Proton Radius Puzzle 2018

The ProRad experiment

Dominique Marchand

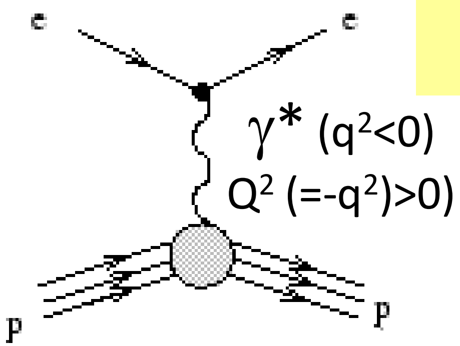
on behalf of the collaboration

Funding agencies:

Mainz, July 23rd - 27th

The ProRad experiment

Electron proton elastic scattering experiment



$1\times10^{-5}(GeV/c^2)^2 \leq Q^2 \leq 3\times10^{-4}\ (GeV/c^2)^2$

$|K^2|[fm^{-2}] = 25{,}7 \times Q^2\ [(GeV/c^2)^2]$

$2.6\times10^{-4}\ fm^{-2} \leq |K^2| \leq 7.7\times10^{-3}\ fm^{-2}$

⇨ **Additional Low K^2** data

to past and forthcoming experimental data

under construction

Platform for Research and Applications with Electrons

- New compact pulsed electron LinAc
  E_{e-} = 30 MeV, 50 MeV, 70 MeV
- Orsay Paris-Saclay (Sud) University Campus
  (25 km south from Paris)

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Outline

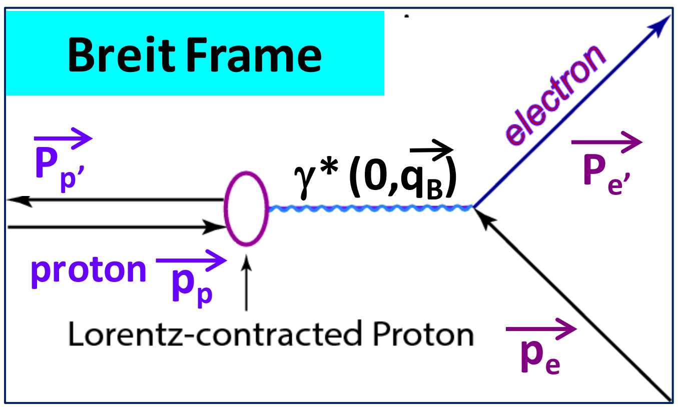
- General Formalism
- Rp extraction: considerations about the method/constraints
- Impact and required precision of/on low K^2 data
- The Platform for Research and Applications with Electrons
- The ProRad experimental strategy and set-up
- Summary / perspectives

Framework of lepton proton scattering experiments

$$G(k) = \int_0^\infty d^3 r\, \rho(r)\, \exp(-i\, k \cdot r) \qquad (1)$$

Electric Form Factor
Measured

Fourier Transform
of the charge probability density



Breit Frame

$\vec{P}_{p'} = -\vec{P}_p$

$\gamma^*(0, \vec{q}_B);\ q_B^2$

$J^0 \propto G_E$

$J^{1,2,3} \propto G_M$

Laboratory

$\vec{P}_p = \vec{0}$

$\gamma^*(q^0, \vec{q}_L);\ q_L^2$

$J^0 = f(G_E, G_M)$

Invariant $q_L^2 = q_B^2 = -\vec{q}_B^{\,2} = -\vec{k}^2 = K^2 \quad (K^2 < 0)$

No global Lorentz Transform (LT) to the lab frame: 1 LT per $|K^2|$ point

Spectroscopy measurement framework ?

Rp interpretation compatibility ?

Formalism

Pro Rad

PRAE

$\Rightarrow$ **Multipole expansion of the exponent**
+ series representation of the 0th order Bessel function

(1) $\rightarrow G(k\ ) = 1 + \sum_{n=1}^{\infty} C_n k^{2n} \equiv G(k^2)$ with $\begin{cases} C_n = \dfrac{(-1)^n}{(2n+1)!} \langle r^{2n} \rangle \\ \langle r^{2n} \rangle = 4\pi \displaystyle\int_0^{\infty} dr\, \rho(r)\, r^{2n+2} \end{cases}$

$G(k^2)$: function of even moments of the probability density

$G(k) \equiv G(k^2)$ **thanks to k^2 dependence in the series**

Mandatory to satisfy the convergence criterion associated to this series representation

$$\boxed{\lim_{n\to\infty} k^2 \left| \frac{C_{n+1}}{C_n} \right| < 1}$$

$$\frac{dG(k^2)}{dk^2} = \sum_{n=1}^{\infty} n C_n k^{2(n-1)} \Rightarrow \boxed{R = \sqrt{\langle r^2 \rangle} = \sqrt{-6 \left. \frac{dG(k^2)}{dk^2} \right|_{k^2=0}}}$$

Breit Frame

Lepton proton elastic scattering exp. $\rightarrow$ **indirect measurement of Rp**

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Formalism (2)

$$R = \sqrt{\langle r^2 \rangle} = \sqrt{-6 \left. \frac{dG(k^2)}{dk^2} \right|_{k^2=0}}$$

Experimentally $k^2 = 0$ inaccessible : data only at $k^2 \neq 0$

$\Rightarrow$ R determination relies on an extrapolation of experimental data measured in a finite k^2 interval determined from density related considerations and based on parametrizations

Extracted R value should be independent from:
the considered k^2 interval satisfying the validity domain

R sensitivity of the data fitting procedure

$$G(k^2) = 1 + C_1 k^2 \left(1 + \sum_{n>1}^{\infty} \frac{C_n}{C_1} k^{2(n-1)}\right)$$

$$\left[C_n = \frac{(-1)^n}{(2n+1)!} \langle r^{2n} \rangle \right]$$

Relative correction to C_1

from **higher order terms** in the expansion

Extracting R from large k^2 data **amplifies the sensitivity of the procedure** to the **$G(k^2)$ functional form** through the k^2 dependence

Convergence of $G(k^2)$ expansion $\boxed{\lim_{n\to\infty} k^2 \left| \frac{C_{n+1}}{C_n} \right| < 1}$ has to be verified

The magnitude of the correction involving ratio of moments ($< r^{2n} >$) of the probability density, so as the convergence criterion, is **model dependent**;

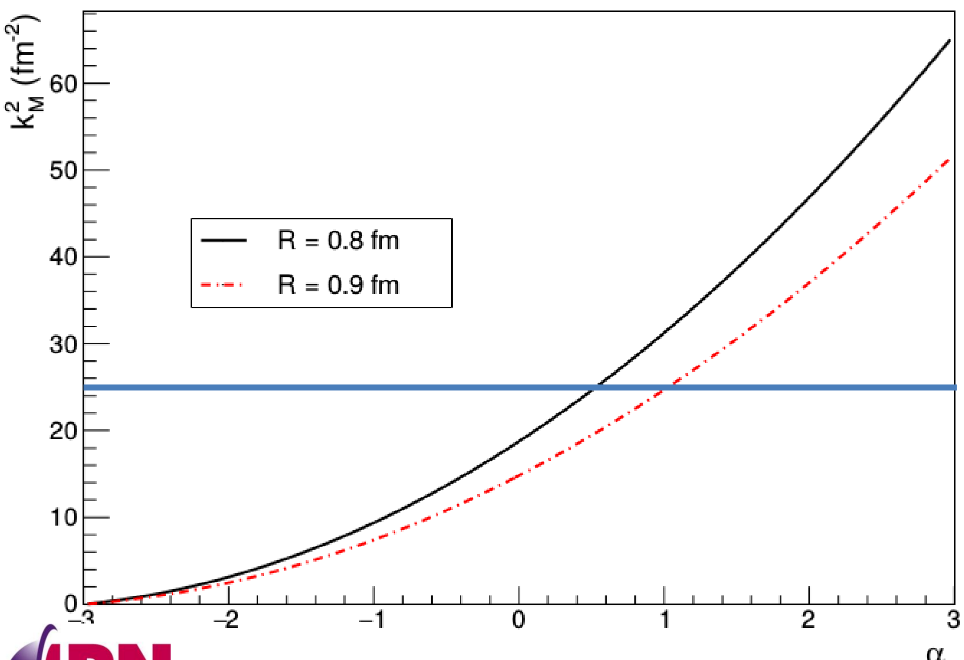
Given a **density model** C_n coefficients can be evaluated to <u>any order</u> in the expansion.

R sensitivity to k^2 upper limit (k^2_M)

Considering $\rho(r) = \rho_0\, r^{\alpha} \exp(-\lambda r)$ **with** $\rho_0 = \dfrac{1}{4\pi}\dfrac{\lambda^{3+\alpha}}{\Gamma(3+\alpha)}$

$$\langle r^{2n} \rangle = \frac{1}{\lambda^{2n}} \frac{\Gamma(2n+\alpha+3)}{\Gamma(\alpha+3)}$$ **and** $$\boxed{R = \sqrt{\frac{(3+\alpha)(4+\alpha)}{\lambda^2}}}$$

Associated **convergence criterion ($k^2 < \lambda^2$)**: $$\boxed{k^2 < k^2_M = \frac{(3+\alpha)(4+\alpha)}{R^2}}$$



k^2_M : upper limit of k^2 range for which series representation of FT is valid

Only at very low k^2 sensitiviy to the largest number of possible values for α. (For example, for k^2_M= 25 fm^{-2}, only a density model with α>0 can be considered)

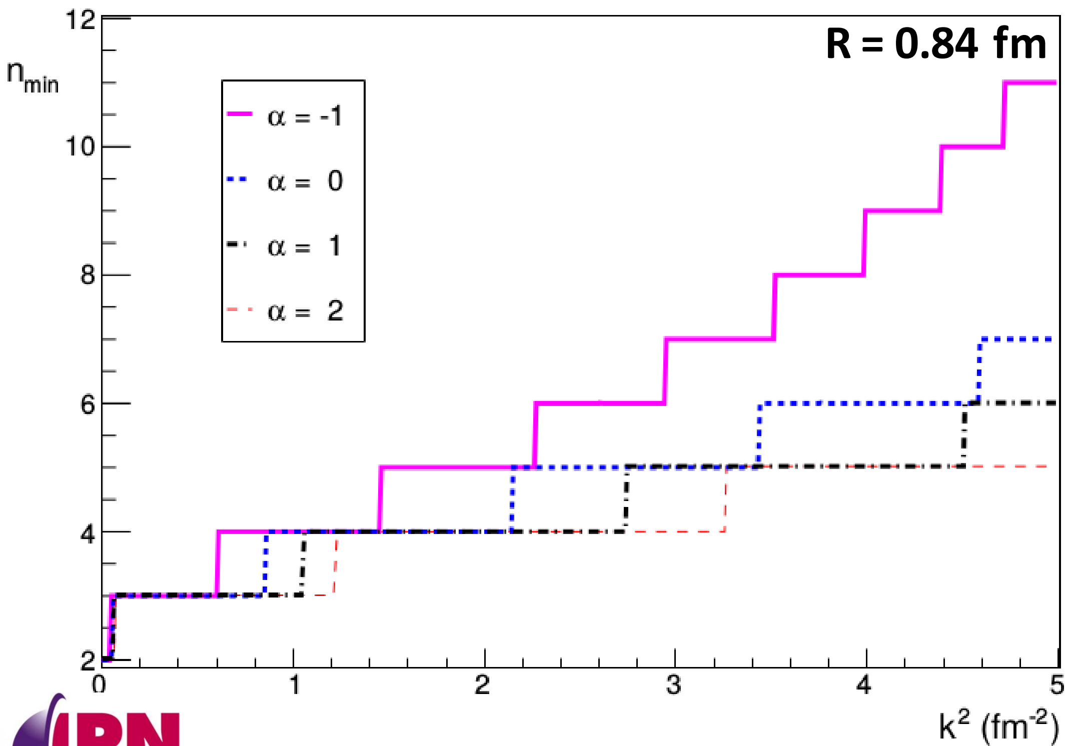
Relation betweeen minimal expansion order (n_{min}) and (k^2)

$$G(k^2) = 1 + C_1 k^2 \left(1 + \sum_{n>1}^{\infty} \frac{C_n}{C_1} k^{2(n-1)}\right)$$

Requiring $G(k^2)$ to be precise to some accuracy corresponds to limiting higher order terms

$$\frac{C_n}{C_1} k^{2(n-1)} \leq 5 \times 10^{-4}$$

Consider $\rho(r) = \rho_0\, r^{\alpha} \exp(-\lambda r)$ **with** $\rho_0 = \frac{1}{4\pi} \frac{\lambda^{3+\alpha}}{\Gamma(3+\alpha)}$



$\mathbf{n_{min}}$ increases with k^2

Only at low k^2 $\mathbf{n_{min}}$ remains almost **independent** from the **α value** of the density model.

For k^2 = 2 fm^{-2}, $\mathbf{n_{min}}$ = **4 or 5**

k^2 upper limit (k^2_M)

$0 < |K^2_M| \leq 2\ \text{fm}^{-2}$ [$0 < Q^2_M \leq 0.08\ (\text{GeV}/c^2)^2$]

- Statisfy the convergence criterion
- Preserve the analyticity properties of G_E ($Q^2 < 4\ m^2_\pi$)

R Sensitivity to fitting procedure: polynomial order

Considering $\rho(r) = \rho_0 \exp(-\lambda r)$ *and* $R_i=0.87$

Dipolar shape $G_E(|K^2|)=\left(1+\frac{|K^2|}{\Lambda_i}\right)^{-2}$ consistent with a proton charge radius R_i such as $\Lambda_i=\frac{12}{R_i}$

n = 4 ➡ $C_n^R = \frac{(-1)^n}{(2n+1)!}\langle r^{2n}\rangle$ $(n \in [1,4])$

Generation of 1000 pseudo-data sets:

[Up to $|K_M^2|$= 2 fm^{-2} = 0.08 (GeV/c^2)^2]

- ★ **Based on Mainz 2010 data**
  - ➢ **position in |K^2|**
  - ➢ **measurement errors**

J.C. Bernauer, Ph.D. Dissertation, Johannes Gutenberg Universität, Mainz (Germany), 2010.

★ **At |K^2|, G$_E$ value gaussianely distributed around the dipolar expectation with a gaussian width corresponding to the Mainz experimental error at that |K^2|**

➡ Fit each pseudo-data set with polynomials $P_m(k^2) = \sum_{i=0}^{m} a_i\,(k^2)^i$
of different order $\mathbf{m \in [2,6]}$ ⇨ a_i (i ∈ [1,4])
to be identified as $C_n^{\boldsymbol{m}}$ (m∈ [2,6]). to reference $C_n^{\boldsymbol{R}}$ (order 4)

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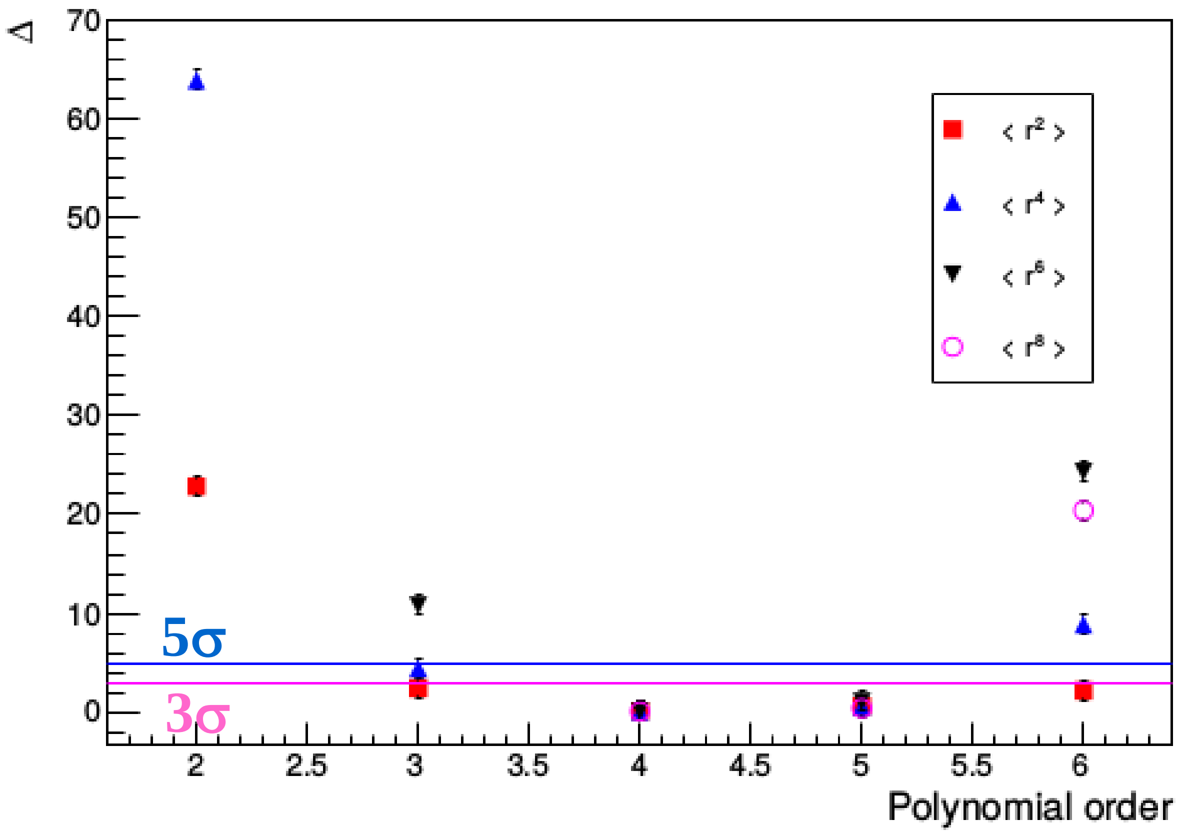
$G(|K^2|)$ parametrization: polynomial order compatibility

Evaluator: $\Delta = \frac{|C_n^m - C_n^R|}{\sqrt{(\delta C_n^m)^2 + (\delta C_n^R)^2}} = \frac{|C_n^m - C_n^R|}{\sigma}$ $[\ \delta C_n^i\ (\mathbf{i} \in [\boldsymbol{m},\boldsymbol{R}])\ ]$

Higher order density moments are physical parameters : have to be recovered



- **$m < (m_{ref} = 4)$**

  Systematics deviations from reference values

- **$m > (m_{ref} = 4)$**

  C_1 recovery

  Failure for higher orders (data overfitting ≡ fitting unphysical fluctuations from point-to-point)

→ **m_{Max}**

World existing data parametrization (1)

Data Set	Ref.	Data Number $< 1\ \mathrm{fm}^{-2}$	Data Number $< 2\ \mathrm{fm}^{-2}$
①	$\boxed{29}$ + $\boxed{28}$	405	688
②	① + $\boxed{27}$	410	693
③	② + $\boxed{26}$	413	700
④	③ + $\boxed{25}$	444	745
⑤	④ + $\boxed{24}$	455	756
⑥	⑤ + $\boxed{23}$	Work still on progress	
⑦	⑥ + $\boxed{22}$	456	760
⑧	⑦ + $\boxed{21}$	466	775
⑨	⑧ + $\boxed{20}$	468	778

20. B. Dudelzak, G. Sauvage, P. Lehmann, Il Nuovo Cim. **28** (1963) 18.
21. L.N. Hand, D.G. Miller, R. Wilson, Rev. Mod. Phys. **35** (1963) 335.
22. D. Frèrejacque, D. Benaksas, D. Drickey, Phys. Rev. **141** (1966) 1308.
23. Yu.K. Akimov *et al.* Sov. Phys. JEPT **35** (1972) 651.
24. J.J. Murphy, II, Y.M. Shin, D.M. Skopik, Phys. Rev. C **9** (1974) 2125.
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26. F. Borkowski, G.G. Simon, V.H. Walther, R.D. Wendling, Nucl. Phys. B **93** (1975) 461.
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28. (A1 Collaboration) J.C. Bernauer *et al.* Phys. Rev. C **90** (2014) 015206.
29. (A1 Collaboration) M. Mihovilovič *et al.* Phys. Lett. B **771** (2017) 194.

World existing data parametrization (2)

$$P_m(k^2) = \sum_{i=0}^{m} a_i \, (k^2)^i$$

k^2 = 1 fm^{-2} ; m = 3
k^2 = 2 fm^{-2} ; m = 4

K^2_{max} (fm^{-2})	Pol. Ord.	a_0	R_p (fm)	χ^2_r	Data Set
1.0	3	0.99926(65)	0.839(16)	1.186	①
		0.99926(65)	0.839(16)	1.172	②
		0.99926(65)	0.839(16)	1.167	③
		0.99920(65)	0.837(16)	1.218	④
		0.99913(65)	0.835(16)	1.226	⑤
		Work still on progress			⑥
		0.99913(65)	0.835(16)	1.226	⑦
		0.99914(65)	0.835(16)	1.218	⑧
		0.99914(65)	0.835(16)	1.211	⑨
2.0	4	1.00052(51)	0.875(10)	0.995	①
		1.00052(51)	0.875(10)	0.987	②
		1.00052(51)	0.875(10)	0.999	③
		1.00058(50)	0.876(10)	1.090	④
		1.00054(50)	0.875(10)	1.098	⑤
		Work still on progress			⑥
		1.00054(50)	0.874(10)	1.095	⑦
		1.00051(50)	0.874(10)	1.111	⑧
		1.00052(50)	0.874(10)	1.106	⑨

a_0 retrieved from the fit

Rp extracted value **in agreement** with 0.84 fm and 0.87fm within the error bars

Extracted Rp value should be independent from the considered $|K^2|$ interval ($|K^2|$ up to 1 and 2 fm^{-2} should lead to the same central value with error bars sufficiently small to discriminate between current μH spectroscopy and lepton scattering results.

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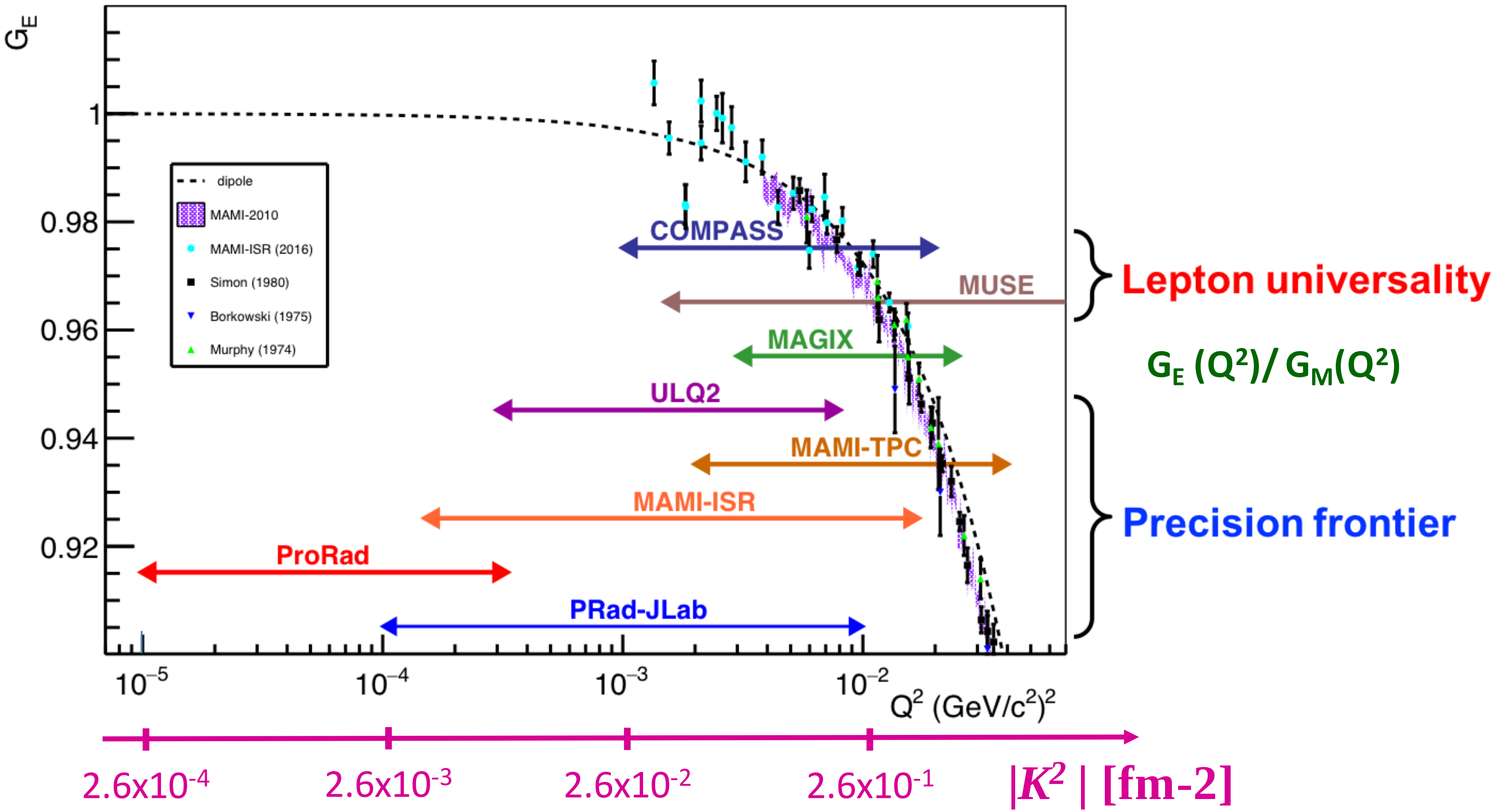
Upcoming low |K²| experiments



Impact of upcoming low $|K^2|$ data (1)

Combining with existing data, how much accurate should be **low $|K^2|$ data** to find **R=0.84 fm** (within **3σ**) and reject **R=0.87** (**>5σ**)

OR

Combining with existing data, how much accurate should be **low $|K^2|$ data** to find **R=0.87 fm** (**within 3σ**) and reject **R=0.84** (**>5σ**)

Impact of upcoming low $|K^2|$ data (1)

Up to $|K^2| = 2\ \mathrm{fm}^{-2} = 0.08\ (\mathrm{GeV}/c^2)^2$

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+ Generation of ProRadpseudo-data: $G_E(|K^2|)$

- dipolar shape $G_E(|K^2|) = \left(1 + \frac{|K^2|}{\Lambda_i}\right)^{-2}$ consistent with a proton charge radius R_i

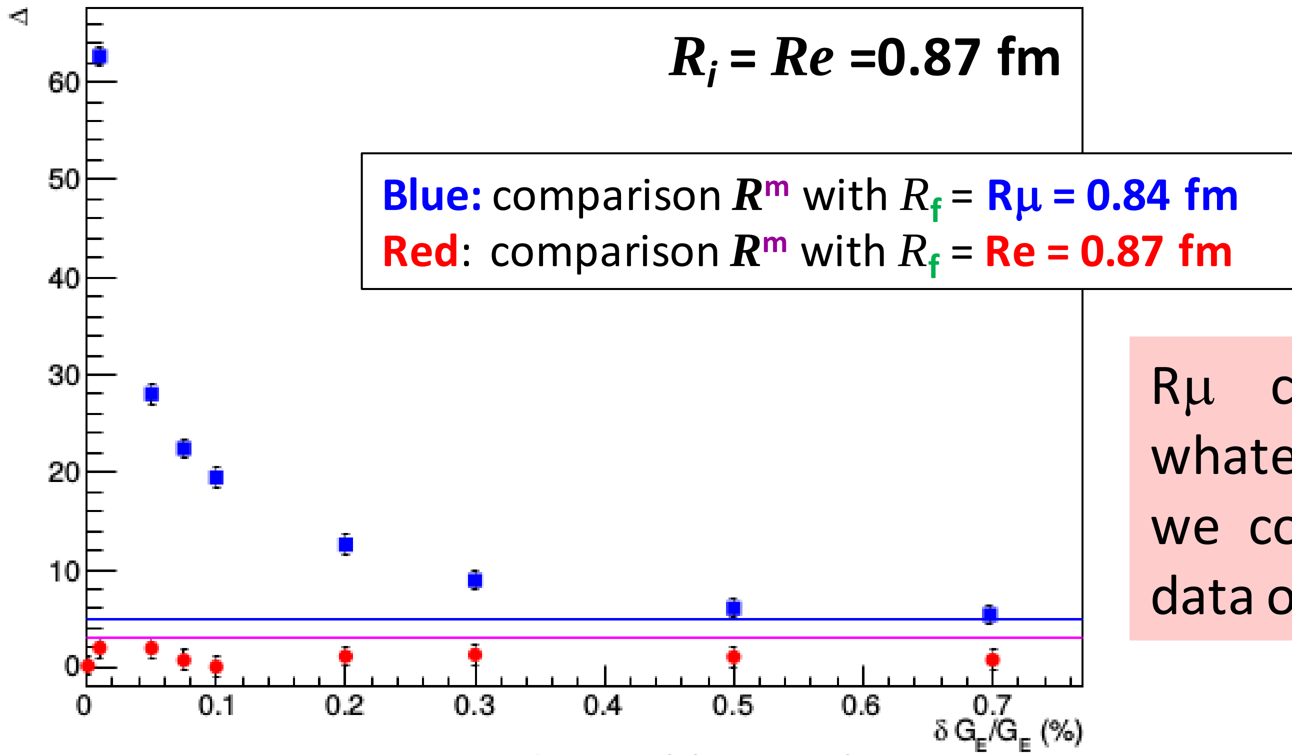
  such as $\Lambda_i = \frac{12}{R_i}$

- at each $|K^2|$, data are redistributed according to a gaussian which *Mean* is the dipolar expectation and the width is absolute δG_E **(the variable)**

Impact of upcoming low $|K^2|$ data (1)

All existing data considered + ProRad pseudo-data (G_E dipolar)

$$\Delta = \frac{|R_p^m - R_f|}{\sqrt{(\delta R_p^m)^2 + (\delta R\ )^2}}$$



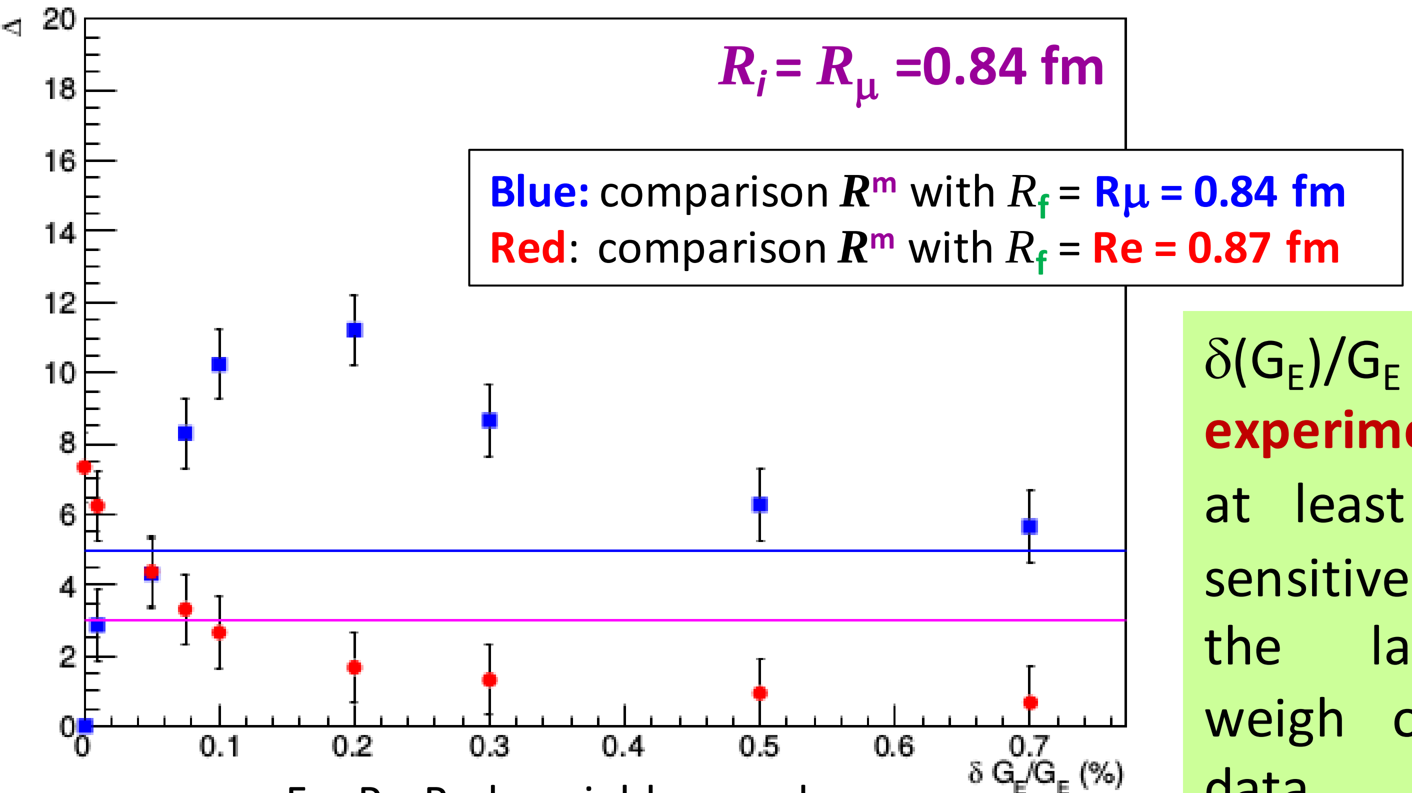
For ProRad, variable error bars

Rμ can't be reached whatever relative error we consider for ProRad data on G_E

Impact of upcoming low $|K^2|$ data (1)

All existing data considered + ProRad pseudo-data (G_E dipolar)

$$\Delta = \frac{|R_p^m - R_f|}{\sqrt{(\delta R_p^m)^2 + (\delta R\ )^2}}$$



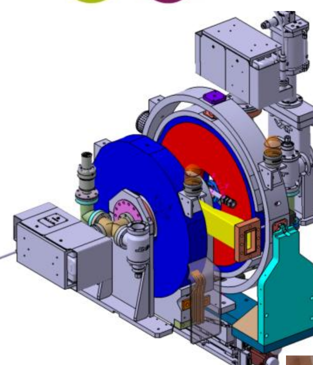
For ProRad, variable error bars

$\delta(G_E)/G_E$ for **low Q2 experiments** has to be at least **5×10^{-4}** to be sensitive to Rμ due to the large statistical weigh of Mainz 2010 data.

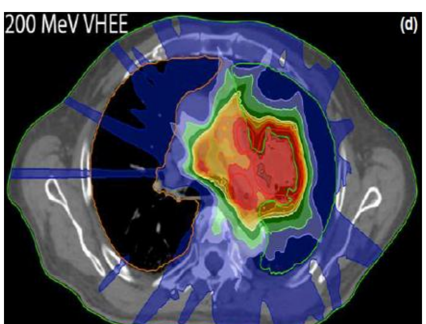
Platform for Research and Applications with Electrons

PRAE

- *The PRAE facility*



- *Radiobiology*



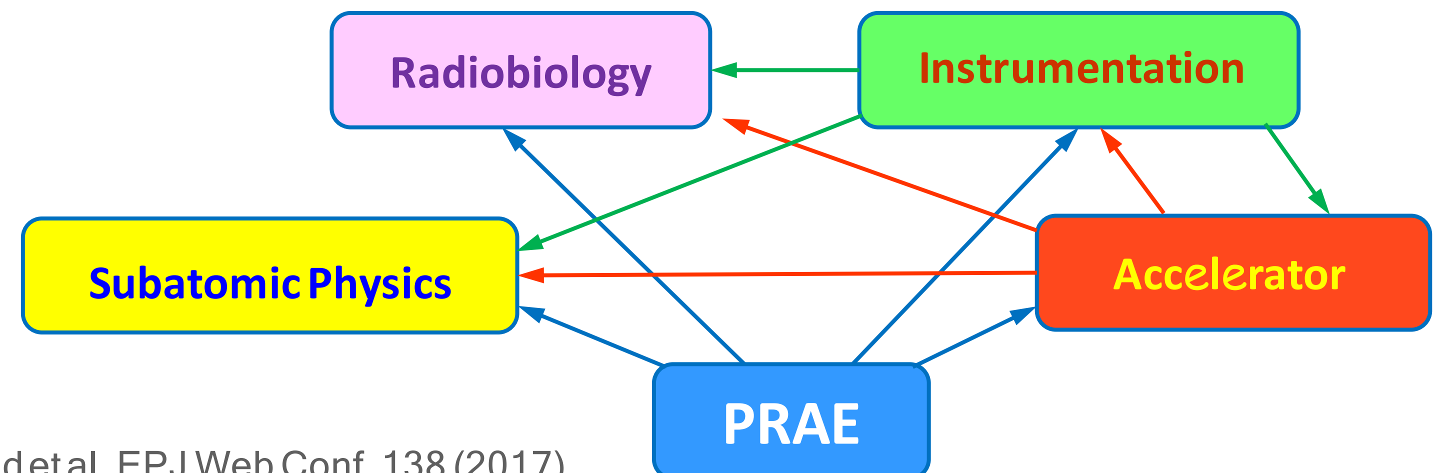
- *Instrumentation*

- *Subatomic physics*

The PRAE project

S. Barsuk, P. Duchesne et al.

PRAE aims at providing, on the Orsay campus, a **multidisciplinary facility** for innovative **R&D** in **radiobiology**, **instrumentation**, and **subatomic physics**… using a **high performance electron beam** in the **30-70** **(140 MeV)** energy range.



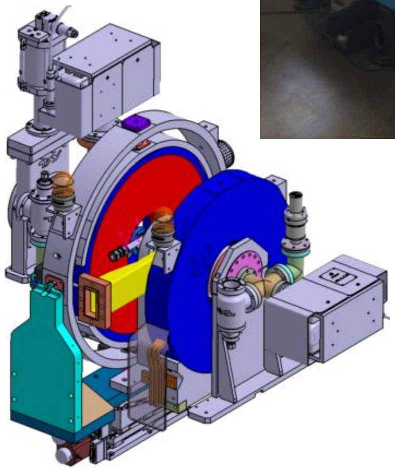
D. Marchand et al. EPJ Web Conf. 138 (2017)
S. Barsuk et al. JACoW (2017) THPVA079

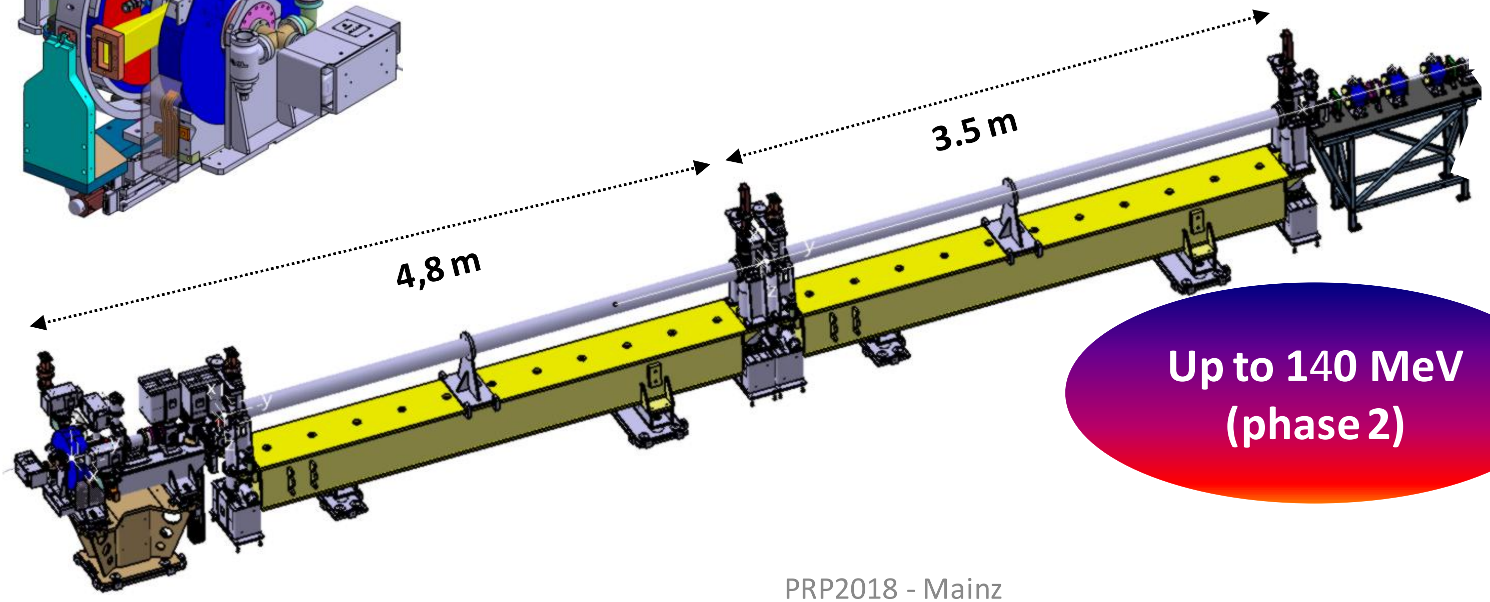
Linear electron accelerator

A. Faus-Golfe et al.

High gradient S-band cavities
25 MV/m

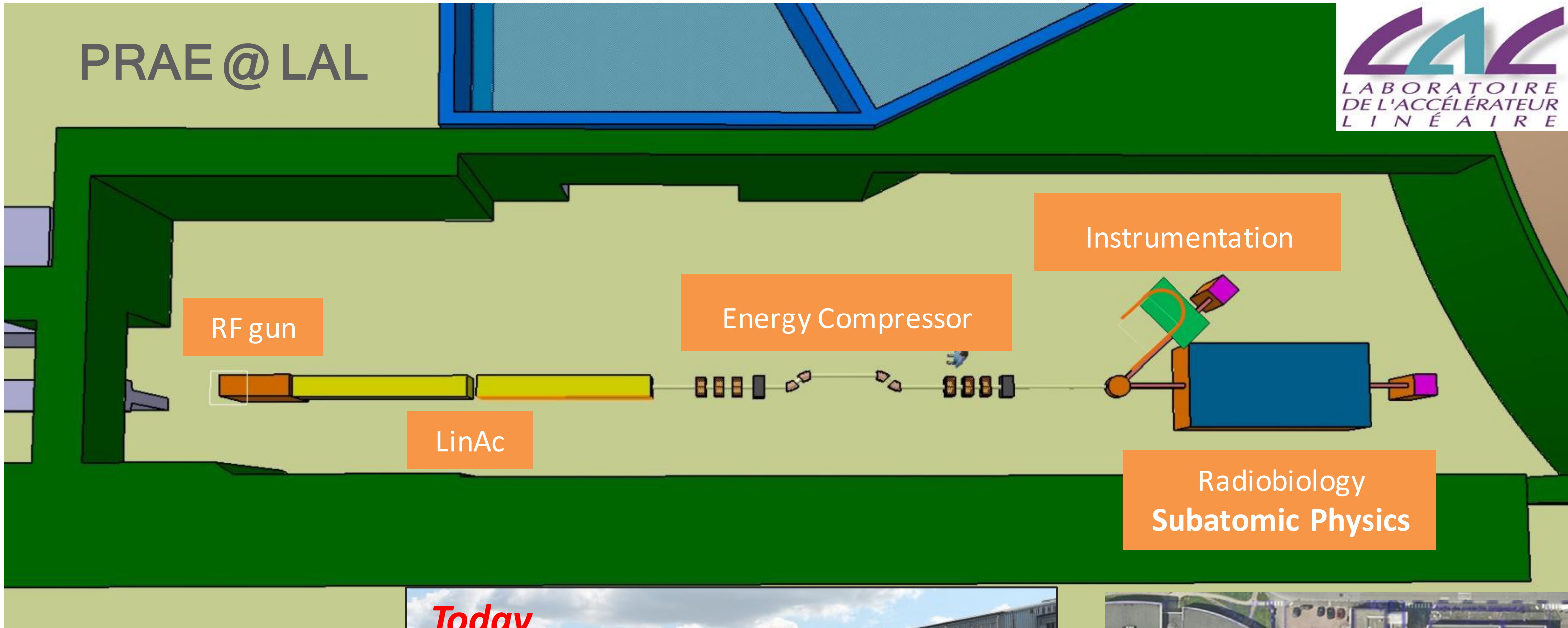
Beam parameters	Time phase 1 (2)
Energy, MeV	30-50-70 (100-140)
Charge (variable), nC/bunch	0.00005 – 2
Normalized emittance, mm.mrad	**3-10**
RF frequency, GHz	3.0
Repetition rate, Hz	**50**
Transverse size, mm	**0.5**
Bunch length, ps	**< 10**
Energy spread, %	**< 0.2**

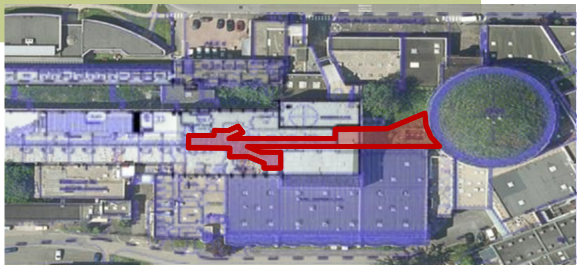




Up to 140 MeV (phase 2)

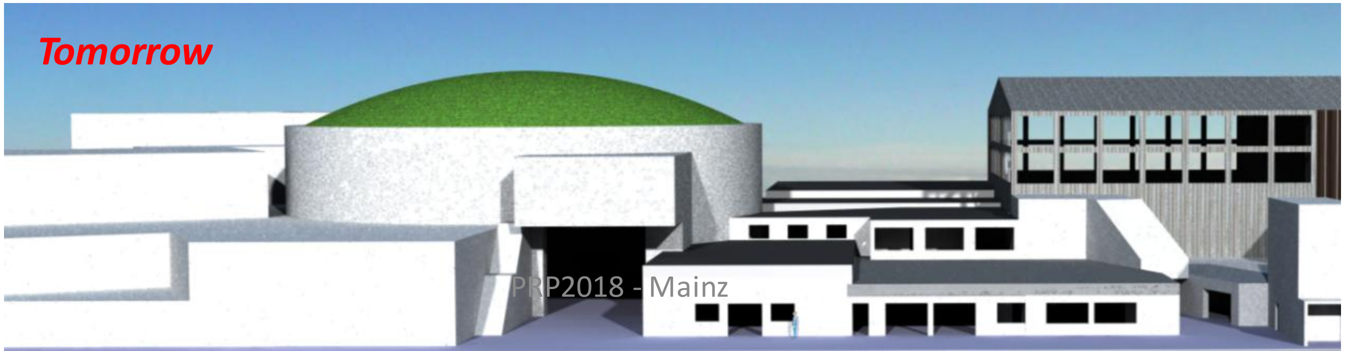
Infrastructure



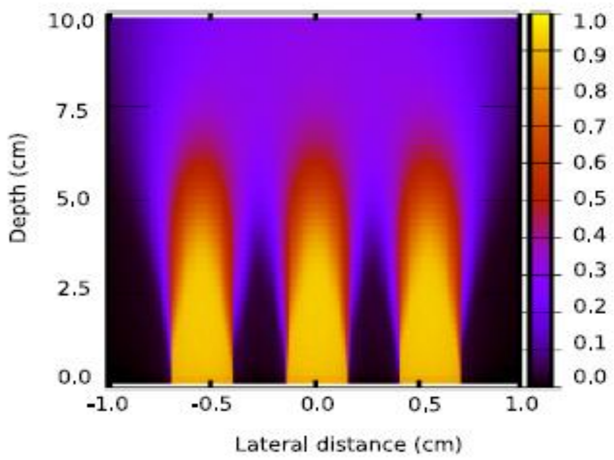


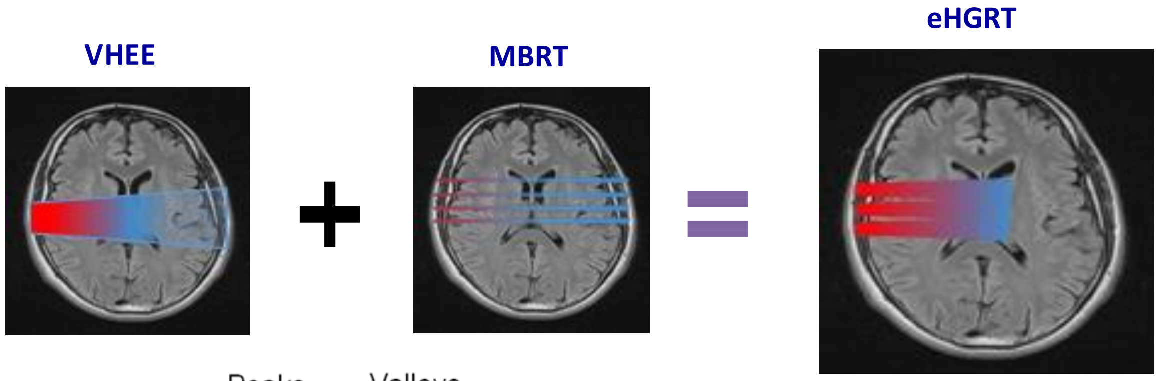
Top view

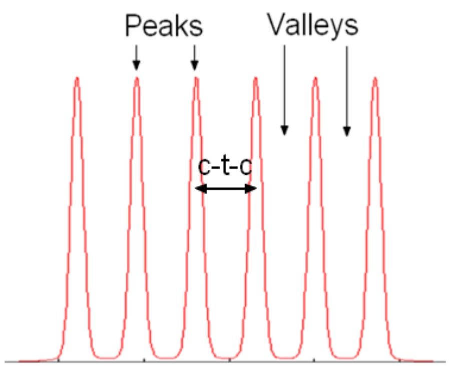
Former site of the Linear Accelerator



I. Martinez-Rovira, G. Fois, Y. Prezado Med. Phys. 42 (2015) 685







- Sub-millimeter beams enlarge because of **multiple scattering**.
- Healthy tissue benefit from the **spatial fractionating** of the dose while the latter is **quasi-homogeneously distributed** in the **tumor**.

PRAE will quantify the biologic potential of this technique.

Instrumentation platform: Detector R&D

B. Genolini, V. Puill et al.

Providing to users a **high-performance platform** to characterize the **time** and **charge response** of **detectors**.

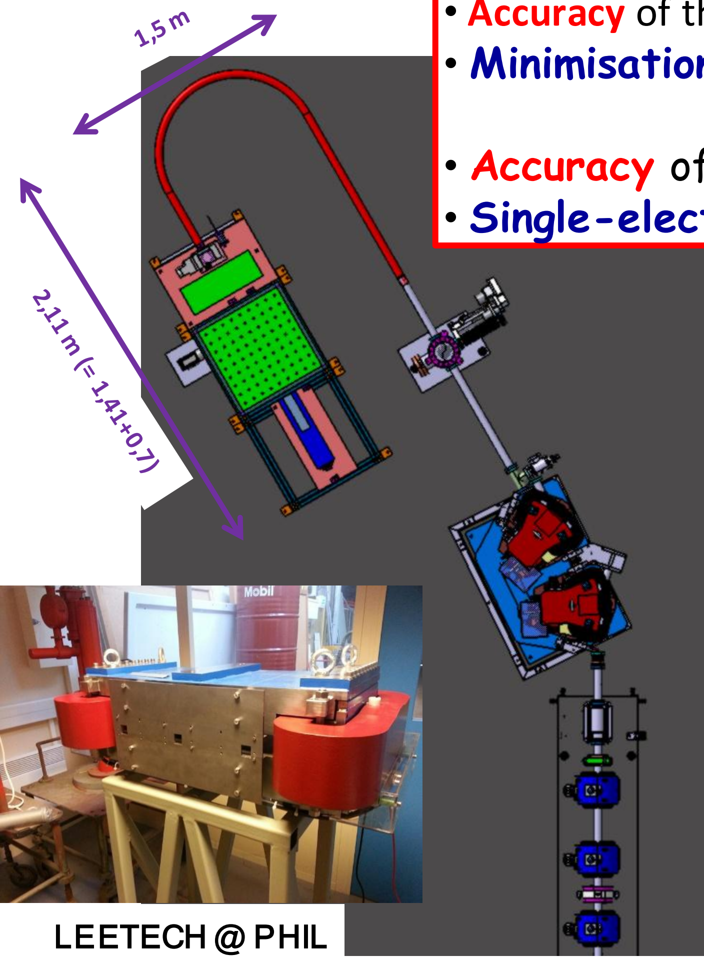
Beam Performances

- **Accuracy** of the reference time (<10 ps)
- **Accuracy** of the beam charge (<0.2%)
- **Minimisation** of dispersive effects

- **Accuracy** of the beam position and profile
- **Single-electron** beam capabilities

Detector to test :

- Maximum volume = **50 x 50 x 50 cm^3**
- Maximum weight = **20 kg**
- Maximum X / Y motion = **200 mm**



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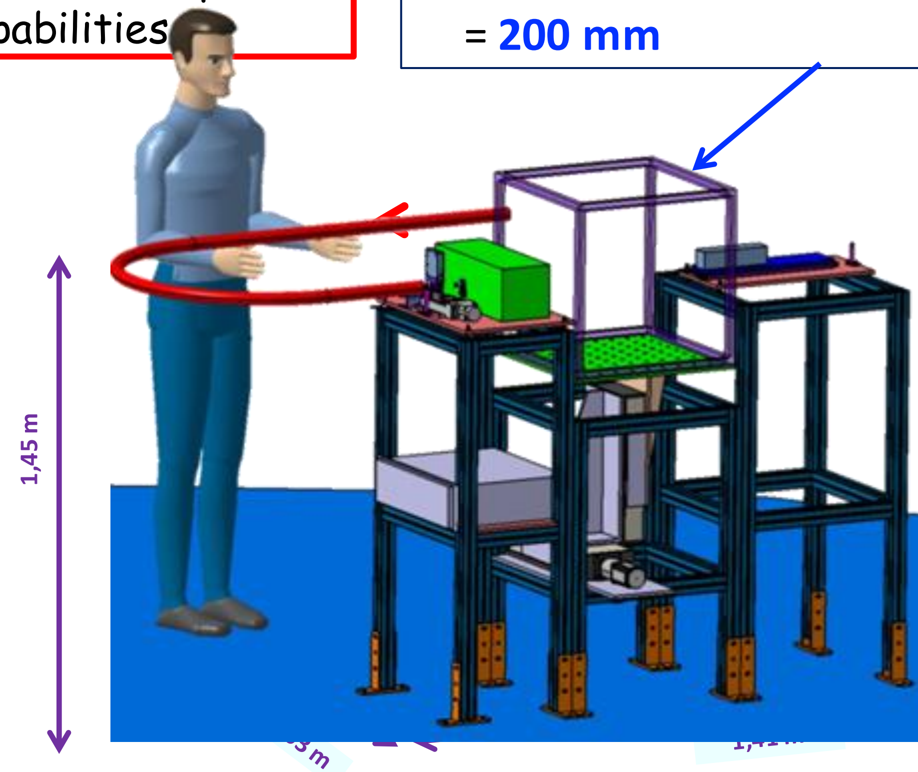


Subatomic physics: the ProRad experiment

The beam line for **Subatomic Physics**:

- designed to allow for **high-precision measurements**
- includes **advanced equipments** for beam **monitoring** and **control**

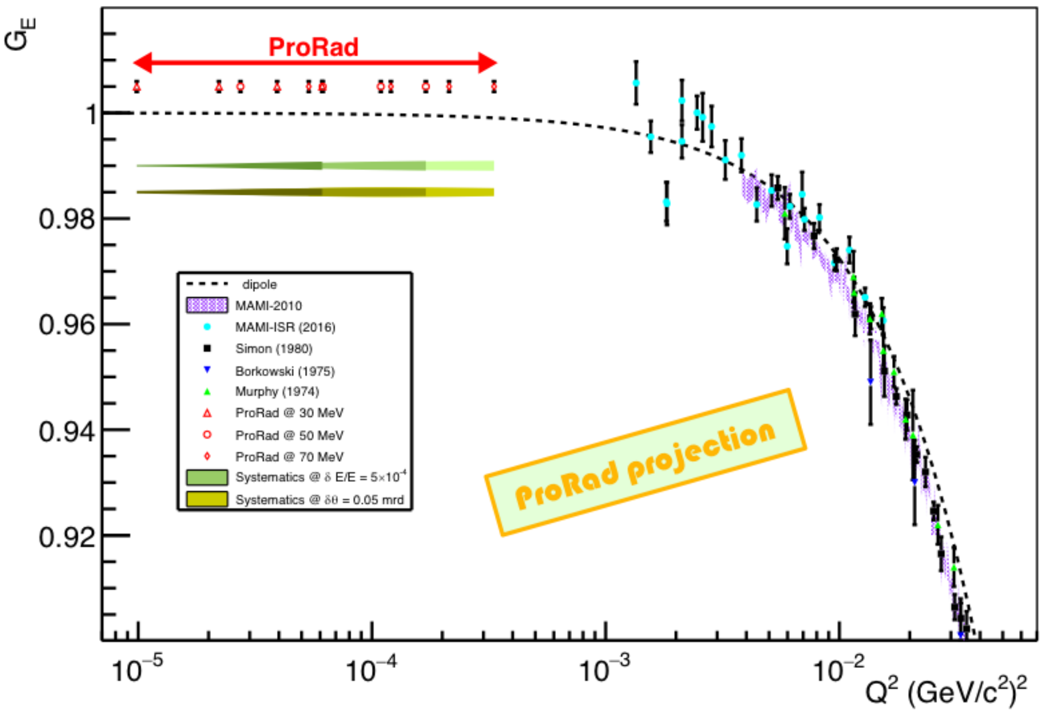
Beam Precision

- Reduced **momentum dispersion** (a few 10^{-4})
- Accurate **energy** measurement (a few 10^{-4})
- Accurate **charge** knowledge before and after the interaction region ($<10^{-3}$)

- Beam **position** feedback loop
- Beam **energy** feedback loop

The ProRad experiment: strategy and experimental set-up

ProRad will measure the proton **electric form factor** $G_E(Q^2)$ in the **unexplored domain** of **very low** energy **transfers** $\mathbf{10^{-5}}$**-**$\mathbf{3\times10^{-4}}$ $(GeV/c^2)^2$.



Expected results

- A better **experimental knowledge** of the Q^2-dependence of G_E.
- A **significant impact** on the **proton charge radius** determination, from the ProRad-data constraint on the **zero-momentum extrapolation** of G_E.

Within the ProRad range, any data different from 1 would be quite a surprise !!

Data taking planned for second half of 2021.

ProRad experiment: experimental principle

$$\rho_\sigma(Q^2) = \left[\frac{d^2\sigma_{ep}}{d\theta d\varphi} \Big/ \frac{d^2\sigma_{ee}}{d\theta d\varphi}\right]^{1/2} \rightarrow r_p = \sqrt{-6(\hbar c)^2 \frac{\partial G_E(Q^2)}{\partial Q^2}\bigg|_{Q^2=0}}$$

Experimental Method

- **0.1%** measurement of the **relative elastic scattering cross section $\rho_\sigma(Q^2)$ off protons** at fixed angles (**6°-15°**) and different beam energies **30-50-70 MeV.**
- **Simultaneous measurement** within the same detector of the known **Møller cross-section** off electrons from the **hydrogen target**.

Detector Concept

- Measurement of the **energy** and **angle** of scattered electrons.

The essential difficulty of the experiment is about minimizing and controlling systematic errors

ProRad experiment: measurement principle

$$\frac{d^2\sigma_{ep}}{d\theta d\varphi} = \frac{Y(e^- p \to e^- p)}{\mathcal{L}_{H_2} A_e\ \epsilon_e\ \delta_{ep}} \qquad \frac{d^2\sigma_{ee}}{d\theta d\varphi} = \frac{Y(e^- e^- \to e^- e^-)}{\mathcal{L}_{H_2} A_e\ \epsilon_e\ \delta_{ee}}$$

$$\boxed{G_E^2(Q^2) = \rho_\sigma(Q^2)\ \frac{\delta_{ee}}{\delta_{ep}}\left(\frac{d^2\sigma_{ee}}{d\theta d\varphi}\Big/\frac{d^2\sigma_{ep}^{Mott}}{d\theta d\varphi}\right)_{th}\left[1 + \mathcal{O}\left(\frac{Q^2}{M^2}\right)\right] - G_M^2(Q^2)\left[\mathcal{O}\left(\frac{Q^2}{M^2}\right) - \mathcal{O}\left(\frac{m^2}{M^2}\right)\right]}$$

- Uncertainties related to **luminosity** disappear.
- **Acceptance** and **efficiency** effects also disappear but remain at the **systematic** level.

- **Radiative effects** must be controlled at a few **10^{-4}** accuracy.
- Correction from the **magnetic form factor** is very small and can be controlled with high enough accuracy.

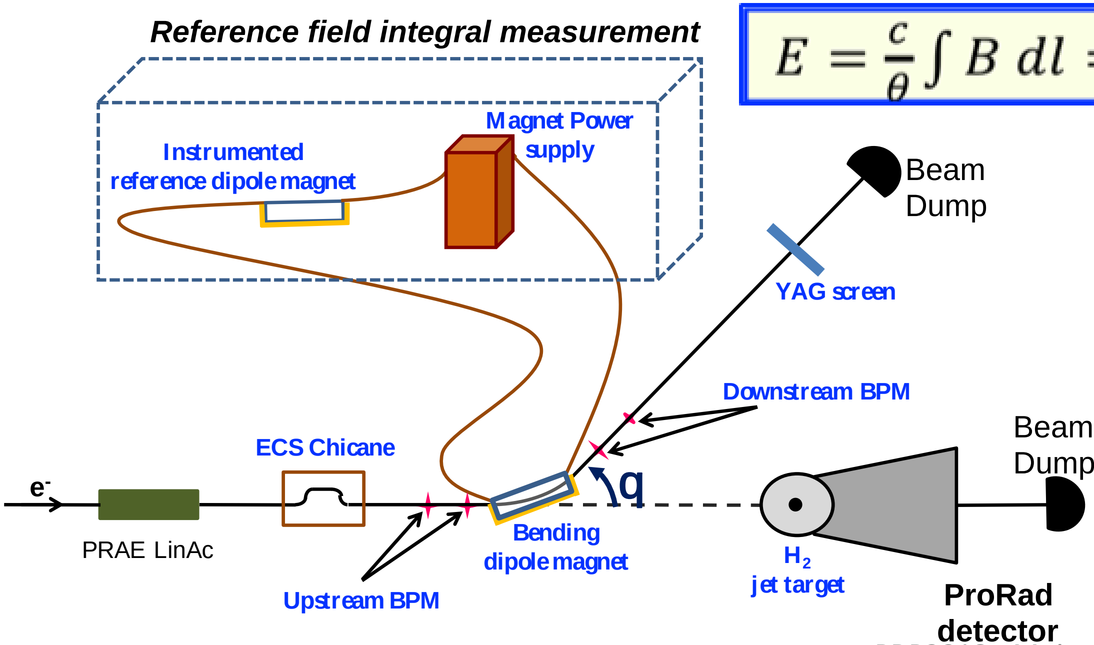
ProRad experiment: systematics errors

➢ The determination of the theoretical **Møller/Mott** cross section ratio involves the **knowledge** of the **incident beam energy** and of the **electron scattering angle**.

The **beam energy** should be known with a **5×10^{-4}** accuracy.

The detector should be designed to allow for a **0.1 mm accuracy** of its **location**.

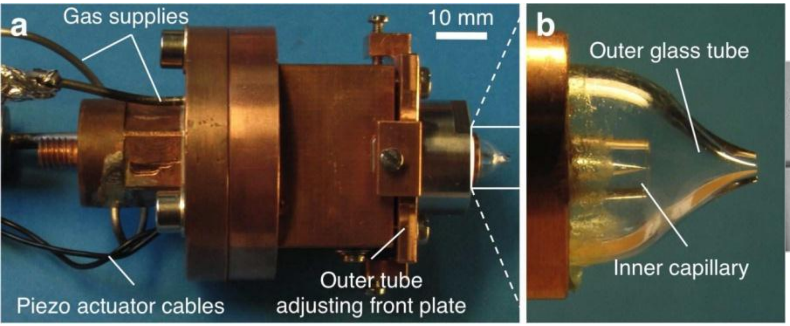
$$E = \frac{c}{\theta}\int B\,dl = \frac{c\,I_B}{\theta}$$

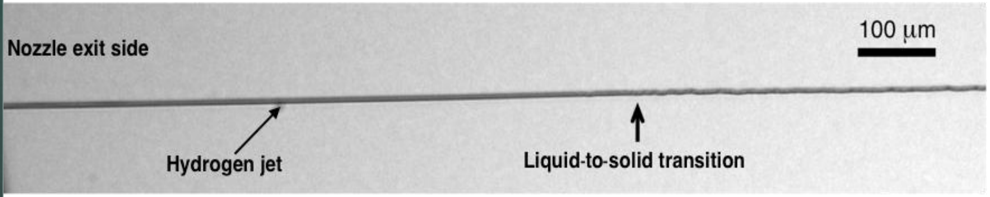


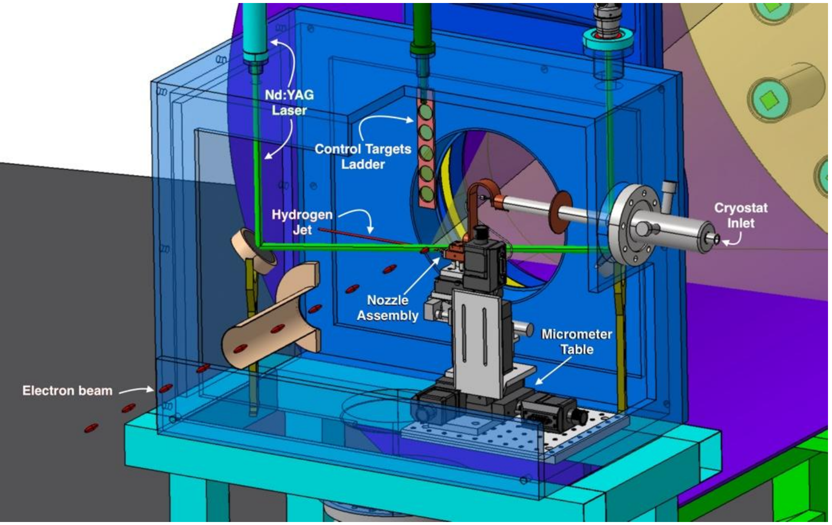
Solid H_2 target

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

windows = background
thickness = background + inaccurate vertex
Low density = increase data taking time



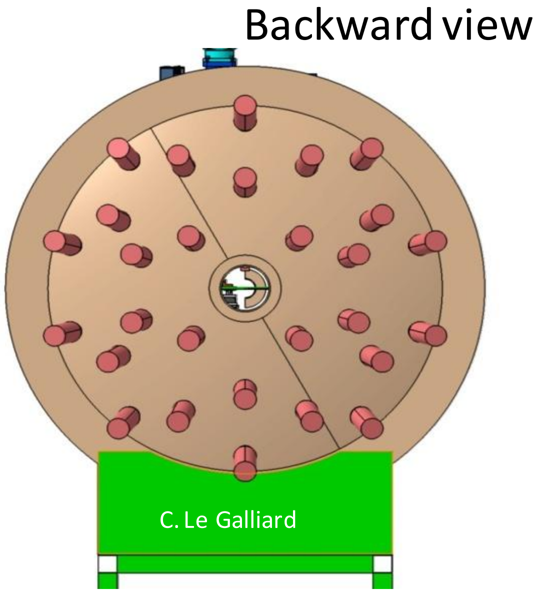


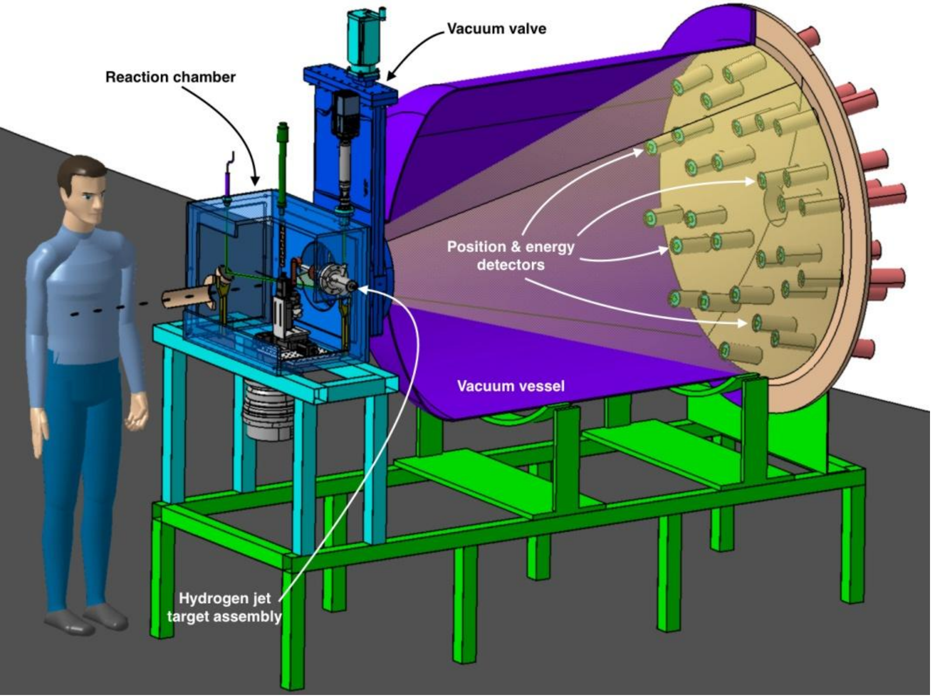


- ✓ ProRad requires a windowless **thin hydrogen target** of enough density.
- ✓ The supercooled liquid technology developped at **Frankfurt University** provides thin (5-15µm) **solid hydrogen wires**.

Detector concept

✓ The detector is composed of **28** independent elementary cells constituting of two scintillator planes followed by a cylindrical **BGO crystal** ($\pi 2.5^2[3.5^2]\times 15\ cm^3$).



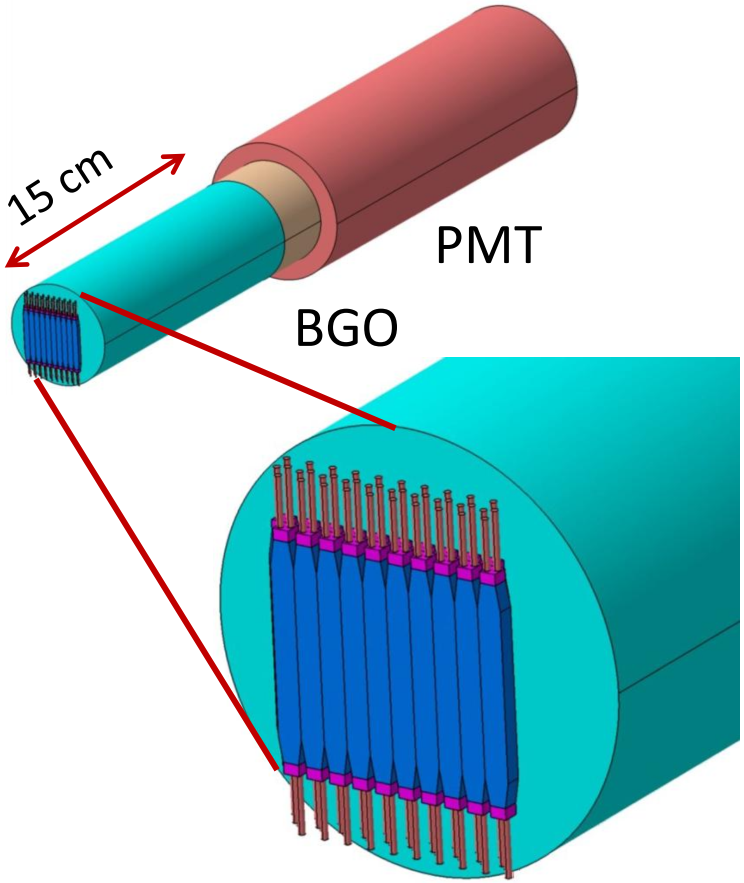


- Scattered electrons travel in **vacuum** over a **2 m** distance before reaching the detection area.
- Smallest angle crystals are the largest for **mimimizing energy leakage** effects.

Position detectors

Prototyping in progress

The position detector is made out of two staggered planes of plastic **scintillator stripes** (**20x4x1.3** mm³) read-out at both ends with **SiPMs** (prototype configuration).



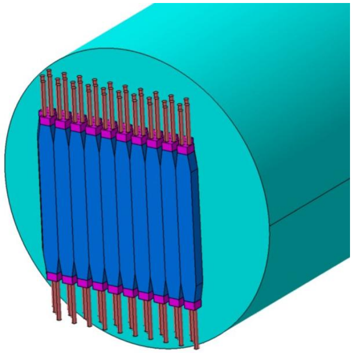
$$\int_{\Delta\Omega} \frac{d^2\sigma}{d\theta d\varphi} d\theta d\varphi = \left.\frac{d^2\sigma}{d\theta d\varphi}\right|_{\theta_0} \mathcal{A}_{\Delta\Omega}$$

- Scintillator stripes **acceptance effects** are **controlled** with **very high accuracy** through a Taylor development of the cross section at the stripe center.
- The position detector also serves as charged particles tagger.

Q^2 points

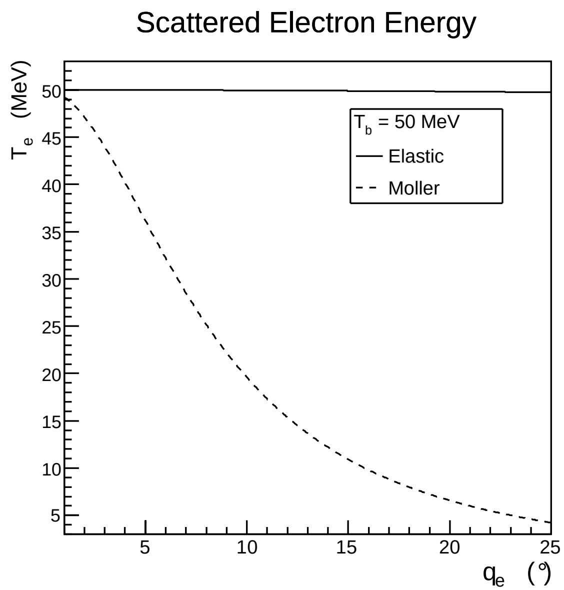
Scatt. Angle (°)	Nb of det./ring
6	4
9	6
12	8
15	10

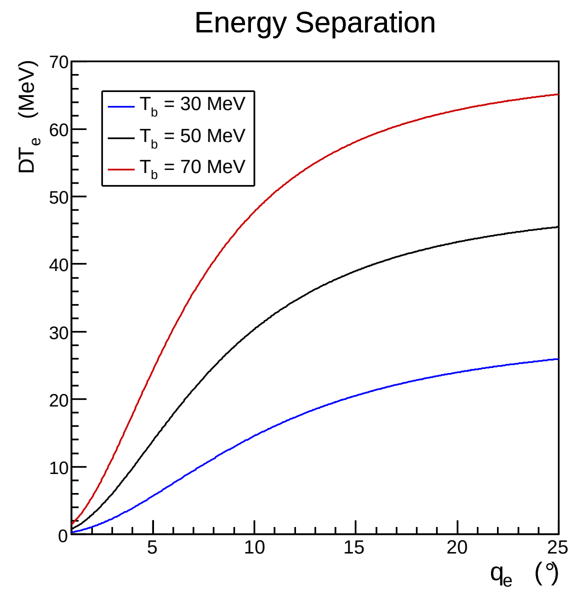
3 beam energy (30, 50 and 70 MeV)



X 5 ⇨ **60** points in **Q^2**

Energy separation of Elastic and Moller events

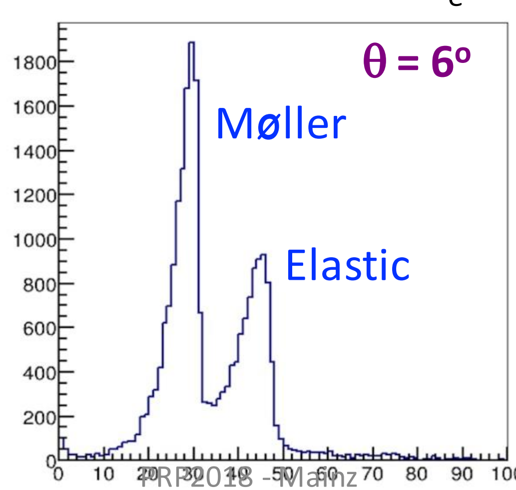


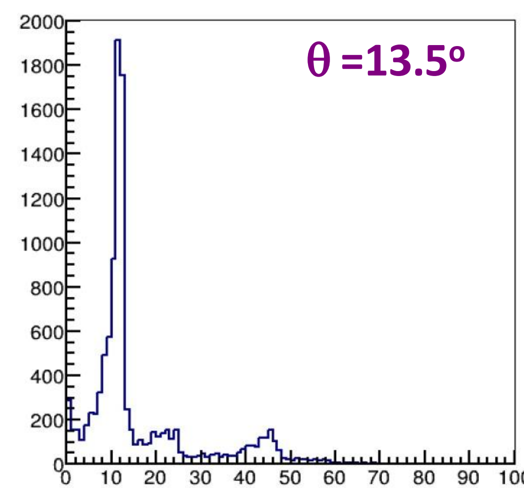


✓ At the same scattering angle, the **energy difference** between **Møller** and **elastic** electrons allows to **separate** processes.

$E_e = 50$ MeV

- At **small angle**, separation of processes is **reduced**.
- At **large angle**, dynamics of cross sections generate **combinatorial effects**.





Summary

- R extracted indirectly from the data within the Breit Frame

- Convergence criterion (density model dependence) → $|K^2|_{Max}$ < $2fm^{-2}$ [=0.08 $(GeV/c^2)^2$], preserve form factor analyticity properties.

- Polynomial order: m_min to cover most density models (given a parametrized density) and m_max to recover higher density moments. Value of $G_E(Q^2=0)$ shouldn't be constrained to avoid bias.

- ProRad: $|K^2|$ interval too small to extract R by itself. Combination with data from other experiments mandory to enlarge the domain in $|K^2|$ (shape of G_E)

- ProRad (low Q^2 exp) relative accuracy on GE has to be at least $5x10^{-4}$ to be able to disentangle Rμ from Re.

- Prototyping of the detector is ongoing. Experiment 2021

- ProRad goal: 0.1% systematics on the cross section.
  60 points in Q^2 ($1x10^{-5} \leq Q^2\ (GeV/c^2)^2 \leq 3x10^{-4}$)

Perspectives (1)

- Take into account PRad results on G_E and generate pseudo-data of other upcoming experiments with their projected errors.
- Study different parametrizations /density models
- Article dedicated to current studies : writing under progress

Perspectives (2)

- PRAE Kick-off workshop, *Oct. 8th-10th*, 2018 – Orsay, France

  http://workshop-prae2018.lal.in2p3.fr/

Result: Fall 2018 ?

- HORIZON 2020 **STRONG2020** proposal:

  Proton Radius European Network (PREN)

  D.M. and R. Pohl

  200k€ (including indirect costs) to increase/improve links between spectroscopy and lepton scattering communities

Collaboration

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ProRad is looking for collaborators

Thank you
for your attention

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