Unique opportunities to measure proton elastic form factors at EIC

Jan C. Bernauer

EIC UG Meeting, July 2016

Massachusetts Institute of Technology

Cross section and form factors for elastic lepton-proton scattering

The cross section:

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

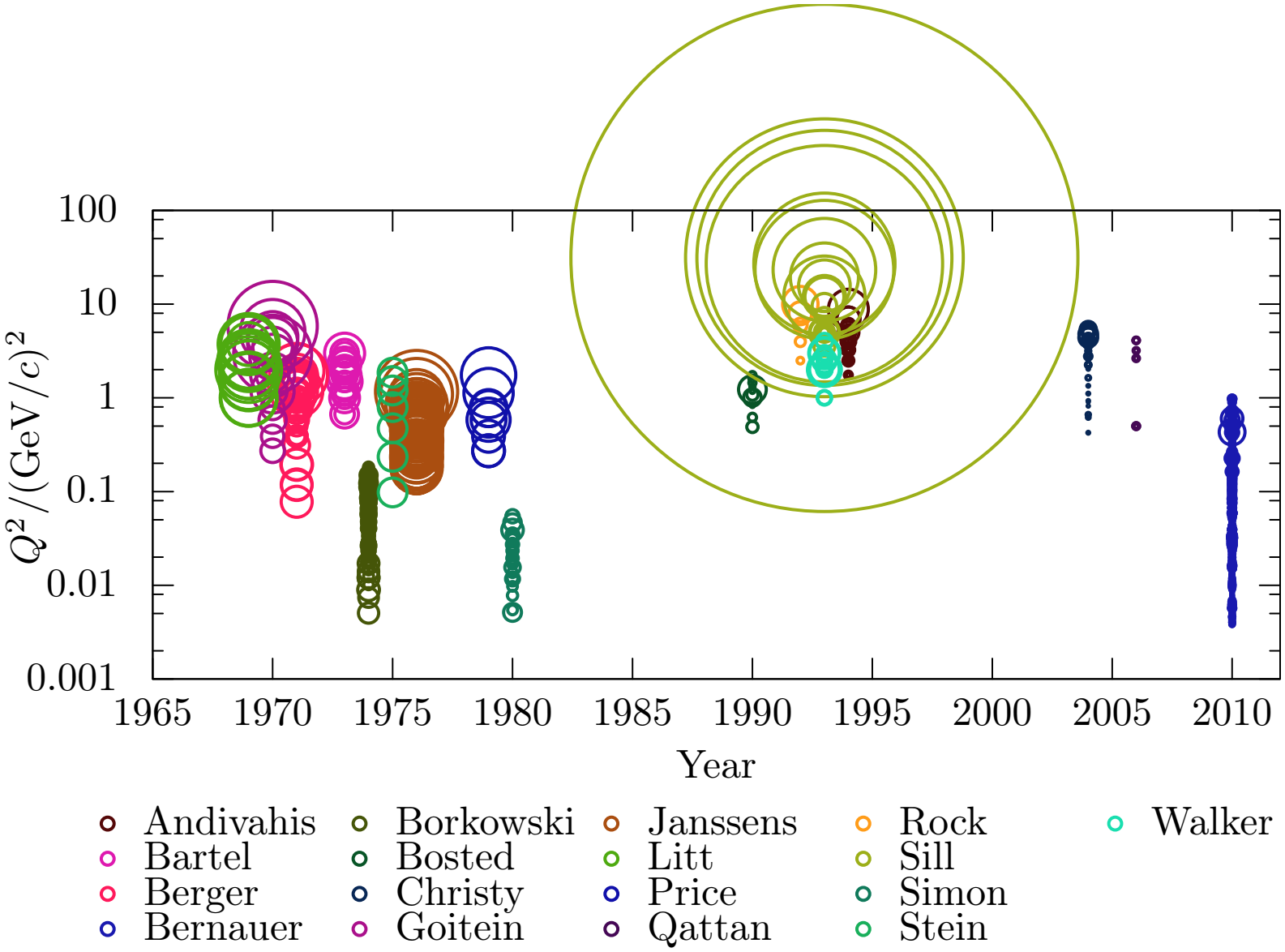
with:

$$\tau = \frac{Q^2}{4m_p^2}, \quad \varepsilon = \left(1 + 2\left(1+\tau\right)\tan^2\frac{\theta_e}{2}\right)^{-1}$$

Fourier-transform of G_E, G_M $\longrightarrow$ spatial distribution (Breit frame)

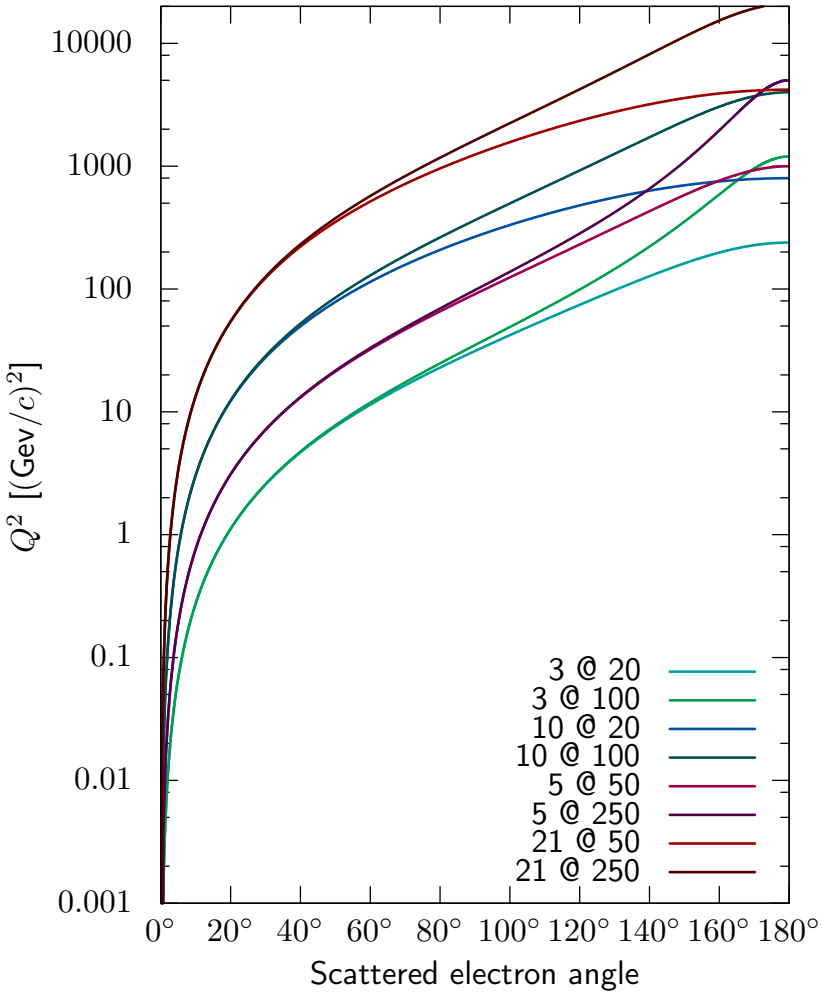
$$\left\langle r_E^2 \right\rangle = -6\hbar^2 \left.\frac{\mathrm{d}G_E}{\mathrm{d}Q^2}\right|_{Q^2=0} \qquad \left\langle r_M^2 \right\rangle = -6\hbar^2 \left.\frac{\mathrm{d}\left(G_M/\mu_p\right)}{\mathrm{d}Q^2}\right|_{Q^2=0}$$

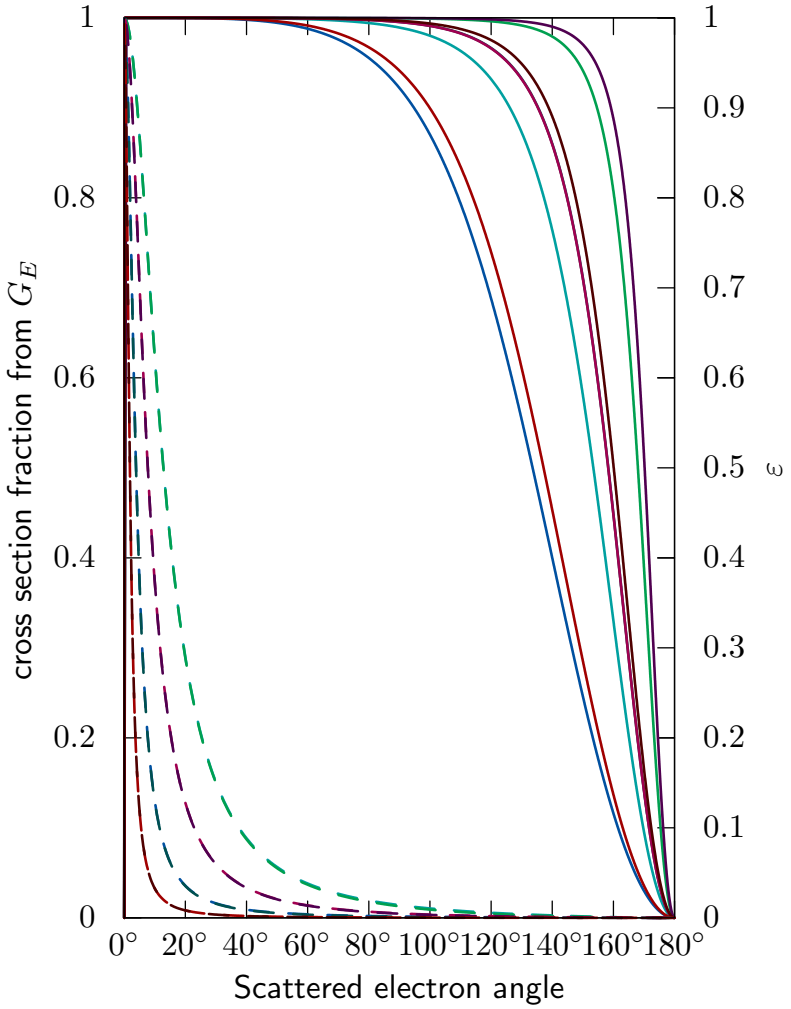
History of unpolarized electron-proton scattering



Collider kinematics

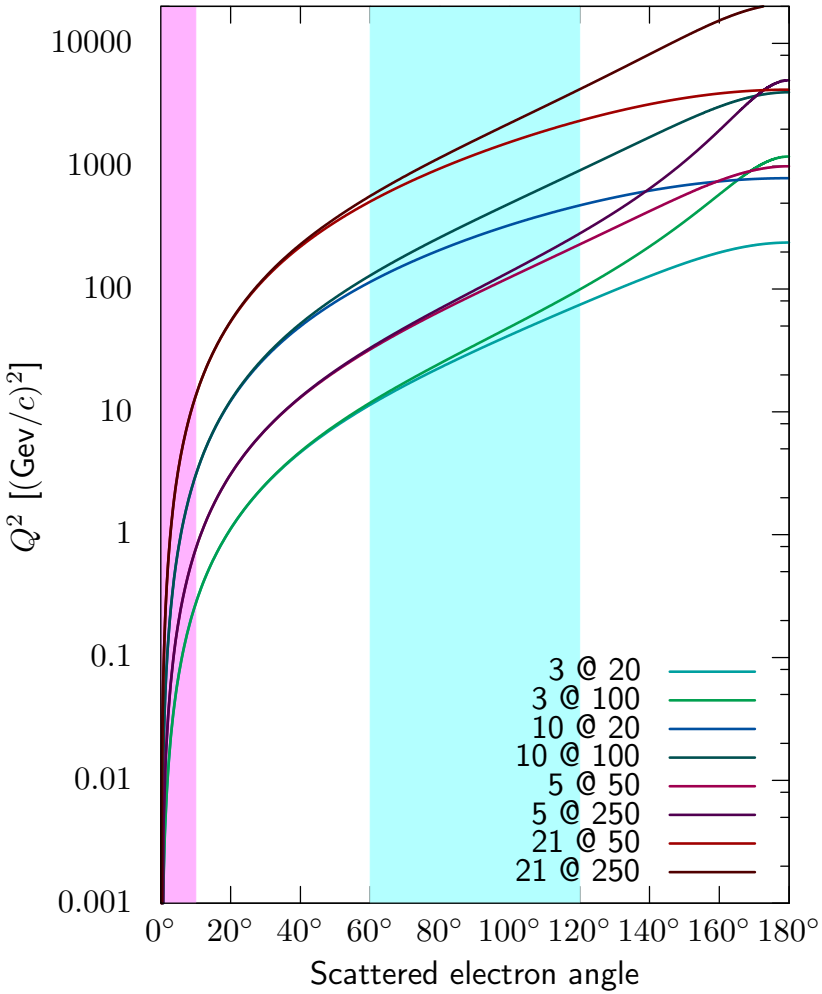
Idea from C. Sofiatti and T. W. Donnelly,"Polarized e-p Elastic Scattering in the Collider Frame," Phys. Rev. C 84, 014606 (2011)

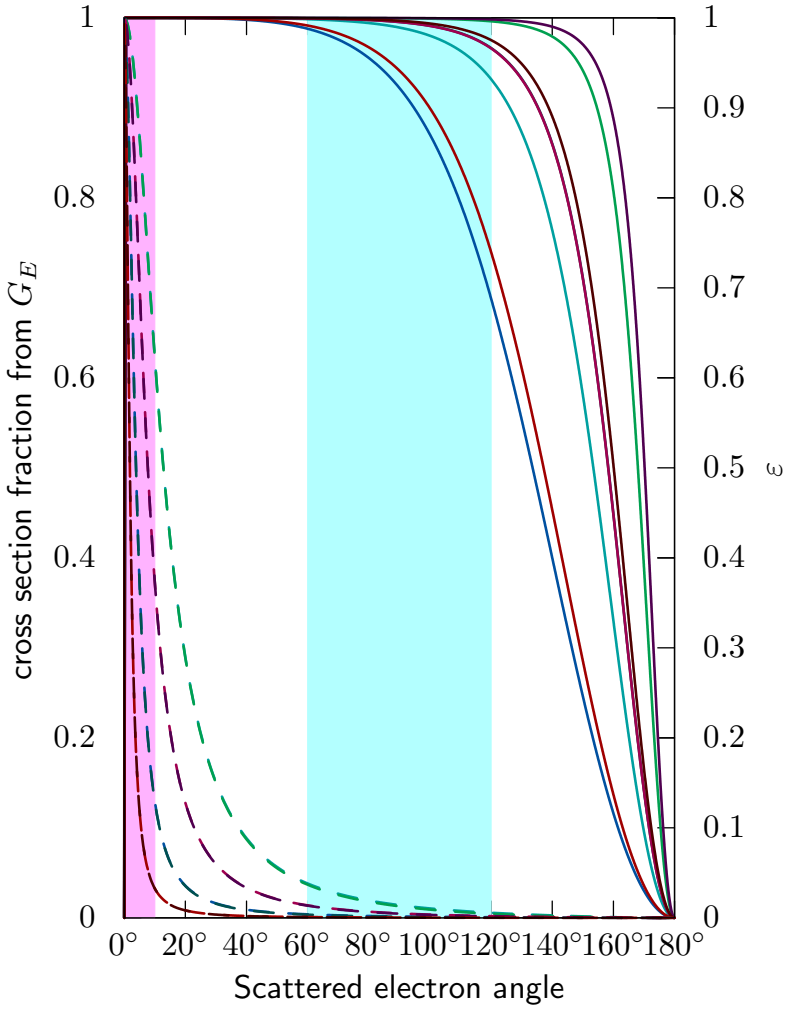




Collider kinematics

Idea from C. Sofiatti and T. W. Donnelly,"Polarized e-p Elastic Scattering in the Collider Frame," Phys. Rev. C 84, 014606 (2011)





G_M at large Q^2

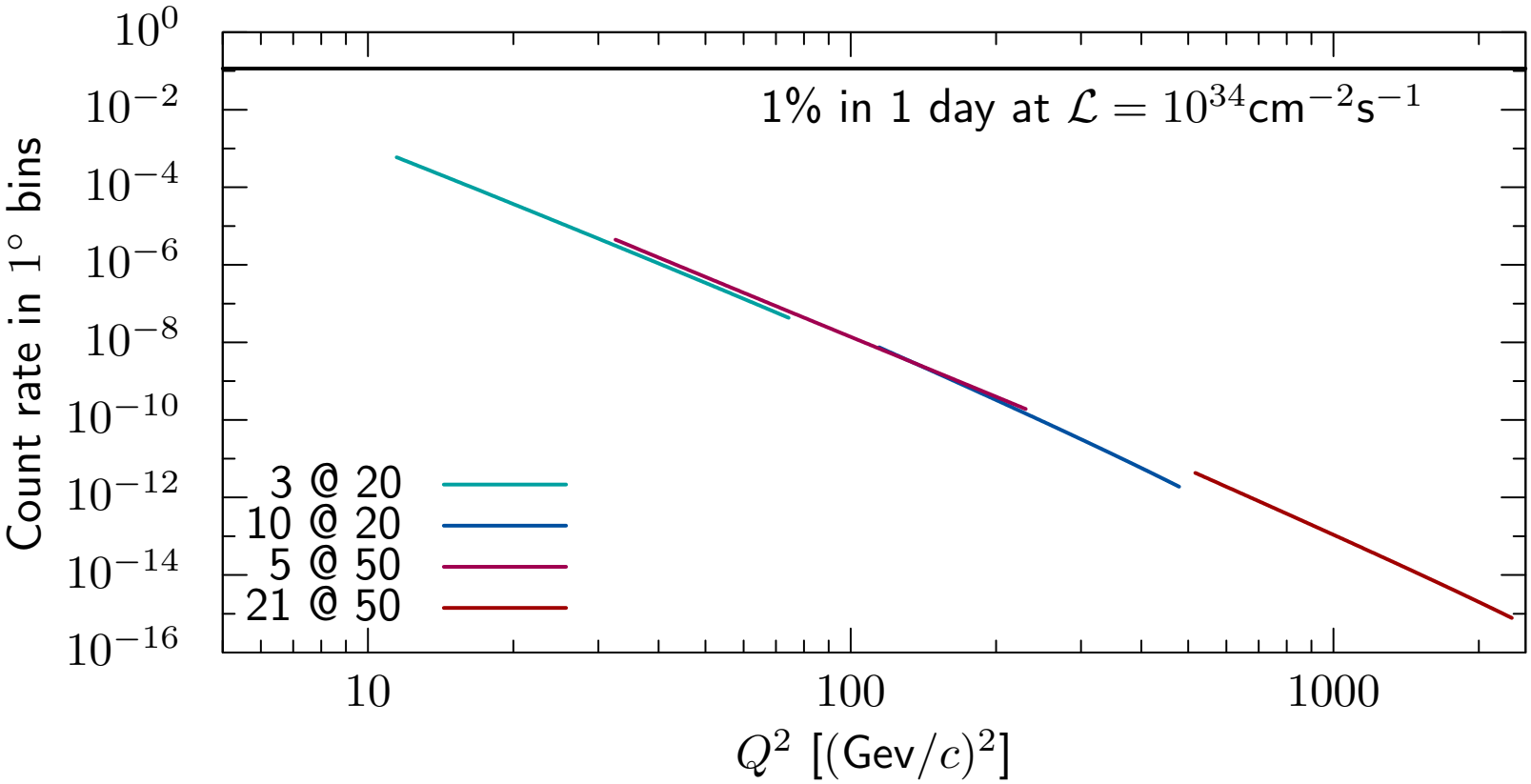
Motivation

- Not much data at high Q^2. Does G_M cross 0?
- clean signal
- $\varepsilon \sim 1$: Two photon exchange suppressed

G_M at large Q^2

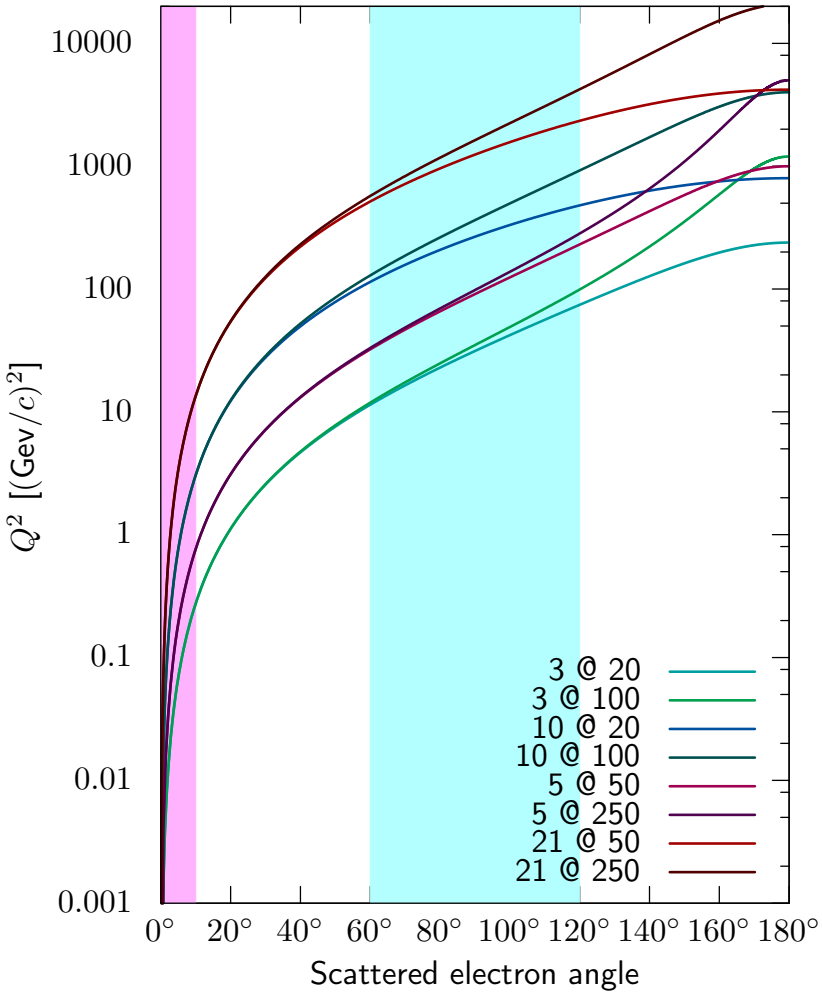
Motivation

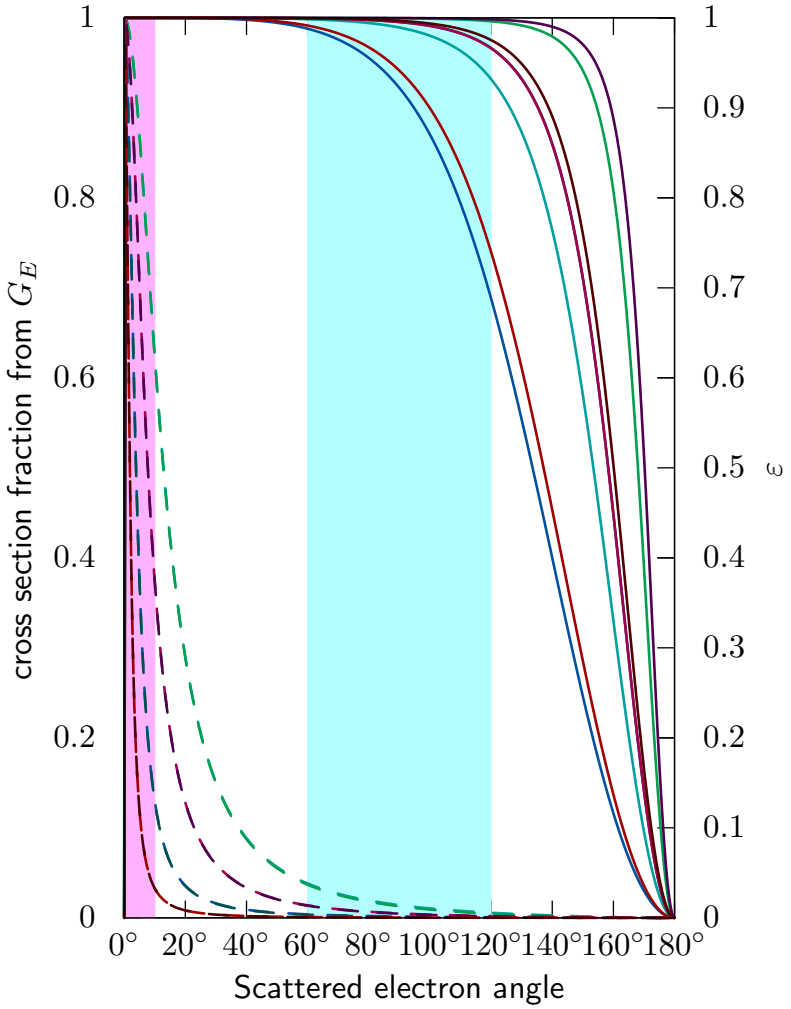
- Not much data at high Q^2. Does G_M cross 0?
- clean signal
- $\varepsilon \sim 1$: Two photon exchange suppressed



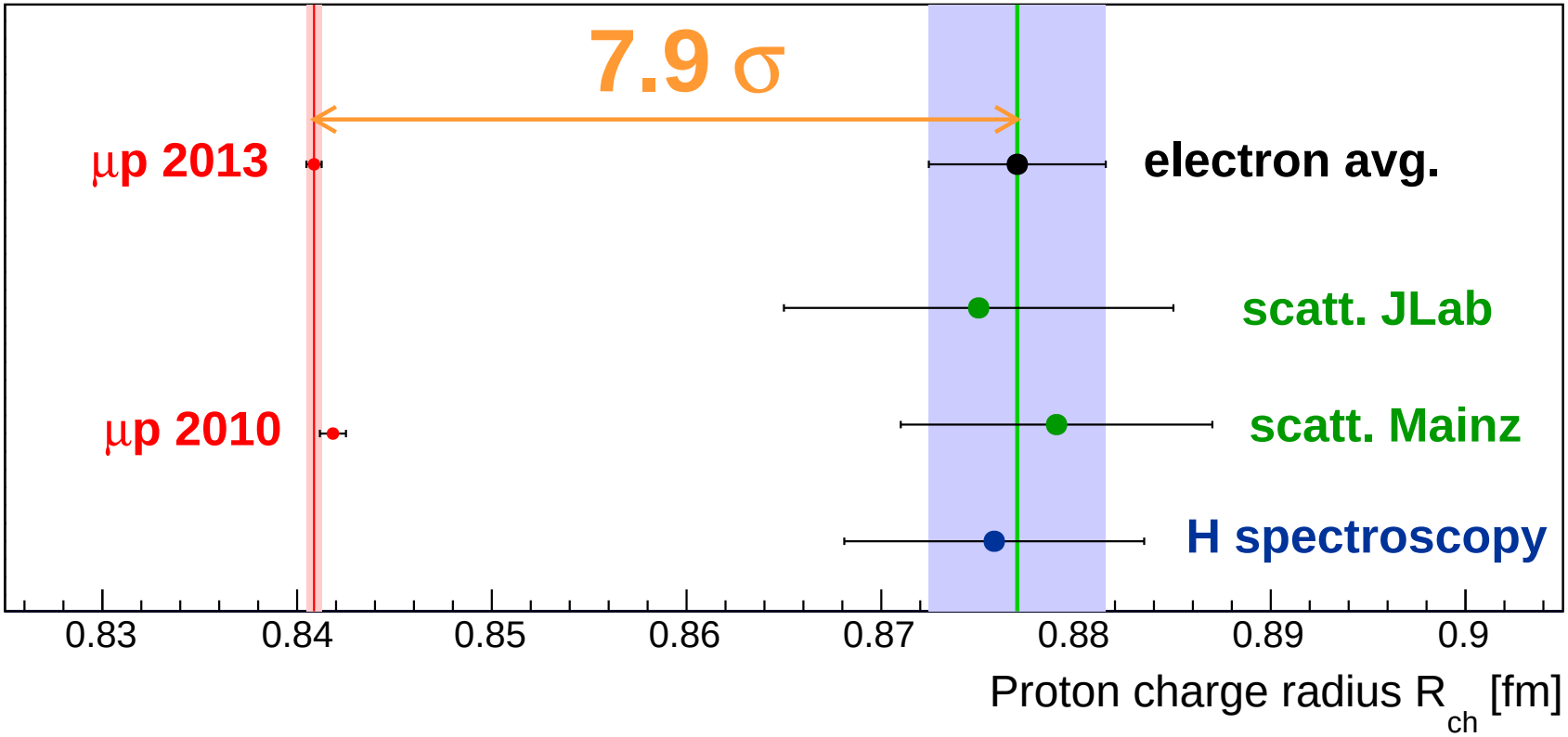
Collider kinematics

Idea from C. Sofiatti and T. W. Donnelly,"Polarized e-p Elastic Scattering in the Collider Frame," Phys. Rev. C 84, 014606 (2011)



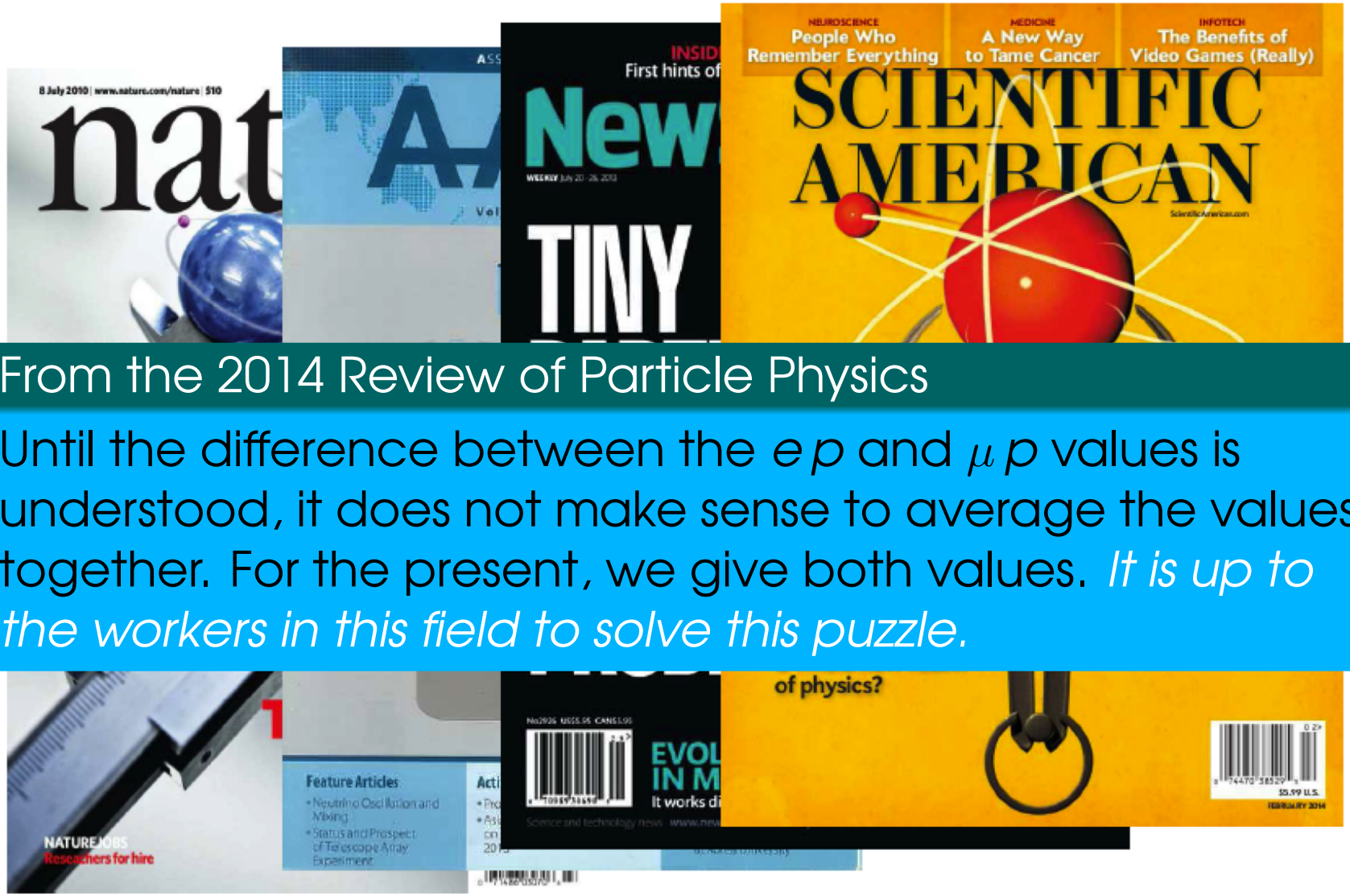


The Proton Puzzle



The Proton Puzzle

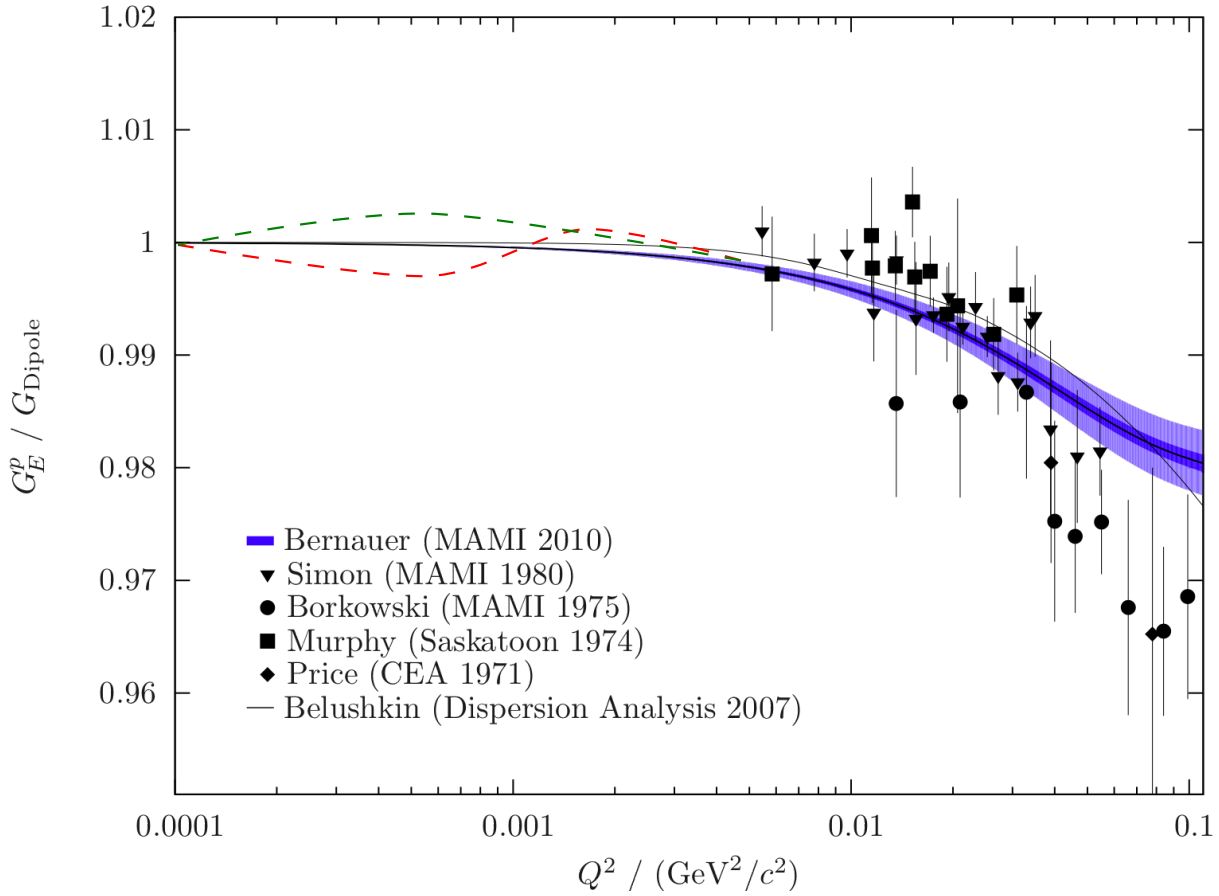
The Proton Puzzle



From the 2014 Review of Particle Physics

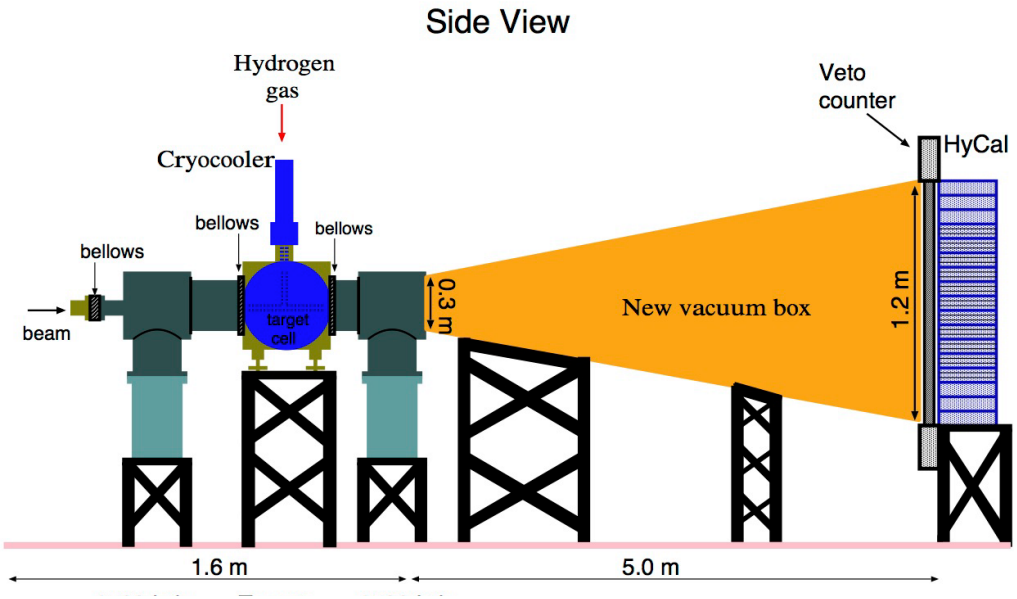
Until the difference between the $e\,p$ and $\mu\,p$ values is understood, it does not make sense to average the values together. For the present, we give both values. *It is up to the workers in this field to solve this puzzle.*

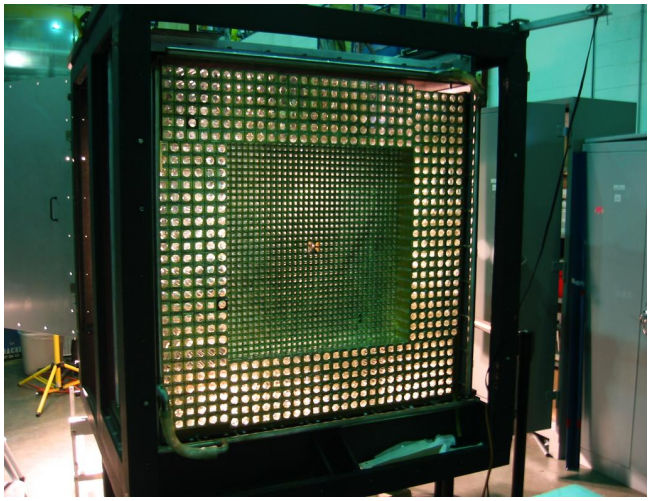
Form factors at very small Q^2



- Is extrapolation invalid?
- Structure at low Q^2?

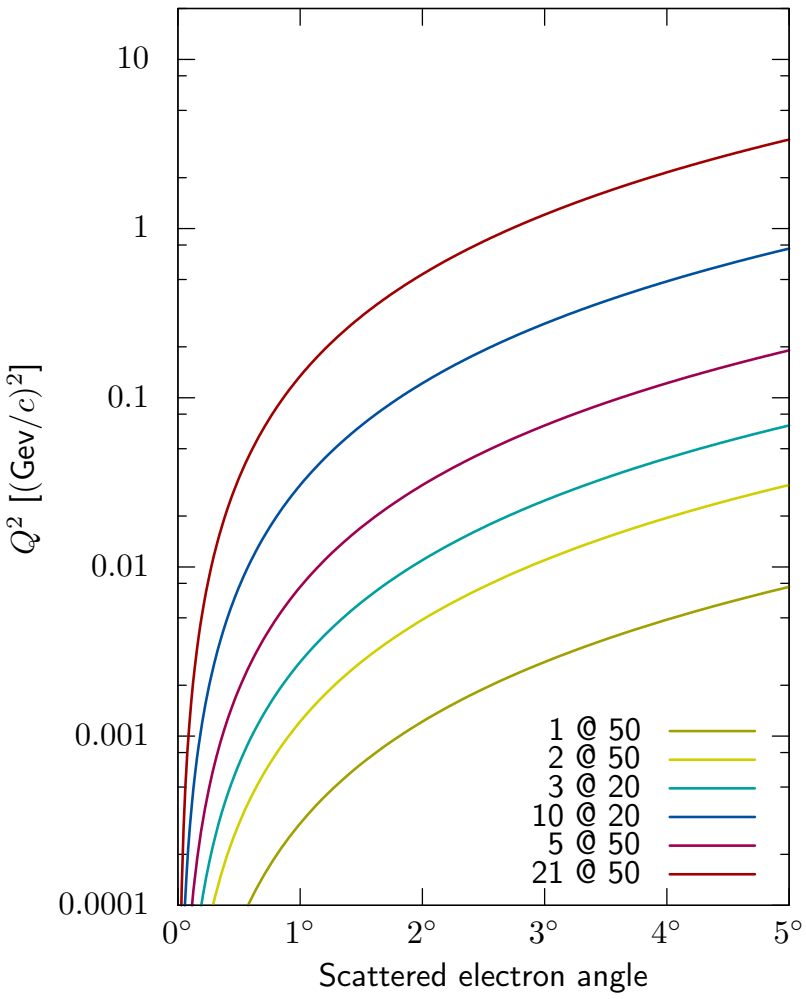
JLAB: PRad

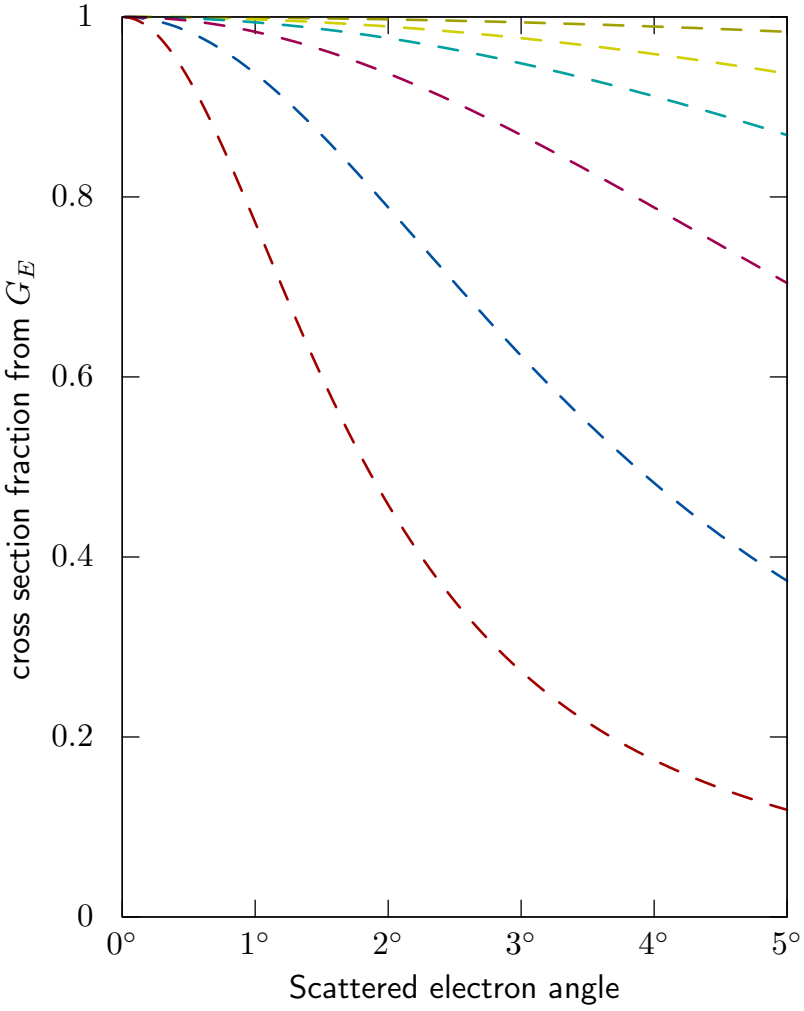




- High resolution, large acceptance hybrid calorimeter+GEM
- Windowless target
- Simultaneous measure ep $\rightarrow$ ep and Møller scattering
- Q^2 range: 2×10^{-4} to 2×10^{-2} $(\mathrm{GeV}/c)^2$

G_E at small Q^2

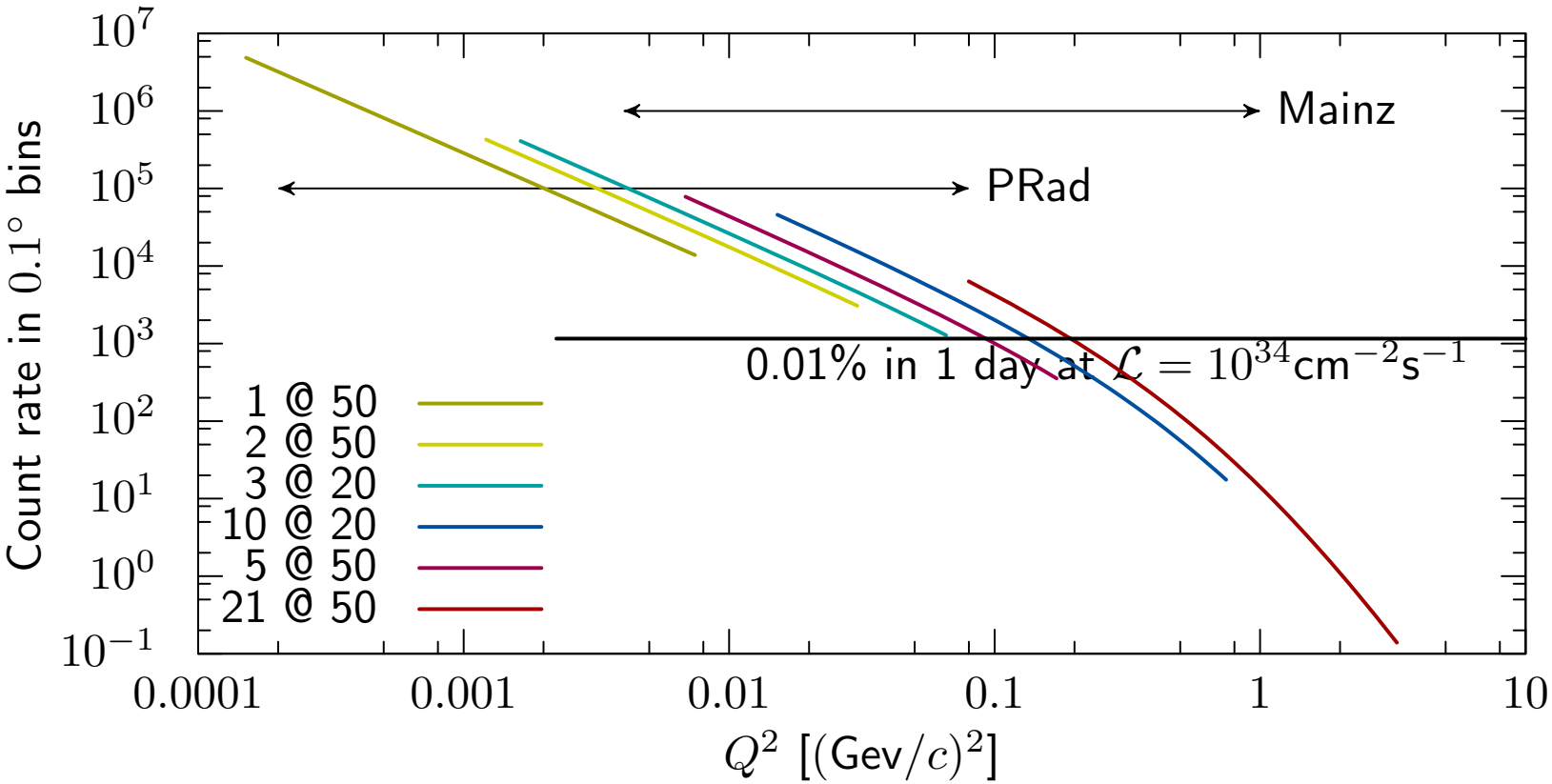




G_E at small Q^2: benefits and feasibility

Benefits

- $\varepsilon = 1$, no hard Two-Photon-Exchange
- minimal contribution from G_M
- No background



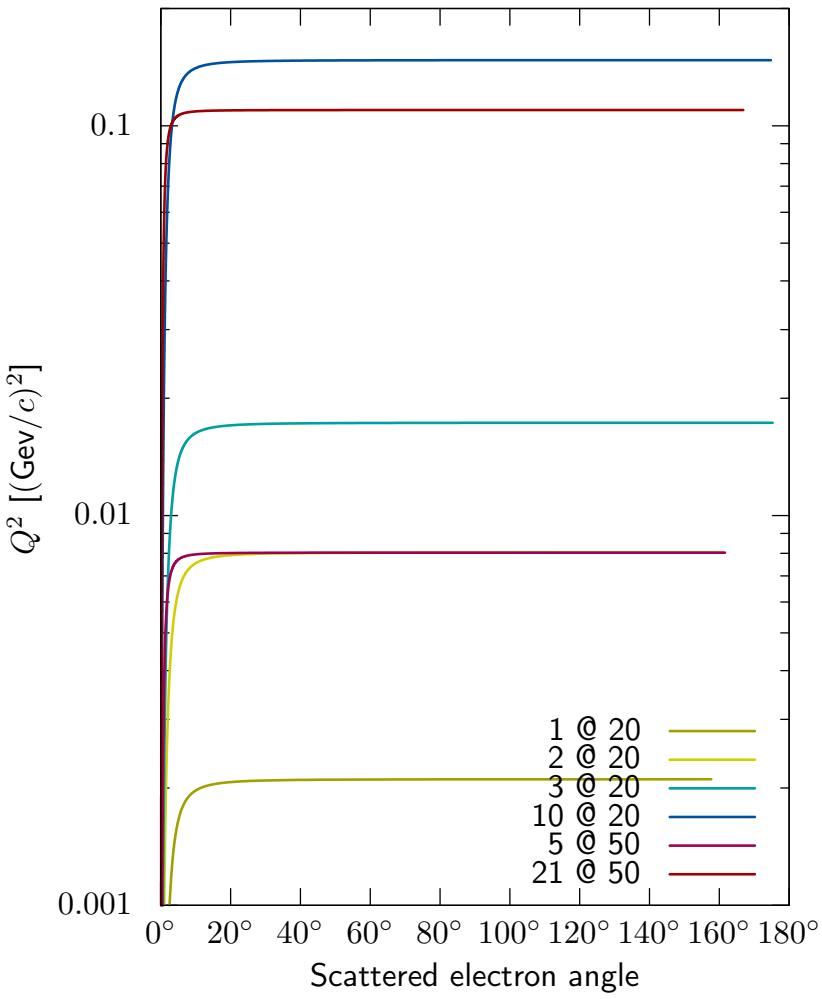
“Race” kinematics

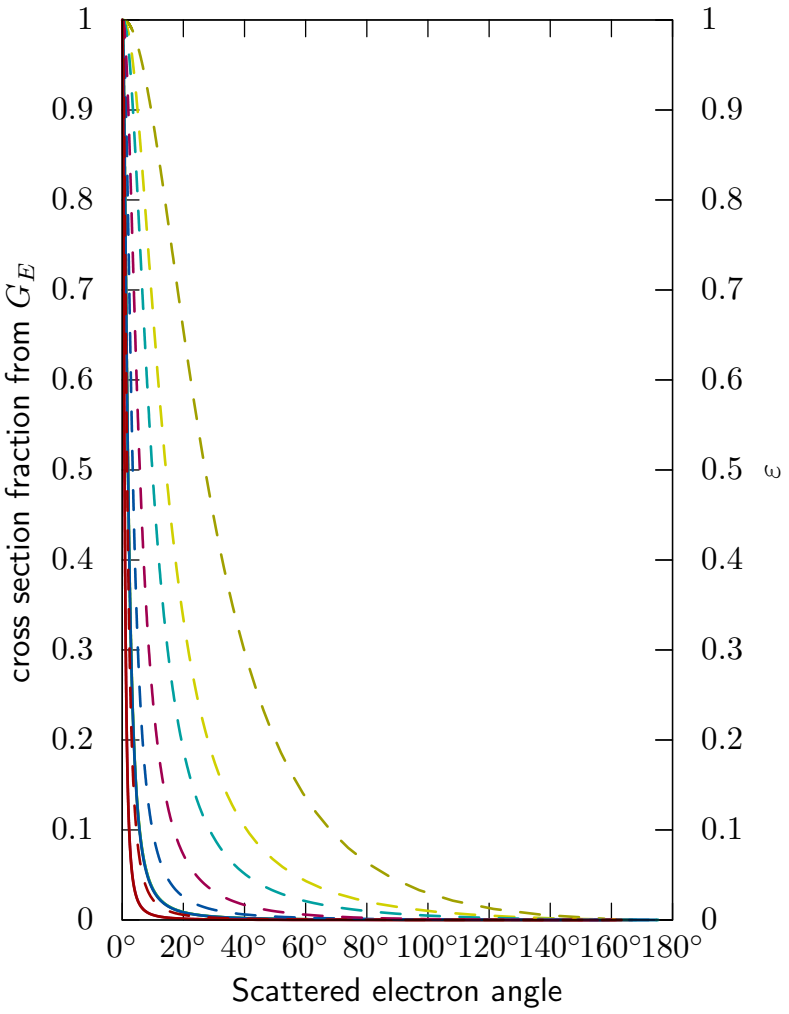
- Collider kinematics: Project out forward angles of fixed target frame
- Can we access backward angles?

“Race” kinematics

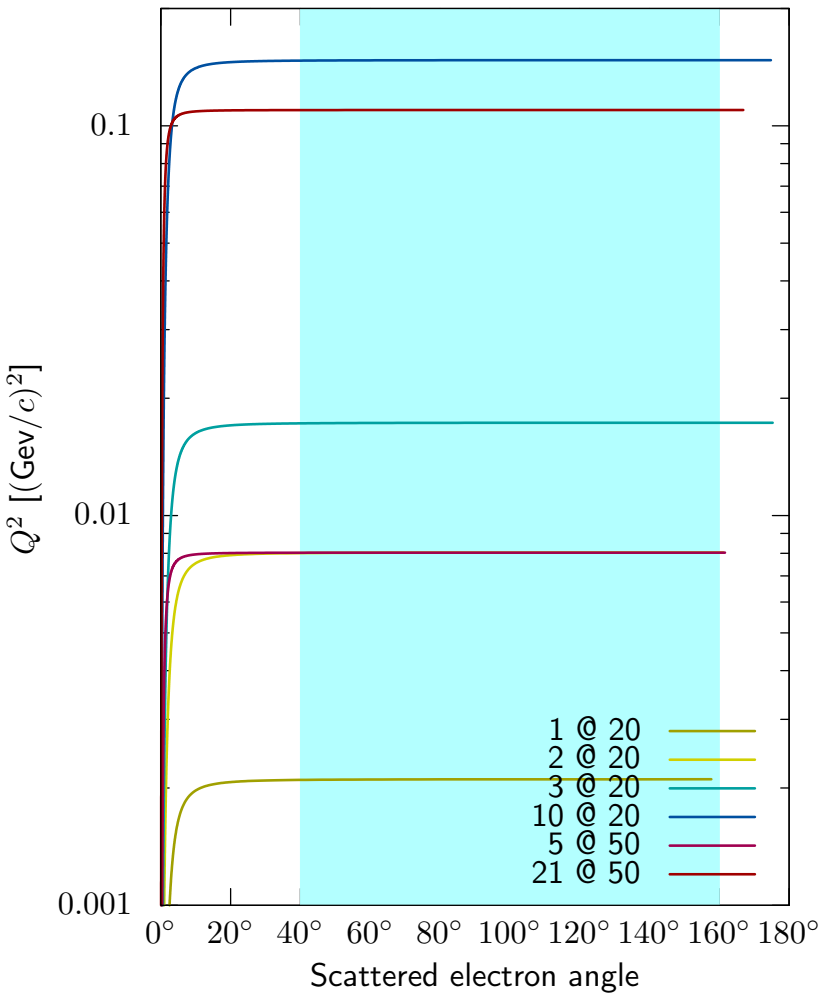
- Collider kinematics: Project out forward angles of fixed target frame
- Can we access backward angles?
- Yes! Have same direction for proton and lepton! Lepton races the proton (and proton loses)
- Technically feasible?! Reverse electron ring or use positrons!

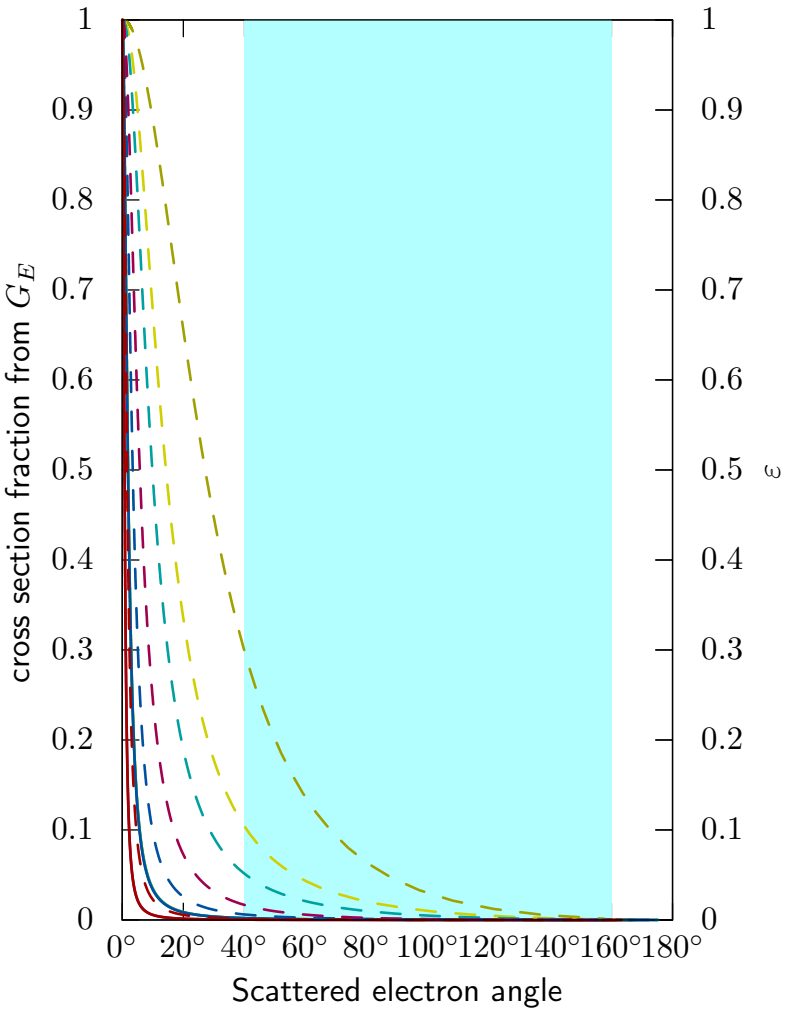
"Race" kinematics: Possibilities



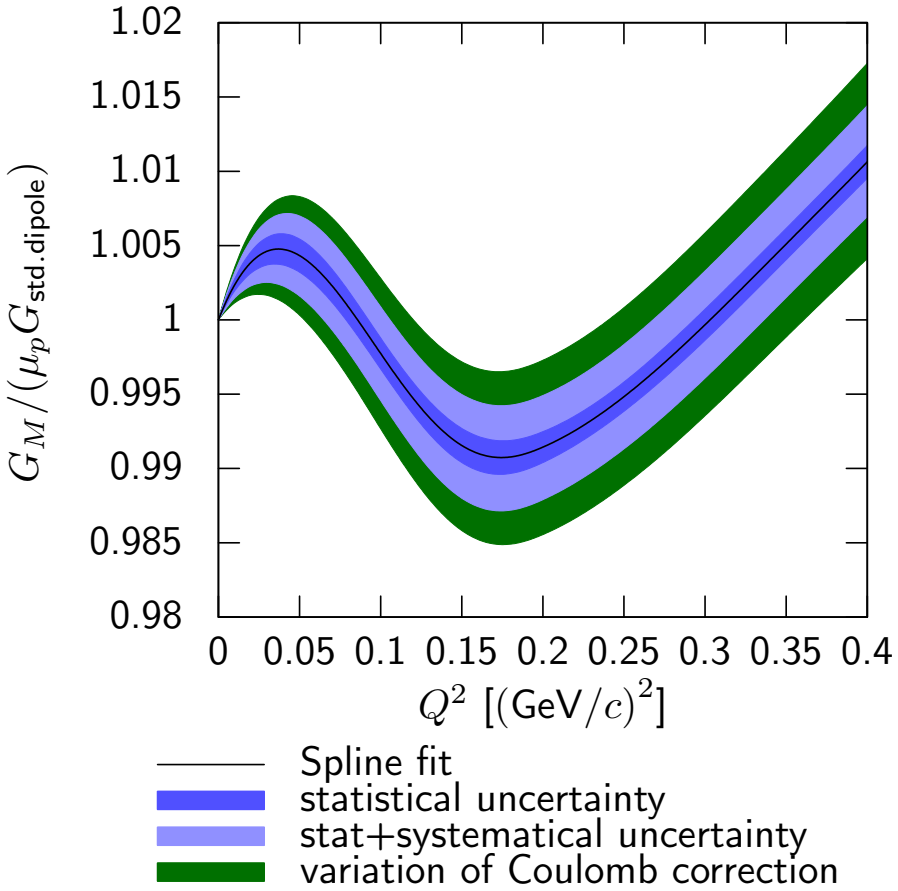


"Race" kinematics: Possibilities



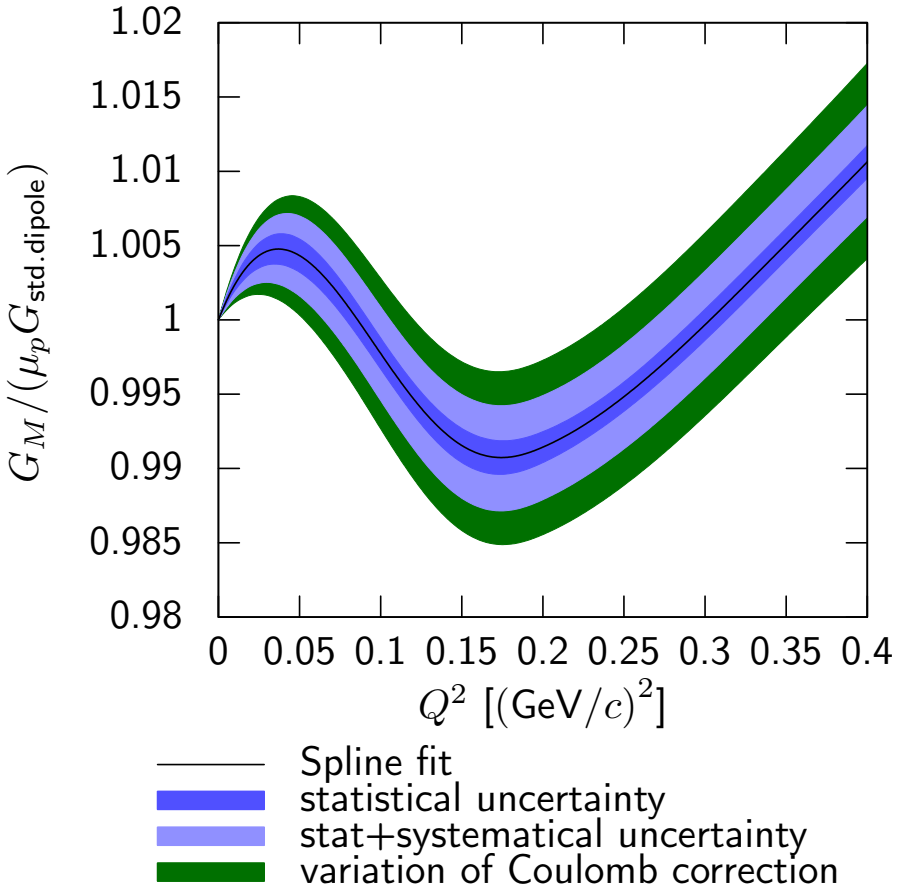


Proton magnetic form factor



- Up-Down-Up structure
- Not seen before
  - Older fits approach from below
  - Lack of data
- Gives rise to small r_m
- Sensitive to radiative corrections

Proton magnetic form factor



- Up-Down-Up structure
- Not seen before
  - Older fits approach from below
  - Lack of data
- Gives rise to small r_m
- Sensitive to radiative corrections

G_M at low-Q

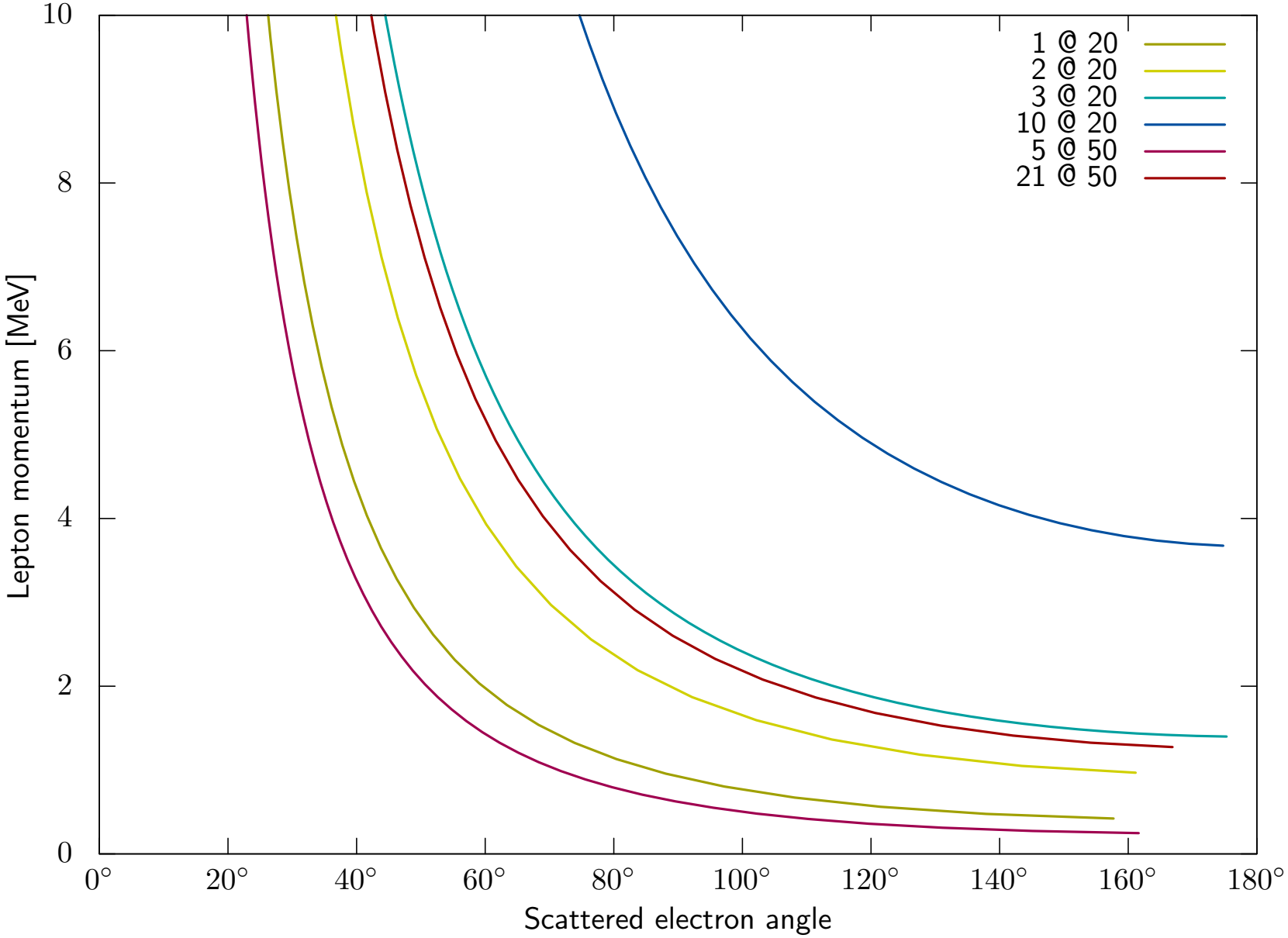
Benefits

- $\varepsilon = 0$, no G_E contribution (but two-photon exchange!)
- completely different systematic

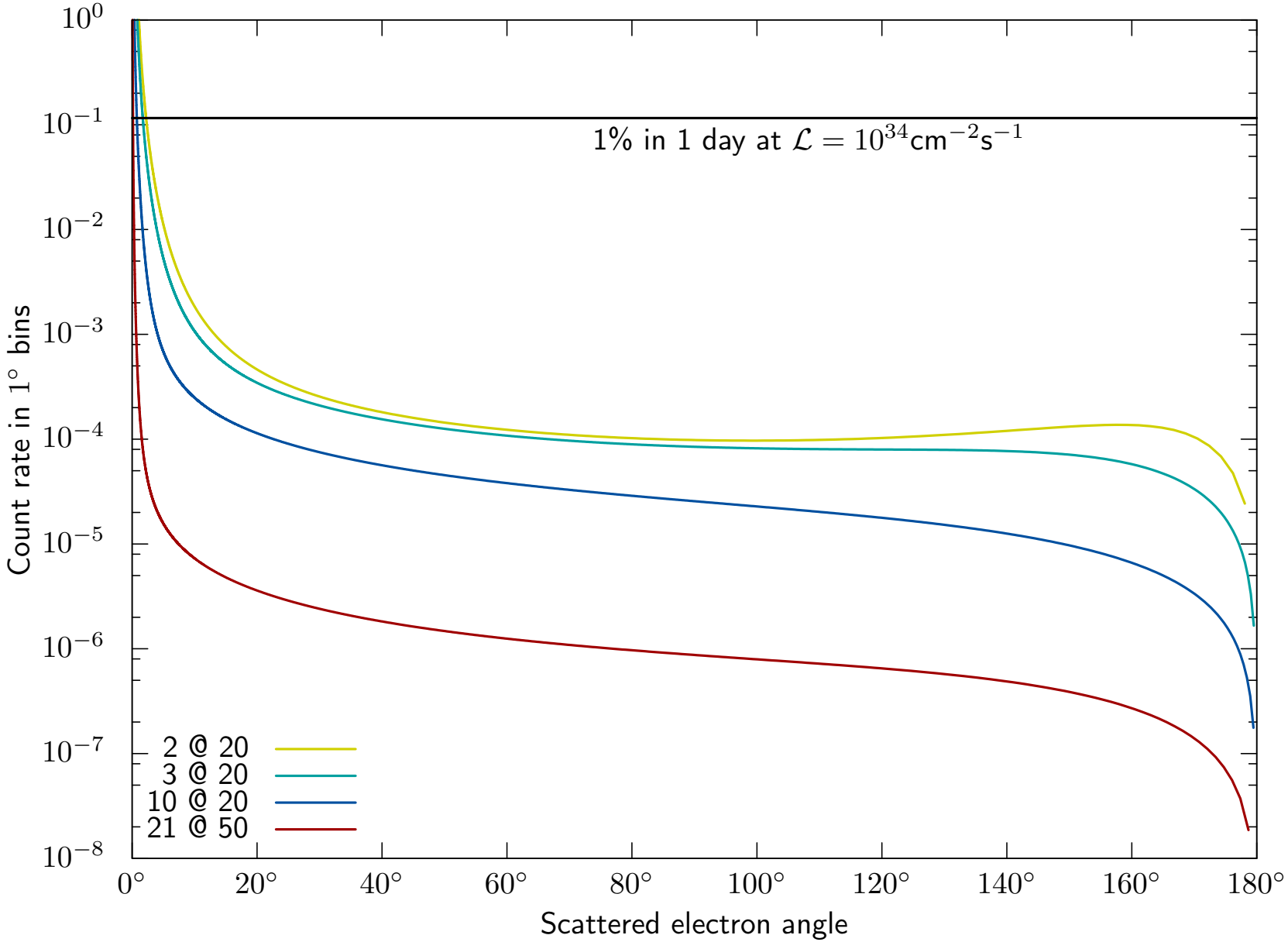
Challenges

- Low particle momentum
- Count rate

“Race” kinematics: particle momentum



"Race kinematics: luminosity



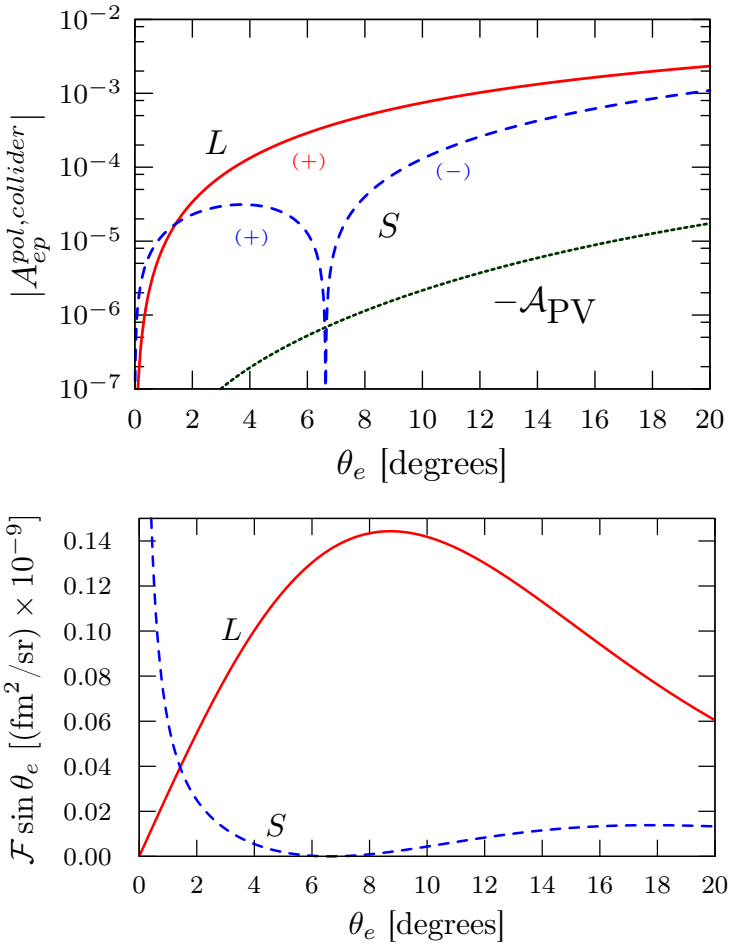
Now he has gone completely mad!

- In principle: Want to have different ε
- Vary angle between incoming beams!
- Technically "challenging"

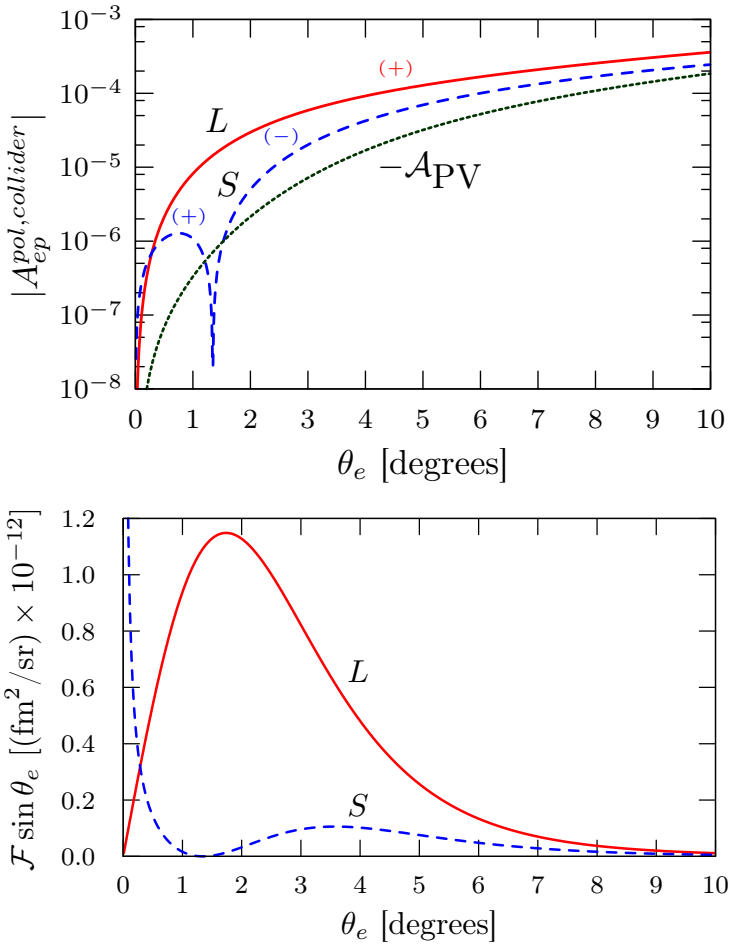
Polarization variables

Blatantly stolen from C. Sofiatti and T. W. Donnelly,"Polarized e-p Elastic Scattering in the Collider Frame," Phys. Rev. C 84, 014606 (2011)

2 @ 50 GeV



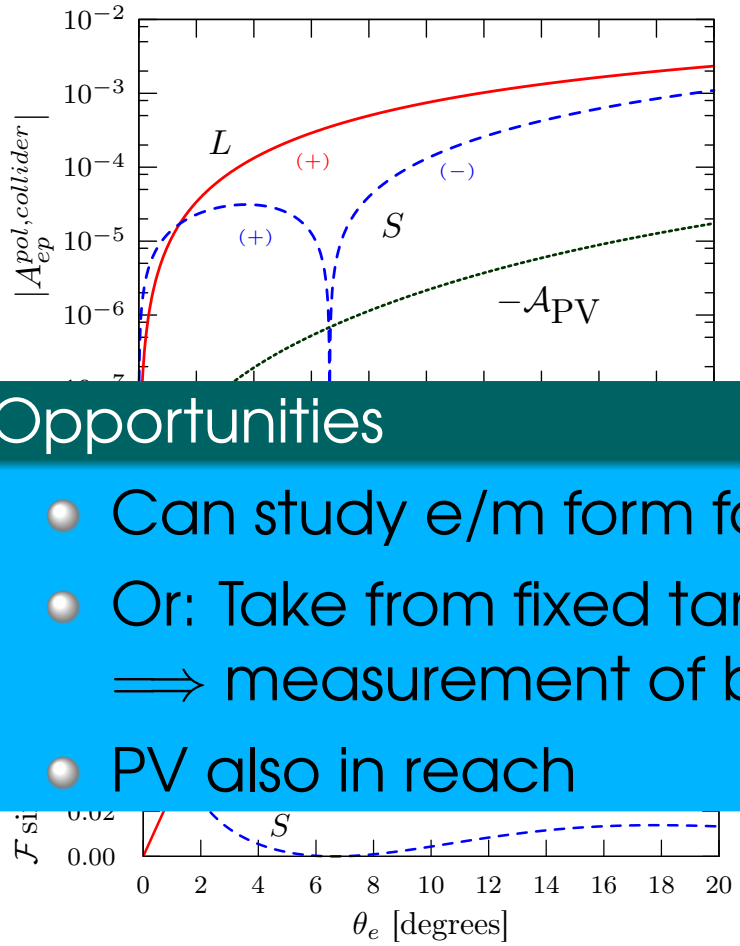
10 @ 250 GeV



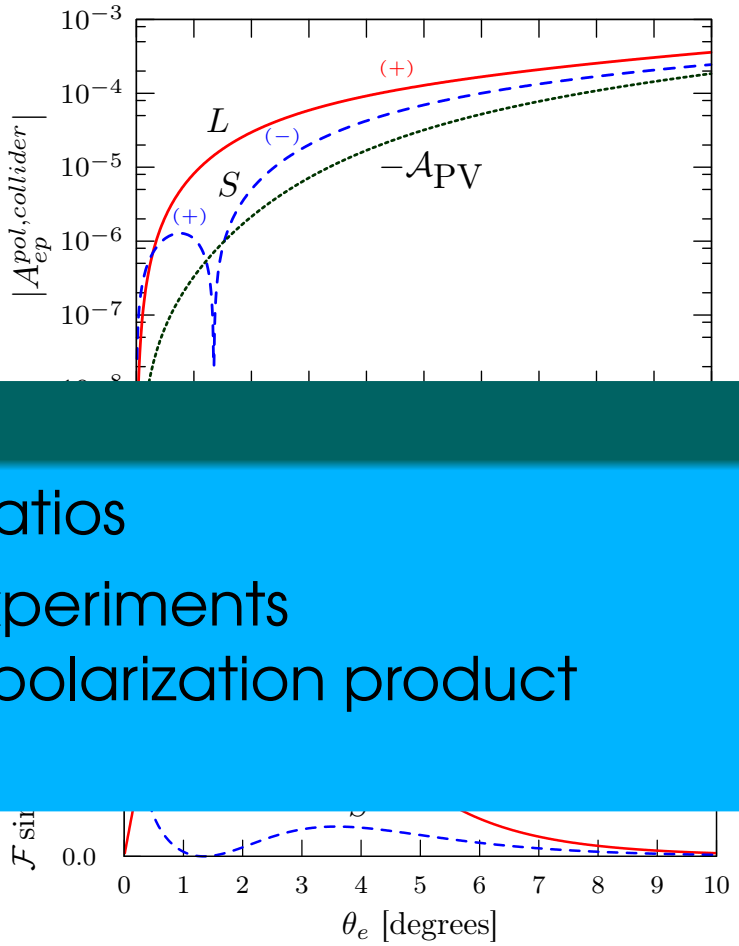
Polarization variables

Blatantly stolen from C. Sofiatti and T. W. Donnelly,"Polarized e-p Elastic Scattering in the Collider Frame," Phys. Rev. C 84, 014606 (2011)

2 @ 50 GeV



10 @ 250 GeV



Opportunities

- Can study e/m form factor ratios
- Or: Take from fixed target experiments
  $\Longrightarrow$ measurement of beam polarization product
- PV also in reach

Conclusion

Collider kinematics

- Small Q: Can measure G_E for radius, clean signal
- Large Q: G_M reachable, but low count rate

"Race" kinematics

- Very unusual kinematical region
- G_M at small Q, unique opportunity for magnetic radius

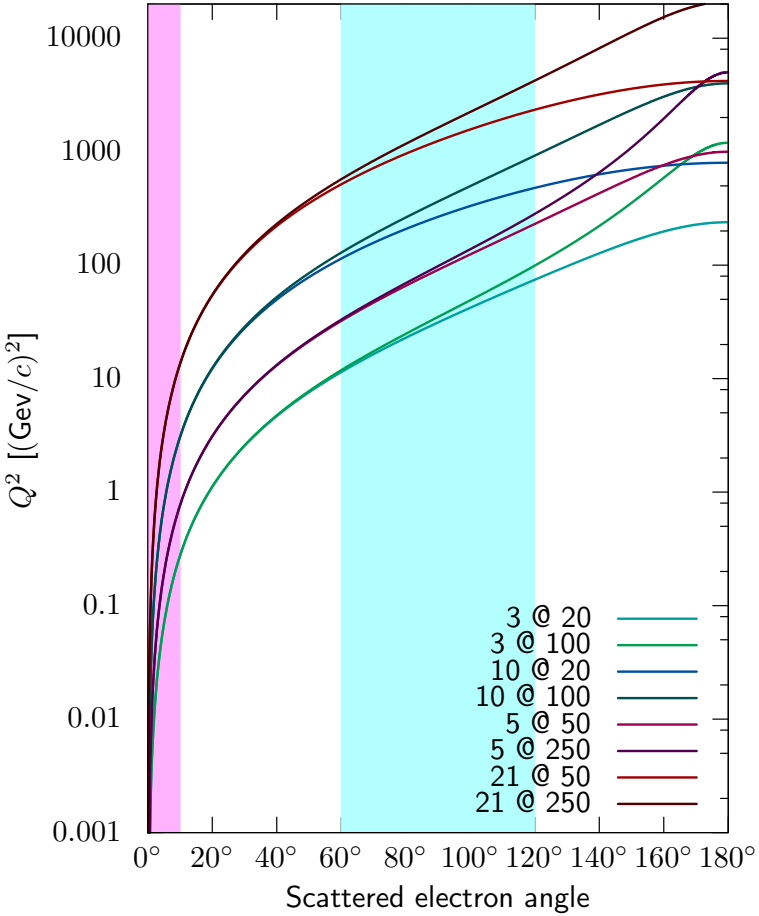
Polarization

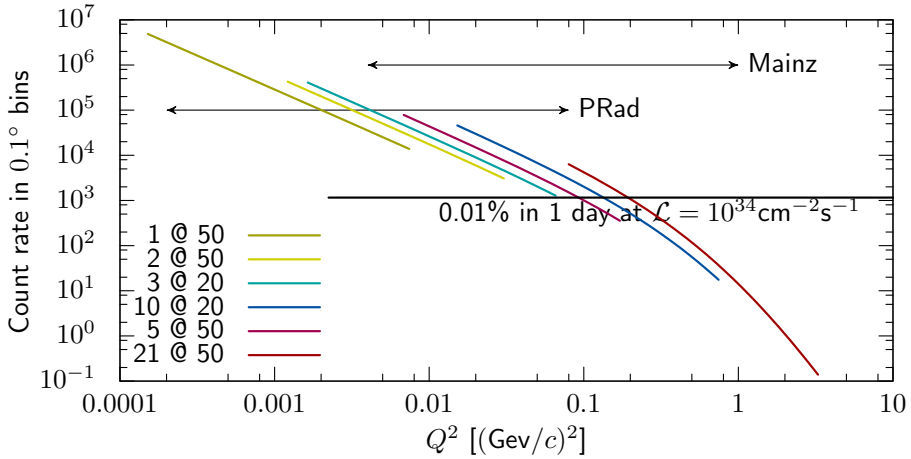
- Double asymmetry: Use as a polarimeter
- PV reachable

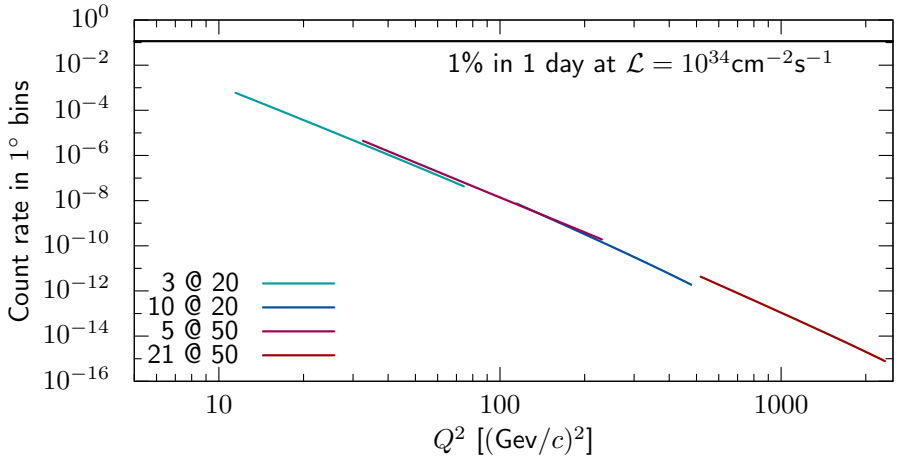
To-do

- Experimental feasibility: Backgrounds, PID etc.

F.F. summary: Collider kinematics

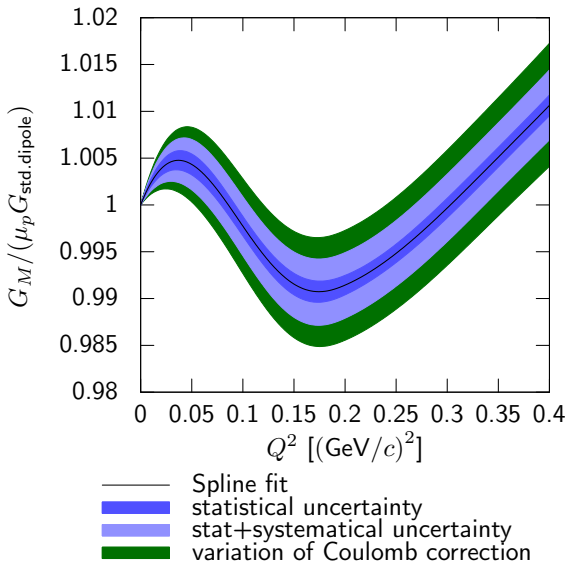


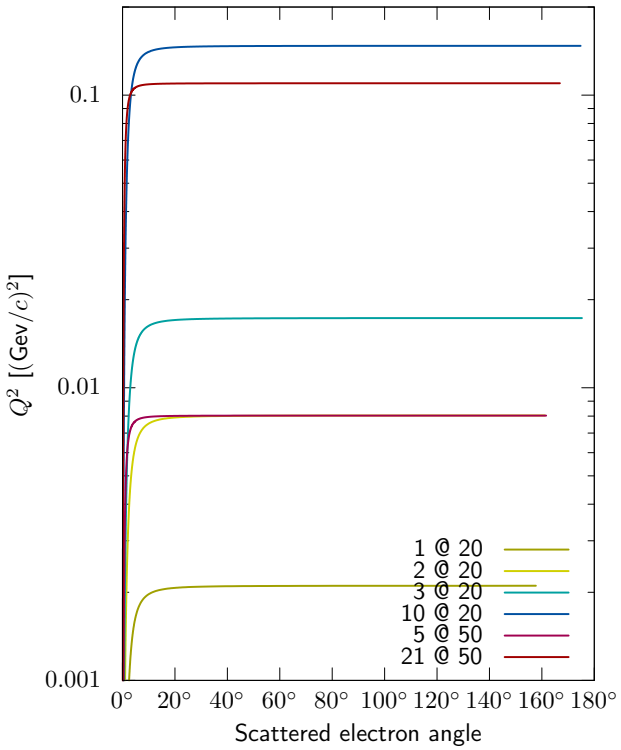


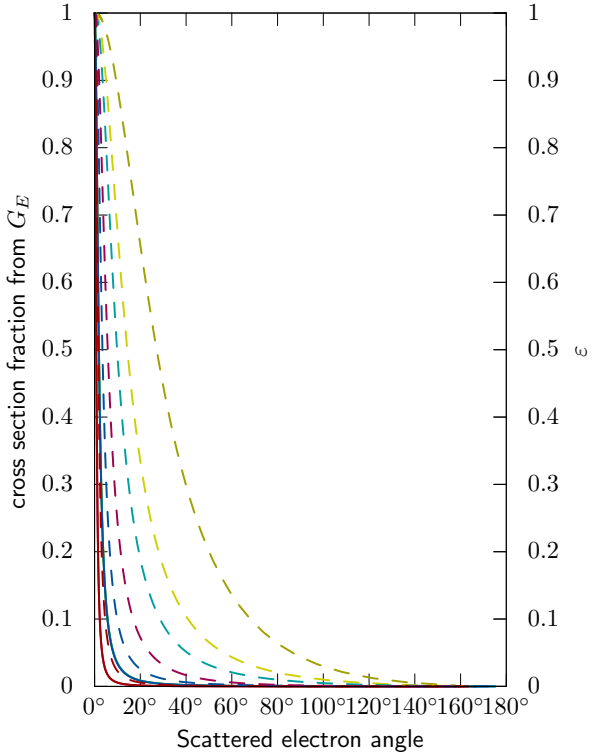


- Can measure proton electric radius without Two-Photon-Exchange effects
- G_M at large Q^2: count rate very small

F.F. summary: "Race" kinematics





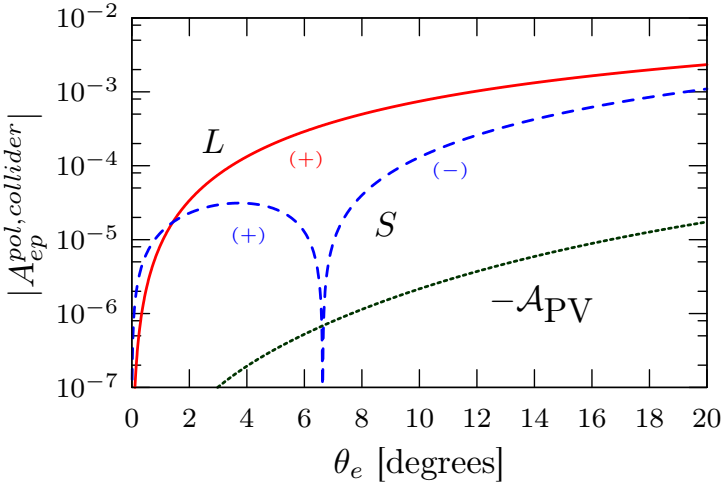


- Unique opportunity to measure low-Q^2 G_M and magnetic radius

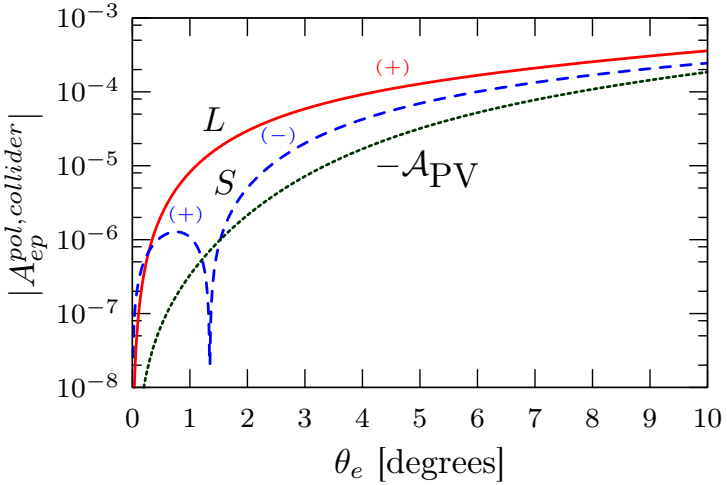
F.F. summary: Polarization variables

Blatantly stolen from C. Sofiatti and T. W. Donnelly,"Polarized e-p Elastic Scattering in the Collider Frame," Phys. Rev. C 84, 014606 (2011)

2 @ 50 GeV



10 @ 250 GeV



- Can study e/m form factor ratios
- Or: Take from fixed target experiments
  $\Longrightarrow$ measurement of beam polarization product
- PV also in reach