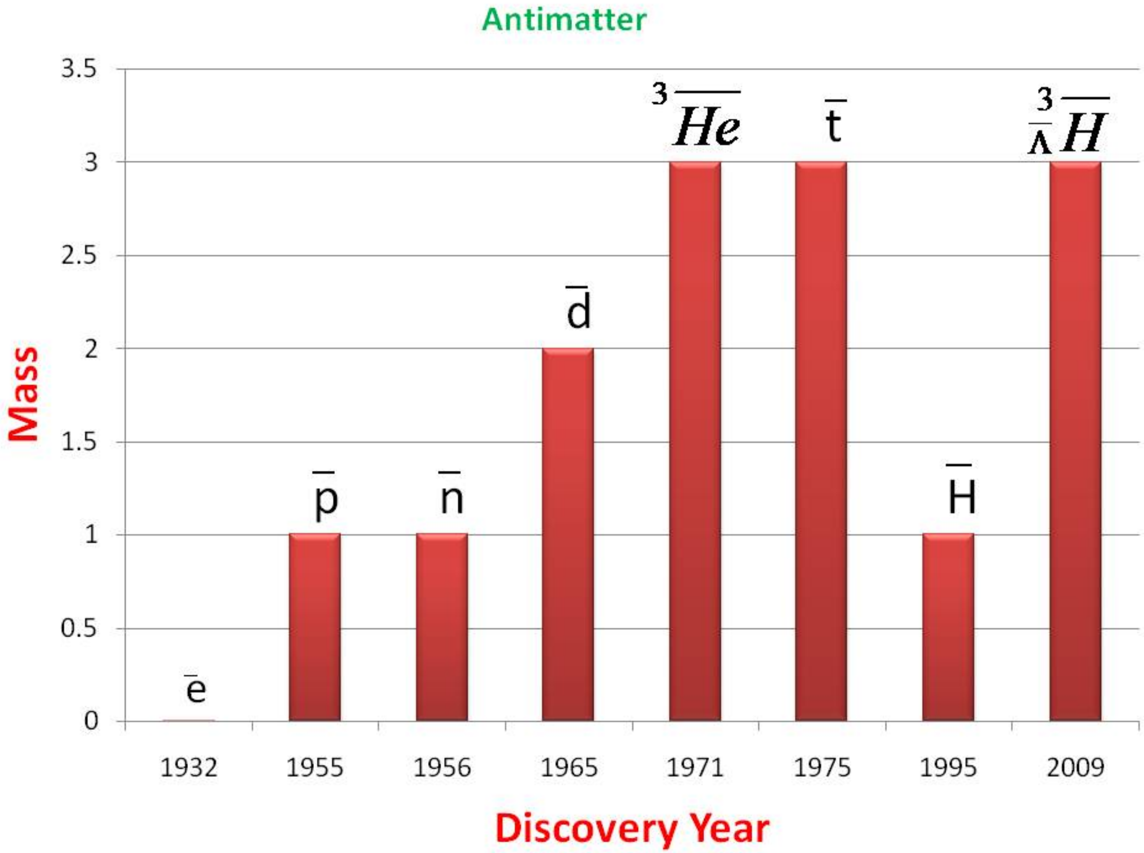
Antimatter with Heavy-Ion Beam

Zhangbu Xu

- Introduction & Motivation
- Evidence of first antihypernucleus
  - $^{3}_{\Lambda}\mathrm{H}$ and $^{3}_{\bar{\Lambda}}\overline{\mathrm{H}}$ signal (for discovery)
  - Mass and Lifetime measurements
- What can we do with the discovery?
  - Yields as a measure of correlation
  - A case for RHIC energy scan
- Outlook and Summary

BROOKHAVEN NATIONAL LABORATORY
a passion for discovery
Office of Science
U.S. DEPARTMENT OF ENERGY

Antimatter



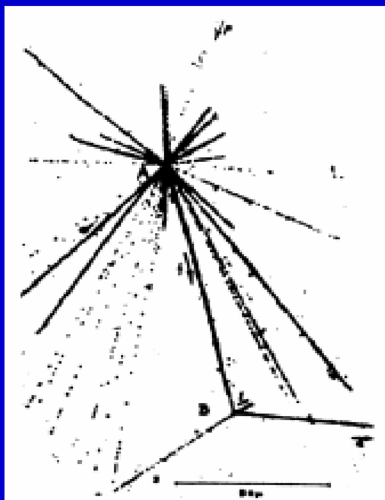
"Those who say that antihydrogen is antimatter should realize that we are not made of hydrogen and we drink water, not liquid hydrogen"
-- Dirac
Quoted from A. Zichichi (2008)
Antiparticles and antimatter: the basic difference

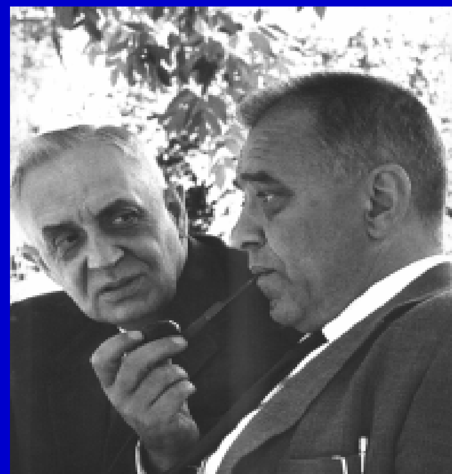
Science AAAS

Observation of an Antimatter Hypernucleus
The STAR Collaboration, *et al.*
Science **328**, 58 (2010);
DOI: 10.1126/science.1183980

What are hypernuclei（超核）？

Nucleus which contains at least one hyperon in addition to nucleons.





The first hypernucleus was discovered by Danysz and Pniewski in 1952. It was formed in a cosmic ray interaction in a balloon-flown emulsion plate.

M. Danysz and J. Pniewski, Phil. Mag. 44 (1953) 348

No one has ever observed
any antihypernucleus before RHIC

Hypernuclei of lowest A

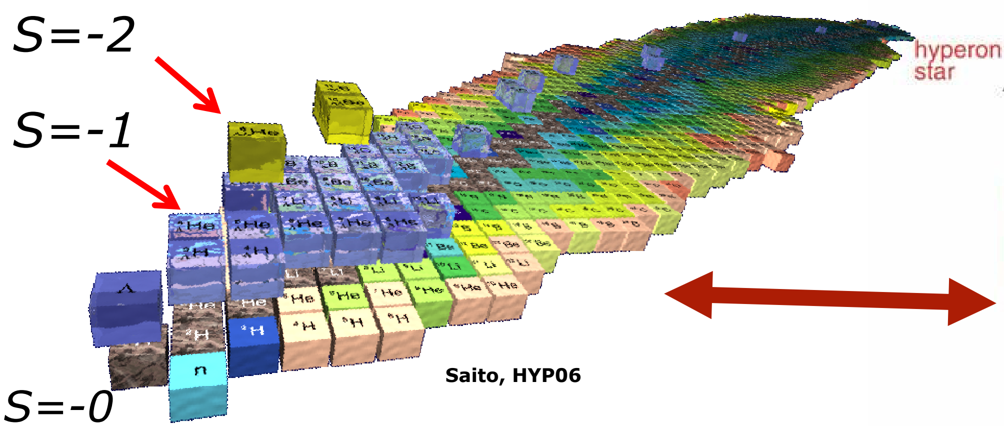
$$^{3}_{\Lambda}H(n+p+\Lambda)$$

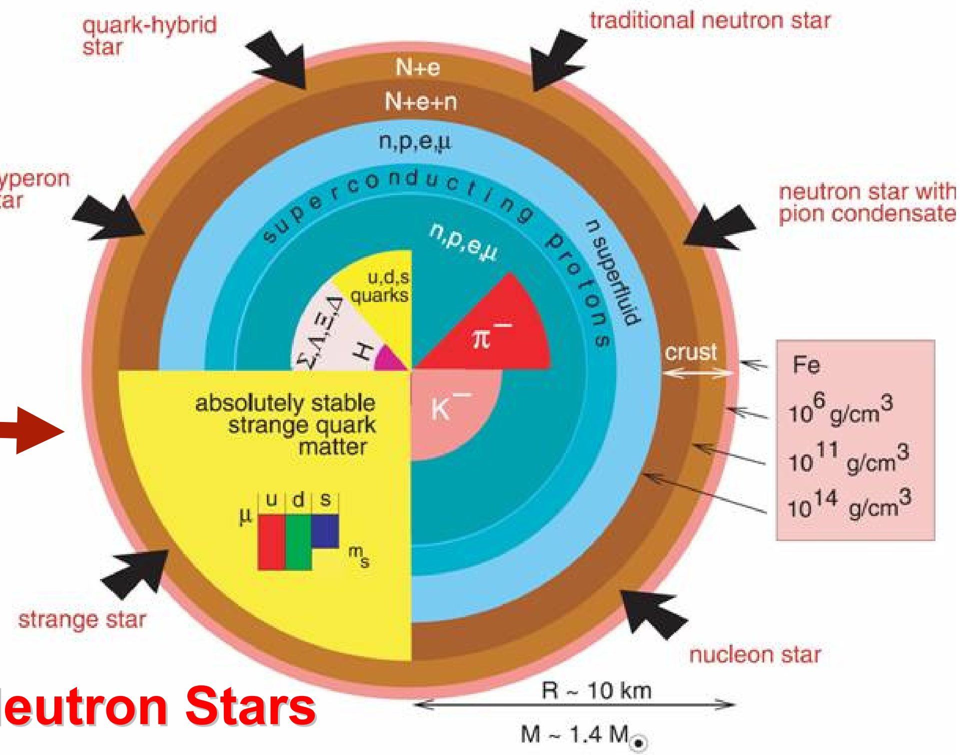
$$^{3}_{\overline{\Lambda}}\overline{H}(\overline{n}+\overline{p}+\overline{\Lambda})$$

- Y-N interaction: a good window to understand the baryon potential
- Binding energy and lifetime are very sensitive to Y-N interactions
- Hypertriton: **ΔB=130±50 KeV; r~10fm**
- Production rate via coalescence at RHIC depends on overlapping wave functions of **n+p+**Λ in final state
- Important first step for searching for other exotic hypernuclei (double-Λ)

from Hypernuclei to Neutron Stars

hypernuclei ← Λ-B Interaction → Neutron Stars





Several possible configurations of Neutron Stars

- **Kaon condensate, hyperons, strange quark matter**

J.M. Lattimer and M. Prakash, "The Physics of Neutron Stars", Science 304, 536 (2004)
J. Schaffner and I. Mishustin, *Phys. Rev. C* 53 (1996): Hyperon-rich matter in neutron stars

Single **and *double* hypernuclei in the laboratory:**

- **study the strange sector of the baryon-baryon interaction**
- **provide info on EOS of neutron stars**

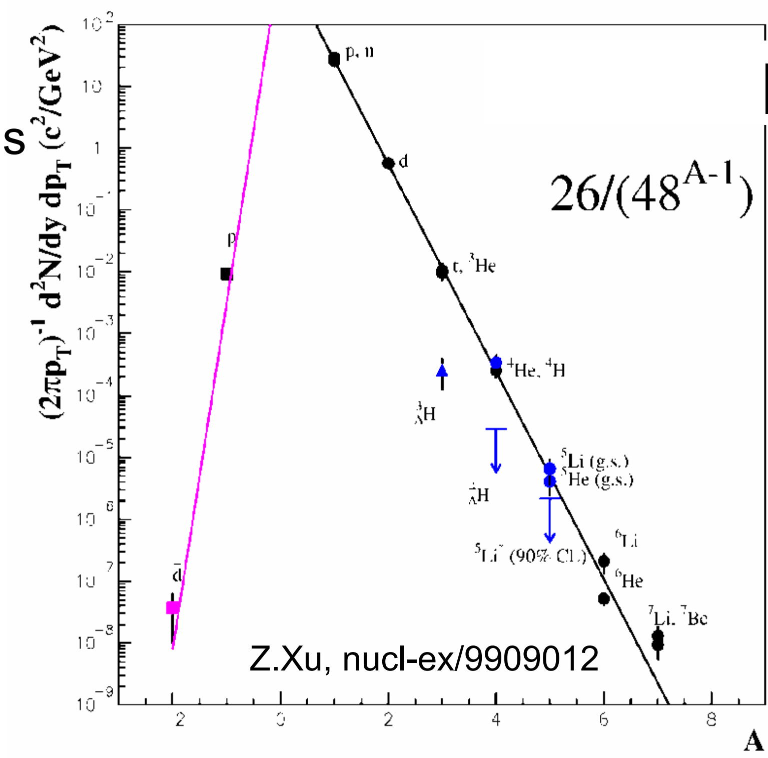
Can we observe hypernuclei at RHIC?

- Low energy and cosmic ray experiments (wikipedia):

  hypernucleus production via
  - Λ or K capture by nuclei
  - the direct strangeness exchange reaction

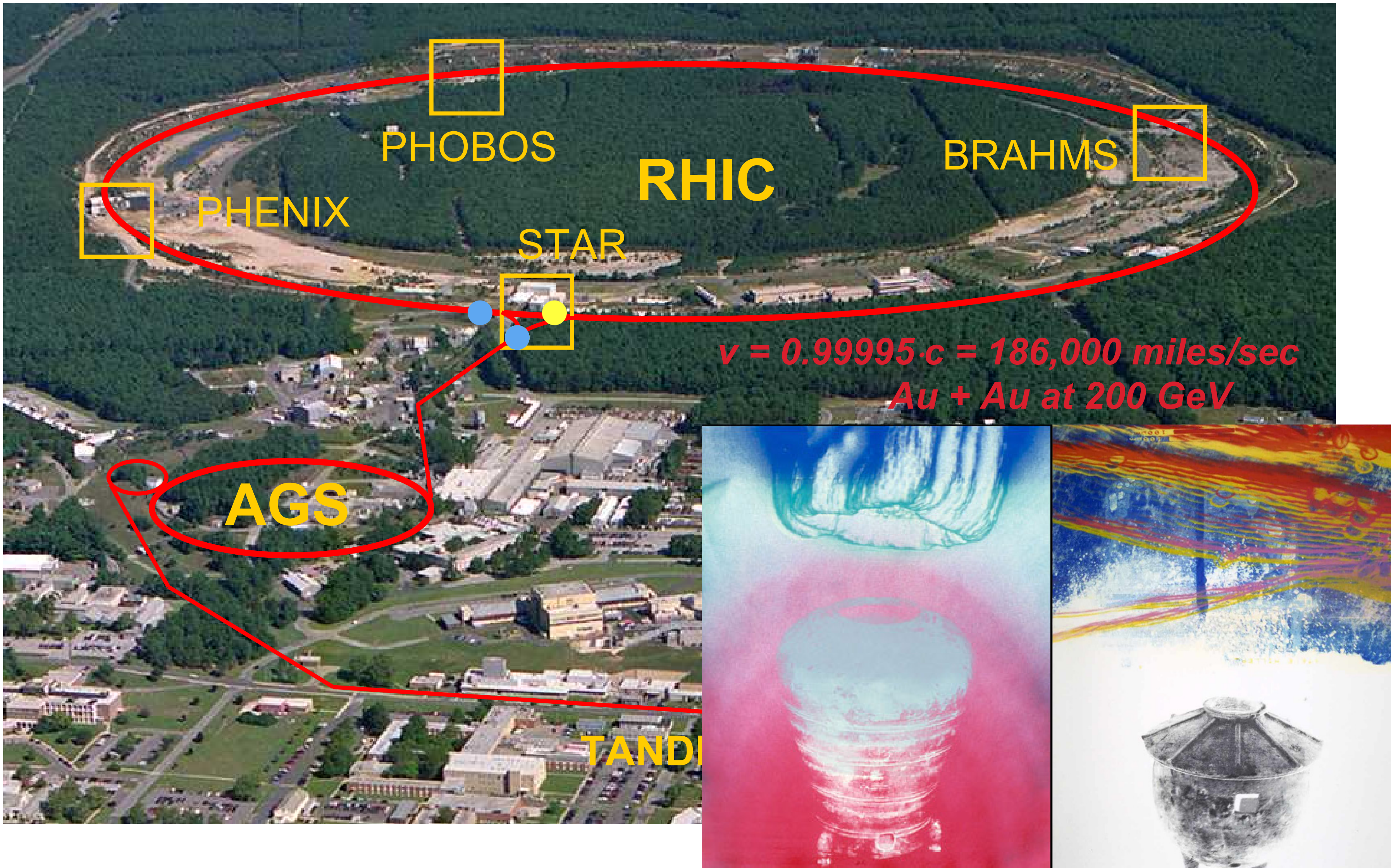
  hypernuclei observed
  - energetic but delayed decay,
  - measure momentum of the K and π mesons

- In high energy heavy-ion collisions:
  - nucleus production by coalescence, characterized by penalty factor. 聚并
  - AGS data[1] indicated that hypernucleus production will be further suppressed.
  - What's the case at RHIC?



[1] AGS-E864, Phys. Rev. C70,024902 (2004)

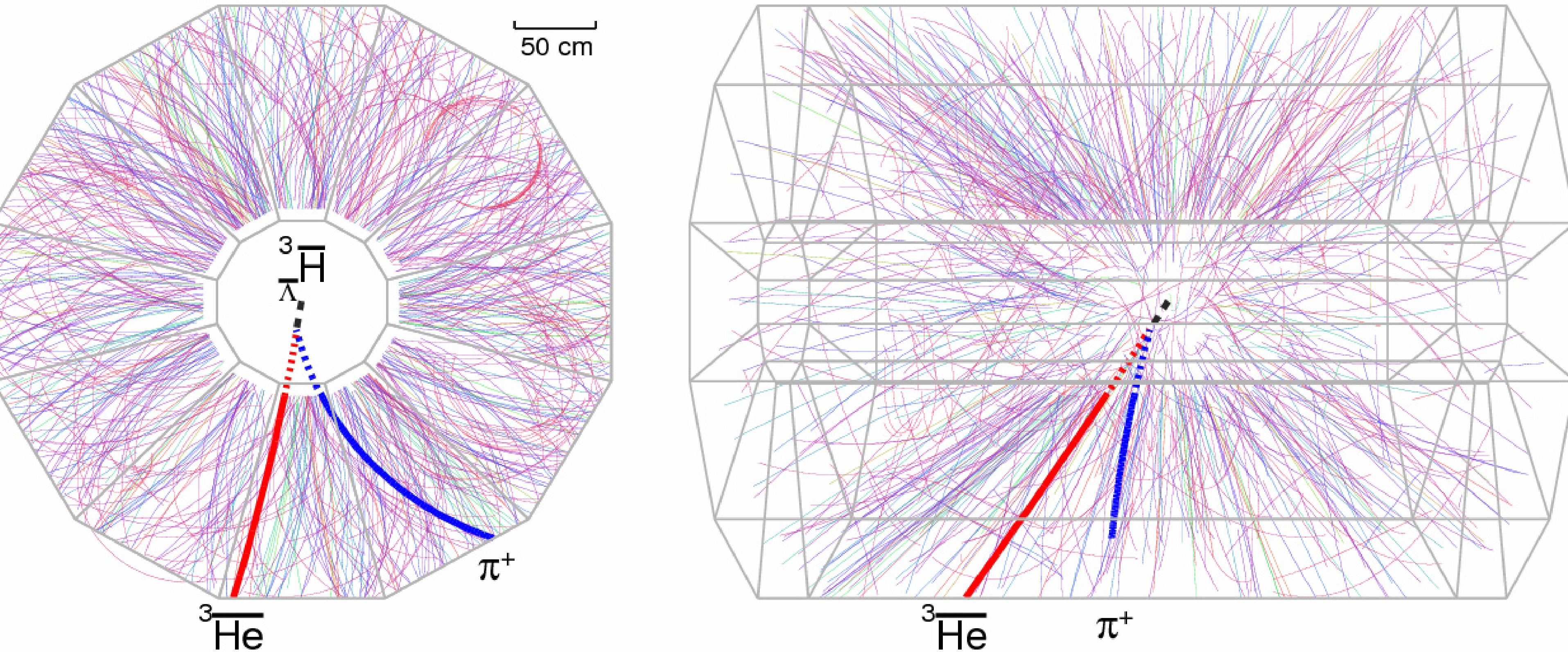
Relativistic Heavy Ion Collider (RHIC)



http://stevemiller.com/index.htm
中国新石器陶器+RHIC

A candidate event at STAR

Run4 (2004)
200 GeV Au+Au collision



Science AAAS

Observation of an Antimatter Hypernucleus
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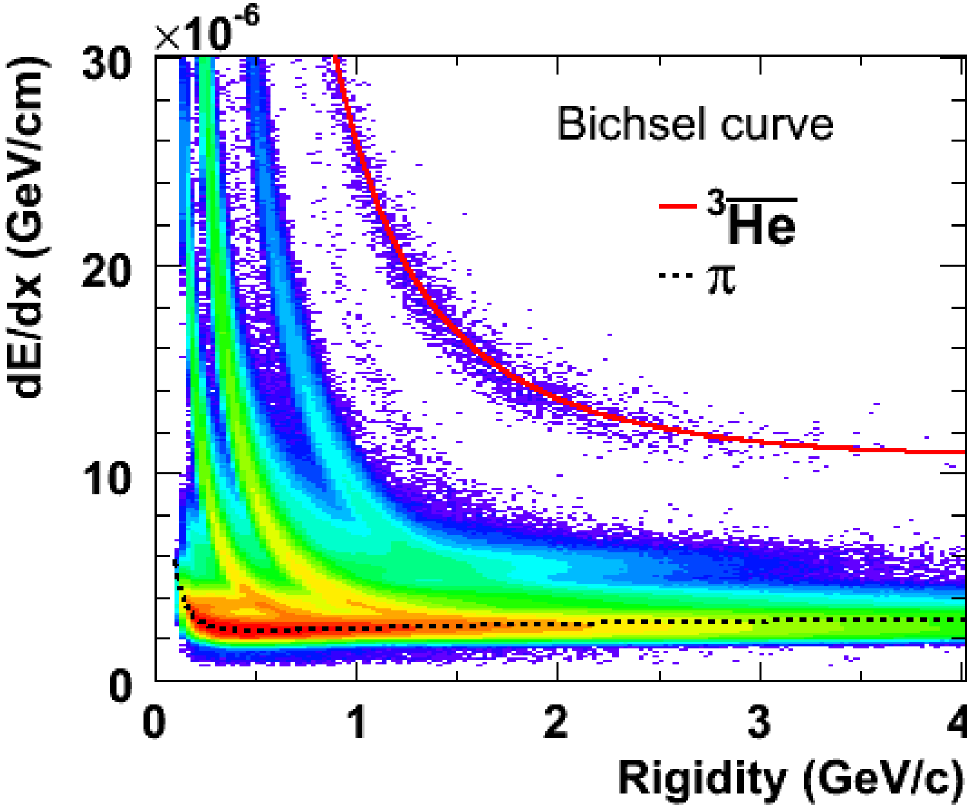
STAR talks:
J.H. Chen, QM09
J.H. Chen, HYP09
Z.B. Xu, RHIC/AGS 09

^{3}He & anti-^{3}He selection



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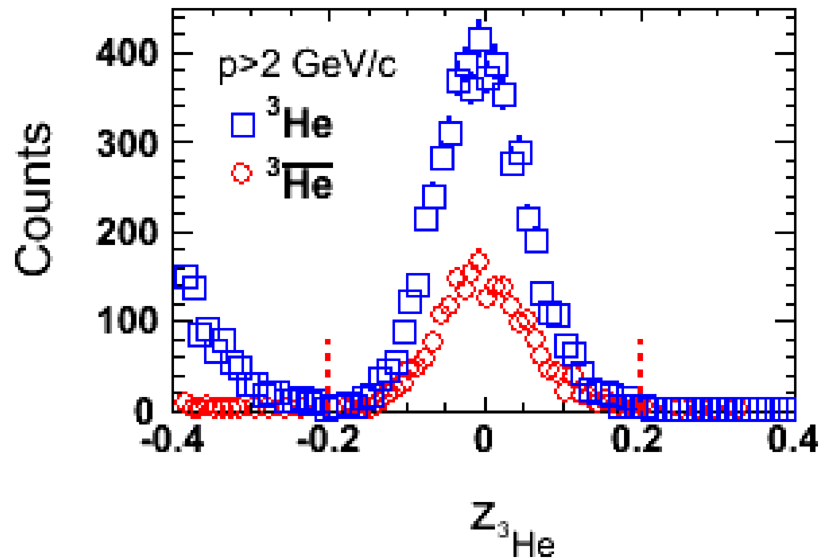


$$Z = \ln\left(\frac{\langle dE/dx \rangle}{\langle dE/dx \rangle^{Bichsel}}\right)$$

Select pure ^{3}He sample: -0.2<Z<0.2 & dca <1.0cm & p >2 GeV

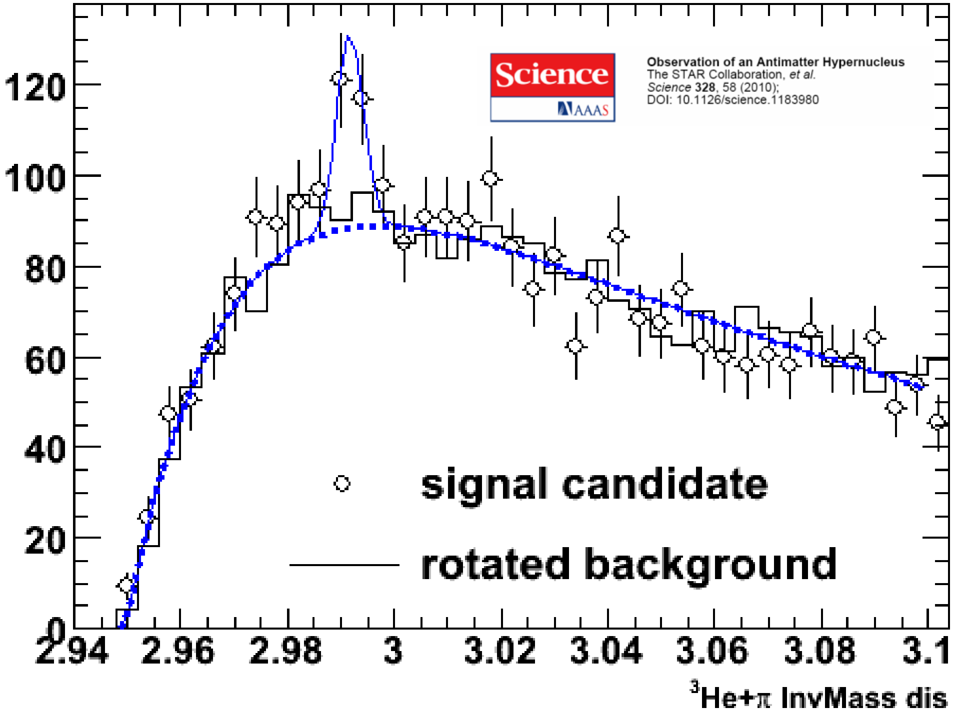
^{3}He: 2931(MB07) + 2008(central04) + 871(MB04) = 5810

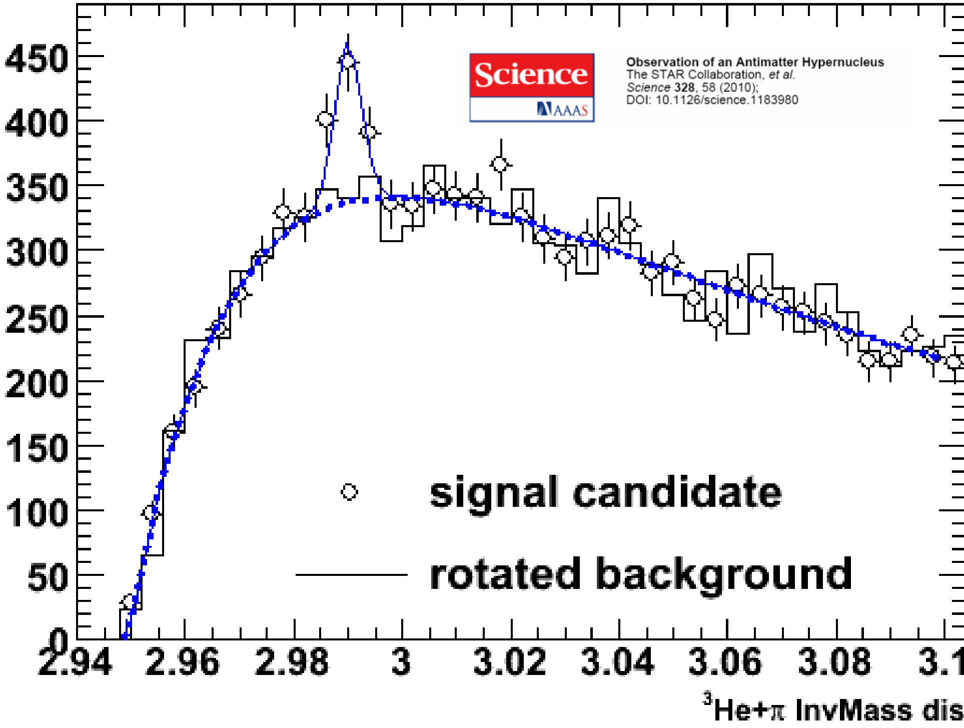
Anti-^{3}He: 1105(MB07) + 735(central04) + 328(MB04) = 2168

${}^{3}_{\bar{\Lambda}}\overline{H}$ and Combined signals

${}^{3}_{\bar{\Lambda}}\overline{H}$

Combine hypertriton and antihypertriton signal: 225±35



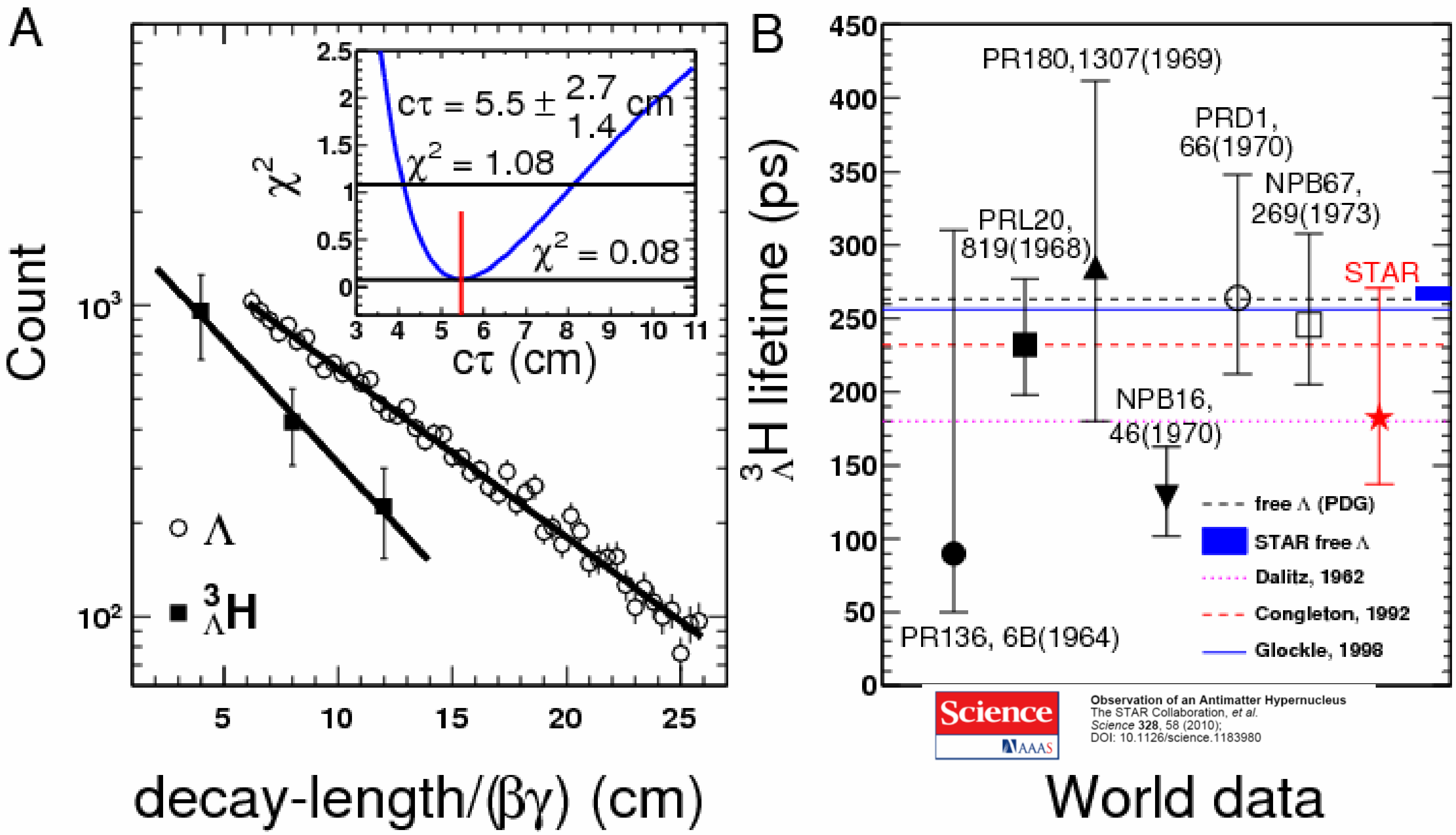


- Signal observed from the data (bin-by-bin counting): **70±17**;

Mass: 2.991±0.001 GeV; Width (fixed): 0.0025 GeV;

This provides a >6σ signal for discovery

Comparison to world data



- Lifetime related to binding energy
- Theory input: the Λ is lightly bound in the hypertriton

[1] R. H. Dalitz, *Nuclear Interactions of the Hyperons* (Oxford Uni. Press, London, 1965).

[2] R.H. Dalitz and G. Rajasekharan, Phys. Letts. 1, 58 (1962).

[3] H. Kamada, W. Glockle at al., Phys. Rev. C 57, 1595(1998).

Measured invariant yields and ratios

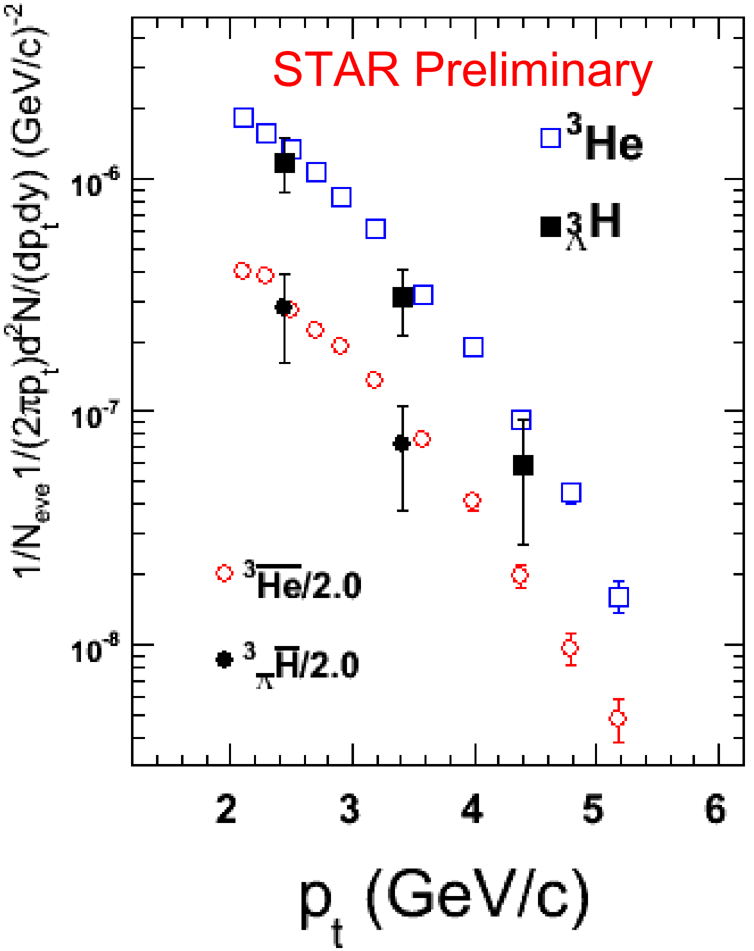


TABLE I: Particle ratios from Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV/c. The ^{3}He ($^3\bar{\mathrm{He}}$) yield have been corrected for $^3_\Lambda$H ($^3_\Lambda\bar{\mathrm{H}}$) feed-down contribution.

Particle type	Ratio
$^3_\Lambda\bar{\mathrm{H}}/^3_\Lambda\mathrm{H}$	$0.49 \pm 0.18 \pm 0.07$
$^3\bar{\mathrm{He}}/^3\mathrm{He}$	$0.45 \pm 0.02 \pm 0.04$
$^3_\Lambda\bar{\mathrm{H}}/^3\bar{\mathrm{He}}$	$0.89 \pm 0.28 \pm 0.13$
$^3_\Lambda\mathrm{H}/^3\mathrm{He}$	$0.82 \pm 0.16 \pm 0.12$

In a coalescence picture:

$$^3_\Lambda\overline{H} / ^3_\Lambda H \propto (\overline{p}/p)(\overline{n}/n)(\overline{\Lambda}/\Lambda)$$

$$^3\overline{He} / ^3He \propto (\overline{p}/p)^2(\overline{n}/n)$$

$0.45 \sim (0.77)^3$

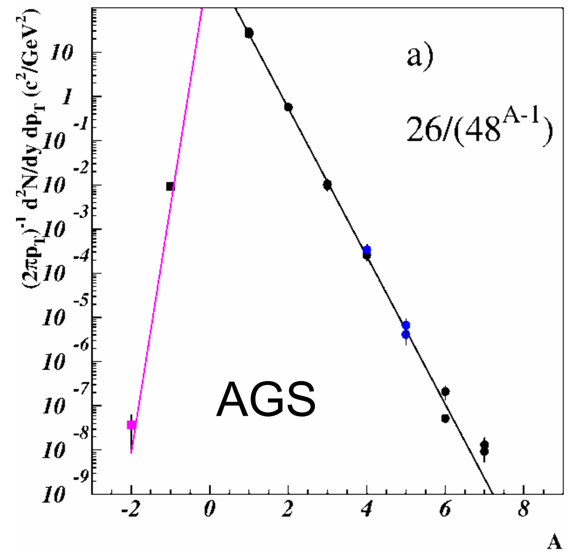
Matter and antimatter are not created equal

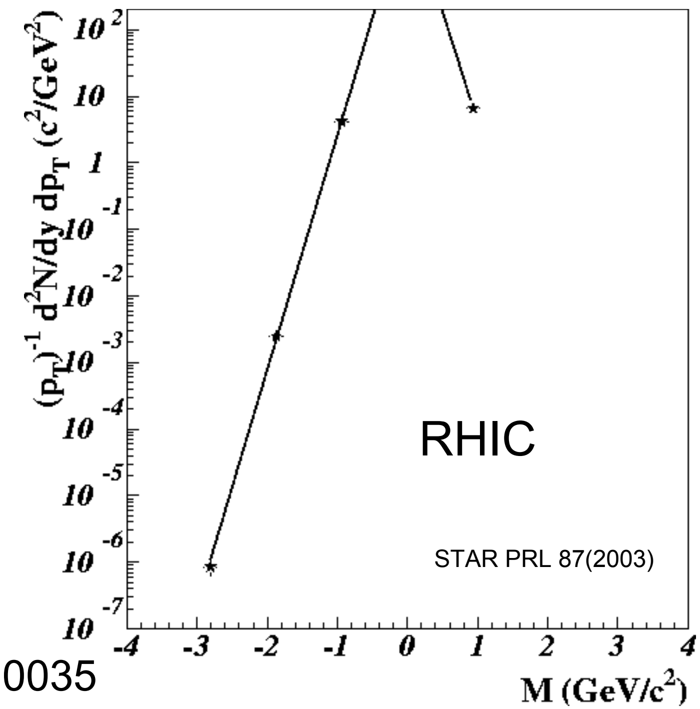
But we are getting there ! 物质和反物质造而不平等

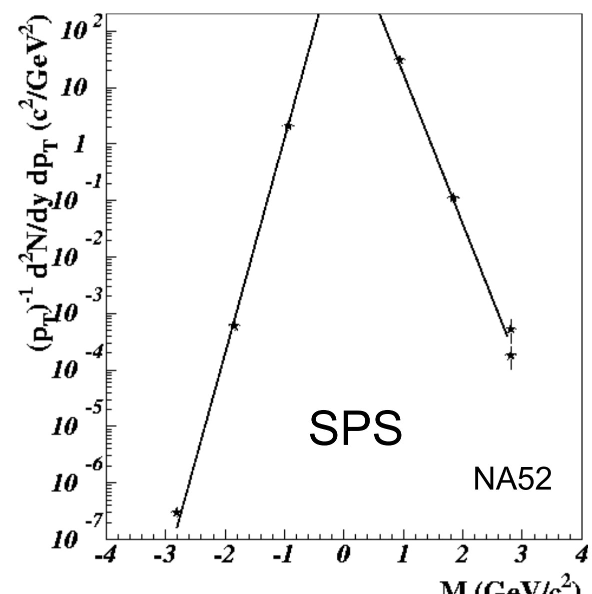
$$^3\overline{He}/^3He \approx 10^{-11}\ \text{(AGS,Cosmic)}$$

$$^3\overline{He}/^3He \approx 10^{-3}\,(SPS)$$

$$^3\overline{He}/^3He \approx 0.5(RHIC)$$



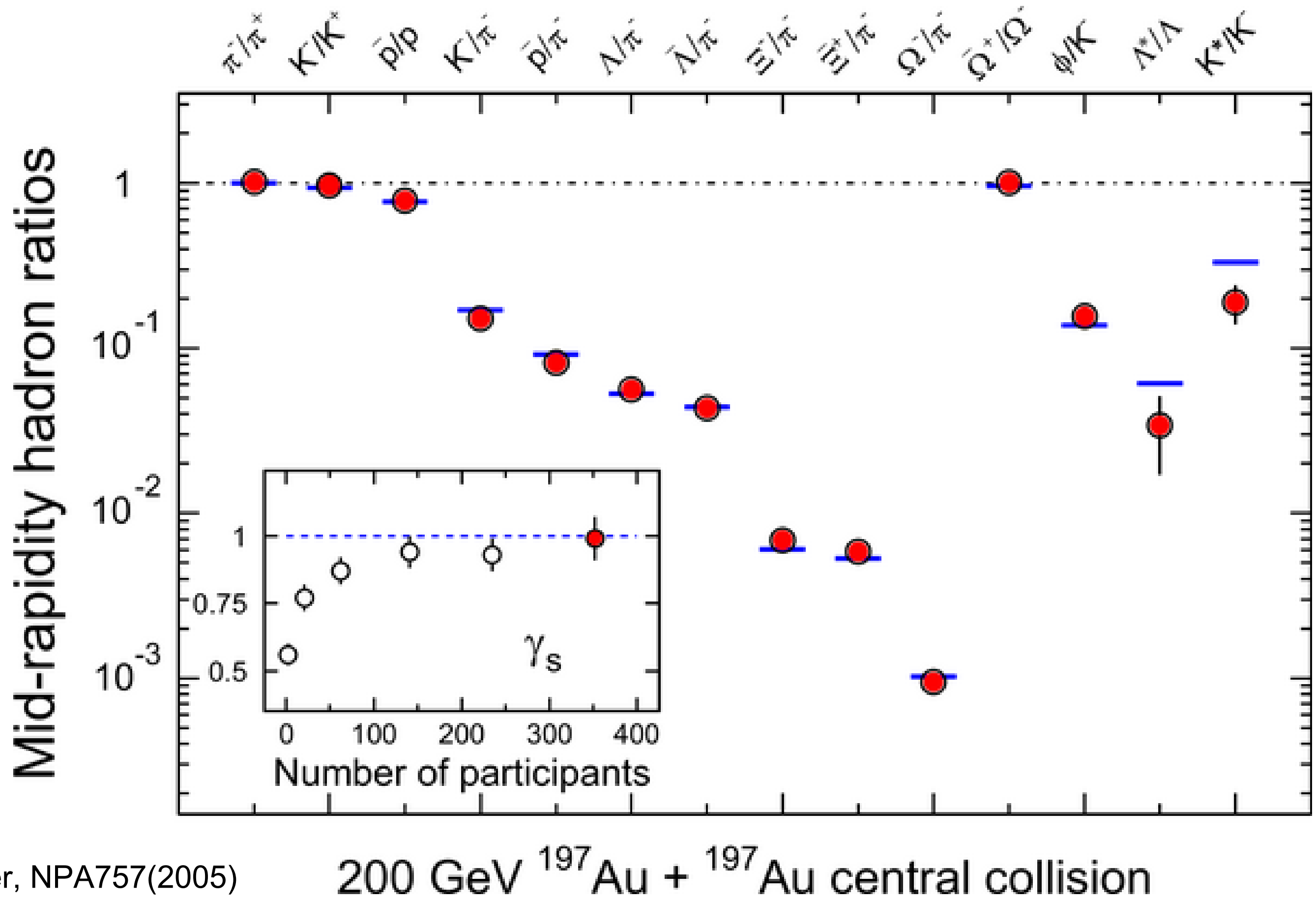




Nucl-ex/0610035

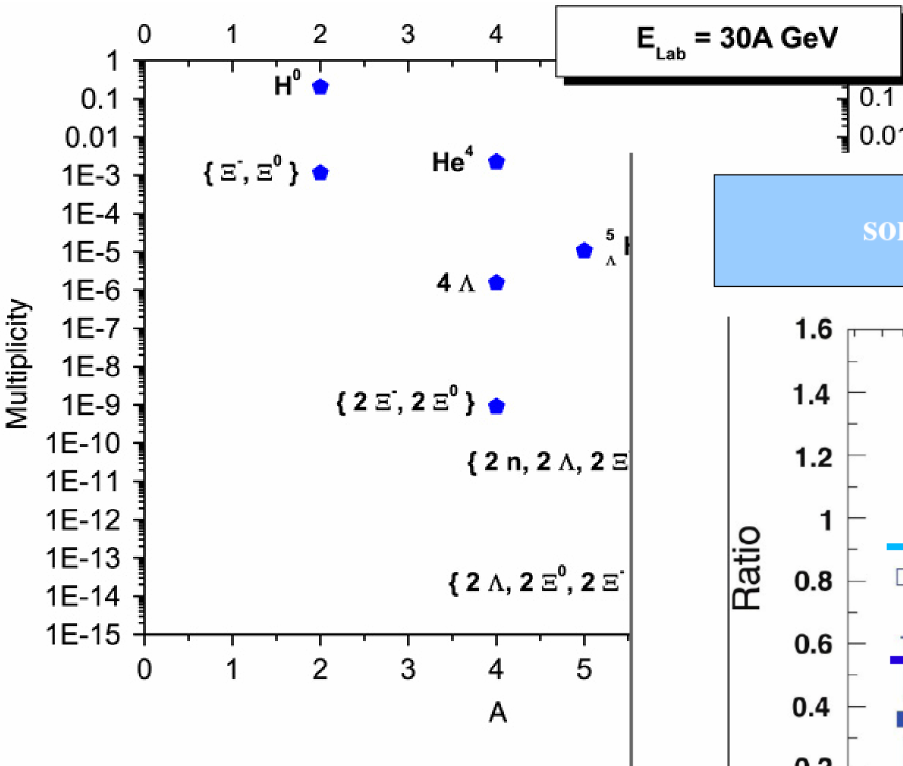
Flavors (u,d, s) are not created equal except in possible QGP

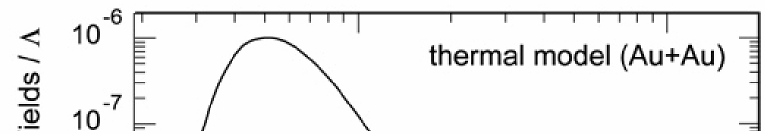
J. Rafelski and B. Muller, Phys.Rev.Lett.48:1066,1982



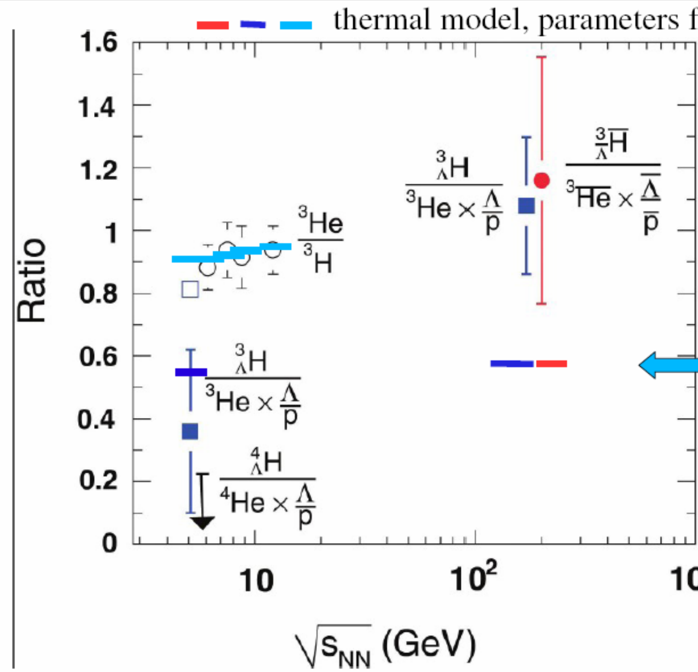
STAR whitepaper, NPA757(2005)

Thermal production





some systematics as function of beam energy



double ratio in model √s independent and always below 1

STAR authors argue that this ratio is expected to be near 1

this is the case only before feeding (which increases yields by factors 5 and 3.5)

in that case thermal ratio is also 0.86

A. Andronic, P. Braun-Munzinger, J.

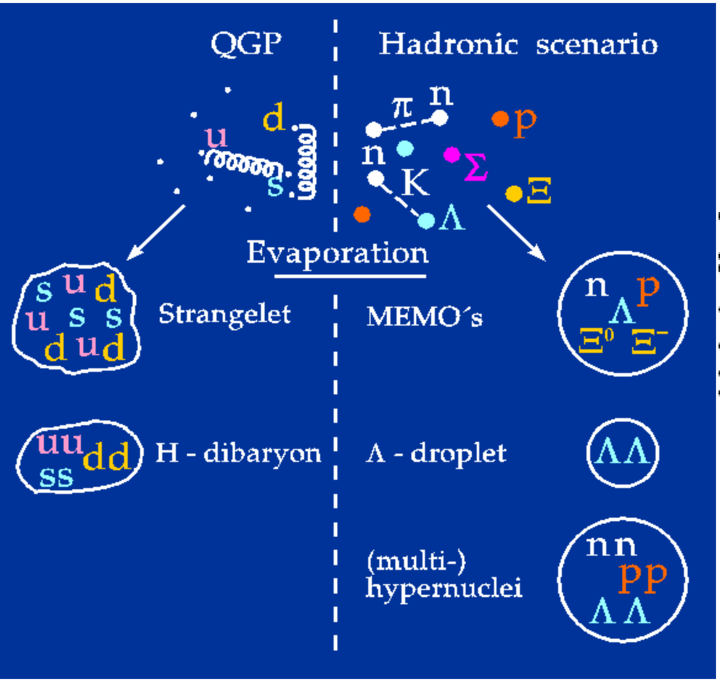
P. Braun-Munzinger, J. Stac

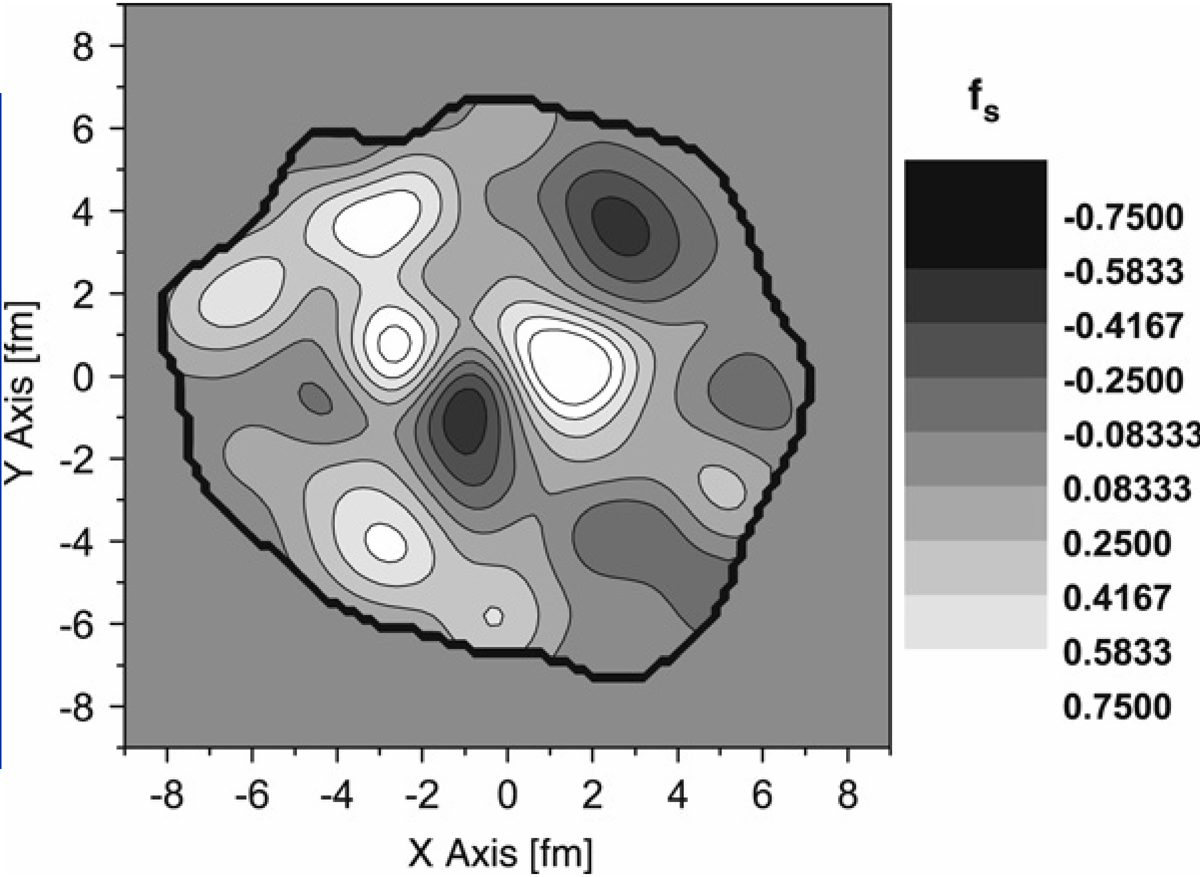
A. Andro

Johanna Stachel

RUPRECHT-KARLS-UNIVERSITÄT HEIDELBERG

Strangeness Fluctuation





UrQMD E-by-E Distribution of the strangeness to baryon fraction in the transverse plane (z=0 fm).

Jan Steinheimer , Horst Stoecker, Ingo Augustin, Anton Andronic, Takehiko Saito,Peter Senger,
Progress in Particle and Nuclear Physics 62 (2009) 313317
J. Steinheimer: SQM09

Yields as a measure of correlation

Volume 98B, number 3 PHYSICS LETTERS 8 January 1981

probability $F_d(\boldsymbol{p})$, which is determined by the deuteron internal wave function ψ_d and the spatial distribution functions D_p and D_n through eq. (9). If the $\boldsymbol{k}$-dependences of $P_p(\boldsymbol{k})$ and $P_n(\boldsymbol{k})$ are weak compared with the $\boldsymbol{p}$-dependence of $F_d(\boldsymbol{p})$, eq. (8) becomes equivalent to eq. (1) for $Z = N = 1$ with

$$\tfrac{4}{3}\pi p_0^3 = \int \mathrm{d}\boldsymbol{p}\, F_d(\boldsymbol{p})\,. \tag{10}$$

Using eq. (9), one can express the coalescence volume in terms of ψ_d, D_p and D_n as

$$\tfrac{4}{3}\pi p_0^3 = 2^3 \cdot \tfrac{3}{4} \cdot (2\pi)^3 \int \mathrm{d}\boldsymbol{r}\, |\psi_d(\boldsymbol{r})|^2 D_2(\boldsymbol{r})\,, \quad D_2(\boldsymbol{r}) \equiv \int \mathrm{d}\boldsymbol{r}'\, D_p(\boldsymbol{r}-\boldsymbol{r}') D_n(\boldsymbol{r}')\,. \tag{11,12}$$

$D_2(\boldsymbol{r})$ gives the distribution of the p–n relative coordinate in the HX and is closely related to the interaction volume introduced by Mekjian [6]. In fact, if the spatial size of the internal wave function ψ_d is much smaller than that of the HX, then eq. (11) gives

$$\tfrac{4}{3}\pi p_0^3 \simeq 2^3 \cdot \tfrac{3}{4} \cdot (2\pi)^3 D_2(0)\,. \tag{13}$$

A=2 ➔ Baryon density $<\rho_B>$

$D_2(0)$ thus corresponds to the inverse of the interaction volume. In the actual situation, however, the size of the deuteron is comparable to that of the HX and therefore one has to use eq. (11) to relate the coalescence volume with the spatial size of the HX.

Expressions analogous to eqs. (8–10) can be obtained for the other composite particles such as ^{3}H, ^{3}He and ^{4}He. In the case of triton (^{3}H) one gets

$$P(1,2;\boldsymbol{k}) = \int \mathrm{d}\boldsymbol{p}_1\, \mathrm{d}\boldsymbol{p}_2\, F_t(\boldsymbol{p}_1,\boldsymbol{p}_2) P_p(\boldsymbol{k}+\boldsymbol{p}_1) P_n(\boldsymbol{k}-\tfrac{1}{2}\boldsymbol{p}_1+\boldsymbol{p}_2) P_n(\boldsymbol{k}-\tfrac{1}{2}\boldsymbol{p}_1-\boldsymbol{p}_2)\,, \tag{14}$$

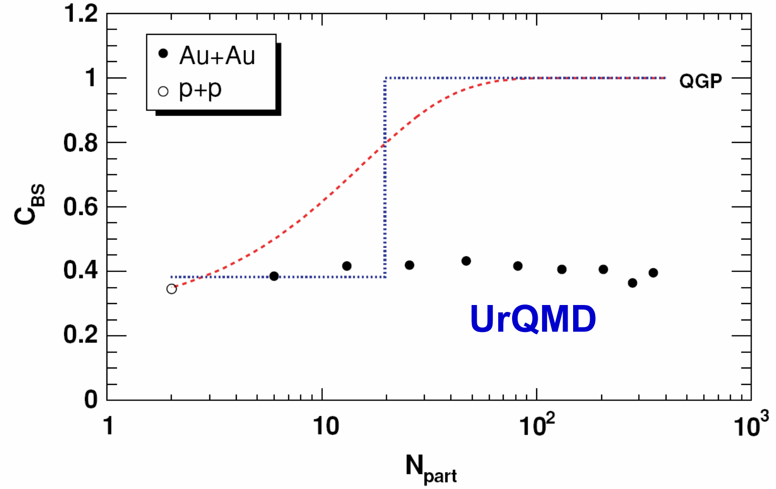
$$F_t(\boldsymbol{p}_1,\boldsymbol{p}_2) = 3^3 \cdot \frac{1}{4} \int \frac{\mathrm{d}\boldsymbol{q}_1 \mathrm{d}\boldsymbol{q}_2}{(2\pi)^6}\, \widetilde{\psi}_t^*(\boldsymbol{p}_1+\tfrac{1}{2}\boldsymbol{q}_1, \boldsymbol{p}_2+\tfrac{1}{2}\boldsymbol{q}_2)\, \widetilde{\psi}_t(\boldsymbol{p}_1-\tfrac{1}{2}\boldsymbol{q}_1, \boldsymbol{p}_2-\tfrac{1}{2}\boldsymbol{q}_2)$$

$$\times\, \widetilde{D}_p(\boldsymbol{q}_1) \widetilde{D}_n(-\tfrac{1}{2}\boldsymbol{q}_1+\boldsymbol{q}_2) \widetilde{D}_n(-\tfrac{1}{2}\boldsymbol{q}_1-\boldsymbol{q}_2)\,, \tag{15}$$

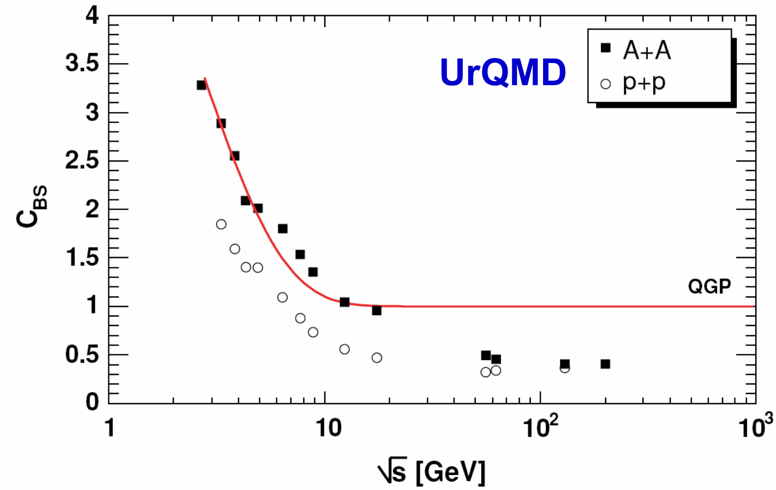
where $\widetilde{\psi}_t$ is the Fourier transform of the triton internal wave function ψ_t. The coalescence volume is related to F_t as

$$\tfrac{1}{2}(\tfrac{4}{3}\pi p_0^3)^2 = \int \mathrm{d}\boldsymbol{p}_1\, \mathrm{d}\boldsymbol{p}_2\, F_t(\boldsymbol{p}_1,\boldsymbol{p}_2)\,. \tag{16}$$

A=3 ➔ $<\rho^2_B>$; $<\rho_\Lambda\rho_B>$



S. Haussler, H. Stoecker, M. Bleicher, PRC73

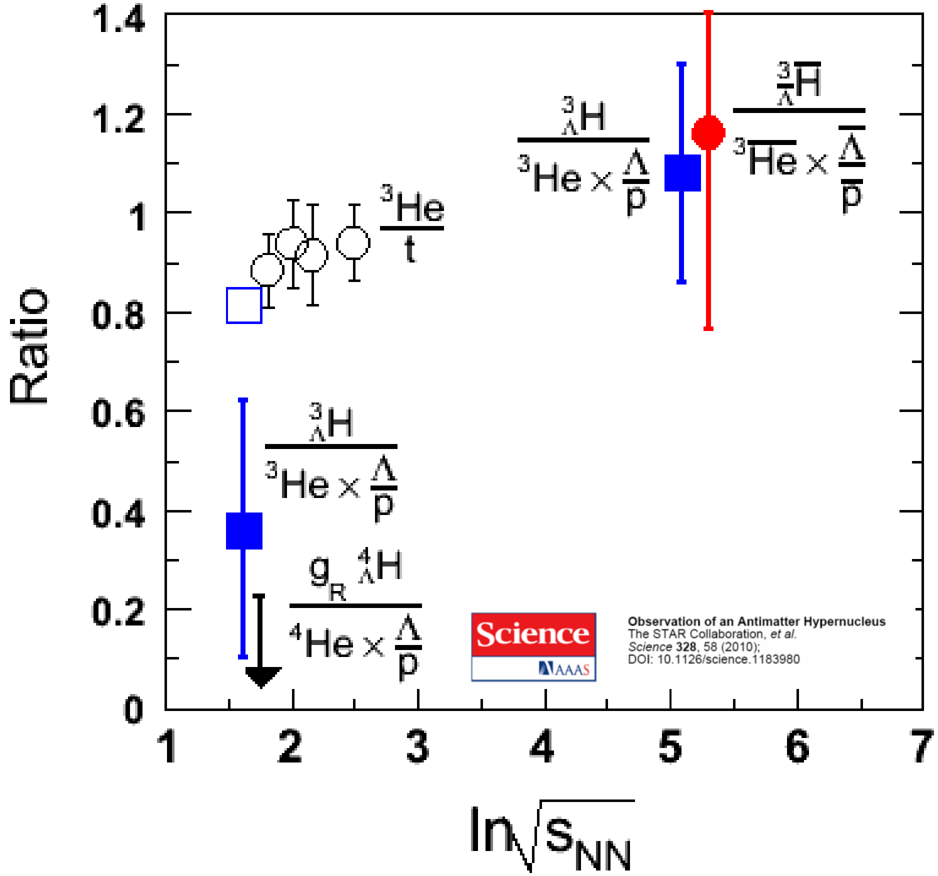


Caution:

measurements related to **local** (strangeness baryon)-baryon correlation

Simulations of (all strangeness)—(all baryon) correlation

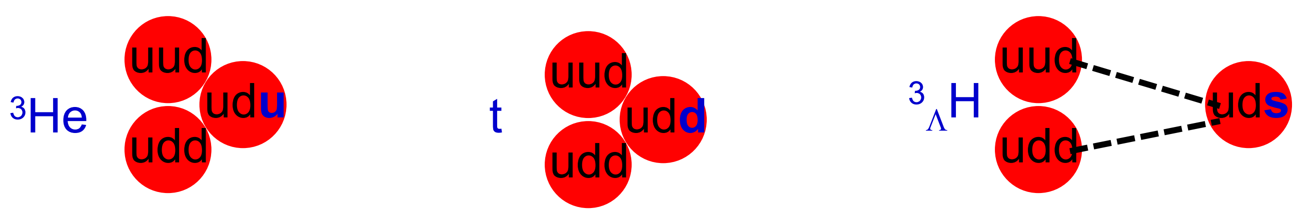
$(^3He, t, {}^3_\Lambda H) \rightarrow (u, d, s)$



- A=3, a simple and perfect system
  9 valence quarks,
  $(^3He, t, {}^3_\Lambda H) \rightarrow (u, d, s)+4u+4d$
- Ratio measures Lambda-nucleon correlation
- RHIC: Lambda-nucleon similar phase space
- AGS: systematically lower than RHIC

→ Strangeness phase-space equilibrium

- $^3He/t$ measures charge-baryon correlation



${}^{3}_{\Lambda}H/{}^{3}He$: Primordial Λ-B correlation

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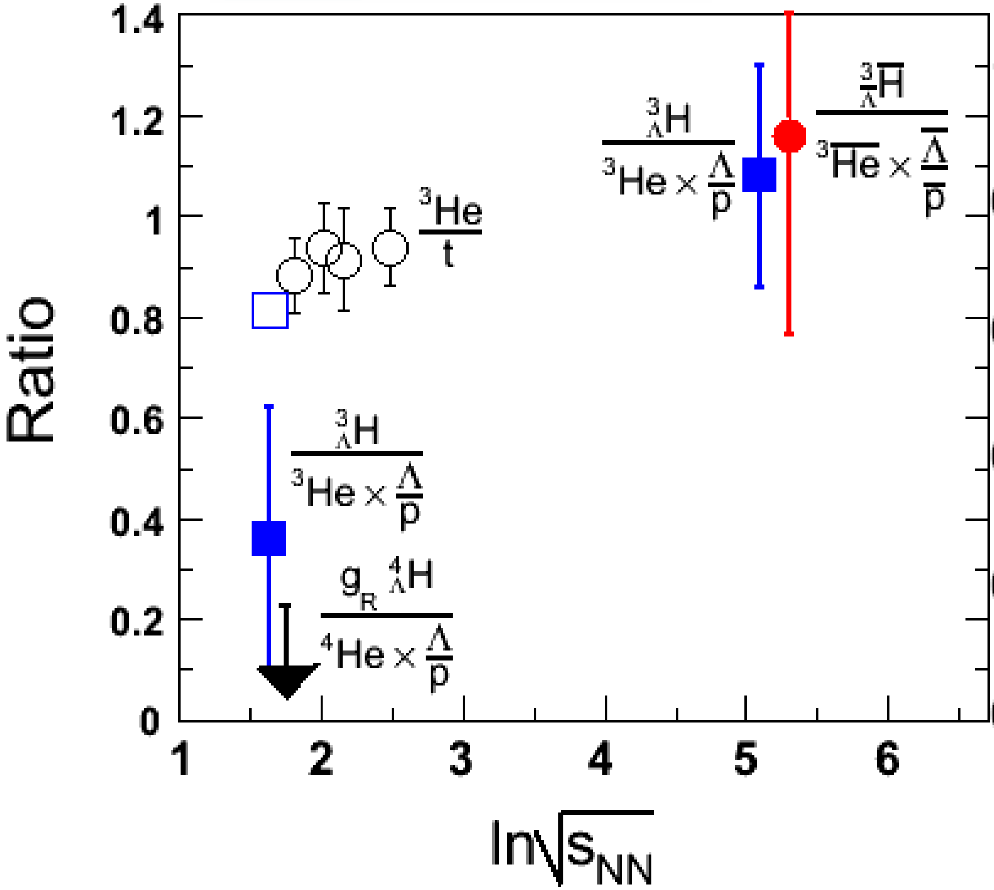
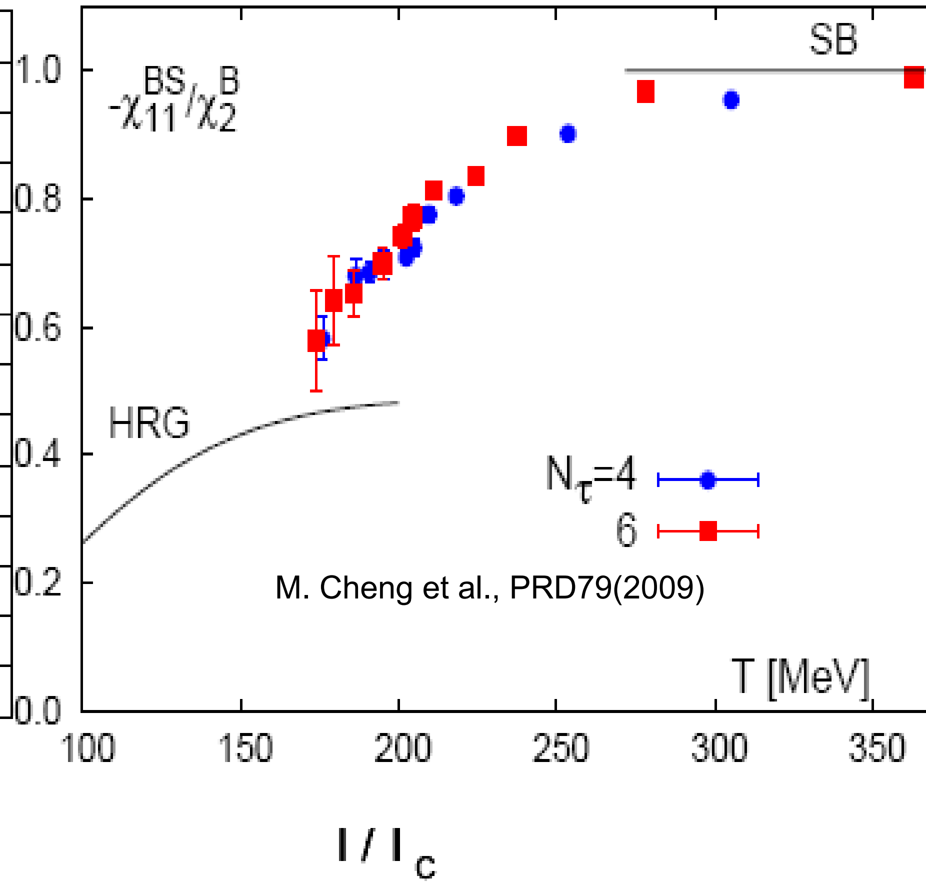


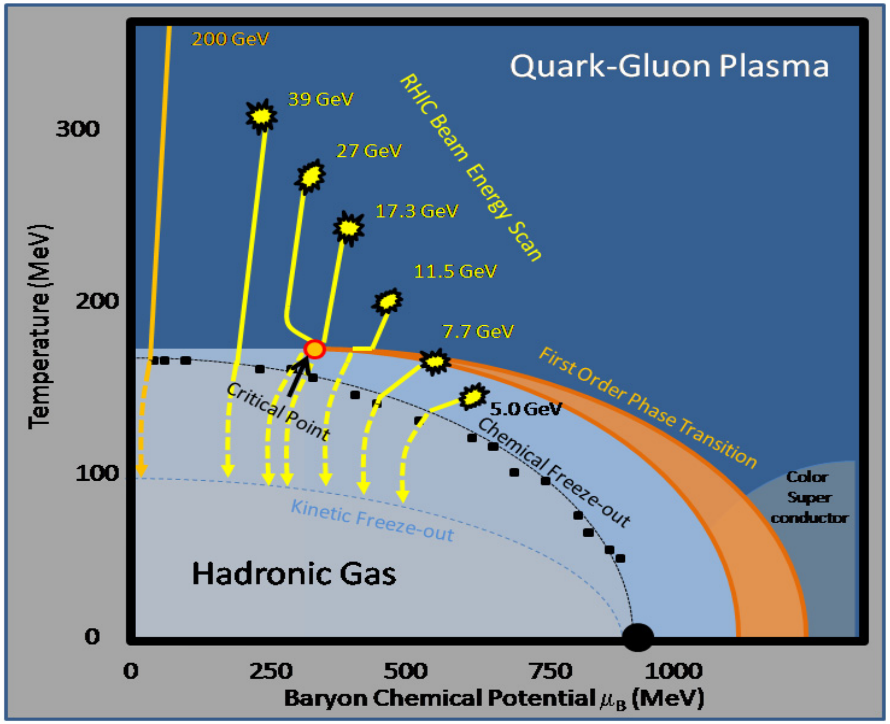


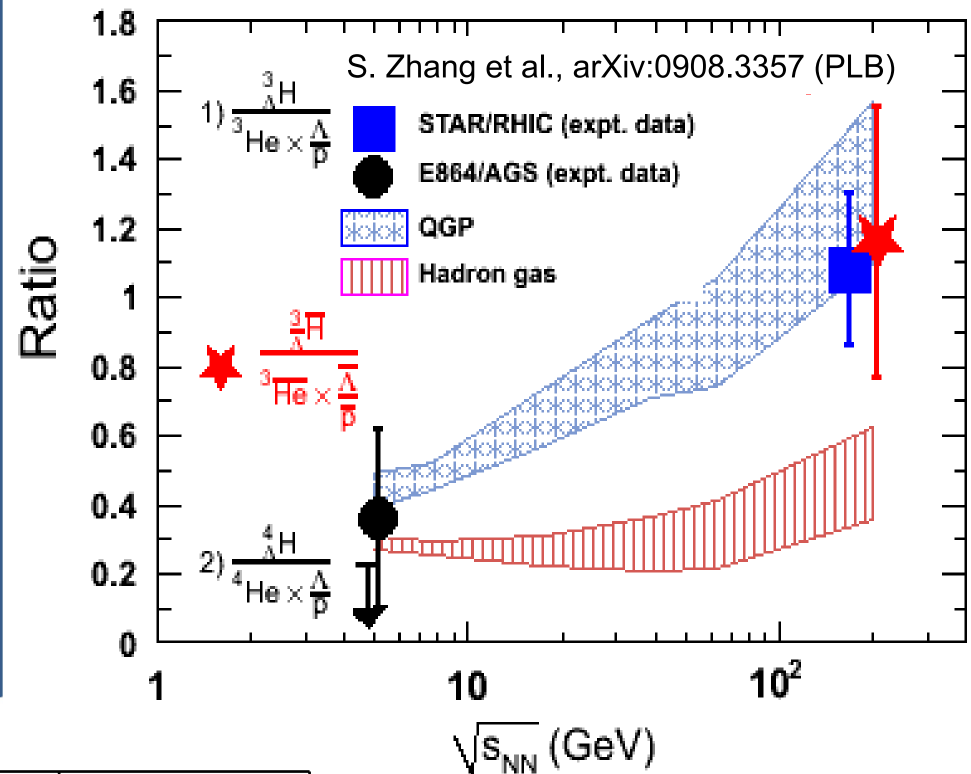
Caution:

measurements related to local (strangeness baryon)-baryon correlation

Lattice Simulations of (all strangeness)—(all baryon) correlation at zero chemical potential

Energy scan to establish the trend



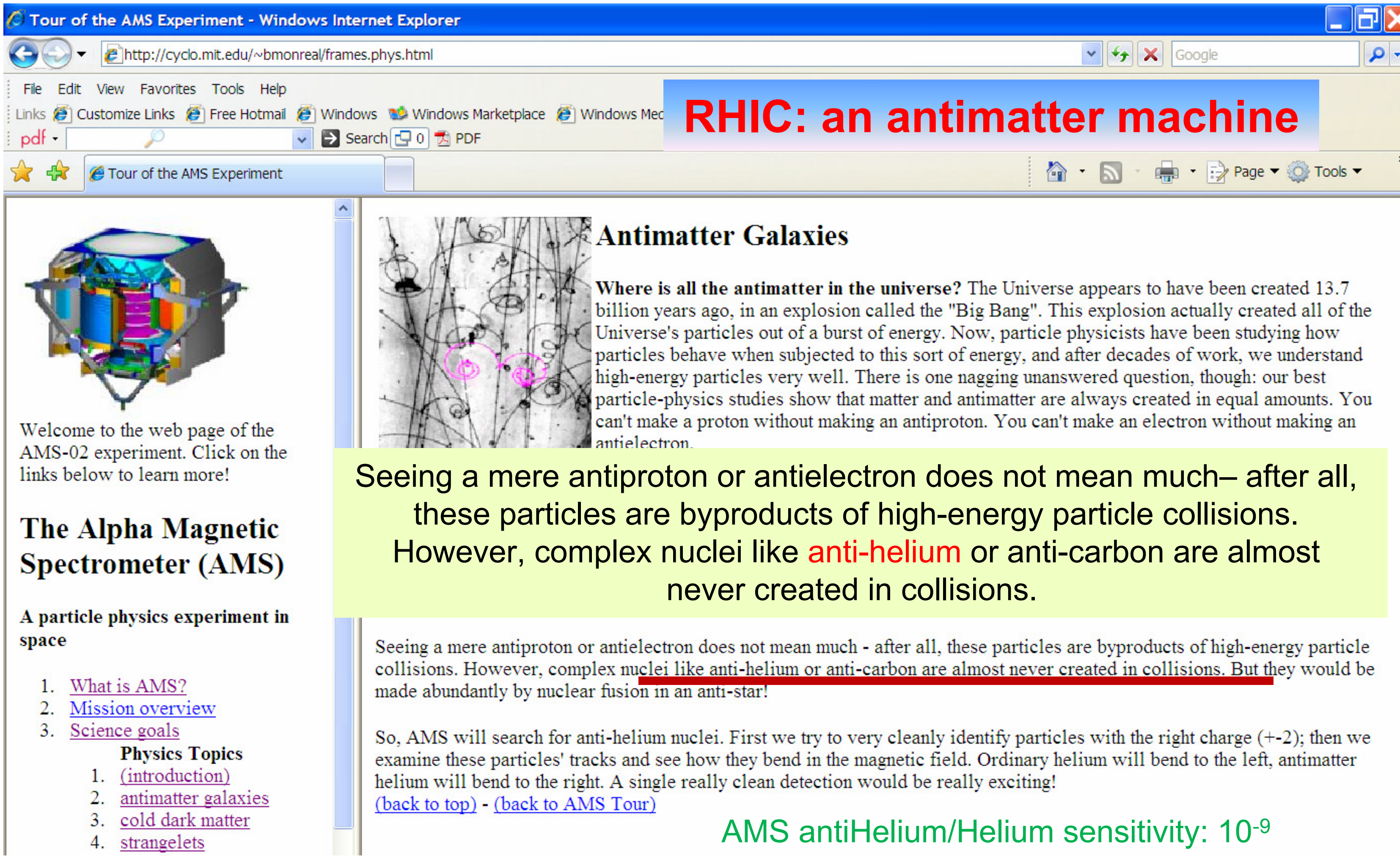


Beam energy	200(30—200) GeV	~17 (10—30)GeV	~5 (5-10) GeV
Minbias events# (5σ)	300M	**~10—100M**	**~1—10M**
Penalty factor	1448	368	48
^{3}He invariant yields	1.6×10^{-6}	2×10^{-4}	0.01
$^3_\Lambda H/^3He$ assumed	1.0	0.3	0.05

Hypertriton only
STAR: DAQ1000+TOF

Antinuclei in nature (new physics)

To appreciate just how rare nature produces antimatter (strange antimatter)



RHIC: an antimatter machine

Seeing a mere antiproton or antielectron does not mean much– after all, these particles are byproducts of high-energy particle collisions. However, complex nuclei like anti-helium or anti-carbon are almost never created in collisions.

AMS antiHelium/Helium sensitivity: 10^{-9}

Dark Matter, Black Hole➔ antinucleus production via coalescence

What can we do with antimatter?

Weapon?

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《天使与魔鬼》

SHARE

Contacts: Kendra Snyder, (631) 344-8191 or Mona S. Rowe, (631) 344-5056

Media Advisory: The Science of "Angels & Demons" Revealed

Could antimatter really destroy the Vatican? Brookhaven scientist, local educators discuss science myths and facts in movie

May 15, 2009

EVENT: During a free and public event, a physicist from the U.S. Department of Energy's Brookhaven National Laboratory and local educators will separate the science facts from the science fiction of "Angels & Demons," a major motion picture based on Dan Brown's best-selling novel. The film, which opens nationally in theaters today, focuses on a plot to destroy the Vatican using antimatter stolen from the Large Hadron Collider (LHC) at the European particle physics laboratory CERN. Speakers will explain the real science of the LHC, including antimatter – oppositely charged cousins of ordinary matter with intriguing properties.

WHEN: Wednesday, May 27, 2009, 5:30 p.m.

WHERE: Berkner Hall Auditorium, Brookhaven National Laboratory. Brookhaven Lab is on William Floyd Parkway, one-and-a-half miles north of Exit 68 on the Long Island Expressway.

Rocket propulsion

AIAA-2003-4676
39th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Huntsville Alabama, July 20-23, 2003

HOW TO BUILD AN ANTIMATTER ROCKET FOR INTERSTELLAR MISSIONS
- - - - -
SYSTEMS LEVEL CONSIDERATIONS IN DESIGNING ADVANCED PROPULSION TECHNOLOGY VEHICLES

Robert H. Frisbee
Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive, Mail Code 125-109
Pasadena CA 91109

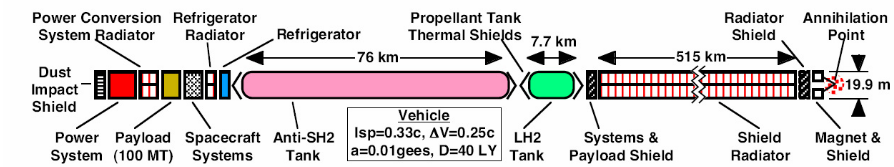
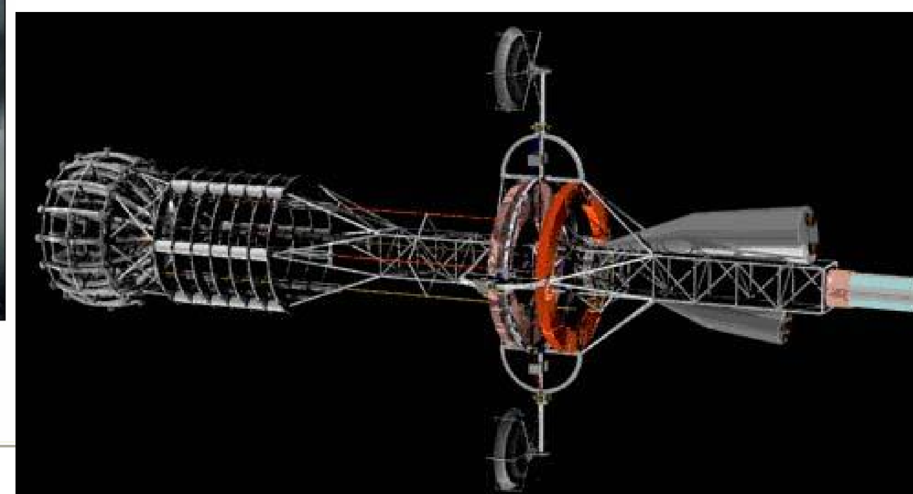


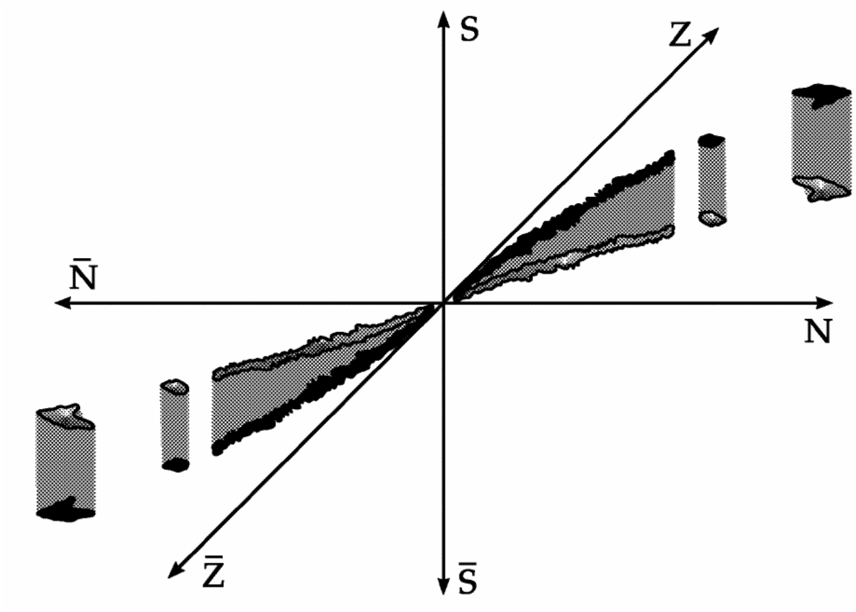
Figure 6. Conceptual Systems for an Antimatter Propulsion System.



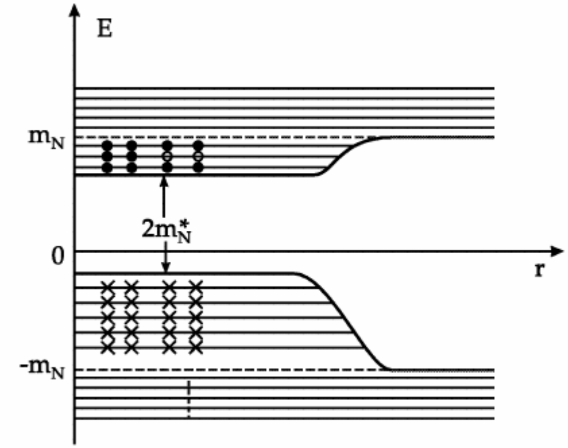
hypernuclei and antimatter from correlations in the Vacuum

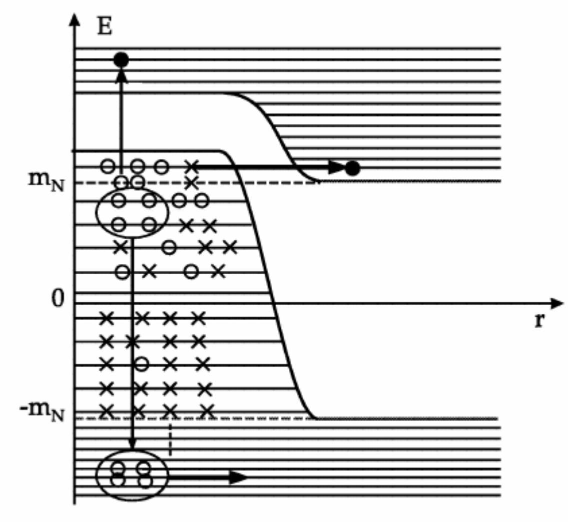
Fundamental Issues in the Physics of Elementary Matter:
Cold Valleys and Fusion of Superheavy Nuclei - Hypernuclei – Antinuclei – Correlations in the Vacuum

Walter Greiner



Real 3-D periodic table

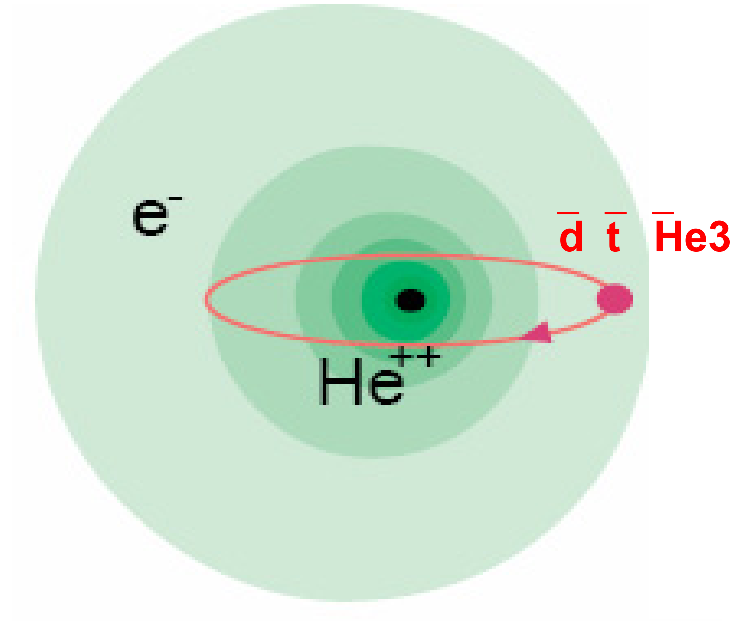




Pull $\bar{\alpha}$ from vacuum (Dirac Sea)

Creating first Antinucleus Atomcules

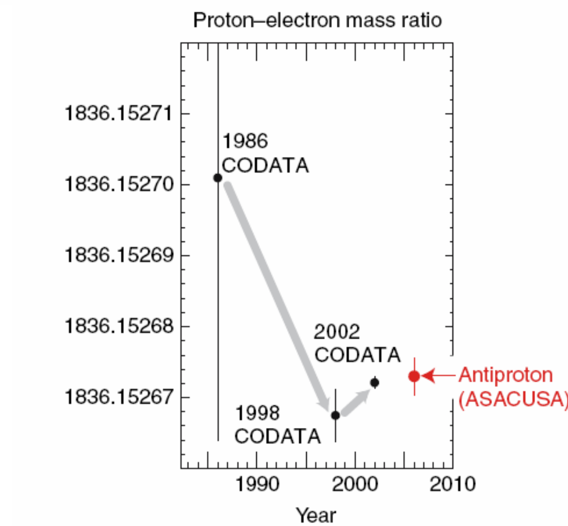
Metastable antiproton-helium atom discovered at KEK:
Iwasaki, **PRL** 67 (1991); **nature** 361 (1993) 238
Mass difference: p-pbar < 2×10^{-9}; Hori, **PRL** 96 (2006);
measurement of baryon mass and magnetic moment
for CPT test at LEAR/CERN
http://asacusa.web.cern.ch/ASACUSA/index-e.html



What happens if we replace antiproton
with **antideuteron, antitriton or antiHelium3**

Atomic structure should be the same
for antideuteron and antitriton (-1 charge)
Reduced mass M* will be different.

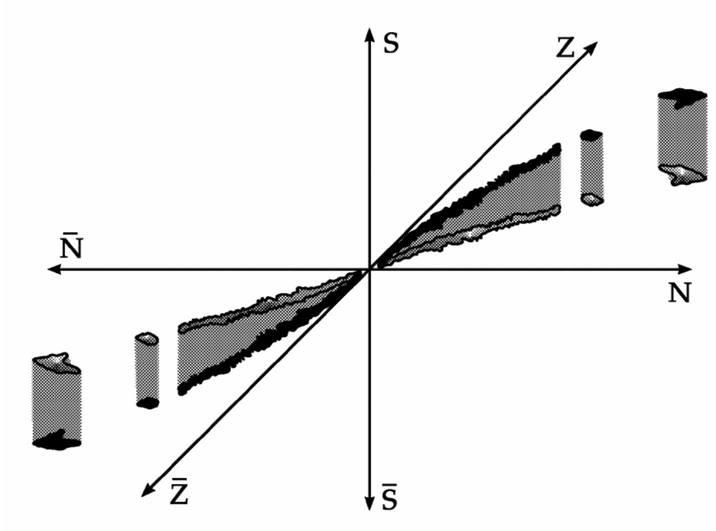
Only RHIC can answer this question with
enough antimatter nuclei for such study

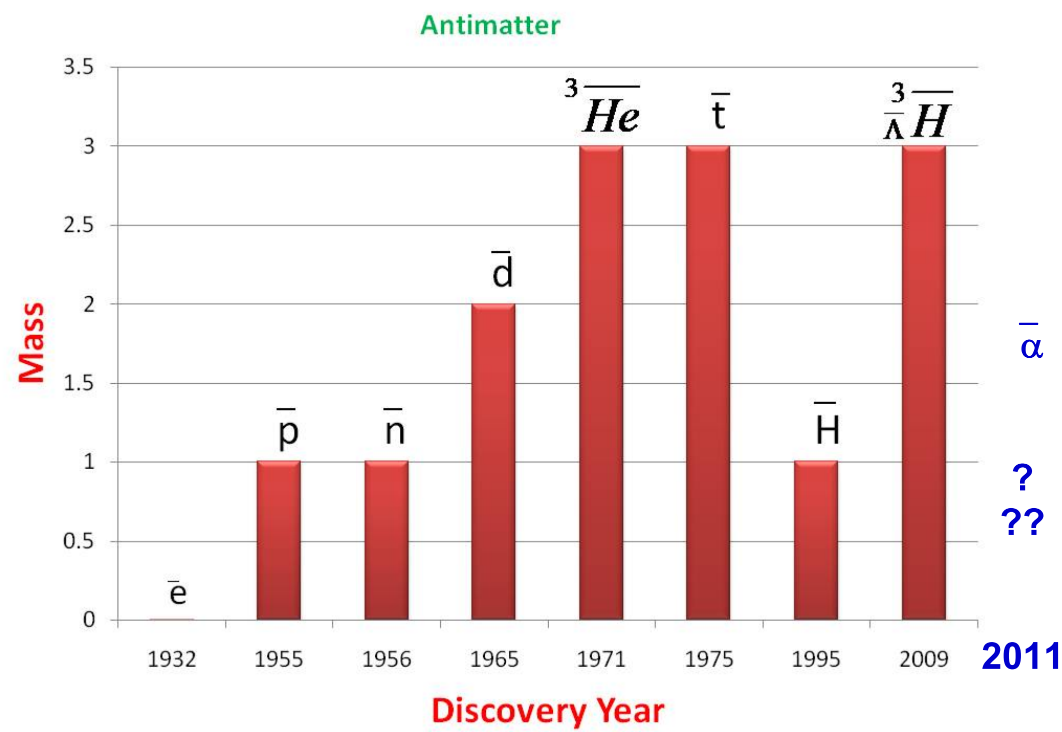


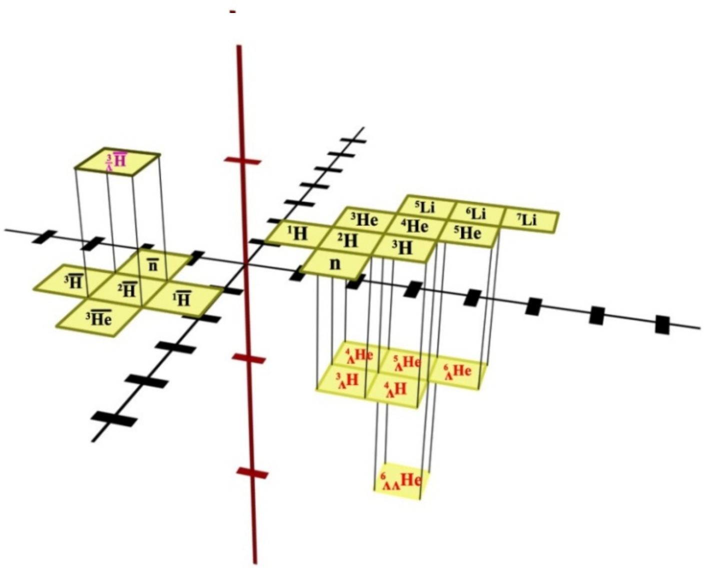
Possible Physics Topics:

- Measure antinucleus mass and magnetic moment for CPT test,
- Study the antinucleus annihilation process (sequence)
- antinucleus-nucleus Annihilation
  (what do they create? Hot or cold matter)
- Maybe even antiAlpha Atomcule

Vision from the past







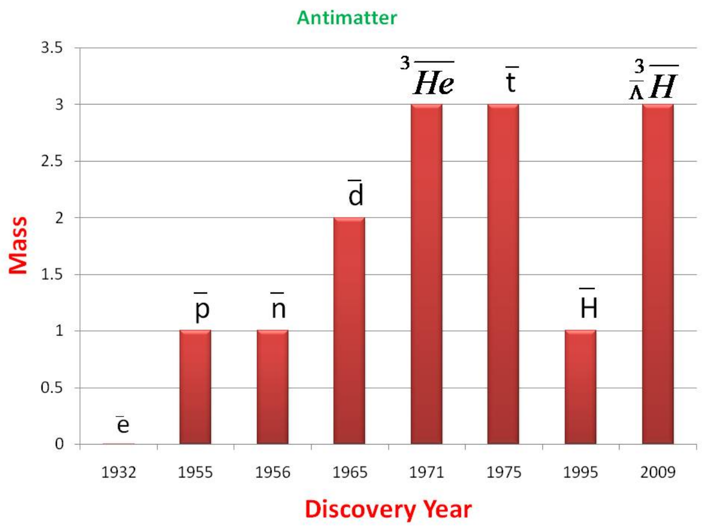
The extension of the periodic system into the sectors of hypermatter (strangeness) and antimatter is of general and astrophysical importance. … The ideas proposed here, the verification of which will need the **commitment for 2-4 decades of research, could be such a vision with considerable** attraction for the best young physicists… I can already see the enthusiasm in the eyes of young scientists, when I unfold these ideas to them — similarly as it was 30 years ago,…

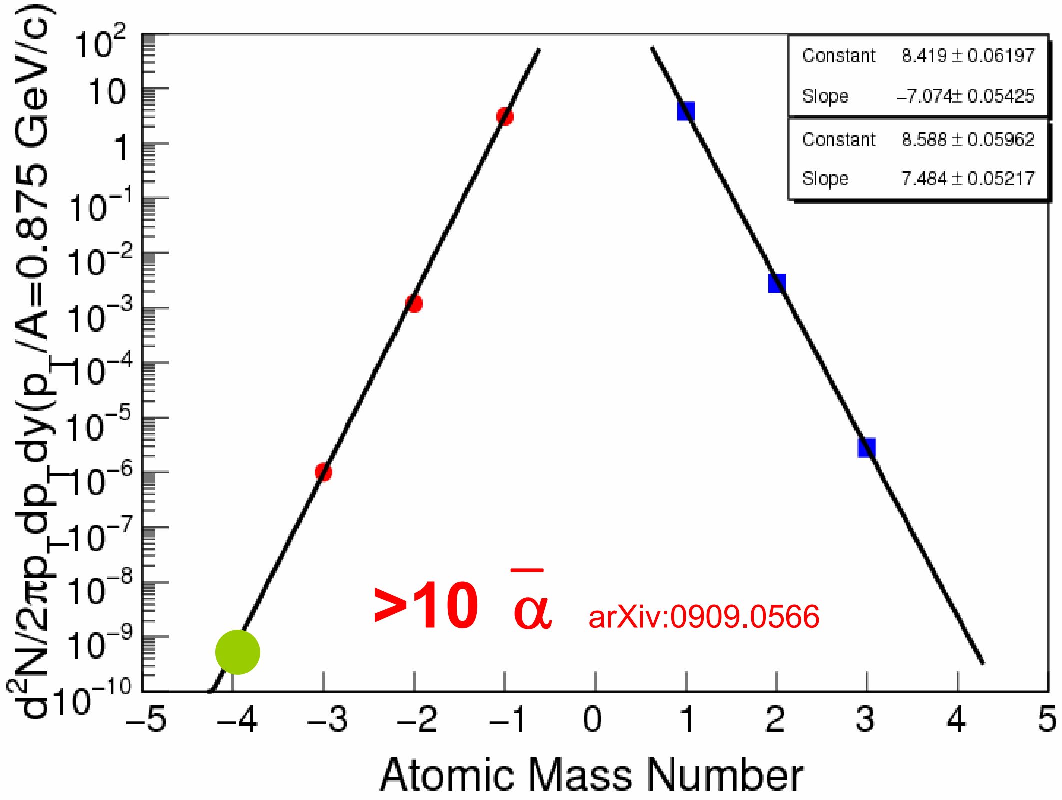
---- Walter Greiner (2001)

Projected Discovery of antimatter alpha particle from STAR run10

How many possible antimatter nuclei can we discover?
Antihypertriton, antialpha; antihyperH4?

Can we get to antimatter ^{6}He?
Unless technology and Physics change dramatically, **NO**!





DOE FY2011 Congressional Budget Request for Science

large Electromagnetic Calorimeter (EMCal) detector to be installed in phases in the ALICE experiment over the next few years. First heavy ion beam operations at the LHC are expected to start in 2010.

The RHIC and LHC research programs are directed primarily at answering the overarching questions that define the first frontier identified by the nuclear science community—Quantum Chromodynamics (QCD). The fundamental questions addressed include: What are the phases of strongly interacting matter, and what roles do they play in the cosmos? What governs the transition of quarks and gluons into pions and nucleons? What determines the key features of QCD, and what is their relation to the nature of gravity and spacetime?

The funding for this subprogram is increased in FY 2011 to operate RHIC near optimal levels and to maintain research efforts.

Selected FY 2009 Accomplishments

- Scientists continued work to determine the physical characteristics of the perfect liquid produced in the highly energetic nucleus-nucleus collisions at RHIC. The temperature is one of the most important of these characteristics because it is a measure of the average energy of the particles inside this liquid. Energetic photons (or light) emanating from this perfect liquid have been observed and are one indicator of temperature. Further, data analysis now suggests that the initial fluid temperature may correspond to an energy greater than 300 MeV which exceeds the critical temperature thought necessary for the formation of the quark-gluon plasma.
- The formation of the anti-hypertriton (a hypertriton is a hypernucleus which is a nucleus that contains at least one hyperon—an unstable particle with a mass greater than a neutron—in addition to nucleons) is a major new discovery at RHIC. This observation could provide important information about the interior structure of neutron stars and the development of the cosmos.
- In FY 2009, RHIC delivered high intensity beams of polarized protons. Polarized protons were successfully accelerated to 250 GeV and first collisions for physics measurements at this energy occurred for several weeks.
- Plans for luminosity improvements for heavy ion collisions by implementing bunched-beam stochastic cooling systems are in progress. Tests have validated modeling codes which predict luminosity enhancement is feasible. Recovery Act funding has accelerated plans for stochastic cooling systems which are expected to be available in each RHIC collider ring by 2012. Accelerator scientists expect the planned implementation of longitudinal and transverse stochastic cooling to both accelerator rings, together with a new 56 MHz storage radio frequency system, will provide a 10-fold increase in gold beam luminosity by 2012. With these technological advances, the previously envisioned RHIC II upgrade is no longer needed and has been canceled by the NP program, saving the federal government approximately $100,000,000.

Detailed Justification

(dollars in thousands)

	FY 2009	FY 2010	FY 2011
Research	**40,649**	**48,780**	**49,083**
▪ **University Research**	**14,009**	**14,474**	**15,511**

Research support is provided for about 120 scientists and 100 graduate students at 30 universities in 19 states. Funding supports research efforts at RHIC and the continuation of a modest program at the

"This experimental discovery may have unprecedented consequences for our view on/of the world" says **Prof. Dr. Horst Stoecker**, vice president of helmholtz gemeinschaft of german national laboratories, a veteran of relaticistic heavy ion physics, "antihypertriton pushes open the door to new dimensions in the nuclear chart: from to the antimatter world and to the world of anti-hypermatter - just a few years ago this would have been viewed as impossible.“

PHYSICS

Fishing Antihypernuclei Out of a Quark-Gluon Soup

Rare antimatter hypernuclei can form when an ultrahigh-energy plasma of quarks and gluons cools down.

Thomas D. Cohen

Quantum field theory is the general framework for combining special relativity and quantum mechanics; it is the formalism that describes the standard model of particle physics. The mathematical structure of quantum field theory requires that all types of particles have antiparticles of the same mass but the opposite electric charge. In fact, the implications are broader: Any physical system describable in quantum field theory—no matter how complex or exotic—has an antimatter analog with an identical mass. Thus, a version of quantum field theory rich enough to allow for the existence of elephants must equally allow for antielephants. On page 58 of this issue, The STAR Collaboration (*1*, *2*) discusses the formation of a complex particle, an antihypertriton, an exotic relative of the nucleus of tritium that contains a particular variety of elementary particle known as the strange quark.

Of course, antielephants have yet to be seen; our universe has a vast preponderance of ordinary matter over antimatter. It is not completely understood why our universe displays this asymmetry, but because it does, it is very hard to make complicated states of antimatter. Antiparticles can be made and even used. For example, positrons—positively charged electrons—are emitted in certain nuclear decay processes and used in imaging. However, antiparticles usually encounter normal matter soon after they form, which results in their annihilation by conversion into neutral particles such as photons. In practice, even if one had the vast number of positrons, antiprotons, and antineutrons needed for an antielephant, they would be annihilated long before they could be arranged into an antielephant.

Antielephants may not be practical to create, but it is possible to create relatively complex antimatter systems. One way to create such systems is via extremely energetic heavy-ion collisions such as those produced at the Relativistic Heavy-Ion Collider (RHIC) at Brookhaven National Laboratory. The STAR Collaboration was able to form and detect an antihypertriton, which may crudely be thought of as a variant of an ordinary triton, or tritium nucleus ^3H, the heavy isotope of hydrogen with one proton and two neutrons (see the figure).

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Fun news about the discovery

Brookhaven National Laboratory
Office of Science / U.S. Dept. of Energy
BROOKHAVEN NATIONAL LABORATORY

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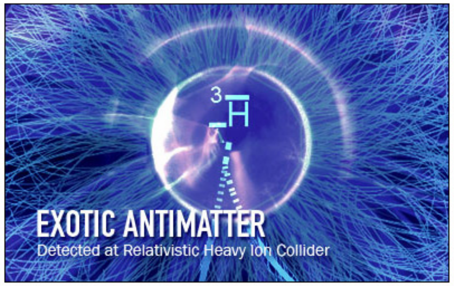
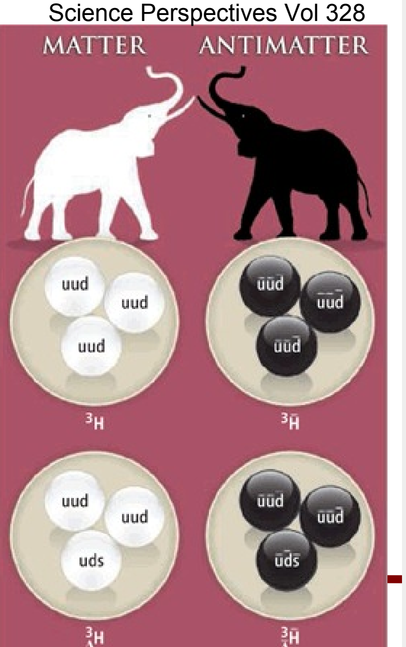


An international team of scientists studying high-energy collisions of gold ions at the Relativistic Heavy Ion Collider has published evidence of the most massive antinucleus discovered to date. Th... charged state of antim... antineutron, and an a...

Laboratory Ne...

LHC & ATLAS — Large Hadron Collider & ATLAS detector
Center for Functional Nanomaterials
NSLS — National Synchrotron Light Source
NSLS II — The Future National Synchrotron Light Source
RHIC — Relativistic Heavy Ion Collider

Science Perspectives Vol 328



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This article elsewhere

Published online 4 March 2010 | Nature | doi:10.1038/news.2010.108

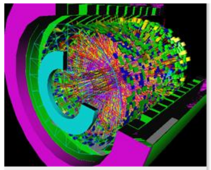
News

Heavy antimatter created in gold collisions

Most massive antimatter nucleus yet identified in particle experiments.

Geoff Brumfiel

Physicists have rooted through a morass of collisions to find the heaviest antimatter nucleus yet inside one of their particle accelerators.



Millions of collisions produce just a few antihydrogen nuclei.

Collisions between gold nuclei at the Relat... Colli... Long... York... inclu...

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'Negatively strange' antihypermatter made out of gold

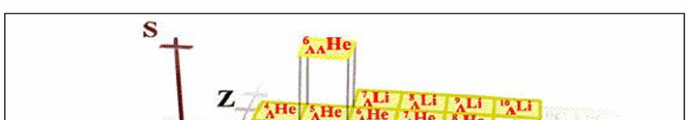
Atomsmash boffins' reverse alchemy bizarro-stuff triumph

By Lewis Page • Get more from this author

Posted in Physics, 5th March 2010 15:36 GMT

Topflight international reverse-alchemy boffins say they have managed to transmute gold into an entirely new form of "negatively strange" antihypernucleic antimatter, ultra-bizarre stuff which cannot possibly occur naturally - except perhaps inside the cores of collapsed stars.

The transmutation was carried out at the Relativistic Heavy Ion Collider (RHIC), a powerful atom-smasher located at America's Brookhaven National Laboratory. Blasting a pair of high-energy gold nuclei into each other as is their wont, RHIC boffins found they had created something very odd indeed.



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Twisted Physics: 7 Recent Mind-Blowing Findings

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The antimatter particle was created at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory in Upton, N.Y.

7 6 5 4 3 2 1

A New Antimatter Particle Created

By smashing particles together at close to light speed inside an atom smasher, scientists created a never-before-seen type of matter: an anti-hypertriton.

This particle is weird in many ways. First, it's not normal matter, but its eerie opposite, called antimatter, which annihilates whenever it comes into contact with regular mass. Second, the anti-hypertriton is what's called a "strange" particle, meaning it contains a rare building block called a strange quark, which isn't present in the protons and neutrons that make up regular atoms.

The experiment was conducted at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory in Upton, N.Y. The results were announced in March 2010.

Conclusions

- $^{3}_{\bar{\Lambda}}\overline{\mathrm{H}}$ has been observed for 1st time; significance ~4σ.
- Consistency check has been done on $^{3}_{\Lambda}\mathrm{H}$ analysis; significance is ~5σ
- The lifetime is measured to be $\tau = 182 \pm^{89}_{45} \pm 27\ ps$
- The $^{3}_{\bar{\Lambda}}\overline{\mathrm{H}} / ^{3}_{\Lambda}\mathrm{H}$ ratio is measured as 0.49$\pm$0.18, and $^{3}\overline{\mathrm{He}}$ / ^{3}He is 0.45$\pm$0.02, favoring the coalescence picture.
- The $^{3}_{\Lambda}\overline{\mathrm{H}}$ / $^{3}\overline{\mathrm{He}}$ ratio is determined to be 0.89 $\pm$ 0.28, and $^{3}_{\Lambda}\mathrm{H}$ / ^{3}He is 0.82 $\pm$ 0.16. No extra penalty factor observed for hypertritons at RHIC.
  Strangeness phase space equilibrium

Outlook

- **Lifetime:**
  - **data samples with larger statistics**

- **Production rate:**
  - **Strangeness and baryon correlation**
    Need specific model calculation for this quantity
  - **Establish trend from AGS—SPS—RHIC—LHC**

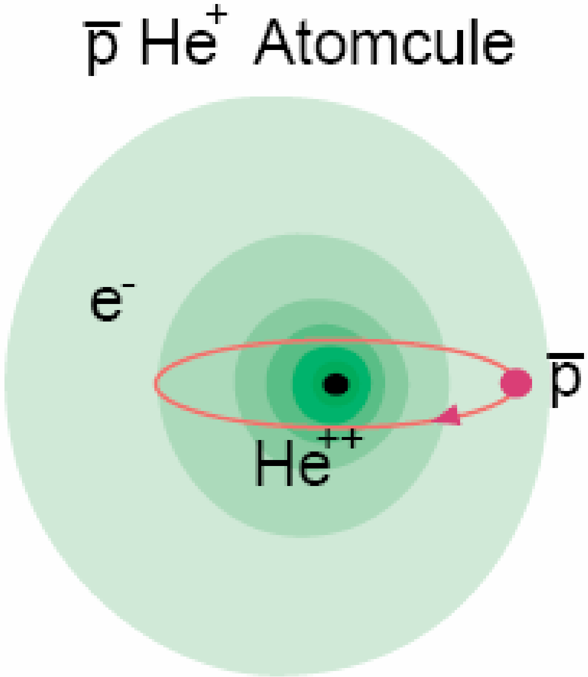
- **${}^{3}_{\Lambda}H \rightarrow d+p+\pi$ channel measurement: *d* and dbar via ToF.**

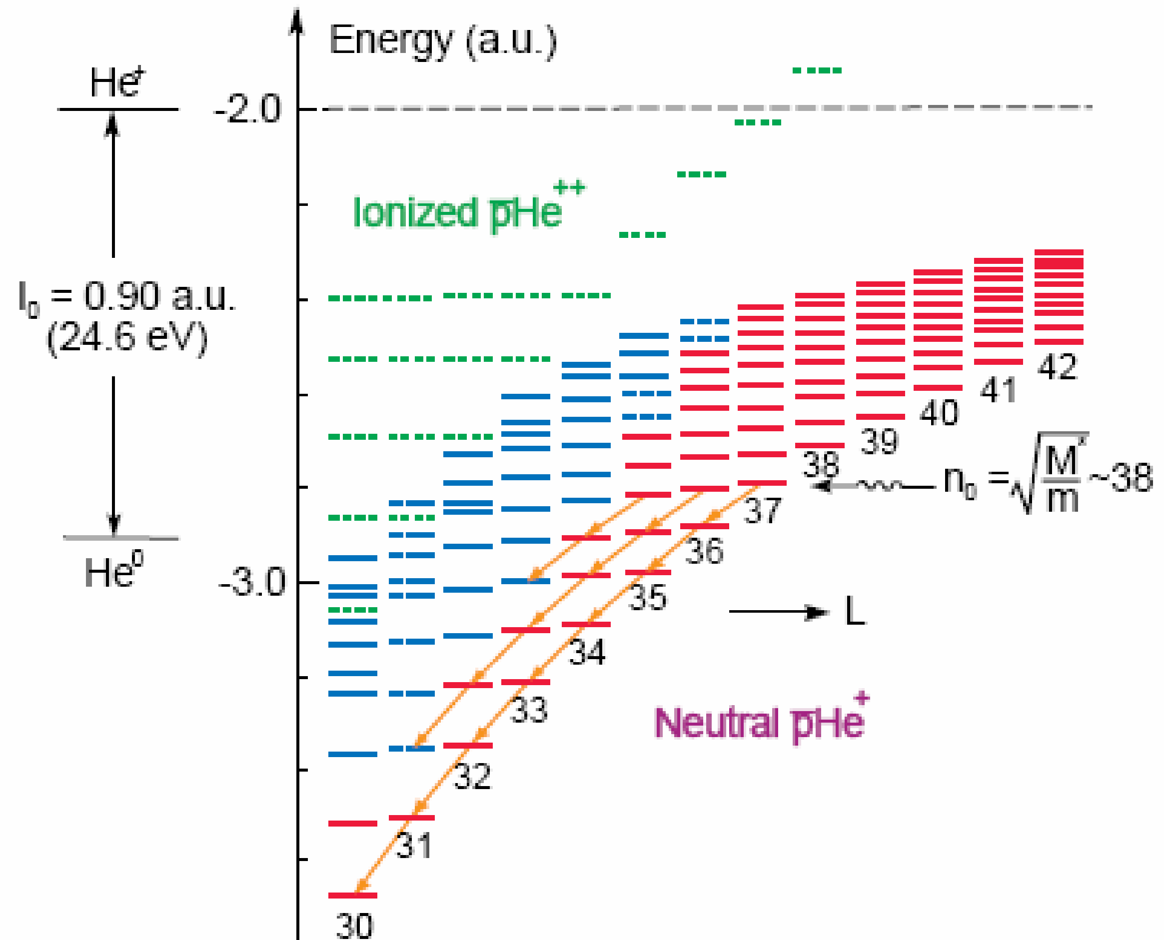
- **Search for other hypernucleus: ${}^{4}_{\Lambda}H$, double Λ-hypernucleus.**

- **Search for anti-α, antinucleus atomcules**

- **RHIC: best antimatter machine**

Antiproton Atomcules

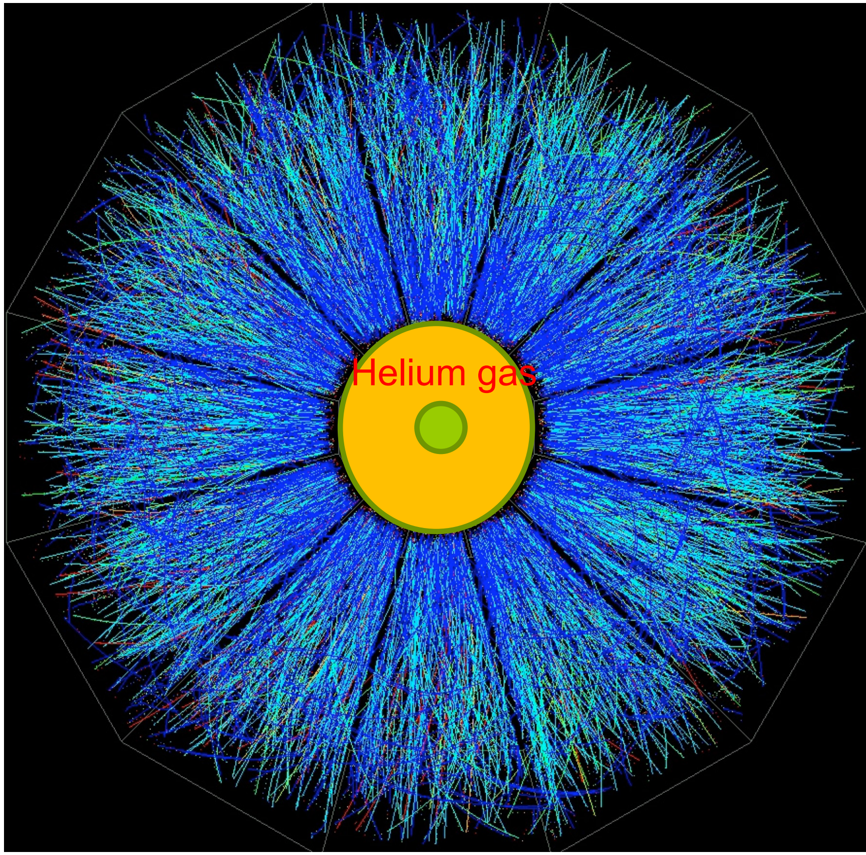




Metastable antiproton-helium atom discovered at KEK: Iwasaki, PRL 67 (1991)
Mass difference: p-pbar < 2×10^{-9}; Hori, PRL 96 (2006);
best measurement of baryon mass and magnetic moment for CPT test at LEAR/CERN
http://asacusa.web.cern.ch/ASACUSA/index-e.html

Proposal

1. Phase0 (run10: search for possible signals):
   - Using TPC and its material for possible atomcule creation
   - Signature: Au+Au collisions followed by a delayed burst of charged pions originated in TPC
   - Trigger and Delayed emmission using TOF
     ZDC+TOF (Au+Au) coincidence with
     delayed TOF multiplicity (dt~>200ns)
   - Antiproton actomcule (3<NdTOF<5)
     Antideuteron atomcule (5<NdTOF<10)
     Antitriton atomcule (NdTOF>10)
2. Phase1 (run11: Helium bag)
   - Using Helium gas to create antinucleus Helium Atom
     Helium is the only known material to create atomcules
   - Replace the air between TPC and beampipe by helium bag (PHENIX has done this in the past)
   - Reduce radiation length and create atomcules
   - Using trigger logics from Phase0
3. Phase2: (precision measurements)
   - Liquid Helium (tank or TPC) surrounding beam pipe
     Dedicated runs
   - Liquid Helium (tank or TPC) replaces one of the BEMC module
4. Phase3 and beyond:
   Dedicated beam line for laser spectroscopy ?



Current proposal concerns phase0 and phase1

Current hypernucleus experiments