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

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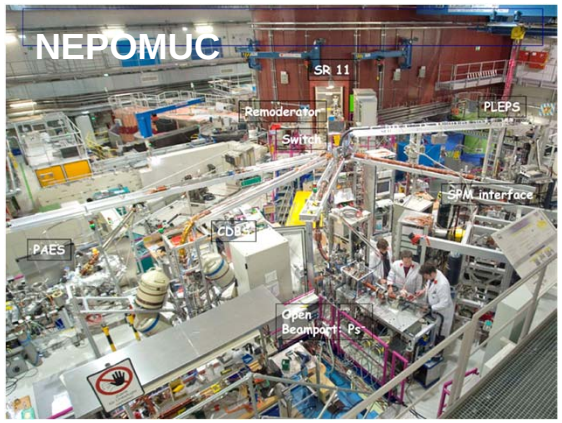
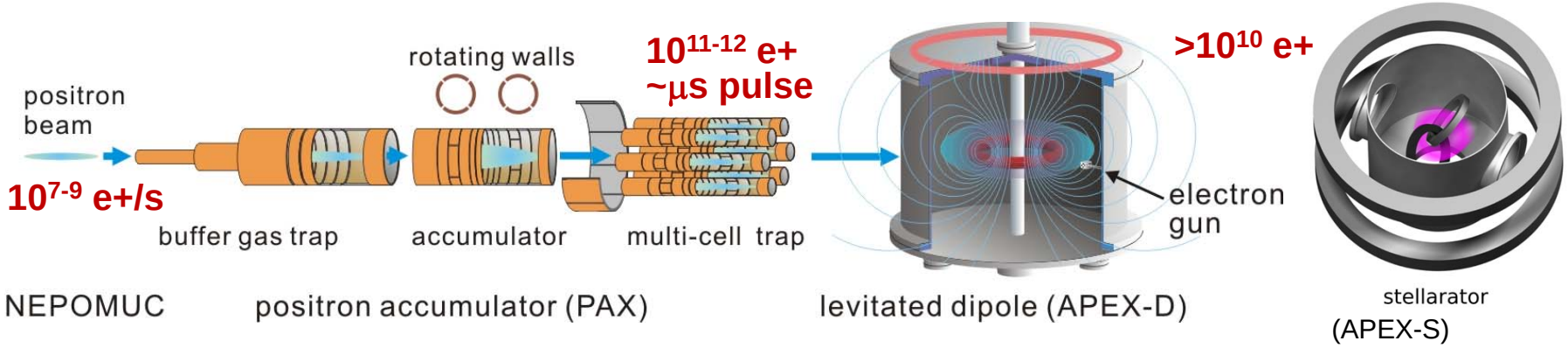
Overall plan of the PAX/APEX project to create e+/e-plasmas*: NEPOMUC slow positron source** + accumulator*** + SC dipole/stellarator

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

*2012 Pedersen+ New J. Phys, 2017 Stenson+ J. Plasma Phys.; **2012 Hugenschmidt+, New J. Phys.; ***2015 Danielson+, Rev. Mod. Phys.

PAX/APEX experiments and research topics

PAX (Greifswald and Garching)

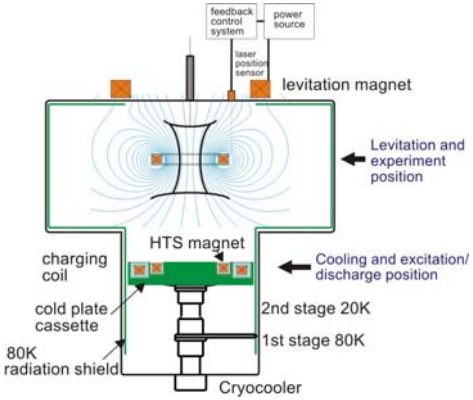
IPP Garching, Greifswald University (L. Schweikhard)

- 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

SC toroidal traps

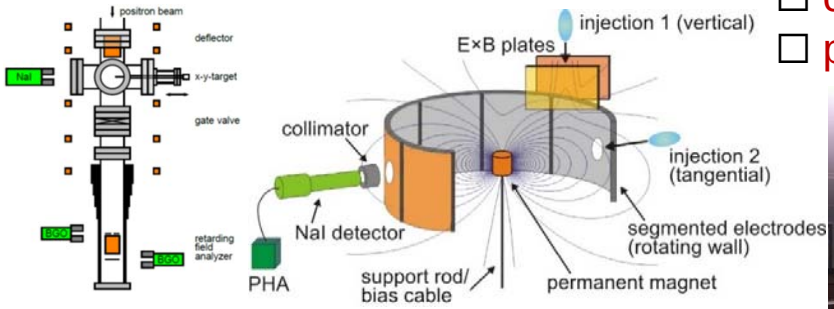
- APEX-D levitated dipole****
- closed field lines



☑ levitation system
☐ optimized SC magnet
☐ cooling/excitation system
☐ plasma experiments…

APEX (TUM-MLZ / IPP Garching)

- Retarding field analyzer
- prototype dipole trap (Neodym magnet)**



☑ beam characterization*** at the OBP of NEPOMUC
☑ drift injection and trapping technique for positrons
☐ development of compact SC levitated dipole

SC coil development with NIFS, Japan

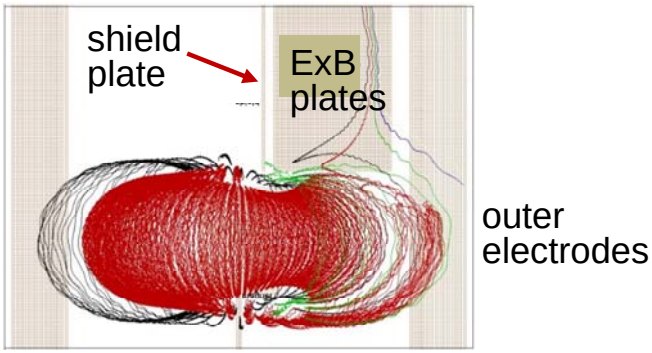
*2018 Stenson+ Phys. Rev. Lett.; 2018 Hergenhahn+ AIP procs.; ***2016 Stanja+ NIMA; ****2018 Stoneking+ AIP procs.

Efficient injection of positrons into dipole magnetic field

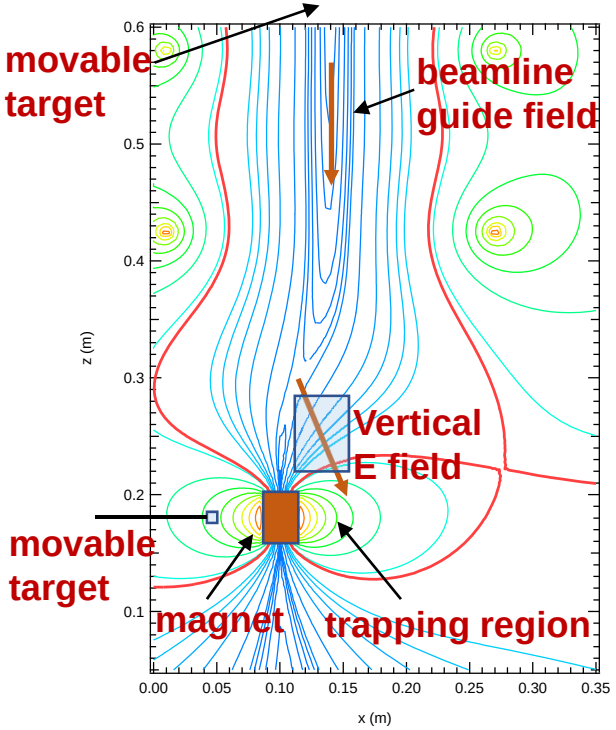
E.V. Stenson+, O4.407, submitted to PRL

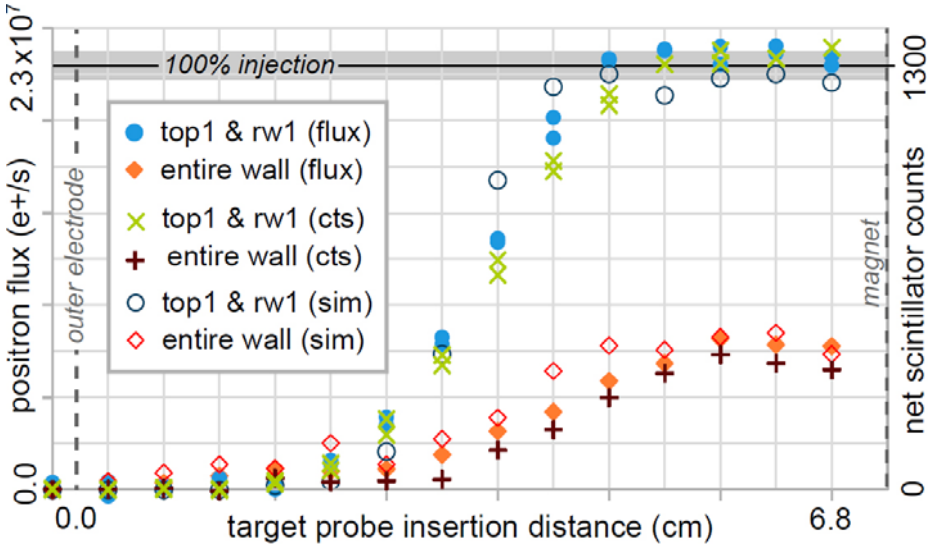
- Positron injection efficiency is essential
  - beam ~ 10^7-8 e+/s, accumulator ~ 10^9
  - at least 10^9 positrons are needed in dipole
- Cross-field injection is not straightforward
  - drift injection across separatrix
  - beamline ~ 5mT << magnet ~ 0.6T

➡ ExB drift by perpendicular electric fields*



Injection into transit orbits avoiding Loss toward magnet and walls





- 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+

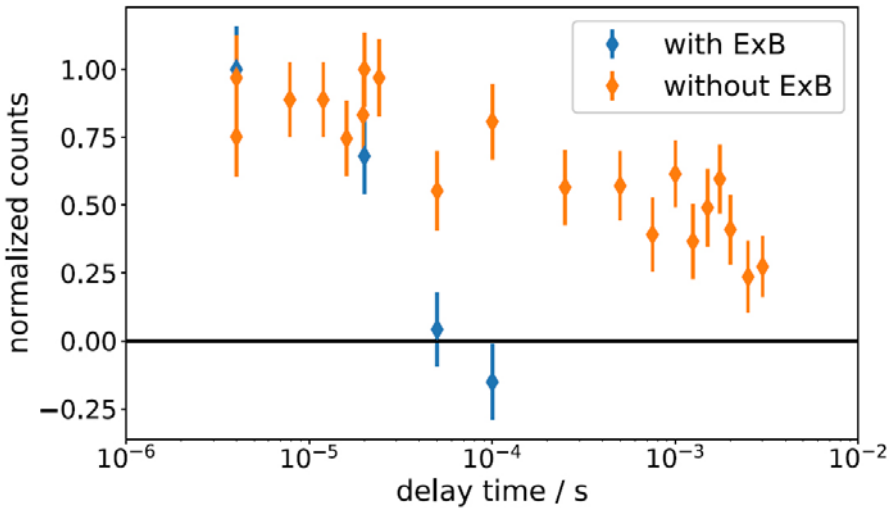
Long trapping of positrons in a dipole magnetic field

J. Horn-Stanja+, submitted to PRL

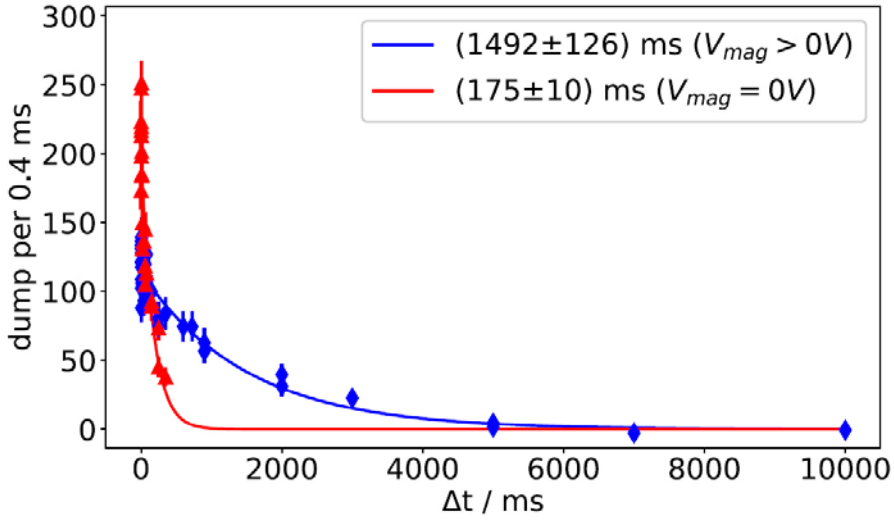
- trapping time of positrons after drift-injected into the dipole field
- the trapping time strongly depends on system symmetry
  - by gating ExB plate voltages (0 at trapping): τ ~ 0.1ms ➡ ~ 10ms
  - by gating other injection electrodes ➡ τ ~ 100ms
  - by positively biasing the magnet to reduce mirror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

Move to loss cone by neutral collisions

- 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



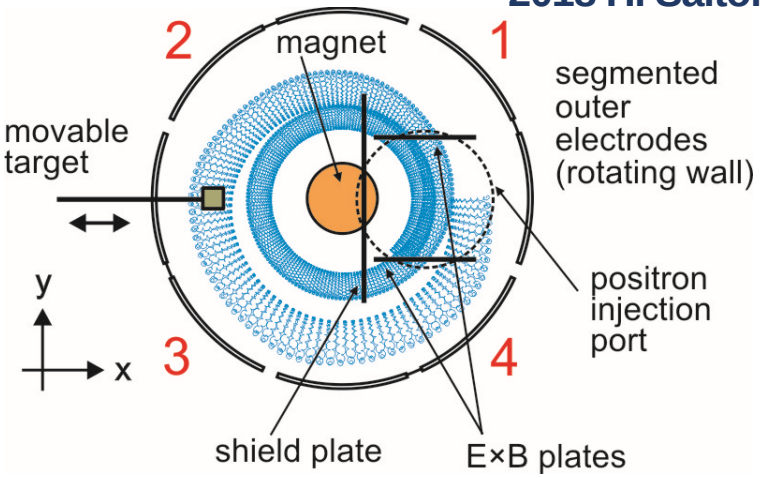
Trapping with positively biasing and grounding the magnet

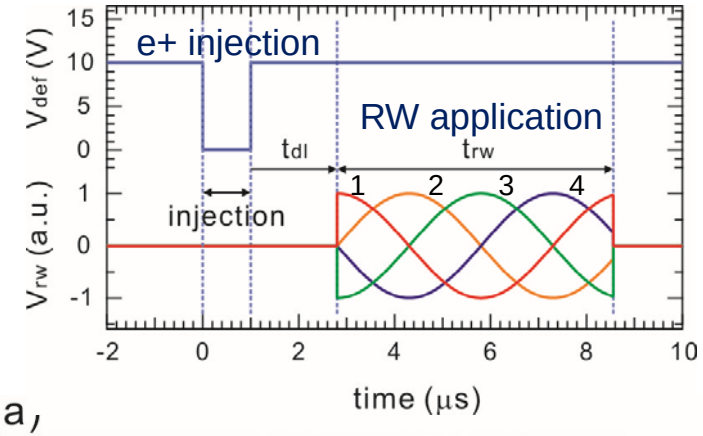
Radial compression of positrons in a dipole field by rotating wall

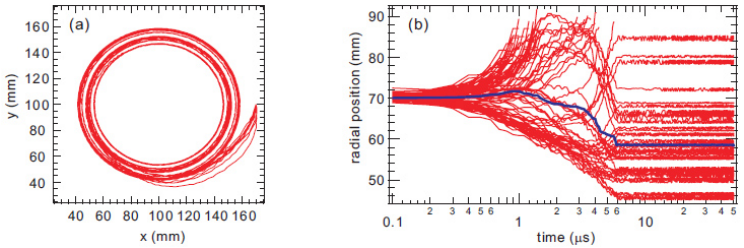
2018 H. Saitoh+ AIP procs.

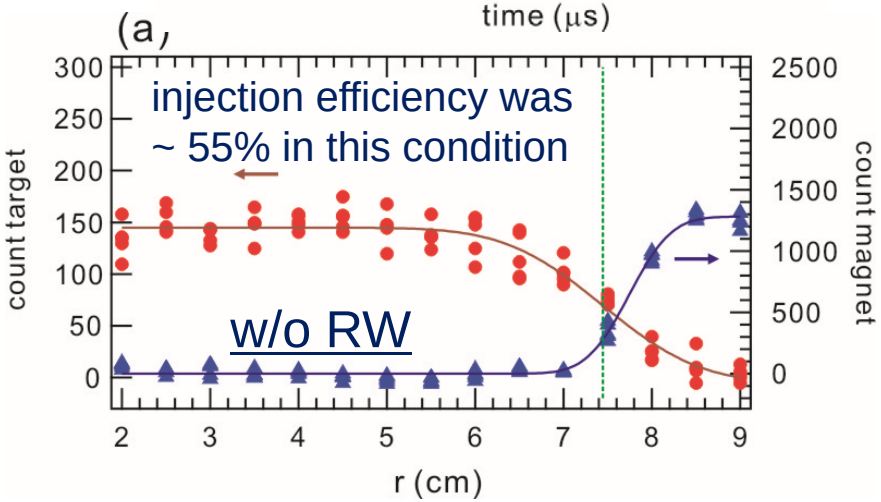
- high-density state is needed for positrons
  - asymmetry is needed for radial transport
  - "rotating wall" by segmented electrodes
  - short time modulation

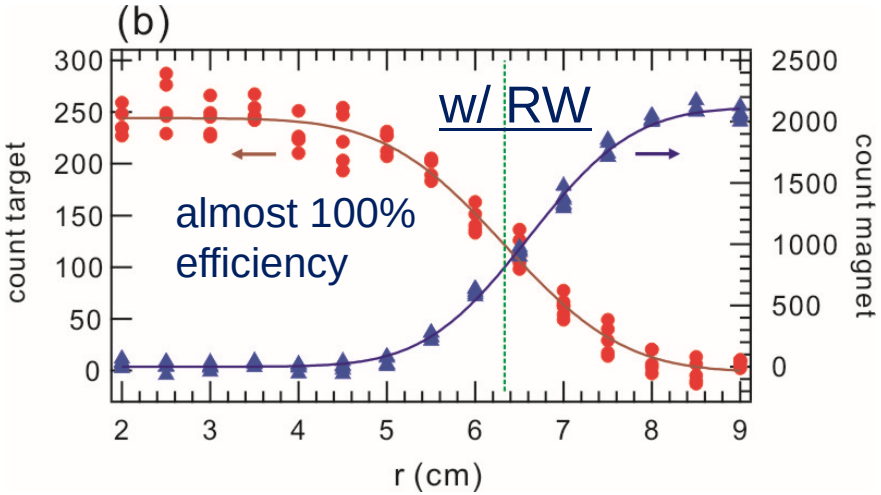
➡ Compression and increased injection efficiency







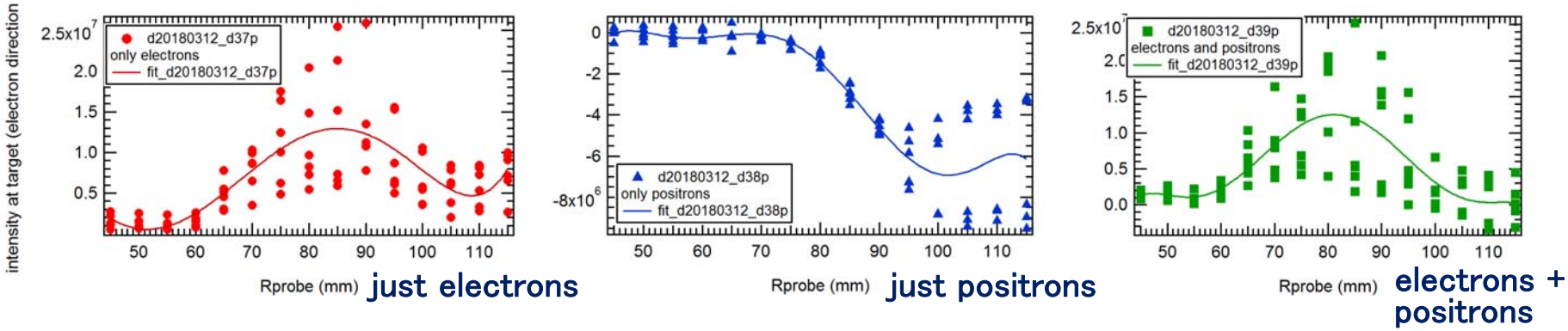




Simultaneous injection of positrons and electrons into dipole

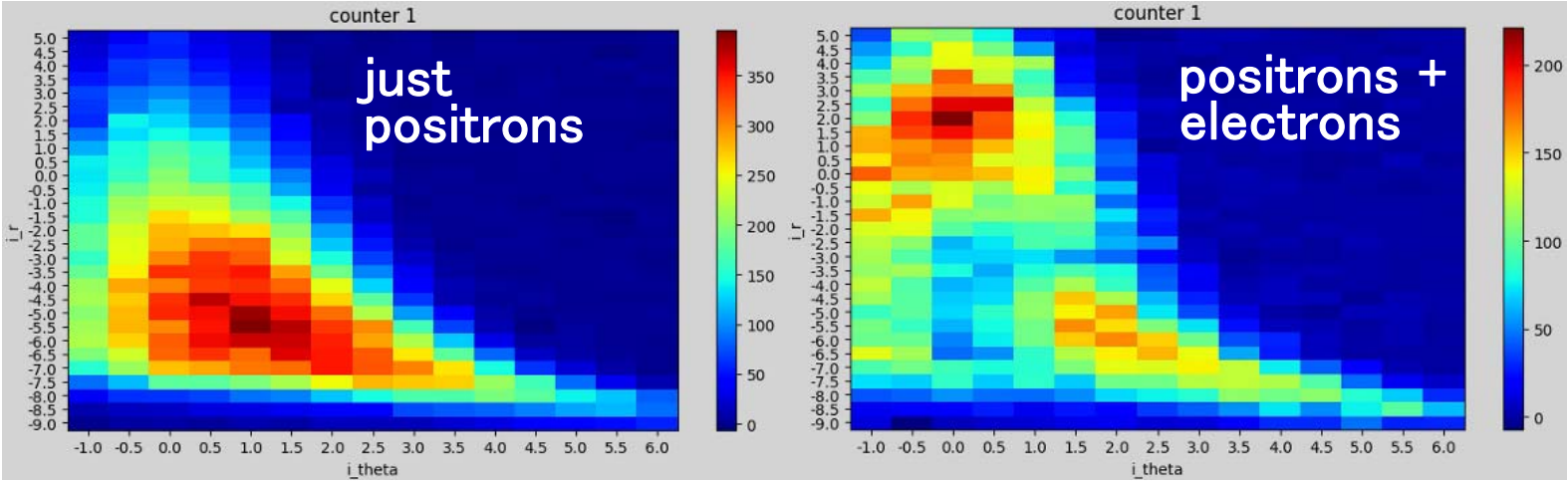
M. Singer+, to be submitted

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

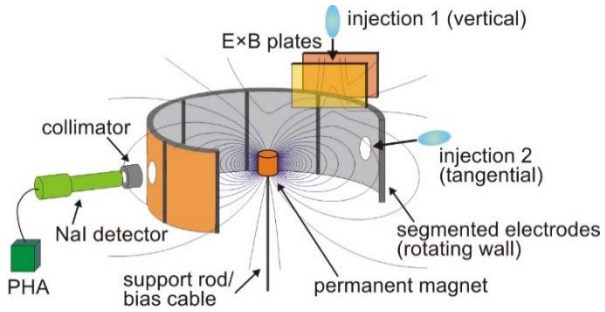


- electron injection sometimes results in reduced positron number

  to be studied with improved experiments in coming beamtime

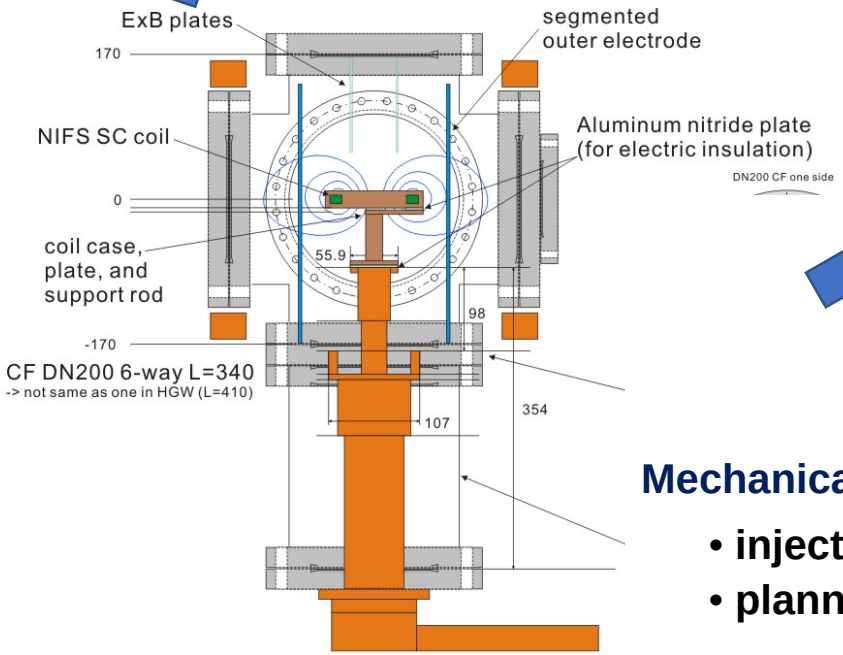


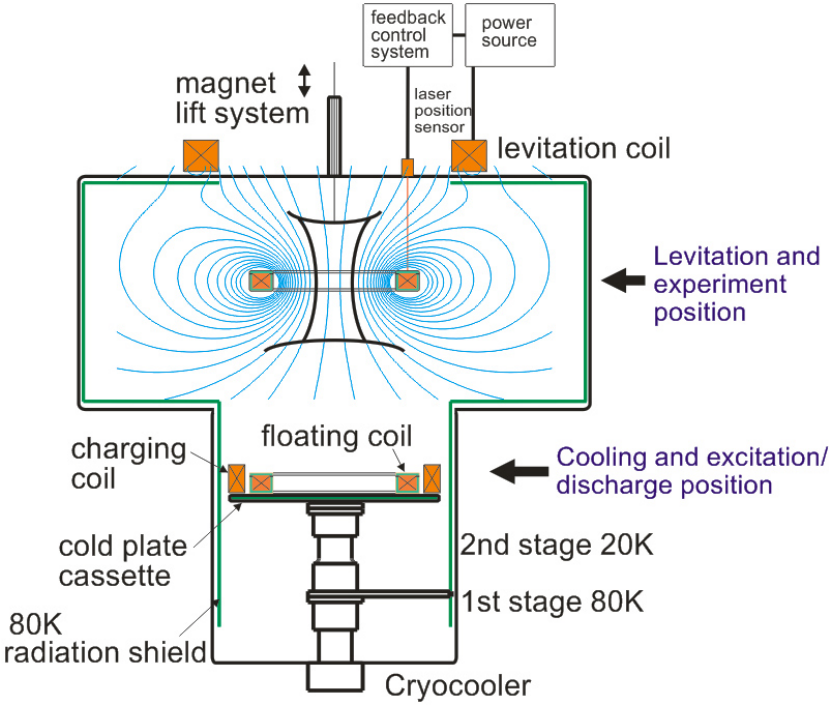
Development status of dipole experiments and tasks



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**

* 2010 Yoshida+ Phys. Rev. Lett. (RT-1), 2010 Boxer+ Nature Phys. (LDX), 2018 Stoneking+ AIP procs.

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

Talk of E.V. Stenson, O4.407

- 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