JOHANNES GUTENBERG UNIVERSITÄT MAINZ

HELMHOLTZ GEMEINSCHAFT
Helmholtz-Institut Mainz

The Olympus experiment

R. Pérez Benito

Helmholtz-Institut Mainz
Johannes Gutenberg-Universität Mainz

OLYMPUS

On behalf of the OLYMPUS Collaboration
19 July, 2013 at JLab.

Outline

Two photon exchange amplitude and implications for determination of the electromagnetic form factors.

The Olympus experiment

Symmetric Møller/Bhabha luminosity monitor

Extraction of form factors

Measurement of cross section

Sensitive to radiative corrections

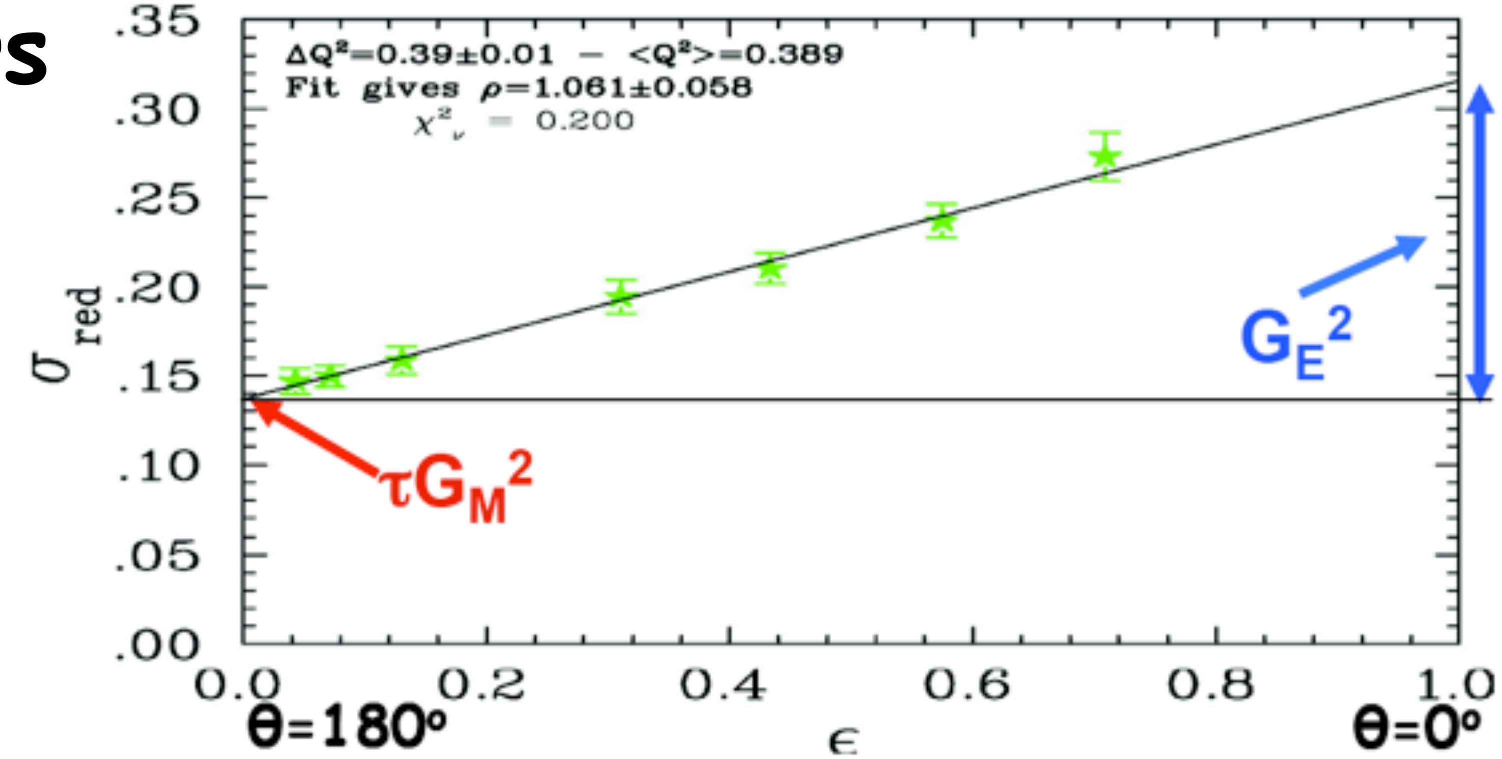
$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \frac{1}{1+\tau}\left(G_M^2 + \frac{\epsilon}{\tau} G_E^2\right)$$

$$\tau = \frac{Q^2}{4M_P^2}$$

$$\epsilon = \left(1 + 2(1+\tau)\tan^2\frac{\theta_e}{2}\right)^{-1}$$

ϵ relative flux of longitudinally polarized virtual photon

with $G_E(Q^2)$ the electric and $G_M(Q^2)$ the magnetic form factor of the proton

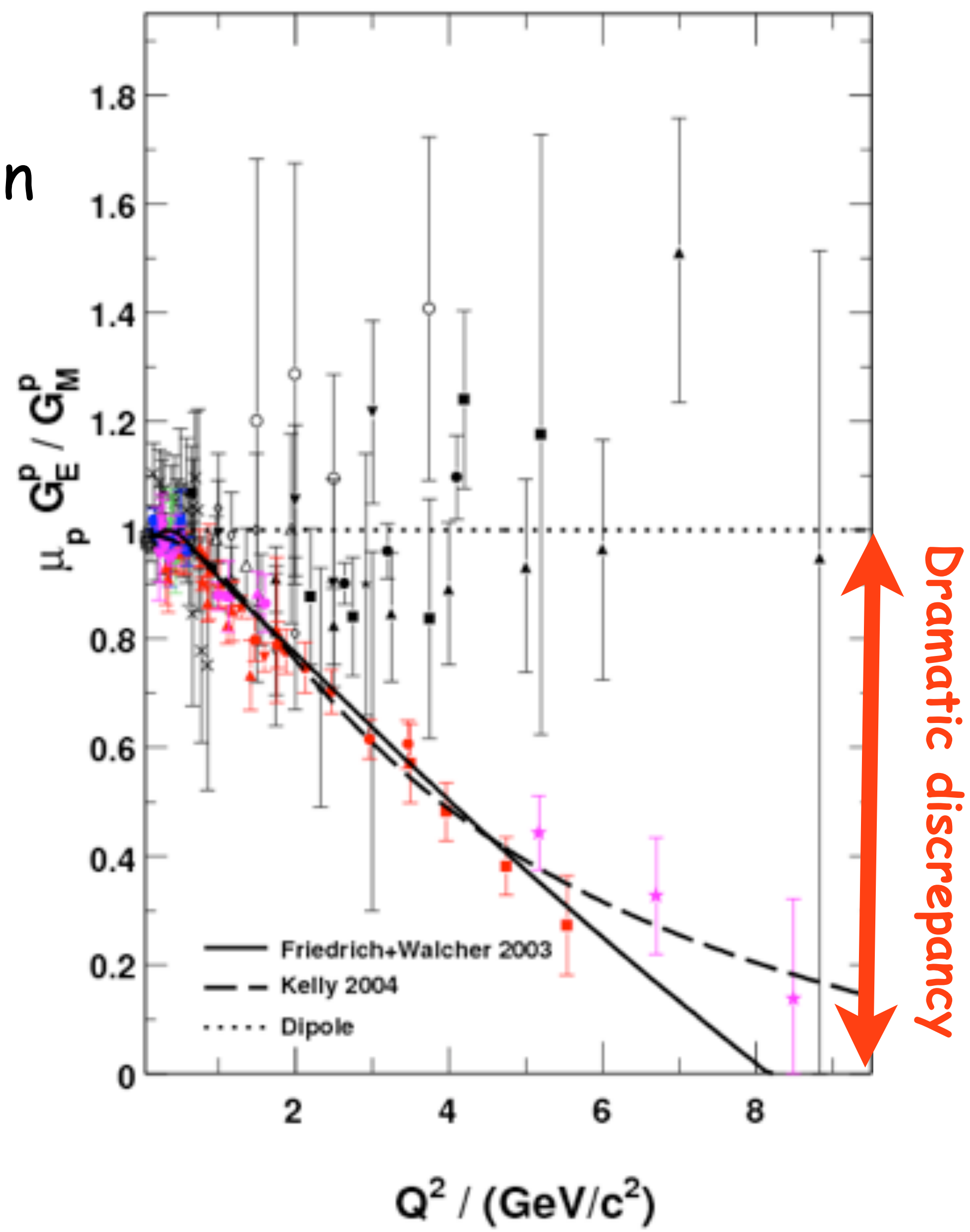


Measurement of polarization transfer

Ratio measurement

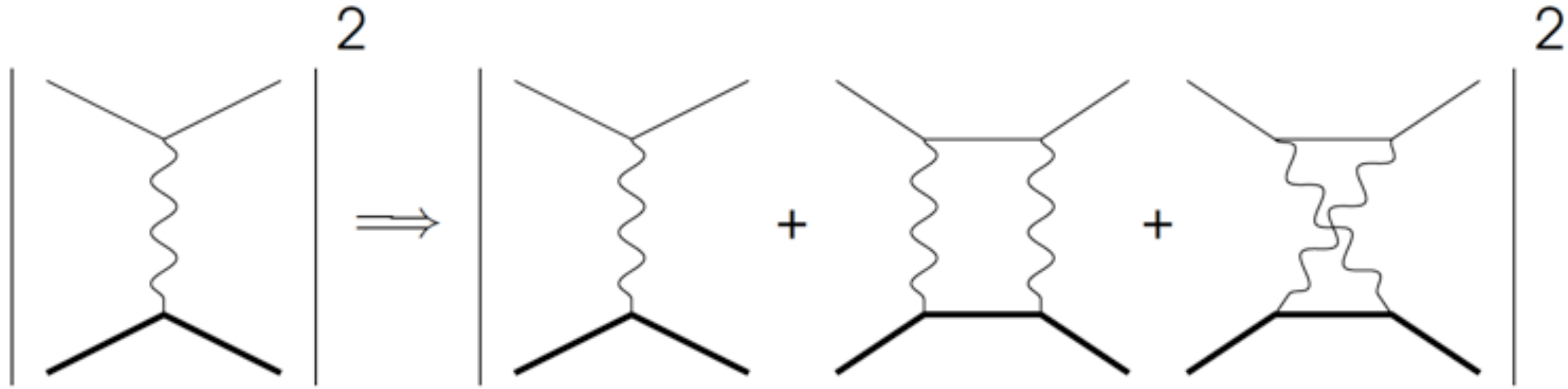
Less sensitive to radiative corrections

$$\frac{A_\perp}{A_\parallel} \propto \frac{G_E}{G_M}$$

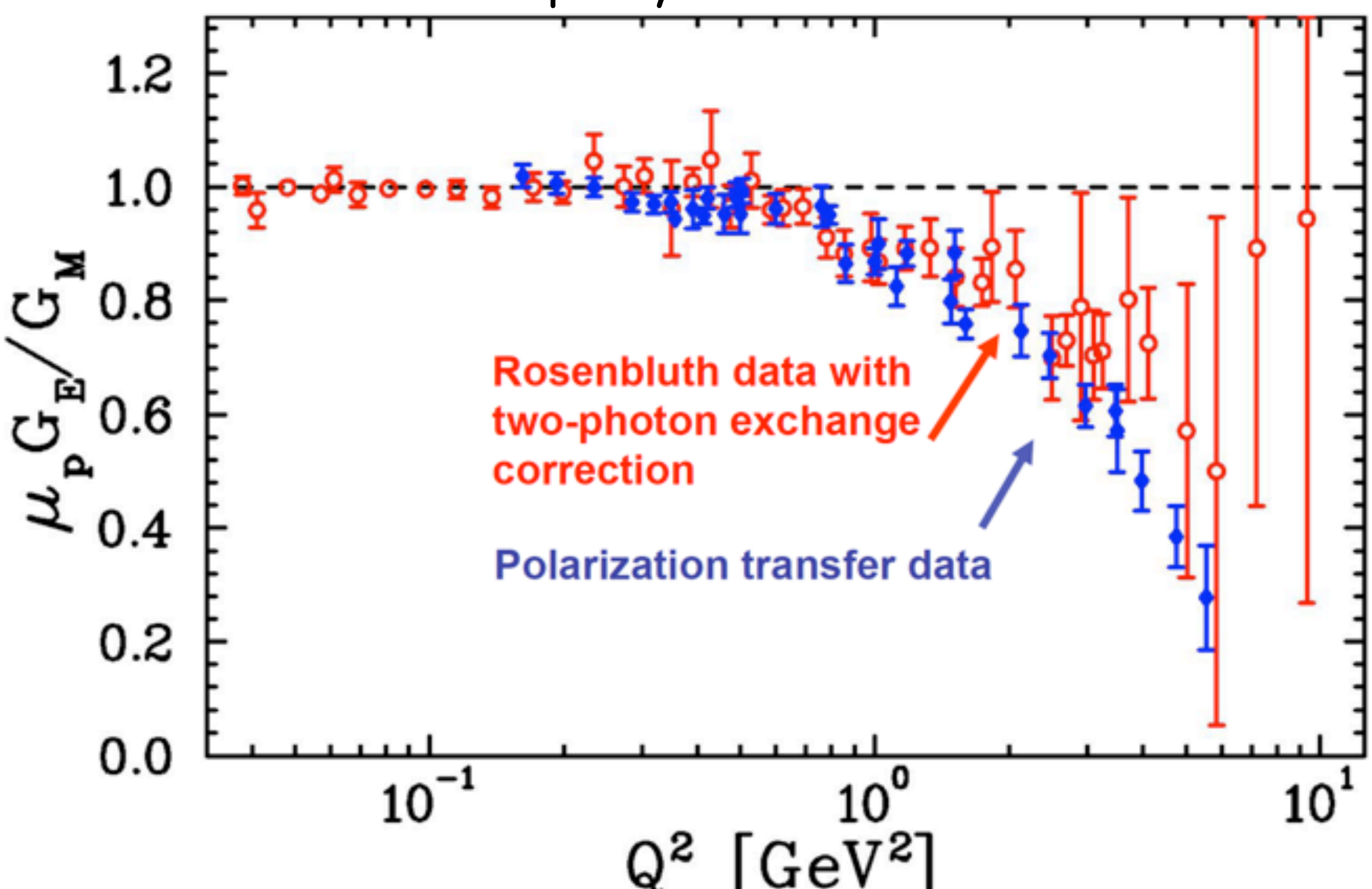


Two-photon exchange (TPE)

Important correction not taken into account so far (two photon exchange)

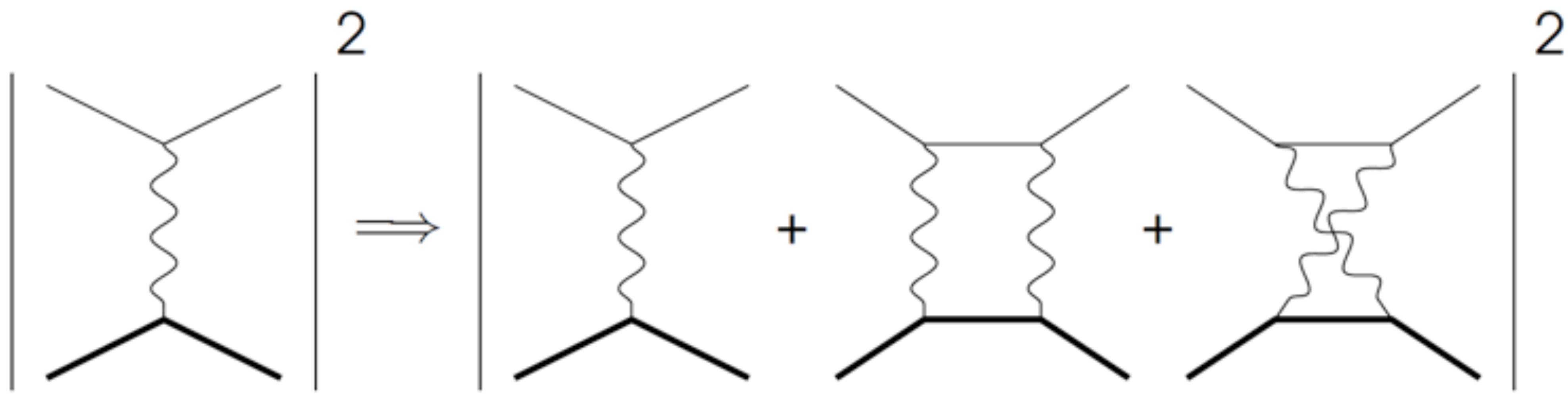


TPE can explain form factor discrepancy



J. Arrington, W. Melnitchouk, J.A. Tjon, Phys. Rev. C 76 (2007) 035205

Accessing the two-photon exchange amplitude



Interference term depends on lepton charge sign (C-odd)

$$\sigma(\mathbf{e^-p}) = |\mathbf{M_{1\gamma}}|^{\mathbf{2}}\alpha^{\mathbf{2}} - \mathbf{2}\Re(\mathbf{M}^\dagger_{\mathbf{1}\gamma} \cdot \mathbf{M_{2\gamma}})\alpha^{\mathbf{3}} + \ldots$$

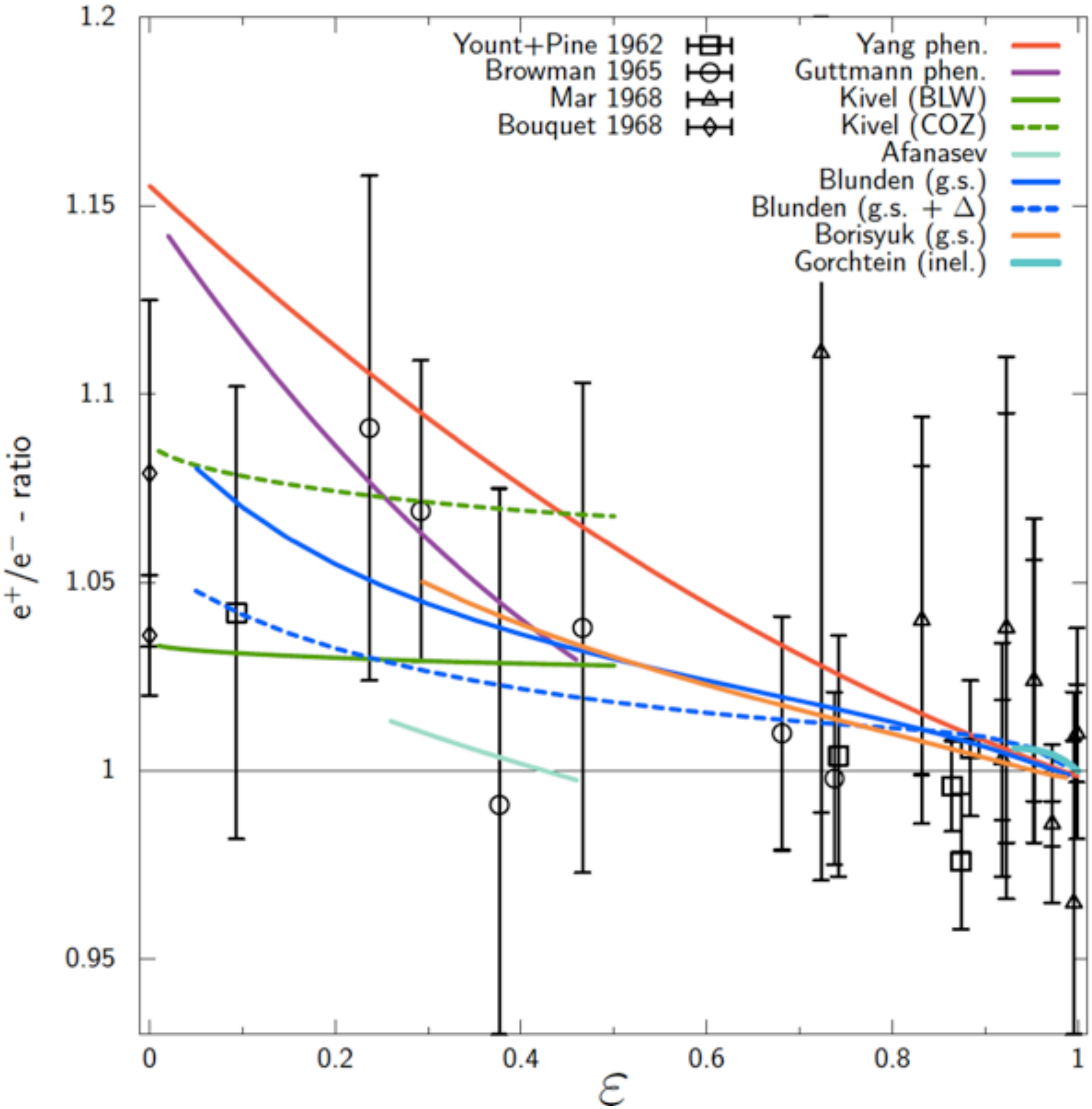
$$\sigma(\mathbf{e^+p}) = |\mathbf{M_{1\gamma}}|^{\mathbf{2}}\alpha^{\mathbf{2}} + \mathbf{2}\Re(\mathbf{M}^\dagger_{\mathbf{1}\gamma} \cdot \mathbf{M_{2\gamma}})\alpha^{\mathbf{3}} + \ldots$$

Cross section ratio for elastic e^+/e^- proton scattering:

$$\mathbf{R} = \frac{\sigma(\mathbf{e^+p})}{\sigma(\mathbf{e^-p})} = \mathbf{1} + \alpha\frac{\mathbf{4}\Re(\mathbf{M}^\dagger_{\mathbf{1}\gamma} \cdot \mathbf{M_{2\gamma}})}{|\mathbf{M_{1\gamma}}|^{\mathbf{2}}} + \ldots$$

e^+/e^- ratio deviates from unity by two photon contribution

Measurement of two-photon contribution



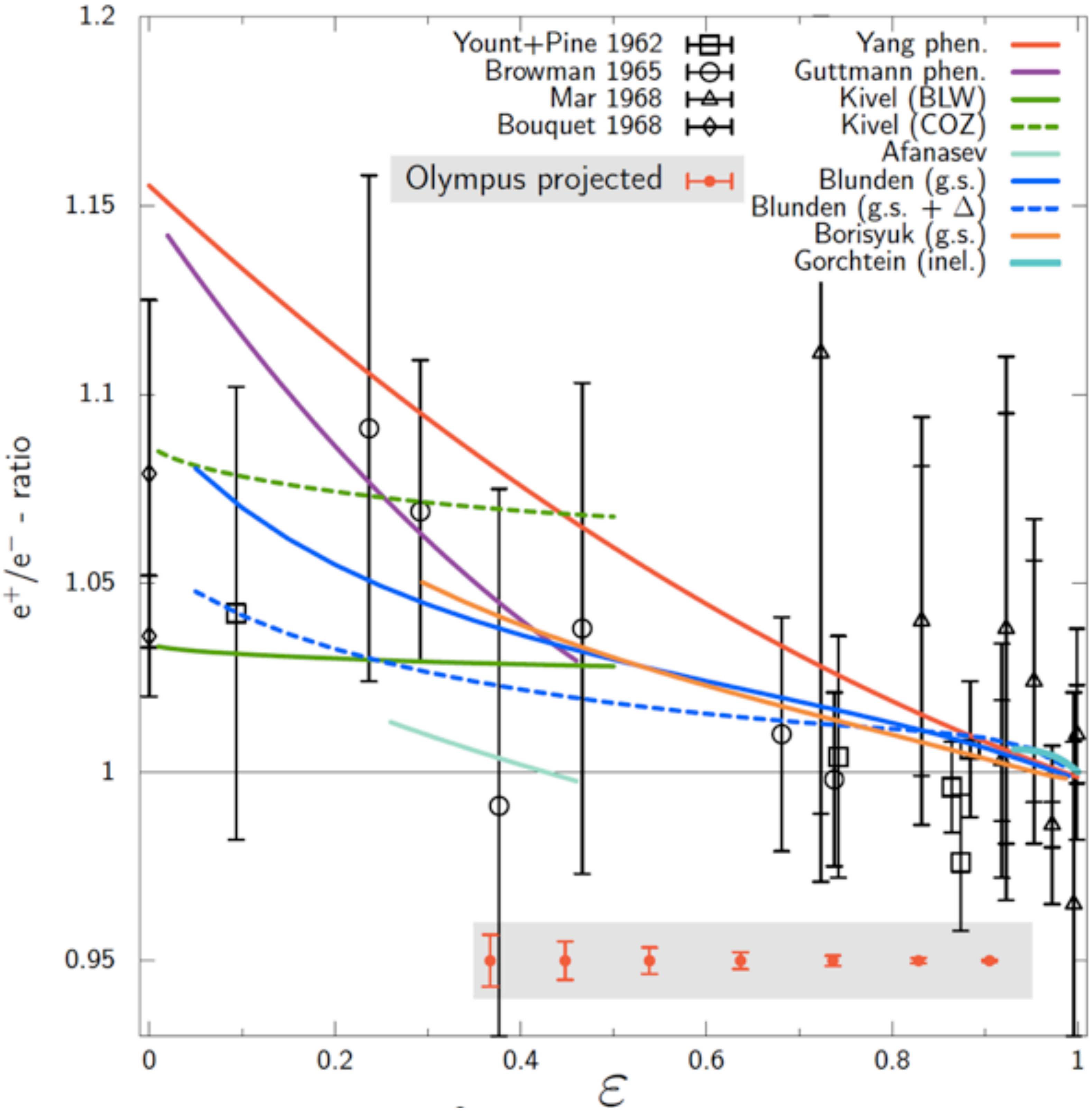
Only data from 1960's

- large errors (~6% absolute)

Calculation vary (model dependence)

- predict effect up to 6%

Projected performance



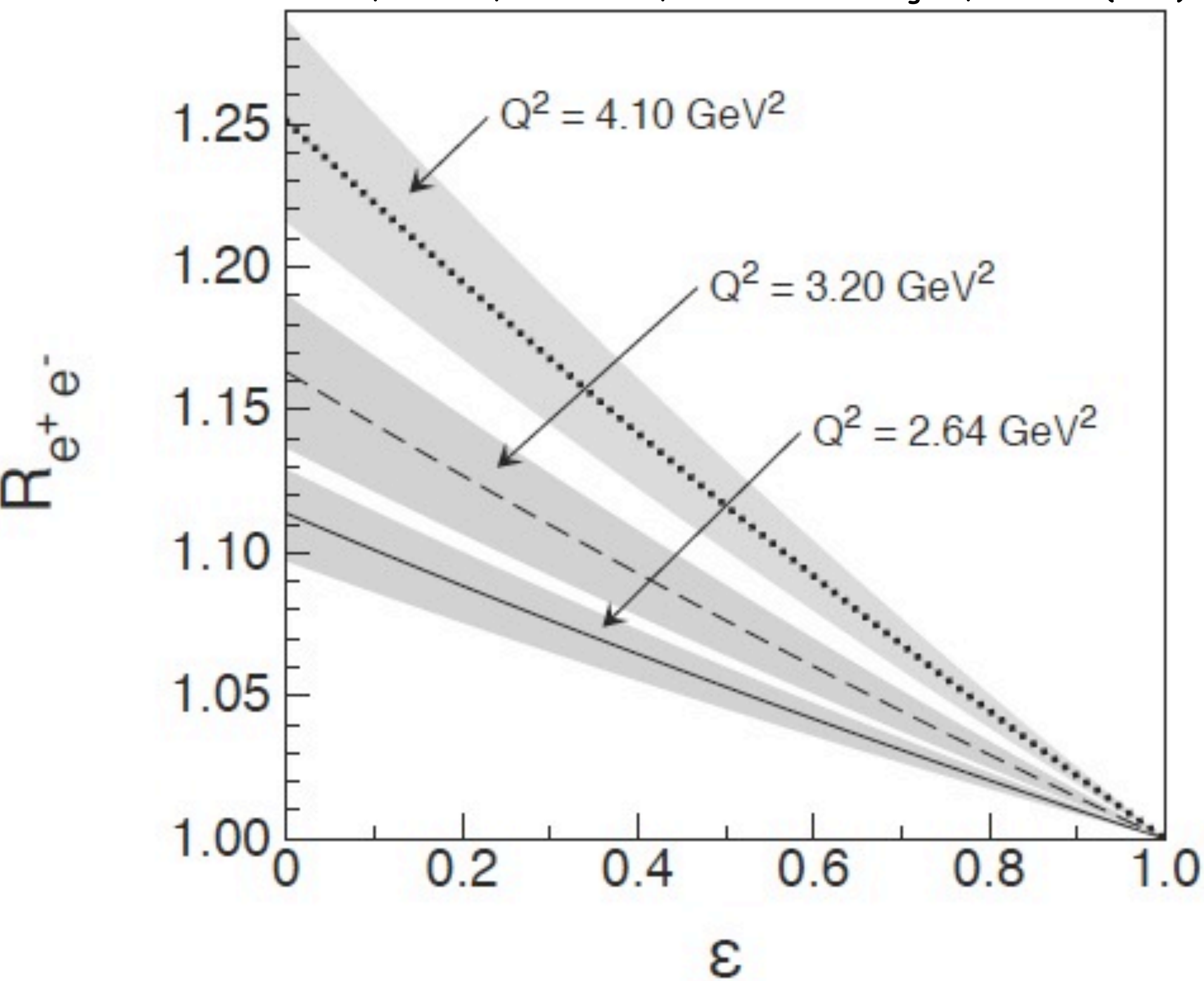
Precise (statistical error) and accurate (control of systematics)

$20° < \theta < 80°$ and $-15° < \varphi < +15°$
$0.37 < \varepsilon < 0.9$
$0.6 < Q^2 < 2.2$ GeV^2/c^2

Expected Olympus statistical sensitivity

Experimental sensitivity and expectation at Olympus

J. Guttmann, N. Kivel, M. Meziane, and M. Vanderhaeghen, EPJA 47 (2011) 77



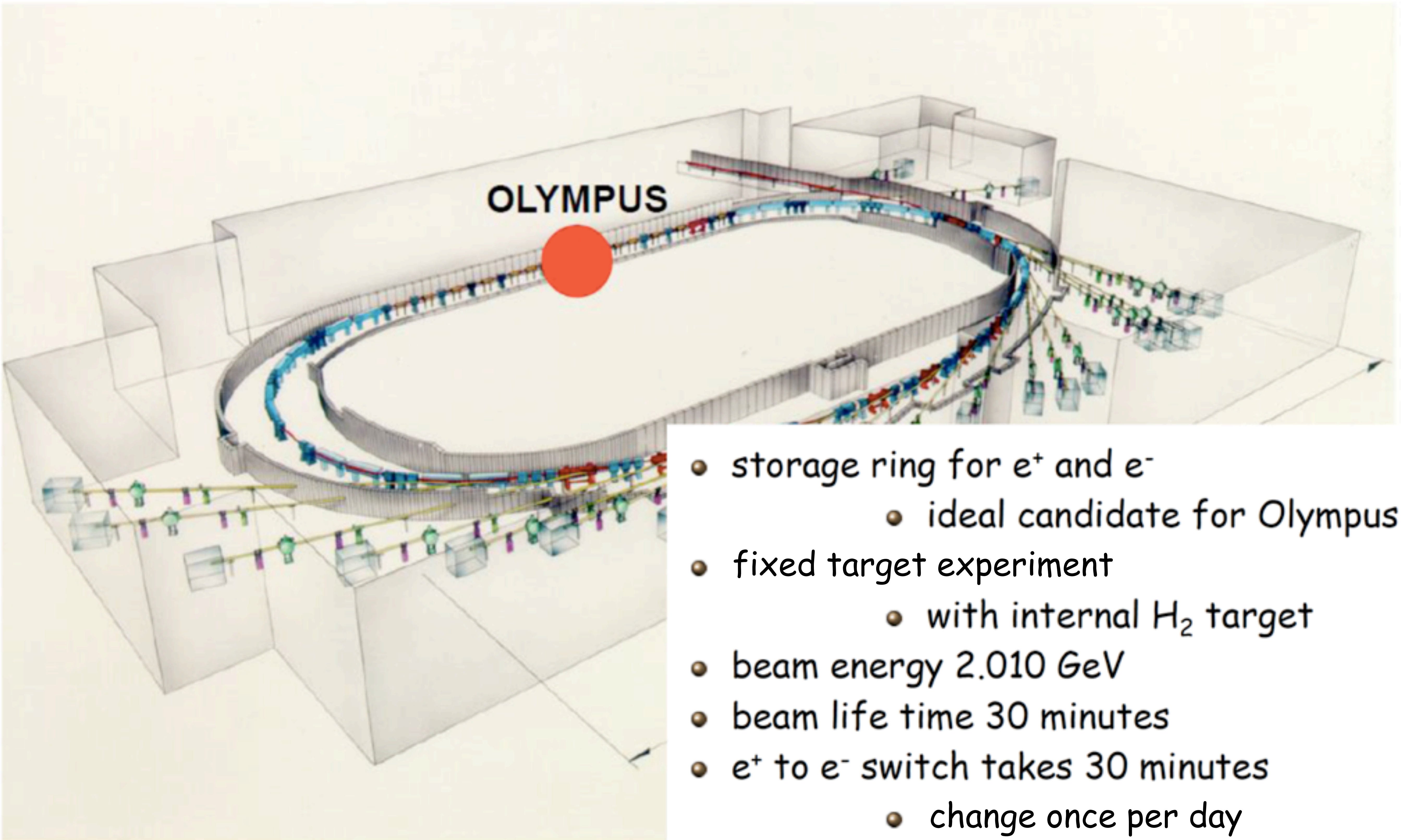
grows with Q^2

One possible theoretical prediction within Olympus measurement rang

$\epsilon_{min} = 0.37$

$Q^2_{max} = 2.2$ GeV^2/c^2

Olympus at DESY: DORIS

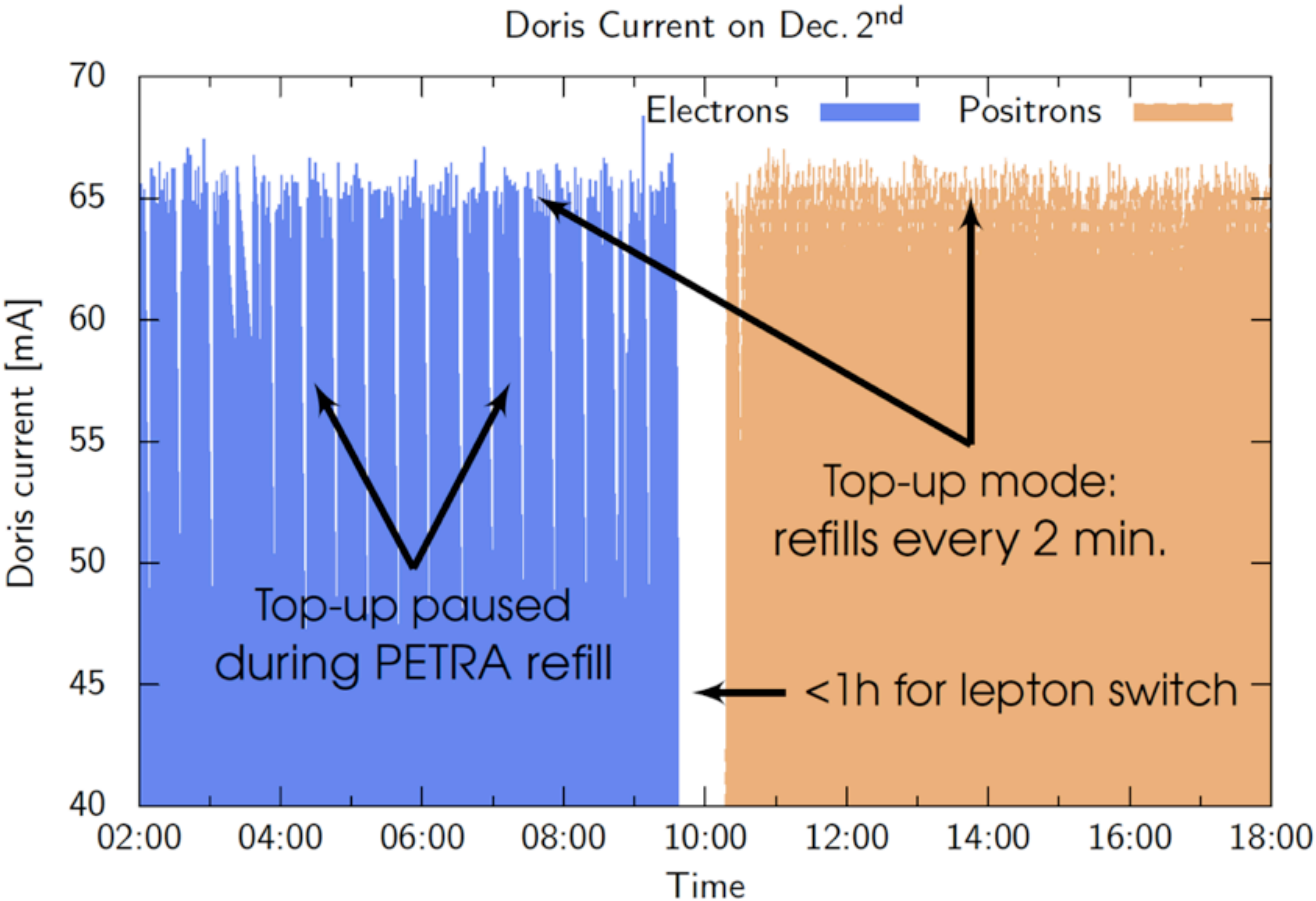


- storage ring for e^+ and e^-
  - ideal candidate for Olympus
- fixed target experiment
  - with internal H_2 target
- beam energy 2.010 GeV
- beam life time 30 minutes
- e^+ to e^- switch takes 30 minutes
  - change once per day

Run: Doris performance

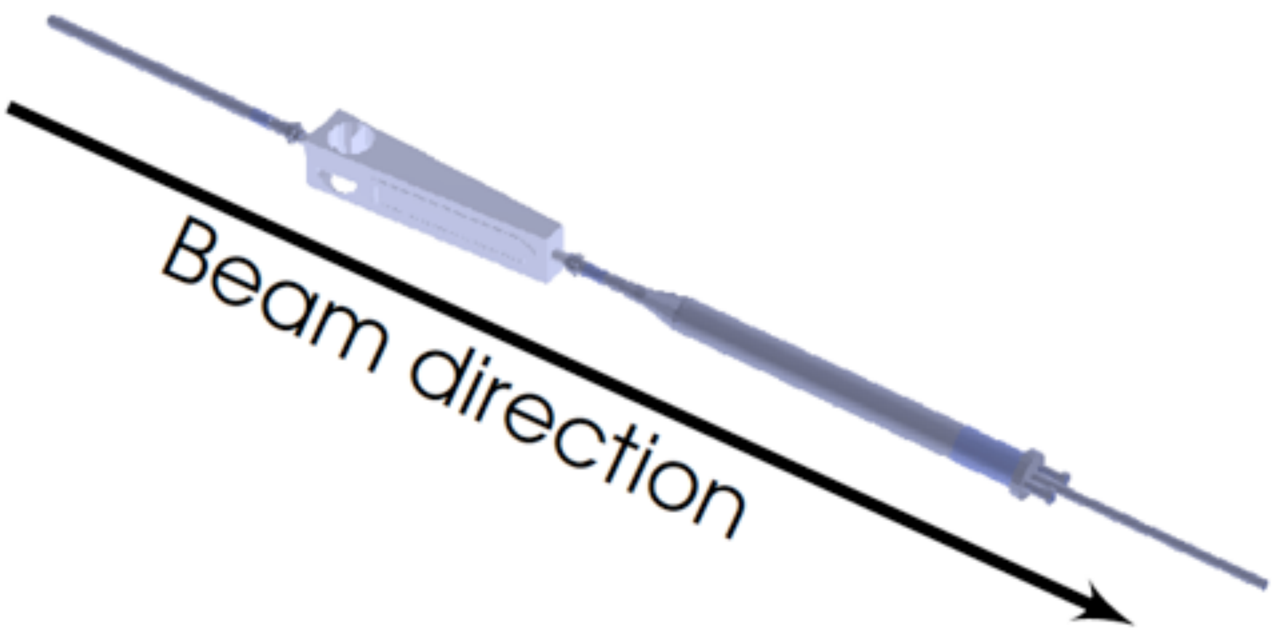
Doris top-up mode established
Typically 65mA/0.5sccm

Refills every ~2 minutes by few mA
PETRA refills every 30 minutes

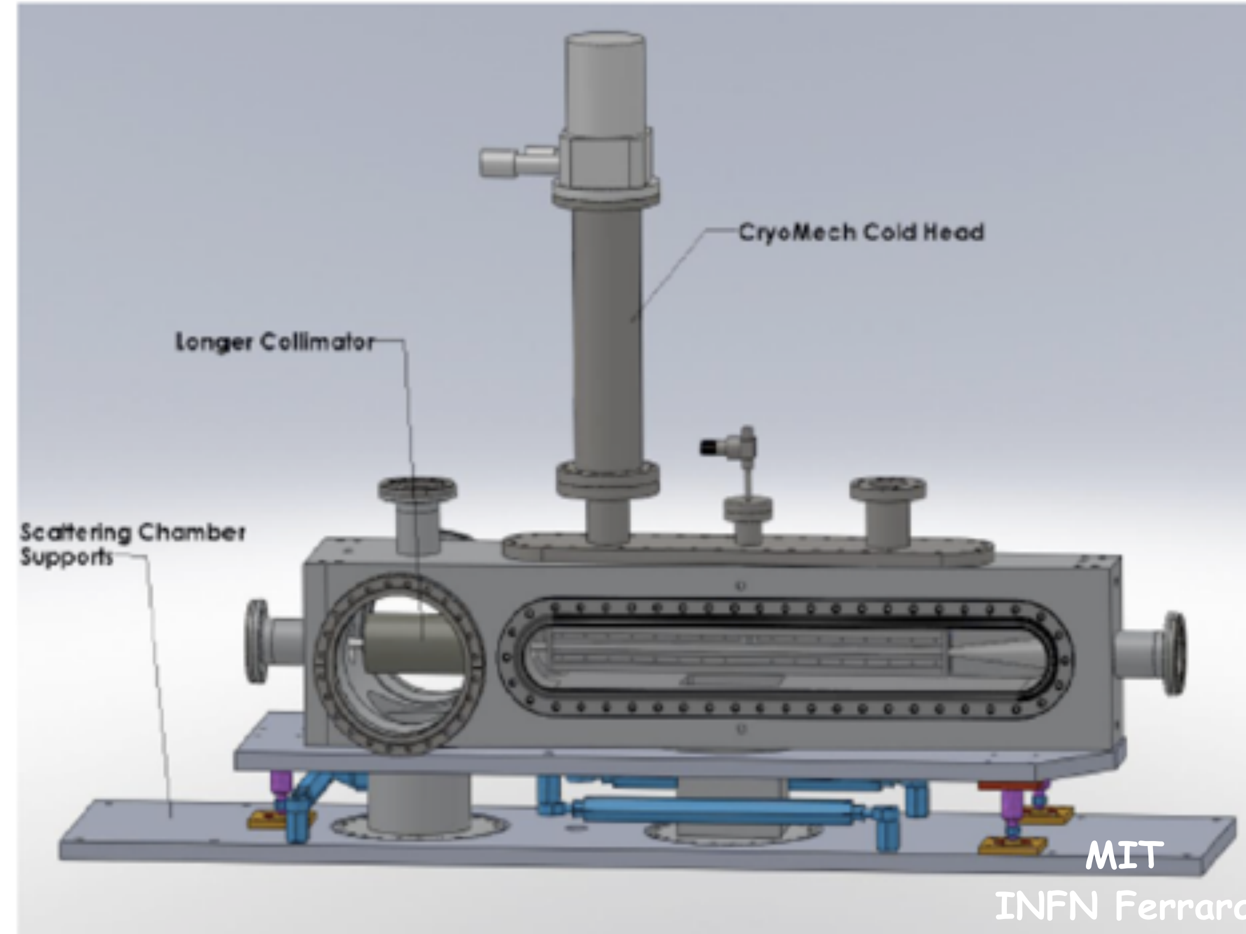


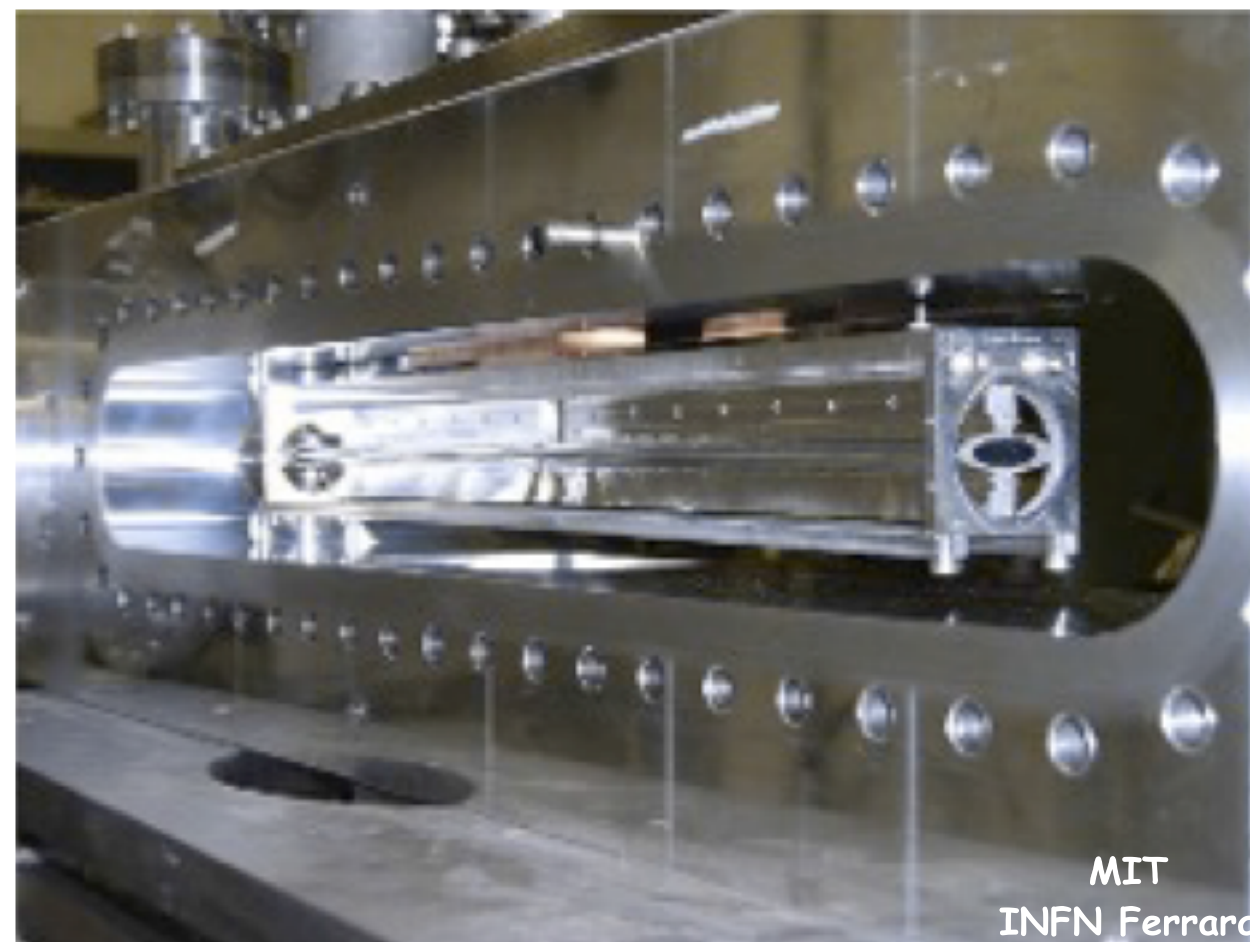
Target/Vacuum

Designed and built in 2010
Very stable operation after repairs

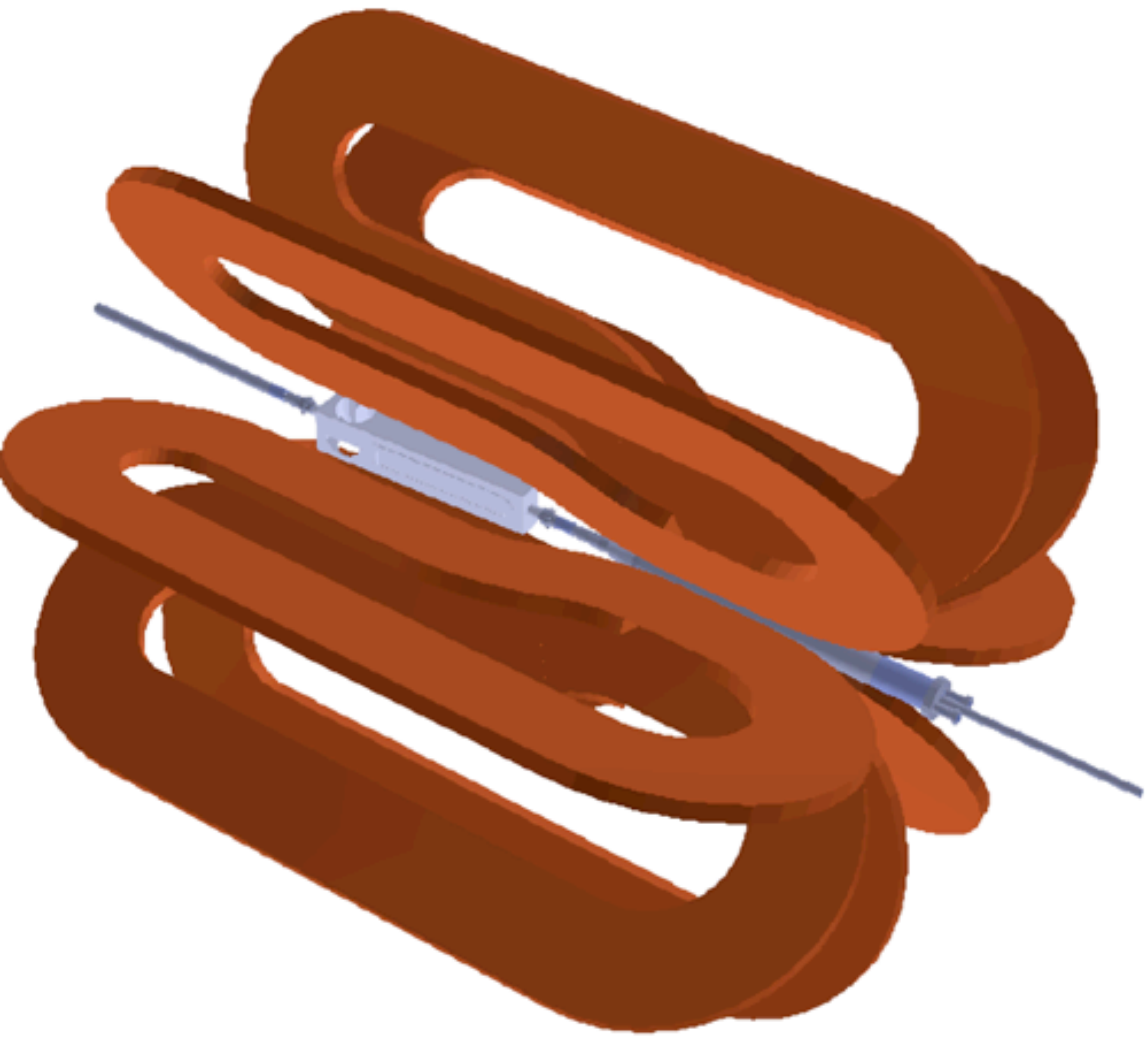


Open cell design,
60cm long storage cell
Elliptical cross section (27mm X 9mm)
100μm aluminium
Cryogenically cooled to 40K
Target density: 3.10^{15} atoms/cm^2
Multi-stage pump system





Toroid magnet



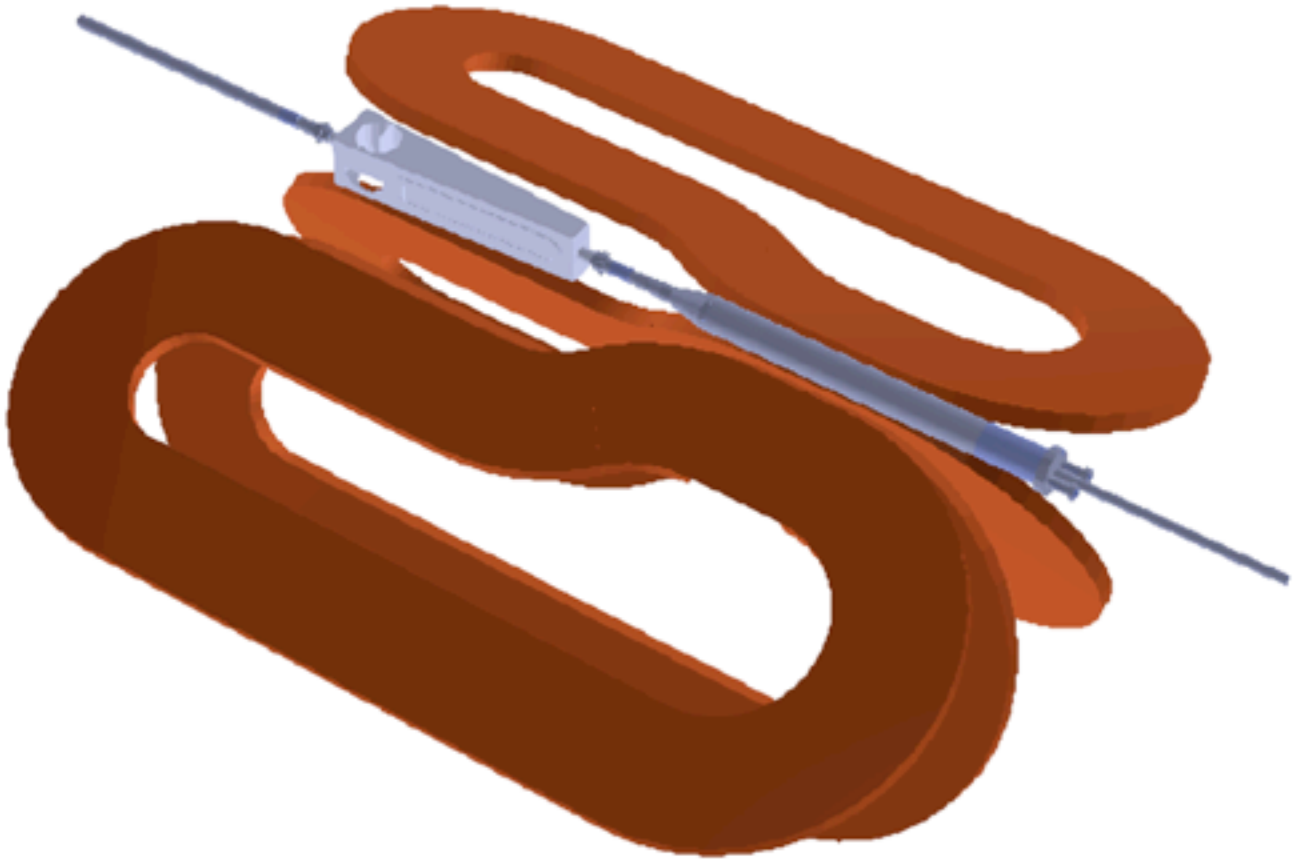
From BLAST

±5000A = 75% of BLAST

Peak field: 2.8kG

8 coils

Toroid magnet



From BLAST

±5000A = 75% of BLAST

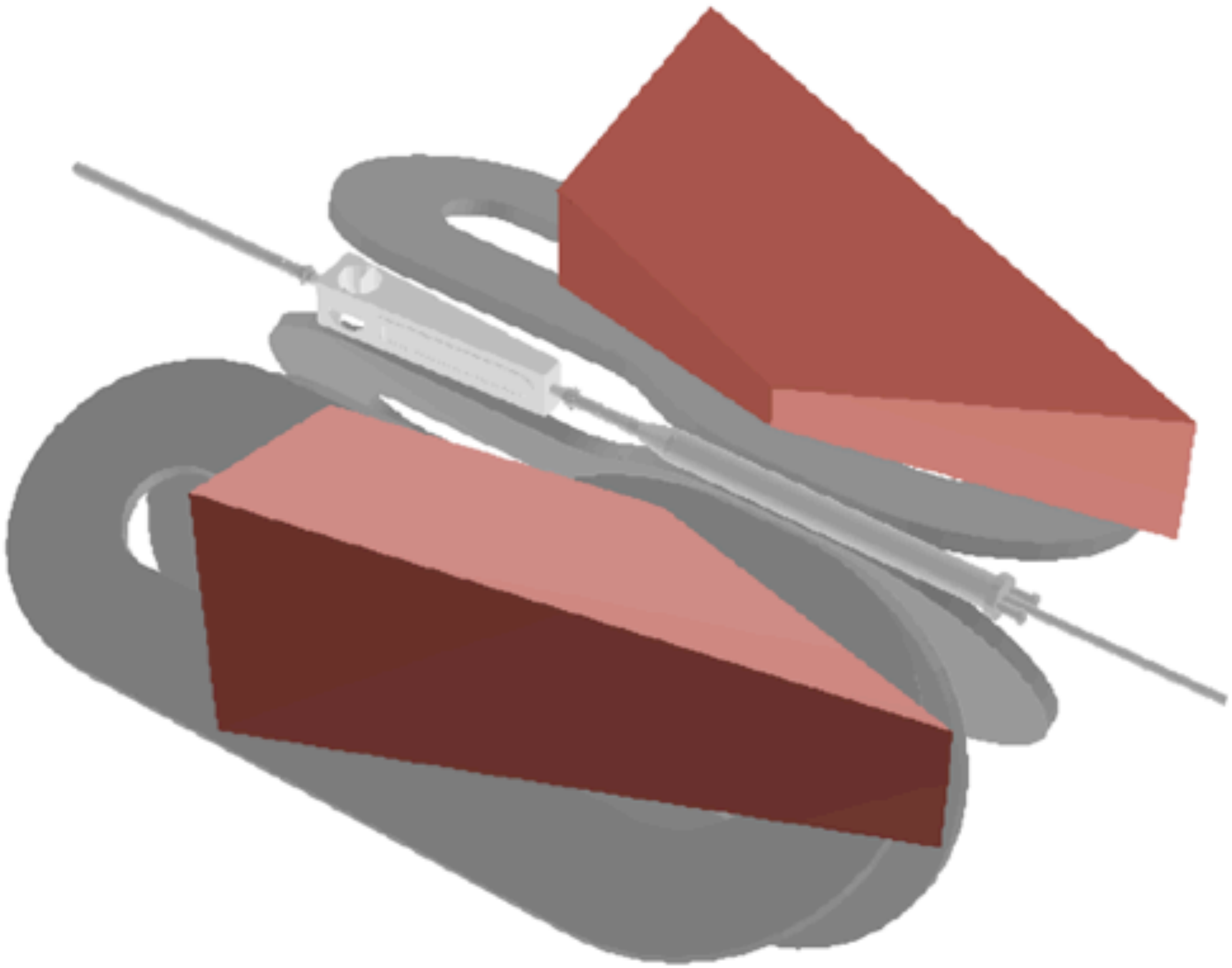
Peak field: 2.8kG

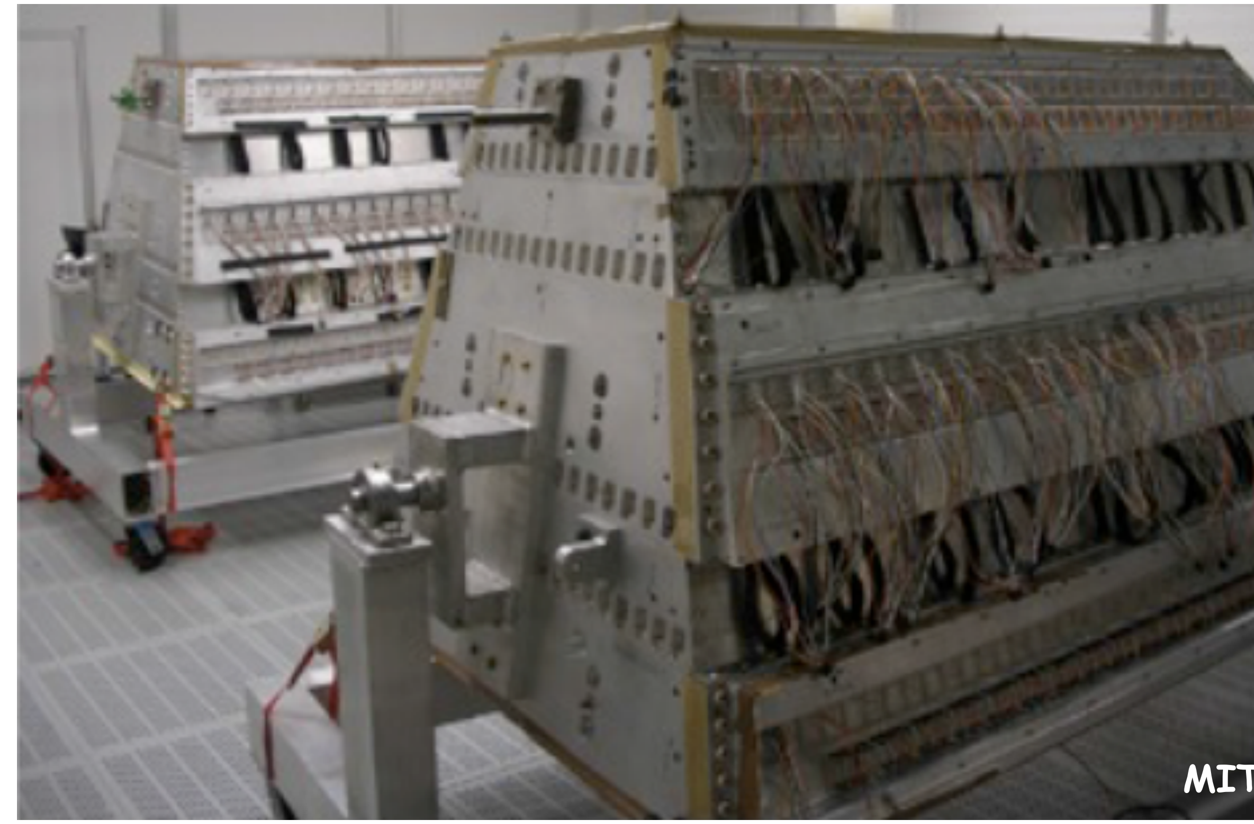
8 coils

4 shown

Wire chamber

2 WCs for PID and tracking (z, θ, φ, p)
Large acceptance
$20° < \theta < 80°$ and $-15° < \varphi < +15°$





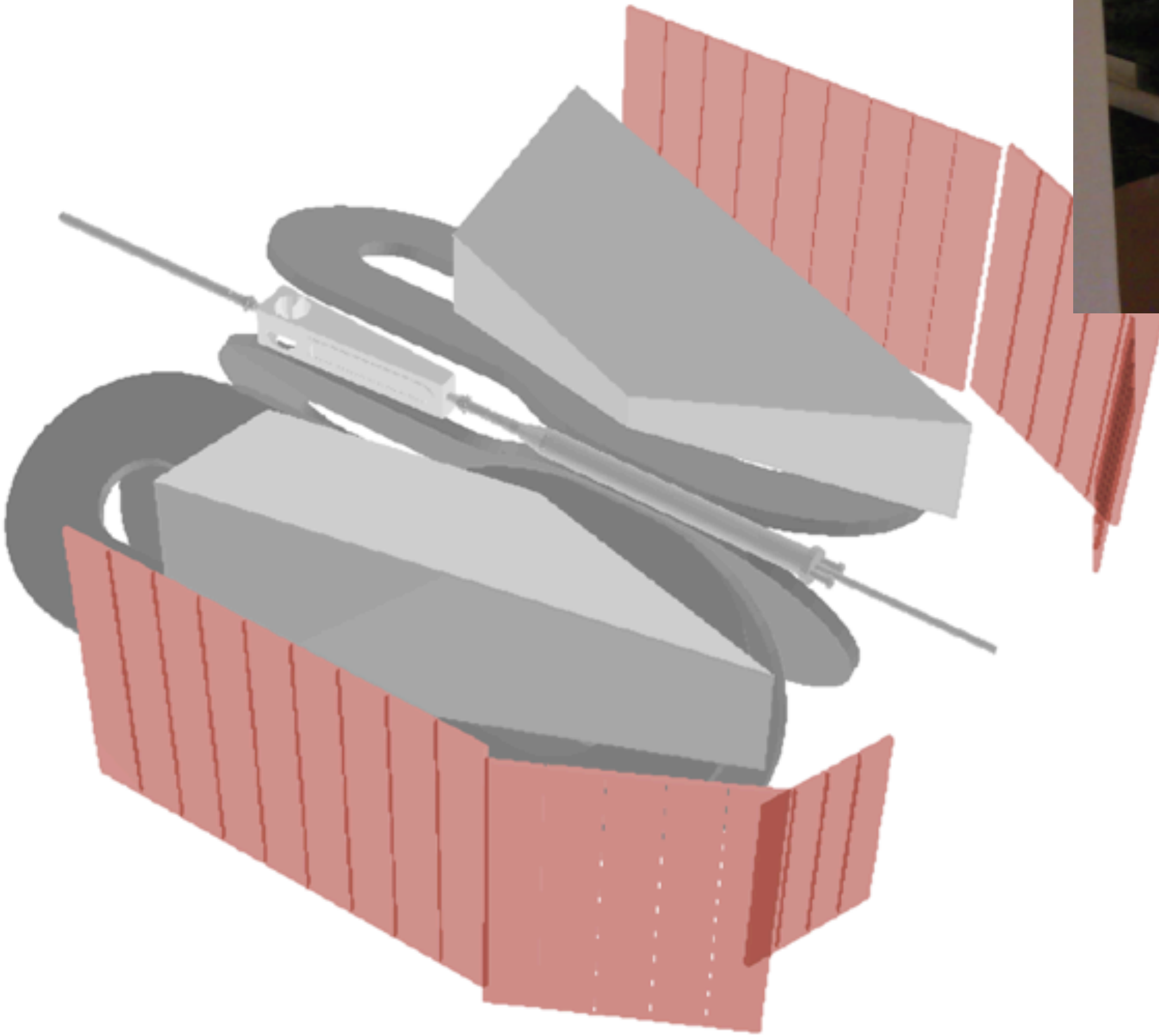
From BLAST

completely rewired

2 superlayers per chamber, each superlayer has 3 planes of sense wires,
3 chambers per sector
10° stereo angle

Time of flight

2x18 TOFs for PID, timing and trigger

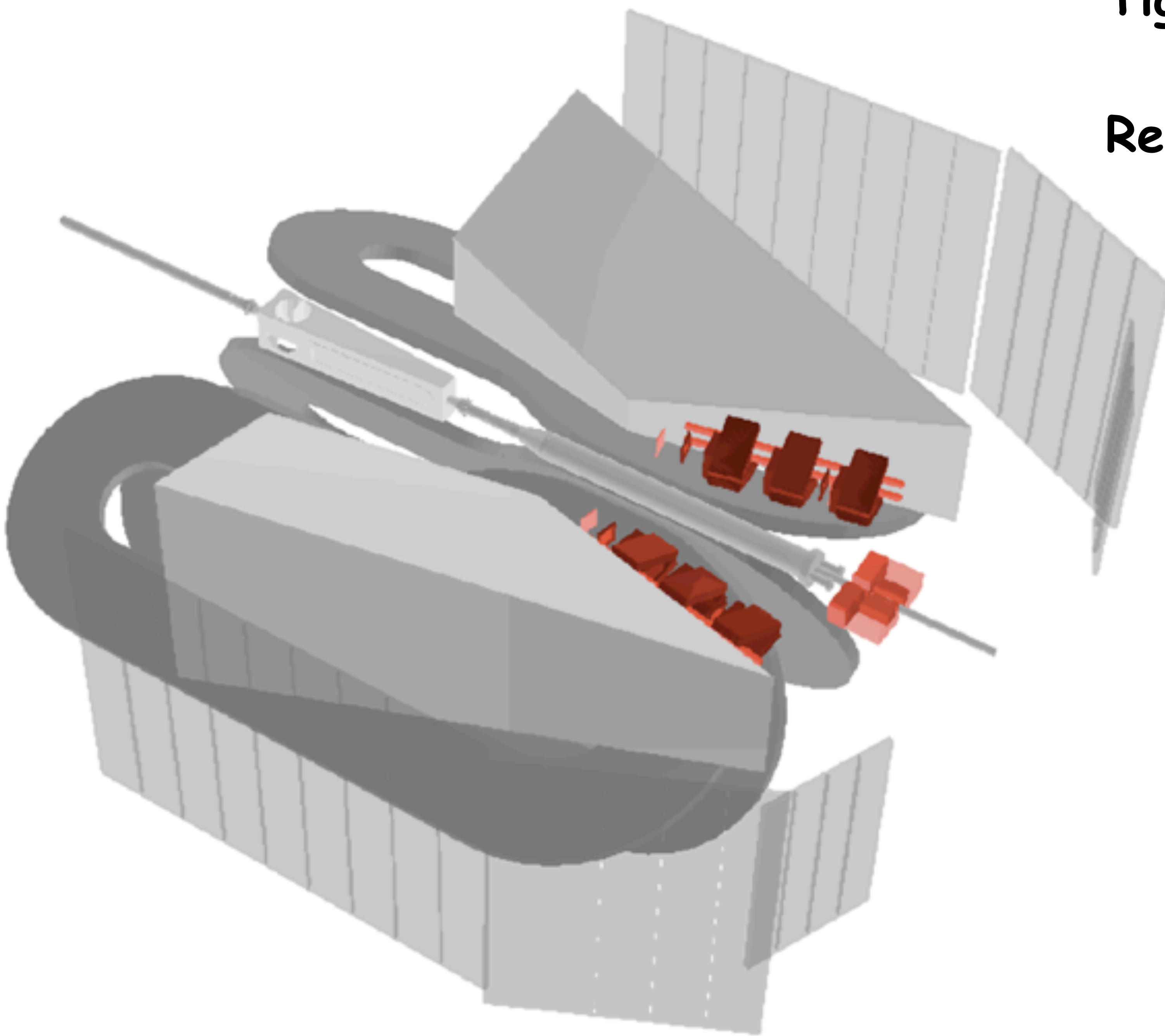


From BLAST

Rewrapped, tested

Trigger
- Top/bottom coinc.
- kinematically constrained
- +2nd level WC

Luminosity



Tight control crucial

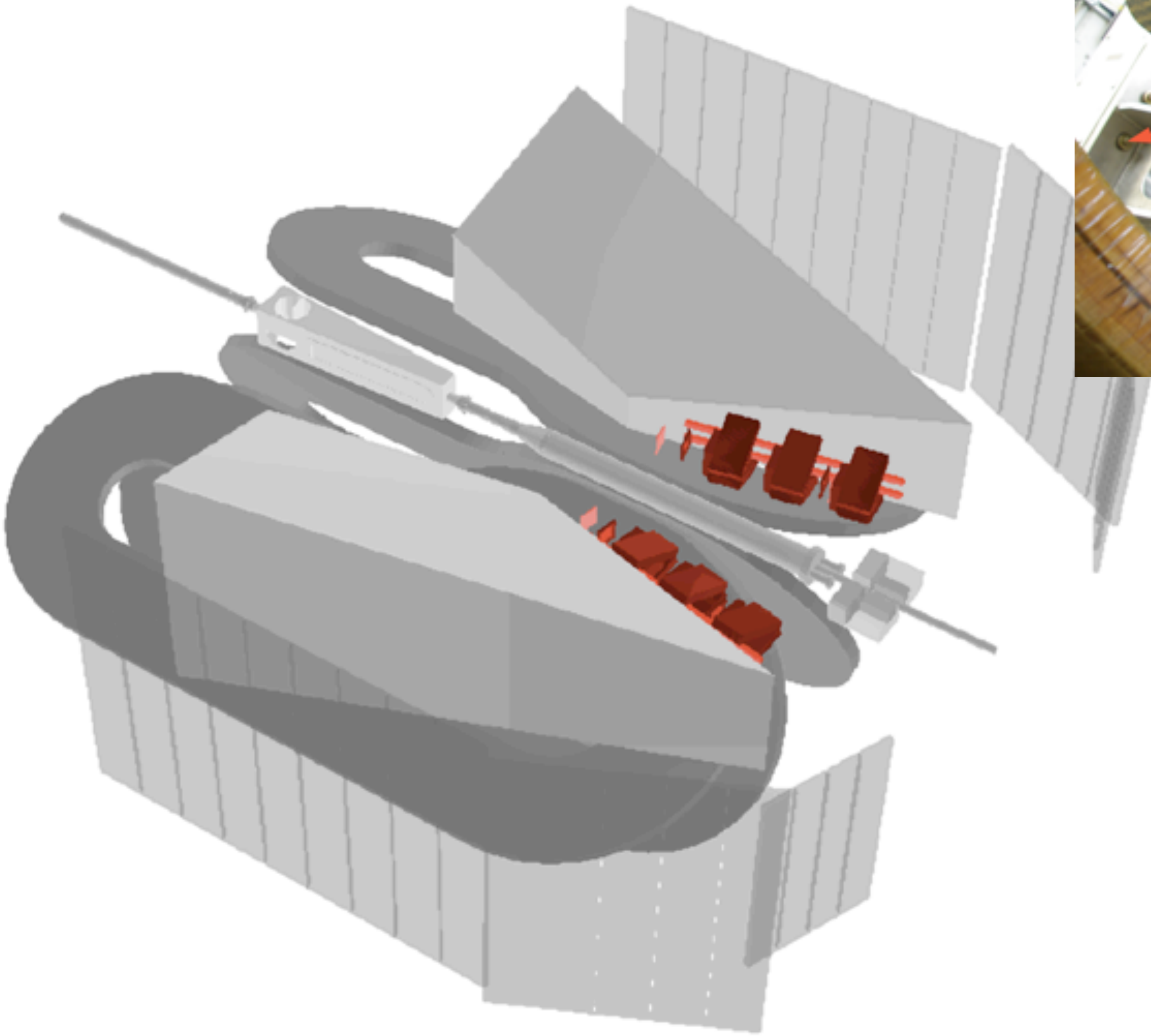
Redundant systems:

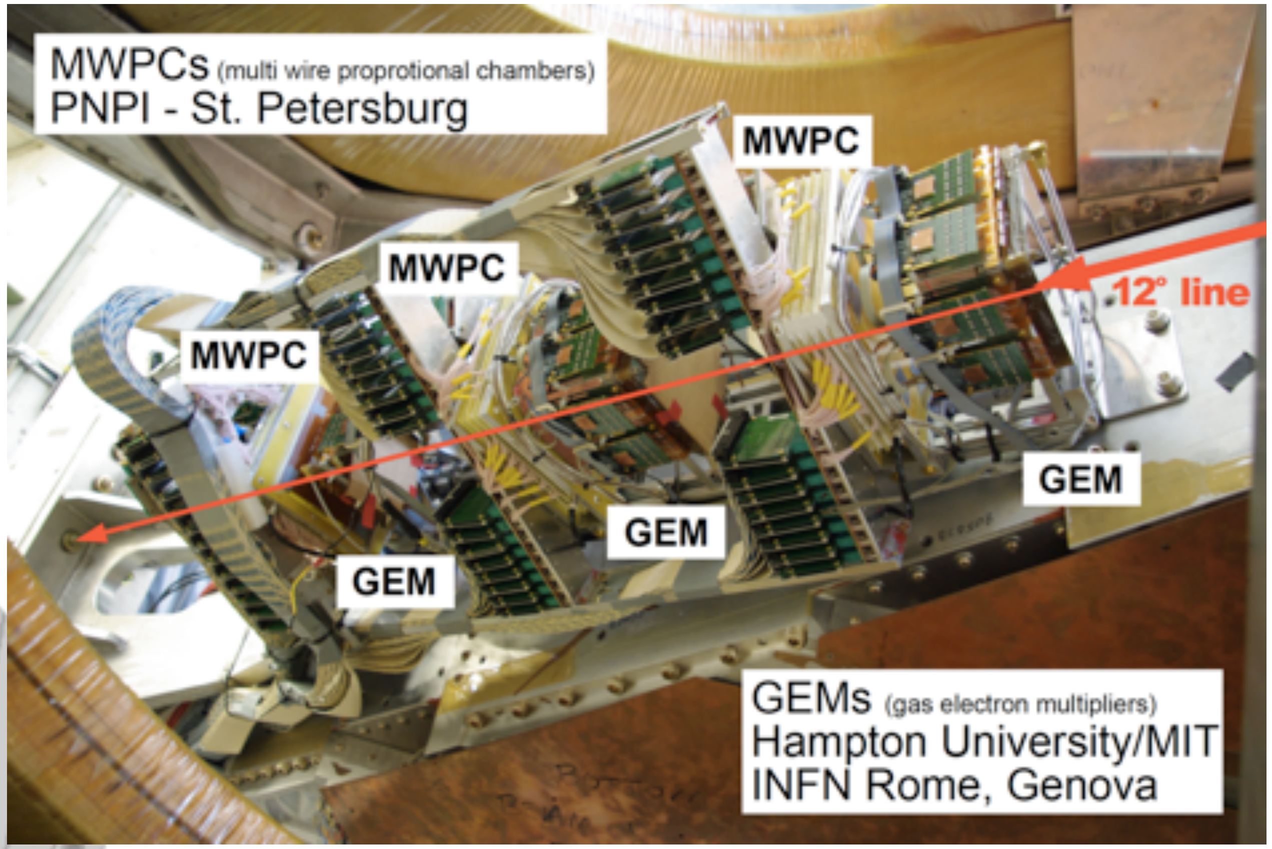
12° Tracking Telescopes
✓Two photon contribution negligible

Symmetric Møller/Bhabha
✓Pure QED processes
✓Independent measurement

12° Tracking telescopes

Forward elastic scattering of lepton at 12° in coincidence with proton in main detector





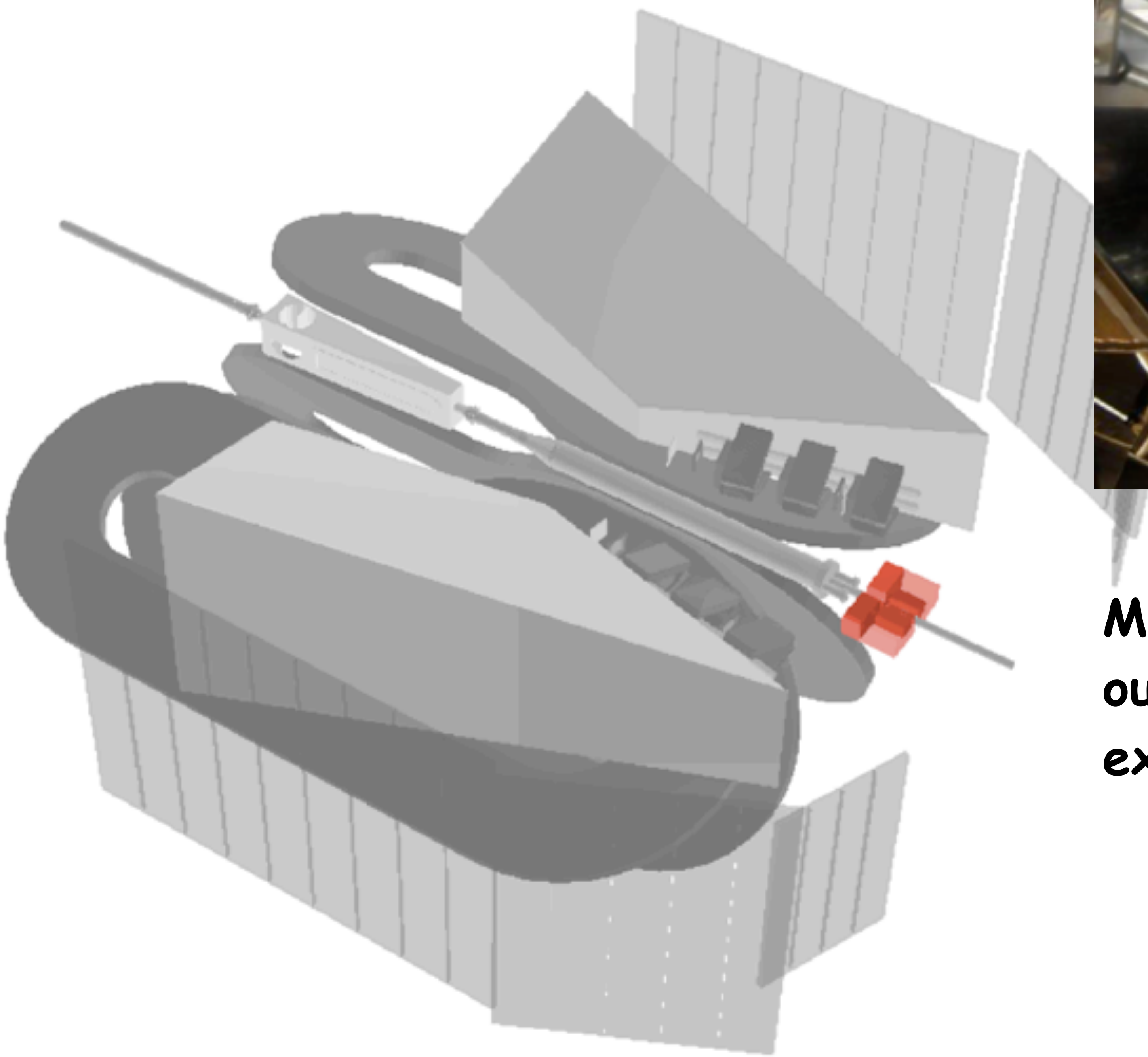
3 GEM (Hampton) + 3MWPC (PNPI) each

Highly redundant

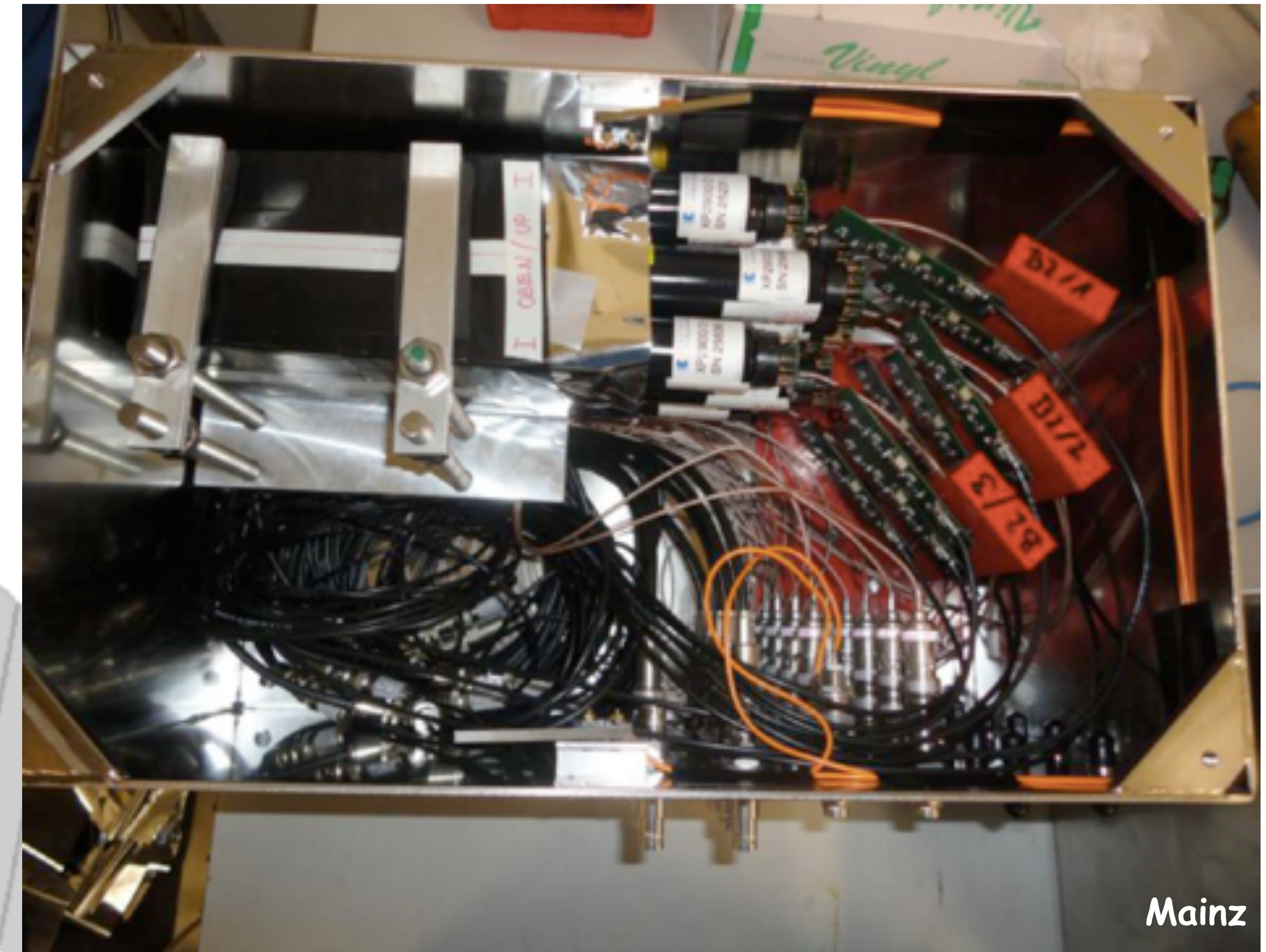
SiPM trigger scintillators

Symmetric Møller/Bhabha

Based on (symmetric) Møller (e^-e^-)
and
Bhabha (e^+e^-) scattering



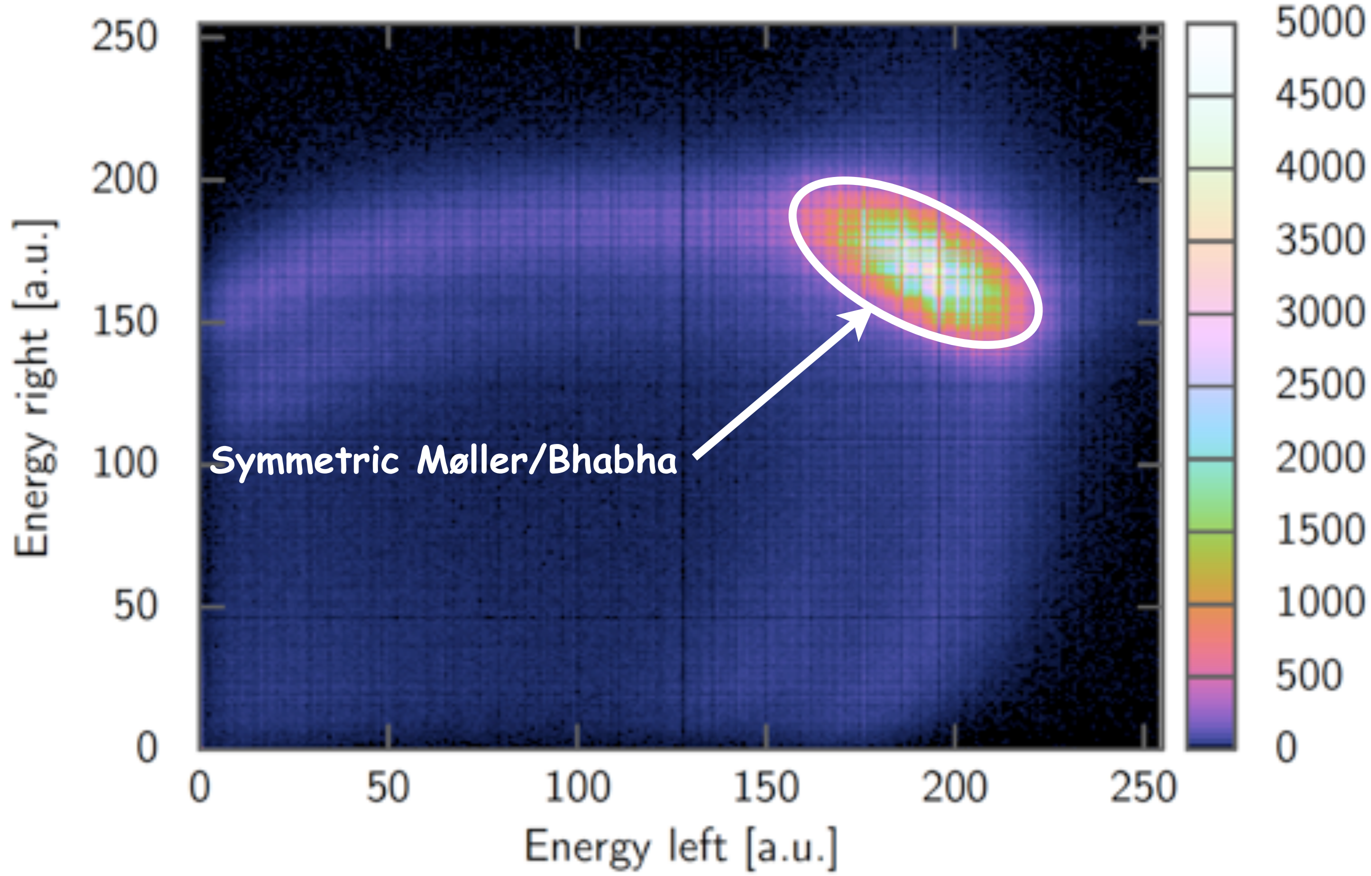
Pure QED processes
Independent measurement

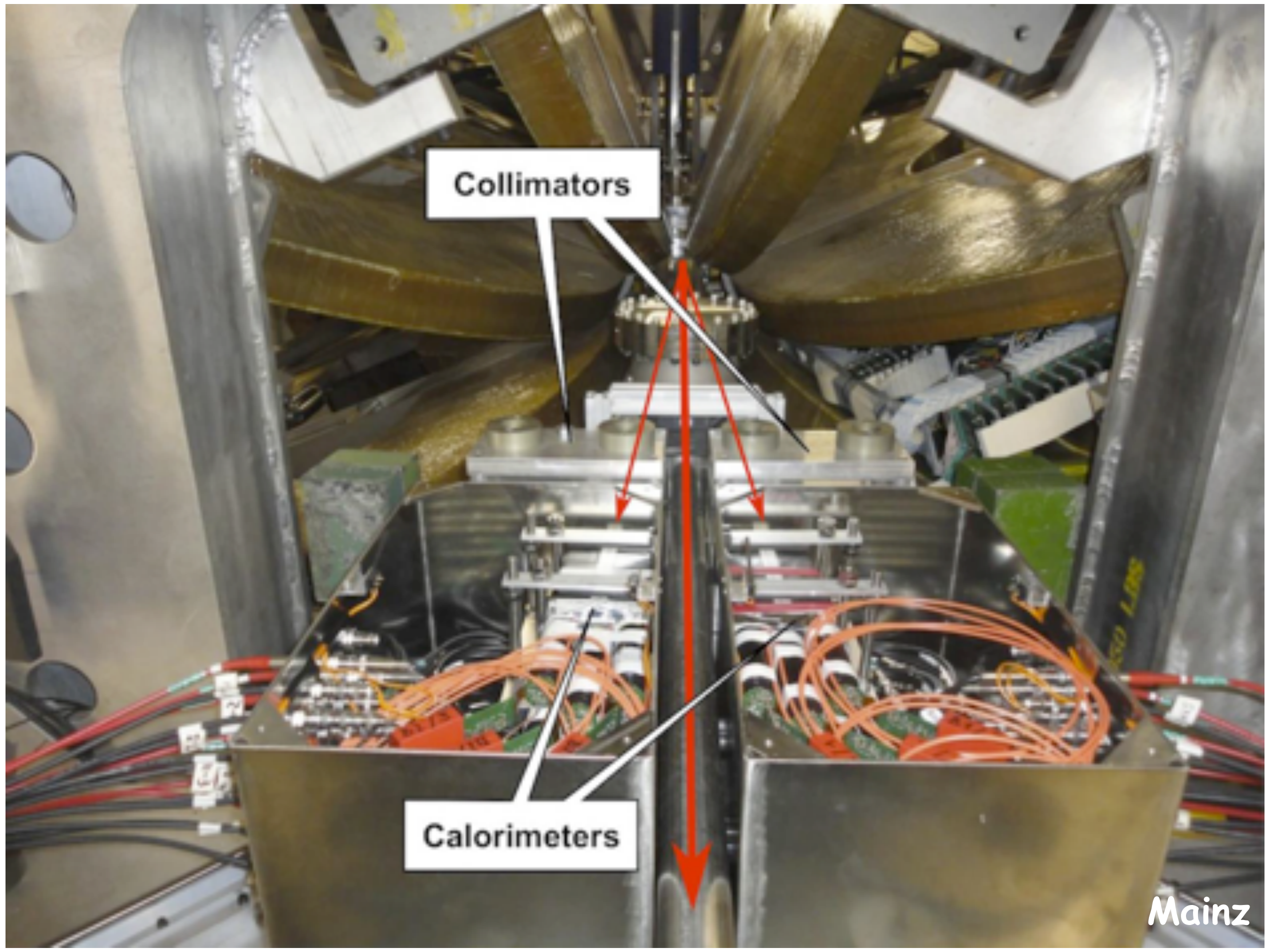


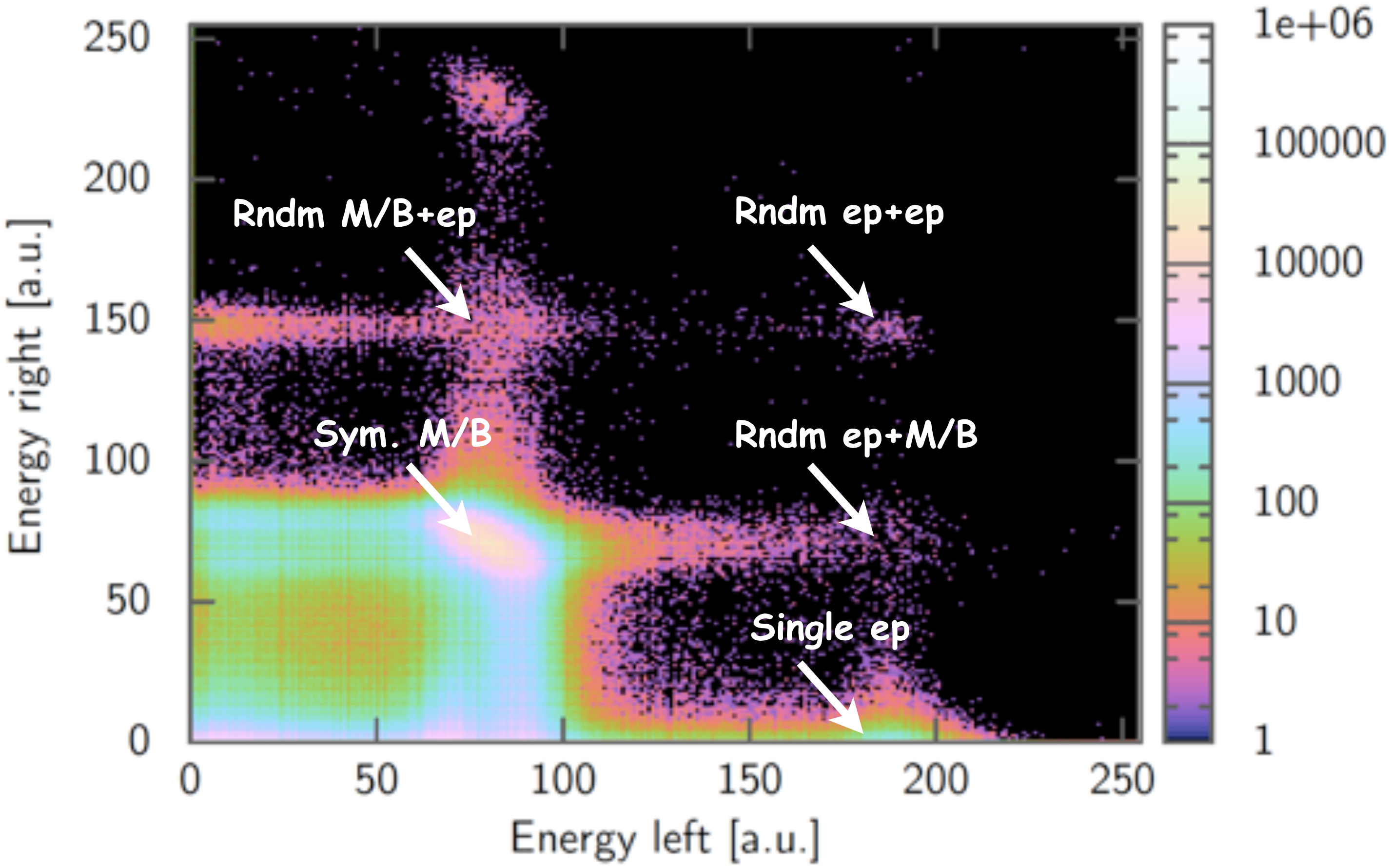
Matrix of 3x3 PbF_2 crystals and read out electronics from the parity violation experiment at MAMI

✓2MHz PMT, 50MHz peak DAQ
✓Histogramming, self-triggered operation (2MHz dead time free)
✓Coincidence operation possible

Symmetric Møller/Bhabha







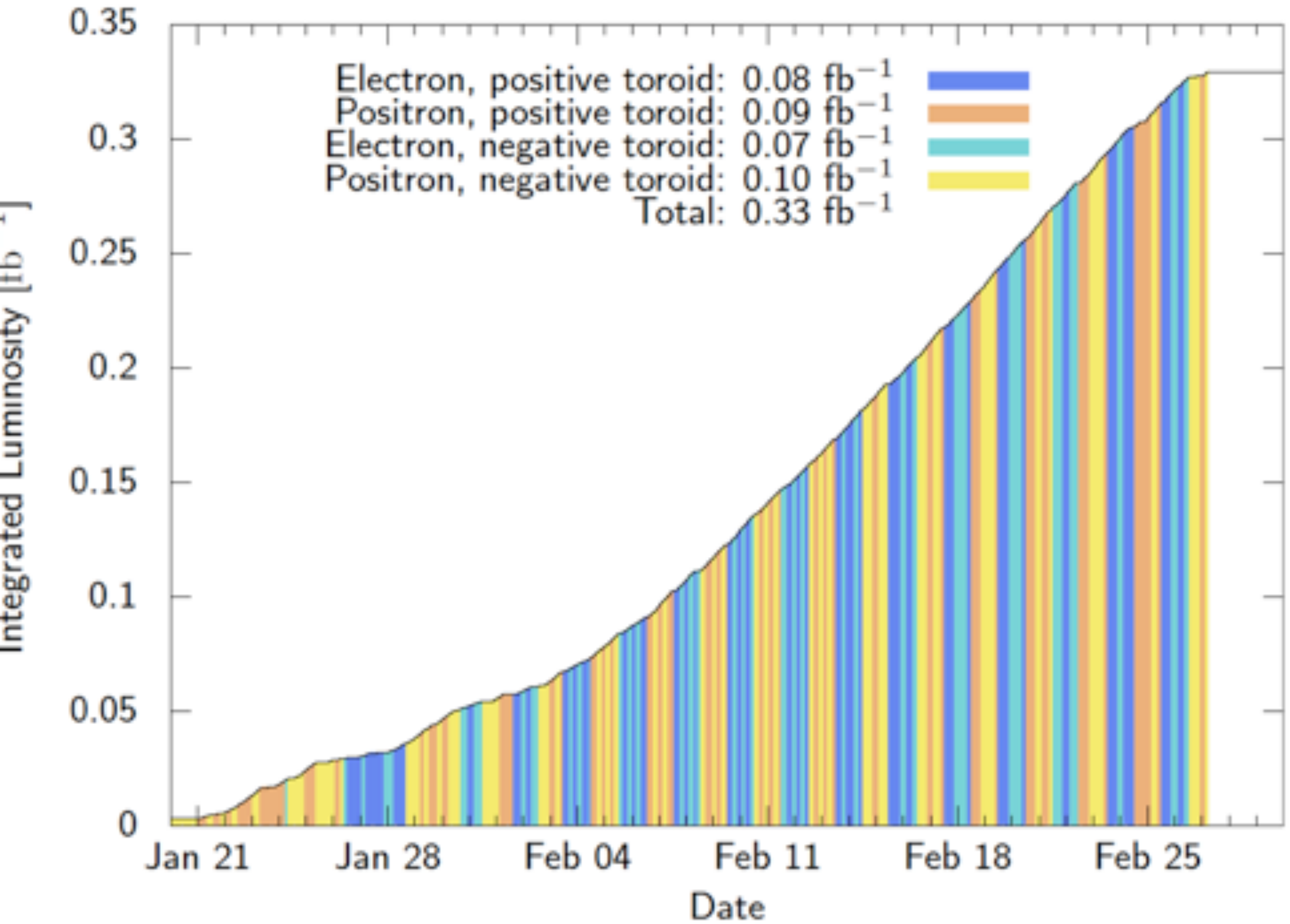
Cross check

✓Can detect lepton from lepton-lepton scattering

✓Cross check for energy calibration

✓Cross check for rate estimate

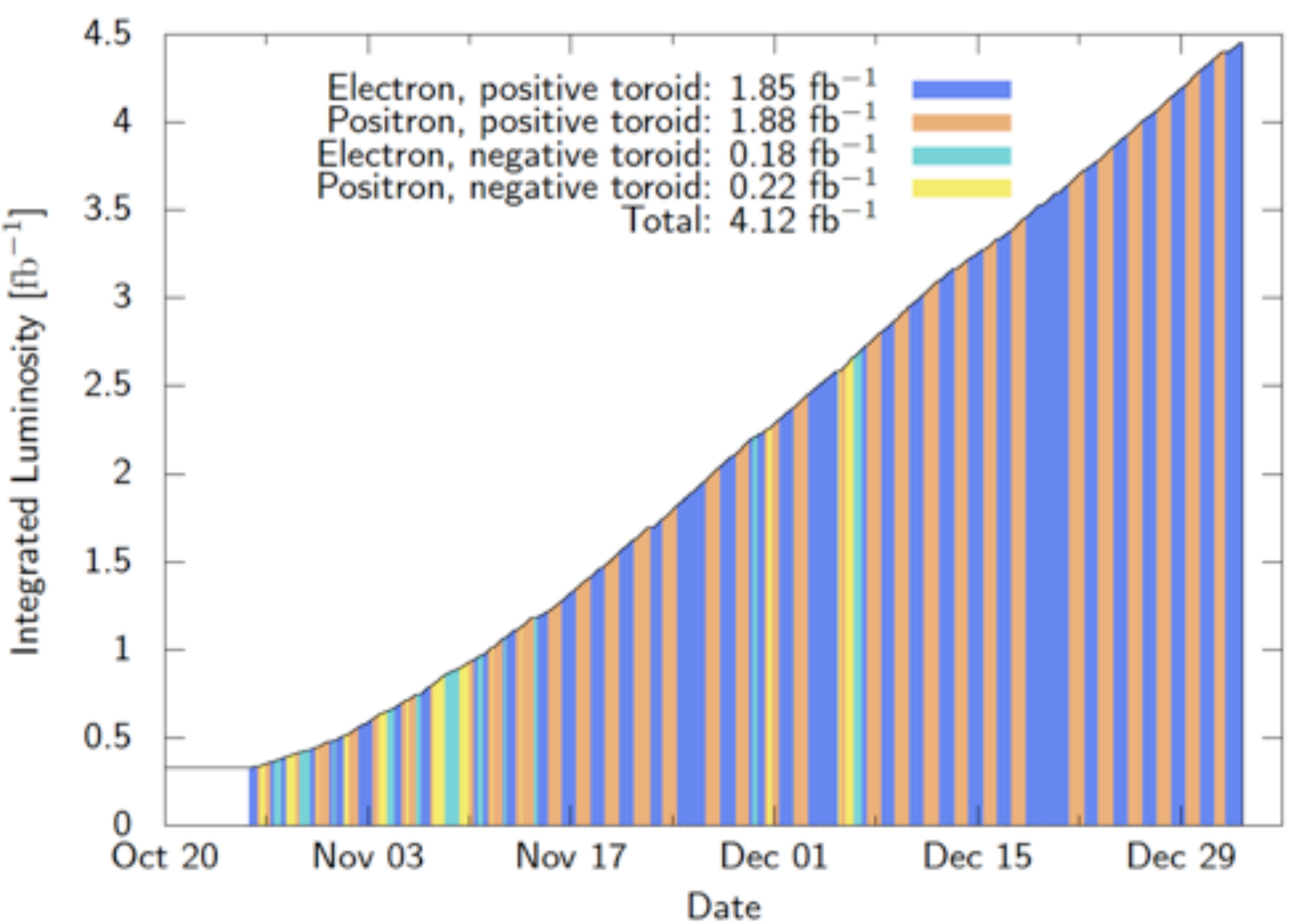
Slow control luminosity



First run:(Jan 30 -Feb 27, 2012)

✓All four settings

✓Leak in target ⟹only 1/8 of density could compensate to 1/4 with higher flow …acquired ~0.3fb^{-1}



Second run:(Oct.24, 2012-Jan.2, 2013)

✓Exceeded goal for integrated luminosity: >4fb^{-1}

✓Full flow + negative toroid ⟹outbending electrons cause high noise and prevented running consequently most data with positive polarity.

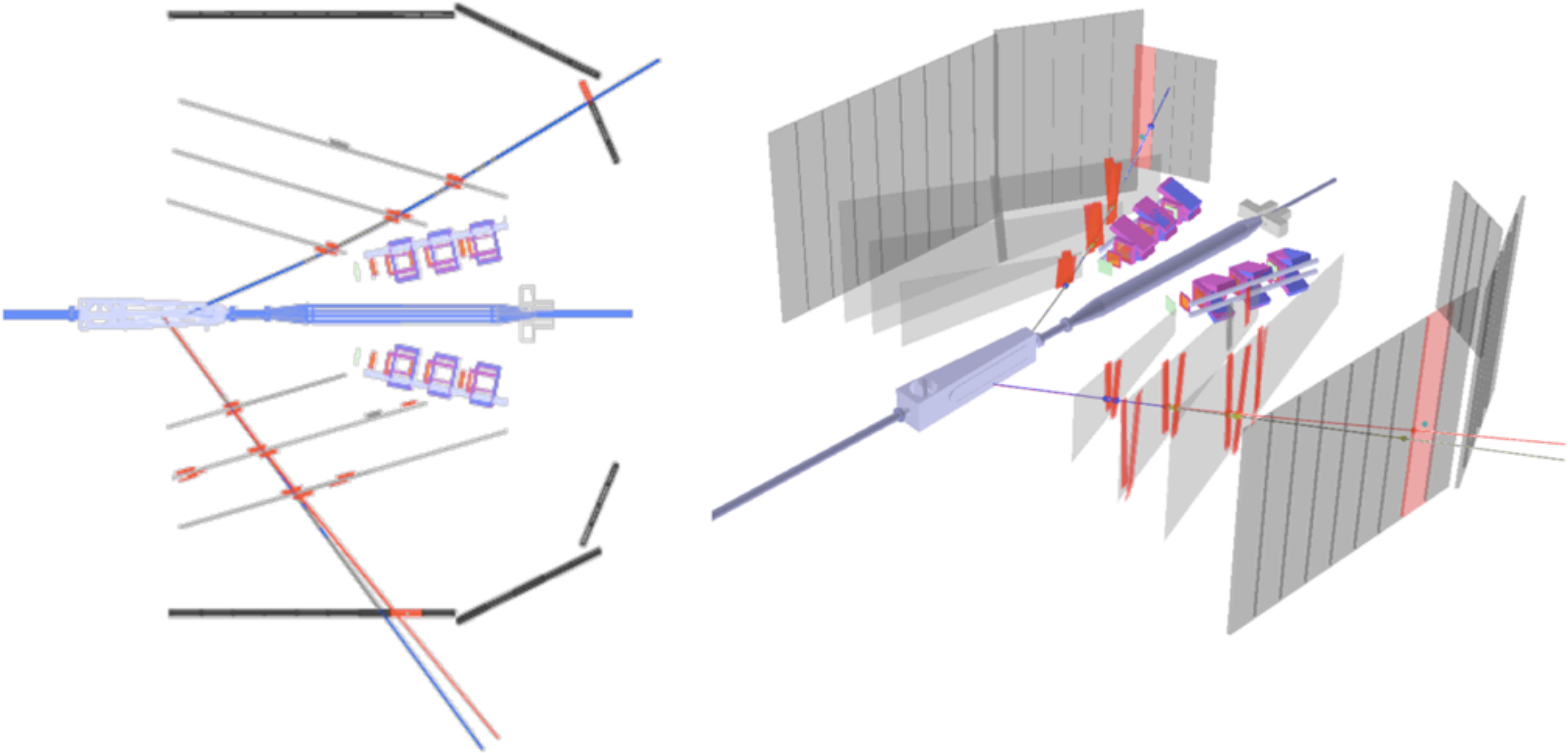
✓Smooth performance of machine, target, detector

Aiming at:

preliminary results: End of 2013

final results: Early summer 2014

Event display (3D)



Run 4975, event 78

Summary

✓The TPE hypothesis is suited to explains form factor discrepancy, however calculations of TPE are model-dependent

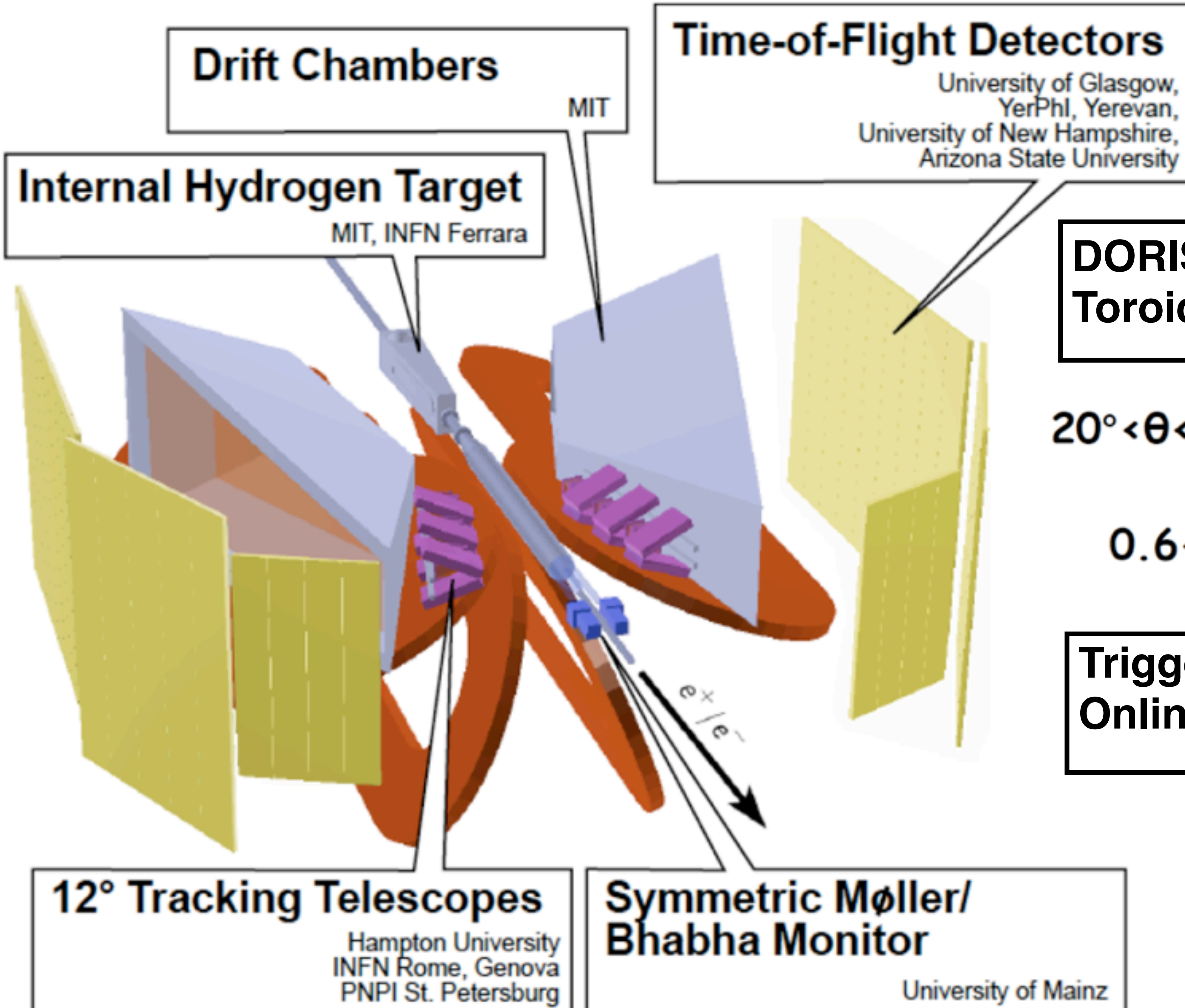
✓Experimental probes: Real part of TPE
- ✓ε-dependence of polarization transfer
- ✓ε-nonlinearity of cross sections
- ✓Comparison of positron and electron scattering

✓ Need both positron and electron beams for a definitive test of TPE

✓OLYMPUS prepared and commissioned at DESY/DORIS in 2010-2011
- ✓First running block in February 2012
- ✓Second running block October 24, 2012 - January 2, 2013
- ✓Will probe TPE to ~1% up to Q^2 ~2.2$(GeV/c)^2$ and ε~0.4

Backup

Olympus experiment



based on a figure by R. Russell

DORIS Upgrade, Toroid Support
DESY

$20^\circ < \theta < 80^\circ$ and $-15^\circ < \phi < 15^\circ$

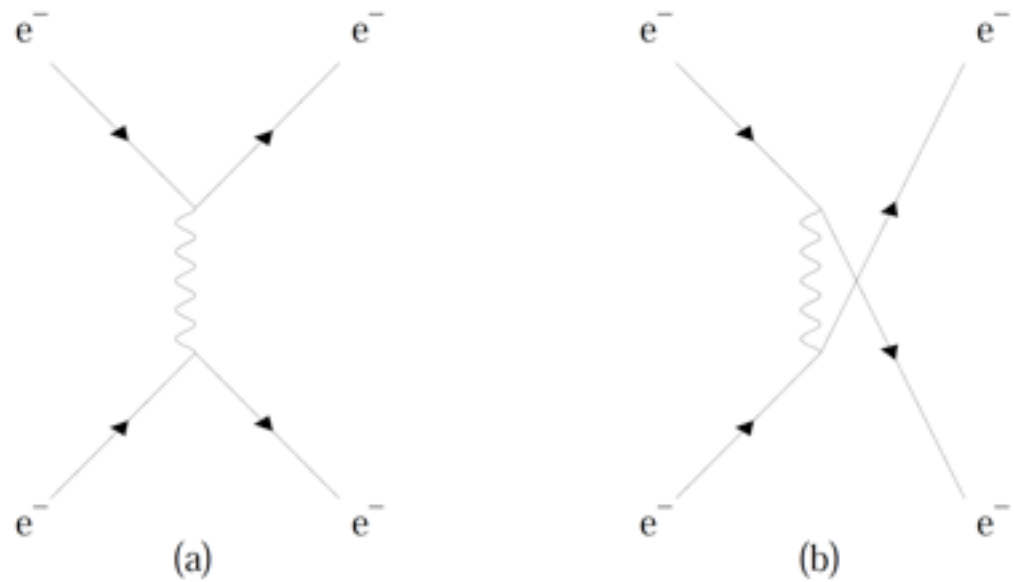
$0.37 < \varepsilon < 0.9$

$0.6 < Q^2 < 2.2 (GeV^2/c^2)$

Trigger, DAQ, Online-Monitor
University of Bonn

Møller process

Tree level diagrams are included without radiative correction



(a) scatter diagram
(b) interchange diagram

statistical factor

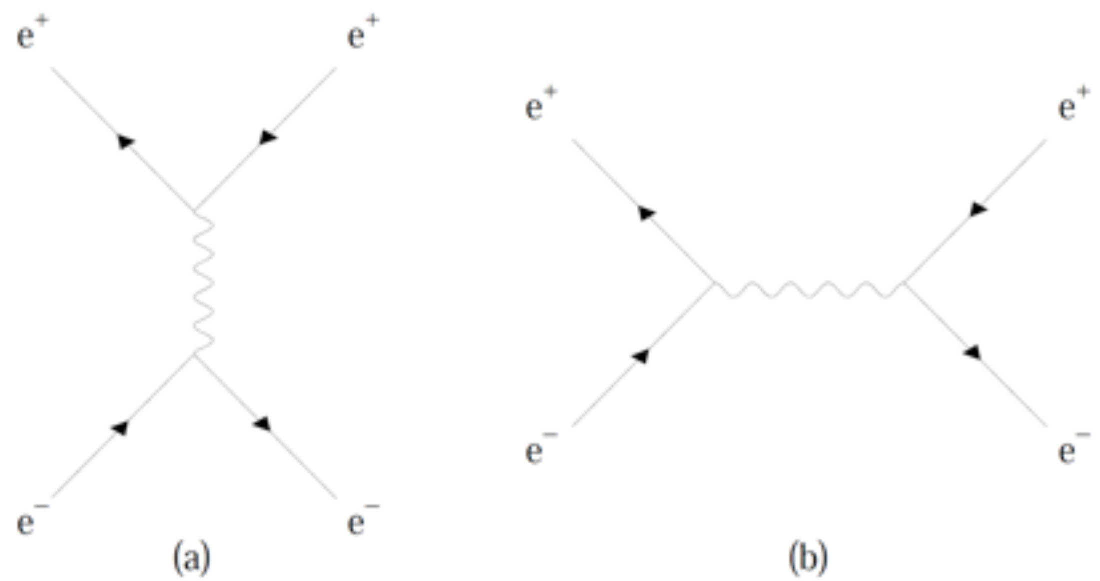
$$\frac{d\sigma}{d\omega} = \frac{2\pi\alpha^2}{s}\left(\frac{u^2+s^2}{t^2} + \frac{s^2+t^2}{u^2} + \frac{2s^2}{tu}\right) \times \frac{1}{2}$$

statistical factor is used to avoid twice counts

fine-structure constant $\alpha = e^2/4\pi\varepsilon_0\hbar c = 1/137.03599911$
conversion constant $(\hbar c)^2 = 0.389379323\,[GeV^2 mbar]$

Bhabha process

Tree level diagrams are included without radiative correction



(a) scatter diagram
(b) interchange diagram

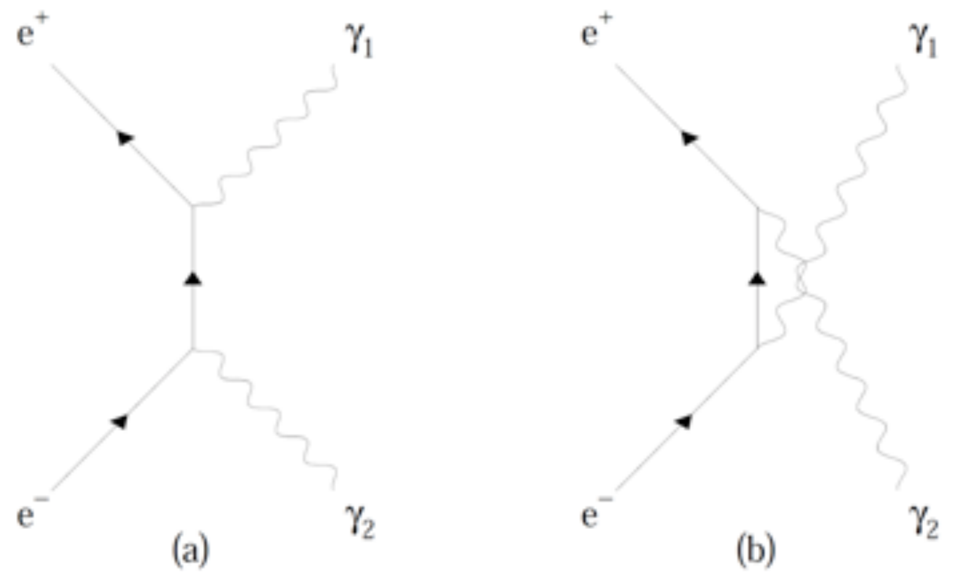
$$\frac{d\sigma}{d\omega} = \frac{2\pi\alpha^2}{s}\left(\frac{s^2+u^2}{t^2} + \frac{u^2+t^2}{s^2} + \frac{2u^2}{ts}\right)$$

The differential cross section for Bhabha case is the same as for Møller crossing s↔u

fine-structure constant $\alpha = e^2/4\pi\varepsilon_0\hbar c = 1/137.03599911$
conversion constant $(\hbar c)^2 = 0.389379323\,[GeV^2 mbar]$

Annihilation process

Tree level diagrams are included without radiative correction



(a) scatter diagram
(b) interchange diagram

statistical factor

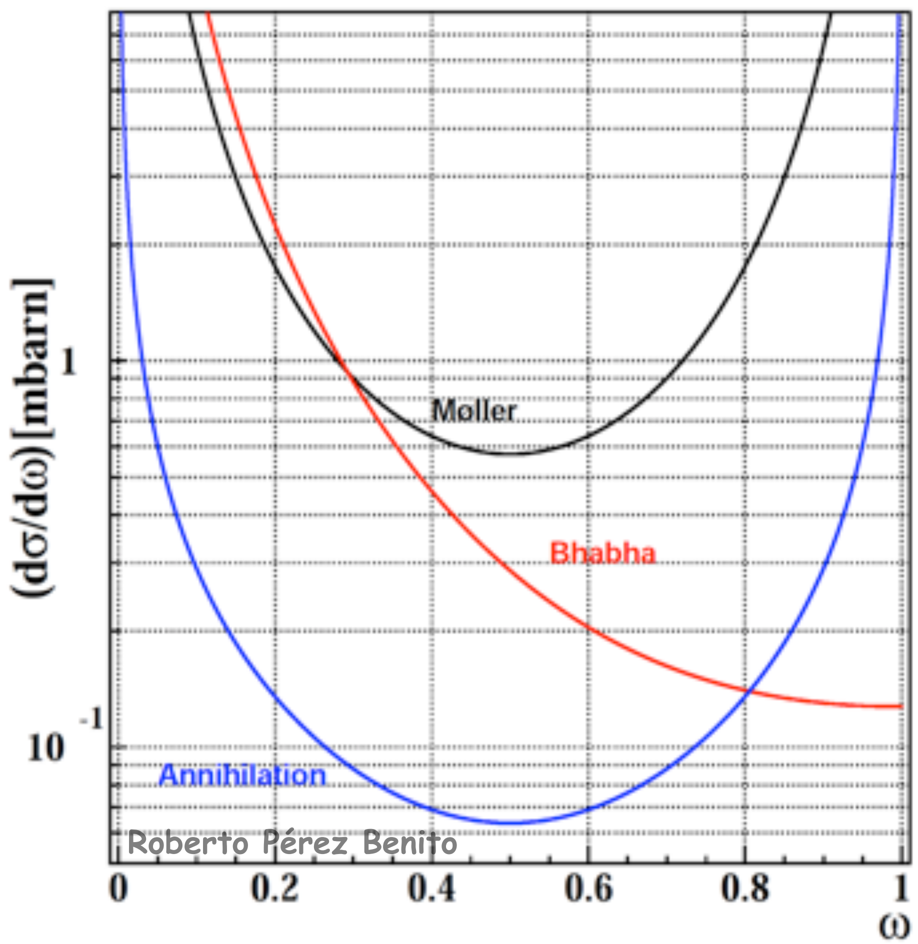
$$\frac{d\sigma}{d\omega} = \frac{2\pi\alpha^2}{s}\left(\frac{u}{t} + \frac{t}{u}\right) \qquad \times\frac{1}{2}$$

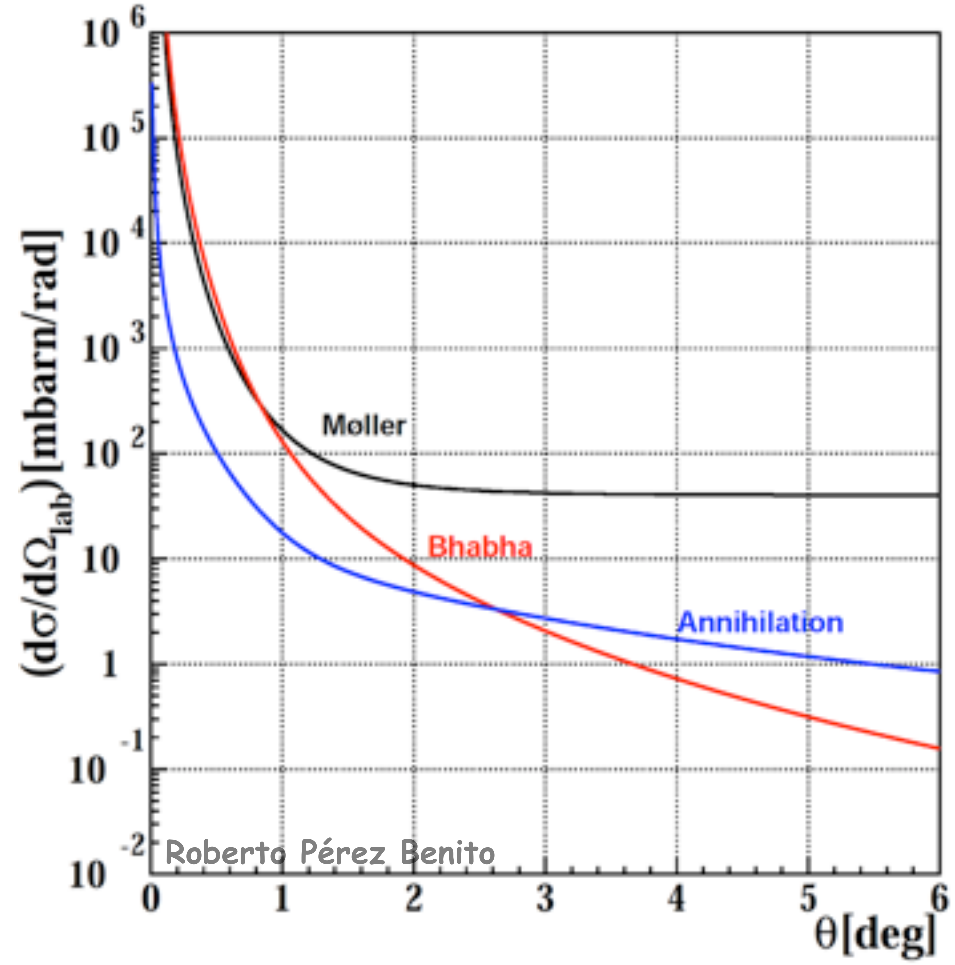
statistical factor is used to avoid twice counts

fine-structure constant $\alpha = e^2/4\pi\varepsilon_0\hbar c = 1/137.03599911$

conversion constant $(\hbar c)^2 = 0.389379323\,[GeV^2 mbar]$

Expected differential cross section





for the ideal detectors position and ideal beam position and slope (x=y=x'=y'=0)

expected differential cross section

$$\left.\frac{d\sigma}{d\Omega_{lab}}\right|_{M\o ller} = \frac{1}{2\pi\sin\theta}\cdot\frac{2\pi\alpha^2}{s}\left(\frac{u^2+s^2}{t^2}+\frac{s^2+t^2}{u^2}+\frac{2s^2}{tu}\right)\cdot(\hbar c)^2\cdot\frac{\frac{E}{m}\sin\theta}{\left[1+\frac{E}{m}(1-\cos\theta)\right]^2}\cdot\frac{1}{2}$$

178.78 mbarn/sr

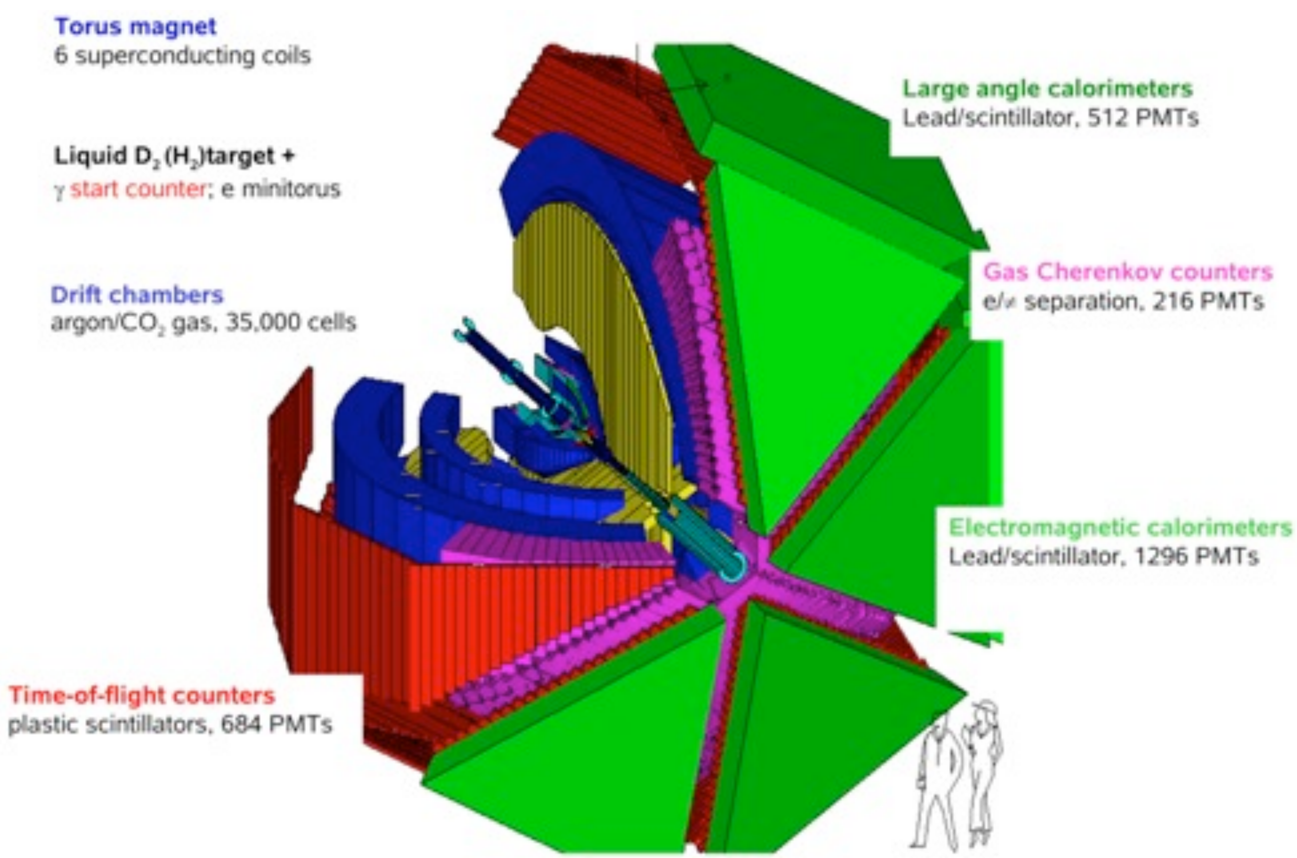
$$\left.\frac{d\sigma}{d\Omega_{lab}}\right|_{Bhabha} = \frac{1}{2\pi\sin\theta}\cdot\frac{2\pi\alpha^2}{s}\left(\frac{s^2+u^2}{t^2}+\frac{u^2+t^2}{s^2}+\frac{2u^2}{ts}\right)\cdot(\hbar c)^2\cdot\frac{\frac{E}{m}\sin\theta}{\left[1+\frac{E}{m}(1-\cos\theta)\right]^2}$$

89.34 mbarn/sr

$$\left.\frac{d\sigma}{d\Omega_{lab}}\right|_{Annihilation} = \frac{1}{2\pi\sin\theta}\cdot\frac{2\pi\alpha^2}{s}\left(\frac{u}{t}+\frac{t}{u}\right)\cdot(\hbar c)^2\cdot\frac{\frac{E}{m}\sin\theta}{\left[1+\frac{E}{m}(1-\cos\theta)\right]^2}\cdot\frac{1}{2}$$

19.84 mbarn/sr

CLAS TPE experiment
Jefferson Laboratory Newport New VA, USA
preliminary results: arXiv:1306.2286



Large lepton scattering angle (small ε)
Azimuthal (φ) acceptance > 67%
Scattering angles 45° < θ < 130°

Small lepton scattering angles (large ε)
Proton detected at larger angles (60° < θp < 90°)

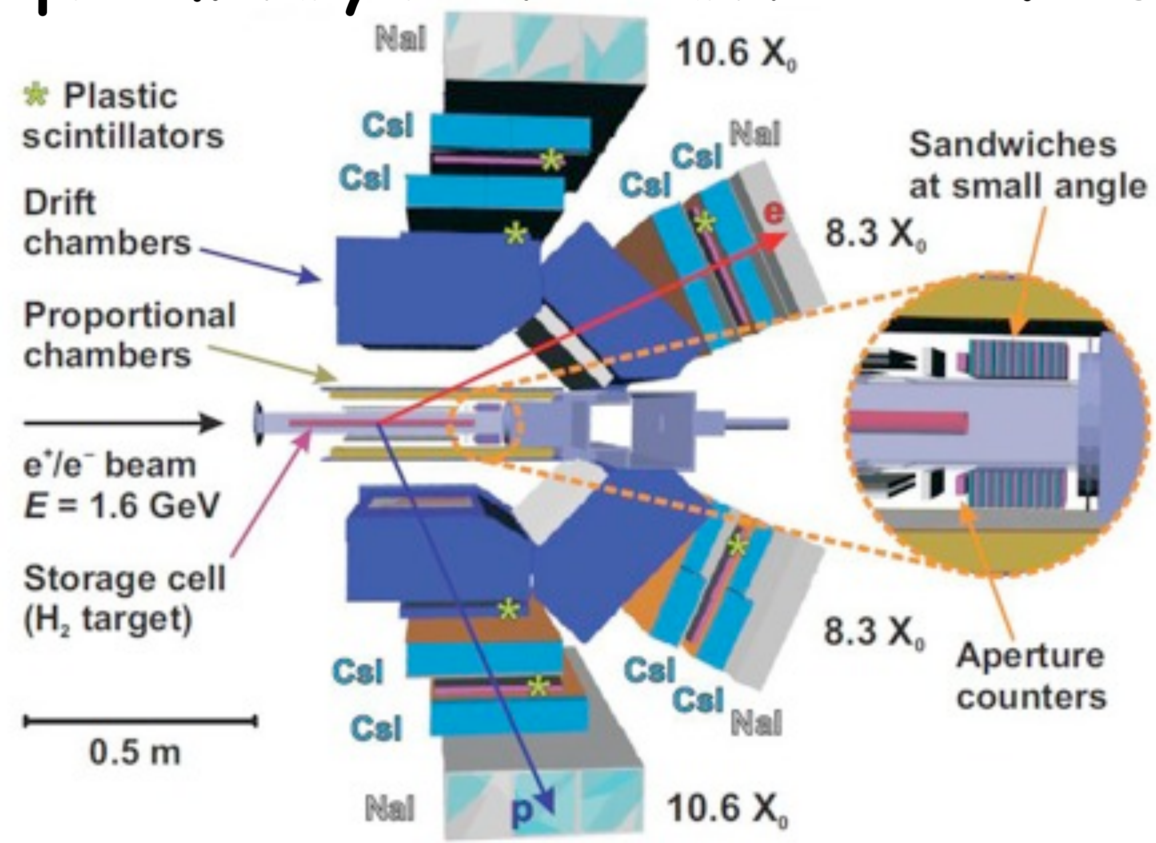
Cut on -20° < φp < 20° in each sector
Proton acceptances identical for the two field polarities.

Primary electron beam: 5.5 GeV and 100 nA

$0.2 \leq Q^2 \leq 2.0$ (GeV/c)^2
$0.1 < \varepsilon < 0.96$

No accurate measure of luminosity ~2.5x10^{32} cm^{-2}s^{-1}
for electron and positron separately (Simulation).

VEPP-3 storage ring
Novosibirsk, Russia
preliminary results: arXiv:1112.5369



Alternation of electron and positron beams
suppress effects of drift in time,
the target thickness and detection efficiency

Lepton scattering angle around 10°, 18° and 64°.
The small angle region is used for
the luminosity monitoring

Electron/positron beam at 1.6 GeV and 140 mA

$0.05 \leq Q^2 \leq 1.32$ (GeV/c)^2
$0.55 < \varepsilon < 0.99$

1500 hours with a mean luminosity of 5x10^{31} s^{-1}.cm^{-2}