Why we are here and things that bother me

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ECT* RadCorr workshop 2022, Trento

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Welcome

Good news: I will not talk for 30 min.

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I will talk for 45.

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I will talk for 45.

JK.

This has happened before...

- CFNS Ad-Hoc Meeting: Radiative Corrections, July 2020!
- `https://indico.bnl.gov/event/8844/`
- Whitepaper/proceedings: arXiv: 2012.09970
- Should we write another one?

What I worry about

....from a theoretical perspective....

Reminder: The Proton Radius puzzle

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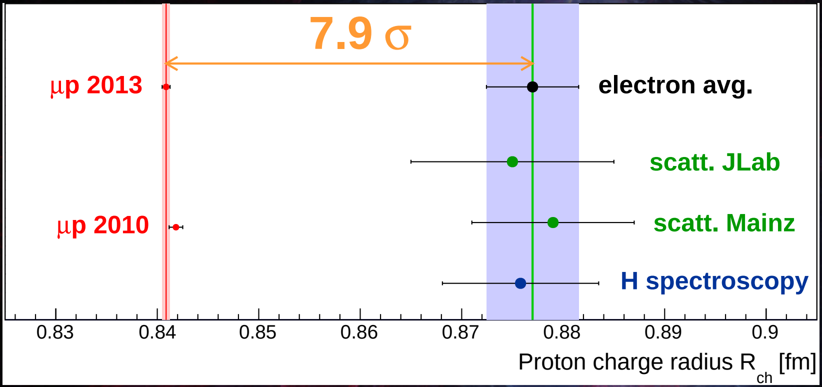


Elastic lepton-proton scattering

Method of choice: Lepton-proton scattering

- Point-like probe
- No strong force
- Lepton interaction "straight-forward" (Haha)

e^-

Measure cross sections and reconstruct form factors.

Cross section for elastic scattering

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

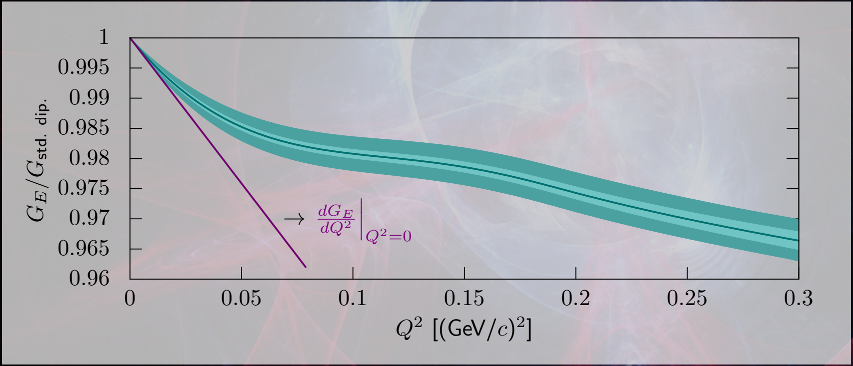
with:

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

- Rosenbluth formula
- Electric and magnetic form factor encode the shape of the proton
- Fourier transform (almost) gives the spatial distribution, in the Breit frame

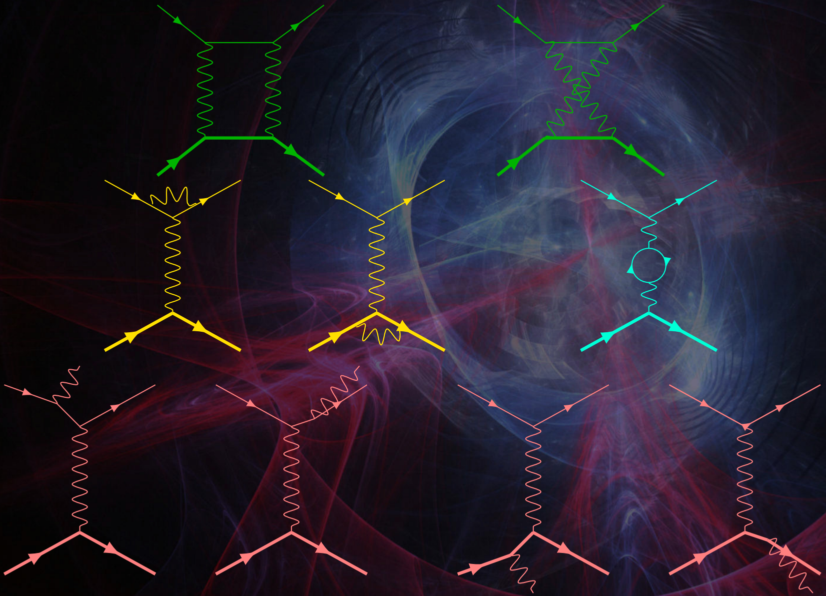
How to measure the proton radius

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



Complications

We are actually measuring $ep \to ep\gamma^N$



Does low Q^2 help?

$$\frac{d\sigma}{d\Omega} \propto 1 - \underbrace{A}_{\mathcal{O}(6)} \cdot Q^2 + \underbrace{B}_{\mathcal{O}(30)} \cdot Q^4 + \ldots$$

(Q in units of GeV/c)

We want to measure the radius ($\propto \sqrt{A/2}$) to within 0.5%, without knowing B. So:

$$B/A \cdot Q^2 \ll 0.02 \longrightarrow Q^2 \ll 0.004\,(\text{GeV}/c)^2$$

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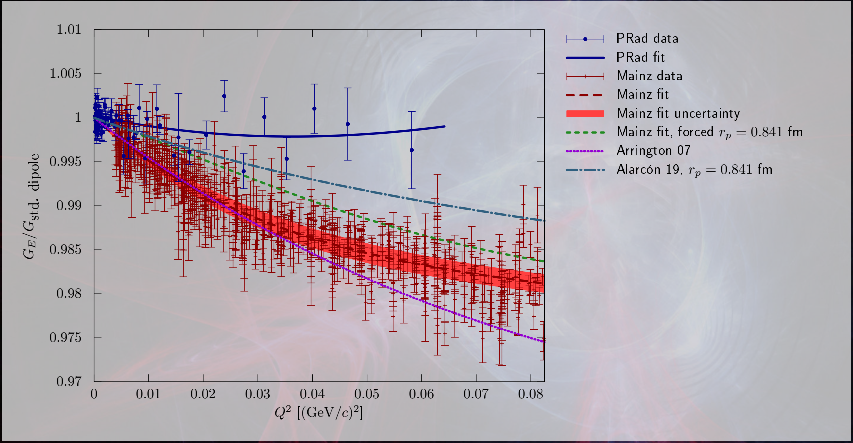
But: Need to measure A to 2%, so measure $\frac{d\sigma}{d\Omega}$ to $6 \cdot 0.004 \cdot 0.02 = 0.048\%$.

I'd call that challenging....

PRad

- @JLAB,
- 1 and 2 GeV beam, very forward angles
- "open" cell, so less background
- Calorimeter
  - worse energy resolution
  - but only 1 setting per energy
  - calibration with Møller scattering
- Fit using function determined before data was available!
- See more in Ashot Gasparian's talk later today

No agreement on form factor level



Takeaways

- Getting the same radius in fits to Mainz and PRad does not mean the data is in agreement.
- Hard to see how both results can be right
  - At least one of the experiments wrong.
  - But is it a problem in the experimental part or in theory?
- If PRad is fully right, what do we know about FFs after all?

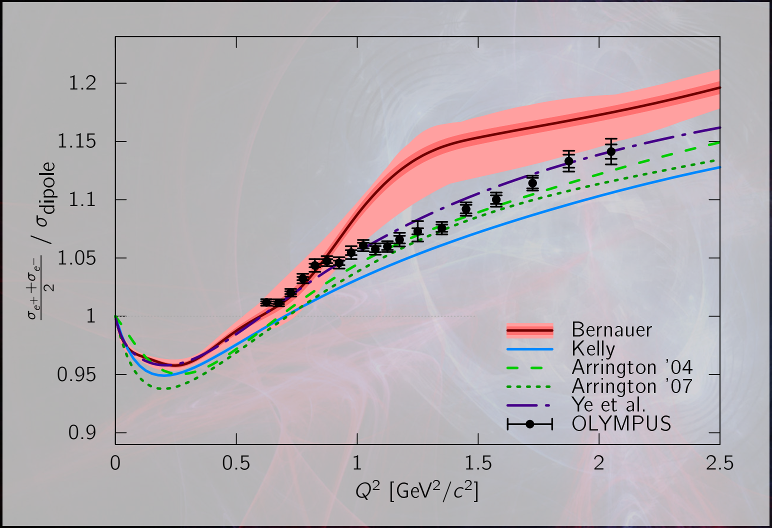
What could have gone wrong

- Will not speculate on the experimental part
- What is different?
  - Momentum resolution (tail shape!)
  - Kinematics: PRad is very forward, all other are not. $\Rightarrow$ Radiative corrections?
  - See talk by Miha on Wednesday

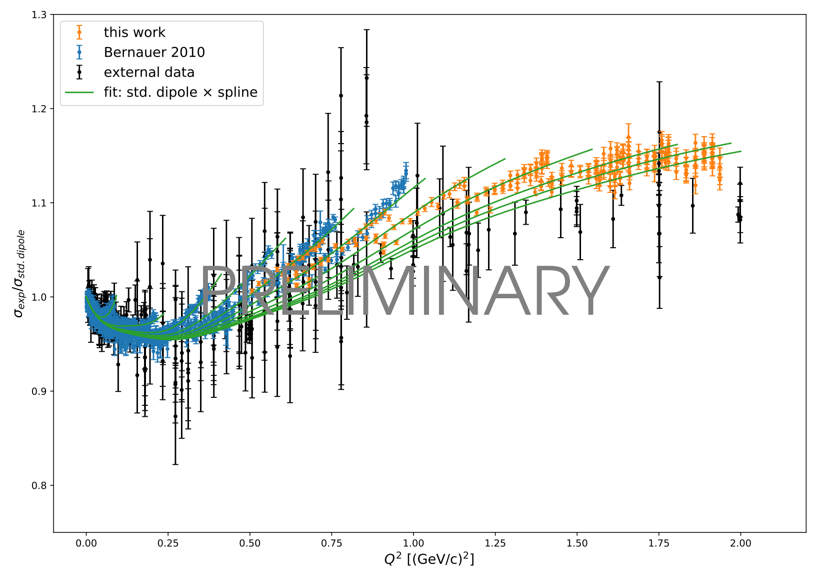
Why I believe Mainz high Q^2 is right

- OLYMPUS yields
  - TPE measurement via ratio of e^+p to e^-p
  - But can use charge average to cancel TPE.
- New Mainz high energy proton ff. measurement
  - Same machine but partially double coincidence
  - Not analyzed by me

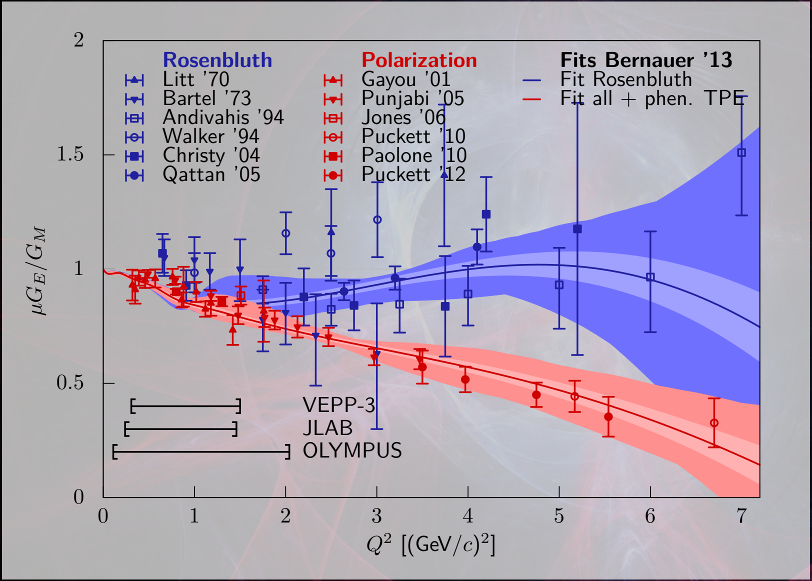
OLYMPUS yields



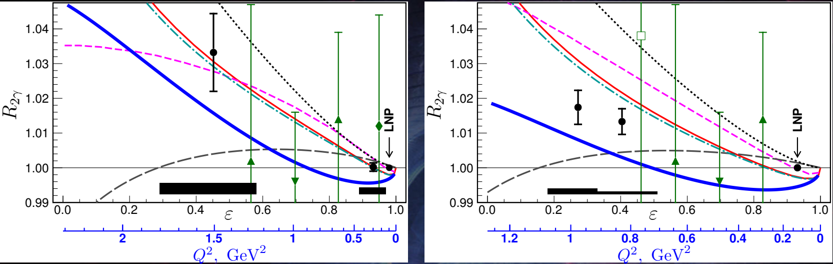
Mainz large Q^2 ff (PhD. thesis Julian Mueller)



Speaking of large Q^2

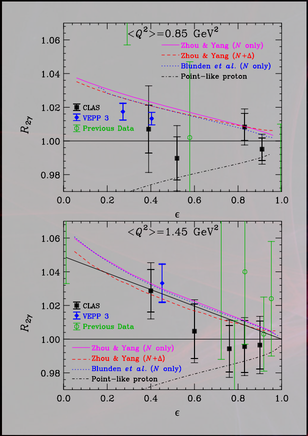


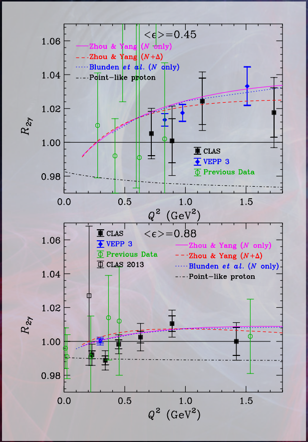
VEPP-3 results (I. A. Rachek et al., Phys. Rev. Lett 114, 062005)



	$R_{2\gamma}^{\mathrm{LNP}}$	$\frac{\chi^2}{n_{\mathrm{d.f.}}}$	$R_{2\gamma}^{\mathrm{LNP}}$ Run-I	$R_{2\gamma}^{\mathrm{LNP}}$ Run-II	$\frac{\chi^2}{n_{\mathrm{d.f.}}}$
Borisyuk and Kobushkin	1	2.14	0.998	0.997	3.80
Blunden, et al.	1	2.94	0.998	0.997	4.75
Bernauer, et al.	1	4.19	0.997	0.995	1.00
Tomasi-Gustafsson, et al.	1	5.09	1.001	1.001	5.97
Arrington and Sick	1	7.72	1.000	1.000	8.18
Qattan, et al.	1	25.0	1.000	1.002	22.0
No hard TPE ($R_{2\gamma} \equiv 1$)	1	7.97	1	1	7.97

CLAS (D. Rimal et al., arXiv:1603.00315 , D. Adikaram et al., Phys. Rev. Lett 114, 062003) (color adjusted)



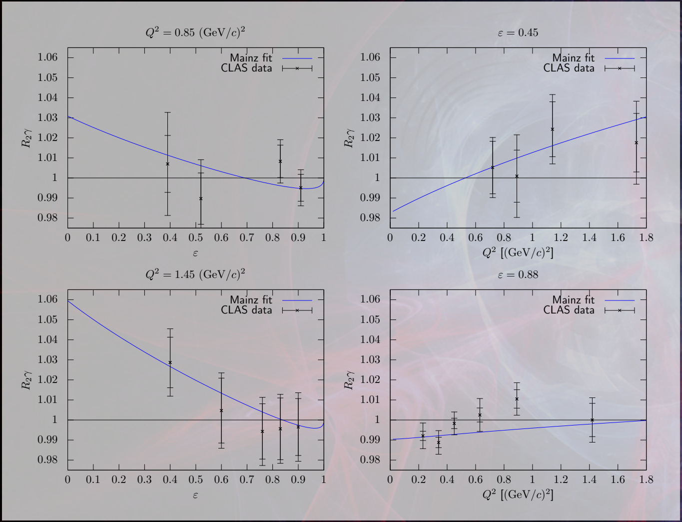


Fit to world data set:

- 12 non-overlapping points from CLAS
- 4 Vepp-3 points

	$\frac{\chi^2}{n_{d.f.}}$
Z & Y (N)	1.09
Z & Y (N+Δ)	1.03
Blunden (N)	1.06
No TPE	2.10
Point-proton	6.96

CLAS data + Mainz fit

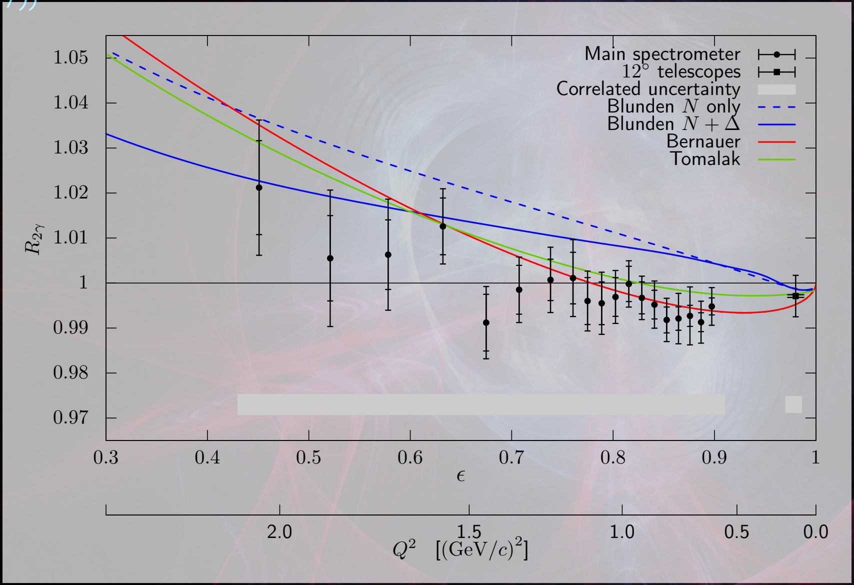


Comparison with predictions:

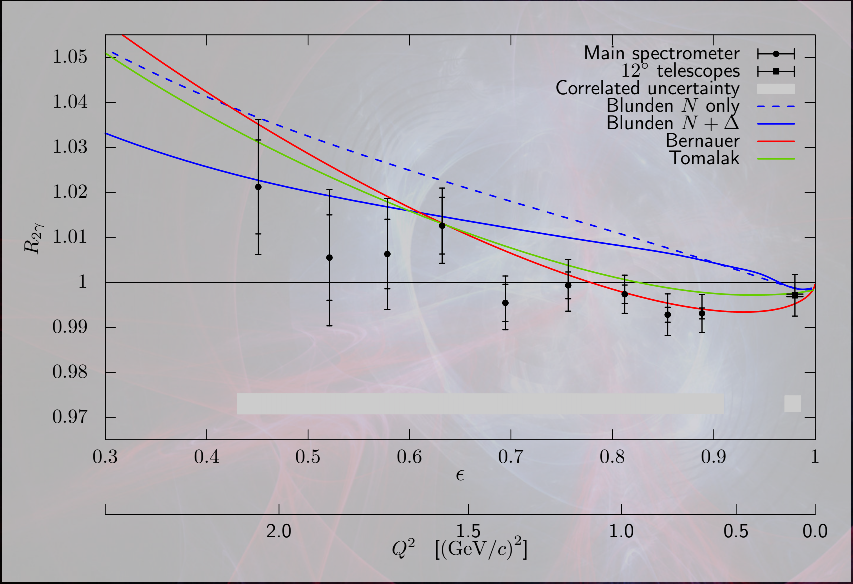
- 12 non-overlapping points from CLAS
- 4 Vepp-3 points

	$\frac{\chi^2}{n_{\mathrm{d.f.}}}$
Z & Y (N)	1.09
Z & Y (N+Δ)	1.03
Blunden (N)	1.06
No TPE	2.10
Point-proton	6.96
Mainz	0.666

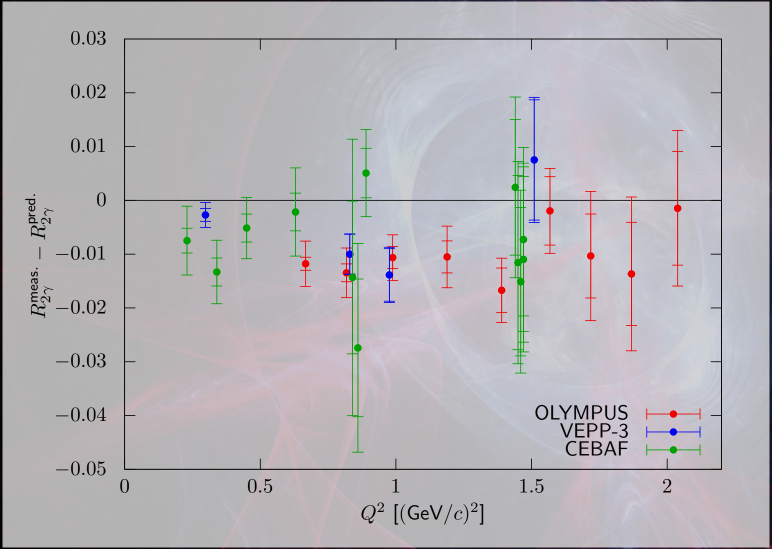
OLYMPUS results (B. Henderson et al., Phys. Rev. Lett. 118, 092501 (2017))



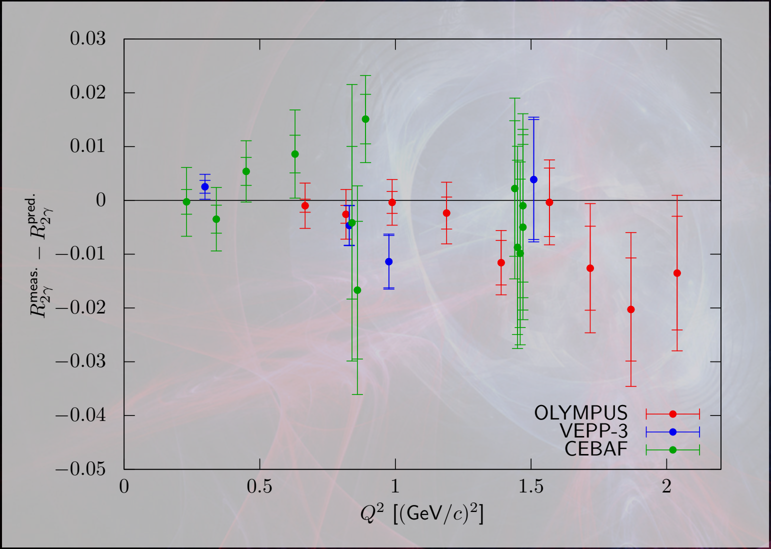
OLYMPUS results re-binned



Difference of data to prediction: Blunden's hadronic calculation



Difference of data to prediction: Bernauer et al. phenomenological prediction



Takeaways

- Calculations don't fit data particularly well
- Phenomenological fit fits data, but what happens at larger Q^2?
- Is something else going on?

Future experiments at JLAB and EIC

- We are changing from being statistics limited to being systematics limited
- More energy, more problems?
- We need efficient, accurate generators.

Proton CS/FF database

- World fits have to normalize data to same level of radiative corrections
- Needs meta data beyond published CS, FF etc.
- Better fit CS then FF (correlations!)
- Ethan Cline, Axel Schmidt, Craig McRae and I are working on open database with this meta information.
  - Few clicks to download selected datasets
  - Check for independence of selected sets
  - Auto-normalized to selected radiative corrections
  - Auto-fill of kinematic variables
- Who else wants to help?

This workshop

- Be ready for a group picture, likely Wednesday.
- Lunch will be organized by ECT*
- There is an organized dinner today and on Thursday.
- The other days, you are left to your own devices. But feel free to self-organize.