Proton radii and low-q form factors
Classic + ISR

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Intense Electron Beams Workshop
Cornell University
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Massachusetts Institute of Technology

Motivation I

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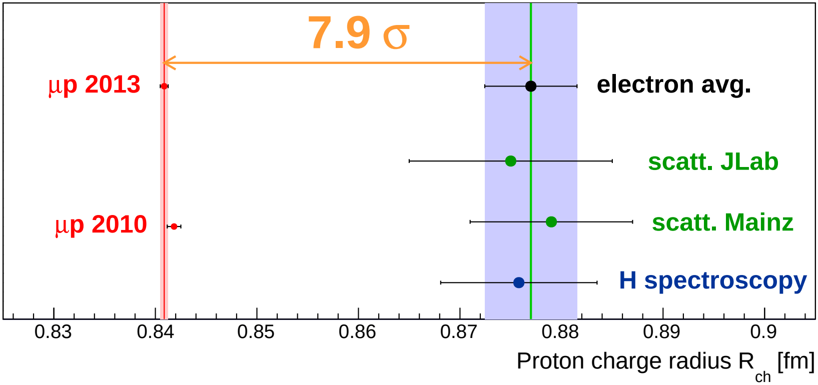
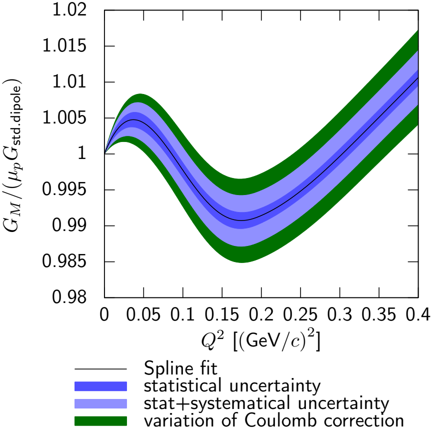


Motivation I

From the 2014 Review of Particle Physics

Until the difference between the $e\,p$ and $\mu\,p$ values is understood, it does not make sense to average the values together. For the present, we give both values. *It is up to the workers in this field to solve this puzzle.*

But wait, there is more: Motivation II



- Up-Down-Up structure in magnetic Form factor
- Gives rise to small radius ~ 0.77 fm
- Not seen before
  - Older fits approach from below
  - Lack of data!

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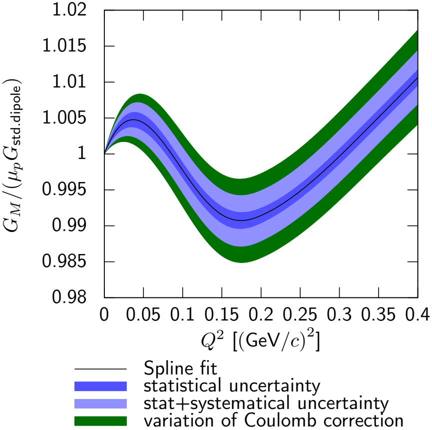

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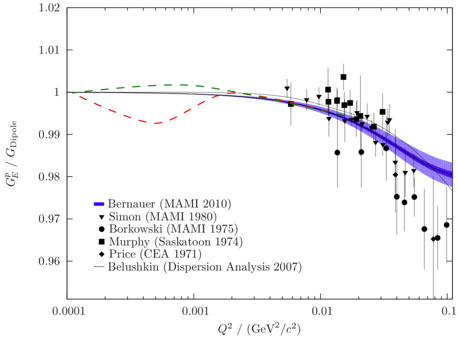
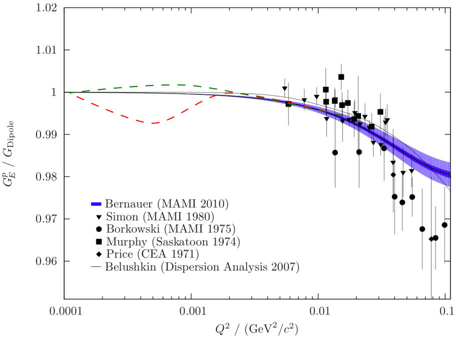


Attack vectors

- Did I mess it up? I.e. verify scattering result!
- Anything funky going on below minimum Q^2?
- What about heavier atoms? Deuterium, Helium, Lithium
- MUSE and other things...



Revamped "Classic" approach

- Modern version of Rosenbluth
- This is what we did in Mainz
- Measure angle scans at constant energy
- Fit different FF models directly to all cross section data

Hypothetical experiment

- Baseline:
  - Measure every 5° from $15 - 165^\circ$
  - At energies 100, 200, 300, 400, 500 MeV
- Assumed errors:
  - 0% systematic error
  - 0.2% statistical
  - 1% normalization

About 5 times smaller $Q^2_{\text{min.}}$

Projected performance I

- Input: Spline fit from Mainz
- Analyzed with 5th order polynomial$\times$dipole
- Baseline: $\delta r_E = 0.004\,\mathrm{fm}$, $\delta r_M = 0.006\,\mathrm{fm}$

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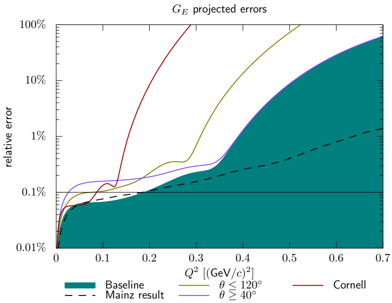
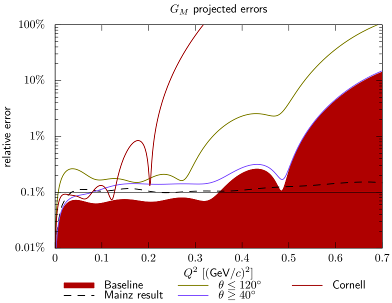
- "Cornell": $\delta r_E = 0.008\,\text{fm}$, $\delta r_M = 0.019\,\text{fm}$

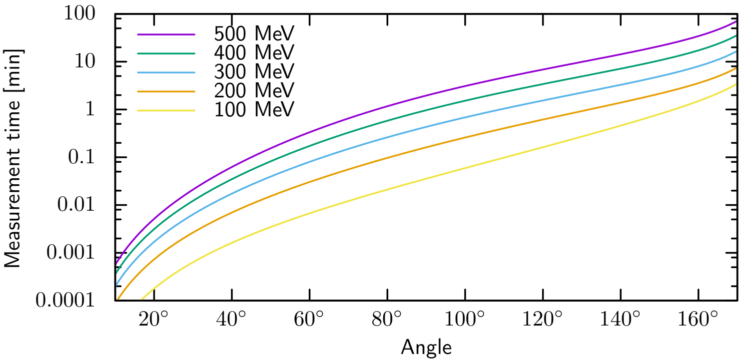
Projected perfomance II





Thoughts

- 100-300 MeV would cover interesting region in G_M, but needs more energies in between
- 50 MeV gives 10 times smaller Q^2 than Mainz
- More energies / more angles to test for systematics
- 20 msr detector, 500 MeV, 165° @ 100mA and $10^{19} cm^{-2}$ target: 50 min.



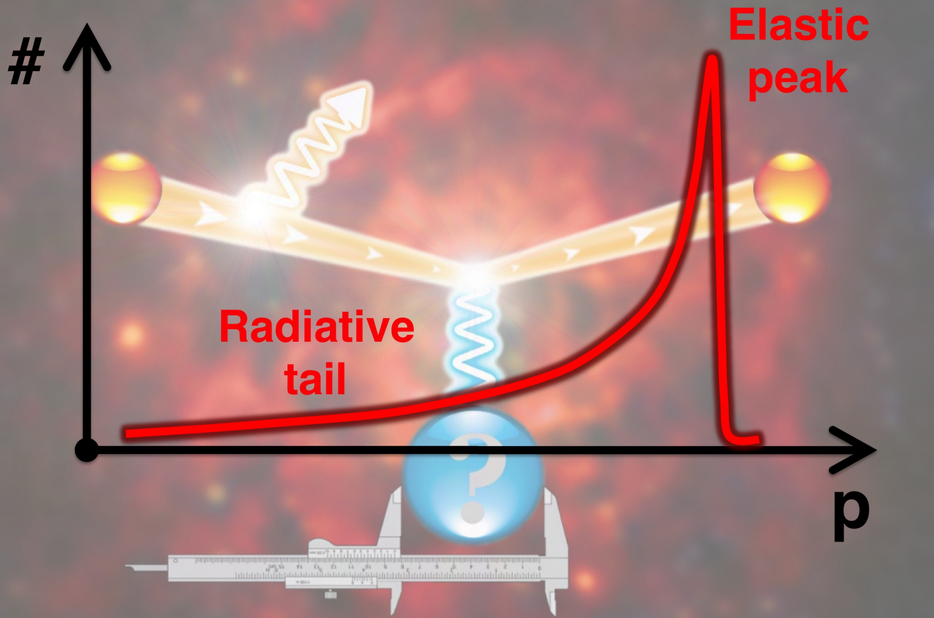
Caveats

- Same approach $\Longrightarrow$ Same systematical errors as before!
- How good do we really know the radiative corrections?
  - especially at back angles!
- How well do you know the acceptance? Better point-like target
- How well do you know the efficiency? Online monitoring!

The following slides have been provided by

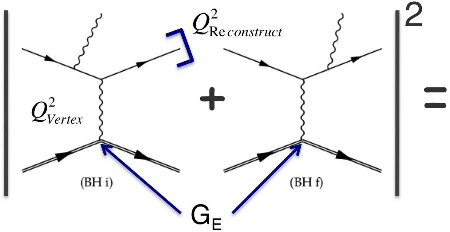
Miha Mihovilovic

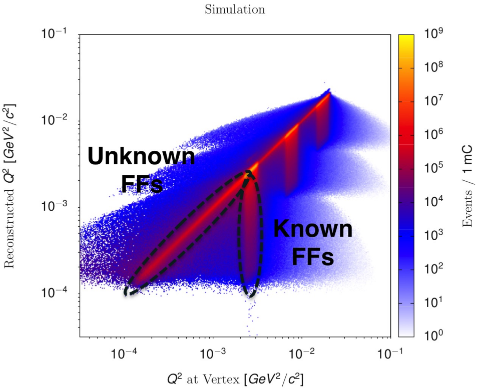
ISR Experiment at MAMI



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 with the simulation, ISR information can be reached**.
- Idea behind new MAMI experiment to extract 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).

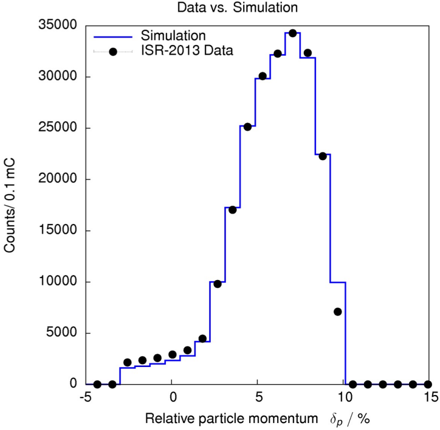
- Approach analogous to Bernauer et al. will be used, where **simulated distributions are directly compared to measured data**.

- 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.

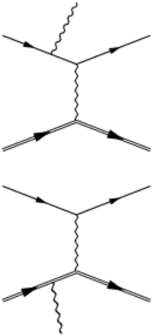
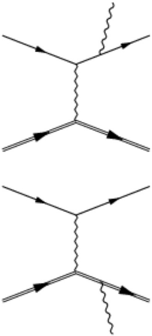
- Final values of FFs will be determined by a χ^2-minimization.

Searching for G_e^p which gives the best agreement between data and simulation



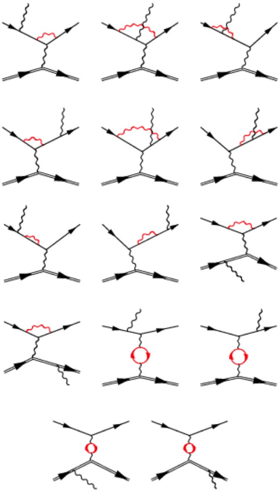
Going beyond simple approximation

- `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.



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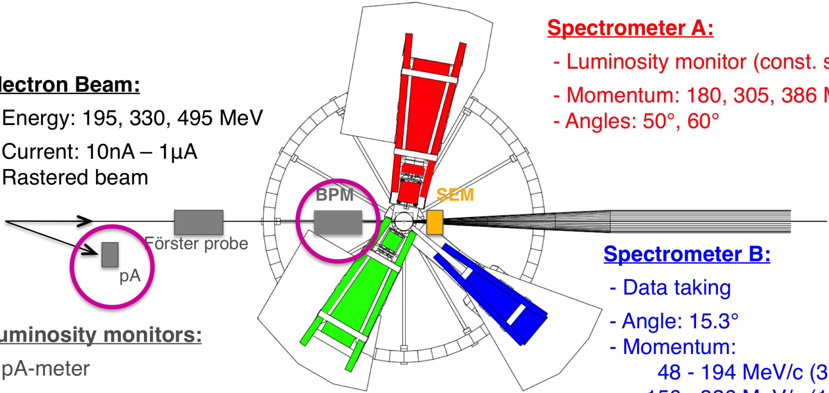
The Experiment

- 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:

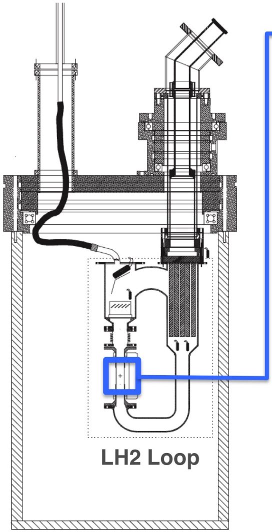
- Not used

Beam control module:

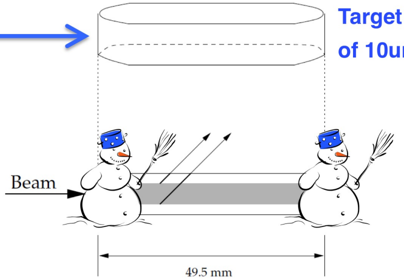
- Communicates with MAMI and ensures very stable beam.
- BPM and pA-meter measurements performed automatically every 3min.

LH_2 target and its challenges

- Experiment utilizes a standard Liquid-Hydrogen target.



Scattering chamber

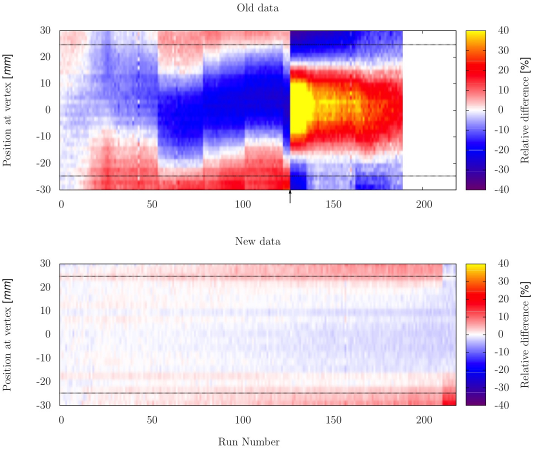


Target Cell made of 10um Havar

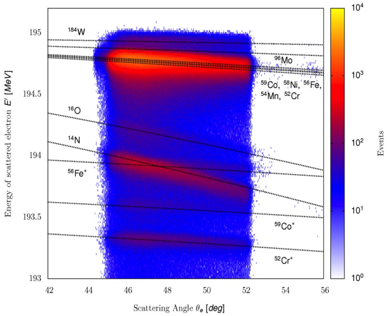
- Due to <u>limited vacuum and low beam intensities</u>, layer of **Cryogens covered the target cell**.
- Depositions consists mostly of residual N_2, O_2.
- Affects not only particle energy-losses but changes also the detection rates.
- Disturbs Luminosity determination.
- Amount of snow <u>changes with time.</u>

Minimizing cryogenic depositions

- **<u>Solid vacuum</u>** in target chamber (10^{-6} mbar).
- New target windows with additional layer of Aramid.
- Fixing Spectrometer A to elastic settings to see effects of snow gathering more clearly.

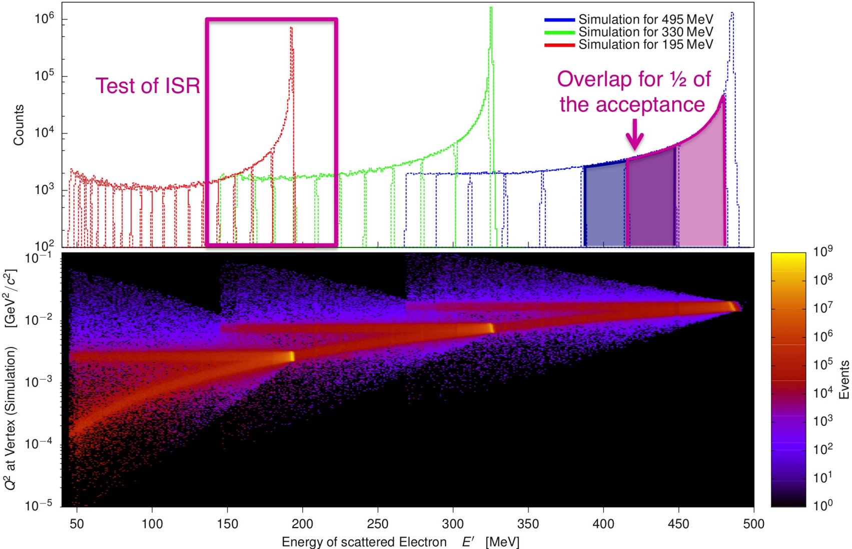


Spectrometer A has enough resolving power for clear identification of Nitrogen and Oxygen.



Kinematic settings of the full experiment

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



The offline analysis

- **Goal:** determine the cross-sections with **accuracy of ~ 1%.**
- The analysis ongoing, so far:

Spectrometer calibrations:

- New optics calibration, absolute momentum optimization.
- Calibration of detector setup and evaluation of efficiencies.

Luminosity:

- New and improved luminosity calculator.

Background studies:

- Optimization of event selection cuts.
- Determination of thickness of the cryogenic depositions.

Simulation:

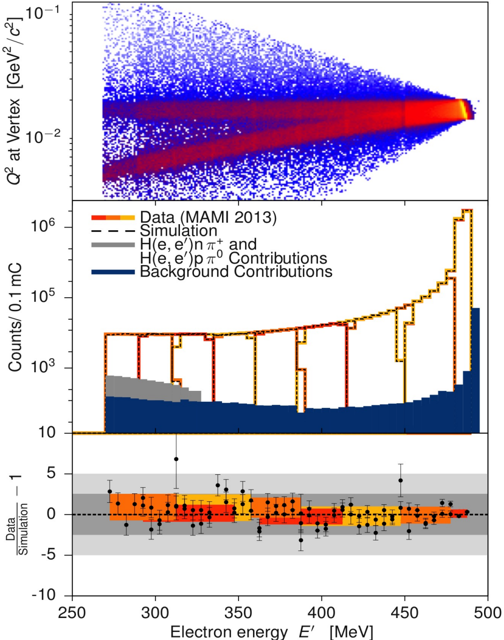
- Explicit (effective) inclusion of virtual and real 2γ corrections.
- Complete simulation of effects related to target walls and cryogenic depositions.

Data analysis:

- First analysis of the dataset at 495MeV to prove the ISR principle.

Preliminary Results

- First results for 495 MeV setting.
- Data are normalized to 0.1mC using Förster probe & Spec-A.
- Only basic kinematic cuts considered.
- Pion production processes contribute ~10% at smallest momenta.
- Contributions from target wall not negligible.
- **Agreement between data and simulation justifies use of `Simul++`.**



The upcoming challenges

- A **~ 2% agreement** between data and simulation **200 MeV** away from the elastic peak motivates further analysis:

Background studies:

- Identification and consideration of other sources of background (e.g. snout of spectrometer B).
- Full study of the Empty cell and Solid-state target data.

Simulation:

- Exact calculations of 2γ corrections required.
- Improvements to the simulation of background.

Data analysis:

- Analysis of the 330MeV and 195MeV settings.
- Extraction of the proton charge form-factor at $Q^2 \geq 3 \times 10^{-4}$ GeV^2.

Summary

- Need multiple beam energies for separation / verification
- Spectrometers! (at least two: measurement + normalization)
- ISR can access smallest Q^2; Separation can access magnetic radius / form factor
- Think about your systematics! More variation is better than minimal uncertainty per point.
- Change target, rinse, repeat!