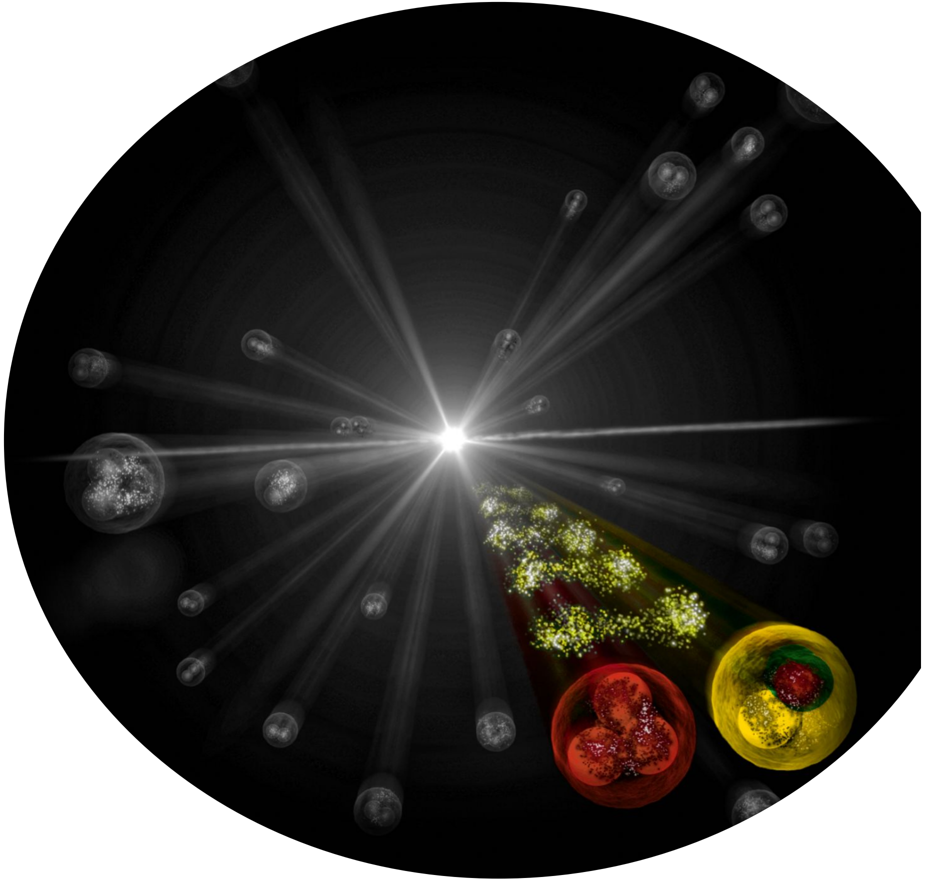
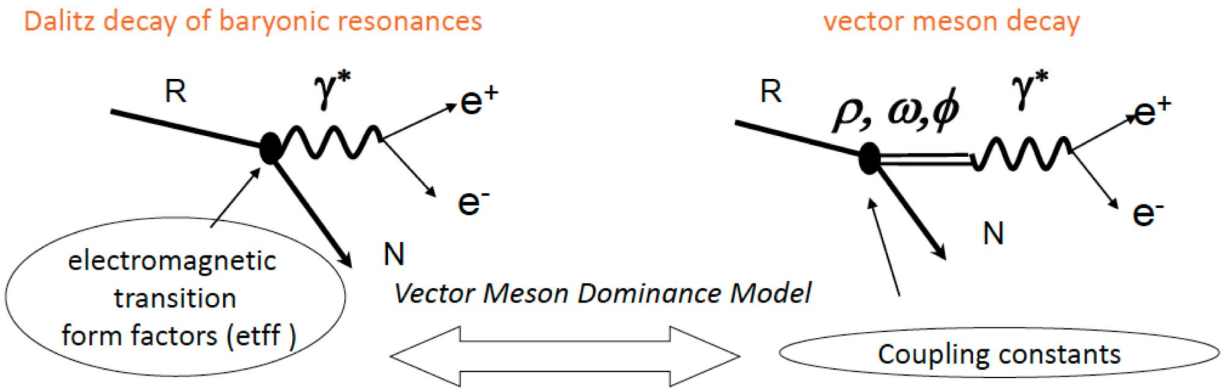
Direct observation of the ρ^0N coupling

M. Korwieser on behalf of ALICE Coll.
Technical University of Munich, E62

19th of July 2024
ICHEP 2024, Prague



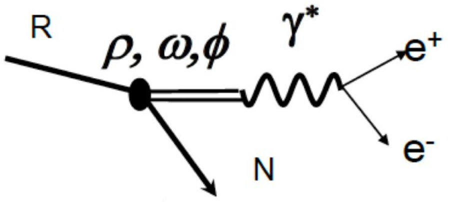
Vector meson nucleon interaction



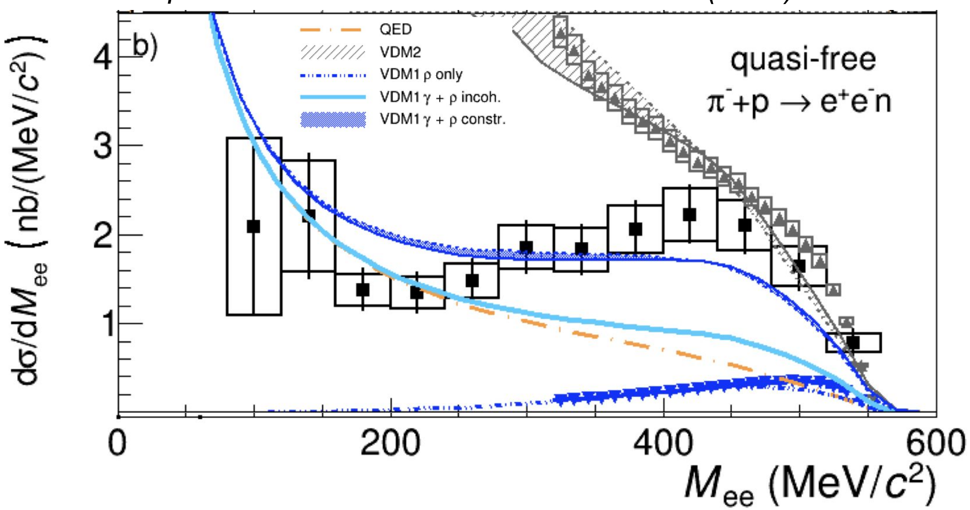
- Usually probed by Vector Meson Dominance (VMD[1]) Models
  1: J. J. Sakurai, Phys. Rev. Lett. 22, 981 (1969)
  - Hadronic contribution to the photon propagator
  - Off-shell vector mesons

- Important to understand…
  - … in-medium dilepton production
  - … dynamically generated states N* and Δ* (pole positions) from unitarised chiral perturbation theory (UChPT[2])
    2: N. Kaiser, P. B. Siegel and W. Weise, Phys. Lett. B 362, 23 (1995)

Vector meson nucleon interaction



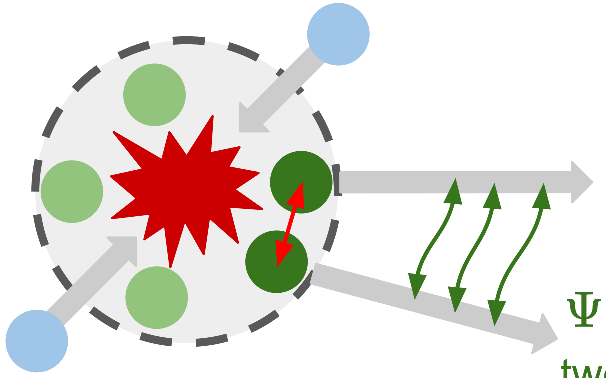
Adapted from HADES arXiv:2205.15914v2 (2022)



- Test of VMD at HADES
  - Low-energy beams (π)
  - M_{ee} excess compared to QED reference
- Excess modeled
  - With low-lying intermediate resonances (R) (N(1440), N(1520), N(1535) in a Rγ*N vertex)
- But how can one access the interaction between the ρ^0 and nucleon directly?

Femtoscopy in a nutshell

L. Fabbietti and V. Mantovani Sarti and O. Vazquez Doce, Ann.Rev.Nucl.Part.Sci.55:357-402, 2005



Measure the correlation function *C(k*)*

$\Psi(\vec{k}^*, \vec{r}^*)$

two-particle wave function

$$C(k^*) = \mathcal{N}\frac{N_{\mathrm{SE}}(k^*)}{N_{\mathrm{ME}}(k^*)}$$

Particle pair observed in the same event

Particle pair constructed from different events

Femtoscopy in a nutshell

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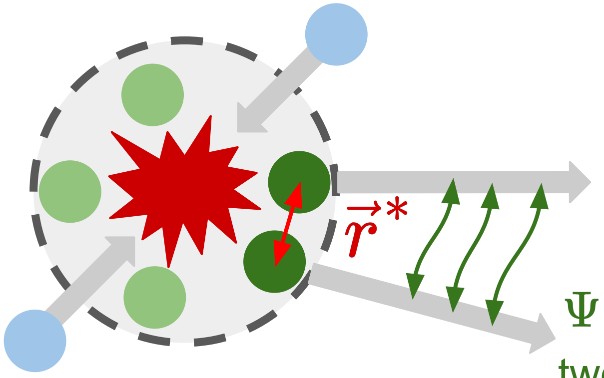


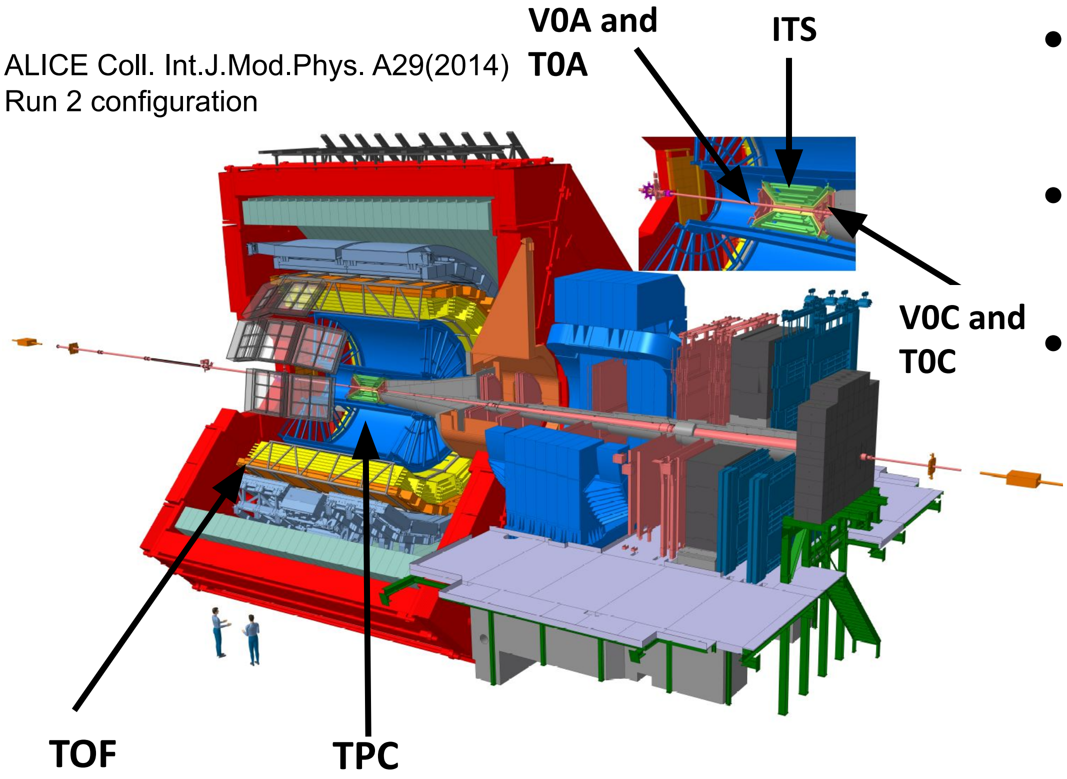
$$C(k^*) = \int S(r^*) \left| \Psi(\vec{k}^*, \vec{r}^*) \right|^2 d^3 r^* \xrightarrow{k^* \to \infty} 1$$

- **Measure *C*(*k**), use constrained *S*(*r**), study interaction**
  ALICE, PLB, 811:135849 (2020); ALICE, arXiv:2311.14527 (2023) (Accepted by EPJC)

- For evaluation of integral and *S*(*r**) use CATS framework
  D. L. Mihaylov et al. Eur.Phys.J.C 78 (2018) 5, 394

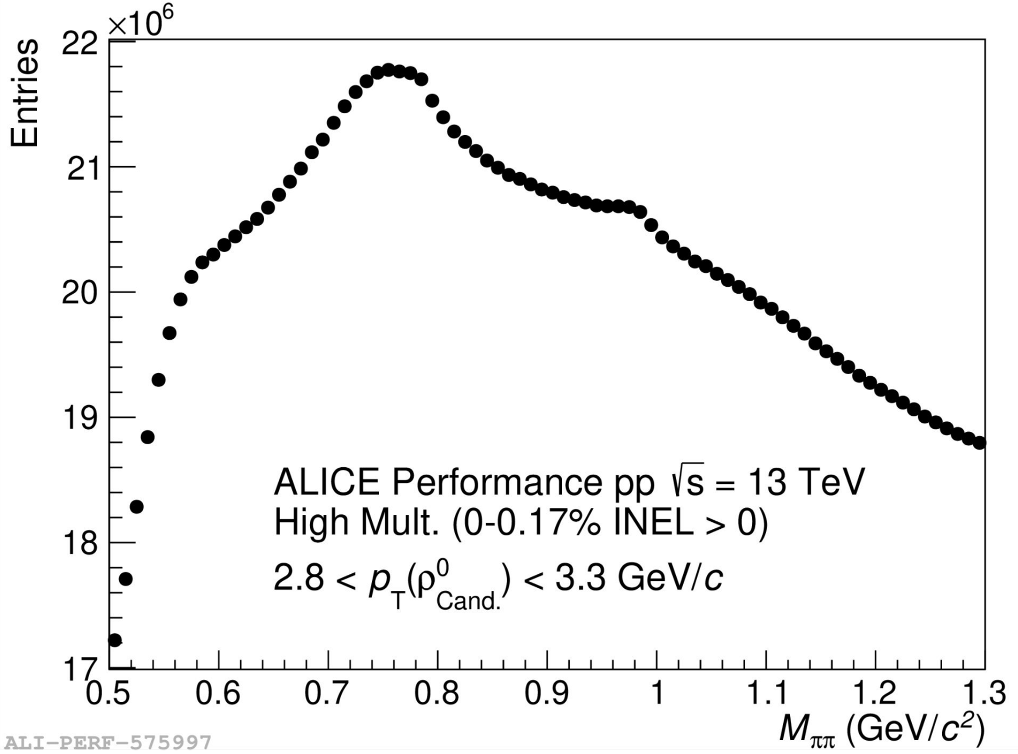
ALICE Run 2

ALICE Coll. Int.J.Mod.Phys. A29(2014)
Run 2 configuration



- HM pp collisions @ 13 TeV
  - 1 Billion events in Run 2
- Direct detection of charged particles (π, K, p) by TPC and TOF
- Particle identification
  - Mean energy loss in TPC
  - Momentum reconstruction by TOF
  - Purity of about 99% for π, K, p due to excellent PID capabilities

Reconstruction of ρ^0



- Access to ρ^0 ($c\tau$ = 1.2 fm/c)
  - Pair all π in an event
- Purity of the ρ^0 around 5%
  - Obtained by fit
- Two types of background
  - Combinatorial due to $(\pi\pi)_{Comb.}$
  - Mini-jet correlations

Extraction of the genuine ρ^0–p correlation

$$C_{\text{measured}}(k^*) = C_{\text{minijet}}(k^*)\left[\lambda_{\rho^0-\text{p}} \cdot C_{\rho^0-\text{p}}(k^*)\right] + (1-\lambda_{\rho^0-\text{p}}) \cdot (\omega_{\text{left}} C_{\text{SB}}^{\text{left}}(k^*) + (1-\omega_{\text{left}}) C_{\text{SB}}^{\text{right}}(k^*)).$$

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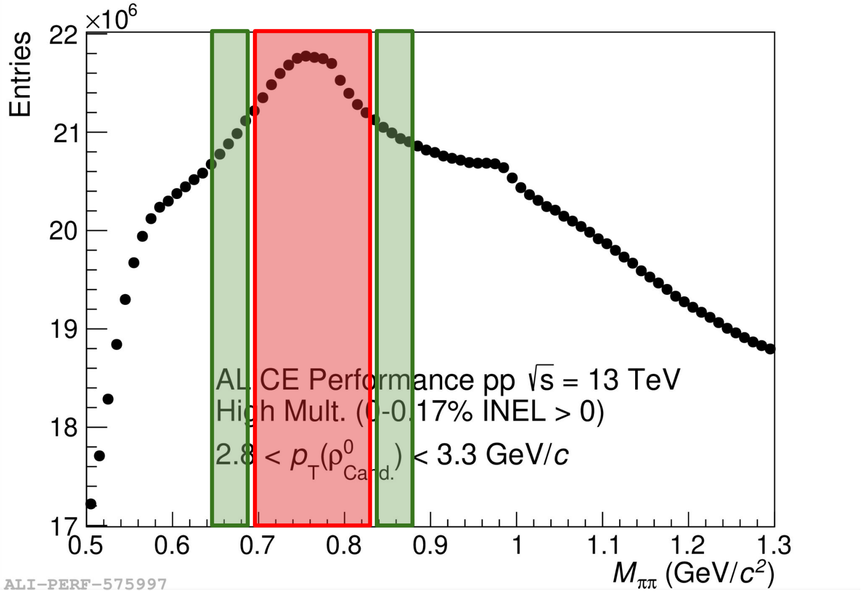
- Account for correlation of $(\pi\pi)_{\text{Comb.}}$ underneath ρ^0 signal
- Employ sideband (SB) analysis
  - Compute correlation function selecting $\rho^0_{\text{Cand.}}$ from left and right sideband region



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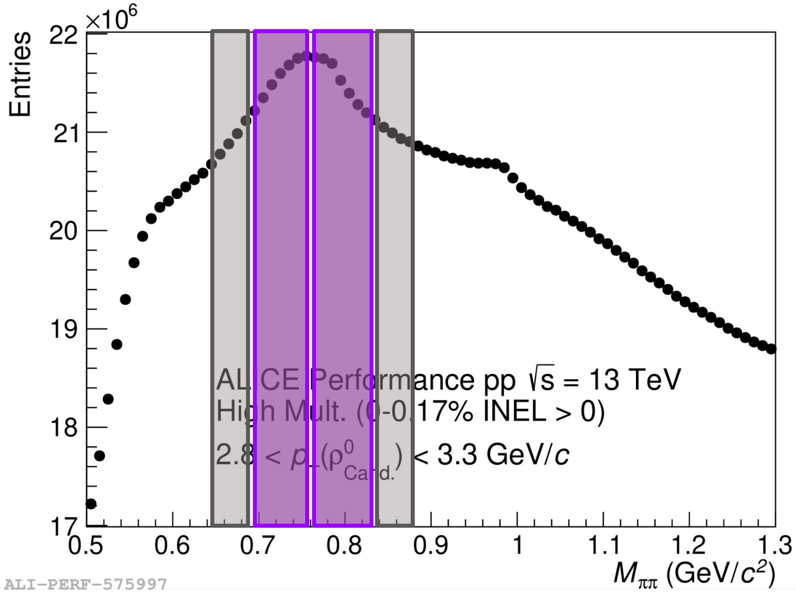
- Account for correlation of $(\pi\pi)_{\text{Comb.}}$ underneath ρ^0 signal
- Employ sideband (SB) analysis
  - Compute correlation function selecting $\rho^0_{\text{Cand.}}$ from left and right sideband region
  - Calculate weights by integration
  - Obtain SB correlation by a weighted average



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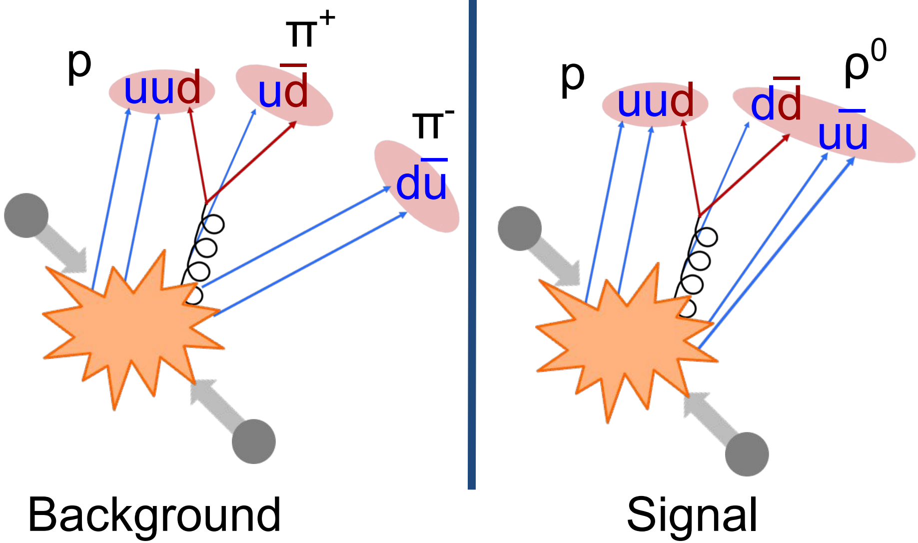
- Mini-jets
  - Partons share a common production (i.e. via gluon splitting)
  - Introduces momentum correlations
  - Contained in signal and SB regions
  - Use sideband correlation functions



Extraction of the genuine ρ^0–p correlation

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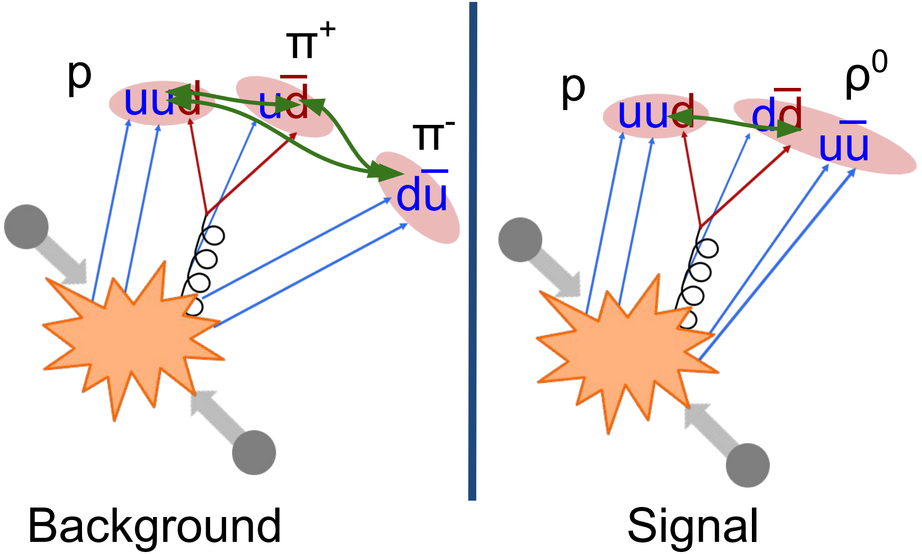

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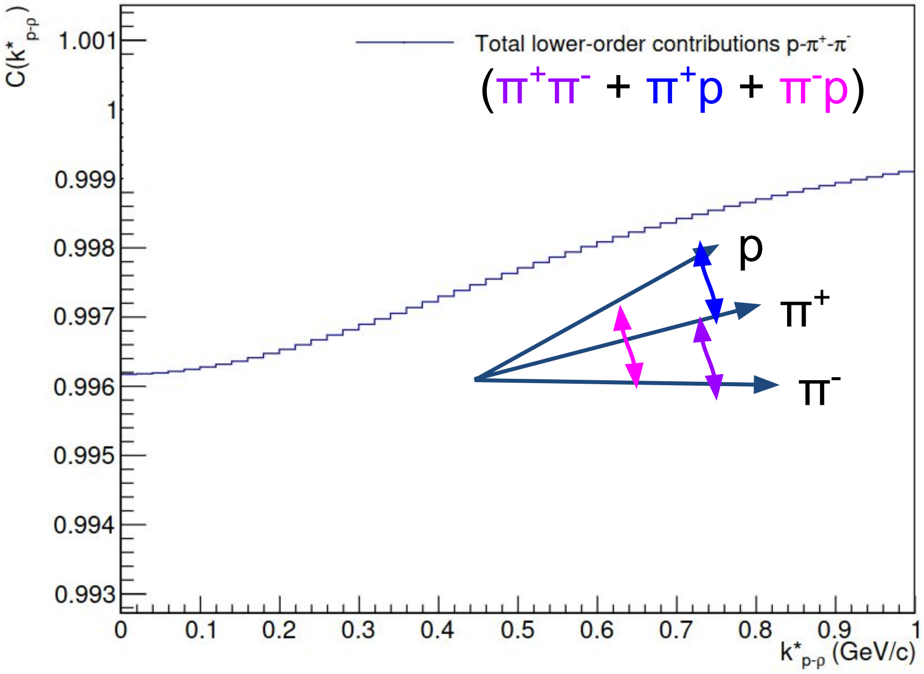
- Mini-jets
  - Partons share a common production (i.e. via gluon splitting)
  - Introduces momentum correlations
  - Contained in signal and SB regions
  - Use sideband correlation functions
- Residual 2-Body correlations
  - Analytical projection in ρ^0–p system
  - Projected[1] 2-Body correlations flat in ρ^0–p kinematic system

➔ SB dominated by mini-jets



1: R. Del Grande et. al. EPJC 82 (2022)

Extraction of the genuine ρ^0–p correlation

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- Weight each contribution with corresponding λ
  - Depends on the single-particle properties (purity and fractions)
  - Dominated by ρ^0 purity amounts to 5%

- Due to small purity extract the genuine ρ^0–p correlation from data

Extraction of the genuine ρ^0–p correlation

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- Weight each contribution with corresponding λ
  - Depends on the single-particle properties (purity and fractions)
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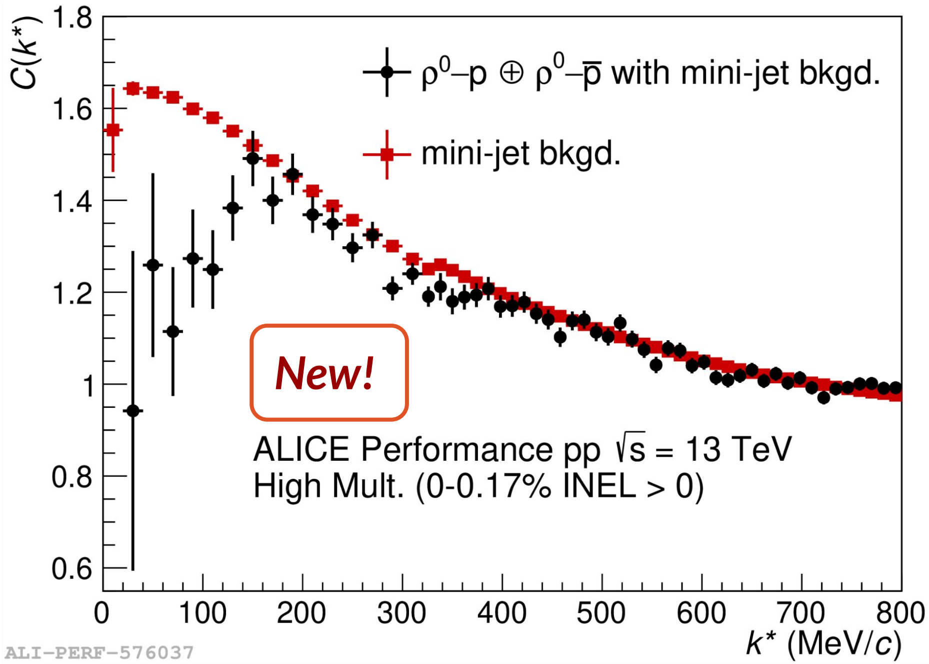
- Due to small purity extract the genuine ρ^0–p correlation from data

$$C_{\rho^0-\mathrm{p}}(k^*) = \frac{1}{C_{\mathrm{minijet}}}\left\{\frac{1}{\lambda_{\rho^0-\mathrm{p}}}\left[C_{\mathrm{measured}}(k^*) - (1-\lambda_{\rho^0-\mathrm{p}}) C_{\mathrm{SB}}(k^*)\right]\right\}.$$

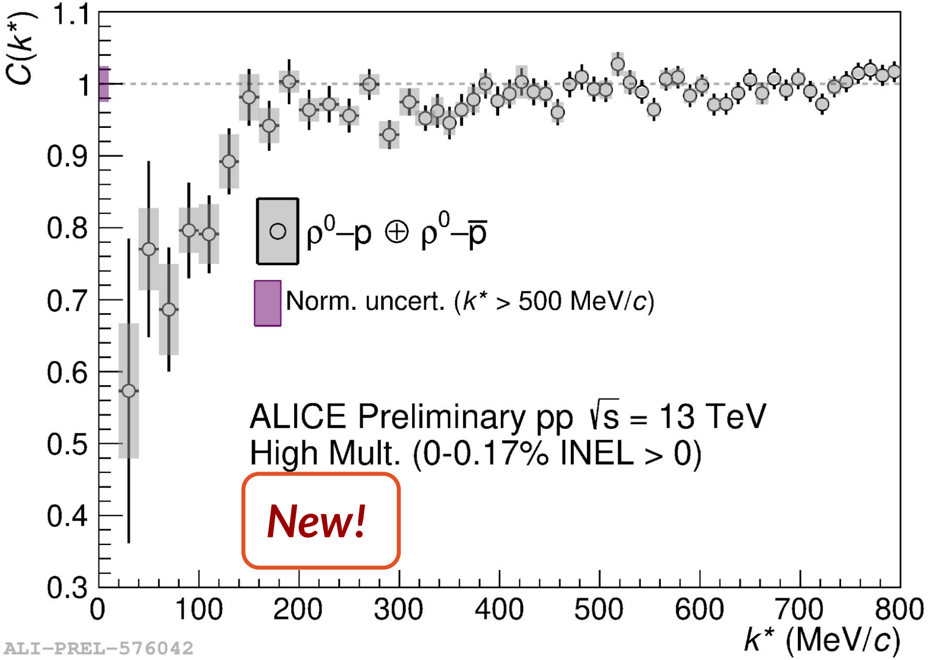
ρ^0-p without $(\pi\pi)_{comb.}$p correlation

$$C_{\rho^0-\mathrm{p}}(k^*) = \frac{1}{C_{\mathrm{minijet}}}\left\{\frac{1}{\lambda_{\rho^0-\mathrm{p}}}\left[C_{\mathrm{measured}}(k^*) - (1-\lambda_{\rho^0-\mathrm{p}})C_{\mathrm{SB}}(k^*)\right]\right\}.$$



- Normalized in 600–800 MeV
- $\lambda_{\rho\text{–}p}$**(= 5%)** dominated by ρ^0 purity
- Correct for mini-jet in next step
- Deviation to minijet due to final-state interaction

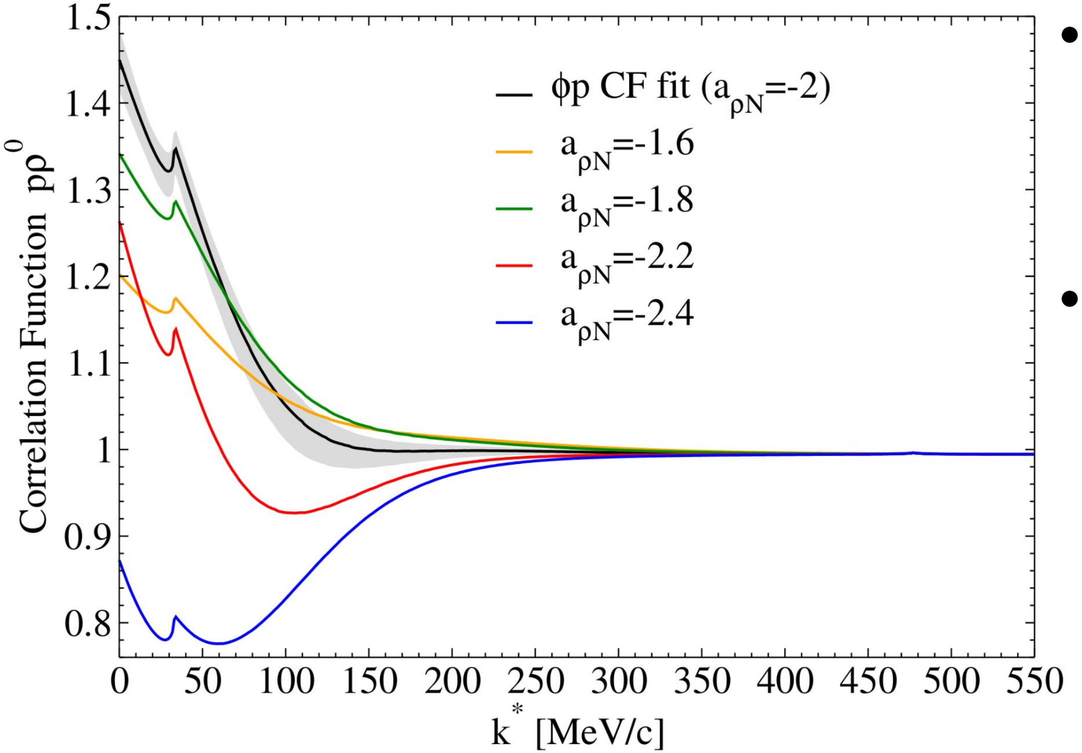
First direct observation of the ρ^0N coupling



- **First direct measurement** of ρ^0N coupling
  - Far above low-lying resonance states traditionally used
- nσ values w.r.t unity for
  - < 100 MeV/*c*: 3.4σ
  - < 120 MeV/*c*: 4.2σ
  - < 200 MeV/*c*: 3.9σ
- Coupled channels:
  ρ+n, ωp, ϕp, K*Λ, K*Σ
- Other N* and Δ* states (4* in PDG)
  - N*(1700) below threshold (1713 MeV)

Prediction from UChPT for ρ^0–p

A. Feijoo, M. Korwieser and L. Fabbietti arXiv:2407.01128 (priv. communication)

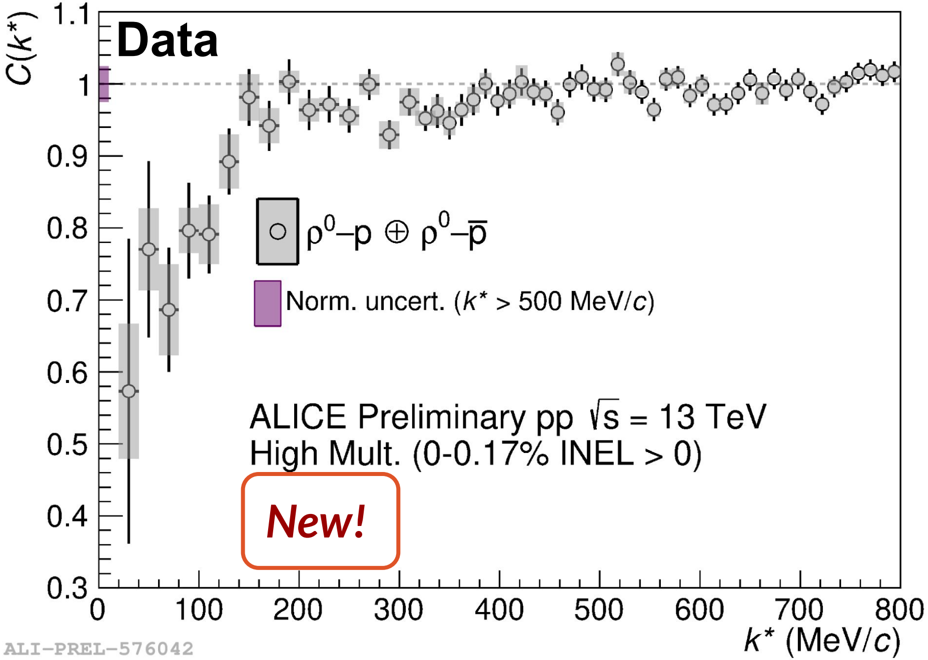


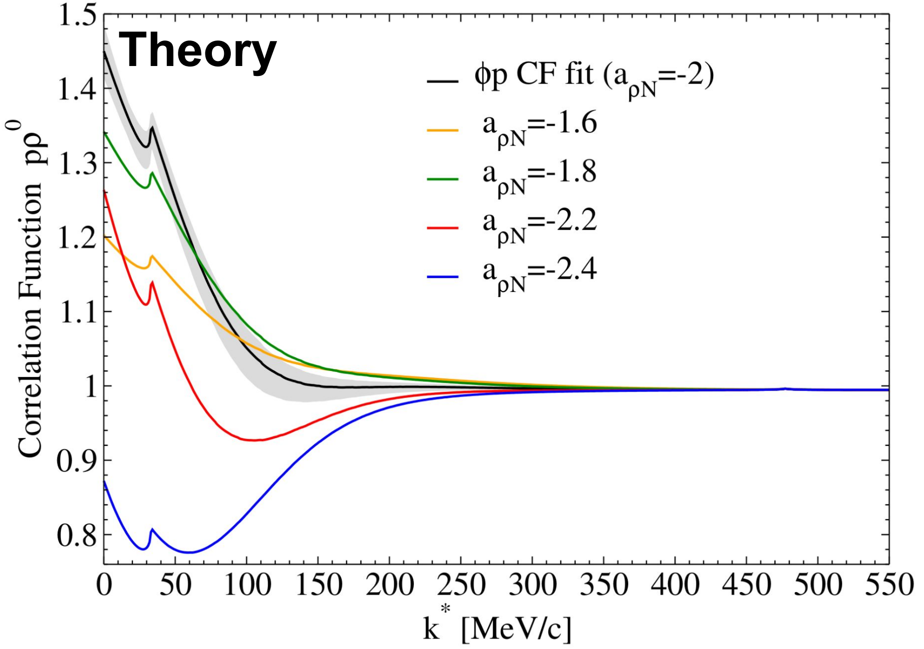
- Prediction obtained within UChPT for S=0
  - Coupled channels: ρ^+n, ωp, ϕp, K*Λ, K*Σ
  - Includes dynamical states N*(1700) and N*(2000)
- Obtain estimate for ρ^0–p
  - Use ϕ–p CF result[1] to fit parameters
  - Data needed to constrain $a_{\rho N}$ which is tightly coupled to pole position of N*(1700)

1: ALICE PRL 127 (2021)

Comparing to UChPT

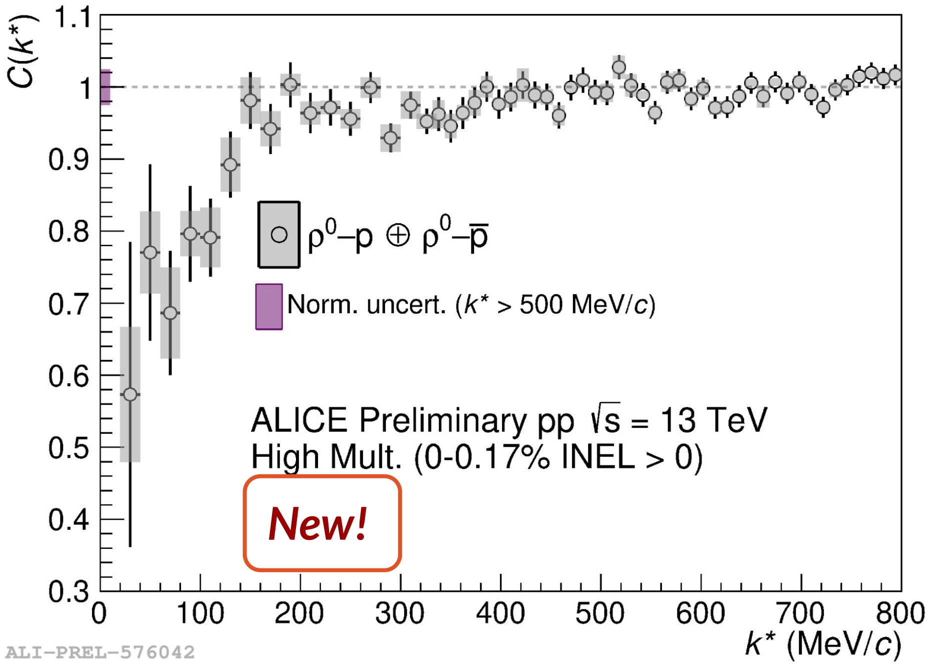
A. Feijoo, M. Korwieser and L. Fabbietti arXiv:2407.01128 (priv. communication)





- Data provide a unique constraint on the pole position of the N*(1700)

Essential Takeaways



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- What's next?
  - Employ UChPT to fit the data
  - Provide unique constraints on pole position of the N*(1700)

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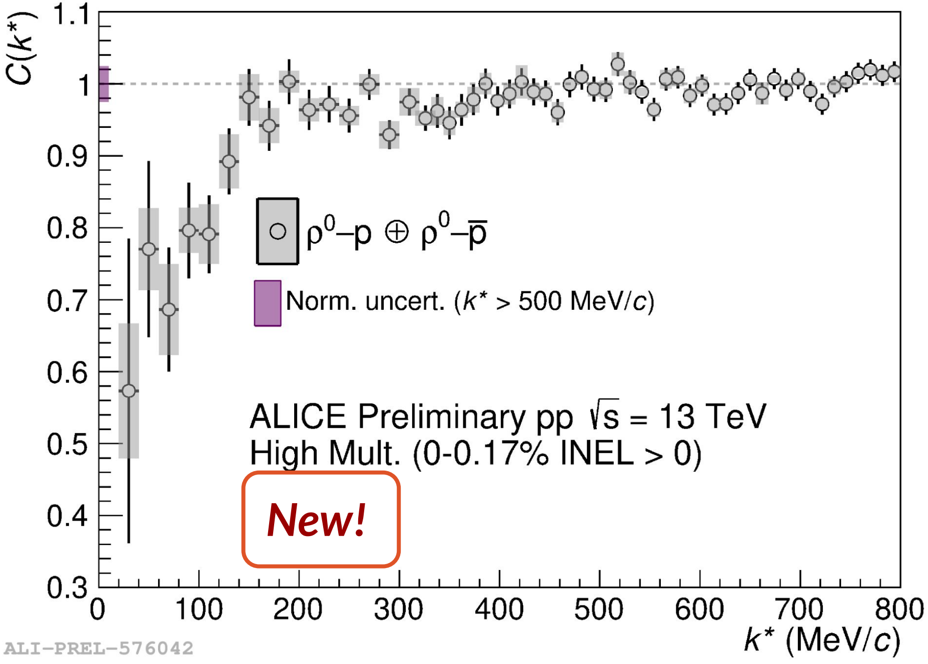

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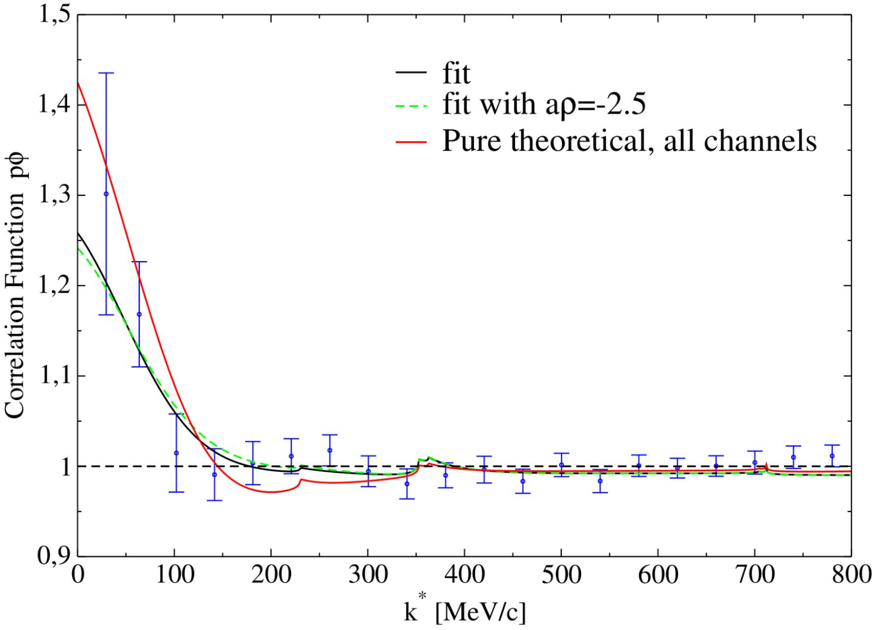
THANK YOU!

Back-up

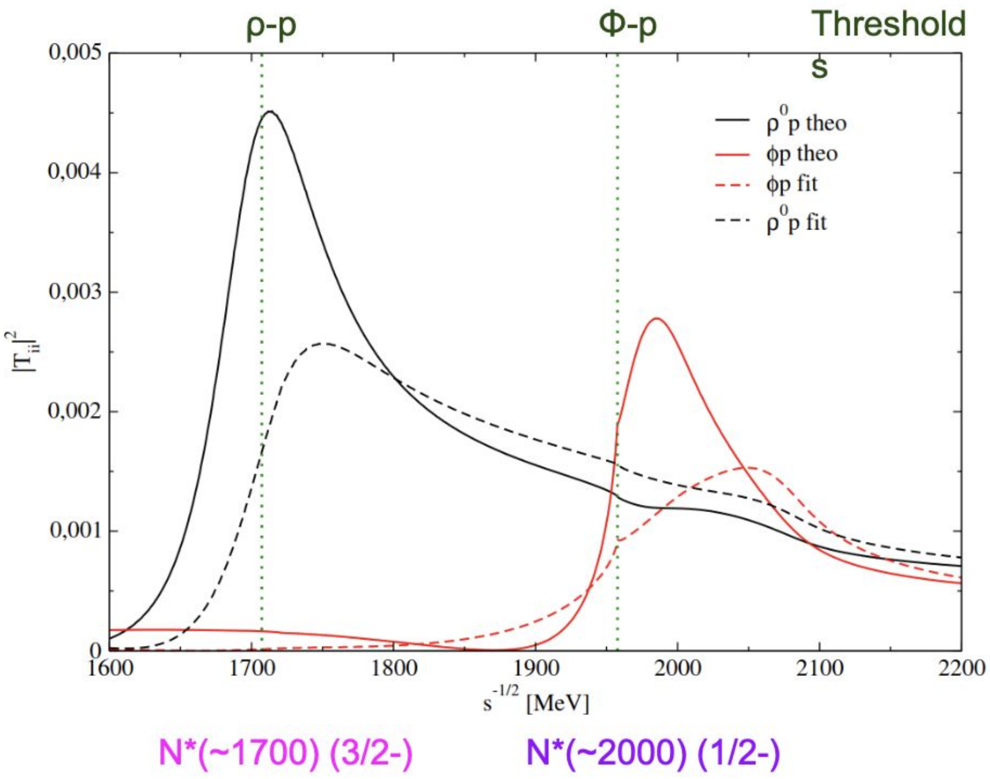
UChPT - Plots

Comparison with model (courtesy of A. Feijoo)



- Use ϕ-p result to fit parameters of UChPT
  - employs coupled channel approach
  - Weights obtained using
    - Thermal model
    - kinematic toy model (Kp)
- Obtain estimate for aρ

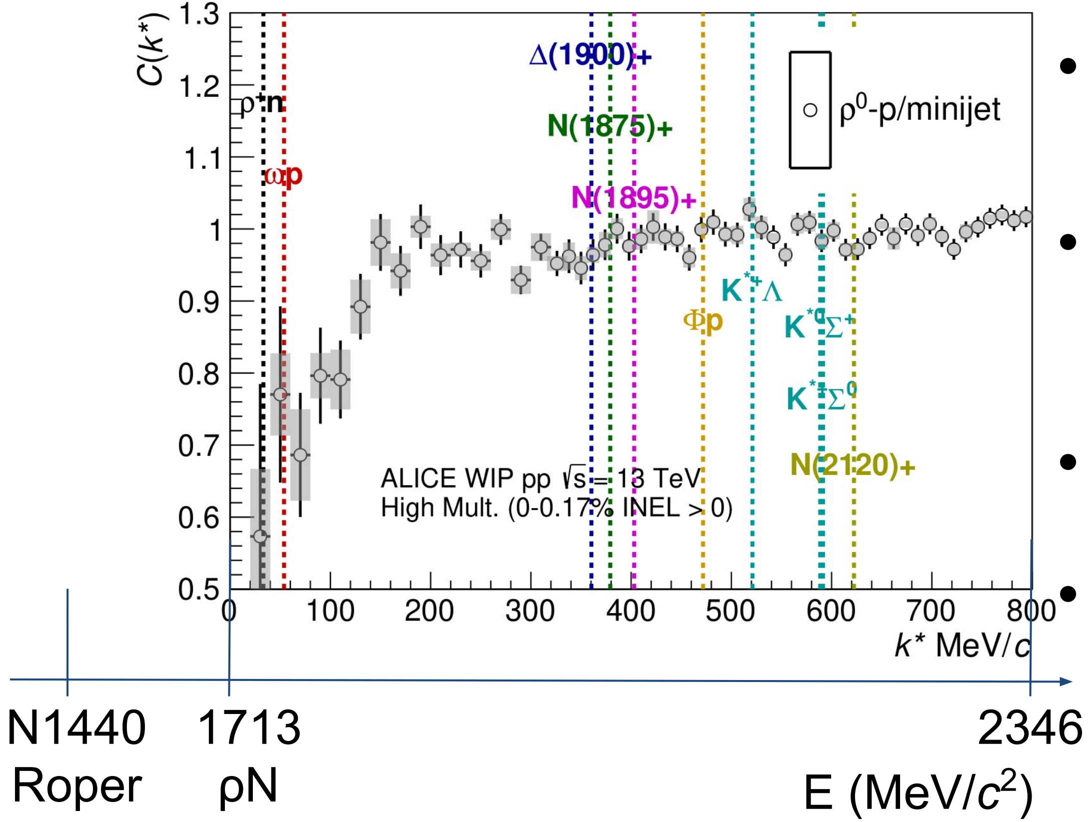
Comparison with model (courtesy of A. Feijoo)



- Use ϕ-p result to fit parameters of UChPT
- Modification of dynamically generated states
  - PDG links:
    - N*(~1700) (3/2-) (3*)
    - N*(~2000) (1/2-) (4*) (not clear if this is the correct state 1895, formerly 2090)

Threshold - Plots

First direct observation of the ρ^0N coupling



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- Other N* and Δ* states (4* in PDG)
  - N*(1700) below threshold (1713 MeV)

Resonances < 1700 MeV

Resonance	B.R. (%)	k* (MeV)
N(1440)+	0.0133	-
N(1520)+	0.0667	-
N(1535)+	0.0067	-
N(1650)+	0.0267	-
N(1675)+	0.0067	-
N(1680)+	0.03	-

Resonances > 1700 MeV

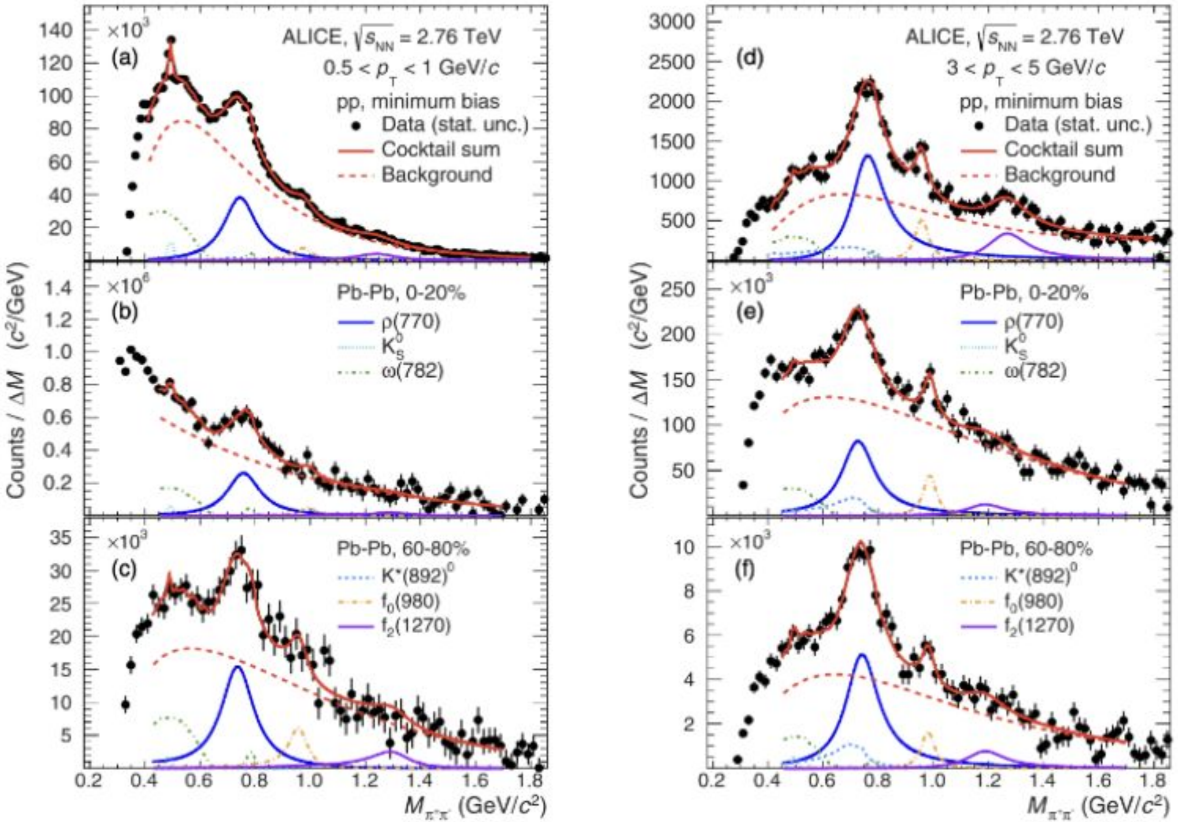
rho-p
1713

Resonance	B.R. (%)	k* (MeV)
Delta(1700)+	0.2	-
N(1710)+	0.05	-
N(1720)+	0.255	77.16
N(1875)+	0.02	379.76
Delta(1930)+	0.22	442.97
N(2190)+	0.0333	680.33
N(2250)+	0.0533	727.49
N(2600)+	0.0533	976.04

Old measurement - Plots

Motivation

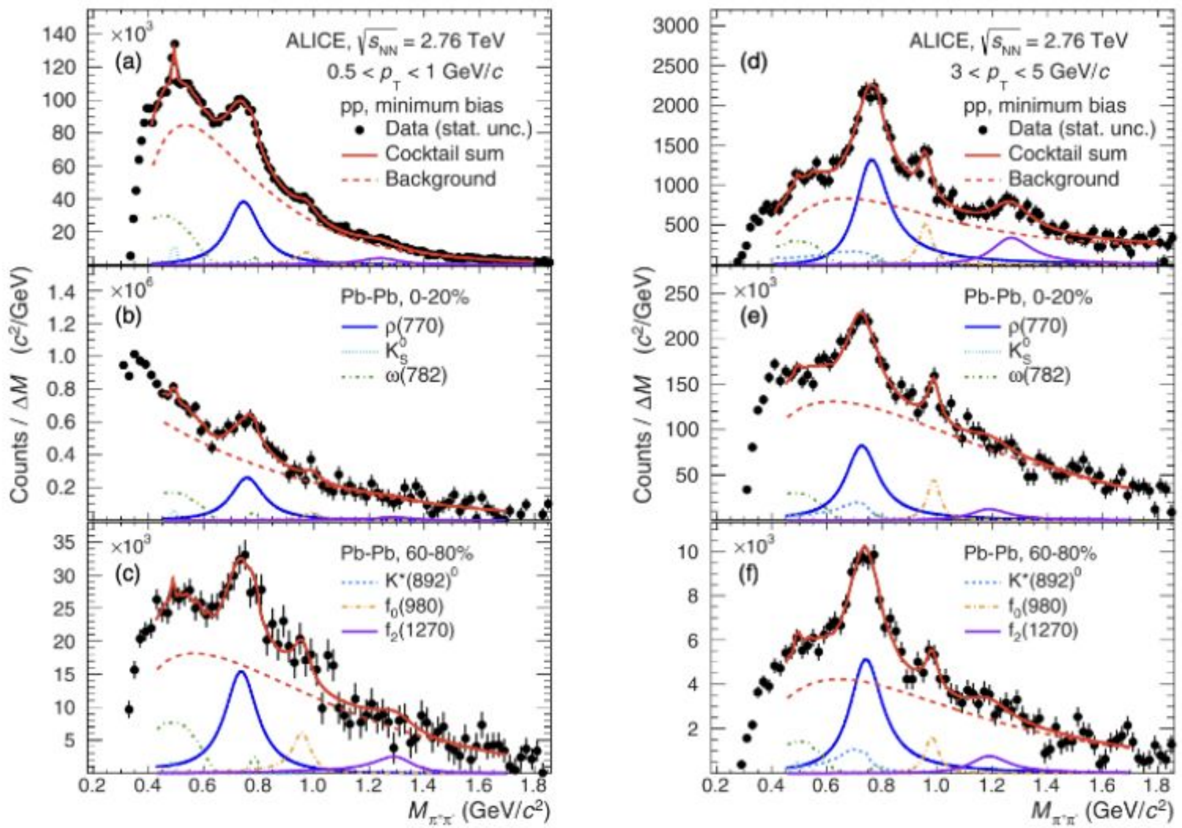
PHYSICAL REVIEW C **99**, 064901 (2019)



- ALICE measurements of ρ^0
  - Γ = 150 MeV
  - m = 775 MeV

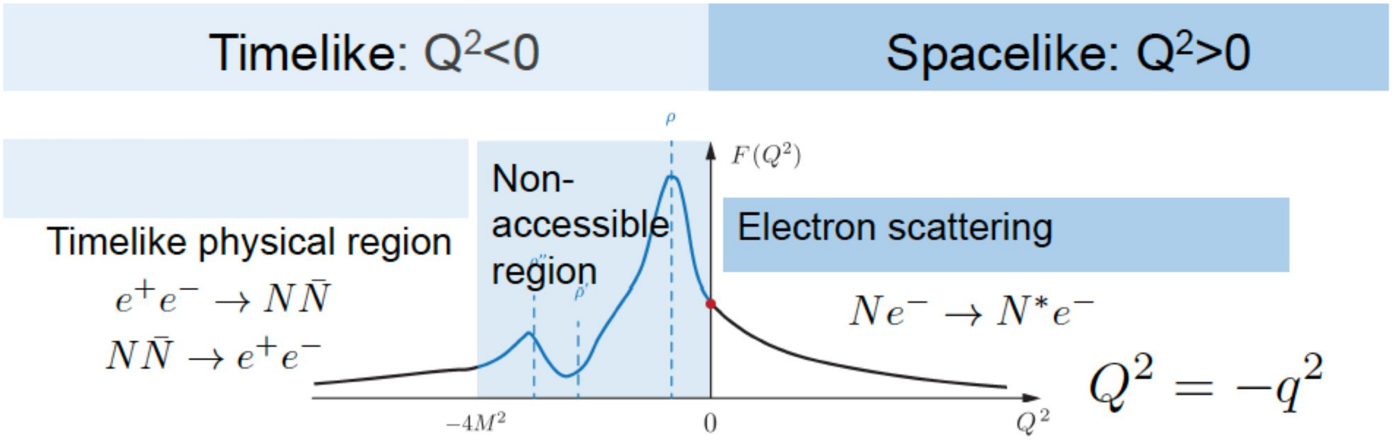
Motivation

PHYSICAL REVIEW C **99**, 064901 (2019)



- ALICE measurements of ρ^0
  - Γ = 150 MeV
  - m = 775 MeV
- Important to constrain Vector Meson Dominance Models/ Vector Meson-Baryon interactions
  - couplings; scattering param.
  - validating theoretical approaches
  - First time direct measurement
- Further the understanding of dynamically generated states N* and Δ* (pole positions) from UChPT
- Good candidate to search for signatures of chiral symmetry restoration

Vector meson nucleon coupling



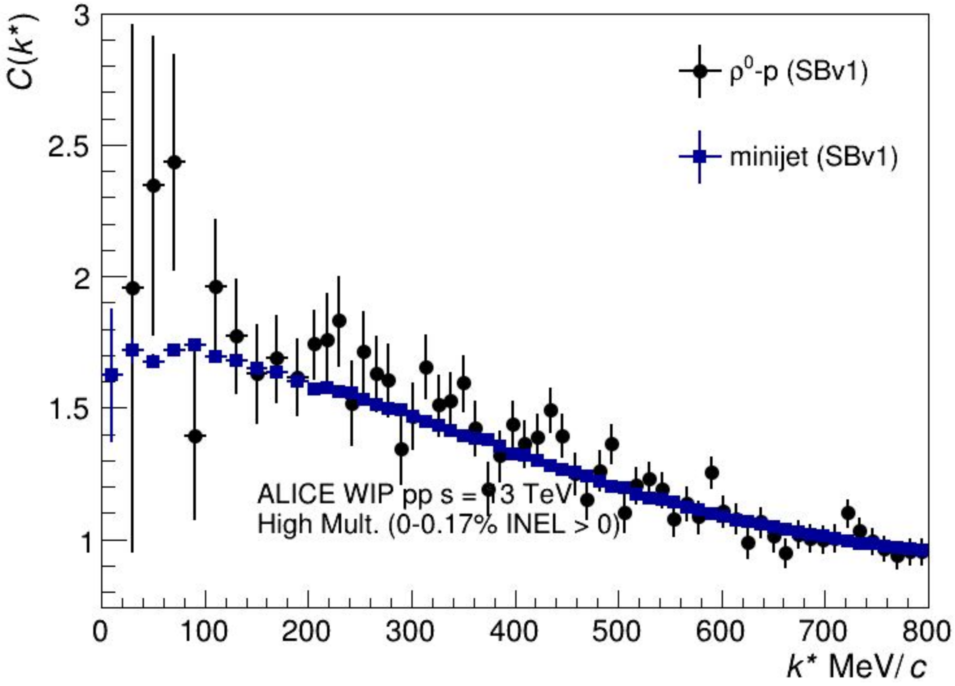
- Important to constrain Vector Meson Dominance Models/Vector Meson-Baryon interactions

- Usually probed by low energy experiments (HADES)
  - Access the time like form factor ($q^2 > 0$!)
  - Test of VDM (Rγ*N vertex) with low lying intermediate resonances N(1440), N(1520), N(1535)

- Important to understand
  - In-medium dilepton production
  - Dynamically generated states N* and Δ* (pole positions) from UChPT

MC - Plots

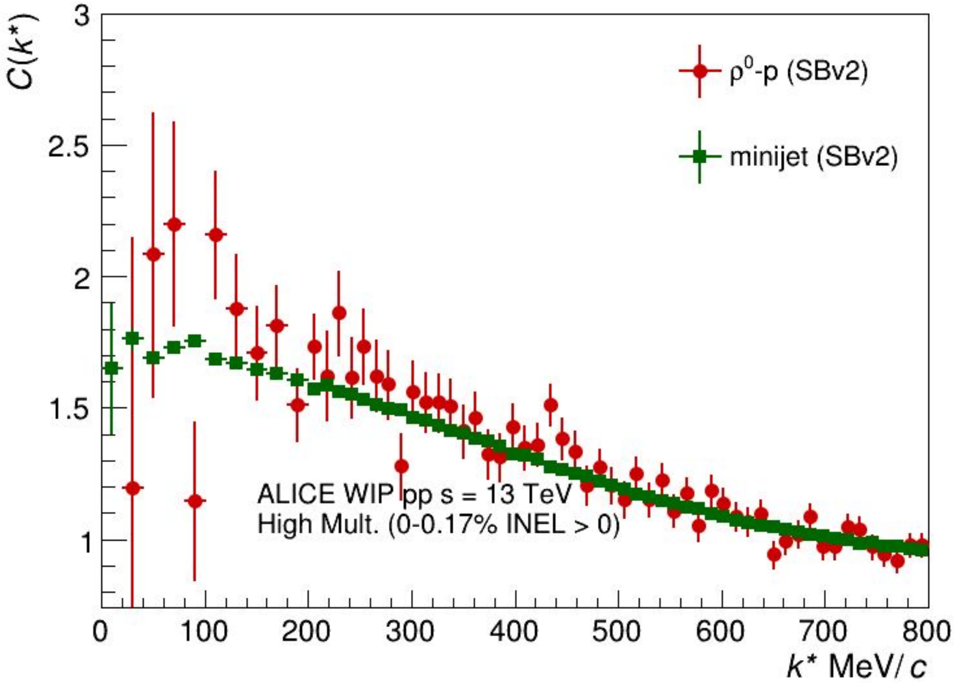
Constraining the minijet MC



- Minijet describe data for all *k**
- Divide ρ^0-p by Minijet

v1 = close
v2 = overlap

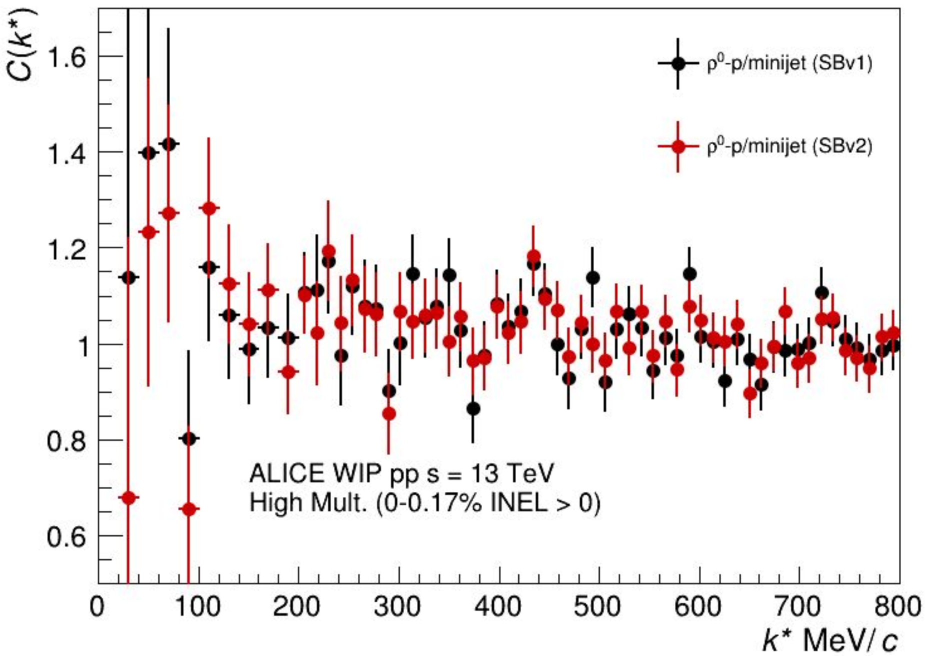
Constraining the minijet MC



- Minijet describe data for all k^*
- Divide ρ^0-p by Minijet

v1 = close
v2 = overlap

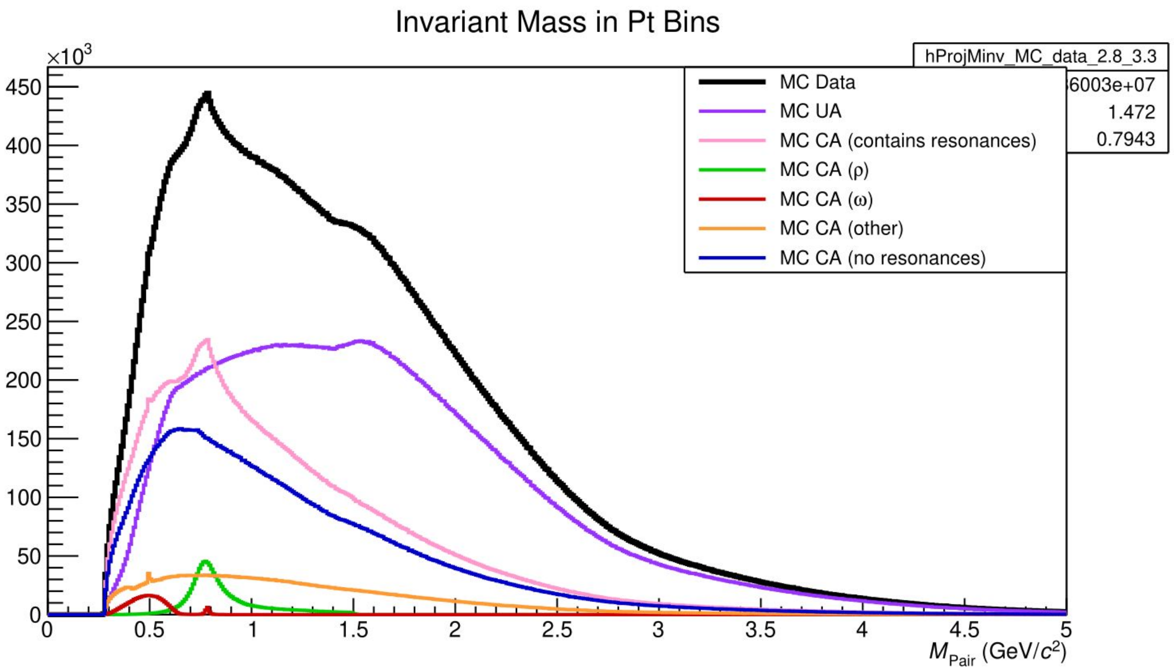
ρ^0-p without SB and divided for Minijet MC



- Consistent with unity
- No structures
- Re-run whole chain now that trains are available again (anchored to META_17)
  - include META_16 and META_18

v1 = close
v2 = overlap

Ancestor Method for ρ (MC only)



- For the fit to data MC UA and MC CA (no reso.) will be used
- In MC no f0 and f2