Multistrange particle production in Statistical Hadronization Model

Michal Petran
University of Arizona, Tucson
&
ALICE group at CTU, Prague

With Johann Rafelski
University of Arizona, Tucson

Outline

- Multistrange hadron ratios at SPS and RHIC
- Statistical Hadronization Model (SHARE, Cracow – Tucson)
- Hadron chemistry of the final stage in HI collisions
- Implications for RHIC
- Predictions for LHC

Multistrange particle ratios

- Ratios sensitive to quark flavor content
- Wide range of energies, centralities (7.61-200 GeV)

$$\frac{\Xi}{\phi} \propto \gamma_q$$

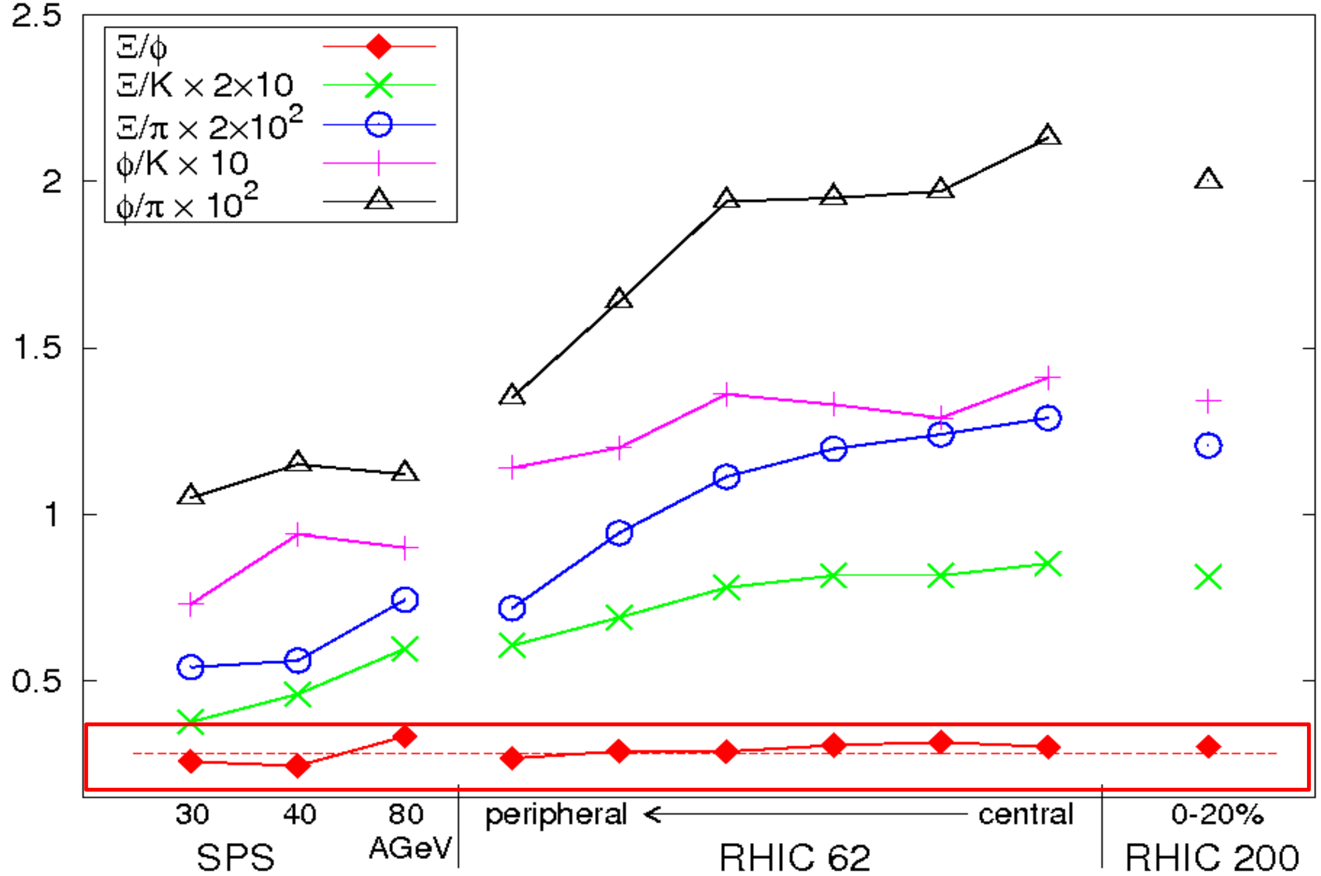
$$\frac{\Xi}{K} \propto \gamma_s$$

$$\frac{\Xi}{\pi} \propto \frac{\gamma_s^2}{\gamma_q}$$

$$\frac{\phi}{K} \propto \frac{\gamma_s}{\gamma_q}$$

$$\frac{\phi}{\pi} \propto \left(\frac{\gamma_s}{\gamma_q}\right)^2$$

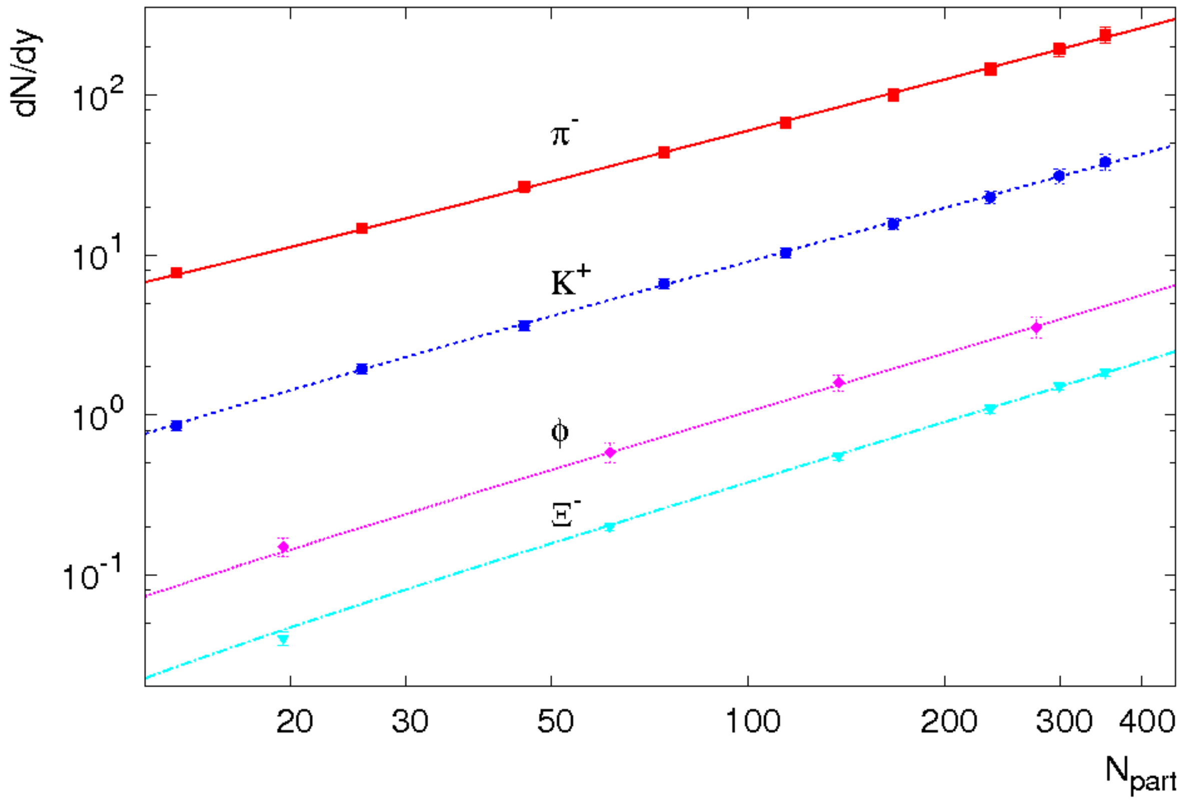
Implications on quark chemistry during hadronization



Centrality dependence of Ξ,φ yields

- Individual yields follow $f(N_{part}) = a \cdot N_{part}^{b} + c$
- $b \simeq 1.2$
- Ξ and φ yields rise equally →
- Ξ/φ constant

RHIC 62 GeV data and interpolation



$$\frac{\Xi}{\phi} \in \langle 0.249, 0.304 \rangle$$

- Common hadronization conditions for all the studied systems
- γ_q = constant
- $\frac{\Xi}{\phi} \equiv \sqrt{\frac{\overline{\Xi}^{+}\,\Xi^{-}}{\phi\,\phi}} \simeq \gamma_q f(T, m_\phi, m_\Xi)$

Particle production in Statistical Hadronization Model (SHM)

- **T** - (chemical freeze-out) temperature
- Overall normalization – Volume **V**

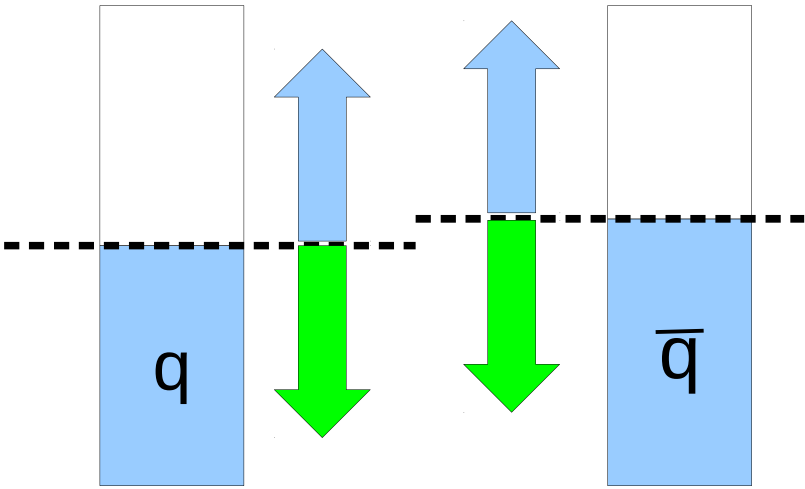
$$\frac{N}{V} = g\gamma \int d^3p\,\lambda\, e^{-\sqrt{p^2+m^2}/T} \simeq g\gamma \frac{4\pi}{(2\pi)^3} \lambda m^2 T K_2\left(\frac{m}{T}\right)$$

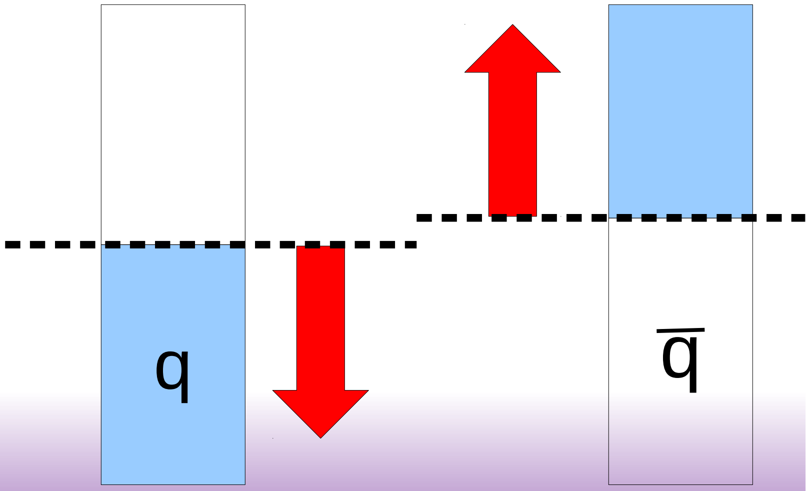
$$\lambda = \prod_q \lambda_q, \qquad \gamma = \prod_q \gamma_q$$

- conservation of baryon number, charge, strangeness, ...

Chemistry in SHM

- γ_i phase space occupancy
  - Absolute chemical equilibrium (size of accessible phase-space)
  - Affects yield of quark and anti-quark of i-th family
  - slow
- λ_i fugacity factor, $\lambda_i = e^{\mu_i/T}$
  - Relative chemical equilibrium
  - Difference between quark and anti-quark of i-th family
  - fast





Ξ/φ in detail

- Ξ/φ (include contributions from decays)

$$\frac{\Xi}{\phi} \equiv \sqrt{\frac{\overline{\Xi}^{+}(\bar{d}\,\bar{s}\,\bar{s})\,\Xi^{-}(dss)}{\phi(s\bar{s})\,\phi(s\bar{s})}} \simeq \frac{\gamma_q \gamma_s^2 \lambda_s \lambda_s^{-1} \lambda_q^{1/2} \lambda_q^{-1/2}}{\gamma_s^2 \lambda_s \lambda_s^{-1}} f(T, m_\phi, m_\Xi)$$

$$\simeq \gamma_q f(T, m_\phi, m_\Xi);$$

$$f(T, m_\phi, m_\Xi) \simeq \sum_i \frac{g_i}{3} \left(\frac{m_{\Xi_i}}{m_\phi} \right)^{3/2} e^{\frac{m_\phi - m_{\Xi_i}}{T}}$$

Eliminates:
- normalization
- chemical potentials
- strange phase space occupancy

Tested for parameter dependence and quantum vs. Boltzmann statistics correction

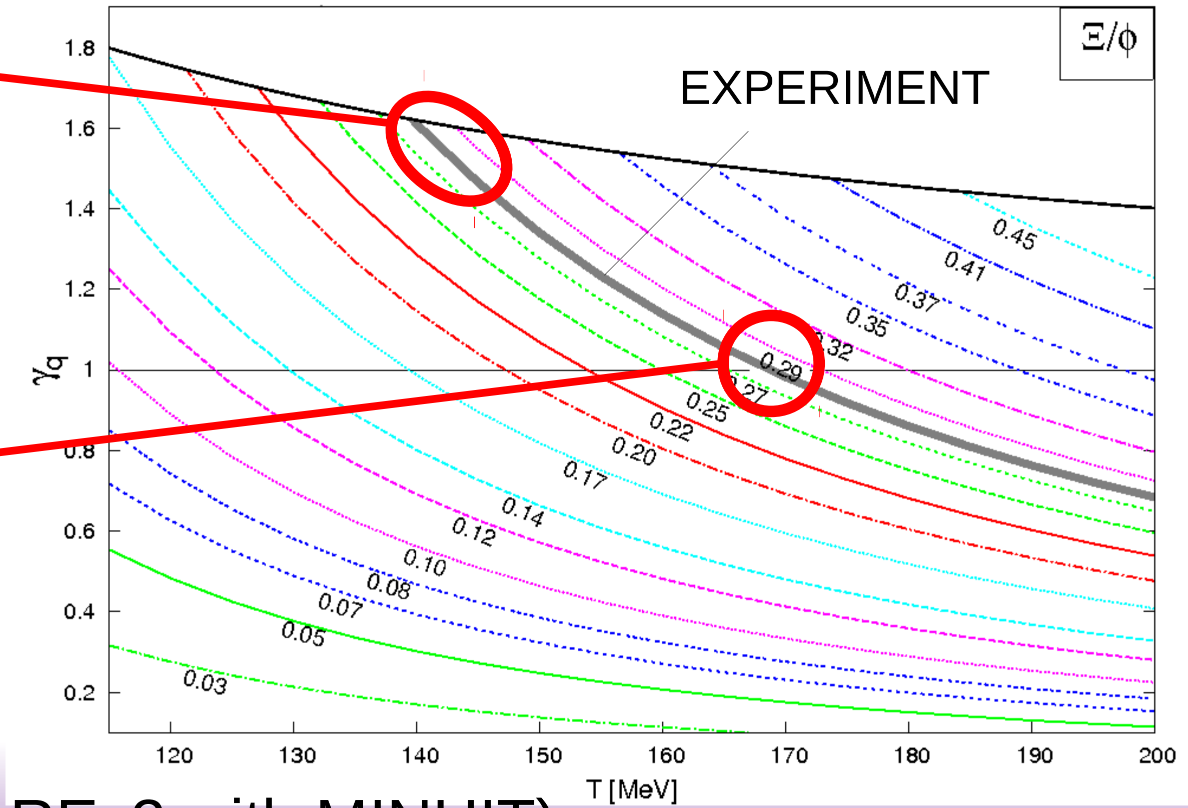
Consistency check (SHAREv2)

- Global fits
  - Non-equilibrium (RHIC 62 central (peripheral))

    T = 141 MeV
    γ_q = 1.54 (1.56)
    γ_s = 2.04 (1.68)

  - Semi-equilibrium

    T = 171 MeV
    γ_q = 1.
    γ_s = 1.05 (0.9)



Minimization procedure in 6(7) dimensional parameter space (use SHAREv2 with MINUIT)

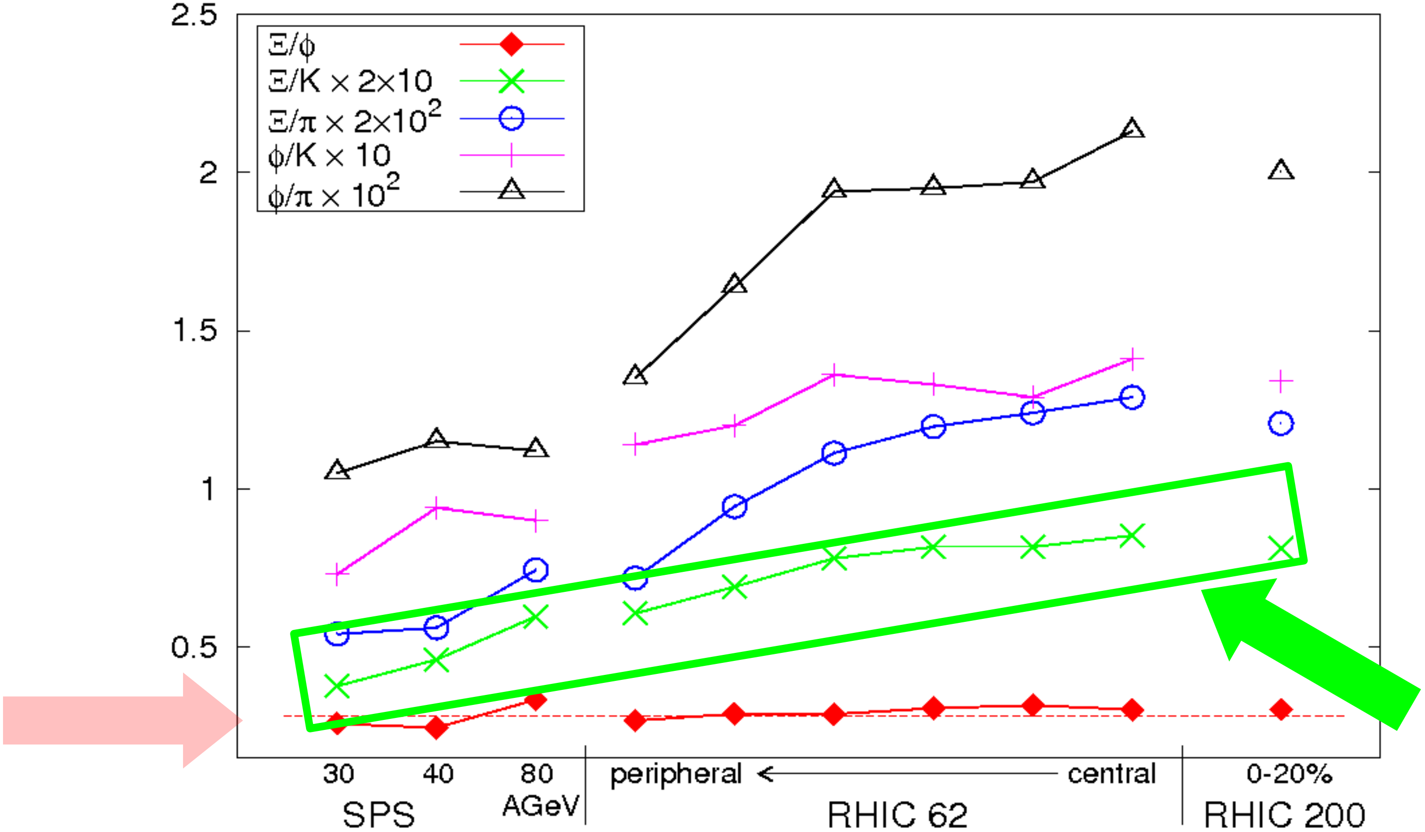
Strangeness

$$\frac{\Xi}{K} \propto \gamma_s$$

$$\frac{\Xi}{\pi} \propto \frac{\gamma_s^2}{\gamma_q}$$

$$\frac{\phi}{K} \propto \frac{\gamma_s}{\gamma_q}$$

$$\frac{\phi}{\pi} \propto \left(\frac{\gamma_s}{\gamma_q}\right)^2$$

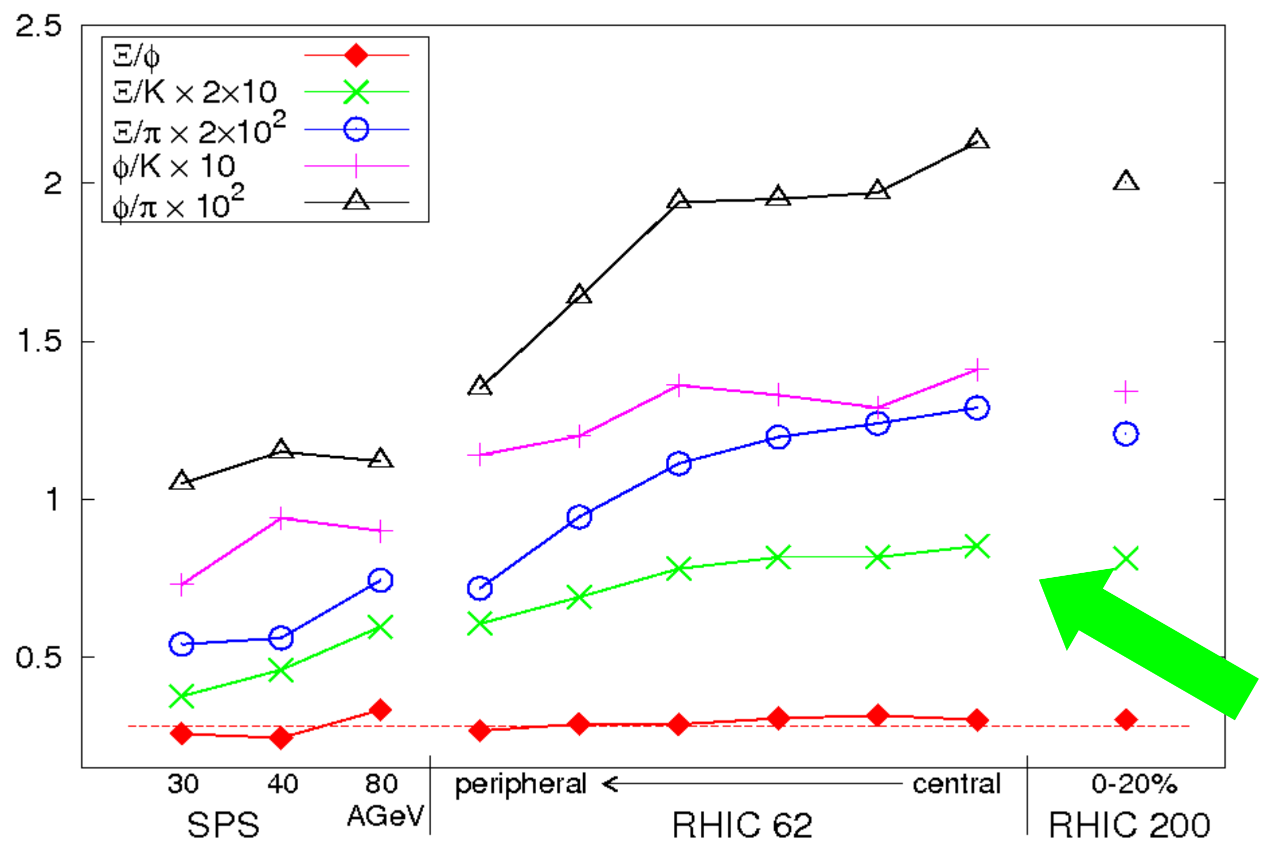


$$\frac{\Xi}{K} \propto \gamma_s, \qquad \frac{\Omega}{\phi} \propto \gamma_s$$

Ξ/K - Strange phase space - γ_s

- Factor 1.5x residual dependence on $\gamma_s \neq 1$
- $\gamma_s \neq 1$, fast hadronization $\frac{\Xi}{K} \equiv \sqrt{\frac{\Xi^- \bar{\Xi}^+}{K^+ K^-}} \simeq \gamma_s \, f\,(T, m_\Xi, m_K)$

Collision	Ξ/K x 10^2
STAR 62 0-5%	4.19
STAR 62 5-10%	4.08
STAR 62 10-20%	4.06
STAR 62 20-40%	3.79
STAR 62 40-60%	3.38
STAR 62 60-80%	2.84
SPS 7.61 GeV 7%	1.85
SPS 8.76 GeV 7%	1.89

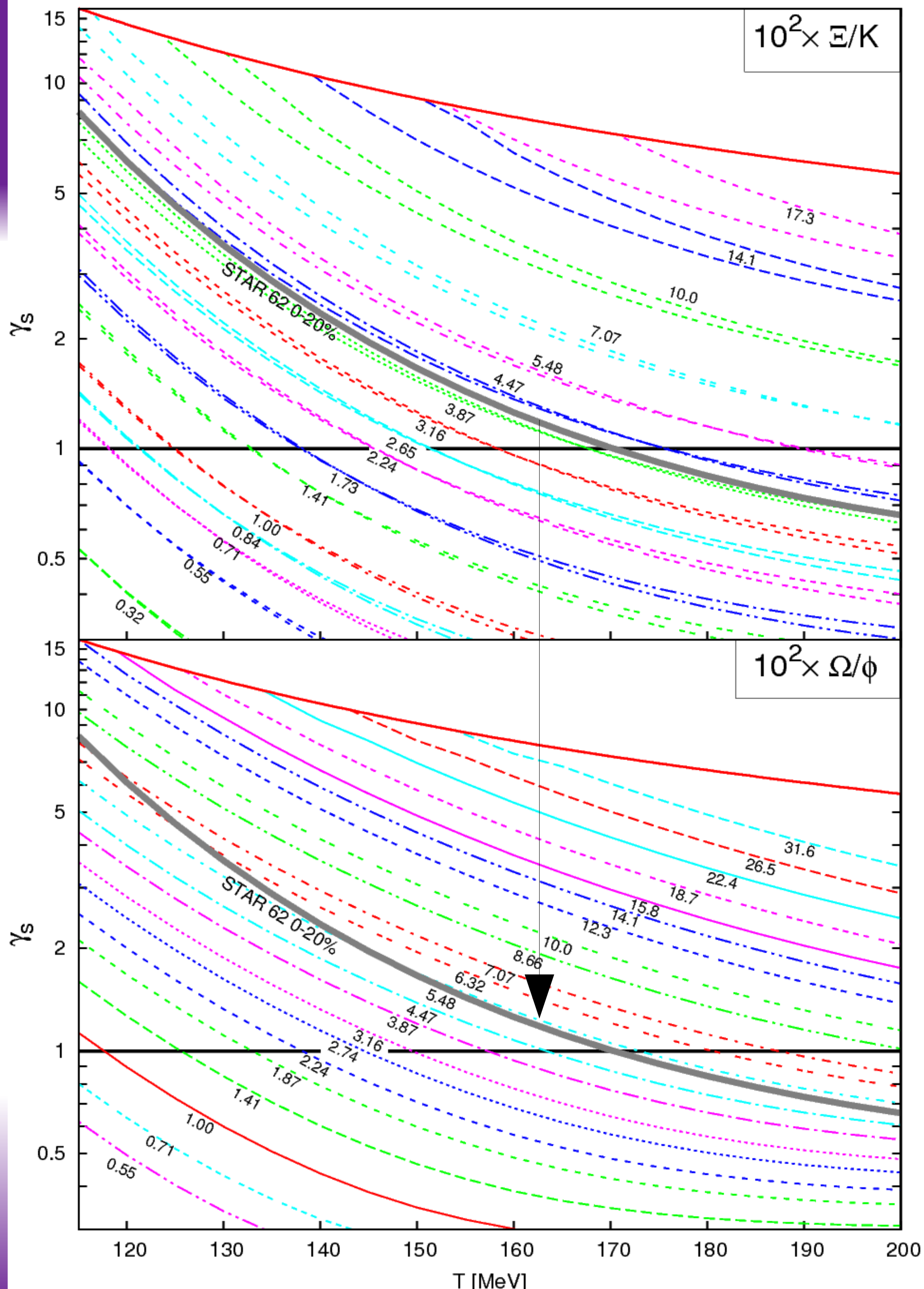


Predictions

- Given Ξ/K (RHIC 62 central) →

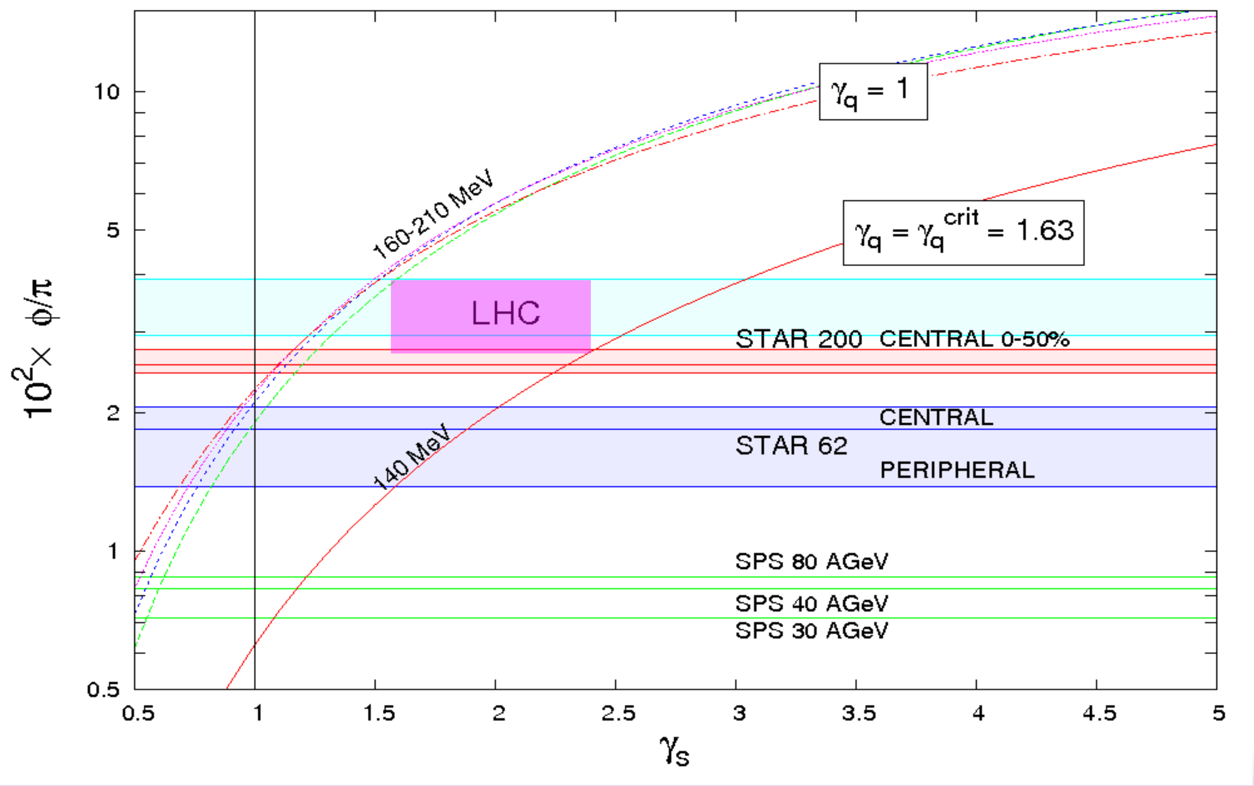
$$\frac{\Omega}{\phi} \propto \gamma_s \rightarrow$$

$$5.5\times10^{-2} < \Omega/\phi < 7.0\times10^{-2}$$



Predictions for LHC

- Constant Ξ/φ ~ 0.28 ← No c,b decays included
- s/S ~ 0.037 → $\gamma_s/\gamma_q \simeq 1.55 \rightarrow \phi/\pi \in \langle 2.95, 3.90 \rangle \times 10^{-2}$
- Require $\gamma_s > 1$
- Chemical non-equilibrium not consistent
- $\dfrac{\phi}{\pi} \propto \left(\dfrac{\gamma_s}{\gamma_q}\right)^2$



Conclusions

- Ξ/φ constant over wide range of energies and centralities
  - Common hadronization conditions
  - Multistrange particles produced at the same conditions as other particles
- Ξ/K changes with energy and centrality
  - Chemical equilibrium excluded ($\gamma_s \neq$ constant)
  - Fast hadronization required
- $\gamma_s > 1$ - sign of strangeness dense initial phase (QGP), expected at LHC
- Predictions for RHIC and LHC

Outlook

- Look at other systems/experiments/energies
  - RHIC (CuCu, Beam Energy Scan run)
  - LHC (High multiplicity pp, PbPb)
    - Decision between semi- and non-equilibrium model
    - Detailed understanding of strangeness production, dependence on system size and energy
    - Establishing general hadronization conditions

Acknowledgements

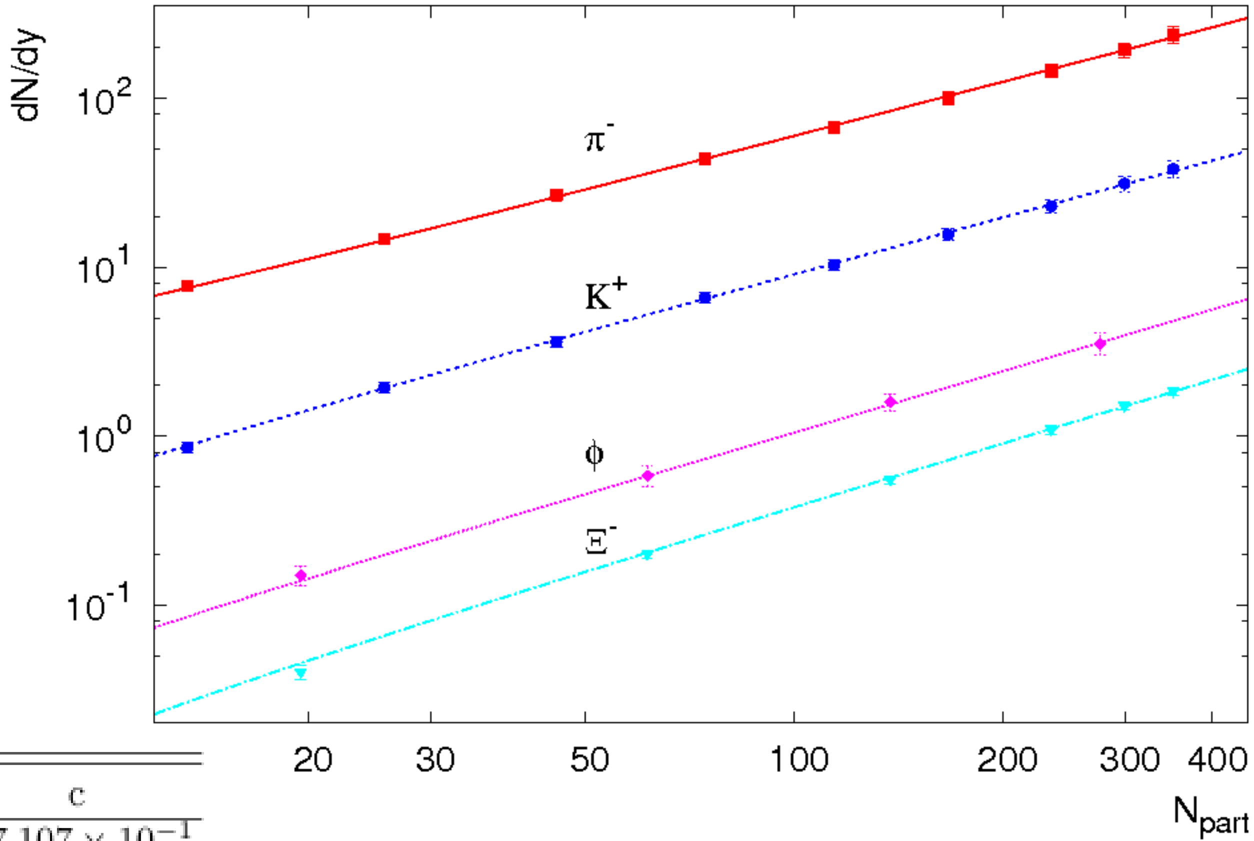
- Johann Rafelski, Univ. of Arizona, Tucson
- Vojtech Petracek, CTU, Prague
  - ALICE group @ Center for Physics of Ultra-relativistic Nuclear Collisions (CFRJS), Prague

THANK YOU

BACKUP SLIDES follow

STAR 64 Particle yields vs. Centrality

- Interpolated with $f(N_{part}) = a \cdot N_{part}^{b} + c$



	a	b	c
π^-	4.179×10^{-1}	1.072	7.107×10^{-1}
π^+	4.247×10^{-1}	1.048	6.422×10^{-1}
K^+	5.433×10^{-2}	1.111	-1.014×10^{-1}
K^-	4.812×10^{-2}	1.107	-3.859×10^{-2}
Ξ^-	1.228×10^{-3}	1.247	-4.678×10^{-3}
$\bar{\Xi}^+$	8.978×10^{-4}	1.221	9.390×10^{-4}
ϕ^0	4.162×10^{-3}	1.203	-9.311×10^{-3}

B-E condensation of π^0 and η

$$m_{\pi^0} = 135\, MeV/c^2$$

$$\gamma_{\pi^0} = \gamma_q^2 \le (\gamma_q^{crit})^2 = \exp\left(\frac{m_{\pi^0}}{T}\right)$$

$$m_\eta = 547.8\, MeV/c^2$$

$$\eta = 0.559\,(u\bar{u} + d\bar{d}) + 0.441\,(s\bar{s})$$

$$0.559\,\gamma_q^2 + 0.441\,\gamma_s^2 \le \exp\left(\frac{m_\eta}{T}\right)$$

$$(\gamma_s^{crit})^2 = 1/0.441\left(\exp\left(\frac{m_\eta}{T}\right) - 0.559\,(\gamma_q^{crit})^2\right)$$

Chemical (Non-/Semi-)Equilibrium