# Study of exclusive η meson production in proton-proton collisions with HADES

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Outline

1. Motivation
2. HADES detector
3. Analysis procedure overview
4. Data - SMASH comparison
5. Data - Eff. Lagr. models comparison

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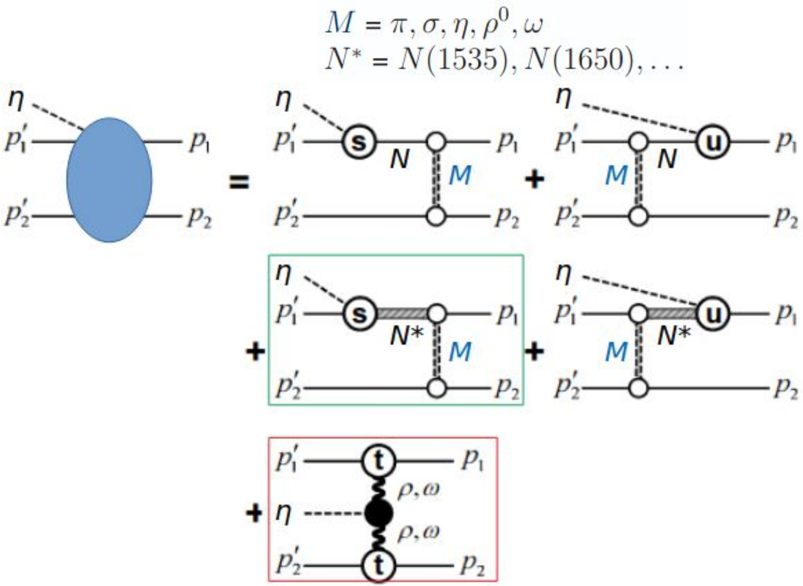
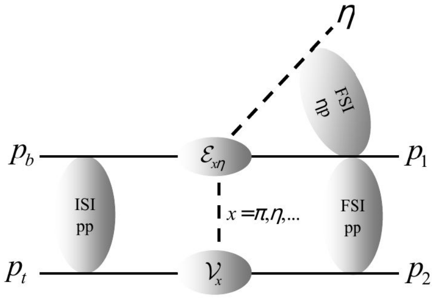
# Description of the η production in pp collisions

- Effective Lagrangian approach
- Exchange of mesons (π, ρ, ω, σ, η)
- Intermediate baryon resonances (e.g. N(1535))
- Coupling constants and form factors fitted to data or derived from other models
- Interference effects: coherent sum of amplitudes
- Initial/Final State Interactions impact




[Phys. Rev. C **112**, 015201 (2025)]




[Phys. Scr. **73** 663 (2006)]

# Motivation - analysis objectives

Measure total and differential cross-sections for exclusive $\eta$ production:

- Study resonance contribution, excitation mechanism, FSI, ISI
- Input for heavy-ion transport models (GIBUU, SMASH, RQMD, … )
- Test models prepared by IFJ PAS theory group - important in the context of future CBM@FAIR experiments

Variables of interest:

- Invariant masses
- Dalitz plot of $pp \rightarrow pp\eta$
- $\eta$ production angle
- Helicity angles
- Gottfried-Jackson angles
- Momenta and transverse momenta of protons and $\eta$

# Previous measurements

Some of the most recent measurements:

- WASA@COSY (1.4, 2.0 GeV)
- DISTO Collaboration (2.115, 2.5, 2.85 GeV)
- HADES Collaboration (2.2, 3.5 GeV)
-

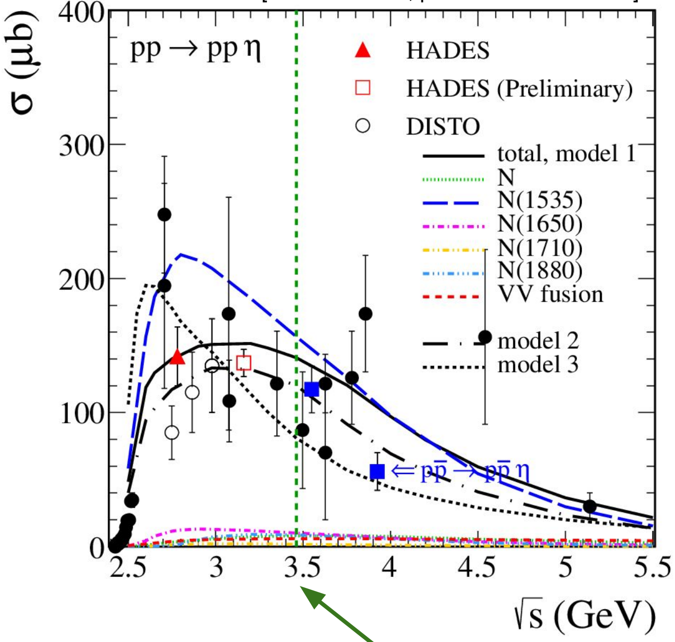
Close to threshold:

- ❑ FSI/ISI needed to take into account
- ❑ very important role played by baryonic resonances, mostly N(1535)
- ❑ Depending on model: ρ, ω, η, σ, exchanges, destructive ρ/π interference
  → **Excitation mechanism is still open question**

Higher energies (>20 GeV):

- ❑ pomeron-pomeron exchange
- ❑ reggeon exchange
- ❑ diffraction processes

[P. Lebiedowicz, private communication]



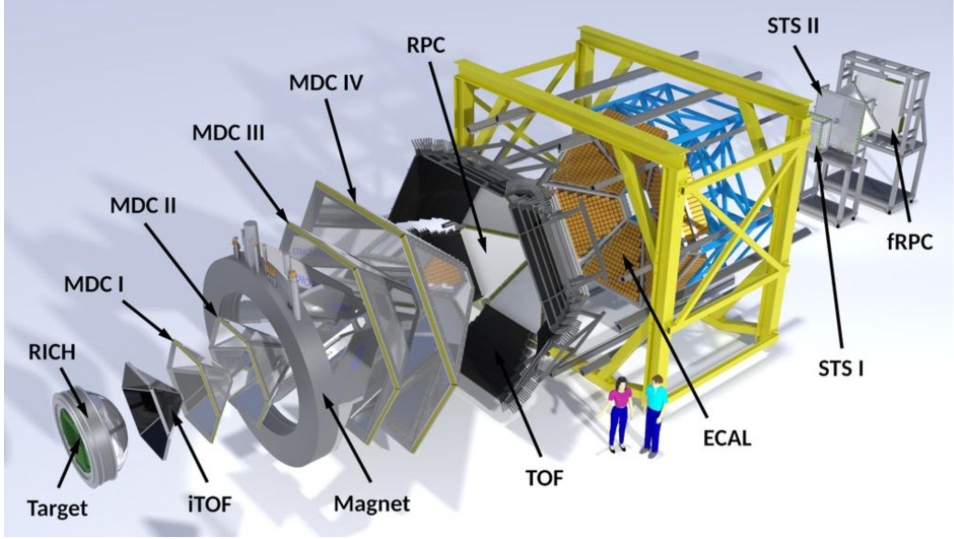

**This measurement: 4.5 GeV** (√s = 3.46 GeV)
→ far from threshold, probes a kinematic region that has been poorly studied so far - important for testing theoretical models

# HADES Detector

## **H**igh **A**cceptance **D**i-**E**lectron **S**pectrometer

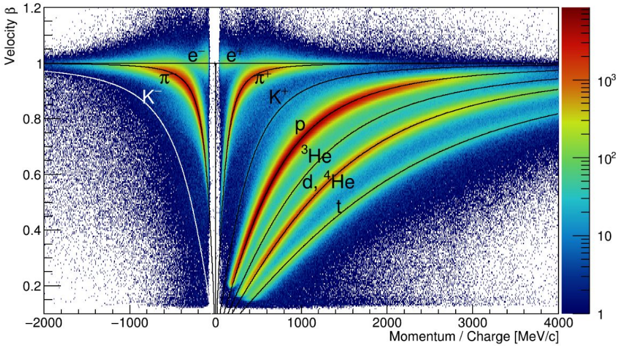
Fixed-target experiment at the SIS18 (GSI), utilizing π, p, d, and heavy-ion beams

- **Large acceptance**: $\phi \in [0°, 360°]$ and $\theta \in [1°, 6°] \cup [18°, 85°]$
- **Start + RPC/TOF** - velocity measurement
- **RICH** - lepton identification (e±)
- **MDC + Magnet** - momentum determination
- **ECAL** - e± and γ energy measurement

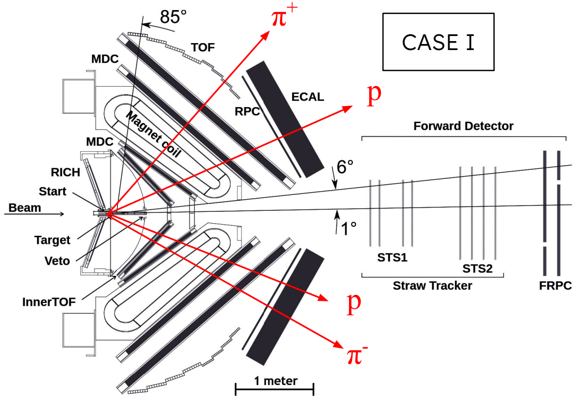


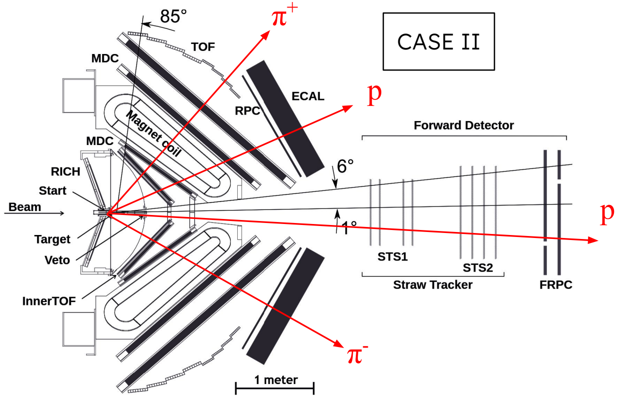

## P+p 2022 run:

- Beam kinetic energy = 4.5 GeV ($\sqrt{s}$ = 3.46 GeV)
- Luminosity = 5.66 $pb^{-1}$
- Forward Detector added



# Analysis overview




## Study $\eta$ production in channel:

$$pp \rightarrow pp\eta \rightarrow pp\pi^{+}\pi^{-}\pi^{0}$$

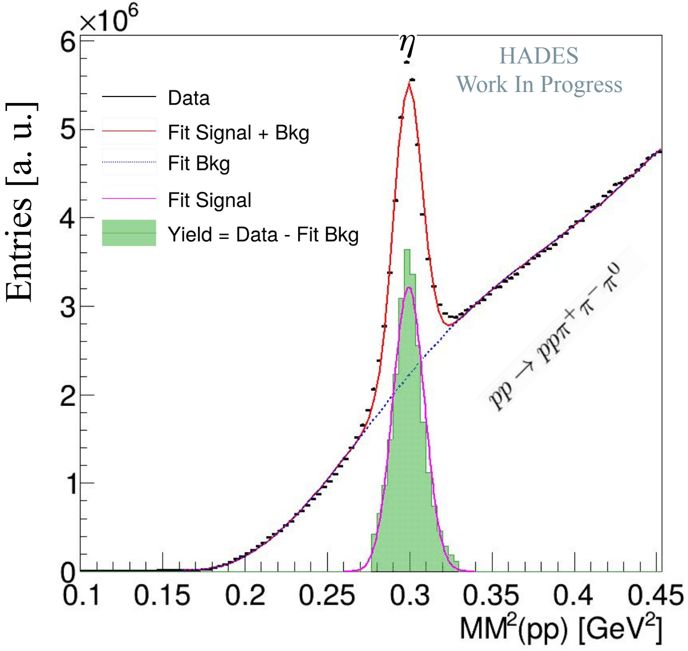
**[Channel which offers greatest statistic]**

$\pi^0$ obtained from kinematic fit (missing particle constraint)

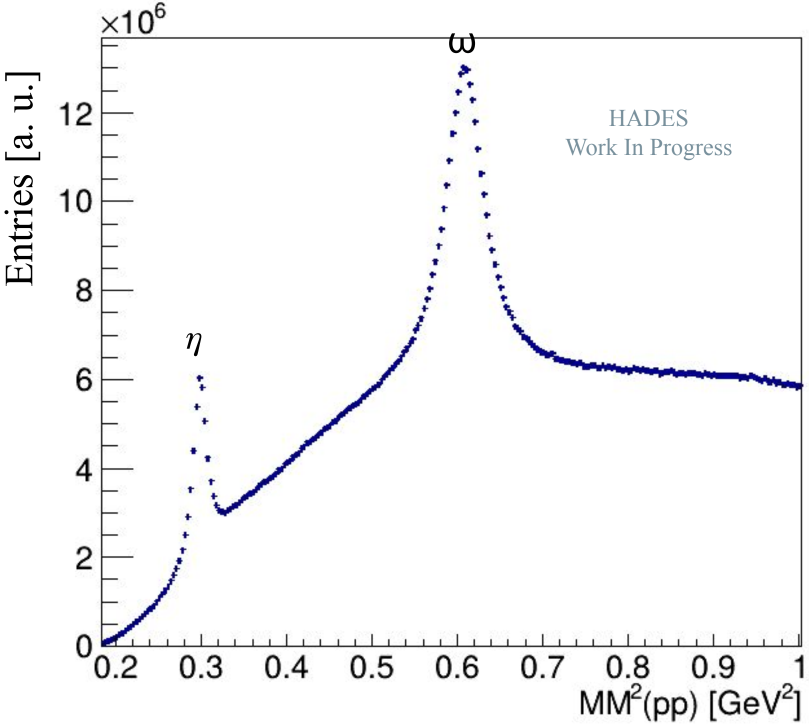
- 4-particle hypothesis: 2 protons, $\pi^+$, $\pi^-$
- Particle identification:
  - In Magnetic spectrometer - beta vs momentum relationship
  - In Forward Detector - assumed to be protons
- Two topological cases:
  - Both protons in Magnetic Spectrometer
  - One proton in MS, one in Forward Detector **[Larger detector acceptance compared to previous HADES pp measurement]**
- Using kinematic fit with $\pi^0$ missing mass and total 4-mom conservation constraints **[Bkg suppression and improvement of mass resolution]**
- Correcting Data for detector Acceptance x Efficiency (3D matrices, SMASH-based) **[Possibility to study reaction in 4π]**

# Background Subtraction

A pol5 (background) + Gaussian (signal) function is fitted to the data corrected for acc x eff




(Outlook) The analysis procedure also provides a good opportunity to study exclusive ω production



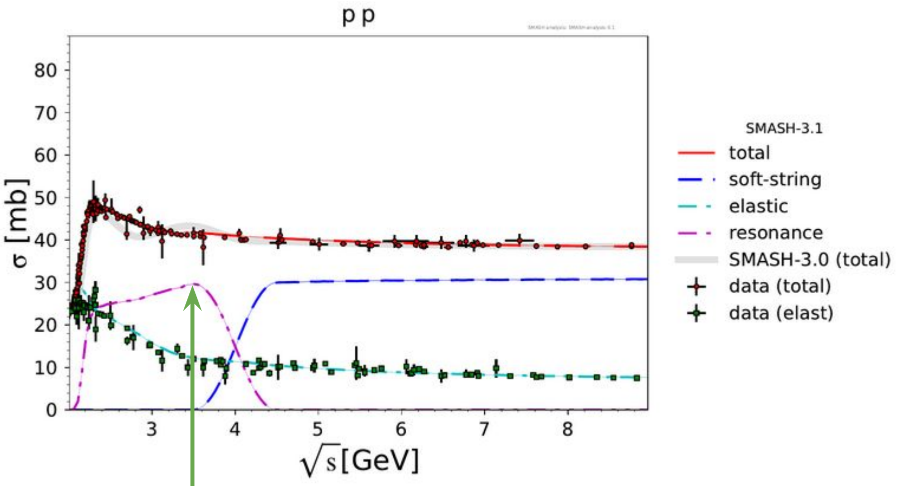
# Simulation reference: SMASH

## Relativistic hadronic transport model

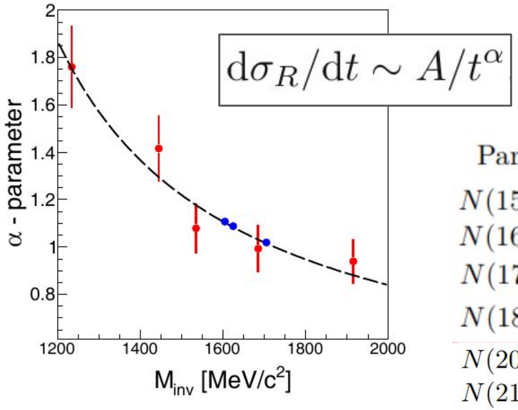
(Phys.Rev.C 94 (2016) 5, 054905)

In context of eta production in pp at √s = 3.46 GeV

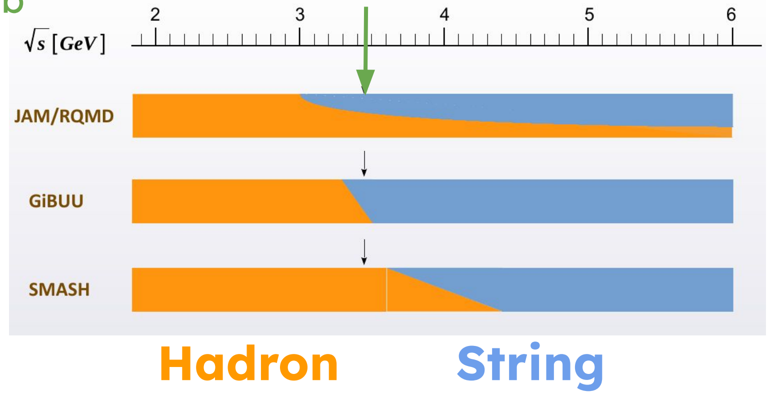
- Production always via baryon resonances
  $pp \to pN^* \to pp\eta \to pp\pi^+\pi^-\pi^0$
- N* incoherent sum
- Parametrization of angular distribution production of N* obtain from experimental measurements (Eur. Phys. J. A (2014) 50: 82)




√s = 3.46 GeV (4.5 GeV) $\sigma_{\text{total pp inelastic}}$ = 30 mb




| Particle | $J^P$ | $N\eta$ | DECAY MODES Fraction $(\Gamma_i/\Gamma)$ $N\eta$ |
|---|---|---|---|
| $N(1535)$ | $1/2^-$ | **** | 30–55 % |
| $N(1650)$ | $1/2^-$ | **** | 15–35 % |
| $N(1710)$ | $1/2^+$ | *** | 10–50 % |
| $N(1895)$ | $1/2^-$ | **** | 15–45 % |
| $N(2060)$ | $5/2^-$ | * | |
| $N(2100)$ | $1/2^+$ | * | |




Significant uncertainty of BR, σ(pp→pN*), α parameter

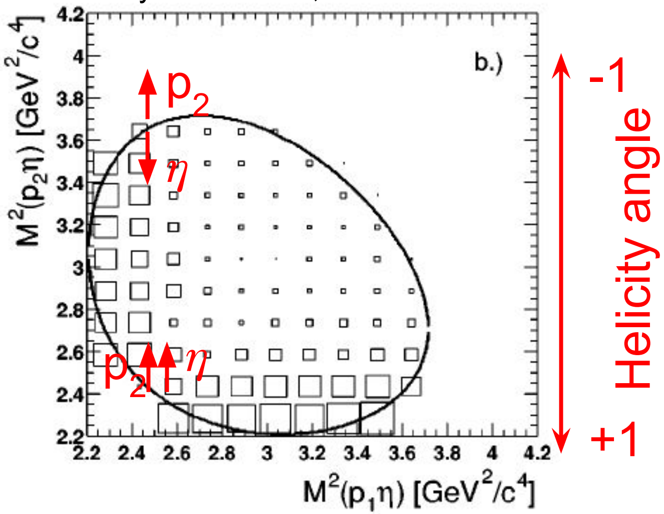
# Observables sensitive to the production mechanism

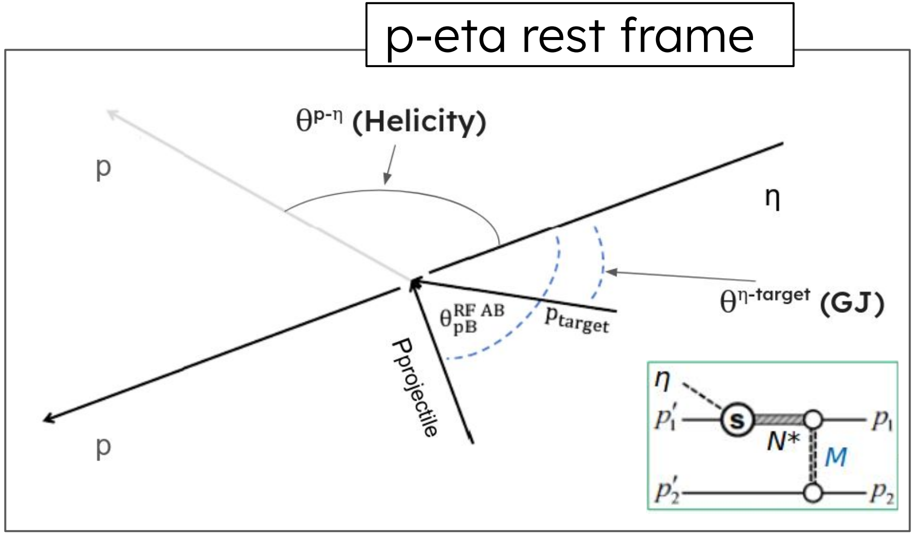
**Gottfried-Jackson angles** - connect entrance and exit channels, sensitive to 2-body scattering (to the spin and parity of baryon resonances)

**Helicity angles** - quantify relations within the exit channel, special projection of Dalitz plot:

- uniformly populated Dalitz plot → isotropic helicity angle distribution
- physical, kinematical effects modifying Dalitz plot → anisotropic helicity angle distribution

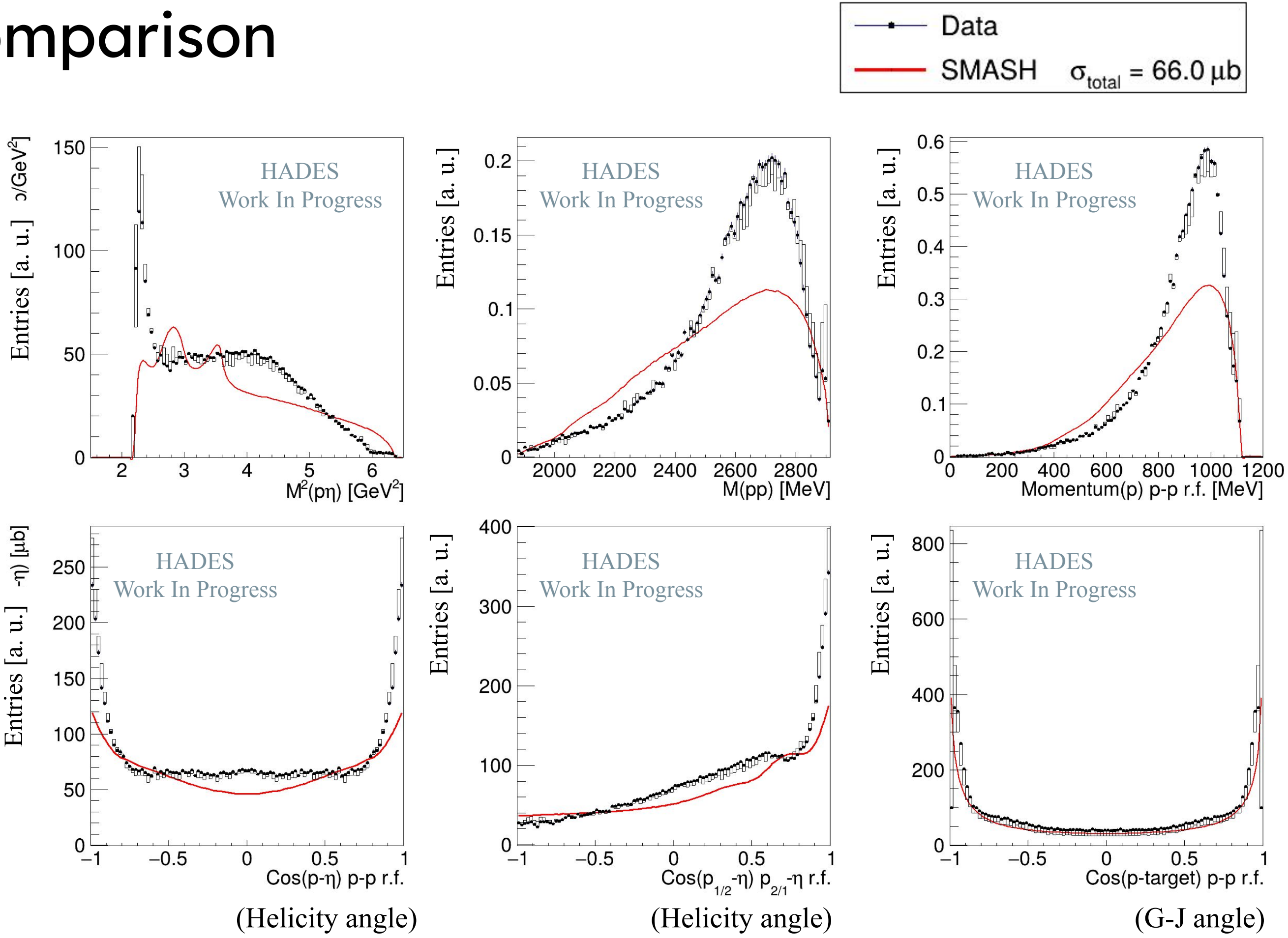
Phys. Rev. C **69**, 064003



# Data - SMASH comparison

**SMASH** underestimates the N(1535) contribution, further deviations seen in other distributions, however it provides reasonable description of Helicity and G-J angles



# Effective Lagrangian models

P. Lebiedowcz [Phys. Rev. C **112**, 015201 (2025)]

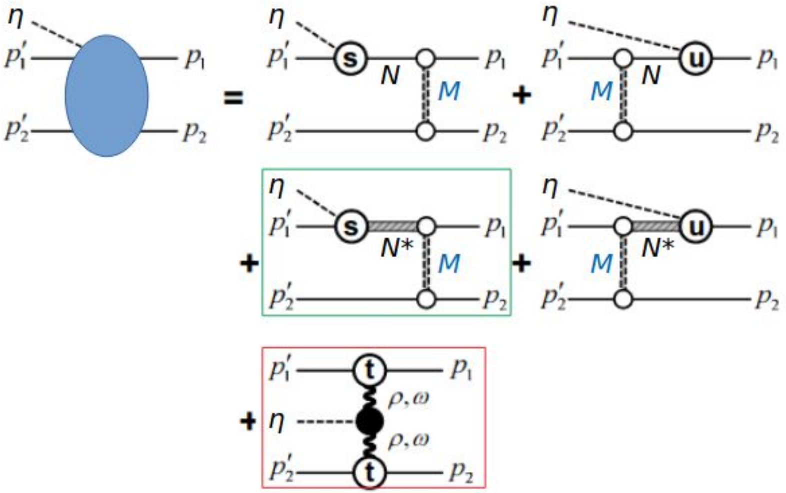
Three models developed by IFJ theory group:

- Effective lagrangian approach
- Production via N(1535), N(1650), N(1710) and N(1880), VV-fusion
- Coherent sum of all contributions

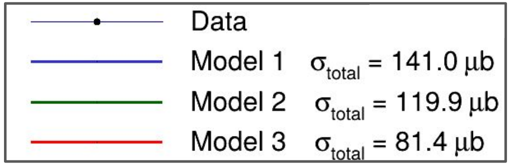
➢ **Model 1** - ρ meson exchange only, pseudoscalar couplings for all N* [$\sigma_{total}$ = 141.0 μb]

➢ **Model 2** - ρ meson exchange only, pseudoscalar couplings for N(1535), N(1650), pseudovector couplings for N(1710), N(1880) [$\sigma_{total}$ = 119.9 μb]

➢ **Model 3** - ρ, $\pi^0$ and η mesons exchange, pseudoscalar couplings for all N* [$\sigma_{total}$ = 81.4 μb]

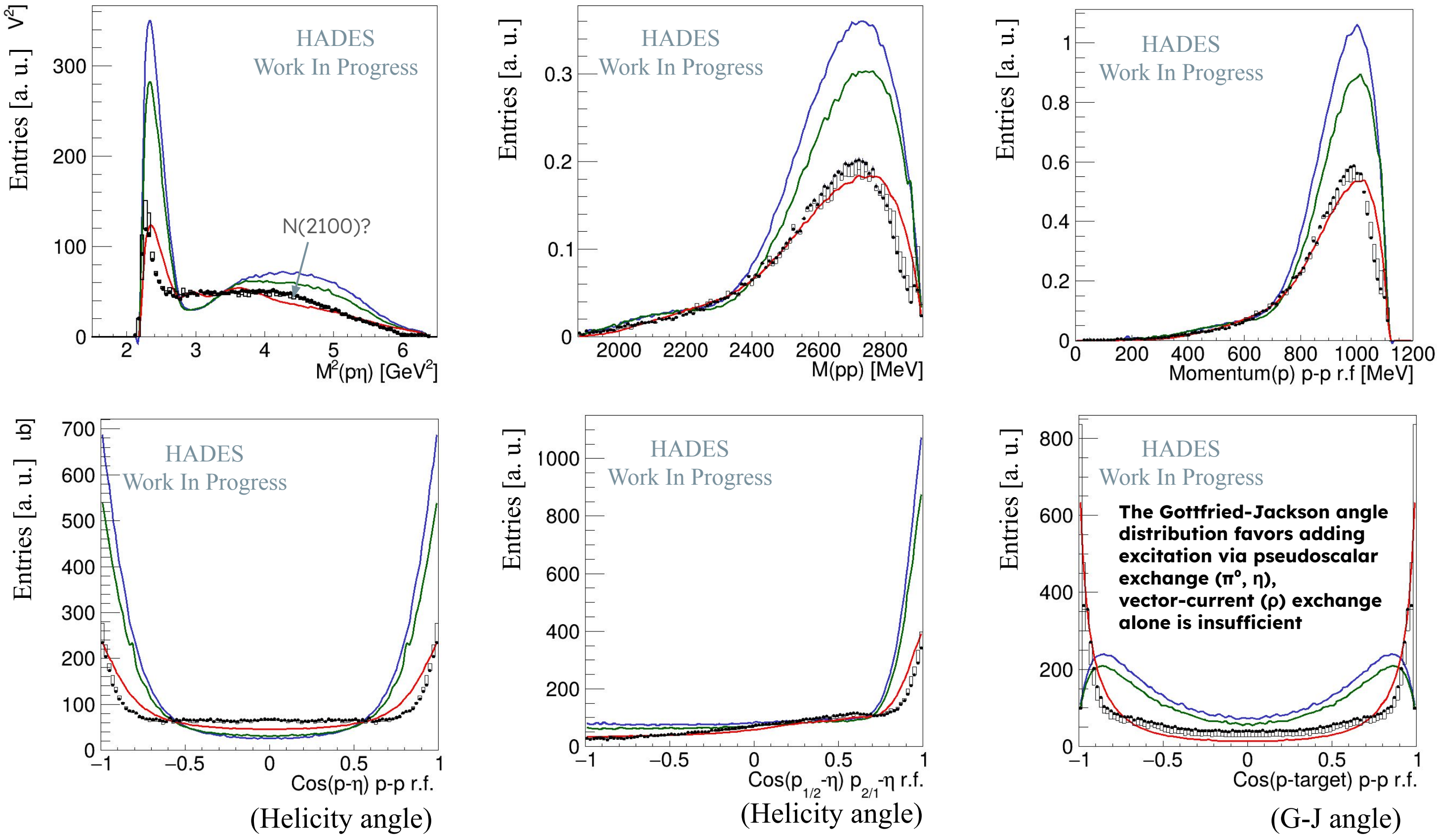


# Data - Effective Lagrangian models comparison




Data favor Model 3, particularly in the G–J angular distribution, with better overall agreement across all distributions

Adding N(2100) may further improve agreement with the data.



# Summary & Outlook

## Summary

- Ongoing analysis favors Model 3: η production proceeds via an excitation mechanism that requires pseudoscalar meson exchange ($\pi^0$, η), not just vector (ρ) exchange.
- Data may indicate the need for an including N(2100) contribution.
- Models 1 and 2 (ρ-exchange only) fail to describe the data, demonstrating that vector-current exchange alone is not a sufficient description of the reaction.
- SMASH significantly underestimate N(1535) contribution

## Outlook

- Determine total cross-section with systematic error estimation
- Study Dalitz plots of pp → ppη for deeper insight into baryonic resonance contributions.
- Study polar angle, momenta, and transverse momenta of the proton and η for further insight into the excitation mechanism.

69. Studies of exclusive production of $\eta'$ and $f_1(1285)$ mesons in $p + p$ collisions at 4.5 GeV with HADES
Yehor Bondar (Institute of Nuclear ...
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