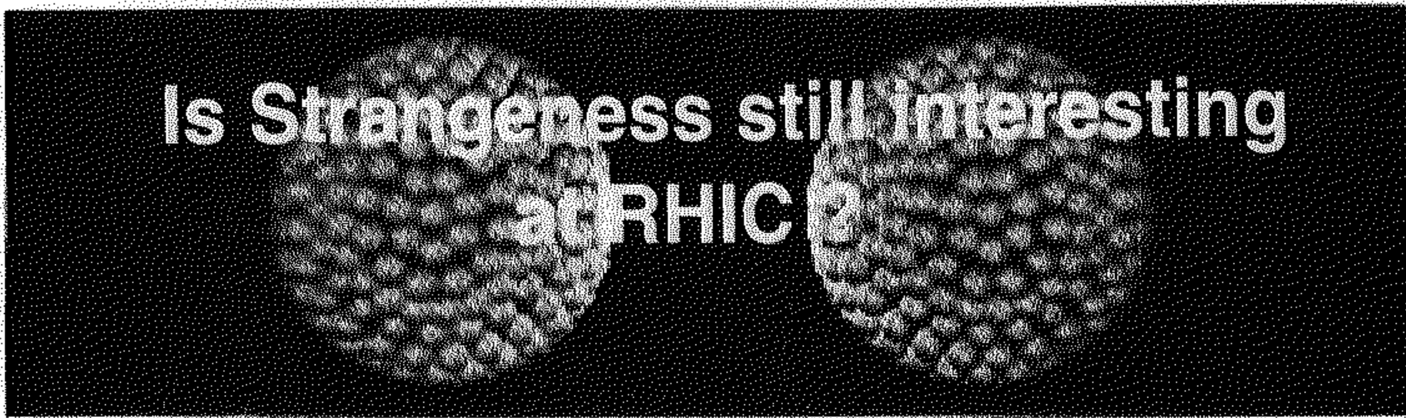
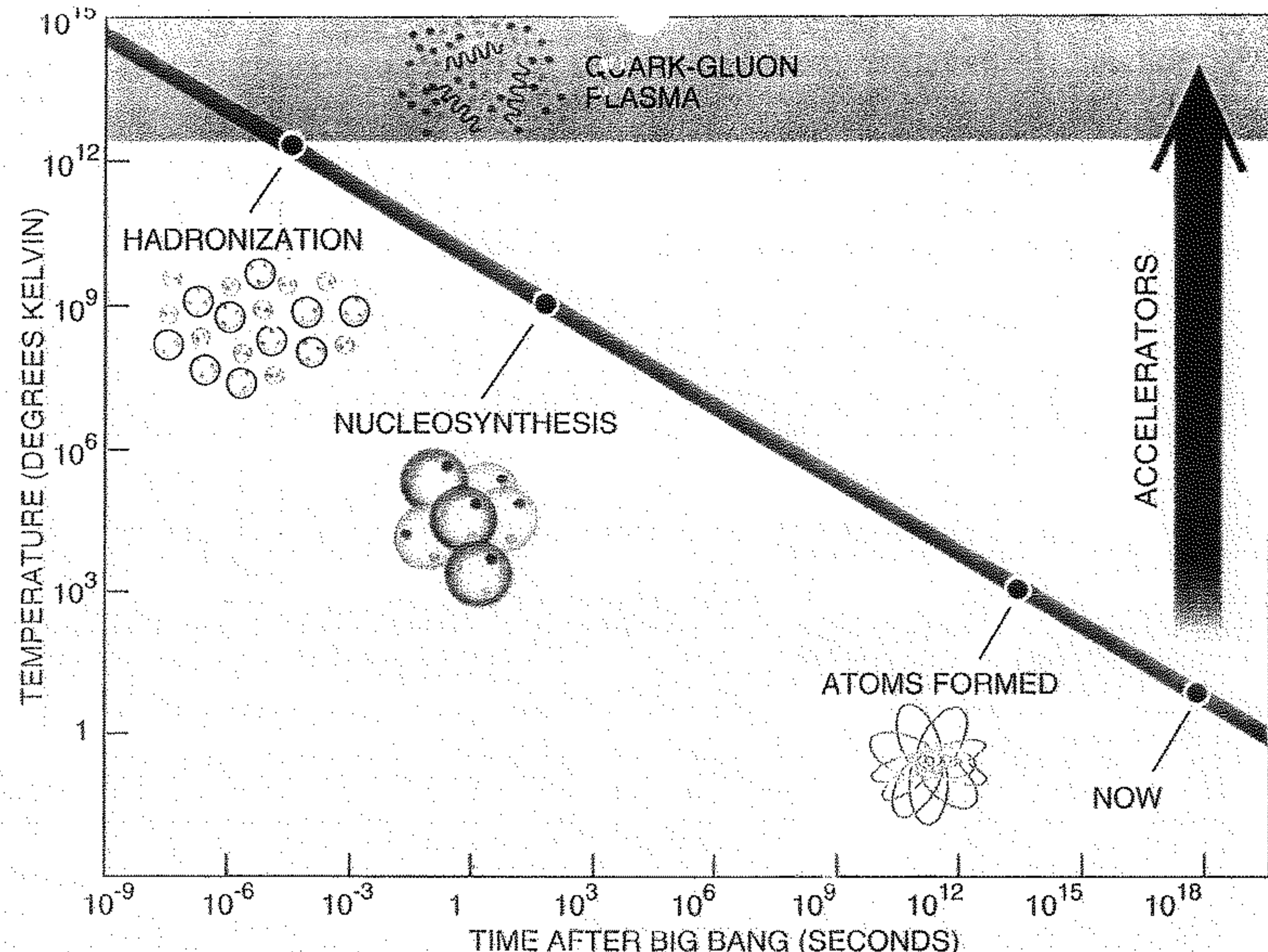
Is Strangeness still interesting at RHIC ?



Rene Bellwied
Wayne State University

HYPERON 99 Symposium
ember 29, 1999 FERMI

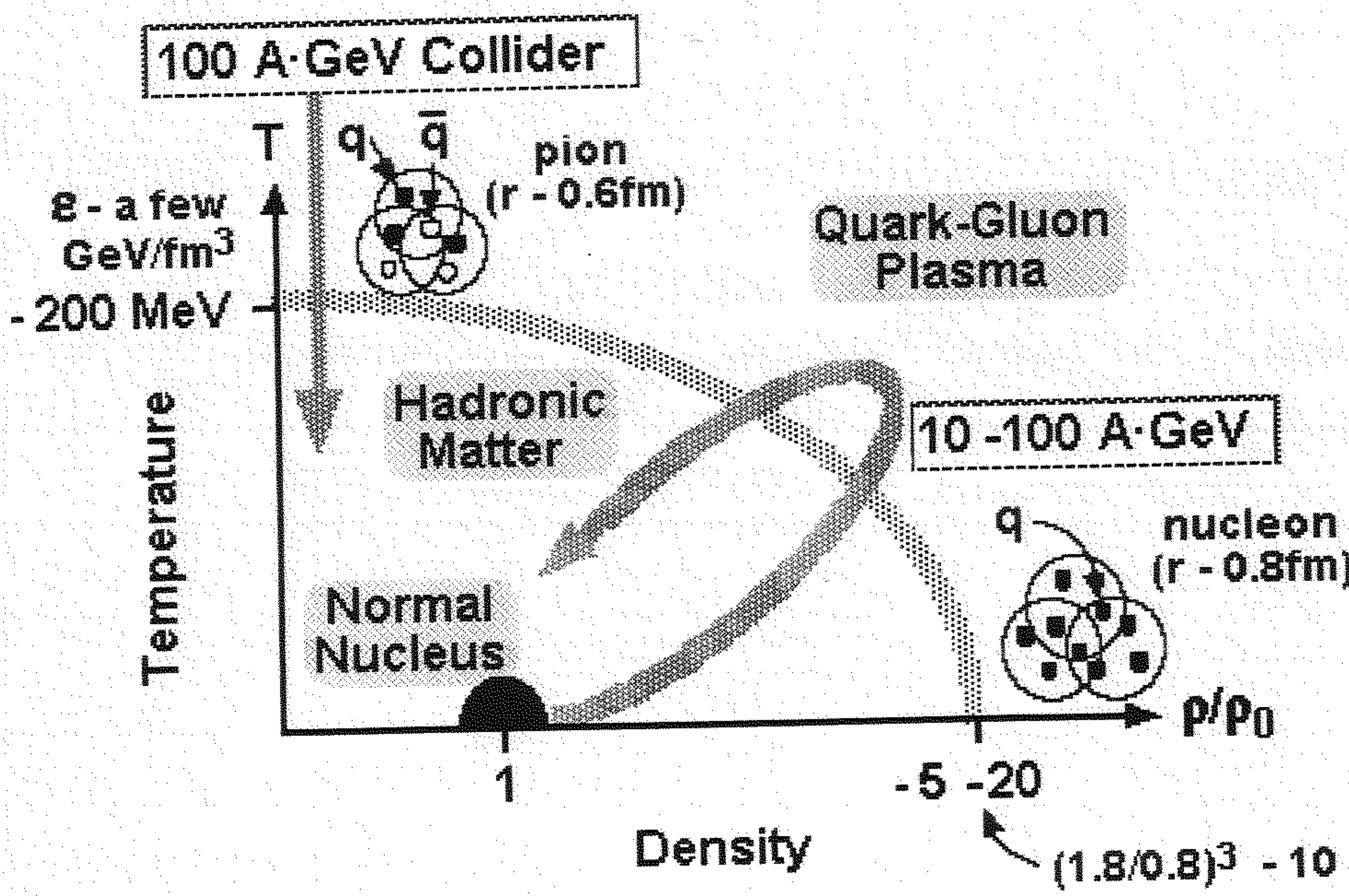


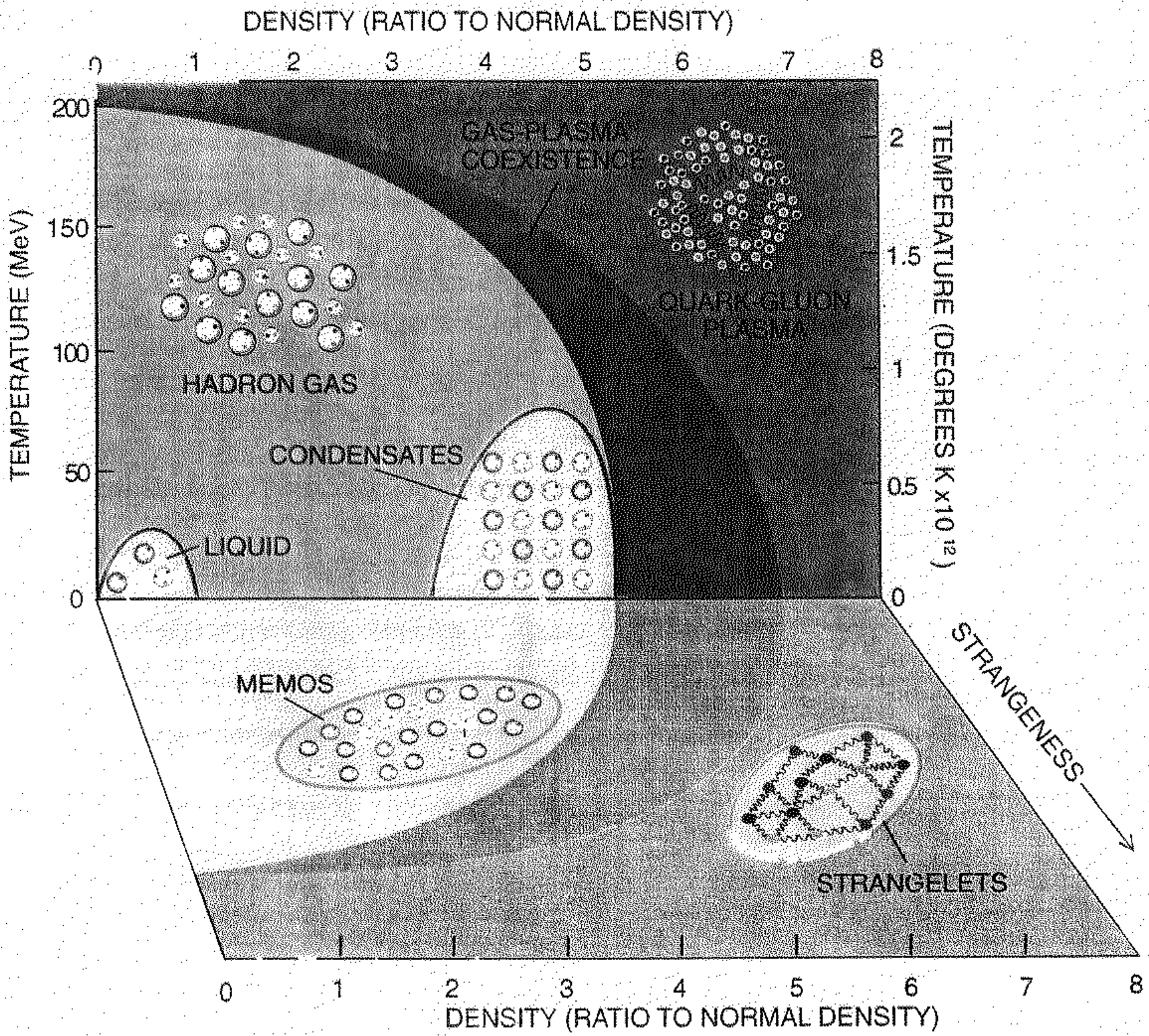
TEMPERATURE OF THE UNIVERSE has been falling since the big bang. During the first microsecond, all matter is thought to have existed as quark-gluon plasma. As the universe expanded and cooled, more complex matter condensed out of the plasma, eventually forming the atoms observable today. Accelerators now under construction should be able to heat nuclei to 2×10^{12} kelvins (200 million electron volts [MeV]), perhaps creating the much sought after primordial quark matter.

The evolution of the Universe in time

Age of Universe	Energy	Matter in Universe
0	10^{19} GeV	"Grand Unification" Electro–Weak–Strong: quarks,gluons, leptons, neutrinos
10^{-35} s	10^{14} GeV	1st phase transition strong: quarks, gluons electro–weak: leptons, neutrinos
10^{-10} s	10^{2} GeV	2nd phase transition strong: quarks, gluons electro: photons weak: leptons, neutrinos
10^{-5} s	0.2 GeV	3rd phase transition strong: hadrons electro: photons weak: leptons, neutrinos
3 min	0.1 MeV	Nuclei
$6 * 10^{5}$ y	0.3 eV	Atoms
$1.5 * 10^{8}$ y	$3 * 10^{-4}$ eV	now, 3 K background

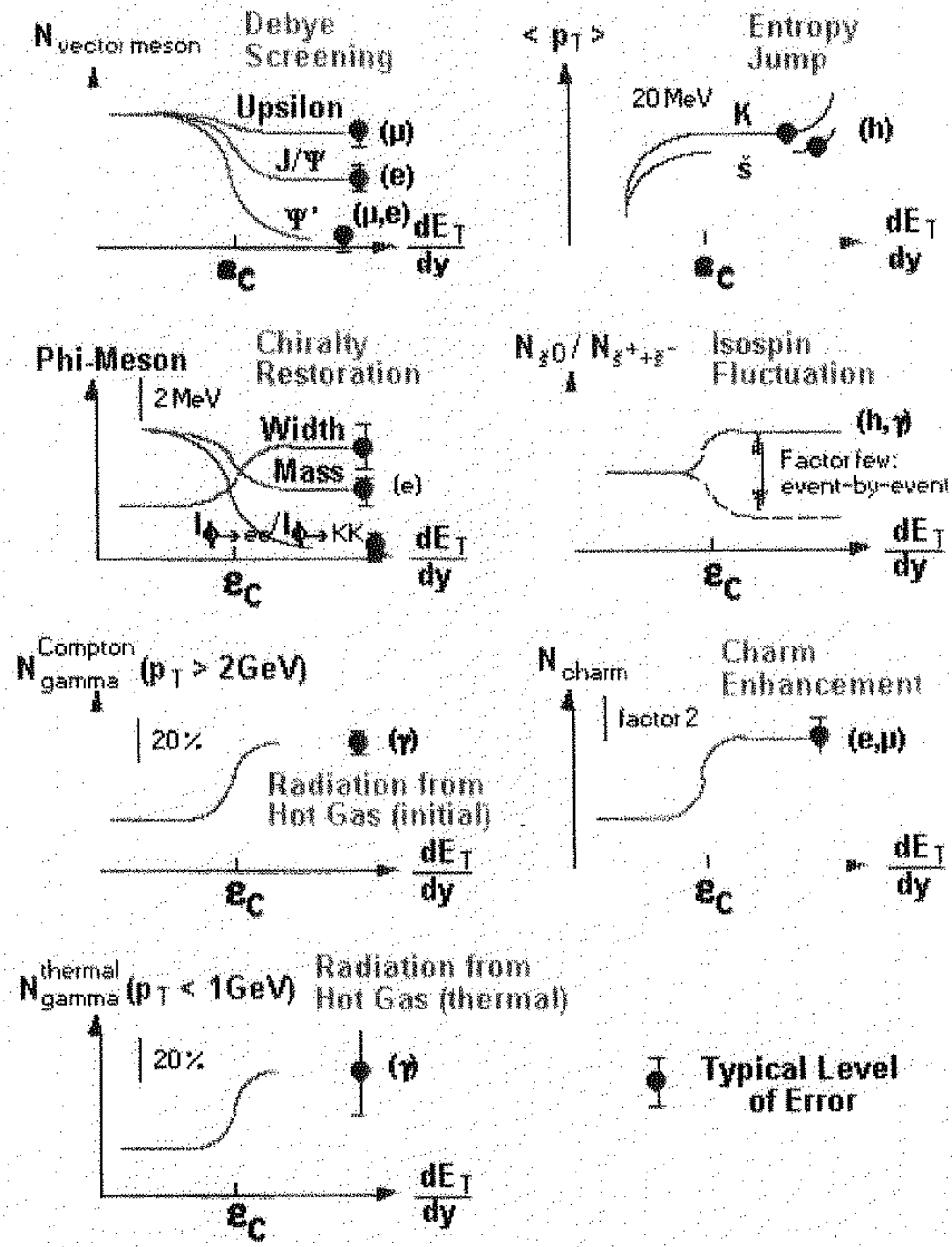
Phase Diagram of Nuclear Matter & Nuclear Collisions





PHASE DIAGRAM renders the nuclear equation of state in graphic form. Nuclear matter in its normal phase resembles a liquid. Increasing the temperature or density "boils" nuclei into the hadron gas phase. Under extreme density but low temperature, nucleons could become "frozen," forming condensates. Further heating or compression may produce the plasma phase, which would consist of free quarks and gluons. The gas and plasma phases may exist simultaneously over a wide region. Particles that have strange quarks, such as multistrange, metastable objects ("memos") and strangelets, may also form.

Signatures of Quark-Gluon Plasma



Why is strangeness enhancement and equilibration so uniquely linked to the plasma ?

Universe is a slow expanding system which maintains equilibrium by always minimizing the free energy in the system

-> weak interactions allowed to convert u,d to s

HIC are shock wave like interactions with a very short collision time.
Weak processes are suppressed

-> strangeness is a conserved quantum number

Early universe might behave like heavy ion collisions (little big bang)

-> adiabatic equilibration boils off strange quark matter lumps (Alcock (89), Madsen (91))

Relevant issues:
----

a.) equilibration time for hadron gas is long
b.) s–sbar separation in baryon rich regime
c.) in rescattering hyperon production is enhanced over anti–hyperon production
d.) the higher the strangeness content in an elementary particle the less likely its formation in a rescattering process (cascade)

Strangeness can be enhanced through different mechanisms:

In a hadron gas through secondary multiple rescattering.

In a QGP through partial chiral symmetry restoration and/or Pauli blocking.

Strangeness can be equilibrated through different mechanisms:

In a hadron gas through strange and antistrange production in final state scattering.

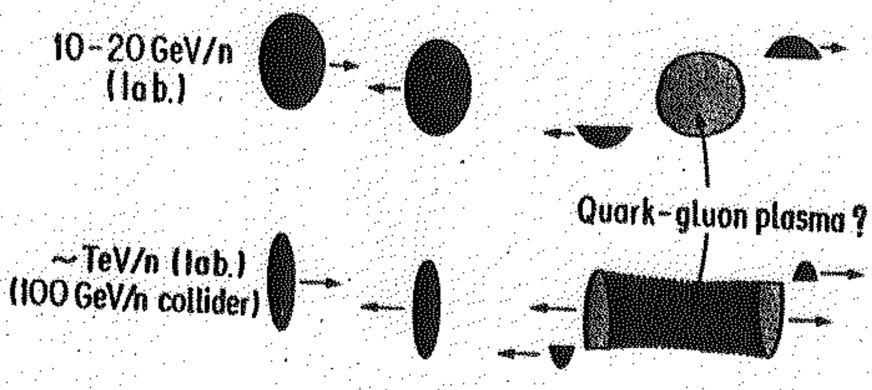
In a QGP intrinsically through the main production process, namely gluon fusion.

Hadron gas time scale: > 30 fm/c
QGP time scale: a few fm/c

TWO WAYS :

STOPPING :

TRANSPARENCY :



STOPPING : EXTREME COMPRESSION

HIGH INCIDENT ENERGY → BARYON RICH QGP

NUCLEAR TRANSPARENCY : EXTREME HEATING

VERY HIGH INCIDENT ENERGY → BARYON FREE QGP

ACCELERATORS: (FOR HEAVY IONS)

PAST:

1970's: GSI - DARMSTADT ($E_{inc} \le 100$ MeV/A) UP TO ^{238}U

BEVALAC - BERKELEY ($E_{inc} \le 1$ GeV/A) UP TO ^{197}Au

PRESENT:

1980's: CERN - GENEVA ($E_{inc} \le 200$ GeV/A) UP TO ^{32}S (^{208}Pb)

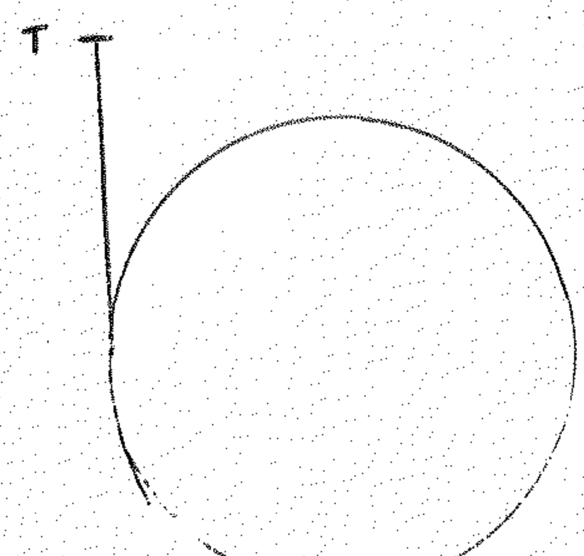
BNL - BROOKHAVEN ($E_{inc} \le 14.5$ GeV/A) UP TO ^{28}Si; (^{197}Au)

FUTURE:

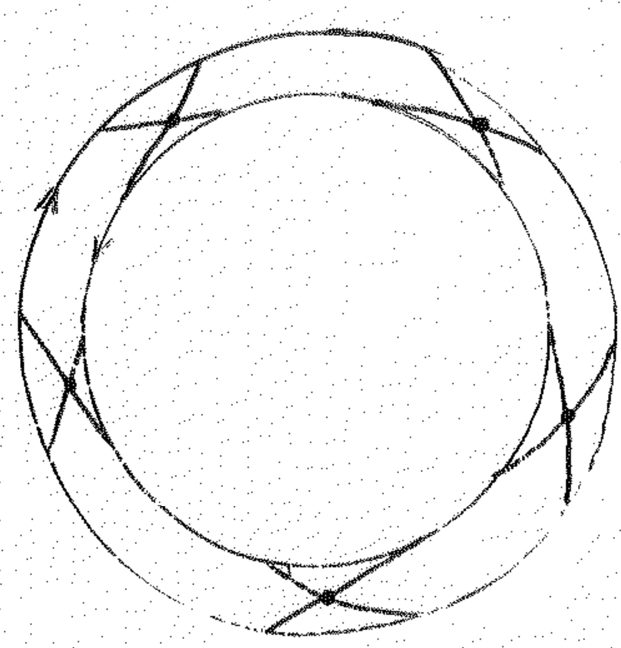
1990's - 2000's: BNL - BROOKHAVEN ($E_{inc} = 100+100$ GeV/A) UP TO Au+Au

CERN - GENEVA ($E_{inc} = 200+200$ GeV/A) UP TO Pb+Pb

CYCLOTRON



COLLIDER



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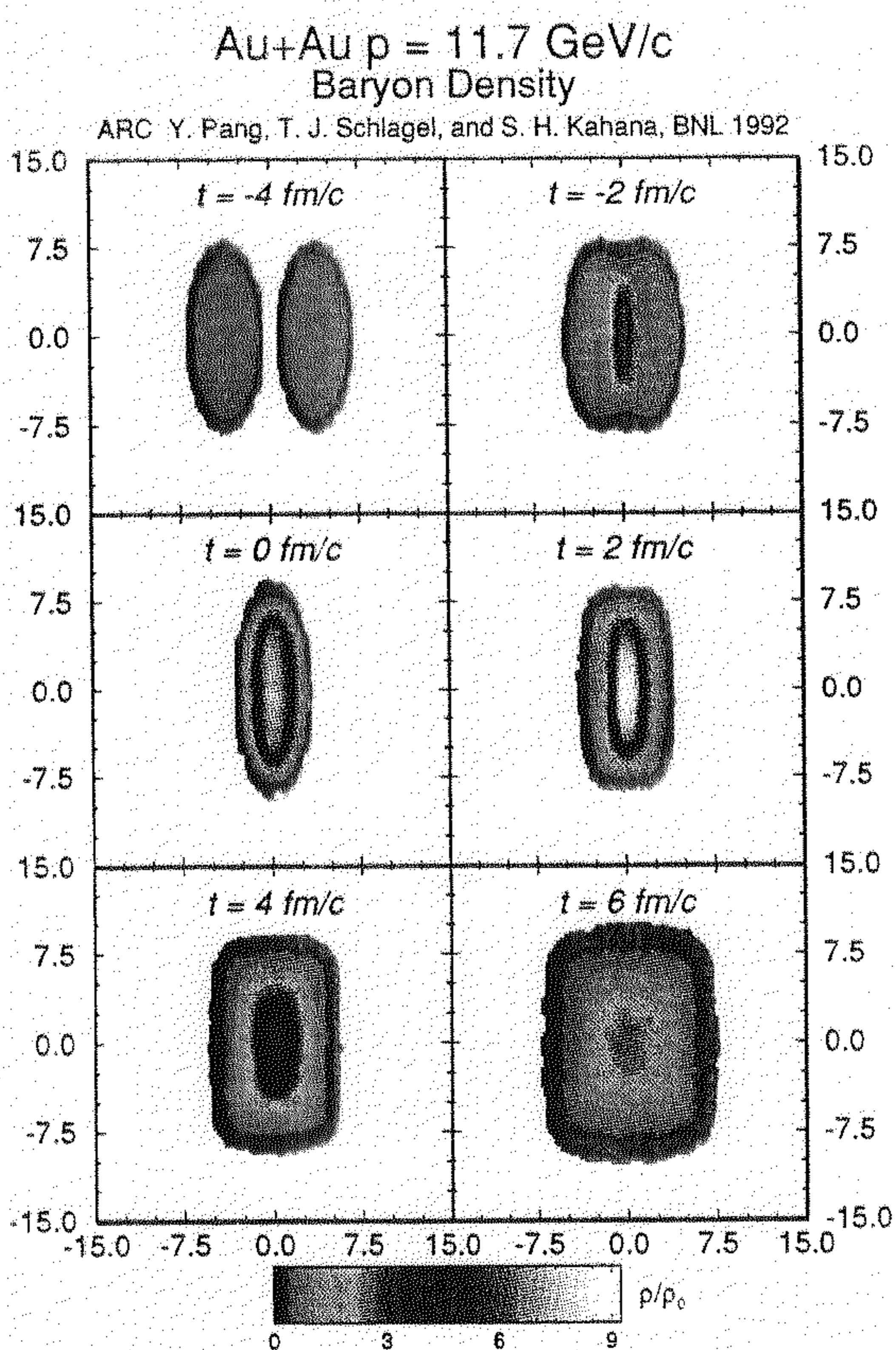


Au+Au p = 11.7 GeV/c
Baryon Density
ARC Y. Pang, T. J. Schlagel, and S. H. Kahana, BNL 1992
t = -4 fm/c
t = -2 fm/c
t = 0 fm/c
t = 2 fm/c
t = 4 fm/c
t = 6 fm/c
15.0
7.5
0.0
-7.5
-15.0
-15.0
-7.5
0.0
7.5
15.0
ρ/ρ0
0
3
6
9

The many facets of strangeness:

1.) strangeness enhancement

2.) strangeness equilibration

3.) strange particle interferometry

4.) strange matter production

5.) strange particle condensation

6.) strange particle polarization

The main issues for RHIC:

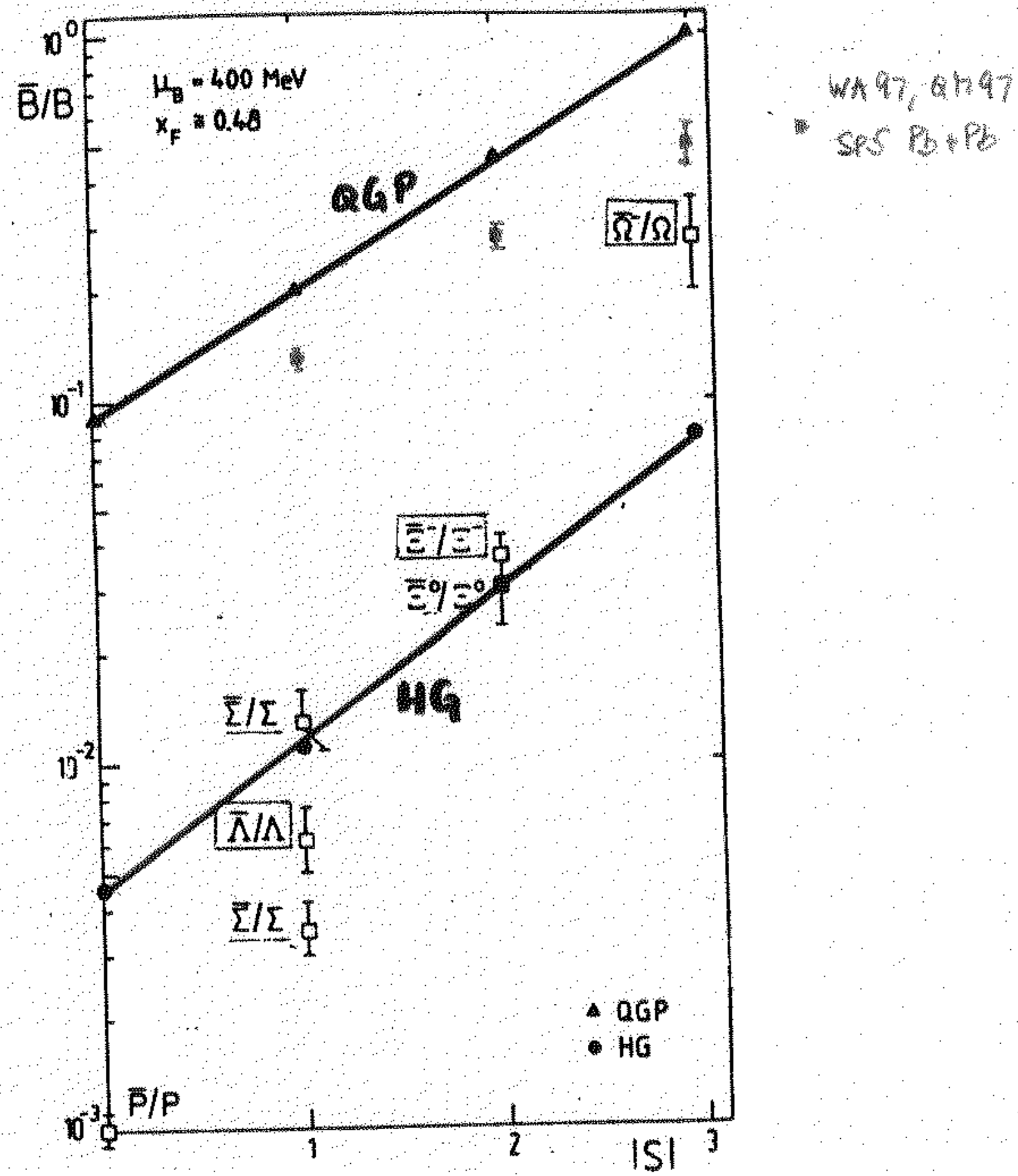
1.) What is left at 100+100 GeV/c ?

2.) What can be measured ?

3.) How do we measure it ?:
RHIC – LHC, STAR – ALICE

Hyperon Ratios as reliable QGP Signature

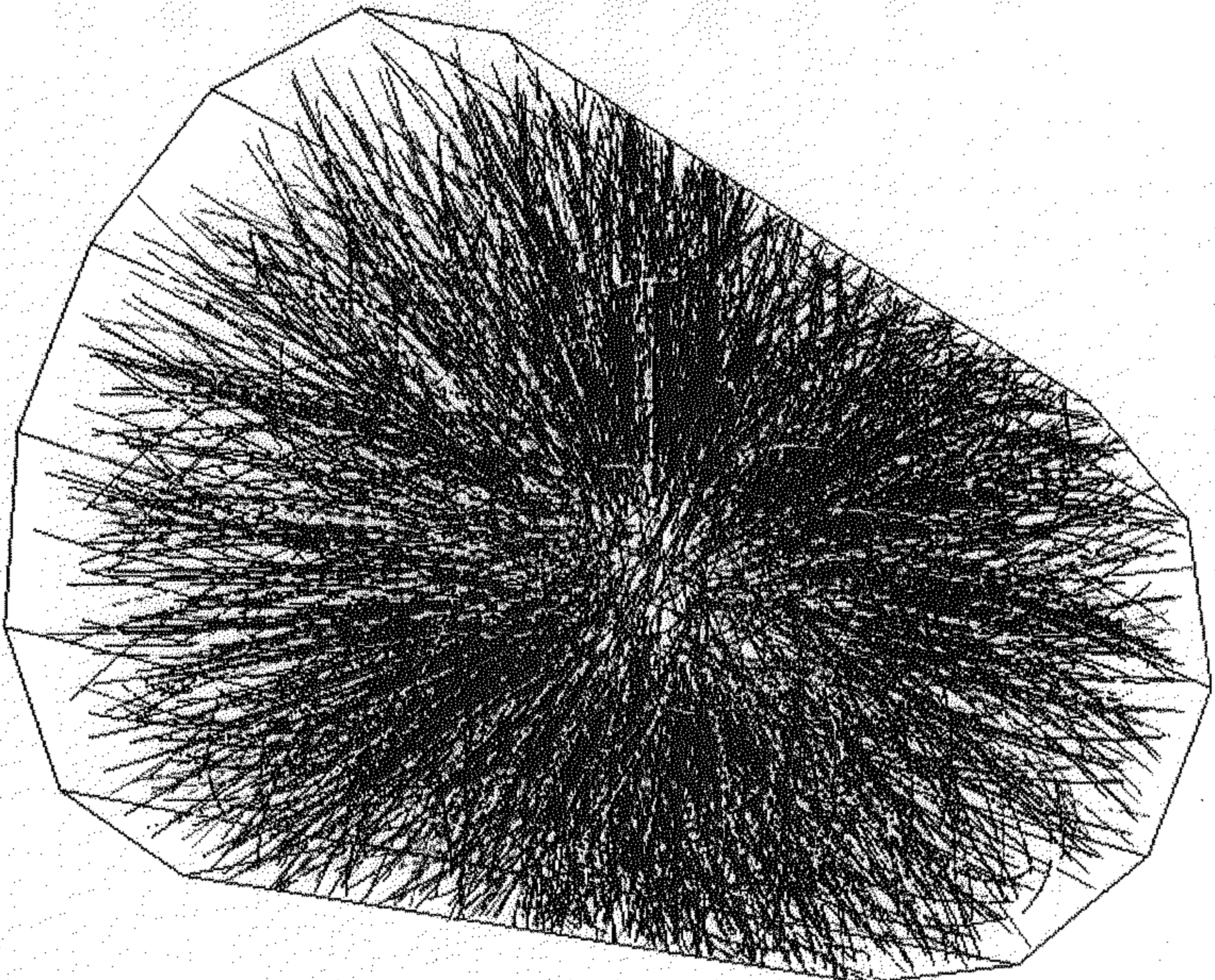
(P. Koch, Z.Phys. C38 (1988) 269)



Main argument:

in HG: high baryon density leads to small Antibaryon yield

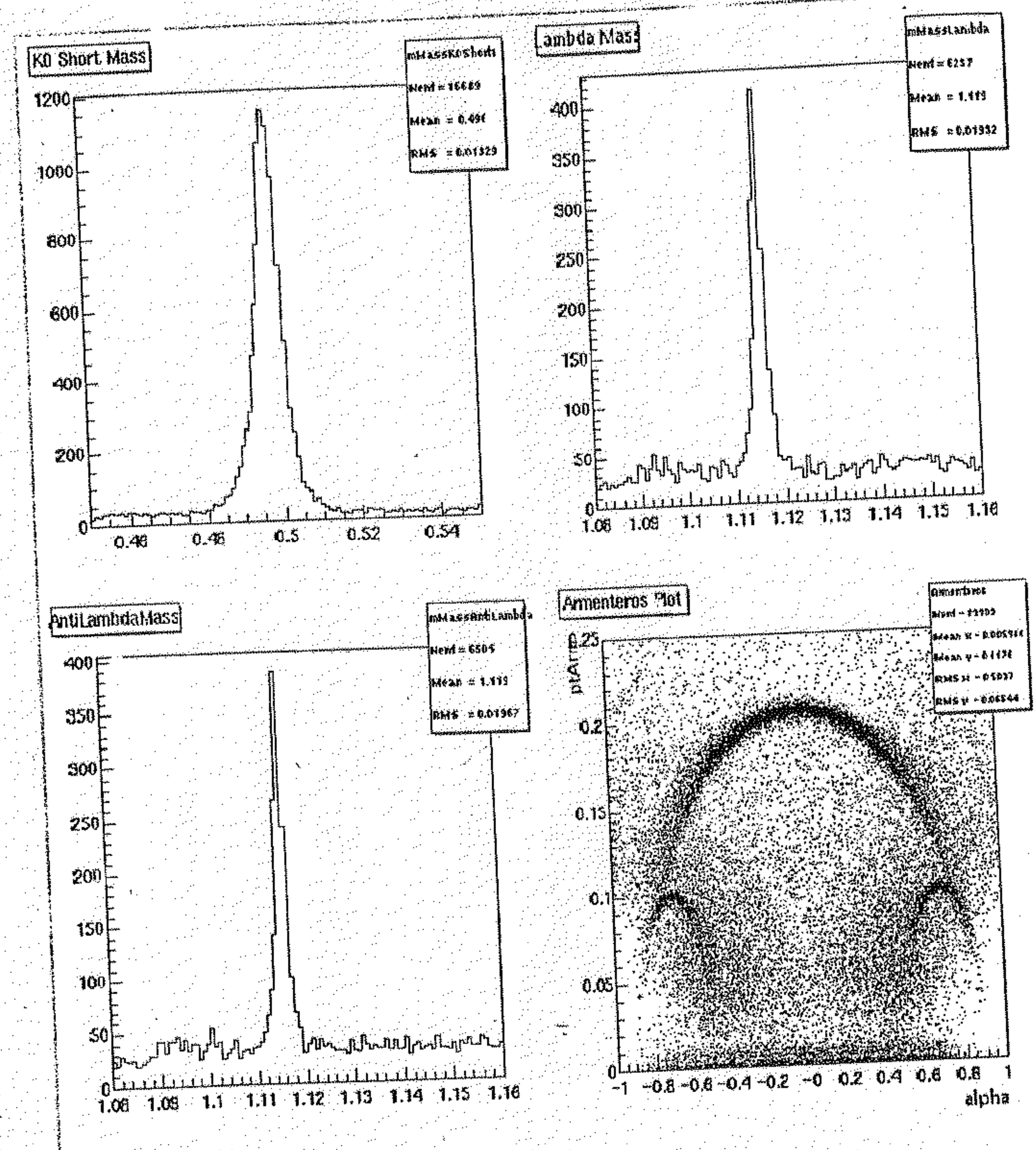
in QGP: gluon interactions lead to enhanced Antibaryon yield



Single Central Au–Au collision at RHIC (100 GeV/A + 100 GeV/A)

~10,000 charged particles produced

~2,500 charged particles detected and identified in STAR detector



α = fractional difference in daughter momenta

P_t = momentum component of positive decay product transverse to parent trajectory

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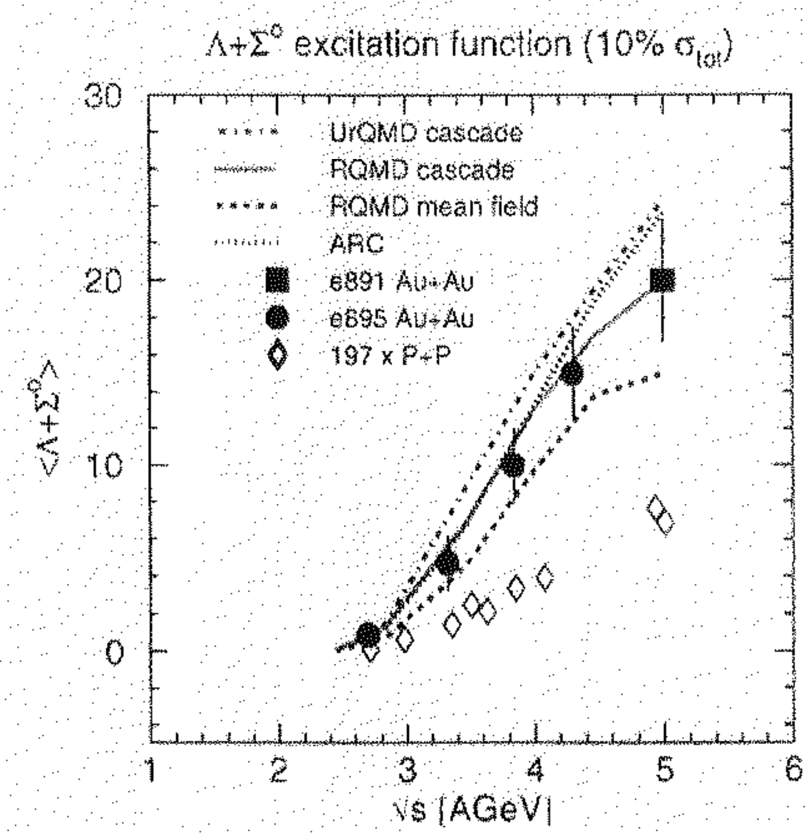
e895 preliminary data, D. Best

Λ Yields



Monotonic increase.

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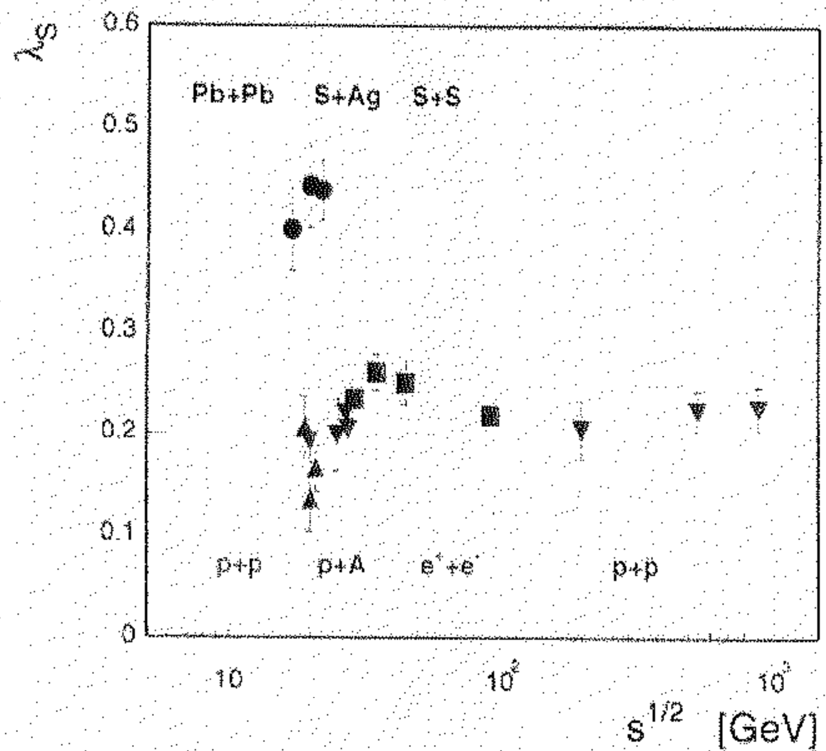
F. Becattini, M. Gazdzicki, J. Sollfrank,
Eur. Phys. J. C5 (1998) 143

NA49/NA35 Pb+Pb, S+A
Total Strangeness Enhancement



$$\lambda_S = \left. \frac{2\langle s+\bar{s}\rangle}{\langle u+\bar{u}\rangle + \langle d+\bar{d}\rangle} \right|_{produced}$$

Strangeness Enhancement Unique Feature of Nucleus - Nucleus Collisions

Strangeness enhancement (WA97) $E = \frac{\sigma_{AA}}{\sigma_{pA}}$

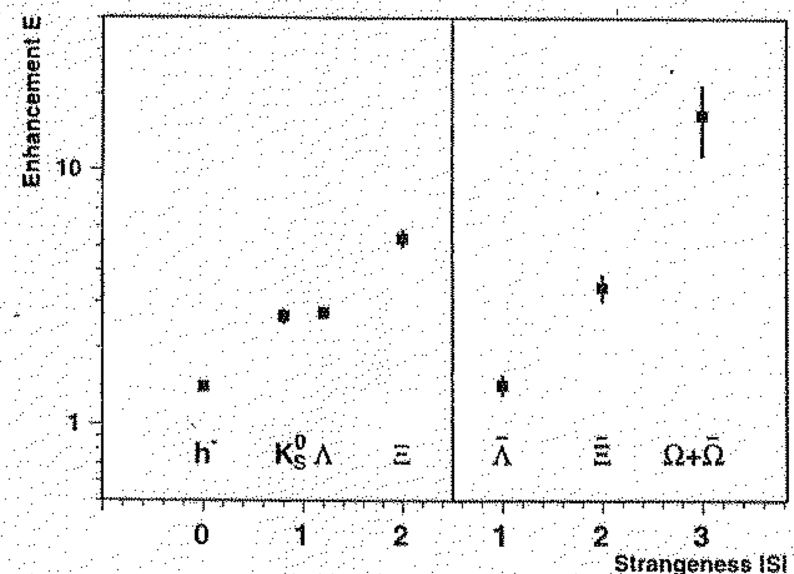
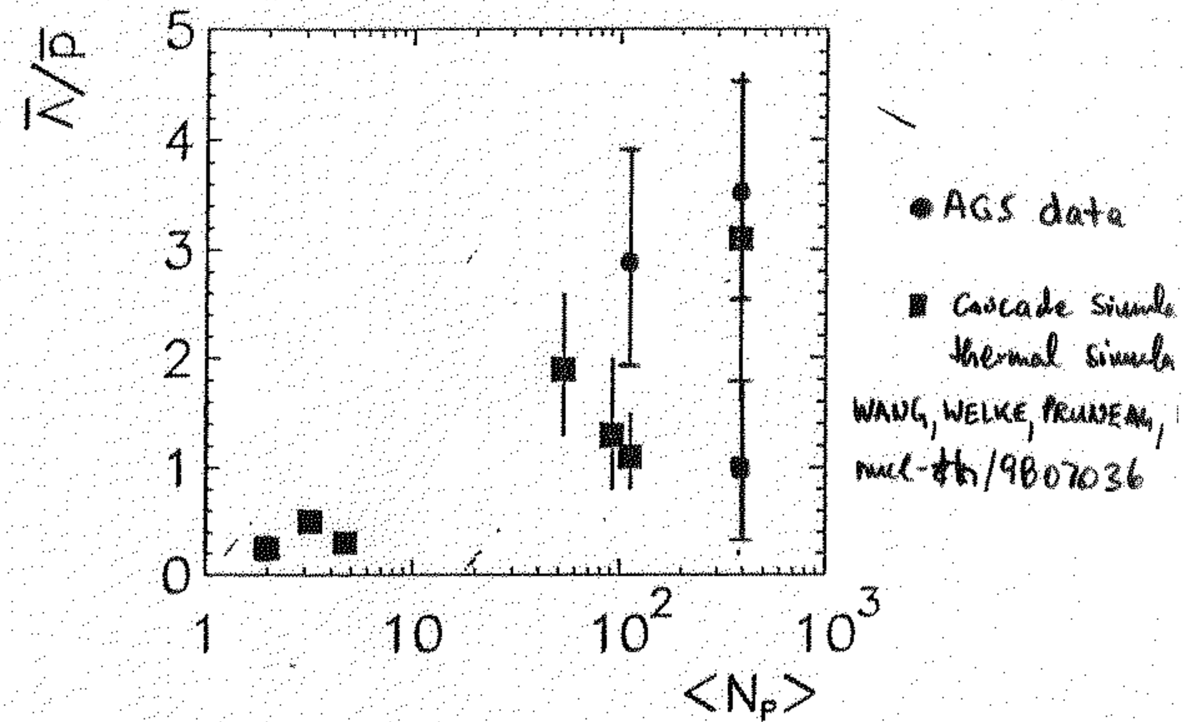


Figure 4. Strangeness enhancement versus strangeness, WA97 collaboration [21].

The $\overline{\Lambda}$ / $\overline{p}$ Puzzle

The CERN measurements (NA35/NA49)



The AGS measurements (E859, E864/E878)

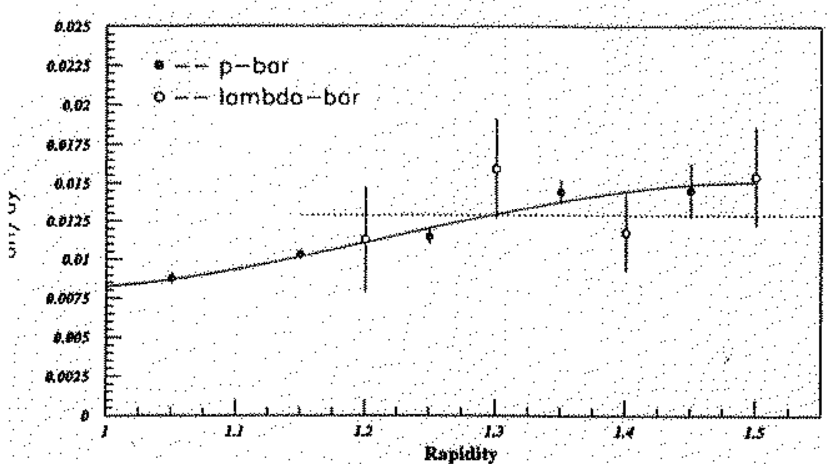
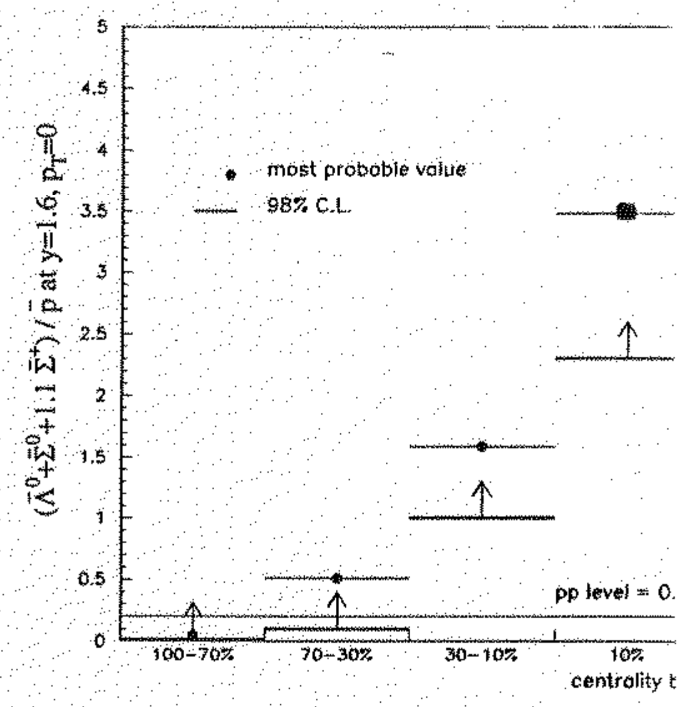


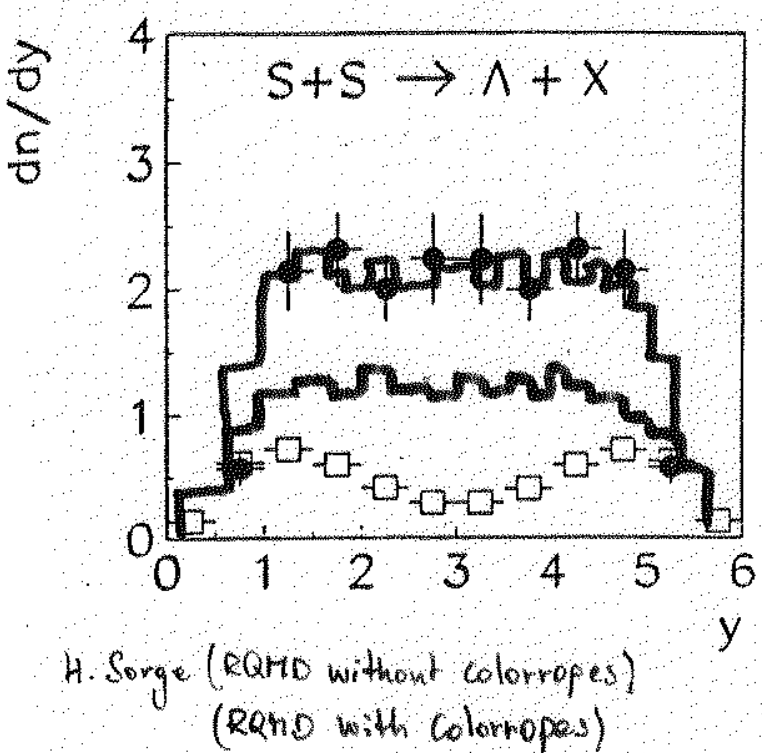
Table 2. $\bar{p}$, $\bar{\Lambda}$ dn/dy and their ratios in the rapidity range from 1.15 to 1.55. The error on $\bar{p}$ dn/dy is statistical only. The errors on $\bar{\Lambda}$ dn/dy and the ratios are statistical (first) and systematic.

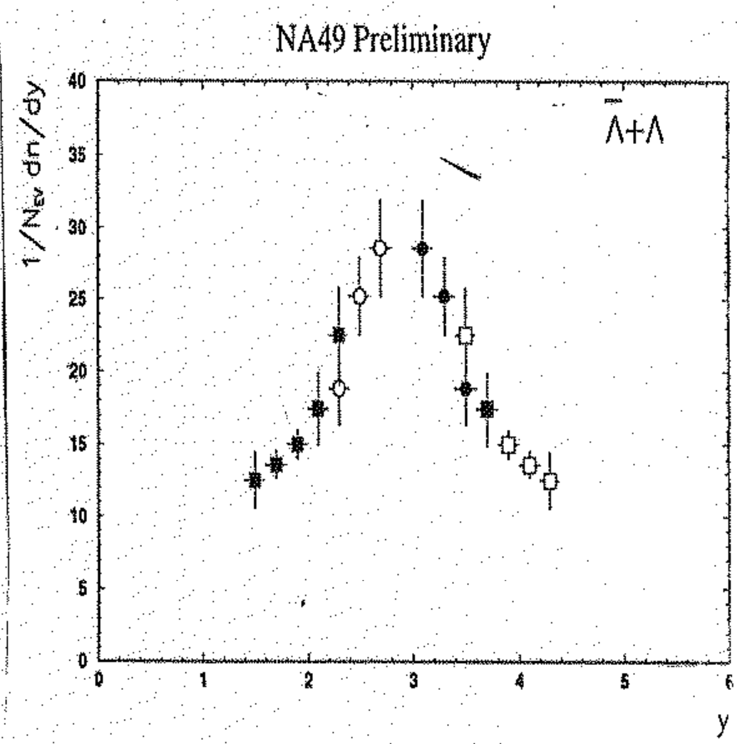
$\bar{p}$ dn/dy	$\bar{\Lambda}$ dn/dy	dn/dy ratio of $\bar{\Lambda}/\bar{p}$ (experimental)	dn/dy ratio of $\bar{\Lambda}/\bar{p}$ (primordial)
0.0127 ± 0.0010	0.0129 ± 0.0025 ± 0.0013	1.02 ± 0.21 ± 0.10	2.9 ± 0.9 ± 0.5



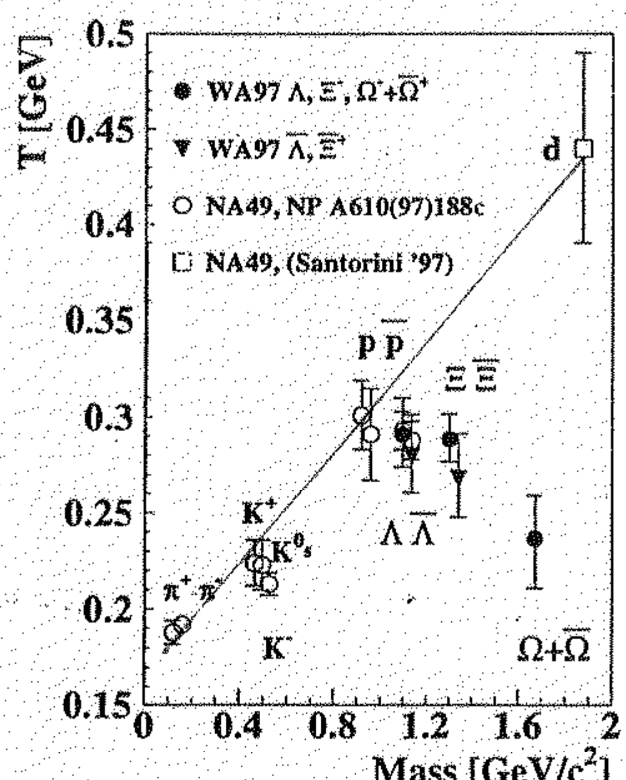
Rapidity and transverse momentum distr. at SPS

Rapidity distributions of Lambda's in S+S and Pb+Pb





Inverse transverse mass slope parameter as f (particle mass)



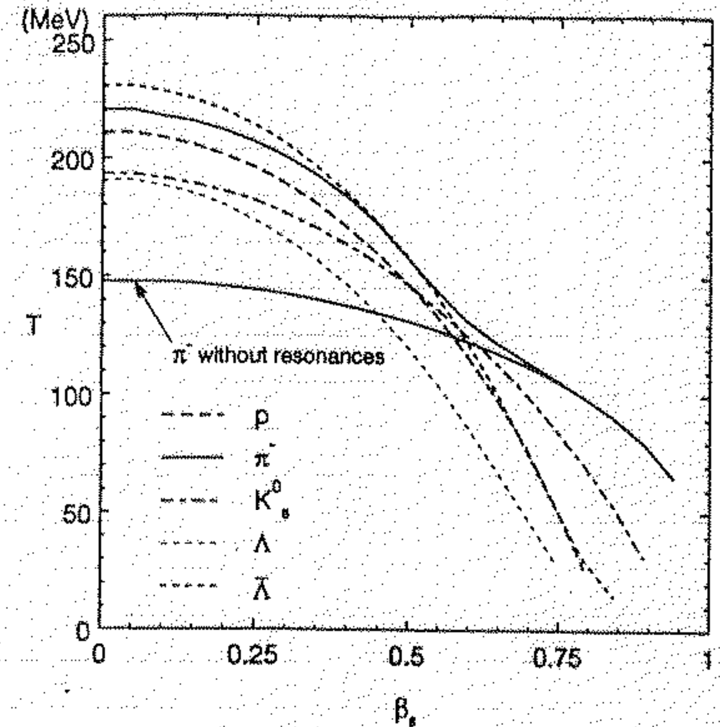


Figure 10: All fit pairs (T, β_f) compatible with the measured $m_\perp$-spectra. Every point on these curves results in a good fit of the computed $m_\perp$ spectrum (including resonance decays and transverse flow) to the respective measured[98,157] particle spectra. From Ref. 96.

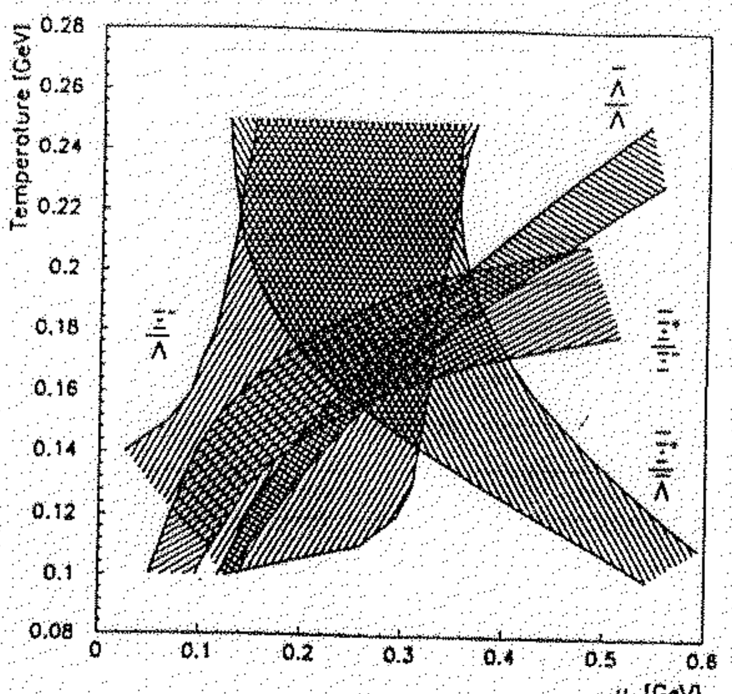
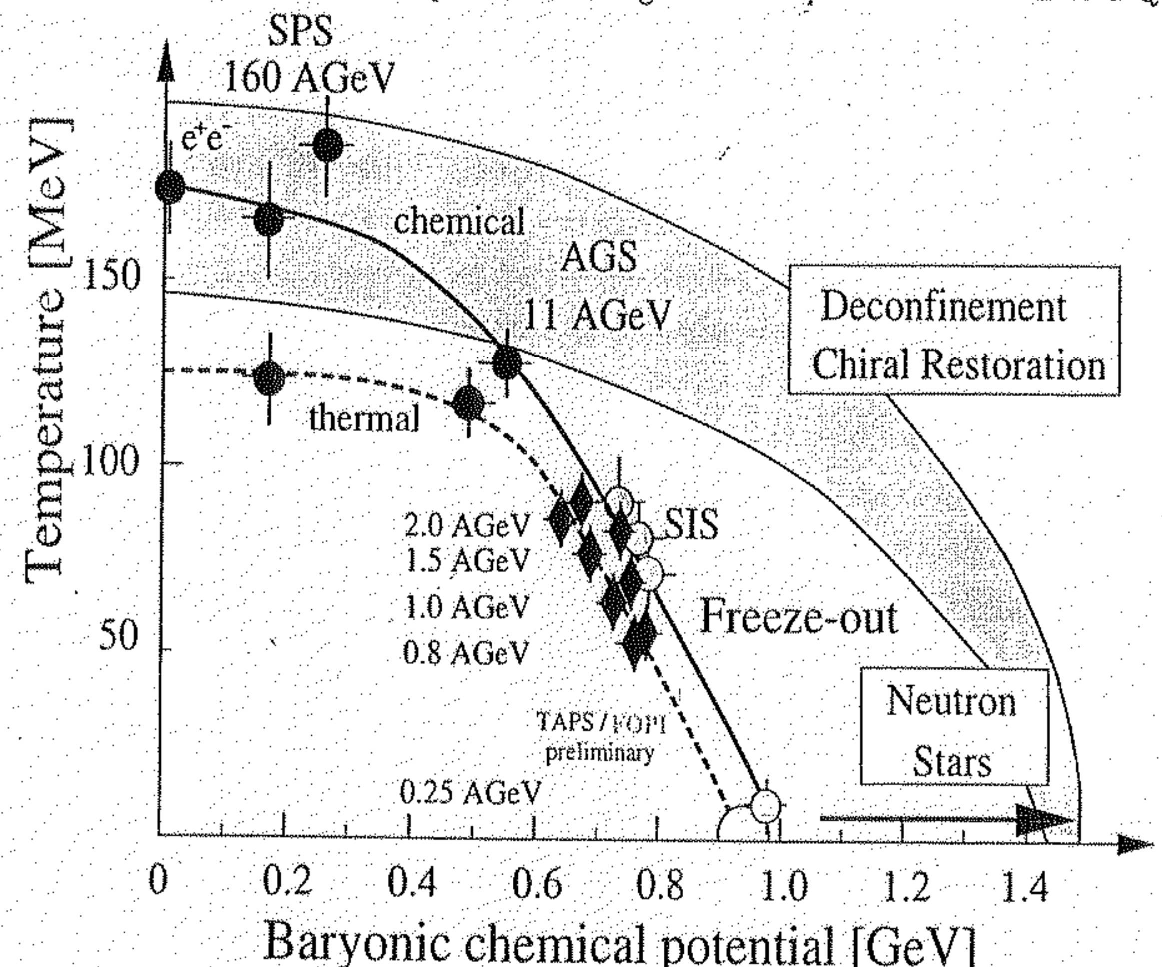


Figure 15: The $T - \mu_B$-plane for strangeness neutral resonance gas wi $\gamma_s = 1$. The values compatible with tl measured particle ratios within one sta dard deviation (after resonance decays) a shown as hatched areas. The commo overlap region defines the boundary of a lowed values for T and μ_B. The Figure wa taken from Ref. 173.

Ulli Heinz - nucl-th/9810056

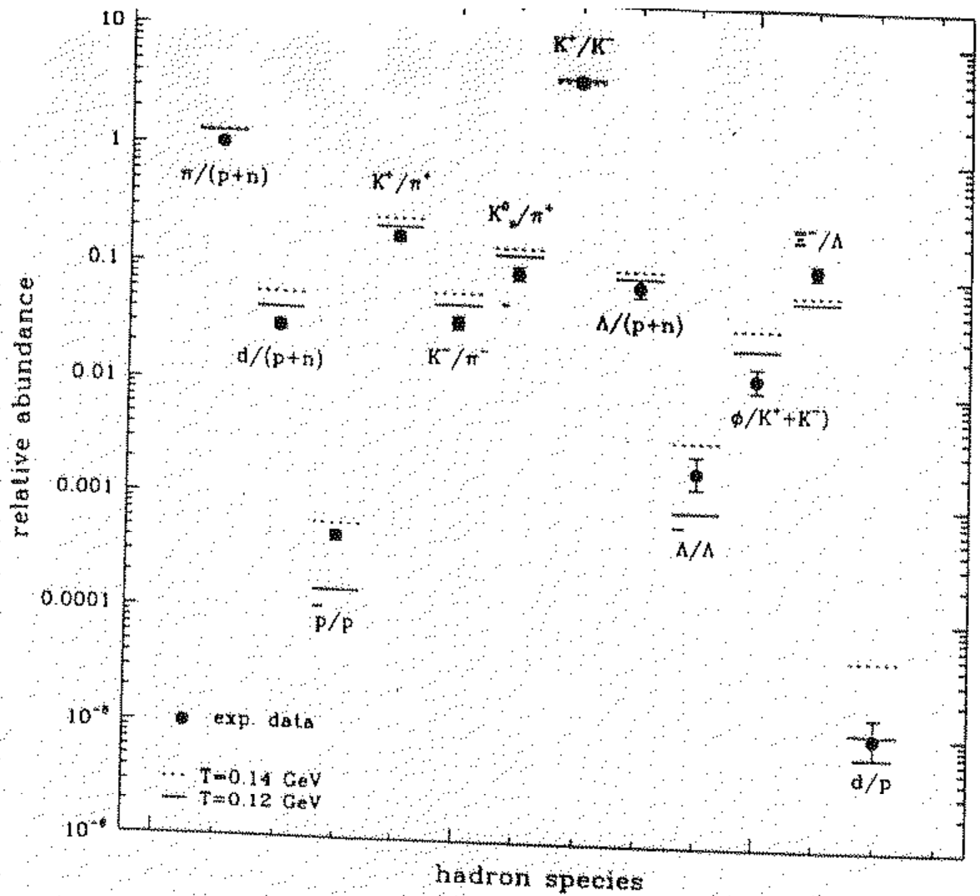
Figure 1. Compilation of freezeout points from SIS to SPS energies. Filled symbols: chemical freeze-out points from hadron abundances. Open symbols: thermal freeze-out points from momentum spectra and two-particle correlations. For each system, chemical and thermal freeze-out were assumed to occur at the same value μ_B/T. The shaded region indicates the parameter range of the expected transition to a QGP.

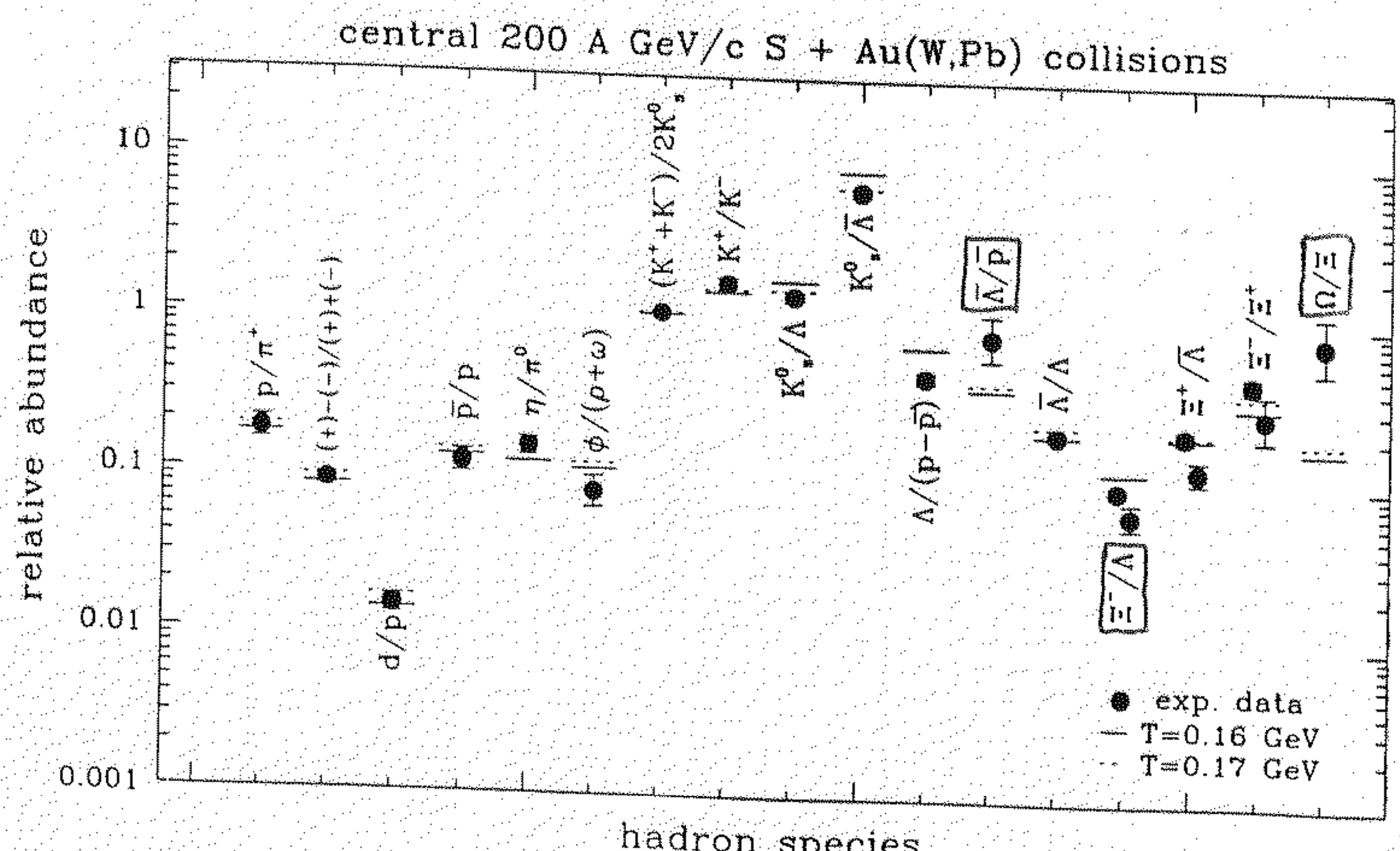


thermal freezeout (T_f) and chemical freezeout decoupled.

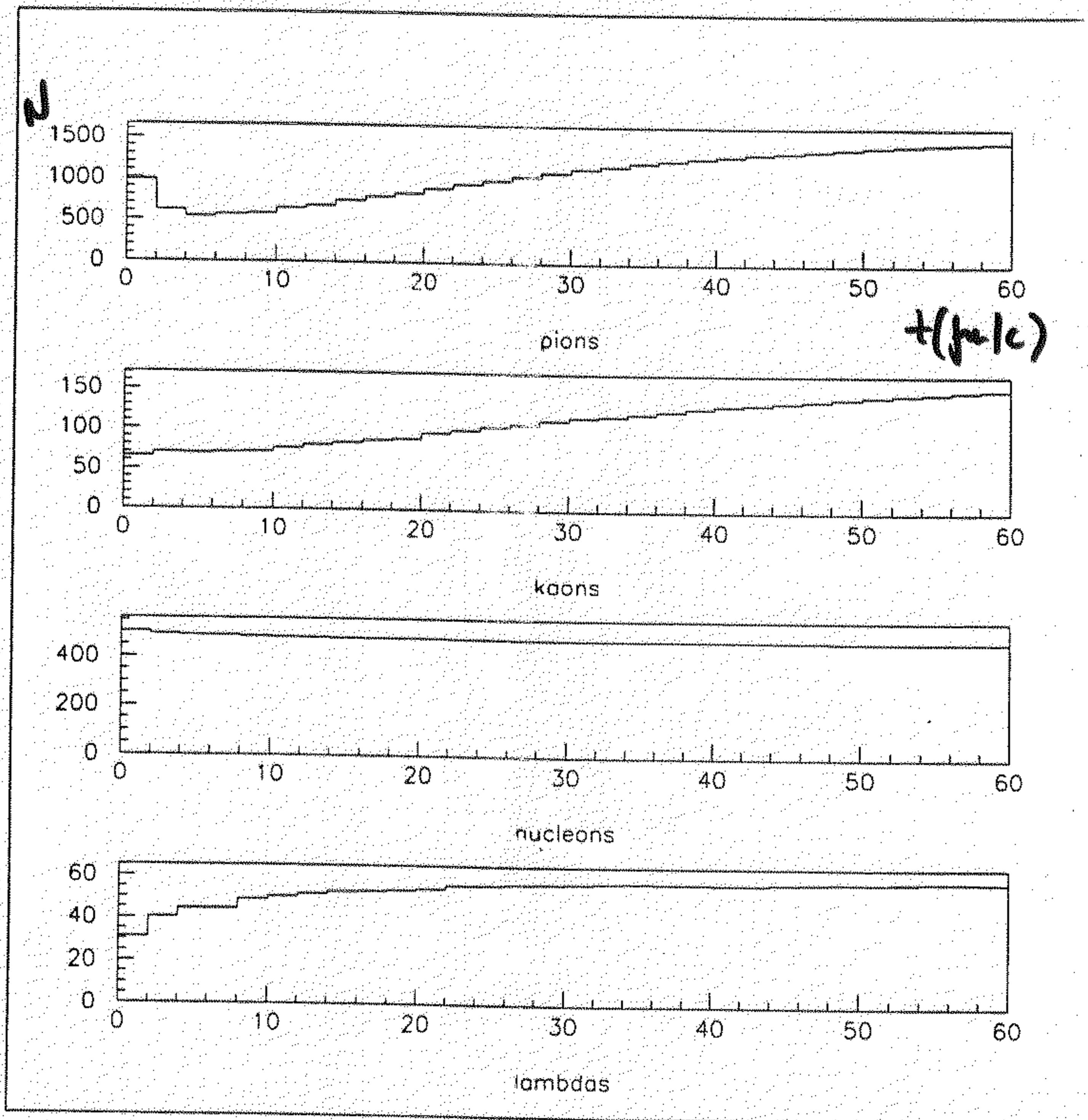
thermal and chemical equilibration

chemical freezeout (T_h) occurs first.


relative abundance
hadron species
exp. data
T=0.14 GeV
T=0.12 GeV
π/(p+n)
d/(p+n)
p̄/p
K⁺/π⁺
K⁻/π⁻
K⁰s/π⁺
K⁺/K⁻
Λ/(p+n)
Λ̄/Λ
φ/(K⁺+K⁻)
Ξ⁻/Λ
d̄/p

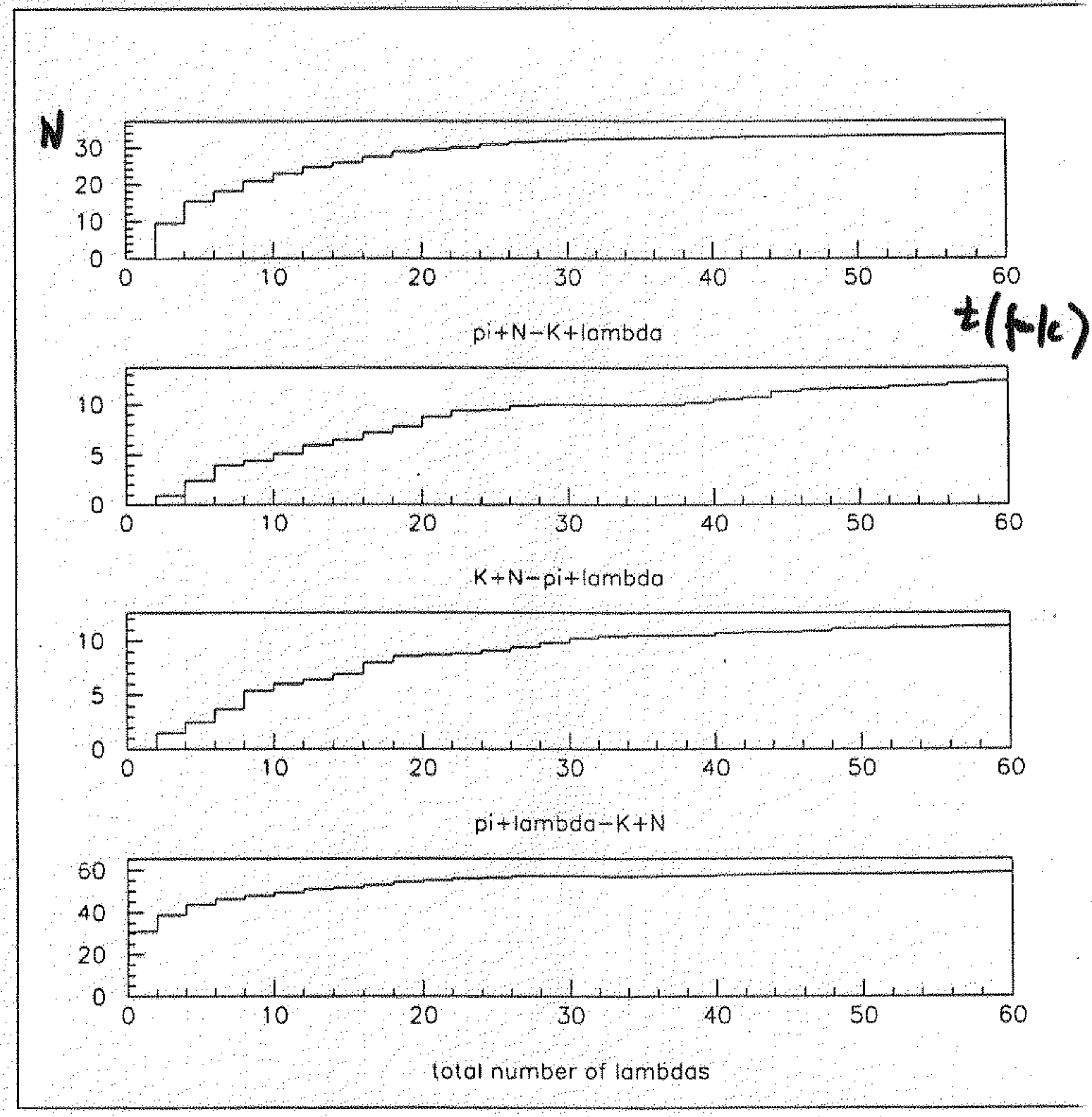

central 200 A GeV/c S + Au(W,Pb) collisions
relative abundance
hadron species
exp. data
T=0.16 GeV
T=0.17 GeV
p/π⁺
(+)-(-)/(+)+(-)
d/p
p̄/p
η/π⁰
φ/(ρ+ω)
(K⁺+K⁻)/2K⁰s
K⁺/K⁻
K⁰s/Λ
K⁰s/Λ̄
Λ/(p-p̄)
Λ̄/p̄
Λ̄/Λ
Ξ⁻/Λ
Ξ̄⁺/Λ̄
Ξ̄⁻/Ξ⁺
Ω/Ξ

Particle abundances as a f(t) after hadronization



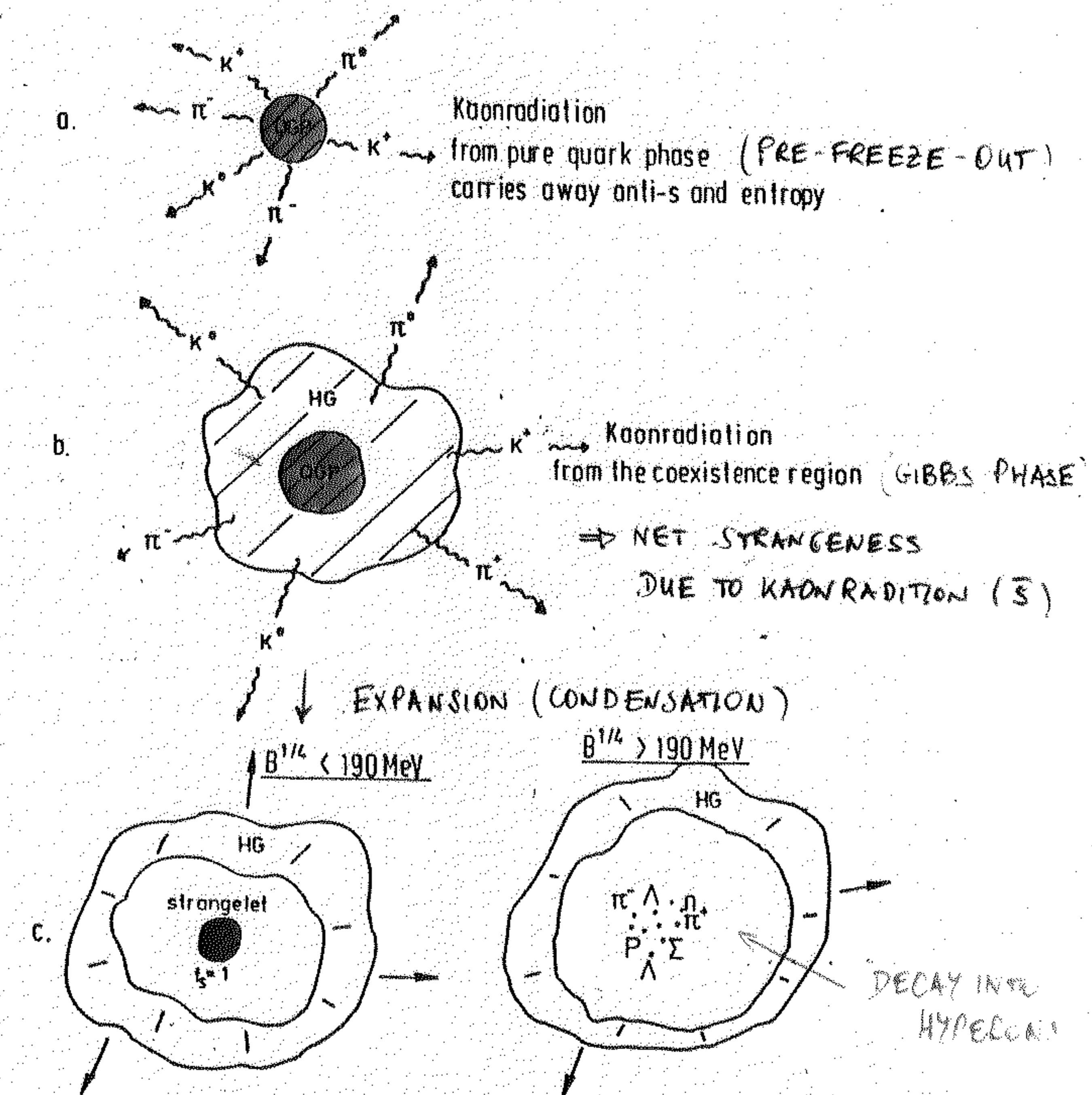
Bellwied, Caines, Humanic (99

Contribution to Λ abundance as a f(t)



Bellwied, Caines, Humanic (9

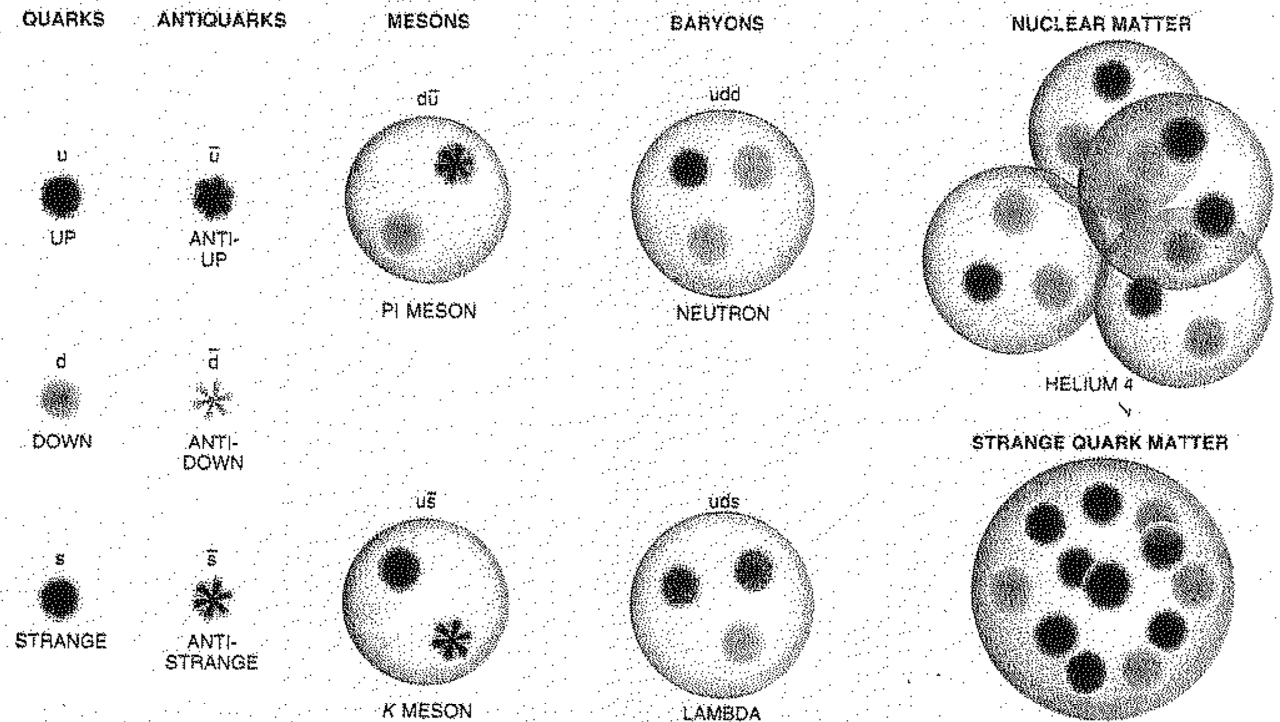
L. GREINER ET AL.
(1988)



● T, S VERY SMALL ($\tau > 10^{-4}$ s) final two scenarios

STRANGELET DECAY
ONLY VIA WEAK
INTERACTIONS
⇒ STRANGELET METASTABLE

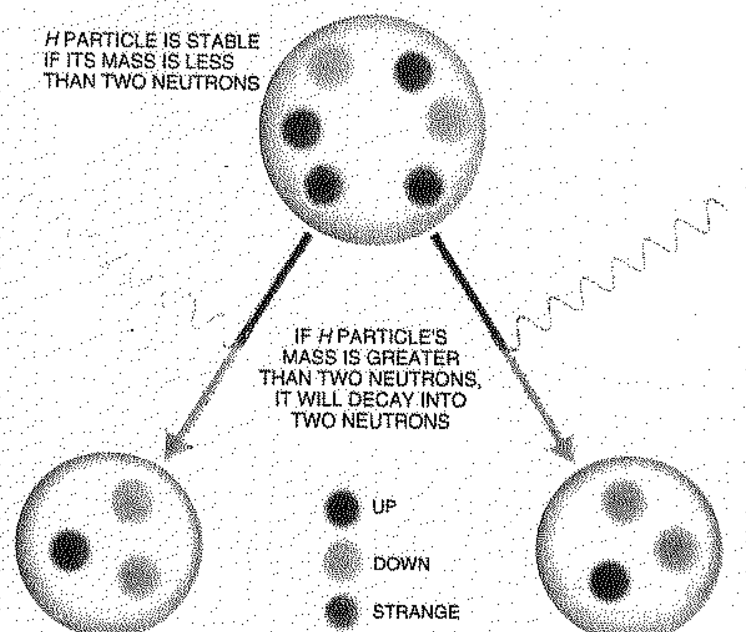
STRANGELET INSTABLE !
(INSTABLE EVEN FOR T=0)



QUARKS IN VARIOUS COMBINATIONS form all known hadronic particles. Only the lightest two, "up" and "down" quarks, are needed to make ordinary matter of the kind that accounts for the world around us and the visible universe. A third type, the "strange" quark, has so far been found only in unstable particles. Under normal conditions, quarks behave as though they were confined in bags in which they can move freely but from which they cannot escape. Baryons consist of three quarks; mesons of a quark and an antiquark. No other combinations of quarks have yet been observed.

Stability of Strange Quark Matter

In 1977 Robert L. Jaffe of the Massachusetts Institute of Technology considered the possibility that particles containing more than three quarks might be stable. He started by imagining a bound state of two lambda particles, each of which is made of an up, a down and a strange quark. He called this state the *H* particle and pointed out that in order for it to be stable it would have to weigh less than two lambda particles. Otherwise, it would quickly decay into two lambdas. He also realized that the *H* particle must weigh less than two neutrons for it to be absolutely stable. If not, the two strange quarks would each decay via the weak interaction into a down quark. The resulting quarks could then form two neutrons. Unfortunately, accurately calculating the mass of the *H* particle from the Standard Model is beyond the current ability of physicists.



H–Dibaryon searches: Past, Present, Future

H - Search experiments

Laboratory		Reaction	
BNL *	9	(K^-, K^+), $\Delta S = -2$	6
CERN	1	Light Hadroproduction	9
FNAL	2	Relativ. Heavy Ions	4
FSU **	4		
KEK *	3		

Decay Mode		Results	
$H \to \Sigma N$	10	Negative (UL)	10
$H \to \Lambda\pi p$	3	"Positive"	4
Indep.	6	Analysing	2
		Running/Future	4

* Incl. running/future ** Former S.U.

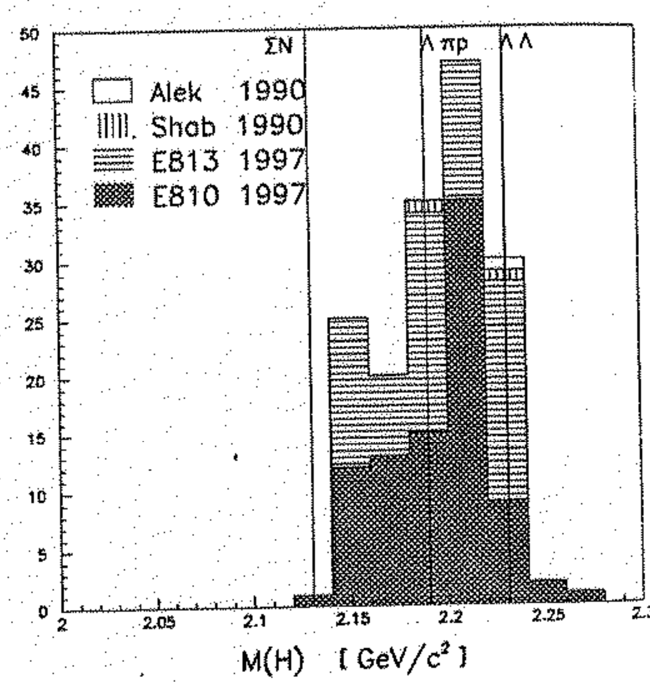
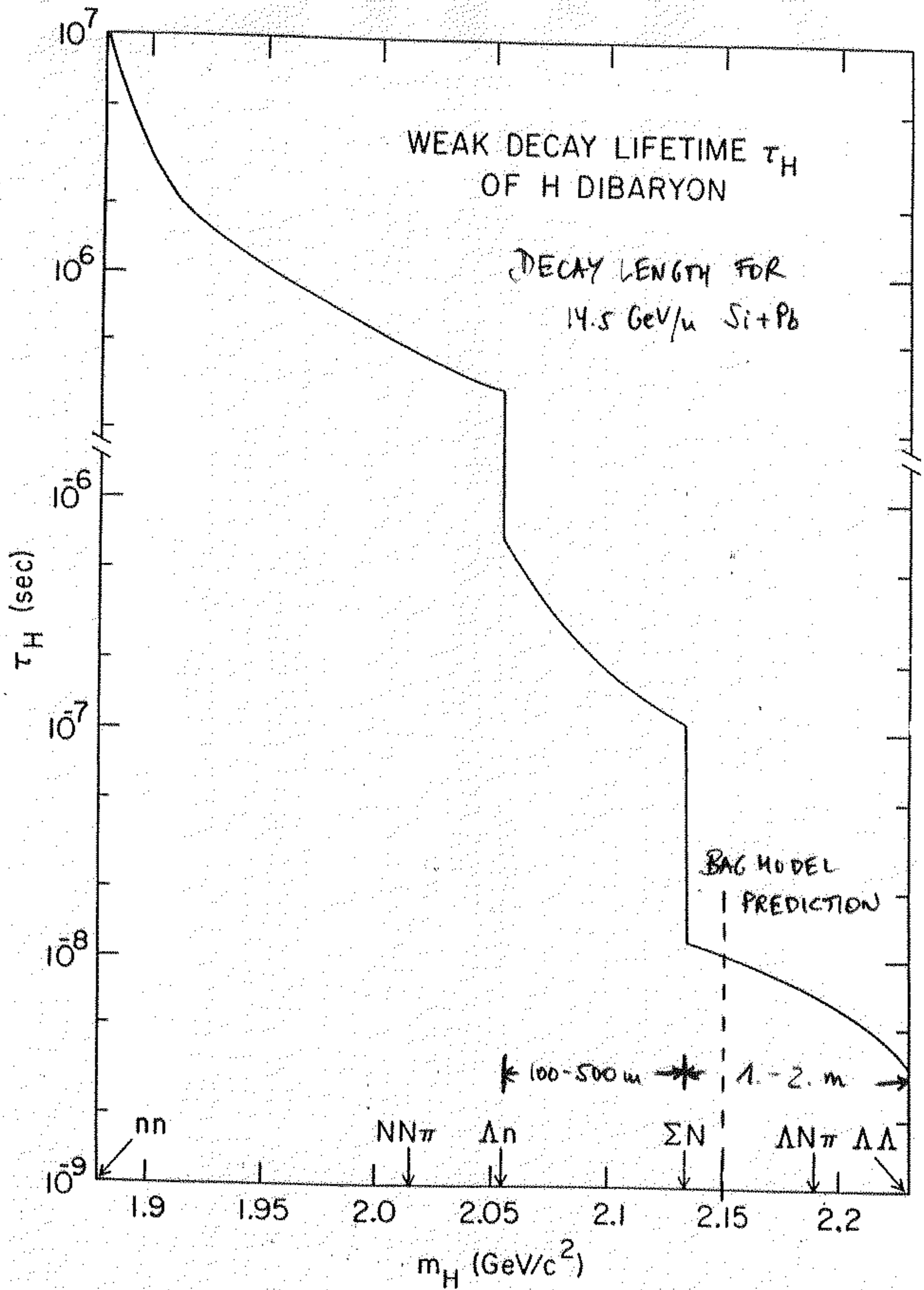


Figure 6: Observed events which may contain H candidates

Ongoing and Proposed Searches

We now list and very briefly describe ongoing and proposed experiments to search for the H dibaryon or for double-Lambda hypernuclei:

- BNL E885: Search for $_{\Lambda\Lambda}^{A}Z$ Hypernuclei. Used $^{12}C(K^-, K^+)\Xi^- X$, stop the Ξ to make $_{\Lambda\Lambda}^{12}B$ + n. Use SCIFI + CCD for tracking, detect neutrons. Data reduction completed, expect $\sim$ 20,000 stopped Ξ events. This should lead to ~ 50 $_{\Lambda\Lambda}^{12}B$.
- BNL E906: Search for $_{\Lambda\Lambda}^{A}Z$ Hypernuclei. Use $^9Be(K^-, K^+)\Xi^- X$, stop Ξ to make $_{\Lambda\Lambda}^{5}H$. Use Cylindrical Detector System (CDS) for tracking, detect π^- from sequential decays: $_{\Lambda\Lambda}^{5}H \to _{\Lambda}^{5}He + \pi^-$; $_{\Lambda}^{5}He \to ^4He + p + \pi^-$. Experiment started; expect to detect $\sim$ 500 coincident π^-.
- BNL E896: 11.6 × A GeV/c Au on Au target. Detect $H \to \Sigma^- p$, $H \to \Lambda\pi^- p$. Use sweeping magnet to remove charged particles and an analysing magnet to detect H decay products. Experiment started.
- KEK E248: $p + p \to K^+ K^+ X$, P(p) = 12.9 GeV/c. Use Asymmetric Double-Arm Spectrometer, measure m(X). Taking data since Feb. '97, expect 100pb sensitivity.



⇒ WHY RHI-COLLISIONS AS PRODUCTION MECHANISM ?

How to measure strange quark matter ?

1.) strangelets

a.) Features:

– Mass: A = 10 – 15

– Charge/Baryon: Z/A small, close to zero

– Strangeness/Baryon: f_s close to 1

b.) method of choice (E814, E864, NA52)

measure via calorimetry, use tracking for background subtraction
employ 'late energy trigger (LET)'

2.) H–Dibaryon

a.) Features:

– Six quark bag which will decay into hyperon states

– Lifetime depends on mass, decay channel depends on mass

– Most likely mass M = 2150 – 2230 MeV/c

b.) method of choice (E896, all K experiments)

measure via track reconstruction in drift chamber or Silicon device

most likely decay channel: $H \to \Sigma^- + p \to \pi^- + n + p$
: $H \to \Lambda + \Lambda \to \pi^- + p + \pi^- + p$

if metastable (M < 2130 MeV/c) then apply strangelet method (E864)

Expected Hyperon Yields in E896

The following yields are based on the E891 Λ measurement and RQMD, which describes the E891 data reasonably well. (ARC yields about 30% more Hyperons)

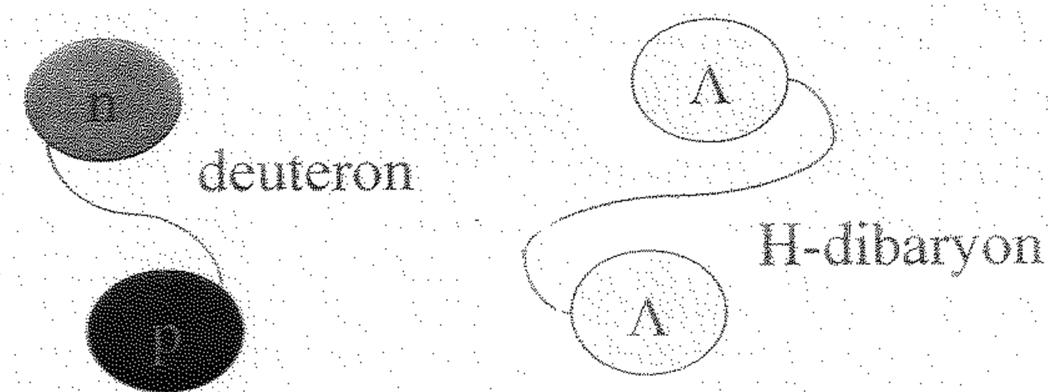
The H–Dibaryon yields are based on the Dover coalescence model assuming 0.1 H/central collision production cross section and a $c\tau$ of 4 cm ($0.5c\tau(\Lambda)$).

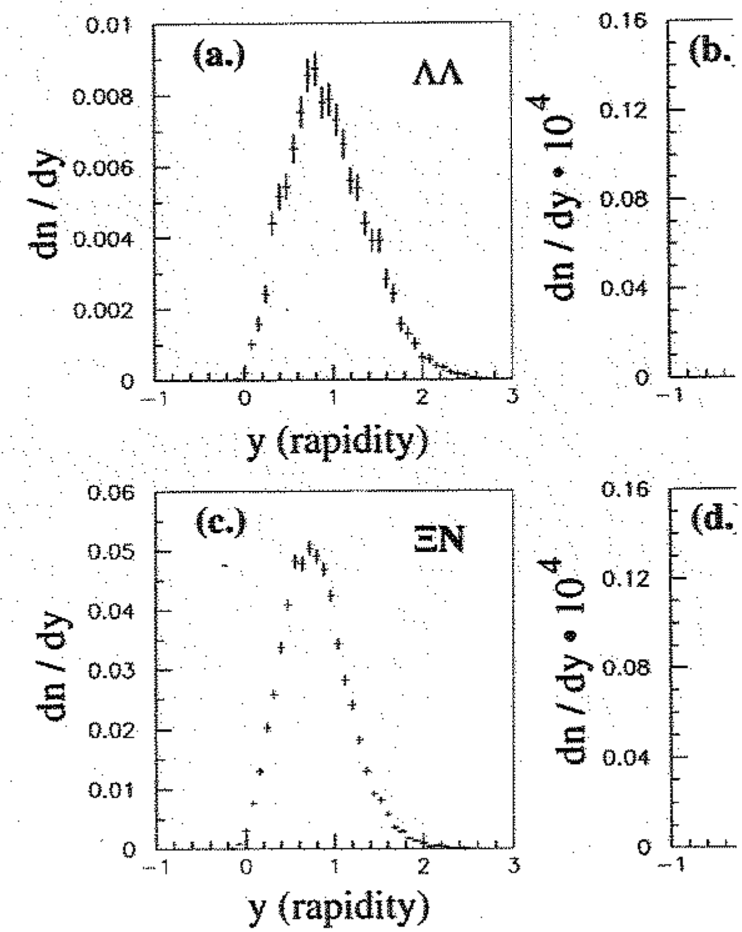
SDDA yields/event:	Λ	$\overline{\Lambda}$	Ξ	$\overline{p}$	H
generated in RQMD	15	0.045	0.4	0.015	0.1
geometrical acceptance	3.5	0.01	0.04	0.011	0.003
reconstructed	0.3	6E–4	7E–4	4E–4	2E–4
# of particles in SDDA	200,000	400	450	250	100

DDC yields/event:	Λ	H
generated in RQMD	15	0.1
geometrical acceptance	0.07	8E–6
reconstructed	0.0056	2.5E–6
# of particles in DDC	450,000	200

Strange Nucleo-synthesis

Calculations for **hypernuclei** and **H-dibaryon** assume same transition probability as for normal nuclei !

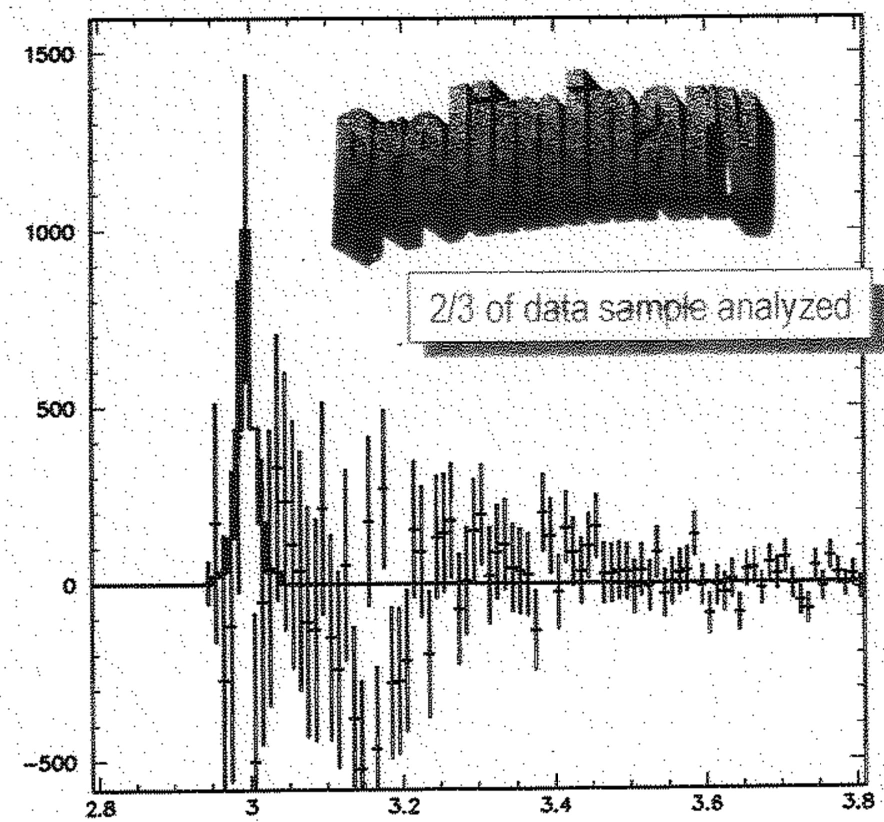




Testing this assumption to is **critical** understanding E896, E910, E888, E864…..which assume **H** coalescence

A.J. Baltz, C. Dover et al., Phys. Lett. B325, 7 (1994).
B.A. Cole, M. Moulson, W.A. Zajc, Phys. Lett. B350, 147 (1995).

Hyper-Nuclei Production



Sampled 9.5 billion central Au+Pt interactions

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

Branching Fraction 25%

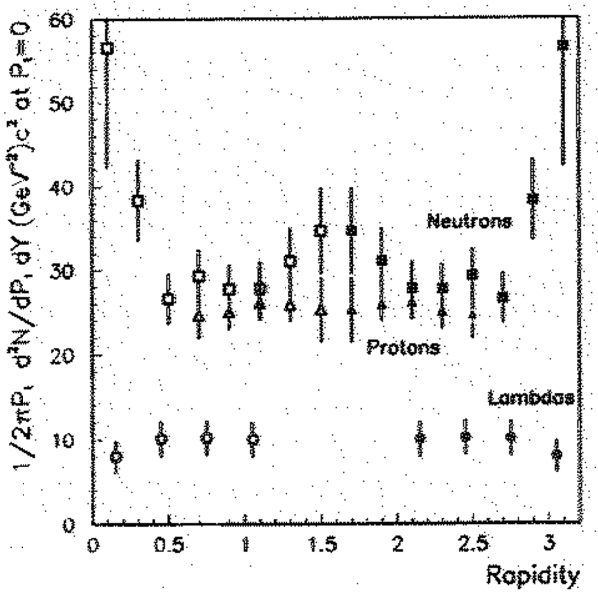
Signal observed at the 1.8 sigma level....

⟹ Invariant Multiplicity $[1.6 < y < 2.8;\ 0 < p_t < 2\ GeV] = 2.6 \pm 1.4 \times 10^{-4}\ c^2/GeV^2$

Hyper-nucleus Production Rate

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

$$\frac{{}^{3}_{\Lambda}H}{{}^{3}He} = 0.03 \pm 0.18$$



E864

E891

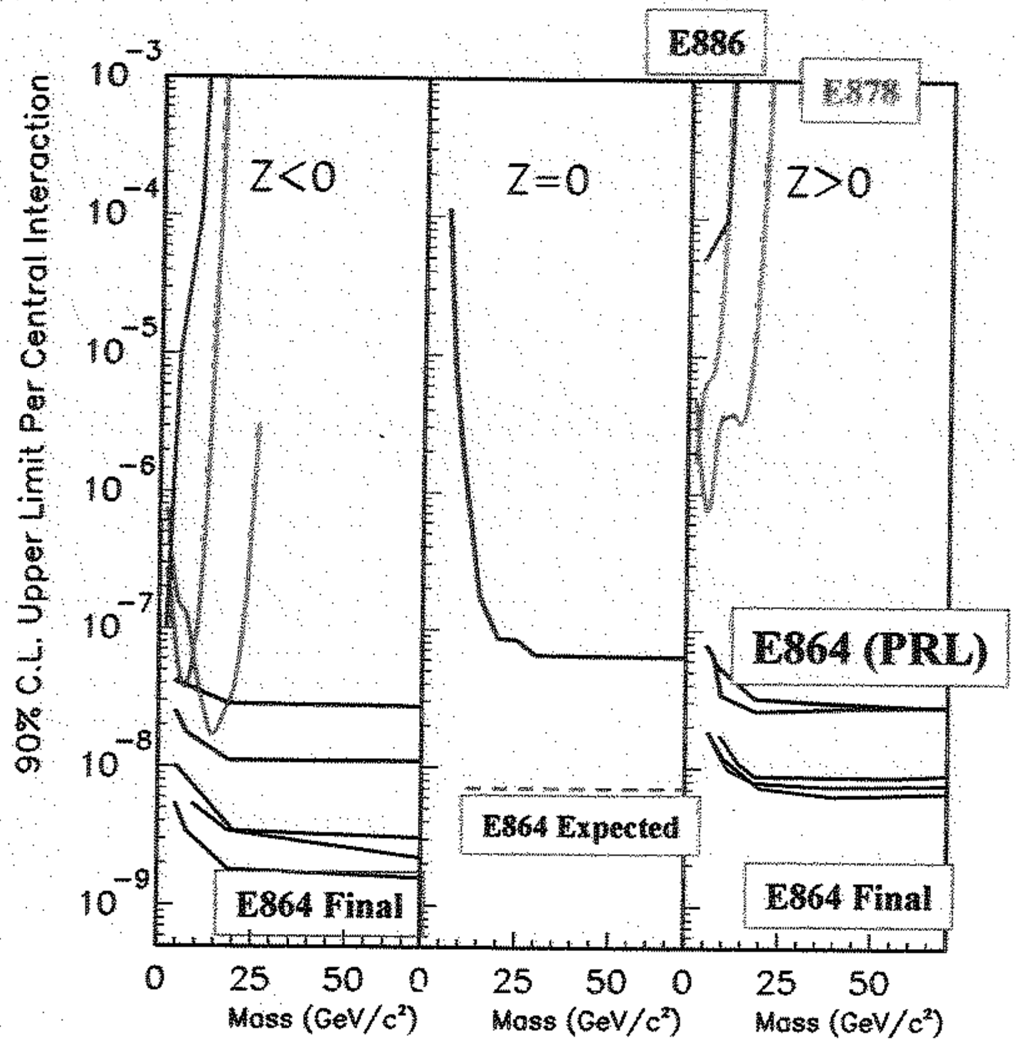
Compare:

$$\frac{\left(\dfrac{{}^{3}_{\Lambda}H}{p \times n \times \Lambda}\right)}{\left(\dfrac{{}^{3}He}{p \times p \times n}\right)} = \mathbf{0.162 \pm 0.088}$$

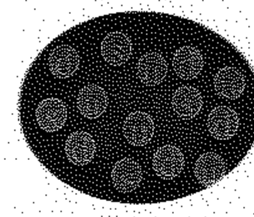
Preliminary

In same region in phase space.

Strange Quark Matter (SQM) Search



SQM = many quarks in a color-singlet configuration



Null Result….

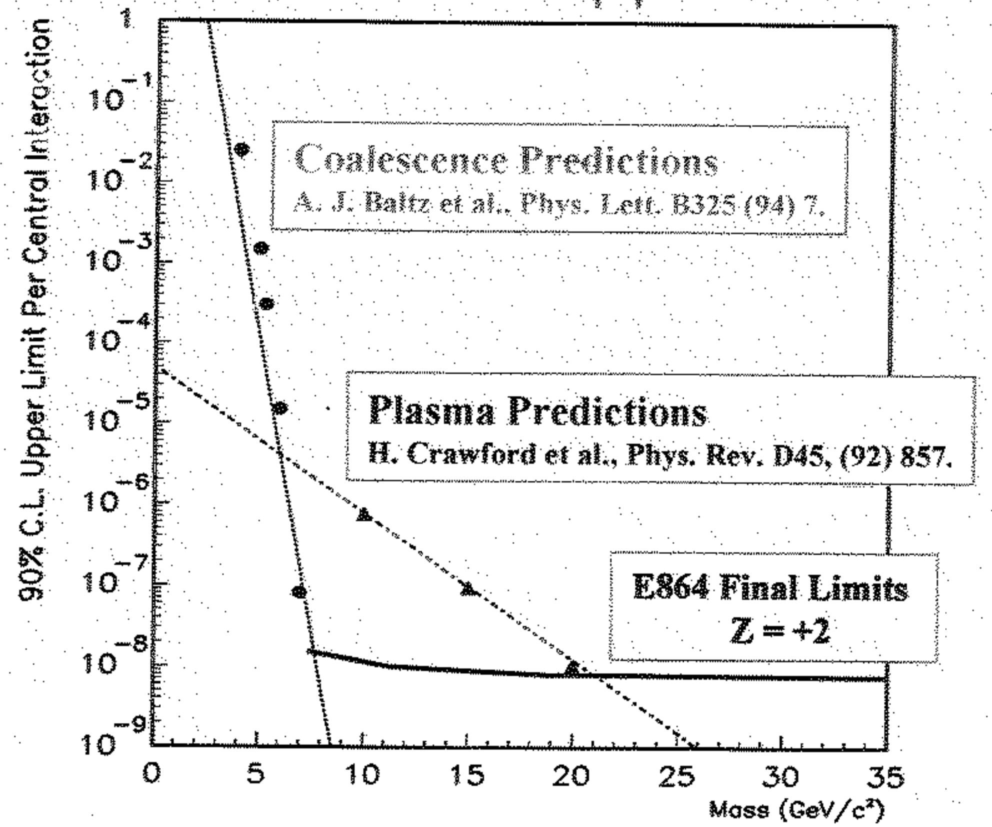
10^{-8} to 10^{-9}

For SQM $\tau > 50$ ns

- T.A. Armstrong *et al.*, Phys. Rev. Lett. 79, 3612 (1997).
- T.A. Armstrong *et al.*, Nucl. Phys. A 625, 494 (1997).
- T.A. Armstrong et al., Phys. Rev. C, R1829 (1999).

SQM Search Implications

- **Production via a QGP**
  - Many predictions ruled out, but calculations are not precise.
- **Production by coalescence of (strange) baryons**
  - Sensitive to: **A = 6-7** and **|S| = 2-3**



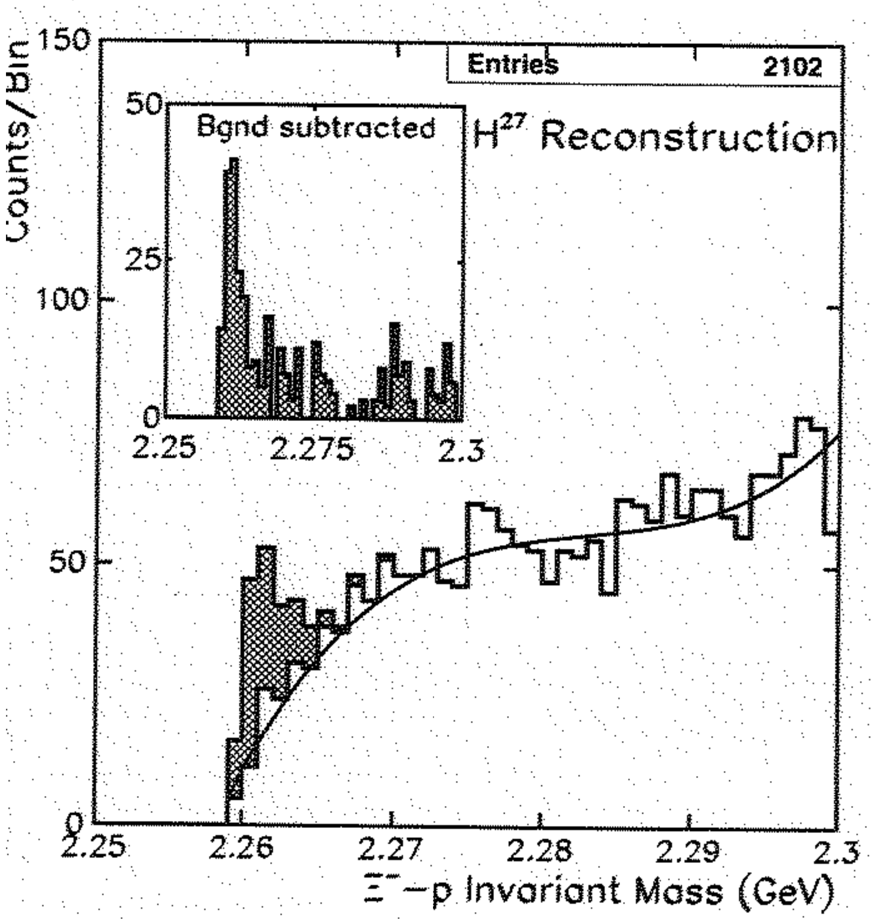


Figure 4: FSDR $p\Xi^-$ invariant mass spectrum for $H^{27} \rightarrow p\Xi^-$ reconstruction for 600 central Au+Au HIJET events at a collision energy of 200 A·GeV, assuming an average of 2.6 $H^{27} \rightarrow p\Xi^-$ resonance decays per event into the acceptance with resonance energy 1 MeV above threshold and Gaussian width parameter (σ) of 2 MeV. The cross-hatched portion indicates the number of correctly reconstructed $H^{27} \rightarrow p\Xi^-$ decays. The background subtracted peak is shown in the inset panel. Bin size is 1 MeV.

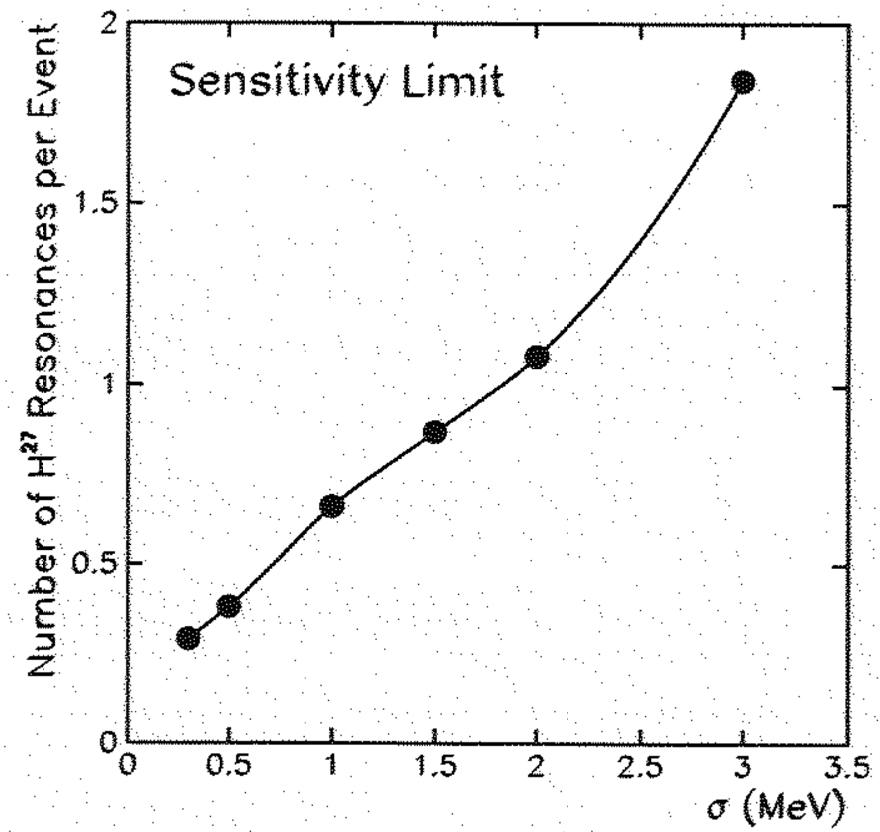
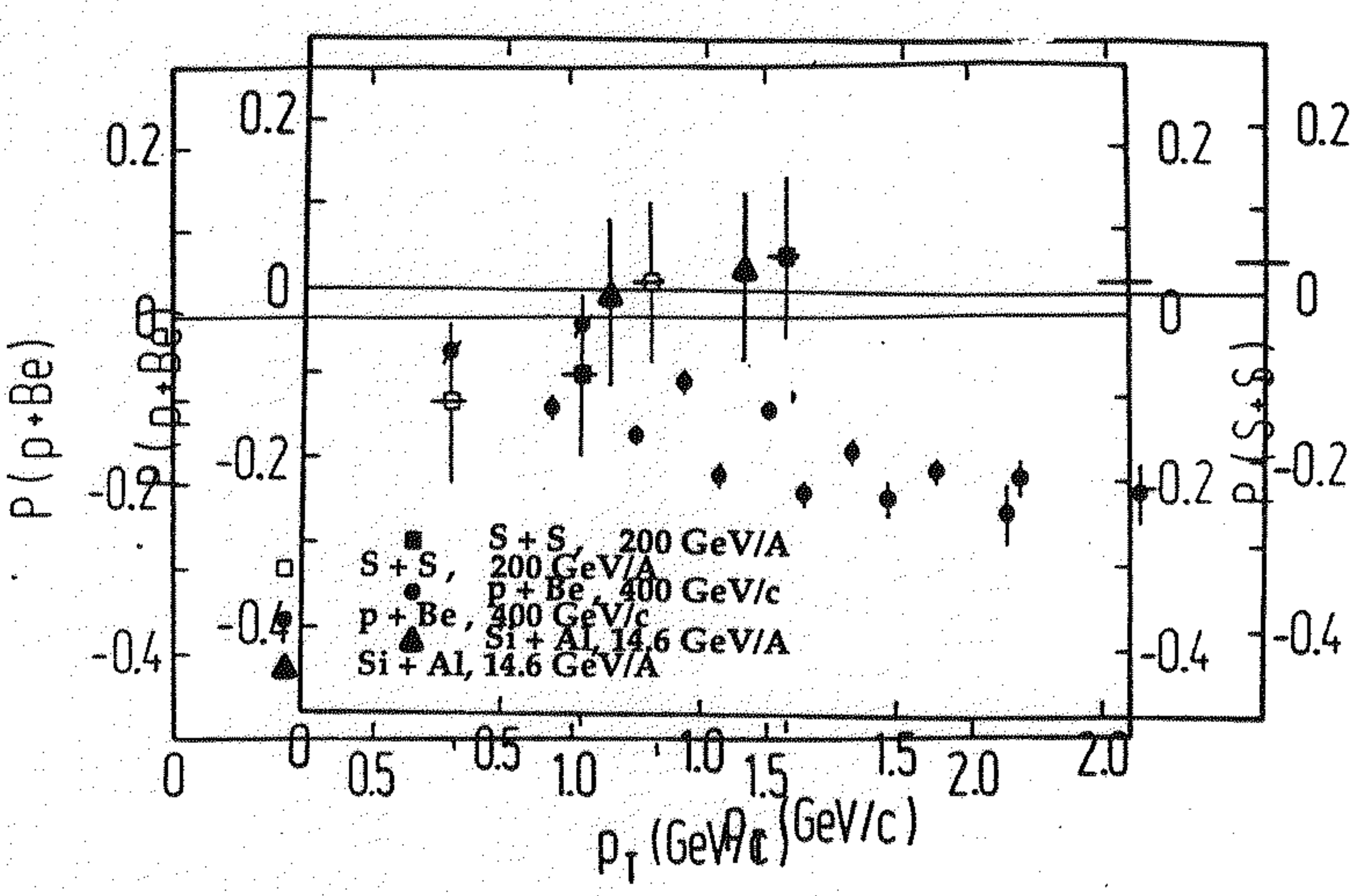


Figure 5: Experimental detection limit based on the reconstruction method described in the text for $H^{27} \rightarrow p\Xi^-$ resonance decays in terms of production rate (number per event into STAR's acceptance) as a function of Gaussian width parameter. Solid dots indicate the cases studied; the line simply connects the dots.



S + S , 200 GeV/A
p + Be , 400 GeV/c
Si + Al, 14.6 GeV/A
P (p + Be)
P (S + S)
p_T (GeV/c)
0.2
0
-0.2
-0.4
0
0.5
1.0
1.5
2.0

Can Doubly Strange Dibaryon Resonances be Discovered at RHIC?

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Table II: Optimum decay channels and mass ranges for $J^\pi = 0^+, 1^+ \quad Y = 0$ dibaryon resonance searches.

$SU(3)_f$ Irrep.	$(J^\pi$,I,$I_3)$	Decay Channels and Mass Ranges (MeV)	Accessible to STAR
1	0^+ 0 0	$\Lambda\Lambda \gtrsim 2231$	Yes
8	1^+ 0 0	$\Lambda\Lambda \gtrsim 2231$; $n\Xi^0 \gtrsim 2254$; $p\Xi^- \gtrsim 2260$	Yes
8	1^+ 1 1	$p\Xi^0 \gtrsim 2253$	
8	1^+ 1 0	$\Lambda\Lambda \gtrsim 2231$; $n\Xi^0 \gtrsim 2254$; $p\Xi^- \gtrsim 2260$	Yes
8	1^+ 1 −1	$n\Xi^- \gtrsim 2261$	
10	1^+ 1 1	$p\Xi^0 \gtrsim 2253$	
10	1^+ 1 0	$\Lambda\Lambda \gtrsim 2231$; $n\Xi^0 \gtrsim 2254$; $p\Xi^- \gtrsim 2260$	Yes
10	1^+ 1 −1	$n\Xi^- \gtrsim 2261$	
$\overline{\mathbf{10}}$	1^+ 1 1	$p\Xi^0 \gtrsim 2253$	
$\overline{\mathbf{10}}$	1^+ 1 0	$\Lambda\Lambda \gtrsim 2231$; $n\Xi^0 \gtrsim 2254$; $p\Xi^- \gtrsim 2260$	Yes
$\overline{\mathbf{10}}$	1^+ 1 −1	$n\Xi^- \gtrsim 2261$	
27	0^+ 0 0	$\Lambda\Lambda \gtrsim 2231$	Yes
27	0^+ 1 1	$p\Xi^0 \gtrsim 2253$	
27	0^+ 1 0	$\Lambda\Lambda$ from 2231 to 2254;[a] $n\Xi^0 \gtrsim 2254$; $p\Xi^- \gtrsim 2260$	Yes
27	0^+ 1 −1	$n\Xi^- \gtrsim 2261$	
27	0^+ 2 2	$\Sigma^+\Sigma^+ \gtrsim 2379$	
27	0^+ 2 1	$p\Xi^0$ from 2253 to 2381;[b] $\Sigma^+\Sigma^0 \gtrsim 2381$	
27	0^+ 2 0	$\Lambda\Lambda$ from 2231 to 2384;[a] $\Sigma\Sigma \gtrsim 2384$	Yes[c]
27	0^+ 2 −1	$n\Xi^-$ from 2261 to 2389;[d] $\Sigma^0\Sigma^- \gtrsim 2389$	
27	0^+ 2 −2	$\Sigma^-\Sigma^- \gtrsim 2395$	

[a]If strong decay via isospin admixture dominates EM decay and resonance remains narrow; otherwise $\Lambda\Lambda$ for mass $\gtrsim 2231$ MeV only.

[b]If strong decay via isospin admixture dominates EM decay and resonance remains narrow; otherwise $p\Xi^0$ for mass $\gtrsim 2253$ MeV only.

[c]$\Lambda\Lambda$ decay channel only.

[d]If strong decay via isospin admixture dominates EM decay and resonance remains narrow; otherwise $n\Xi^-$ for mass $\gtrsim 2261$ MeV only.

From CERN to RHIC (under some assumptions)

Assumption: Parton Cascade with hydrodynamical afterburner
(Reference: Dumitru and Rischke 1998)

Cylindrically symmetric, longitudinal boost invariant expansion

	RHIC	CERN
Energy density ε_i	17 GeV/fm^3	5.3 GeV/fm^3
Baryon density ρ_B	2.3 ρ_o	4.5 ρ_o
dN_B/dy	25	80
Initial temperature T_i	300 MeV	216 MeV
Chemical potential μ_q	47 MeV	167 MeV
Strange chem. pot. μ_s	0 MeV	0 MeV
Entropy S/ρ_B	200	40
Freezeout temp. T_f	160 MeV	130 MeV
Hadronization time	16 fm	10 fm

©

Ready for blastoff: a Brookhaven engineer puts finishing touches to the ion collider

Big Bang machine could destroy Earth

by Jonathan Leake
Science Editor

A NUCLEAR accelerator designed to replicate the Big Bang is under investigation by international physicists because of fears that it might cause "perturbations of the universe" that could destroy the Earth. One theory even suggests that it could create a black hole.

Brookhaven National Laboratories (BNL), one of the American government's foremost research bodies, has spent eight years building its Relativistic Heavy Ion Collider (RHIC) on Long Island in New York state. A successful test-firing was held on Friday and the first nuclear collisions will take place in the autumn, building up to full power around the time of the millennium.

Last week, however, John Marburger, Brookhaven's director, set up a committee of physicists to investigate whether the project could go disastrously wrong. It followed warnings by other physicists that there was a tiny but real risk that the machine, the most powerful of its kind in the world, had the power to create "strangelets" - a new type of matter made up

Next: Aitken fights auction of his private letters

Science & Technology
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- Making Small Planes Safer
- Valley of the Doll-Less
- A Protein That Senses Sun Damage

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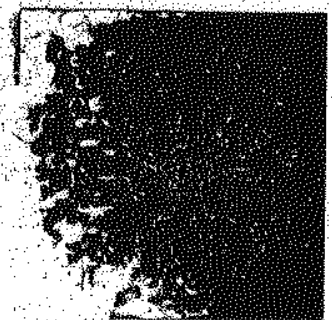
  - My Turn
  - Letters
  - Perspectives
  - Newsmakers
  - The Last Word by George F. Will

International Edition
Special Issues

The Big Bang Is Back

A high-powered physics experiment promises to turn back the clock to a microsecond after the birth of the universe

By Adam Rogers



Small bang: Computer simulation of output from collision of gold ions (Star Collaboration and Brookhaven National Laboratory)

This is probably not the way the world ends: sometime this fall, researchers at Brookhaven National Laboratory will tap a few commands into a computer terminal, bringing their new particle accelerator-the Relativistic Heavy Ion Collider, or RHIC-up to full power. Atoms of gold-heavy enough to cause some real quantum fireworks-will course around two nearly circular, 2.4-mile "racetracks" in opposite directions at 99.9 percent of the speed of light. The nuclei will smash into each other, exploding at a temperature 10,000 times hotter than at the center of the sun. For a hundred trillionths of a trillionth of a second, conditions will mirror the universe immediately after the big bang. From that brief genesis, though, a new universe will not be born. It won't grow, and it won't destroy the pre-existing universe, one we know and love. No Apocalypse, no Big Goodbye.

So don't panic. Brookhaven physicists really are shaking down RHIC. And while they checked to make sure they weren't going to bring about the End Time in the process, they are going to be playing with some seriously primal forces. The $365 million collider will accelerate heavier ions-charged atomic particles-at higher energies than anywhere else in the world. If all goes well, RHIC will indeed simulate the universe right after the big bang and create a state of matter unseen on Earth, testing basic theories about what the universe is made of and how it got that way. "It's like a tiny peephole into the whole way cosmology works," says Miklos Gyulassy, a physicist at Columbia University. "We're trying to re-create the birth of the universe in a laboratory."

Under construction since 1991, RHIC is the largest accelerator at Brookhaven, on New York's Long Island. Other accelerators, like those at CERN in Switzerland or Fermilab in Illinois,

/

Atlas Shrugs

Commentary

If scientists can be counted on for anything, it's for creating unintended consequences. (Michael Dougan)

Special to ABCNEWS.com

ON TECHNOLOGY
FRED MOODY

David Melville is an eccentric physicist and thinker, and a friend of mine. He's also terrified.

Melville is preoccupied with what he regards as the most dangerous event in human history: an experiment, scheduled for November, at the Brookhaven National Laboratory in Upton, N.Y. Brookhaven has a device, called the Relativistic Heavy Ion Collider, that has the world's physicists tremendously excited. Scientists believe they can use the collider to duplicate the conditions that prevailed milliseconds after the Big Bang, when the universe consisted of a primordial soup called the quark-gluon plasma. Brookhaven scientists think that by colliding gold ions at extremely high speed, they can create a tiny, fleeting version of quark-gluon plasma to gain a better understanding of the origins of the universe.

Sounds like fun. The only problem, according to David Melville's panicky e-mail, is that, "It has been theorized by Steven Hawking that from this quark-gluon plasma other forms of matter are also produced. The most dangerous being a black hole."

SUMMARY

The hubris of trying to replicate the universe just after the Big Bang could have catastrophic consequences.

Related Stories

Black Hole May Have Been Born in Supernova

Scientific American **contains letters debating the black-hole possibility, and the London** ***Sunday Times*** **has editorialized**

Should research that has the potential to destroy the Earth be funded by the government ??

Which of the effects are still interesting for RHIC

1.) strangeness equilibration

-> measurement of s–sbar ratio (for Λ, Ξ, Ω)

2.) strange particle interferometry

-> measurement of K^0K^0 and $\Lambda\Lambda$

3.) strangeness enhancement

-> measurement of yields for Λ, Ξ, Ω, K, ϕ

4.) strange particle polarization

-> measurement of Λ in pp, pA, AA

Effects that might require high baryon density and relatively low temperatures

1.) strange matter production

2.) strange particle condensation

Parton Cascade and Hydodynamical Evolution at RHIC energies.

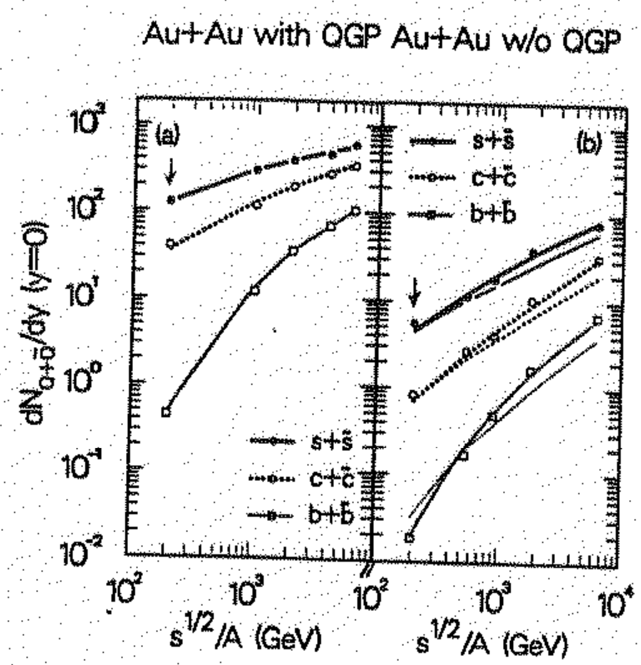
References (Parton Cascades and Hydro–model)

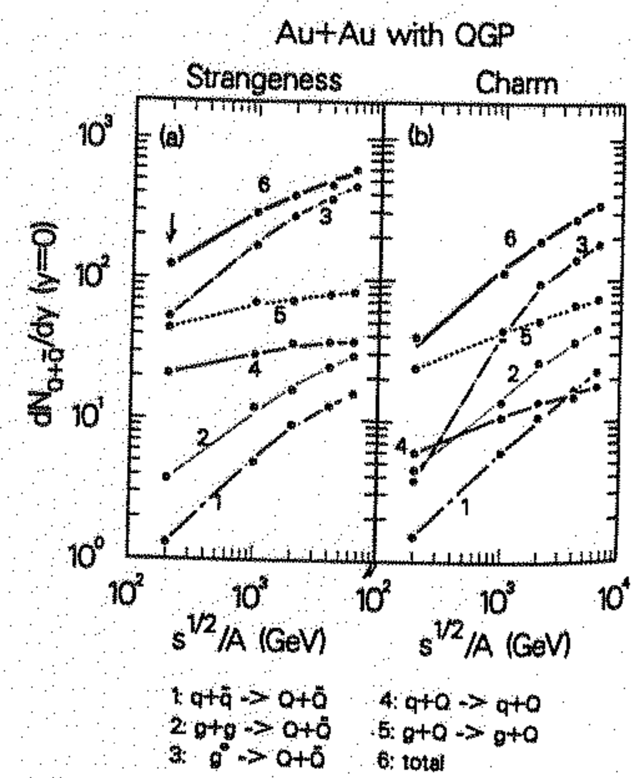
Strangeness in VNI: K. Geiger, Phys. Rev. D 48 (1993) 4129
Strangeness in HIJING: B. Zhang et al., nucl–th/9608052
Strangeness in VNI/HIJET: Geiger +Longacre, nucl–th/9705041
Strangeness in Hydro–Model: Dumitru + Rischke, nucl–th/9806003

Hard and pre–equilibrium processes

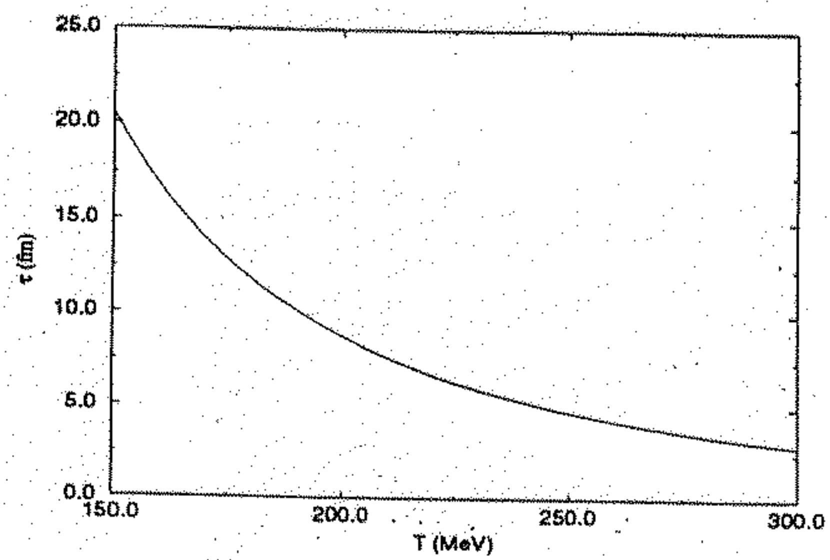
–> strong strangeness enhancement through hard initial and pre–equilibrium (cascade) processes

main contributions by:
- gluon–gluon fusion
- gluon decay
- gluon–gluon scattering
- gluon–cluster coalescence

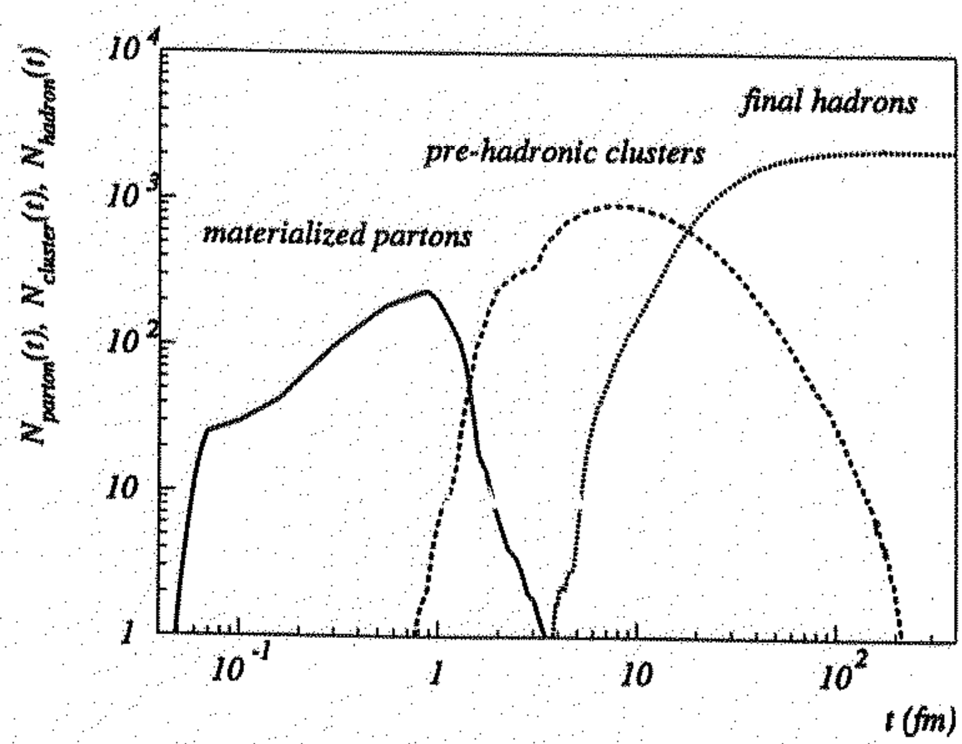




Strangeness Equilibration time at RHIC



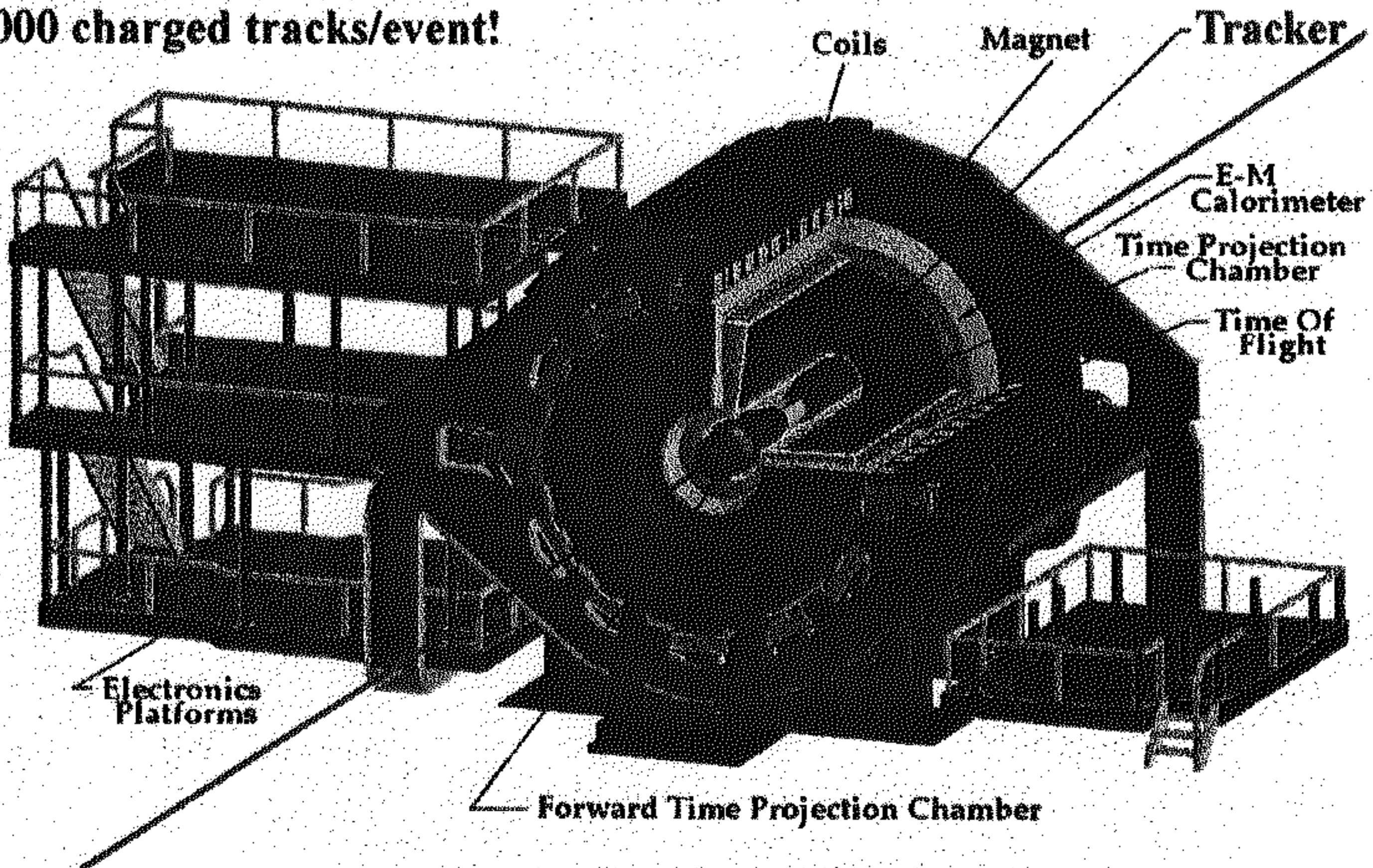
Parton Cascades do not lead to chemical equilibrium, but they lead to fast local thermal equilibration



Hard processes contribute significantly to the particle yield as well as the distributions in rapidity and p_T

STAR Detector

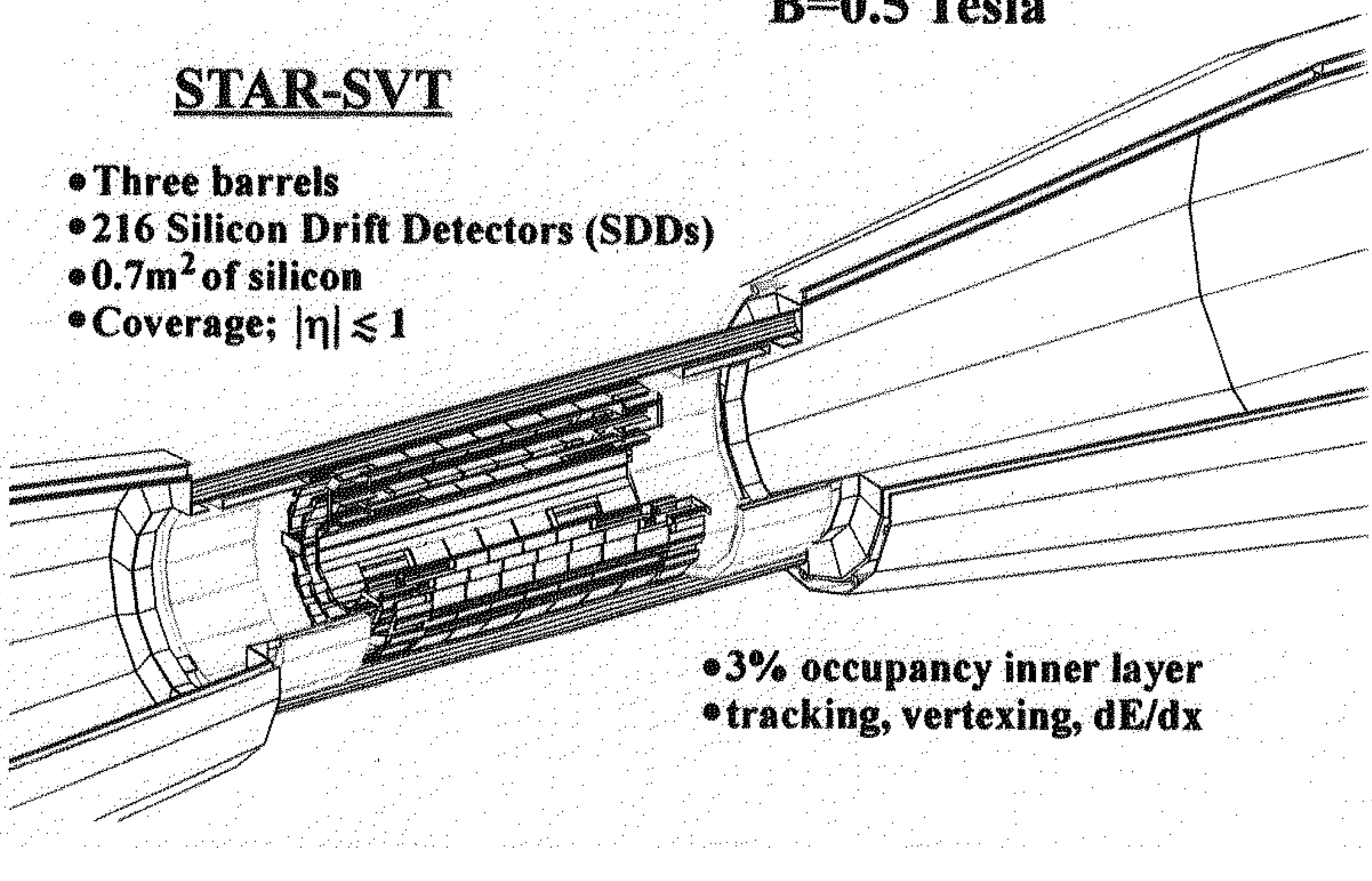
~ 2000 charged tracks/event!



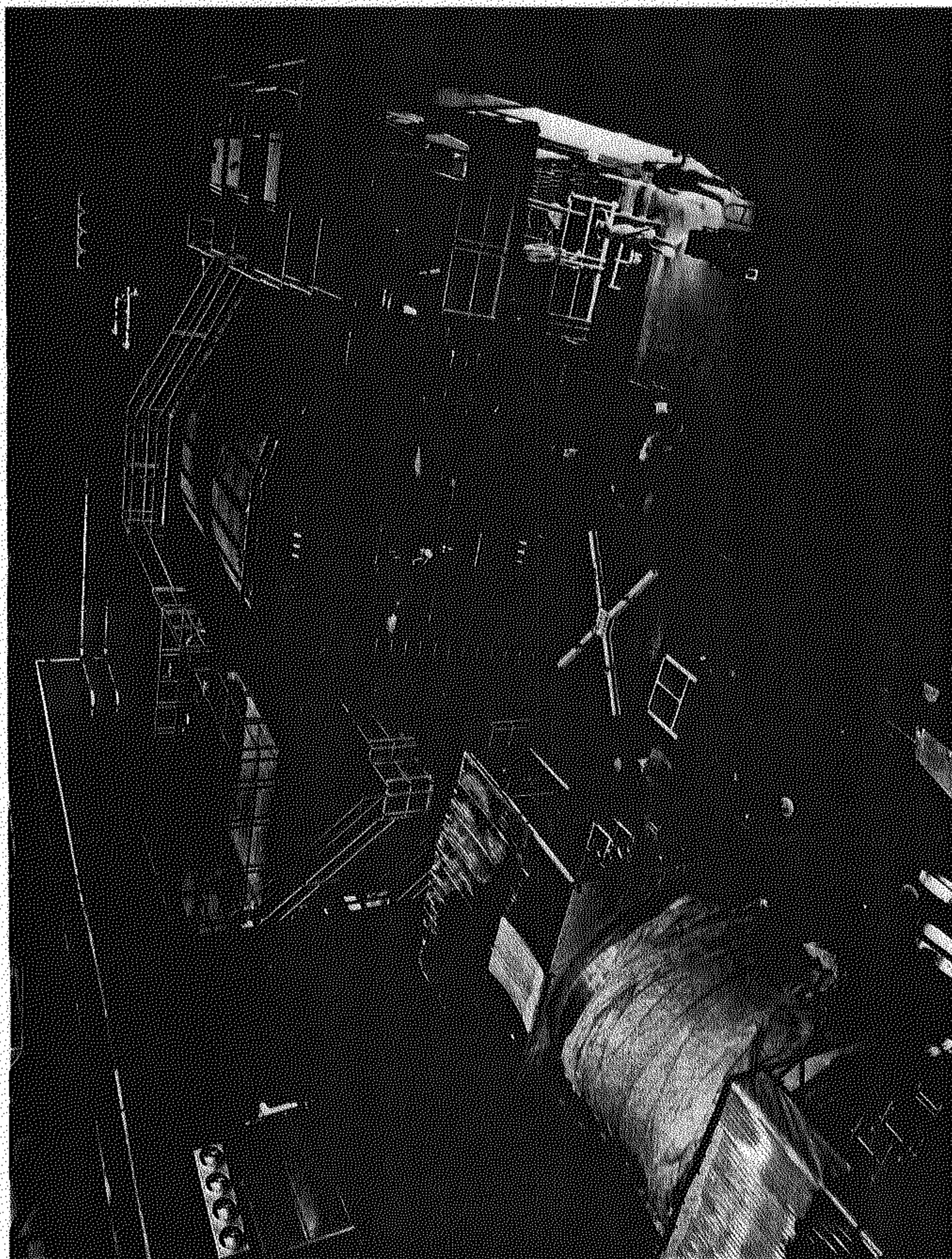
B=0.5 Tesla

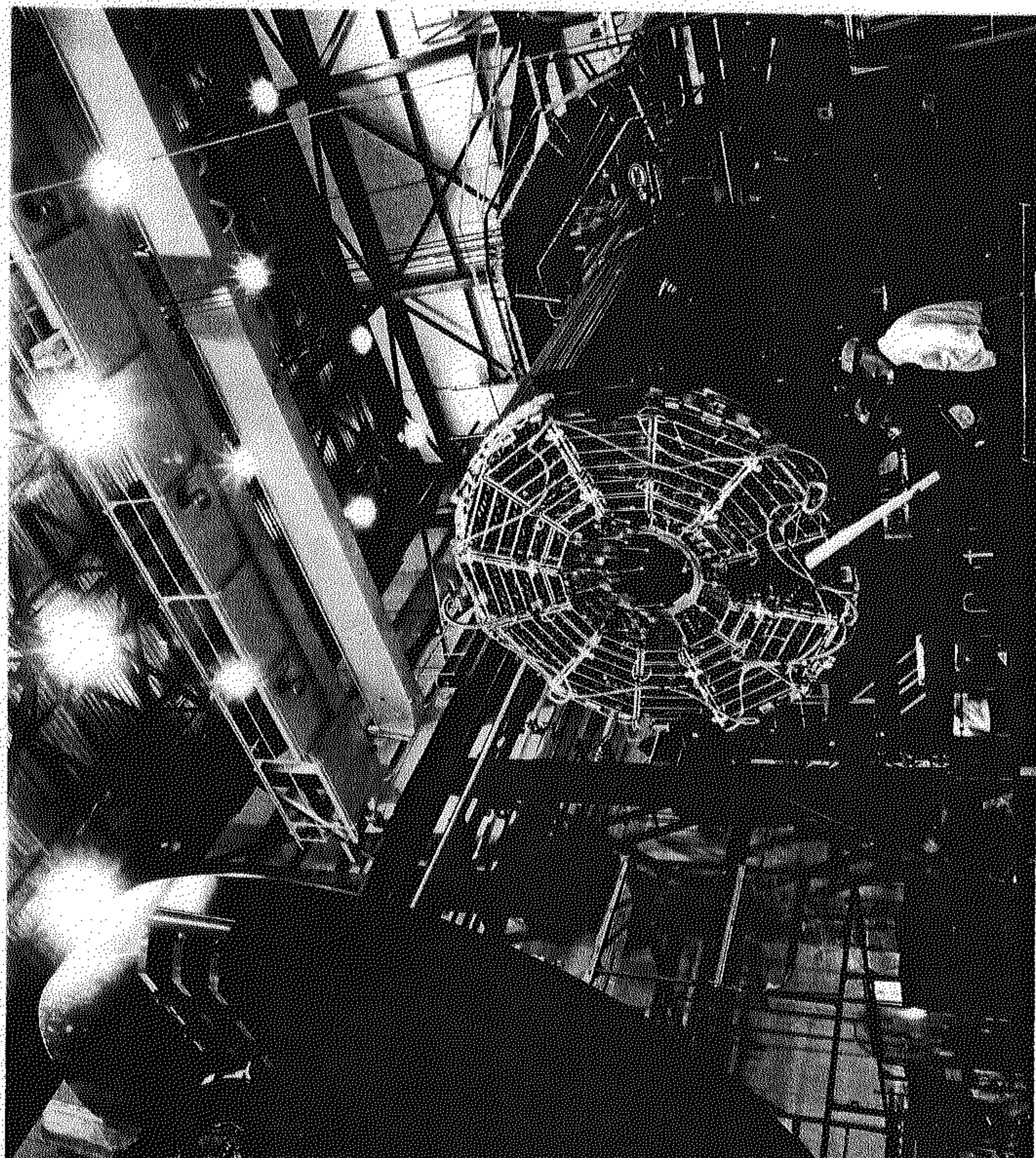
STAR-SVT

- Three barrels
- 216 Silicon Drift Detectors (SDDs)
- $0.7 m^2$ of silicon
- Coverage; $|\eta| \lesssim 1$



- 3% occupancy inner layer
- tracking, vertexing, dE/dx





Accelerator Operation

0.) Year-1 : 12/6/99 - 6/30/00

1.) Initial Beam will be Au+Au at 200 GeV

2.) First Year mostly dedicated to Au+Au

3.) Luminosity Goals:

10% of design luminosity by end of Year–1
(200 Au+Au collisions/sec)

100% of design luminosity by end of Year–2
(2000 Au+Au collisions/sec)

Important: STAR is not luminosity limited !
(w.TPC we record 1 collision/sec)

STAR Year–1 Plans

Either one beam change (Si+Si ?, no p+p)

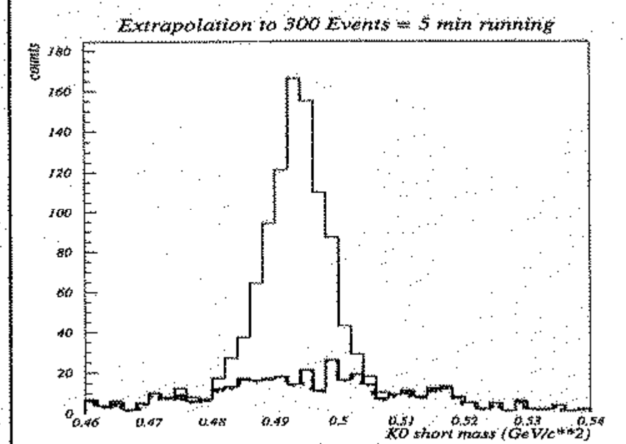
or

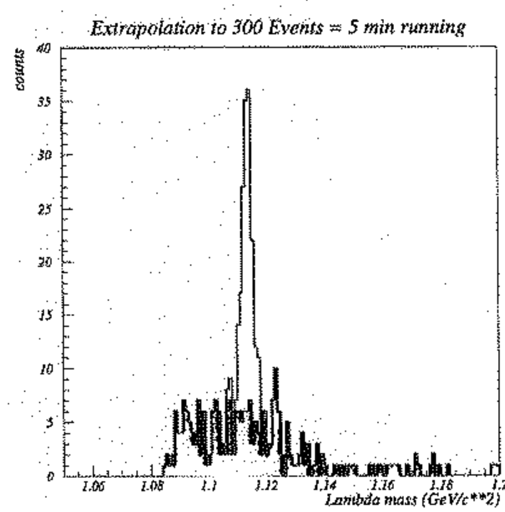
Au+Au excitation function (60 –> 200 GeV)

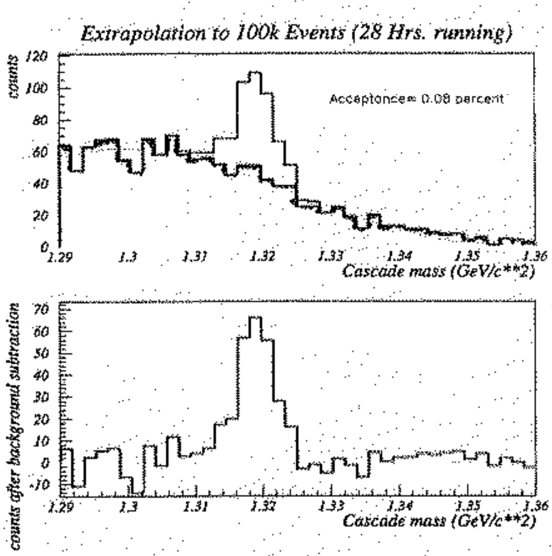
or

both ?

4) Invariant Mass of Reconstructed K^0_s, Λ, and Ξ^-







Summary of STAR strangeness yields

Particle	overall efficiency (incl. reconstr., acceptance and branching ratios)	# of particles/event	run time (to obtain 1000 particles)
K^0	3.7%	2.5	7 min.
Λ	8%	0.5	35 min.
Ξ^-	0.08%	0.003	4.1 days
Ω^-	0.07%	0.00005	several months

TOTAL : ~12 MILLION / YEAR ([illegible])

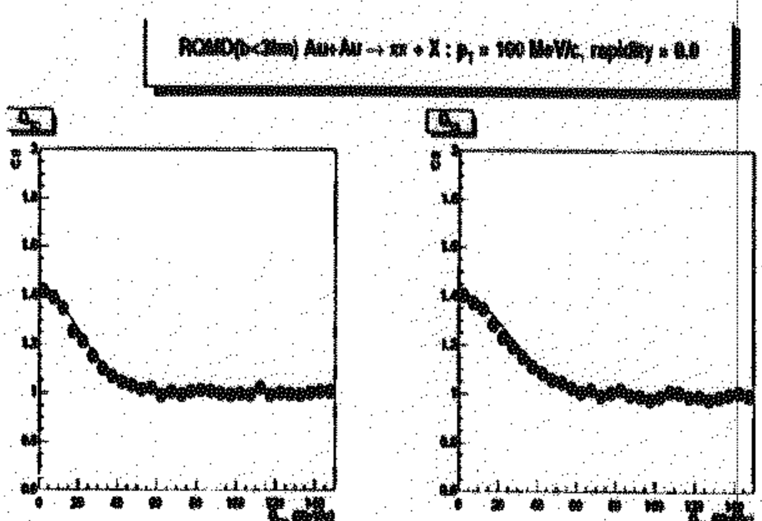
Two Particle Interferometry

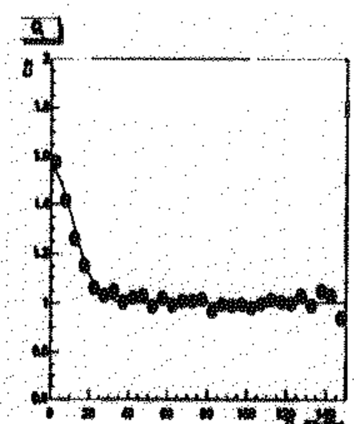
Year 1: $\pi\pi$, KK, pp, non–identical particle correlations

Year 2: $K^{O}K^{O}$, $\Lambda\Lambda$, many particle correlations

Requirements: 3–D Analysis requires 100 K events / sample

p_t–y Analysis requires > 500 K events / sample





R_{TO} = 6.94 ± 0.13 fm

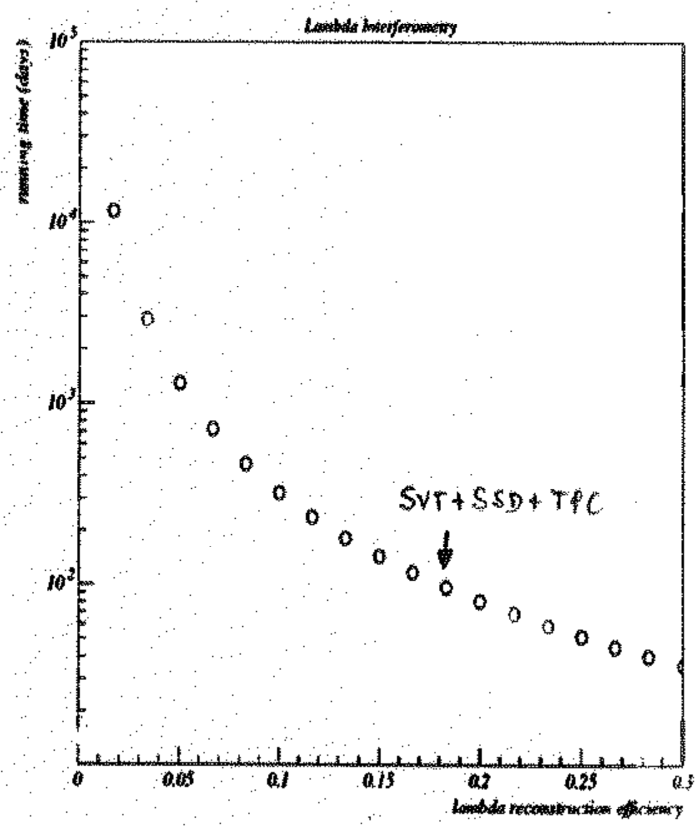
R_{TS} = 5.59 ± 0.10 fm

R_{L} = 12.42 ± 0.25 fm

λ = 0.69 ± 0.02

χ^2/DOF = 26318/2699

Year–2 Run Time Estimate
$\Lambda\Lambda$–HBT (5 Million Pairs)



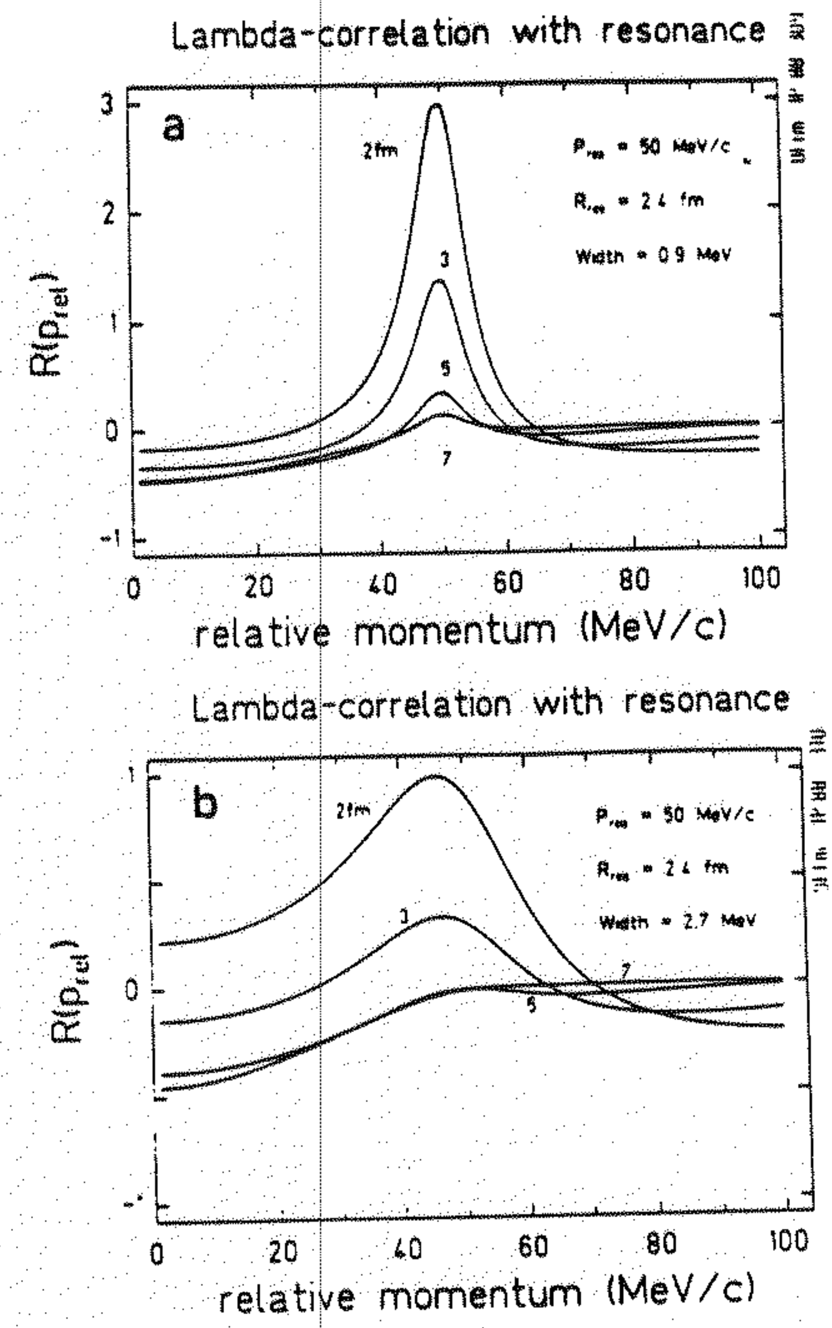


Fig. 3. The pair correlation function of the emitted Λ might be drastically changed, if a possible resonance channel contributes at low relative momenta. If this is the case, the fireball size in a heavy ion collision has a much stronger influence on the shape of the correlation function and thus the size r_0 may be obtained more precisely. Two examples ((a) and (b)) with the same resonance position, but with different widths are shown.

Strangelet searches in STAR (Strasbourg)

Strangelet formation requires high baryon density

Mid–rapidity at RHIC should have zero net baryon density ($\mu_B = 0$) but fluctuations in stopping power and net baryon content could lead to non–zero μ_B (C.Spieles et al., Phys. Rev. Lett. 76 (1996) 1776) or coalescence of enhanced strange anti–matter.

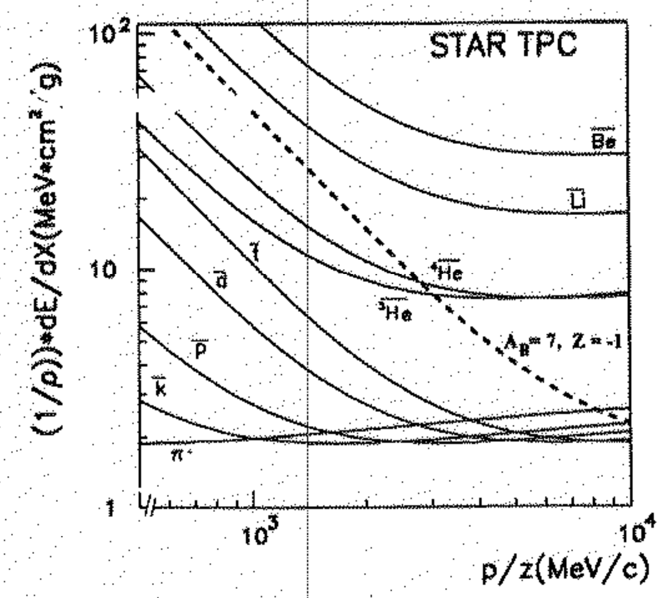
Characteristics: $A = 2 - 40$
$Z/A = -0.5 \rightarrow 0.5$
$f_S = 0.5 - 1.5$

1.) short lived ($< 10^{-7}$s) –> identification via secondary tracking
(e.g. $H \rightarrow \Sigma^- p \rightarrow \pi^- np$)

Estimated Lifetime close to Λ–$c\tau$
Experience from E896 at the AGS

2.) long lived ($> 10^{-7}$ s) –> particles does not decay in STAR
(has to be charged to be identified)

Detection scheme for long lived strangelets: via de/dx and RICH



K^0_S

Greiner

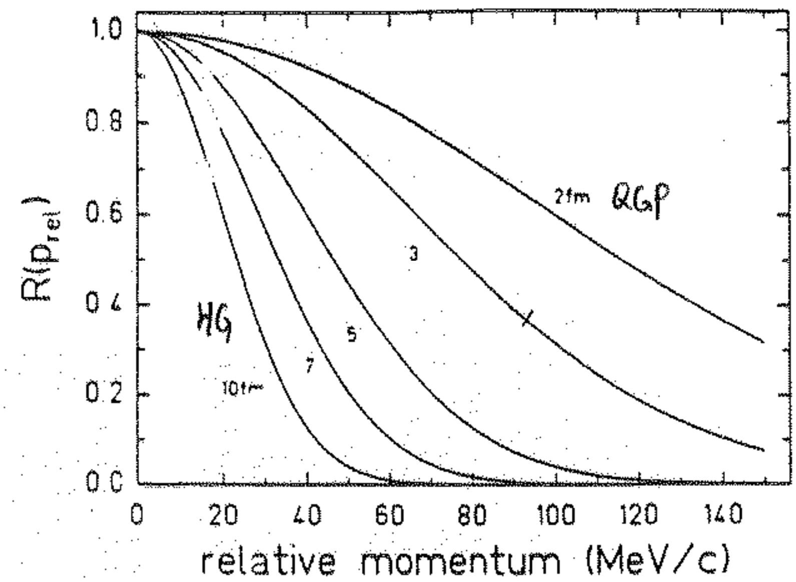


Fig. 1. The pair correlation function $R(p_{rel})$ of emitted neutral kaons. The expected size of the fireball lies around 7 fm. This both should be the case, whether originally a quark–gluon plasma (QGP) or an excited hadronic resonance gas (HRG) is created in an ultrarelativistically heavy ion collision.

Λ

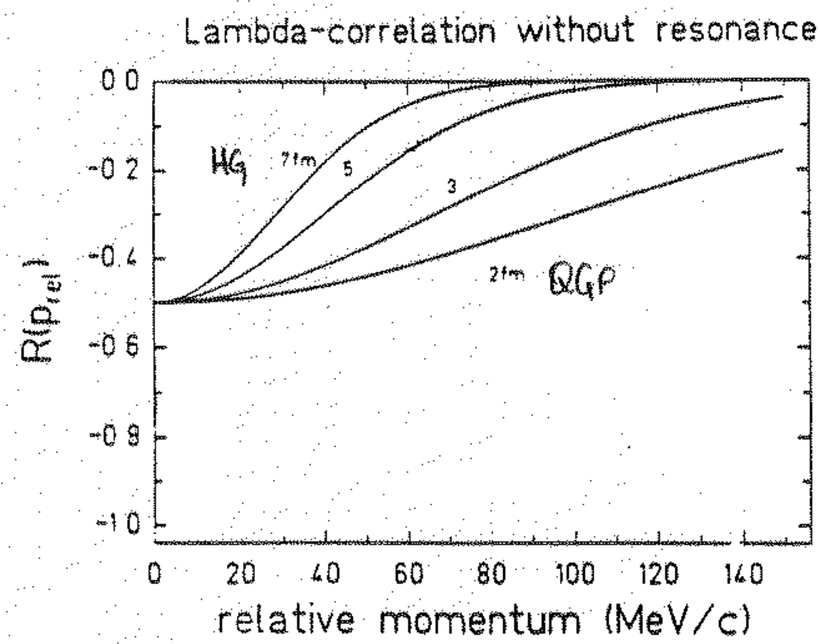


Fig. 2. The pair correlation function of the Λ depends sensitively on the source radius r_0 of the spacial volume, where the particles are located at freeze-out. The two different expected scenarios are outlined (i.e. whether the fireball has undergone a phase transition from quark–gluon plasma to hadronic matter (labeled QGP) near chemical equilibrium or whether only a state of strongly interacting hadronic matter (labeled HRG) has been built up in the collision). One clearly can determine the size r_0 from analyzing the shape.

Summary

Strangeness Physics is still the key hadronic signature for a QGP

If the system behaves collective and thermodynamical, then the equilibration of strangeness is a powerful parameter to signal a phase transition.

Strange mesons are strongly affected by final state interactions, but hyperons seems to decouple early and thus are a reliable probe of the initial conditions.

Besides the kinetic and abundance spectra and ratios, HBT and polarization offer new insights into high T and high density regime

Production of exotics (H–Dibaryons, strangelets, memos) will be enhanced in the case of a phase transition

STAY TUNED FOR RHIC RESULTS !!