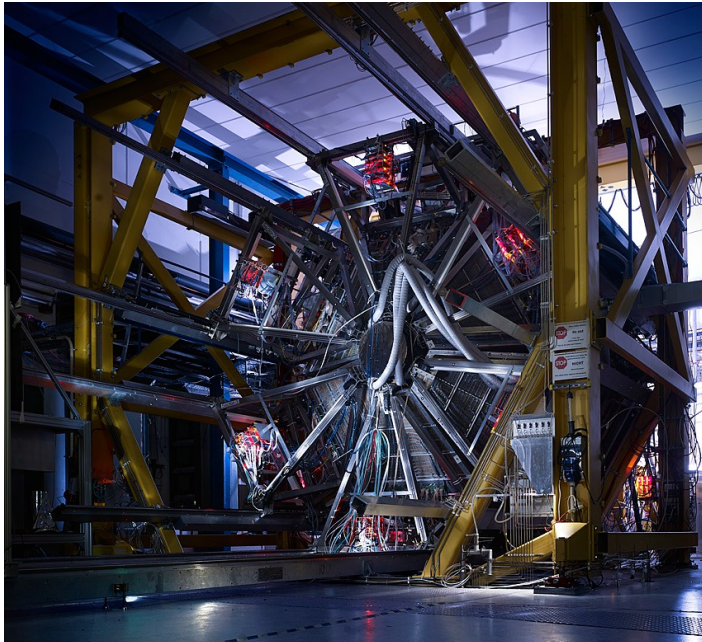


Studies of Baryon Transition Form Factors with HADES

NSTAR2024

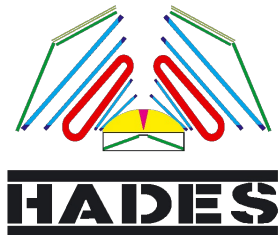


GSI Helmholtzzentrum für Schwerionenforschung



OUTLINE:

- 1) Motivations of the HADES experiment.
- 2) The HADES detector.
- 3) Electromagnetic structure of baryons.
- 4) Results on baryon time-like transition form factors from proton- and pion-induced reactions.
- 5) Studies of hyperons transition form factors.
- 6) Summary and outlook.



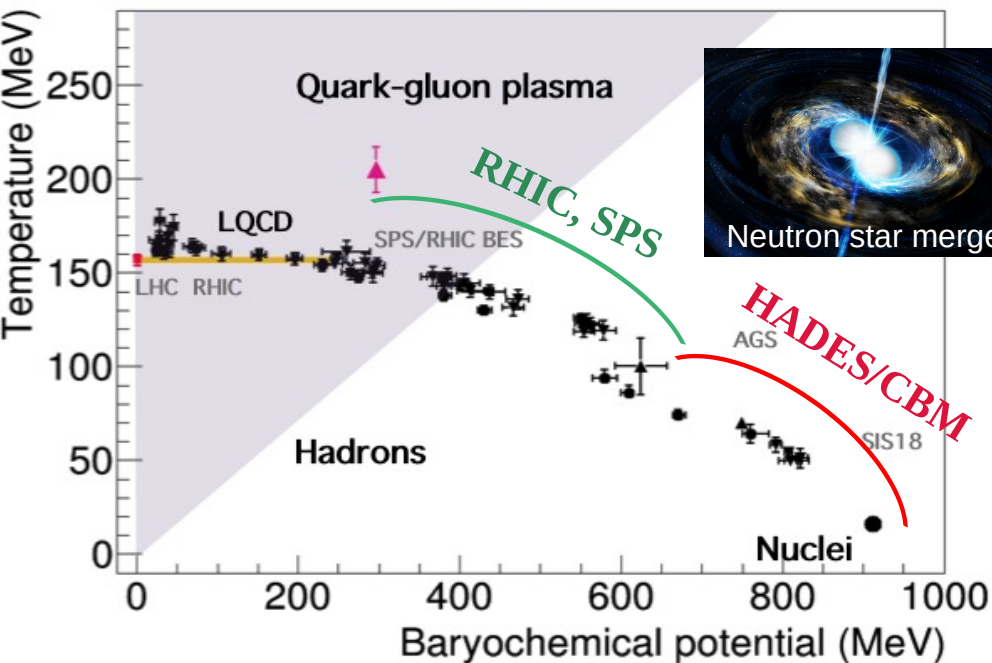
Izabela Ciepał



THE HENRYK NIEWODNICZAŃSKI
INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES



Motivations



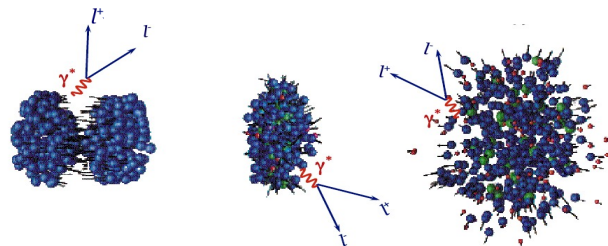
- Baryon dominated matter
- Similar conditions as expected in neutron star mergers
HADES, Nature Phys. 15, 10, 1040 (2019)

- Hadron properties in hot and dense nuclear matter
- Electromagnetic structure of hadrons
- **Role of vector mesons, baryonic resonances, hyperons**
- Complementary to SPS, RHIC,...

Di-leptons ($\gamma^* \rightarrow l^+l^-$)

- carry information of each step of a collision
- no strong FSI - leave reaction volume undisturbed
- encode information on matter properties

A+A: 1-3A GeV
 $\sqrt{s}=2-2.4$ GeV

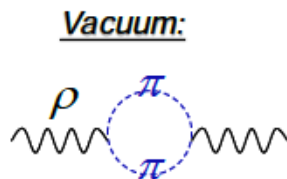
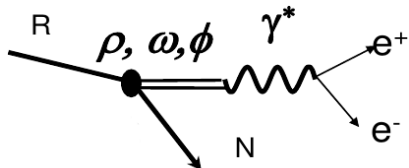




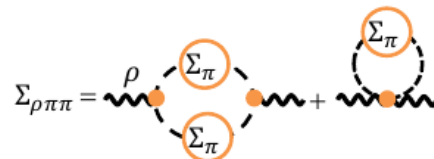
Motivations

HI & elementary collisions

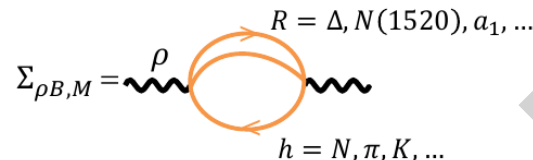
→ important role of vector mesons



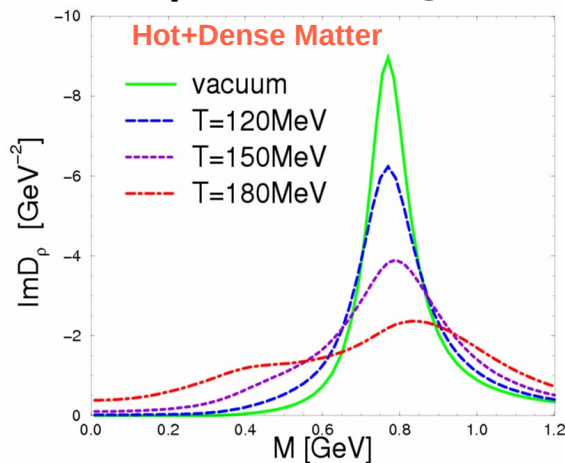
Nuclear matter: additional terms (ρ self-energies)



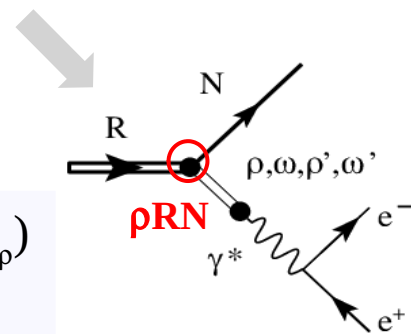
→ important role of barionic resonances Δ, N^*



ρ broadening



→ in-medium spectral function ($\text{Im}D_\rho$) depends on ρ RN coupling studied in $N^* (\Delta) \rightarrow N e^+ e^-$ Dalitz decays



→ dedicated HADES hadron physics program to study Dalitz decays in NN and π N collisions

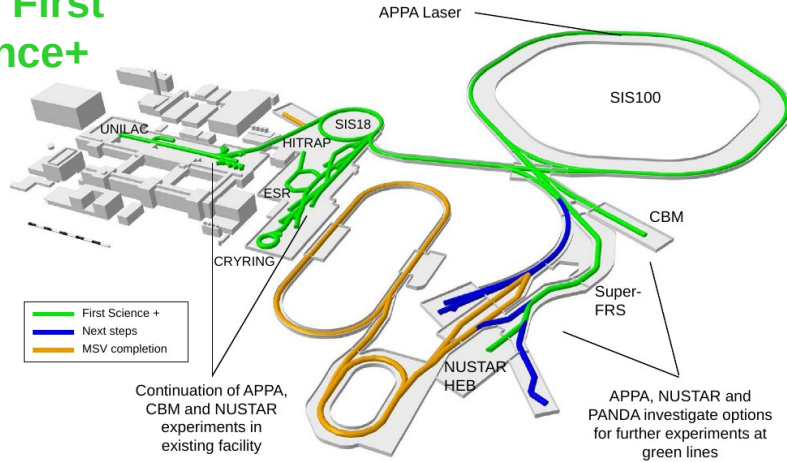
R. Rapp, J. Wambach, *Eur. Phys. J. A* 6, 415 (1999)

HADES - High Acceptance DiElectron Spectrometer

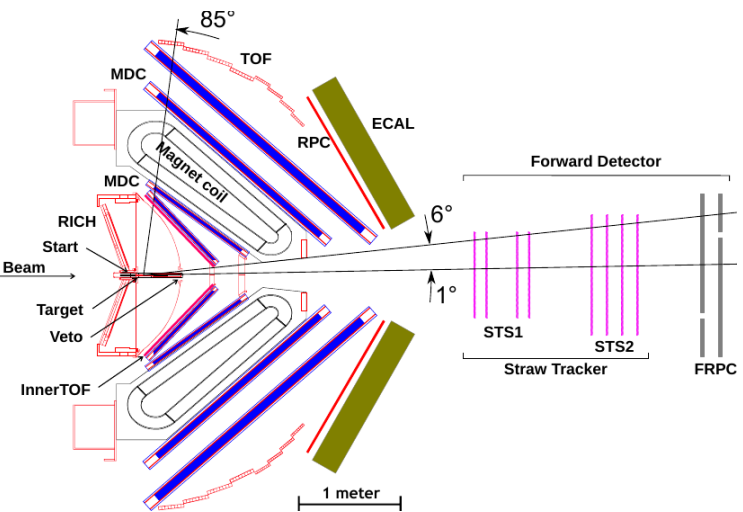


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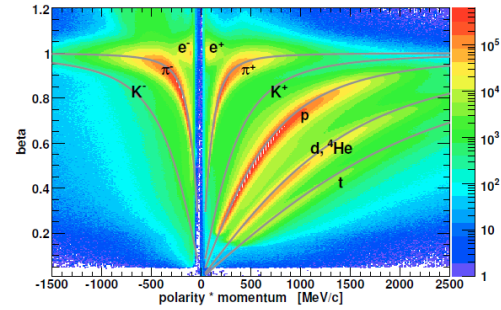
FAIR First Science+



- ✓ SIS18 beams: protons (1-4.5GeV), nuclei (1-2AGeV), pions (0.4-2 GeV) secondary beam
- ✓ Spectrometer with $\Delta M/M \sim 2\%$ at ρ/ω
- ✓ PID ($\pi/p/K$): ToF (TOF/RPC, T0 detector), tracking (dE/dx)
- ✓ momenta, angles: MDC+ magnetic field
- ✓ e^+, e^- : RICH
- ✓ neutral particles: ECAL
- ✓ full azimuthal, polar angles $18^\circ - 85^\circ$
- ✓ e^+e^- pair acceptance ~ 0.35



- FAIR - Phase0 upgrade:**
- ECAL (2017-2021)
 - RICH (2018)
 - Forward Detector (2021)
 - iTOF (2021)
 - START - LGAD

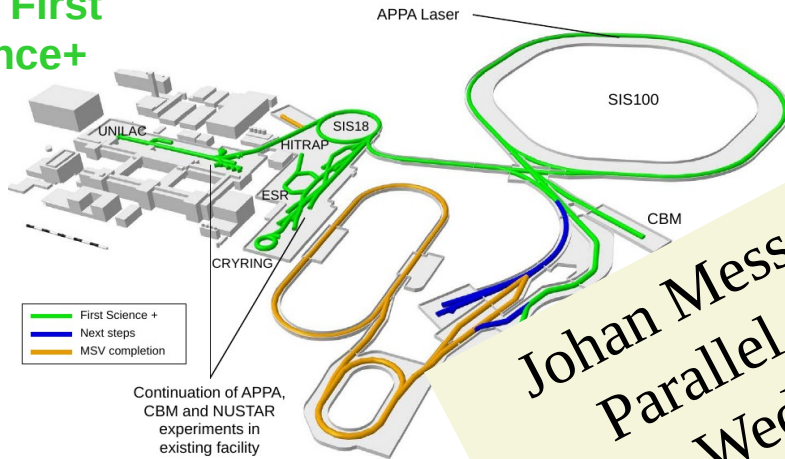


HADES - High Acceptance DiElectron Spectrometer



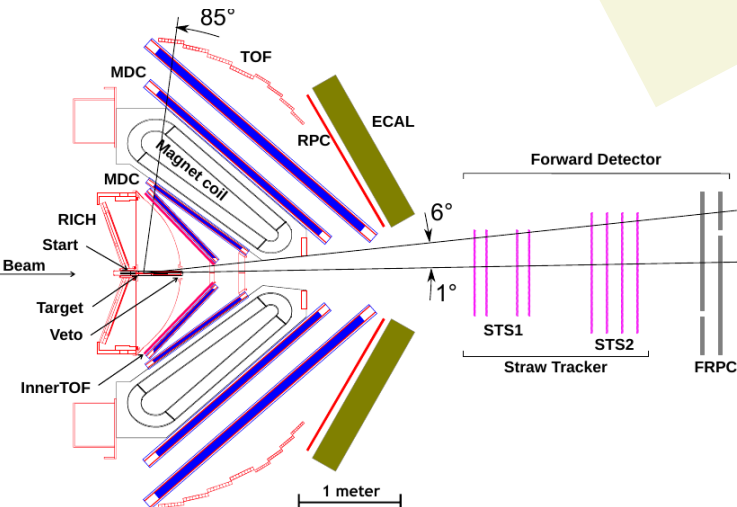
GSI Helmholtzzentrum für Schwerionenforschung

FAIR First Science+

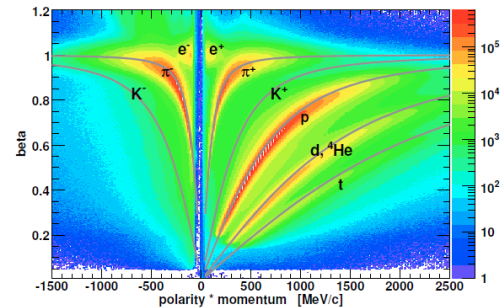


Johan Messchendorp
Parallel Sessions
Wednesday

- ✓ SIS18 beams: protons (1-4.5GeV), nuclei (1-2AGeV), pions (0.4-2 GeV) secondary beam
- ✓ Spectrometer with $\Delta M/M \sim 2\%$ at p/ω
- ✓ Detectors (K): ToF (TOF/RPC, T0 detector), dE/dx
- ✓ Angles: MDC+ magnetic field
- ✓ RICH
- neutral particles: ECAL
- ✓ full azimuthal, polar angles $18^\circ - 85^\circ$
- ✓ e+e- pair acceptance ~ 0.35

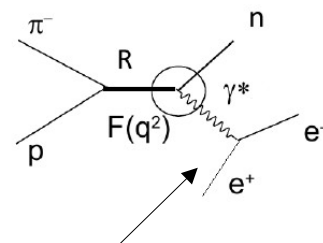


- FAIR - Phase0 upgrade:**
- ECAL (2017-2021)
 - RICH (2018)
 - Forward Detector (2021)
 - iTOF (2021)
 - START - LGAD





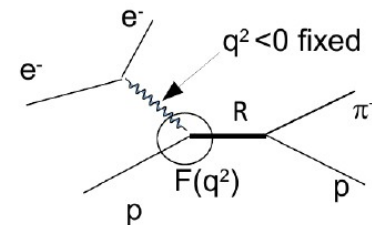
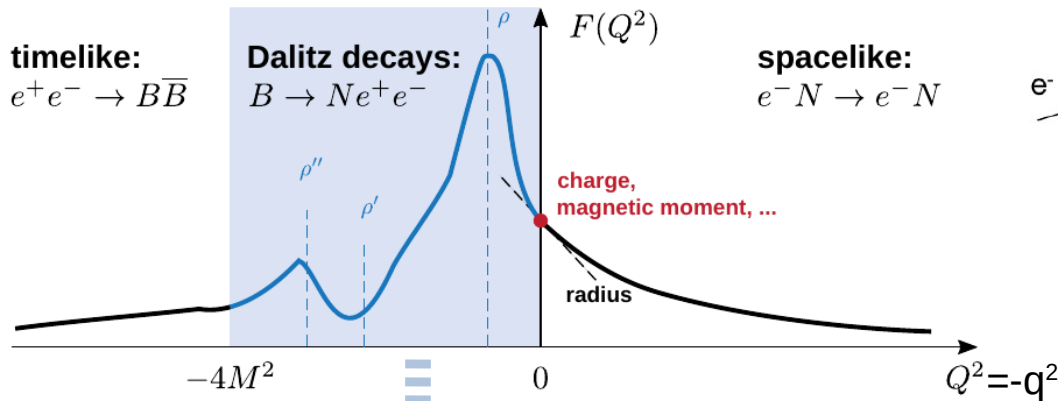
Electromagnetic structure of baryons



$$4m_{ee}^2 < q^2 < (M_R - M_n)^2$$

variable

HADES



CLAS/JLab,
MAMI,ELSA,
JLab-Hall A, ...



$$q^2 = M_{inv}^2(e^+ e^-) = M_{\gamma^*}^2 > 0$$

R → N Transition
Form Factor

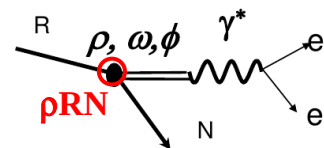
$$\frac{d\Gamma(\Delta \rightarrow N e^+ e^-)}{dq^2} = f(m_\Delta, q^2) \left(|G_M^2(q^2)| + 3|G_E^2(q^2)| + \frac{q^2}{2m_\Delta^2} |G_C^2(q^2)| \right)$$

M. I. Krivoruchenko, et. al
Annals Phys. 296, 299 (2002)

QED
transition
of point-like
particles

G_{M/E/C}: Form-Factors ($A_{1/2}, A_{3/2}, S_{1/2}$)
internal structure of hadrons
(various models)

Vector Meson Dominance model:
important role of vector mesons: $J^{PC} = 1^{--}$ (γ^*)





Dalitz decays of baryon resonances

Vector Meson Dominance Models (VMD)

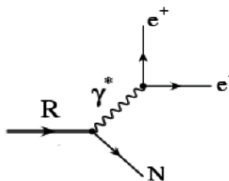
hadrons \longleftrightarrow photons

Meson Dalitz decays: (Crystal Ball/TAPS, A2, Na60 data), many theoretical studies

Baryons Dalitz decays: (Hades), most of the calculations of eTFF are based on VMD

→ QED “point-like”

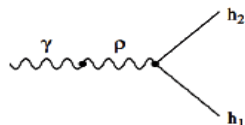
R - γ^* vertex



*M. Zetenyi et al.,
PRC 67, 044002 (2003)*

→ strict VMD (VMD2)

- $N\rho$ coupling
- used in HI transport models

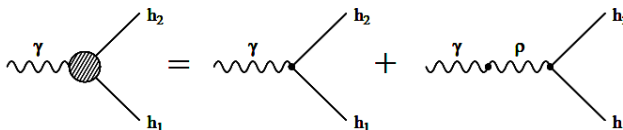


$$\Gamma_{\rho}^{VDM2} = \left(\frac{M_0}{M}\right)^3 \Gamma_{\rho}^0$$

Sakurai, Phys. Rev 22 (1969) 981
*M. I. Krivoruchenko et al.,
Ann. Phys. 296, 299 (2002)*

→ 2-component VMD (VMD1)

- $N\rho$ and $N\gamma$ couplings
- used in calculations of in-medium spectral functions



$$\Gamma_{\rho}^{VDM1} = \left(\frac{M}{M_0}\right) \Gamma_{\rho}^0$$

*Kroll, Lee & Zumino
Phys. Rev. 157, 1376 (1967)*



etFF of baryons: models

Covariant quark model +VMD

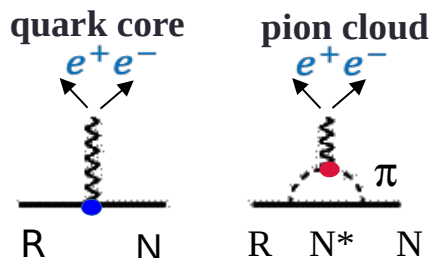
T. Pena & G. Ramalho

N- $\Delta(1232)$: *Phys.Rev. D93, 033004 (2016)*

N-N(1520): *Phys. Rev. D95, 014003 (2017)*

N-N(1535): *Phys.Rev. D101, 114008 (2020)*

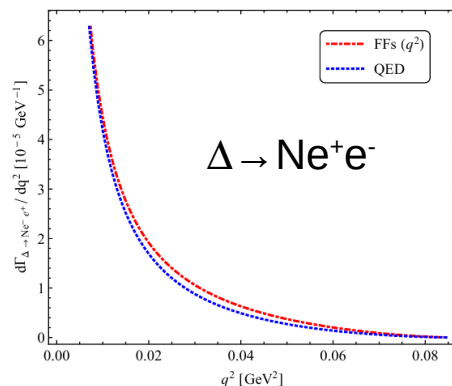
VMD:
quark FF
pion FF



Dispersion theory

S. Leupold et al.

S. Leupold
arXiv:2401.17756 (2024)



Two-component Lagrangian model

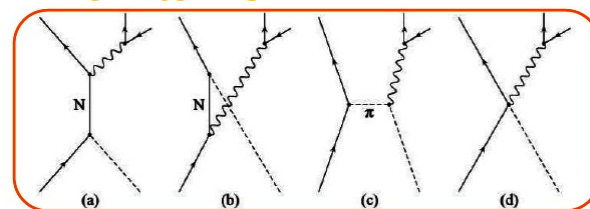
M. Zetenyi & G. Wolf

PRC 86, 065209 (2012)

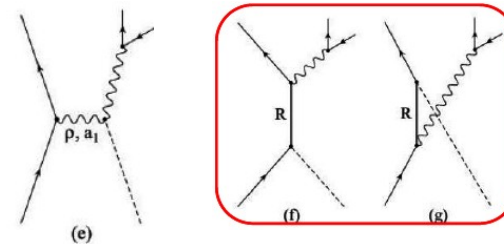
PRC 104, 015201 (2021)

microscopic calculations of $\pi N \rightarrow Ne+e^-$

Born terms

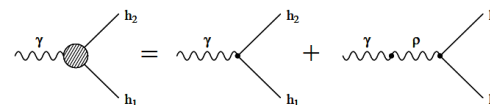


baryon resonances



N*(1440)
N*(1520)
N*(1535)

2-component VMD:

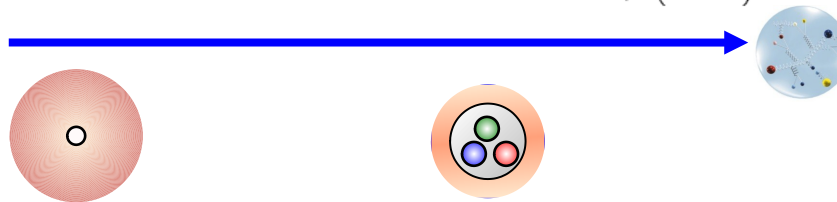
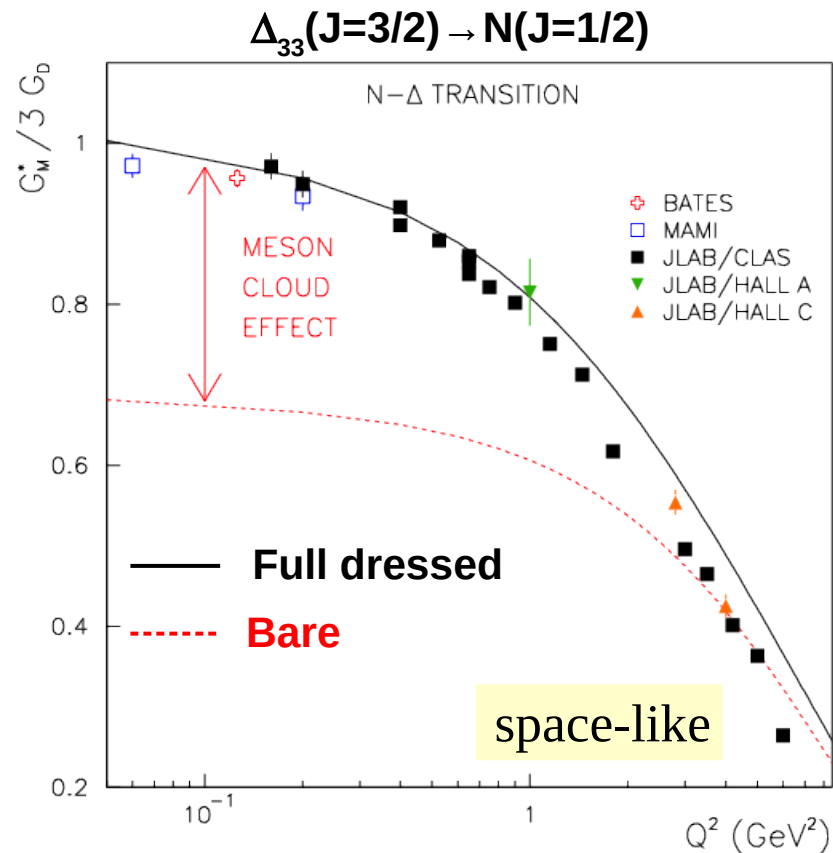
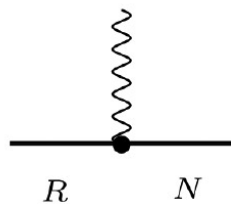
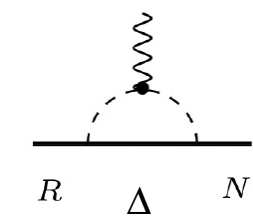
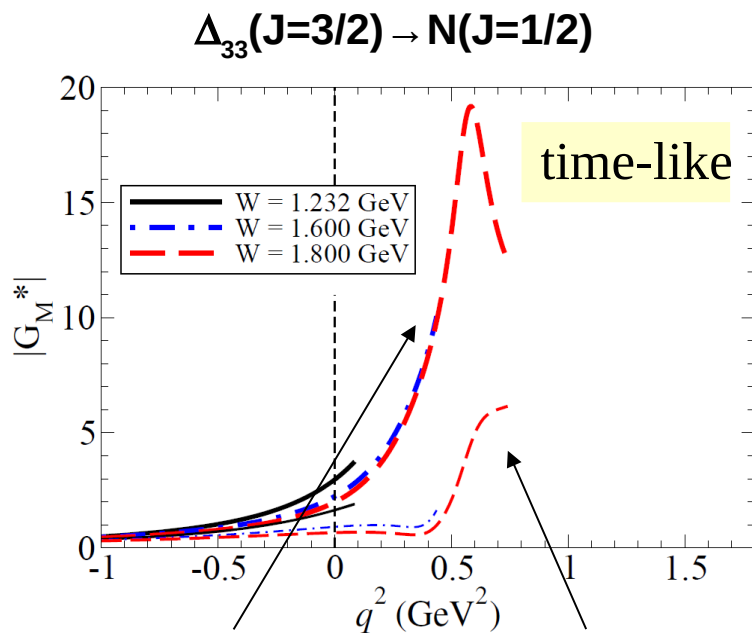


interference
between
 γ and ρ
contributions



Meson cloud effect

G. Ramalho, T. Peña
Phys. Rev. D 93, 033004 (2016)



dressed quark core
+ dense meson clouds

small meson cloud
dressed quark core dominates

I. G. Aznauryan and V. D. Burkert,
Prog. Part. Nucl. Phys. 67, 1 (2012)

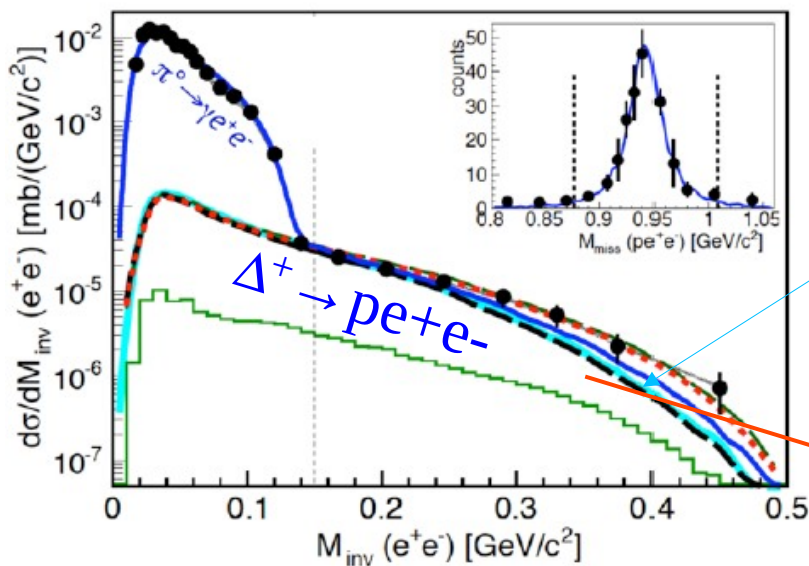


Δ (1232) resonance - **exclusive** pe^+e^- analysis

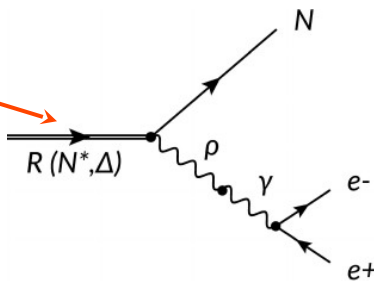
HADES: *Phys. Rev. C* 95, 065205 (2017)

$pp \rightarrow ppe^+e^-$ @1.25 GeV

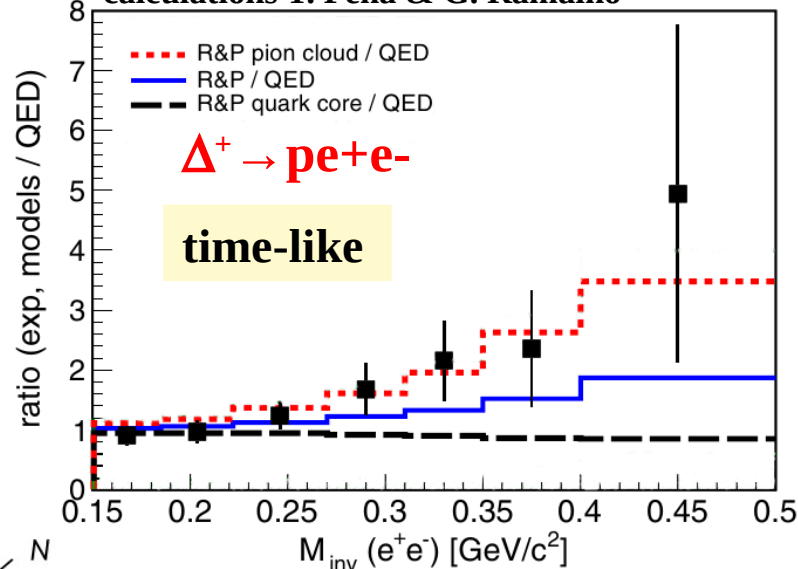
- energy below η production threshold
- cross sections for Δ^+ ($p\pi^+$, $p\pi^0$) from PWA



QED



calculations T. Pena & G. Ramalho



$\Delta(1232) 3/2^+$

$I(J^P) = \frac{3}{2}(\frac{3}{2}^+)$

Re(pole position) = 1209 to 1211 (≈ 1210) MeV
 $-2\text{Im}(\text{pole position}) = 98$ to 102 (≈ 100) MeV
 Breit-Wigner mass (mixed charges) = 1209 MeV
 Breit-Wigner full width (mixed charges) = 100 MeV

$\Delta(1232)$ DECAY MODES

Mode	Branching Ratio (%)	Width (MeV)
$N\pi$	99.4	229
$N\gamma$	0.55-0.65	259
$N\gamma$, helicity=1/2	0.11-0.13	259
$N\gamma$, helicity=3/2		259
pe^+e^-	$(4.2 \pm 0.7) \times 10^{-5}$	259

$$\frac{d\Gamma(\Delta \rightarrow Ne^+e^-)}{dq^2} = f(m_\Delta, q^2) \left(|G_M^2(q^2)| + 3|G_E^2(q^2)| + \frac{q^2}{2m_\Delta^2} |G_C^2(q^2)| \right)$$

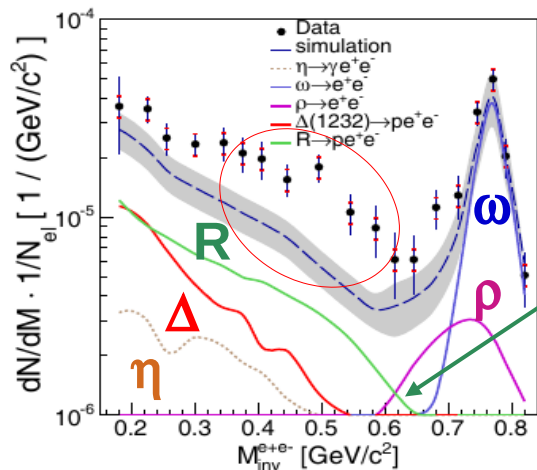
effective eTFF



Dalitz decay studies of heavier baryons

HADES: EPJ A50, 82 (2014)

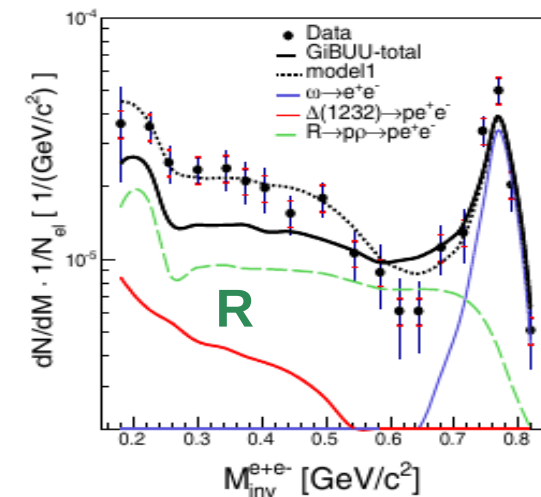
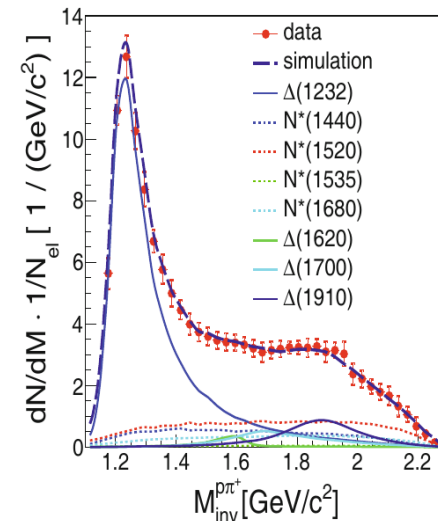
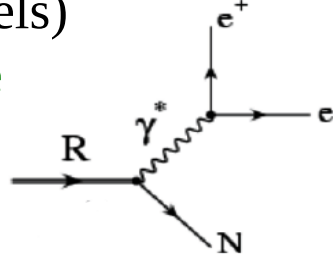
$pp \rightarrow ppe^+e^- @ 3.5 \text{ GeV}$



Dalitz decays of **point-like** baryonic resonances (constrained by $pp\pi^0$ and $p\pi^+$ channels)

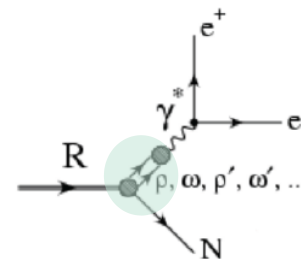
QED reference

$R \rightarrow pe+e-$

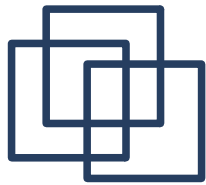


- comparison to GiBUU transport model with a 2-step process:

$R \rightarrow pp \rightarrow pe+e-$



model 1 = GiBUU, but with modified cross sections (HADES simul.)

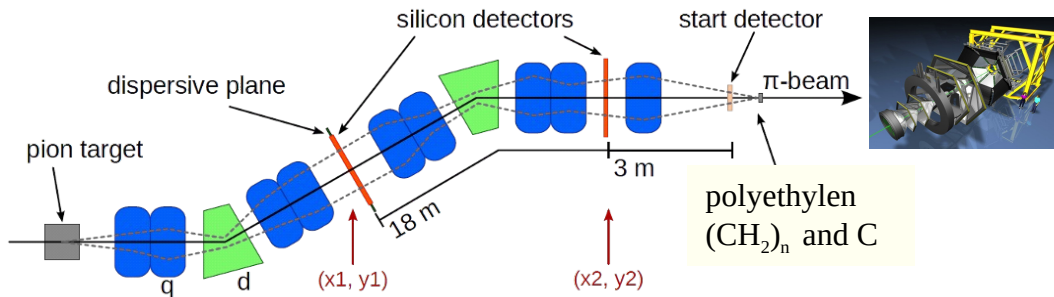


Pion beam facility @ GSI

Eur. Phys. J. A 53, 188 (2017)

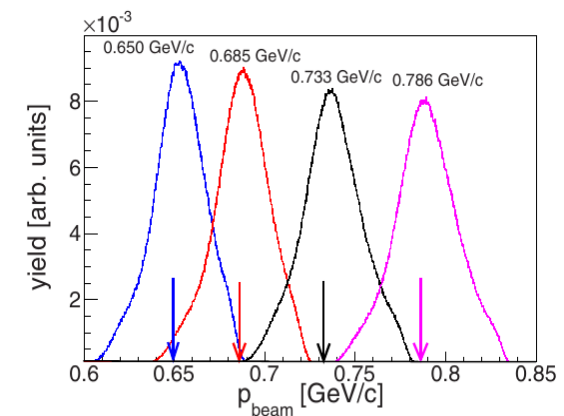
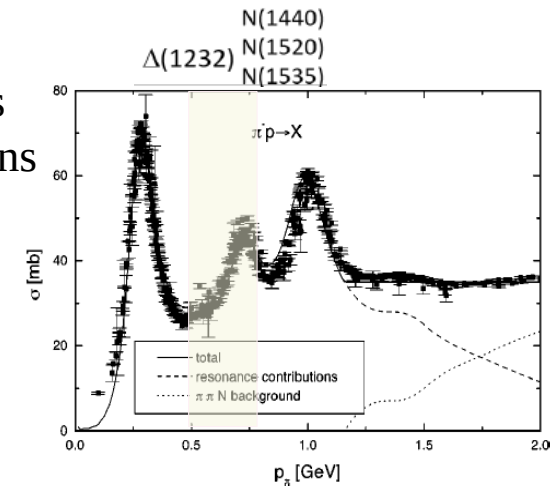


- **selectivity:** production of resonance with given mass in s-channel
- **2-pion channels:** $\pi p \rightarrow n\pi^+\pi^-$, $\pi p \rightarrow p\pi^-\pi^0$ ($\sqrt{s} = 1.46 - 1.55 \text{ GeV}$)
 - complete the very scarce pion beam data base for hadronic couplings
- **dilepton channel** $R \rightarrow Ne+e-$, **never** measured in pion induced reactions
 - time-like electromagnetic structure of baryons



- reaction **N+Be**, $8-10 \cdot 10^{10} \text{ N}_2$ ions/spill (4s)
- secondary π^- with **I** $\sim 2-3 \cdot 10^5/s$
- $p = 650, \mathbf{685}, 733, 786$ (+/- 1) MeV/c
- **PE** $(\text{CH}_2)_n$ and **C** targets

2nd resonance region





2-pion production in πp

HADES: *Phys. Rev. C* 102, 024001, (2020)

Bn-Ga PWA: pwa.hisp.uni-bonn.de

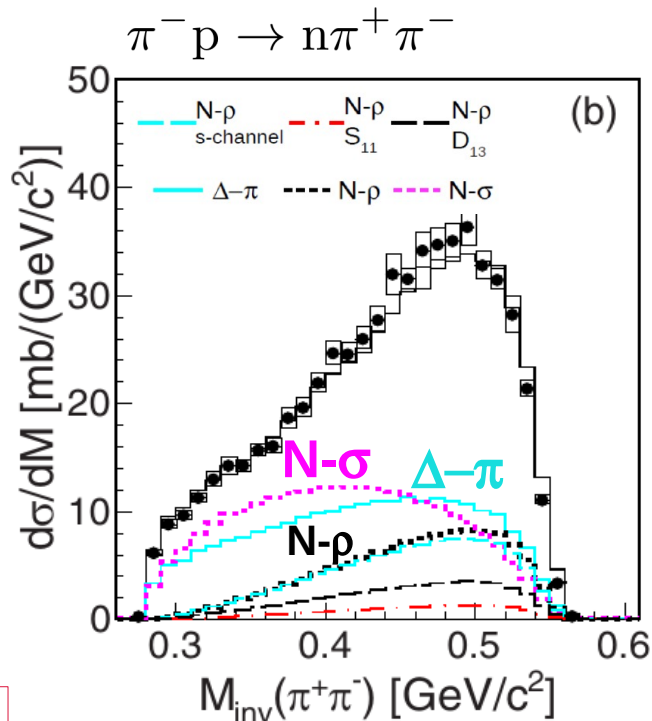
2 π data included in the fit

Reaction	Observable	W (GeV)	
$\gamma p \rightarrow \pi^0 \pi^0 p$	DCS, Tot	1.2-1.9	MAMI
$\gamma p \rightarrow \pi^0 \pi^0 p$	E	1.2-1.9	MAMI
$\gamma p \rightarrow \pi^0 \pi^0 p$	DCS, Tot	1.4-2.38	CB-ELSA
$\gamma p \rightarrow \pi^0 \pi^0 p$	P, H	1.45-1.65	CB-ELSA
$\gamma p \rightarrow \pi^0 \pi^0 p$	T, P_x, P_y	1.45-2.28	CB-ELSA
$\gamma p \rightarrow \pi^0 \pi^0 p$	P_x, P_x^c, P_x^s (4D)	1.45-1.8	CB-ELSA
$\gamma p \rightarrow \pi^0 \pi^0 p$	P_y, P_y^c, P_y^s (4D)	1.45-1.8	CB-ELSA
$\gamma p \rightarrow \pi^+ \pi^- p$	DCS	1.7-2.3	CLAS
$\gamma p \rightarrow \pi^+ \pi^- p$	I^c, I^s	1.74-2.08	CLAS
$\pi^- p \rightarrow \pi^0 \pi^0 n$	DCS	1.29-1.55	Crystal Ball
$\pi^- p \rightarrow \pi^+ \pi^- n$	DCS	1.45-1.55	HADES
$\pi^- p \rightarrow \pi^0 \pi^- p$	DCS	1.45-1.55	HADES

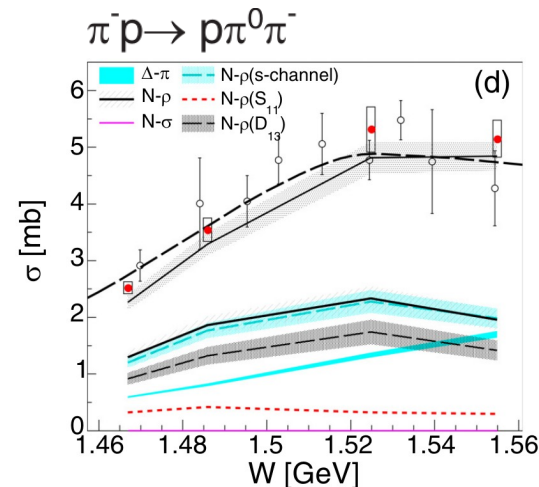
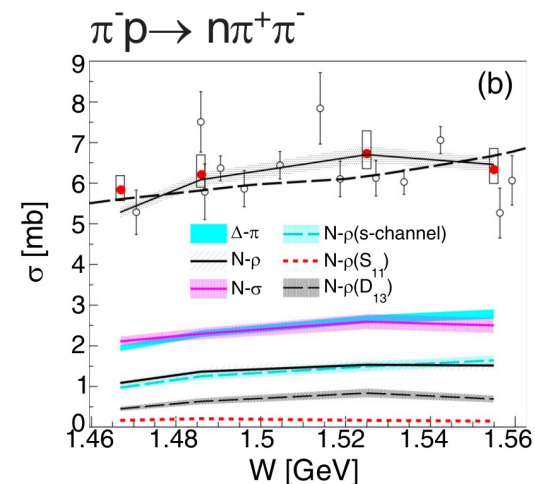
unique data set

ρ meson production:

- s-channel D_{13} (N(1520) 3/2-) dominant contribution
- $N(1520) \rightarrow N\rho$ BR=12.2 +/- 2 %
- $N(1535) \rightarrow N\rho$ BR=3.2 +/- 0.6 %



reference ρ mass spectrum
for e^+e^- analysis

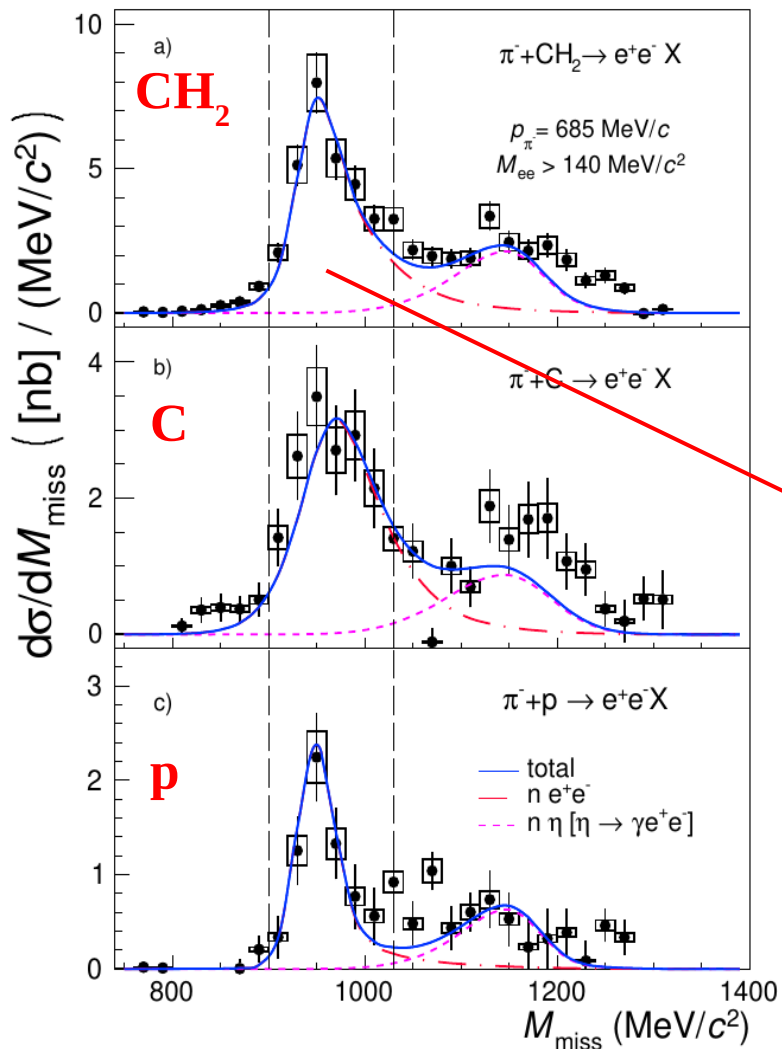




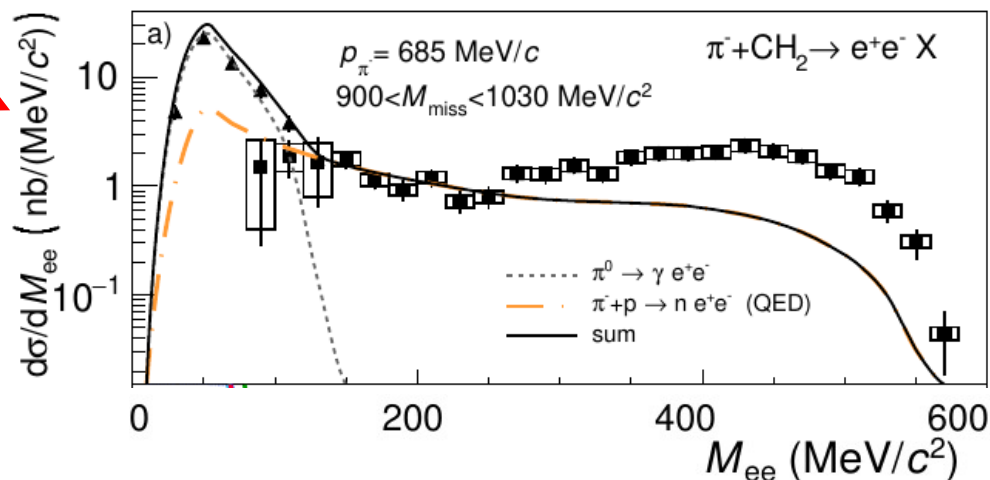
Selection of quasi-free $\pi^- p \rightarrow ne^+e^-$

HADES Coll. arXiv:2205.15914 [nucl-ex]

HADES Coll. arXiv:2309.13357 [nucl-ex]



- cut on $\text{inv}M_{e^+e^-} > 140 \text{ MeV}$ (π^0 removed)
- selection of $\pi^- p \rightarrow ne^+e^-$ exclusive channel using **missing mass cut** (η removed)
- quasi-free treatment of $\pi^- \text{C}$ interaction



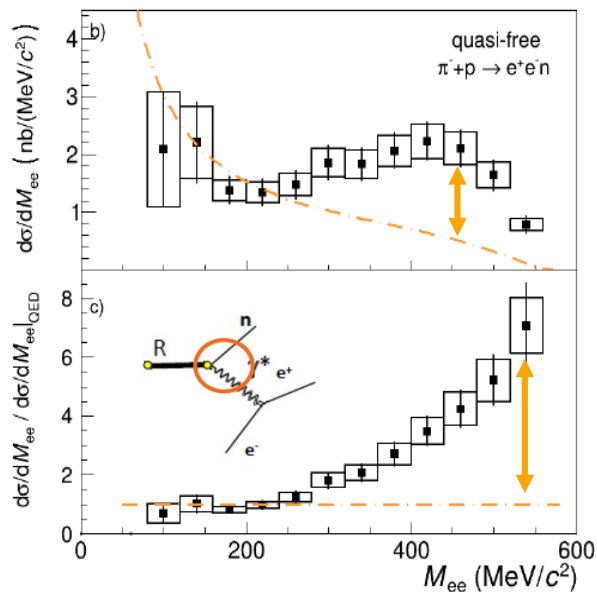


Effective time-like transition form factor

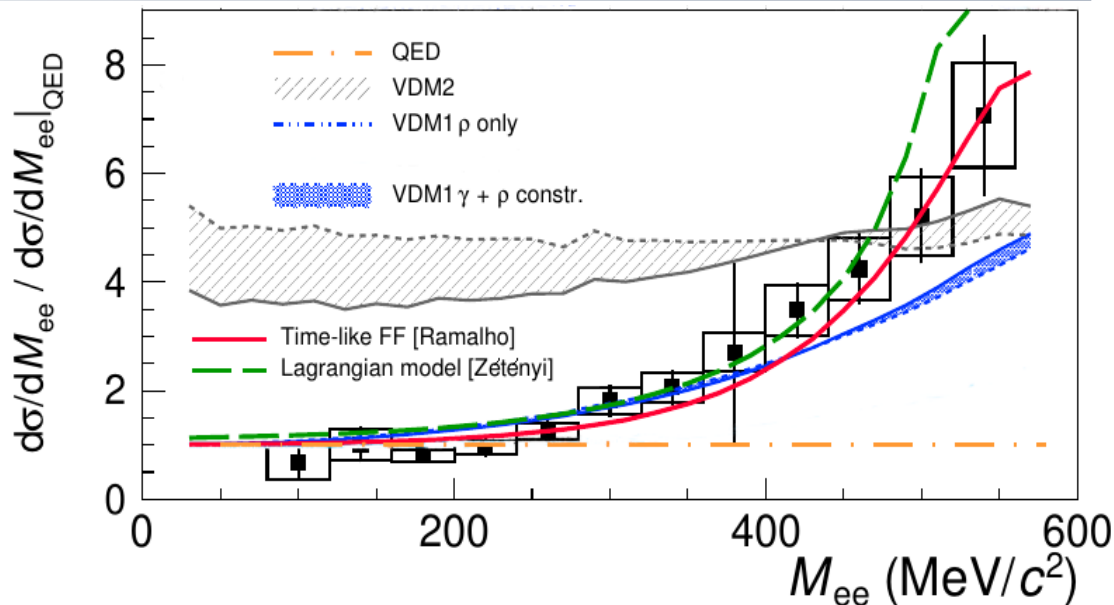
HADES Coll. arXiv:2205.15914 [nucl-ex]

HADES Coll. arXiv:2309.13357 [nucl-ex]

excess over point-like QED



- $M_{ee} < 200$ MeV/c² data consistent with **QED**
- strong excess at large M_{ee} (up to factor 5)



- **VMD2** (*strict* VMD) overestimates data below 400 MeV (used in HI transport models)
- 2-component VMD (VMD1) gives reasonable description
- Lagrangian model – very promising
- Time-like FF - dominant pion cloud contribution (pion emFF)

$$\Gamma_{\rho}^{VDM2} = \left(\frac{M_0}{M}\right)^3 \Gamma_{\rho}^0$$

$$\Gamma_{\rho}^{VDM1} = \left(\frac{M}{M_0}\right) \Gamma_{\rho}^0$$



Virtual photon polarization

E. Speranza et al. Phys. Lett. B764, 282 (2017)

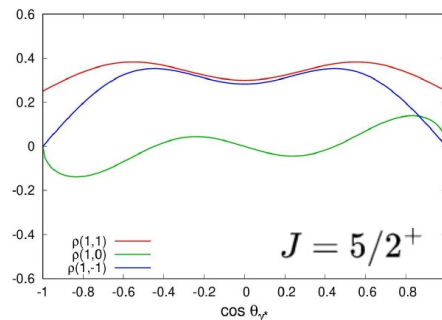
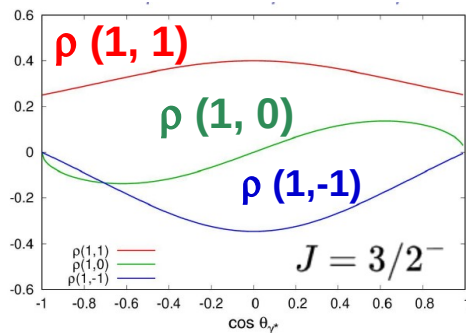
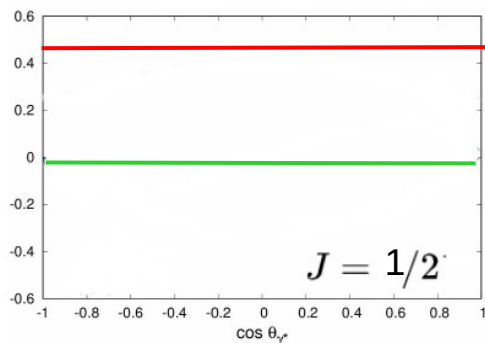
angular distribution of $e^+e^- \rightarrow$ polarization of γ^* \rightarrow spin density matrix elements ($\rho_{\Lambda\Lambda}$)

$$\pi N \rightarrow N\gamma^* \rightarrow Ne^+e^- \quad \frac{d^3\sigma}{dM_{ee}d\Omega_{\gamma^*}d\Omega_e} \sim |A|^2 = \frac{e^2}{Q^4} \sum_{\Lambda\Lambda'} \rho_{\Lambda\Lambda'}^{(H)} \rho_{\Lambda\Lambda'}^{(dec)} \quad \text{QED: } \gamma^* \rightarrow e^+e^-$$

$R \rightarrow N + \gamma^*$

Angular distribution of the lepton pair:

$$|A|^2 \propto 8k^2 [1 - \rho_{11} + (3\rho_{11} - 1) \cos^2 \Theta + \sqrt{2} \text{Re} \rho_{10} \sin 2\Theta \cos \phi + \text{Re} \rho_{1-1} \sin^2 \Theta \cos 2\phi]$$



- $\rightarrow \rho_{\Lambda\Lambda}$ depends on γ^* polarization
- $\rightarrow \rho_{\Lambda\Lambda}$ are combination of G_E, G_M, G_C
- \rightarrow **the angular distribution is sensitive to J^P of the resonance**
- \rightarrow can be obtain from fit to the experimental angular distribution

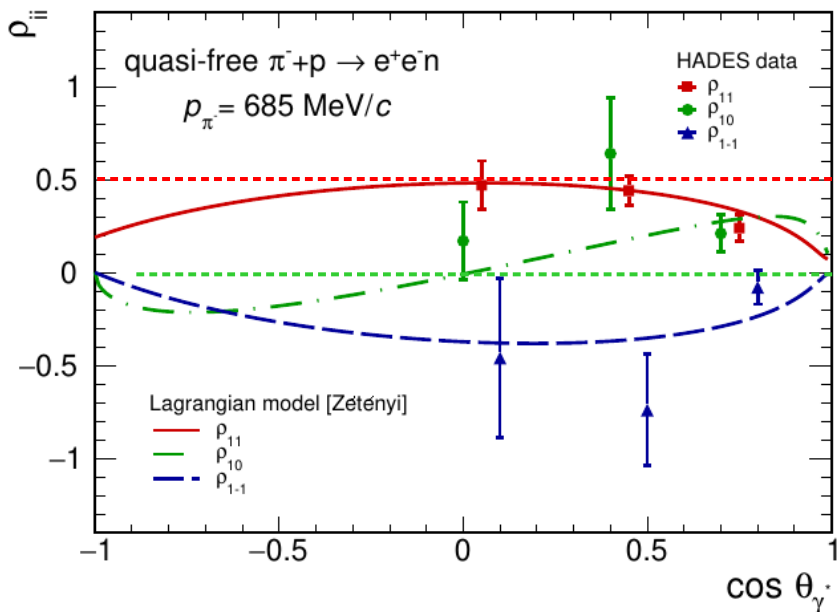


Virtual photon polarization

HADES Coll. arXiv:2205.15914 [nucl-ex]

$$|A|^2 \propto 8k^2 [1 - \rho_{11} + (3\rho_{11} - 1) \cos^2 \Theta + \sqrt{2} \text{Re} \rho_{10} \sin 2\Theta \cos \phi + \text{Re} \rho_{1-1} \sin^2 \Theta \cos 2\phi]$$

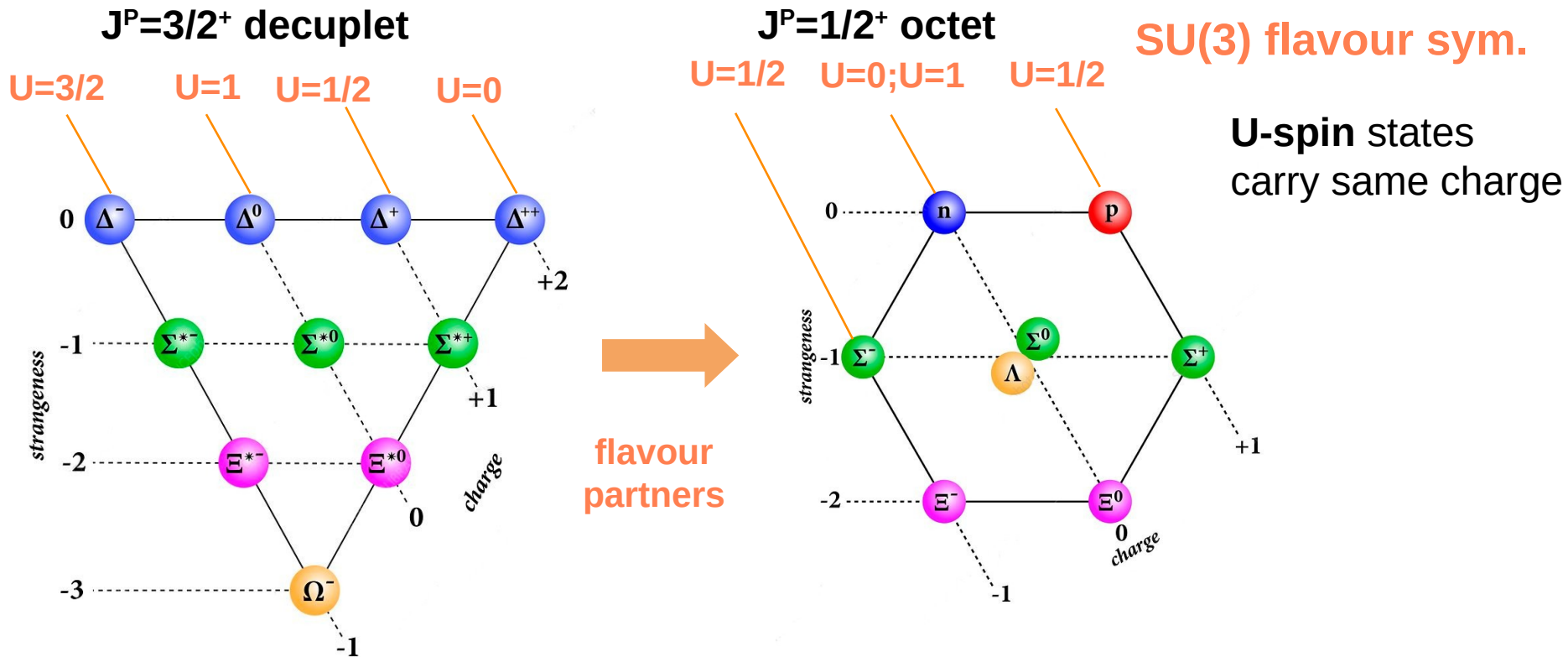
- SDME ρ_{11} , ρ_{10} , ρ_{1-1} extracted from experiment taking into account acceptance and efficiency (A. Sarantsev) in 3 bins in $\cos\theta_\gamma^*$



- $\rho_{11} = 0.5$, $\rho_{10} = 0$ for transverse polarization (real photon)
- we see angular dependence
 => contribution from a virtual photon
 => contributions of spins larger than $\frac{1}{2}$:
 N(1520) resonance
- **more precise data needed !**



etFF of hyperons



- Transitions **decuplet** \rightarrow **octet** with conserved U-spin are allowed in SU(3)
- $\Sigma^*(1385) \rightarrow \Lambda \gamma^*$ \longleftrightarrow $\Delta(1232) \rightarrow N \gamma^*$
- $\Lambda(1520) \rightarrow \Lambda \gamma^*$ \longleftrightarrow $N^*(1520) \rightarrow N \gamma^*$

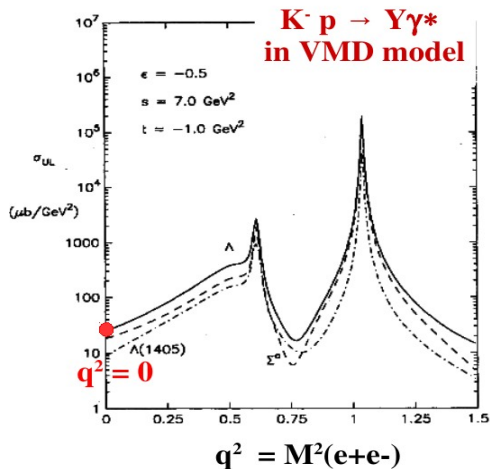
} strange vs non-strange baryons

G. Ramalho, K. Tsushima
Phys. Rev. D 87, 093011 (2013)



etFF of hyperons model predictions for the Dalitz decay

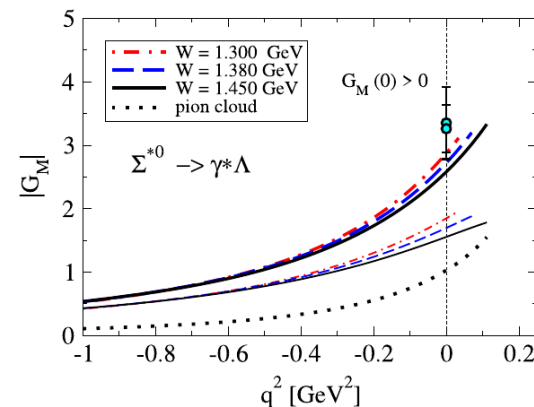
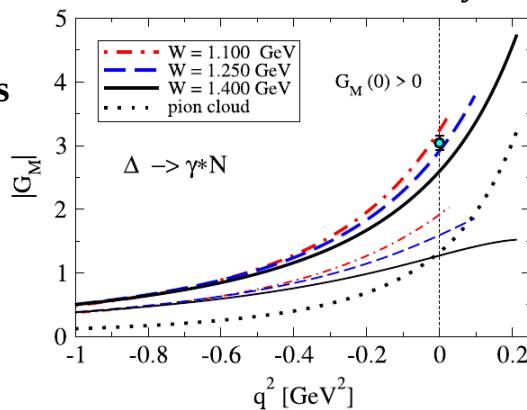
R. Williams et. al. PRC48, 1381 (1993)



**VMD:
large effect
of vector mesons
predicted**

covariant spectator quark model (Σ^* , Ξ^*)

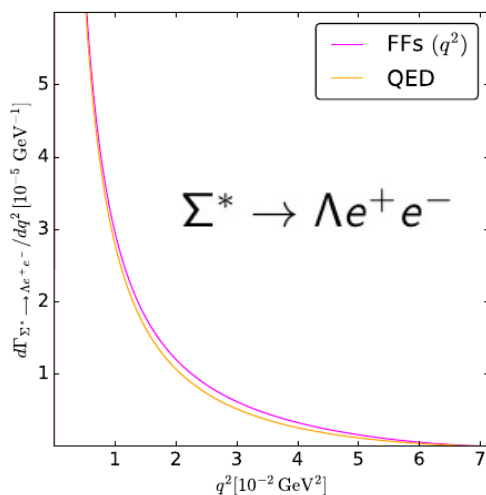
G. Ramalho, *Phys. Rev. D* 102, 054016 (2020)



Dispersion theory

N. Salone, S. Leupold
Eur. Phys. J. A 57, 183 (2021)

O. Junker, S. Leupold et al.
Phys. Rev. C 101, 015206 (2020)

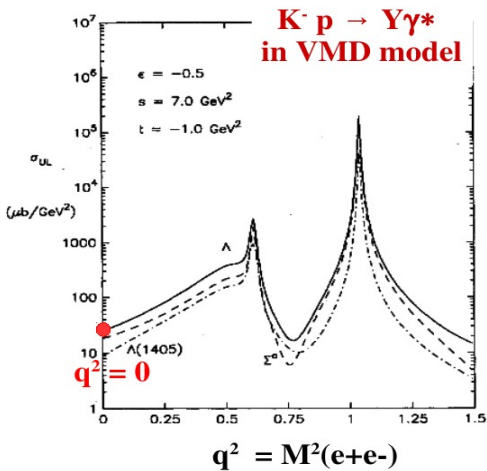


- pion cloud contribution
- kaon cloud contrib. ?



etFF of hyperons model predictions for the Dalitz decay

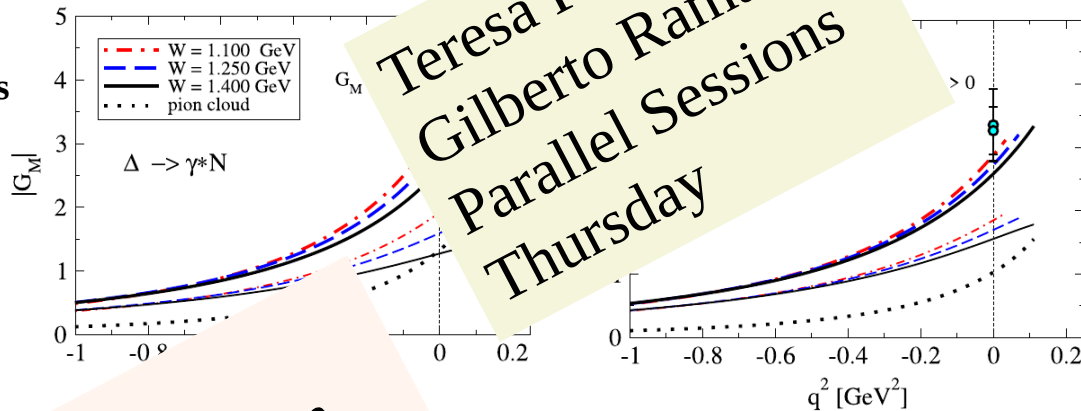
R. Williams et. al. PRC48, 1381 (1993)



VMD:
large effect
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covariant spectator model (Σ^* , Ξ^*)

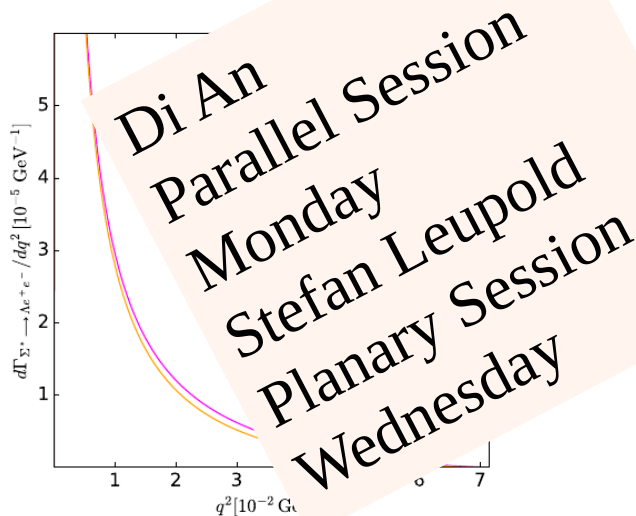
G. Ramalho, *Ph...*



Teresa Pena
Gilberto Ramalho
Parallel Sessions
Thursday

Dispersion theory

N. Salone, S. Leupold
Eur. Phys. J. A 57, 183 (2021)
O. Junker, S. Leupold et al.
Phys. Rev. C 101, 015206 (2020)



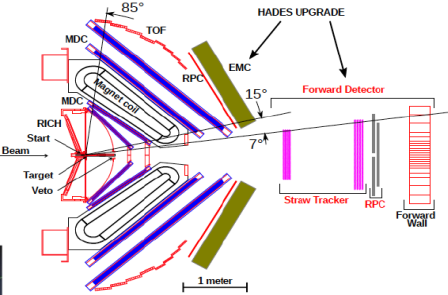
Di An
Parallel Session
Monday
Stefan Leupold
Planary Session
Wednesday

- pion cloud contribution
- kaon cloud contrib. ?

Hyperons @ HADES

pp @ 4.5 GeV

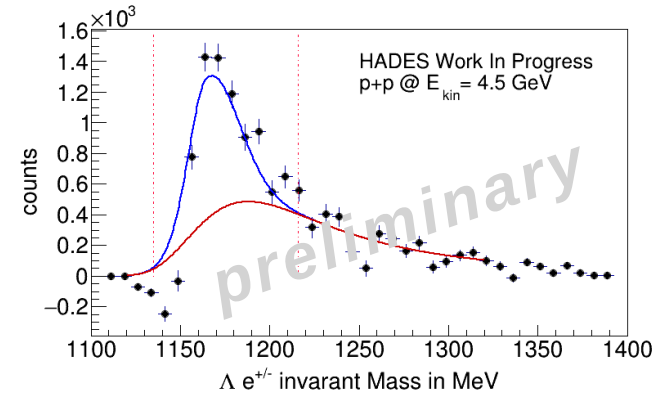
HADES: *Eur. Phys. J. A57, 138 (2021)*



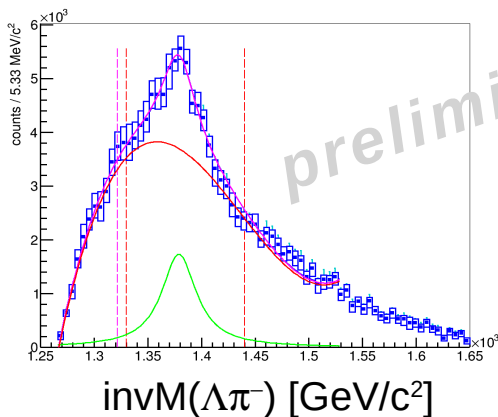
February 2022: beam time at SIS18 FAIR-Phase0

- $\Lambda(1405)$, $\Lambda(1520)$, Σ production cross sec., decays,...
- Σ , $\Lambda(1405)$, $\Lambda(1520)$ **Dalitz decays** → attempt to measure upper limits of branching ratios (obtained luminosity $L \sim 6 \text{ pb}^{-1}$)
- the BR important information for future measurement @CBM and other hyperon factories
- information on hyperon structure, role of pion/kaon cloud

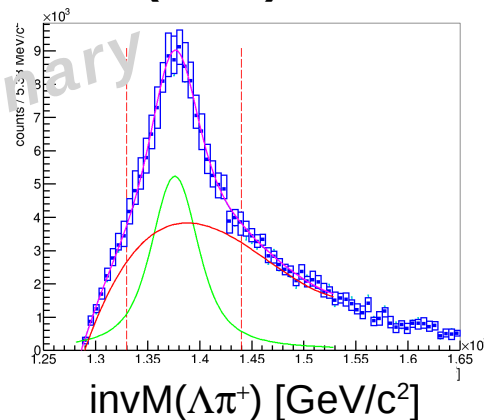
$\Sigma^0(1192) \rightarrow \Lambda \gamma^*$ Dalitz decay



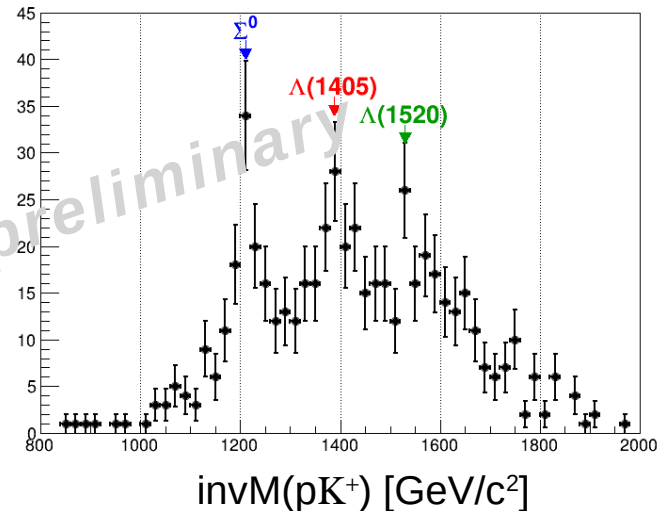
$\Sigma^{*-}(1385) \rightarrow \Lambda \pi^-$



$\Sigma^{*+}(1385) \rightarrow \Lambda \pi^+$



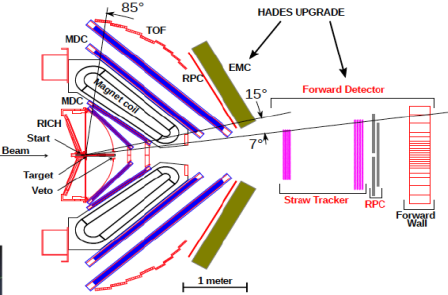
exclusive study of $pp \rightarrow pK^+ \Lambda(1405) (\rightarrow \Sigma^0 \pi^0)$



Hyperons @ HADES

pp @ 4.5 GeV

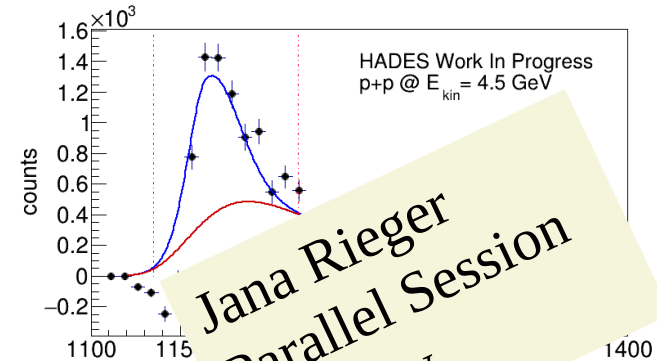
HADES: *Eur. Phys. J. A57, 138 (2021)*



February 2022: beam time at SIS18 FAIR-Phase0

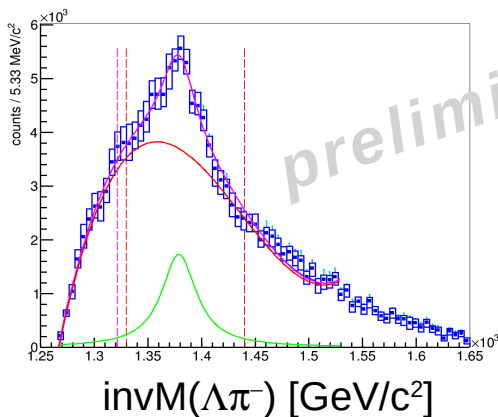
- $\Lambda(1405)$, $\Lambda(1520)$, Ξ production cross sec., decays,...
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$\Sigma^0(1192) \rightarrow \Lambda \gamma^*$ Dalitz decay

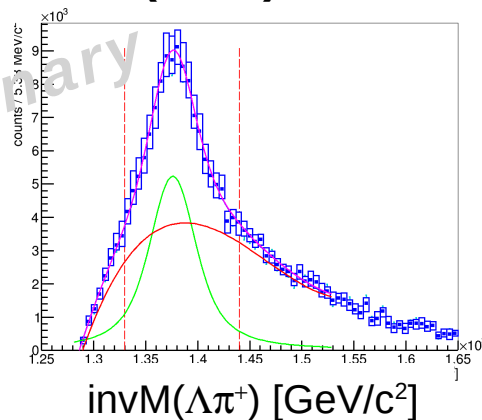


Jana Rieger
Parallel Session
Tuesday

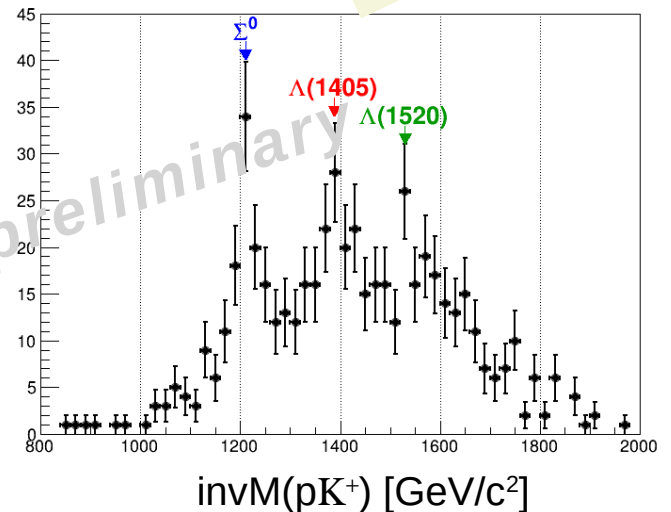
$\Sigma^{*-}(1385) \rightarrow \Lambda \pi^-$



$\Sigma^{*+}(1385) \rightarrow \Lambda \pi^+$



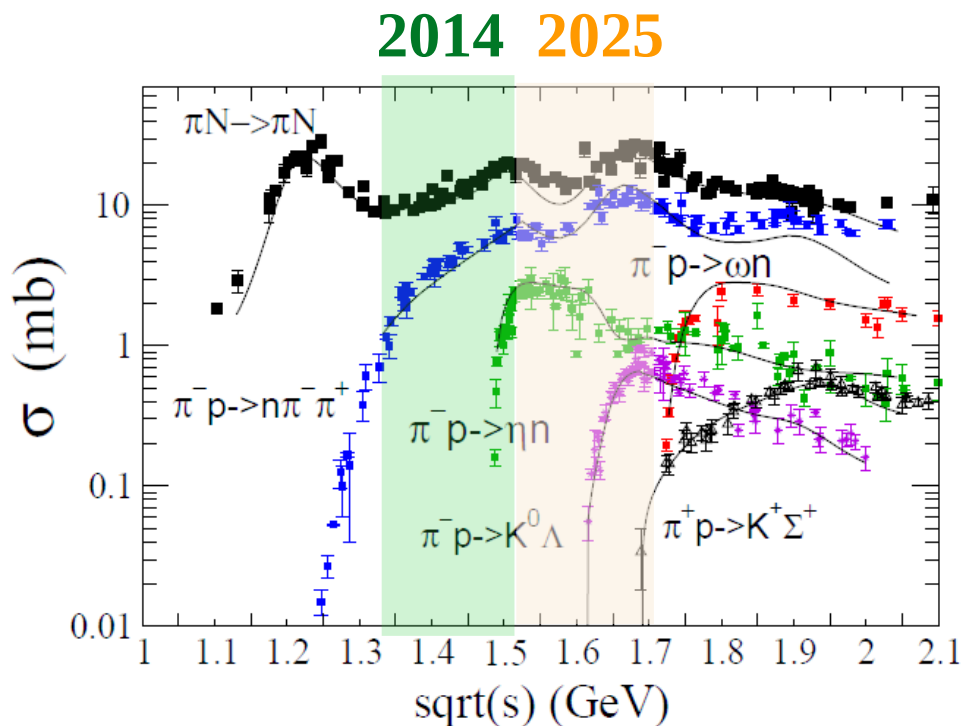
exclusive study of pp → ... (1405) (→ Σ⁰ π⁰)





OUTLOOK

HADES Physics Program with Pion Beams explore the 3rd resonance region $\sqrt{s} = 1.7 \text{ GeV}/c^2$



Beam energy scan **2025**:
continuation and extension
to 3rd resonance region

1) Baryon-meson couplings:

- $\pi\pi N$, ωn , ηn , $K^0\Lambda$, $K^0\Sigma$, ...
including neutral mesons (ECAL),
- ρR couplings S31(1620),
D33(1700), P13(1720),...

2) Hyperon polarization: Λ , Σ

3) Exotic states:

- the lowest glueballs, 4q systems,
hybrids, bound states of mesons:
 $f_0(500)$, $f_0(980)$, $a_0(980)$, $f_0(1370)$,...
- unknown region of $\text{inv}M(\pi\pi) \sim 1 \text{ GeV}$
very precise data needed!

CBM@ SIS100 pp @ 30 GeV

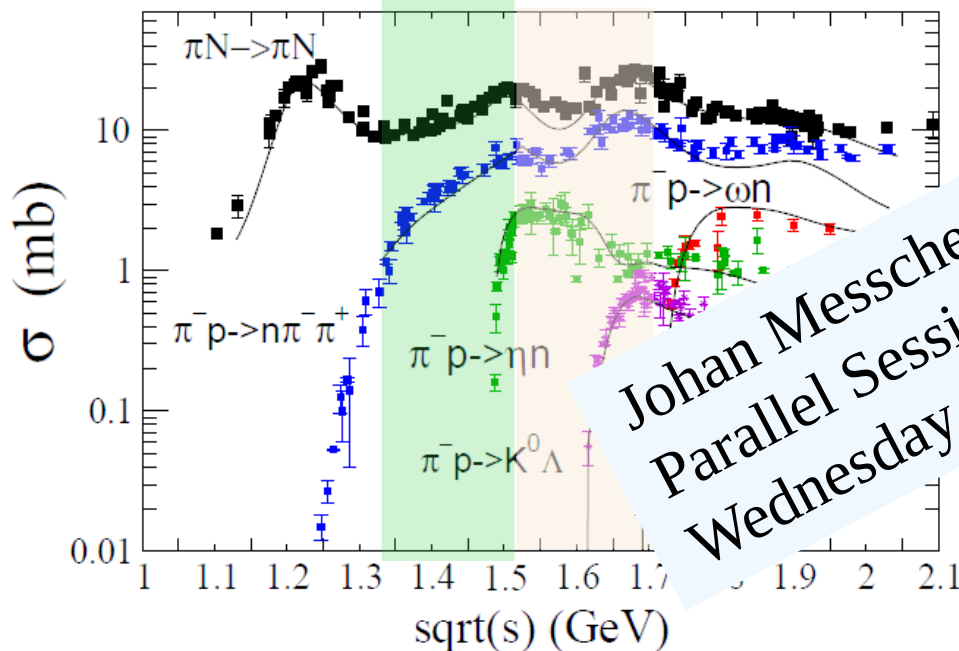
- prod. cross sec. higher than at SIS18:
 $\sigma(\Sigma^*, \Lambda^*) \sim 1 \text{ mb}$
- much higher luminosity



OUTLOOK

HADES Physics Program with Pion Beams explore the 3rd resonance region $\sqrt{s} = 1.7 \text{ GeV}/c^2$

2014 2025



Beam energy scan **2025**:
continuation and extension
to 3rd resonance region

- 4) Meson couplings:
to $\eta, \eta', \eta, \eta, K^0\Lambda, K^0\Sigma, \dots$
to neutral mesons (ECAL),
couplings S31(1620),
D33(1700), P13(1720),...
- 5) Hyperon polarization: Λ, Σ
- 6) Exotic states:
→ the lowest glueballs, 4q systems,
hybrids, bound states of mesons:
 $f_0(500), f_0(980), a_0(980), f_0(1370), \dots$
→ unknown region of $\text{inv}M(\pi\pi) \sim 1 \text{ GeV}$
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CBM@ SIS100 pp @ 30 GeV

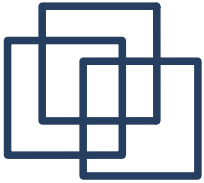
- prod. cross sec. higher than at SIS18:
 $\sigma(\Sigma^*, \Lambda^*) \sim 1 \text{ mb}$
- much higher luminosity

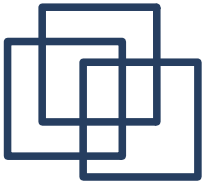


Summary

- **HADES & pion beam** is an unique tool to understand in details **baryon- ρ couplings**:
 - significant off-shell contribution originating from $N(1520)D_{13}$ shown by combined PWA ($D_{13}(1520)$ coupling to ρ -N: 12+/-2 %),
 - improved knowledge of baryon resonances- meson (ρ) couplings (new BR measurements),
 - very new information on electromagnetic baryon transitions in the time-like region,
- First test of Vector Dominance Model below 2π threshold and time-like electromagnetic transition form factor models
 - important inputs for medium effects of ρ meson calculations
- Studies of etFF of hyperons in pp@ 4.5 GeV.
- Proposal for pion beam experiment in 2025 in the third resonance region.
- Studies of hyperon structure @CBM.

Thank You for Your Attention !





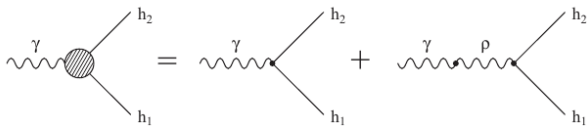
Two-component Lagrangian model

M. Zetenyi and G. Wolf

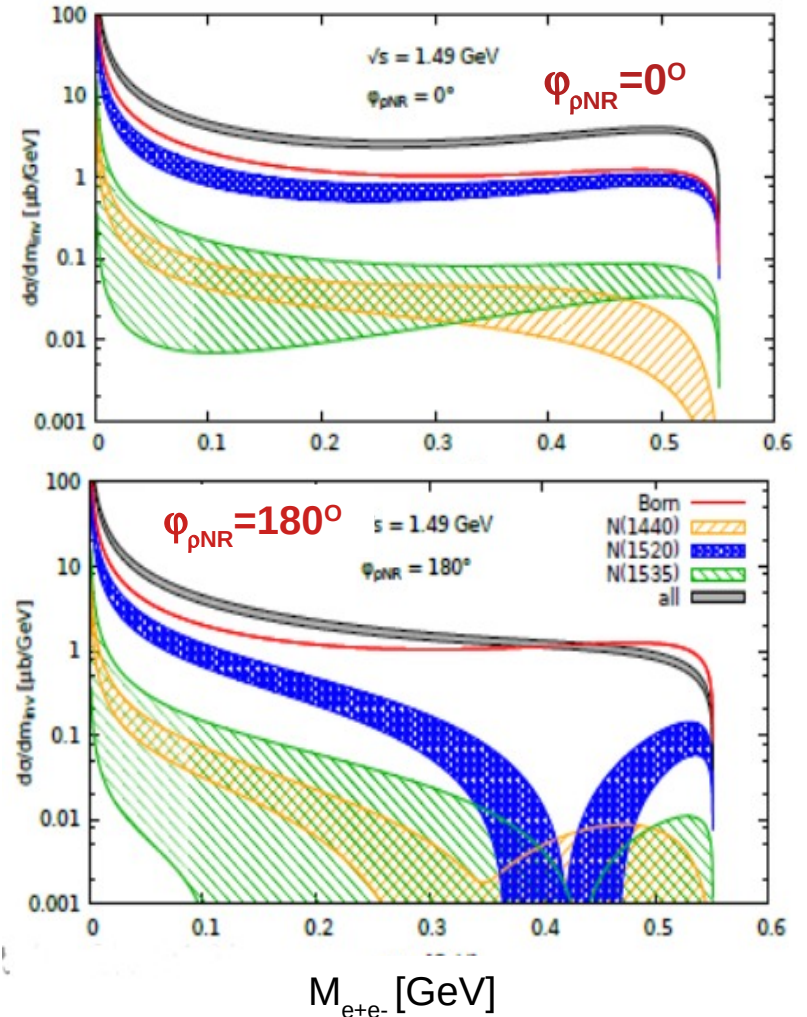
Phys. Rev. C 86, 065209 (2012)

Phys. Rev. C 104, 015201 (2021)

VDM1 Lagrangian



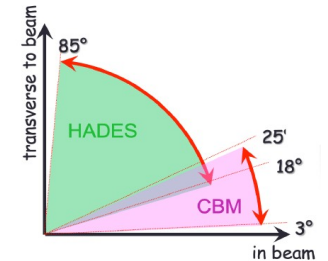
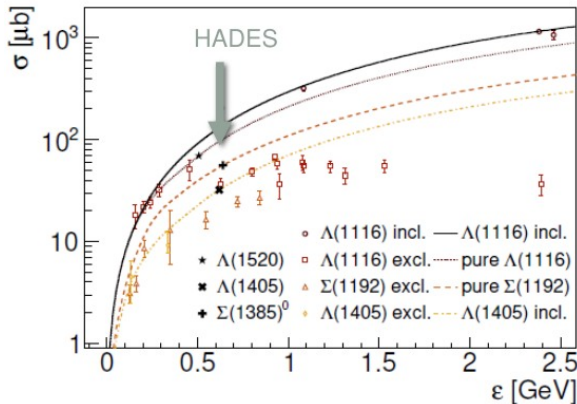
Shape and yield sensitive to the interference between the γ and ρ contributions





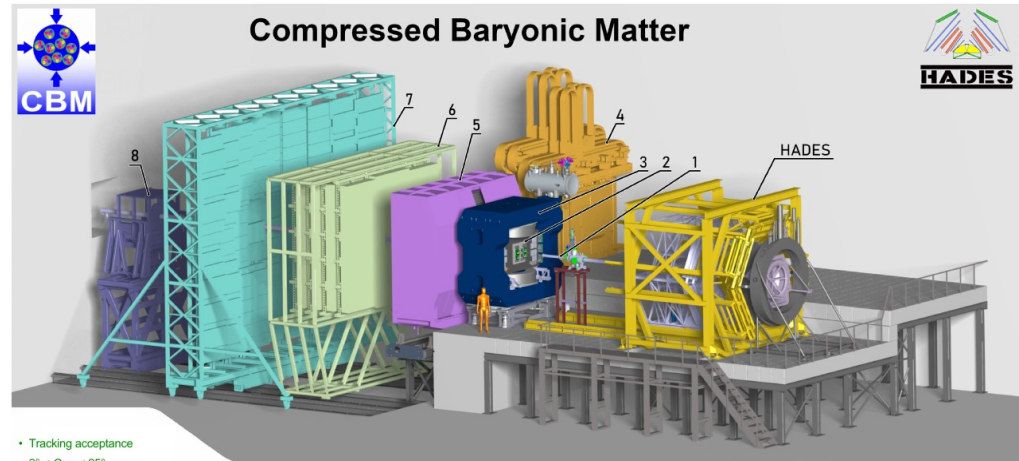
proton-CBM

- structure and spectroscopy of hadrons (hyperons)
- mass distribution of barionic resonances with strange and charm content
- strangeness and charm production
- intrinsic charm in the proton



CBM@ SIS100 pp @ 30 GeV

- prod. cross sec. higher than at SIS18: $\sigma(\Sigma^*, \Lambda^*) \sim 1$ mb
- much higher luminosity



- Tracking acceptance $2^\circ < \Theta_{lab} < 25^\circ$
- Free streaming readout
- Front-end connectivity up to $R_{ex} = 10$ MHz
- Software-based event selection

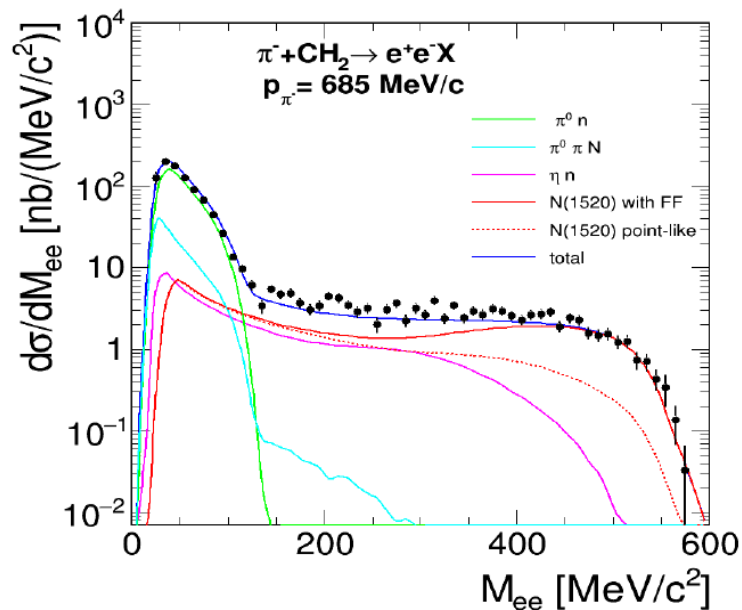
- 1: Time-Zero Detector & Beam Diagnostics
- 2: Silicon Tracking System / Micro Vertex Detector
- 3: Superconducting Dipole Magnet
- 4: Muon Chambers

- 5: Ring Imaging Cherenkov Detector
- 6: Transition Radiation Detector
- 7: Time of Flight Detector
- 8: Forward Spectator Detector



Inclusive e+e- cocktail

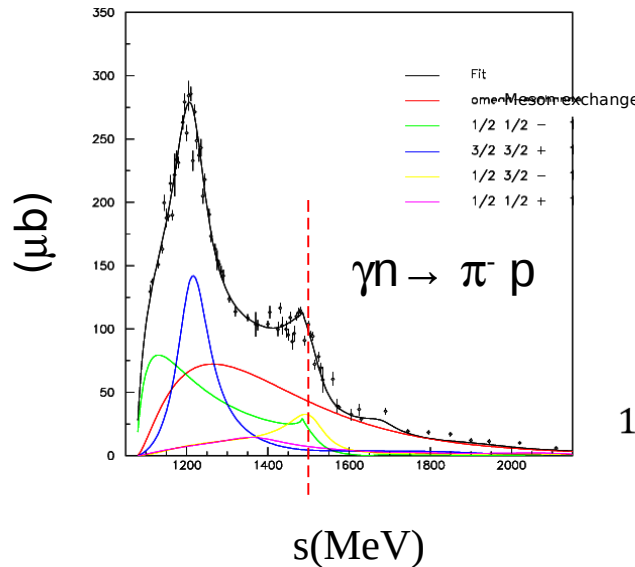
Fixing cocktail ingredients



$\pi^- p \rightarrow n \pi^0$ [9 mb] (SAID)
 $\pi^- p \rightarrow n \pi^0 \pi^0$ [1.9 mb] (L.-B.)
 $\pi^- p \rightarrow p \pi^0 \pi^-$ [4.0 mb] (L.-B.)
 $\pi^- p \rightarrow n \eta$ [0.83 mb]

Dalitz Decay BR
 π^0 : 0.012
 η : 0.006

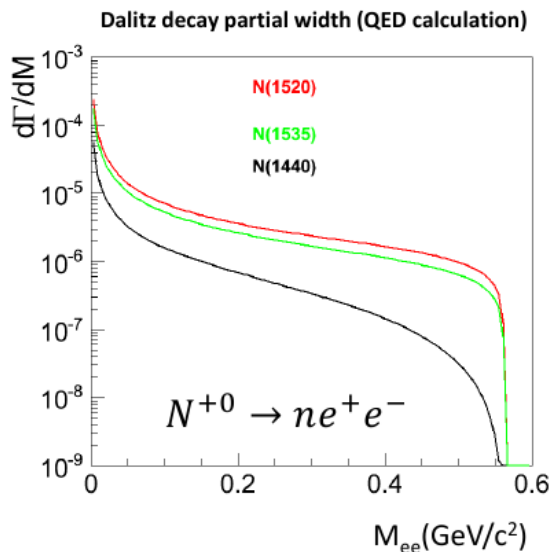
Arndt et al., PRC72 (2005) 045202



Bonn-Gatchina PWA

$N(1520)$ to $\pi p \rightarrow \gamma n$: 21%
 $N(1535)$ to $\pi p \rightarrow \gamma n$: 15%

$$\sigma(\pi^- p \rightarrow n e^+ e^-) \sim 1.35 \alpha \sigma(\pi^- p \rightarrow n \gamma) = 2 \mu\text{b}$$

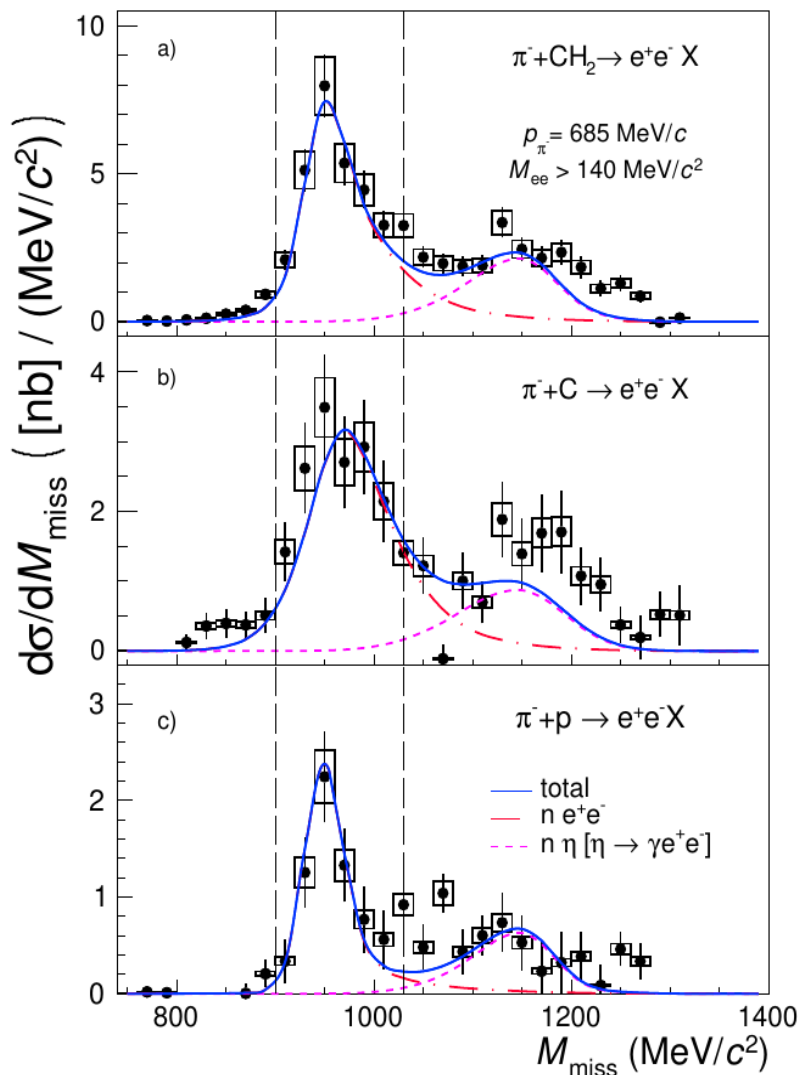


input for $\pi p \rightarrow \gamma^*(e^+ e^-) n$
 QED Dalitz decay contribution



Selection of quasi-free $\pi^- p \rightarrow n e^+ e^-$

HADES coll. arXiv:2205.15914 [nucl-ex]



- cut on $\text{inv} M_{e^+ e^-} > 140 \text{ MeV}$ (above π^0 mass)
- missing mass cut on M_{miss} (η removed)

- $\pi^- \text{C}$ simulations using Pluto (qfs participant-spectator model)
- production cross sec. on C for: $\pi^0, \eta, \rho, \gamma$ deduced from the scaling: $R_{C/H} = \sigma_C / \sigma_H$

- CH_2 target:

$$\left(\frac{d\sigma}{dM_{ee}} \right)_{\text{CH}_2} = \left(\frac{d\sigma}{dM_{ee}} \right)_C + 2 \left(\frac{d\sigma}{dM_{ee}} \right)_H$$