Future experiments at the new MESA accelerator in Mainz

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Mainz University

Annual Meeting of the GDR PH-QCD,

CEA Saclay, November 26, 2013

Outline

- The new MESA accelerator in Mainz
- Experiments in ERL mode
  (Energy recovering mode)
- P2: Experiment in EB mode
  (External beam mode)

Hadron physics in Mainz

... A lot of developments in the past five years!

Helmholtz Institute Mainz:
Structure, Symmetrie and Stability of Matter and Antimatter
Close cooperation between Mainz Univsersity and GSI Darmstadt

German excellence initiative: Cluster of Excellence
"Precision Physics, Fundamental Interactions and Structure of Matter" (PRISMA)

New Collaborative Research Center at Johannes Gutenberg-University Mainz:
The Low-Energy Frontier of the Standard Model
From Quarks and Gluons to Hadrons and Nuclei.

Hadron physics in Mainz

... A lot of developments in the past five years!

MESA:
Mainz energy recovering superconducting accelerator

Project P2:
The weak charge of the proton

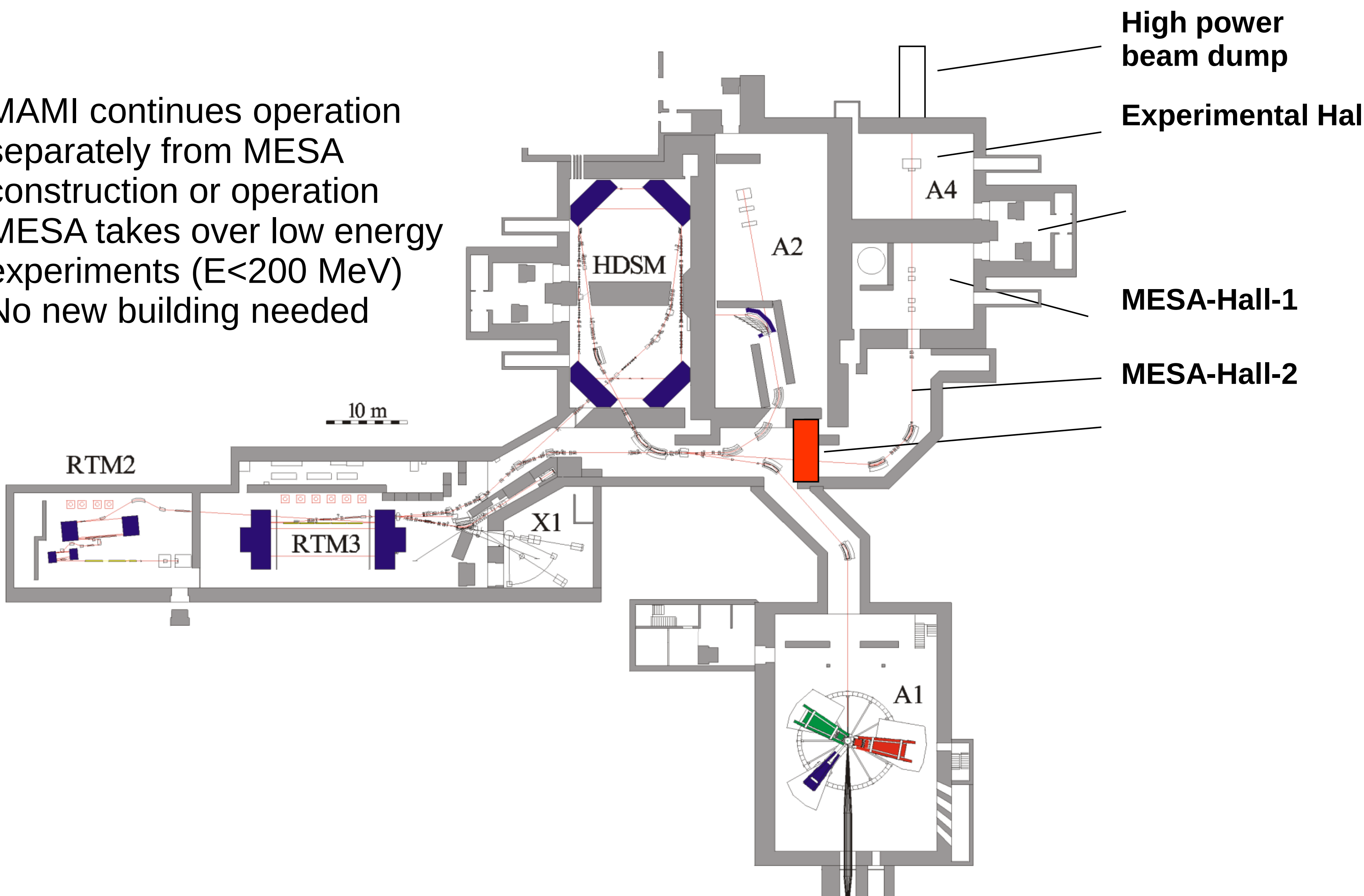
PRISMA

SFB 1044

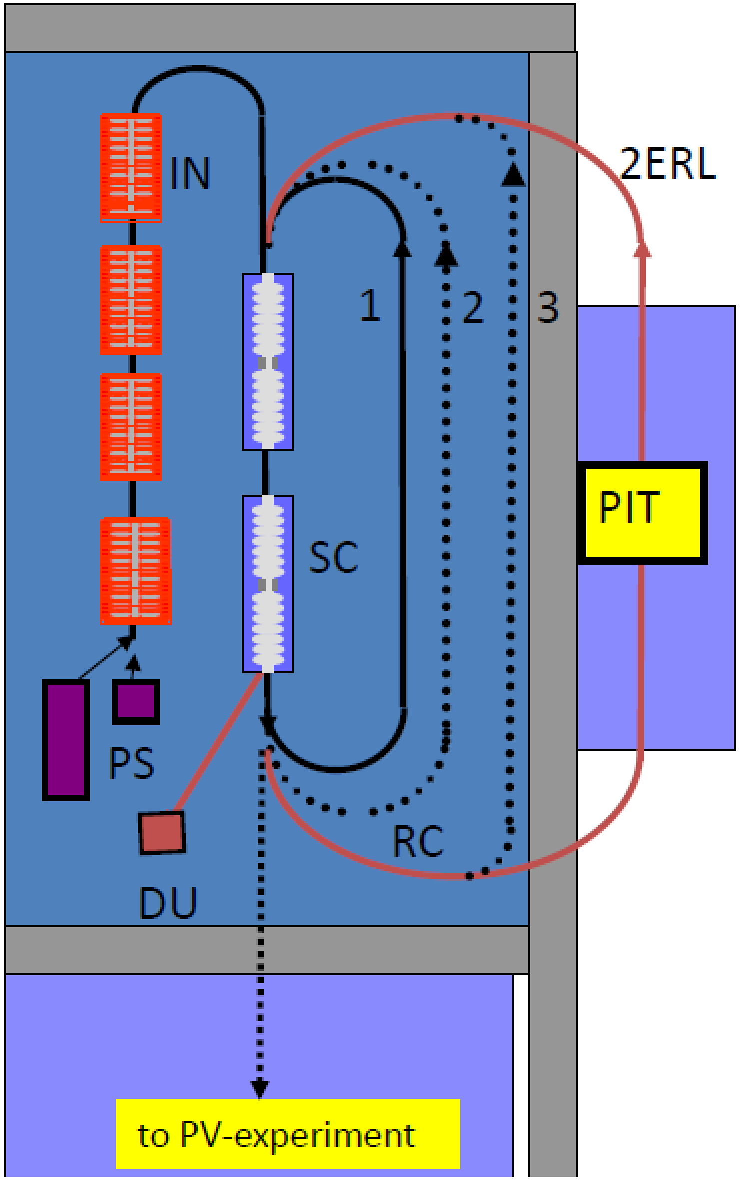
New Collaborative Research Center at Johannes Gutenberg-University Mainz:
The Low-Energy Frontier of the Standard Model
From Quarks and Gluons to Hadrons and Nuclei.

Basic idea of a new accelerator at MAMI facility

- MAMI continues operation separately from MESA construction or operation
- MESA takes over low energy experiments (E<200 MeV)
- No new building needed



Concept of MESA



Mainz **e**nergy recovering **s**uperconducting **a**ccelerator

1.3 GHz c.w. beam
Normal conducting injector LINAC
Superconducting cavities in recirculation beamline

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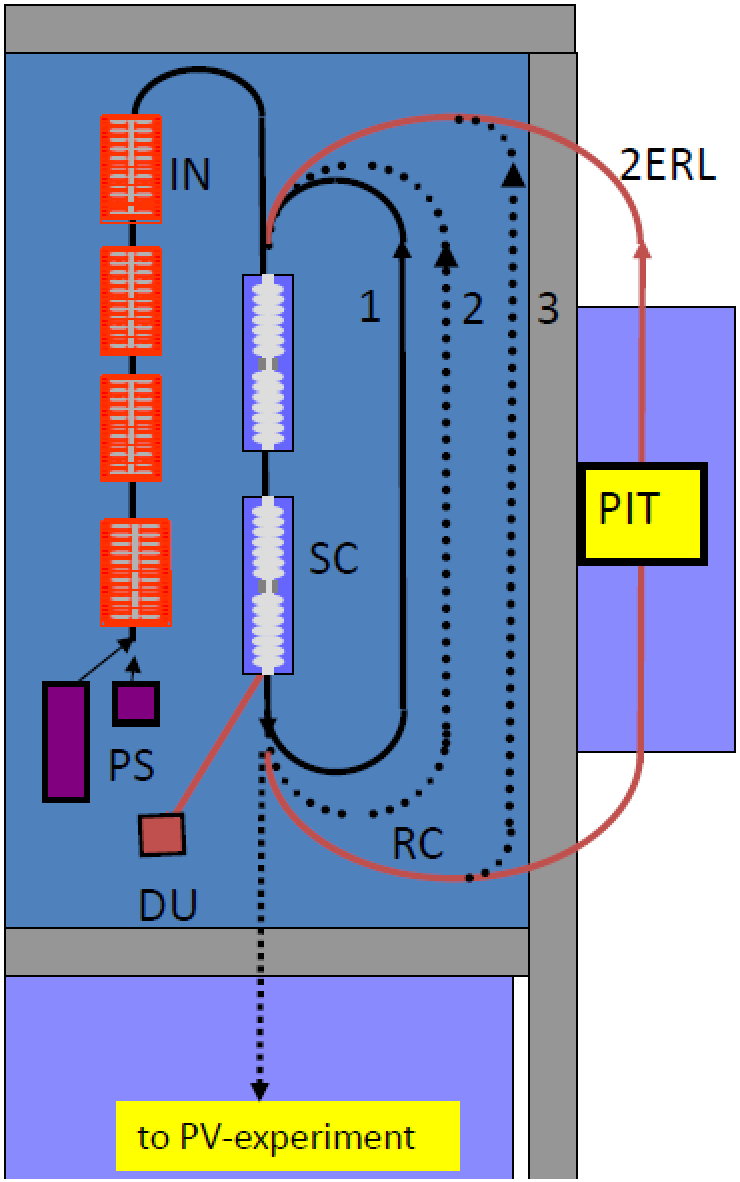

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ERL mode (Energy recovering mode):
10 mA, 100 MeV unpolarized beam (pseudo internal gas hydrogen target L~10^{35} $cm^{-2}s^{-1}$)

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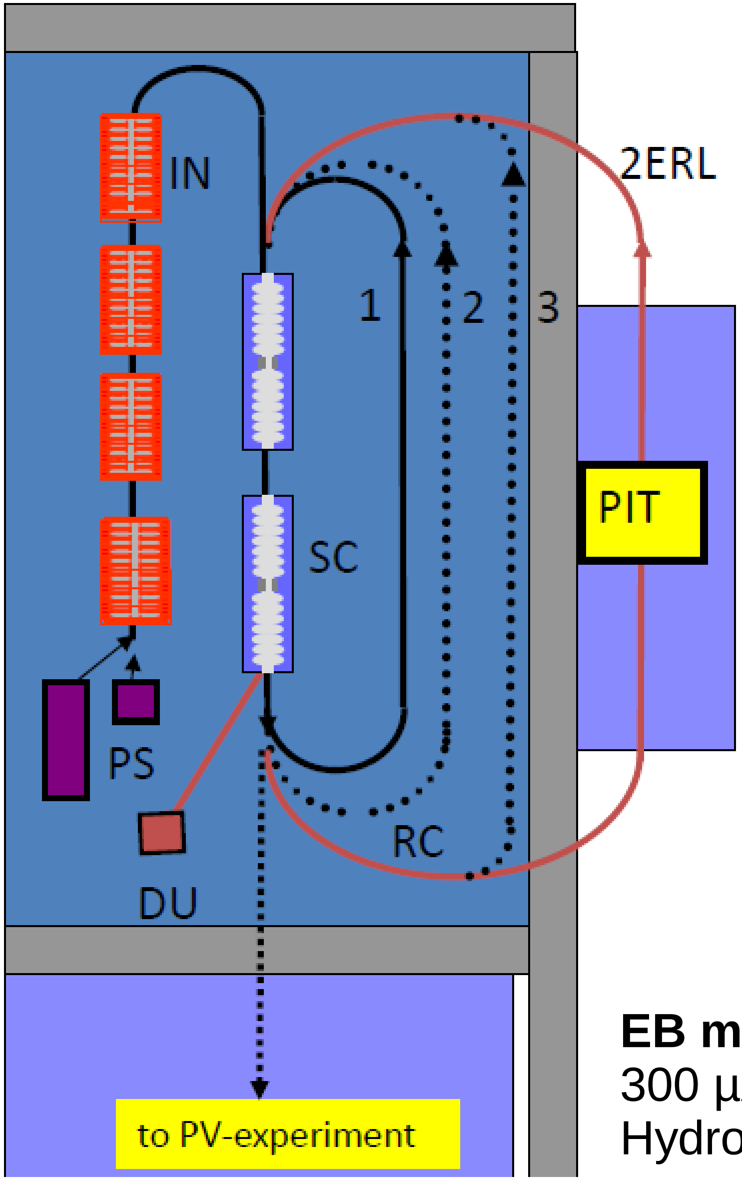

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ERL mode (Energy recovering mode):
10 mA, 100 MeV unpolarized beam (pseudo internal gas hydrogen target L~10^{35} $cm^{-2}s^{-1}$)

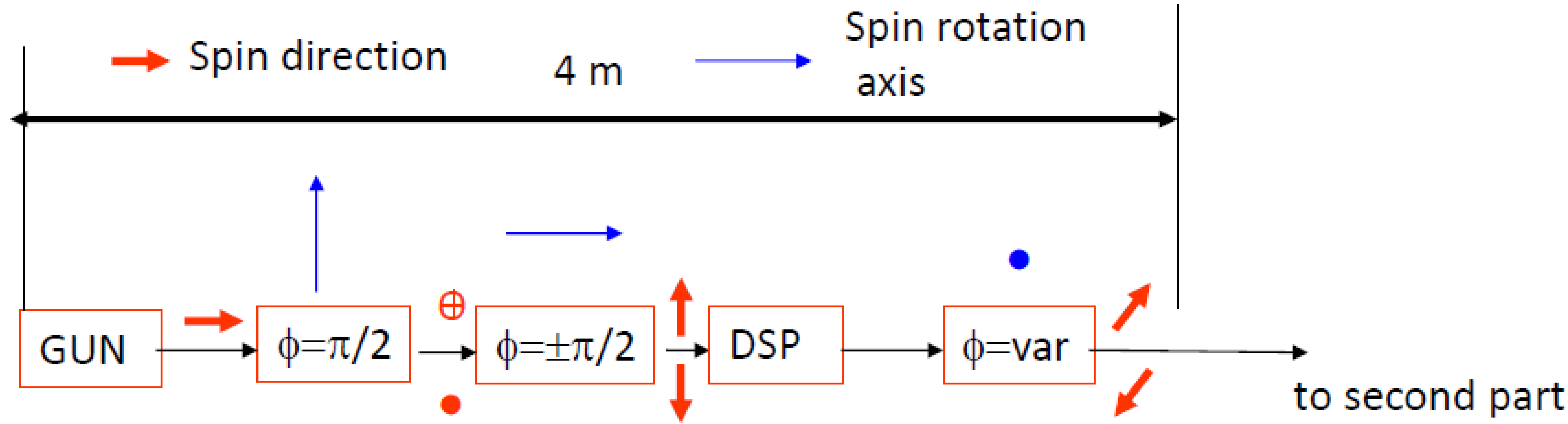
EB mode (External beam):
300 µA, 150 MeV polarized beam (liquid Hydrogen target L~10^{39} $cm^{-2}s^{-1}$)

MESA: Beam parameter

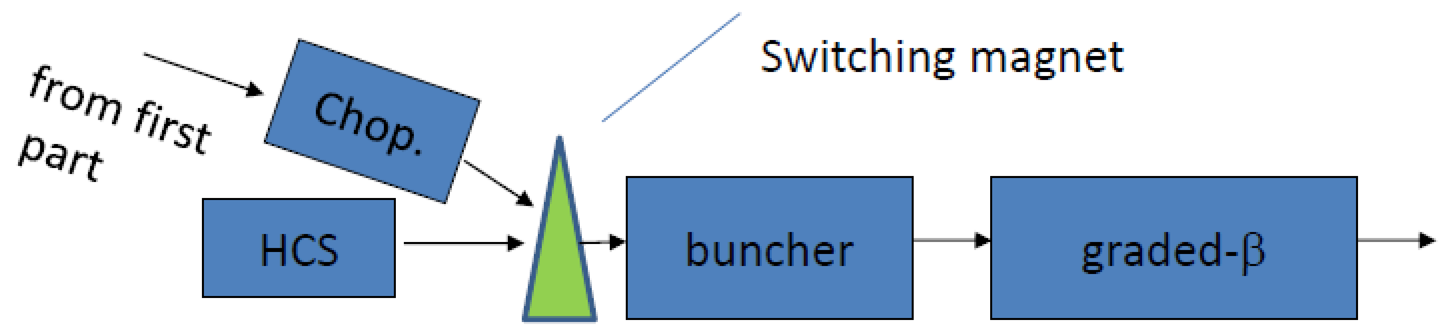
Beam Energy ERL/EB [MeV]	105/155 (105/205)
Operation mode	1300 MHz, c.w.
Elektron-sources	1.) Polarised : NEA GaAsP/GaAs superlattice , 200keV (?) 2.) unpolarised KCsSb, 200keV
Bunch Charge EB/ERL [pC] 7.7pC=10mA@1300MHz	0.15/0.77 (0.15/7.7)
Norm. Emittance EB/ERL [µm]	0.1/<0.5 (0.1/<1)
Spin Polarisation (EB-mode only)	> 0.85
Recirculations	2 (3)
Beampower at Exp. ERL/EB [kW]	100/22.5 (1050/30)
R.f.-Power installed [kW]	140 (180)

MESA: Polarized source layout

strongly influenced by need of 'false' asymmetry control! A_{false} <0.2ppb



Systematic electron optical helicity reversal! (similar to JLAB/QWEAK)



- Polarized Source& Injector overall length ~15m

MESA: Cryomodules

ELBE
Cryomodule

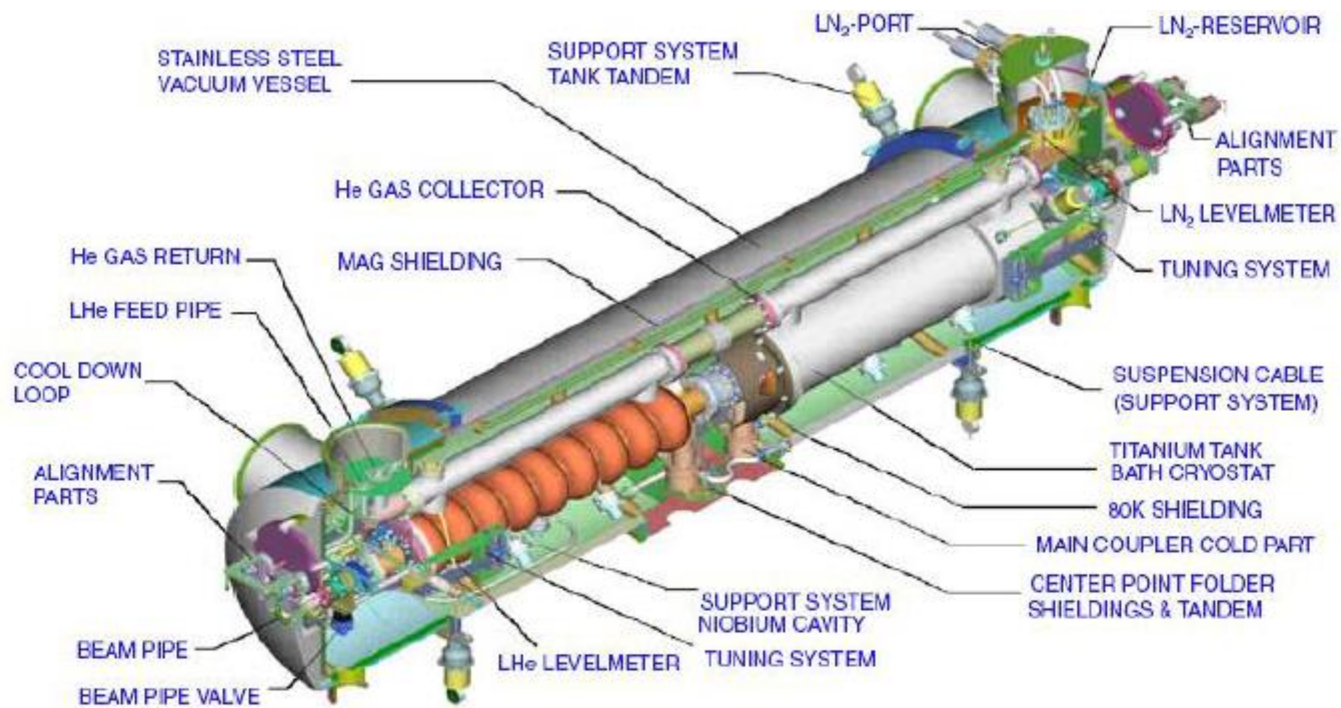
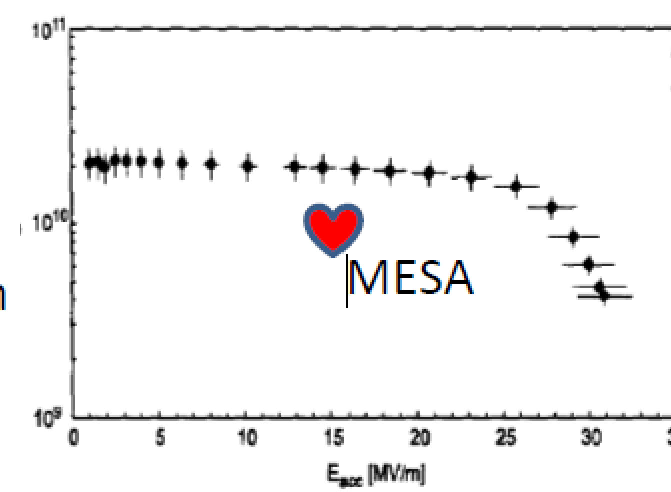


Fig. 1. Three-dimensional drawing of the ELBE cryomodule.

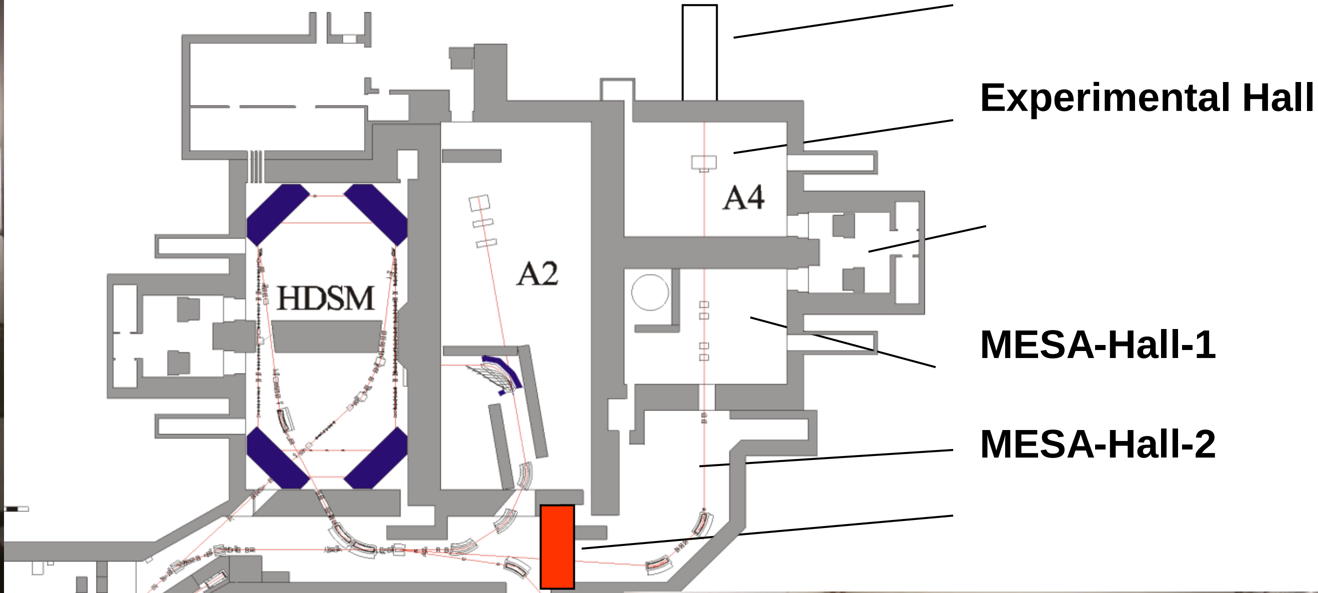
J. Teichert et al. NIMA 557 (2006) 239

- "ELBE" –Modules are suitable for high gradient c.w. operation.
- Commercially available, no additional R&D
- Costs & Delivery time are (to some extent) predictable
- Limitation in Cryopower requires $Q_0=10^{10}$ at 14MeV/m (achieved at DESY/FLASH in operation with TESLA cavity)

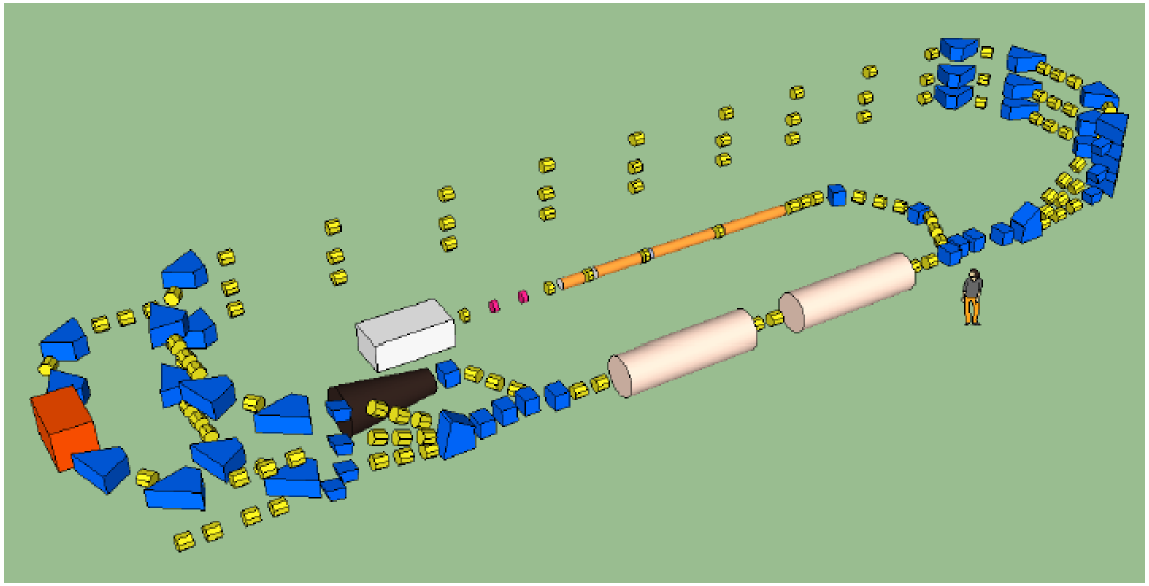


MESA: Preparatory Work

Broom indicates size…..

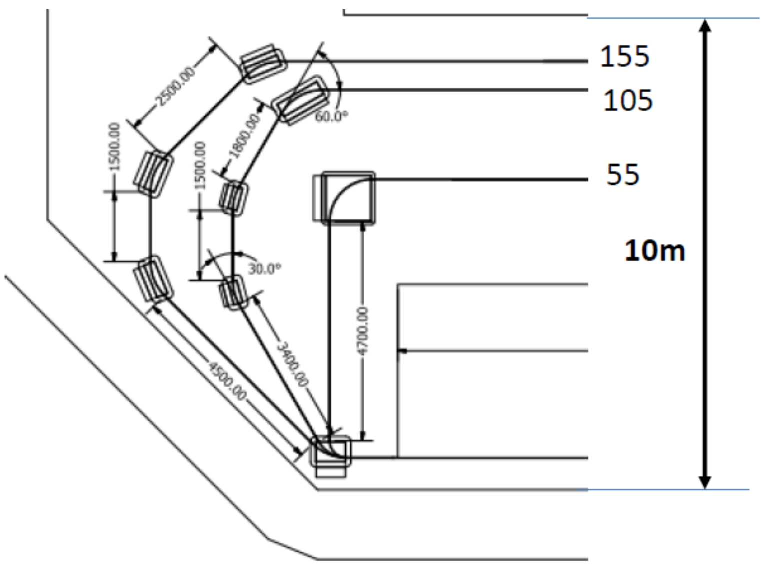


MESA: Lattices under investigation



„CEBAF“ inspired

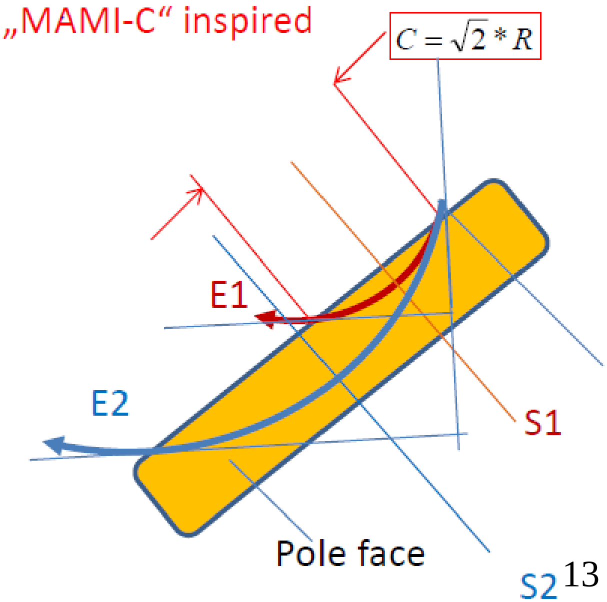
Design: Ralph Eichhorn



„S-DALINAC“ inspired

90 degree Segment

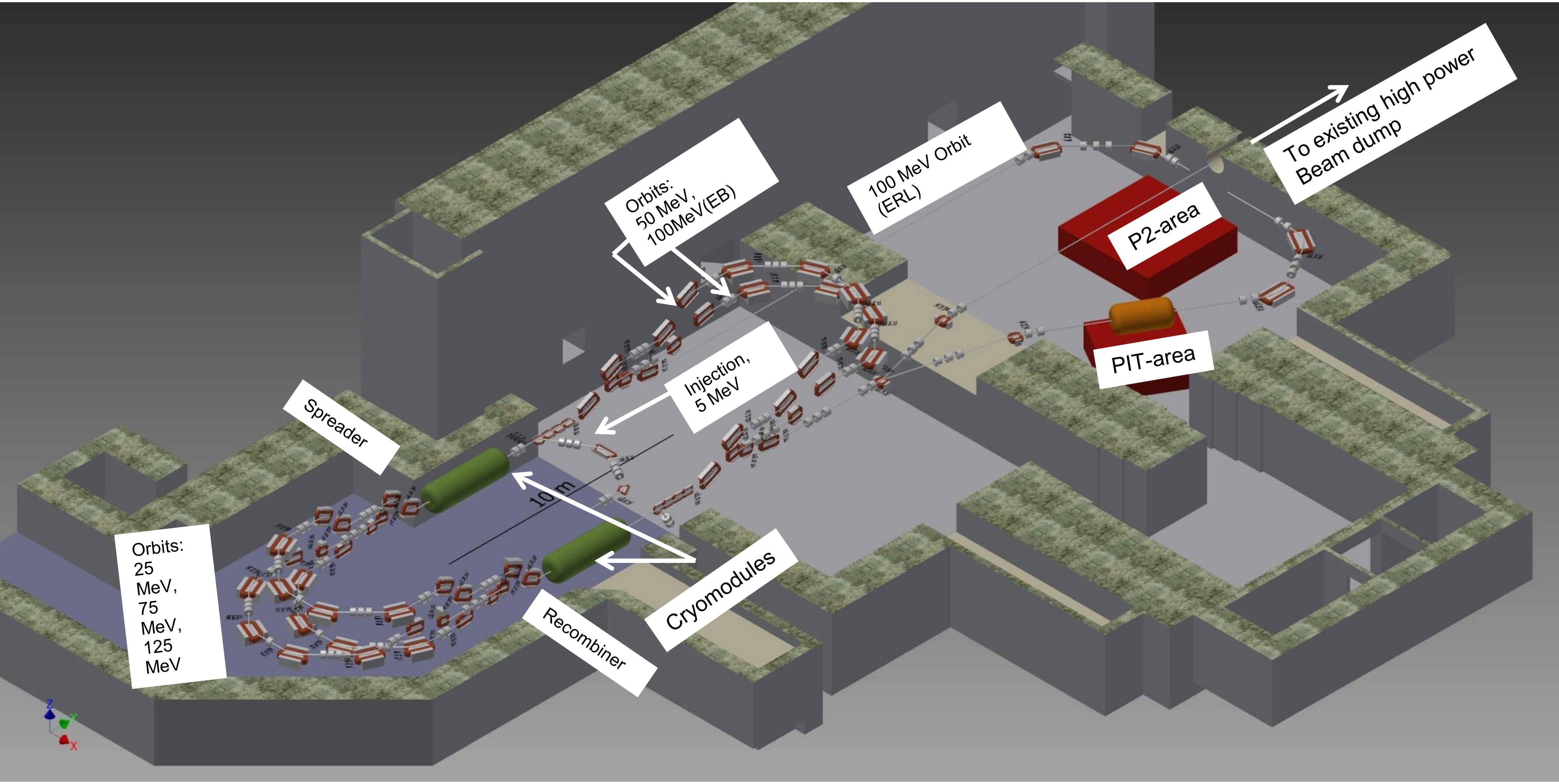
„MAMI-C“ inspired



Design: Daniel Simon,

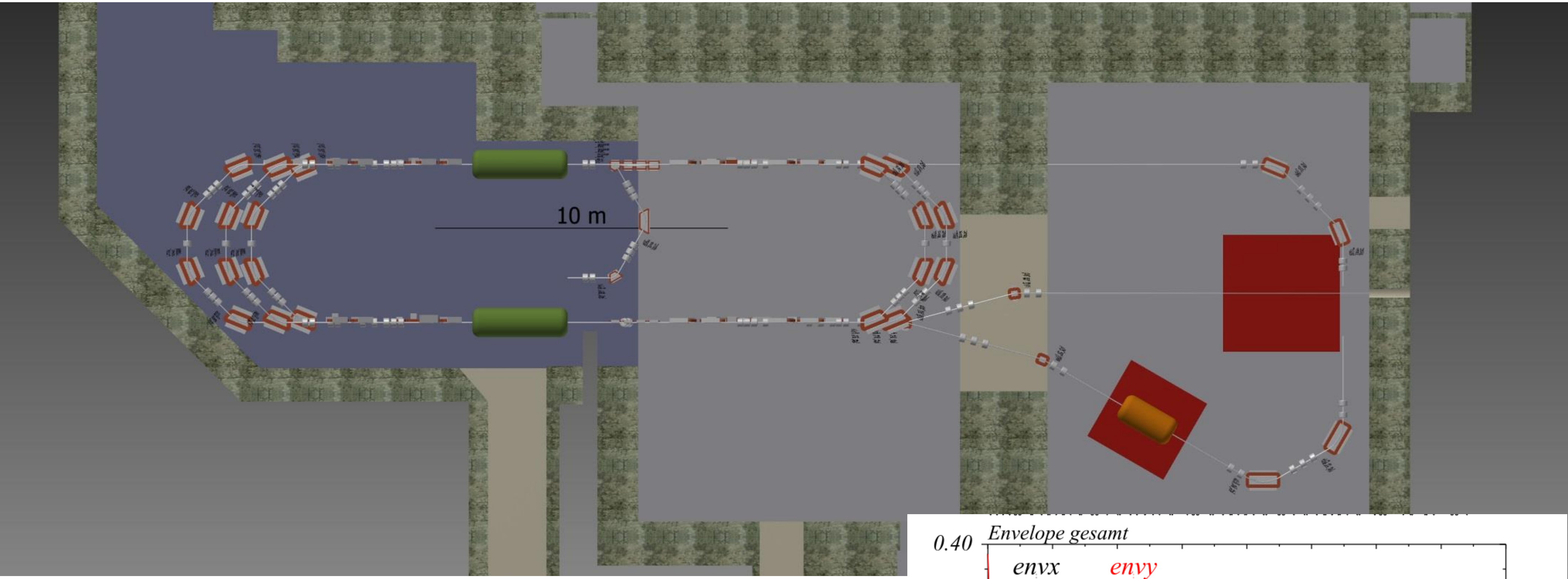
Diploma thesis: Scetch of flat lattice with realistic dipole dimensions

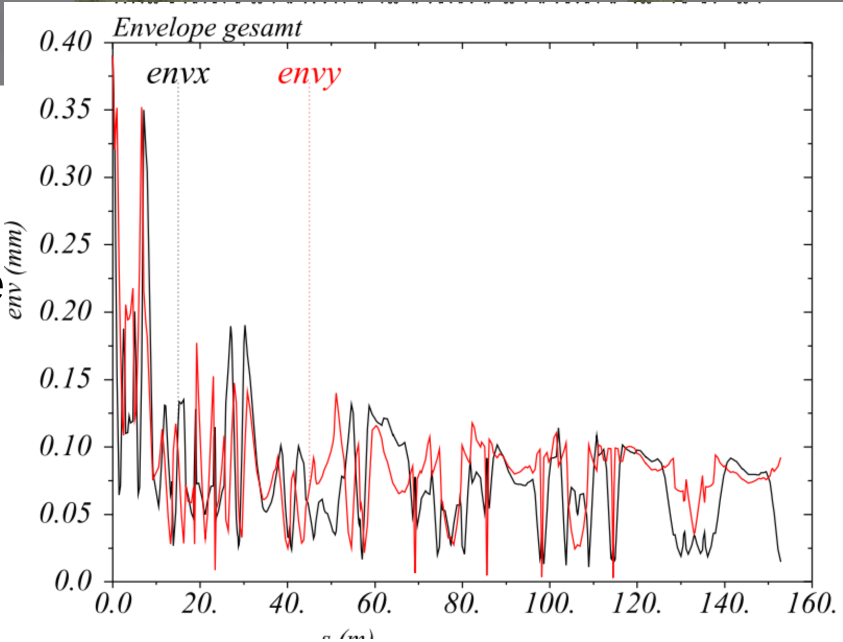
MESA-Lattice concept



„Double axis“ acceleration, CEBAF inspired

MESA-Layout





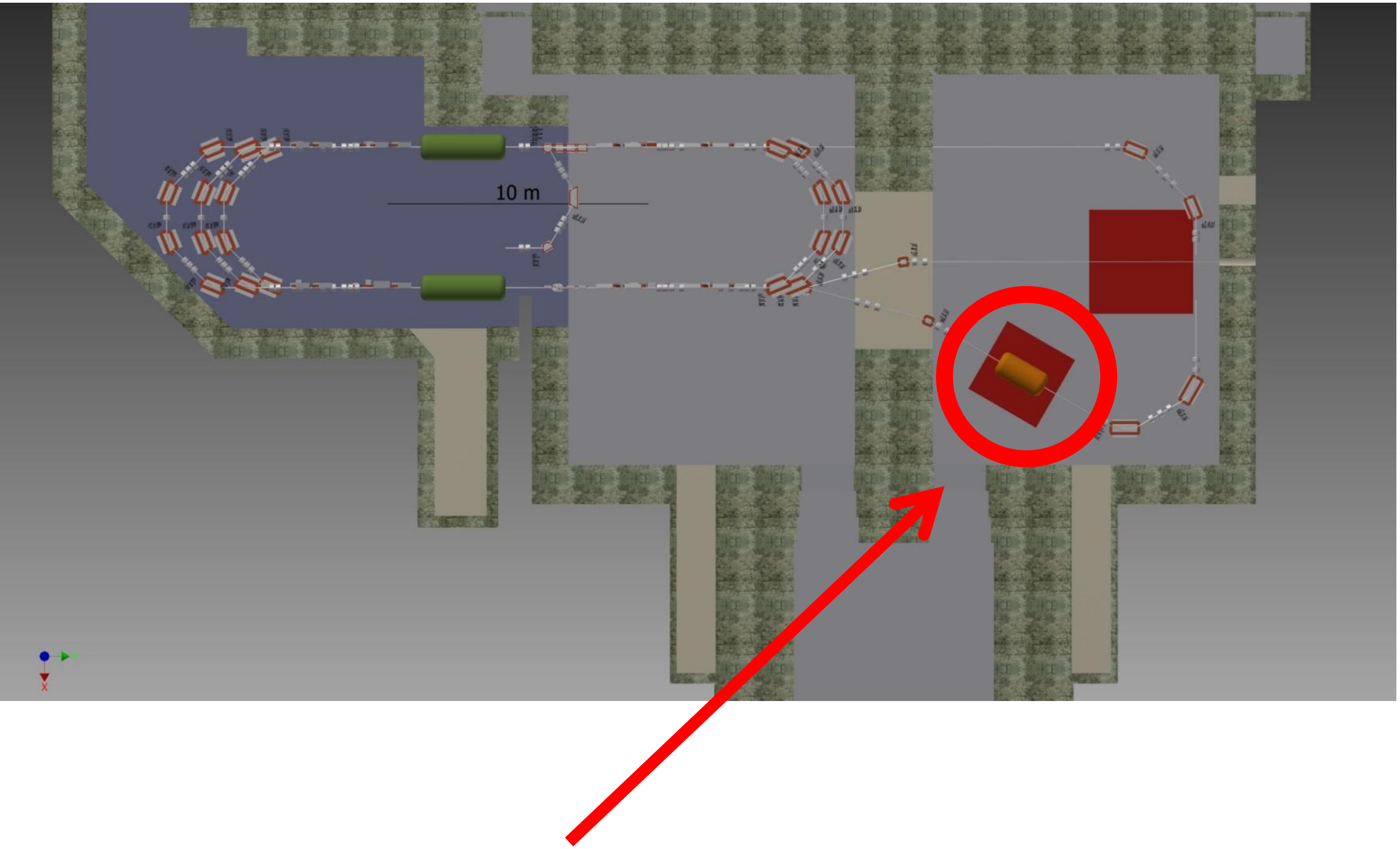
Features:

1.) Minimized intrusion into building
2.) Beam transport EB/ERL trough lattice feasible
3.) Can be made compatible with four seater cryomodule
4.) Energy doubling seems in principle feasible
(200MeV ERL/300MeV EB)

MESA: Outlook

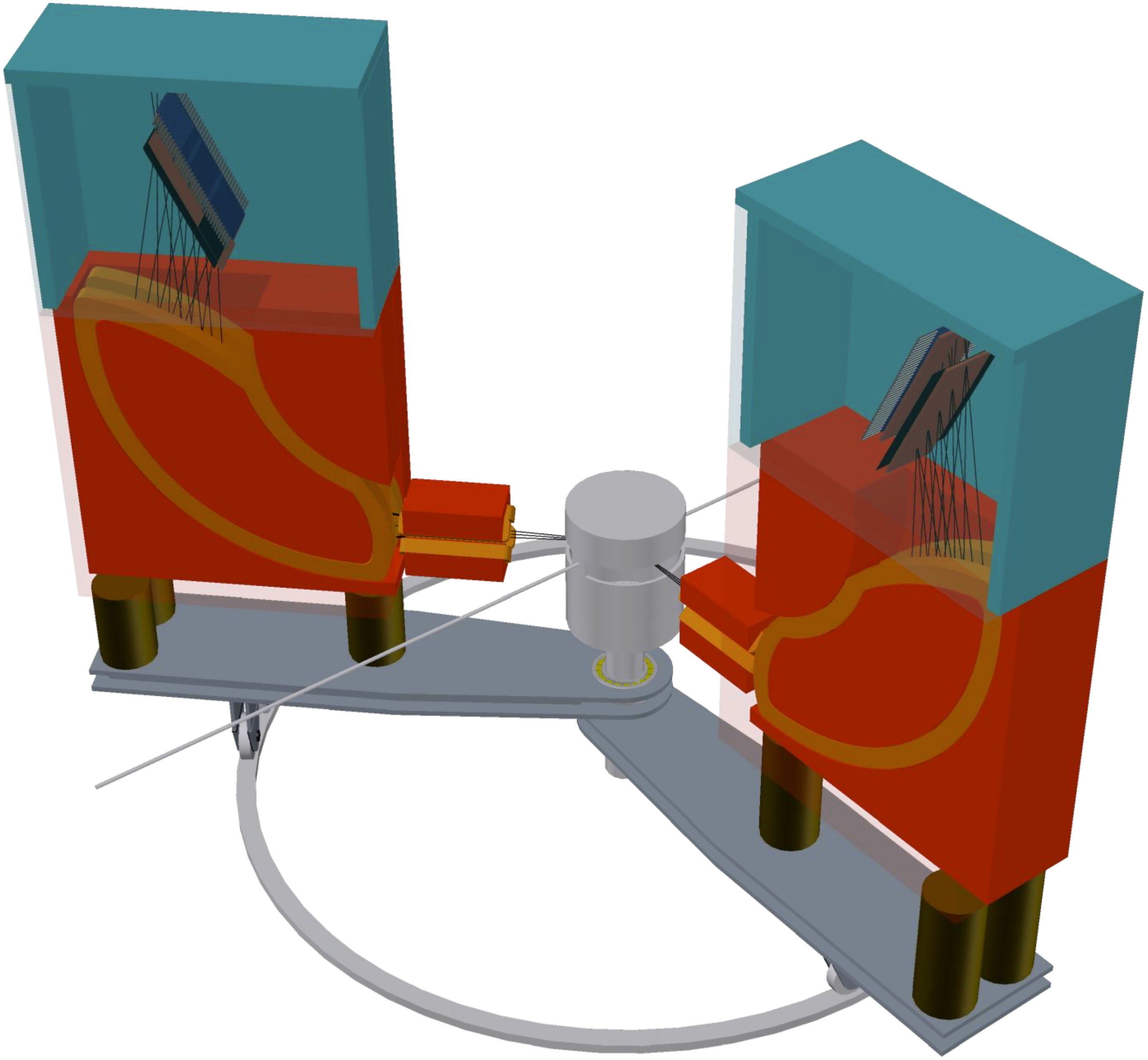
- End 2013 Decision Cryomodule
- Spring 2014 Decision Lattice
- Summer 2014 Infrastructure modifications
- End 2014 Start Injector assembly
- 2015/16 Assembly Lattice, Cryoplant ready.
- End 2016 Delivery Cryomodule
- 2017 Commisioning Cryomodule
- End 2017 MESA commissioning

Experiments in ERL mode



Use pseudo-internal target
10 mA, 100 MeV unpolarized beam (L~10^{35} cm^{-2}s^{-1})

Experiments in ERL mode

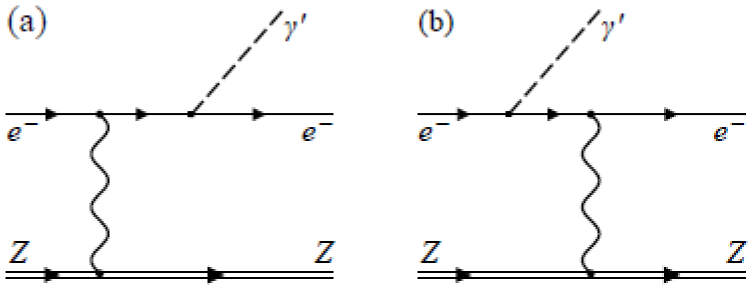


High resolution double spectrometer

- **Dark photon search**
- Nucleon structure
- Nuclear physics
- ...

Design and calculations already done

Dark photon search



$$e + Z \rightarrow e' + Z + \gamma'$$
$$\hookrightarrow e^+ + e^-$$

Weizsäcker-Williams approximation:

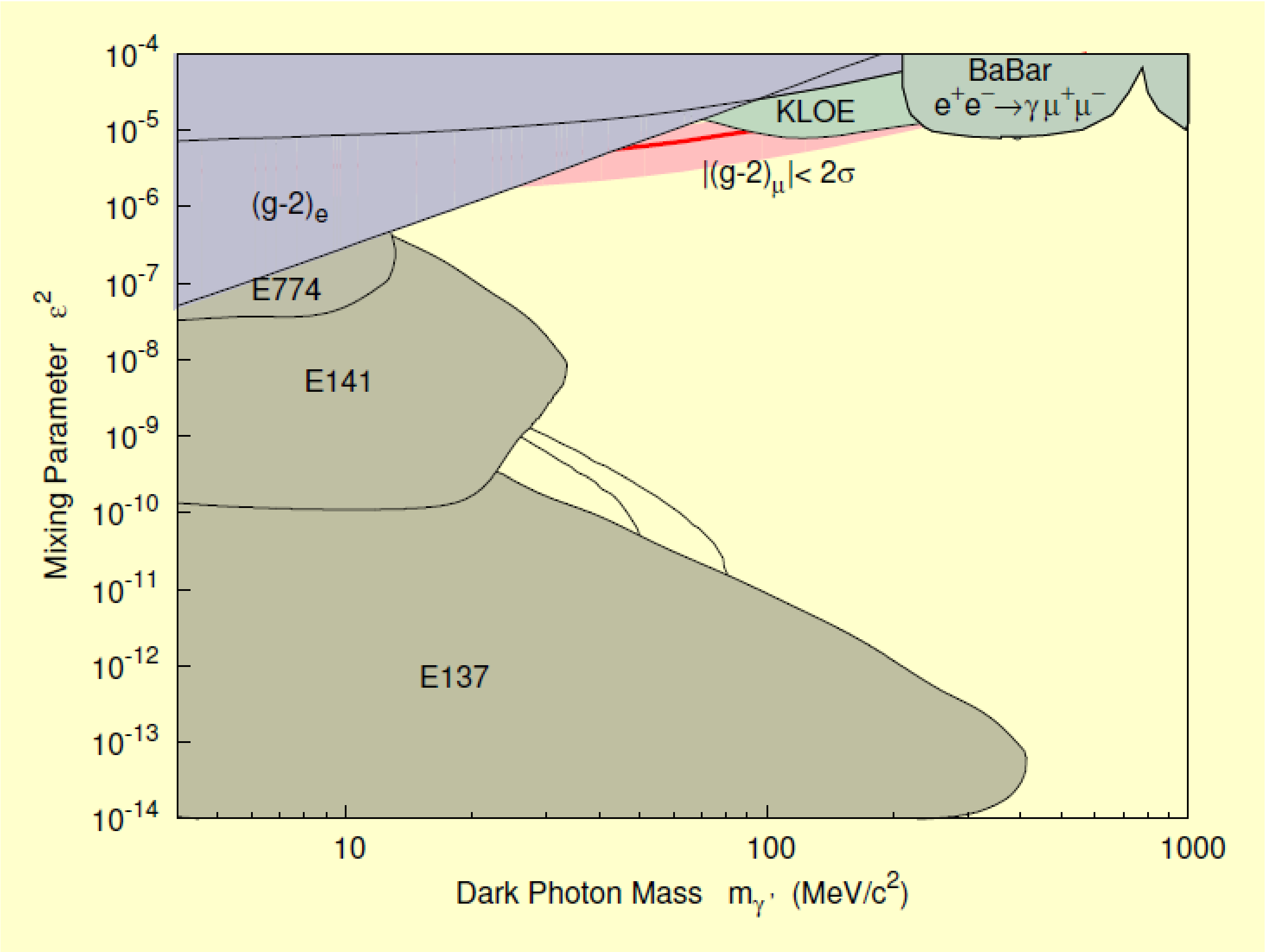
$$\frac{d\sigma}{dx\, d\cos\theta_{\gamma'}} \approx \frac{8 Z^2 \alpha^3 \varepsilon^2 E_0^2 x}{U^2} \tilde{\chi} \left[\left(1 - x + \frac{x^2}{2}\right) - \frac{x(1-x)\, m_{\gamma'}^2 \left(E_0^2 x \theta_{\gamma'}^2\right)}{U^2} \right]$$

with
$$x = \frac{E_{\gamma'}}{E_0}$$
$$U(x, \theta_{\gamma'}) = E_0^2 x \theta_{\gamma'}^2 + m_{\gamma'}^2 \frac{1-x}{x} + m_e^2 x$$

Lifetime:

$$\gamma c \tau \sim 1\ \mathrm{mm} \left(\frac{\gamma}{10}\right) \left(\frac{10^{-4}}{\varepsilon}\right)^2 \left(\frac{100\,\mathrm{MeV}}{m_{\gamma'}}\right)$$

Dark photon: Exclusion limits from existing experiments

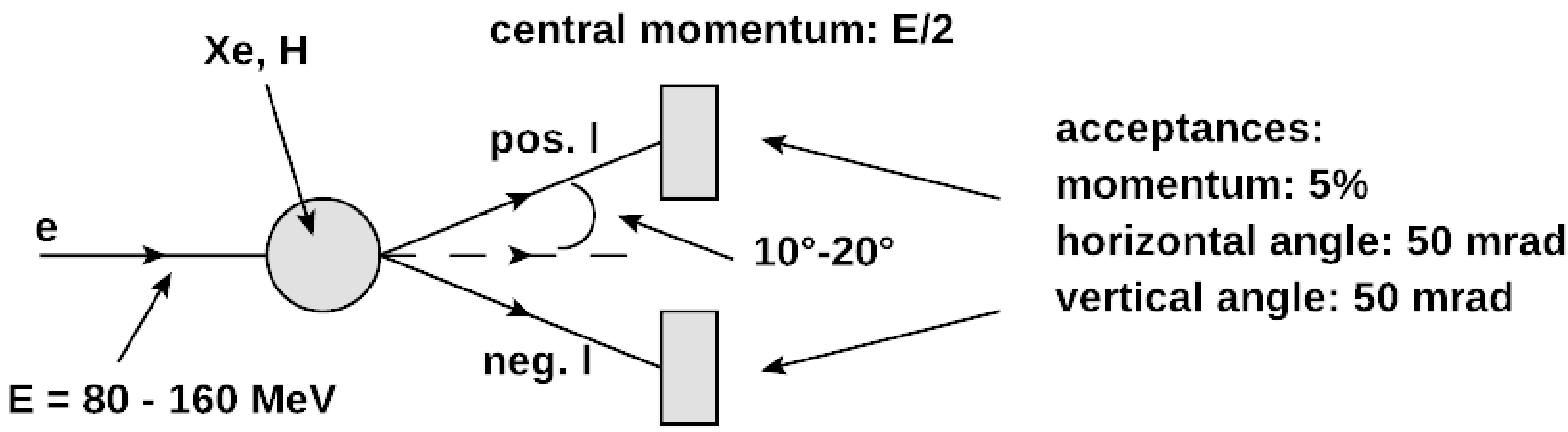


Dark photon: First measurements at MAMI

Performed by A1 collaboration

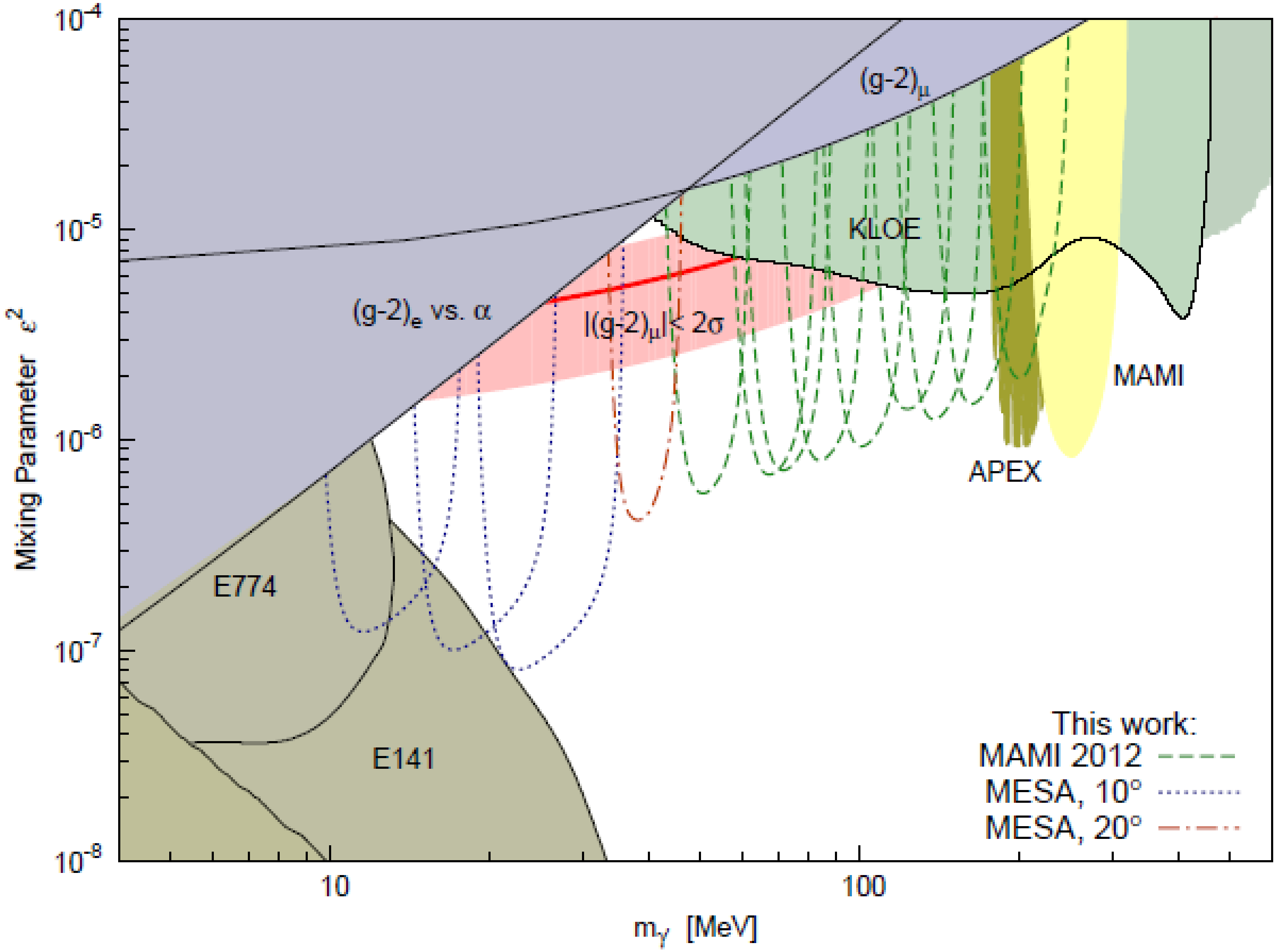
- Target: 0.05 mm Tantalum (mono-isotopic ^{181}Ta)
- Beam current: $100\mu A$
- Luminosity: $L = 1.7 \cdot 10^{35} \frac{1}{\mathrm{s\,cm}^2}$ $\quad (L \cdot Z^2 \approx 10^{39} \frac{1}{\mathrm{s\,cm}^2})$
- Complete energy transfer to γ' boson ($x = 1$)
- Minimal angles for spectrometers
- Spectrometer setup as symmetric as possible (background reduction)

Dark photon: Feasibility study for MESA

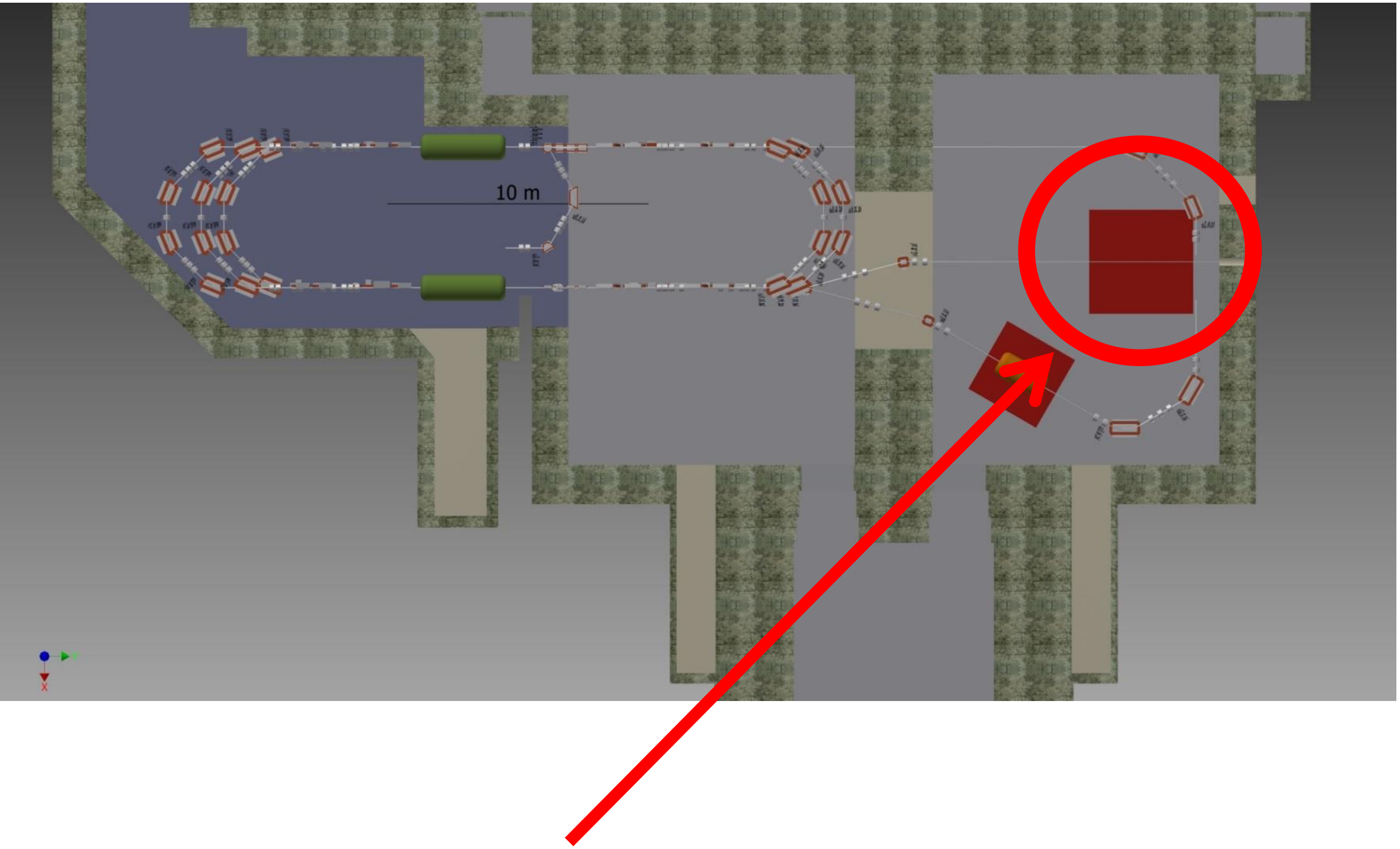


- Use two small spectrometers
- Beam energies: 80, 120, 160 MeV
- Scattering angle: 10° and for higher masses 20°
- Xenon or Hydrogen as target

Dark photon search: Explorable range with MAMI and MESA

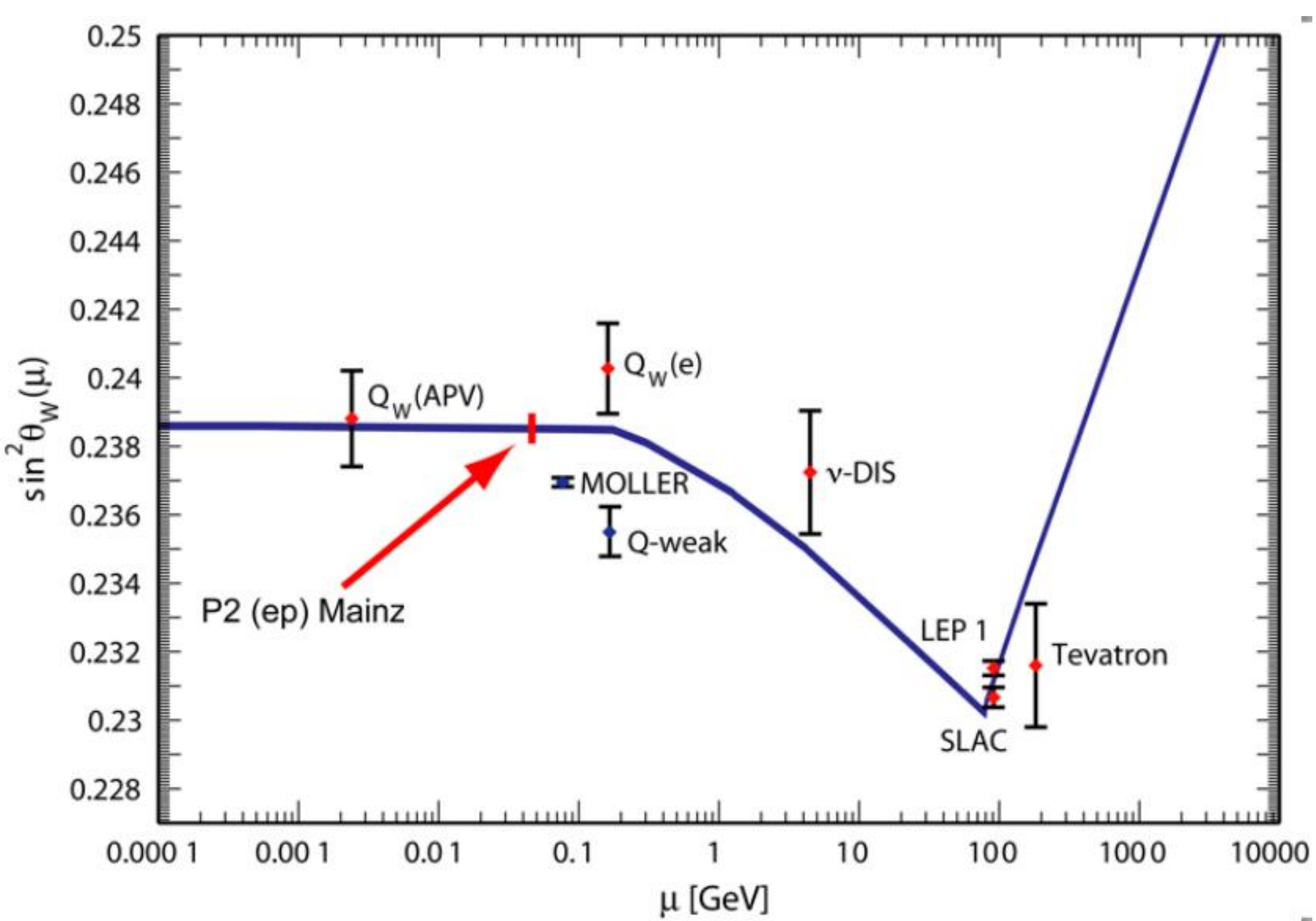


Experiment in EB mode: P2



External beam, no energy recovery
300 µA, 150 MeV polarized beam ($L \sim 10^{39}$ $cm^{-2}s^{-1}$)

The weak mixing angle $\sin^2\Theta_W(\mu)$



Measurements:

- Atomic parity violation
- Neutrino scattering
- LEP and SLAC
- Tevatron
- Q-weak (finished data taking)
- Moller (planned)
- **P2 (planned)**

Standard model relations

Relations at tree-level (classical level), e.g.,

- electric charge $e = \sqrt{4\pi\alpha} = g_1 \cos\theta_W = g_2 \sin\theta_W$
- $\cos\theta_W = M_W / M_Z$
- Muon decay constant: $G_\mu = \frac{\pi\alpha}{\sqrt{2}\sin^2\theta_W M_W^2}$
- ... and many more

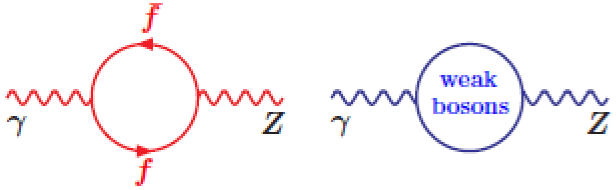
Including quantum corrections (perturbation theory):

- $G_\mu = \frac{\pi\alpha}{\sqrt{2}\sin^2\theta_W M_W^2}(1+\Delta r)$

  with

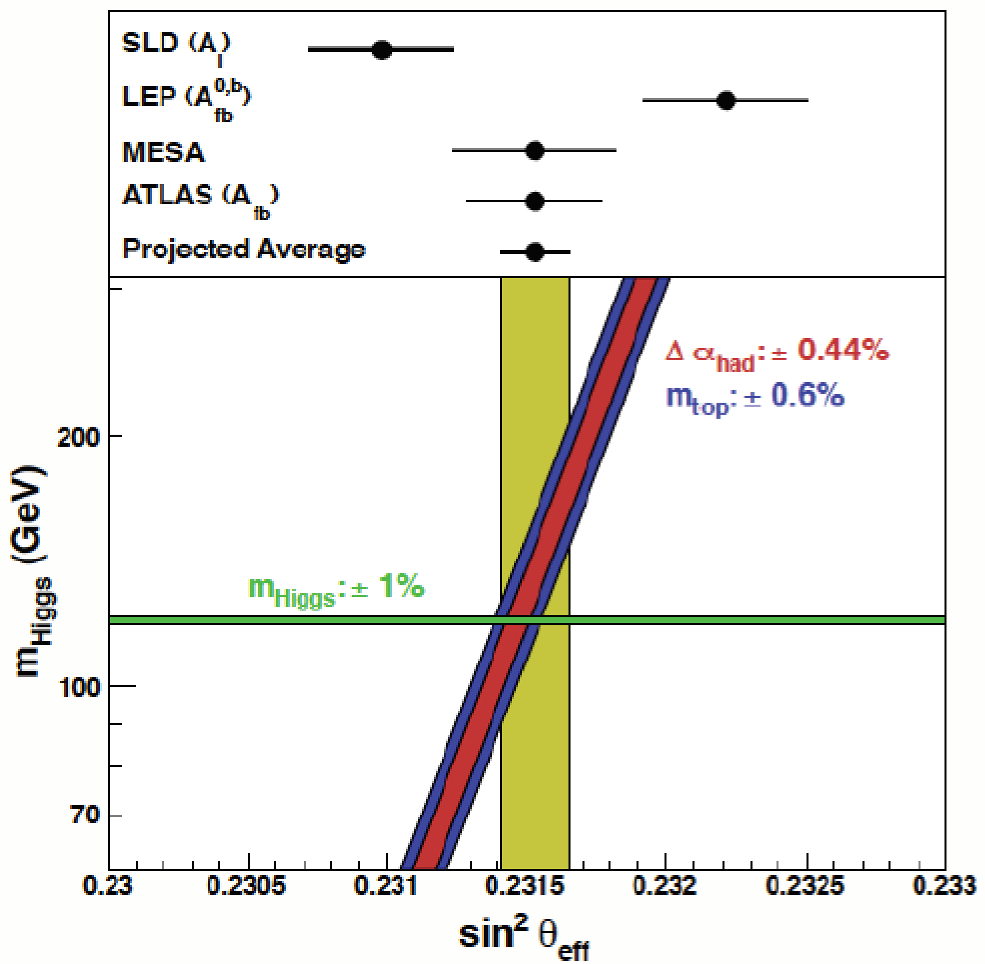
  $\Delta r = \Delta r(\alpha, M_W, \sin\theta_W, m_{top}, M_{Higgs}, \ldots)$

- Absorb universal quantum corrections



  into effective, running, scale-dependent parameters, denoted $\sin^2\theta_{\rm eff}$ or $\sin^2\theta_W(\mu)$ where μ is a characteristic energy scale

Standard model relations

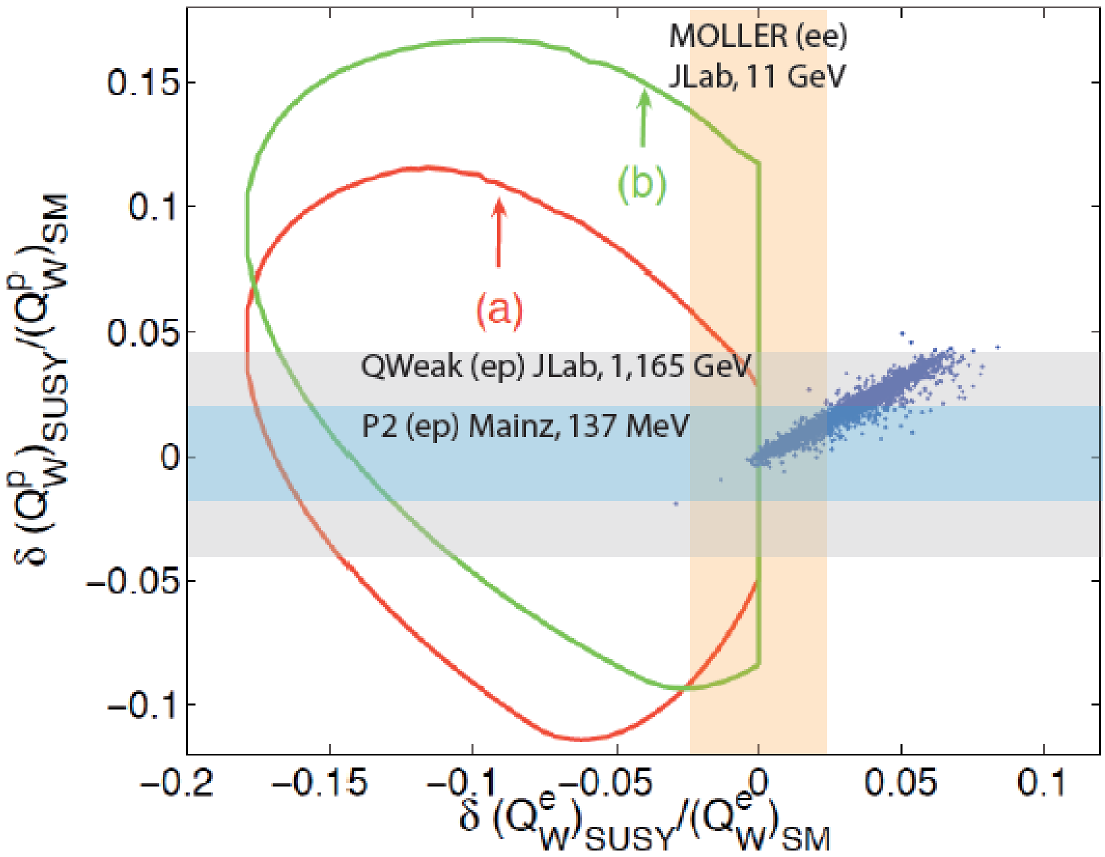


Combination of precision measurements at the Z-pole
→ M_{Higgs} - $\sin^2\theta_W(\mu)$ relation (red-blue band)

Precision measurement of $\sin^2\theta_W(\mu)$ provides indirect evidence for the range of allowed Higgs mass values

Combination of measurements provide strong tests of the SM,
. . . and maybe evidence for new physics (notice: conflicting measurements from LEP/SLD)

The weak charge and supersymmetric models



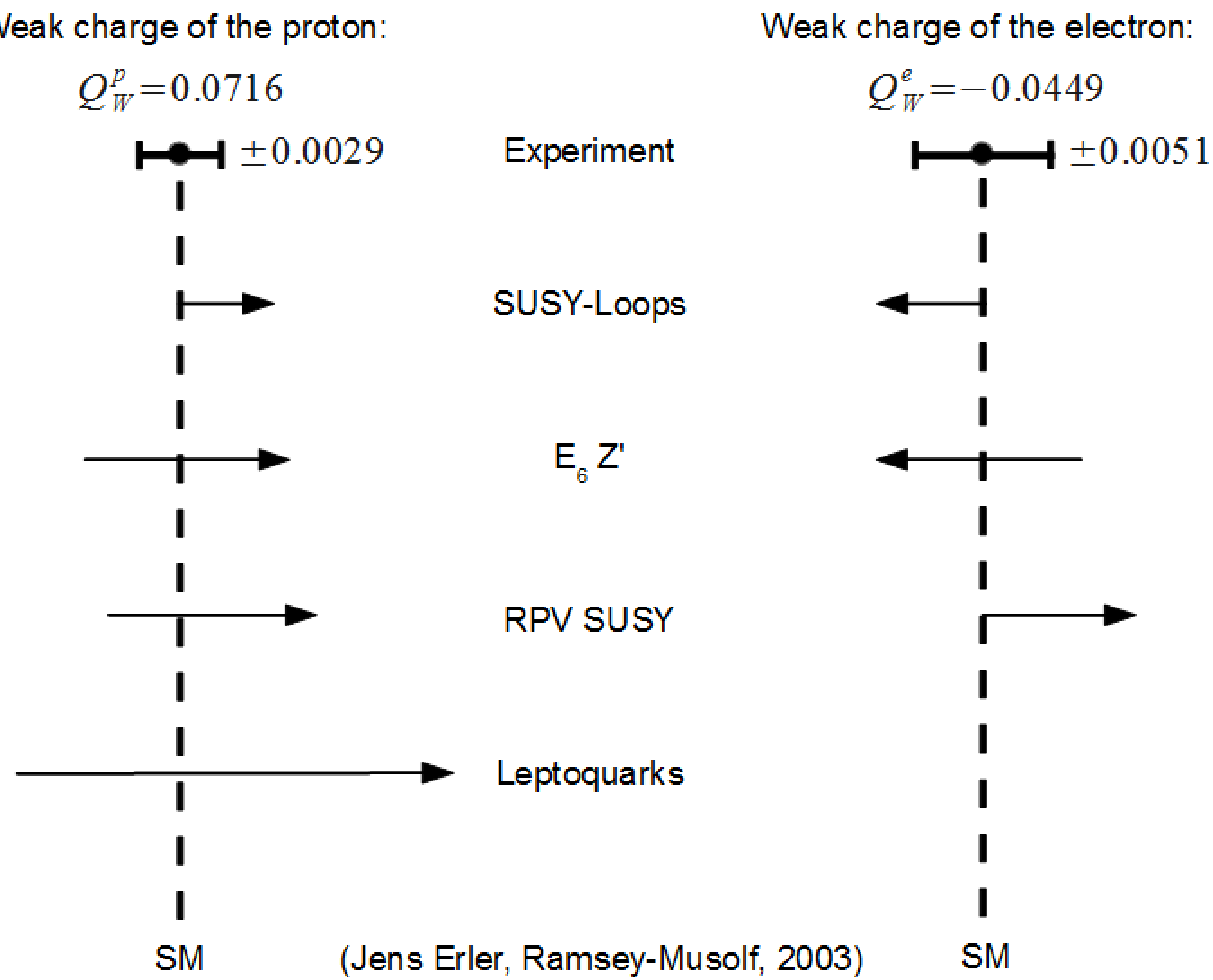
Characteristic shifts of Q_W predicted by extensions of the Standard Model

Example: supersymmetric models with and without R-parity violation

Precision measurement Mainz P2 is sensitive to TeV-scale physics

Weak charges: Sensitivity to new physics

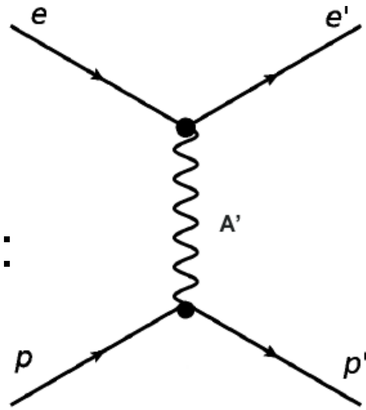
- Complementary access by weak charges of proton and electron



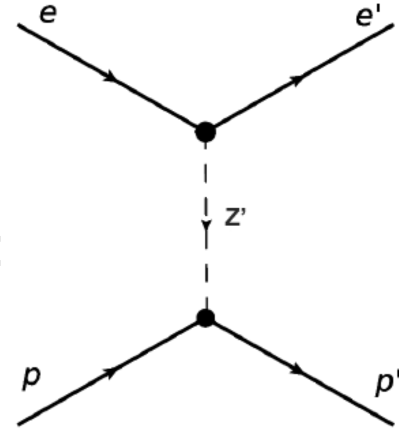
(Jens Erler, Ramsey-Musolf, 2003)

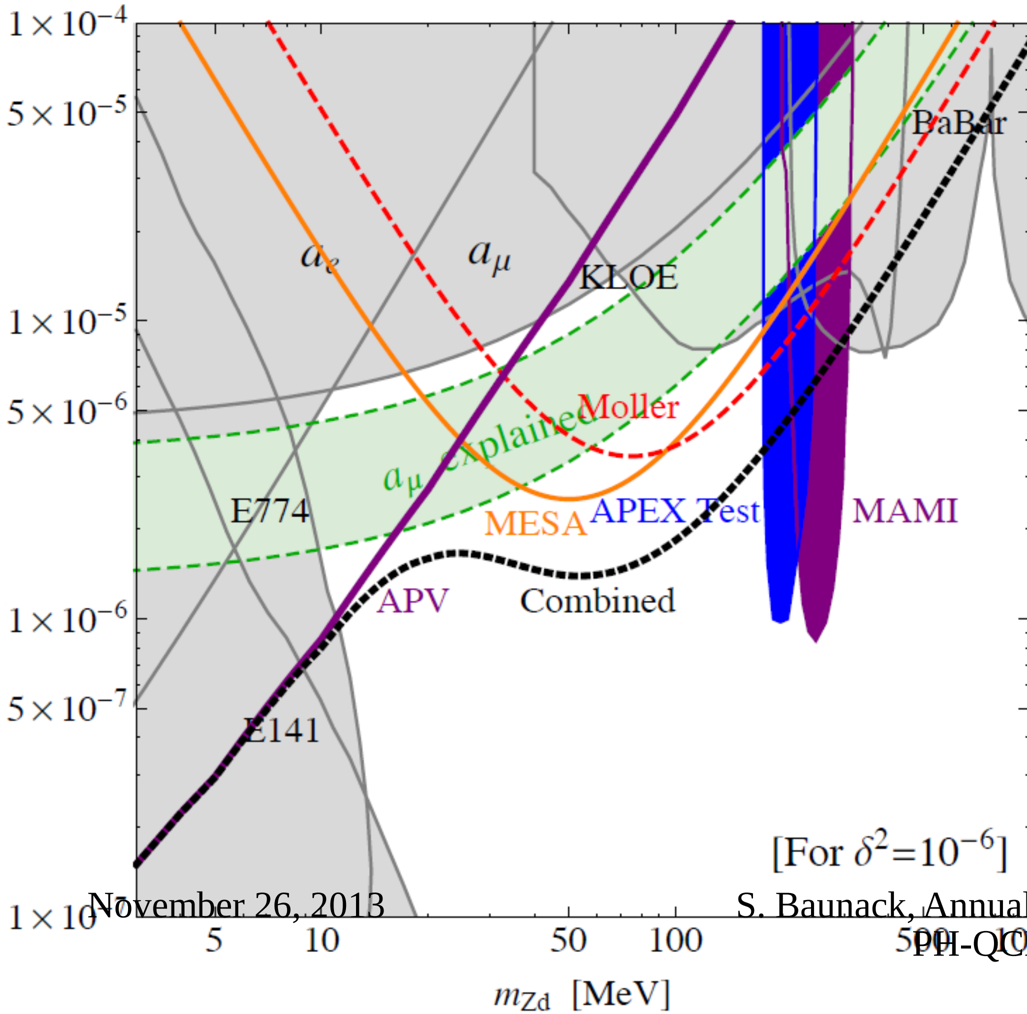
New physics: The dark sector

Dark Photon A':



Dark Z':



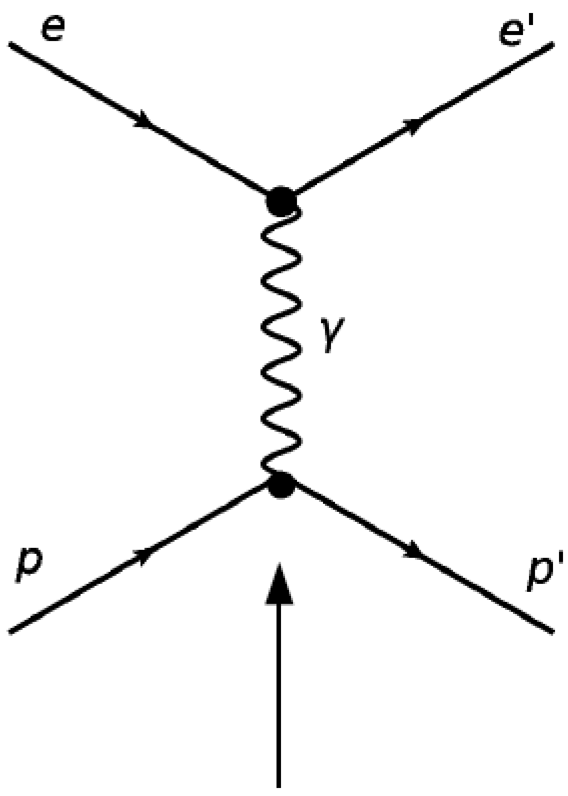


Mass mixing: $\epsilon_Z = \frac{m_{Z_d}}{M_Z}\delta$

Davoudiasl, Lee, Marciano:
Phys.Rev. D85 (2012) 115019

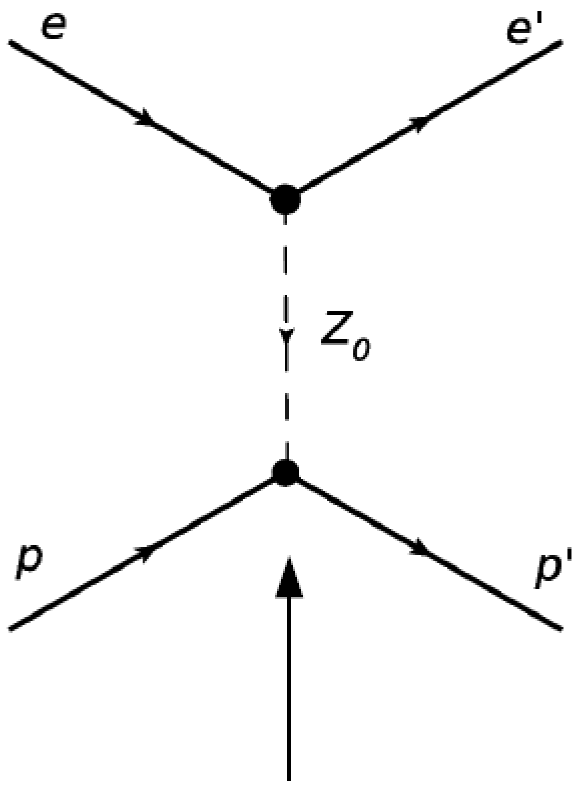
Complementary to direct heavy photon searches:
Lifetime/branching´ratio
Model dependence
vs. mass mixing assumption

The weak charge of the proton



$$Q_e(p) = +e$$

electric charge of the proton



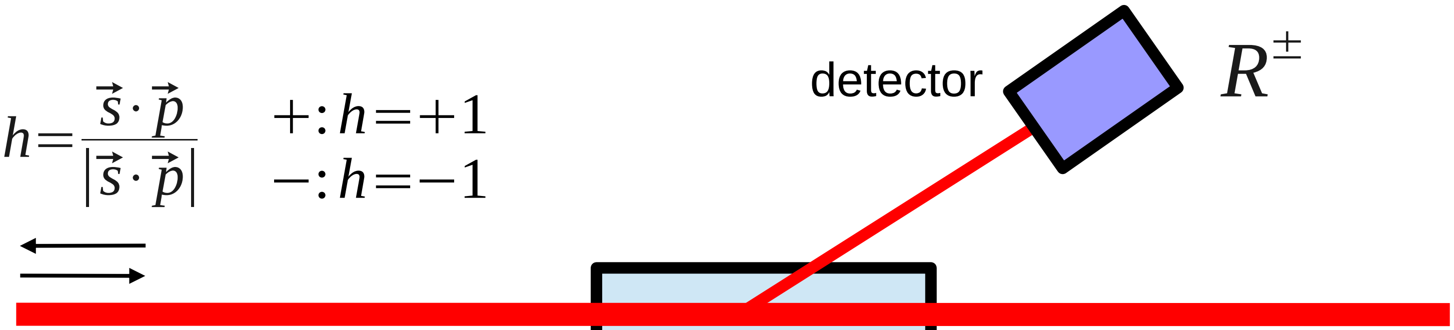
$$\boxed{Q_w(p) = 1 - 4\sin^2(\theta_W)}$$

weak charge of the proton

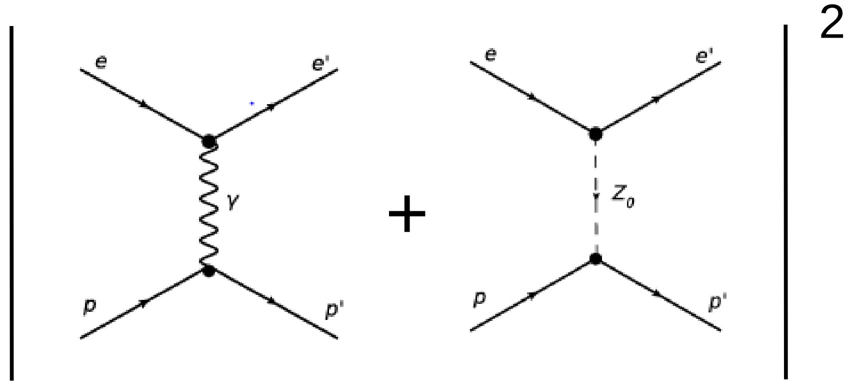
The weak charge provides access to the weak mixing angle.

Experimental access to $Q_W(p)$: Elastic ep-scattering

$$h = \frac{\vec{s}\cdot\vec{p}}{|\vec{s}\cdot\vec{p}|} \qquad \begin{array}{l} +: h=+1 \\ -: h=-1 \end{array}$$



Cross section: σ_{ep} ~



~ $|M_{\gamma}+M_{Z}|^2$

At low momentum transfer:

$Q^2 \longrightarrow 0$:
$$A_{PV} = \frac{-G_F Q^2}{4\sqrt{2}\pi\alpha}\left(Q_W(p) - F(Q^2)\right)$$

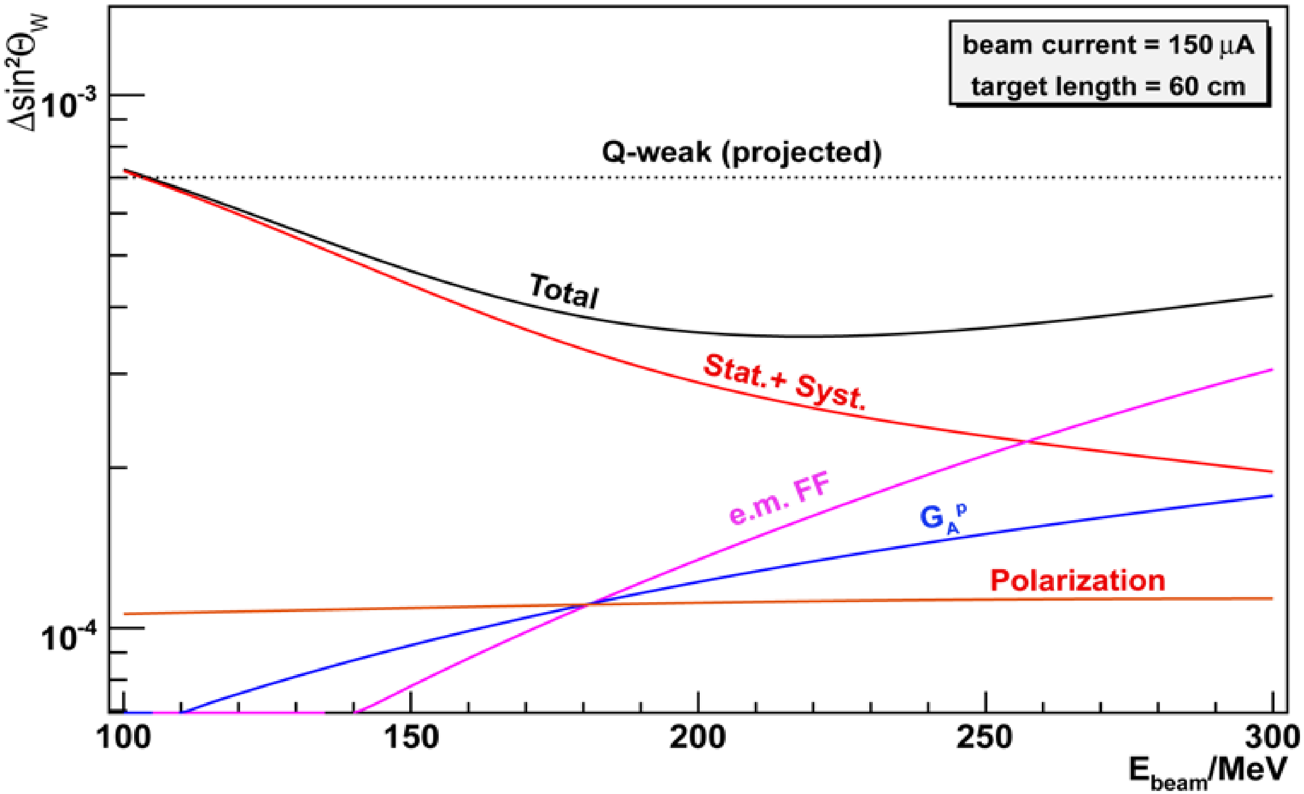
Weak charge of the proton:

$$Q_W(p) = 1 - 4\sin^2(\theta_W)(\mu)$$

Proton structure:

$$F(Q^2) = F_{EM}(Q^2) + F_{Axial}(Q^2) + F_{Strange}(Q^2)$$

Precision of P2: Monte-Carlo-Studies



Proposed experimental conditions:

- Beam energy: 200 MeV
- Beam current: 150 μA
- Polarization: 85% ± 0.5%

$\theta_{lab} = 20° \pm 10°$

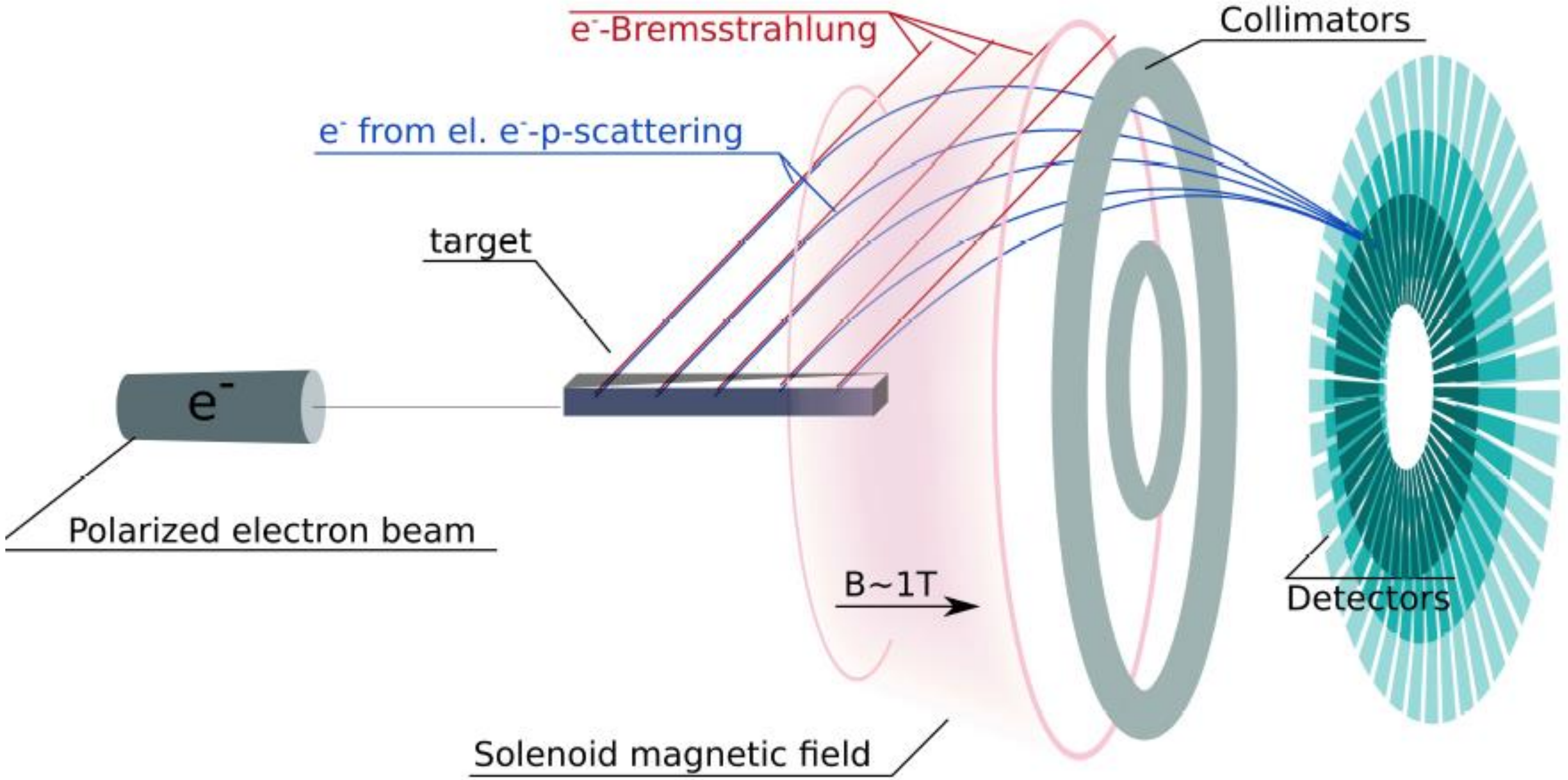
$\Delta\phi = 2\pi$

- Target: 60 cm liquid hydrogen
- Measuring time: 10000 h

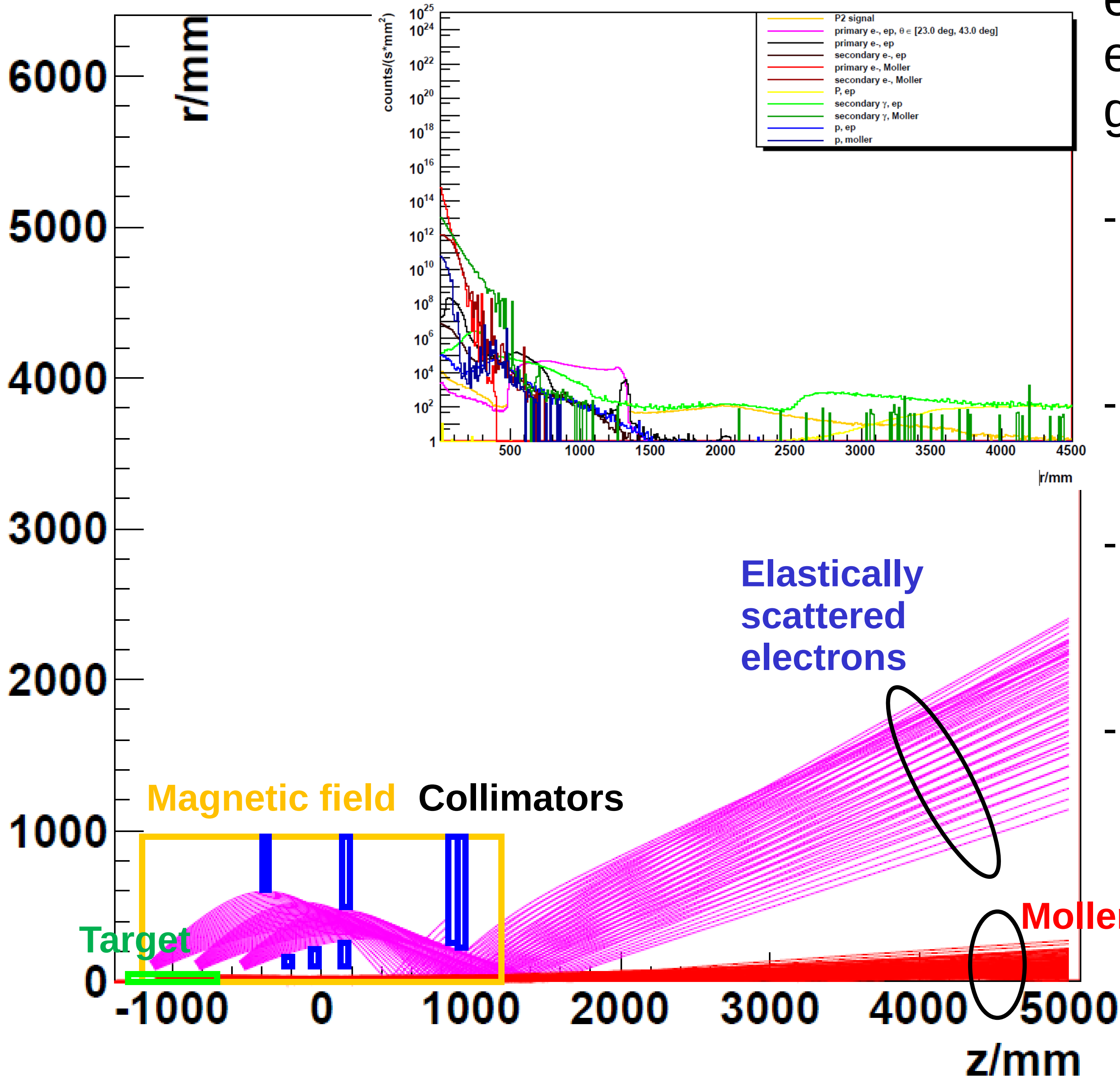
Q^2	0.0048 GeV^2
A_{phys}	-20.25 ppb
ΔA_{tot}	0.34 ppb (1.7 %)
ΔA_{stat}	0.25 ppb
ΔA_{sys}	0.19 ppb (0.9%)
Rate	0.44 10^{12} Hz
$\Delta\sin^2\theta_{W\ stat}$	2.8 10^{-4}
$\Delta\sin^2\theta_{W\ tot}$	3.6 10^{-4} (0.15 %)

P2: Sketch of the experiment

GEANT simulations: General concept of the experiment (Solenoid or Toroid solution)
Detector development: Detector materials, PMT, light guides



P2: Geant simulations



Aim: Separation of elastically scattered electrons from back-ground events

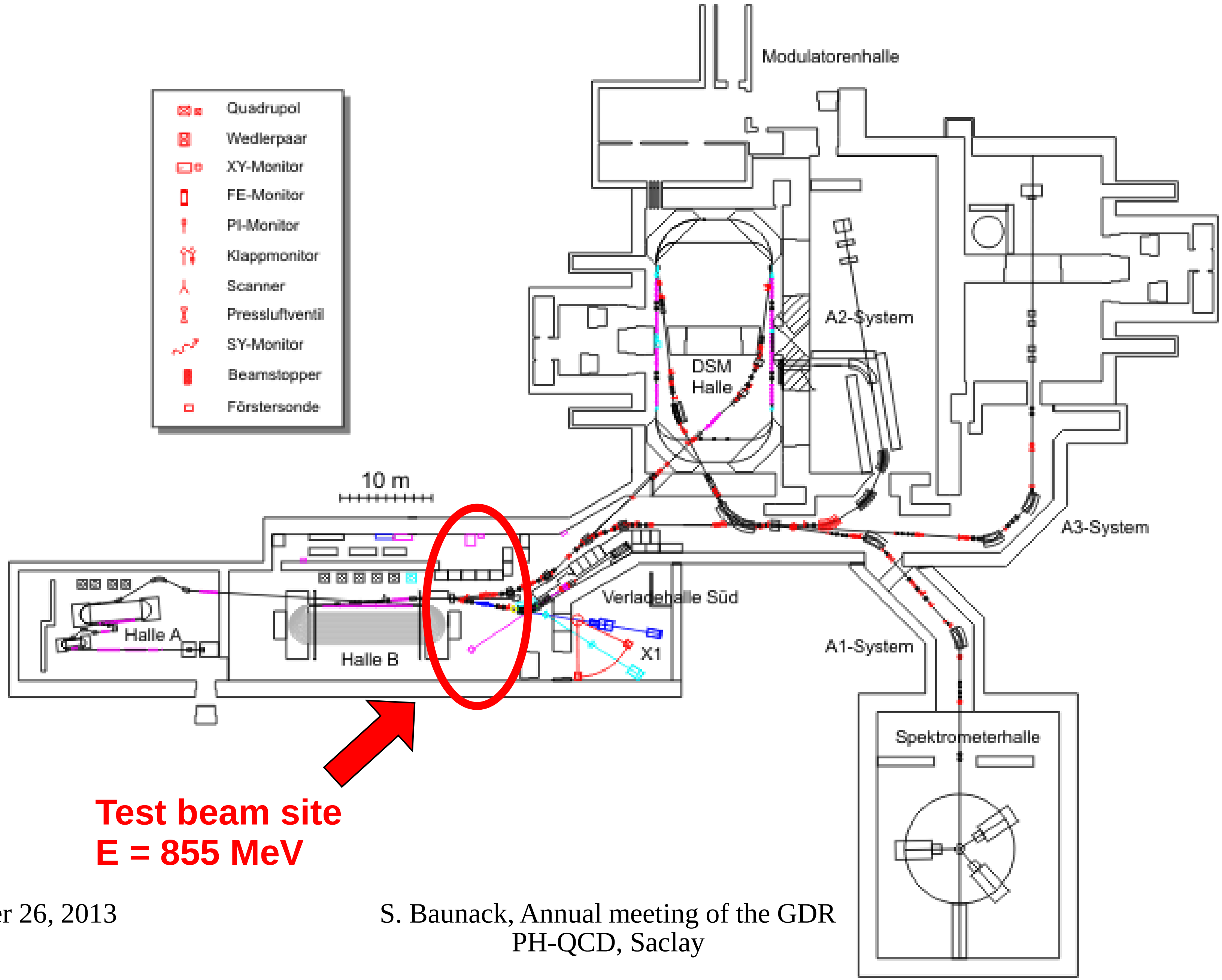
- Full GEANT4 simulations with solenoid and toroid fields

- Solenoid setup is favored (compact setup)

- Iterative optimization of field strenghts, collimators etc.

- **Solenoid solution seems feasible**

P2 Test beam at MAMI accelerator



Test beam site
E = 855 MeV

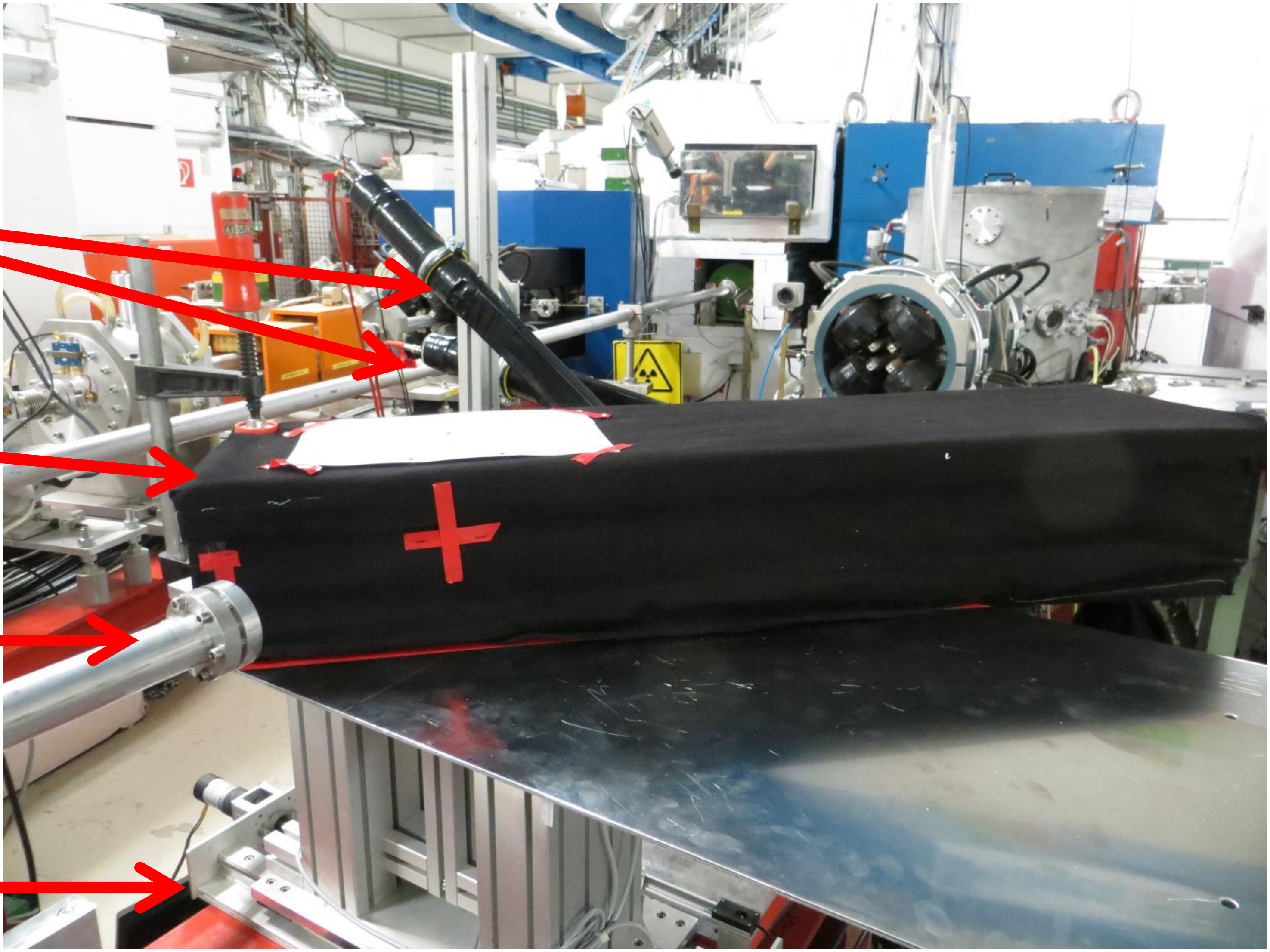
Setup at test area

Trigger scintillators

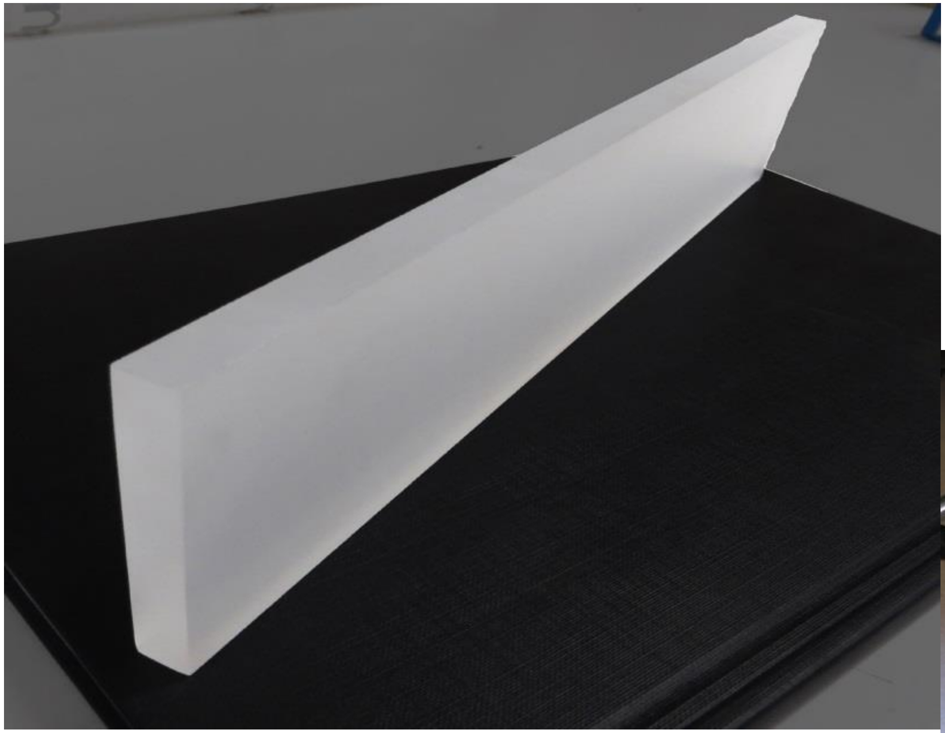
Light tight box

Beam pipe exit

Translation table



P2 detector materials

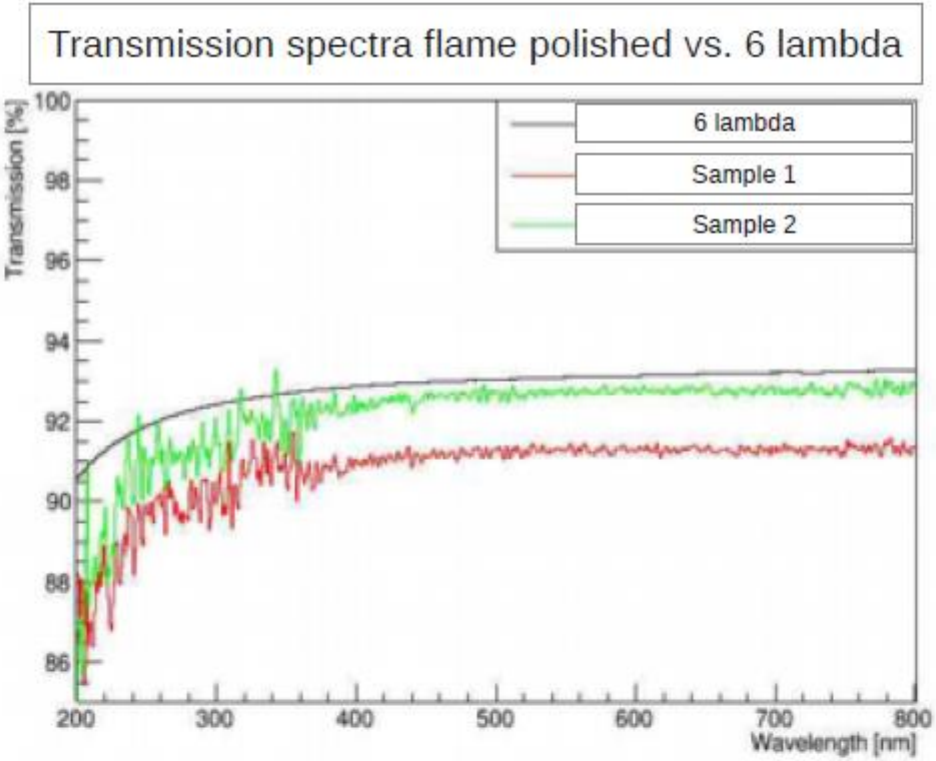


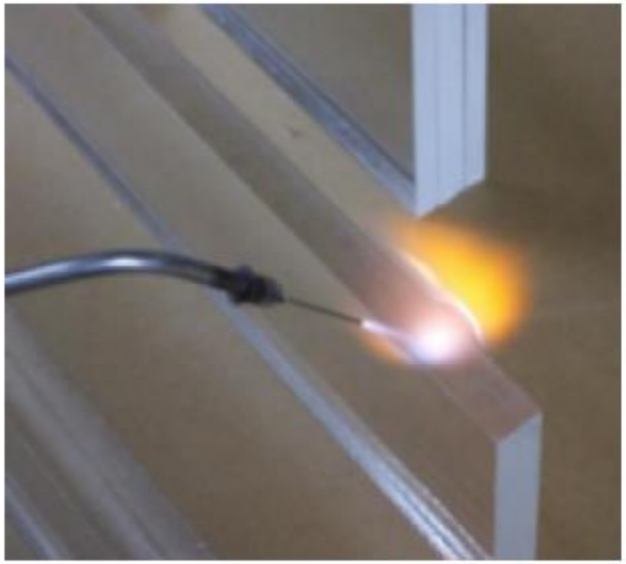
Quartz bar: Fused silica Spectrosil 2000
Dimensions: 30 cm x 7 cm x 1 cm
flame polished / unpolished

Trigger: Two plastic scintillators
EPJ-204
from A4 electron tagger system

Fused silica: Surface quality

Plain surfaces crucial for efficient internal reflection





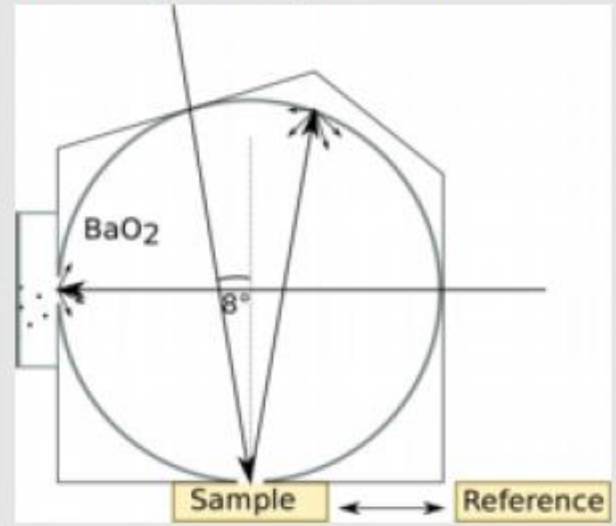
Higher losses from surface non-flatness compared to better polish
High fluctuations between samples

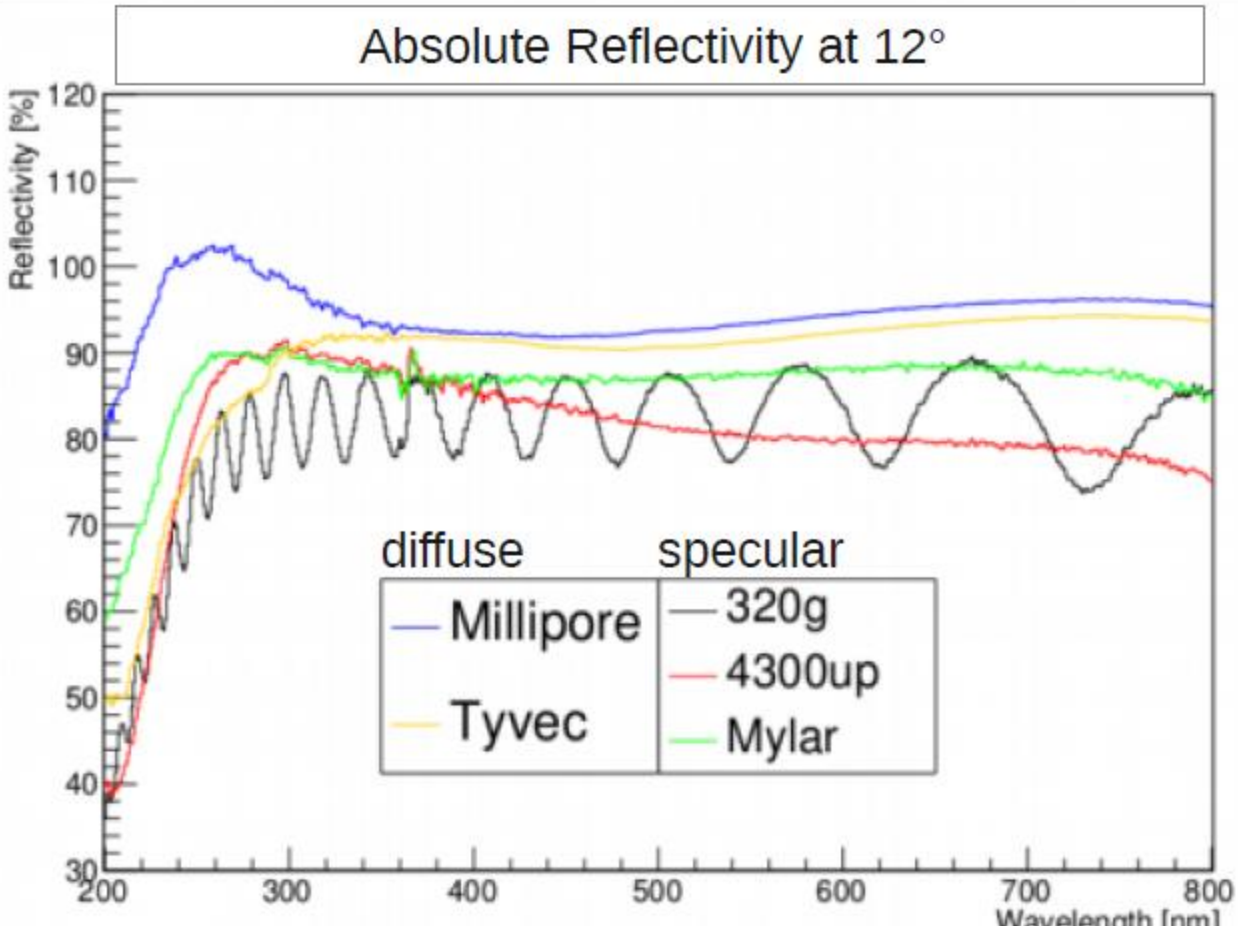
Future plans: studies with optical and 6 lambda polishes

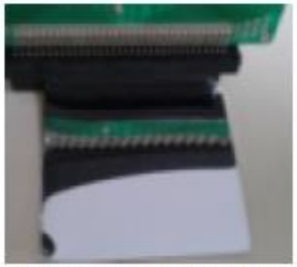
Light guide foiles and wrapping material

Reflectivity measurement of light guide foils in integrating sphere of spectrophotometer

$$S(\lambda)=\frac{S_{exp}(\lambda)}{R_{exp}(\lambda)}\cdot R(\lambda)$$







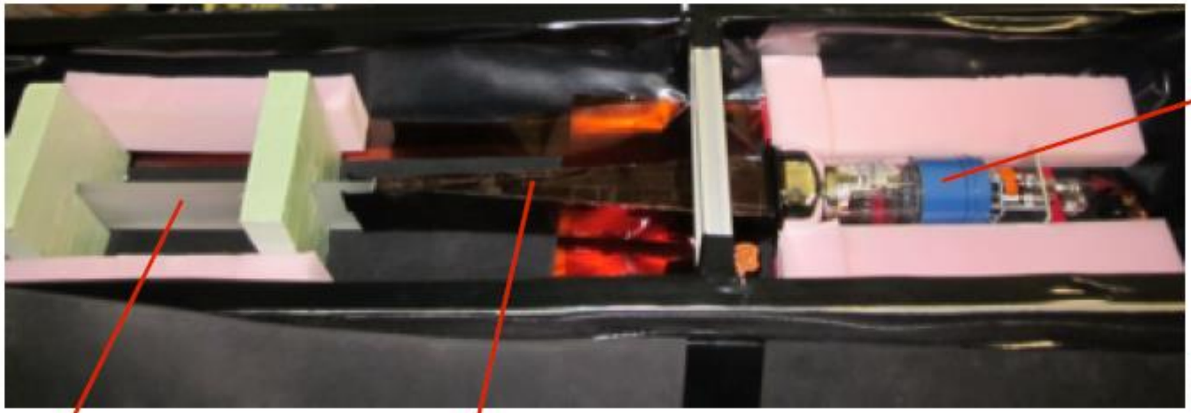
Alanod 4300

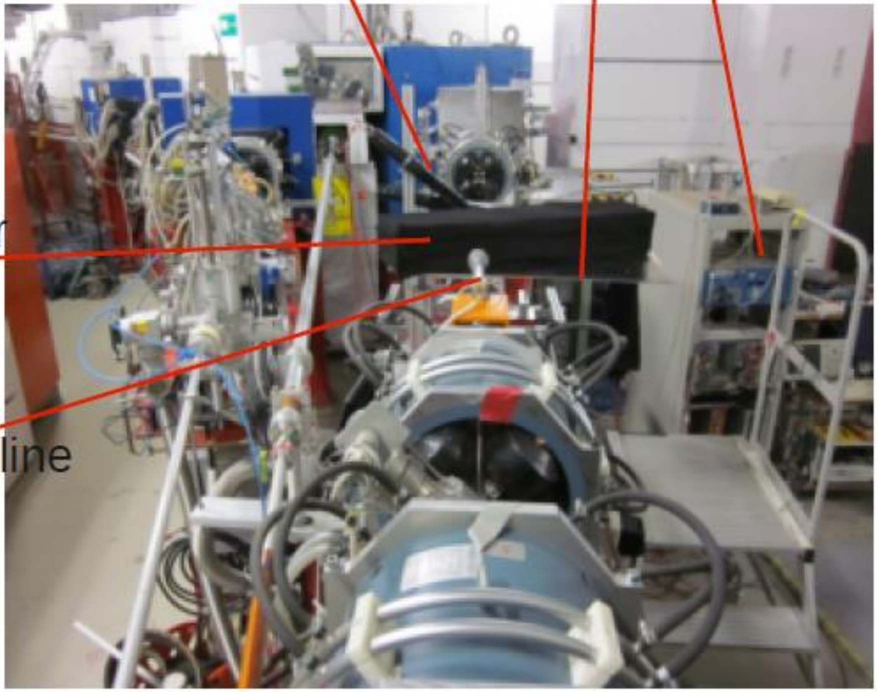
Aluminized mylar

Tyvec

Millipore

P2 test setup





Quartz: Fused silica Spectrosil 2000
Dimensions: 30 cm x 7 cm x 1 cm
flame polished / unpolished

Light guide: Air
Reflectors: Alanod 4300 UP
Mylar

PMT: EMI 9305 QKMB from Electron tubes

List of measurements

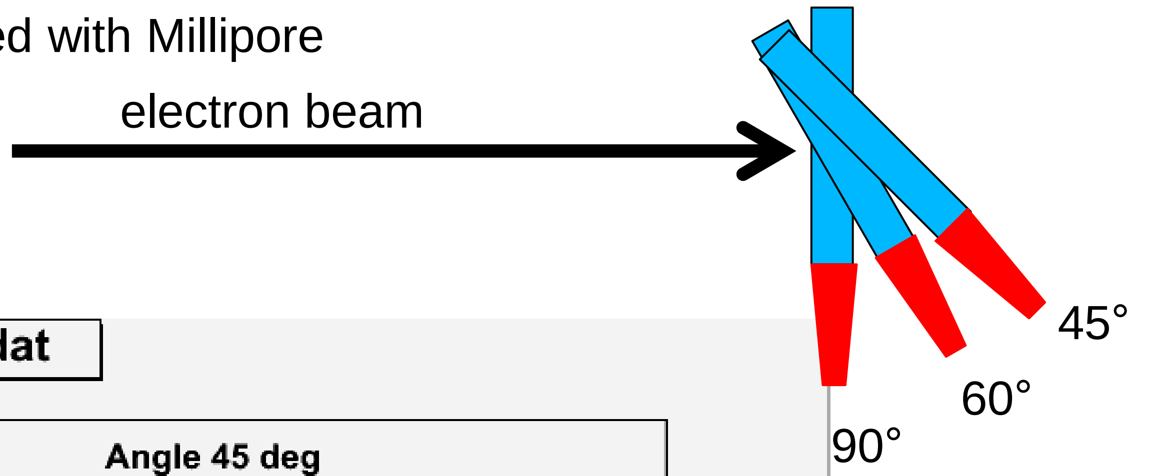
About 100 runs taken
Variation of

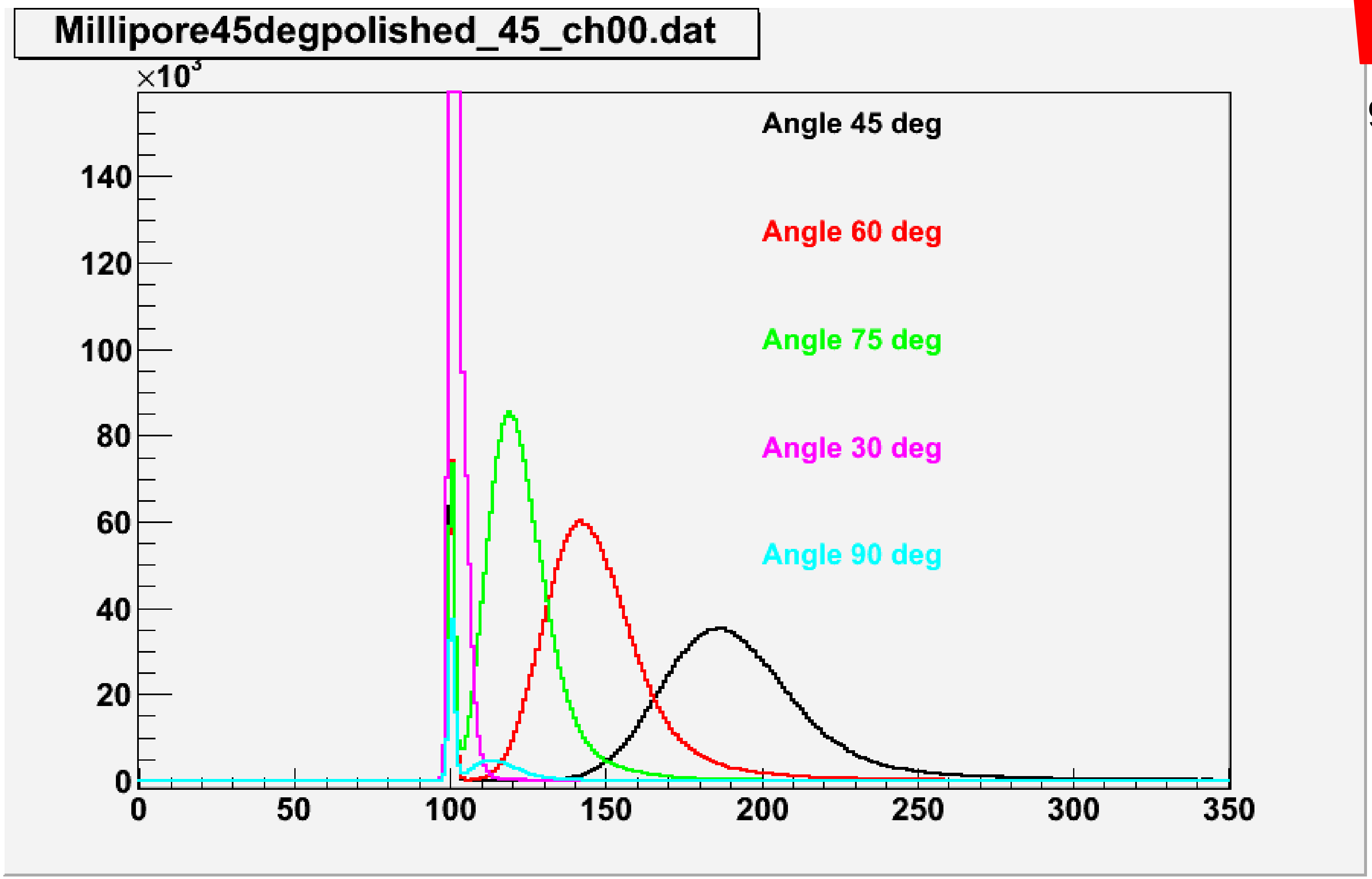
- Flame polished/unpolished
- Wrapping
- Light guide material
- Impact positions
- Orientation

Setup	Varying parameter
Spectrosil 2000 polished Wrapped with Alanod Light guide: Alanod	Different impact positions horizontal, vertical **In total 25 runs**
Spectrosil 2000 polished Wrapped with Millipore Light guide: Alanod	Different angles **In total 15 runs**
Spectrosil 2000 unpolished Light guide: Alanod	Unwrapped, Wrapped 45°, 90° **In total 6 runs**
Spectrosil 2000 polished Wrapped with Millipore Lightguide: Mylar	Different angles **In total 12 runs**
Spectrosil 2000 polished Wrapped with Alanod No Lightguide	Different impact positions **In total 19 runs**
Spectrosil 2000 polished Wrapped with Mylar No Lightguide	Different impact positions **In total 9 runs**
Spectrosil 2000 polished Wrapped with Millipore No lightguide	Different impact positions Different angles **In total 13 runs**

Beam test with different orientations

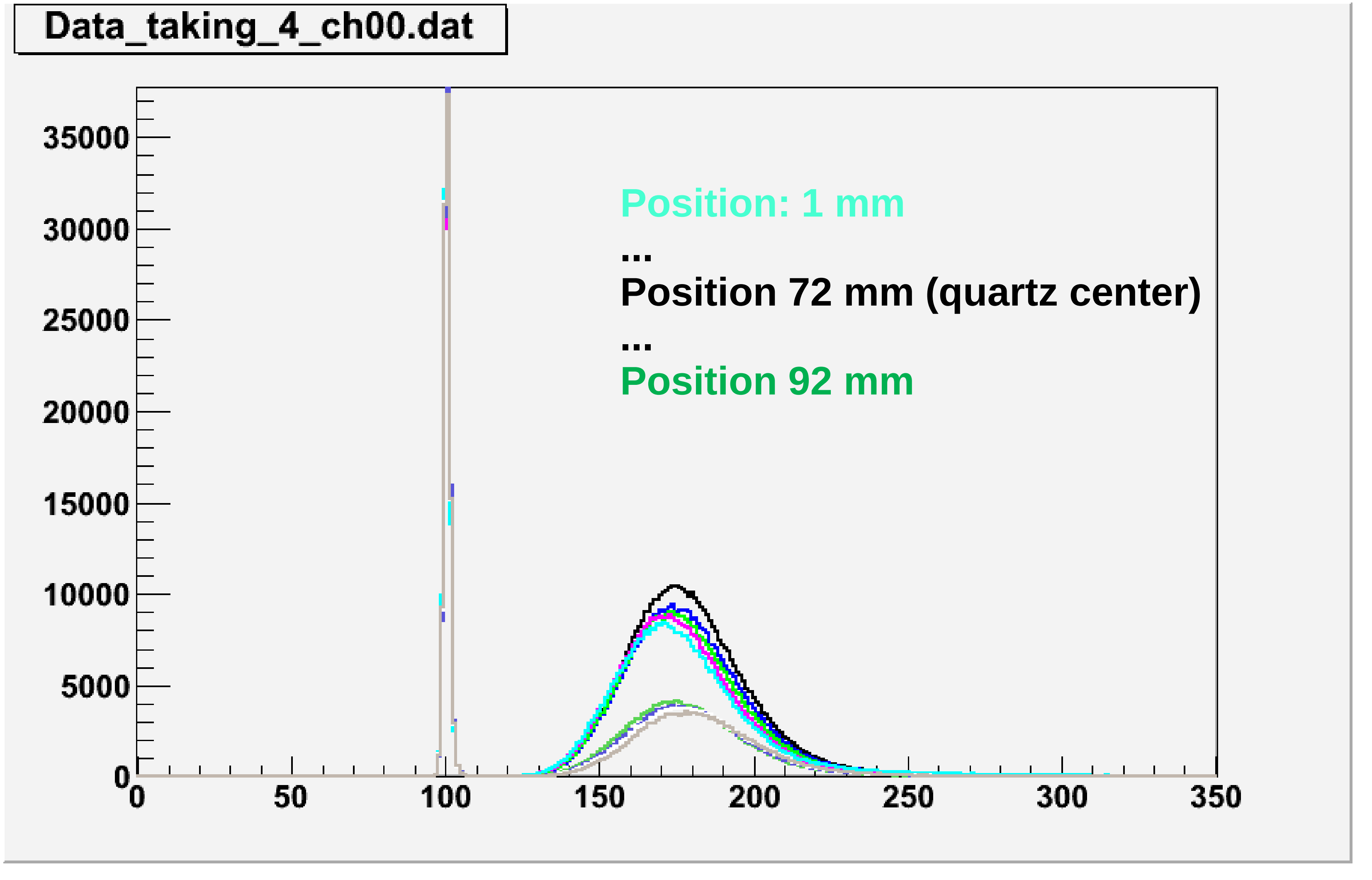
- Spectrosil 2000 polished, wrapped with Millipore
- Light guide: Mylar





Beam test with different impact positions

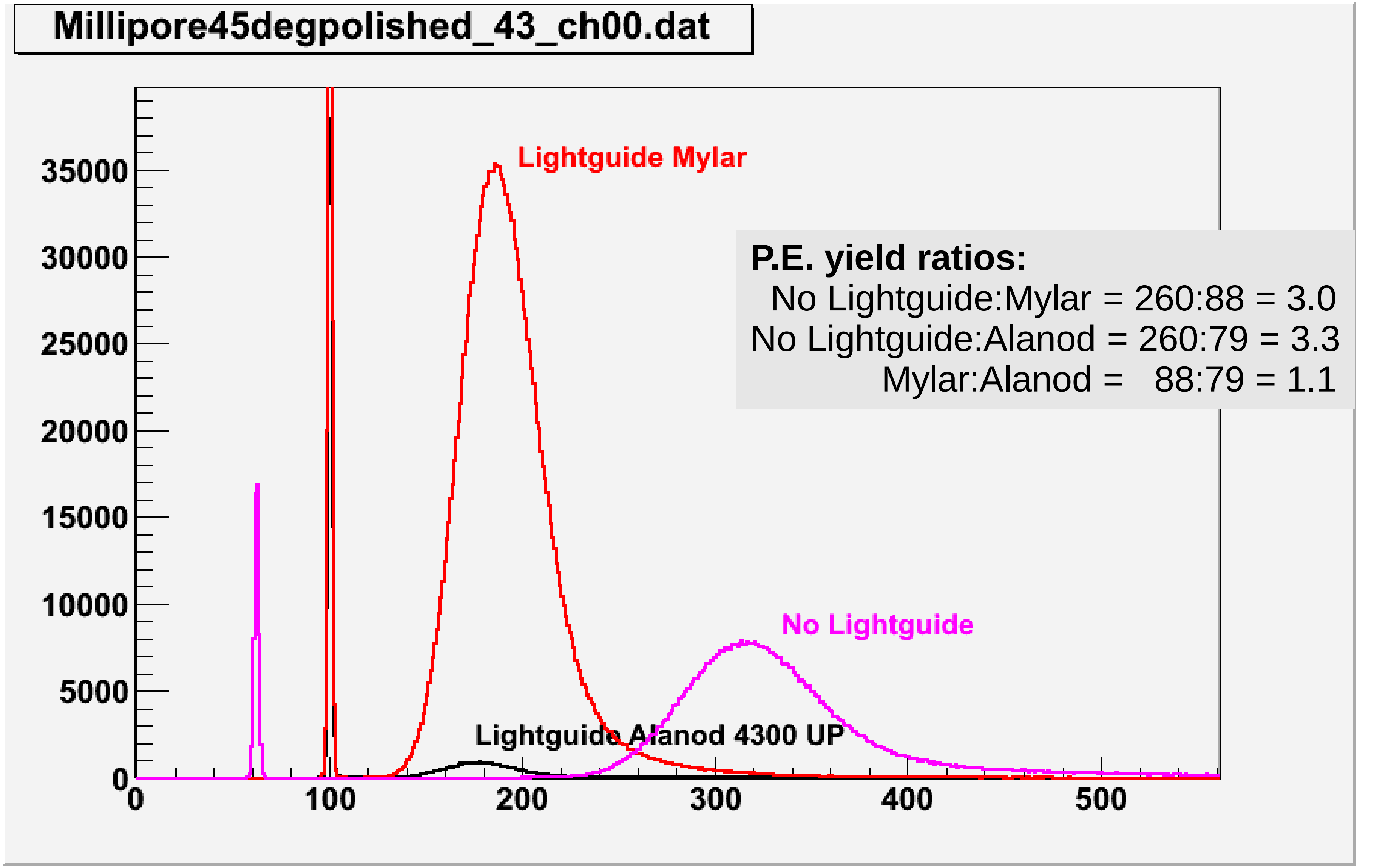
- Spectrosil 2000 polished, wrapped with Alanod, 45° orientation
  Light guide Alanod
- Move translation table **horizontally** in steps of 1 cm or 2 cm



Beam test with different lightguide materials

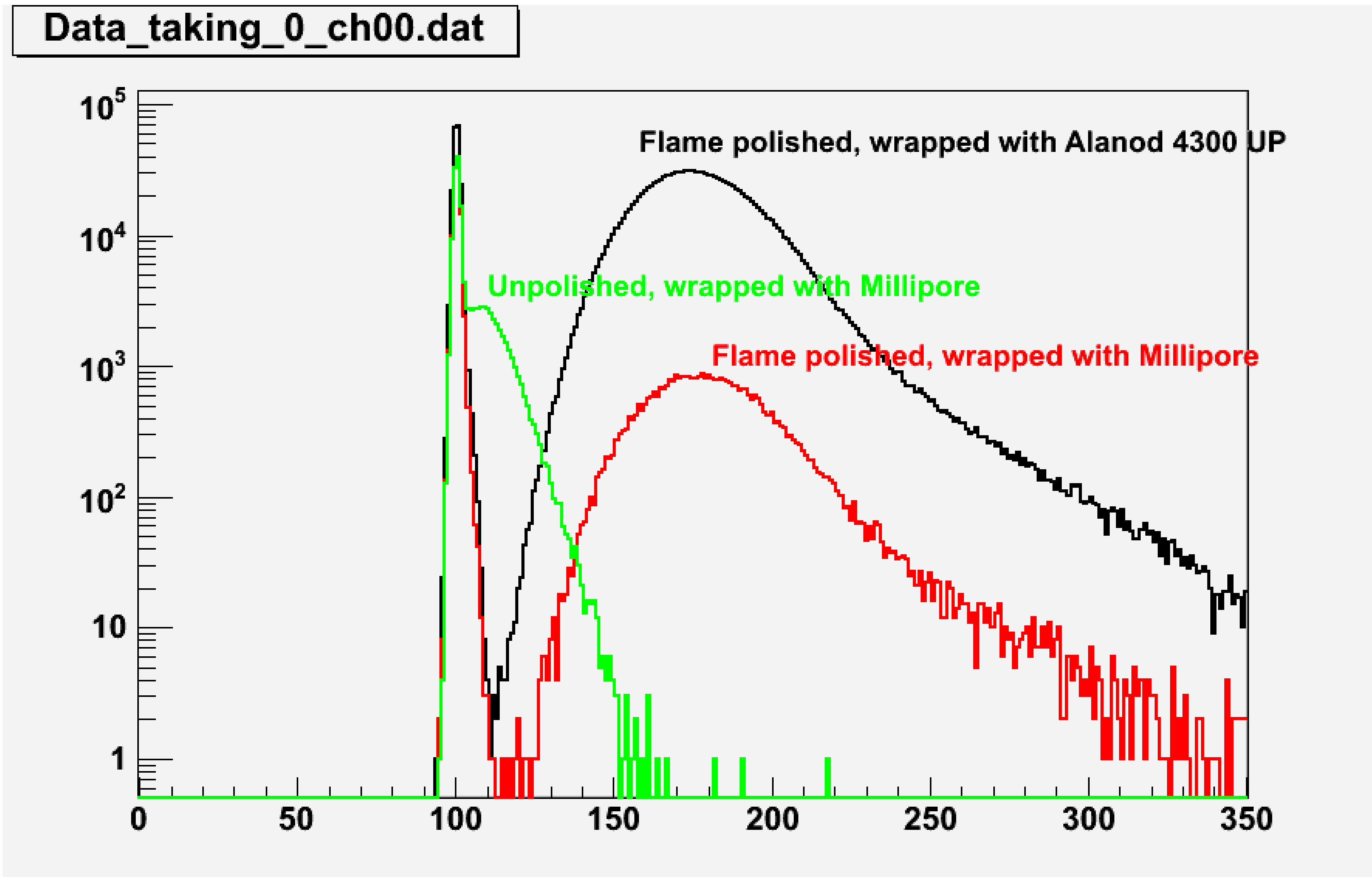
- Spectrosil 2000 wrapped with Millipore, 45° orientation
- Light guide materials: Alanod 4300 UP, Mylar, No lightguide (PMT direct at Quartz)

- Note: Different electron rates, different measurement times and different pedestals

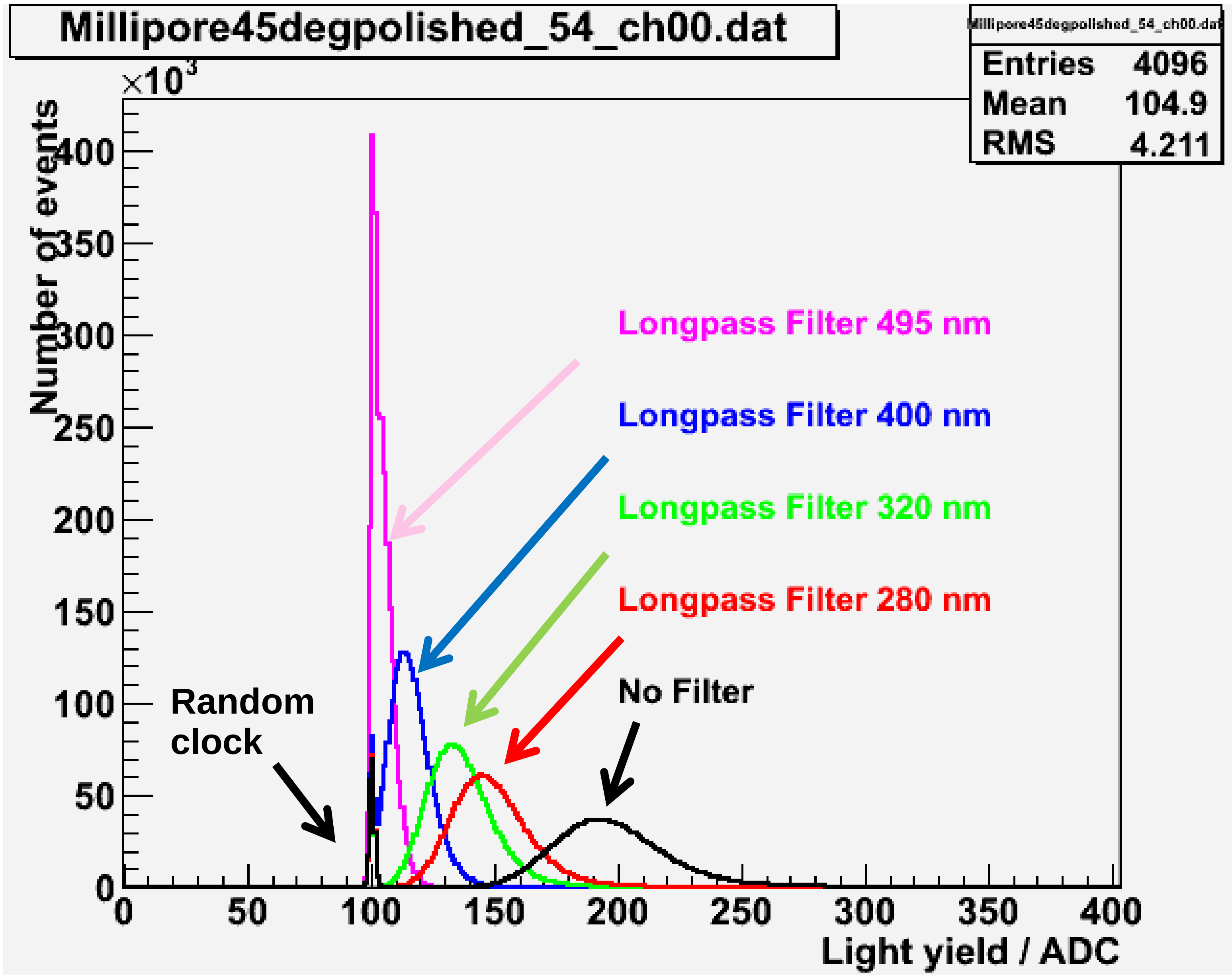


Beam test with different quartz setups

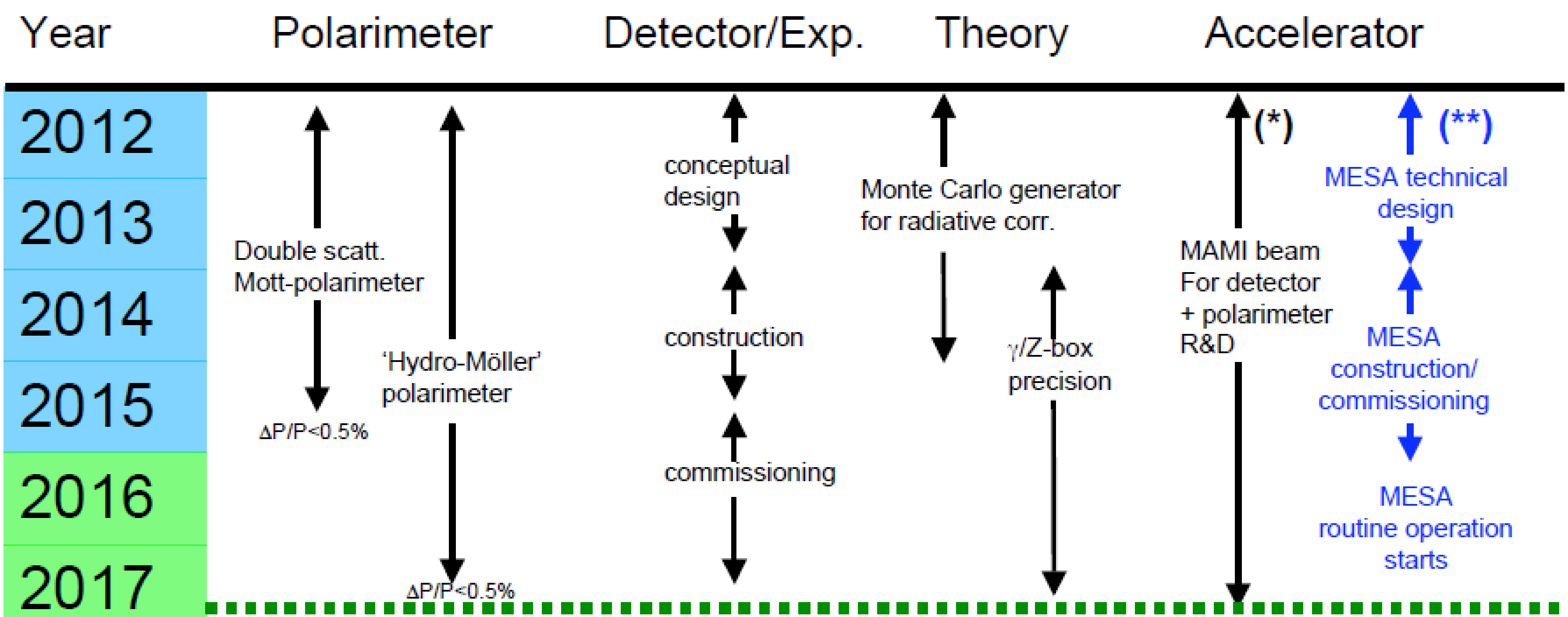
- Spectrosil 2000 with 45° orientation
  Light guide material: Alanod 4300 UP
- Note: Different electron rates and different measurement times



Beam test with optical filters



P2: Outlook


Year
Polarimeter
Detector/Exp.
Theory
Accelerator
2012
2013
2014
2015
2016
2017
Double scatt.
Mott-polarimeter
ΔP/P<0.5%
'Hydro-Möller'
polarimeter
ΔP/P<0.5%
conceptual
design
construction
commissioning
Monte Carlo generator
for radiative corr.
γ/Z-box
precision
(*)
MAMI beam
For detector
+ polarimeter
R&D
(**)
MESA technical
design
MESA
construction/
commissioning
MESA
routine operation
starts

Summary

- MESA: New accelerator project at MAMI, Mainz
- High currents at moderate beam energies E<300 MeV

- Experiments with ERL mode
- High resolution double spectrometer
- Dark photon searches

- Experiment with EB mode: P2
- Precise measurement of the weak mixing angle
- Provides strong tests of the Standard Model

- Thanks to: K. Aulenbacher, T. Beranek, F. Maas, H. Merkel