22 November 2024, JINR Laboratory of Nuclear Problems, Dubna, Russia

Исследование поляризационных эффектов на ускорителях в Майнце и Бонне с использованием поляризованной мишени, созданной в ЛЯП ОИЯИ

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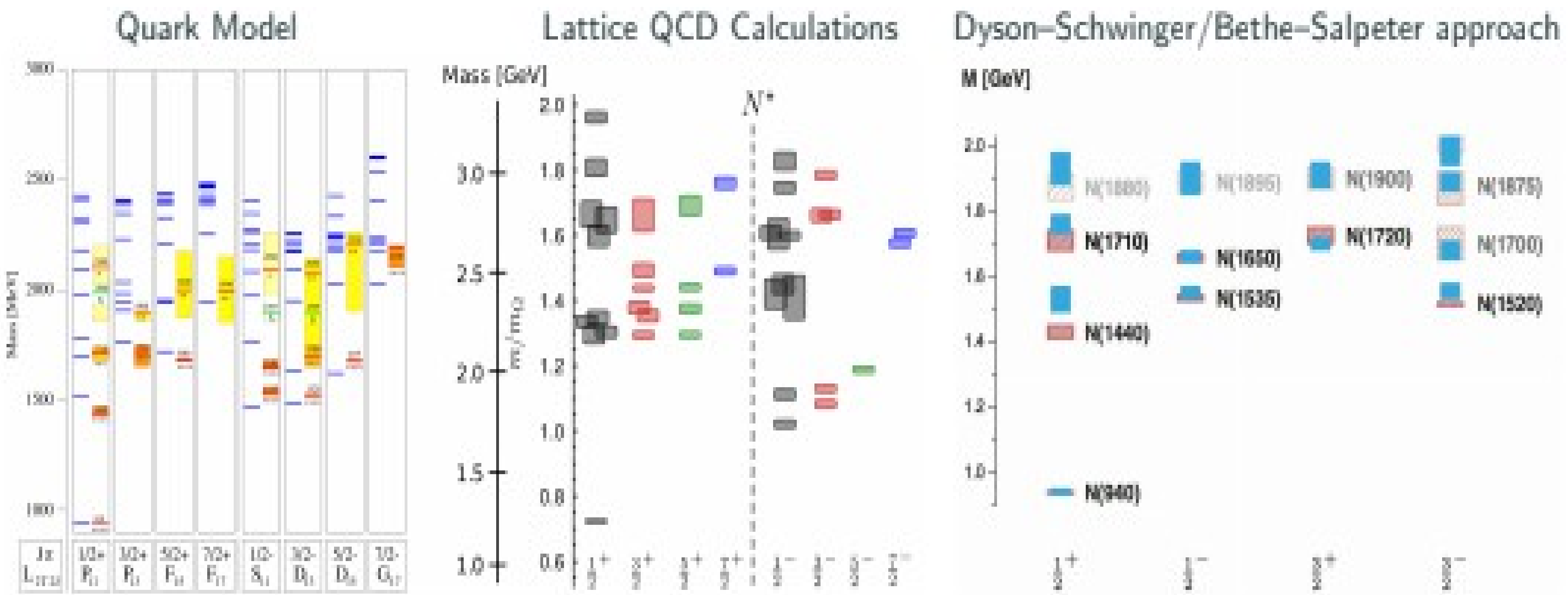
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Outline

- Physical program and selected results
  - light quark baryon spectroscopy
  - complete experiment
  - search for exotic resonance states
  - Gerasimov-Drell-Hern (GDH) sum rule
  - polarisabilities of nucleons and mesons
- Experimental facilities
- Publications
- Future plans : MeSa P2 Collabortion

Light quark baryon spectroscopy

Theoretical Predictions

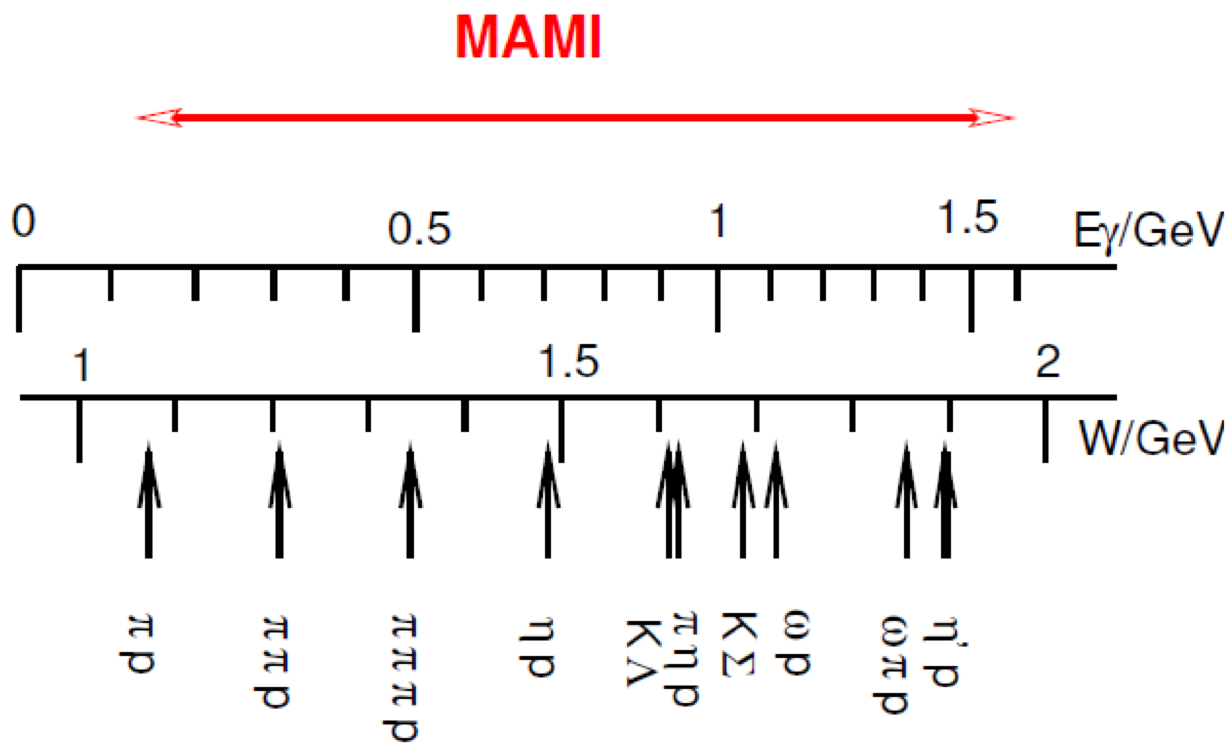


[U. Loering, et al., Eur.Phys.J.A10:395 (2001)] [R. Edwards et al., Phys.Rev.D 84 (2011) 07450] [Eichmann, Fischer, Few Body Syst. 60 (2019) 1,2]

Discrepancies between measurement and calculations:

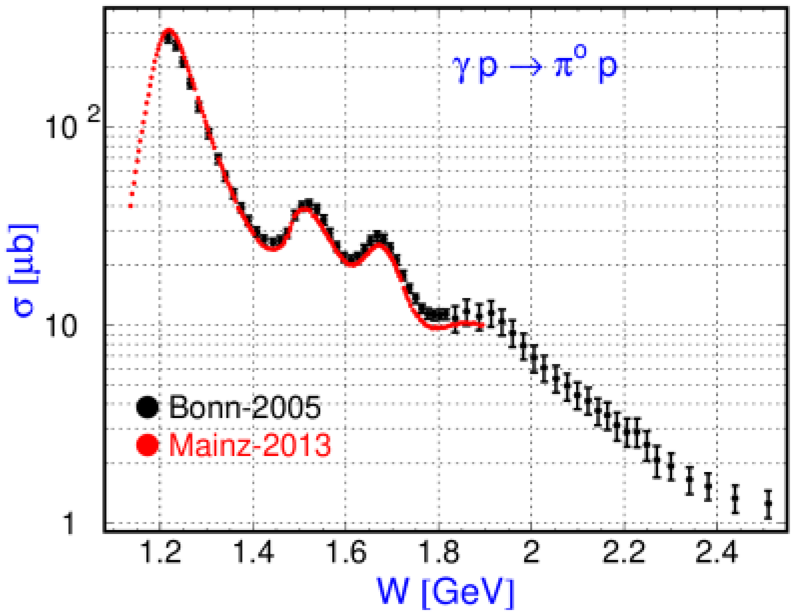
"missing resonances" and level ordering

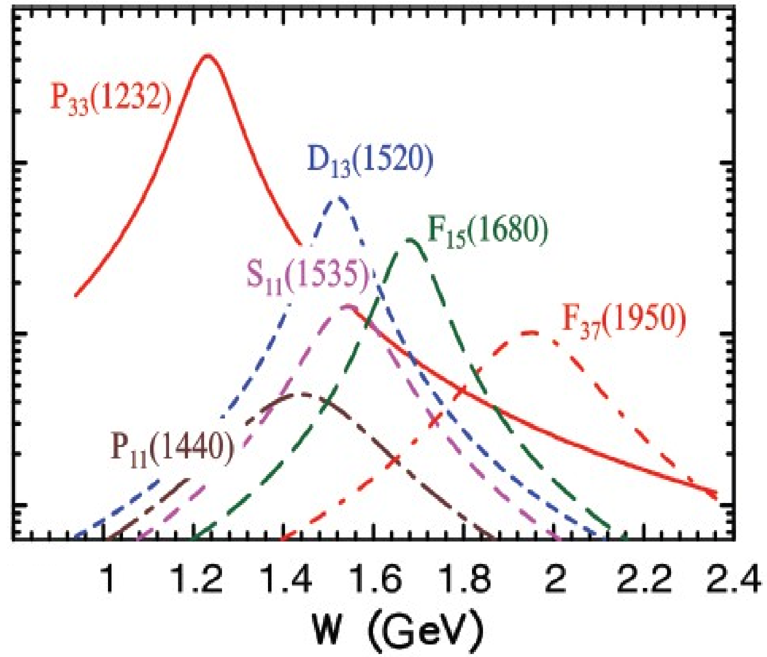
Meson photoproduction with MAMI C



Energy thresholds in γN

$\gamma\, p \rightarrow \pi^o\, p$





- Only the P_{33}(1232), D_{13}(1520), F_{15}(1680), and perhaps the F_{37}(1950) are directly visible;
- the P_{11}(1440), S_{11}(1535), and many other resonances can only be analyzed in a Partial Wave Analysis.

P33(1232)
P11(1440)
D13(1520)
S11(1535)
S31(1620)
S11(1650)
D15(1675)
F15(1680)
D33(1700)
P13(1720)
F35(1905)
P31(1910)
F37(1950)

Bonn-2005: O. Bartholomy et al., PRL 94 (2005) 0122003
Mainz-2013: P. Adlarson et al., PRC 92(2015) 024617

Light quark baryon spectroscopy

Models:

MAID (Mainz) photo- and electroproduction for individual channels
BnGa (Bonn) multichannel, photoproduction
SAID (Washington – J lab) multichannel, photoproduction
BnJu (Juelich) photoproduction of K mesons

MTZ (Mainz-Tuzla-Zagreb Collaboration) Complete experiment

The first MAID program appeared in 1998:




1. D. Drechsel, O. Hanstein, S. S. Kamalov, L. Tiator
   Unitary isobar model for pion photoproduction and electroproduction on the proton up to 1-GeV, Nucl. Phys. A 645 (1999) 145.

Soon afterwards the Dubna-Mainz-Taipei (DMT) dynamical model was developed:

2. S. S. Kamalov, Shin Nan Yang,
   Pion cloud and the Q**2 dependence of gamma* N <--->Delta transition form-factors,
   Phys. Rev. Lett. 83 (1999) 4494.

3. S. S. Kamalov, S. N. Yang, D. Drechsel, O. Hanstein, L. Tiator,
   Gamma* N --->Delta transition form-factors: A New analysis of the JLab data ...
   Phys. Rev. C 64 (2001) 032201.

Light quark baryon spectroscopy

https://maid.kph.uni-mainz.de

M A I D

Photo- and Electroproduction of Pions, Eta, Etaprime and Kaons on the Nucleon

Institut für Kernphysik, Universität Mainz

Mainz, Germany

MAID2007	unitary isobar model for (e,e'π)
DMT2001	dynamical model for (e,e'π)
KAON-MAID	isobar model for (e,e'K)
ETA-MAID	EtaMAID2000 isobar model for (e,e'η) EtaMAID2018 isobar model for (γ,η) and (γ,η') NEW
Chiral MAID	chiral perturbation theory approach for (e,e'π)
2-PION-MAID	isobar model for (γ,ππ)
archive	MAID2000 DMT2001original EtaMAID2003 ETAprime2003

Light quark baryon spectroscopy

EtaMAID 2018

Institut für Kernphysik, Universität Mainz, Germany

update info NEW

An Isobar Model for Eta and Etaprime Photoproduction on the Nucleon

Victor Kashevarov and Lothar Tiator

Reference:

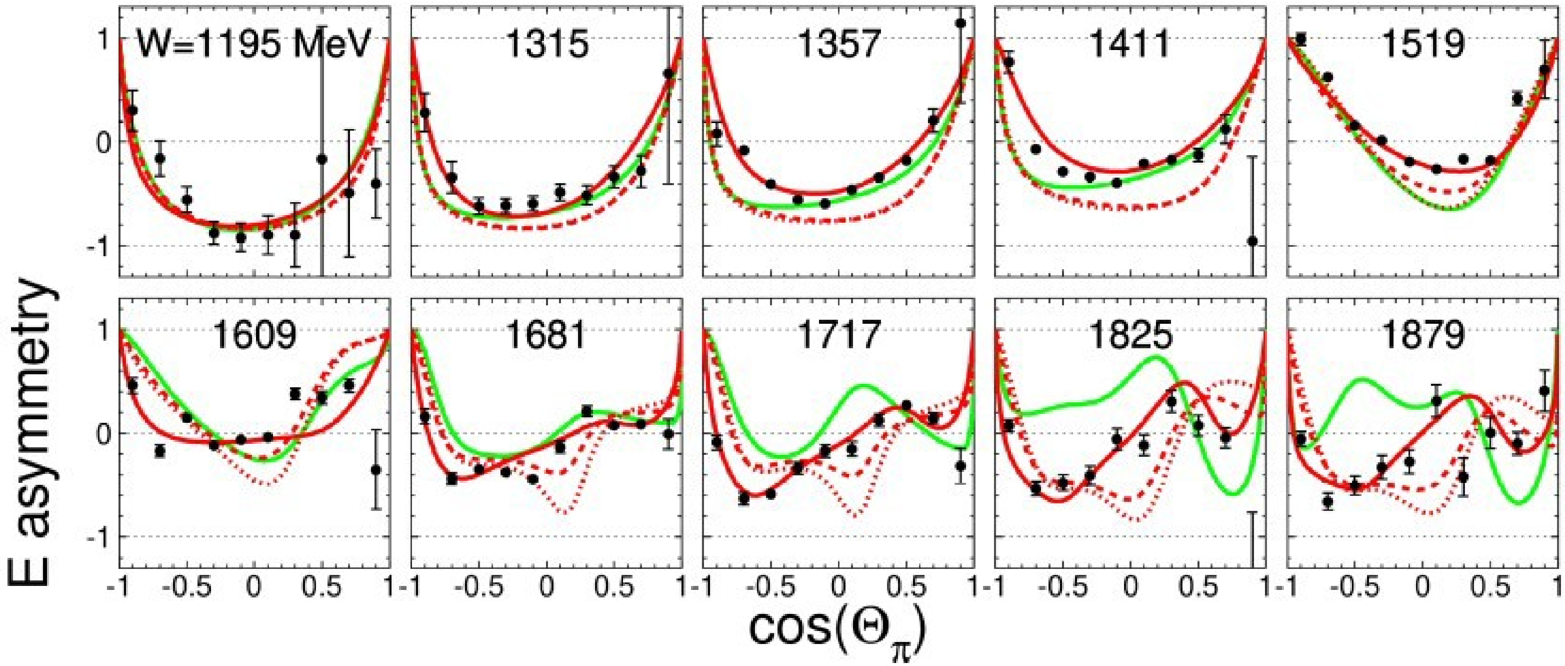
L. Tiator, M. Gorchtein, V.L. Kashevarov, K. Nikonov, M. Ostrick (Mainz),
M. Hadzimehmedovic, R. Omerovic, H. Osmanovic, J. Stahov (Tuzla),
and A. Svarc (Zagreb),arXiv:1807.04525,
Eur. Phys. J. A (2018) 54: 210

- **Electromagnetic Multipoles ($E_{l\pm}$, $M_{l\pm}$)**
- **CGLN and Helicity Amplitudes ($F_1,...,F_4$, $H_1,...,H_4$)**
- **Observables (with beam, target and recoil polarization)**
- **Total Cross Sections**

Light quark baryon spectroscopy

Selected results: E asymmetry (A2 Mainz - 2022)

$\gamma\, n \rightarrow \pi 0\, n$



Red lines: PionMAID2021 green: MAID2007

Light quark baryon spectroscopy

PDG summary table for nucleon resonaces

Black – status for 2010

Red - 2023

Particle	J^P	overall	$N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$	$N\eta'$
N	$1/2^+$	****										
$N(1440)$	$1/2^+$	****	****	****	****	***	-			-		
$N(1520)$	$3/2^-$	****	****	****	****	**	****			- - - -		
$N(1535)$	$1/2^-$	****	****	****	***	*	****			- -		
$N(1650)$	$1/2^-$	****	****	****	***	*	****	* - -	- -	- -		
$N(1675)$	$5/2^-$	****	****	****	****	***	*	*	*	-		
$N(1680)$	$5/2^+$	****	****	****	****	***	*	*	*	- - - -		
$N(1700)$	$3/2^-$	***	**	***	***	*	*	- -	-	-		
$N(1710)$	$1/2^+$	****	****	****	* -		***	**	*	*	*	
$N(1720)$	$3/2^+$	****	****	****	***	*	*	****	*	* -	*	
$N(1860)$	$5/2^+$	**	*	**		*	*					
$N(1875)$	$3/2^-$	***	**	**	*	**	*	*	*	*	*	
$N(1880)$	$1/2^+$	***	**	*	**	*	*	**	**		**	
$N(1895)$	$1/2^-$	****	****	*	*	*	****	**	**	*	*	****
$N(1900)$	$3/2^+$	****	****	**	**	*	*	**	**	-	*	**
$N(1990)$	$7/2^+$	**	**	**			*	*	*			
$N(2000)$	$5/2^+$	**	**	* -	**	*	*	-	-	- -	*	
$N(2040)$	$3/2^+$	*		*								
$N(2060)$	$5/2^-$	***	***	**	*	*	*	*	*	*	*	
$N(2100)$	$1/2^+$	***	**	***	**	**	*	*		*	*	**
$N(2120)$	$3/2^-$	***	***	**	**	**		**	*		*	*
$N(2190)$	$7/2^-$	****	****	****	****	**	*	**	*	*	*	
$N(2220)$	$9/2^+$	****	**	****			*	*	*			
$N(2250)$	$9/2^-$	****	**	****			*	*	*			
$N(2300)$	$1/2^+$	**		**								
$N(2570)$	$5/2^-$	**		**								
$N(2600)$	$11/2^-$	***		***								
$N(2700)$	$13/2^+$	**		**								

Complete experiment

Conception of the complete experiment in two body scattering of particles with spin was introduced by
L. D. Puzikov, R. M. Ryndin, and Ya. A. Smorodinsky in 1957.

Observables expressed in CGLN amplitudes

$$\sigma_0 = \mathrm{Re}\{F_1^*F_1 + F_2^*F_2 + \sin^2\theta\,(F_3^*F_3/2 + F_4^*F_4/2 + F_2^*F_3 + F_1^*F_4 + \cos\theta\, F_3^*F_4) - 2\cos\theta\, F_1^*F_2\}\,\rho$$

$$\hat{T} = \sin\theta\,\mathrm{Im}\{F_1^*F_3 - F_2^*F_4 + \cos\theta\,(F_1^*F_4 - F_2^*F_3) - \sin^2\theta\, F_3^*F_4\}\,\rho$$

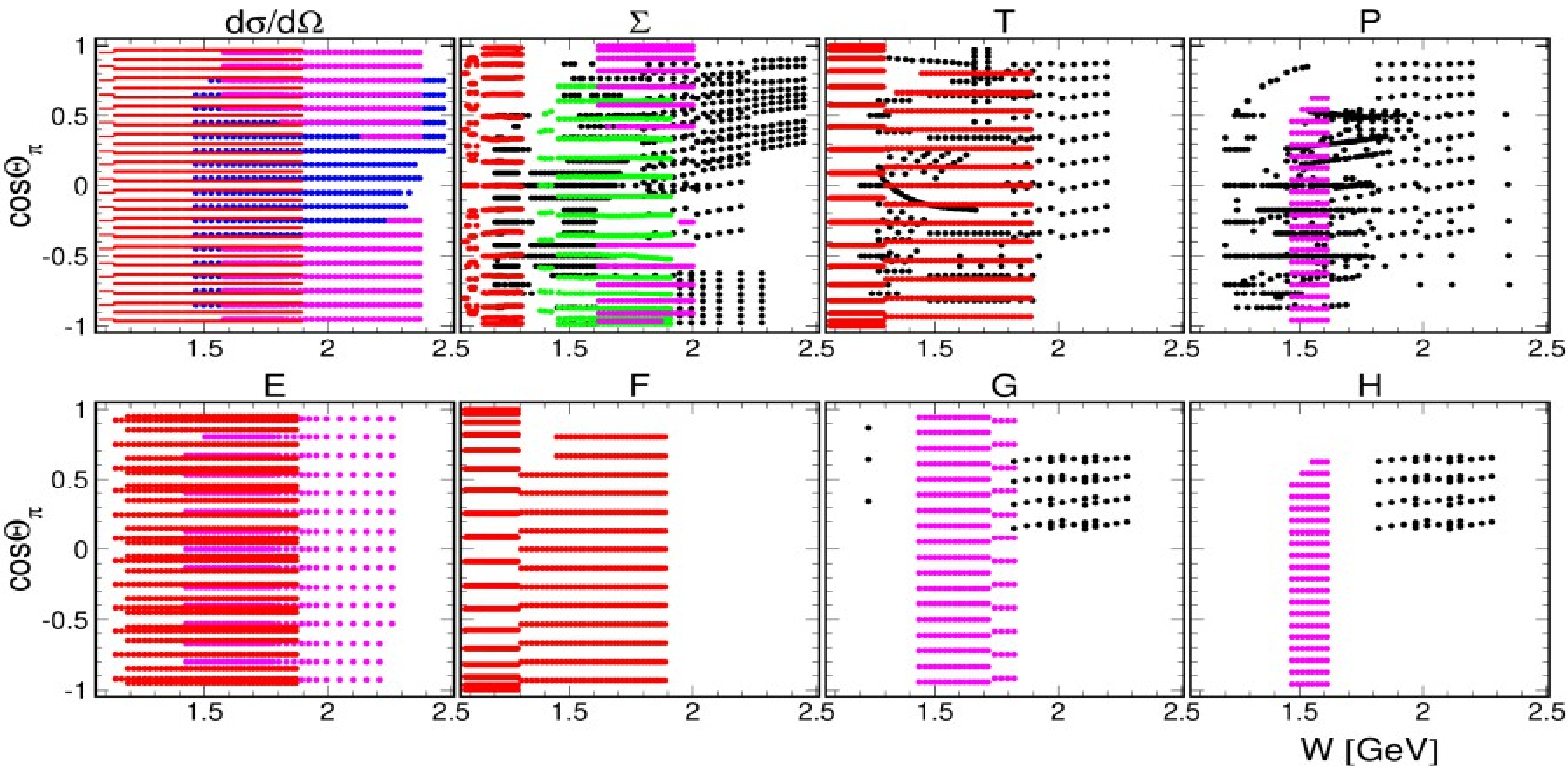
$$\hat{F} = \sin\theta\,\mathrm{Re}\{F_1^*F_3 - F_2^*F_4 - \cos\theta\,(F_2^*F_3 - F_1^*F_4)\}\,\rho$$

where $\hat{T} = T\,\sigma_0$ e.t.c. and $\rho = q/k$

Complete experiment

Data base for $\gamma p \to \pi^0 p$

The biggest data set exist for this reaction:
200 publications with experimental results for 10 observables.
For dσ/dΩ in resonance region used only latest data from A2MAMI and CLAS Collaborations

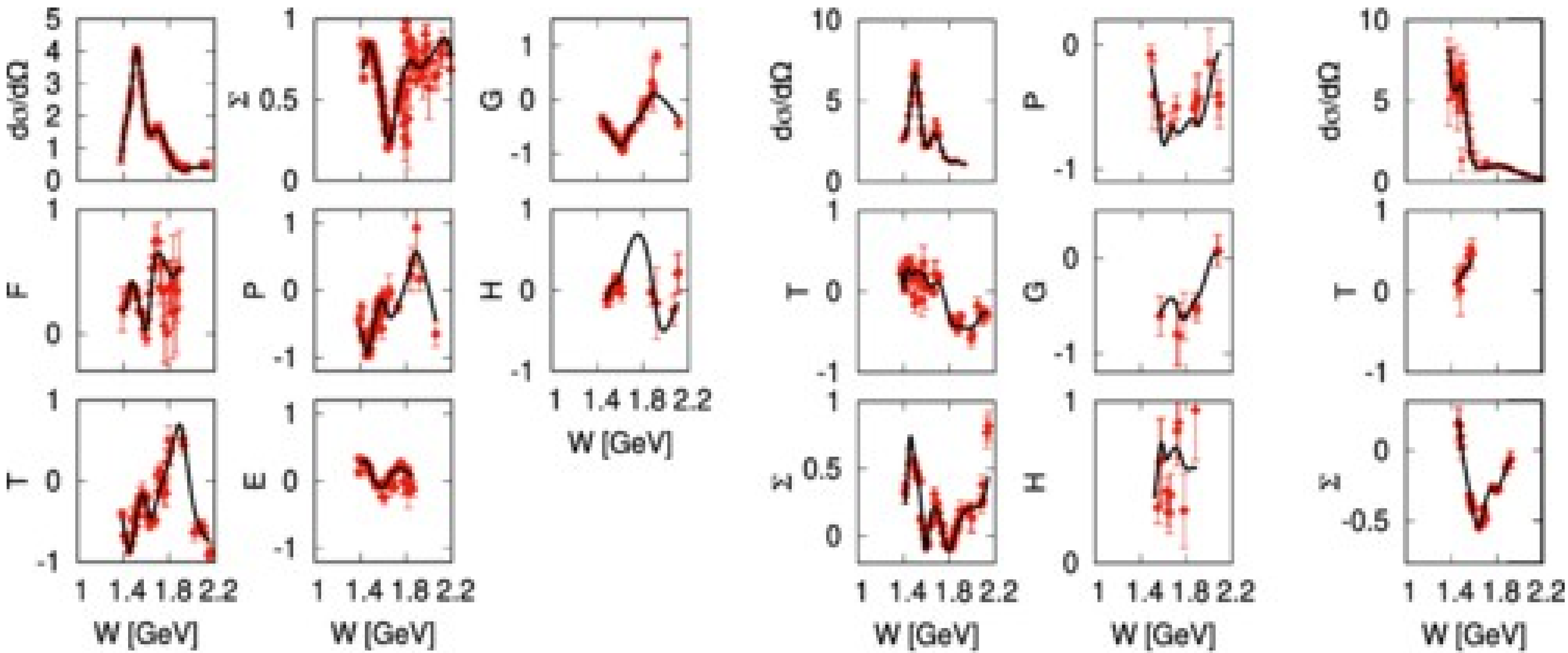


A2MAMI (red), CB/ELSA (magenta), CLAS (blue), GRAAL (green).
Black points correspond to the old data (before 2000).

Complete experiment

MTZ Collaboration
H. Osmanović, M. Hadžimehmedović, R. Omerović, J. Stahov,
V. Kashevarov, M. Ostrck, L. Tiator, Phys.Rev.C 104 (2021)

$\gamma\, p \to \pi^0\, p$ | $\gamma\, p \to \pi^+\, n$ | $\gamma\, n \to \pi^-\, p$



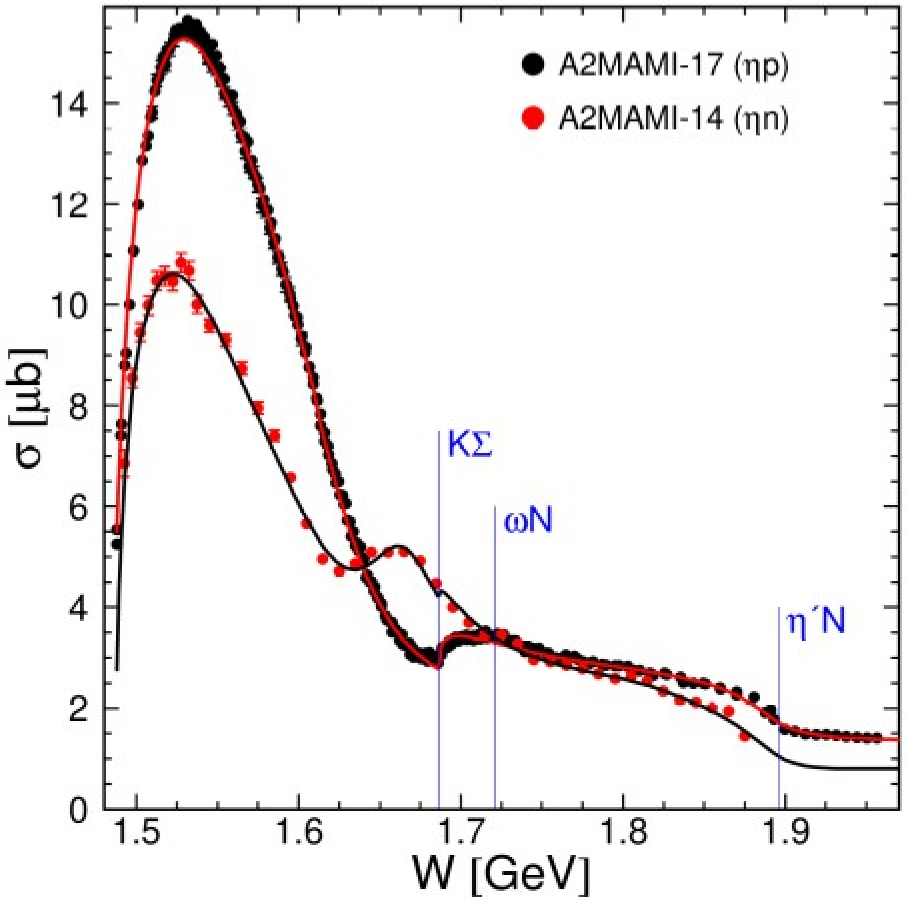
(a) (b) (c)

Search for exotic states

Pentaquarks

Narrow structure at W = 1670 wit width 30 MeV was firstly interpreted as pentaquark

$\gamma N \rightarrow \eta N$



EtaMAID2018 explains narrow bump in (η n) and dip in (η p) channels without pentaquark:

the first is a result of interference of a few resonances, and the second is a threshold effect due to opening KΣ decay channel of $N(1650)1/2^-$ resonance.

.

Data: A2MAMI-17

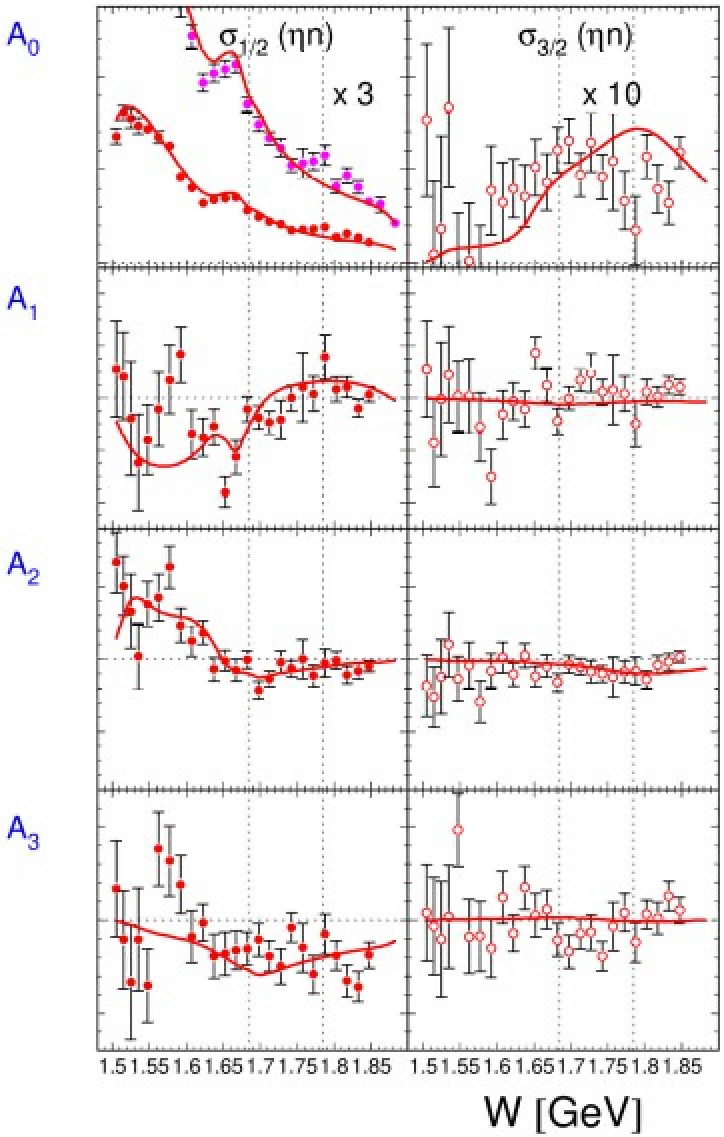
V.L.Kashevarov et al, PRL, **118** , 212001 (2017)

Lines: EtaMAID-2018, full solution for γp (red) and γn (black) channels.

Search for exotic states

Pentaquarks

Second narrow resonance in γ n → η n?



1. Narrow structure at W=1680 appears only in $\sigma_{1/2}$ and is thus related to S_{11} and/or P_{11} (in good agreement with our solution)

2. The second narrow structure at W=1726 MeV (second vertical line) is discused in V. Kuznetsov et al, JETP Lett. 105 (2017) 625. One of explanation is ωn production cusp.

Data: A2MAMI-17

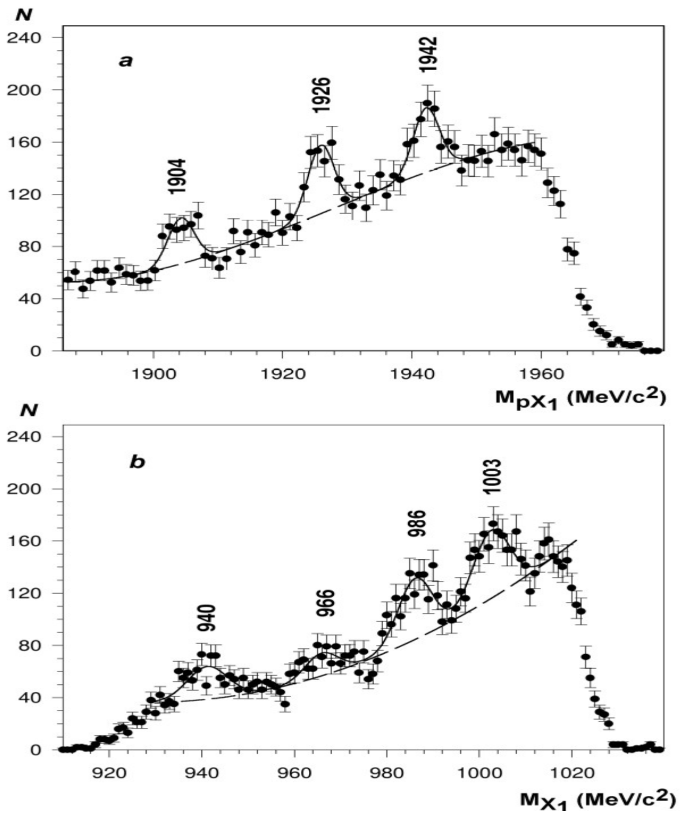
L. Witthauer et al, Phys. Rev. C**95** (2017) 055201

Red lines: EtaMAID2018, full solution

Search for exotic states

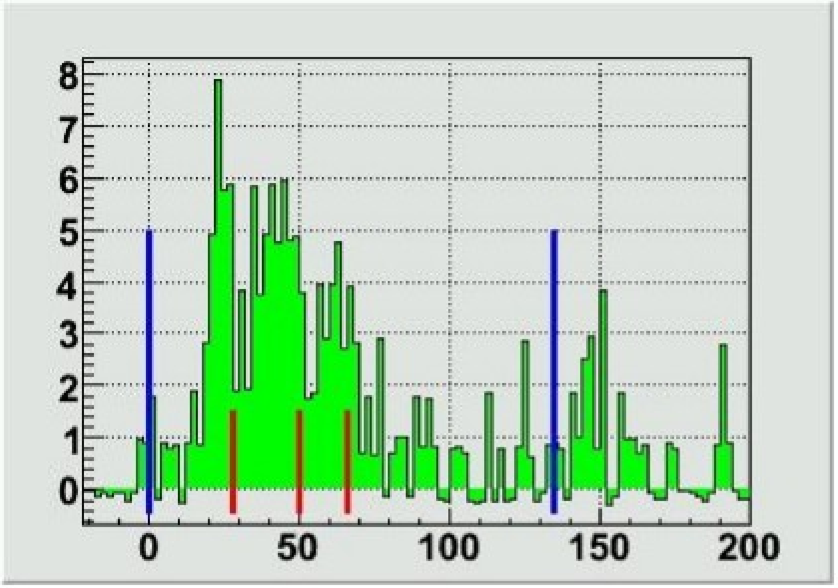
Dibaryons

pd → p+pX1 and pd → p + dX



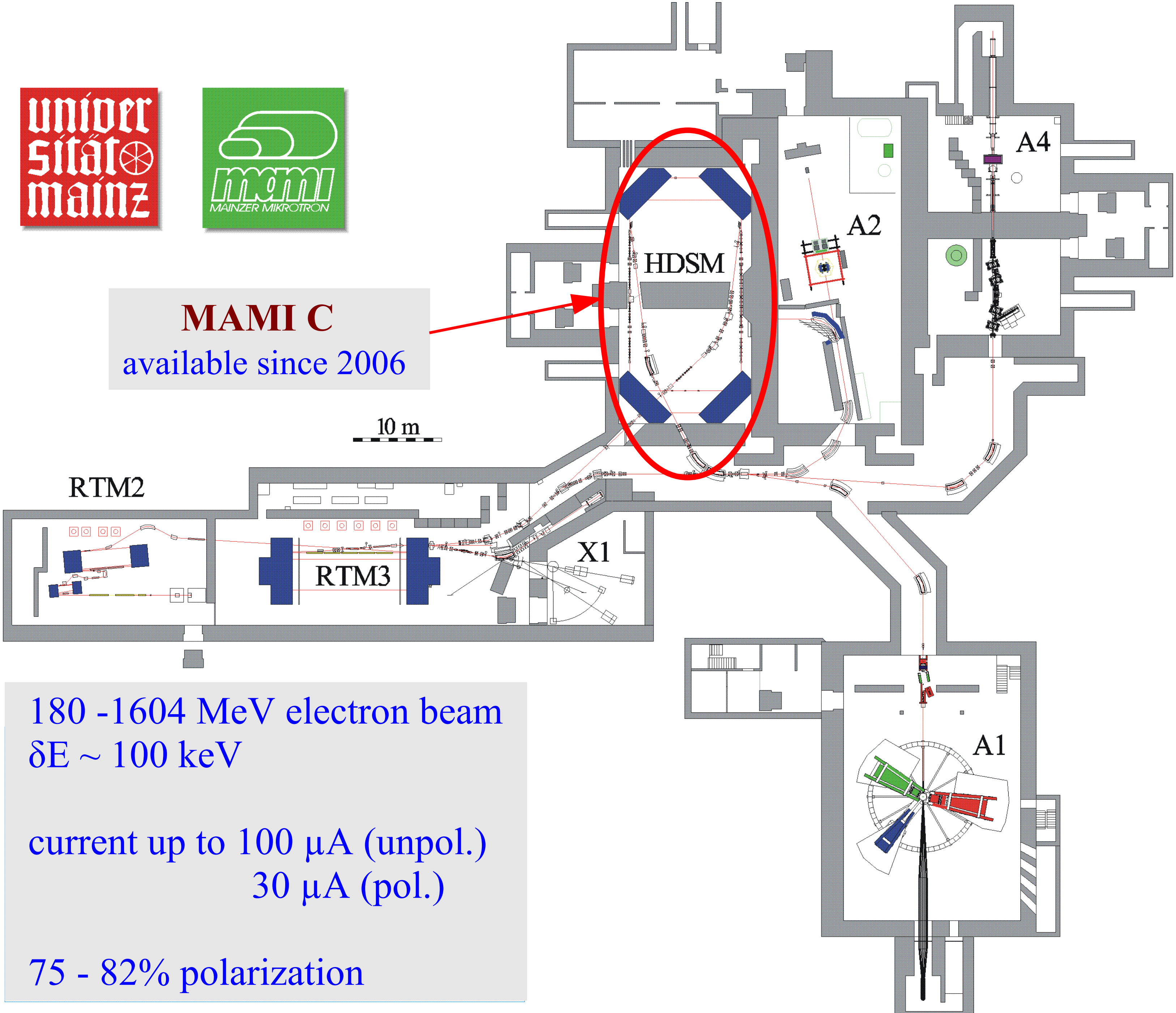
M_deuteron = 1875.6 MeV
M_dibaryon = 1904, 1926, 1942 MeV
M_dibaryon - M_deuteron = 28.4, 50.4, 66.4 MeV
red lines exactly correspond to these values!

γ d → π^0 D*



M_dibaryon - M_deuteron (MeV)

L.V. Fil'kov, V.L. Kashevarov, E.S. Konobeevski, M.V. Mordovskoy, S.I. Potashev et al.
Phys.Rev.C 61 (2000) 044004.
Eur.Phys.J.A 12 (2001) 369-374



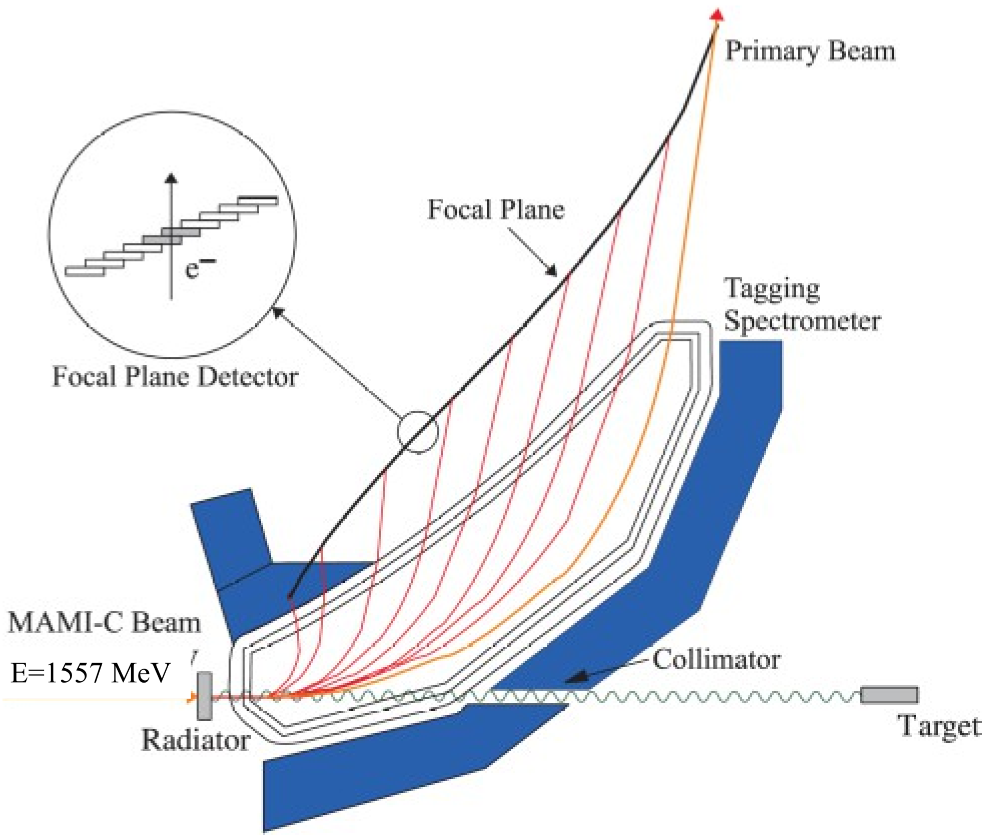
MAMI C
available since 2006

180 -1604 MeV electron beam
$\delta E \sim 100$ keV

current up to 100 μA (unpol.)
30 μA (pol.)

75 - 82% polarization

Experimental apparatus: photon beam



Tagged photon beam

- unpolarized
- circular polarization
- linear polarization

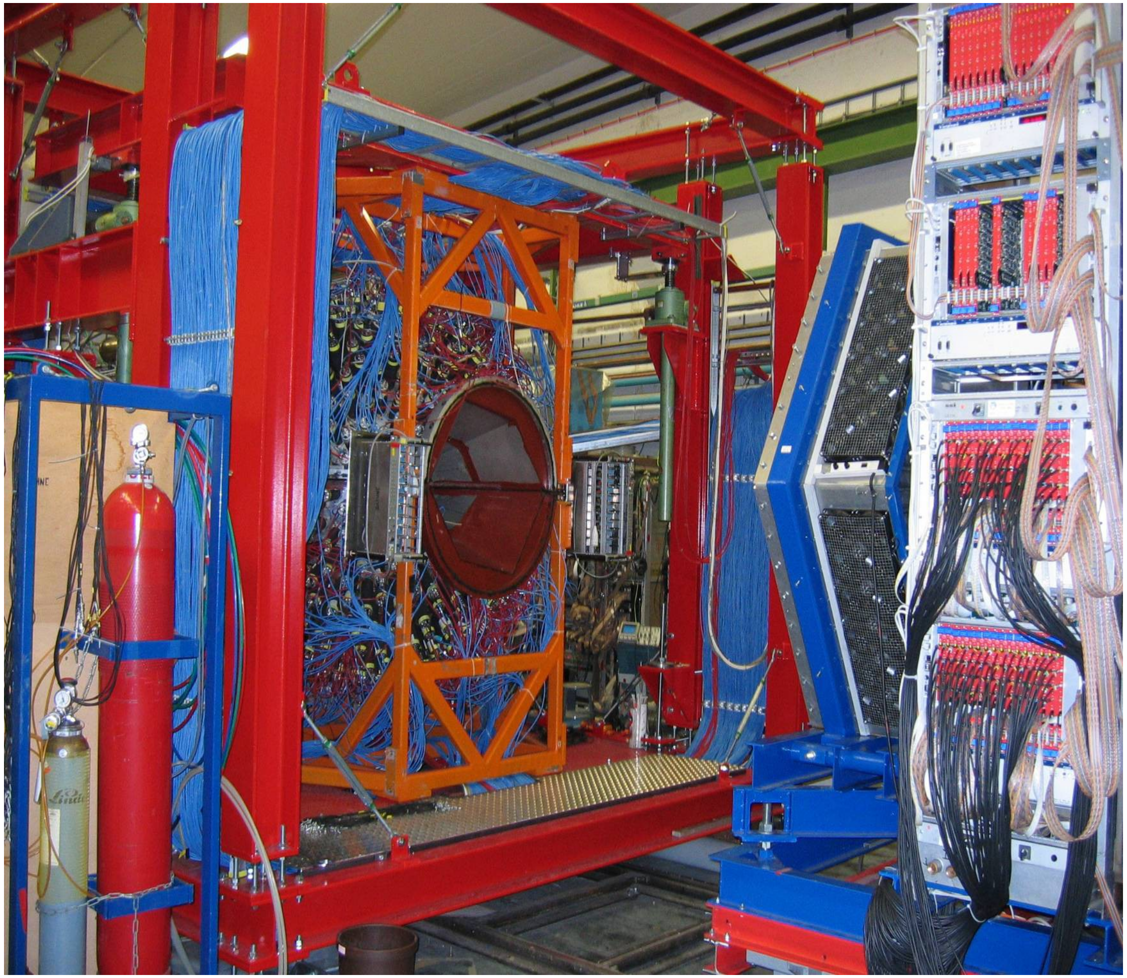
The Glasgow photon tagging spectrometer

352 channels

2 – 5 MeV energy resolution

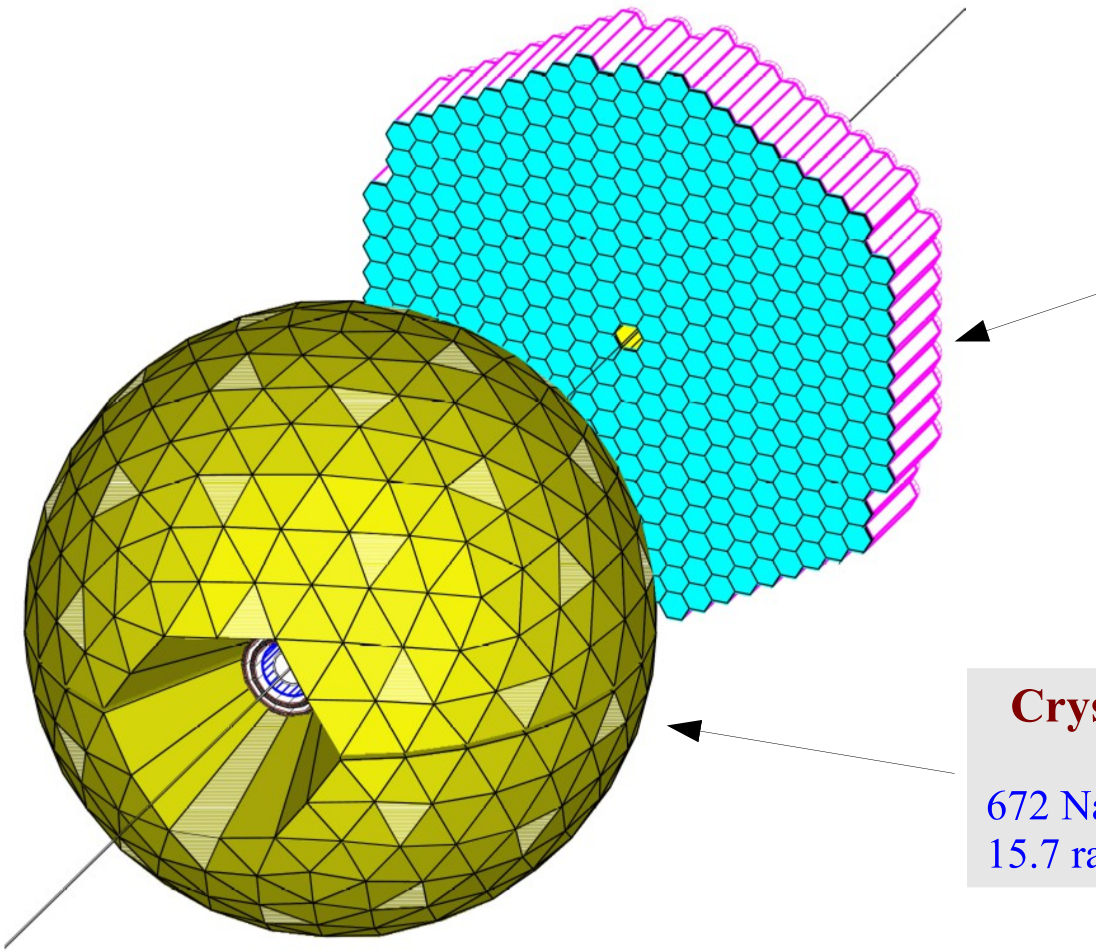
Experimental apparatus: detector system

4π photon spectrometer (97% of 4π)
Detection of neutrons and charged particles is also possible at restricted energy regions



Crystal Ball:
$20^o - 160^o$ (94%)
and
TAPS : $1^o - 20^o$ (3%)

Experimental apparatus: detector system



TAPS (Giessen, Basel)

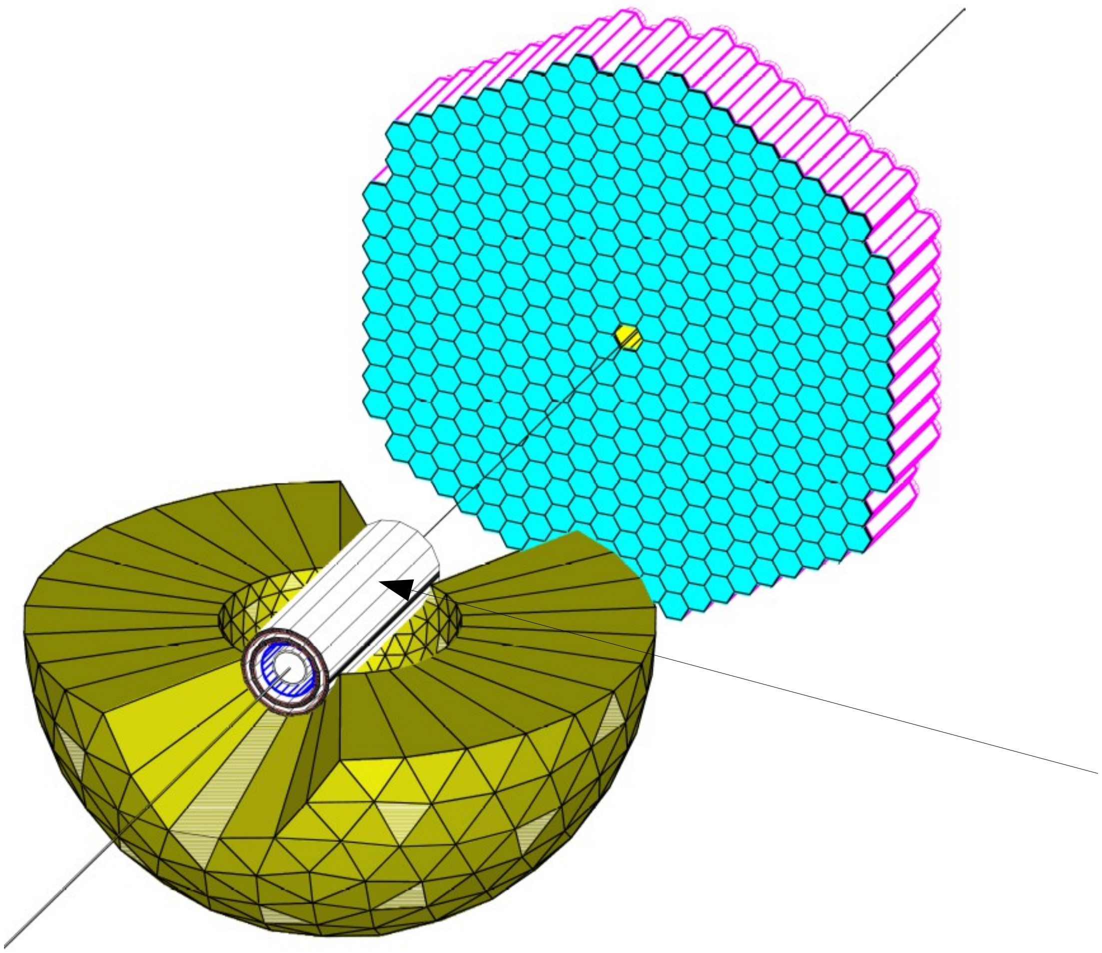
366 BaF_2 crystals
12 radiation lengths

and 5mm plastic scintilator
in front of each module (**VETO**)

Crystal Ball (UCLA, JWU, Mainz)

672 NaI(Tl) crystals
15.7 radiation lengths

Experimental apparatus: detector system

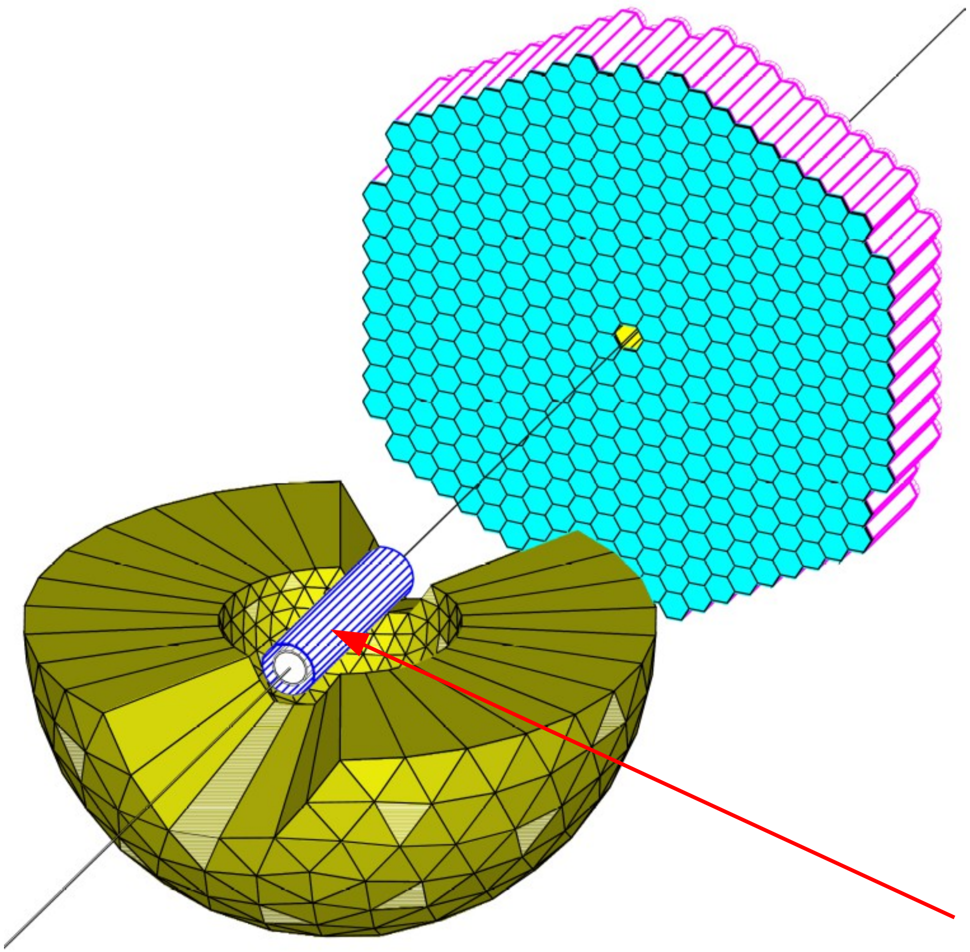


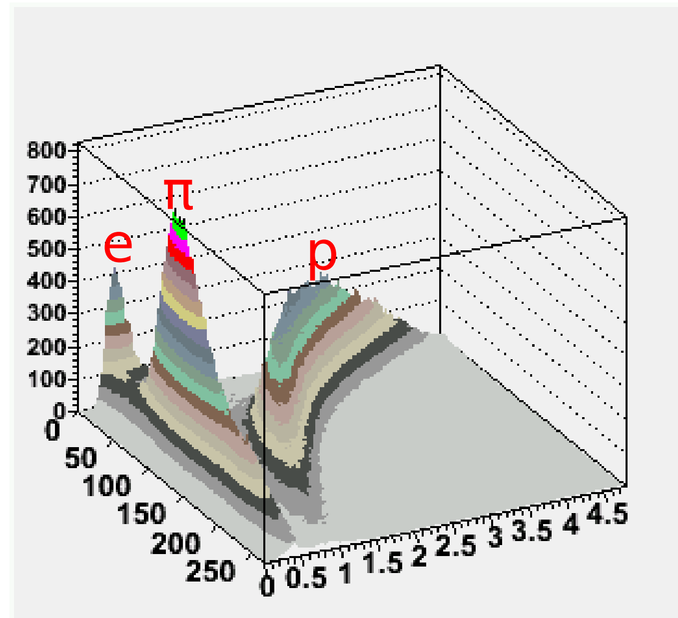
MWPC (Pavia)

2 cylindrical chambers

Vertex reconstruction:
- target position correction (z),
- beam position control (x,y),
- improve angular resolution.

Experimental apparatus: detector system





ΔE (PID) vs $E_{cluster}$ (CB) , MeV

PID (Edinburg)

barrel of 24 2-mm-thick plastic scintilator strips;

VETO detector for photons in CB;

ΔE for charged particle identification in CB.

Experimental apparatus: target

Frozen Spin Target
(Mainz, Dubna)
available since 05.2010

Butanol or D-Butanol;

3He/4He dilution refrigerator;

Superconducting holding magnet;

Longitudinal or transverse polarizations are possible;

Maximal polarization
for protons ~90%,
for deuterons ~75%;

Relaxation time ~2000 hours

A2 publications with JINR
(N. Borisov, A. Lazarev, A. Neganov, Yu. A. Usov. I. Gorodnov, A.Dolzhikov)

1. Measurement of the Transverse Target and Beam-Target Asymmetriesin η Meson Photoproduction at MAMI,
   PRL 113 (2014) 102001.
2. First measurement of target and beam-target asymmetries in the ɣ p → pi0 eta p reaction,
   PRC 91 (2015) 055208.
3. Measurements of Double-Polarized Compton Scattering Asymmetries
   and Extraction of the Proton Spin Polarizabilities,
   PRL 114 (2015) 112501.
4. Measurement of pi0 photoproduction on the proton at MAMI C,
   PRC 92 (2015) 024617.
5. Threshold π0 photoproduction on transverse polarised protons at MAMI,
   PLB 750 (2015) 252.
6. T and F asymmetries in pi0 photoproduction on the proton
   PRC 93 (2016) 055209.
7. Photon asymmetry measurements of ɣp → pi0 p for Eg=320-650 MeV,
   EPJA 52 (2016) 333.
8. Insight into the Narrow Structure in η Photoproduction on the Neutron from Helicity-Dependent Cross Sections,
   PRL 117 (2016) 132502.
9. Measurement of the omega→e+e- and eta→e+e-g Dalitz decays with the A2 setup at MAMI,
   PRC 95 (2017) 035208.
10. Measurement of the π0→e+e−γ Dalitz decay at the Mainz Microtron,
    PRC 95 (2017) 025202.
11. First measurement of the polarization observable E and helicity-dependent
    cross sections in single π0 photoproduction from quasi-free nucleons,
    PLB 770 (2017) 523.
12. Helicity-dependent cross sections and double-polarization observable
    E in η photoproduction from quasifree protons and neutrons,
    PRC 95 (2017) 055201.

A2 publications with JINR (continue)

13. Determination of the scalar polarizabilities of the proton using beam asym-metry $\mathbf{E_3}$ in Compton scattering.
    Eur. Phys. J. **A 53** No. 2 (2017) 14.
14. Study of η and η' photoproduction at MAMI.
    Phys. Rev. Lett. **118** Iss. 21, 212001 (2017).
15. High-statistics measurement of the η→3π0 decay at the Mainz Microtron.
    Phys. Rev. **C 97** No. 6, 065203 (2018).
16. Measurement of the decay *eta' -> pi0 pi0 eta* at MAMI.
    Phys. Rev. **D 98** (2018) 012001.
17. Photoproduction of pi0 Mesons off Protons and Neutrons in the Second and Third Nucleon Resonance Region.
    Phys. Rev. **C 97** (2018) 065205.
18. First measurement of helicity-dependent cross sections in $\pi^0\eta$ photo-production from quasi-free nucleons.
    Phys. Lett. **B 786** (2018) 305.
19. Experimental study of the γp→K0Σ+, γn→K0Λ, and γn→K0Σ0 reactions at the Mainz Microtron.
    Eur .Phys. J. A 55 (2019) 11, 202.
20. Deuteron photodisintegration by polarized photons in the region of the d*(2380).
    Phys. Lett. **B 789** (2019) 7.
21. Cross section for γn → π0n at the Mainz A2 experiment.
    Phys. Rev. C 100 (2019) 6, 065205.
22. Measurement of the beam-helicity asymmetry in photoproduction of π0η pairs on carbon, aluminum, and lead.
    Phys. Lett. B 802 (2020) 135243.
23. Signatures of the d*(2380) Hexaquark in d(γ,pn).
    Phys. Rev. Lett. 124 (2020) 13, 132001.
25. Extracting the spin polarizabilities of the proton by measurement of Compton double-polarization observables.
    Phys. Rev. C 102 (2020) 3, 035205.

.

26. M. Dieterle at.al., Helicity-Dependent Cross Sections for the Photoproduction of π0 Pairs from Nucleons. *Phys. Rev. Lett.* 125 (2020) 6, 062001.

27. Single π0 production off neutrons bound in deuteron with linearly polarized photons. *Eur. Phys. J. A* 57 (2021) 6, 205.

28. Measuegnetic Polarizabilities of the Proton. *Phys. Rev. Lett.* 128 (2022) 13, 132503.

29. First Measurement Using Elliptically Polarized Photons of the Double-Polarization Observable E for γp→pπ0 and γp→nπ+
Phys.Rev.Lett. 132 (2024) 12, 121902

CBELSA|TAPS publication with JINR

N. Borisov, A. Lazarev, A. Neganov, Yu. A. Usov.
I. Gorodnov, A.Dolzhikov, A. Fedorov

N. Jermann et al. Measurement of polarization observables T, P, and H in pi0 and η photoproduction off quasi-free nucleons.
Eur.Phys.J.A 59 (2023) 10, 232

A2 Collaboration at MAMI

F. Afzal,[1, ∗] K. Spieker,[1] P. Hurck,[2] S. Abt,[3] P. Achenbach,[4] P. Adlarson,[4] Z. Ahmed,[5] C.S. Akondi,[7] J.R.M.,Annand,[2] H.J. Arends,[4] M. Bashkanov,[6] R. Beck,[1] M. Biroth,[4] N. Borisov,[8] A. Braghieri,[9] W.J. Briscoe,[10] F.Cividini,[4] C. Collicott,[11] S. Costanza,[12, 9] A. Denig,[4] M. Dieterle,[3] E.J. Downie,[10] P. Drexler,[4, 13] S. Fegan,[6] S. Gardner,[2] D. Ghosal,[3] D.I. Glazier,[2] I. Gorodnov,[8] W. Gradl,[4] D. Gurevich,[15] L. Heijkenskj¨old,[4] D. Hornidge,[16] G.M. Huber,[5] V.L. Kashevarov,[4, 8] S.J.D. Kay,[6] M. Korolija,[17] B. Krusche,[3] A. Lazarev,[8] K. Livingston,[2] S. Lutterer,[3] I.J.D. MacGregor,[2] R.G. Macrae,[2] D.M. Manley,[7] P.P. Martel,[4, 16] R. Miskimen,[18] M. Mocanu,[6]
E. Mornacchi,[4] C. Mullen,[2] A. Neganov,[8] A. Neiser,[4] M. Oberle,[3] M. Ostrick,[4] P.B. Otte,[4] D. Paudyal,[5]P. Pedroni,[9] A. Powell,[2] G. Reicherz,[14] T. Rostomyan,[3] C. Sfienti,[4] V. Sokhoyan,[4] O. Steffen,[4] I.I. Strakovsky,[10] T. Strub,[3]I. Supek,[17] A. Thiel,[1] M. Thiel,[4] A. Thomas,[4] Yu.A. Usov,[8] S. Wagner,[4] N.K. Walford,[3] D.P. Watts,[6] D. Werthm¨uller,[6] J. Wettig,[4] L. Witthauer,[3] M. Wolfes,[4] and N. Zachariou[6]

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5 4University of Regina, Regina, SK S4S0A2 Canada
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7 Kent State University, Kent, Ohio 44242, USA
8 Joint Institute for Nuclear Research, 141980 Dubna, Russia
9 INFN Sezione di Pavia, I-27100 Pavia, Pavia, Italy
10 Center for Nuclear Studies, The George Washington University, Washington, USA
11 Department of Astronomy and Physics, Saint Mary's University, E4L1E6 Halifax, Canada
12 Dipartimento di Fisica, Universit`a di Pavia, I-27100 Pavia, Italy
13 II. Physikalisches Institut, University of Giessen, D-35392 Giessen, Germany
14 Institut f˙ur Experimentalphysik, Ruhr Universit¨at, 44780 Bochum, Germany
15 Institute for Nuclear Research, RU-125047 Moscow, Russia
16 Mount Allison University, Sackville, New Brunswick E4L1E6, Canada
17 Rudjer Boskovic Institute, HR-10000 Zagreb, Croatia
18 University of Massachusetts, Amherst, Massachusetts 01003, USA

Future plans: MESA

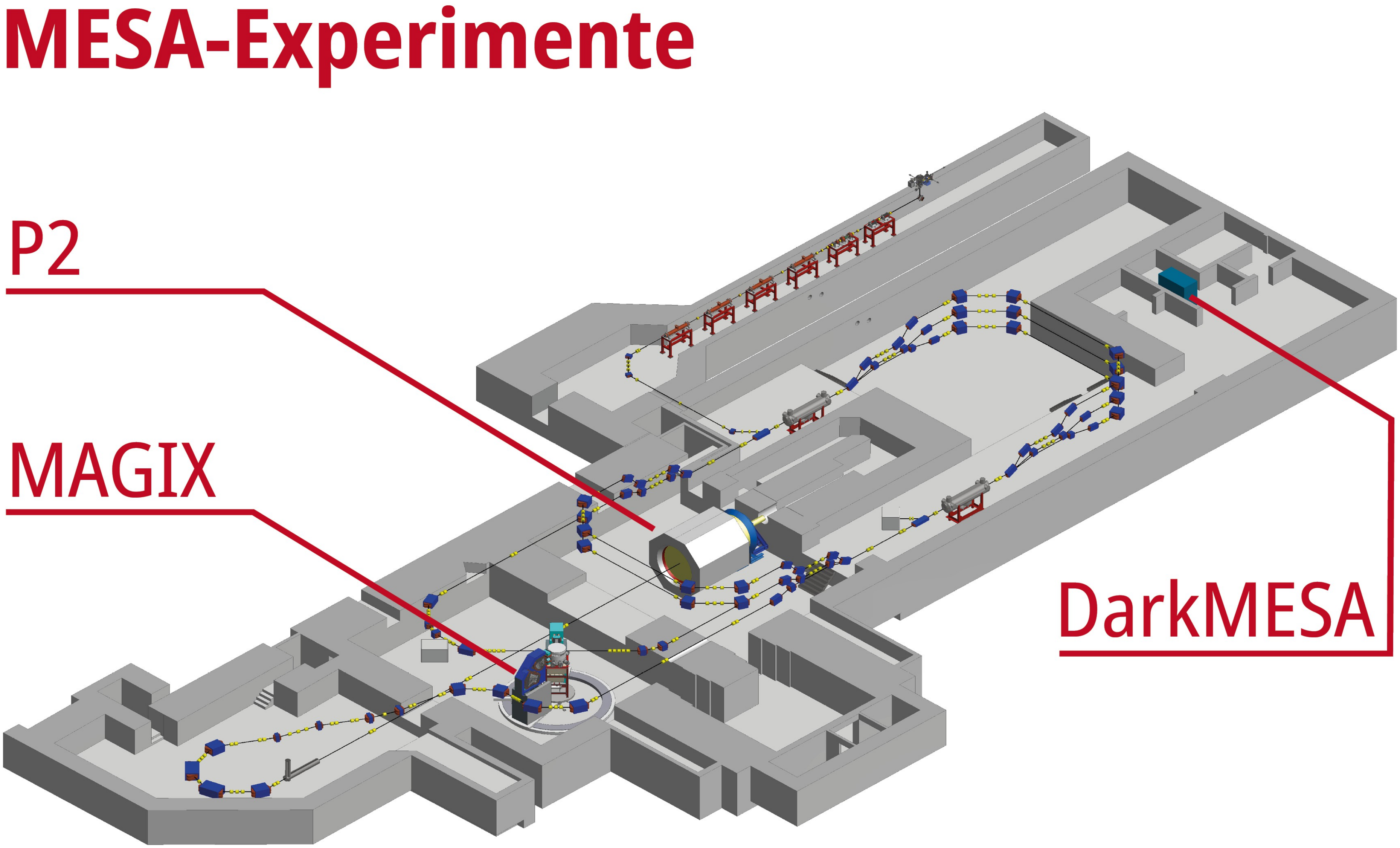
New accelerator in Mainz:
MESA (Mainz Energy-recovering Superconducting Accelerator)
Energy of electronos – 155 MeV
Extremly high intensity – 150 μA

P2 – high precission measurement of the weak mixing angle.
By measuring the parity violating asymmetry in elastic e
electron-proton scattering

Cosine of this angle – ratio of masses of W and Z bosons
Standard Model does not predict this value,
But predictions of Standard Model depend on it !.

The polarization of the electron beam in this case must be determined with an uncertainty of 0.5% by Moeller polarimeter, **the most important element of which is a 3He/4He Dilution cryostat. DLNP JINR.**

I. Gorodnov, A. Dolzhikov.
Dilution Refrigerator for Hydro-Møller Polarimeter @ MESA P2 Experiment
Phys.Part.Nucl.Lett. 20 (2023) 5, 1183.


MESA-Experimente
P2
MAGIX
DarkMESA

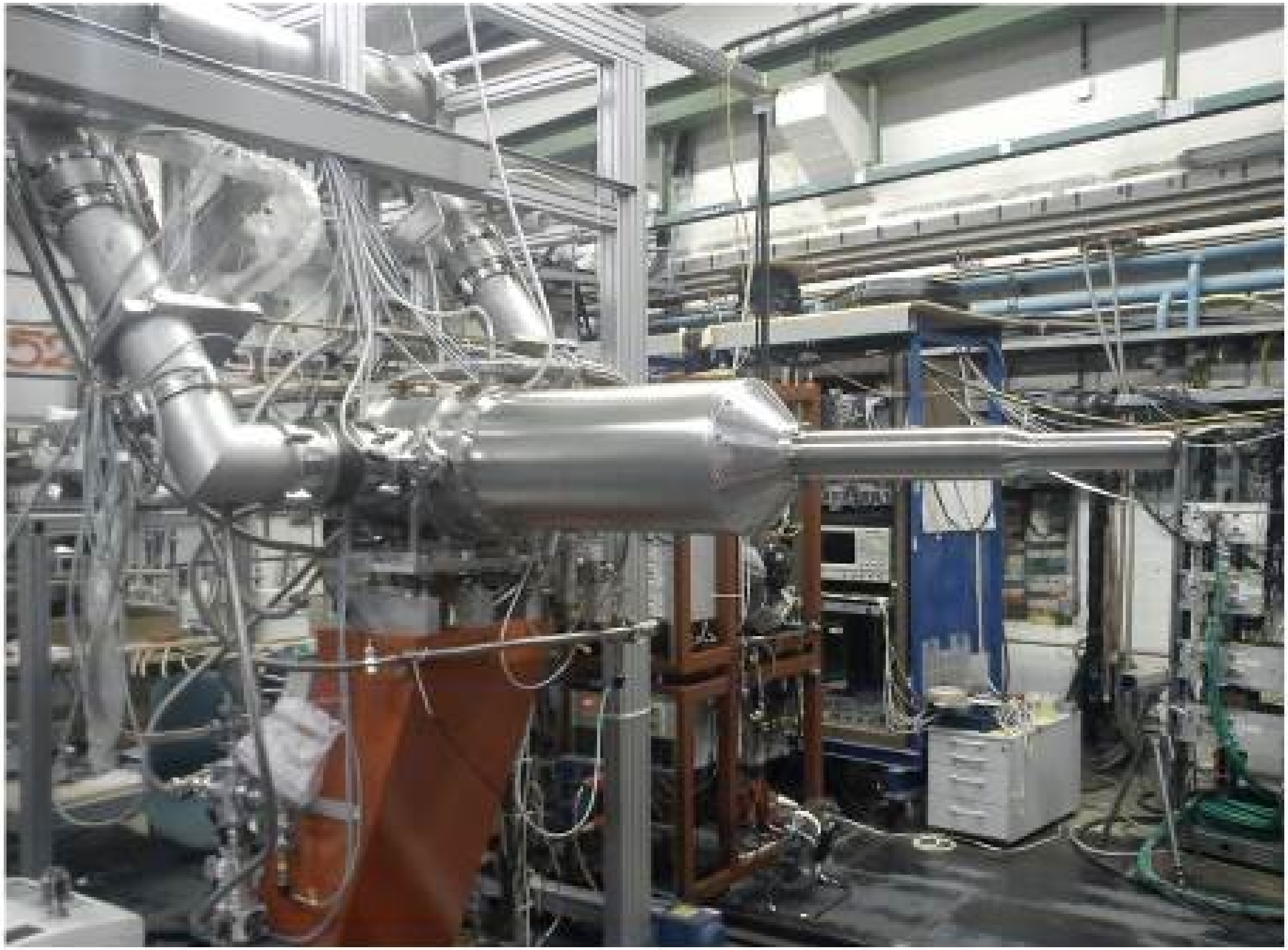
Summary

- A2 Collaboration performs a broad program of the polarization experiments since 2010. Additional runs are needed to increase statistics.
- Experiments are carried out with high intensity unpolarized, linearly or circularly polarized photons and transversely or longitudinally polarized nucleons.
- Scientific program includes the study of the spectrum and properties of baryon resonances and the internal structure of the nucleons.
- Measurements was continued in 2017 in Bonn together with CBELSA/TAPS Collaboration.
- The most measurements requare Dubna cryostat for polarized targets.
- Future plan: new cryostat for P2 experiment at MESA.

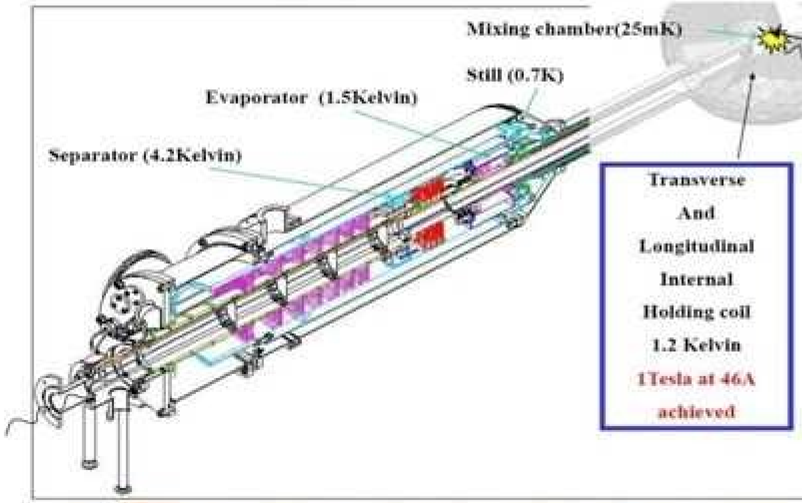
A2 Collaboration at MAMI

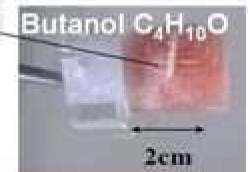
25th International A2 Collaboration Meeting, Dubna, Russia, September 2014

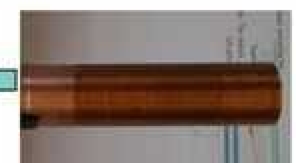
Cryostat of the Frozen spin target

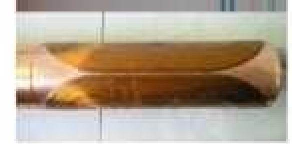


Frozen spin polarized target (Dubna, Moscow, Mainz)

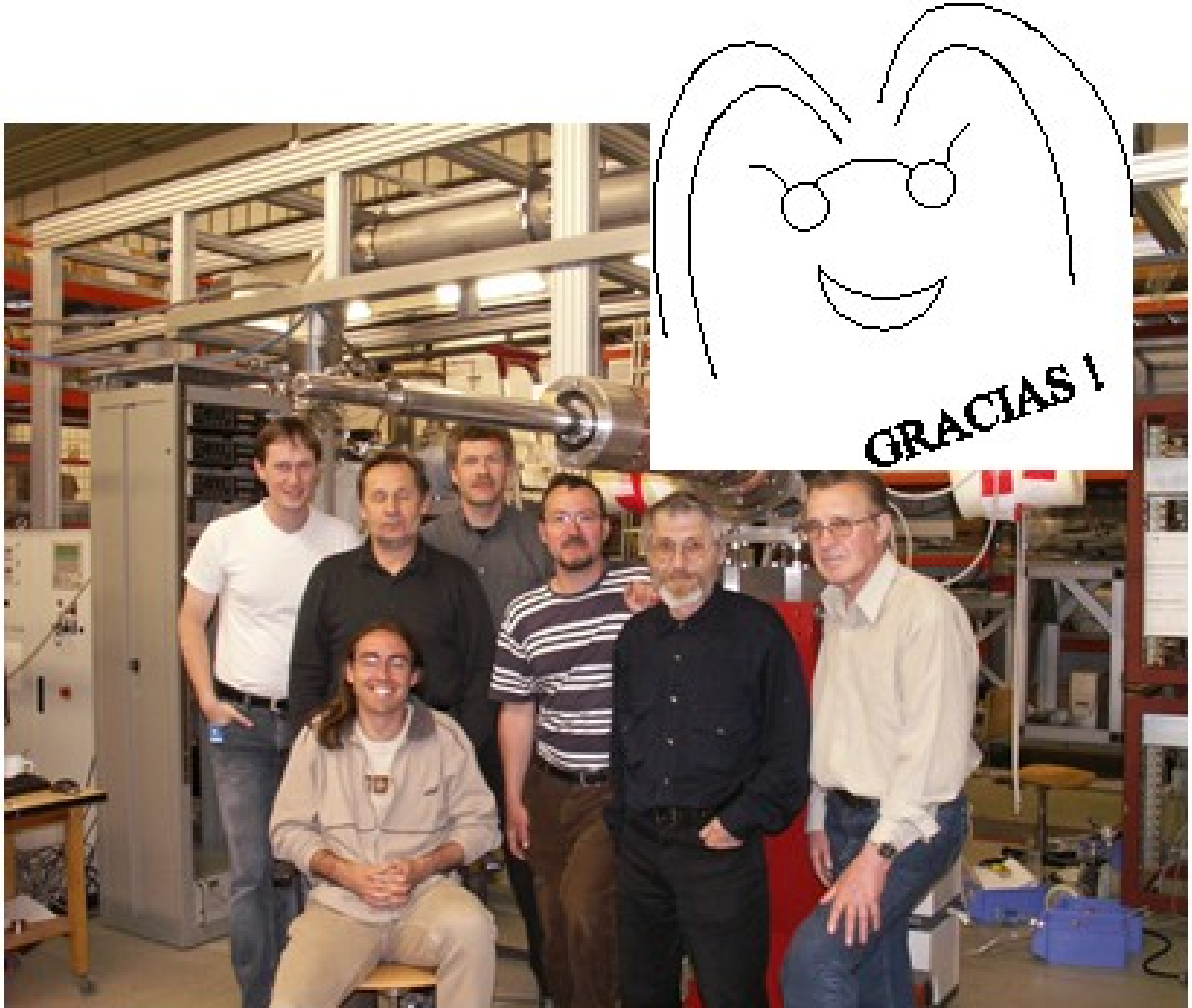




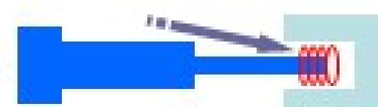


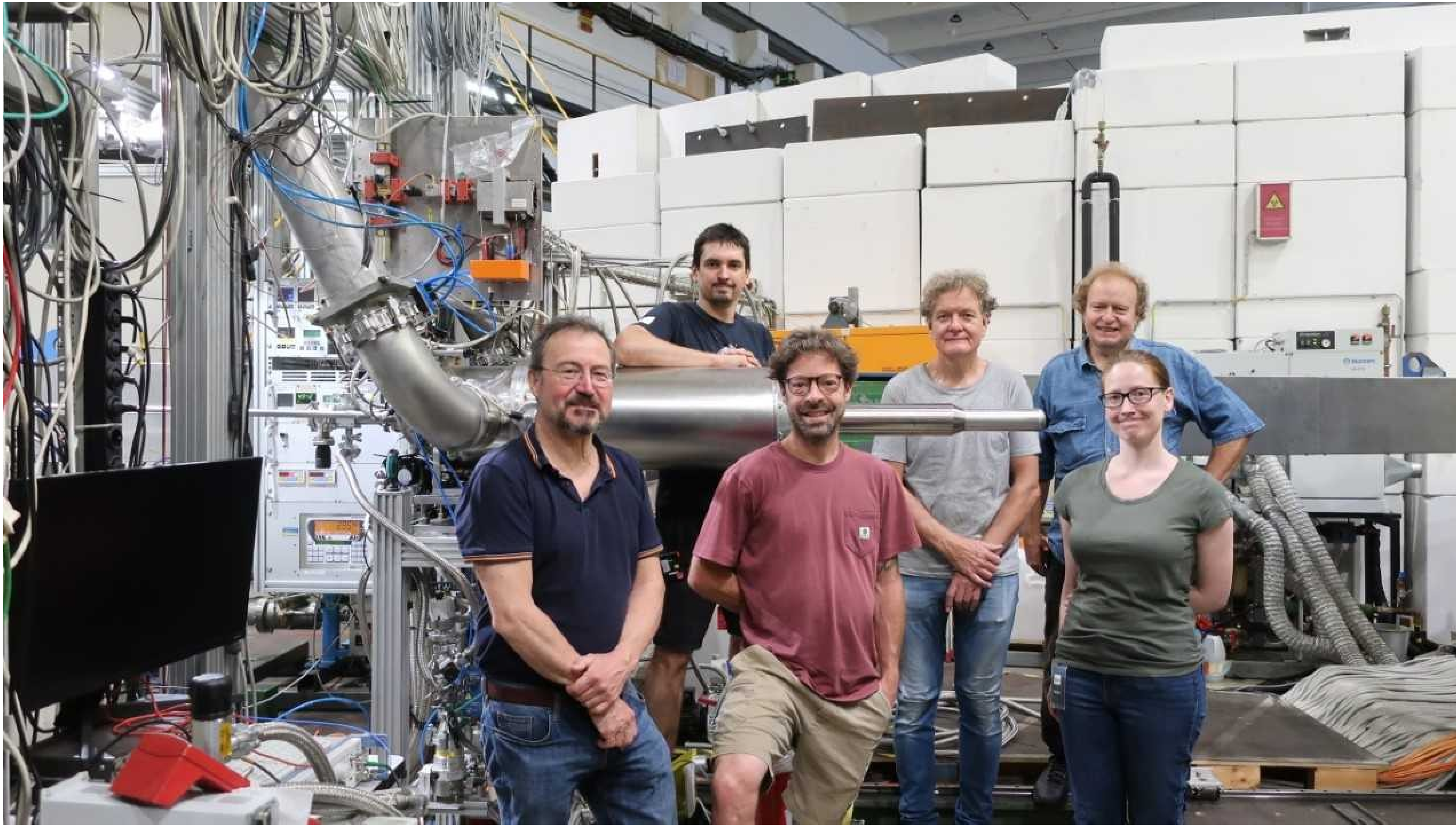


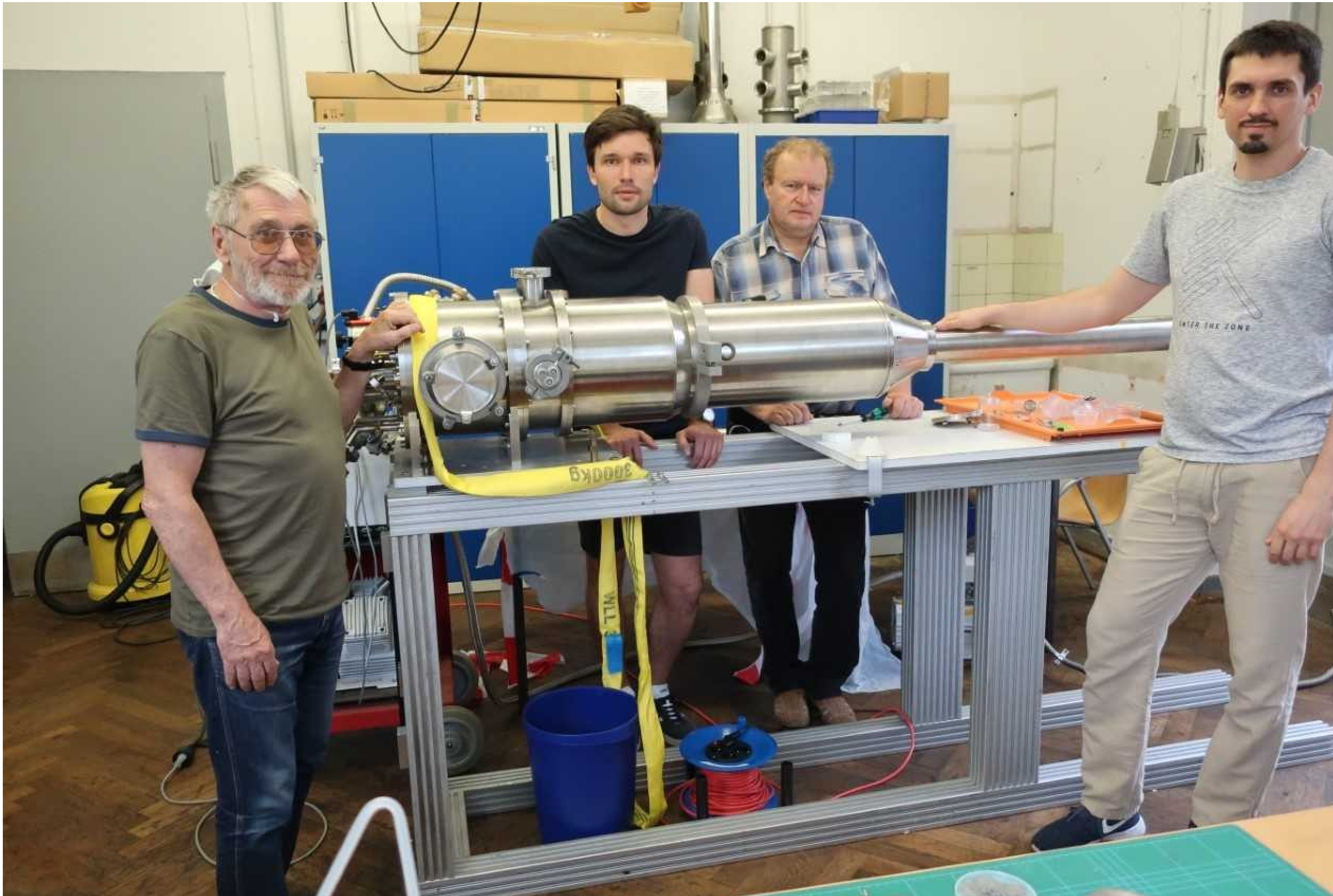
Target Group

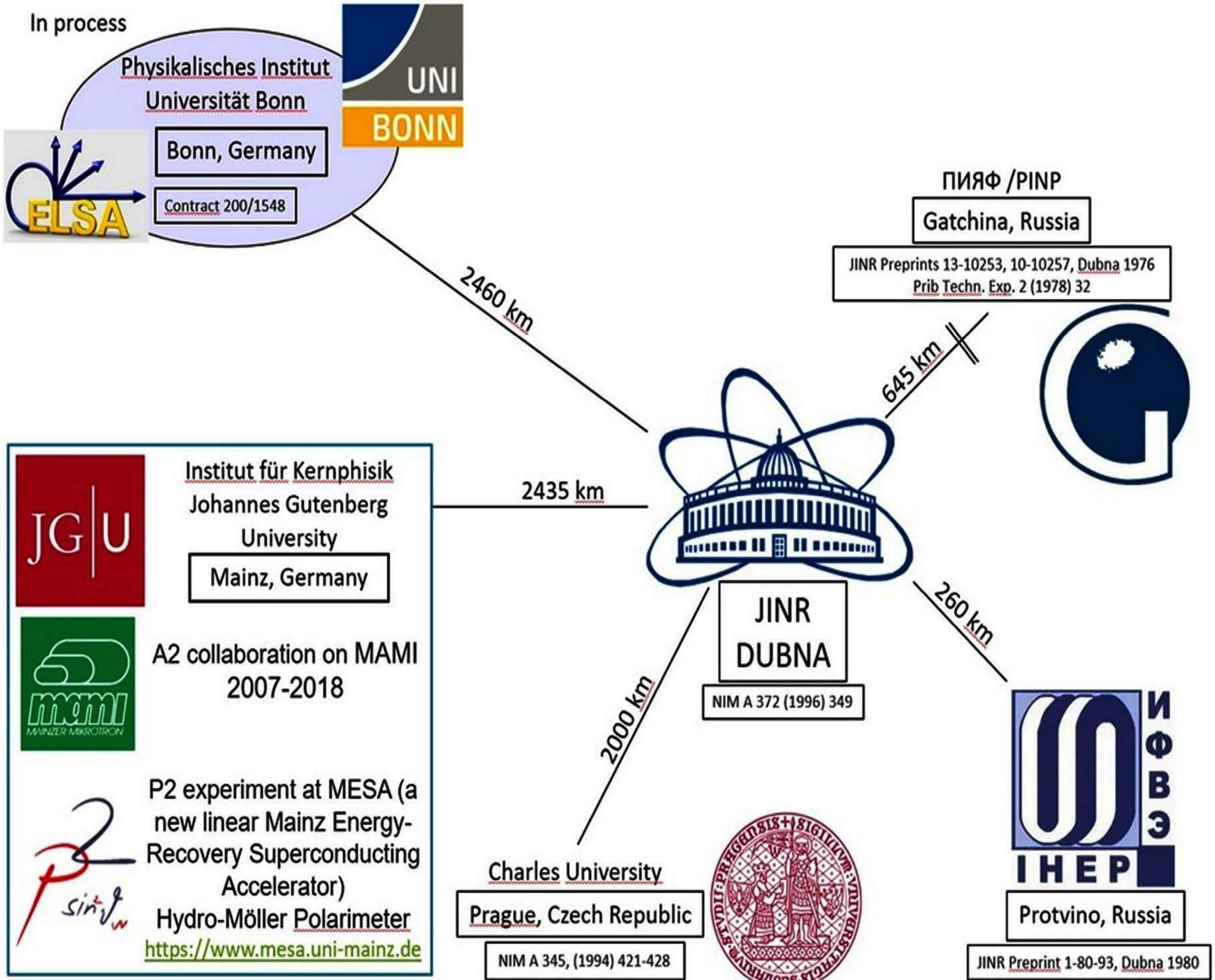


Andreas Thomas
Mauricio Martínez
Garik Palagasvilik
Oleksandr Kostivov
Sasha Neganov
Nicolai Borinov
Yuri Usov
+
Rudolf Kondradiev
Milorad Korolija
Henry Ortega
Patricia Aguar
+
Bonn & Bochum
+
Joachim, Mohamed,
Vicenta, Noelia, Dave,
Steven, Chris...








In process
Physikalisches Institut
Universität Bonn
UNI
BONN
Bonn, Germany
ELSA
Contract 200/1548
2460 km
ПИЯФ /PINP
Gatchina, Russia
JINR Preprints 13-10253, 10-10257, Dubna 1976
Prib Techn. Exp. 2 (1978) 32
645 km
Institut für Kernphisik
Johannes Gutenberg
University
JG|U
Mainz, Germany
2435 km
A2 collaboration on MAMI
2007-2018
mami
MAINZER MIKROTRON
P2 experiment at MESA (a new linear Mainz Energy-Recovery Superconducting Accelerator)
Hydro-Möller Polarimeter
https://www.mesa.uni-mainz.de
JINR
DUBNA
NIM A 372 (1996) 349
260 km
2000 km
Charles University
Prague, Czech Republic
NIM A 345, (1994) 421-428
ИФВЭ
IHEP
Protvino, Russia
JINR Preprint 1-80-93, Dubna 1980

В этом смысле характерны высказывания известных теоретиков, например англичанина Эллиота Лидера: « Спин в экспериментах убил больше теорий, чем любой другой физический параметр» (Elliot Leader. Spin in Particle Physics, Cambridge U. Press (2001)) или американца Джеймса Бьёркена: «Поляризационные данные часто были кладбищем модных теорий. Если бы теоретики были в силах, в целях самозащиты им стоило бы вообще запретить такие измерения» (J.D.Bjorken. Proc. Adv. Workshop on QCD Hadronic Processes, St. Croix, Virgin Islands, 1987). Сегодня нет теории, претендующей на полное описание всех наблюдаемых поляризационных эффектов в адронном секторе.