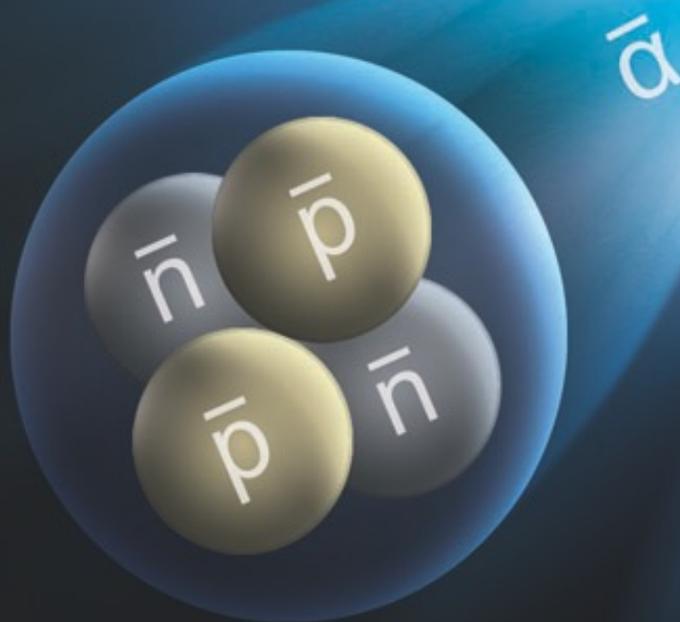


# Observation of the antimatter helium4 nucleus



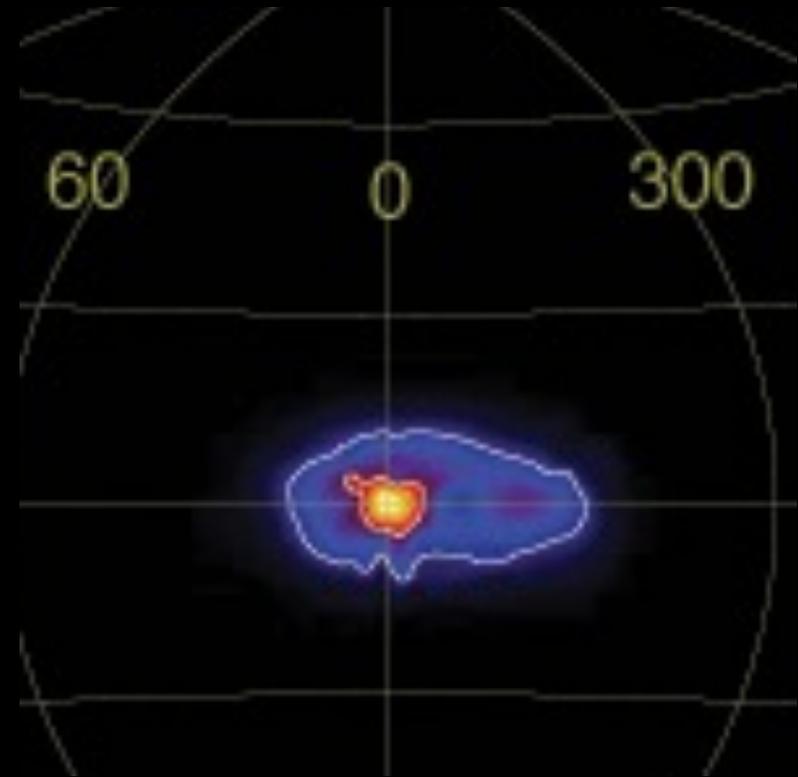
RHIC



# Why Antimatter ?



*Nature* 451, 159 (2008)

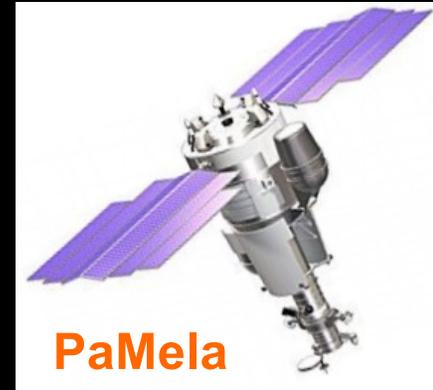


**Clue to the matter anti-matter asymmetry.**

**Antimatter matters !**

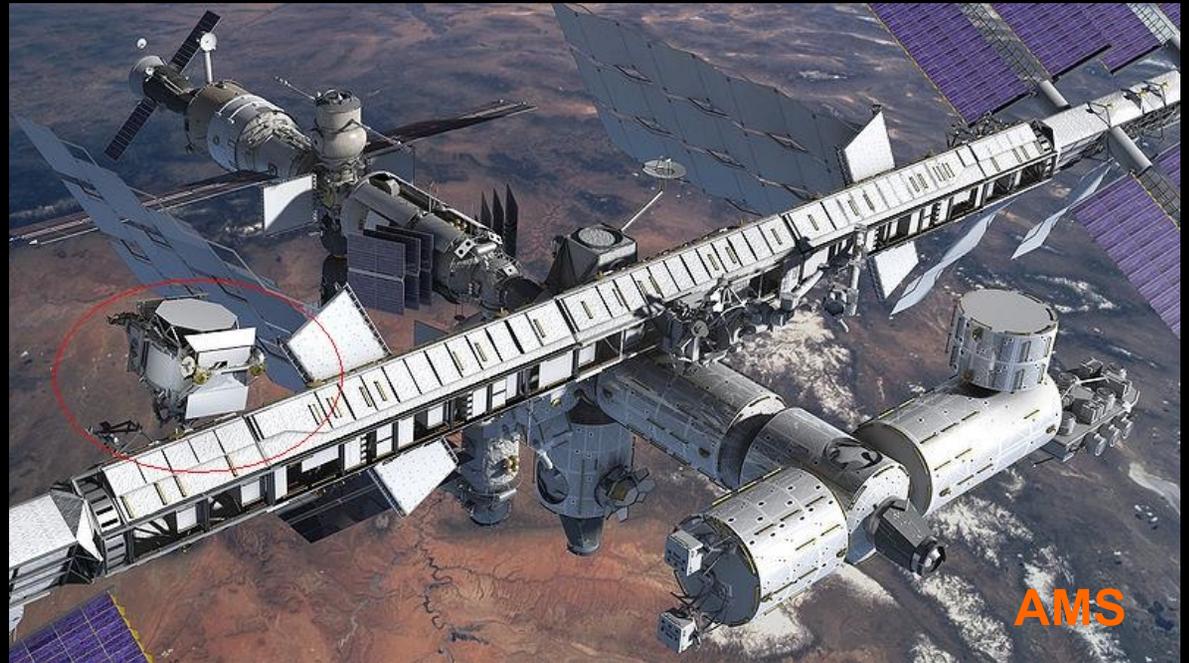
# Why Antihelium 4 (anti- $\alpha$ ) ?

**BESS**



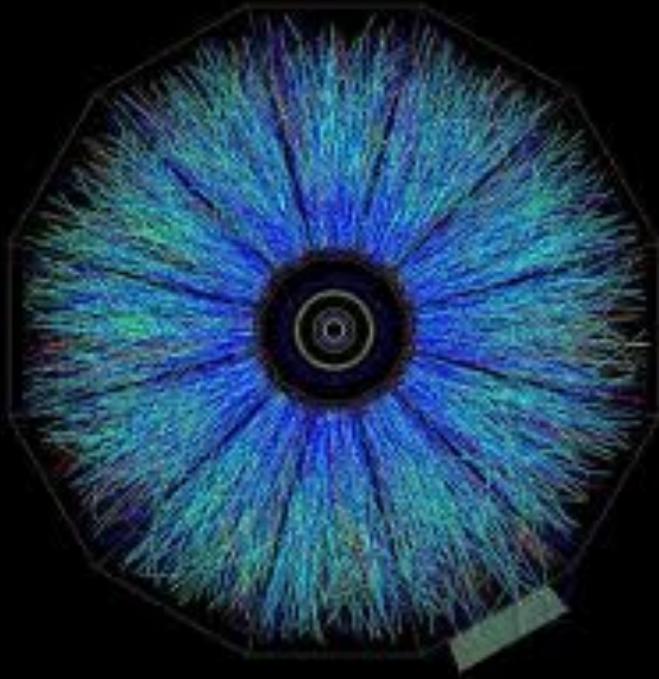
**PaMela**

**Finger print of anti-star !**



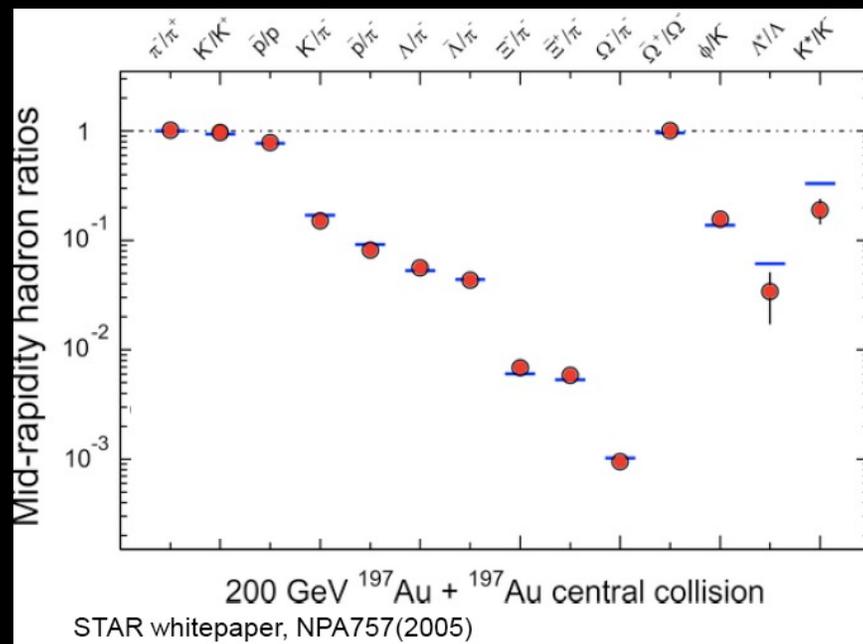
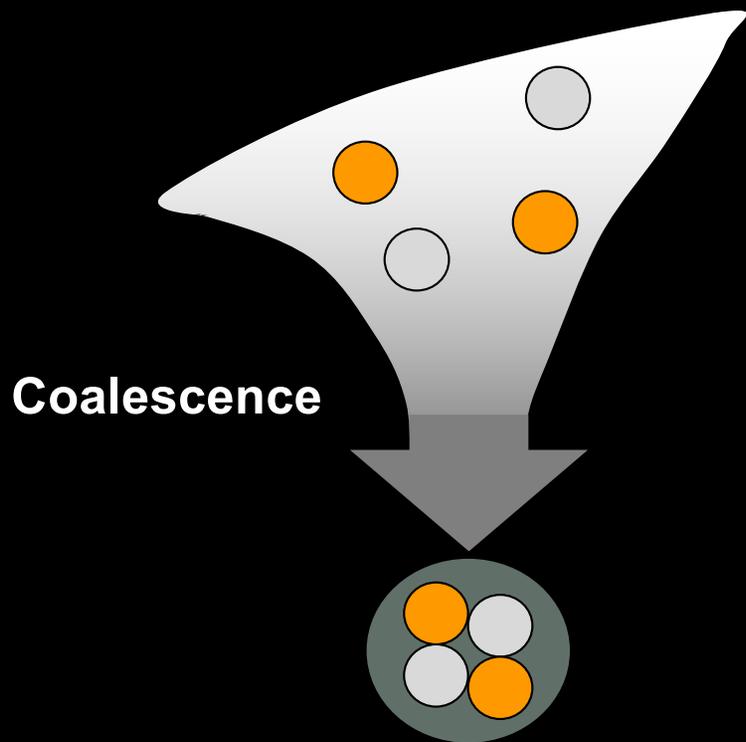
**AMS**

# 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

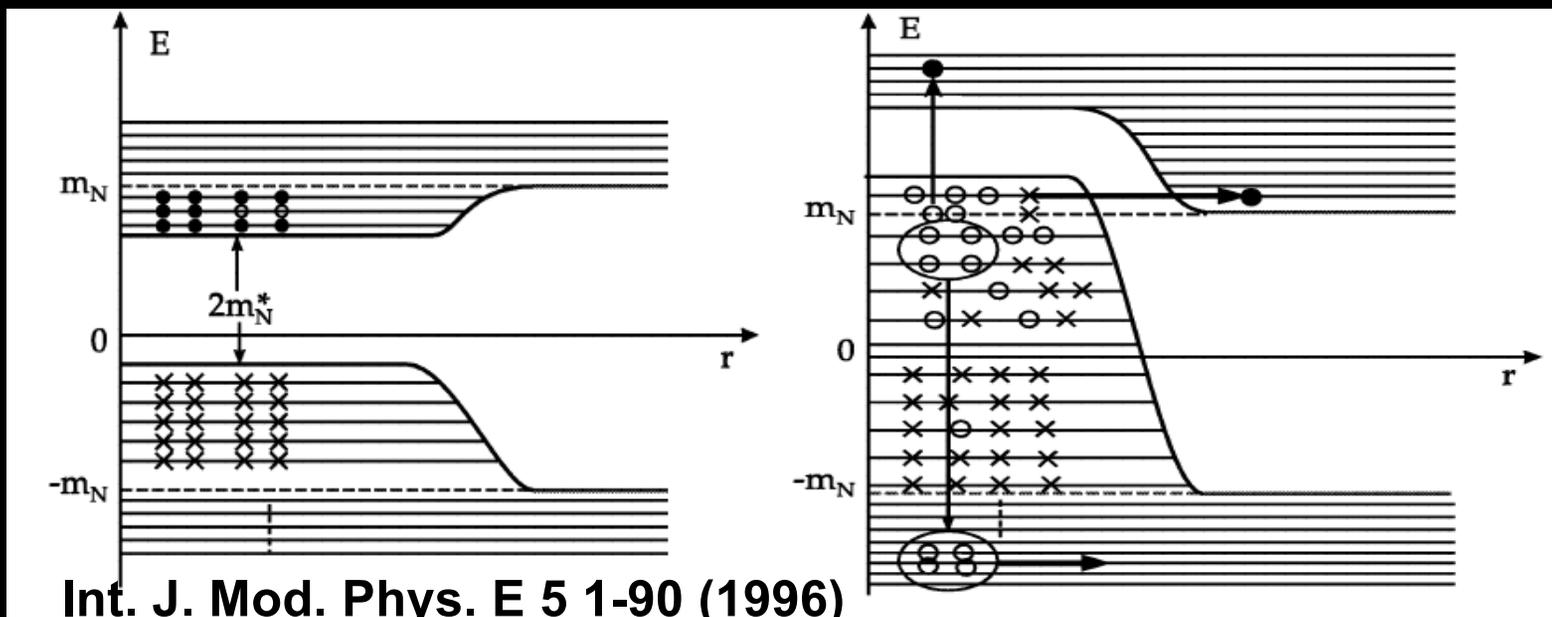


$$N_i = V g_i \int \frac{d^3p}{(2\pi)^3} \exp\left(-\frac{E_i}{T} + \frac{\mu_i}{T}\right)$$

**Thermal production**

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

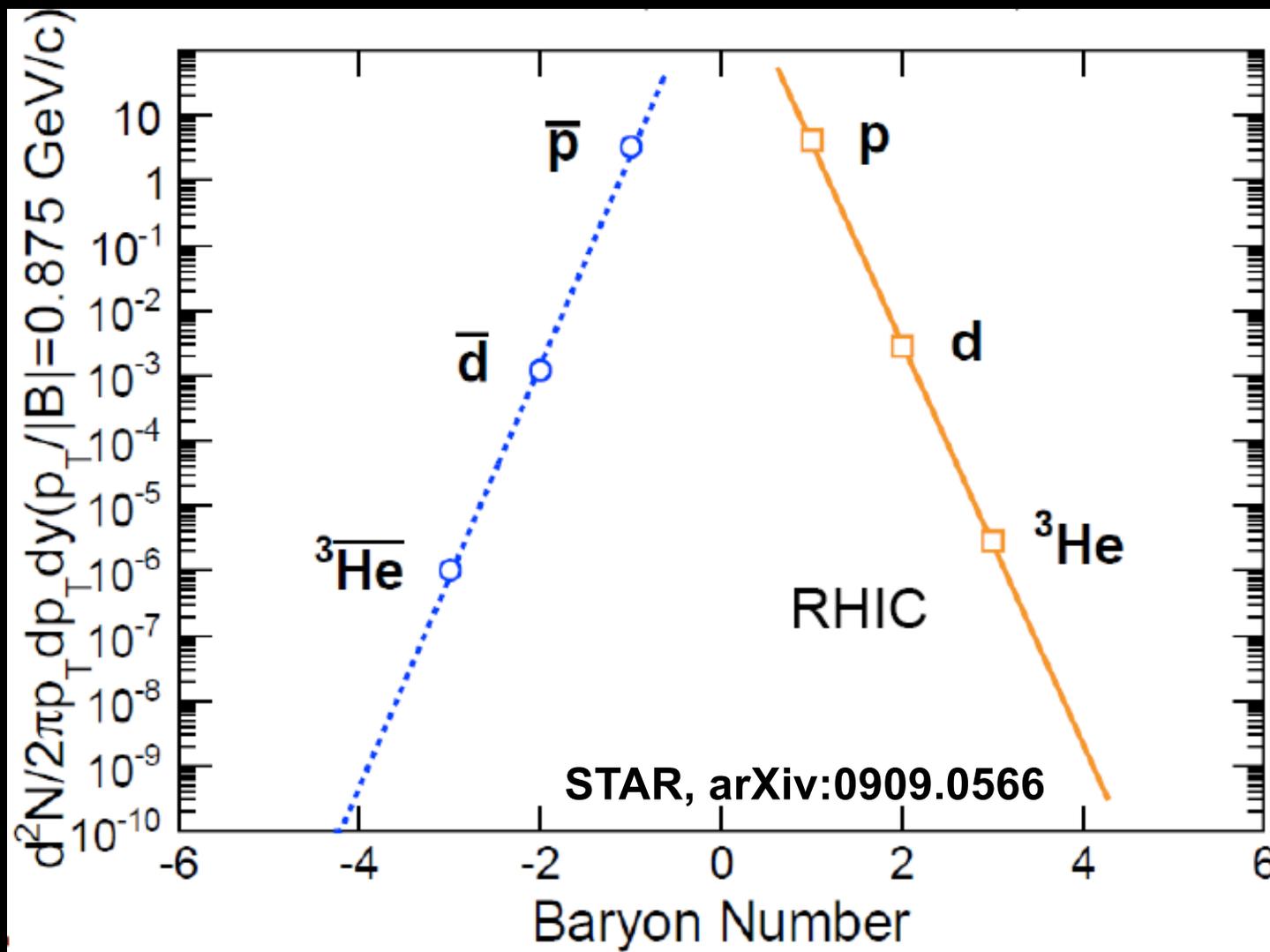
# Production Mechanisms



Idea from Walter Greiner: correlations are present in vacuum, allowing antinucleus like anti- $\alpha$  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

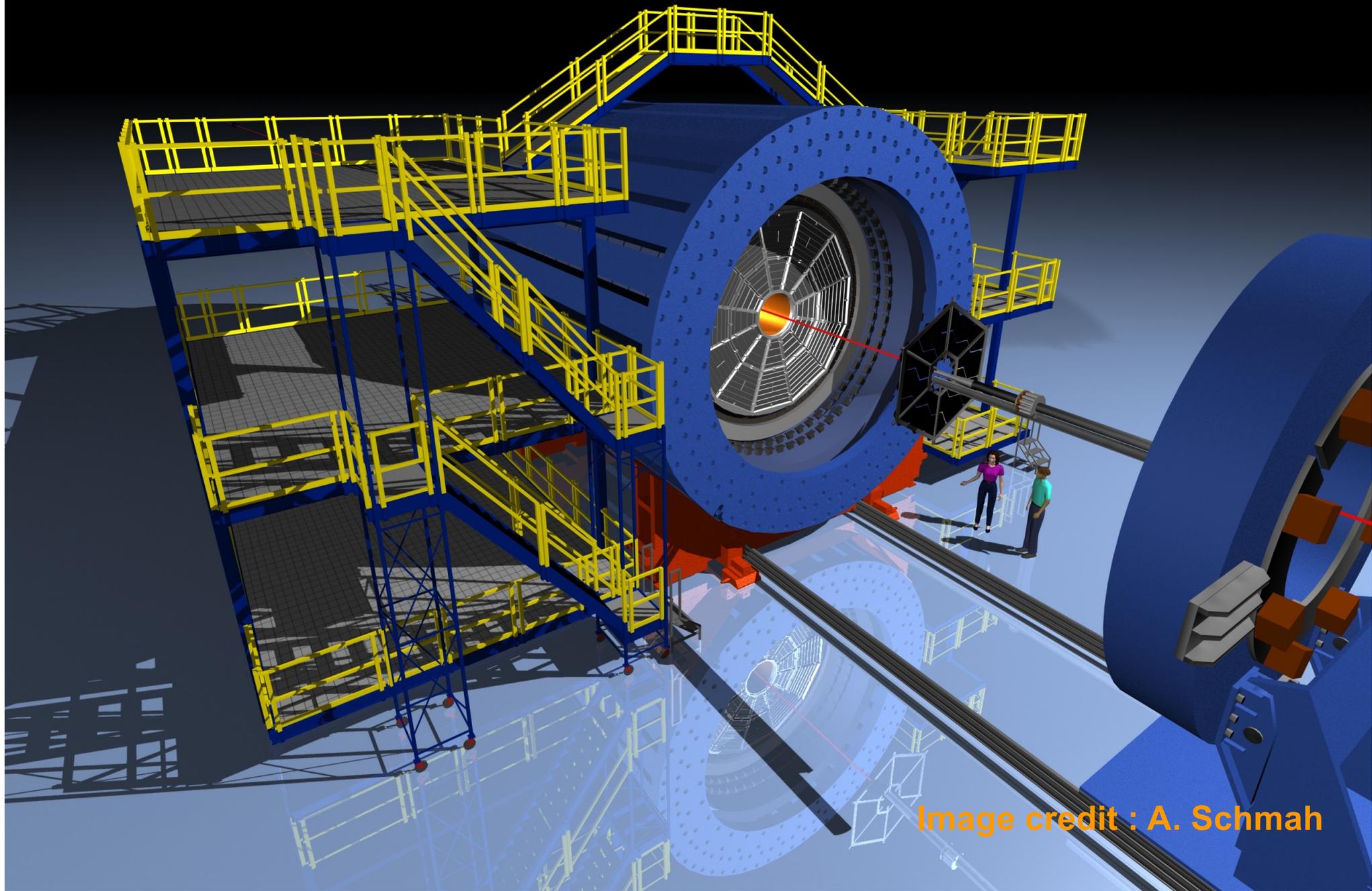
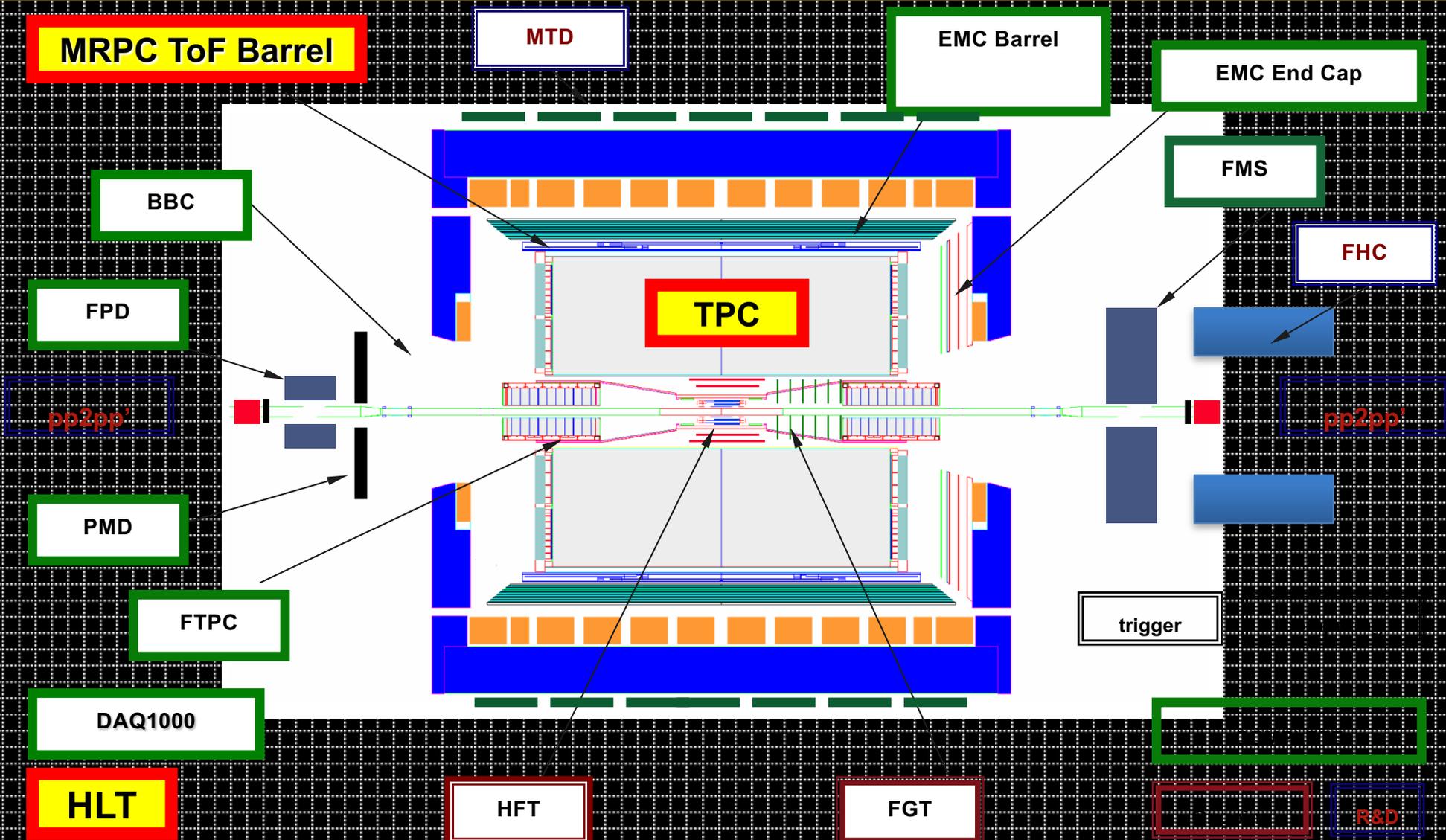
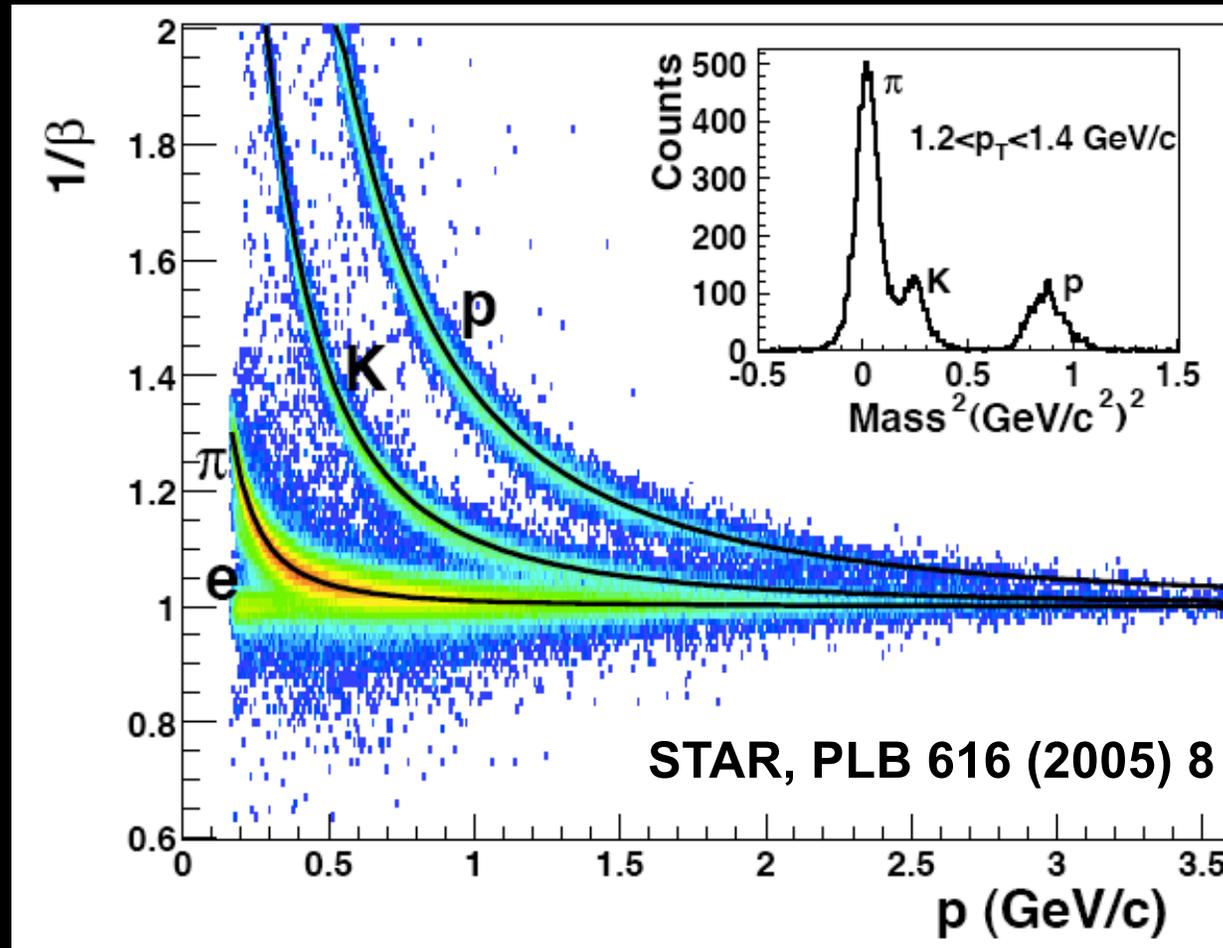


Image credit : A. Schmah

# Key Components for this Search

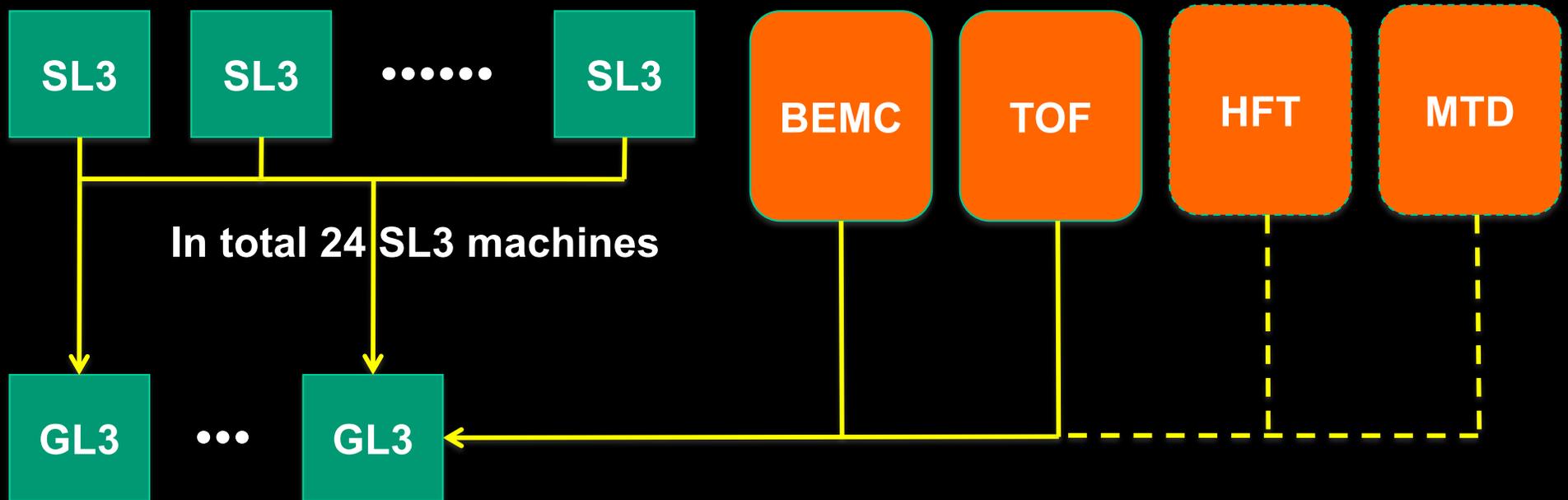


# PID : TPC + TOF



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.

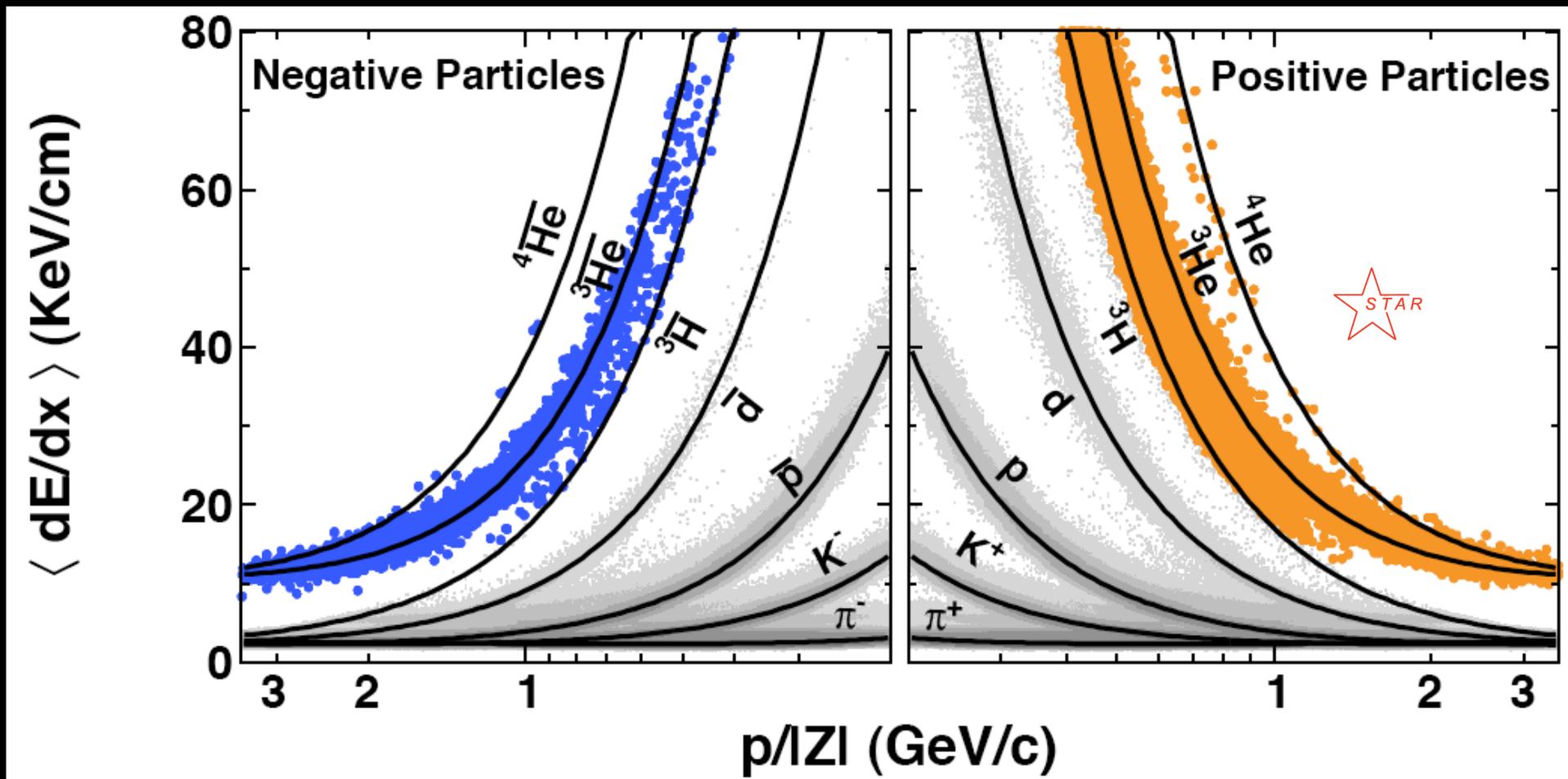
**Fast physics output with HLT**

# 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.**

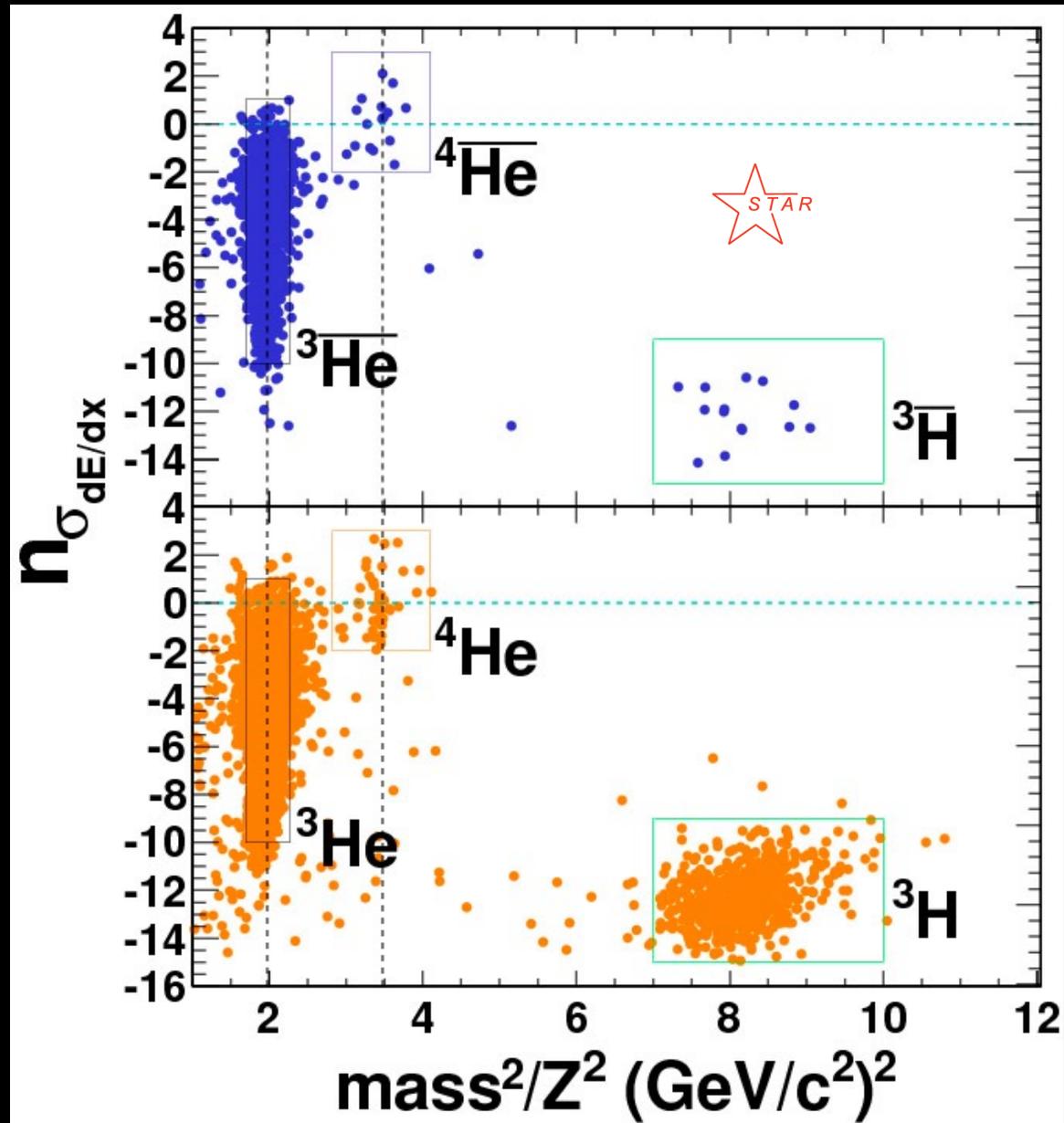
**In total one billion AuAu events sampled**

# dE/dx vs Rigidity

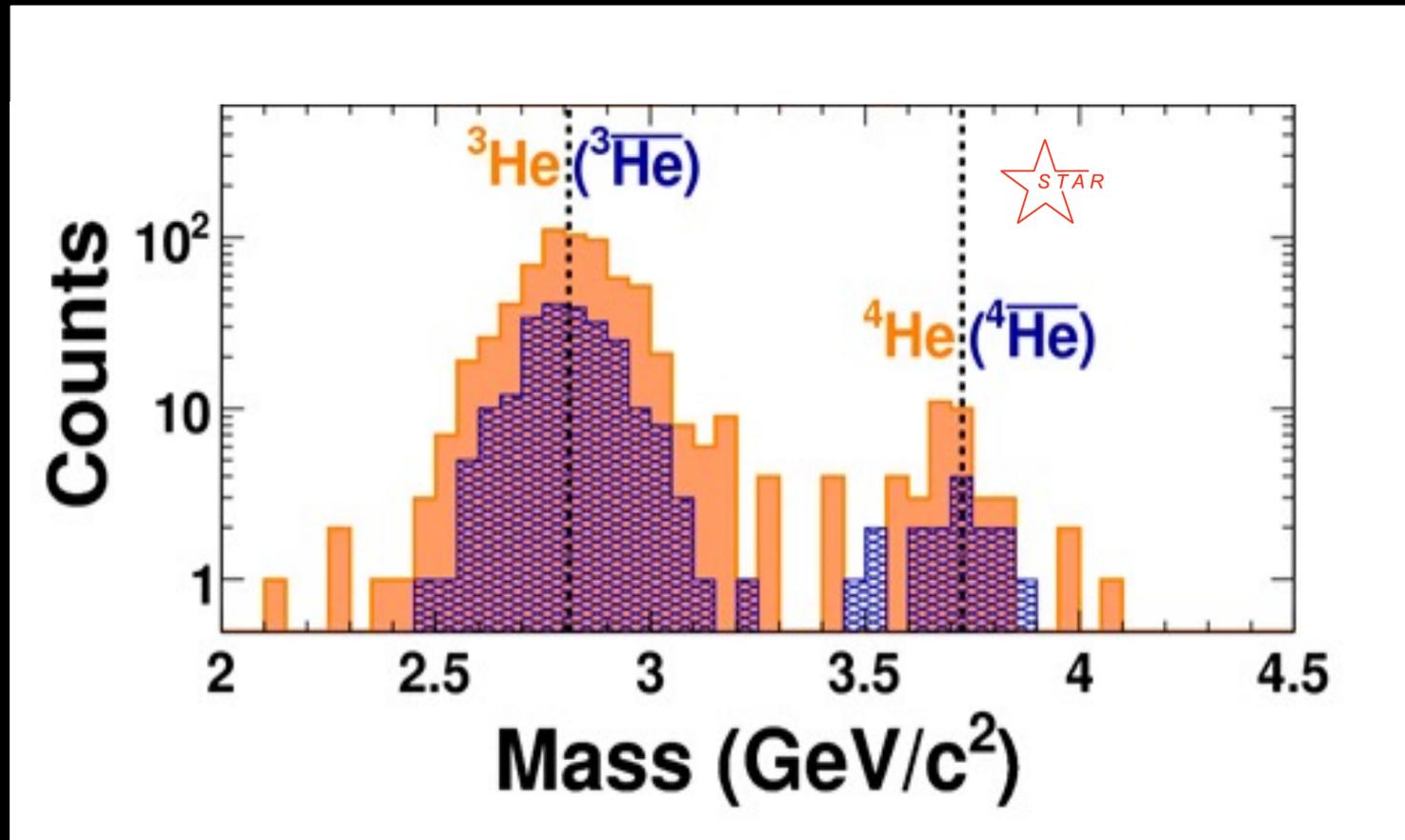


HLT has processing power to do rudimentary event reconstruction in real time, allowing events with a  $|Z| = 2$  track to be tagged and fast-tracked via the normal offline calibration & reconstruction chain.

# 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- $\alpha$  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

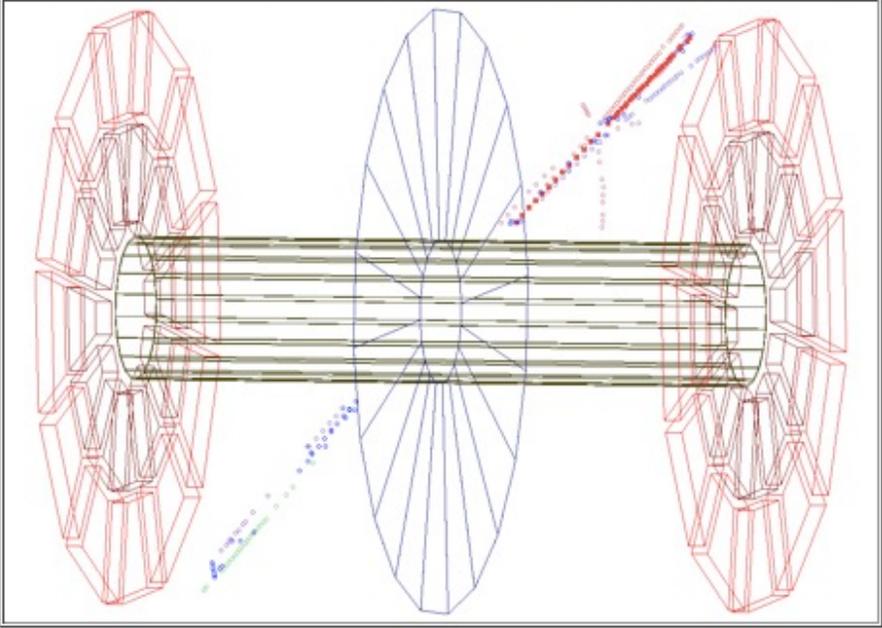
## Anti- $\alpha$ track qualities and event figs

**Anti- $\alpha$  information:**

- Run10 200GeV Au+Au collisions

1. First anti- $\alpha$  candidate track qualities.

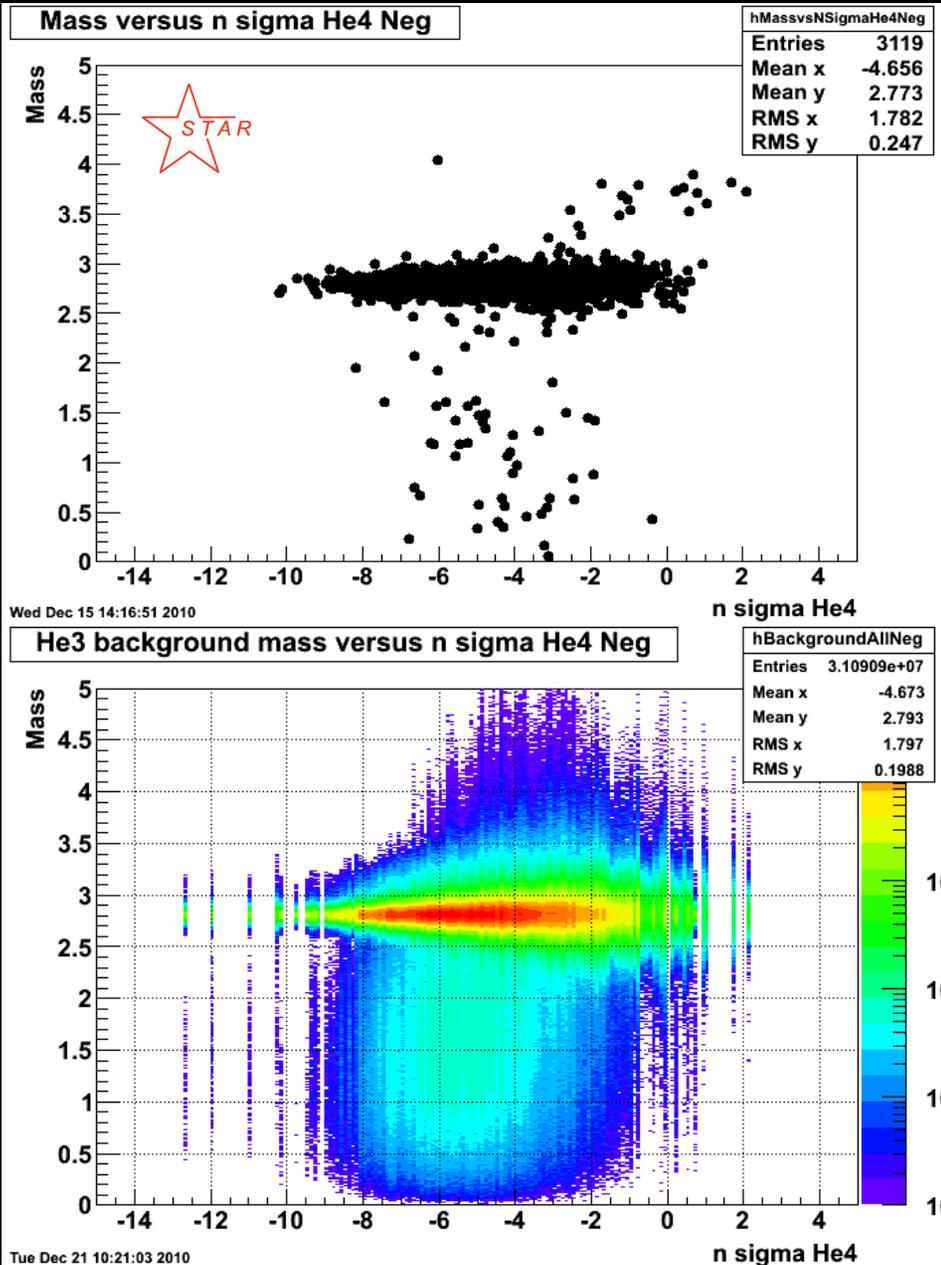
run ID	event ID	vertexZ	Ref Mult	nHits	nHitsdEdx	Rigidity (primary)	eta	phi	dca	path length	chi2	$n\sigma^4_{He}$	EMC Energy	tofLocalZ	tofLocalY	tot	tof	$\beta$	Mass
11073003	164108	-4.207	478	41	20	2.319	0.791	2.835	0.789	250.747	1.616	2.11	--	-0.916	-1.489	25.915	12.135	0.780	3.726



STAR Preliminary

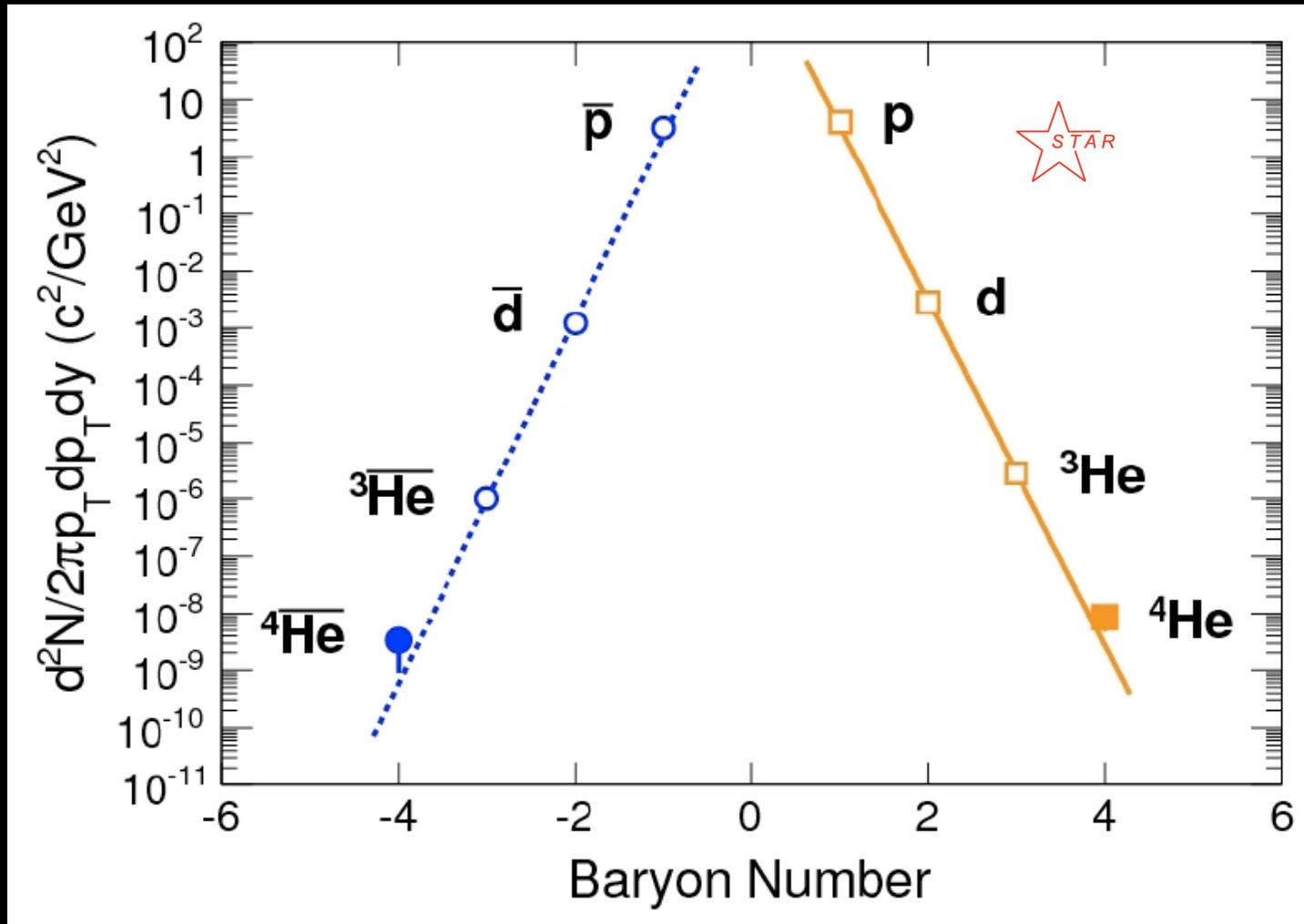
2. Second anti- $\alpha$  candidate track qualities.

# 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  $1.6 \times 10^3$  ( $1.1 \times 10^3$ ) for each additional antinucleon (nucleon) added to the antinucleus (nucleus).

# Race for the Heaviest

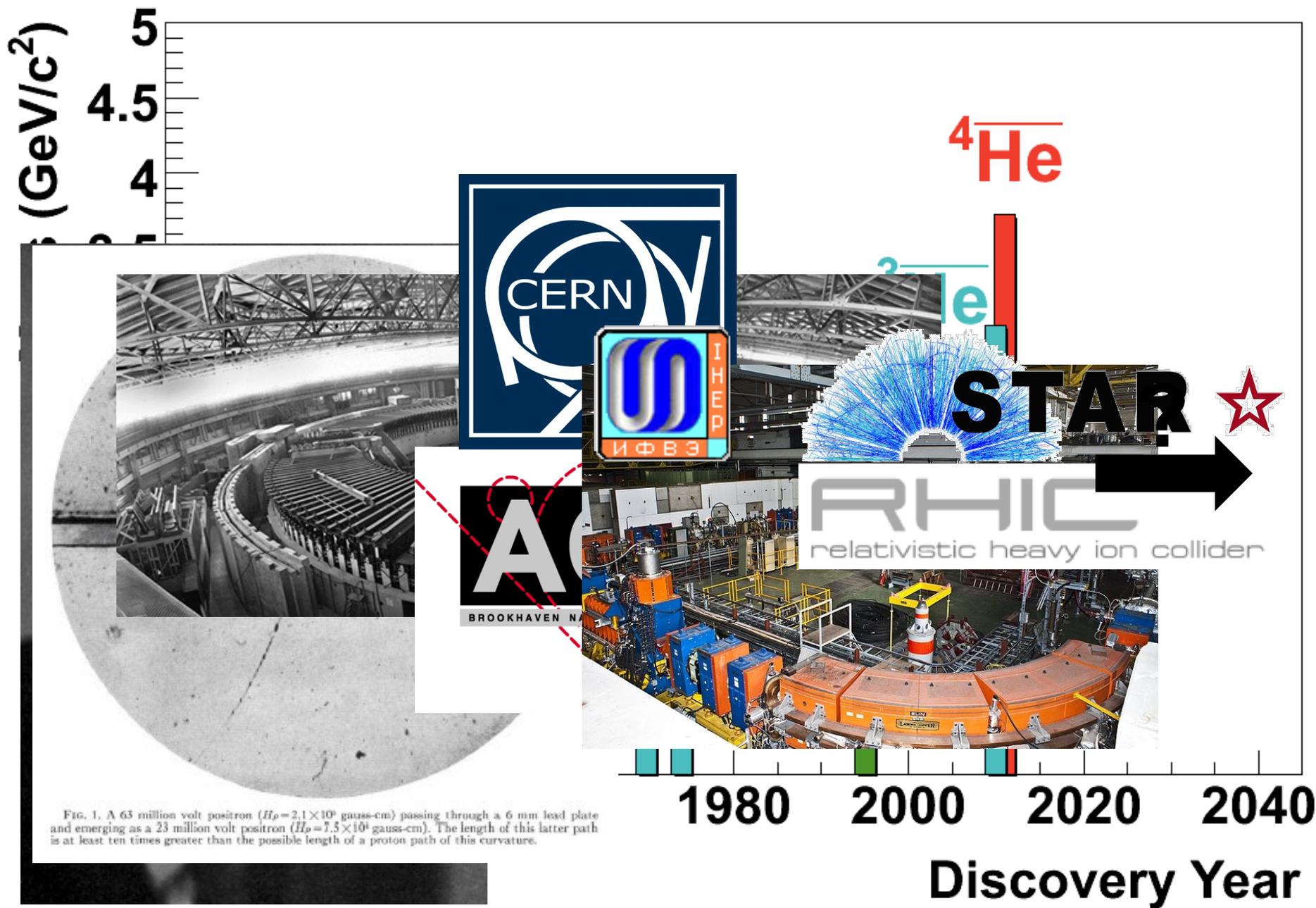
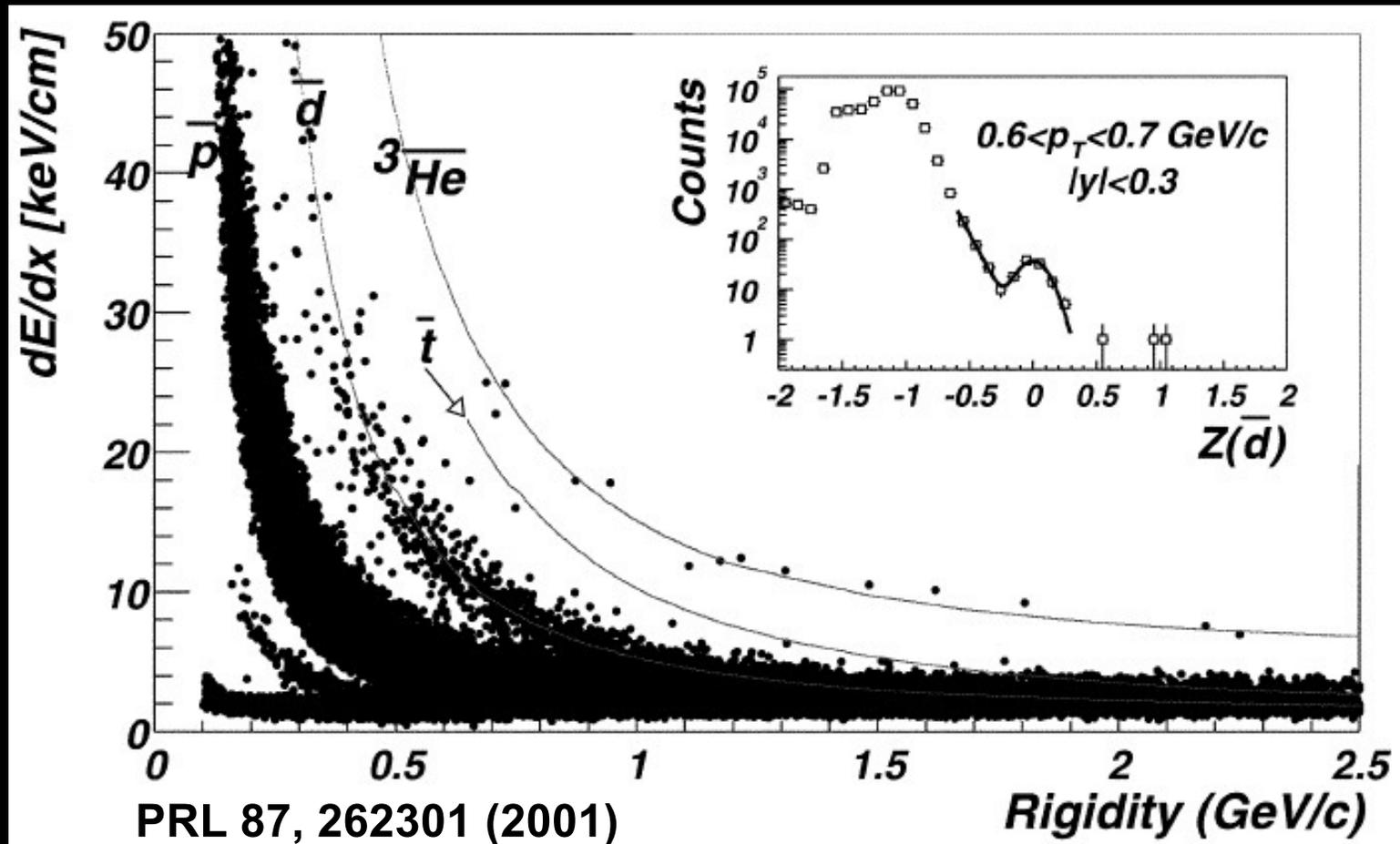


FIG. 1. A 63 million volt positron ( $H\rho = 2.1 \times 10^6$  gauss-cm) passing through a 6 mm lead plate and emerging as a 23 million volt positron ( $H\rho = 7.5 \times 10^4$  gauss-cm). The length of this latter path is at least ten times greater than the possible length of a proton path of this curvature.

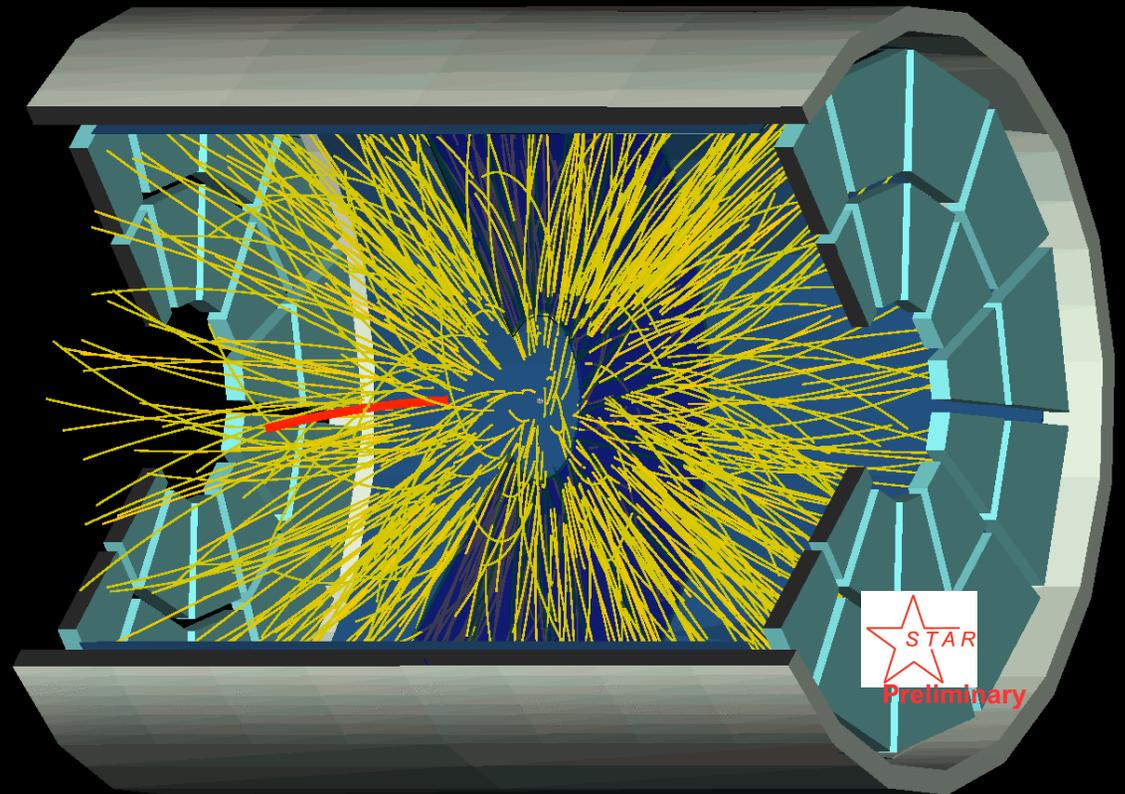
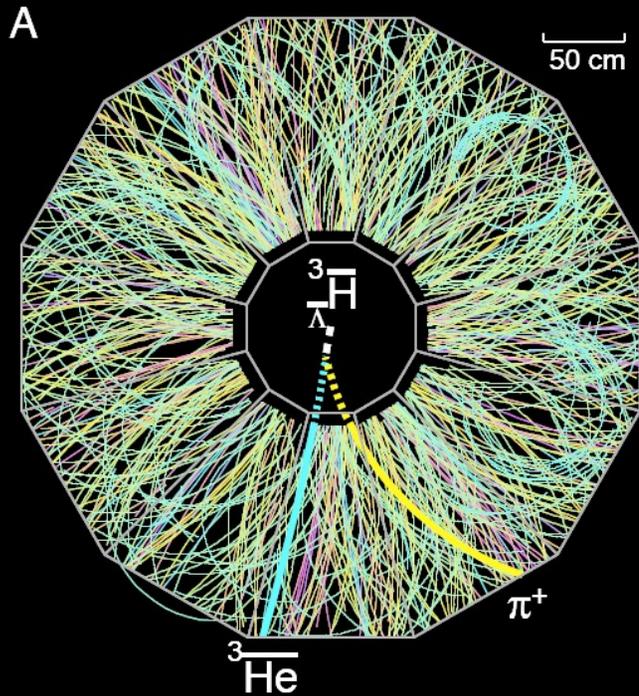
# RHIC as an Exotic/Antimatter Machine



First STAR results for antinuclei

# RHIC as an Exotic/Antimatter Machine

100 cm



Science

Science 328, 58 (2010)

nature

Nature 473 353 (2011)

Latest STAR results for antinuclei

# News Coverage

IOP A website from the Institute of Physics

## physicsworld.com

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### Heaviest ever antimatter

Mar 25, 2011 5 comments

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宇宙探秘 yuzhoutami.cn

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相对论重离子对撞机中形

时间: 2011年03月25日

美国布鲁克海文国家实验室相对论重离子对撞机国际

今科学家观察到的最重反物质。

TAGs: 反物质 相对论重离子对撞机

## Discovery News

... has gone fishing.

EARTH SPACE TECH ANIMALS DINOSAURS ARCHAEOLOGY HISTORY HUMAN

Discovery News > Space News > Antimatter

### ANTIMATTER GETS HEAVIEST

Analysis by Jennifer Ouellette  
Wed Mar 30, 2011 01:03 PM EST

technology review  
Published by MIT

English | en Español | auf Deutsch | in Italiano

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### First Observation of the creation of 18 nuclei of energy physics.

KFC 01/21/2011  
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### US scientists get glimpse of antihelium

Heaviest particles of antimatter seen in a lab survive for about 10 billionths of a second before crashing into collider's detector

ian Sample, science correspondent  
guardian.co.uk, Sunday 24 April 2011 17.59 BST

### Antimatter of Fact: Collider Generates Most Massive Antinucleus Yet

The Relativistic Heavy Ion Collider has produced several nuclei of the antimatter counterpart to helium 4

By John Matson | March 24, 2011 | 32

### Antihelium-4 nucleus, antinucleus yet

30 in Physics & Chemistry

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March 21st, 2011, 09:12 GMT | By Tudor Vieru

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Helium Balonnen Met Helium Location D Helium Anti Acne Anti Envelhecimento

A group of high-energy physics experts in the United States announces the production of 18 antinuclei of helium-4, the antimatter opposite of the common chemical element. This is a tremendous achievement and breakthrough in this branch of physics, analysts say.

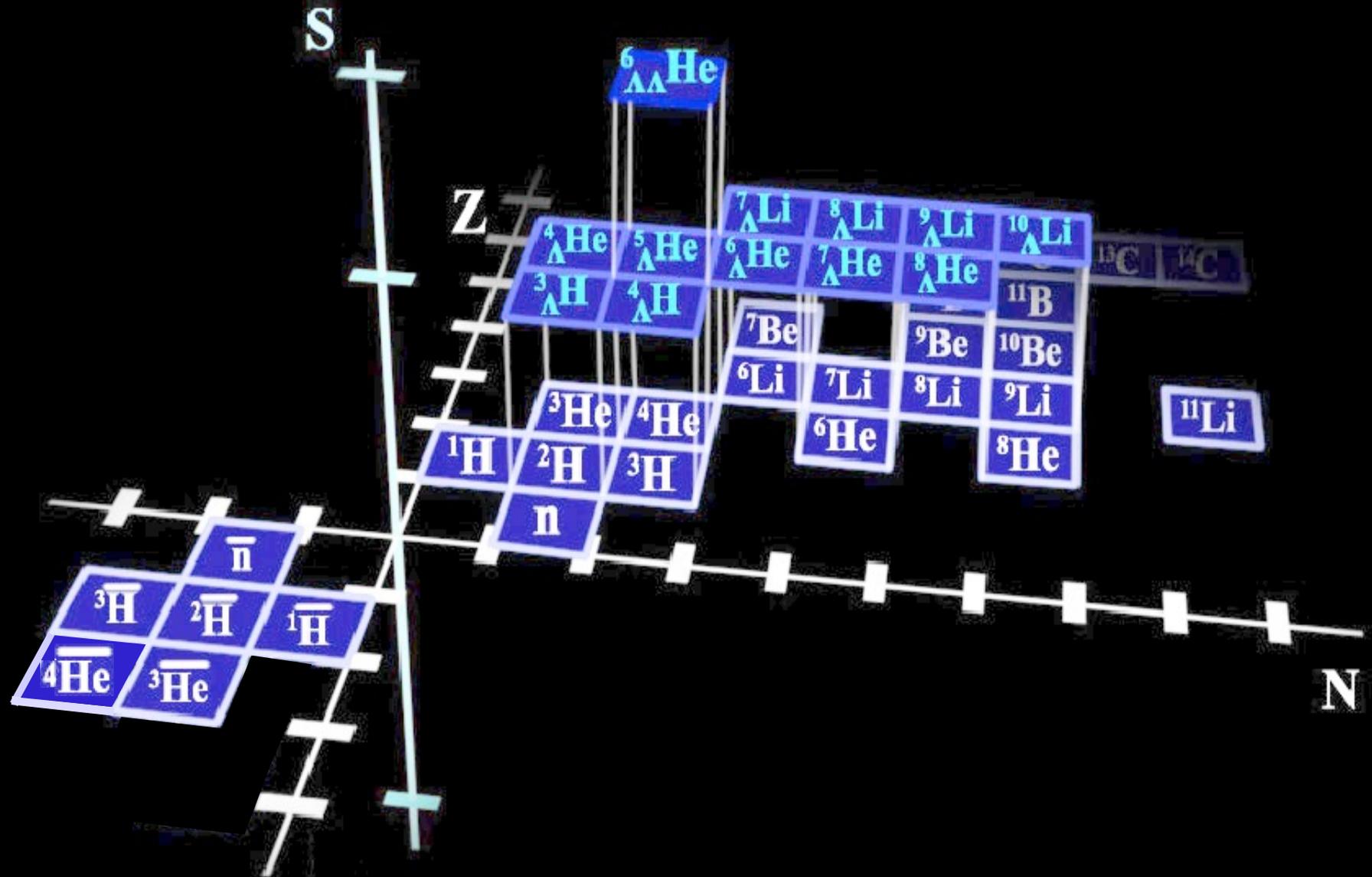
Using data obtained from in-depth analysis of these nuclei could allow experts to understand why normal matter prevailed over antimatter shortly after the Big Bang, and why the Universe exists.

**We will not stop searching**





# Filling 3-D Chart of the Nuclides

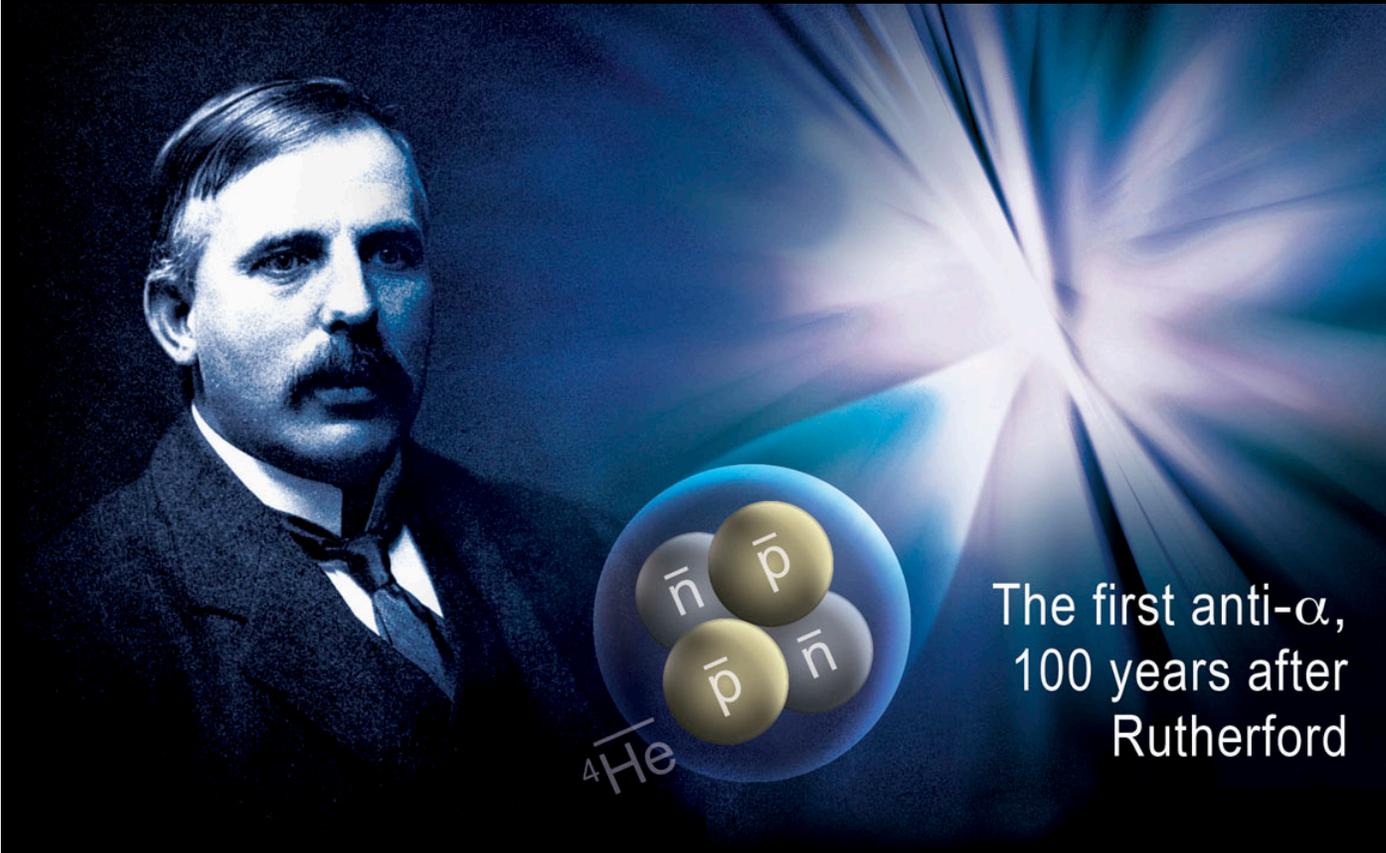


Antinuclei → extend chart to negative Z & negative N

Hypernuclei → add 3rd axis for strangeness S

Antihypernuclei → S axis also flips sign

## Synergy with Major Scientific Anniversary



Year 2011 : the 100<sup>th</sup> anniversary of Rutherford's  $\alpha$  particle scattering experiments which marked the dawn of modern sub-atomic physics.

The first anti- $\alpha$ ,  
100 years after  
Rutherford

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

**We are proud of that connection !**

# Implication Beyond Nuclear Physics

- **Proved that anti- $\alpha$  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- $\alpha$  in the cosmos were from coalescence, the ratio of anti- $\alpha/\alpha$  would be  $10^{-16}$ . With a sensitivity of  $10^{-9}$ , even a single anti- $\alpha$  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.**