Observation of antimatter hypernuclei at RHIC

Jinhui Chen[a,b] for the STAR Collaboration

a) Kent State University

b) Shanghai Institute of Applied Physics, CAS

10th International Conference on

Hypernuclear and Strange Particle Physics

" Hyp-X "

September 14 - 18, 2009

Ibaraki, Japan

Outline

- Introduction & Motivation
- Our measurement
  - $^{3}_{\bar{\Lambda}}\overline{\mathrm{H}}$ and $^{3}_{\Lambda}\mathrm{H}$ signal
  - Lifetime measurement
  - Production rate and particle ratio
- Conclusions and Outlook

Introduction & Motivation

- Hypernuclei: ideal lab for YN and YY interaction
  - Baryon-baryon interaction with strangeness sector
  - Input for theory describing the nature of neutron stars

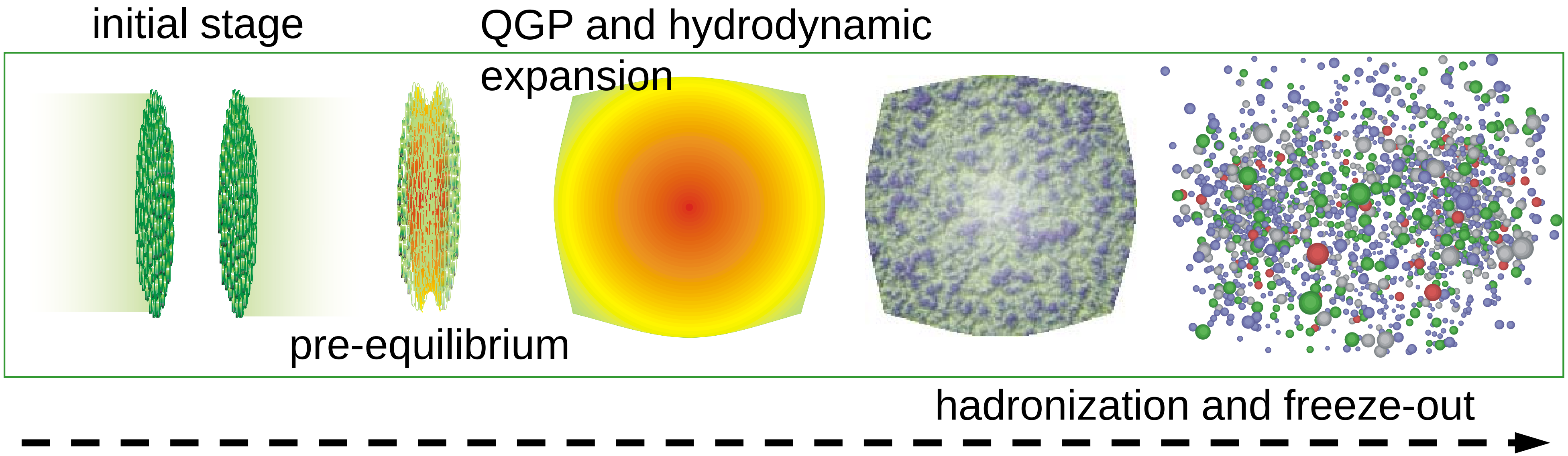
- No anti-hypernuclei have ever been observed

- Coalescence mechanism for production: depends on overlapping wave functions of Y+N at final stage

- Anti-hypernuclei and hypernuclei ratios: sensitive to anti-matter and matter profiles in HIC
  - Extension of the nuclear chart into anti-matter with S [1]

[1] W. Greiner, *Int. J. Mod. Phys. E 5 (1995) 1*

Relativistic Heavy-ion Collisions

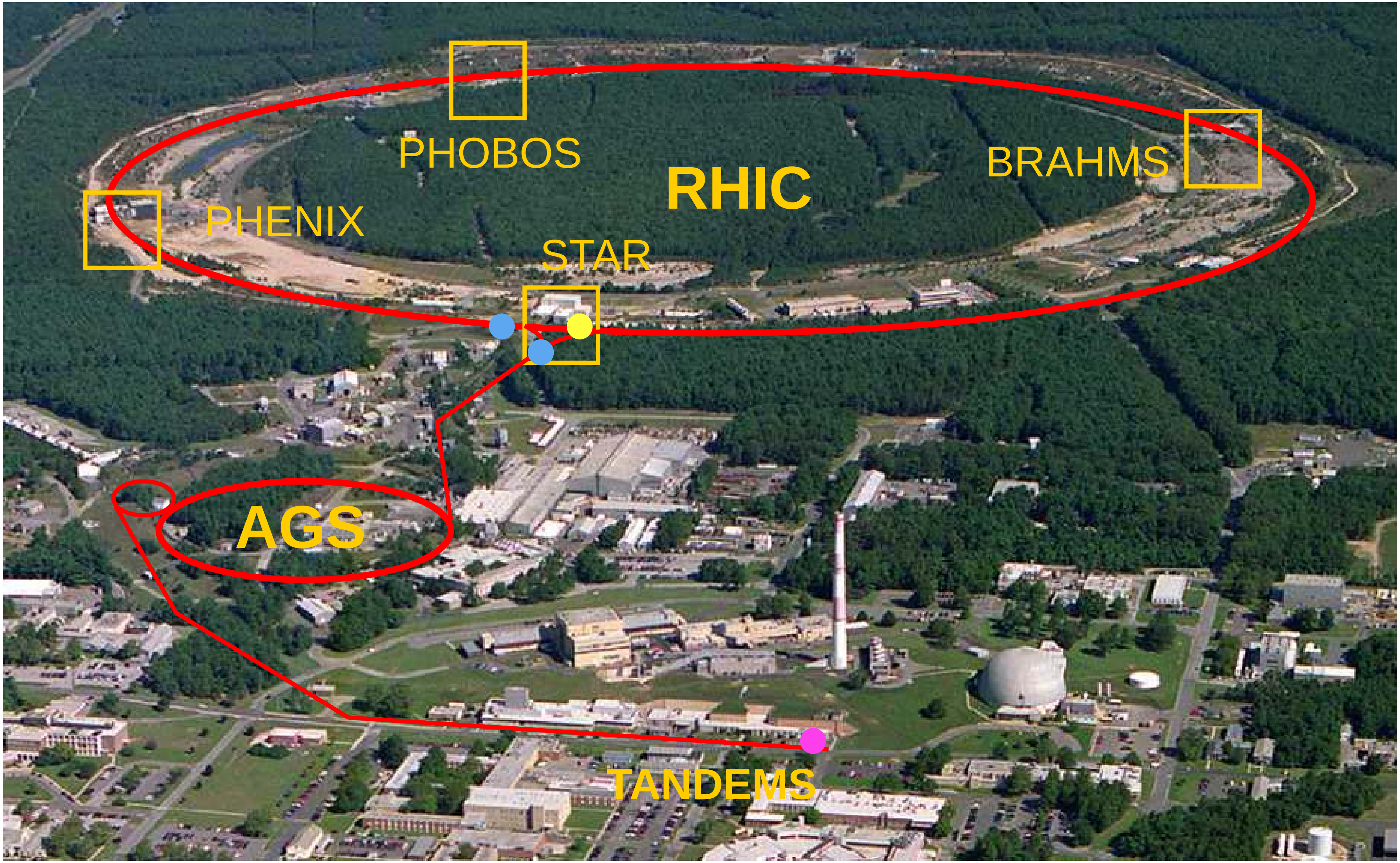


- Initial condition of collisions
- New matter of state: QGP
- Hadronization and hadronic interaction

★ RHIC creates hot and dense matter, containing about equal numbers of q and anti-q: ideal source of anti-nuclei.

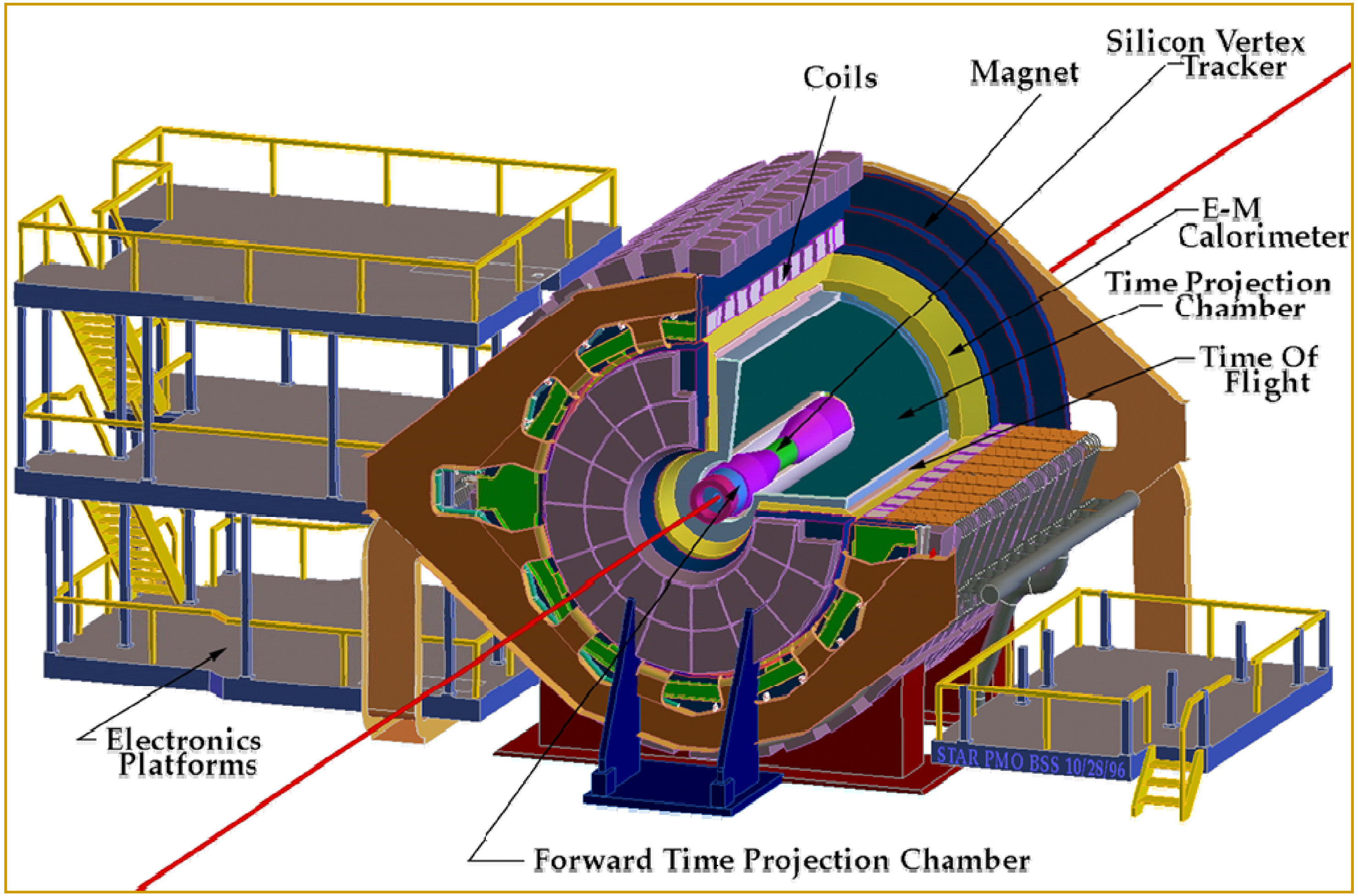
RHIC white paper: Nucl. Phys. A 757

Relativistic Heavy Ion Collider (RHIC)



Animation M. Lisa

STAR Detector



- TPC: effectively 3-D ionization camera with over 50 million pixels.
- STAR: a complex set of various detectors, a wide range of measurements and a broad coverage of different physics topics.

STAR-TPC: *NIMA 499 (2003) 659*

STAR-detector: *NIMA 499 (2003) 624*

Event display

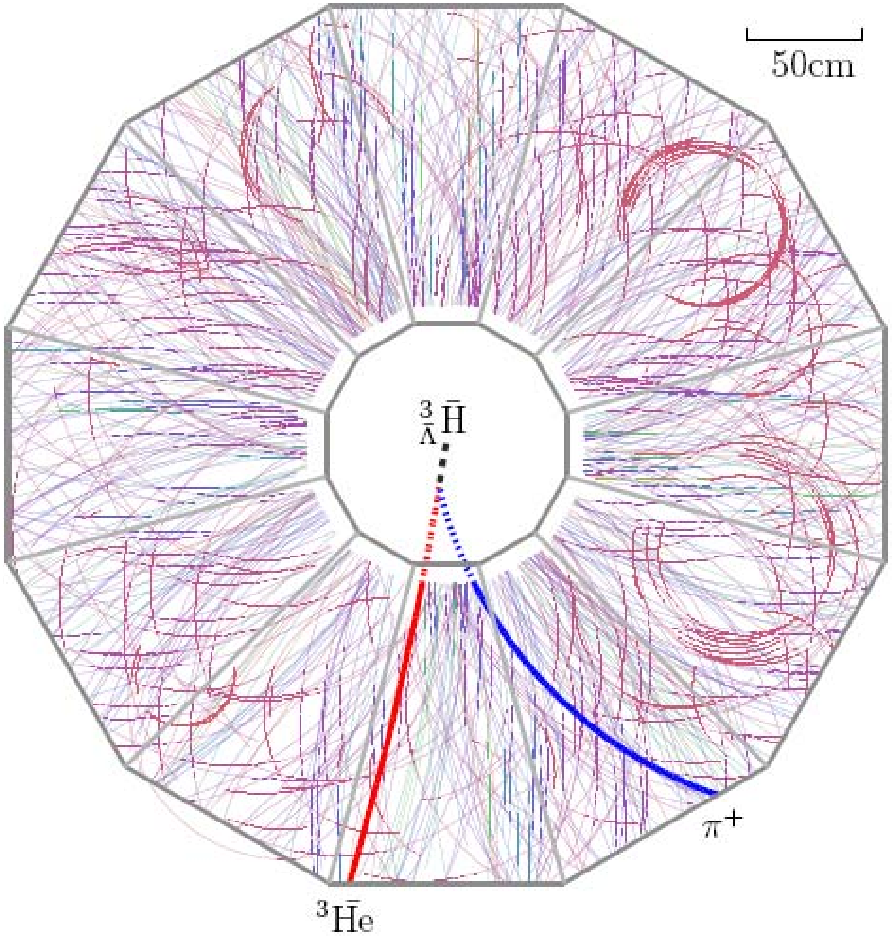


Figure 1: "Beam's eye view" of a typical event in the STAR detector when a $^{3}_{\Lambda}\bar{H}$ candidate is produced. STAR's main tracking device reconstructs charged particle trajectories in 3-D; in this 2-D projection, the apparent track density is extremely large. The thick red line shows the $^{3}\bar{He}$ daughter while the blue line marks the π^+ coming from the decay of the $^{3}_{\Lambda}\bar{H}$ candidate (black dash line). Dashed lines represent extrapolated trajectories which are not observed directly in the detector.

Data-set and track selection

$^{3}_{\Lambda}H$ mesonic decay, m=2.991 GeV, B.R. 0.25;

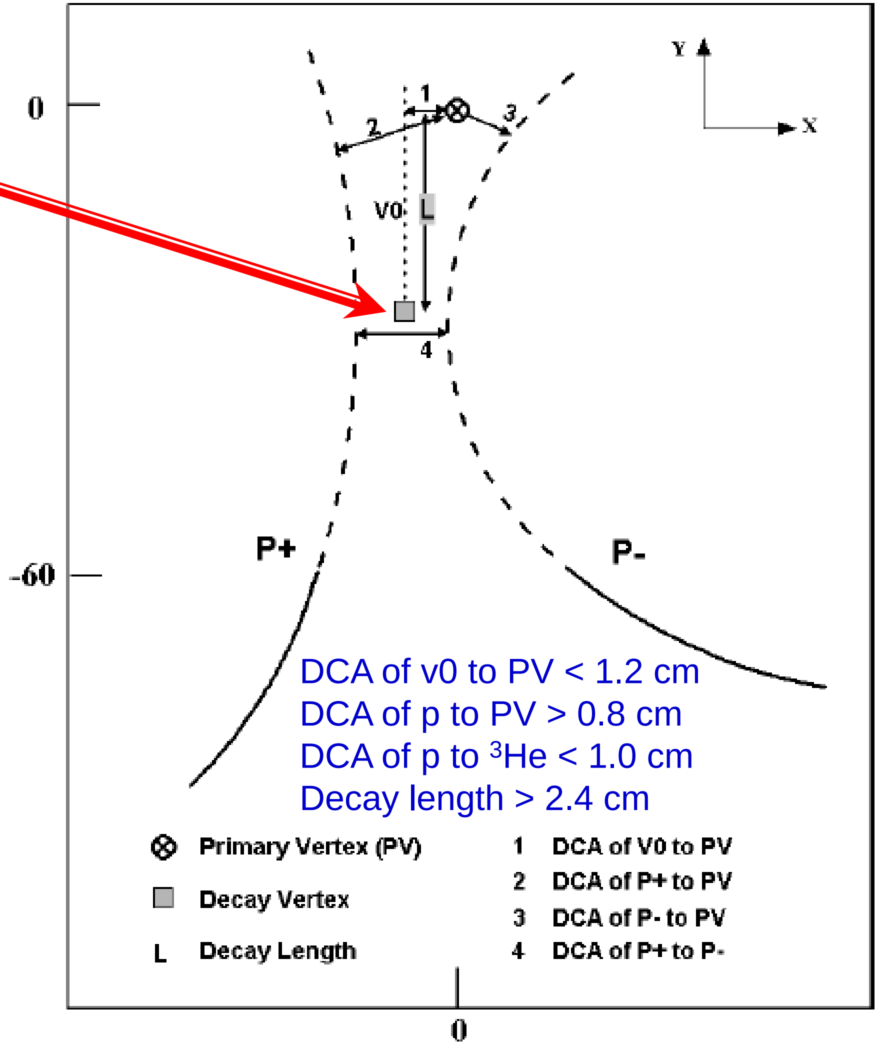
$$^{3}_{\Lambda}\overline{H} \rightarrow {}^{3}\overline{He} + \pi^{+}$$

$$^{3}_{\Lambda}H \rightarrow {}^{3}He + \pi^{-}$$

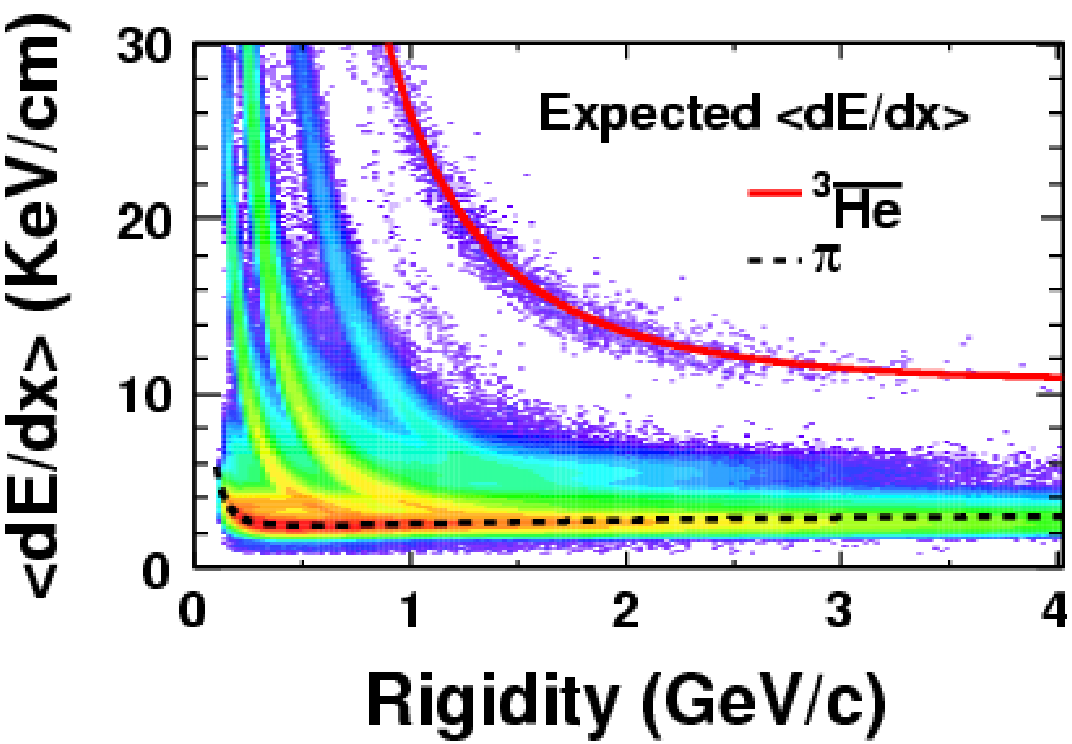
- Data-set used, Au+Au 200 GeV
  - ✓~67M year 2007 minimum-bias
  - ✓~22M year 2004 minimum-bias
  - ✓~23M year 2004 central,
  - ✓$|V_Z|<30$cm
- Tracks level: standard STAR quality cuts, i.e. , *not near edges of acceptance, good momentum & dE/dx resolution.*

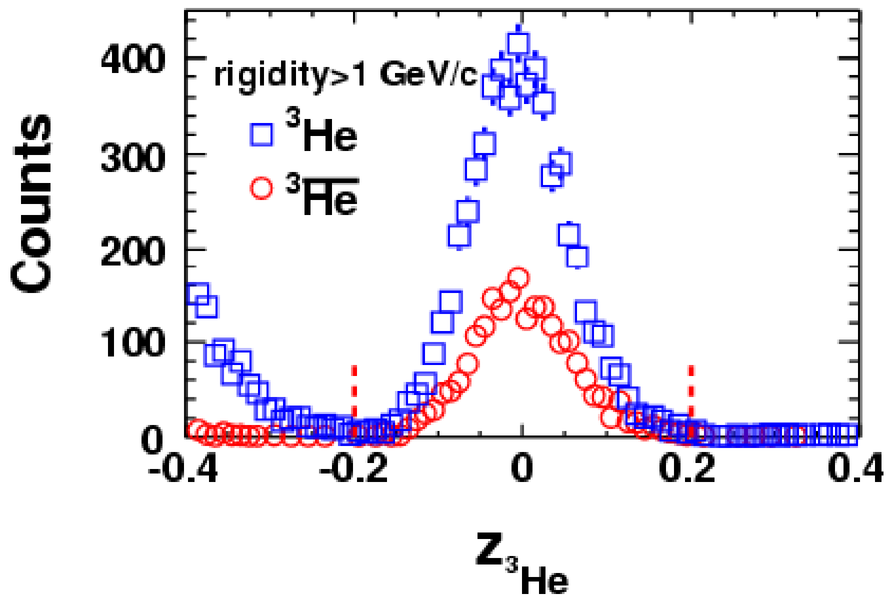
QM09 proceeding: arXiv:0907.4147

Secondary vertex finding technique



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





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

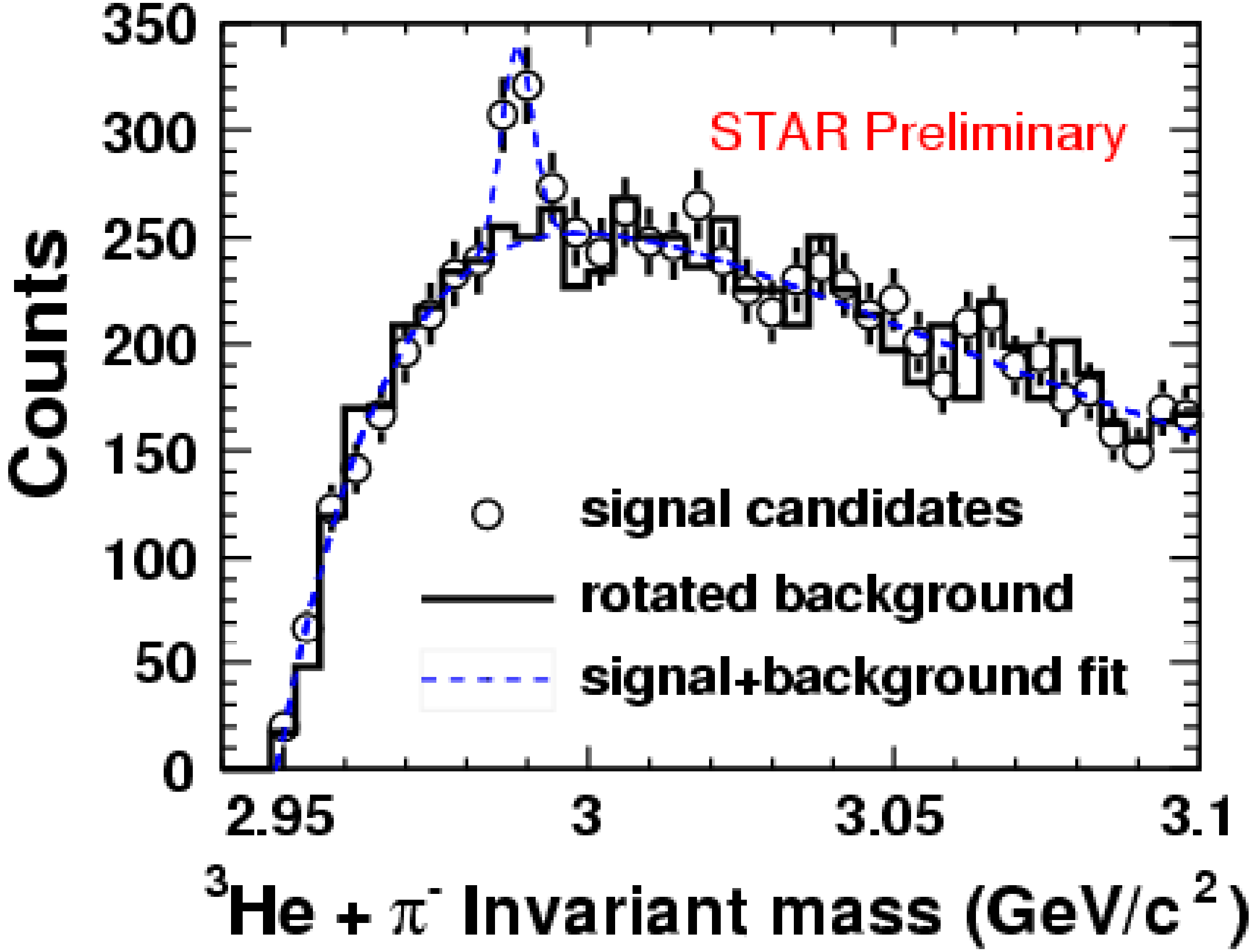
Theory curve: *Phys. Lett. B 667 (2008) 1*

★ **Select pure ^{3}He sample:** **^{3}He: 5810 counts**

anti-^{3}He: 2168 counts

condition: -0.2<z<0.2 & dca<1.0cm & p>2 GeV/c…

${}^{3}_{\Lambda}H$ signal from the data

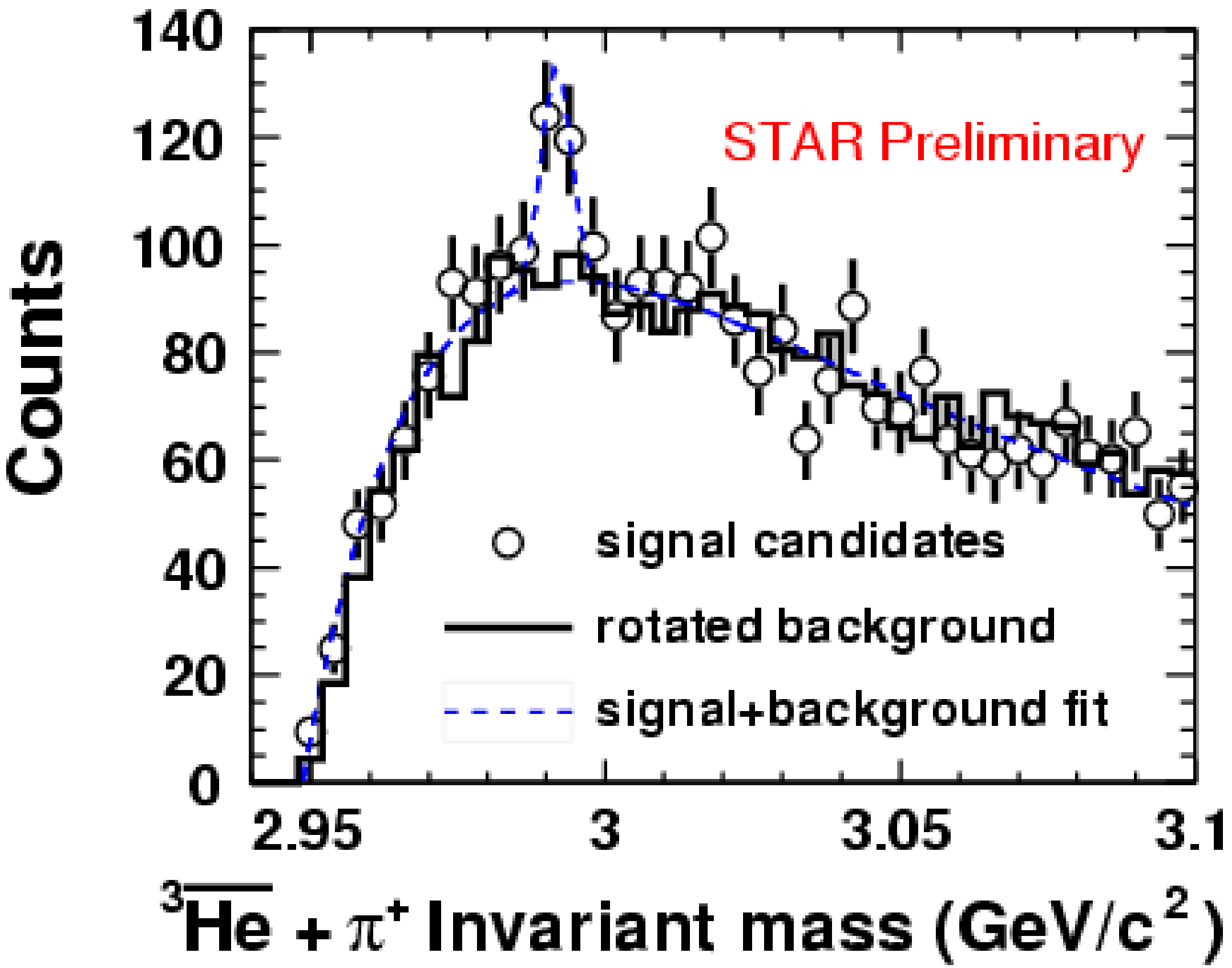


★ Signal observed from the data (bin-by-bin counting): **157±30**;

Mass: 2.989±0.001±0.002 GeV; Width (fixed): 0.0025 GeV.

★ Projection on anti-hypertriton yield: ${}^{3}_{\Lambda}\overline{H} = {}^{3}_{\Lambda}H \times {}^{3}\overline{He} / {}^{3}He$ =157*2168/5810= **59±11**

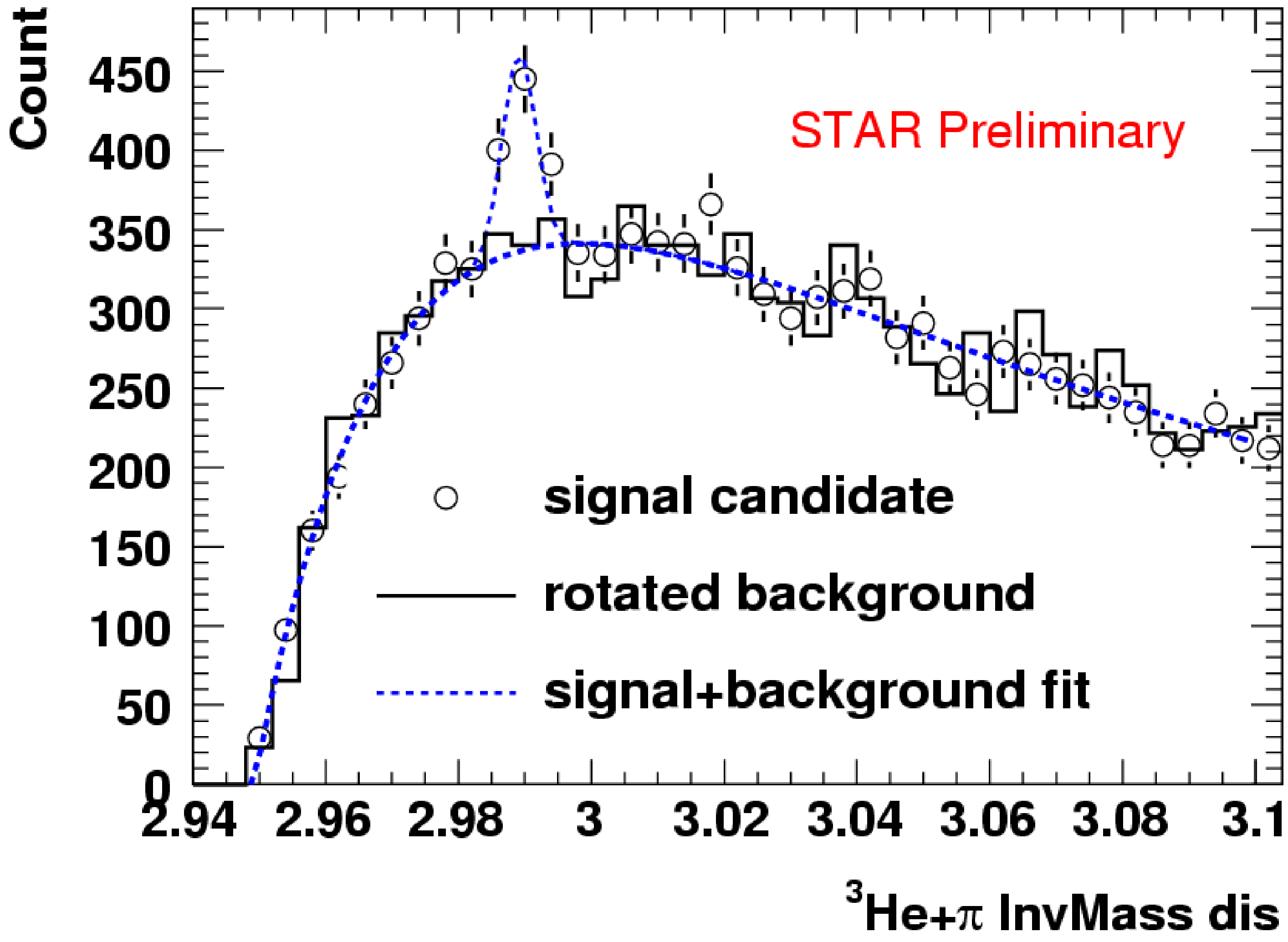
$^{3}_{\bar{\Lambda}}\overline{H}$ signal from the data



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

Mass: 2.991±0.001±0.002 GeV; Width (fixed): 0.0025 GeV.

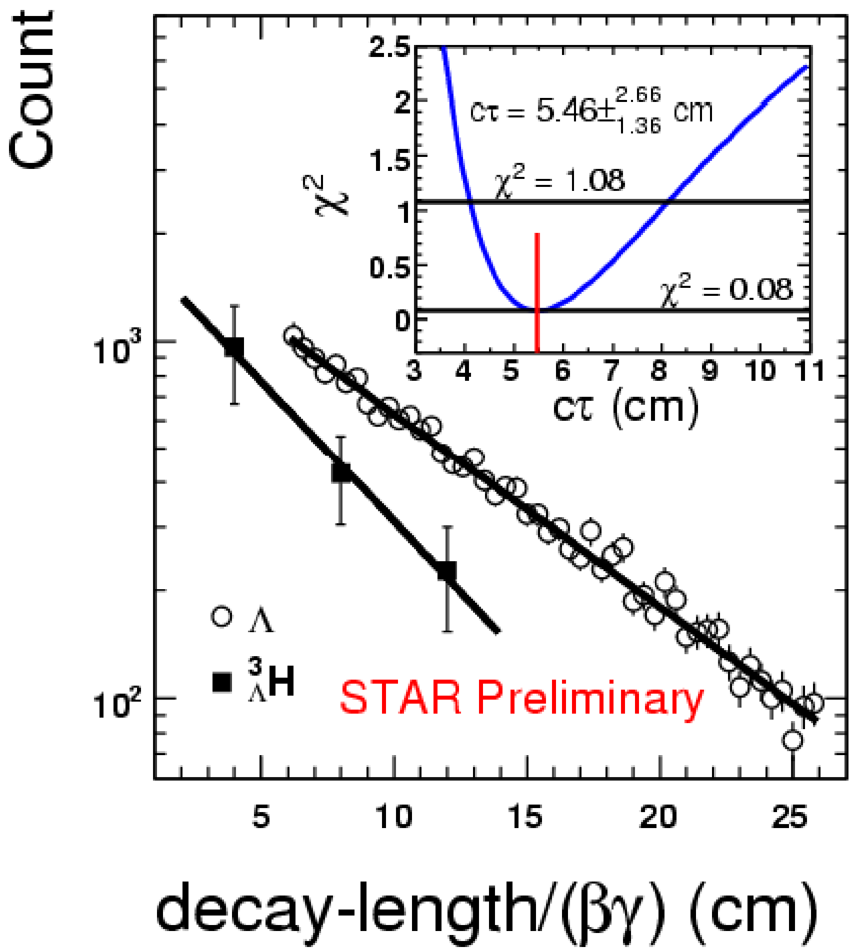
Combined the signal

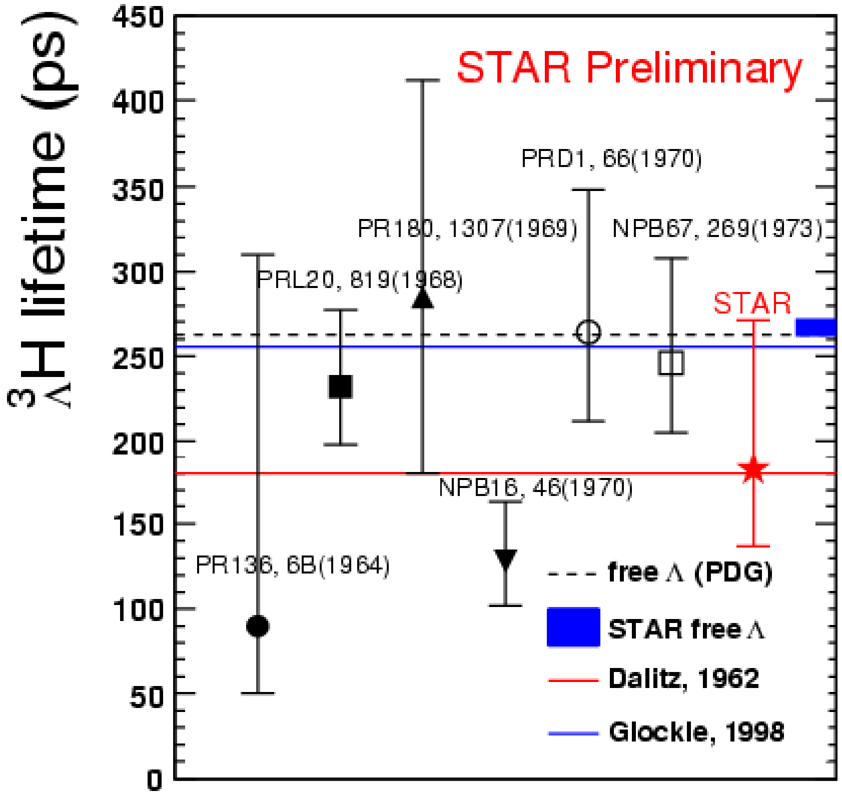


★ Combined hyperT and anti-hyperT signal : **225±35**;

It provides a >6σ significance for discovery.

Measure the lifetime





World data

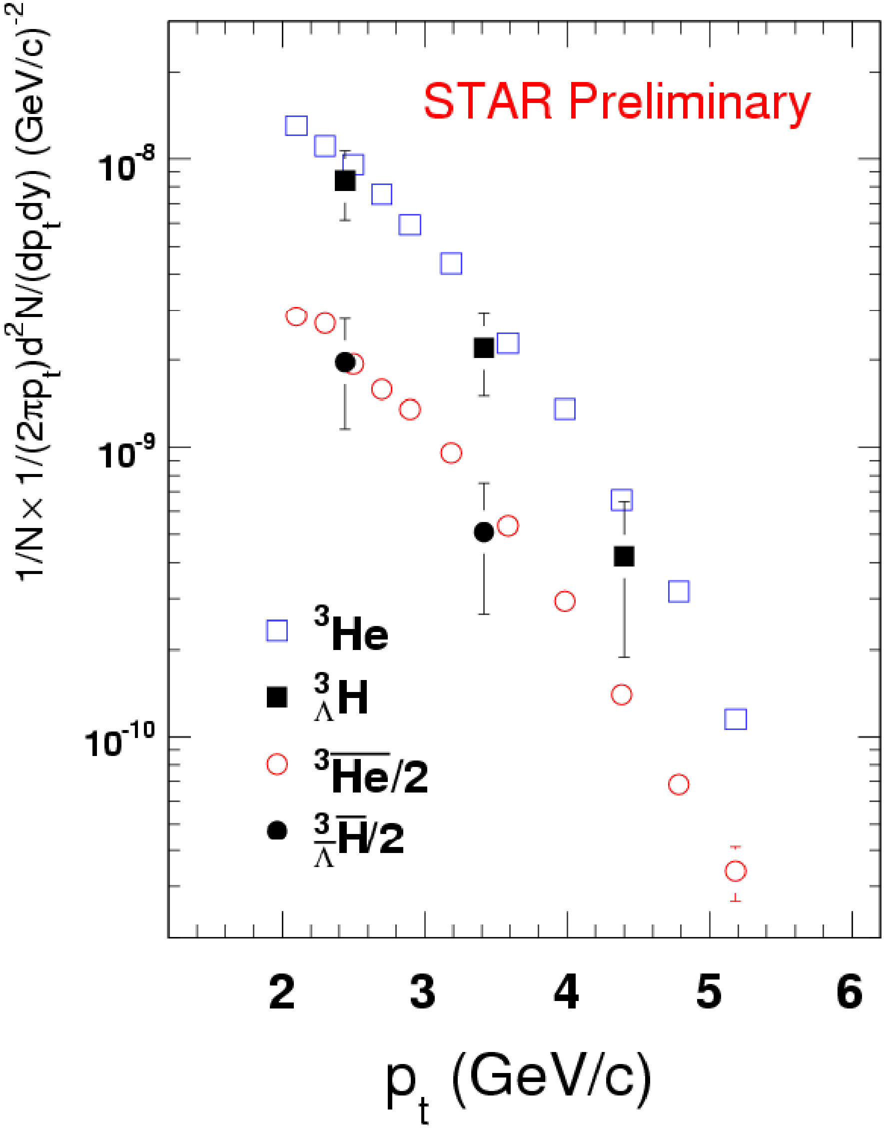
$$\tau = 182 \pm^{89}_{45} \pm 27 \text{ ps}$$

We measure τ_Λ = 267±5 ps

PDG value is τ_Λ = 263±2 ps

PDG: *Phys. Lett. B 667 (2008) 1*

Production rate



$$N = (N_{eve}^{MB} N_{part}^{MB} + N_{eve}^{central} N_{part}^{central})/2$$

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

Particle type	Ratio
$^3_{\bar\Lambda}\overline{\text{H}}/^3_\Lambda\text{H}$	0.49 ± 0.18 (stat.) ± 0.07 (sys.)
$^3\overline{\text{He}}/^3\text{He}$	0.45 ± 0.02 (stat.) ± 0.04 (sys.)
$^3_{\bar\Lambda}\overline{\text{H}}/^3\overline{\text{He}}$	0.89 ± 0.28 (stat.) ± 0.13 (sys.)
$^3_\Lambda\text{H}/^3\text{He}$	0.82 ± 0.16 (stat.) ± 0.12 (sys.)

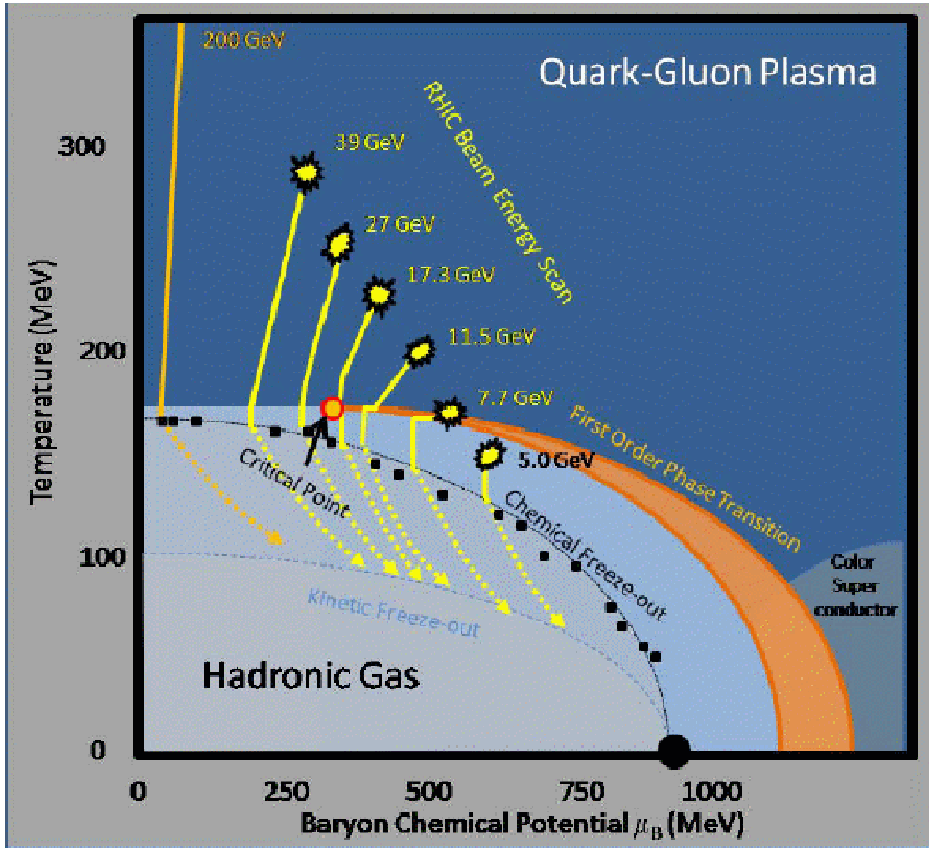
Coalescence => $^3_{\bar\Lambda}\overline{\text{H}} / ^3_\Lambda\text{H} \propto (\bar{p}/p)(\bar{n}/n)(\bar{\Lambda}/\Lambda)$

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

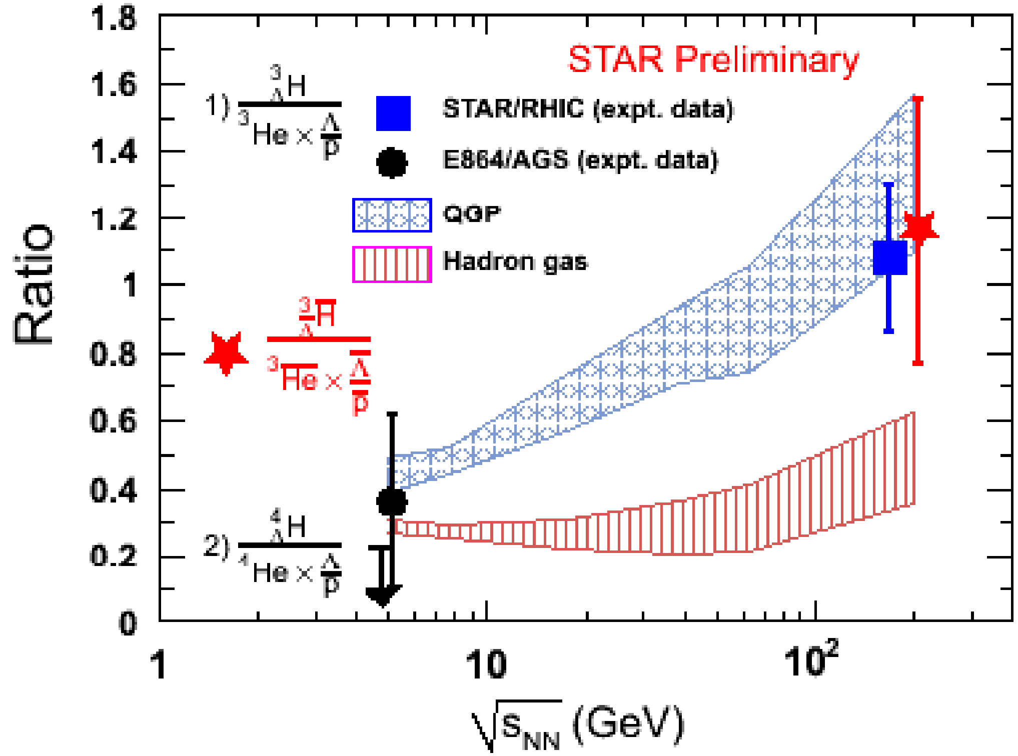
0.45 ~ 0.77*0.77*0.77

Tabulated ratios favor coalescence

A case for energy scan



Phase diagram plot: arXiv:0906.0630



Baryon-strangeness correlation: *PRL 95 (2005) 182301*, *PRC 74 (2006) 054901*, *PRD 73 (2006) 014004.*

- RHIC is scheduled to run Energy Scan beginning early 2010.
- Baryon-strangeness correlation via hypernuclei: a viable experimental signal to search for the onset of deconfinement.

model calculation : arXiv:0908.3357

Conclusion

- $^{3}_{\bar{\Lambda}}\overline{\mathrm{H}}$ has been observed for first time; 70 candidates, with significance ~4σ.

- Consistency check has been done on $^{3}_{\Lambda}\mathrm{H}$ analysis; 157 candidates, with significance better than 5σ.

- The measured lifetime is $\tau = 182 \pm^{89}_{45} \pm 27$ ps, consistent with free Λ lifetime (263 ps) within uncertainty.

- The $^{3}_{\bar{\Lambda}}\overline{\mathrm{H}} / ^{3}_{\Lambda}\mathrm{H}$ ratio is measured as 0.49±0.18±0.07, and $^{3}\overline{\mathrm{He}}$ / $^{3}\mathrm{He}$ is 0.45±0.02 ±0.04, favoring coalescence.

Outlook

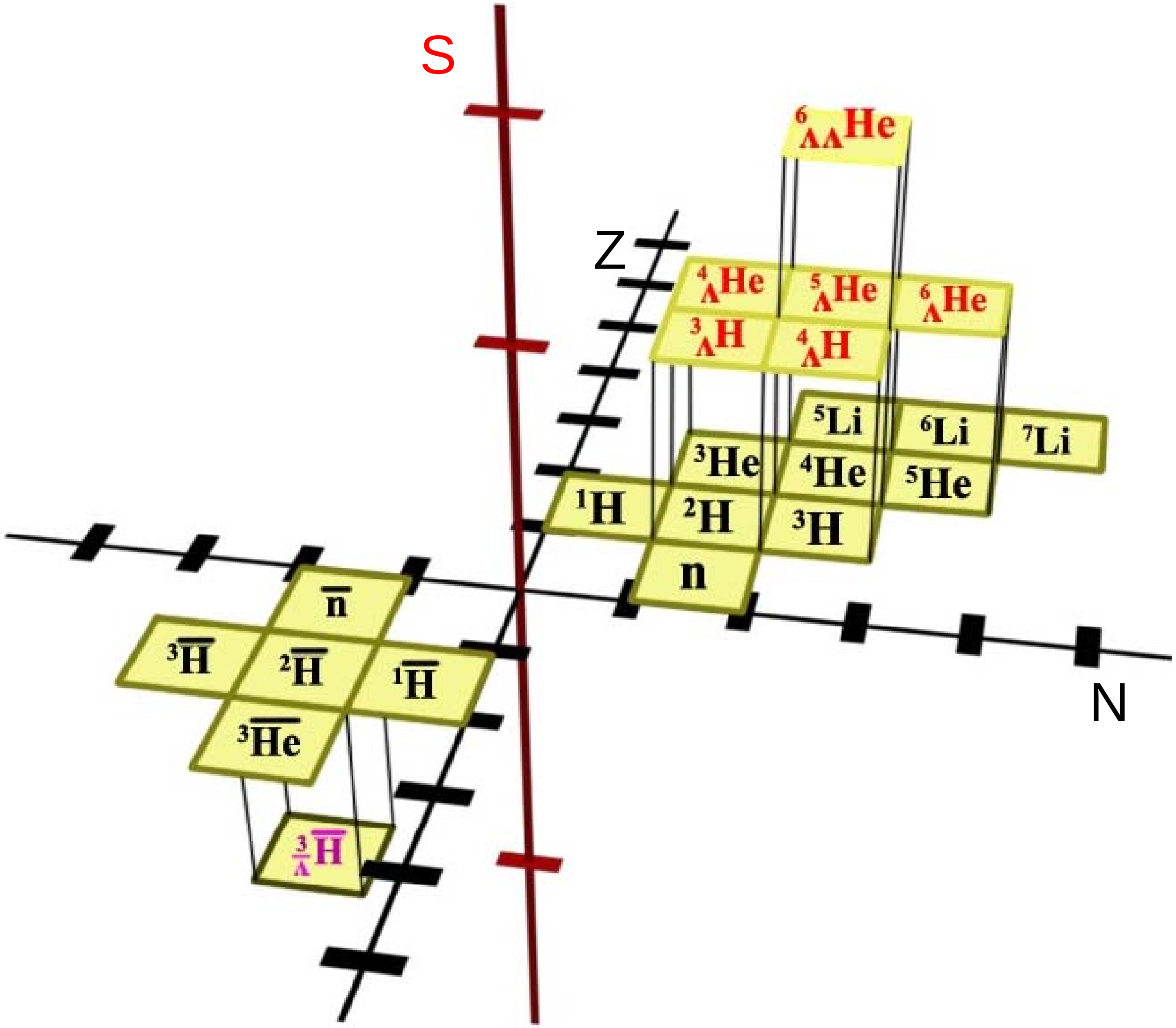
- **Lifetime:**
  - **data samples with larger statistics (~factor 10 more within a few years)**
- **Production rate:**
  - **baryon-strangeness correlation**
    - **a case for energy scan**
    - **establish trend from AGS-SPS-RHIC-LHC**

- **${}^{3}_{\Lambda}H \rightarrow d+p+\pi$ channel measurement: *d*-identification via ToF.**
- **Search for other hypernucleus: ${}^{4}_{\Lambda}H$, ${}^{4}_{\Lambda}He$, ${}^{4}_{\Lambda\Lambda}H$, ${}^{3}_{\Xi}H$,**

AGS-E906, Phys. Rev. Lett. 87, 132504 (2001)

- **Search for anti-α**
- **RHIC: best antimatter machine ever built**

Extension of the chart of the nuclides into anti-matter with Strangeness sector



Back-up

STAR Detector