Centrality and Transverse Momentum Dependence of Strange and Multi-strange Hadron Production in in O+O Collisions at $\sqrt{s_{NN}} = 200$ GeV

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Yale University

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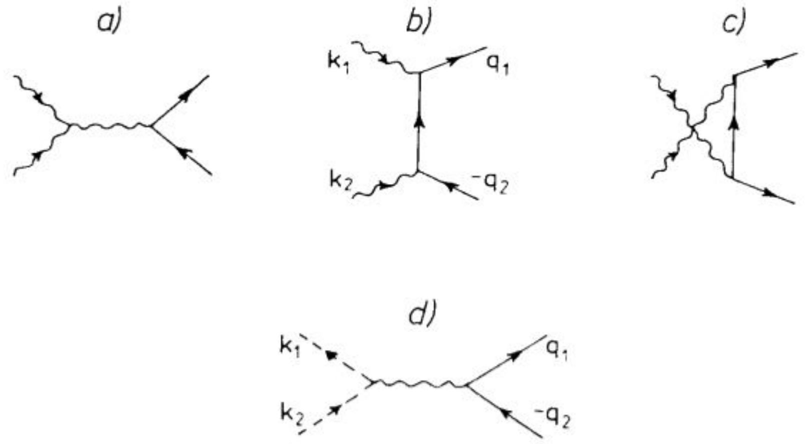
Strangeness Enhancement and the QGP

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



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

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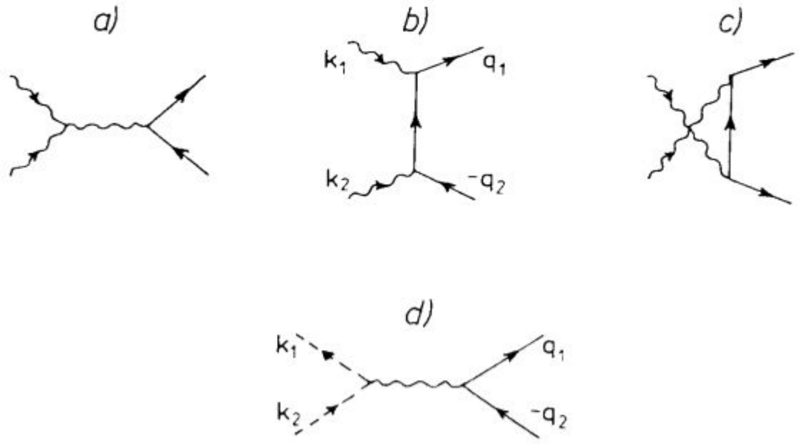
- The thermal production of s-$\bar{s}$ pairs is favorable in the QGP since the s-$\bar{s}$ masses are close to the QGP transition temperature ~157 MeV.
    - $2 \times m_s$ ~192 MeV
    - There are abundant thermal gluons in the QGP medium.

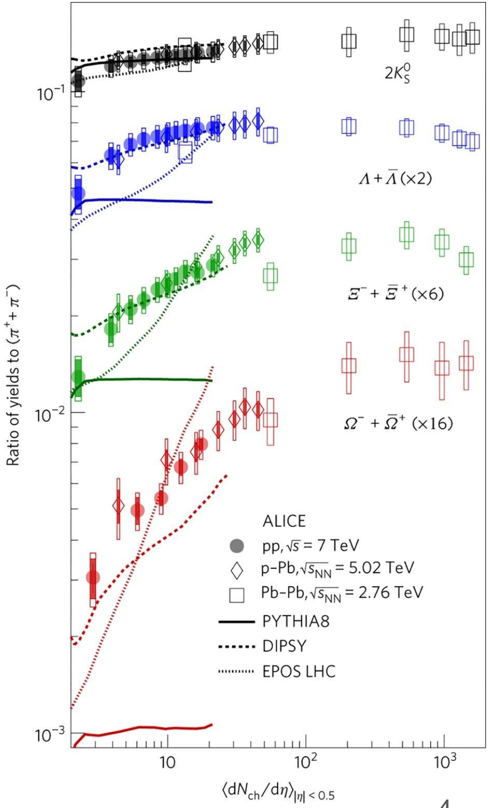
- Multi-strange ($\Xi^{\pm}$, $\Omega^{\pm}$) hadrons are more sensitive to the existence of QGP.



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).



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

Motivation

[STAR Collaboration. Phys. Rev. Lett. 98, 062301 (2007)](#)
[STAR Collaboration. Phys. Rev. C 77, 044908 (2008)](#)
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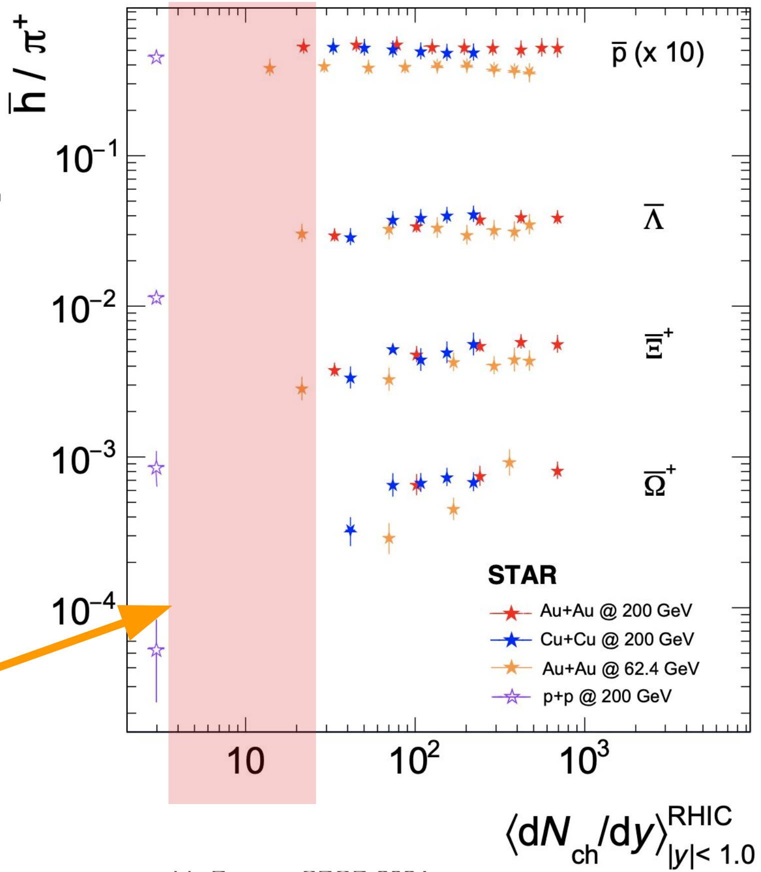
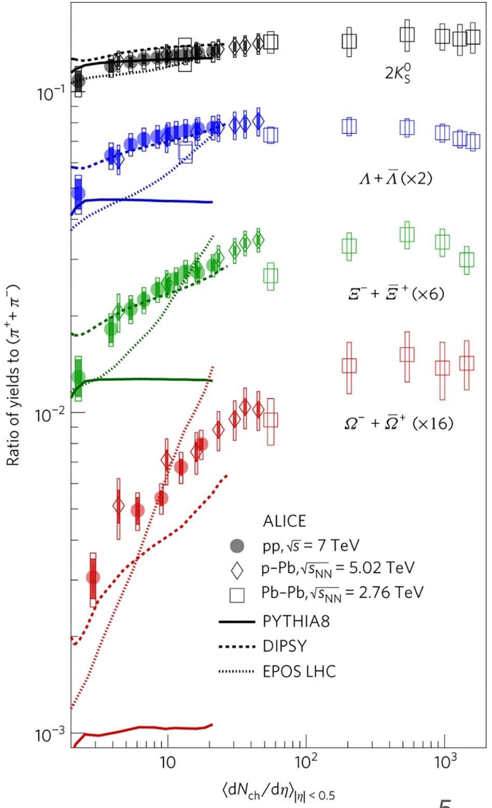
- A smooth increase in the ratio of strange hadron production to the pion yield as a function of multiplicity has been found in various collision systems (p+p, p+A, A+A).
  - STAR has reproduced these ratios.

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





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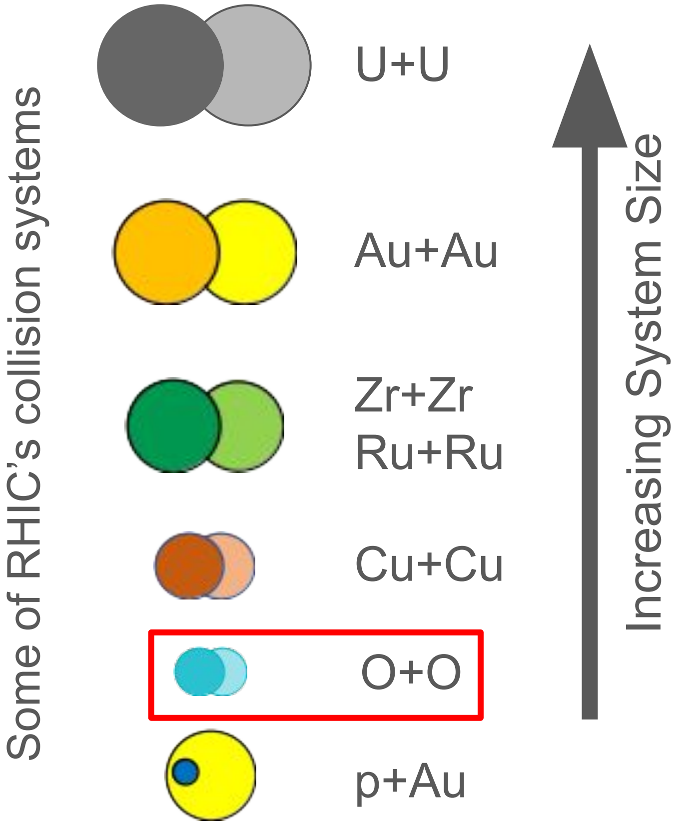
- Oxygen is one of the smallest ions used at RHIC.
    - Fill in the hyperon to pion ratio in the low multiplicity gap
    - Allows a more straightforward geometry mapping with centrality than those asymmetric small system collisions like He+Au, or d+Au



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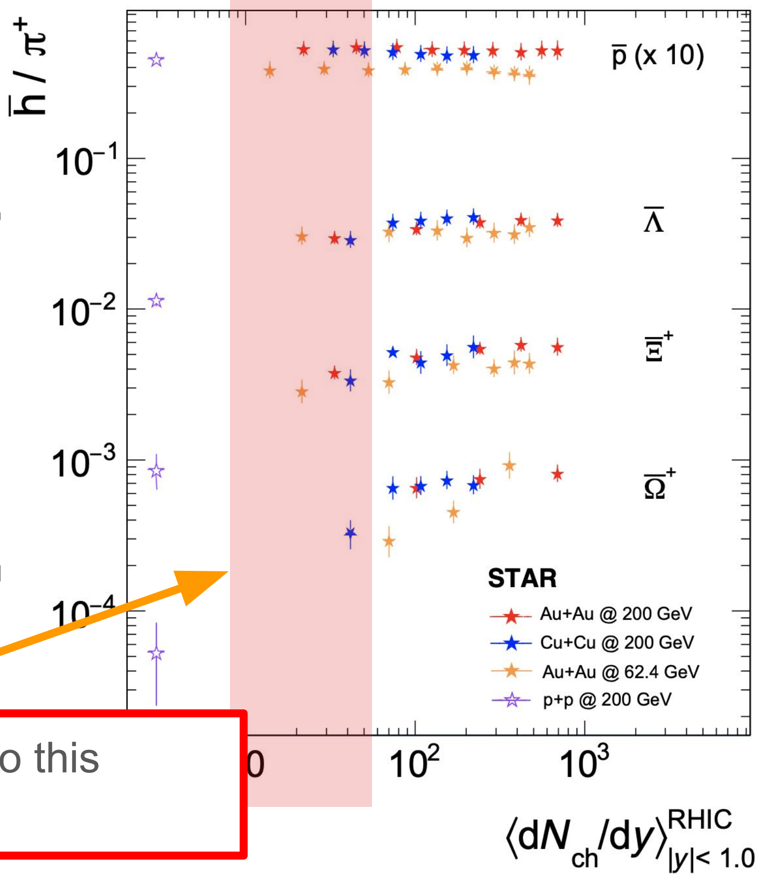
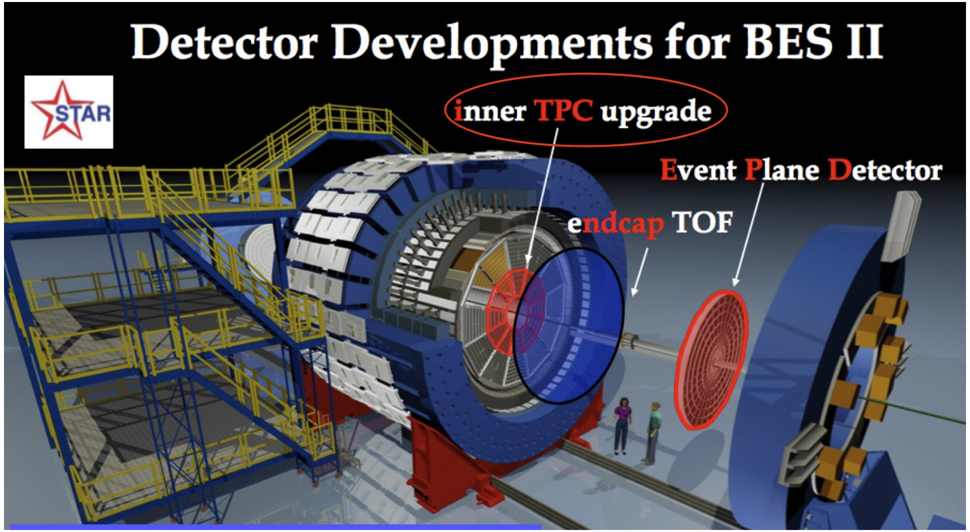


O+O's multiplicity can extend to this unexplored region

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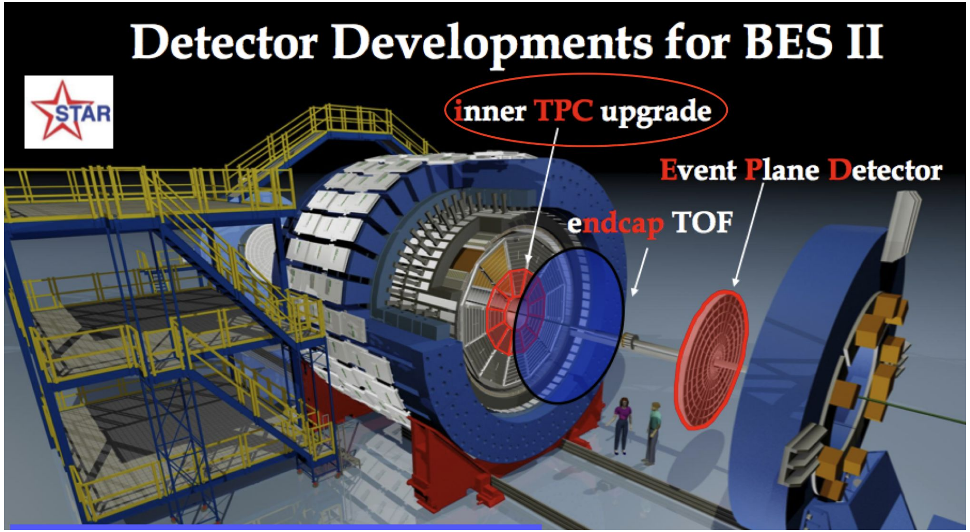
- From 2018 on, STAR had two detector upgrades: iTPC and eTOF
  - Improved coverage:
    $|\eta| < 1.5$ from $|\eta| < 1.0$
  - Lower p_T coverage 125 MeV => 60 MeV

- 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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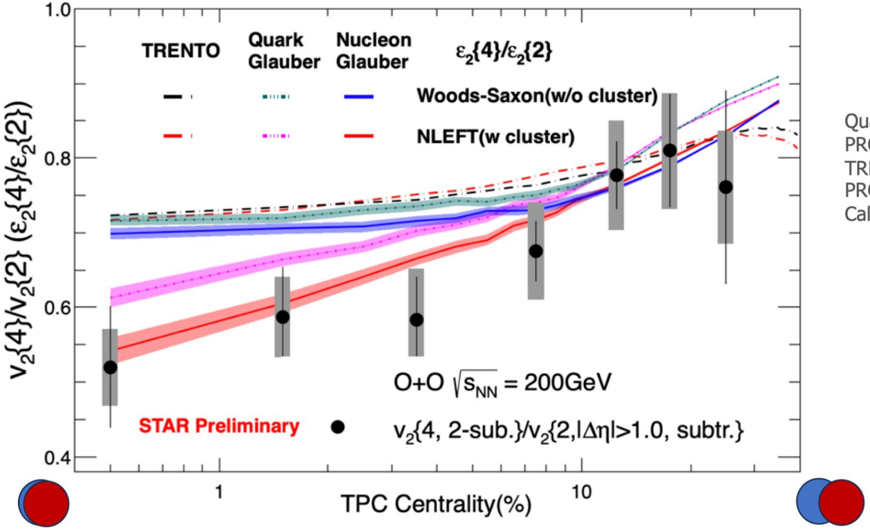
Flow Measurements in O+O collisions shown in QM2023

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	$1{,}019.461 \pm 0.020$	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^0_S results will follow soon.

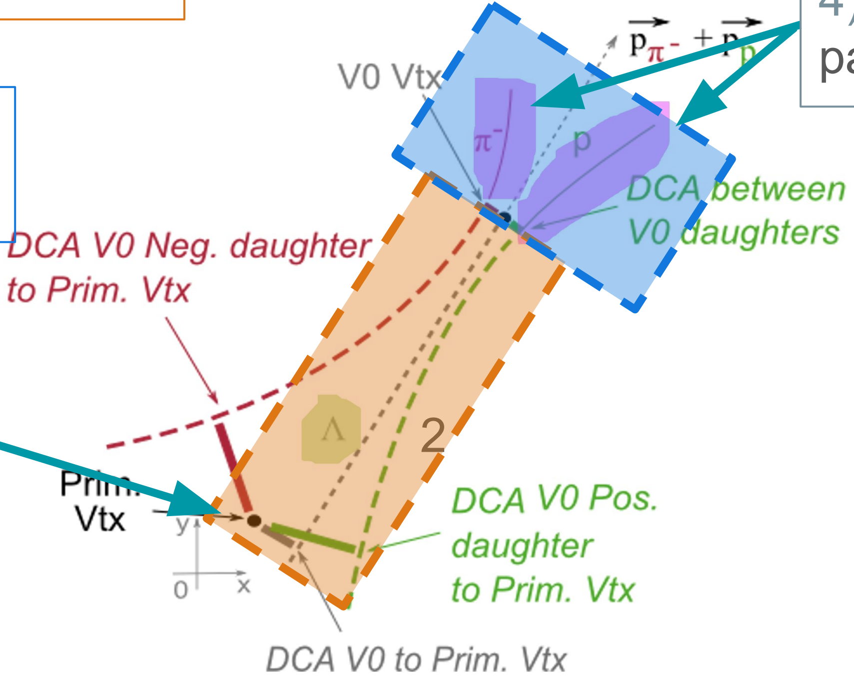
Reconstruction Details and Topological Cuts

1) The distance to Primary Vertex

2) The distance between daughter particles

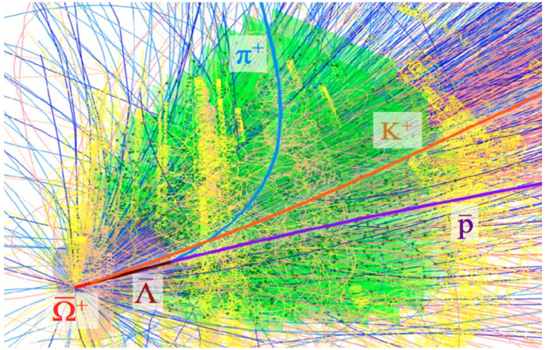
3) Primary Vertex location

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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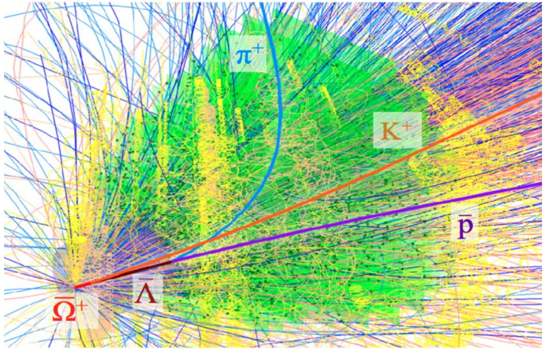

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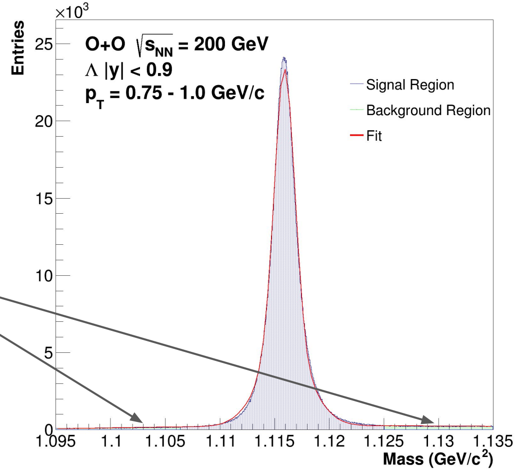
Λ

For the Λ Signal Extraction:

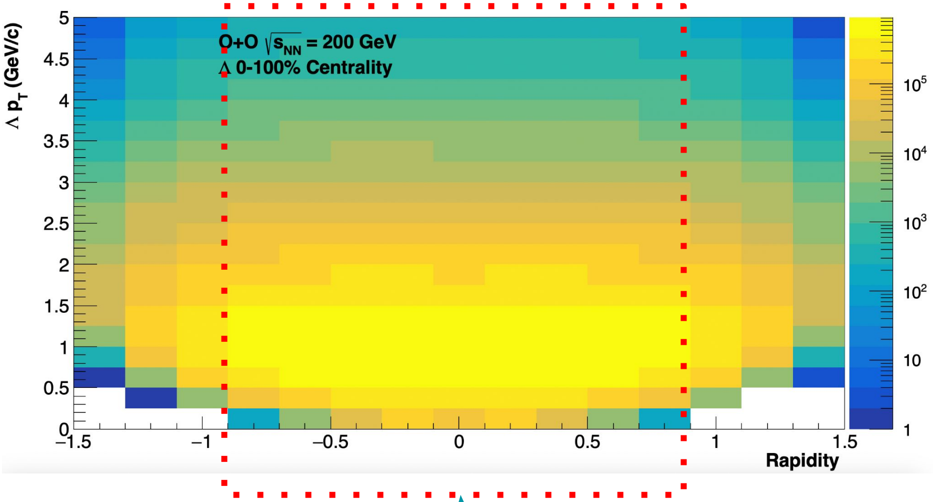
- The signal (without background subtraction) region is [μ-3σ,μ+3σ], and the background region is [0 to μ-3σ, μ+3σ to Xmax].
- Fitting function: 2nd poly + double Gauss function.

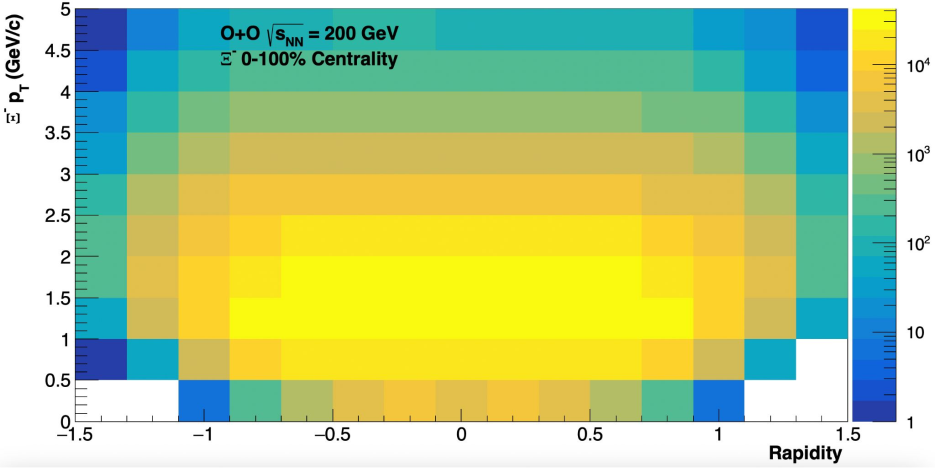
The blue region is the signal w.o background subtraction.

The green region is the background region.



What does our rapidity coverage looks like?

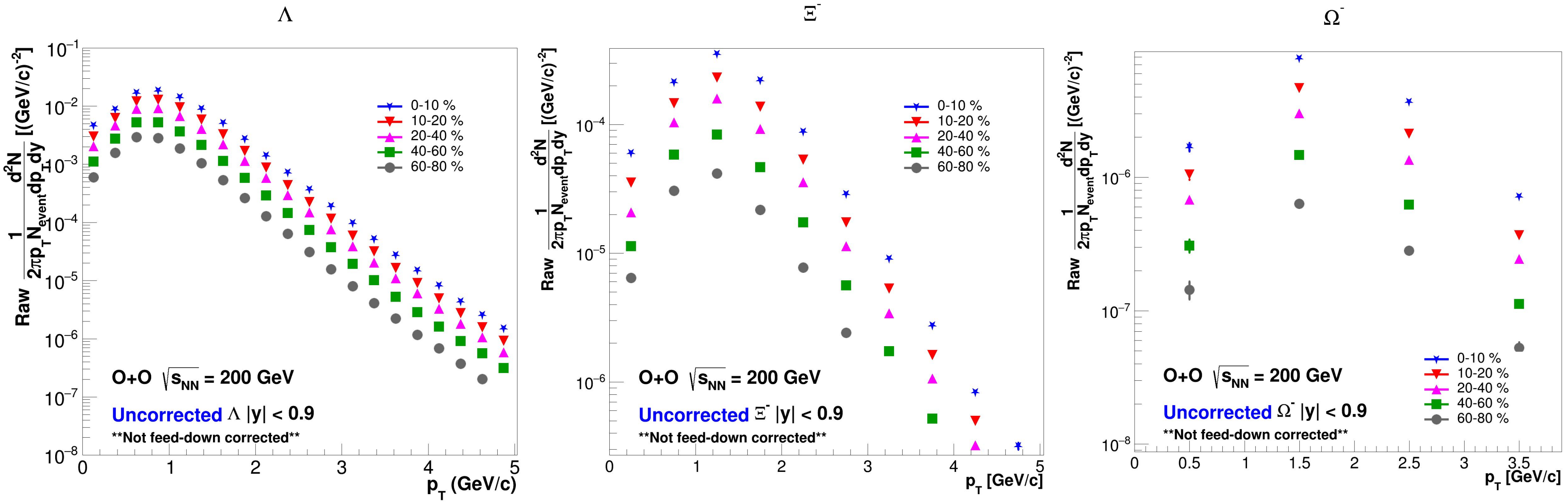




The iTPC provides extended coverage.

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

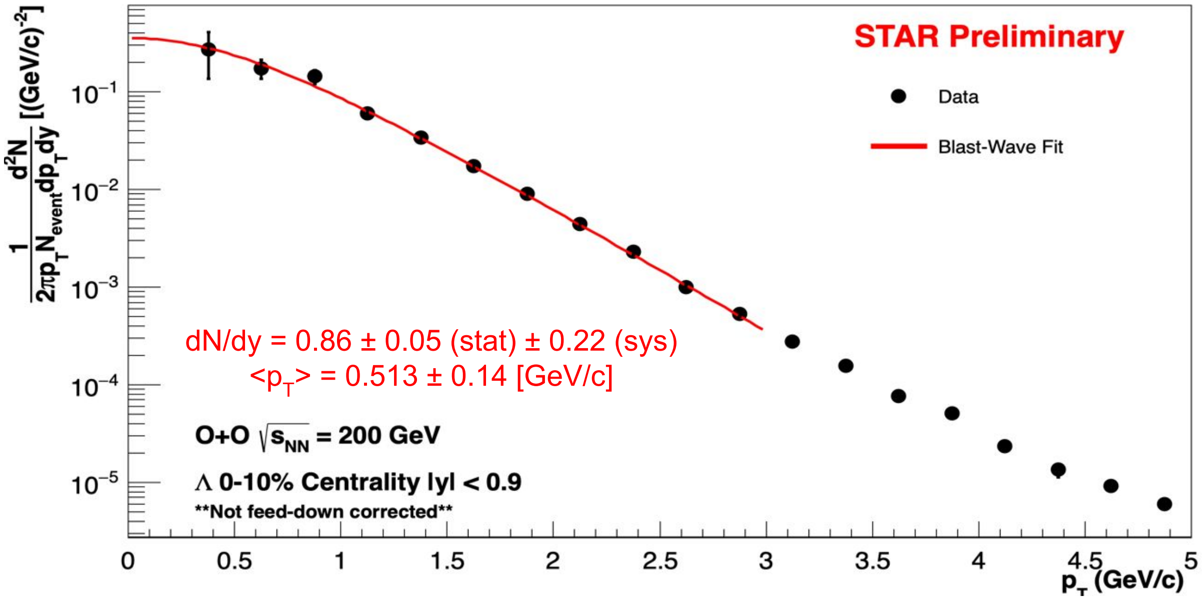
Uncorrected Raw Spectra for Hyperons in O+O



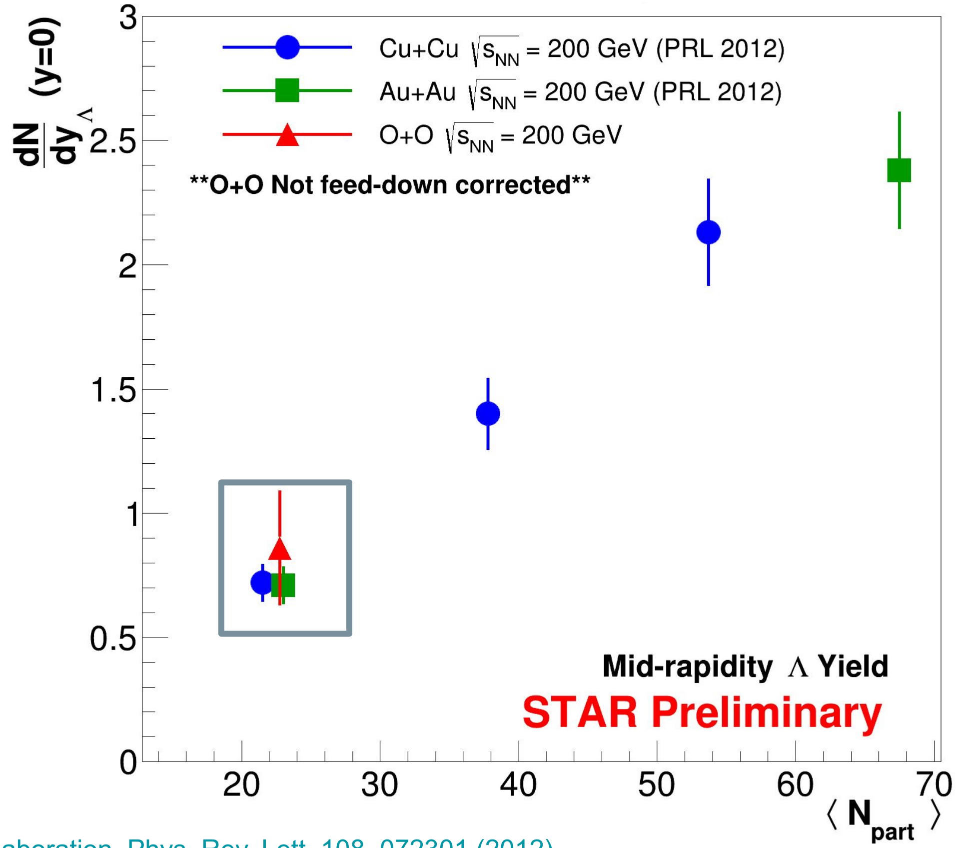
- The large statistics, improved p_T and rapidity coverage enables STAR to have good statistics for multi-strange hadrons.
- There is good coverage through 0 - 80% centralities.

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 a 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 spectrum from 0 to ∞ the yield (dN/dy) is 0.86 ± 0.05 ± 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 have been made but is pending the corrections.

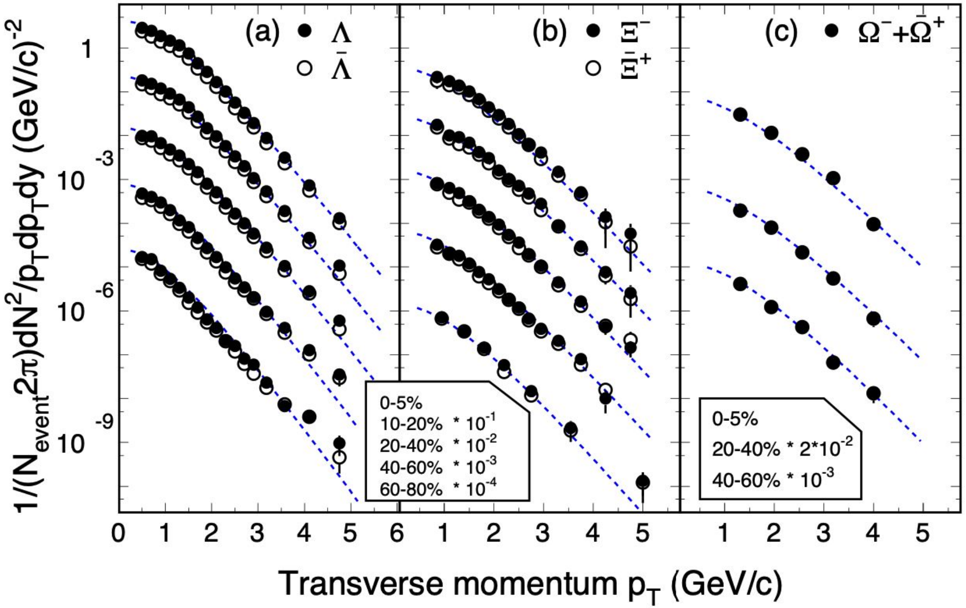
- Calculate the yields from corrected spectra.

- Calculate the pion yields.

- 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.
- We 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!

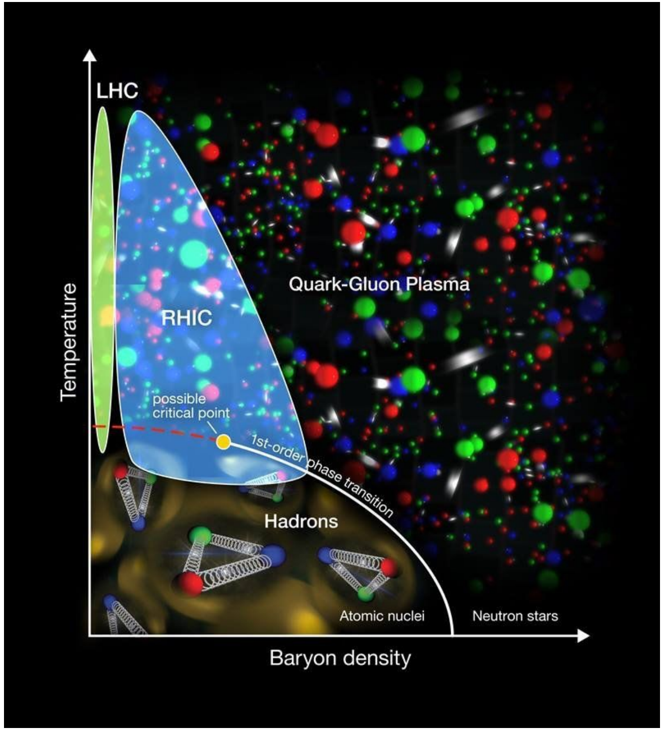
Some of STAR's other strangeness results at CPOD

- 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!

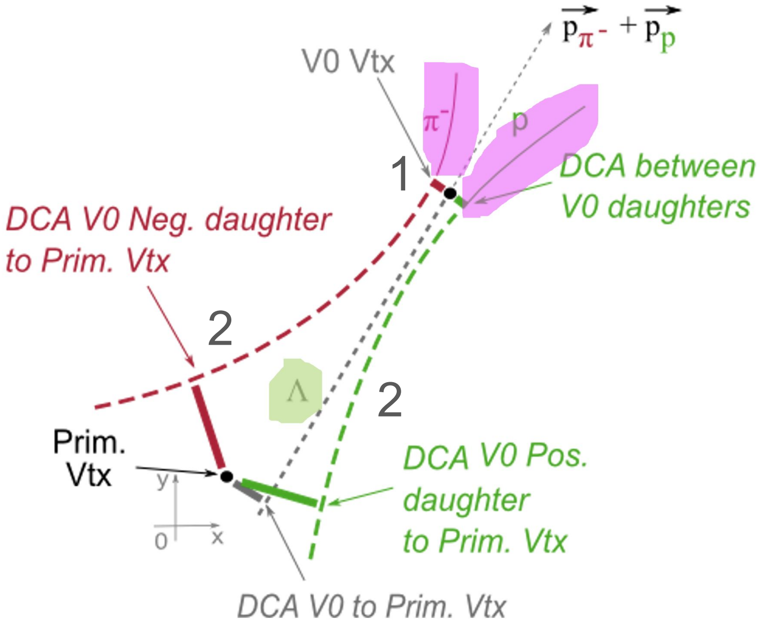


https://www.bnl.gov/newsroom/news.php?a=121072

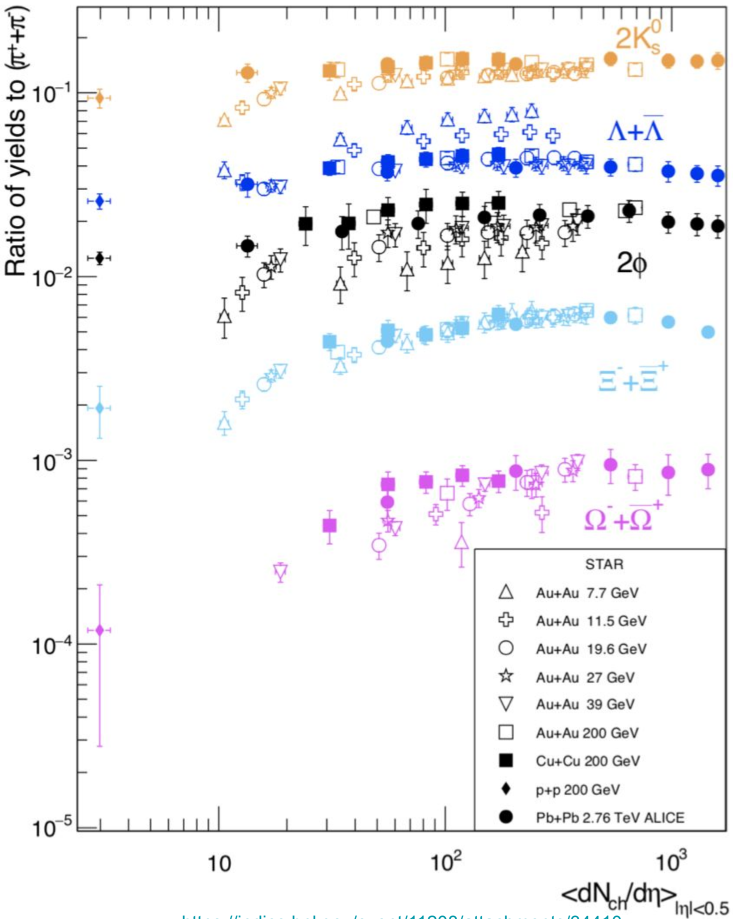
Backup

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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