On Hypernuclear State in High Energy Heavy Ion Collisions

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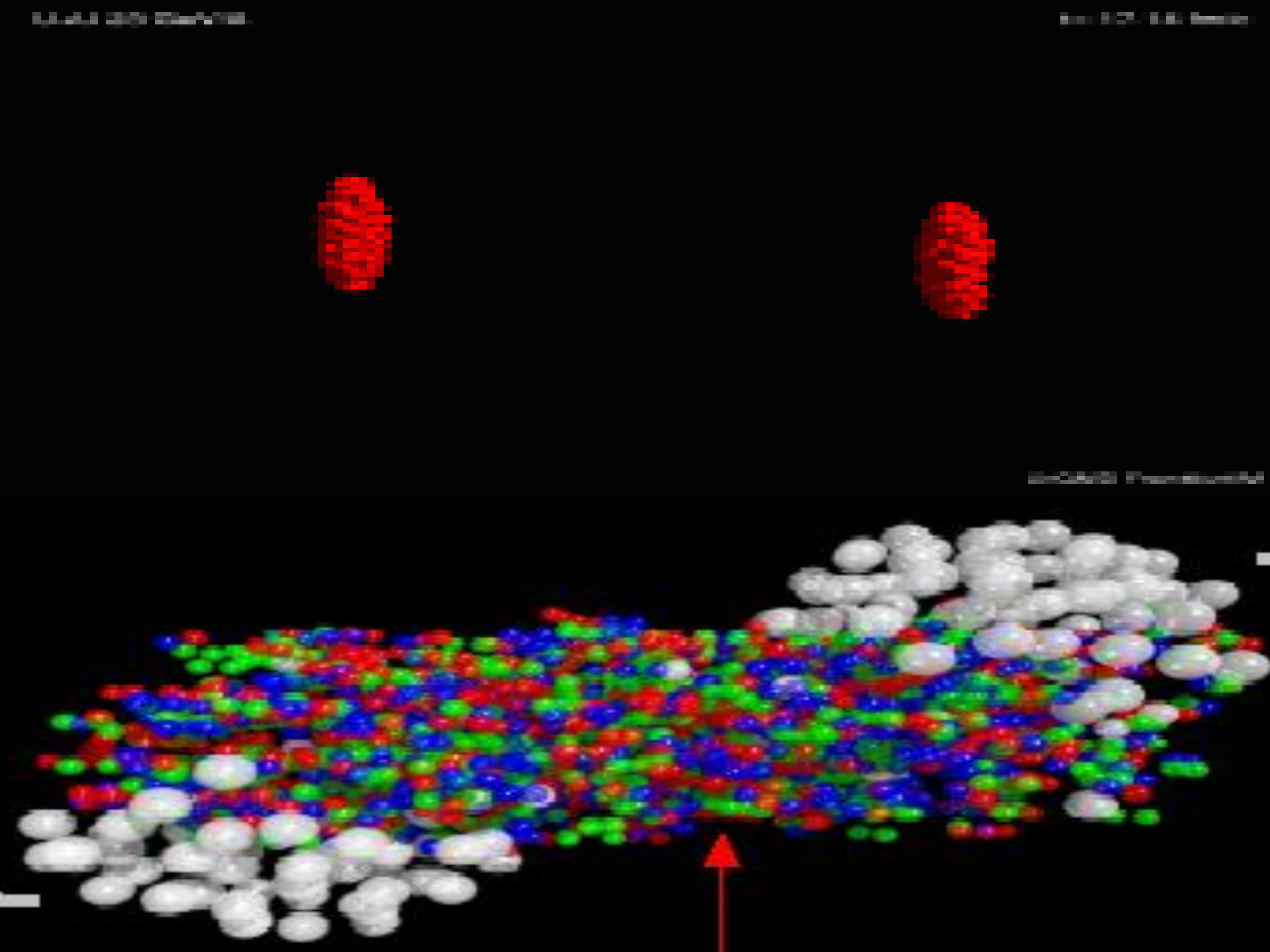
Content

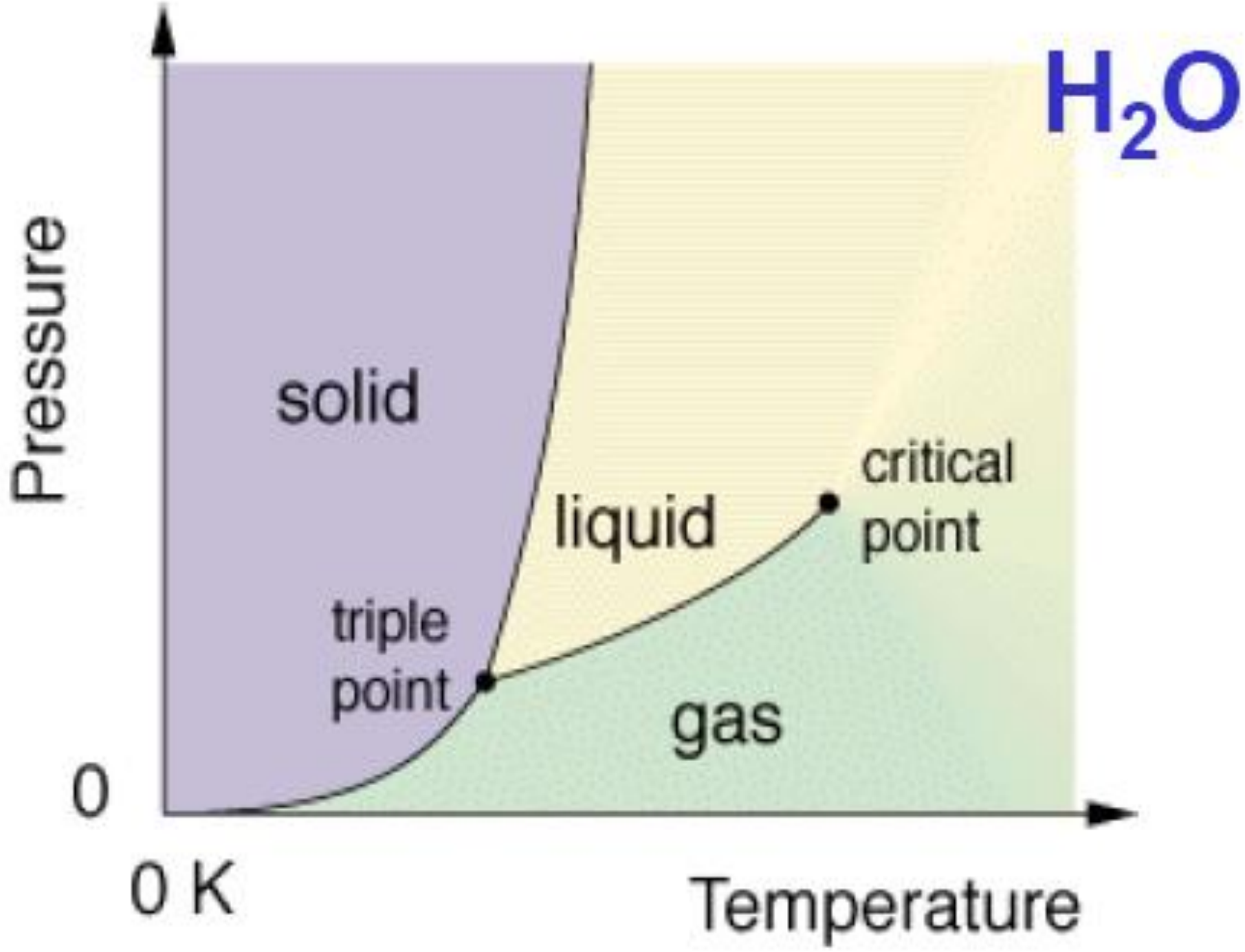
- Heavy Ion Collision: What do we expect?
- NA-49 results:
  - Strange to non-strange yield ratio: ‘horn’ effect
  - Spectra of kaons
- Models describing the ‘horn’ effect.

My proposal:

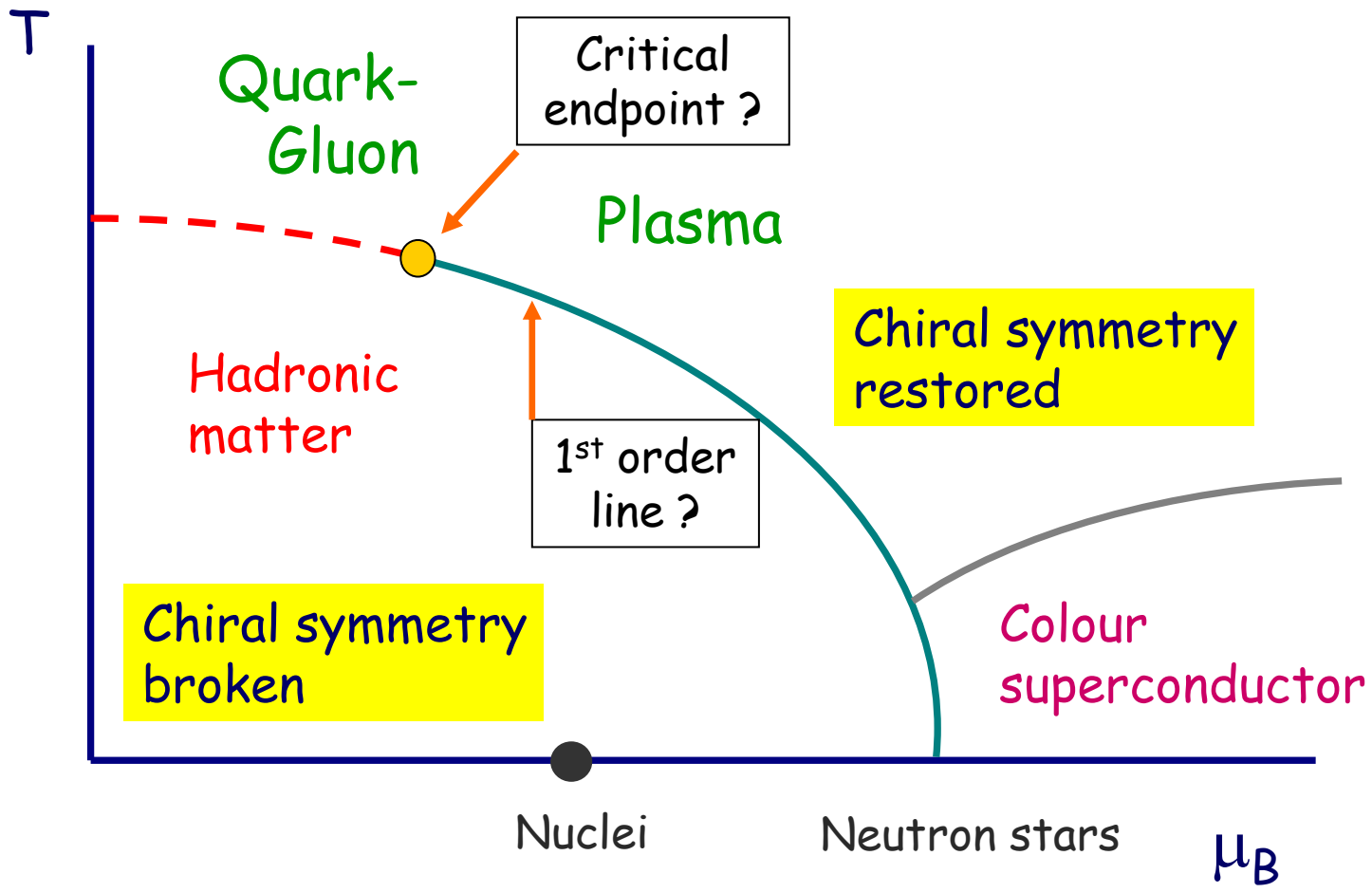
Action-Reaction mechanism in **HIC**:

- **Initial state**
- **Overlap time**
- Discussion

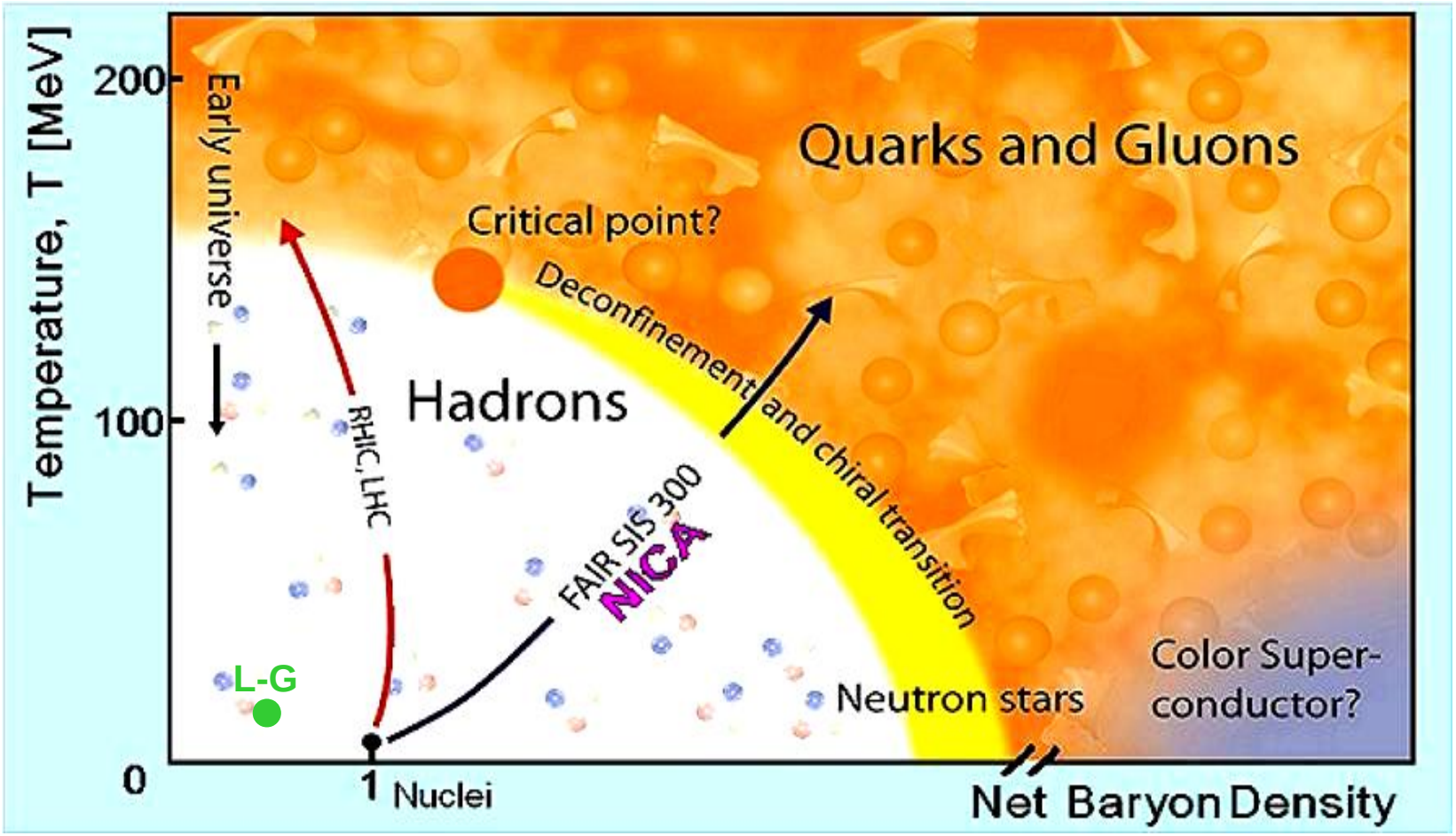



H_2O
Pressure
solid
liquid
gas
critical
point
triple
point
0
0 K
Temperature

Critical Endpoint?

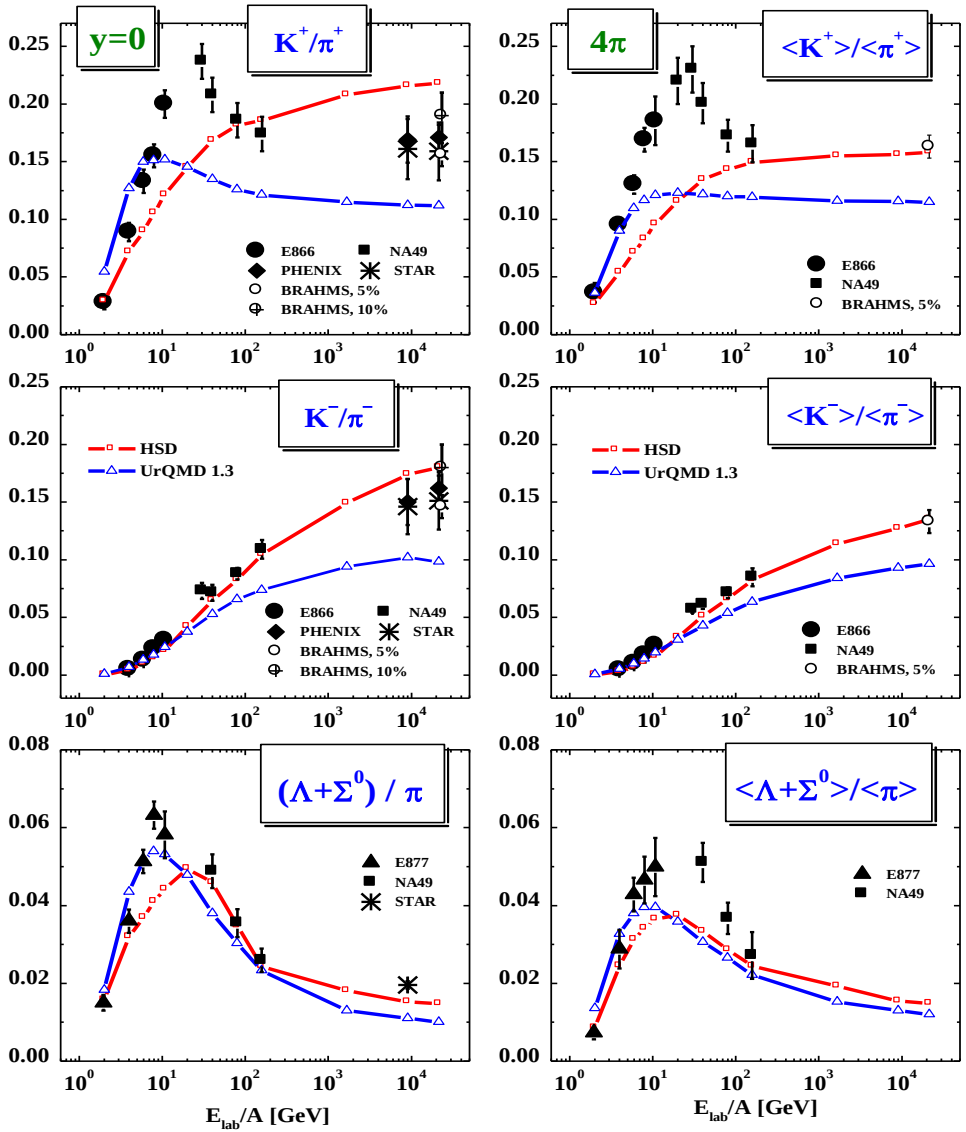


Phase diagram – artist's view



Phases of strongly interacting nuclear matter

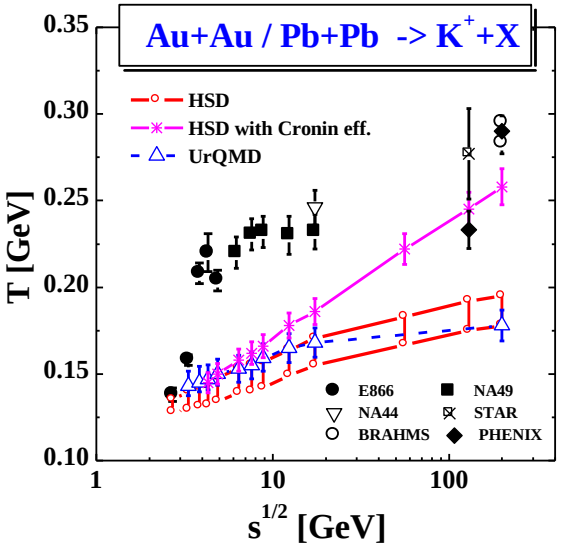
K/π and Λ/π ratio in central Pb-Pb collisions (**NA49**)



Clear evidence for horn structure in K^+/pi^+ and Lambda/pi+

Non-horn structure in K^-/pi^-

Transport models fail to describe experimental data

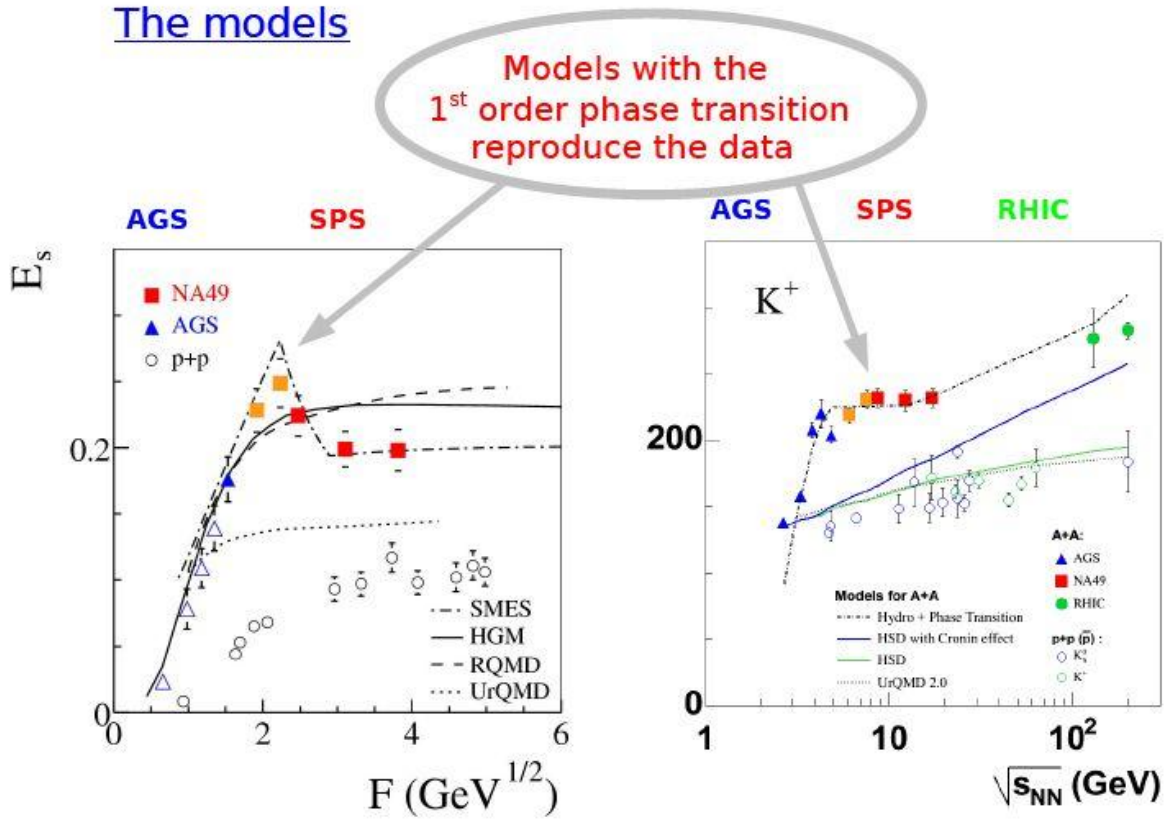


Models

- **Statistical Model of Eearly Stage (SMES)**
  M. Gazditzki, M. Gorenstein
- **Thermal-Statistical Model** *P. Brawn-Munzinger, et al.*
- **Hadronic Kinetic Model** *E. Kolomeitsev, B. Tomasic*

Models

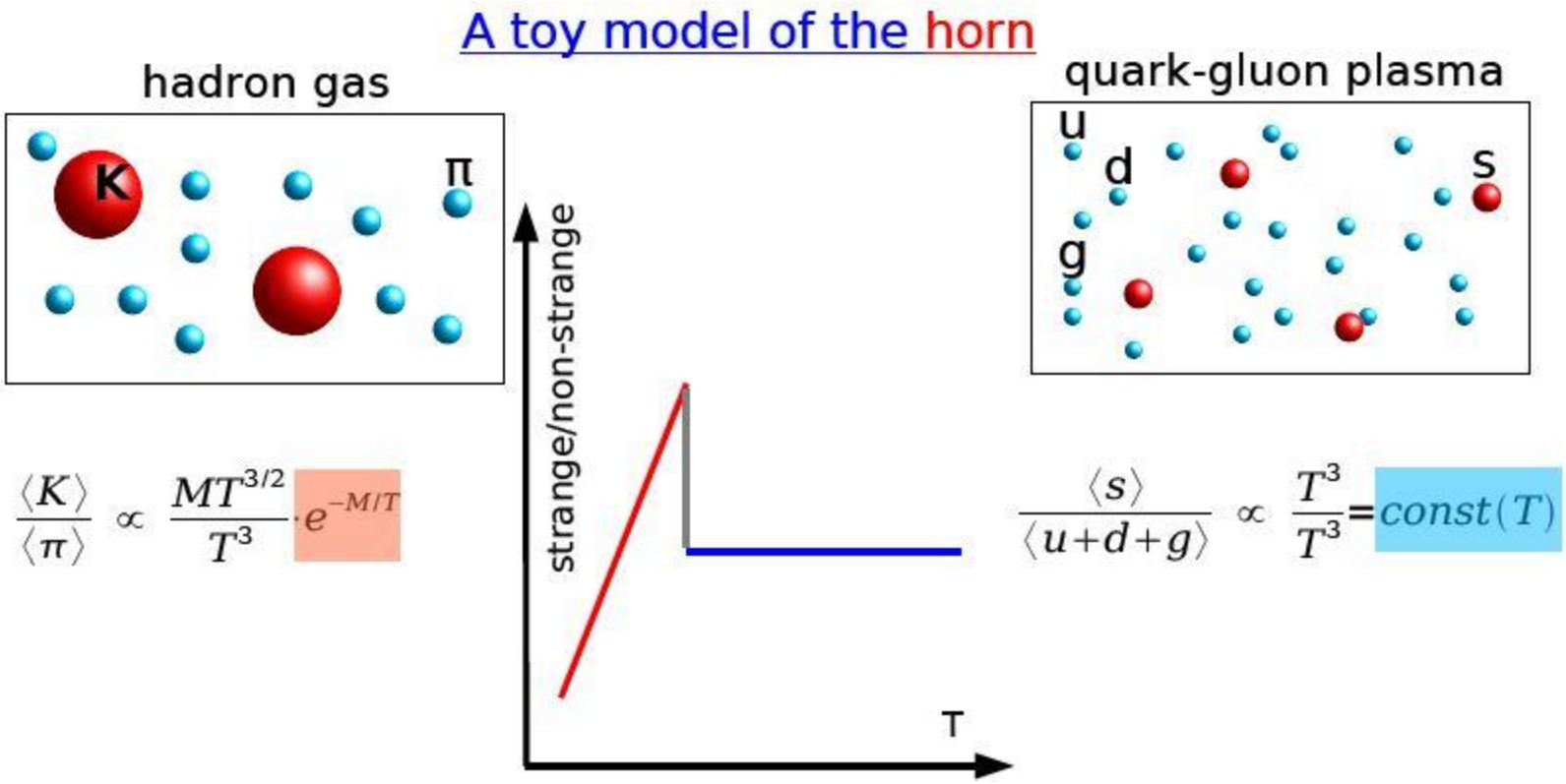
SMES *M. Gazditzki, M. Gorenstein*



$$E_S=(\langle\Lambda\rangle+\langle K+\overline{K}\rangle)/\langle\pi\rangle$$

Models

SMES *M. Gazditzki, M. Gorenstein*

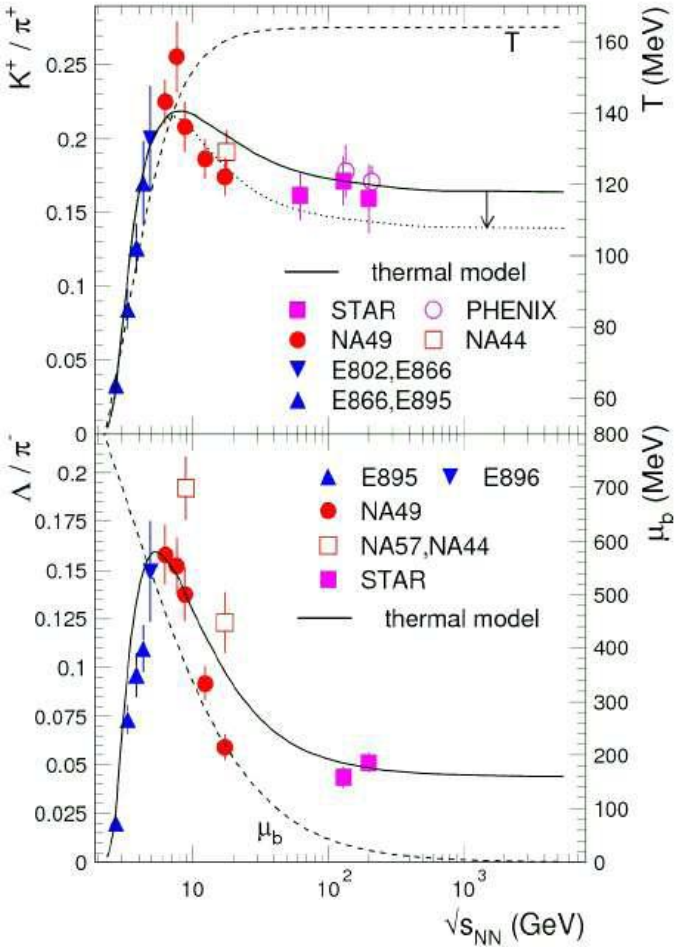


Models

Thermal-Statistical Model *P. Brawn-Munzinger, et al.*

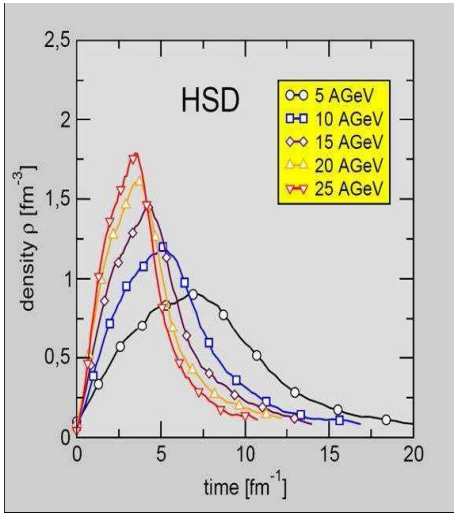
„Horn“ is described as an interplay between QGP phase boundary and the higher resonance spectrum.

Higher resonances in conjunction with additional pions from the sigma describes “horn” structure well

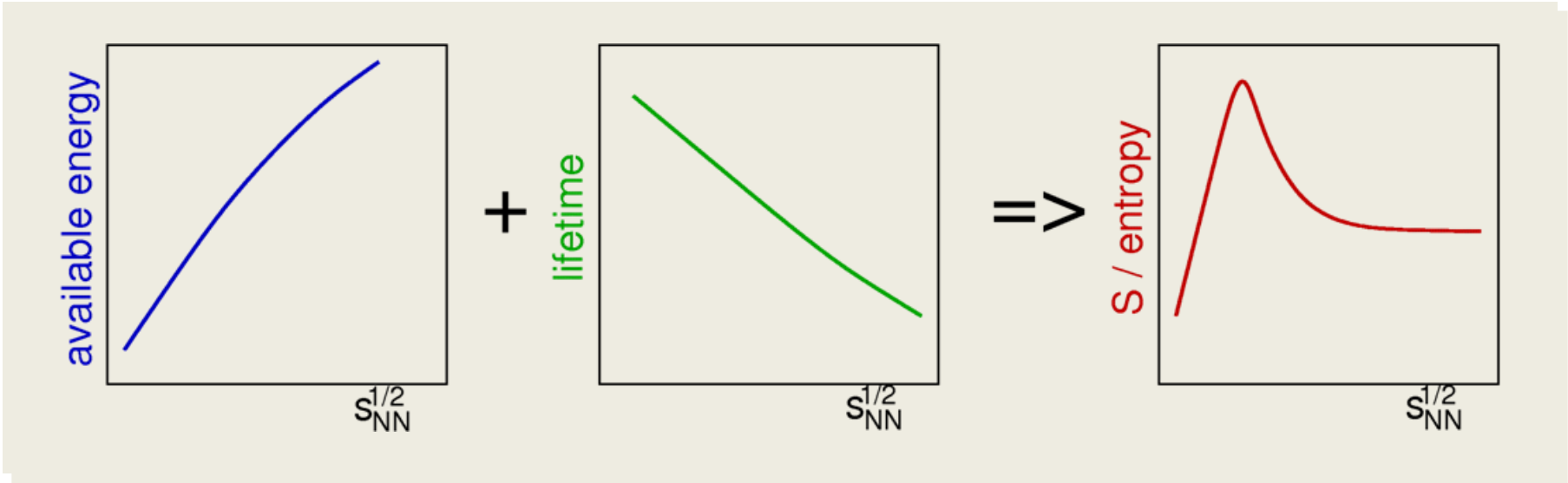


Models

Non-equilibrium Kinetic Model *E. Kolomeitsev, B. Tomasik*



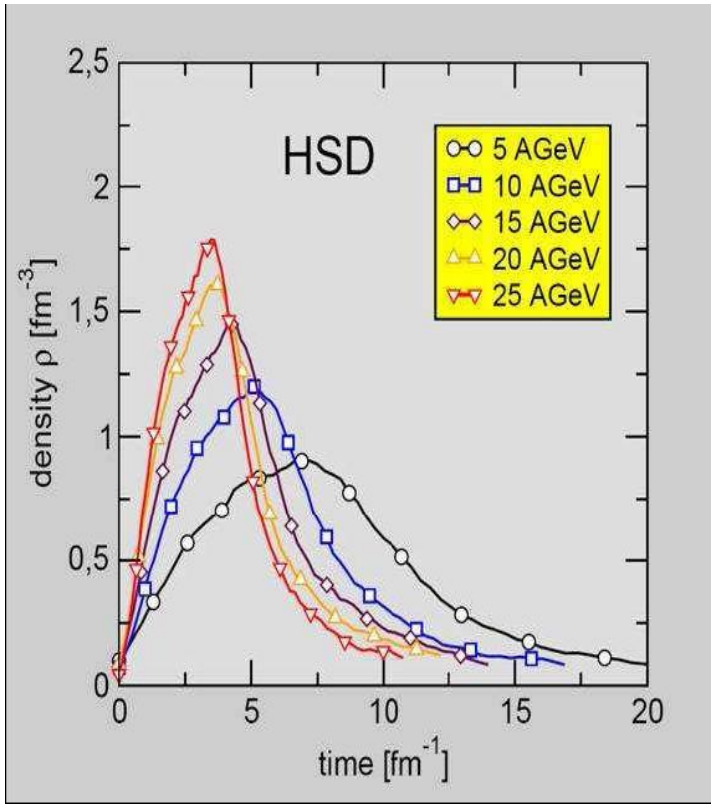
energy vs. time



Action-Reaction Mechanism in HIC

Baryon density evolution

At NICA energies ρ/ρ_0 ~ 5 - 10

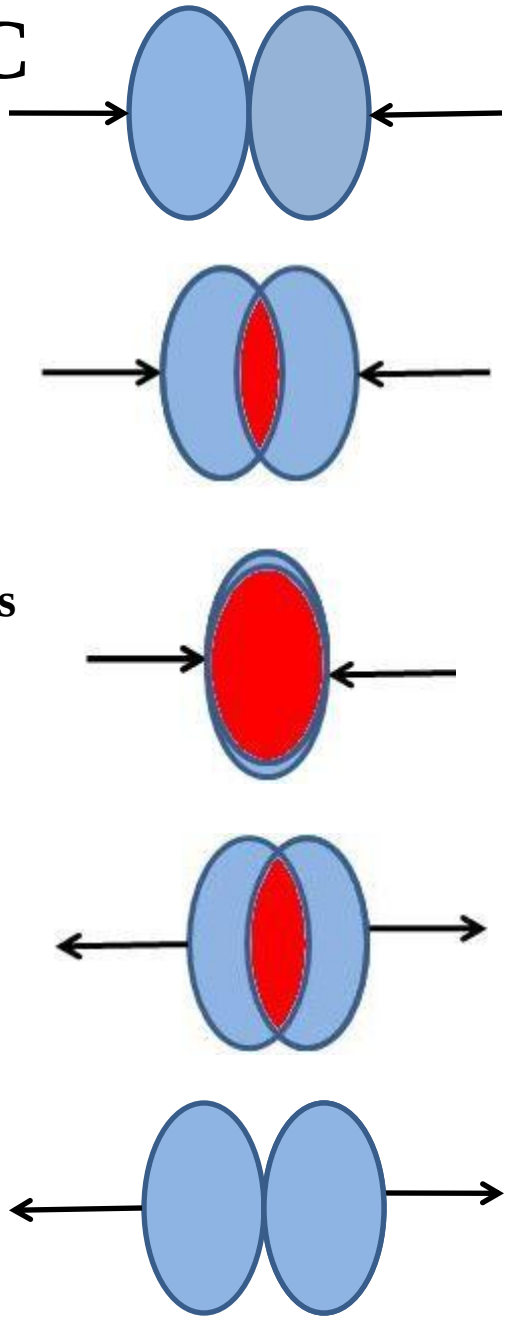


- **At NICA energies ρ/ρ_0 ~ 5 – 10.**

- **In overlap region nucleons are suppressed and forced to occupy much less space volume.**

- **Overlap time:**

$$\tau_O = 2R_A/(\gamma v)$$



Action-Reaction Mechanism in HIC

Conjecture 1:

In dense nuclear matter the baryon number conserves locally (nucleon is a topological soliton).

How can baryons conserve their identity in a smaller volume inside a suppressed medium?

Answer : according to action-reaction mechanism.

Conjecture 2:

- **With a definite probability nucleons in the overlap region transform into hyperons (the heavier quark content of a baryon the less the spatial dimensions of it)**

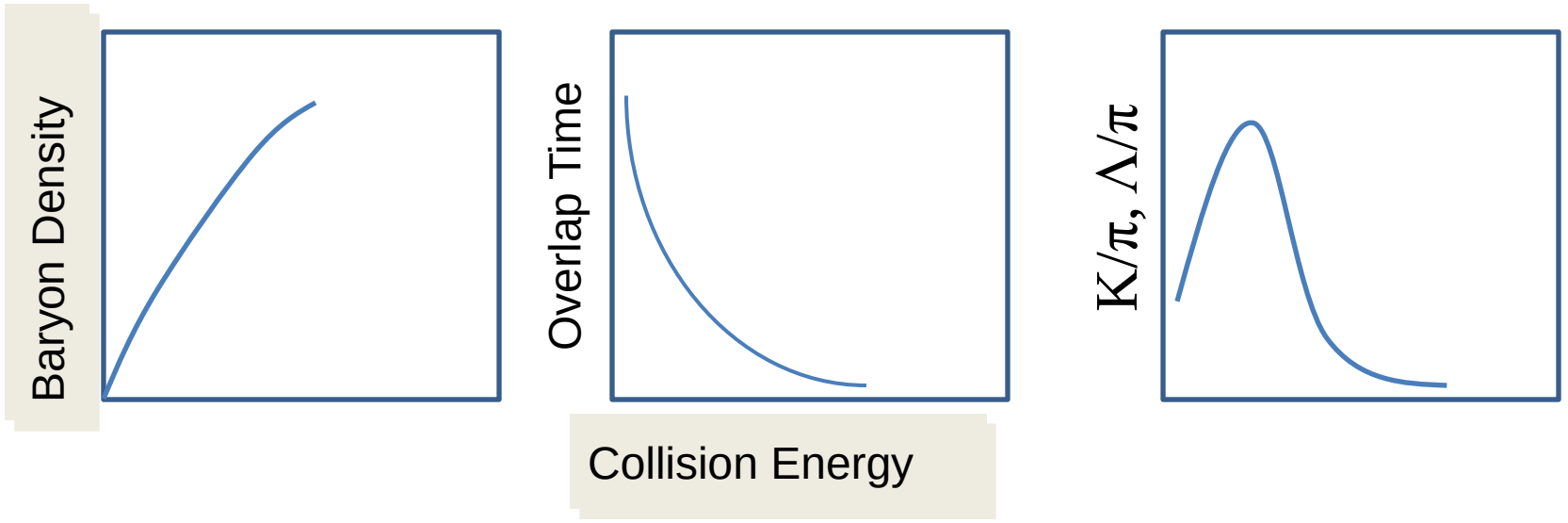
$$p, n \rightarrow \text{hyperons} + \text{kaons}$$

Conjecture 3:

- **All spins of quarks both in hyperons and kaons should be parallel (hyperons and kaons oppose to the external suppression)**

Action-Reaction Mechanism in HIC

K/π and Λ/π ratio



Mechanisms of Strangeness Production

- **Non-equilibrium kinetic mechanism**

$$\sim 1/\lambda_{int} \sim \rho\sigma_{hN}$$

λ_{int} - mean free path

σ_{hN} - hadron-nucleon cross section

- **Nucleons transformation to hyperons**

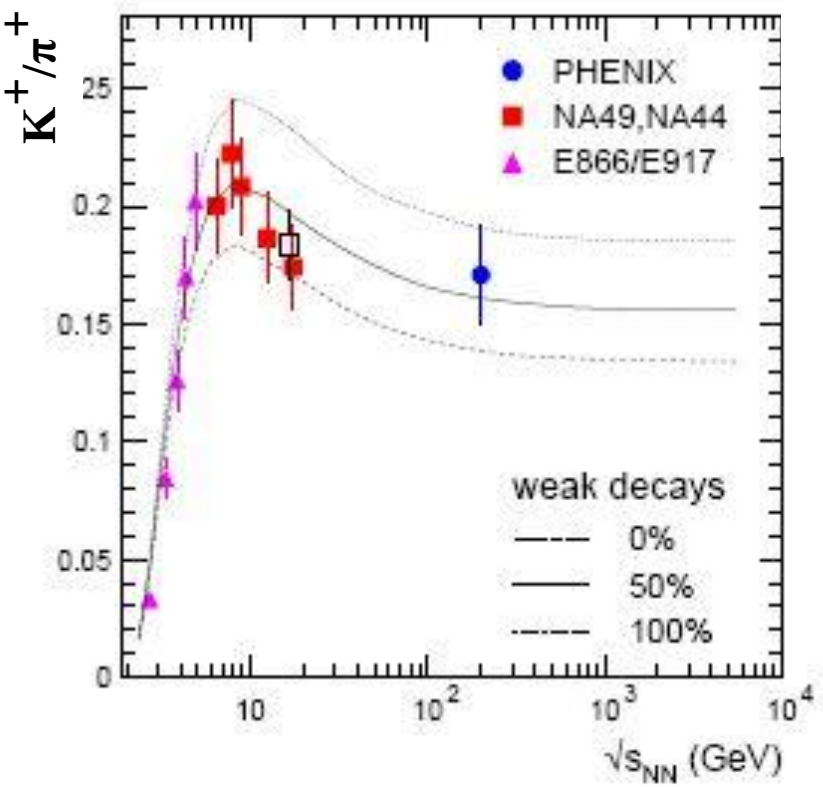
$$\sim (\tau_o/\tau_{re})\, f(\rho)$$

τ_o - overlap time

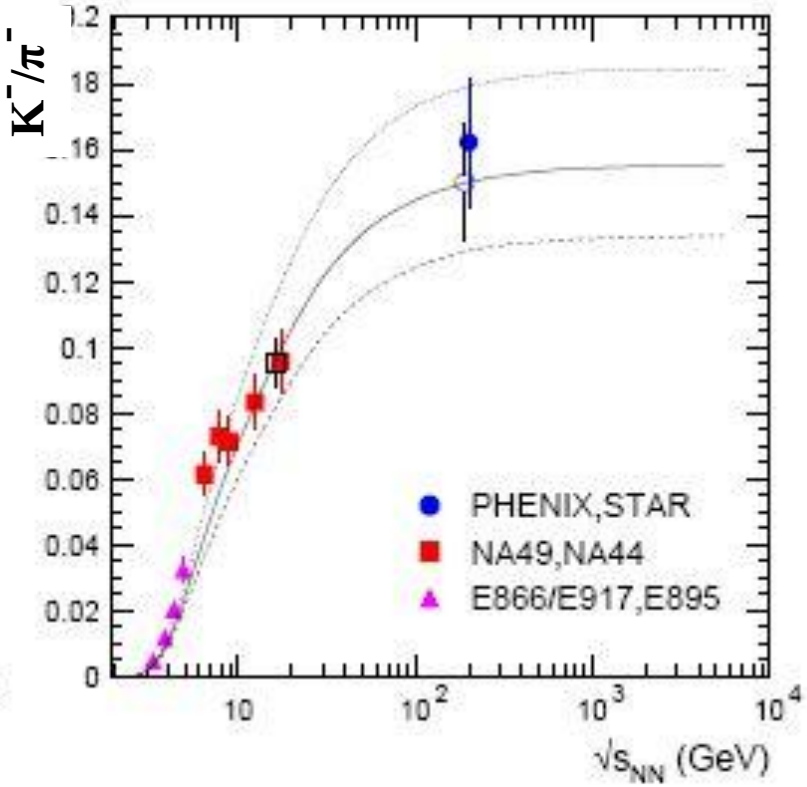
τ_{re} - rearrangement time

Why ‘horn’ structure takes place for K^+/π^+ but not for K^-/π^- ?

!



?



Proton Transformations channels

$$p = (uud), \quad u, d \to s$$

$$\left.\begin{aligned} p(uud) &\to \Sigma^{+*}(uus) + K^{0*}(d\bar{s}) \\ &\to \Sigma^{0*}(uds) + K^{+*}(u\bar{s}) \end{aligned}\right\} S = -1, 1$$

$$\left.\begin{aligned} &\to \Xi^{-*}(dss) + 2K^{+*}(u\bar{s}) \\ &\to \Xi^{0*}(uss) + K^{0*}(d\bar{s}) + K^{+*}(u\bar{s}) \end{aligned}\right\} S = -2, 2$$

$$\left.\begin{aligned} &\to \Omega^{-}(sss) + 2K^{+*}(u\bar{s}) + K^{0*}(d\bar{s}) \end{aligned}\right\} S = -3, 3$$

$$K^{0/+*} \to K^{0/+} + \pi^{0}$$

No one K^- is created!

Neutron Transformations channels

$$n(udd), \quad u,d \to s$$

$$\left.\begin{aligned} n(ddu) &\to \Sigma^{-*}(dds) + K^{+*}(u\bar{s}) \\ &\to \Sigma^{0*}(uds) + K^{0*}(d\bar{s}) \end{aligned}\right\} S = -1, 1$$

$$\left.\begin{aligned} &\to \Xi^{0*}(uss) + 2K^{0*}(d\bar{s}) \\ &\to \Xi^{-*}(dss) + K^{0*}(d\bar{s}) + K^{+*}(u\bar{s}) \end{aligned}\right\} S = -2, 2$$

$$\left.\begin{aligned} &\to \Omega^{-}(sss) + 2K^{0*}(d\bar{s}) + K^{+*}(u\bar{s}) \end{aligned}\right\} S = -3, 3$$

$$K^{0/+*} \to K^{0/+} + \pi^{0}$$

No one K^- is created!

Hyperon Resonances Decay

$$\Sigma^{0*} \rightarrow \Lambda + \pi^0 \quad 88\%$$
$$\rightarrow \Sigma^0 + \pi^0 \quad 12\%$$

$$\Sigma^{+*} \rightarrow \Lambda + \pi^+ \quad 88\%$$
$$\rightarrow \Sigma^+ + \pi^0 \quad 12\%$$

$$\Xi^{0*} \rightarrow \Xi^0 + \pi^0$$

$$\Xi^{-*} \rightarrow \Xi^{-0}$$

$$\Omega^- \rightarrow \Lambda + K^- \quad 68\%$$
$$\rightarrow \Xi^0 + \pi^- \quad 24\%$$
$$\rightarrow \Xi^- + \pi^0 \quad 8\%$$

Stangeness Production in central HIC

AGS: Kinetic + AR mechanisms

- Nucleons transform to Δ- isobars and hyperons + kaons

$$(\tau_o/\tau_{re}) \sim 1,$$

NICA, CBM, SPS: Kinetic + AR mechanisms

- Nucleons transform to (multi)strange hyperons + kaons

$$(\tau_o/\tau_{re}) \leq 1$$

RHIC, LHC: Kinetic mechanism

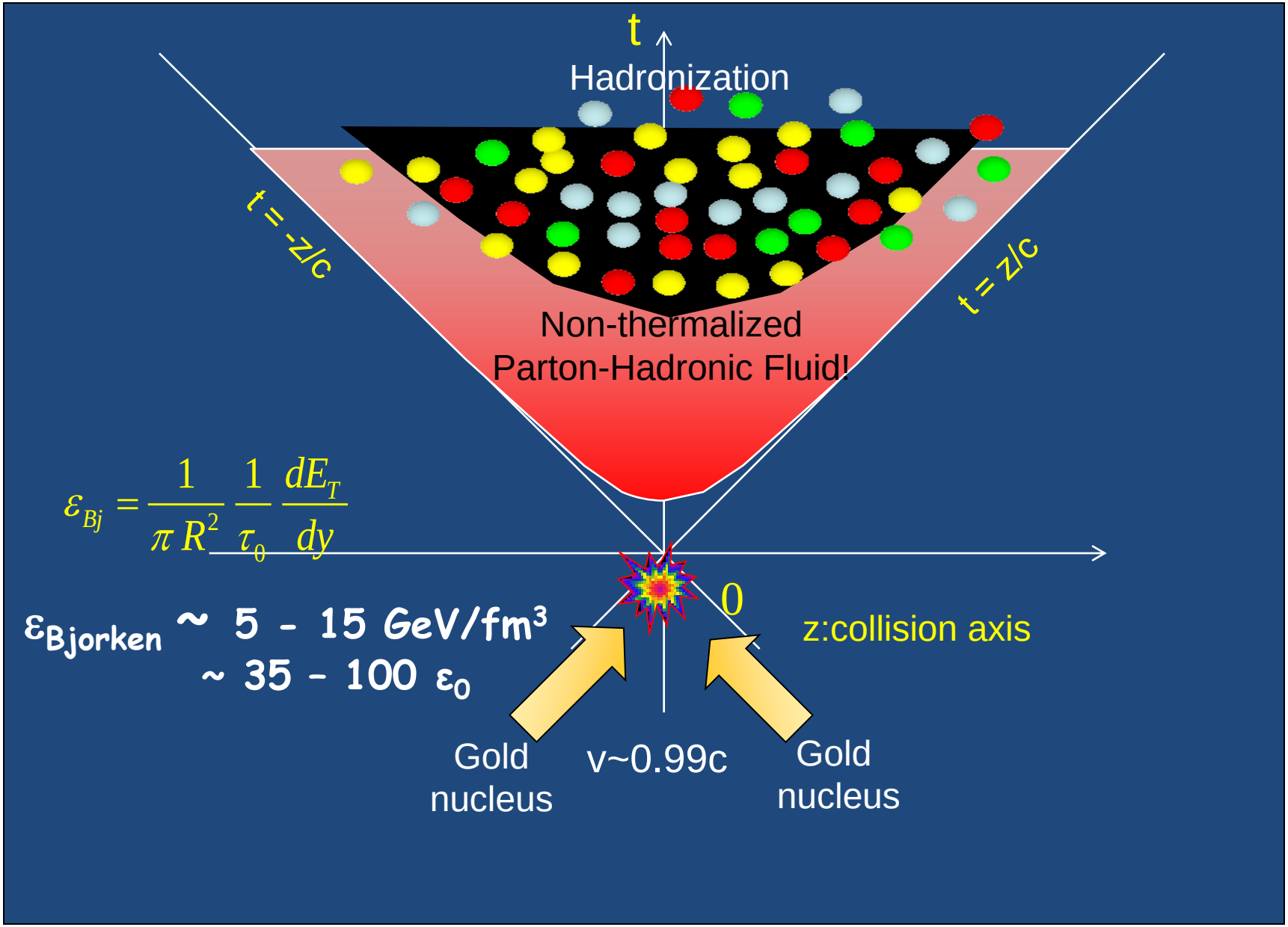
$$(\tau_o/\tau_{re}) \ll 1$$

Action-Reaction Mechanism at RHIC and LHC

Early stage of the fireball evolution:

- Very high medium density

- Predominant production of (heavy) vector resonances at the early (high density) stage of the fireball evolution.


t
Hadronization
t = -z/c
t = z/c
Non-thermalized
Parton-Hadronic Fluid!
$\varepsilon_{Bj} = \frac{1}{\pi R^2}\frac{1}{\tau_0}\frac{dE_T}{dy}$
$\varepsilon_{Bjorken}$ ~ 5 - 15 GeV/fm^3
~ 35 - 100 ε_0
0
z:collision axis
Gold nucleus
v~0.99c
Gold nucleus

Conclusions

Bad News

Early stage of the fireball evolution:

- Predominant production of (heavy) vector resonances.
- **QGP at FAIR and NICA and even at RHIC and LHC energies is not realized:**
- No room for the 1st order phase transition and critical point.
- No room for dynamical fluctuations
- P or CP invariance is not violated neither at NICA and FAIR nor at RHIC and LHC.

Conclusions

Good News

The most observables and effects can be explained using the proposed mechanism.

To test it quatitatively one needs to implement it into the transport (URQMD, HSD, QGSM) and hybrid models.

Parameters:

- **reaction time;**
- **probability of transition of nucleon to hyperon + kaon.**

Conclusions

Good News

The most interesting physics is expected at NICA, FAIR and low energy region of SPS:

- Nuclear compressibility, EOS
- The Isobar- and hyperon- nuclear states (application to the physics of neutron stars)
- Enhancement yield of (multi)strange baryons
- Correlations between strange baryons and kaons
- Effects of the Strong magnetic field:
  - ✓Polarization of (multi)strange particles
  - ✓Vorticity effects
  - ✓Skewness/asymmetry of particle emissions

Neutron star

Gravitational suppression

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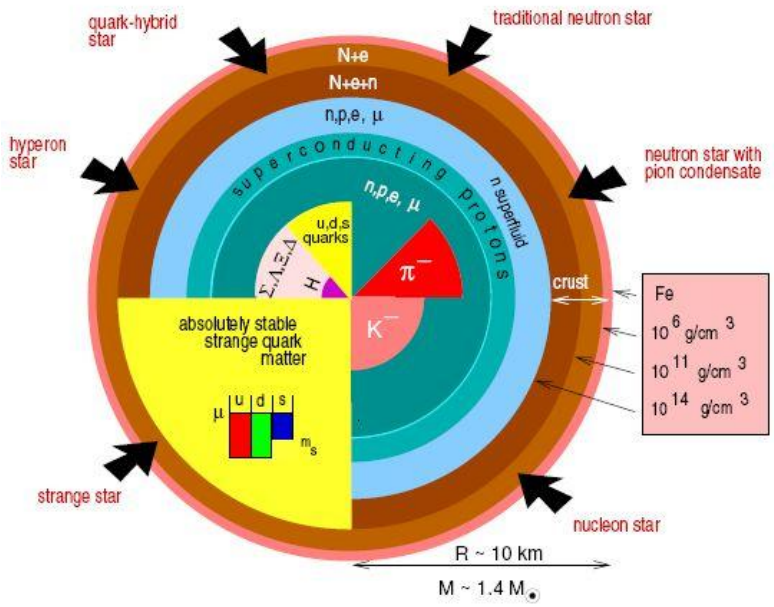
Nuclear matter

neutrons, hyperons ?

quarks?



Gravitational suppression

. . . . . .

Nuclear matter

Δ- isobar matter

Hyperonic matter

Charmonic matter

Botonic matter

Toponic matter

Thanks for your attention!

Current quark states in bound nucleons are **suppressed**

Bound Nucleon, N^*

$$\left|N^*\right\rangle = c_1\left|q_1q_2q_3\right\rangle + c_2\left|q_1q_2q_3\bar{q}q\right\rangle + c_3\left|q_1q_2q_3g\right\rangle + \ldots$$

suppressed

Nucleons inside nuclei are in constituent state!

Color Transparency “Breaking”
in quasielastic scattering

p+A → pp+X at $\theta_{cm}=90^0$

Observable:

$$T = \sigma^A/(Z\,\sigma^N)$$

Color transparency :

$T \rightarrow 1$