

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

Iris Ponce for the STAR Collaboration
Yale University
CPOD 2024



U.S. DEPARTMENT OF
ENERGY

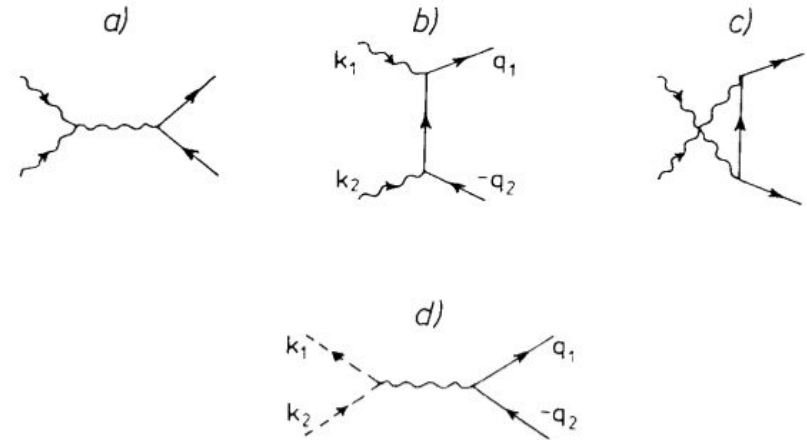
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Strangeness Enhancement and the QGP

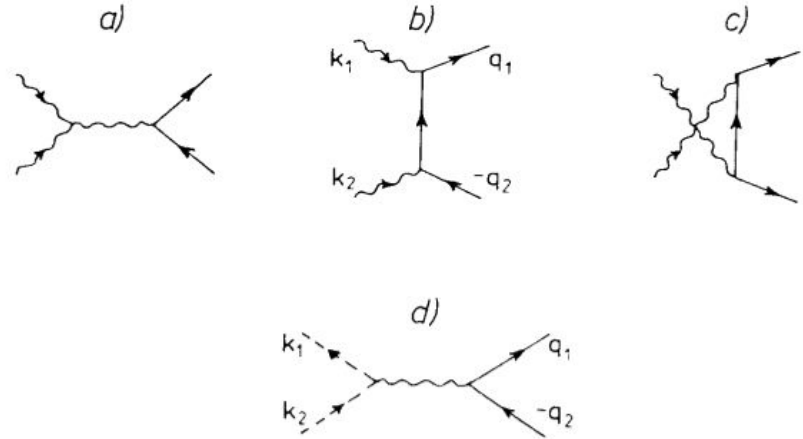
- Strangeness enhancement was one of the first observables predicted as a signature of the QGP.



P. Koch, B. Müller and J. Rafelski, "Strangeness in Relativistic Heavy Ion Collisions," 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 $s\bar{s}$ pairs is favorable in the QGP since the $s\bar{s}$ masses are close to the QGP transition temperature ~ 156 MeV.
 - $2 \times M_s \sim 192$ MeV
 - There are abundant thermal gluons in the QGP medium.
- Multi-strange (Ξ^\pm, Ω^\pm) hadrons are more sensitive to the existence of QGP.

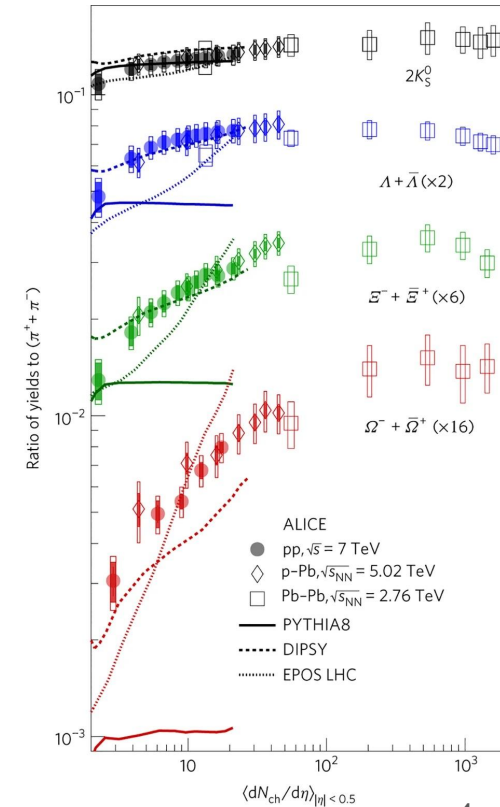


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Motivation

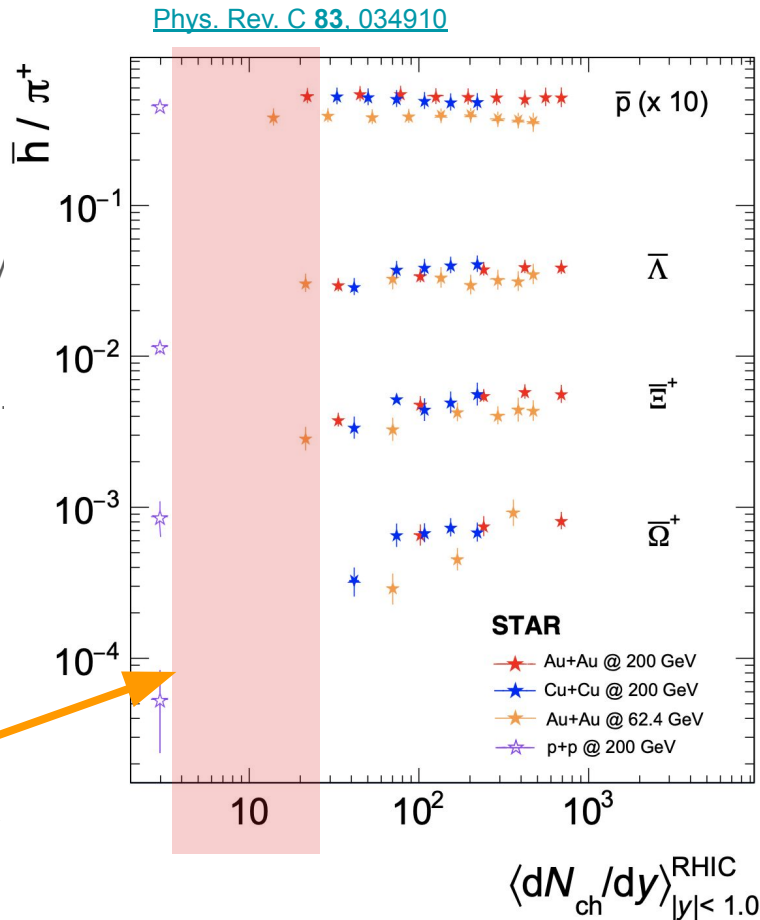
- A smooth increase in the ratio of strange hadron production to the pion yield as a function of multiplicity has been found in various collision systems (p+p, p+A, A+A).



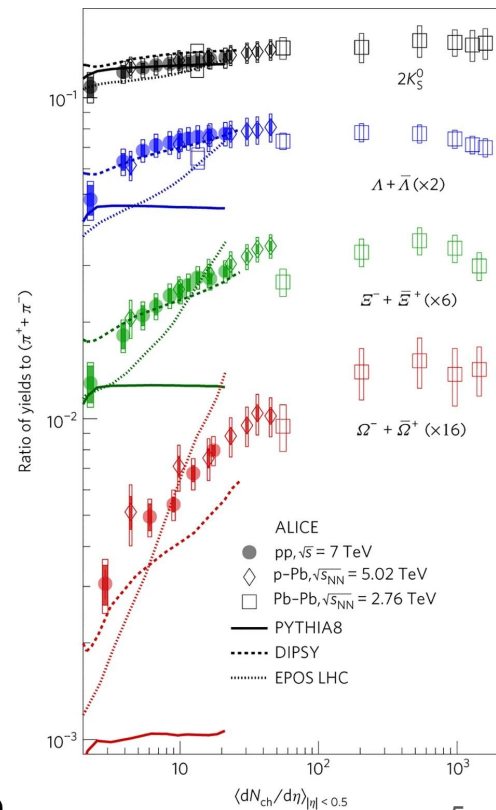


Motivation

- 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).
 - STAR has reproduced this ratio.



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

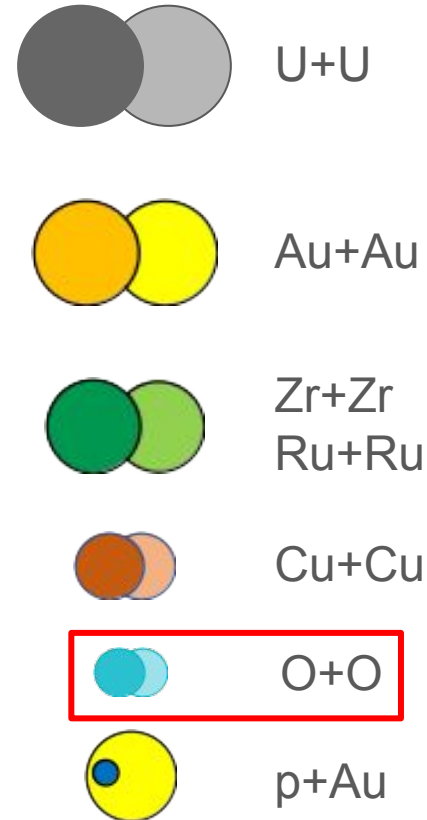




Motivation

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

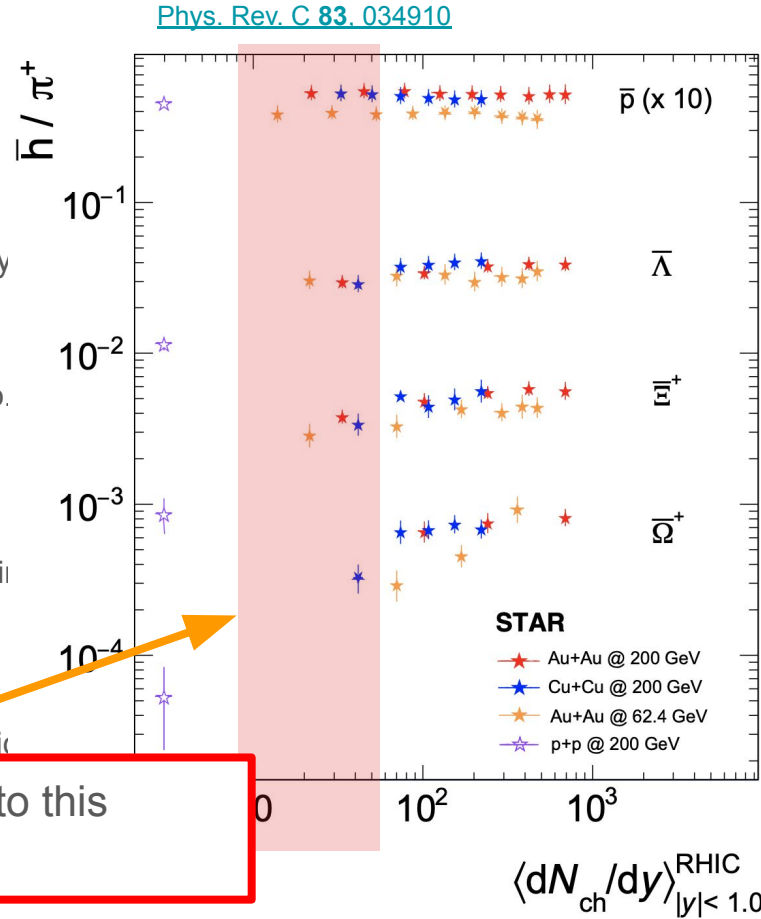
Some of RHIC's collision systems





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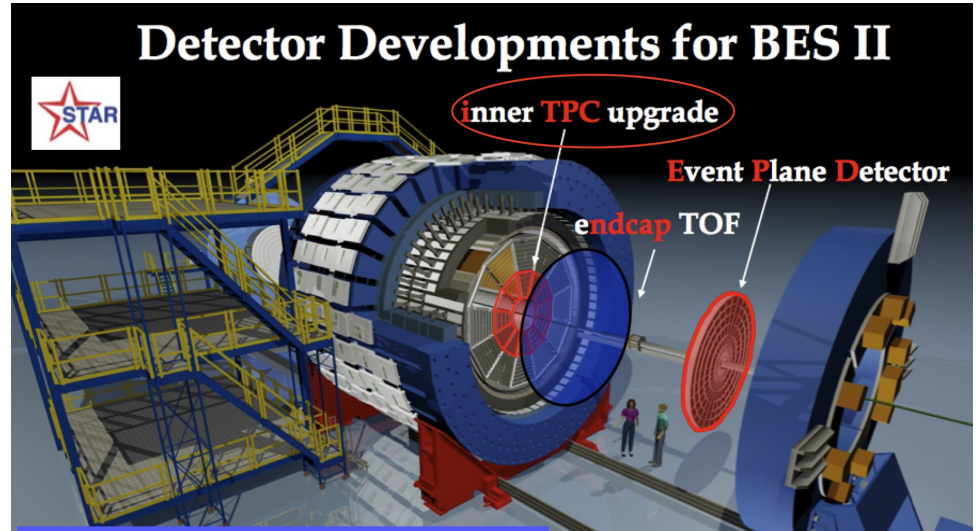


O+O's multiplicity can extend to this unexplored region

O+O	Reference Multiplicity
0-10%	37
10-20%	29
20-40%	18
40-60%	11
60-80%	6

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

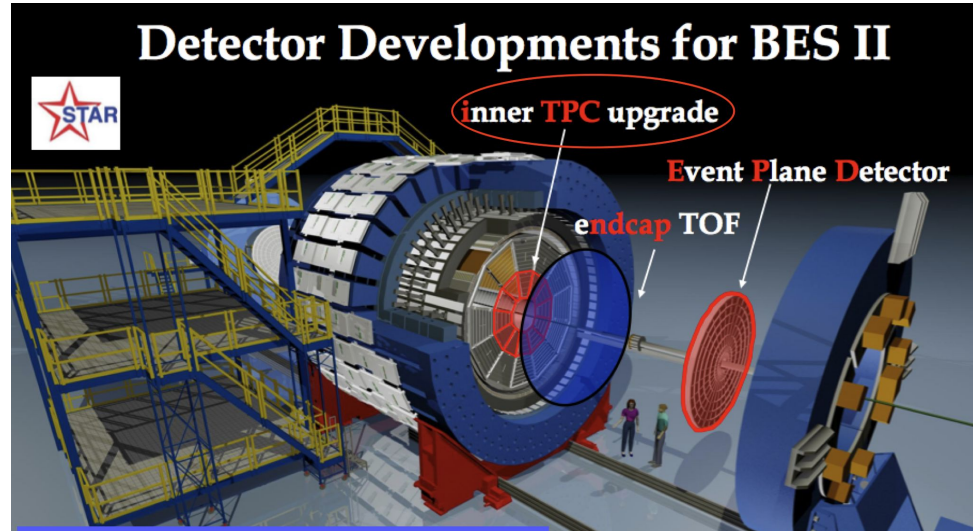


Picture: Alex & Maria Schmah

[Q. Xu. \(STAR Collaboration\). 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:
 - | η | < 1.5 from | η | < 1.0
 - Lower pT coverage 125 MeV => 60 MeV
- There are ~650M O+O minimum bias events total.
 - 1/4 of the O+O run was taken with the magnetic field reversed.
 - Testing calibration and TPC distortions



Picture: Alex & Maria Schmah

[Q. Xu. \(STAR Collaboration\). 8th Workshop on Hadron Physics \(2016\)](#)

Flow Measurements in O+O collisions shown in QM2023

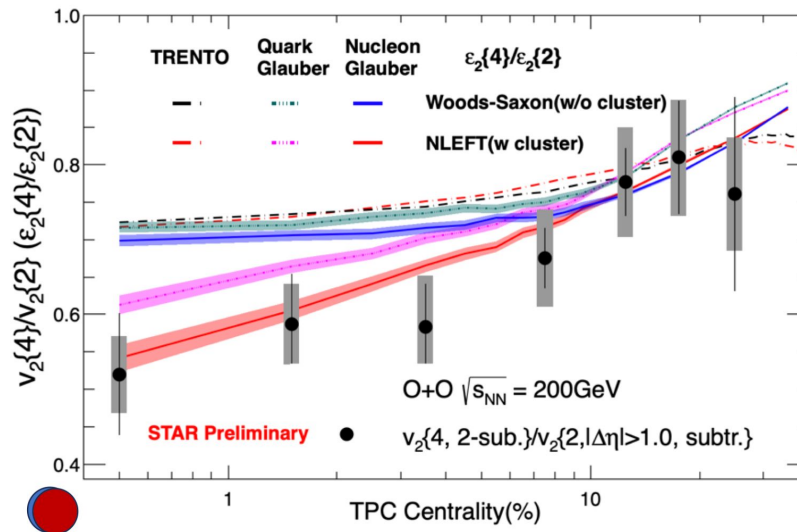
Bulk Results:

Similar N_{part} to ${}^3\text{He}\text{-Au}$

$$v_2(\text{O+O}) < v_2(\text{d+Au}) \approx v_2({}^3\text{He+Au})$$

$$v_3(\text{O+O}) \approx v_3(\text{d+Au}) \approx v_3({}^3\text{He+Au})$$

- v_n/ε_n are similar between O+O and ${}^3\text{He+Au}$, within a quark Glauber model
- $v_2\{4\}/v_2\{2\}$ show clear decrease in ultra-central collisions, consistent with $\varepsilon_2\{4\}/\varepsilon_2\{2\}$, indicating enhanced fluctuations due to possible many-nucleon correlations.



Quark Glauber:
PRC **94**, 024914 (2016)
TRENTO:
PRC.92.011901(2015)
Calculated by Giuliano

[S. Huang \(STAR Collaboration\). QM2023](#)



Particles To Be Reconstructed

I am interested in reconstructing particles with s-quarks, as listed below.

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%

- This presentation will focus on Λ 's.
- The Ξ^- , Ω^- , ϕ , and K_s^0 results will follow soon.

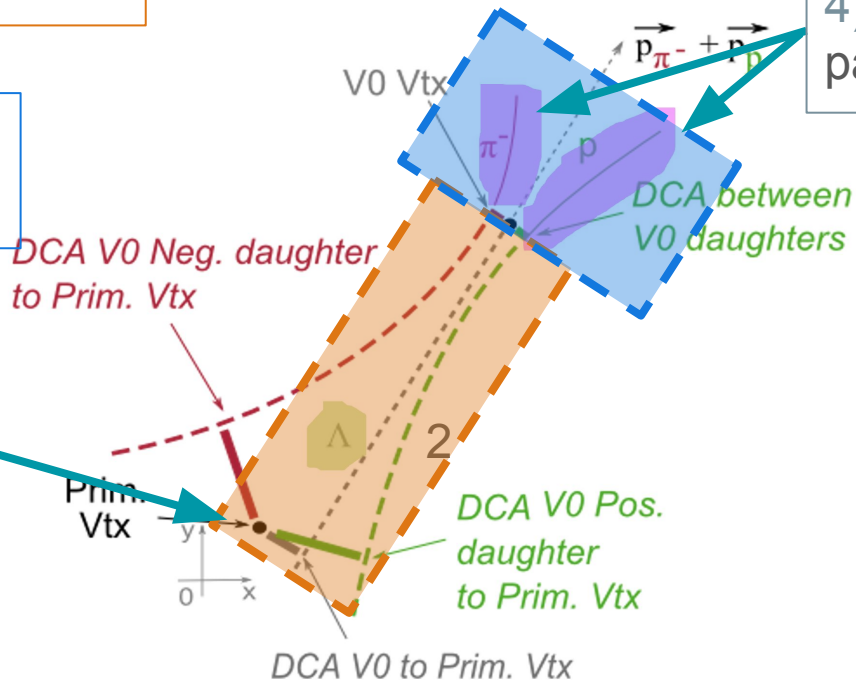
Reconstruction Details and Topological Cuts

1) The distance to primary vertex

2) The distance between daughter particles

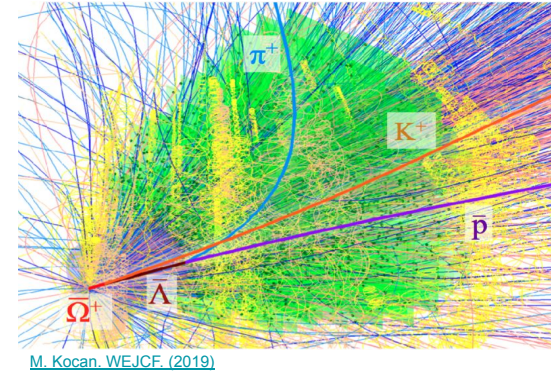
3) Vertex location

4) χ^2 cuts on particle fits



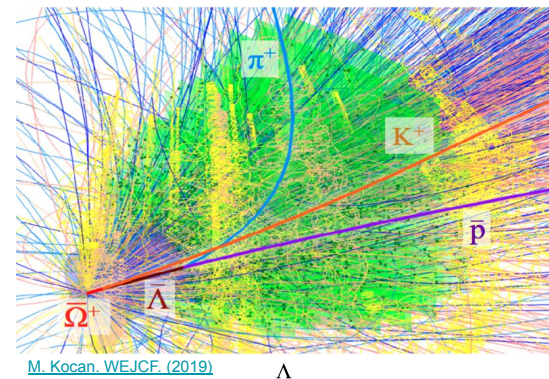
Reconstructing Lambdas and Signal Extraction

- 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.



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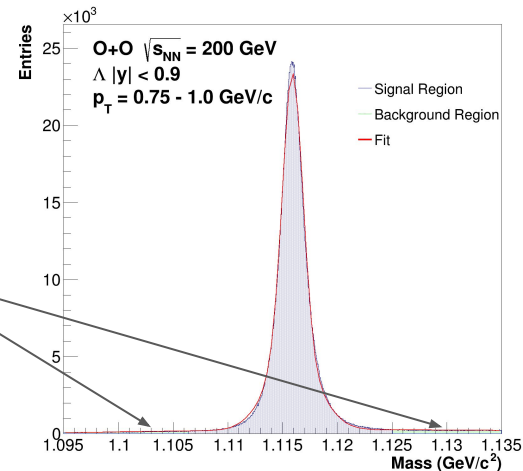


For the Λ Signal Extraction:

- The signal (without background subtraction) region is $[\mu-3\sigma, \mu+3\sigma]$, and the background region is $[0$ to $\mu-3\sigma$, $\mu+3\sigma$ to $X_{max}]$.
- Fitting function: 2nd poly + double Gauss function.

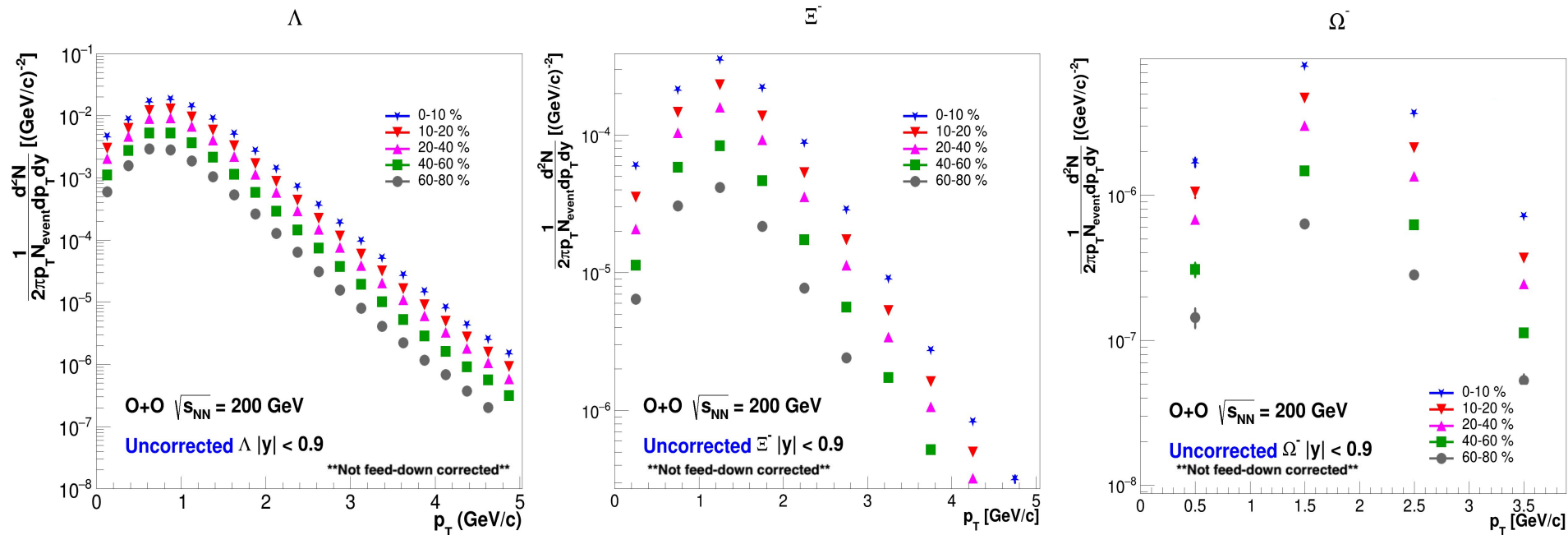
The blue region is the signal w.o background subtraction.

The green region is the background region.



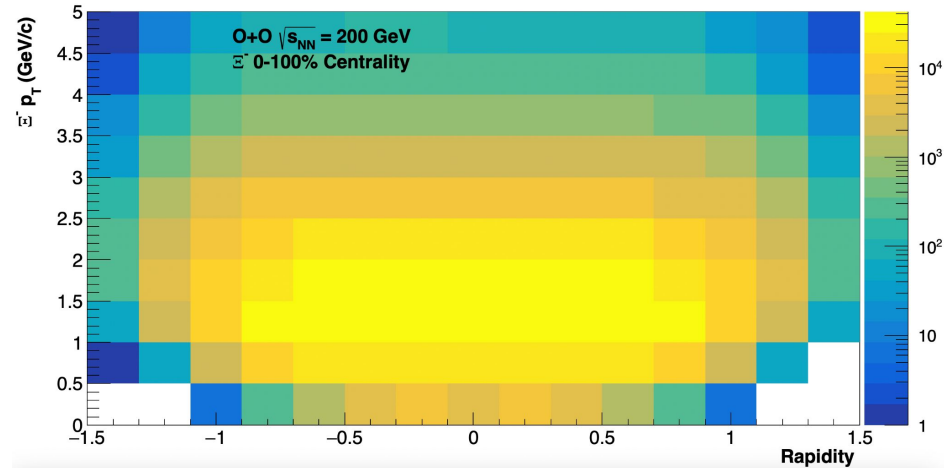
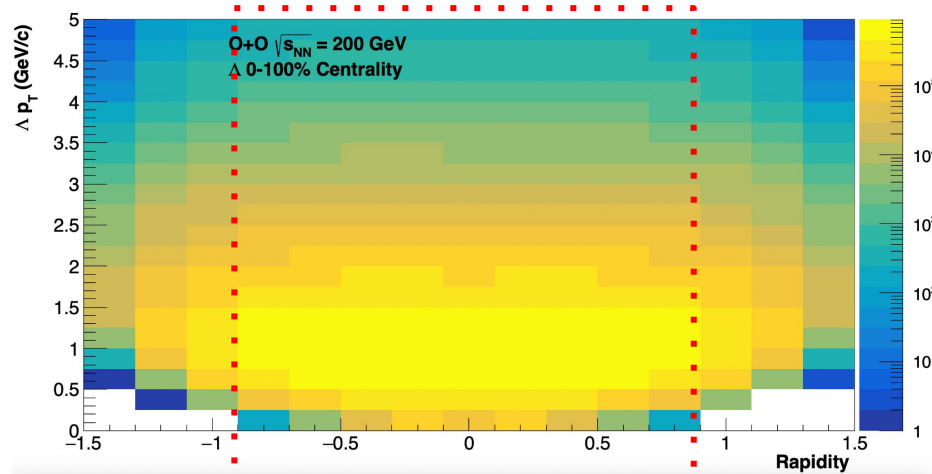


Uncorrected Raw Spectra for Hyperions in O+O



- The large statistics, improved p_T and rapidity coverage enables STAR to have good statistics for multi-strange hadrons.
- There is good coverage through 0 - 80% centralities.

What does our rapidity coverage looks like?



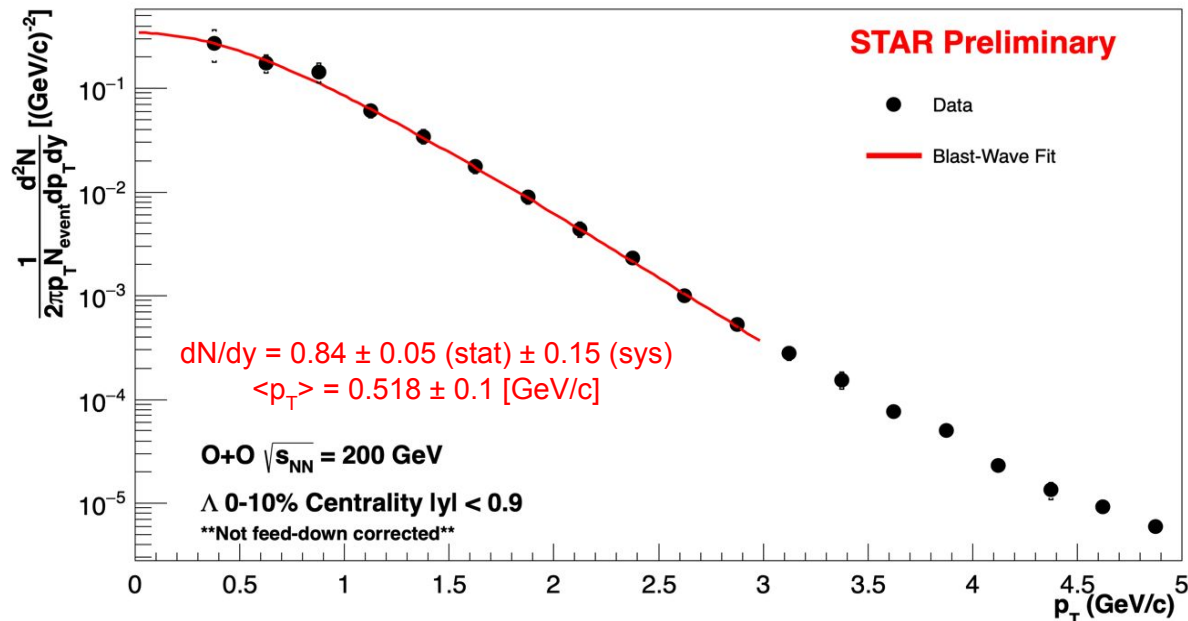
The iTPC provides extended coverage.

The rest of the talk will focus on this phase-space.

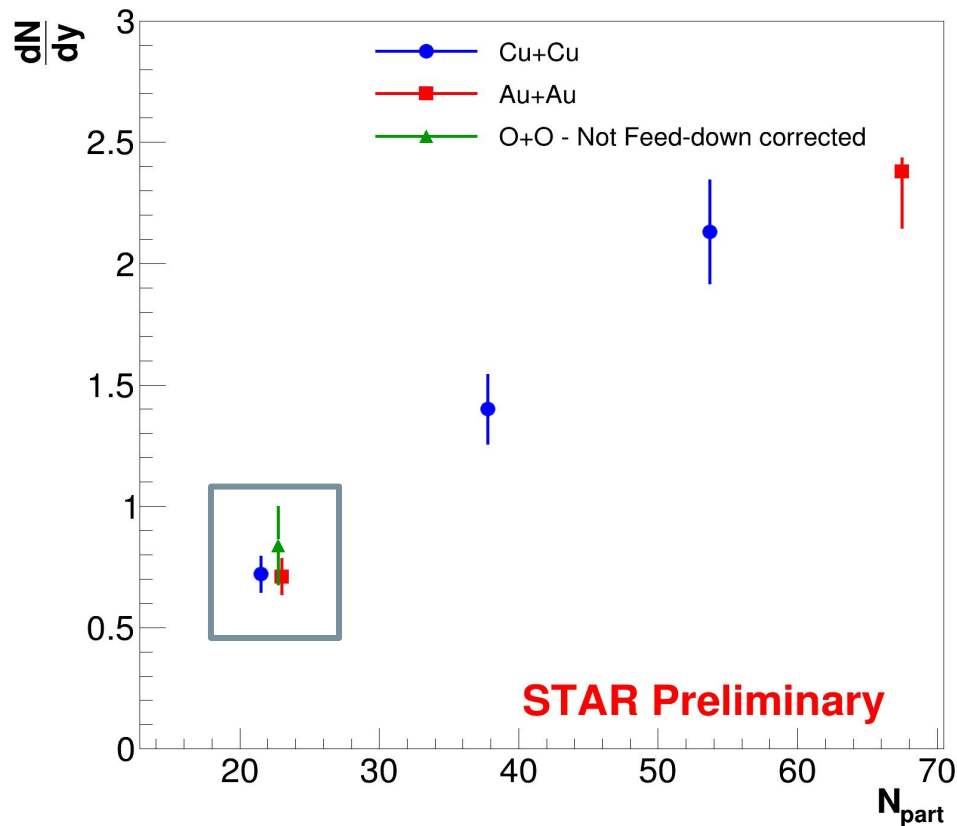


Corrected p_T spectrum for Λ 's in O+O

- The p_T spectra is calculated from the Λ 's invariant mass distributions for the different momenta.
- The reconstruction efficiency is calculated using monte carlo which is embedded in real data and then propagated through the detector simulation.
- The Λ 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 collisions.

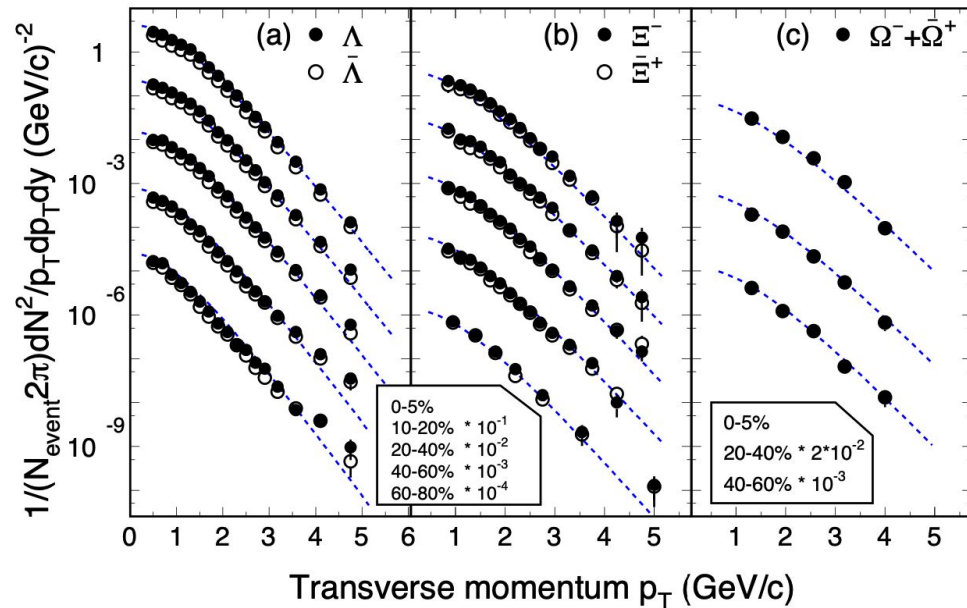
Integrating the Λ p_T spectra from 0 to ∞ the yield (dN/dy) is $0.84 \pm 0.05 \pm 0.15$

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

Next Steps for Analysis

- Extend the analysis to other hyperons.
 - The raw p_T spectra have been made but is pending the corrections.
- Calculate the yields from corrected spectra.
- Calculate the pion yield.
- 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.

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



[STAR Collaboration. Phys. Rev. Lett. 98, 062301 \(2007\)](https://arxiv.org/abs/0705.3802)

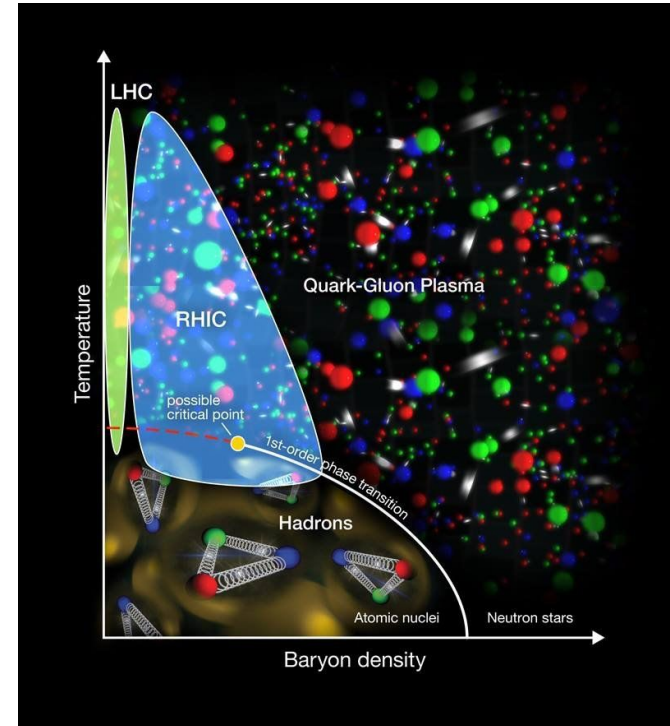


Conclusions

- The O+O at $\sqrt{s_{NN}} = 200$ GeV is a newer data set for STAR.
- The O+O dataset can fill in the gaps in the low multiplicity regions in the ratio of strange hadron production to the pion yield for the STAR data.
- I presented the first yield calculation for Λ 's in the 0-10% centrality region for O+O.
- With the great statistics there will be interesting results for the near future!

Some of STAR's other strangeness results at CPOD

- [Y. Zhou](#) presented measurements of K_S^0 , Λ , Ξ^- production at $\sqrt{s_{NN}} = 3 - 4.5$ GeV in Au + Au collisions.
 - Soon there will be more measurements from BESII too.
- [Y. Leung](#) presented on hypernuclei production at $\sqrt{s_{NN}} = 3 - 27$ GeV in Au+Au.
- Plus several other analysis!
- Covering different phase-space of the QCD diagram!



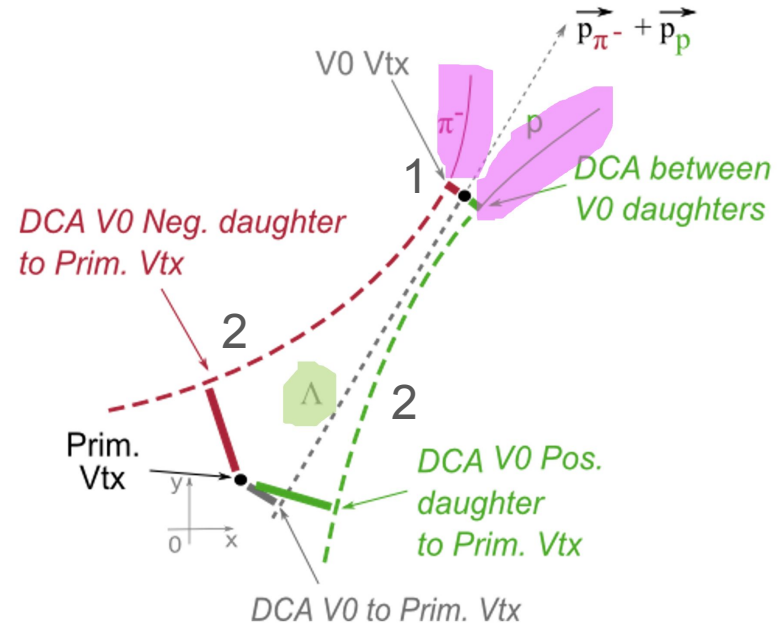
<https://www.bnl.gov/newsroom/news.php?a=121072>



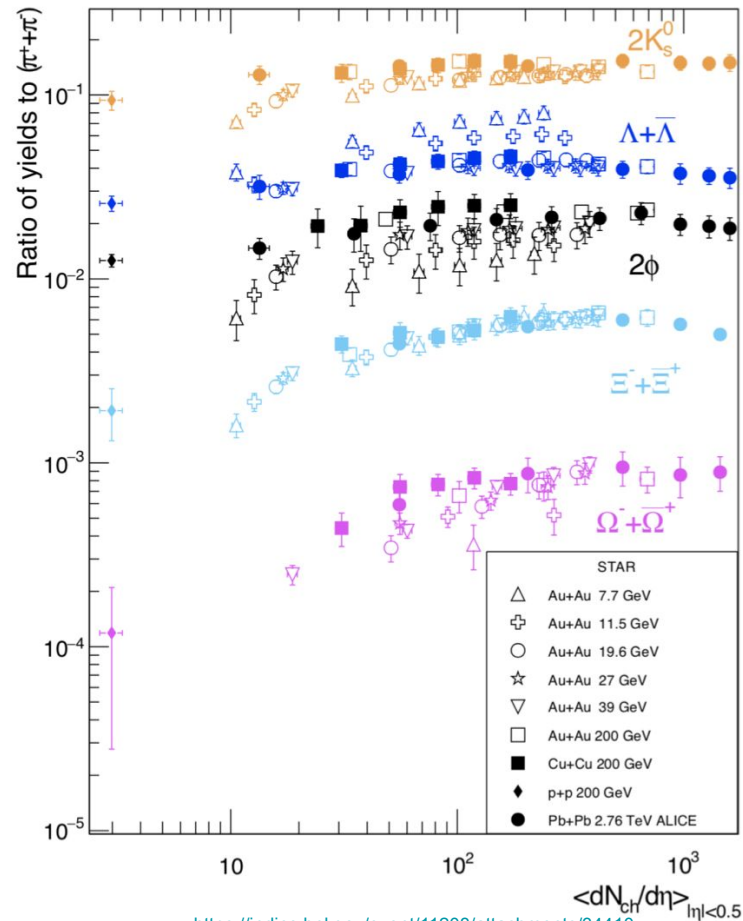
Backup

Reconstruction Details and Topological Cuts

- 1) **MaxDistanceBetweenParticlesCut** (DCA between daughters): 5 cm
- 2) **LCut** (distance to primary vertex): > 1 cm
- 3) **Chi2Cut2D** (cut on χ^2 of the particle fit): > 20
- 4) **ChiPrimaryCut** (cut on χ^2 of the tracks to the PV to divide tracks into primary and secondary) : > 3.
- 5) **ChiPrimaryCut2D** (cut on χ^2 of the track to the PV): > 3.
- 6) **LdLCut2D** (cut on the distance to PV normalized on the error): > 3
- 7) **Vz** < | 145 | cm
- 8) **Vr** < 2 cm
- 9) **nHitsFit** > 15



Full spectra with BES yields



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