Baryon Production and Multi-Gluon Dynamics

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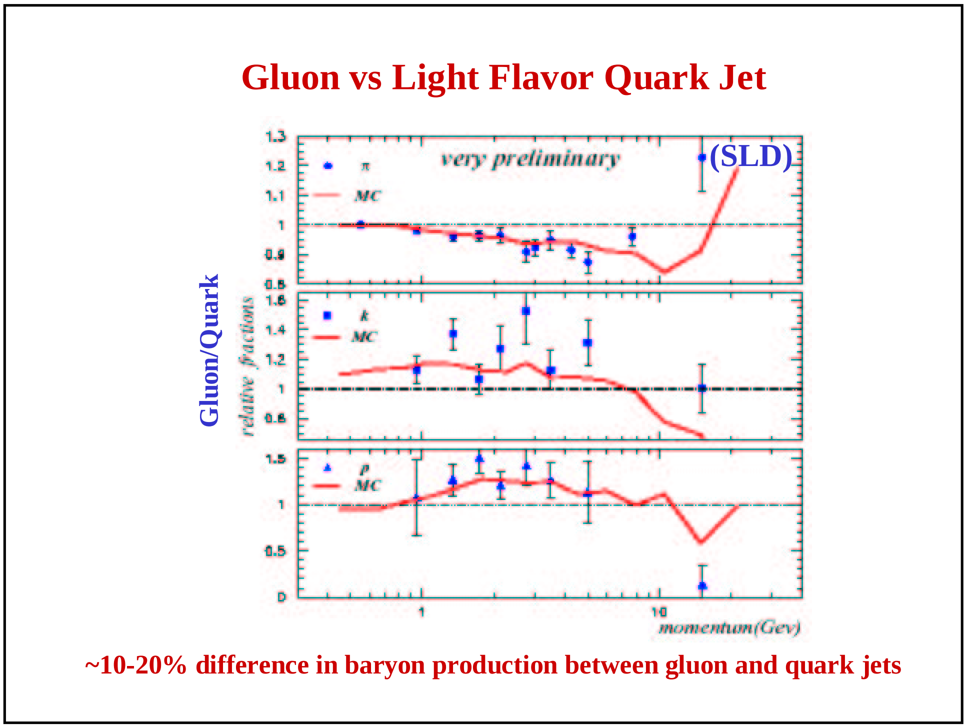
Gluonic Dynamics Dominant at Mid-Rapidity at RHIC

1) **Conceptually appealing: the gluon structure function much larger than quarks at the x relevant for mid-rapidity at RHIC; gluon-parton interaction cross sections are larger than quark-quark….**

2) **The measured ratio of anti-particle/particle close to unity: small net baryon density at mid-rapidity at RHIC; Valence quarks less important.**

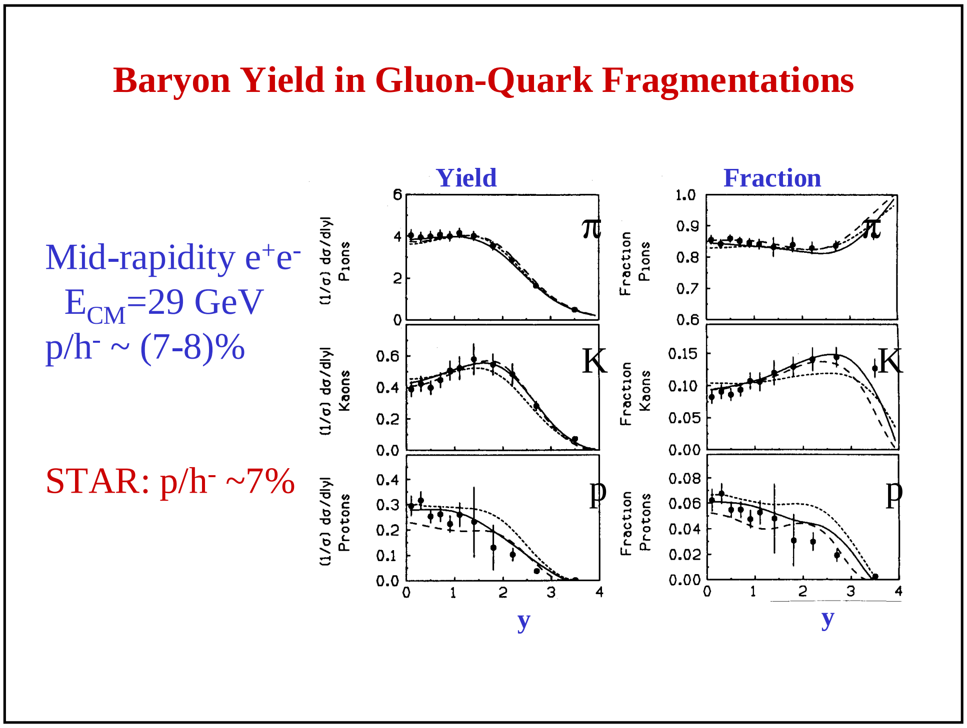
3) **Multiplicity ←→ Gluon saturation model;**
   e.g., Kharzeev and Levin, Physi. Lett. 523, 79 (2001).
   HIJING;
   minijet particle production presumably induced mostly by gluons.

4) **Elliptic flow, v_2, larger at RHIC: effective in transferring initial geometrical anisotropy to momentum anisotropy ! Strongly interacting gluonic system may be able to provide the driving force for both v_1 and v_2.**



Gluon vs Light Flavor Quark Jet

~10-20% difference in baryon production between gluon and quark jets



Baryon Yield in Gluon-Quark Fragmentations

Mid-rapidity e^+e^-
E_{CM}=29 GeV
p/h^- ~ (7-8)%

STAR: p/h^- ~7%

Baryon Yield Comparison

LEP (OPAL)	**STAR Preliminary**
N_{ch}= 20.92 +- 0.24	h^- = 290
P = 0.92 +- 0.11	$\bar{P}$ = 20.5 +- 0.5
Λ= 0.348 +- 0.013	$\bar{\Lambda}$ = 12.0 +- 0.3
Ξ^- = 0.0238 +- 0.0024	$\bar{\Xi}^+$ ~ 3.0
Ω = 0.0051 +- 0.0013	$\bar{\Omega}$?
p/h^- = (8.8 +- 1.1) %	$\bar{p}/h^-$ = 7.1 %
Λ/p = (38 +- 5) %	$\bar{\Lambda}/\bar{p}$ = (59 +- 3) %
Ξ^-/p = (2.6 +- 0.4) %	$\bar{\Xi}^+/\bar{p}$ ~ 14.6%
Ω/p = (0.55 +- 0.15)%	$\bar{\Omega}/\bar{p}$?

A+A vs e+e Collisions

- **Production rate for the total number of baryons (inclusive protons and anti-protons) relative to that of mesons is similar between A+A and e+e collisions.**
- **The production of high mass hyperons is strongly enhanced in nucleus-nucleus collisions at RHIC.**
- **What determines the mass dependence for baryon production and how does the dynamical picture change from e+e to A+A collisions?**

------ Multi-Gluon Dynamics ------
(Gluon Junctions)

What determines the mass penalty factor?

For p, Λ, Ξ and their anti-particle production

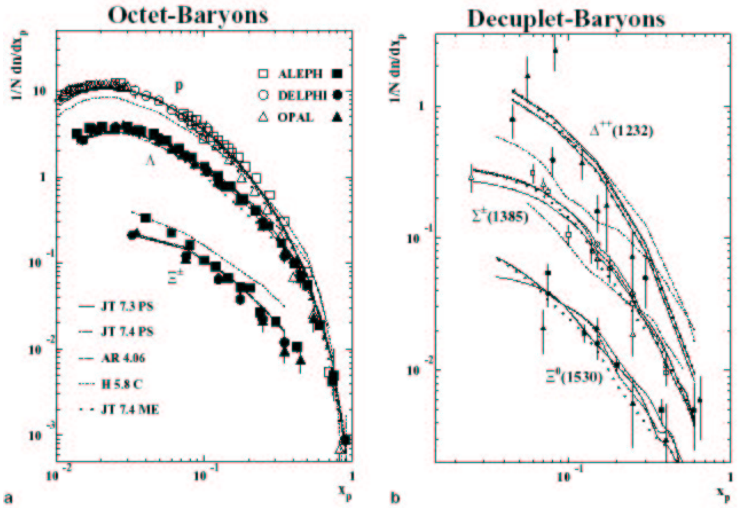
Statistical Model ~ $m^{3/2} e^{-m/T}$

String Fragmentation ~ $e^{-\pi m^2/\kappa}$

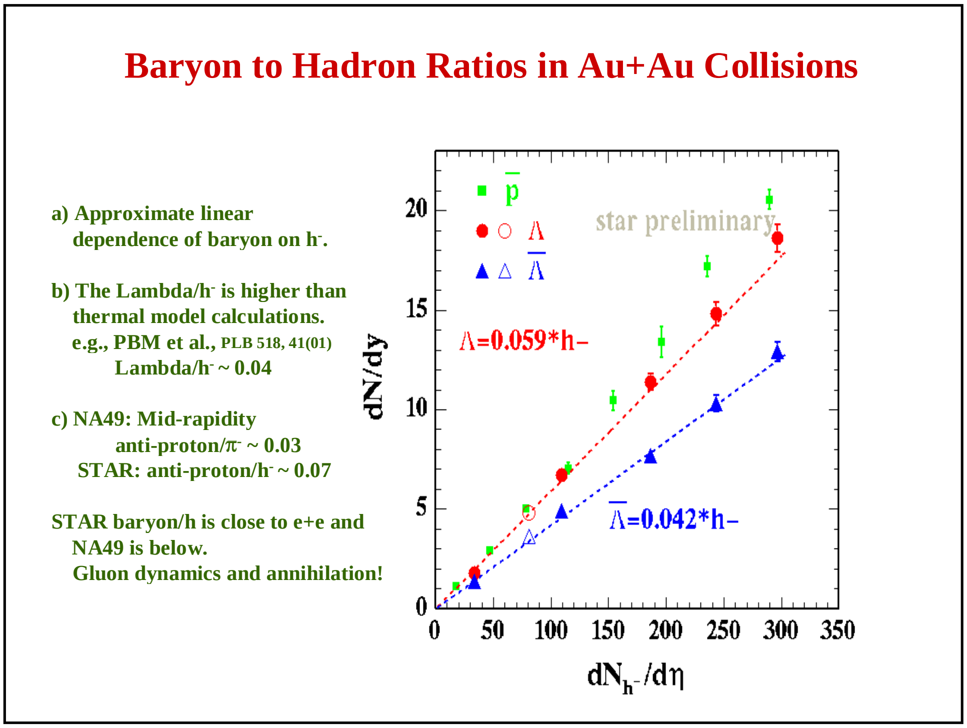
Some proposed models with different mass dependence:

Baryons through topological defect formation
e.g., J. Ellis et al., Phys. Lett B233, 223 (1989)
OR
ALCOR – quark coalescence picture
J. Zimanyi et al., hep-ph/0103156

String Fragmentation Models Work for e+e



PS→Parton Shower; AR→ARIADNE; H→HERWIG; ME→Matrix Element



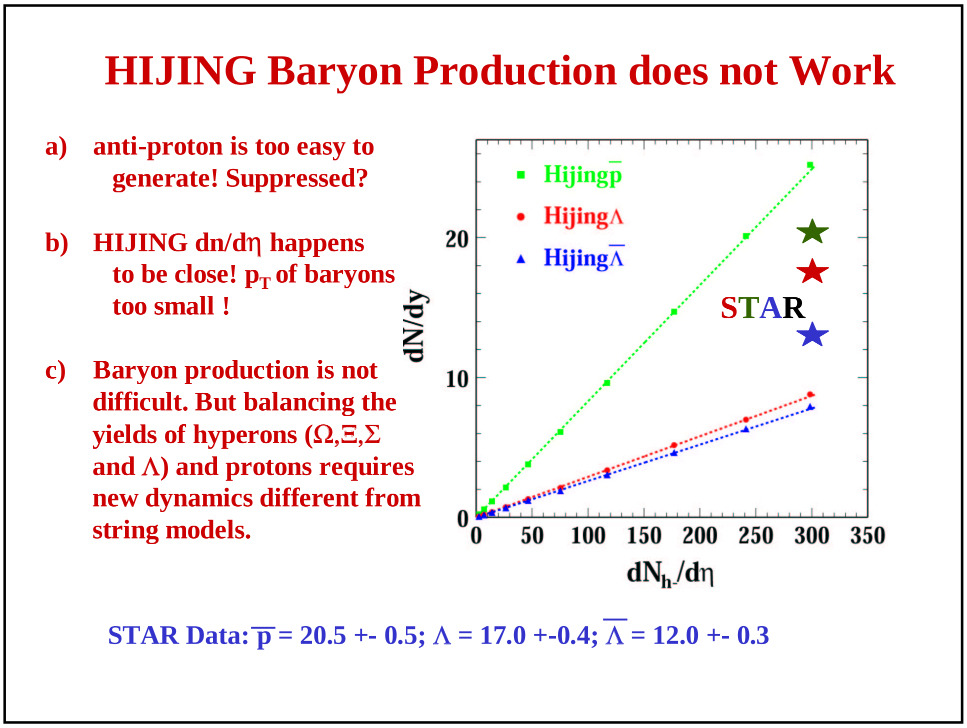
Baryon to Hadron Ratios in Au+Au Collisions

a) Approximate linear dependence of baryon on h^-.

b) The Lambda/h^- is higher than thermal model calculations.
e.g., PBM et al., PLB 518, 41(01)
Lambda/h^- ~ 0.04

c) NA49: Mid-rapidity
anti-proton/π^- ~ 0.03
STAR: anti-proton/h^- ~ 0.07

STAR baryon/h is close to e+e and NA49 is below.
Gluon dynamics and annihilation!



HIJING Baryon Production does not Work

a) **anti-proton is too easy to generate! Suppressed?**

b) **HIJING dn/dη happens to be close! p_T of baryons too small !**

c) **Baryon production is not difficult. But balancing the yields of hyperons (Ω,Ξ,Σ and Λ) and protons requires new dynamics different from string models.**

STAR Data: $\bar{p}$ = 20.5 +- 0.5; Λ = 17.0 +-0.4; $\bar{\Lambda}$ = 12.0 +- 0.3

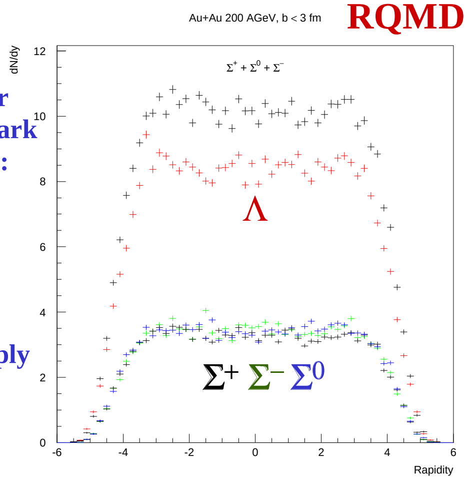
Baryon Production from Diquark Fragmentation ---- Ruled Out?!

RQMD

Standard string fragmentation for baryon formation through diquark tunneling out of string potential:

$e^{-\pi m^2/\kappa}$ dependence
m(ud-1) = 0.49 GeV
m(ud-0) = 0.42 GeV
predicts Σ=0.35Λ.

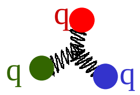
If Σ=0.35Λ, STAR data would imply Ξ>Σ , very unlikely !



Where Does the Mass of Baryons Come From and How Is the Baryon Flavor Determined?

Entities in Production Processes are:
Diquark-Masses
Constituent Quark Masses → Baryon Mass and Flavor
Strong Mass Suppression if they have to be produced from dynamical QM tunneling!

High Energy Density Gluonic Fireball:
Baryon Mass: → Mostly from gluon junction !
(preexist in high density gluon field)
No large mass penalty is needed !



Baryon Flavor: → string break for q-qbar production !
(the quark mass involved is not the constituent mass)

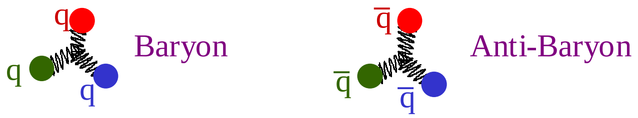
A Novel Mechanism?!

Basic Assumptions:

1) Nuclear Matter at Mid-rapidity – Gluon Dominant! (Low Net Baryon Density) and Gluons Strongly Interacting (Effective DOF unlike that of Naive QGP)

2) Gluon Junction Can be a Seed for Baryon Formation and Dynamically Create a Baryon Number

3) The Baryon Flavor is Determined by the Flavors of Quarks Connected to the Gluon Junction.



4) Baryon Production is Determined by the Probability of Gluon Junction Having Three Quarks or Anti-quarks in Hadronization and Probability of gluon junction topological configuration in a hot gluon fireball?

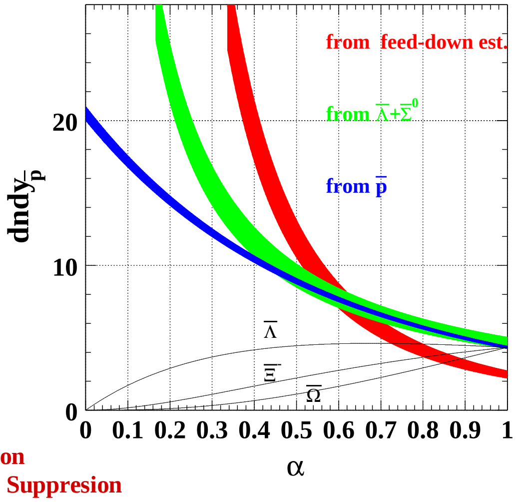
Vance/Gylassy previously proposed Baryon-AntiBaryon production from dynamical gluon junction pair production from string fragmentation!

A Consistent Picture for anti-Baryon Production

Key Prediction of the Model:

$$\overline{\Lambda}^0 = \overline{\Sigma}^0 = \overline{\Sigma}^+ = \overline{\Sigma}^-$$

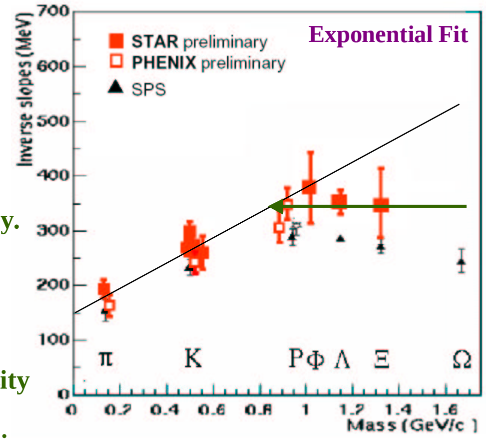
$$\frac{\overline{\Lambda}^0}{\overline{p}} = \frac{\overline{\Xi}}{\overline{\Lambda}^0} = \alpha \geq \frac{\overline{\Omega}}{\overline{\Xi}}$$



The important constraint will be from Ξ and Ω measurement:
Topological Model Predicts:
Ξ-bar = 3
Ω-bar < 1-2

Σ^0 and Λ^0 Measurement:
Ratio: ~ 1.0 – Novel Mechanism
~ 0.35 – String Fragmentation
~ 0.67-0.75 – Thermal Mass Suppresion

Slope Parameters of Baryons



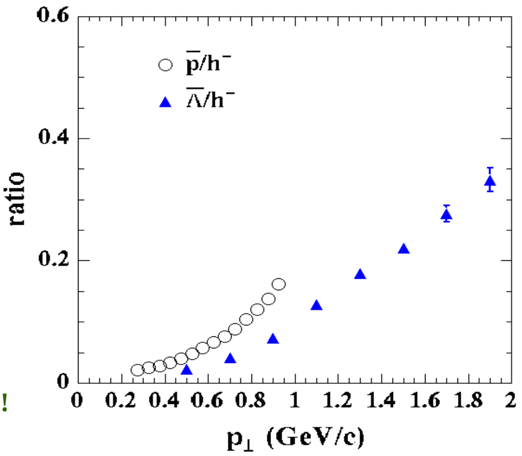
Hydrodynamic:
Mass dependence –
common expansion velocity
Strange baryons freeze-out early.

Gluon Junction Picture:
Baryon from gluon junctions
approximately the same m_T
indicative of gluon energy density
at the baryon formation.
effect due to final state interactions
small → same slopes regardless of hadronic interaction
cross sections.

Baryon to Hadron Ratios vs p_T

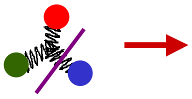
The total Baryon/h
is not significantly
increased !
STAR p/h^- ~ 7%
e^+e^- E_{cm}=29 GeV
p/h^- ~ 7-8%

More baryons are
produced at high p_T
at RHIC:
source is hotter or
final state interaction!

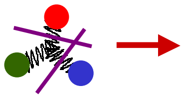


In the proposed baryon production picture:
Hot source = partonic interaction → large p_T of baryons

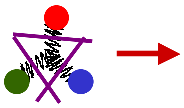
Schematic Representation for Baryon Number Transport Dynamics



Di-quark and quark Fragmentation
Leading baryon + meson

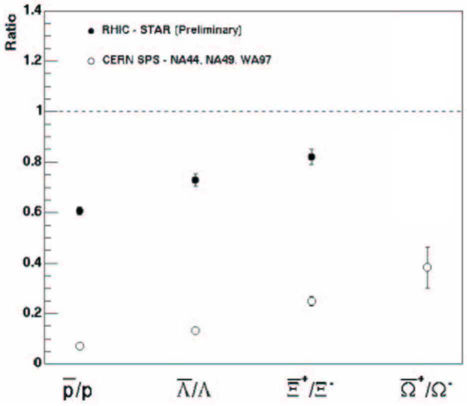


Three quark Fragmentation
Leading baryon + meson + meson



Gluon Junction Fragmentation
Leading meson + meson + meson and a Baryon

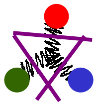
Anti-Baryon to Baryon Ratios



How is baryon number transferred to Ω? at SPS!

Scenarios for Baryon Number Transport to Hyperons

Direct Transport Through Gluon Junctions …



$\longrightarrow$ $\Omega + K + K + K + (X)$

Indirect Transport Through Pair Production Modified by Baryon Chemical Potential …

$\Omega\,\overline{\Omega}$ and $\Omega\,\overline{\Xi}$ K

$\Xi\;\overline{\Xi}$ and $\Xi\;(\overline{\Lambda}\,/\,\overline{\Sigma})$ K

$\Lambda\;\overline{\Lambda}$ and $\Lambda\;(\overline{p}\,/\,\overline{n})$ K

Net Baryon Density Increases the Associated Production and Transfers net baryon number to multiply-strange baryons !

Event-by-Event STAR Hyperon Correlations Doable with STAR TOF and SVT Upgrade !

Summary

- **Gluon Dynamics play an important role in particle production at mid-rapidity at RHIC.**
- **Multi-gluon dynamics, probably gluon junctions, may contribute to increased Λ, Ξ and Ω yields.**
- **The dynamics of string fragmentation model cannot reproduce the baryon and hyperon yields. The mass dependence in di-quark tunneling is problematic.**
- **Baryon production from gluon junction hadronization may be topological: the rate depends on topological configuration probability, not strongly on the mass of the hyperons.**
- **Future measurement on event-by-event hyperon correlations can shed light on mechanisms of baryon number transport to hyperons**