Proton-extraction electrode system for PENeLOPE

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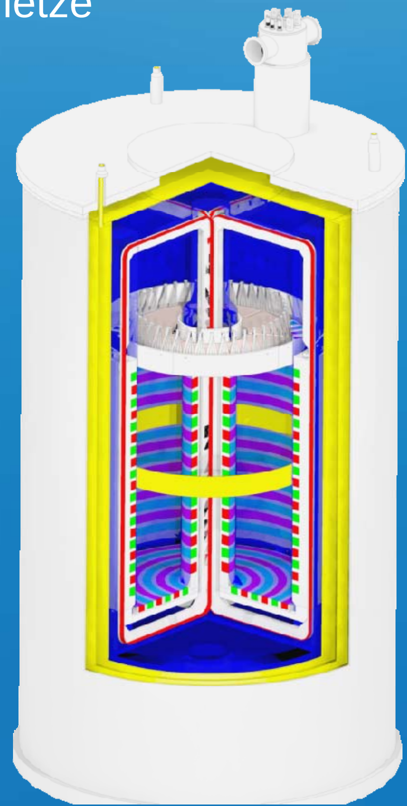

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Outline

- Introduction to Electrode system
- Monte Carlo simulations on
  proton extraction efficiencies
- Diamond-like carbon as resistive layer
- Summary & Outlook

PENeLOPE

Reminder:

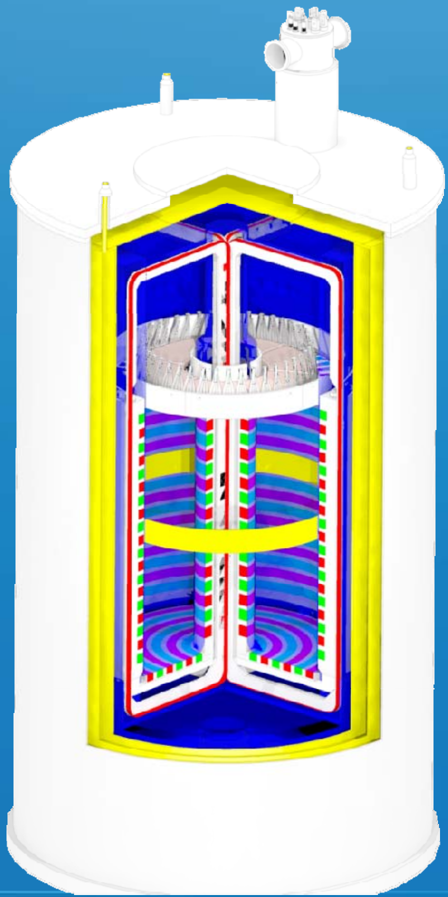
- τ_n has impact on CKM quark mixing matrix & primordial ^{4}He abundance
- τ_n (Serebrov 05) = 878.5 $\pm$ 0.8 s; τ_n (PDG) = 885.7 $\pm$ 0.8 s;

- Ultracold neutron (UCN) experiment (i.e. neutrons in the neV range)
- Magnetic storage to avoid losses due to wall collisions
- Online counting of decay protons

→ **extract as many protons as possible!**

Electrode system

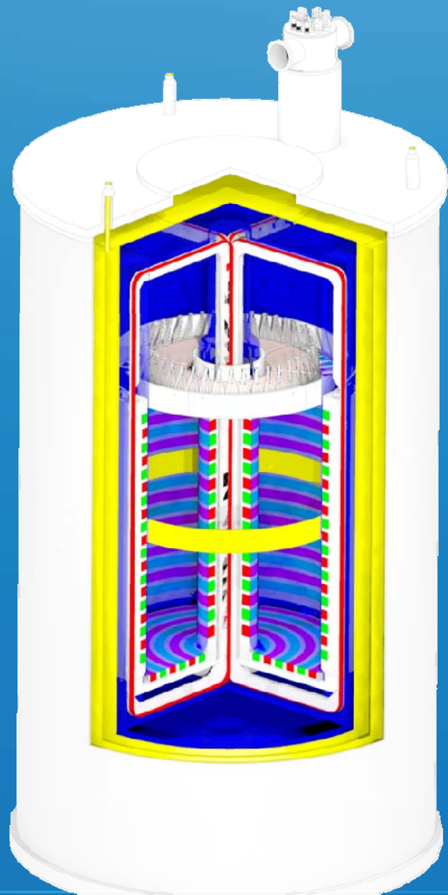
- $\rightarrow$ vertical electric field to increase number of protons reaching the detector
- $\rightarrow$ electrode system as field cage inside storage volume



Electrode system

Requirements:

- 4K
- UCN exposure
- ~10 kV potential difference
- Heat input < 5 W



Electrode system

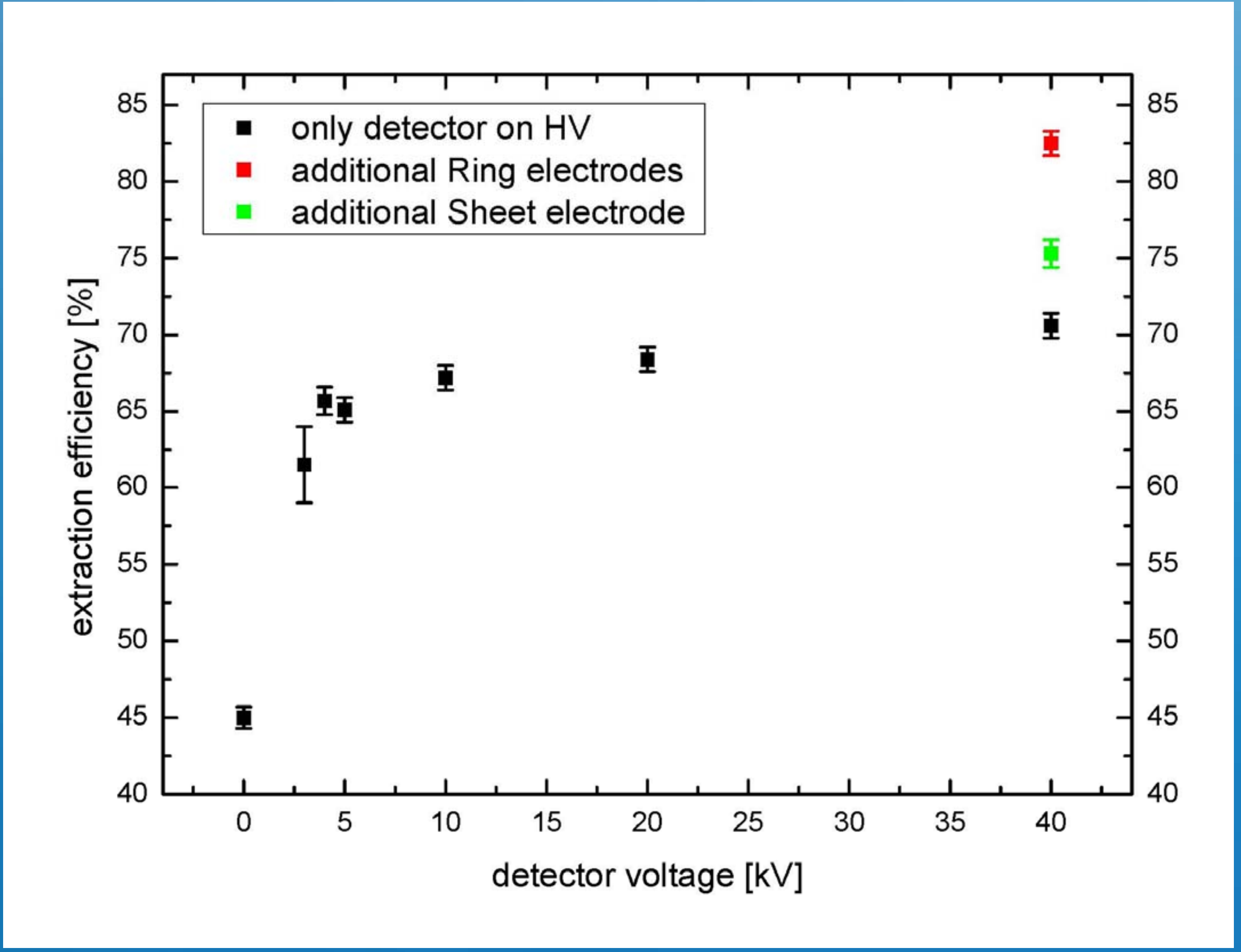
Possible implementations:

- Assembly of **ring electrodes** one above the other
- Apply high voltage to a **resistive foil** to create linear voltage drop along trap height

Simulations on proton extraction efficiencies

- Monte Carlo simulations with the TRACKER code (PhD R. Picker)
- Magnetic and electrostatic fields (OPERA® software)

Extraction efficiencies

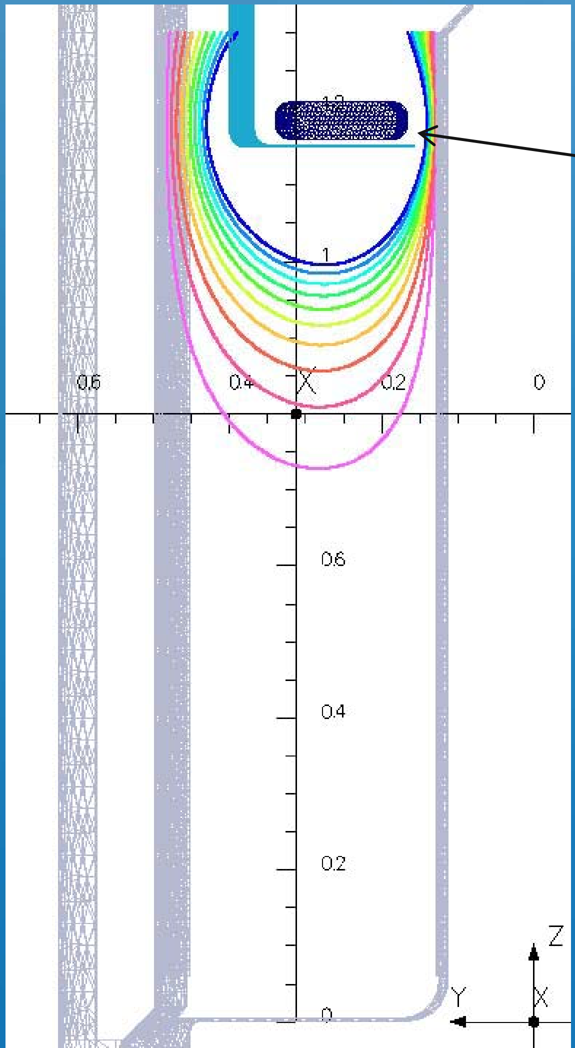


Simulations on proton extraction efficiencies

Comparison:

- **Only detector** at HV
- **Additional extraction-field** is applied generated either by **ring electrodes** or by a linear voltage gradient on a **sheet electrode**

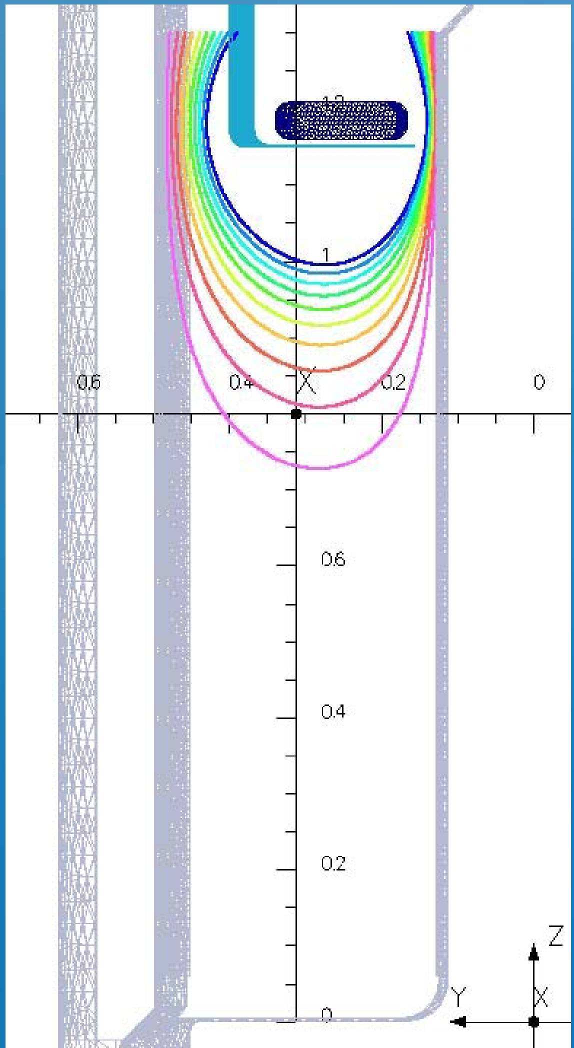
Electrostatic fields

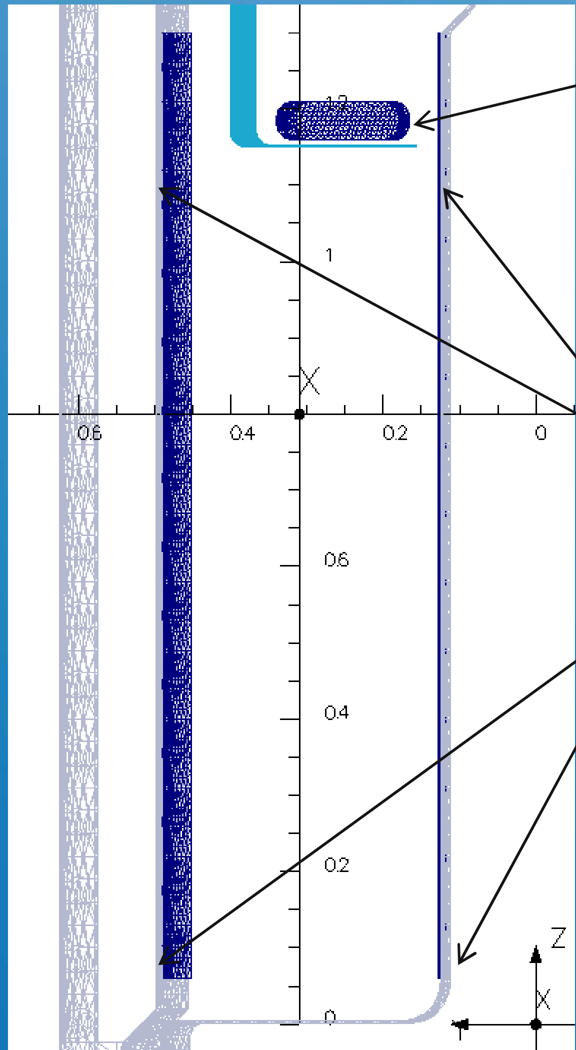


Detector:
-40 kV

Electrostatic fields

SHEET ELECTRODE



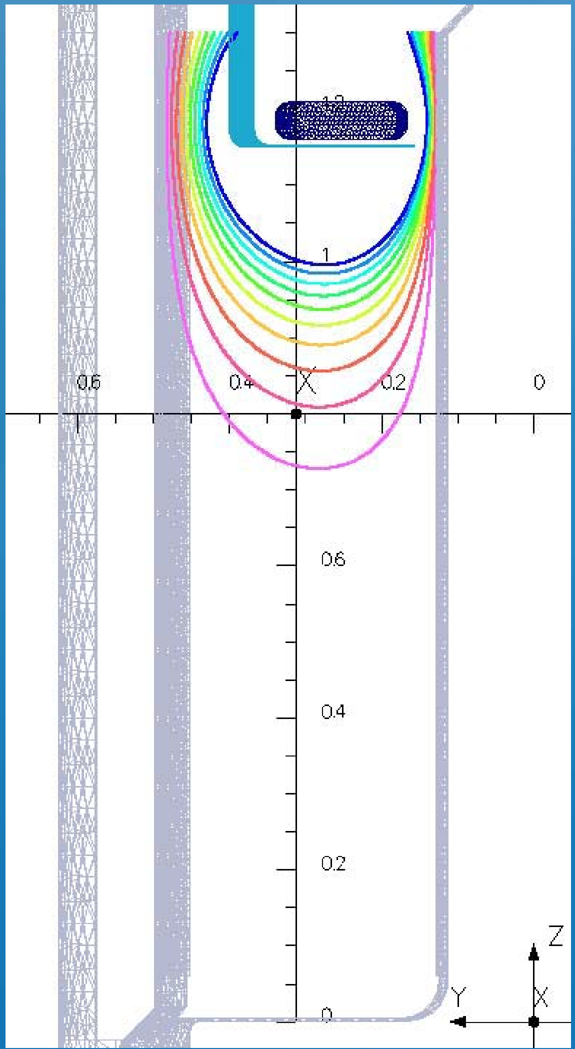


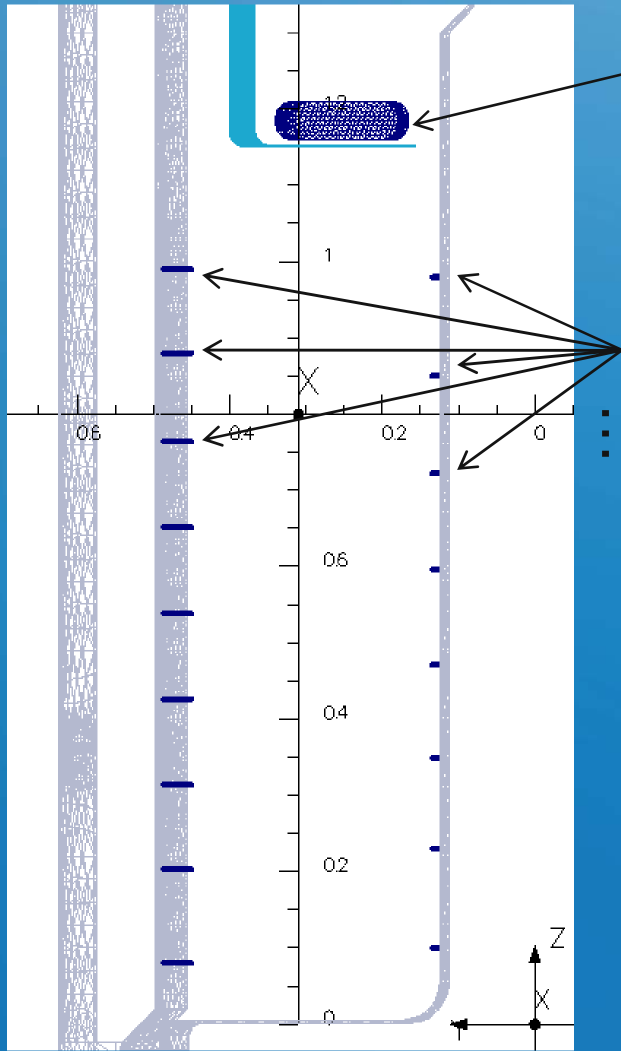
Detector:
-40 kV

Potential drop from -10 kV to ground

Electrostatic fields

RING ELECTRODES



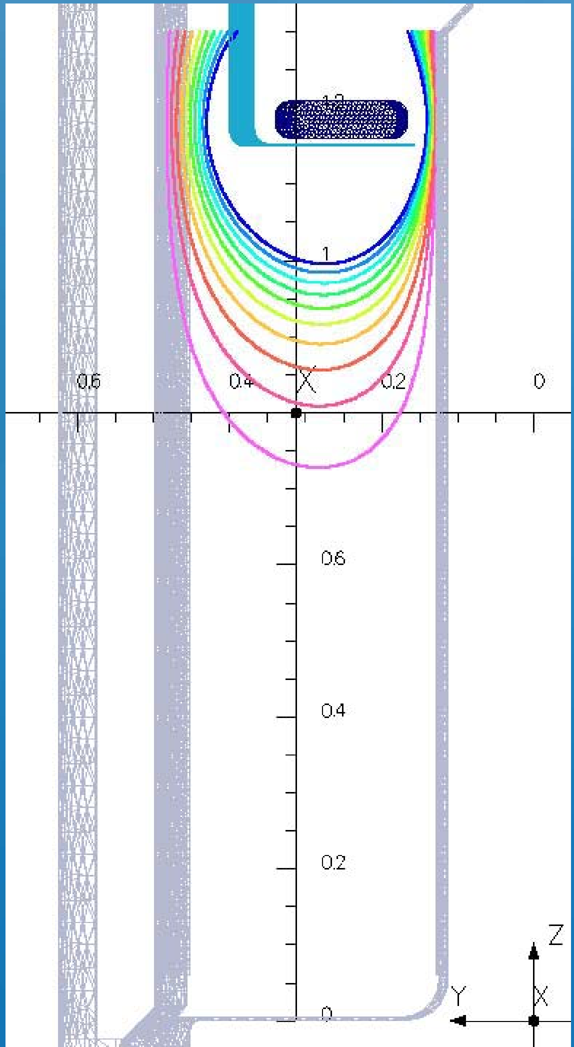


Detector:
-40 kV

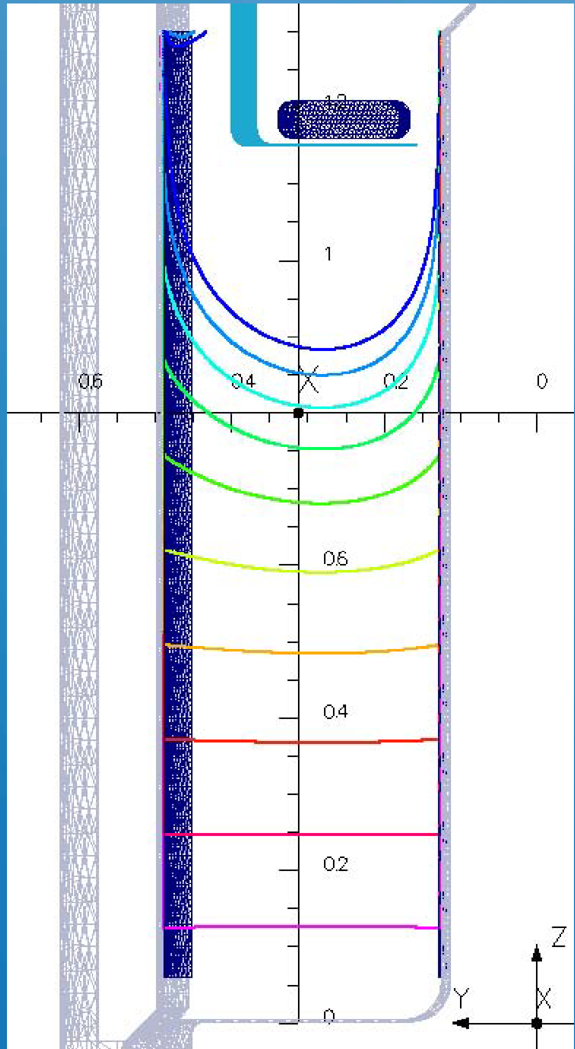
Ring electrodes:
Apply Successively increasing HV to each
(-1 kV,
-2 kV, -3 kV...)

Electrostatic fields

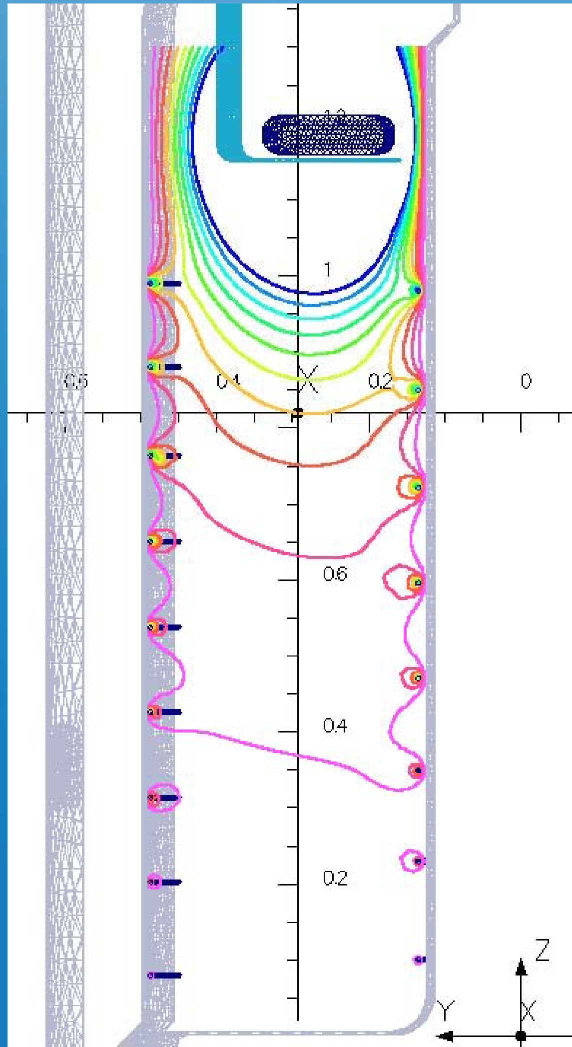
ONLY DETECTOR @ HV



SHEET ELECTRODE



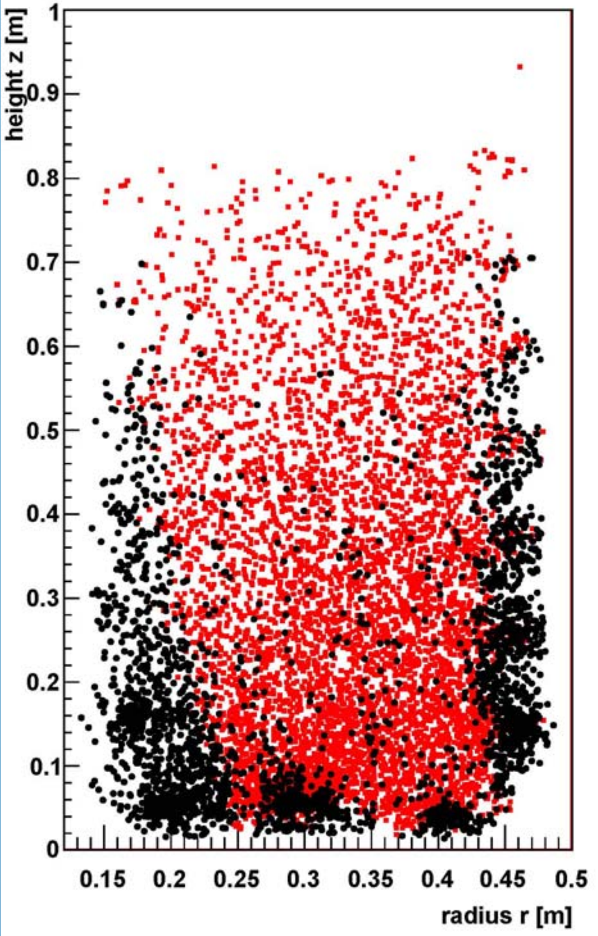
RING ELECTRODES



Extraction efficiendies!

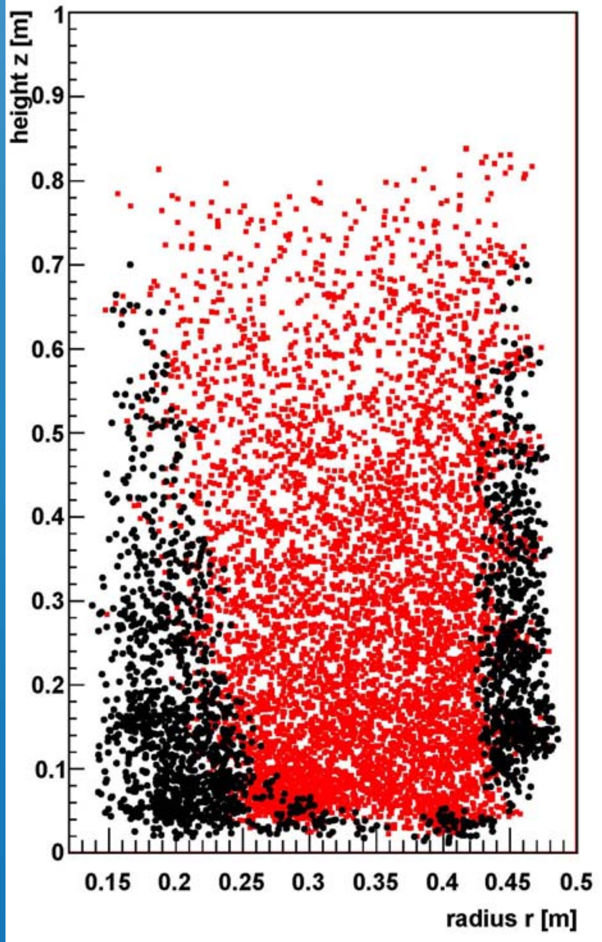
ONLY DETECTOR @ HV

70.6±0.8%



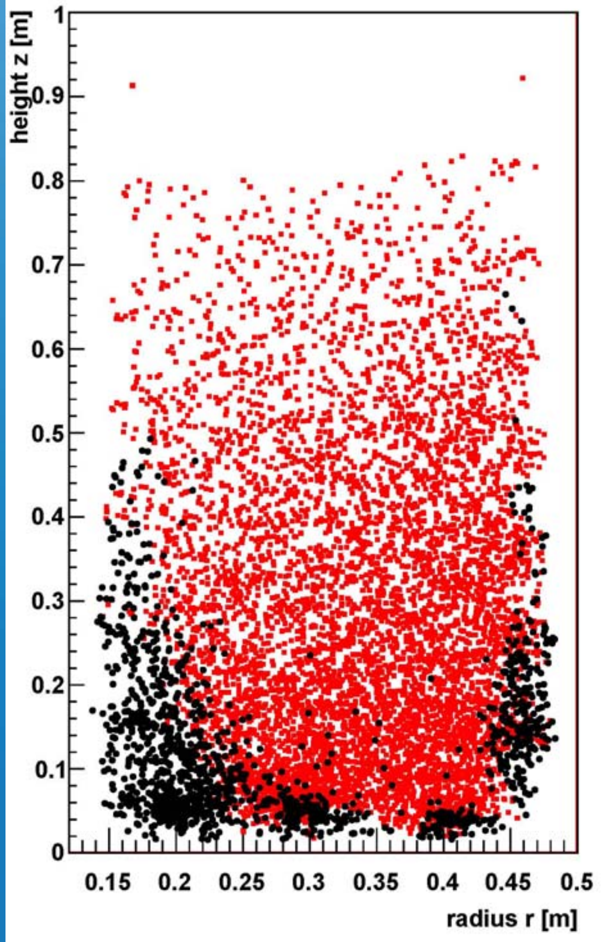
SHEET ELECTRODE

75.3±0.9%



RING ELECTRODES

82.5±0.9%



Diamond-like carbon as resistive layer

- Improve UCN storage properties
  and use as sheet electrode at same time

- Apply **HV to top** of foil +
  ground bottom of foil
  to create **potential drop** along foil
  (voltage divider)

- Plastic substrate: (F. Atchinson *et al*, Nucl. Instr. and Methods B 260 (2007) 647)
  insulator between HV and cryostat walls

Diamond-like carbon as resistive layer

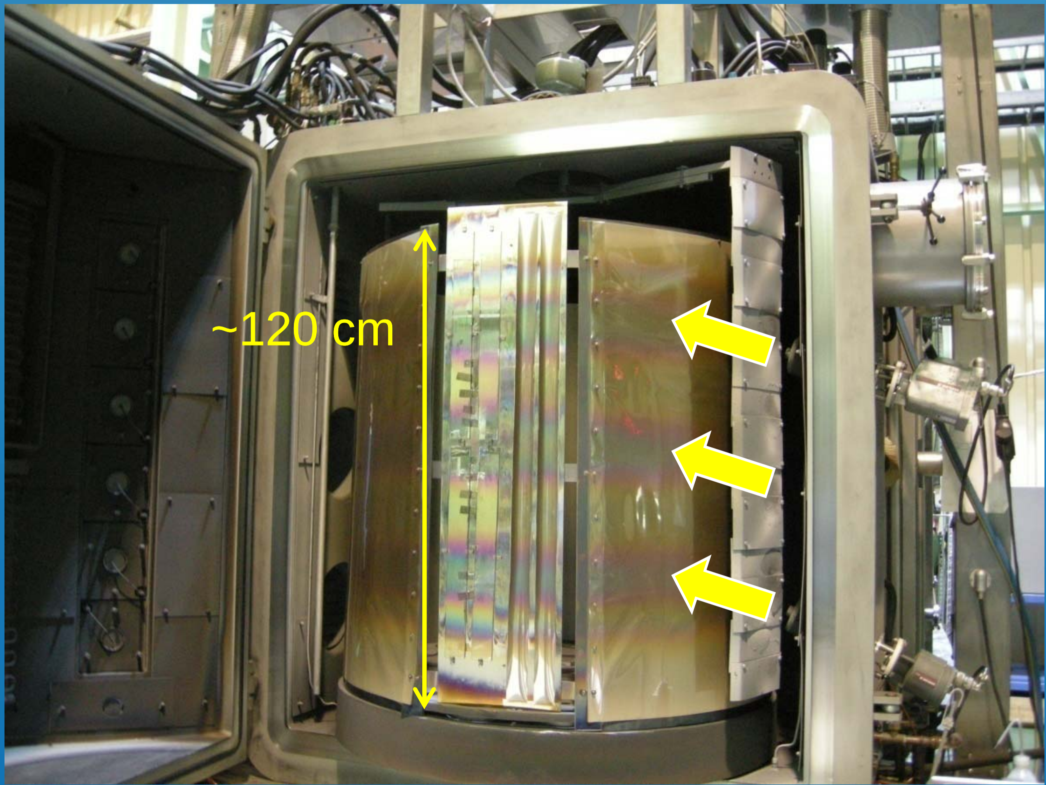
Diamor® from Fraunhofer IWS Dortmund, Germany:

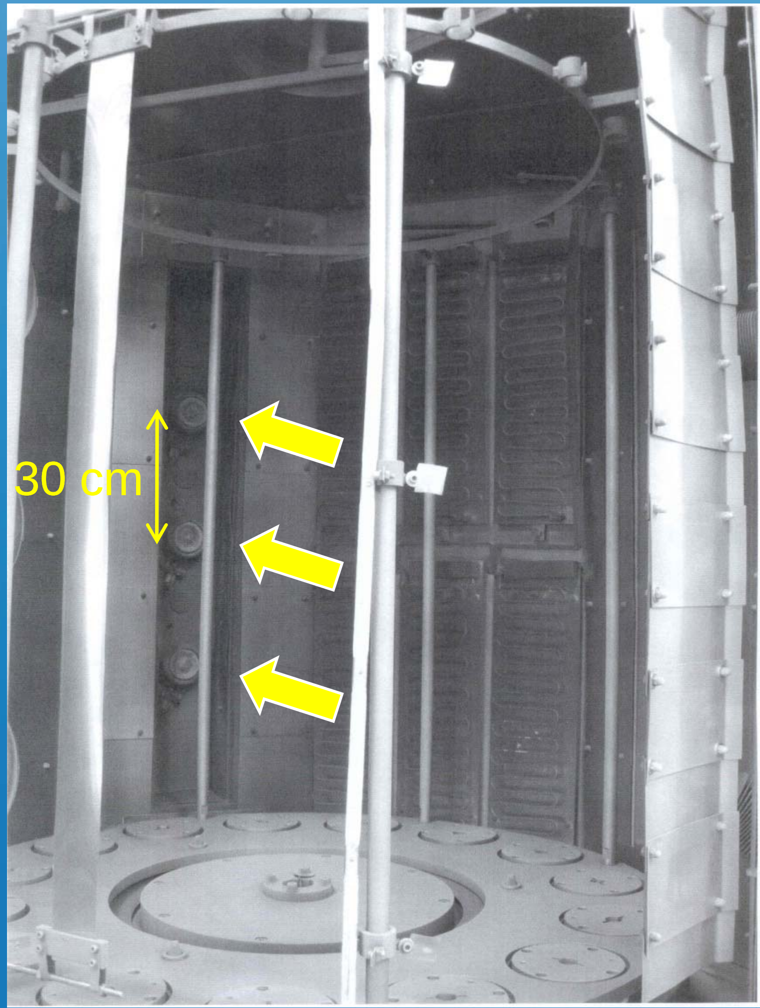
- Fermi potential ~ 250neV
- Hydrogen content < 1%
- Mixture of *t-a-C* and *a-C* *(tetrahedal amorphous Carbon)*
- 40 – 50% sp^3 hybridization
  (sp^2 hybridization == graphitic atomic bonds
  sp^3 hybridization == diamond atomic bonds)

Electric properties have to be investigated!

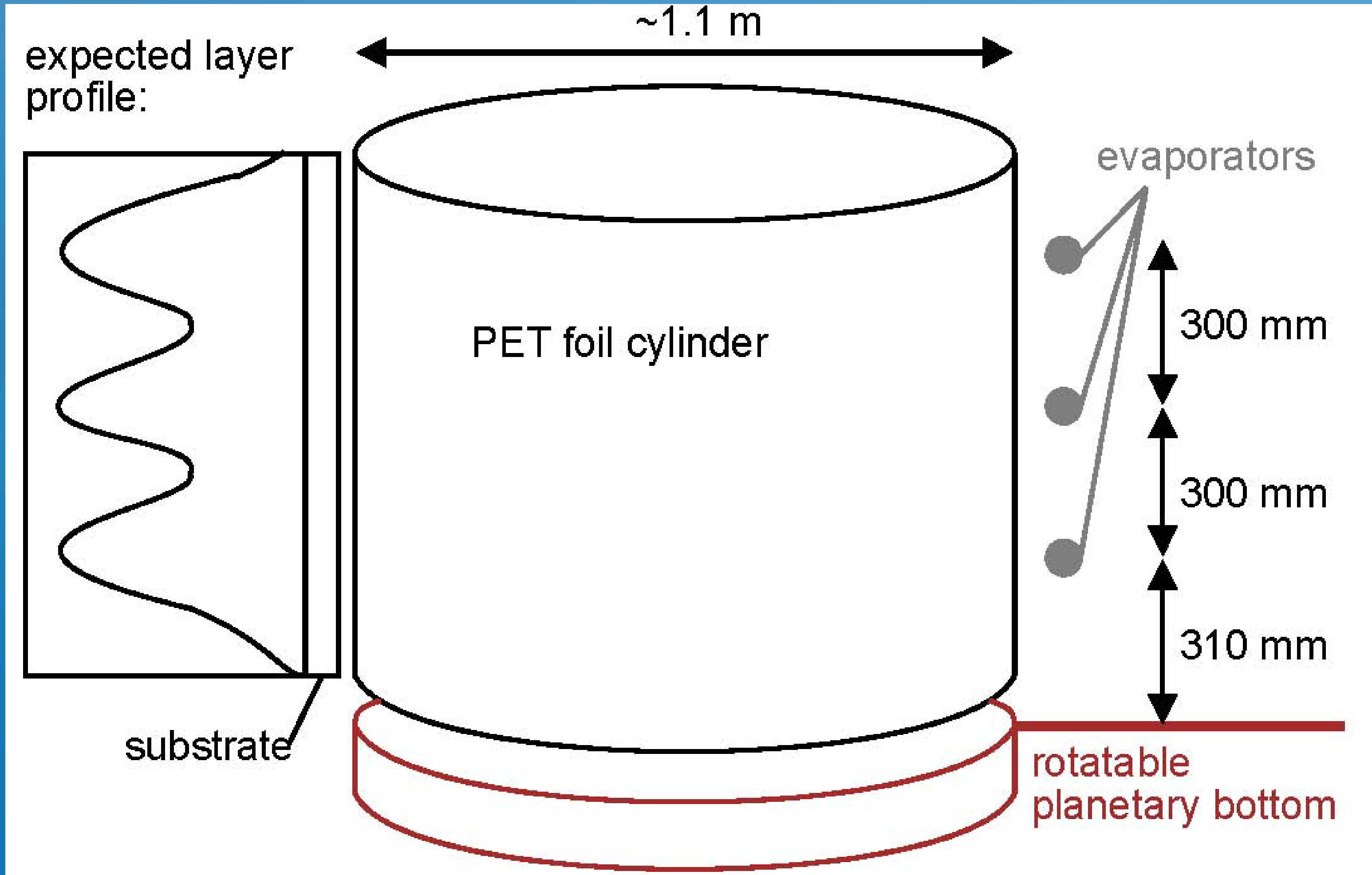
Diamond-like carbon as resistive layer

Coating chamber:





Diamond-like carbon as resistive layer

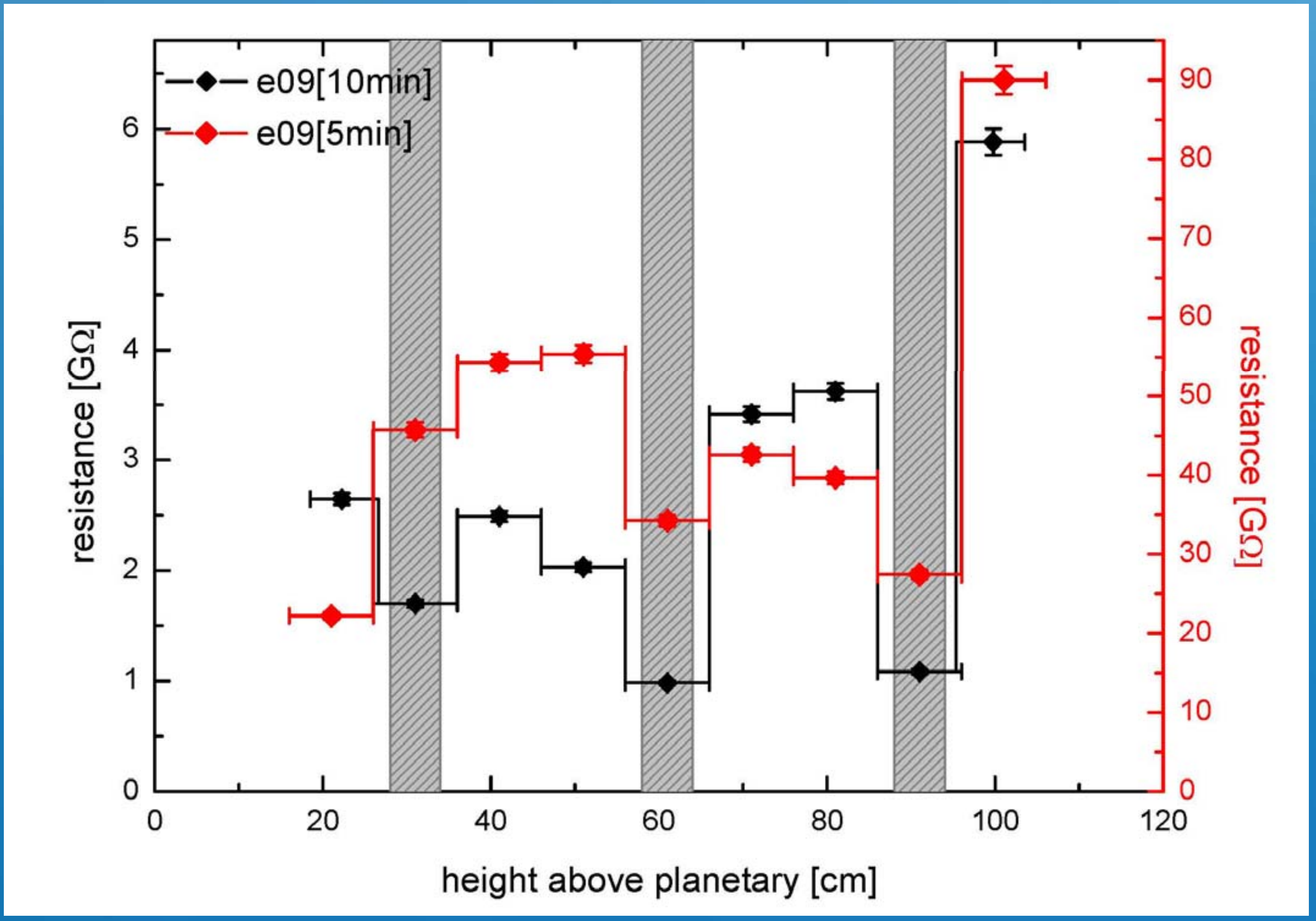


Test stripes: DLC on PET

- Thickness inhomogeneous due to coating process
- Inhomogeneities in layer **observable in resistance**

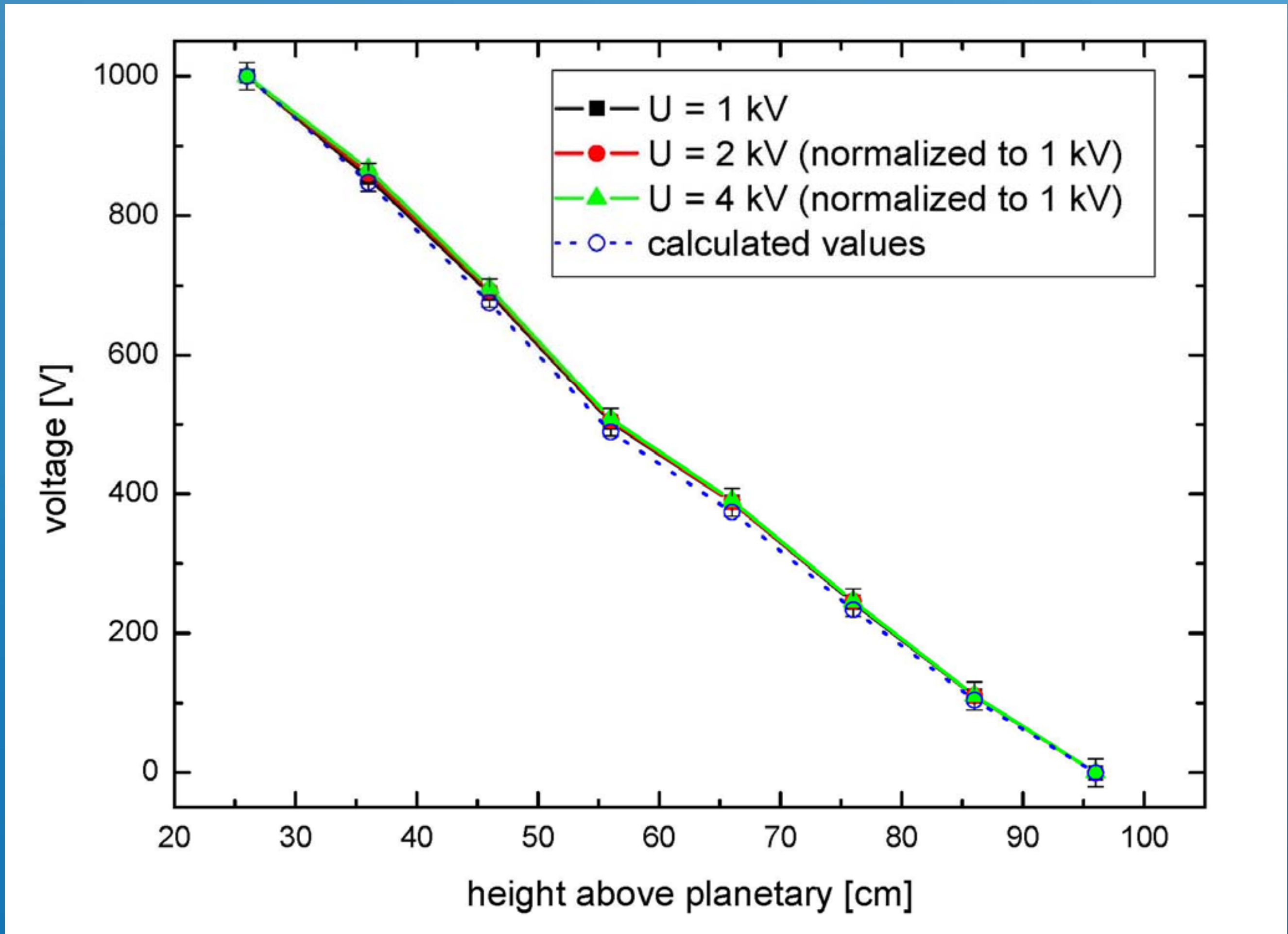
Test stripes: DLC on PET

What did we observe?



Test stripes: DLC on PET

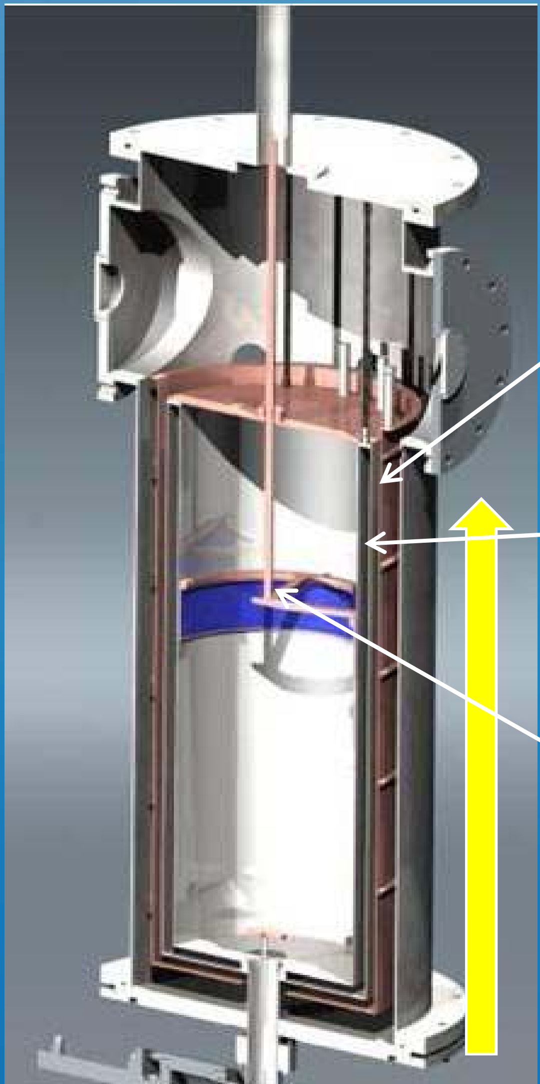
What did we observe?

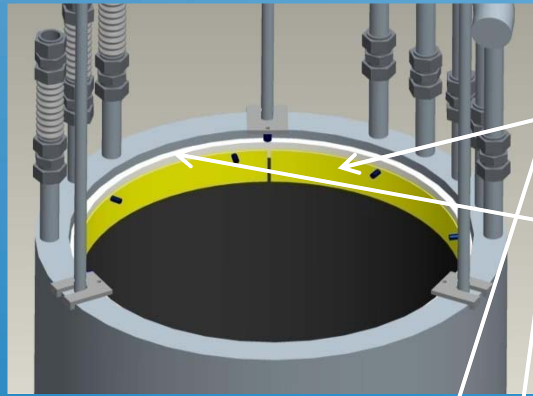


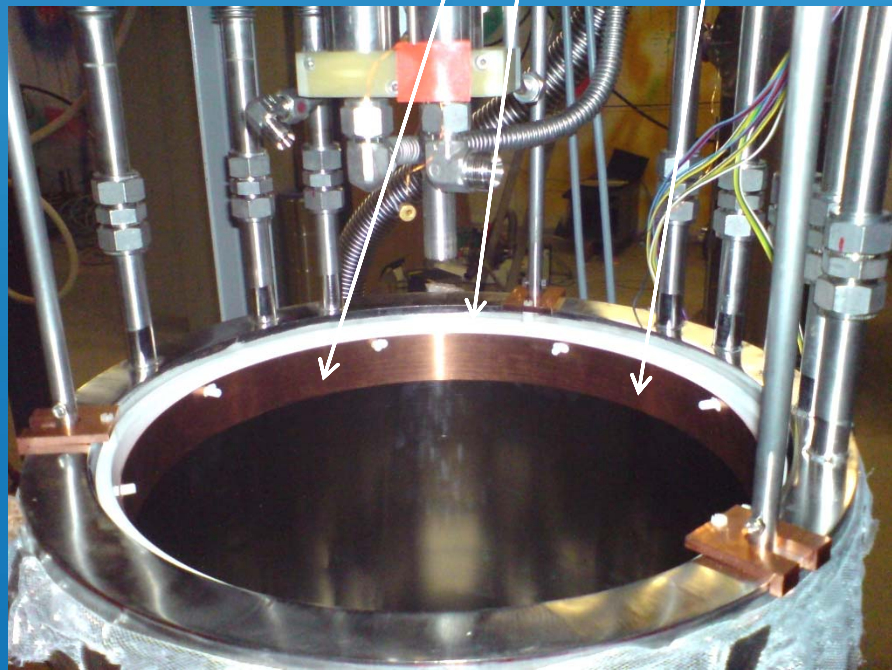
Test measurements on DLC foil cylinder

Conditions similar to PENeLOPE:

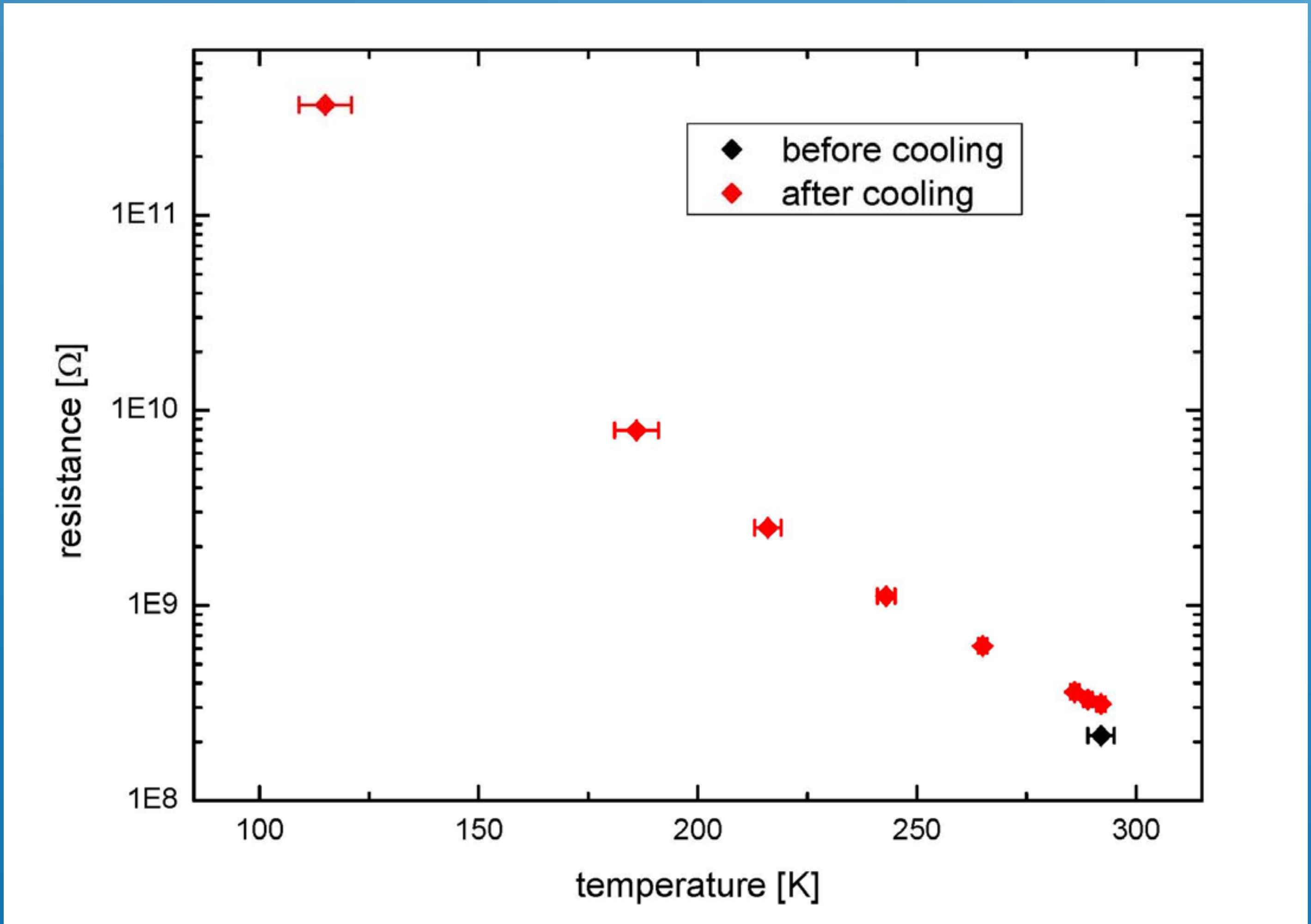
- cylindrical geometry
- vacuum
- lHe-temperature


lN shield
lHe bath cryostat
vertically adjustable unit
height: 1 m
diameter: 40 cm

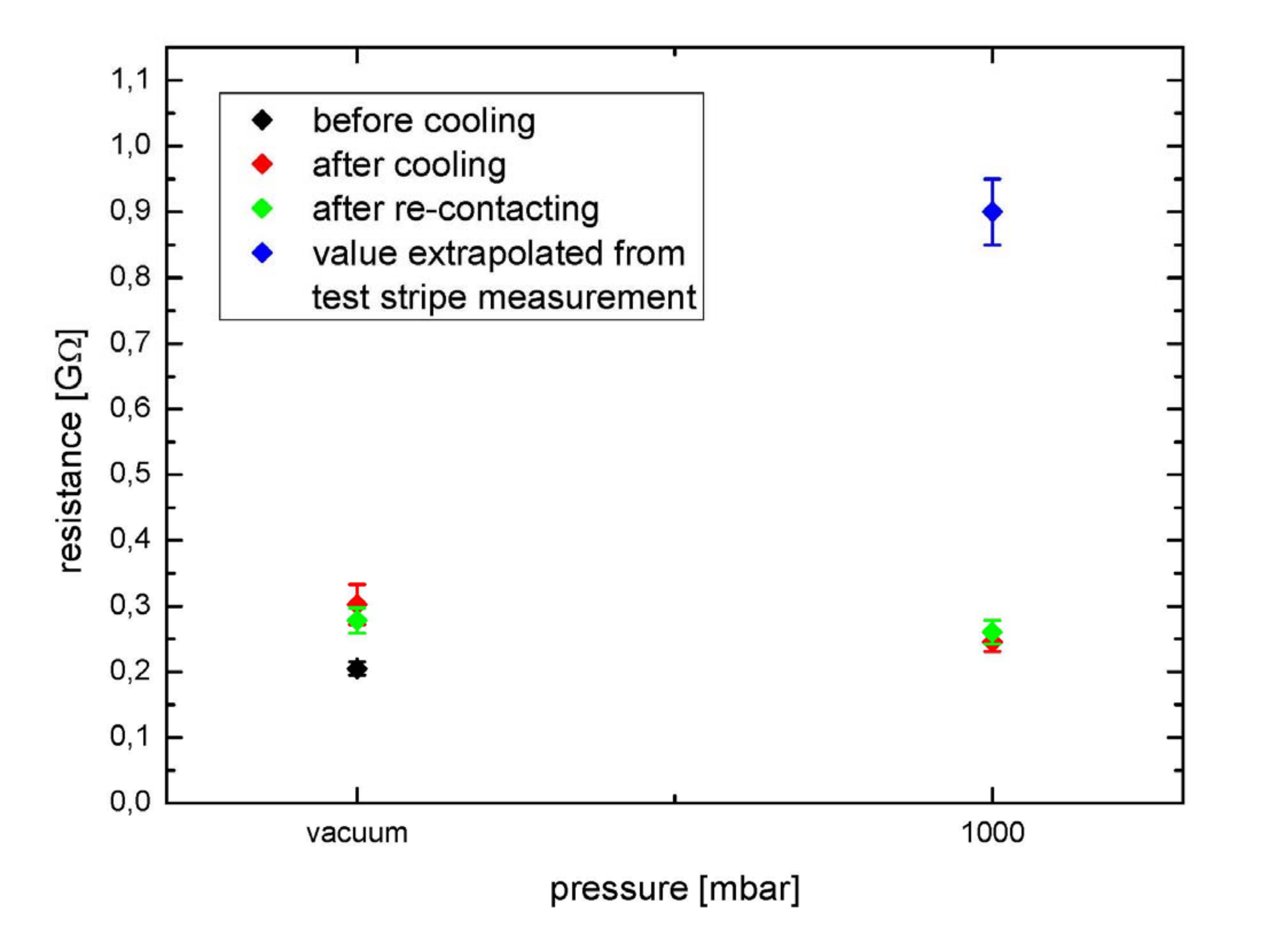



clamp fixture for DLC-coated foil
Insulating teflon ring
HV electrode

Test measurements on DLC foil cylinder



Test measurements on DLC foil cylinder



Test measurements on DLC foil cylinder

$R = \rho \times L/A;\ \ A = d \times b$

change of width

⇨ $R\,/\,R' = b'\,/\,b$

b (stripe)= 5 cm ; b (foil)= 117 cm

R (stripe)= 24 GΩ ; R (foil)= 1 GΩ expected!

Summary

- Proton extraction efficiency at least 70%

- Reproducibility is not given yet:

  DLC is very sensitive to

  - coating process and
  - temperature
  - storage history

- Resistance @ 4 K:

  if *R* is too high, no field can be created anymore

  ⇨ reduce *R* by thicker layer,

  but too thick layers do not adhere to PET

Outlook

- Further cooling runs to investigate resistive behaviour of DLC at 4K

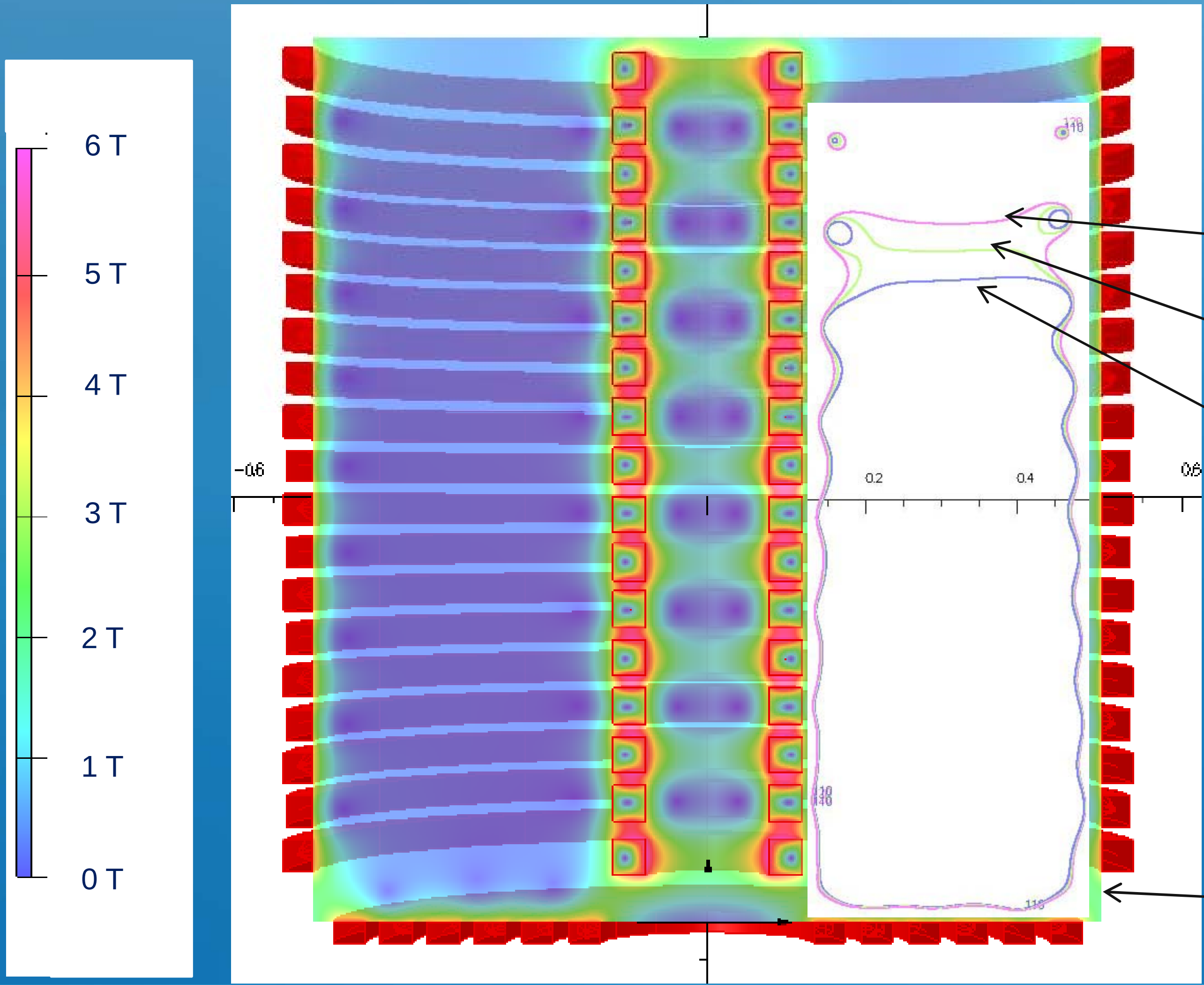
- UCN beam time requested at ILL, France, autumn 09

  - storage tests with large DLC-coated foils (1 m^2) as well as DLC-coated stainless steel sheets
  - test **proton extraction efficiency** with **DLC field cage** and proton **detector**

Thank you for your attention!

Available space

Combination of **magnetic and gravitational potential** for *low-field seekers*:



V= - μ·B + mgh

Equipotential lines:

120 neV

115 neV

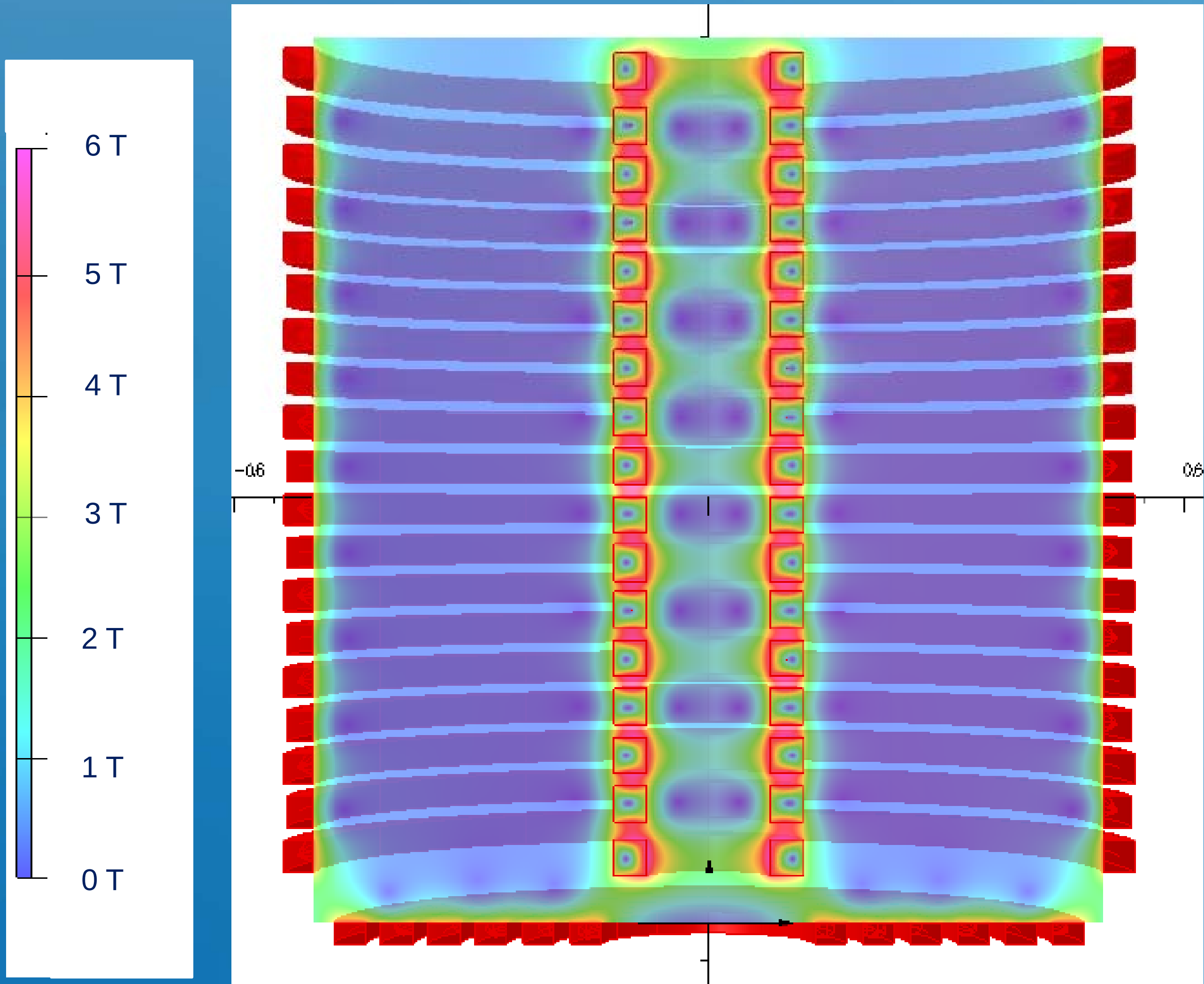
110 neV

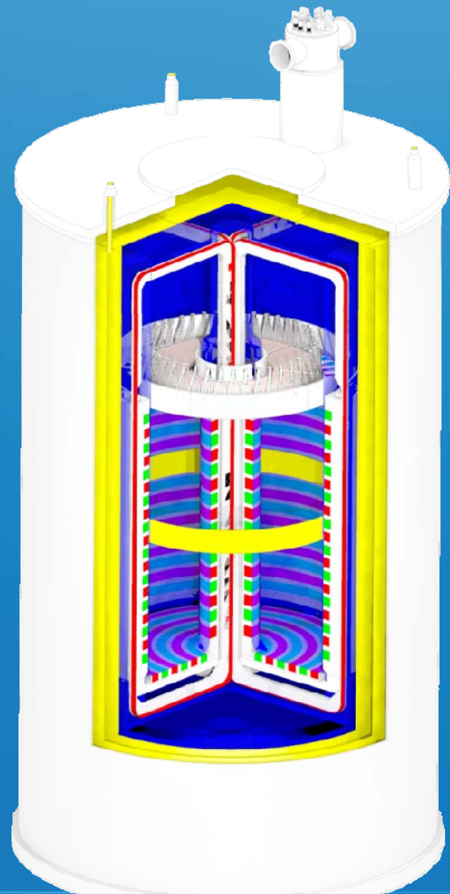
Trap depth: 108 neV

Emptying slit

Available space

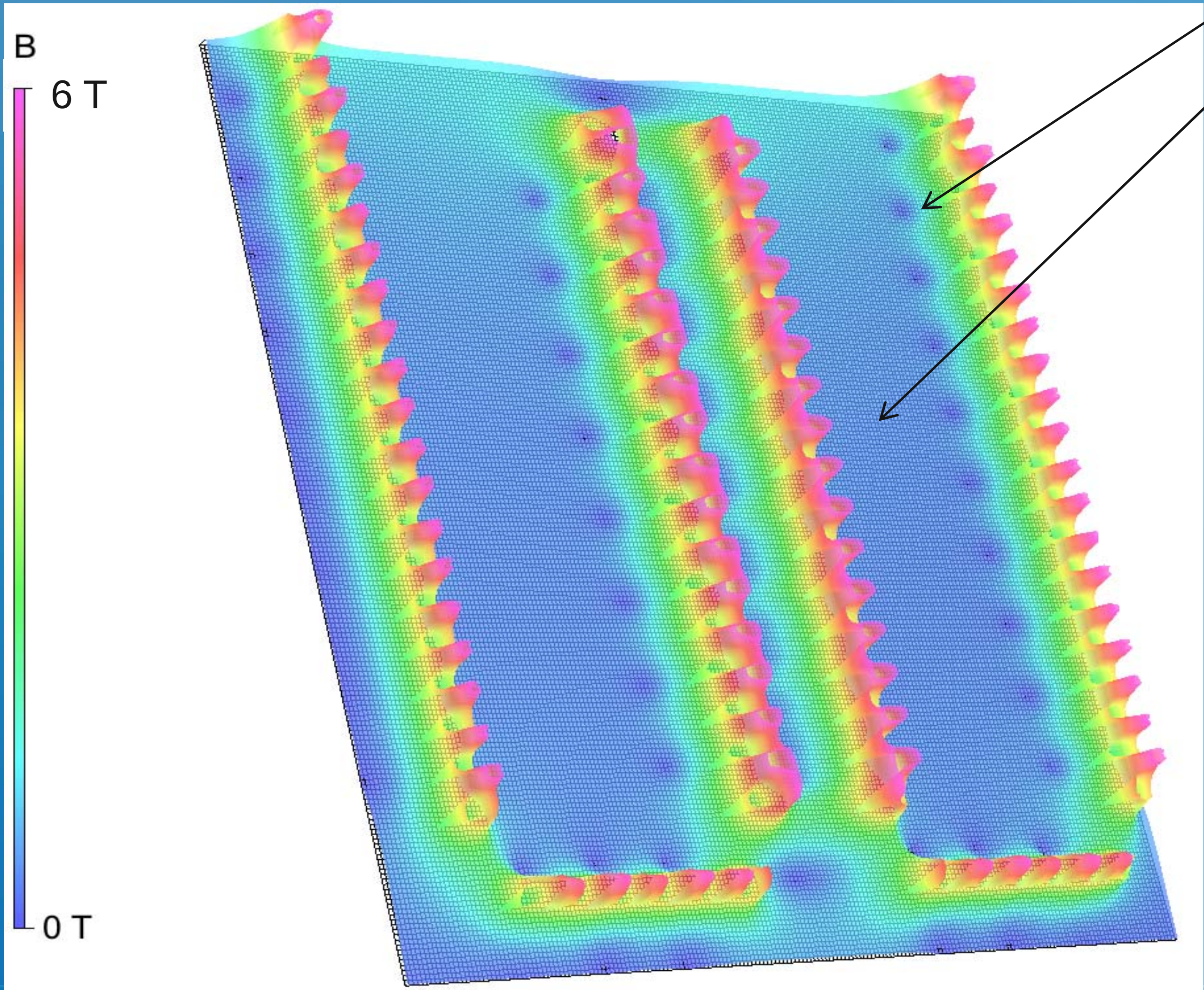
Magnetic field map of the PENeLOPE storage coils:





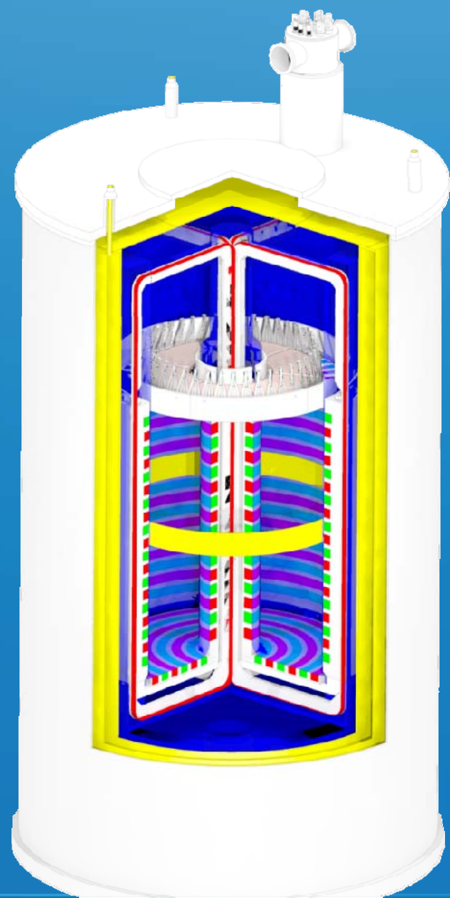
Available space

Magnetic field map of the PENeLOPE storage coils:



2 T (magnetic „walls“)

0.3 T (mean field inside)



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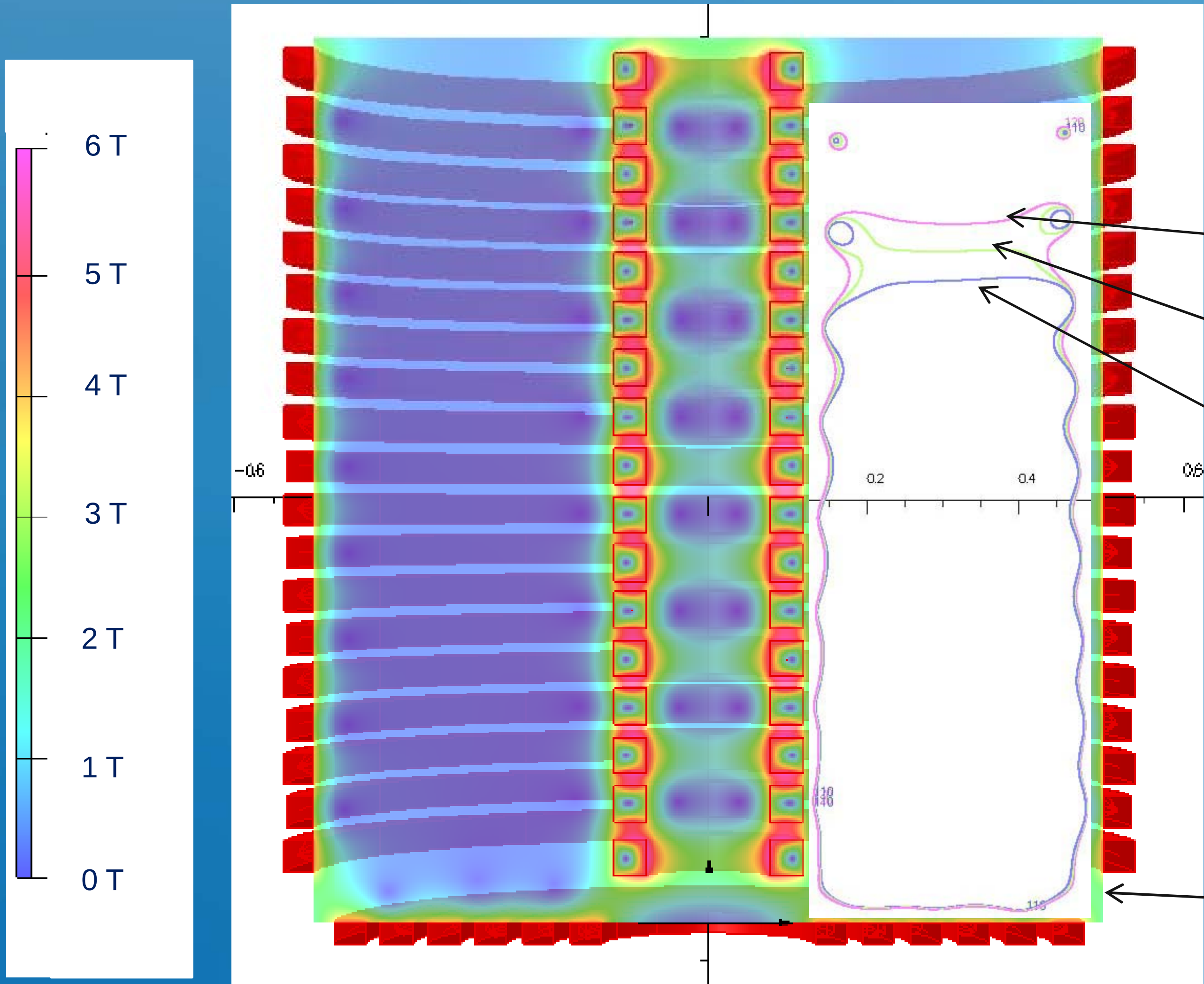

$V = -\mu \cdot B + mgh$

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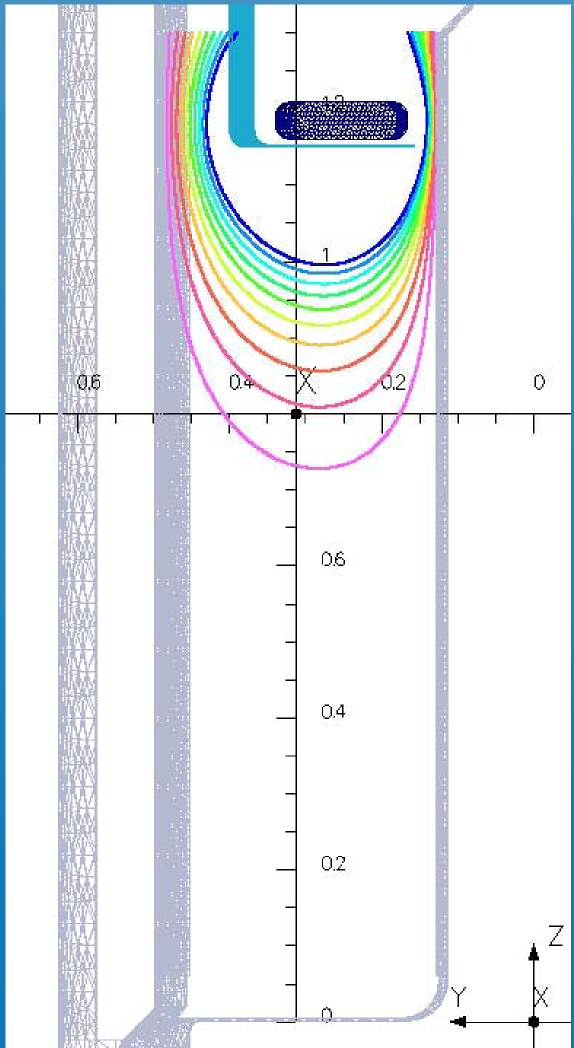
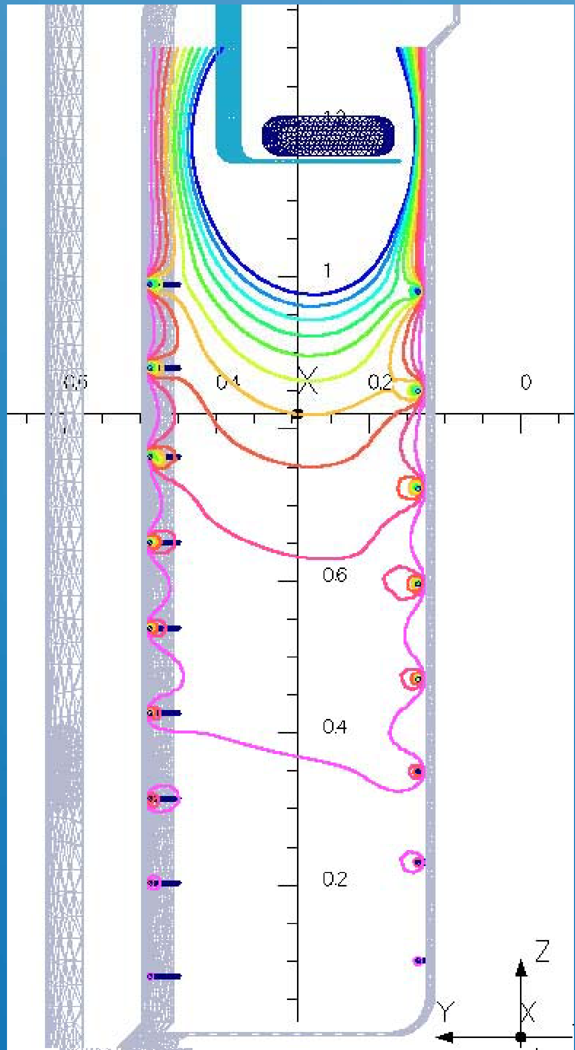
Emptying slit

Electrostatic fields

RING ELECTRODES





Electrostatic fields

SHEET ELECTRODE