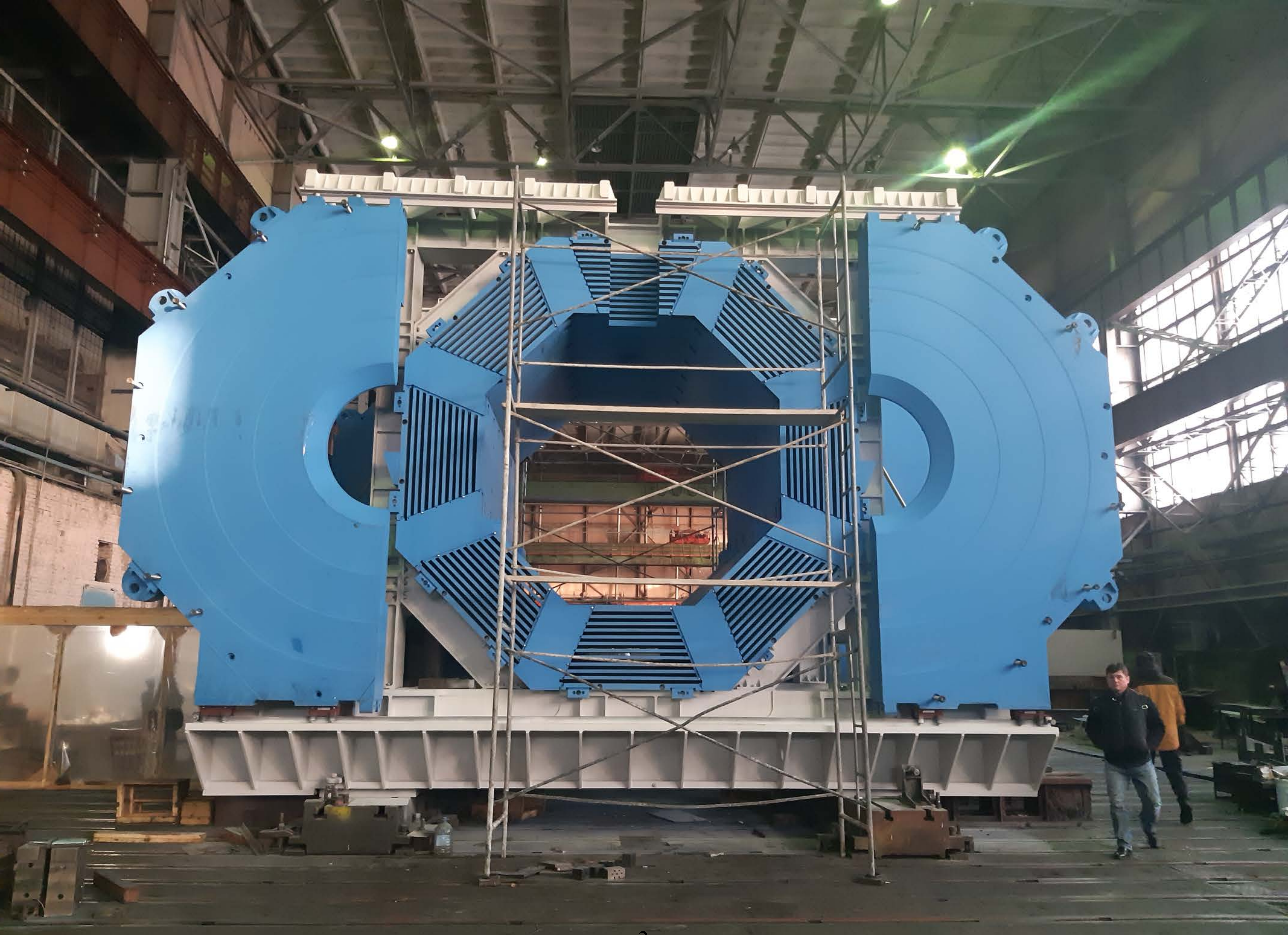
PANDA

Status and response to the “First Science and Staging Review of the FAIR project

Ulrich Wiedner
(Ruhr-University Bochum)
on behalf of the PANDA Collabortion

Excerpts from the review

… "With its use of a stored anti-proton beam, PANDA is unique and is the only experiment in the world that can definitely answer the question as to whether or not the states under study are new, 'exotic', forms of hadronic matter. PANDA's unique glueball discovery program will provide the critical tests of strong interaction theory that predict masses of the only particles with mass generated entirely through the strong interaction." …



PANDA Superconductor

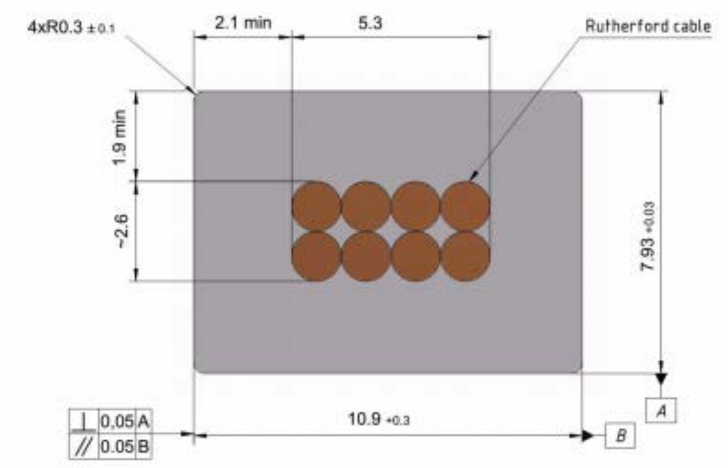
Conductors for Detector Magnets
- Al stabilised conductors are still state-of-art for safe operation
- Currently no commercial producer

Superconductor Layout
- Nb/Ti in Cu strands
- Rutherford cable 2x8
- Co-extrusion in pure Al

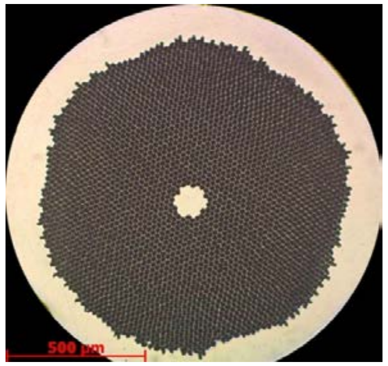
Status of Production:
- Joint venture with 4 partners in Russia
- Consulting by ATLAS/CERN
- Production was to be completed in 2022

Strategy on Aluminum Extrusion
- Contact to producer of machinery
- Establish knowhow at extrusion lab
- Cooperation for nearest projects (PANDA, EIC, BabyIAXO)

Workshop on Superconducting Detector Magnets
CERN, September 12-14, 2022

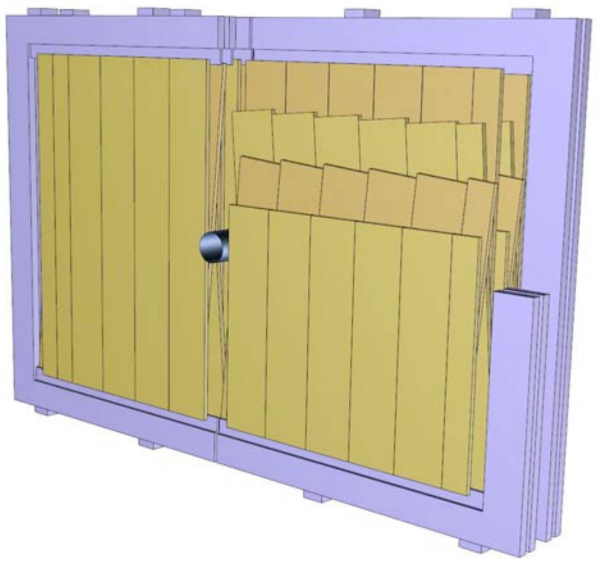


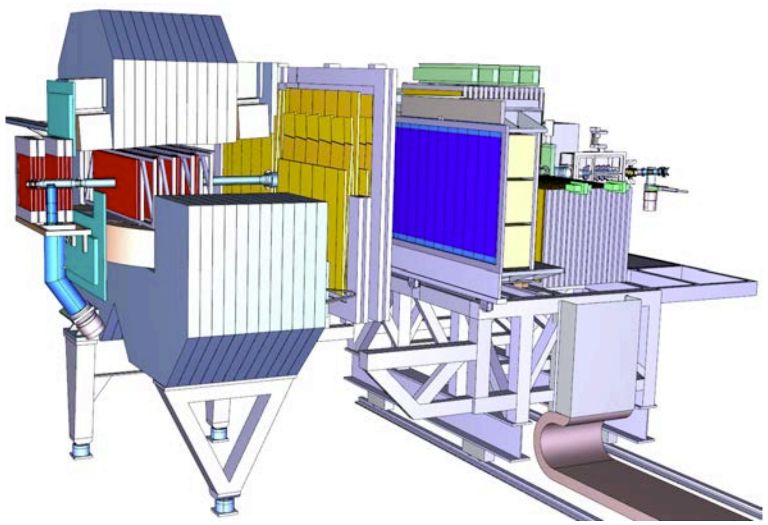
PANDA SC Cable LAyout



Superconducting strand

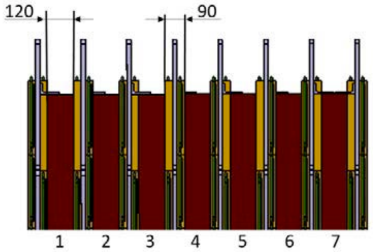
LHCb Outer Tracker for PANDA

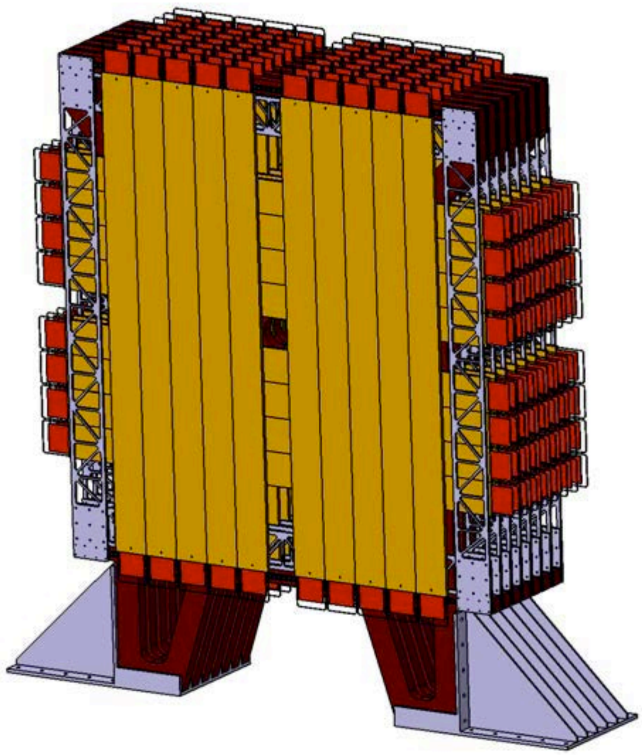


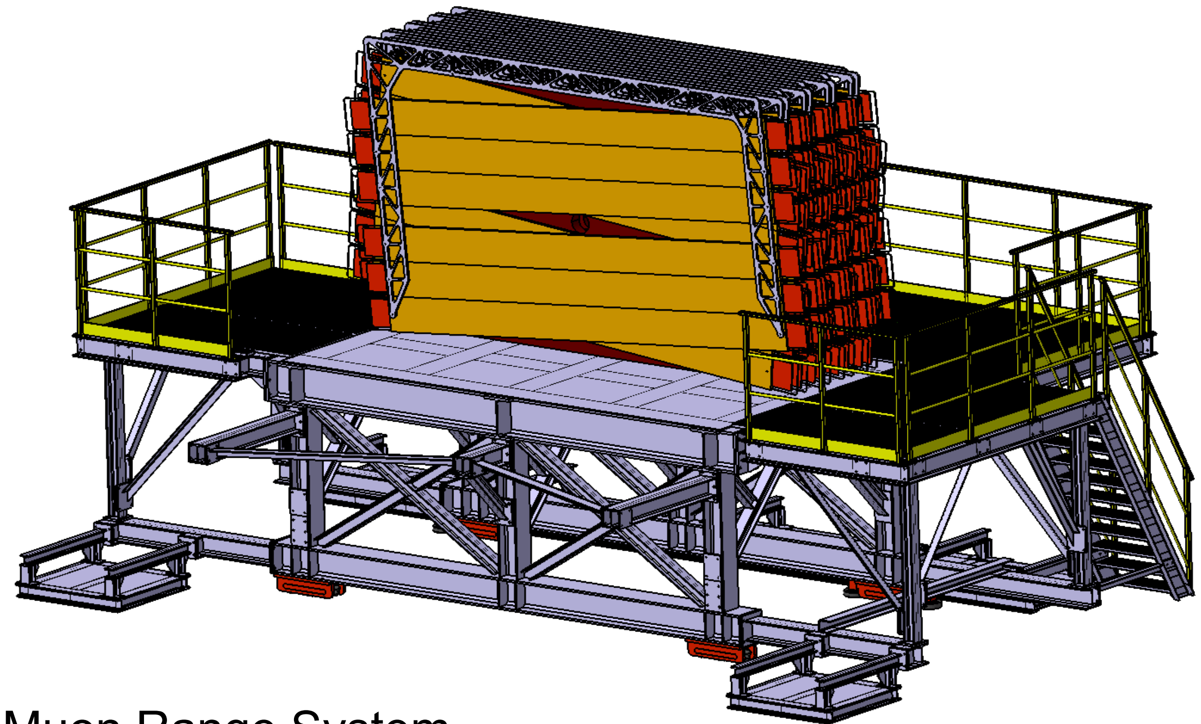


LHCB OT half modules for PANDA Forward Tracker

H x W x L: 4.9m x 3.5m x 7m, weight: 22t

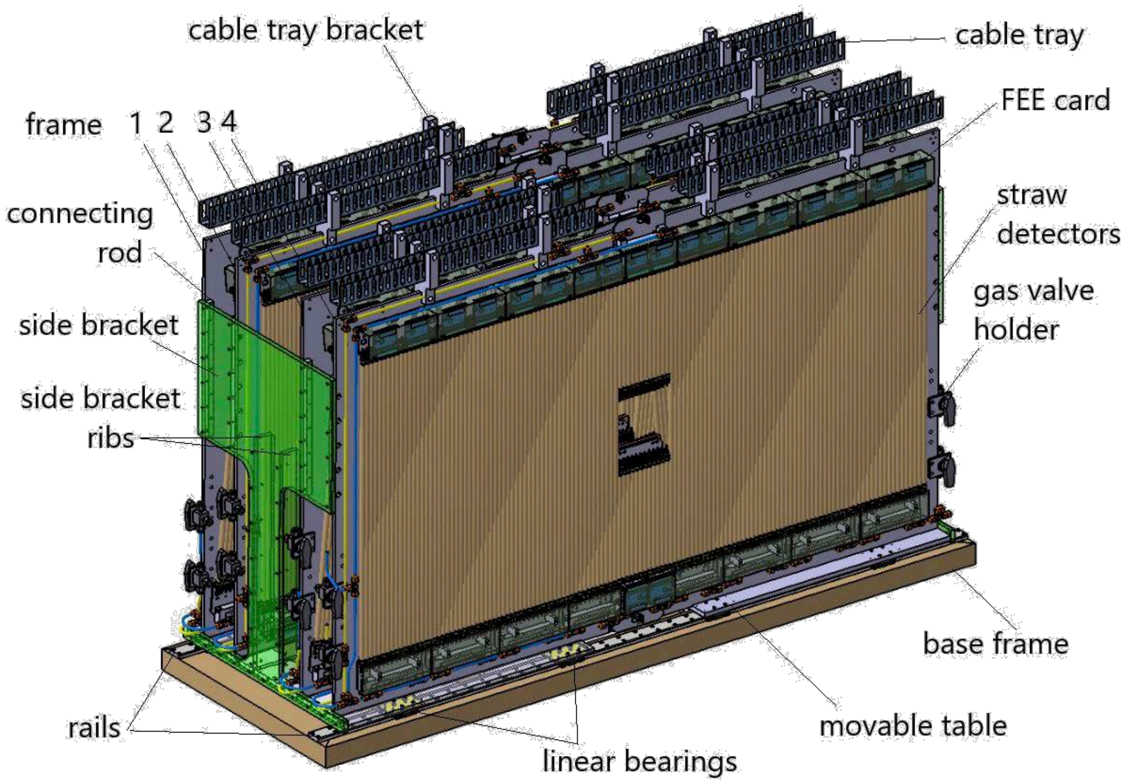




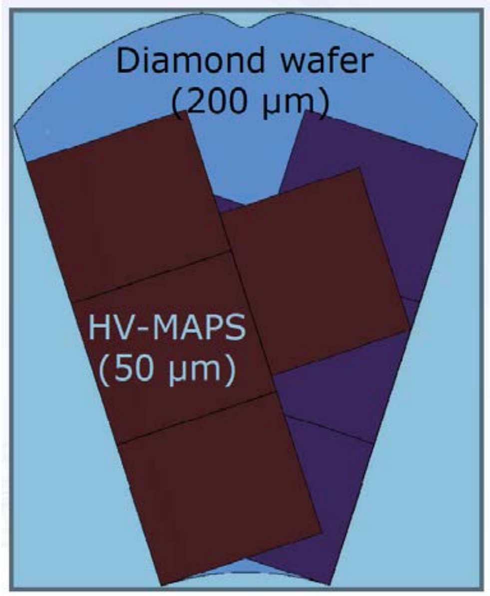


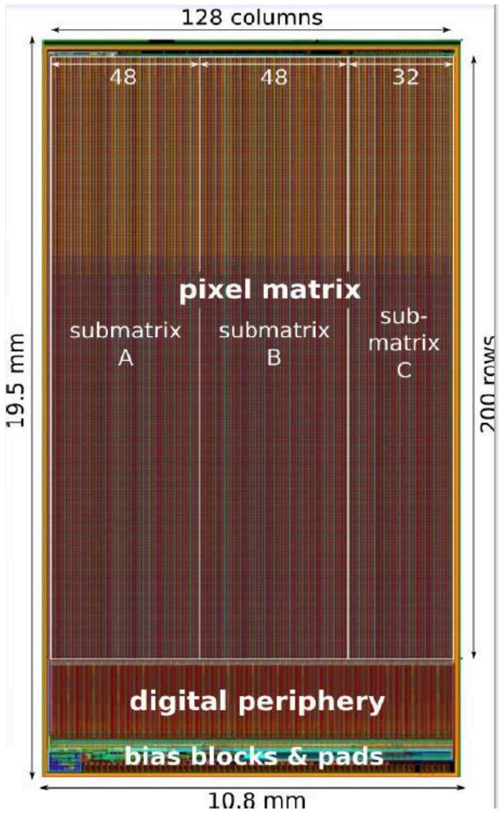
LHCB OT long modules for PANDA Muon Range System

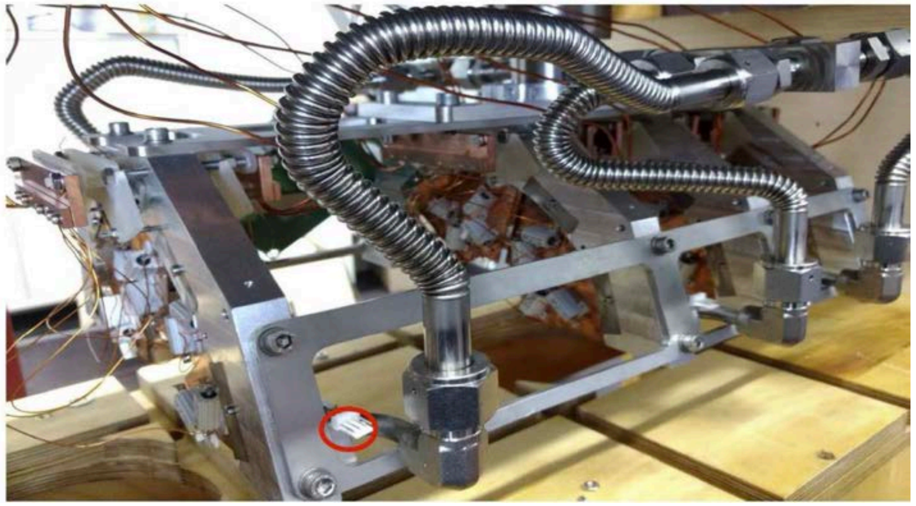
Forward tracker (in-kind JU Krakow)



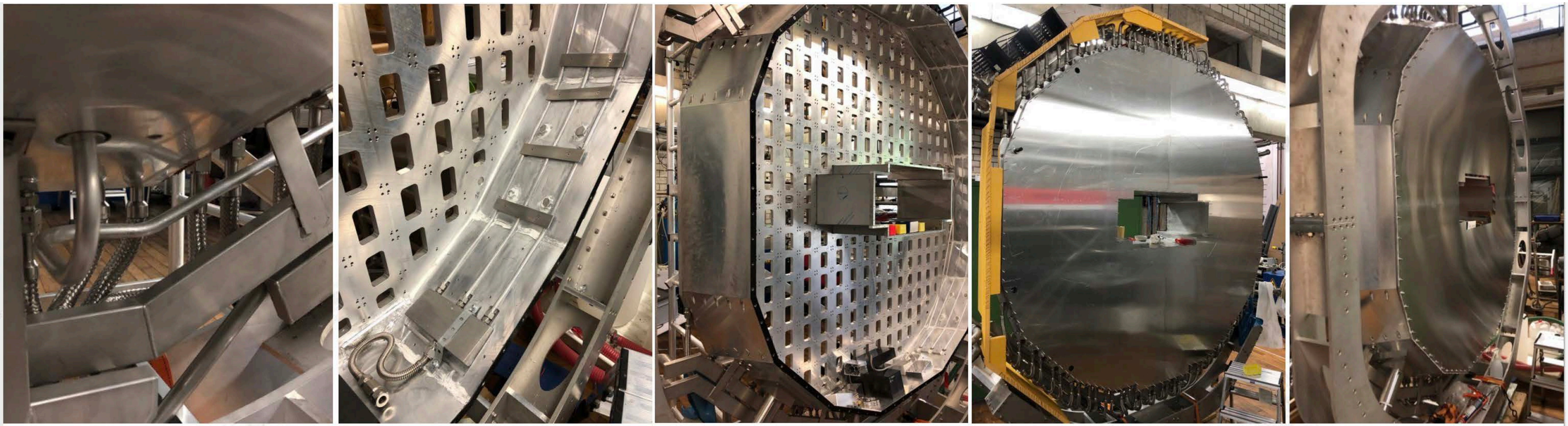
Luminosity detector







The EMC calorimeter

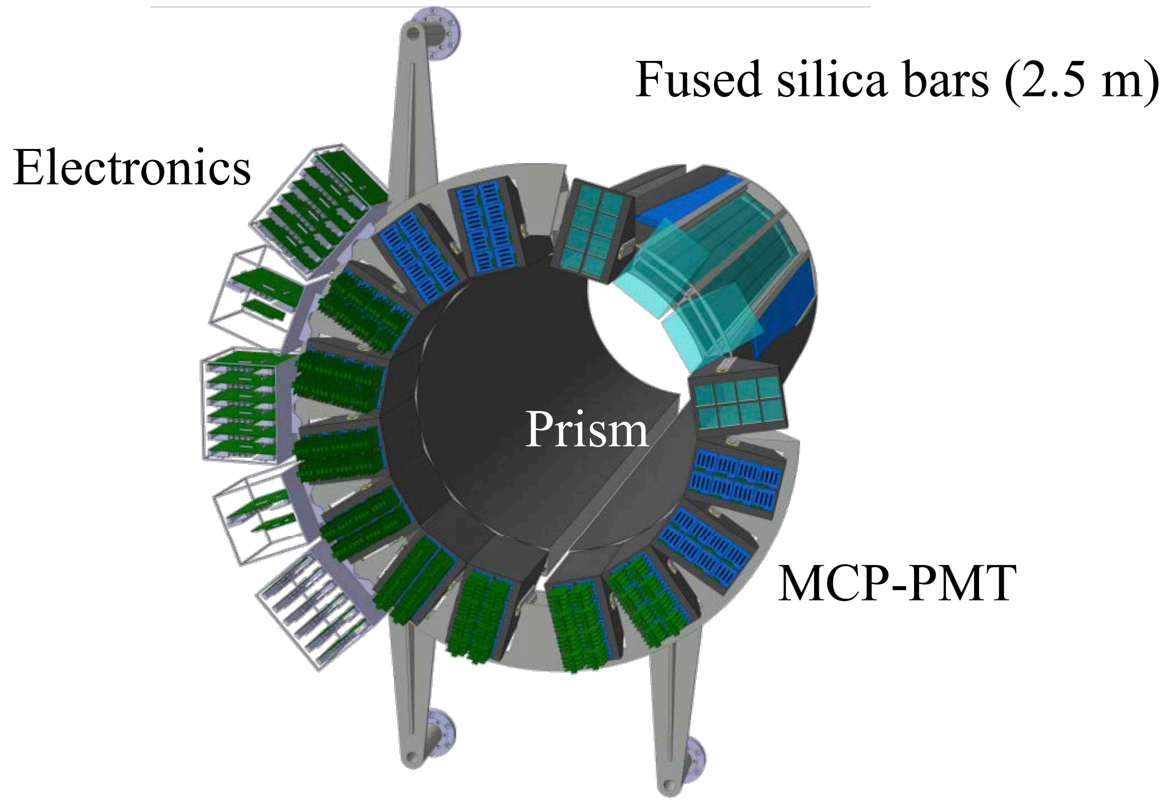


Mechanics of the cooling system at the forward endplate is finished

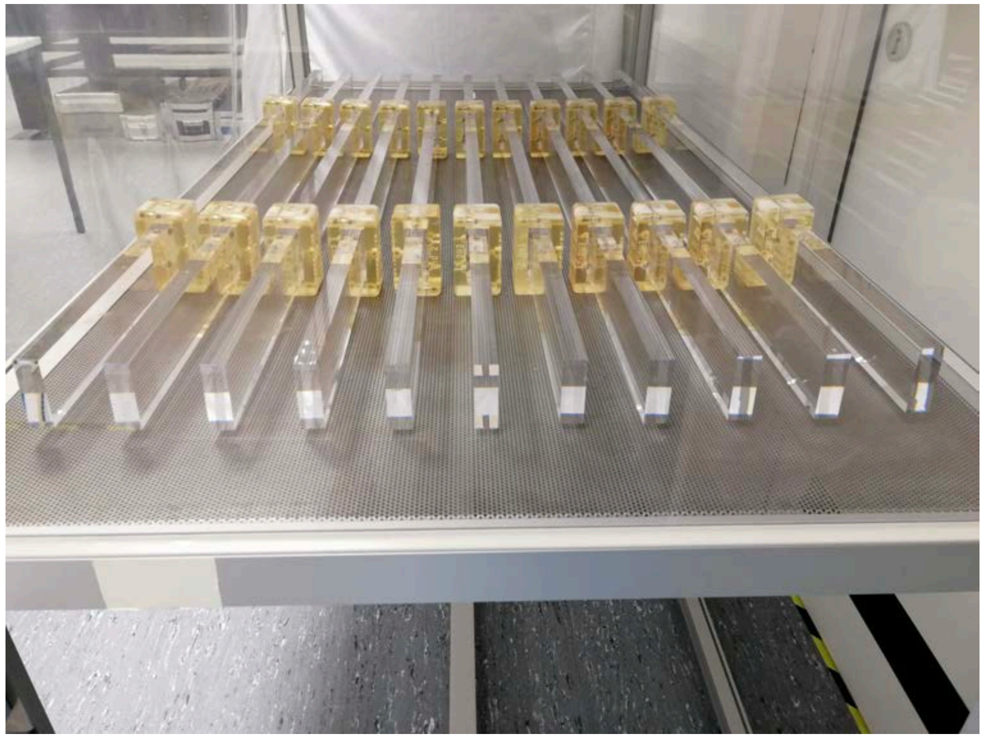
Pre-calibration of modules with cosmics ongoing

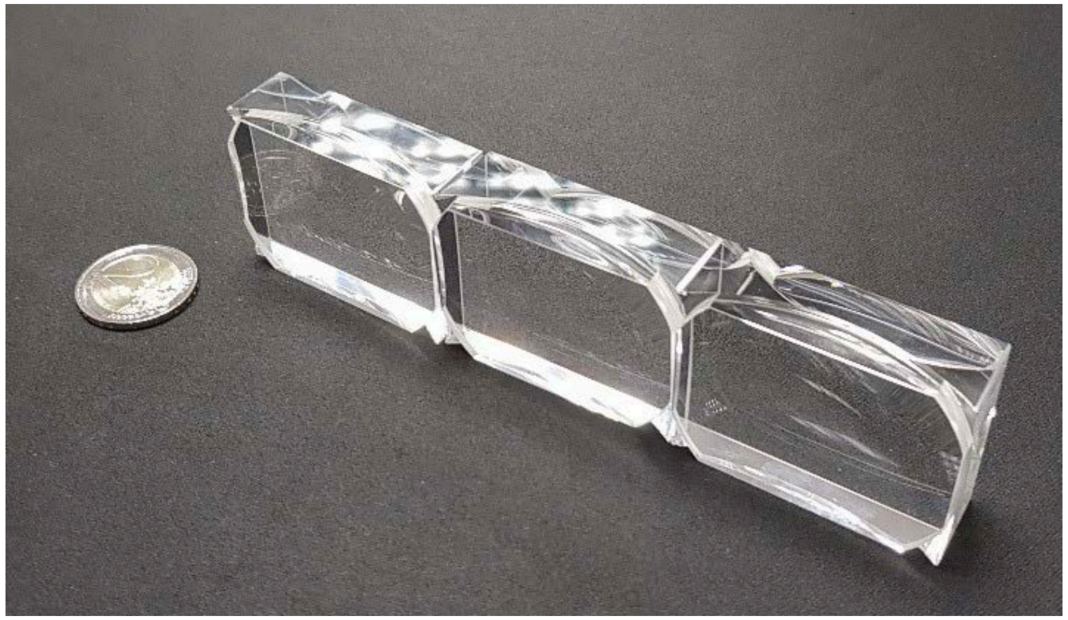
Preparation for mounting at Jülich

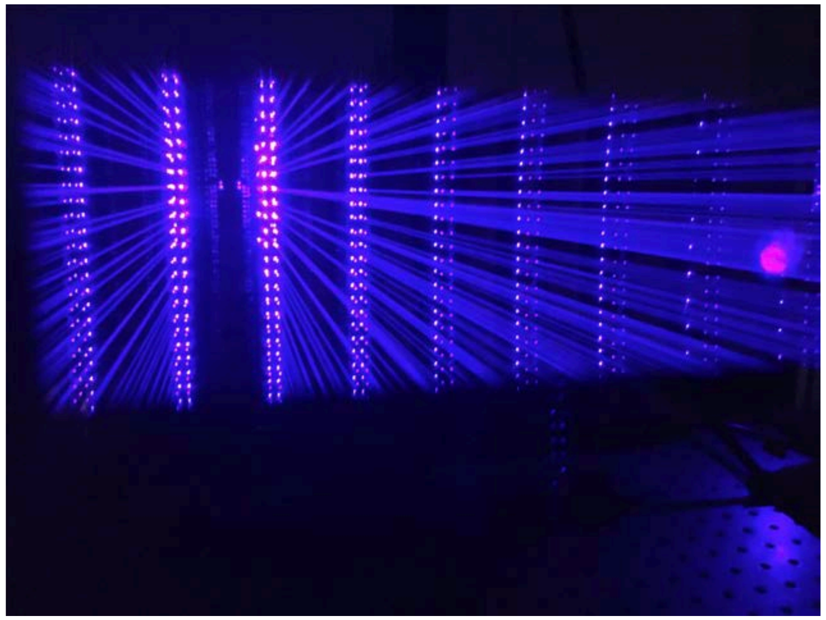
The DIRC



All 112 bars delivered to GSI







3-layer lens prototype (laser tests at CUA-USA)

PANDA detector staging

Stage 1:

- Order Solenoid from industry (e.g. ANSALDO)
- Muon detectors (e.g. Al-drift tubes)

… in addition to target charged tracking / PID / endcap EMC / lumi detector

Stage 2:

- Add full Target Spectrometer EMC (crystals from CRYTUR)

Stage 3:

- Add Forward Shashlyk EMC
- Add Forward TOF
- Add Forward Muon system
- Add Forward RICH

Unique PANDA physics in different stages

Stage 1:

- Hybrids, four-quark states, hadronic molecules unique for those with higher spins
- First-time study of hadron structure with $\bar{p}$ in the μ channels (GPDs, TDAs, …)

  by concentrating on charged final states and μ detection
- Very high statistic production of hyperon-antihyperon pairs, in particular $\Lambda\bar{\Lambda}$ and $\Xi\bar{\Xi}$

Stage 2:

- Complement μ measurements in spectroscopy by including electron channels and radiative transitions to further clarify nature of states, all decay channels, identify the whole excitation spectra (e.g. glueballs)
- Study hadron structure in the electron channels, by comparing to μ-results → test e-μ universality, access to complete time-like region including the special region
- Hyperon-antihyperon: unknown cross-sections of different and excited hyperons production

  by adding full high-resolution calorimetry in the Target Spectrometer

Stage 3:

- Hyperon-antihyperon physics to test CP in the strange baryon sector
- Strangeness and Charm in Nuclei to observe properties of hadrons in different nuclei
- Hypernuclei studies to study bound states of hyperons in nuclei, search for the H-dibaryon

  by adding full solid angle coverage and PID in the Forward Spectrometer

PANDA: intermediate physics program

(brainstorming process) - no Council decision on FAIR yet

- Test, develop and use existing PANDA detectors
- Keep the expertise of detector experts
- Keep the expertise of software experts
- Provide the opportunity for young scientists to perform physics measurements

4 lines of thinking:

1) Continue collaboration with HADES in view of pion beams and proton beams

   Baryon spectroscopy with pion beam

2) Continue the Phase-0 experiment at MAMI

   Formfactor measurements

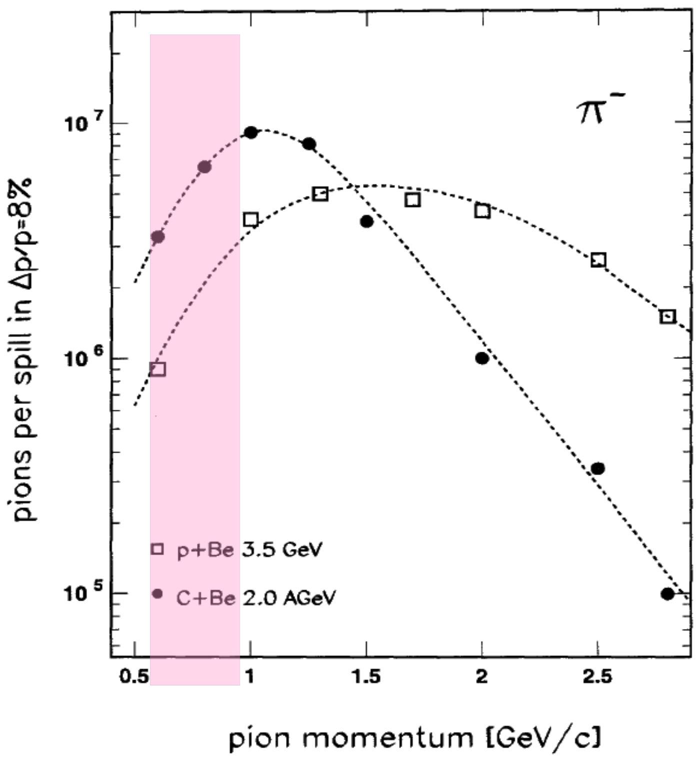
3) Participate in photon-beam baryon spectroscopy with CBELSA

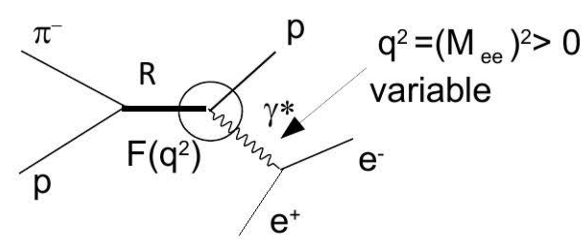
   Complementary baryon spectroscopy to the HADES measurements incl. polarization

4) If space and beam time is available at GSI start buildup and use of PANDA components

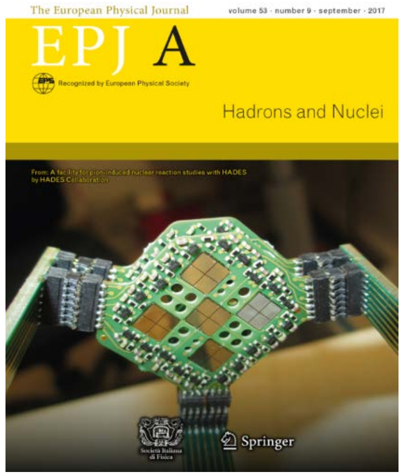
   Get ready for PANDA at FAIR

Pion Beam @ GSI





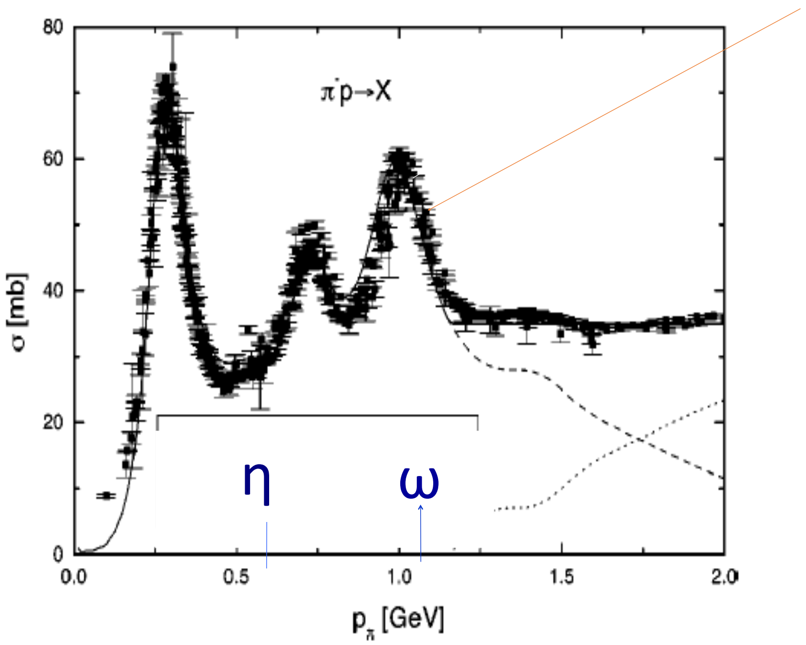
Eur. Phys. J. A (2017) 53: 188



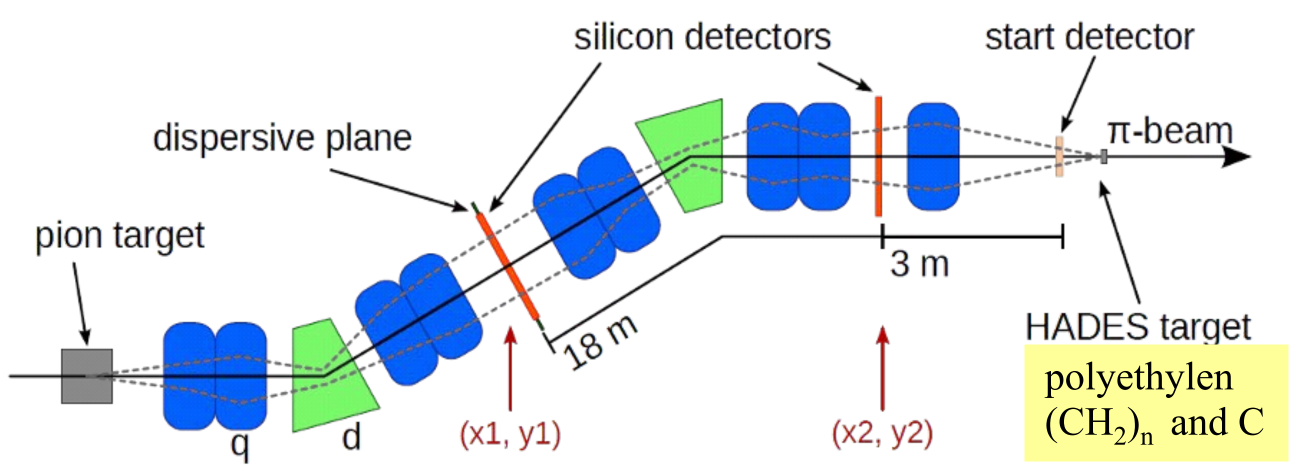
- ➢ reaction **N+Be**, 6×10^{10} N_2 ions/spill (4s)
- ➢ secondary π^- with **I ~ 2-3 10^5/s**
- ➢ pion momentum $\Delta p/p$ =2.2% (σ)
- ➢ 50% acceptance of pion beam line

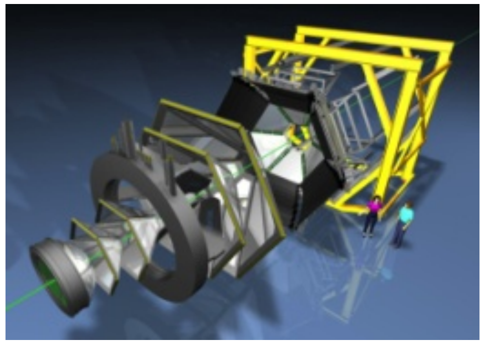
First run:

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

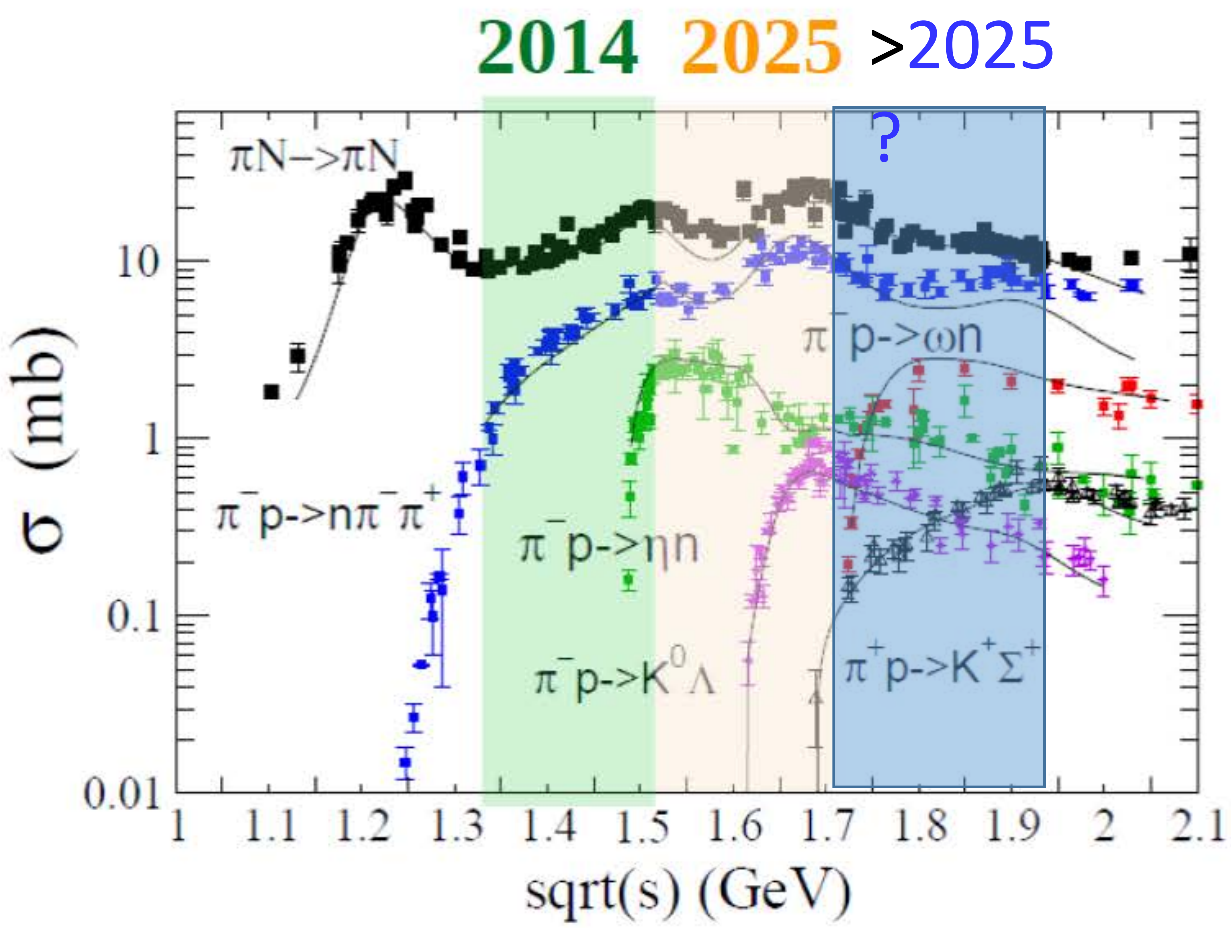


pion beam tracker **diamond detector**





HADES pion beam program – past and future



High statistics beam energy scan: continuation and extension to 3rd resonance region

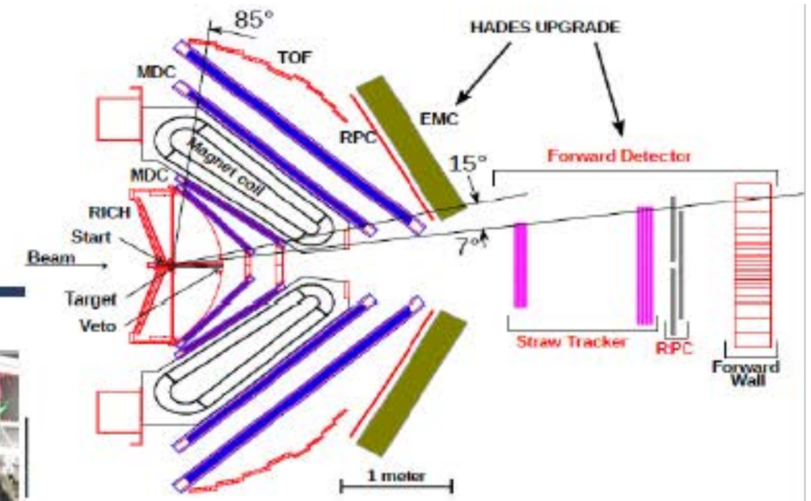
1) **Baryon-meson couplings:**

- $\rho/\omega/\phi$-N, η-N, $K^0\Lambda$, $K^0\Sigma^0$
- two, three pion final states (sequential resonance decays: $\Delta\pi$, $N^*\pi$

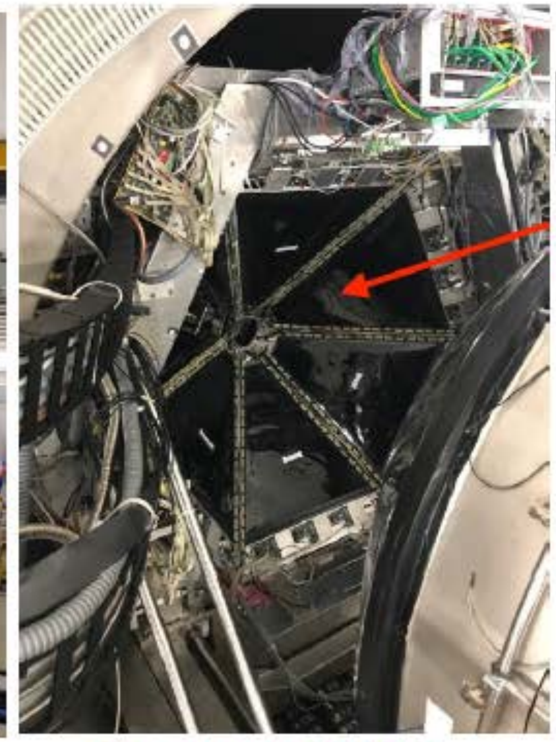
2) **Time-like em. baryon transitions**
$\pi^- p \rightarrow ne+e-$,
test of VMD for ρ and ω,
spin-density matrix elements,

3) **Cold nuclear matter studies:**
→ ω absorption
→ ρ spectral function
→ strangeness production

HADES Spectrometer UPGRADE

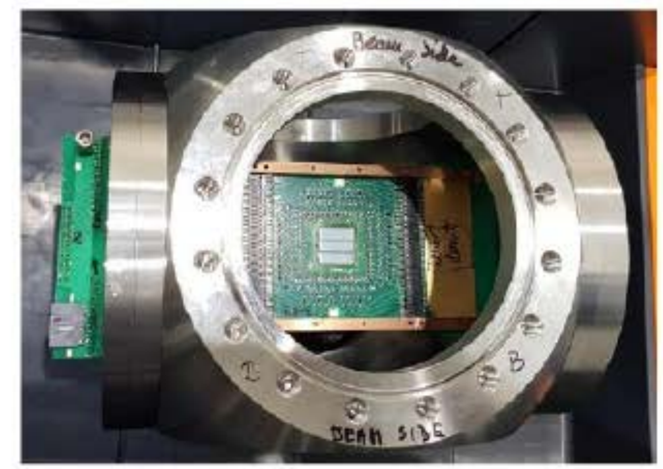


HODO, fRPC, STS2, STS1



innerTOF (fast trigger)

- START T0 detector

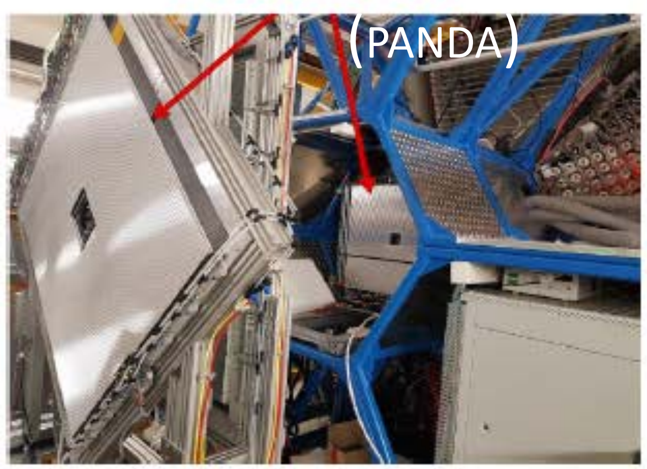


Low Gain Avalanche Detectors for the HADES reaction time (T) detector upgrade (Eur. Phys. J. A (2020) 56: 183)

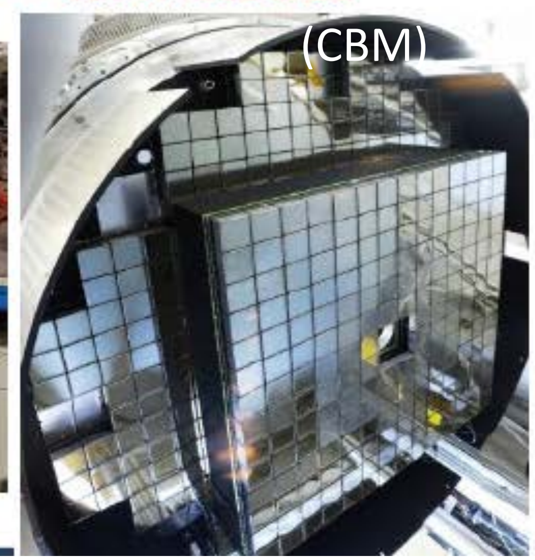
- timing < 100 ps

- ECAL (lead glass)

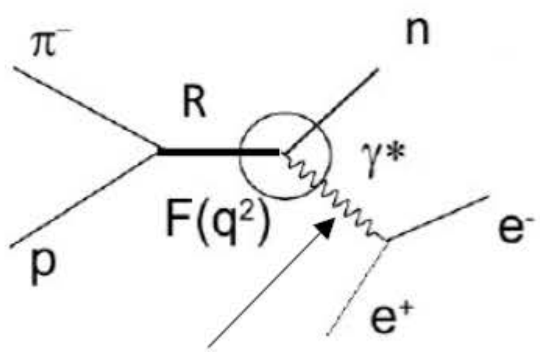
STS2 STS1 (PANDA)



- new RICH (CBM)

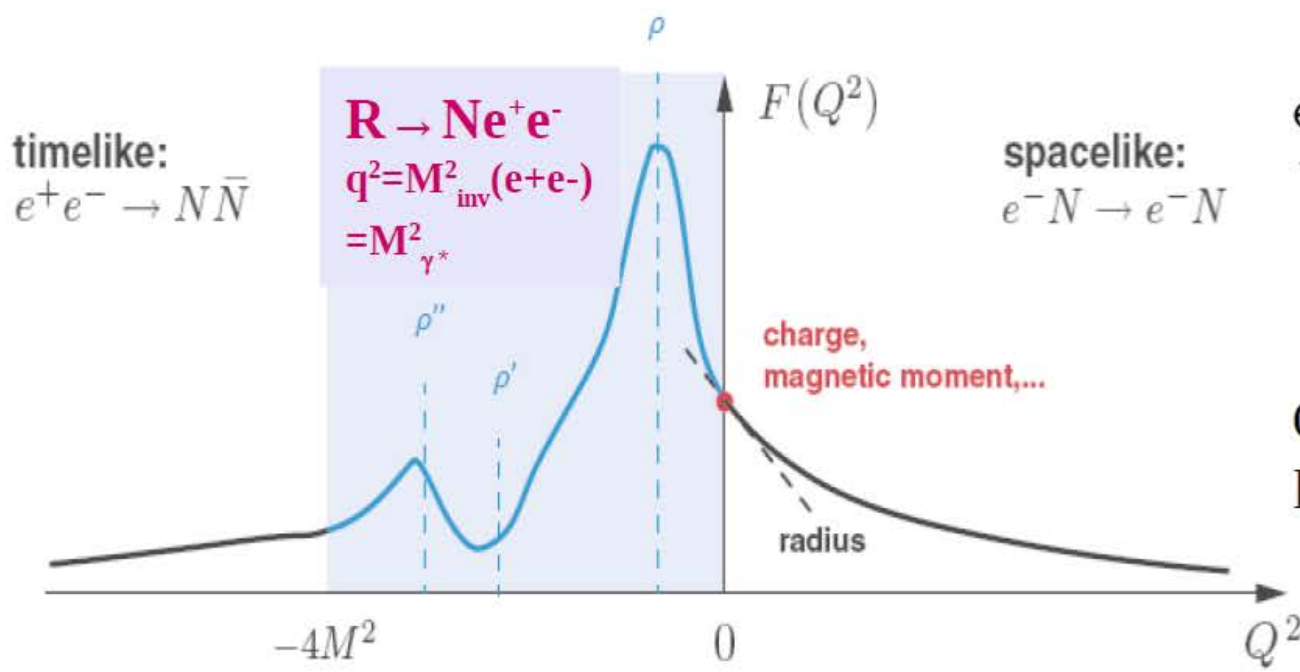


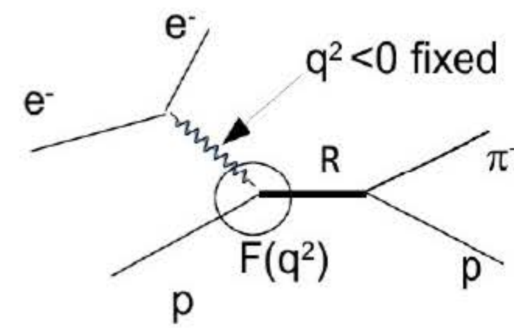
Electromagnetic structure of baryons



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

no data available





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

Dalitz decays - em. transition Form-Factor

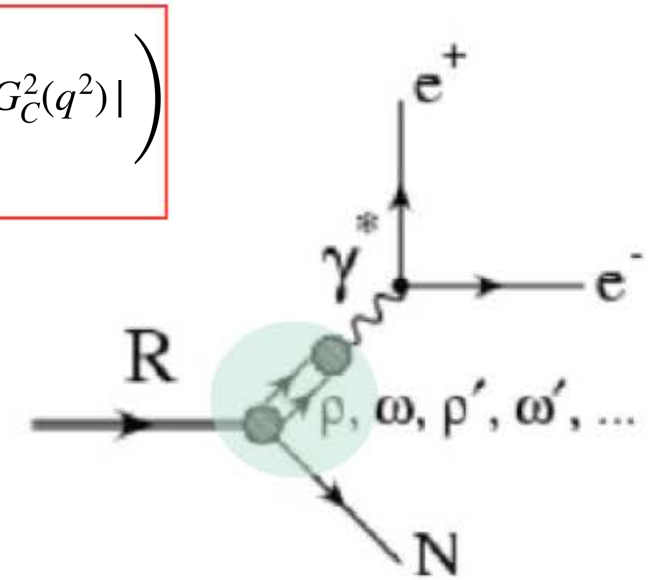
for $\Delta \rightarrow Ne^+e^-$ transition

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

QED
transition
of point-like
particles

Form-Factors
internal structure
of hadrons
(various models)

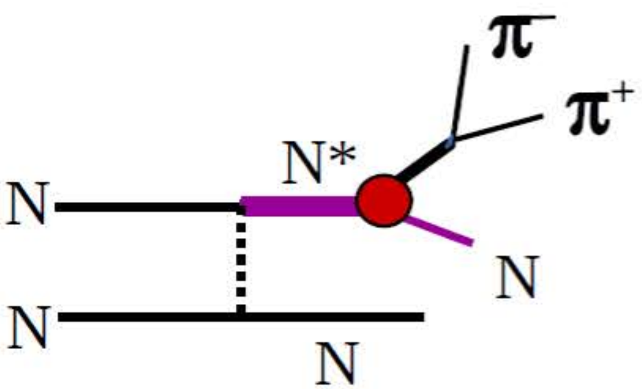
Vector Meson Dominance Model

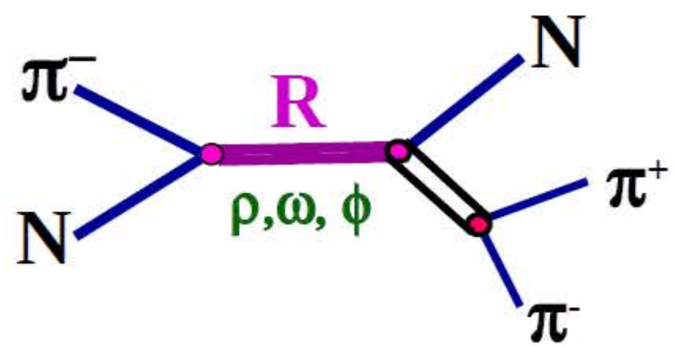


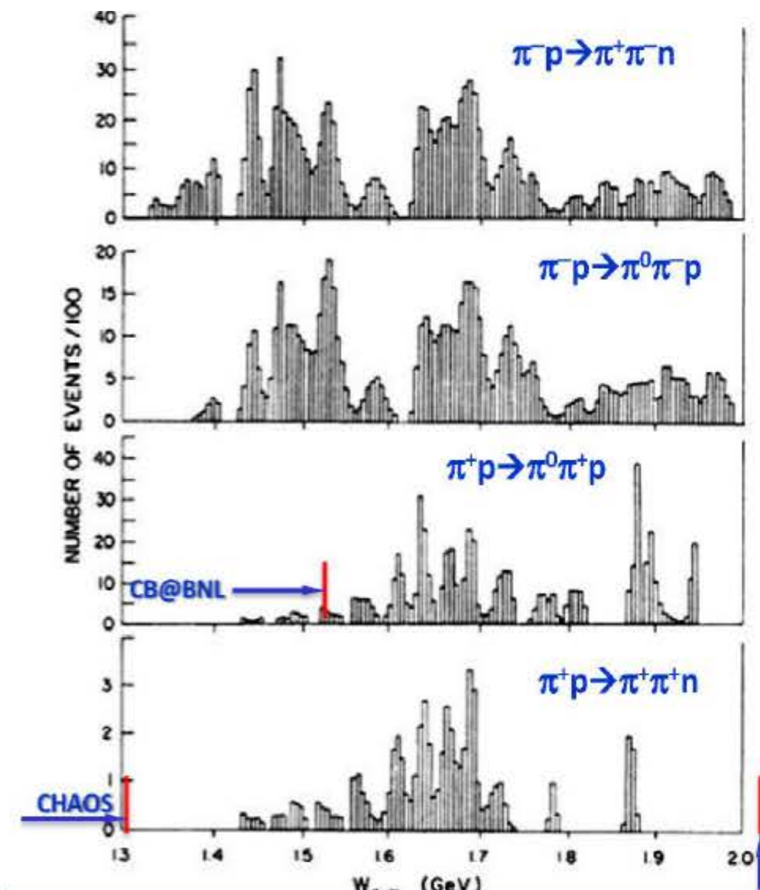
Baryon spectroscopy

→ **selectivity:** resonances can be excited at given mass in s-channel by choosing the beam (pion) momentum, HADES starts with $\sqrt{s}$ = (1.46-1.55) GeV

→ 2nd resonance region,







Manley *et. al* PRD30 (1984) 904, 241214 bubble chamber events analysed in isobar PWA model

→ **$\pi^+\pi^-$, $\pi^+\pi^0$ production:** off-shell coupling of ρ to resonance, ρ → ππ (~100%) „golden channel",

→ **BR** of resonances in the ρN decay,

→ two-pion production channels,

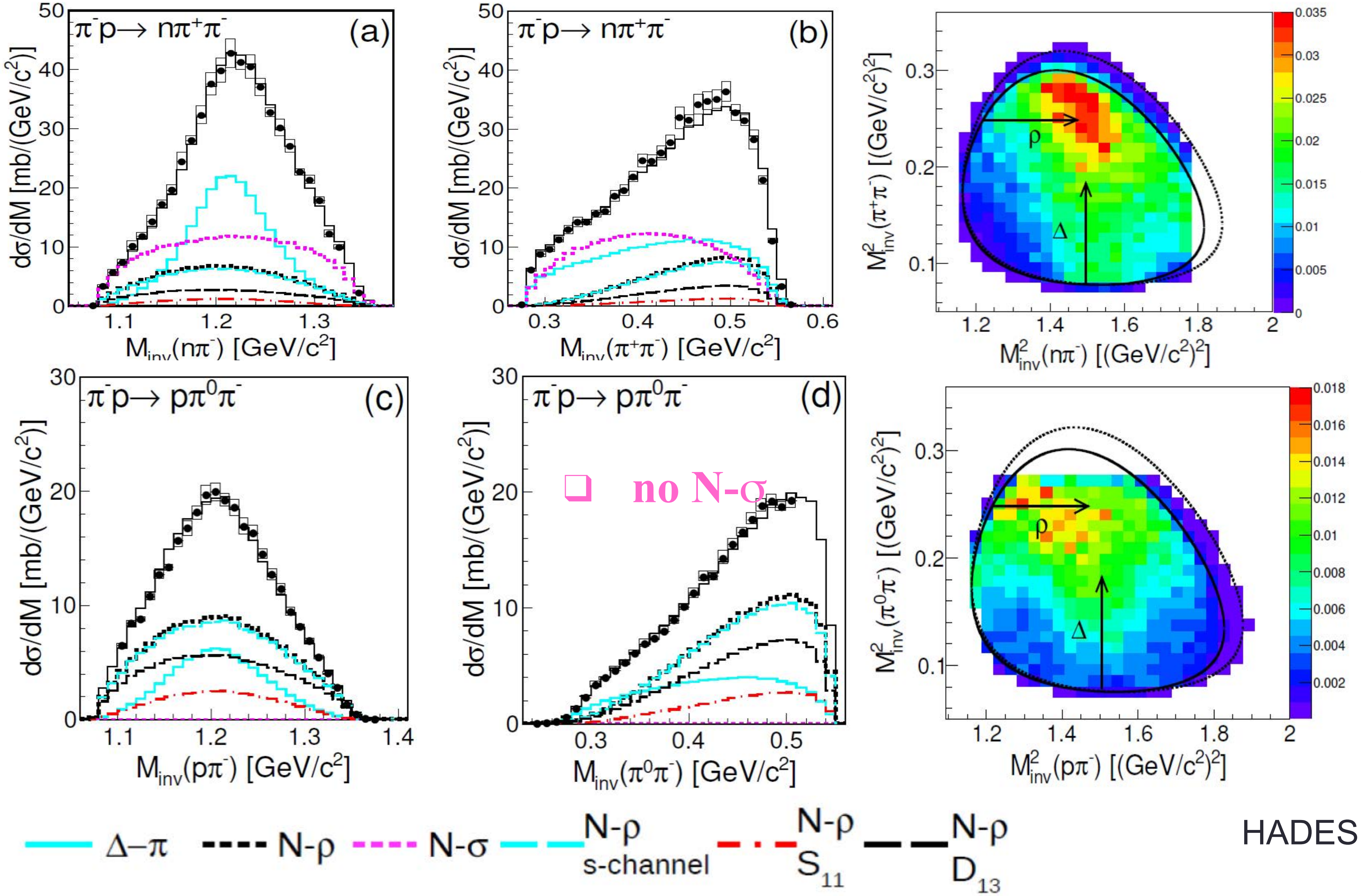
→ **dilepton channel** R → N e+e-, never measured in pion induced reactions,

→ **very scarce data** base for pion-nucleon reactions.

- Recent post-Bubble Chamber measurements:
  - **349,611** events for $\pi^- p \to \pi^0\pi^0 n$ from **CB@BNL** at W = **1213** to **1527** MeV. [S. Prakhov *et al* Phys Rev C **69**, 045202 (2004)]
  - **20,000** events for $\pi^\pm p \to \pi^\pm \pi^\pm n$ from TRIUMF **CHAOS@TRIUMF** at W = **1257** to **1302** MeV. [M. Kermani *et al* PRC **58**, 3431 (98)]
  - **40,000** events for $\pi^- p \to \pi^- \pi^+ n$ from **ITEP** at W = **2060** MeV. [I. Alekseev *et al* Phys At Nucl **61**, 174 (1998)]

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

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

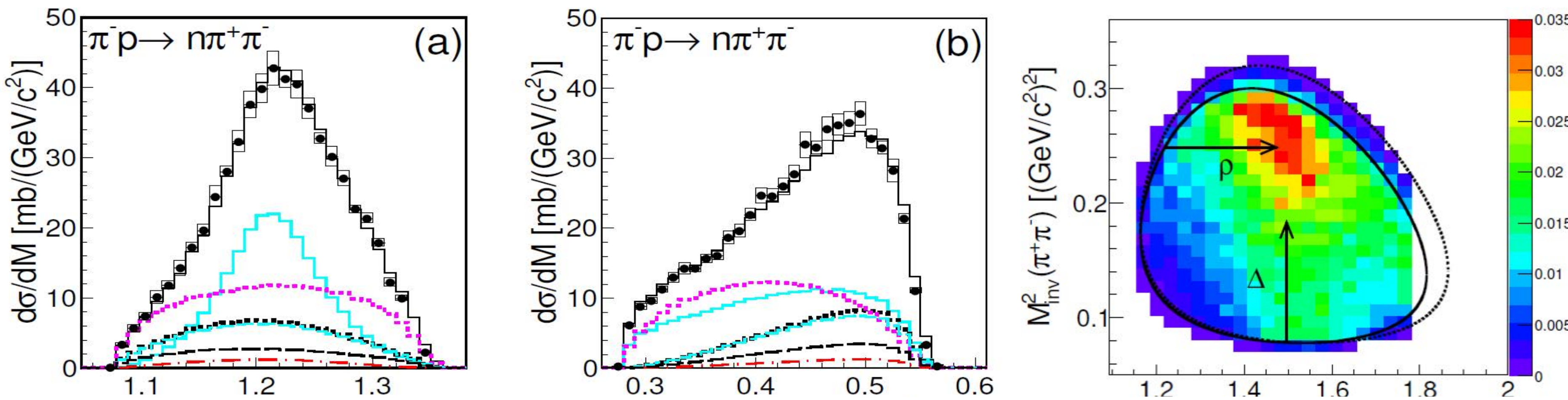


- Combined PWA fit with many other channels from e^-p, γp, Kp reactions
- Input solution: resonance properties fixed, except branches to VM
- Final solution (Log L) with HADES 2pion data Bn-Ga 2019 (pwa.hisp.uni-bonn.de)

HADES:PRC *C102 (2020) 024001*

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, γp, Kp reactions

- Input solution:

Eur. Phys. J. C (2020) 80:453
https://doi.org/10.1140/epjc/s10052-020-7930-x

THE EUROPEAN PHYSICAL JOURNAL C

Check for updates

Regular Article - Experimental Physics

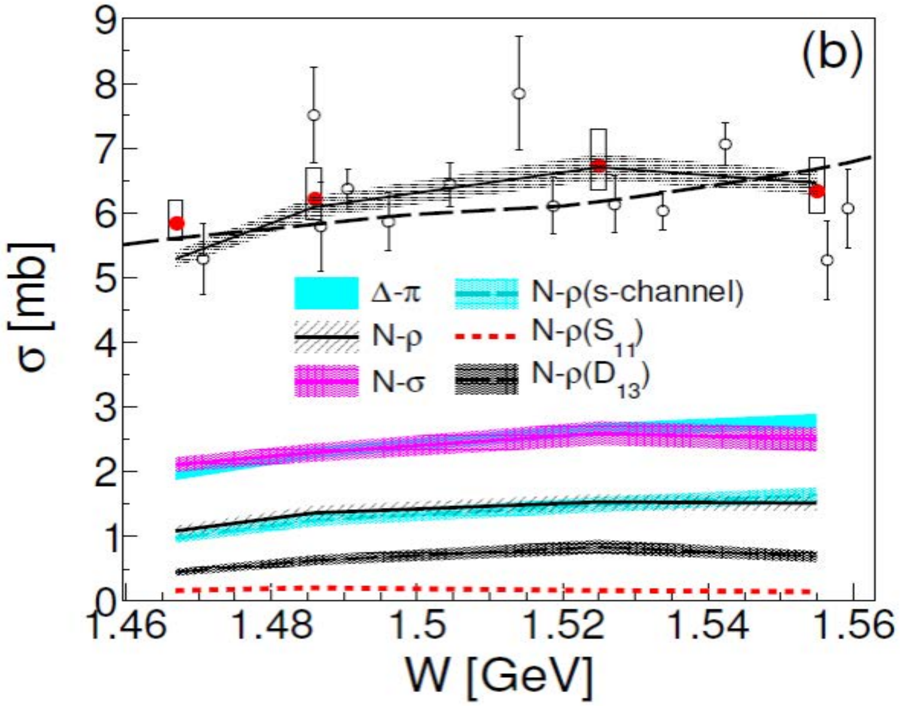
Coupled channel analysis of $\bar{p}p \rightarrow \pi^0\pi^0\eta, \pi^0\eta\eta$ and $K^+K^-\pi^0$ at 900 MeV/c and of $\pi\pi$-scattering data

The Crystal Barrel Collaboration

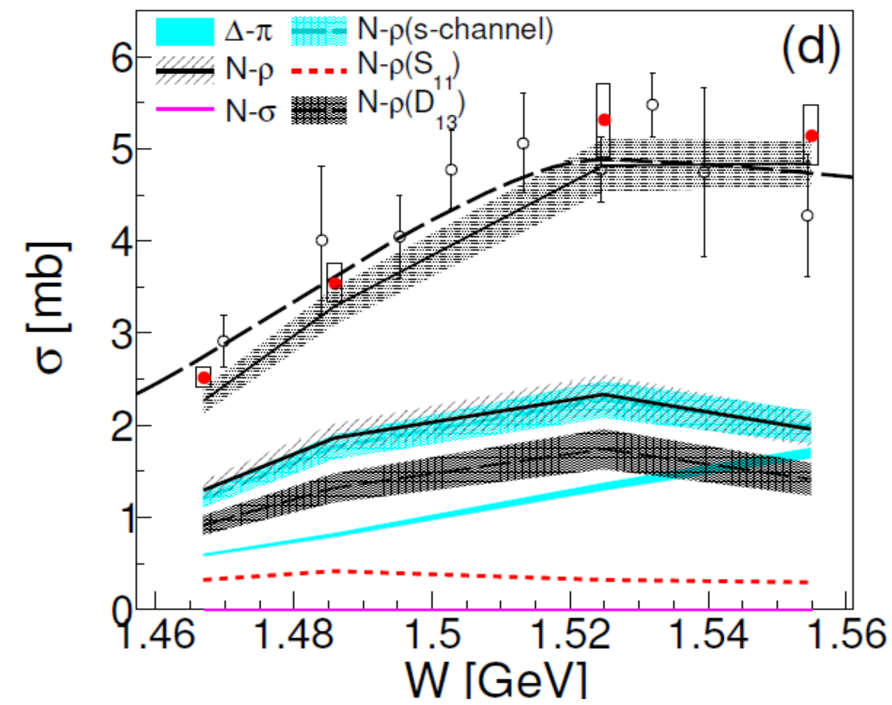
M. Albrecht[1], C. Amsler[4,5], W. Dünnweber[3], M. A. Faessler[3], F. H. Heinsius[1], H. Koch[1], B. Kopf[1,a], U. Kurilla[1,6], C. A. Meyer[2], K. Peters[1,6], J. Pychy[1], X. Qin[1], M. Steinke[1], U. Wiedner[1]

Total Cross Sections

$n\pi^+\pi^-$



$p\pi^-\pi^0$



world data — HADES data — PWA Refs. [8-9] — PWA Bn-Ga

- consistent descripton of HADES and world data
- **N (1520) →N ρ BR =12.2 ± 2 % N(1535)** →N ρ **BR=3.2 ± 0.6 %**

+ BR for Δπ and **N**σ

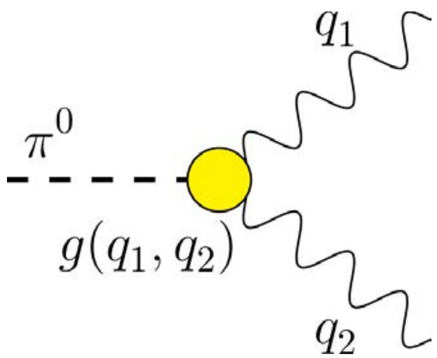
PDG particle data group **8 new entries**

branching ratios of N(1440), N(1535), N(1520) to 2π channels (Δπ, Nρ, Nσ)

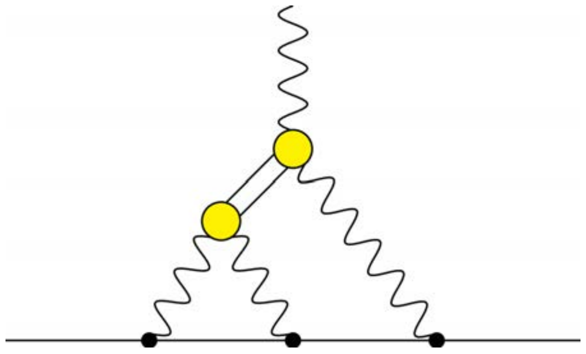
[8-9]
D. M. Manley *et al*. *Phys. Rev. D 30 (1984) 904*
D. M. Manley and E.M. Saleski, Phys. Rev. D 45,

MAMI: Measurement of π^0 Transition Form Factor

Parametrises the $\pi^0 \to \gamma^*\gamma^*$ transition



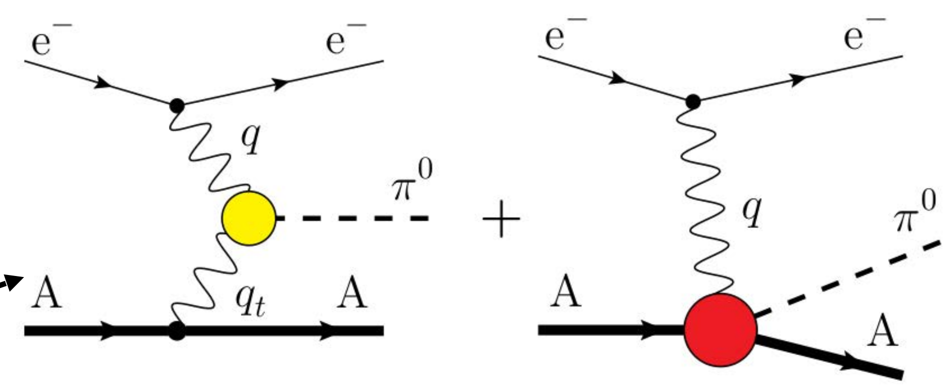
Enters the hadronic corrections to $g_\mu - 2$ through the HLbL scattering diagram (Hadronic Light-by-Light-scattering)



Can be accessed in single pion electroproduction on a nucleus:

$$e^- + A(Z,N) \to e^- + \pi^0 + A(Z,N)$$

Dominant contributions:



"Virtual Primakoff" contribution (negative momentum transfer) :

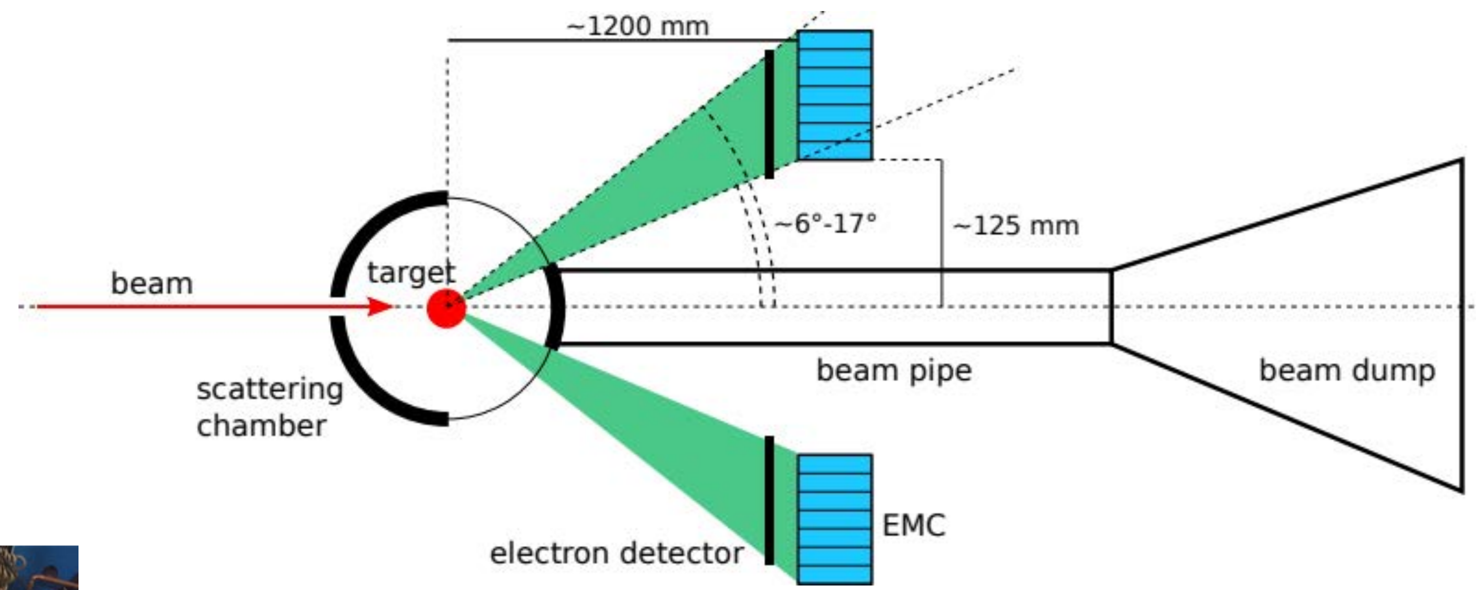
- proportional to the transition form factor
- enhanced at small $t = q_t^2$
- enhanced for high Z targets

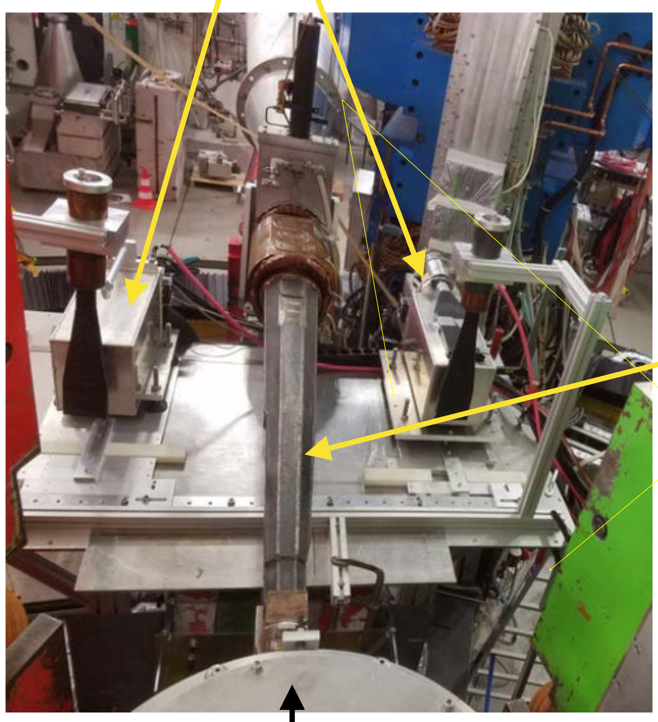
The experimental setup at MAMI

- at A1 electron scattering facility
- beam energy: 1.5 GeV
- Ta target (Z=73)

Modified version of PANDA backward EMC

- 640 $PbWO_4$ crystals
- APD+APFEL readout





Test measurements with prototypes

- real experimental condition
- measurement of total detector rates
- ⇒ determination of feasible luminosity
- measurement of energy spectra

Time plans for the MAMI experiment

Experiment construction

- PANDA backward endcap calorimeter setup finished: first half of 2023
- MAMI A1 hall infrastructure (target chamber, beam pipe, EMC support): end of 2023
- Experiment installation in MAMI A1 hall: first 2024

Last test with prototypes

- test of final readout electronics
- second half of 2023

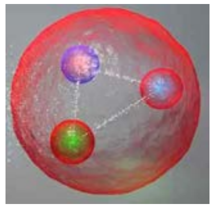
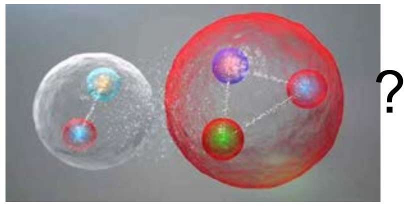
Commissioning and production beam times
(subject to MAMI beam schedule)

- commissioning run (1 week) and pilot run, small Q^2 values (2 weeks): second half of 2024
- Analysis of pilot run
- full statistics run (4 extra weeks): 2025
- Analysis of data: 2026/2027

Early science @ ELSA – Baryon spectroscopy

Investigating the spectrum and properties of baryons ⇔ complex bound states of QCD

- **Effective degrees of freedom**
- **Forces between them**

e.g.  or  ?

qqq

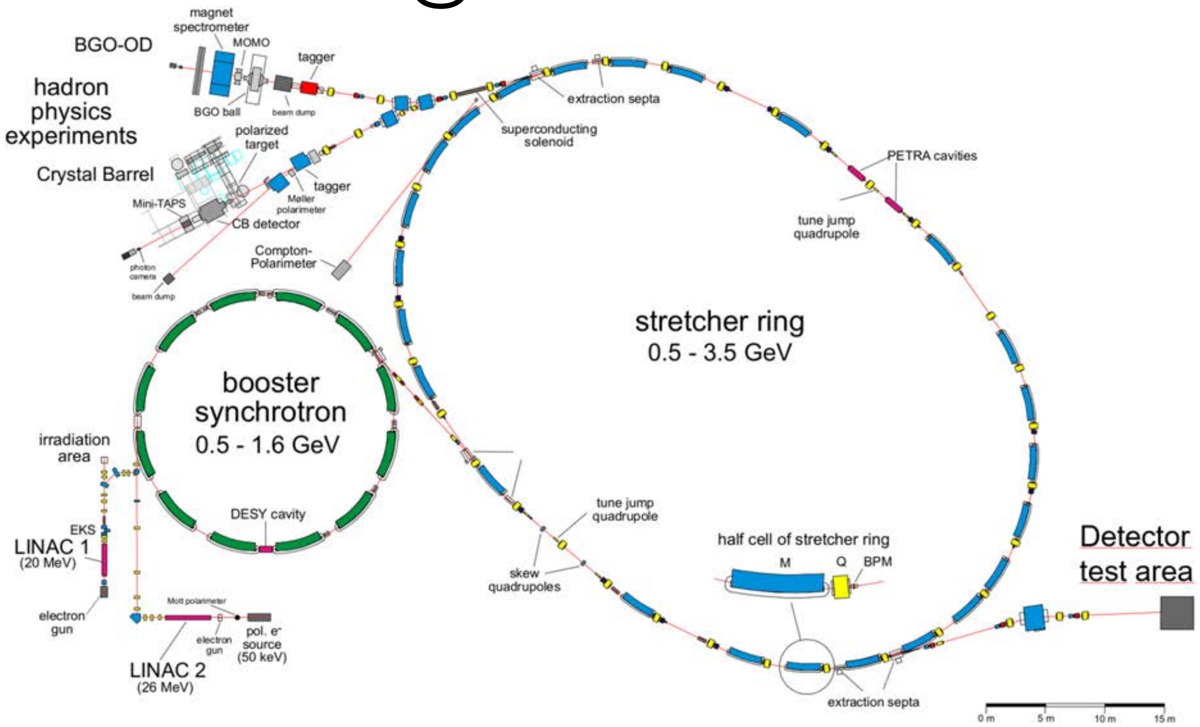
meson-baryon

(e.g. Λ(1405))

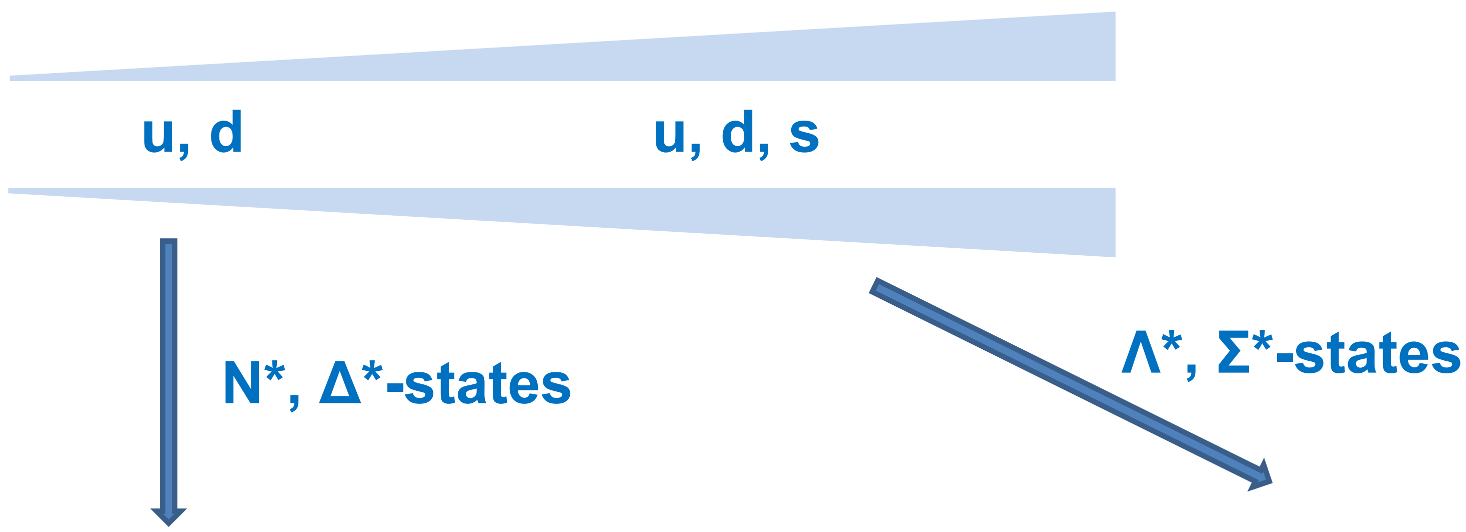
u, d **u, d, s** **u/d, s, s** **s, s, s** **charm**

decreasing knowledge

@ELSA **@HESR**



Early science @ ELSA - Baryon spectroscopy -



Existing states and properties

To gain a complete picture of the light-quark baryon spectrum:

- **Polarized photoproduction off the polarized proton and neutron!**

⇔ unambiguous PWA not possible without the measurement of polarization observables

- **Multi-meson photoproduction**

Existing states and properties

More states expected than in the u,d-sector but much less states found so far!

⇔ **Do they exist ?**

⇔ **Are they consistent with SU(6)xO(3)-symmetry?**

⇔ **Nature of the observed states=?**

e.g. Λ(1405)

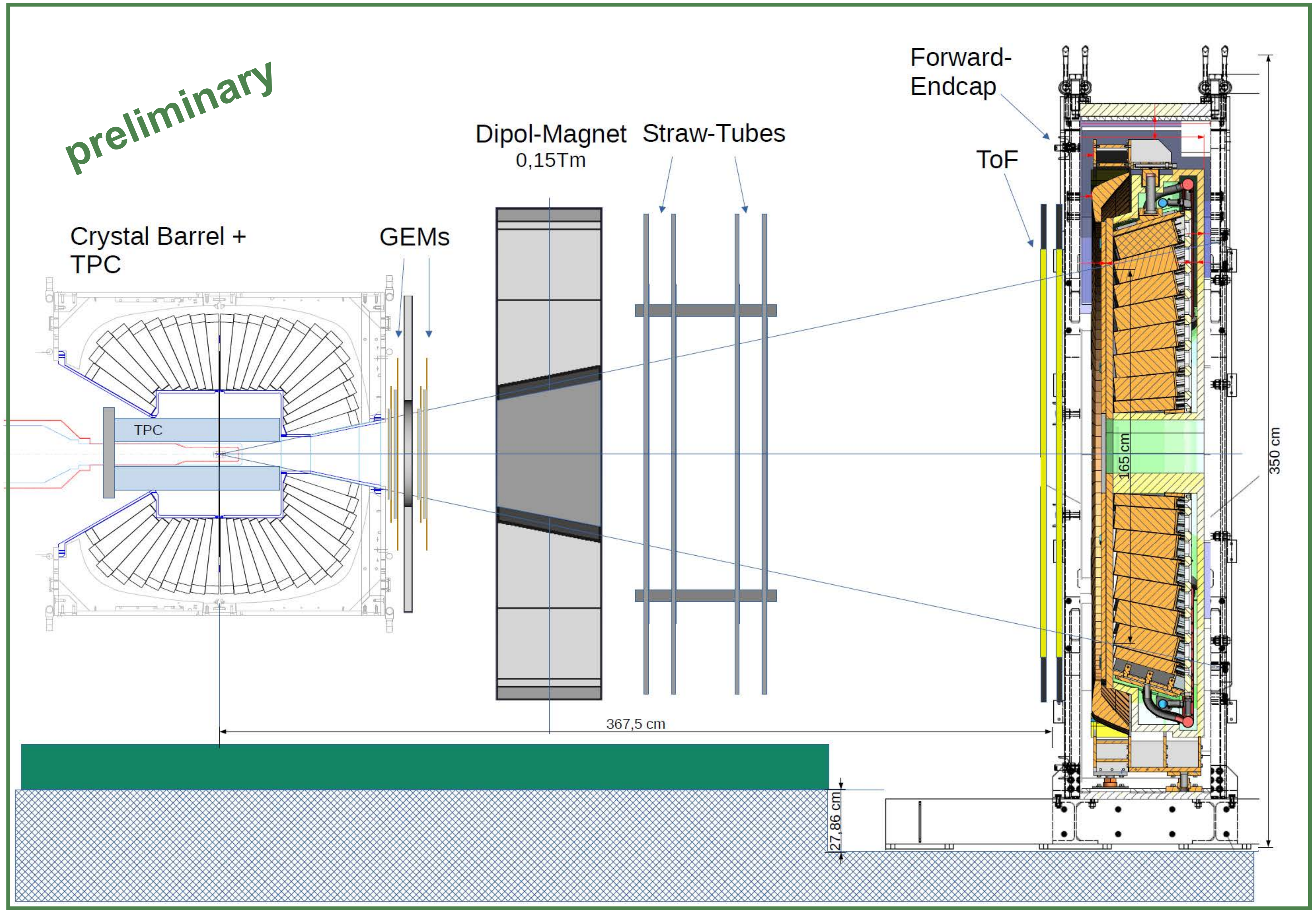
The problem:

PDG'2022: ".., the field is starved for data"

<=> ELSA

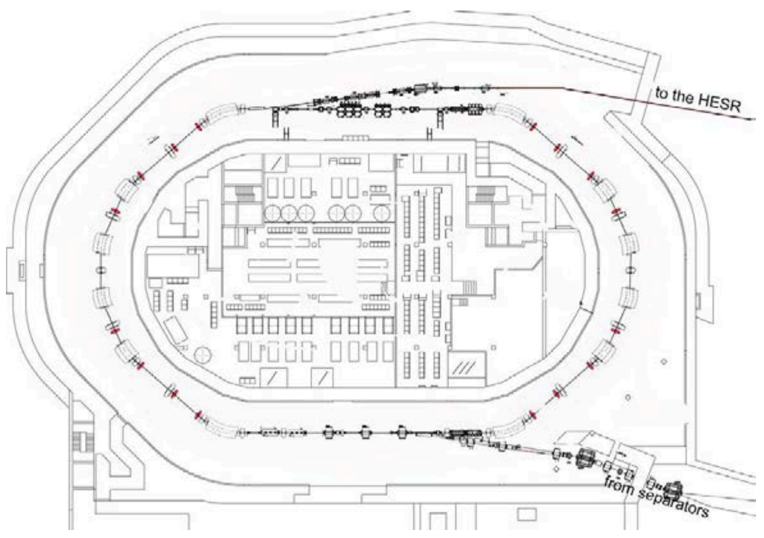
Future: Hadron spectroscopy perspectives @ ELSA

- **Upgrade of the detector system**
  ~ 4π for photons and for charged particles + polarized target



- **Polarized photoproduction off proton and neutron in the non-strange and strange baryon sector**
  - spectrum / properties of baryons, search for multi-quark states

Options for Antiproton collection at FAIR (MAC)



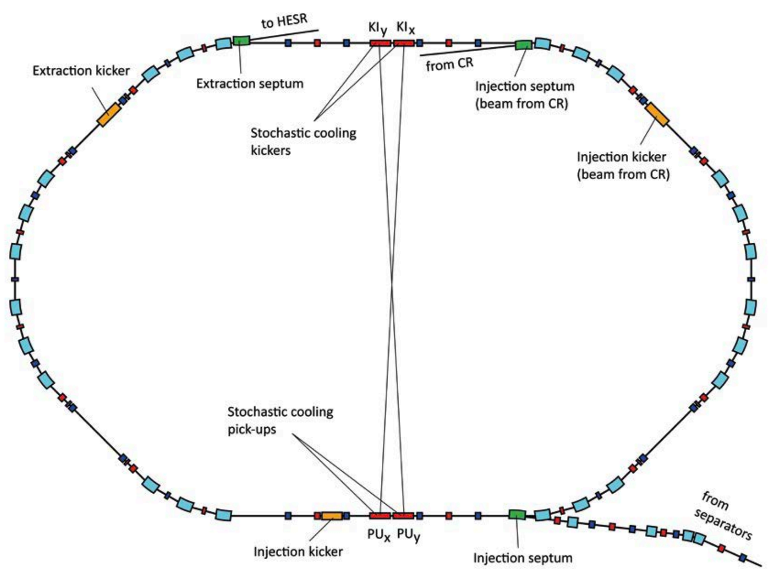
Option 1: AA

Components of CERN AA used for a new collector ring (CR)

Option 2: COSY

- Refurbishing vacuum system for new geometry
- All other COSY components ready
- Serve as collector for commissioning
- Later COSY can be used as accumulator (“RESR”)

⇒ Having both rings allows 8× previous Phase 1 luminosity



Option 3: New Superferric CR

- Superferric CR derived from Super-FRS design
- Higher investment costs, long-term lower operation cost

MAC Recommendations:

Baseline CR with AA magnets followed by COSY as RESR

Thank you for your attention!

and many thanks to

Piotr Salabura

Ulrike Thoma

Frank Maas

Lars Schmitt

for helping with transparencies