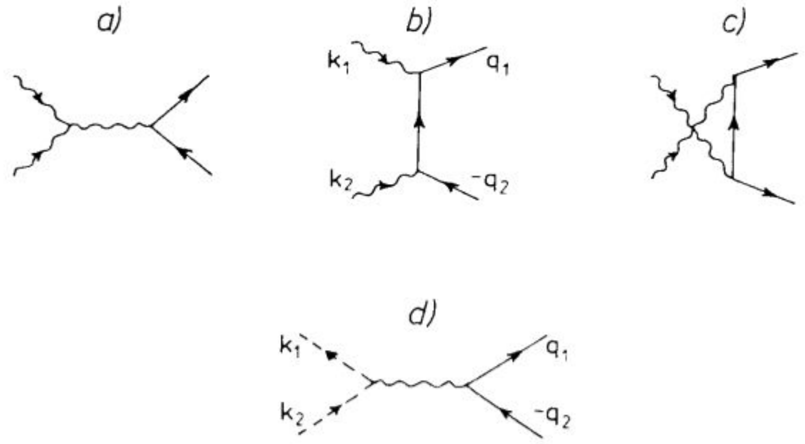
# Strangeness Production in O+O Collisions at $\sqrt{s_{NN}}$ = 200 GeV

**Iris Ponce** for the STAR Collaboration
Yale University
CPOD 2024

# 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

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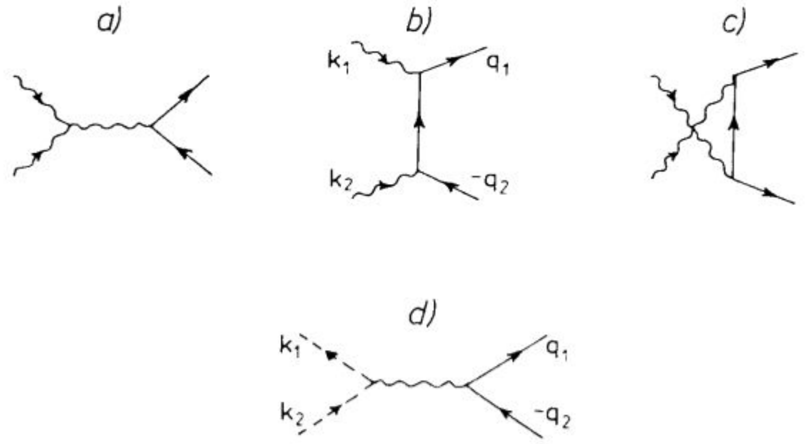
- The thermal production of s-$\bar{s}$ pairs is favorable in the QGP since the s-$\bar{s}$ masses are close to the QGP transition temperature ~156 MeV.
    - $M_{ss}$ ~192 MeV
    - There are abundant thermal gluons in the QGP medium.

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

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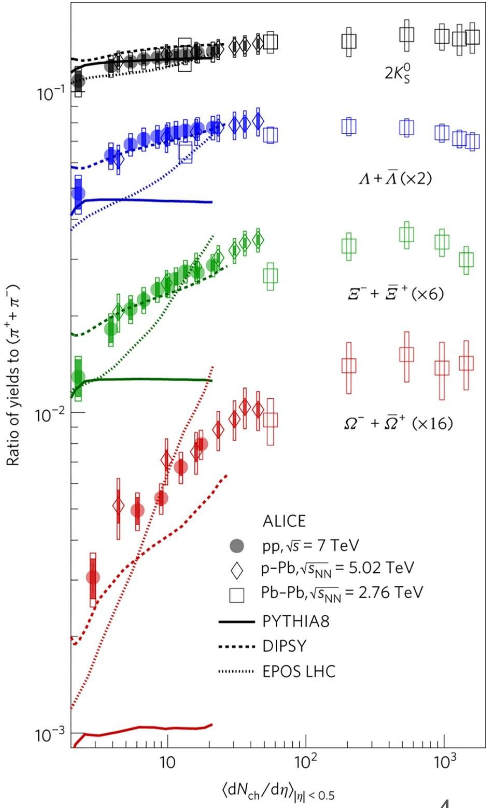
# Motivation

- 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).




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

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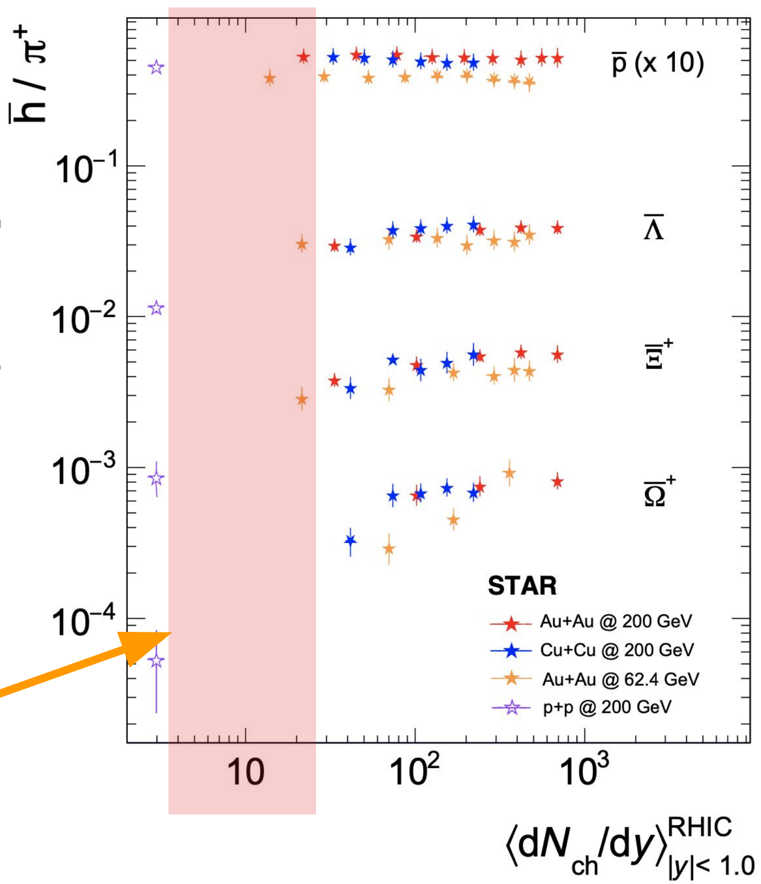
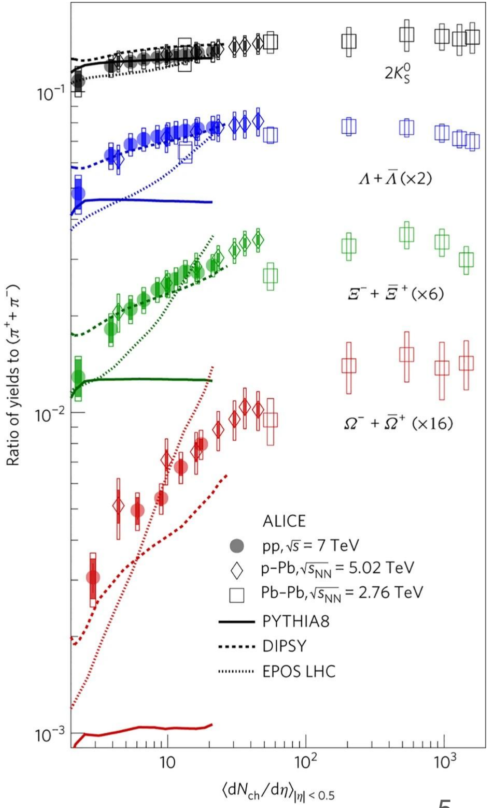
Phys. Rev. C **83**, 034910




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

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

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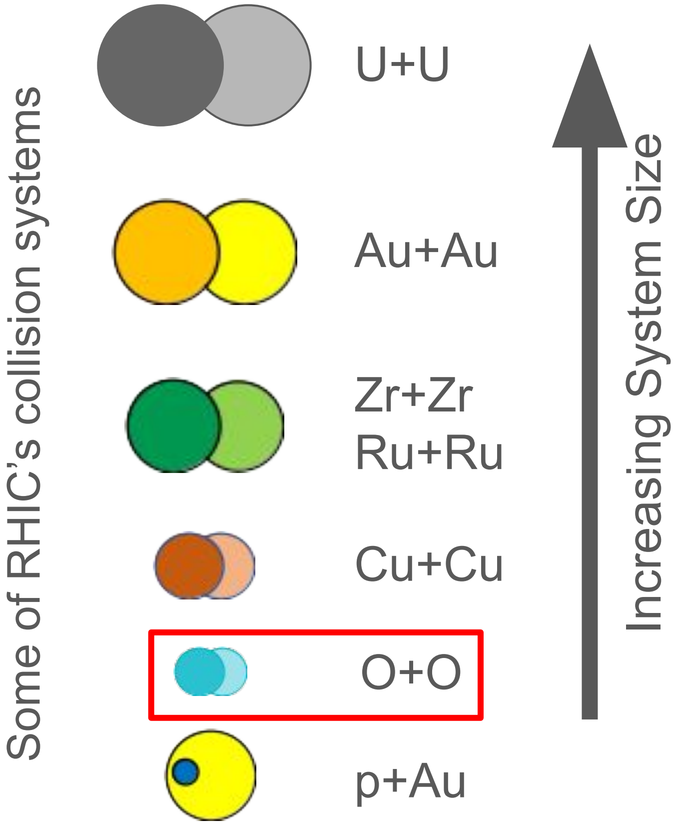
    - STAR has reproduced this ratio.

- 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



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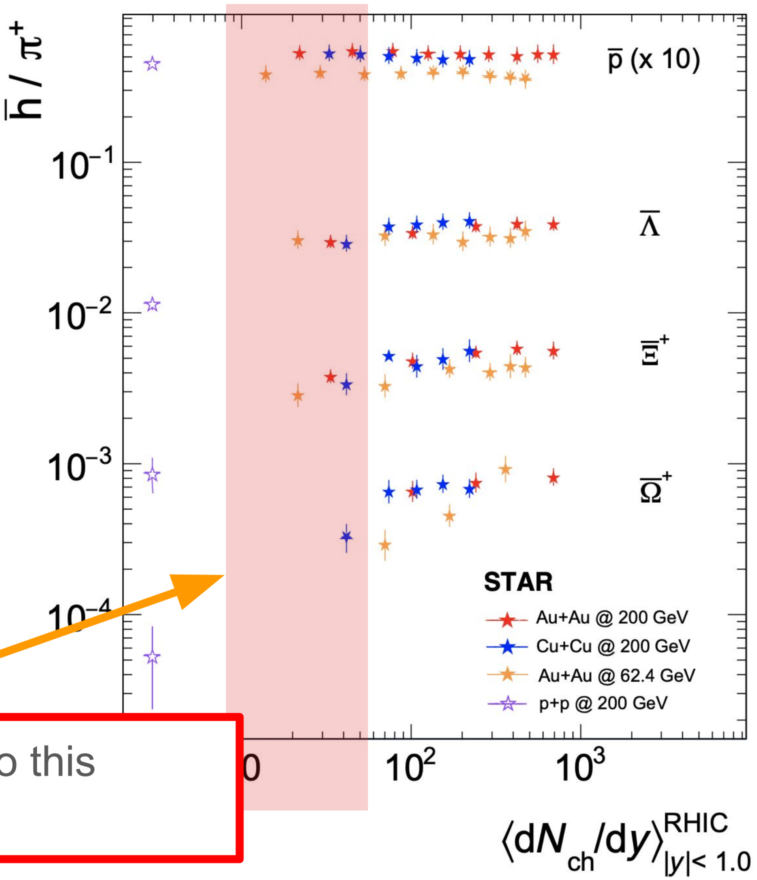
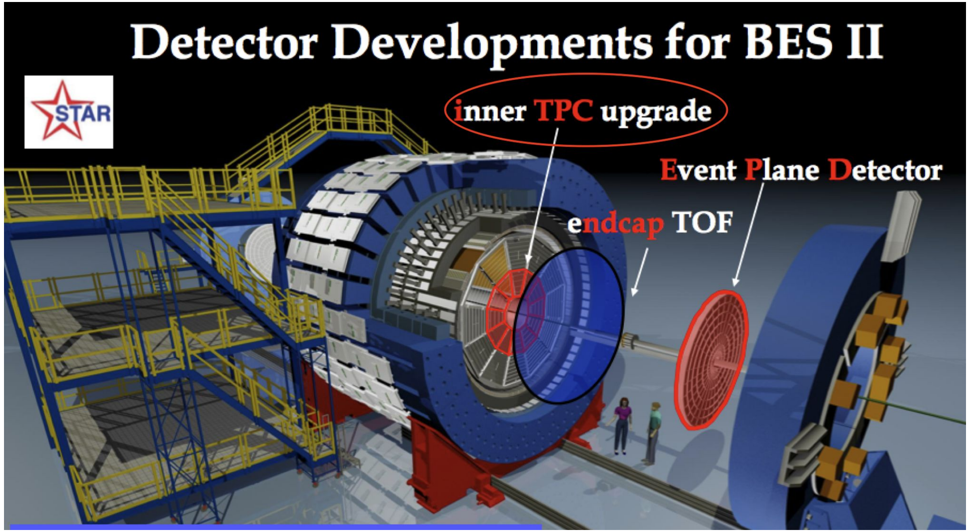



O+O's multiplicity can extend to this unexplored region

| 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)]

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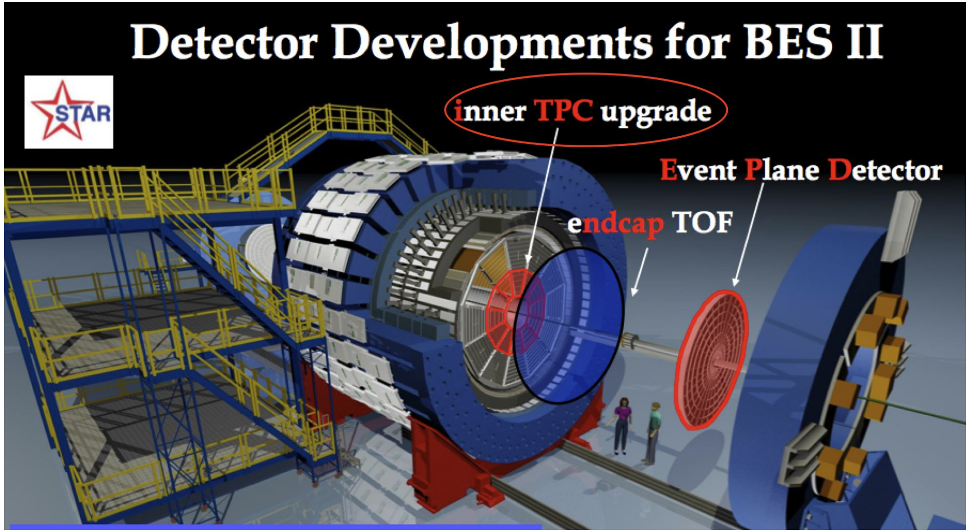
- From 2018 on, STAR had two detector upgrades: iTPC and eTOF
  - Improved coverage: $|\eta| < 1.5$ from $|\eta| < 1.0$
  - Lower pT coverage 125 MeV => 60 MeV

- There are ~650M O+O minimum bias events total.
  - ¼ of the O+O run was taken with the magnetic field reversed.
    - Testing calibration and TPC distortions

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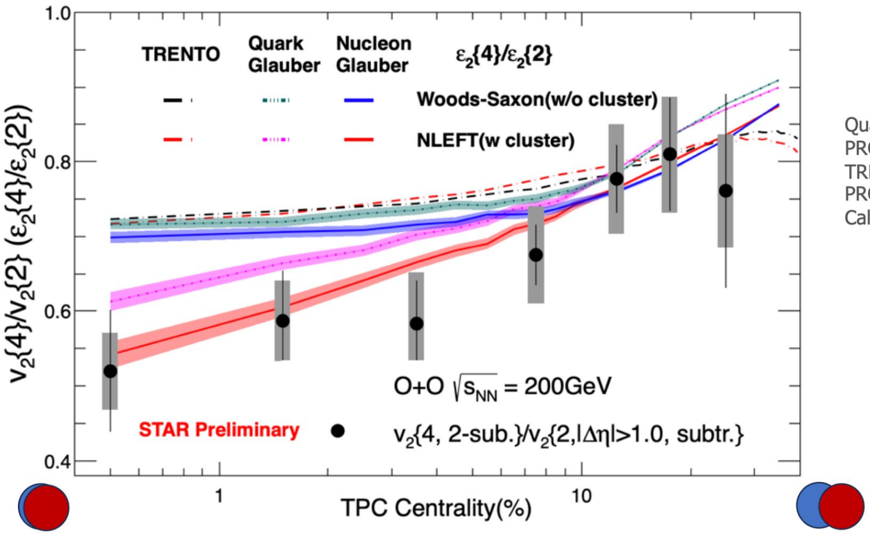
# Flow Measurements in O+O collisions shown in QM2023

## Bulk Results:

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

$v_2(O+O) < v_2(d+Au) \approx v_2(^3He+Au)$
$v_3(O+O) \approx v_3(d+Au) \approx v_3(^3He+Au)$

- $v_n/\varepsilon_n$ are similar between O+O and $^{3}$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 % |
| $K_s^0$ | $\pm$1 | 497.611$\pm$0.013 | $\pi^+\pi^-$ | 69.20 % |
| $\Lambda$ | -1 | 1,115.683$\pm$0.006 | $p\pi^-$ | 64.1 % |
| $\Xi^-$ | -2 | 1,321.71$\pm$0.07 | $\Lambda\pi^-$ | 99.887% |
| $\Omega^-$ | -3 | 1,672.45$\pm$0.29 | $\Lambda K^-$ | 67.8% |

- This presentation will focus on **Λ**’s.
- The $\Xi^-$, $\Omega^-$, $\phi$ , and $K^0_S$ results will follow soon.

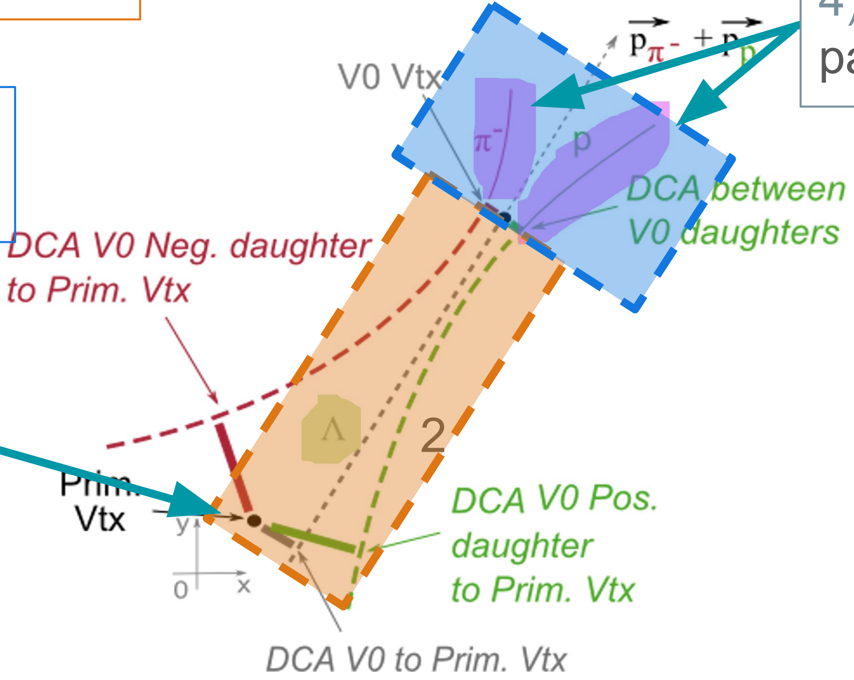
# Reconstruction Details and Topological Cuts

1) The distance to primary vertex

2) The distance between daughter particles

3) Vertex location

4) $\chi^2$ cuts on particle fits



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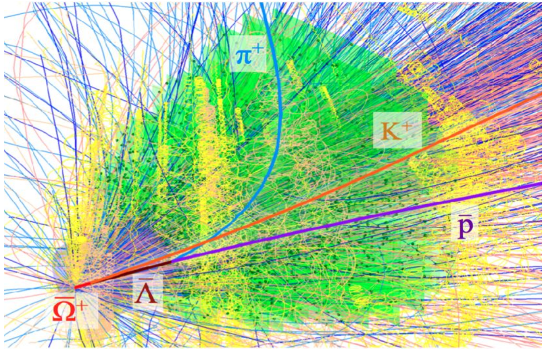
# Reconstructing Lambdas and Signal Extraction

- 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)

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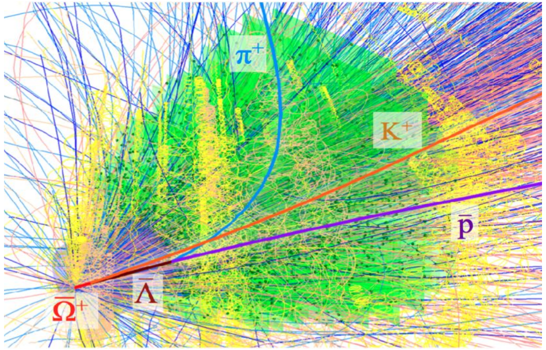



M. Kocan, WEJCF, (2019)

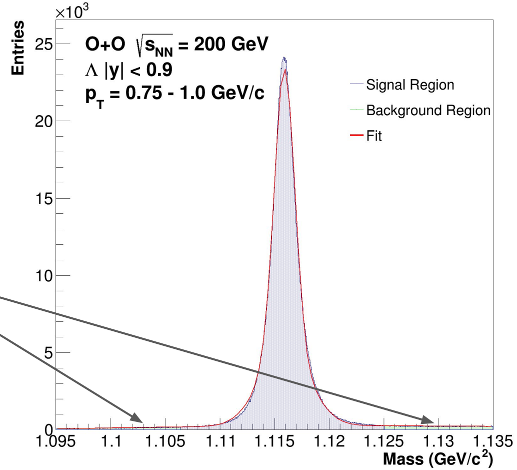
$\Lambda$

## For the $\Lambda$ 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 Xmax].
- Fitting function: 2nd poly + double Gauss function.

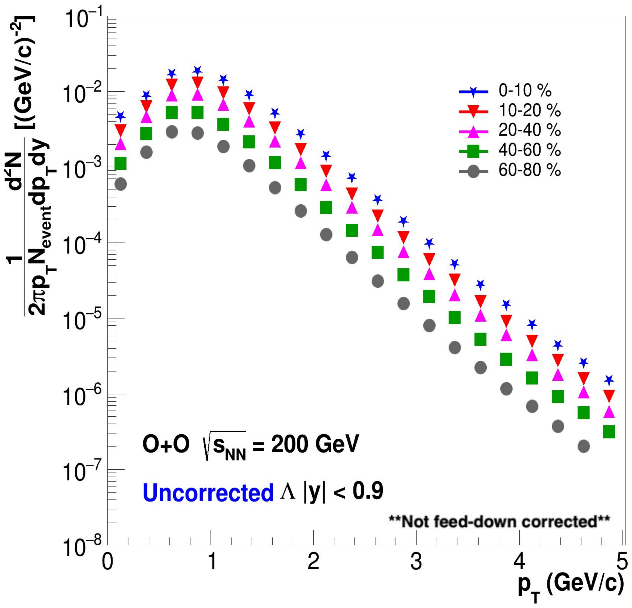
The blue region is the signal w.o background subtraction.

The green region is the background region.

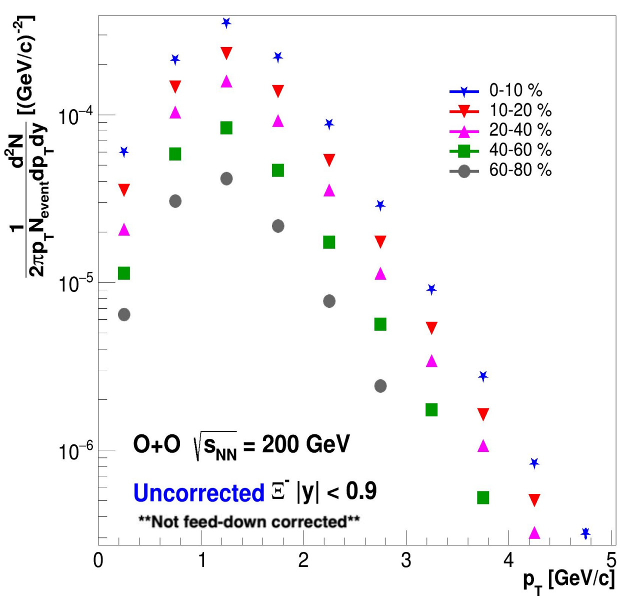


# Uncorrected Raw Spectra for Hyperions in O+O

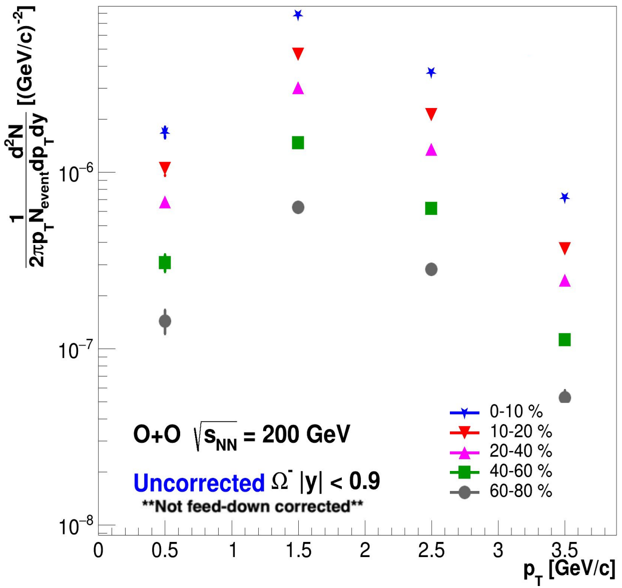
Λ




$\Xi^-$

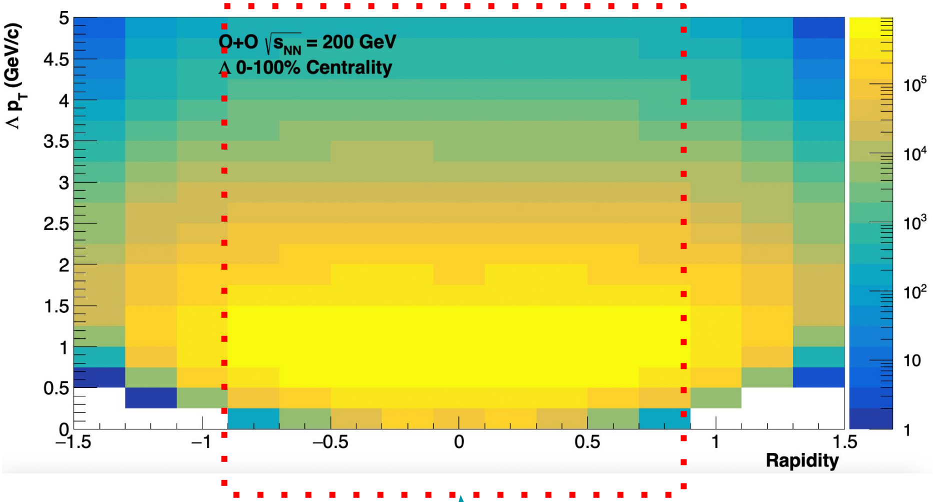


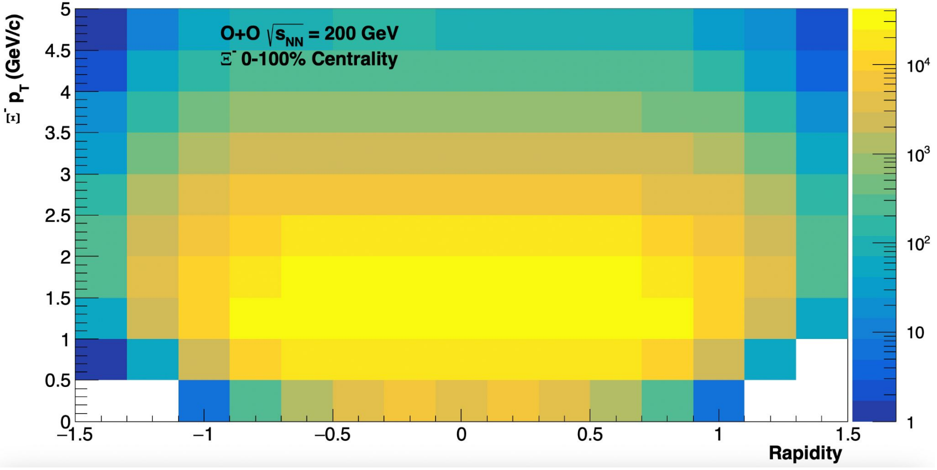

$\Omega^-$




- 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?



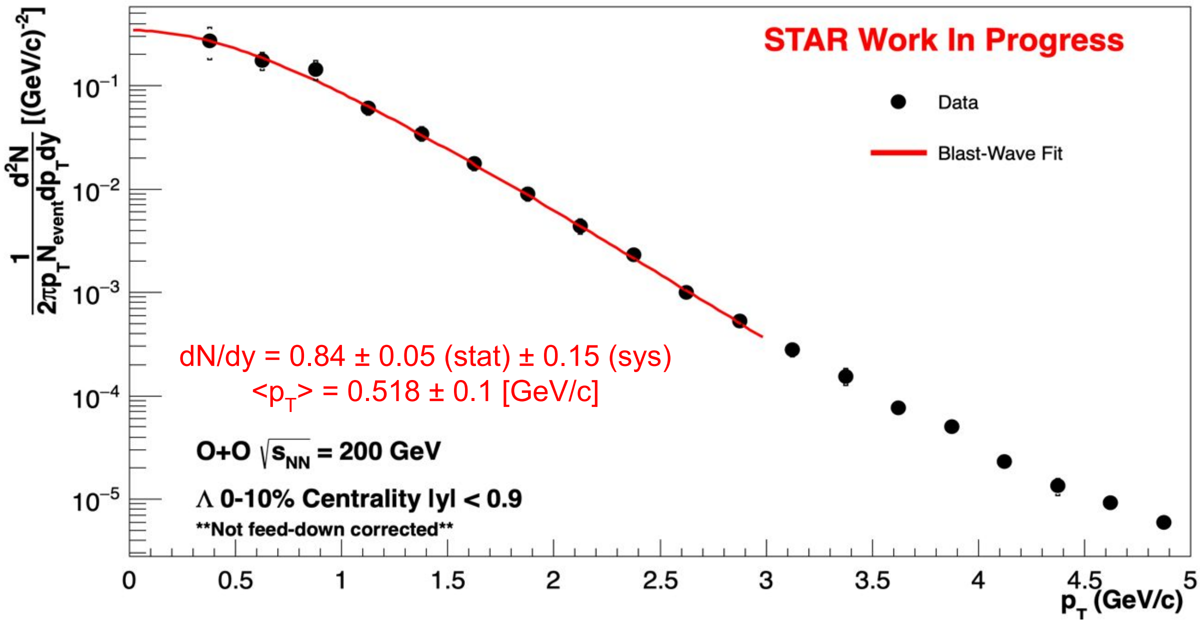




The iTPC provides extended coverage.

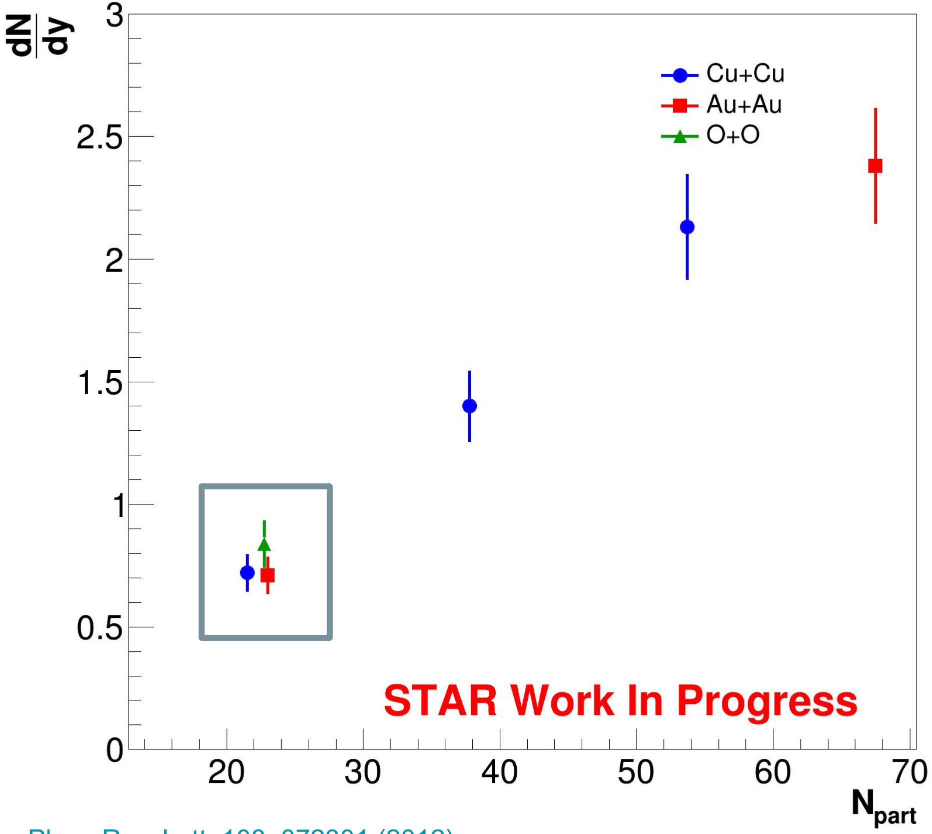
The rest of the talk will focus on this phase-space.

# Corrected $p_T$ spectrum for $\Lambda$'s in O+O

- The $p_T$ spectra is calculated from the $\Lambda$'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 $\Lambda$ 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 => ∞ the yield (dN/dy) is 0.84 ± 0.05 ± 0.15

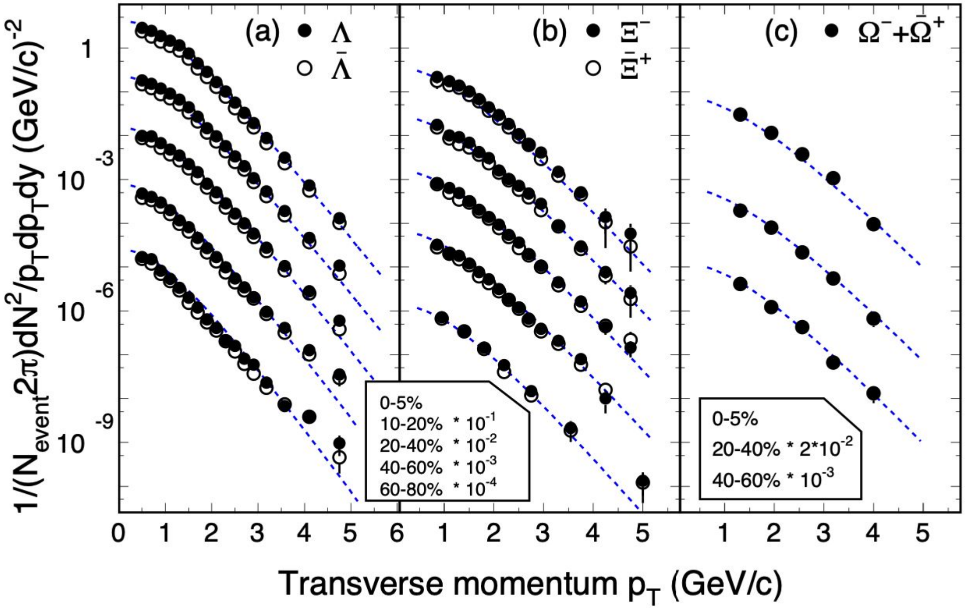
**O+O yield is not feed-down corrected.

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

# Next Steps for Analysis

- Extend the analysis to other hyperons.
  - The raw $p_T$ spectra 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. $\mu_B$ , $T_{ch}$) extraction.

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




STAR Collaboration. Phys. Rev. Lett. 98, 062301 (2007)

# 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!

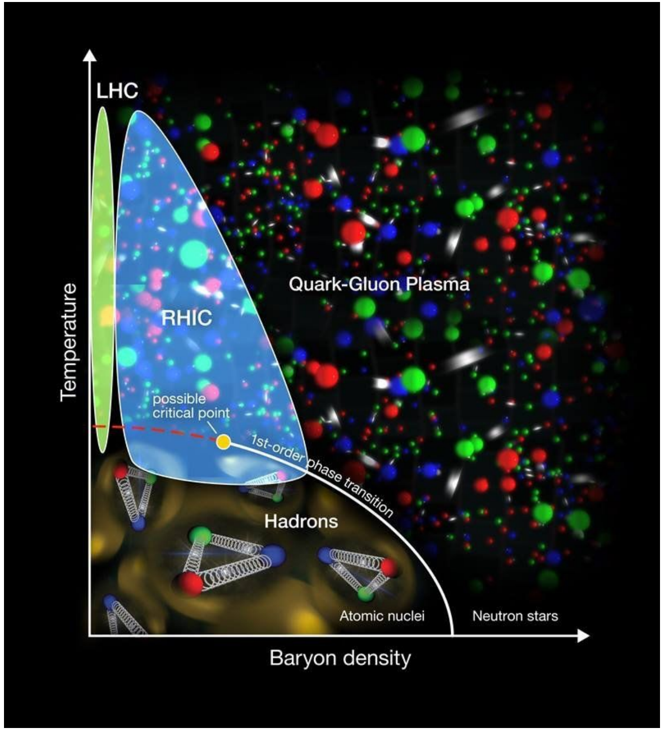
# Some of STAR's other strangeness results at CPOD

- Y. Zhou presented measurements of $K_s^0$, Λ, $\Xi^-$ 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!

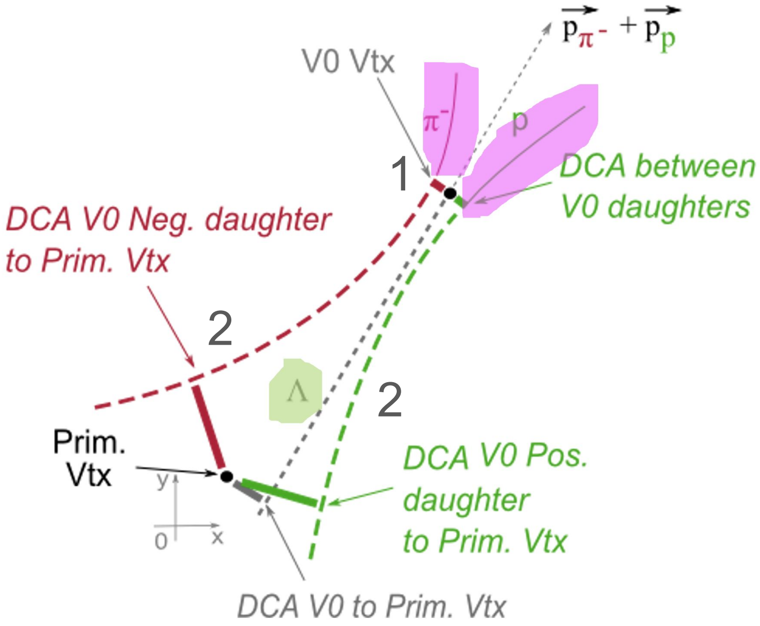



https://www.bnl.gov/newsroom/news.php?a=121072

# 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 $\chi^2$ of the particle fit): > 20
4) **ChiPrimaryCut** (cut on $\chi^2$ of the tracks to the PV to divide tracks into primary and secondary) : > 3.
5) **ChiPrimaryCut2D** (cut on $\chi^2$ 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

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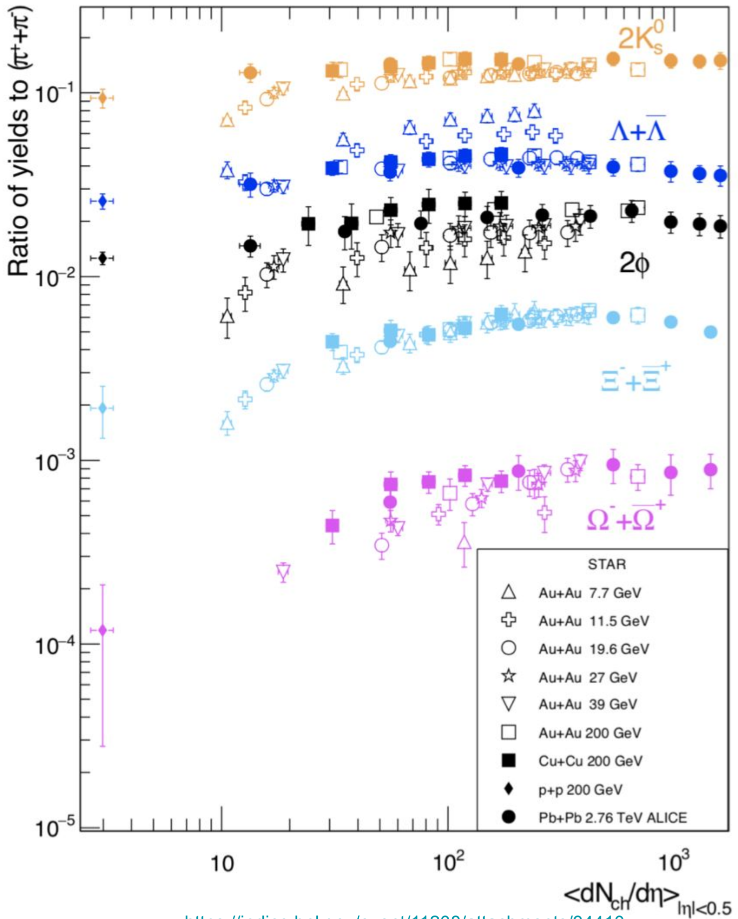
# Full spectra with BES yields




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