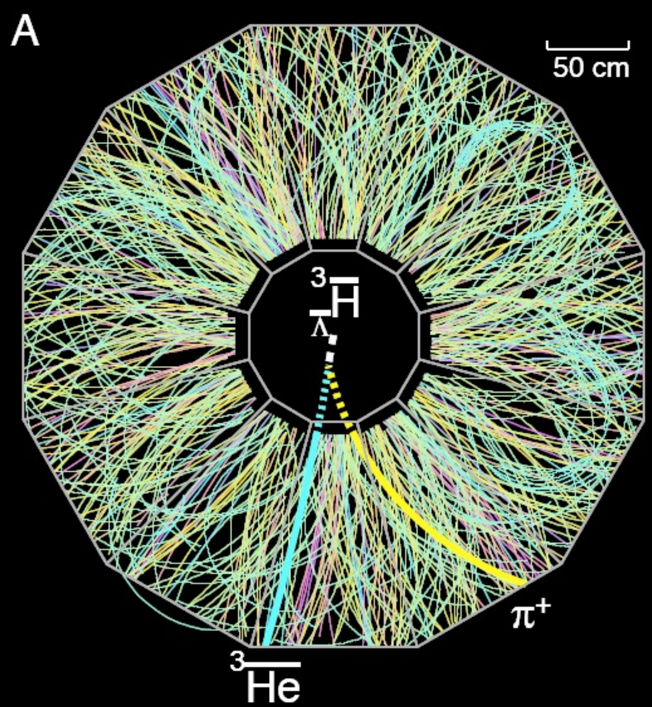
RHIC as an Exotic/Antimatter Machine

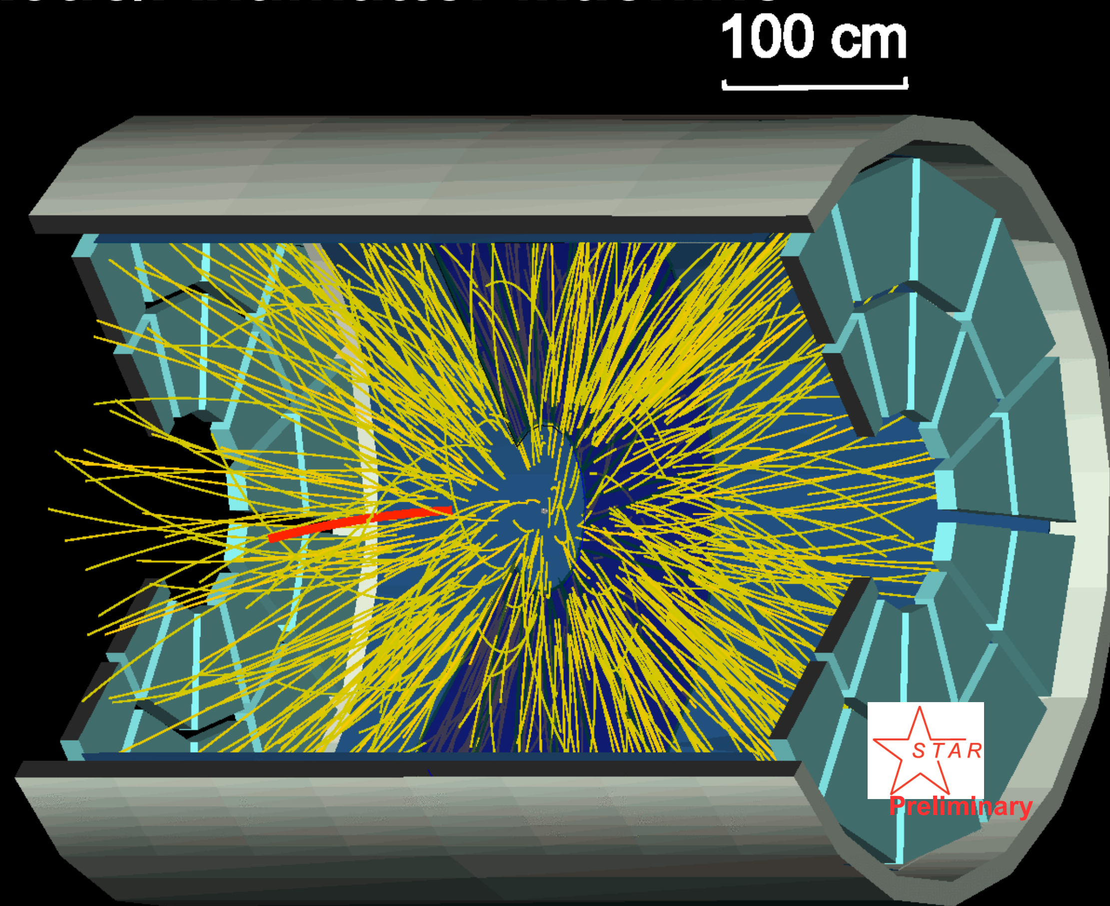


PRL 87, 262301 (2001)

First STAR results for antinuclei

RHIC as an Exotic/Antimatter Machine





Science 328, 58 (2010)

Nature 473 353 (2011)

Latest STAR results for antinuclei

News Coverage

We will not stop searching

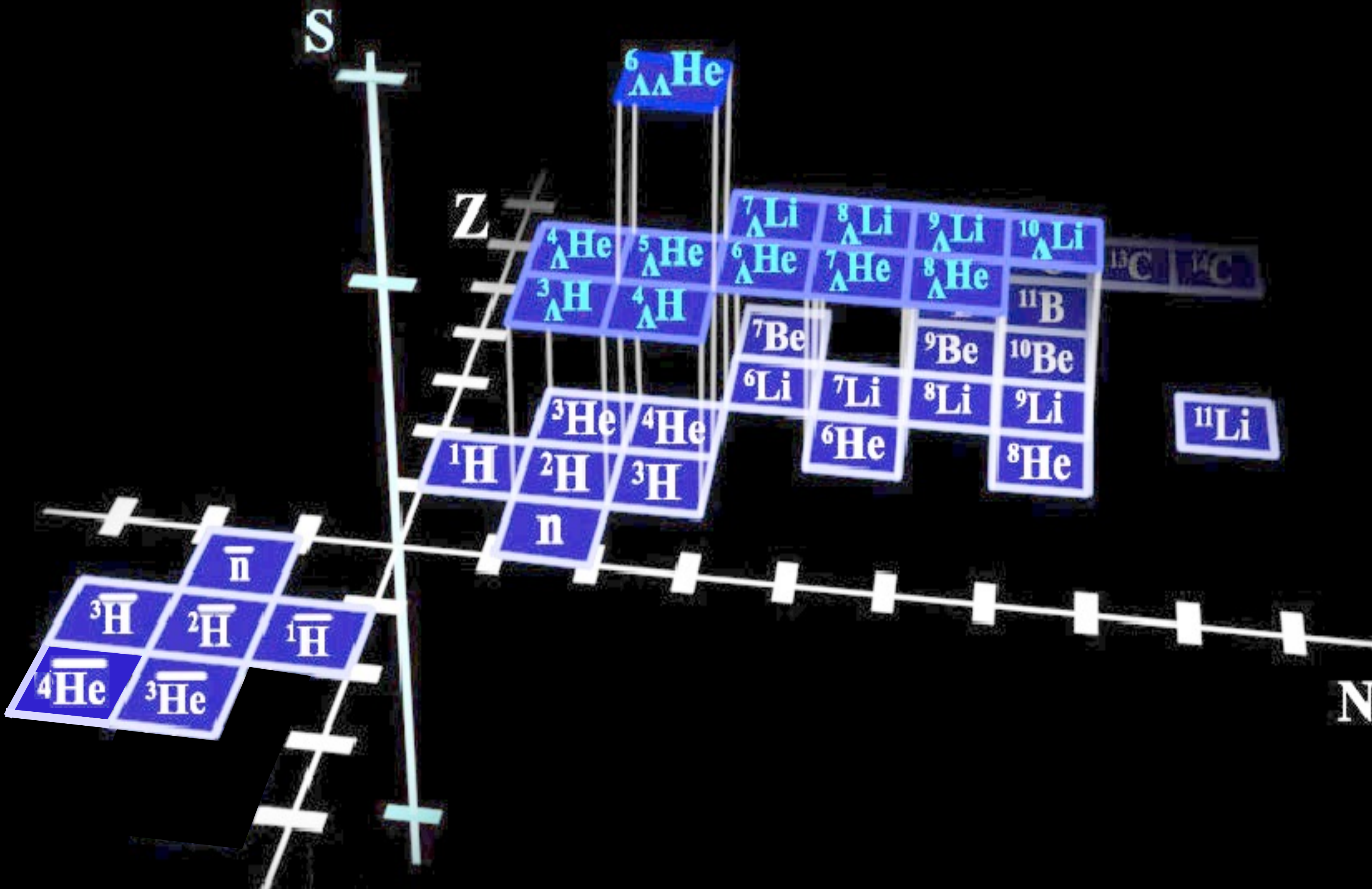
3-D Chart of the Nuclides

Antinuclei ➔ extend chart to negative *Z* & negative *N*

Hypernuclei ➔ add 3rd axis for strangeness *S*

Antihypernuclei ➔ *S* axis also flips sign

Filling 3-D Chart of the Nuclides

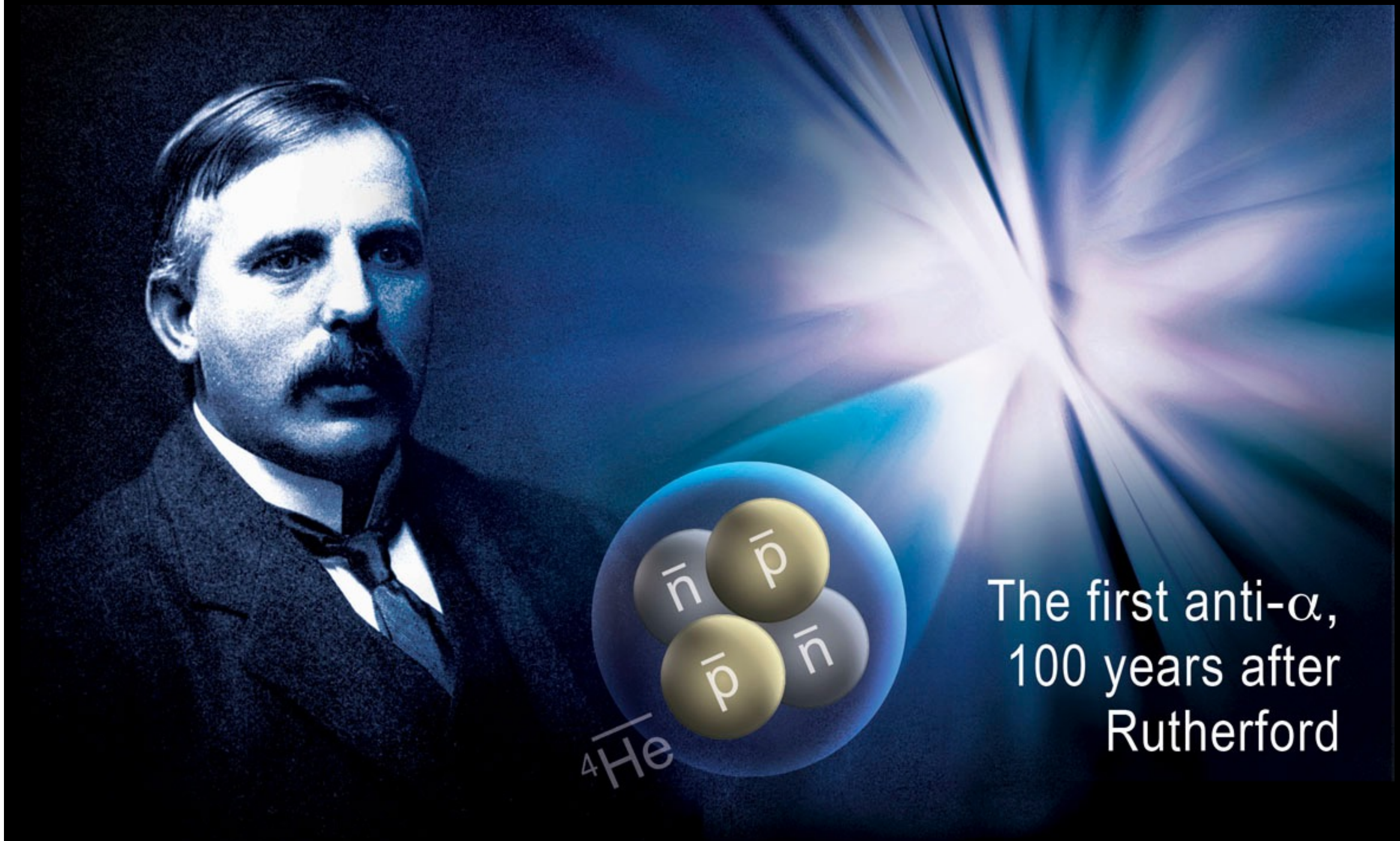


Antinuclei ➔ extend chart to negative *Z* & negative *N*

Hypernuclei ➔ add 3rd axis for strangeness *S*

Antihypernuclei ➔ *S* axis also flips sign

Synergy with Major Scientific Anniversary



Year 2011 : the 100th anniversary of Rutherford's α particle scattering experiments which marked the dawn of modern sub-atomic physics.

1911 : Rutherford used α + gold to discover the nucleus;
2011 : RHIC used gold + gold to discover the anti-α.

We are proud of that connection !

Homework

- Name a few other antimatter experiments, and explain their major goals

- Have we found anti-alpha in cosmos ? Tip : search for the progress of the AMS-02 experiment

- Is there any antimatter present in our surroundings ? Is there any practical applications for antimatter ?

Implication Beyond Nuclear Physics

•**Proved that anti-**α exists.

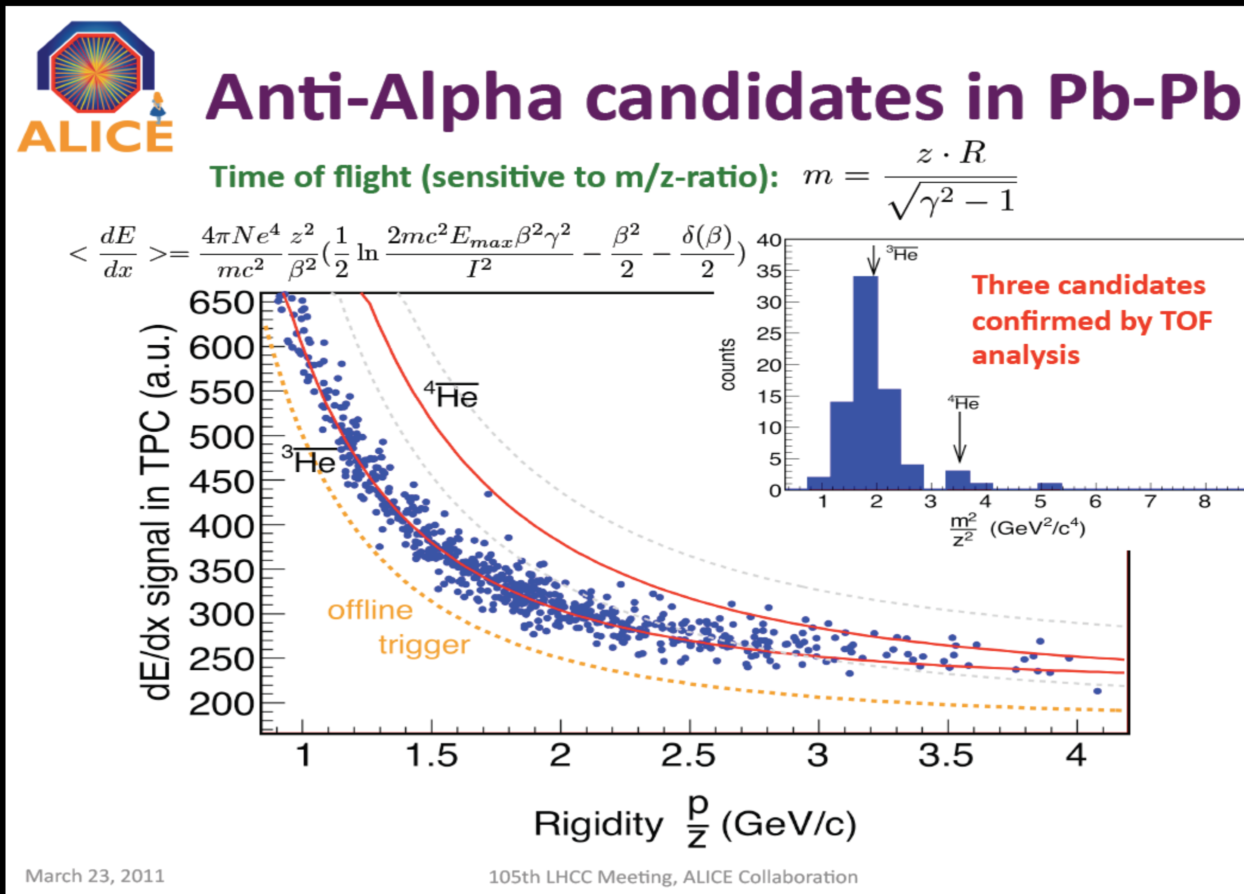
•**Provides the point of reference for various searches for new phenomena in the cosmos.**

The production rate of antihelium4 in nuclear collisions is consistent with thermodynamic and coalescent nucleosynthesis models.

If anti-α in the cosmos were from coalescence, the ratio of anti-α/α would be 10^{-16}. With a sensitivity of 10^{-9}, even a single anti-α count seen by the AMS experiment would be a strong evidence of anti-star.

• **Unless accelerator technology has major break through, our record for the heaviest stable antimatter will stand for the foreseeable future.**

The Competition



STAR :

Paper submitted to Nature on March 14th.

Posted on arXiv on March 16th.

Alice :

Candidates presented to public on March 23rd.

Without STAR's High Level Trigger, anti-helium 4 would be eventually observed at RHIC, but LHC would claim the prize for sure.

Special thanks to CAD for providing us high quality beam in run 2010, which makes this discovery possible.