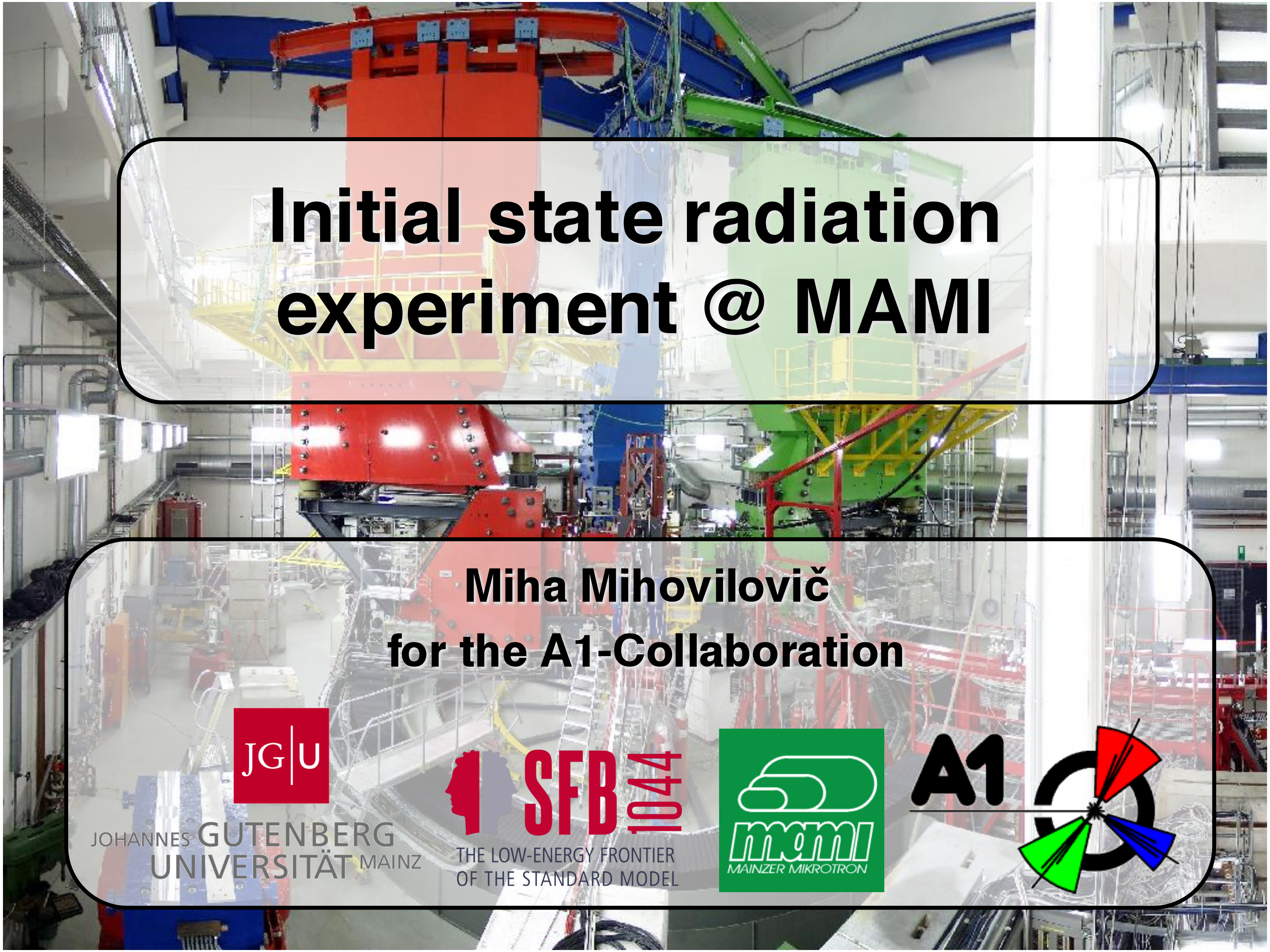

Initial state radiation experiment @ MAMI

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for the A1-Collaboration

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

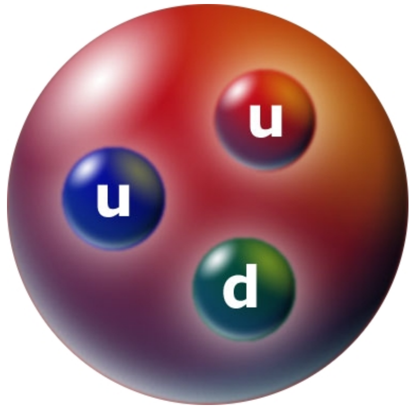
SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

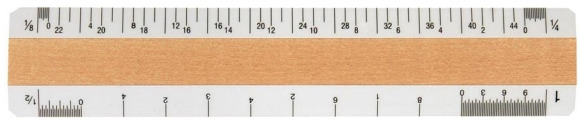
MAINZER MIKROTRON

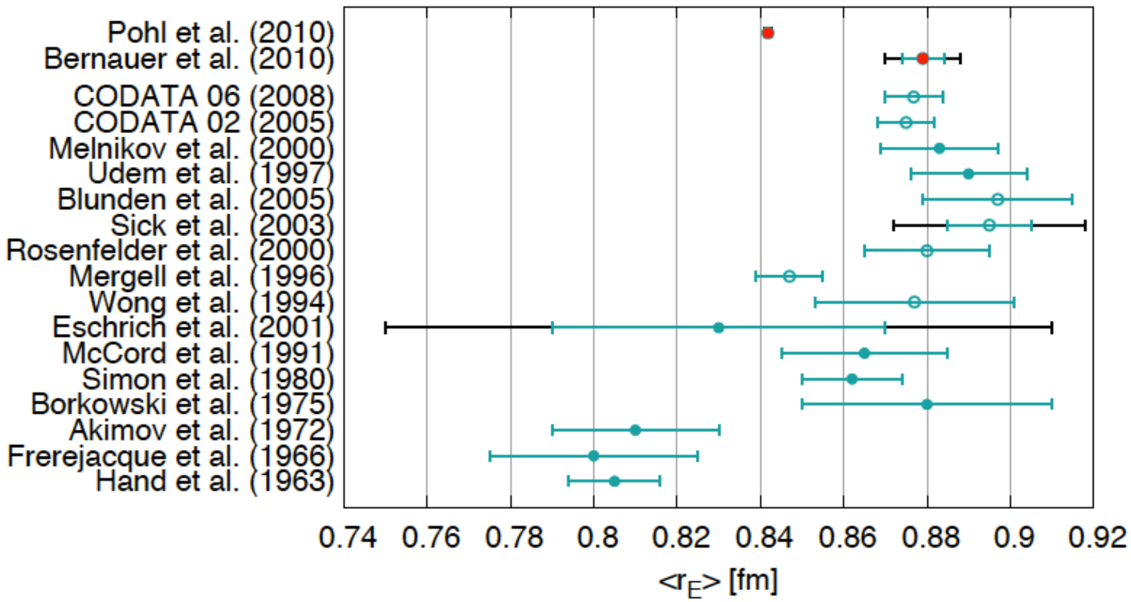
A1

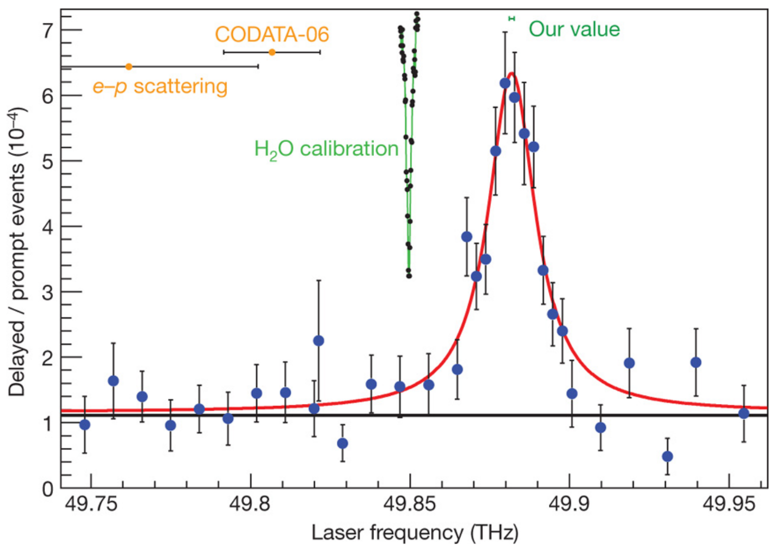
The proton radius puzzle

- **What is the size of the proton ?**
- Many different measurements (scattering exp., Lamb shift) done through the years.
- Consistent results.
- New μ-p Lamb measurement, 7σ away.
- Further investigations necessary.









Elastic Cross-Section measurement

- Radius can be obtained by measuring cross section of H(e,e')p:

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

$$\varepsilon = \left[1 + 2(1+\tau)\tan^2\frac{\vartheta_e}{2}\right]^{-1} \qquad \tau = \frac{Q^2}{4m_p^2},$$

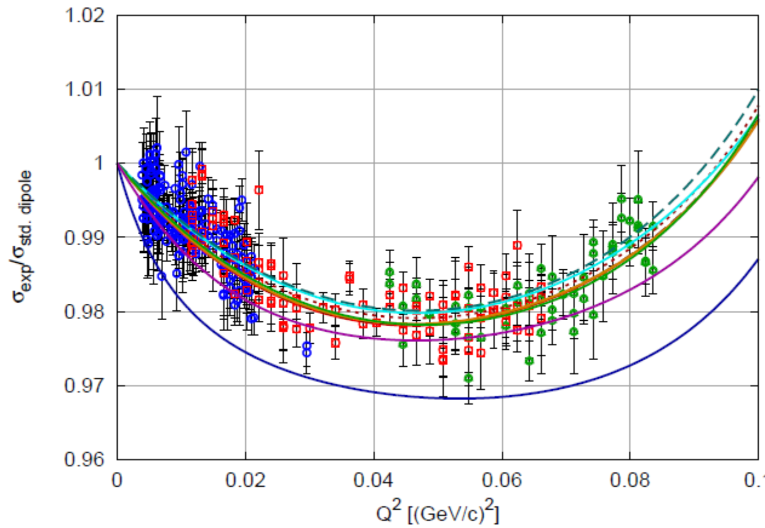
- Extraction of FF via Rosenbluth, Super-Rosenbluth Separation:

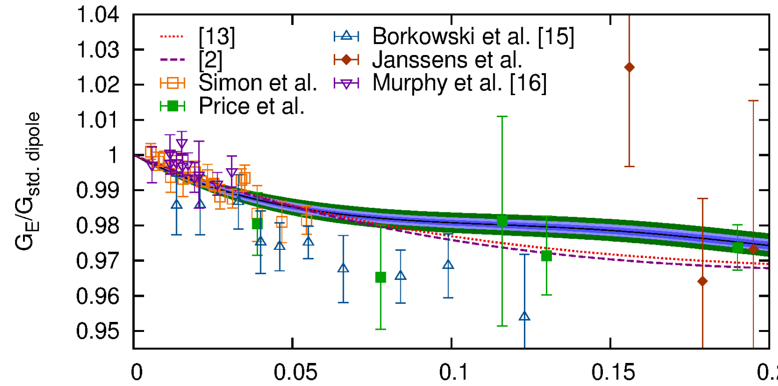
$$G_E(Q^2) \approx G^{Dipole}(Q^2) = \left(1 + \frac{Q^2}{0.71}\right)^{-2}$$

- Best estimate for radius:

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

$$\rho_{Dipole}(r) = \frac{1}{8\pi}\left(\frac{12}{\langle r_E^2\rangle}\right)^{\frac{3}{2}} \exp\left(-r\sqrt{\frac{12}{\langle r_E^2\rangle}}\right)$$





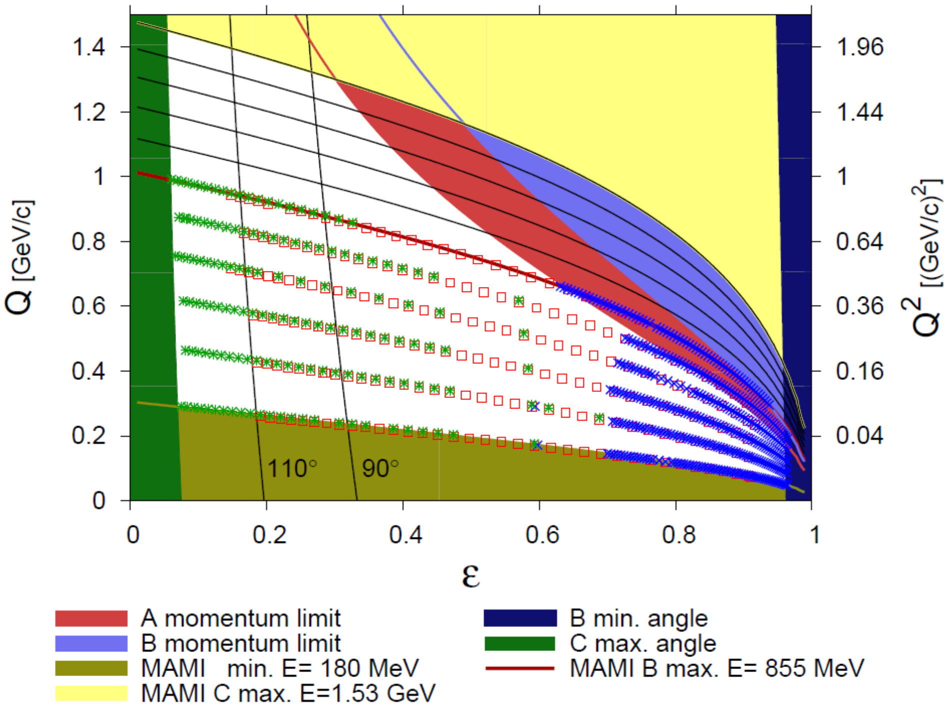
No data at lowest Q^2. Determination of proton radius depends on the slope of FF (Q^2->0).

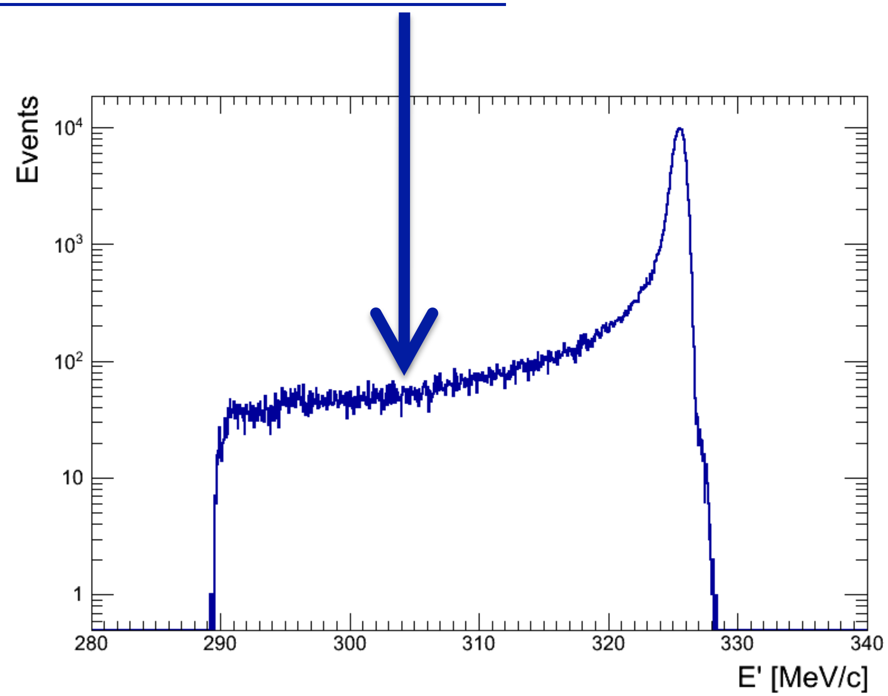
Exploiting the radiative tail

- To test the behavior of FFs at $Q^2 \sim 0$, elastic cross-section measurements at lower Q^2 would be needed.

- Lowest Q^2 is constrained by the limitations of experimental apparatus (Beam Energy, Scattering angle …).

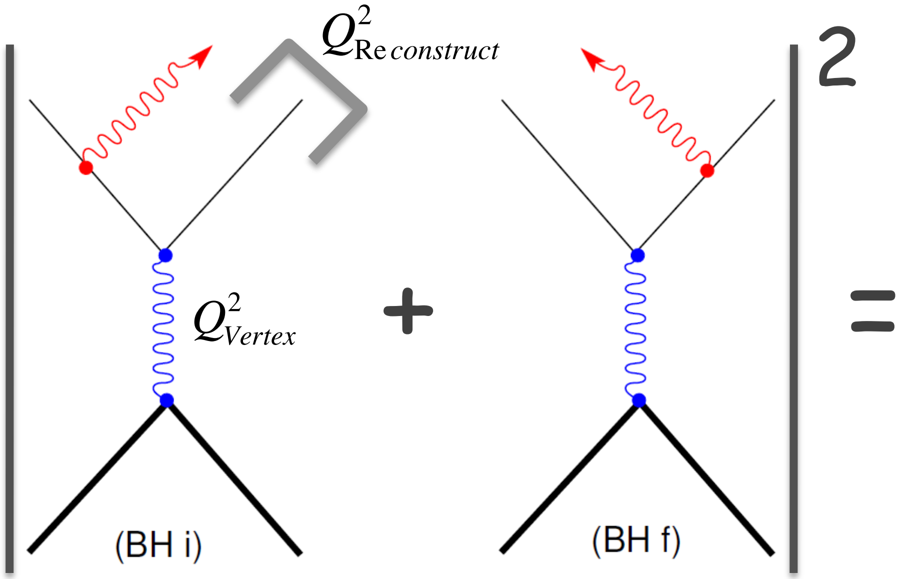
WAY AROUND: Use information stored in the radiative tail.

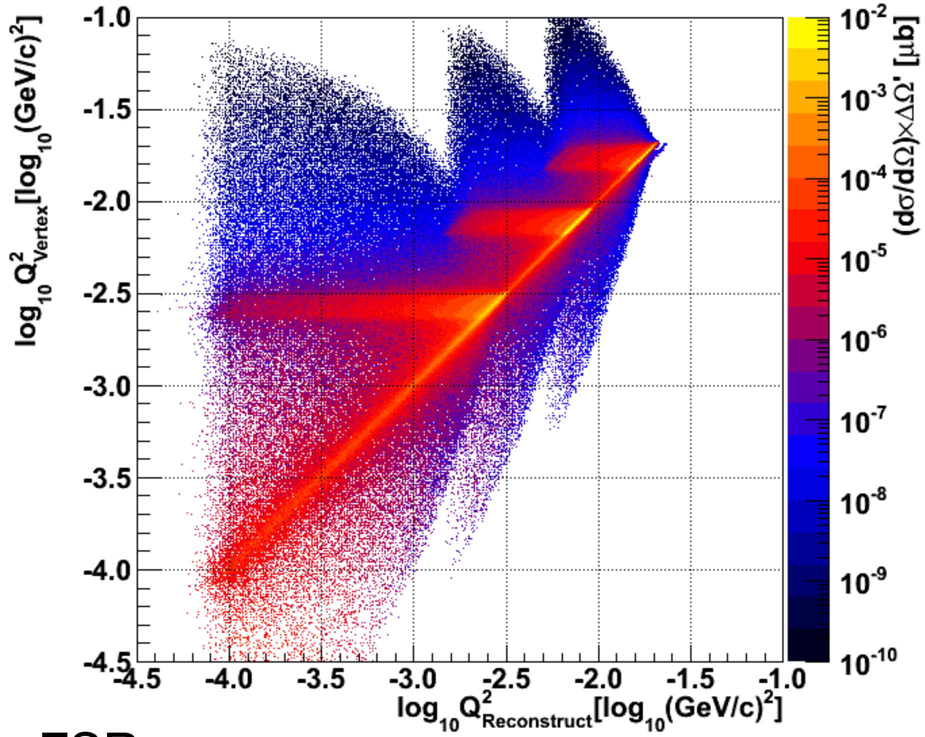




Initial state radiation

- Radiative tail dominated by coherent sum of two Bethe-Heitler diagrams.





- In data ISR can not be distinguished from FSR.

- **Combining data to the Simulation, ISR information can be reached**.

- Idea behind new MAMI experiment to extract $\mathbf{G_e^p}$ at **$Q^2 \sim 10^{-4}$ (GeV/c)^2**

- Redundancy measurements at higher Q^2 for testing this approach in a region, where FFs are well known.

Simul++

- In the experiment **the G_e^p will not be directly extracted** from data.

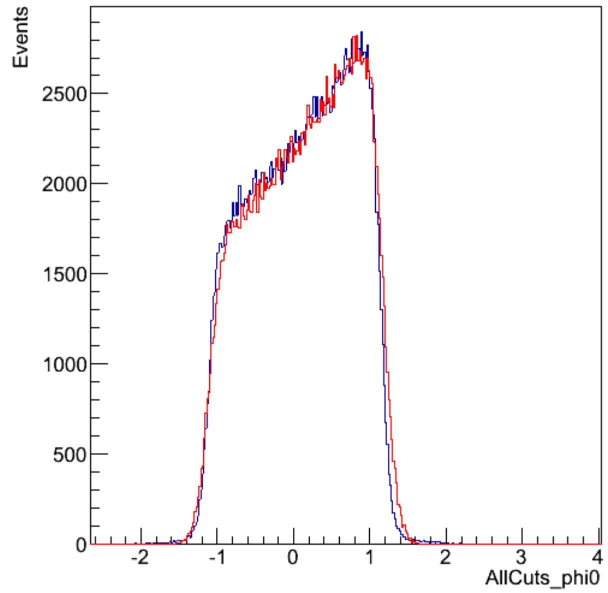
- <u>FF are camouflaged</u> by effects that accompany FSR and ISR diagrams (Born diagrams, vertex corrections).

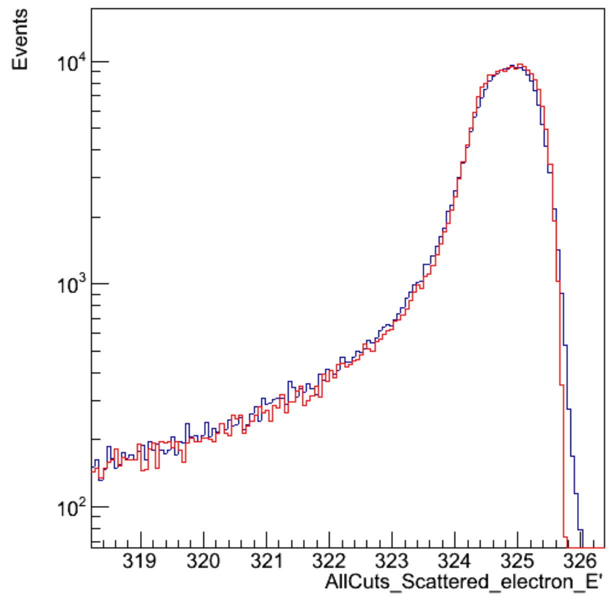
- Approach analogous to Bernauer et al. will be used, where **simulated distributions are directly compared to measured data**.

- Simulate **ep->epγ** with a sophisticated Monte-Carlo simulation Simul++.

- Simulation will be run with various values of G_E^p. Contribution of G_M^p is neglected @ Q^2~0.

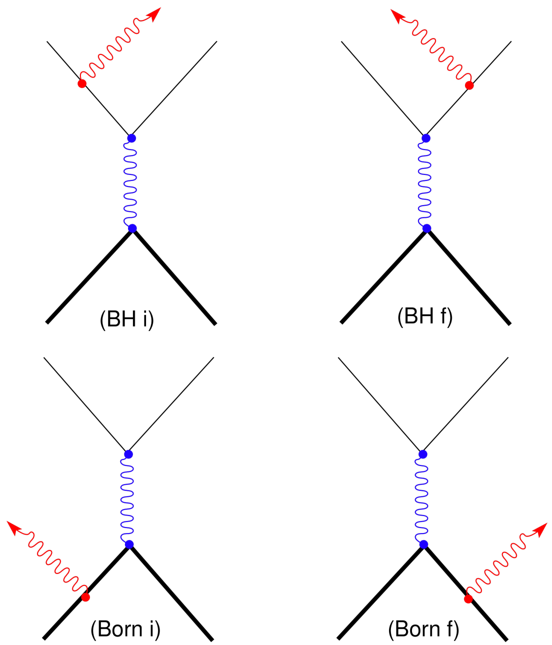
- Final values of FFs will be determined by a χ^2-minimization.





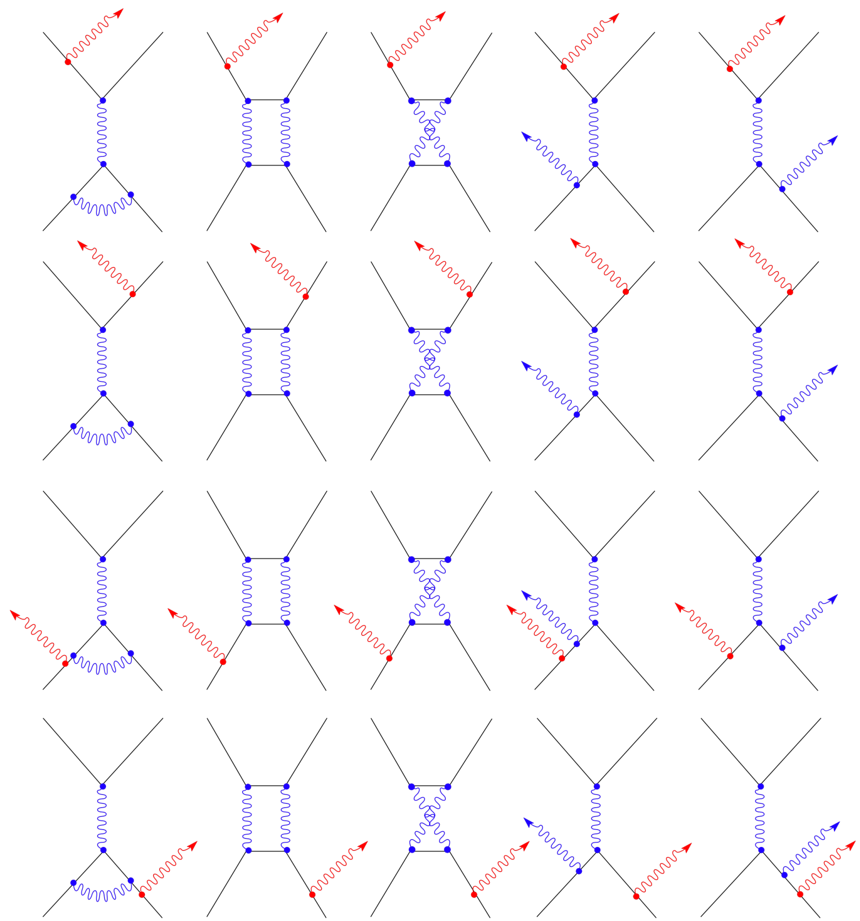
Going beyond simple approximation

- `Simul++` employs an advanced event generator, **which exactly calculates amplitudes for four leading order diagrams.**



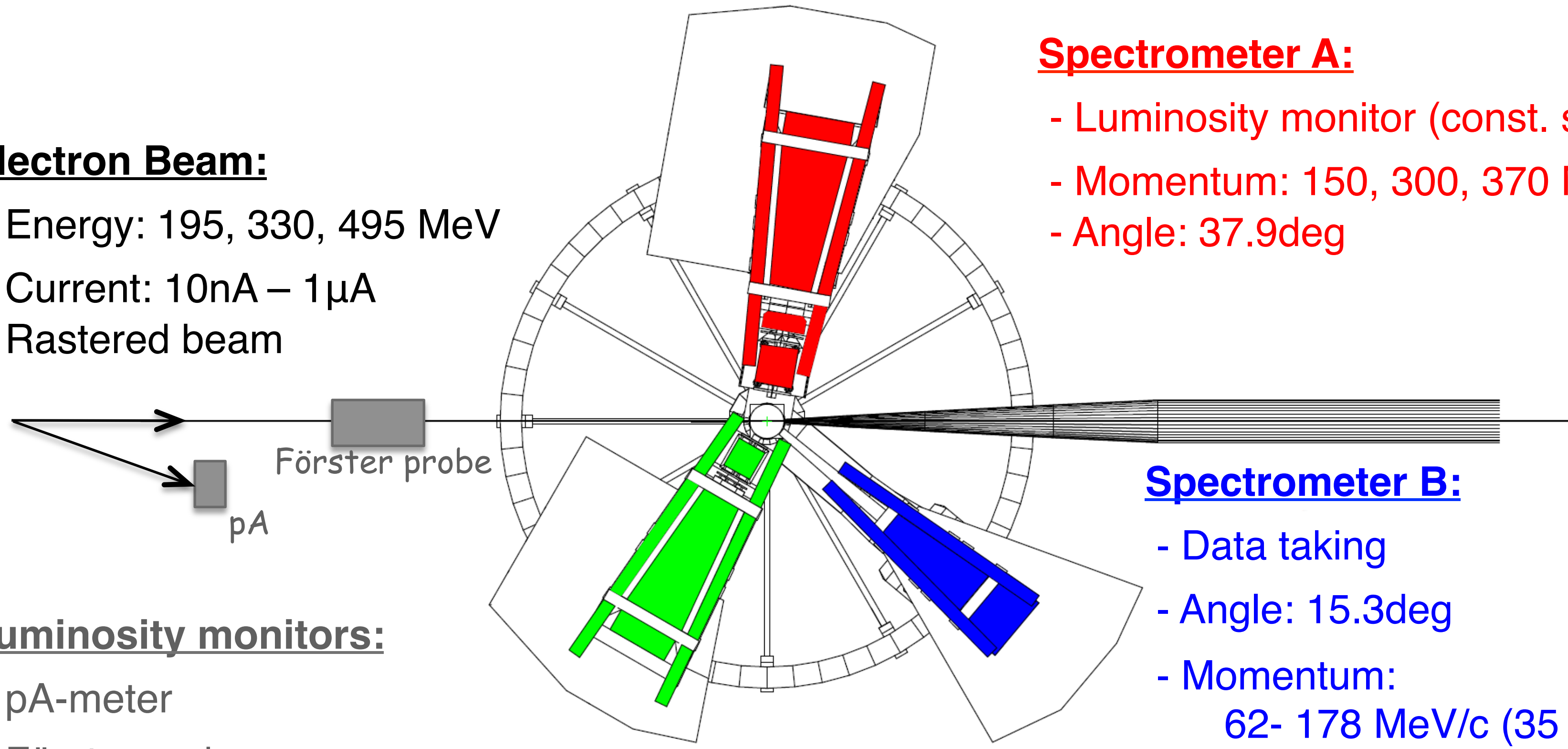
- Precise spectrometer acceptances, particle energy-losses and rescatterings are also implemented.

- Next order terms considered via effective correction to the cross-section.



First experiment

- First measurements done in 2010. Three weeks of data taking.
  (2 weeks with full target, 1 week with empty target)
- **Purpose:** Is the experiment feasible? Discover potential problems.



Spectrometer A:

- Luminosity monitor (const. setting)
- Momentum: 150, 300, 370 MeV/c
- Angle: 37.9deg

Electron Beam:

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

Spectrometer B:

- Data taking
- Angle: 15.3deg
- Momentum:
  62- 178 MeV/c (35 setups)
  167- 313 MeV/c (9 setups)
  236- 468 MeV/c (16 setups)

Luminosity monitors:

- pA-meter
- Förster probe

Spectrometer C:

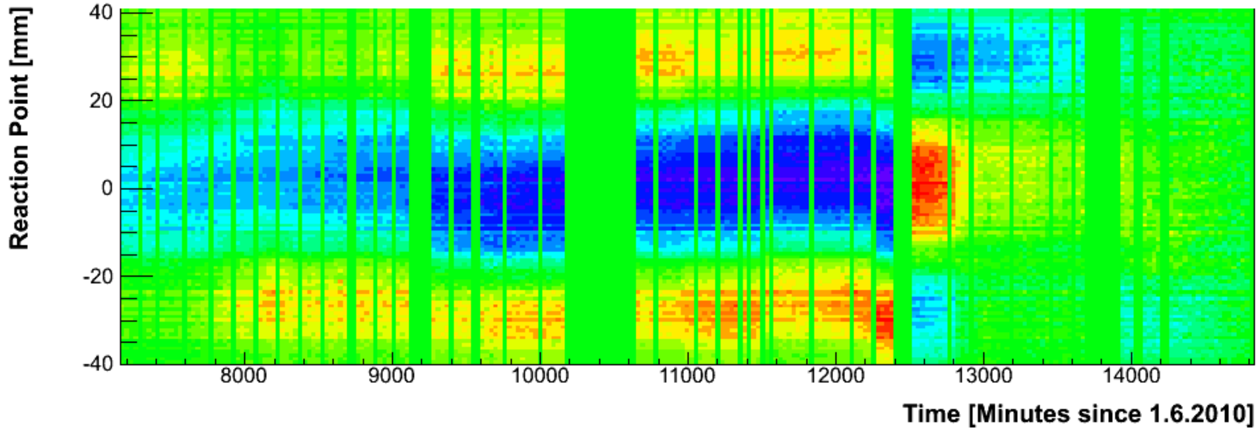
- Not used

Handicaps of the pilot measurement

- For many momentum settings no NMR available. Spectrometer momentum determined using Hall probes, which not absolutely calibrated.

- Optics matrix needs adjustments to improve resolution.

- Due to poor vacuum and low beam intensities, layer of **cryogens covered the target cell**.



+ Cryogenic depositions consist of residual Nitrogen, Oxygen and H_2O.

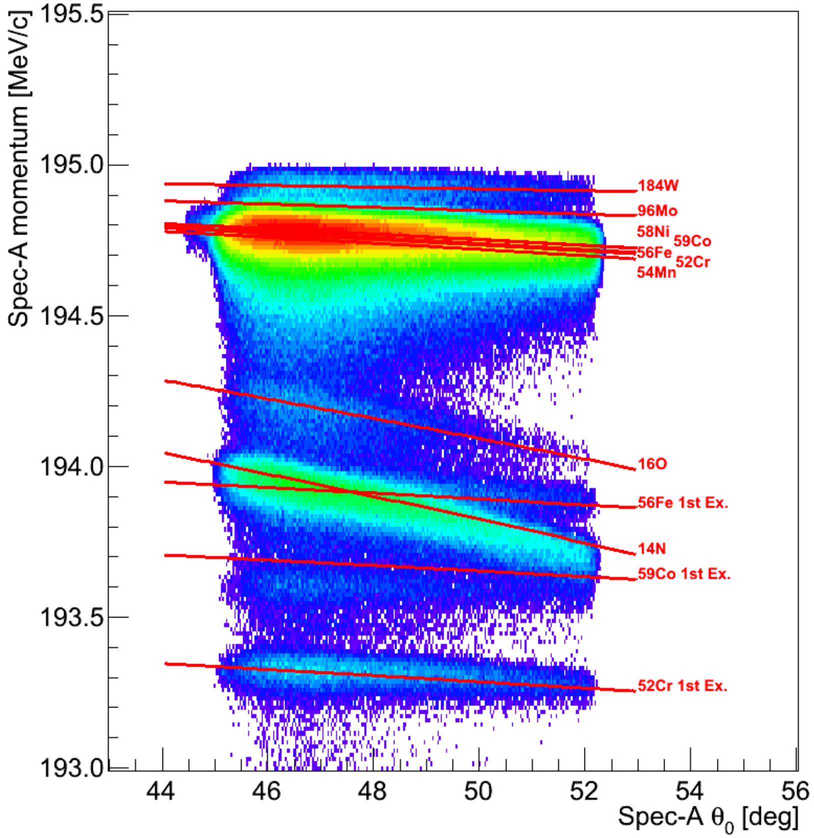
+ Disturbs Luminosity determination.

+ Amount of snow changes irregularly with time.

Improvements for the full experiment

To minimize the thickness of cryogens:

- Ensured **better vacuum** in target chamber ($10^{-4} \rightarrow 10^{-6}$ mbar).
- New target windows.
- Additional Aramid windows.
- Fixing Spectrometer A to elastic settings to see effects of snow gathering more clearly.



Spectrometer optics:

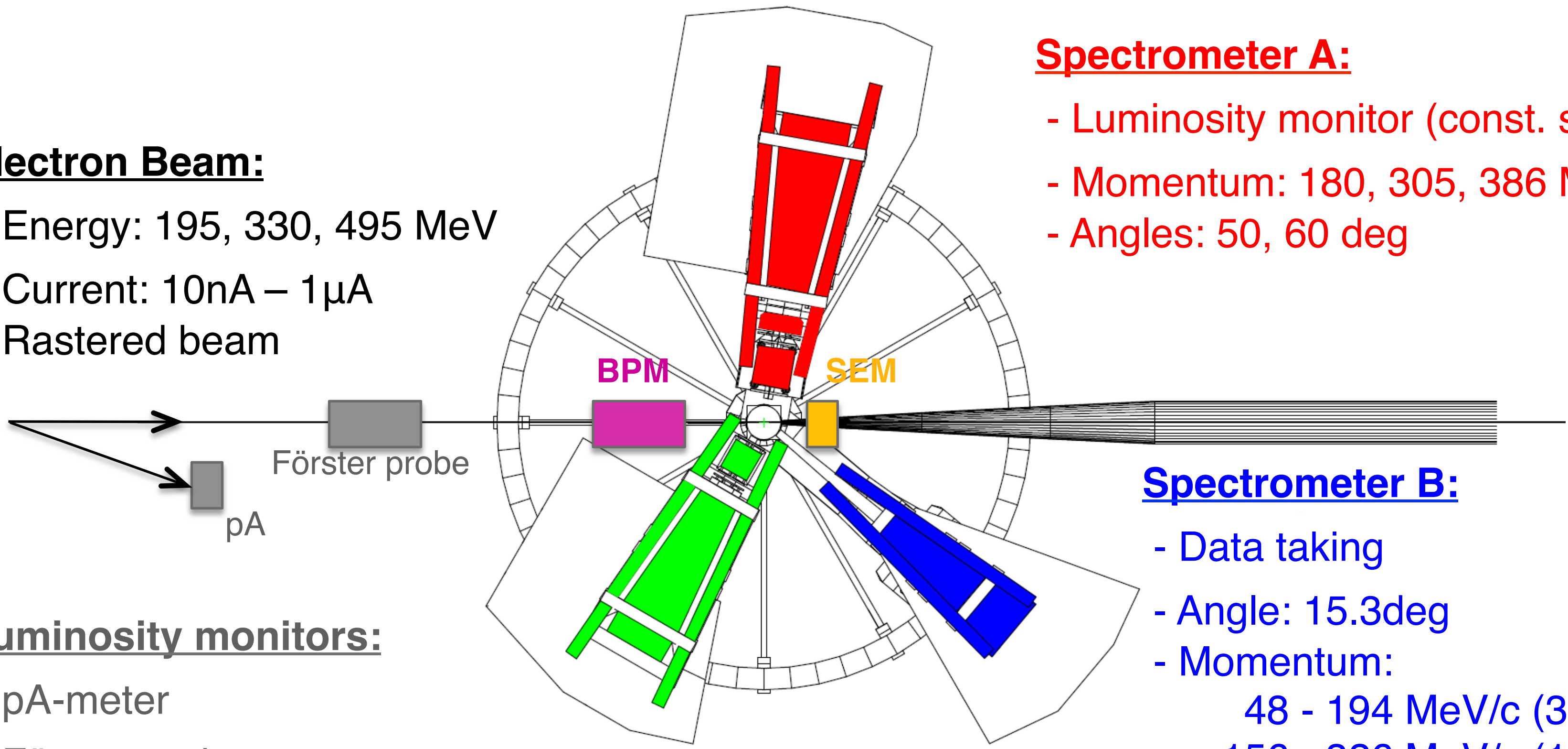
- Ensured that NMR signal is present for all kinematic points.
- Dedicated 2-week beam time for the optics calibration.
- Detailed analysis of detector efficiencies.
- For each kin. setting solid-state target data were collected.

Full experiment

- Full experiment done in August 2013. Four weeks of data taking.

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 deg

Spectrometer B:

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

Luminosity monitors:

- pA-meter
- Förster probe
- SEM

Spectrometer C:

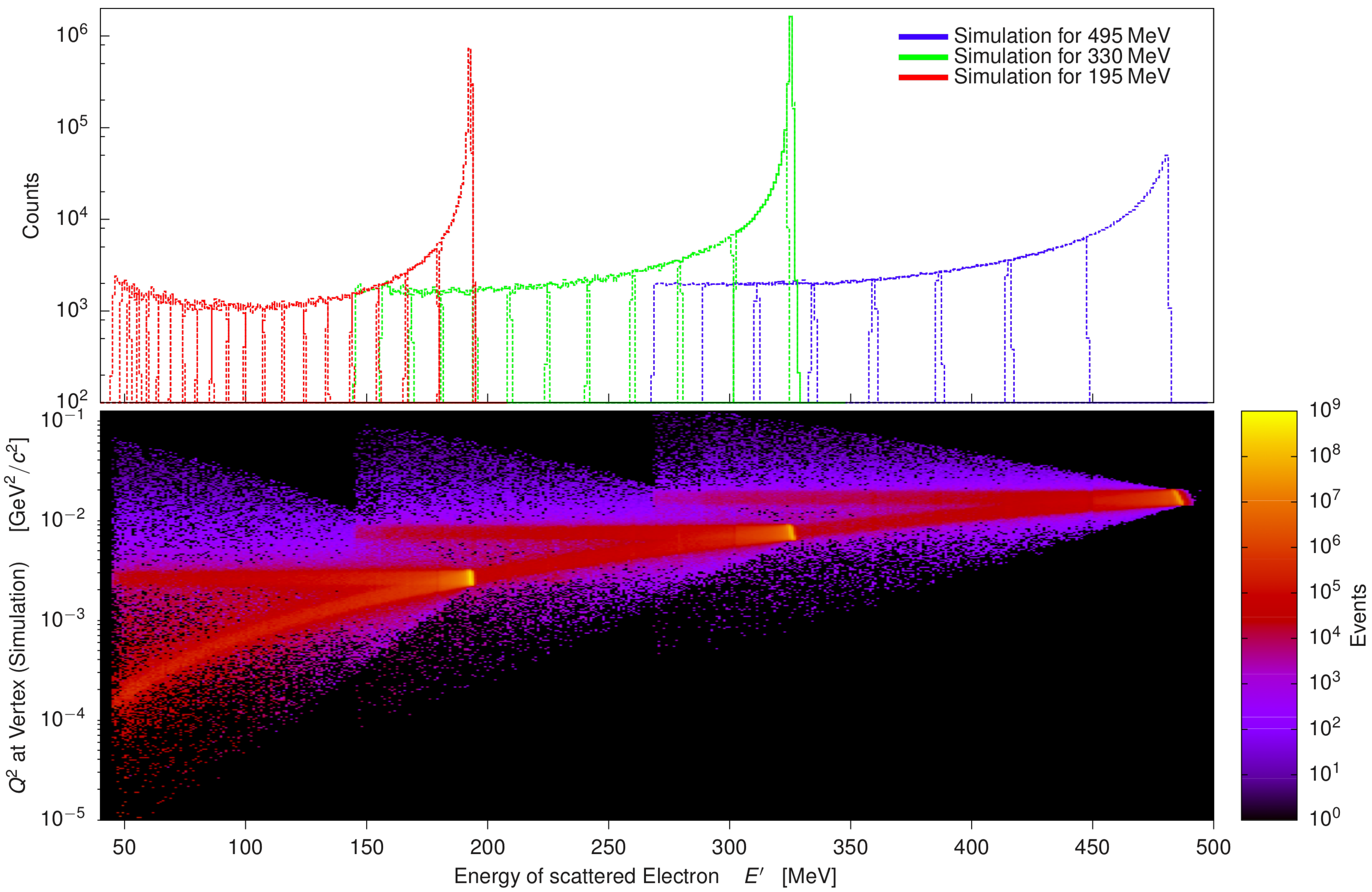
- Not used

Beam control module:

- Communicates with MAMI and ensures very stable beam.
- BPM and pA meter measurements performed automatically every 3min.

Kinematic settings of the full experiment

- Measured kinematic points and corresponding Q^2 at vertex.
- Three kinematic regions overlap to verify ISR approach.



First Results

- First findings of online analysis.

- Data are normalized to 0.1mC using Forster probe & Spek-A.

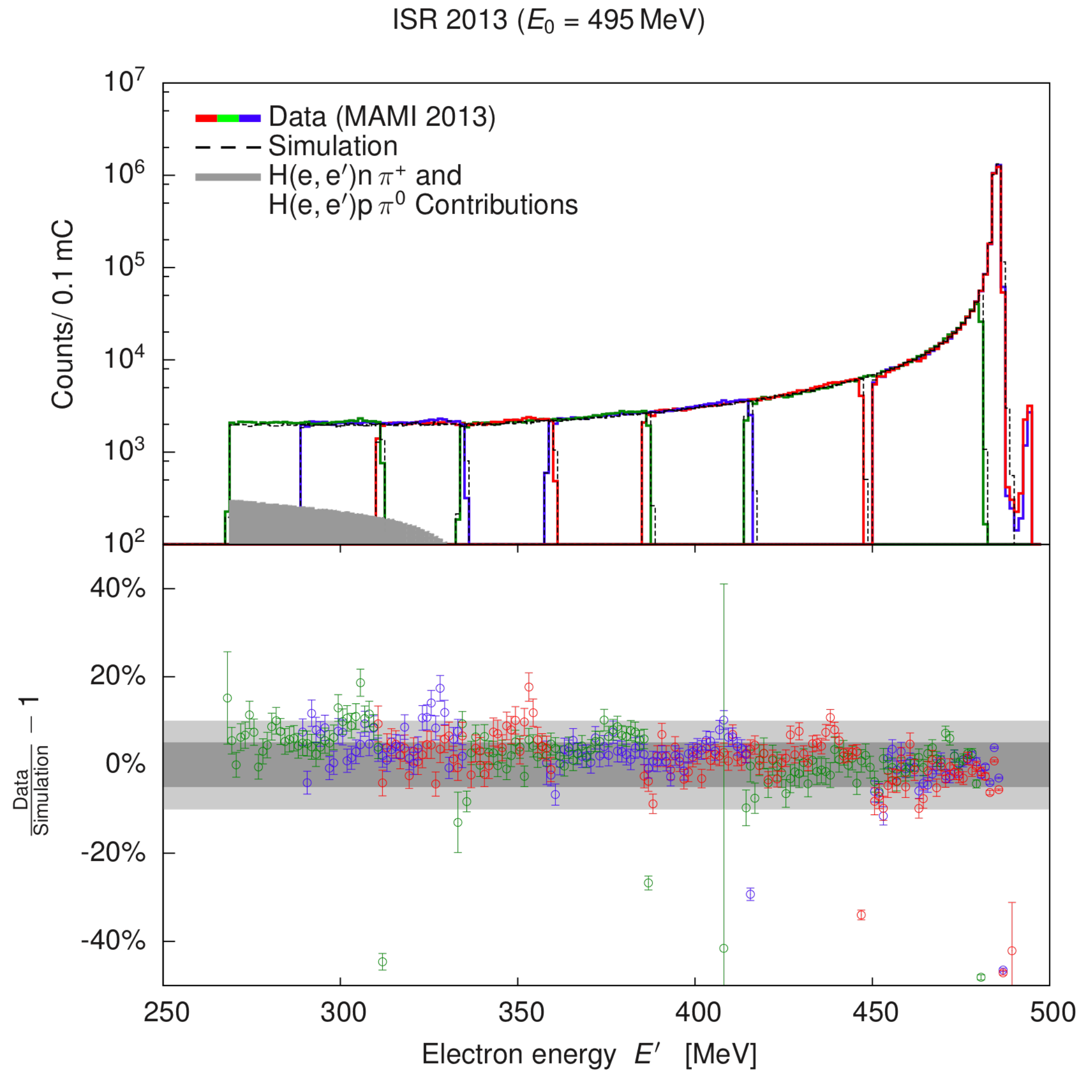
- Only acceptance and Vertex-z cuts considered.

- Pion production processes contribute ~10% at smallest momenta.

- Coarse structure on top of distributions caused by changing detection efficiency.

- Visible effects of finite resolution. (wall contributions still present)

- **Agreement between data and simulation justifies use of Simul++.**

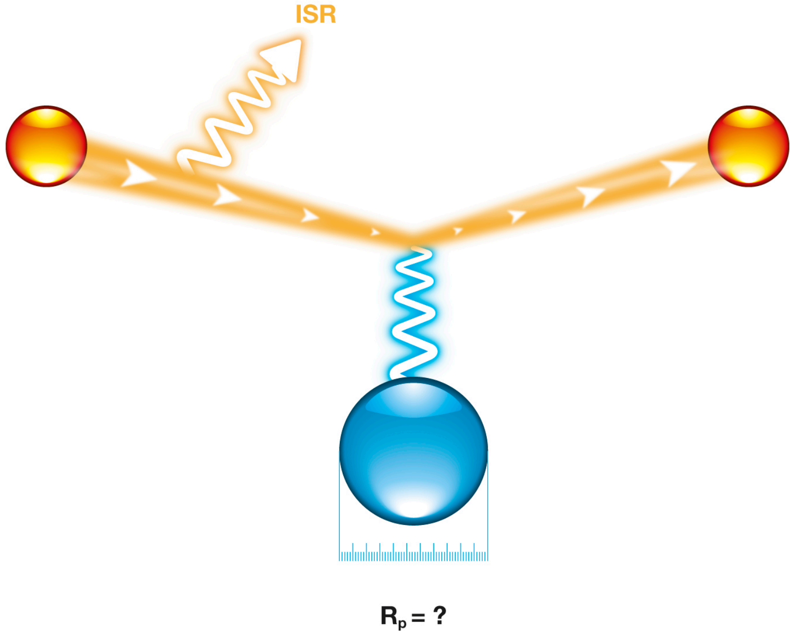


Conclusions

- Proton radius puzzle is an important open question of nuclear physics.

- A new experiment is underway at MAMI to measure G_E^p at very low Q^2.

- A new technique is being used based on ISR, which exploits information from radiative tail to determine FF at lowest Q^2.



- First test measurements in 2010 revealed problems with cryogens covering the target cell and spectrometer optics.

- All diagnosed obstacles were addressed.

- Full experiment was successfully run in August 2013.

- **Data analysis is now underway.**


Thank you !