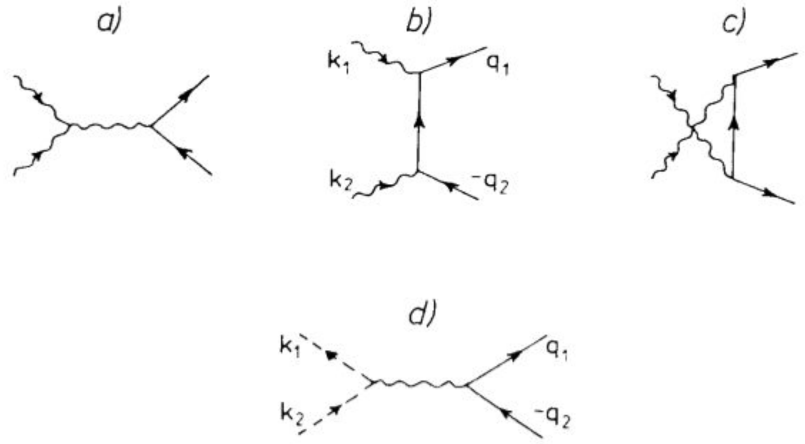
Strangeness Production in O+O Collisions at $\sqrt{s_{NN}}$ = 200 GeV

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).

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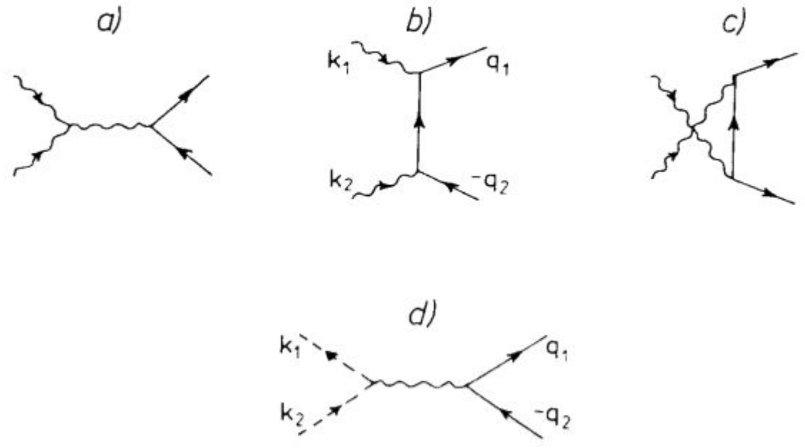
- The thermal production of s-$\bar{s}$ pairs is favorable in the QGP since the s-$\bar{s}$ masses are close to the QGP transition temperature ~156 MeV.
  - M_{ss} ~192 MeV
  - There are abundant thermal gluons in the QGP medium.

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



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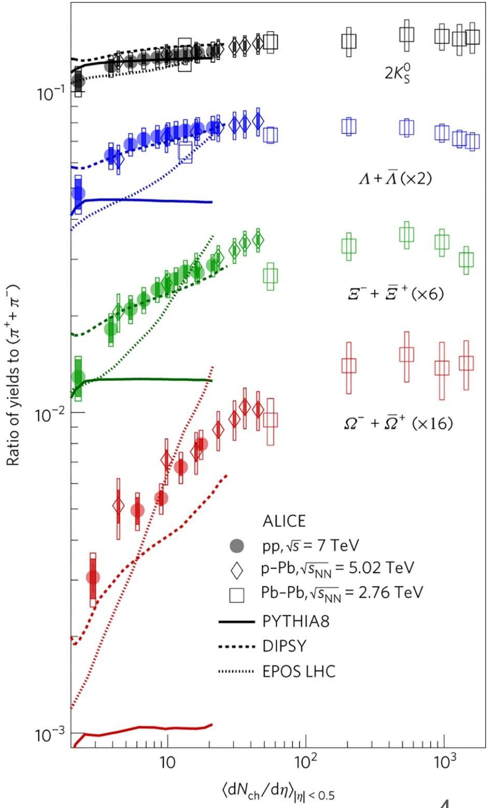
Motivation

- 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)

Motivation

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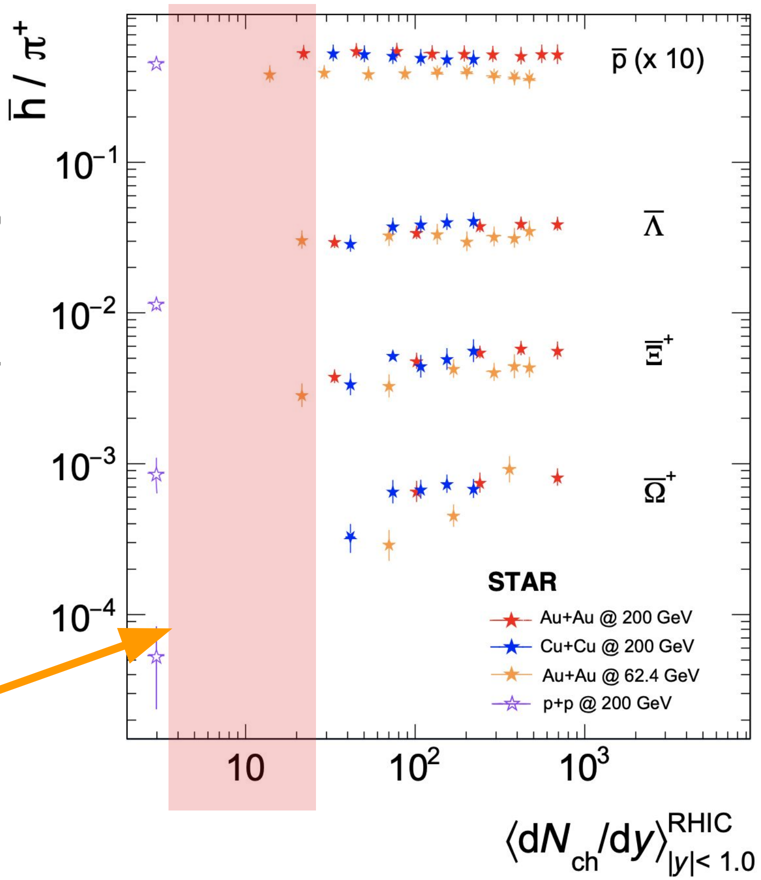
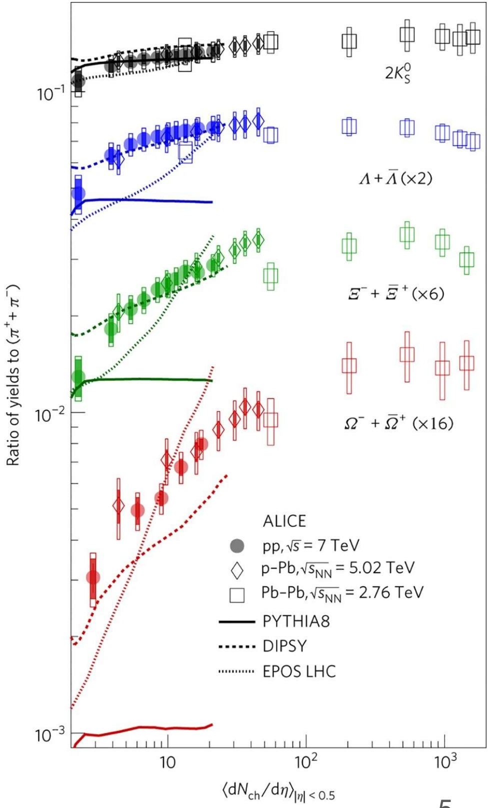
  - STAR has reproduced this ratio.

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

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





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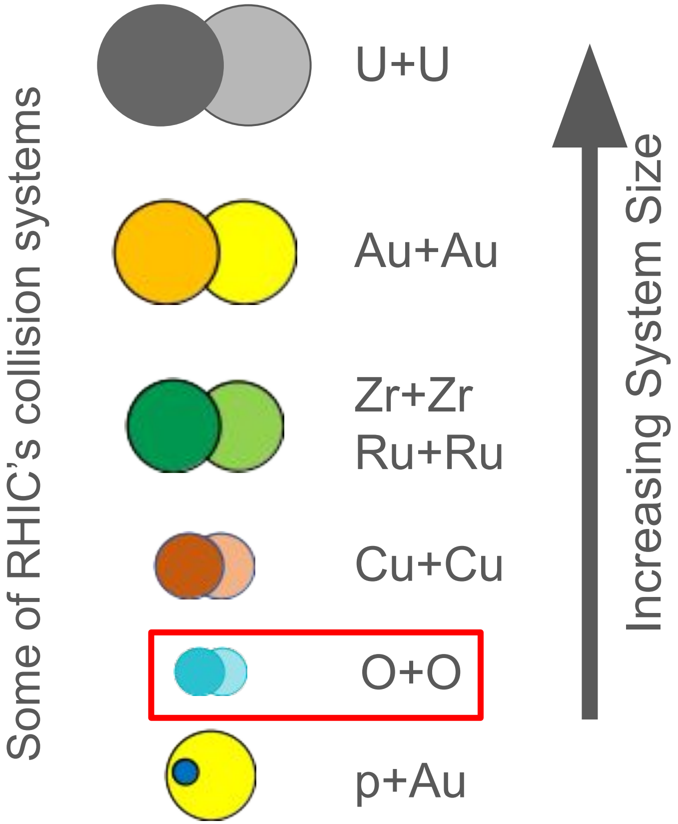
    - STAR has reproduced this ratio.

- 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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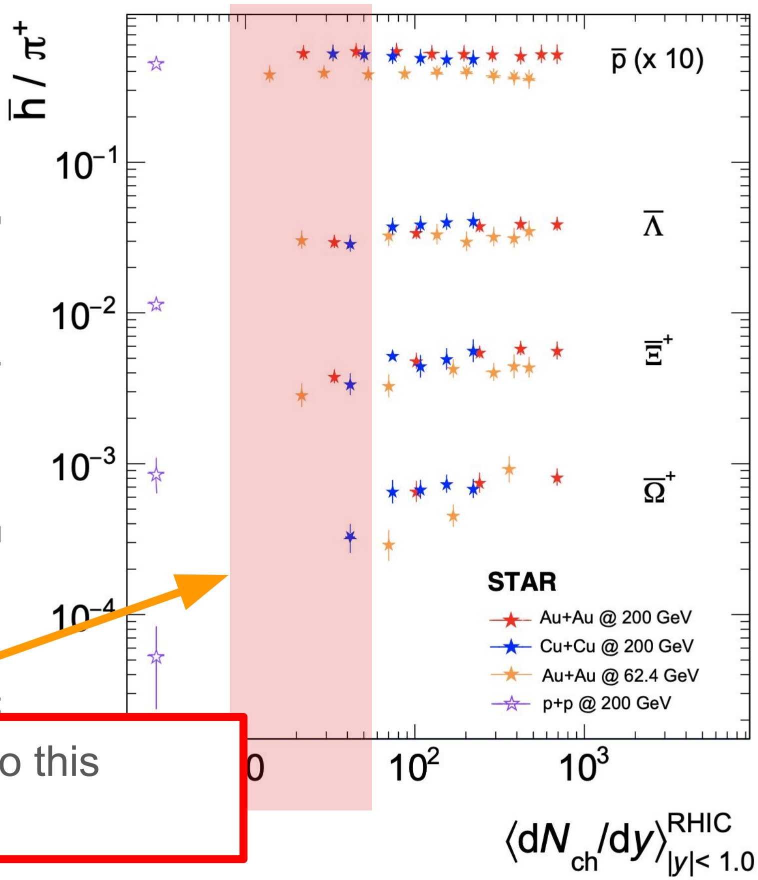
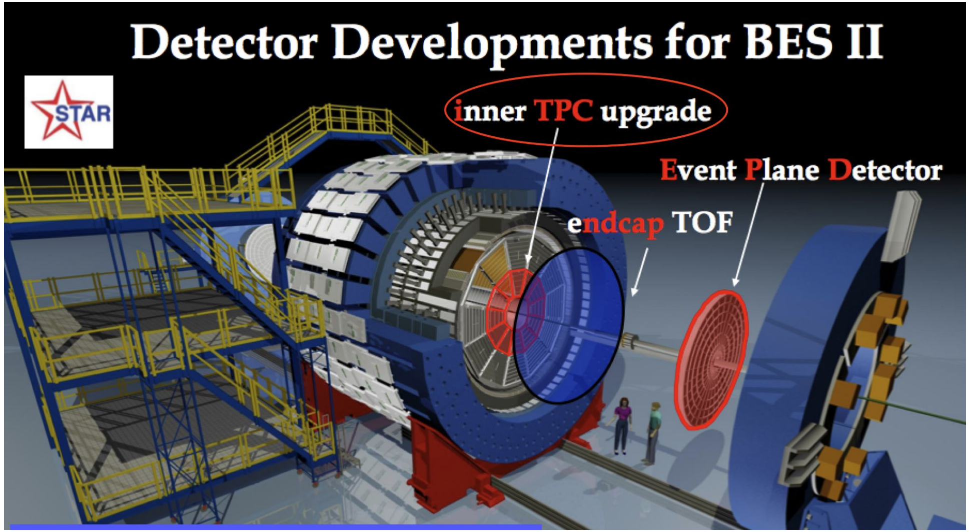


O+O's multiplicity can extend to this unexplored region

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 2021 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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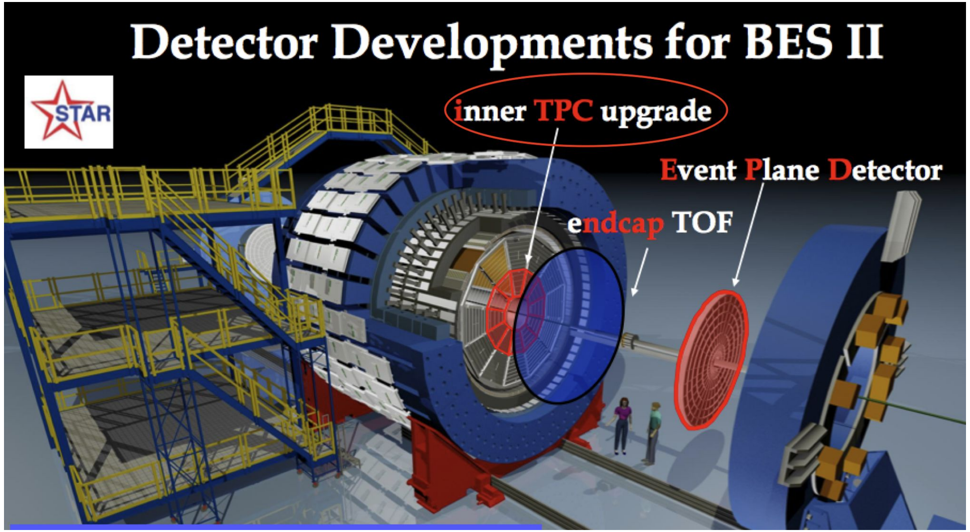
- From 2021 on, STAR had two detector upgrades: iTPC and eTOF
  - The O+O run is one of the first runs with the iTPC installed
    - Improved coverage: $|\eta| < 1.5$ from $|\eta| < 1.0$
    - Lower pT coverage 125 MeV => 60 MeV
- There are ~650M O+O minimum bias events total.
  - ¼ of the O+O run was taken with the magnetic field reversed.
    - Testing calibration and TPC distortions



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Flow Measurements in O+O collisions shown in QM2023

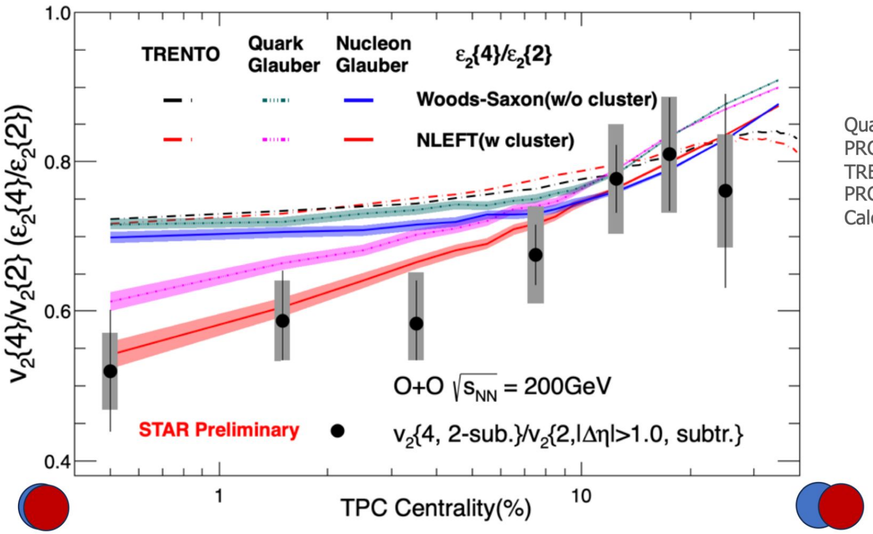
Bulk Results:

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/ε_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 ± 0.020	K^+K^-	49.5 %
K_s^0	±1	497.611±0.013	$\pi^+\pi^-$	69.20 %
Λ	-1	1,115.683±0.006	$p\pi^-$	64.1 %
Ξ^-	-2	1,321.71±0.07	$\Lambda\pi^-$	99.887%
Ω^-	-3	1,672.45±0.29	ΛK^-	67.8%

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

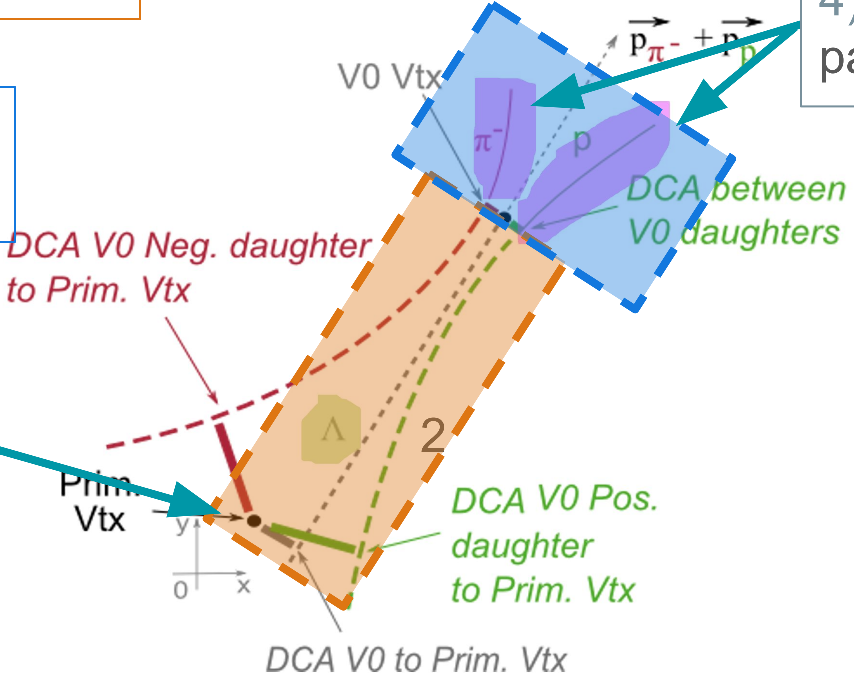
Reconstruction Details and Topological Cuts

1) The distance to primary vertex

2) The distance between daughter particles

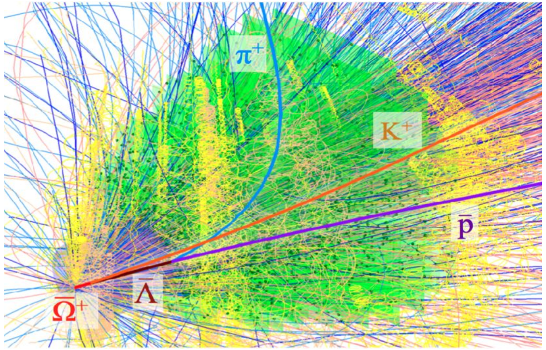
3) Vertex location

4) 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.



M. Kocan. WEJCF. (2019)

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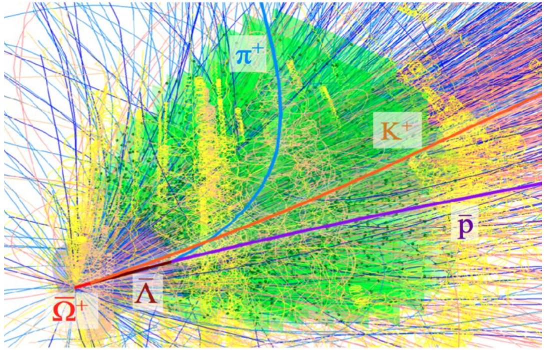


M. Kocan, WEJCF, (2019)

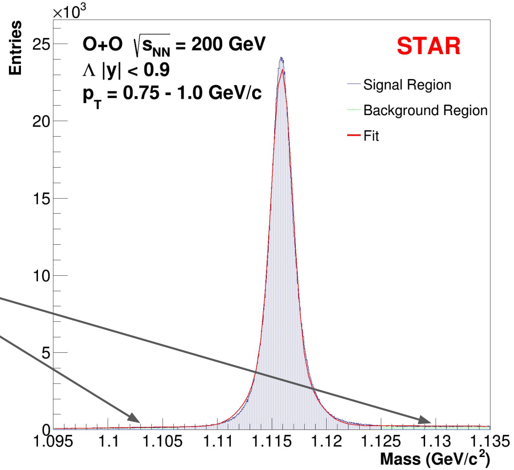
Λ

For the Λ Signal Extraction:

- The signal (without background subtraction) region is [μ-3σ,μ+3σ], and the background region is [0 to μ-3σ, μ+3σ to Xmax].
- Fitting function: 2nd poly + double Gauss function.

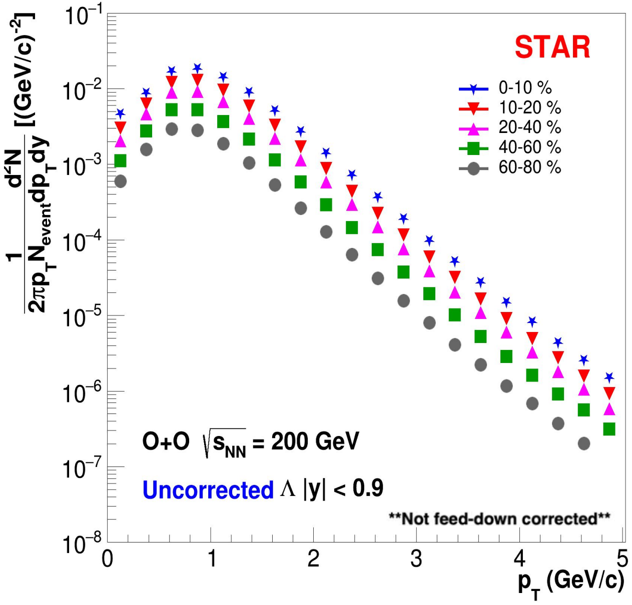
The blue region is the signal w.o background subtraction.

The green region is the background region.

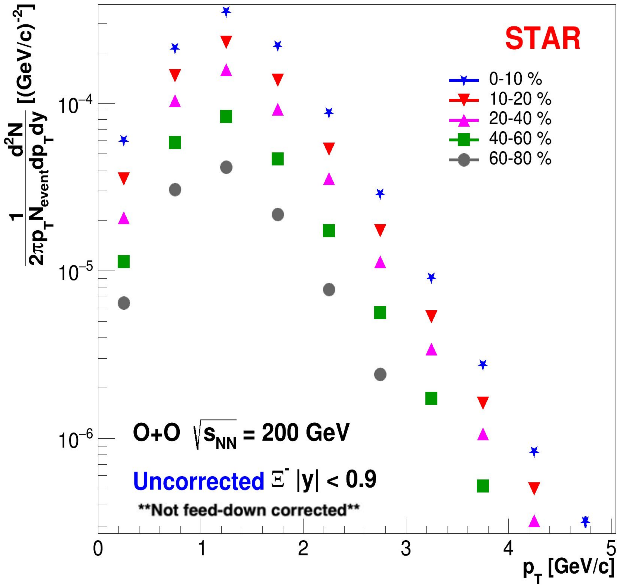


Uncorrected Raw Spectra for Hyperions in O+O

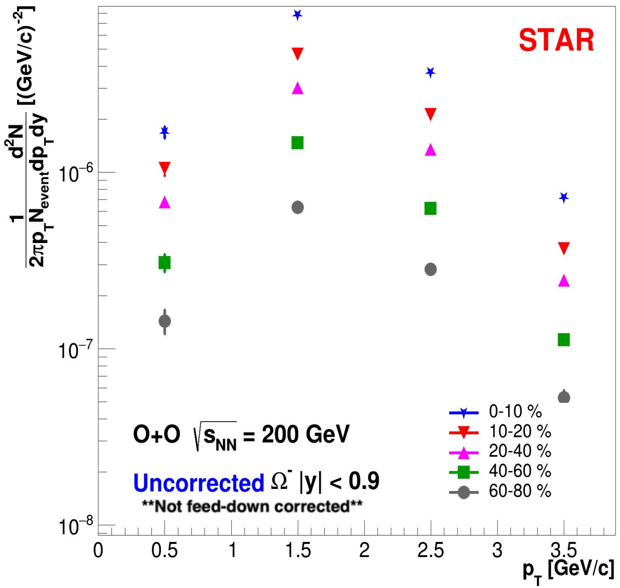
Λ



Ξ^-

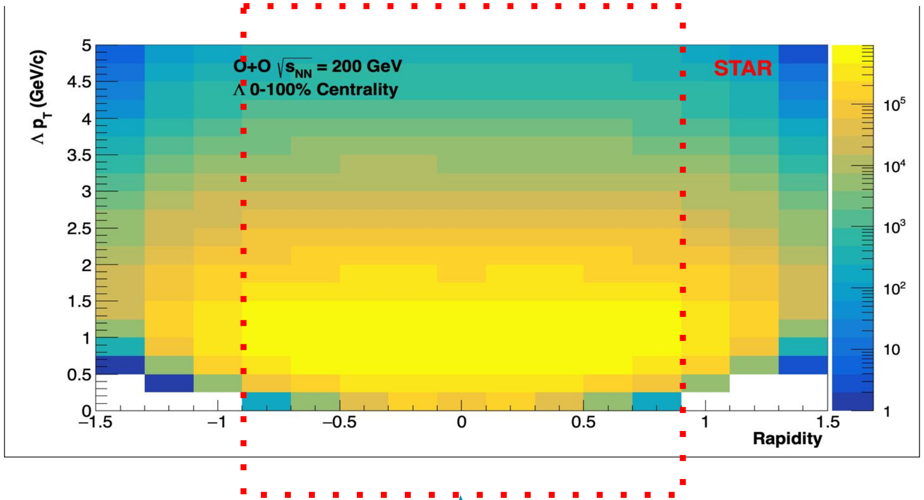


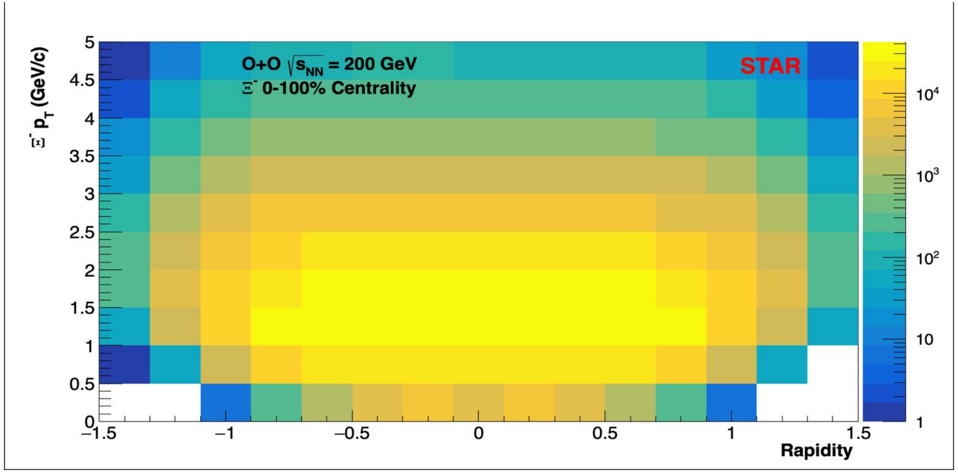
Ω^-



- 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?



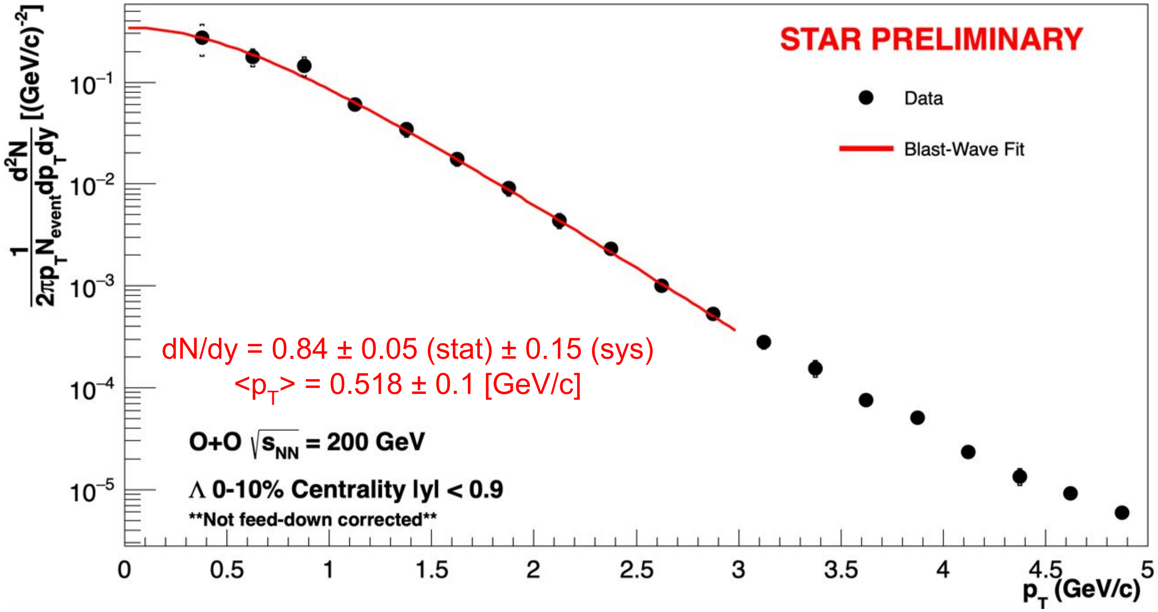


The iTPC provides extended coverage.

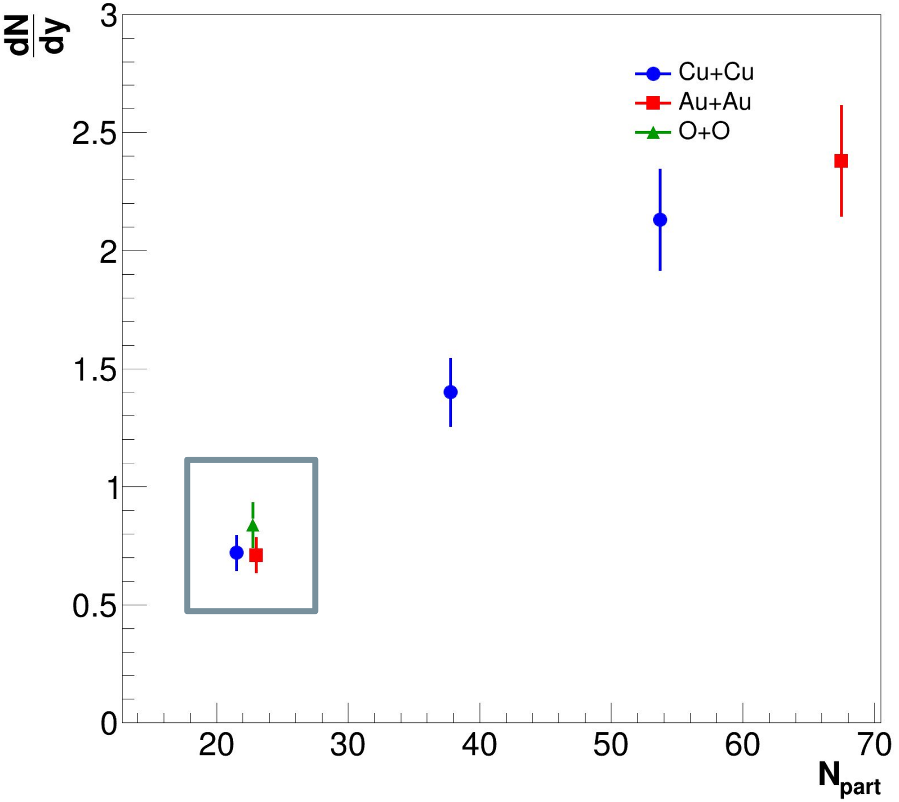
The rest of the talk will focus on this phase-space.

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 => ∞ the yield (dN/dy) is 0.84 ± 0.05 ± 0.15

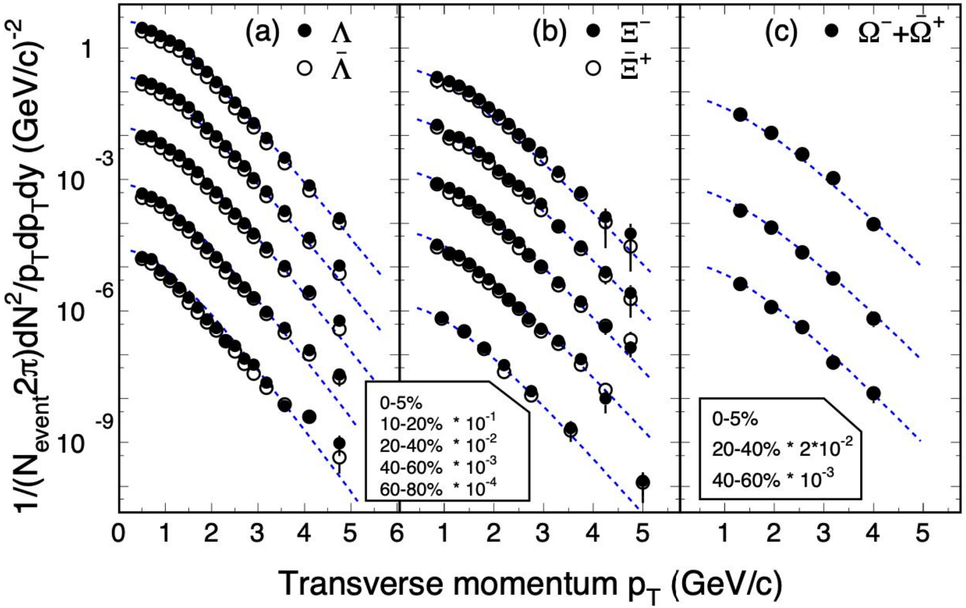
**O+O yield is not feed-down corrected.

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. 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)

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!

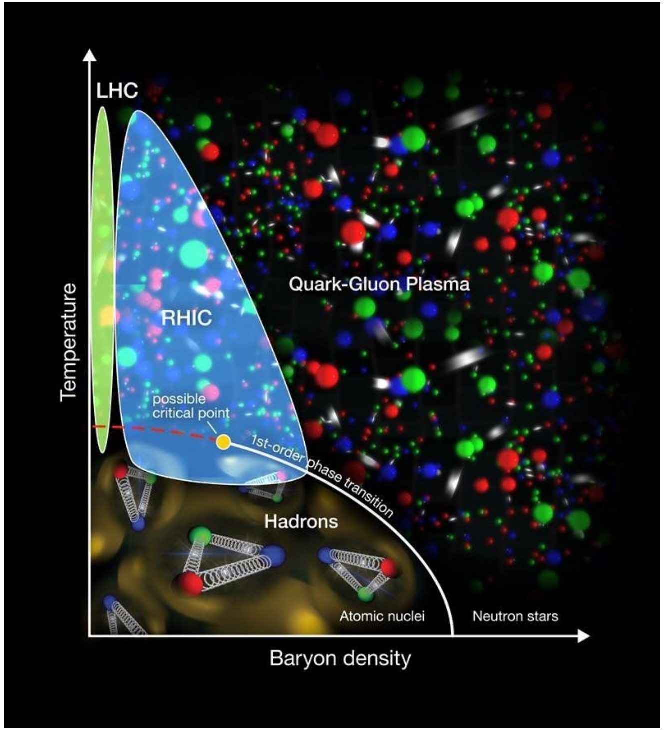
Some of STAR's other strangeness results at CPOD

- 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!

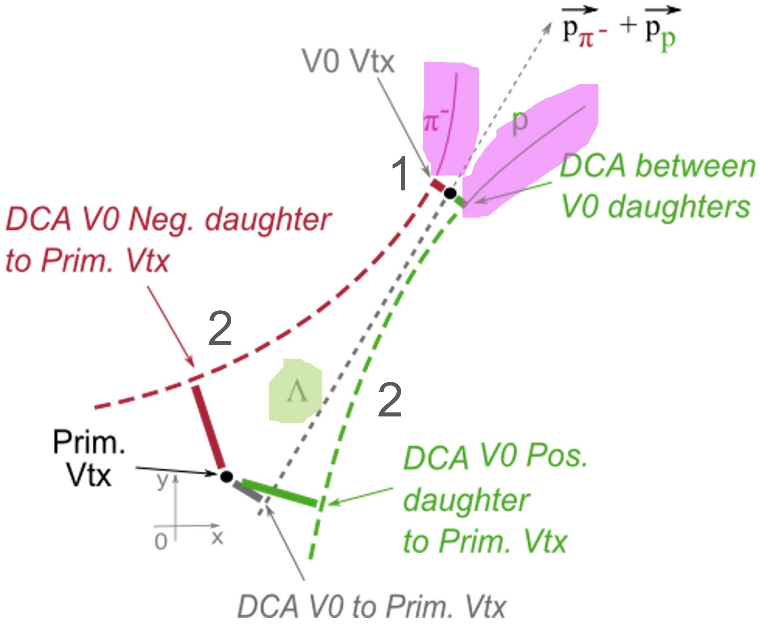


https://www.bnl.gov/newsroom/news.php?a=121072

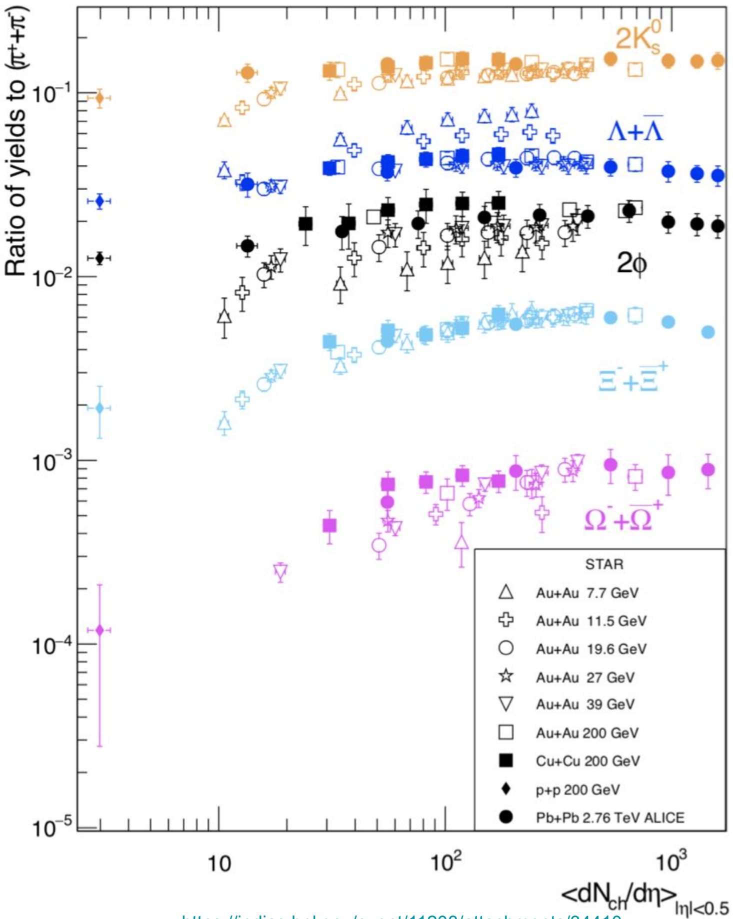
Backup

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



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