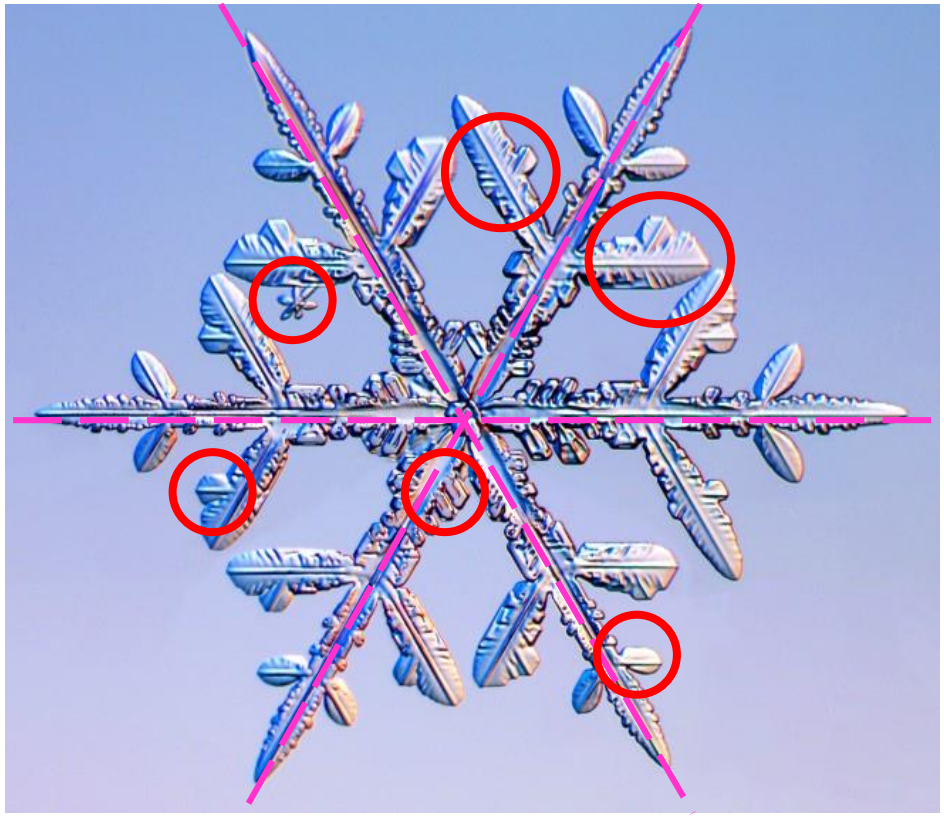
Time Reversal Invariance at COSY (TRIC)

Yury Valdau

Symmetries in Nature



Six fold symmetry

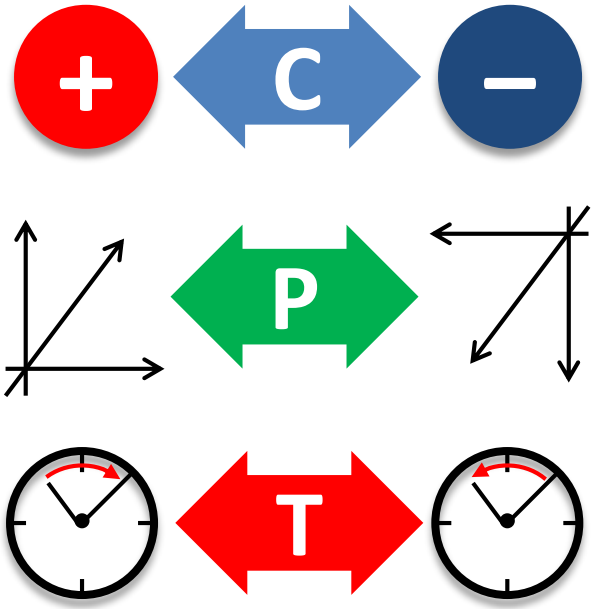
But not perfect

"…physics is the study of *a*symmetry"

P.W. Anderson, Nobel prize physics (1977)

Symmetries in Physics

- 3 *discrete* symmetries C, P, and T
- C, P, T, and CP violated in weak interactions
- Combined CPT conserved
- Combined CP/T symmetry links matter and anti-matter



All known symmetry violations incorporated in Standard Model (SM)

CP/T Violation in Early Universe

Big Bang → Time → Today

Matter and Antimatter

Only Matter!

New CP/T violation beyond SM must exist!

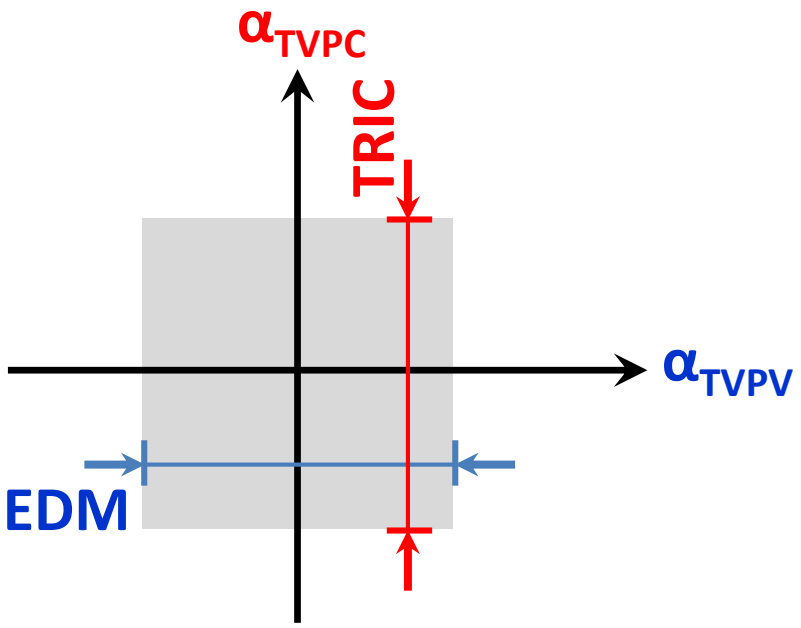
Physics Beyond SM

Consider T violation (with and without P conservation)

$$L = L_{SM} + \alpha_{\mathrm{TVPV}}\, L_{\mathrm{TVPV}} + \alpha_{\mathrm{TVPC}}\, L_{\mathrm{TVPC}} + \ldots$$

EDM

TRIC



EDM and TRIC test different extensions of SM

Search for TVPC effects

Null observable in double polarized forward scattering

Optical theorem: $\sigma_{\mathrm{Total}} = \frac{4\pi}{k}\, Im\left[F\left(0^{\circ}\right)\right]$

Present limit: $\vec{n} + {}^{165}\overrightarrow{\mathrm{Ho}}$ $\qquad A = \frac{\sigma_{\mathrm{TVPC}}}{\sigma_{\mathrm{Total}}} \leq 2.2 \times 10^{-5}$

TRIC (Time Reversal Invariance at Cosy):

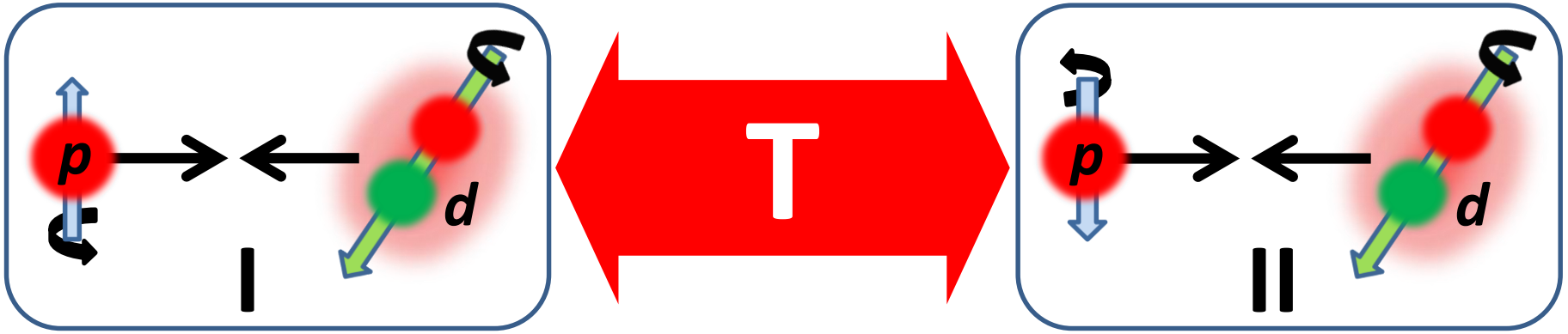
- search for direct T violation in $\vec{p}\vec{d}$ scattering
- transmission experiment in Storage Ring

Goal: improve limit by at least one order

Principle of TRIC

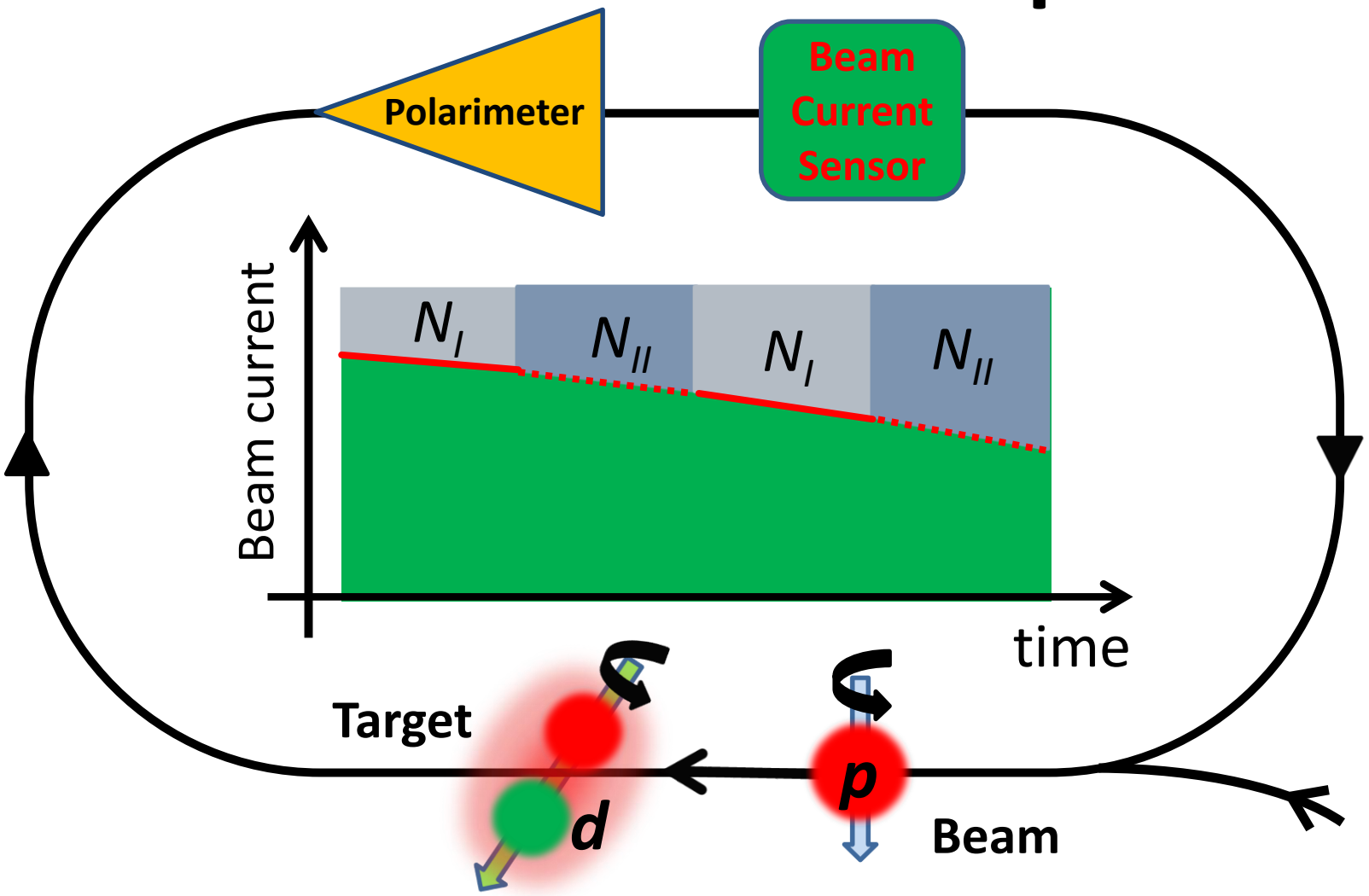
Genuine T-violating observable in $\vec{p}\vec{d}$ scattering:

$$A_{\vec{p},\vec{d}} \sim \frac{N_I - N_{II}}{N_I + N_{II}} \begin{cases} = 0 & \text{T conserved} \\ \neq 0 & \text{T violated} \end{cases}$$



Trick behind TRIC: T reversal via spin-flip!

Measurement Principle

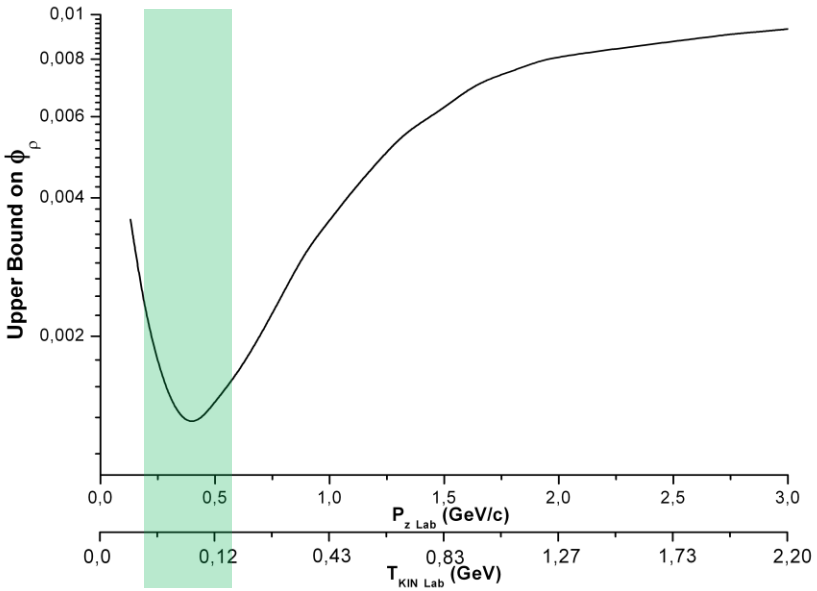


Comparison of slopes for I and II

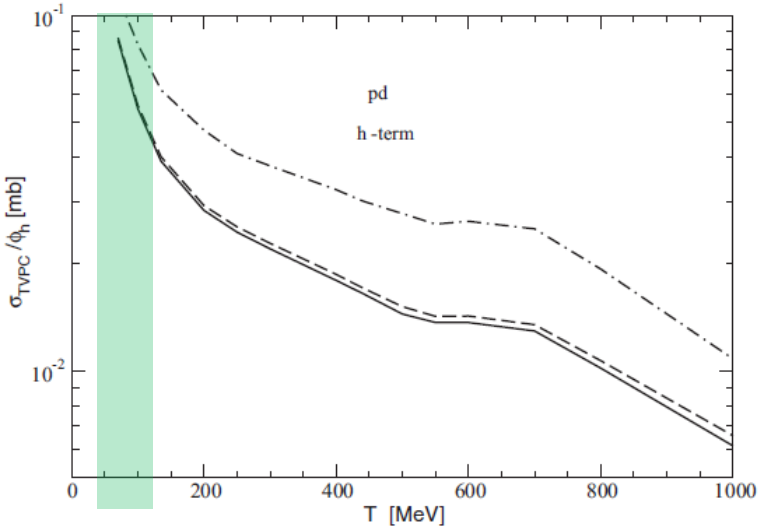
Prerequisites

- Polarised $\vec{p}$ beam
- Polarised $\vec{d}$ target
- Beam/Target polarimeter
- Beam current sensor

Beam Energy for TRIC



M. Beyer NPA 560 (1993) 895



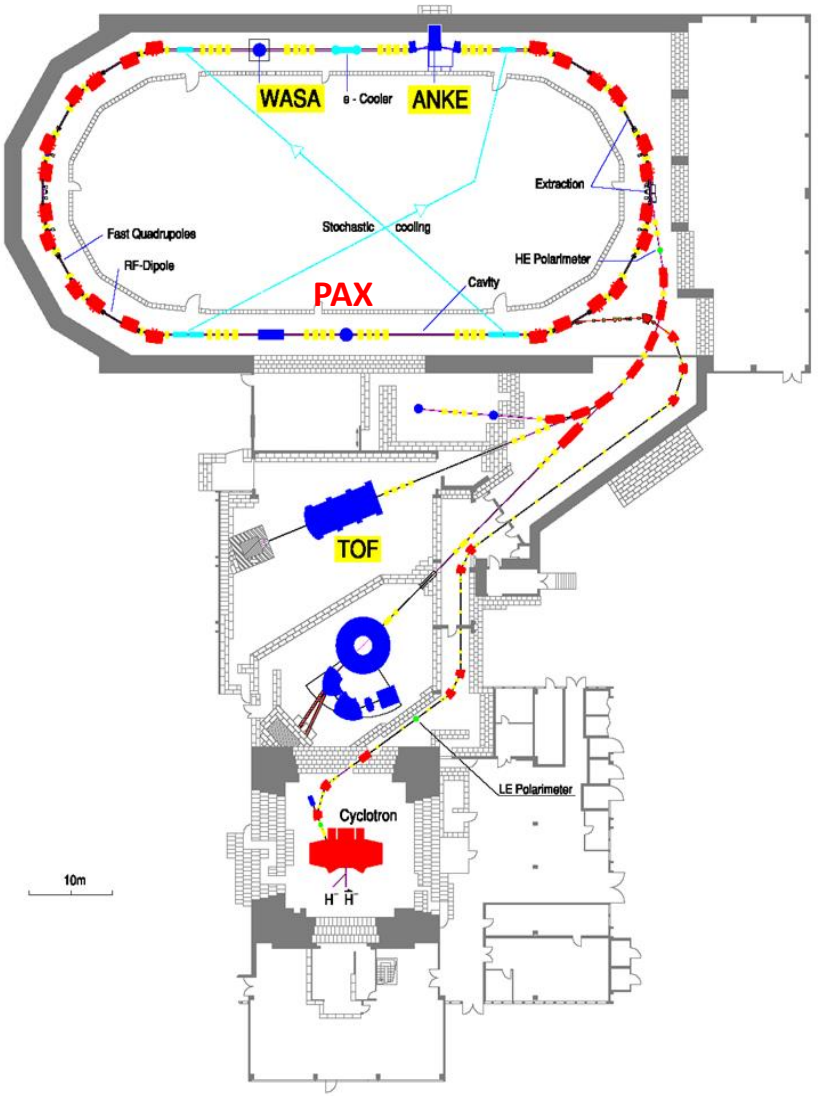
Yu. Uzikov PRC 92 (2015) 014002

Two independent theoretical calculations suggests to perform TRIC below 200 MeV

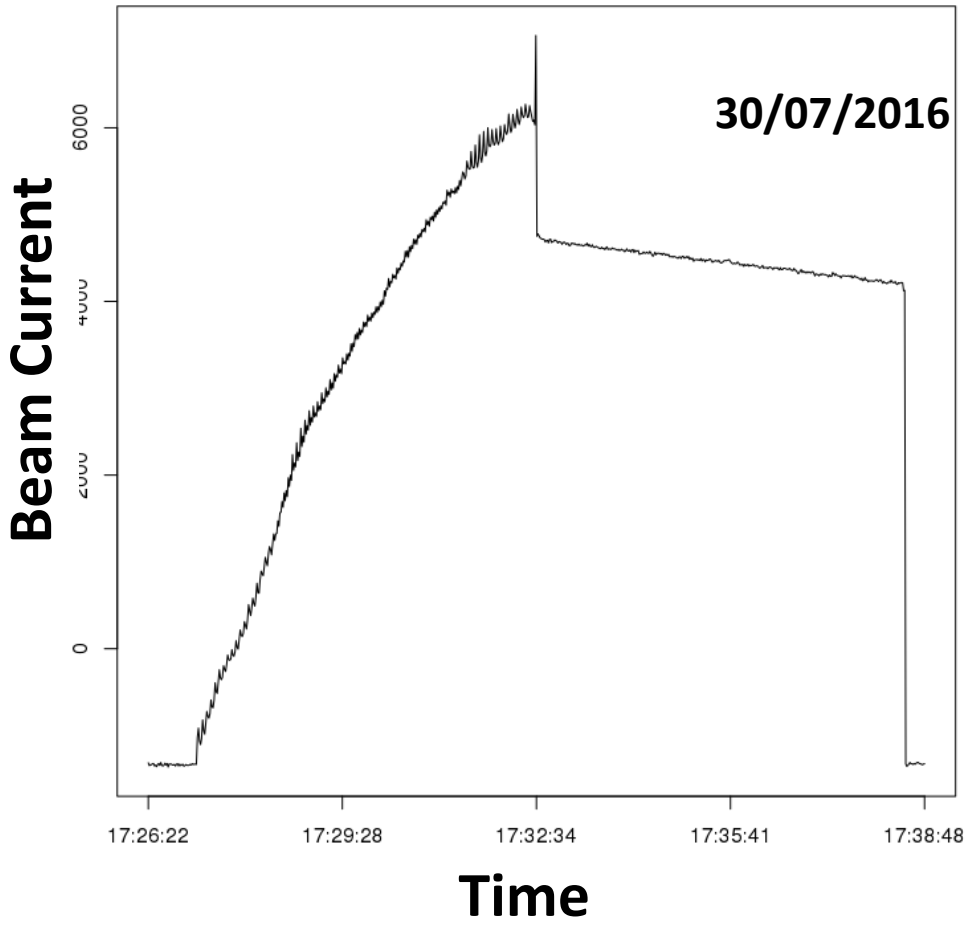
- COSY injection energy is 45 MeV
- COSY 100 kV e-cooler is operational up to 184 MeV
- Polarimetry data at 135 MeV is available (PRC 74 (2006) 064003)

COoler-SYnchrotron COSY-Jülich

- Momentum range:
  0.045-3.700 GeV/c
- Polarised and unpolarised
  p/d beams
- Stochastic and electron
  cooling
- Internal polarised gas
  targets
- Beam and target
  polarimeters



Polarised beam @ COSY



- Polarised beam intensity after stacking for:
  - 120 s → 1.7×10^9
  - 600 s → 5.0×10^9
- Polarisation in the ring
  - >50%
- Polarisation life time
  - >10000s
- Beam life time 5000 s (12000 s in Sep 2012)

COSY can provide beam for TRIC

Prerequisites

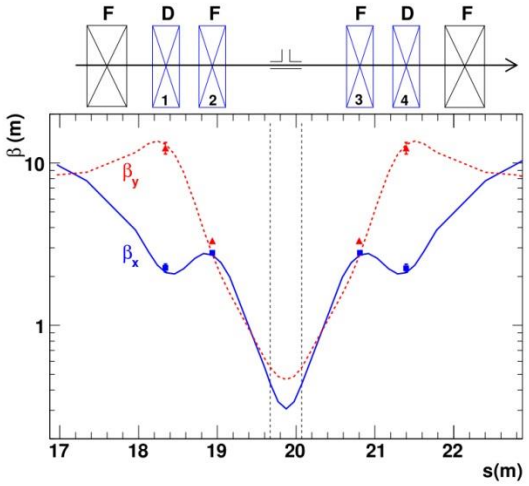
- Polarised $\vec{p}$ beam
- Polarised $\vec{d}$ target
- Beam/Target polarimeter
- Beam current sensor

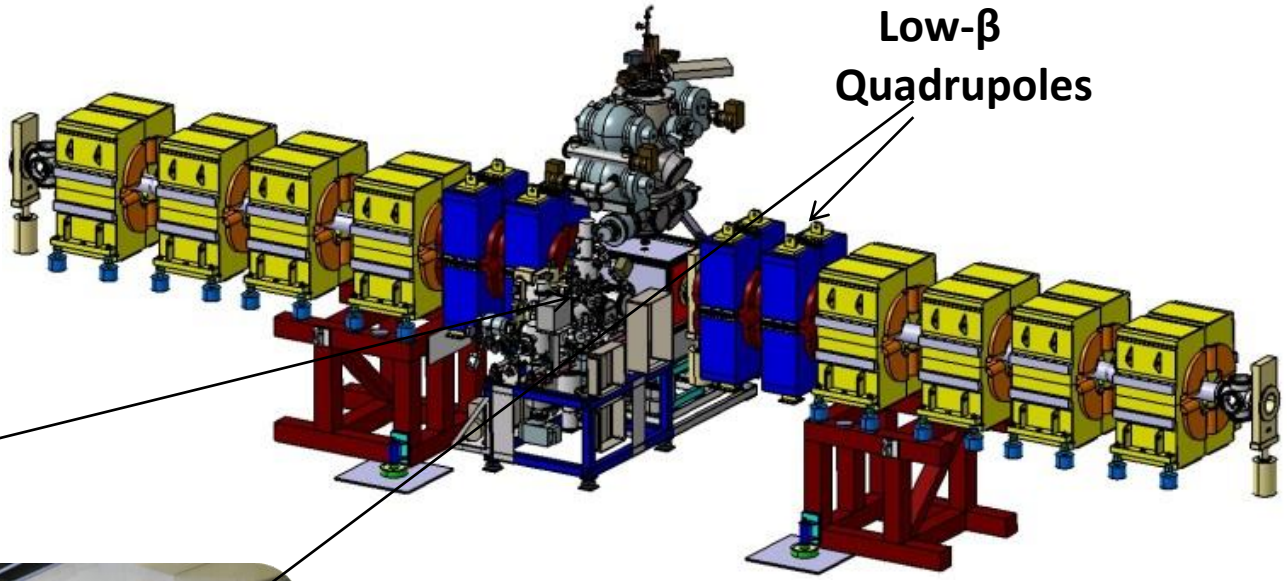
COSY Storage Ring

Prerequisites

- Polarised $\vec{p}$ beam COSY
- Polarised $\vec{d}$ target
- Beam/Target polarimeter
- Beam current sensor

PAX@COSY



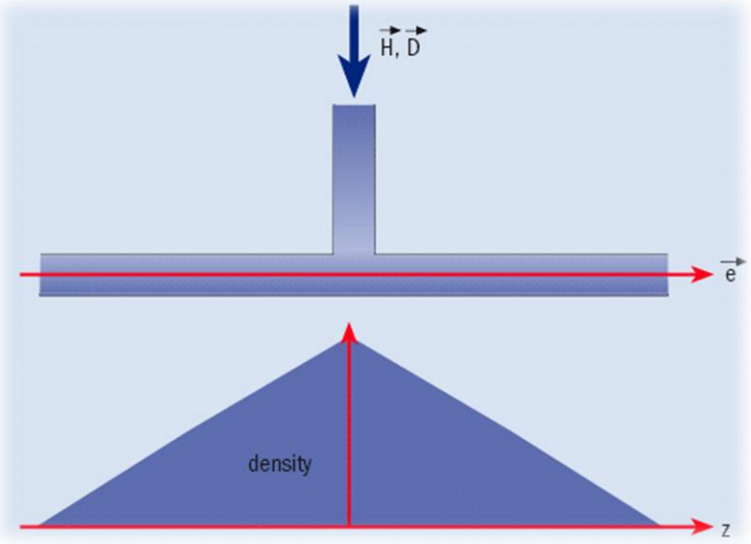


Target
Chamber

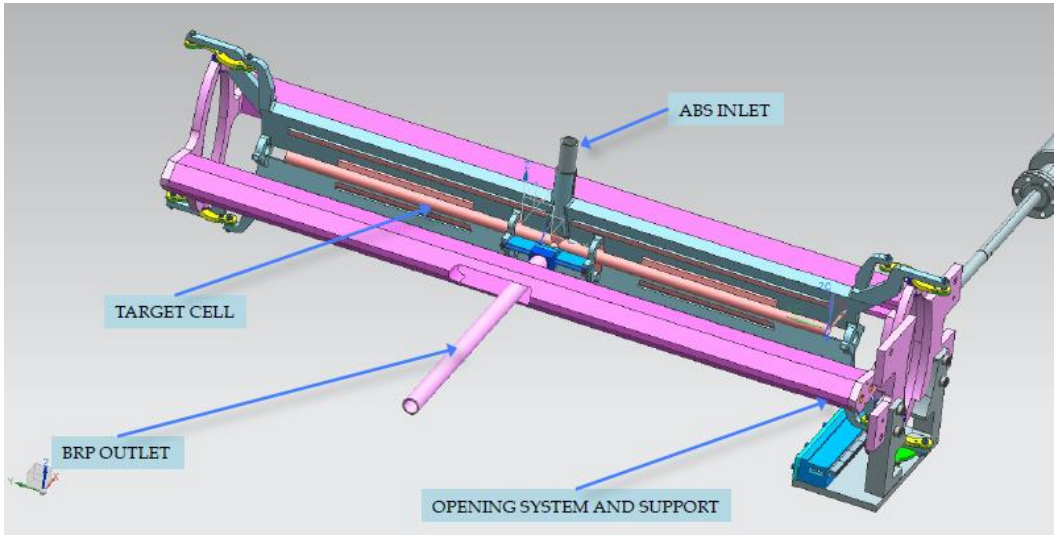
- The low-β section allows to use a storage cell of small diameter
- The storage cell and detector can be place inside a PAX target chamber
- The holding field system allows to control and flip the target polarisation

Storage Cell

Closed storage cell

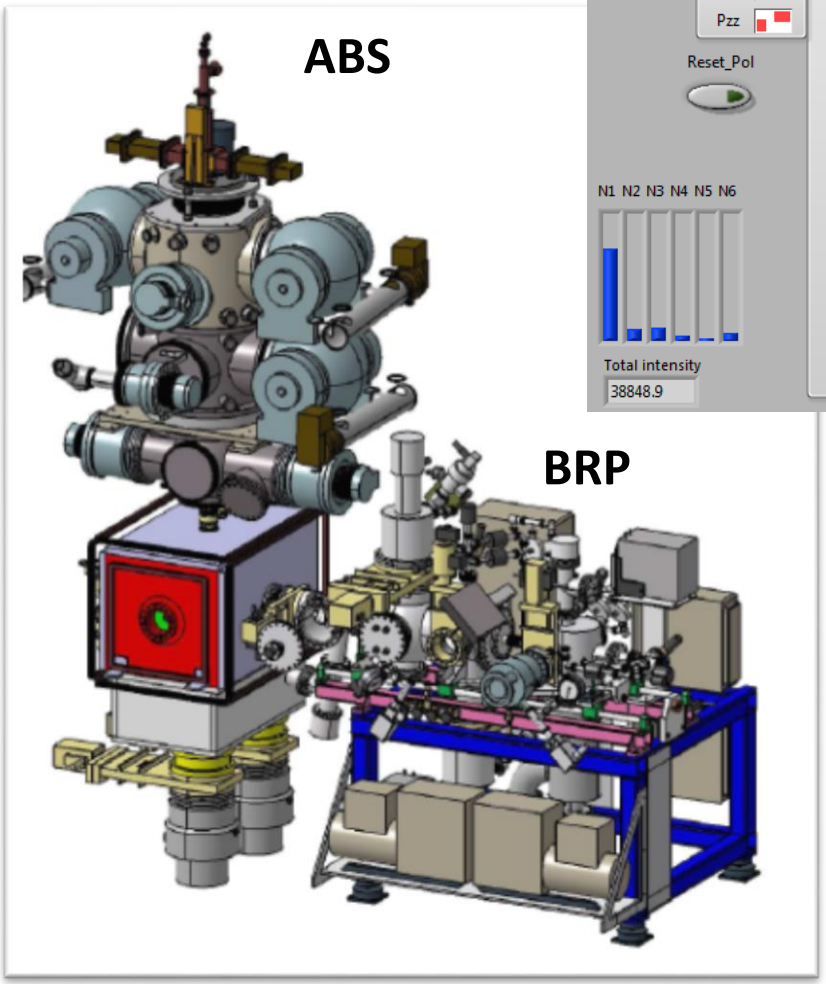


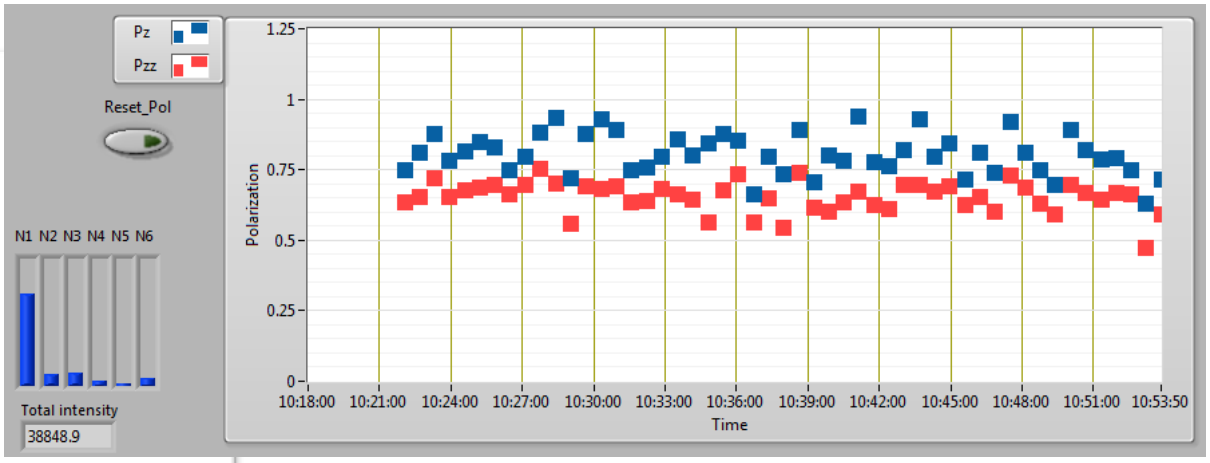
Opennable storage cell



- At PAX we have option to installation both types of the storage cells
- An opennable storage cell is under the preparation by the Ferrara group (2017)

Polarised D Target and Polarimeter





- During experiment in June 2016 PAX ABS and BRP were commisioned with D gas at COSY
- Deuterium Vector and Tensor polarisations more than 75% were measured with BRP

PAX D target is ready for TRIC

Prerequisites

- Polarised $\vec{p}$ beam — COSY
- Polarised $\vec{d}$ target — **PAX target**
- Beam/Target polarimeter
- Beam current sensor

Prerequisites

- Polarised $\vec{p}$ beam — COSY
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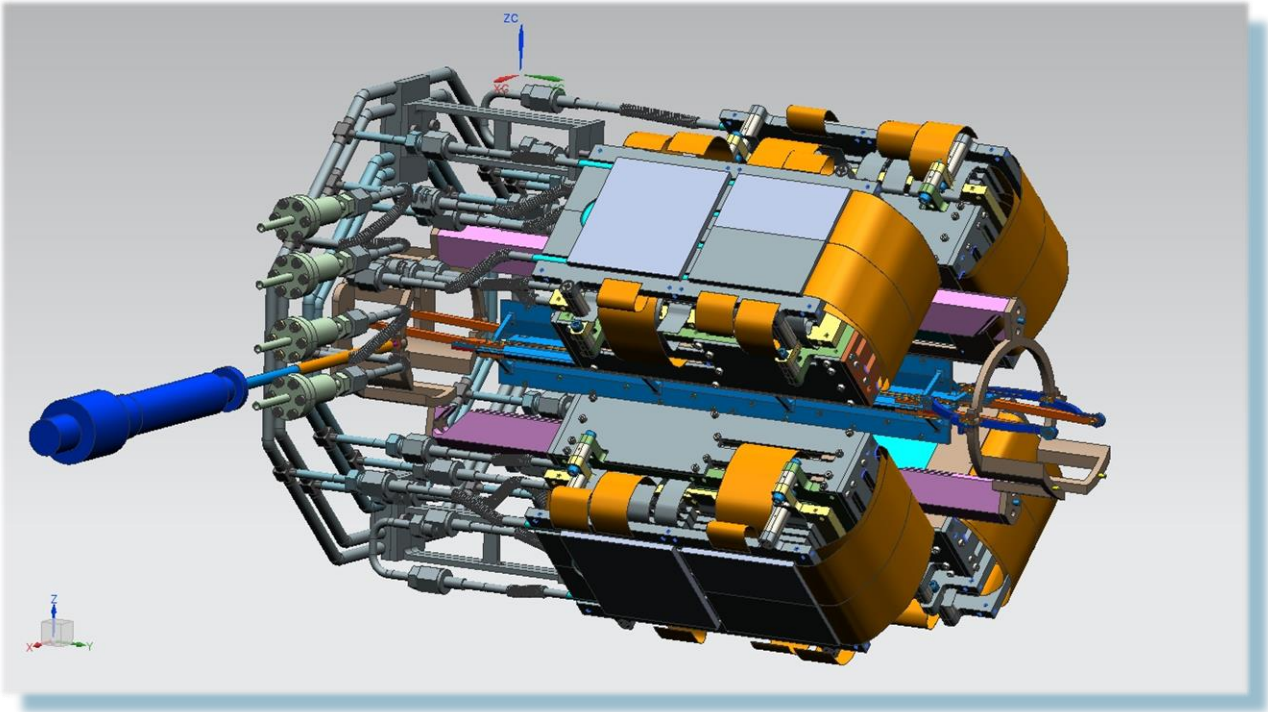
PAX Detector



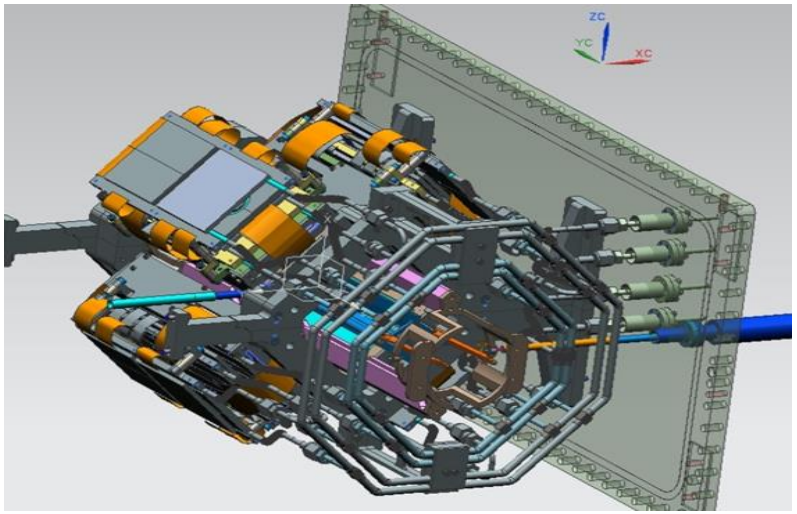
- φ-symmetric detection system
- 24 double-sided silicon strip detectors (300 µm, 300 µm, 1500 µm)
- Strip pitch of 0.7 mm results in a vertex resolution of ≤ 1 mm
- All spin observables measurable with φ-dependence ($\cos(\varphi)$, $\cos(2\varphi)$)

Setup and commissioning by COSY-PAX collaboration in 2017

Courtesy: PAX detector group

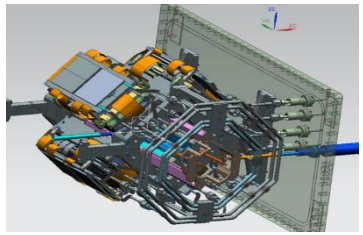
Prerequisites

- Polarised $\vec{p}$ beam — COSY
- Polarised $\vec{d}$ target — PAX target
- Beam/Target polarimeter — **PAX detector**
- Beam current sensor



Prerequisites

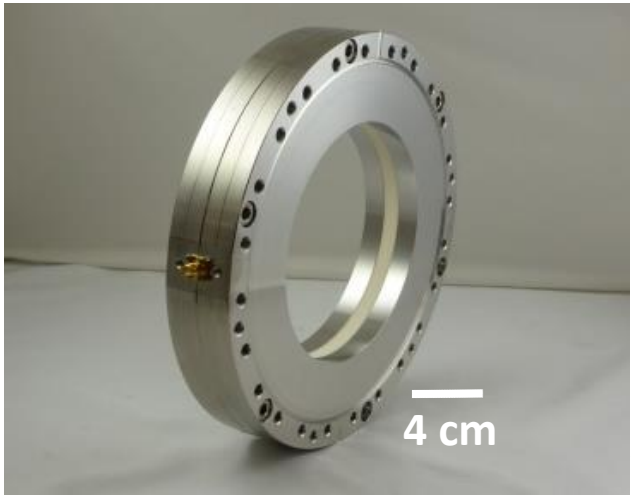
- Polarised $\vec{p}$ beam — COSY
- Polarised $\vec{d}$ target — PAX target
- Beam/Target polarimeter — PAX detector
- Beam current sensor — **Challenge $\Delta I/I \sim 10^{-4}$**



Meeting the Challenge

Fast Current Transformer:

- Commercial device (Bergoz)
- Sensor for bunched beam

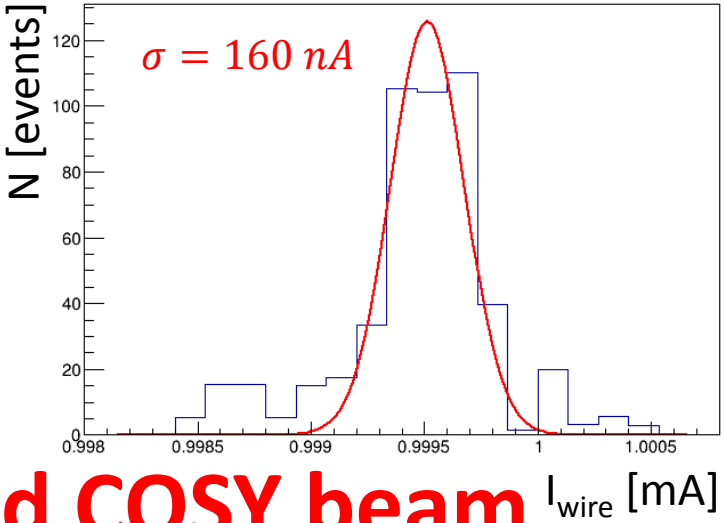


Readout Electronics:

- Lock-In-Amplifiers
- High resolution ADC

Achieved in Lab:

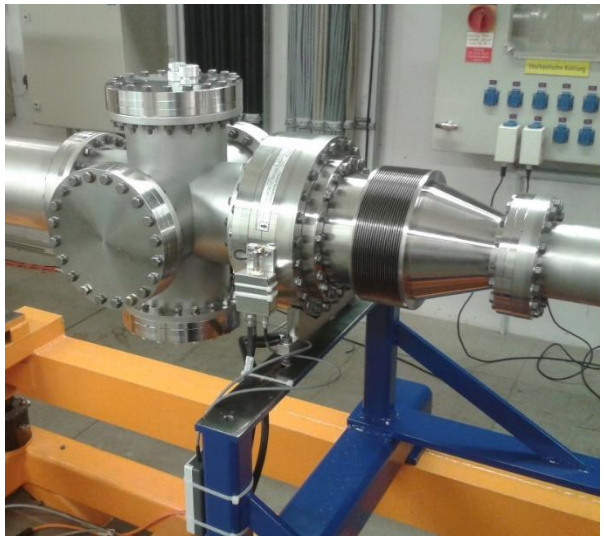
- Wire & Generator to simulate beam
- Relative resolution $\Delta I/I \sim 10^{-4}$

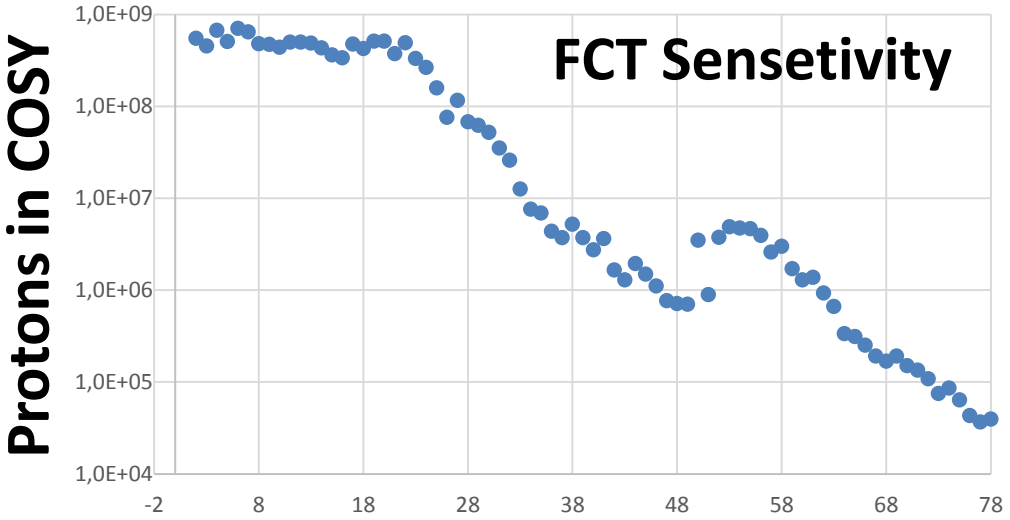


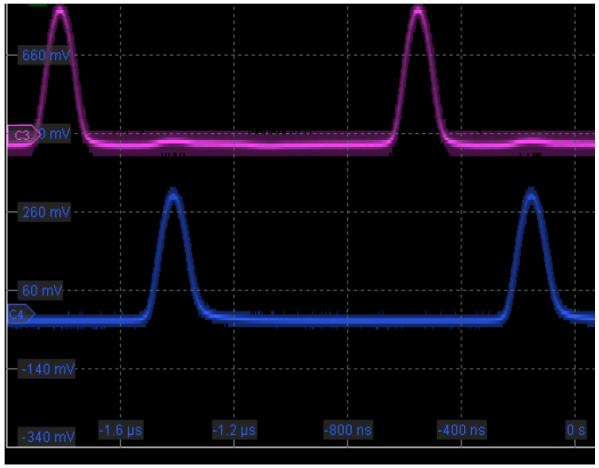
Challenge:

Same resolution for stored COSY beam

FCT Commisioning @ COSY





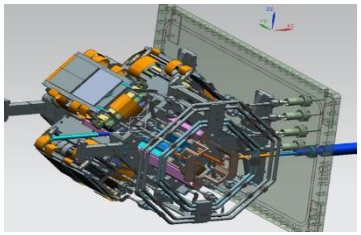


- FCT & analog readout have been commissioned at COSY in June 2016
- With FCT we can detect down to 40000 protons stored in COSY

FCT is ready for TRIC

Prerequisites

- Polarised $\vec{p}$ beam — COSY
- Polarised $\vec{d}$ target — PAX target
- Beam/Target polarimeter — PAX detector
- Beam current sensor — FCT



TRIC is possible at COSY

Summary & Outlook

- TRIC is search for physics beyound of SM
- TRIC is precision transmission null experiment at COSY
- COSY, PAX ABS, PAX BRP, and FCT are ready for the TRIC experiment
- Data collected in June 2016 allow to develop TRIC analysis methods
- We plan to apply for a new beam time in 2017