WITCH, a Penning Trap for Weak Interaction Studies

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G. Ban[1], M. Breitenfeldt[2], P. Finlay[2], X. Fabian[1] X. Fléchard[1], P. Friedag[3], F. Glück[5], A Knecht[6],V. Kozlov[5], E. Liénard[1], G. Soti[2], M. Tandecki[2], S. Van Gorp[2] , Ch. Weinheimer[3], D. Zákoucký[4], N. Severijns[2]

[1]*LPC-Caen, ENSICAEN, Université de Caen, CNRS/IN2P3, Caen, France*
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Outline

- Introduction & motivation
- Overview of the WITCH experiment
- Recent results & analysis
- Investigation of the systematic effects

    - SimWITCH3D

    - Space-charge effects

    - Detector efficiency

- Outlook

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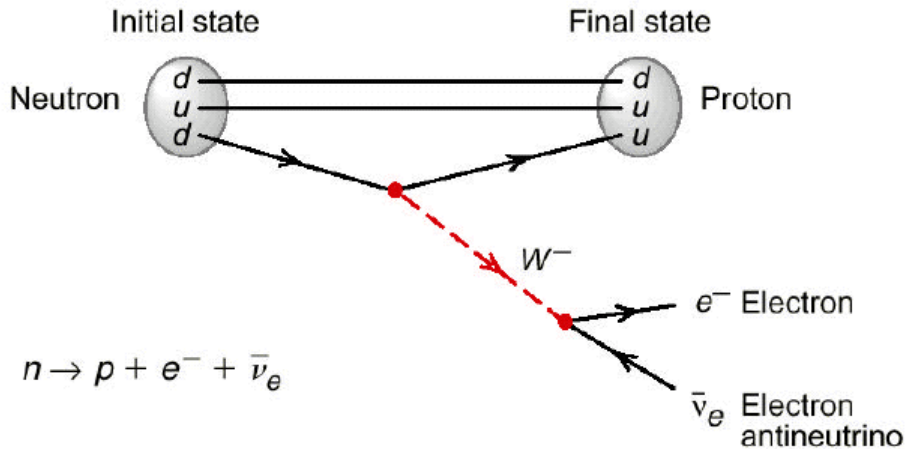# Motivation: New Physics

Search for physics beyond the standard model

High energy
Direct production - LHC

High precision
Low energy – β-decay

Beta decay:

$$n \rightarrow p + e^- + \bar{\nu}_e$$

- Our focus: beta-decay of ^{35}Ar

Motivation

Why measure the recoil spectra of ^{35}**Ar**?
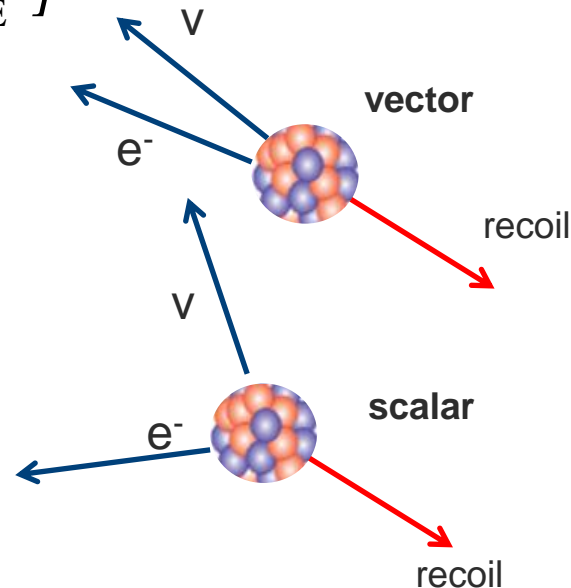
Standard Model: Vector, Axial-Vector
Non-SM: Scalar, Tensor
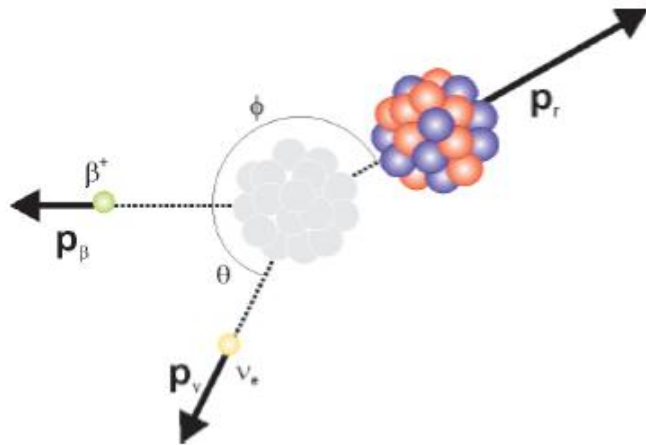
Standard Model ⎴ Non-SM

$$H_\beta = H_{Vector} + H_{Axial} + H_{Scalar} + H_{Tensor}$$

$$W(E,\theta) = W(E)\left[1 + a\frac{v_e}{c}\cos(\theta) + b\frac{m}{E}\right]$$

Fermi transition

vector

Standard Model

recoil

scalar

Non-SM

recoil

Current experimental limits:
(from nuclear & neutron β decay)
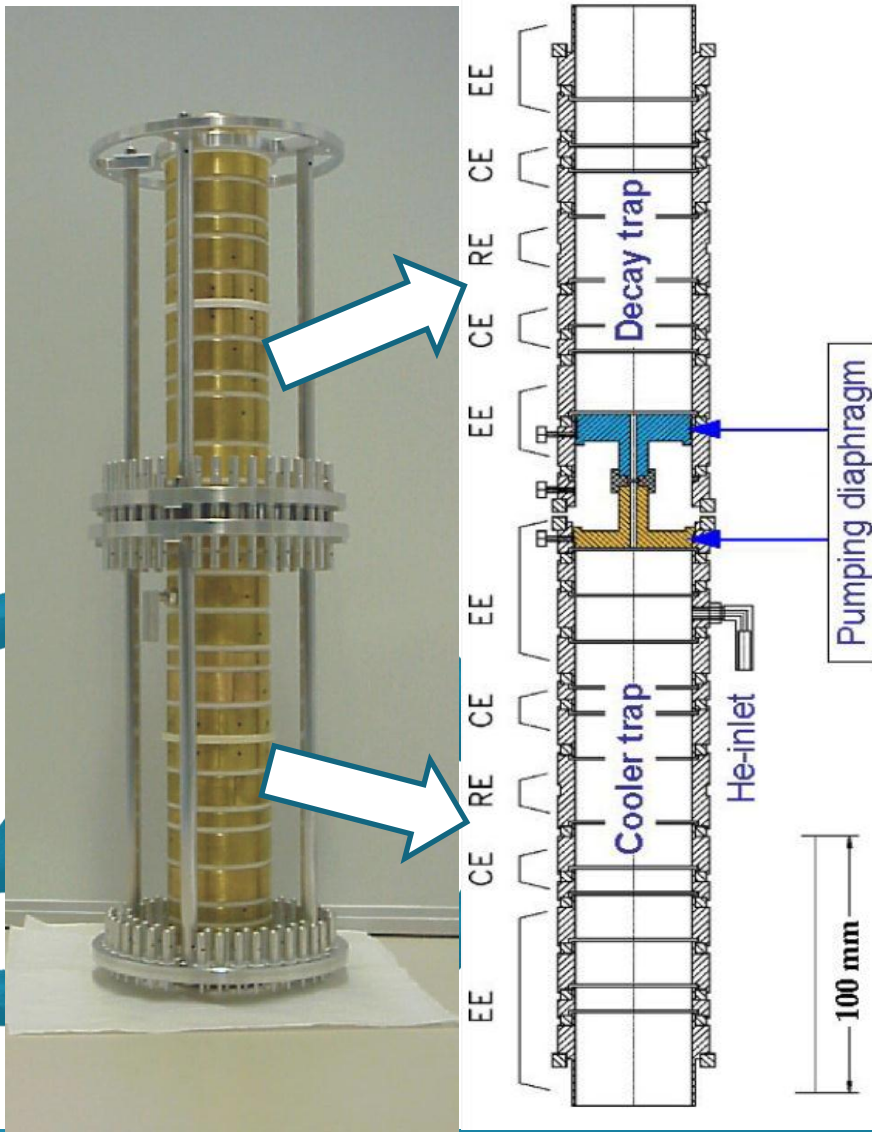$\frac{C_S}{C_V} < 7\%$, $\frac{C_T}{C_A} < 9\%$

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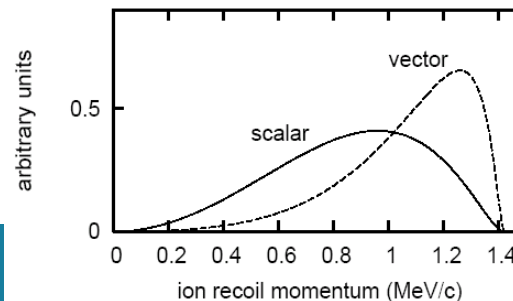
The WITCH experiment

1. Cooled and bunched beam of ^{35}Ar @ 30 keV
2. Pulsed drift tube for deceleration
3. Buffer-gas cooling of the ions in 1st Penning Trap (Cooler Trap)
4. Decay of the ions in the 2nd Penning Trap (Decay Trap)
5. Probing the ions' recoil energy in the Spectrometer
6. Counting the ions on the main MCP
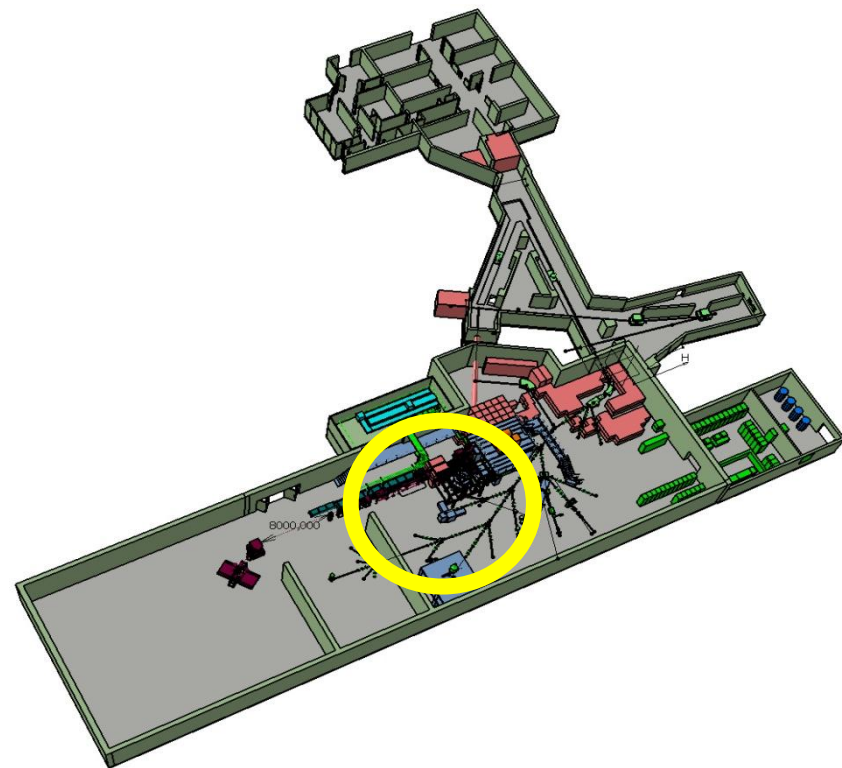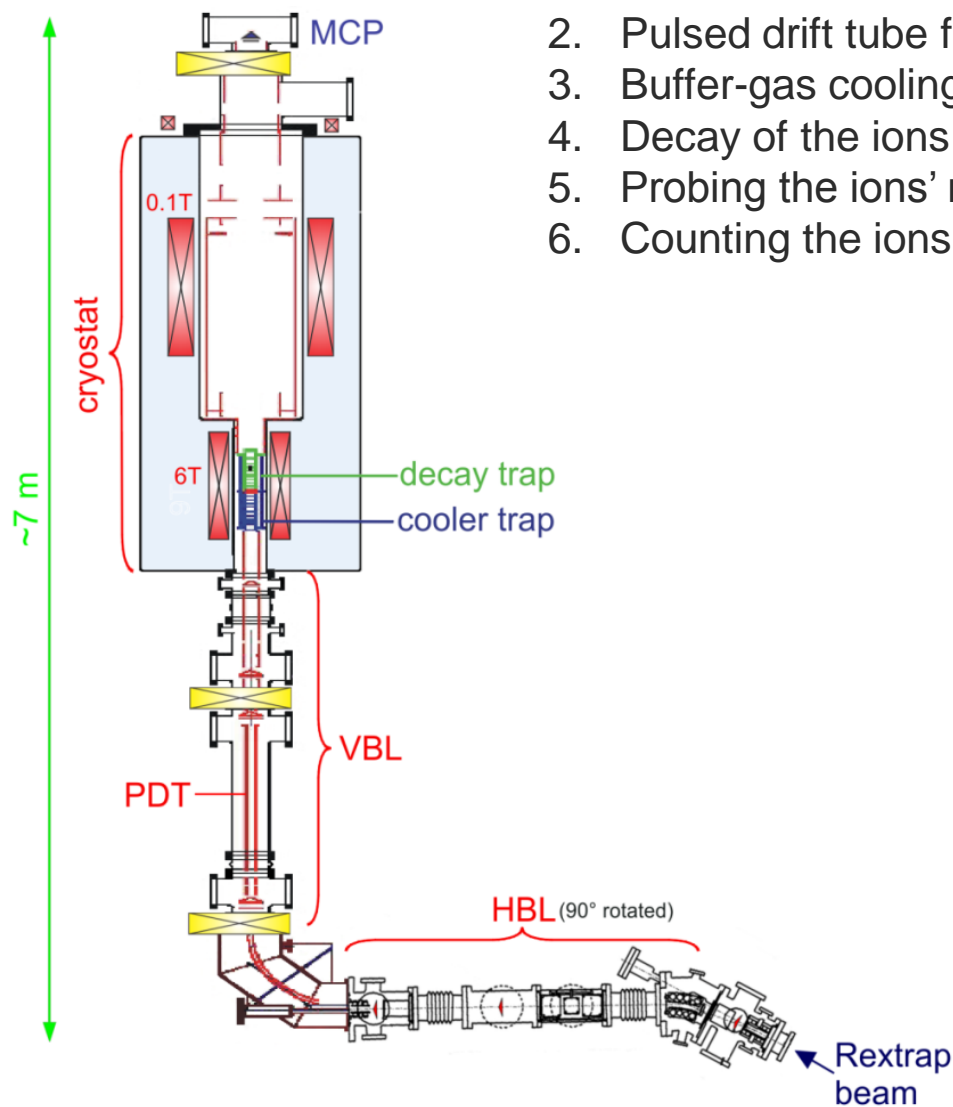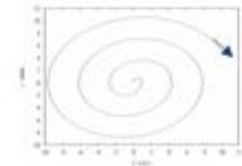
Penning traps at WITCH

- **Scattering-free source**
- **He buffer gas** in the cooler trap
- **Dipole excitation** at magnetron ω_- frequency – mass independent removal from trap center
- **Quadrupole excitation** at cyclotron frequency ω_c – mass selective centering & buffer gas --> cooling of the ion cloud
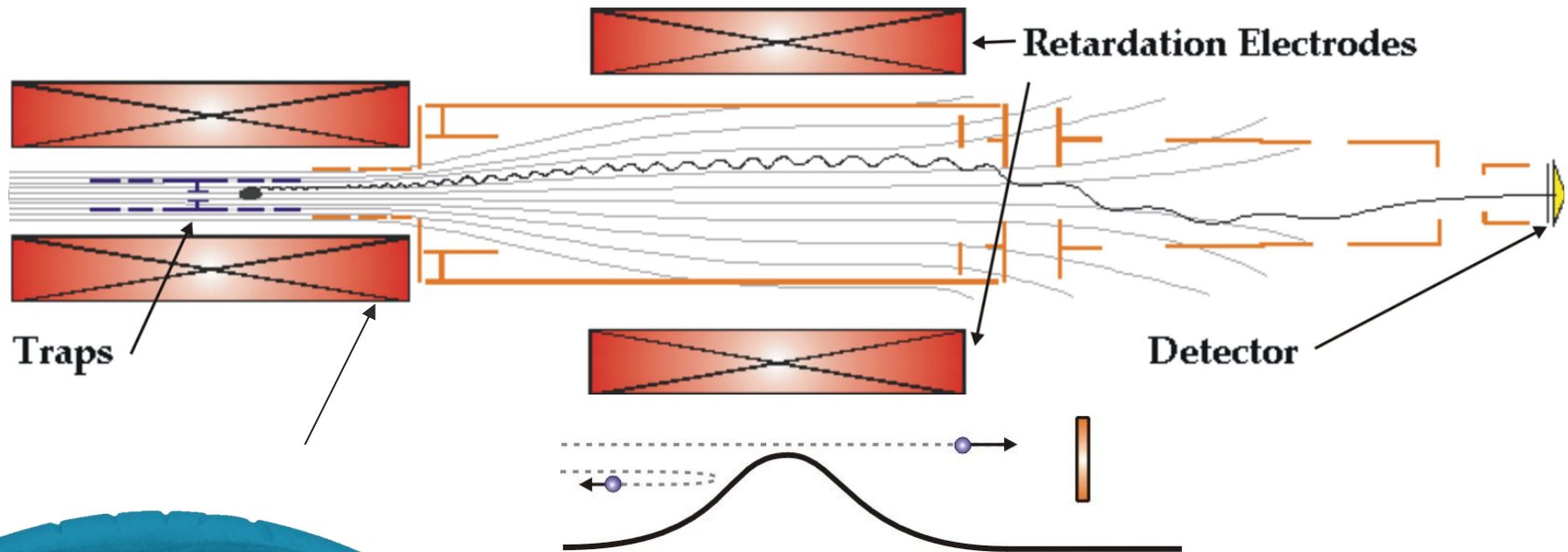
Quadrupole Excitation + buffer gas

Dipole Excitation

WITCH: Spectrometer

- High field (9 T) at the traps, low (0.1 T) in the analyzing plane
- Adiabatic approximation: field gradient in a single cyclotron gyration radius is small
- E_{cycl} /B is an adiabatic invariant -> if $B_{source} >> B_{plane}$, then $E_{cycl,plane} << E_{cycl,source}$
- Combination of electrostatic filter and inhomogenous mag. field => high energy resolution + high statistics

# November 2012 online experiment

- Further improvements of the diagnostics, measurement systems and transmission
- New data acquisition system from LPC Caen
- More information in the datastream
- High background level

- Retardation spectrum extracted
- Systematic effects still not fully accounted for
- Studies of main MCP energy-dependent efficiency ongoing

Experimental cycle
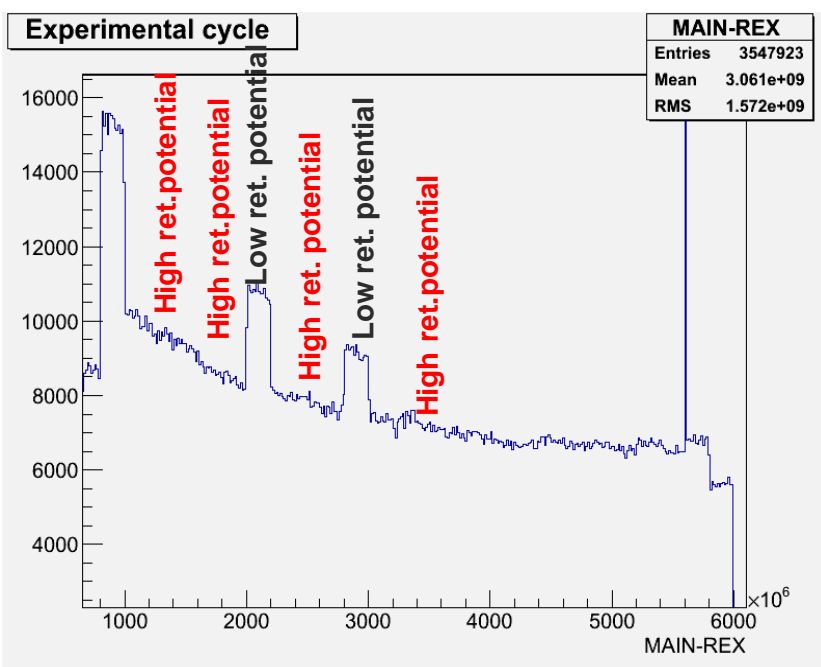
Retardation spectrum
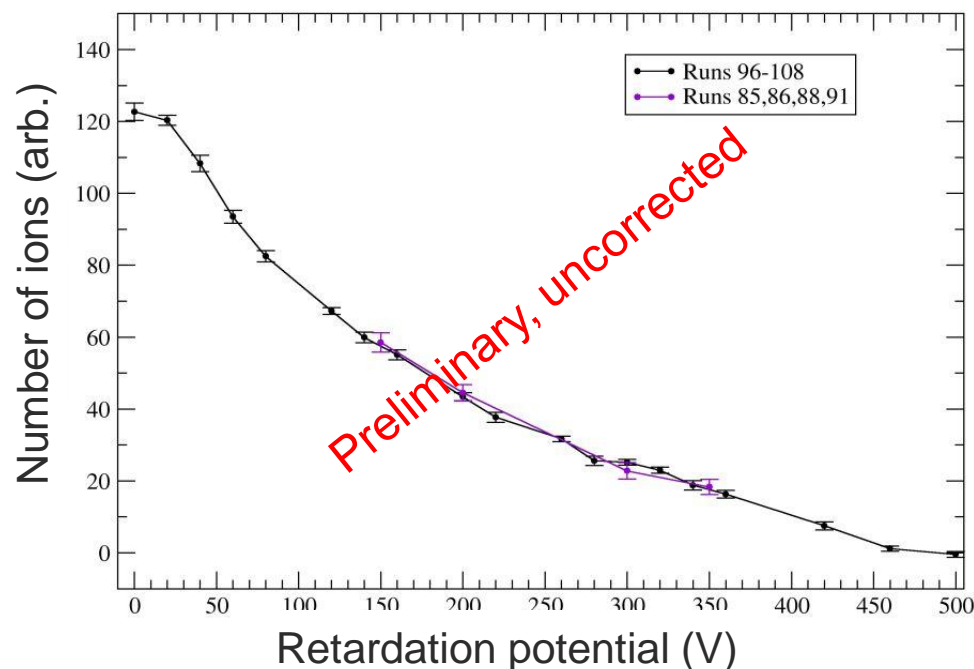
Systematic effects investigation

1. Spectrometer effects

- 2D symmetry breaking structures found, upgrading tracking simulation software to 3D was needed
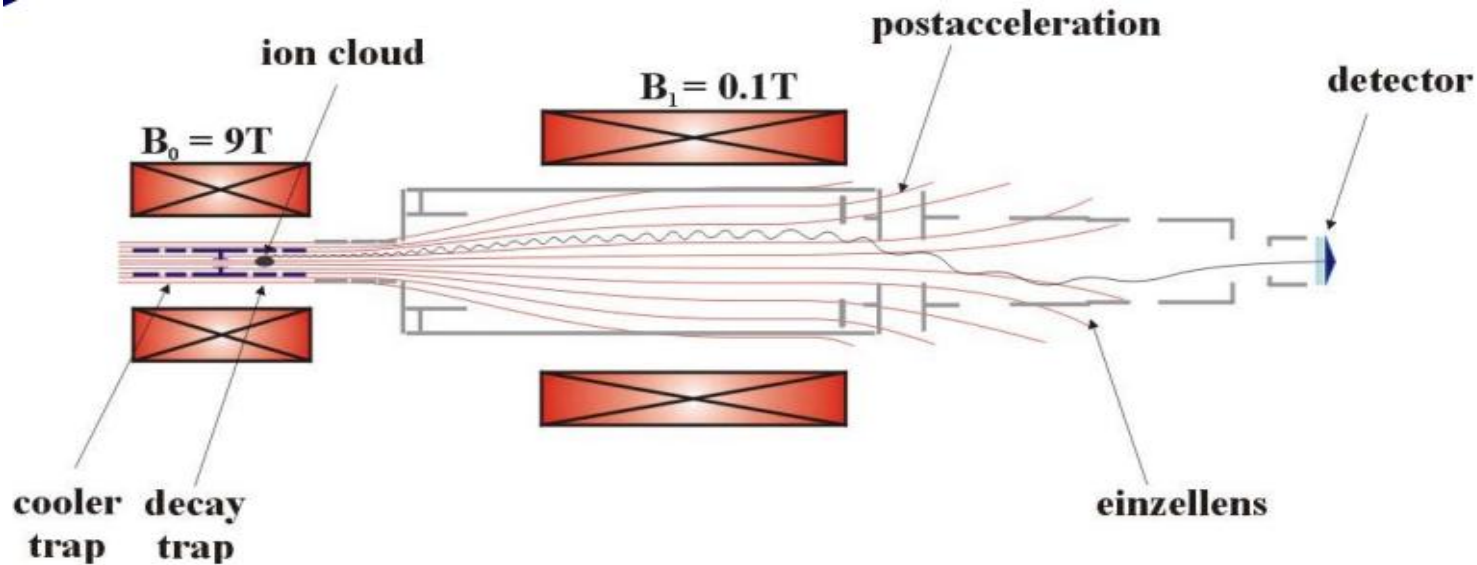
2. Penning trap effects

- investigation of space-charge effects with offline ions and simulations
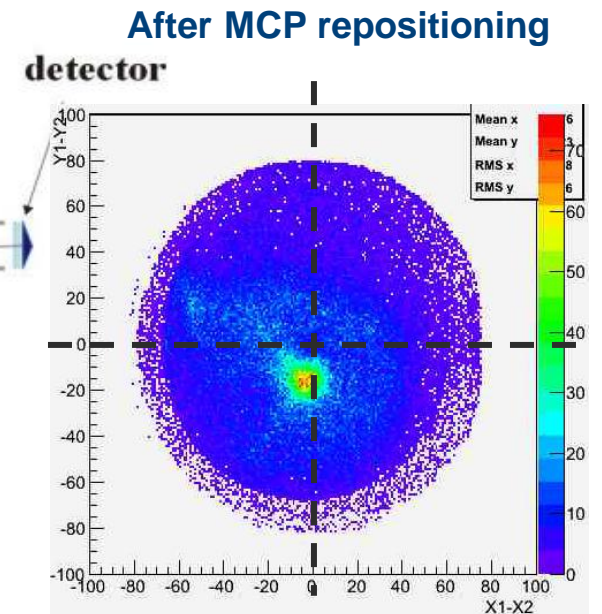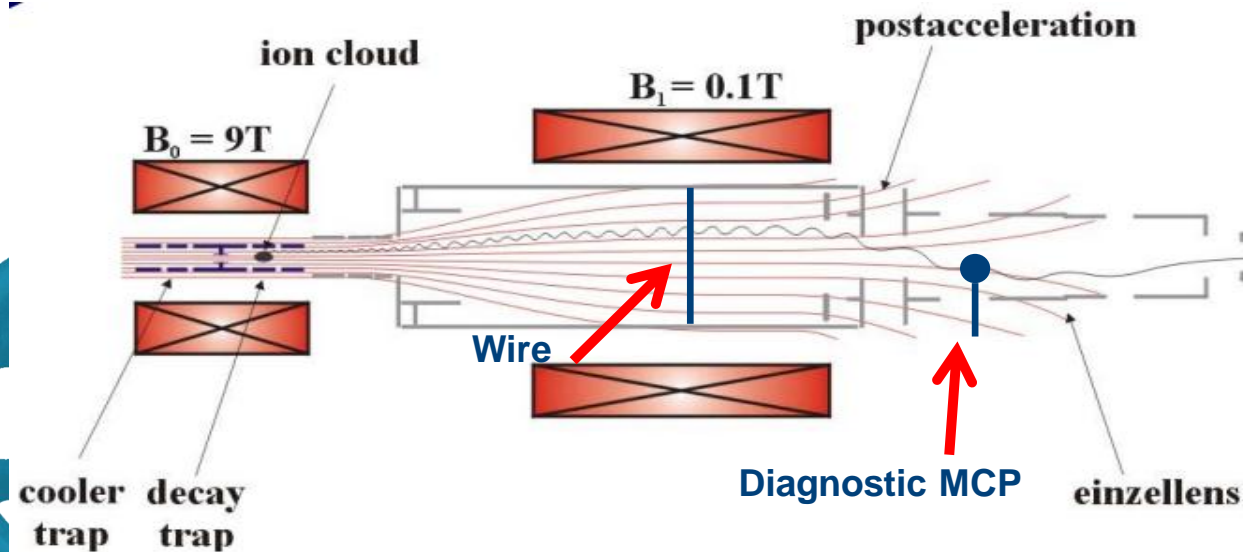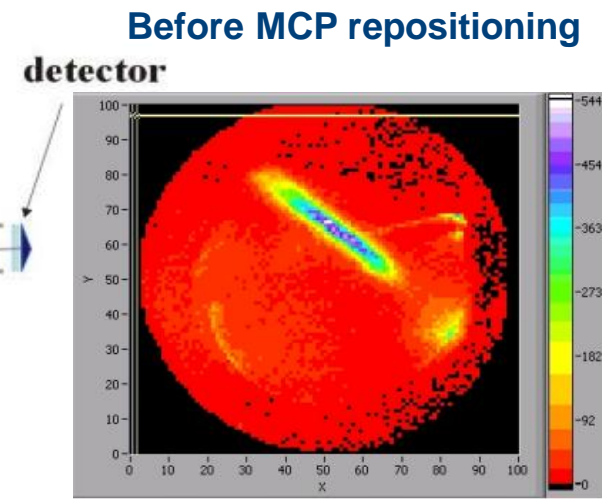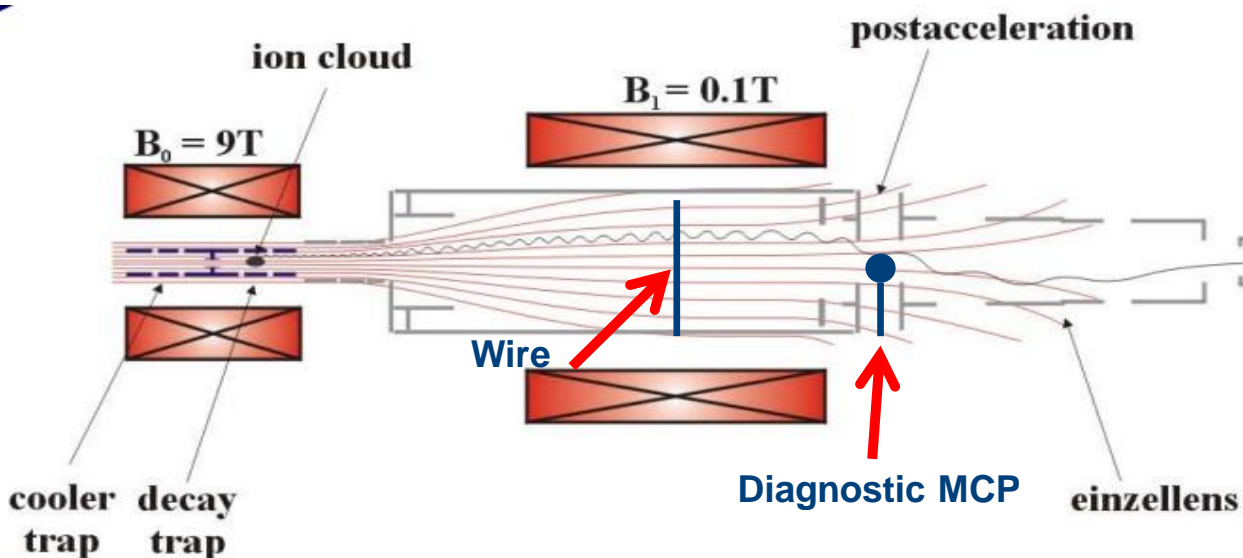
3. Main MCP energy dependent efficiency

- 1^+, 2^+, 3^+ charge states of decay products
- reacceleration in front of the main MCP results in different energies for charge states

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1. SimWITCH: Ion tracking simulation in the spectrometer

- **Monte Carlo ion tracking in the spectrometer**
- Originally 2D, recently upgraded to 3D
- Tracks the recoil ions from the trap to the Main MCP
- Ion transport simulated for
  various retardation voltages (0 V – 450 V)
- Also for all ^{35}Ar charge states (1^+, 2^+, 3^+, 4^+, 5^+)
  (*charge state measurement by LPC trap @GANIL [1]*)
- Axial symmetry broken by a diagnostic MCP and
 anti-ionization wire

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[1] Electron shakeoff following the β+ decay of trapped ^{35}Ar+ ions, Couratin et al, submitted

Before MCP repositioning

After MCP repositioning

- **Diagnostic MCP** and **anti-ionization wire** affected ion trajectories significantly
- Repositioned the MCP

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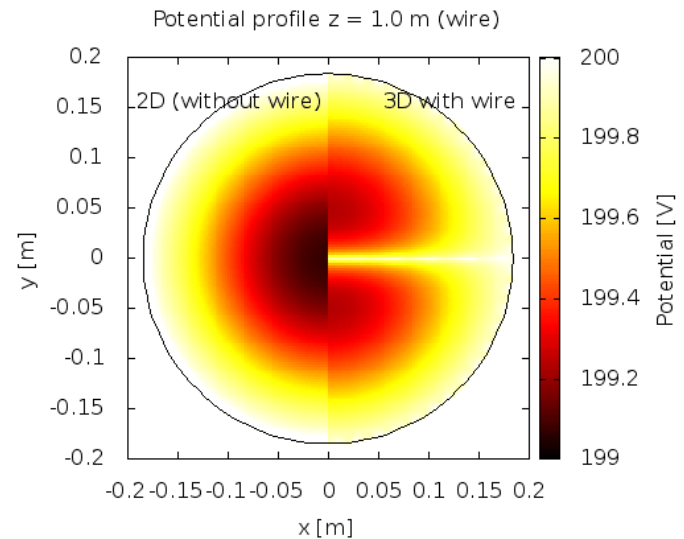# SimWITCH-3D: influence of the wire on the potential in the spectrometer

- Upgraded SimWITCH to include 2D symmetry breaking elements

Wire influence on the potential X-Z plane
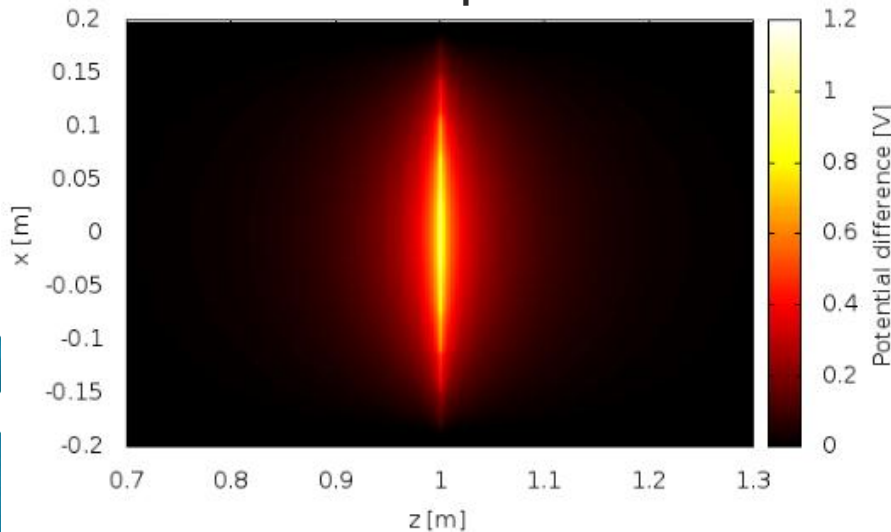
Wire influence on the potential X-Y plane

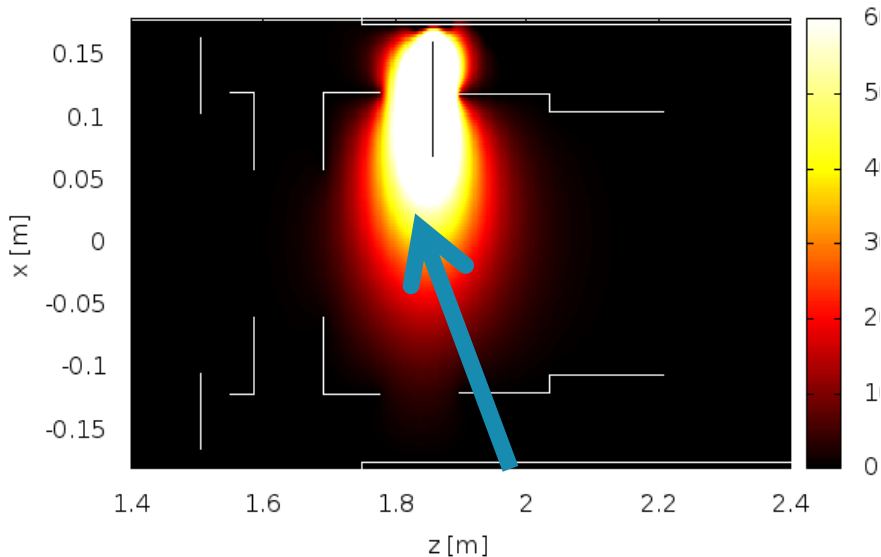The potential in the center is higher by ~1.1 V (0.5%)

- Implemented by Paweł Bączyk, ISOLDE summer student

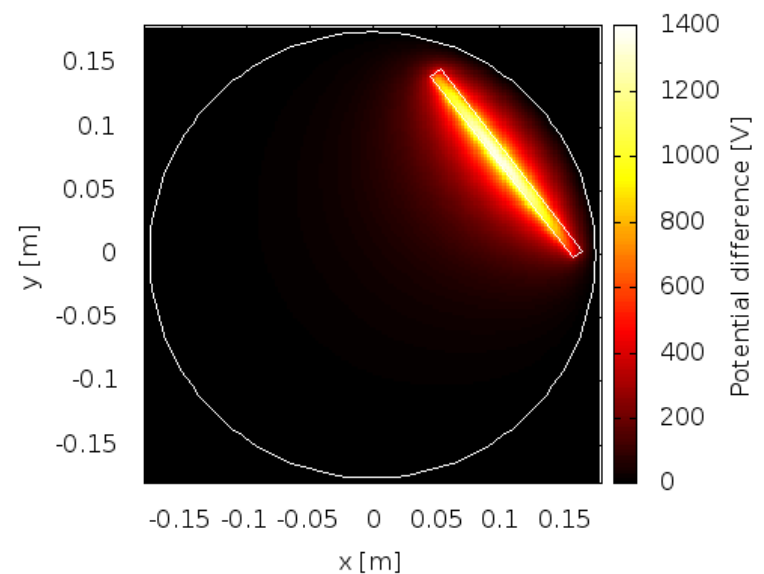# SimWITCH-3D: diagnostic MCP influence on the potential in the spectrometer

MCP influence on the potential X-Z plane

Potential difference profile y = 0.0 m
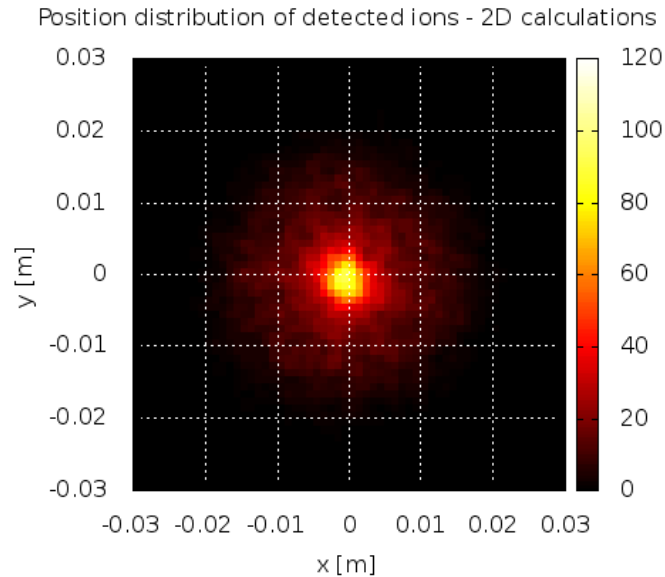

MCP influence on the potential X-Y plane

Potential difference profile at z = 1.856 m (arm)
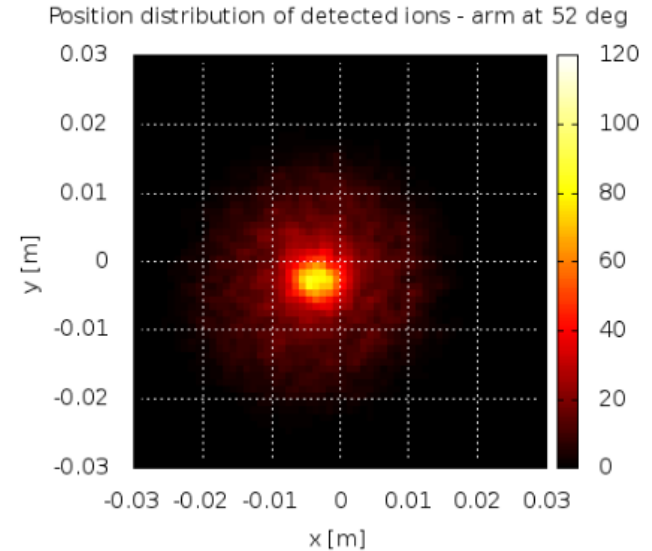

The potential in the center is higher by ~38 V (1.3%)

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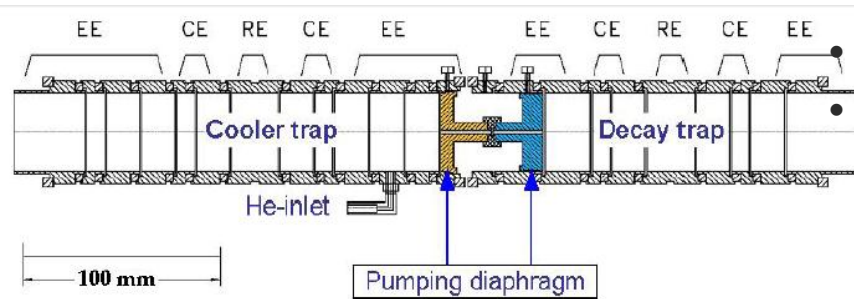# Influence on the ions – preliminary simulation results

Without the MCP

Position distribution of detected ions - 2D calculations

With the MCP

Position distribution of detected ions - arm at 52 deg

Deflection of the ions can be simulated!

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2. Simbuca: ion cloud dynamics and space-charge



- **Ion cloud in the traps simulations: Simbuca**[1]
- Simbuca: calculates ion cloud evolution in ion traps for large numbers of ions using GPU parallelization

- Simulated many-ion space-charge effects: cyclotron & magnetron resonant frequency shift, energy and other systematic effects
- Of interest to wider ion trapping community
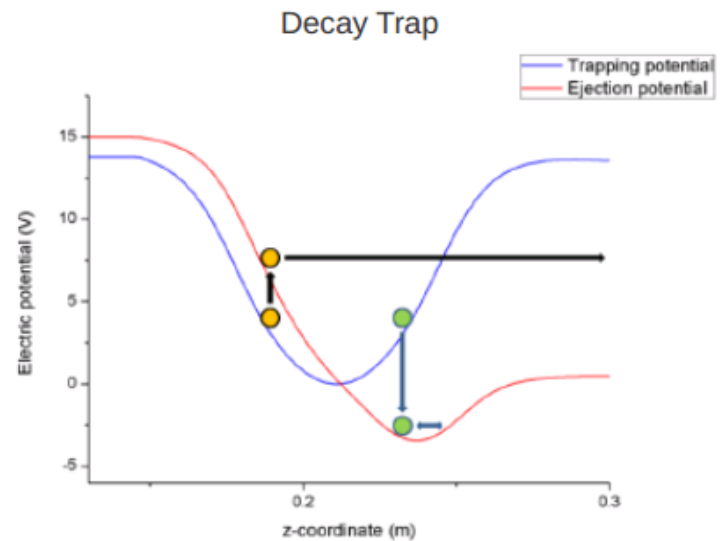- To be published
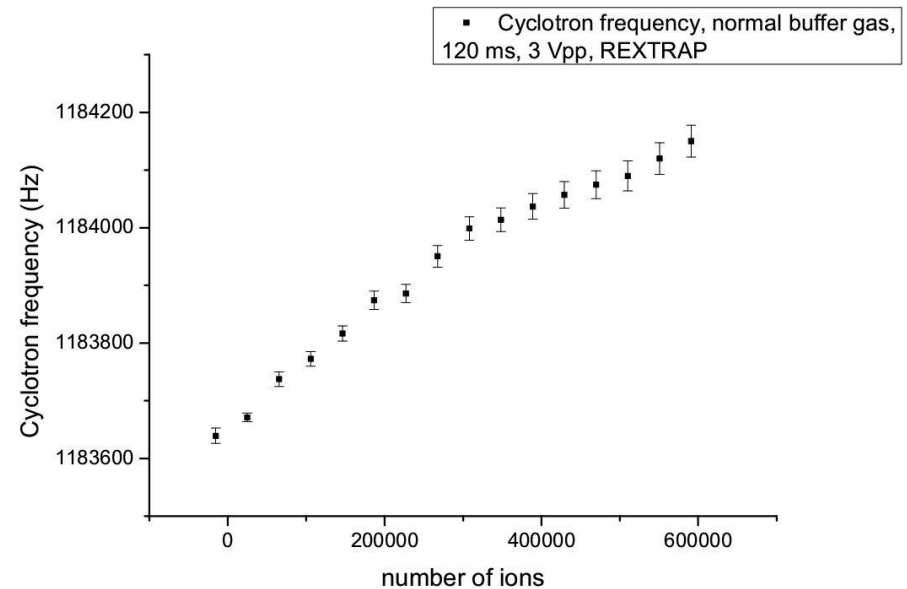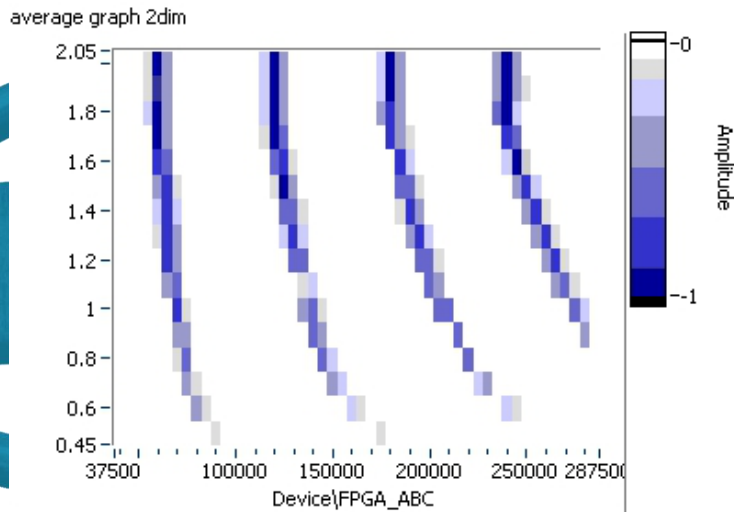
- [1]S. Van Gorp et al. Nucl. Instr. and Meth. A 638 (2011) 192-200.

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Simbuca: Transfer between traps
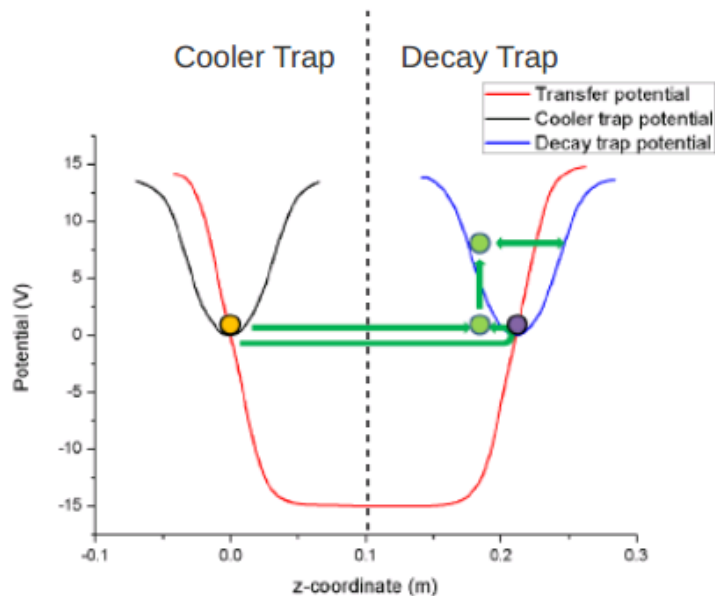
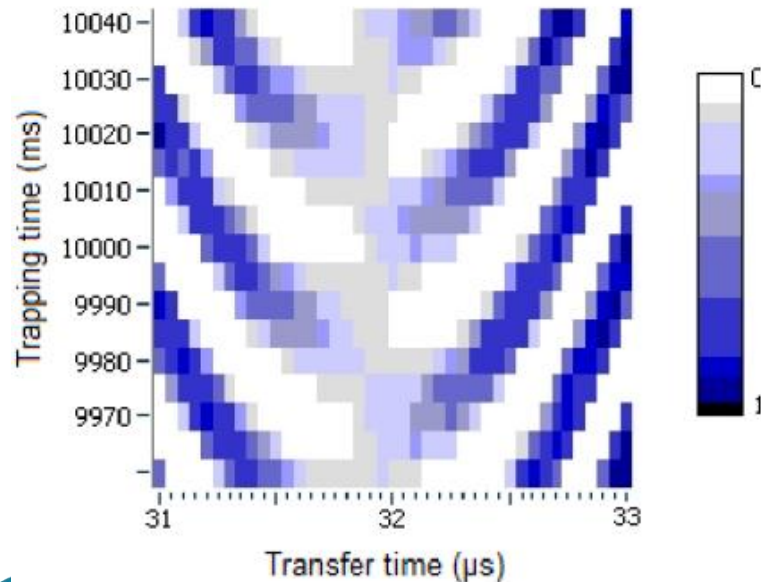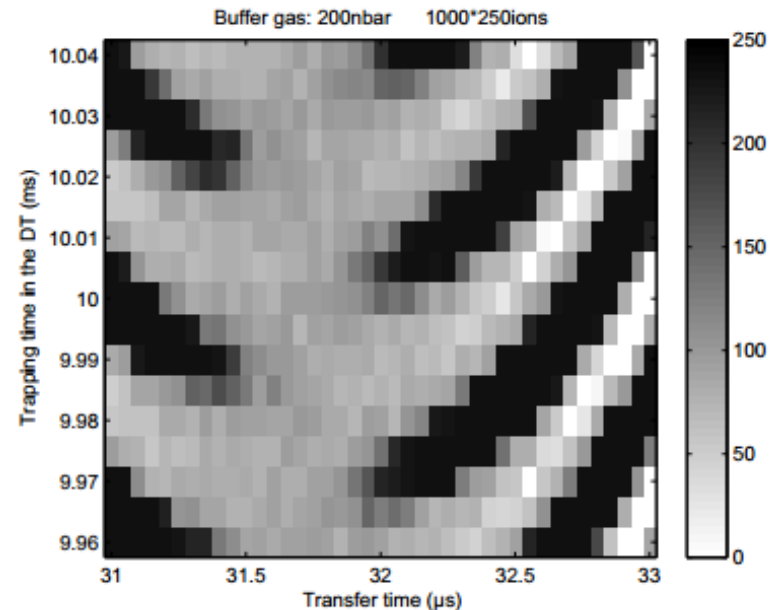Coller trap – decay trap transfer scan

Decay trap energy scan

- Transfer time - very sensitive to electric field imperfections, provides information on trap systematics

Simbuca: Transfer between traps
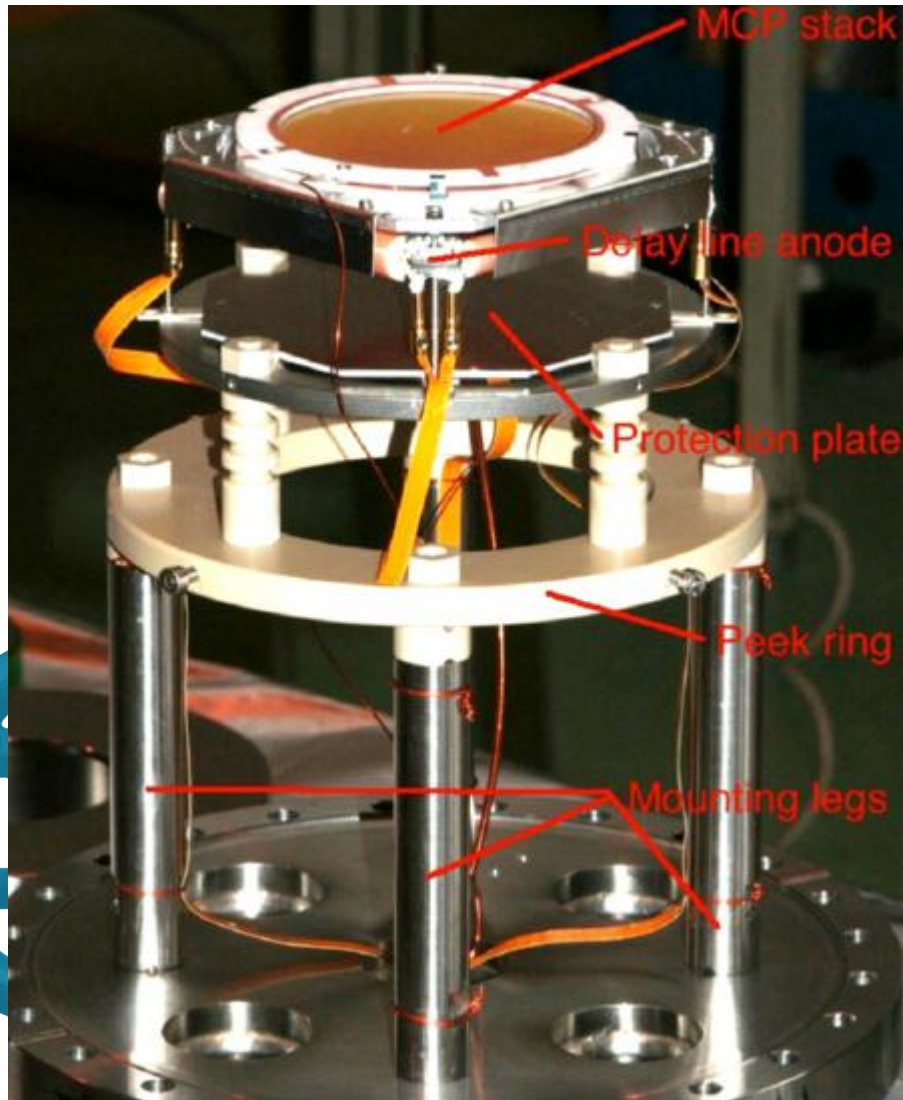
Experimental Scan
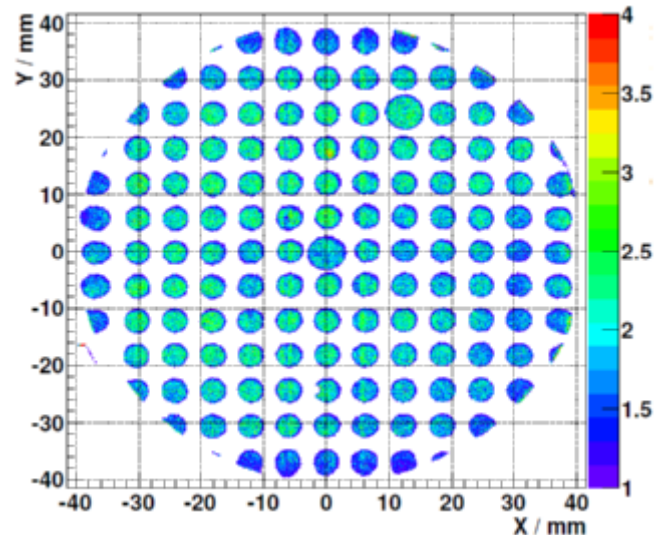

Simulation [2]

Buffer gas: 200nbar   1000*250ions

- Simulation agrees well with experiment
- Minor differences caused by transient states of the power supply
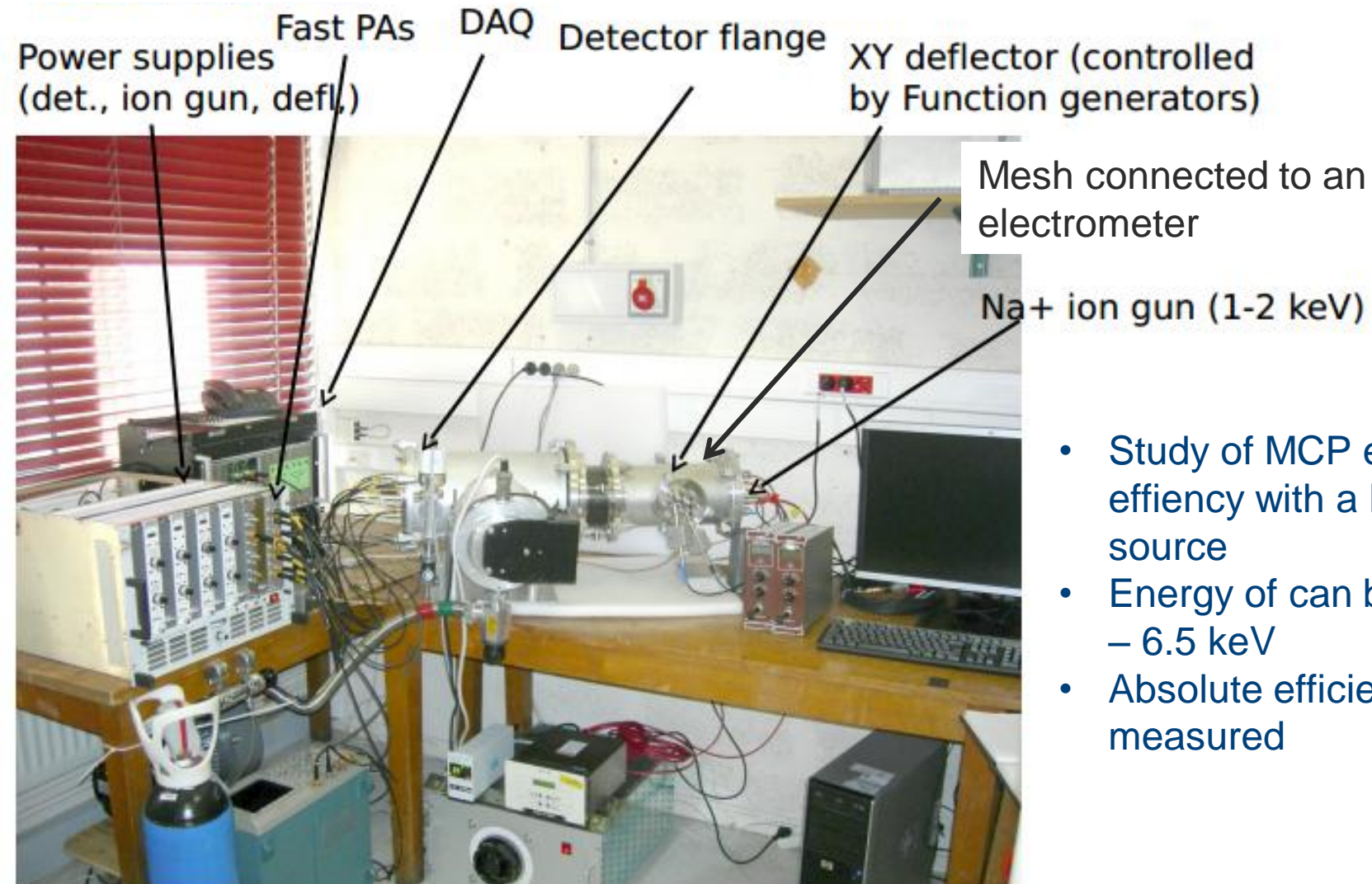
[2] E. Wursten, Master Thesis

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3. Main MCP detector

- 8 cm diameter
- delay lines, position resolution 0.2 mm
- Total efficiency is 40(11)%
- <u>Found energy dependent efficiency for 0 – 6 keV ions – major systematic effect</u>
- Caused by wear of the plates

MCP test bench at LPC-Caen

Power supplies (det., ion gun, defl.)

Fast PAs

DAQ

Detector flange

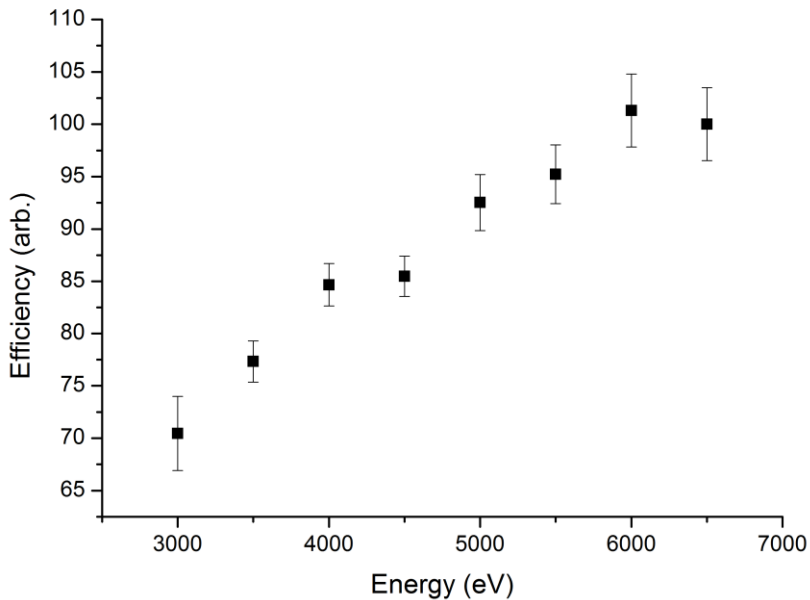XY deflector (controlled by Function generators)

Mesh connected to an electrometer

Na+ ion gun (1-2 keV)

- Study of MCP energy effiency with a Na⁺ ion source
- Energy of can be varied 0 – 6.5 keV
- Absolute efficiency measured

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MCP energy dependent efficiency

- Our MCP efficiency increases with ion energy
- More data needed (with $^{39}K^+$ ions, improved improved normalization) for a precision correction of online data

Summary & outlook

- **Retardation spectrum** extracted
- **SimWITCH-3D** code successfully models systematics of the ion tracking, including axial symmetry breaking
- **Simbuca** code successfully simulates ion cloud evolution in the traps and transfer between traps, including space-charge effects
- **MCP efficiency** crucial for extracting the β-ν correlation coefficient, further study needed

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