Overview of the status of PAX/APEX pair-plasma project

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Overall plan of the PAX/APEX project to create e+/e-plasmas*:
NEPOMUC slow positron source** + accumulator*** + SC dipole/stellarator

NEutron-induced
POsitron source MUniCh

Fast neutron-based
slow positron facility

DC positron beam of
$10^9$/s at 1 keV, $10^7$/s at 5 eV

Positron Accumulation eXperiment
- accumulation of many positrons
- buffer gas cooling & multi-cell trapping***
- pulse extraction of $10^{11-12}$ (target value) e+

A Positron-Electron eXperiment
- formation of e+ / e- pair-plasma
- dipole and stellarator
- cross-field injection of particles

PAX/APEX experiments and research topics

- **PAX (Greifswald and Garching)**
  IPP Garching, Greifswald University (L. Schweikhard)
  - First point scientific system
  - high field traps for e-/e+ experiments
  - positron accumulator system
  - cooling and injection of e+ (Na$^{22}$) in a linear trap
  - phosphor screen responses to e+ and e-
  - e- experiments with high-field (5T) trap
  - buffer gas trap and multi-cell trap at NEPOMUC

- **APEX (TUM-MLZ / IPP Garching)**
  - Retarding field analyzer
  - prototype dipole trap (Neodym magnet)**

- **SC toroidal traps**
  - APEX-D levitated dipole****
  - closed field lines
  - levitation system
  - optimized SC magnet
  - cooling/excitation system
  - plasma experiments...

**Notes:**


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Efficient injection of positrons into dipole magnetic field

- Positron injection efficiency is essential
  - beam ~ $10^7$-$8$ e+/s, accumulator ~ $10^9$
  - at least $10^9$ positrons are needed in dipole

- Cross-field injection is not straightforward
  - drift injection across separatrix
  - beamline ~ $5$ mT << magnet ~ $0.6$ T

  ➡️ **ExB drift** by perpendicular electric fields*

- Loss is minimized by optimizing electrode voltages
  ➡️ **100% efficiency** of injection into dipole magnetic field

*another method: photo-ionization of Ps Rydberg atoms 2012 Pedersen+
Long trapping of positrons in a dipole magnetic field

J. Horn-Stanja+, submitted to PRL

- trapping time of positrons after drift-injected into the dipole field
- the trapping time strongly depends on system symmetry
  - by gating ExB plate voltages (0 at trapping): \( \tau \approx 0.1\text{ms} \rightarrow \approx 10\text{ms} \)
  - by gating other injection electrodes \( \rightarrow \tau \approx 100\text{ms} \)
  - by positively biasing the magnet to reduce mirror loss \( \rightarrow \approx 1\text{s} \)

- Field asymmetry due to the beamline field and magnetization direction of the magnet can be a loss reasons

![Trapping time with and without gating the ExB plate voltages](image1)

![Trapping with positively biasing and grounding the magnet](image2)
Radial compression of positrons in a dipole field by rotating wall

- high-density state is needed for positrons
- asymmetry is needed for radial transport
- "rotating wall" by segmented electrodes
- short time modulation

Compression and increased injection efficiency

- w/o RW injection efficiency was ~ 55% in this condition
- w/ RW almost 100% efficiency
Simultaneous injection of positrons and electrons into dipole

M. Singer+, to be submitted

- Using an electron gun installed in the beamline, electron injection was realized while keeping the 100% injection conditions for positrons.

- Electron injection sometimes results in reduced positron number to be studied with improved experiments in coming beamtime.
Development status of dipole experiments and tasks

Prototype trap with permanent magnet
- drift injection scheme
- positron trapping
- radial compression

Levitated SC dipole*
- simultaneous trapping of e+ and e-
- SC coils and levitation system
- planned to be operated before 2019

Mechanically supported SC dipole
- injection and trapping in symmetric system
- planned to be run in 2018 September beamtime

Summary and future work toward e+/e- pair plasmas

The PAX/APEX team aims to create and study magnetically-confined electron-positron pair plasmas in stellarator and levitated dipole devices.

Results obtained so far (today, mainly dipole activities were reported):

- e+ system from first point Inc. assembled and operated in IPP
- first observation of different phosphor screen response to e+ and e-
- trapping of electron plasma and diocotron mode of e- in high-field trap
- characterisation of e+ beam at the open beam port of NEPOMUC
- efficient (~100%) injection of intense slow e+ beam into dipole field
- long (> 1 s) confinement of positrons in the prototype trap
- shaping of radial profiles of positron orbits by RW electric fields

Ongoing and future work

- application of RW to control radial inward diffusion of positrons
- development of levitated SC dipole and compact SC stellarator
- development of positron accumulator at NEPOMUC