High Strangeness Dibaryon Search with STAR Data

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Outline

- Introduction
- NΩ dibaryon
- Two-particle correlation function
  - PΩ correlation function
- Summary and Outlook

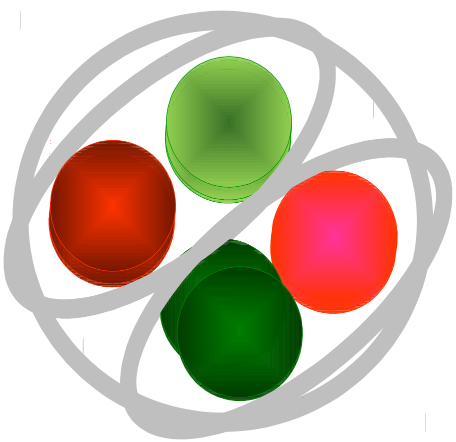
Introduction (1)

- **Standard Model: Baryons – 3 quarks and Mesons – pair of quark-antiquark**

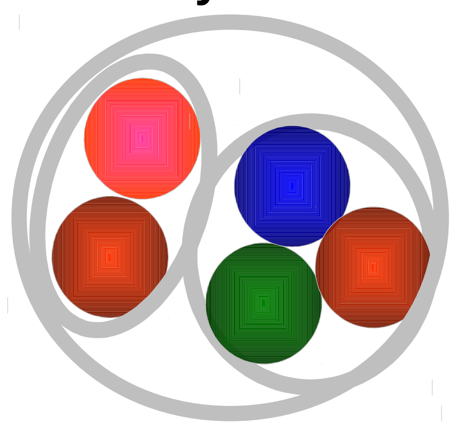
- **1977: within Quark Bag Model, Jaffe predicted H-dibaryon made of six quarks (uuddss)** **(Phys. Rev. Lett. 38,195 (1977); 38, 617(E)(1977))**

- **Exotic hadrons – long standing challenge in hadron physics**

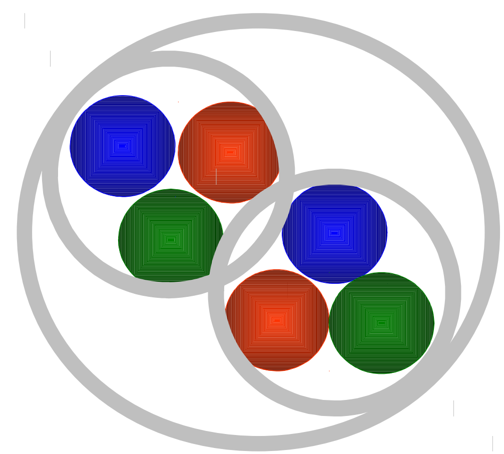
Tetraquark
Meson-Meson molecule



Pentaquark
Meson-Baryon molecule

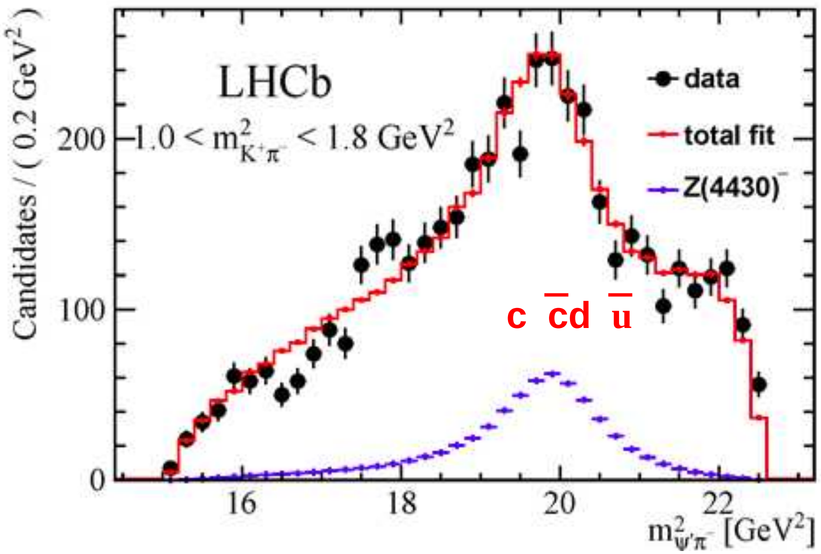


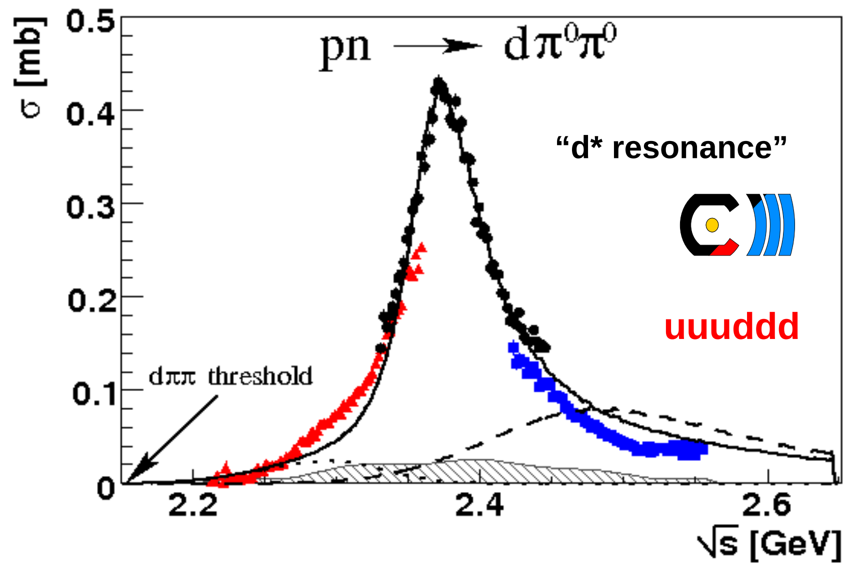
Hexaquark
Baryon-Baryon molecule

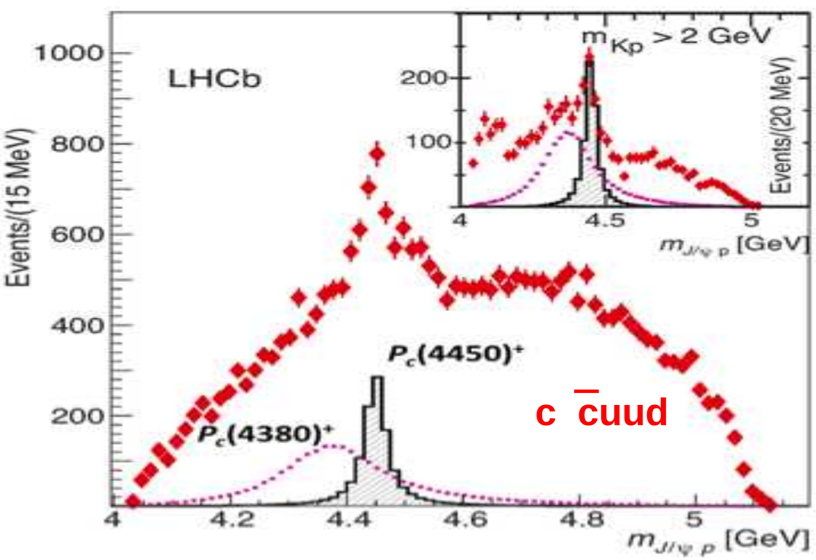


Introduction (2)

Observation of exotic states @ WASA-at-COSY, Belle, LHCb







Multi-quark states or molecular states?

Phys. Rev. Lett. 115 (2015) 072001
Phys. Rev. Lett. 112 (2014) 222002
Phys. Rev. Lett. 106 (2011) 242302
…

Exotics in Strangeness Sector

Quark content, decay modes and mass of exotic states in strangeness sector:

particle	Mass (MeV)	Quark composition	Decay mode
f_0	980	$q\bar{q}s\bar{s}$	$\pi\pi$
a_0	980	$q\bar{q}s\bar{s}$	$\pi\eta$
K(1460)	1460	$q\bar{q}q\bar{s}$	$K\pi\pi$
$\Lambda(1405)$	1405	$qqqs\bar{q}$	$\pi\Sigma$
$\Theta^+(1530)$	1530	$qqqq\bar{s}$	KN
H	2245	uuddss	$\Lambda\Lambda$
$N\Omega$	2573	qqqsss	$\Lambda\Xi$
$\Xi\Xi$	2627	qqssss	$\Lambda\Xi$
$\Omega\Omega$	3228	ssssss	$\Lambda K^- + \Lambda K^-$

Phys. Rev. C 84 (2011) 064910, Phys. Rev. C 83 (2011) 015202

☑ **Recent results on H-dibaryon search:**

– STAR Col., Phys. Rev. Lett. 114 (2015) 022301

– ALICE Col., Phys. Lett. B 752 (2016) 267

NΩ Dibaryon

- **Nucleon-Ω (NΩ): A strangeness = -3 dibaryon is stable against strong decay**

  "…there is no color-magnetic effect and the energies are dominated by modification to the single-quark wave function"

  – **Phys. Rev. Lett. 59 (1987) 627, Phys. Rev. C69 (2004) 065207, Phys. Rev. C70 (2004) 035204.**

- **Scattering length, effective range and binding energy (BE) of NΩ-dibaryon:**

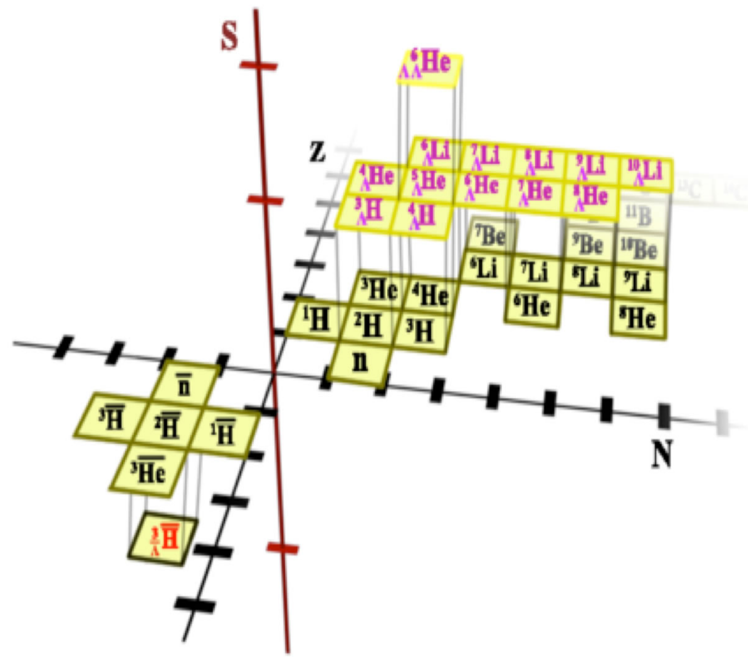
	Scattering length (a_0) fm	Effective range (r_{eff}) fm	BE (sc) MeV	BE (cc) MeV
SU(2)	1.87	0.87	23.2	19.6
SU(3)	-4.23	2.1	ub	ub
QDCSM	2.58	0.9	8.1	7.3
HALQCD	$-1.28+0.13^{0.14}_{-0.15}$	$0.499+0.026^{0.029}_{-0.048}$	$18.9+5.0^{12.1}_{-1.8}$	

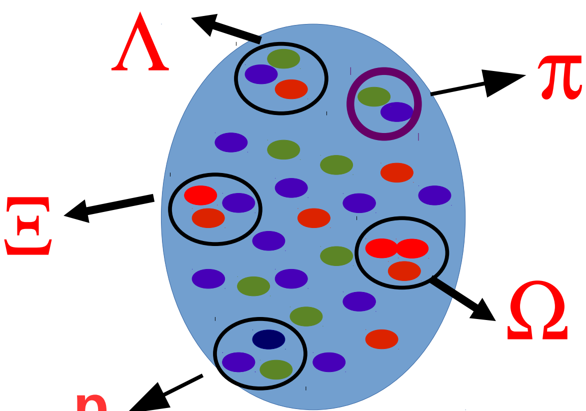
Phys. Rev. C 83 (2011) 015202, Nucl. Phys. A 928 (2014) 89

Venues for Dibaryon Search

☑ Systematic study of double strangeness systems

- Binding energies
  Experiments at J-PARC, KEK



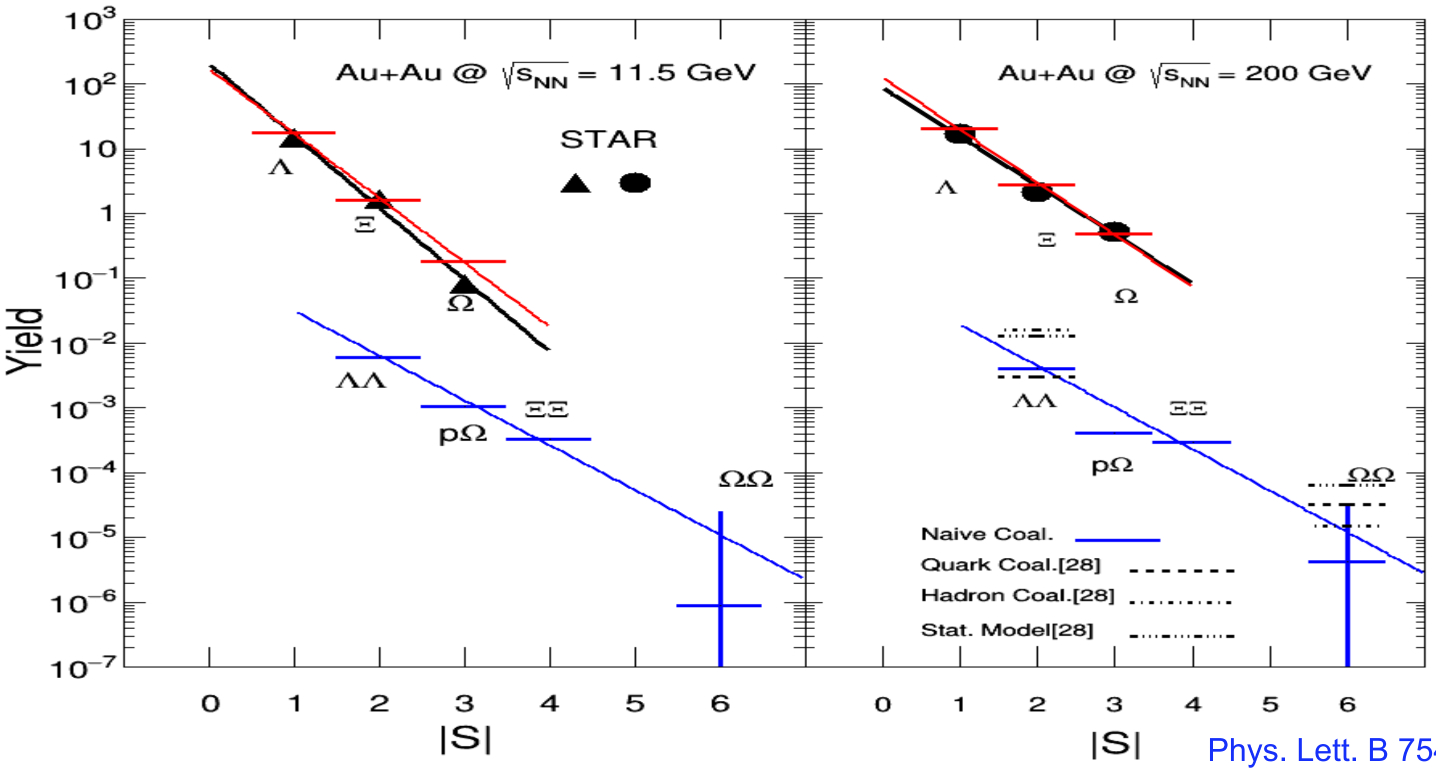


☑ Heavy Ion Collisions

- Hot and dense, strongly interacting partonic matter
- Environment suitable for existence of exotic hadron

NΩ-dibaryon from Heavy-Ion Collisions

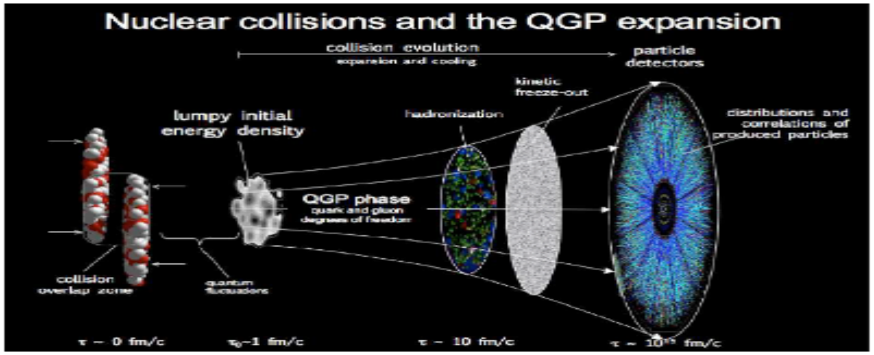
- NΩ-dibaryon is an isospin 1/2 doublet and has both pΩ and nΩ channels possible



Phys. Lett. B 754 (2016) 6

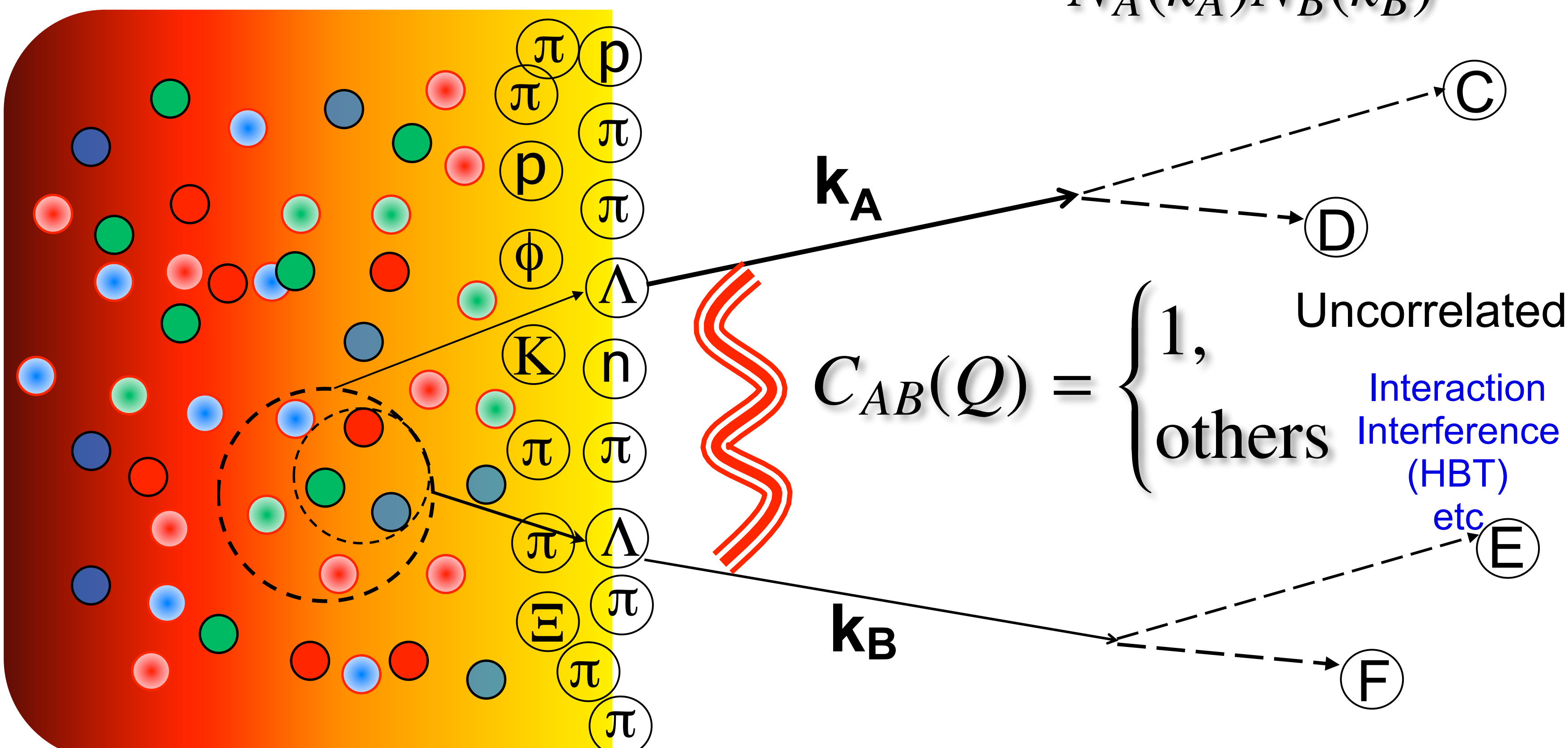
- In experiments, we can look at pΩ channel with two particle correlation analysis or invariant mass analysis (the J=2, S=-3 state weakly decay is challenging)
  - Invariant mass
    - Significant combinatorial background in central Au+Au collisions makes exotic particle searches difficult in heavy-ion collisions

Two Particle Correlation in HIC



- ☑ Baryon interaction via two particle correlation

$$C_{AB}(Q) = \frac{N^{\text{pair}}_{AB}(k_A, k_B)}{N_A(k_A)N_B(k_B)}$$

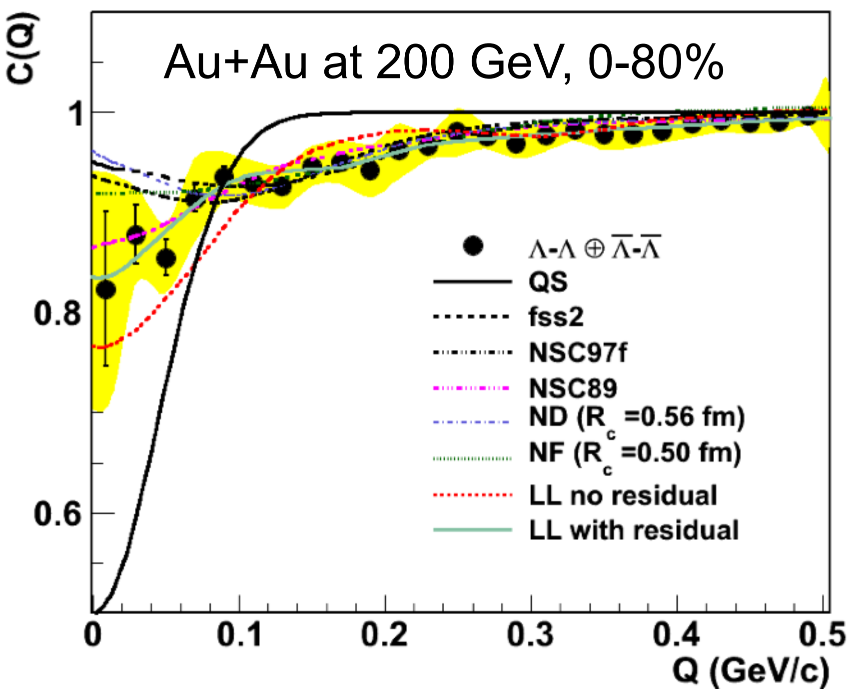


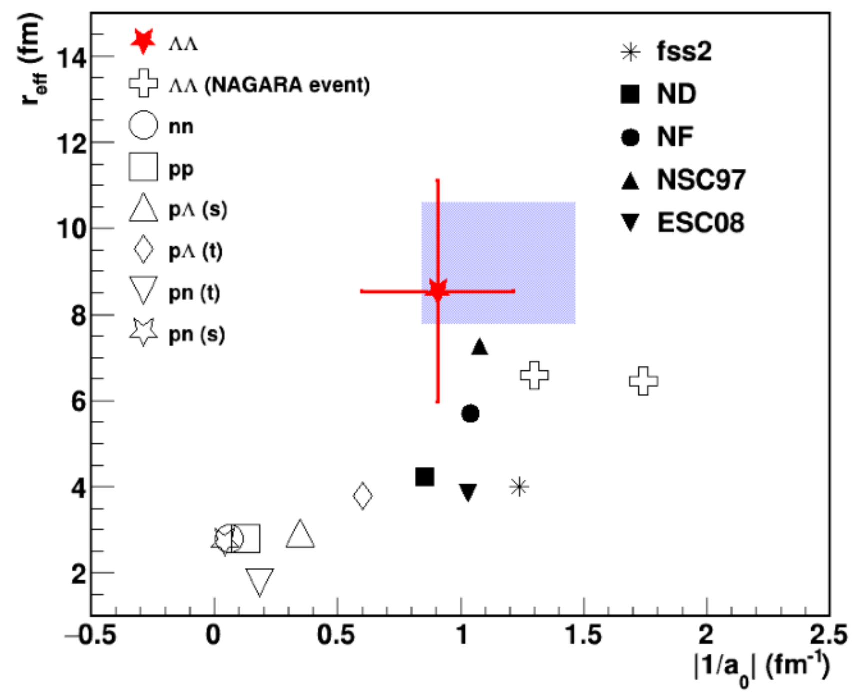
$$C_{AB}(Q) = \begin{cases} 1, & \text{Uncorrelated} \\ \text{others} & \end{cases}$$

Lambda-Lambda Correlation Function

STAR Col. Phys. Rev. Lett. **114**, 022301 (2015)

$$|a_{\Lambda\Lambda}| < |a_{p\Lambda}| < |a_{NN}|$$





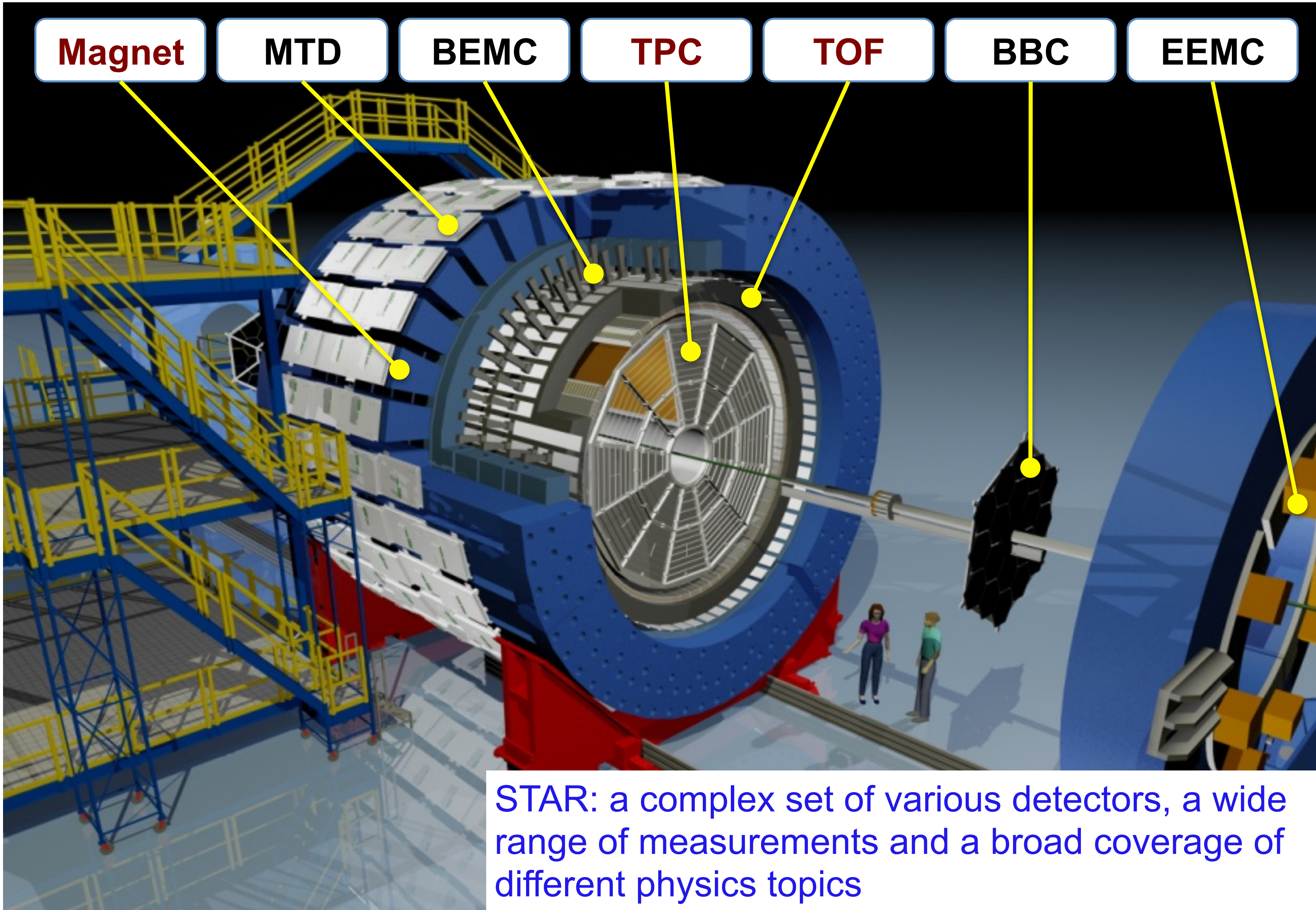
t → for triplet state

s → for singlet state

All model fits to data suggest that a rather weak interaction is present between $\Lambda\Lambda$ pairs

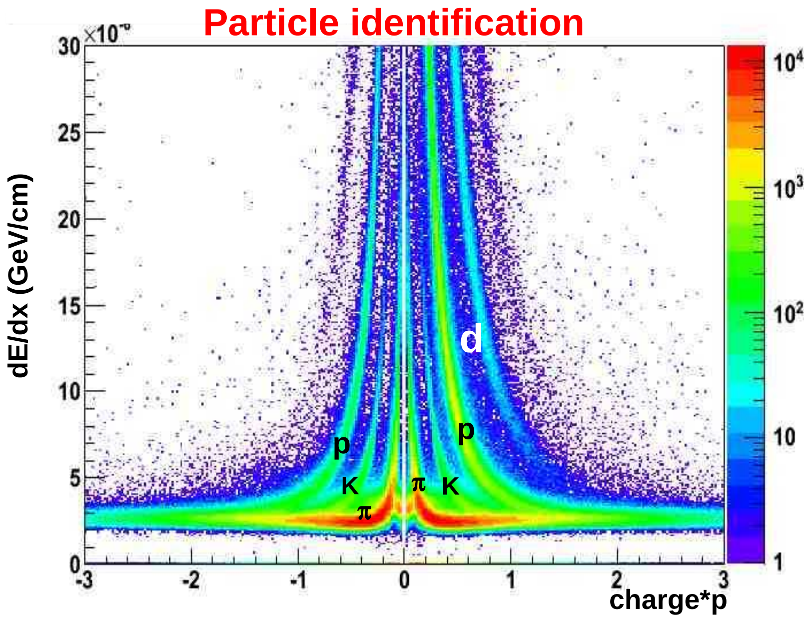
n-n → Phys. Lett. B, 80 (1979) 187
p-n → Phys. Rev. C 66, 047001 (2002)
p-p → Mod. Phys. 39 (1967) 584
p-Λ → Phys. Rev. Lett. 83, 3138 (1999)
$\Lambda\Lambda$ → Phys. Rev. C 66, 024007(2002)
$\Lambda\Lambda$ → Nucl. Phys. A 707 (2002) 491

The STAR Detector at RHIC



STAR: a complex set of various detectors, a wide range of measurements and a broad coverage of different physics topics

Ω Reconstruction (1)



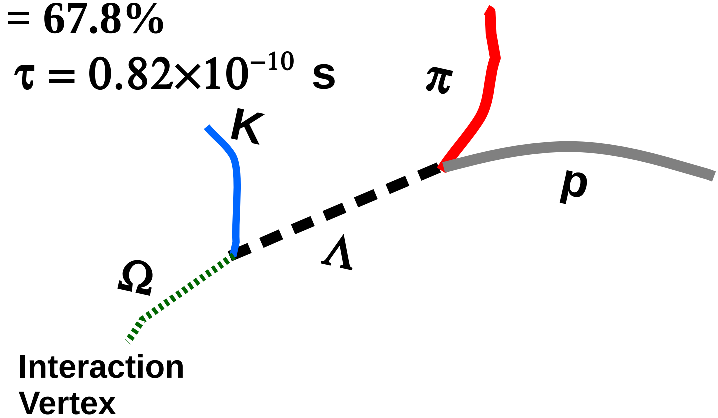
Au+Au $\sqrt{s}$ = 200 GeV (1.41 B events)

$\Omega \rightarrow \Lambda K$ (Mass = 1.672 GeV/c^2)

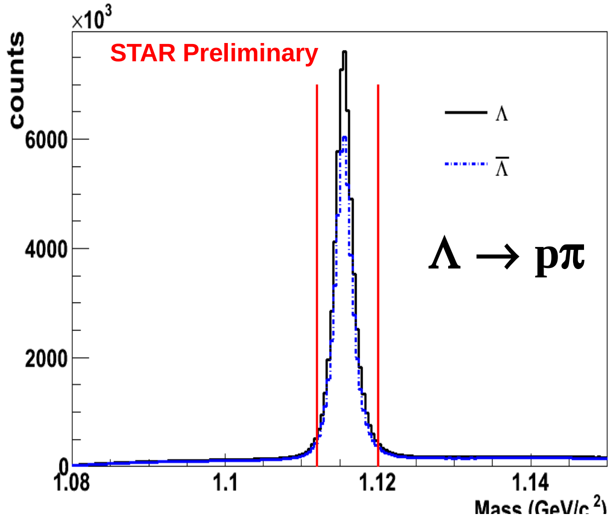
Branching ratio = 67.8%

Mean Life time: $\tau = 0.82 \times 10^{-10}$ s

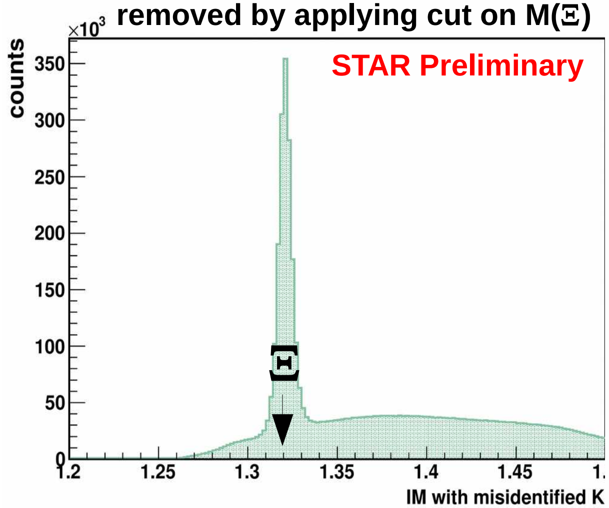
$c\tau$ = 2.46 cm



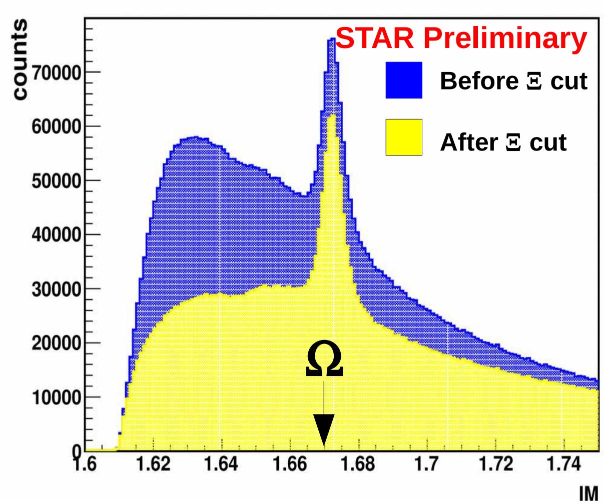
Reconstructed Λ



Background due to misidentified K removed by applying cut on M(Ξ)

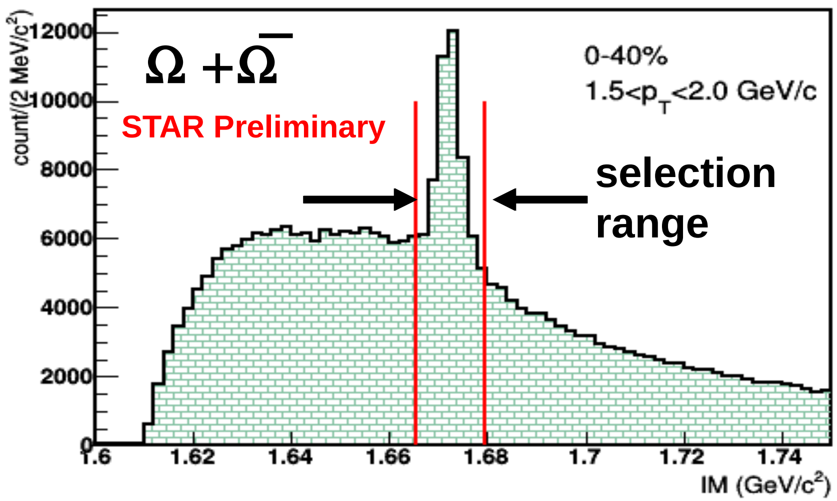


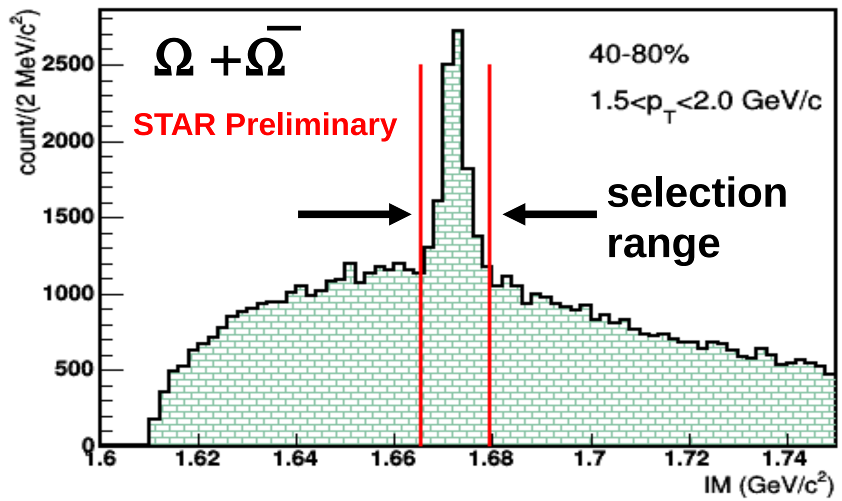
Reconstructed Ω

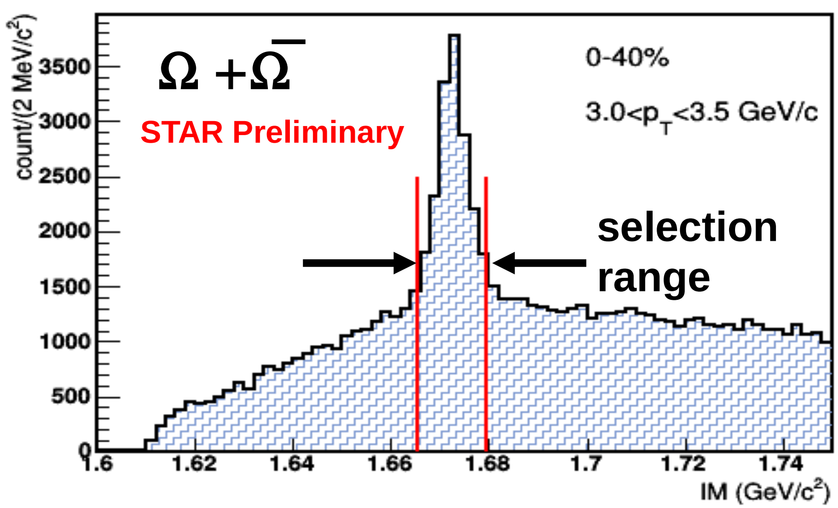


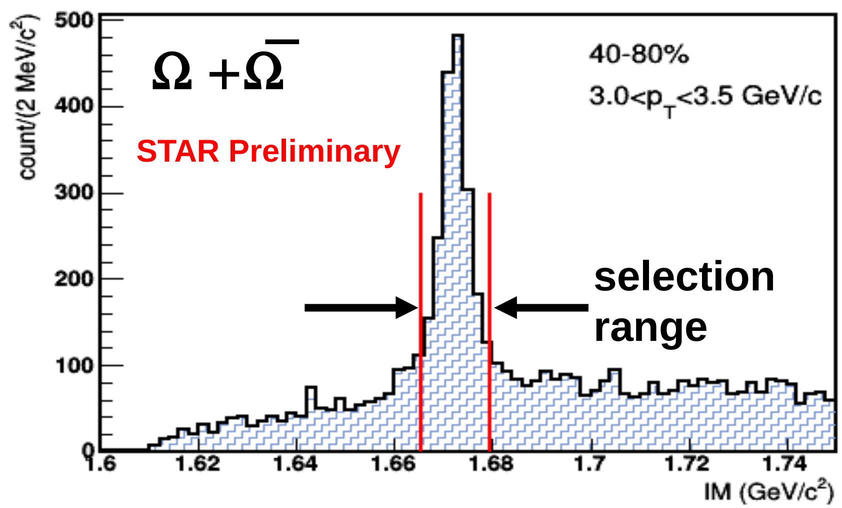
Ω Reconstruction (2)

Reconstructed invariant mass of $\Omega+\bar{\Omega}$





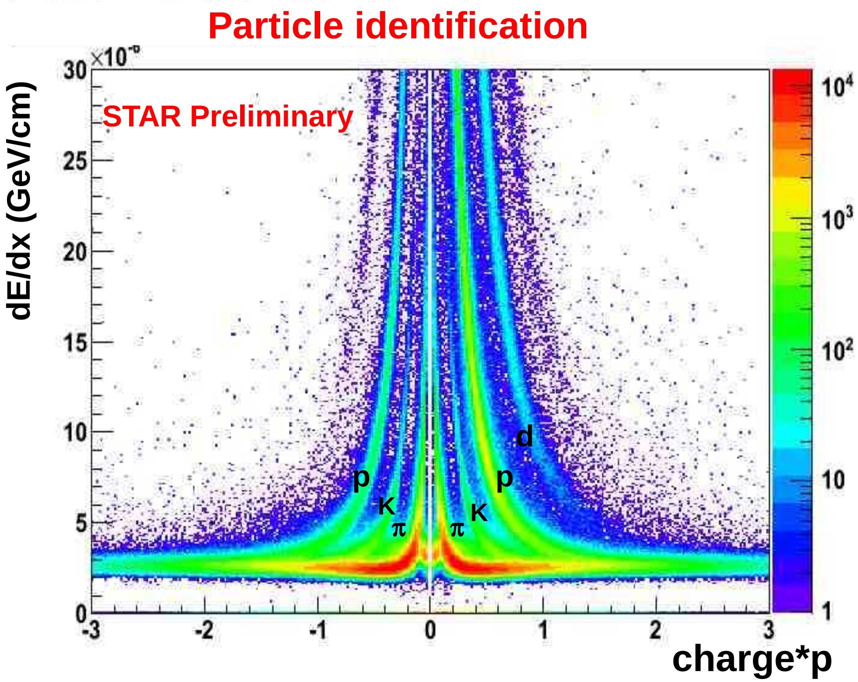


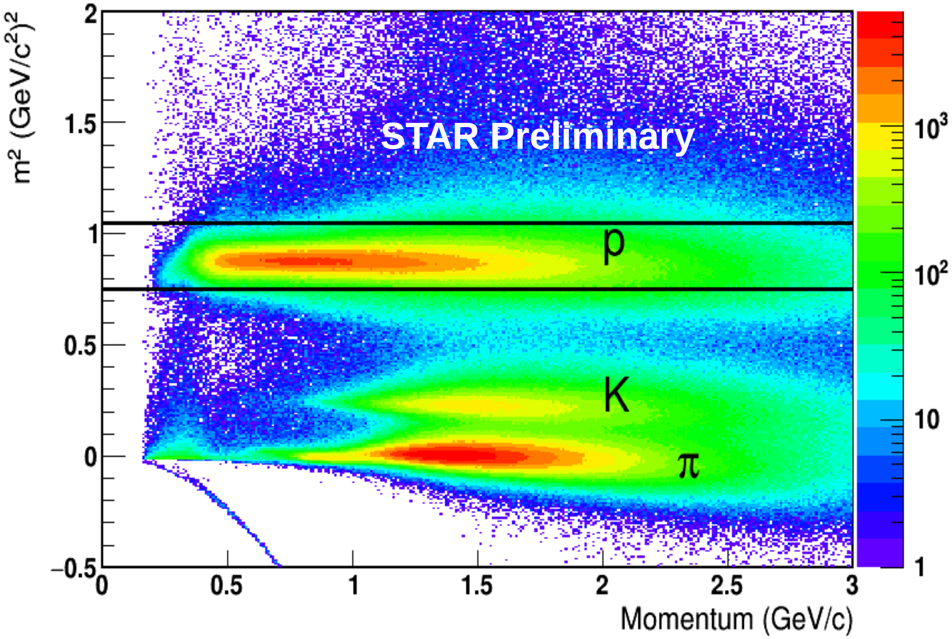


Proton Identification with TPC+TOF

Excellent PID with TPC+TOF

- ✔ Number of fit points > 15
- ✔ Ratio of fit points to possible points > 0.52
- ✔ p_T cut for proton tracks > 0.15 GeV/c
- DCA < 0.5 cm
- $0.75 < m^2 < 1.1\ (GeV/c^2)^2$





With proton and anti-proton S/(S+B) ~ 99%

Few Definitions and Corrections

Step-I Raw correlations

$$C(k^*) = \frac{P(p_a, p_b)}{P(p_a)P(p_b)} = \frac{real\ pairs}{mixed\ pairs}$$

p – momentum of particles a and b
Q – relative momentum

Step-II Purity correction

$$CF_{corrected}(k^*) = \frac{CF_{measured}(k^*) - 1}{PP(k^*)} + 1$$

PP(k*) = P(Ω)×P(p) is pair purity.

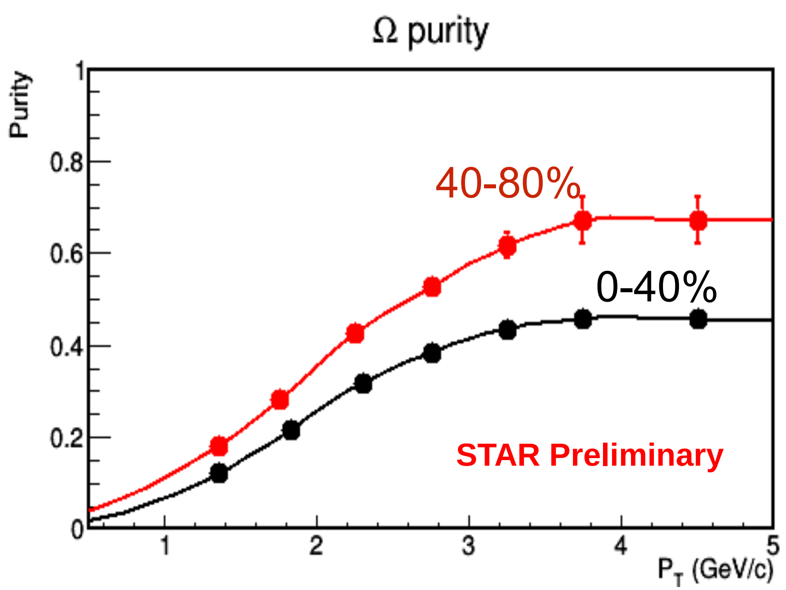
P(Ω) = S/(S+B)*Fr(Ω) and P(p) = S/(S+B)*Fr(p)
where Fr(x) is Fraction of primary particles

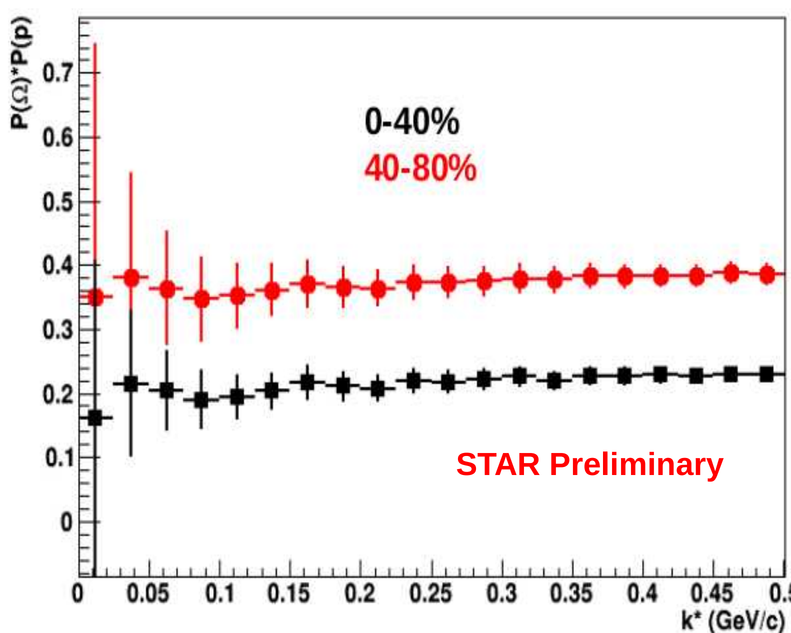
Fr(Ω) = 1 and Fr(p) = 0.52

Step-III Momentum smearing

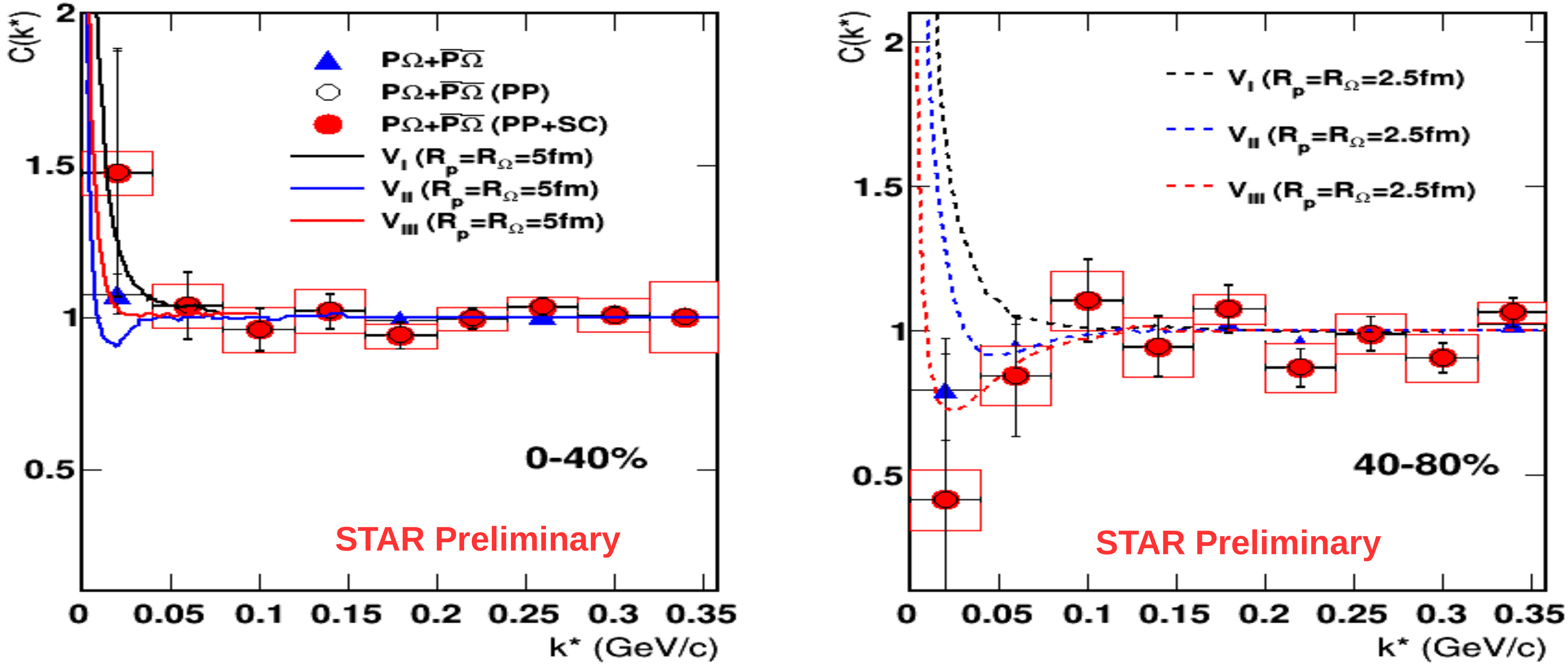
$$CF(k^*) = CF(k^*)\frac{CF_{nosmearing}}{CF_{smearing}}$$

Smearing correction factor is 0.99





PΩ Correlation Function



PP → Pair Purity Correction
PP+SC → Pair Purity + Mom. Smearing Correction
R → Emission source size
Boxes → systematic uncertainty

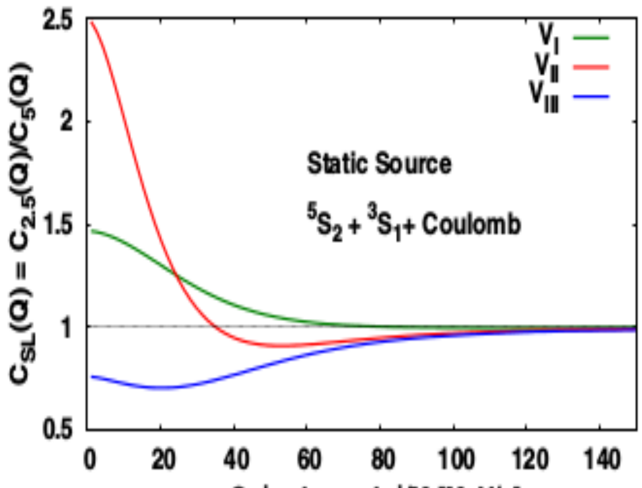
Spin-2 pΩ potentials	V_I	V_{II}	V_{III}
Binding energy E_B (MeV)	-	6.3	26.9
Scattering length a_0 (fm)	-1.12	5.79	1.29
Effective range r_{eff} (fm)	1.16	0.96	0.65

Comparison of measured PΩ correlation function from 0-40 and 40-80% centrality with the predictions for PΩ interaction potentials V_I, V_{II} and V_{III}.

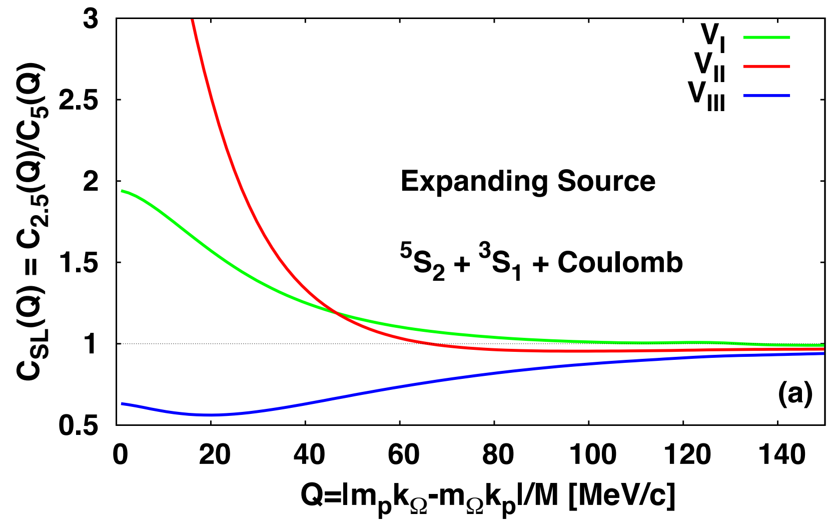
Phys. Rev. C 94, 031901 (2016)

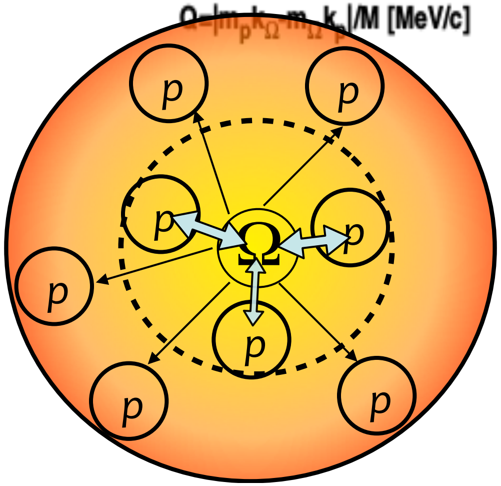
Proposal on Source Size Dependence Analysis

☑ The ratio of the correlation function between the small and large collision system is insensitive to the Coulomb interaction and also to the source model of the emission, thus it provides a useful measure to extract the strong interaction part of the pΩ attraction from experiments at RHIC/LHC



Phys. Rev. C 94, 031901 (2016)





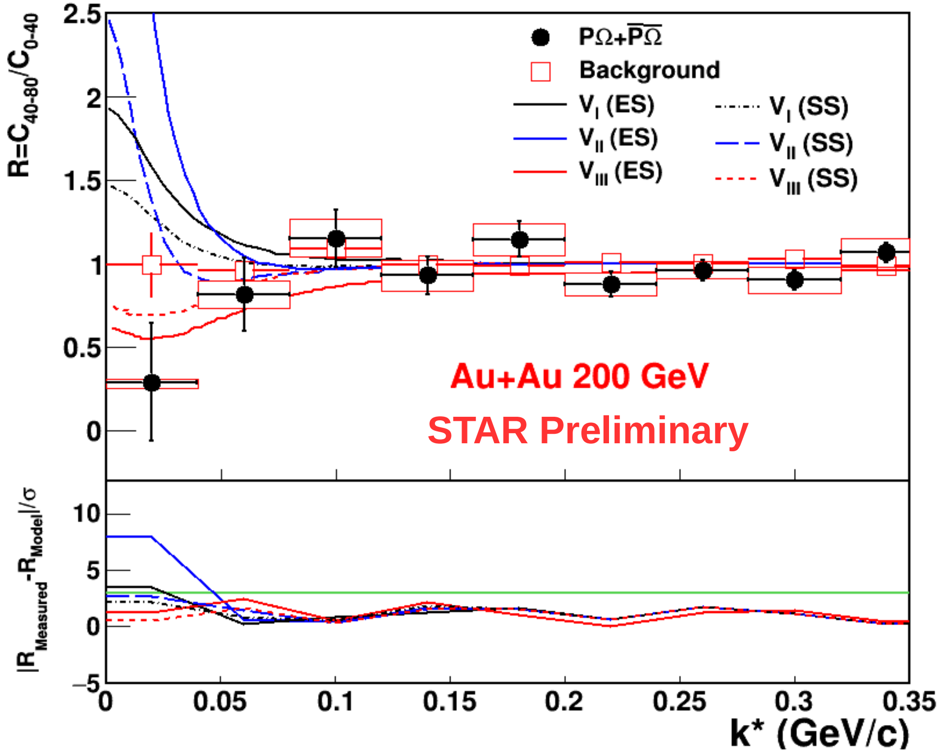
Ratio of C(Q): small/large system:

- Loose : Enhancement at low Q
- Tight : C(Q) < 1
- No Bound: Slightly above 1

STAR Source Size Analysis on PΩ Correlation Function

The ratio of correlation function between small and large collision systems for the background is unity within uncertainties.

The ratio of correlation function between small and large collision systems at low k* is lower than background.



SS → Static source
ES → Expanding source
Background → Ω sideband is used
Boxes → systematic uncertainty

Spin-2 pΩ potentials	V_I	V_{II}	V_{III}
Binding energy E_B (MeV)	-	6.3	26.9
Scattering length a_0 (fm)	-1.12	5.79	1.29
Effective range r_{eff} (fm)	1.16	0.96	0.65

Phys. Rev. C 94, 031901 (2016)

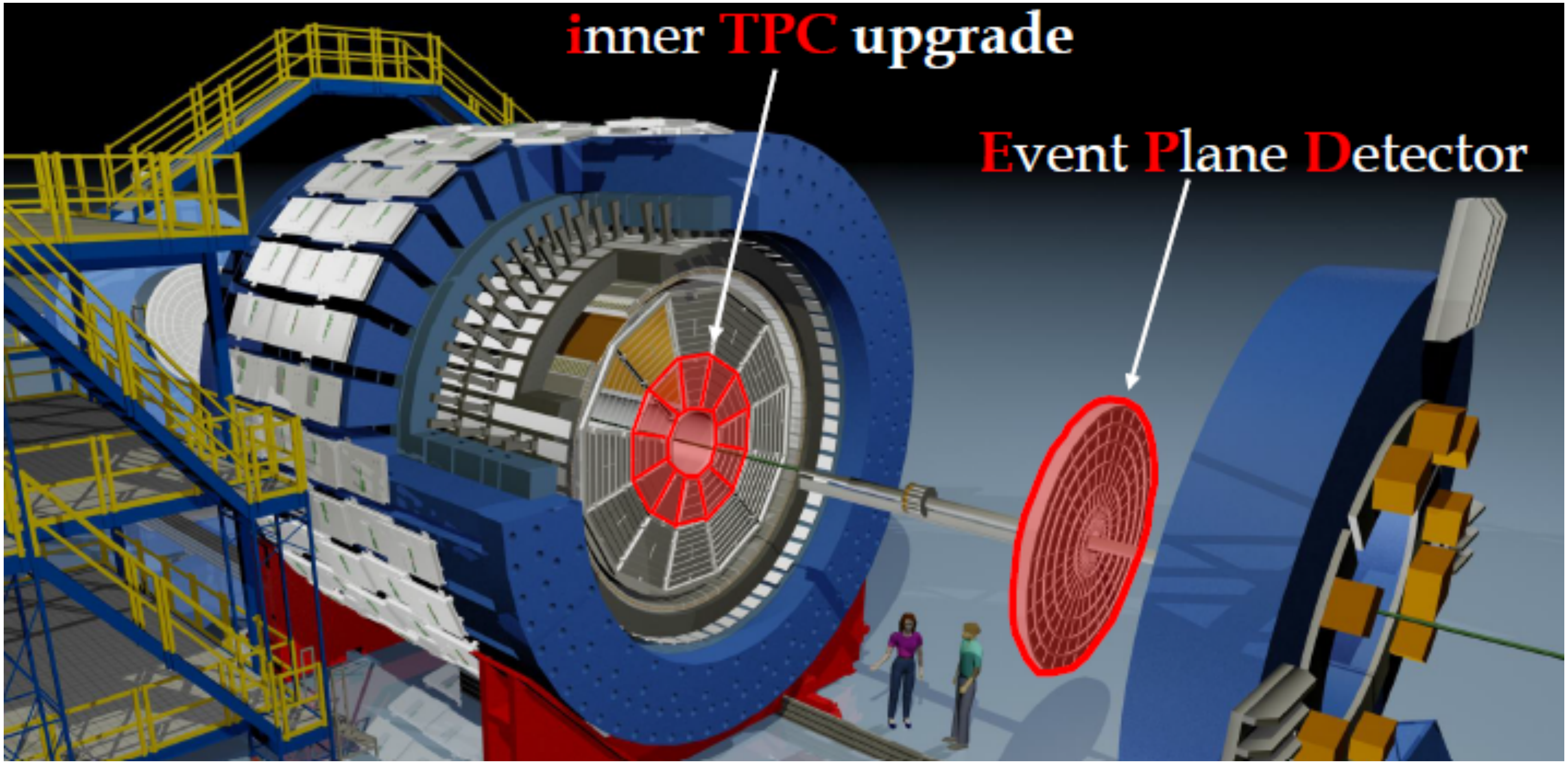
Summary

- ☑ Present the 1st measurement of correlation function for PΩ from Au+Au collisions @ 200 GeV

- ☑ The ratio of correlation function for the small (peripheral collisions) to the large (central collisions) system is smaller than unity at low k*

- ☑ The measured ratio of correlation function from peripheral to central collisions is compared with predictions based on the PΩ interaction potentials derived from lattice QCD simulations

STAR Major Upgrades before 2020



☑ **iTPC Upgrade:**

- Rebuilds the inner sectors of the TPC
- Continuous Coverage
- Improves dE/dx
- Extends η coverage from 1.0 to 1.5
- Lowers p_T cut-in from 125 MeV/c to 60 MeV/c

☑ **EPD Upgrade:**

- Allows a better and independent reaction plane measurement critical to BES physics
- Improves trigger
- Reduces background

Status of the Inner TPC Upgrade

☑ SAMPA FEE (MWP2)

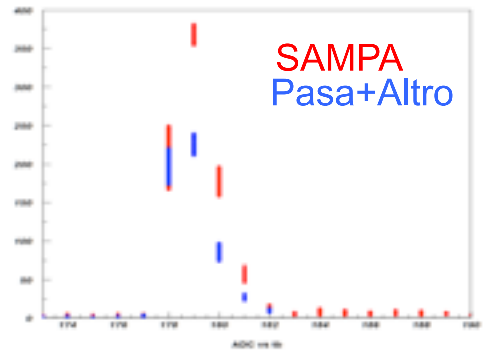
- 2FEEs and RDO installed on one inner most row of TPC
- Running through USB port with beam
- Design and producing pre-production RDO and FEE to instrument one Full sector for tests in fall

☑ Sectors (strongback + padplane + MWPC)

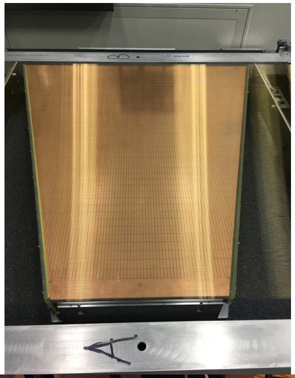
- Precision assembly at LBL of padplane to strongbacks and sidemounts ongoing
- Sector production started at SDU (3 completed, testing ongoing) with first fully tested sectors expected to be installed in STAR in October

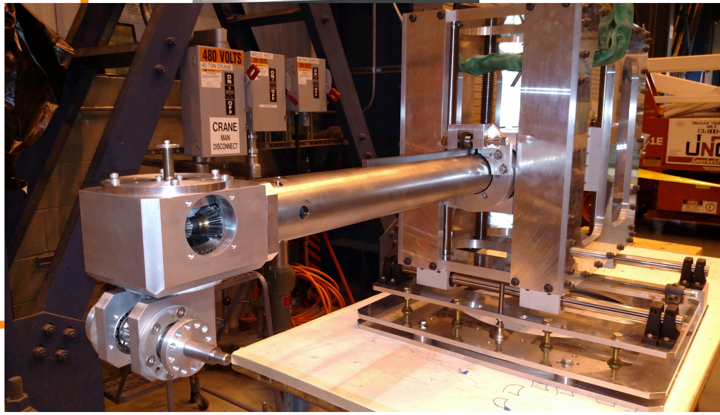
☑ Insertion tool

- Completed at UIC and currently being commissioned at BNL



SAMPA is well behaved





Thank You for Your Attention!

Proposal on source size dependence analysis

The ratio of correlation function between small and large collision systems to extract strong p-Omega interaction w/o much contamination from Coulomb interaction.

Morita etc. arXiv:1605.06765

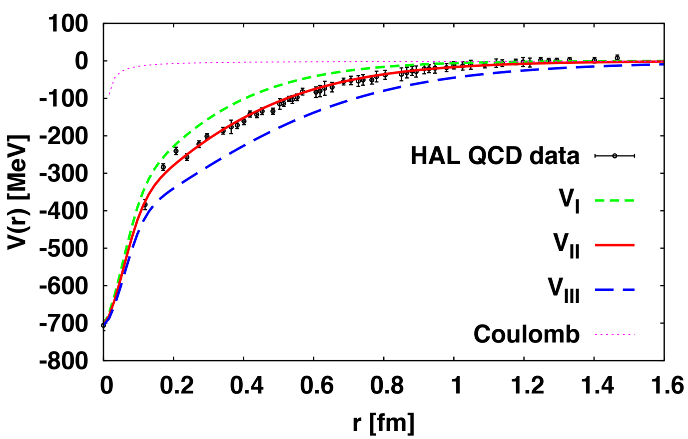


TABLE I: The binding energy (E_B), the scattering length (a_0) and the effective range (r_{eff}) with and without the Coulomb attraction in the $p\Omega$ system. Physical masses of the proton and Ω are used.

Spin-2 $N\Omega$ Potentials		V_{I}	V_{II}	V_{III}
without Coulomb	E_B [MeV]	–	0.05	24.8
	a_0 [fm]	−1.0	23.1	1.60
	r_{eff} [fm]	1.15	0.95	0.65
with Coulomb	E_B [MeV]	–	6.3	26.9
	a_0 [fm]	−1.12	5.79	1.29
	r_{eff} [fm]	1.16	0.96	0.65