The Strange Story of Strangeness

REU meeting 16th July 08

Introduction

A few years ago I worked at the CERN SPS on NA57.

This was an exciting time as SPS was at the forefront of data taking for a signal that seemed to show a clear sign of matter going though a phase transition from ordinary matter to a QGP

We were excited as we were further ahead of the curve than RHIC at that time

Here I will give a bit you a bit of history of how this signal was born, found fame then notoriety...

History

•Nowadays, there is a lot of evidence for the formation of a QGP from different signals found in heavy ion experiments conducted at CERN and RHIC but one of the first ideas proposed was in 1982, well before heavy ion results were available

•Mueller and Rafelski suggested that the production of a QGP phase should enhance the production of Strange quarks

•Importantly, this signal would survive hadronization

•Experiments conducted at the CERN SPS which looked for this signature were used to make an announcement about the detection of a new state of matter in heavy ion collisions during a press release in 2000

Strangeness and the Plasma

- The colliding ions will consist of ud quarks, so any strange quarks will have to be produced during the interaction
- If Chiral symmetry is restored the energy to make strange (and anti-strange) is reduced and occurs predominately via gg in equal measure
- In hadronic decays it is energetically harder to produce strange baryon (Lambda) and even harder to produce anti-strange baryon (Anti-Lambda)

In the QGP gg is dominent channel producing strange

$$g + g \rightarrow s + \bar{s}$$

$$\pi + N \rightarrow \Lambda + K$$

E ~ 530MeV (hadronic)

$$K + \pi \rightarrow \bar{\Lambda} + N$$

E ~ 1420MeV (hadronic)

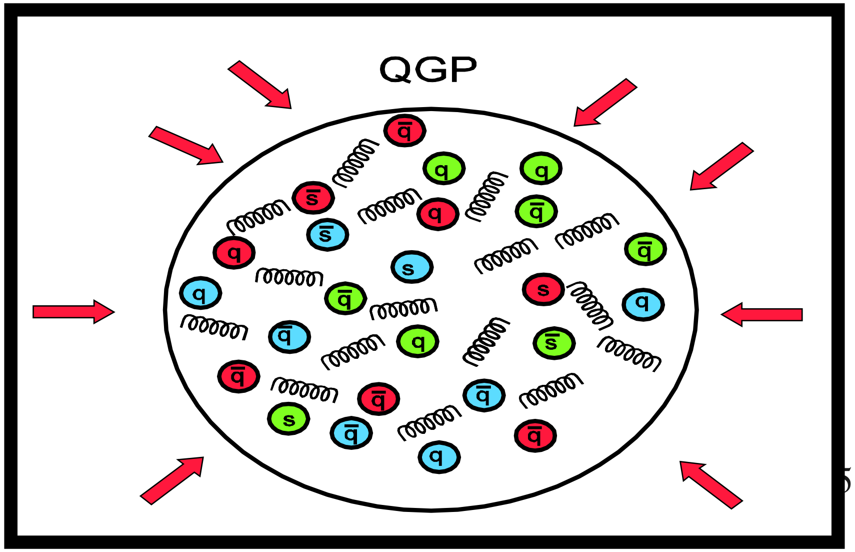
Strangeness and the Plasma

- In a purely hadronic collision it takes longer to produce strange particles
- Equilibrium time is less then the QGP phase:

$$\mathrm{Time}_{\mathrm{QGP}}(s\bar{s}) \approx \frac{1}{10} \times \mathrm{Time}_{\mathrm{Hadronic}}(s\bar{s})$$

$$\mathrm{Time}_{\mathrm{QGP}} \approx \mathrm{Time}_{\mathrm{Interaction}}$$

- An increase in strange particles **<u>was</u>** thought to be an ideal signal that plasma formation has taken place



Particle reconstruction

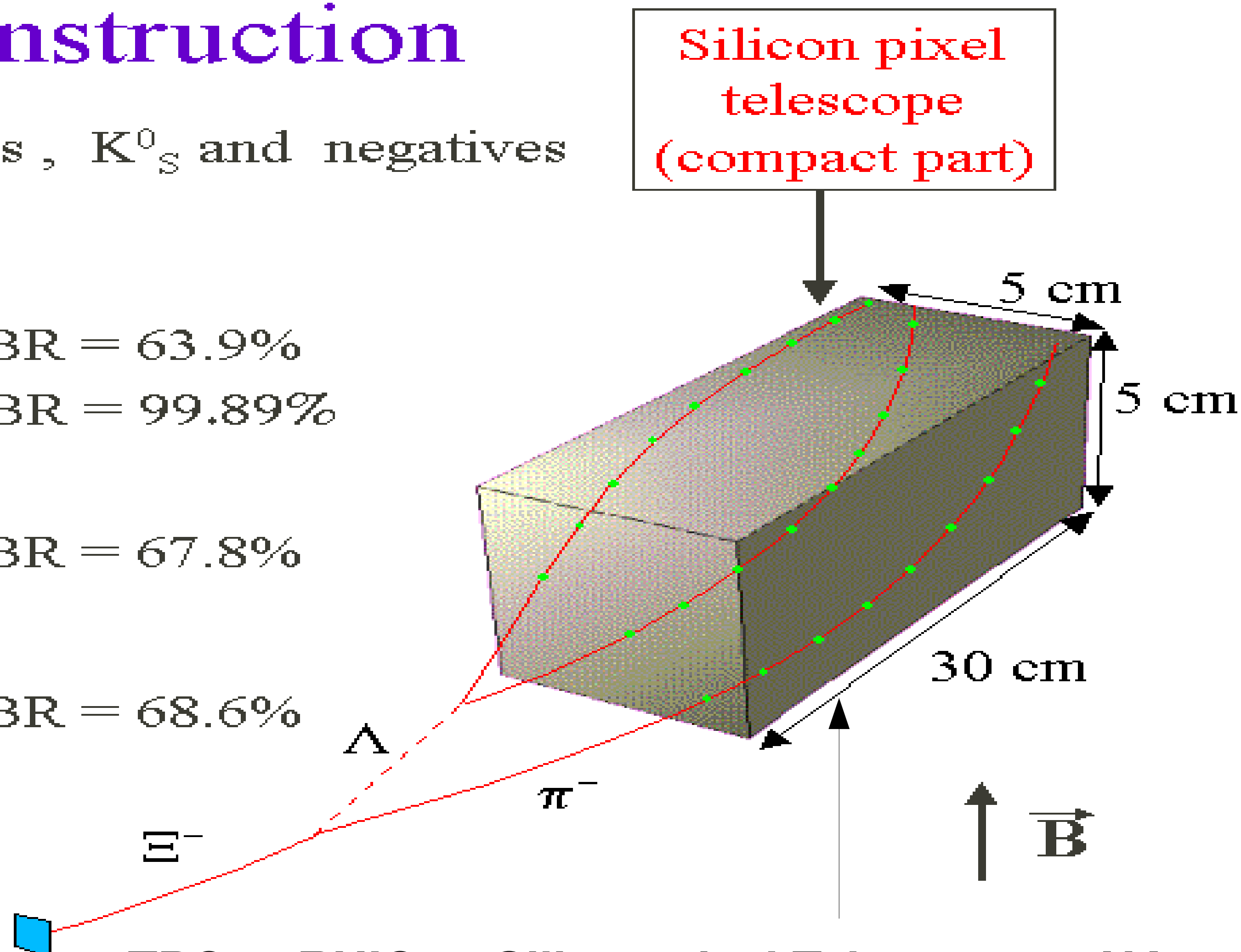
The weak decay of Λs and K^0s have a 'Vee' shape in the detector and are called V0s.

This shape easy to detect at all rapidities/Pt compared to single PID

Particle reconstruction

- Λ, Ξ, Ω + anti-particles , K^0_S and negatives (mainly pions)

$\Lambda \longrightarrow p + \pi^-$	BR = 63.9%
$\Xi^- \longrightarrow \Lambda + \pi^-$	BR = 99.89%
$\quad \hookrightarrow p + \pi^-$	
$\Omega^- \longrightarrow \Lambda + K^-$	BR = 67.8%
$\quad \hookrightarrow p + \pi^-$	
$K^0_S \longrightarrow \pi^+ + \pi^-$	BR = 68.6%



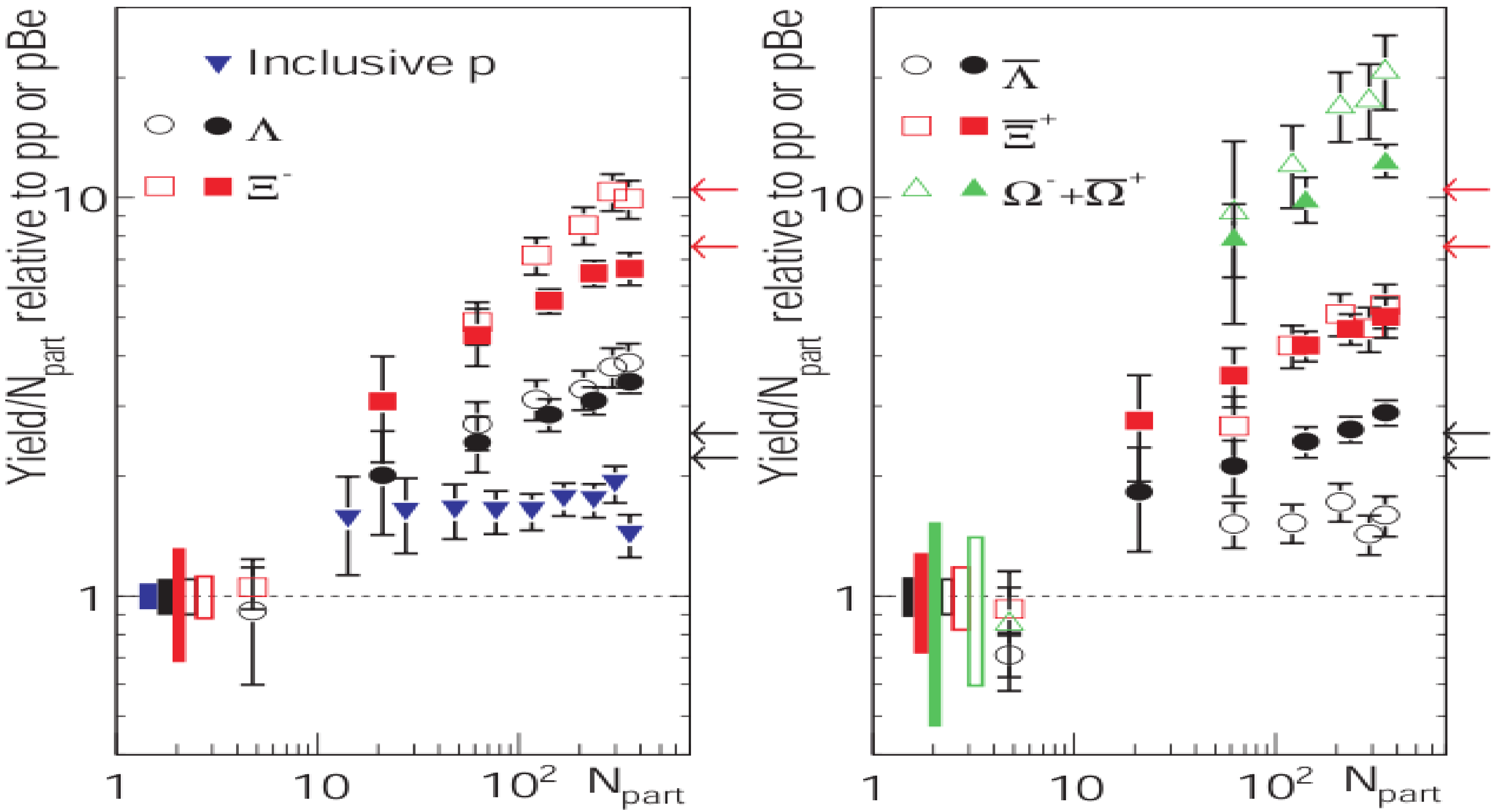
K0 long decays outside detector

TPC at RHIC or Silicon pixel Telescope at NA57

Enhancement of Strangeness at SPS and RHIC

Open = SPS PbPb 17.3
Closed = Star AuAu s200 GeV

Anti-particles (Summed Omega)



So we found the QGP right?

•Enhancement of strange particles in heavy ion seen at mid rapidity compared to p-p, not a great enhancement of inclusive protons

•Particles enhanced in a hierarchy as expected in QGP model:
-> Lambda with one strange bottom
-> Xi with two next
-> Triple strange Omega enhanced most

•Anti-lambda enhanced in RHIC but not at SPS
-> This suggests strange saturation at RHIC energy
-> Higher chemical potential at lower SPS energy

•Triple strange omega enhanced factor or 20 times!

Must be a signal of QCD formation right?

Well, it **was** a pretty convincing signal a few years ago **but.....**

Alternative points of view

Against:

Enhancements (Lambda) may be explained using a statistical model, the Grand Canonical mode (i.e not from the QGP)

The trends in the Bayron/Anti-Baryon can also be explained with the GC model

At the SPS we have the question of secondary collisions

The SPS enhancement could come from an increase in system volume size (proportional to multiplicity) giving a larger phase space to the strange quarks, the strangeness correlation volume

But:

Models have trouble explaining the SPS Omega enhancement, very large

Why are RHIC and SPS enhancements are so similar over such a large order of magnitude, SPS 17 GeV, RHIC 200 GeV?

Chemical Freeze-out Temperature with Centrality

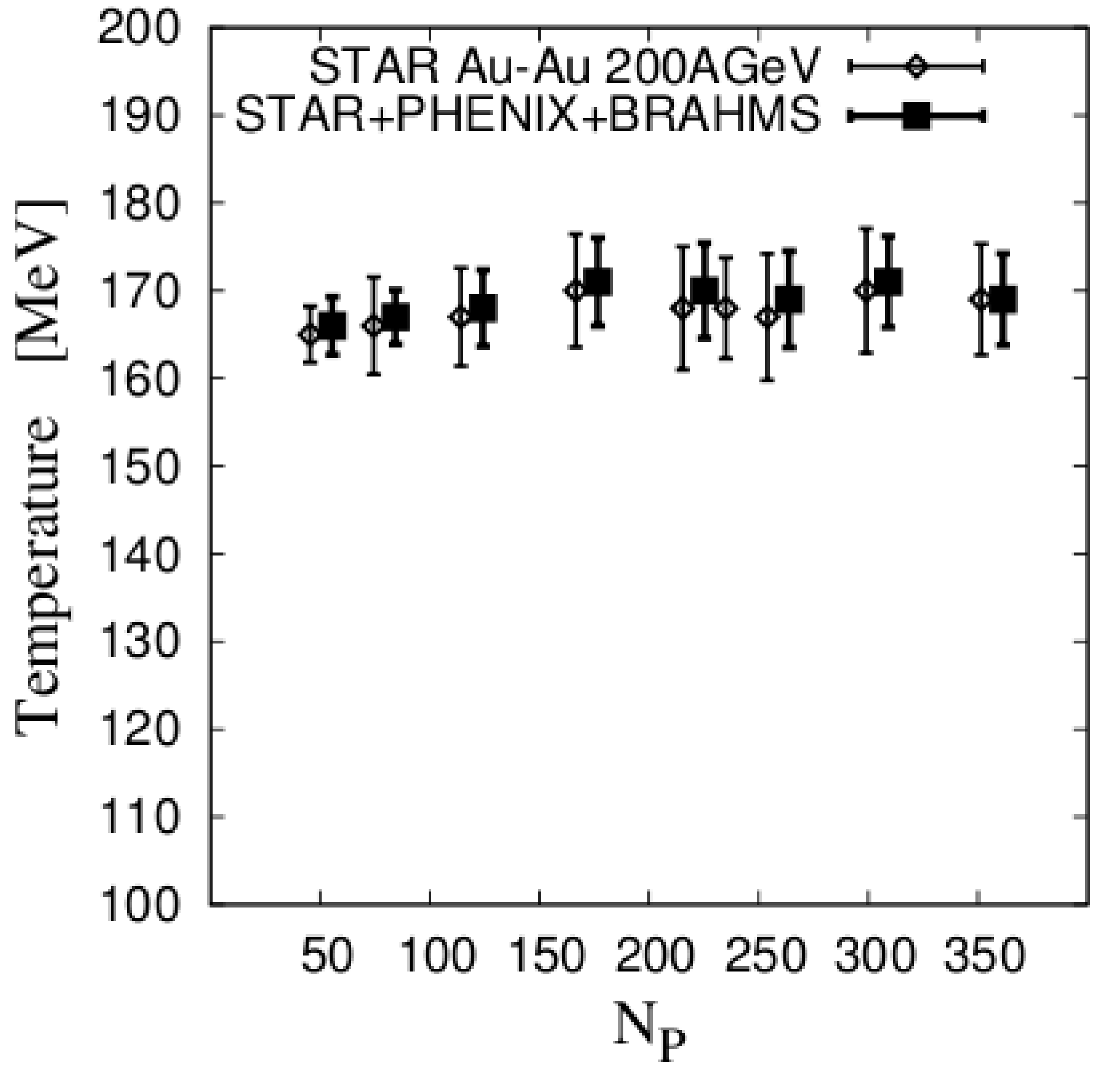


Figure 3. Chemical freeze-out as a function of centrality in Au-Au collisions at $\sqrt{s}_{NN} = 200$ GeV [7].

This seems to show that the freeze out temperature is constant at all rapidity
What does this mean?

1) If a QGP formed and strangeness was in equilibrium we would expect to find a 'temperature' at high centrality

2) At high centrality, moving to low centrality, there should be a point where there is not enough energy density for a QGP to form

3) If this were true we would expect to see a discontinuity in this plot at low centrality

4) This suggests that freeze out is a hadronic process, available at all centralities

5) Then, there may exist a hot soup of highly interacting hadrons where strangeness may be enhanced without a QGP

So is it a QGP signal or not?

Well, it depends who you ask:

On the one hand (and the majority opinion at time of writing)...

I think now a majority of the community think that Strangeness Enhancement can be explained within a framework of hot dense hadronic gas

This would explain the SPS enhancement as pure hadronic, and the lack of Anti-Lamba enhancment. We think there is QGP at RHIC but hot hadronic soup would would wash the QGP signal away

On the other... (Rafelskia '08)

The hadronic scenario still has a lot of external “fudge factors” needed to make it work and still does not explain enhancement as cleanly as a QGP system

The flat temperature with centrality can be explained if we assume that deconfinment where quarks are free, happens before and chiral symmetry restoration, where quarks drop to their mass and gluon production starts. This makes the QCD vacuum a two phase system

In this case we get a constant the freeze out temperature from the free quarks and enhancement at high enough energy density for chiral restoration

Conclusion

1) The LHC may throw more light on this but the situation is uncertain, leaning toward the hot hadronic gas scenario, from a few years ago when it was thought that this was a clear QGP signal

2) Strangeness has other uses as a probe for re-hadronization and flow as it will be produced along the surface of a flowing fireball/QGP and can be used to study dynamics such as v2