Time Invariance ViOLating Interactions

Exploiting spin as a "time-reversal" knob

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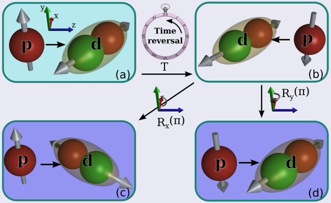
for the PAX and JEDI Collaborations

Mainz - September 29^{th}, 2022

TIVOLI: motivation

$A_{Y,XZ}$ "pure" T-violating observable in $\vec{p}$-$\vec{d}$ scattering

- Total cross section:
  - $\sigma_{total} = \sigma_0(1 + A_{Y,XZ} P_Y^{beam} P_{XZ}^{target})$
- Experimental approach: spin as a "time-reversal" knob



- Requirements:
  - Vector pol. p-beam: P_Y^{beam}
  - Tensor pol. d-target: P_{XZ}^{target}

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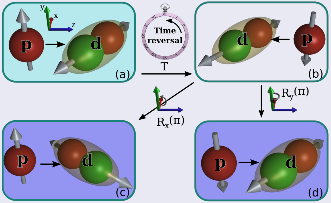

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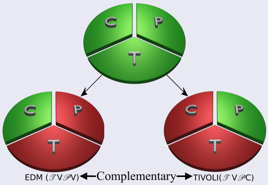
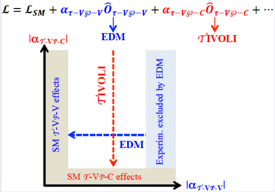
BSM physics search complementary to EDM search





TIVOLI: experimental concept

Storage rings offer a unique experimental environment

- Optical theorem relates forward scattering amplitude to total cross-section
- Use of storage ring as a zero degree detector
- Total cross section affects beam lifetime ($I = I_0 e^{-\sigma \rho_d}$)
- Sensitive beam current sensor required

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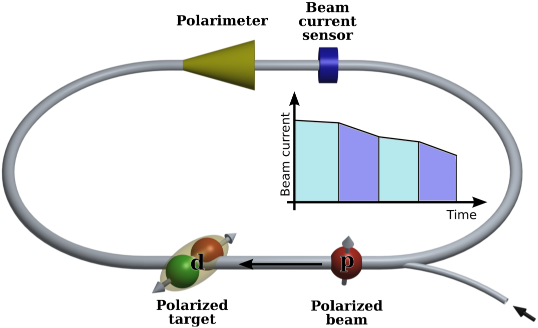
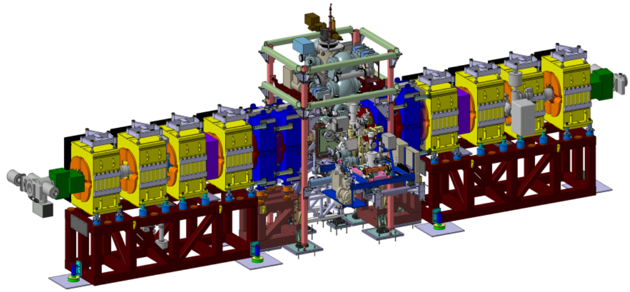


- Objective: improve the limit on α_T by 1-2 orders of magnitude

Available setup

Interaction point (commissioned at COSY)

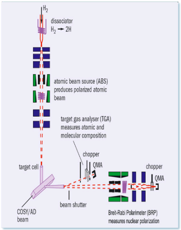
- Low-beta section
- Polarized target with storage cell
- Silicon vertex detector for target and beam polarimetry

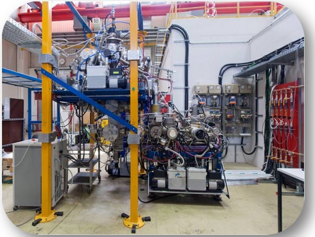


Polarized internal H/D target with storage cell

Polarized H/D target and Breit-Rabi polarimeter

- Injection and online monitoring of target polarization





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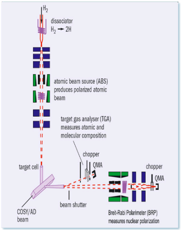
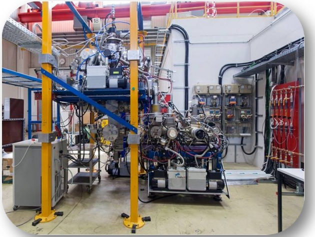
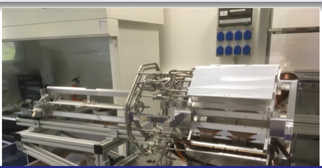


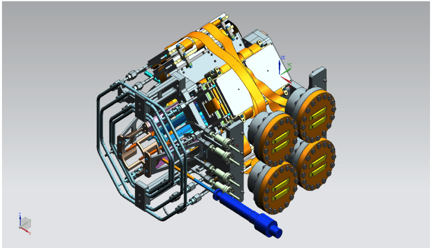


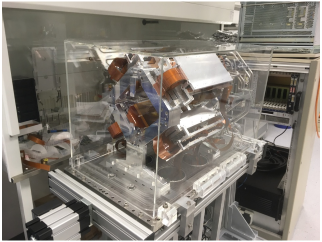
Openable storage cell

- Increases target density by 2 orders of magnitude
- Opens at beam injection to increase ring acceptance



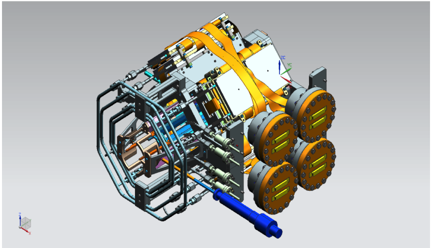
Si vertex-detector for target and beam polarimetry

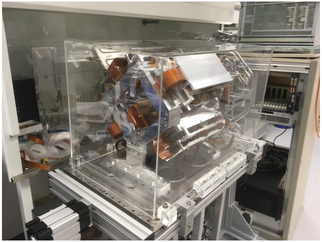




Multipurpose silicon telescope detector installed around the storage cell

- p-p (and $\bar{p}$-p) elastic
- p-d elastic
- deuteron breakup
- In the range 40-150 MeV beam energy





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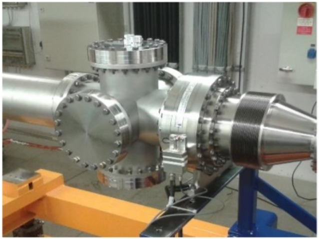
Purpose of detector for the TIVOLI experiment:

- absolute measurement of the deuteron target polarization
- calibration of the Breit-Rabi polarimeter for d
  - A_y in p-d elastic scattering
- measurement of the beam polarization
- beam position monitor in the cell

Fast Current Transformer

- Inductive pickups with bunched beam
- Preliminary test at COSY in the range: 4×10^4 - 2×10^9 stored protons



Conclusions

TIVOLI

- T-violating interactions not easily experimentally accessible
  - $A_{Y,XZ}$ "pure" T-violating observable in $\vec{p}$ - $\vec{d}$ scattering
- Search for physics BSM
  - TIVOLI (T-odd/P-even) complementary to EDMs (P-odd,T-odd)
- Storage rings represent an ideal zero-degree detector
  - Exploitation of beam and target polarization as "time-reversal" knob

Potential improvement of 1-2 orders of magnitude limit on α_T

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Implementation in ESR

- Staged approach required
  1. Polarized jet target
  2. Polarized proton beam in ESR and polarization preservation
  3. Implementation of low-β section with storage cell and detector
  4. Further improvement: long spin-coherence time

Appendix: T-V experimental limits

Measurement	Limit	Comments	Ref.
$\gamma-\gamma$ correlations in ^{57}Fe	$\alpha_T < 5\cdot10^{-6}$	direct $\mathcal{T}$-V	[14]
$\vec{n}$ transmission through polarized ^{165}Ho target	$g_{\rho T} < 2.3\cdot10^{-2}$ $\alpha_T < 2.8\cdot10^{-4}$	direct $\mathcal{T}$-V; heavy target corrections	[15,16]
Detailed balance in $p+^{27}Al \leftrightarrows {}^{4}He+^{24}Mg$	$\alpha_T \sim 10^{-3}$	direct $\mathcal{T}$-V; kinematic corrections	[17]
Charge Symmetry Breaking (CSB) ΔA for polarized np and pn scattering	$g_{\rho T} < 6.7\cdot10^{-3}$	direct $\mathcal{T}$-V	[18,19]
Polarization, analyzing power in (pol.) p-p scattering	$g_T < 3\cdot10^{-2}$	direct $\mathcal{T}$-V	[30]
Time evolution in B^0 mesons; exchange of $\|i\rangle$ and $\|f\rangle$ state	$\Delta S_T^+ = -1.37 \pm 0.15 < 0$ $\Delta S_T^- = 1.17 \pm 0.21 > 0$	direct $\mathcal{T}$-V; 1st observ., consistent with $\mathcal{CP}$-V	[31]
Time evolution $K^0 \leftrightarrow K^0$_bar transition probabilities (flavor mixing asymmetry)		indirect (via $\mathcal{CP}$-V)	
Double pol. pd-scatt. $A_{y,xz}$ "null observable"	Goal: $\delta A_{y,xz} \sim 10^{-6}$	direct $\mathcal{T}$-V	TIVOLI

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