Selected highlights from the STAR experiment at RHIC

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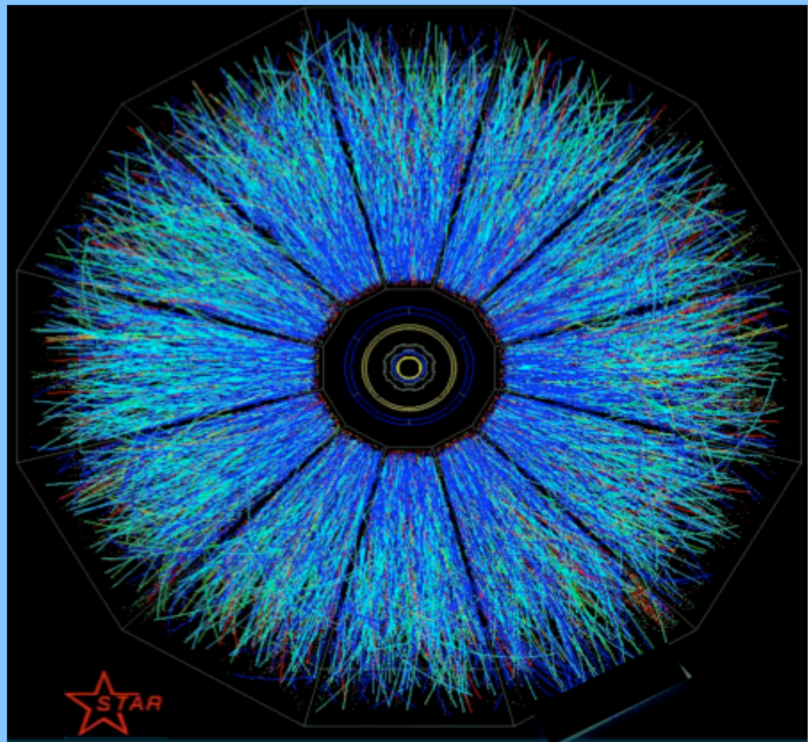
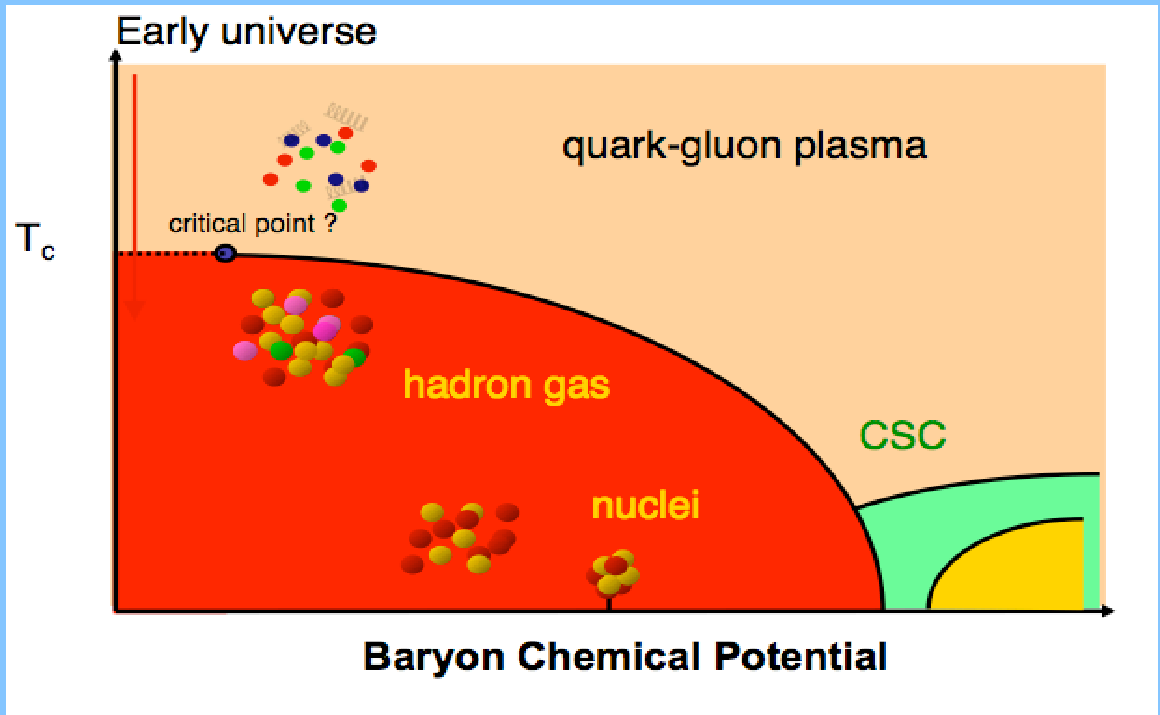


"Excited QCD 2010", Slovakia

Outline

- o **Introduction and experimental set up**
- o **Strangeness and elliptic flow**
- o **(Anti-)hypertriton**
- o **Low energy scan**
- o **Future plans for spectroscopy with STAR**
- o **Summary and Outlook**

Introduction

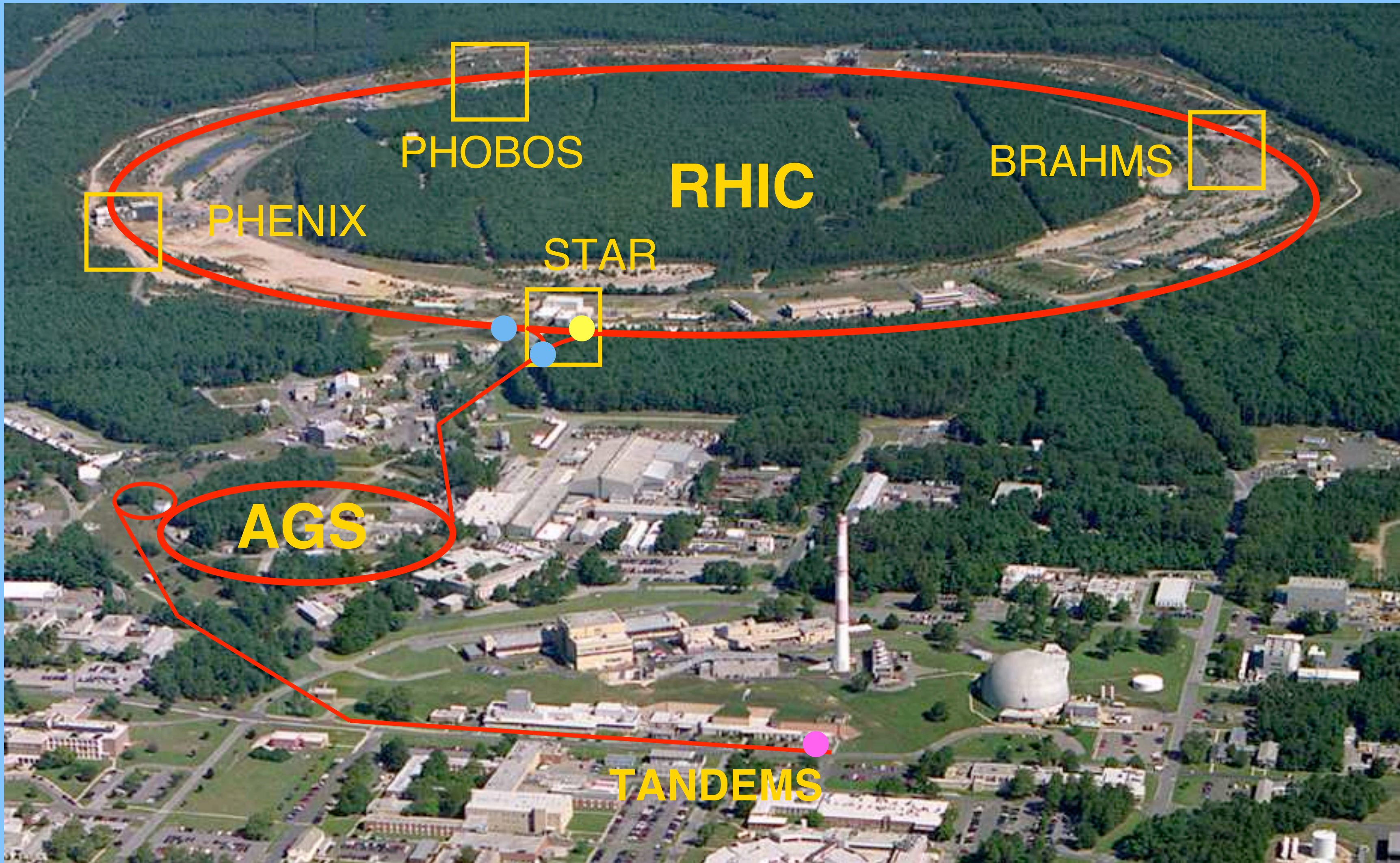


Heavy Ion collisions: exploring the QCD phases

Formation of sQGP in central Au+Au collisions at sqrt(s)=200 GeV at RHIC

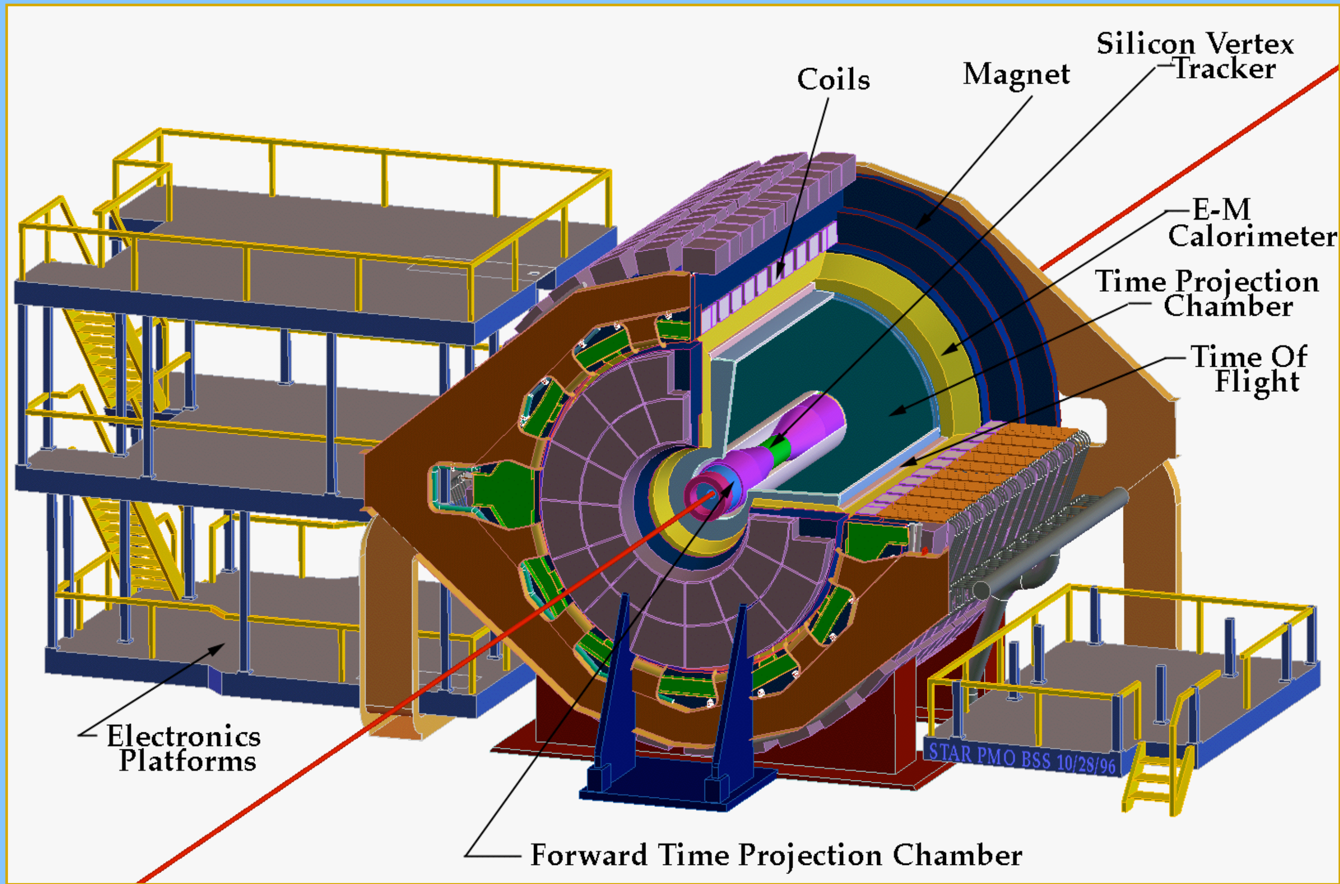
Initial Bjorken energy density ~5 GeV/fm^3

Relativistic Heavy Ion Collider (RHIC)



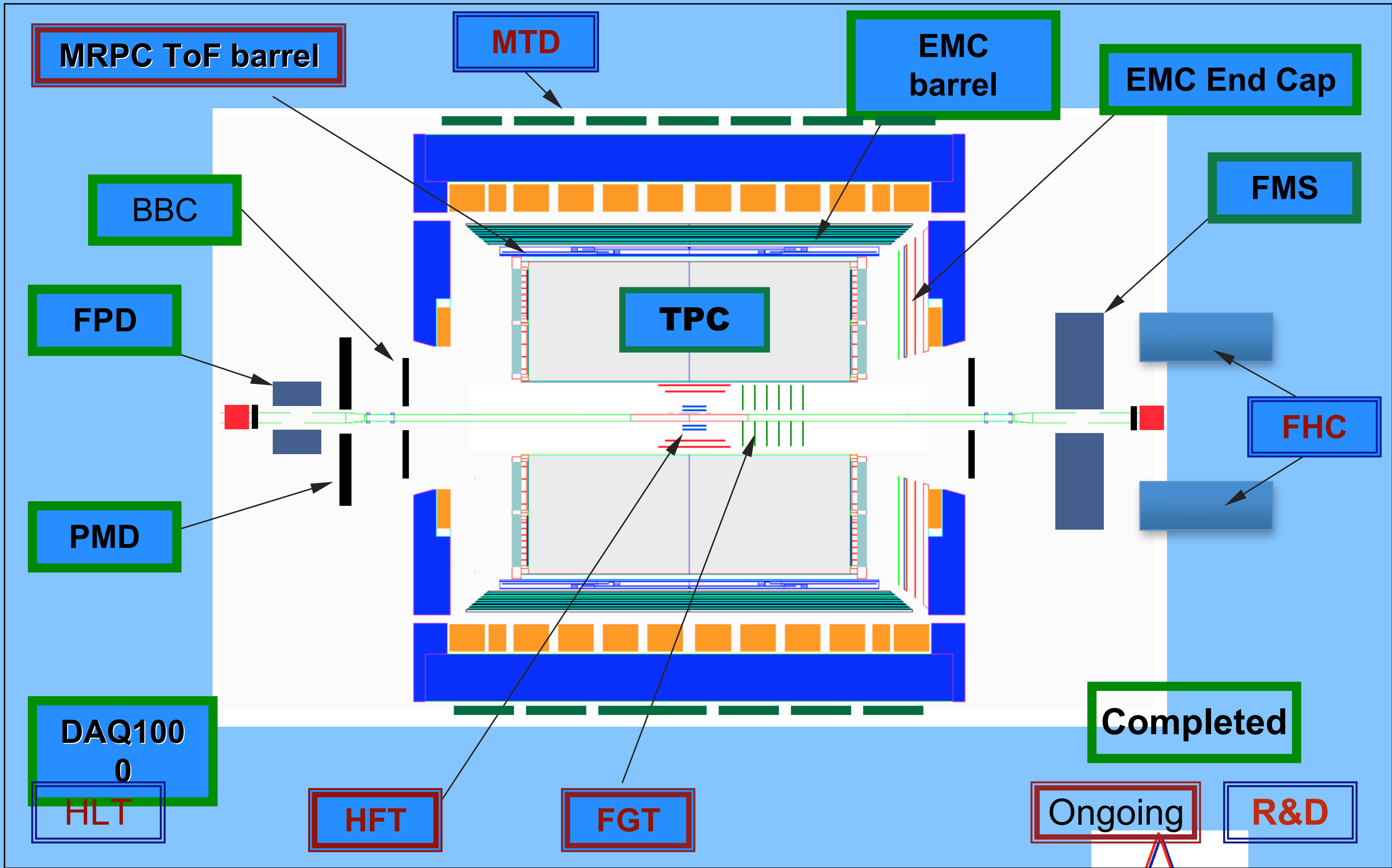
Animation M. Lisa

STAR Detector



STAR-TPC: *NIMA 499 (2003) 659*
STAR-detector: *NIMA 499 (2003) 624*

STAR Detector



Strangeness and elliptic flow

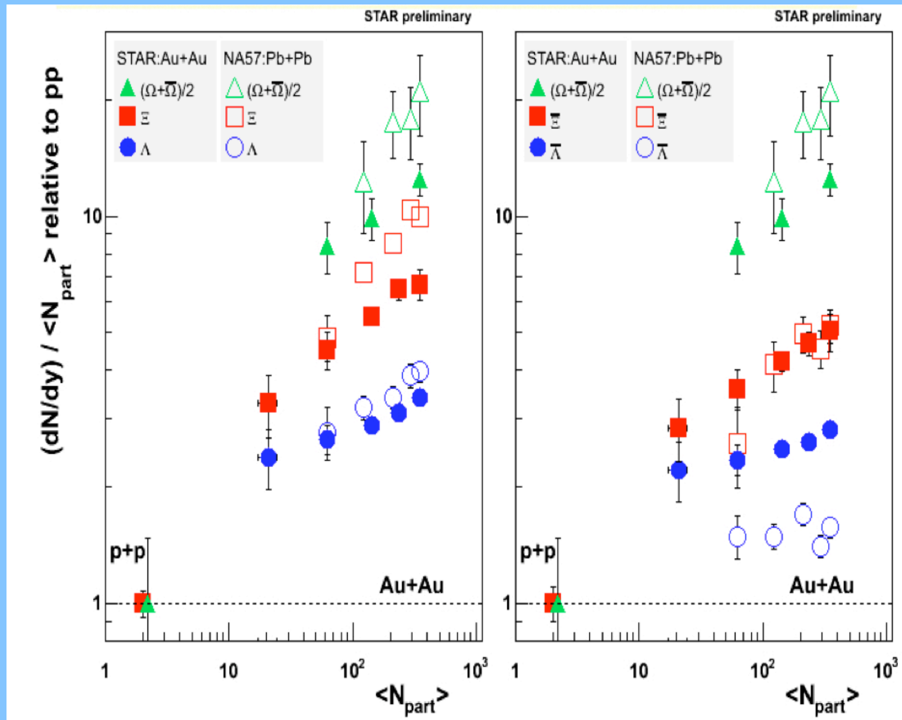
Strangeness Production versus N(part)

- Strange hadrons are enhanced relative to p+p
- Relative enhancement seems to be slightly lower than in SPS for baryons, similar for anti-Ξ and higher for anti-Λ.
- Strangeness content "hierarchy"
- Proposed to be linked to canonical suppression in p+p (e.g. J. Cleymans, A Muronga, Phys. Lett. B 388 (1996) 5).

$$E = \frac{Yield_{(A+A)}/ < N_{part} >}{Yield_{(p+p)}/2}$$

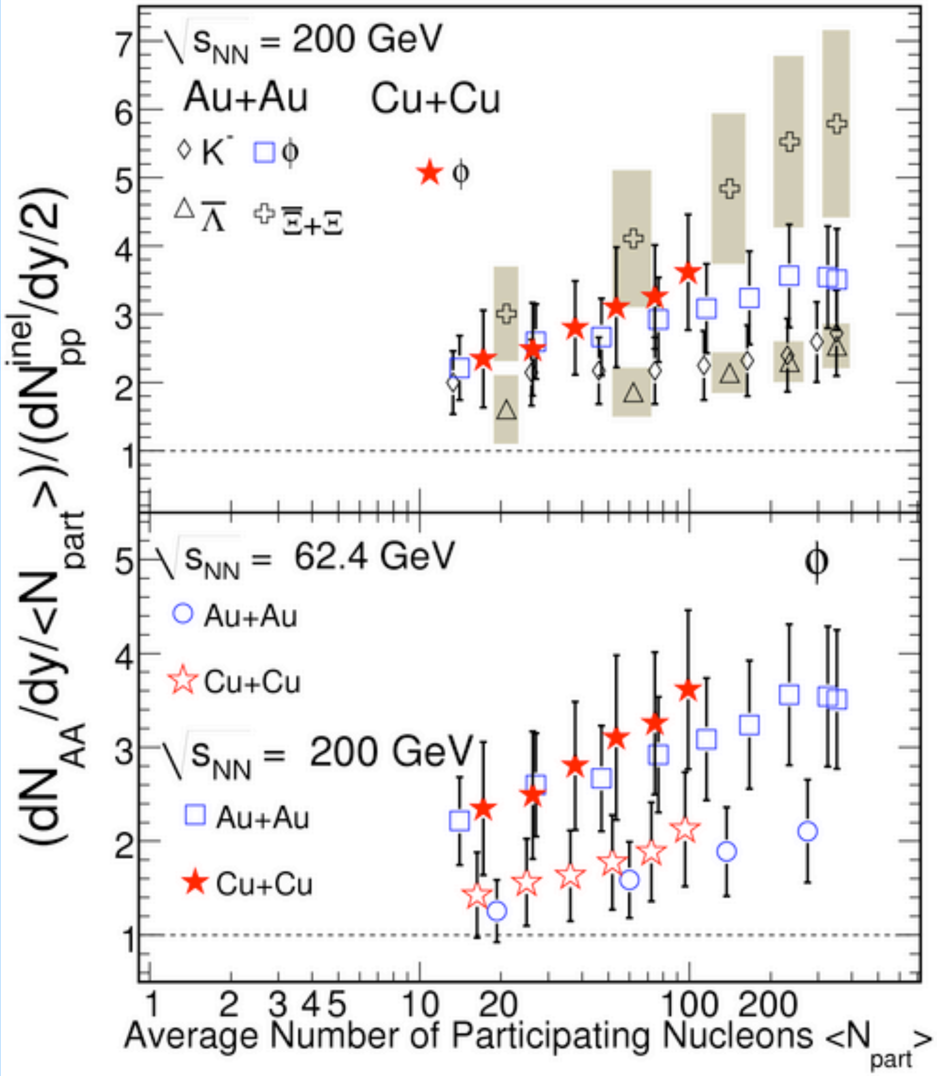
Rich set of strange particle measurements at STAR.

STAR Collaboration, nucl-ex/0809.0823



M Munhoz, SQM2009

Phi meson enhancement



STAR Coll., Phys. Lett. B 673 (2009) 183

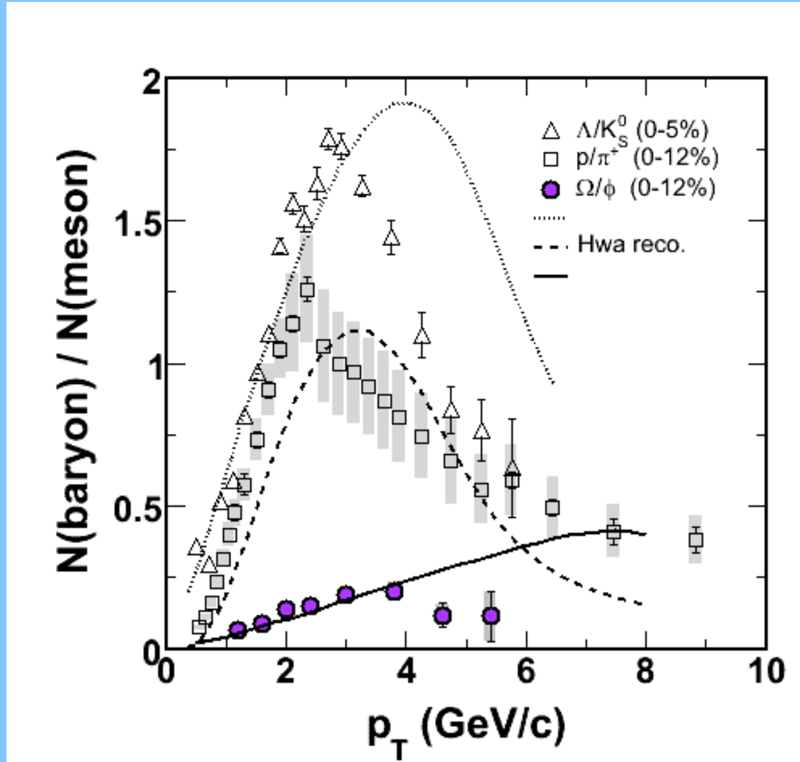
- Phi meson enhancement indicates that strangeness enhancement is not due to canonical suppression.
- More enhancement seen at higher energy
- Phi enhancement does not follow enhancement hierarchy with number of s-quarks.

  - Not a baryon-meson effect, not mass effect.
  - “Corona” effect ? (J. Aichelin, K. Werner, arXiv:0810.4465, F. Becattini, J. Manninen, arXiv:0811.376.)

→strange quark enhancement in dense partonic medium formed in HI collisions

Baryon to meson ratio

- Baryons are more abundantly produced than mesons at intermediate p_T in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV
  - p/π, Λ/K_s^0, Ω/Φ
- This behavior can be qualitatively reproduced by models that assume the coalescence of partons

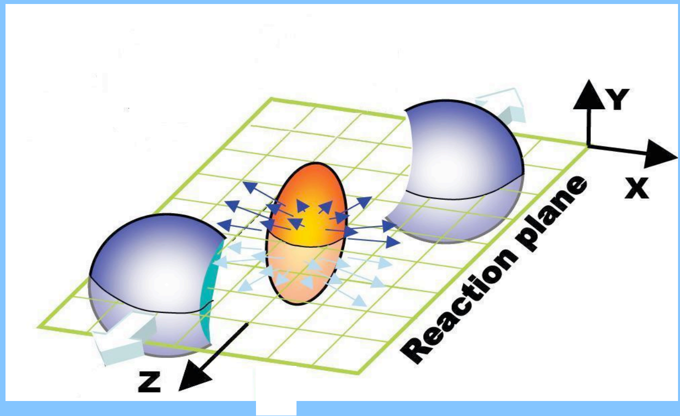


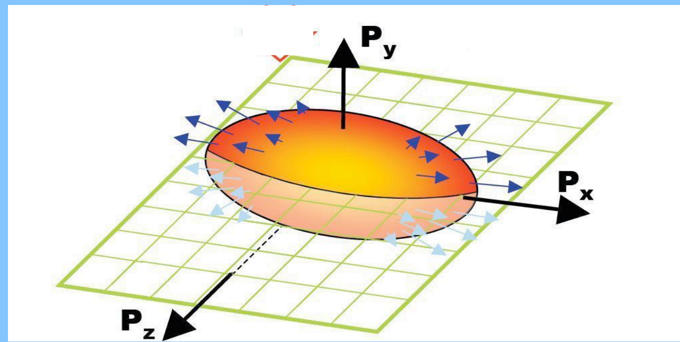
M Munhoz, SQM2009

STAR Collaboration,
J. Phys. G34, S933-936, 2007

R. J. Fries et al, Phys. Rev., C68:044902, 2003
R. C. Hwa and C. B. Yang, Phys. Rev., C67:034902, 2003
V. Greco et al, Phys. Rev. Lett., 90:202302,2003.

Azimuthal Anisotropy: Elliptic Flow



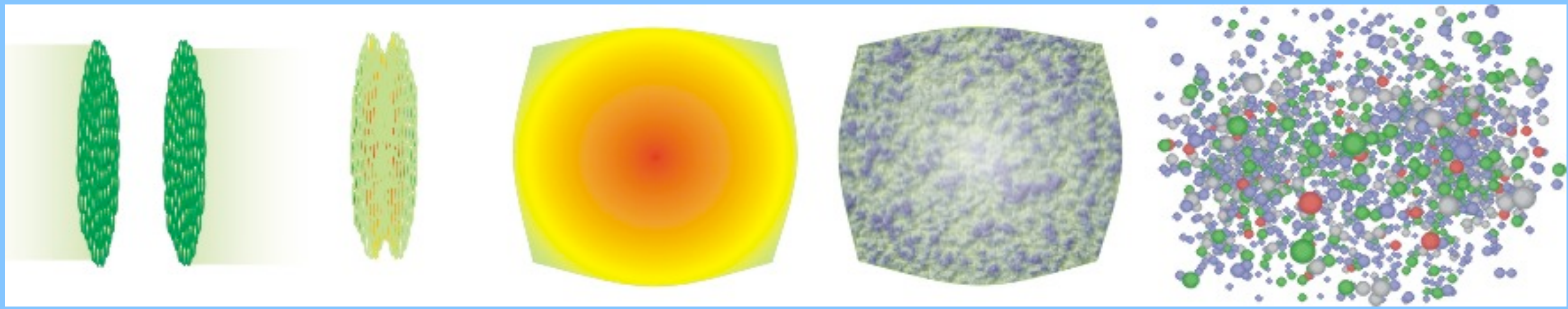


Almond shape overlap region in coordinate space → Interactions/ Rescattering → Anisotropy in momentum space

- Important tool to probe the early stages of the collision dynamics

Elliptic Flow and Strangeness

partonic *hadronic*



J/Ψ, D   φ, Ω, Ξ, Λ, K_S^0 π, K, p

- Elliptic flow: reveal the early stage collision dynamics

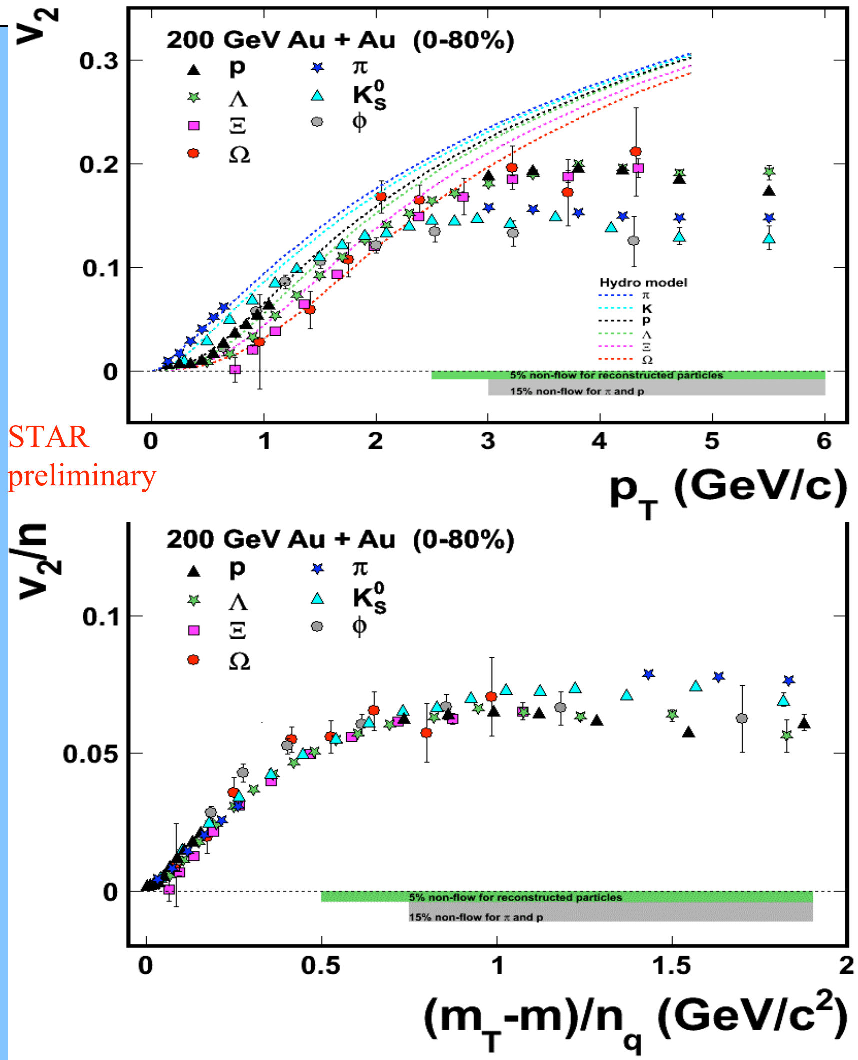
Good probe of the early medium

Look at particle type dependence (K_s^0, Λ, Ξ)

Low hadronic interaction (Ω, φ): probe partonic collectivity

No of quarks scaling of v_2 in Au+Au collisions

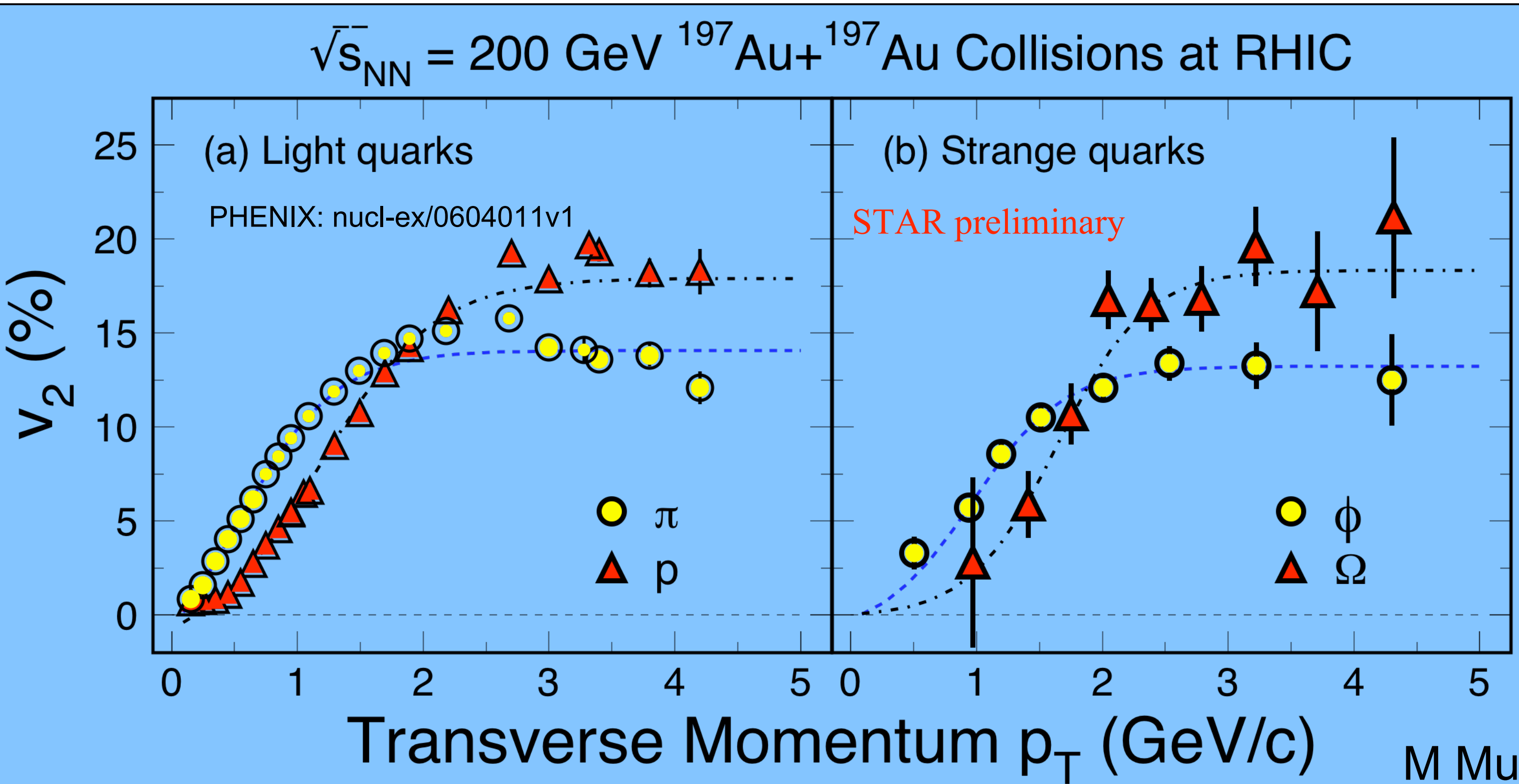
- Hydro approach reproduces mass ordering
- v_2 of strange hadrons shows baryon-meson difference.
  - $v2/n_q$ scaling-> suggests coalescence/recombination scheme for hadronization of bulk partonic matter at low pT.
  - v2 build up at partonic level
  - Indications of a different behavior for higher p_T



Hydro: *P. Huovinen and P. V. Ruuskanen, Annu. Rev. Nucl. Part. Sci. 56, 163 (2006)*

M Munhoz, SQM2009

Elliptic Flow of Ω and φ

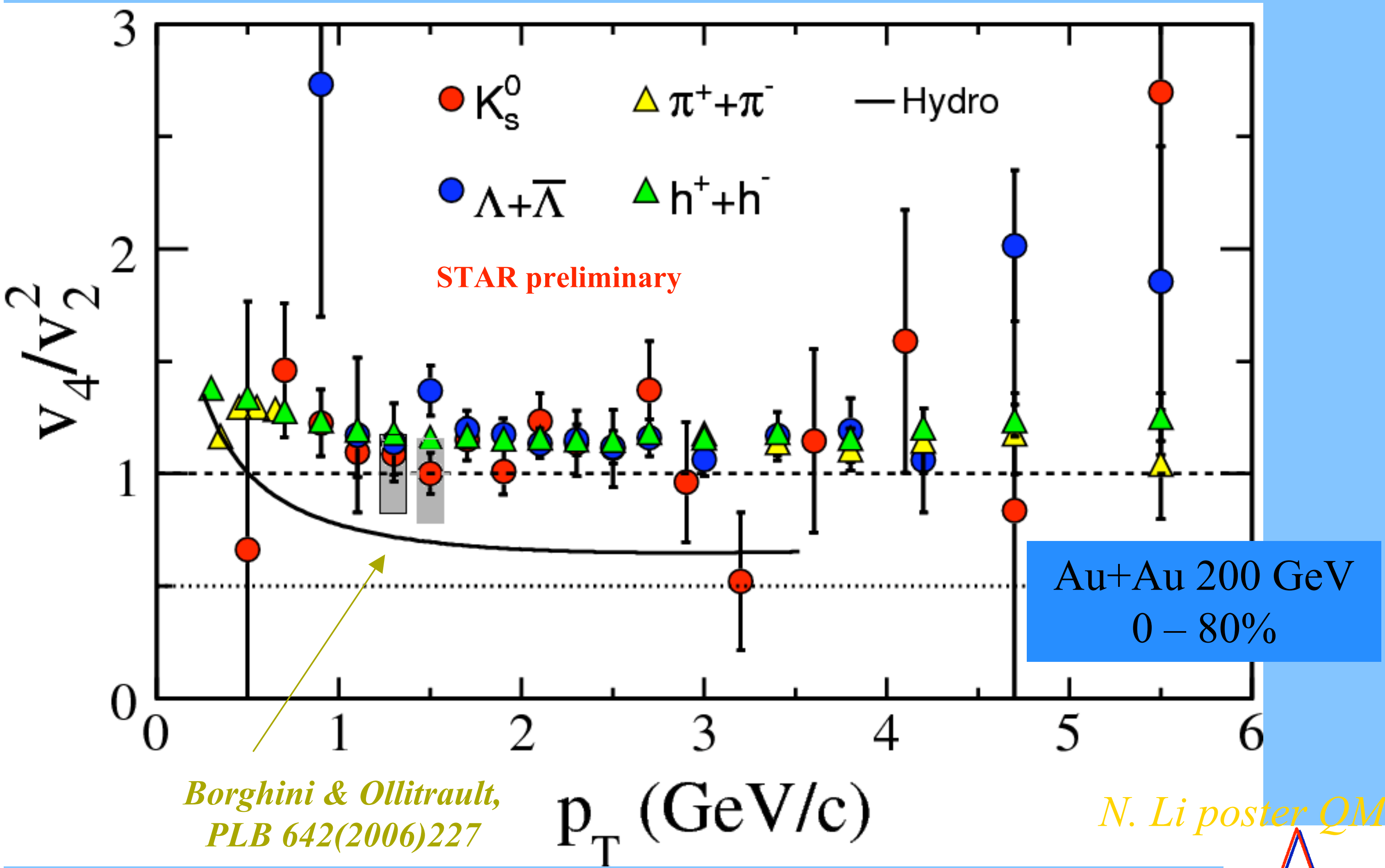


M Munhoz, SQM2009

- **Ω and φ:** low hadronic interaction --> partonic flow

Ideal hydrodynamic limit

v_4/v_2^2 results suggest that ideal hydro limit is not reached



N. Li poster QM09.

Partial summary : flow, strangeness

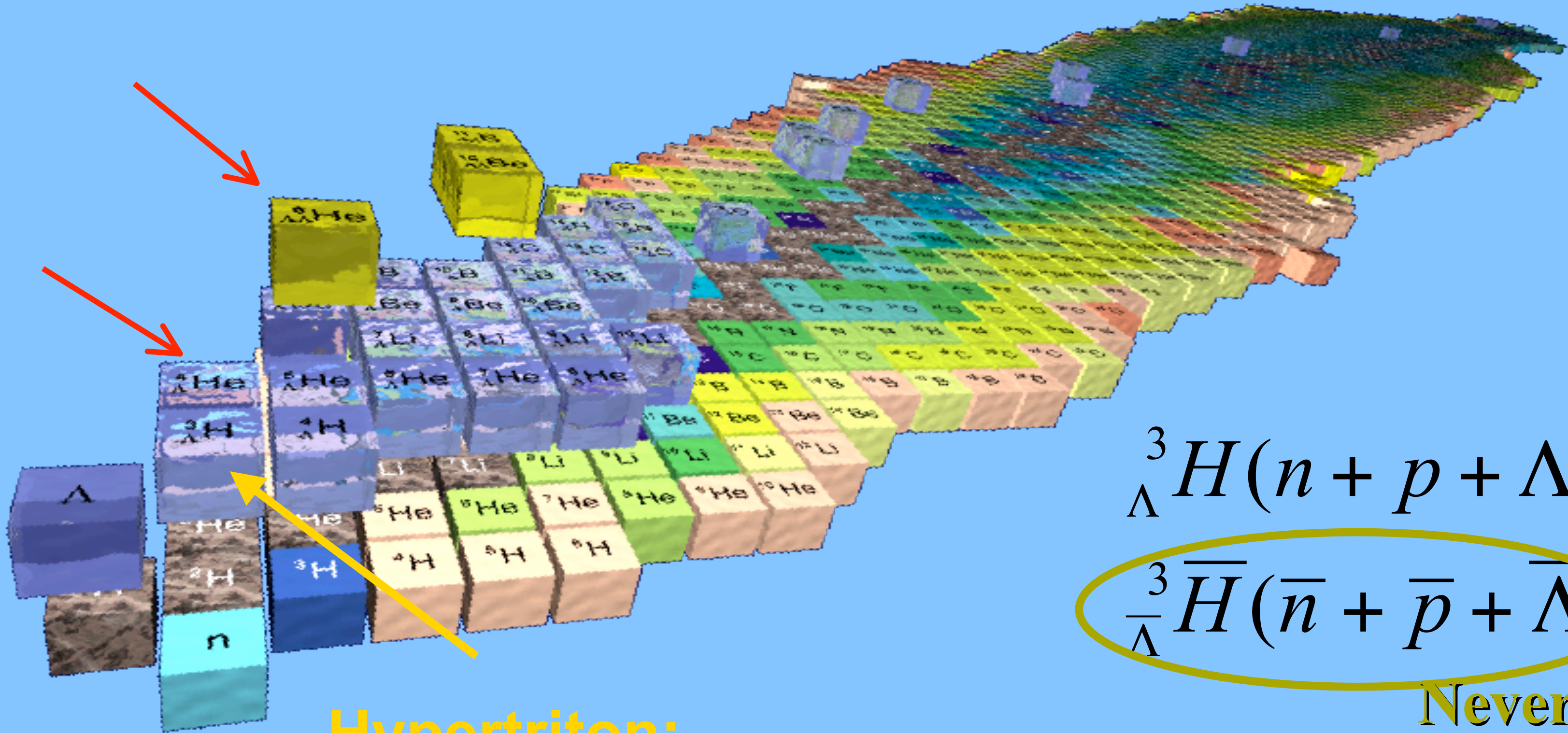
- Elliptic flow develops early at partonic level - low pT (v2/n_q scaling)
- Hydrodynamics applicable in bulk - low pT (v2 vs pT)
- Ideal hydrodynamic limit not reached (v4/v2^2)
- Deviation from n_q scaling seen at high pT
- Quark coalescence/recombination dominant hadron production mechanism in heavy ion collisions at RHIC in the bulk - low pT (v2/n_q scaling, baryon/meson ratios)

(Anti-)hypertriton discovery

Observation of antihypertriton at RHIC

S=-2

S=-1



S=-0

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

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

Never observed before

Hypertriton:
hypernucleus with lowest A

Observation of (anti)hypertriton

Jin Hui Chen QM09 and HypX 2009, Zhangbu Xu, RHIC-AGS meeting june 2009.

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 up to now

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*

Data-set and track selection

Jin Hui Chen QM09 and HypX 2009, Zhangbu Xu, RHIC-AGS meeting june 2009.

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

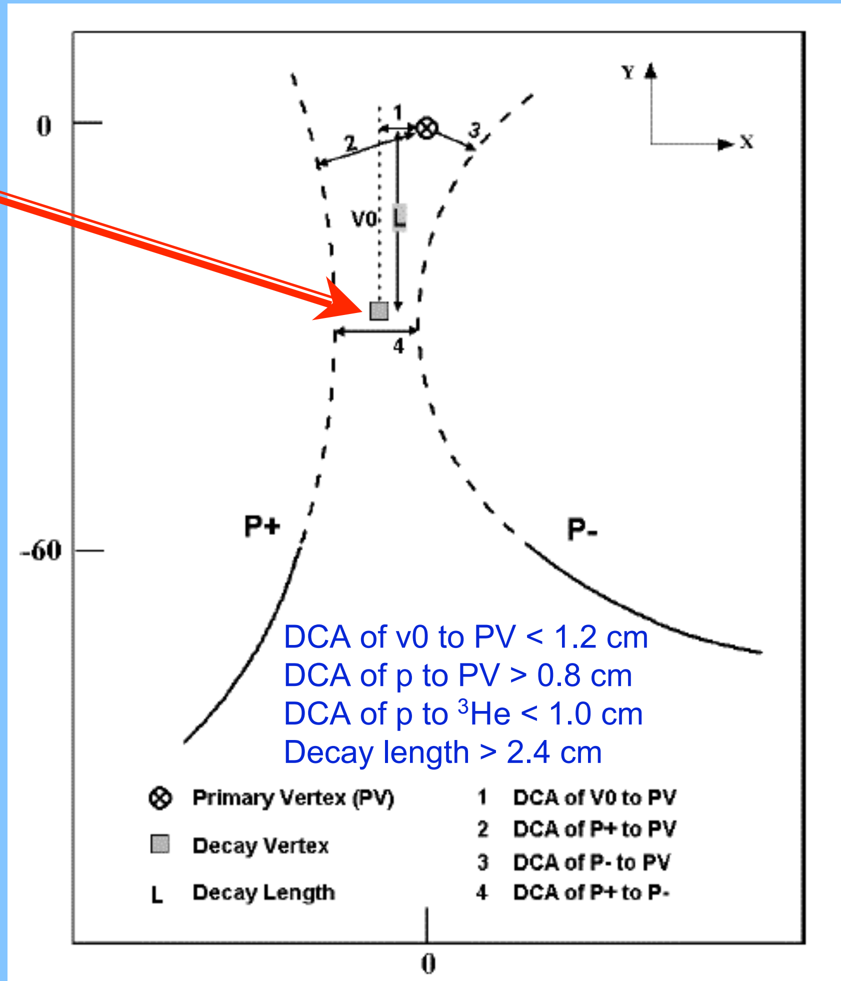
$$^{3}_{\bar{\Lambda}}\overline{H} \rightarrow {}^{3}\overline{He} + \pi^{+}$$

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

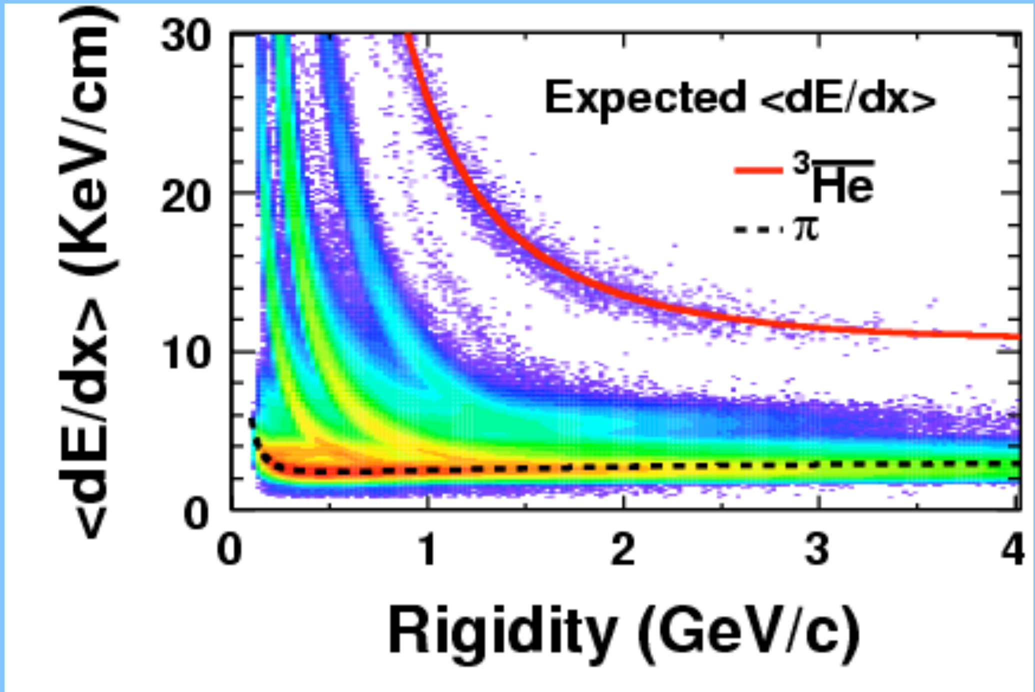
- Data-set used, Au+Au 200 GeV
  - ✓~67M year 2007 minimum-bias
  - ✓~22M year 2004 minimum-bias
  - ✓~23M year 2004 central,
  - ✓$|V_Z|$<30cm
- Tracks level: standard STAR quality cuts, i.e. , *not near edges of acceptance, good momentum & dE/dx resolution.*

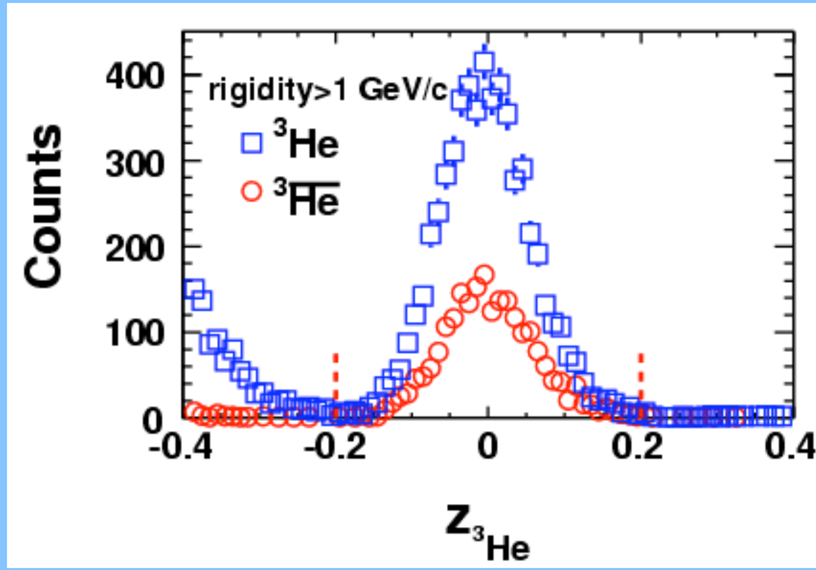
QM09 proceeding: arXiv:0907.4147

Secondary vertex finding technique



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





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

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

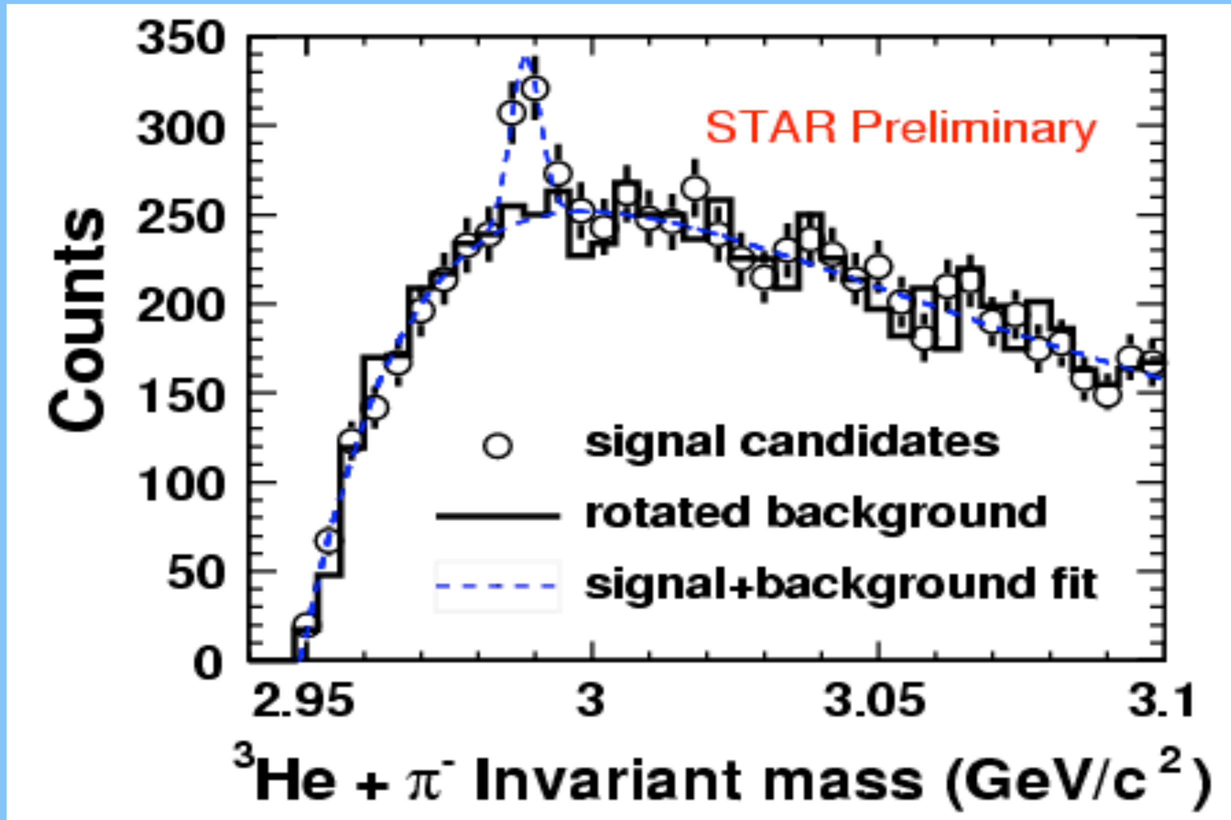
Theory curve: *Phys. Lett. B 667 (2008) 1*

anti-^{3}He: 2168 counts

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

Jin Hui Chen QM09 and HypX 2009, Zhangbu Xu, RHIC-AGS meeting june 2009.

Hypertriton inv. mass



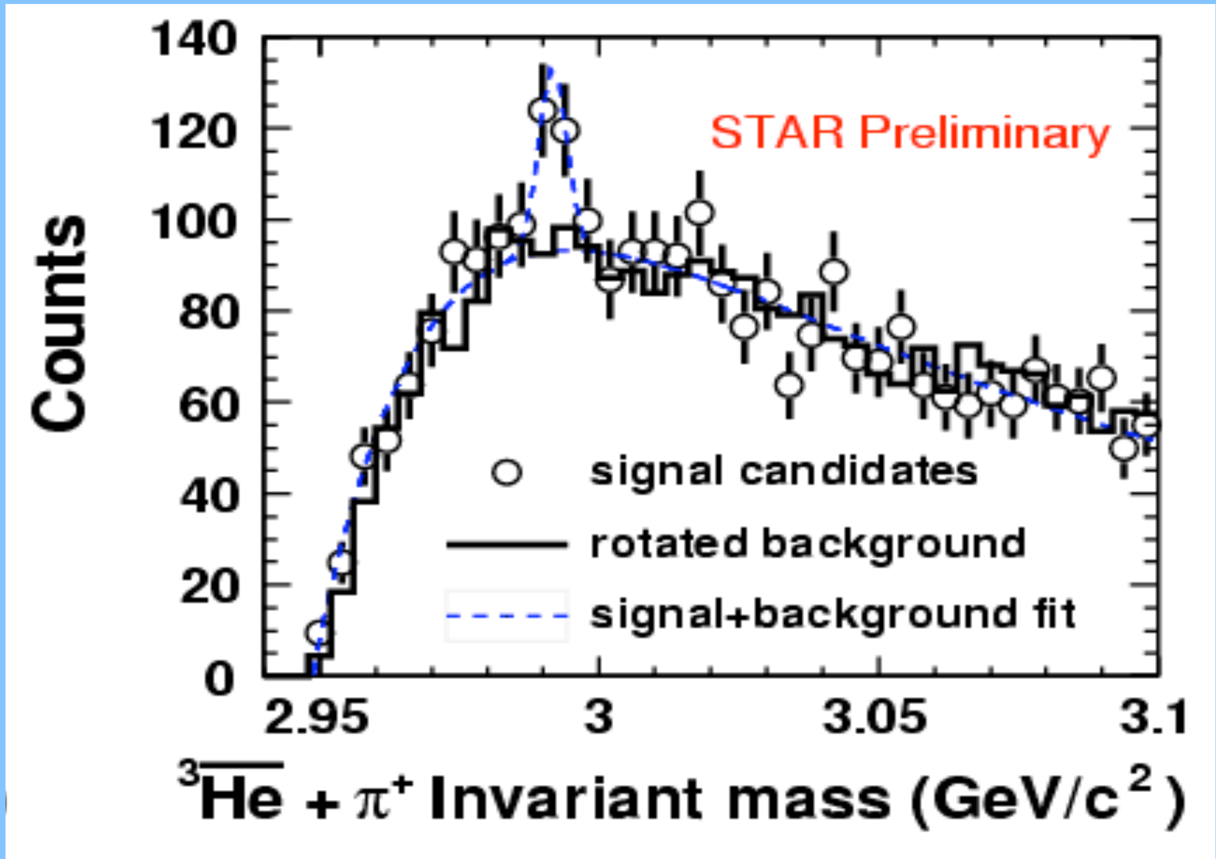
Jin Hui Chen QM09 and HypX 2009, Zhangbu Xu, RHIC-AGS meeting june 2009.

- 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: =157*2168/5810= **59±11** ${}^3_{\bar{\Lambda}}\overline{H} = {}^3_{\Lambda}H \times {}^3\overline{He}/{}^3He$

Antihypertriton inv. mass

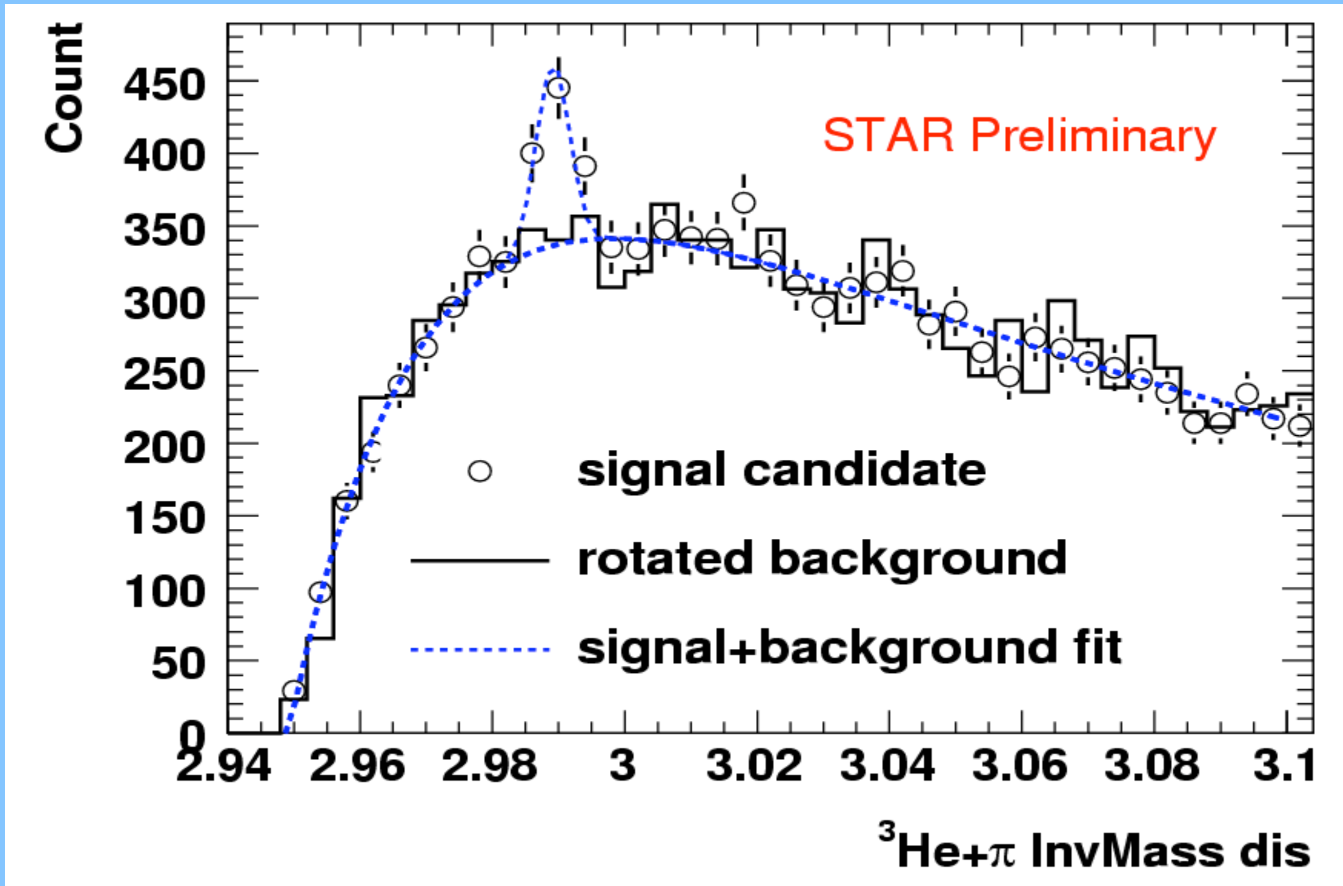


Jin Hui Chen QM09 and HypX 2009, Zhangbu Xu, RHIC-AGS meeting june 2009.

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

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

Hypertriton+Antihypertriton inv. mass

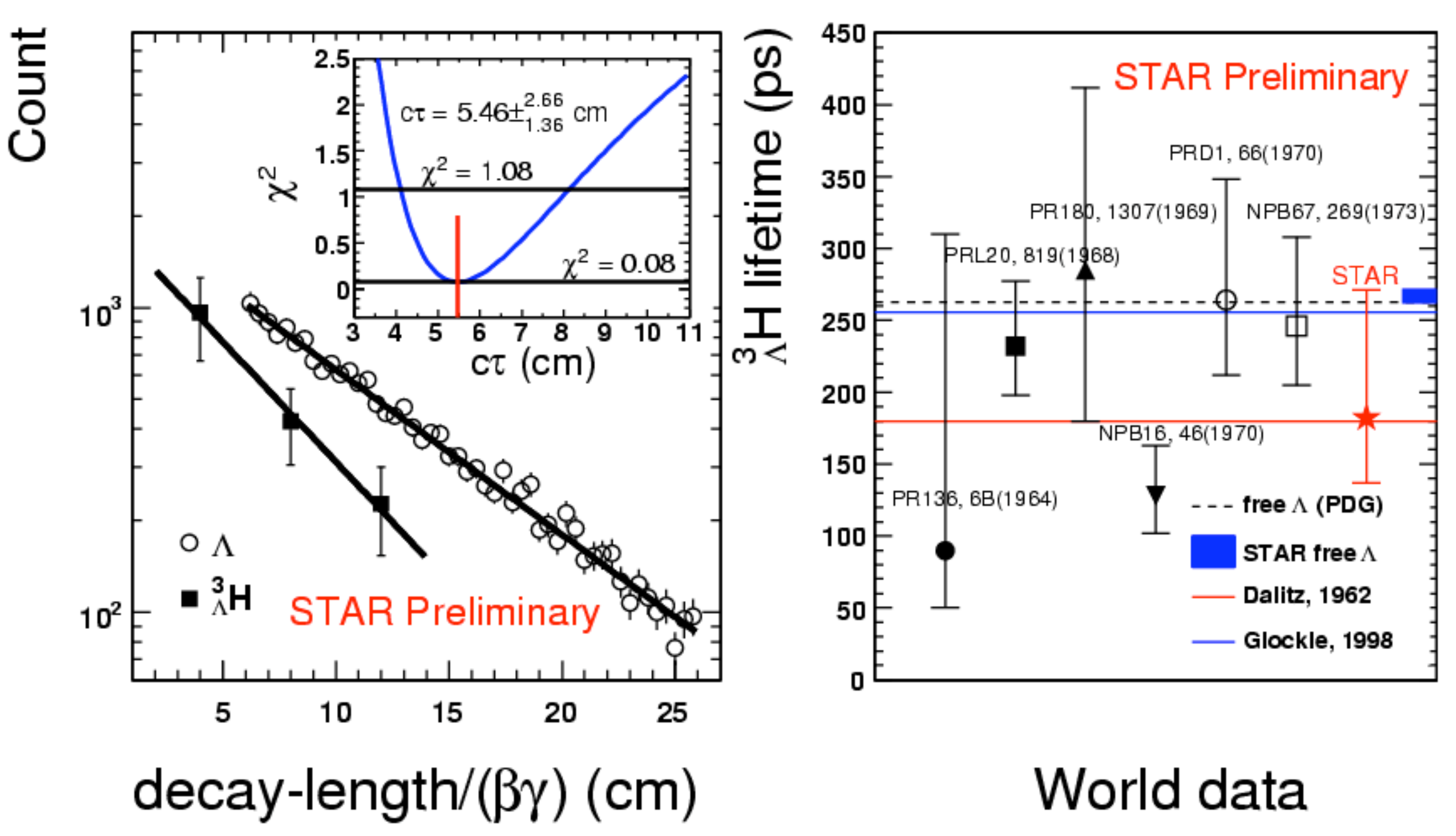


Jin Hui Chen QM09 and HypX 2009, Zhangbu Xu, RHIC-AGS meeting june 2009.

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

It provides a >6σ significance for discovery.

Measurement of the lifetime



Jin Hui Chen QM09 and HypX 2009, Zhangbu Xu, RHIC-AGS meeting june 2009.

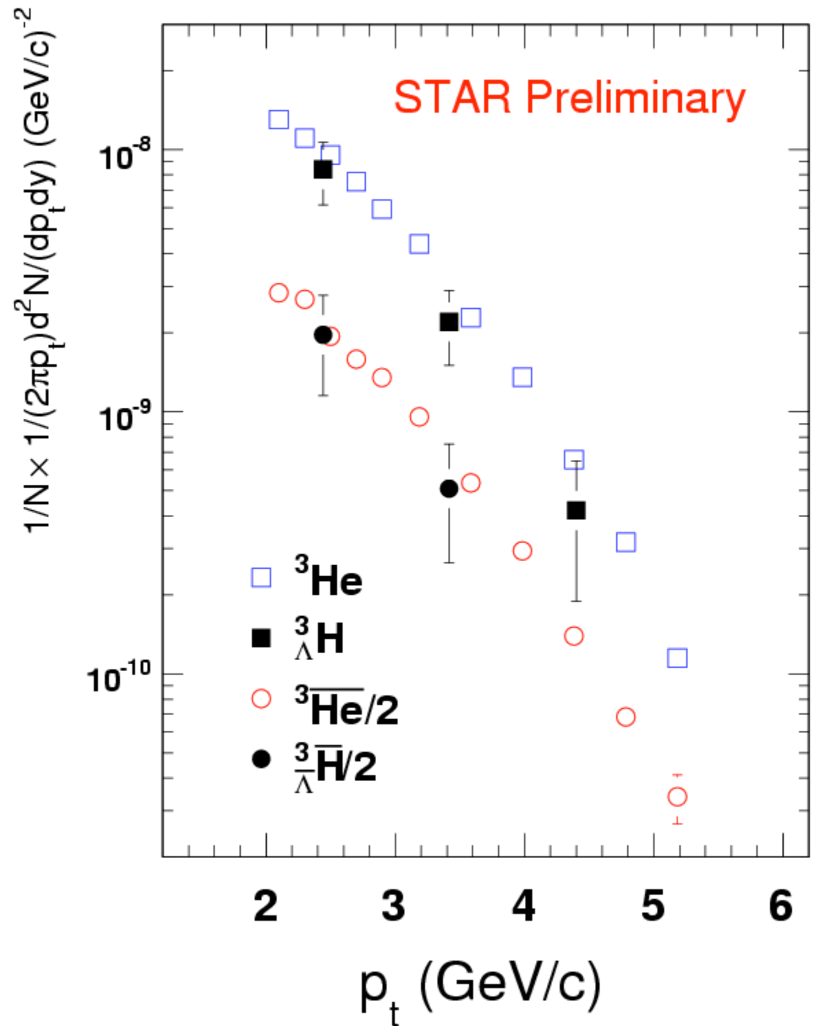
$$\tau = 182 \pm^{89}_{45} \pm 27 \text{ ps}$$

We measure τ_Λ = 267±5 ps
PDG value is τ_Λ = 263±2 ps

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

Production rate

Jin Hui Chen QM09 and HypX 2009, Zhangbu Xu, RHIC-AGS meeting june 2009.



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

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 ($^3_{\overline{\Lambda}}\overline{\text{H}}$) feed-down contribution.

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

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

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

0.45 ~ 0.77*0.77*0.77

Antiparticle/particle ratios favor coalescence

Summary : (anti)-hypertriton

Jin Hui Chen QM09 and HypX 2009, Zhangbu Xu, RHIC-AGS meeting june 2009.

- Antihypertriton has been observed for first time; 70 candidates, with significance ~4σ.

- Consistency check has been done on hypertriton 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 antihypertriton/hypertriton ratio is measured to be 0.49±0.18±0.07, and anti-^{3}He / ^{3}He is 0.45±0.02 ±0.04, favoring coalescence.

Outlook - anti-(hyper)-nuclei

Lifetime:

–data samples with larger statistics (~factor 10 more within a few years)

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

Search for other hypernucleus: $^{4}_{\Lambda}H$, $^{4}_{\Lambda}He$, $^{4}_{\Lambda\Lambda}H$, $^{3}_{\Xi}H$,

Search for anti-α

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

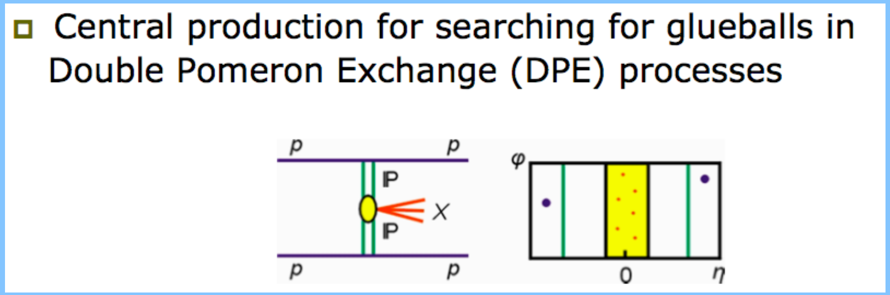
RHIC: best antimatter machine ever built

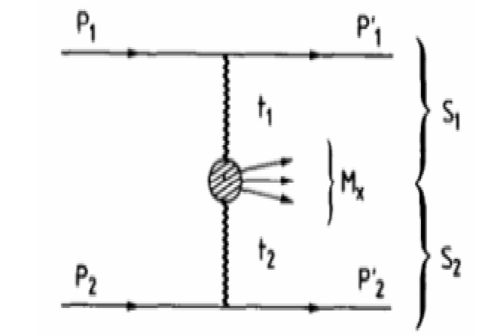
Future plans for spectroscopy with STAR at RHIC

J. H. Lee, Hadron 2009

Search for glueball production in Double Pomeron Exchange processes

- Roman Pots (used for pp2pp exp. at RHIC) for forward proton tagging
- rapidity gap > 4 units for M_X < 3 GeV
- polarized p+p collisions



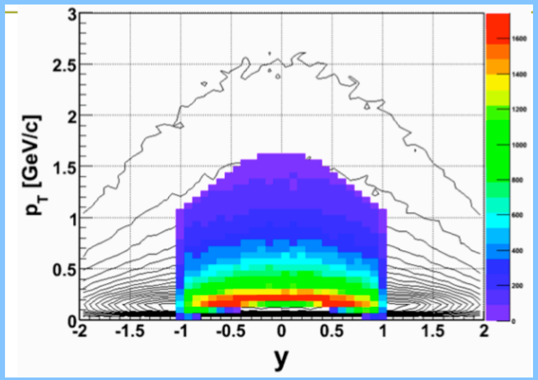


p1 p2 -> p1' M_X p'2

M_X centrally produced

Search for gb candidates in M_X

M_X (1-3 GeV) --> pi+pi-, pi+pi-pi+pi-, K+K-



Acceptance for decay pions from

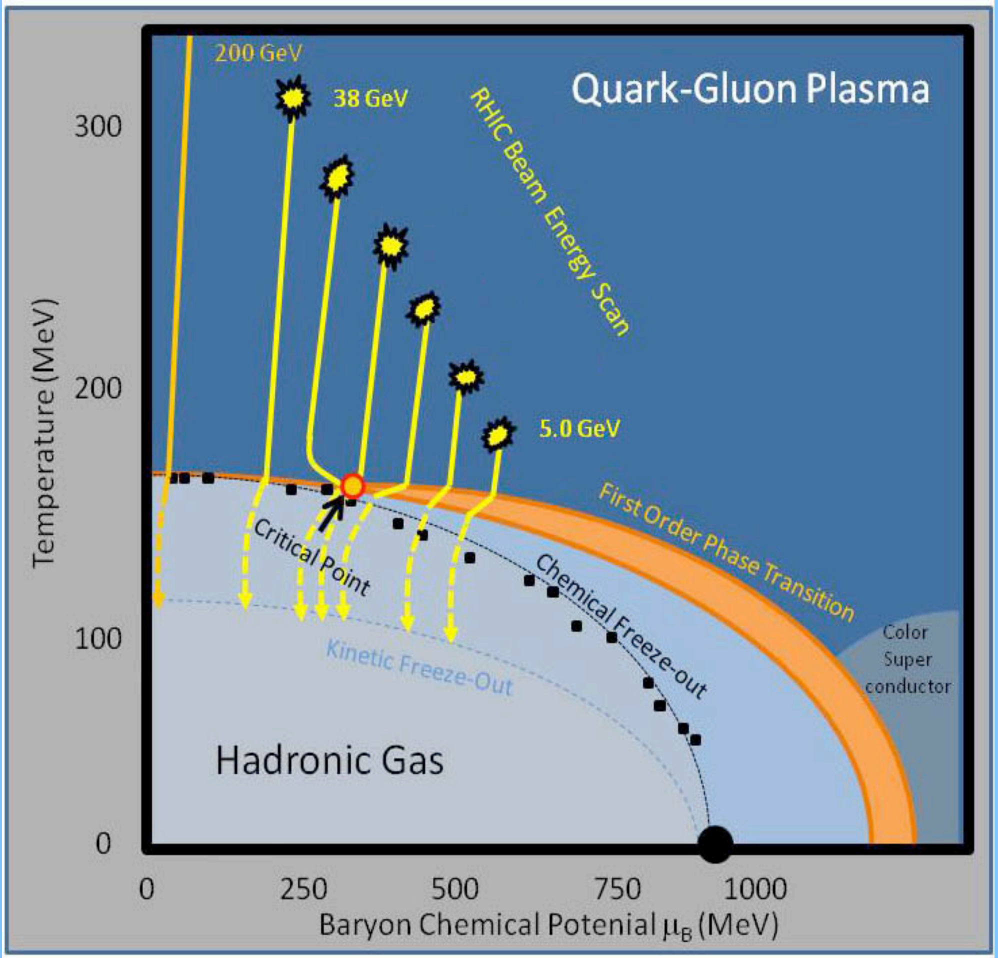
M-X -> pi+pi-pi+pi-

Low energy scan

Low energy scan happening this year !

Key idea: study Phase Diagram throughout energy scan region

Critical point search

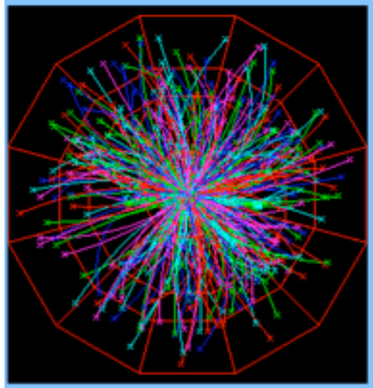


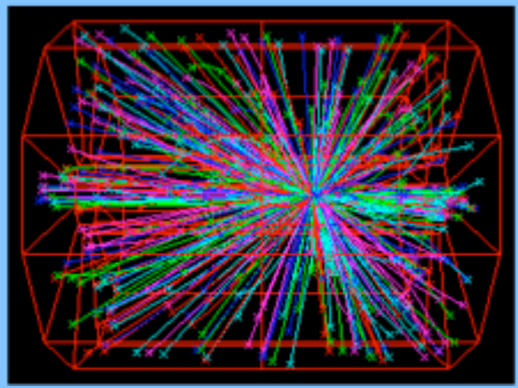
Beam Energy sqrt(s) (GeV)	μ_B (MeV)
5	550
7.7	410
11.5	300
17.3	230
27	150
39	110

- Measurement of direct signatures of the critical point e.g. fluctuations
- Turn off sQGP signatures already established at RHIC

Energy scan: 9.2 GeV

STAR coll., arXiv:0909.4131, acc. for publication in PRC

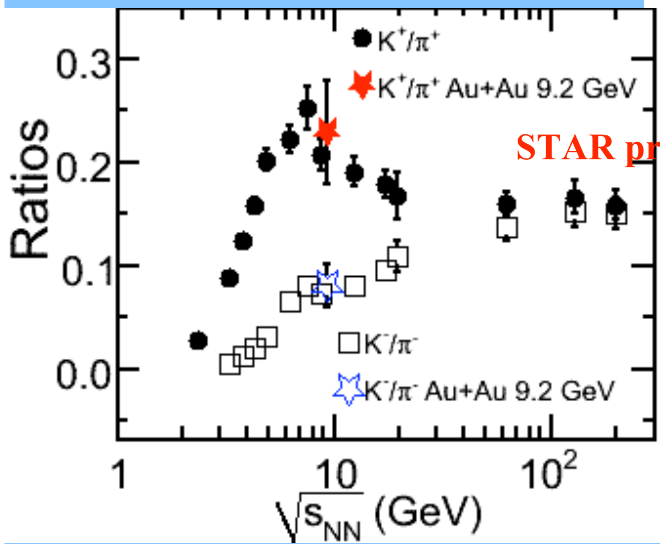


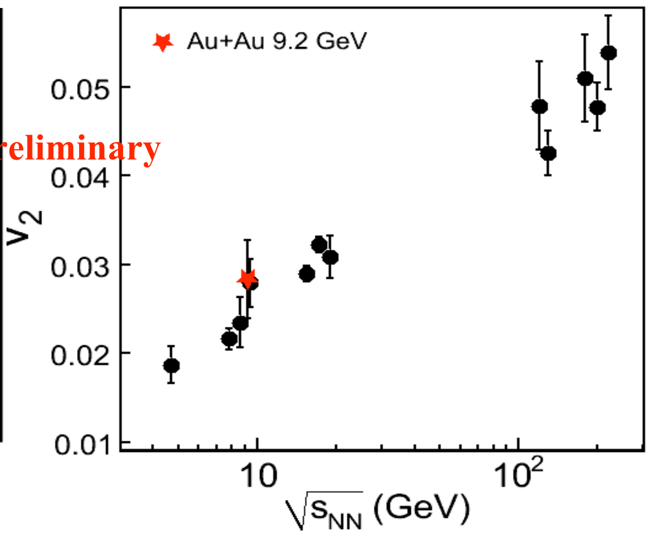


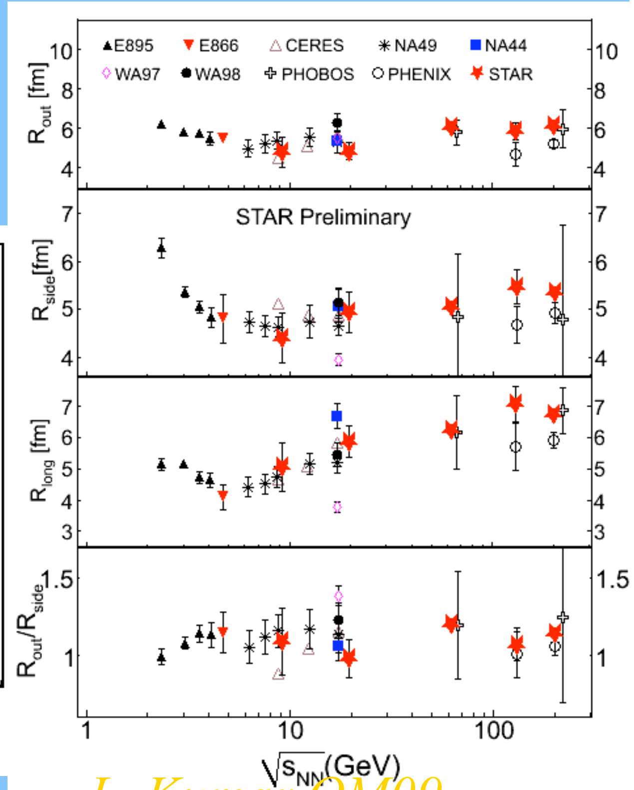
4 hours and 40 minutes in year 2008:
~3000 good events
(good ≡ primary vertex along beam and within acceptance)

Unambiguous beam+beam events

Pparticle ratios, v_2 and HBT results are comparable to SPS results at a similar energy.

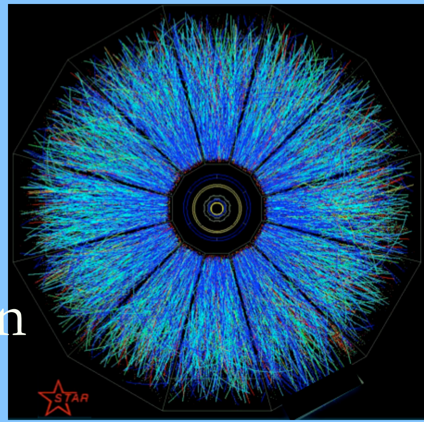






L. Kumar QM09

Summary



- Elliptic flow, B/M ratios, strangeness suggest -->
  Parton coalescence as dominant mechanism for hadron production in the bulk

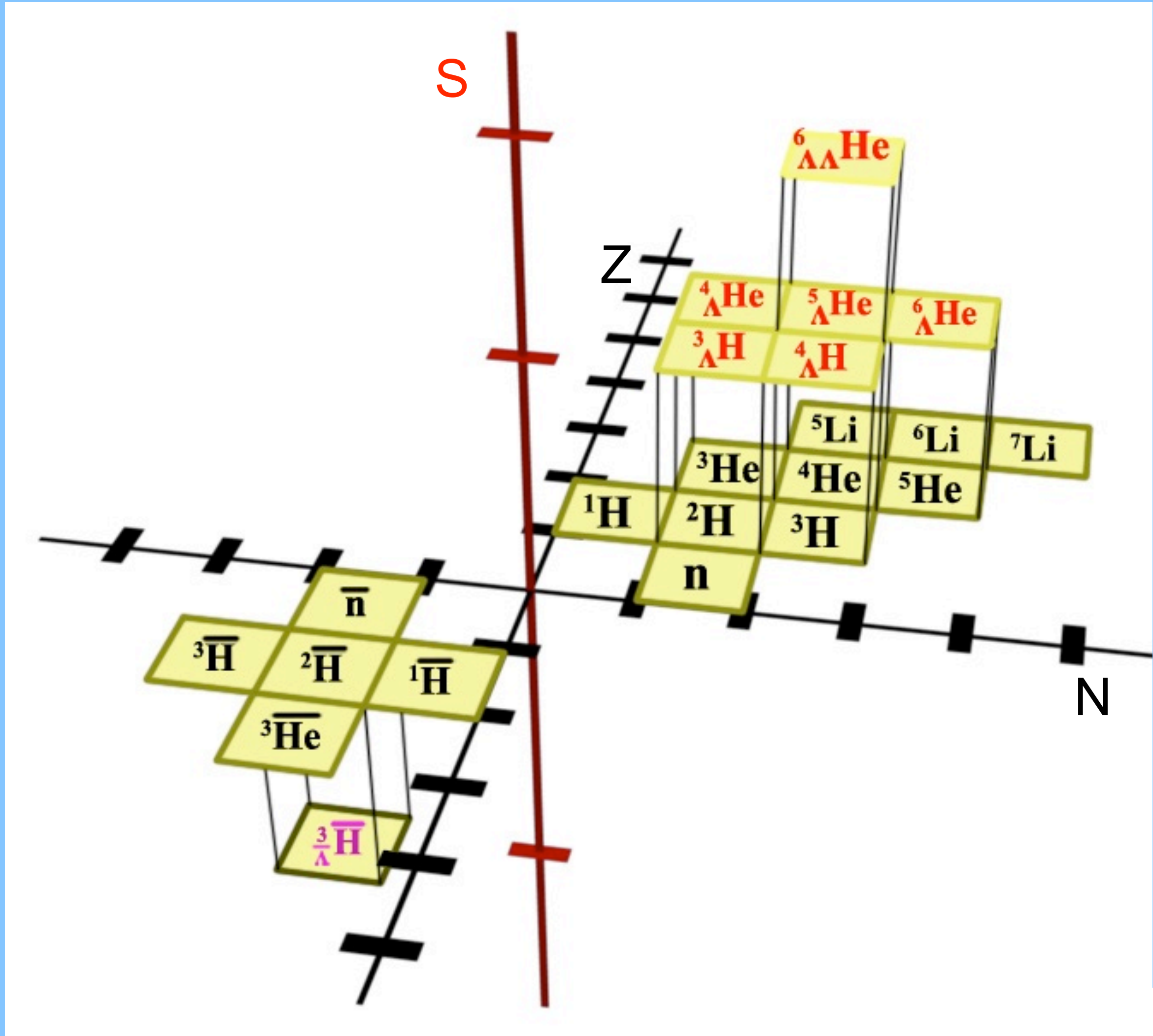
- First observation ever of anti-hypertriton in Au+Au collisions at sqrt(s)=200 GeV. Data suggest production through coalescence.

- **RHIC: best antimatter machine ever built**

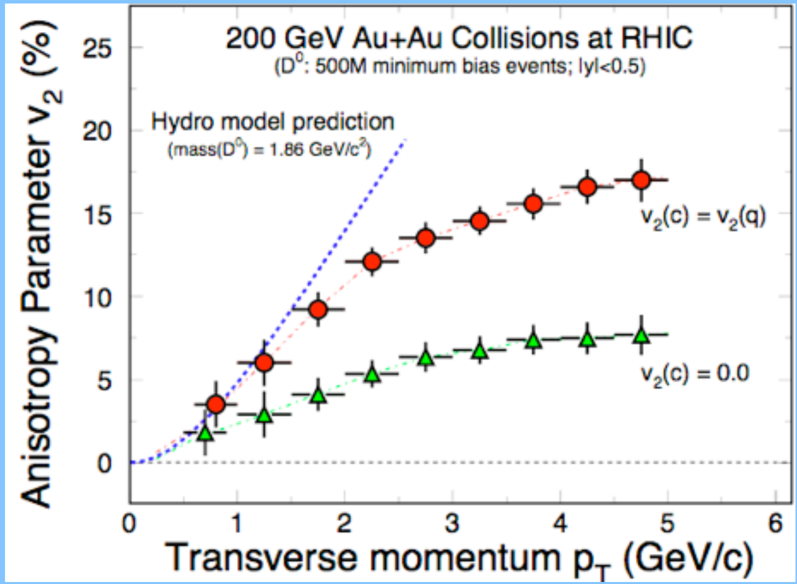
- Low μ_b, high number and energy density of partons at top RHIC energy -->

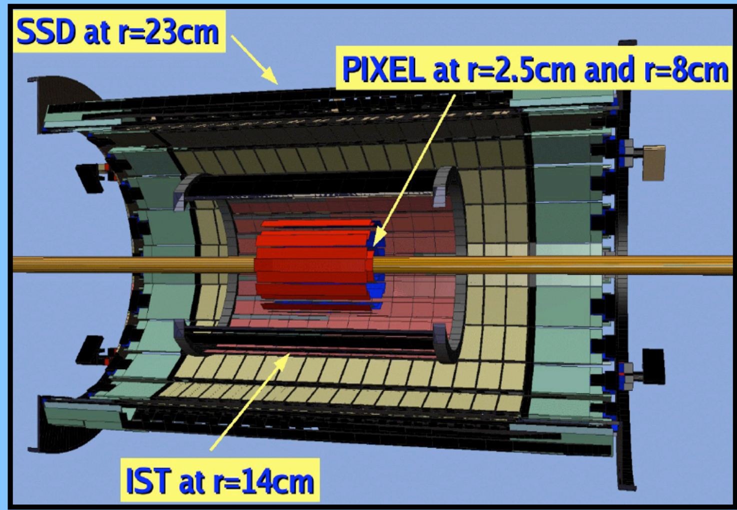
- **RHIC: a unique source of exotics ?**

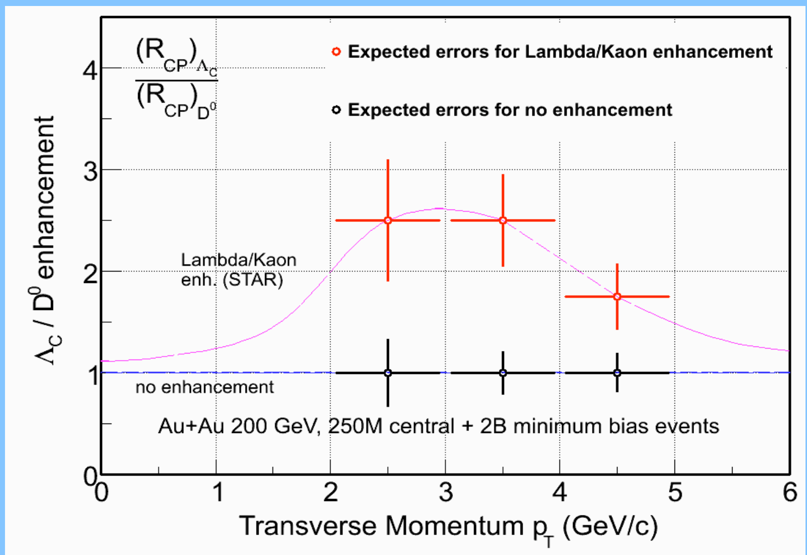
Extension of the chart of the nuclides into anti-matter with Strangeness sector



Heavy Flavour Tracker







Key measurements:

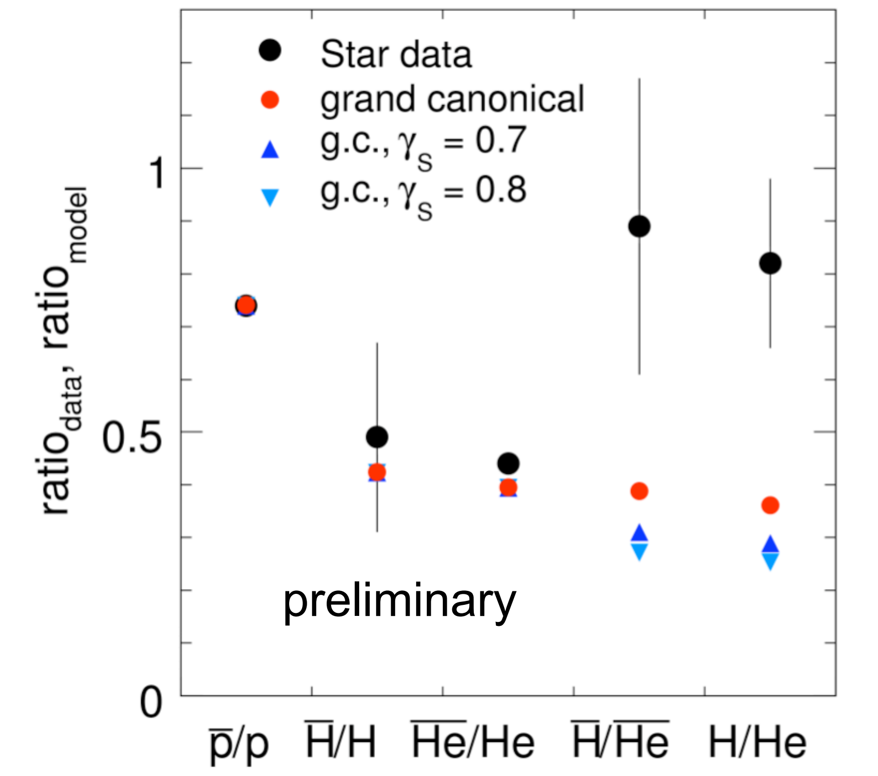
- v_2 and R_{cp} of D^0
- Charm baryon Λ_c
- Bottom cross sections

see next talk of S. Margetis

ONE NO STAR-SLIDE

Thermal model prediction for the (anti) - hypertriton

I. Kraus, S. Kabana, H. Oeschler



Thermal model with parameters fixed by other hadron ratios in Au+Au collisions at RHIC:

T = 170 MeV

mu_B = 27 MeV

(values from PRC 74 (2006) 034903 J Cleymans et al)

gamma_s = 1 (GC), 0.8 , 0.7

m(3He) = 2.809 GeV

m(hypertriton)=2.991 GeV

Antiparticle to particle ratios measured are compatible with thermal model prediction for both Helium3 and hypertriton

Ratios between (anti-)hypetriton and (anti-)helium-3 are higher in the data than in the model. This is due -at least partially- (BR=0.25) to Helium-3 feeding uncorrected in the model.

BACK-UP SLIDES

Event display

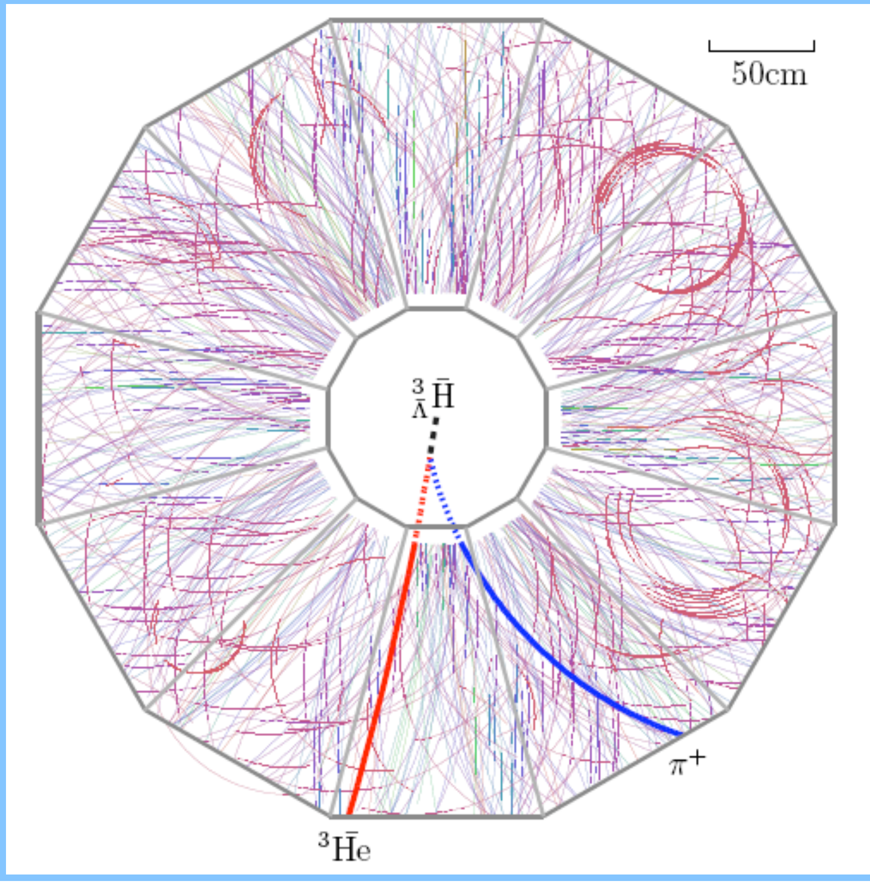
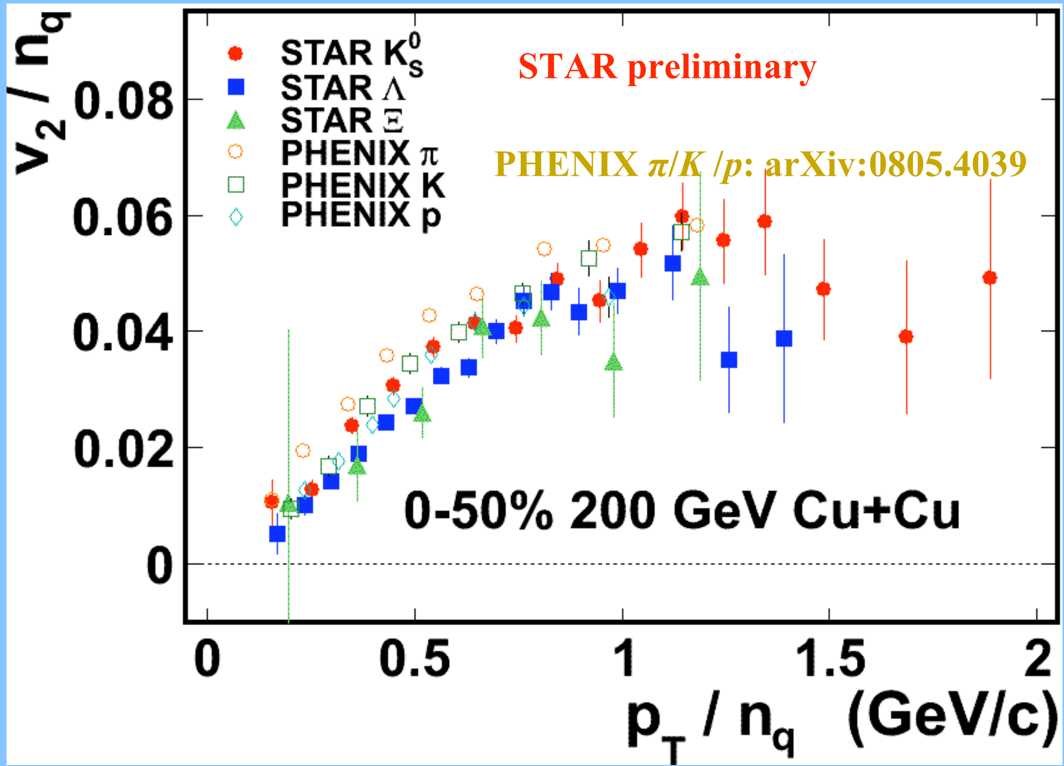


Figure 1: "Beam's eye view" of a typical event in the STAR detector when a $^3_{\bar{\Lambda}}\bar{H}$ candidate is produced. STAR's main tracking device reconstructs charged particle trajectories in 3-D; in this 2-D projection, the apparent track density is extremely large. The thick red line shows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

Nr of quarks scaling of v_2 in Cu+Cu collisions

Nr of Quarks scaling works with Cu+Cu collisions.



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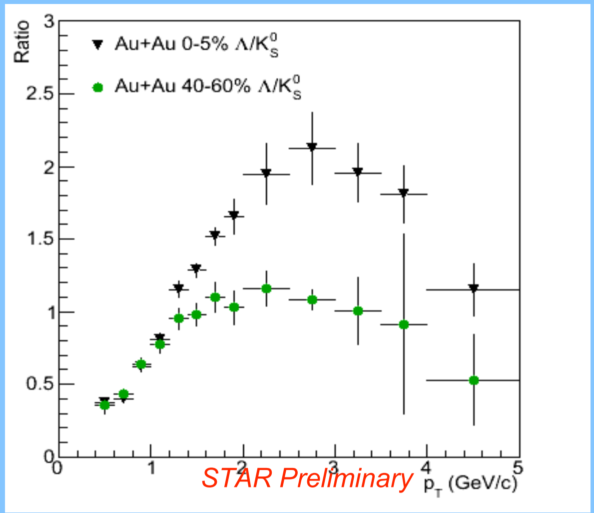
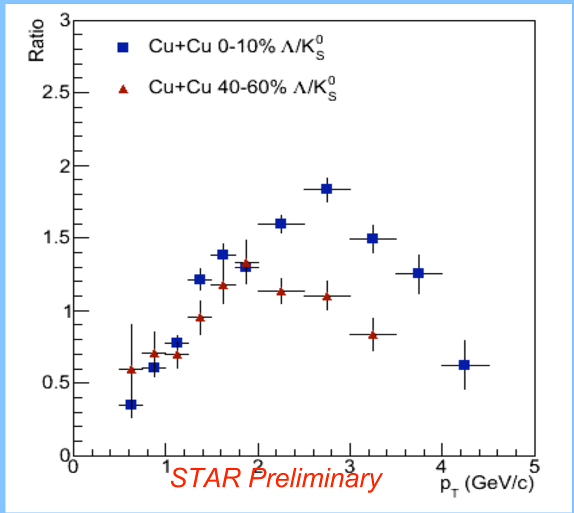
Λ/K_s^0 ratio at 62.4 GeV versus pT , centrality and collision system

Au+Au, $\sqrt{s_{NN}}$ = 62.4 GeV



Cu+Cu, $\sqrt{s_{NN}}$ = 62.4 GeV



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- Same behavior of Λ/K_s^0 ratio observed for Au+Au and Cu+Cu at $\sqrt{s_{NN}}$ = 62.4 GeV
- Greater Λ/K_s^0 ratio reached in central than in peripheral collisions.