OLYMPUS and fits

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Massachusetts Institute of Technology

Overview

- TPE: Motivation
- Status of OLYMPUS
- Mainz fits
- TPE results from VEPP-3, (JLab)

Cross section and form factors for elastic e-p scattering

The cross section:

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

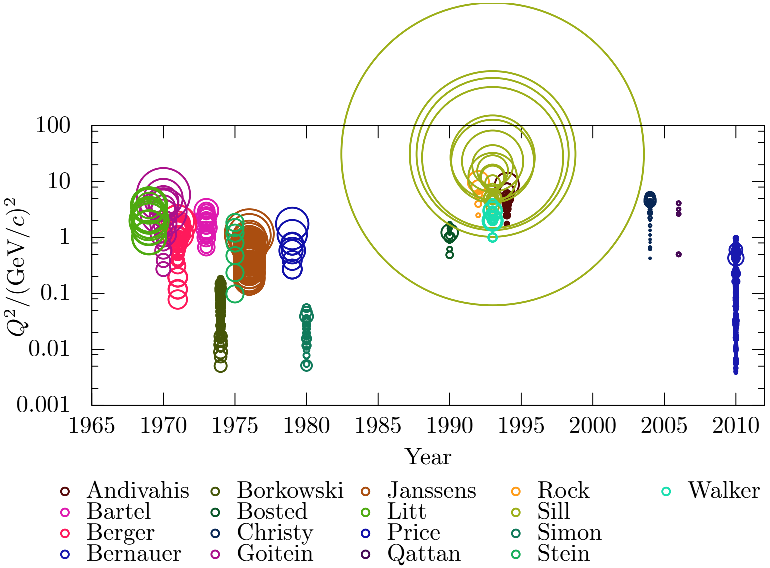
with:

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

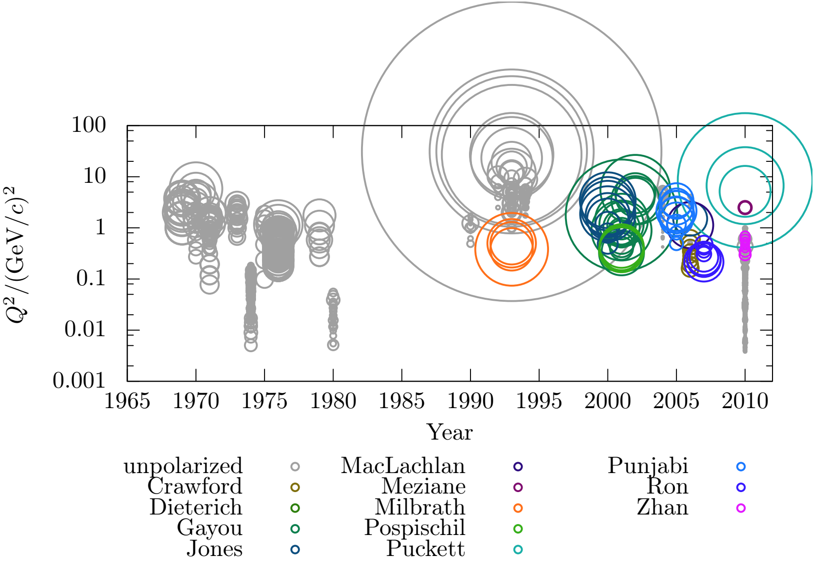
Fourier-transform of $G_E,\ G_M \longrightarrow$ spatial distribution (Breit frame)

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

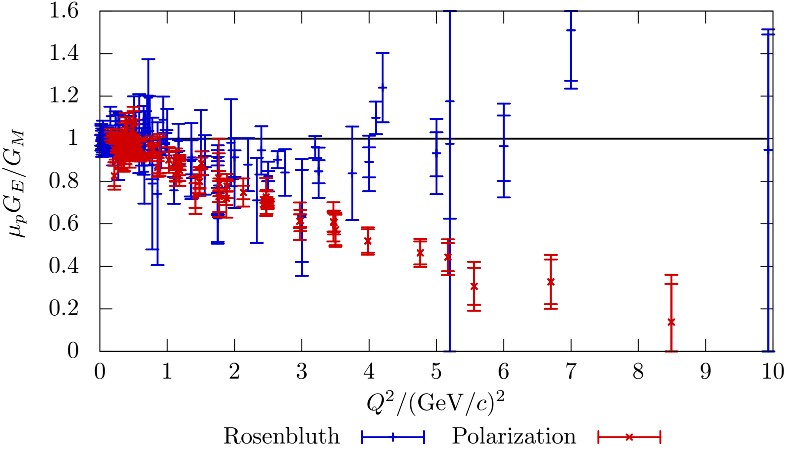
Unpolarized: Rosenbluth



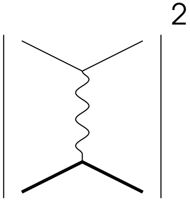
Polarized: Ratio



Ratio: Difference!



Most likely solution: Two Photon Exchange



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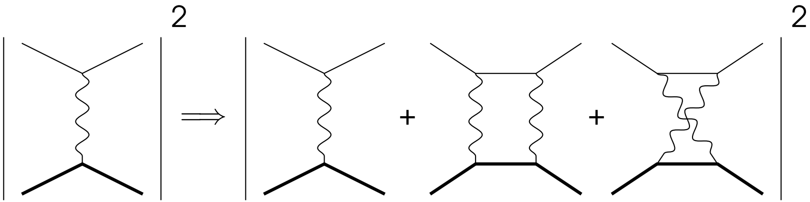

Two-Photon-Exchange

- Not in standard radiative corrections
- Off-shell proton!
- How to handle high momenta in loop?

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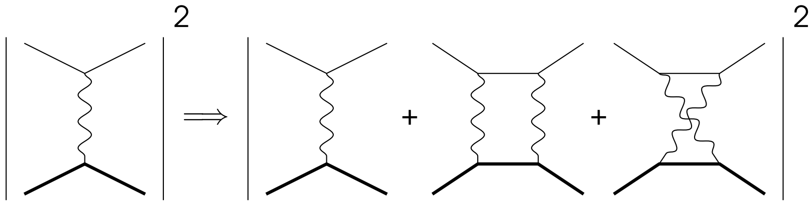

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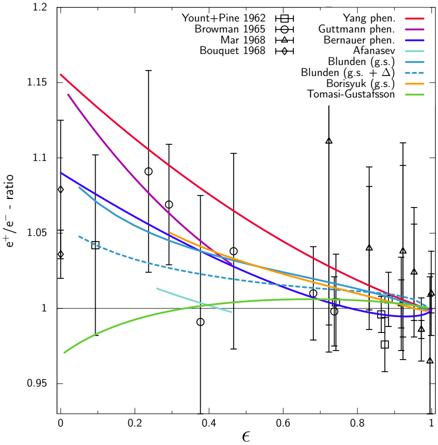
Measurement

- Rosenbluth/polarized reconciled?
- How to treat the hadron line?

Measure Two Photon Exchange

- Interference term changes sign with lepton sign!
- Measured in the 1960s
- Not much data
- A lot of predictions!



Three modern experiments

CLAS

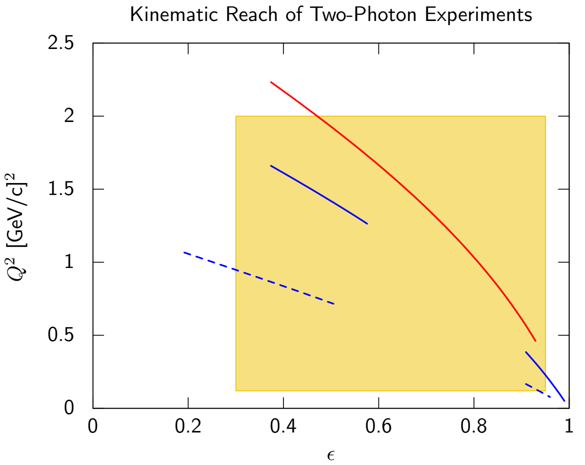
- e^- to γ to $e^{+/-}$ -beam

VEPP-3

- 1.6/1 GeV beam
- no field
- preliminary results

OLYMPUS

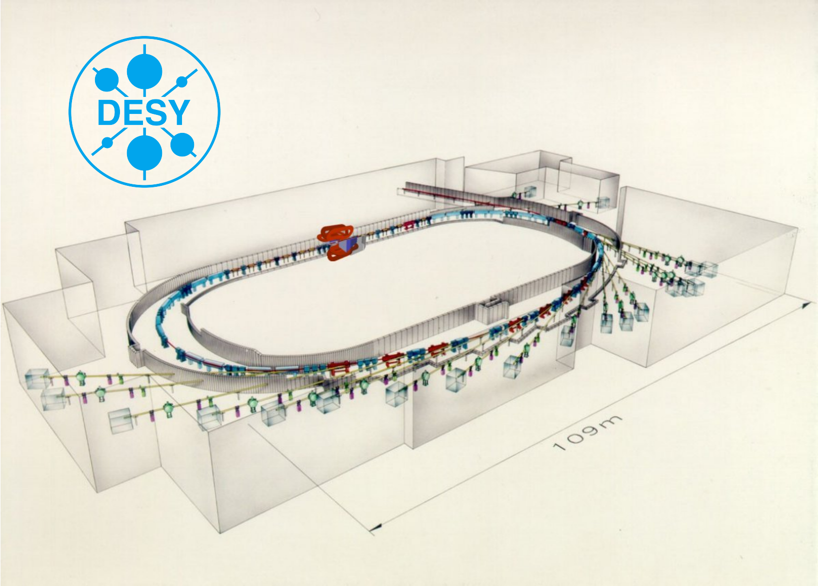
- DORIS @ DESY
- 2 GeV beam
- data taking finished 01/2013
- no results yet :(



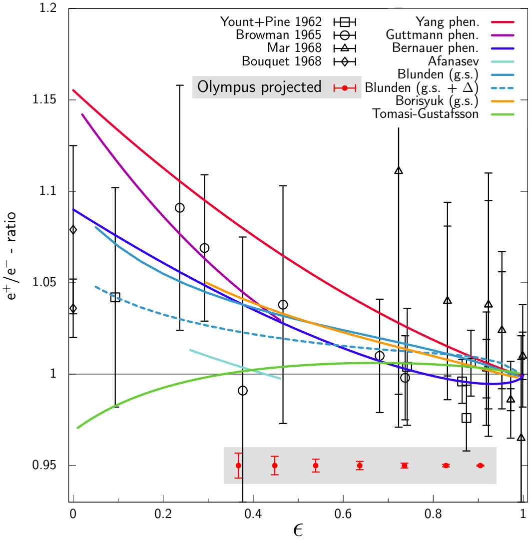
The OLYMPUS collaboration

- Arizona State University, USA
- DESY, Hamburg, Germany
- Hampton University, USA
- INFN, Bari, Italy
- INFN, Ferrara, Italy
- INFN, Rome, Italy
- MIT Laboratory for Nuclear Science, Cambridge, USA
- Petersburg Nuclear Physics Institute, Gatchina, Russia
- University of Bonn, Bonn, Germany
- University of Glasgow, United Kingdom
- University of Mainz, Mainz, Germany
- University of New Hampshire, USA
- Yerevan Physics Institute, Armenia

At DESY: DORIS

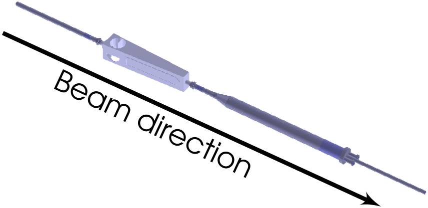


Projected performance

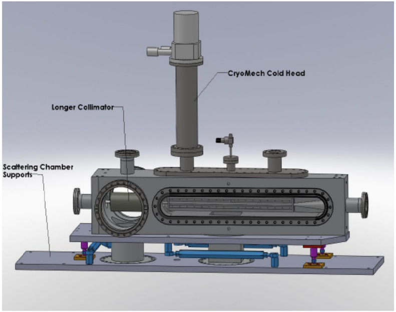


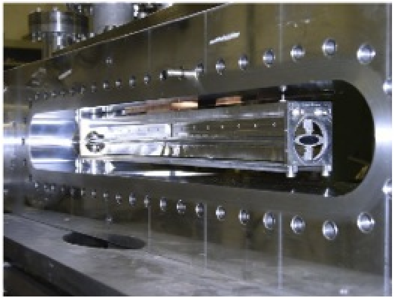
2 GeV beam, Q^2-range: 0.6 to 2.2 GeV^2

Target / Vacuum

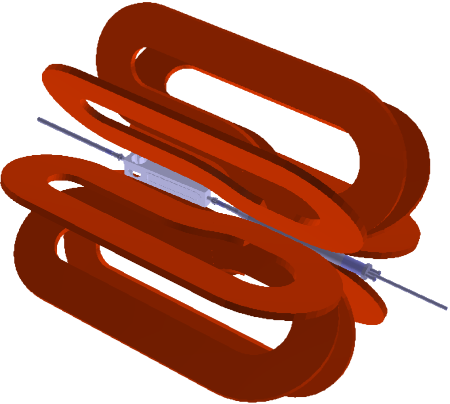


- Open cell design
- Cryogenic
- Target density: $3 \cdot 10^{15}\ \mathrm{cm}^{-2}$
- Multi-stage pump system



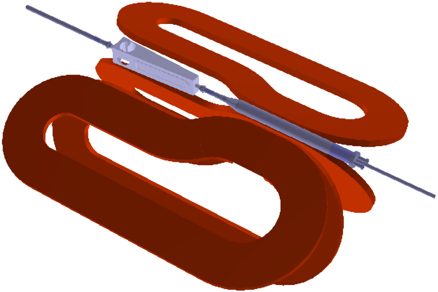


Toroid



- From BLAST
- $\pm$5000 A = 75% of BLAST
- $\Longrightarrow$ Peak field: 2.8 kG
- 8 coils

Toroid



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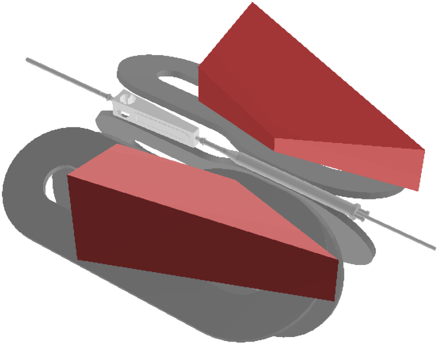
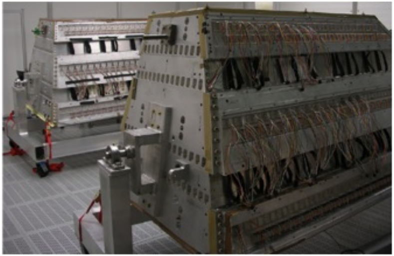
- 4 shown

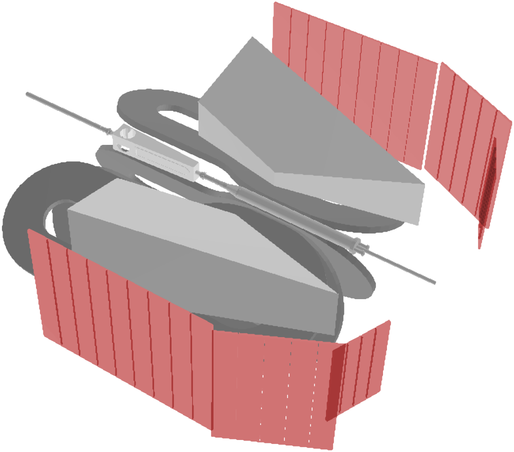
Wire chamber





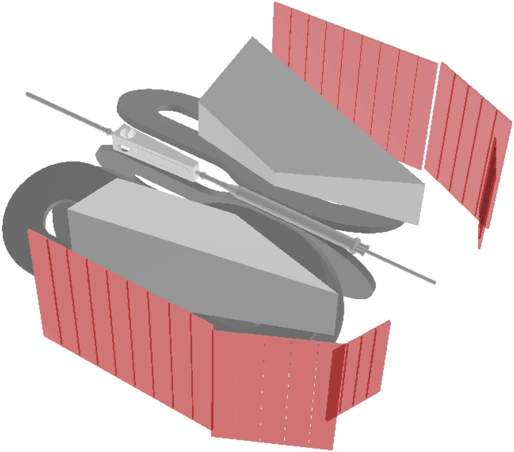
- From BLAST
- HDC design, 3 signal wires
- completely rewired
- $2 \cdot 3$ planes / chamber, 3 chambers / side
- 10° stereo angle

Time Of Flight



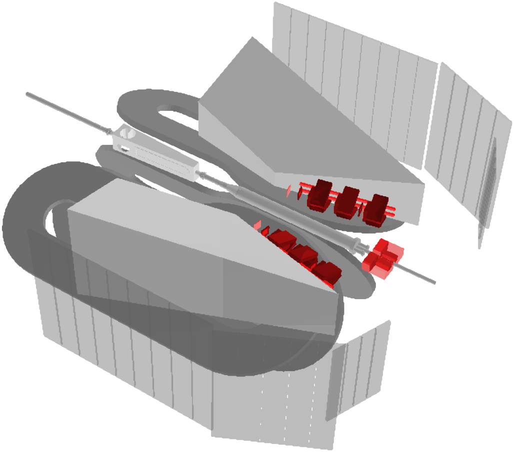
- From BLAST
- Rewrapped, tested
- Trigger
  - Top/bottom coinc.
  - kinematically constrained

Time Of Flight



- From BLAST
- Rewrapped, tested
- Trigger
  - Top/bottom coinc.
  - kinematically constrained
  - + 2nd level WC

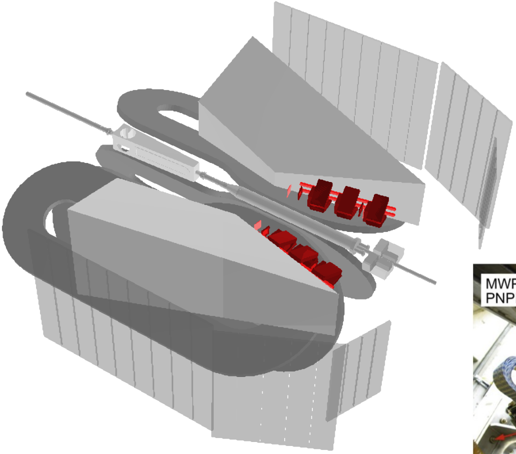
Luminosity



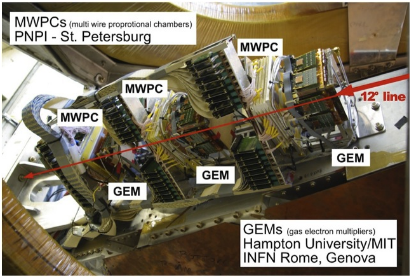
Tight control crucial!
Redundant systems:

- 12°-detector
- Symmetric Møller/Bhabha

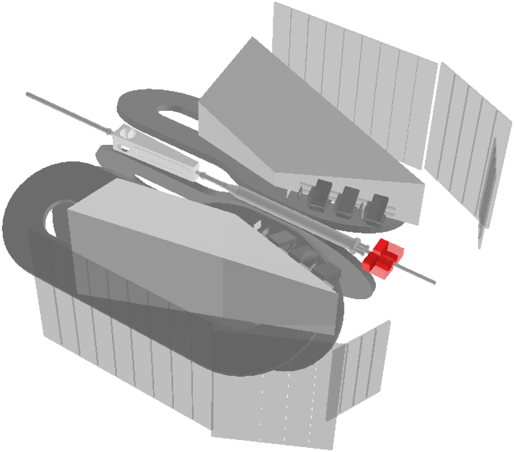
12°-detector

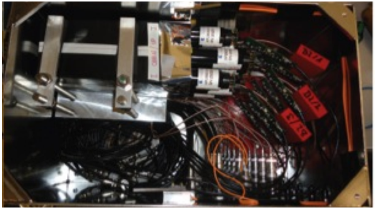


- 3 GEM (Hampton) + 3 MWPC (PNPI) each
- highly redundant
- SiPM trigger scintillators

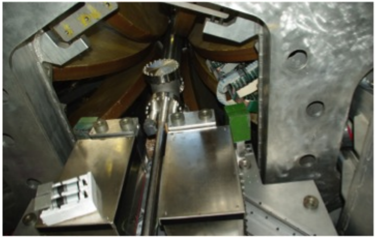


Symmetric Møller/Bhabha





- 2×9 crystals (Mainz)
- 1.2° symmetric angle
- high rate, no deadtime



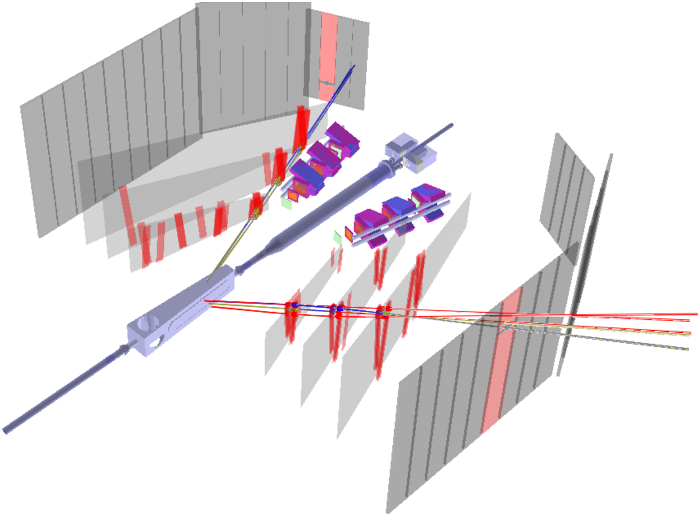
Timeline

OLYMPUS full proposal	September 2008
Experiment funded by DOE	January 2010
BLAST moved to Germany	Spring 2010
Target test experiment	February 2011
Drift chambers installed	Spring 2011
Luminosity monitors installed	Summer 2011
Olympus roll-in	July 2011
First full Olympus test	August 2011
Sym. Møller/Bhabha installed	Fall 2011
First data run	January 2012
Second data run	October-December 2012
DORIS shut down	January 2013

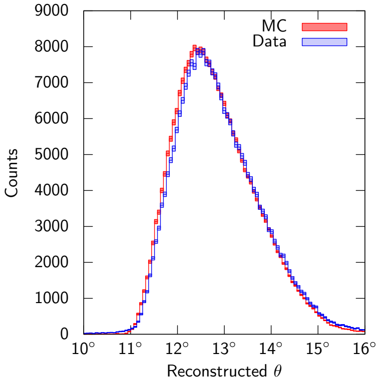
Analysis

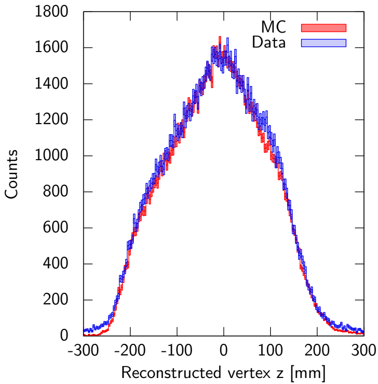
CAVEAT: The analysis is ongoing. All plots are preliminary.

Wire chamber / Event-Display



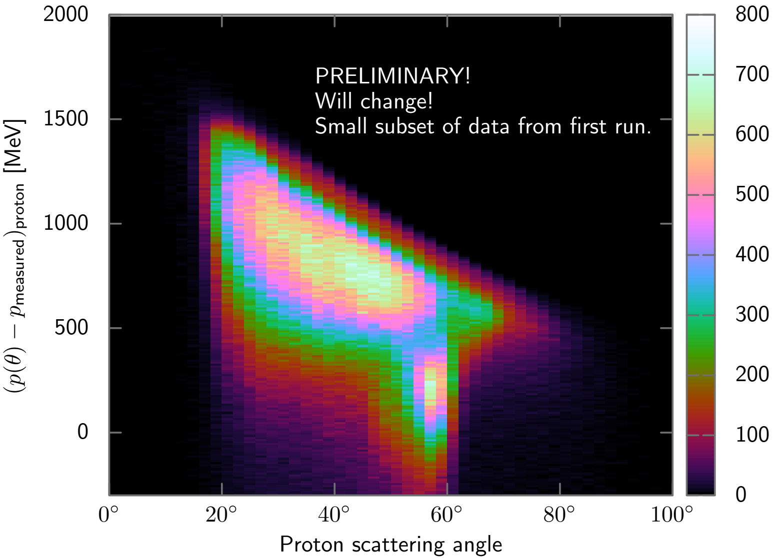
Luminosity: Comparison Data/MC





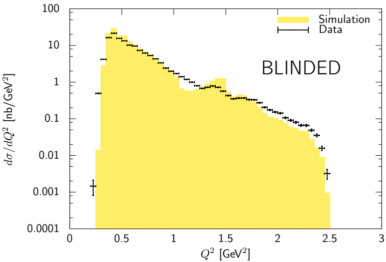
Analysis: Brian Henderson

Reconstructed proton momentum

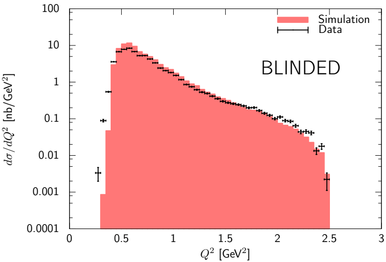


Preliminary Analysis

Positrons



Electrons



Analysis: Axel Schmidt

Preliminary Analysis

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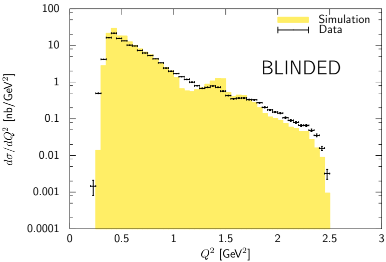
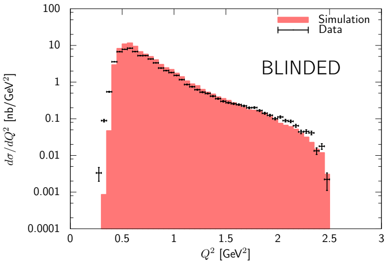


Electrons



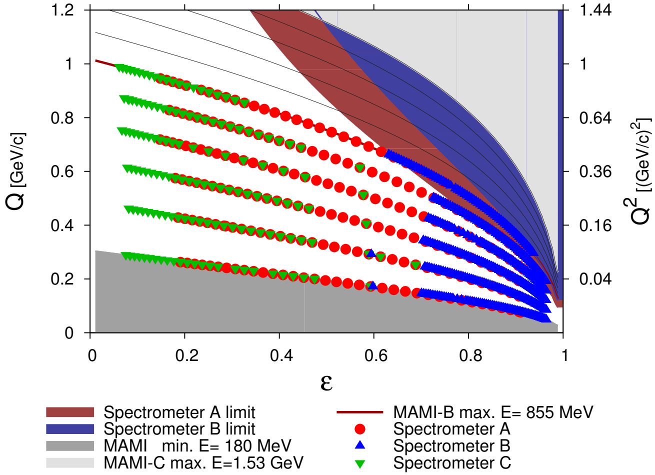
Analysis: Axel Schmidt

Expect results end of 2014

Form factor fits

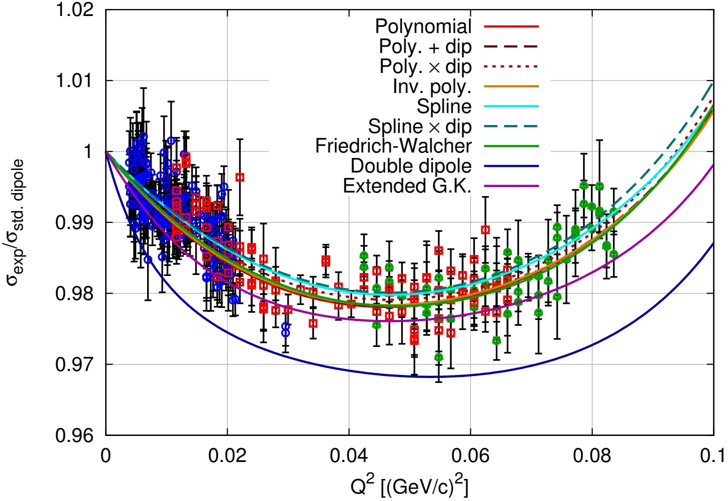
Three spectrometer facility of the A1 collaboration:

Measured settings



1400 settings

Cross sections: 180 MeV



Inclusion of world data

- Extend data base with world data
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  - One normalization parameter per source (Andivahis: 2)

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- Two models:
  - Splines with **variable** knot spacing
    $\Longrightarrow$ Adapt knot density to data density
  - Padé-Expansion
    $\Longrightarrow$ Low(er) flexibility, for comparison

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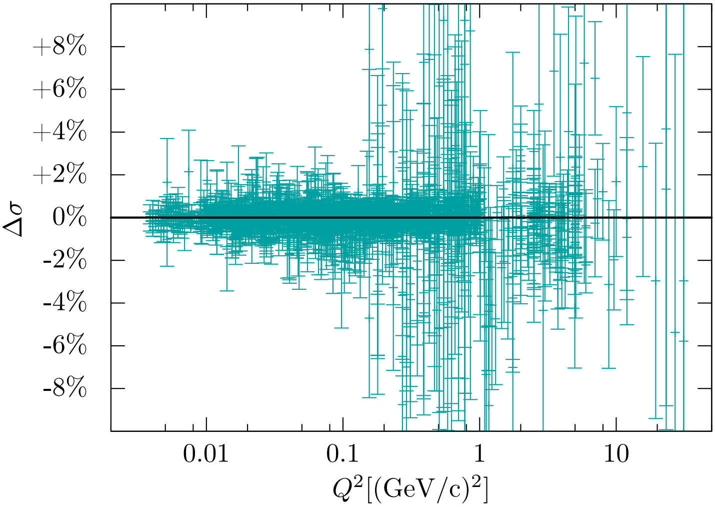
It works!



Model dependence

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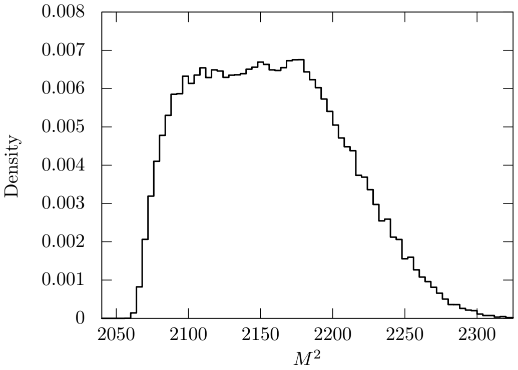

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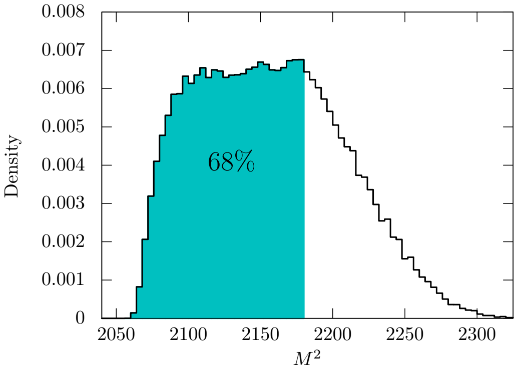
- Select the 68% best tries.



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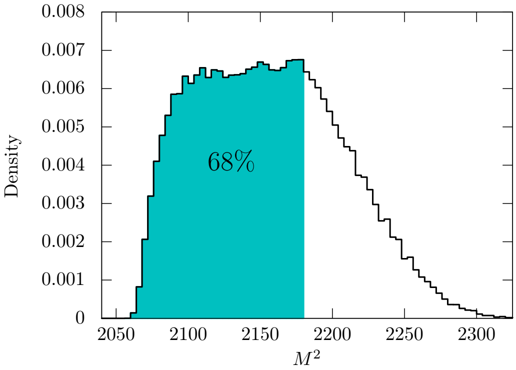
- Construct envelope of models.



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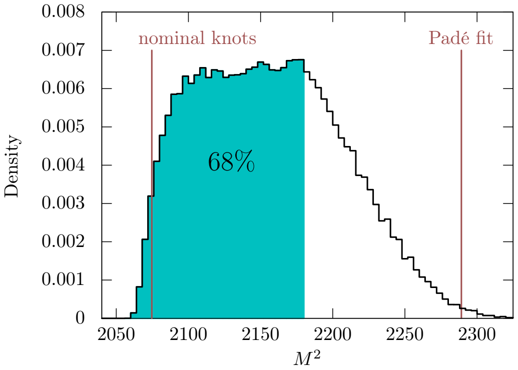
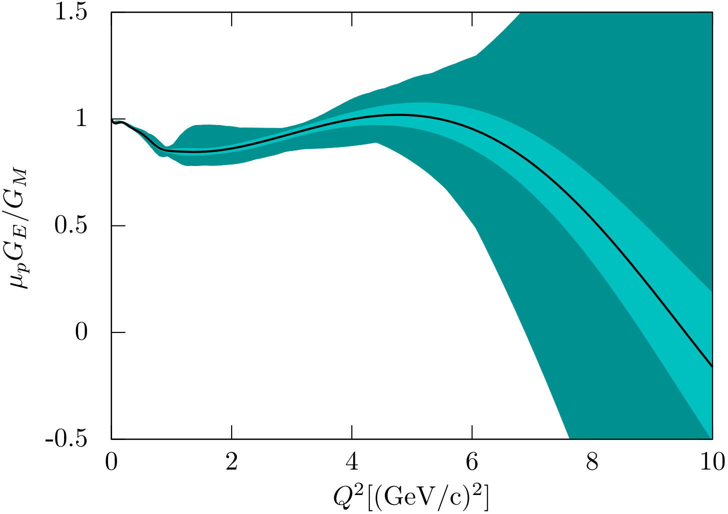


Band will cover at least 68% of all model variations!

Form factor ratio G_E/G_M



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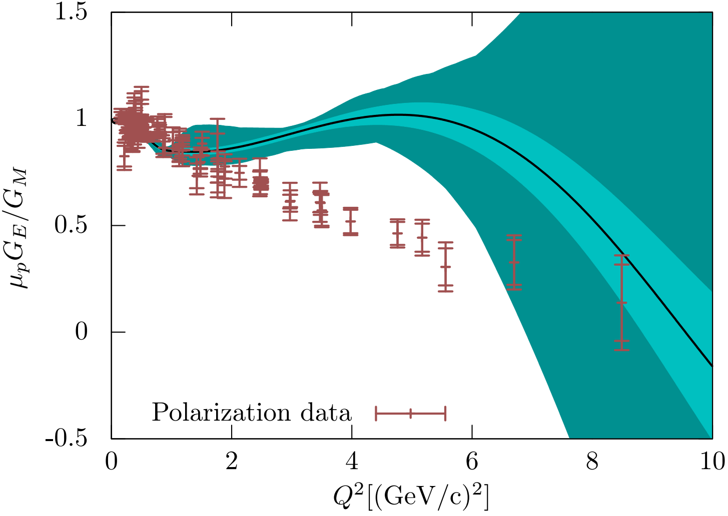

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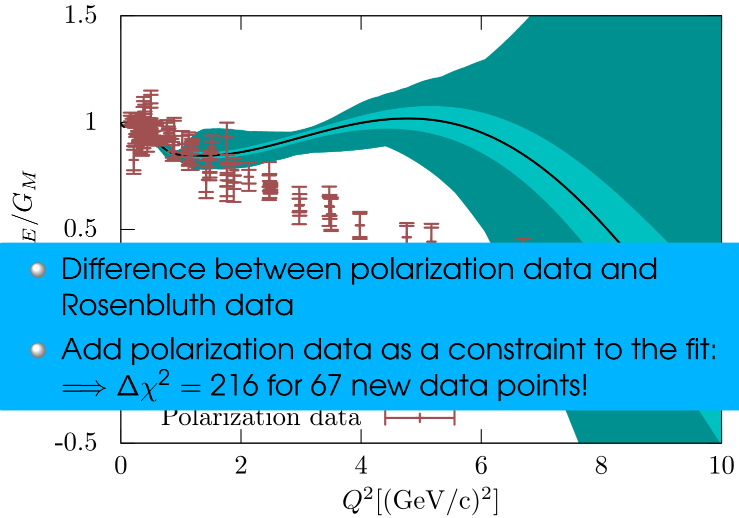

- Difference between polarization data and Rosenbluth data
- Add polarization data as a constraint to the fit: $\Longrightarrow \Delta\chi^2 = 216$ for 67 new data points!

Two Photon Exchange - A parametrization

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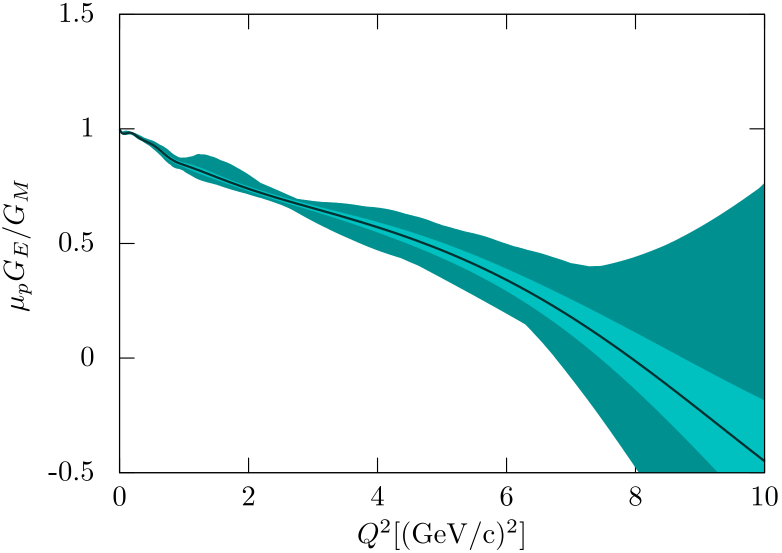
- Mostly Q^2 dependence
- Few data on ε dependence
- Only possible to fit simple model
- In addition to Feshbach Coulomb-correction!

$$\delta = a \cdot (1 - \varepsilon) \cdot \log\left(1 + b \cdot Q^2\right)$$

G_E/G_M fit incl. polarized data



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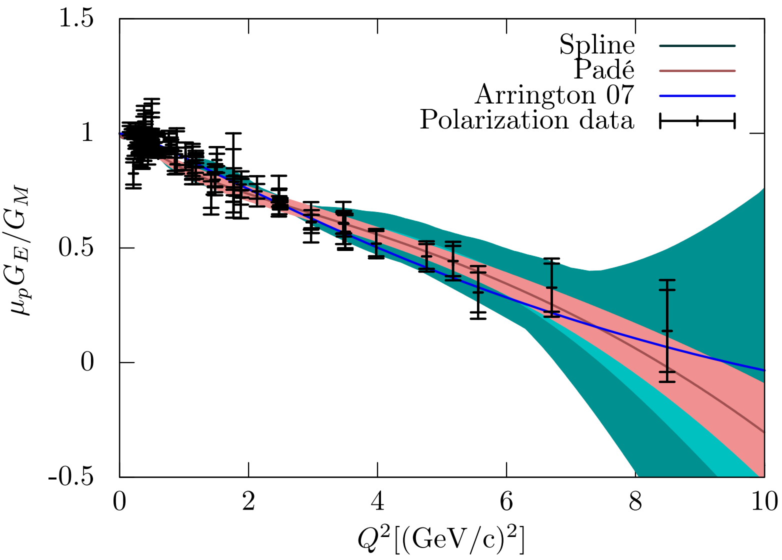

How does this all affect the radius?

Final result from flexible models

$$r_E = 0.879 \pm 0.005_{\mathrm{stat.}} \pm 0.004_{\mathrm{syst.}} \pm 0.002_{\mathrm{model}} \pm 0.004_{\mathrm{group}}\ \mathrm{fm},$$
$$r_M = 0.777 \pm 0.013_{\mathrm{stat.}} \pm 0.009_{\mathrm{syst.}} \pm 0.005_{\mathrm{model}} \pm 0.002_{\mathrm{group}}\ \mathrm{fm}.$$

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More fits

	r_E (fm)	r_M (fm)
spline-type fits	0.875(5)(4)(2)	0.775(12)(9)(4)
polynomial-type fits	0.883(5)(5)(3)	0.778(15)(10)(6)

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var. spline +world cs.	0.878	0.772

How does this all affect the radius?

Final result from flexible models

$$r_E = 0.879 \pm 0.005_{\text{stat.}} \pm 0.004_{\text{syst.}} \pm 0.002_{\text{model}} \pm 0.004_{\text{group}} \text{ fm},$$
$$r_M = 0.777 \pm 0.013_{\text{stat.}} \pm 0.009_{\text{syst.}} \pm 0.005_{\text{model}} \pm 0.002_{\text{group}} \text{ fm}.$$

More fits

	r_E (fm)	r_M (fm)
spline-type fits	0.875(5)(4)(2)	0.775(12)(9)(4)
polynomial-type fits	0.883(5)(5)(3)	0.778(15)(10)(6)
var. spline +world cs.	0.878	0.772
" " + polarization	0.878	0.769

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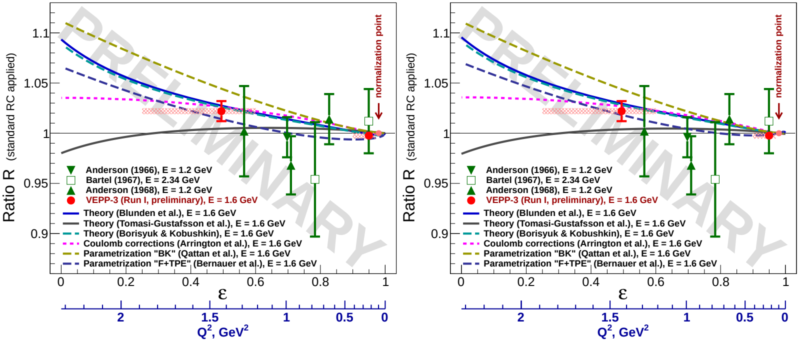
" "+ world (Bad χ^2)	0.875	0.787

Comparison with TPE experiments

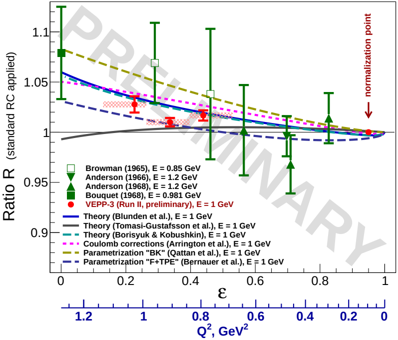
Both VEPP-3 and JLab have preliminary results - let's see.

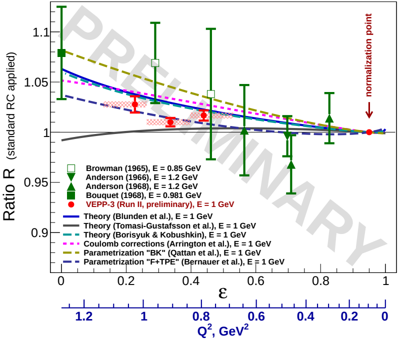
VEPP-3 result: Run I



Plots by Alexander Gramolin

VEPP-3 result: Run II





Plots by Alexander Gramolin

The take-away

- TPE prime candidate to resolve form factor discrepancy at high Q^2
- Preliminary results from VEPP-3 and JLab + Mainz fit indicate effect is of right magnitude.
- OLYMPUS progesses nicely.
- TPE has so far small effect on extracted charge radius.
- Bigger on magnetic radius!

Backup slides

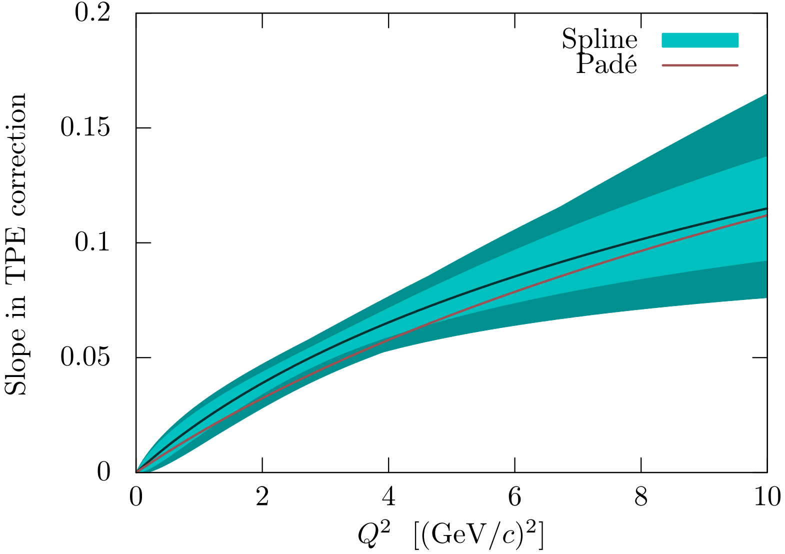
Model dependence: Charge Radius

Input		Analysis							
		Dipole	Dbl-D.	Poly.	P.+D.	P.×D.	Spline	S.×D.	F./W.
Std. dipole	811	0±1	0±1	0±3	0±3	0±4	0±5	0±7	0±1
Arrington 07	878	−18±1	3±3	−3±3	−2±3	−1±4	−4±5	−1±6	−2±3
Arr. 03 (P)	829	29±1	10±1	1±3	1±3	0±4	−1±5	0±6	2±6
Arr. 03 (R)	868	−9±1	0±2	0±3	0±3	0±4	−3±5	0±6	−1±3
FW	860	−4±1	31±14	−1±3	−1±3	1±4	0±5	0±6	0±3

Arrington 07: Phys. Rev. C 76 035205 (2007)
Arr. 03: Phys. Rev. C 68 034325 (2003)
FW: Eur. Phys. J. A 17 607 (2003)

Model dependence: Magnetic Radius

Input		Analysis							
		Dipole	Dbl-D.	Poly.	P.+D.	P.×D.	Spline	S.×D.	F./W.
Std. dipole	811	0±1	0±1	−1±7	0±7	0±10	2±14	1±18	0±1
Arrington 07	858	−55±1	4±4	−5±6	−4±6	−1±9	2±13	0±17	−10±4
Arr. 03 (P)	837	−33±1	12±3	−1±7	0±7	0±9	2±13	0±19	−5±5
Arr. 03 (R)	863	−52±1	2±4	−4±6	−3±6	0±9	3±13	0±17	−8±4
FW	805	4±1	49±2	0±7	1±7	−1±10	1±13	−1±18	−1±4


Spline
Padé
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
Slope in TPE correction
Q^2 [(GeV/c)^2]

TPE dependence on ε