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Probing the Standard Model via ^{35}Ar β decay with the WITCH spectrometer

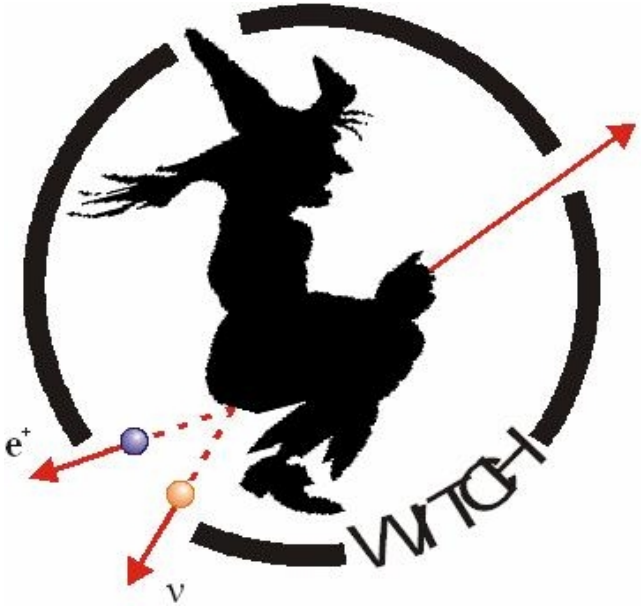
Paul Finlay, for the WITCH collaboration

3rd Workshop on the Physics of Fundamental Symmetries and Interactions at low energies and the precision frontier

Sept. 9-12, 2013, Paul Scherrer Institute, Switzerland

Outline

- β-υ Angular Correlations in the Standard Model
- The WITCH Apparatus
  - Recent developments and improvements
- Advances in understanding our system
  - SimWITCH-3D
  - Ion transfer with Simbuca
- Summary



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Nuclear beta decay = semi-leptonic process governed by weak interaction

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

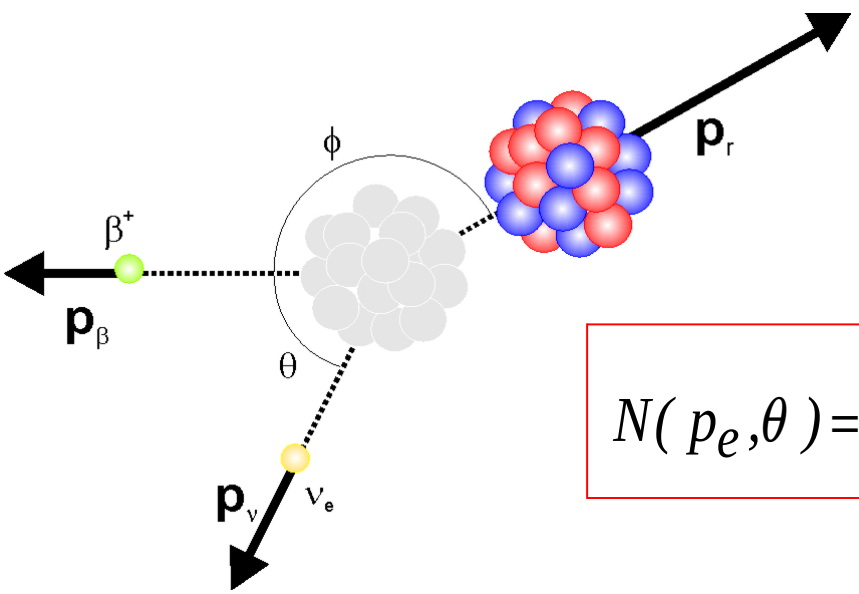
decay constant

Fermi's Golden Rule

$$\lambda = \frac{2\pi}{\hbar} |V_{fi}|^2 \frac{dN}{dE_0}$$

density of final states

transition probability $(\langle f | H_\beta | i \rangle)^2$



$$H_\beta = H_S + H_V + H_T + H_A + H_P$$

$$N(p_e, \theta) = KW(p_e)\xi\left(1 + a\frac{v_e}{c}\cos(\theta) + b\frac{2m_e c^2}{E_e}\right)\sin(\theta)$$

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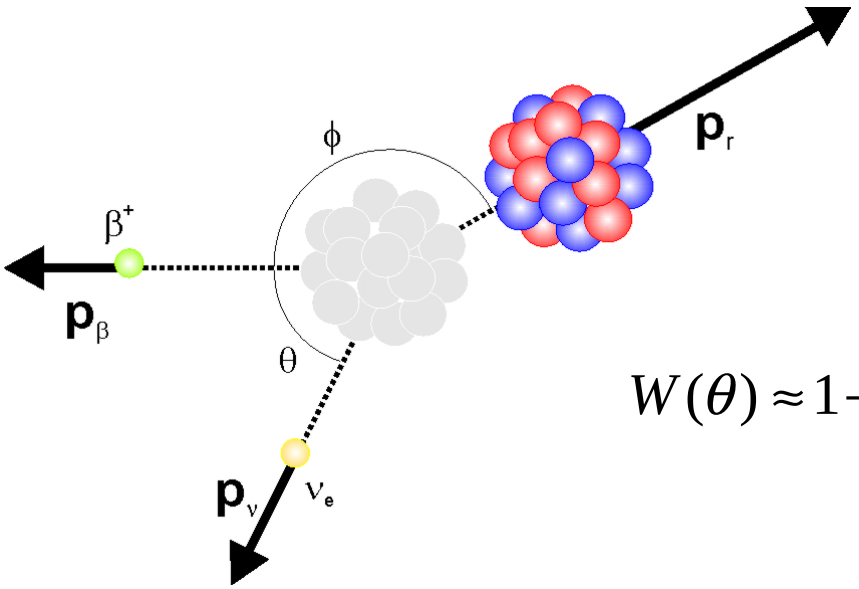
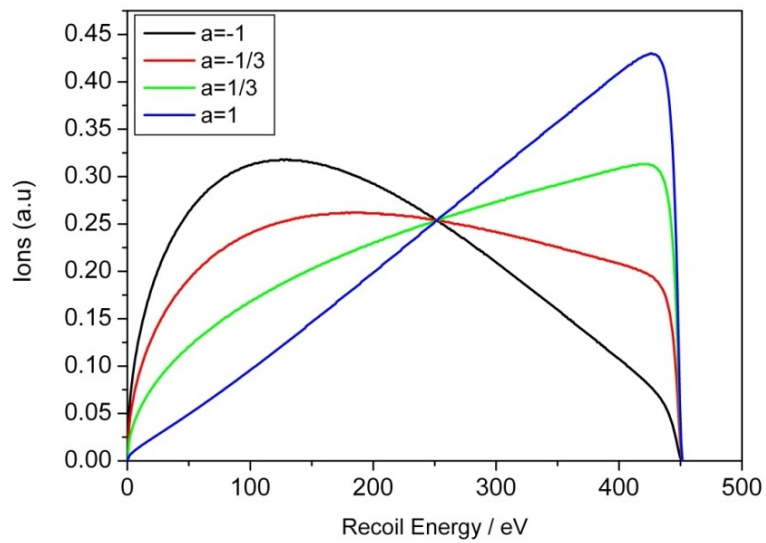
β–ν correlation in allowed β decays for non-oriented nuclei:

$$a = \frac{[|C_V|^2 + |C'_V|^2 - |C_S|^2 - |C'_S|^2]|M_F|^2 + \frac{1}{3}[|C_T|^2 + |C'_T|^2 - |C_A|^2 - |C'_A|^2]|M_{GT}|^2}{[|C_V|^2 + |C'_V|^2 + |C_S|^2 + |C'_S|^2]|M_F|^2 + [|C_T|^2 + |C'_T|^2 + |C_A|^2 + |C'_A|^2]|M_{GT}|^2}$$

For Fermi decay: $a = 1 - \frac{|C_S|^2 + |C'_S|^2}{|C_V|^2}$ currently $\frac{C_S}{C_V} < 7\%$



$$W(\theta) \approx 1 + a\frac{v}{c}\cos\theta$$



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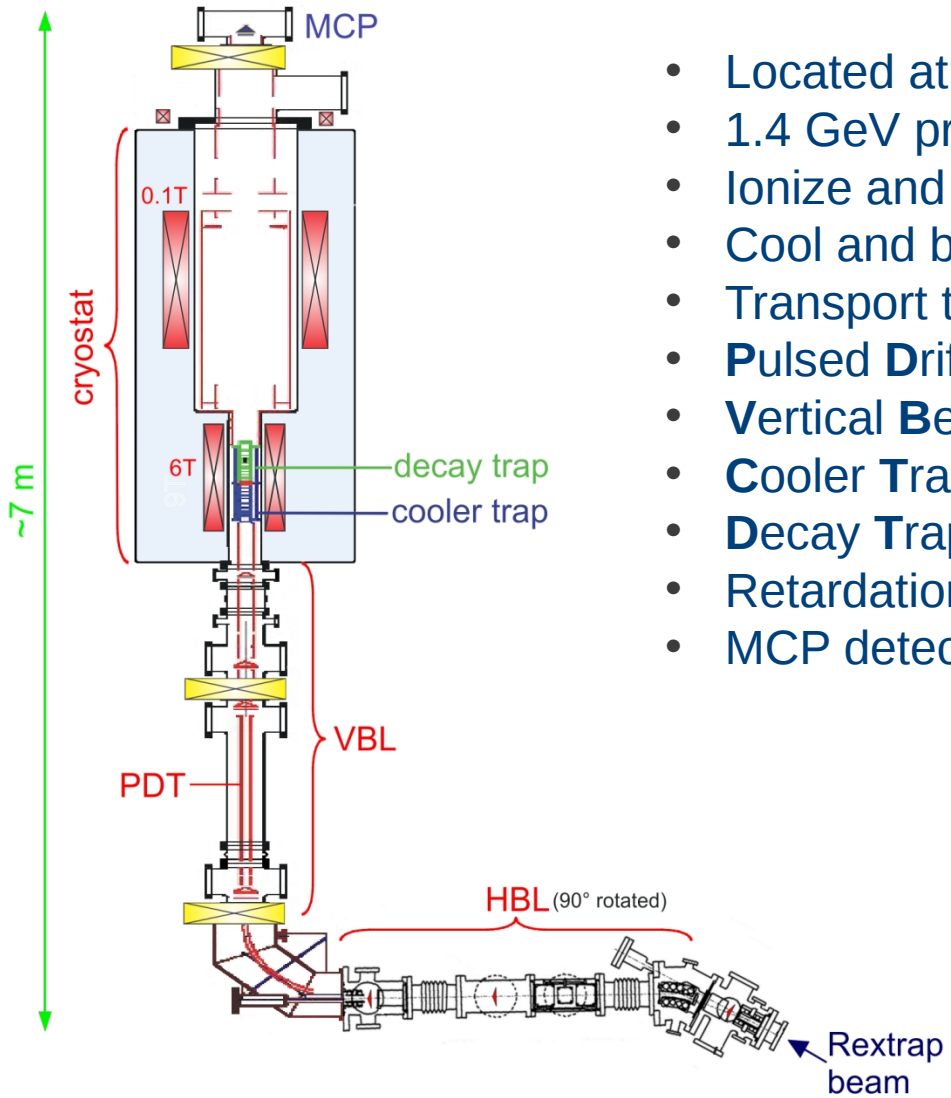
WITCH setup



- Located at CERN-ISOLDE
- 1.4 GeV protons on solid target
- Ionize and mass separate products (^{35}Ar)
- Cool and bunch in REXtrap → 30 keV
- Transport through **H**orizontal **B**eam **L**ine
- **P**ulsed **D**rift **T**ube reduce total energy ~0
- **V**ertical **B**eam **L**ine decelerates ions
- **C**ooler **T**rap (buffer gas) cool/center ions
- **D**ecay **T**rap to store scattering free source
- Retardation Spectrometer for energy analysis
- MCP detector as ion counter

References:
M. Tandecki et al., NIMA 629 (2011) 396-405.
E. Traykov et al., NIMA 648 (2011) 1-14.
S. Van Gorp et al., NIMA 638 (2011) 192-200
M. Beck et al., NIMA 503 (2003) 567
M. Beck et al., EPJA 47 (2011) 45.

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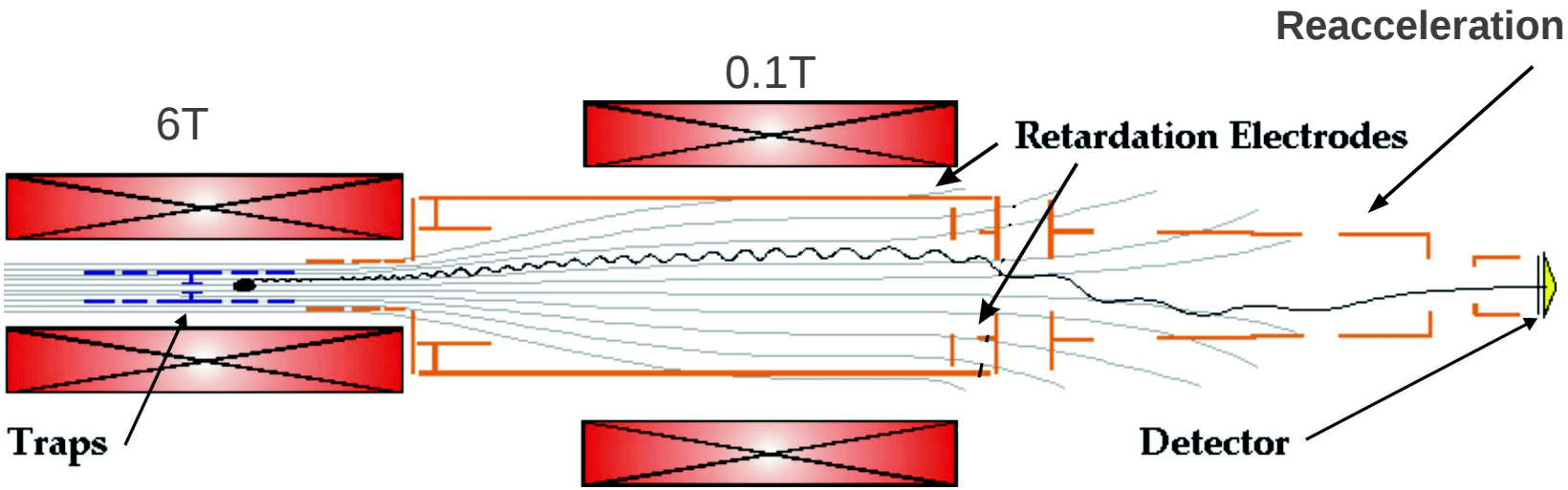
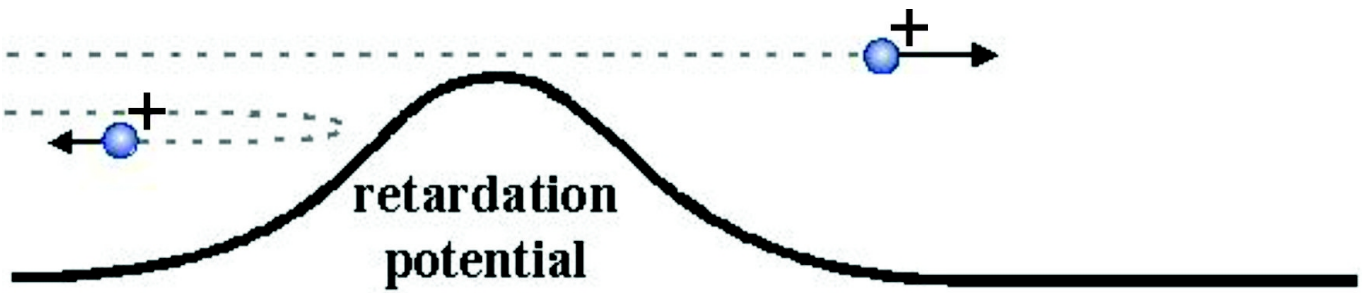
WITCH Spectrometer





Conversion of radial energy $= 1 - B_{spec}/B_{trap} = 98.3\%$

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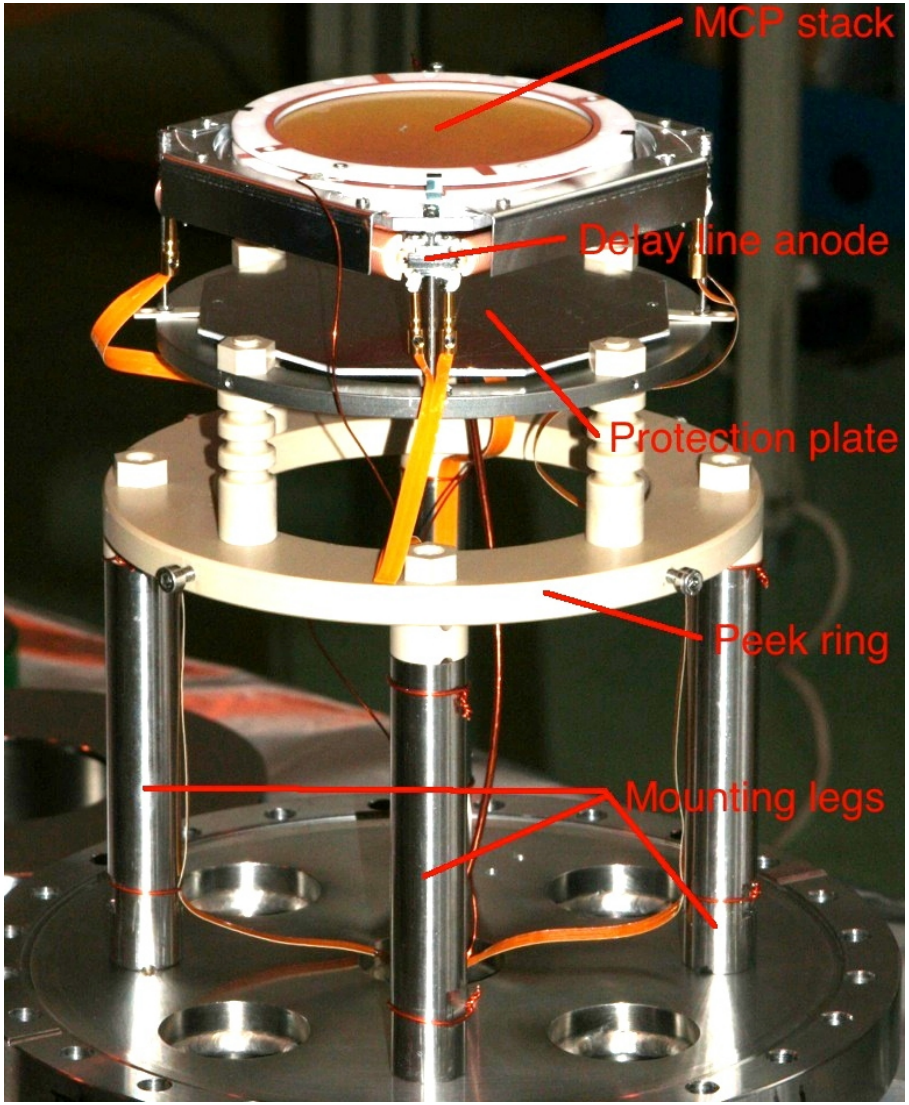
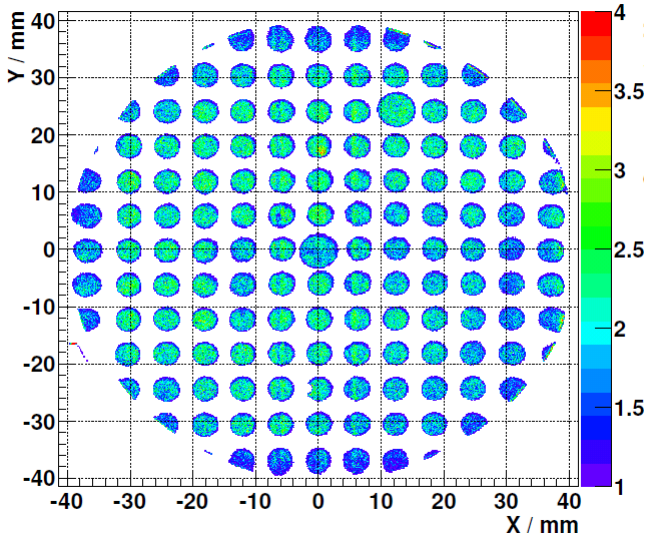
Detector - Position sensitive MCP



- 8cm diameter MCP
- 2x2 delay lines for XY, signal and reference for bkg subtraction
- Total efficiency is 40(11)%
- Position resolution 0.2mm
- Relative efficiency calibrated



PhD work, P. Friedag, U. Münster

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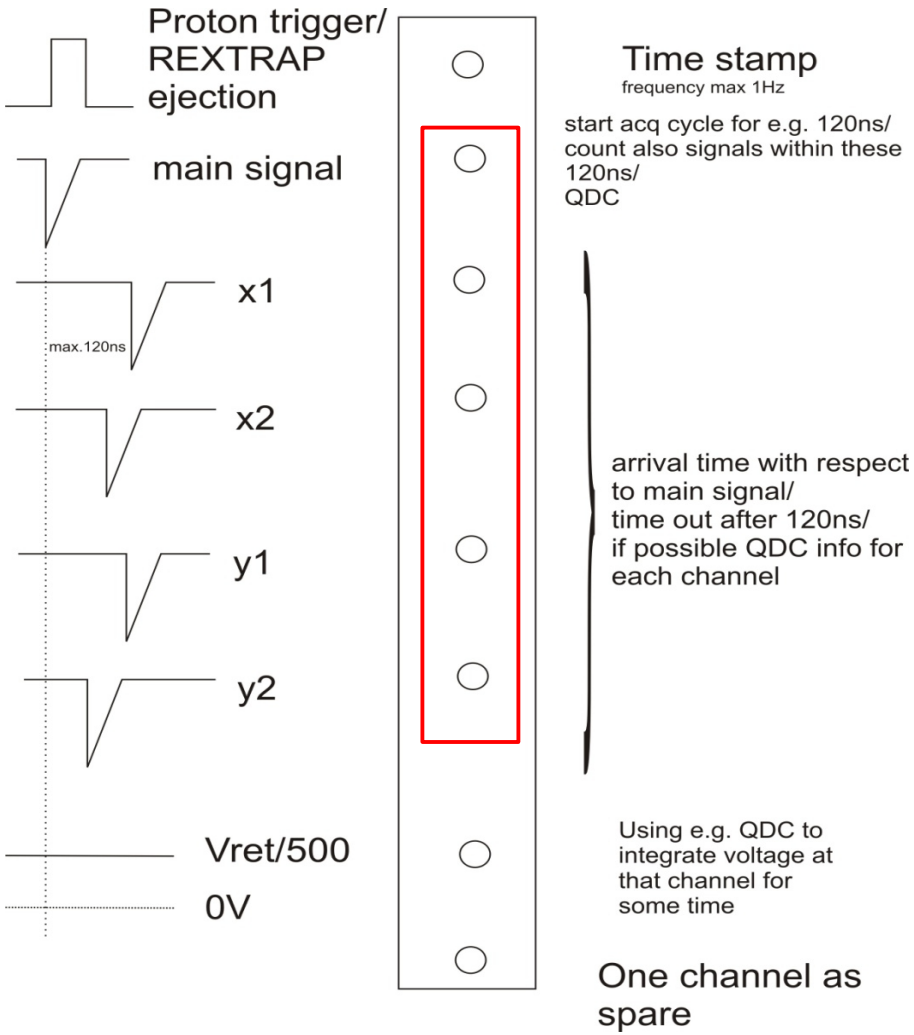
New Data Acquisition - FASTER

FASTER: **F**ast **A**cquisition **S**ystem on **E**thernet netwo**R**k

- Flexible, modular digital system with 8 channels:
  - Trigger (Proton/Rex)
  - Main MCP signal
  - 4 delay lines
  - Retardation voltage

- Two QDC integration windows of -16ns to 50ns and -16ns to 200ns
- TDC time stamp of each channel with ~2ns precision
- Fixed nonextendable dead time of ~280ns

Developed at LPC-Caen



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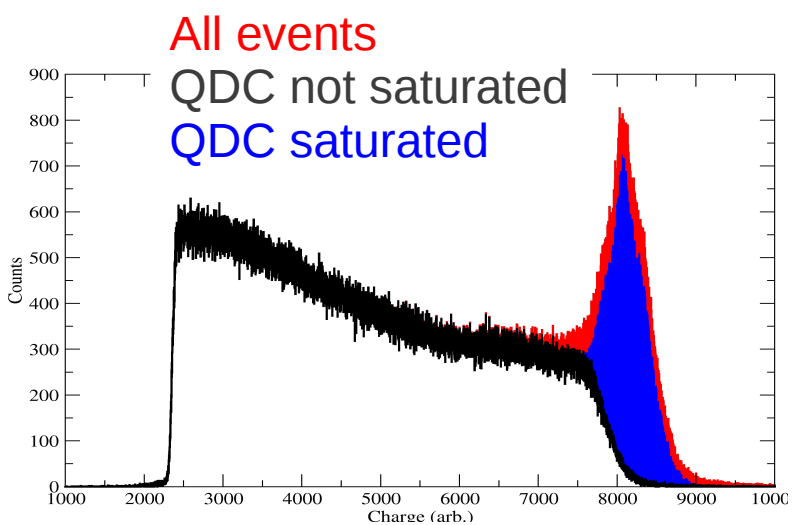
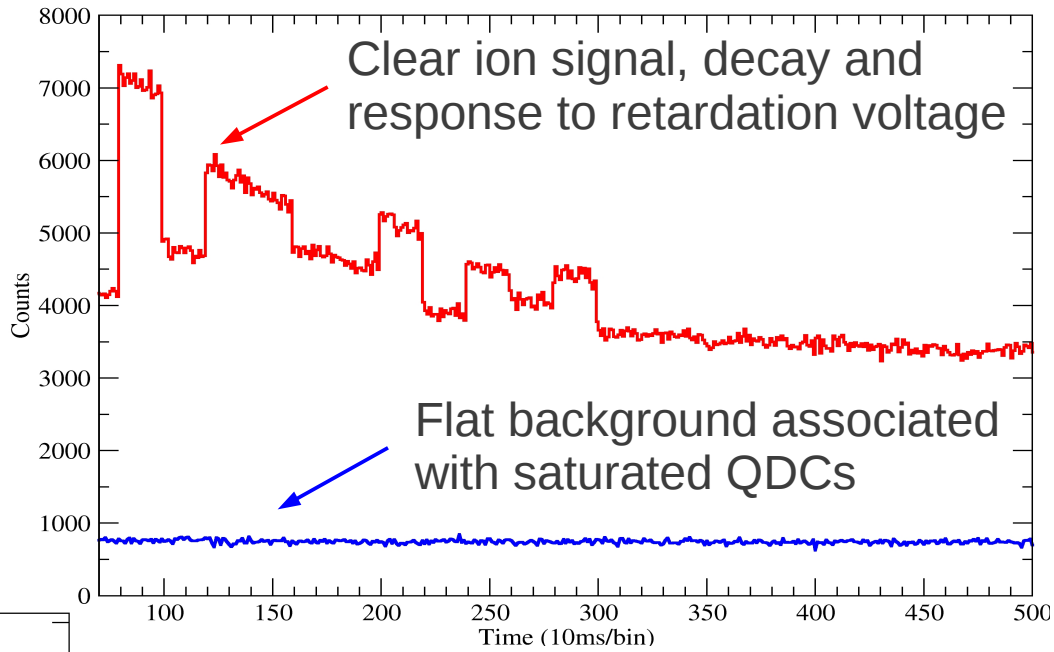
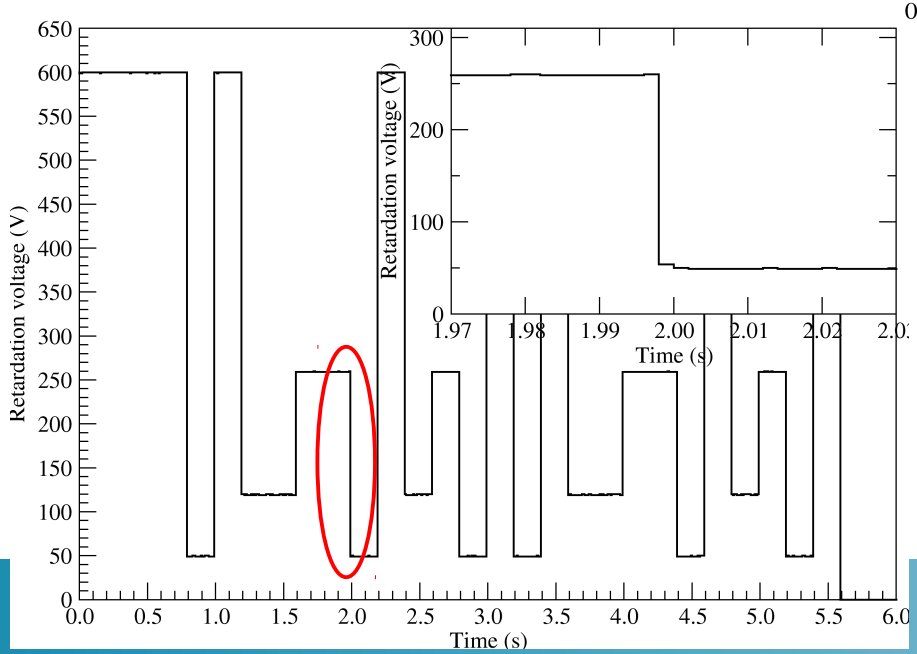
New Data Acquisition - FASTER







- Charge information allows for the rejection of high-energy background
- Monitoring applied retardation voltage in time allows more accurate analysis

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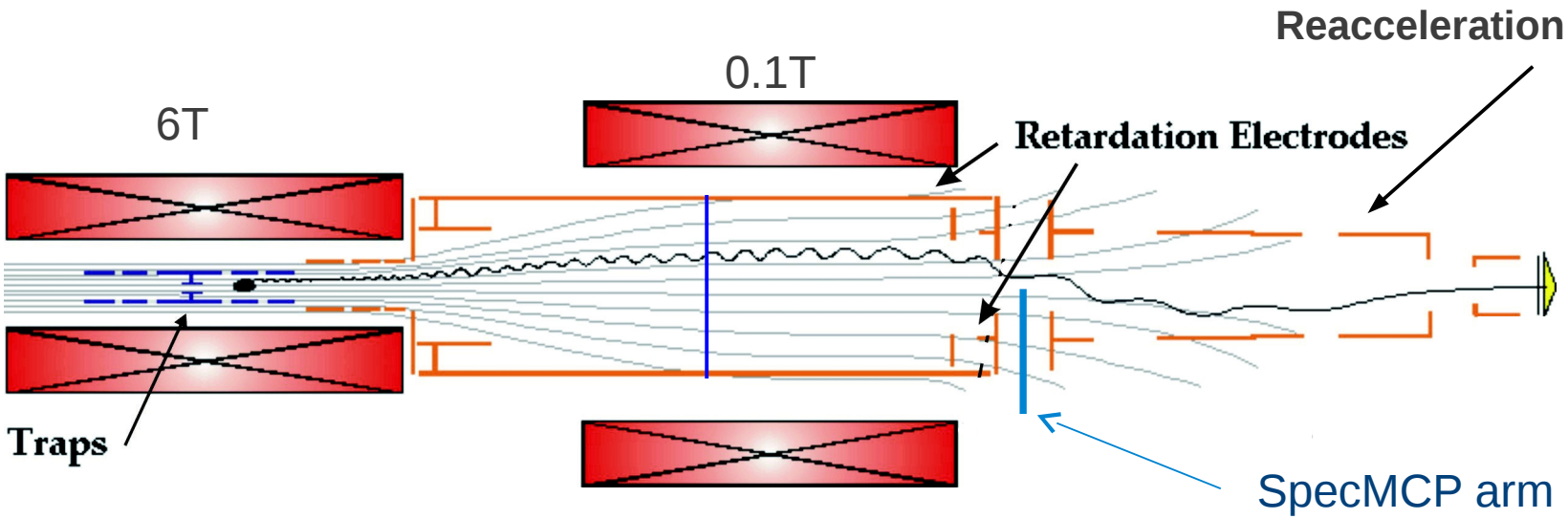
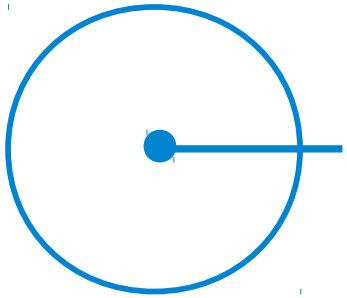
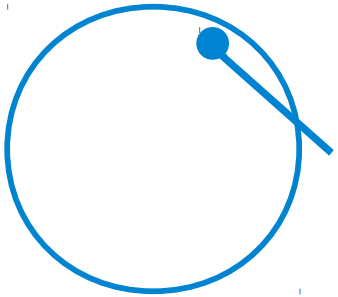
Diagnostic MCP on movable arm

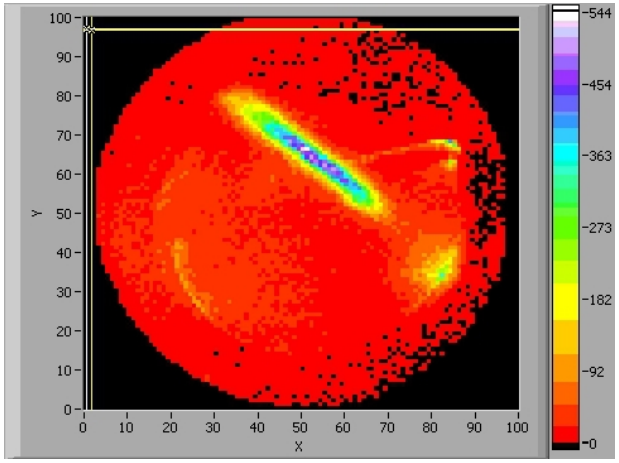


SpecMCP in



SpecMCP out





Even when out:
Grounded arm between -2kV and -7 kV

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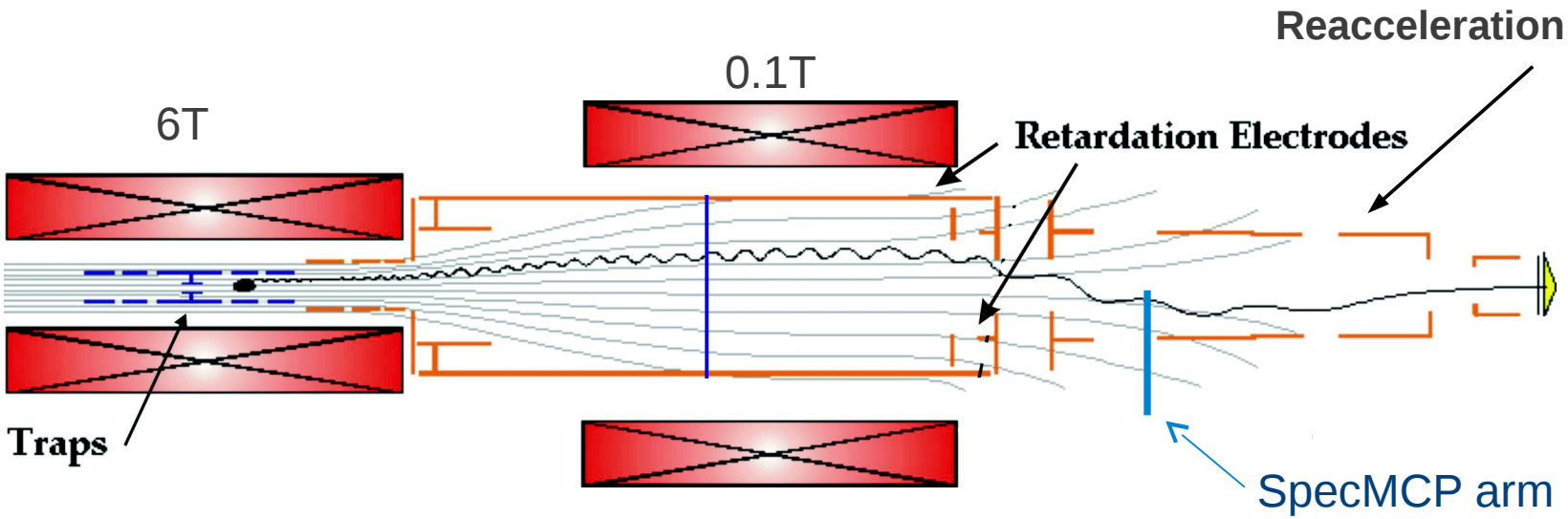
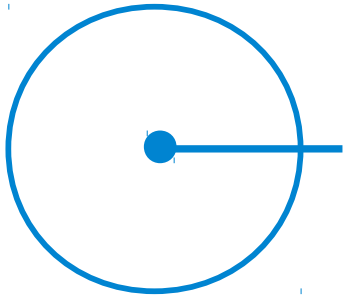
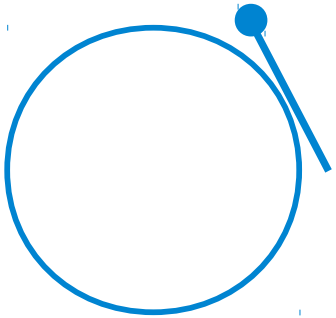
Diagnostic MCP on movable arm



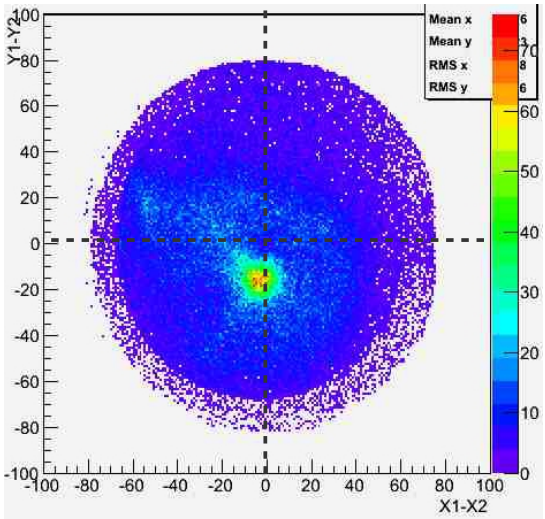
SpecMCP in



SpecMCP out



Moving the SpecMCP axially



Even when out:
Grounded arm between -2kV and -0.4 kV

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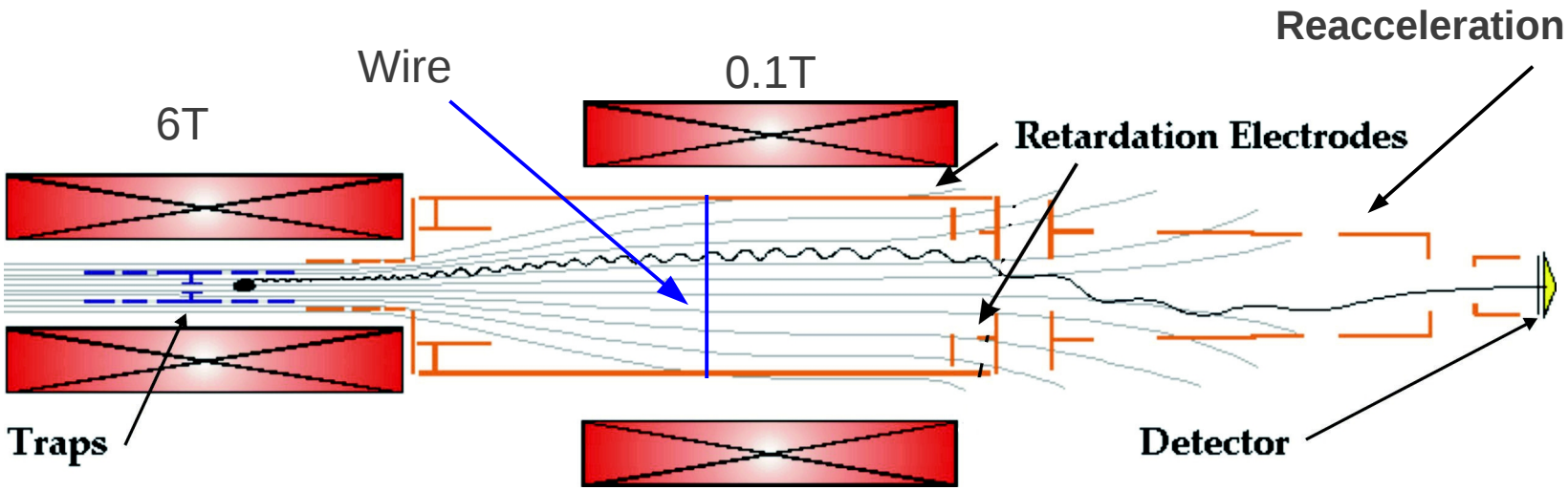
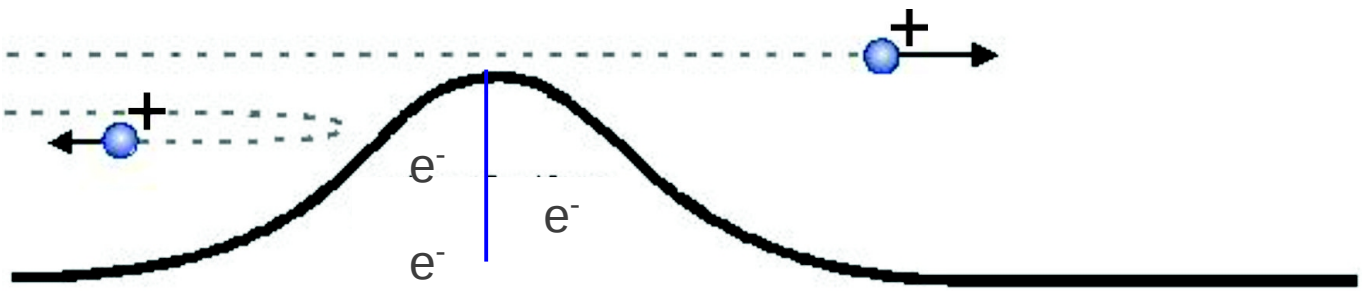
Anti-ionization wire





Grounded wire removes electrons trapped in the blocking potential well

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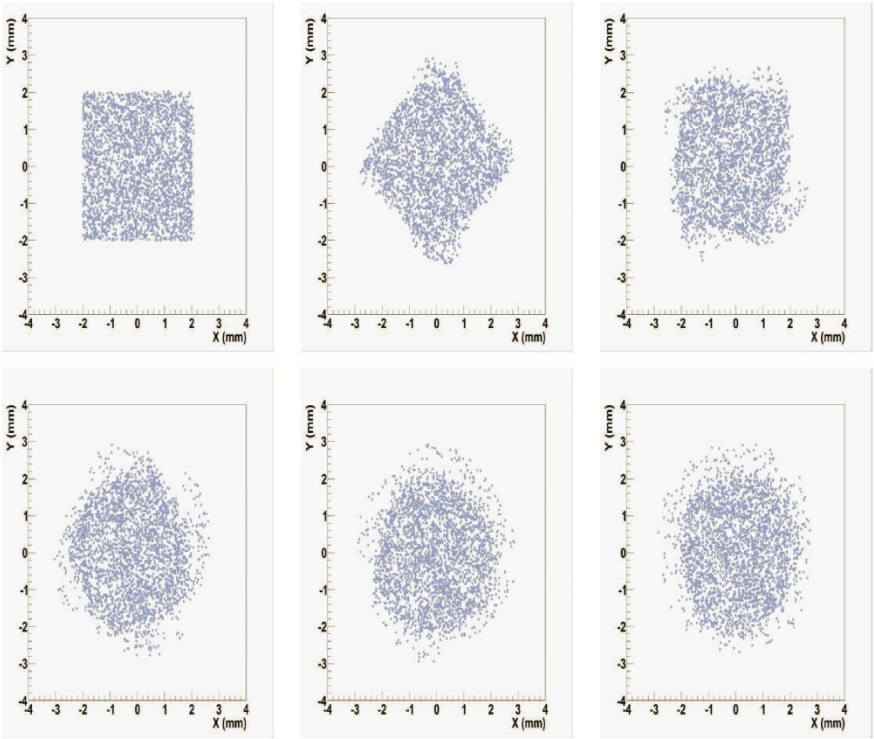
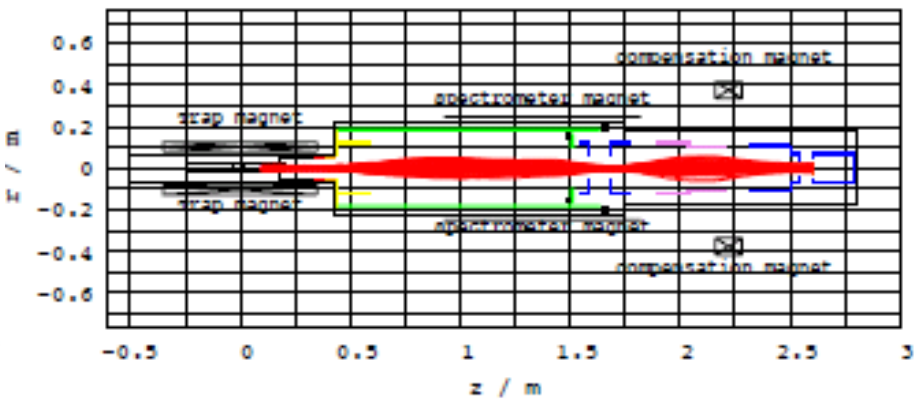
Simulation Programs

Simbuca



- Designed for Coulomb interactions between several 1000 particles in a trap
- Determine the initial conditions of the ion cloud in the cooler and decay traps, simulate transfer between them

SimWITCH



- 2D, cylindrically symmetric (r,z)
- Designed for particle tracking from ion source (DT) to detector
- Draws momentum distribution from Simbuca results “plus” recoil momentum from standard model distributions

S. Van Gorp et al., NIMA 638 (2011) 192-200.
Diploma thesis, P. Fridag, U. Muenster

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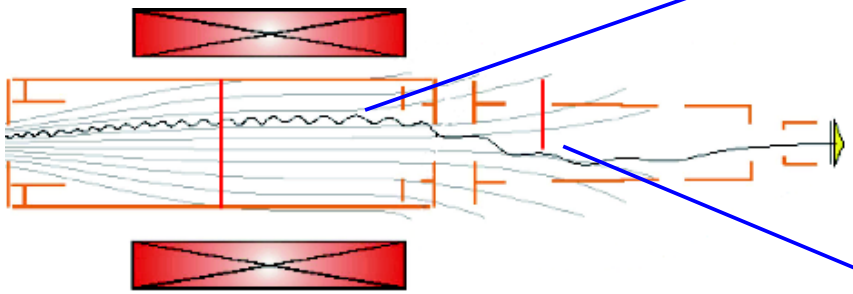
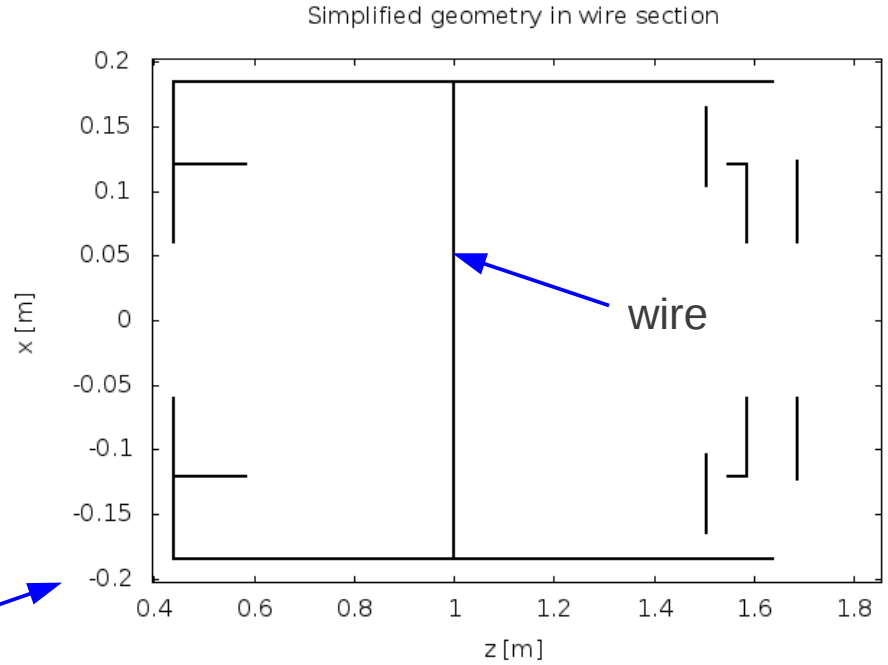
Electric potential calculations

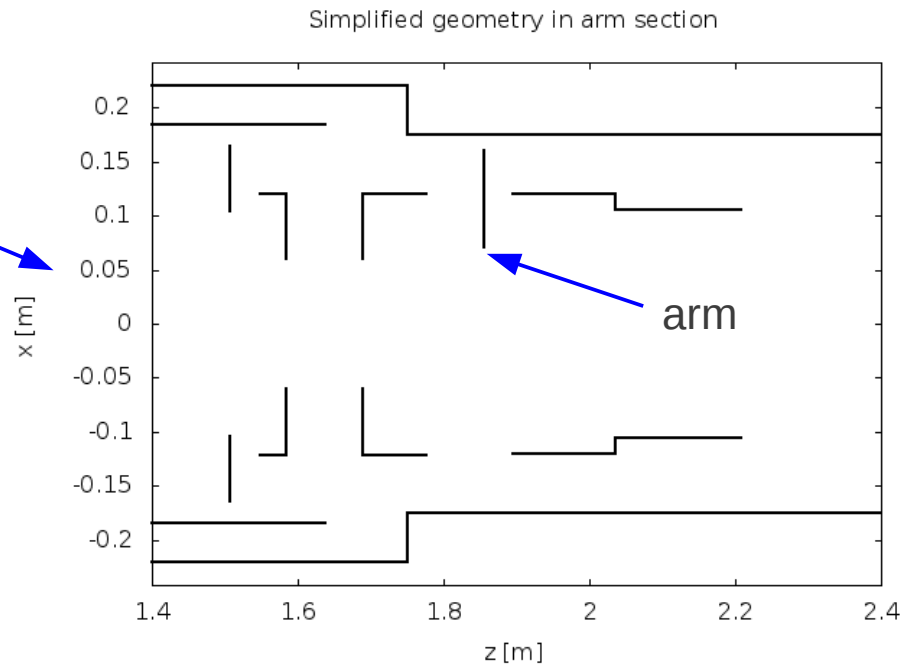
Calculations of electrical potential:

- **2D** – full geometry
  – without wire/arm

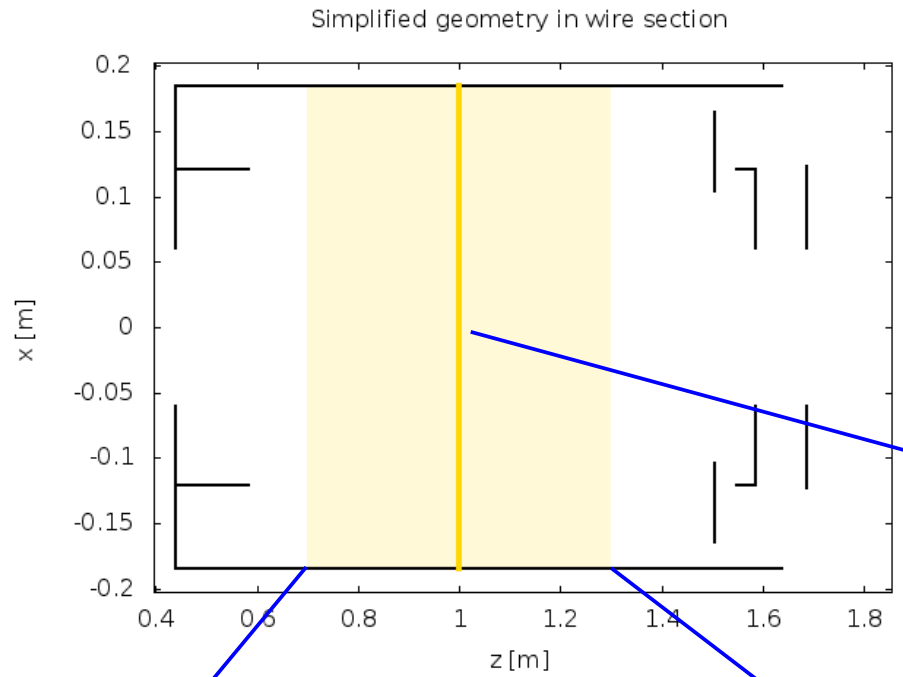


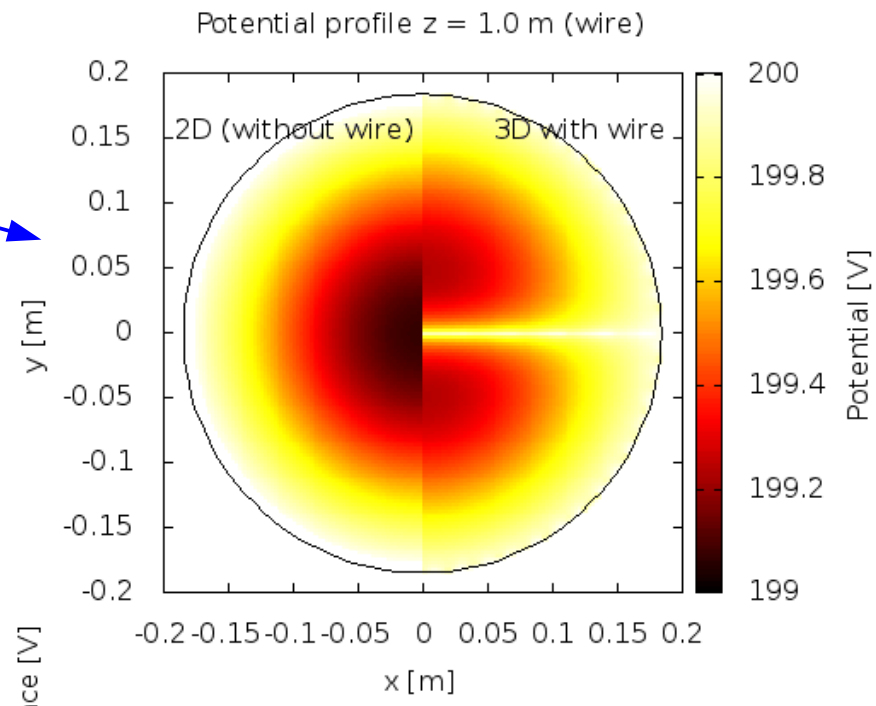
- **3D** – simplified geometry:
  – without wire/arm
  – with wire/arm

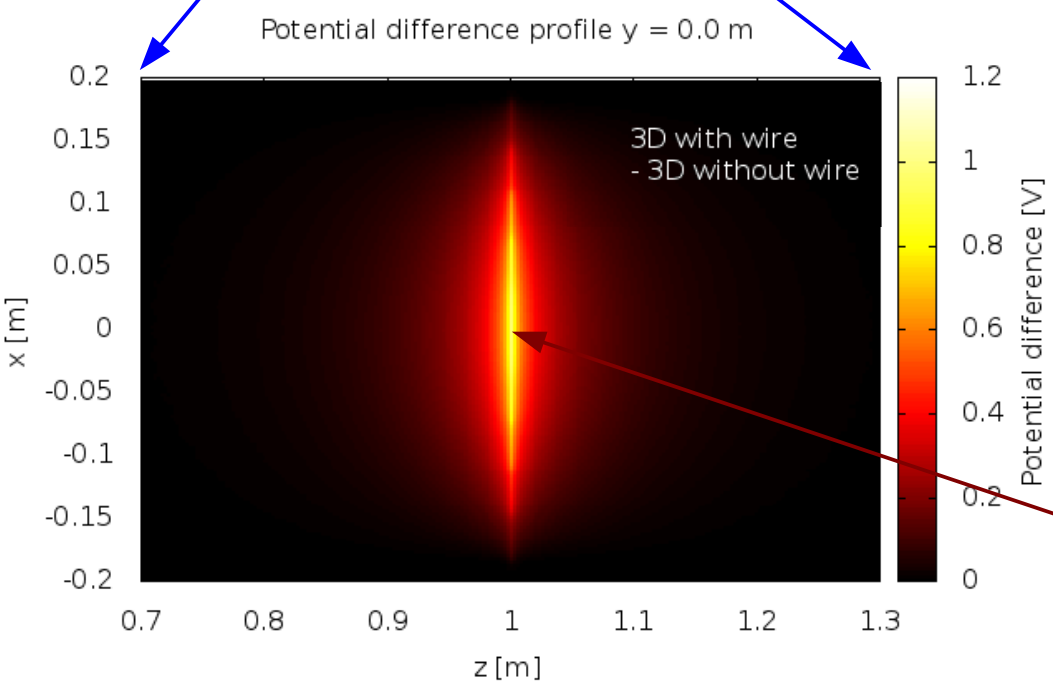




Wire

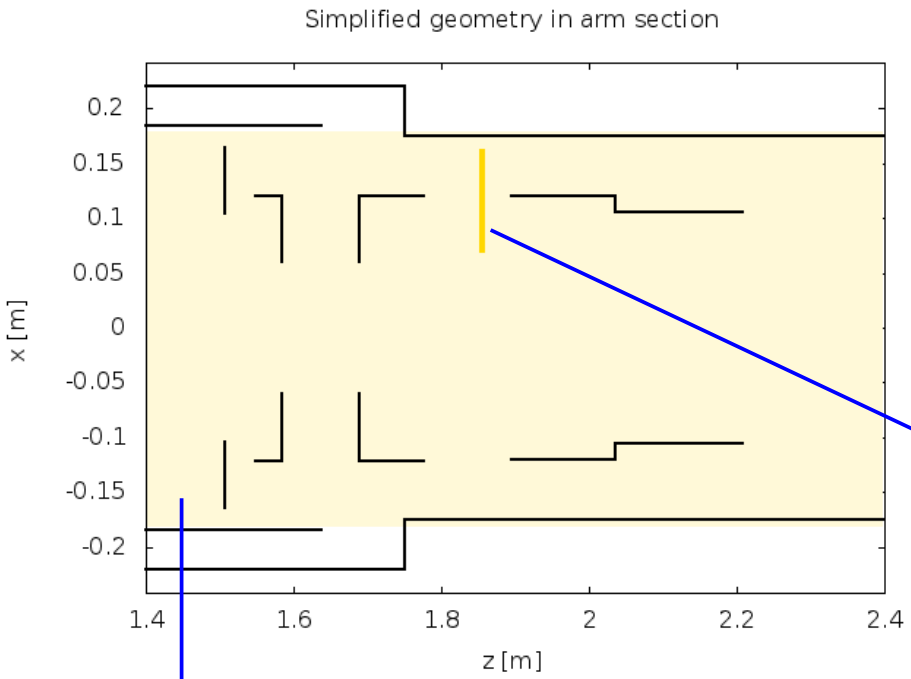


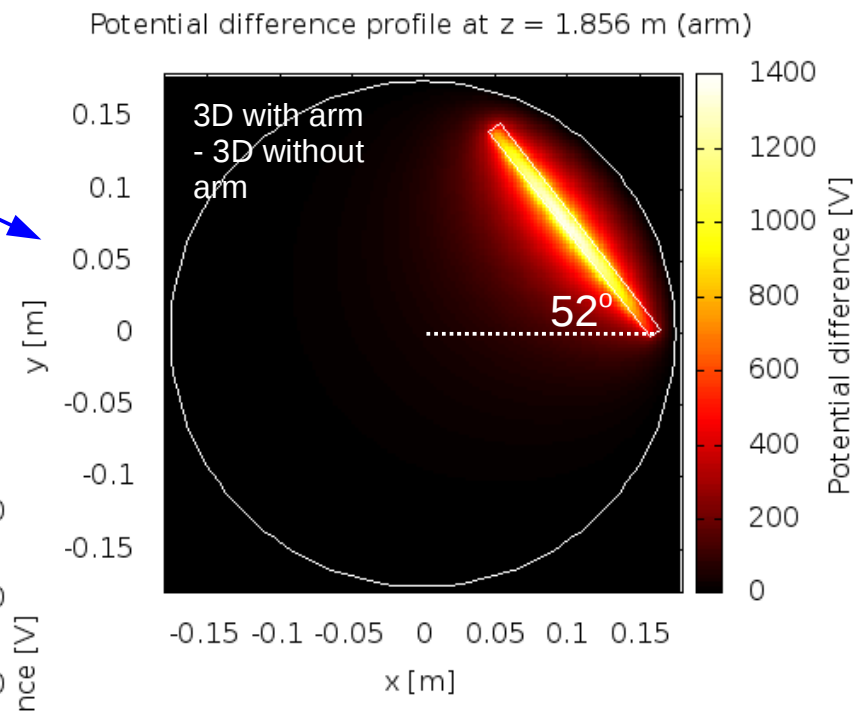


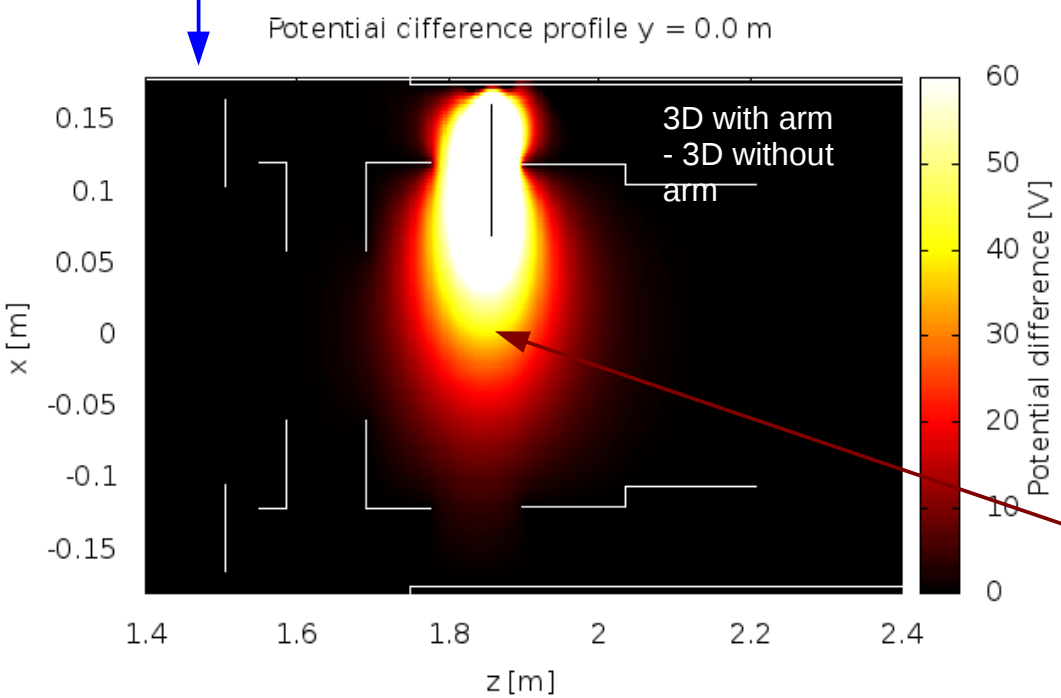


The wire rises the potential in the centre by ~1.1 V (0.5%)

Arm







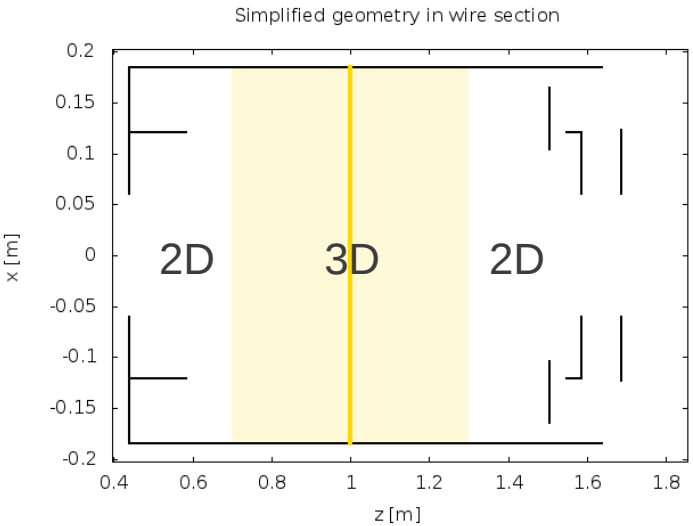
The potential in the centre (0, 0, 1.855) is higher by ~38 V (1.3%)

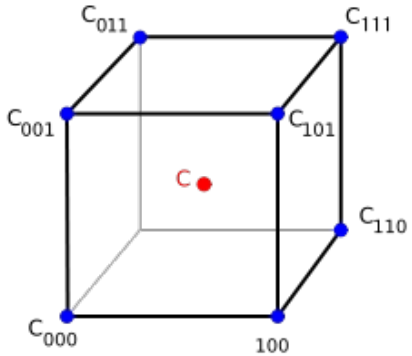
Ions simulations – tracking

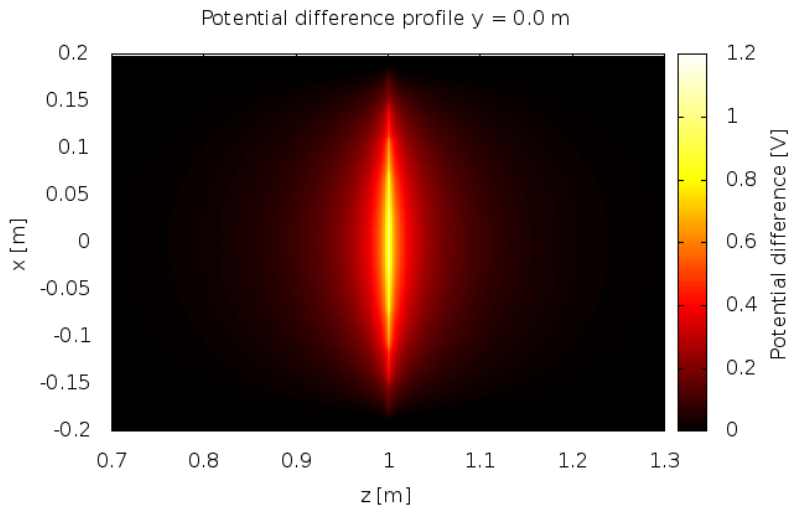
- 3D calculations take 2000× more time than 2D
- Efficient 3D tracking:
  - switching between 2D and 3D routines
  - 3D interpolation using potential map
  - map of potential difference (with-without element) from 3D calculations
  - adding this difference to 2D calculations

→ 3D simulations only 20% longer

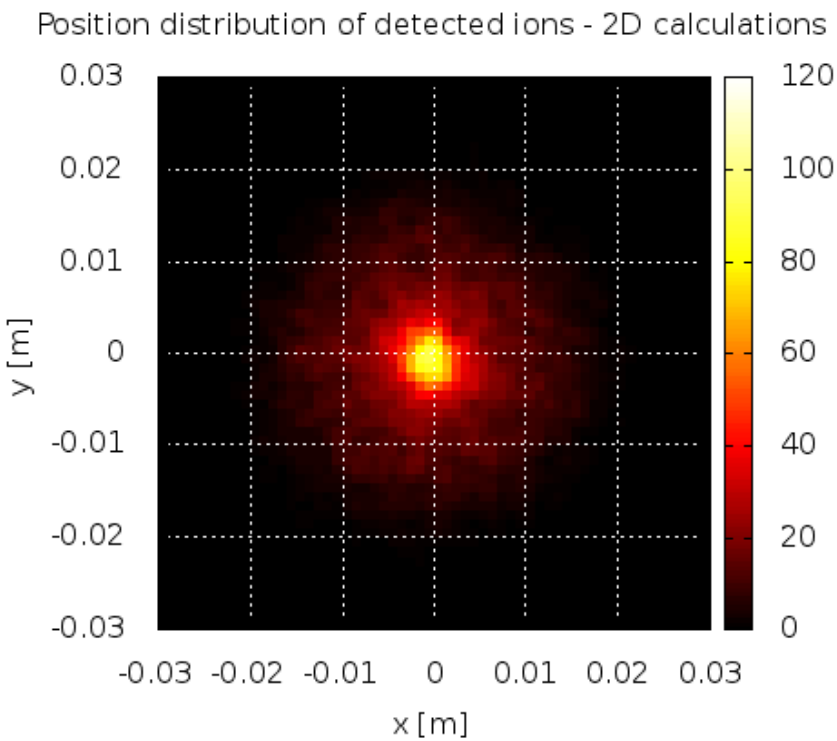
Implemented by Paweł Bączyk

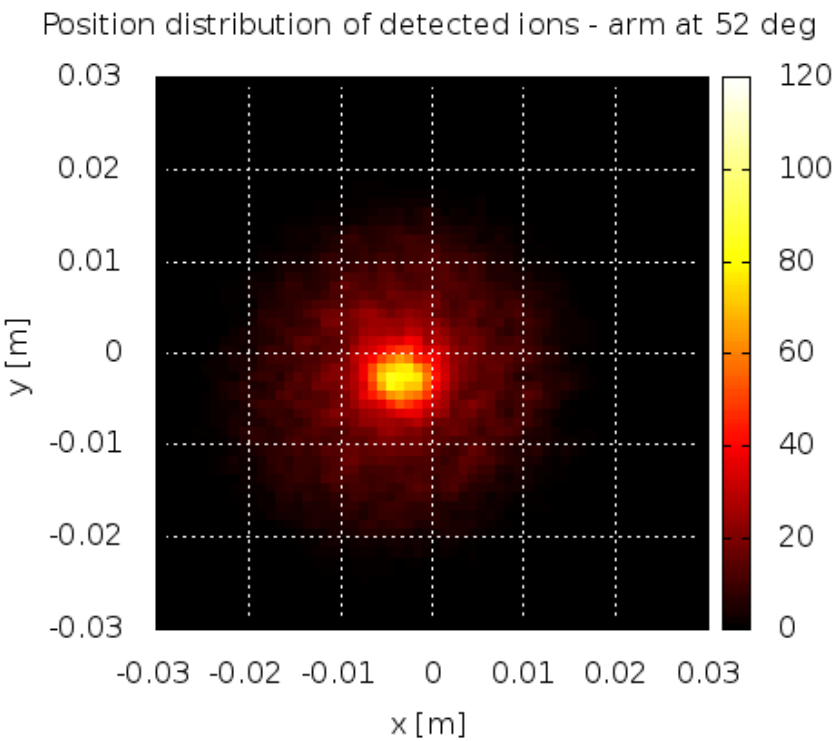






Preliminary results

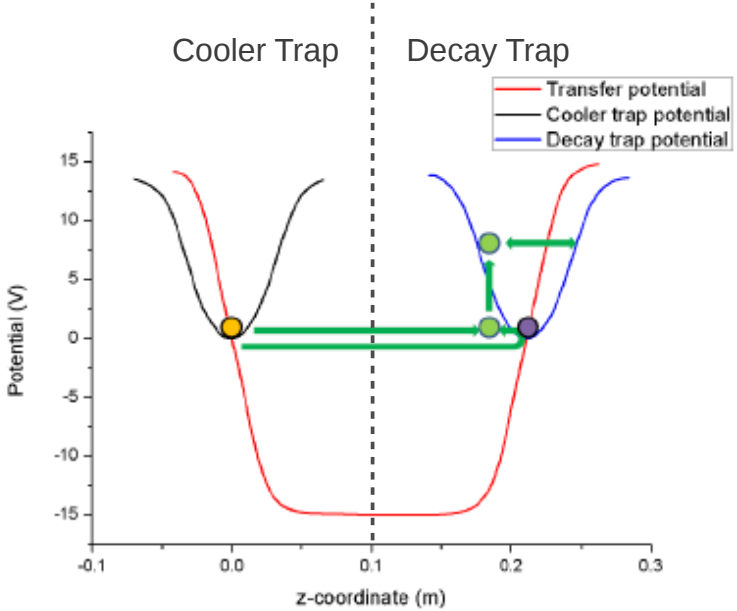


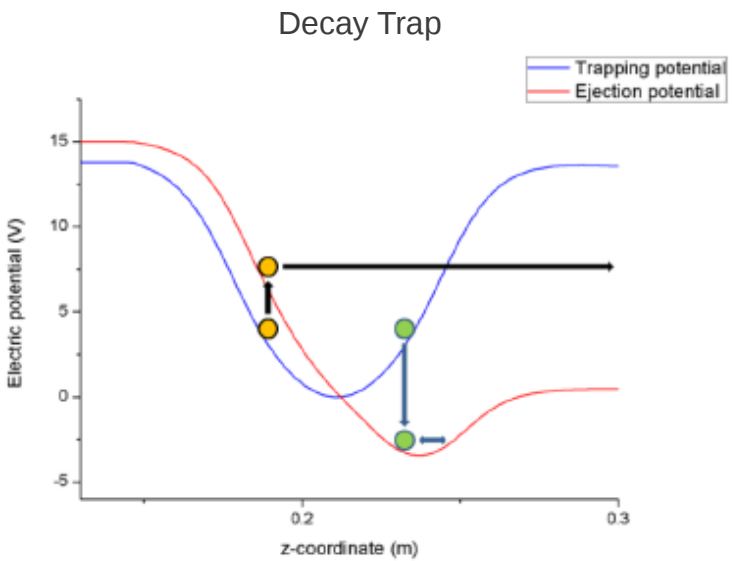


The arm is deflecting ions!

Simbuca – Transfer between traps

Investigation of the axial motion in decay trap:





Scanning transfer time and trapping time maps out the axial movement in the trap

Ions are ejected if they are below the centre of the decay trap -> high signal otherwise no signal

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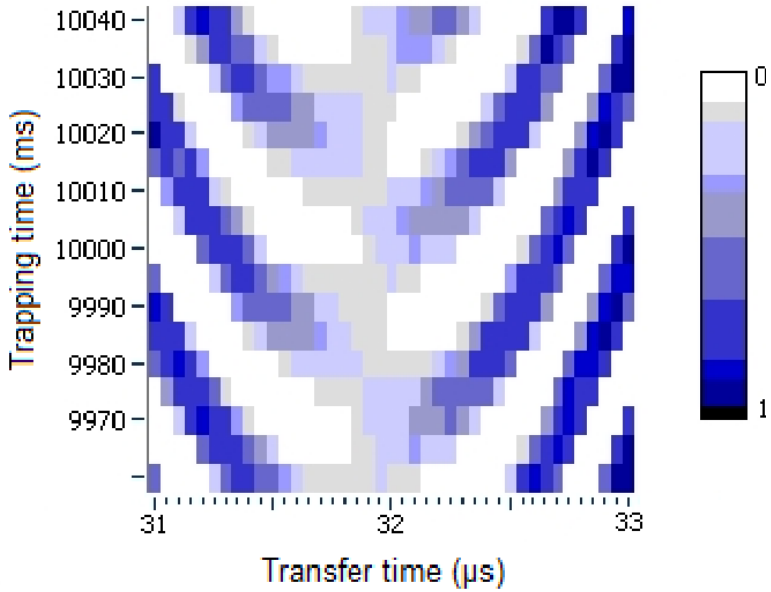
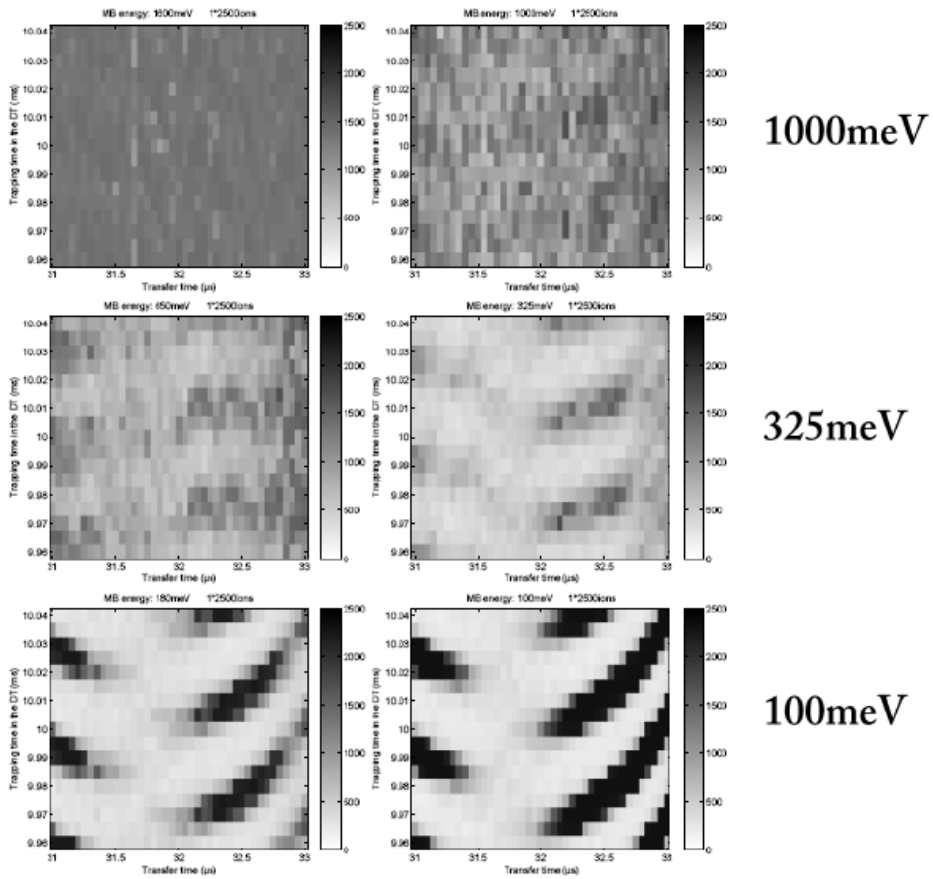
Experimental Scan



Simulation

2500 ions



- Good agreement between simulation and experiment
- Small differences in optimal transfer time and slope of “wings”
- Differences likely due to infinitely fast switching time in simulation and small difference in real and applied voltages

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Summary

- Major improvement in the detection capabilities following the installation of the **FASTER DAQ.**

- The asymmetry in the system due to the SpecMCP has been greatly reduced, and the effects on the ion trajectories due to all symmetry breaking elements is know incorporated into **SimWITCH-3D.**

- The **Simbuca** code has been benchmarked for physical correctness and long-term stability against some demanding experimental data, giving further confidence in its accuracy.

- All of these developments are crucial in order to take full advantage of the **latest online experiment** completed in November 2012 which is the largest, high-quality data set yet collected at WITCH.

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WITCH Collaboration

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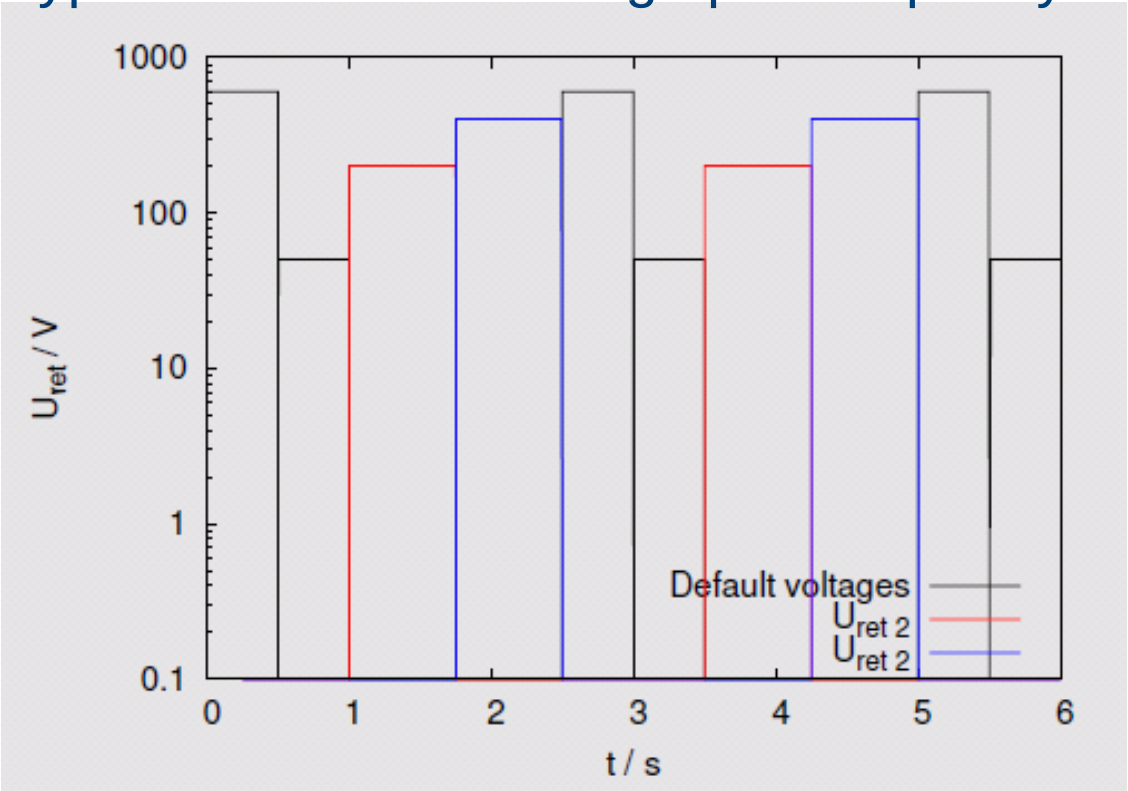
Online experiment 2012

Statistics from Experiment

- 14 shifts @ 8 hours
- 90 recoil ion runs
- 27k cycles @ 6s
- 25M counts in total

Dedicated background, half-life, ion cloud energy and efficiency calibration measurements before, during, and after experiment

Typical retardation voltage pattern per cycle



2 reference voltages (50V, 600V)
2 measurement voltages
(~20 different values spanning recoil spectrum)

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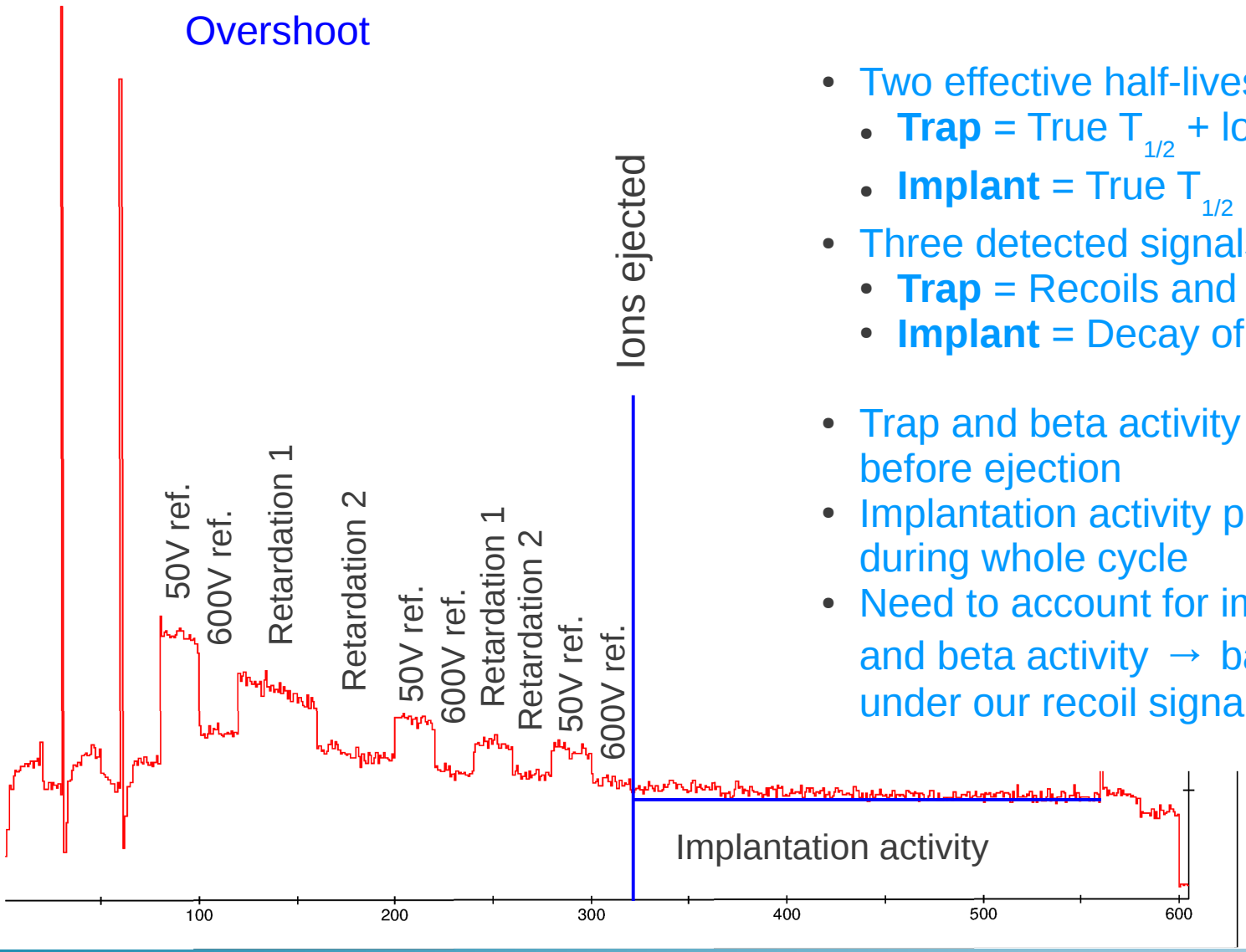
Typical ^{35}Ar Cycle

$T_{1/2}(^{35}Ar) = 1.775(4)$ s

Recoil endpoint = 452 eV



- Two effective half-lives:
  - **Trap** = True $T_{1/2}$ + losses
  - **Implant** = True $T_{1/2}$ + diffusion
- Three detected signals:
  - **Trap** = Recoils and betas
  - **Implant** = Decay of ions

- Trap and beta activity present before ejection
- Implantation activity present during whole cycle
- Need to account for implantation and beta activity → background under our recoil signal

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Background cycles

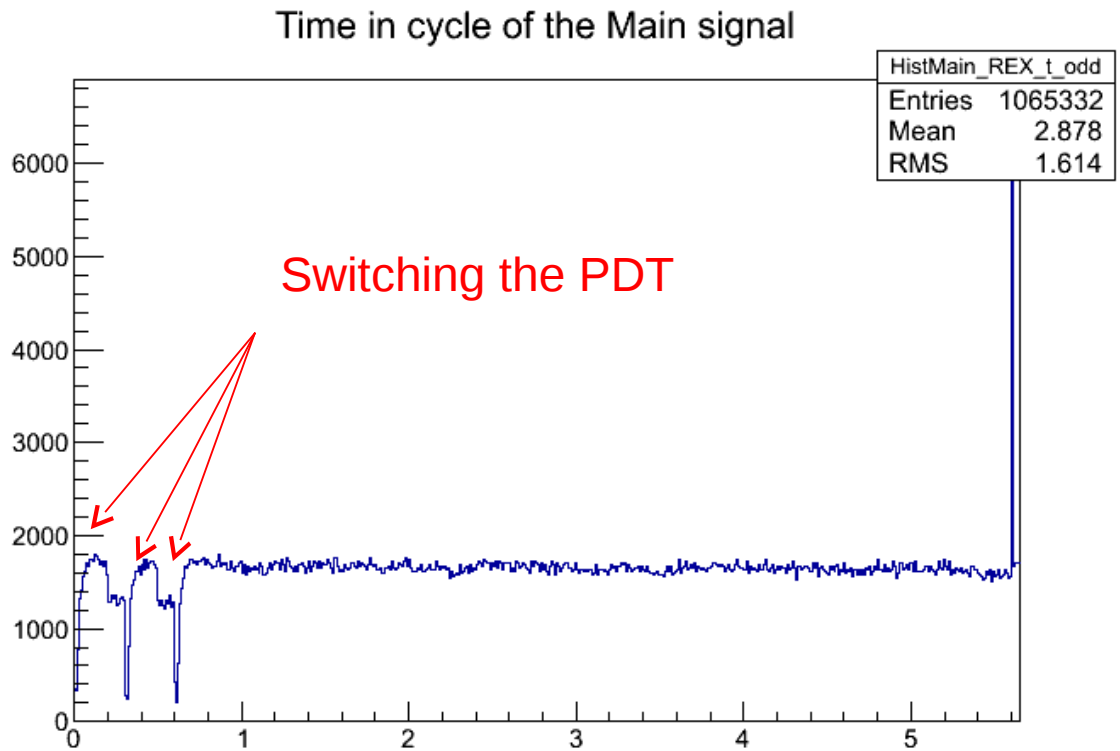
Dedicated background cycle following each recoil cycle.

Ions deflected in the first part of the WITCH beam line

Background not statistically distributed $\chi^2/\nu \sim 1.4$

Discharges (reduction of back ground) when switching the PDT

Example Run of ~ 200 cycles



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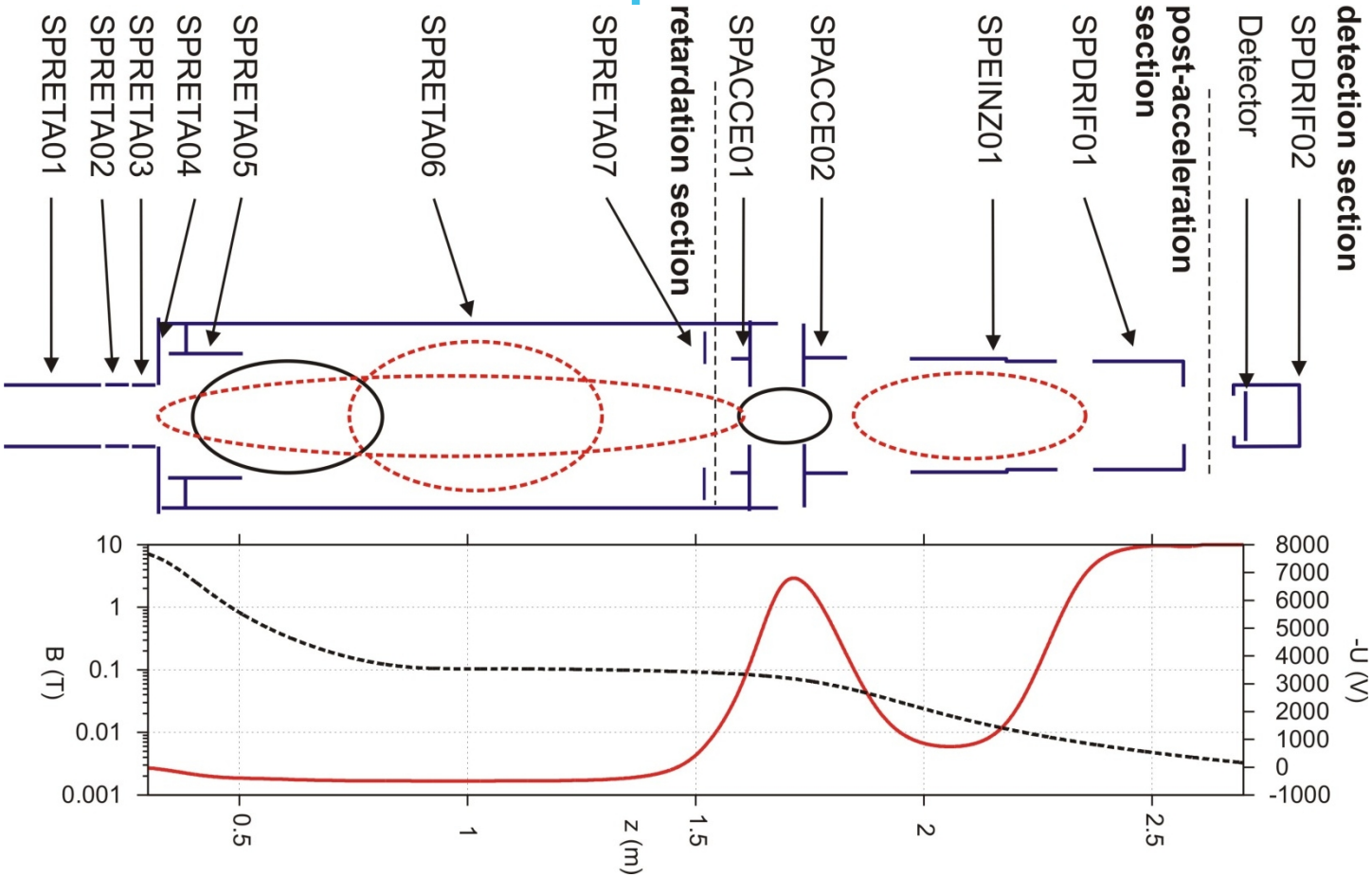
More unwanted traps



PhD thesis M. Tandecki, KU. Leuven, 2011

In addition on the other side of the magnet:
there is a trap between the B-field and the PDT

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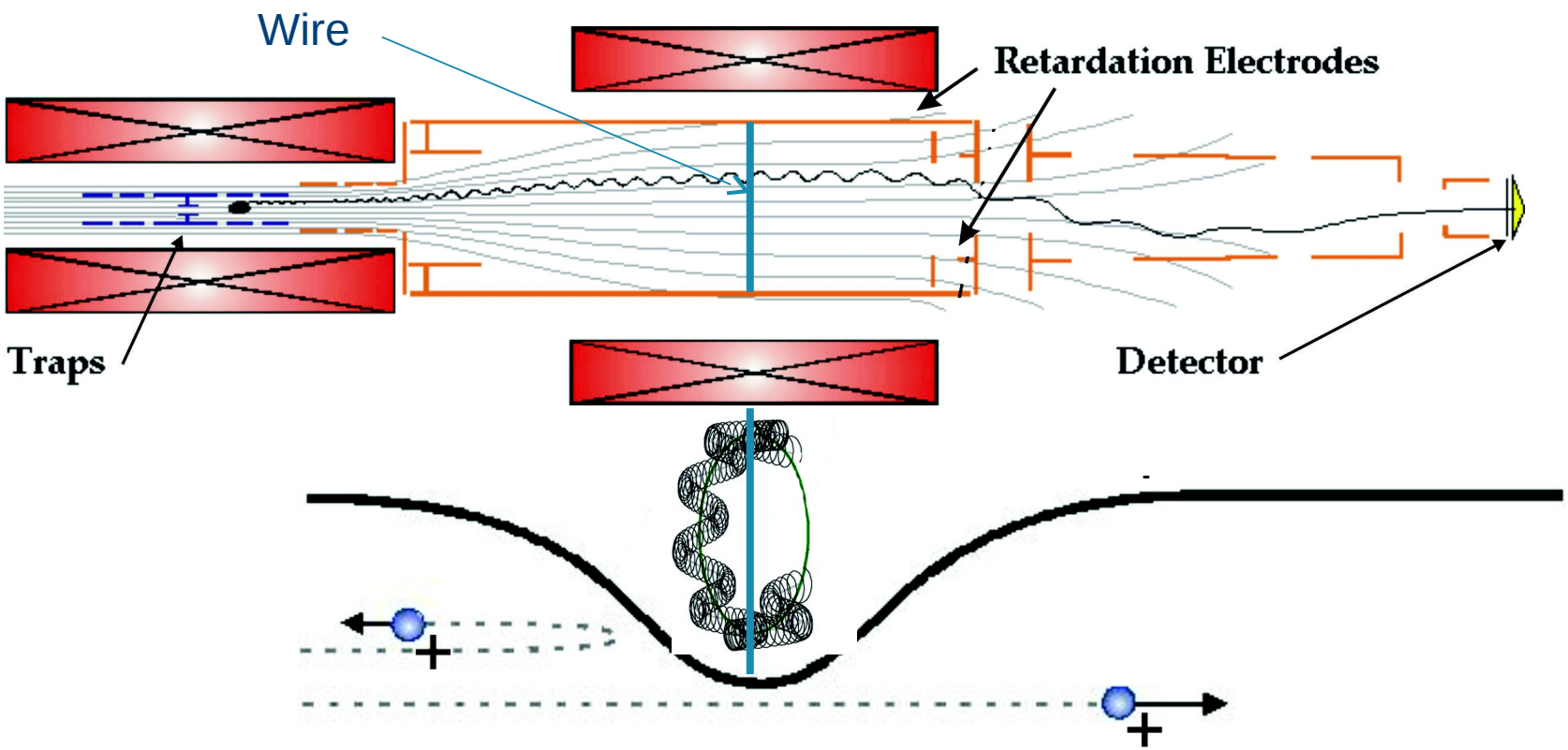
Ionization in the WITCH Spectrometer



Potential wall for positive ions Valley for electrons

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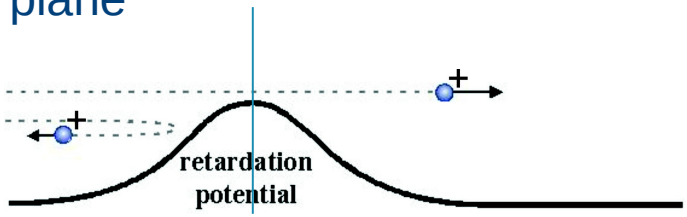
The Anti-Ionization Wire

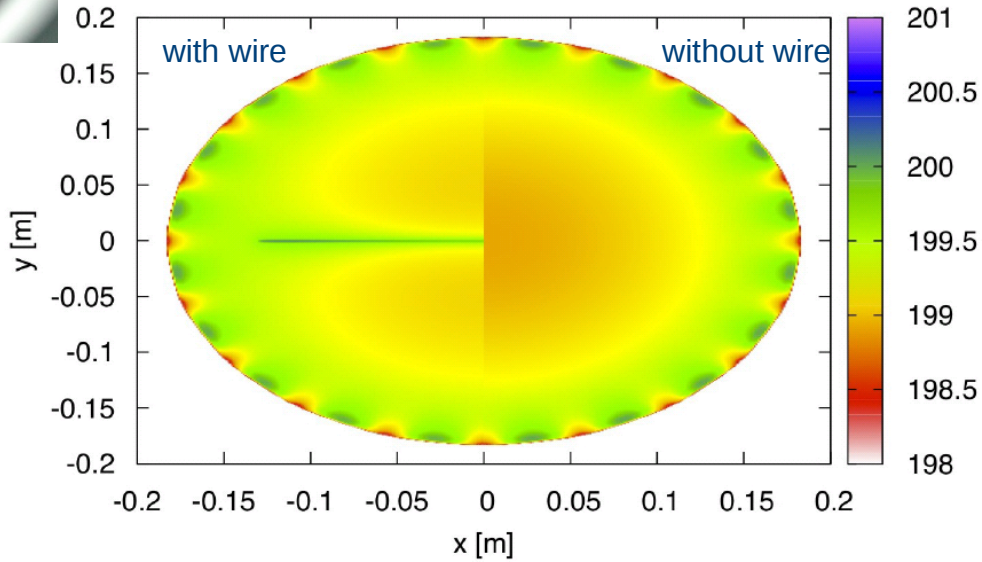
Installation of the wire reduced the ionization significantly!!

Brakes cylindrical symmetry

Absorbes/ deflects ions systematic effect

Potential map in the analysis plane





PhD work P. Friedag, U. Münster

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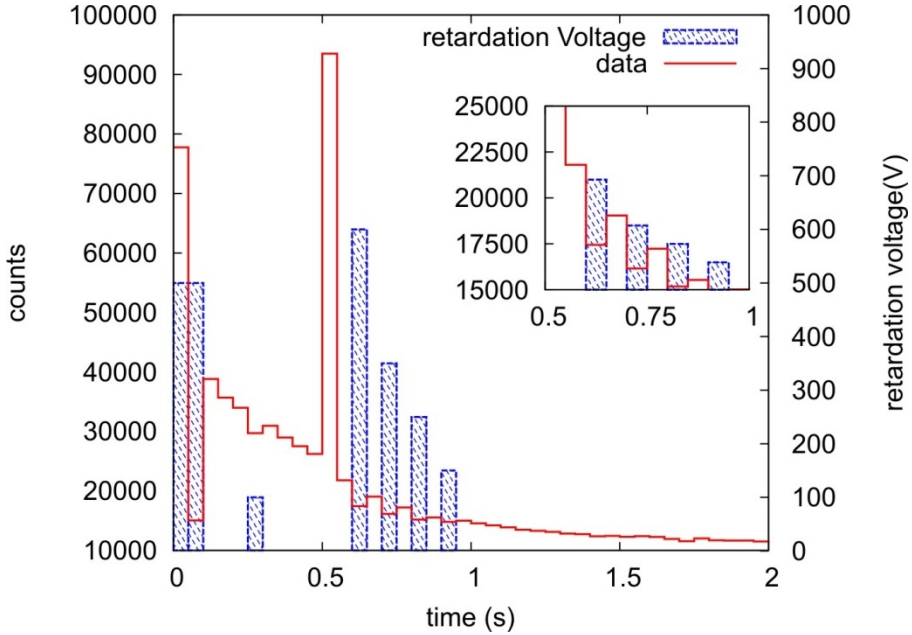
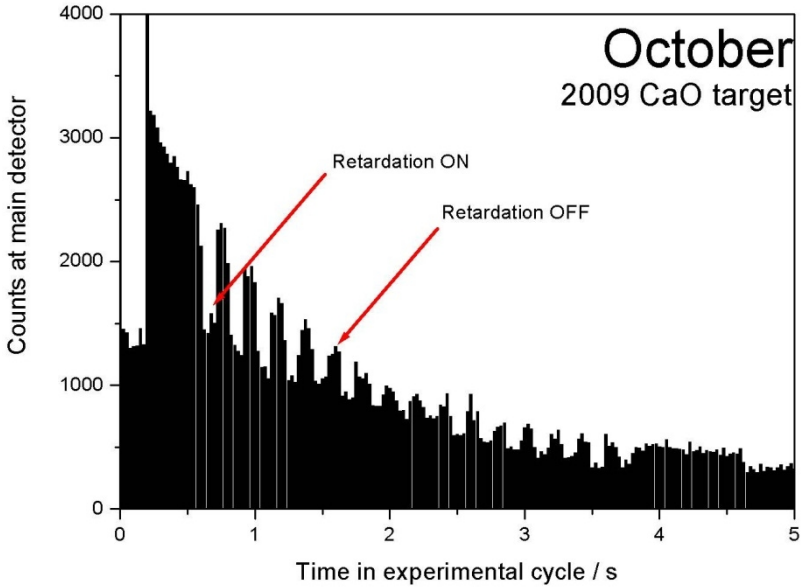
Online Experiments with 35Ar

In 2011:

First 35Ar data taken in June
Data analyzed by S. Van Gorp
For his PhD thesis





6000cts

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