Building a Tracking Detector for the P2 Experiment

DPG Frühjahrstagung, Münster 2017

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Institute for Nuclear Physics
March 28, 2017

SFB 1044
THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

Cluster of Excellence
PRISMA
Precision Physics, Fundamental Interactions and Structure of Matter

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

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The P2 Experiment: Overview

The Idea

Precision measurement of the weak mixing angle at low Q^2

Motivation

- Fundamental quantity of the Standard Model
- Sensitive for New Physics

Method

- Measure parity-violating asymmetry in electron-proton scattering
- **M**ainz **E**nergy-recovery **S**uperconducting **A**ccelerator (MESA)

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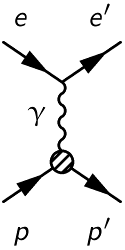
The Weak Mixing Angle θ_W in the Standard Model (SM)

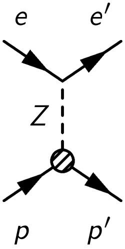
Definition

$\tan \theta_W = \frac{g}{g'}$ with $SU(2)_L \times U(1)_Y$ gauge couplings g, g'



Proton electric charge

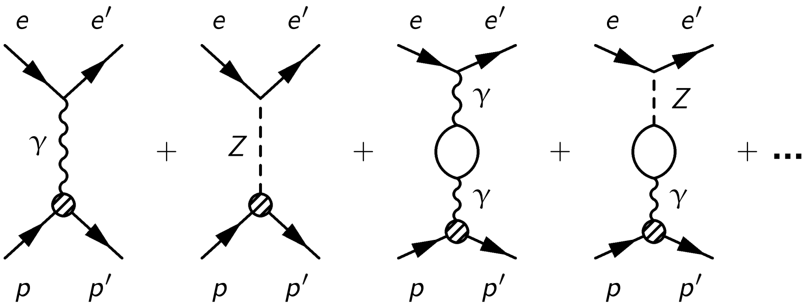
$+1$



Proton weak charge

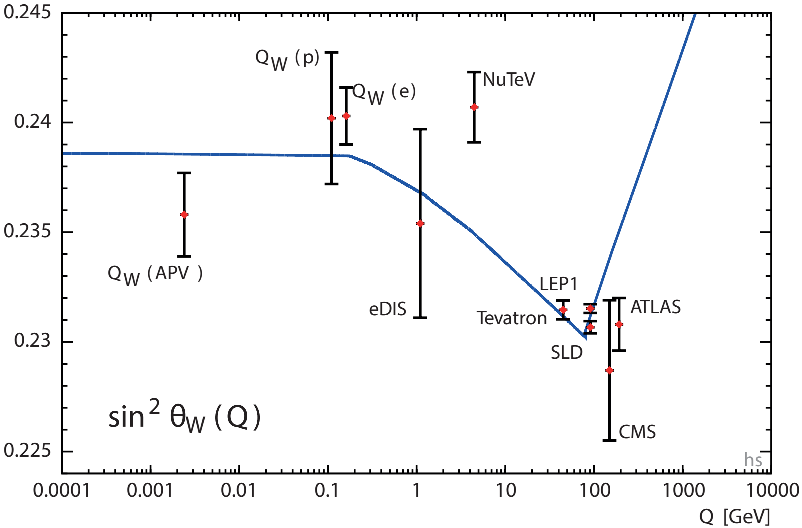
$1 - 4\sin^2\theta_W$

Scale dependence of $\sin^2\theta_W$

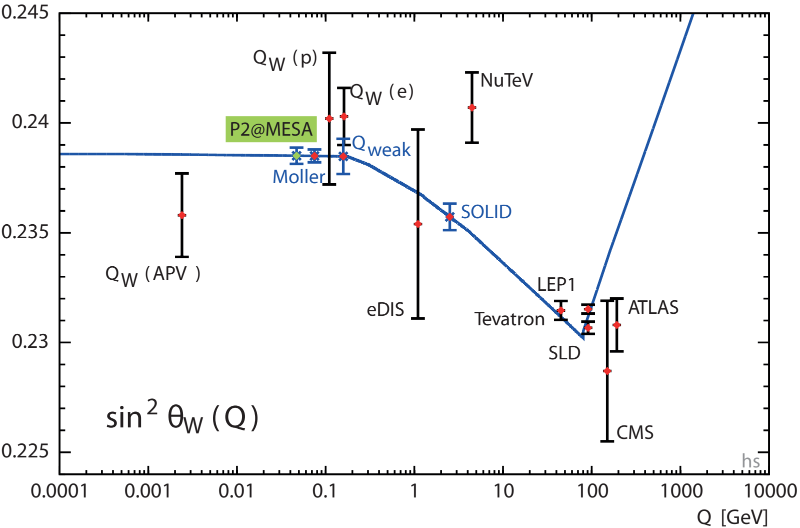


Absorb radiative corrections into effective, scale-dependent ("running") $\sin^2\theta_W(Q^2)$

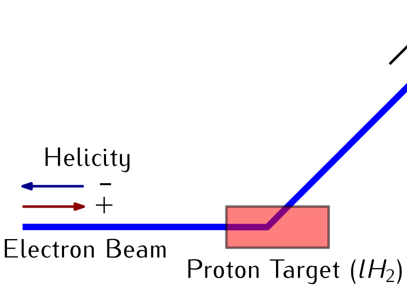
Running $\sin^2\theta_W$ Measurements



Running $\sin^2\theta_W$ Measurements



Measure $\sin^2\theta_W$ via Parity Violating ep-Scattering



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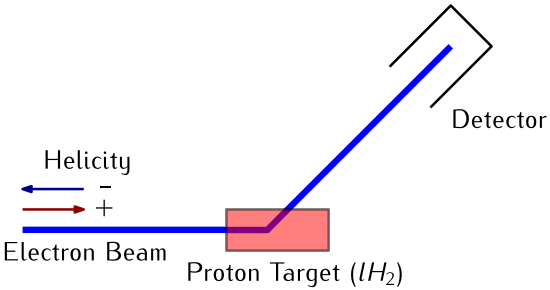
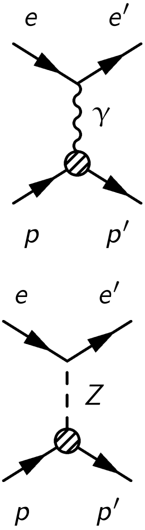
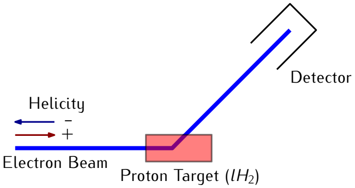




Parity violating asymmetry

- Photon exchange parity invariant
- Z-boson exchange violates parity!
- $A_{\text{PV}} \equiv \frac{N_- - N_+}{N_- + N_+}$
- Flip helicity and count!

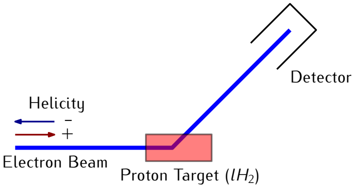
Measure A_{PV} in ep-Scattering



- $A_{PV} \equiv \frac{N_- - N_+}{N_- + N_+} = \frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\left(1 - 4\sin^2\theta_W - F(Q^2)\right)$
  - Q^2 = momentum transfer
  - $F(Q^2)$ = proton form factor

- Need very high statistics and precise control of systematics
  - 150 μA beam current, 10 000 h measuring time
  - 60 cm liquid hydrogen target for high luminosity
  - MESA beam
    - $E = 150\,\mathrm{MeV}$
    - Highly polarized ($\geqslant 85\,\%$), flip helicity at 2 kHz
    - Low helicity-correlated uncertainties

Measure A_{PV} in ep-Scattering



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  - $150\,\mu A$ beam current, $10\,000\,\mathrm{h}$ measuring time
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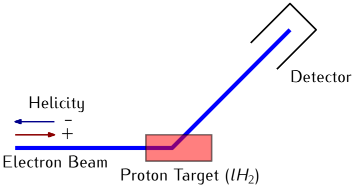

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- Need very high statistics and precise control of systematics
  - $150\,\mu A$ beam current, $10\,000\,\mathrm{h}$ measuring time
  - $60\,\mathrm{cm}$ liquid hydrogen target for high luminosity
  - MESA beam
    - $E = 150\,\mathrm{MeV}$
    - Highly polarized ($\geqslant 85\,\%$), flip helicity at $2\,\mathrm{kHz}$
    - Low helicity-correlated uncertainties $\leqslant 0.1\,\mathrm{ppb}$

$\frac{\Delta \sin^2\theta_W}{\sin^2\theta_W} \sim 0.13\,\%$

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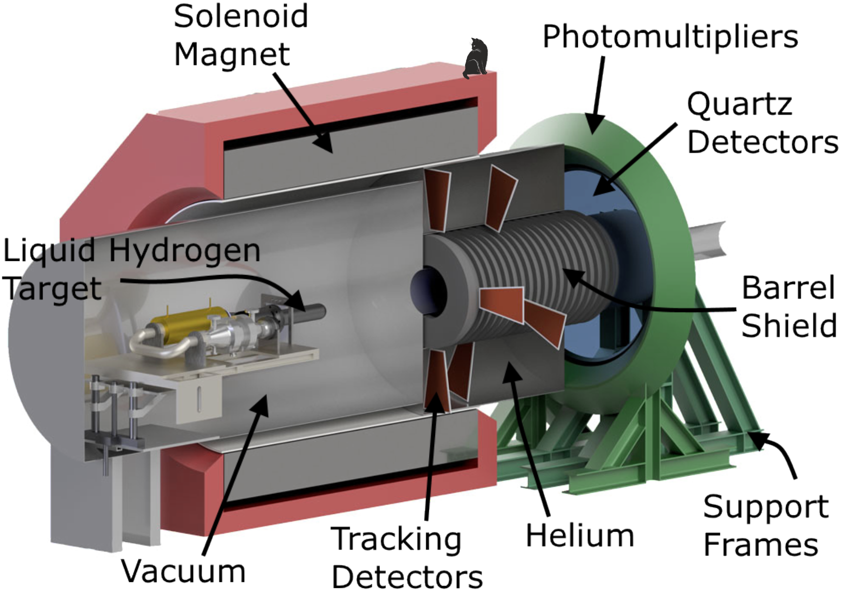
P2 Detector Layout



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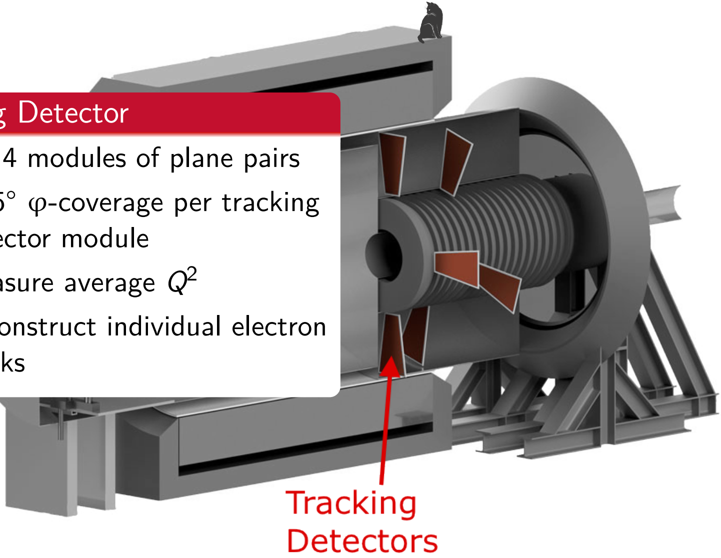
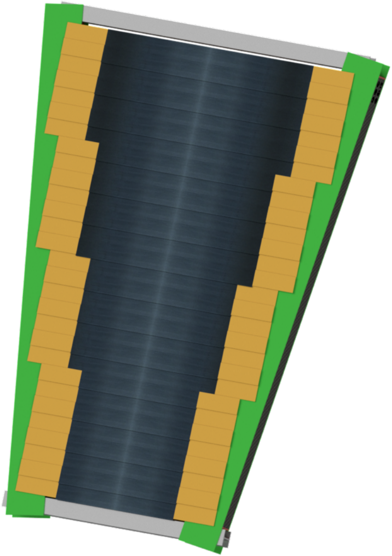


Tracking Detector

- 2×4 modules of plane pairs
- $\sim 15°$ φ-coverage per tracking detector module
- Measure average Q^2
- Reconstruct individual electron tracks

Tracking Detector Layout

- $50\,\mu\mathrm{m}$ thin silicon High Voltage Monolithic Active Pixel Sensors (HV-MAPS)
- $\sim 50\,\mu\mathrm{m}$ thin Kapton layer
- Overlapping strips to minimise inactive area
- Less than 1 ‰ of a radiation length per tracker plane
- $\sim 2 \times 316$ chips with size $2 \times 2\,\mathrm{cm}^2$ per module



Tracking Detector Layout

- 50 μm thin silicon High Voltage Monolithic Active Pixel Sensors (HV-MAPS)
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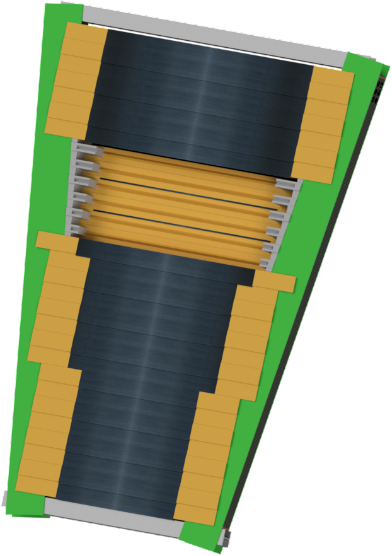
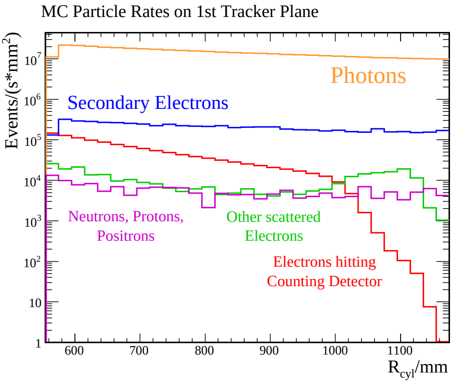


Challenges for the Tracking Detector

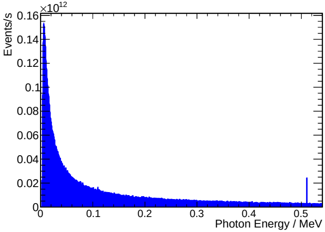
- Very high particle rates at full beam intensity
  - $\mathcal{O}(10^{15})$ beam electrons per second
  - Large amount of background, mostly bremsstrahlung photons



Test the Detector Response to Photons

Photon Background

- Continuous bremsstrahlung energy spectrum
- Photoelectric Effect
- Compton Scattering
- Pair Creation



- Radioactive Sources
  First result: $\eta \sim 29\%@6\,\mathrm{keV}$ (Fe55)
- MAMI beamtest for higher photon energies

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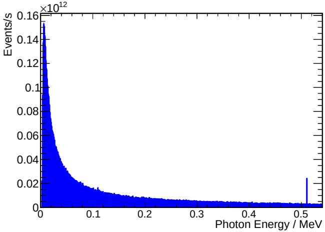

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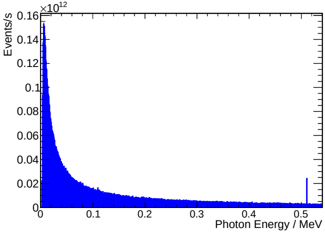
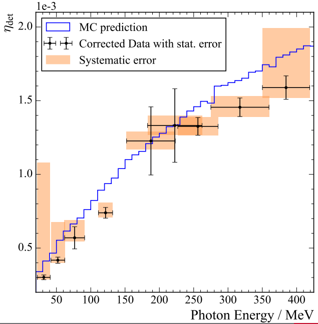
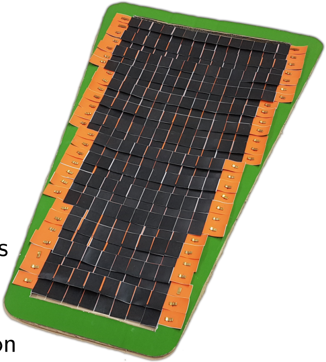




Summary and Conclusions

- P2 Experiment
  - Measure $\sin^2\theta_W$ at low Q^2 in parity violating ep-scattering
  - Start data taking around 2020
  - A_{PV} measurement with integrating Cherenkov detectors
- Tracking Detector
  - Q^2 Measurement and systematic studies
  - Low material budget
  - Very high (background) particle rates
  - Detailed track finding and reconstruction studies ongoing
  - Development of mechanical layout started

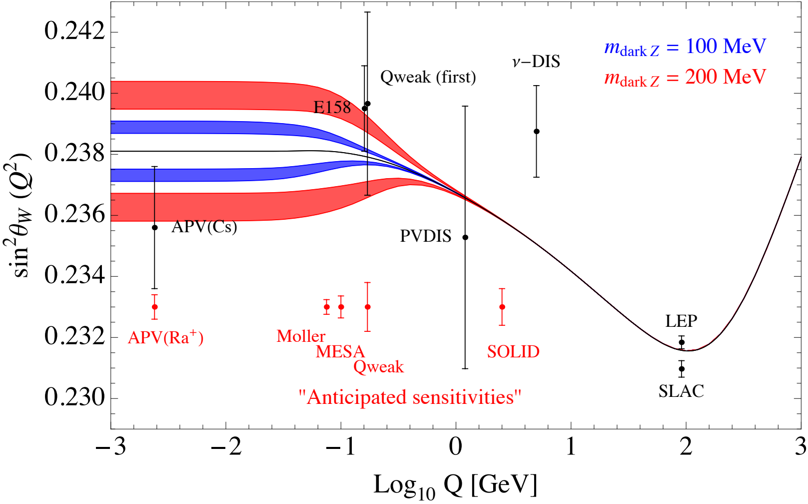


Thank you for your attention.

Backup

Sensitivity to New Physics

Hooman Davoudiasl, Hye-Sung Lee, and William J. Marciano
Phys. Rev. D 89, 095006



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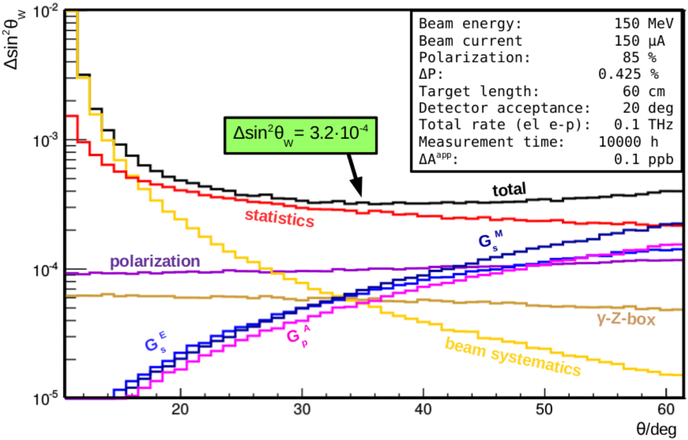
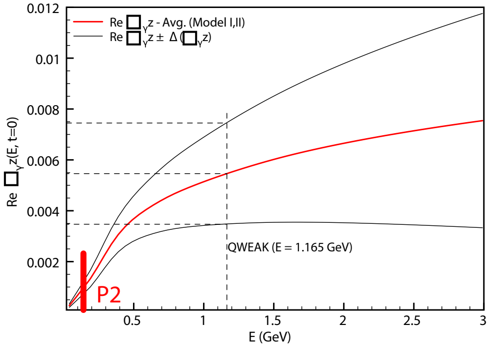
Beam Stability Requirements

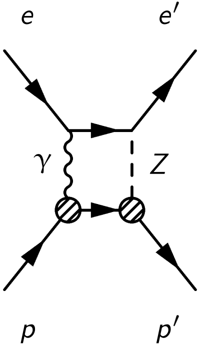
	Achieved at MAMI	A_{PV} uncertainty	requirement
Energy fluctuation	$0.04\,eV$	$< 0.1\,\mathrm{ppb}$	ok!
Position fluctuation	$3\,\mathrm{nm}$	$5\,\mathrm{ppb}$	$0.13\,\mathrm{nm}$
Angle fluctuation	$0.5\,\mathrm{nrad}$	$3\,\mathrm{ppb}$	$0.06\,\mathrm{nrad}$
Intensity fluctuation	$14\,\mathrm{ppb}$	$4\,\mathrm{ppb}$	$0.36\,\mathrm{ppb}$

Systematic Uncertainties

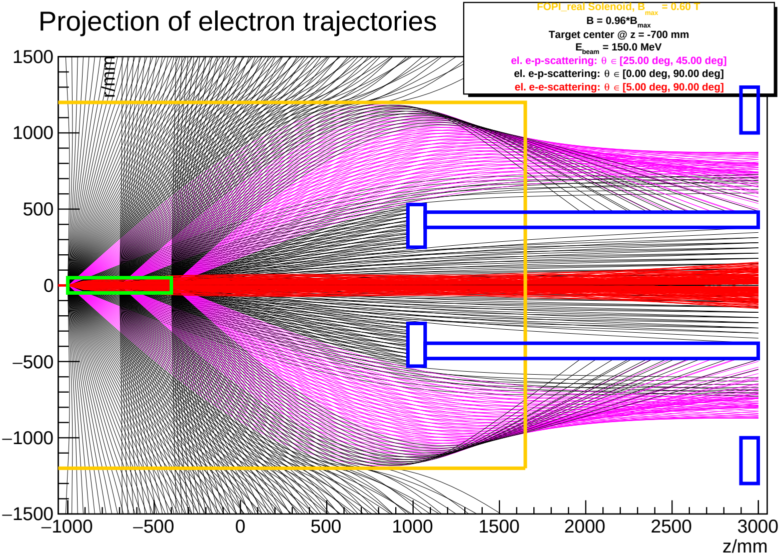


γ/Z-box processes uncertainty contribution

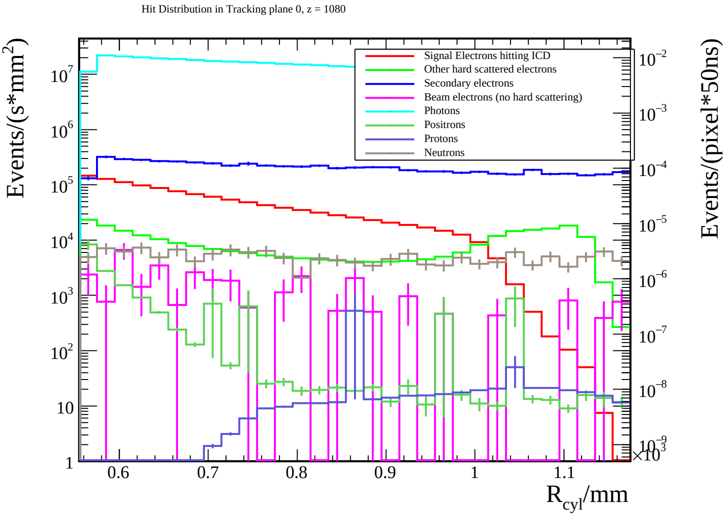




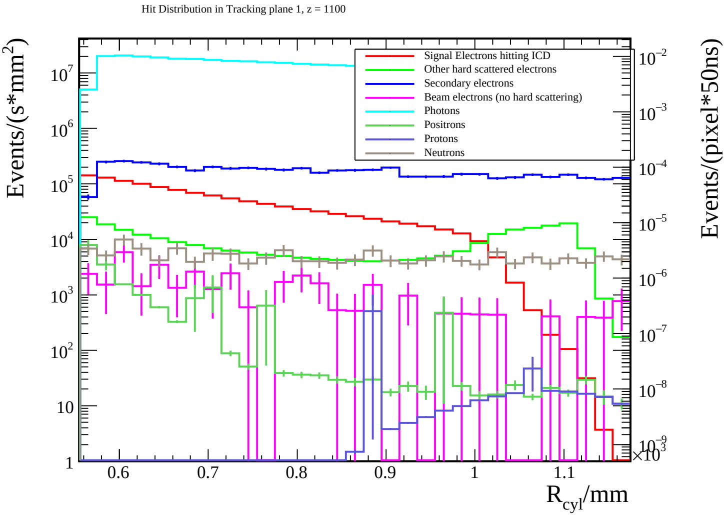
Projection of Expected Electron Trajectories



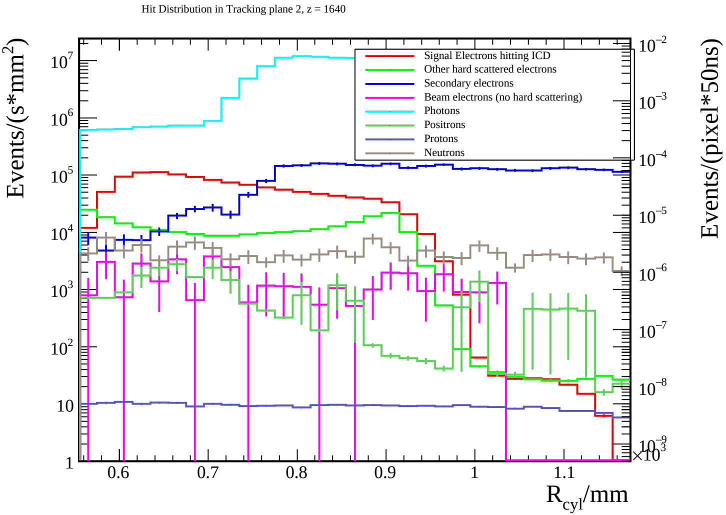
Expected Particle Rates on First Plane



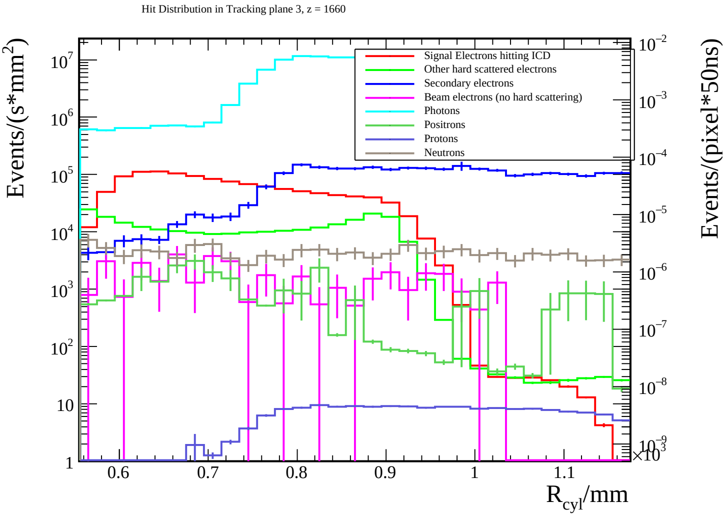
Expected Particle Rates on Second Plane



Expected Particle Rates on Third Plane



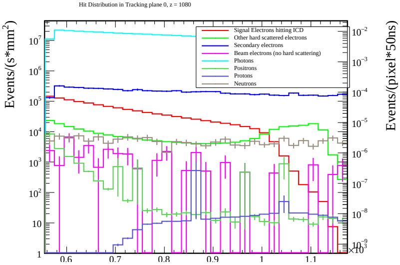
Expected Particle Rates on Fourth Plane

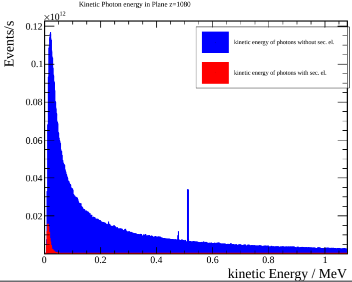


Photon Background

- Continuous bremsstrahlung energy distribution
- Secondary electrons mainly produced by photo-effect
- Low detection rate of higher energetic photons
- Reduced rate of secondary electrons on “covered” plane
- Detailed investigation of detector response to low energy photons needed

First Tracker Plane

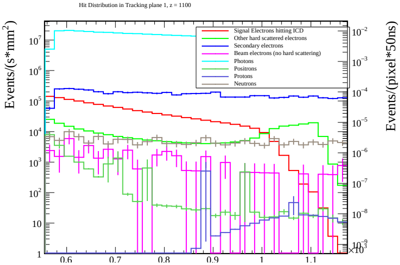


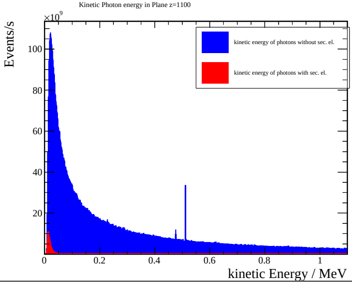


Photon Background

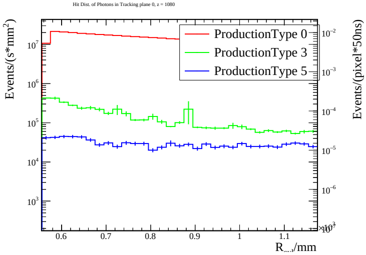
Second Tracker Plane

- Continuous bremsstrahlung energy distribution
- Secondary electrons mainly produced by photo-effect
- Low detection rate of higher energetic photons
- Reduced rate of secondary electrons on "covered" plane
- Detailed investigation of detector response to low energy photons needed

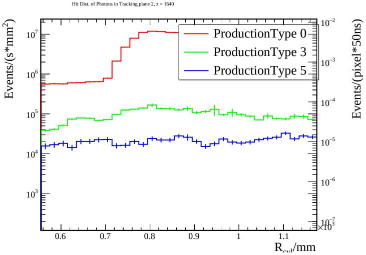




Photon Production Processes



1



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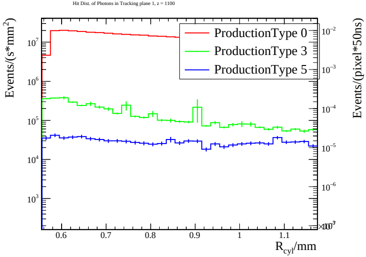
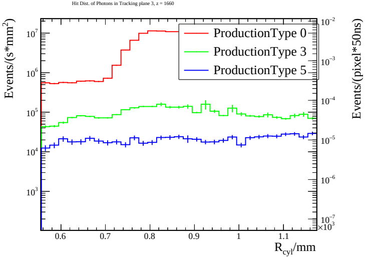


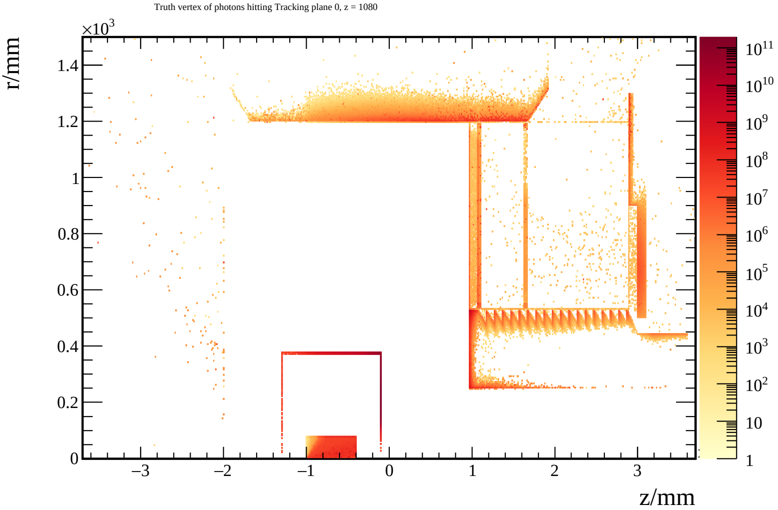
2



4

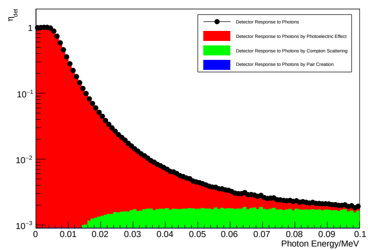
process encoding: 0 = bremsstrahlung in the target, 3 = bremsstrahlung in other detector parts, 5 = pair annihilation

Photon Vertices

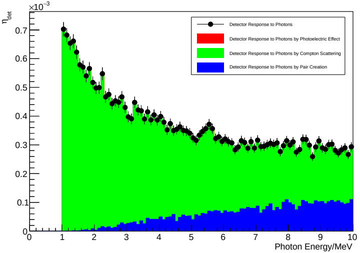


MC Detector Response to Photons

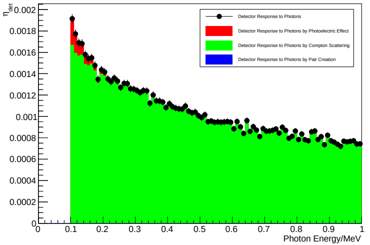
Detector Response to Photons



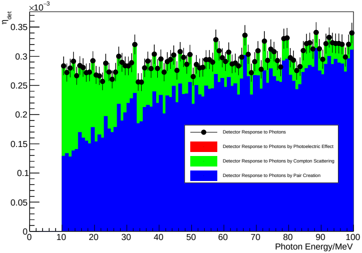
Detector Response to Photons



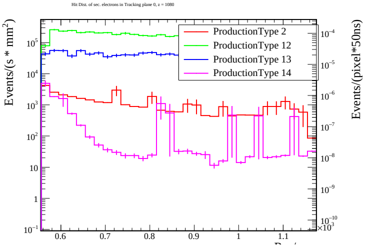
Detector Response to Photons



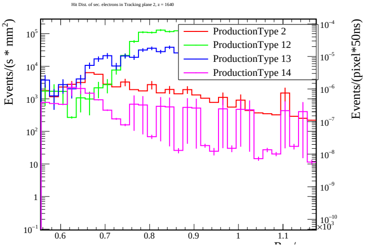
Detector Response to Photons



Secondary Electrons Production Processes



1



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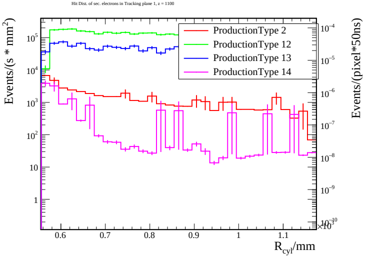
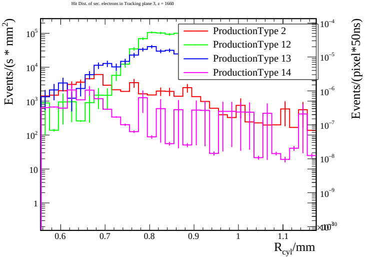


2

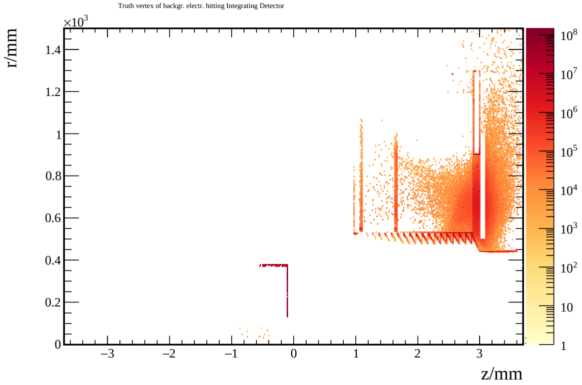


4

Process encoding: 2 = ionisation, 12 = Photoeffect, 13 = Compton Scattering, 14 = Pair creation

Background Electrons Hitting Integrating Cherenkov Detector

Production Vertices



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Additional Electron Loss due to Segmented Tracker Layers