Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

ETH Institute for Particle Physics

R&D on HV in LAr towards Glacier

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High Voltage in Noble Liquids - FNAL - November 9th, 2013

Outline

Intro on LAGUNA-LBNO and GLACIER

Overview on the R&D towards GLACIER

High voltage issues in liquid argon

HV R&Ds

LAGUNA-LBNO

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Expression of Interest

for a very long baseline neutrino oscillation experiment

(LBNO)

LAGUNA-LBNO Expression of interest
~300 members, 14 countries + CERN

CERN site:

Beam:

- Wide band ν_μ beam ~1-10GeV
- SPS protons at 400GeV
- SPS upgrade 800GeV 2MW

Near detector:

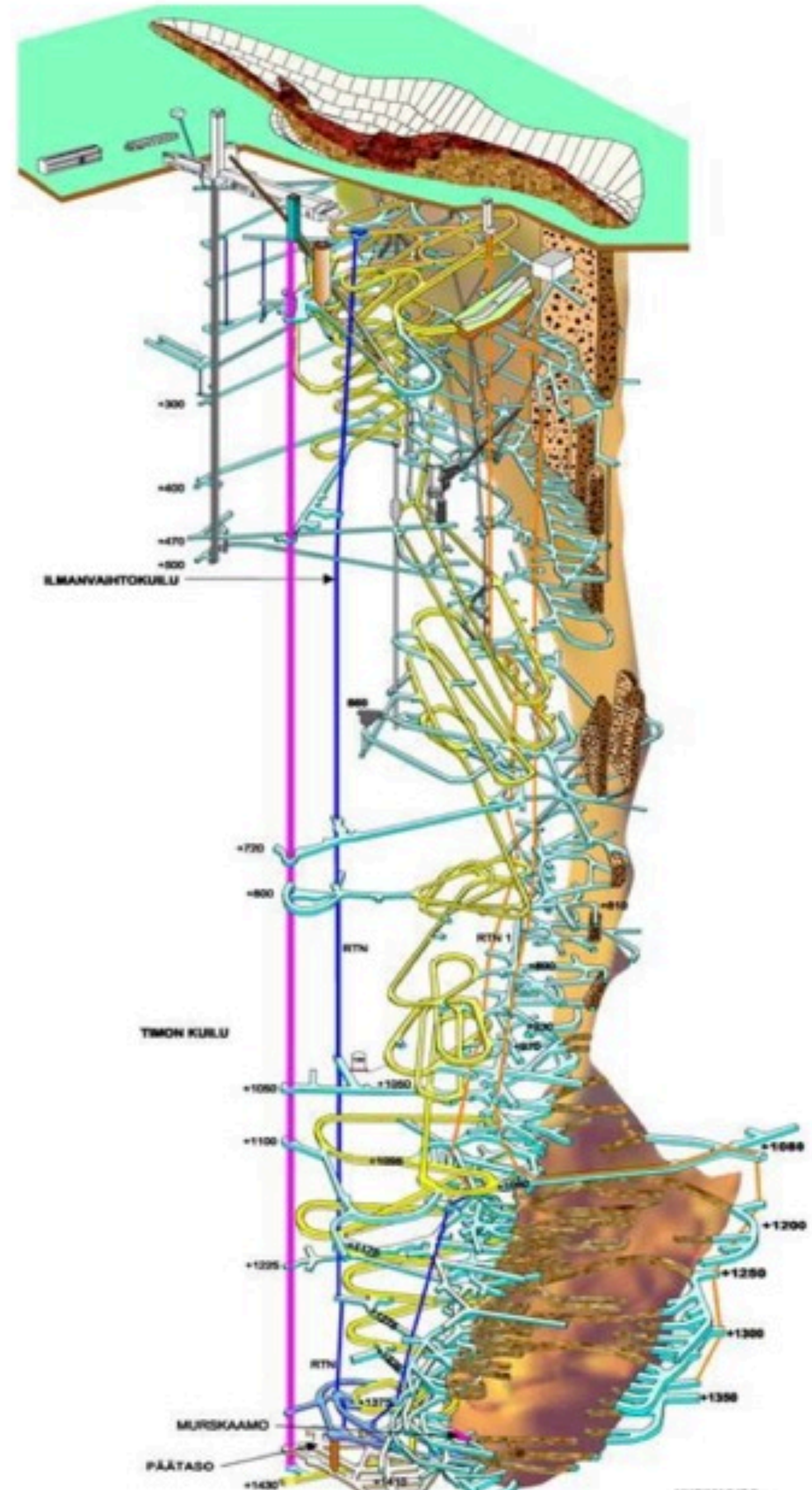
- HpAr TPC + magnetized iron detector (MIND)

Far site underground:

- Giant double-phase Ar TPC + magnetized iron detector.
- Neutrinos from MeV to 10‘sGeV: beam but also supernovae, solar, atmospheric, proton decay, …

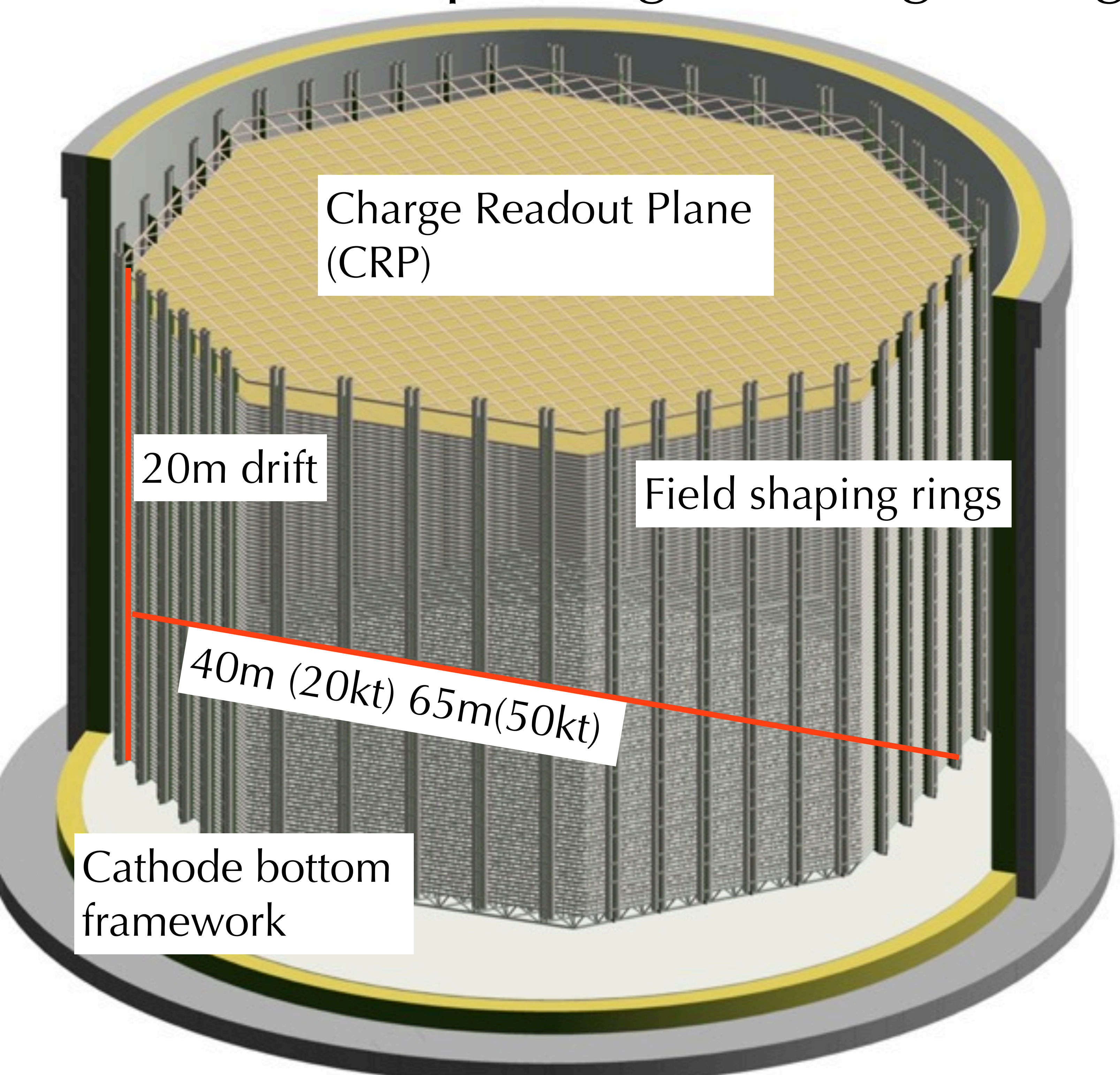
Far site: Pyhäsalmi mine

- Middle of Finland
- 4000 m.w.e overburden
- Excellent infrastructure for underground access.
- 2300km baseline
- Low background from reactors
- Interesting distance from other potential neutrino sources (DESY, Protvino)



GLACIER

Giant Liquid Argon Charge Imaging expERiment



2003 - Glacier concept:
- A. Rubbia, hep-ph/0402110.

2008-2011 - double phase argon TPC proof of principle:
- A. Badertscher et al., Nucl. Sci. Symp. Conf. Rec. (2008) 1328
- A. Badertscher et al., NIM A 617 (2010) 188
- A. Badertscher et al., NIM A 641 (2011) 48

2012 - 80x40cm^2 charge readout demonstrator:
- A. Badertscher et al., JINST 7 (2012) P08026
- A. Badertscher et al., JINST 8 (2013) P04012

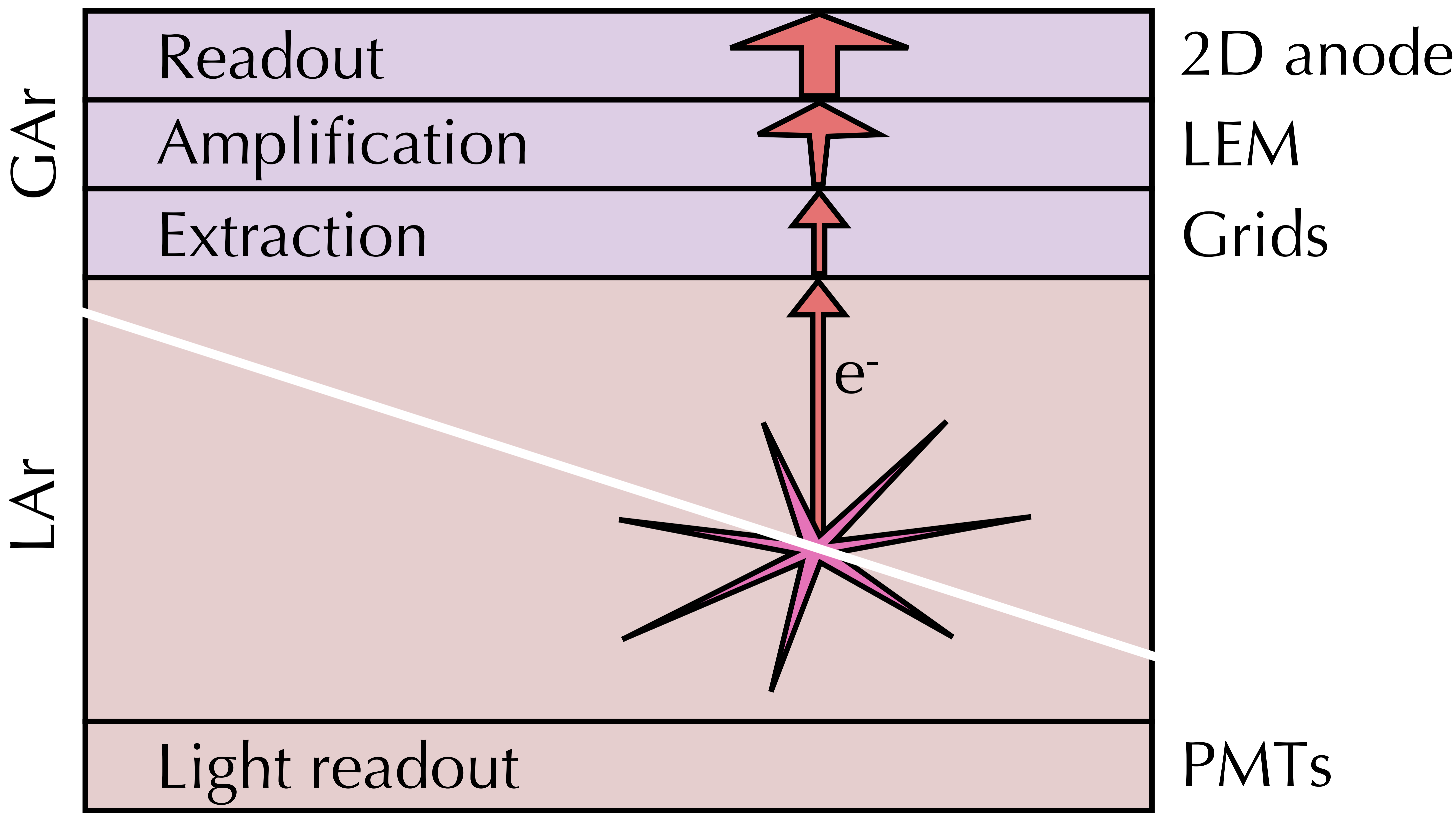
2012-2013 - Further R&D on design simplification:
- paper in preparation

R&D towards Glacier

- Large charge readout
- Front-end electronics
- Long drift
- Argon purity in non evacuated vessel

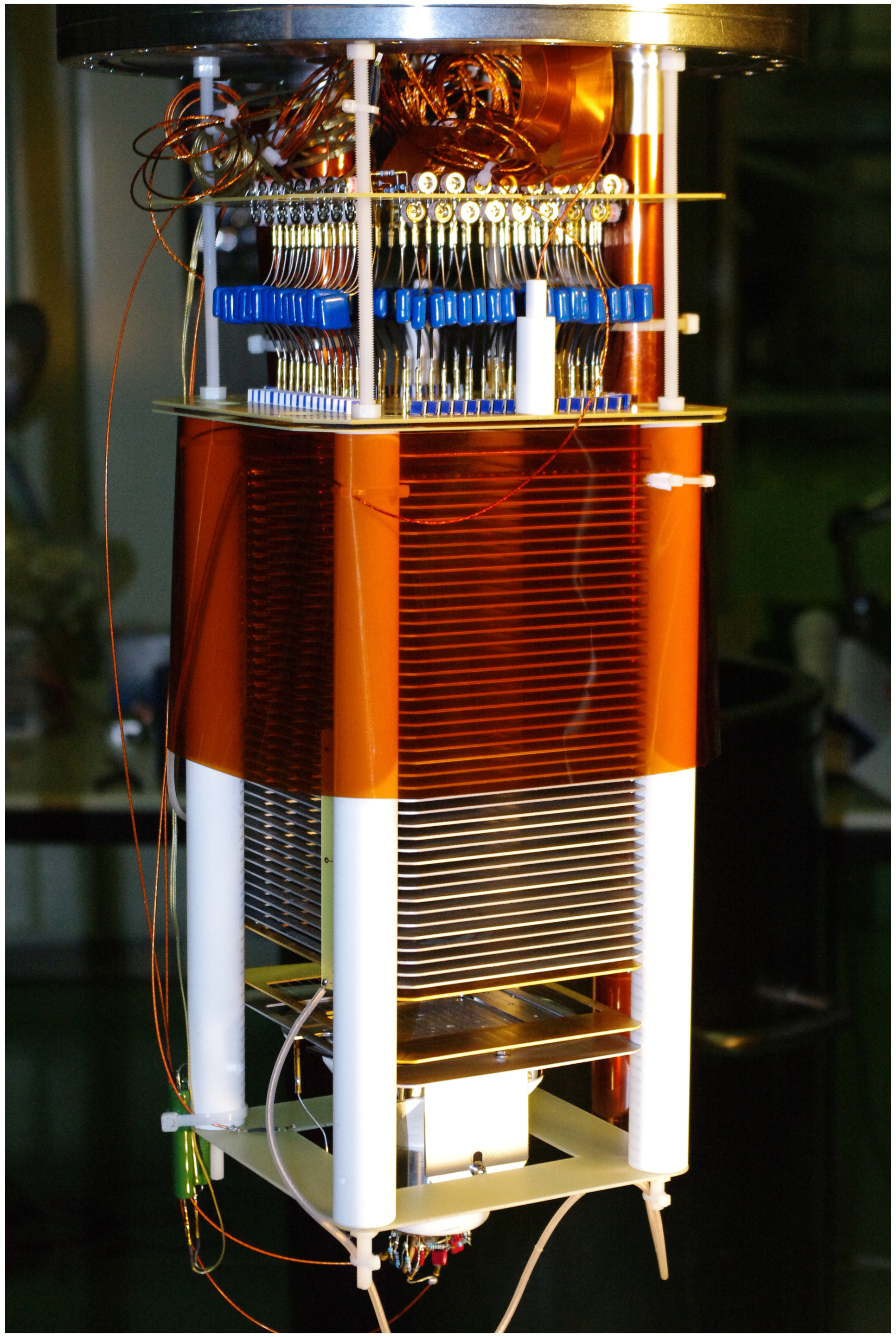
- HV at the MV scale

Double phase technology

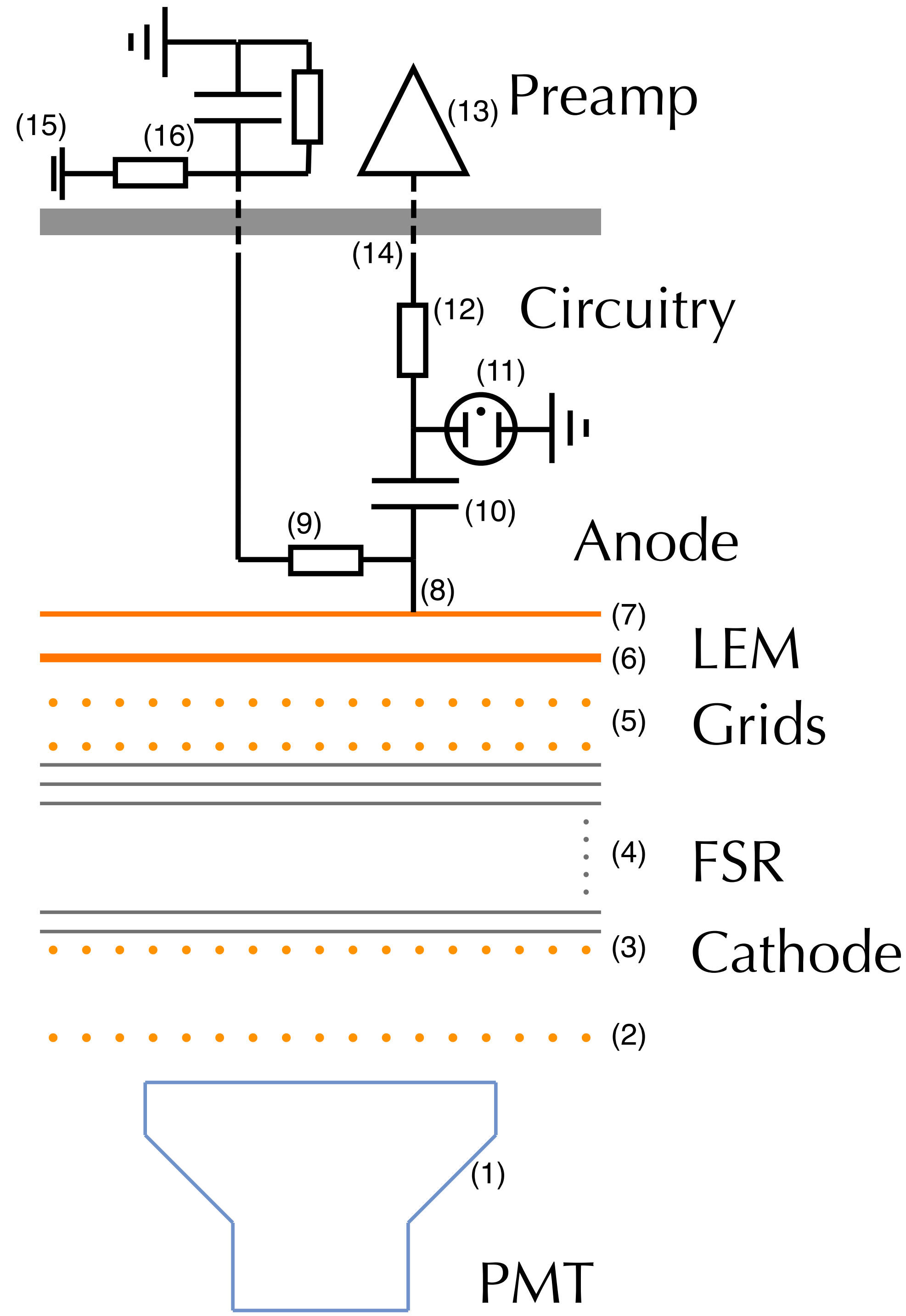


3L prototype

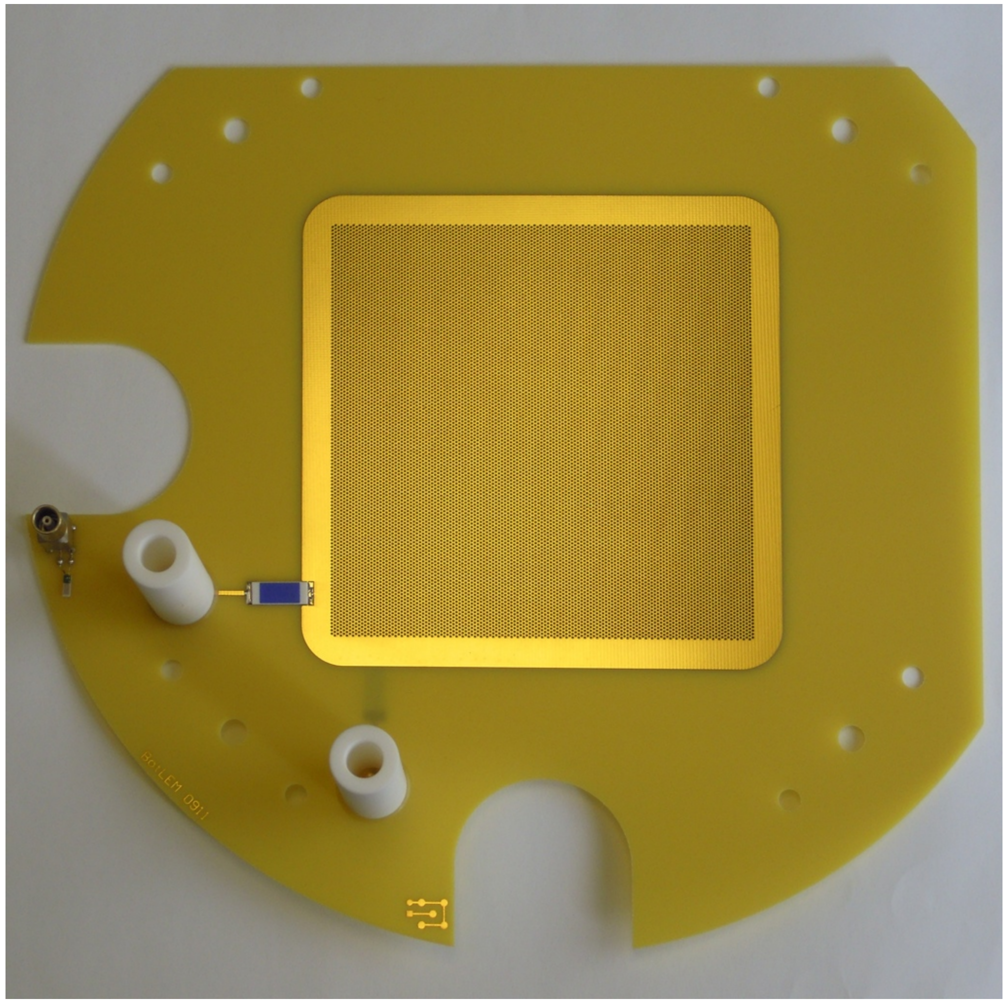
Nucl. Sci. Symp. Conf. Rec. (2008) 1328
NIM A 617 (2010) 188
NIM A 641 (2011) 48

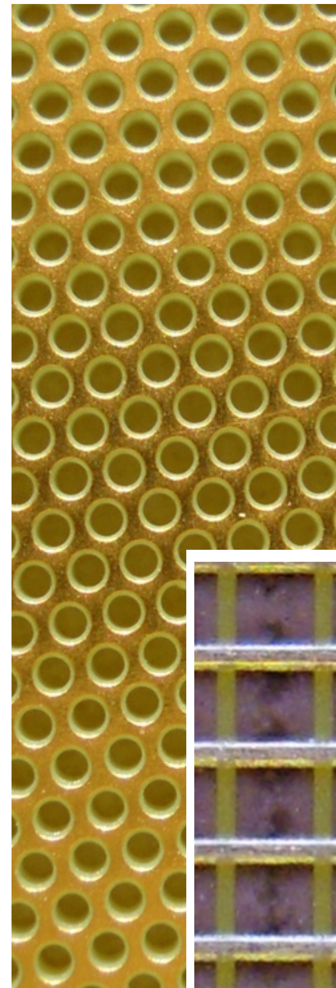


3 L, 10×10 cm2

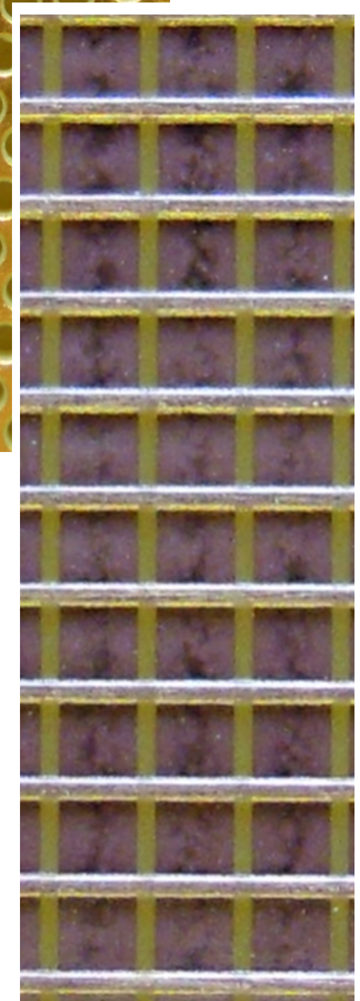


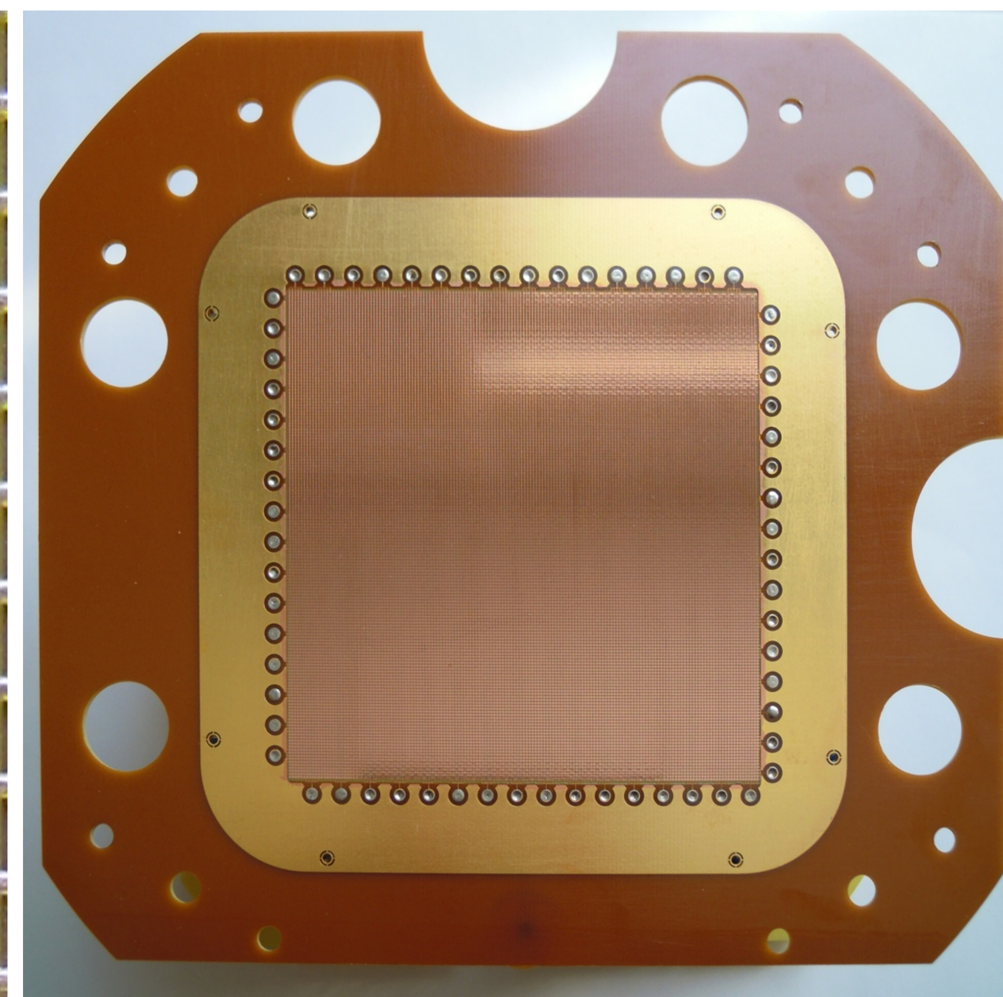
LEM and anode





500 μm diameter
800 μm pitch
100 μm rim
1 mm thick

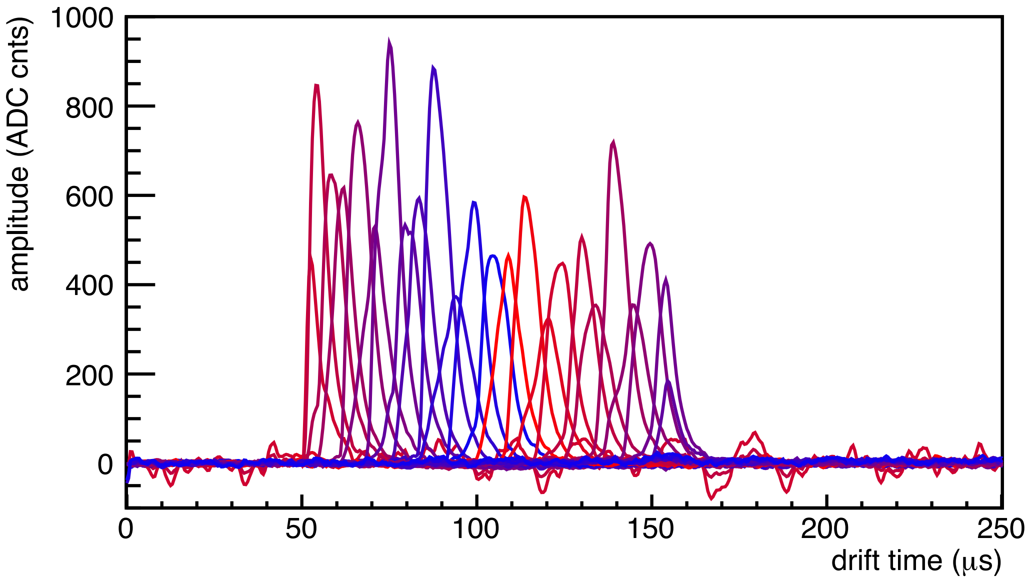


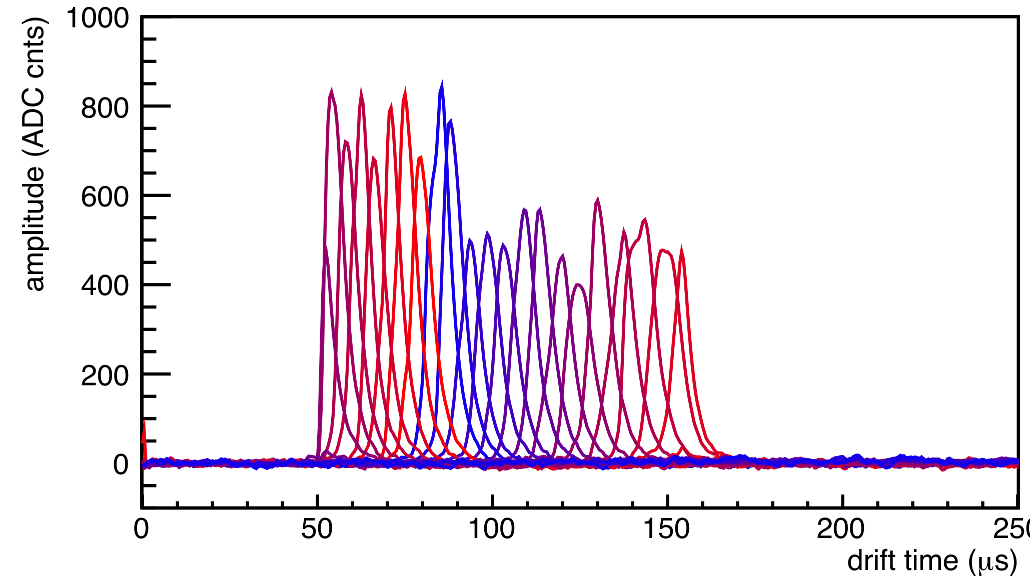


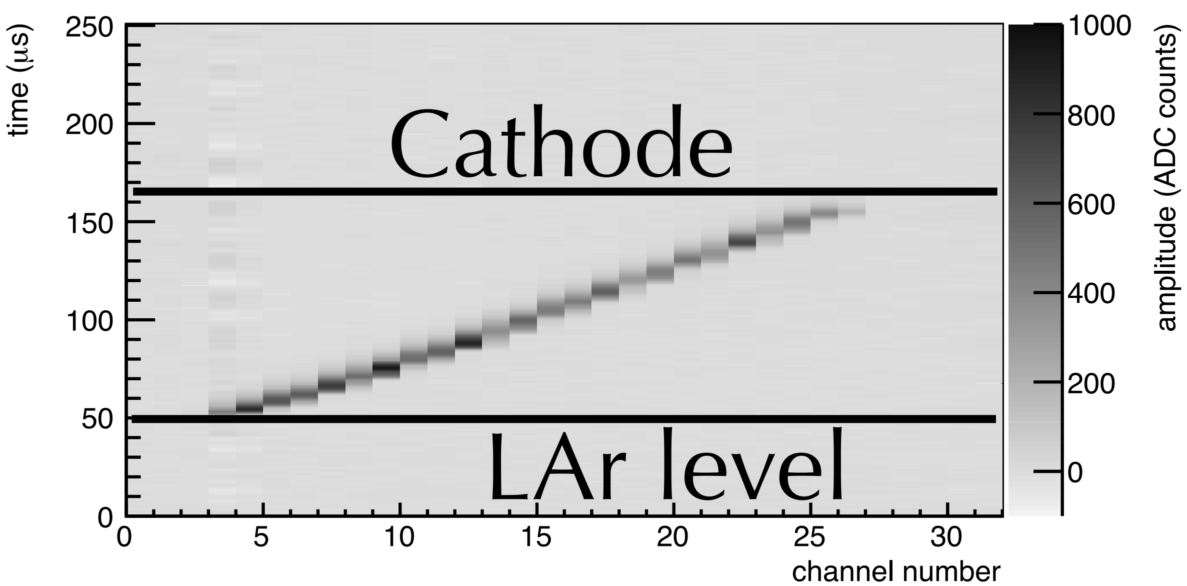
Electrode geometry ensure
X-Y equal charge sharing

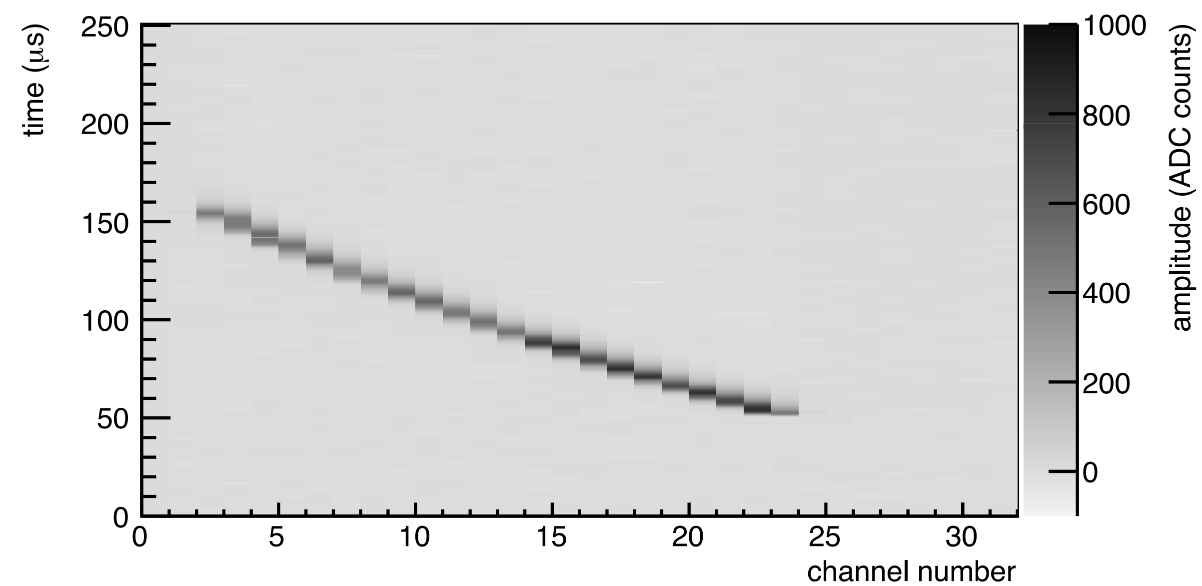
Sample event: gain 30

S/N > 100



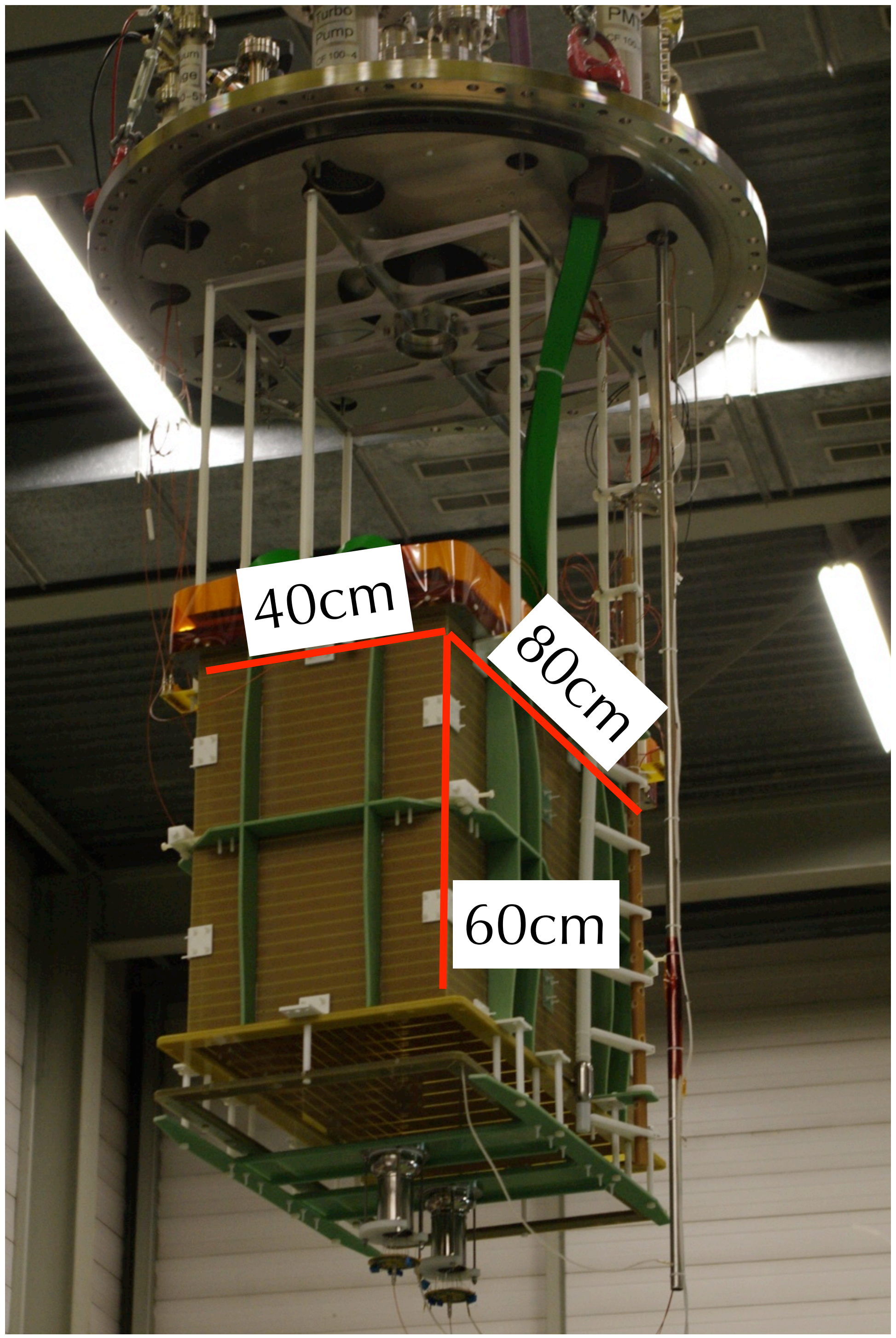


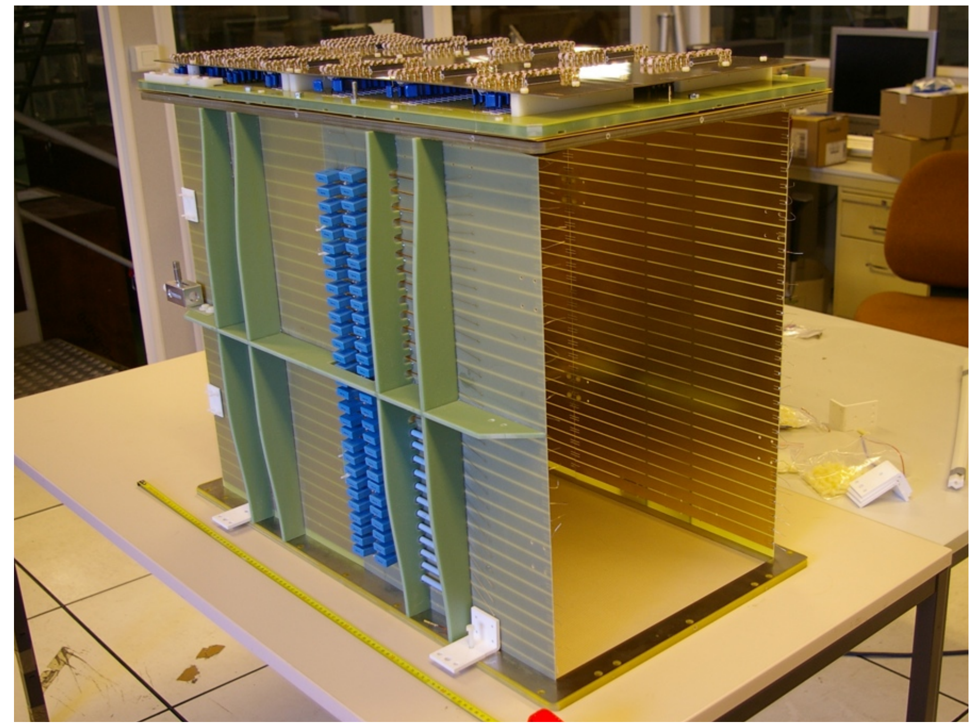


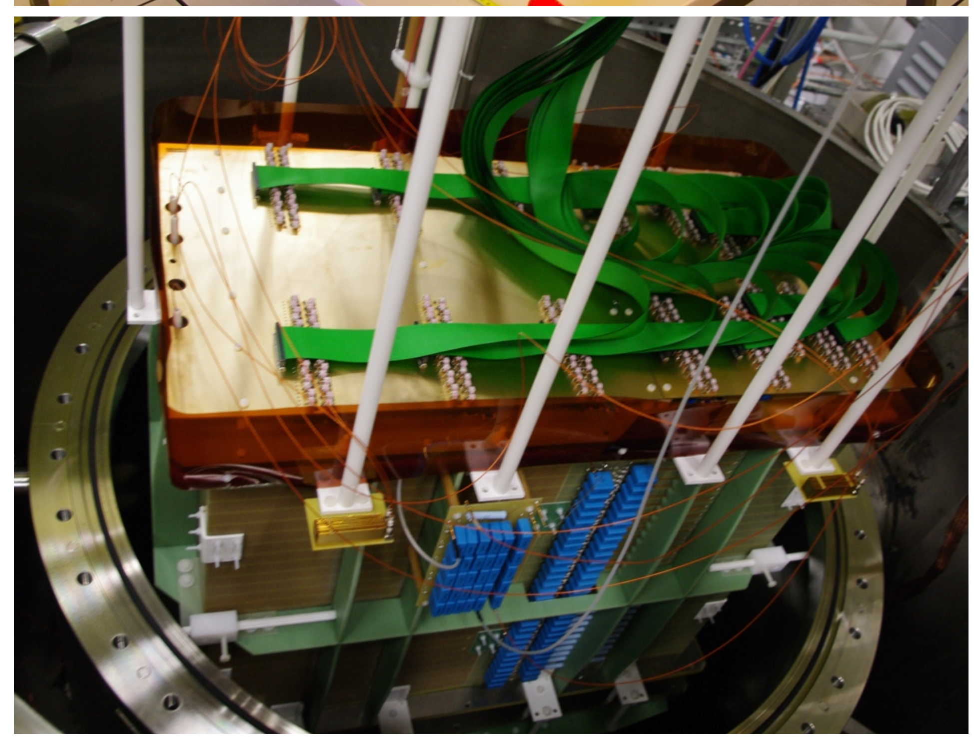


Going bigger

JINST 7 (2012) P08026
JINST 8 (2013) P04012





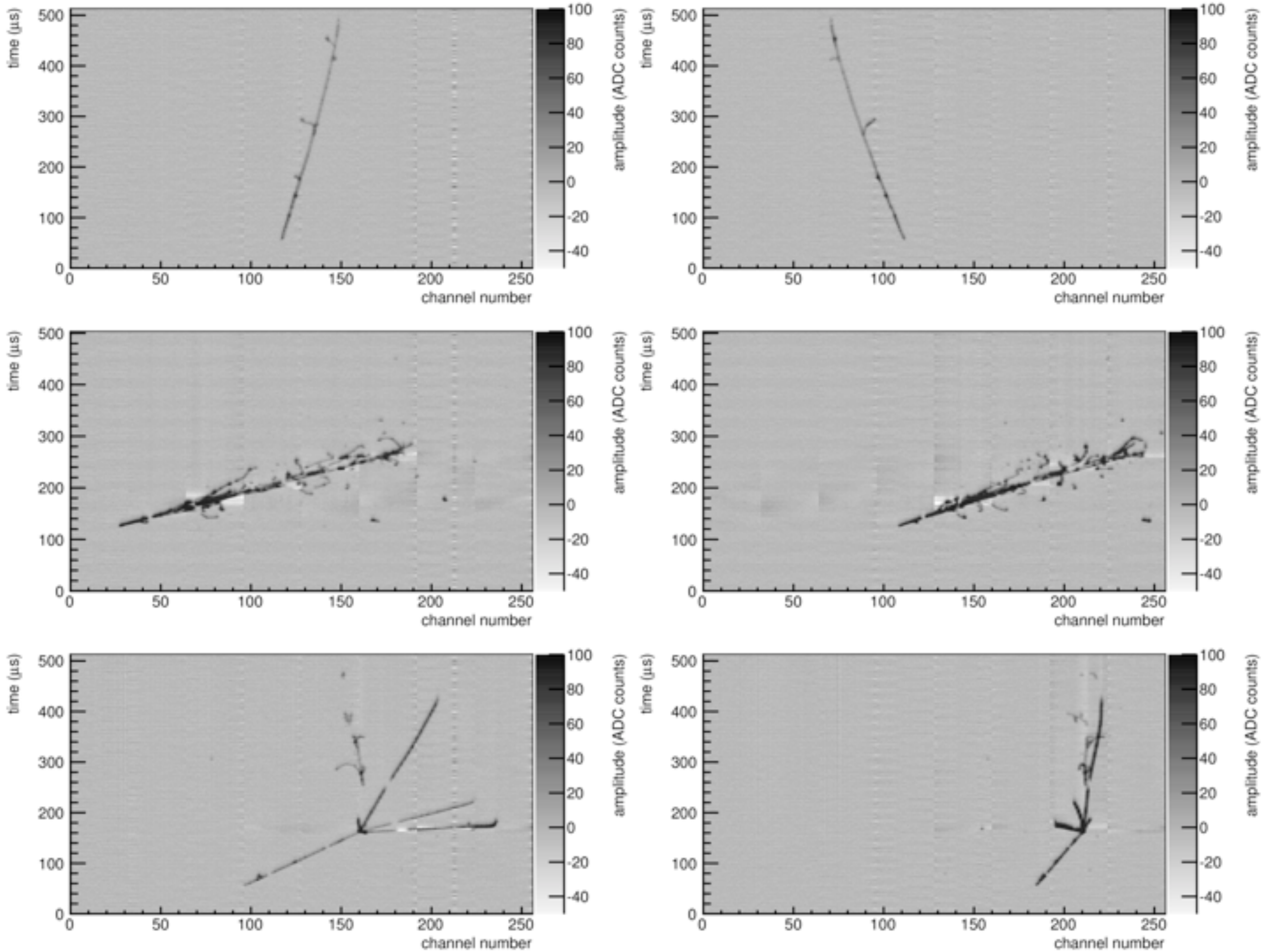


Going bigger

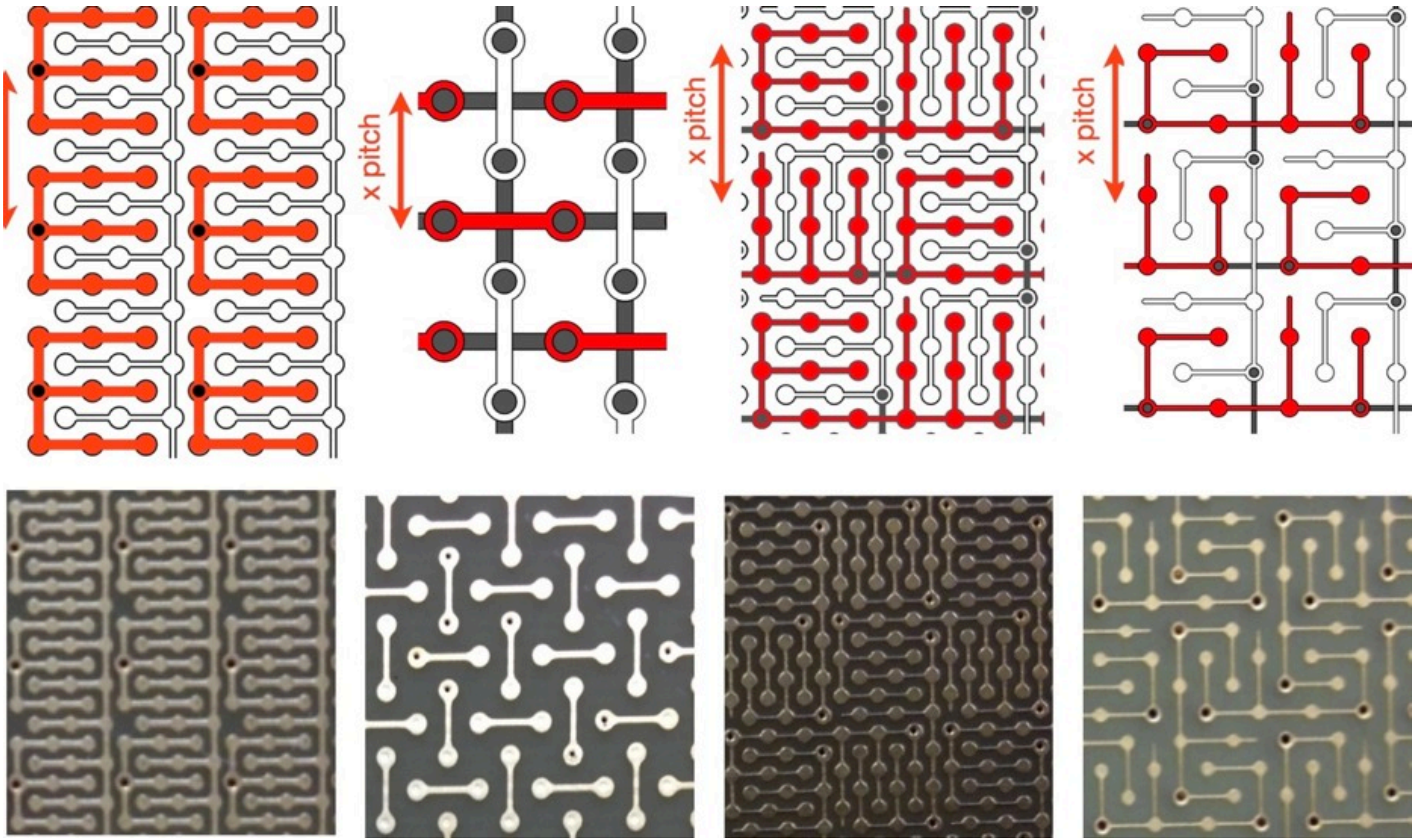
Muon

Electromagnetic shower

Hadronic interaction

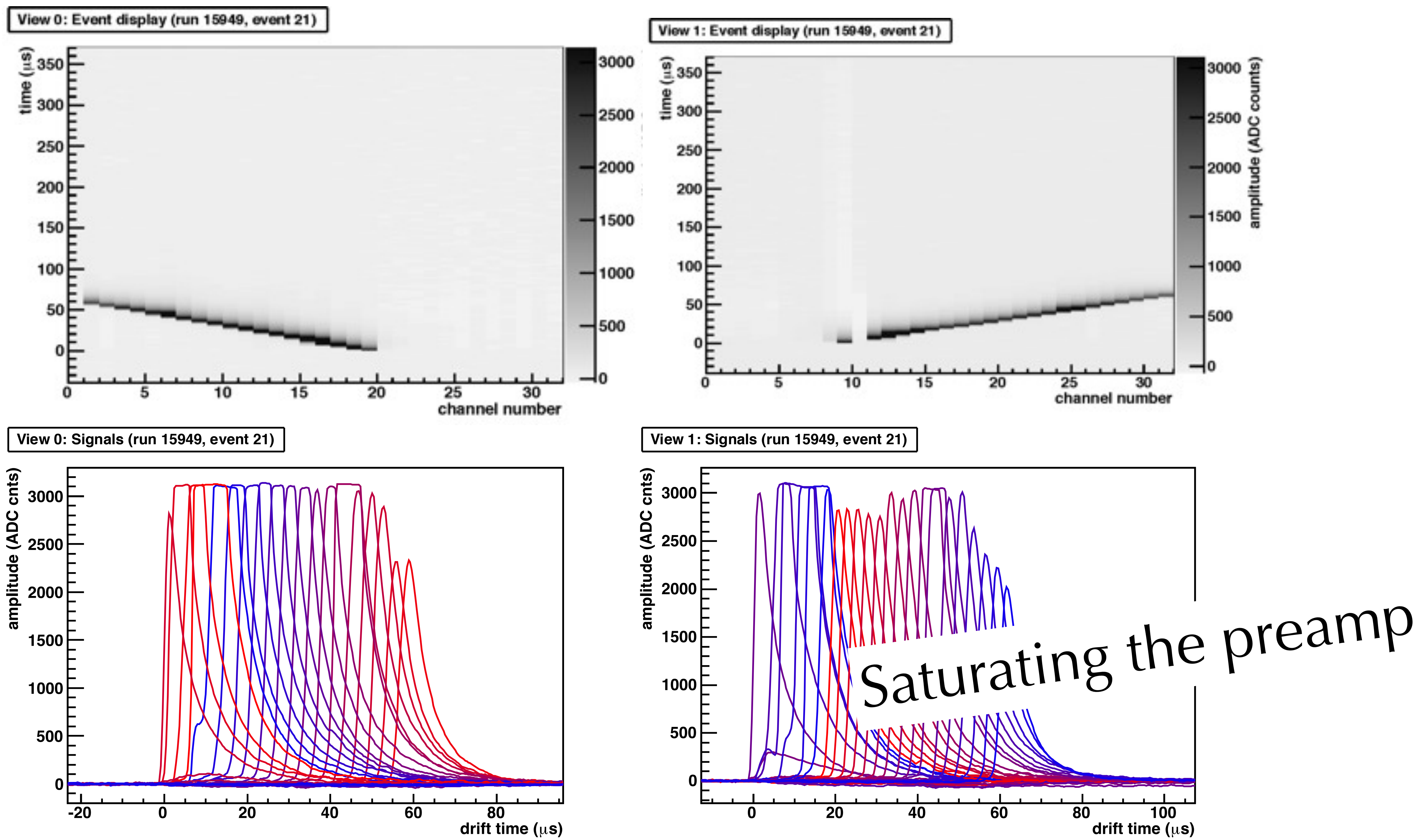


Going simpler: the anode



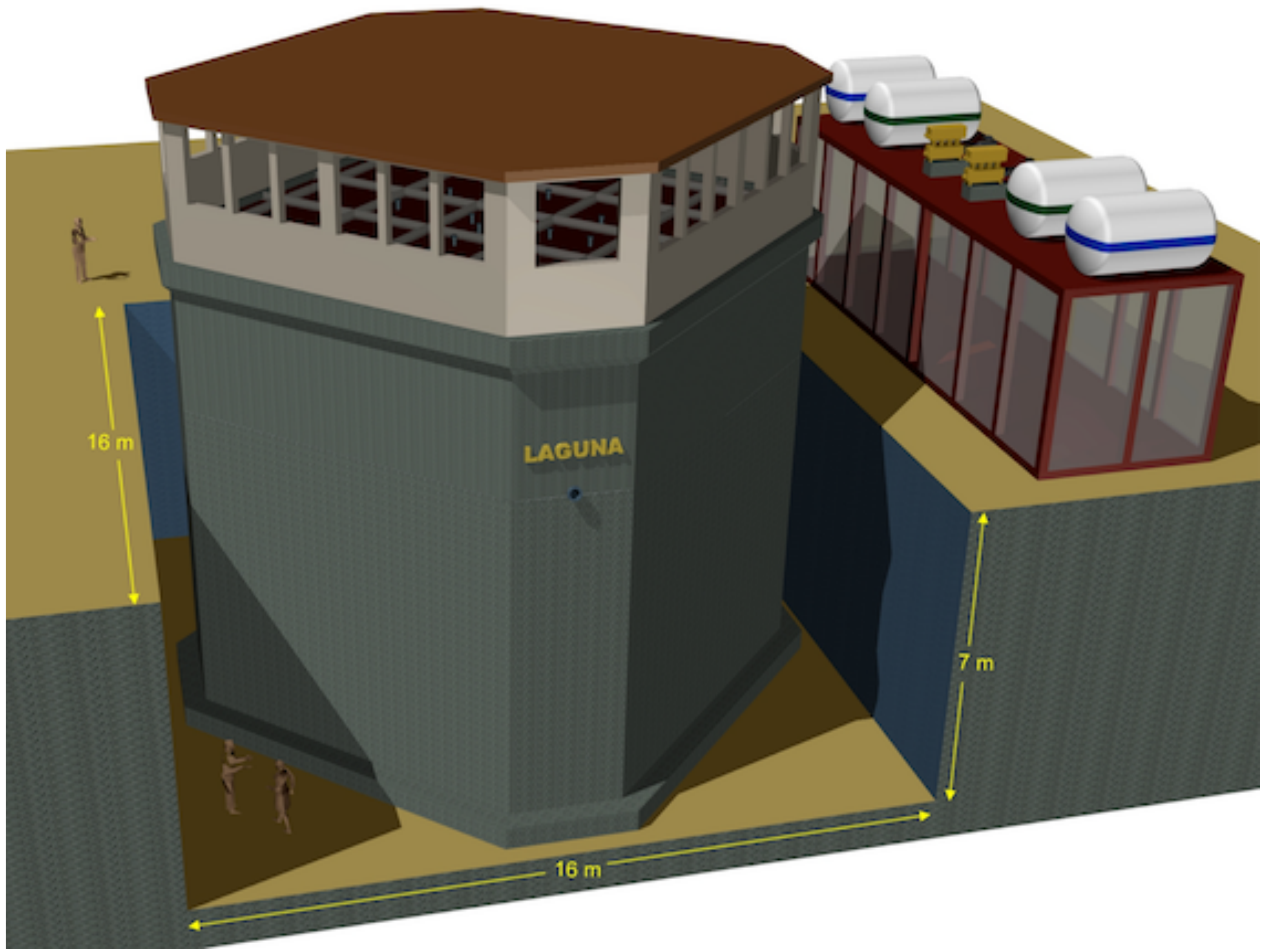
Going simpler: gain 100

… and other simplifications: grids, signal decoupling



Next milestone: 6^3 m^3

Priority emphasis on a large double-phase argon demonstrator, using charged-particle test beams (2014-2017)
TDR submitted to SPS Committee in June



GLACIER requirements

Drift velocity: 1.6÷2.0 mm/μs
Charge recombination for MIPs: 70÷80%
Drift field: 0.5÷1 kV/cm
Drift length: up to 20 m
Potential at the cathode: -1÷2 MV

GLACIER requirements

–2 MV DC:

\+ External HV power supply

\+ feedthrough

\+ resistor divider

- Solutions from companies - Heinzinger:
  - Presently available commercial 400 kV PS
  - 600 kV PS to be custom developed for the 6^3 m^3

Electrical breakdown in LAr

- Not many recent papers in the literature:
    - Swan, Lewis and Gallagher in the 1960s
- Non trivial mechanism:
    - Townsend avalanche
    - Impurities effects
    - Electron emission from metals
    - Field emission from the cathode
    - Space charge effect
    - Suspended solid particles effect
    - Nucleation, cavitation and bubble effect

Some details

- Townsend avalanche:
  - Ionization probability per path length $\alpha(E)$ increase with the field
- Impurity effects:
  - Impurity can remove the charge and/or be more easily ionized
- Electrons emission from metals
  - UV photons and Ar^+ can extract e^- from metals

Some details

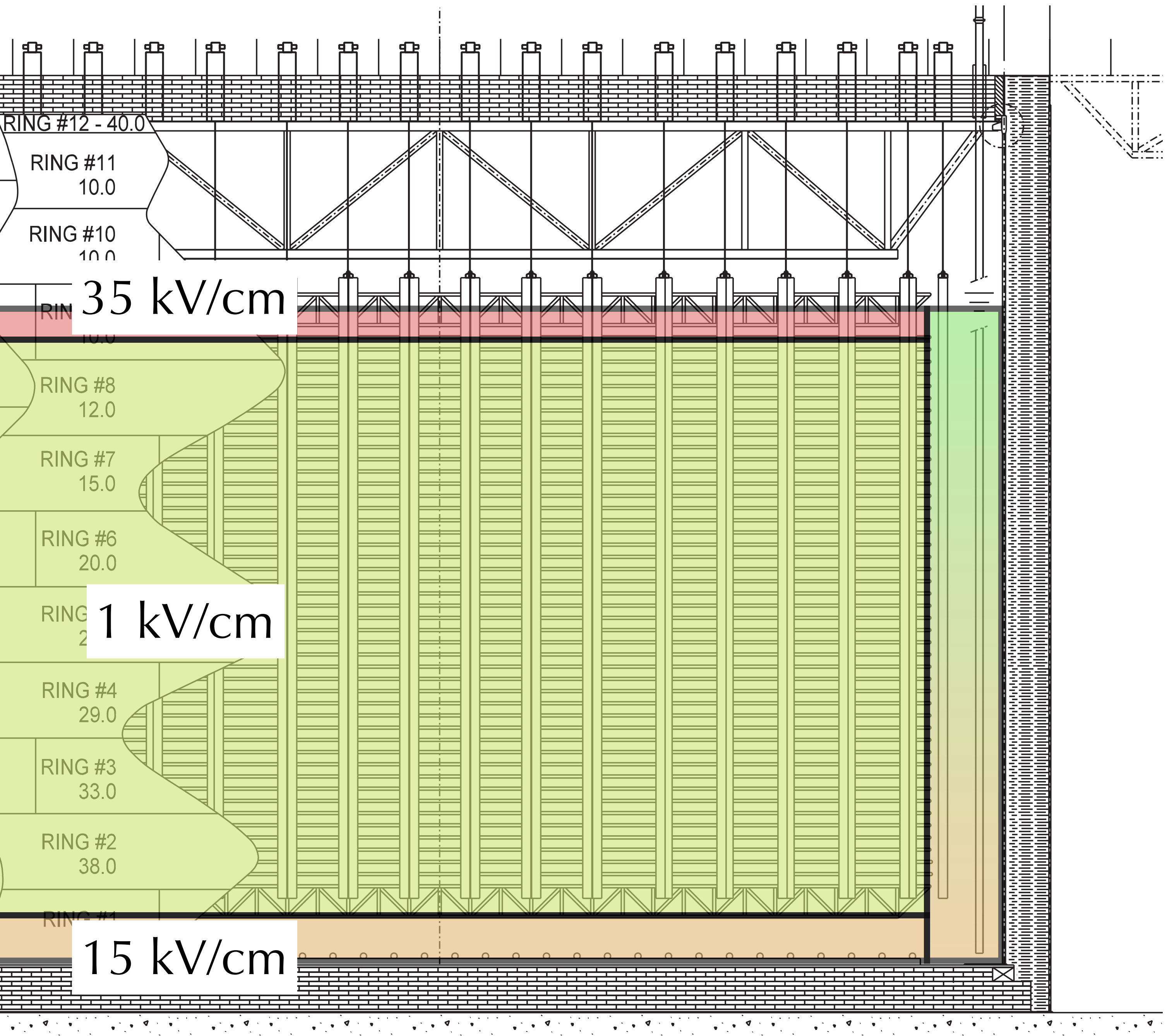
- Field emission:
  - Schottky effect: e^- are more easily extracted from metals in presence of an electric field
  - Field effect: electron extraction from metals when the electric field > some MV/cm

- Space charge accumulation:
  - Resistive layers on metals yield to a local enhancement of the electric field

Some details

- Suspended particles:
  - Dielectric particles (with large ε_r) gather where the electric field is largest, distorting the field
  - They link to each other and can form a bridge
- Nucleation and cavitation:
  - Bubbles, e.g. caused by corona discharges, behave like suspended particles
  - Bubbles can be electrically charged
  - In the gas the spark is more easily triggered

Electric field in Glacier



- The maximum average electric field is in vapor!
- Largest average electric field in liquid ~15 kV/cm
- Sharp edges imply large electric field → caution designing the electrodes
- Need to know the LAr behavior at high fields

R&D on HV

- HV PS and cable → industrial solutions
- HV feedthrough → custom development based on our previous experience
- Electrode design and materials: finishing

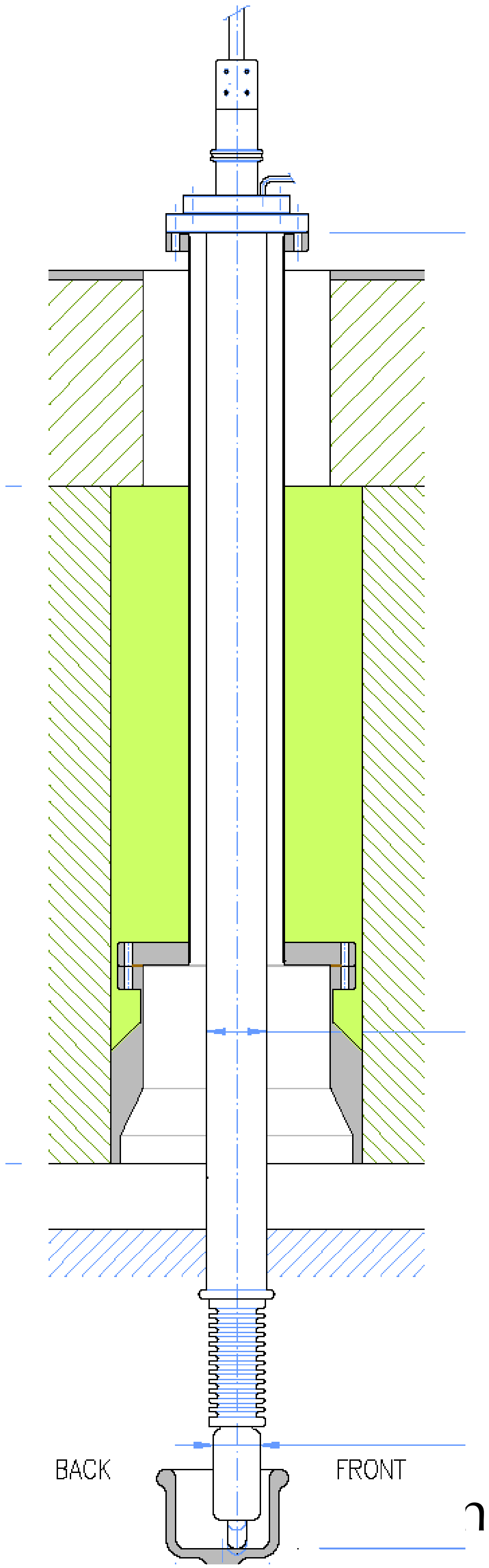
R&D on HV

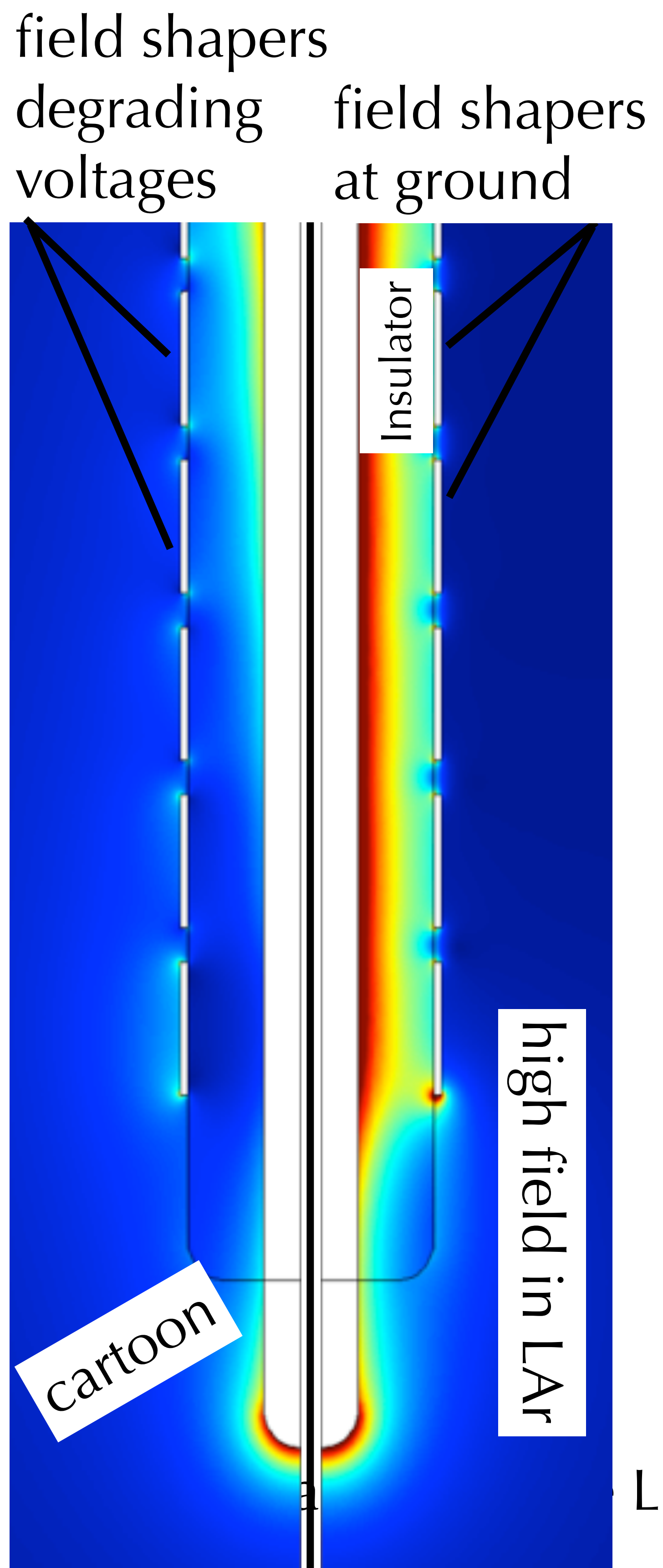
- Unknowns to be known before the final design:
  - Liquid argon dielectric rigidity versus electrode distance
  - Bubble and liquid argon purity effects on discharges
  - Argon ionization and space charge effects
  - Electrode material impact and properties of insulating materials

The feedthrough

ICARUS like
It works at -150 kV

The feedthrough

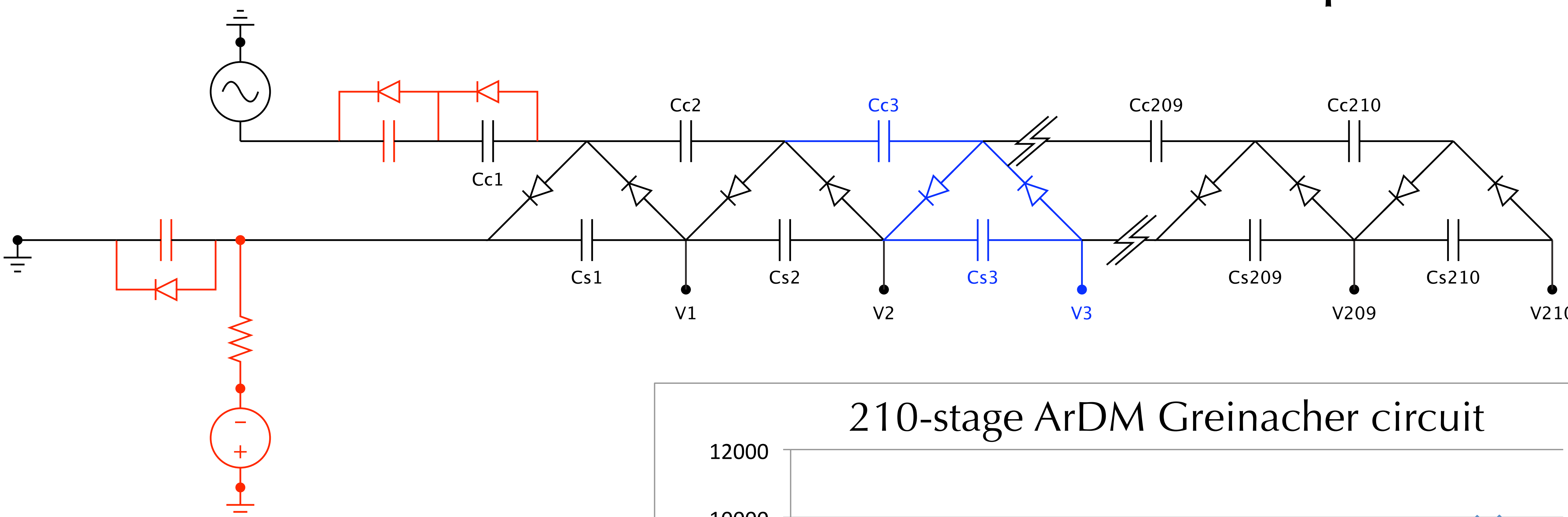




- Two concentric cylinders and a dielectric
- Designed for 300 kV
- Tested up to 150 kV
- Ideas to increase the nominal max potential
- Installation inside the field cage (planned in the 6x6x6 m^3)

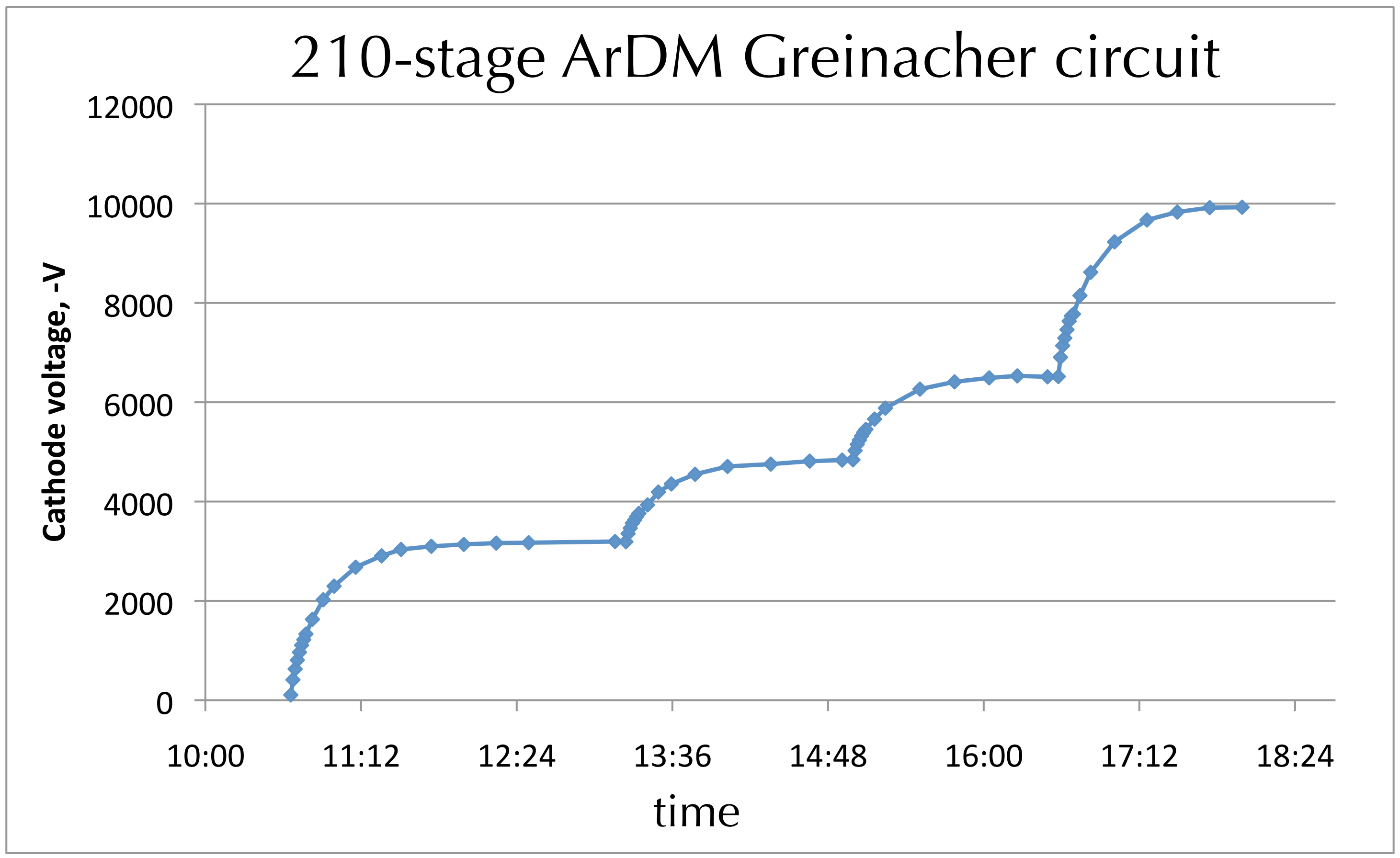
Greinacher

Also known as Cockcroft-Walton HV multiplier

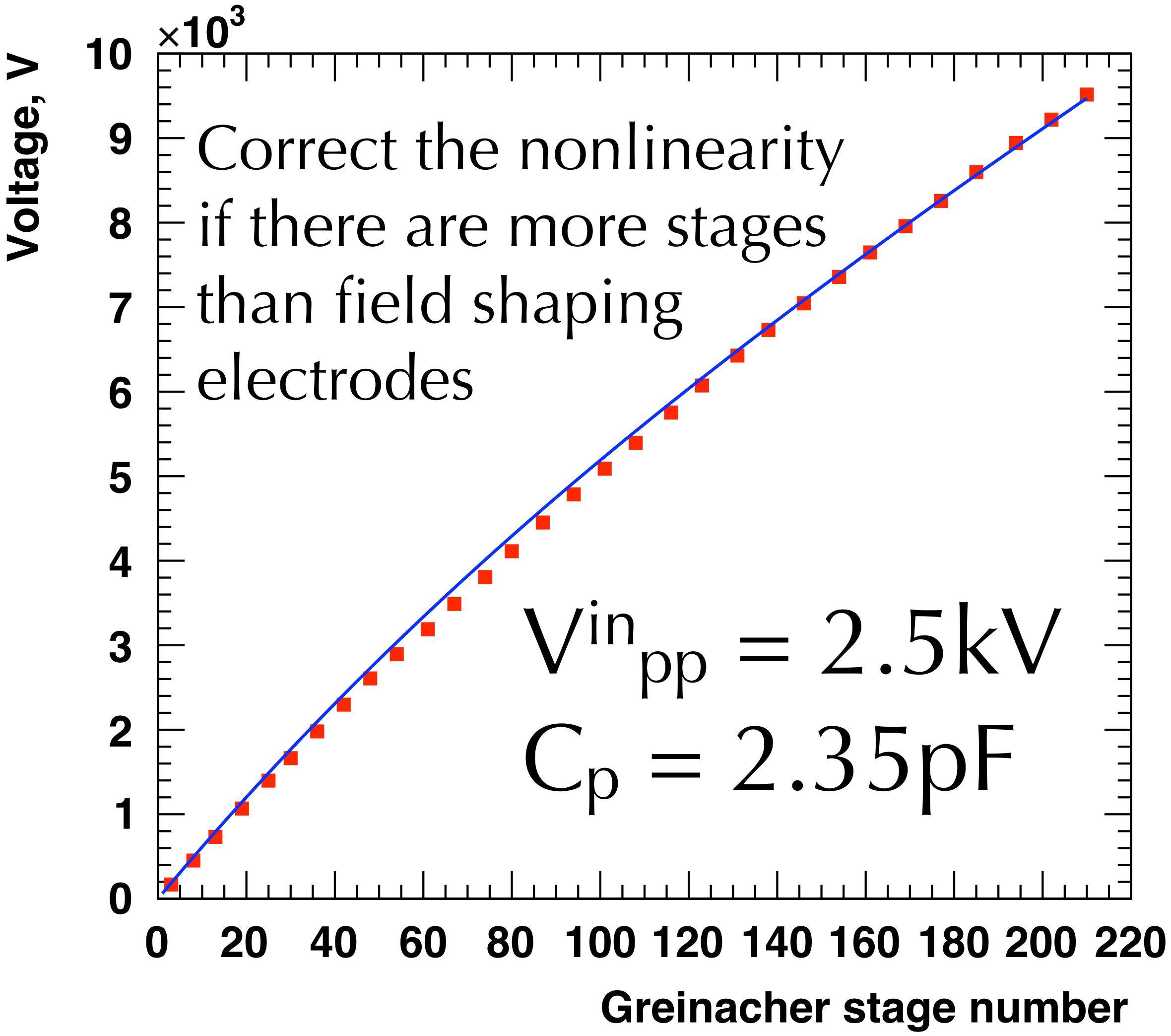


V^{in}: 50 Hz AC input

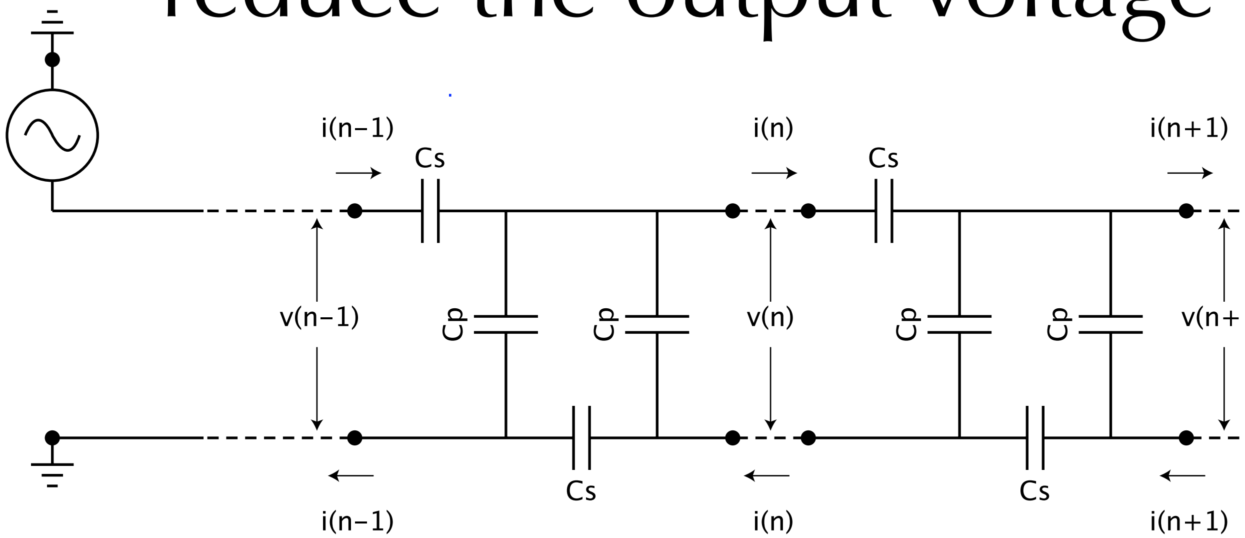
V^{out}: ~DC $N \times V^{in}_{pp}$



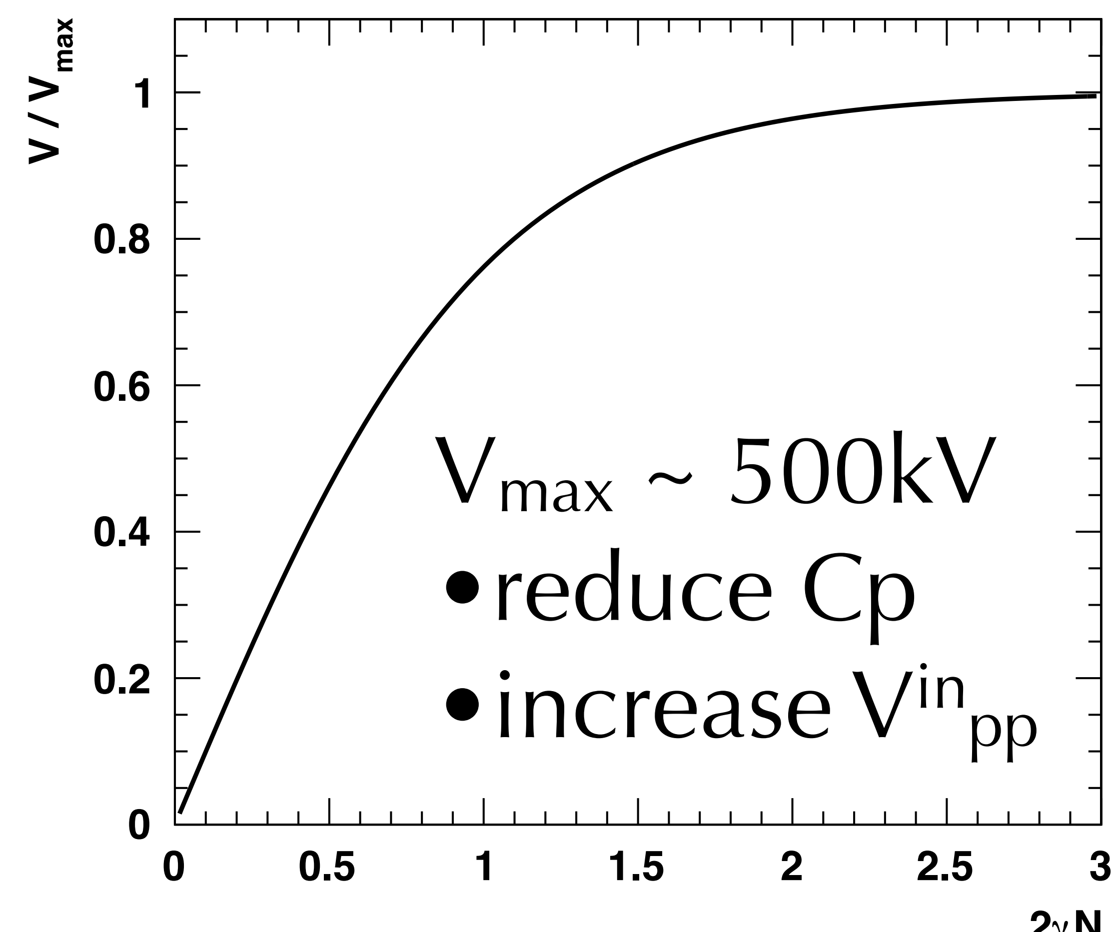
Greinacher



Shunt capacitances Cp reduce the output voltage



$$V_{\rm max} \propto \frac{V^{\rm in}_{\rm pp}}{\gamma} \qquad \gamma \approx \sqrt{\frac{C_{\rm p}}{C_{\rm s}}}$$



JoP 308 (2011) 012027
JINST 7 (2012) P08026

HV power supply & cable

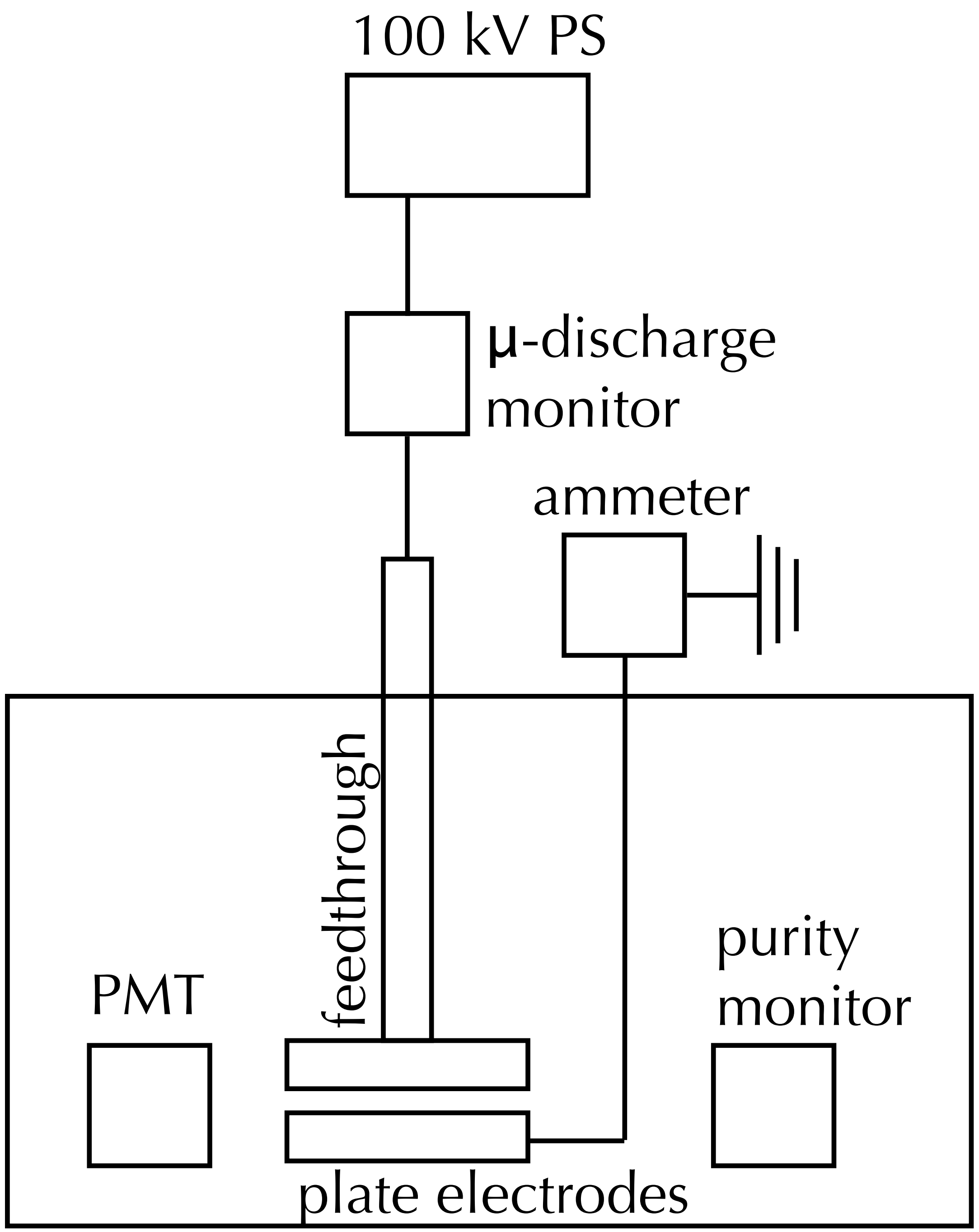
In contact with Heinzinger to design a 600 kV PS
They are interested in going beyond!

LAr dielectric rigidity test

Goal is to measure:

- Liquid argon dielectric strength up to a uniform 100 kV/cm field across 1cm
- Impact of the electronegative impurities
- Insulating properties of dielectric materials, e.g. surface and volume resistance.

LAr dielectric rigidity test



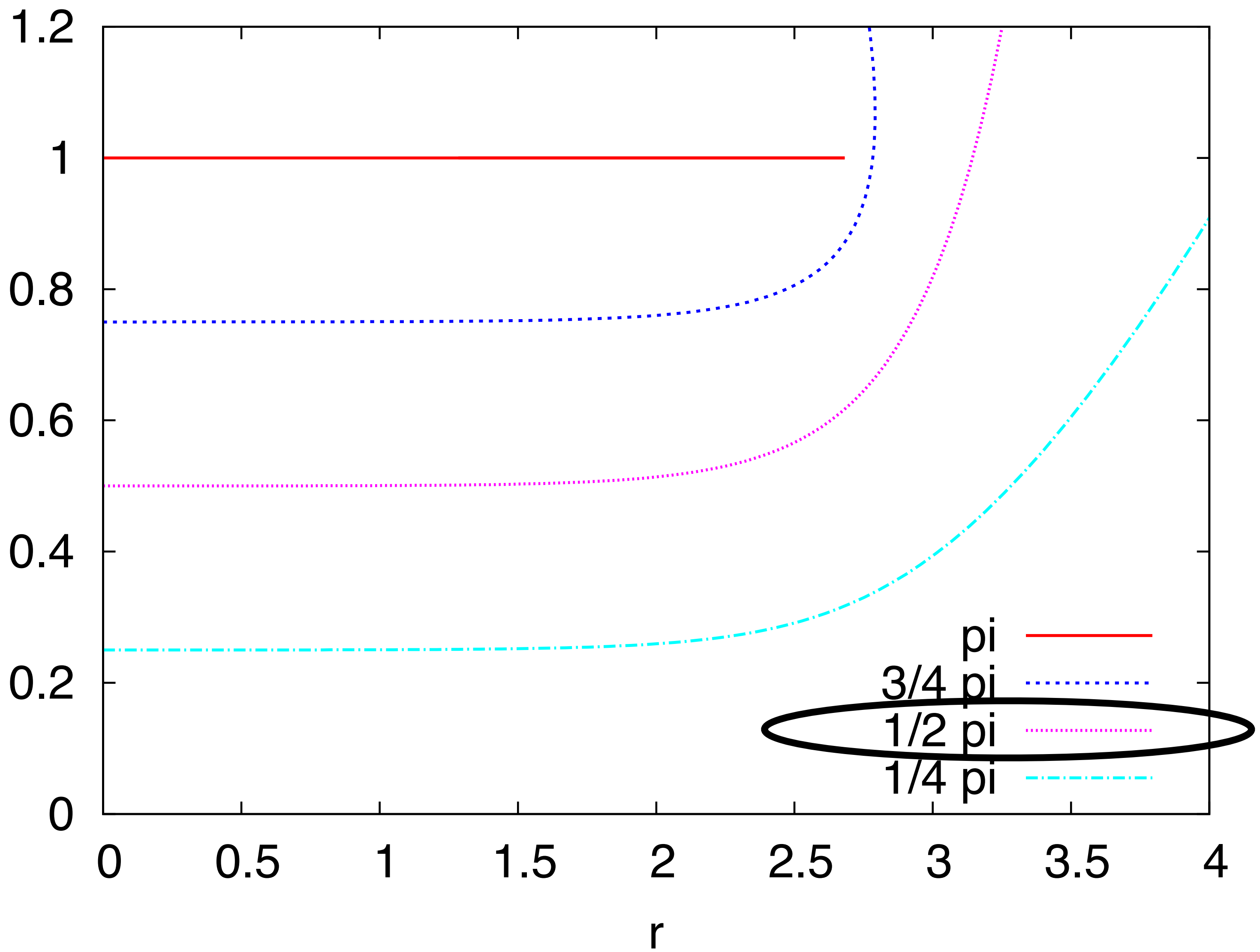
μ-discharge monitor:

- 1:1 transformer + preamp
- 10MHz band sensitive to pulse of ~10μA 20ns long

At the beginning:

- No argon recirculation
  - purification only at the input contamination order of ppb $[O_2]_{eq}$
- No PMT (but window)
- No Purity monitor
- No ammeter

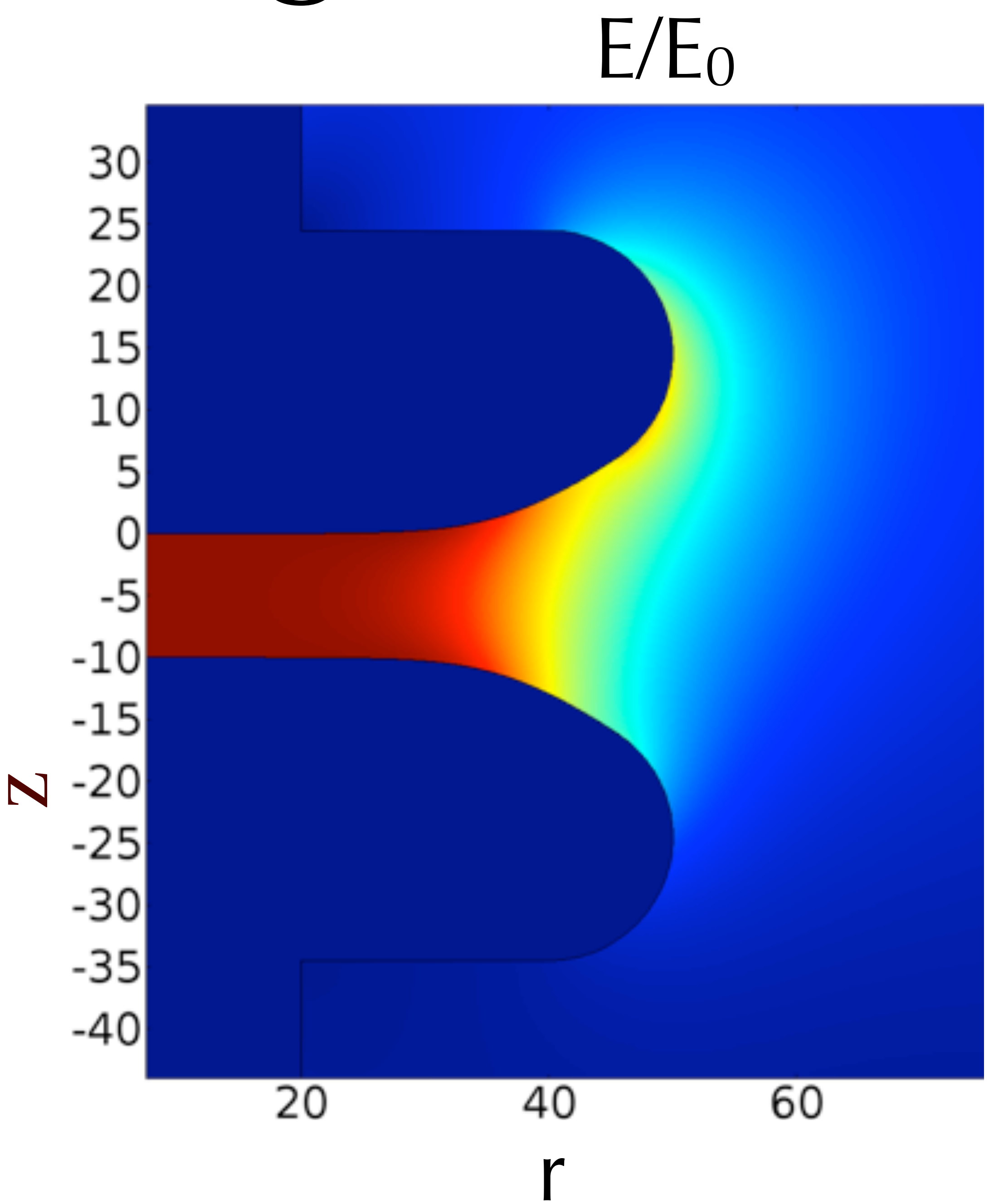
Rogowski profile

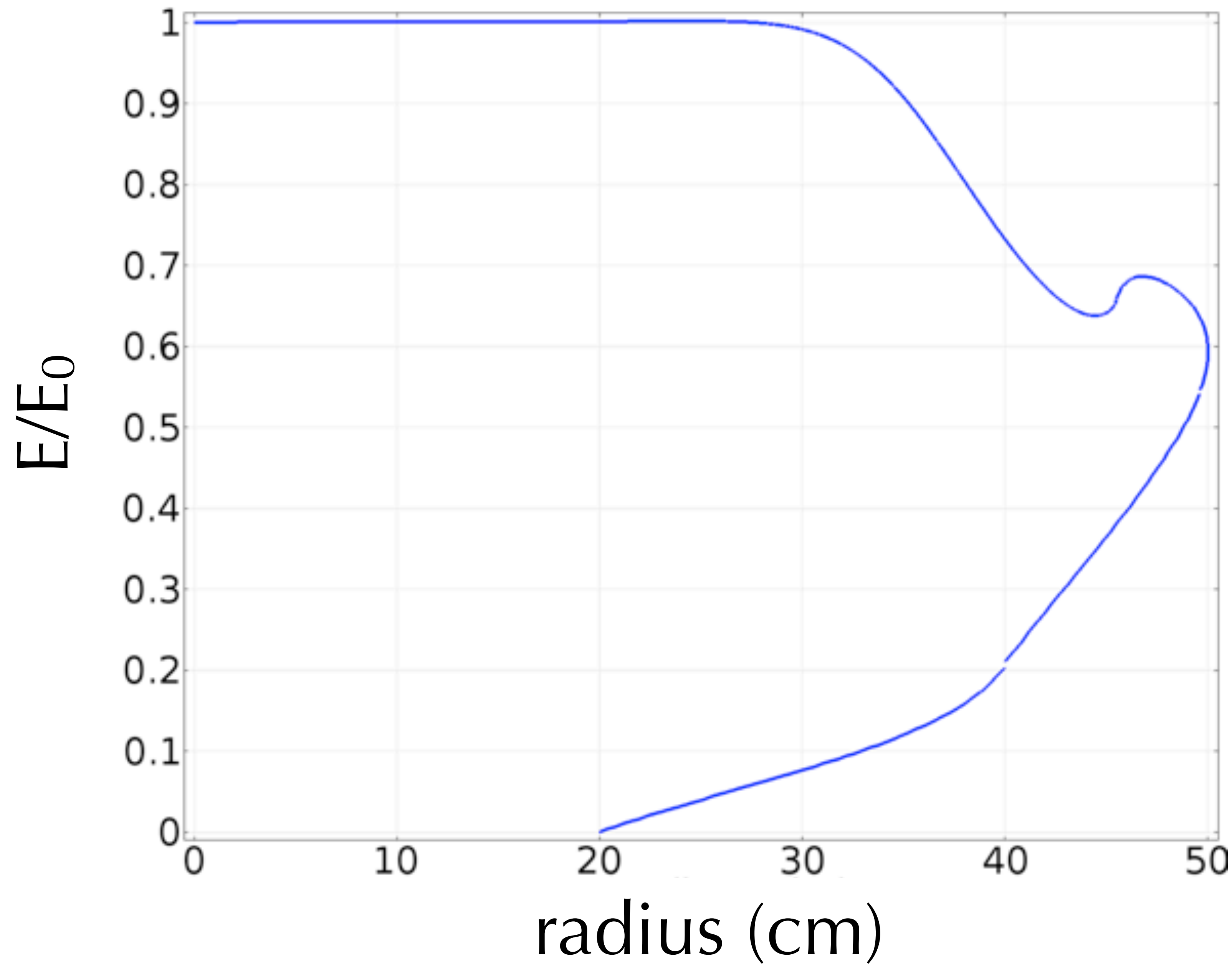


- High field region only within the two disks: Rogowski problem
- Infinitely thin disk of a finite diameter at some potential parallel to an infinite plane at ground
- Equipotential lines (ψ constant varying φ):

$$r(\phi,\psi) = Z_0(\phi + e^{\phi}\cos(\psi))/\pi$$
$$z(\phi,\psi) = Z_0(\psi + e^{\phi}\sin(\psi))/\pi$$

Rogowski electrodes

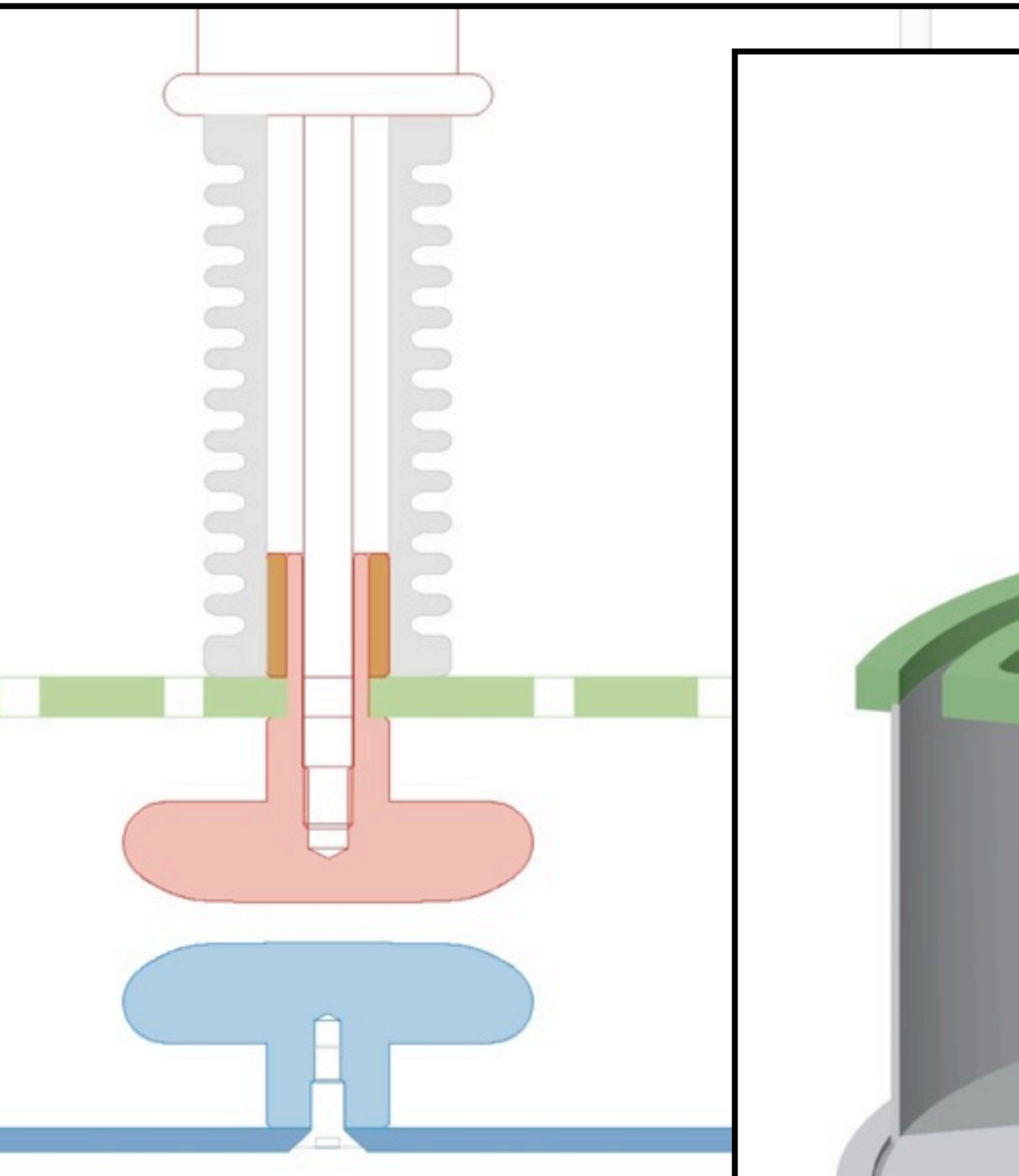


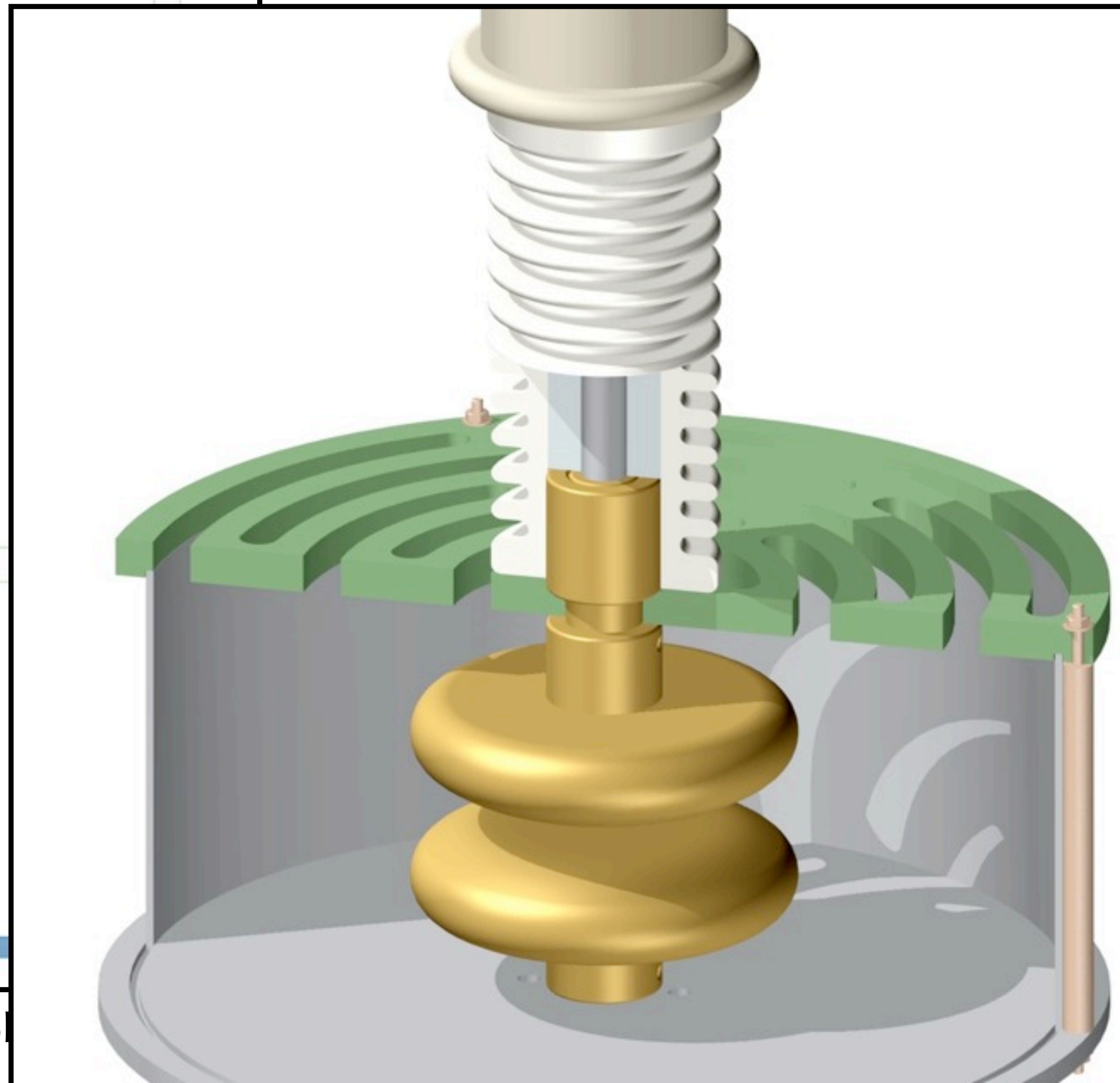


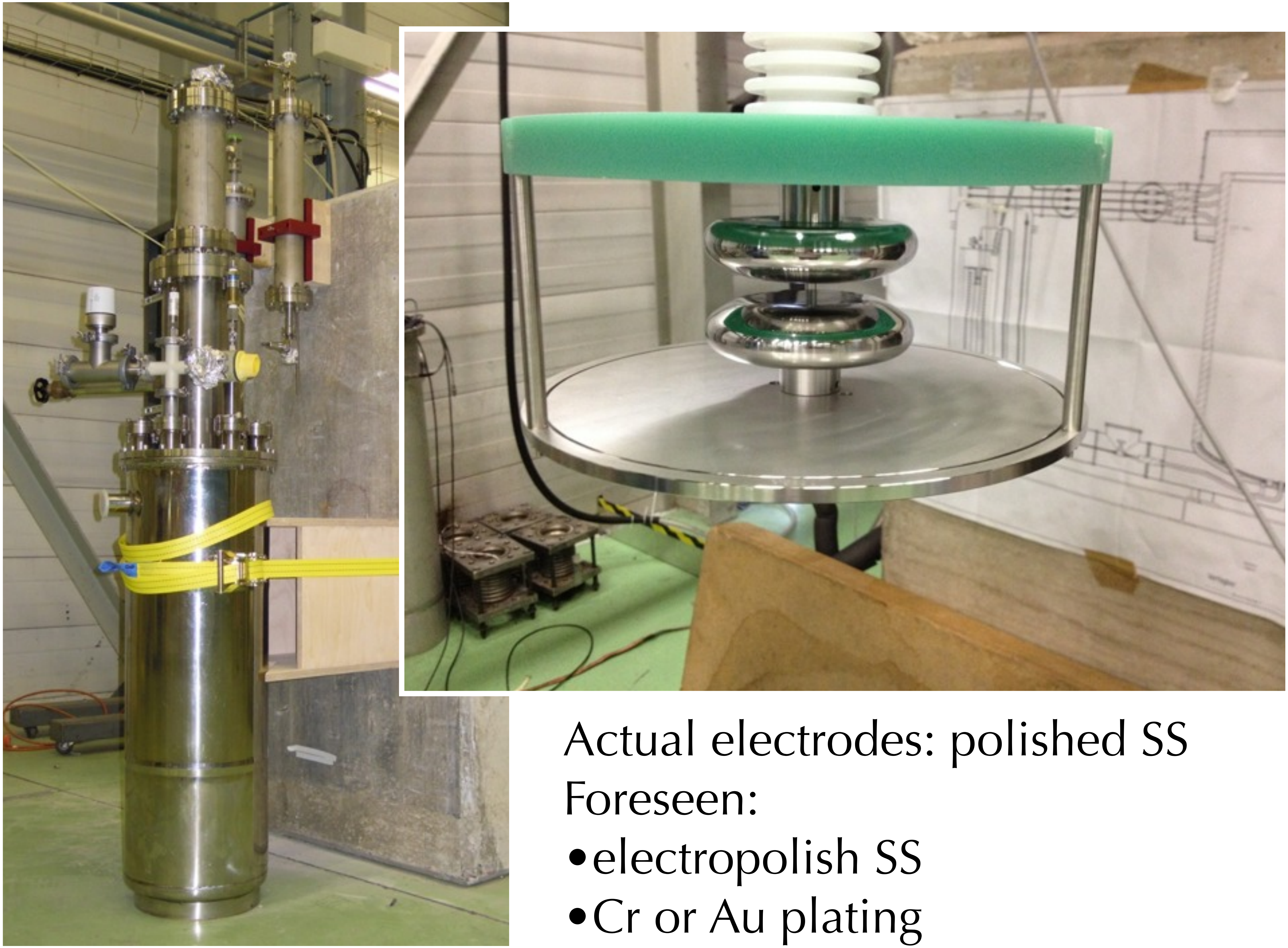
Diameter of the electrode 10 cm
Uniform field in a disk of diameter ~5 cm
Maximum field outside the plates ~0.7 x E_0

Assembling the setup

The chamber







Actual electrodes: polished SS

Foreseen:

- electropolish SS
- Cr or Au plating

Outlooks

- A number of R&D activities are ongoing towards GLACIER
- Started the systematic studies of the behavior of argon in large electric fields
- Study of material performances in LAr
- Develop new feedthrough for the MV
- Soon the first results…