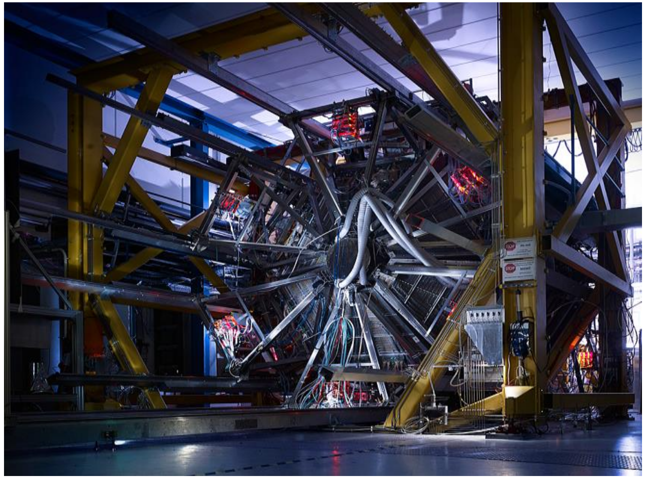
Studies of baryon timelike transition Form-Factors in QCD matter with dileptons

- ✓ Motivations(emissivity of QCD matter -> Low mass dileptons, ρ in-medium spectral function → timelike baryon em. transitions)
- ✓ Measurements of baryon electromagnetic transitions in NN and πN reactions in HADES
- ✓ Summary & Outlook



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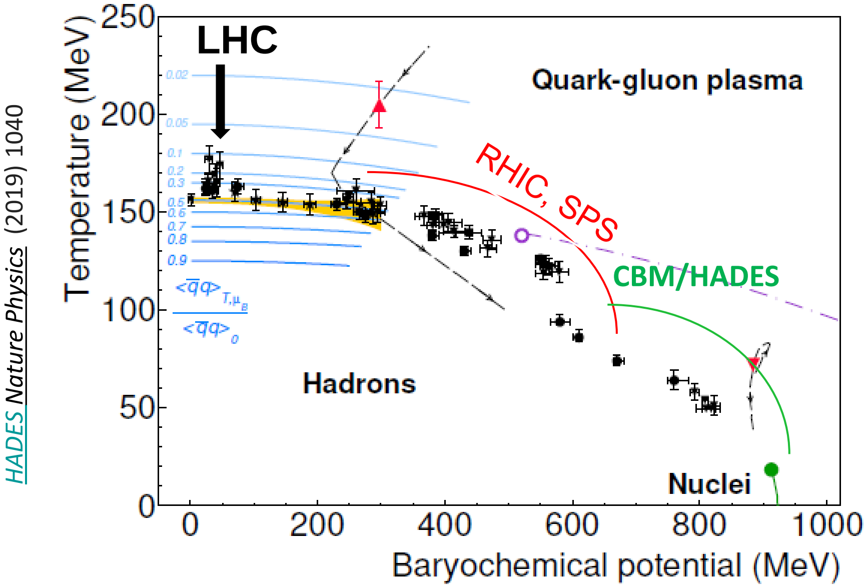
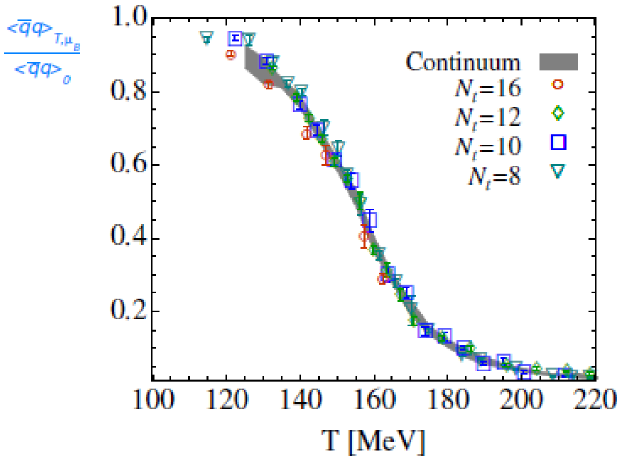
FONDAZIONE BRUNO KESSLER

QCD phase diagram and chiral symmetry restoration



Lattice QCD S. Borsnyi JHEP 73 '2010

Order par:. Chiral symmetry restoration $T \cong 155$ MeV, $\mu_B = 0$

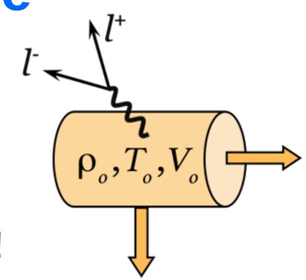


- ❑ at vanishing μ_B QGP-hadron gas transition associated with chiral symmetry restoration (χSR)
- ❑ no first principle QCD calculations available for large μ_B
- ❑ Dileptons are excelent probe to study QCD matter properties:

access to early phase (T, flow) and are promising observable for χSR

Emissivity of QCD matter with dilepton probe

$$\frac{dN_{ll}}{d^4q d^4x} = -\frac{\alpha_{em}^2}{\pi^3}\frac{L(M^2)}{M^2} f^{BE}(q_0,T)\,\mathrm{Im}\Pi_{em}(M,q,T,\mu_B)$$



McLerran - Toimela formula, Phys. Rev. D 31 (1985) 545

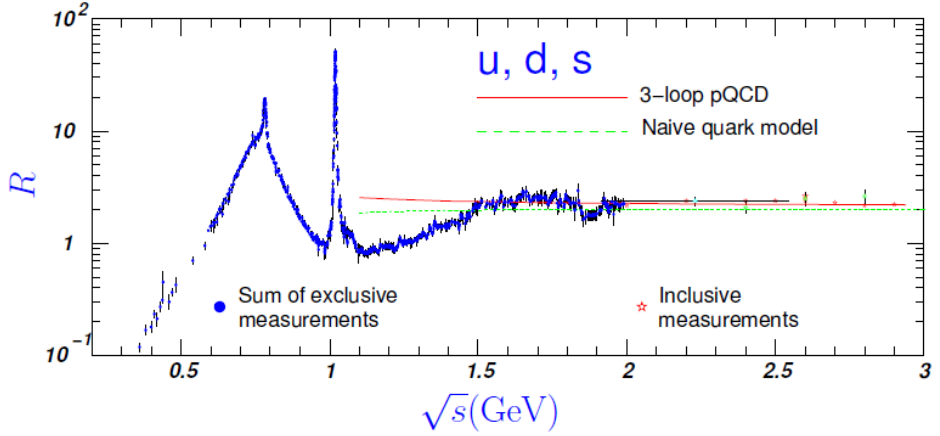
- Not disturbed by finite state interactions ! But needs integration over volume and time !
- *Π_{em} em. current-current correlator :$q^2 < 1$ GeV - in-medium VM (**ρ**) spectral functions-*

Vector Meson Dominance

$$\mathrm{Im}\,\Pi_{em}^{\mathrm{had.}} = \sum_{V=\rho,\omega,\phi} \left(\frac{m_V^2}{g_V}\right)^2 \mathrm{Im}\, D_V(M)\,. \qquad R_{\mathrm{had.}} = \frac{\sigma\,(e^+e^- \to \mathrm{hadrons})}{\sigma\,(e^+e^- \to \mu^+\mu^-)} \propto \frac{1}{M^2}\,\mathrm{Im}\,\Pi^{em}$$

LM dilepton yield in HIC is dominated by ρ in-medium propagator

$q^2 > 1.5$GeV qq radiation pQCD (flat)

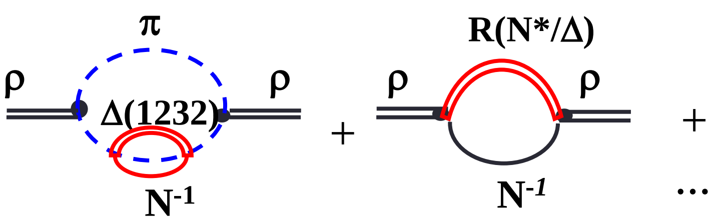


- Thermal distribution *f^{BE} (T) – thermometer*

In medium ρ spectral function

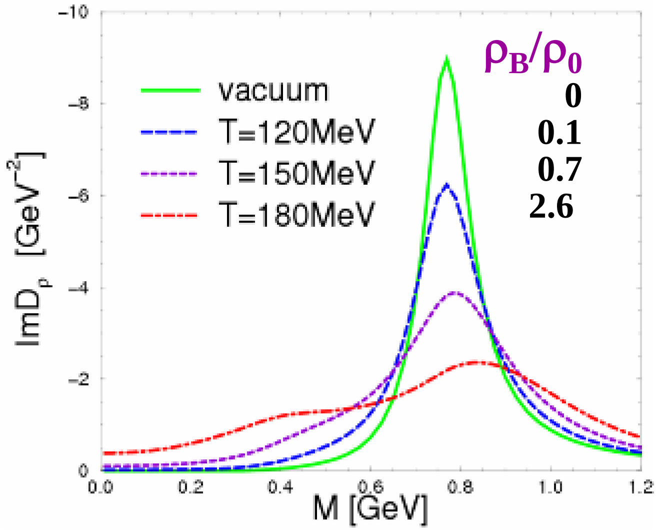
$$D_\rho(M,q,T,\mu_B) = \frac{1}{\left[M^2 - m_\rho^2 - \Sigma_{\rho\pi\pi} - \Sigma_{\rho B} - \Sigma_{\rho M}\right]}$$

In Medium Im Σ_ρ:



dominant role of ρ - R couplings

Rapp, Wambach, Adv. Nucl. Phys. A25 (2000)1



@ SPS
full energy

ρ -meson : connection to χSR

QCD sum rules

$$\frac{1}{M^2}\int_0^\infty ds \frac{\rho_V(s)}{s} e^{-s/M^2} = \frac{1}{8\pi^2}\left(1+\frac{\alpha_s}{\pi}\right) + \frac{m_q\langle\bar{q}q\rangle}{M^4} + \frac{1}{24M^4}\langle\frac{\alpha_s}{\pi}G^2_{\mu\nu}\rangle - \frac{56\pi\alpha_s}{81M^6}\langle\mathcal{O}_4^V\rangle \ldots$$

[Weinberg '67, Das et al '67]

[Hatsuda+Lee '91, Asakawa+Ko '93, Leupold et al '98, …]

Weinberg Sum rules

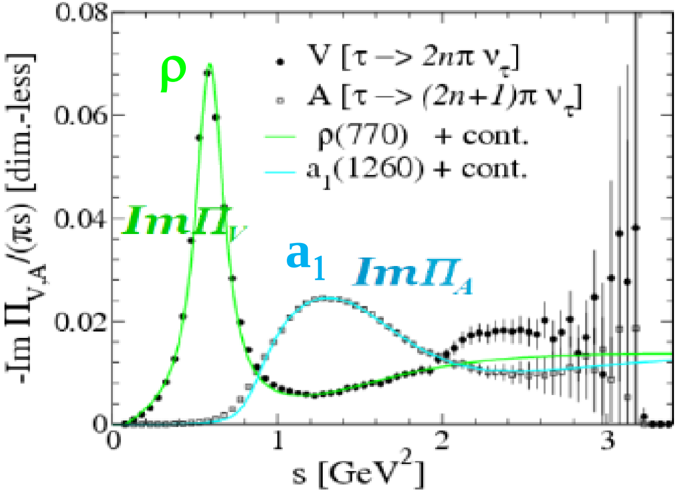
$$\int ds \frac{1}{s}(\rho_V - \rho_A) = f_\pi^2$$

$$\int ds\,(\rho_V - \rho_A) = -m_q\langle\bar{q}q\rangle$$

$$\int ds\, s\,(\rho_V - \rho_A) = c\alpha_s\langle(\bar{q}q)^2\rangle^{SB}$$

[Weinberg '67, Das et al '67; Kapusta+Shuryak '94]

P. M. Hohler and R. Rapp, NPA 892, 58 (2012)



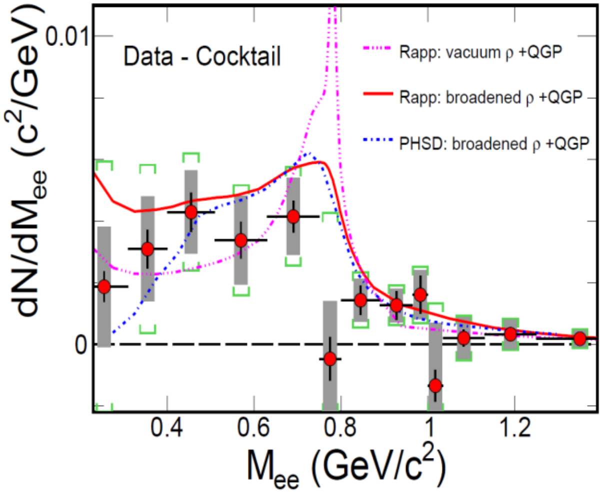
- in vacuum ρ-a_1 mass splitting

due to χS breaking (~ f_π ,$\langle\bar{q}q\rangle$, …)

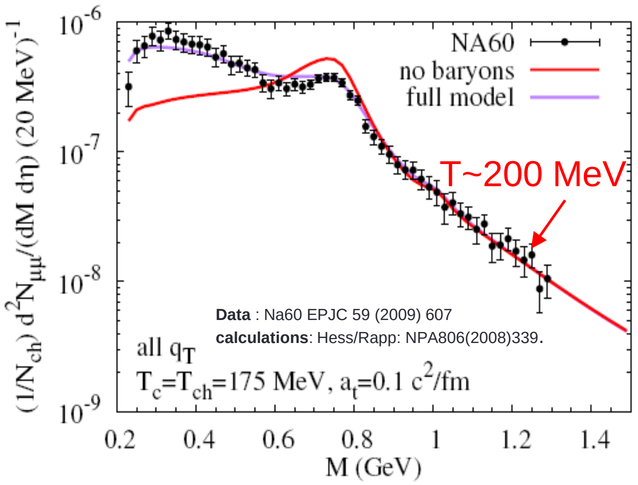
- χSR – both spectra functions overlap at T_c - demonstrated by Hohler&Rapp PLBB731(2014)

Dielepton thermal rates from HIC from SIS18 to RHIC

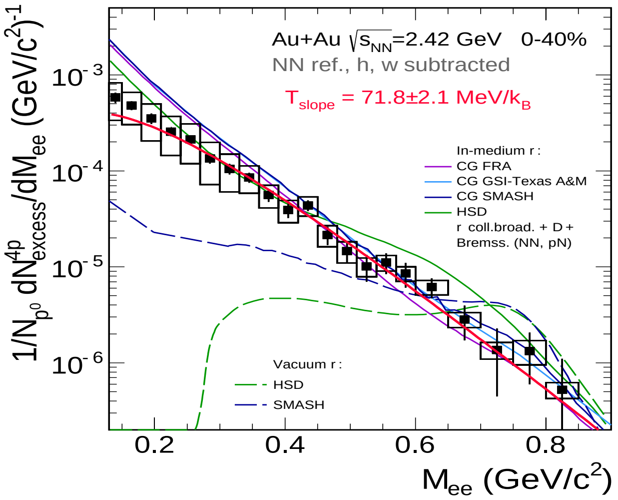
STAR √s=200 GeV PRC92 (2015)



Na60 @ SPS In+In (μ+μ-) √s=17.3 GeV



HADES: Nature Phys. 15 (2019) 10, 1040-1045

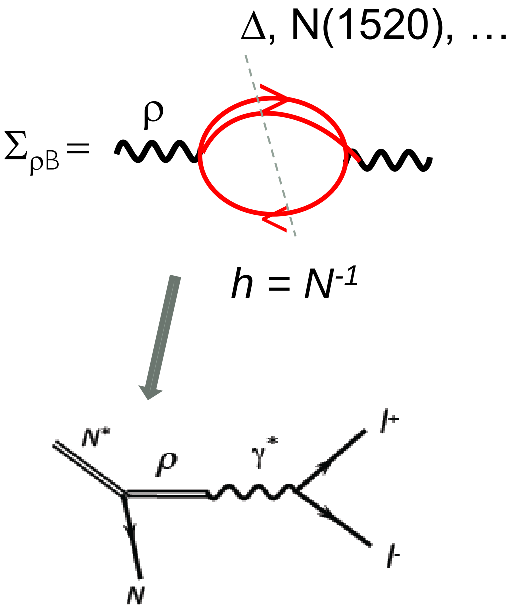


- Successful description of excess yield over large energy region by thermal radiation from in-medium ρ with significant broadening

..at LHC we still awaiting precision measurements : ALICE in Run4 and ALICE3 optimized for low mass dileptons !

- NA60: T ~ 200 MeV - <T> of the early phase, HADES T~ 70 MeV „hot baryonic matter”
- next step search for ρ/a_1 mixing ALICE3, NA60+, CBM ..

In medium ρ-B interactions–connection to Baryon Dalitz Decay



Baryon Dalitz decays → em. Transition Form Factors

Baryonic loops

- sensitive to **ρN N*/Δ couplings (BR N/Δ→Nρ)**
- related to **baryon Dalitz Decay decays Δ/N*→Ne+e-**

Important microscopic input to hadronic models

so far constraint in model calculations was provided by

photo-absorption on nulceon, BR (R→Nρ), BR (R→Nγ)

Measure Dalitz decays NN and πN collisions ! → dedicated HADES hadron physics programme

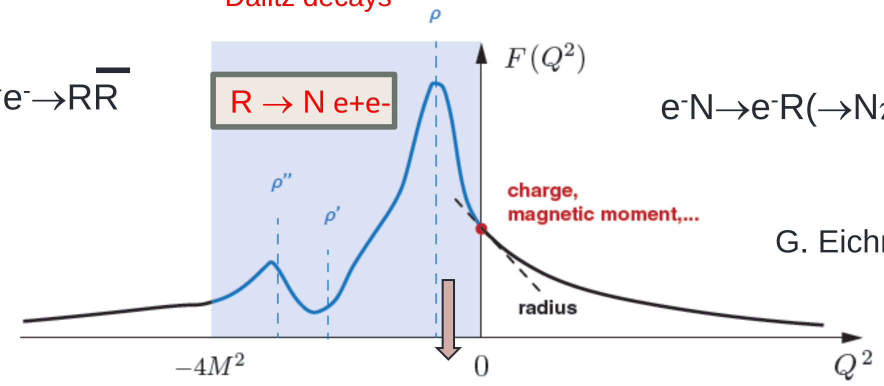
Baryon electromagnetic transitions

Dalitz decays

$e^+e^- \to R\bar{R}$

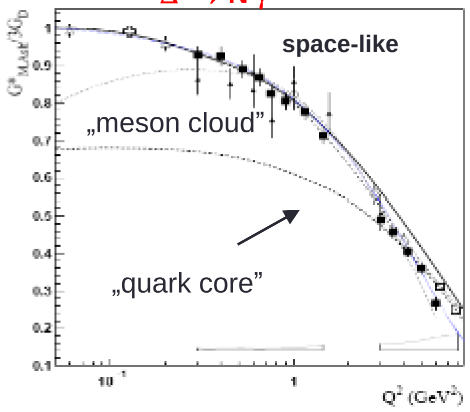
R → N e+e-

$e^-N \to e^-R(\to N\pi)$



G. Eichmann

$\Delta \to N\gamma$



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

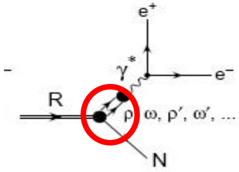
- Dalitz decays : em. Transition Form Factors (timelike) (complementary to spacelike region)

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

„QED"

Transition of point-like baryon

Effective Transition Form-Factor



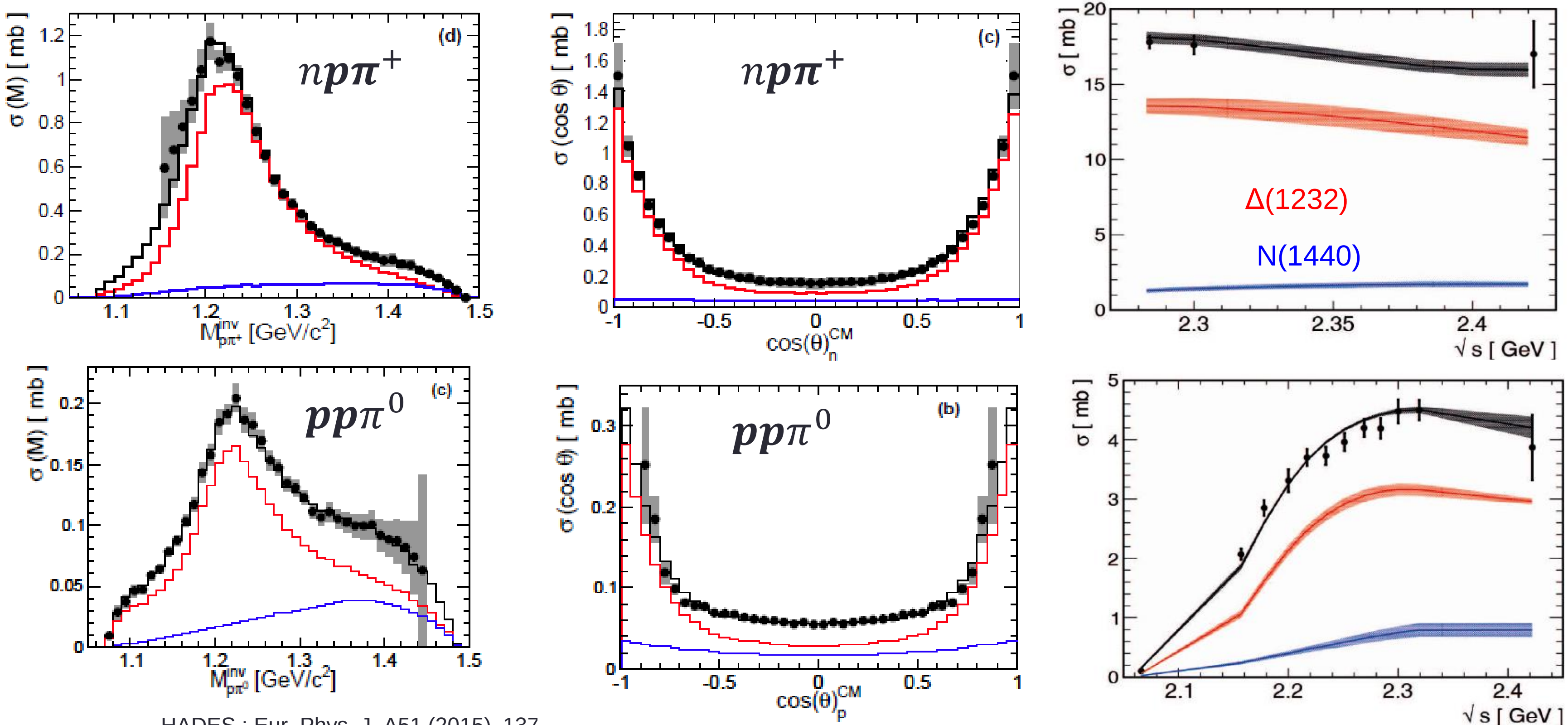
models (timelike baryon transitions):

M. I. Krivoruchenko, et. al. An. Phys. 296, 299 (2002)
Q. Wan and F. Iachello, Int. J. Mod. Phys. A 20 (2005) 1846.
G. Ramalho and M.T. Peña, PRD 80 (2009) 013008
T. Pena and G. Ramalho, Phys.Rev. D85 (2012) 113014
M. Zetenyi, Gy. Wolf, Heavy Ion Phys. 17, 27 (2003).

Δ (pπ⁺, pπ⁰) excitation in pp →ΔN √s= 2.42 GeV

13 PNPI + 2 HADES data sets

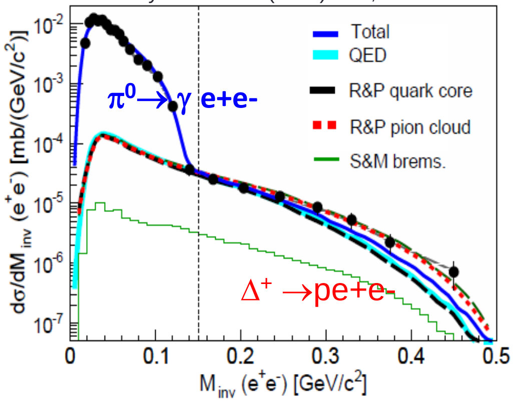
Bn-Ga PWA solutions: resonances: Δ(1232) and N(1440)



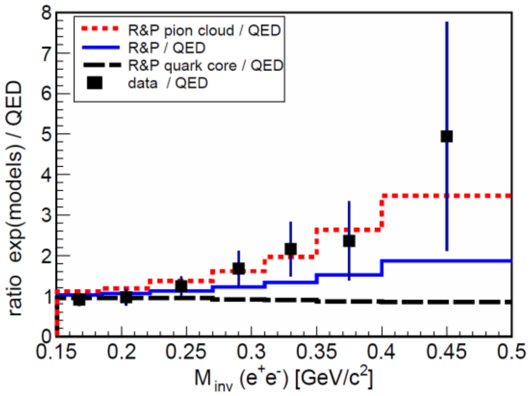
HADES : Eur. Phys. J. A51 (2015) 137

pp → p(Δ→pe$^+$e$^-$) Δ Dalitz decay

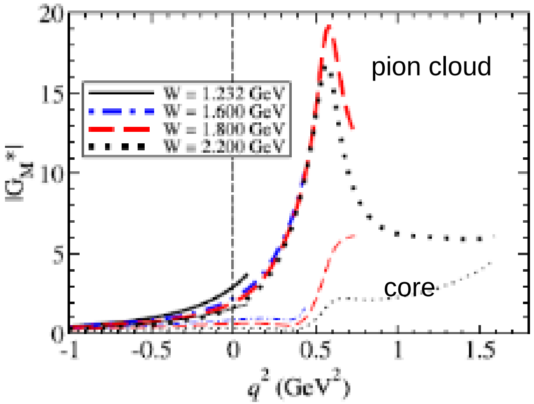
HADES Phys. Rev. C95 (2017) no.6, 065205

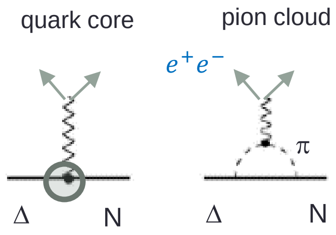


$M_{e+e-} > M_\pi$ $\langle M_\Delta \rangle$ ~1.4 GeV



T. Pena and G. Ramalho, Phys.Rev. D85 (2012) 113014





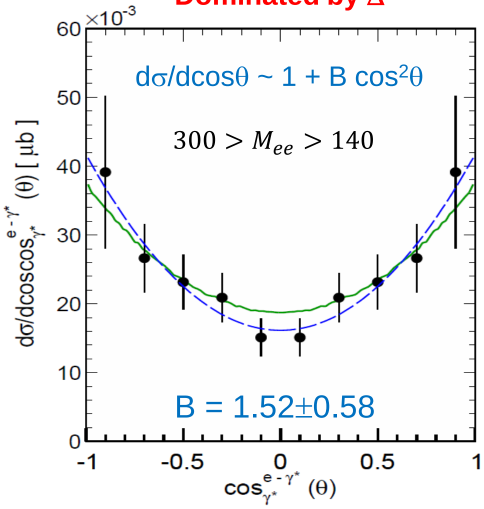
- ❑ **BR (Δ→pe+e-)= 4.19 10^{-5} ± 0.62 (sys) ± 0.32(stat)**
  (First measurement ! : PDG entry)

- ❑ Good agreement with 2 component model of TFF Ramahlo & Pehna (R&P) -> Slight rise v.s Mass due to VM(ρ) - pion cloud effect

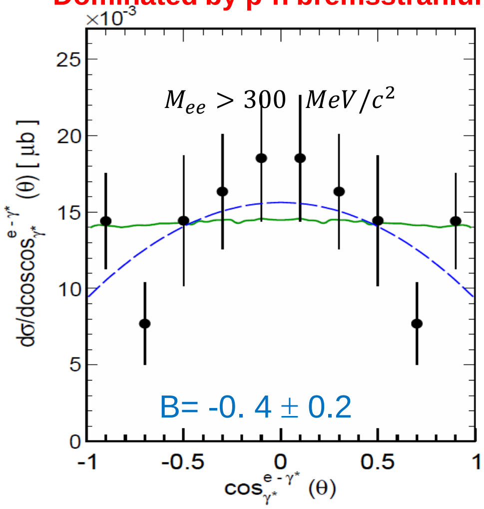
- ❑ Lepton angular distributions confirm dominance of G_M
  (transverse polarized γ^* ->B=1)

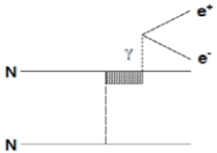
p-n data: γ^* polarization : e distributions in (helicity) frame

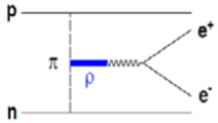
Dominated by Δ



Dominated by p-n bremsstrahlung ρ

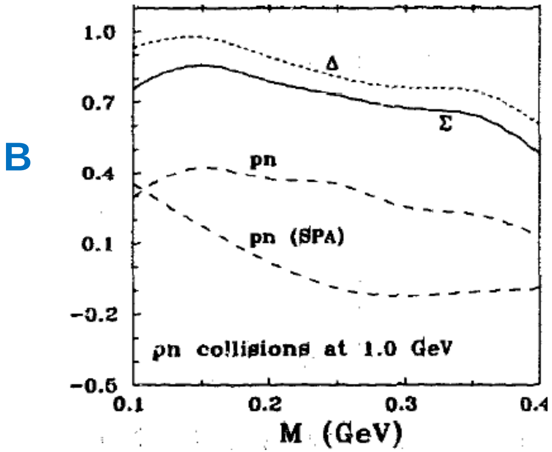






OBE calculations

E. L. Bratkovskaya, at. al PLB 348, 325 (1995).

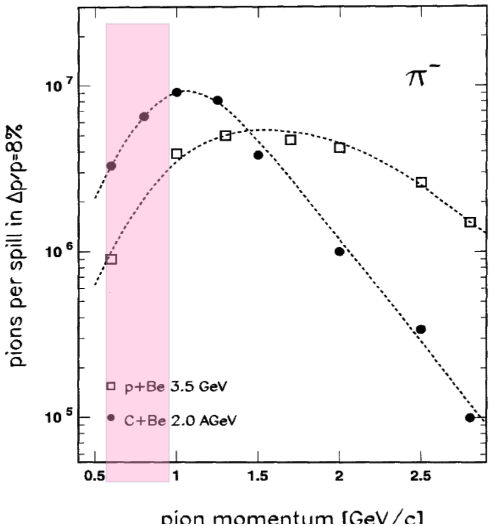


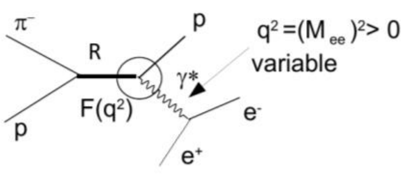
- B≈1 expected for Δ→pe+e- dominance of G_M and transverse polarized photons

- change of angular distribution
- B ≈0 expected for p-n bremsstrahlung (see right for OBE) , B≈ -1 for ρ dominance

Pion Beam @ GSI

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



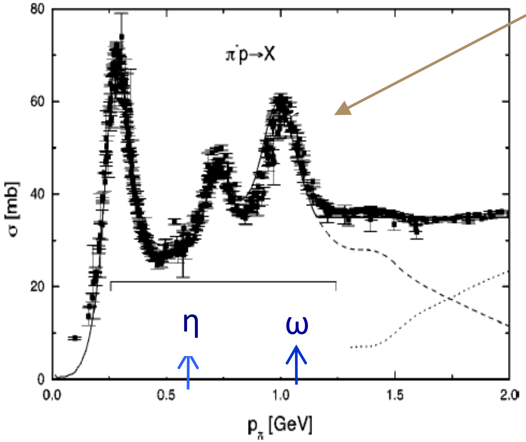


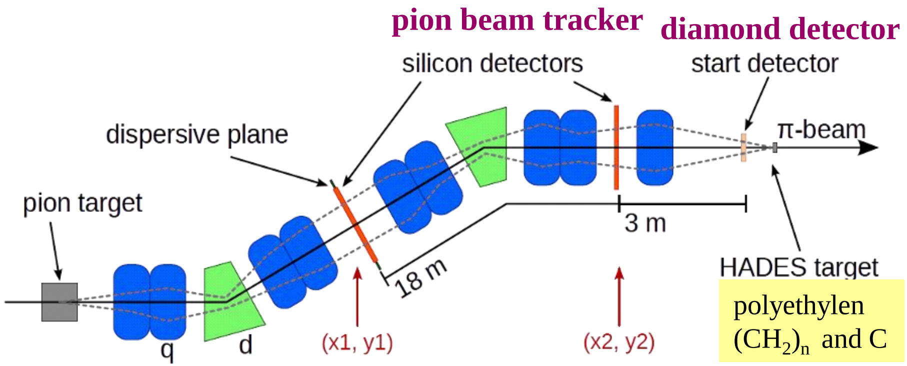
Resonance production with $m_R = \sqrt{s}$!

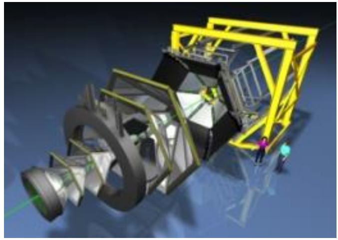
- reaction **N+Be**, secondary **π^-** with **I ~ 2-3 10^5/s**
- pion momentum $\Delta p/p$ =2.2% (σ)
- 50% acceptance of pion beam line

First run:

- **$\sqrt{s}$ =1.46-1.55 GeV (4 points)-second resonance region**
- **PE $(CH_2)_n$** and **C** targets : 2-pion and e+e- production

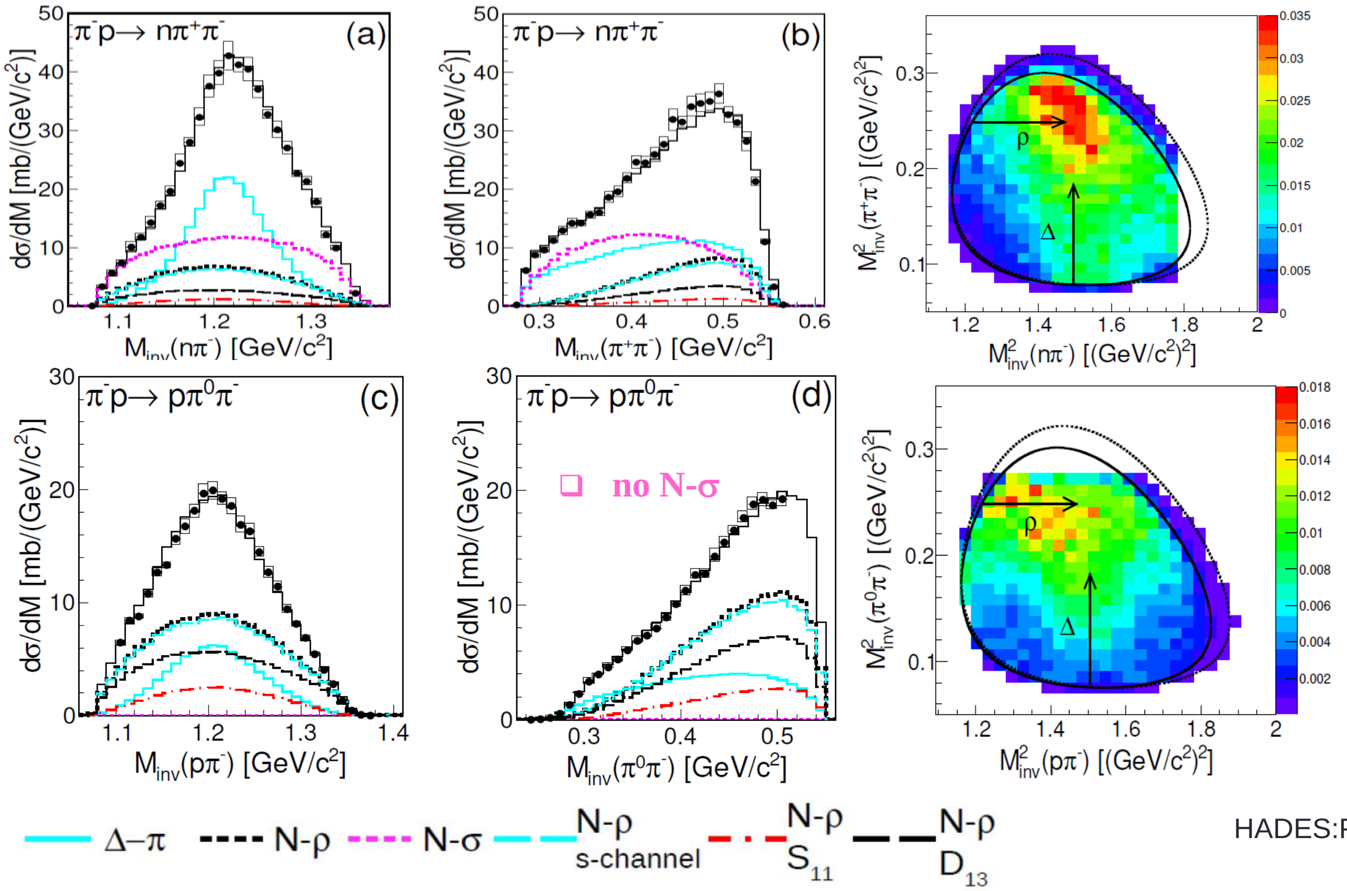






2 pion production: PWA (Bn-Ga) decomposition √s=1.49 GeV

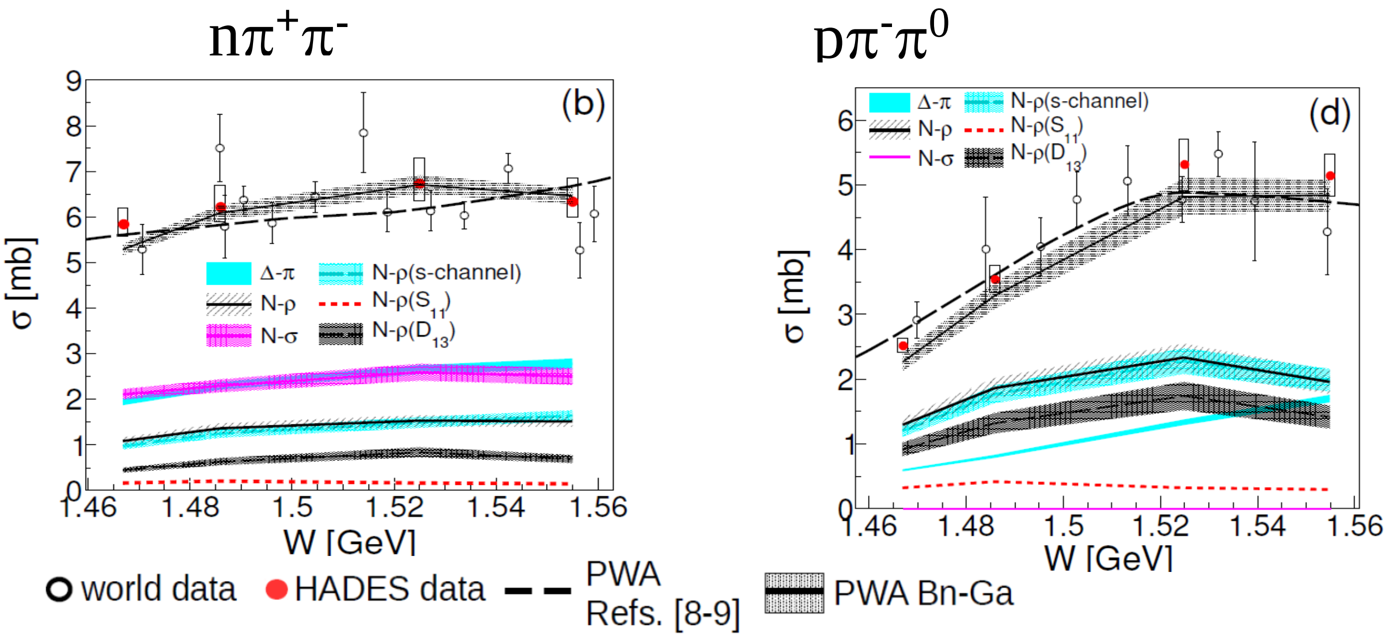
„subthreshold" – no ρ peak in $\pi^+ \pi^{-,0}$ mass distributions



- Combined PWA fit with many other channels from $e^- p, \gamma p, \ p$ reactions
- Input solution: resonance properties fixed, except branches to VM
- Final solution with HADES 2pion data Bn-Ga 2019 (pwa.hisp.uni-bonn.de)

HADES:PRC *C102 (2020) 024001*

Total Cross Sections



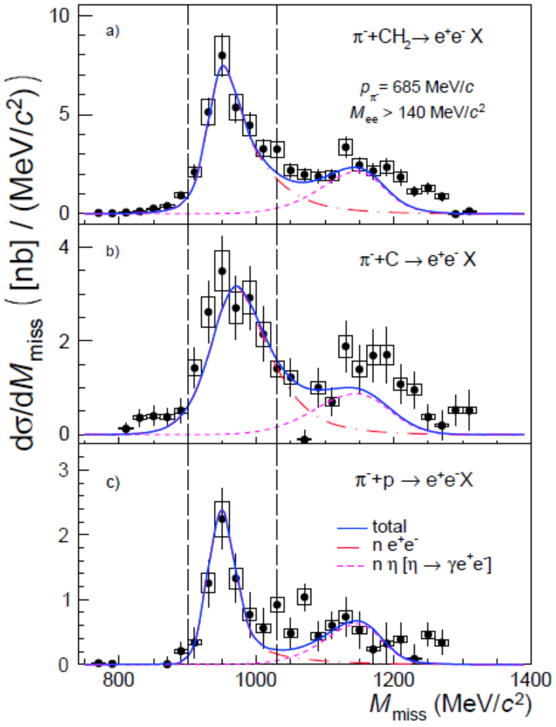
[8-9]
D. M. Manley *et al*. *Phys. Rev. D 30 (1984) 904*
D. M. Manley and E.M. Saleski, Phys. Rev. D 45,

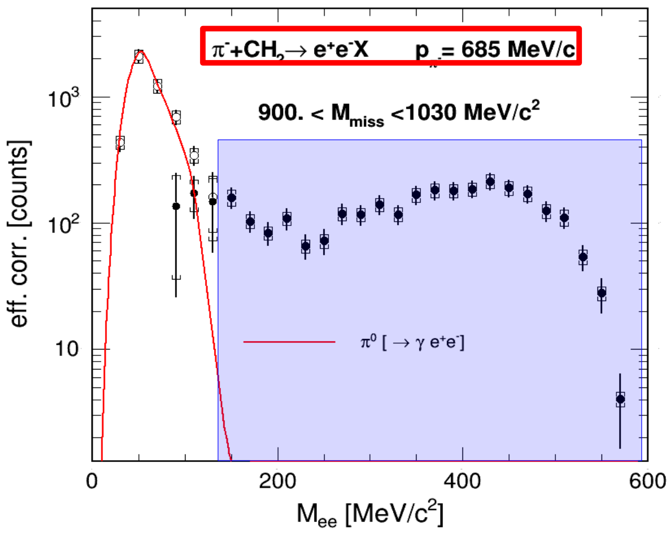
HADES coll. Phys.Rev.C 102 (2020) 2, 024001

- consistent descripton of HADES and world data
- ρ meson production dominated by s-channels with dominant contribution from D_{13} $(N(1520))$
- **N (1520) →N ρ BR =12.2 ± 2 % N(1535)** →N ρ **BR=3.2 ± 0.6 %**

 + BR for **Δπ** and **Nσ** (8 new entries in PDG'2020)

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



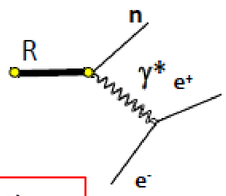


$\pi^- p \rightarrow n e^+ e^-$

- Selection of the exclusive $\pi^- p \rightarrow n e^+ e^-$ channel using missing mass

QED reference for eTFF

- Limit at $q^2=0$ given by $\pi^- p \to n\gamma$



Contribution of D13 to $\pi^- p \to \gamma n$ 27% (N1520 21%)
of S11 to $\pi^- p \to \gamma n$ 27% (N1535 15%)

- Generalization to finite q^2 (QED)

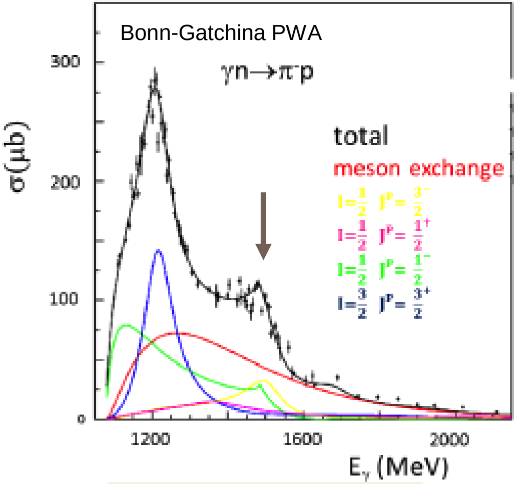
*M. Krivoruchenko et al., Ann. of Phys. **296**, 299–346 (2002)*

→ "point-like" description of $R \to Ne^+e^-$:

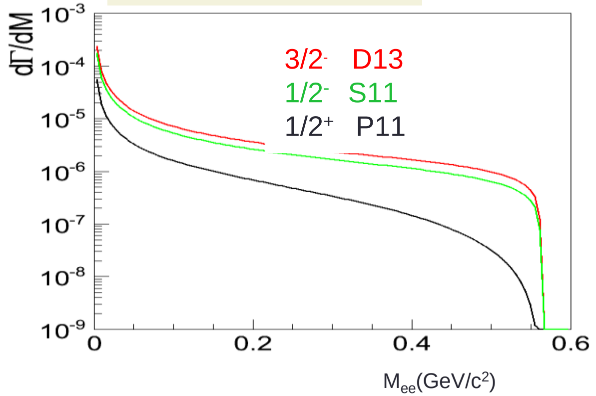
invariant mass distribution depends on J^P
(S11 and D13 same shape)

$$\sigma(\pi^- p \to n e^+ e^-) \sim 1.35\ \alpha\ \sigma(\pi^- p \to n\gamma)$$

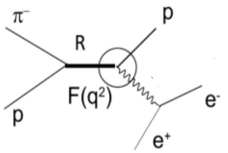
« γ « or « QED « reference



$N^{*0} \to ne^+e^-$



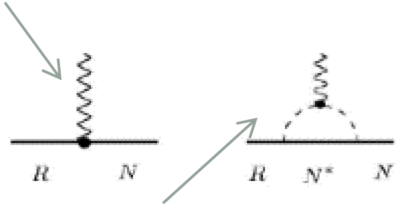
eTFF (quark+meson cloud) model



Model for N-N(1520) transition

G. Ramalho and M. T. Pena, Phys. Rev. D95, 014003 (2017)

Quark core contribution :
- Quark form factors inspired by VMD

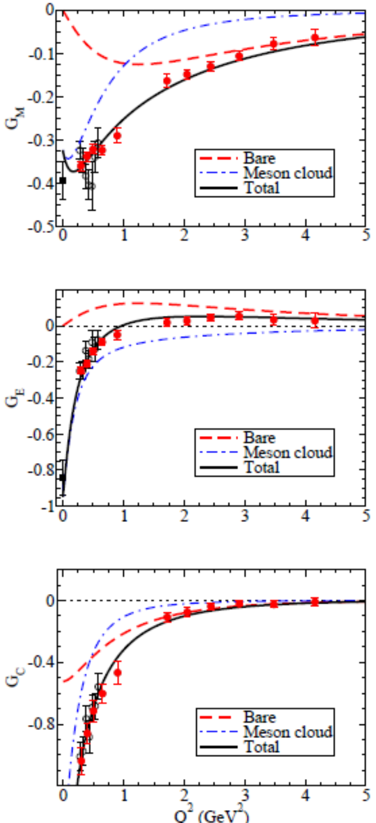


Meson cloud contribution:
- Based on pion electromagnetic form factor
- Dominant contribution in the timelike region

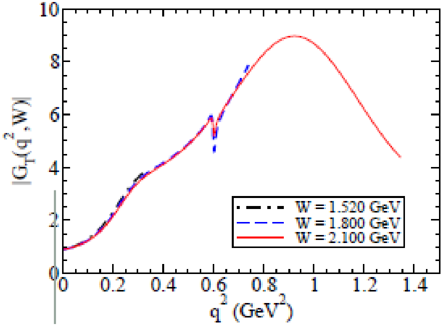
Similar model for N-N(1535) transition

Phys.Rev. D101 (2020)114008

Parameters of the model fitted to spacelike data

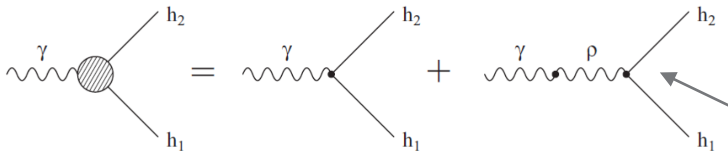


Predictions for the timelike region



$$|G_T(q^2, W)|^2 = 3|G_M(q^2, W)|^2 + |G_E(q^2, W)|^2 + \frac{q^2}{2W^2}|G_C(q^2, W)|^2.$$

Two-component Lagrangian model



« Kroll-Lee-Zuminio »
« VDM1 » Lagrangian is used

$$\mathcal{L}_{\rho\gamma} = -\frac{e}{2g_\rho} F^{\mu\nu} \rho^0_{\mu\nu},$$

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

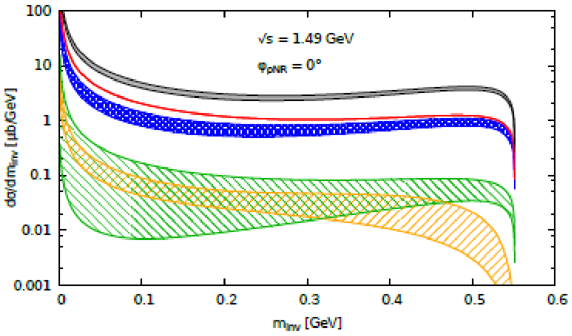
- Various non-resonant (Born term)

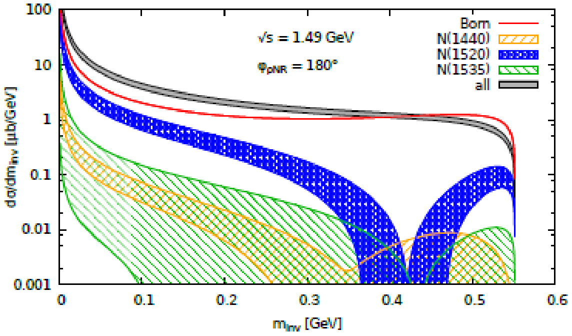
and resonant D13(1520), P11(1440), S11(1535),..)

- **Strong contribution of the Born term**

M. Zetenyi and G. Wolf, Phys. ReV. C ***86****, 065209 (2012)*

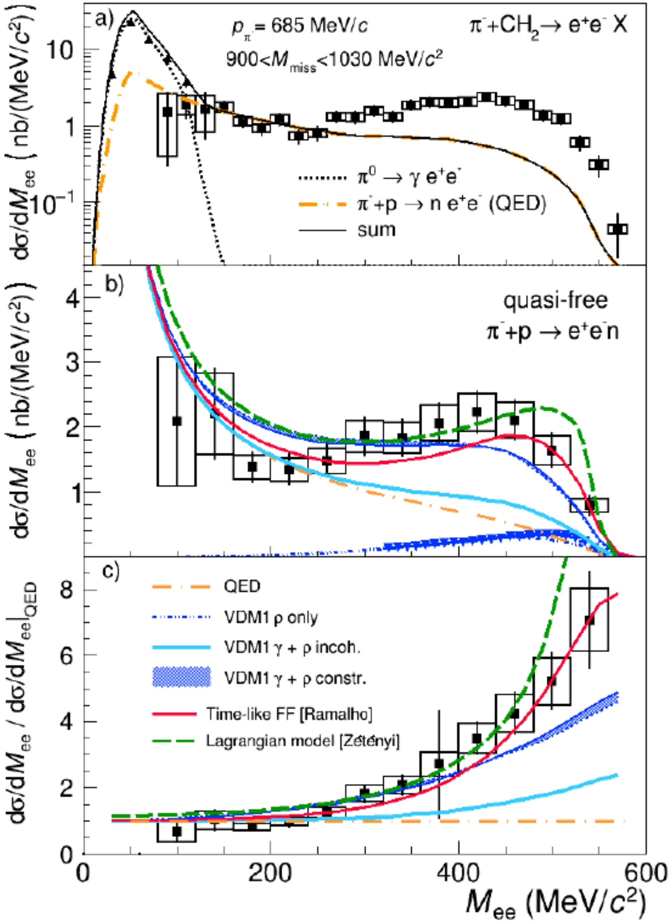
M. Zetenyi, et al. arXiv:2012.07546[nucl-th], 2020





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

„effective" N*/N em. TFF



- **QED reference constrainted by $\pi^- p \to n\gamma$ data and** available Bn-Ga solutions

- **Model independent results:**
  - Strong excess with respect to the **point-like contribution-QED reference** (up to a factor 5) -

❑ **Data driven model VDM1: QED (direct γ) + ρ→e+e-** with constructive interferences gives a **good description of the full spectrum**

❑ **Two microscopic models describe also data very well :**

a) Lagrangian (production + baryon Decay with VDM1)

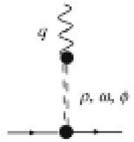
b) eTFF model of N(1520)+N(1535) (quark + meson cloud)

M. Zetenyi et al. PRC 104(2021) 1,015201

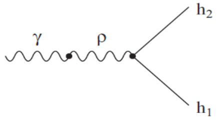
G. Ramalho and M. T. Pena, Phys. Rev. D95, 014003 (2017)

VMD in baryon decays

Test of VMD versions (equivalent for universal coupling $g_\rho = g_{\rho\pi\pi}$)
Discussed in O'Connell Prog. Part. Nucl. Phys., Vol. 39,pp. 201-252, 1997



VMD2 : *Sakurai, Phys. Rev 22 (1969) 981*
- most commonly used in Heavy Ion transport models
- one single ρN coupling

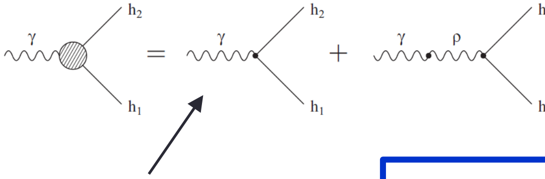


mass dependent
decay width to e+e-

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

VMD1 : *Kroll, Lee & Zuminio Phys. Rev. 157 (1967) 1376*
ρ contr. vanishes at m_γ*=0,
γN and ρN couplings fixed independently allows to fix BR(R→Nγ) and BR(R→Nρ) consistently

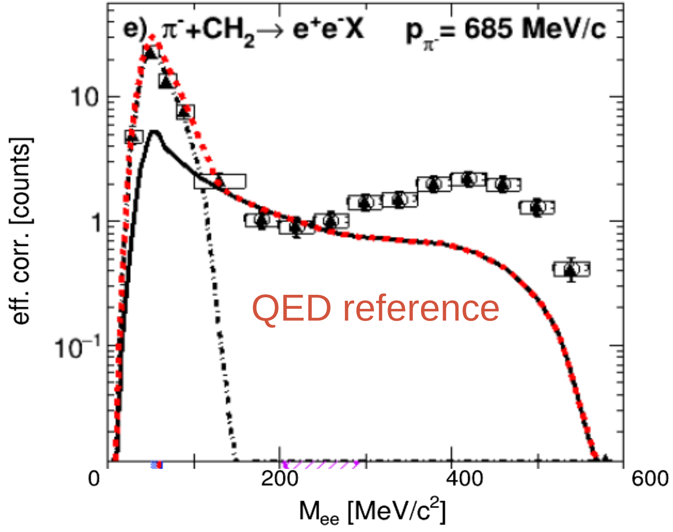
Important for in-medium rho-meson calculations as pointed out in
B. Friman, H.J Priner, Nucl. Phtys. A 617(1997)496
- Phase between γ and ρ contributions to be fixed by data

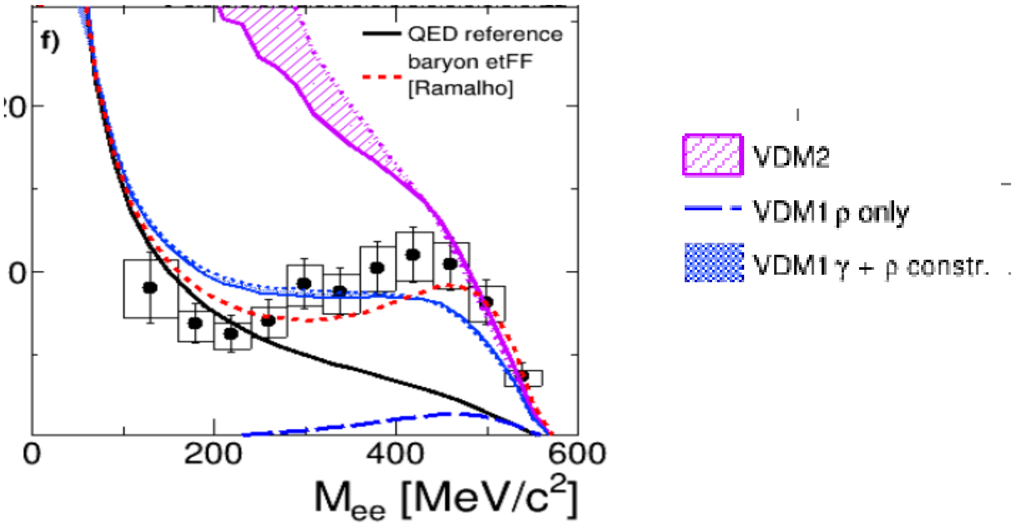


γ or point-like contribution

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

VDM1/VDM2 comparison to data





- VDM2 (transition saturated by ρ) overestimate data below 400 MeV
- VDM1 with constructive γ+ρ interference in good agreement

Polarisation of resonances in pion induced reactions

Z- CMS quantization axis

$\vec{L} \perp$ R.P

- π is spinless hence

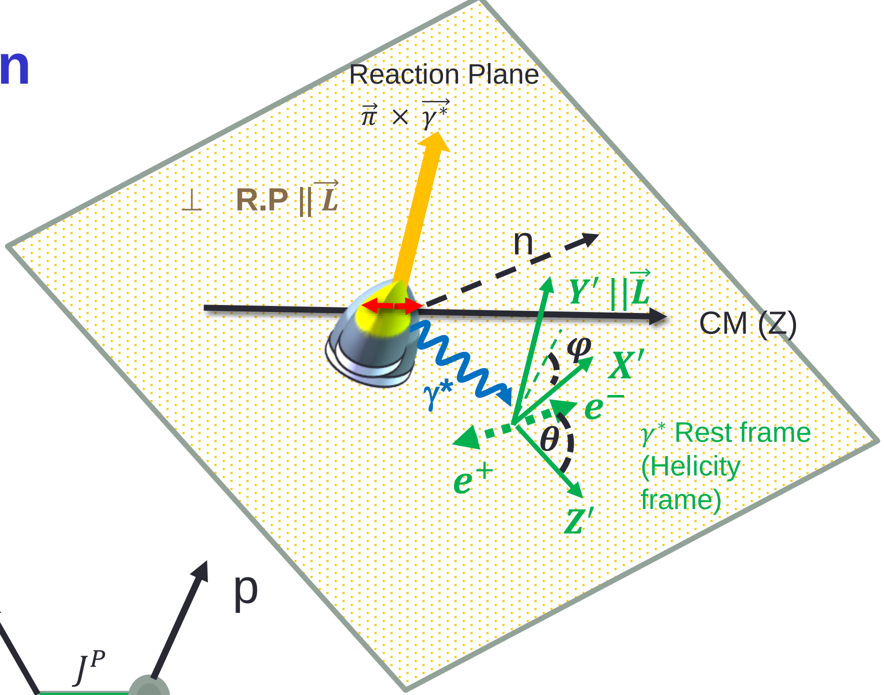
$$J_Z^{N*} = S_Z^N = \pm\frac{1}{2}$$

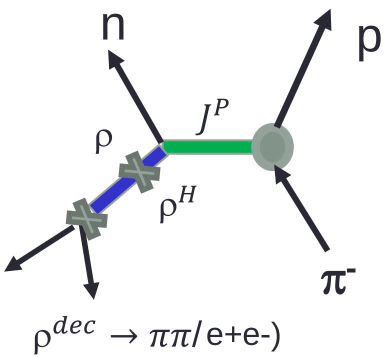
- Polarization for $J^{N*} \geq \frac{3}{2}$ expected (only spin projections $\pm\frac{1}{2}$) allowed

$$|A|^2 = \sum_{\Lambda\Lambda'} \rho^{(H)}_{\Lambda\Lambda'} \rho^{(dec)}_{\Lambda\Lambda'}$$

ρ^{dec} known, find ρ^H from data

for e+e-





Models: GSI/Budpest

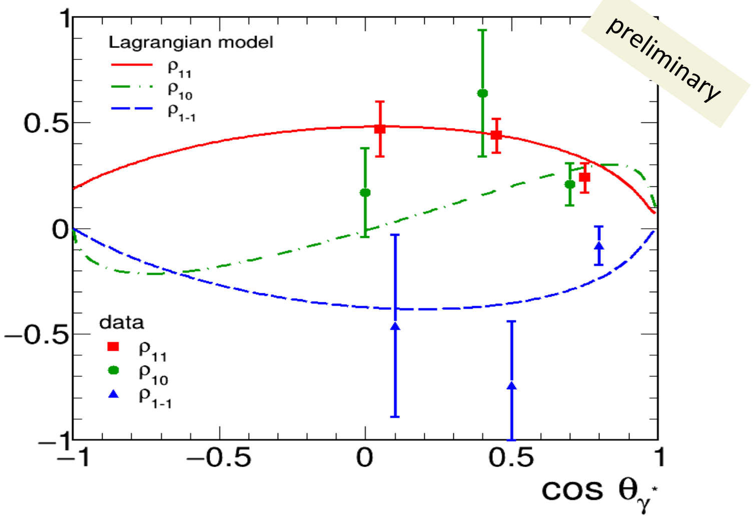
E.Speranza et al.. PLB 764(2017)282

$$|A|^2 = 8p_{\gamma*}^2(1 - cos^2\theta_1 - \rho^H_{11}(3cos^2\theta_1 - 1) + \sqrt{2}\sin(2\theta)\, cos\varphi Re\rho_{10} + sin^2\theta\cos(2\varphi)\, Re\rho^H_{1-1}$$

spin density matrix elements from e^+/e^- data

$$|A|^2 = 8p_{\gamma*}^2 (1 - cos^2\theta_1 - \rho_{11}^H (3cos^2\theta_1 - 1) + \sqrt{2}\sin(2\theta) cos\varphi Re\rho_{10} + sin^2\theta \cos(2\varphi) Re\rho_{1-1}^H$$

ρ_{11} , ρ_{10}, ρ_{1-1} extracted in 3 bins in cos θ_γ



sdme sensitive to :

- J^P : *for J=1/2* no dependence on θ_γ

$\rho_{10} = 0$, only transverse polarization $\rho_{11} = 0.5$

- sdm are combination of G_E , G_M, G_C

$$\rho_{11} = \frac{1+\lambda}{3+\lambda} = \frac{A_\perp}{2A_\perp + A_\parallel}$$

J=1/2

$$\lambda = \frac{\left|G^\pm_{E/M}\right|^2 - |G^\pm_C|^2}{\left|G^\pm_{E/M}\right|^2 + |G^\pm_C|^2}$$

J>1/2

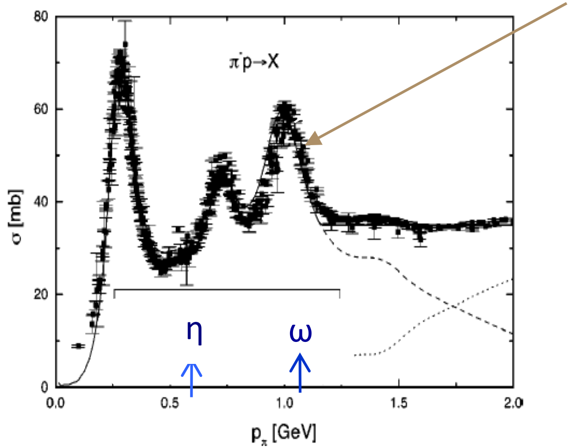
$$A_\perp = \frac{l+1}{l}\left|G^\pm_{M/E}\right|^2 + (l+1)(l+2)\left|G^\pm_{E/M}\right|^2$$

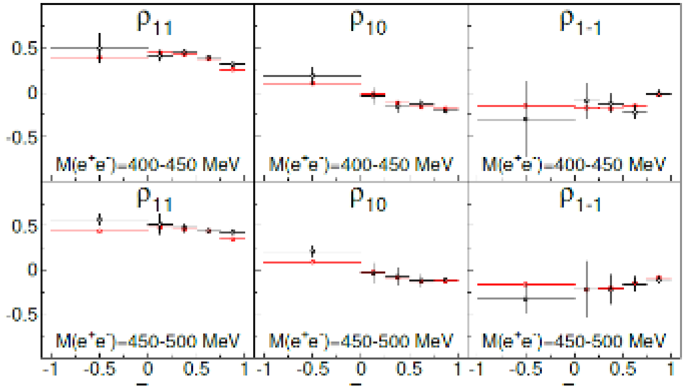
$$A_\parallel = \frac{M^2}{m_\star^2}|G^\pm_C|^2$$

- data consistent with dominance of N1520 (J=3/2)
- Good agreement with Lagrangian model (predictions!)
- **Powerfull observable.. but more precise data needed**

Outlook : experiments with pion beam

Exp. proposal at FAIR0/SIS18 : 2023-2025: explore the **third resonance region** ($\sqrt{s}$~1.7 GeV/c^2)





1. Baryon meson couplings $\pi\pi N$, ωn, ηn , $K^0\Lambda$, $K\Sigma$,….

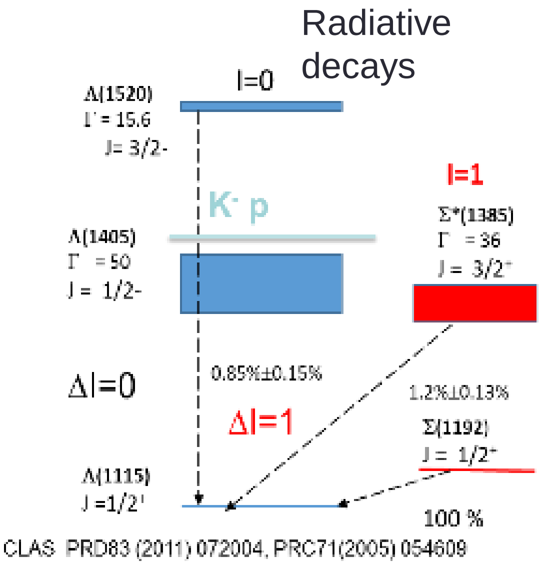
$\rightarrow$ *Inputs for Partial Wave Analysis*
$\rightarrow$ *Many baryon structure issues: confirmation of N'(1720), Cascade decays (R$\rightarrow$R'π$\rightarrow$ Nπ π), „missing resonances"*

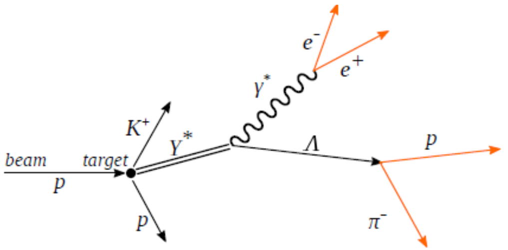
2. Time-like electromagnetic baryon transitions $\pi^- p \rightarrow n e^+ e^-$

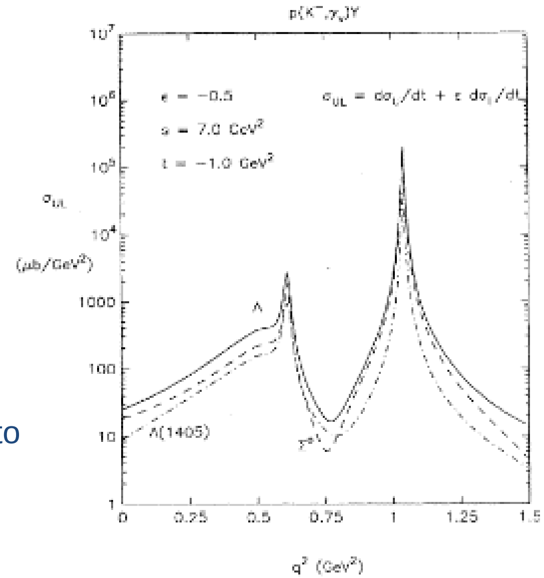
- Broad range of $q^2=(M_{ee})^2 \rightarrow$ sensitivity to form factors
- Check of Vector Dominance (both for ρ and ω)
- High prec. measureements of photon polarization - spin density matrix elements

expected sensitivity for spdme for N*(1520)

Hyperon Dalitz decays-em. transition Form Factors







- Well separated states
- VMD: Enhancement in e+e- inv. mass due to low mass vector mesons ρ / ω / φ

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

G. Ramahlo PRD 102 (2022) 054016, PR D 93, 033004 (2016)

S.Leupold Eur. Phys. J. A (2021) 57 :183

- SU(3) flavour partners
  Σ(1385) - Δ(1232)
  Λ(1520) – N(1520) ?

HADES measured Δ(1232) N(1520) transitions – significant enhancement (up to 5) w.r.t point-like (QED) – dominated, by pion cloud contribution.

Pion and Kaon cloud for hyperons ?

Summary

- ✓ VM (ρ) do play an important role in baryon – γ^* couplings
- ✓ Baryon resonance studies with the GSI pion beam + HADES detector (2^{nd} resonance region $\sqrt{s}$~1.5 GeV)

  → improved knowledge of baryon resonances- meson (ρ) couplings (new BR measurements!)

  → very new information on time-like electromagnetic baryon transitions

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

- ✓ Electromagnetic decays of higher mass N*/Δ resonances in pion induced reactions and hyperons $Y \to \Lambda\gamma$, $Y \to \Lambda e^+e^-$ in pp reactions

2023-2025 : pion beam experiment in the third resonance region

→ Investigate heavier resonances N(1620), N(1720),…in e^+e^- channels and many hadronic channels, e.g. $\pi^- p \to \omega/\rho$ n , $\pi^- p \to \eta$n , $K^0\Lambda$, $K\Sigma$,….

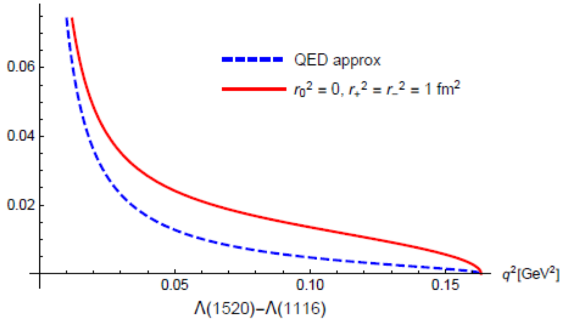
→ Study cold matter effects for VM with πA

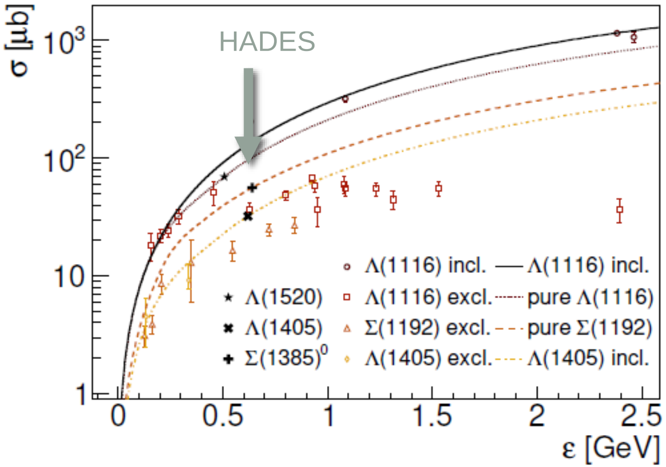
Back-up

Y* radiative/Dalitz decays

- Information on hadron structure (size of hyperon)
- Dalitz decays of e.g. Λ(1405), Σ(1385), Λ(1520),..(narrow states)
- radtiative BR about 10^{-5}
- Large rates needed (→ CBM) and SIS100 beam energy (First attempt by HADES in pp @4.5)

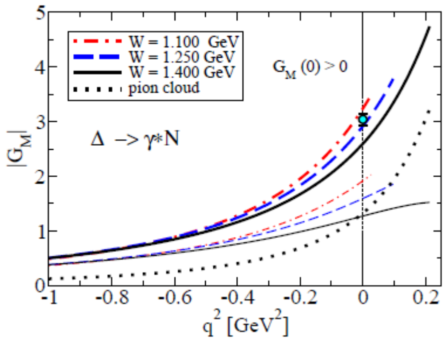
S.Leupold Eur. Phys. J. A (2021) 57 :183

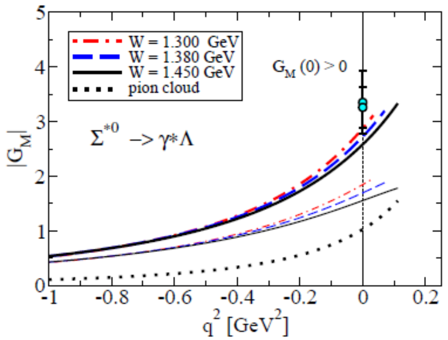




Σ*
Λ*
~1 mb @ 30 GeV
~20 more than at SIS18

G. Ramahlo Phys.Rev.D 102





p+p @ 4.5 GeV

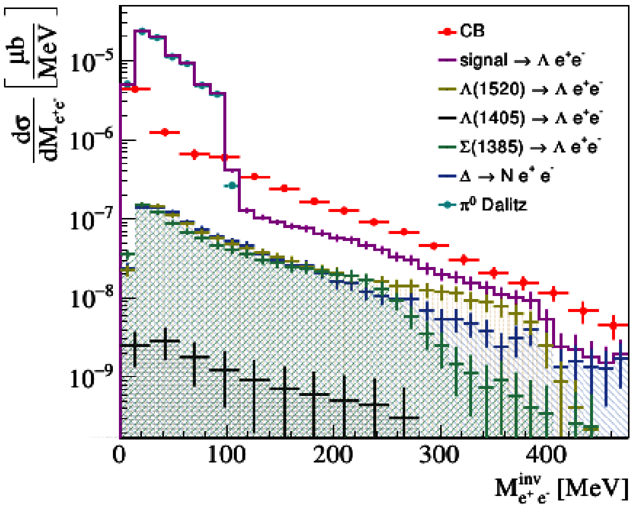
- **February 2022**: pp @ 4.5GeV

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

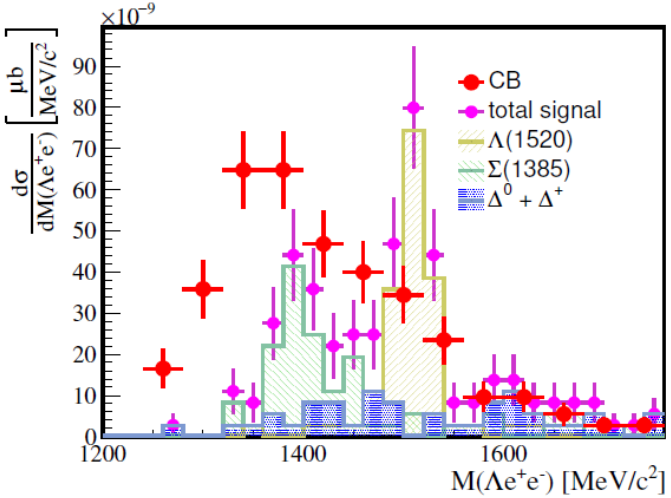
- Hyperon Dalitz decays: pp→pK$^+$Λ(1520) [Λe$^+$e$^-$] [Λγ]
  pp→pK$^+$Σ(1385) [Λe$^+$e$^-$] [Λγ]
- Ξ, Λ(1405), Λ(1520) production and decays
- Λ–Λ correlations
- dilepton production (higher mass baryon resonance decays, pair production above ϕ, mass,..)

Projections for Hyperon Dalitz decays

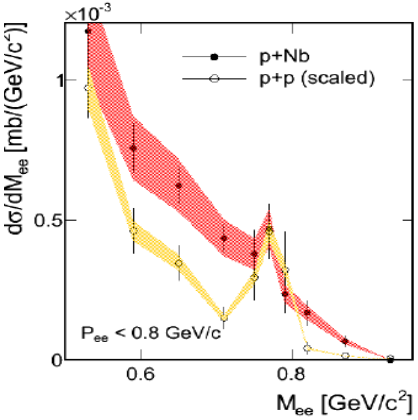
Y → Λ e$^+$e$^-$

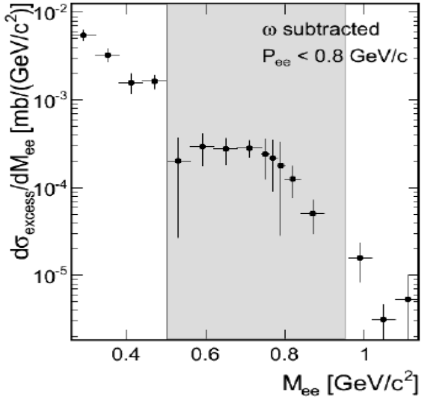


M > M_π



Vector meson in cold matter $\pi^- A \to e^+ e X$



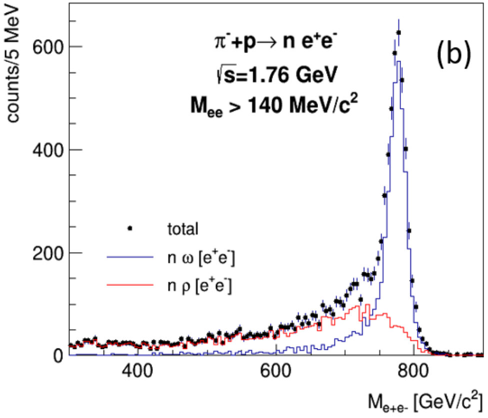


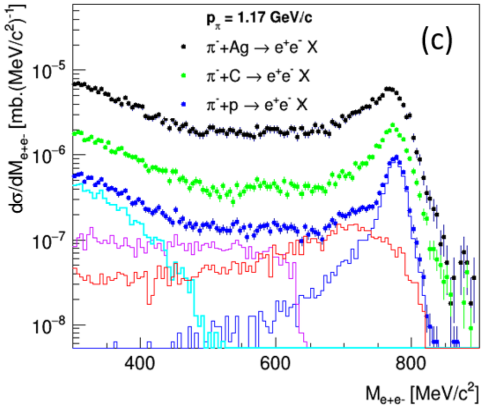
HADES PL715 (2012) 304

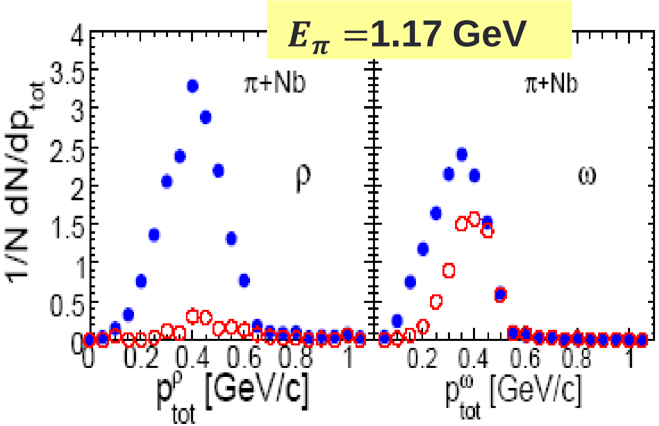
- p+ Nb @ 3.5 GeV
- Significant cold matter effect for slow γ^* (p<0.8 GeV/c)
- due to secondary πN reactions?

Projections for $\pi^- A$

- π-A better sensitivity to inside decays and low momentum



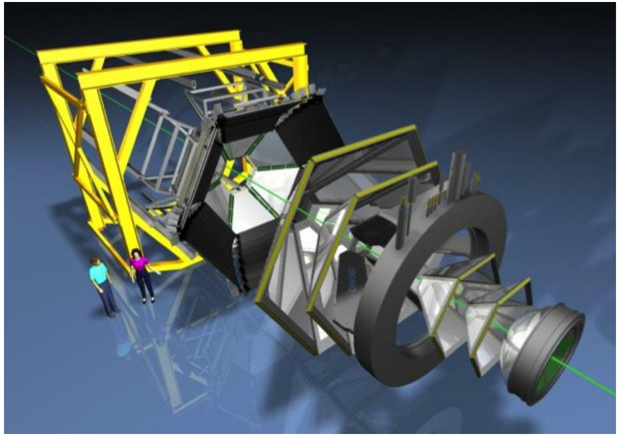


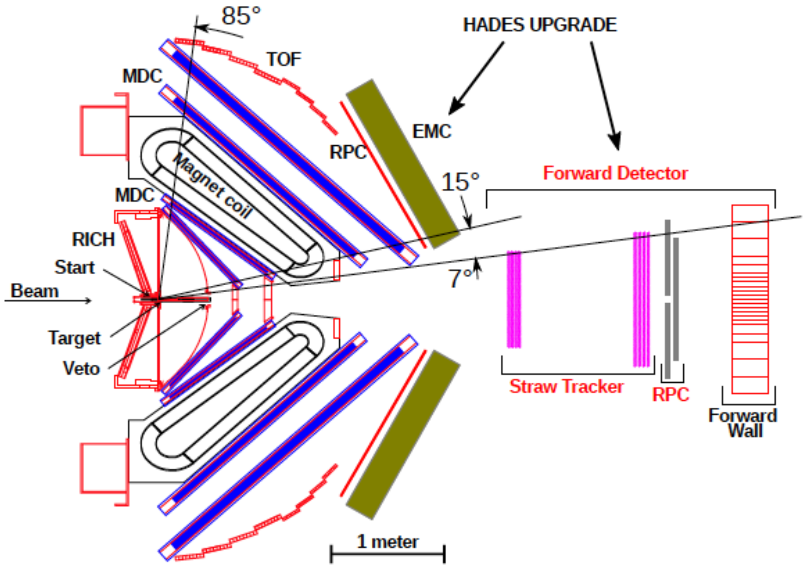


HADES

- ✓ Spectrometer with ΔM/M - 2% at ρ/ω @ GSI/FAIR
- ✓ electrons : RICH (hadron blind)
- ✓ hadrons: TOF & dE/dx vs p
- ✓ 2004-2014: HI (A+A √s~2.4-2.6 GeV)

p+p, d+p, p+A √s =2.4-3.0 GeV π+p √s= 1.5 GeV





Upgrade 2018/2019

- New RICH photon det (HADES/CBM)
- Forward tracking straws +RPC – Λ/Ξ reconstruction in pp/pA (HADES/PANDA)
- Elec. Calorimiter (lead glass)- neutral mesons
- Planned: 200 kHz DAQ , **10 × count rate increase**

PWA results–8 new PDG entries!

PDG Verification

ρN coupling not present in PDG since 2016

$\Gamma(N(1520) \to \Delta(1232)\pi, S\text{-}wave)/\Gamma_{total}$

VALUE (%)	DOCUMENT ID
12.1 ±2.1	ADAMCZEWSKI- 2020

$\Gamma(N(1520) \to \Delta(1232)\pi, D\text{-}wave)/\Gamma_{total}$

VALUE (%)	DOCUMENT ID
6 ±2	ADAMCZEWSKI- 2020

$\Gamma(N(1520) \to N\rho, S{=}3/2, S\text{-}wave)/\Gamma_{total}$

VALUE (%)	DOCUMENT ID
11.8 ±1.9	ADAMCZEWSKI- 2020

$\Gamma(N(1520) \to N\rho, S{=}1/2, D\text{-}wave)/\Gamma_{total}$

VALUE (%)	DOCUMENT ID
0.4 ±0.2	ADAMCZEWSKI- 2020

$\Gamma(N(1520) \to N\sigma)/\Gamma_{total}$

VALUE (%)	DOCUMENT ID
7 ±3	ADAMCZEWSKI- 2020

$\Gamma(N(1535) \to \Delta(1232)\pi, D\text{-}wave)/\Gamma_{total}$

VALUE (%)	DOCUMENT ID
3 ±1	ADAMCZEWSKI- 2020

$\Gamma(N(1535) \to N\rho, S = 1/2)/\Gamma_{total}$

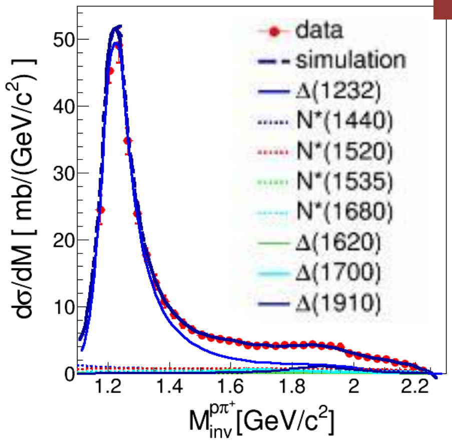
VALUE (%)	DOCUMENT ID
2.7 ±0.6	ADAMCZEWSKI- 2020

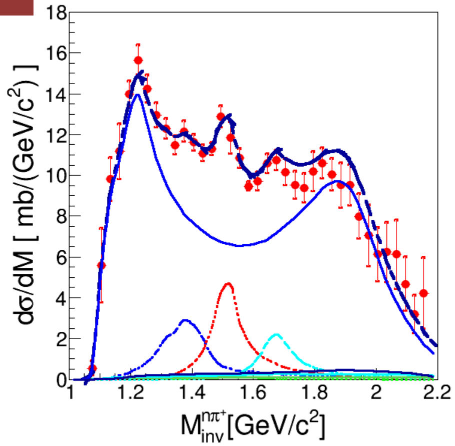
$\Gamma(N(1535) \to N\rho, S{=}3/2, D\text{-}wave)/\Gamma_{total}$

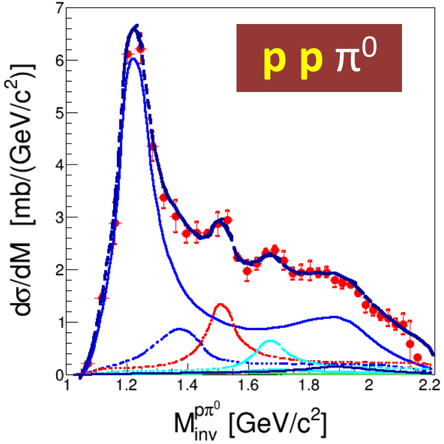
VALUE (%)	DOCUMENT ID
0.5 ±0.5	ADAMCZEWSKI- 2020

Resonance excition @ √s=3.1 GeV

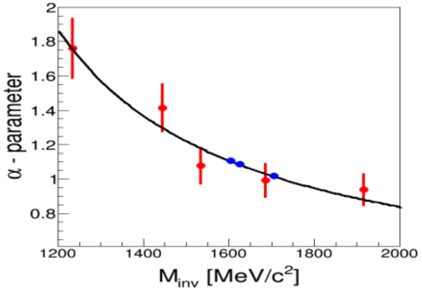
n p π+







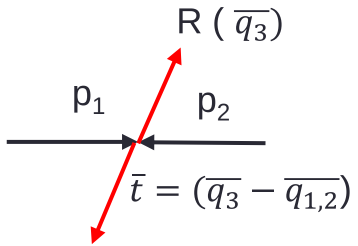
$$\frac{d\sigma}{dt}(M_R) \propto \frac{A}{t^{\alpha(M)}}$$



Resonance model:

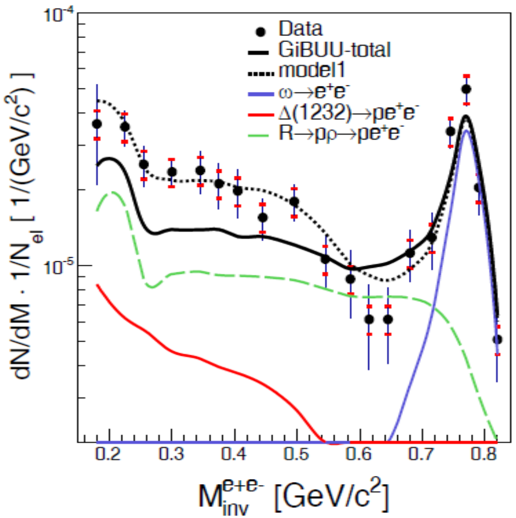
Z. Teis et al., Z. Phys. A356 (1997) 421
J. Weil et al. (GiBUU) Eur. Phys. J. A48 (2012) 111
HADES : EPJA 50(2014) 42

Incoherent sum of (Δ, N*) resonances

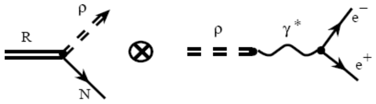


Empirical parametrisation of Resonance production as a function of
$t(M_R)$
t- channel dominance

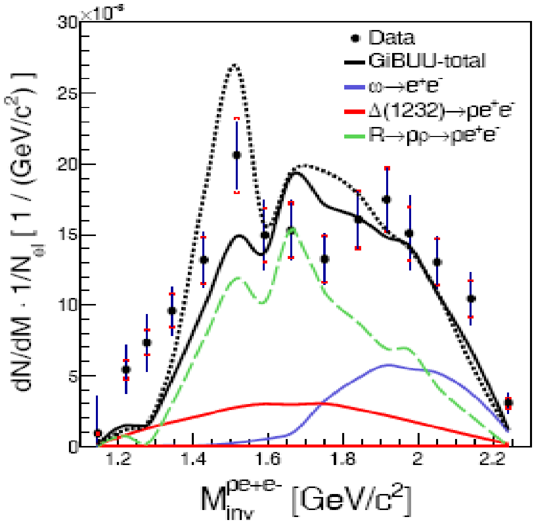
Higher mass resonances: pp→ppe+e- √s=3.1 GeV



Resonance model + „strict” VDM



$$\Gamma_{VDM}(M) = \frac{M_\rho}{M^3} \bullet \mathrm{BR}(M = M_\rho)$$



- ❑Good description of one pion production by „HADES resonance model” $\rightarrow N^*, \Delta$ **contributions**
- ❑ **Comparison with VMD : works well .. but with lower BR for R→ Nρ than PDG** (upper limits from Bn-Ga)

Since 2018 – no data on BR in PDG any more !

pion beam !

Resonance -> Nρ Branching Ratios

Contr. to e+e-	Resonances	GiBUU	UrQMD	KSU	BG	CLAS
38%	$N(1520)$	21	15	20.9(7)	10(3)	13(4)
15%	$\Delta(1620)$	29	5	26(2)	12(9)	16
22%	$N(1720)$	87	73	1.4(5)	10(13)	–
7%	$\Delta(1905)$	87	80	< 14	42(8)	–

PDG @ 2015