Selected highlights from the STAR experiment at RHIC

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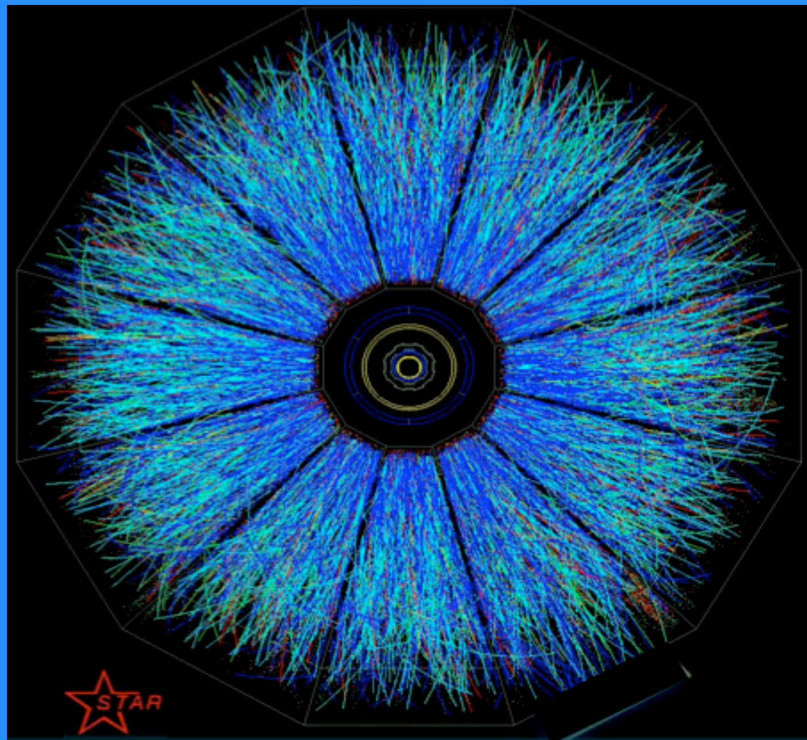
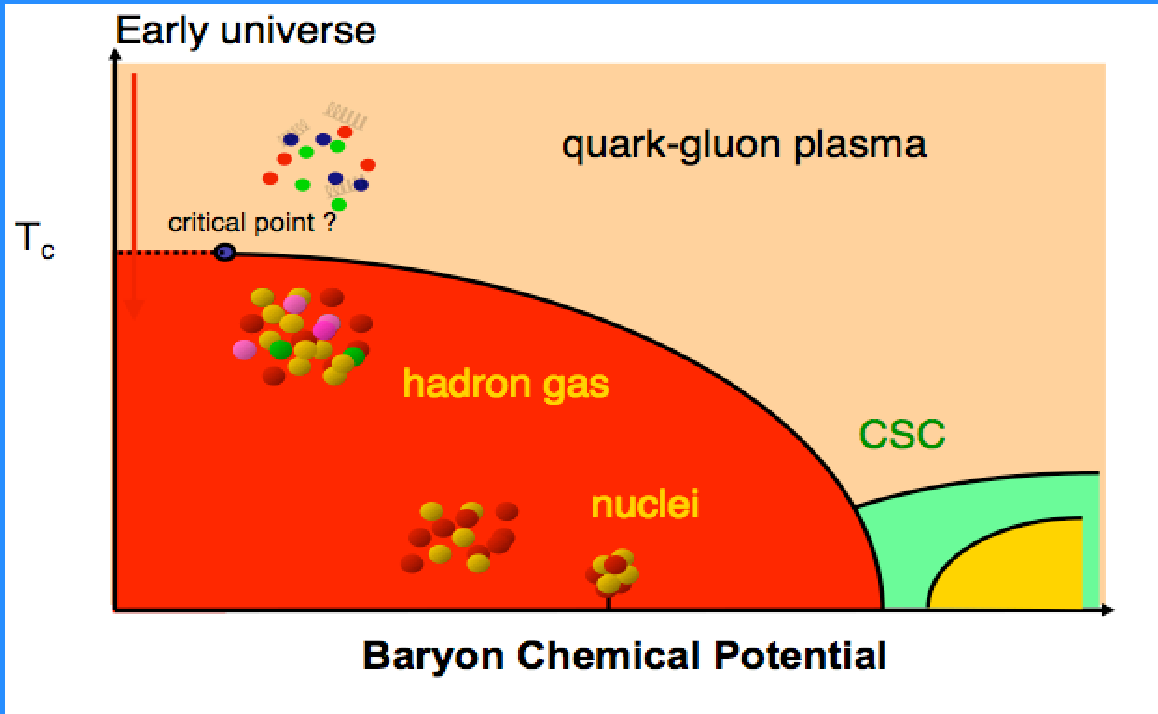


“Excited QCD 2010”, Slovakia

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 Conclusions and Outlook

Introduction

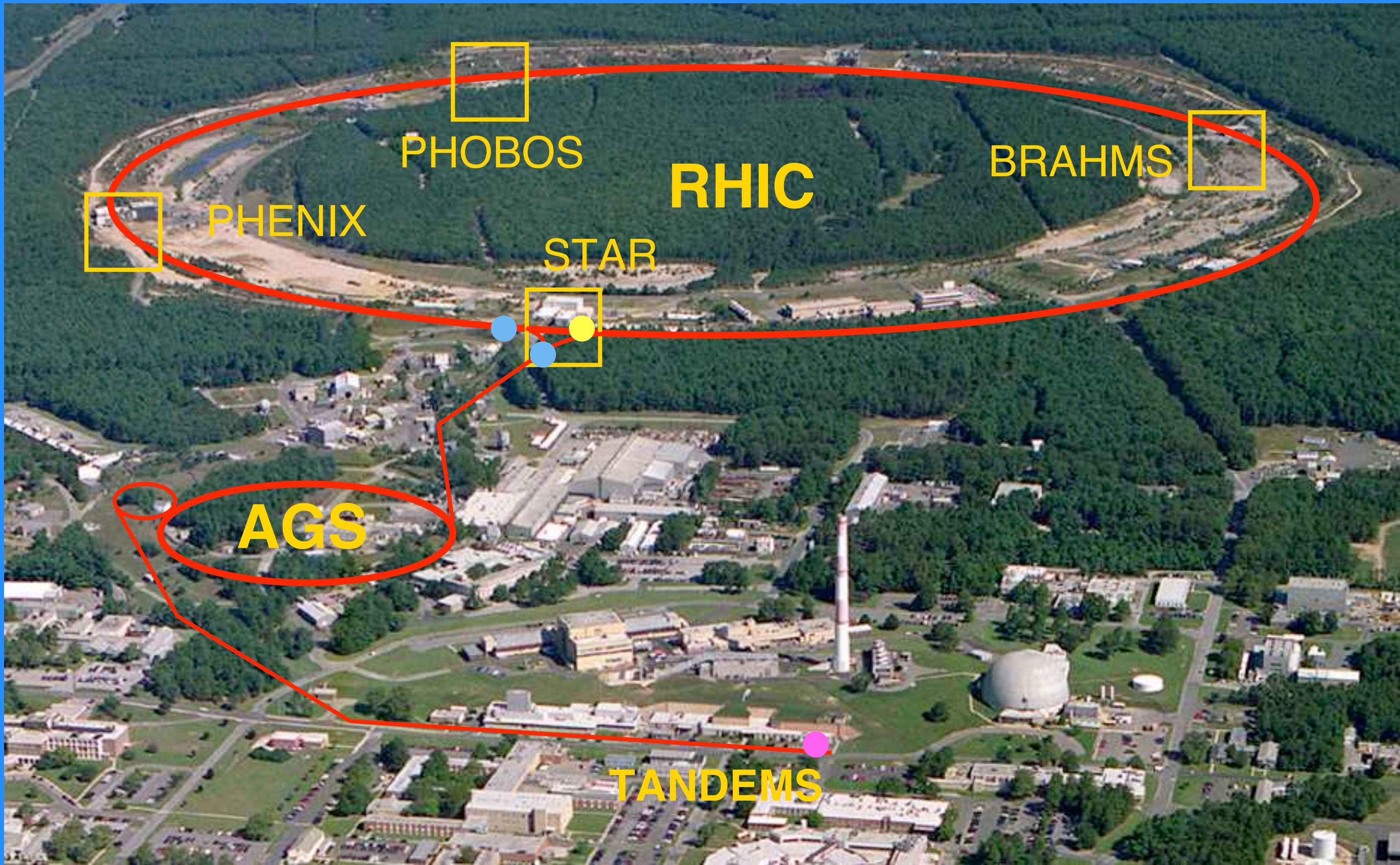


Heavy Ion collisions: exploring the QCD phases

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

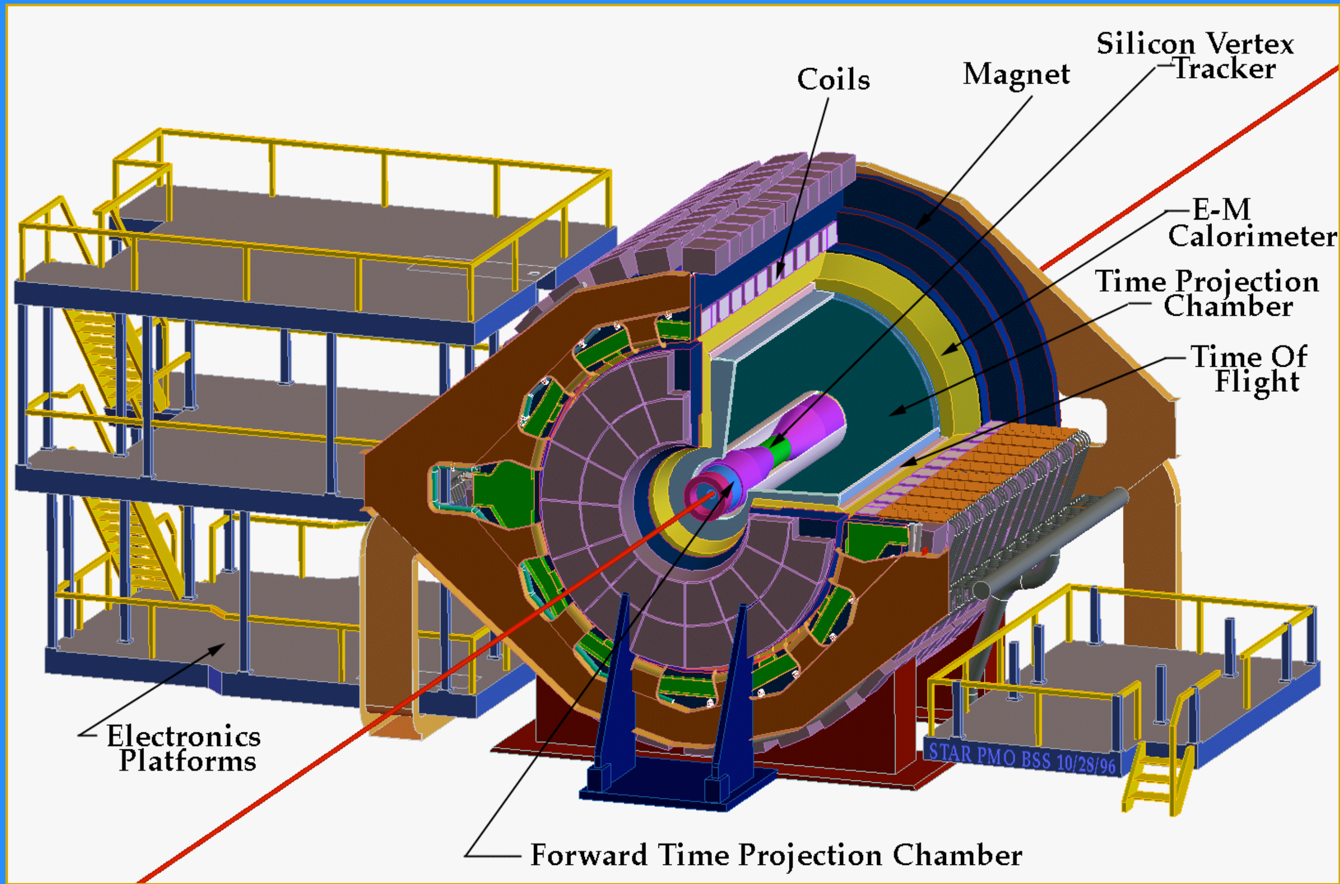
Initial Bjorken energy density ~5 GeV/fm^3

Relativistic Heavy Ion Collider (RHIC)



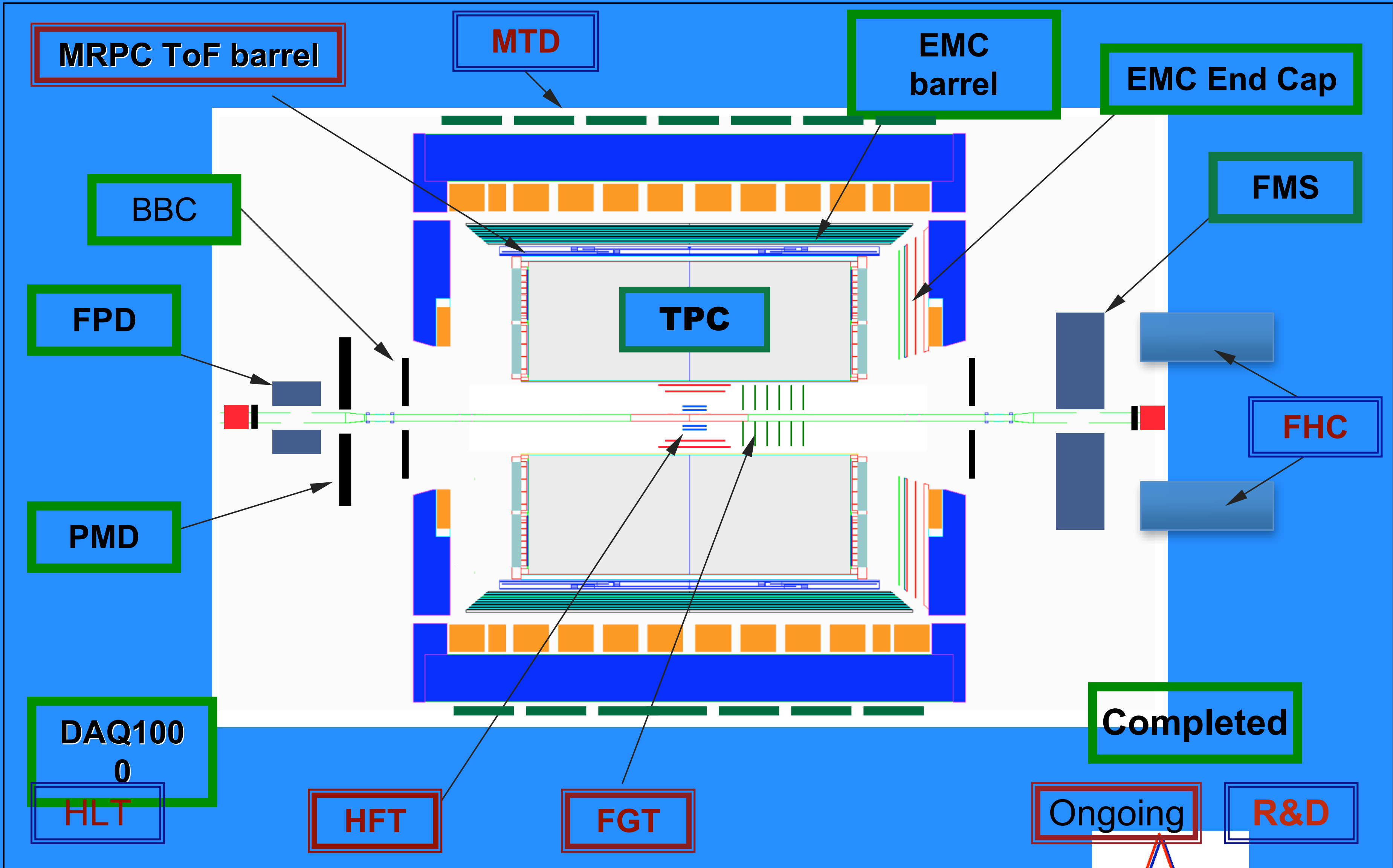
Animation M. Lisa

STAR Detector



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

STAR Detector



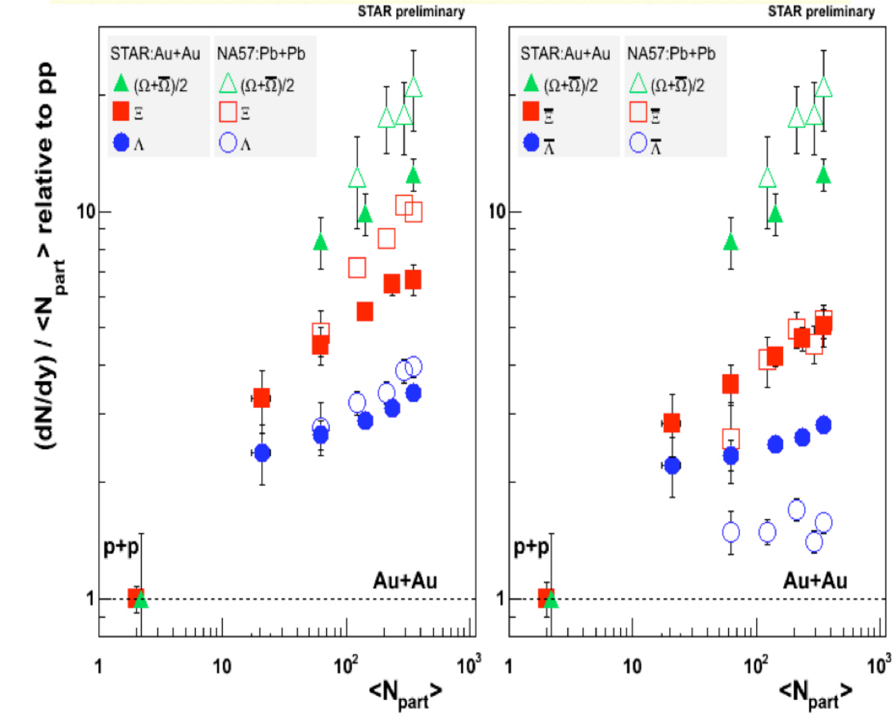
Strangeness and elliptic flow

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-Xis and higher for antilambdas.
- Strangeness content "hierarchy"
- Production volume not proportional to N_{part}

Rich set of strange particle measurements at STAR.

STAR Collaboration, nucl-ex/0809.0823

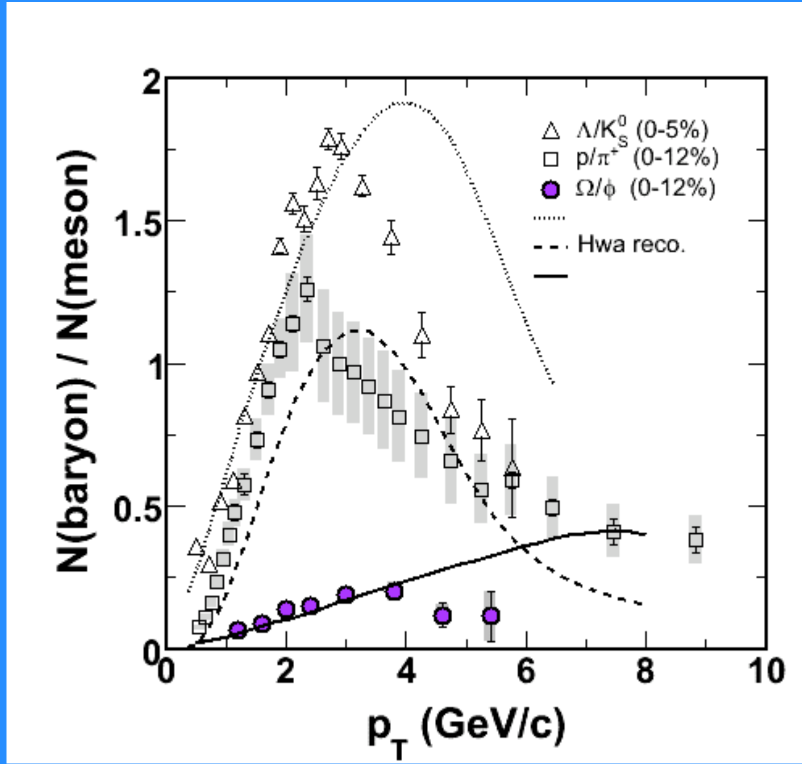


M Munhoz, SQM2009

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

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



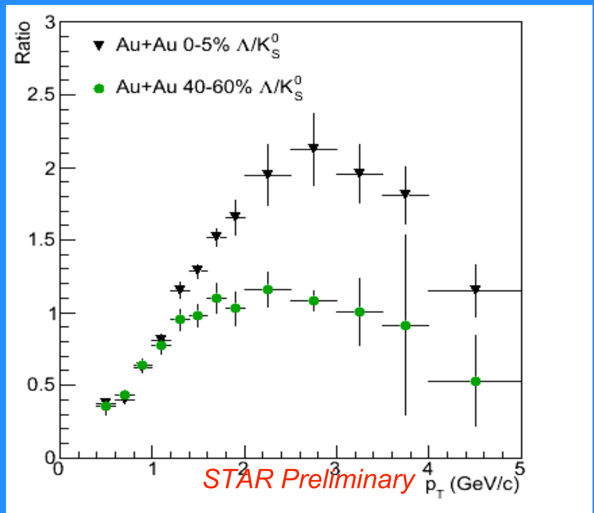
M Munhoz, SQM2009

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

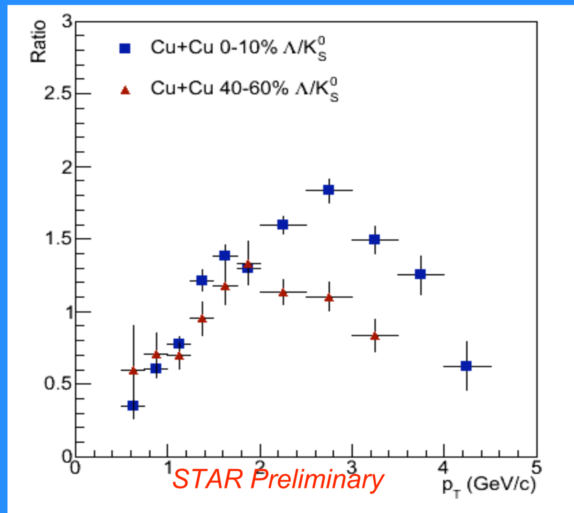
R. J. Fries et al, Phys. Rev., C68:044902, 2003
R. C. Hwa and C. B. Yang, Phys. Rev., C67:034902, 2003
V. Greco et al, Phys. Rev. Lett., 90:202302,2003.

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

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



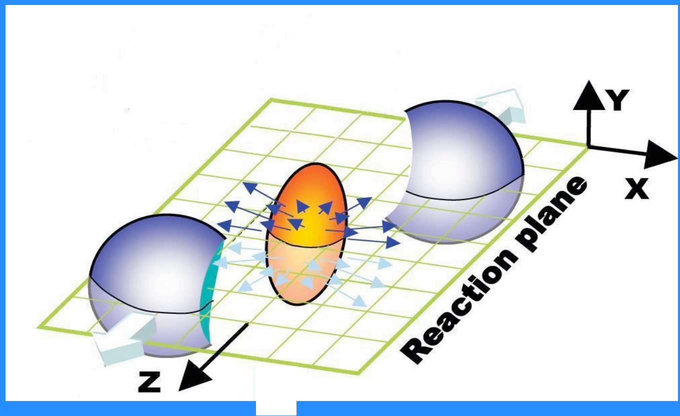
Cu+Cu, $\sqrt{s_{NN}}$ = 62.4 GeV

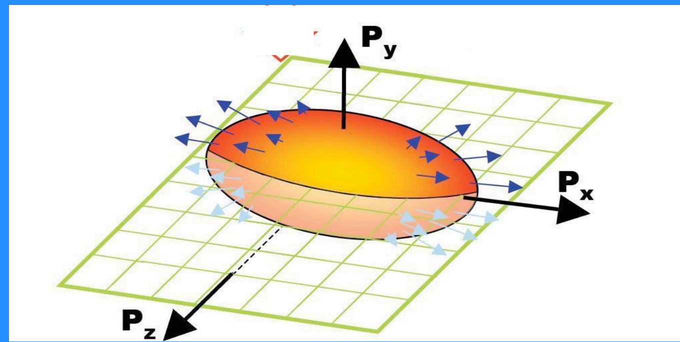


M Munhoz, SQM2009

- 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.

Azimuthal Anisotropy: Elliptic Flow

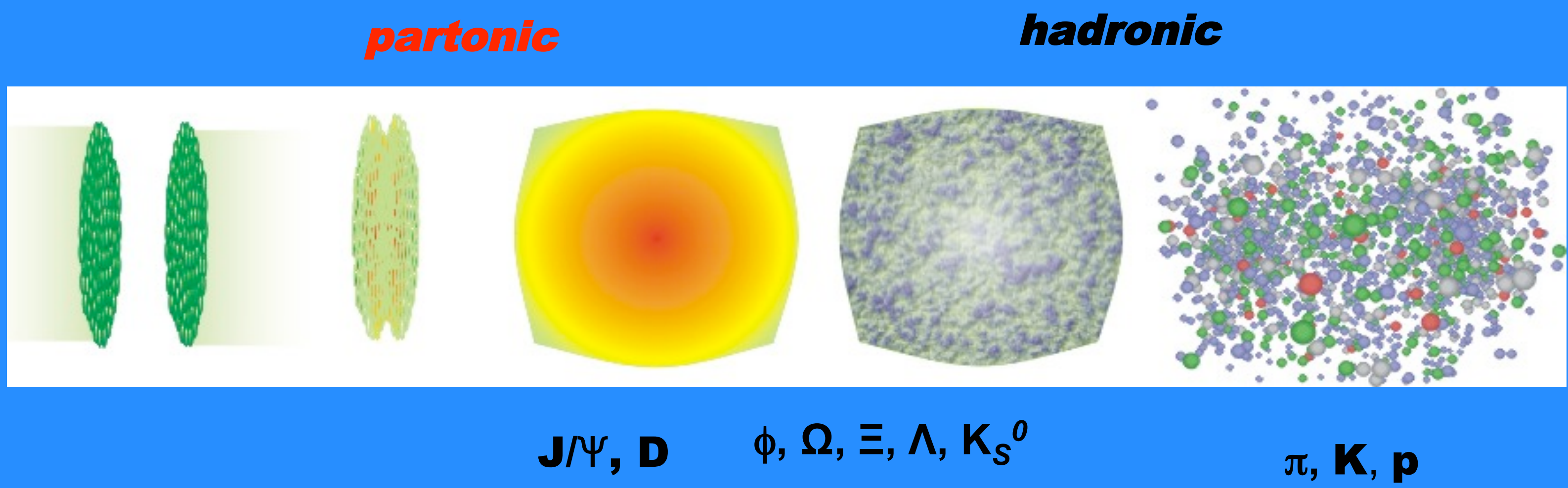




Almond shape overlap region in coordinate space → Interactions/ Rescattering → Anisotropy in momentum space

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

Elliptic Flow and Strangeness



- **Elliptic flow: reveal the early stage collision dynamics**

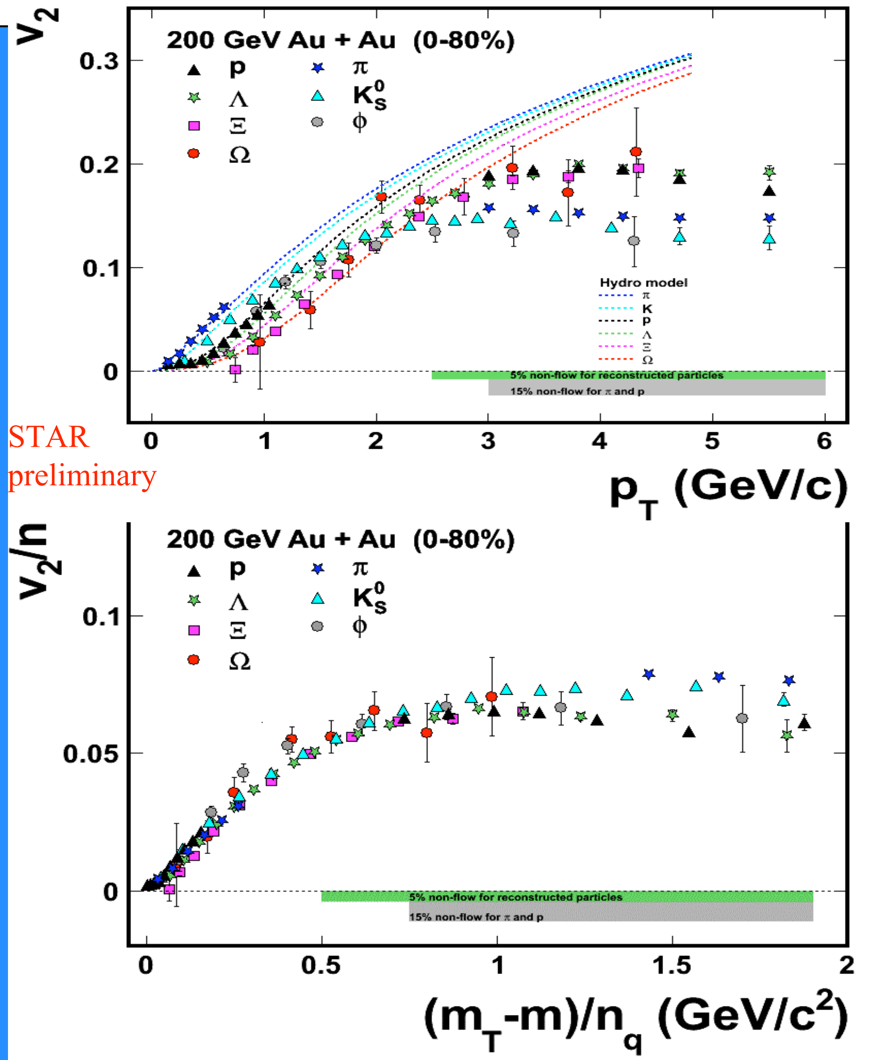
  Good probe of the early medium

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

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

Nr 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.
  - v2 build up at partonic level
  - Indications of a different behavior for higher p_T

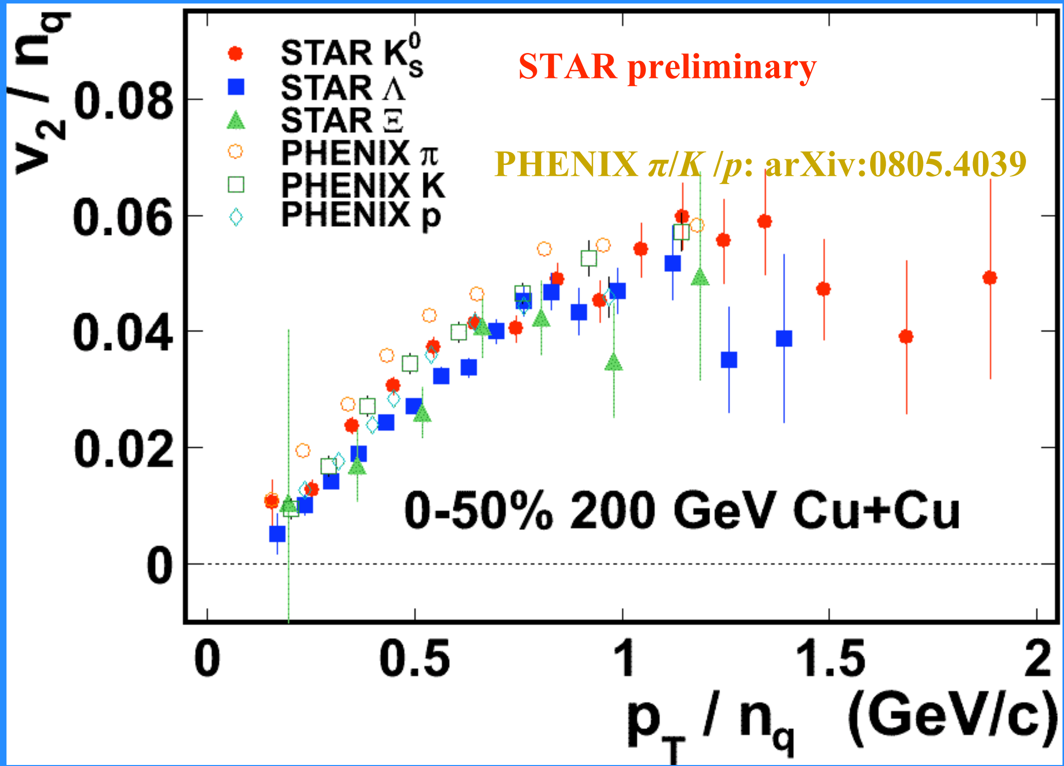


Hydro: *P. Huovinen and P. V. Ruuskanen, Annu. Rev. Nucl. Part. Sci. 56, 163 (2006)*

M Munhoz, SQM2009

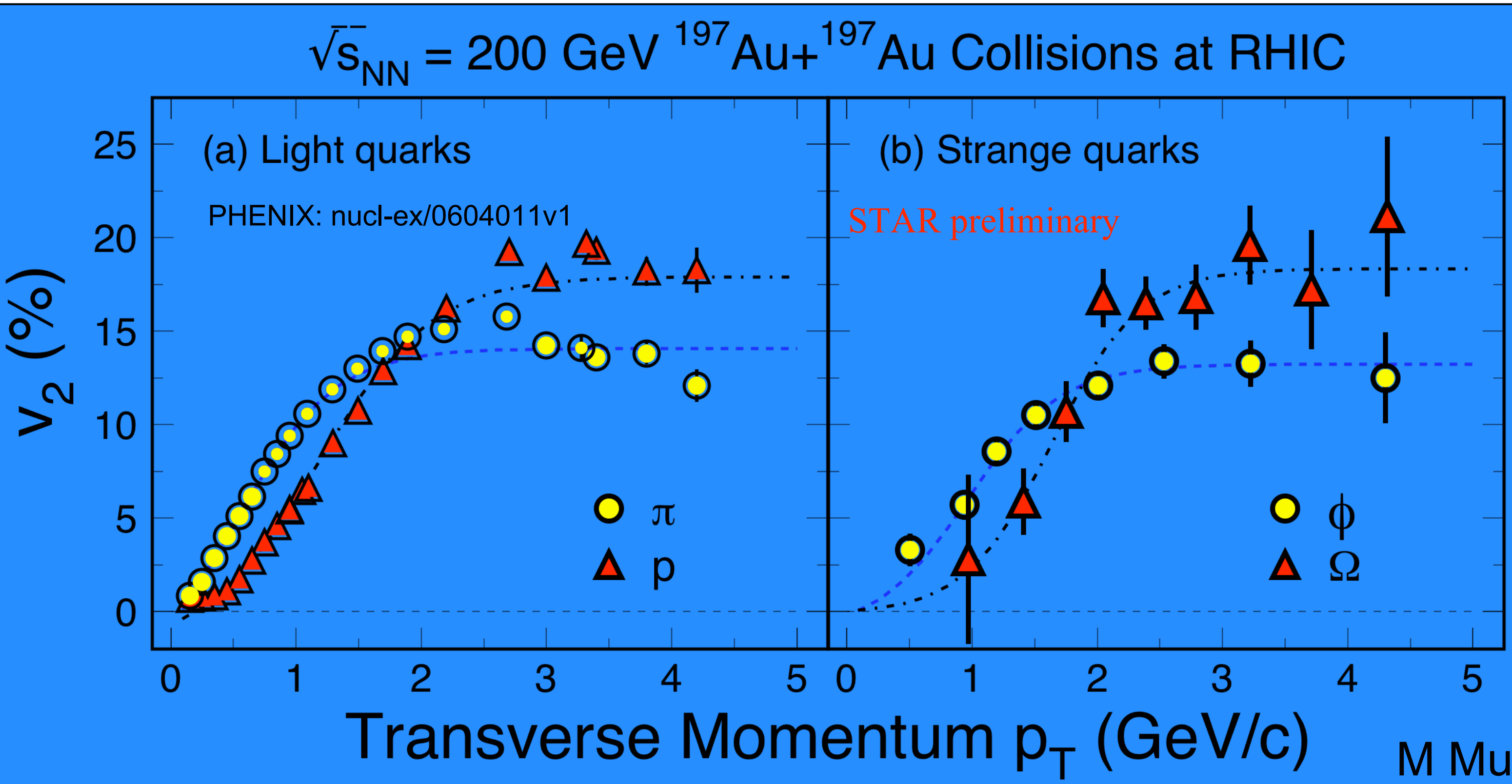
Nr of quarks scaling of v_2 in Cu+Cu collisions

Nr of Quarks scaling works with available data in Cu+Cu collisions.



G. Wang, QM2009

Elliptic Flow of Ω and φ

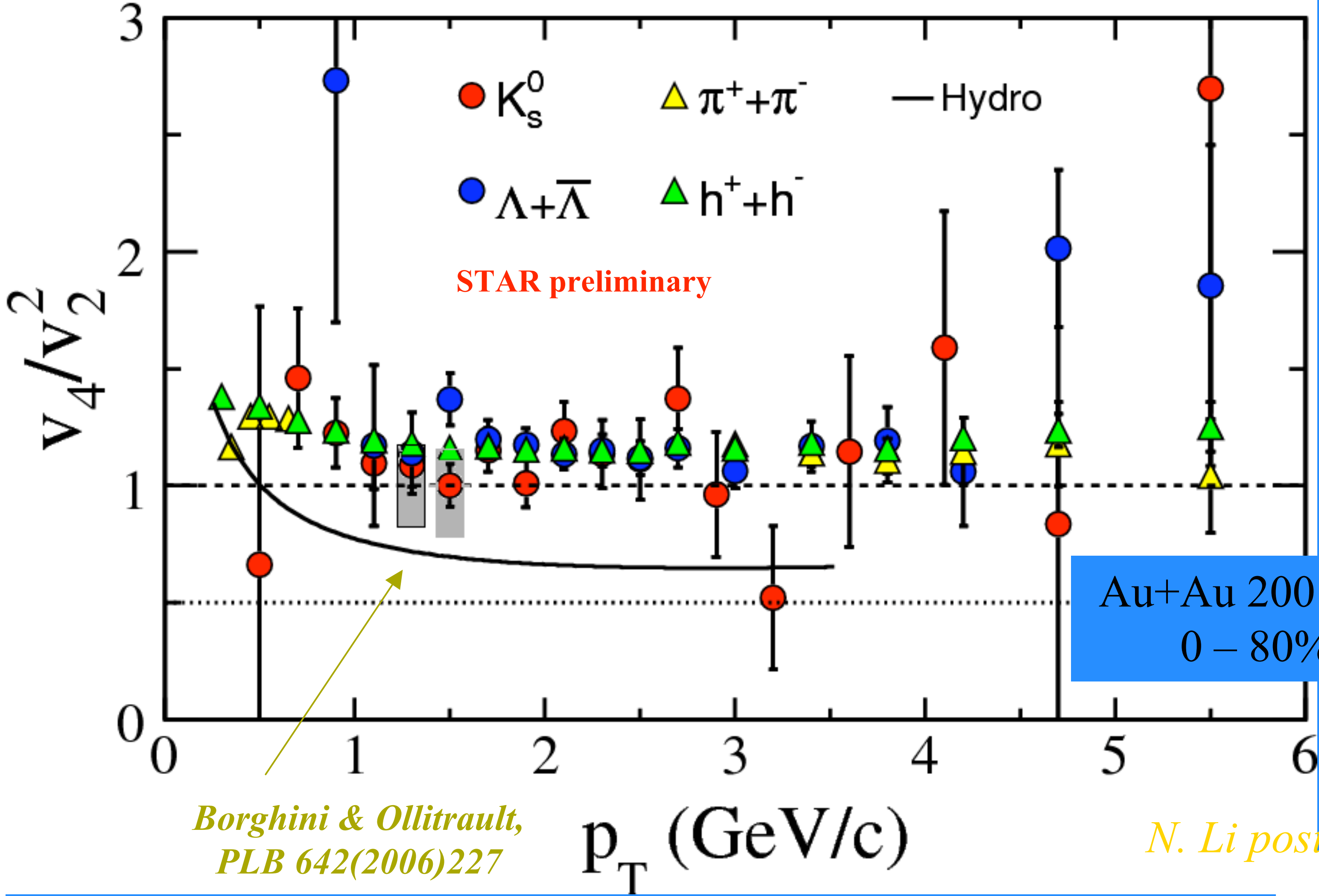


M Munhoz, SQM2009

- **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



Borghini & Ollitrault, PLB 642(2006)227

N. Li poster QM09.

Partial summary : flow, strangeness

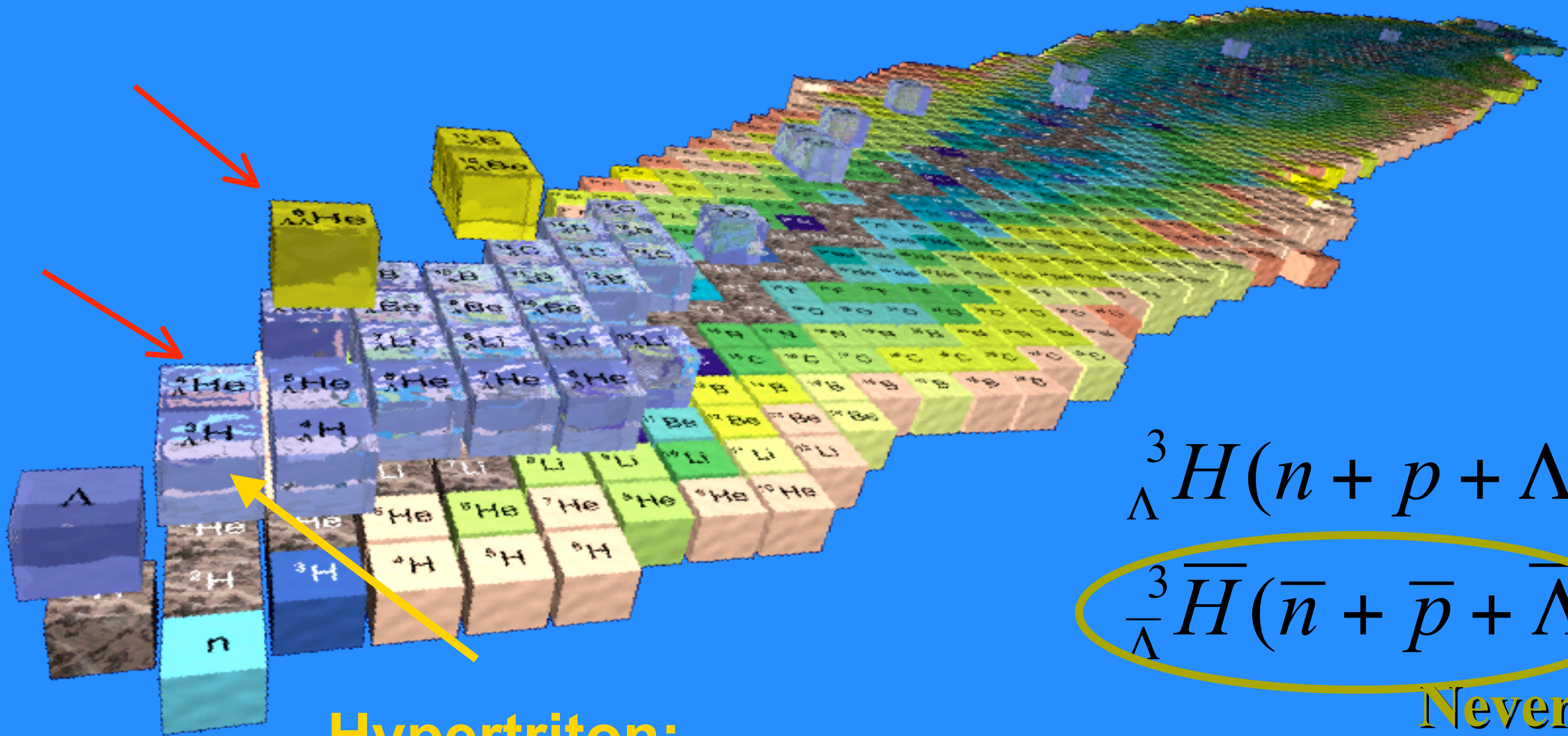
- Elliptic flow seem to develop early at partonic level (v2/n_q scaling)
- Hydrodynamics seems applicable in bulk - low pT (v2 vs pT)
- Ideal hydrodynamic limit not reached (v4/v2^2)
- Deviation from n_q scaling seen at high pT
- Quark coalescence/recombination dominant hadron production mechanism in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

(Anti-)hypertriton discovery

Observation of antihypertriton at RHIC

S=-2

S=-1



S=-0

Hypertriton:

hypernucleus with lowest A

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

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

Never observed before

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

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.

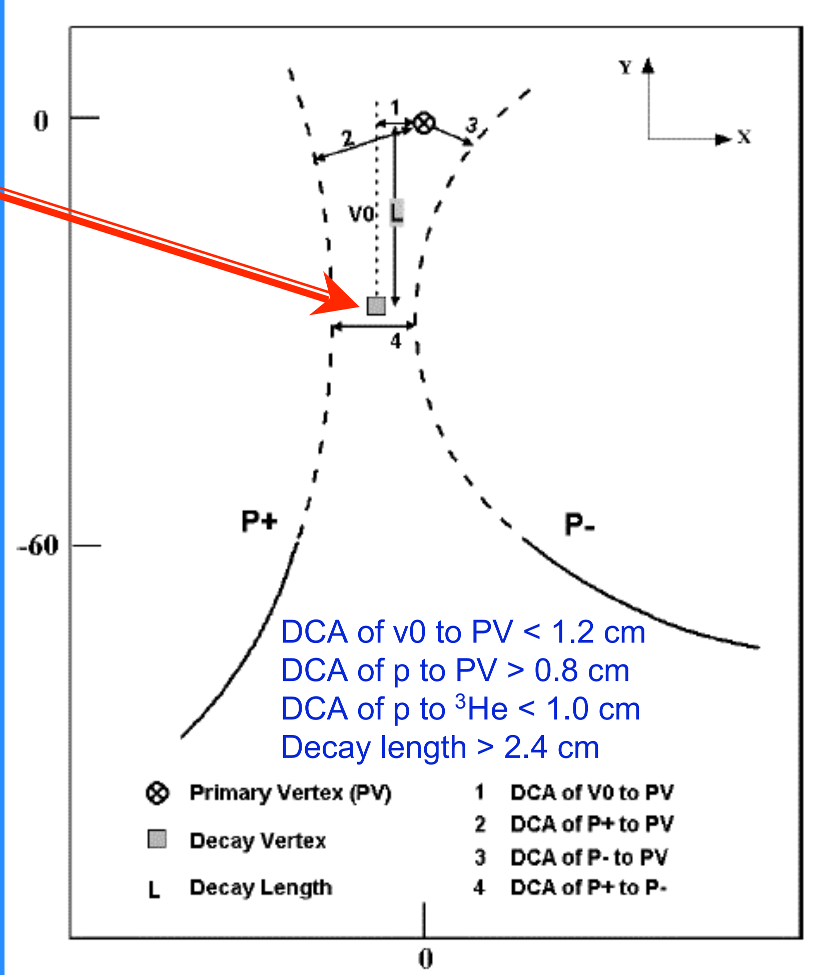
${}^{3}_{\Lambda}H$ mesonic decay, m=2.991 GeV, B.R. 0.25;

Secondary vertex finding technique

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

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

- 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.*



<u>*QM09 proceeding: arXiv:0907.4147*</u>

Event display

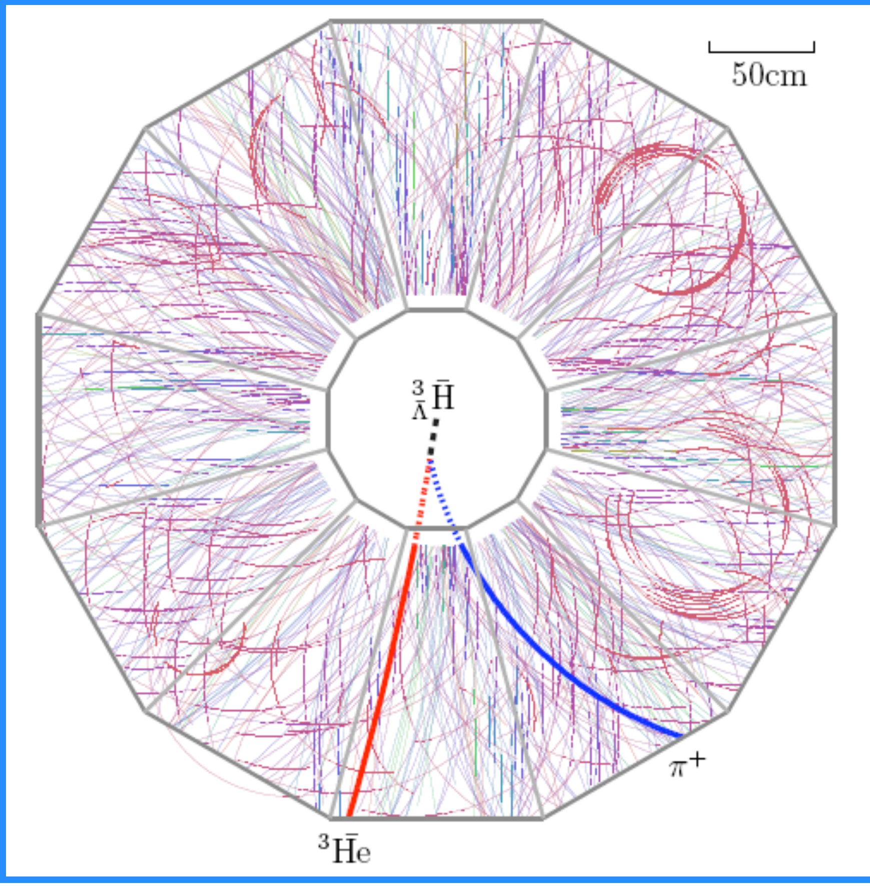
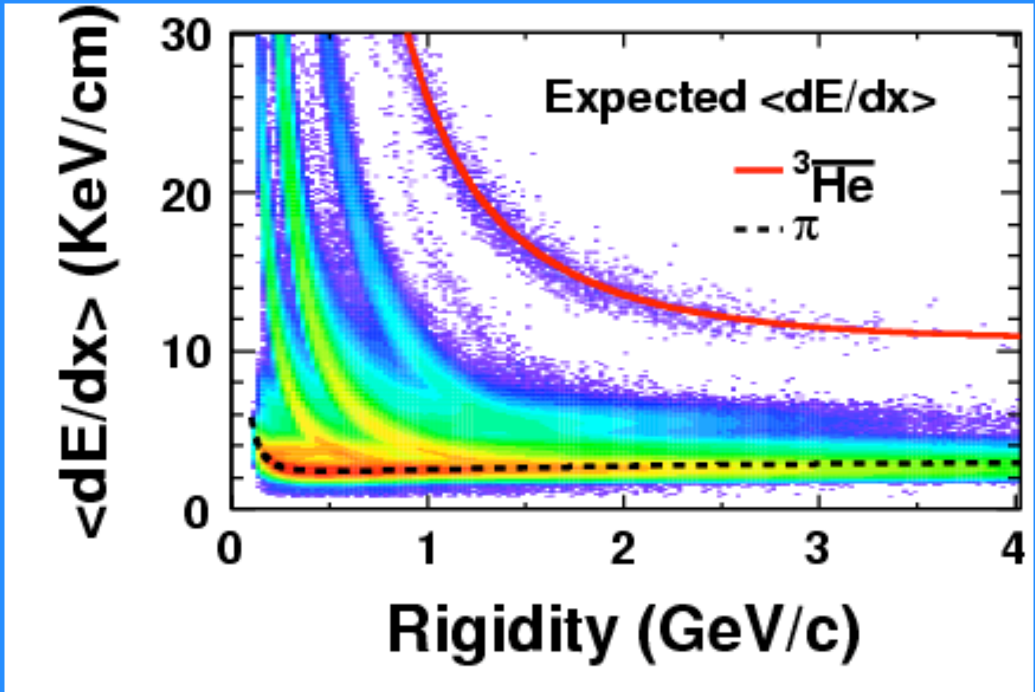
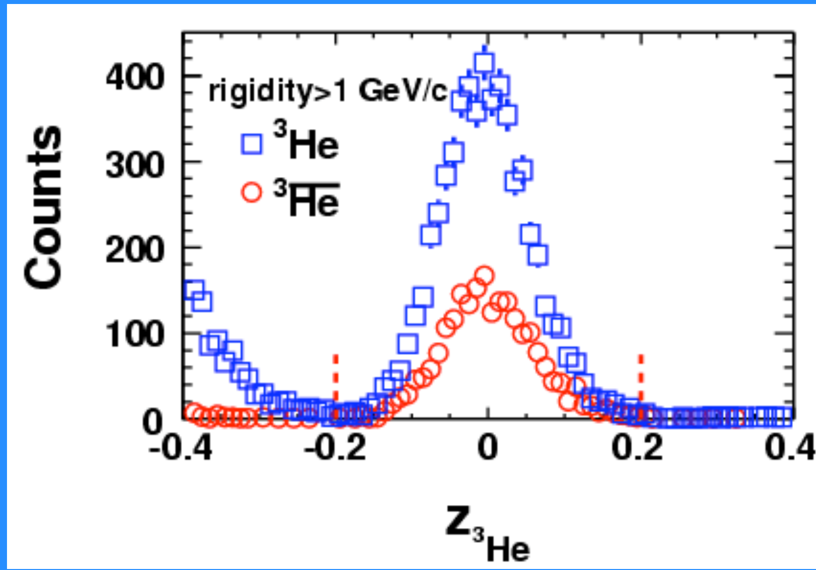


Figure 1: "Beam's eye view" of a typical event in the STAR detector when a $^{3}_{\bar{\Lambda}}\bar{H}$ candidate is produced. STAR's main tracking device reconstructs charged particle trajectories in 3-D; in this 2-D projection, the apparent track density is extremely large. The thick red line shows 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.

^{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**

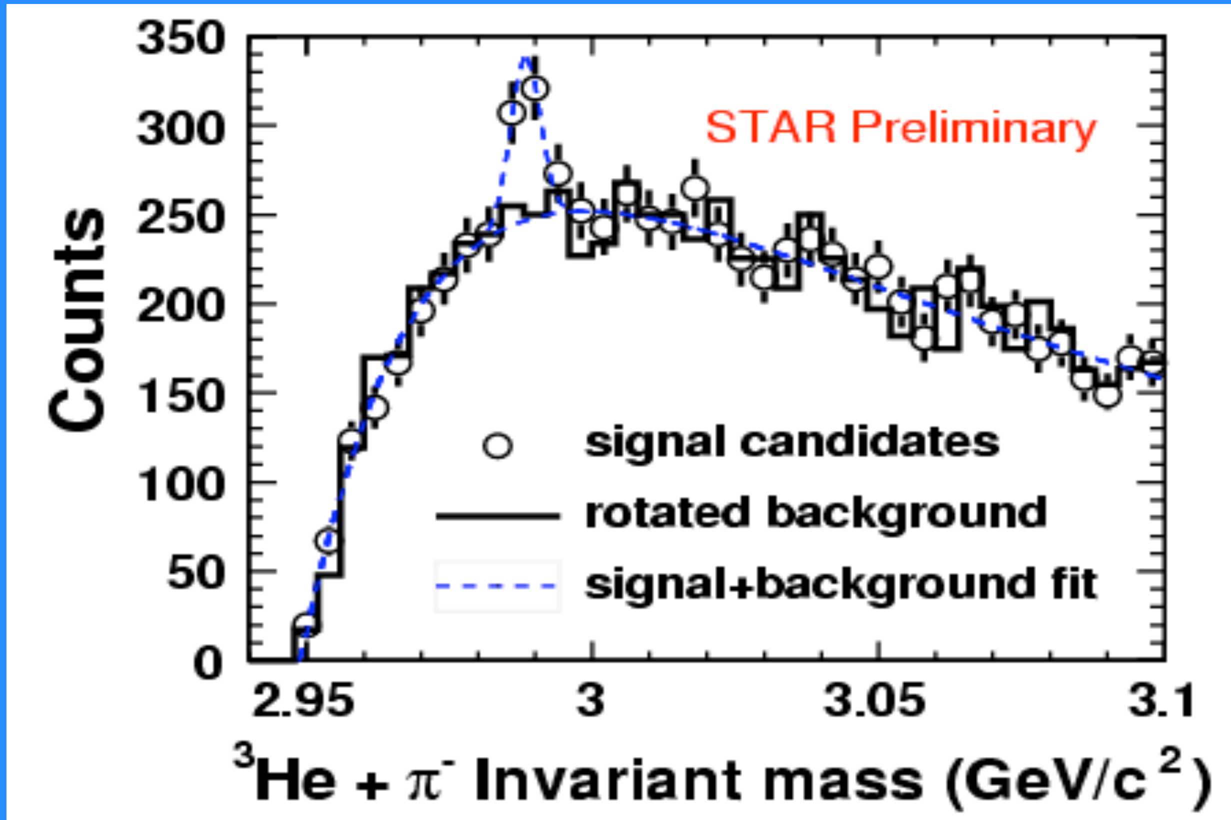
Theory curve: *Phys. Lett. B 667 (2008) 1*

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



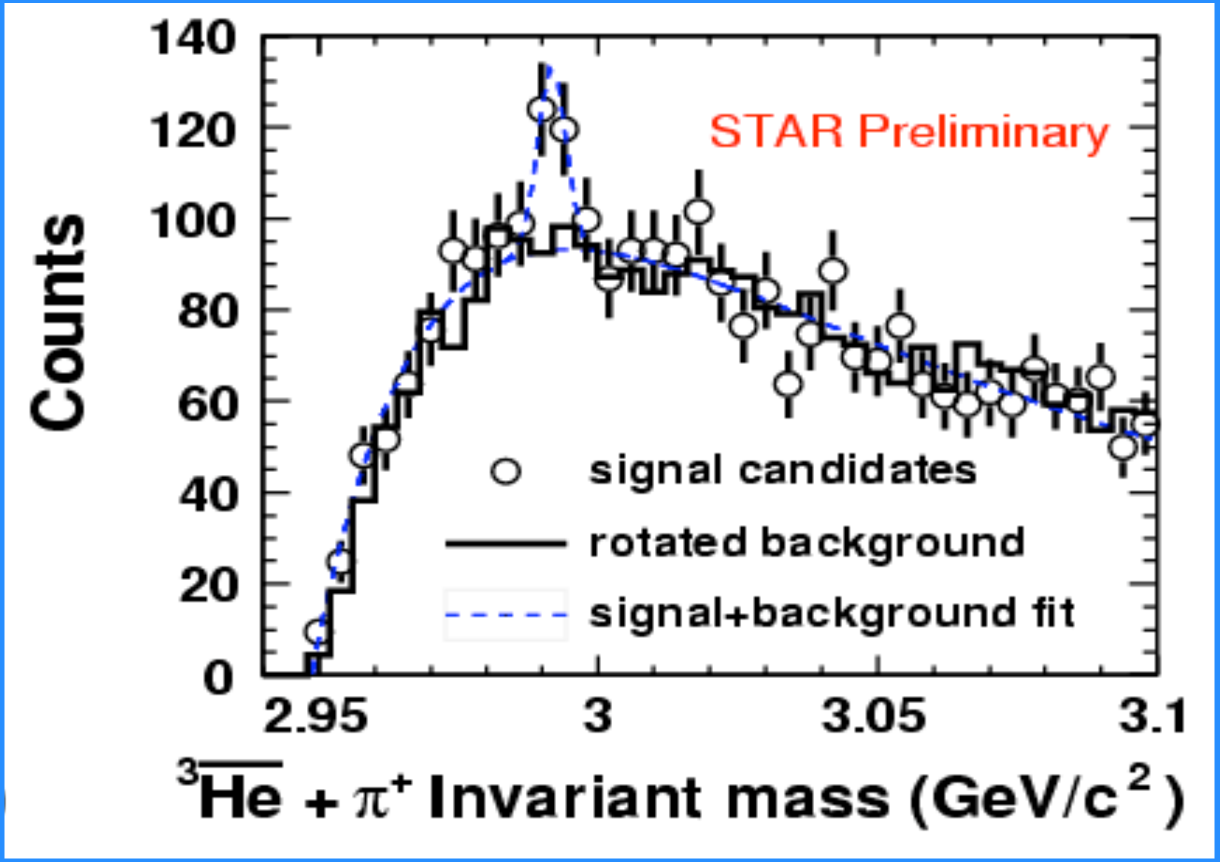
Jin Hui Chen QM09 and HypX 2009, Zhangbu Xu, RHIC-AGS meeting june 2009.

- 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** $^{3}_{\bar{\Lambda}}\overline{H} = {}^{3}_{\Lambda}H \times {}^{3}\overline{He}/{}^{3}He$

Antihypertriton inv. mass

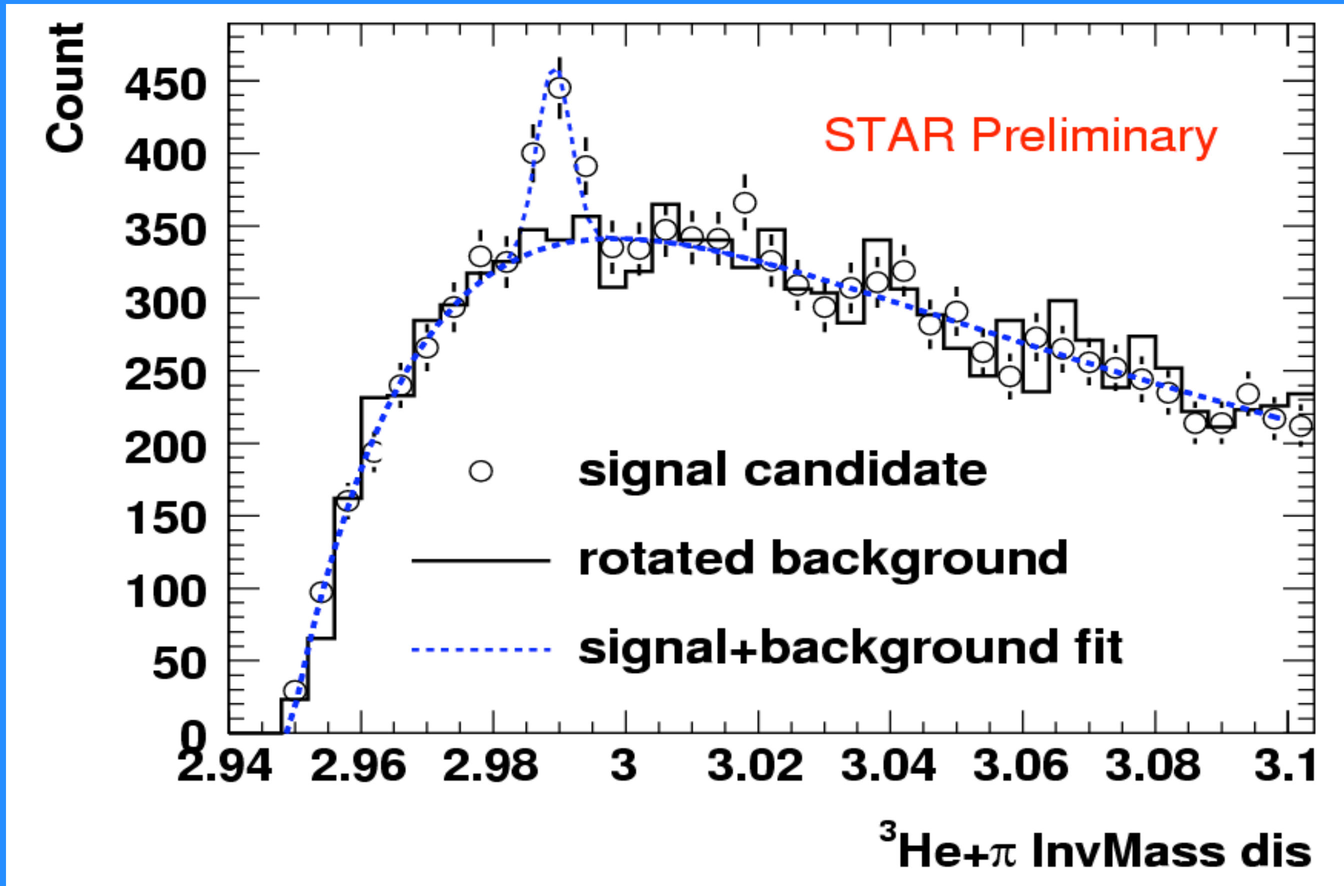


Jin Hui Chen QM09 and HypX 2009, Zhangbu Xu, RHIC-AGS meeting june 2009.

- ☆ 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



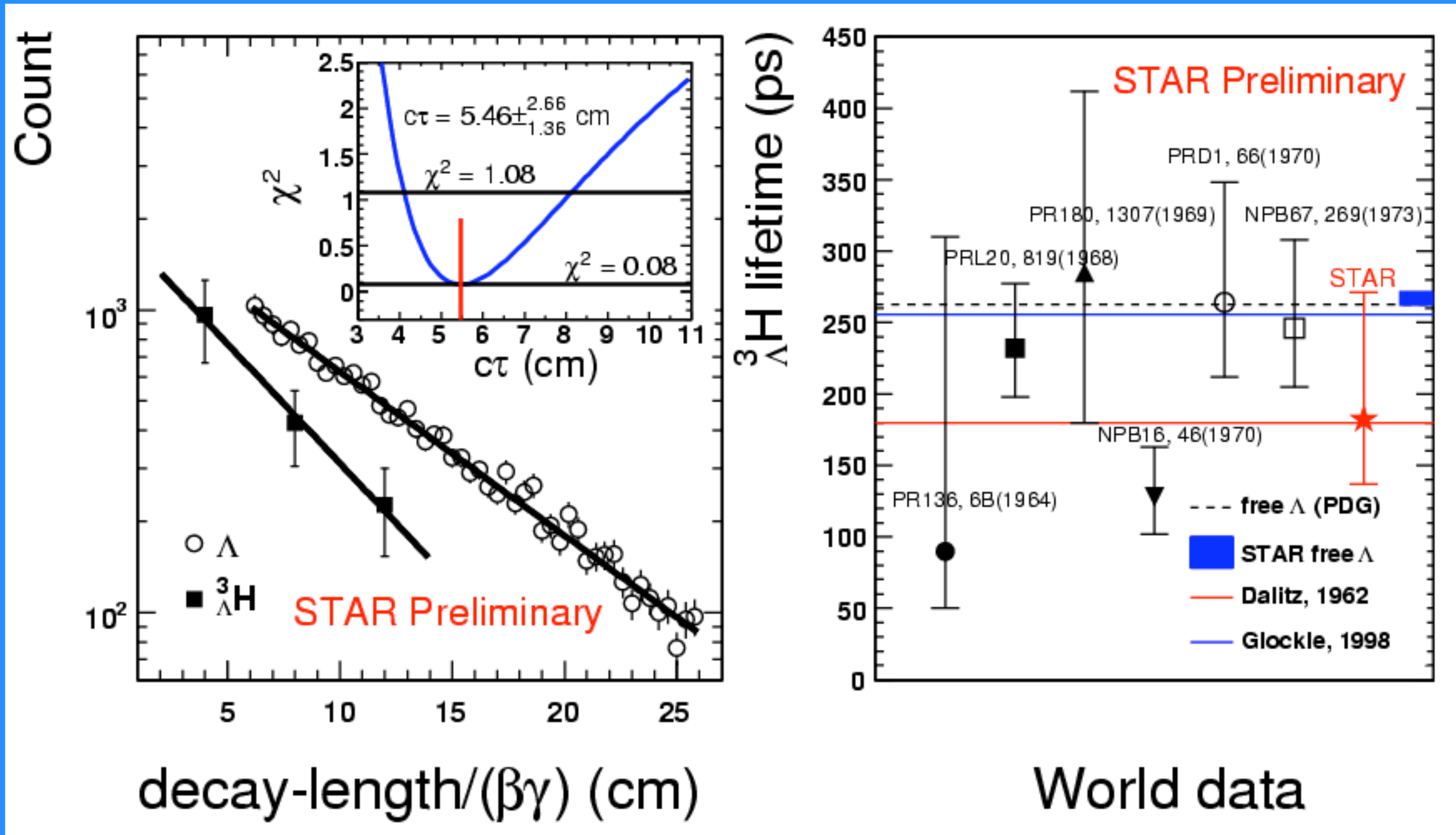
Jin Hui Chen QM09 and HypX 2009, Zhangbu Xu, RHIC-AGS meeting june 2009.

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

It provides a >6σ significance for discovery.

STAR

Measurement of the lifetime



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

We measure τ_Λ = 267±5 ps

PDG value is τ_Λ = 263±2 ps

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

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

Production rate

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

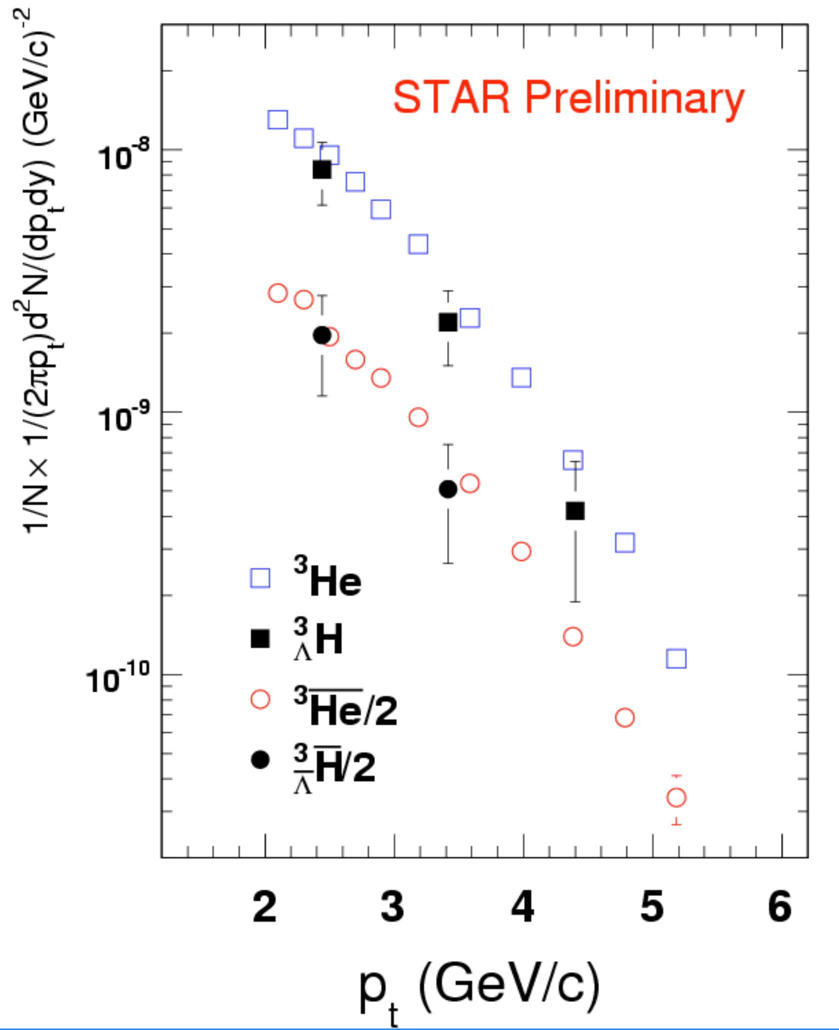


TABLE I: Particle ratios from Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV/c. The ^{3}He ($^3\overline{\mathrm{He}}$) yield have been corrected for $^3_\Lambda$H ($^3_{\bar\Lambda}\overline{\mathrm{H}}$) feed-down contribution.

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

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

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

0.45 ~ 0.77*0.77*0.77

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

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

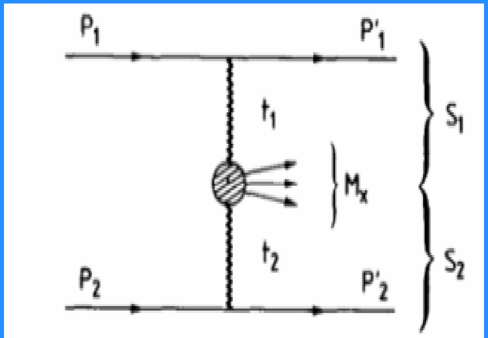
J. H. Lee, Hadron 2009

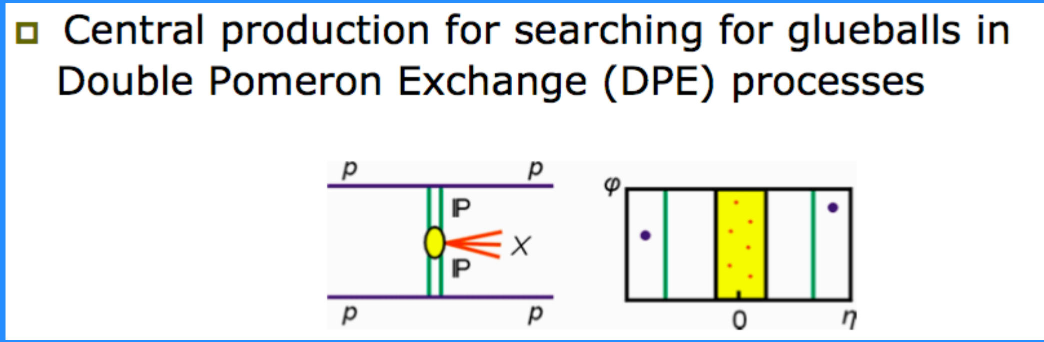
Search for glueball production in Double Pomeron Exchange processes

- 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





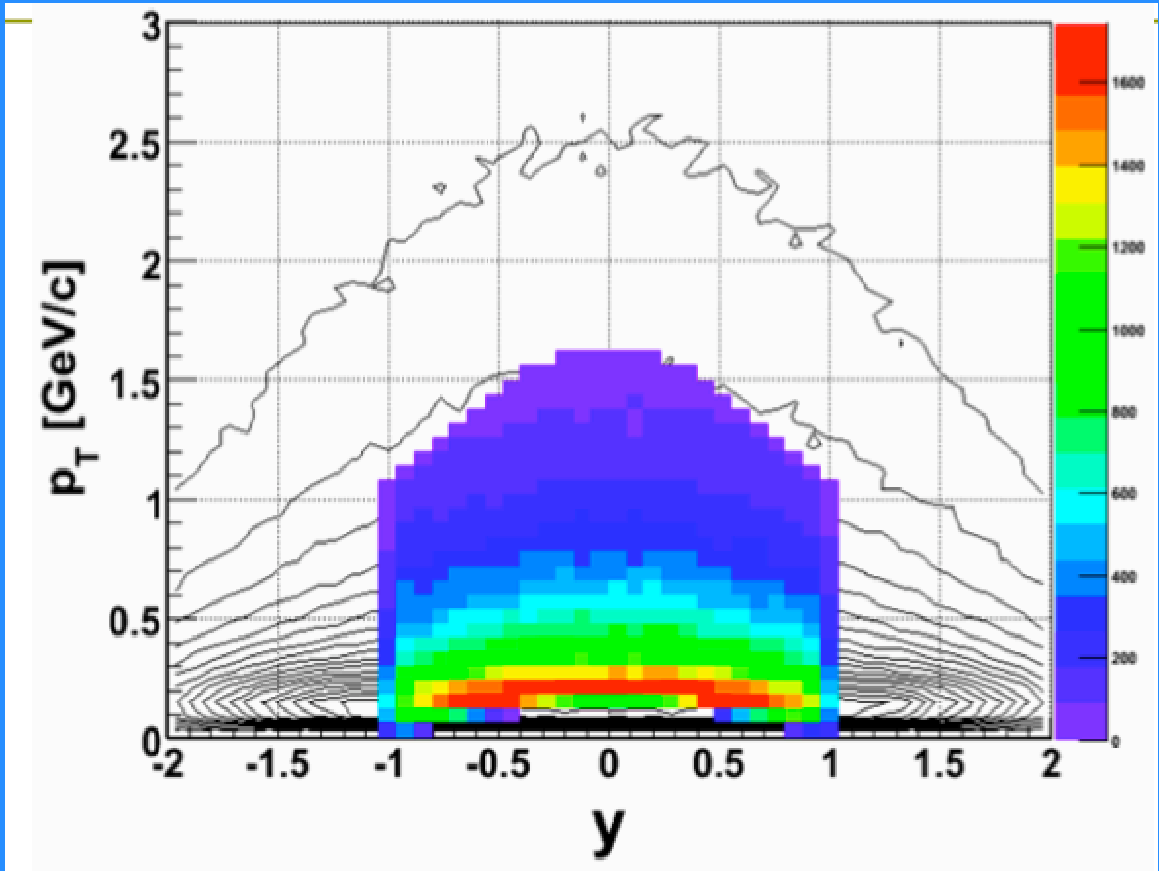
p1 p2 -> p1' M_X p'2

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



acceptance for
decay pions from

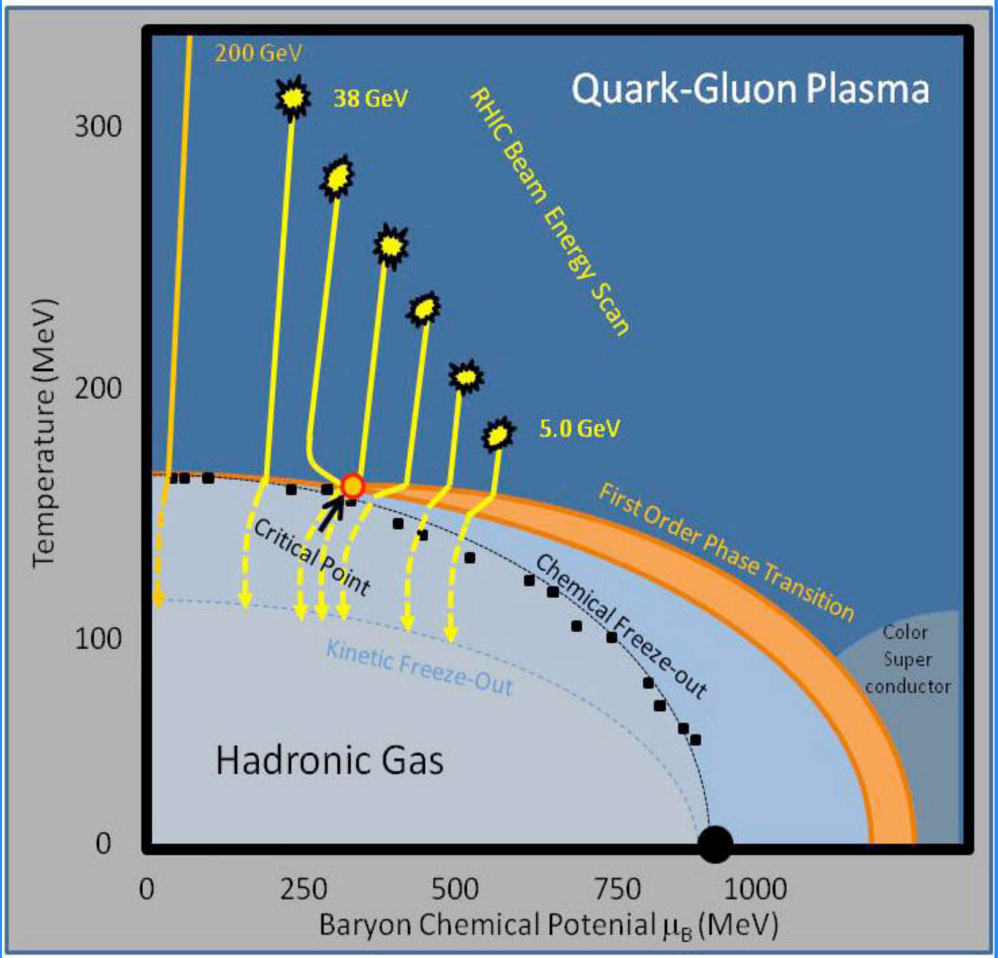
M-X -> pi+pi-pi+pi-

J. H. Lee, Hadron 2009

Low energy scan

Low energy scan happening this year !

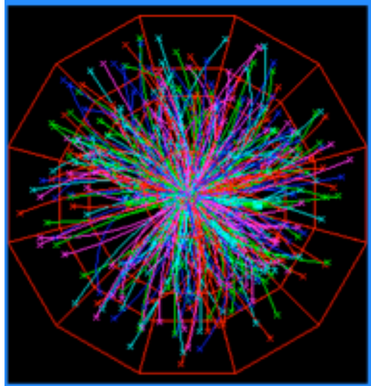
Key idea: study Phase Diagram throughout energy scan region

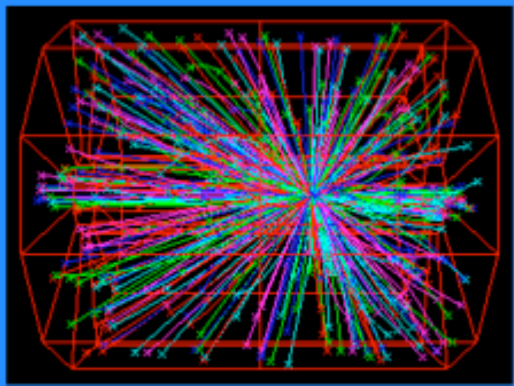


Critical point search

Turn-off major sQGP signatures already established at top RHIC energies?

Energy scan: 9.2 GeV



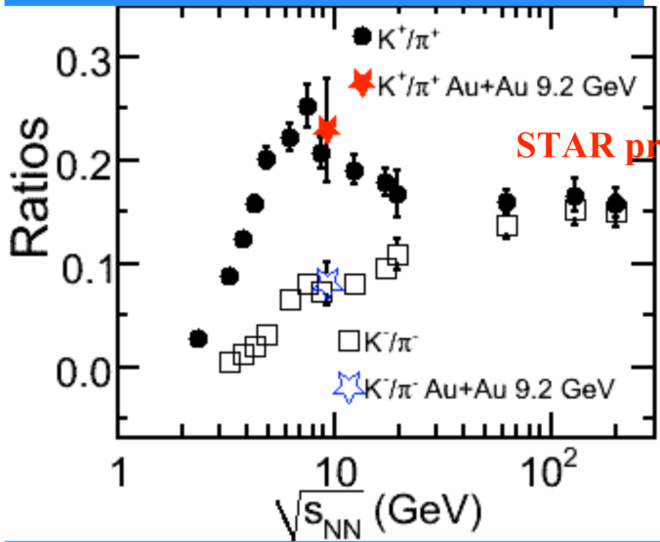


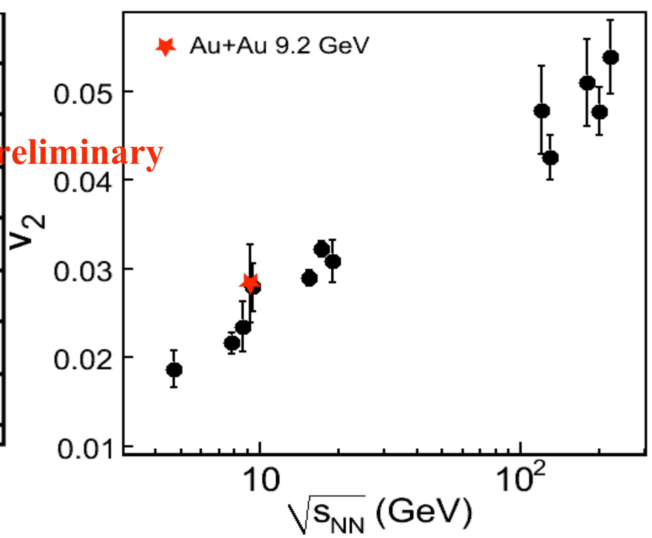
4 hours and 40 minutes in year 2008:
~3000 good events

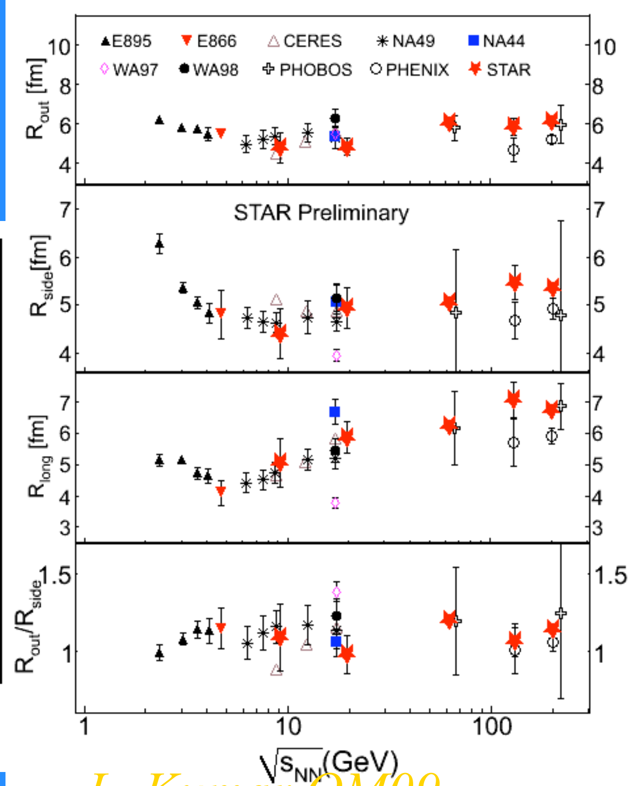
(good≡ primary vertex along beam and within acceptance)

Unambiguous beam+beam events

Publishable quality data show particle ratios, v_2 and HBT results are comparable to SPS results at a similar energy.

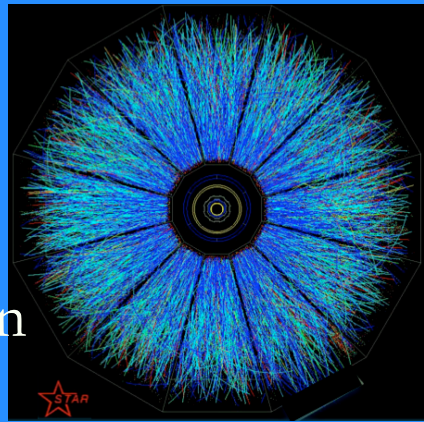






L. Kumar QM09

Summary



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

- 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