OLYMPUS

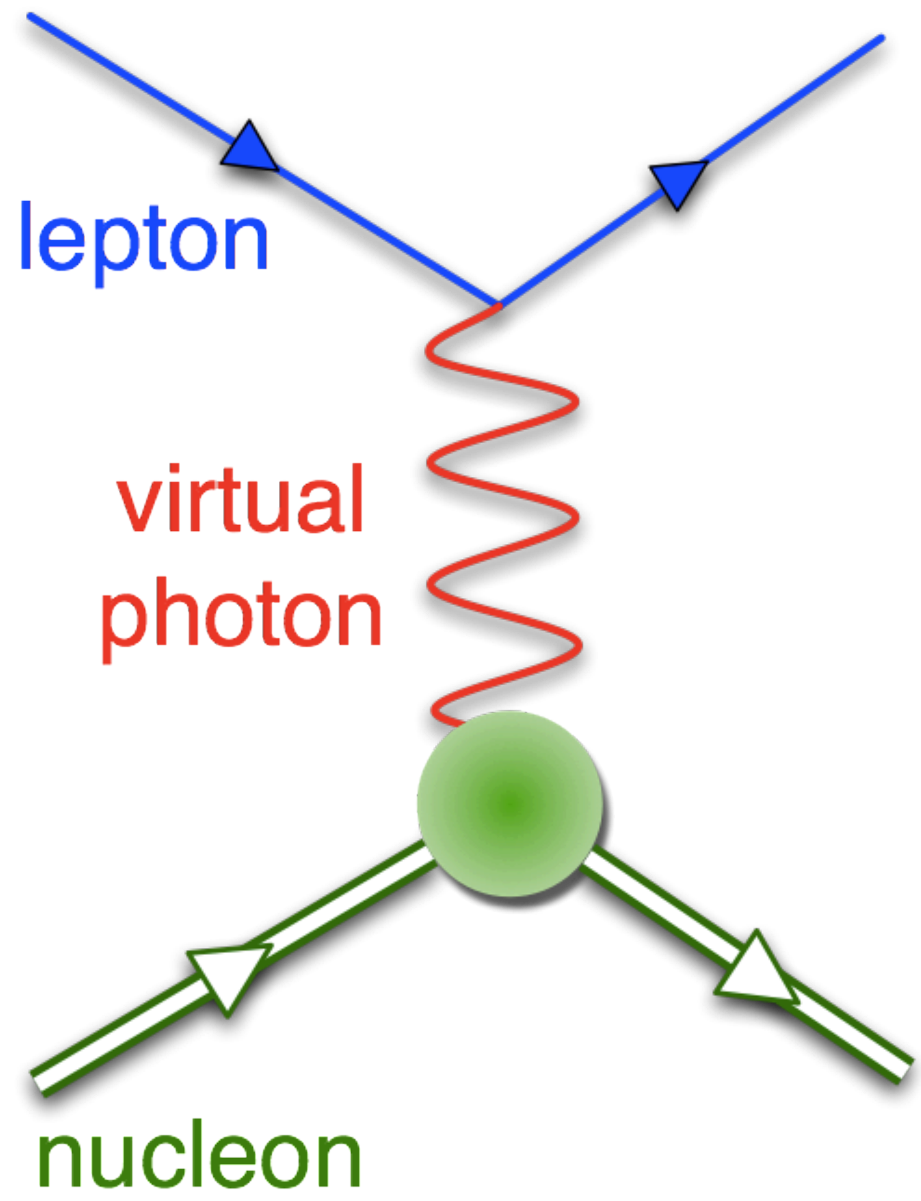
An Experiment to Determine the Two-Photon Contribution to Elastic Lepton-Proton Scattering

Nucleon Form Factor

One photon exchange approximation

$$\langle N(P')|J^{\mu}_{EM}(0)|N(P)\rangle =$$

$$\bar{u}(P')\left[\gamma^{\mu}F_1^N(Q^2) + i\sigma^{\mu\nu}q_{\nu}\frac{\kappa}{2M}F_2^N(Q^2)\right]u(P)$$



Electric and magnetic form factors

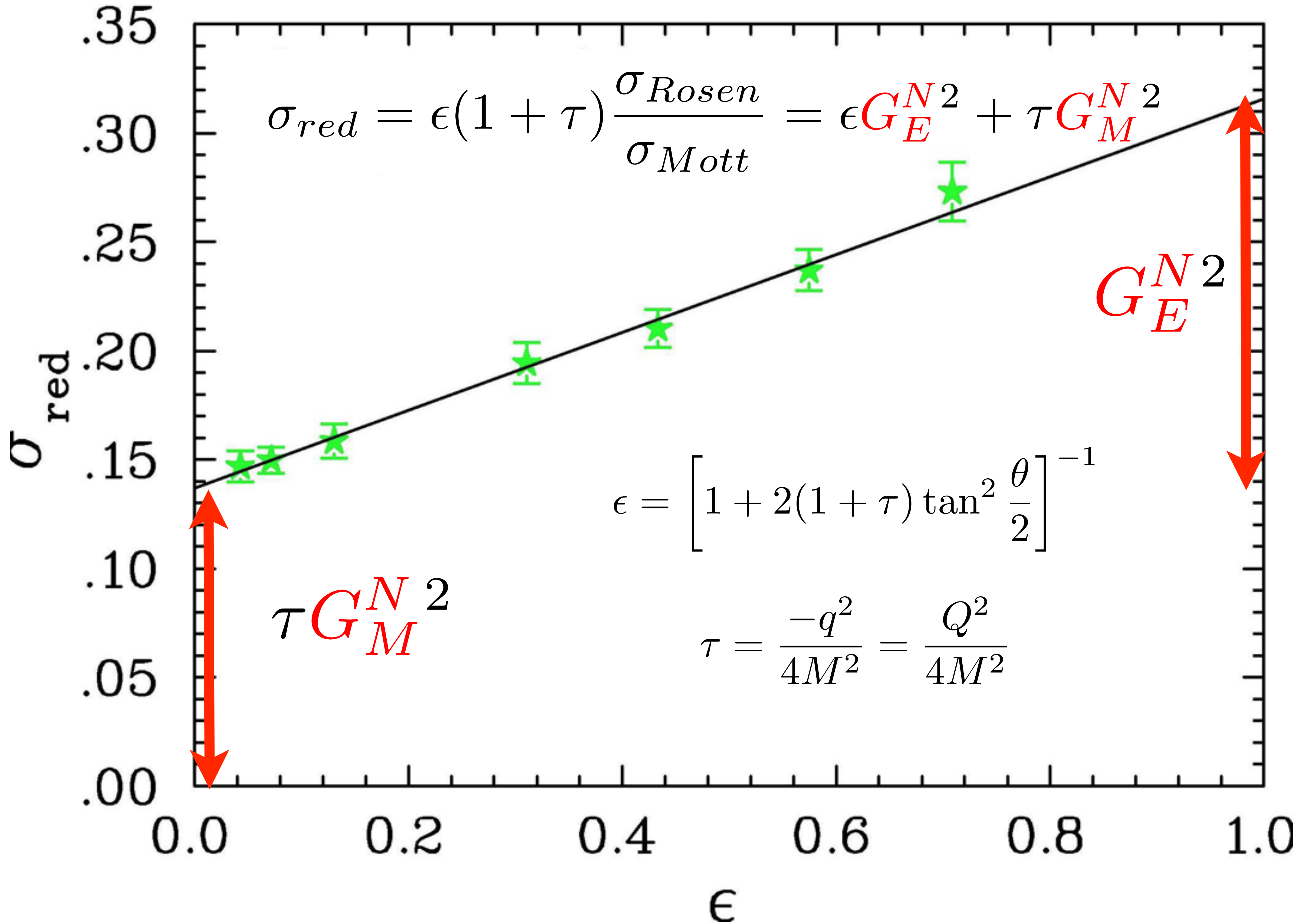
$$G_E^N = F_1^N - \tau\kappa F_2^N; \qquad G_M^N = F_1^N + \kappa F_2^N$$

Rosenbluth cross section

$$\left(\frac{d\sigma}{d\Omega}\right)_{Mott}\left[\left(\frac{{G_E^N}^2 + \tau {G_M^N}^2}{1+\tau}\right) + 2\tau {G_M^N}^2 \tan^2\frac{\theta}{2}\right]$$

$$G_E^p \approx \frac{1}{\mu_p}G_M^p \approx \frac{1}{\mu_n}G_M^n \approx G_D \sim \left(1 + \frac{Q^2}{0.71}\right)^{-2} \quad \leftrightarrow \quad \rho_D(r) = \rho_0 e^{-\sqrt{0.71}r}$$

Rosenbluth Separation

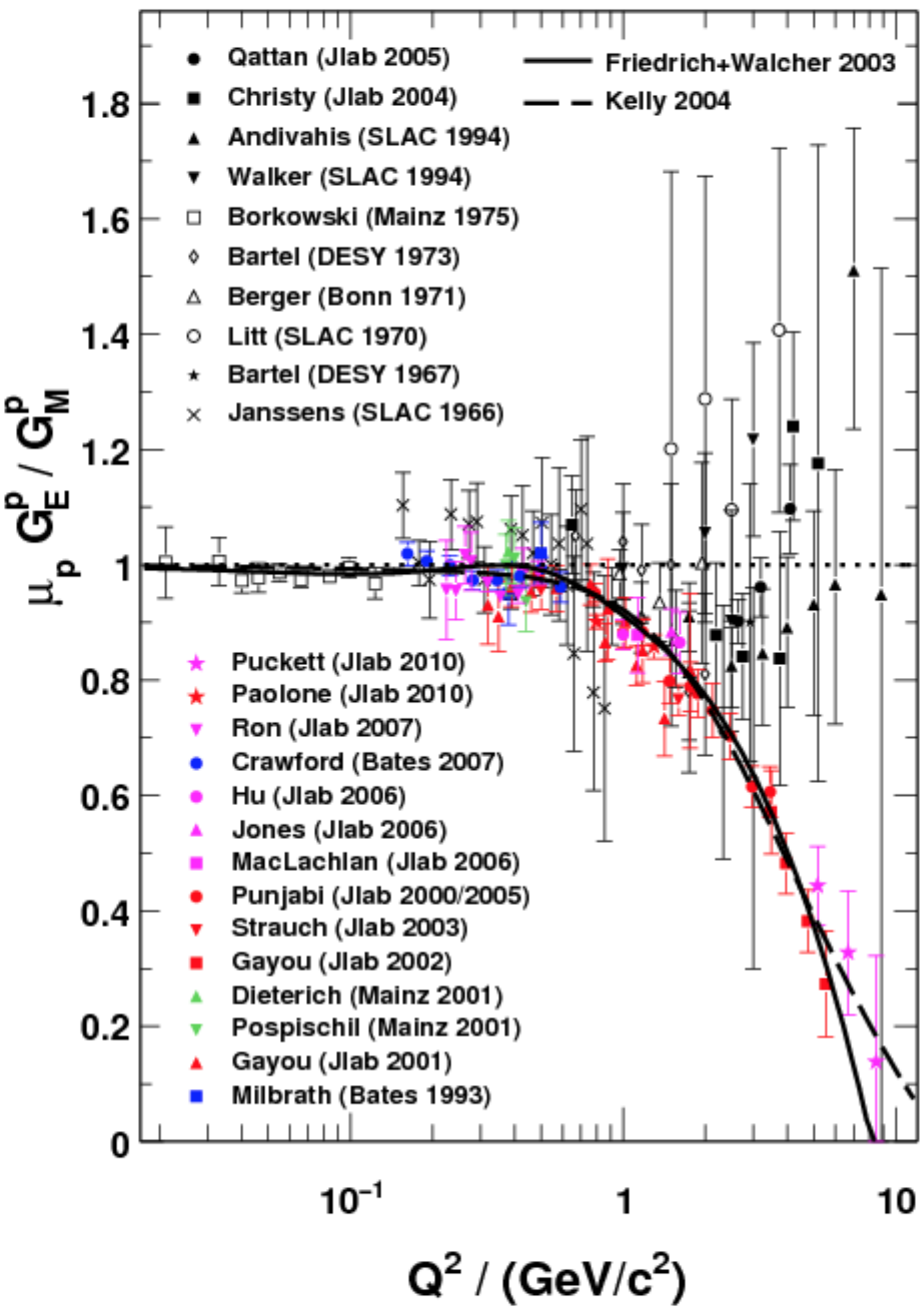


$$\sigma_{red} = \epsilon(1+\tau)\frac{\sigma_{Rosen}}{\sigma_{Mott}} = \epsilon G_E^{N\,2} + \tau G_M^{N\,2}$$

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

$$\tau = \frac{-q^2}{4M^2} = \frac{Q^2}{4M^2}$$

Form Factor Ratio - $\mu_p G_E / G_M$



At low Q^2 simple model okay

- form factor ratio ≈ 1
- dipole shape for G_E and G_M

At high Q^2

- unpolarized results looked okay
  - but were not okay
- Rosenbluth separation difficult
  - cross sections dominated by G_M
  - insensitive to G_E
  - reflected in spread and error bars

Polarized beams and targets

- direct measure of ratio
- striking discrepancy
- Rosenbluth and polarization measurements since confirmed

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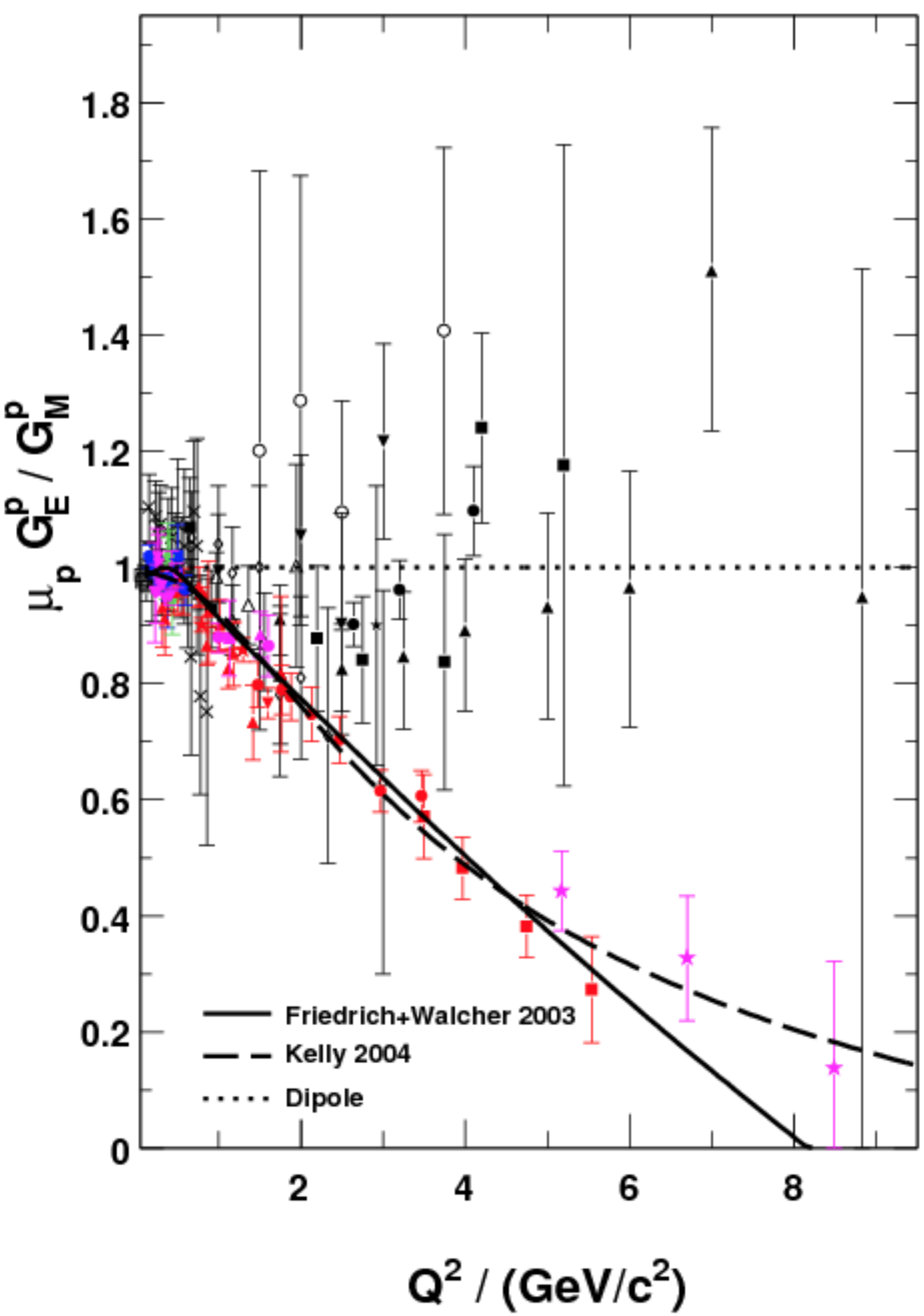

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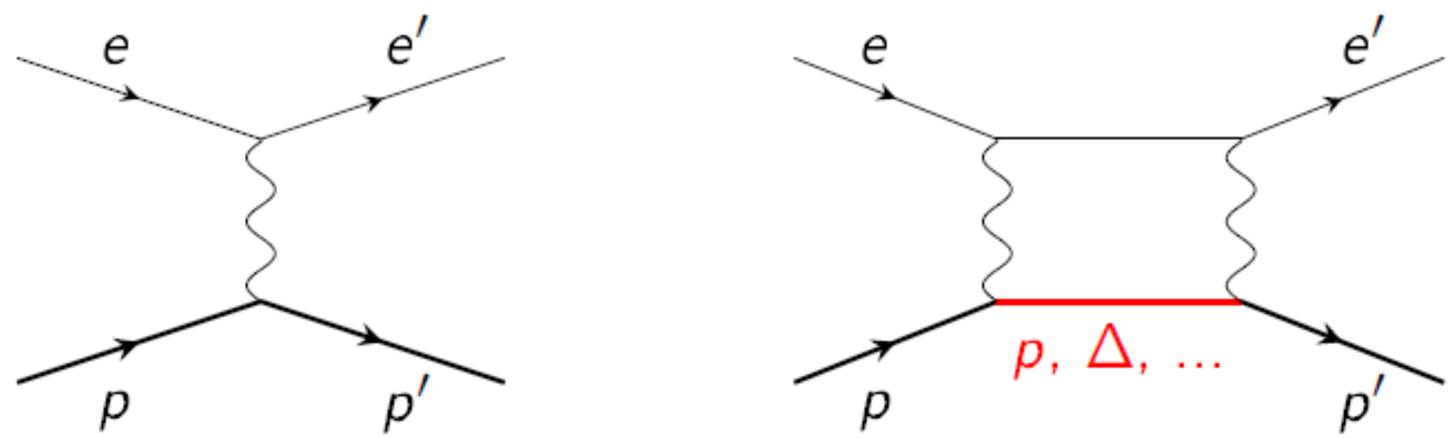
2 Photon Exchange Explanation

Previously dismissed ?

- small effect

Radiative correction ?

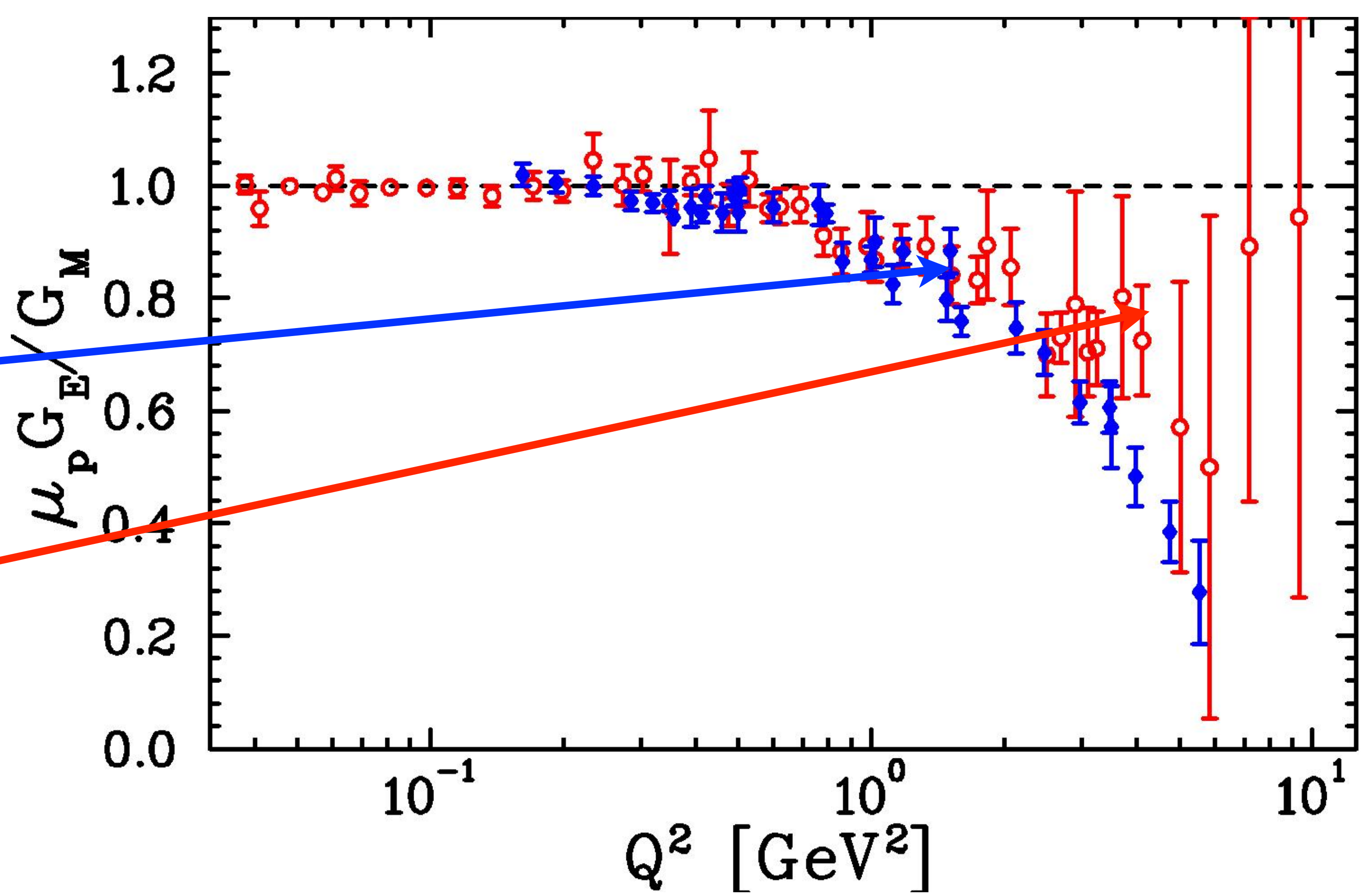
- already included
- difficult to calculate



$$\sigma(e^{\pm}p) \propto |M_{1\gamma}|^2\alpha^2 \pm 2|M_{1\gamma}||M_{2\gamma}|\alpha^3 + \ldots$$

Recent calculations may resolve the discrepancy

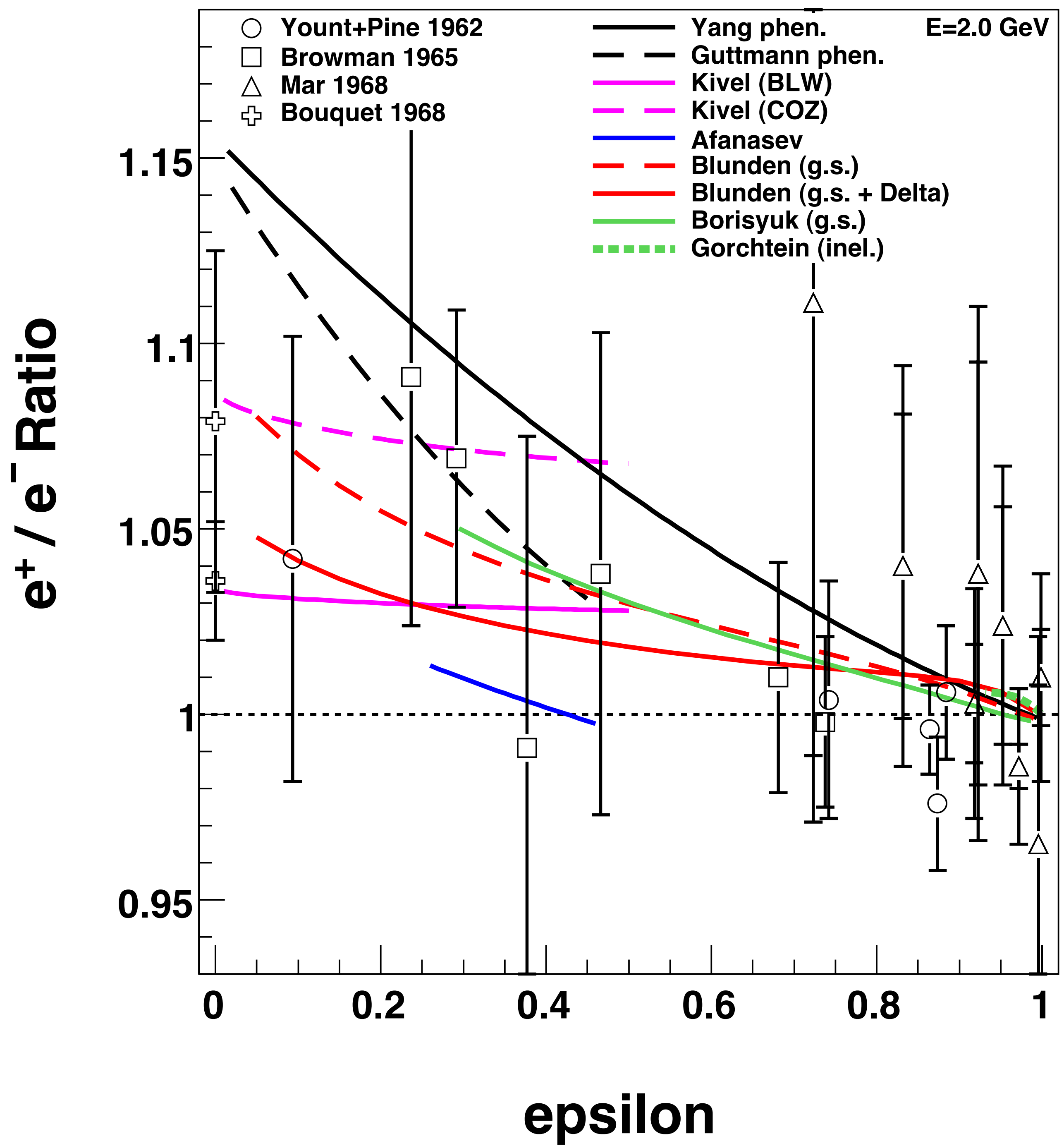
- polarization transfer measurements
- unpolarized Rosenbluth data corrected for two photon exchange



Wednesday, April 10, 13

Definitive Measure of Multi-Photon Effect

$$\sigma(e^{\pm}p) \propto |M_{1\gamma}|^2\alpha^2 \pm 2|M_{1\gamma}||M_{2\gamma}|\alpha^3 + \ldots$$



Measure ratio e^+p / e^-p

- interference term changes sign under $e^- \Leftrightarrow e^+$

Existing data inconclusive

- low Q^2
- large error bars

Range of theoretical results

- large variation in effect
- lack constraint of precise data

Need a definitive experiment

Definitive Measure of Multi-Photon Effect

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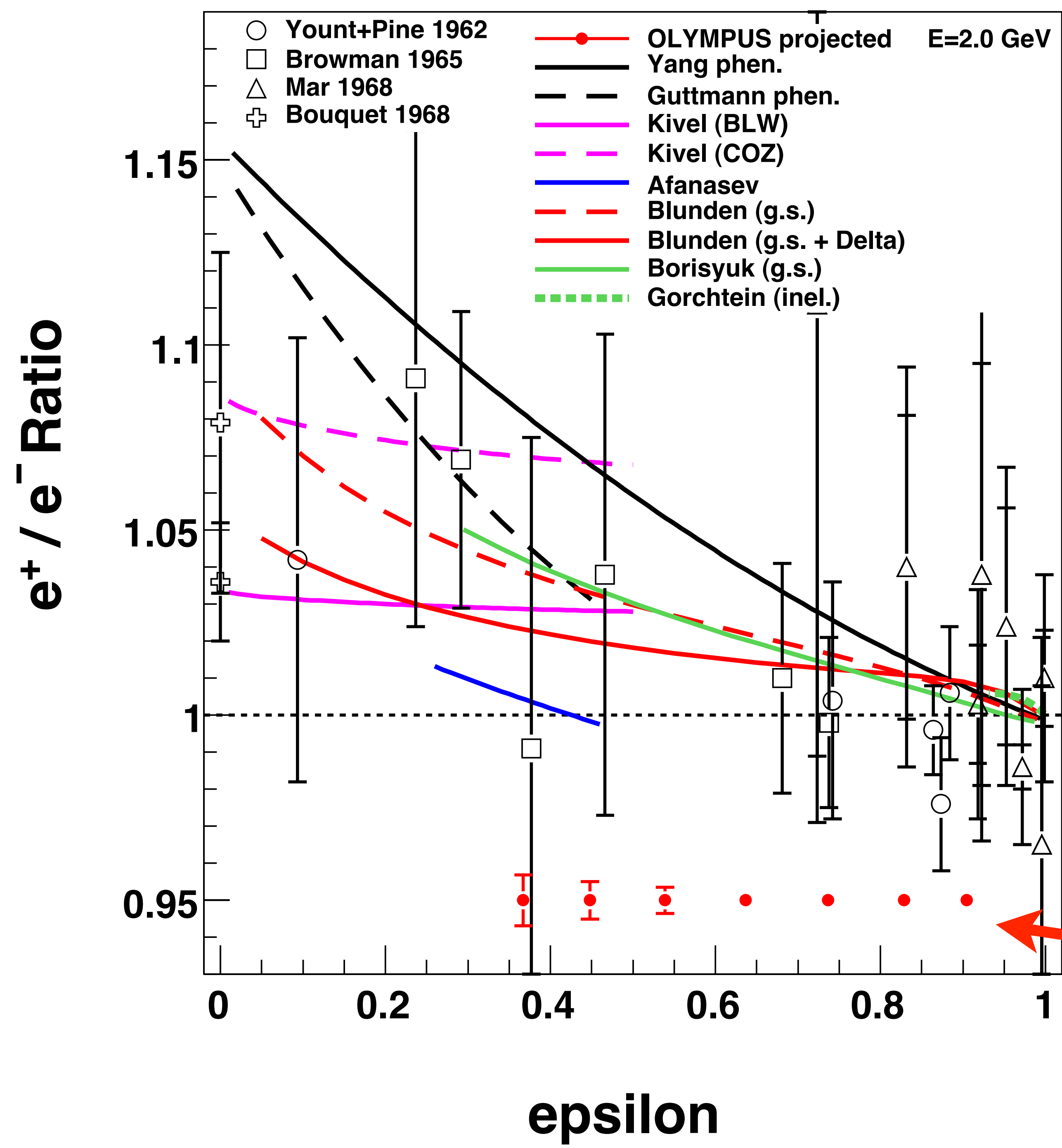

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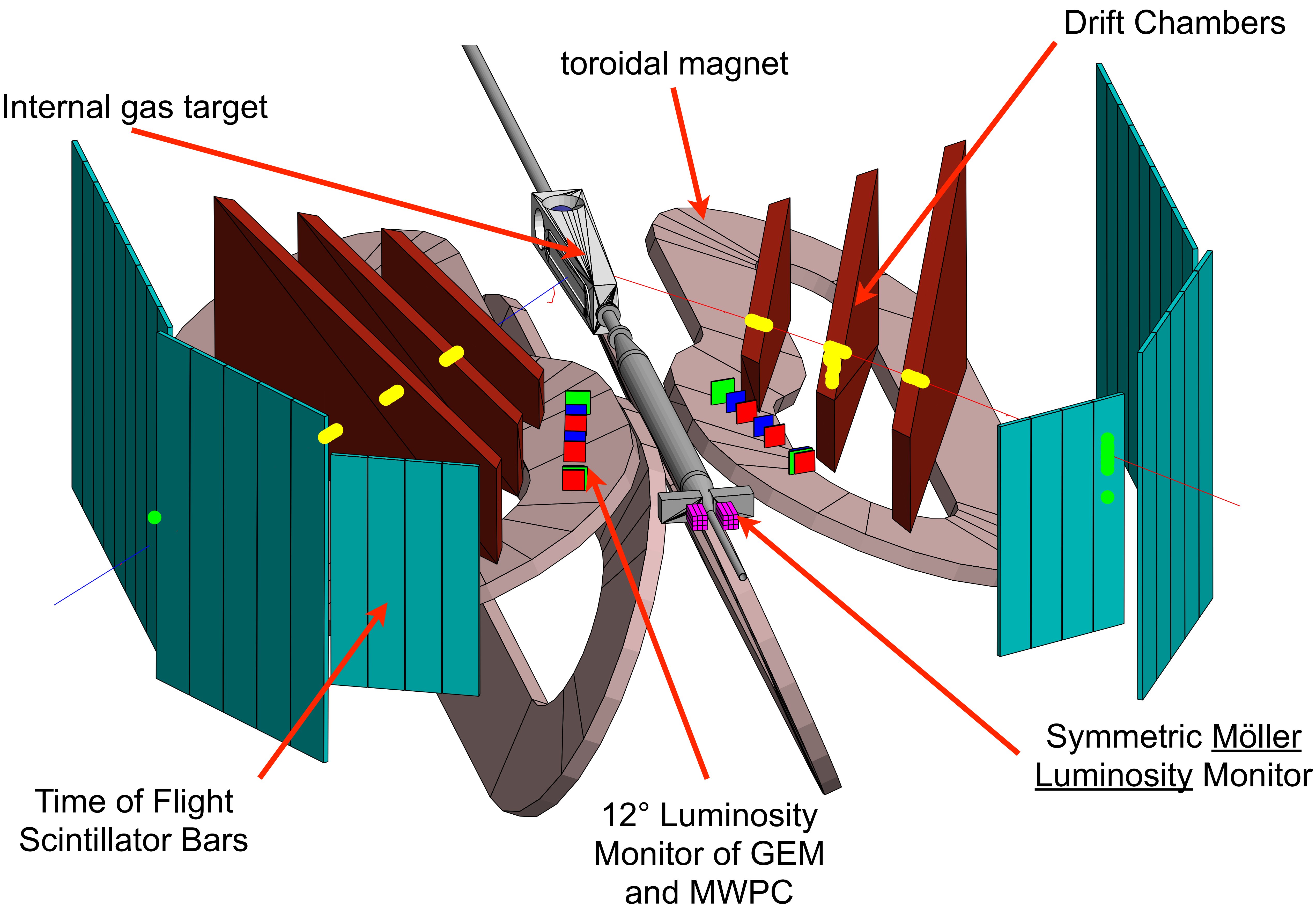
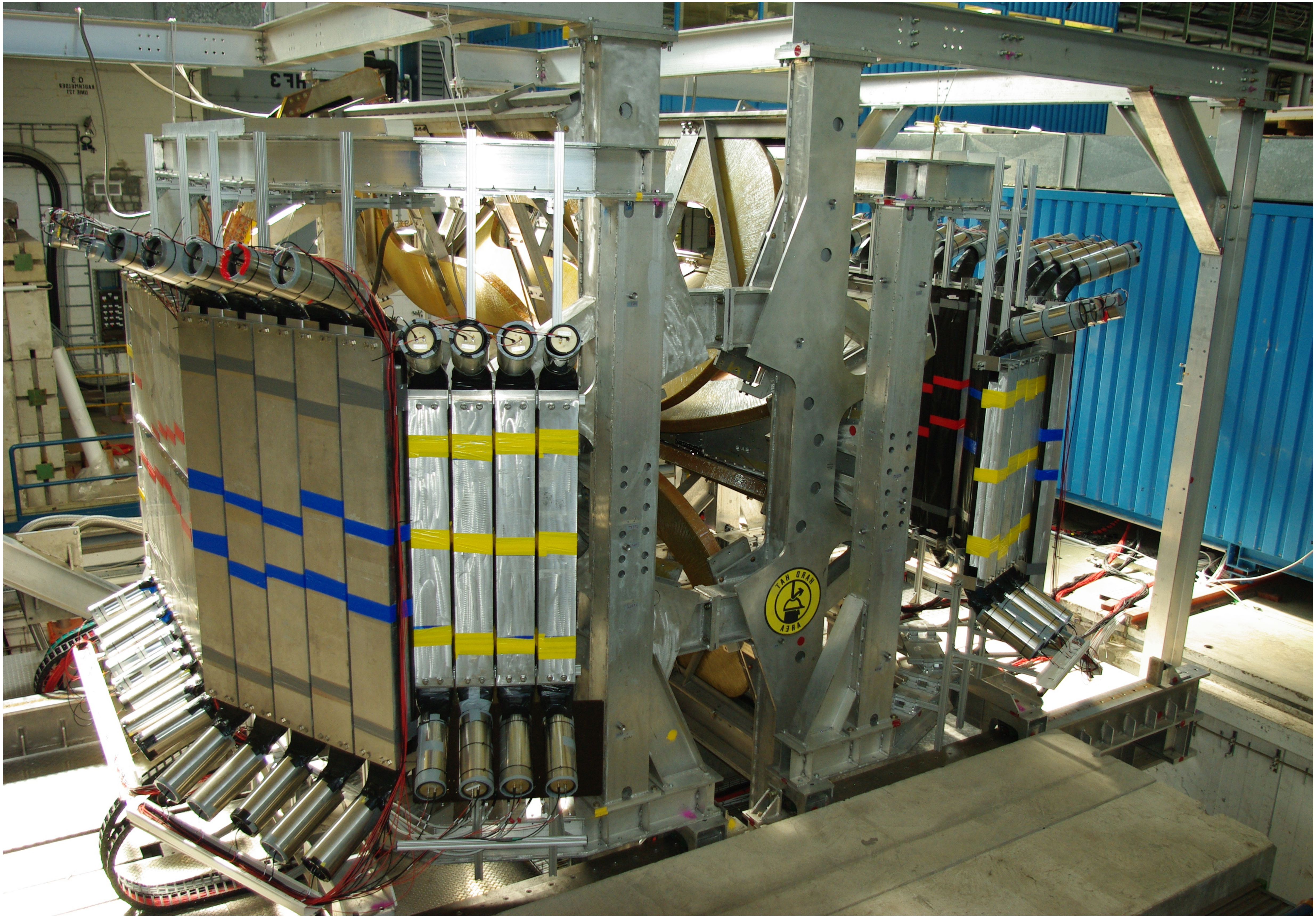
OLYMPUS Detector



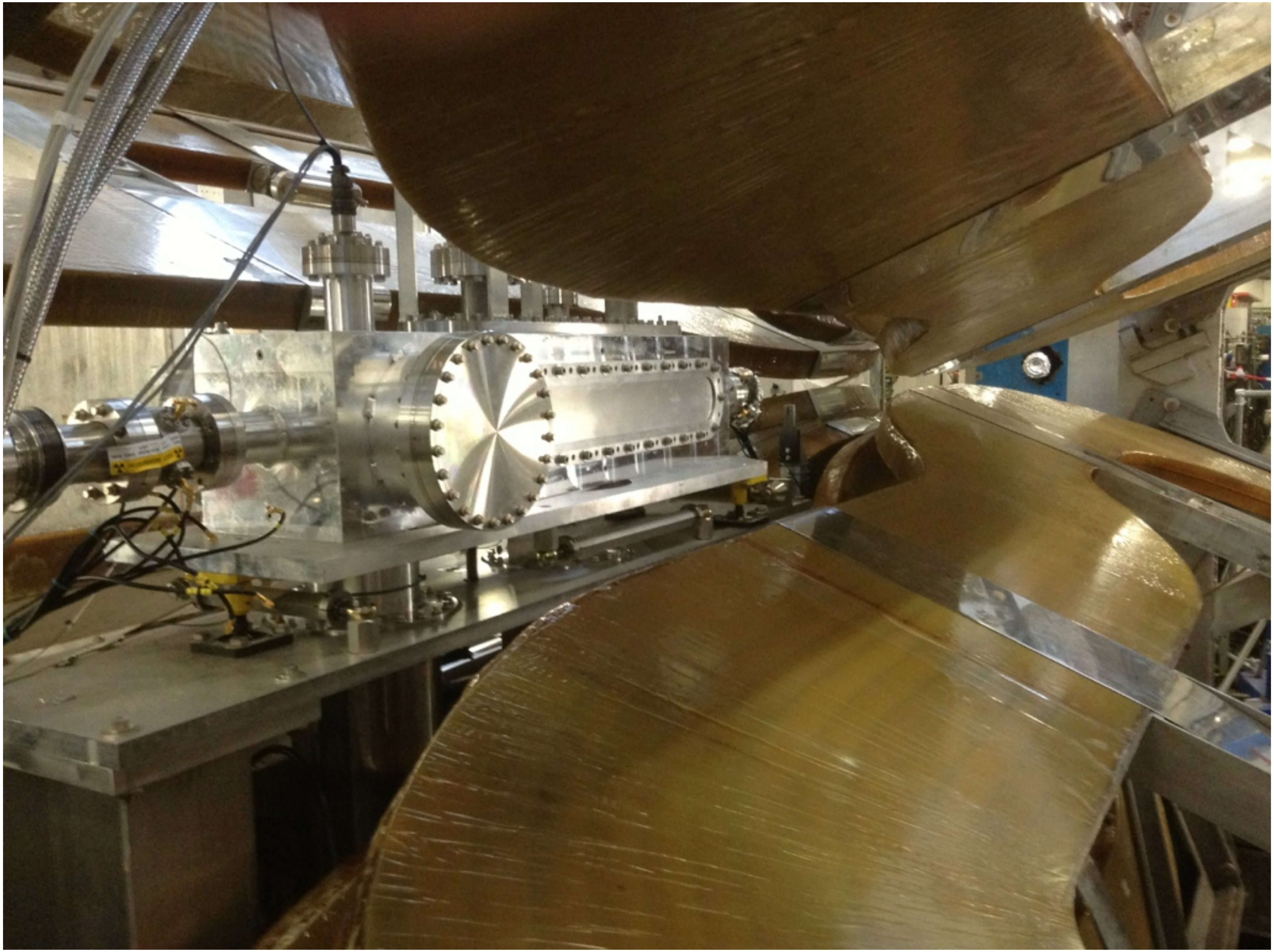
OLYMPUS Detector



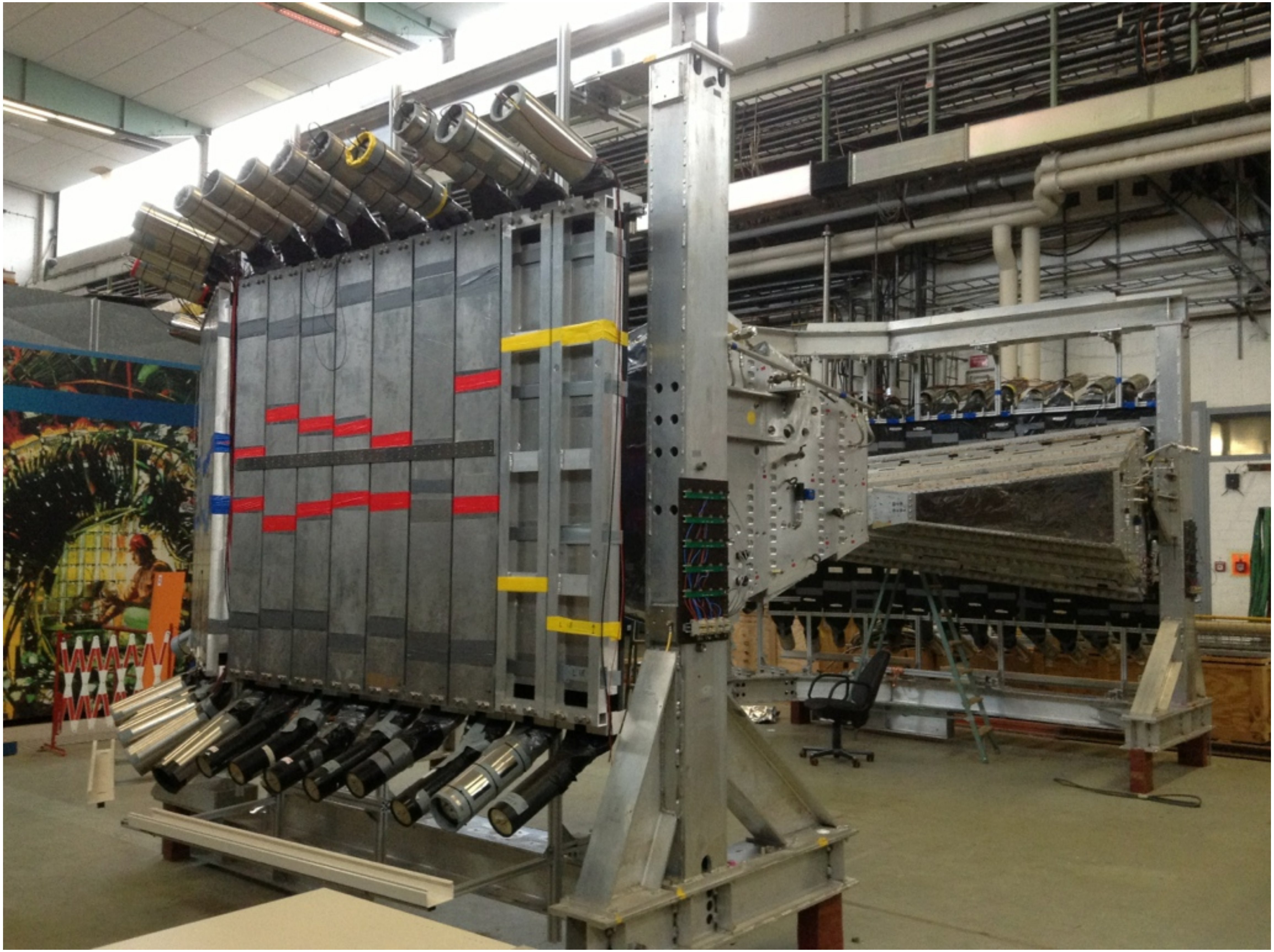
OLYMPUS Toroid Magnet

OLYMPUS Target Cell

OLYMPUS Scattering Chamber



OLYMPUS Wire Chamber and TOF



Experiment as Originally Proposed

3×10^{15} atoms/cm^2 target density

100 mA electron and positron beams

Change beam species and reverse toroid polarity daily

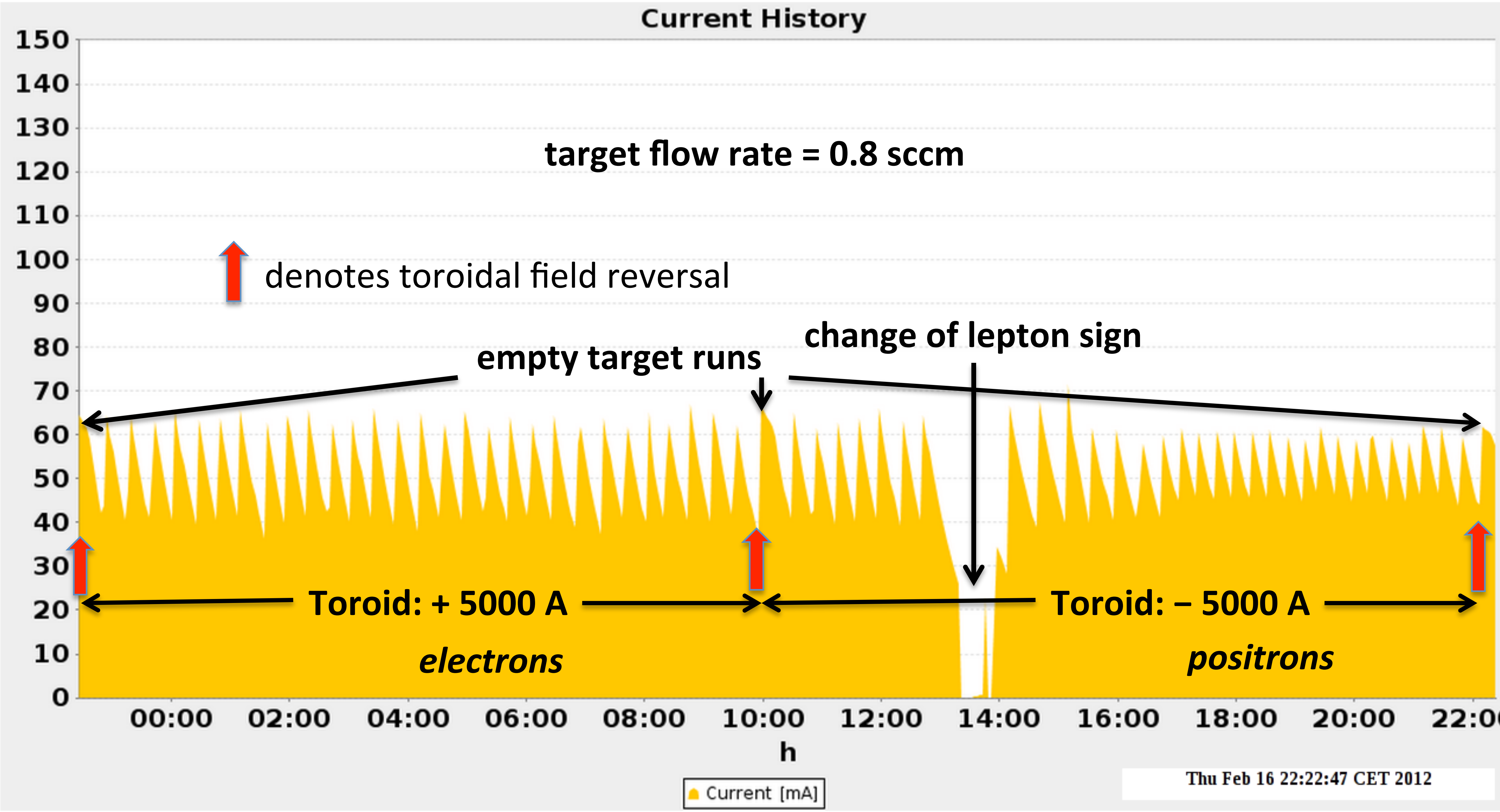
500 hours of e^+ and e^- ⇒ 3.6 fb^{-1} integrated luminosity

$$N_{e^\pm\pm} = L_{e^\pm\pm}\sigma_{e^\pm}\kappa^p_{e^\pm\pm}\kappa^l_{e^\pm\pm}$$

$$\kappa^p_{e^+\pm} \approx \kappa^p_{e^-\pm} \qquad \kappa^l_{e^++} \approx \kappa^l_{e^--} \qquad \kappa^l_{e^+-} \approx \kappa^l_{e^-+}$$

$$\frac{N_{e^++}/L_{e^++}}{N_{e^-+}/L_{e^-+}} \cdot \frac{N_{e^+-}/L_{e^+-}}{N_{e^--}/L_{e^--}} = \left(\frac{\sigma_{e^+}}{\sigma_{e^-}}\right)^2$$

OLYMPUS - February, 2012 Data Run



Experience in February Data Period

DORIS ran very smoothly

- but we could only handle ~50 mA
- limited by deadtime in the data acquisition system

Target density only ~5×10^{14} atoms/cm^2

- able to flow more gas than expected
- limit determined by beam lifetime
- leak in gas system inside scattering chamber before target cell
  - realized after February run
  - large discrepancy between measured luminosity and expectation from beam current and gas flow

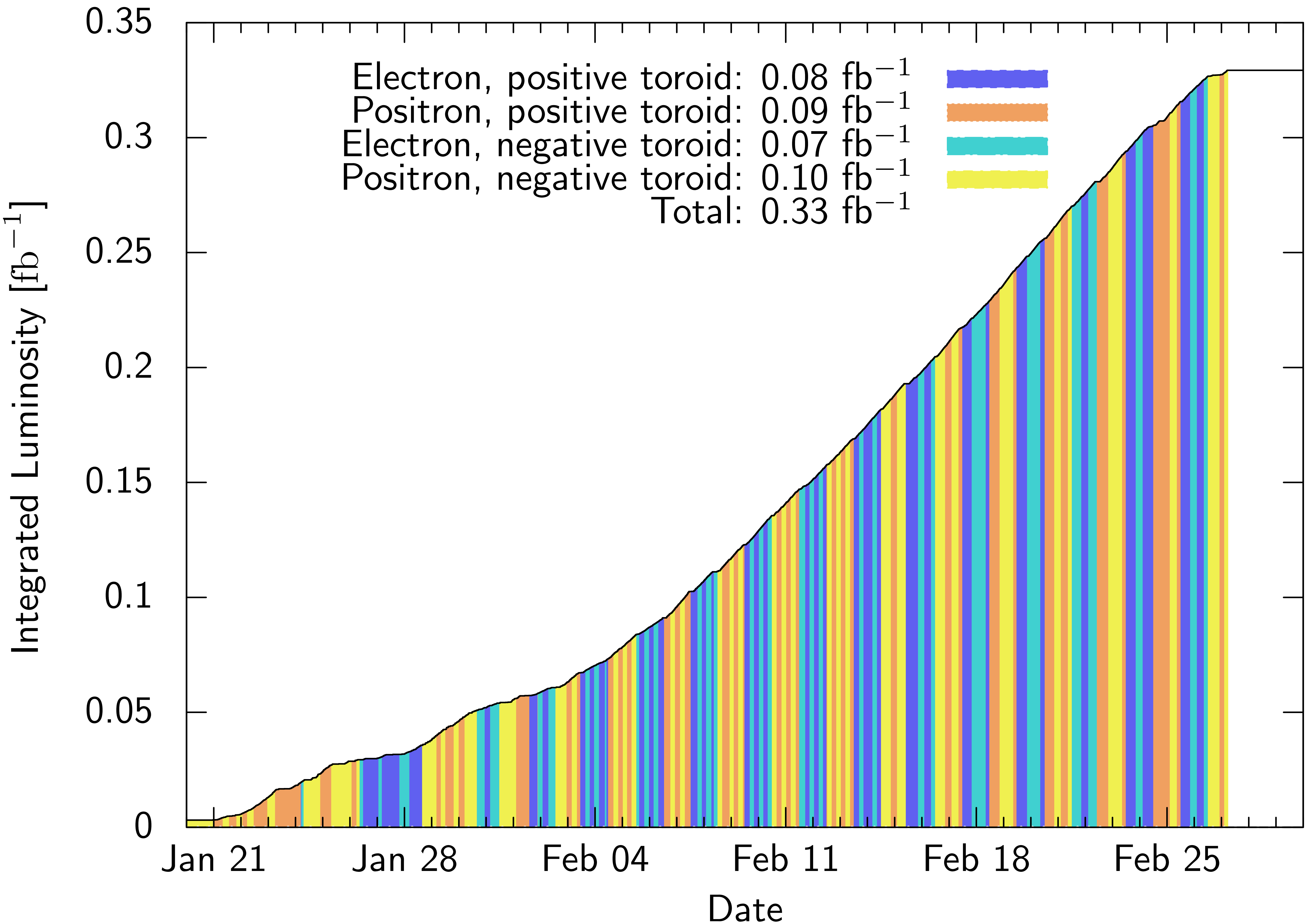
However, data collection efficiency higher than design

- planned for 50% but achieved 80%
- through efficiency of DAQ and slow control systems

February run luminosity collected less than design

- approximately 1/10 of design

Luminosity - February, 2012



October - December, 2012 Data Run

After February run

- repaired leak in target cell
- implemented second level trigger to reduce deadtime
- pursued top-up mode with DORIS
- repaired bad channels in wire chamber
- improved trigger scintillators for 12° detectors
- modified DAQ to run continuously even during injection

Exceeded design luminosity, made up February losses

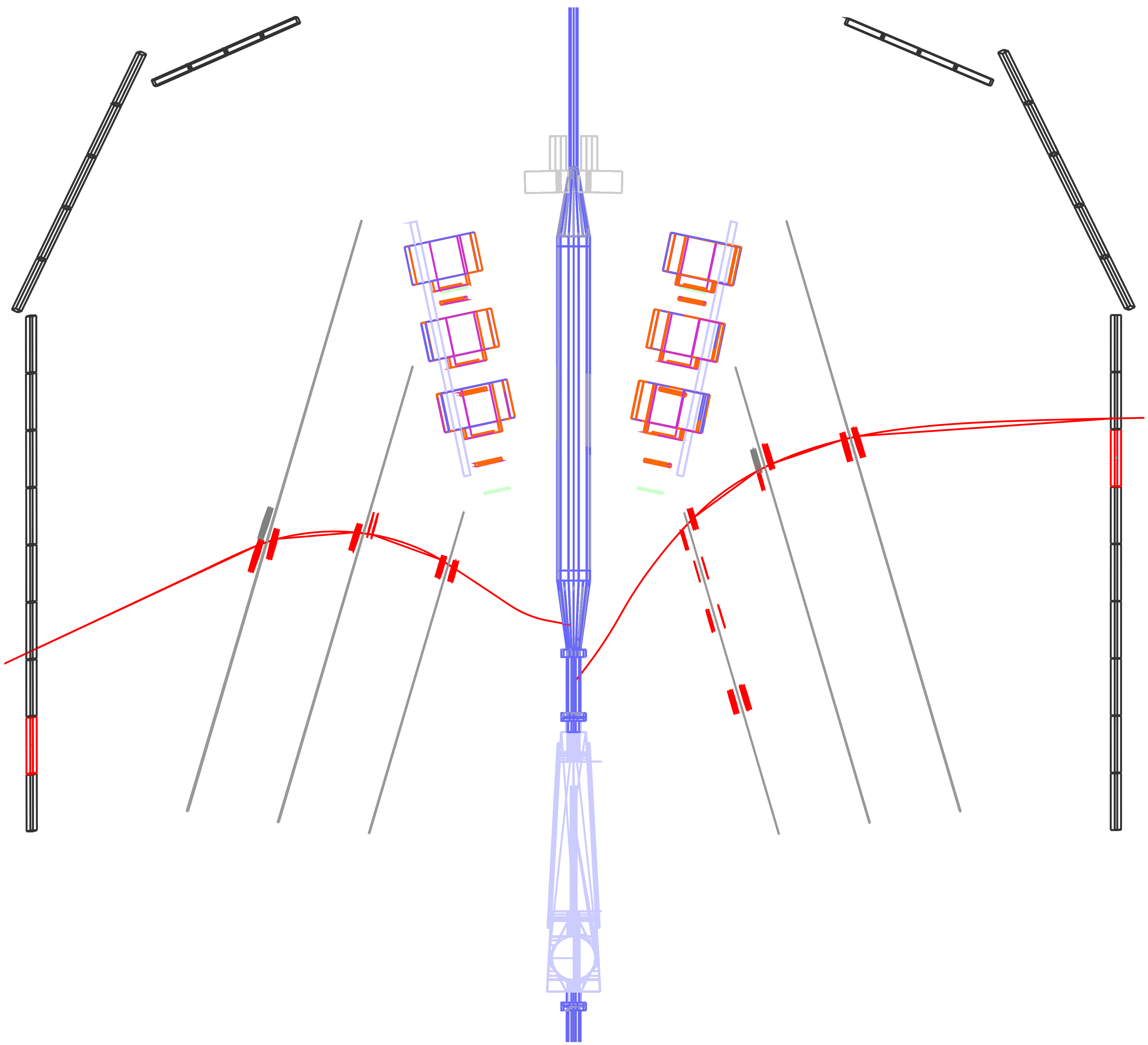
BUT - could not run with negative toroid polarity

- background rate too high at any reasonable luminosity
- electrons from Møller / Bhabha scattering swept into wire chamber
- 3 weeks spent trying to solve problem

Decided to run with just positive polarity on toroid

- concern for systematics, four-fold ratio not possible
- now requires careful understanding of detector

Showering from Møller / Bhabha Events



Toroid B < 0

- negative charged particles bent away from beamline

Møller/Bhabha

- very high rate of e$^-$
- strike scattering chamber, target cell
- bent into chambers

At high luminosity

- high background rate
- unable to run B<0

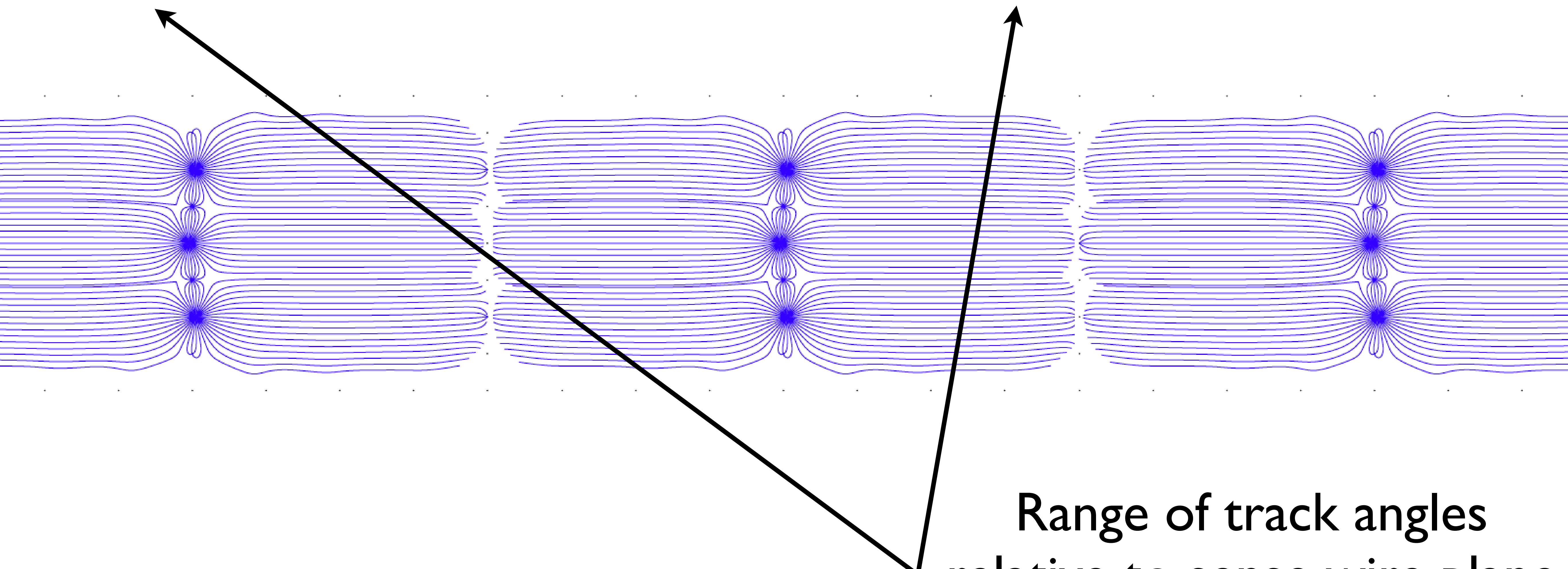
Had to choose

- high luminosity or four fold ratio

Lines of Electron Drift at B = 0 G

Single super-layer of drift cells in OLYMPUS wire chamber

- “Jet-style” drift cells -> sense wires “see” large distances left and right
- longest drift times around 1.1 micro-second (11 beam crossings)

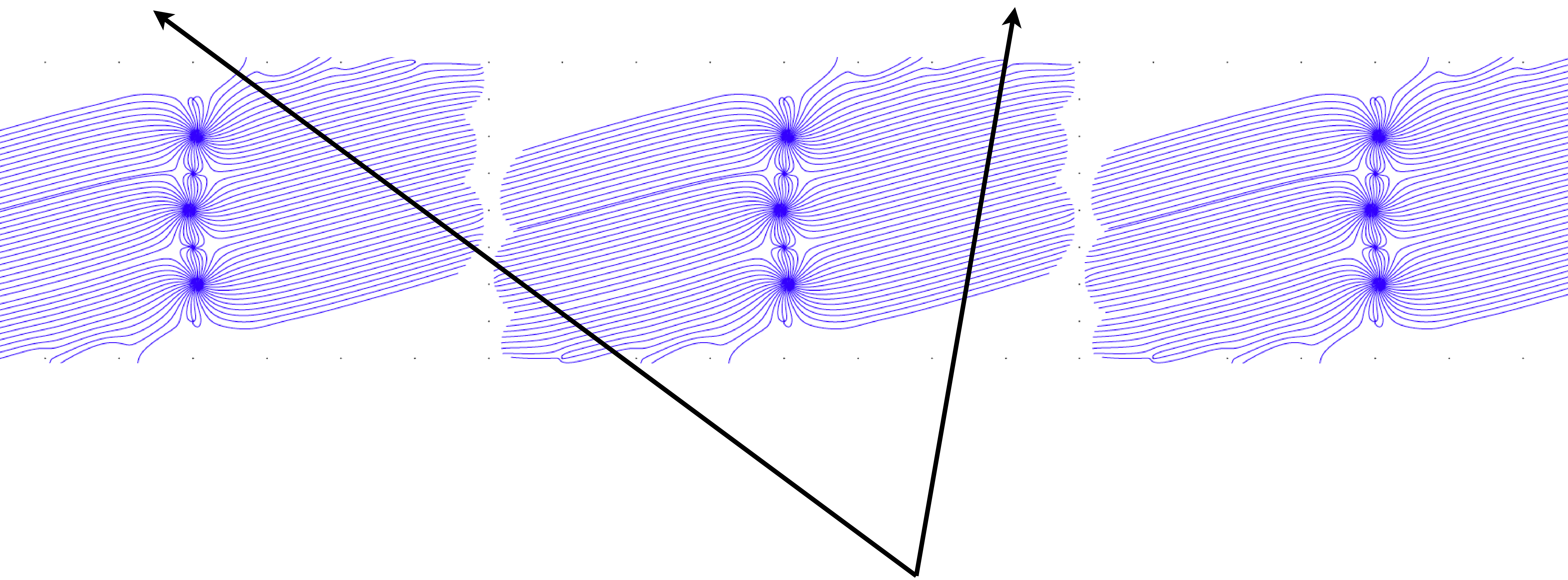


Range of track angles
relative to sense wire plane

- wire chambers subtend 20° - 80° in polar angle
- chamber inclined by 16.5° ⇒ tracks vary -6.5° ⇔ 53.5° to normal
- prefer track perpendicular to electron drift for reconstruction

Lines of Electron Drift at B = 3000 G

Electron drift tilted through Lorentz force
Helps reconstruction at forward angles



3000 G nominal OLYMPUS field

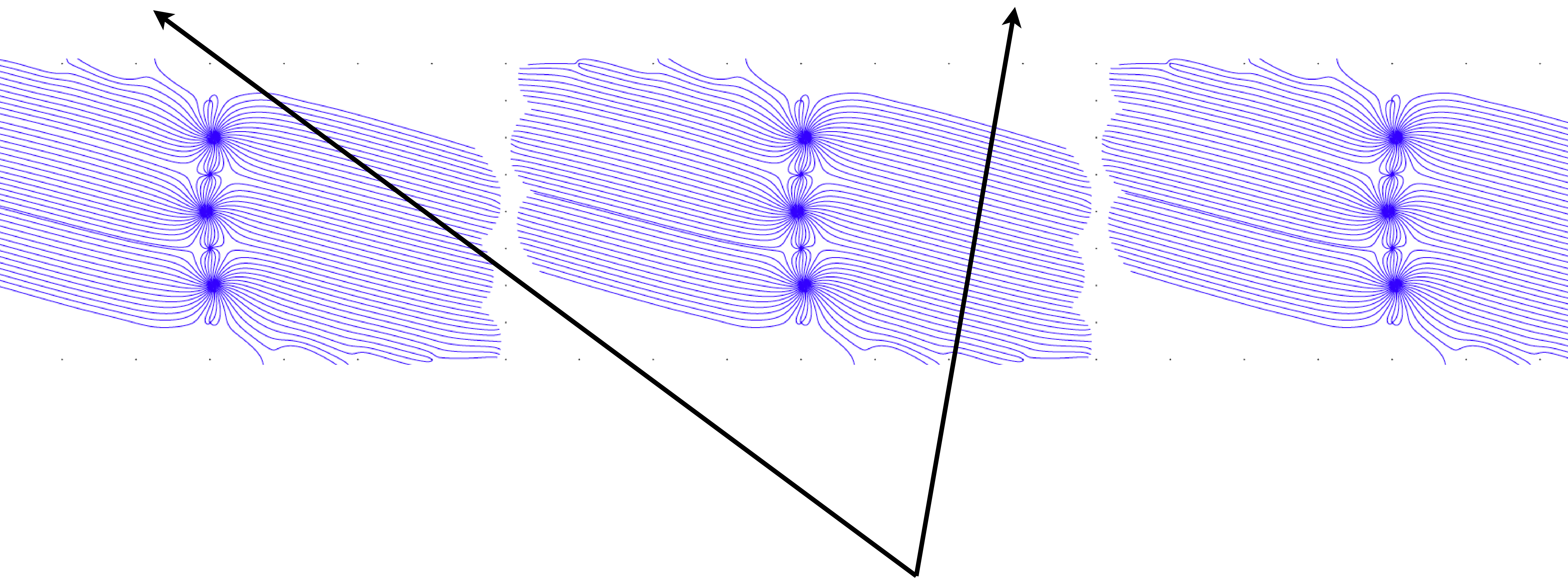
Lines of Electron Drift at B = -3000 G

Reconstruction worse at forward angles

Differences in reconstructing e^+/e^- with ± toroid field

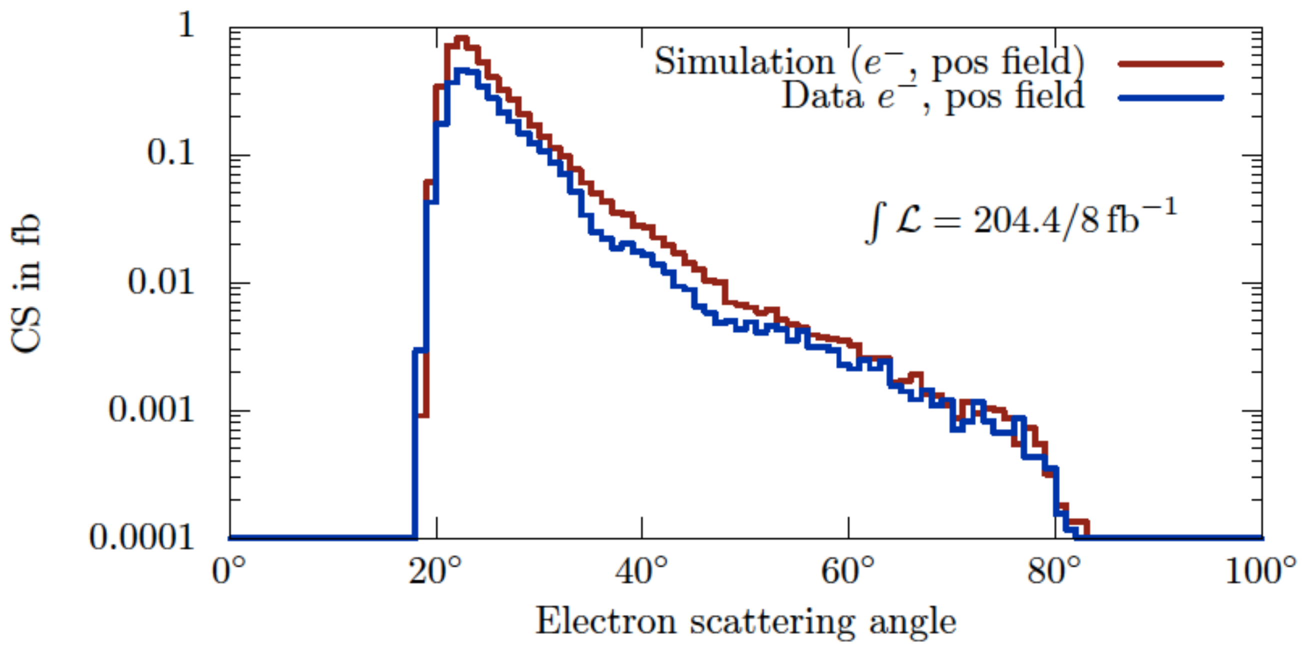
- four-fold ratio may not be as easy as planned

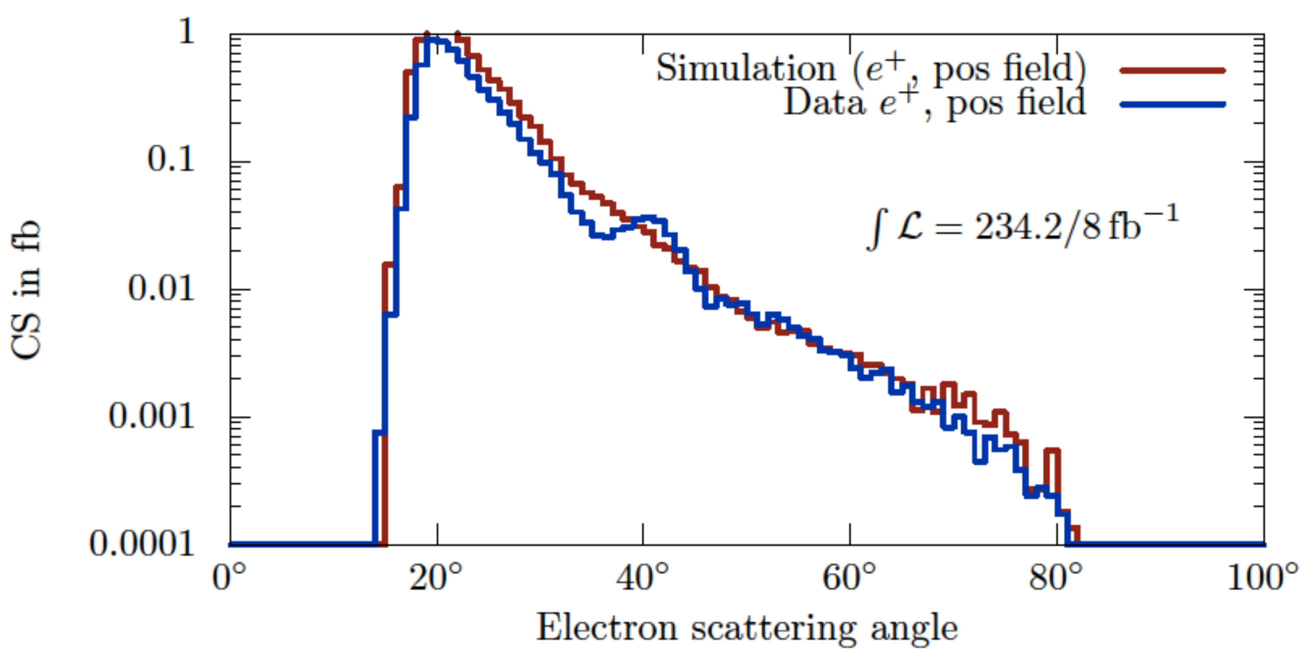
$$\kappa^l_{e^+ +} \not\approx \kappa^l_{e^- -} \qquad \kappa^l_{e^+ -} \not\approx \kappa^l_{e^- +}$$



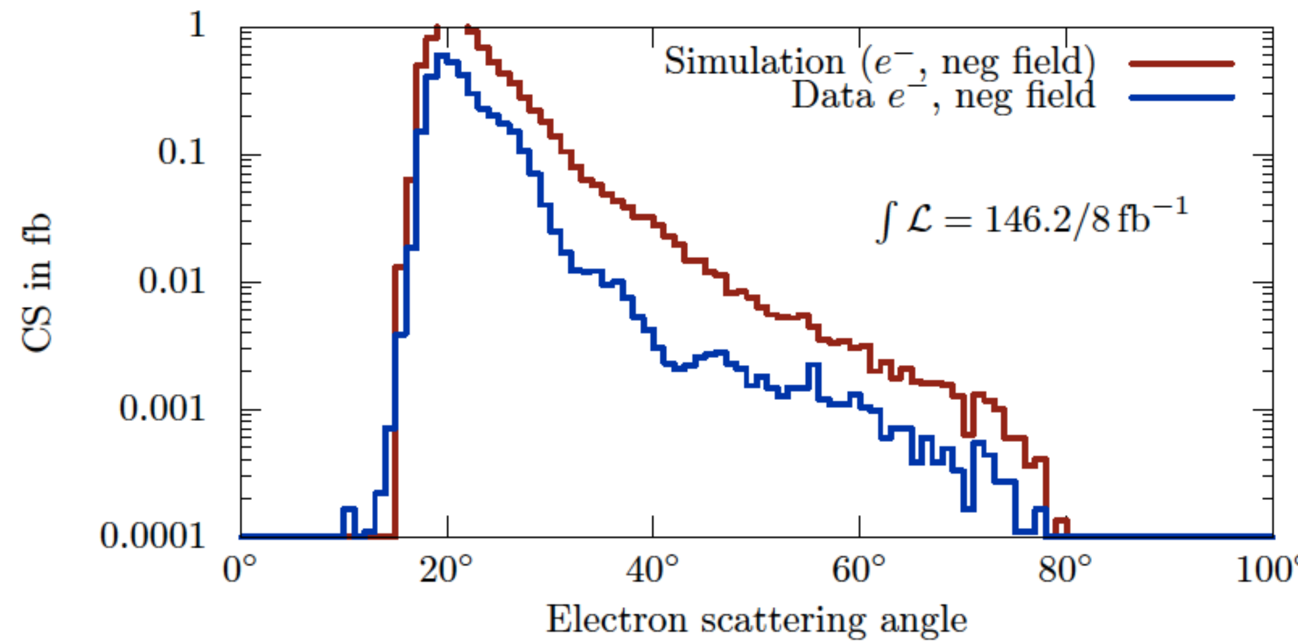
Initial Reconstruction of February Data

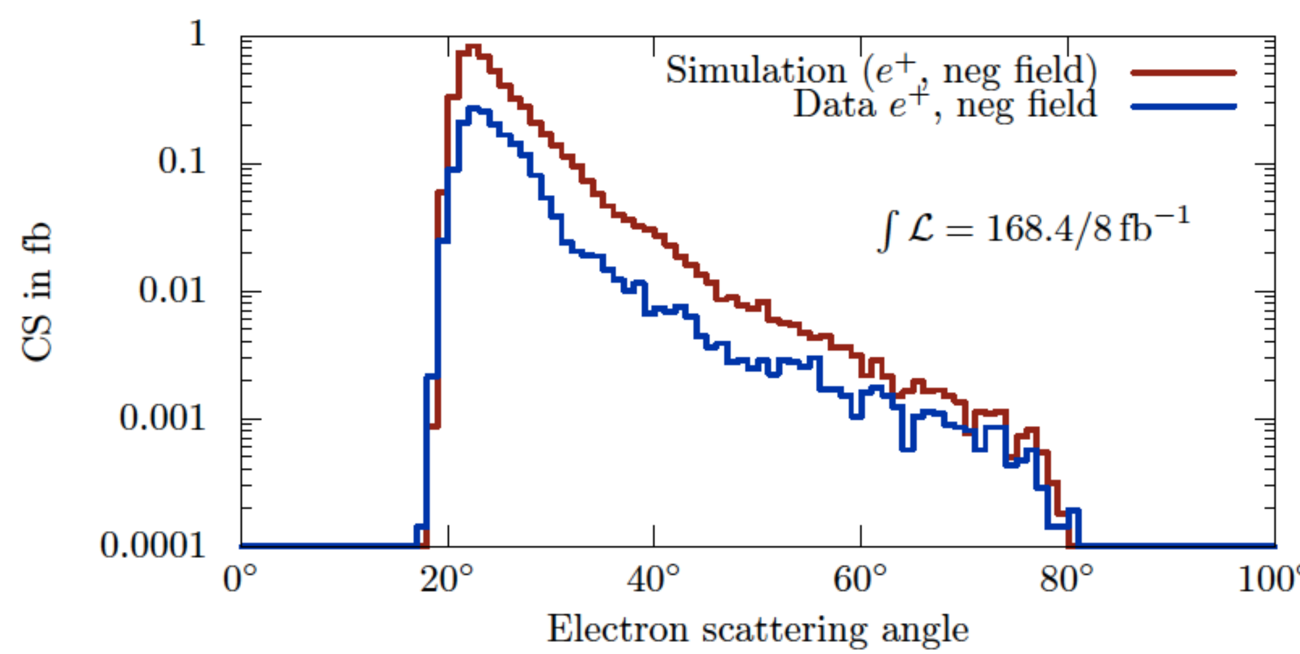
B>0



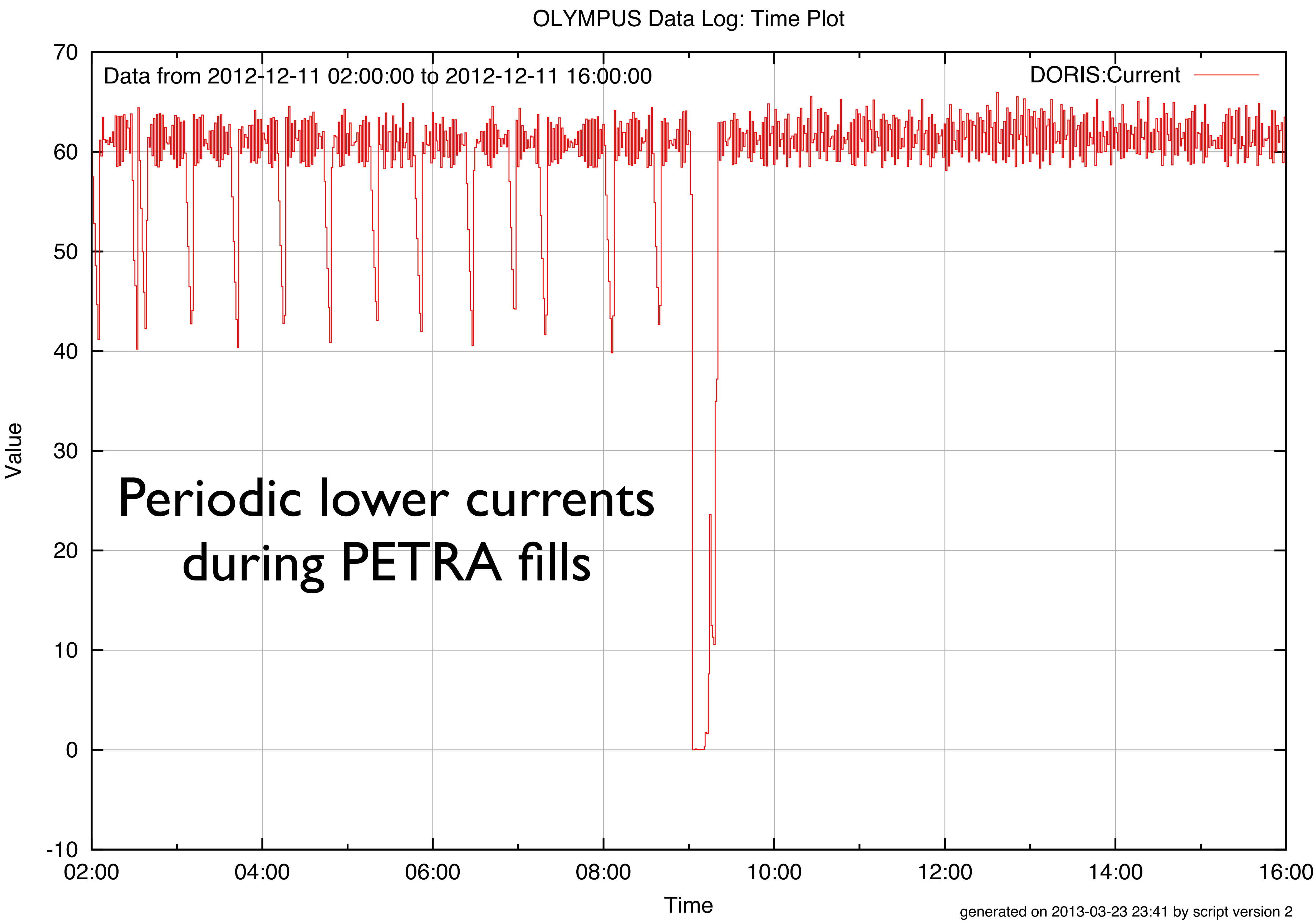


B<0

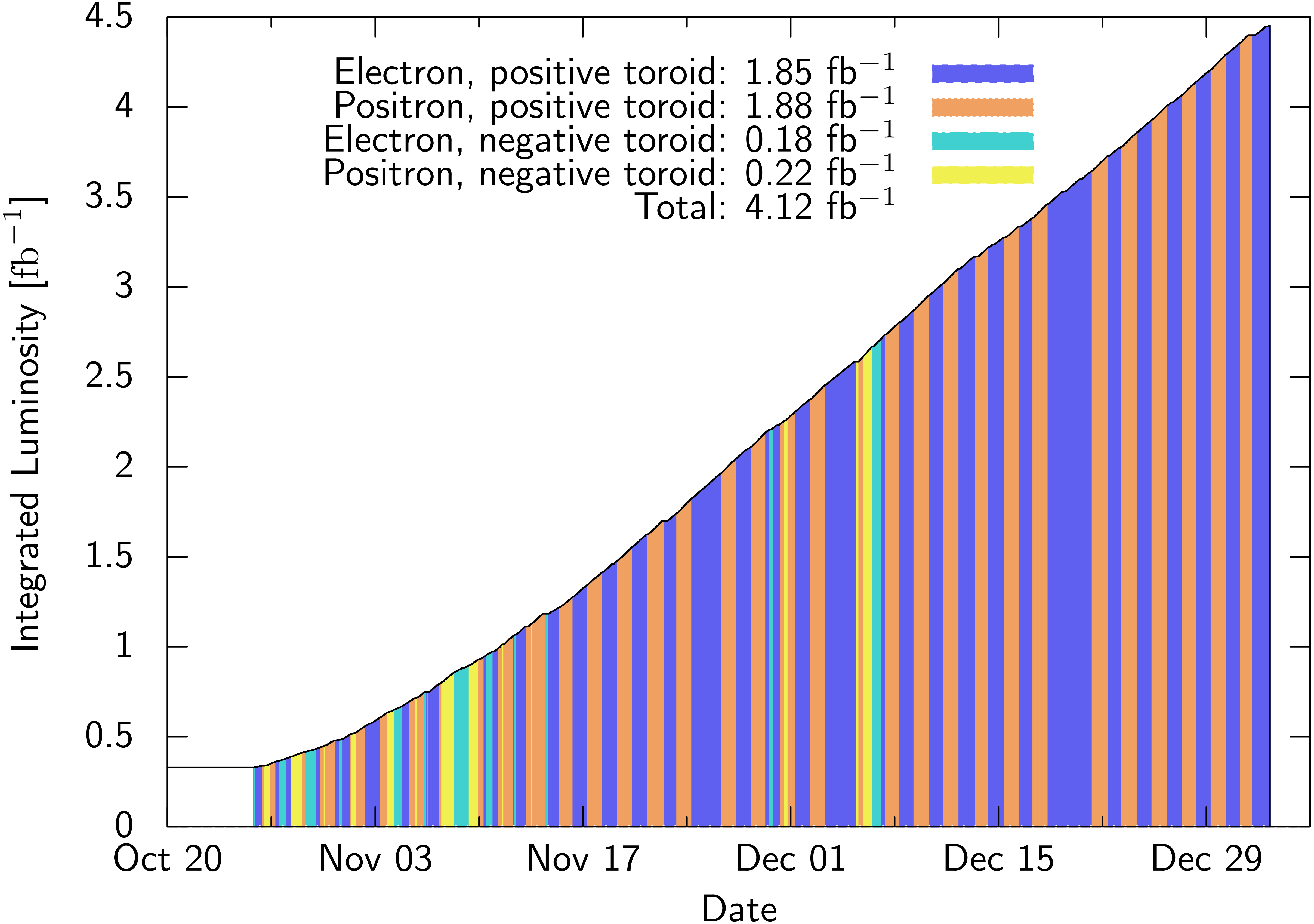




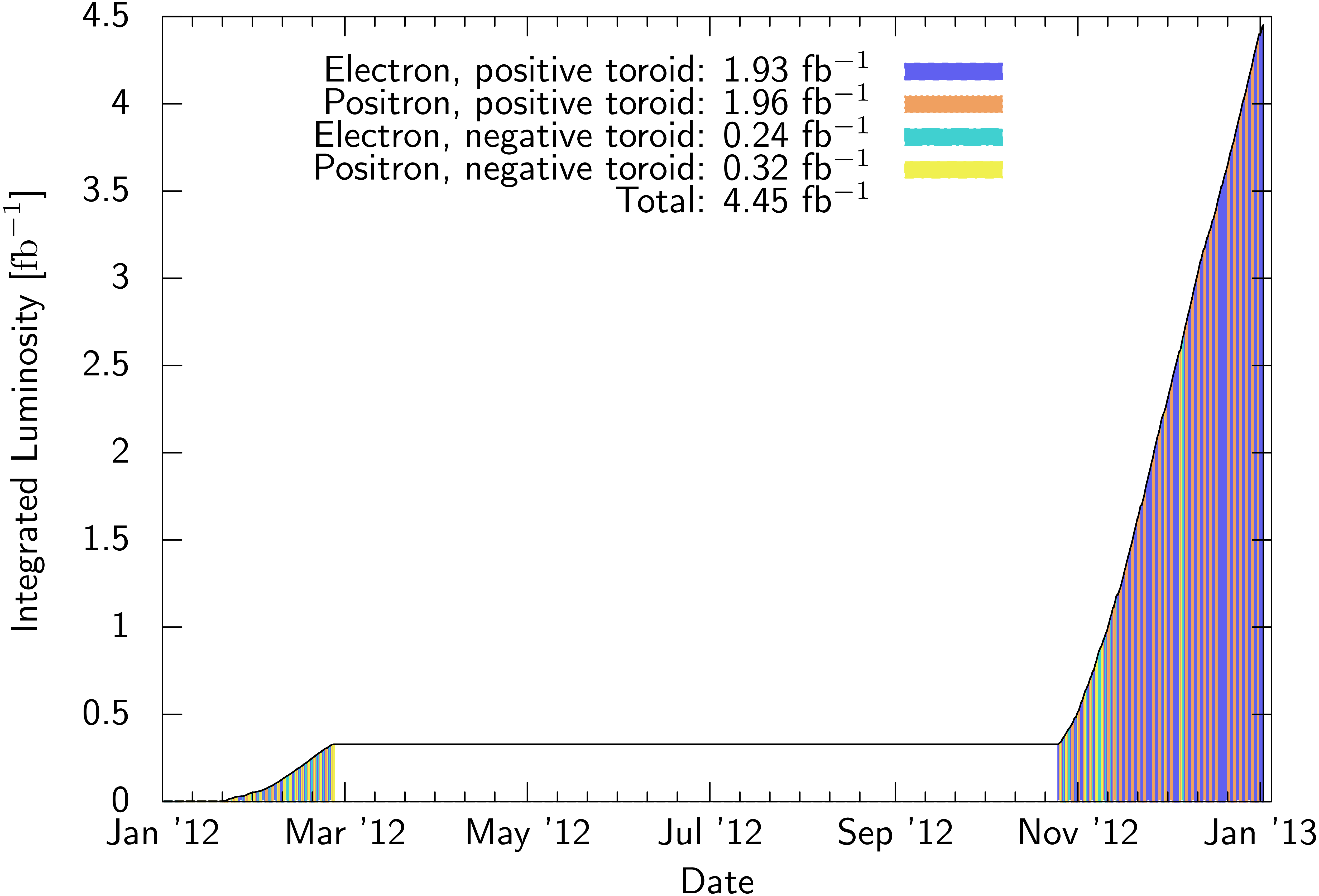
DORIS Operation in Top-Up Mode



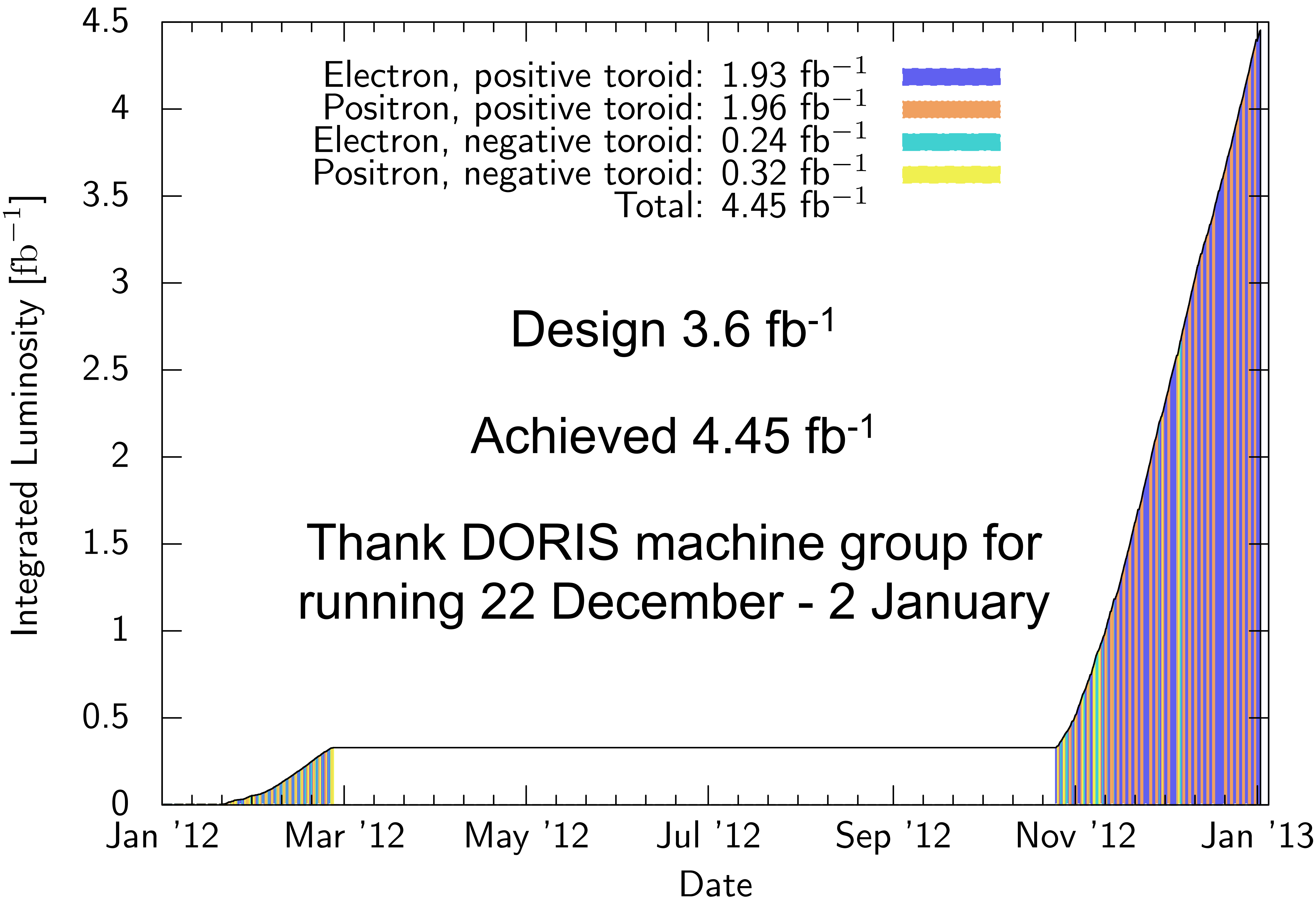
Luminosity - Fall, 2012



OLYMPUS Luminosity



OLYMPUS Luminosity

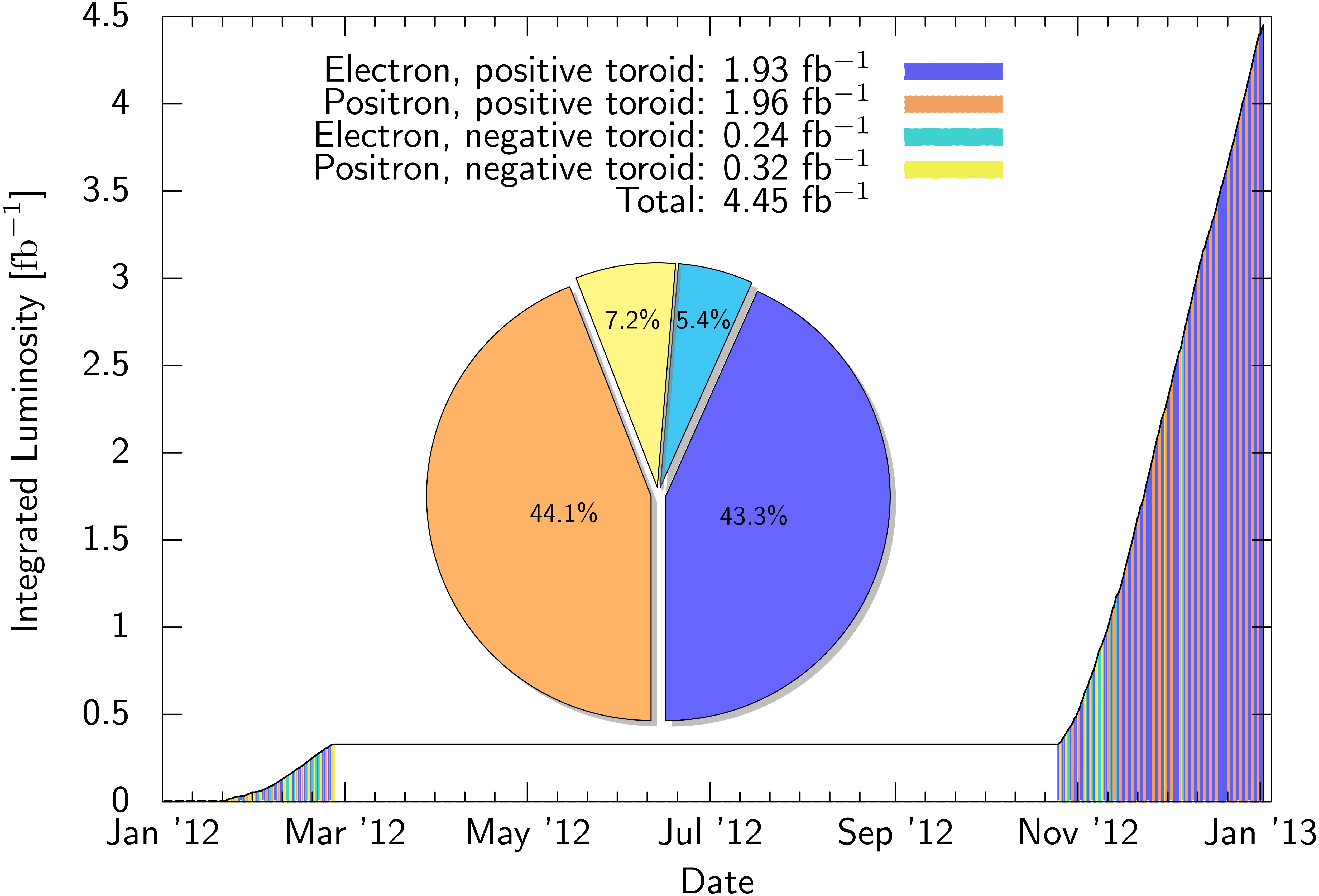


Design 3.6 fb^{-1}

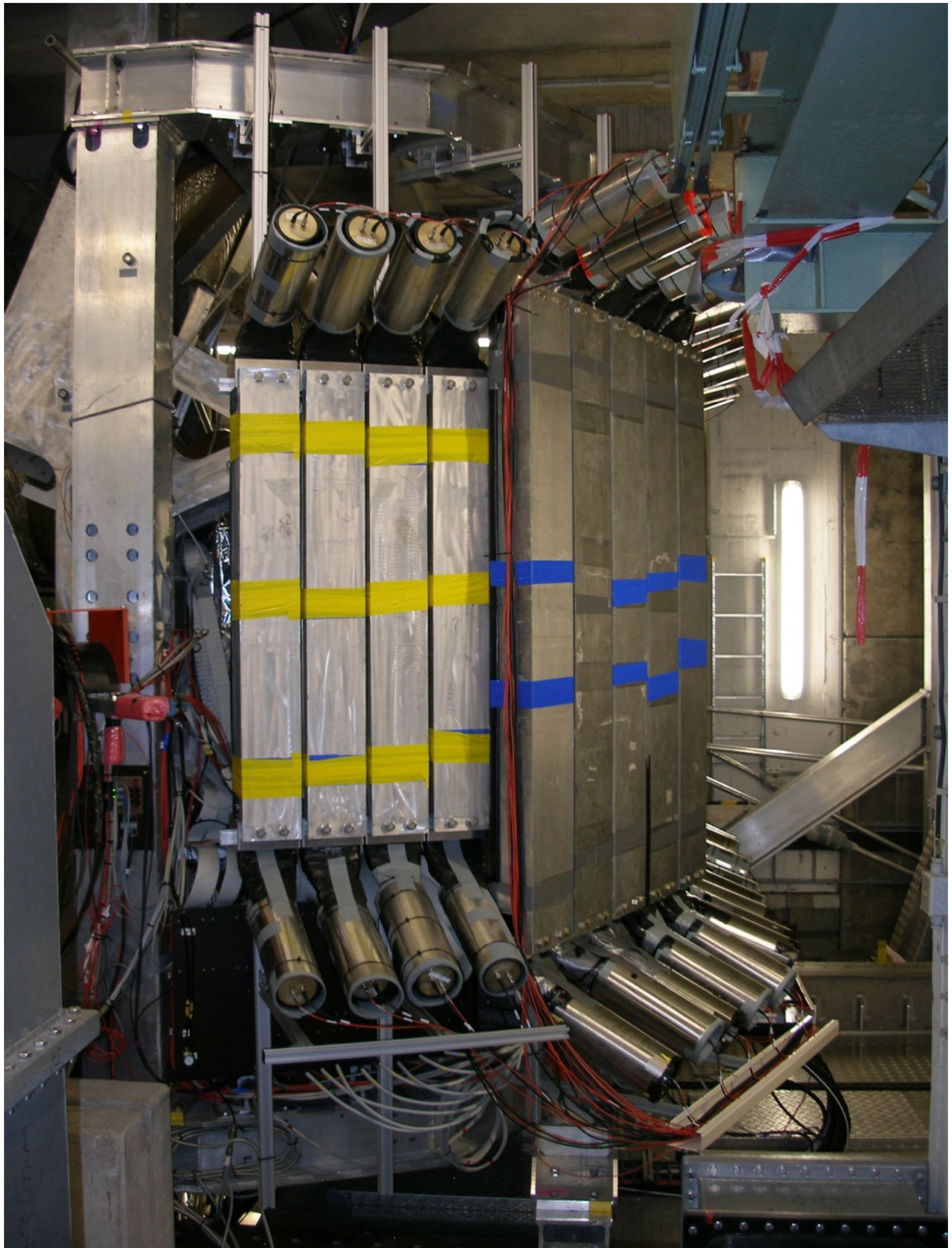
Achieved 4.45 fb^{-1}

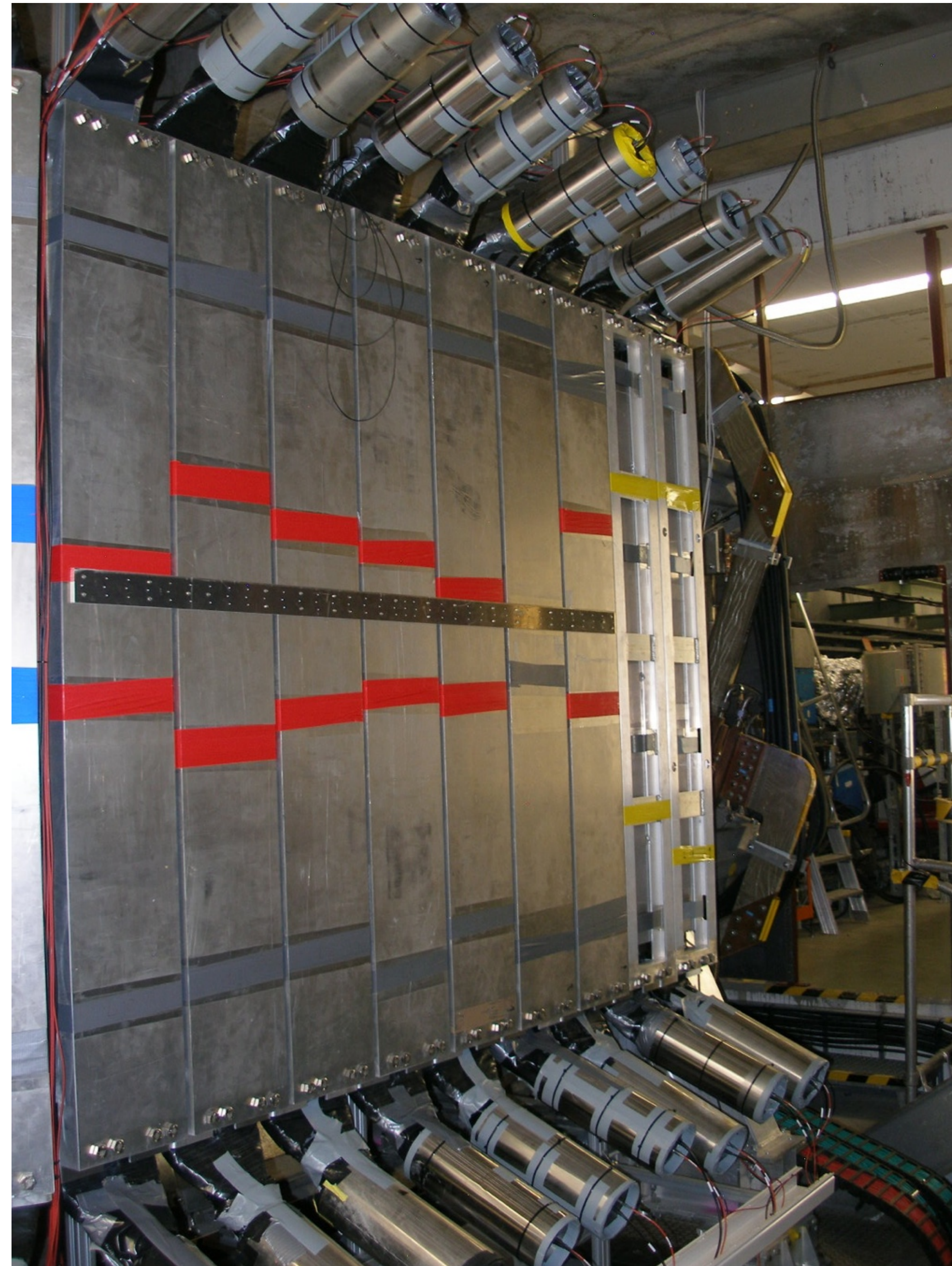
Thank DORIS machine group for running 22 December - 2 January

OLYMPUS Luminosity

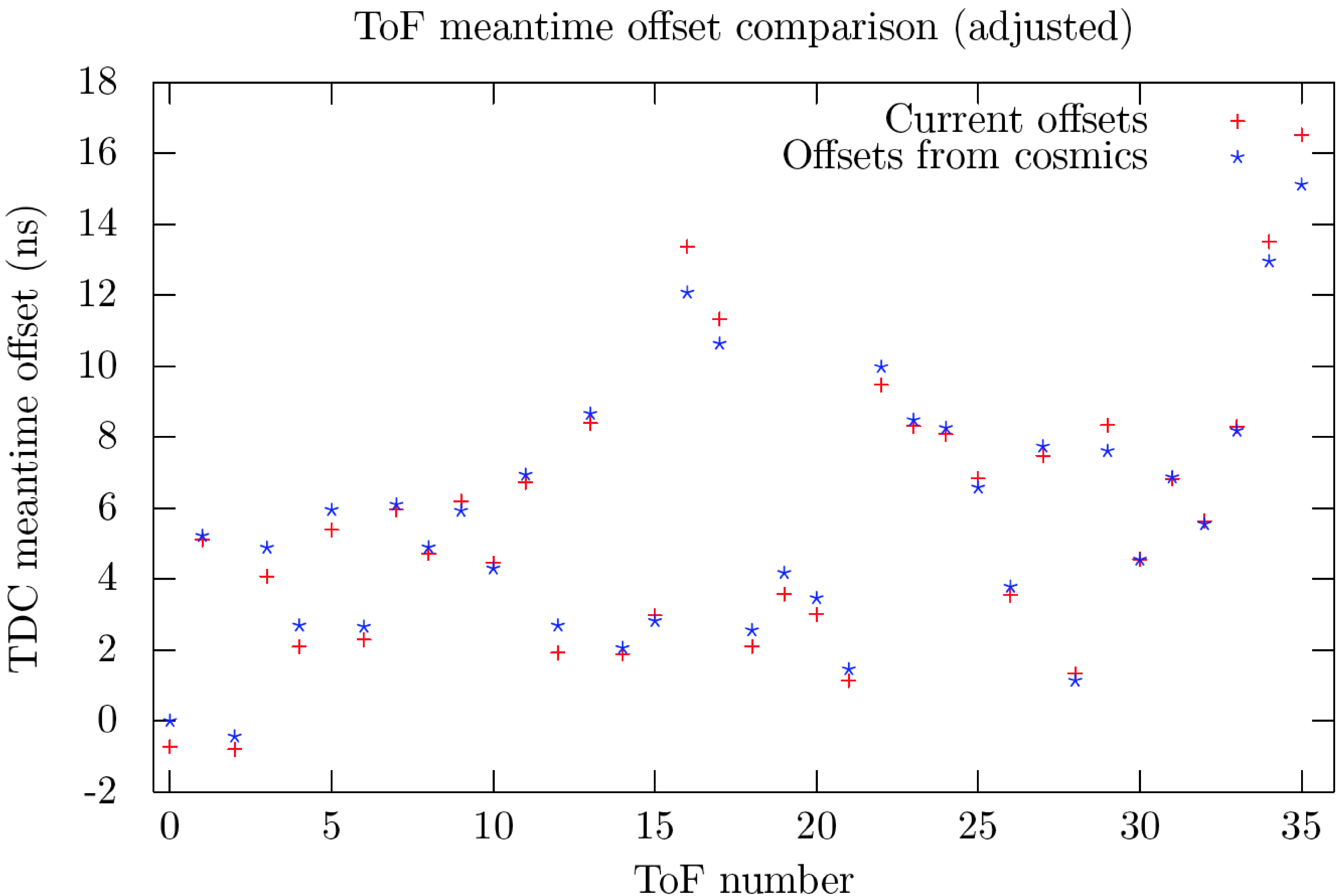


Time of Flight Scintillator Bars





TOF Timing Offsets



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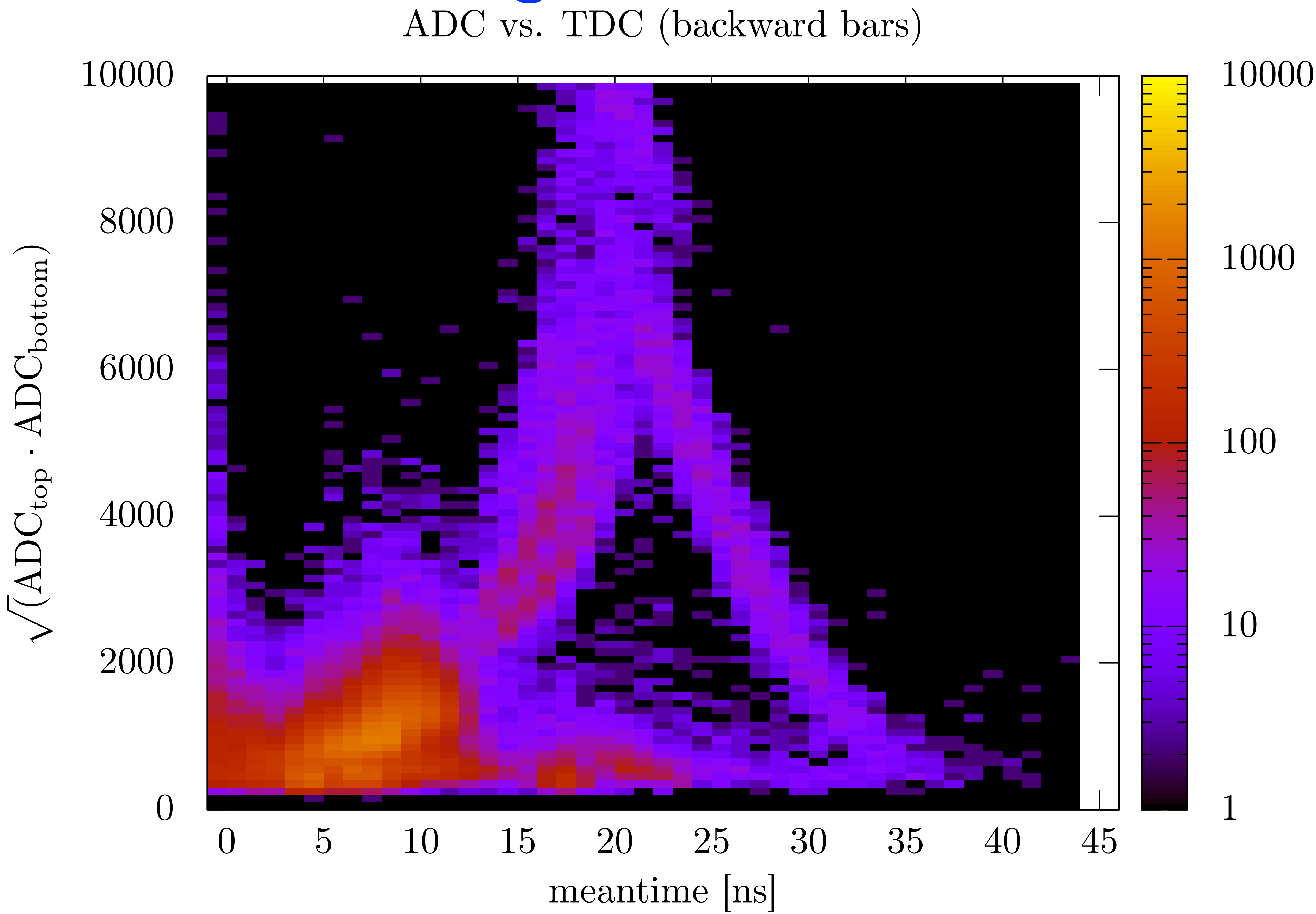
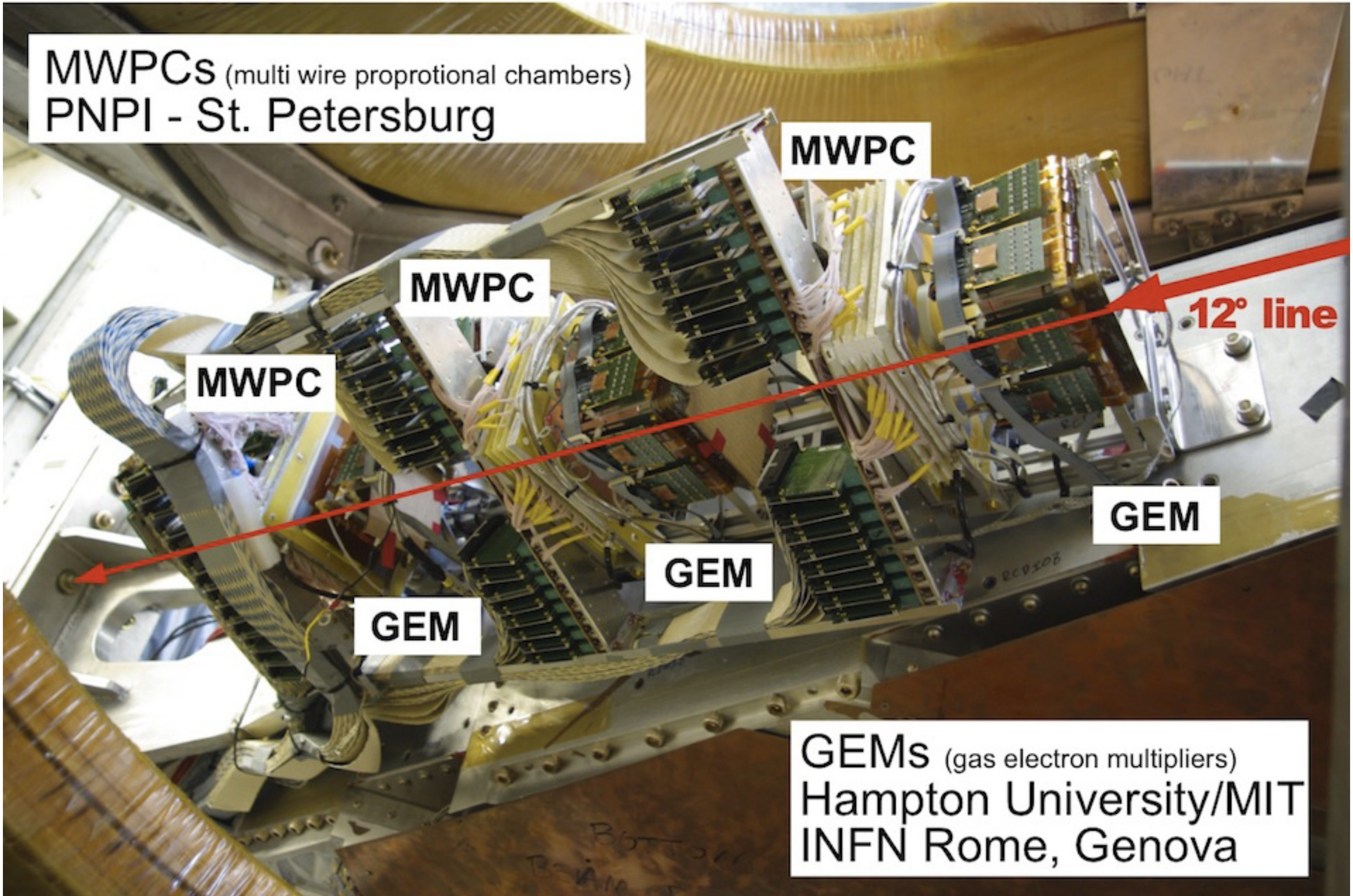


12° GEM and MWPC Luminosity Monitors



12° Luminosity Monitor

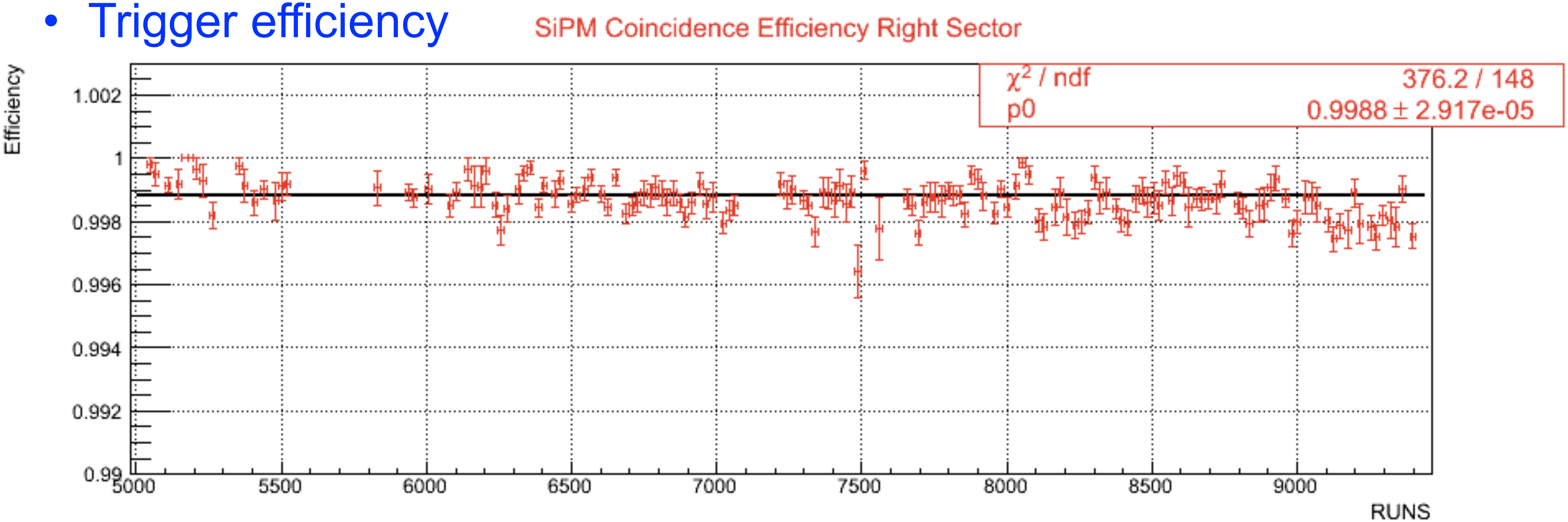
Telescope of 3 GEM and 3 MWPC detectors interleaved

- each ~10×10 cm^2 effective area
- track $e^{\pm}$ in region of 12° depending on magnet polarity
- trigger by pairs of SiPM scintillator tiles and lead glass calorimeter

Single detector resolutions from last data run

- GEM ~80 microns
- MWPC ~260 microns

- Trigger efficiency



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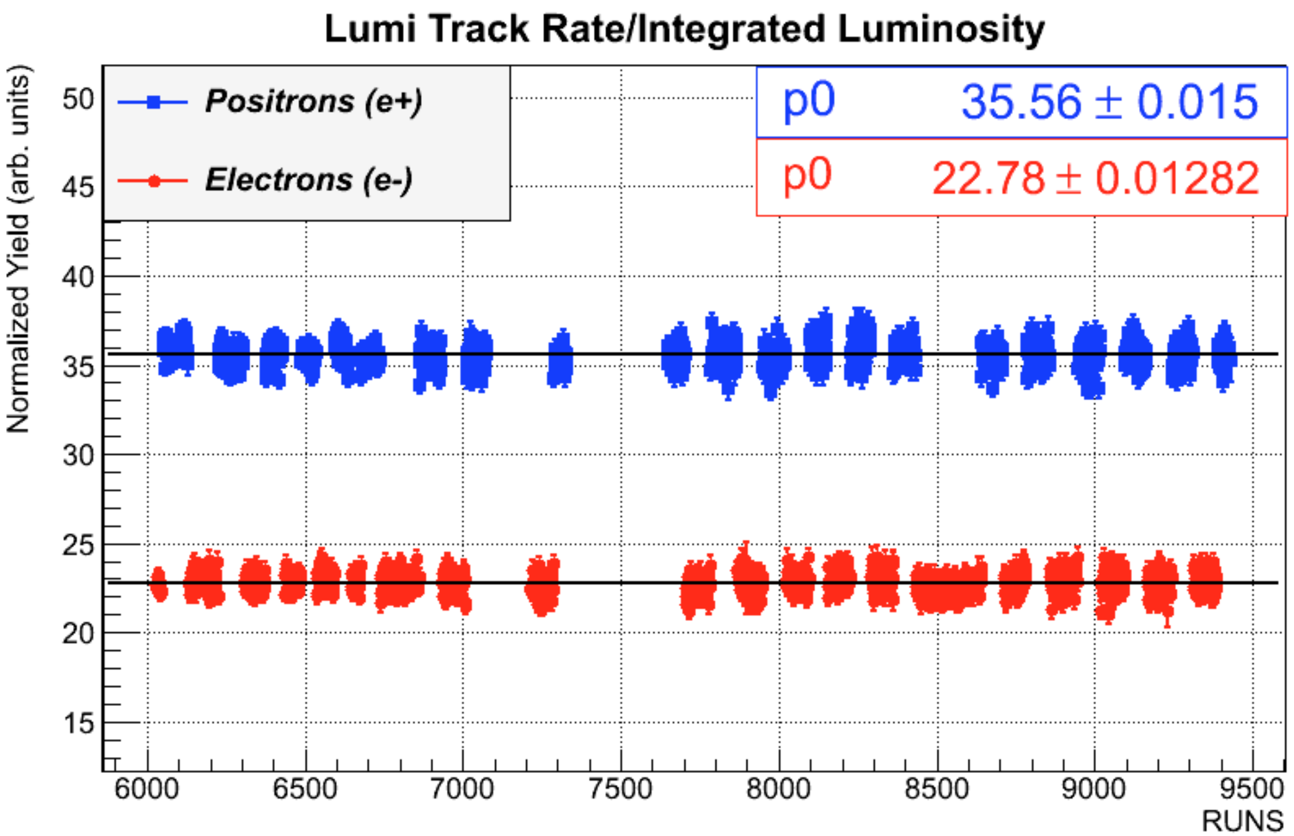
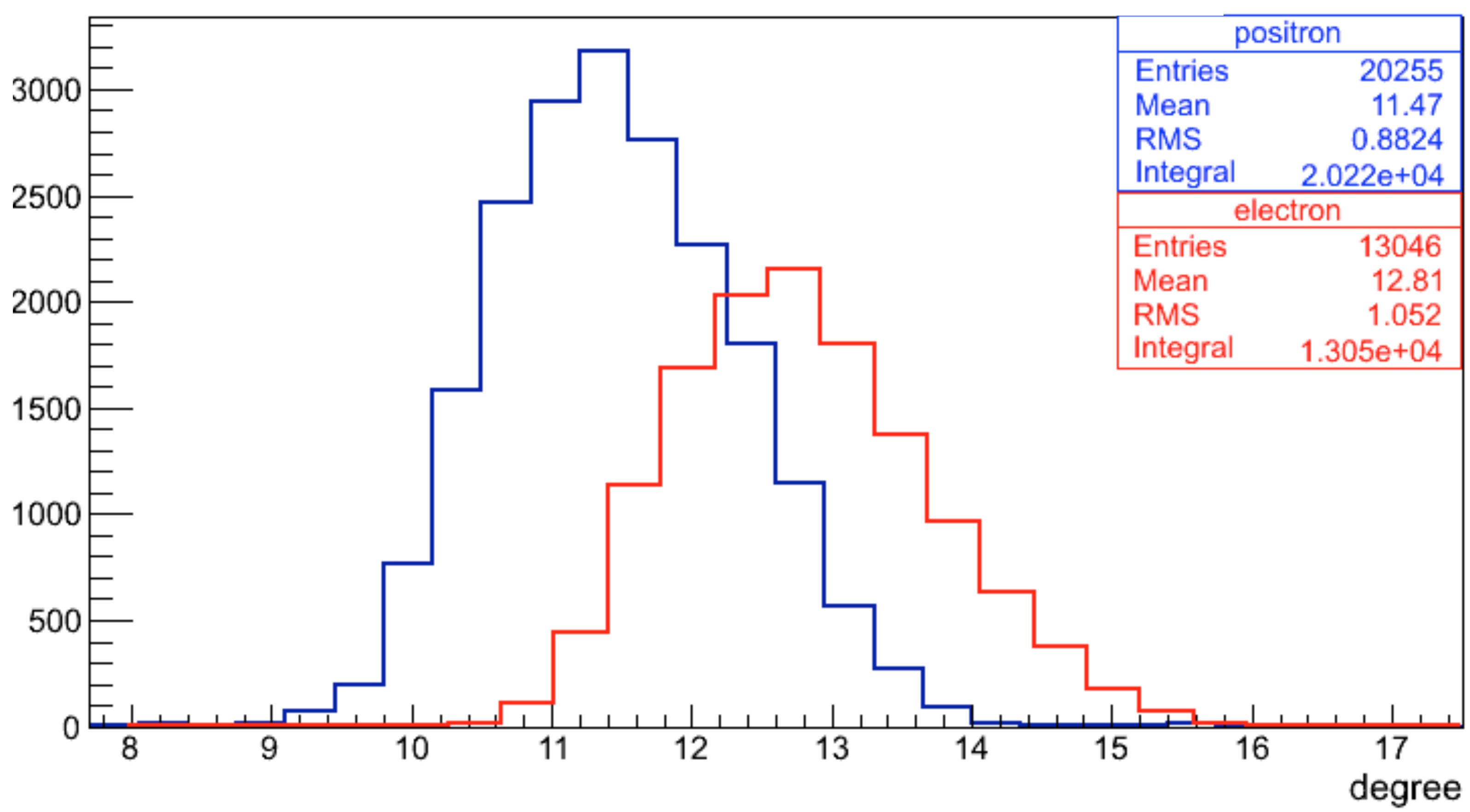
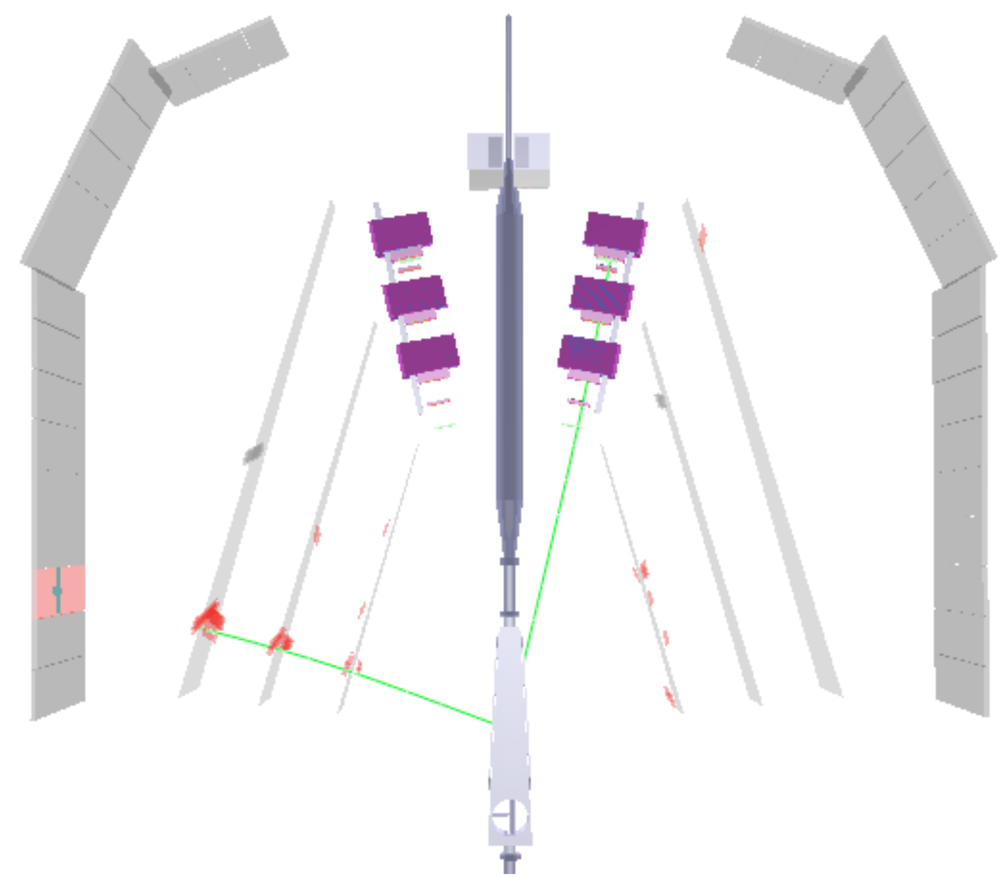


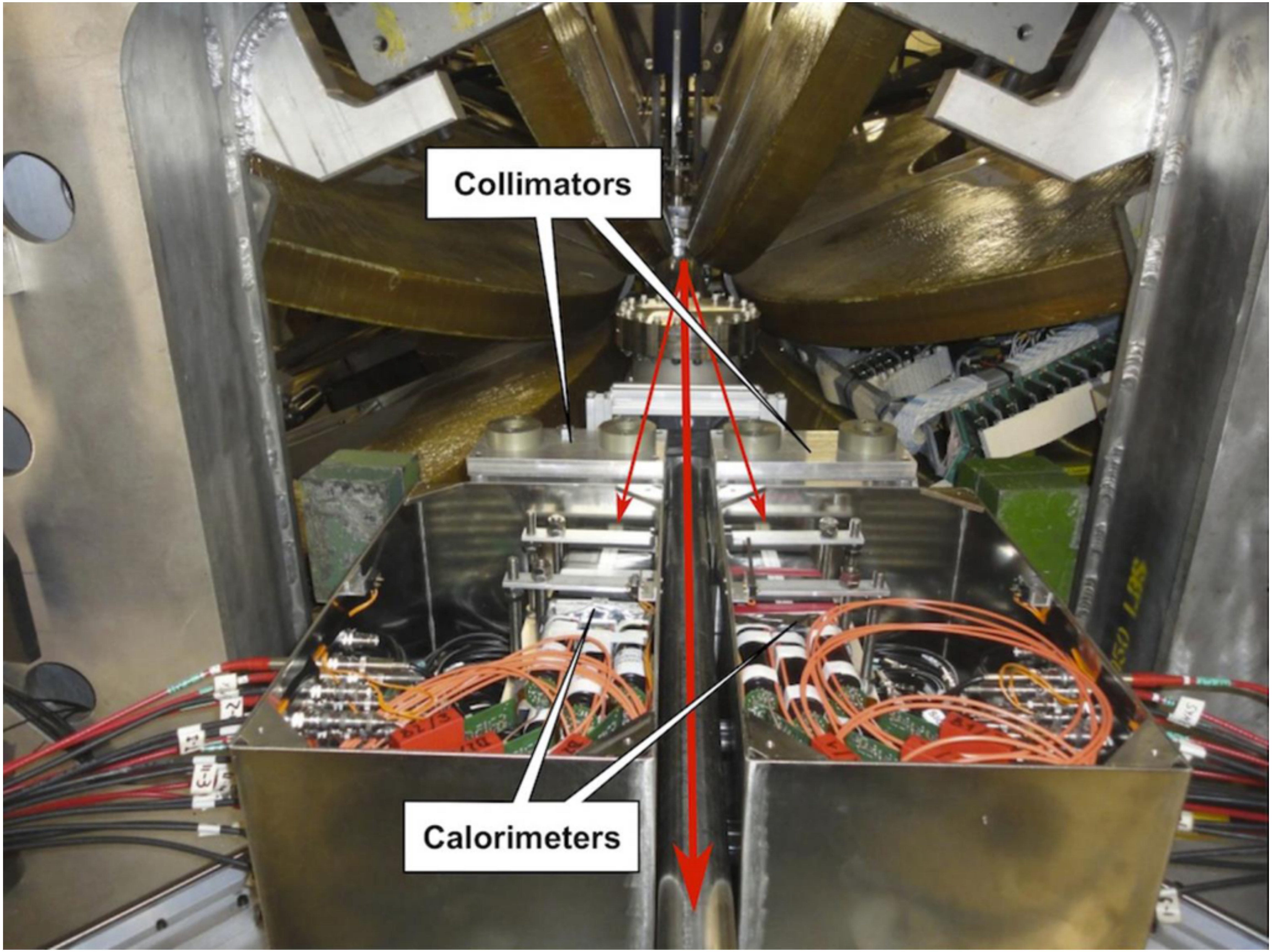
Rates for e±p events
- ratio = 1.56

Acceptance from MC
- ratio = 1.55

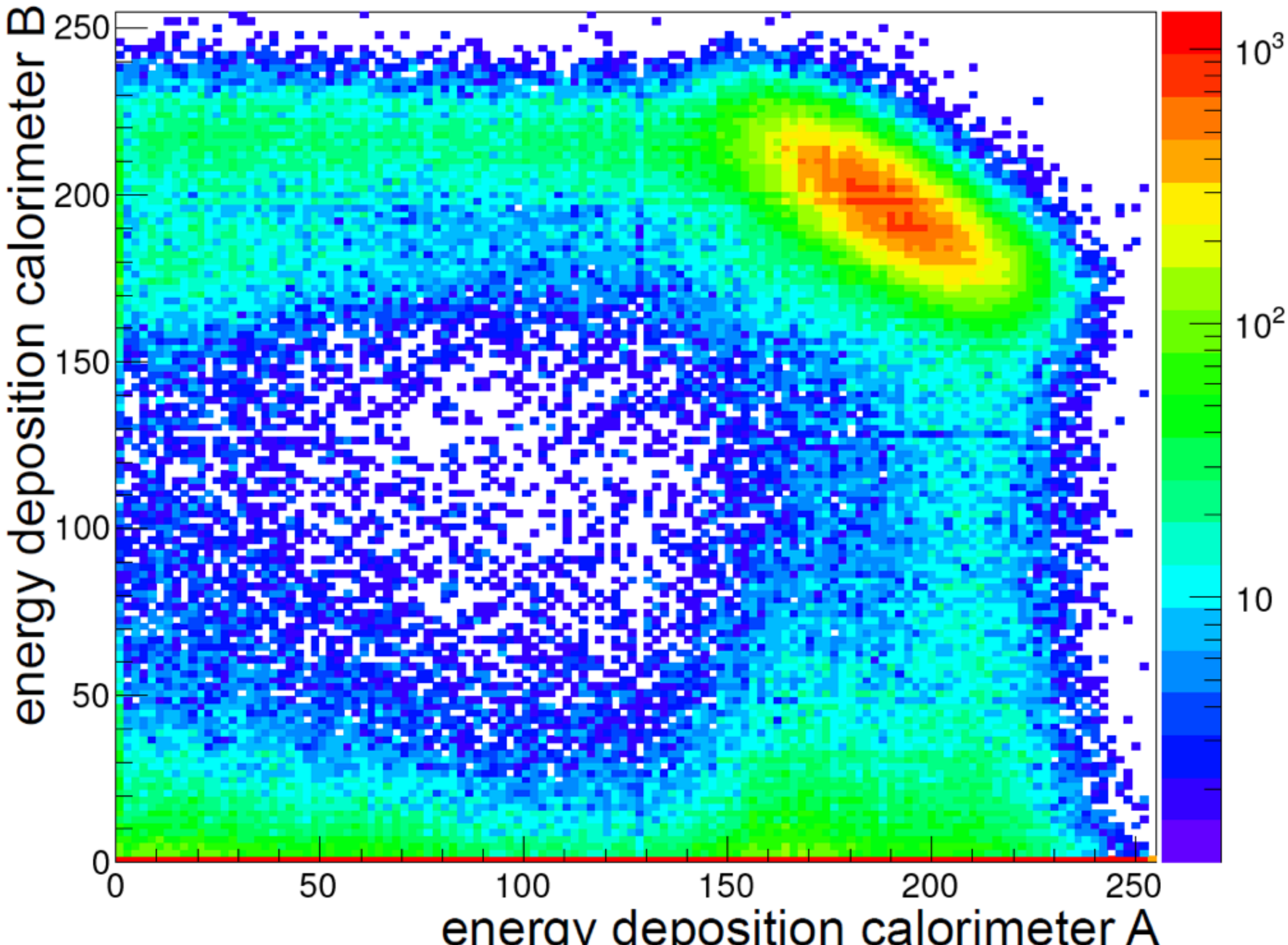




Symmetric Møller / Bhabha Detector



Coincidence of Left and Right Detectors



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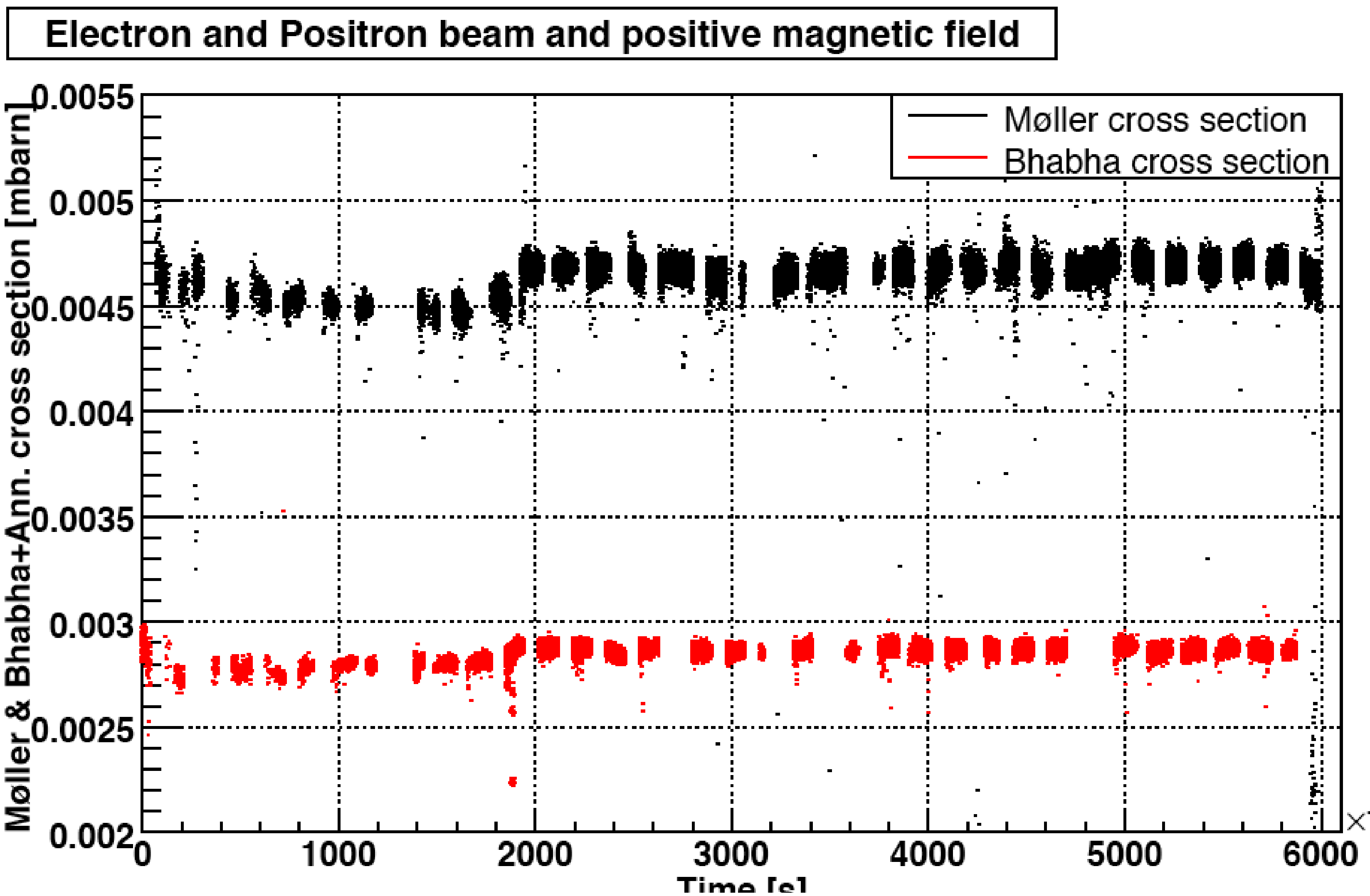
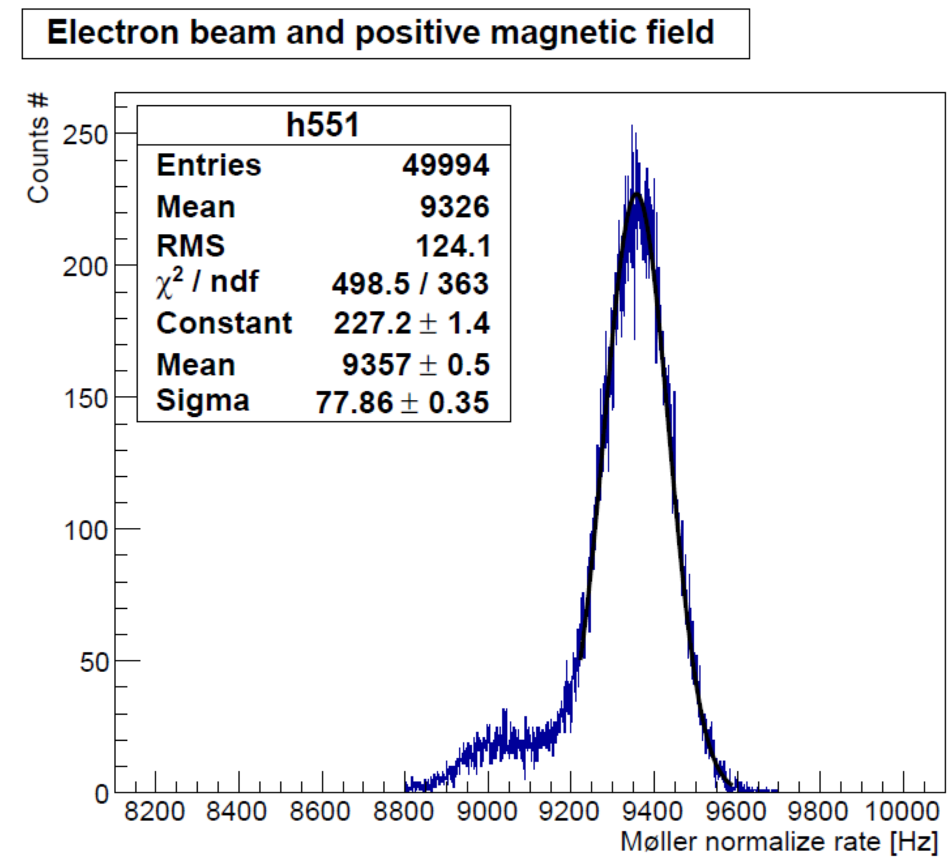
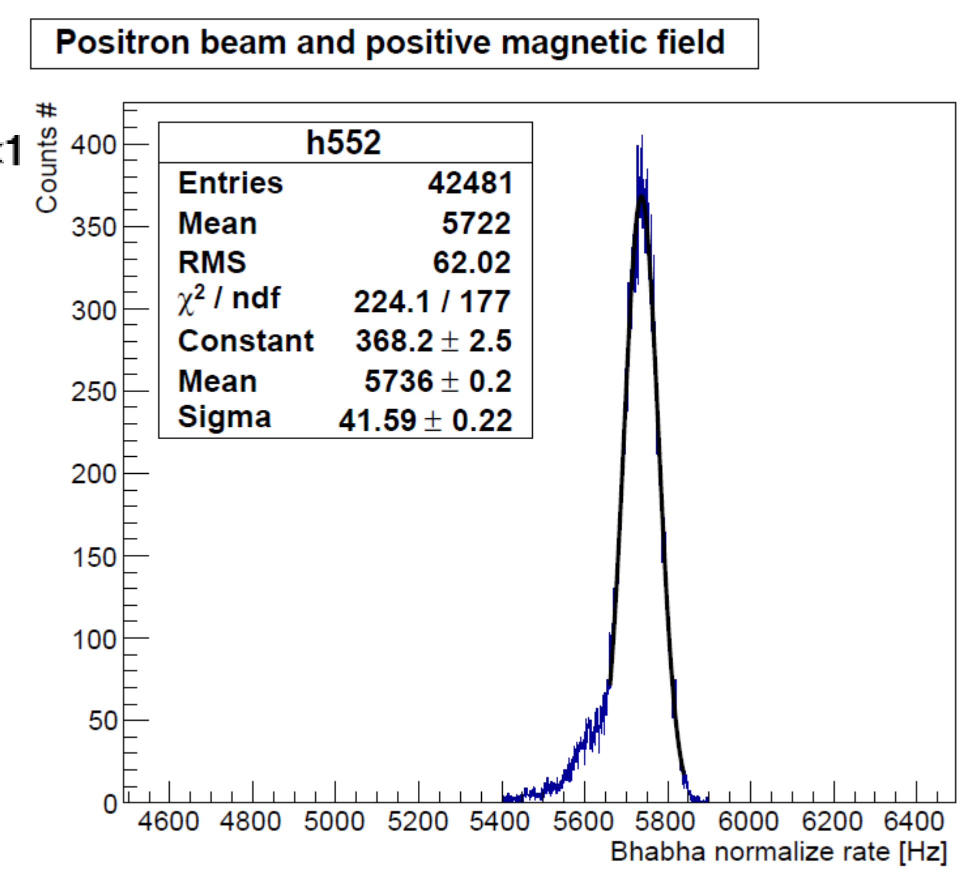
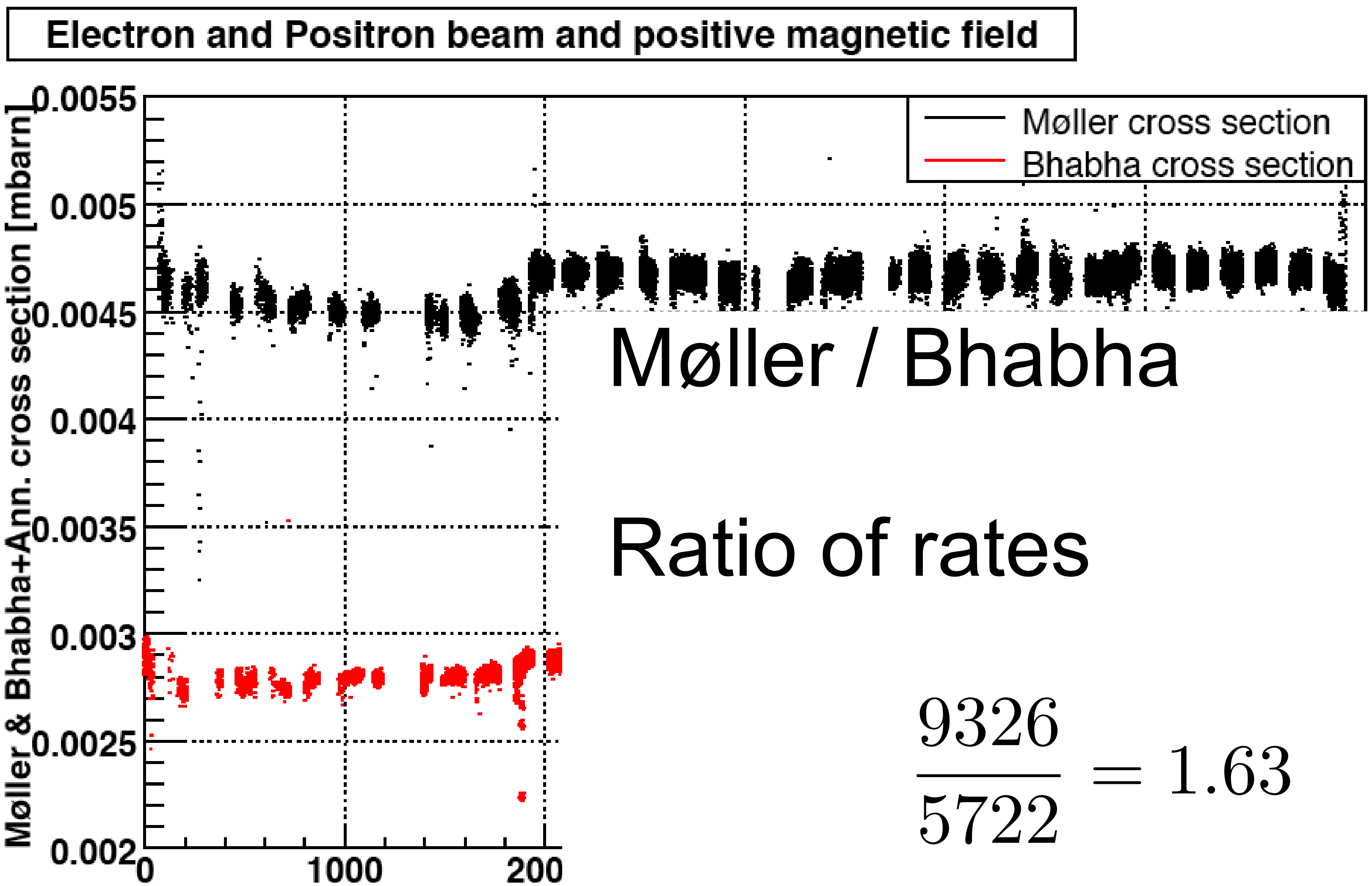


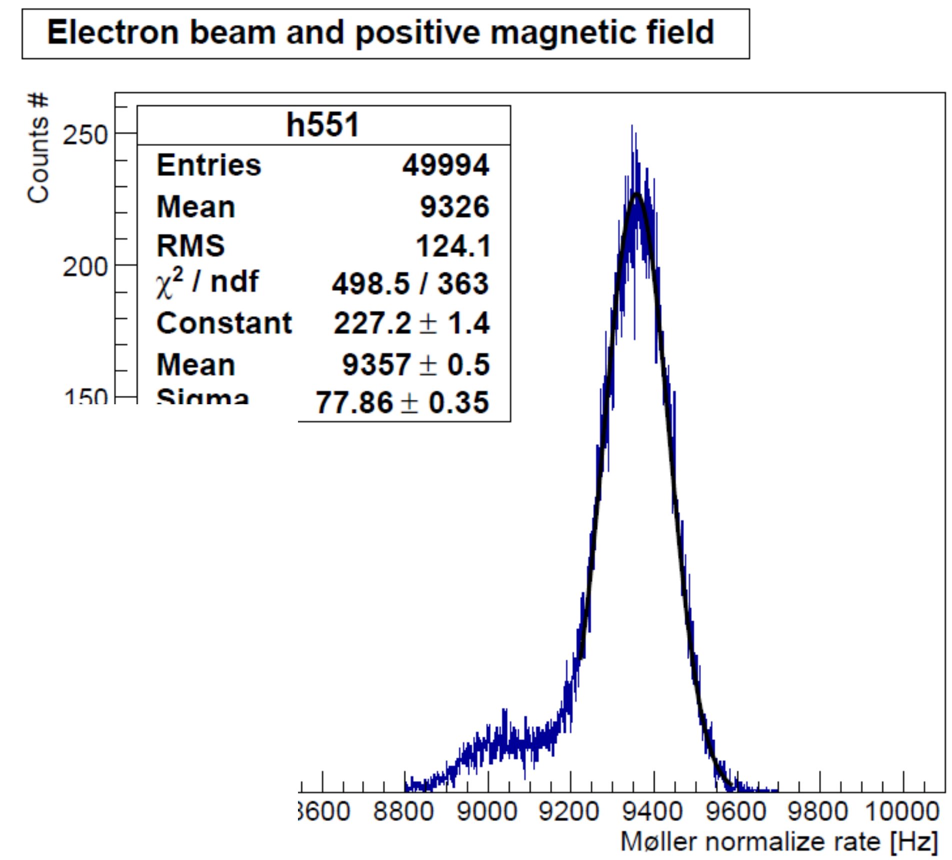


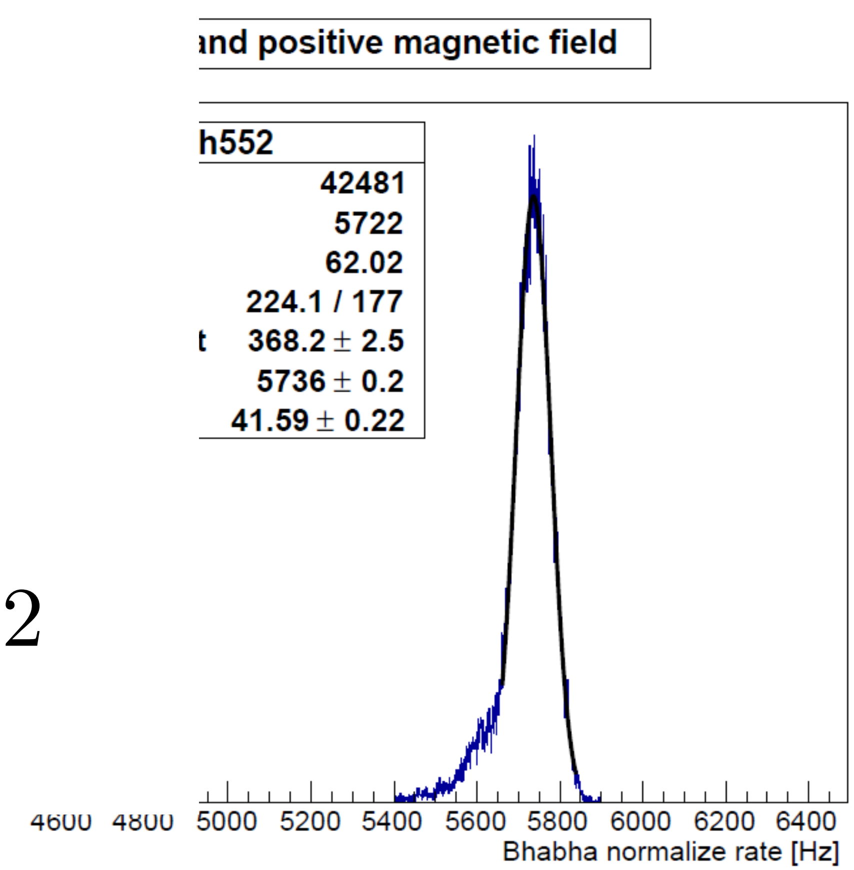


	Effective Cross section [$mbarn$]
Møller	0.00626153
Bhabha	0.00317930
Annihilation	0.00069330

Symmetric Møller / Bhabha Detector







Møller / Bhabha

Ratio of rates

$$\frac{9326}{5722} = 1.63$$

Ratio of cross sections

$$\frac{0.00626}{0.00318 + 0.00069} = 1.62$$

Møller
Bhabha
Annihilation

OLYMPUS Activities After Data Running

January, 2013

- 1 month collecting cosmic ray data ~12 million events
- toroid magnet off most of the time
- straight tracks useful for tuning wire chamber calibration constants
- determine timing offsets for time of flight detectors

TOF efficiency studies

- sandwiching each TOF scintillator bar with SiPM scintillators
- using cosmic found 97-99 % efficiency depending on TOF bar

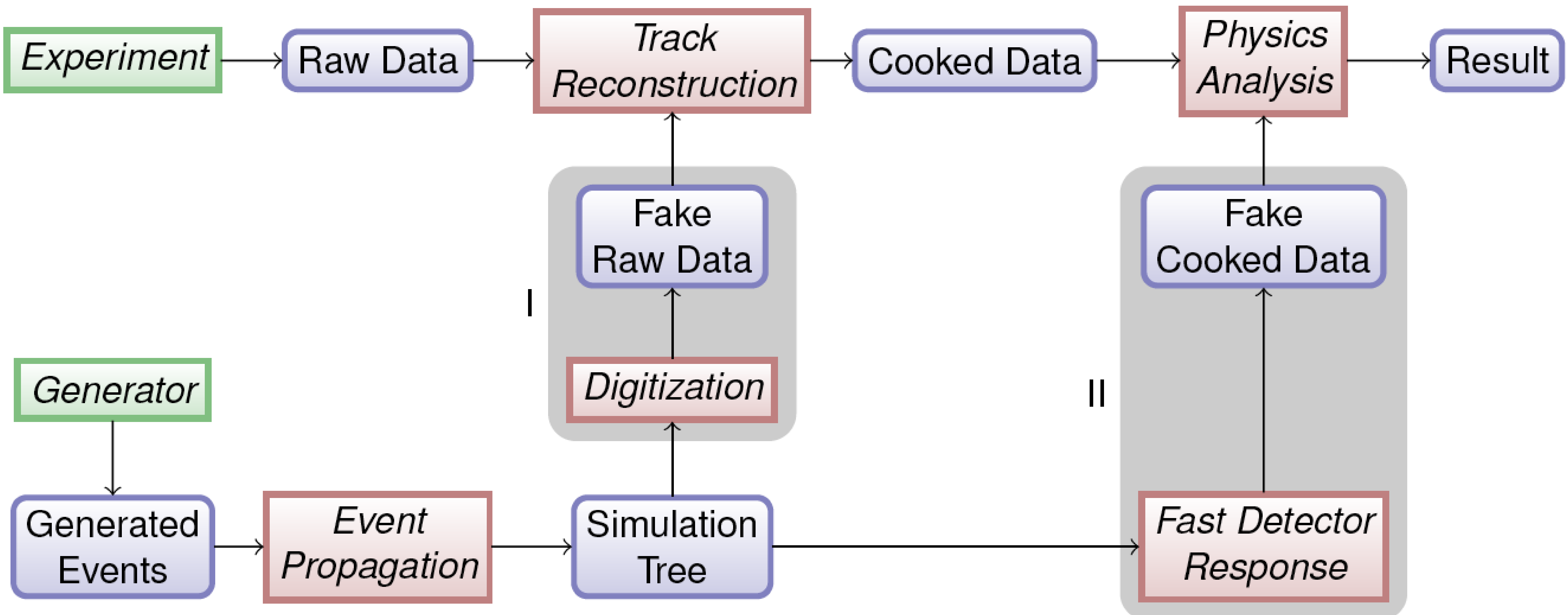
February, 2013

- complete optical survey of target chamber and all detectors
- not completed still need survey TOF

March - April, 2013

- map the OLYMPUS toroid magnet field
- 50×50×50 mm grid in high field regions 100×100×100 mm elsewhere
- also along beamline for Møller detector

Analysis Strategy



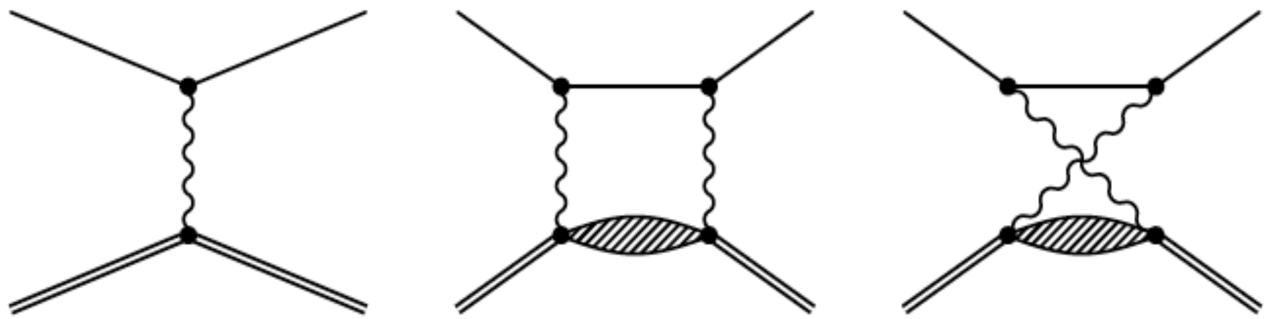
Reconstruction waiting on field map and optical survey

- global fit to optimize time to distance relationship in wire chambers
- code developed and tested

Monte Carlo also needs map and survey

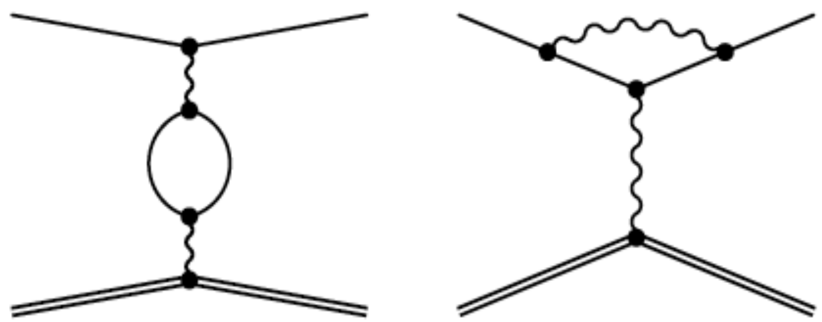
- simulation and digitization of most detectors complete

Radiative Corrections

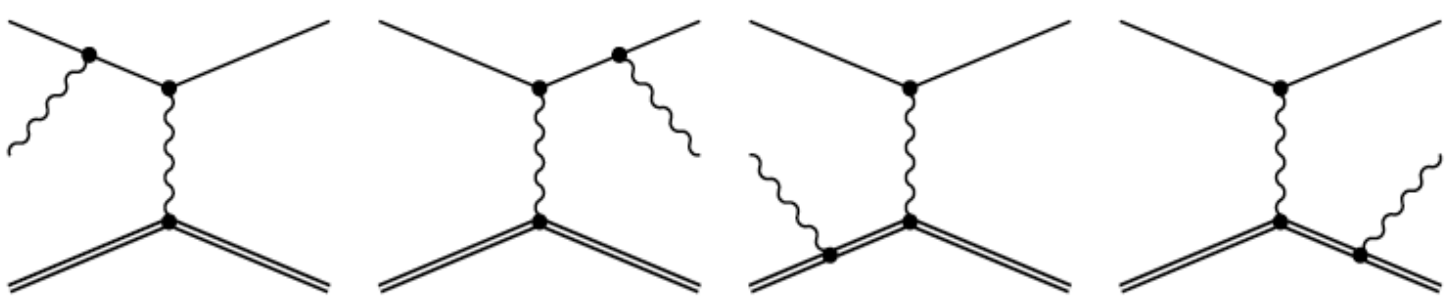


$\mathcal{M}_{\text{Born}}$ $\mathcal{M}_{2\gamma}$

The diagrams of *ep* scattering in the 1γ and 2γ approximations.



Virtual photon corrections, which don't depend on the detector geometry.



$\mathcal{M}_{\text{ei}}$ $\mathcal{M}_{\text{ef}}$ $\mathcal{M}_{\text{pi}}$ $\mathcal{M}_{\text{pf}}$

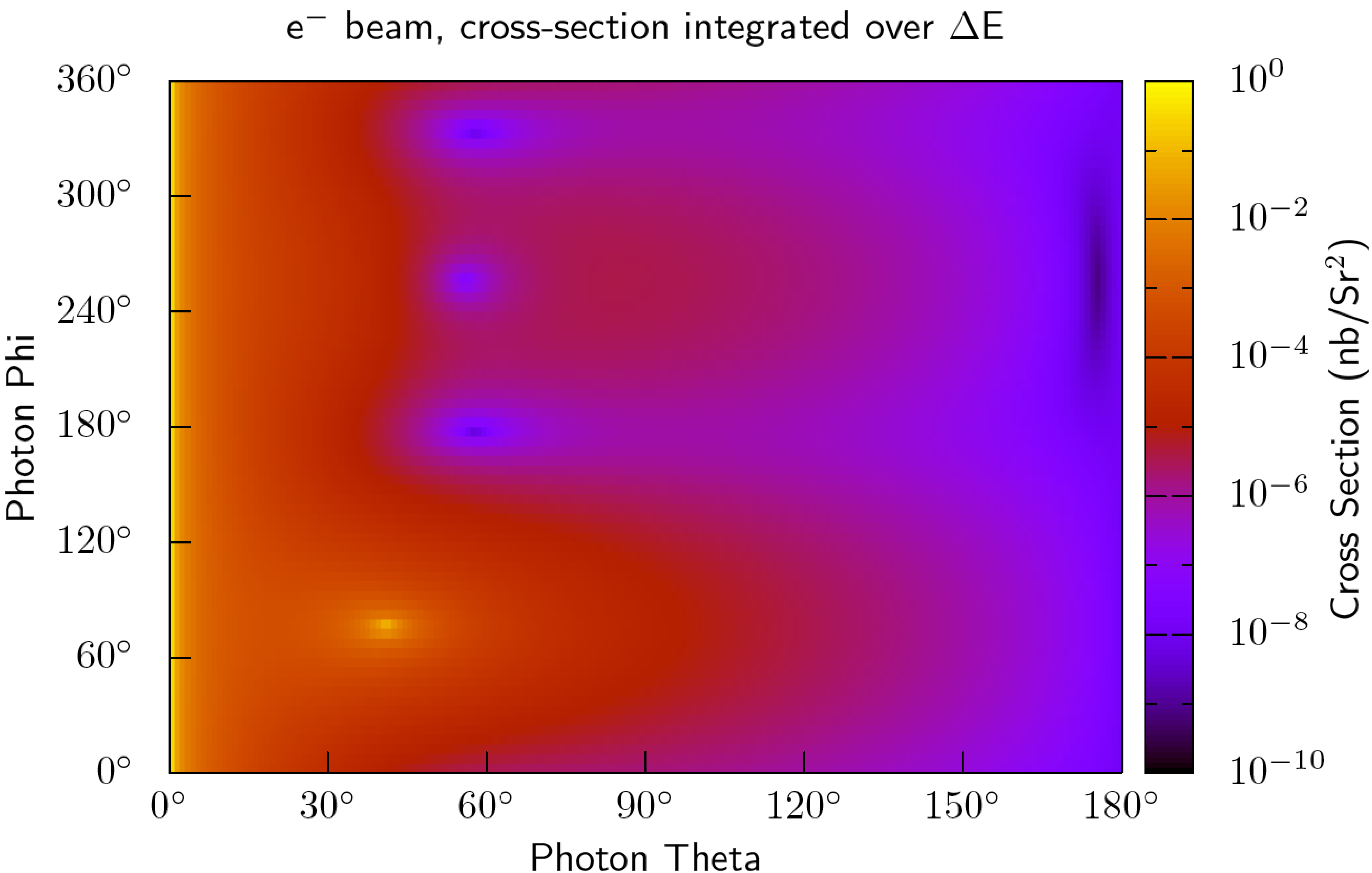
Corrections related to the bremsstrahlung of the first order. Their contribution is determined by the detector geometry!

Corrections are significant

- Depend on detector momentum resolution and cuts applied

Working with Novosibirsk and JLAB on common code

Radiated Photon Distribution



OLYMPUS Collaboration

13 institutions, 45 physicists, 10 students

- Arizona State University, USA - 1, 1
    - wire chambers, particle identification, simulations
- Deutsches Elektronen-Synchrotron, Germany - 4, 0
    - modifications to DORIS, DORIS operation, infrastructure
- Friedrich Wilhelms Universität Bonn, Germany - 4, 1
    - trigger, data acquisition, data quality monitor
- Hampton University, USA - 2, 1
    - 12° GEM luminosity monitor, simulations, data quality monitor
- Instituto Nazionale di Fisica Nucleare Bari, Italy - 2, 0
    - GEM electronics
- Instituto Nazionale di Fisica Nucleare Ferrara, Italy - 3, 0
    - target cell
- Instituto Nazionale di Fisica Nucleare Rome, Italy - 1, 0
    - GEM electronics
- Johannes Gutenberg Universität Mainz, Germany - 3, 1
    - Møller / Bhabha luminosity detector, simulations
- Massachusetts Institute of Technology, USA - 7, 4
    - BLAST spectrometer, wire chambers, target and vacuum system, trigger, slow control, Monte Carlo, analysis framework
- Petersburg Nuclear Physics Institute, Russia - 7, 1
    - 12° MWPC luminosity detector, data acquisition, slow control, simulations
- University of Glasgow, UK - 5, 0
    - time of flight detector, flasher system
- University of New Hampshire, USA - 1, 0
    - time of flight scintillator
- Yerevan Physics Institute, Armenia - 5, 1
    - time of flight scintillator, infrastructure support, simulations

Experimental Phase Nearly Over

Finish magnetic field map and optical survey this month

Concentrate on analysis

- good preliminary result in 6 months
- final result in 1 year

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Many people contributed to the success of OLYMPUS

- Alexander Winnebeck, Jürgen Diefenbach, Alexander Kisselev
  - all have moved on now but hopefully are available for phone calls late at night
- DORIS machine group
  - Frank Brinker
- PRC
- DESY

Thank You

OLYMPUS Timeline

2005

- May - BLAST Experiment at MIT-Bates ends
- November - BLAST @ ELSA - Kohl, Hasell, BLAST @ DORIS - Schneekloth, Hasell

2007

- May - 2-Photon Exchange seminars at DESY, Zeuthen, and PRC - Milner
- June - letter of intent

2008

- September - OLYMPUS proposal
- December - conditionally approved by DESY and the PRC

2009

- August - Technical Design Report
- september - technical review

2010

- January - received funding
- February - June - disassemble BLAST at MIT-Bates and ship to DESY
- July - start reassembly at DESY, rewire wire chambers, modify TOF detectors, remove ARGUS, and modify DORIS ring

2011

- January - install target and test detectors
- February - ring run to test target and measure rates and background
- July - finish assembly of OLYMPUS detector in the DORIS hall and roll into DORIS ring
- August - December - numerous test runs during DORIS service days

2012

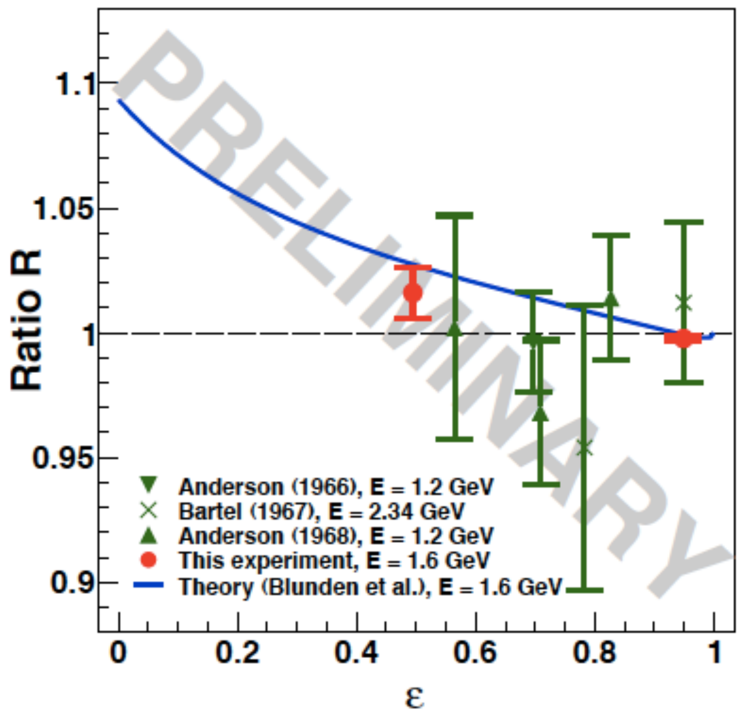
- February - first data run
- July - repair and reinstall target, fix bad channels, upgrade trigger
- October - December - second data run

2013

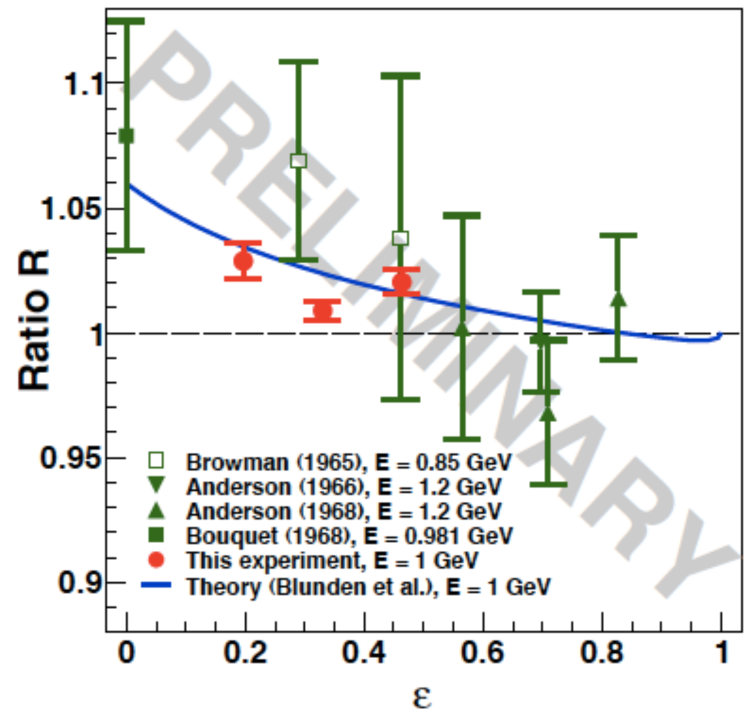
- January - April - cosmic run, optical survey of all detectors, magnetic field map

Novosibirsk and JLAB Experiments

Run I (2009):
$E_{beam} = 1.6$ GeV



Run II (2011–2012):
$E_{beam} = 1$ GeV



Theory: *P. G. Blunden, et al.*, Phys. Rev. C **72** (2005) 034612