Baryonic Resonances at HADES

A. M. Foda

GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, Germany

NSTAR -15th International Workshop on the Physics of Excited Nucleons

Baryon Spectroscopy: Strategy

Goal: Non-perturbative QCD, resonance dynamics in the dense nuclear medium at FAIR.

How: Modular, open-source PWA framework (`AmpTools` [1]) unitary + analytic.

$\pi^- p$: K/D-Matrix Formalism

- Overlapping resonances (2nd/3rd region).
- Chew-Mandelstam unitarization + conformal Left-Hand Cuts (LHC).

pp: JüBo DCC Model

- Production couplings in baryon-meson channels.
- Dynamic Coupled-Channel; exact 2-body unitarity, $L \leq 5$, M=[1,2.5] GeV.

Framework available on GSI GitLab
Users can add their own reactions/amplitudes.

[1] M. Shepherd *et al*, https://doi.org/10.5281/zenodo.7336113

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Friday talk by F. Nerling

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Upcoming Pion Beam
($\sqrt{s} \sim 1.7\ GeV$)

Baryon-Meson couplings
($\pi^- p \rightarrow (\pi\pi/\omega/\eta)\ N$ / $K^0\Lambda$ / $K\Sigma$)

- Sparse π-beam database (PWA)
- Baryon Structure: Cascade decays, ηn couplings

E.M. Baryon Transitions
($\pi^-\ p \rightarrow n\ e^+e^-$)

- Broad range of $q^2 = (M_{ee})^2$ $\rightarrow$ Time-Like
- Confirmation for VMD (ρ, ω)
- Extract SDMEs
- Limited data available

Cold Matter Studies (C, Ag Targets)

- ω absorption, ρ spectral function
- Strangeness production
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APPROVED! 54 Shifts

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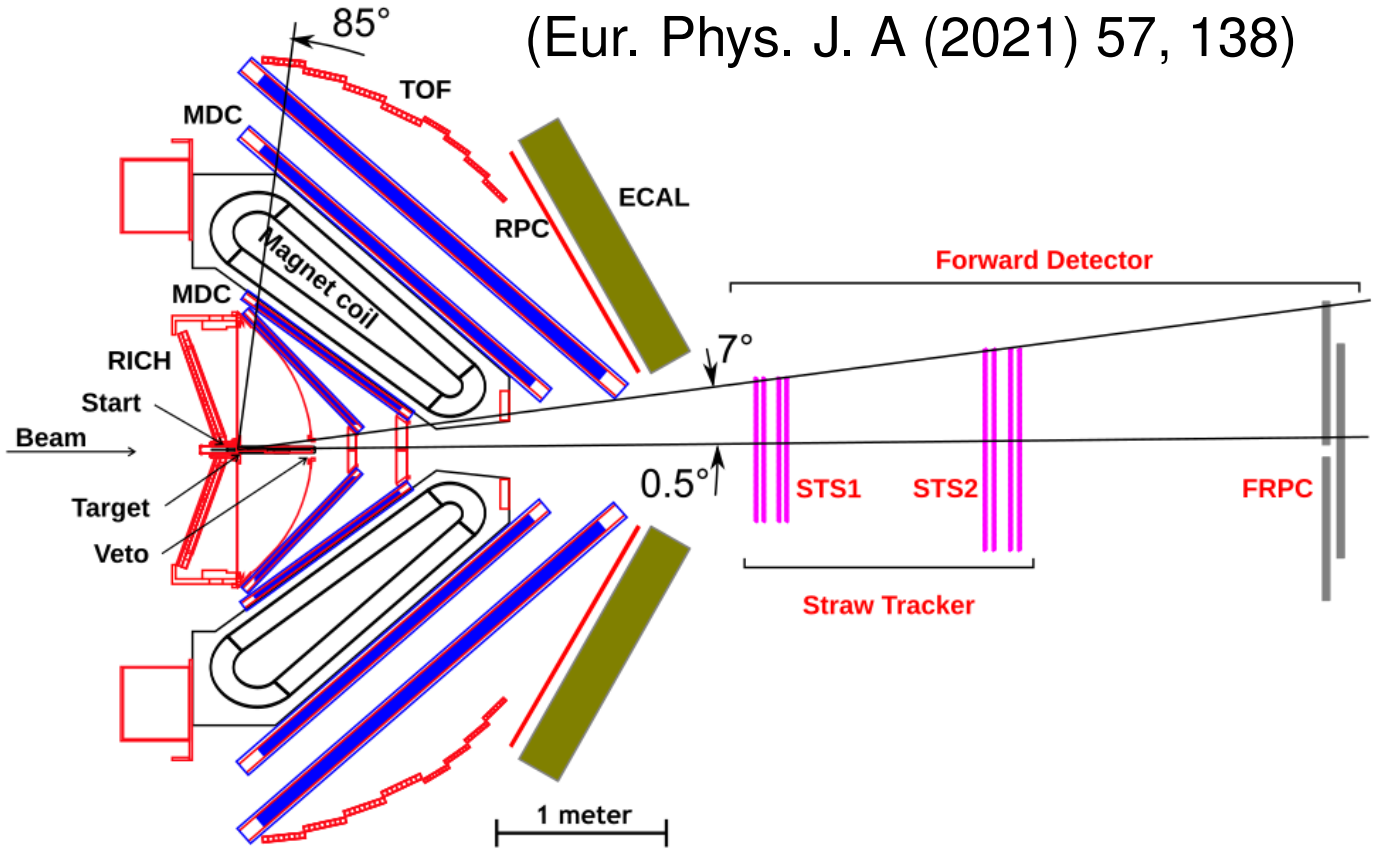
High-Acceptance Di-Electron Spectrometer (HADES)

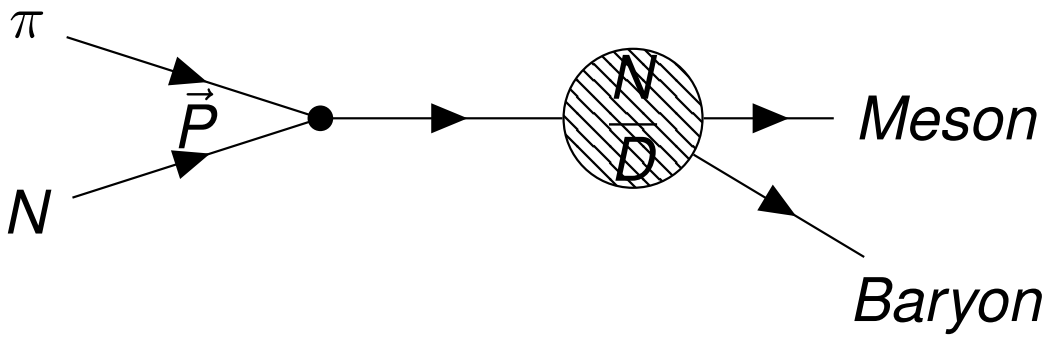
- GSI, SIS18
- π, p, Heavy-Ion beam



(Eur. Phys. J. A (2021) 57, 138)

- Acceptance: 15-85° + Forward Upgrades 1-7°
- Precise spectroscopy of γ, e^+ e^- pairs & charged hadrons

Formalism[2]



$$A_{ab} = \sum_{\alpha,\beta} P_a^{(\alpha)} d_{\alpha\alpha} D_{\alpha\beta} g_b^{L(\beta)}$$

$$\hat{D} = \hat{d}(\hat{I} - \hat{B}\hat{d})^{-1}, \qquad B(s) = B_{\mathrm{RHC}}(s) + B_{\mathrm{LHC}}(s)$$

$d_{\alpha\alpha}$ propagators (resonant & non-resonant)
g_a^{α} coupling of channel a to state α a, b, j: channels, α, β: bare states

[2] PhysRevD.84.076001

The Scattering Denominator Matrix $D(s)$

$$D_{ij}(s) = \delta_{ij}\left[(M_\alpha^2 - s) + \mathrm{LHC}(s)\right] - \Sigma_{ij}(s) \tag{1}$$

- **Left-Hand Cut Background (LHC)**: $\mathrm{LHC}(s) = \alpha + \beta(s - M_\alpha^2)$.
- **Self-Energy Loops** $\Sigma_{ij}(s)$:

$$\Sigma_{ij}(s) = \sum_{k=1}^{N_{\text{channels}}} g_{ik} g_{jk} \cdot F_k(s)^2 \cdot \left[\Omega_k(s) - \frac{1}{2}\left(\Omega_k(M_\alpha^2) + \Omega_k(M_\beta^2)\right)\right]$$

AmpTools Fit

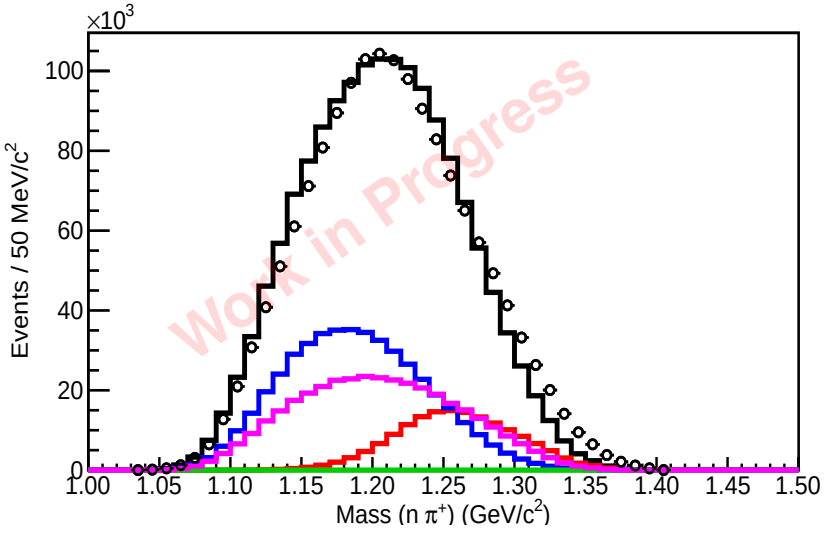
$$\pi^- p \to n\pi^+\pi^-$$

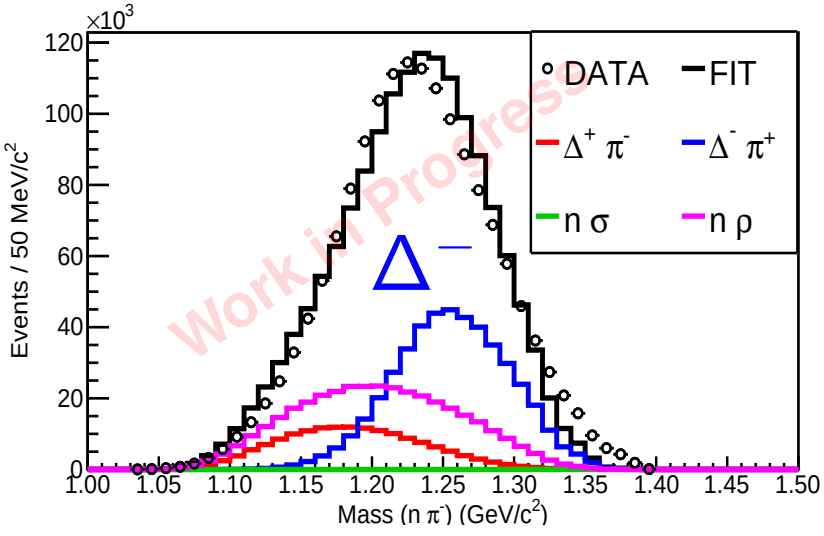
Channels: $\Delta^+\pi^-$, $\Delta^-\pi^+$, $n\sigma$, $n\rho$

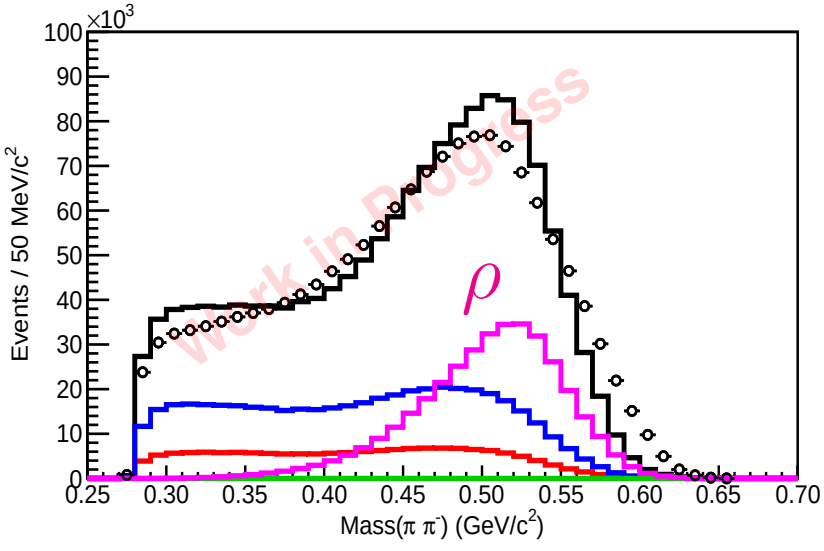
Resonances (Poles): N(1440) P_{11}, N(1520) D_{13} & N(1535) S_{11}

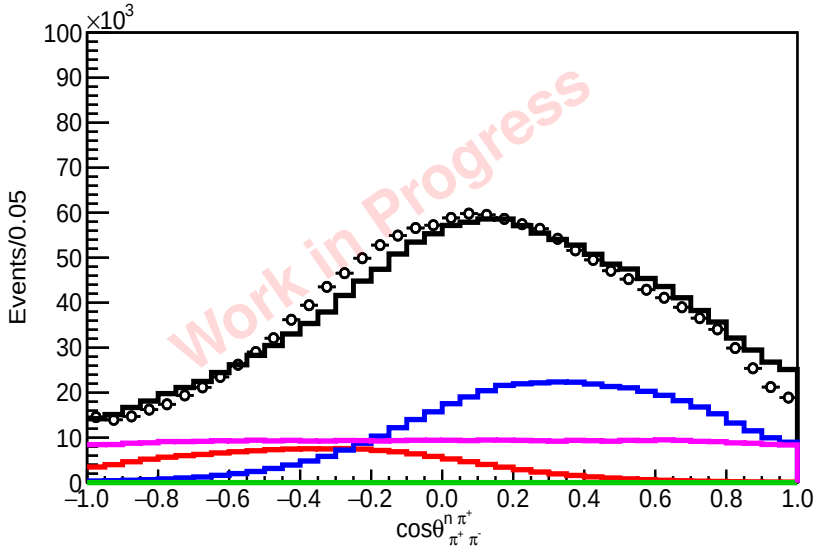
- 4 energy bins: $\sqrt{s} = 1.47 - 1.55$ GeV
- Spectral function description of Δ, σ & ρ.
- Dispersion Matrix: - bare resonance mass
  - Total width = Σ partial widths.
- Fit Parameters: production & decay couplings (energy independent).
- Left-hand cuts disabled.

Example Fit


×10^3
Events / 50 MeV/c^2
Mass (n π+) (GeV/c^2)
Work in Progress


×10^3
Events / 50 MeV/c^2
Mass (n π-) (GeV/c^2)
DATA
FIT
Δ+ π-
Δ- π+
n σ
n ρ
Δ
Work in Progress


×10^3
Events / 50 MeV/c^2
Mass(π π-) (GeV/c^2)
ρ
Work in Progress


×10^3
Events/0.05
cosθ
Work in Progress

Summary & Outlook

PWA @ HADES: Modular partial wave analysis

- K-/Dispersion-matrix amplitudes, Chew-Mandelstam self-energy, Left-Hand Cuts, Production Vector.
- **Channels:** $\pi p \rightarrow \{\pi N, \pi\Delta, \rho N, \sigma N\}$
- **In progress:** HADES 2014 data

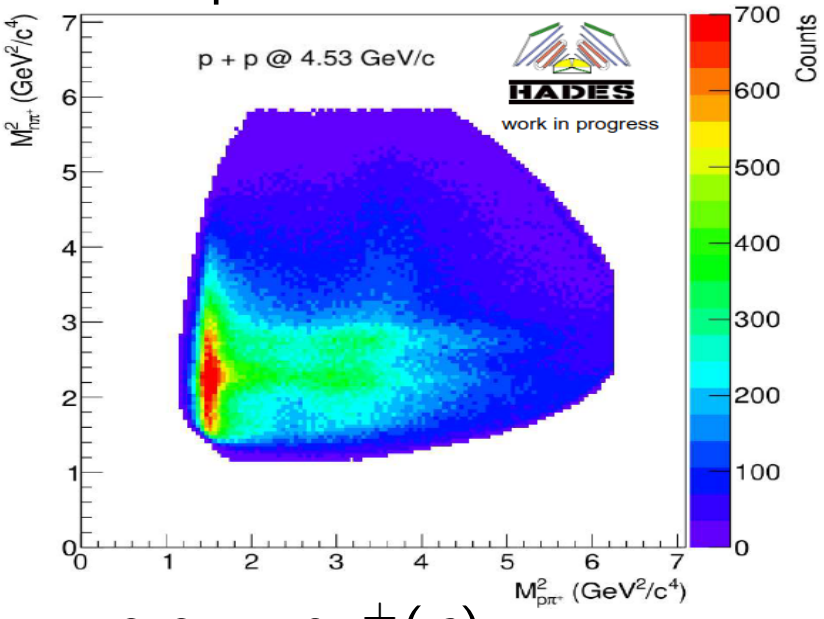
PWA @ HADES: Modular partial wave analysis

- $p\pi^-\pi^0$ data, More channels ($\pi^0\Delta^0, \eta N$)
- Fine Tune 2014 Fit: Left-hand cuts
- Covariant Tensor angular distribution

Proton-Proton Reactions

- **Exclusive production** N^* Δ**:** Differential cross-section & coupling strengths.
- **Rescattering effects:** Resolve overlapping contributions.

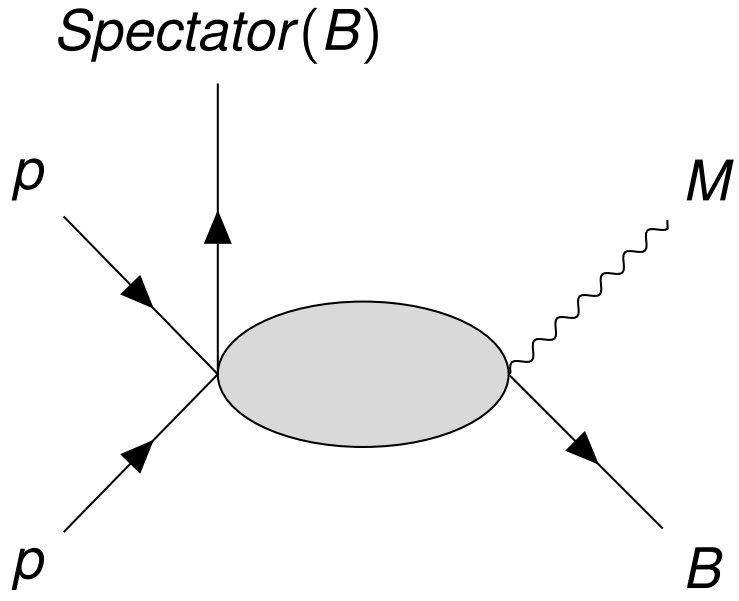
Adapted from S. K. Sahu



p p $\rightarrow p\pi^+(n)$

Julich-Bonn Model

- JuBo: Dynamical coupled-channel (DCC) model for meson-baryon reactions.
- πN, ηN, $K\Lambda$, $K\Sigma$, $\pi\Delta$, ρN, σN [3].
- Partial Waves: Up to L=5, Resonances: 1.07-2.5 GeV
- Exact 2 body unitarity, 3-body unitarity through $\sigma N, \pi\Delta, \rho N$.
- Left-hand cuts: *t*- and *u*-channel exch. (ρ, σ, K^*, N, Λ, Σ).

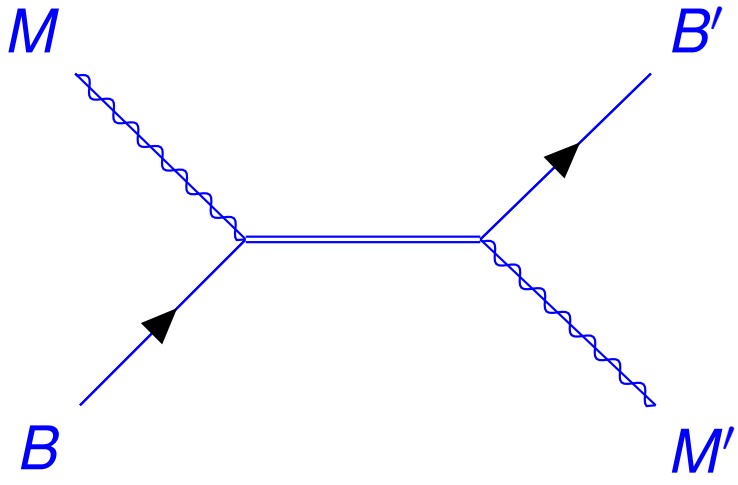


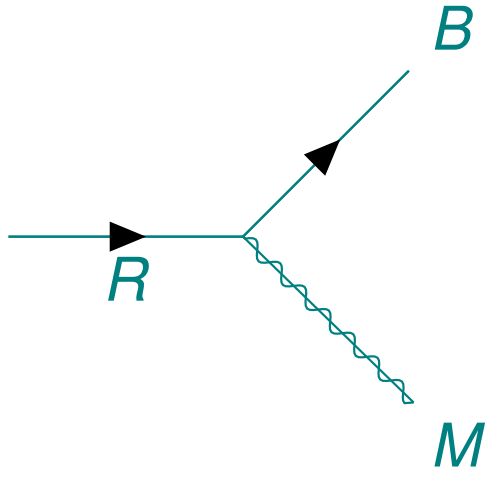
[3] doi:10.1140/epja/s10050-022-00852-1

Amplitude Structure

- The total amplitude is constructed as:

$$\mathcal{A}(L, I, J, s, E) = \alpha_0 + \alpha_1 (E - E_{\text{thr}}) + \sum_{k}^{\text{Channels}} \alpha_k \Gamma_k(E) + \sum_{i=1}^{\text{Resonances}} \gamma_i \Gamma_i^{(R)}(E)$$

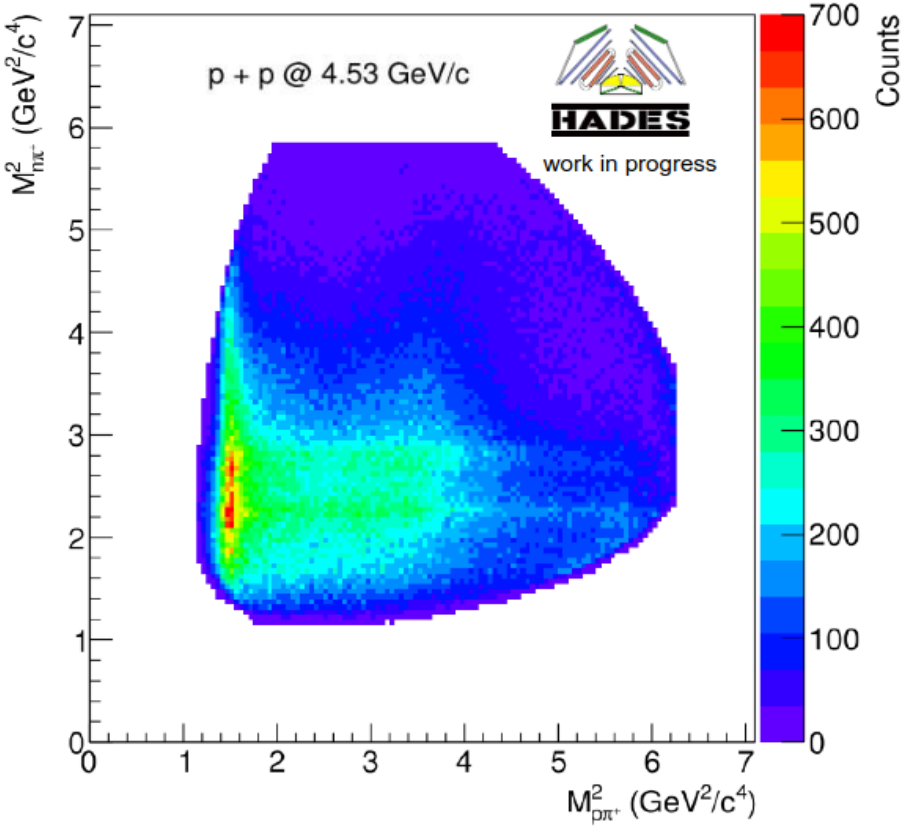




JuBo Model - Proof of Concept

- $pp \rightarrow p\ \pi^+$ (n) ($\sqrt{s} = 3.47$ GeV).
- $p\pi^+$: P_{33}, P_{31}
  $n\pi^+$: S_{11}, P_{11}

Preliminary Fit



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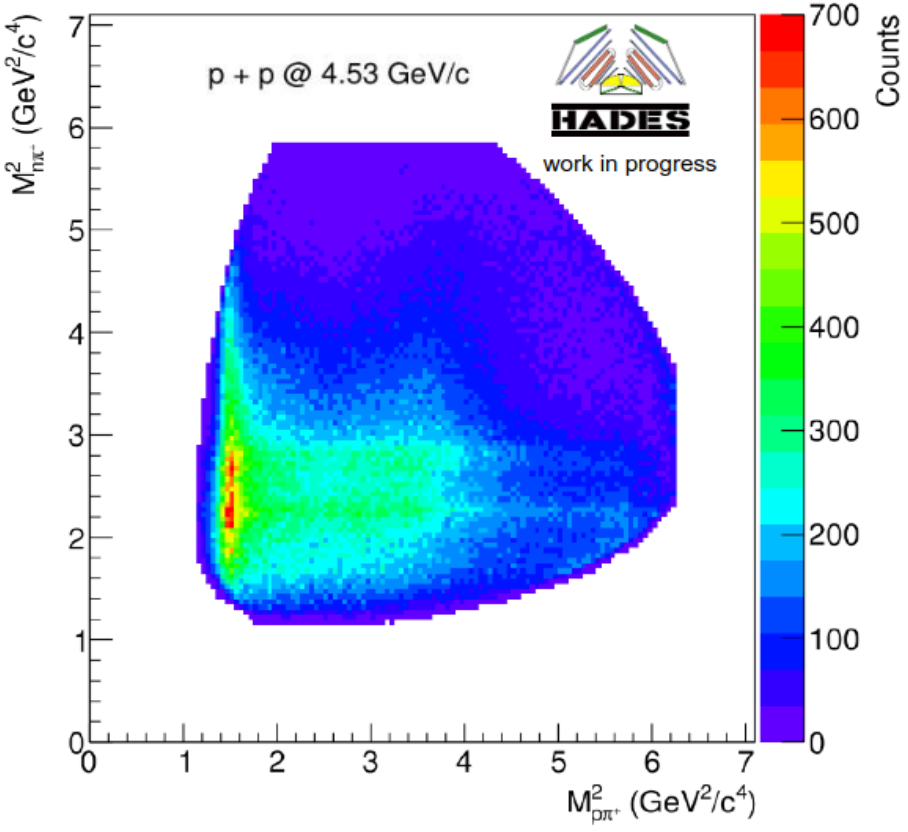
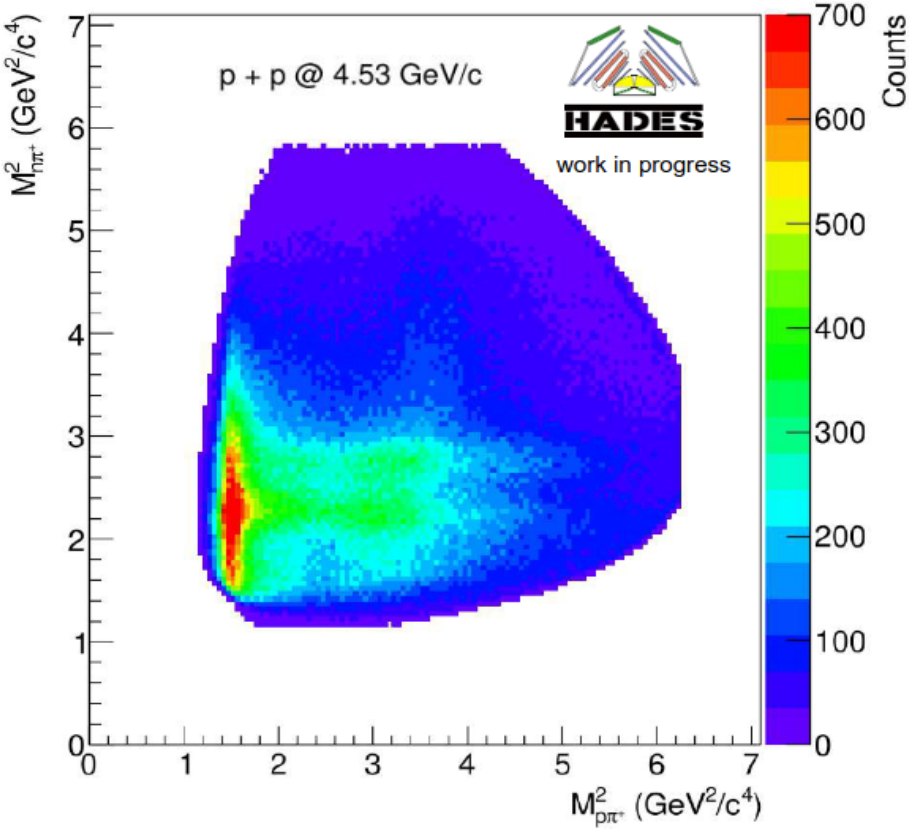


Data



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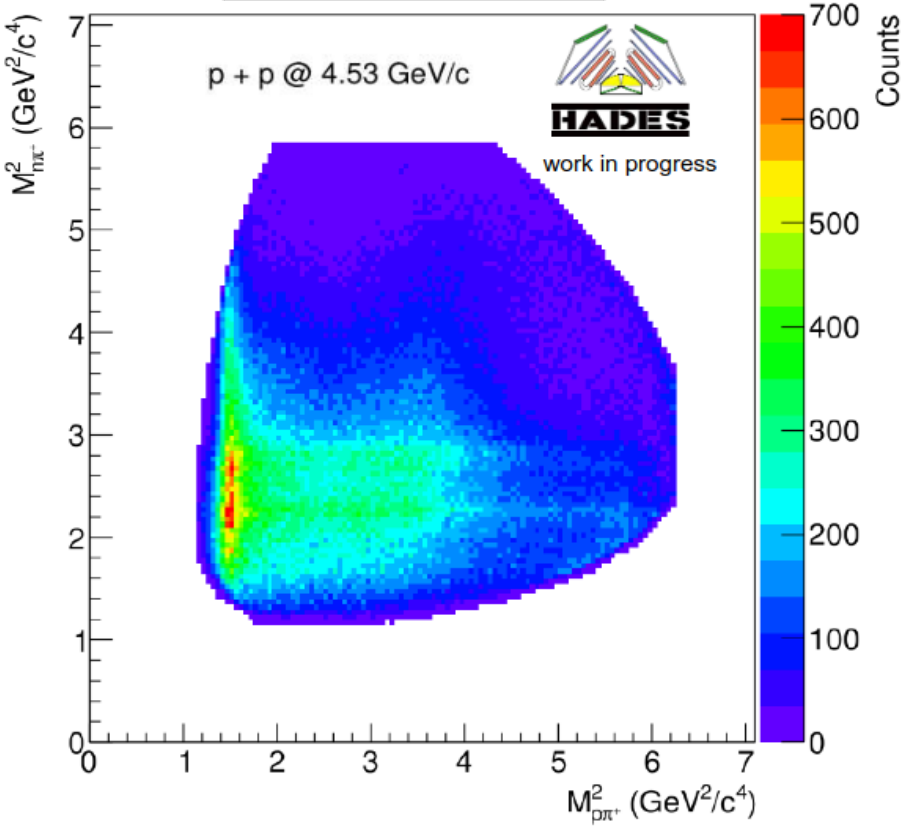
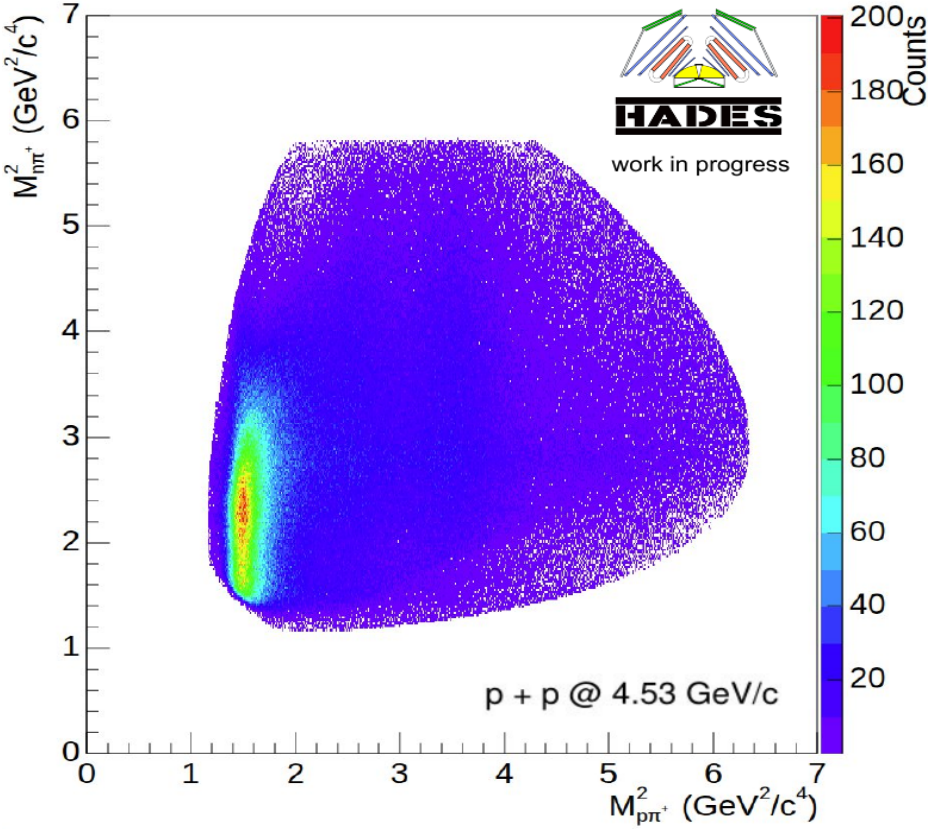


SMASH MC



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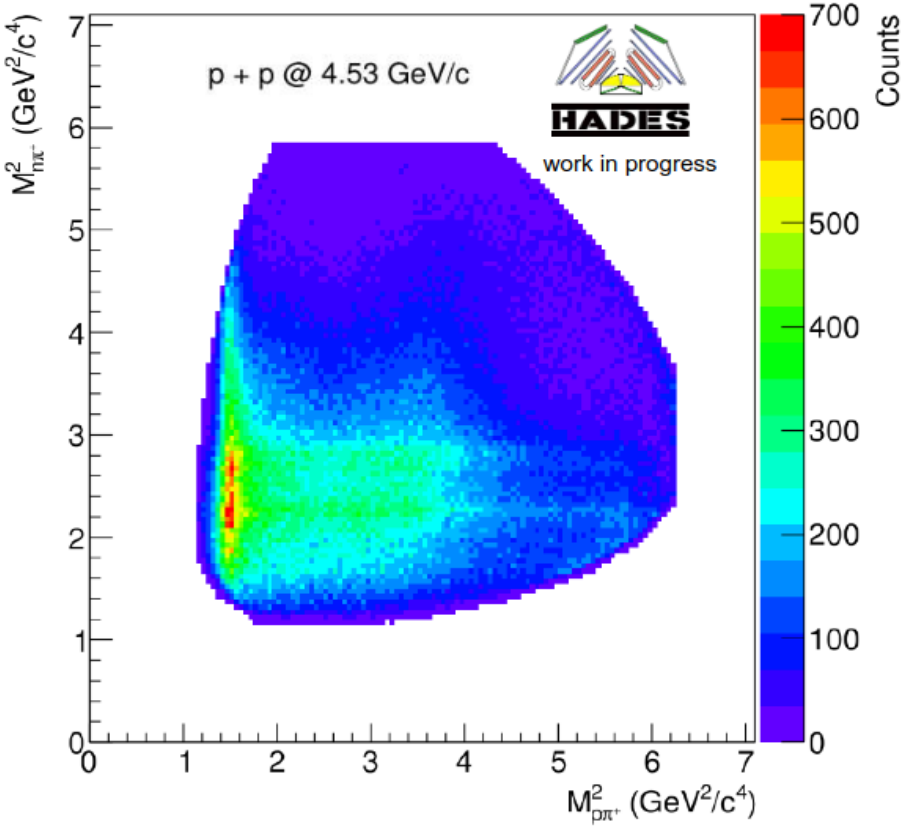
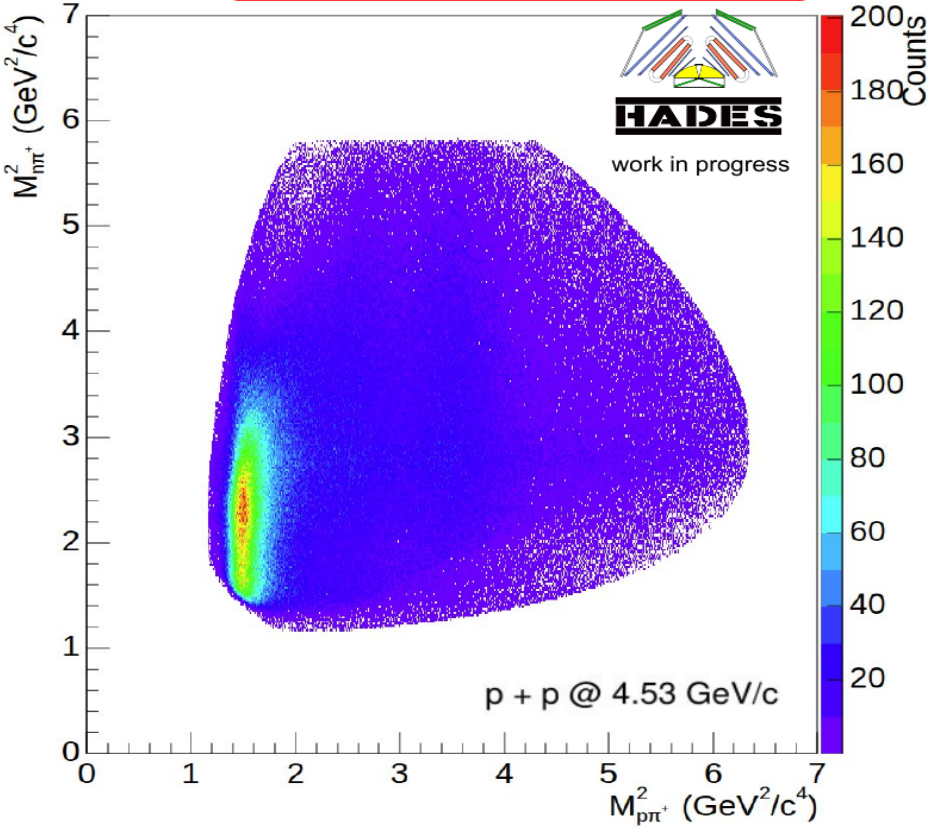


Tue. Talk by S. K. Sahu



Summary & Outlook

JuBoAmp: Event-by-event unitary analytic low comp cost coupled-channel analysis.

- **Channels:** $pp \to \{\pi N, \eta N, K\Lambda, K\Sigma, \pi\Delta, \rho N, \sigma N\}$
- **Resonance Range:** 1.07–2.5 GeV; Partial waves $L = 5$
- **In progress:** pp(@4.5 GeV)$\to$: $\{p\pi^+n, p\pi^0p, \Delta K\Lambda\}$

JuBoAmp: Event-by-event unitary analytic low comp cost coupled-channel analysis.

- Angular distribution
- $\pi^0 p$, $K^+\Lambda$, ηN, ωN

Status & Takeaways

PWA @ HADES (Modular PWA)

- **Status:** Preparation for upcoming π-beam @ 1.7 GeV
- **Scope:** πp scattering into πN, $\pi\Delta$, ρN, σN channels
- **Verification:** Actively fitting HADES π-beam data @ 1.5 GeV

JuBoAmp (Unitary Coupled-Channel)

- **Status:** Fast event-by-event fits for baryon-meson channels
- **Scope:** up to 2.5 GeV ($L = 5$; 7 channels)
- **Preliminary:** pp $\rightarrow$ p π^+ (n)

Next Steps

PWA @ HADES

- Expand to $p\pi^-\pi^0$ data include ($\pi^0\Delta^0$, $p\rho^-$)
- Fine-tune fits@1.5 GeV (left-hand cuts) & implement covariant tensor formalism

JuBoAmp

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HADES Talks A. Koperwas-Wladyszewska V. Kladov

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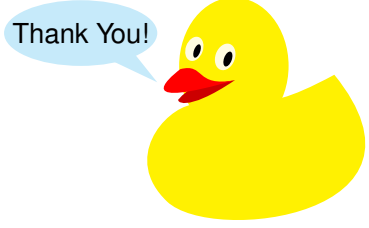

HADES Talks A. Koperwas-Wladyszewska V. Kladov

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