Strange Hadron Production in O+O Collisions at $\sqrt{s_{NN}}$ = 200 GeV at STAR

Iris Ponce for the STAR Collaboration
Yale University

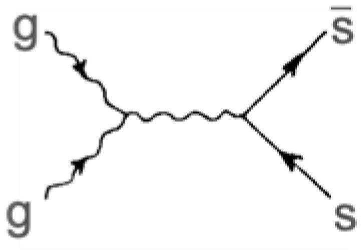
RHIC/AGS Users Meeting 2025

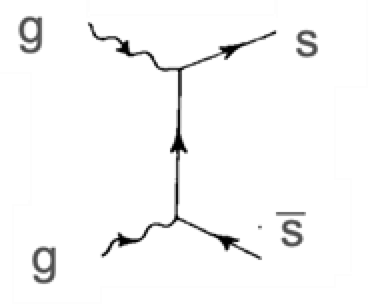
Supported in part by:
U.S. DEPARTMENT OF ENERGY | Office of Science

Strangeness Enhancement and the QGP

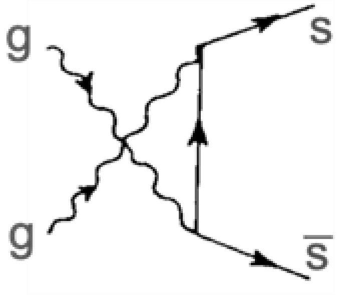
- Strangeness enhancement was one of the first observables predicted as a signature of the QGP.

- The thermal production of s-$\bar{s}$ quark pairs is favorable in the QGP since the s-$\bar{s}$ masses are lower than the predicted QGP temperature with the QGP -> hadron gas transition temperature ~157 MeV.
  - 2 x m_s ~192 MeV
  - There are abundant thermal gluons in the QGP medium.





P. Koch, et al. Phys. Rep. 142, 167 (1986).

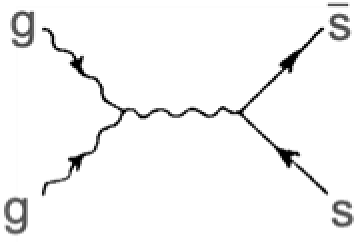


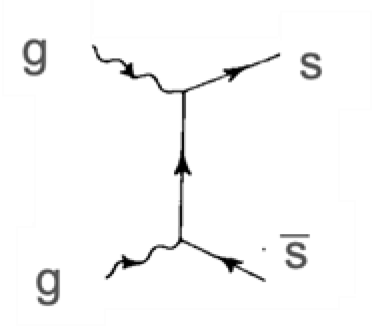
Strangeness Enhancement and the QGP

- Strangeness enhancement was one of the first observables predicted as a signature of the QGP.

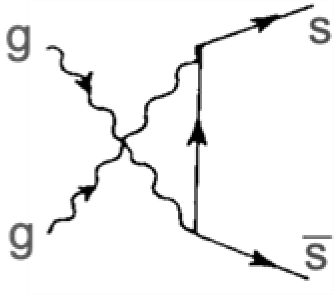
- The thermal production of s-$\bar{s}$ quark pairs is favorable in the QGP since the s-$\bar{s}$ masses are lower than the predicted QGP temperature with the QGP -> hadron gas transition temperature ~157 MeV.
  - 2 x m_s ~192 MeV
  - There are abundant thermal gluons in the QGP medium.

- The production of multi-strange ($\Xi^{\pm}$,$\Omega^{\pm}$) hadrons are more sensitive to the existence of QGP.



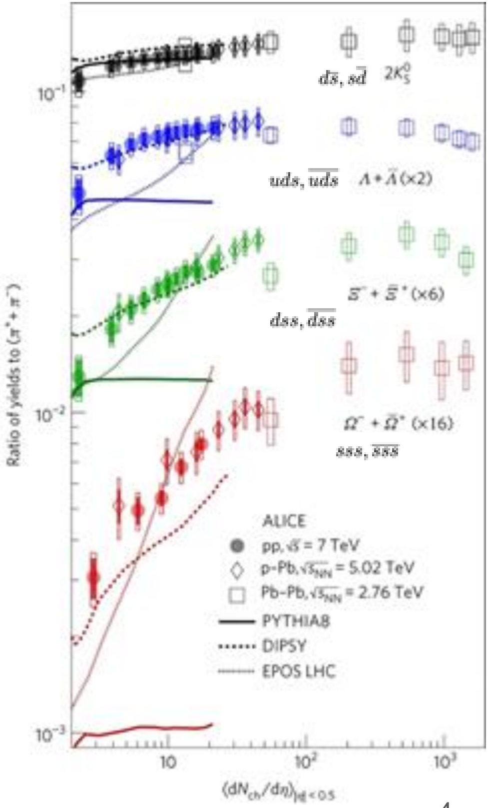


P. Koch, et al. Phys. Rep. 142, 167 (1986).



Motivation

- A smooth increase in the ratio of strange hadron production to the pion yield as a function of multiplicity has been found in various collision systems (p+p, p+A, A+A) at TeV collision energies.



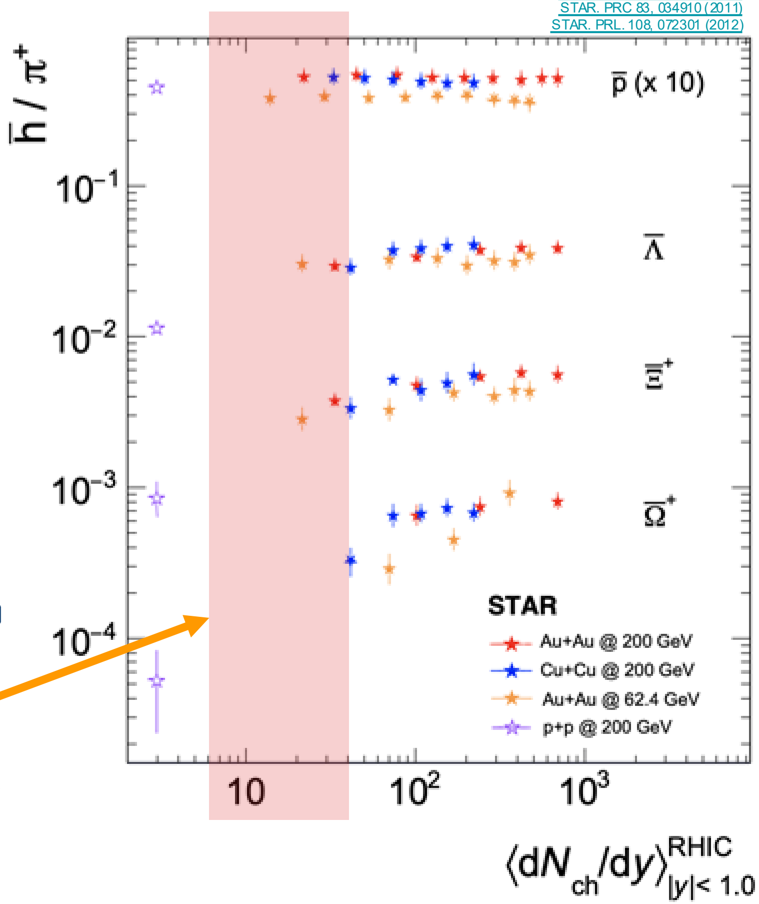
ALICE, Nat. Phys., 13, 535 (2017)

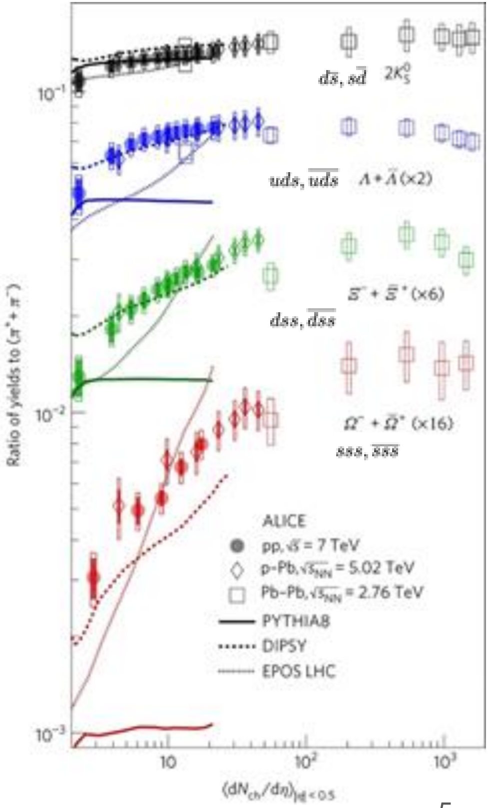
Motivation

- A smooth increase in the ratio of strange hadron production to the pion yield as a function of multiplicity has been found in various collision systems (p+p, p+A, A+A) at TeV collision energies.
  - STAR potentially observes a similar trend at $\sqrt{s_{NN}}$ = 200 GeV but needs more data a low multiplicity.

However, there is a notable data gap in the low multiplicity region

STAR PRL. 98, 062301 (2007)
STAR. PRC 77, 044908 (2008)
STAR. PRC 83, 024901 (2011)
STAR. PRC 83, 034910 (2011)
STAR. PRL. 108, 072301 (2012)

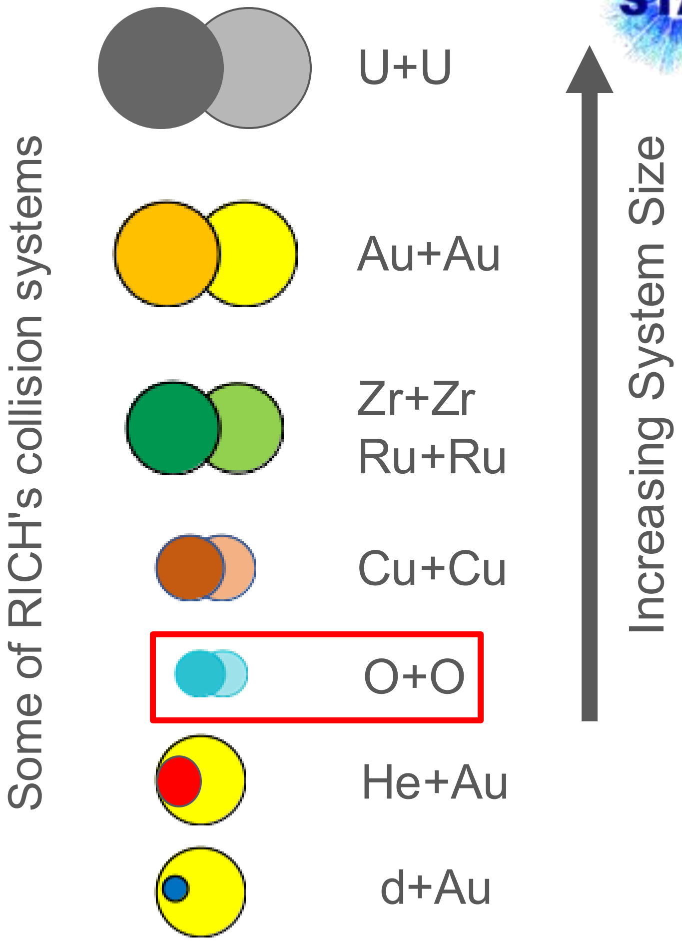




ALICE. Nat. Phys.. 13, 535 (2017)

Motivation

- Oxygen is one of the smallest ions collided at RHIC.
  - Allows a more straightforward geometry mapping with centrality than asymmetric small system collisions like He+Au, or d+Au

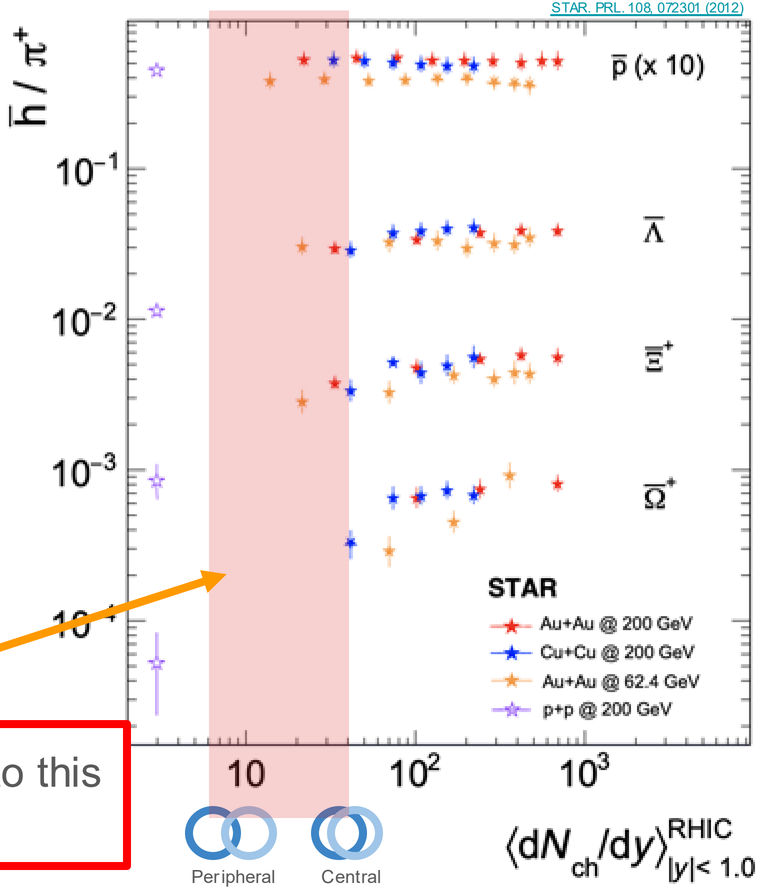


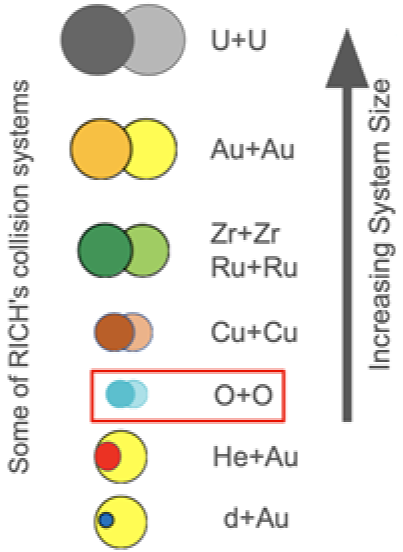
Motivation

- Oxygen is one of the smallest ions collided at RHIC.
  - Allows a more straightforward geometry mapping with centrality than asymmetric small system collisions like He+Au, or d+Au
  - Fill in the hyperon to pion ratio in the low multiplicity gap

O+O's multiplicity can extend to this unexplored region

STAR PRL 98, 062301 (2007)
STAR PRC 77, 044908 (2008)
STAR PRC 83, 024901 (2011)
STAR PRC 83, 034910 (2011)
STAR PRL 108, 072301 (2012)





O+O Run Information at STAR

- The Solenoidal Tracker at RHIC (STAR) has been operating since 2000.

- From 2018 on, STAR had two detector upgrades: iTPC and eTOF
    - Improved coverage:
      From $|\eta| < 1.0$ => $|\eta| < 1.5$
    - Lower p_T coverage 125 MeV => 60 MeV
    - Extended PID with eTOF

Picture: Alex & Maria Schmah
Q. Xu. (STAR). 8th Workshop on Hadron Physics (2016)

O+O Run Information at STAR

- The Solenoidal Tracker at RHIC (STAR) has been operating since 2000.

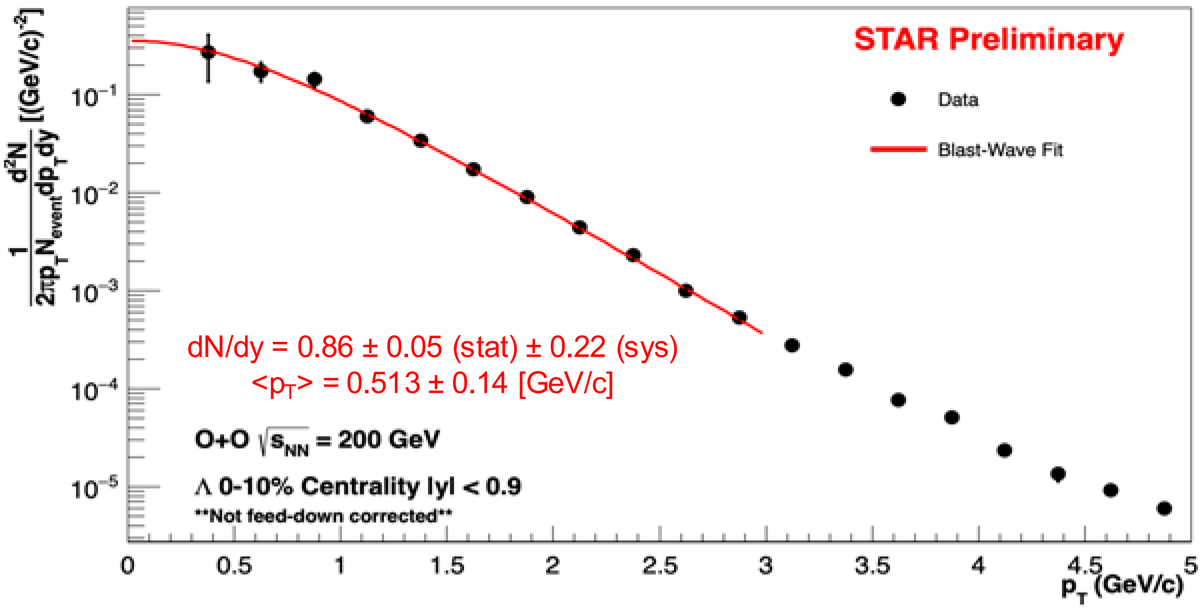
- From 2018 on, STAR had two detector upgrades: iTPC and eTOF
  - Improved coverage: From $|\eta| < 1.0$ => $|\eta| < 1.5$
  - Lower p_T coverage 125 MeV => 60 MeV
  - Extended PID with eTOF

- There are ~650M O+O minimum bias events total at $\sqrt{s_{NN}} = 200$ GeV.
  - ¼ of the O+O run was taken with the magnetic field reversed.
    - Testing calibration and TPC distortions

Picture: Alex & Maria Schmah
[Q. Xu, (STAR), 8th Workshop on Hadron Physics (2016)]

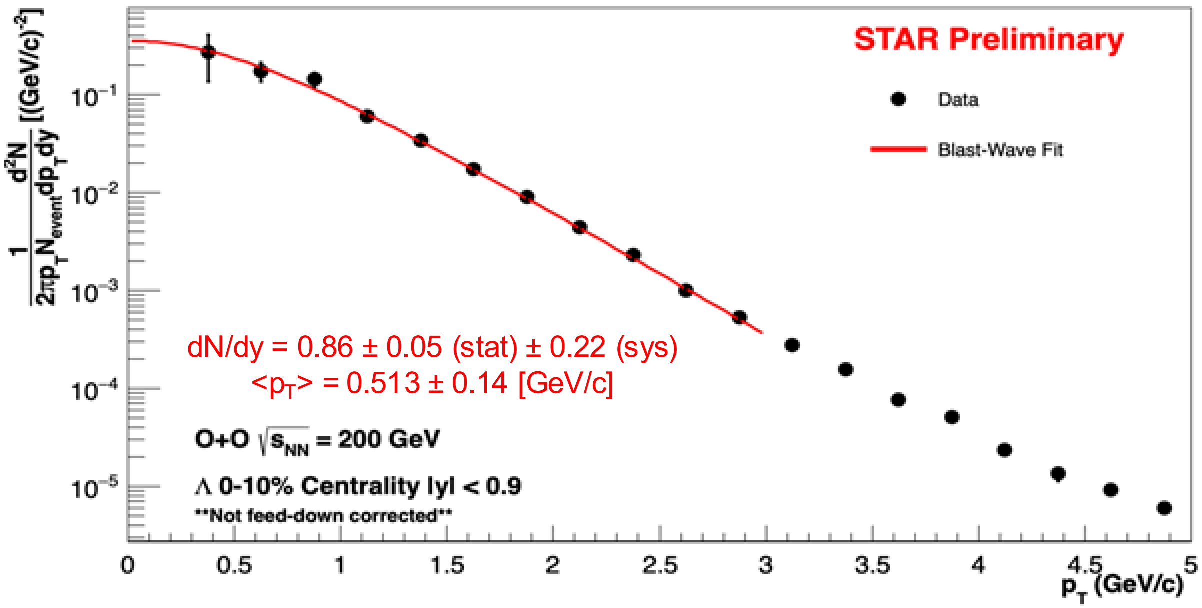
Corrected p_T spectrum for Λ's in Central O+O Collisions

- The p_T spectra is calculated from the Λ's invariant mass distributions in different momentum ranges.

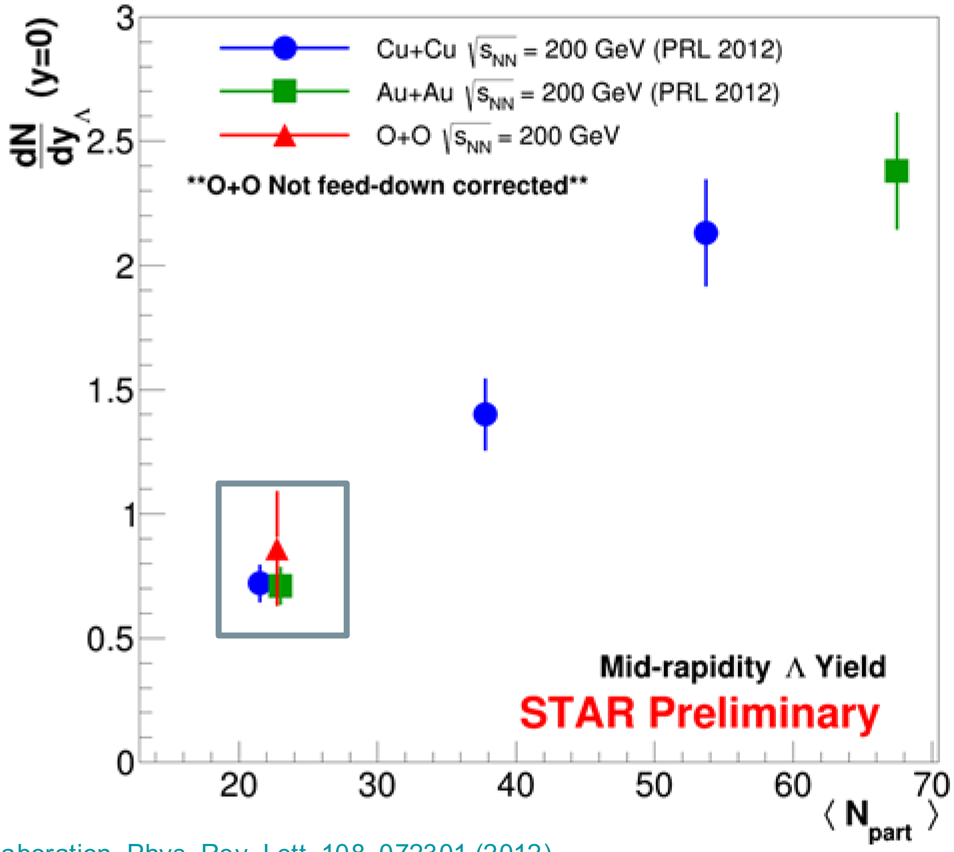


Corrected p_T spectrum for Λ's in Central O+O Collisions

- The p_T spectra is calculated from the Λ's invariant mass distributions in different momentum ranges.
- The p_T spectra is corrected using the reconstruction efficiency with Monte Carlo simulations.
  - **MC_{reco} /MC_{input}**
- The Λ p_T spectra is the average of both magnetic field configurations.



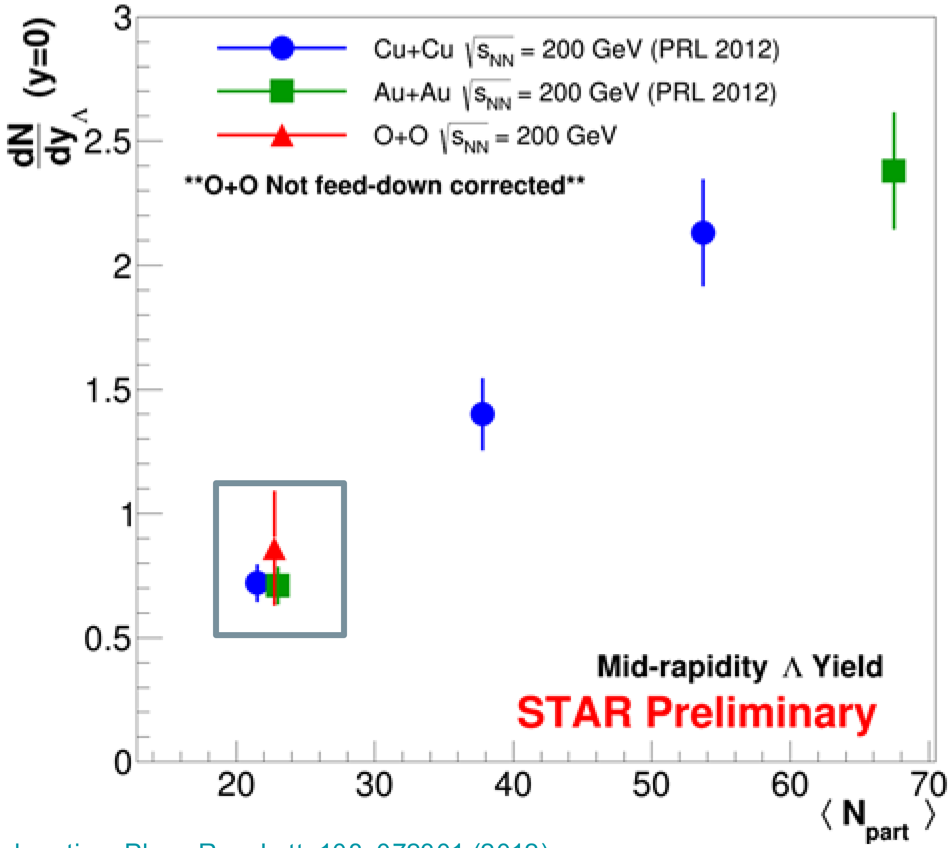
Comparing the O+O yield to similar Collision Systems



Most central O+O collisions have a similar < N_{part}> as peripheral Au+Au and Cu+Cu collisions.

[STAR Collaboration, Phys. Rev. Lett. 108, 072301 (2012)]

Comparing the O+O yield to similar Collision Systems



Most central O+O collisions have a similar $< N_{part} >$ as peripheral Au+Au and Cu+Cu collisions.

$$\frac{dN}{dy} = \int_0^\infty p_t$$

$$\frac{dN}{dy} = 0.86 \pm 0.05 \pm 0.22$$

**O+O yield is not feed-down corrected.

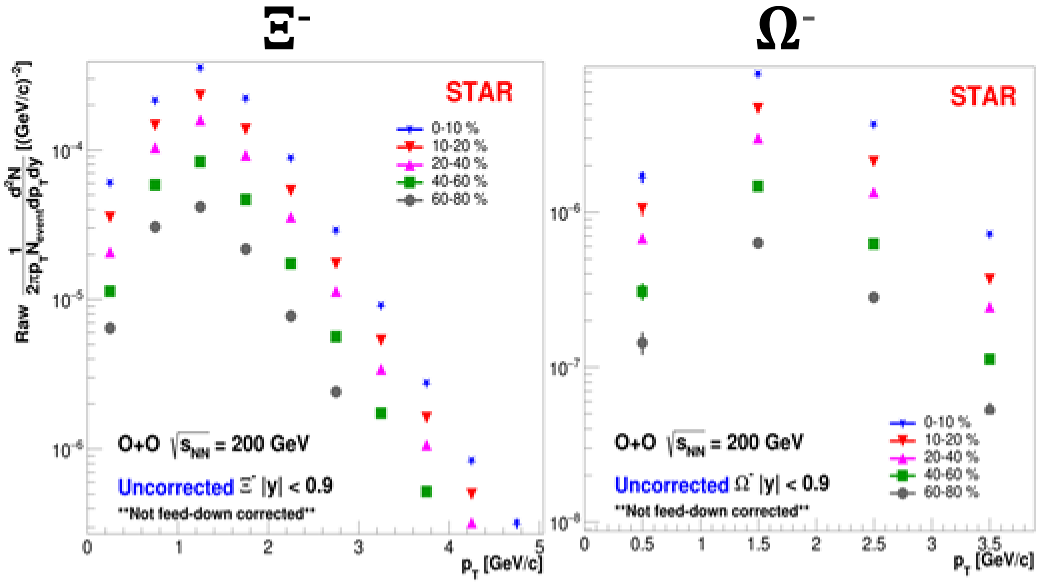
STAR Collaboration, Phys. Rev. Lett. 108, 072301 (2012)

Next Steps for Analysis

- Extend the analysis to other hyperons.
  - The raw p_T spectra are pending the corrections.

- Calculate the yields from corrected spectra.
  - Extend to lower multiplicities to start filling the gaps in N_{ch}

Raw Transverse momenta distribution for O+O at $\sqrt{s_{NN}}$ = 200 GeV



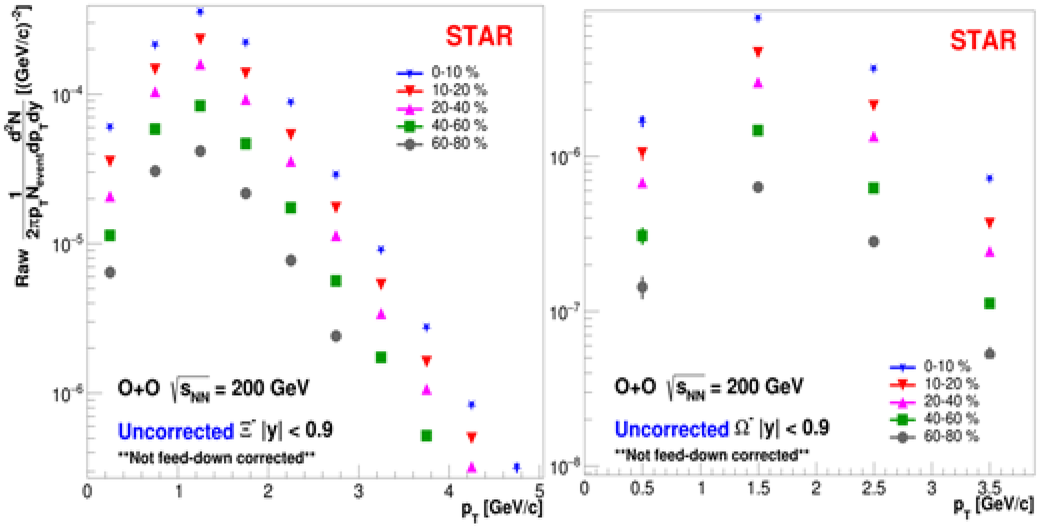
There is good coverage through 0 - 80% centralities for multi-strange hadrons.

Next Steps for Analysis

- Extend the analysis to other hyperons.
  - The raw p_T spectra are pending the corrections.
- Calculate the yields from corrected spectra.
  - Extend to lower multiplicities to start filling the gaps in N_{ch}
- Apply feed-down corrections to spectra for yield calculations.
  - Compute the pion/hyperon ratio in the low multiplicity region
- Use thermal model for freeze-out parameter (e.g. μ_B , T_{ch}) extraction.

Raw Transverse momenta distribution for O+O at $\sqrt{s_{NN}}$ = 200 GeV

Ξ^- Ω^-



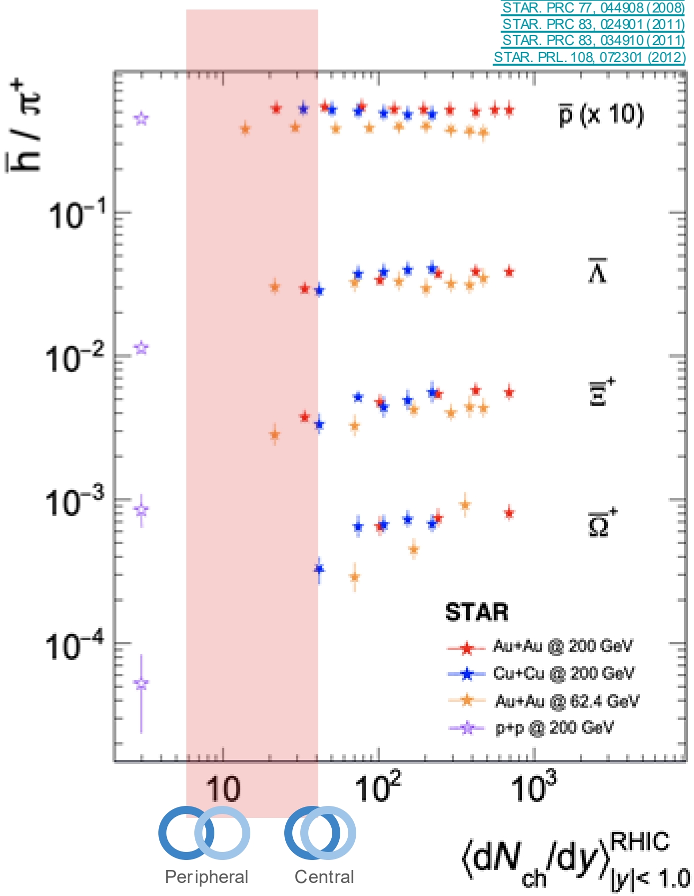
There is good coverage through 0 - 80% centralities for multi-strange hadrons.

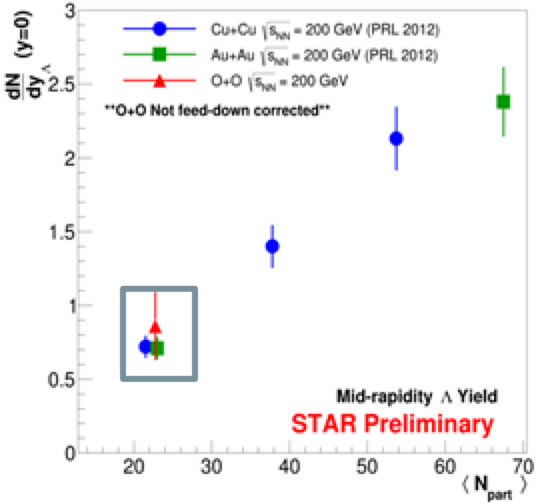
Conclusions

- The O+O dataset can fill in the gaps in the low-multiplicity regions of the ratio of strange hadron production to the pion yield for the STAR data.

- **We presented the first yield calculation for Λ's in the 0-10% centrality region for O+O. The O+O yield agrees with previous published STAR Λ yields at similar N_{part} values.**

STAR PRL. 98, 062301 (2007)
STAR. PRC 77, 044908 (2008)
STAR. PRC 83, 024901 (2011)
STAR. PRC 83, 034910 (2011)
STAR. PRL. 108, 072301 (2012)

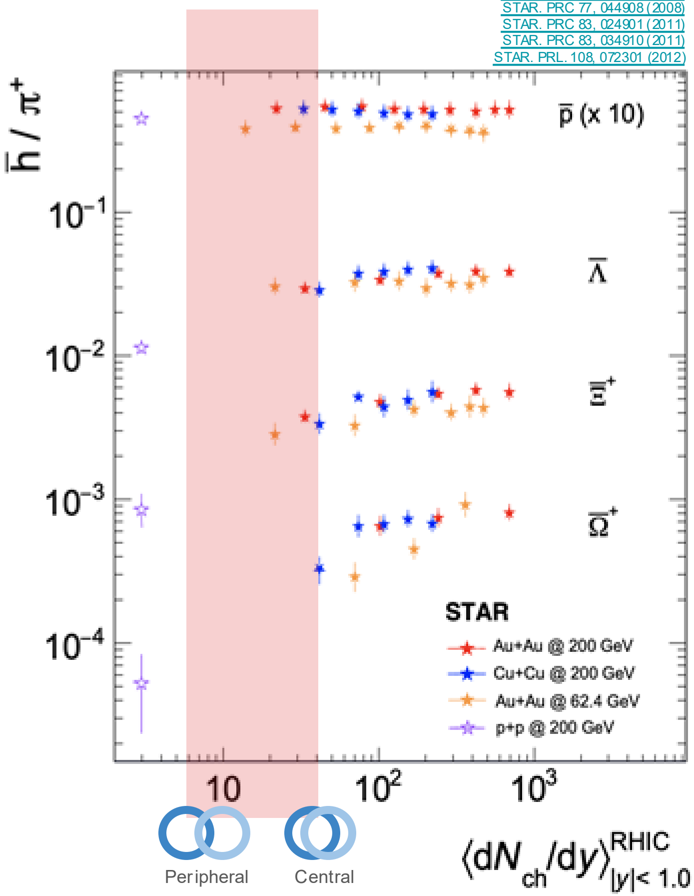


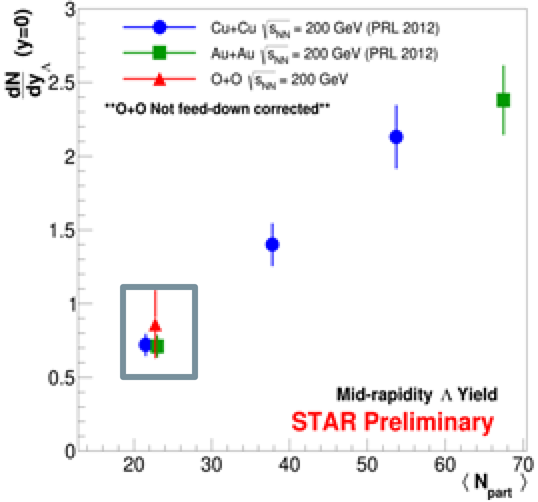


Conclusions

- The O+O dataset can fill in the gaps in the low-multiplicity regions of the ratio of strange hadron production to the pion yield for the STAR data.
- **We presented the first yield calculation for Λ's in the 0-10% centrality region for O+O. The O+O yield agrees with previous published STAR Λ yields at similar N_{part} values.**
- Additional O+O measurements were presented in QM2025 and **more to come!**
- With the LHC colliding O+O for their heavy run, there are many intriguing outcomes in the future!

STAR PRL 98, 062301 (2007)
STAR PRC 77, 044908 (2008)
STAR PRC 83, 024901 (2011)
STAR PRC 83, 034910 (2011)
STAR PRL 108, 072301 (2012)

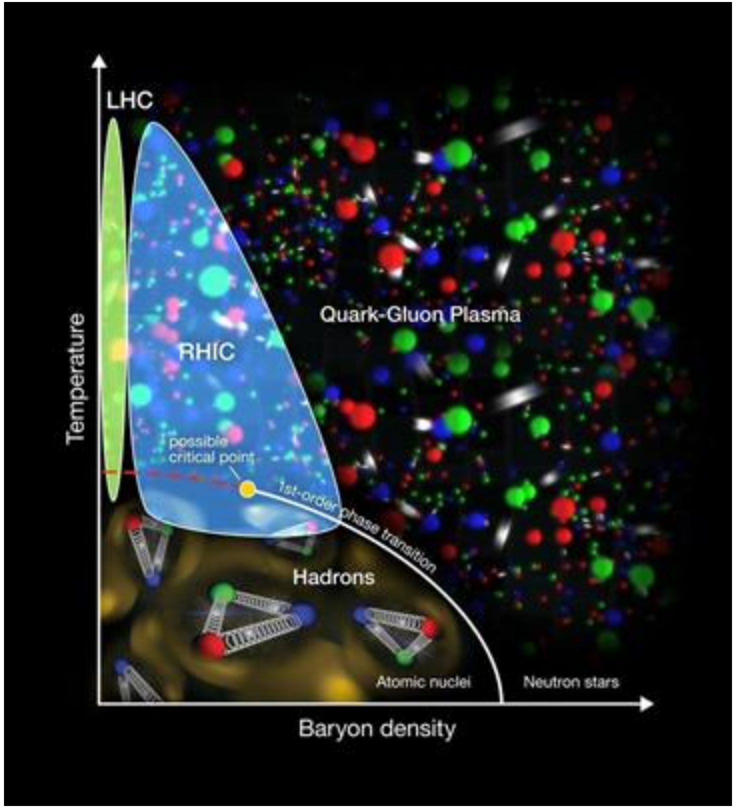




Backup

QCD and the QGP

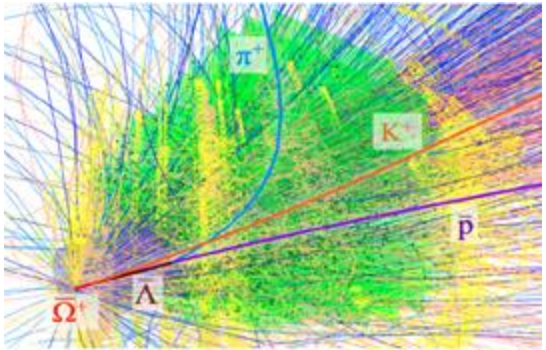
- At high temperatures QCD matter becomes a new state of matter called the Quark-Gluon plasma (QGP).
    - Deconfined strongly coupled fluid.



https://www.bnl.gov/newsroom/news.php?a=121072

Reconstructing Lambdas and Signal Extraction

- Using Kalman Filter Particle (KF Particle) reconstruction algorithm.
  - Standard reconstruction for decayed particles. Including **Λ**, Ξ, **Ω**, K^0_s and their anti-particles

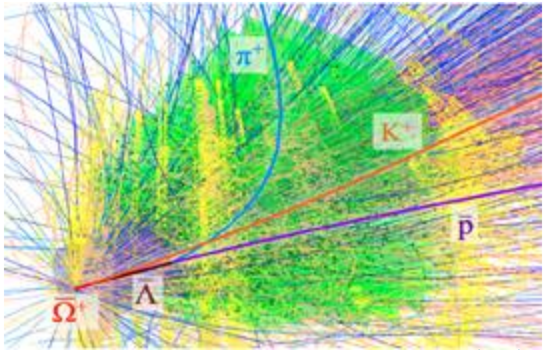


M. Kocan. WEJCF. (2019)

Maksym Thesis (2016)
Ju, XY., Leung, YH., Radhakrishnann, S. *et al* (2023)

Reconstructing Lambdas and Signal Extraction

- Using Kalman Filter Particle (KF Particle) reconstruction algorithm.
    - Standard reconstruction for decayed particles. Including **Λ**, Ξ, **Ω**, K^0_s and their anti-particles



M. Kocan. WEJCF. (2019)

Λ

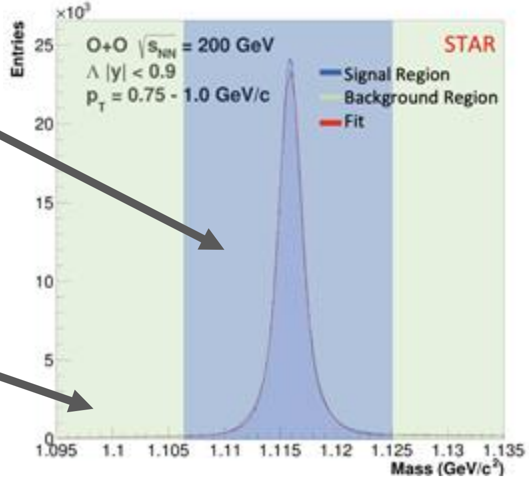
Maksym Thesis (2016)
Ju, XY., Leung, YH., Radhakrishnann, S. *et al* (2023)

For the Λ Signal Extraction:

- The signal (without background subtraction) region is [**μ-3σ**,**μ+3σ**], and the background region is [1.095 to **μ-3σ**, **μ**+3**σ** to 1.135 GeV/c^2]. (**μ** = m_Λ)
- Fitting function: 2nd poly (for background + double Gauss function (signal).

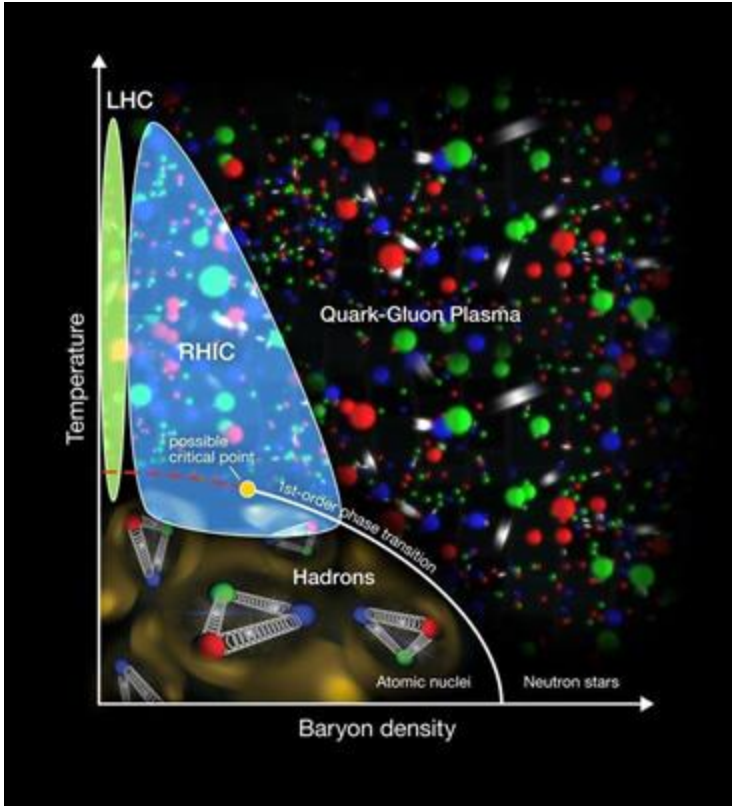
The blue region is the signal w.o background subtraction.

The green region is the background region (very small)..



QCD and the QGP

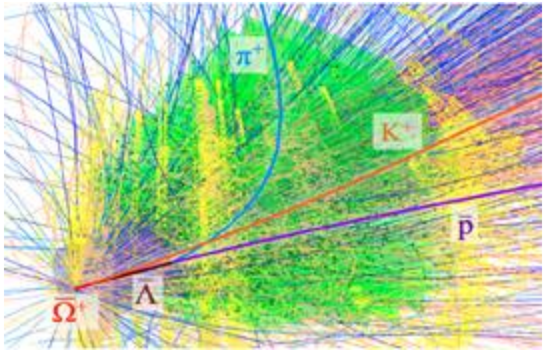
- At high temperatures QCD matter becomes a new state of matter called the Quark-Gluon plasma (QGP).
    - Deconfined strongly coupled fluid.
- Its existence was predicted in 1975 and experimentally discovered in the early 2000s.
- The QGP is predicted to have existed in the early universe
    - First μs after the Big Bang



https://www.bnl.gov/newsroom/news.php?a=121072

Reconstructing Lambdas and Signal Extraction

- Using Kalman Filter Particle (KF Particle) reconstruction algorithm.
  - Standard reconstruction for decayed particles.
  - Initially developed for other heavy ion experiments but was adapted in 2018 for STAR.



M. Kocan. WEJCF. (2019)

Particles To Be Reconstructed

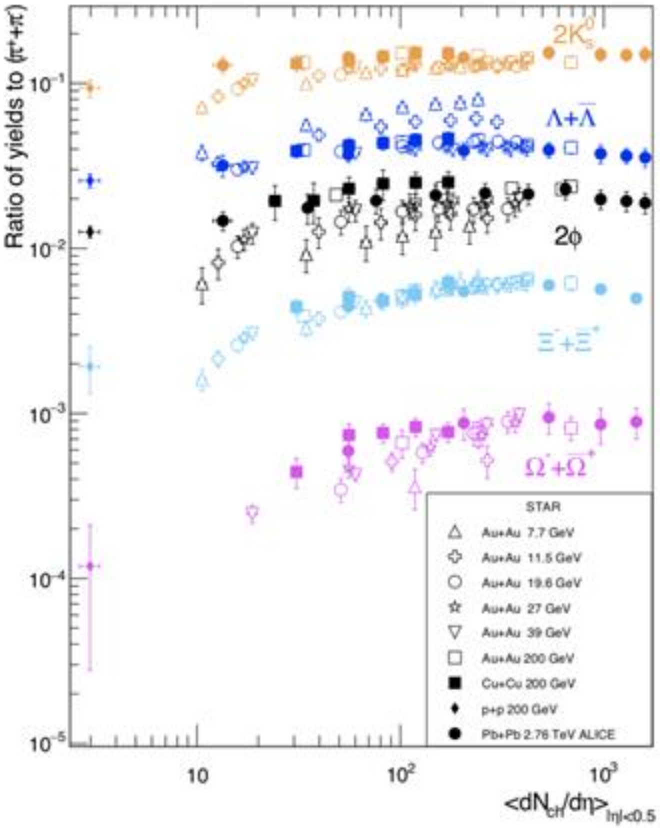
These are some strange hadrons and mesons that are short-lived and decay via hadronic channels!

Particle	Strangeness	Mass (MeV)	Decay Mode	Branching Ratio
$\phi(1020)$	0	$1{,}019.461 \pm 0.020$	K^+K^-	49.5 %
K_s^0	± 1	497.611 ± 0.013	$\pi^+\pi^-$	69.20 %
Λ	-1	$1{,}115.683 \pm 0.006$	$p\pi^-$	64.1 %
Ξ^-	-2	$1{,}321.71 \pm 0.07$	$\Lambda\pi^-$	99.887%
Ω^-	-3	$1{,}672.45 \pm 0.29$	ΛK^-	67.8%

PDG Live

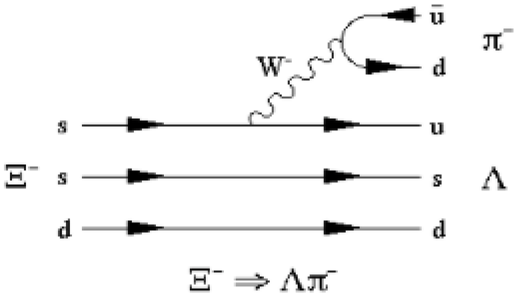
- This presentation will focus on **Λ**’s.
- The Ξ^- ,Ω^-, ϕ , and K^0_S results will follow soon.

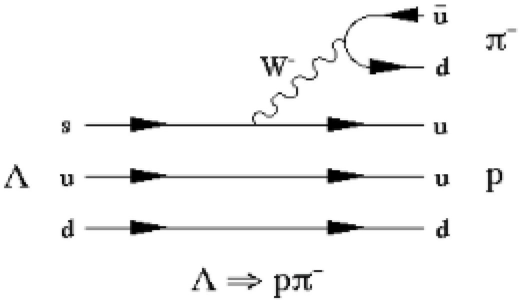
Full spectra with BES yields



https://indico.bnl.gov/event/11208/attachments/34410/55818/zhu_BNL_nuclear_seminar_2021.pdf

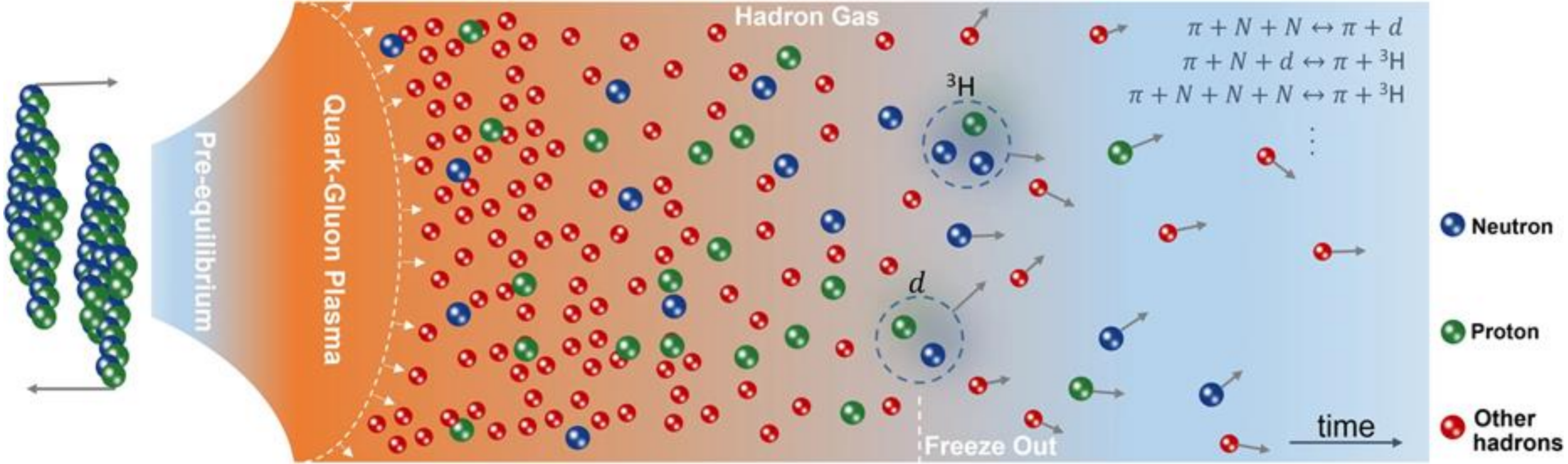
Weak Decay Modes - Feynman Diagrams





https://ppd.fnal.gov/experiments/e871/public/phys_slides.html

Coalescence



https://www.nature.com/articles/s41467-024-45474-x/figures/1