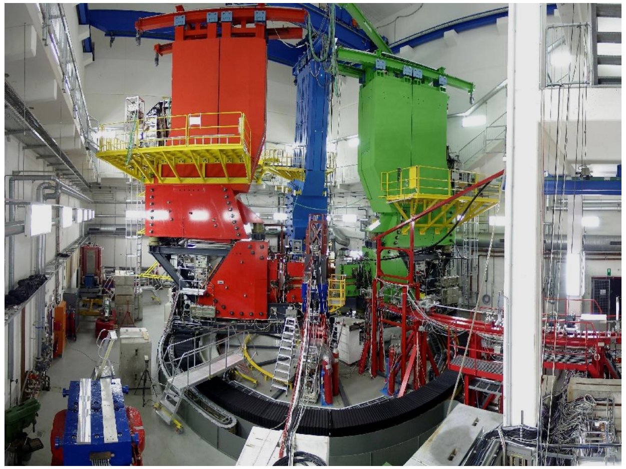
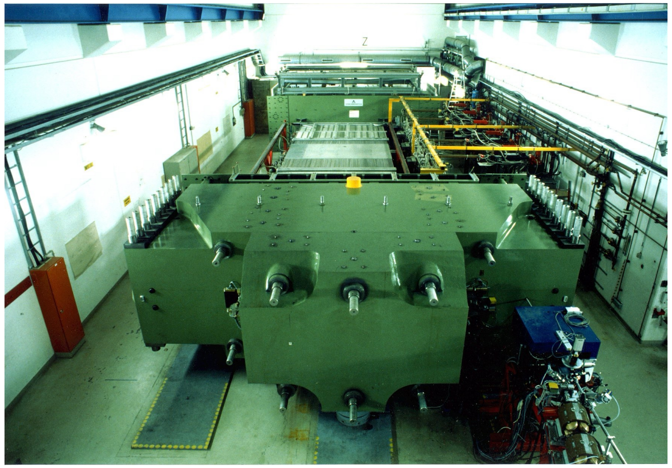
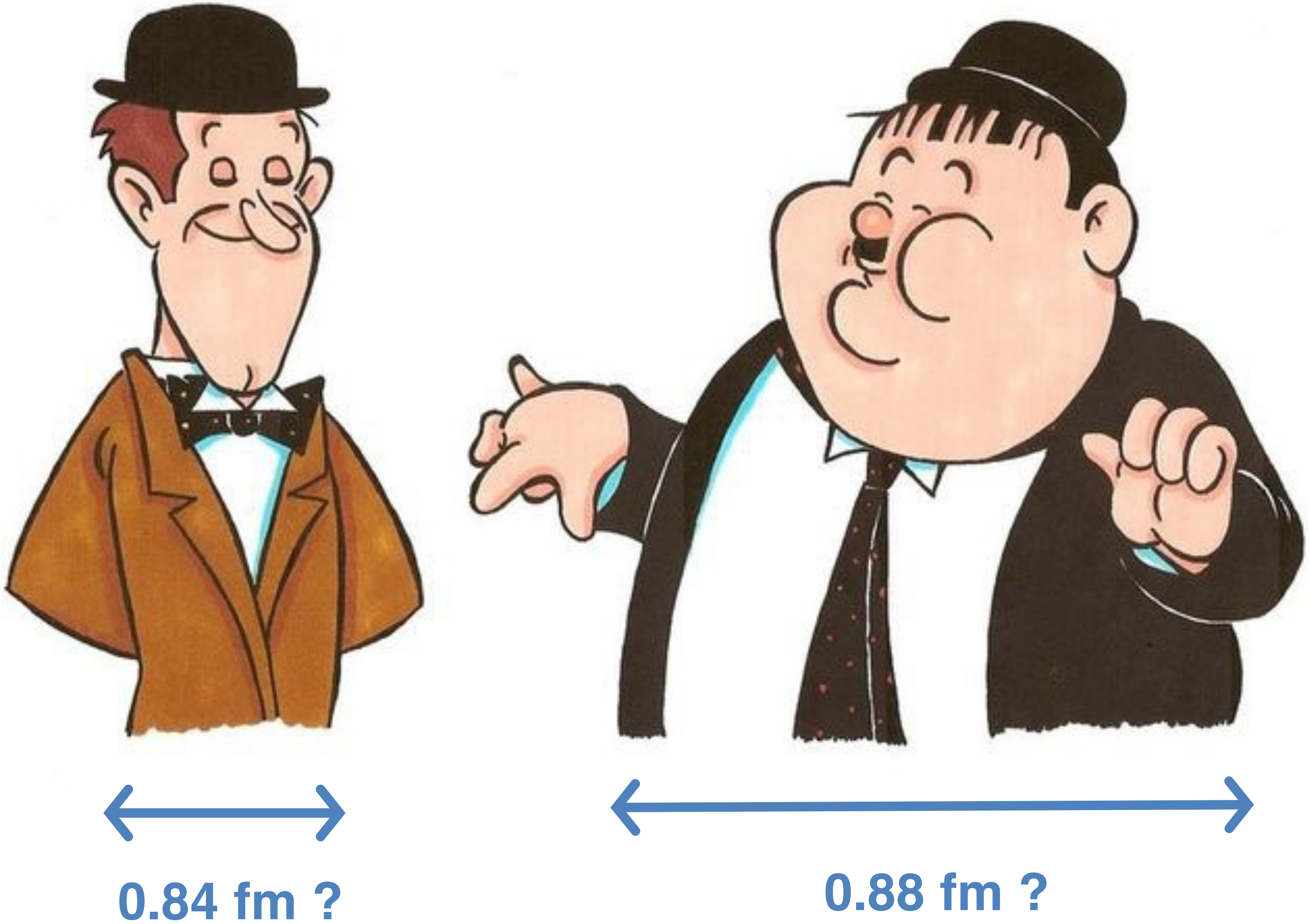




Proton Radius measurements at MAMI/MESA

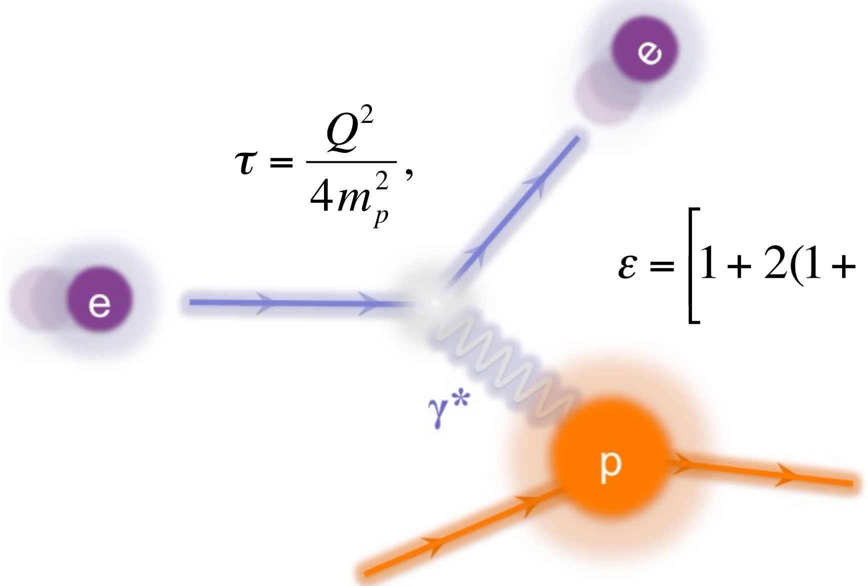
Miha Mihovilovic for A1 Collaboration
U Ljubljana and JSI

PAW 2024

Laurel and Hardy dilemma?!



Radius via Cross-section measurement



$$\tau = \frac{Q^2}{4m_p^2},$$

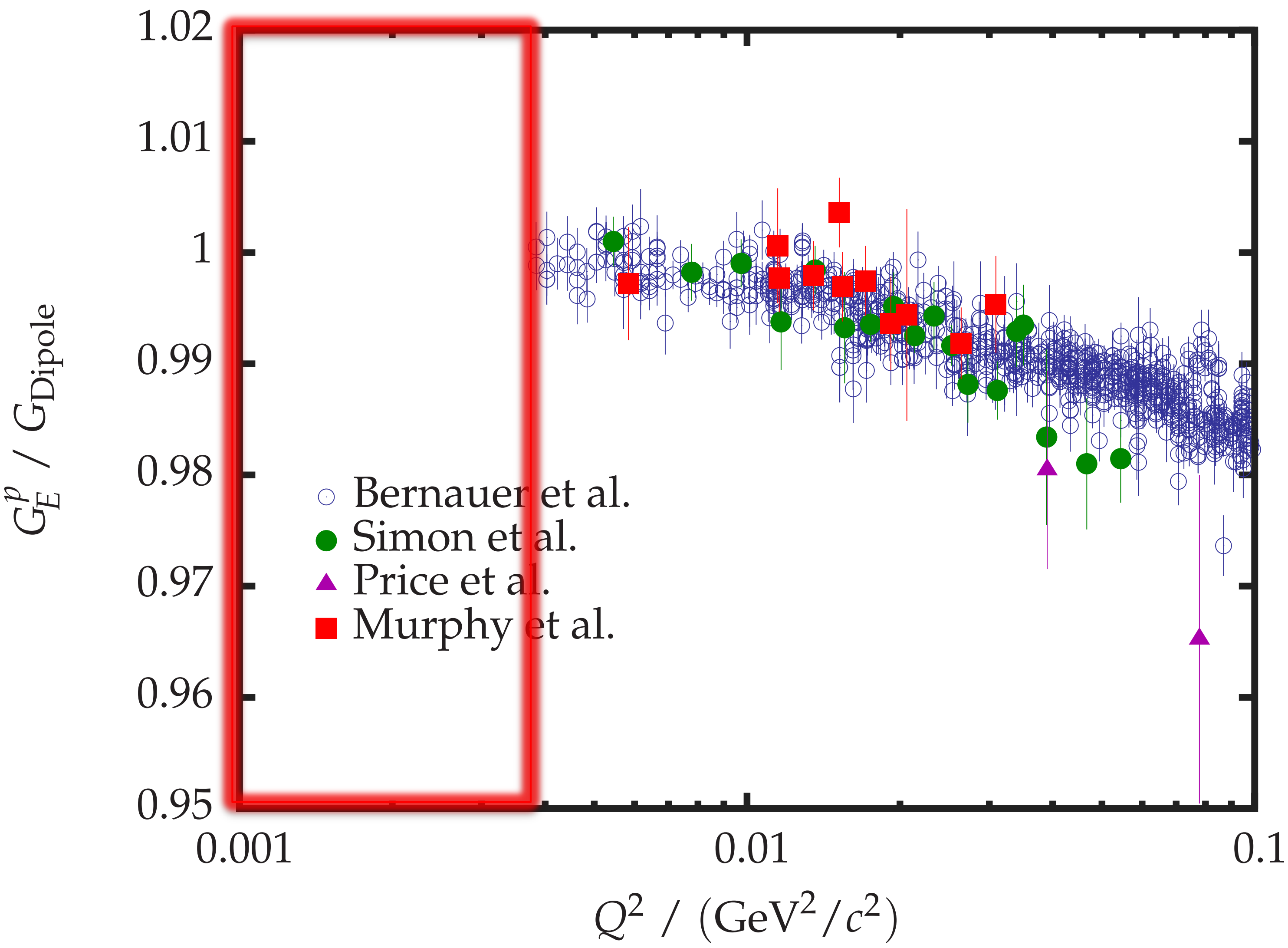
$$\varepsilon = \left[1 + 2(1+\tau)\tan^2\frac{\vartheta_e}{2}\right]^{-1}$$

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \frac{1}{1+\tau}\left[G_E^2(Q^2) + \frac{\tau}{\varepsilon}G_M^2(Q^2)\right]$$

- Extraction of FF via Rosenbluth Separation.
- Best estimate for radius:

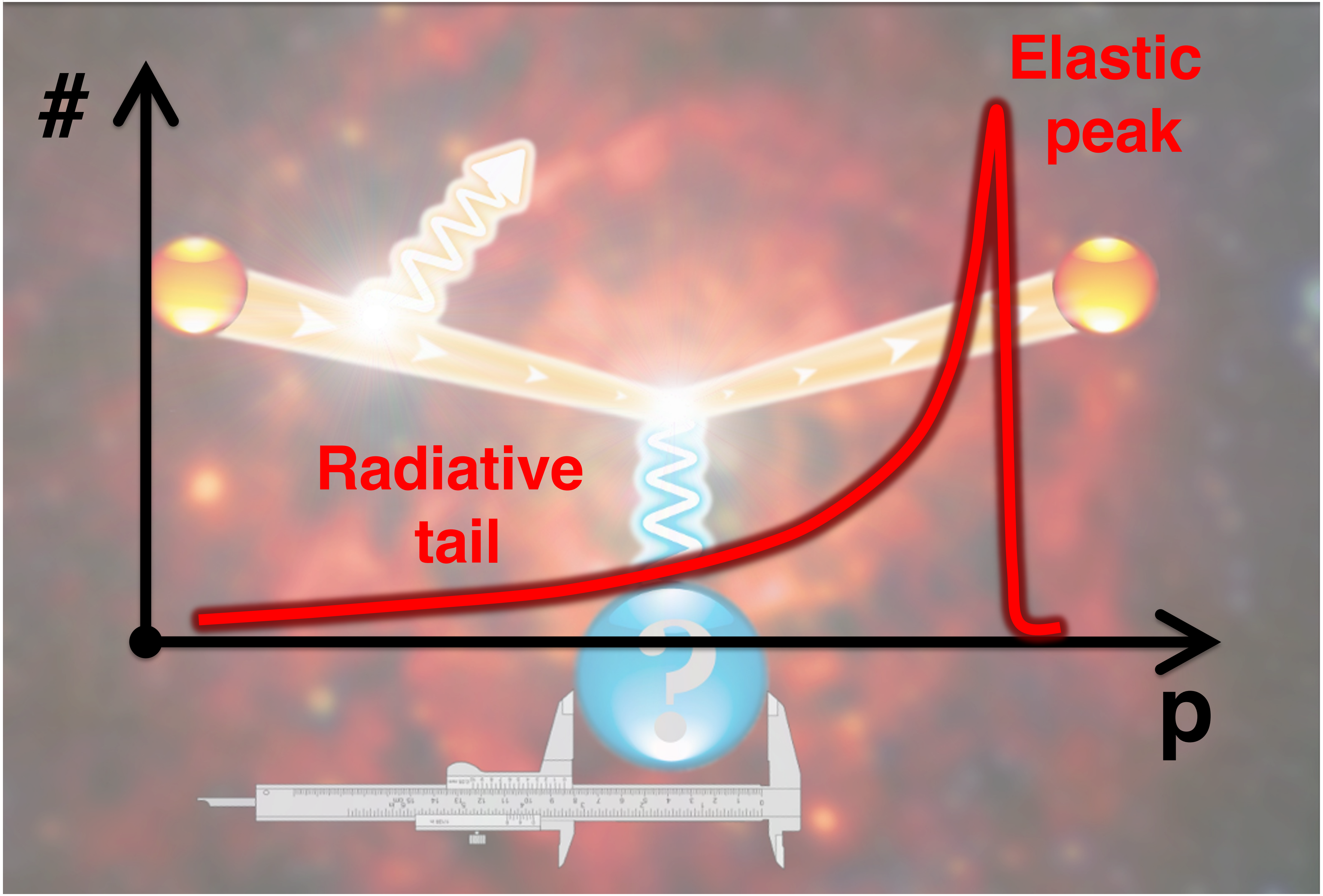
$$r_E^2 = -6\hbar^2 \frac{d}{dQ^2} G_E(Q^2)\Big|_{Q^2=0}$$

Proton's charge form-factor



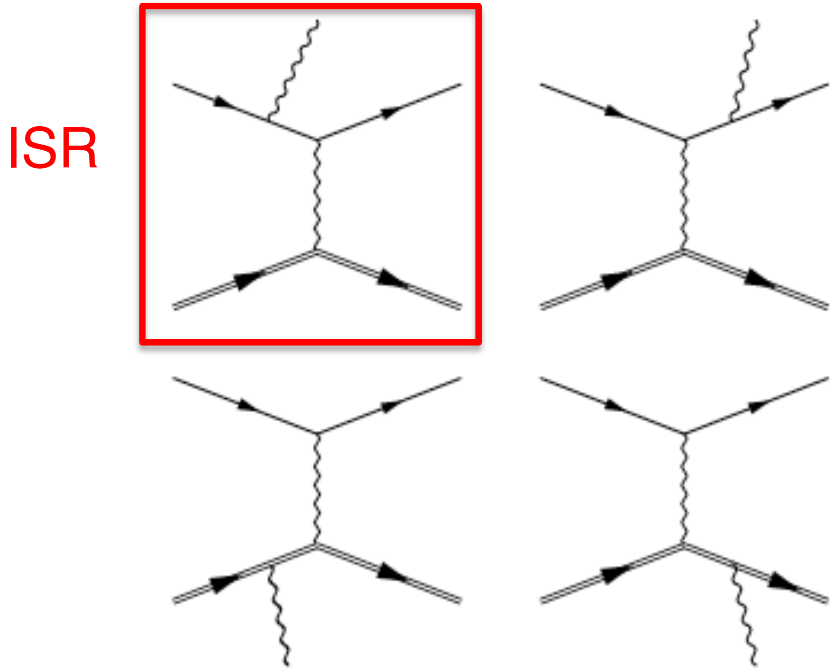
- **Data available only for $Q^2 > 0.004$ (GeV/c)^2.**
- **<u>Extrapolations to zero are needed!</u>**

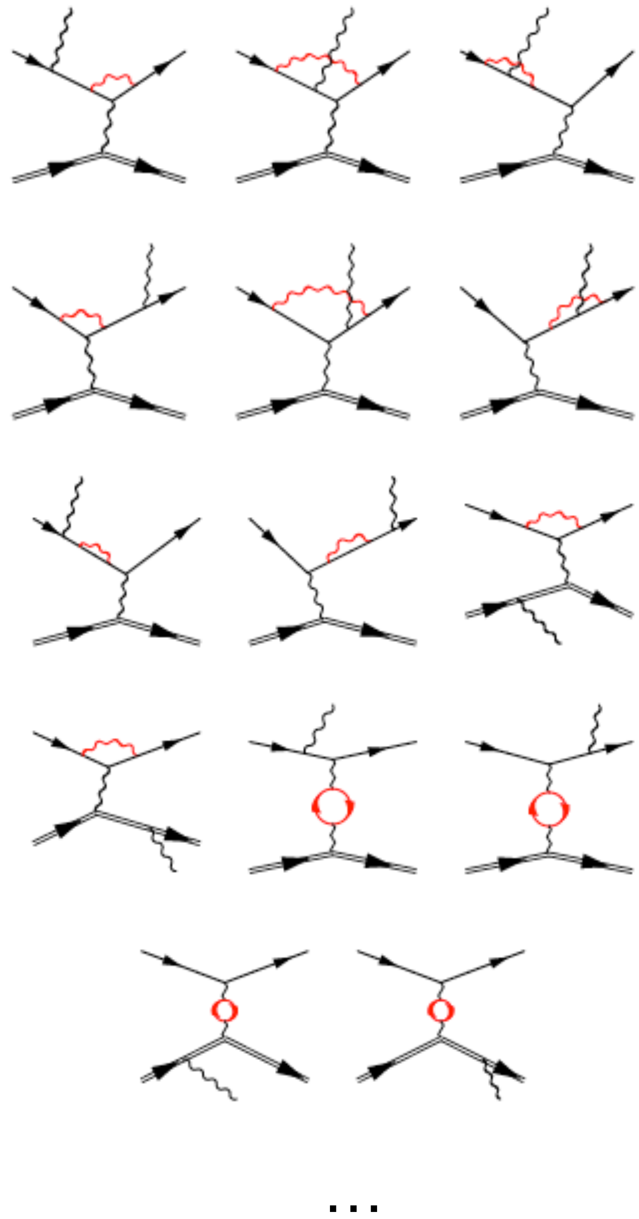
The idea of ISR Experiment



The ISR Simulation

- Based on standard A1 framework.
- Detailed description of apparatus.
- Exact calculation of the leading order diagrams:





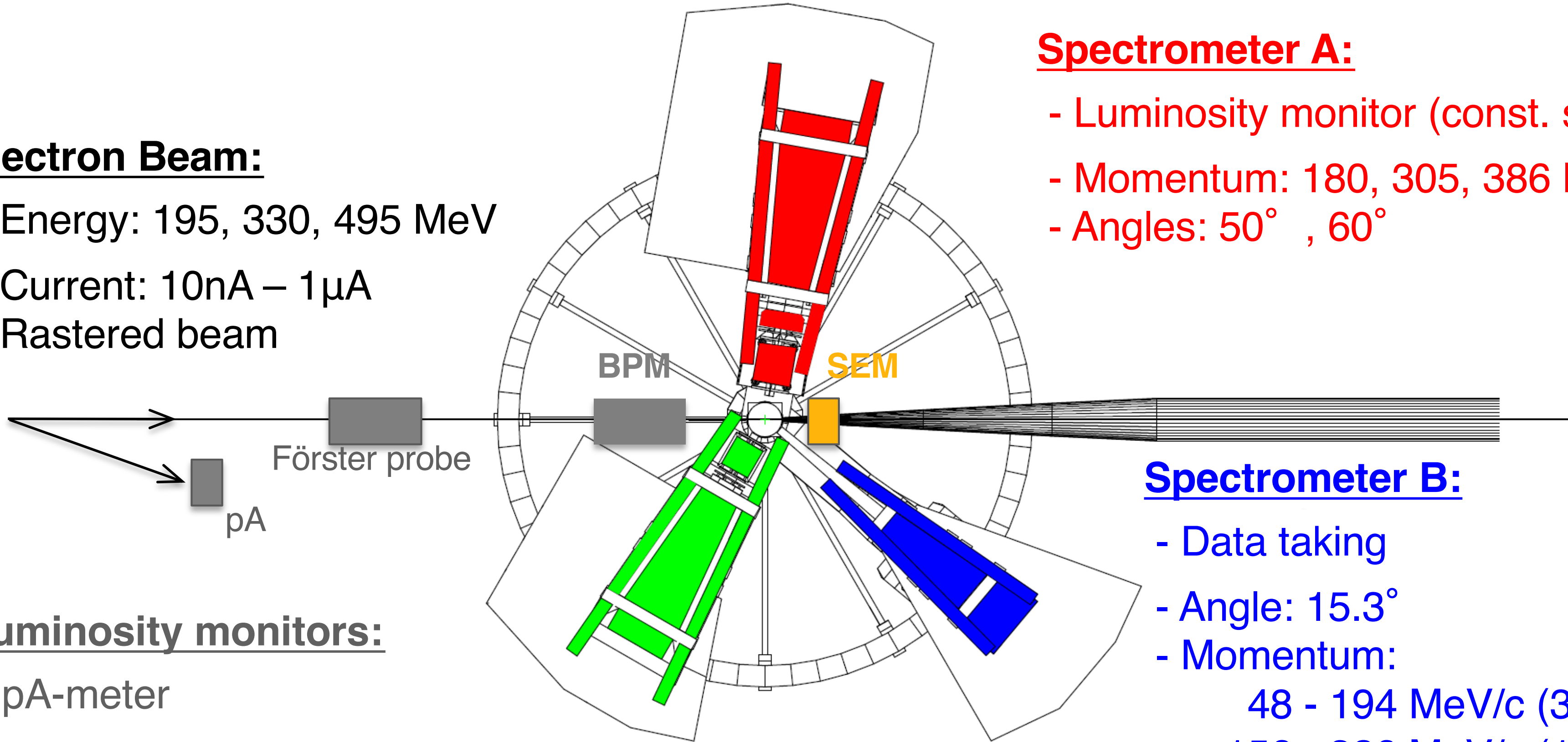
- The NL-order **virtual and real** corrections included via effective corrections to the cross-section.

The ISR experiment

- Full experiment done in August 2013 + additional beam time in 2017.

Electron Beam:

- Energy: 195, 330, 495 MeV
- Current: 10nA – 1μA
- Rastered beam



Spectrometer A:

- Luminosity monitor (const. setting)
- Momentum: 180, 305, 386 MeV/c
- Angles: 50°, 60°

Spectrometer B:

- Data taking
- Angle: 15.3°
- Momentum:
  48 - 194 MeV/c (35 setups)
  156 - 326 MeV/c (12 setups)
  289 - 486 MeV/c (9 setups)

Spectrometer C:

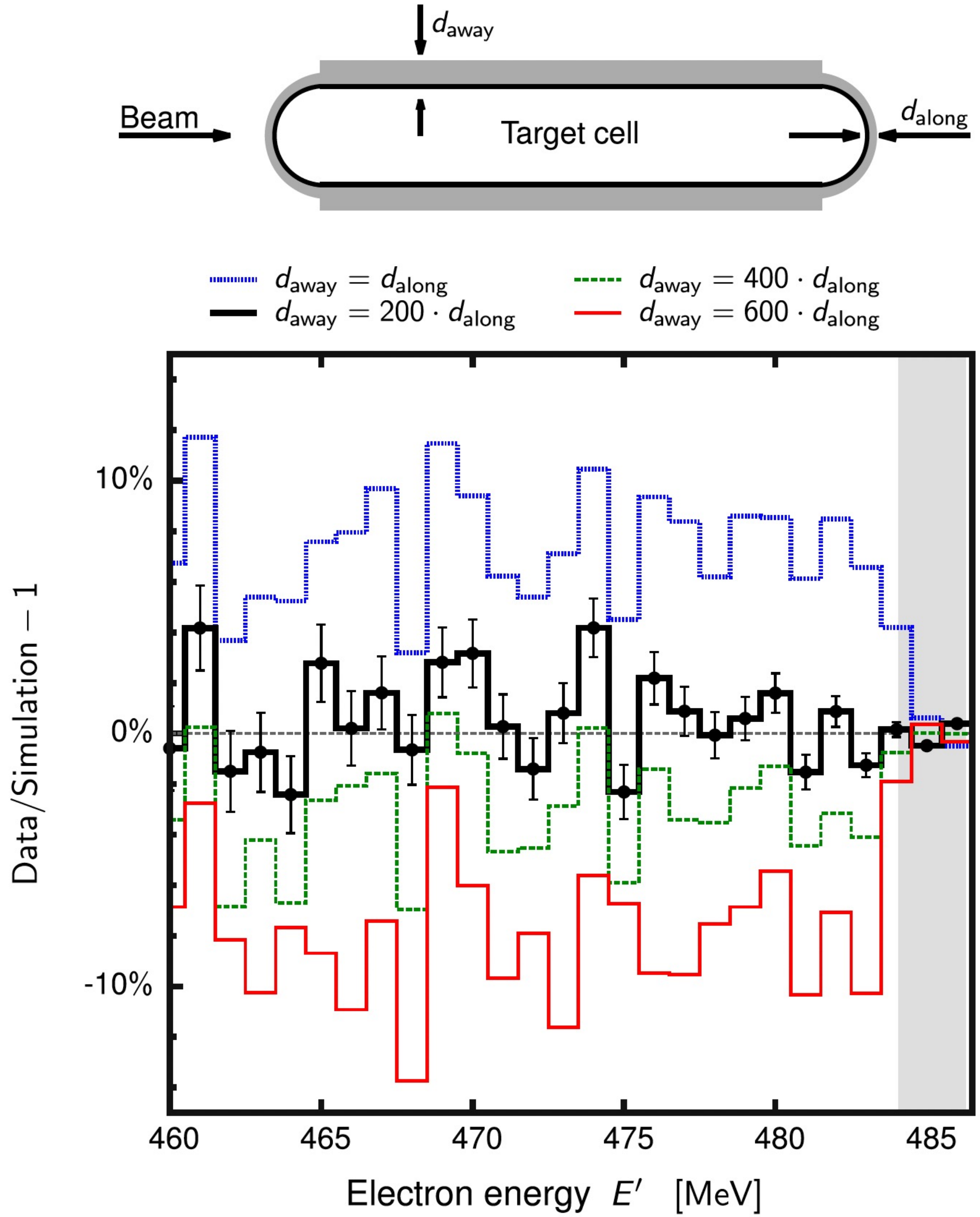
- Not used

Luminosity monitors:

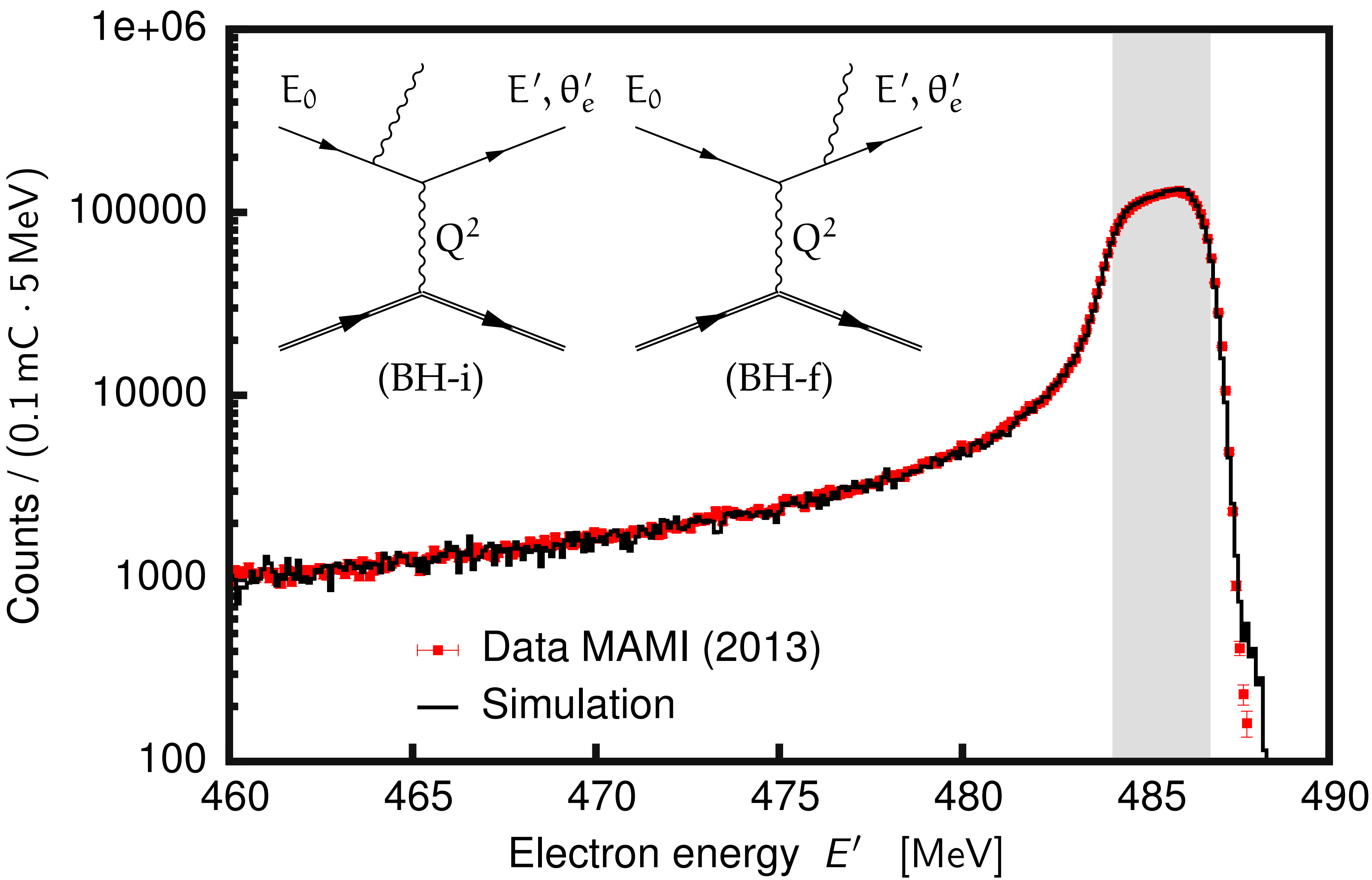
- pA-meter
- Förster probe
- SEM

Shortcomings of Cryogenic target

- Employed an extended cryogenic target.
- Backgrounds from target walls and supporting frame.
- Spectra distorted due to cryogenic depositions on the walls.
- Cryogenic layer on the sides much thicker than in the beam direction. Huge effect on the elastic data! **<u>No control over the thickness of the layer.</u>**



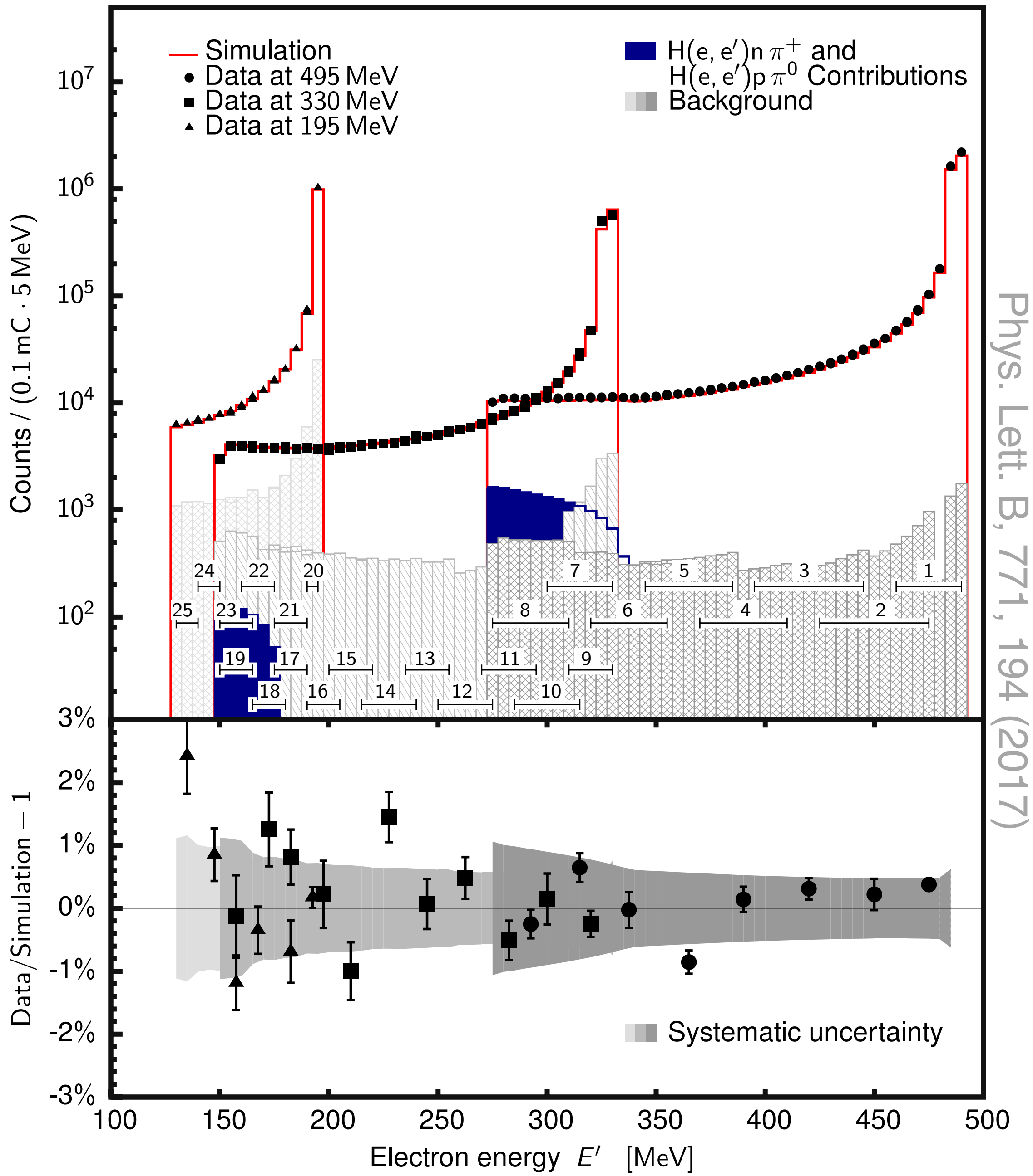
The shape of the elastic peak



- **This effects are important for all high precision experiments using cryogenic target.**

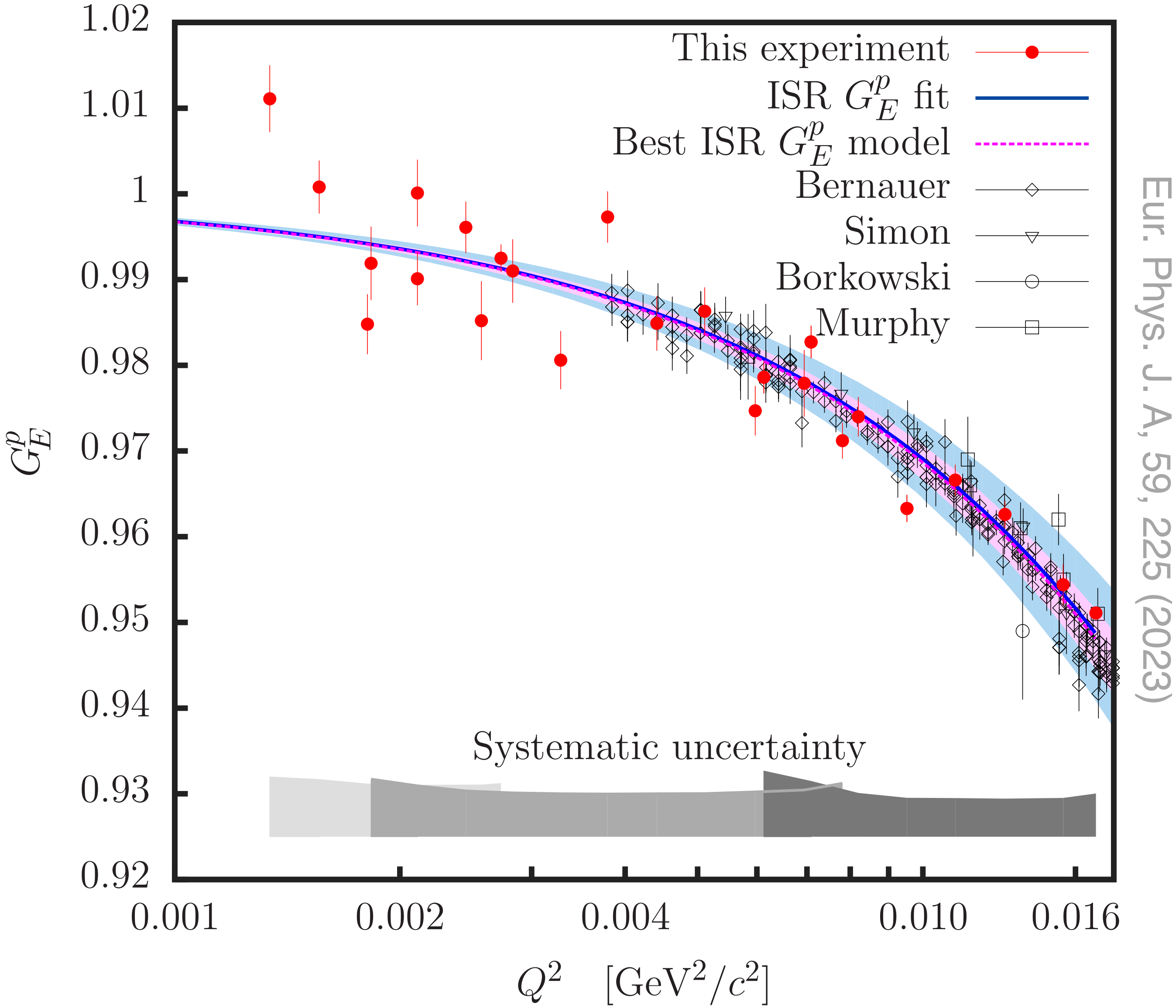
Results

- Existing apparatus limited reach of ISR experiment to E' ~ 130 MeV.
- Elastic points included.
- Simulation performed with Bernauer parameterization of form factors.
- A percent agreement between the data and simulation demonstrates that the radiative corrections are well understood!



Phys. Lett. B, 771, 194 (2017)

ISR form-factors

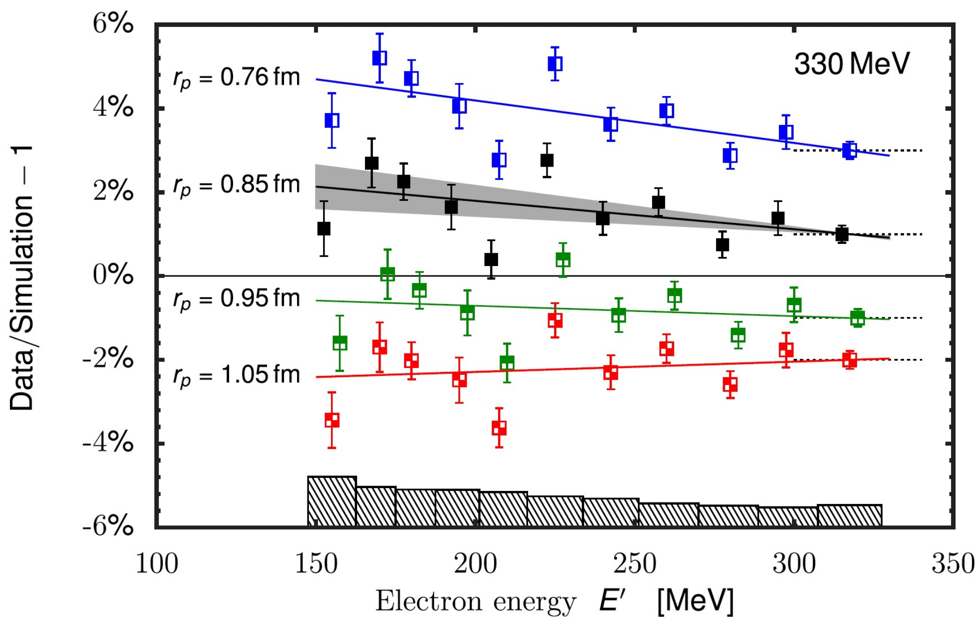


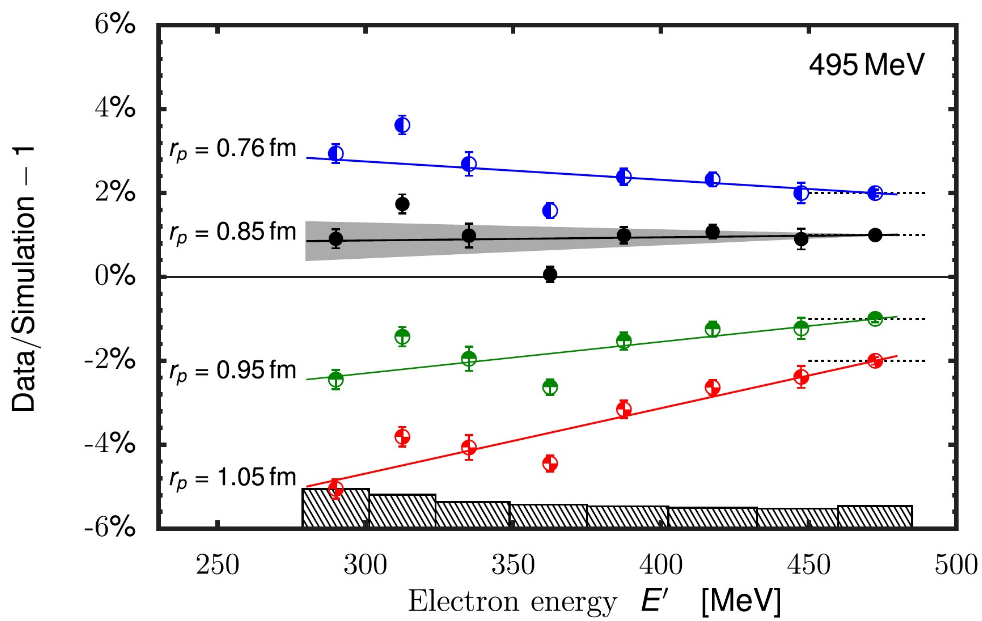
- Form-factors extracted from deviations of the measurements from the Bernauer model, assuming flawless description of radiative corrections.

Analysis of cross-sections

- Determination of the radius directly from the measured cross-sections.
- Small-energy data less sensitive to radius. 195 MeV data excluded.
- Analysis based on a specific form factor model.

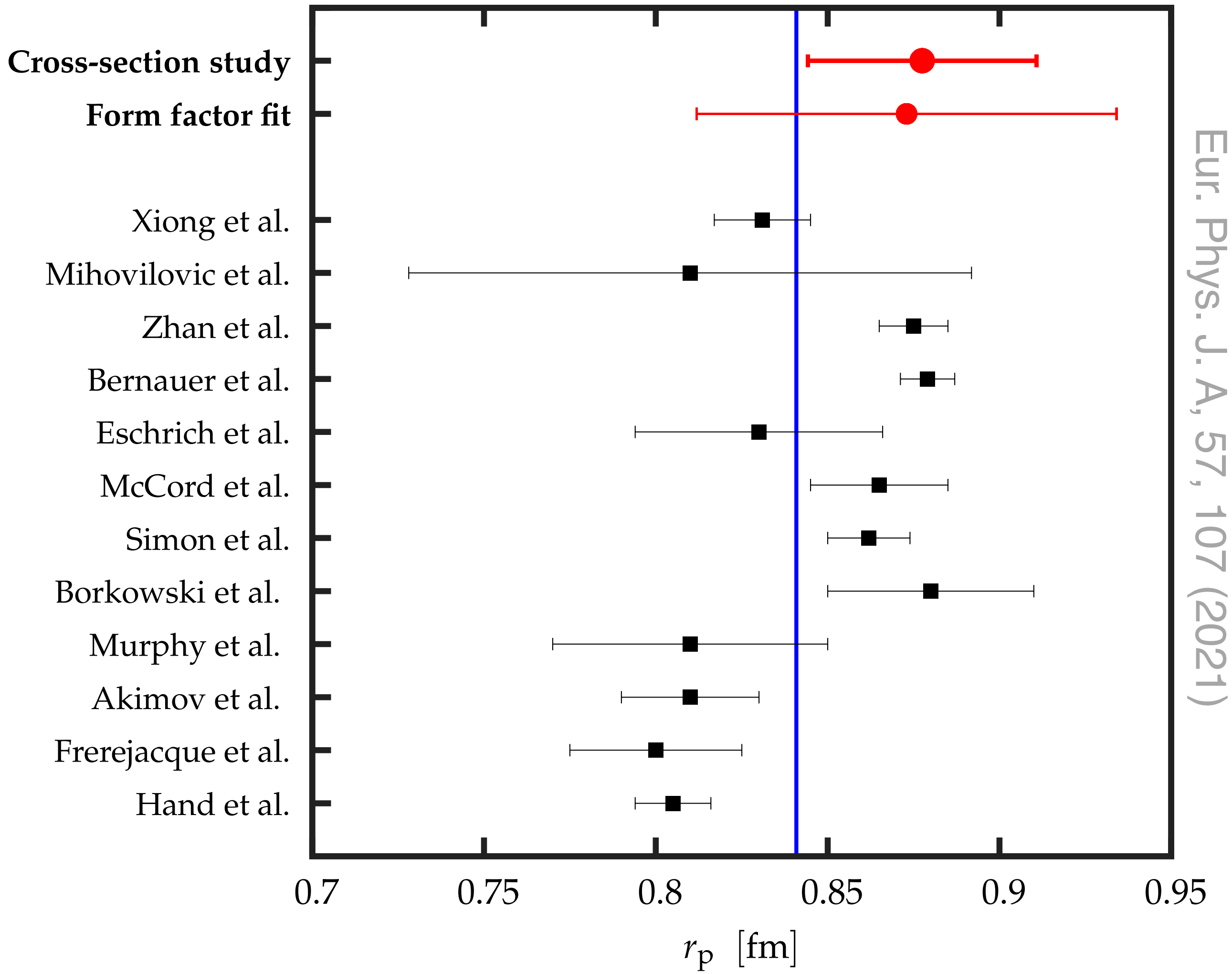
$$G_E^p(Q^2) = \boldsymbol{n}\left(1 - \frac{\mathbf{r_E^2}}{6}Q^2 + \frac{a}{120}Q^4 - \frac{b}{5040}Q^6\right)$$





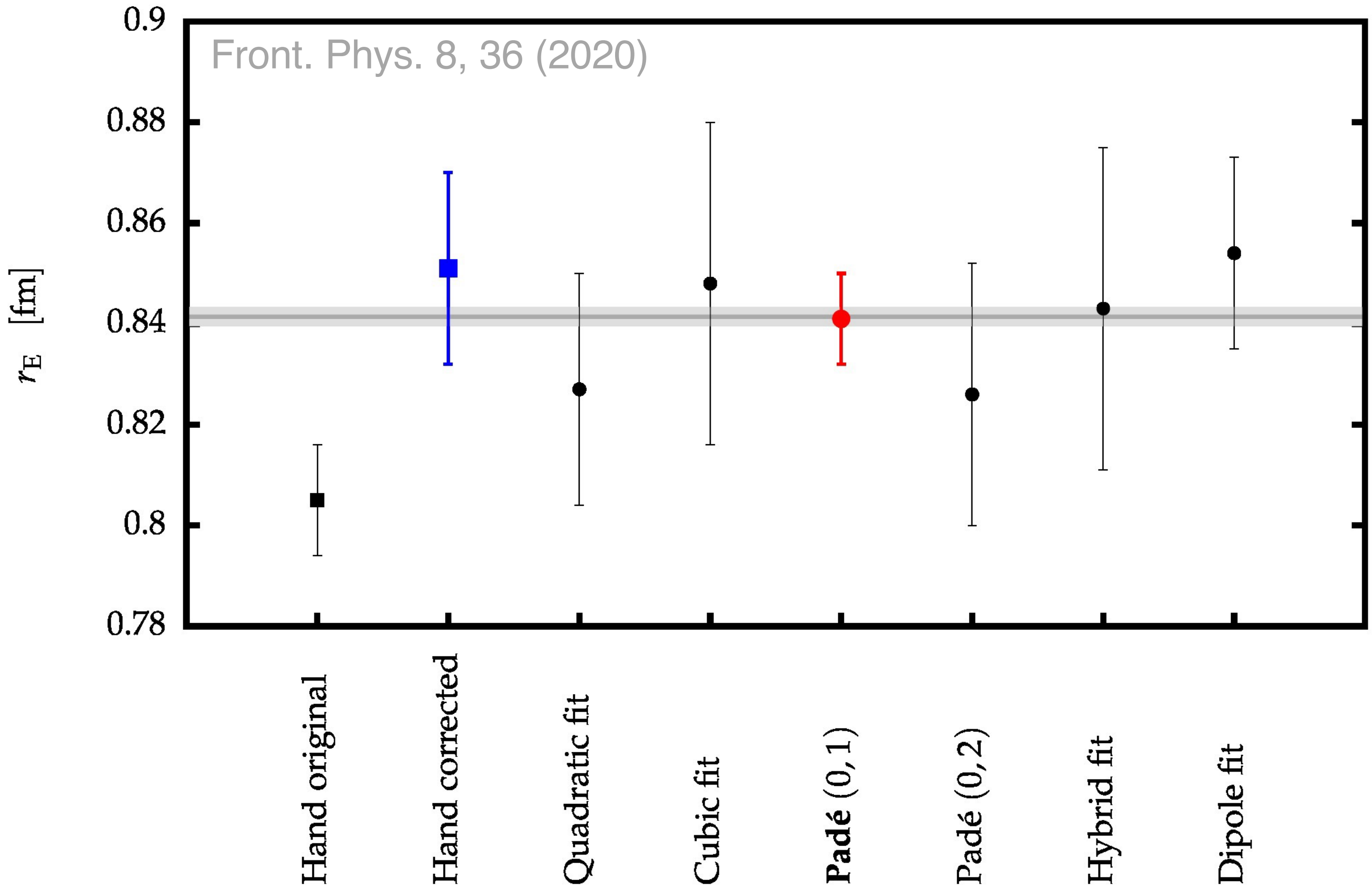
The result of the ISR experiment

- The values from the direct analysis of cross-sections and fit of extracted form-factor.
- Uncertainty combines statistical and systematic uncertainty.



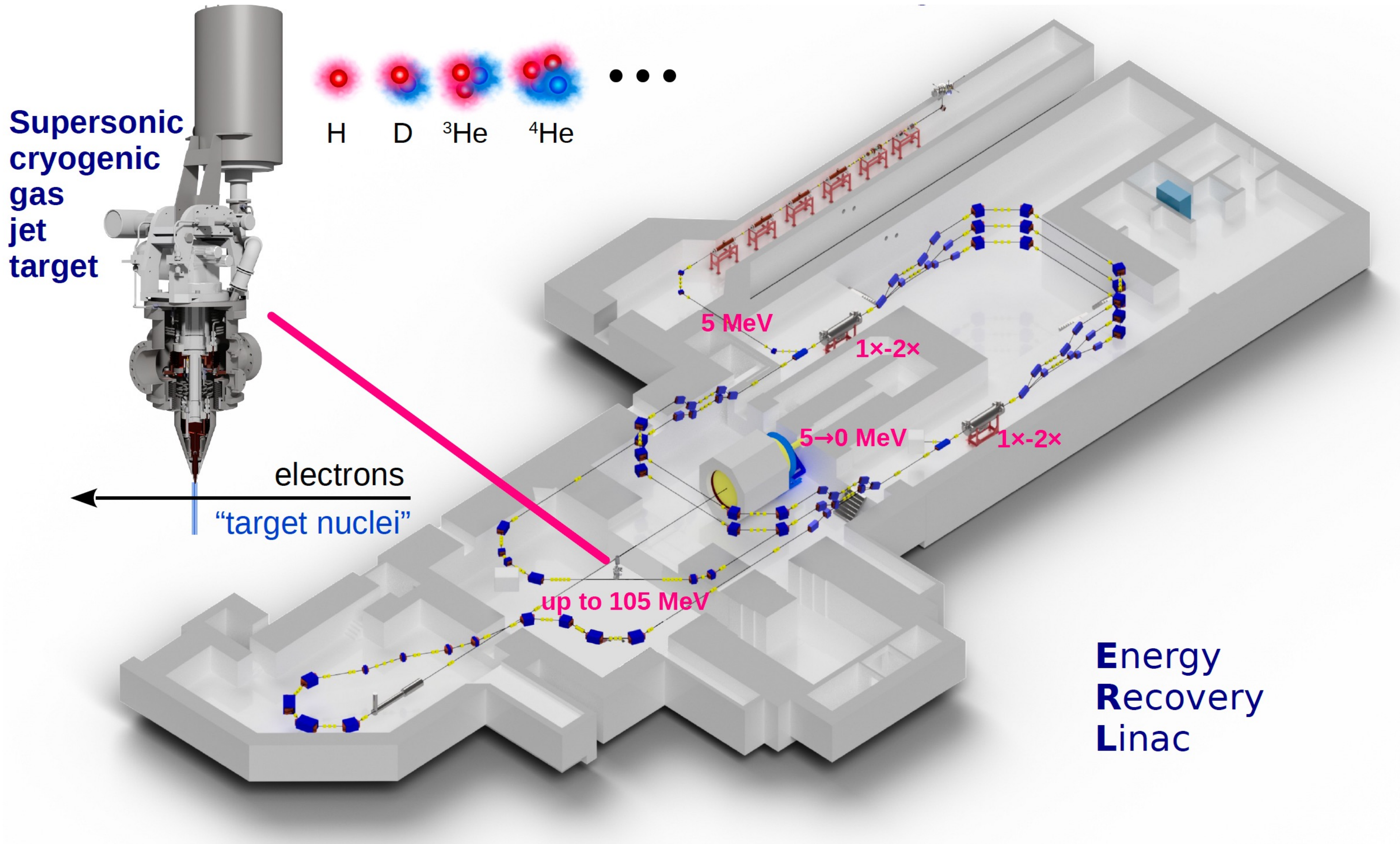
Eur. Phys. J. A, 57, 107 (2021)

Reinterpretation of first measurements



- Mistake in an analysis led Hand to too small value for the radius.
- Reanalysis of original measurements give results consistent with CODATA '18.

Magix @ MESA

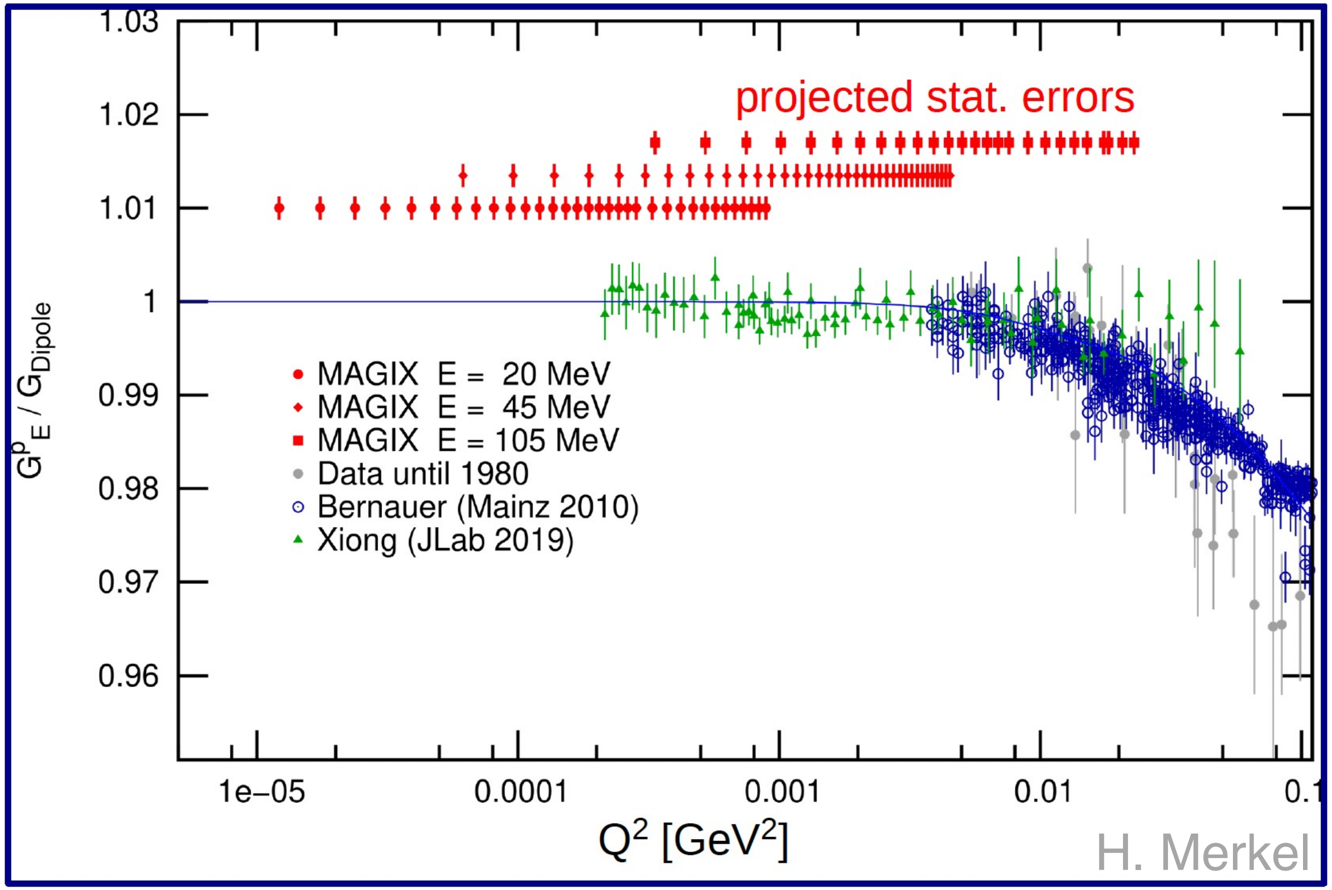



```
P2/DM-EB mode:    ~155 MeV,    150 µA
   MX-EB mode:  20-105 MeV, < 150 µA
     ERL mode:  30-105 MeV, 10000 µA
```

B. S. Schlimme

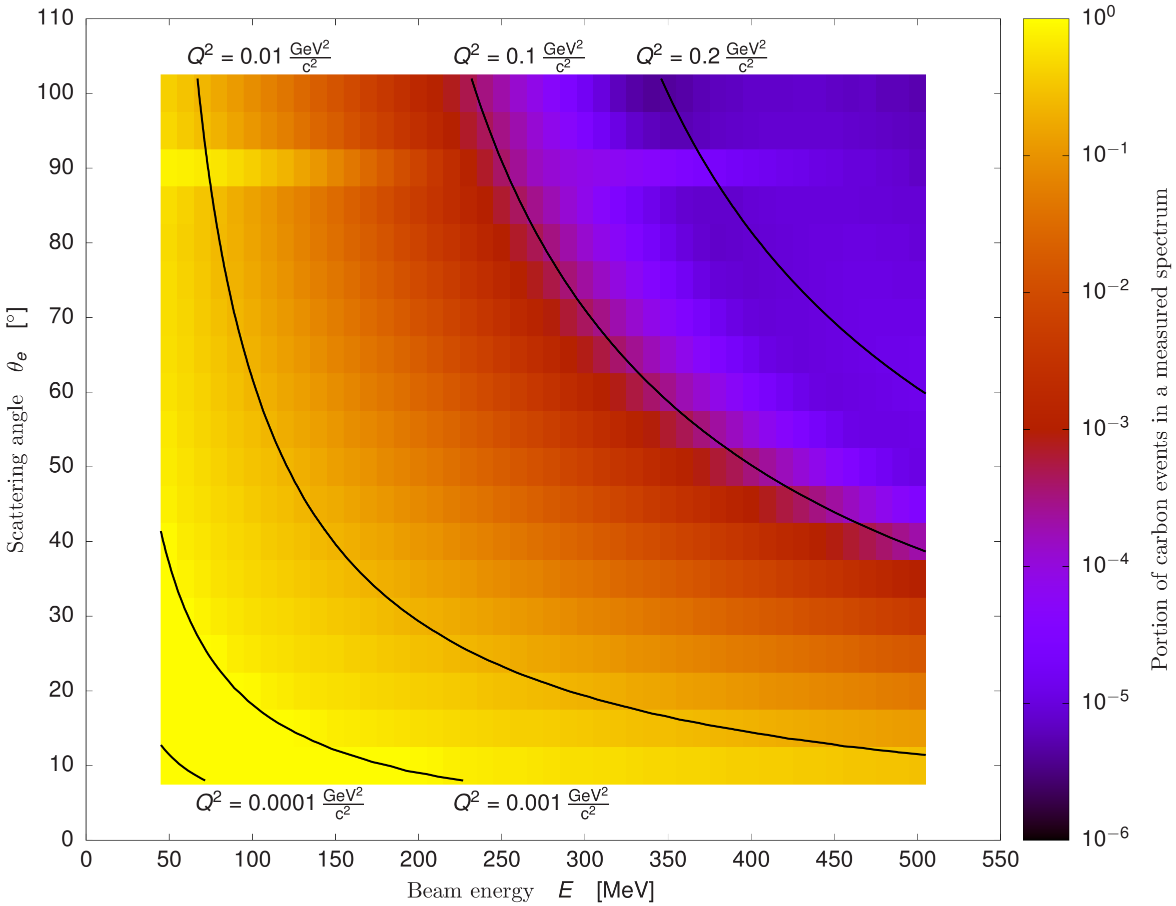
Radius measurements @ Magix

- Persistent discrepancy between different determinations of the proton radius persists demands further measurements.
- New measurement planned also at Magix @ MESA
- Measurement of G_E^p at Q^2 between $1 \cdot 10^{-5}$ and 0.03 GeV^2
- Expected statistical uncertainty ~ 0.1 %.
- Expected systematical uncertainty < 0.5 %.
- Measurement of G_M^p using double-polarized experiments.



Potential experiments with plastic targets

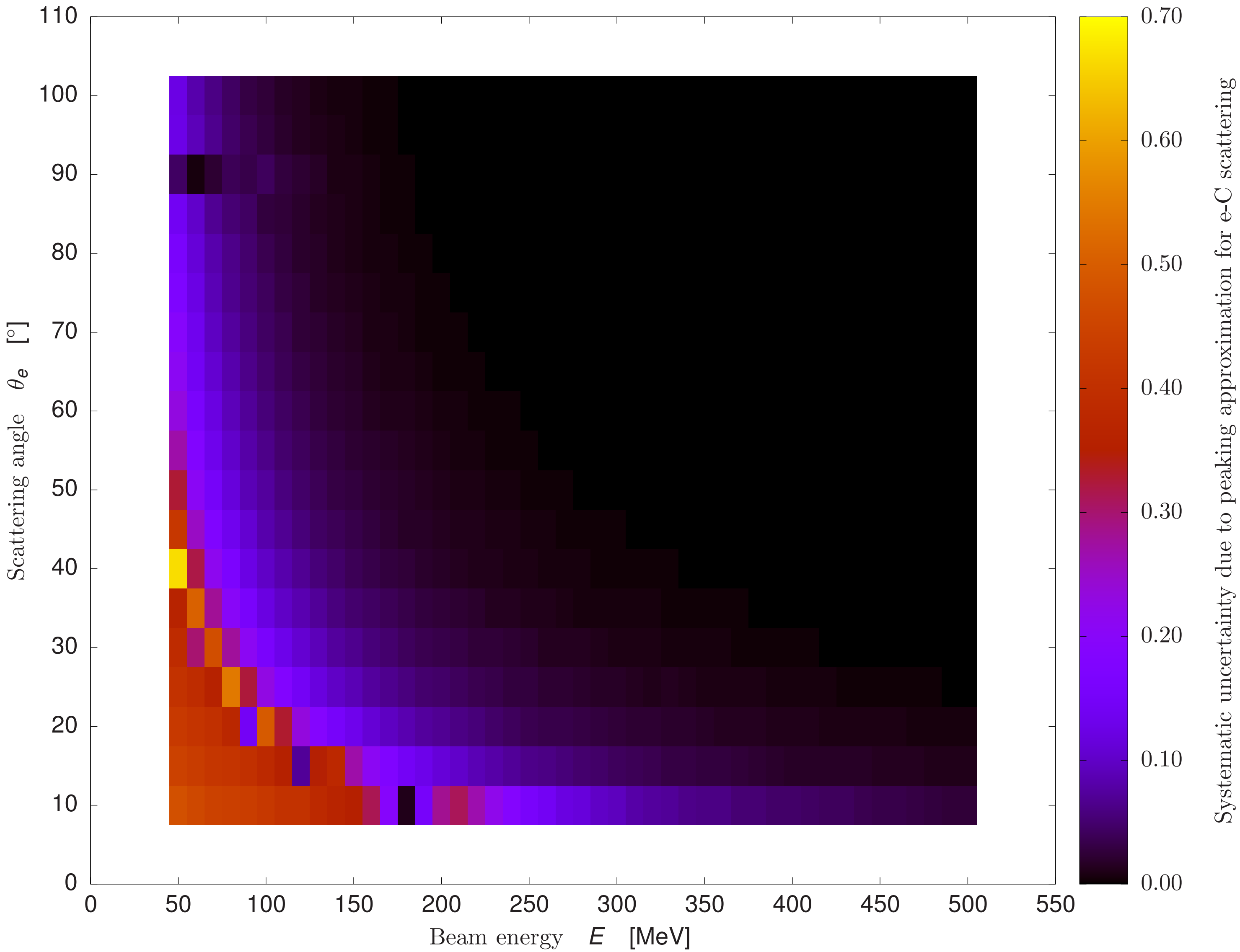
- Uncertainty of experiments dominated by the target-related systematics.
- Desired target is **thin** with **known and constant density** and background, that can be clearly subtracted.
- Plastic (-CH2-) target an effective hydrogen target with carbon background.



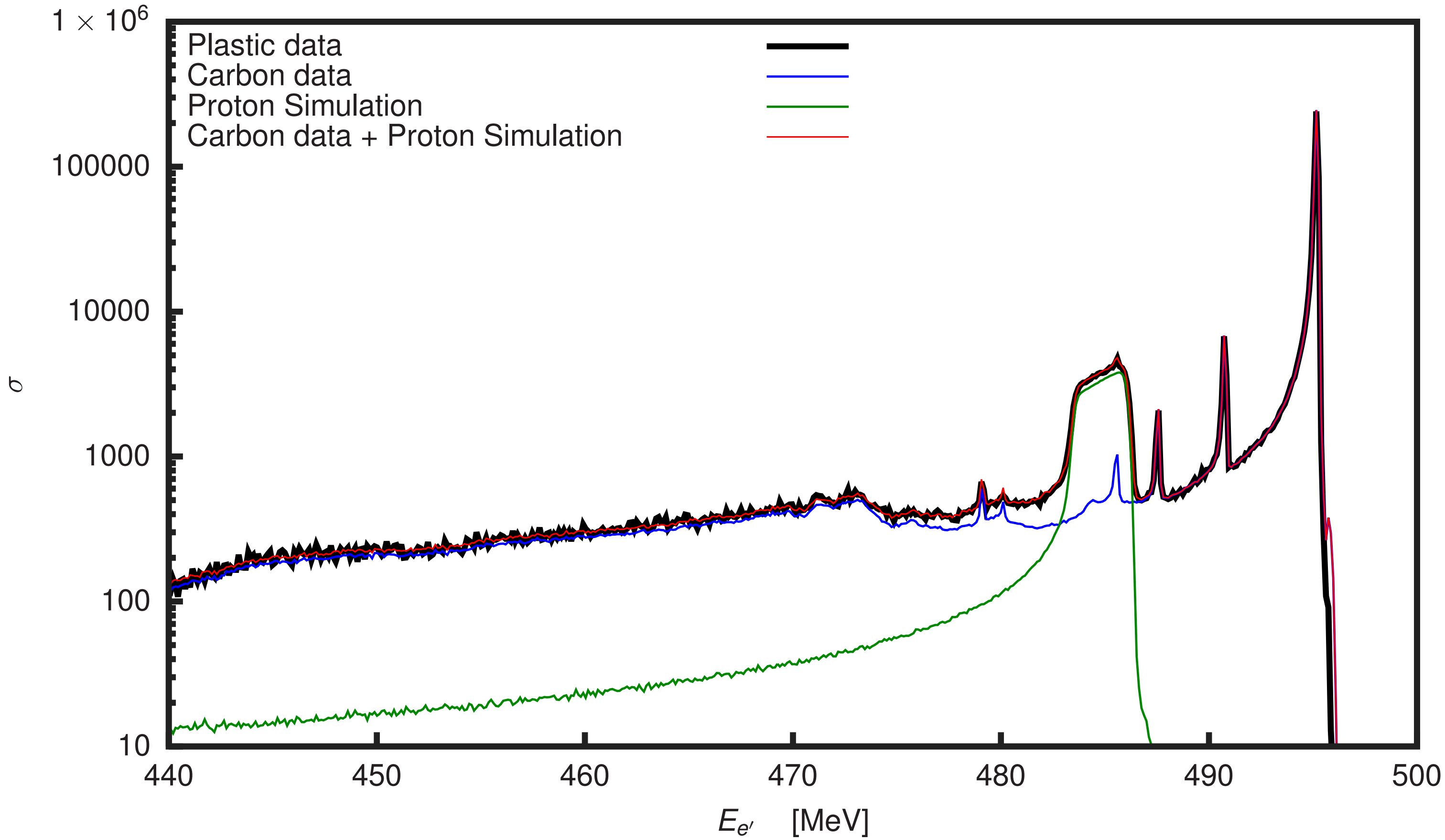
Findings of tests with plastic target

- Peaking approximations **insufficient** for describing carbon background.

Eur. Phys. J. A, 59, 225 (2023)



Findings of tests with plastic target



- Peaking approximations insufficient for describing carbon background.
- Measurements with thin carbon targets are necessary due to the presence of inelastic contributions for adequate background description.
- External radiative corrections need to be applied to match plastic spectra.

Summary

- The ISR experiment used a new experimental technique for determination of the proton form-factors at very small Q^2.
- **Validated radiative corrections far away from elastic settings.**
- Experimental result dominated by the systematic uncertainties arising from the use of LH_2 target.
- Extracted G_E^p at very low Q^2 and the charge radius, but with the limited precision.
- Further measurements with thin windowless targets are needed – **Magix experiment with Hypersonic gas jet target!**
- **Plastic targets are also an option.**
- **Find consensus on how to fit / interpret the nuclear scattering data.**

Thank you!