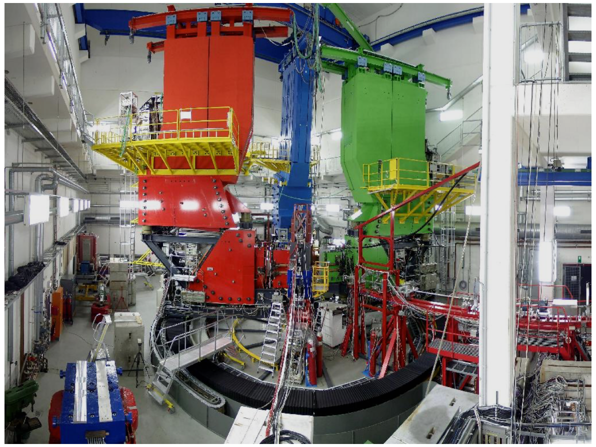
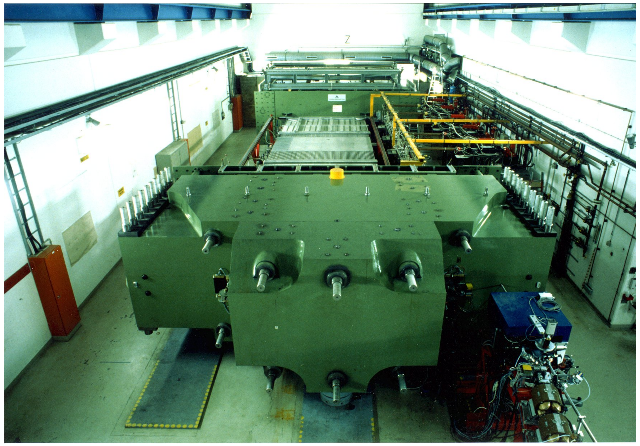
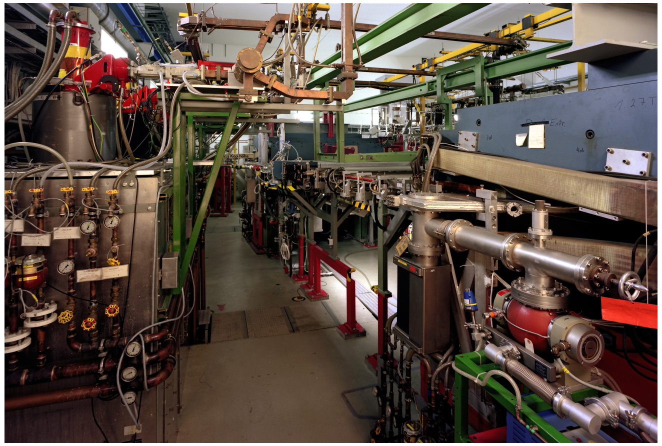




ISR Experiment at MAMI

Miha Mihovilovic

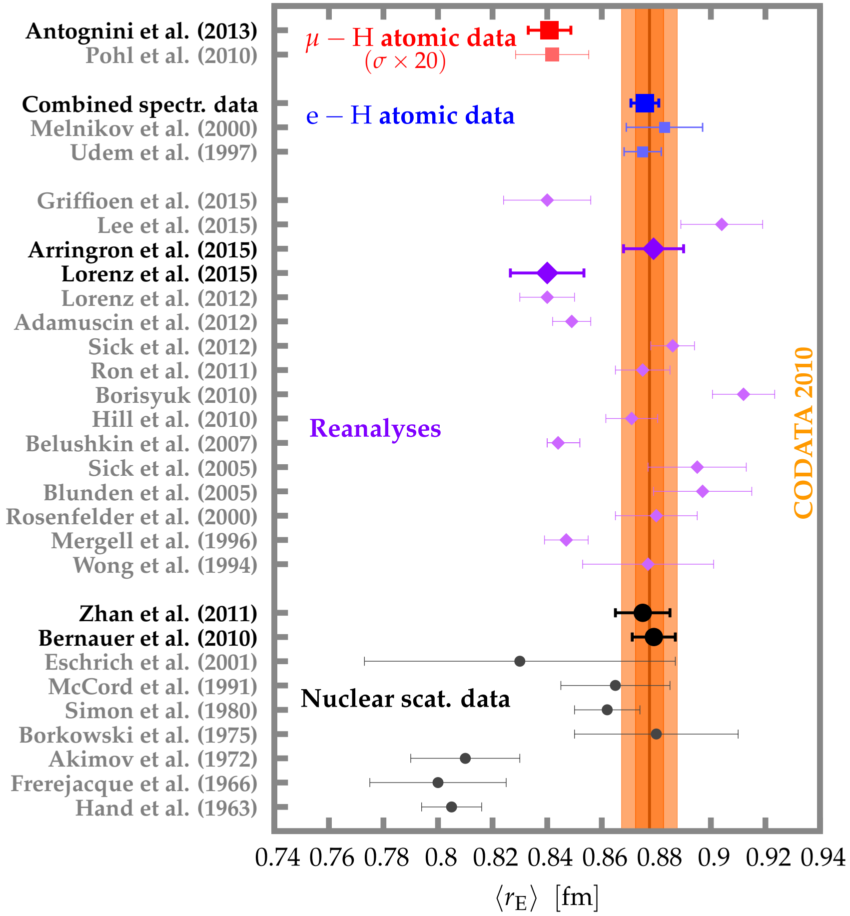
JGU Mainz and JSI

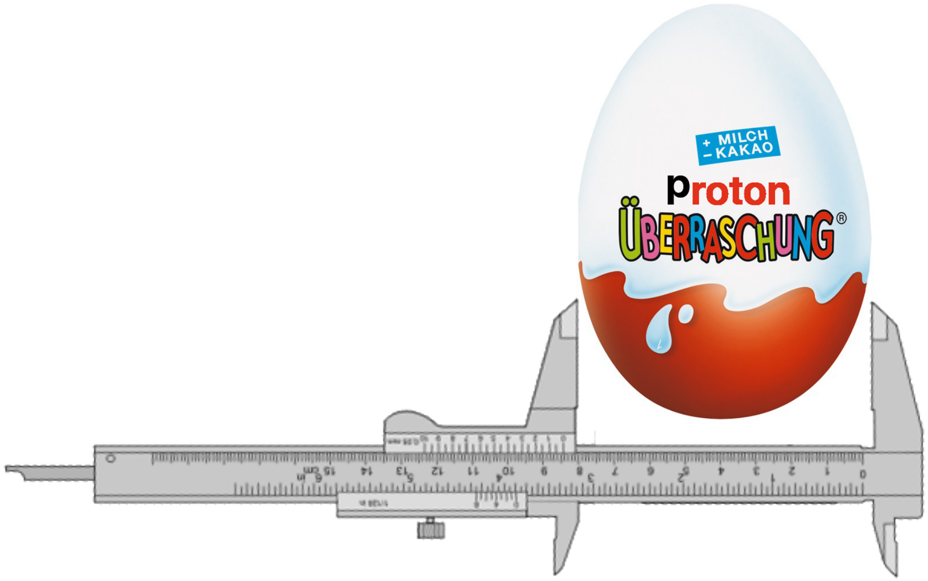
ECT* Workshop, Trento 2016

THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

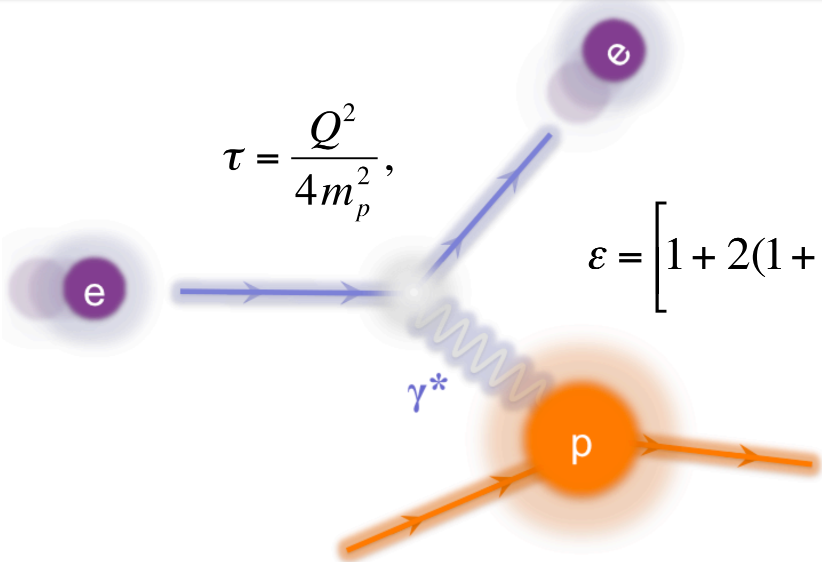
The proton radius problem

- The 8σ discrepancy in the r_p measurements questions QED.
- Nuclear results questionable due to the lack of data at very low Q^2.
- ISR aims to provide new insight into the matter!





Radius via Cross-section measurement



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

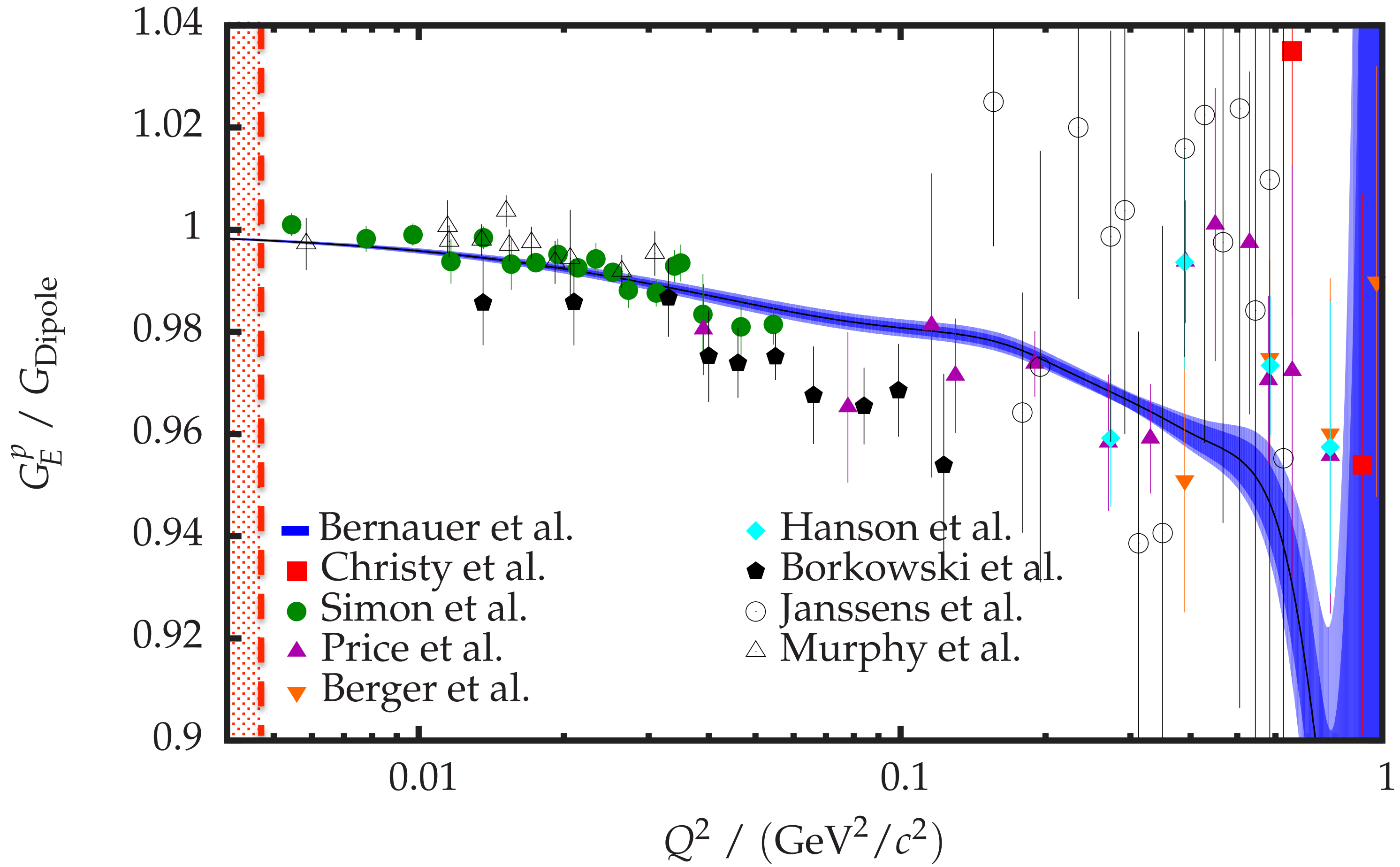
$$\varepsilon = \left[1 + 2(1+\tau)\tan^2\frac{\vartheta_e}{2}\right]^{-1}$$

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

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

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

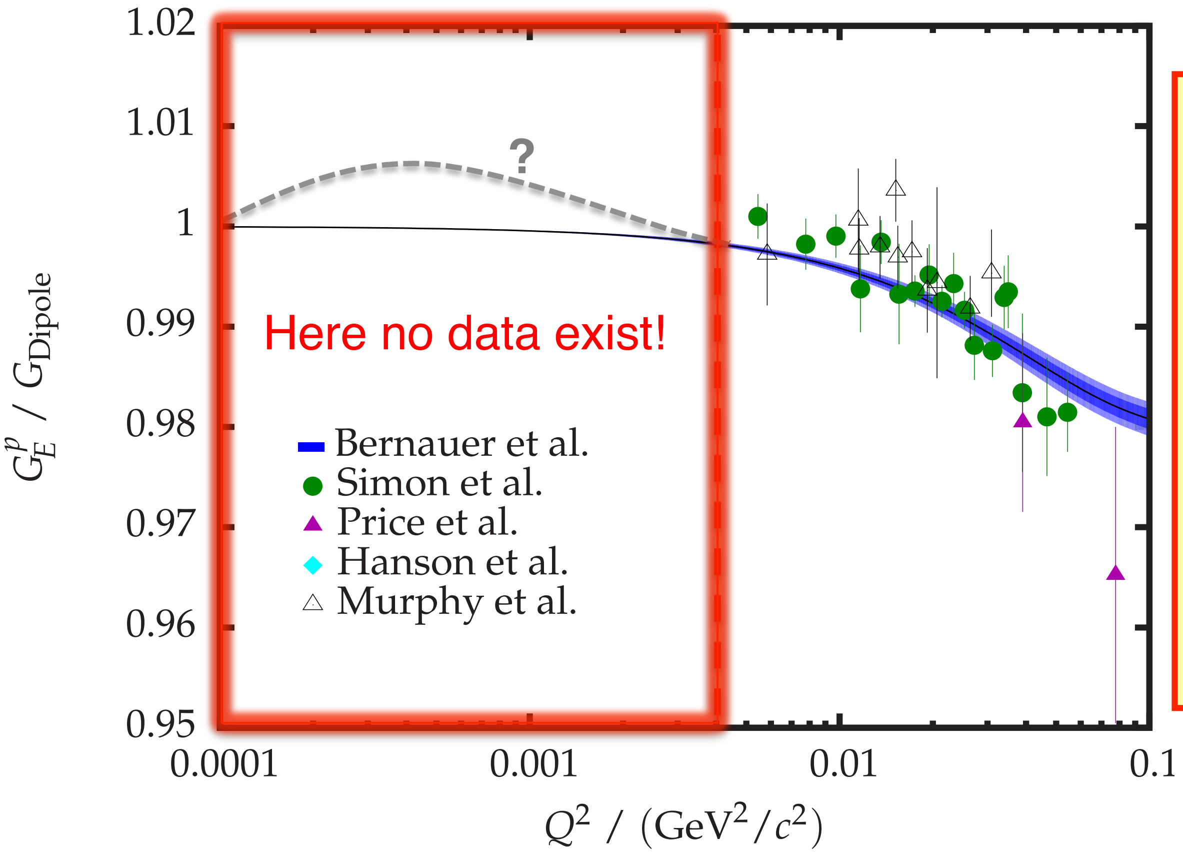
Proton’s charge form-factor



- **Data available only for Q^2 > 0.004 (GeV/c)^2.**
- **Extrapolations to zero are needed!**
- Instabilities related to extrapolation are sources of systematic offsets.

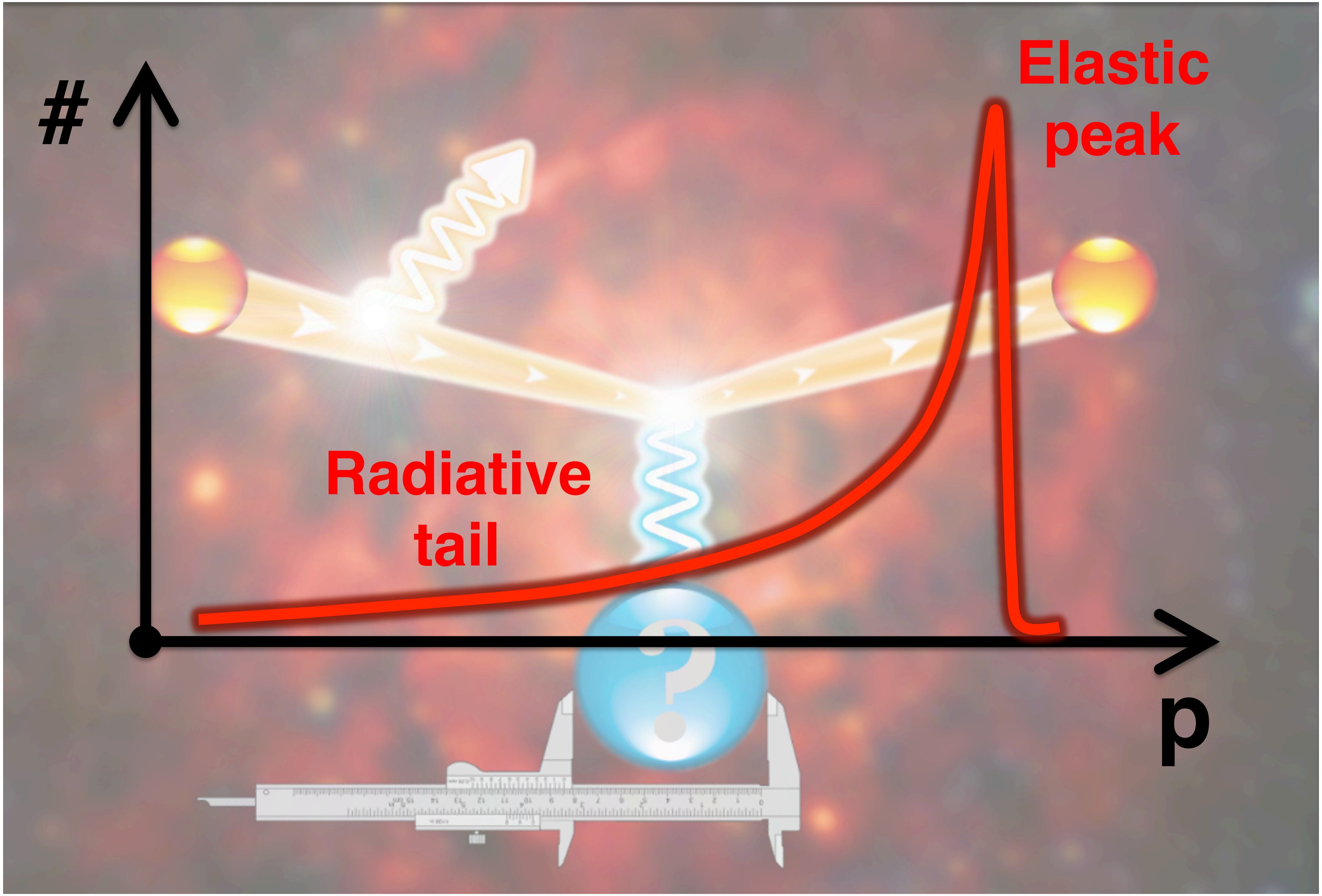
New electron scattering experiment

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



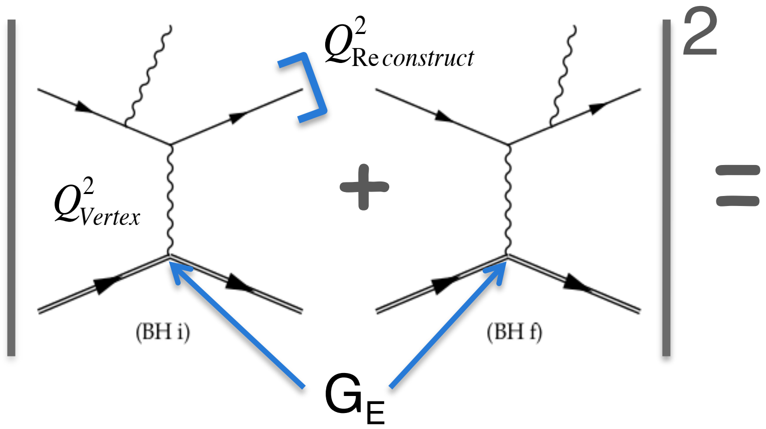
- Region of $Q^2 < 0.004$ (GeV)^2 is extremely hard to reach.
- Kinematic range is **limited by available experimental apparatus.**
- Novel techniques are needed to explore extremely low Q^2 regime.

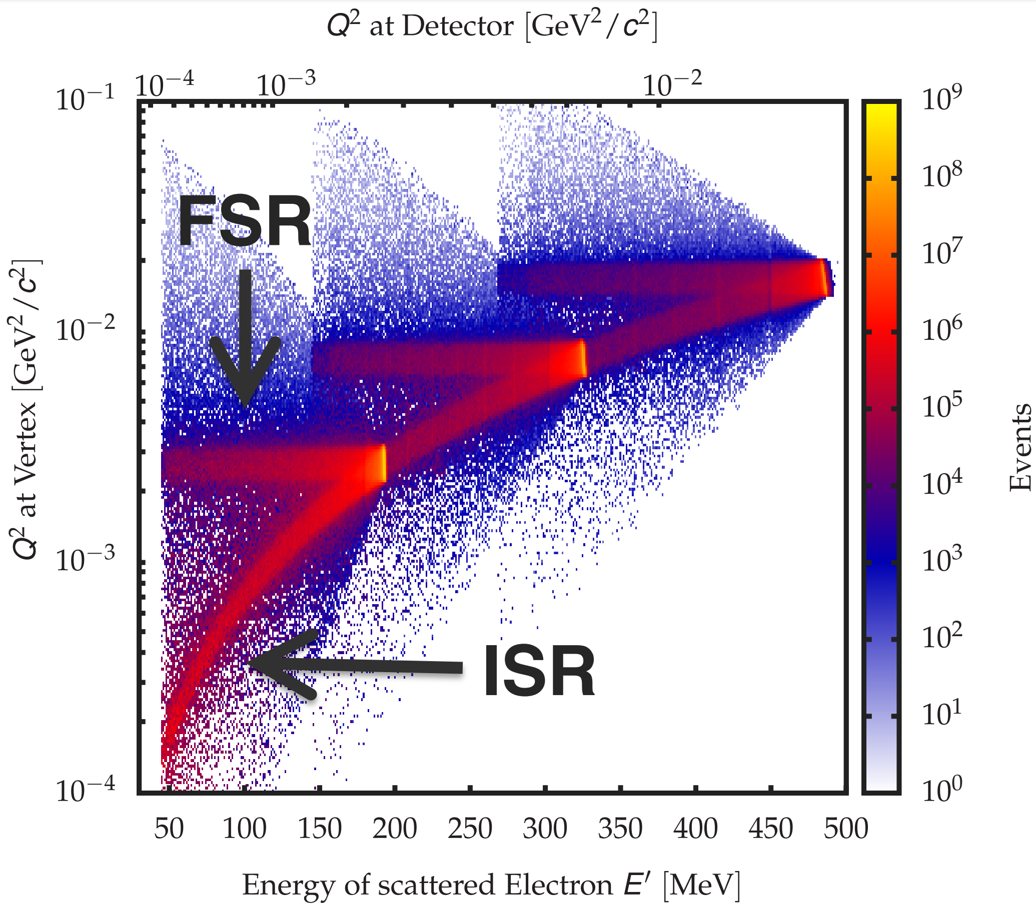
ISR Experiment at MAMI



Radiative tail

- Dominated by coherent sum of two Bethe-Heitler diagrams.

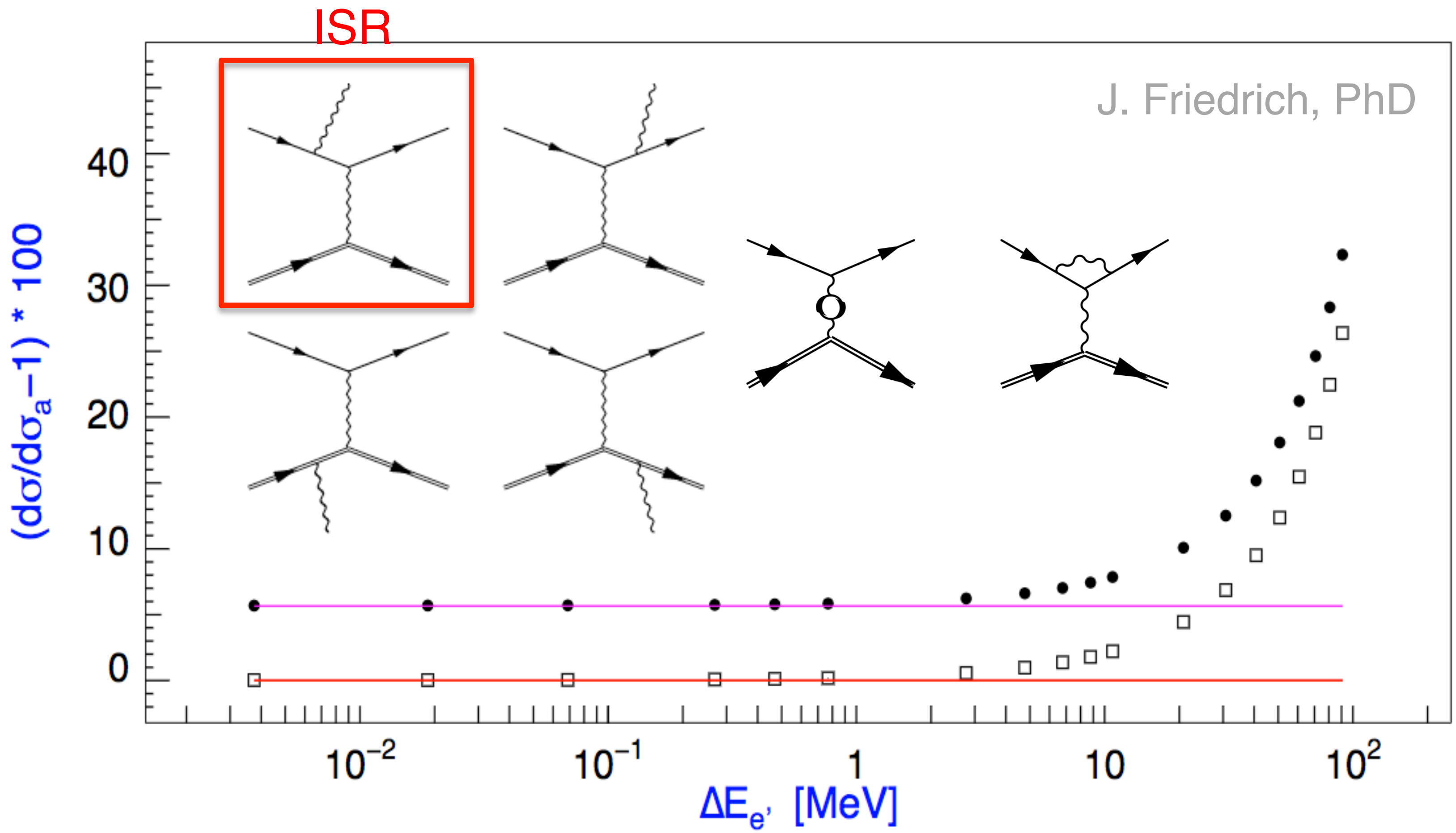




- In data ISR can not be distinguished from FSR.
- **Combining data with the simulation, ISR information can be reached.**
- Redundancy measurements at higher Q^2 for testing this approach in a region, where FFs are well known.

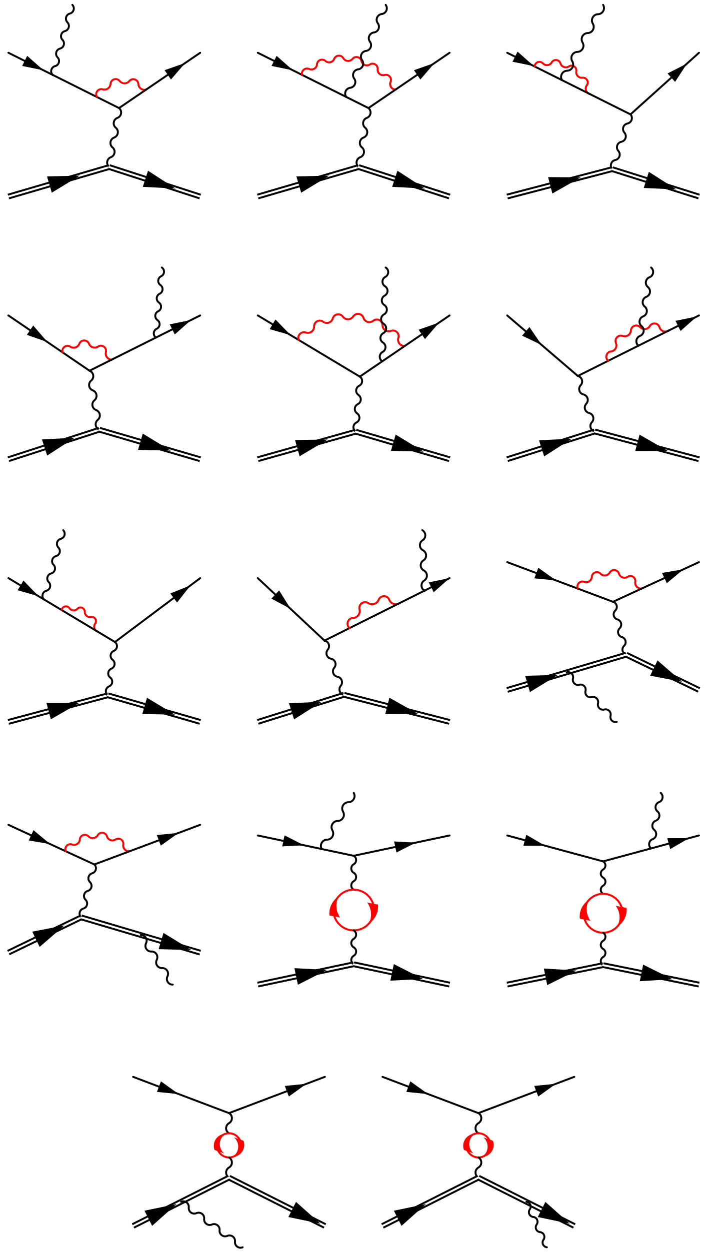
Simul++

- Based on standard A1 framework for the VCS experiments.
- Detailed description of apparatus.
- Exact calculation of the leading diagrams for high precision.



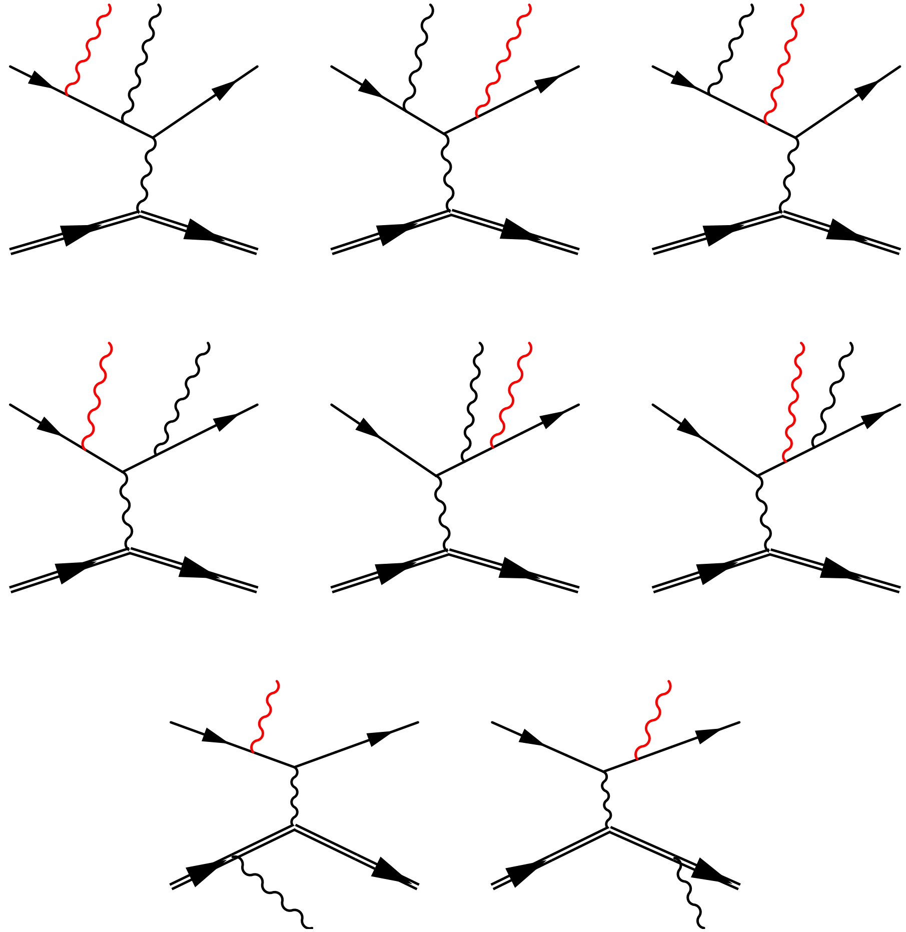
Virtual corrections

- Based on work of Vanderhaeghen et al.
- Due to computational intensiveness used as effective corrections.
- Integration of loops optimized for the VCS conditions **far away from elastic line!**
- Only electrons considered in vacuum polarization loops.



Real corrections

- Second order real photon corrections considered in terms of peaking approximation.

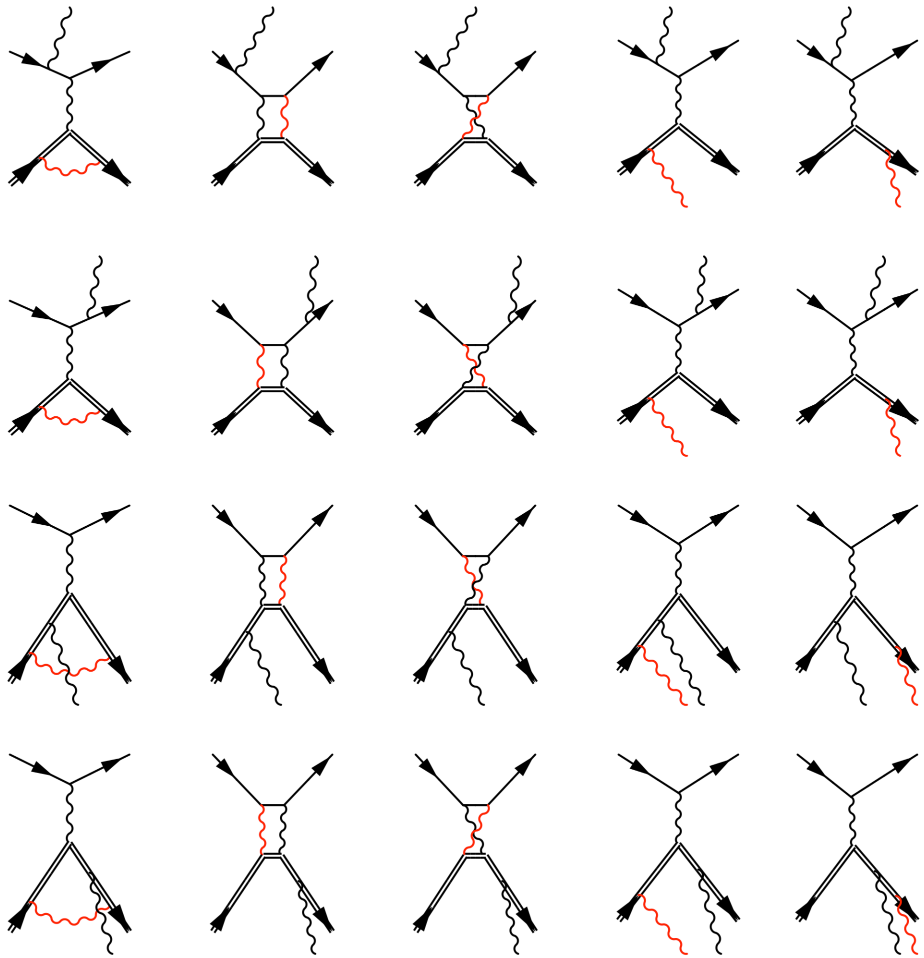


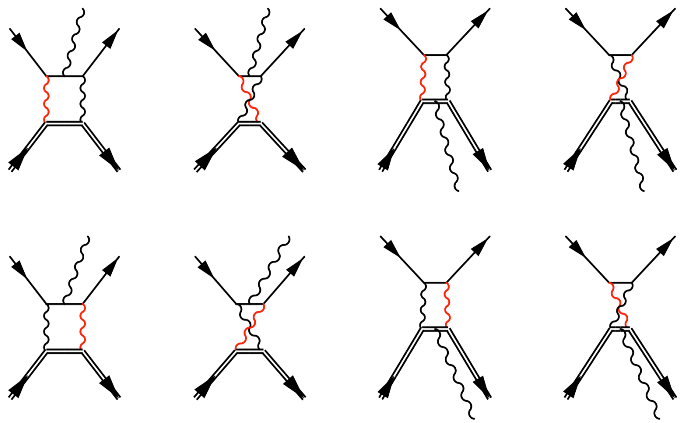
- External radiative corrections (Straggling) considered using approach of Mo-Tsai.
- Only contributions from Hydrogen and Air are relevant.

Hadronic corrections

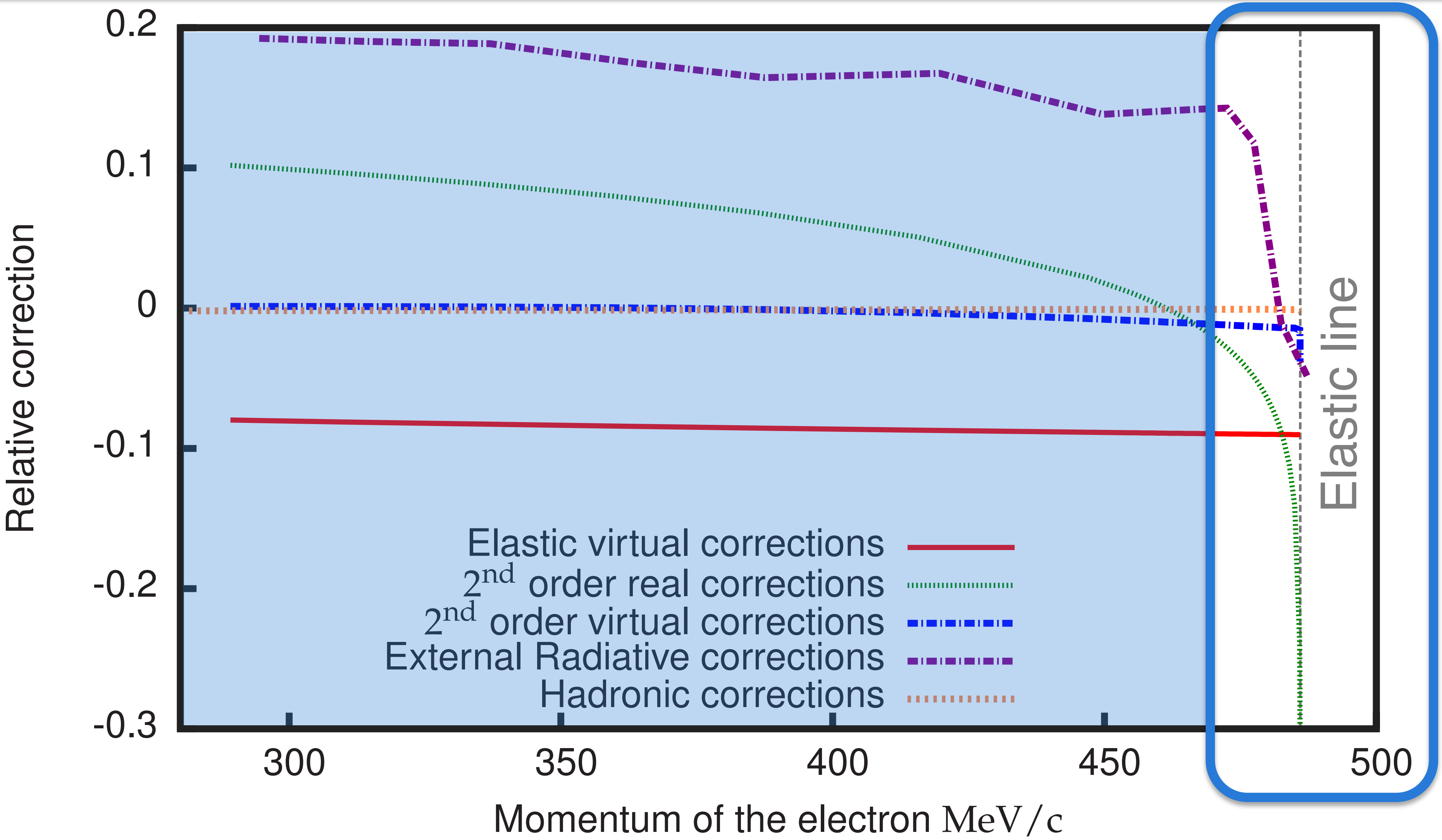
- Hadronic corrections considered in the limit of elastic scattering using approximation of Maximon-Tjon.

- Proton is kept on-shell.





Size of effective corrections



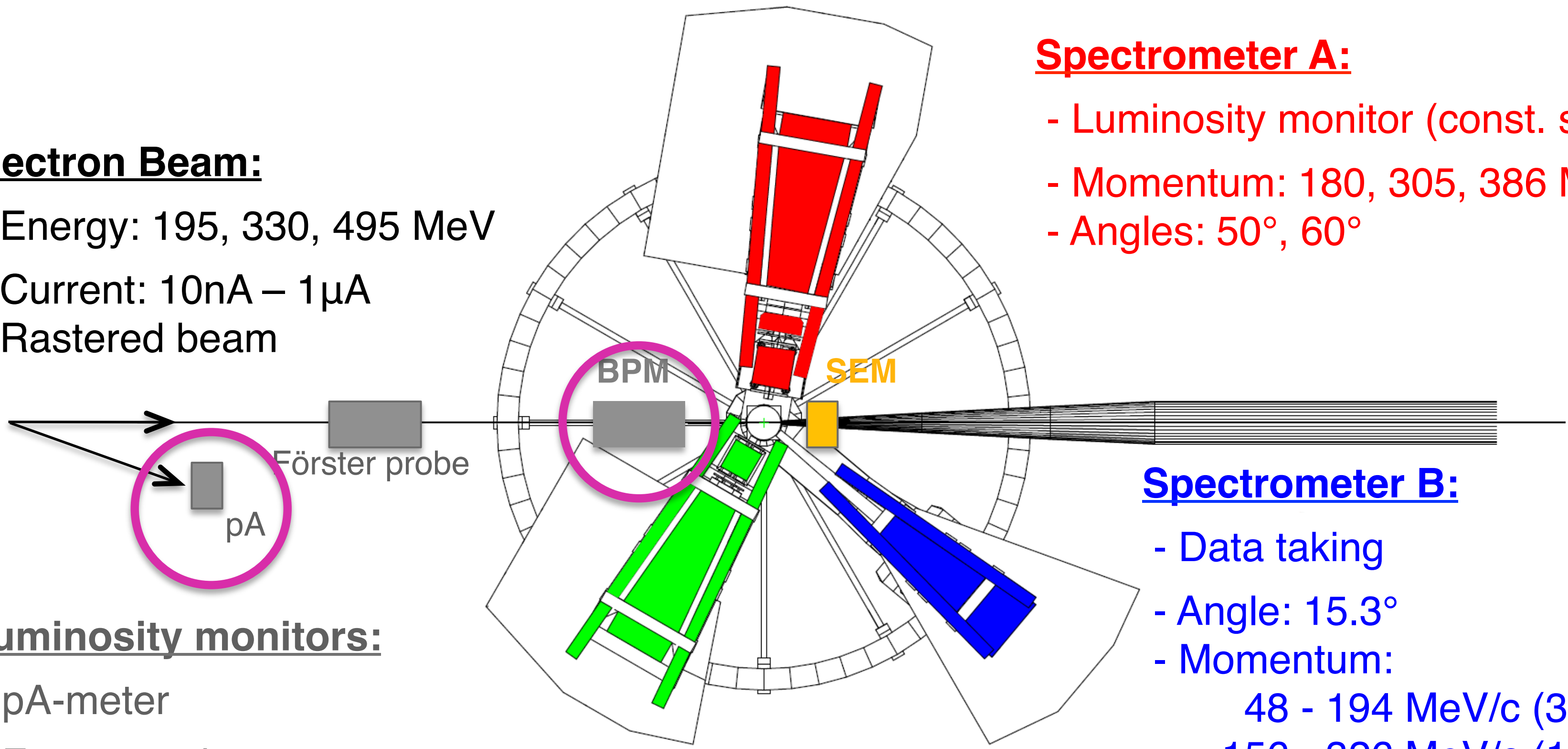
- **Precision of numerical calculations limited at the elastic line.**

The ISR 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°

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)

Luminosity monitors:

- pA-meter
- Förster probe
- SEM

Spectrometer C:

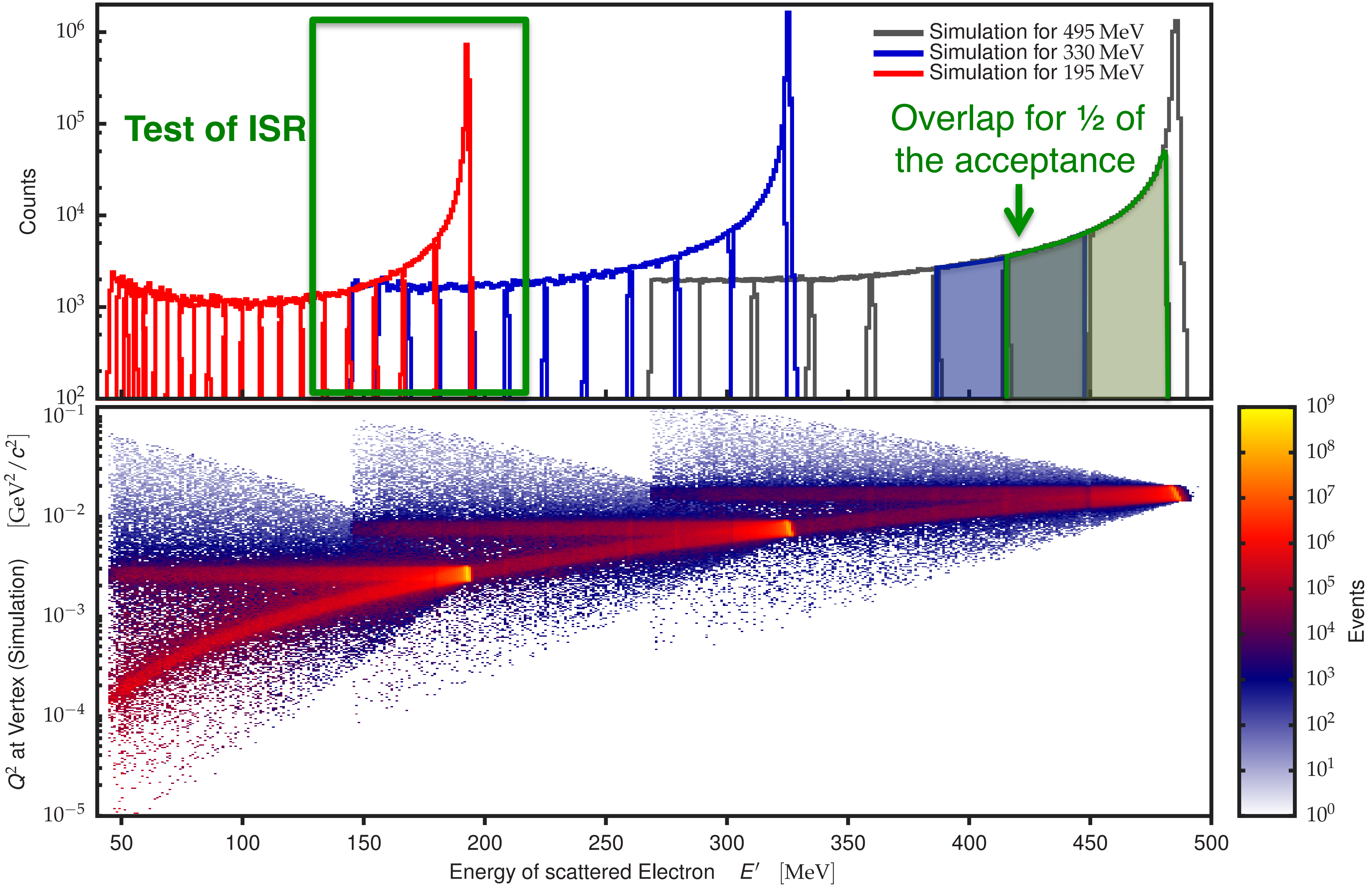
- Not used

Beam control module:

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

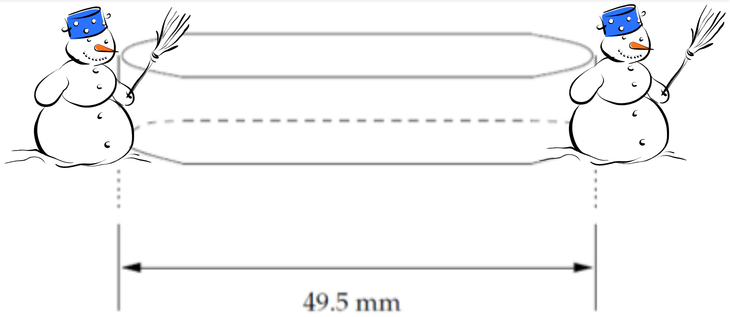
Kinematic settings

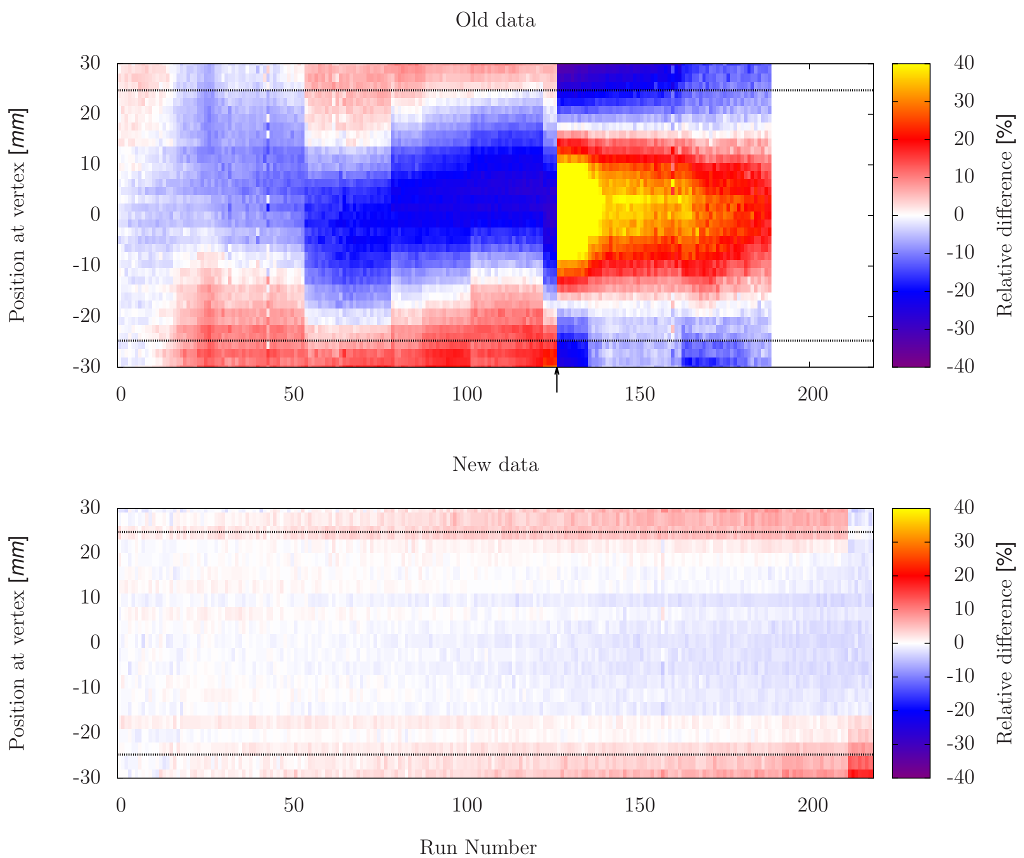
- Overlapping settings for validation of ISR technique.
- Length of the tail limited by Pion production processes!



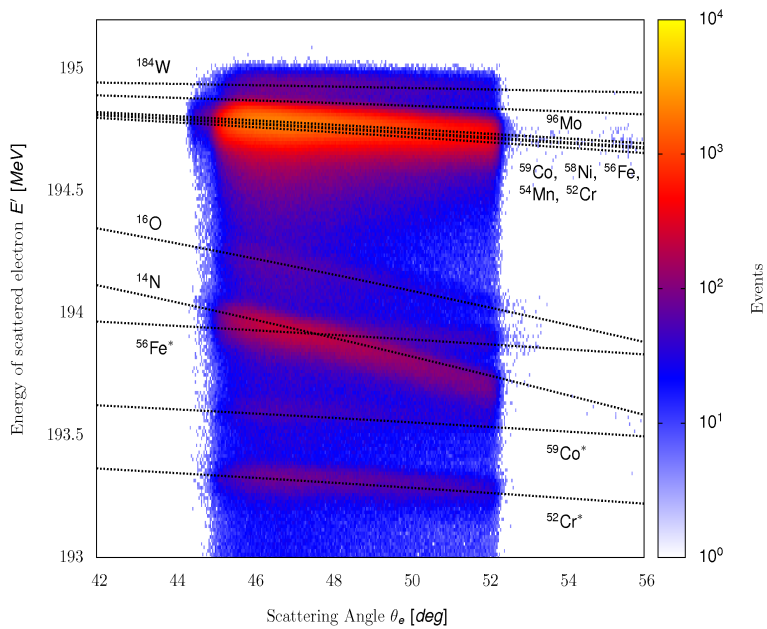
Cryogenic depositions

- Disturbs Luminosity determination.
- **Good vacuum** in target chamber (10^{-6} mbar)
- Fixing Spectrometer A to elastic settings to see effects of snow gathering more clearly.



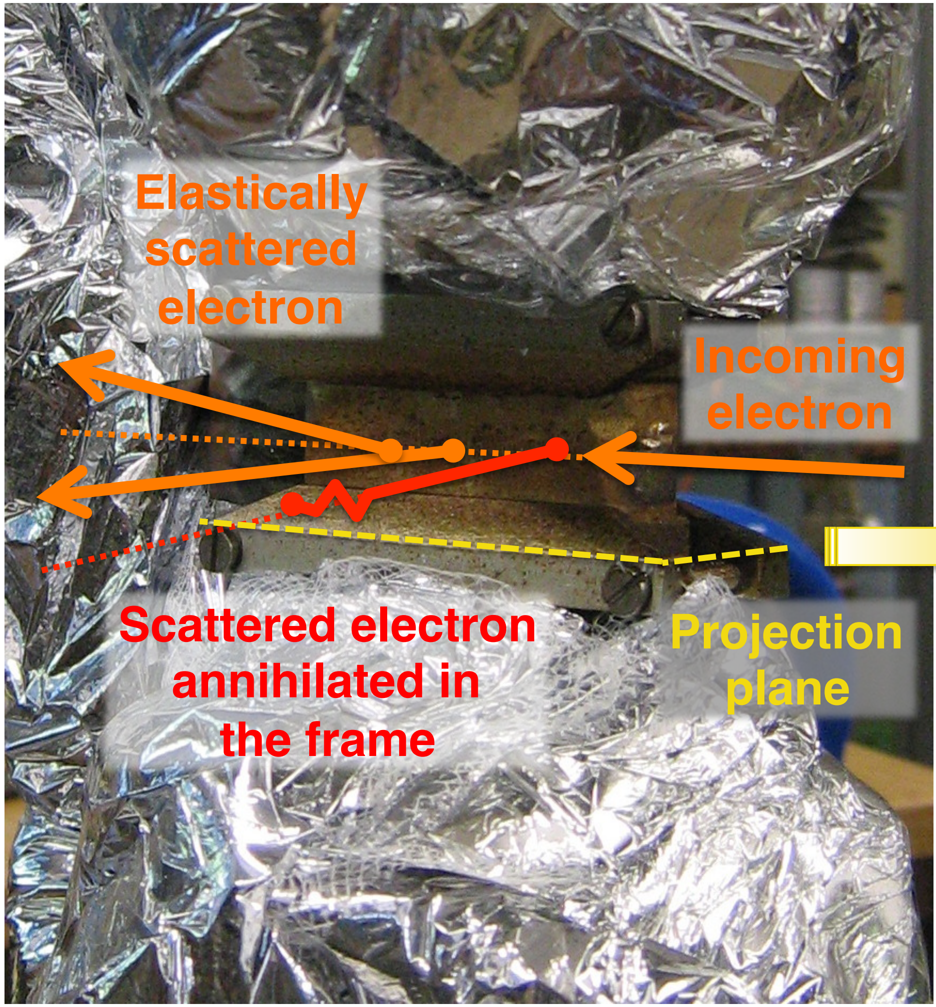


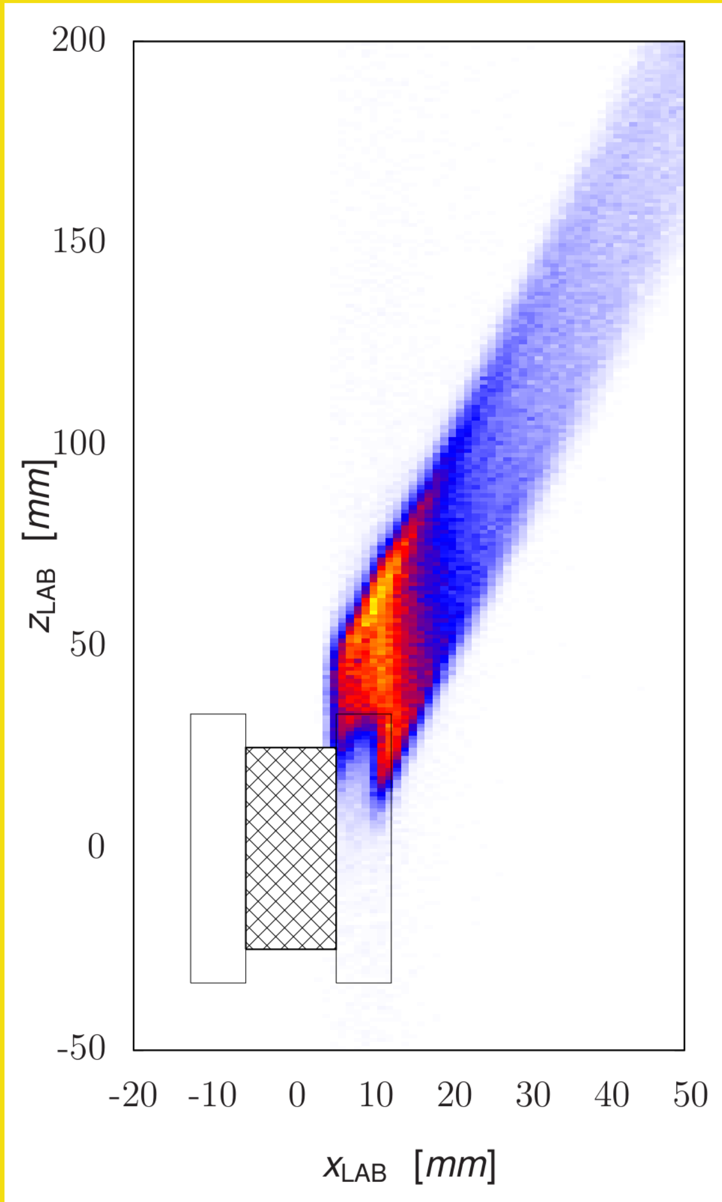
Spectrometer A has enough resolving power for clear identification of Nitrogen and Oxygen.



Target Frame contributions #1

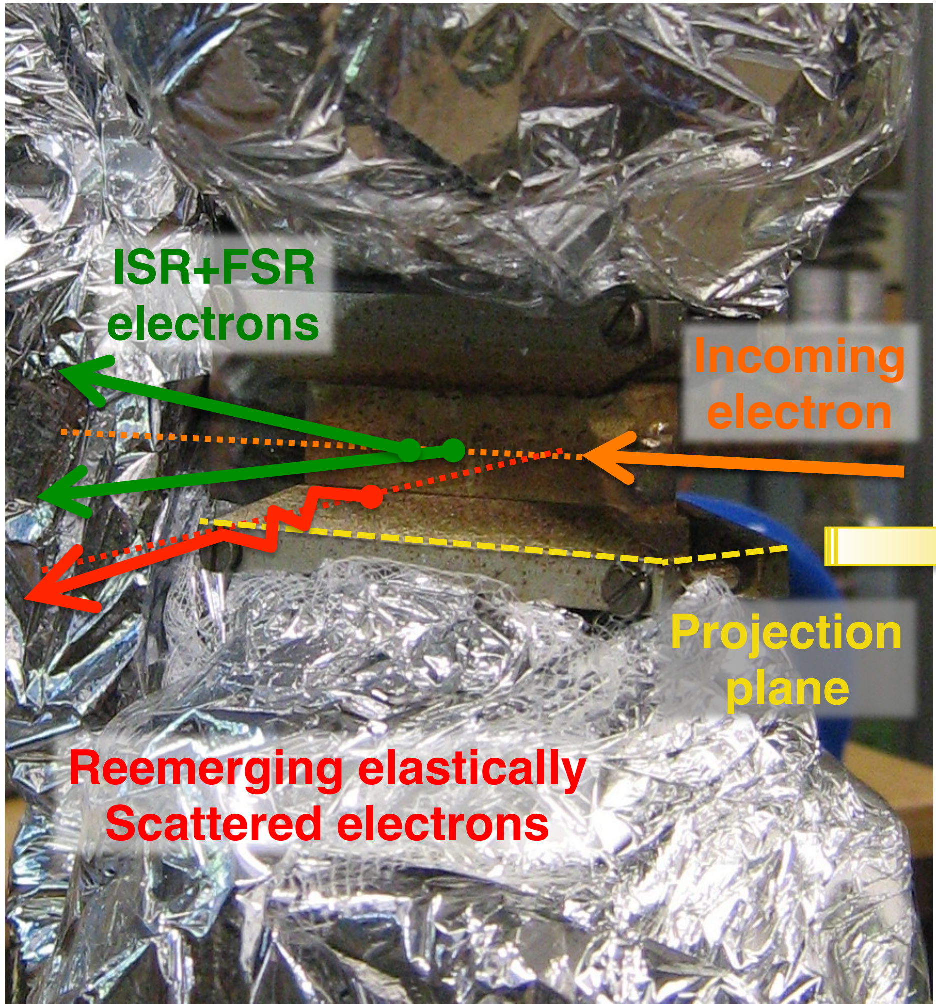
- Presence of target frame results in the deficiency of the elastic events .

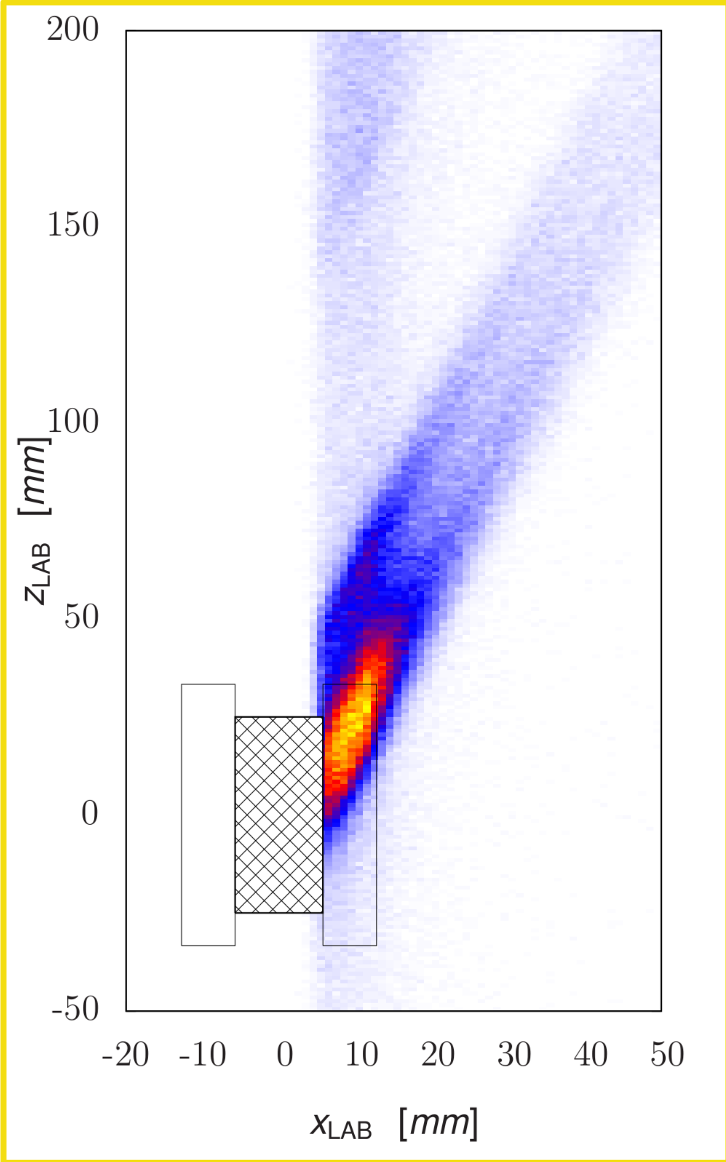




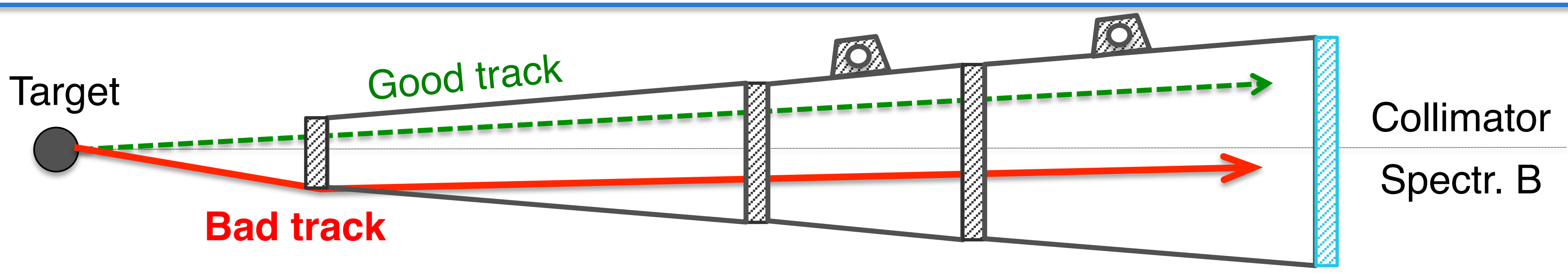
Target Frame contributions #2

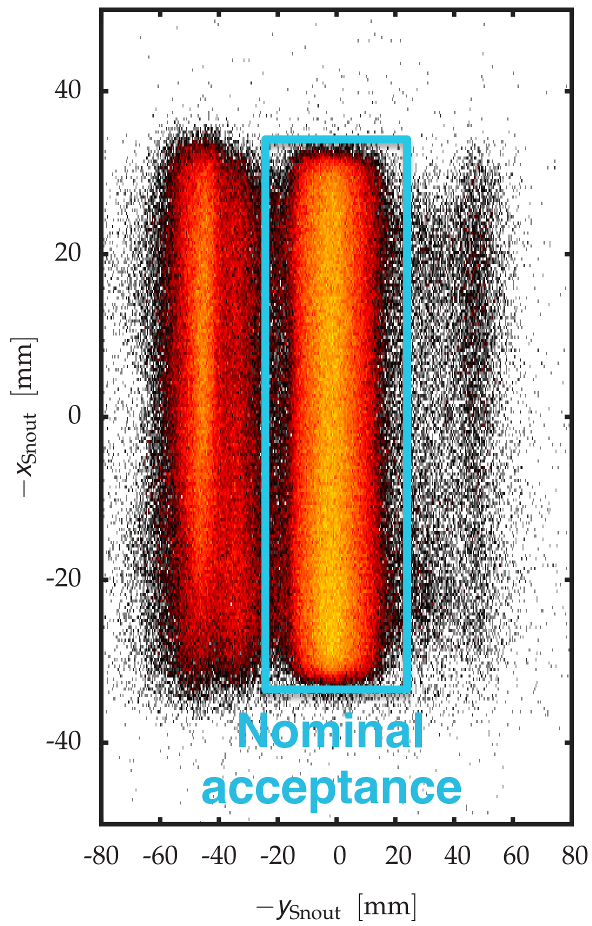
- … and in the abundance of bogus events in radiative tail of the elastic peak.

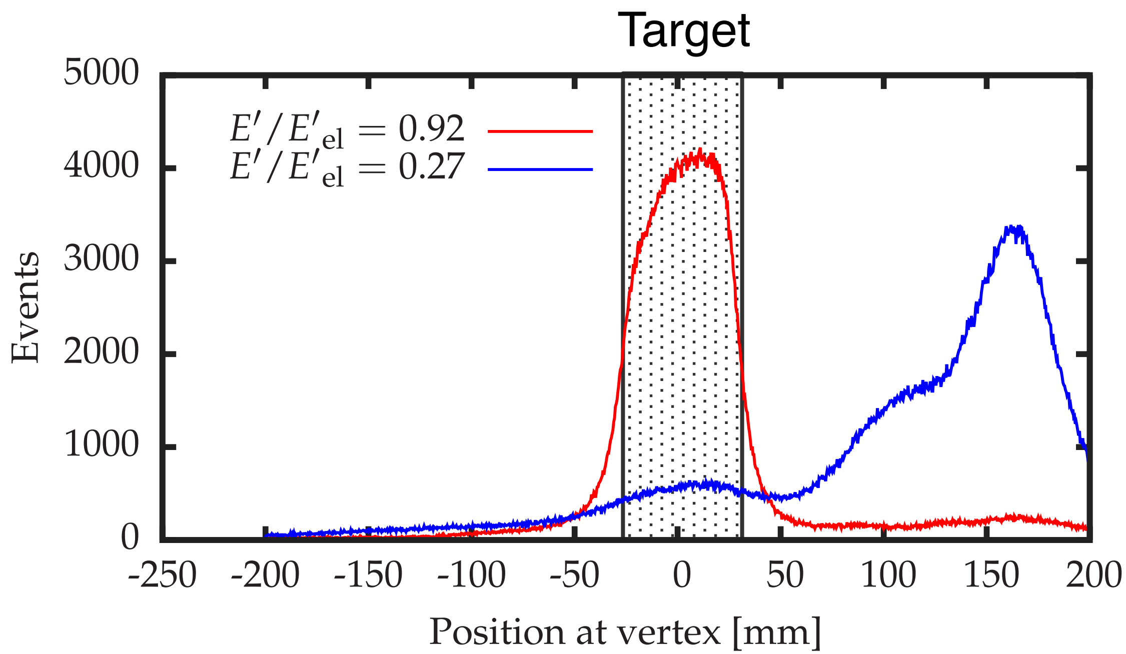




Entrance flange contributions



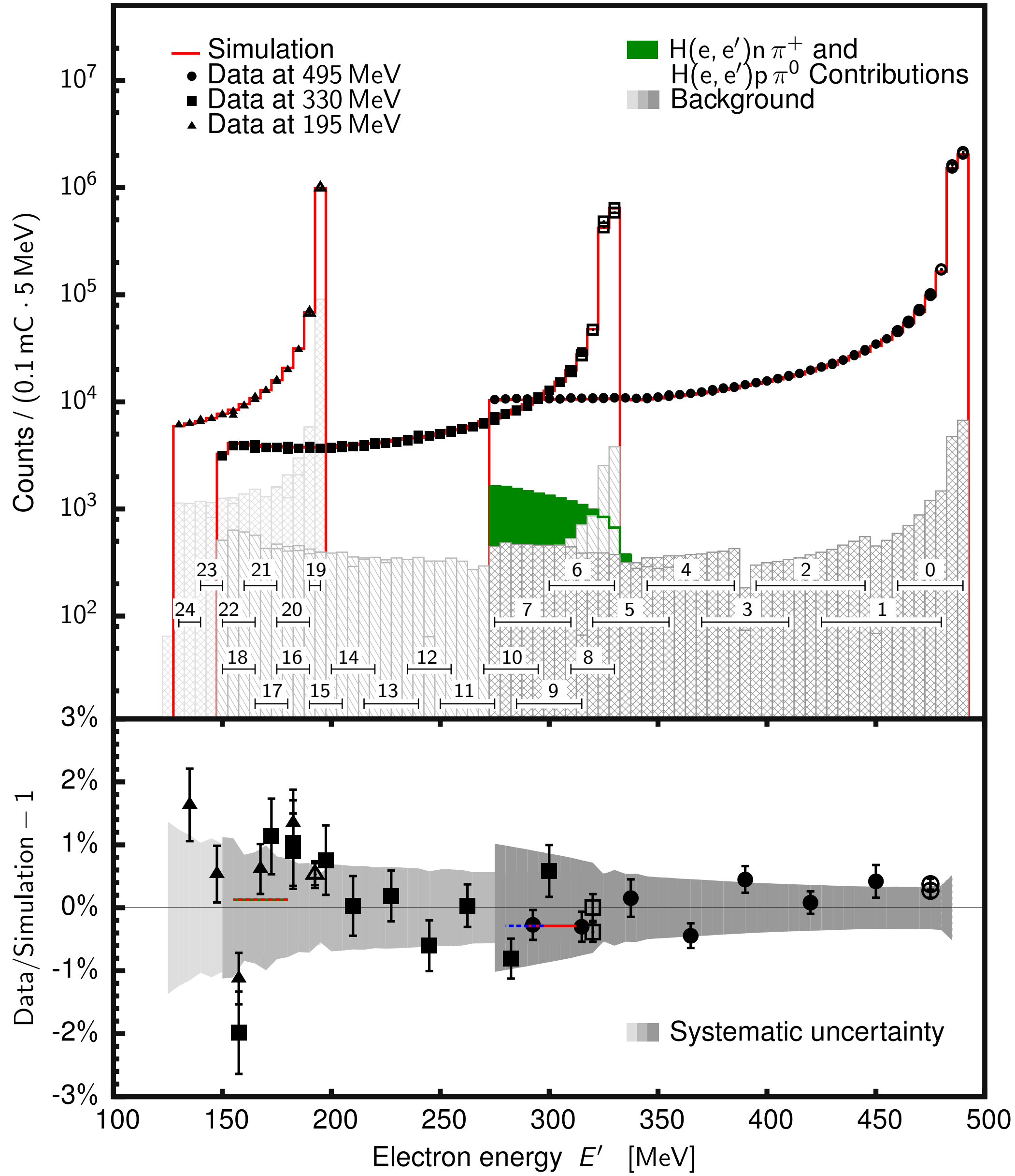




- Spec. B encompasses a long entrance flange.
- Events rescattered from the snout cover the whole vertex acceptance.

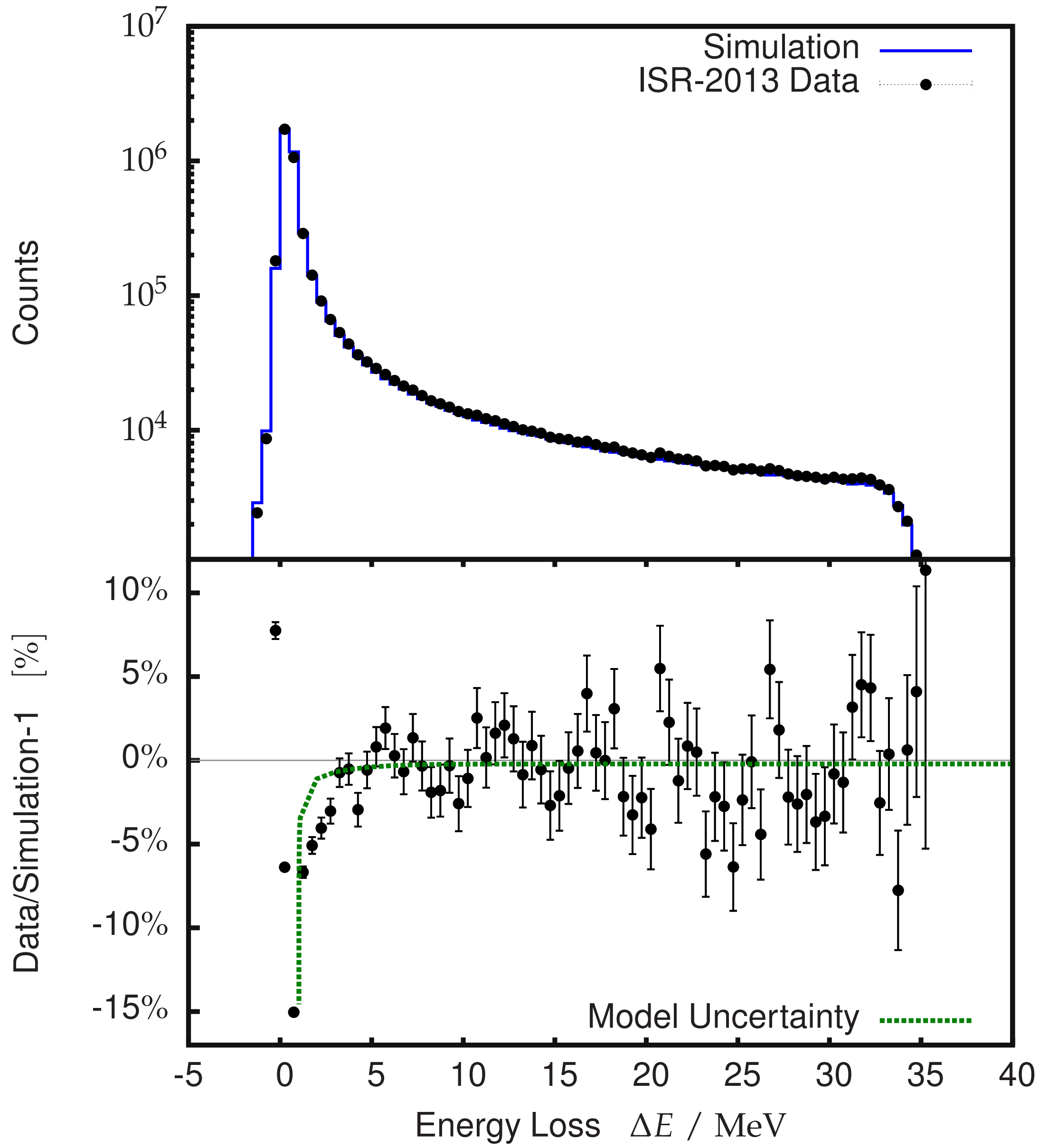
Preliminary Results

- Existing apparatus limits reach and resolution of present ISR experiment to $Q^2 \sim 10^{-3}$ GeV^2.
- Pion production processes contribute ~10% at smallest momenta.
- Simulation performed with Bernauer parameterization of form-factos.
- A sub-percent agreement between the data and simulation validates the ISR technique.
- Elastic points excluded.



Hindrance at the elastic setting

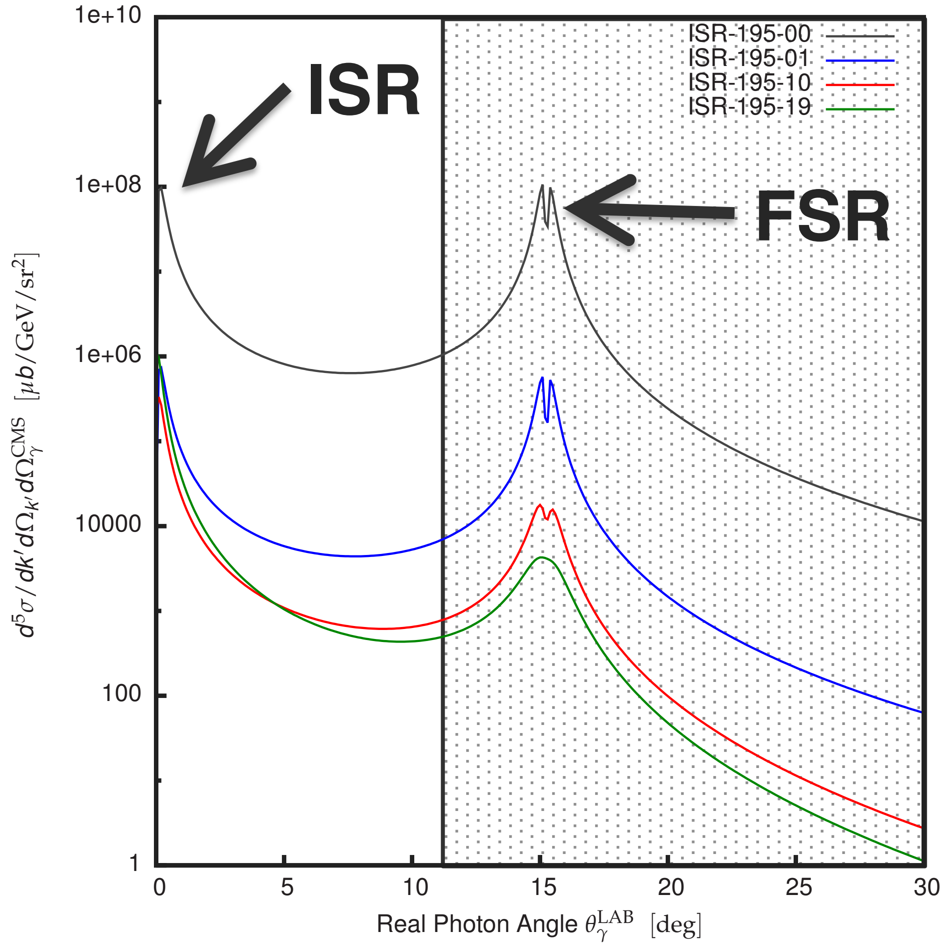
- Significant difference between data and simulation at the elastic peak!
- Excess of simulated events.
- Not a data problem!
- Result of limited precision of corrections at the elastic peak when $\Delta E \sim 0$.
- Number of elastic events influences other corrections!

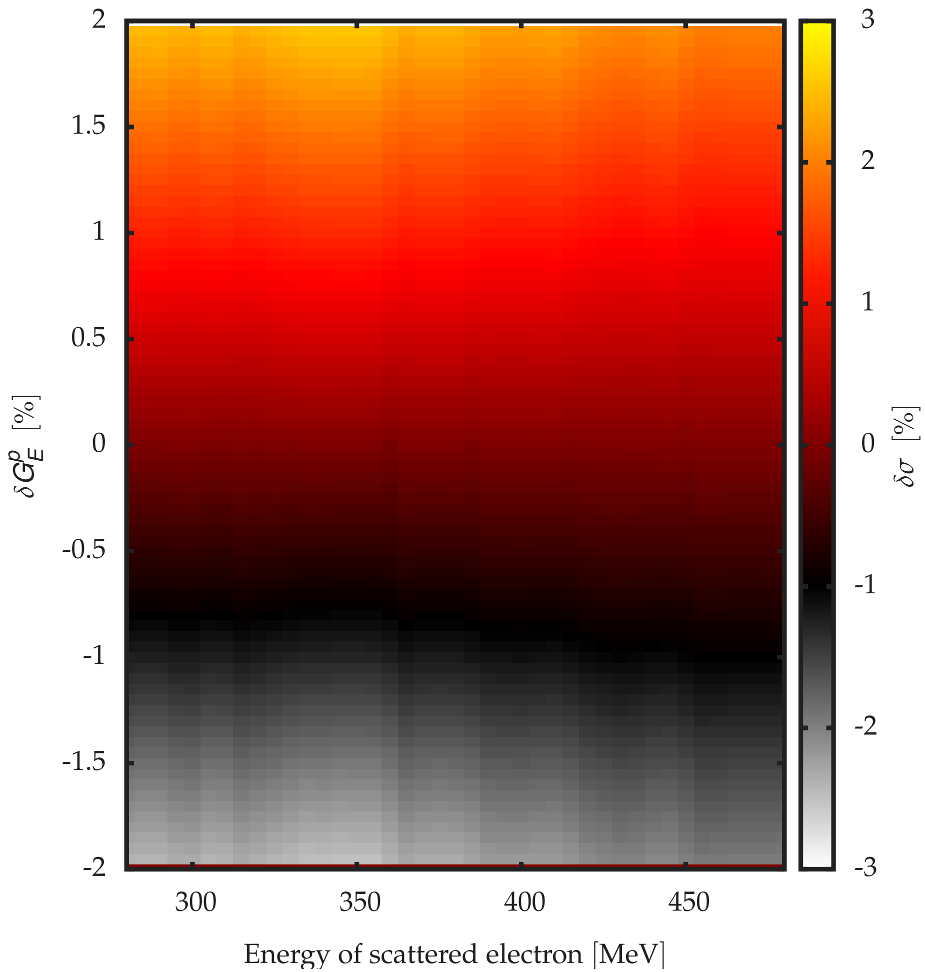


Extracting G_E^p from data

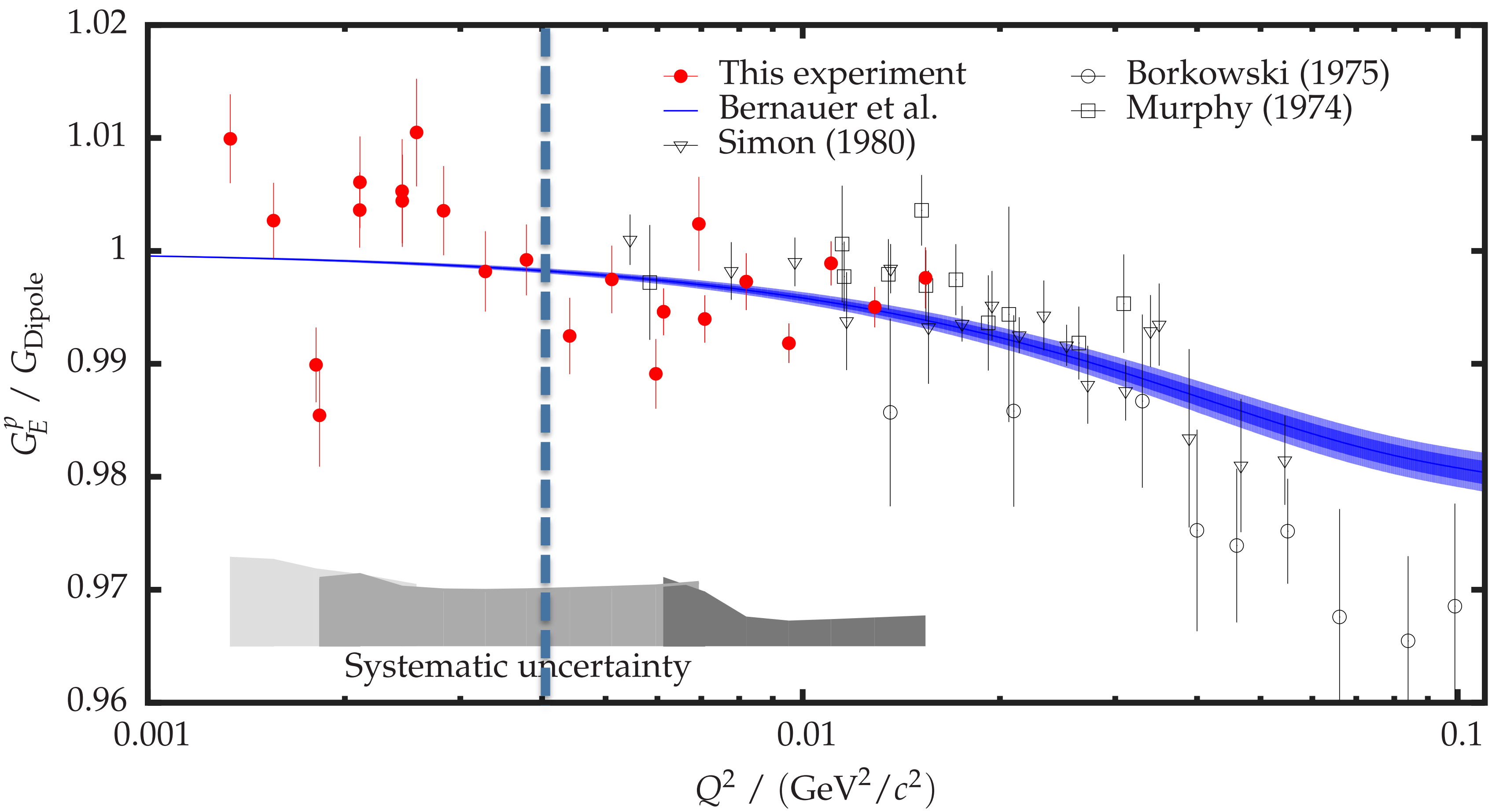
- Scattering angle of emitted photon offers clear separation of ISR and FSR and gives insight into the G_e^p depedence of measured cross-section.

- A lookup table used to transform data to the G_e^p .





ISR form-factors (Preliminary)

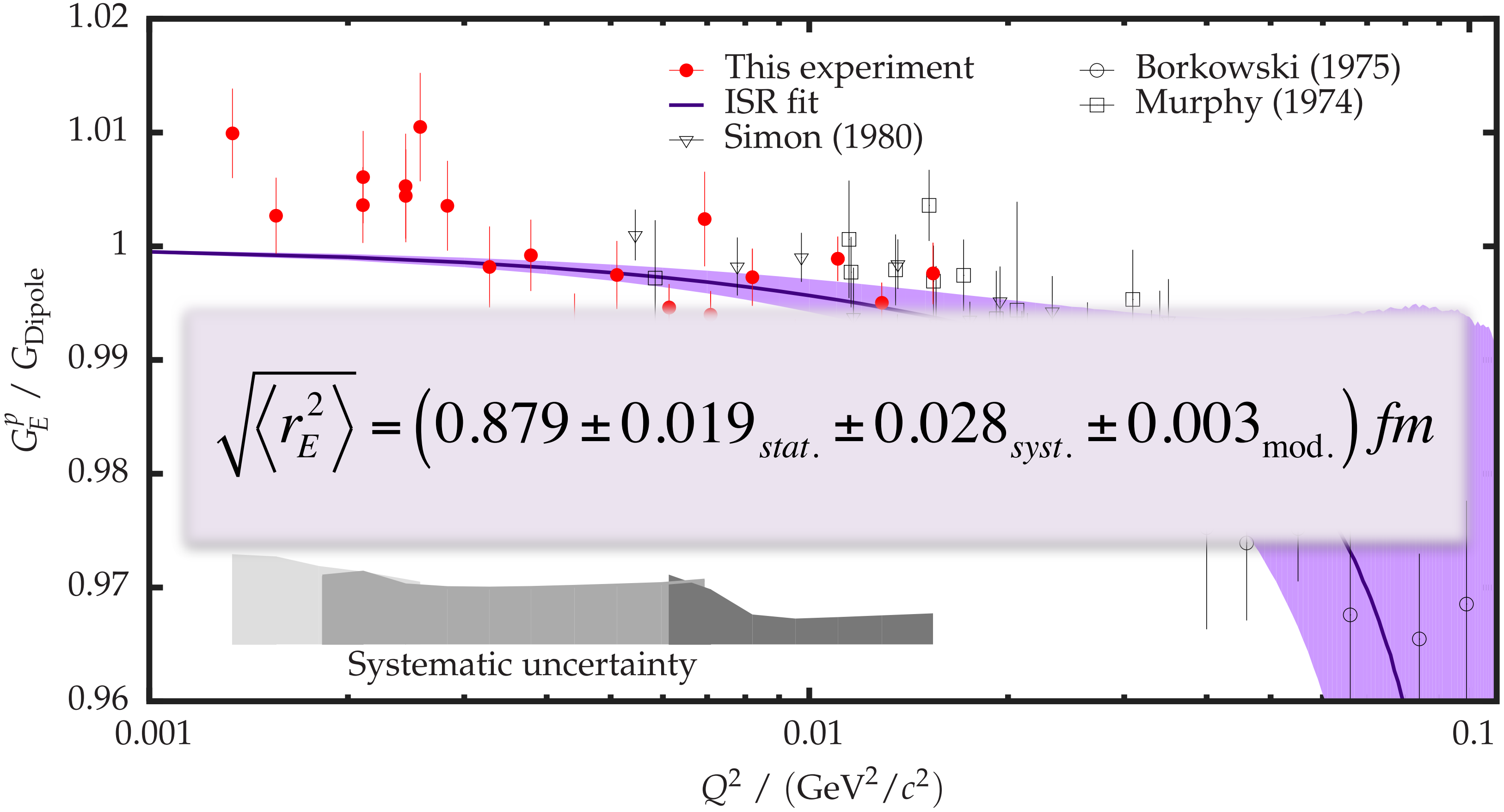


- **First measurement of G_E^p at 0.001 GeV^2 ≤ Q^2 ≤ 0.004 GeV^2**
- Final systematic checks remain to be made!
- (Improve the theoretical description at the elastic line!)

ISR Proton radius (Preliminary)

- G_e^p modeled with the polynomial fit.
- Higher order terms (a,b) known from previous analyses [Distler et al.]

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

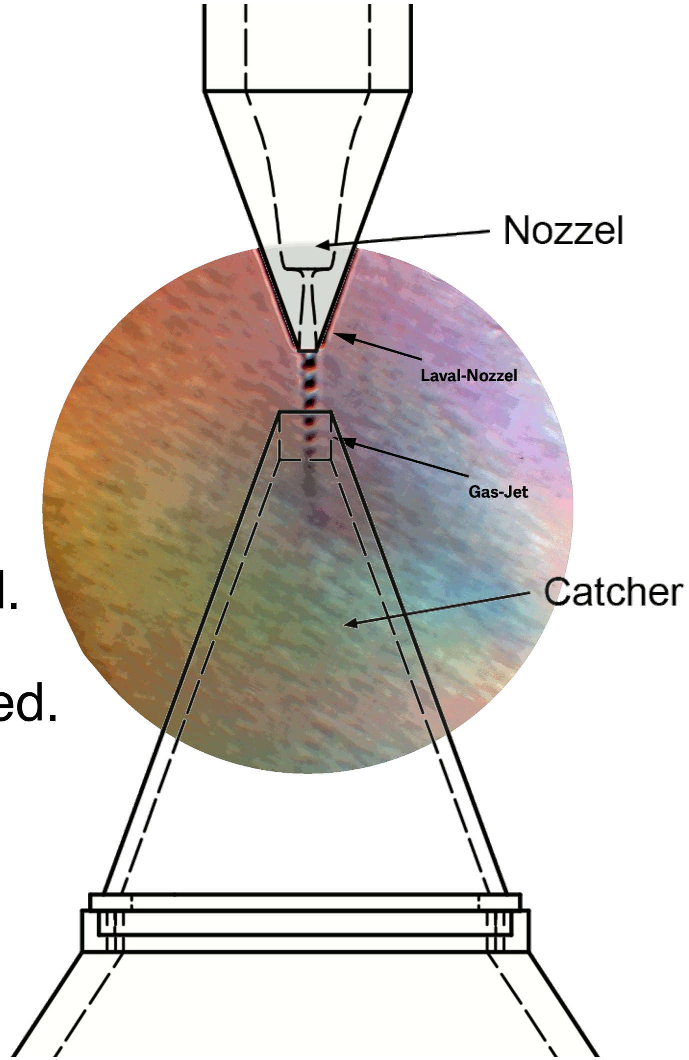


$$\sqrt{\langle r_E^2 \rangle} = (0.879 \pm 0.019_{stat.} \pm 0.028_{syst.} \pm 0.003_{\mathrm{mod.}})\, fm$$

Future measurements

- Next generation of experiments foreseen at:

- ISR valuable technique for future experiments.
- Modifications to the spectrometer setup required.
- A point-like target without extensive frame needed.
  - (Solid-state plastic target not an option).
  - **Hypersonic gas jet target**
    for measurements with minimal background contributions.



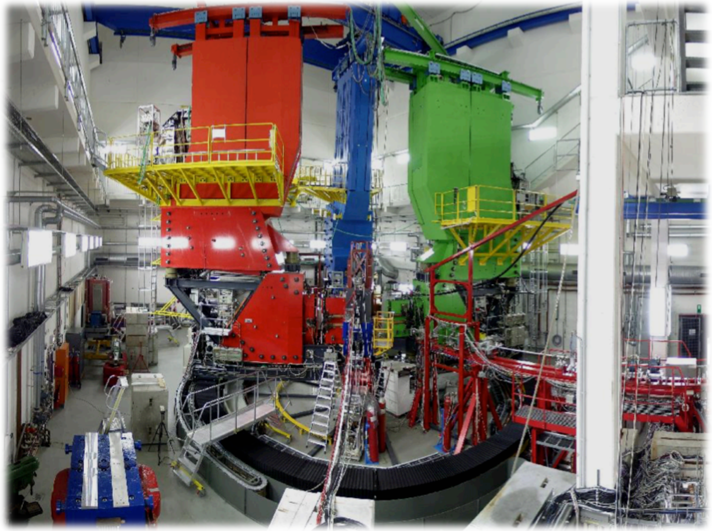
Summary

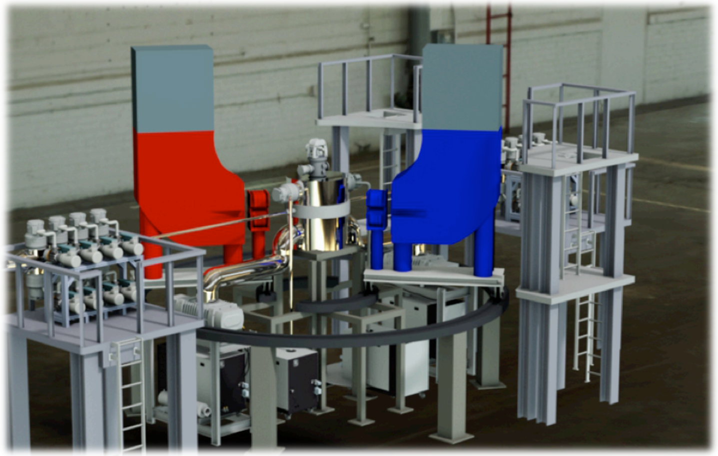
- A pilot experiment has been performed at MAMI to measure G_E^p at very low Q^2.

- A new technique for FF determination based on ISR has been successfully validated.

- Reach of the first ISR experiment limited by unforeseen backgrounds.

- Next generation experiments are scheduled/foreseen at the A1 and at the new accelerator MESA.





Thank you!

Uncertainty of effective corrections