Status of simulation of hyperon Dalitz decays and cascade production

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for the HADES Collaboration

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PANDA Collaboration Meeting
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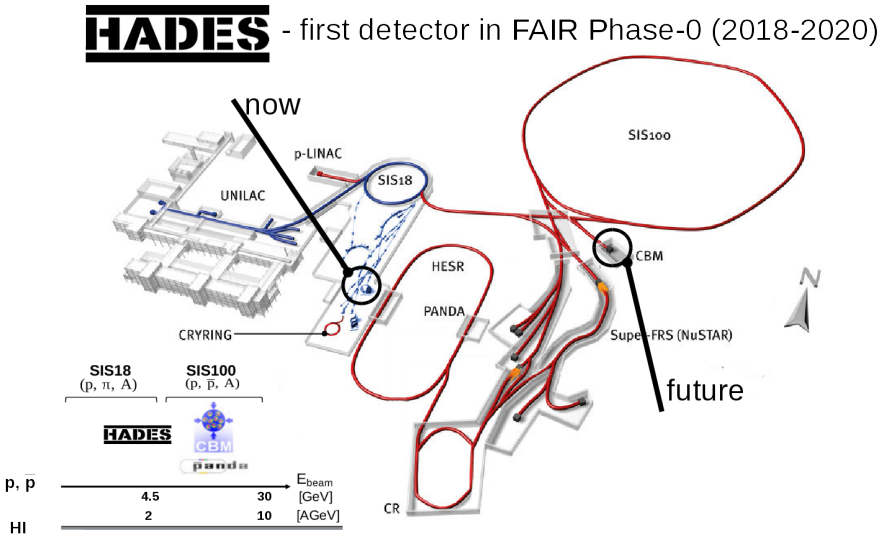
Outline:

1. HADES detector
2. Benchmark reactions
3. Simulations and analysis
4. Summary

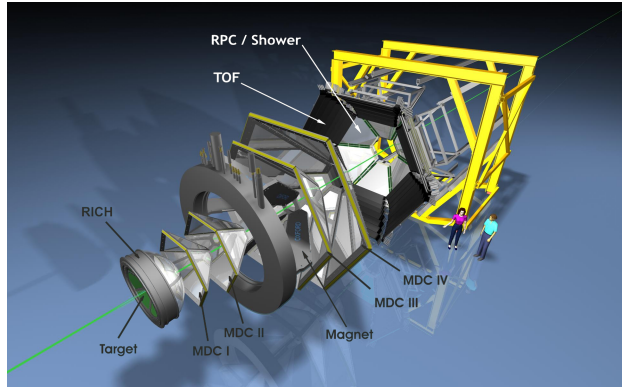
HADES@FAIR


HADES - first detector in FAIR Phase-0 (2018-2020)
now
p-LINAC
UNILAC
SIS18
SIS100
CBM
HESR
PANDA
CRYRING
Super-FRS (NuSTAR)
future
N
SIS18
(p, π, A)
SIS100
(p, p̄, A)
HADES
CBM
PANDA
p, p̄
4.5
30
E_beam [GeV]
HI
2
10
[AGeV]
CR

HADES@FAIR

Rich experimental programme:

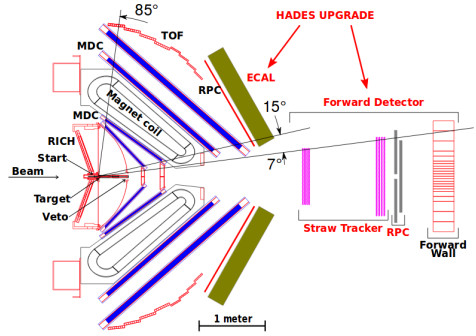
- $Ag + Ag$@1.7 GeV (e^+e^-, strangeness)
- πNN (e+e-, hadron spectroscopy)
- $p + p, p + Pb$ (e^+e^-, meson, $N^*\Delta^*$, hyperon spectroscopy)



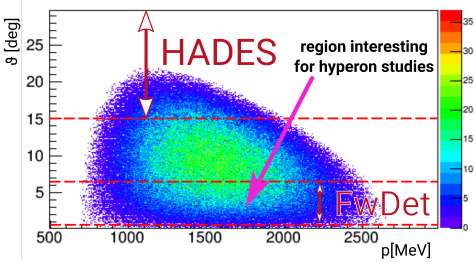
EPJA41(2009)243277

Forward Detector

- Straws — tracking
- RPC — β/ToF measurement
- HADES — p, π, e^+, e^-, K excellent PID and momentum resolution



$\Xi^- \to \Lambda \to p\pi^-$

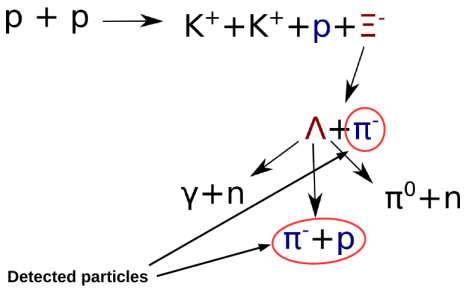


w/o Forward Detector only 8.7 % of all possible p are reconstructed

⇐
STS2
Kraków + Orsay

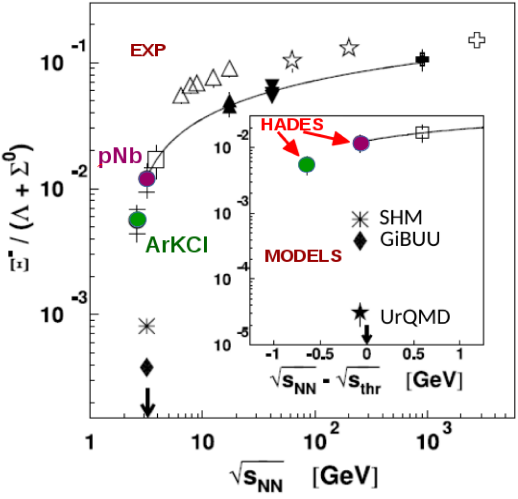
Benchmark reactions

1. Ξ^- (cascade particle) production



- strong enhancement in respect to existing models (UrQMD, GiBUU) in sub-threshold production in Ar+KCl@1.76 AGeV and p+Nb@3.5 GeV reaction
- no data close to threshold in NN reactions
- NN collisions at low energies ⇒ test of cascade production models

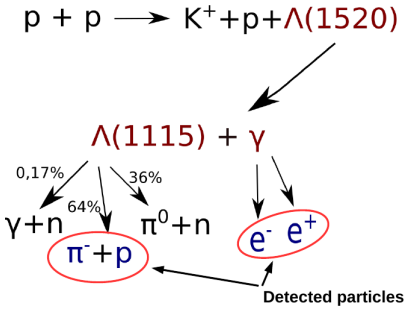
HADES puzzle



PRL114(2015)212301

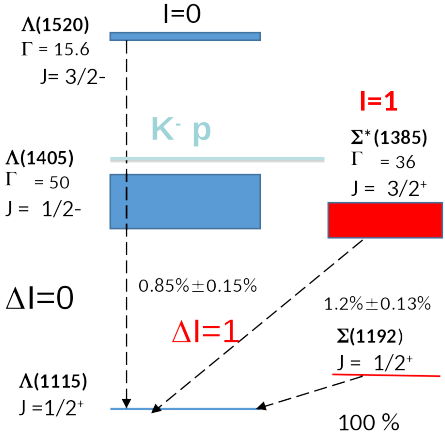
Benchmark reactions

2. Hyperon EM decays



Dalitz decays of $\Lambda(1520), \Lambda(1405), \Sigma(1385)$

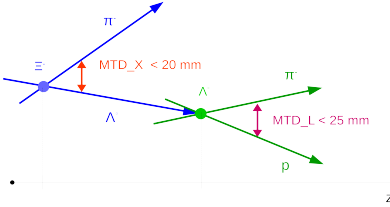
- EM tFF $\Rightarrow$ q distribution
- EM decay widths for $Y^* \to Y\gamma$



PRL114(2015)212301

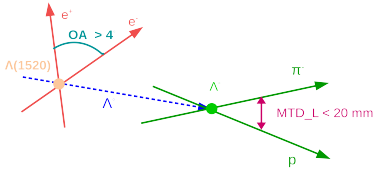
Strategy of the analysis

1. Cascade production



1. $p\pi^-$ pairs $\rightarrow \Lambda(1115)$ reconstruction.
2. Topological cuts:
   - distance between p and π^- tracks,
   - $\Lambda(1115)$ vertex-z.
3. Cut on $\Lambda(1115)$ mass.
4. $\pi^- + \Lambda(1115)$ candidate $\rightarrow \Xi^-$.
5. Topological cut: distance between $\Lambda(1115)$ and π^- tracks.
6. Sum of reconstructed Λ and π^- 4-vectors.

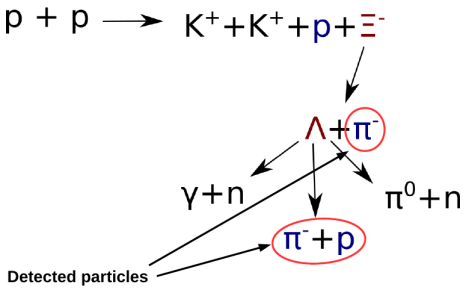
2. Dalitz decays



3. Cut on $\Lambda(1115)$ mass.
4. Dilepton pairs $\Rightarrow OA > 4\,^\circ$, $m(e^+e^-) > m(\pi^0)$.
5. Sum of reconstructed Λ and e^+e^- 4-vectors.

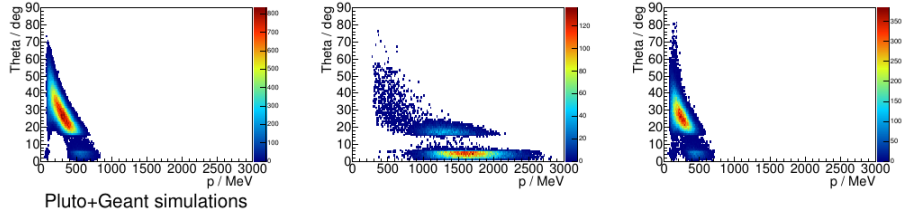
Simulations & analysis

1. Ξ^- (cascade particle) production in HADES @ 4.5 GeV



Registration of 2 π^-s in HADES and p in FD required for the Ξ^- reconstruction.

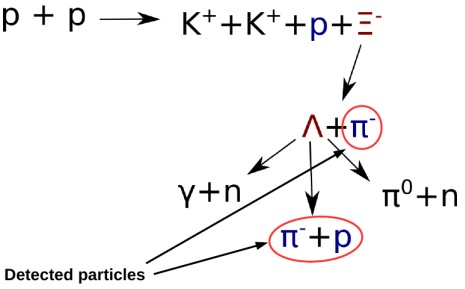
$\Xi^- \rightarrow \Lambda\pi^-$ $\Lambda \rightarrow p\pi^-$ $\Lambda \rightarrow p\pi^-$



Pluto+Geant simulations

Simulations & analysis

1. Ξ^- (cascade particle) production



No.	reaction	cross-section [μb]
0.	$K^+K^+p\Xi^-$	4.8
1.	$pp2\pi^-2\pi^+$	600
2.	$p\Lambda K^0_s\pi^+$	100
3.	$p\Lambda K^+\pi^+\pi^-$	30
4.	$n\Lambda K^0_s2\pi^+$	30
5.	$p\Sigma^0K^0_s\pi^+$	20
6.	$pp2K^0_s$	20

The most contributing BG sources:

$$K^0_s \to \pi^+\pi^-$$
$$\Lambda \to p\pi^-$$
$$\Sigma^0 \to \Lambda\gamma$$

1 multi-π^- production

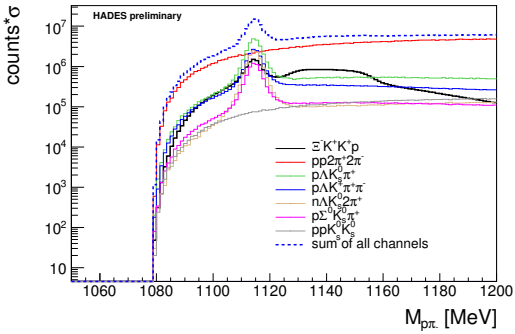
2–5 Λ or Σ^0 and K^0_s as a π^- source

6 $2K^0_s$ as pions source

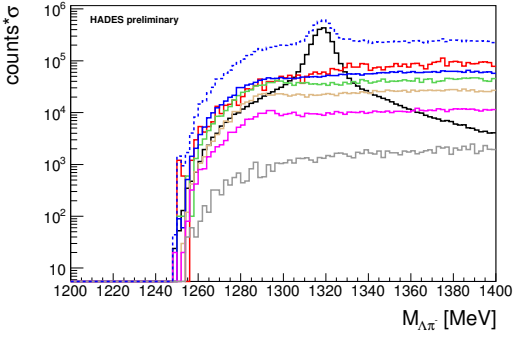
Simulations & analysis

1. Ξ^- (cascade particle) production

$\Lambda(1115)$ reconstruction

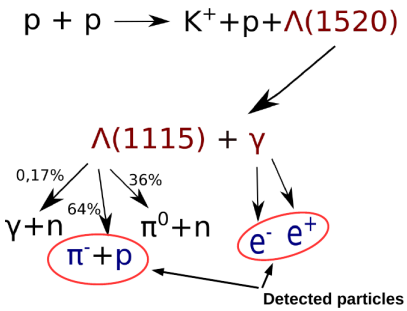


Ξ^- reconstruction



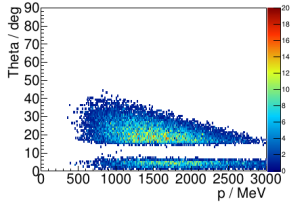
Simulations & analysis

2. Hyperon EM decays in HADES @ 4.5 GeV

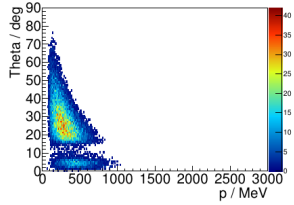


Registration of π^- in HADES, p in HADES or FD and dilepton in RICH required for the $\Lambda(1520)$ reconstruction.

$\Lambda \to p\pi^-$



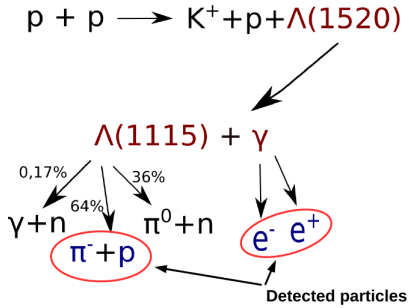
$\Lambda \to p\pi^-$



Pluto+Geant simulations

Simulations & analysis

2. Hyperon EM decays



No.	reaction	cross-section [μb]
0.	$pK^+\Lambda(1520)$	50
1.	$pK^+\Lambda\pi^0$	100
2.	$pK^+\Lambda 2\pi^0$	20
3.	$pK^+\Lambda 3\pi^0$	7
4.	$pp\pi^+\pi^-\pi^0$	1840
5.	$pp\pi^+\pi^- 2\pi^0$	300
6.	$pn2\pi^+\pi^-\pi^0$	200
7.	$\Lambda(1520)$ decays	50

The most contributing BG sources:

$$\pi^0 \to e^+e^-\gamma$$
$$K^+ \to \pi^+e^+e^-$$
$$\Lambda \to p\pi^-$$

1–3 Λ and a dilepton source (K^+ or π^0)

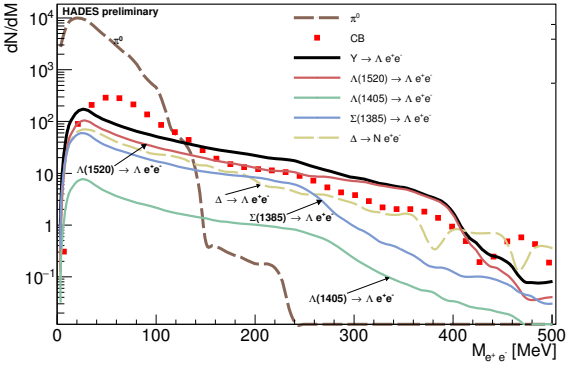
4–6 multi pion production

7 other reactions with $p\Lambda(1520)K^+$ in the final state

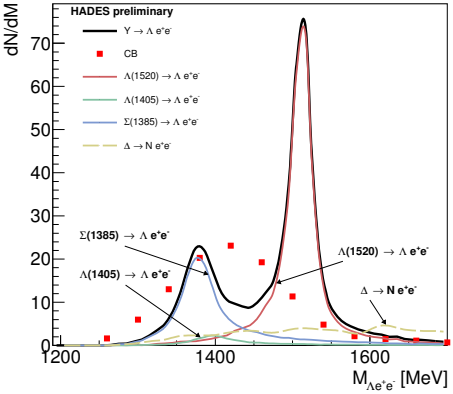
Simulations & analysis

2. Hyperon EM decays

Di-lepton invariant mass



Λe^+e^- invariant mass



Experimental plans

Plans of the HADES Collaboration for the FAIR-Phase0:

- Heavy-ion beam (Ag+Ag) — 2018 → 2019
- Pion beams — 2019 (??)
- **Proton beams (p+p) E=4.5 GeV — 2020 (??) ⇒ FAIR-Phase0/HADES-PANDA**

Count rate estimation (preliminary):

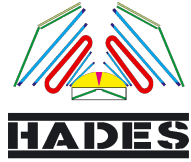
Beam rate = 10^8 part/s
Luminosity = $2 \cdot 10^{31} cm^{-2} s^{-1}$

} extrapolated from pp@3.5 GeV with assumption 200 kHz DAQ

H^* production	$pp \to pK^+\Lambda^*$	$pp \to pK^+\Sigma^*$	$pp \to \Xi^- K^+ K^+ p$
σ_{tot}:	130 μb	80 μb	4.8 μb

H^* Dalitz decay	$\Lambda^* \to \Lambda e^+ e^-$	$\Sigma^* \to \Lambda e^+ e^-$	—
σ_{Dalitz}	$8.3 \cdot 10^{-3} \mu$b	$7.0 \cdot 10^{-3} \mu$b	—
$\varepsilon_{H^* rec}$:	0.5%	0.5%	0.79%
Expected count rate:	34 part/day		$8.64 \cdot 10^4$ part/day

Summary & outlook



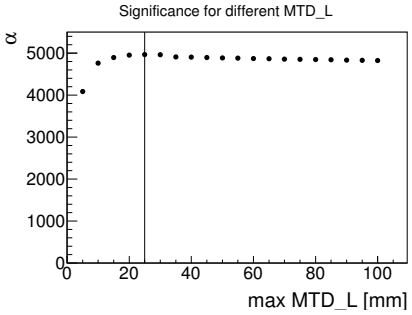
Hyperon studies:

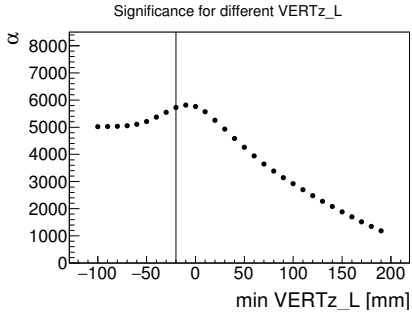
- internal baryonic structure and test of the quark models
- Dalitz decays of hyperons $\Rightarrow$ access to the interesting q^2 region
- enhancement of Ξ production — HADES puzzle

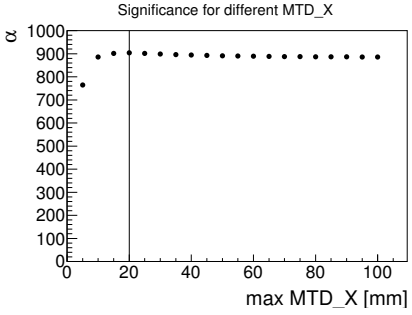
Outlook:

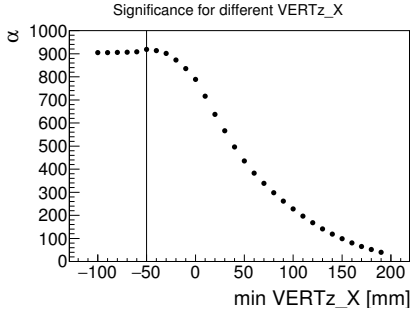
- PID in FD $\rightarrow$ better S/B ratio
- improvement of the PID in HADES
- HADES upgrade and measurements at the SIS18 $\rightarrow$ better statistics
- in the (near) future measurements at the new SIS100@FAIR

Cuts estimation for Ξ^- reconstruction





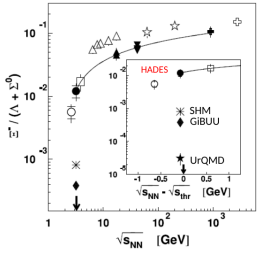




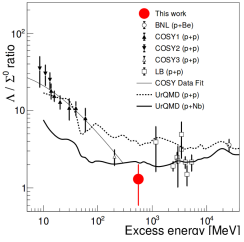
Simulation of the cascade Ξ^-

Simulated reaction channel:

$p(4.5\,\mathrm{GeV})p \rightarrow K^+K^+p\Xi^-$



PRL114(2015)212301



arXiv:1711.05559

Cross section estimation:

1. cross-sections ratio $\frac{\sigma\Xi^-}{\sigma\Lambda + \sigma\Sigma^0}$ measured by HADES in p-Nb and Ar-KCl
2. $\sigma\Lambda$ known from literature (L-B)
3. cross-sections ratio $\frac{\sigma\Lambda}{\sigma\Sigma^0}$ measured by COSY, BNL and LB
4. from 2,3 $\rightarrow \sigma\Sigma^0$
5. from 1,2,4 $\rightarrow \sigma\Xi^-$

Strangeness production via high mass baryon resonances

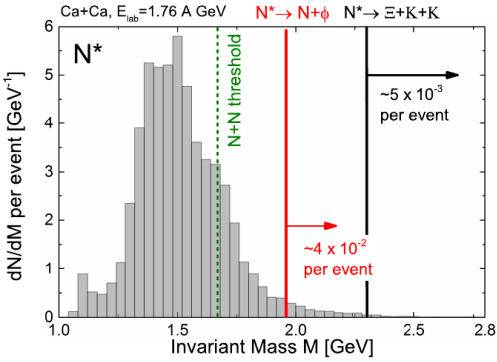


Figure 2. [Color online] Invariant mass distribution of N^* resonances produced in collisions of Ca+Ca at a fixed target beam energy of $E_{\rm lab} = 1.76$ A GeV. We consider events with an impact parameter smaller than $b < 5$ fm, in accordance with HADES experiment specifications. The vertical green dashed line indicates the maximum mass a N^* can have in an elementary $N + N$ collision at the same beam energy. The vertical red line depicts the ϕ production threshold mass while the black line corresponds to the $\Xi + K + K$ threshold mass.

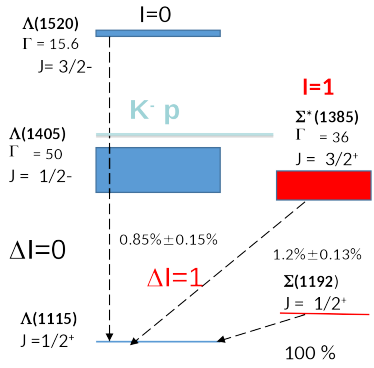
Steinheimer, J.Phys.G43 (2016)015104

Electromagnetic decay widths for $Y^* \to Y\gamma$

Quark models

Model	$\Delta(1232)$ $p\gamma$	$\Sigma^0(1385)$ $\Lambda(1116)\gamma$	$\Sigma^0(1385)$ $\Sigma^0(1193)\gamma$	$\Lambda(1405)$ $\Lambda(1116)\gamma$	$\Lambda(1405)$ $\Sigma^0(1193)\gamma$	$\Lambda(1520)$ $\Lambda(1116)\gamma$	$\Lambda(1520)$ $\Sigma^0(1193)\gamma$
NRQM[3, 4]	360[14]	273	22	200	72	156	55
RCQM[5]		267	23	118	46	215	293
χCQM[6]	350	265	17.4				
MIT Bag[3]		152	15	60, 17	18, 2.7	46	17
Chiral Bag[7]				75	1.9	32	51
Soliton[8]		243, 170	19, 11	44, 40	13, 17		
Skyrme[9, 10]	309-348	157-209	7.7-16				
Algebraic model[11]	343.7	221.3	33.9	116.9	155.7	85.1	180.4
HBχPT[12]†	(670-790)	290-470	1.4-36				
$1/N_c$ expansion[13]		298 ± 30	24.9 ± 4.1				
Previous Experiments	640-720[30]	<2000[22]	<1750[22]	27±8[19]	10±4[19] 23±7[19]	33±11[17] 134±23[16] 109±23±26[18]	47±17[17]
This experiment		$479 \pm 120^{+81}_{-100}$				$167 \pm 43^{+26}_{-12}$	

Taylor et al. (CLAS Collaboration), Phys. Rev. C71 (2005) 054609



Radiative decays are a sensitive test of the hyperon structure

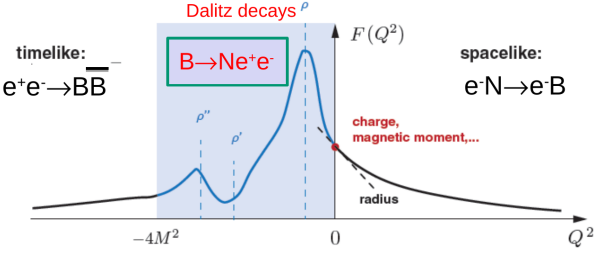
- Predictions of decay widths (Quark, Bag, χPT... models) span over one order of magnitude
- Recent experimental results (CLAS) show very large decay widths

CLAS: PRD83(2011)072004, PRC71(2005)054609

Hyperon Dalitz decays

$$Y^* \to Ye^+e^- \text{ (via virtual massive } \gamma^*)$$
$$Q^2 = -q^2 = -(M_Y - M_\Lambda)^2$$

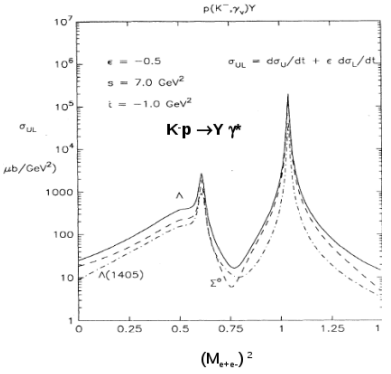
- measurement of time-like γ^* complementary to space-like γ
  $\Rightarrow$ predicted to be sensitive to meson cloud effects
  $\Rightarrow$ coupling to Vector Mesons (ϕ/ω ($s\bar{s}$ content!), ρ)
  (Ramalho, Williams)
- **Dalitz Decays of non-strange baryons: EM Transition Form Factors (TFF)**



$$d\Gamma(B \to N\gamma^*) \sim G_{QED}(Q^2)(a(l)G^2_{M/E}(q^2) + b(l)G^2_{E/M}(q^2) + c(\frac{q^2}{m^2})G^2_C(q^2))$$

Vector Meson Dominance model

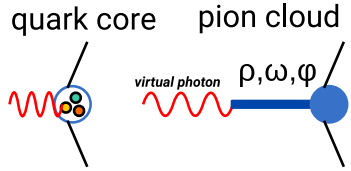
Strong effects for hyperons predicted by VDM:



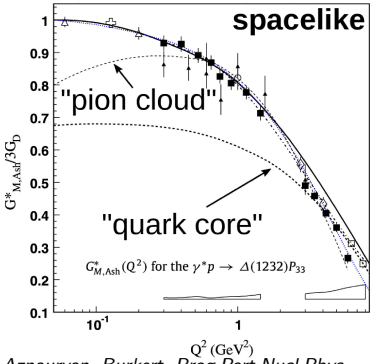
Williams, PRC48(1993)1318

Internal structure of baryons

Quark core - pion cloud model by Ramalho&Peña



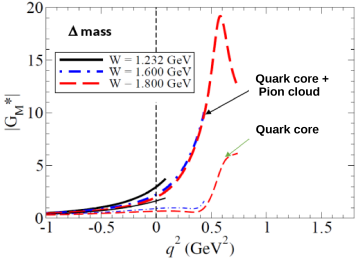
World data $\Delta \to N\gamma^*$ (spacelike)



Aznauryan, Burkert, Prog.Part.Nucl.Phys. 67(2012)1-54

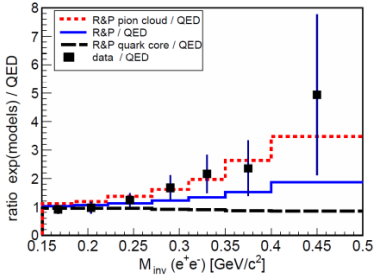
Big role of the pion cloud at small q^2!

Theory:



PRD93(2016)033004

HADES data: $\Delta \to N\gamma^*$ (timelike)



PRC95(2017)065205

In SU(3) flavour symmetry $\Delta \to N\gamma^*$ equal to $\Sigma^*(1385) \to \Lambda\gamma^*$