A Time-Walk Correction Method for the Glasgow Pair Polarimeter

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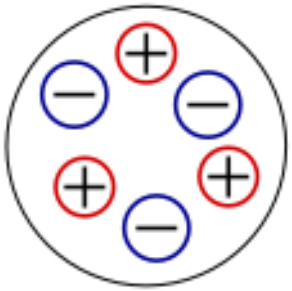
Introduction

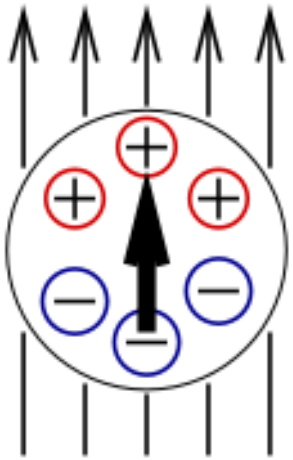
- A2 collaboration
  - Collide real photons with target
  - Energy range of 40 Mev to 1.6 GeV
  - Interested in polarization observables

Nucleon Polarizabilities

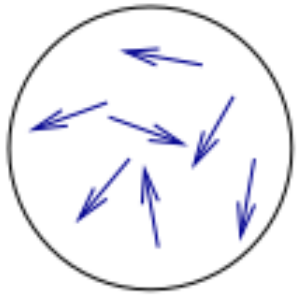
- Fundamental characteristics of nucleons
- Scalar polarizabilities for neutron and proton
  - Electric polarizability = "stretchability"
  - Magnetic polarizability = "alignability"



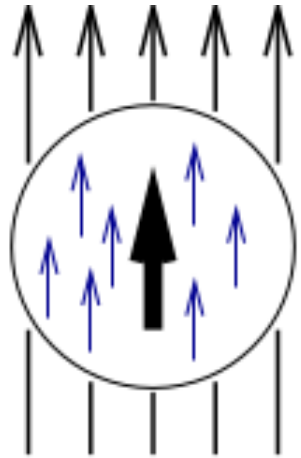
$\boldsymbol{p} = 0$



$\boldsymbol{p} = \alpha \boldsymbol{E}$



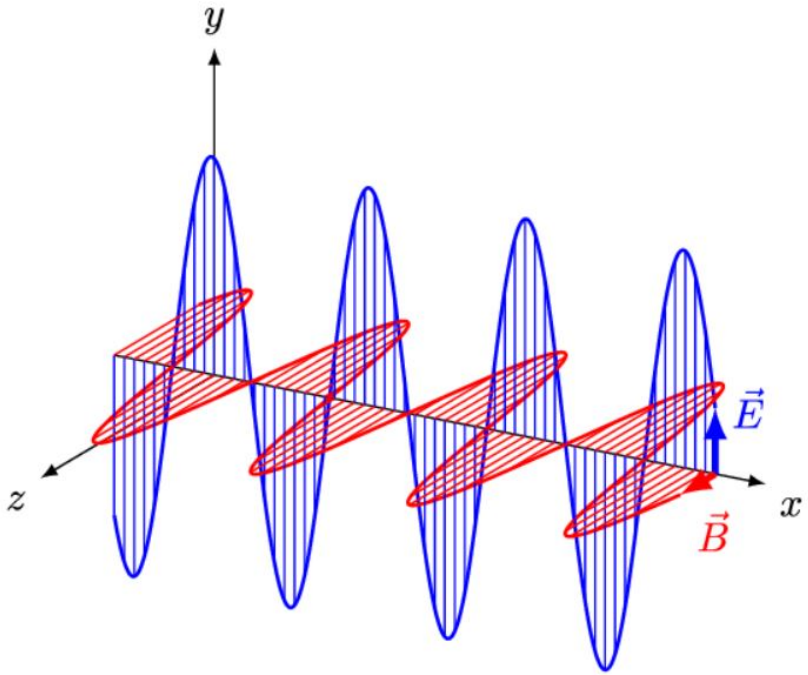
$\boldsymbol{m} = 0$

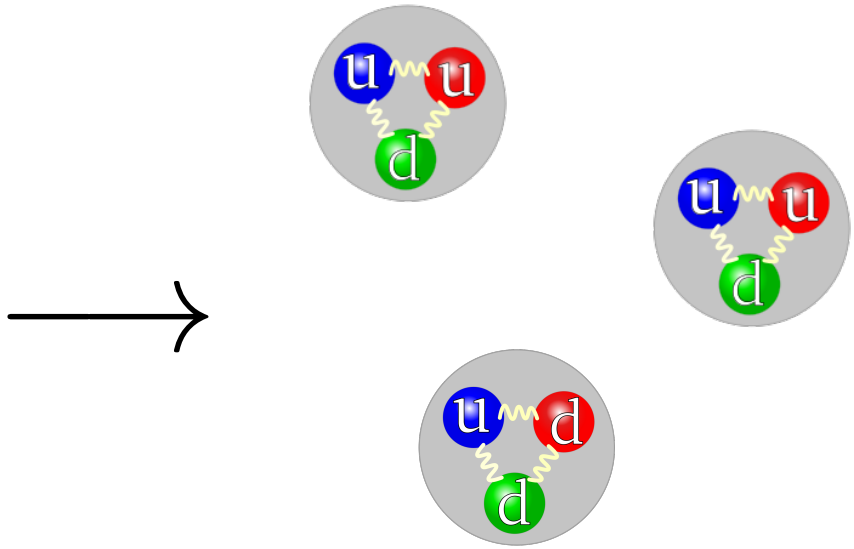


$\boldsymbol{m} = \beta_{para} \boldsymbol{B}$

Nucleon Polarizabilities

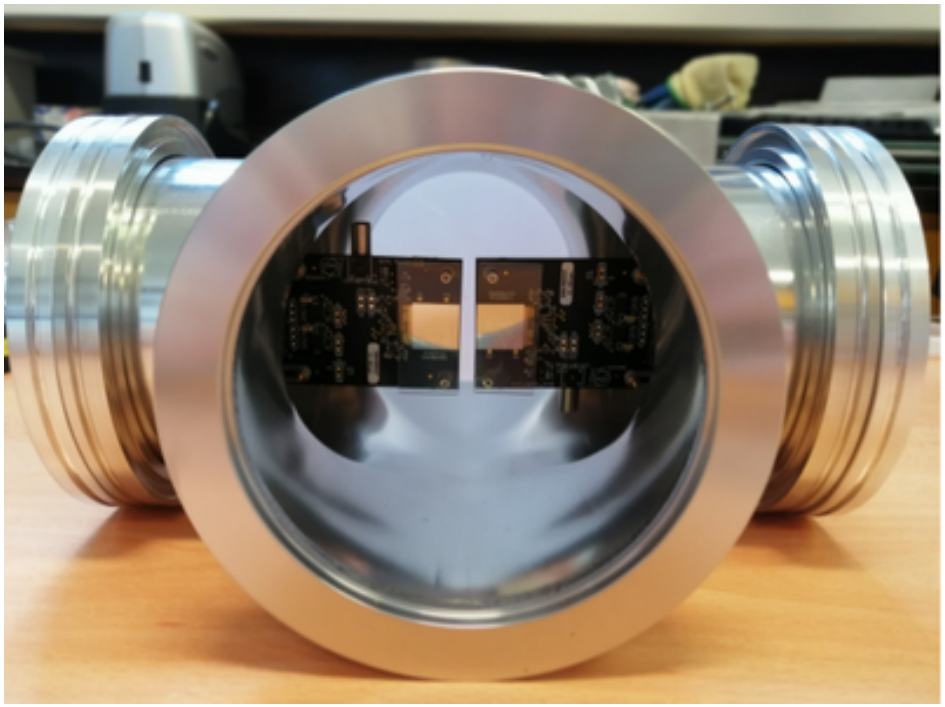
- Utilize the EM field of a photon
- Polarization must be measured





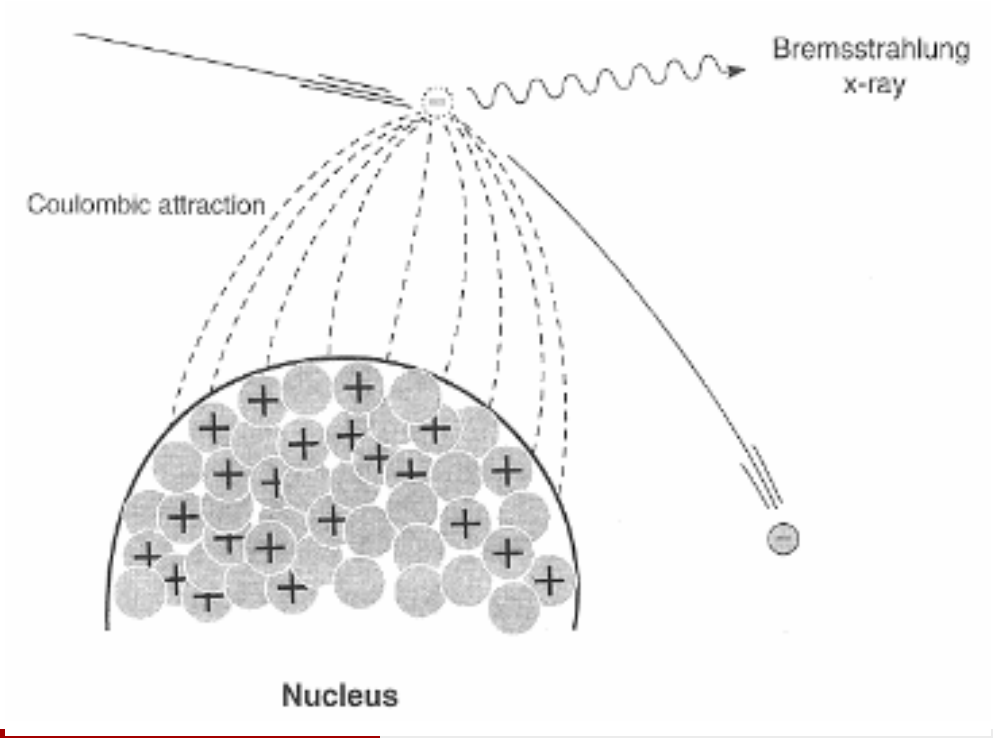
Glasgow Pair Polarimeter

- Measures photon beam polarization
- One particle can cause multiple hits
- Correcting for this phenomenon - time-walk effect



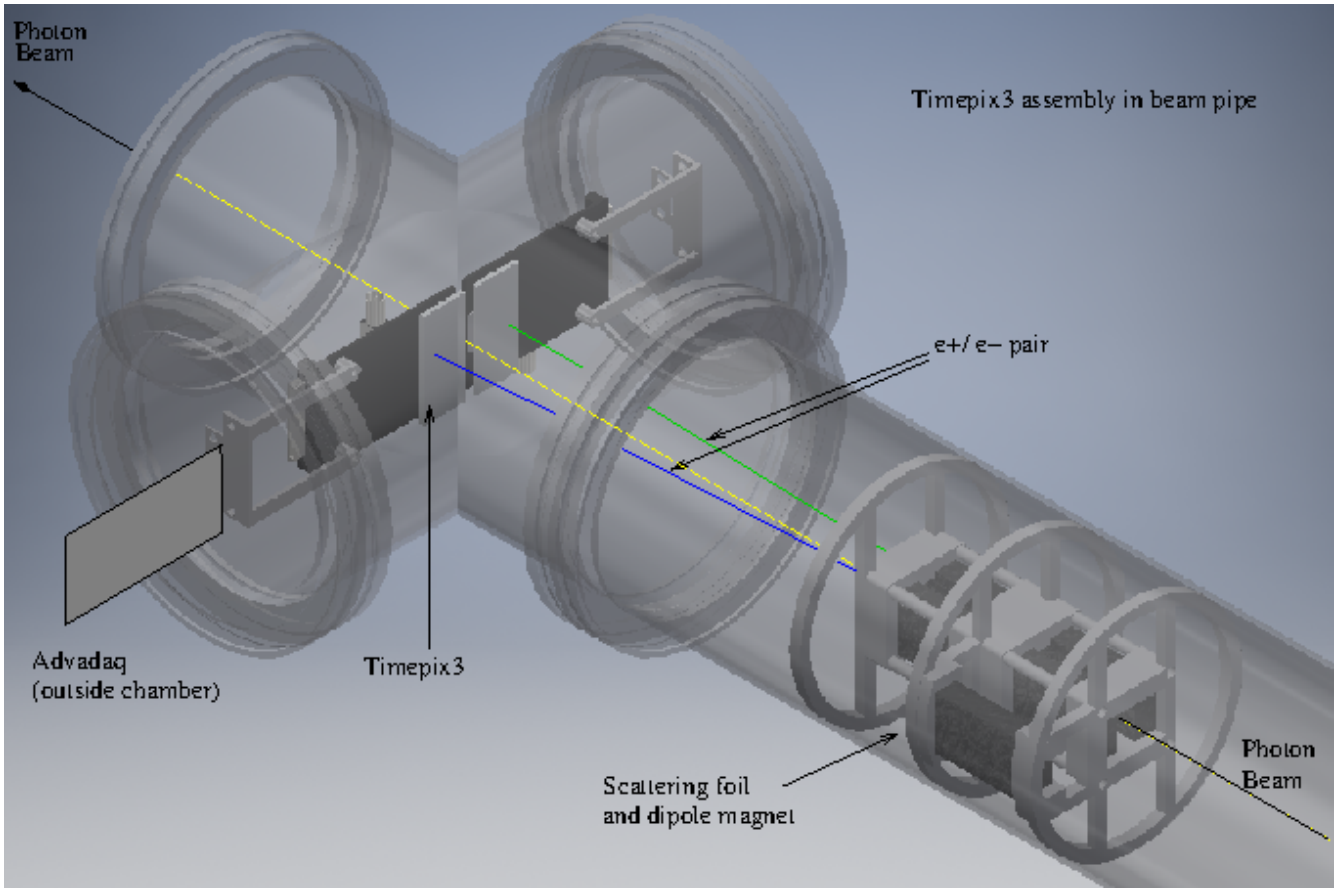
Photon Production

- Diamond radiator creates linearly polarized photon beam via Bremsstrahlung production
- Bremsstrahlung = "braking radiation" in German
- Electrons are accelerated, release energy difference as photon
- $E_\gamma = E_{beam} - E_{electron}$



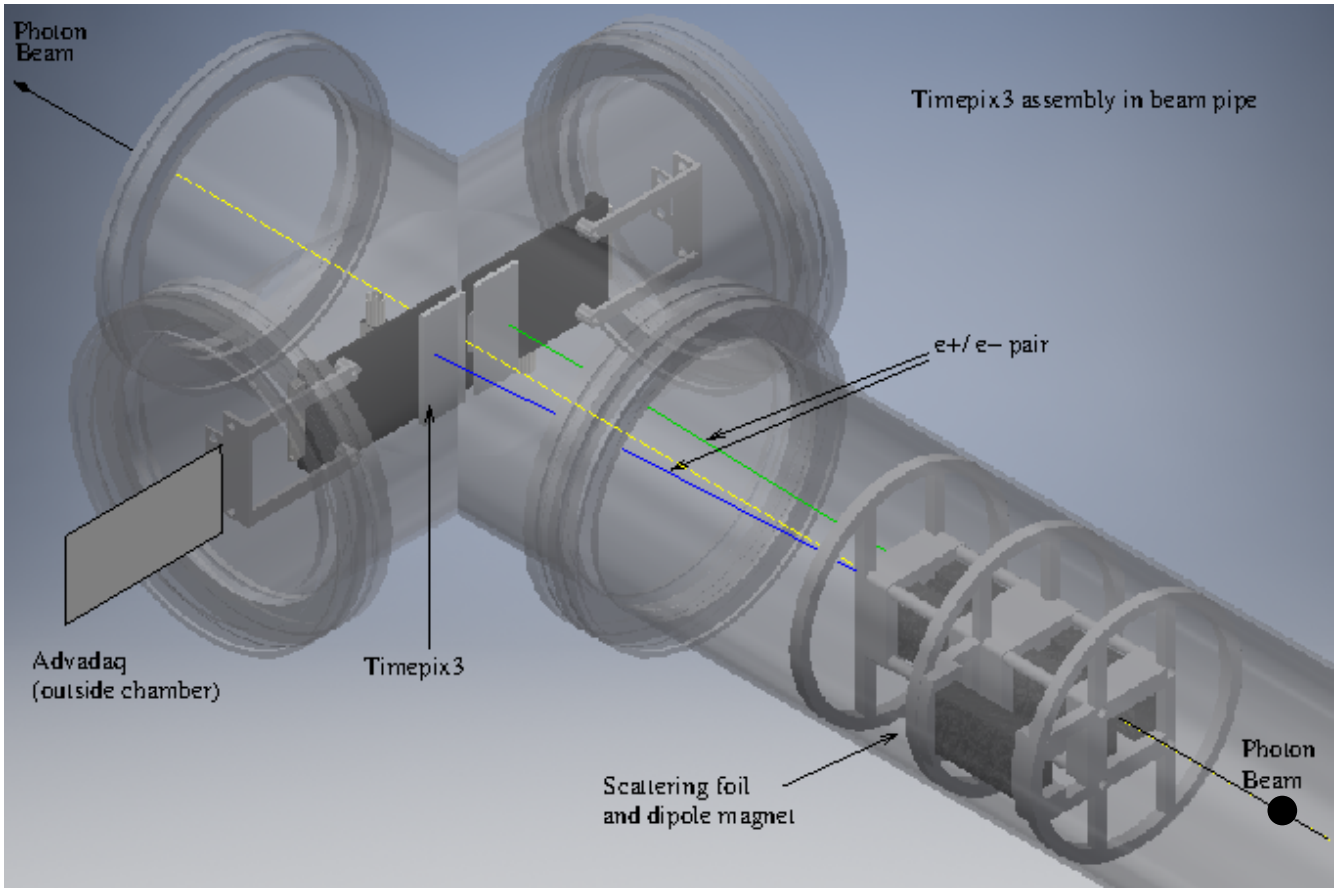
Pair Polarimeter

- Measures photon beam polarization
- Motivation: smaller systematic error ($< 2\%$)



Pair Polarimeter

- Pair production
- Photon beam passed through thin foil$\rightarrow$ produces e^-, e^+ pair



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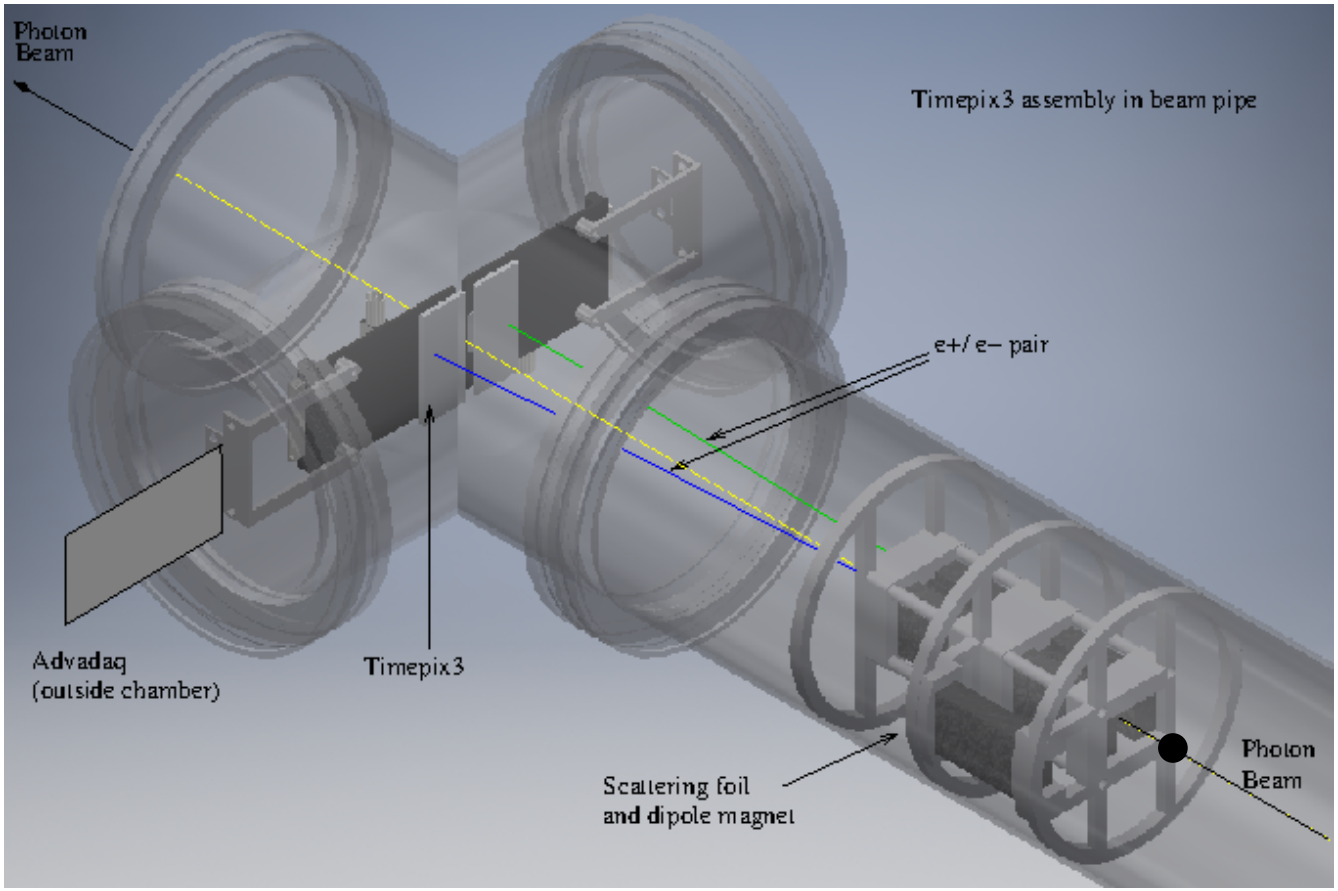
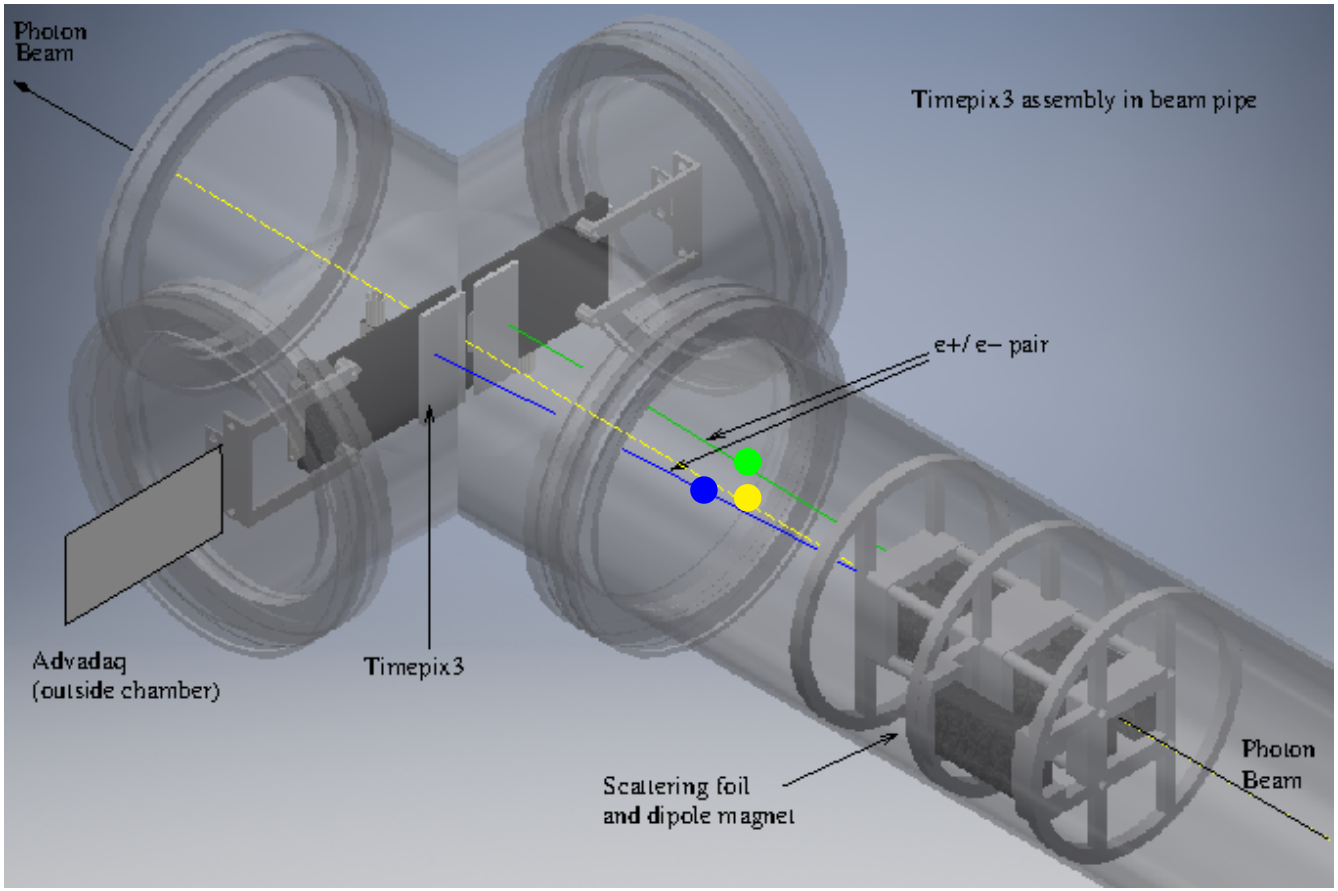


Pair Polarimeter

- Magnetic field separates opening angle further
- Pair hits Timepix3 detectors



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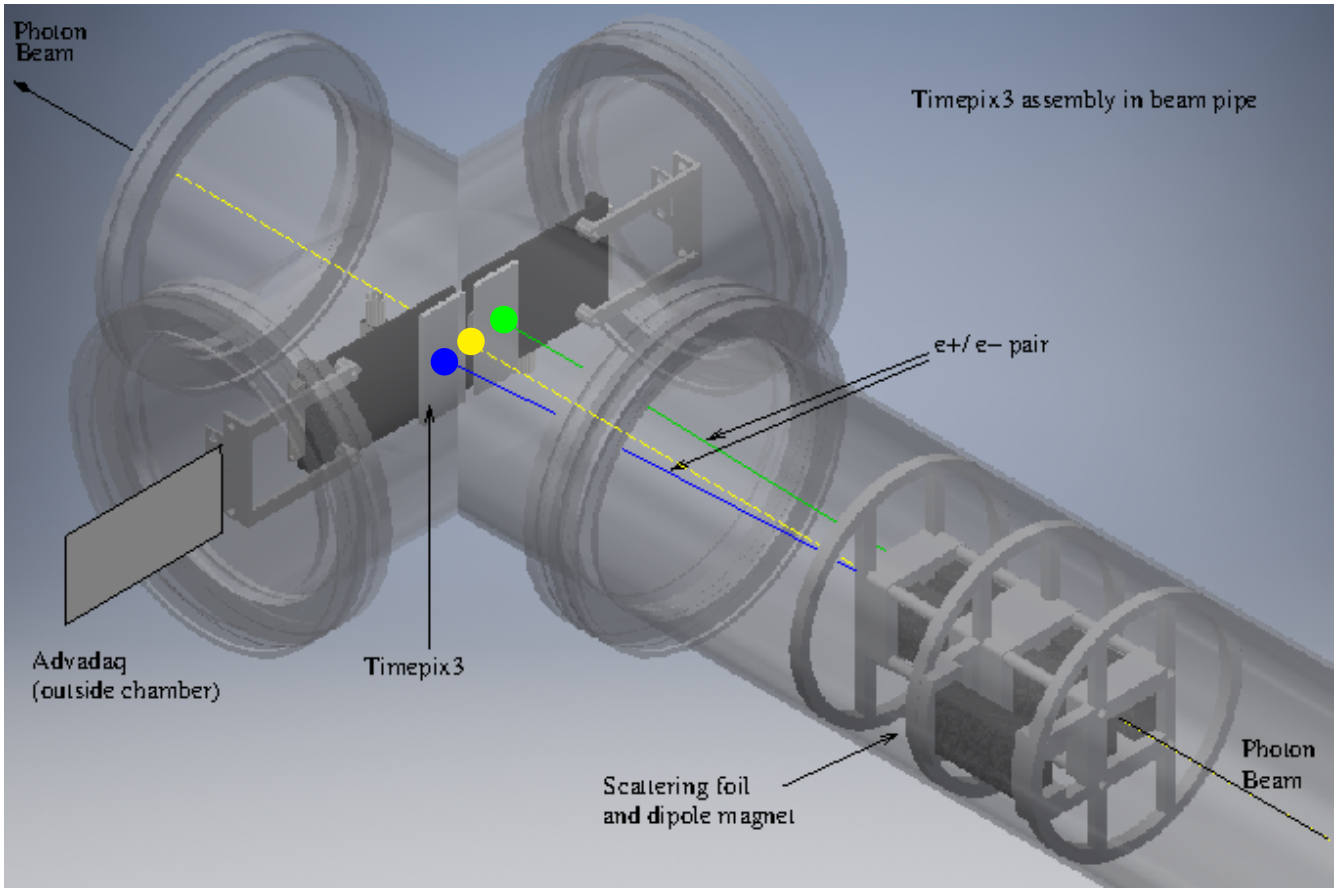

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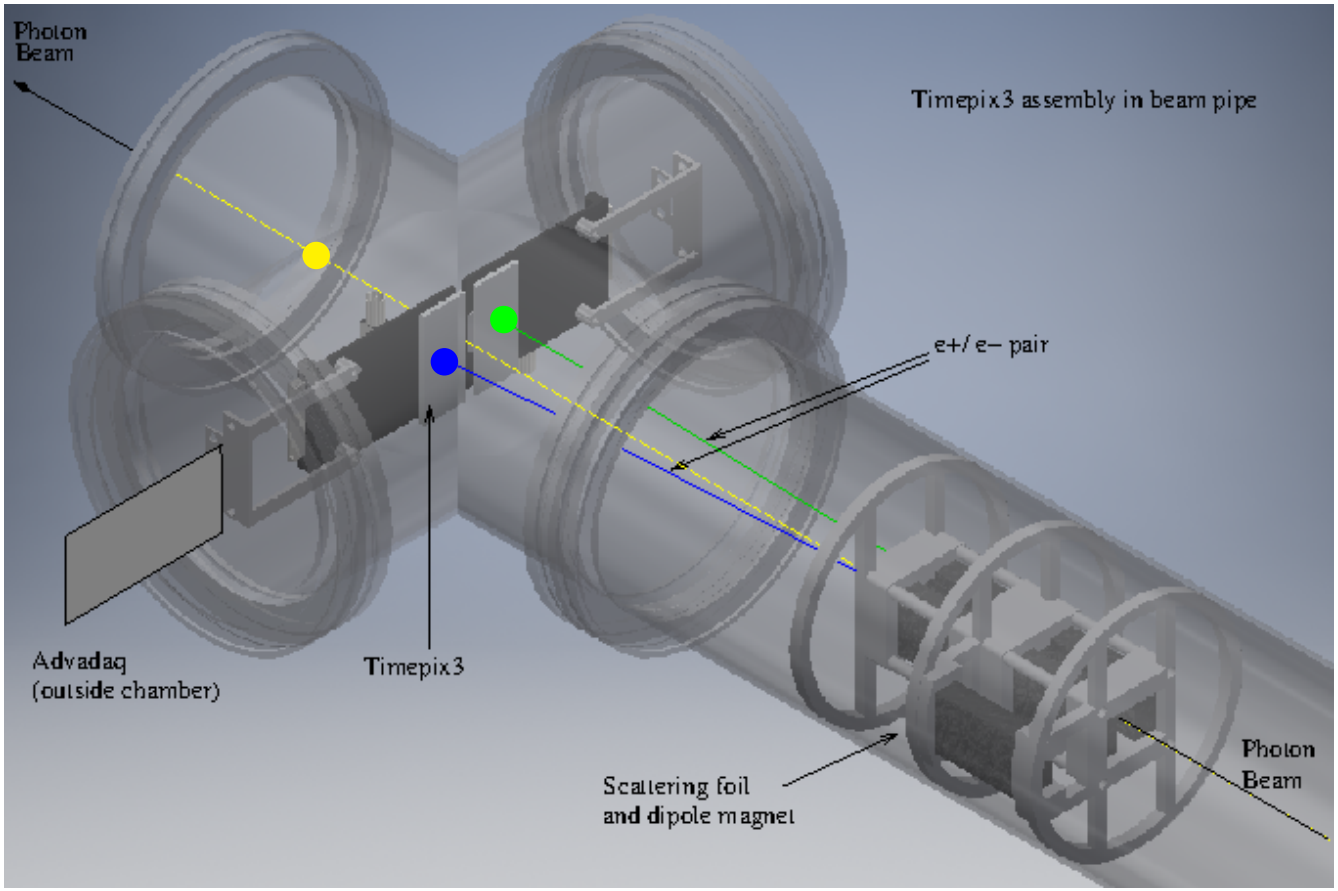
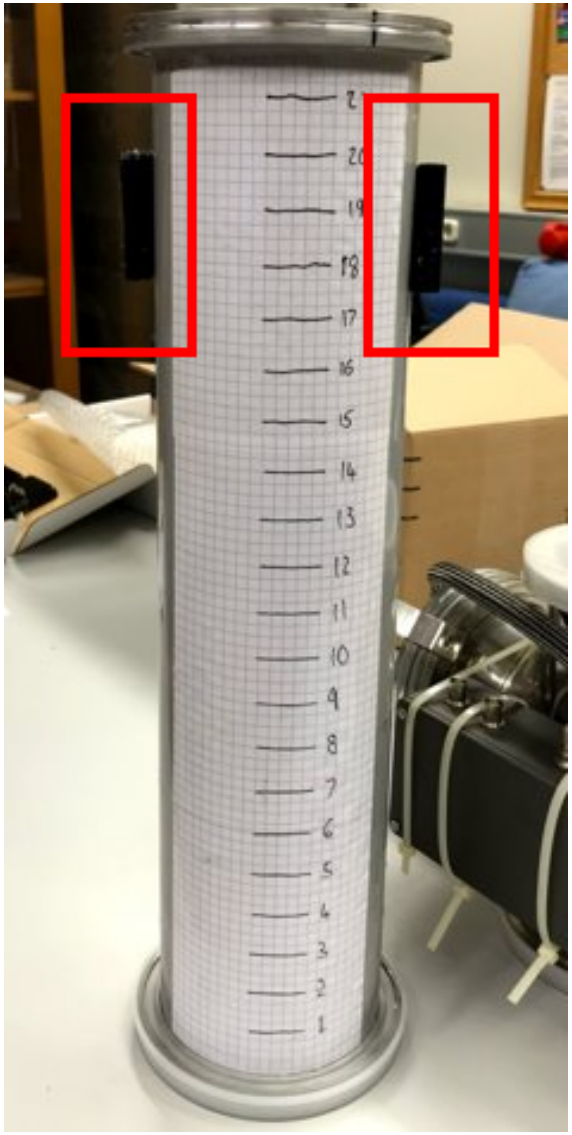
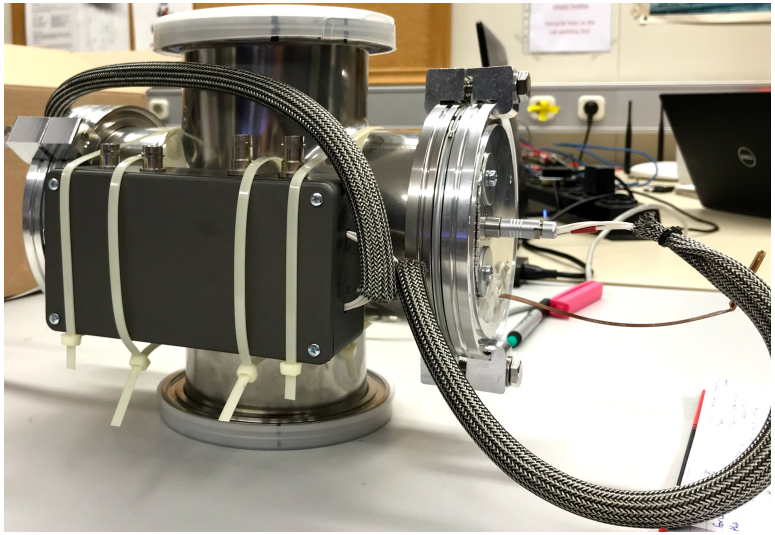
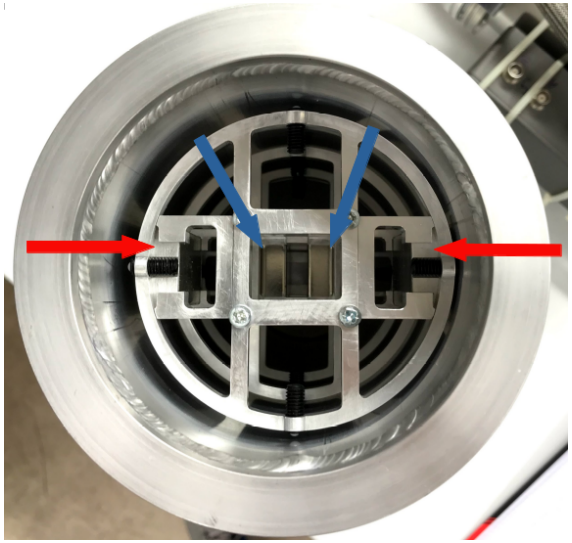


Pair Polarimeter



Beam pipe with steering magnets.





Steering and dipole magnets.

Pair Polarimeter

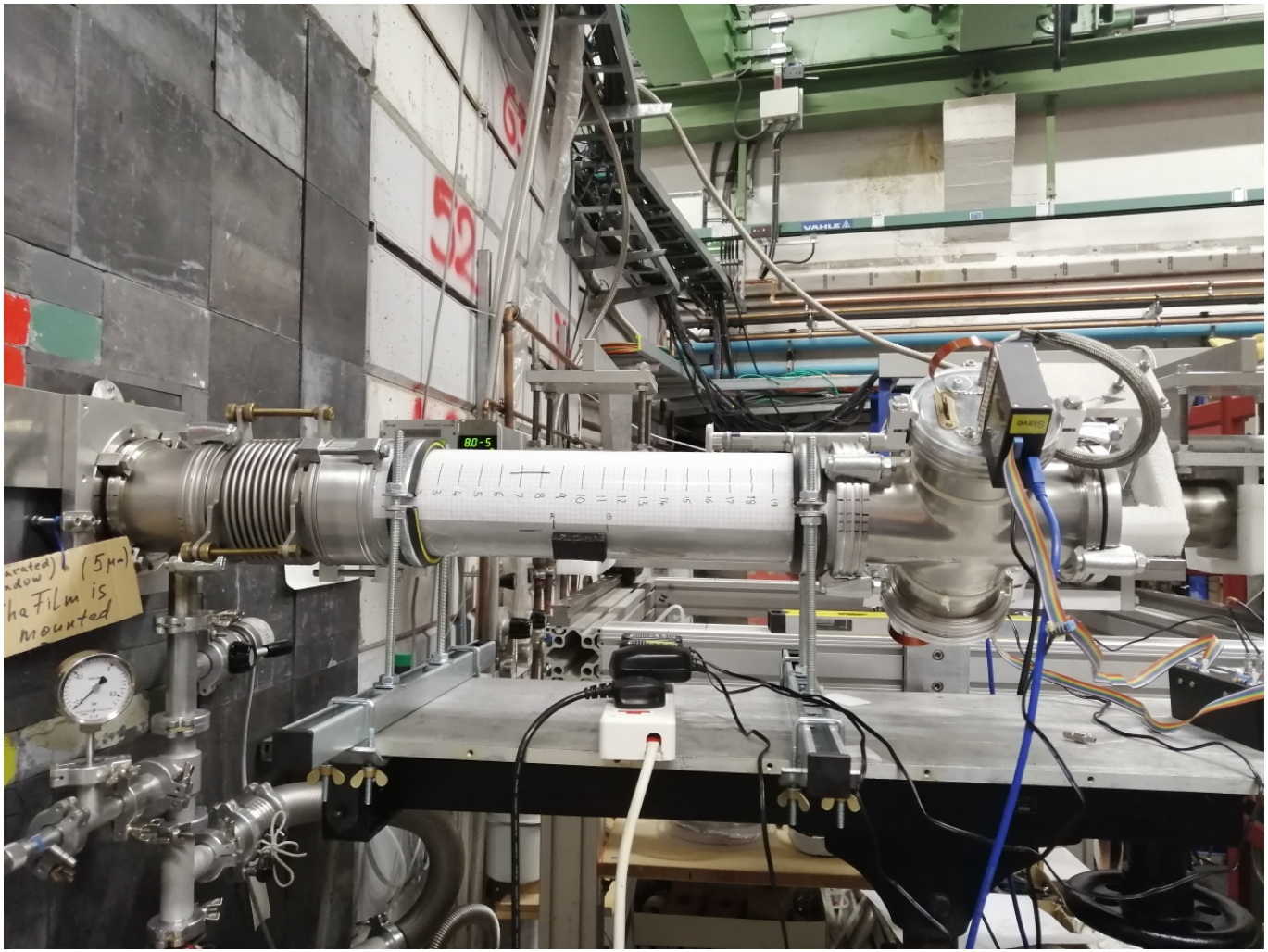
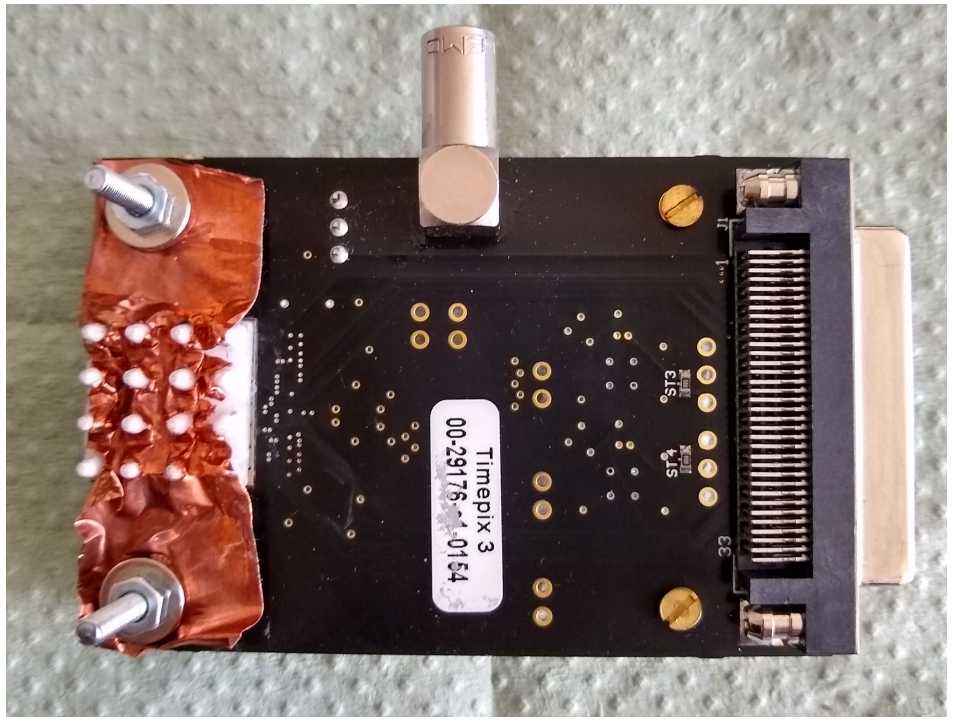


Photo courtesy of Dr. Simon Gardner, University of Glasgow

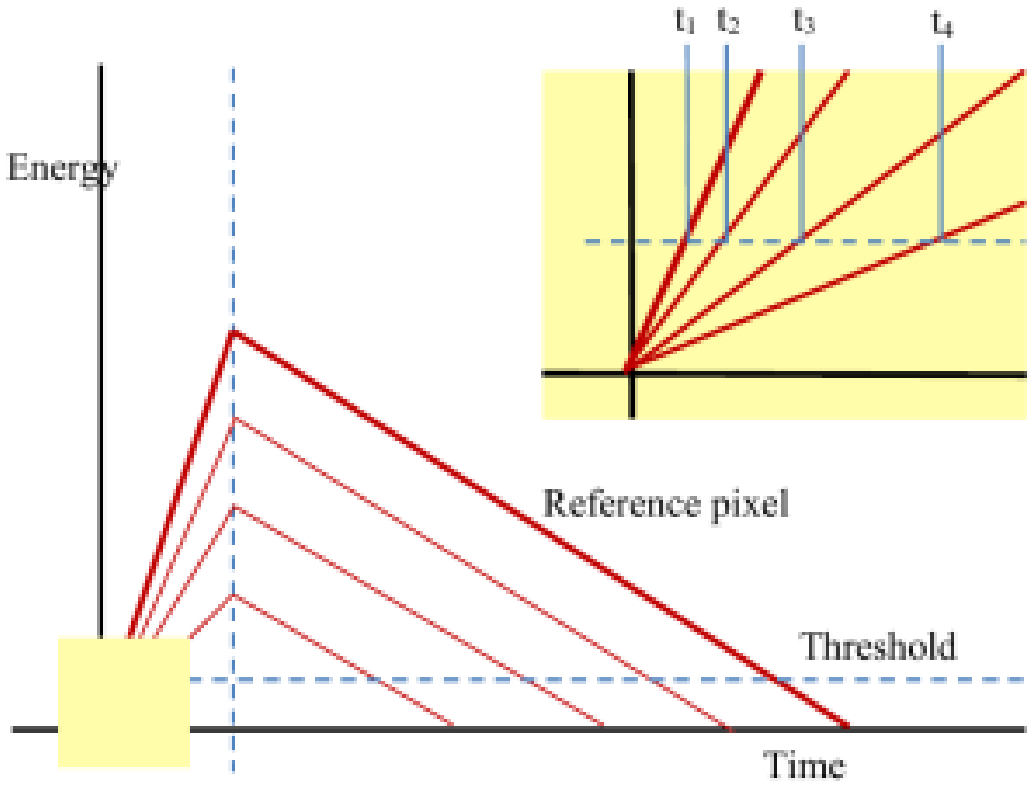
Timepix3 Detectors

- Chip of 256 $\times$ 256 pixels
- x, y position
- ToA: time of arrival of hit
- ToT: measurement of energy deposited in pixel
- Measures ToA and ToT simultaneously



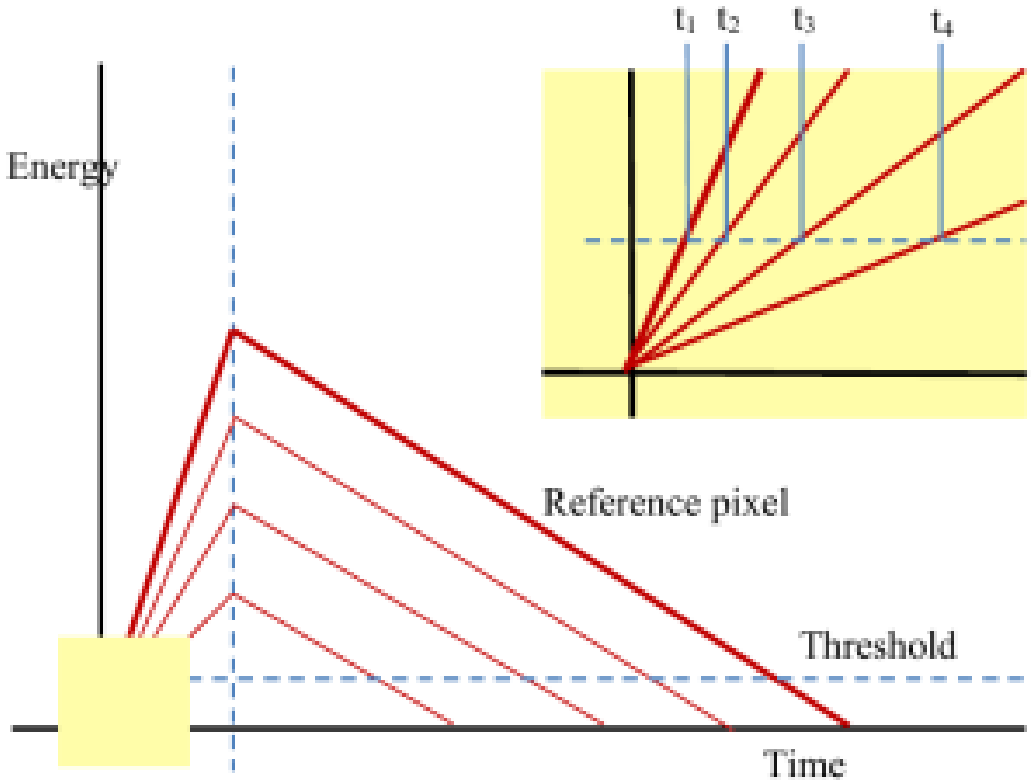
Time-Walk Effect

- Main focus of summer research



Time-Walk Effect

- Main focus of summer research
- Particle can "slide" and make a cluster of hits



Time-Walk Effect

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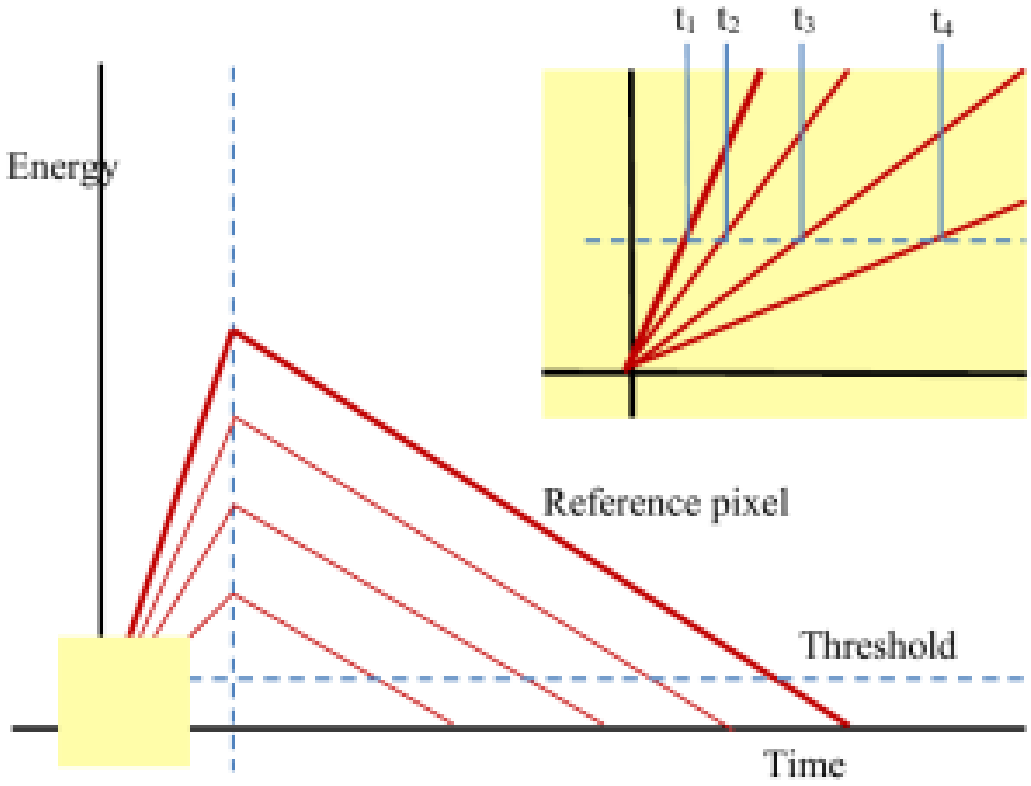
- Particle can "slide" and make a cluster of hits
- Each hit deposits energy



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- Particle can "slide" and make a cluster of hits
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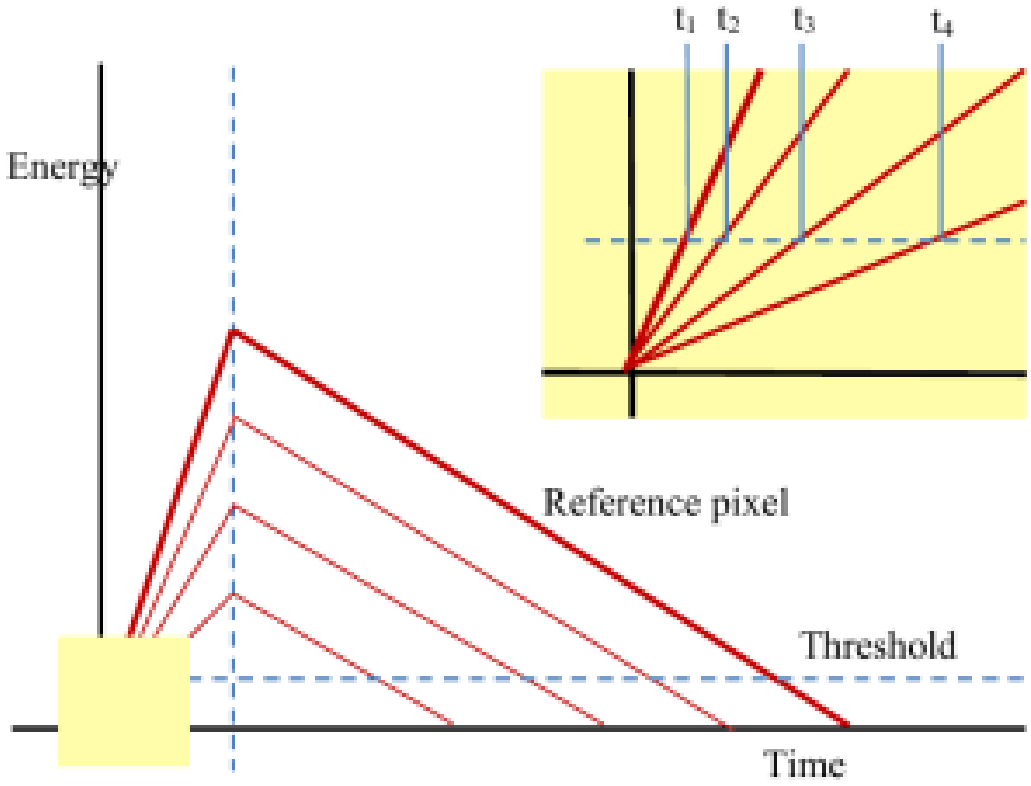
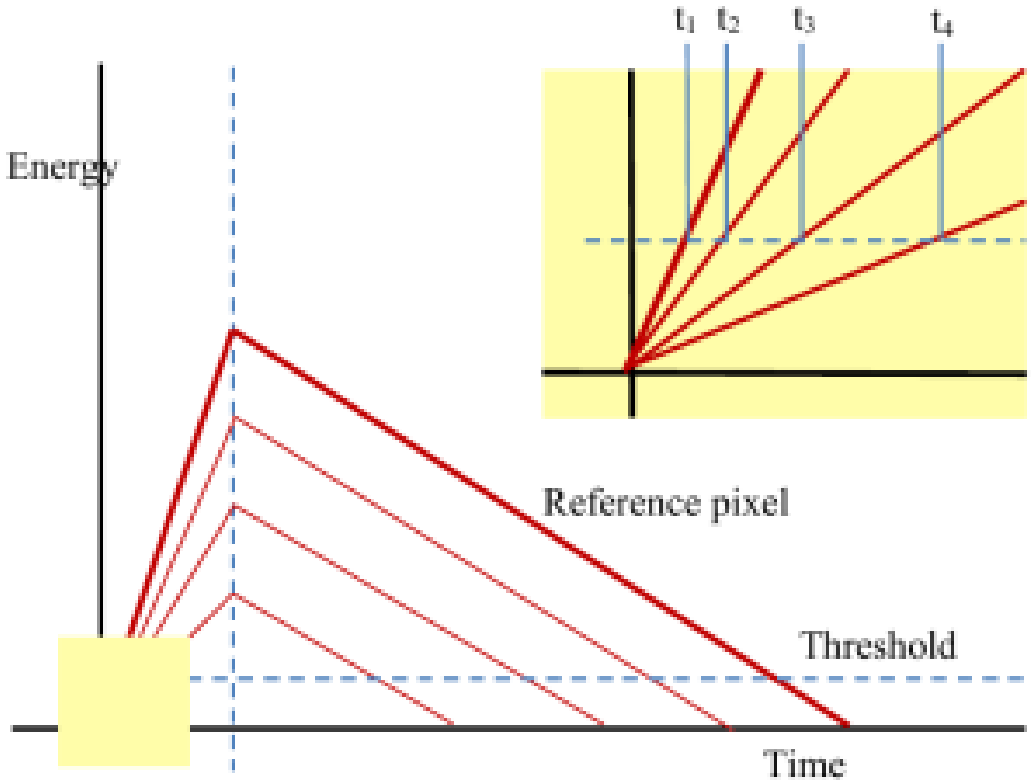
- Voltage pulses of different amplitudes cross the threshold level at different times



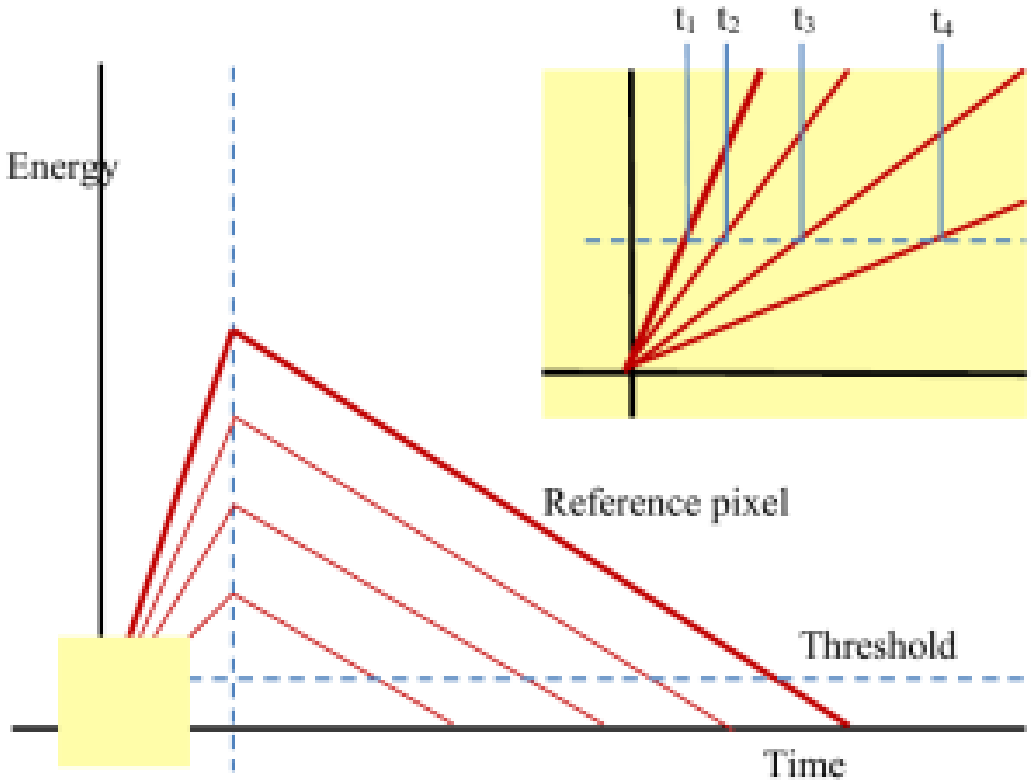
Time-Walk Effect

- Main focus of summer research
- Particle can "slide" and make a cluster of hits
- Each hit deposits energy
- Voltage pulses of different amplitudes cross the threshold level at different times
- ToA depends on slope
- Difference in the measured ToA is caused by the **time-walk**



Time-Walk Effect

- Main focus of summer research
- Particle can "slide" and make a cluster of hits
- Each hit deposits energy
- Voltage pulses of different amplitudes cross the threshold level at different times
- ToA depends on slope
- Difference in the measured ToA is caused by the **time-walk**
- Correct ToA for all hits



Correcting for Time-Walk

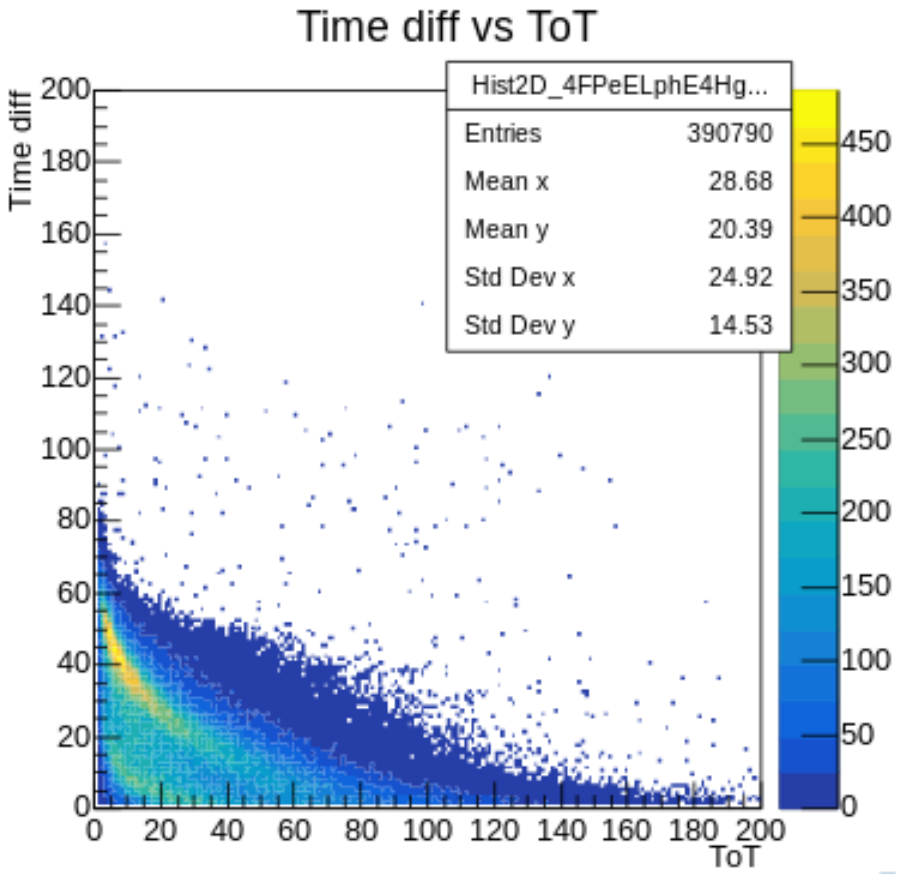
- Correct ToA units
- If time difference is < 156 ns, consider hit to be part of cluster
- twalk, group number

	x	y	ToA	FToA	ToT	ctime	tdiff	twalk	group
0	14	25	12700	15	49	203185	1000	0	1
1	171	114	37385	20	45	598140	394955	0	2
2	171	115	37386	26	45	598150	10	10	2
3	153	105	39185	15	105	626945	28795	0	3
4	153	106	39186	11	47	626965	20	20	3
5	152	105	39187	10	7	626982	17	37	3
6	93	113	39212	5	67	627387	405	0	4
7	92	113	39213	2	32	627406	19	19	4
8	148	230	61859	7	101	989737	362331	0	5
9	181	167	68548	16	119	1096752	107015	0	6

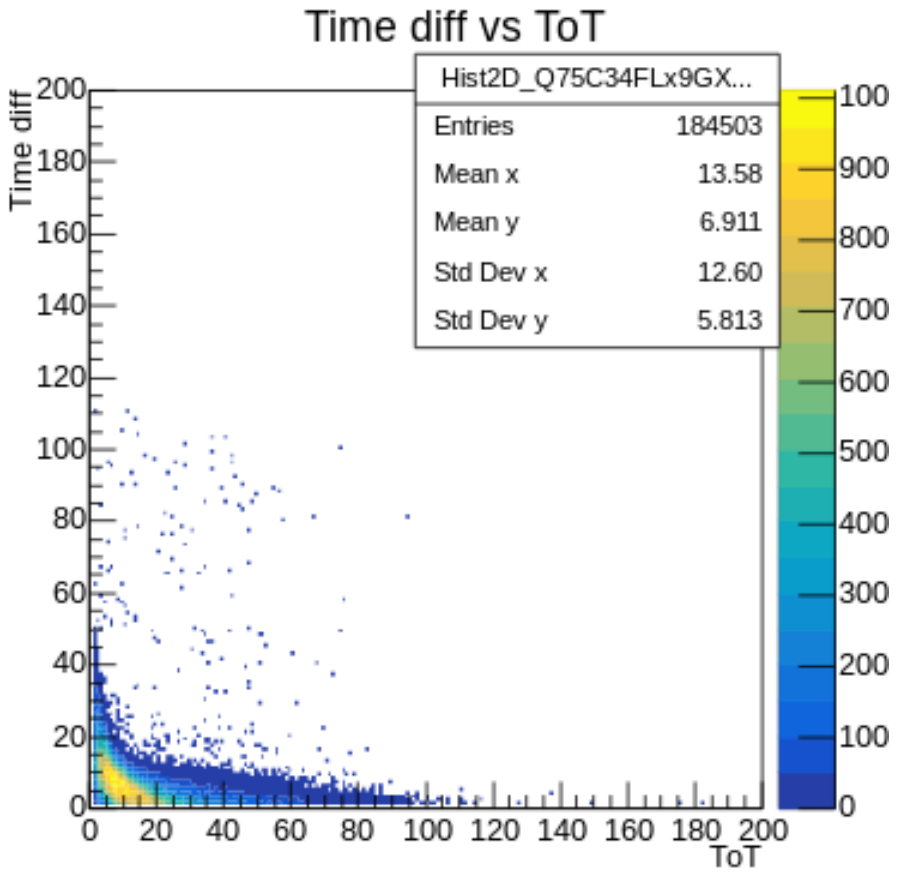
Data from the polarimeter test beamtime at MAMI (May 2019)

Correcting for Time-Walk

- Plot Time diff vs ToT (Time diff = "twalk" from dataframe)



A detector

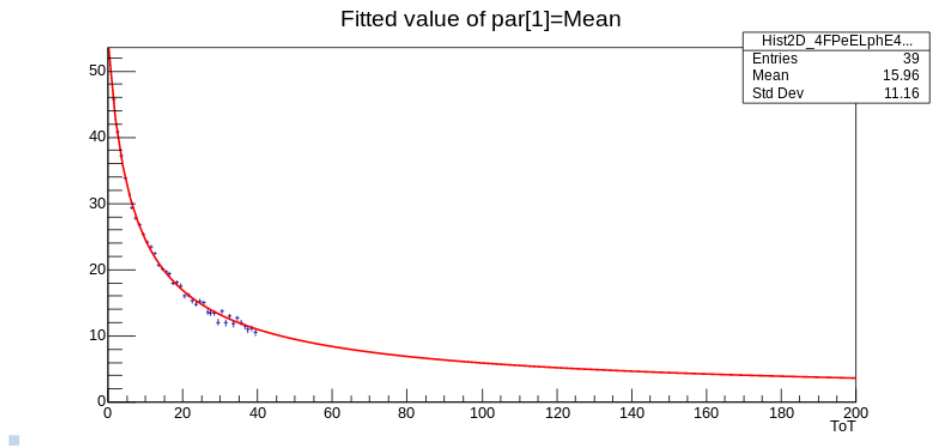


B detector

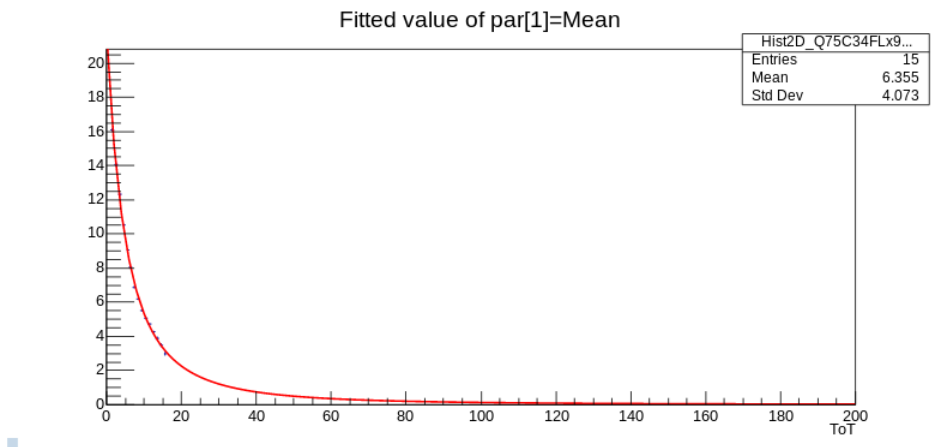
Correcting for Time-Walk

- FitSlicesY, fits slices projected along y from bins in a range of x
- $Dt = \frac{c}{(E-E_0)^d}$, where $E = ToT$ and $E_0 = ToT_0$

```
FCN=67.1054 FROM MIGRAD    STATUS=CONVERGED     407 CALLS         408 TOTAL
                     EDM=2.65522e-09    STRATEGY= 1      ERROR MATRIX ACCURATE
 EXT PARAMETER                                   STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  c           1.77305e+02   1.27922e+01   1.49740e-03  -1.60947e-04
  2  ToT_0      -5.00607e+00   3.59653e-01   1.25293e-04  -1.73369e-03
  3  d           7.30395e-01   1.96439e-02   3.26870e-06   7.15365e-02
```




```
FCN=51.1718 FROM MIGRAD    STATUS=CALL LIMIT    1351 CALLS        1352 TOTAL
                     EDM=0.111712    STRATEGY= 1  ERROR MATRIX UNCERTAINTY  39.2 per cent
 EXT PARAMETER                APPROXIMATE         STEP         FIRST
 NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
  1  c           5.59841e+03   6.22295e+02   1.85327e+02  -3.45947e-02
  2  ToT_0      -1.16115e+01   2.45588e-01  -7.77549e-02  -2.55787e+01
  3  d           2.26243e+00   2.93390e-02   8.32071e-03   5.26900e+02
```



Correcting for Time-Walk

- $Dt = \frac{c}{(E-E_0)^d}$
- Calculate Dt for each hit using the parameters
- Correct time of arrival for all hits by subtracting Dt value

```
parametersA = myFitA.GetParameters()
Ac= parametersA[0]
AToT_0= parametersA[1]
Ad= parametersA[2]
print(Ac,AToT_0,Ad)
```

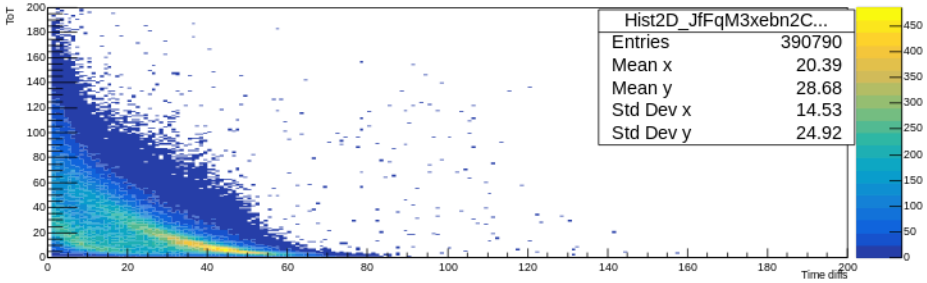
```
(177.30535936189833, -5.006068824861125, 0.7303950623952549)
```

```
parametersB = myFitB.GetParameters()
Bc= parametersB[0]
BToT_0= parametersB[1]
Bd= parametersB[2]
print(Bc,BToT_0,Bd)
```

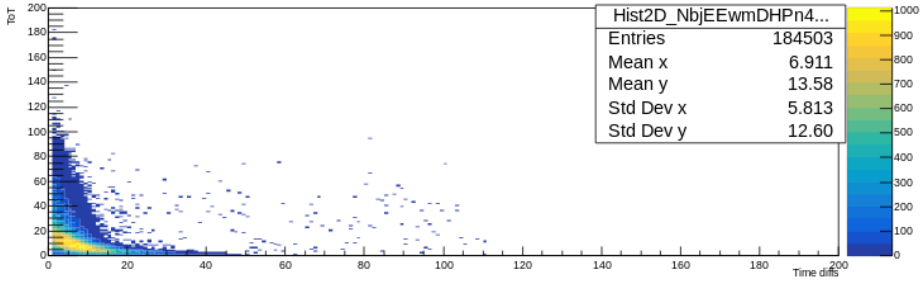
```
(5598.408183790876, -11.611491378349555, 2.2624340675691297)
```

Results for tpx33 Data

ToT vs Time diff not corrected (A)



ToT vs Time diff not corrected (B)



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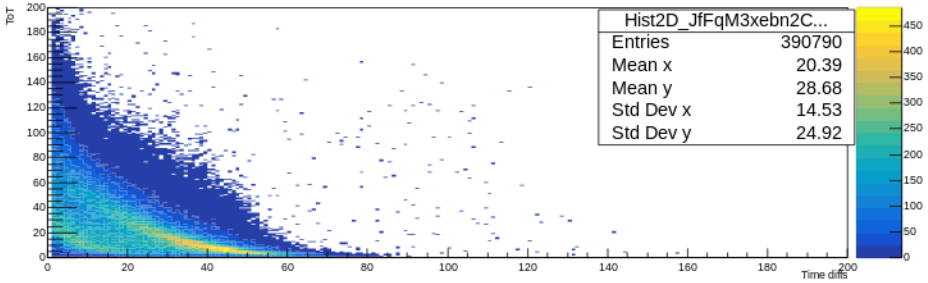
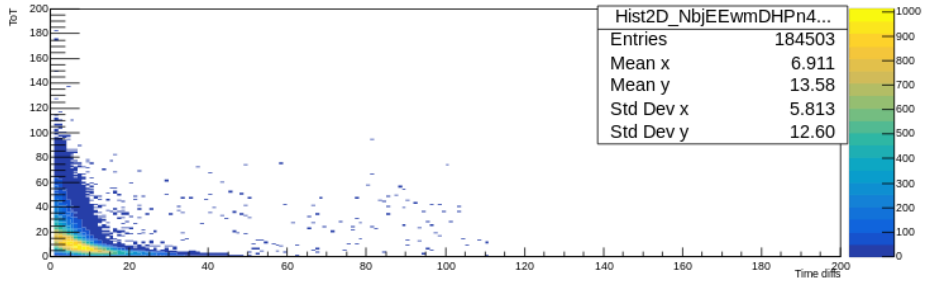
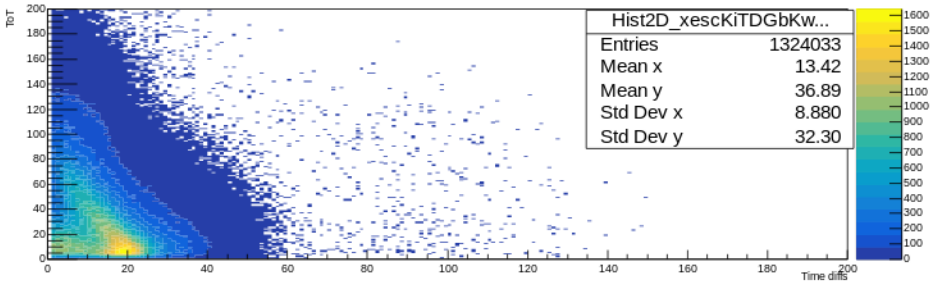


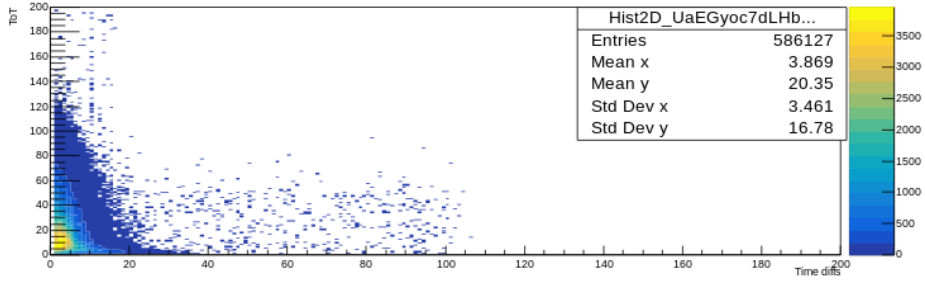
ToT vs Time diff not corrected (B)



ToT vs Time diff corrected (A)

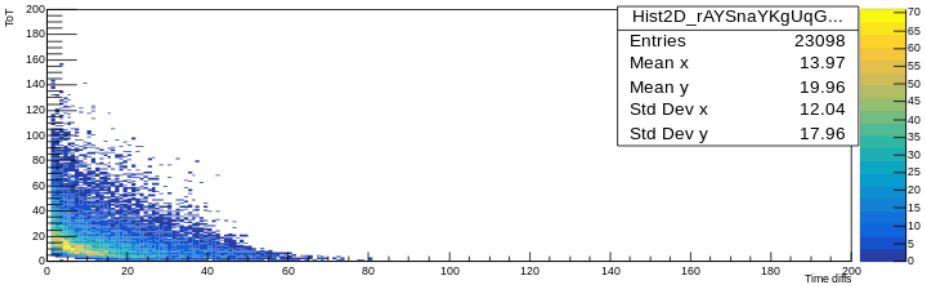


ToT vs Time diff corrected (B)

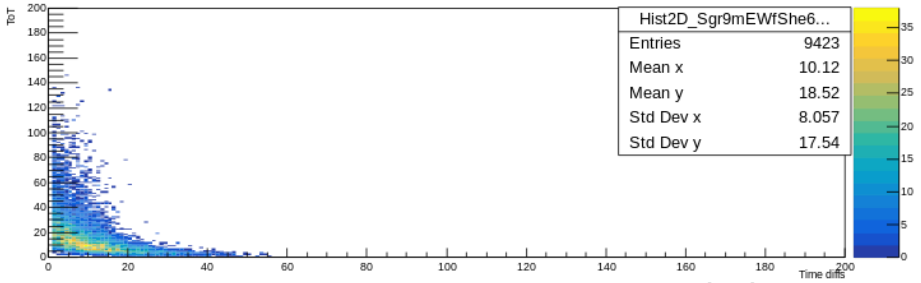


Results for tpx238 Data

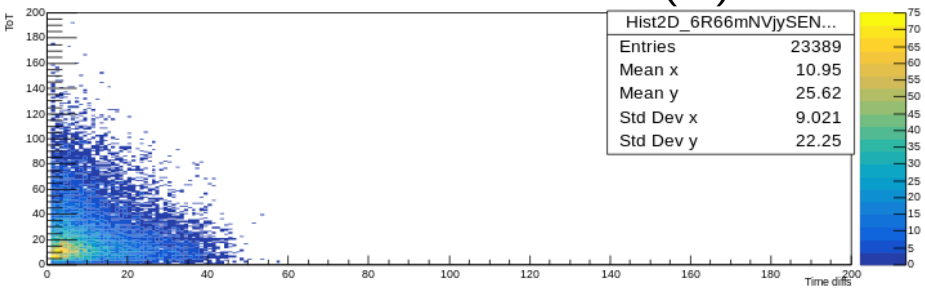
ToT vs Time diff not corrected (A)



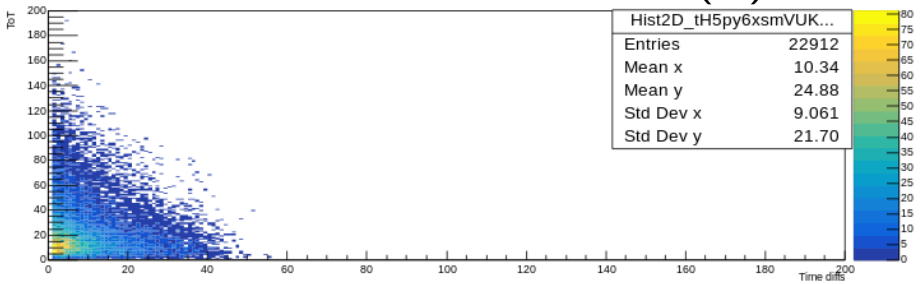
ToT vs Time diff not corrected (B)



ToT vs Time diff corrected (A)

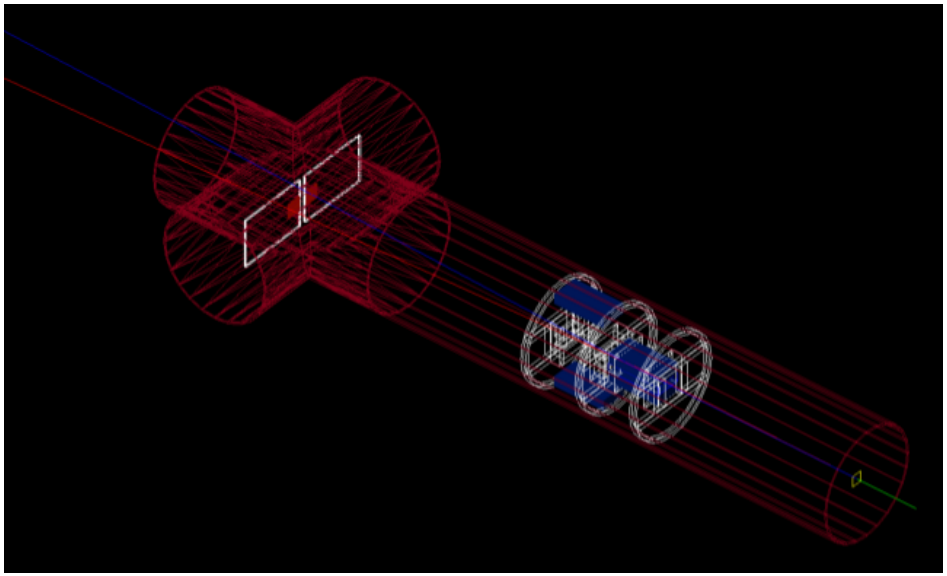


ToT vs Time diff corrected (B)



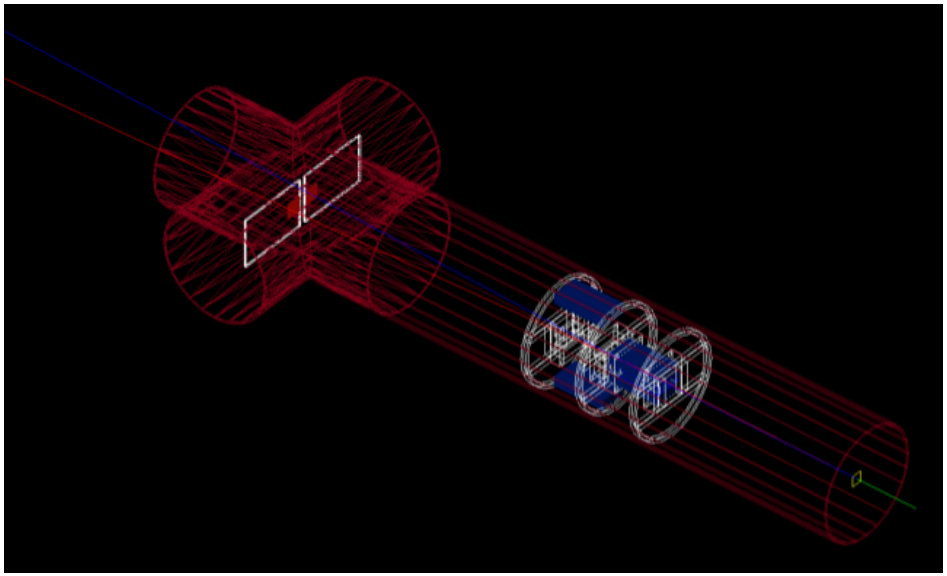
Conclusion

- Electron beam $\rightarrow$ polarized photon beam
- Pair polarimeter $\rightarrow$ polarization with lower systematic error ($<2\%$)
- Hits "slide", must correct ToA for time-walk effect
- Need good timing resolution to find timing coincidences between photons that created the e^-, e^+ and tagged electrons



Conclusion

- Still in the early stages of writing code for calibrations/corrections
- Found proper coincidences between the two timepix3 detectors and the tagged electrons
- Promising results



Thank You!

- Dr. David Hornidge
- The A2 Collaboration
- Dr. Kenneth Livingston and Dr. Simon Gardner the University of Glasgow

University of Glasgow

Works Cited

Germany, image courtesy of Google Maps.
Positive pion meson, image courtesy of https://en.wikipedia.org/wiki/Pion.
Quark composition of proton, image courtesy of https://en.wikipedia.org/wiki/Quark.
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Pair polarimeter design, image courtesy of Dr. Kenneth Livingston, *University of Glasgow*, 2019.
Timepix3 detector photo, image courtesy of Dr. Kenneth Livingston, *University of Glasgow*, 2019.
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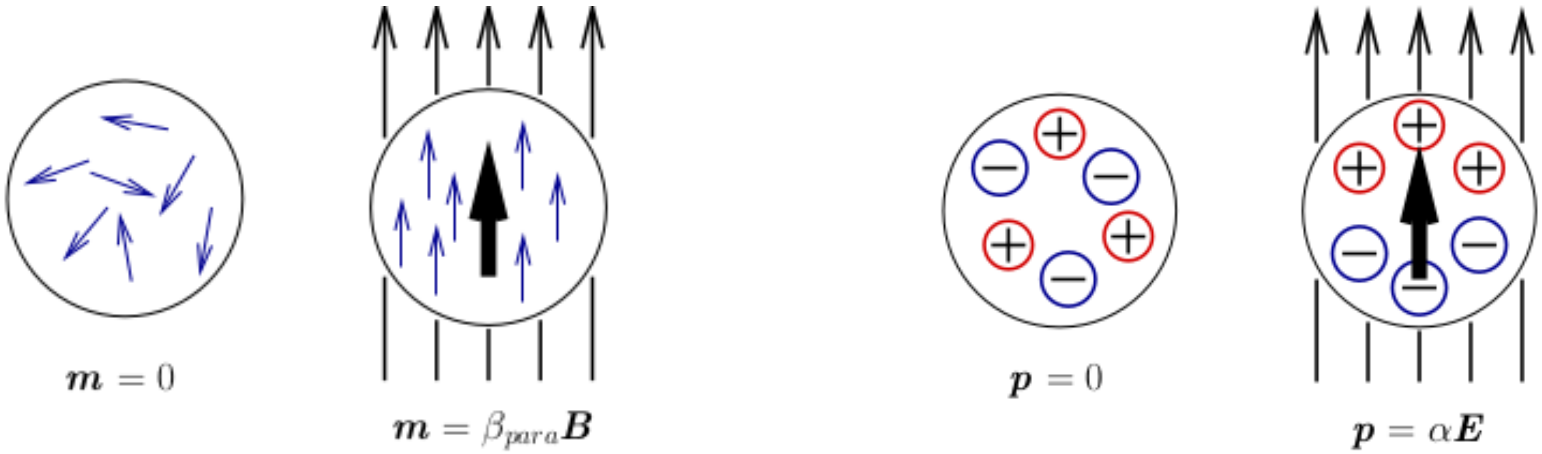
Extra Slides

Polarizabilities

Scalar polarizabilities for neutron and proton

- Magnetic polarizability = "alignability"
- Electric polarizability = "stretchability"
- Experimentally, polarizabilities can be determined by Compton scattering
- Uncertainty in measurement is currently larger for neutron than proton



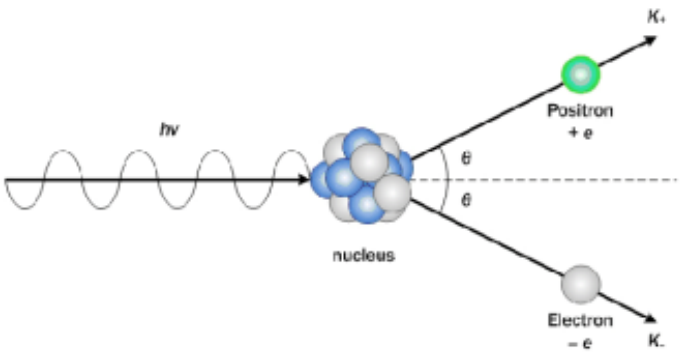
Polarization Calculations

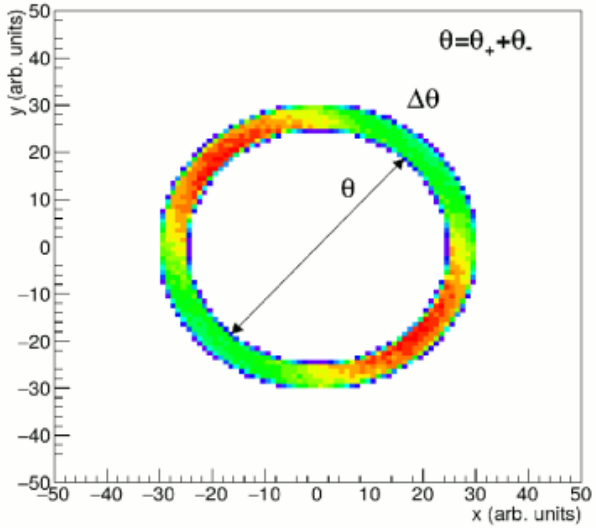
- The ϕ distribution can be fitted with a function of the form given in Eq. 1 and the degree of linear polarization P can be extracted from the fit parameters provided the analysing power A is known. [K. Livingston, 2016]
- $\phi(\theta) = \phi_0\left[1 + PAcos(2\theta)\right]$

  $\phi(\theta)$ = azimuthal angle of pair, ϕ_0 = cross section for unpolarized photons

  θ = cross-section

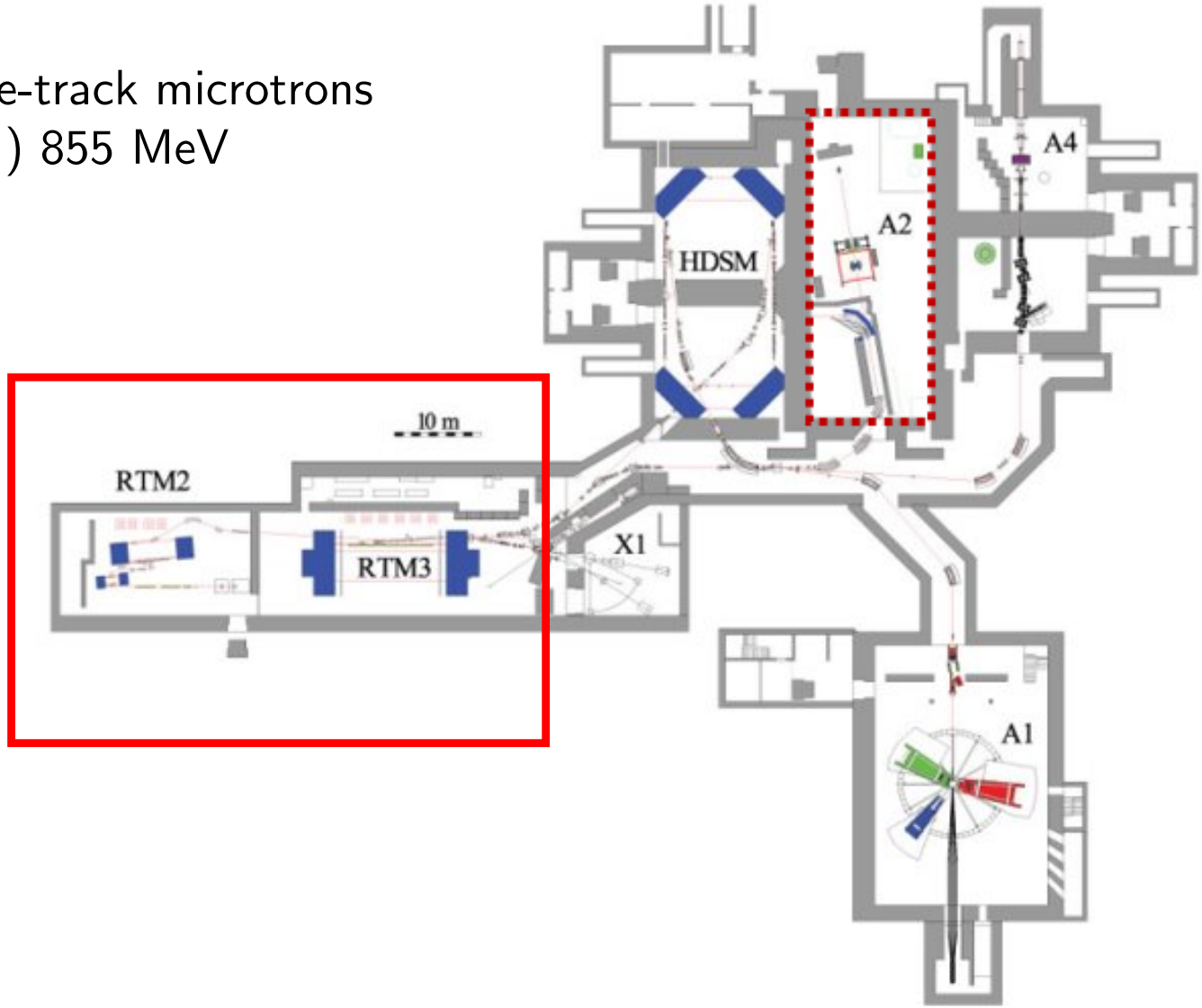
  P = photon polarization





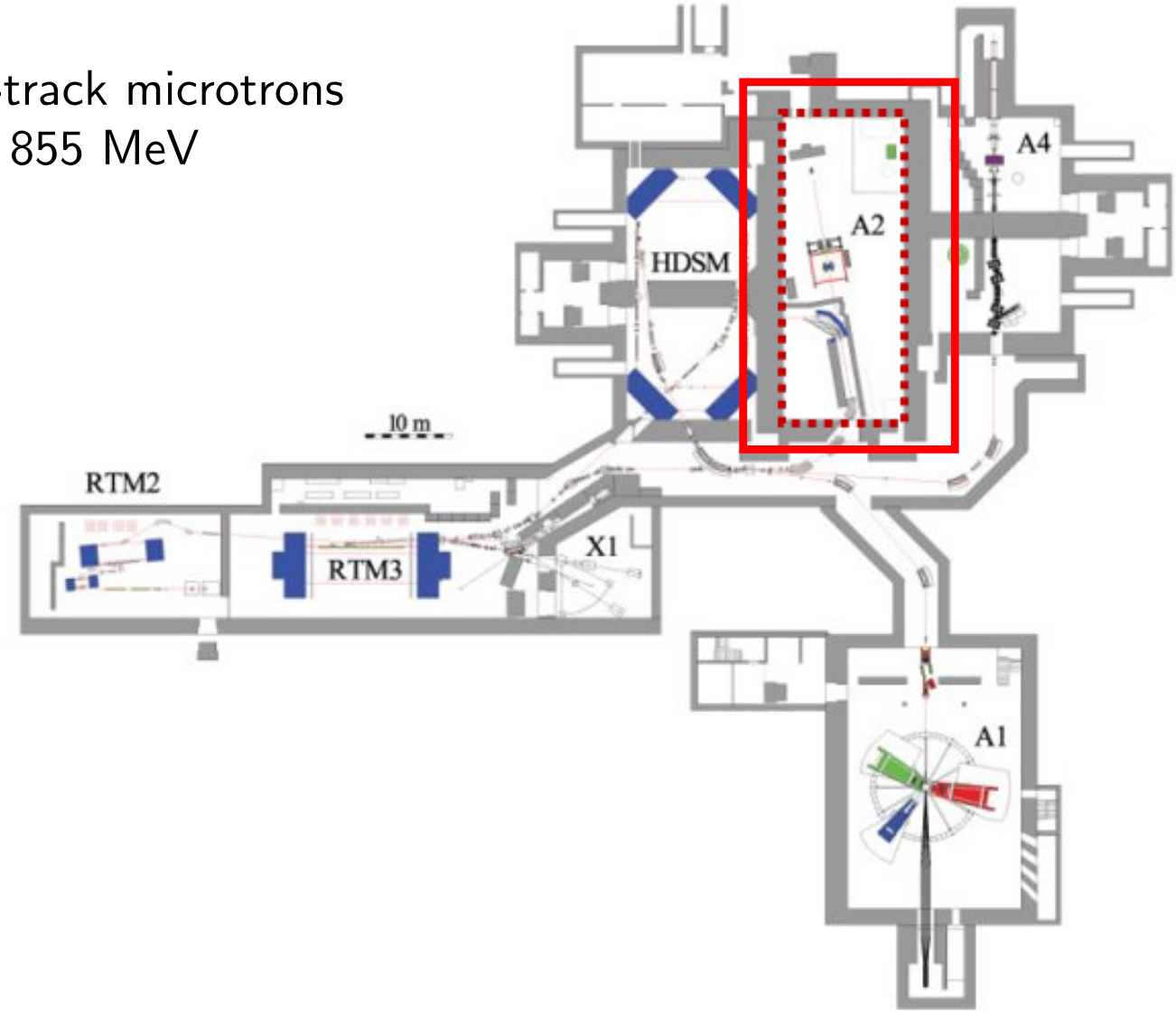
The Mainzer Mikrotron (MAMI)

- 3 Race-track microtrons (RTM) 855 MeV

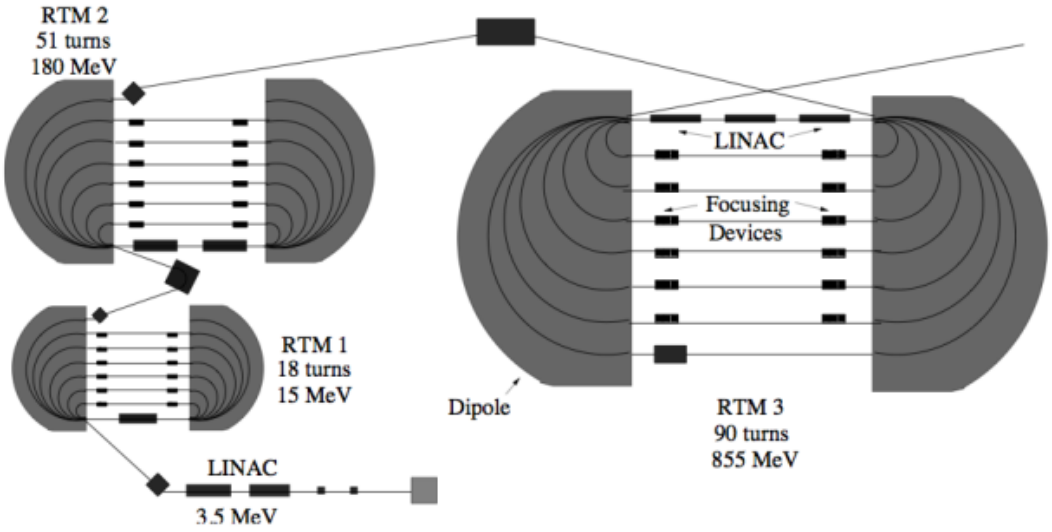


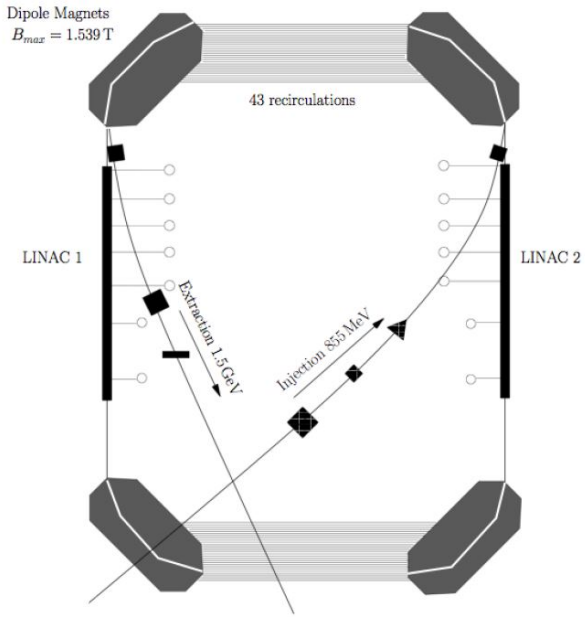
The Mainzer Mikrotron (MAMI)

- 3 Race-track microtrons (RTM) 855 MeV
- A2 hall



MAMI- RTMs and HDSM





- LINACs - alternating voltage to accelerate electrons
- RTM - magnets bend beam 180°, recirculate beam through LINAC multiple times
- As energy ↑, so does beam path
- HDSM - 4 magnets each bend beam 90∘

Photon Tagging

- After electrons radiate photon, bent by dipole magnet and hit Tagger
- Landing position depends on energy
- Timing coincidence between electron hit and event
- $E_\gamma = E_{beam} - E_{electron}$