Test of Time-Reversal Invariance in pd scattering at COSY

COSY Proposal #215

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for ANKE and PAX collaborations

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http://www2fz-juelich.de/ikp/publications/List_of_all_COSY_Proposals.shtml

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- **Physics case**

CP/T invariance violations are observed in K and B meson decays (the most recent one from BaBar **:** *PRL 109(2012)211801*) **but**
their amount is not sufficient to explain baryon-antibaryon asymmetry of the universe in SM.

No Time-Reversal Invariance violation was observed in baryon system so far.

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- **Status of TRI tests in baryon systems**

Strength of T-odd potential

Reaction	Result	Symmetry	Reference
EDM of n	$g_{PT}<10^{-11}$	PT	PR43(1978)409
	$g_T<10^{-4}$	T	PRD63(2001) 07600
γ-γ in ^{57}Fe	$\alpha_T<10^{-4}$	T	PRC53(1996)2546
P-A in pp	$g_T<10^{-2}$	T	PR119(1960)352
$p^{27}Al \rightarrow {}^4He+{}^{24}Mg$	$\alpha_T \approx g_T<10^{-3}$	T	PRL51(1983)355
A_5 in $n^{165}Ho$	$\alpha_T<7.1*10^{-4}$	T	PRC55(1997)2684
	$A_5=8.6*10^{-5}$		
$\vec{p}\vec{d}\ A_{y,xz}(\Delta\sim10^{-6})$	$\alpha_T<10^{-6}$	T	This experiment

g-strength of T-odd NN potential

α-strength of an effective T-odd N-core potential

P-invarience null-test:

Phys.Lett.B 256(1991)11

A_z (pp->pp) observable must vanish if the parity is conserved

Accuracy achieved $\delta A_z \sim 10^{-8}$

P-even T-odd null-test:

A single experimental observable must vanish if TRI is valid

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- **Conception of TRI null-test:** a single P-conserving T-voilating observable of the same reaction must vanish in case of TRI, interpretation based on scattering matrix symmetry only

F.Arash, M.J.Moravcscik and G.R.Goldstein PRL 54(1985)2649

Theorem: For any reaction A+B->C+D it is impossible to construct a null experiment that would unambiguously test the validity of TRI independently of dynamic assumptions.

Exception: total cross section that can be link to the forward scattering amplitude via the optical theorem.

H.E. Conzett PRC 48(1993)423

In double-polarized pd-scattering, the total cross section asymmetry defined by $\mathbf{A_{y,xz}}$ **allows the TRI null-test.** $\sigma_{tot}=\sigma(1+A_{y,xz}p_y p_{xz}) = 4\pi/k\ \mathrm{Im}(\mathrm{Tr}(\rho)\cdot F(0))$

Counting rules(*G.G.Ohlsen, Rep.Progr.Phys. 35(1972)717*)

Time-reversal	: n_x	has to be	odd
Parity conservation	: n_x+n_z	has to be	even
R_z invariance	: n_x+n_y	has to be	even

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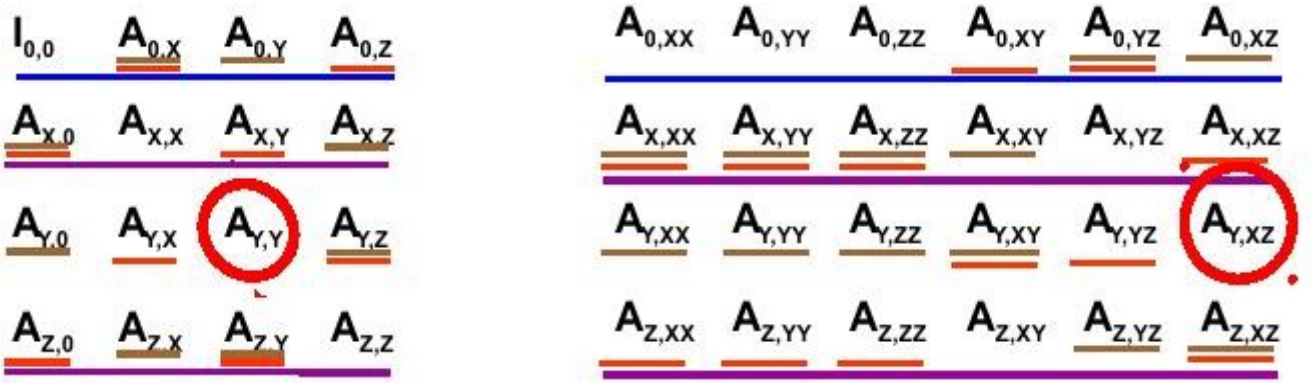
- **Spin observables in double-polarized pd**



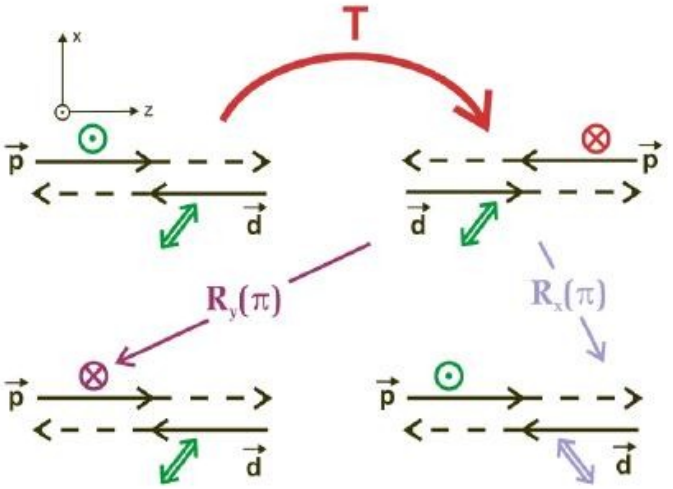
Line cancels because of: Proton spin flip
p_x, p_z negligible for protons

Quantity cancels because of: ~~R~~ ~~P~~

D. Eversheim, B. Lorentz and Yu. Valdau, COSY-Proposal #215

$A_{Y,Y}$ is expected to be small but has to be measured

Spin-flip of P_Y ($P_{X,Z}$) reproduces the time-reversal configuration



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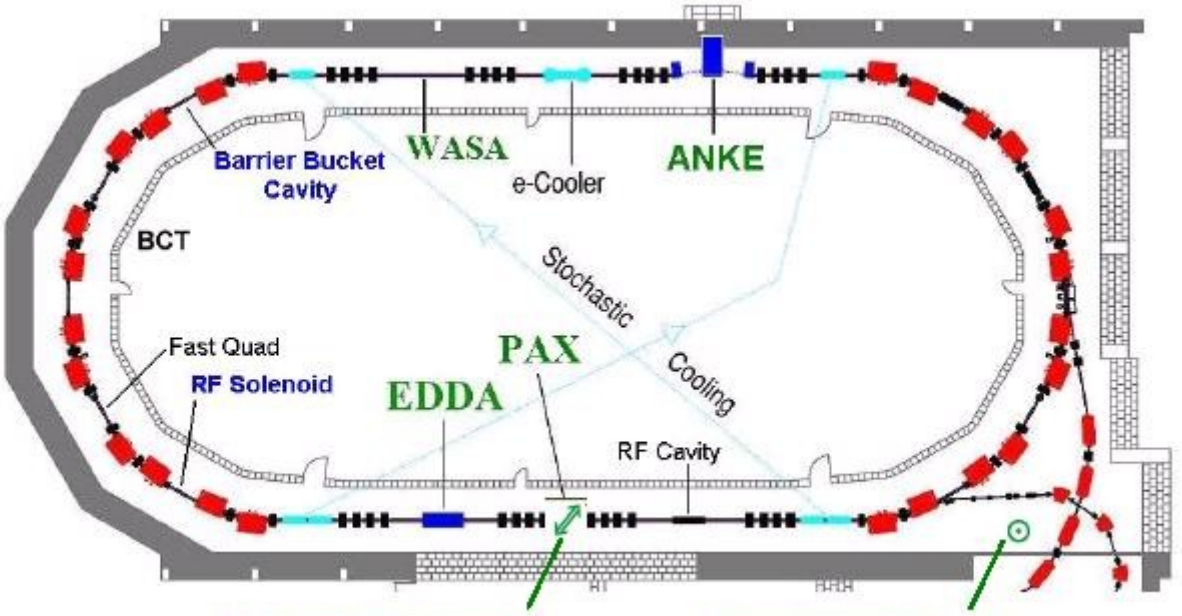
- **σ_{tot} determination: Beam transition through polarized gas target**

Transition factor: $T(n) = I(n) / I(0) = \exp(-(\sigma_T \rho d\, n))$

$$\Delta T_{y,xz} = \frac{T^+ - T^-}{T^+ + T^-} = \frac{\exp-(\chi^+) - \exp-(\chi^-)}{\exp-(\chi^+) + \exp-(\chi^-)} = -\sigma_o\, \rho d\, n\, P_y\, P_{xz}\, A_{y,xz} \quad \chi \ll 1$$

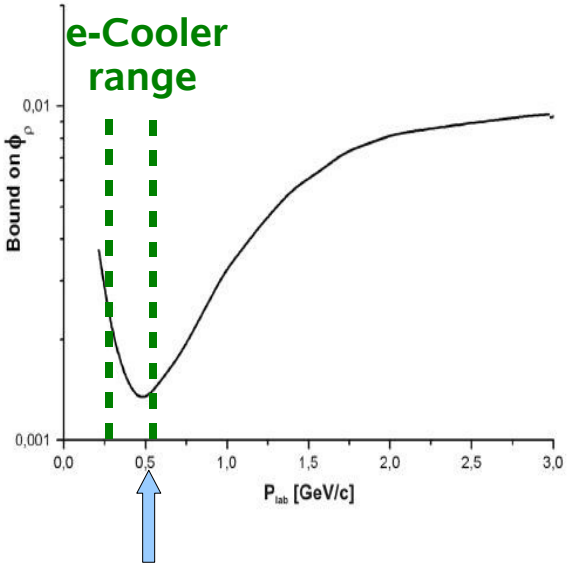
COSY acceptance ~ 5 mrad



Deuteron polarization P_{XZ}
D gas cell diameter ~ 10mm
length 400mm

Proton polarization P_y
Beam diameter ~ 35mm
at the injection (T=45MeV).

Sensitivity to T-odd amlitude
M.Beyer NPA 560(1993)895
(redrawn)



P = 0.52 GeV/c
T = 135 MeV

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- **Expected accuracy**

(D.Samuel,Diss.HISKP,Bonn University(2007)

$$\delta A_{y,xz}^{meas} = \frac{8 \cdot 10^{-6}}{I_0 \, \sigma_0 \, \rho d \, \nu \, P_y \, P_{xz}} \frac{\sqrt{\Delta t}}{h\sqrt{H}} \delta I$$

I_0 - initial beam current ($N_p = 3 \cdot 10^9$)

σ_0 - unpolarized total cross section (80 mb)

ρd - target density ($8 \cdot 10^{13}$ at/cm^2)

ν - beam revolving frequency ($8 \cdot 10^5$ Hz)

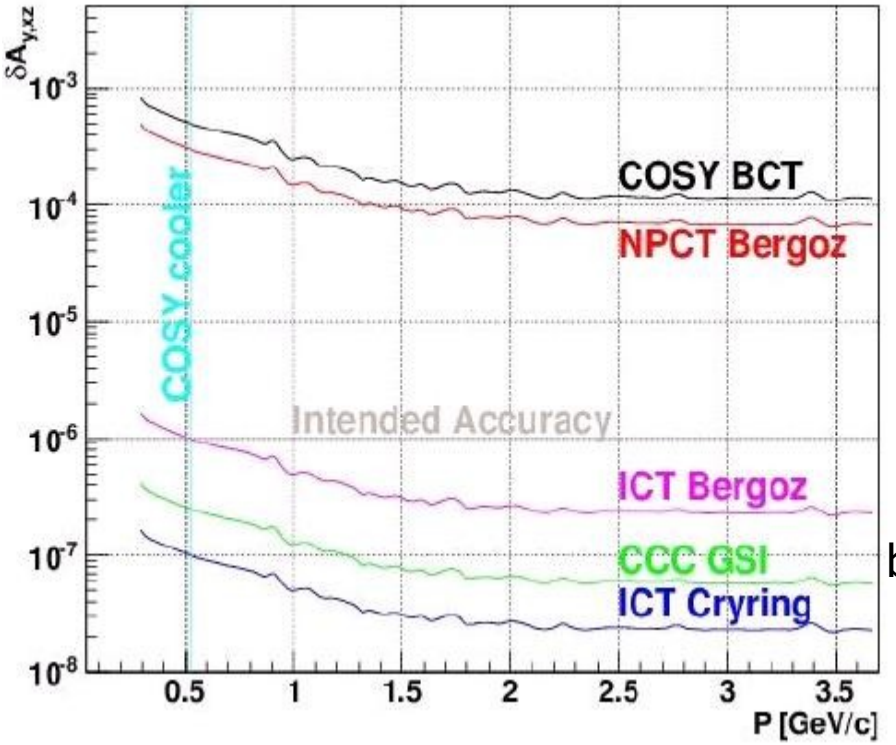
P_y, P_{xz} - beam and target polarization (0.8)

Δt - current measurement interval (1s)

h - one spin state interval (10min)

H - total measurement time (30days)

δI - current measurement error



DC usual beam

AC bunched beam

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- **Experimental requirements and current status**

	Required (T = 135 MeV)	**September 2012 Status**	**Spin_Filtering** (T = 49 MeV)
COSY beam mode	Bunched	Bunched	Unbunched
Intensity(with gas cell)			
unpolarized		$3 \cdot 10^9$	$5 \cdot 10^9$
polarized	$3 \cdot 10^9$	$2 \cdot 10^8$	$1 \cdot 10^9$
Beam life-time	$(1\text{-}3) \cdot 10^4$s	$(1.5\text{-}0.8) \cdot 10^4$s	$8 \cdot 10^3$s
Polarization P_Y	0.8	0.7	0.75
Polarization life-time	$(1\text{-}3) \cdot 10^5$s	$3 \cdot 10^3$s	$2 \cdot 10^5$s
PAX gas target	D	H	H
Density (atom/cm^2)	$8 \cdot 10^{13}$	$6 \cdot 10^{13}$	$5.5 \cdot 10^{13}$
Vector polarization	0	-	0.8
Tensor polarization	0.8	-	0.7 (ANKE D gas target)
Polarimetry:			
Beam	EDDA, PAX Si detector		STT@ANKE
Target	BRP, PAX Si detector		BRP
Beam current monitor	ICT Bergoz(~30000$) planned to be produced in 2014 (SQUID-device availability is under negotiations)		