Puzzling out the proton radius puzzle with initial state radiation

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JOHANNES GUTENBERG UNIVERSITÄT MAINZ

SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

MAINZER MIKROTRON

A1

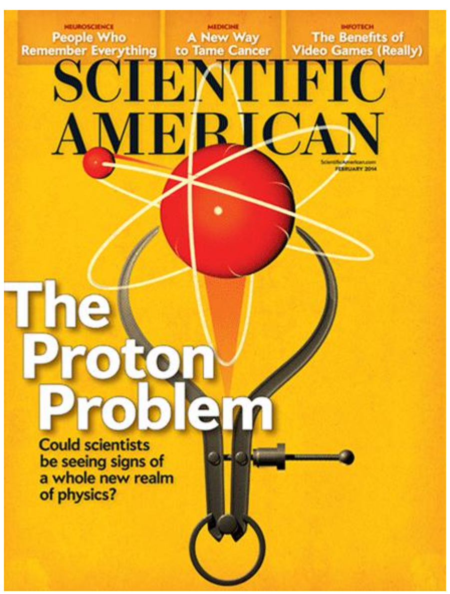
Outline

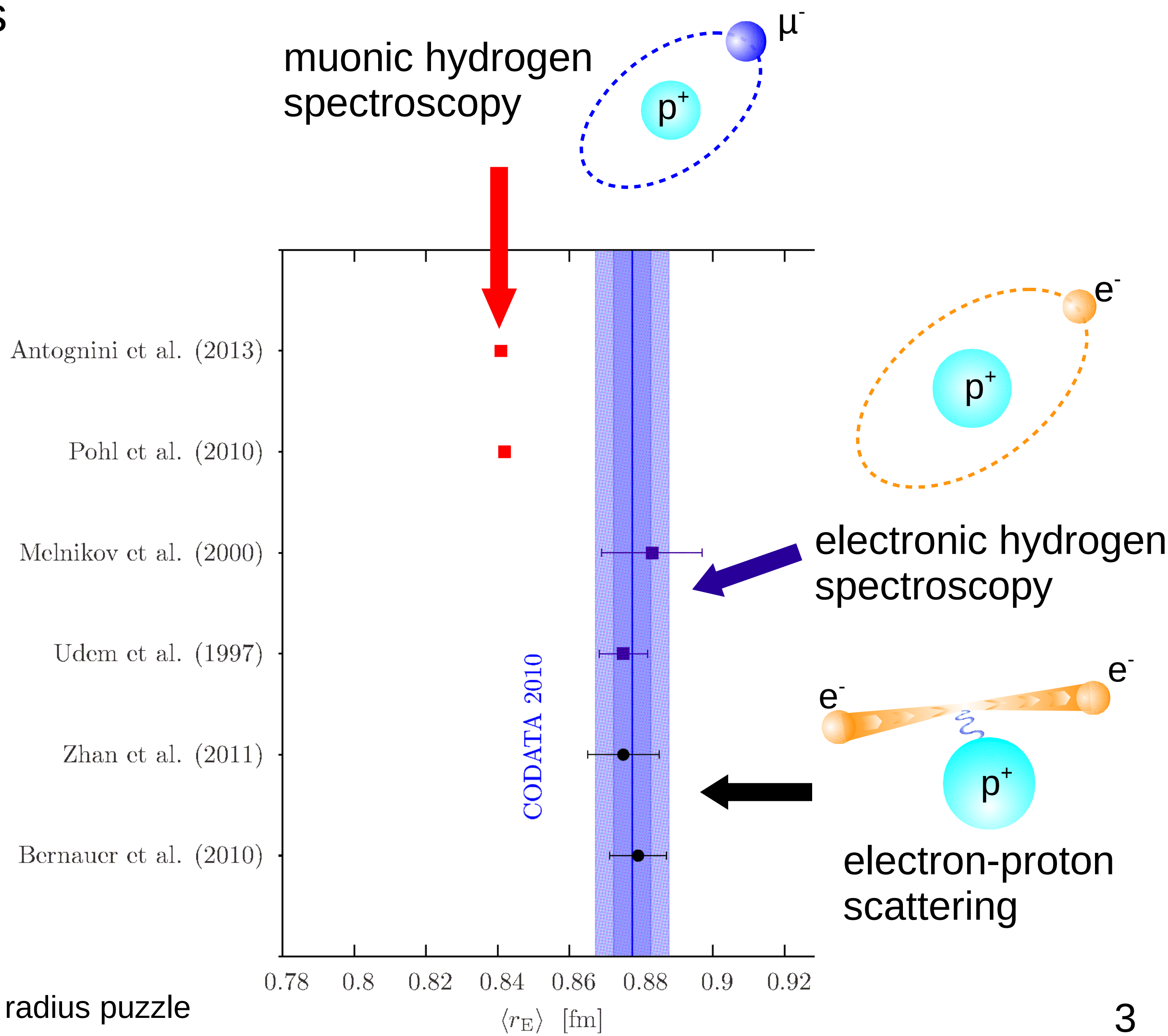
- Motivation: Proton radius puzzle
- Initial state radiation
- Experimental setup
- Data analysis
- Conclusions

The proton radius puzzle

rms proton charge radius for:

- electronic hydrogen:
  → 0.8770±0.0045 fm
- muonic hydrogen:
  → 0.8409±0.0004 fm





Talk this morning: T. Walcher: The proton radius puzzle

Elastic cross section measurement

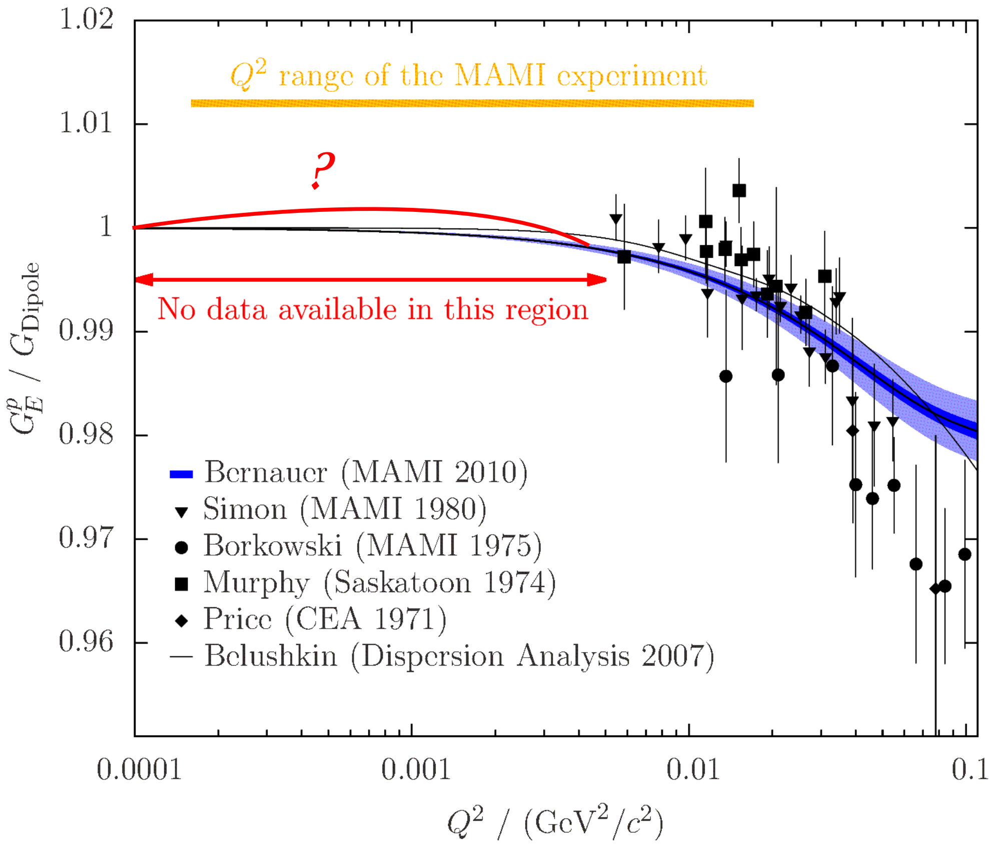
- Elastic cross section of H(e,e')p:

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

- Proton charge radius :

$$r_P^2:=-6\hbar^2\left[\frac{dG_E\left(Q^2\right)}{dQ^2}\right]_{Q^2=0}$$

- No data at very low Q^2
  - ➔ For precise radius determination data in this region needed

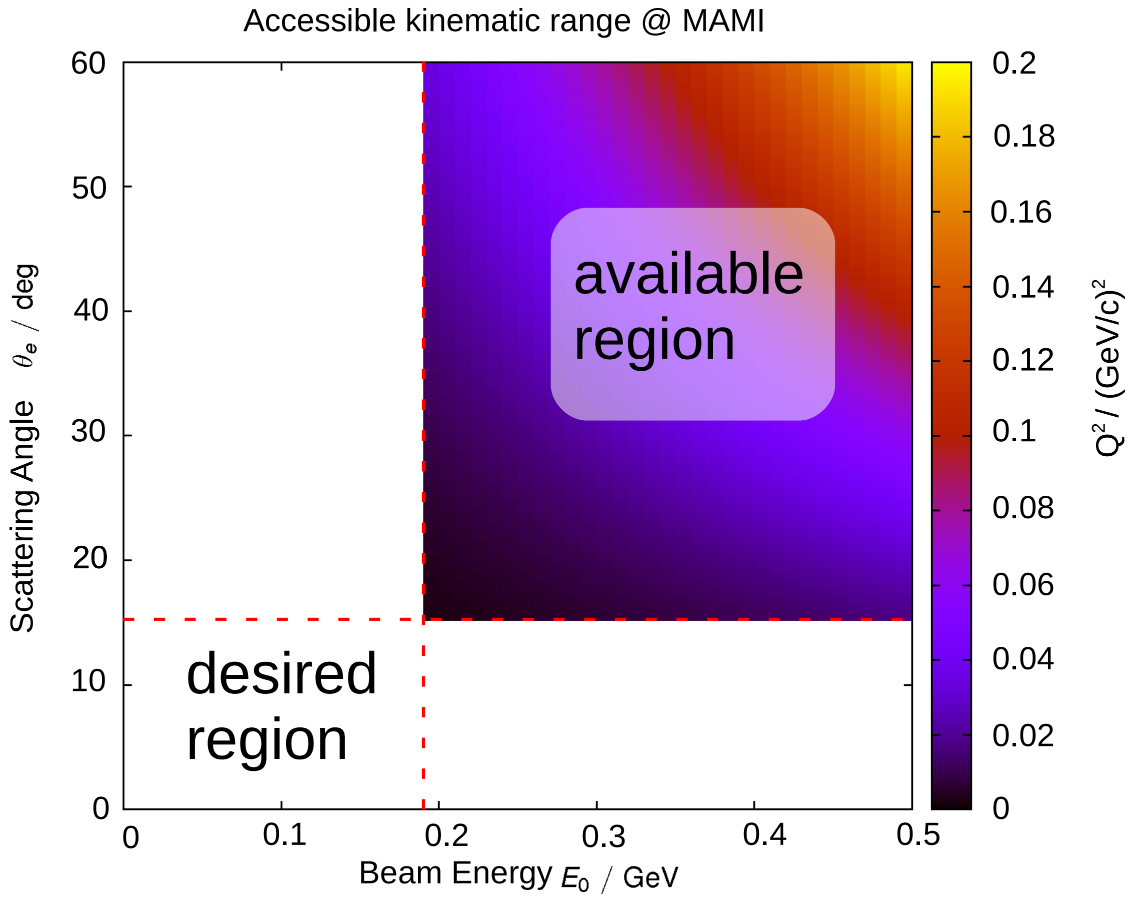


Experimental boundaries

- For elastic cross sections below Q^2=0.004 (GeV/c)^2:

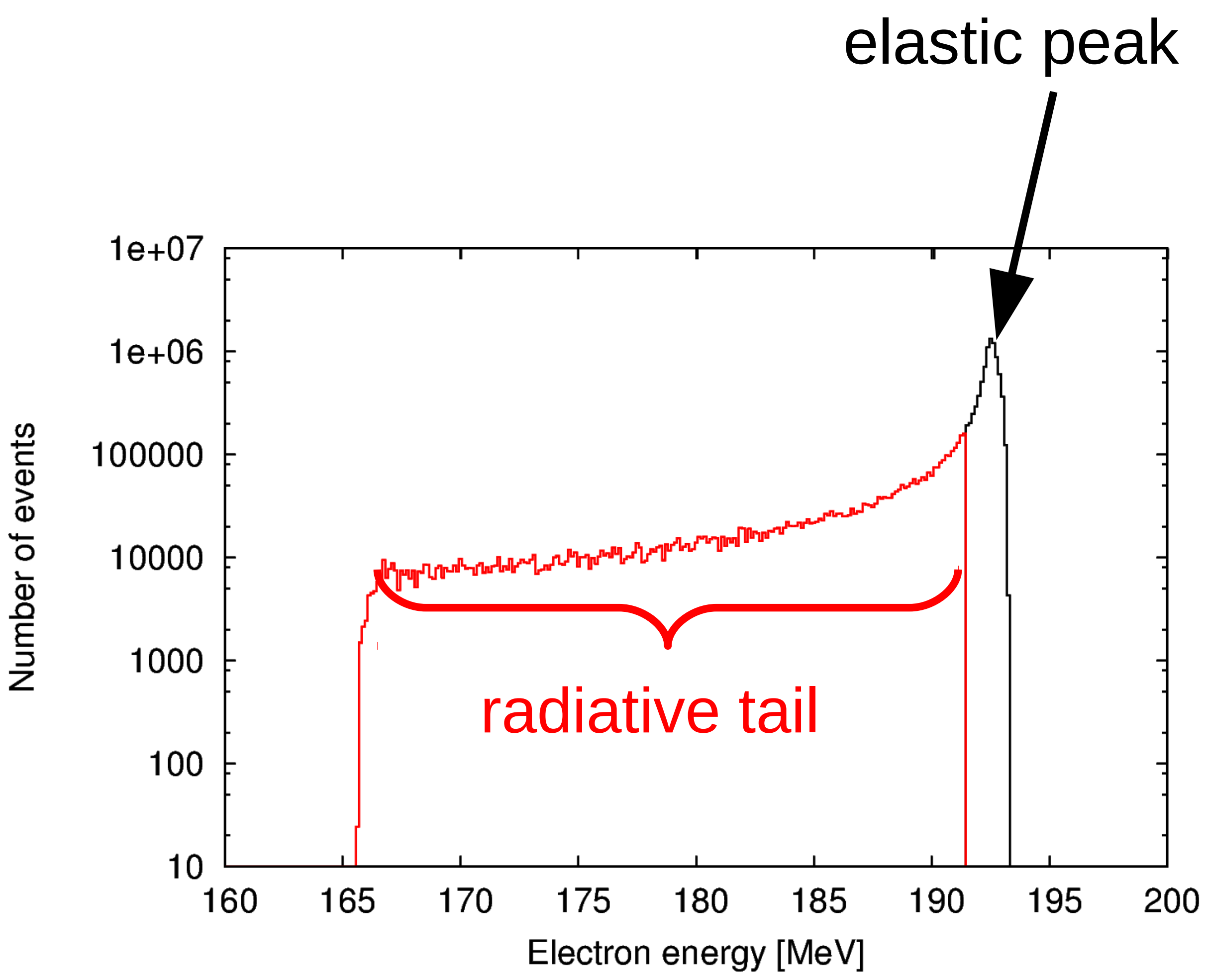
  ➔ lower scattering angles
  ➔ lower beam energies

- Available experimental apparatus limits both.

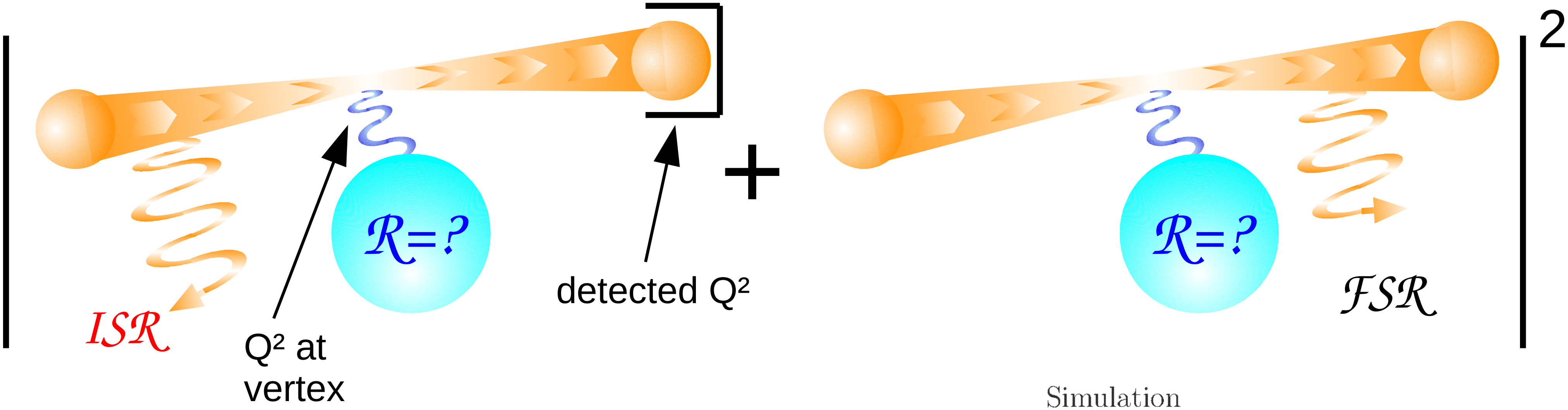


Exploiting the radiative tail

- For even lower Q^2 novel approaches needed:
  - ➔ consider information from radiative tail

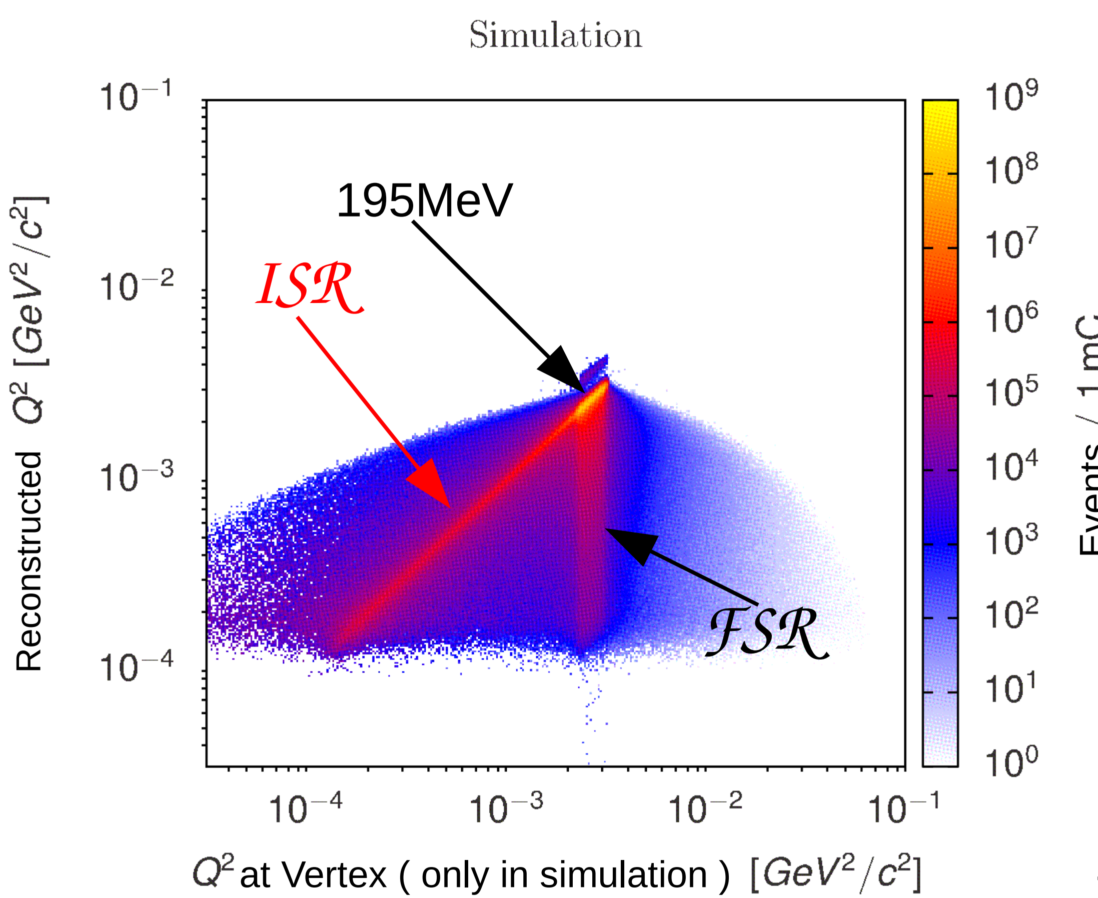


Initial State Radiation

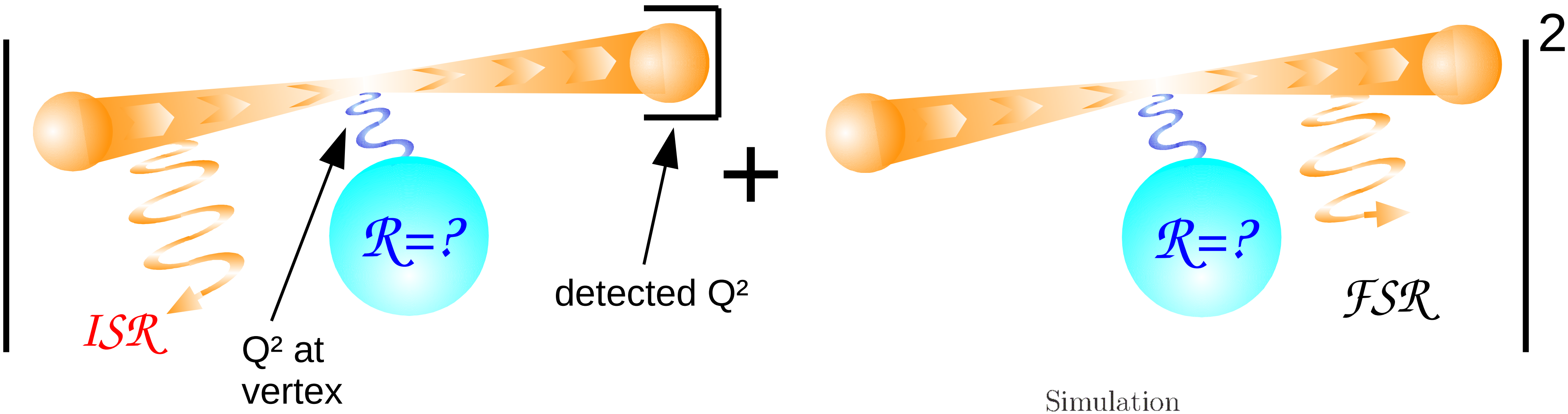


- Combine data with simulation to distinguish ISR from FSR

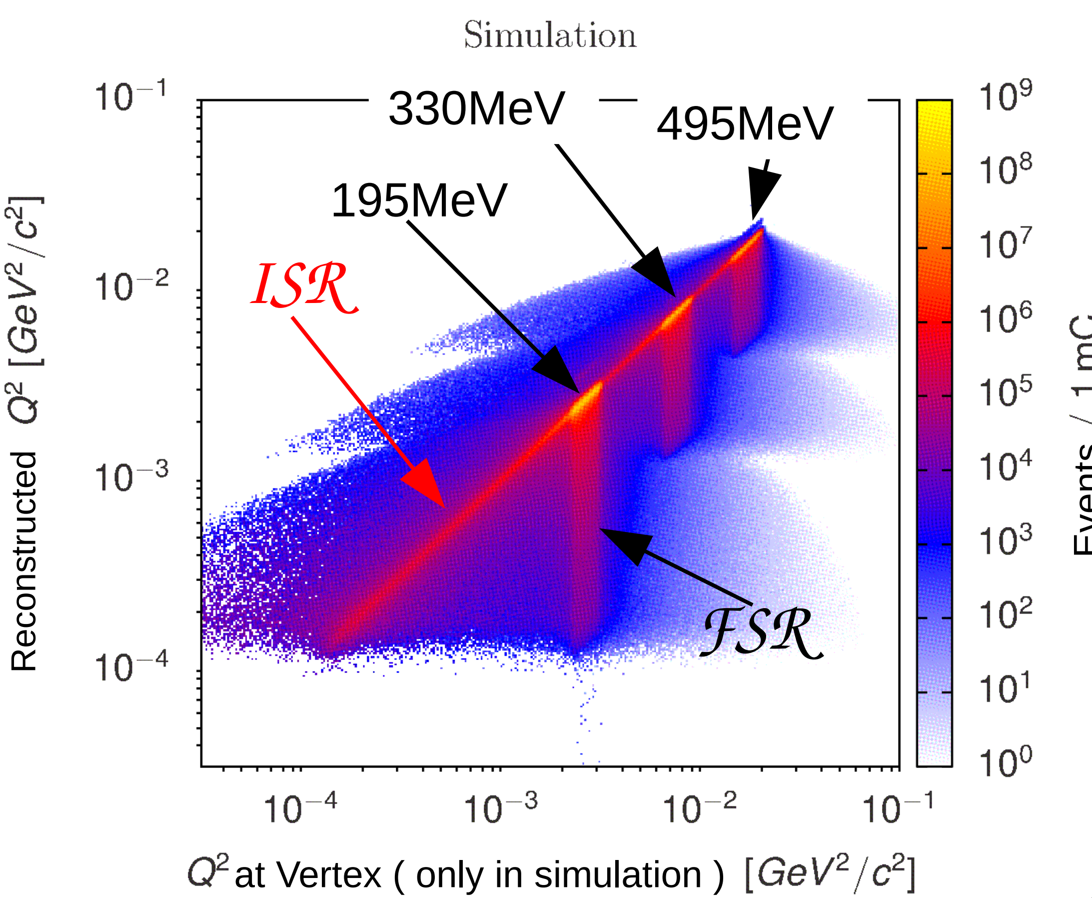
- Using Initial State Radiation allows investigating G_E at lower Q^2 till ~(1-3)·10^{-4} $(GeV/c)^2$



Initial State Radiation

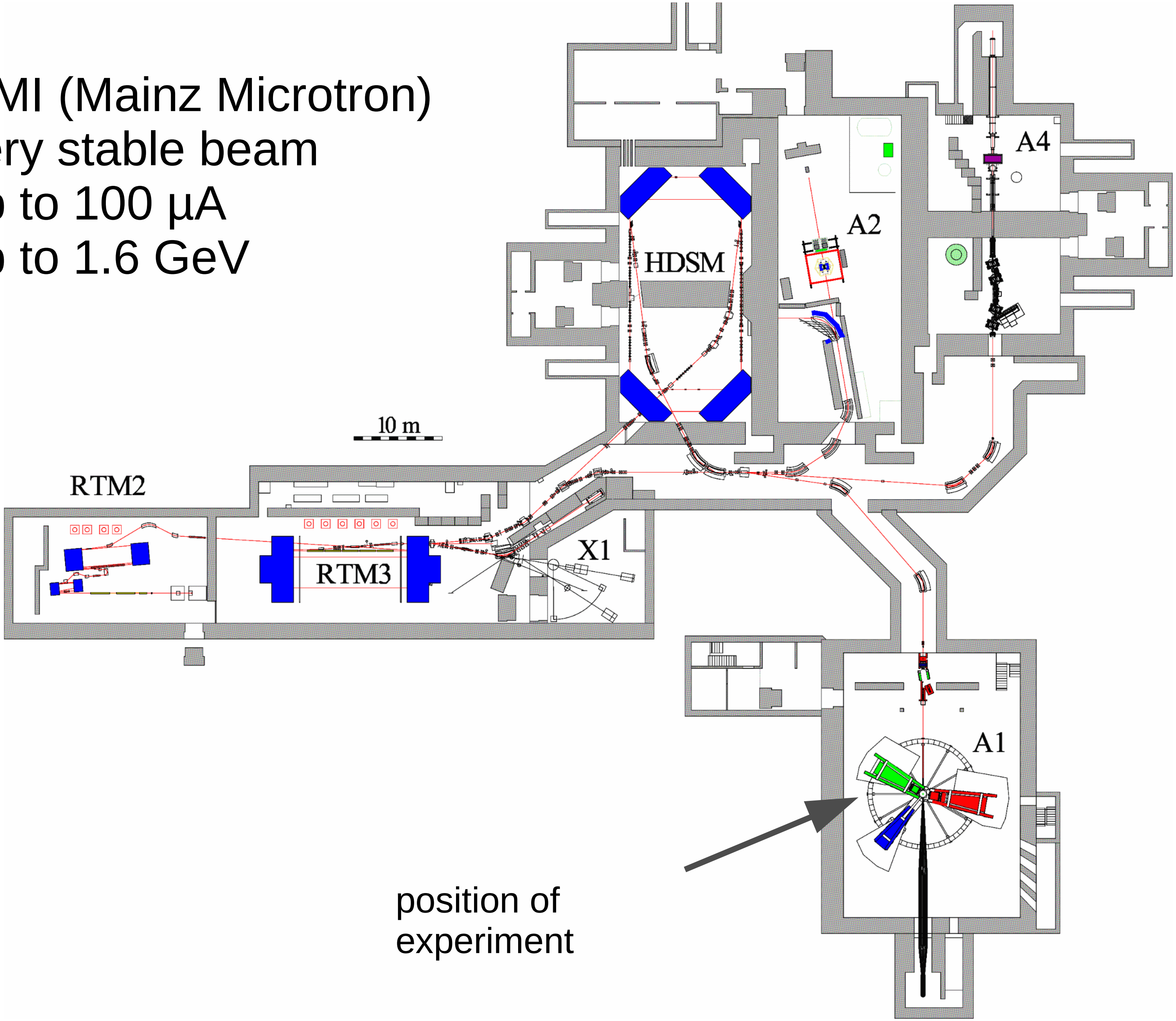


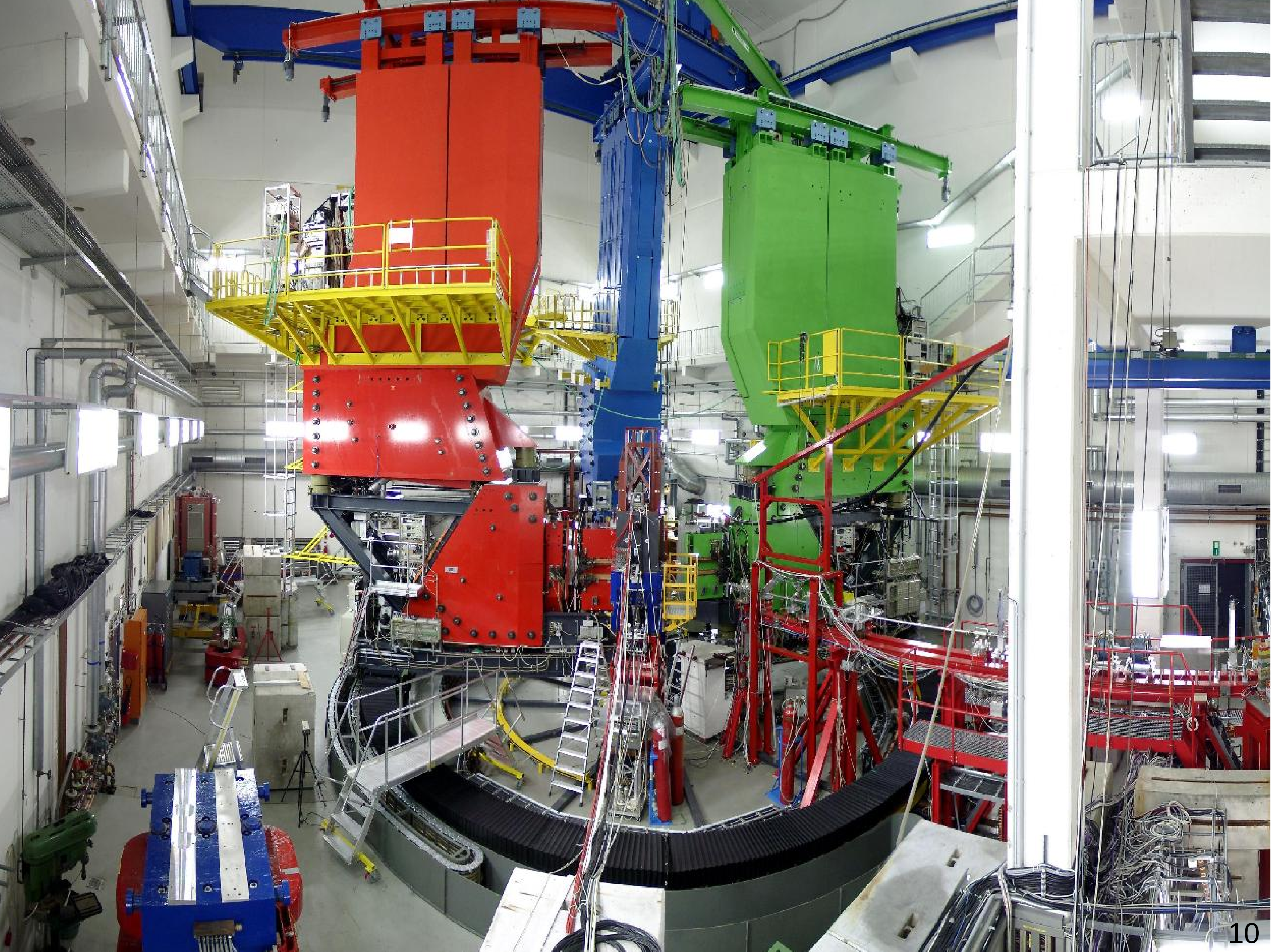
- Cross check new method:
  - ➔ measurements at higher Q²



MAMI

MAMI (Mainz Microtron)
- very stable beam
- up to 100 µA
- up to 1.6 GeV

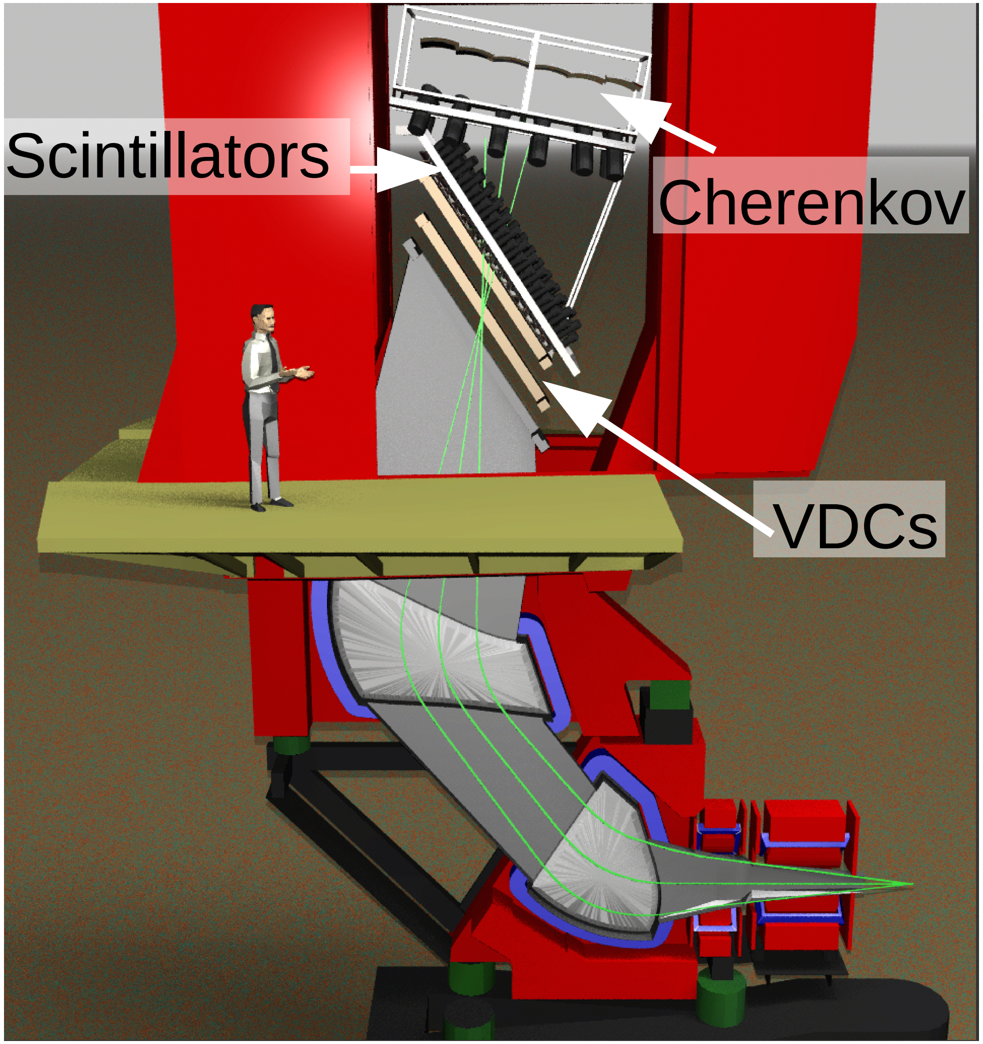




Spectrometers

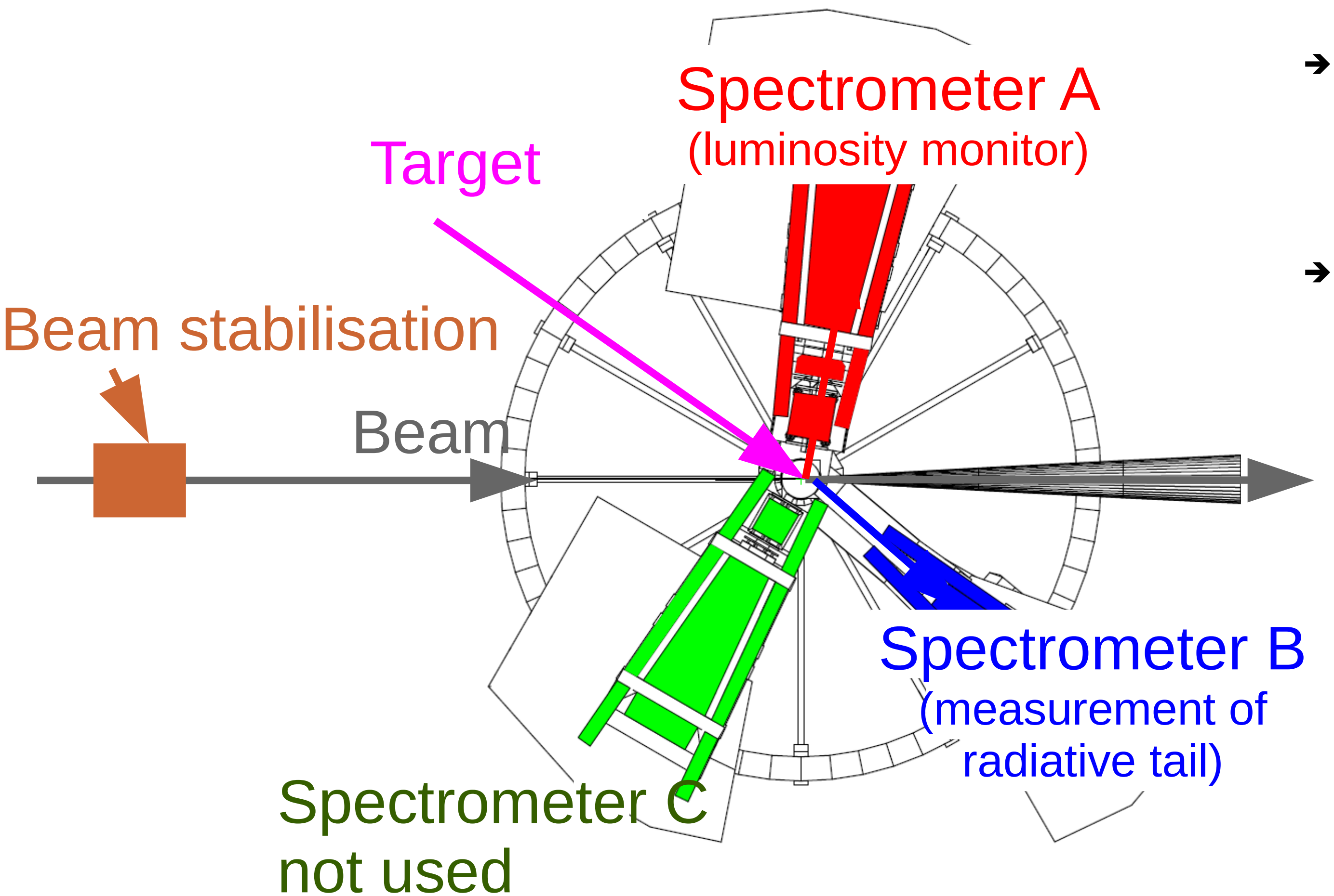
	Spec A	Spec B
relative momentum resolution	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$
resolution at target [mm]	3-5	1

- Both spectrometers use same detector setups:
  - VDCs (Vertical Drift Chambers) for track reconstruction
  - Scintillators for triggering
  - Cherenkov detector for particle identification



The ISR experiment at MAMI

- Beam stabilisation
- Liquid hydrogen target



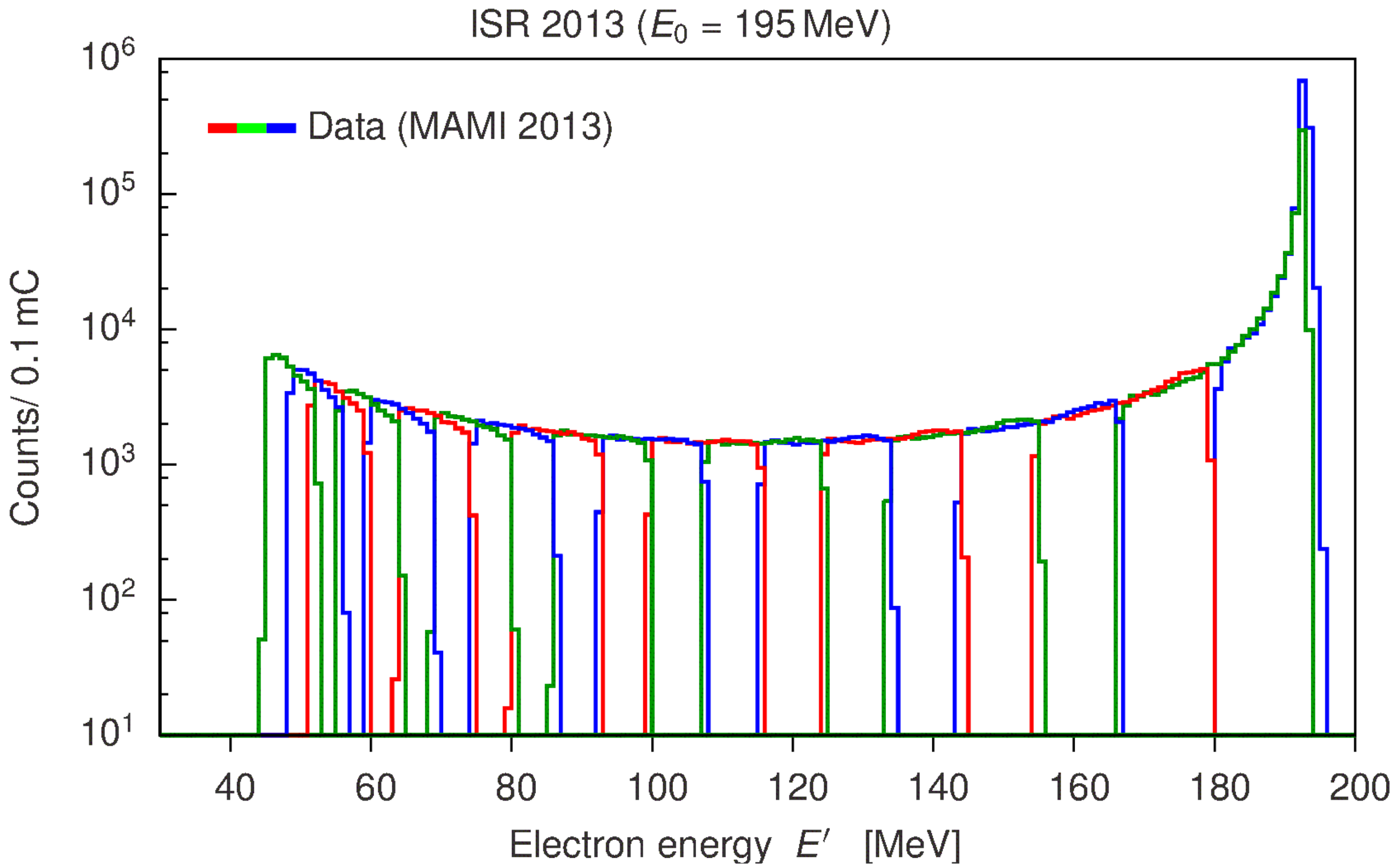
- Three beam energies and various momenta:
  - → 495MeV: 289-486MeV/c
  - → 330MeV: 156-326MeV/c
  - → 195MeV: 48-194MeV/c

Data analysis

Data (2013):
3 beam energies:
495MeV, 330MeV and **195MeV**

Data analysis

- online data: excellent quality



Detector calibration

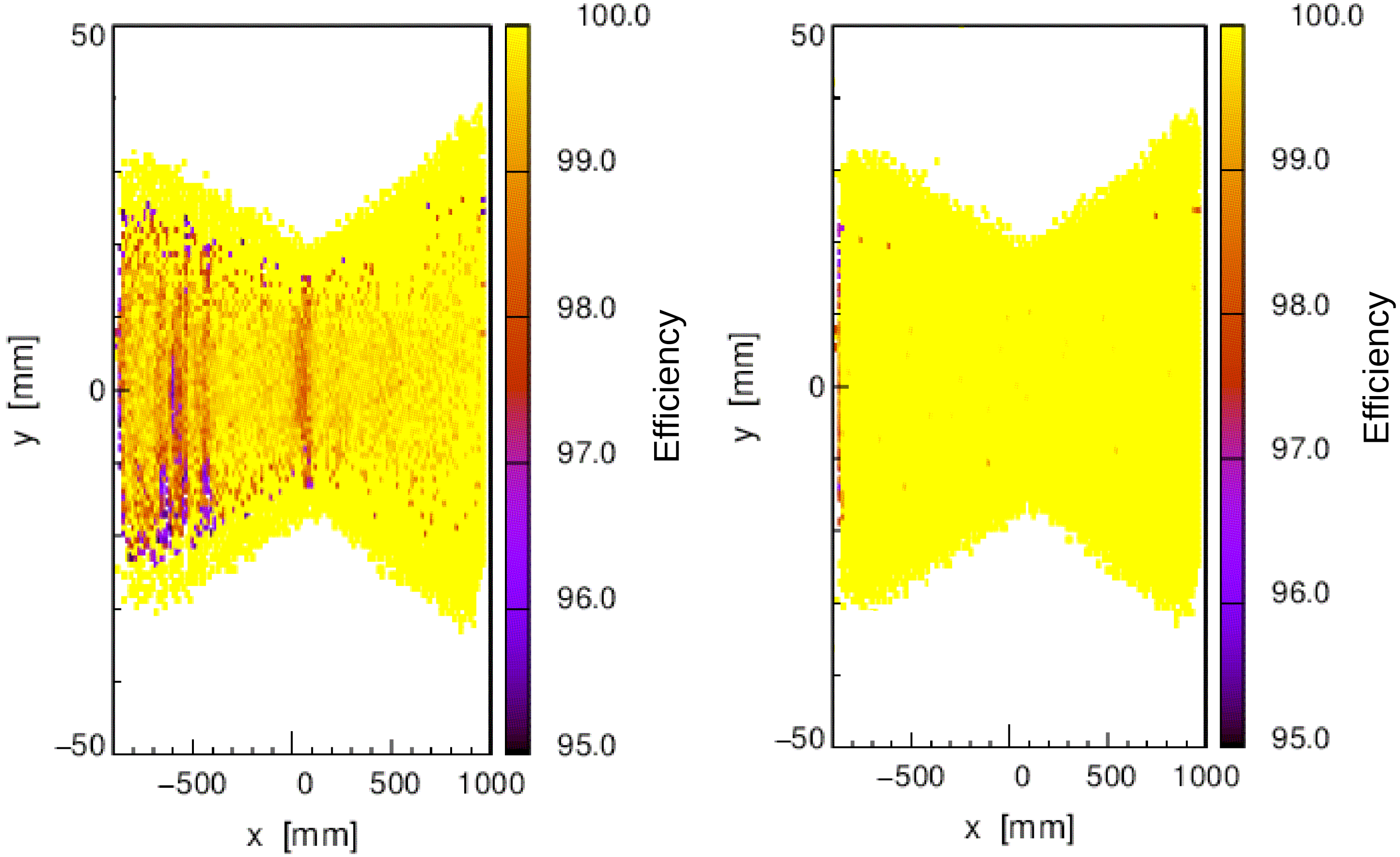
Data (2013):
3 beam energies:
495MeV, 330MeV and
195MeV

Detectors:
Efficiency calibration
New tracking algorithm

Detector efficiency

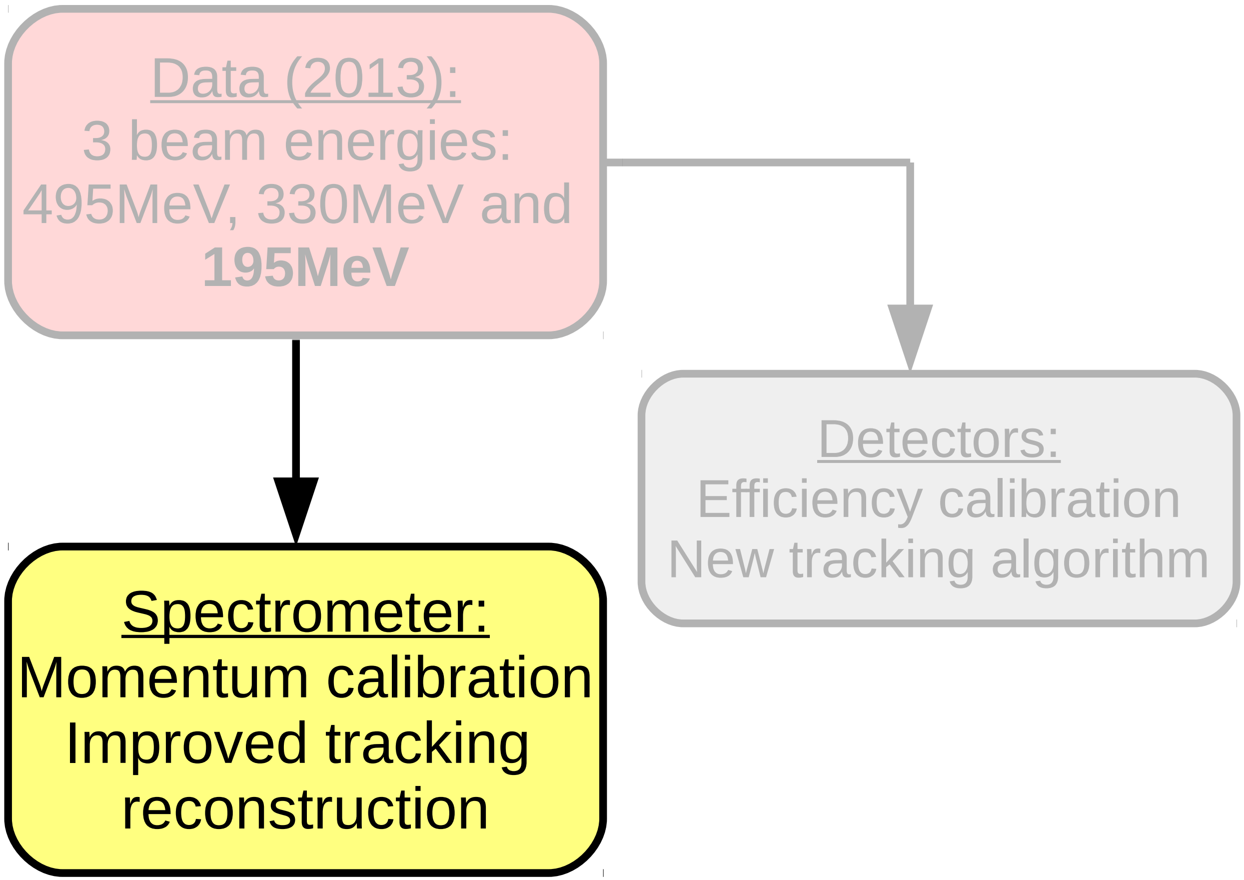
- Efficiency inhomogeneities in VDC layers
- New tracking algorithm developed
  - ➔ further improvement

efficiency plot for 1 of 4 layers



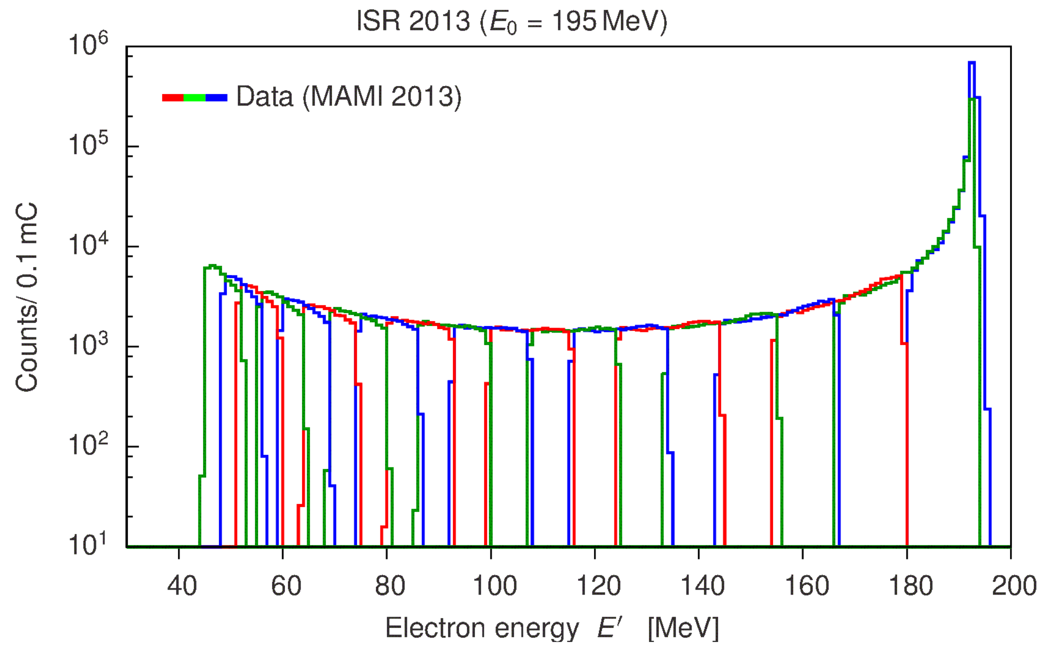
- Scintillator efficiency ~ 99.3 %
- Cherenkov efficiency ~ 99.6 %

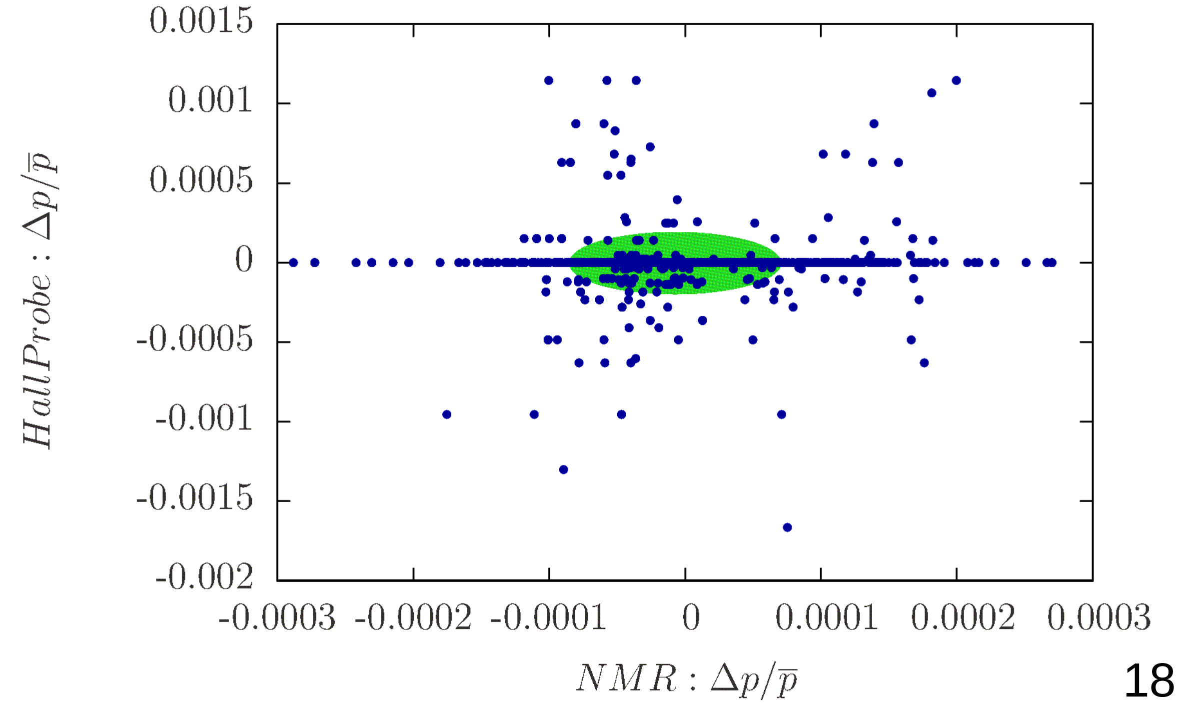
Resolution calibration



Momentum calibration

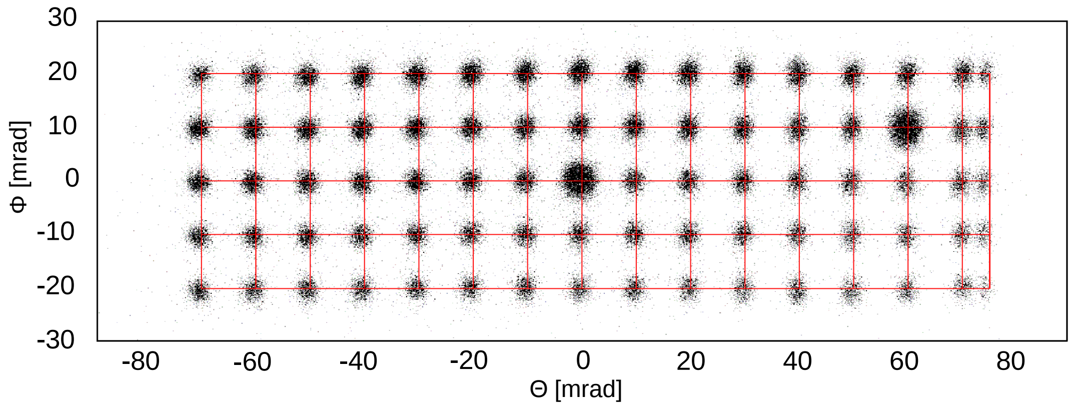
- Good spectrometer resolution is crucial for precise ISR measurements.
- Central momentum and its resolution must be known precisely.
- Central momentum: relative precision ~$1 \cdot 10^{-4}$.

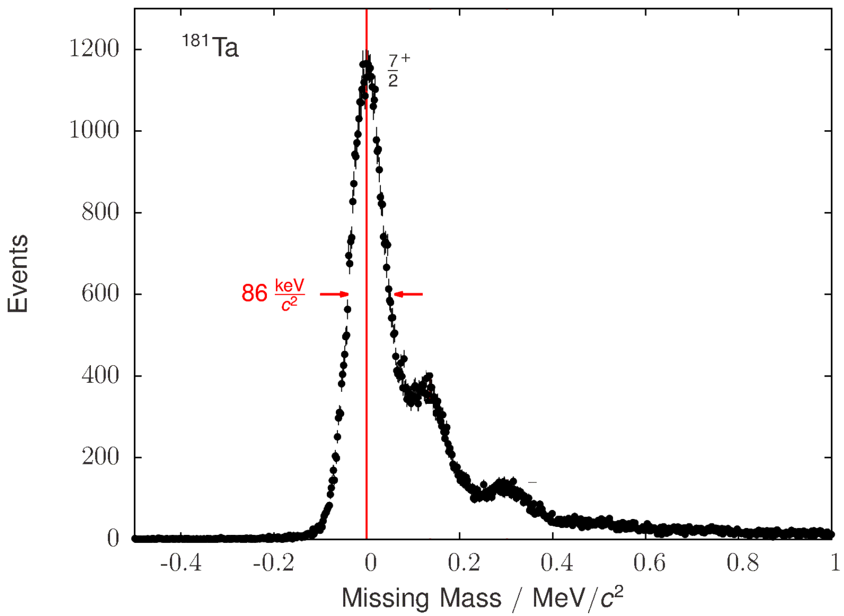




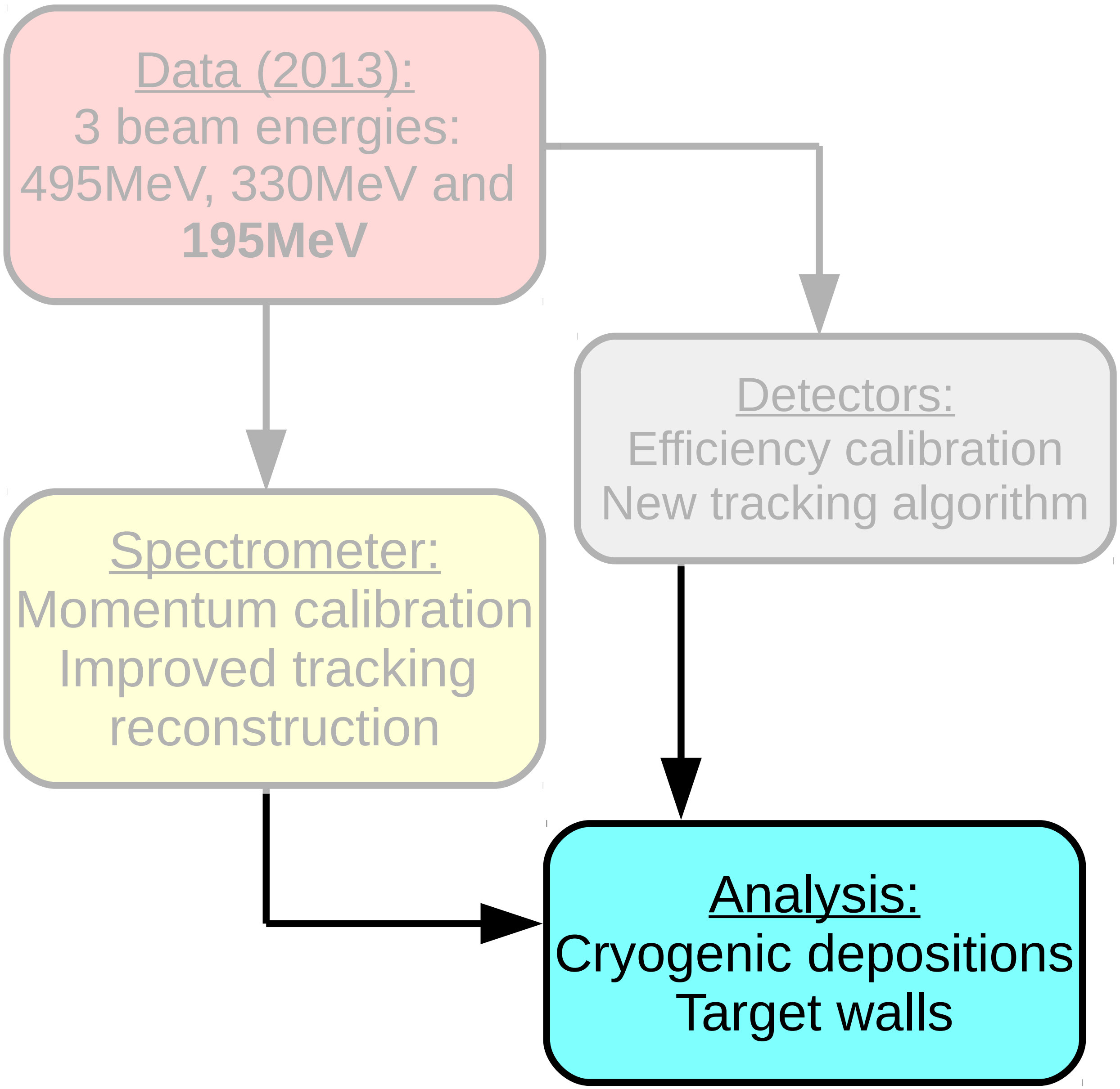
Recalibration of tracking reconstruction

- Transfer matrix for track reconstruction
- Sieve slit collimator used to find best matrix
- Achieved momentum resolution: $1.7 \cdot 10^{-4}$



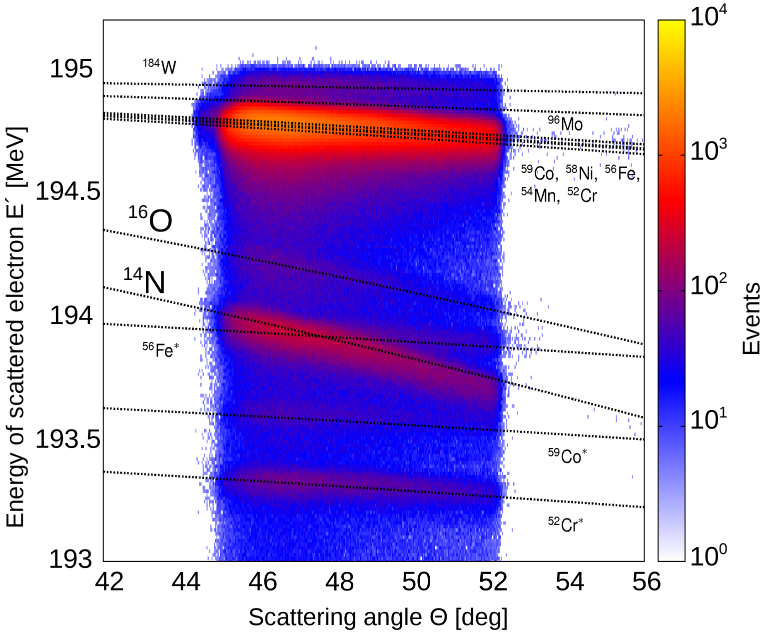


Offline analysis

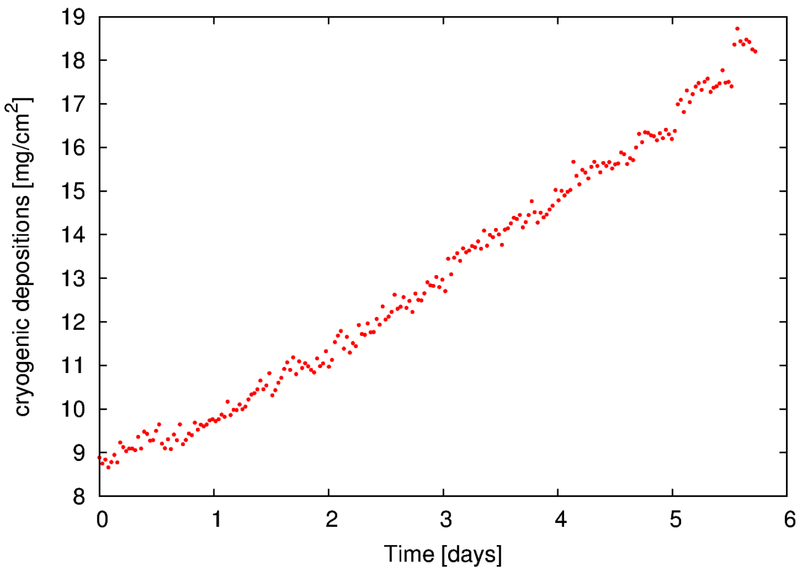


Cryogenic depositions

- For minimal cryogenic depositions:
  - Aramid foils
    - Vacuum as good as possible: 10^{-6}mbar

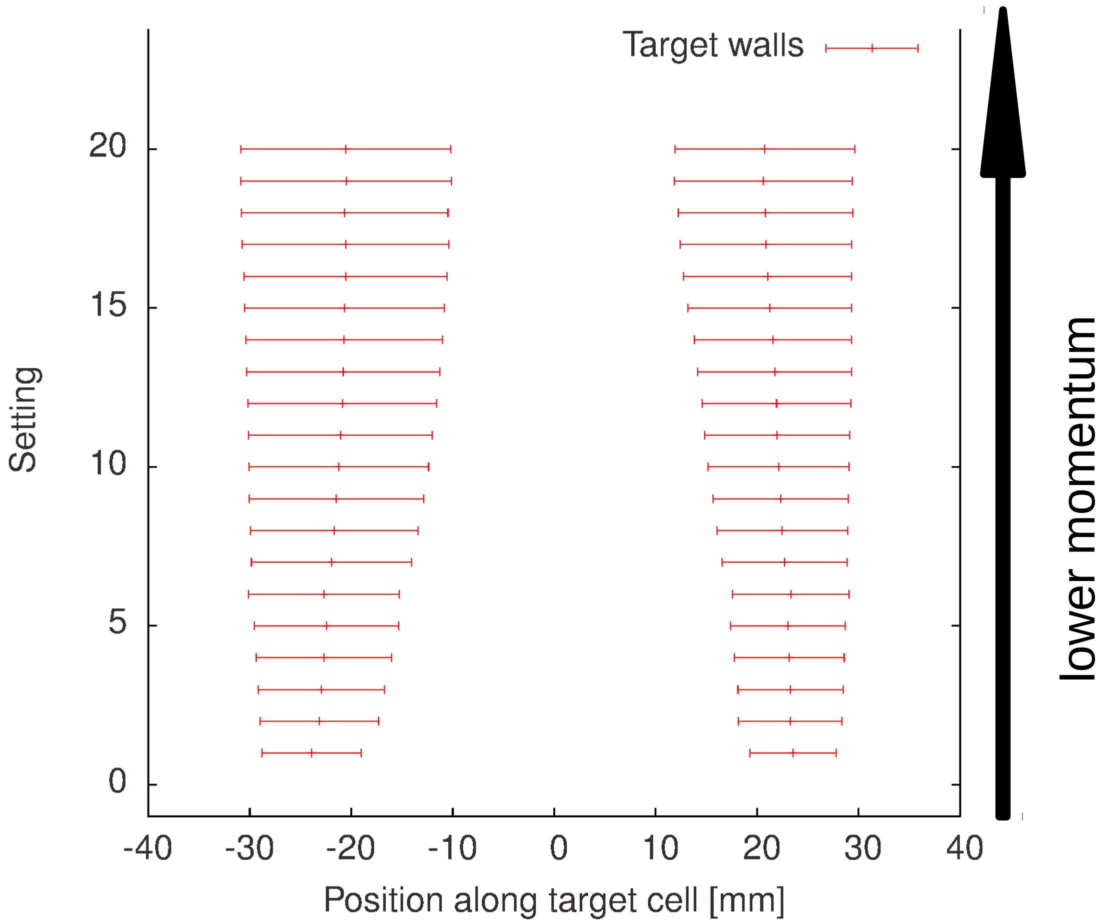


- Spectrometer A monitors nitrogen and oxygen
- Nitrogen and oxygen identified
  - precise tracking of cryogenic depositions

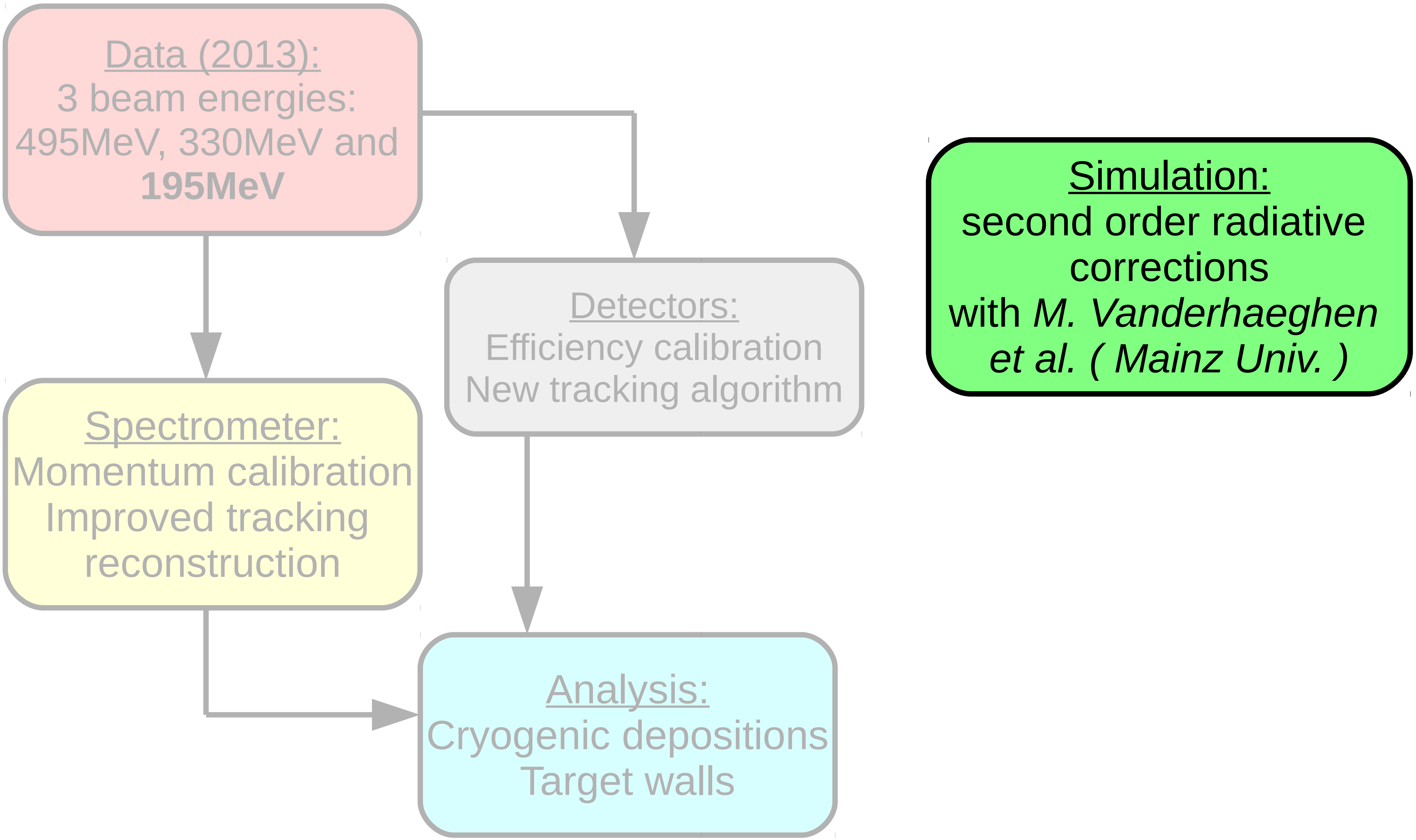


Dealing with the cell walls

- Events from cell walls contaminate hydrogen data
- Lower momenta worsens vertex resolution
  - ➔ no clean vertex cuts possible
- Solution: Subtract empty cell measurements from data
  - ➔ Empty cell measurement for every setting



Simulation


Data (2013):
3 beam energies:
495MeV, 330MeV and
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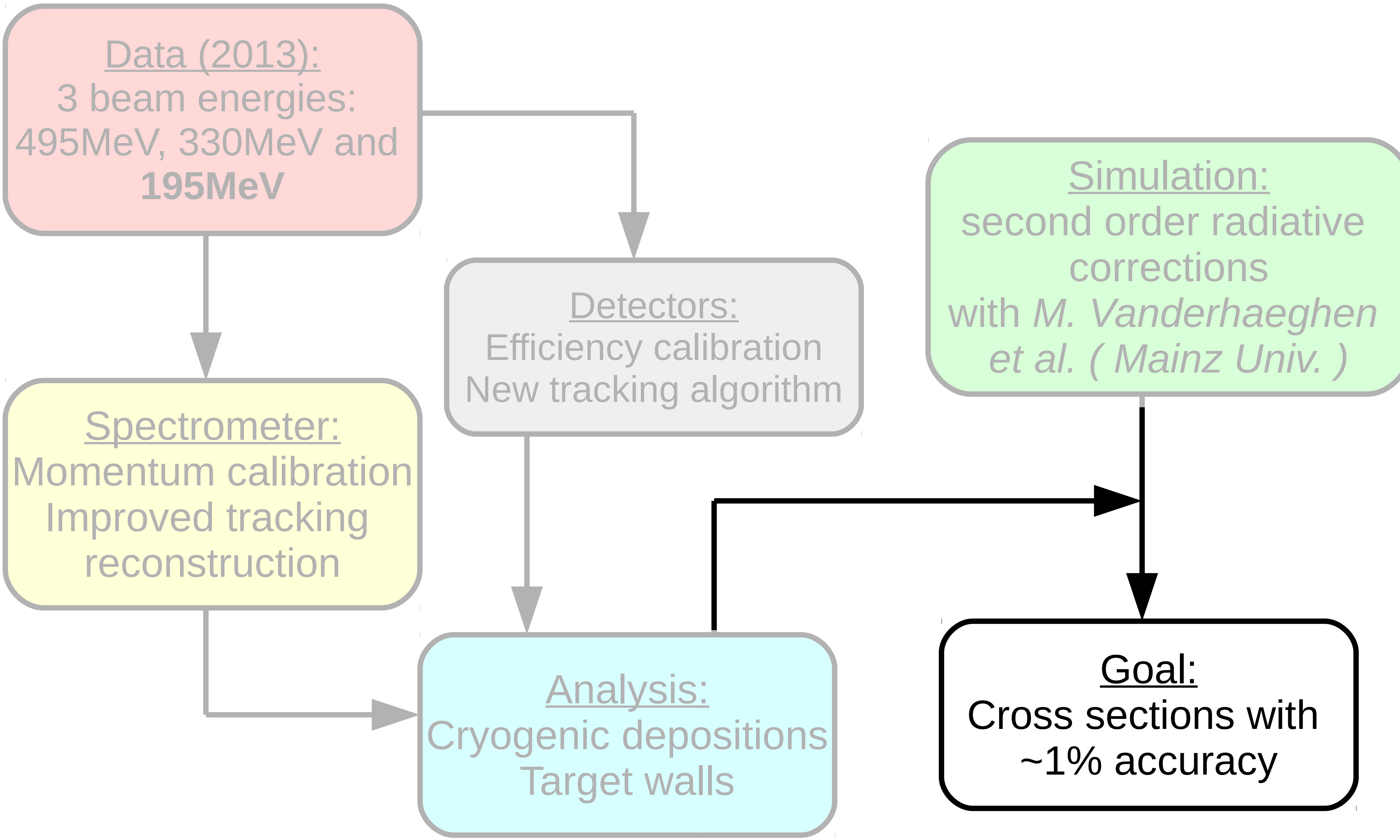
Detectors:
Efficiency calibration
New tracking algorithm
Simulation:
second order radiative
corrections
with M. Vanderhaeghen
et al. (Mainz Univ.)
Spectrometer:
Momentum calibration
Improved tracking
reconstruction
Analysis:
Cryogenic depositions
Target walls

Goal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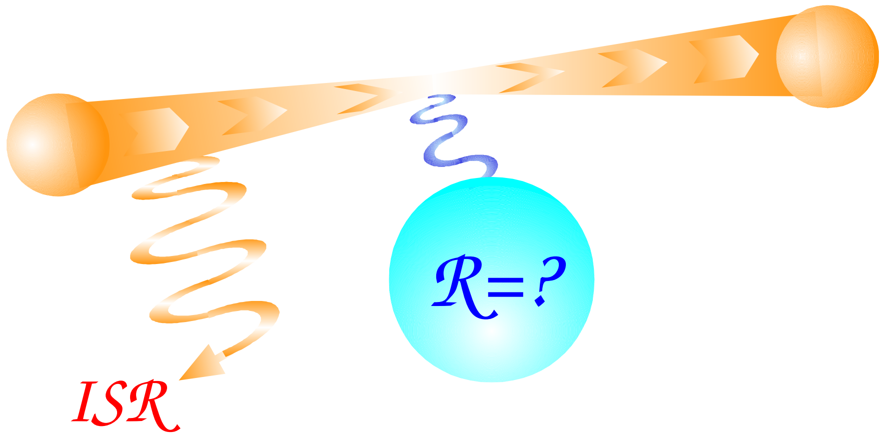
Cryogenic depositions
Target walls
Goal:
Cross sections with
~1% accuracy

Conclusions

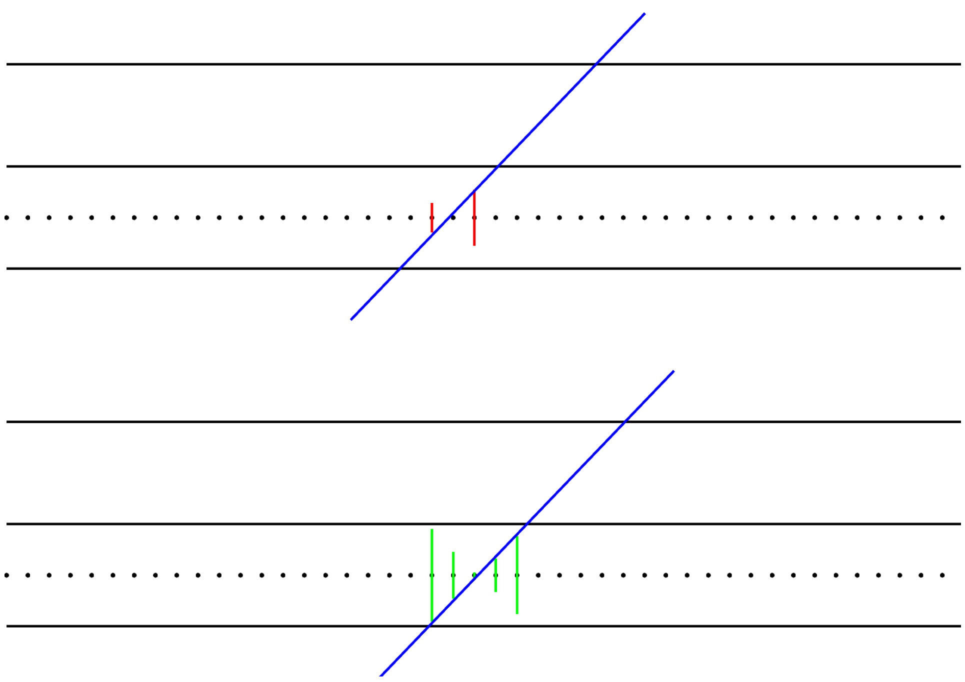
- Proton radius puzzle is an open question in nuclear physics.
- New method based on ISR used to determine G_E at even lower Q^2.
- Experiment took place in summer 2013.
- Data analysis is ongoing.
- Goal: determine cross section with ~1% accuracy.

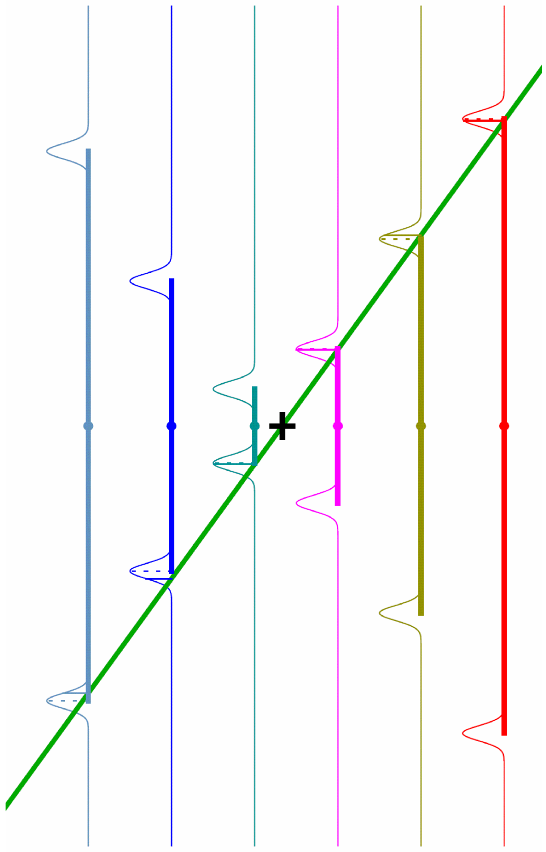


Thank You

A1 collaboration: P. Achenbach, J. Beričič, R. Böhm, D. Bosnar, L. Corea, A. Denig, M. O. Distler, A. Esser, H. Fonvieille, I. Friščić , T. Gogami, M. Gómez, O. Hashimoto, S. Kegel, Y. Kohl, H. Merkel, M. Mihovilovič, J. Müller, U. Müller, S. Nagao, S. N. Nakamura, J. Pochodzalla, B. S. Schlimme, M. Schoth, F. Schulz, C. Sfienti, S. Širca, S. Štajner, A. Tyukin, M. Thiel, K. Tsukada, T. Walcher, A. Weber

New tracking algorithm





Old algorithm:

- Least Square Method
  - ➔ fast
  - ➔ very few tracks were ignored

New algorithm:

- Maximum Likelihood Method
  - ➔ slower
  - ➔ even more efficient