Probing the isobaric Ru and Zr nuclear structure with the diffractive photoproduction of ρ^0 mesons

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(For the STAR collaboration)

Apr. 24, 2023

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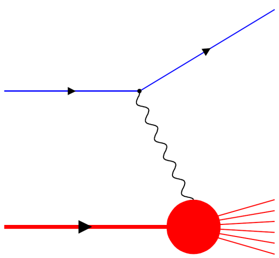
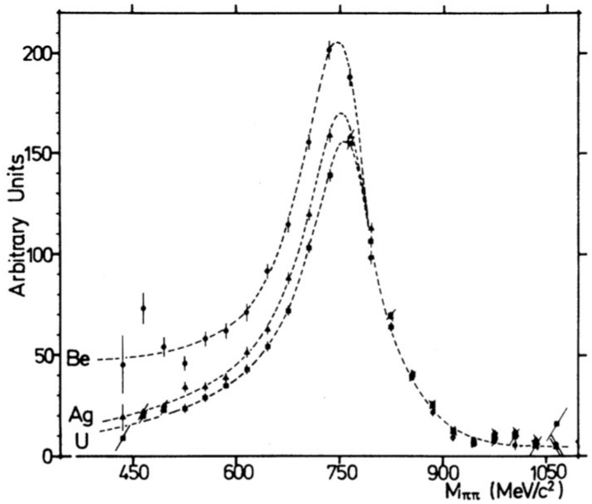
Scattering

R. Hofstadter, Rev. Mod. Phys. 28 214-254 (1956)





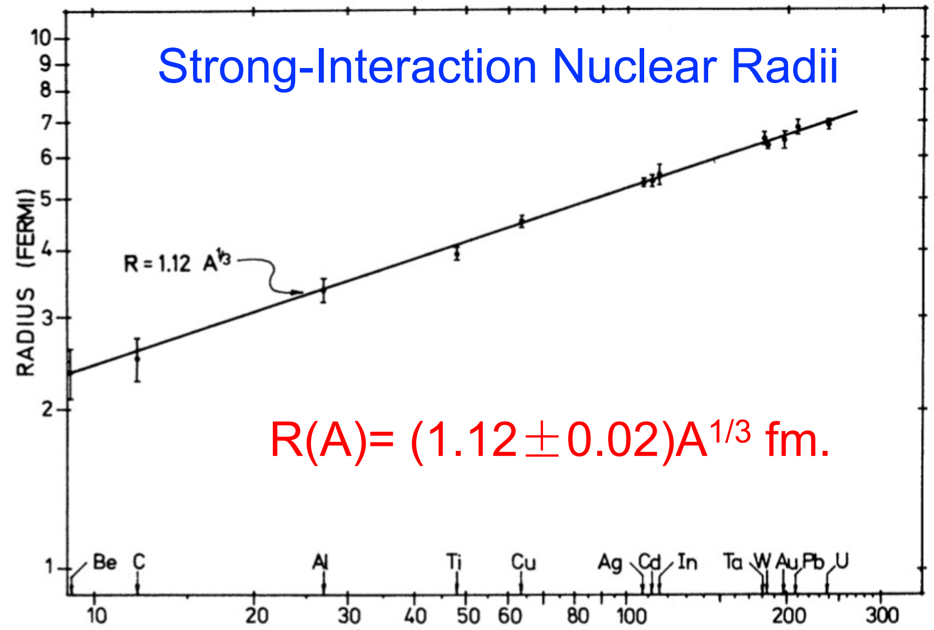
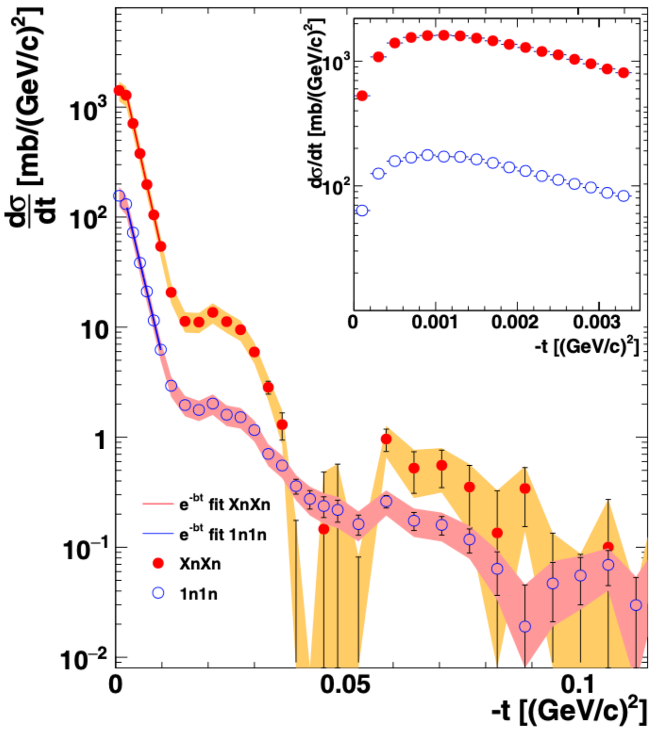


FIG. 1. Results on $R(A)$ and the best fit with $R=r_0A^{1/3}$.

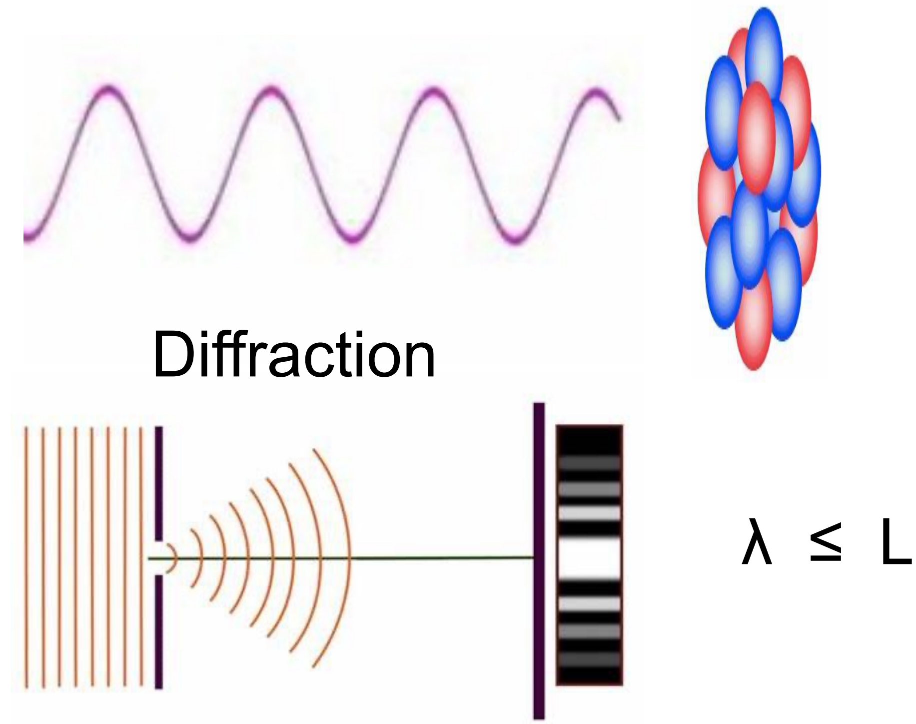
G.F. Chew, et.al, Phys. Rev. 106, 1345 (1957); R.A. Schrack, et.al, Phys. Rev. 127, 1772 (1962);
C.M. Tarbert, et.al, Phys. Rev. Lett. 112, 242502 (2014)
F. Bulos, et.al, Phys. Rev. Lett. 22, 490 (1969); L.J. Lanzerotti, et.al, Phys. Rev. 166, 1365 (1968)
H. Alvensleben et.al, Phys. Rev. Lett. 24, 786 and 792 (1970)

- Electron scattering measures the form factor, charge radius
- Photoproduction of π^0 meson: Δ(1232), the mass radius (1960s)
- Photoproduction of ρ^0 meson:
  "Determination of Strong-Interaction Nuclear Radii" (1970s)

Diffractive ρ^0 meson production



STAR, PRC 96, 054904 (2017)
STAR, PRL 89, 272302 (2002)
Spencer, et.al, PRC 60, 014903, (1999)



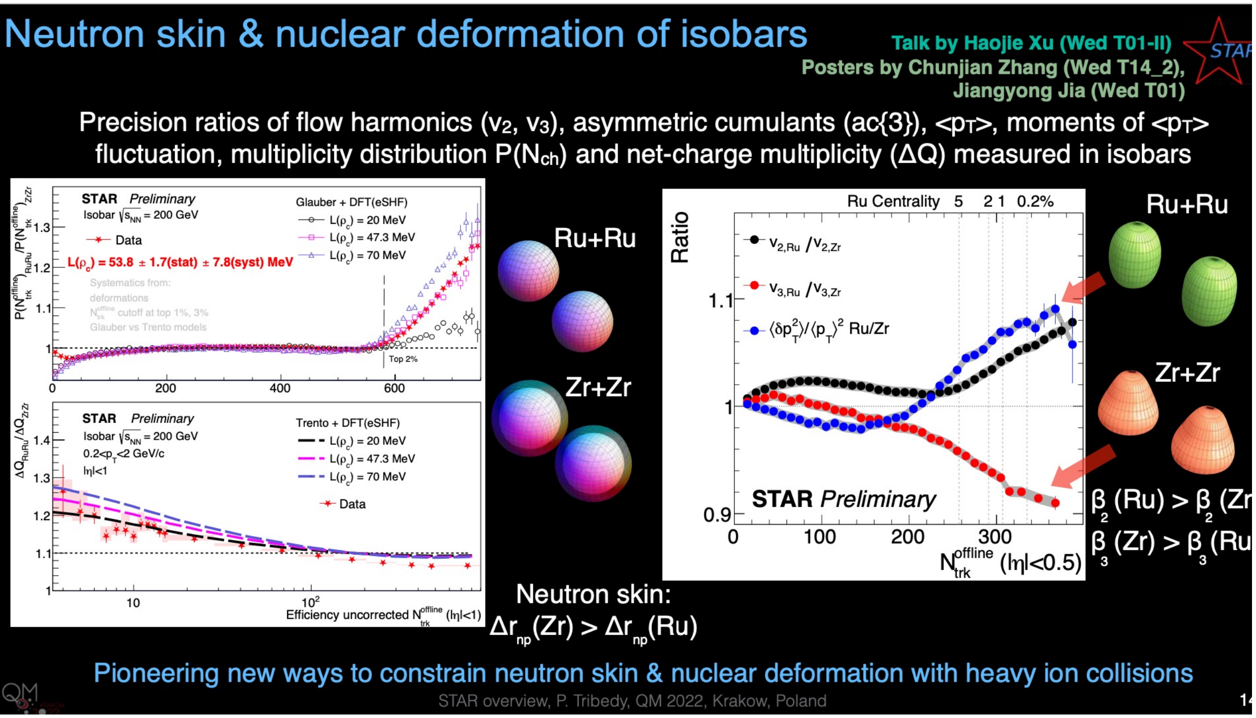
F. Bulos, et.al, Phys. Rev. Lett. 22, 490 (1969)
H. Alvensleben et.al, Phys. Rev. Lett. 24, 786 and 792 (1970)
H. Mäntysaari, F. Salazar, B. Schenke, arXiv:2207.03712

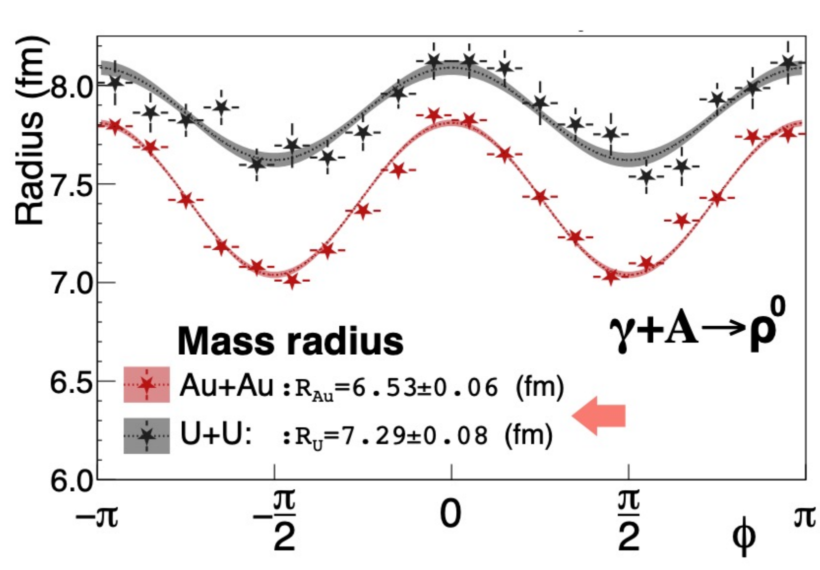
- Diffraction pattern (minima) of the coherent ρ^0 production are sensitive to the nuclear size.
- "The slopes of the diffraction patterns measure directly the nuclear density distribution. For example, at t -> 0, the diffraction pattern behaves as e^{at} where a is a measure of the nuclear size."
- Can used to study the nuclear structure of the isobar Ru and Zr

Isobaric Ru and Zr nuclear structure

STAR, Phys. Rev. C 105 (2022), 014901
T. Prithwish (for STAR), QM2022

STAR, Sci. Adv. 9 (2023) 1





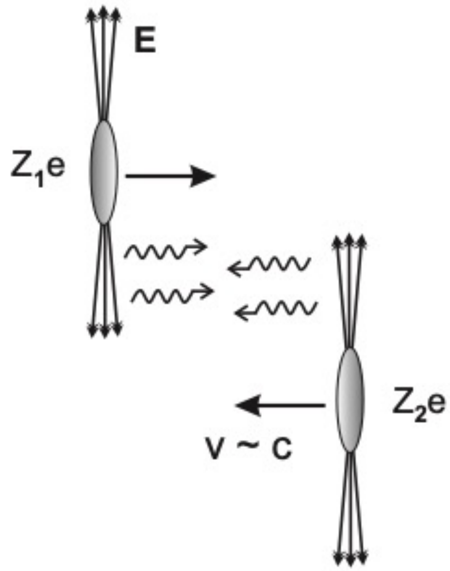
Tomography of ultra-relativistic nuclei with polarized photon-gluon collisions.

> ➢ The γ-A interaction may help to understand the structure of the isobar Ru and Zr nuclei ?

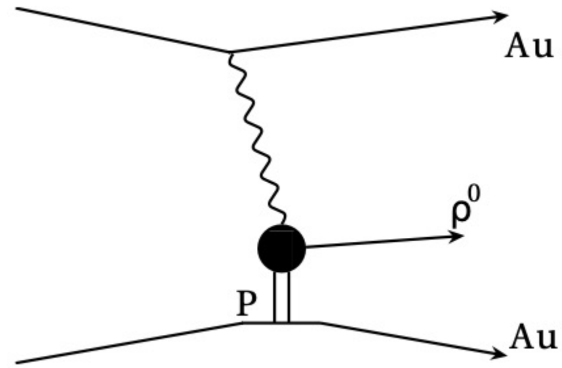
Spencer, et.al, PRC 60, 014903, (1999); STAR, PRL 89, 272302 (2002), PRC 96, 054904 (2017)

γ-A interaction from UPC

C.A. Bertulani, S.R. Klein, J. Nystrand
Ann. Rev. Nucl. Part. Sci. 55 (2005) 271



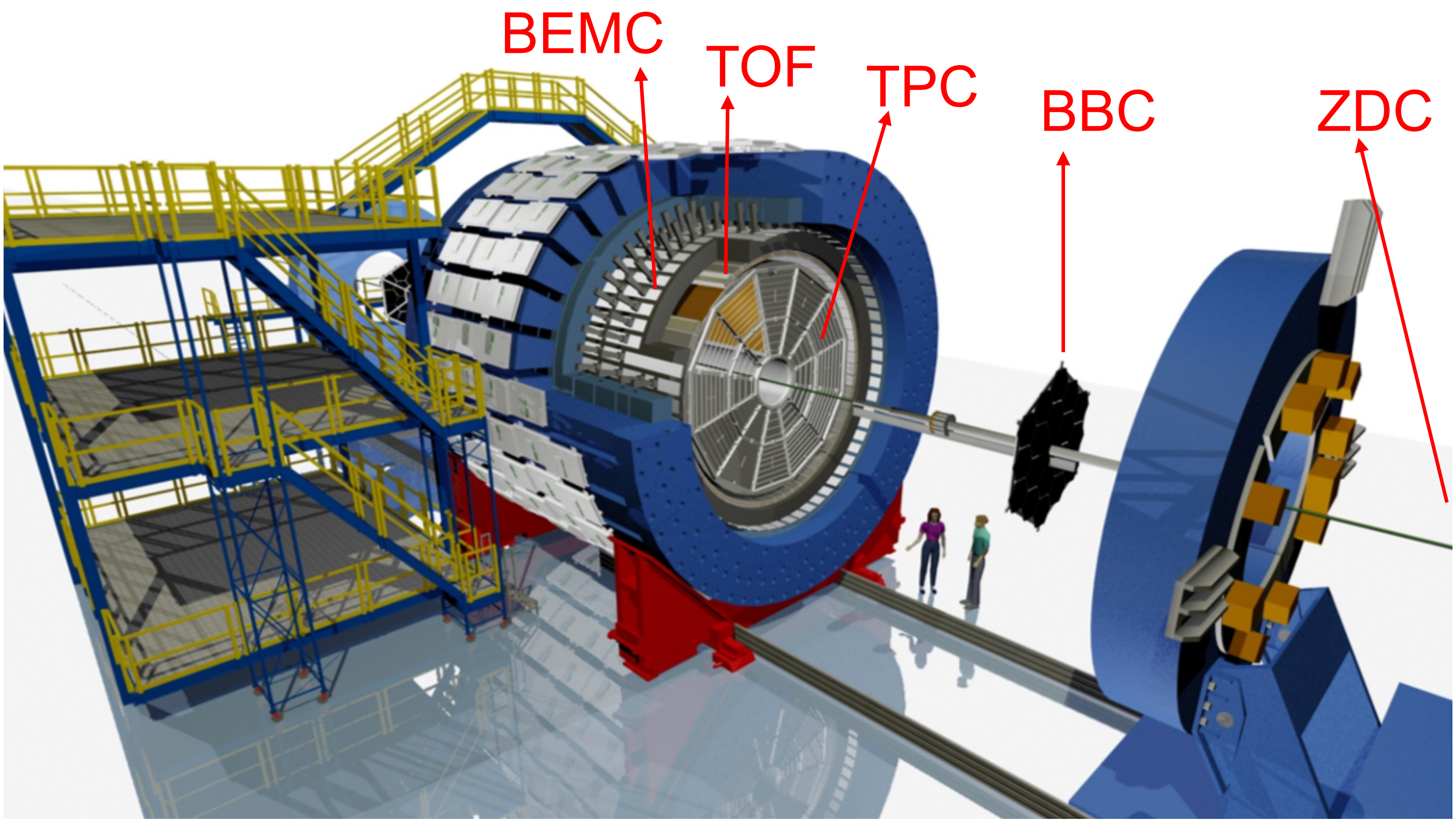
STAR, PRL 89, 272302 (2002)



Soft-Pomeron (gluons) exchange

- Ultra-peripheral heavy-ion collisions (UPC) ($b>2R_0$)
- Electromagnetic field as quasi-real photons (EPA)
- ρ^0 meson production through the soft-pomeron (gluons) exchange, sensitive to the Strong-Interaction Nuclear Radius

STAR detector



- Time Projection Chamber: tracking and particle identification within |η|<1
- Time Of Flight: multiplicity trigger, particle identification and pile-up track removal
- Barrel ElectroMagnetic Calorimeter: topology trigger and pile-up track removal
- Beam-Beam Counters: scintillator counters within 2.1<|η|<5.2, forward veto
- Zero Degree Calorimeters: detection of very forward neutrons, |η| > 6.6

Datasets

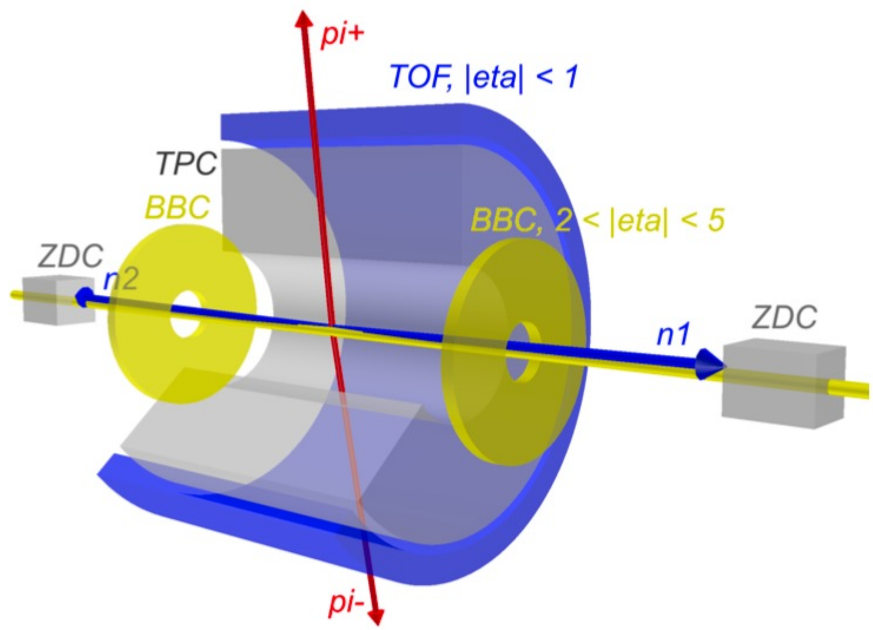
System	Year	Trigger (ID)	|Vz|	Vr
Ru+Ru	2018	UPC-Jpsi	<100cm	<2cm
Zr+Zr	2018	UPC-Jpsi	<100cm	<2cm

Track cuts: (primary track)

nHitFit>15, $|\eta|<1$, dca<3cm

pT>0.2 && <4 GeV/c

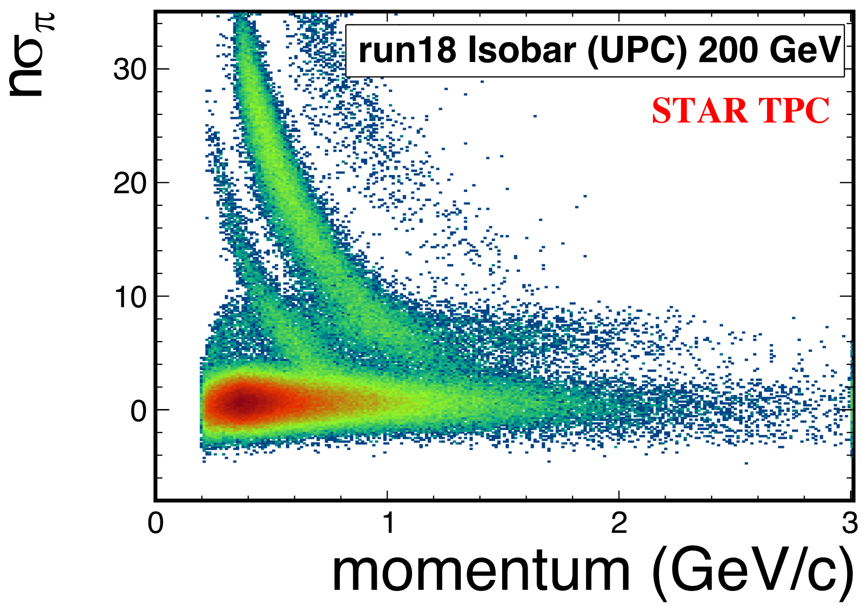
TOF matched>0

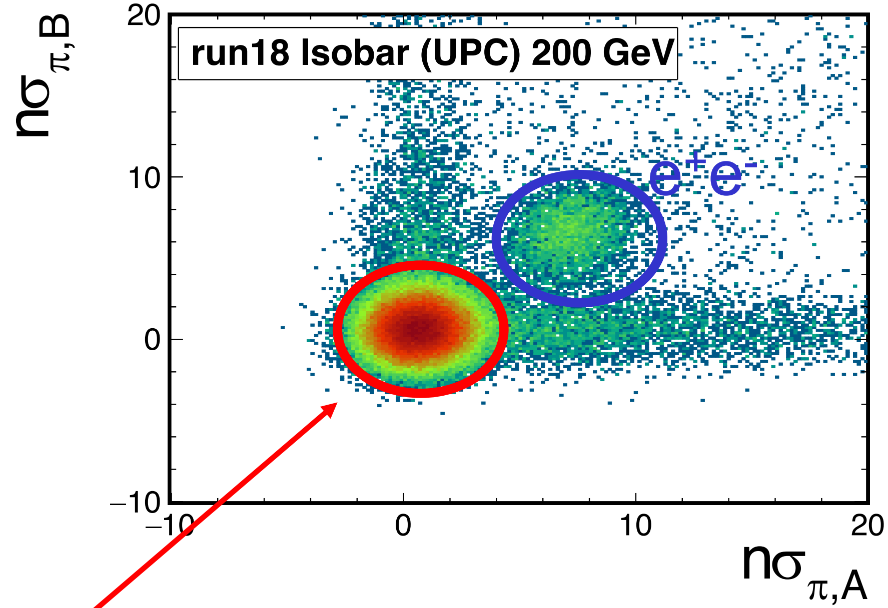


plot from Jaroslav Adam

- Events are selected with number of primary tracks = 2
- Track pair not matched to the BEMC topo. clusters with (E_0>0.5)

PID: remove the e^+e^- contamination



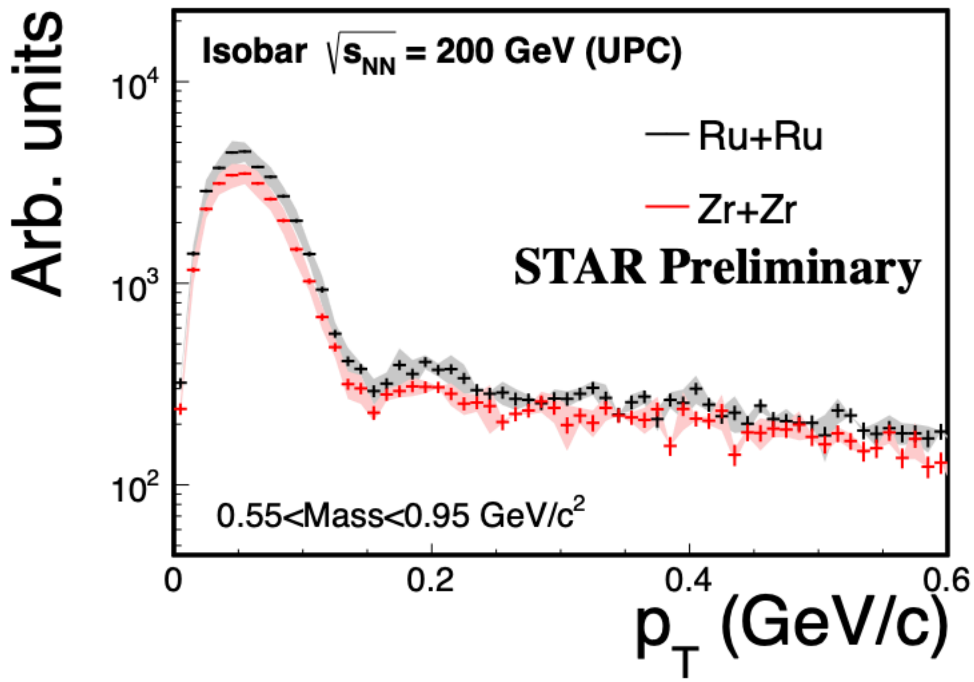


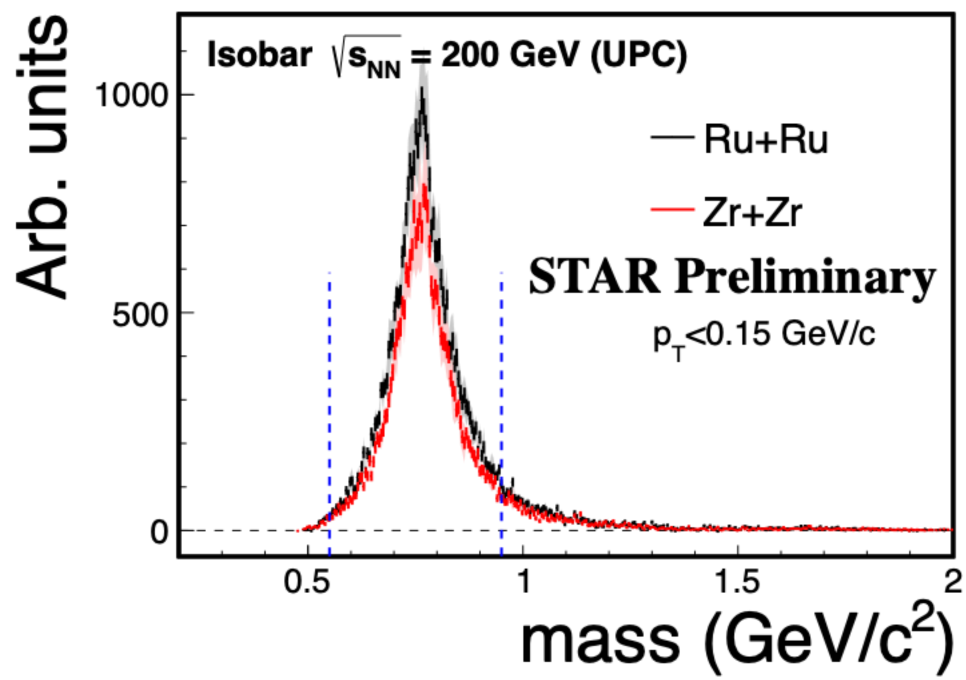
STAR, PRL 127, 052302 (2021)

ALICE, JHEP. 2015, 95 (2015)

- $\boldsymbol{\sigma}_{\boldsymbol{\pi},A}{}^2 + \boldsymbol{\sigma}_{\boldsymbol{\pi},B}{}^2 < 16$,
  remove the e^+e^- contamination from $\gamma+\gamma$ interaction

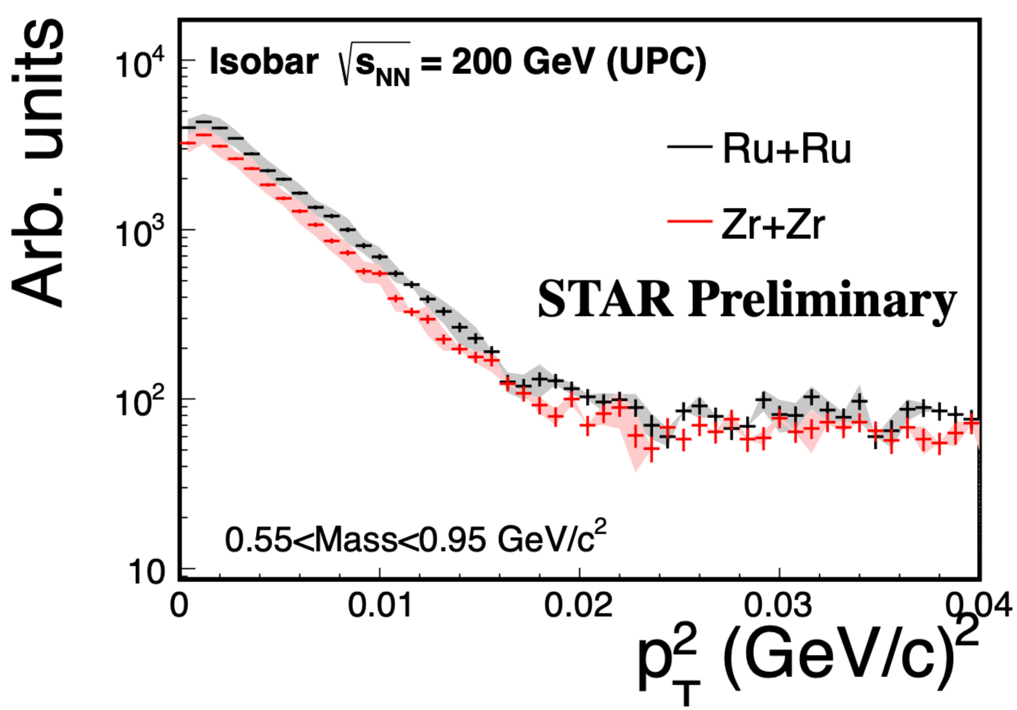
Diffractive photoproduction of ρ^0 in isobar

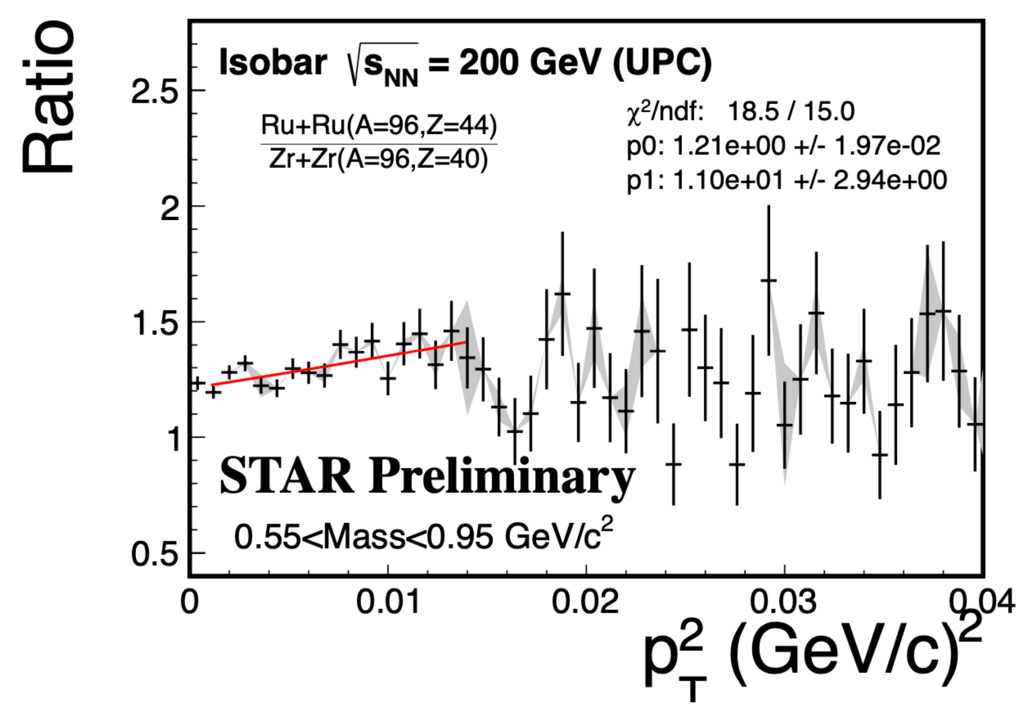




- Systematic uncertainty sources:
  dca: 1.0, 2.0 (3.0) cm; nHitsFit: 20 (15); $|V_Z|$: 50 (100) cm
- Total systemic uncertainty : RMS(σ (dca)) $\otimes$ σ(nHit) $\otimes$ σ(Vz)
- Diffraction pattern (minima) of the coherent ρ^0 production

Ru and Zr nuclear structure





$A^*e^{-b^*t}$, $(t \simeq -p_T^2)$

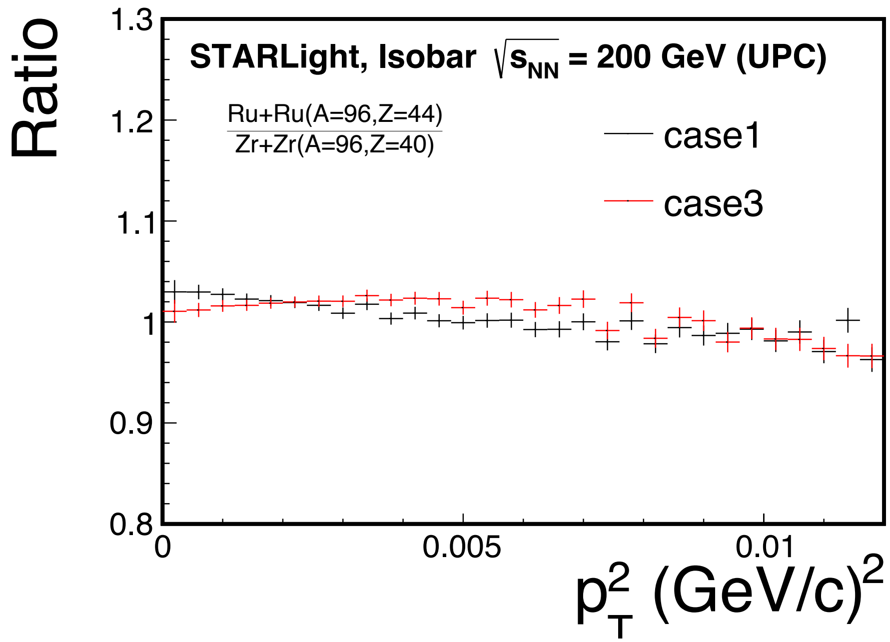
- Indication of larger Zr size than Ru from the γ-A interaction. The slope of the dN/dt ratio is 11.0+/- 2.9 +/- 0.3 (~3σ sigma effect)
- Interference and deformation effects need to be considered

STARLight simulation

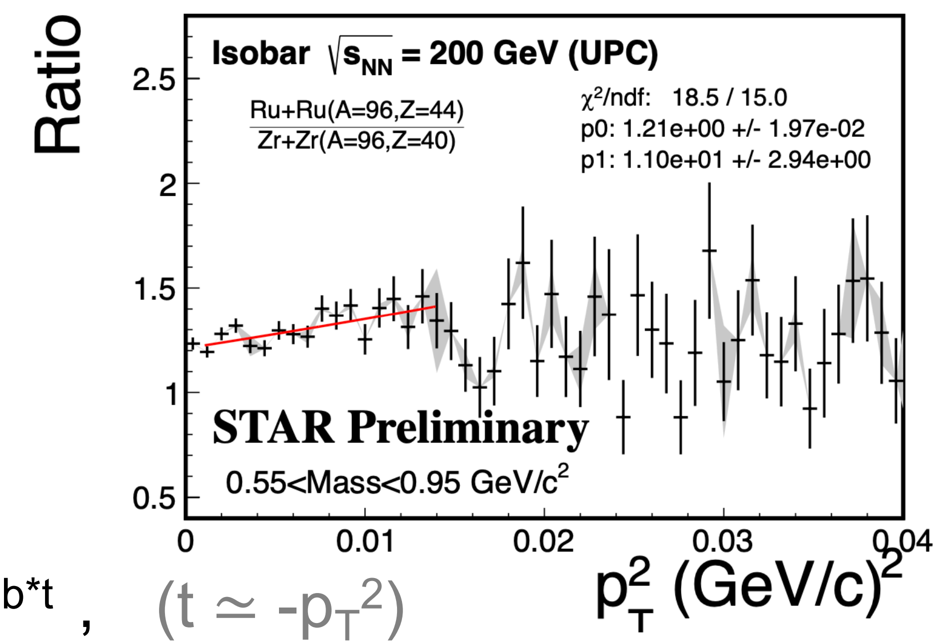
Spencer, et.al, Comput.Phys.Commun. 212 (2017) 258 STAR, Phys.Rev.C 105 (2022), 014901

TABLE II. The Woods-Saxon parameters used in the Glauber simulations for the centrality determination.

Nucleus	Case-1 [83] R (fm)	Case-1 a (fm)	Case-1 β_2	Case-2 [83] R (fm)	Case-2 a (fm)	Case-2 β_2	Case-3 [113] R (fm)	Case-3 a (fm)	Case-3 β_2
$^{96}_{44}$Ru	5.085	0.46	0.158	5.085	0.46	0.053	5.067	0.500	0
$^{96}_{40}$Zr	5.02	0.46	0.08	5.02	0.46	0.217	4.965	0.556	0



$A^*e^{-b^*t}$, ($t \simeq -p_T^2$)



- STARLight simulation with case 1 shows negative slope of the ratio, where Ru size is larger than Zr.
- Case 3: simulation shows positive, which indicates larger Zr size.
- Case 3 agrees better with data, but still large difference (slope ~1.7)

Summary

- Diffractive photoproduction of ρ^0 mesons in isobar
- Indication of larger Zr size than Ru from the γ-A, the slope of the dN/dt ratio is 11.0+/- 2.9 +/- 0.3 (~3σ effect)
- Comparison with simulation also indicates larger Zr size
- Interference and deformation effects need to be considered using model calculations