The ProRad Experiment

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PRAE International Workshop

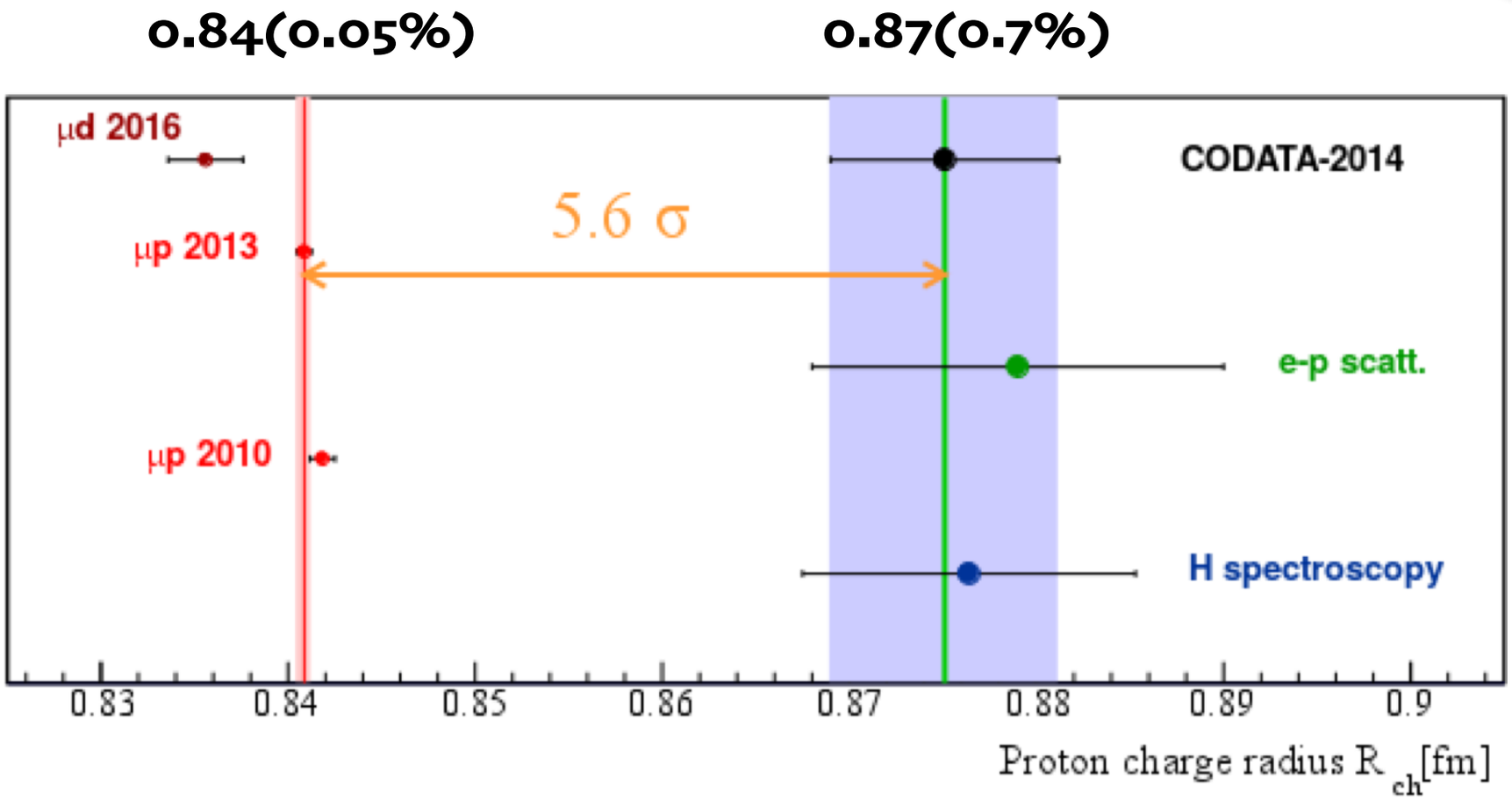
Outline

- Why we do ProRad?
- How we do ProRad?
- What is ProRad?

Why measure the Proton charge radius?

- Different measurements that are significantly different
- No consensus on understanding the origin of the difference
- Need for a high-precision measurement to conclude on this puzzle

ProRad@PRAE

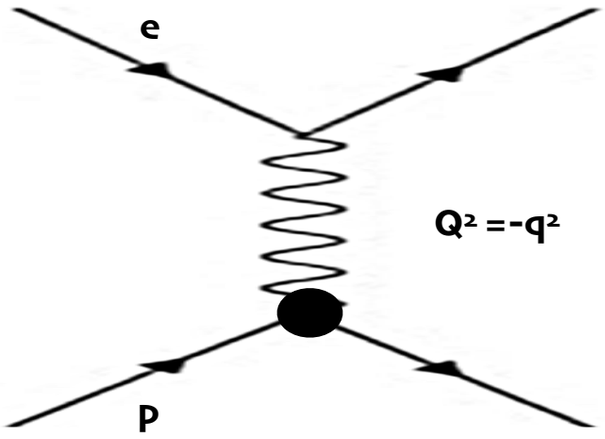


CODATA-2014: Mohr, Taylor, Newell, Rev. Mod. Phys. 88, 035009 (2016)

Experimental method

- Measure the e-p elastic scattering cross section

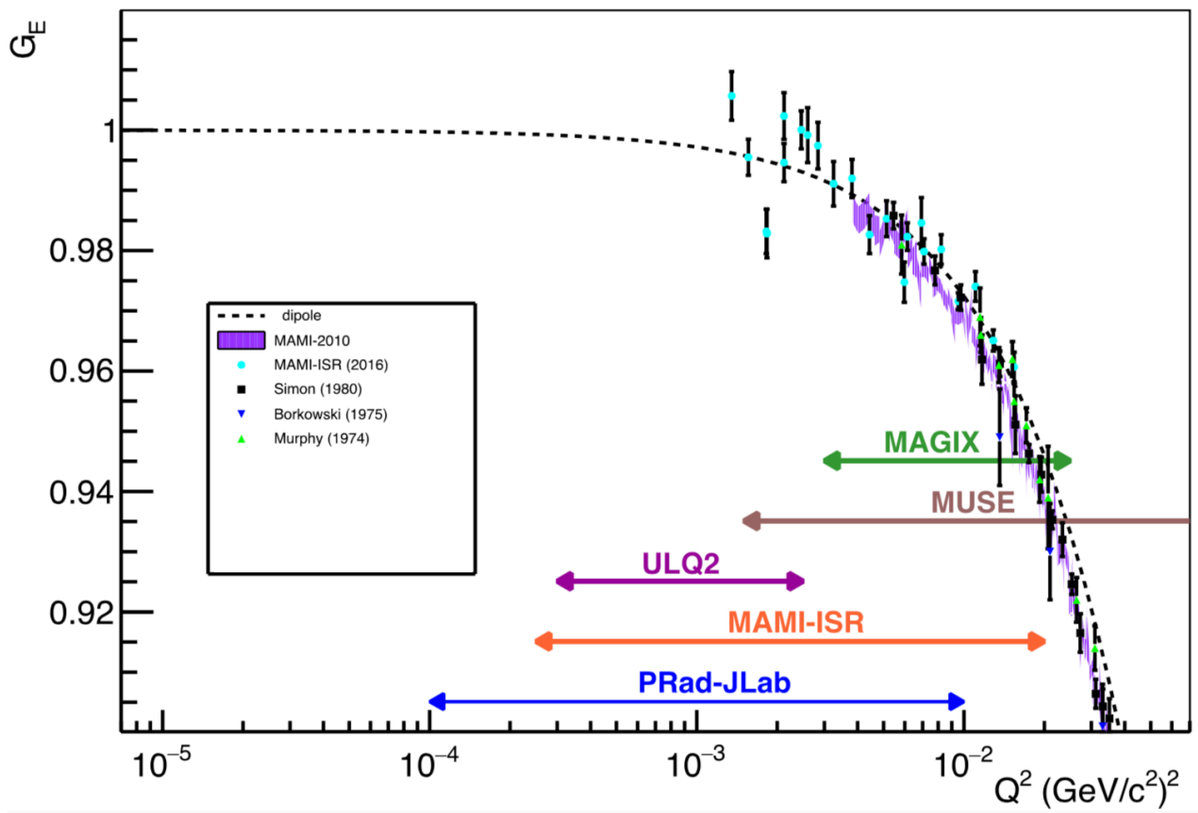
$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}\Big|_p \times \left(\frac{G_E^2(Q^2) + \tau G_M^2(Q^2)}{1+\tau} + 2\tau \tan^2\left(\frac{\theta}{2}\right) G_M^2(Q^2) \right)$$



- Extract the Proton electric form factor at very low Q2

- Extract a value of the proton charge radius including previous data

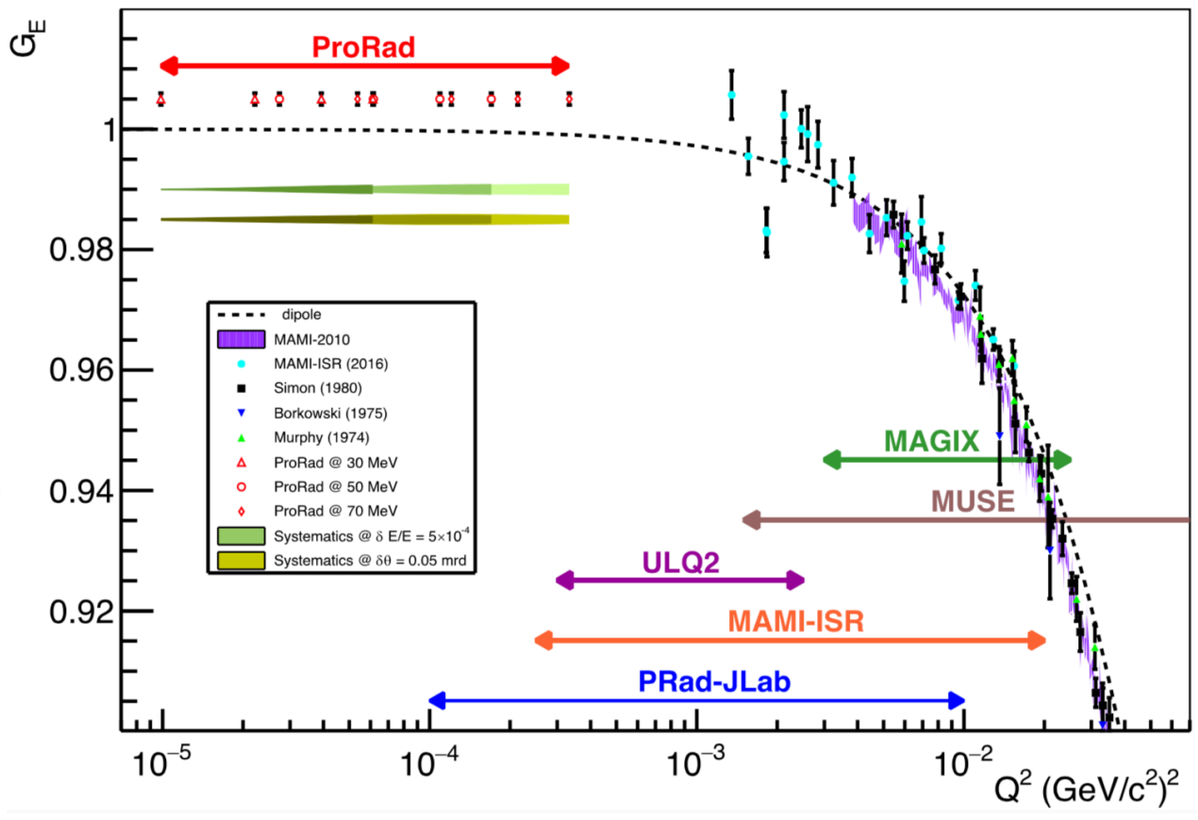
$$r_p = \sqrt{< r^2 >} = \sqrt{-6 \frac{\partial G_E^2(Q^2)}{\partial Q^2}\Big|_{Q^2=0}}$$



Experimental configuration

- Incident electron energies varying between 30-70 MeV
- Angular range of (6°-15°) for scattered electron
- Precise measurement of the electric form factor $G_E(Q^2)$ in the momentum transfer range of 10^{-5}-10^{-4} $(GeV/c)^2$

- 0.1% precision on the measurement of the Proton electric form factor $G_E(Q^2)$
- ProRad will provide the necessary complementary data to significantly conclude on the proton radius puzzle



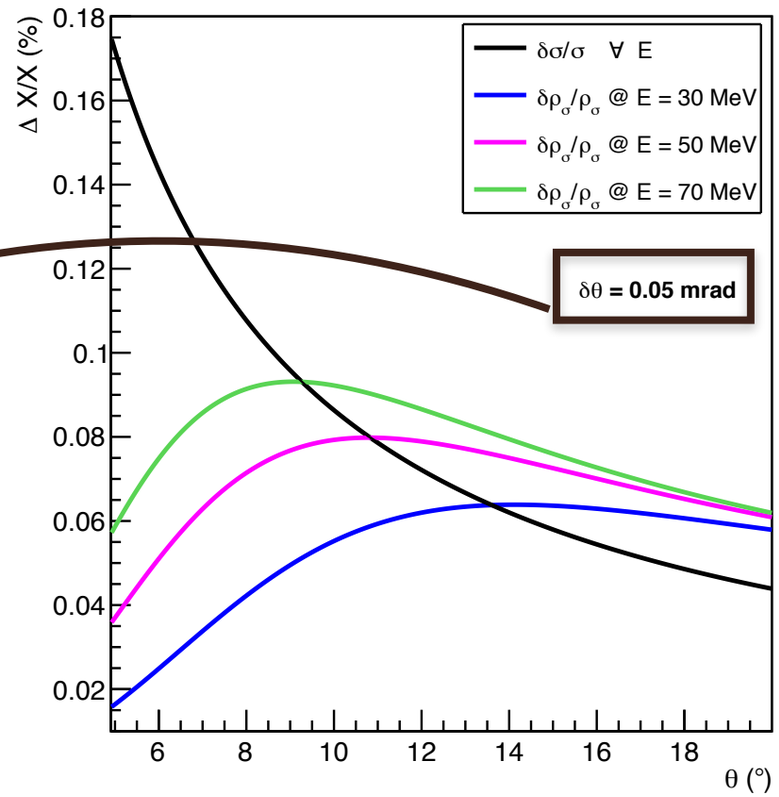
Principle of measurement

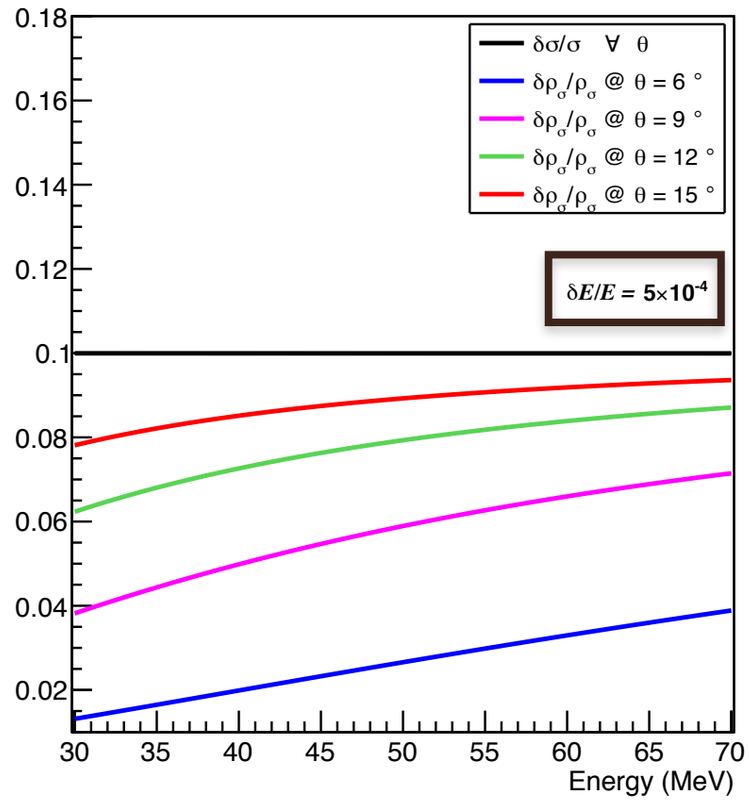
- Experimentally detect both elastic and Moeller scattered electrons
- Normalise the Elastic cross section to that of the well know Moeller cross section
- Estimate systematics on the ratio: precise control of the effects (<0.1%)

$$\rho = \frac{\int \frac{d\sigma}{d\Omega}\Big|_{ep}}{\int \frac{d\sigma}{d\Omega}\Big|_{ee}}$$

Well known theoretically

Mechanical precision of 1/10 mm (at 2 m)

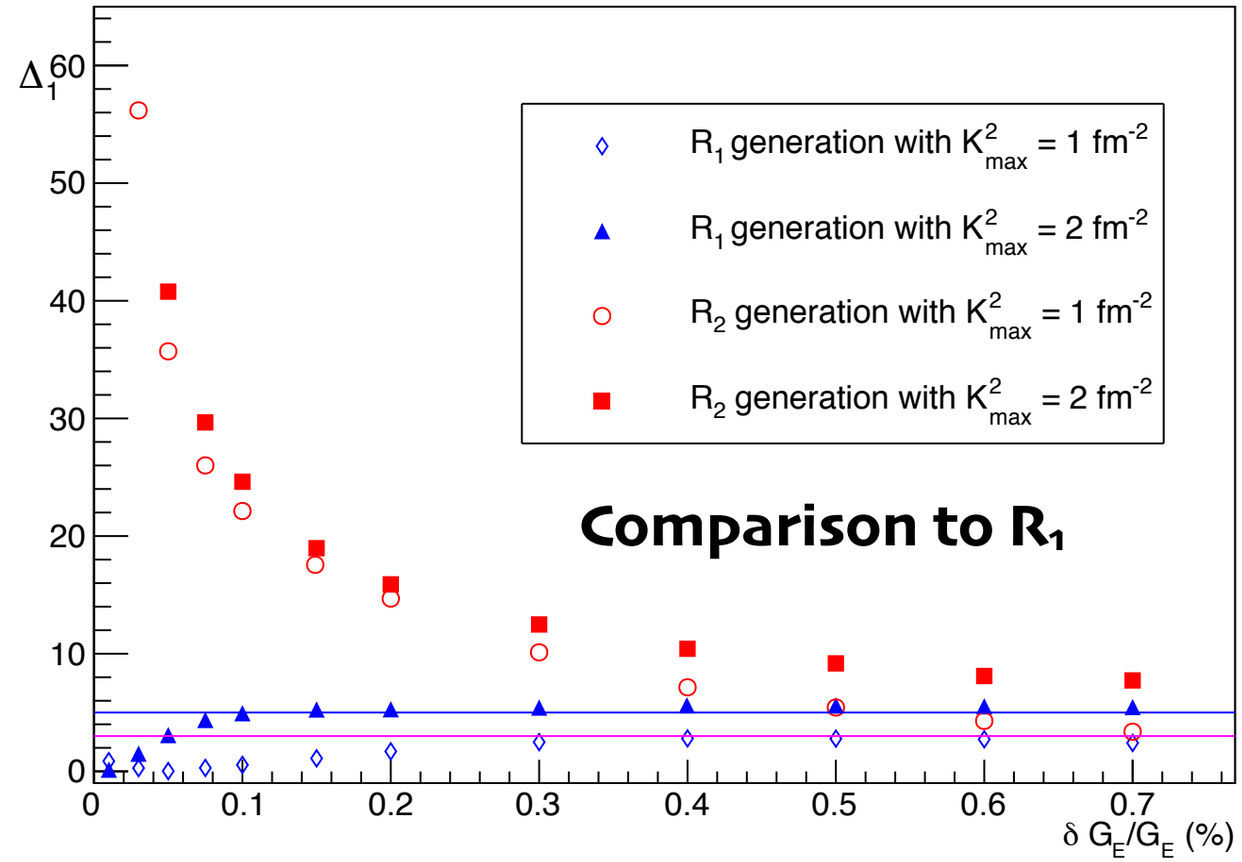


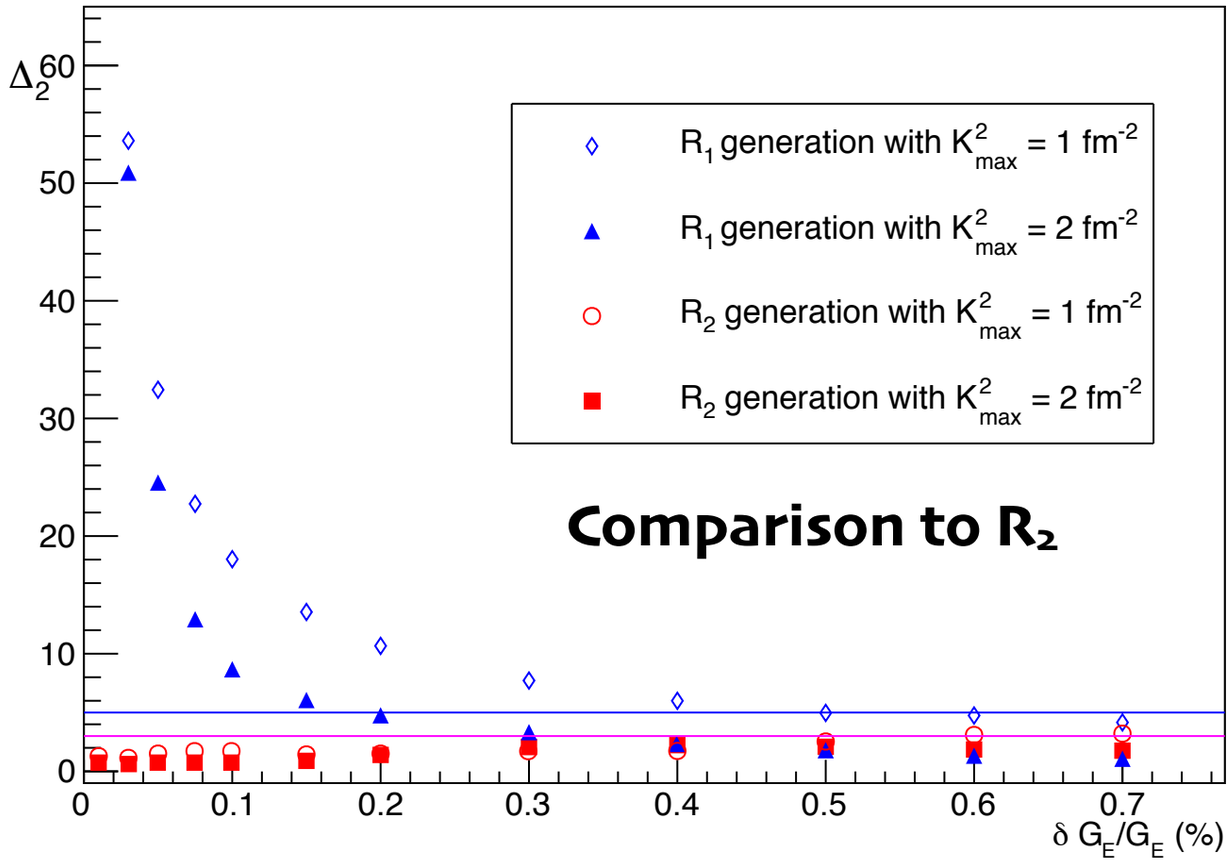


Expected impact

R_1 = muon

R_2 = electron

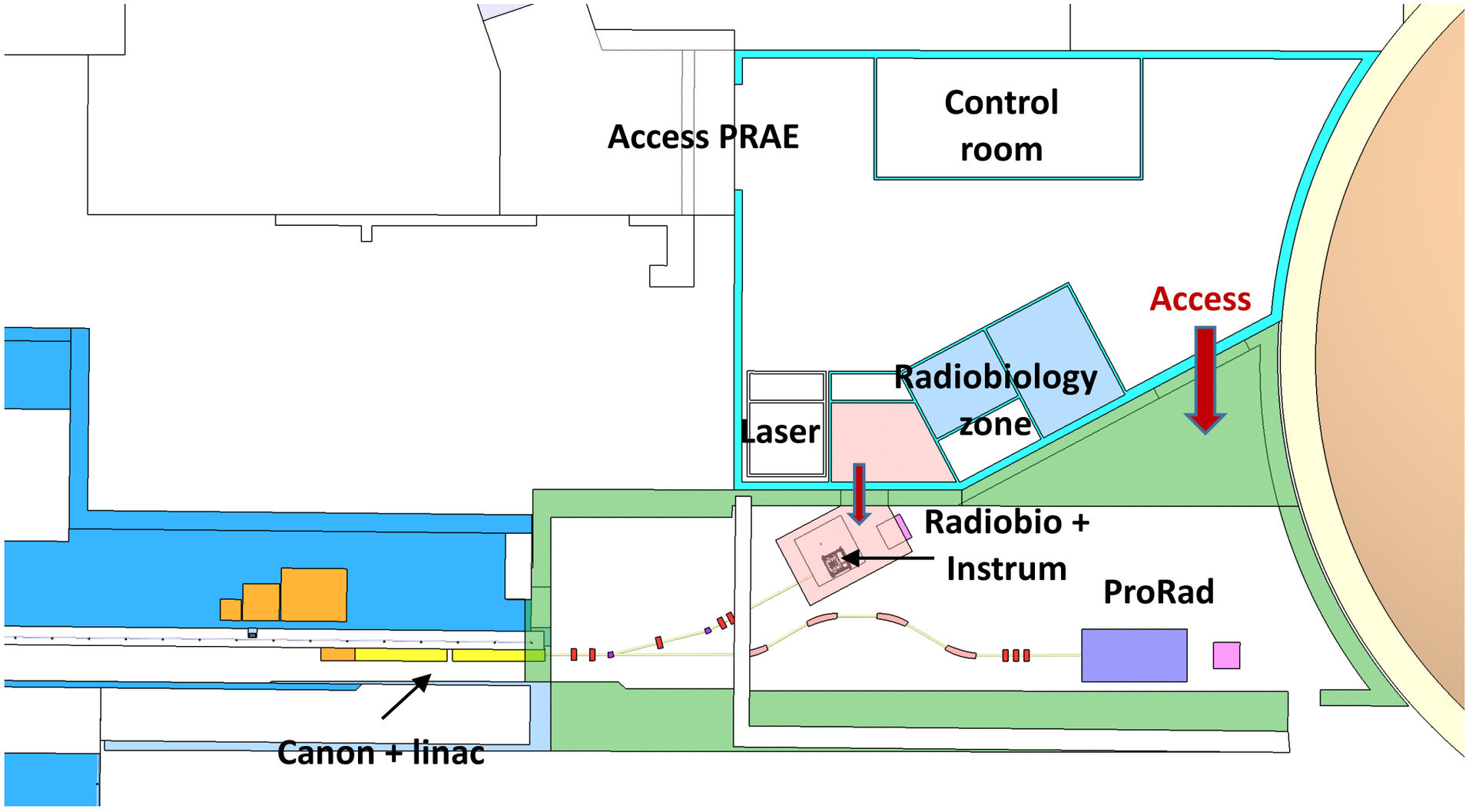




All upcoming experiments are taken into consideration in this study: ProRad, PRad, ULQ2, ISR, MAMI-TPC, MUSE

$\delta(G_E)/G_E$ for low Q2 experiments has to be at least 10^{-3} to be sensitive to R_1 due to the large statistical weight of Mainz 2010 data.

ProRad@PRAE



ProRad experiment requirements:

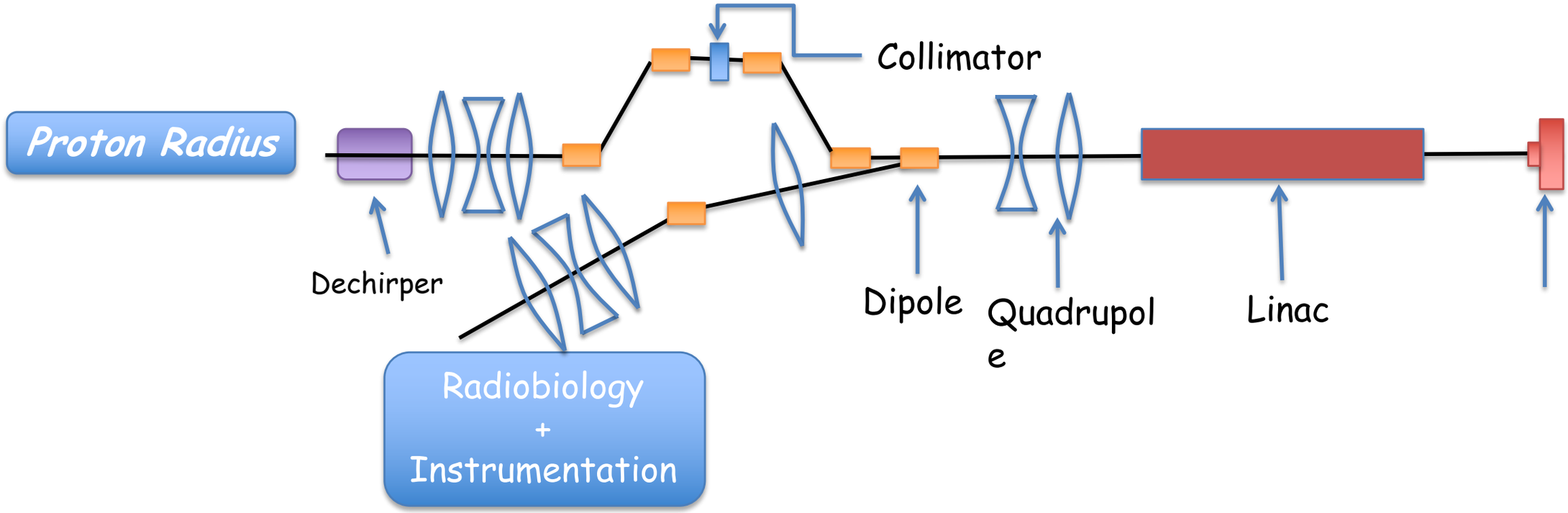
- High precision beam
- Precise knowledge of the beam energy
- A stable target
- Optimised measurement of the scattered electron energy and position

PRAE beam characteristics

Beam requirements for ProRad goals:

- $\sigma_x \approx 20 - 30$ μm
- $\sigma_y \approx 100 - 200$ μm
- $\sigma_E / E <\approx 5 \times 10^{-4}$
- $\sigma_{x',y'} < 50$ μrad

Studies are ongoing Yanliang Han



Beam Energy Absolute Measurement (BEAM)

Beam
Energy
Absolute
Measurement

- Precise knowledge of the beam energy value is crucial to obtain a sub-percent uncertainty on $G_E(Q^2)$

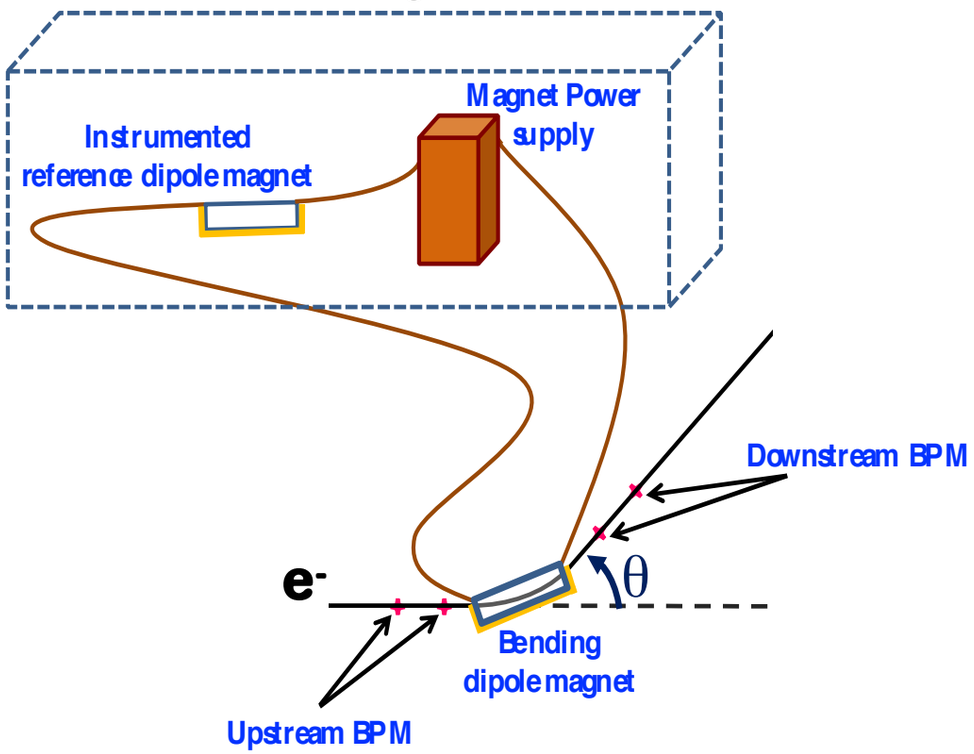
$$\delta E/E = 5 \times 10^{-4}$$

$$E = \frac{c}{\theta}\int B\, dl = \frac{c\, I_B}{\theta}$$

Beam Position Monitors to measure θ

A control magnet connected serially with the dipole magnet to measure the field integral along the electron path

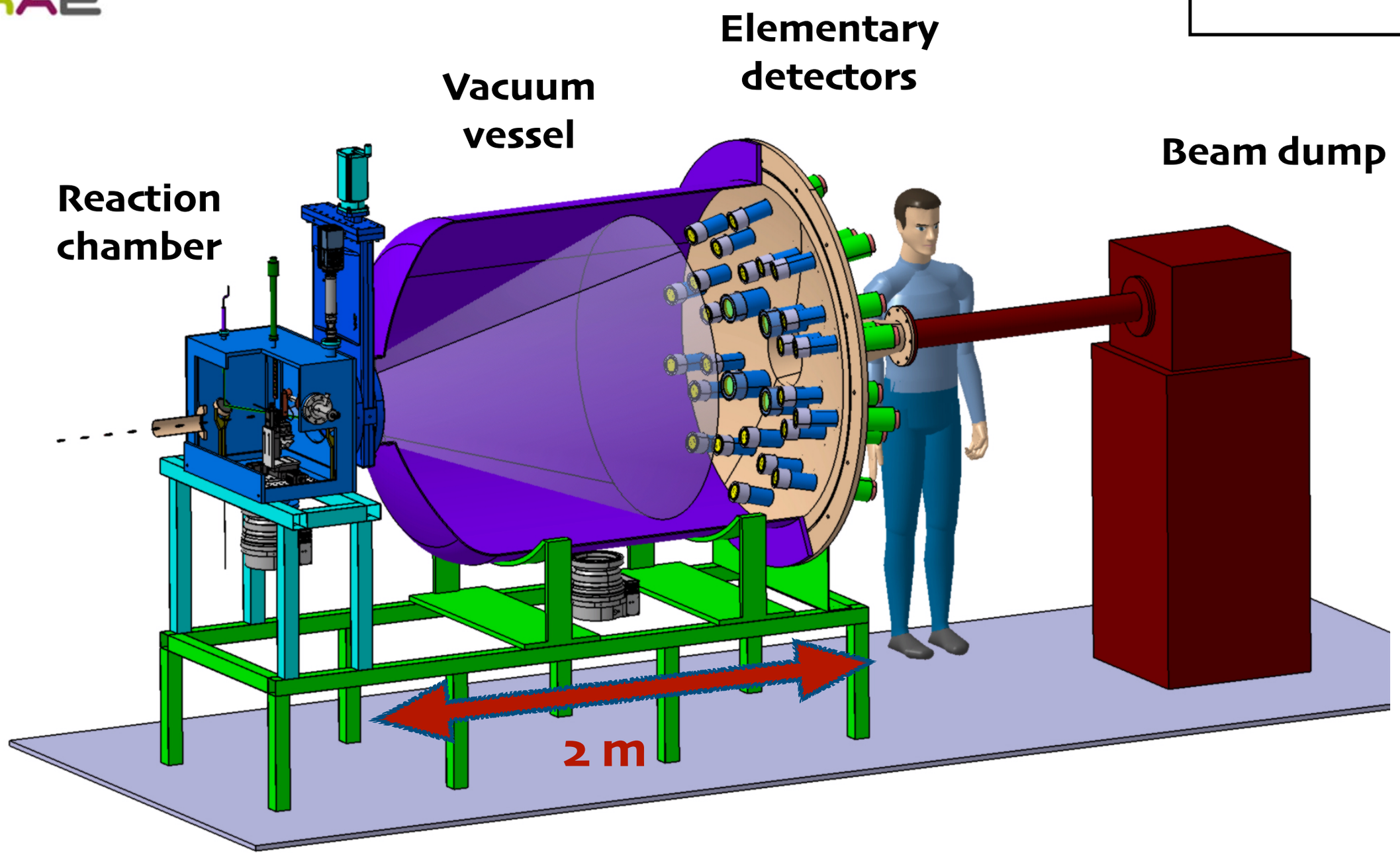
Reference field integral measurement



New PhD student
Lucien Causse

The Experimental Setup

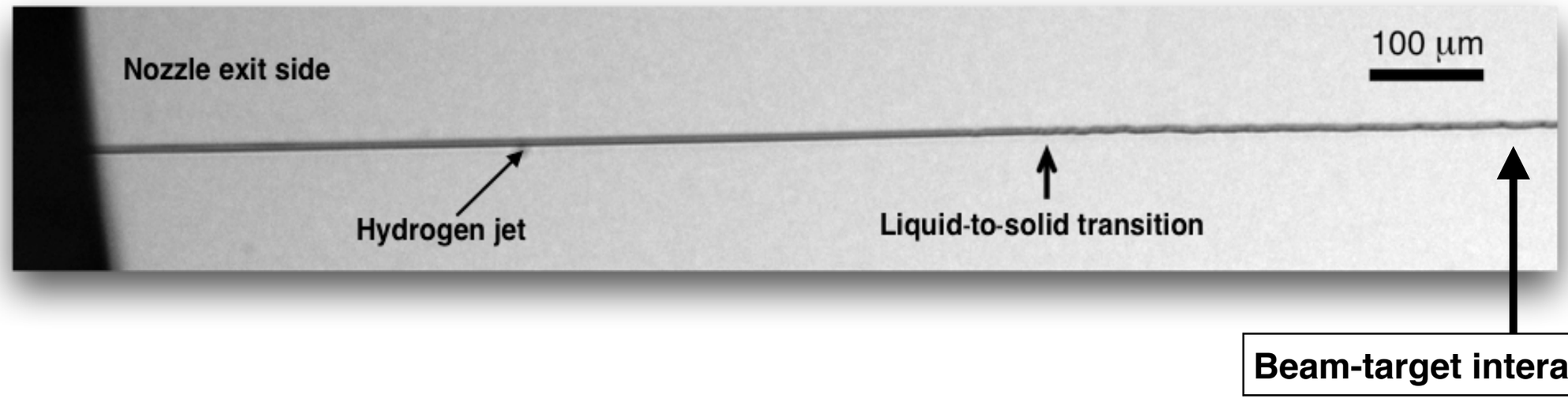
Non magnetic system



28 elementary detectors placed at 4 different scattering angles

The Hydrogen target

R.A. Costa Fraga et al. RSI 83 (2012) 025102



- Windowless: Target purity and less background contamination
- Small size: accurate determination of the scattering angle 15 μm
- Dense target: reduced data taking time

Nominal source pressure = 12 bar

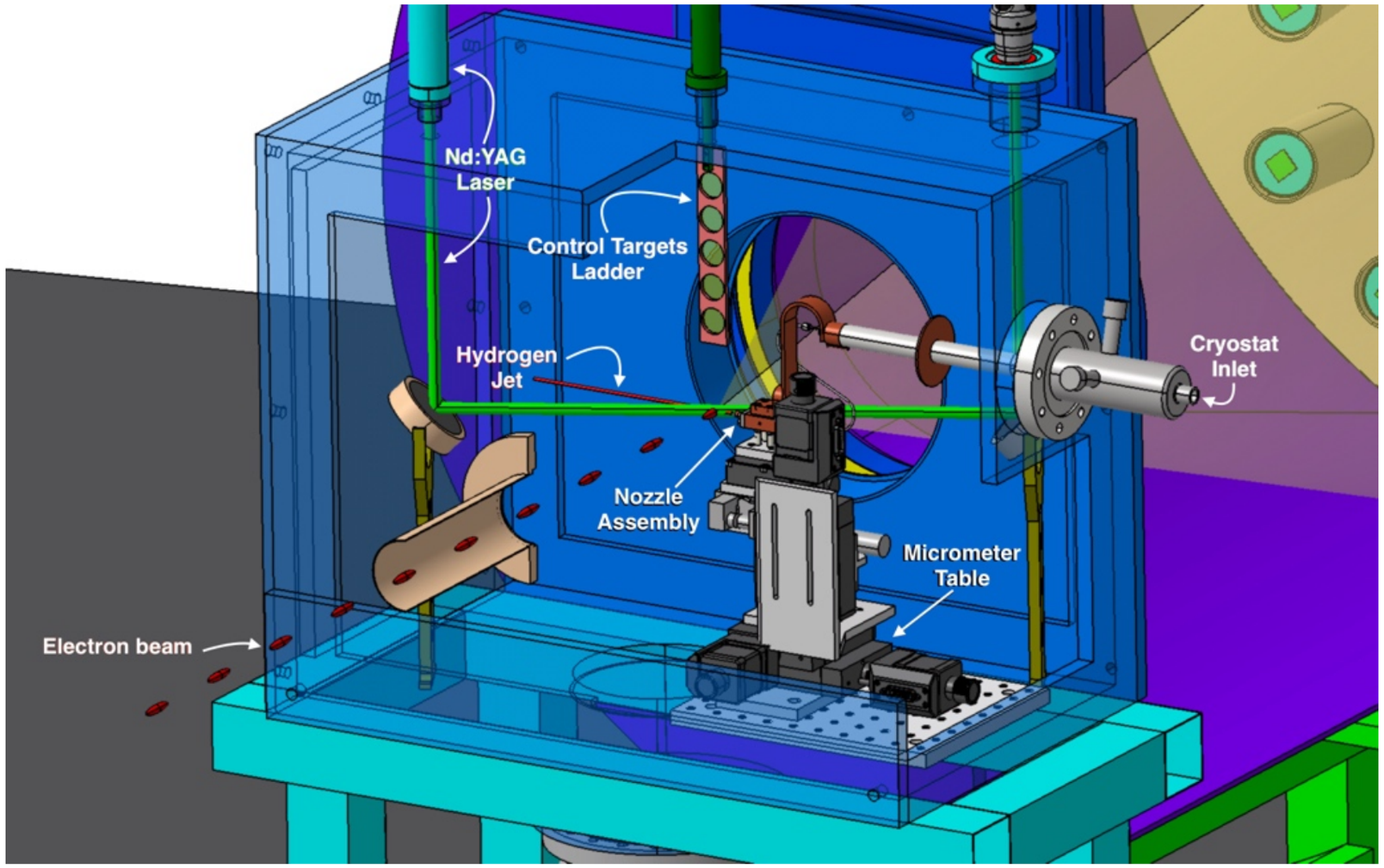
Nominal source temperature =15 K

→ **Laminar flow conditions**

Evaporative cooling rates exceeding 10^7 Ks^{-1}

→ **No Rayleigh breakup**

The Hydrogen target

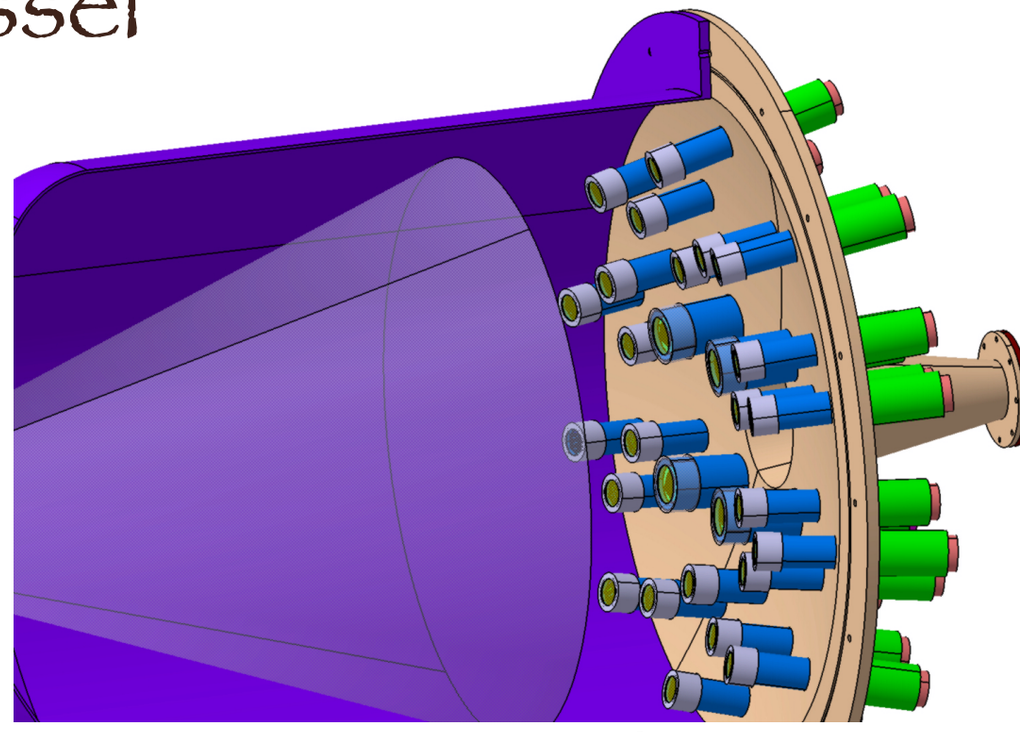


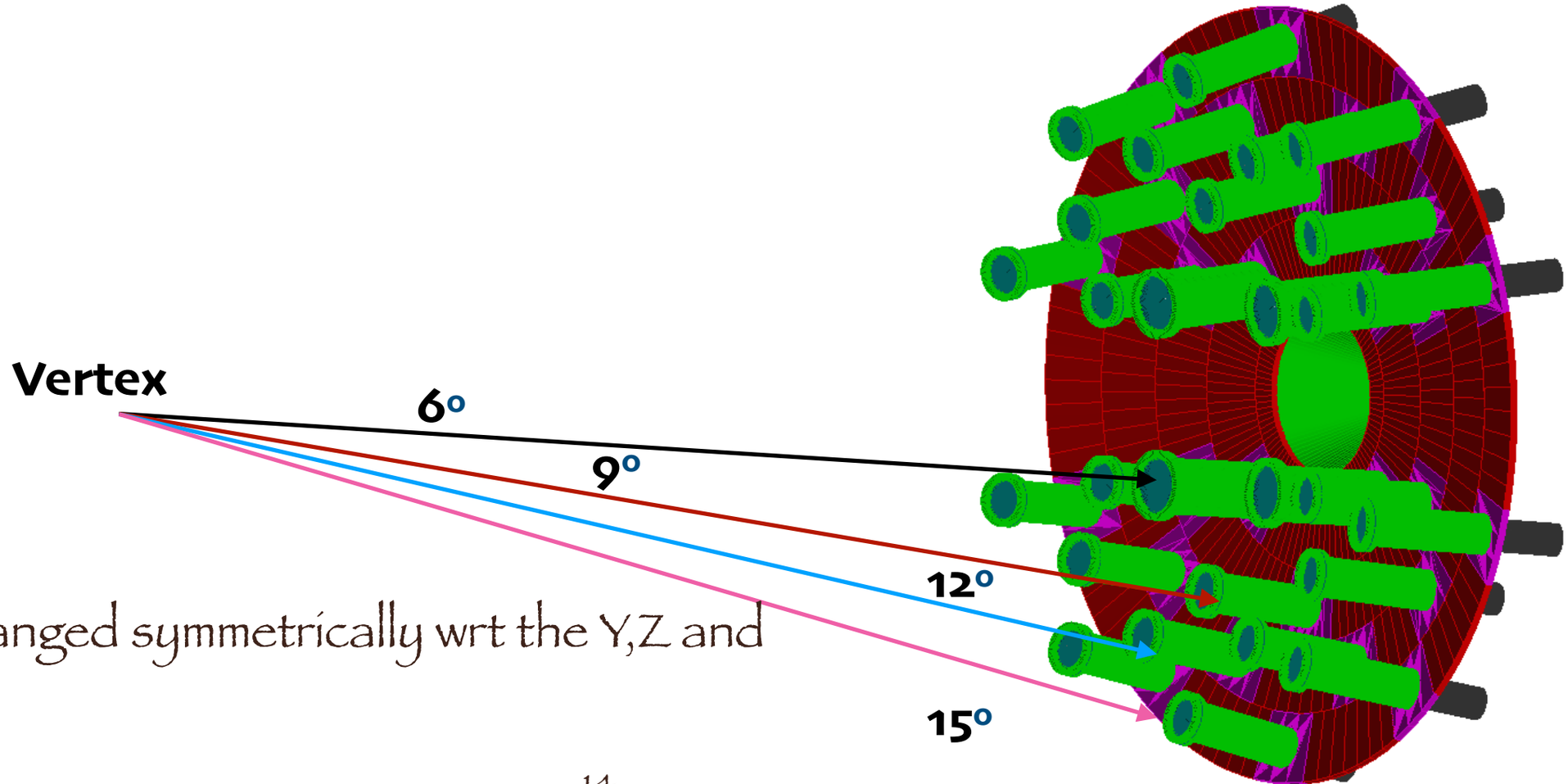
- Nd:YAG laser synchronised with a CCD camera: live streaming of the target with optical resolution of 2-4 μm

- Closed cycle cryostat to insure laminar flow conditions

The vacuum vessel

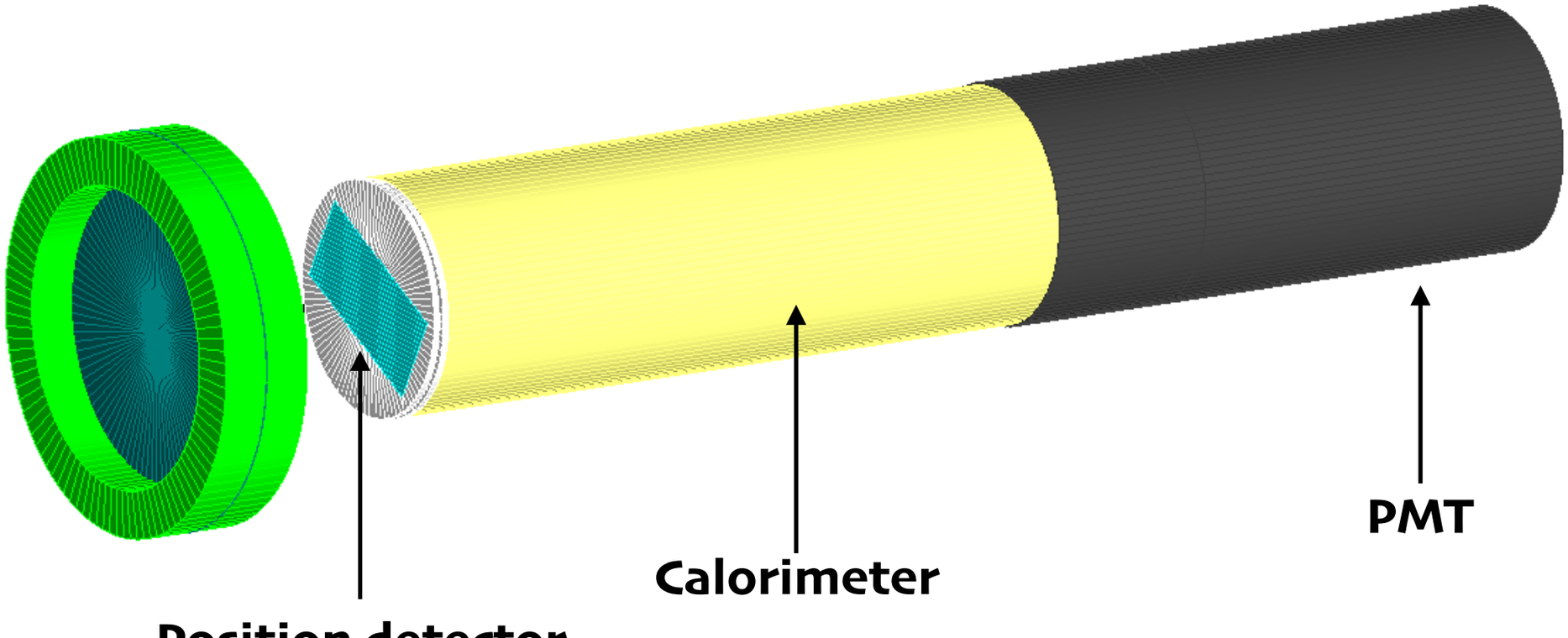
- Mostly made of vacuum
- And the 28 elementary detectors held at the end cap
- Arranged at 4 fixed angles: scattering angle defined by the position of the crystal at first order





Detectors are arranged symmetrically wrt the Y,Z and X,Z plane

The elementary detector



- Role of the elementary detector:

- Measure the scattered electron's energy: BGO crystal (πx3.5^{2}x15 cm^3 at 6° πx2.5^{2}x15 cm^3 elsewhere)

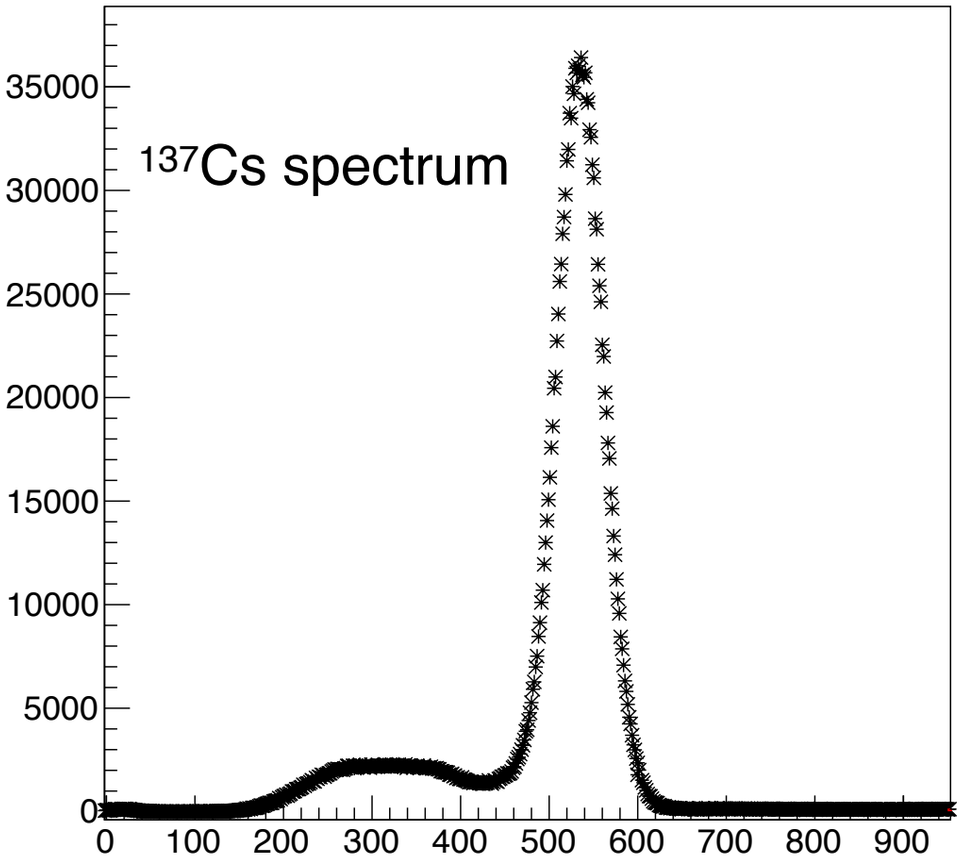
- Measure the scattered electron's position: 2 interleaved planes of 20 scintillators (40 for larger angles) (fibres of 1x1x20 mm^3) 0.35 mrad precision on the scattering angle

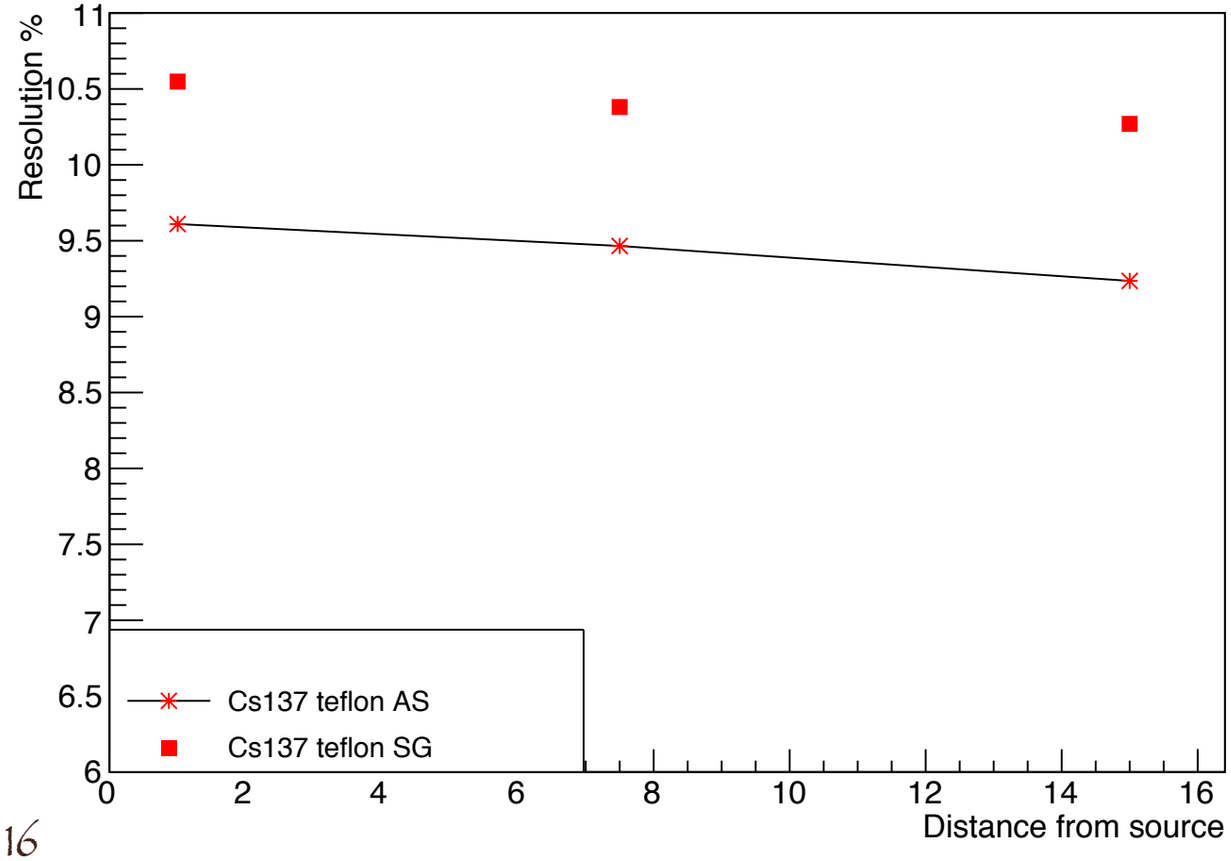
The BGO crystal

- Main constraint on the crystal is the energy resolution: separate the Moeller and the Elastic contributions in the energy spectrum

- Using cesium source: Resolution measured to be < 11% with teflon wrapping.

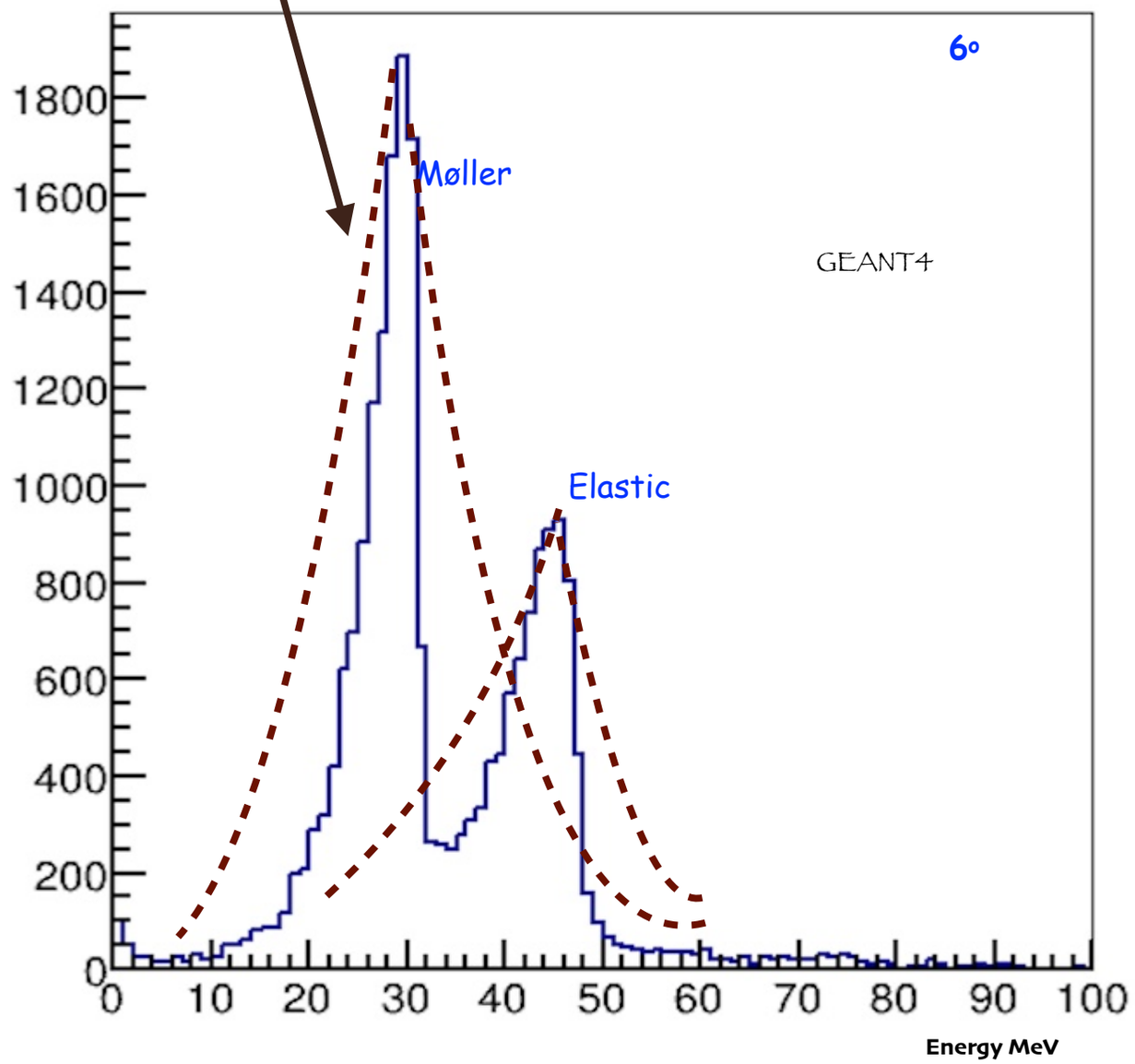
With PMT Hamamatsu R1306





The BGO crystal

Avoid bad resolution



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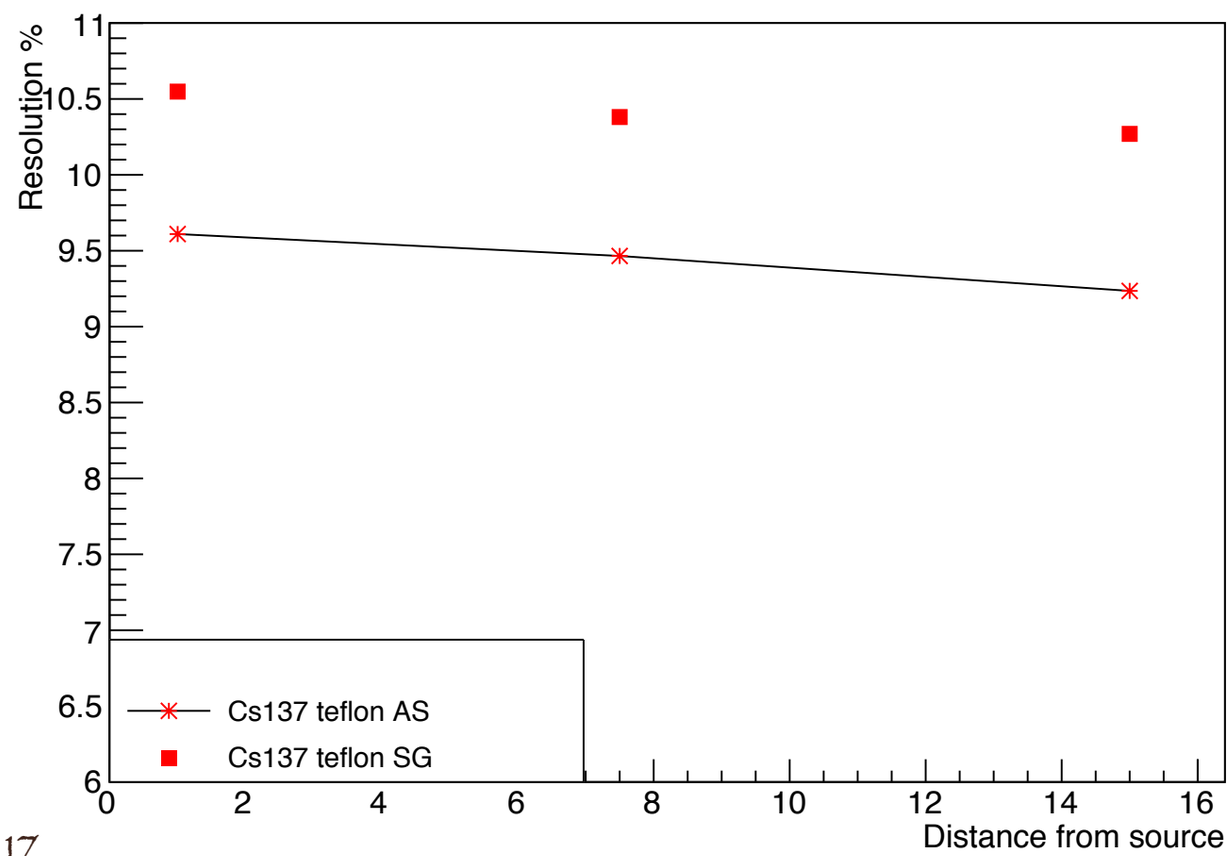
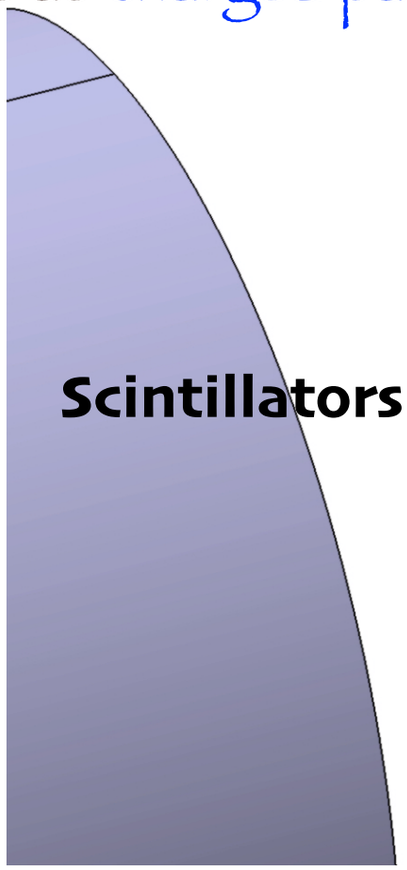
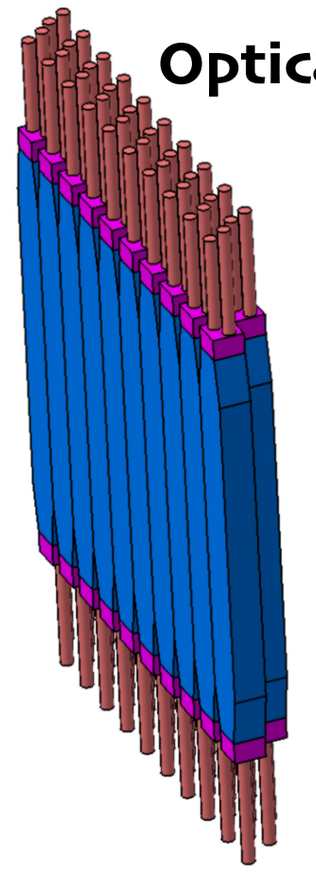


The position detector

- Scintillators read by SiPMs
- Huge effort in building the position detector: coupling the scintillators!
- Mechanical positioning of the detector in front of the crystal
- The position detector also serves as charged particles tagger

Prototype (dimensions modified)





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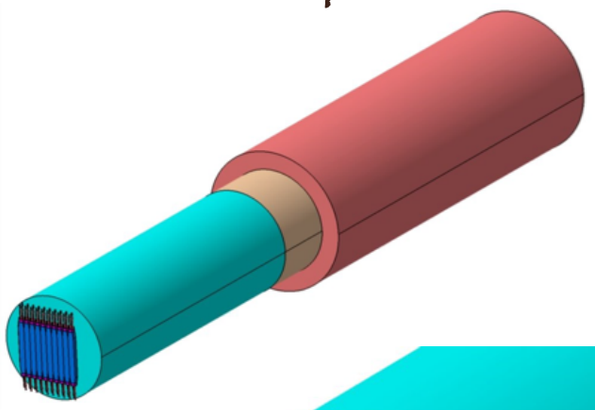
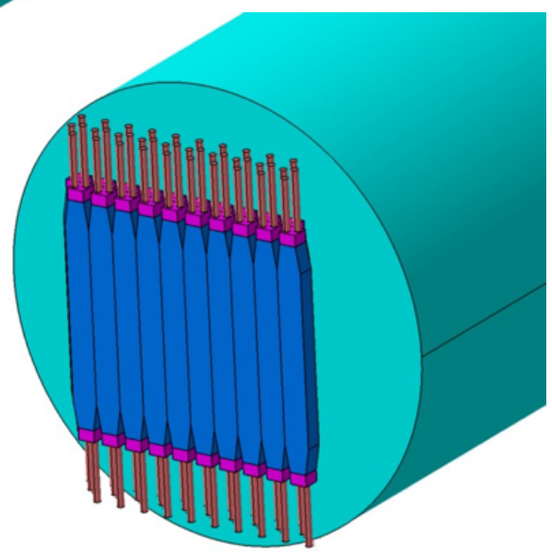
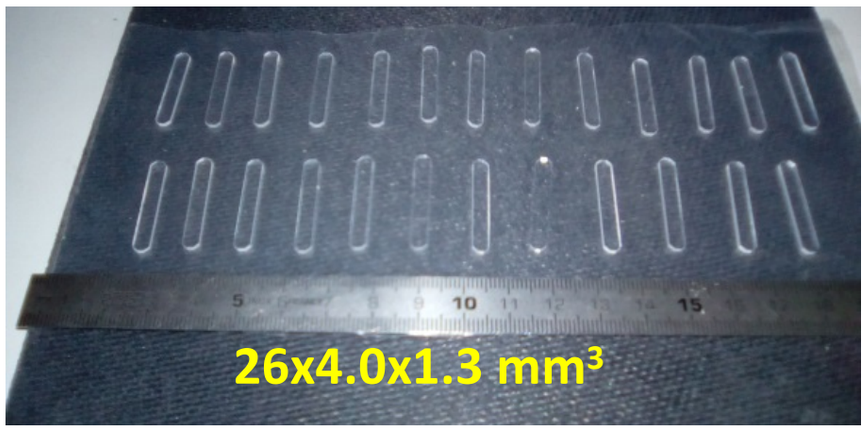






GEANT simulation

Tracking of events: (Θ, model, beam, setup)

↓

Events to bursts: (Poisson distribution)

↓

Combine channels

↓

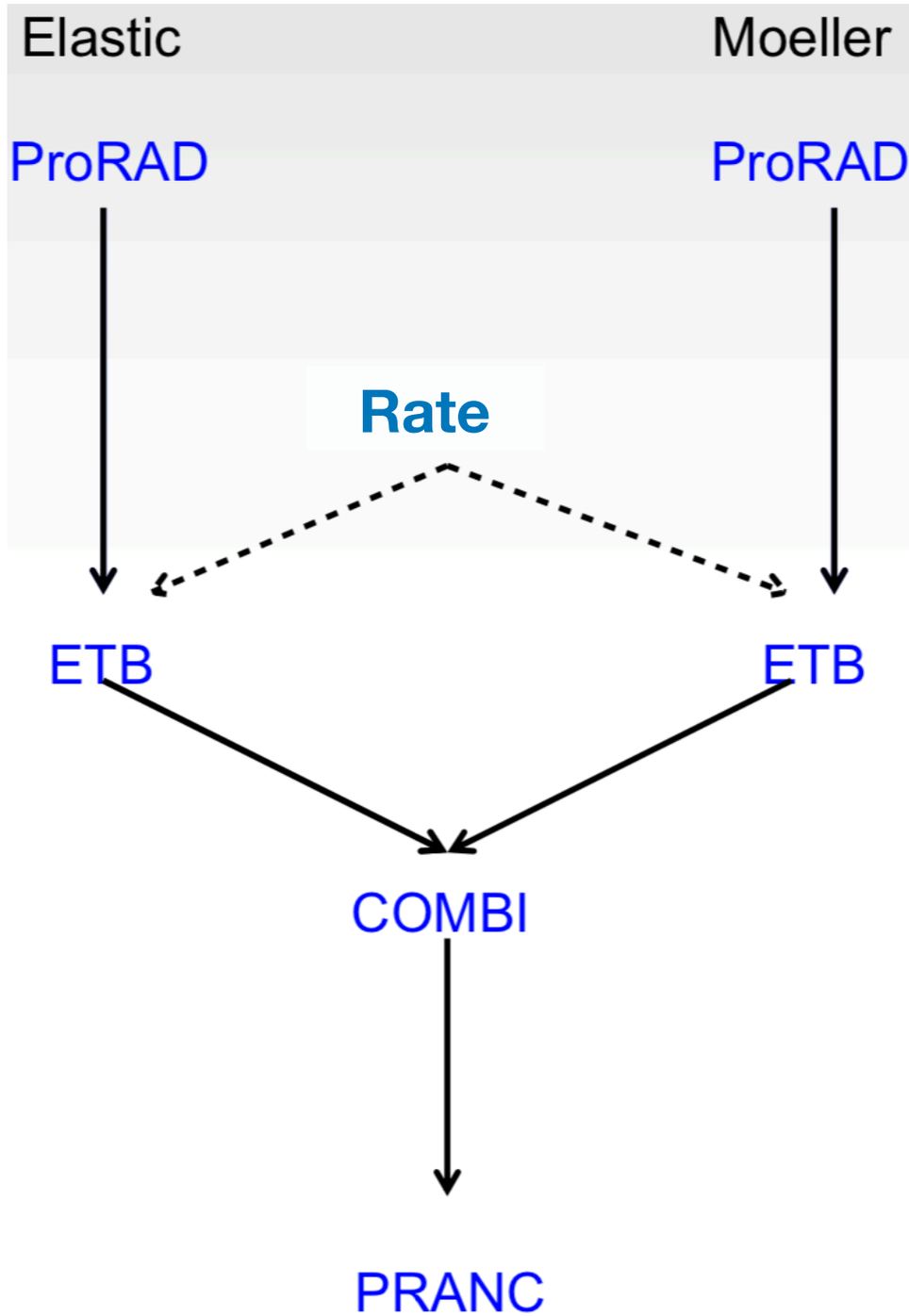
ProRad Analysis Code

Manage: gestion of data flows
decoding of the burst data
filling of the data container

Geom: contains detector geometry data

Container: contains data from one burst
- underlaying events
- crystal & fiber info

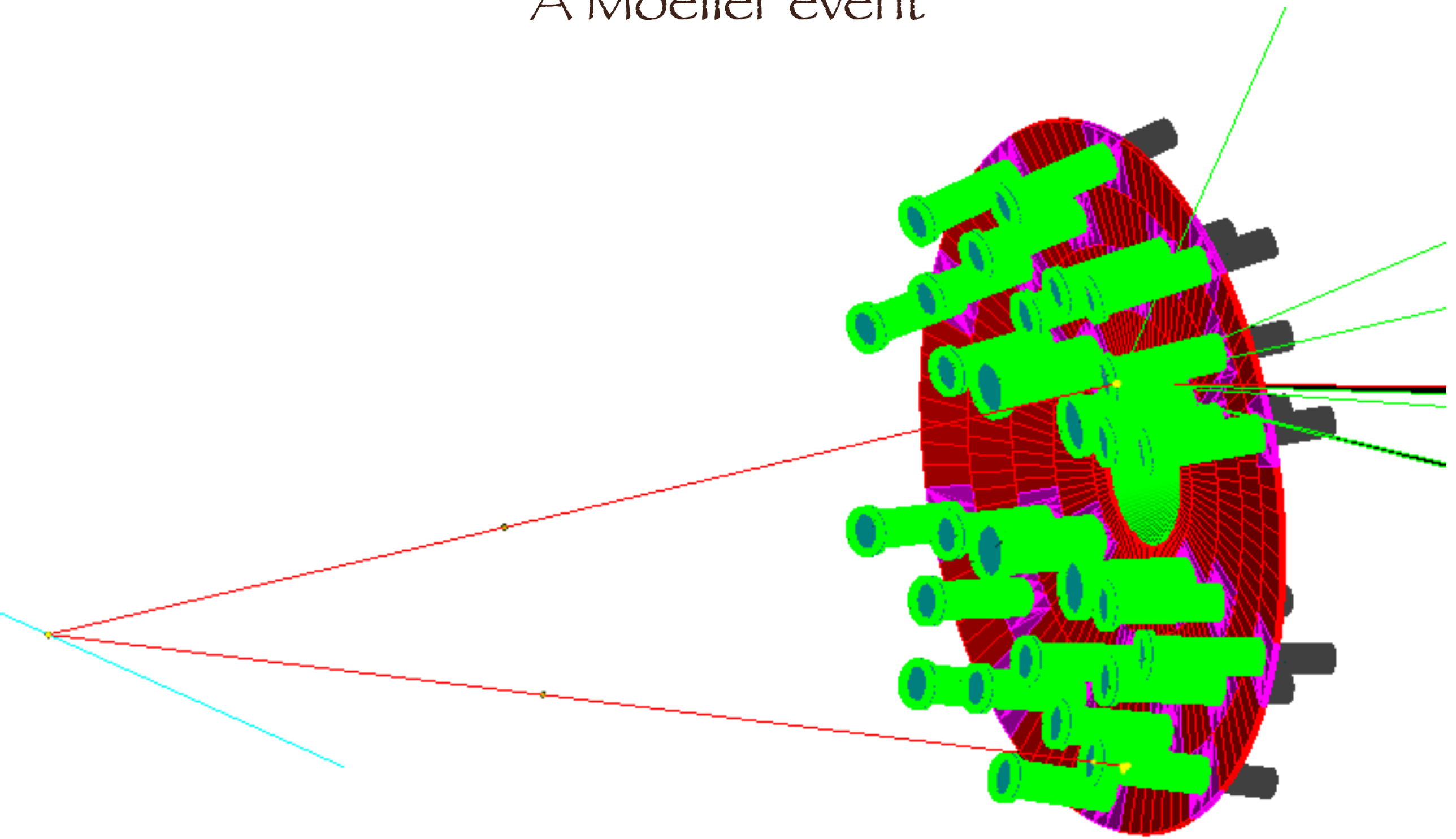
MC chain of programs



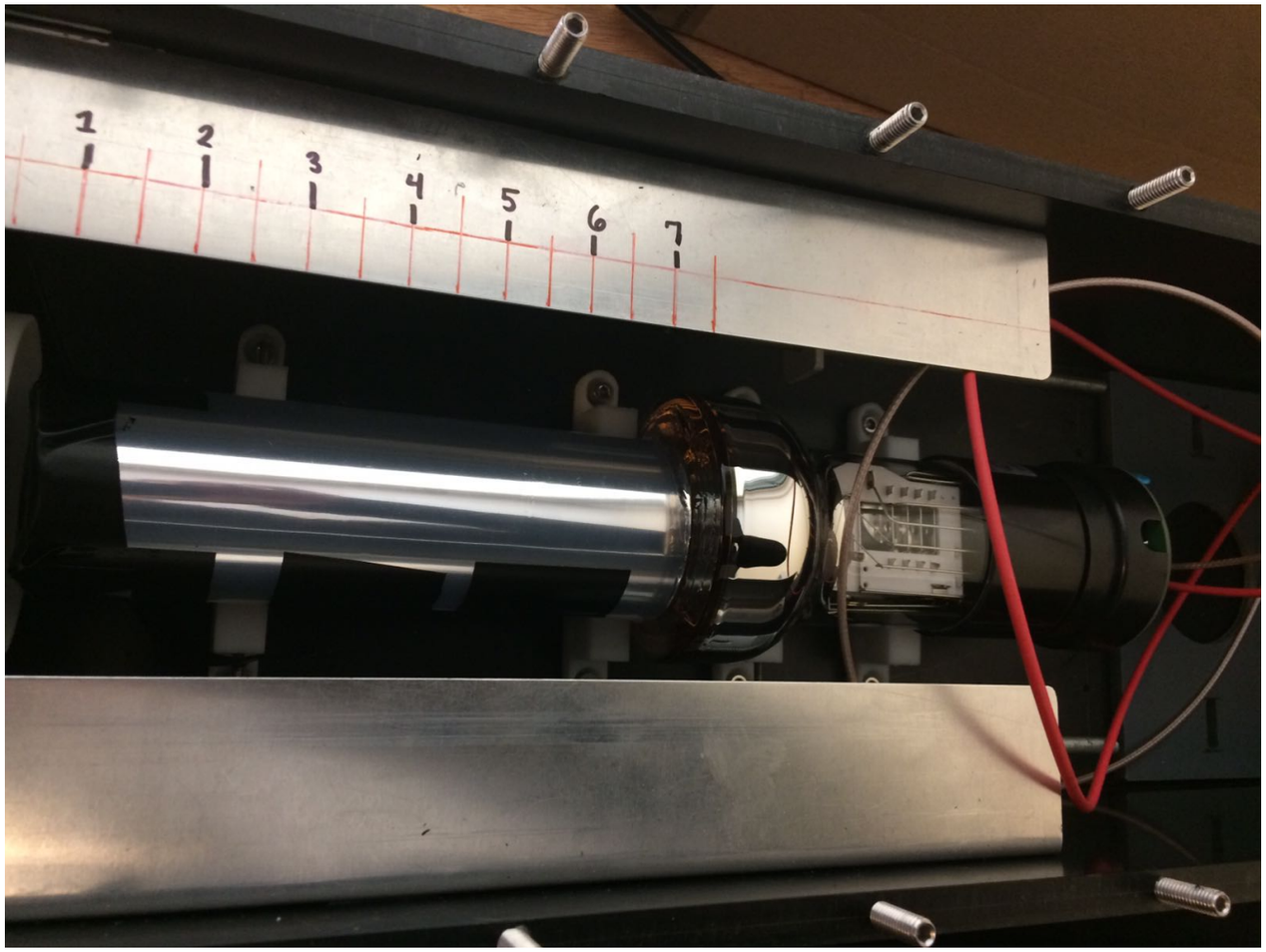
Summary

- ProRad will contribute significantly to the investigation of the proton radius puzzle
- Precision on all aspects is a key point for ProRad to reach its goals
- Detector conception is in a very elaborated phase
- Started building the DAQ system
- Data taking is foreseen in second half 2021

A Moeller event




8-CHANNEL WAVECATCHER
CAC
ORSAY
Irfu
CH0
CH1
CH2
CH3
CH4
CH5
CH6
CH7
EXT
ETHERNET
USB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