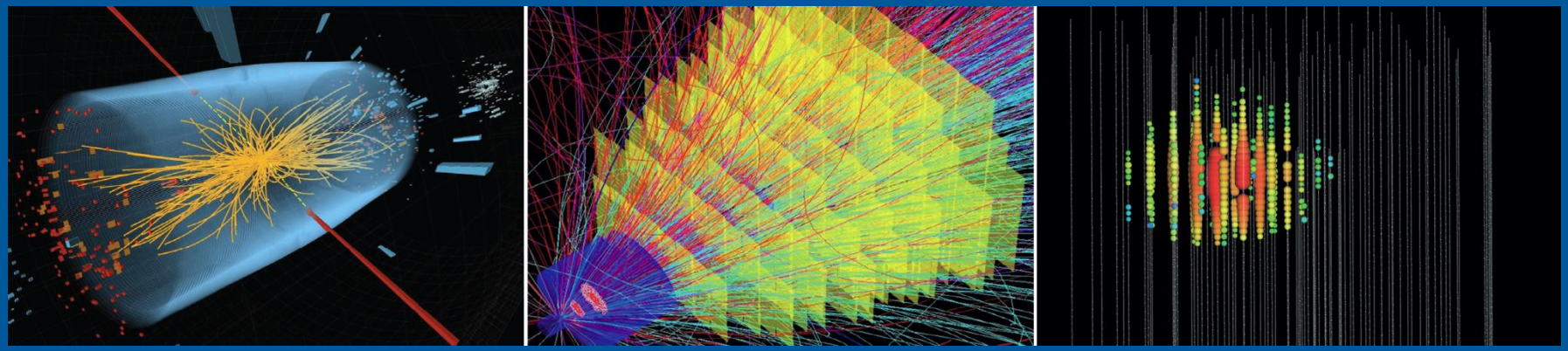
Matter and the Universe

HELMHOLTZ ASSOCIATION

COSY: Achievements and Ramp-up Towards FAIR



Frank Goldenbaum, IKP, FZ-Jülich, Germany

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NARODOWA STRATEGIA SPÓJNOŚCI

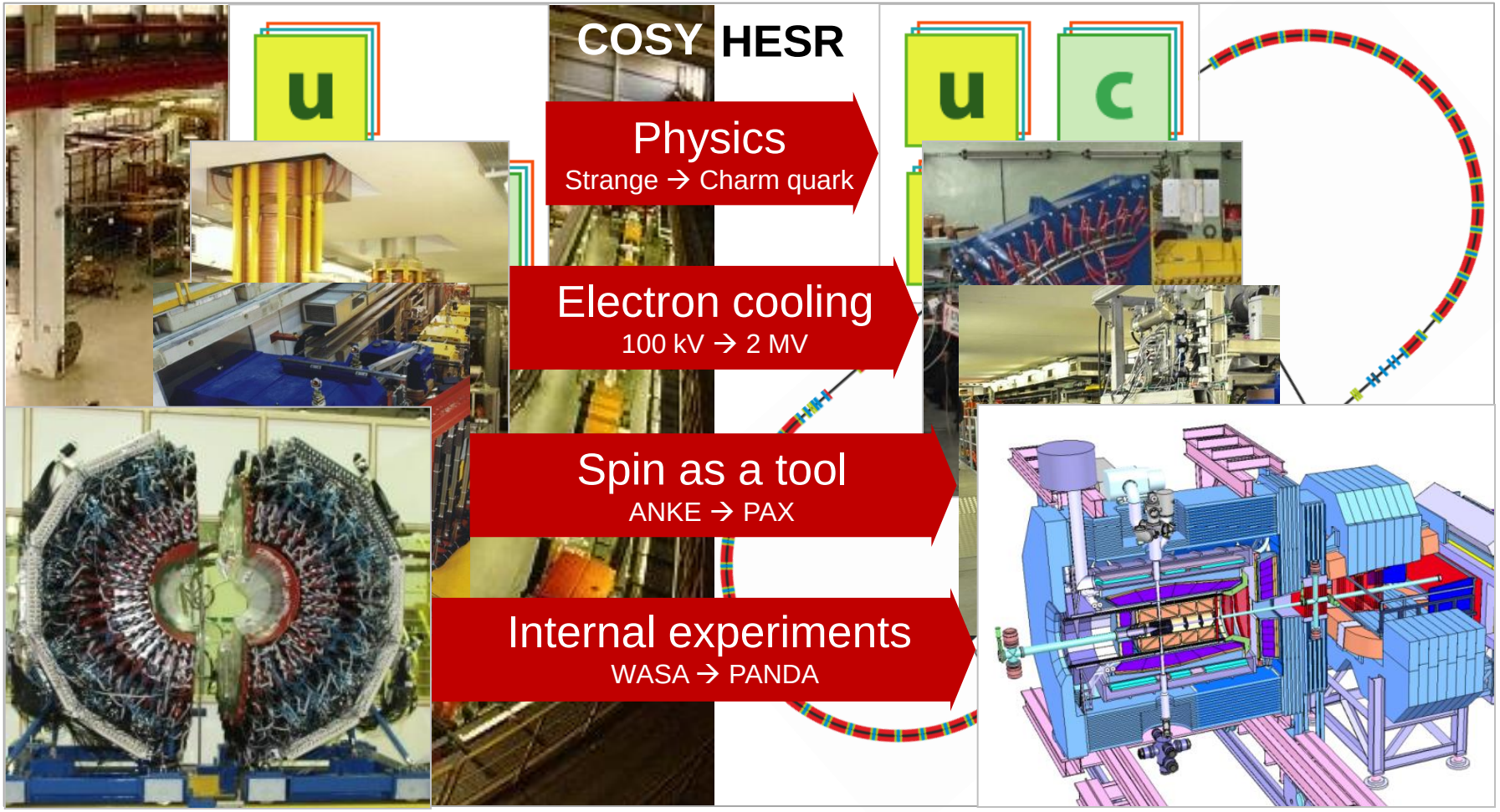
UNIWERSYTET JAGIELLOŃSKI W KRAKOWIE

FNP
Fundacja na rzecz Nauki Polskiej

UNIA EUROPEJSKA
EUROPEJSKI FUNDUSZ ROZWOJU REGIONALNEGO

INTERNATIONAL PHD PROJECTS IN APPLIED NUCLEAR PHYSICS AND INNOVATIVE TECHNOLOGIES
This project is supported by the Foundation for Polish Science – MPD program, co-financed by the European Union within the European Regional Development Fund

FZJ: from COSY to HESR at FAIR

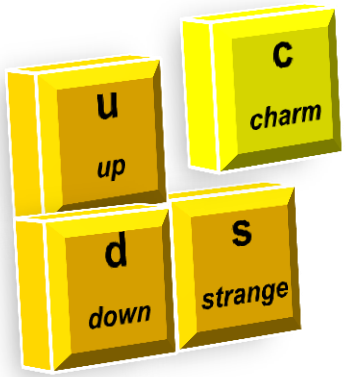


PoF 2: Hadron physics at COSY (ANKE, TOF, WASA and PAX)

PoF 3: COSY required as essential **test facility** – and **EDM machine**

Introduction: Physics Case and Tools

COSY: Non-perturbative QCD in the (u,d,s) sector



Structure of hadrons

nucleon, hyperons, mesons

Dynamics & interactions

nucleon-nucleon, meson-nucleon, hyperon-nucleon

meson-nucleus, medium effects

Symmetries and symmetry breaking

chiral symmetry

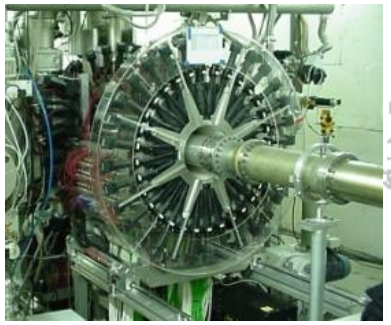
isospin & charge symmetry in reactions

discrete symmetries in meson decays

COSY (COoler SYnchrotron):

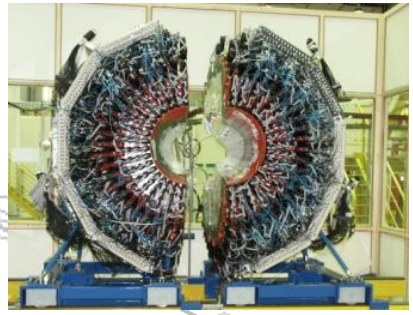
external and internal experiments, polarized beams & polarized targets

COSY Facility

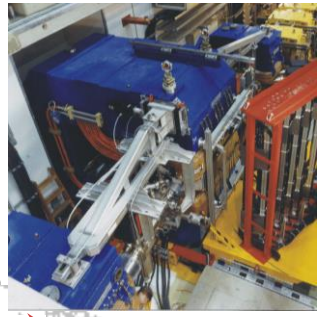


COSY

EDDA
(polarimeter)



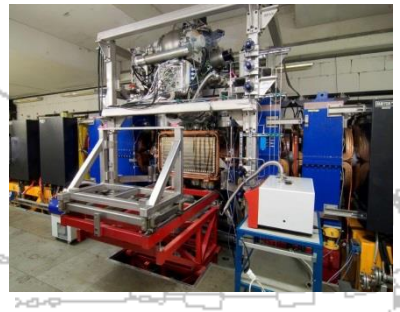
WASA



ANKE

TOF

PAX



COSY:

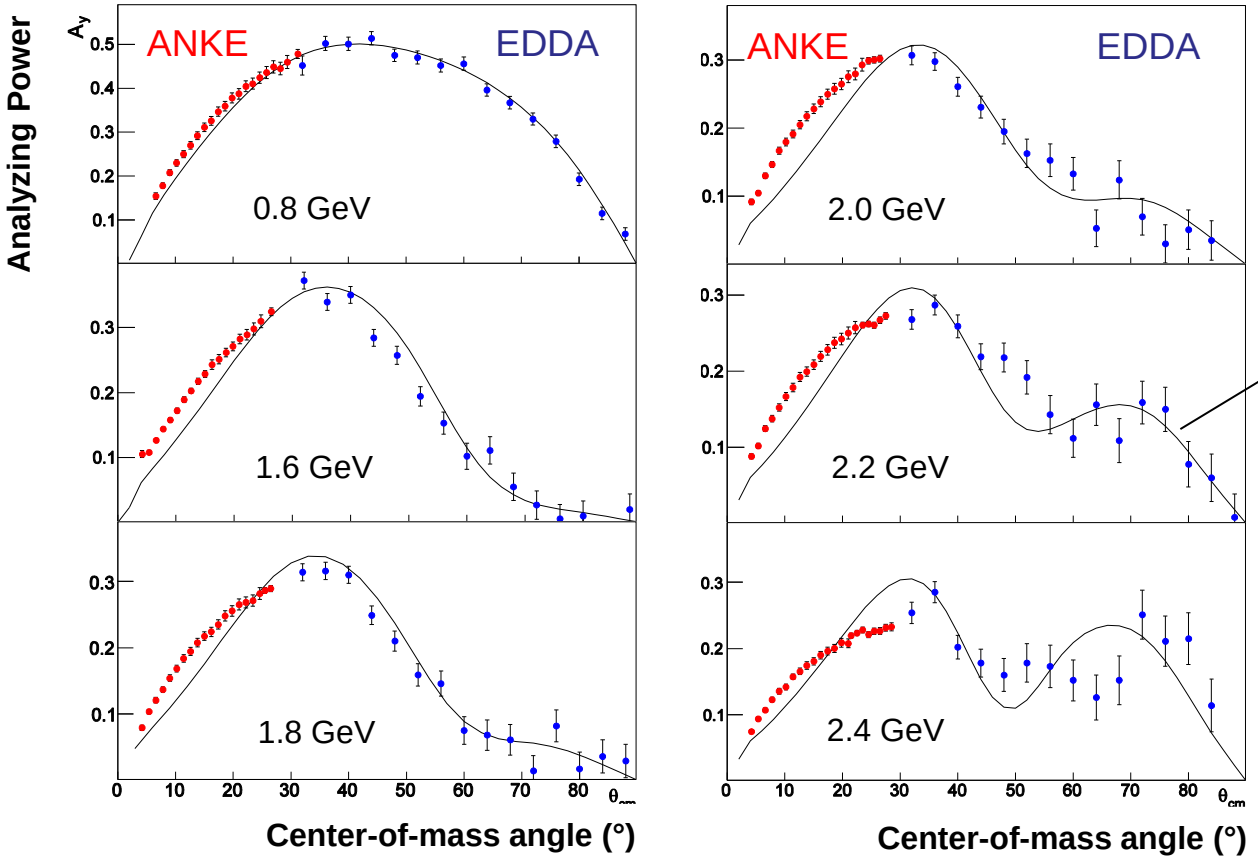
Circumference: 183 m
Beam momentum: 0.3 - 3.7 GeV/c
Electron and stochastic cooling
(Un-)polarized proton and deuteron beams

Detectors:

ANKE: magnetic spectrometer, polarized targets
PAX: polarized targets
TOF: time-of-flight spectrometer
WASA: electromagnetic calorimeter, pellet target

ANKE Result: Nucleon-Nucleon (NN) Scattering

Single polarized **pp** elastic scattering: analyzing power A_y

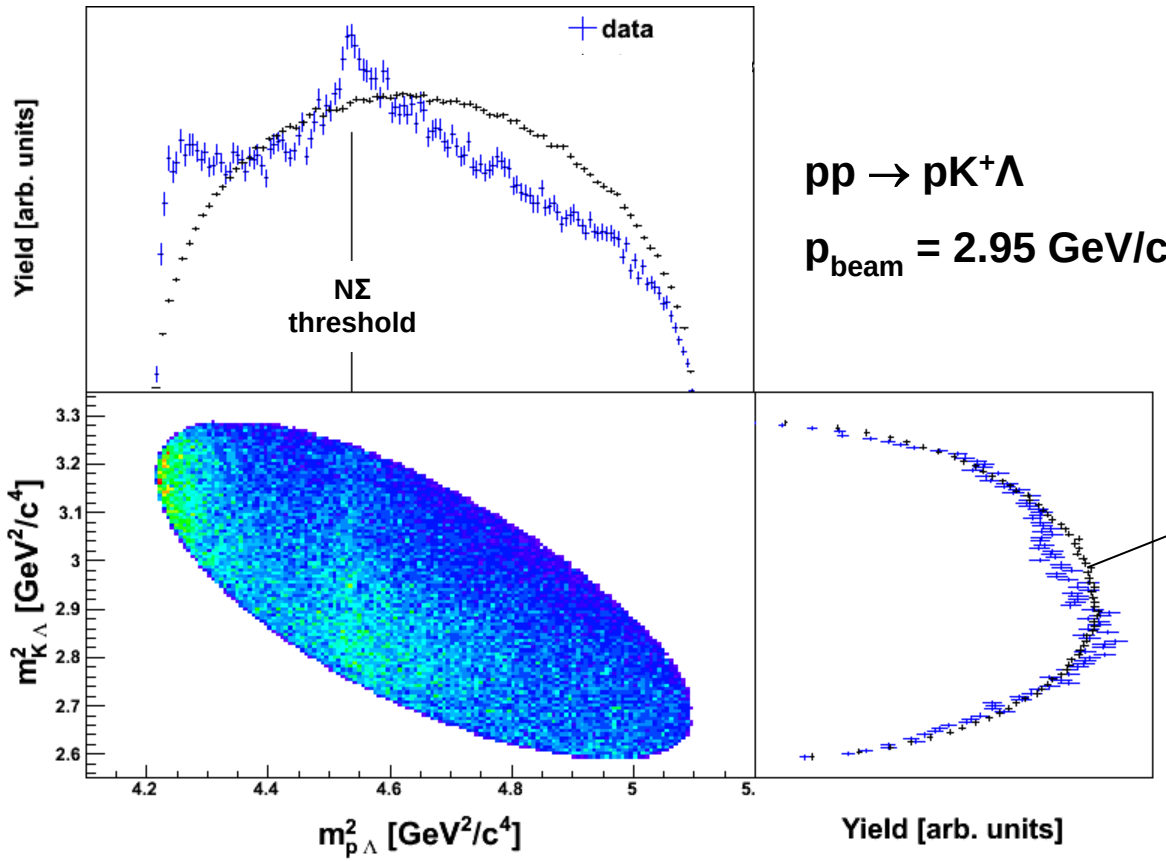


SAID (partial wave analysis) description of NN world data without new ANKE results

- **ANKE**: dedicated facility for forward region (5° – 30°); precision data
- Significant change in quantitative description of short-distance NN interaction
- Ongoing: double polarized measurements (np system)

TOF Result: Hyperon Production

Production mechanism (nucleon resonances, hyperon polarization)
Hyperon-nucleon interaction and (pΛ – NΣ) channel coupling



pp → pK⁺Λ

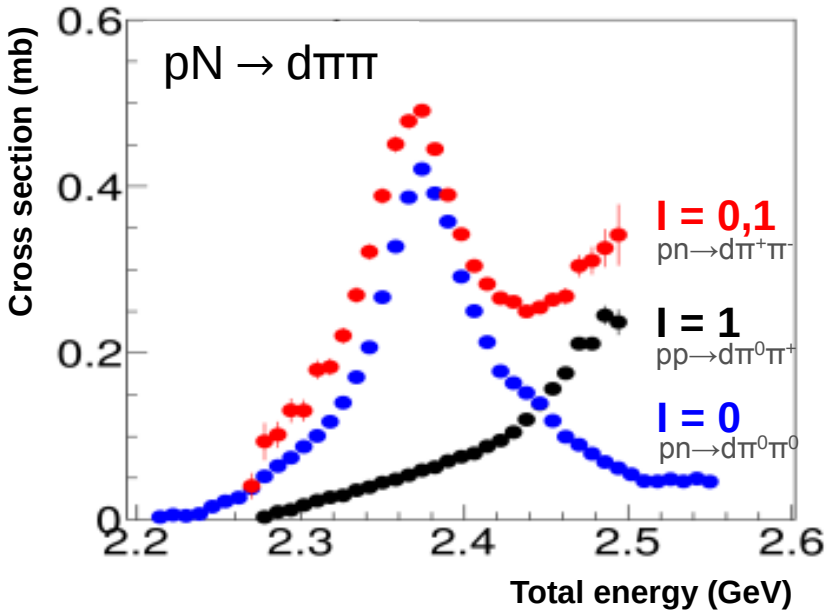
p_{beam} = 2.95 GeV/c

- **TOF**: provides full phase space coverage
- Impact on nuclear strangeness production and hypernuclei
- Ongoing: spin-resolved hyperon-nucleon scattering lengths

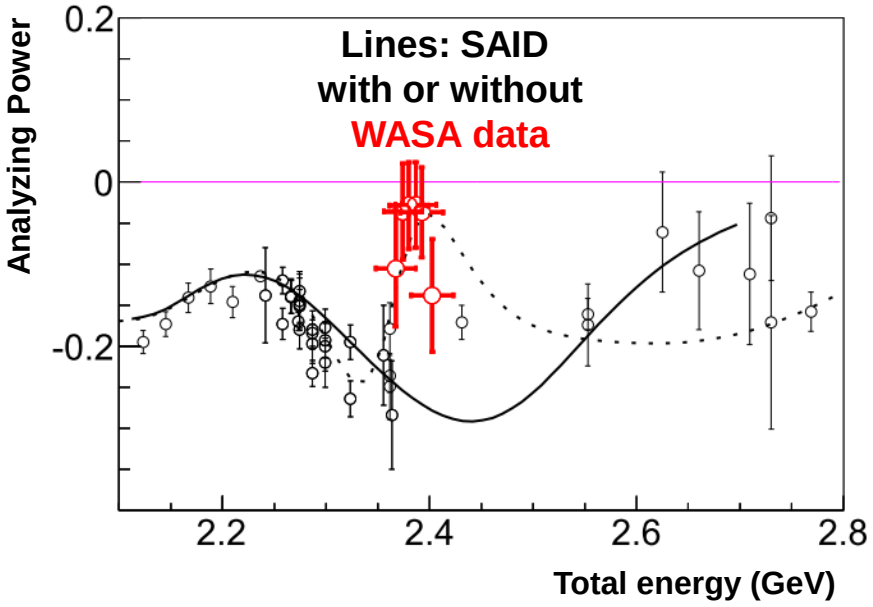
WASA Result: Exotic NN Resonance? Dibaryon

ABC effect in double-pion fusion reactions

Isospin dependence (I = 0,1)



New: impact on elastic np-scattering



- **WASA**: structure (at 2.37GeV, 70MeV width) in isoscalar (I=0) channel
- Origin of structure: 6 quark bound state? Quantum numbers: I(J^P)=0(3^+)
- Ongoing: Partial wave analysis (SAID), quantum numbers

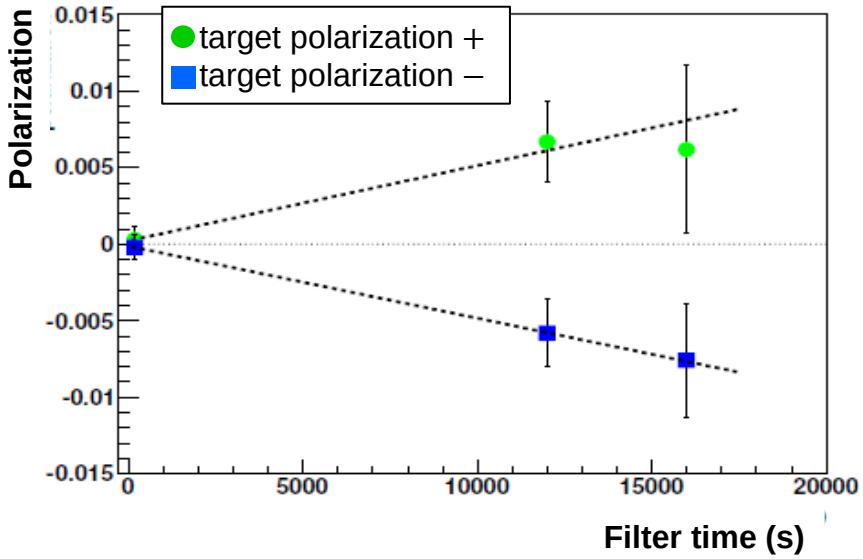
Phys.Rev.Lett., 112, 202301 (2014)
PhysRevC 90, 035204 (2014).
CERN Courier.54 ,6, (2014)

PAX Result: Spin Filtering; Goal: Pol. Antiprotons

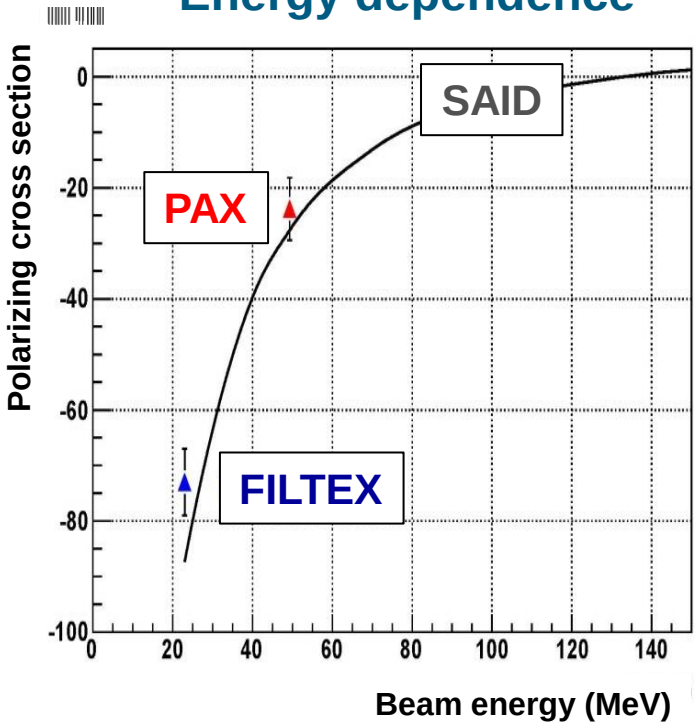
Polarization build-up by spin filtering in storage rings
Tests with **protons at COSY**
New: low-ß section, intense polarized target, precision polarimetry

European Research Council
Advanced Grant
POLPBAR

Transverse build-up



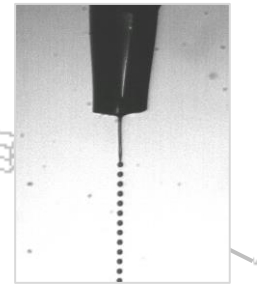
Energy dependence



- **PAX**: spin filtering works and is well understood in NN scattering
- Preparations for spin-filtering with **antiprotons** at CERN/AD (or FAIR)
- Ongoing: longitudinal build-up with protons at COSY (Siberian snake needed)

COSY Facility: Developments Related to HESR

Barrier Bucket Cavity
mean energy loss compensation



Pellet Target
beam-target interaction

e-Cooler
100 kV

Stochastic Cooling
(prototyp pick-up tank 1.5-15 GeV/c)

e-Cooler (2 MV; 2013)

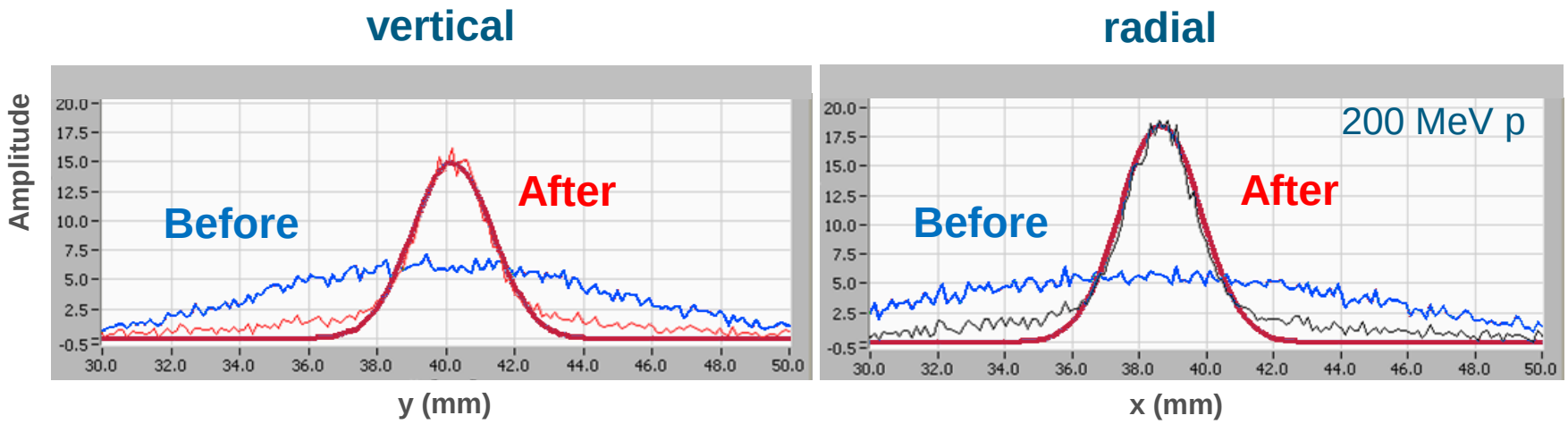
Residual Gas Profile Monitor

Test bench for accelerator components and operation

Example: 2 MV Electron Cooler for HESR

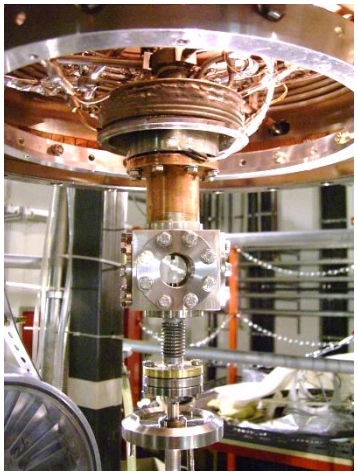
Joint development with Budker Institute (BINP, Russia),
injection cooler for HESR, milestone towards 8 MV cooler

Parameters demonstrated so far:
- Voltage up to 1.5 MV (5 bar SF6)
- Cooling at 900 kV / 300 mA (1.8 GeV p)



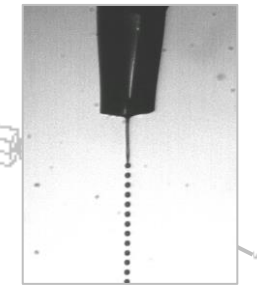
- Electron cooling achieved for 1.8 GeV protons
- Ongoing: commissioning for full COSY energy range (3 GeV)

COSY Facility: Developments for PANDA



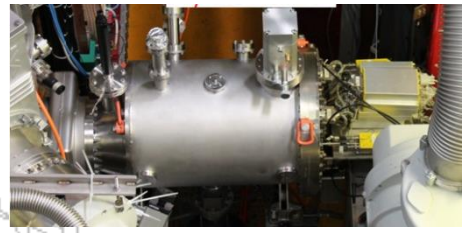
Pellet Target
(in laboratory)

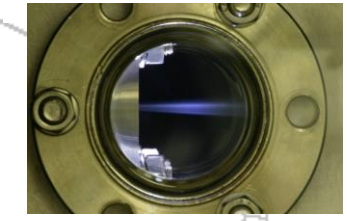
Internal targets



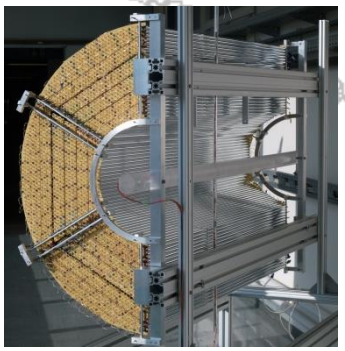
Pellet
Target

Luminosity Monitor

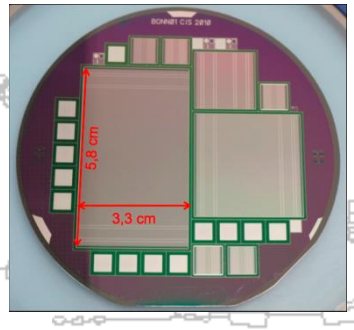




Cluster Jet
Target



Straw Detectors



Micro-vertex Detectors

Tracking detectors

Pre-assembly of major PANDA components in Jülich

COSY Facility: User Activities for FAIR

PANDA:

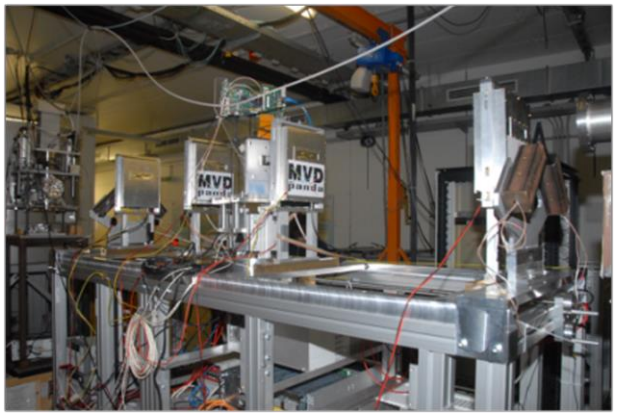
- Straw-tube tracker
  Cracow, Frascati, Pavia, Ferrara, Bucharest, Jülich
- Micro-vertex detector
  Giessen, Turin, Jülich
- Calibration detector for luminosity monitor
  Jülich, Lanzhou
- Disk DIRC
  Erlangen, Tübingen, Giessen, Jülich
- Radiation hardness of high purity Ge-detector
  Mainz (HIM)

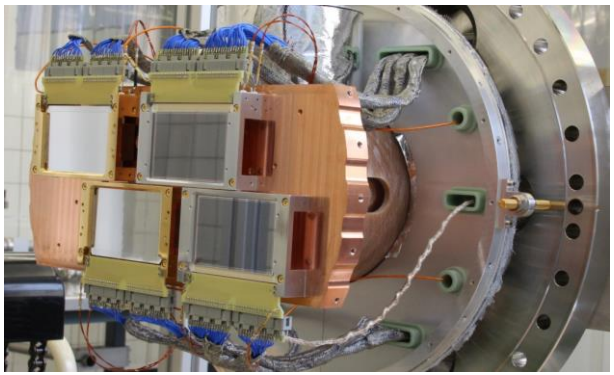
CBM/Hades:

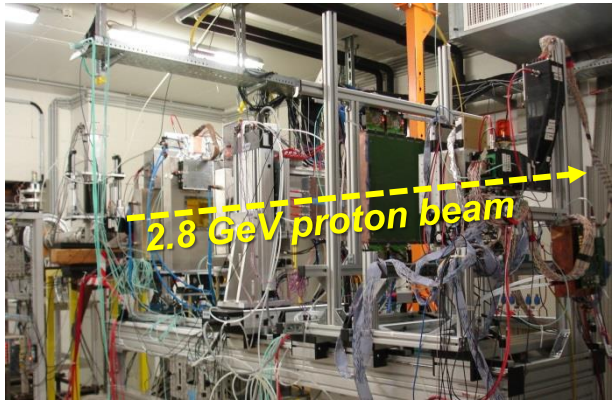
- Tracking detectors, diamond detectors
  München, Frankfurt, Darmstadt, Kolkata, Wuppertal

NuSTAR:

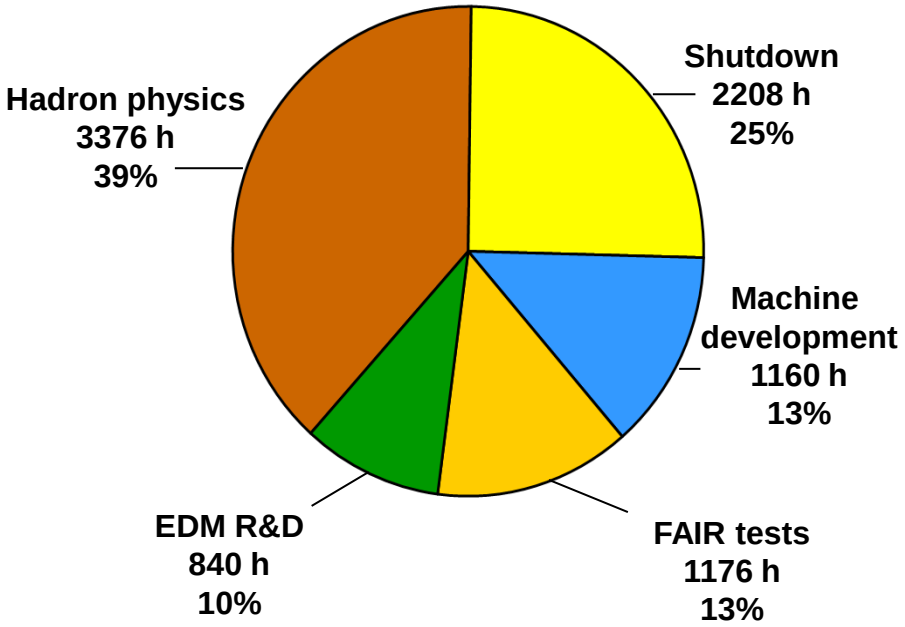
- Cherenkov, Time Projection Chamber
  Giessen, Kyoto



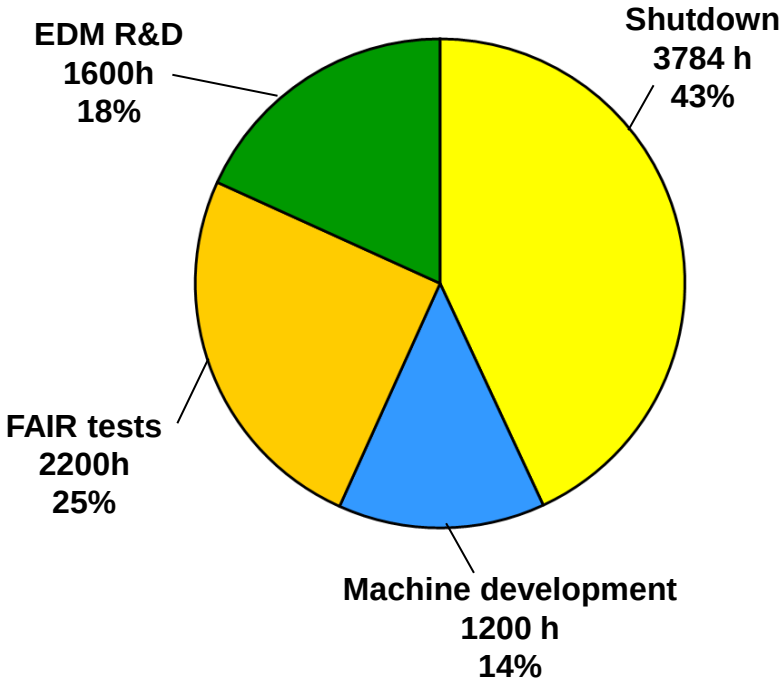




COSY: Transition PoF2 → PoF3 (2015-2019)



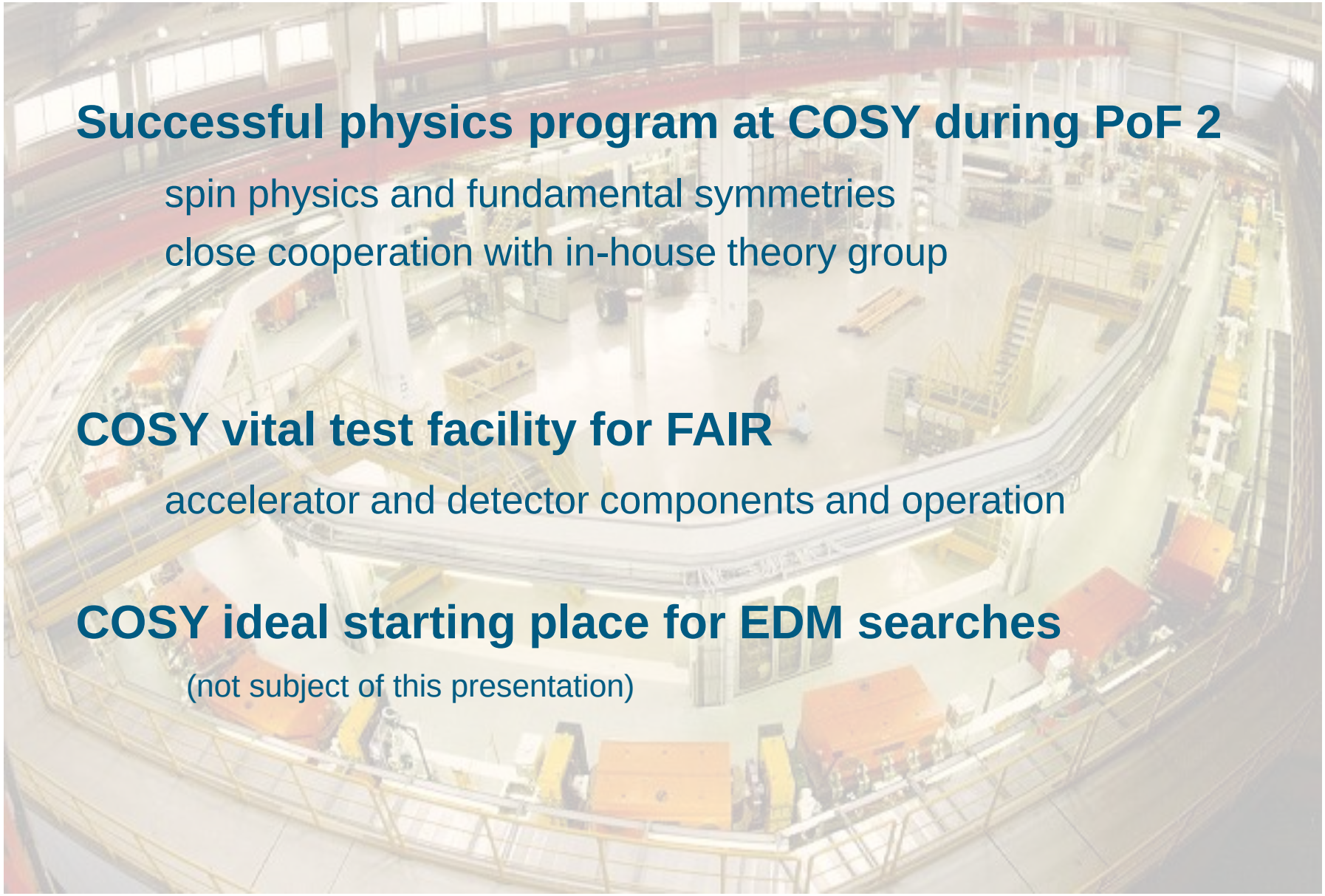
PoF2



PoF3

Phase-out of hadron physics program at COSY
Use of COSY as accelerator and detector test facility

Summary and Outlook



Successful physics program at COSY during PoF 2

spin physics and fundamental symmetries

close cooperation with in-house theory group

COSY vital test facility for FAIR

accelerator and detector components and operation

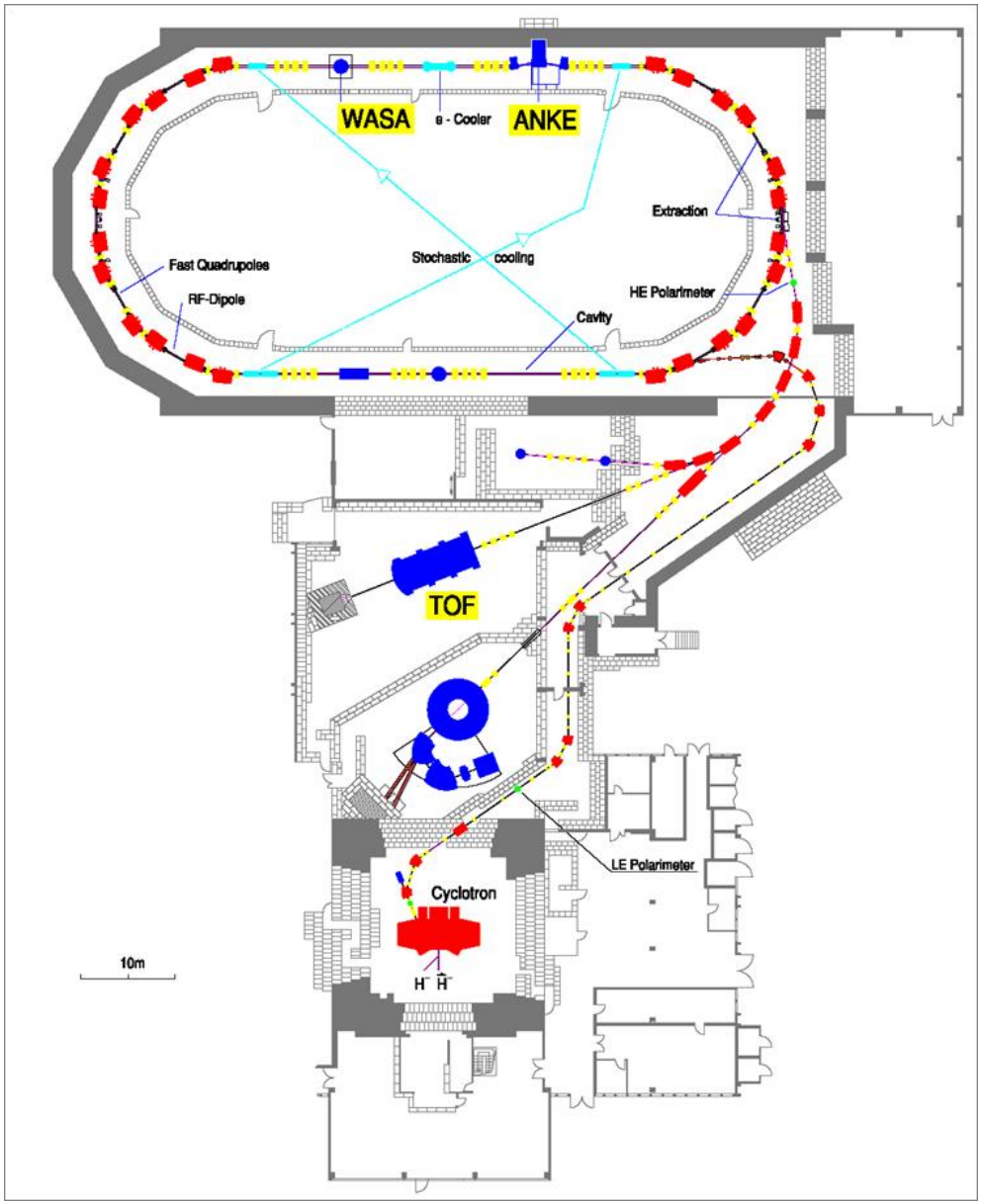
COSY ideal starting place for EDM searches

(not subject of this presentation)

Spare slides…

COSY

COSY Accelerator



Energy range

0.045 – 2.8 GeV (p)
0.023 – 2.3 GeV (d)
(momentum 3.7 GeV/c)

Cooling (transverse & longitudinal)

2 methods:
electron, stochastic
$\Delta p/p \leq 5 \cdot 10^{-5}$

Polarization

p, d beams & targets

Beams

internal, extracted

Experiments, detectors

ANKE, TOF, WASA, PAX

~ 340 users, 15 countries

Mitglied in der Helmholtz-Gemeinschaft

COSY Beam Parameter

JÜLICH FORSCHUNGSZENTRUM

- **beam quality**:

  without cooling: $\Delta p/p \sim 2 \cdot 10^{-4}$

  electron cooling: $\Delta p/p \leq 5 \cdot 10^{-5}$ $p_p < 0.5$ GeV/c

  stochastic cooling: $\Delta p/p \leq 5 \cdot 10^{-5}$ $p_p > 1.5$ GeV/c

  $\varepsilon = \pi$ mm mrad 1mmØ·0,18°

- **beam intensities (cooled):**

  protons, unpolarized: $1 \cdot 10^{11}$

  protons, polarized: $1 \cdot 10^{10}$

  deuterons, unpolarized: $1 \cdot 10^{11}$

  deuterons, polarized: $6 \cdot 10^{9}$ (by stacking)

- **extracted beam:**

  10^5 ... 10^9 protons/s in spill

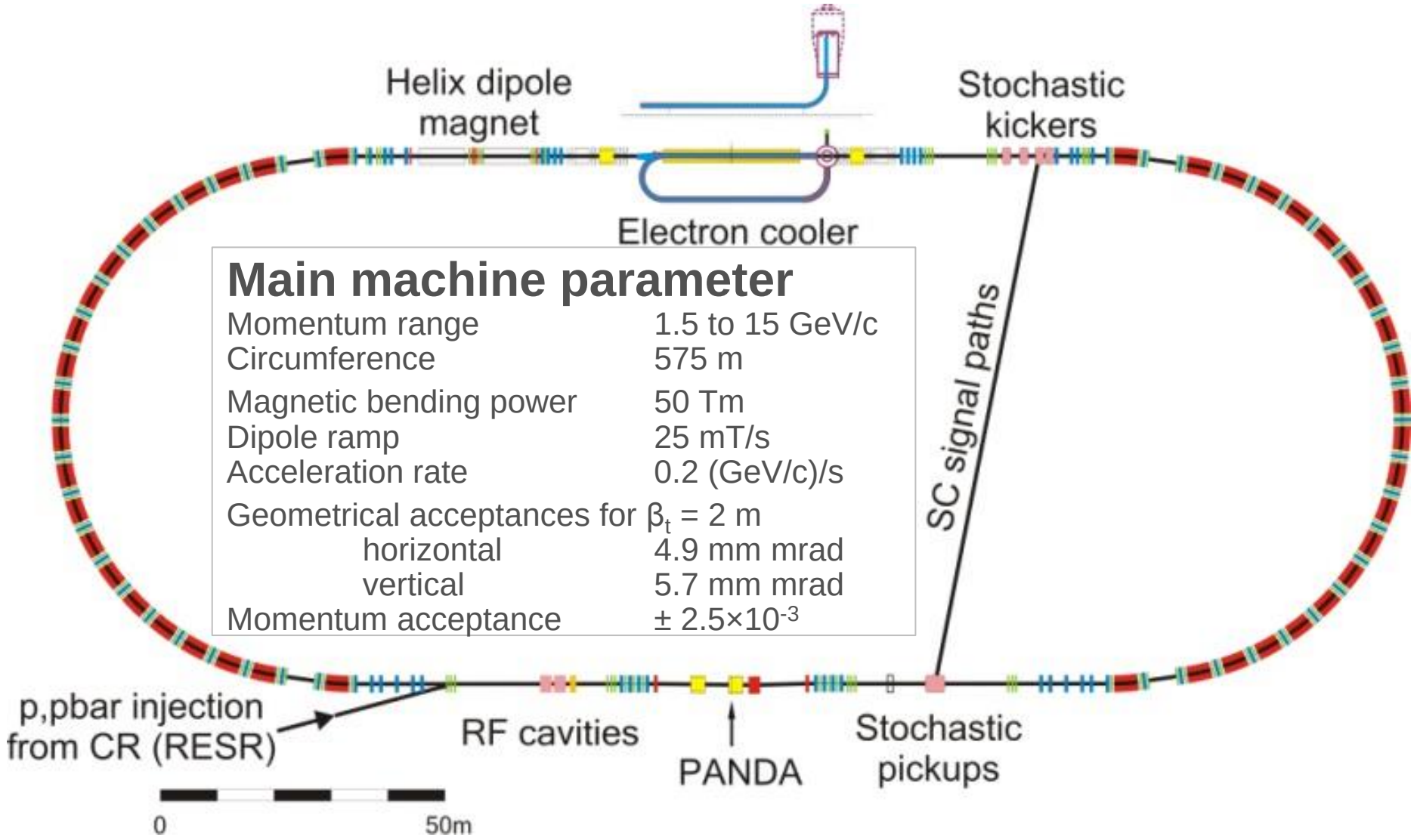
  slow extraction: 10 s ... > 10 min spill, quasi-DC beam

  10(5) s inter-spill (un)cooled

  fast extraction: $2 \cdot 10^9$ protons in 200 ns, every 15 s

Mitglied in der Helmholtz-Gemeinschaft

HESR Layout



Main machine parameter

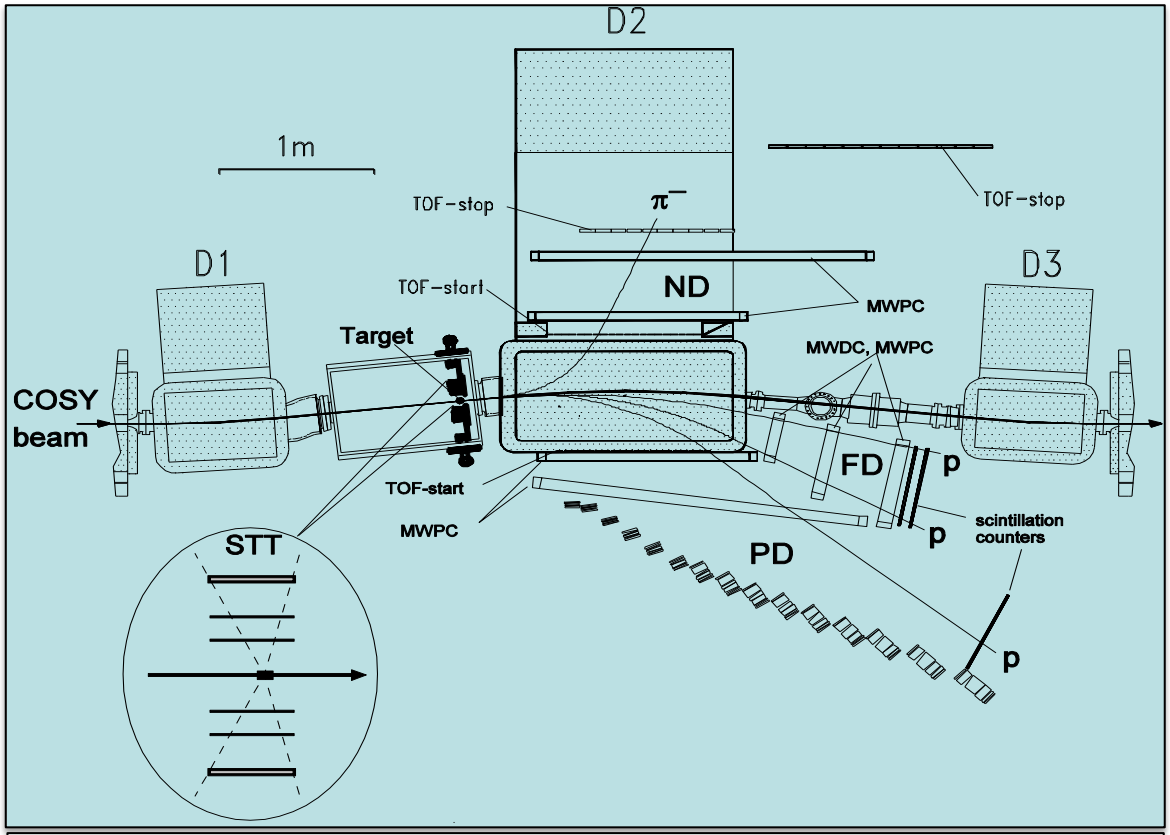
Momentum range	1.5 to 15 GeV/c
Circumference	575 m
Magnetic bending power	50 Tm
Dipole ramp	25 mT/s
Acceleration rate	0.2 (GeV/c)/s
Geometrical acceptances for β_t = 2 m	
horizontal	4.9 mm mrad
vertical	5.7 mm mrad
Momentum acceptance	$\pm 2.5\times10^{-3}$

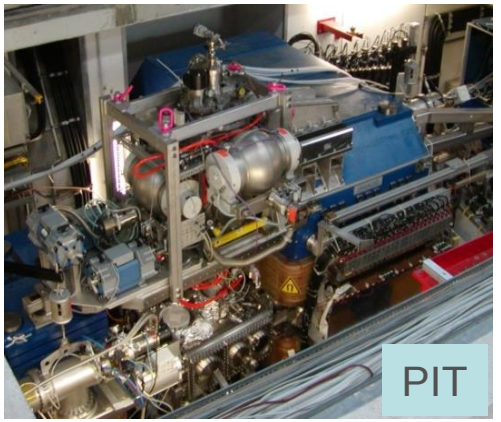
Pre-Assembly of PANDA components in Jülich

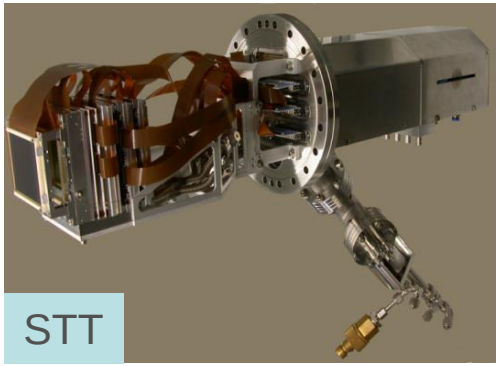
- high rate in-beam tests of individual detector components in the COSY-TOF area
- Mechanical integration of “full” PANDA in the COSY test-hall
- Infrastructure available:
  - ✓ M&E Workshop capacity
  - ✓ staging space for detectors
  - ✓ (limited) clean room space
  - ✓ office space available
- Transport to and setup in Darmstadt 2017

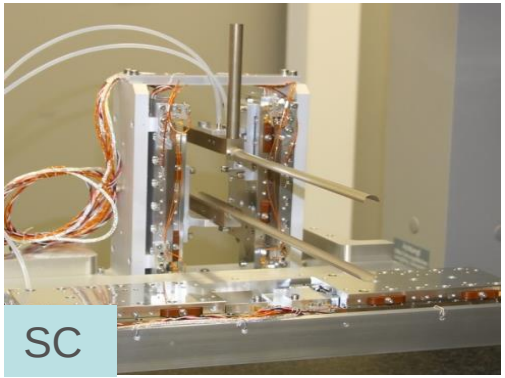
ANKE

ANKE Spectrometer: Apparatus









Main features:

- Excellent Kaon identification (Positive and Negative)
- Di-proton ($\{pp\}_s$) selection by Forward Detector (FD)
- Low energy proton (spectator) detection (STT)
- Polarized (unpolarized) dense targets (PIT)
- Openable storage cell (SC)

ANKE: Scientific Program

Since 2005 ANKE has been equipped with a **Polarized Internal Target** (PIT) and embarked to measure the **spin** dependence of many polarized reactions

Nucleon-nucleon interaction

pp- and np-amplitudes, nuclear forces, di-proton system in $^1S_0$ -state $\{pp\}_s$

Meson prodution

NNπ amplitudes (PWA), extension of ChPT to the NN→NNπ process via measuring all observables in $pp \rightarrow \{pp\}_s\pi^0$ and $np \rightarrow \{pp\}_s\pi^-$

Meson-nucleus interaction

η-^{3}He interaction (FSI), η-mesic ^{3}He , precision η-mass determination

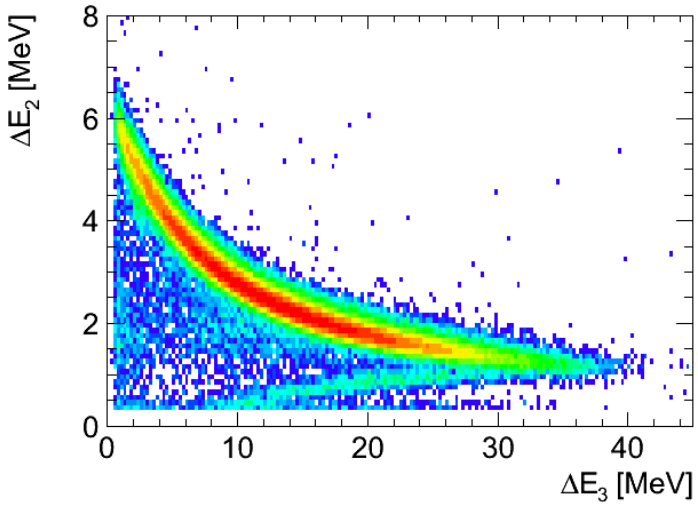
Strangeness degree of freedom

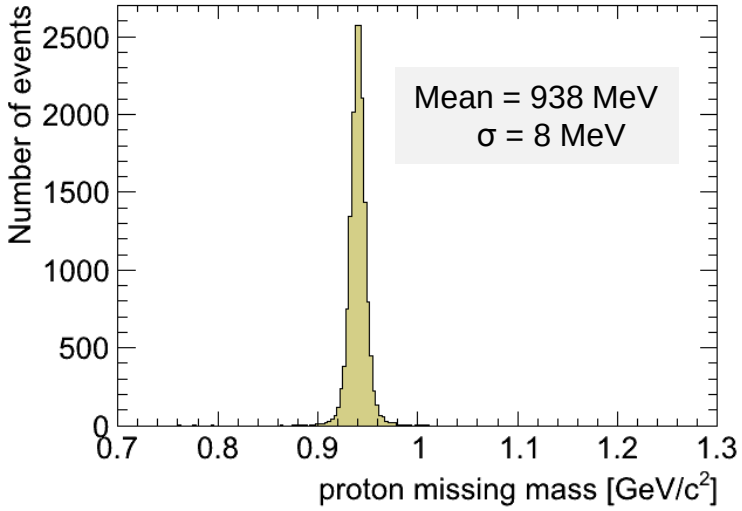
YN interaction, ΛN scattering lengths, separation of spin-singlet (a_s) and spin triplet (a_t) Λp production amplitudes, SU(3) symmetry

Summary of recent results: **N**uclear **P**hysics **N**ews (NuPECC, issue 3, 2013)

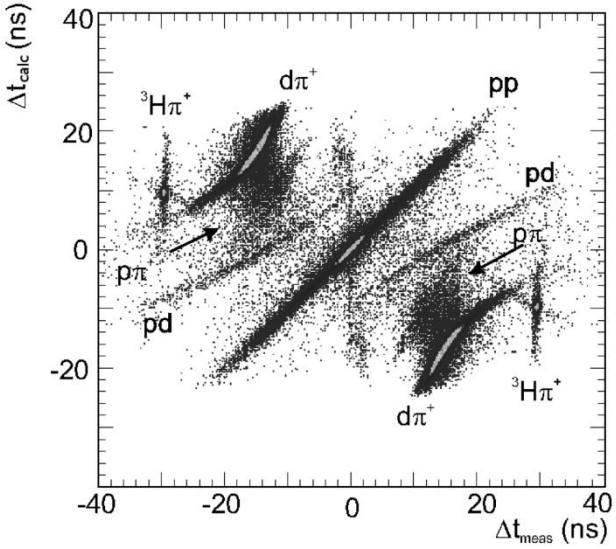
ANKE: Examples of Analyses

pp elastic: recoil slow proton detection (**STT**)

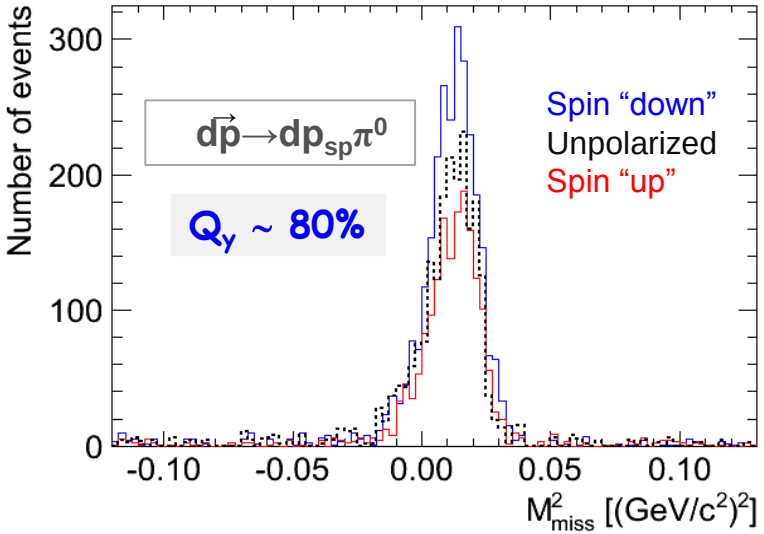




Reaction identification (FD)



Target polarization (PIT)



ANKE: Scientific Output

50 scientific **papers** (since spin program started in 2005)

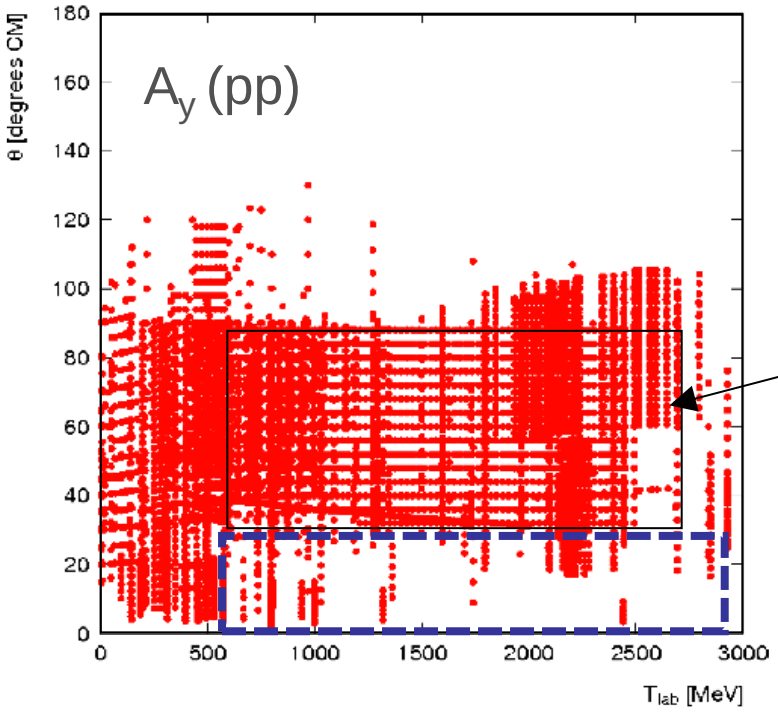
Topics:

- NN-interaction (HEPI Tbilisi, IKP)
- Deuteron breakup at large momentum transfer (JINR Dubna, IKP)
- Complete measurement for NN → NNπ (JINR, Erlangen, IKP)
- High energy bremsstrahlung (JINR, IKP)
- Two-pion production (JINR, Münster, IKP)
- The η-meson production (Münster, IKP)
- Vector meson (φ, ω) production (RCNP, PNPI Gatchina, IKP)
- Medium modifications (ITEP Moscow, IKP)
- Kaon-pair production (PNPI, IKP)
- Hyperon production (PNPI, IKP)
- ….

Very strong collaboration groups !

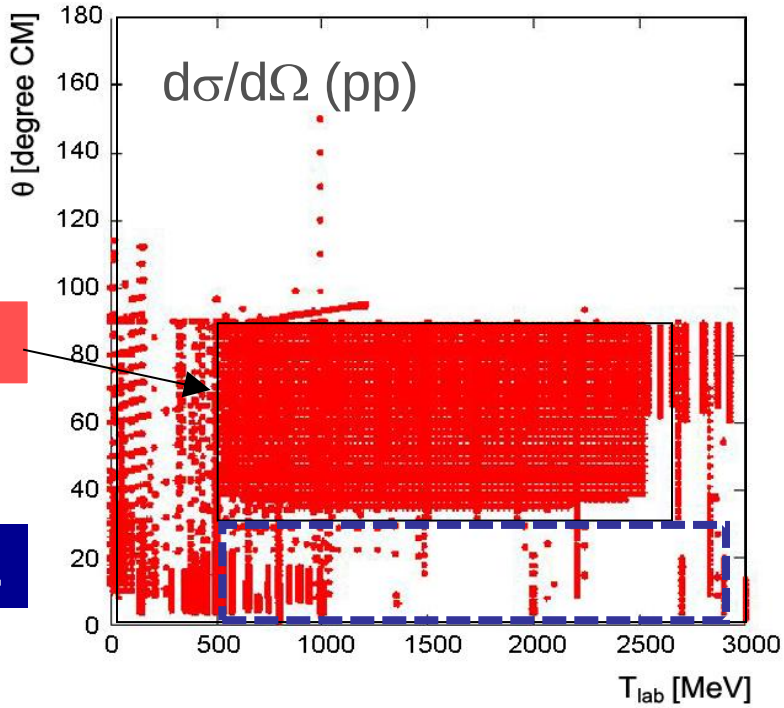
NN Scattering: Motivation (pp)

Data distribution plots (SAID)



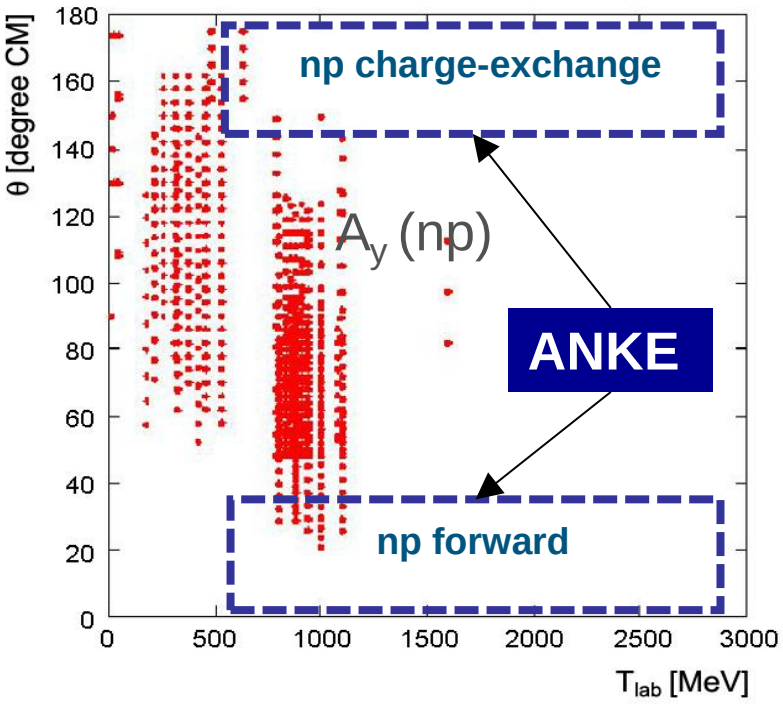
EDDA

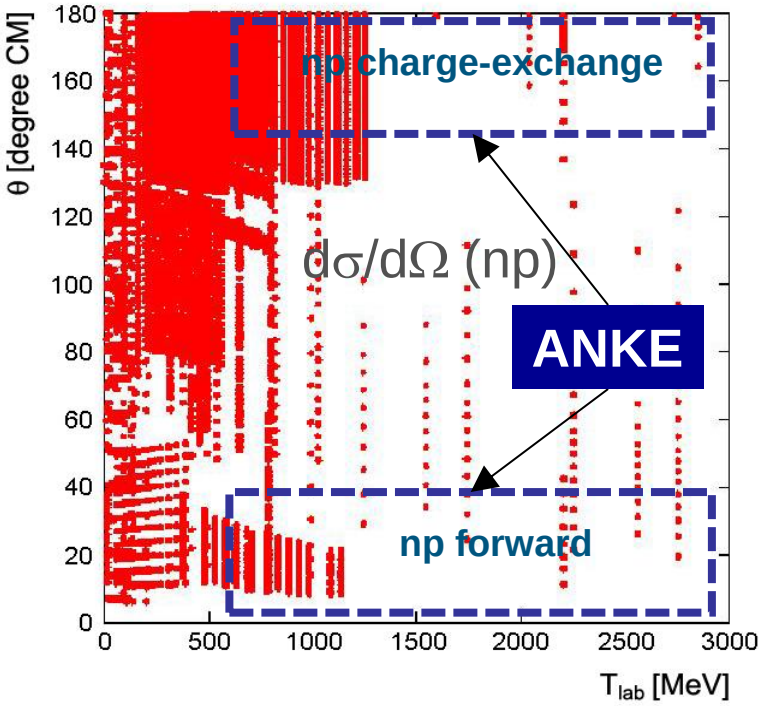
ANKE



NN Scattering: Motivation (pn)

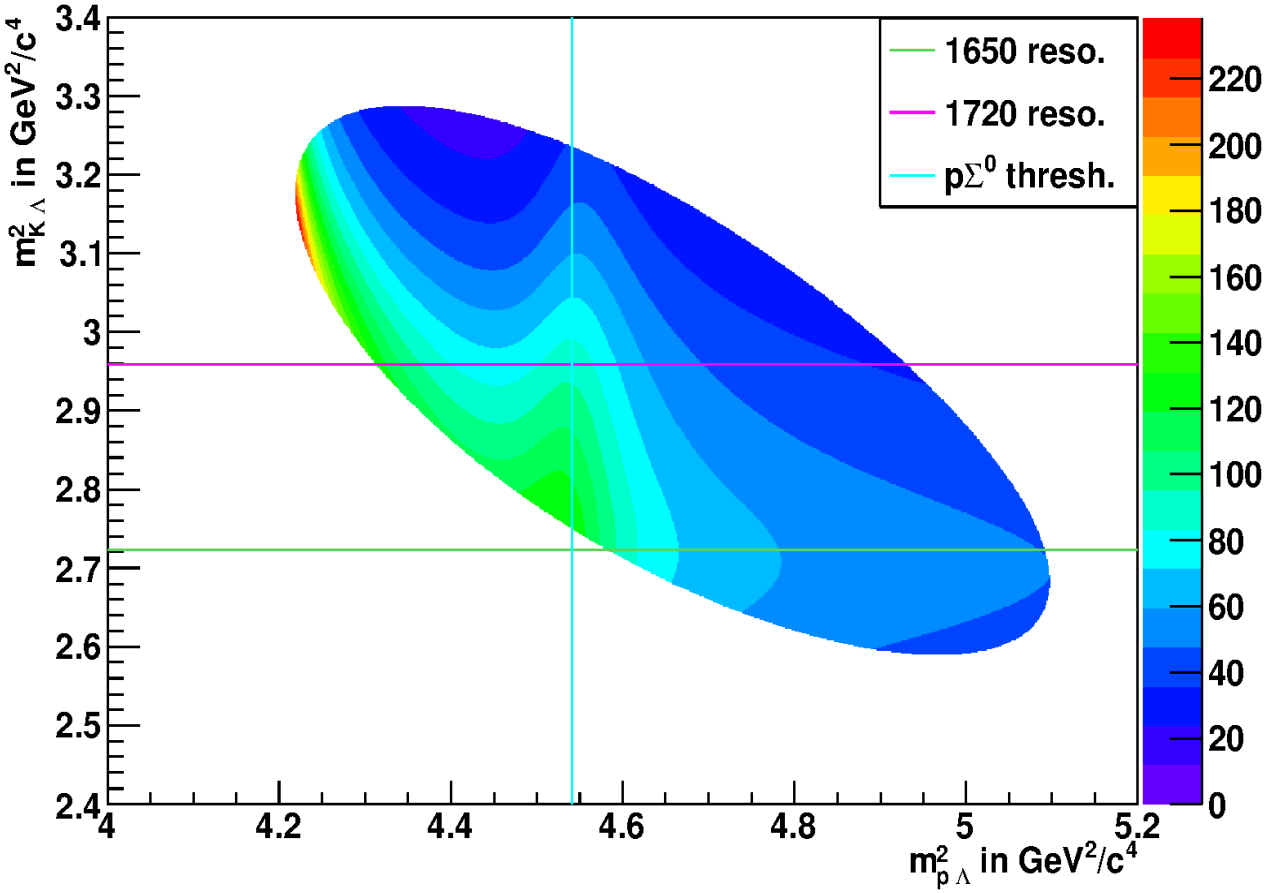
Data distribution plots (SAID)





TOF

Fit of the Dalitz plot for 2.95 GeV/c (Isobar Model*)



Fit properties

pΛ – NΣ cusp
as a resonance with
a 30 MeV width

N*(1650) / N*(1720)
~ 2/1

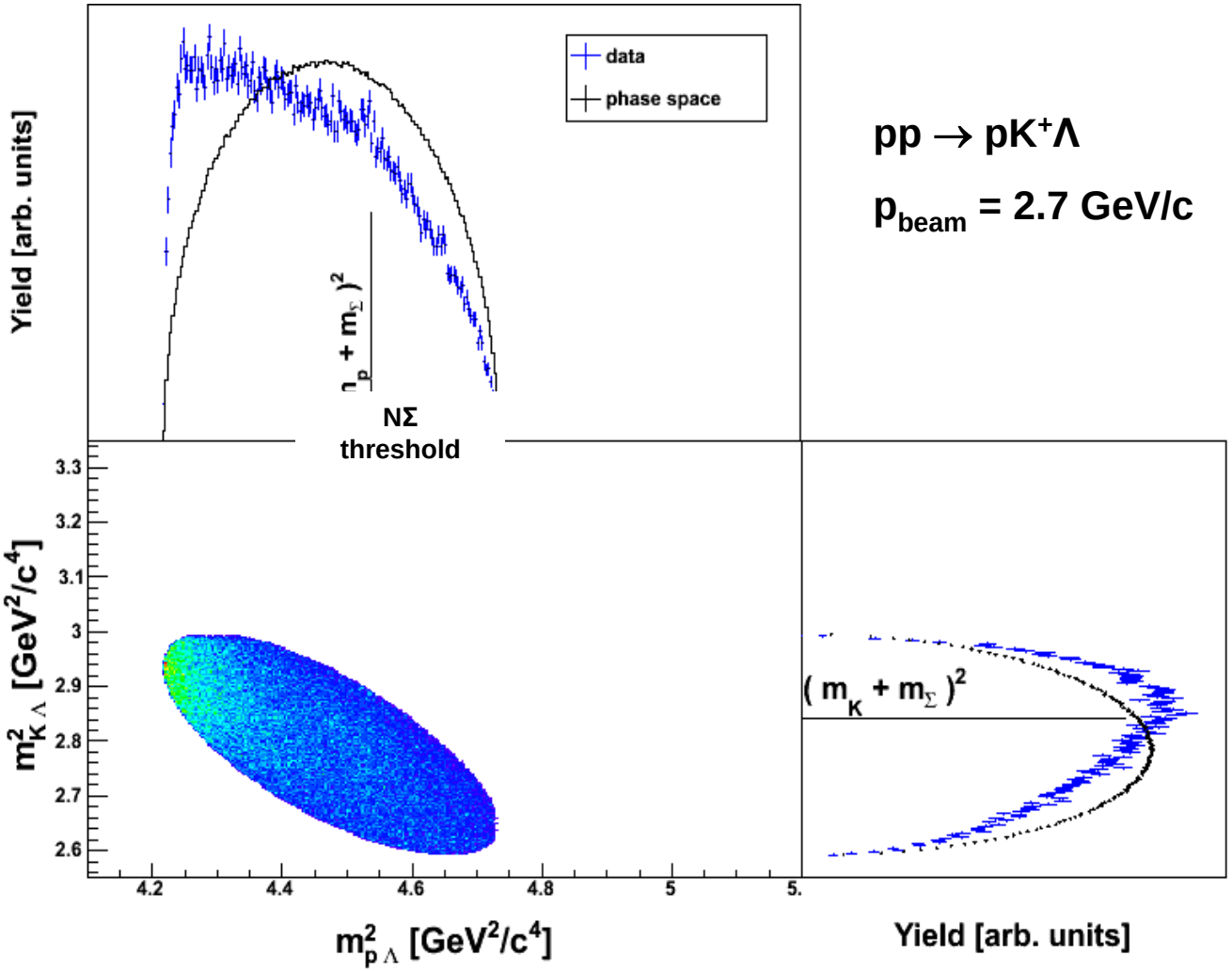
- Fit of the Model to extract resonance strength
- Study at different beam momenta

* A. Sibirtsev et al, Eur. Phys. J. **A27** (2006) 269

Hyperon Production at 2.7 GeV/c

Production mechanism (nucleon resonances, hyperon polarization)
Hyperon-nucleon interaction and (pΛ – NΣ) channel coupling

No significant observation of pΛ – NΣ coupled channel effect

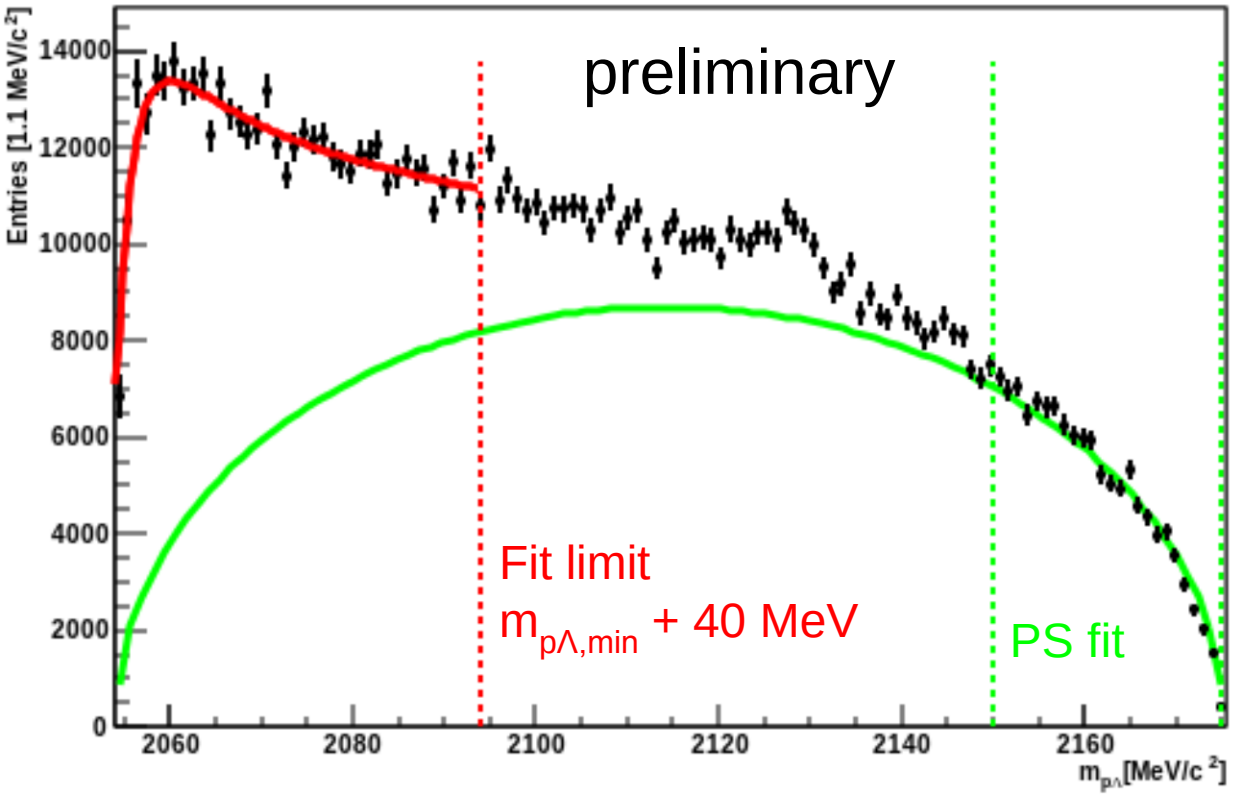


$pp \rightarrow pK^+\Lambda$

$p_{beam} = 2.7$ GeV/c

pΛ Effective Scattering Length

Extraction of effective pΛ scattering length from final state enhancement in the pΛ invariant mass spectrum with known theoretical precision (method adopted from A.Gasparyan et al., Phys. Rev. C69, 034006 (2004))

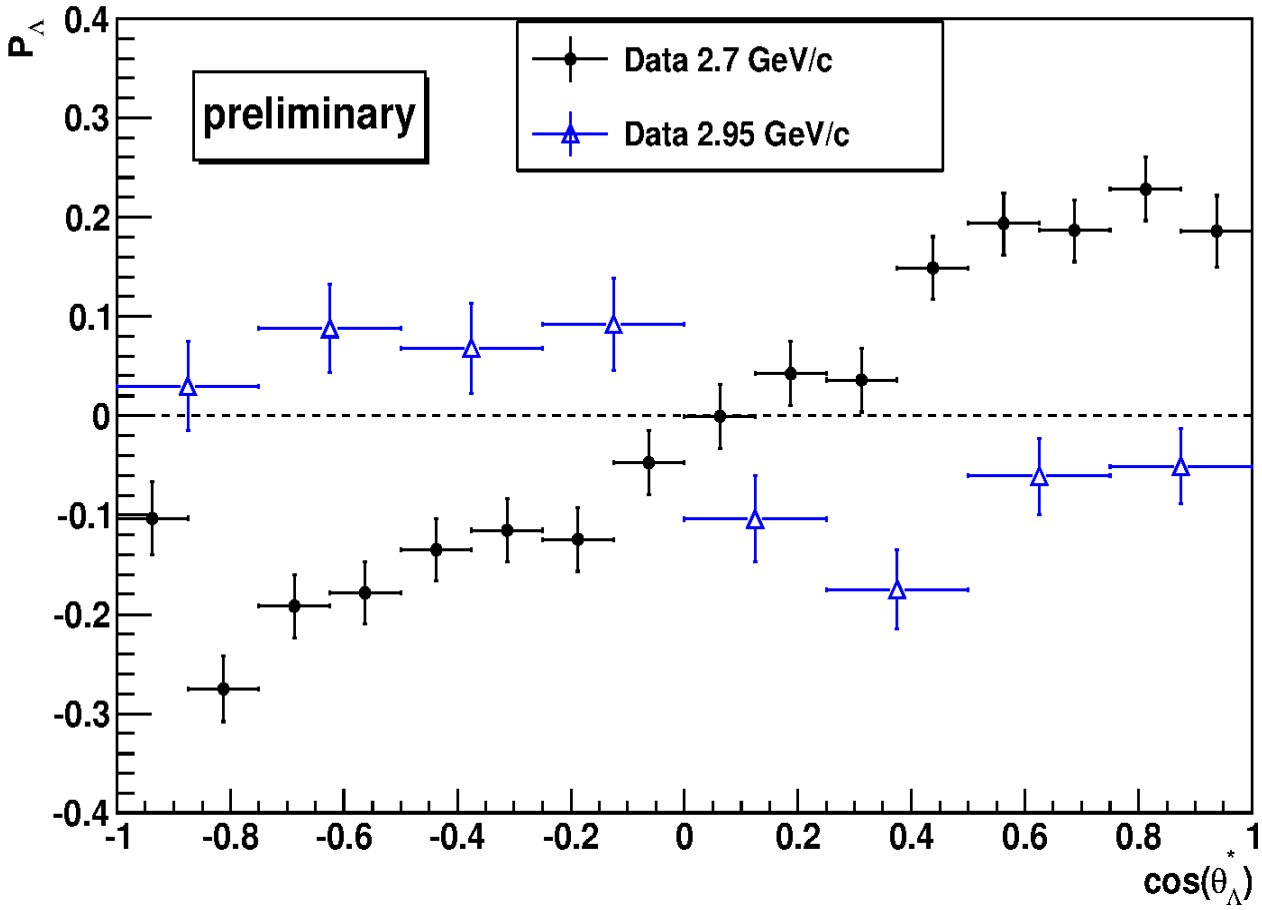


Result from Fit and Likelihood analysis

a = (-1.343 ± 0.016) fm

- Ongoing: Spin-resolved hyperon-nucleon scattering length

Λ Polarization



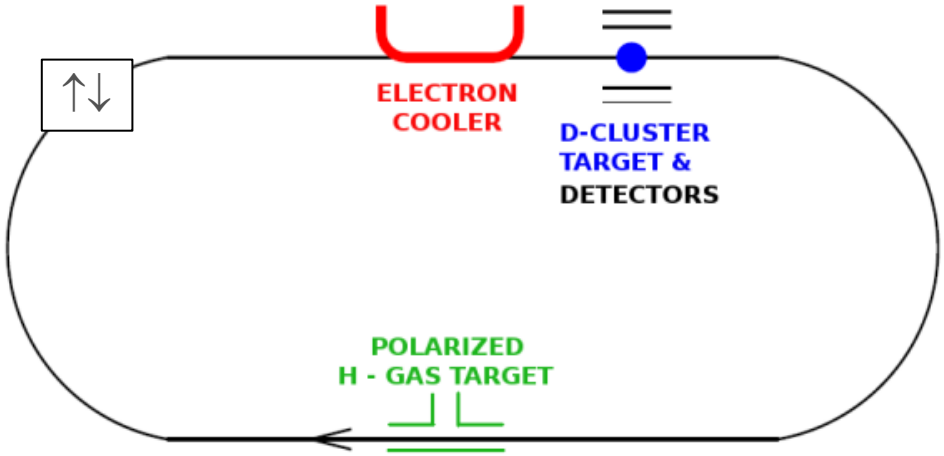
- Λ **Polarization** changes strongly between the two beam momenta
- Ongoing: Theoretical description for understanding

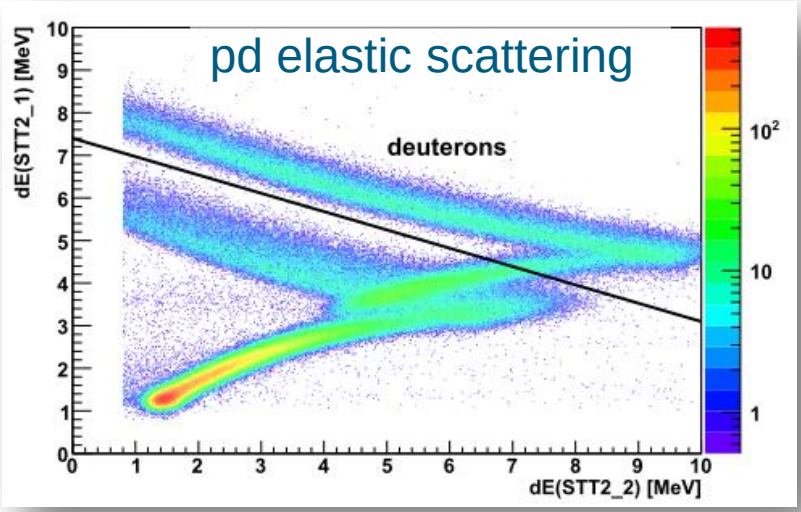
PAX

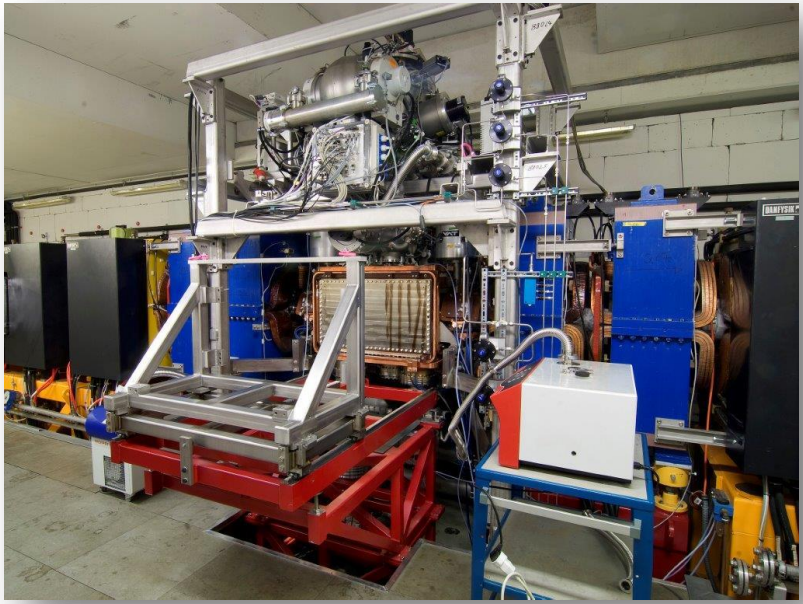
PAX: Experimental setup for Spin-filtering

Spin flipper
(better systematics)

Polarization analysis at ANKE







Spin filtering
with PAX target

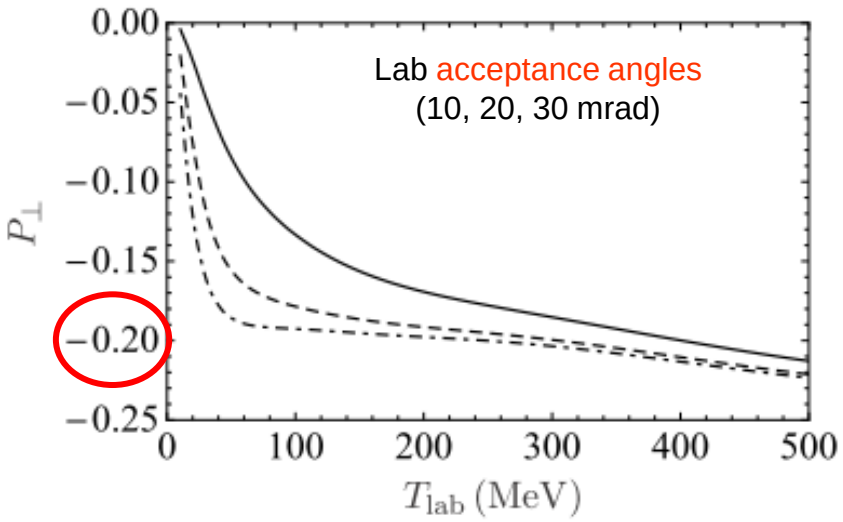
PAX: Theoretical predictions for $\bar{p}$ polarization

Physics Letters B **690**, 427 (2010)

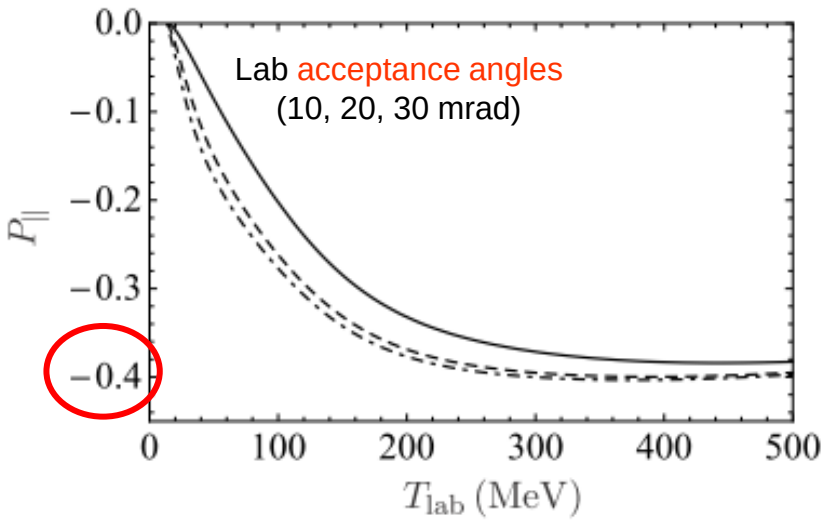
Spin-dependent part of $p\bar{p}$ interaction cross section and Nijmegen potential

V.F. Dmitriev[a, b], A.I. Milstein[a, b], S.G. Salnikov[a, b]

transverse ($\approx \sigma_1$)



longitudinal: ($\approx (\sigma_1+\sigma_2)$)

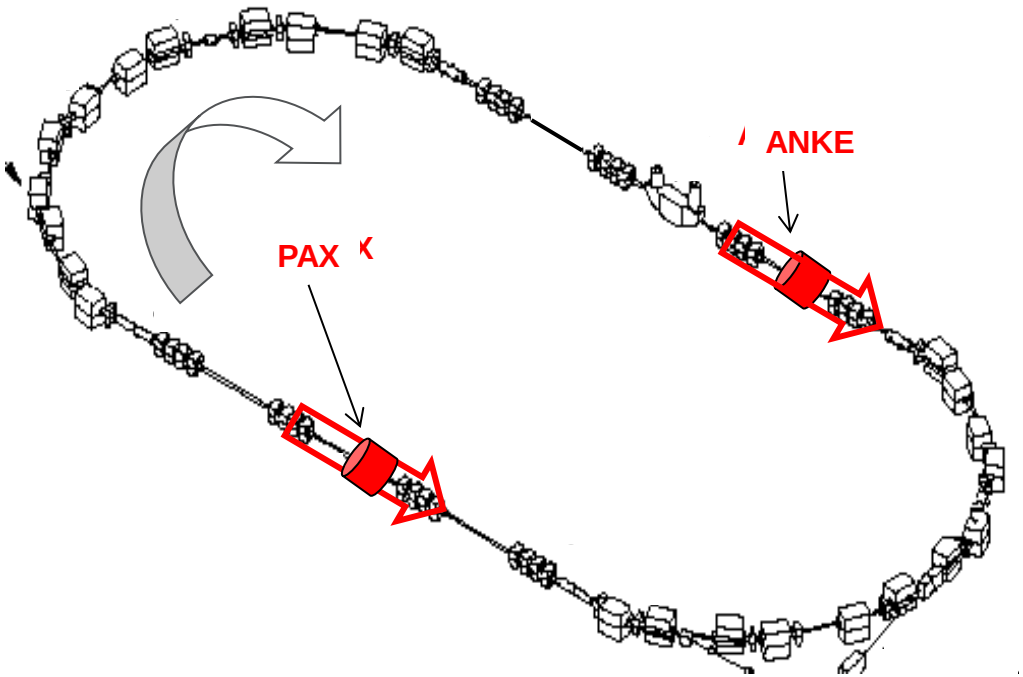


PAX: Siberian snake for COSY

Spin filtering using a longitudinally polarized target

$$\sigma_{tot} = \sigma_0 + \sigma_1 \vec{P} \cdot \vec{Q} + \sigma_2 (\vec{P} \cdot \vec{k})(\vec{Q} \cdot \vec{k})$$

- Should allow for flexible use at two locations (ANKE and PAX)
- Fast ramping (< 30 s)
- Cryogen-free system



	B·dl (Tm)
$pn \to \{pp\}_s \pi^-$ at 353 MeV	3.329
PAX at COSY (140 MeV)	1.994
PAX at AD (500 MeV)	4.090
$T_{\max}$ at COSY (2.88 GeV)	13.887

PAX: Publications

F. Rathmann et al.
Phys. Rev. Lett. **94**, 014801 (2005)
A Method to polarize stored antiprotons to a high degree

V. Barone et al. (PAX collaboration), Proposal to FAIR QCD-PAC
http://arxiv.org/abs/hep-ex/0505054 (2005)
Antiproton-proton scattering experiments with polarization

D. Oellers et al.
Phys. Lett. B **674**, 269 (2009)
Polarizing a stored proton beam by spin flip?

C. Barschel et al. (PAX collaboration), CERN-SPSC-2009-012 (2009)
Measurement of the Spin-Dependence of the p anti-p Interaction at the AD-Ring

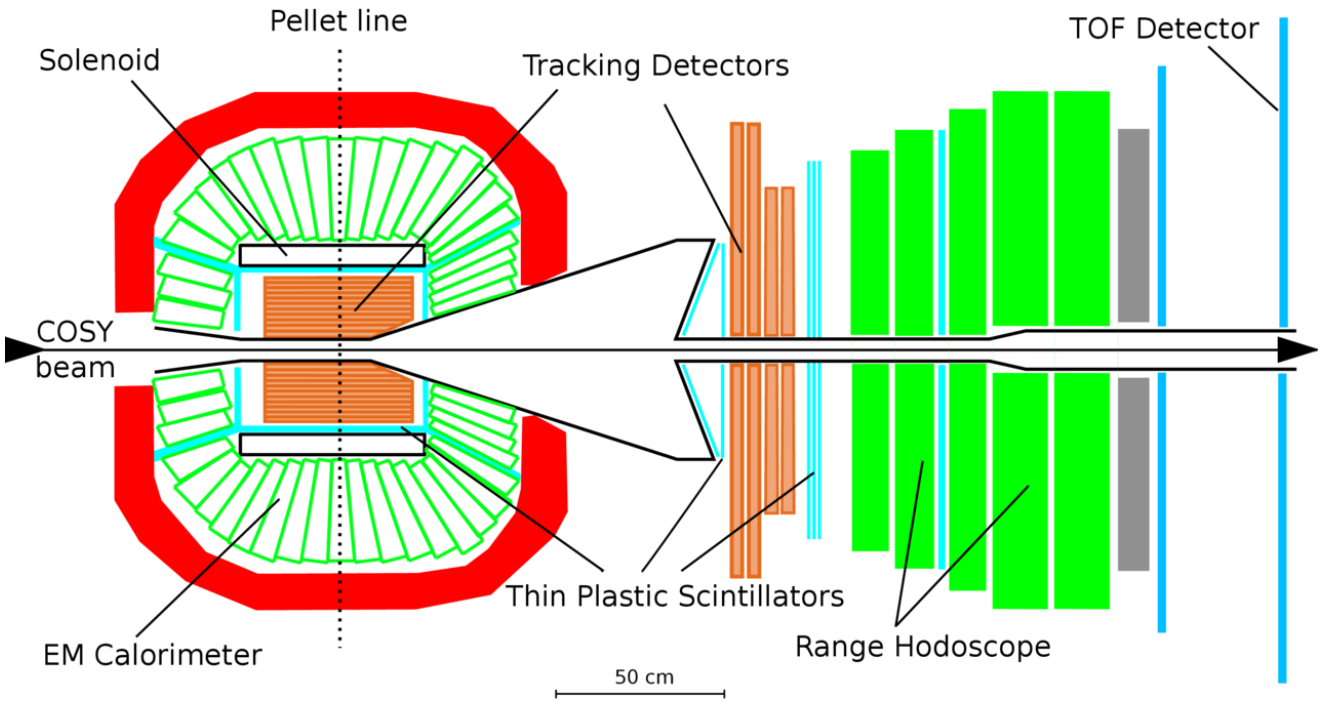
P. Lenisa and F. Rathmann
CERN Cour., **50N6**, 21 (2010)
PAX promotes beams of polarized antiprotons

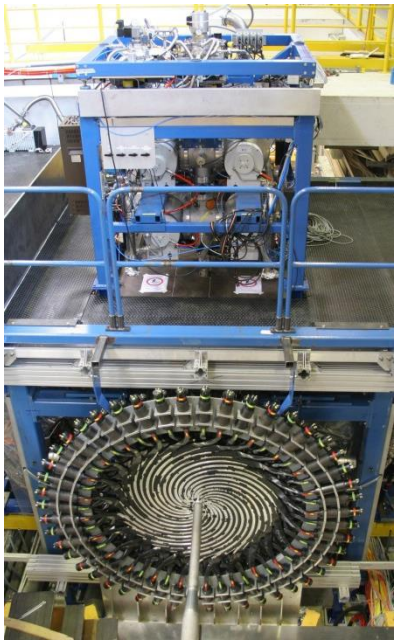
W. Augustiniak et al.
Phys. Lett. B, **718**, 64 (2012)
Polarization of a stored beam by spin-filtering

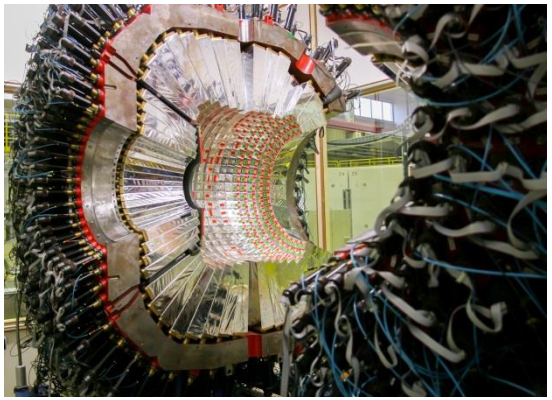
P. Lenisa and F. Rathmann
Nucl. Phys. News **23**, 27 (2012)
Perspectives for polarized antiprotons

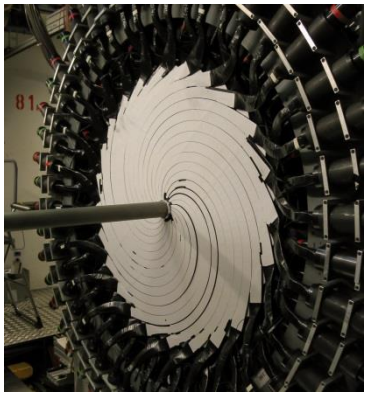
WASA

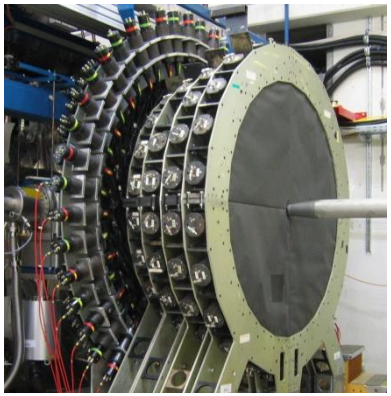
WASA: Setup

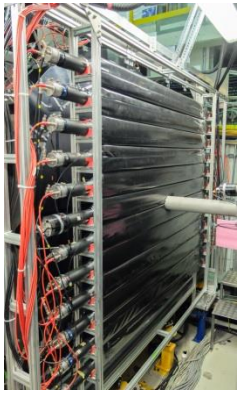

Pellet line
Solenoid
Tracking Detectors
TOF Detector
COSY
beam
Thin Plastic Scintillators
EM Calorimeter
Range Hodoscope
50 cm











WASA: Physics Program

Symmetries and symmetry breaking in η decays
chiral symmetry, C and CP tests

Structure of mesons
transition form factors in π, η and ω Dalitz decays

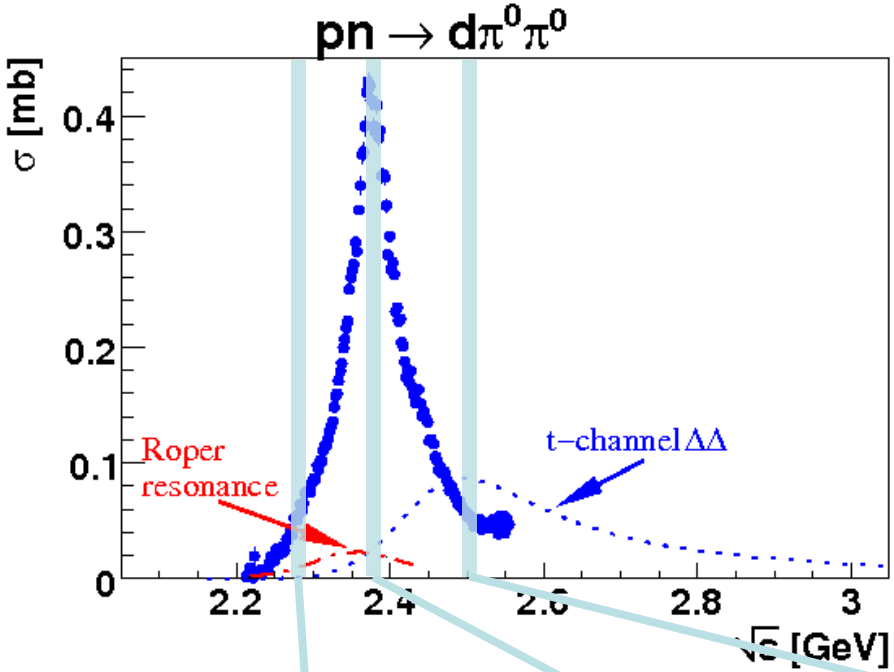
Physics beyond the Standard Model
dark photon search in $\pi^0 \rightarrow e^+e^-\gamma$

Nucleon-nucleon interaction, meson-nucleon interaction
ABC effect in pN → dππ, pd → ^{3}He ππ, dd → ^{4}He ππ

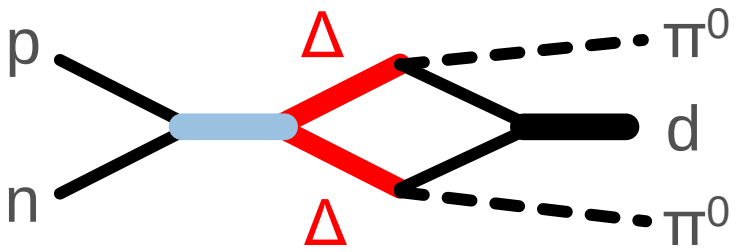
Quark mass effects
Charge symmetry breaking in dd → ^{4}He π^0

Meson-nucleus interactions
η-mesic ^{3}He and ^{4}He

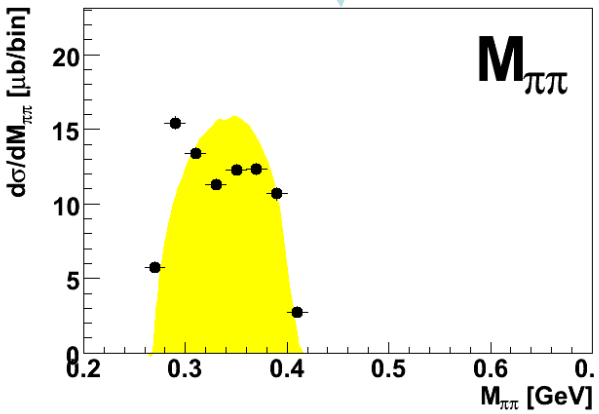
WASA: ABC Resonance

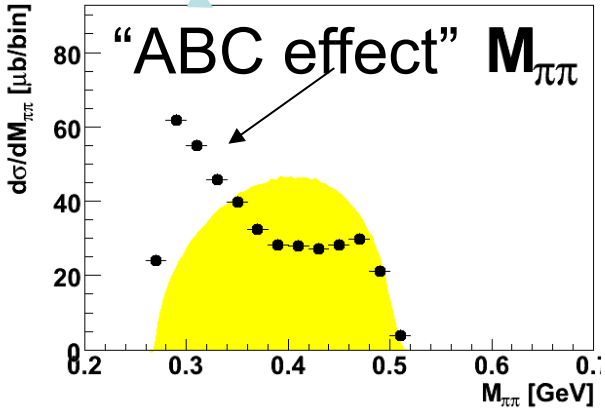


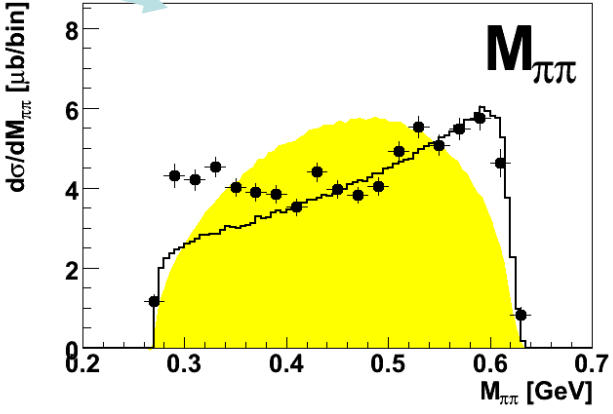
Resonance model



$I(J^p) = 0(3^+)$







WASA: References

Measurement of the pn → ppπ⁰π⁻ reaction in search for the recently observed resonance structure in dπ⁰π⁰ and dπ⁺π⁻ systems *Phys. Rev. C 88 (2013) 055208)*

Search for a dark photon in the π⁰ → e⁺e⁻γ decay *Phys.Lett. B726 (2013) 187-193*

Investigation of the dd → ³He n π⁰ reaction with the FZ Jülich WASA-at-COSY facility *Phys. Rev. C 88 (2013) 014004*

Isospin Decomposition of the Basic Double-Pionic Fusion in the region of the ABC Effect *Phys.Lett. B721 (2013) 229*

Search for eta-mesic ⁴He with the WASA-at-COSY detector *Phys.Rev. C87 (2013) 035204*

Abashian-Booth-Crowe resonance structure in the double pionic fusion to ⁴He *Phys.Rev. C86 (2012) 032201*

Exclusive Measurement of the η → π⁺π⁻ gamma Decay *Phys.Lett. B707 (2012) 243-249*

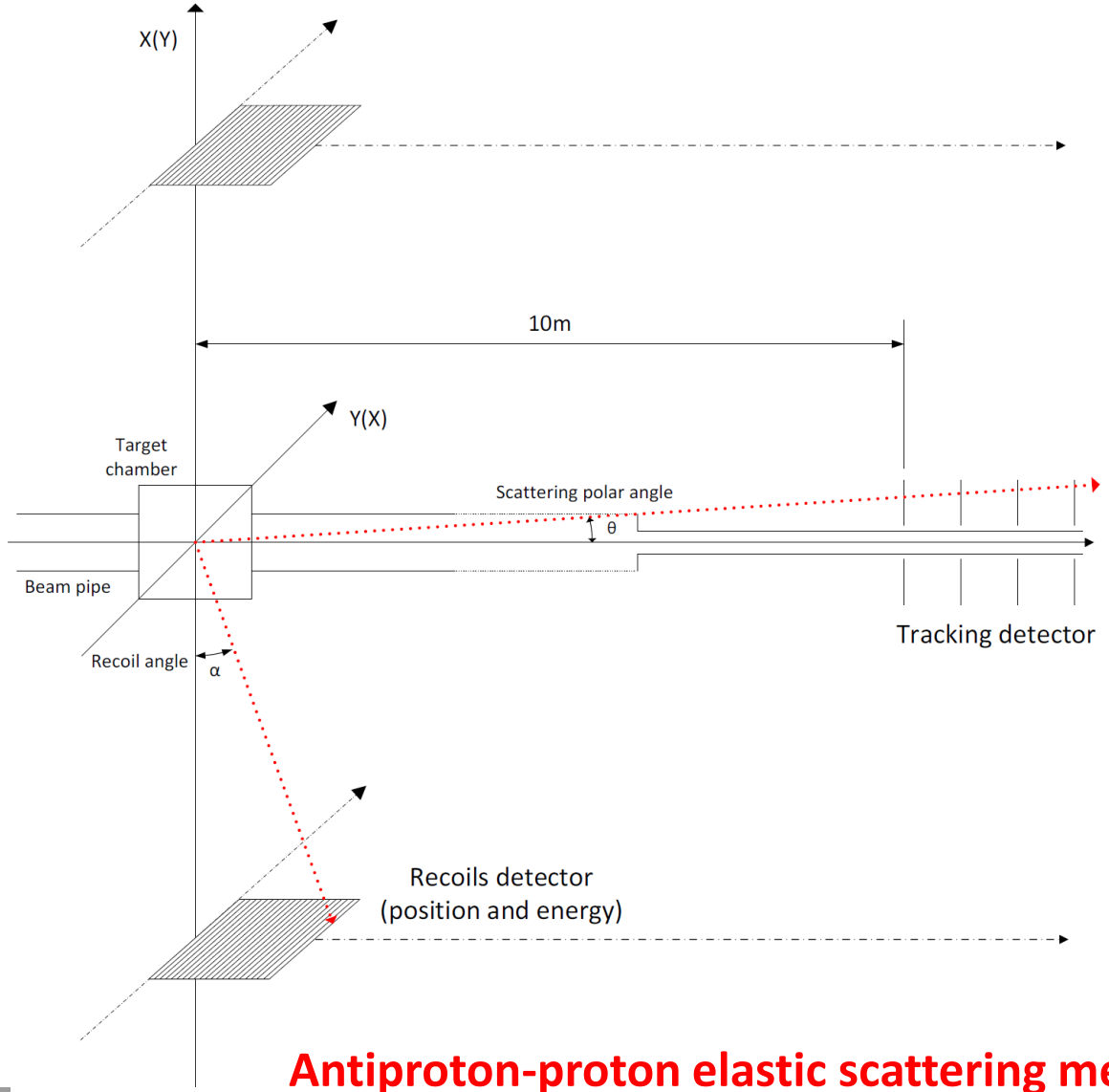
Experimental Investigation of π⁰π⁰ Production in Proton-Proton Collisions at T_p = 1400 MeV *Phys.Lett. B706 (2012) 256-262*

ABC Effect in Basic Double-Pionic Fusion --- Observation of a new resonance? *Phys.Rev.Lett. 106 (2011) 242302*

Measurement of the η → 3π⁰ Dalitz Plot Distribution with the WASA Detector at COSY *Phys.Lett. B677 (2009) 24-29*

Calibration detector for Luminosity monitor

Calibration Detector for luminosity monitor at HESR



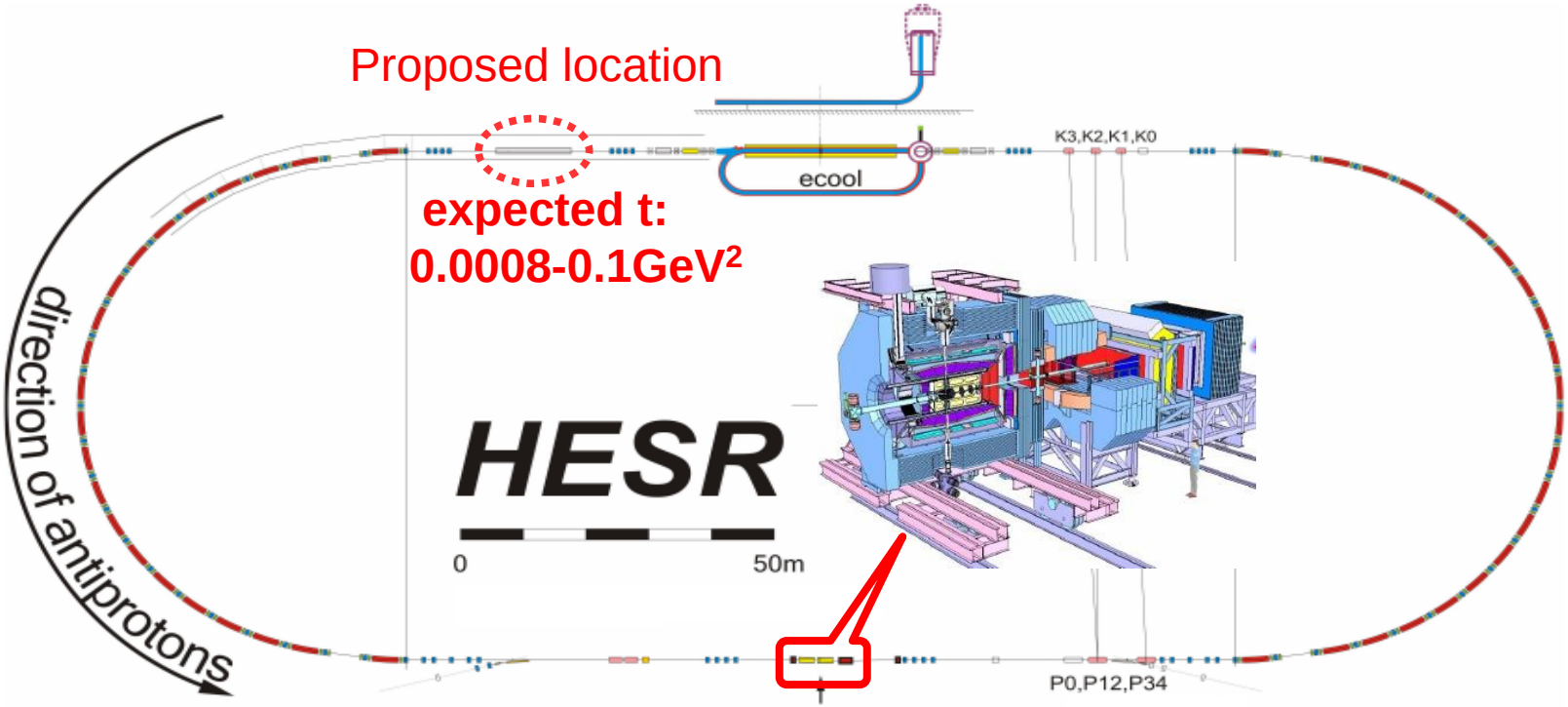
Goal is to determine parameter σ_{tot}, ρ and b for PANDA luminosity monitor

- Forward tracking detector to measure scattered beam particles
- Recoil detector to measure energy and angle of recoil protons
- Large t range,0.0008-0.1 GeV^2, measurement
- Coincidence for background suppression

Antiproton-proton elastic scattering measurement

Mitglied in der Helmholtz-Gemeinschaft

Large t-range measurement at HESR?



- Forward scattering measurement
  (e.g. polar angle 4.6-8 mrad ~ t range of 0.0008-0.0025 GeV²@6.2GeV/c)
- Recoils measurement
  (e.g. recoil angle 1.0° -11.5° ~ t range of 0.0008-0.1 GeV²@6.2GeV/c)

Dedicated day-one experiment at HESR

Mitglied in der Helmholtz-Gemeinschaft

Matter and the Universe, Topic 2, FZJ

Standing

COSY is *the* storage ring facility for polarized beams and hadron physics worldwide

IKP scientists have widely acknowledged experience in

- **storage rings**
- **polarized beams**
- **polarized targets**
- **spin physics**

Balance

Operation of COSY and construction of HESR was mastered during PoF 2

Building of HESR and work for the EDM project can well be handled during PoF 3

Potential

The physics case for charged particle EDM searches is outstanding („must-do“ experiment)

COSY is the *ideal starting point* for the storage ring EDM project; FZJ provides an excellent environment; staging is the approach of choice