LUXE SAS Meeting, 16th October 2023

Laser polarisation effects on positron

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Introduction

- High-power laser systems are normally linearly polarised, and the peak electric field at focus is reduced by a factor of $\sqrt{2}$ if converted to circular polarisation.
- Circular polarisation assumed in earlier studies as predictions are easier to produce.
- Linear polarised samples available in ptarmigan v0.11.
- Goal: quantify what we can expect at the tracker going from circular to linear polarisation.
- Comparing samples from ptarmigan v0.8.1 (CP) to v0.11 (LP, LMA).
    - Linear laser polarisation along x.

Comparison

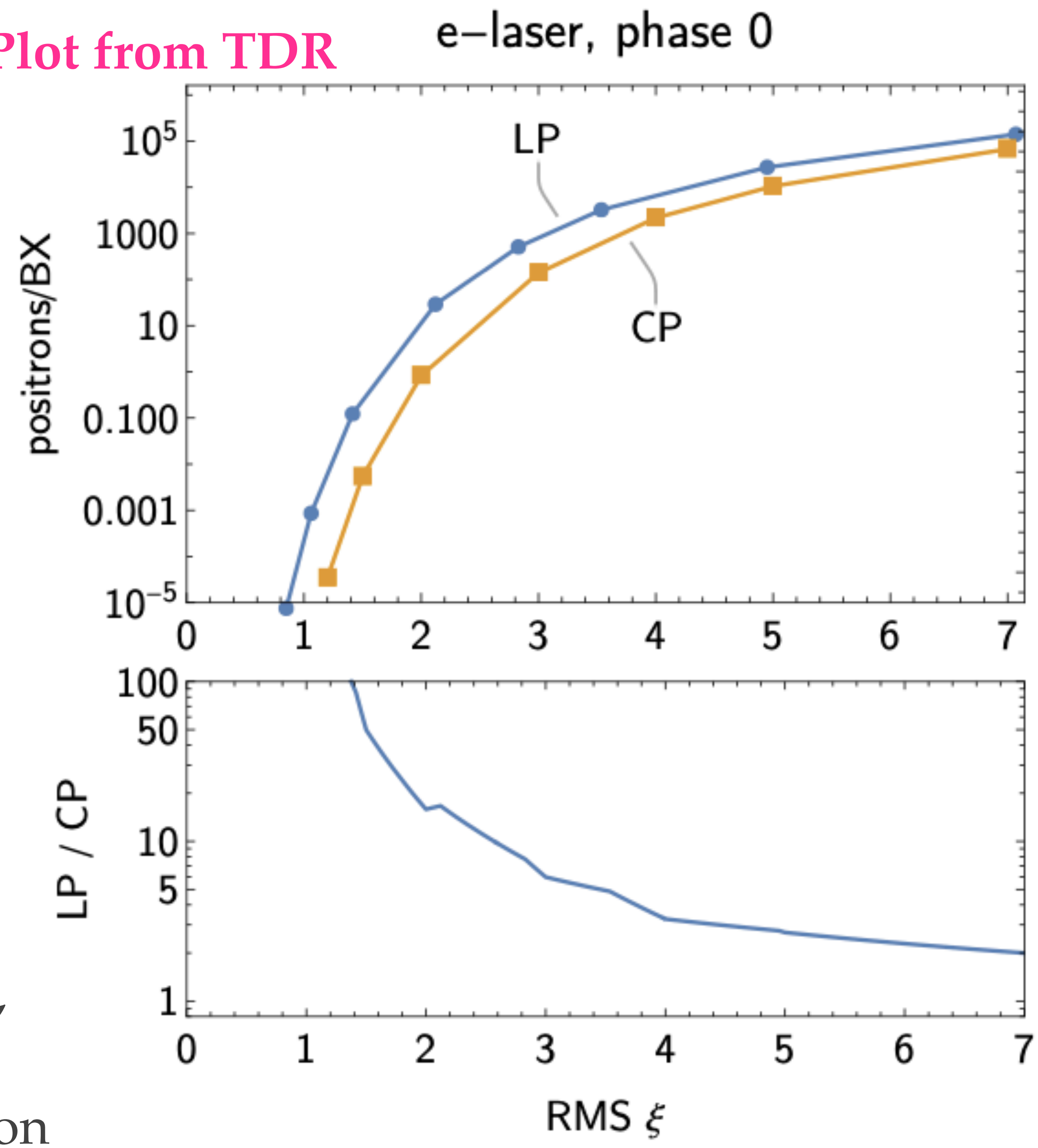
- E-laser phase-0 highest ξ chosen, averaged over 10 BX.
- dt_multiplier affects how close weights of positrons are to 1 (the smaller the better, but more CPU intensive).

Ptarmigan versions	v0.8.1	v0.11	
Nominal ξ	7	7	10
Polarisation	Circular	Linear	
dt_multiplier	0.5	0.2	
Waist	3.38μm	√2 x 3.38μm	3.34μm
Average ξ_{rms}	3.25	2.46	3.22
# positrons (raw)	40601	27025	108325
# positrons (weighted)	67043	27374	140982

Positron rate

- For a given laser waist (and RMS ξ) , the positron rate is larger for linear polarisation than for circular polarisation.

Plot from TDR



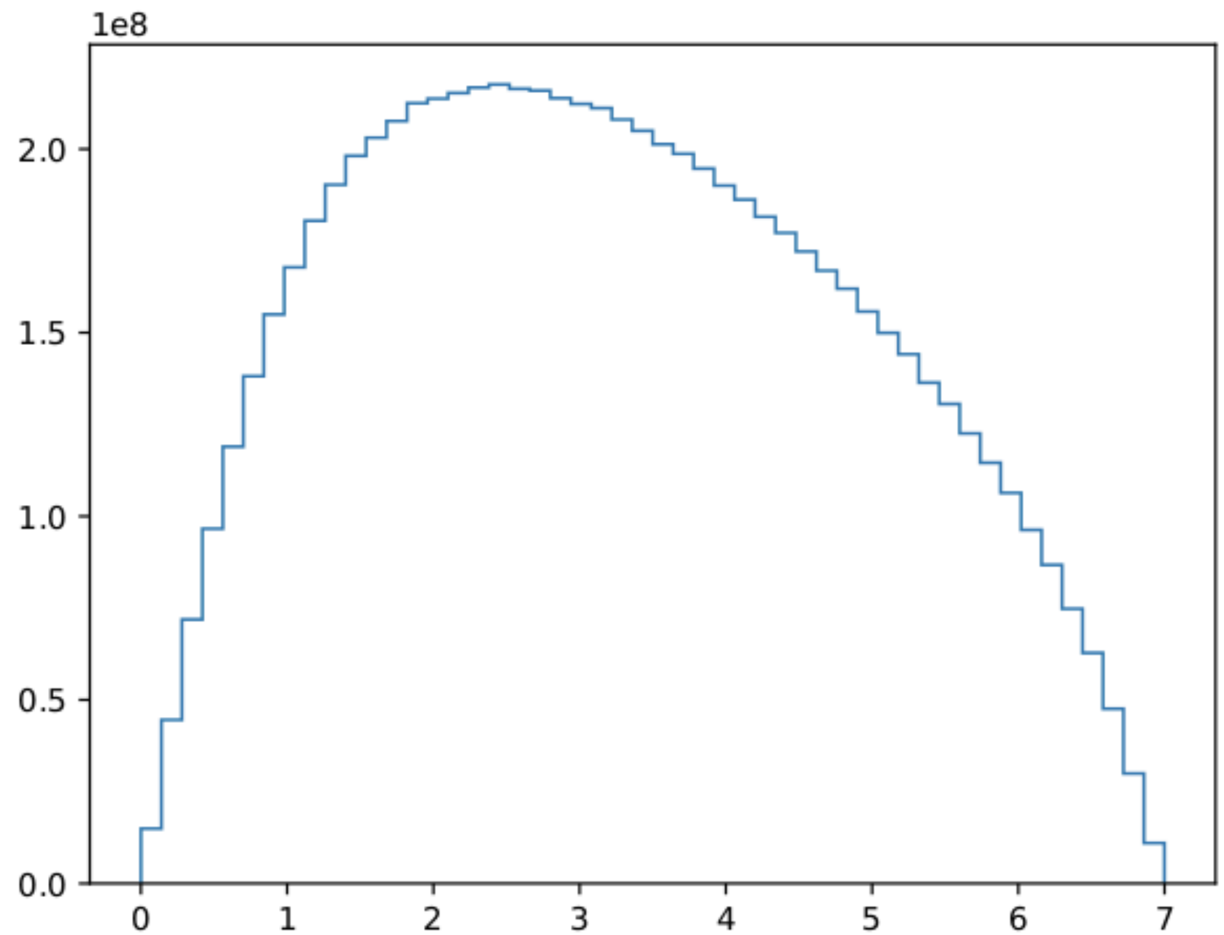
$$\xi_{RMS} = \frac{eE_{RMS}}{m\omega} \text{ for circular polarisation,}$$

$$\xi_{RMS} = \sqrt{2}\frac{eE_{RMS}}{m\omega} \text{ for linear polarisation}$$

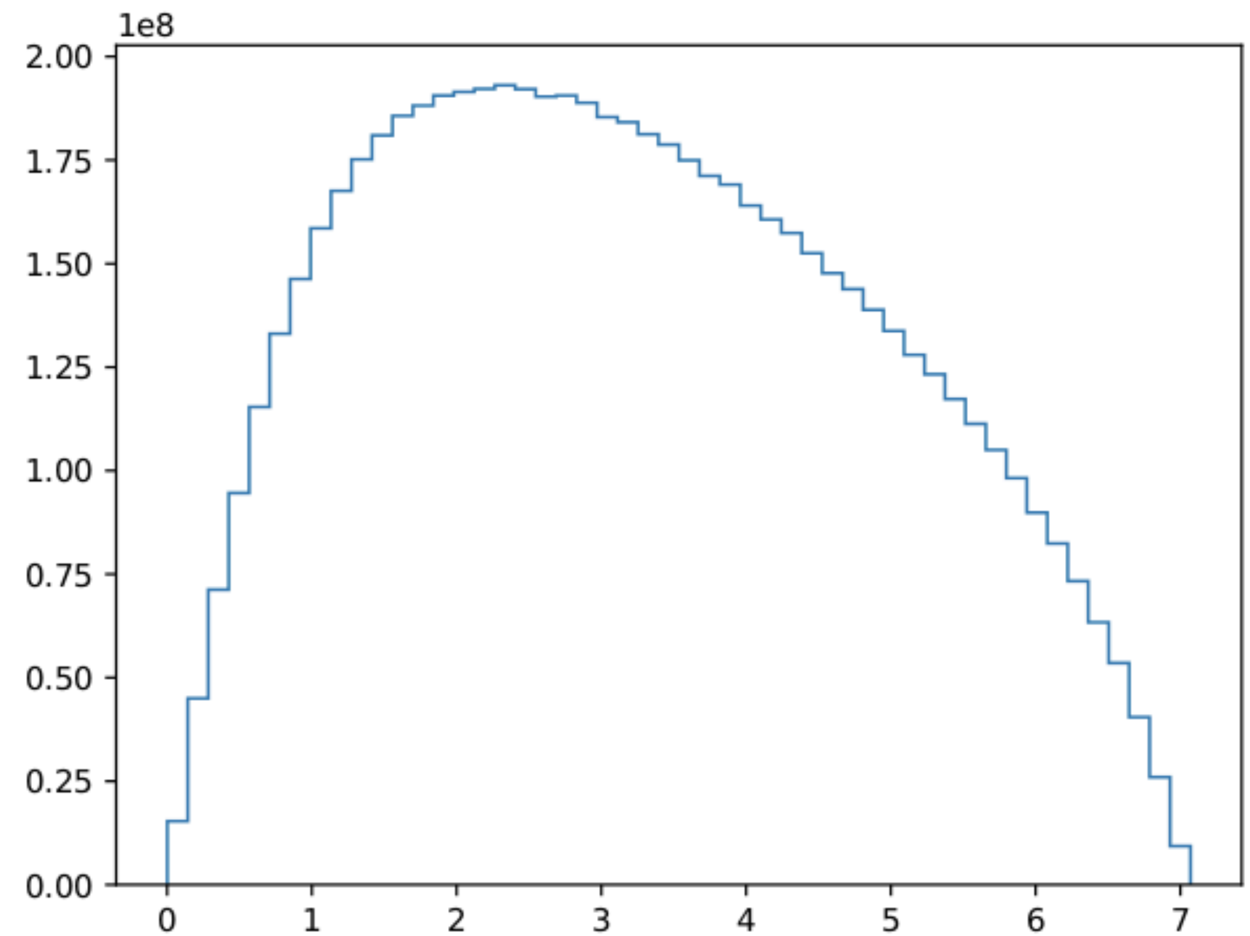
photon ξ at creation (RMS)

- Summed over 10 BX.
- For LP, ξ_{nom}=10, ξrms=10/sqrt(2)=7.07.

ptarmigan v0.8.1 (CP, ξ_{nom}=7)



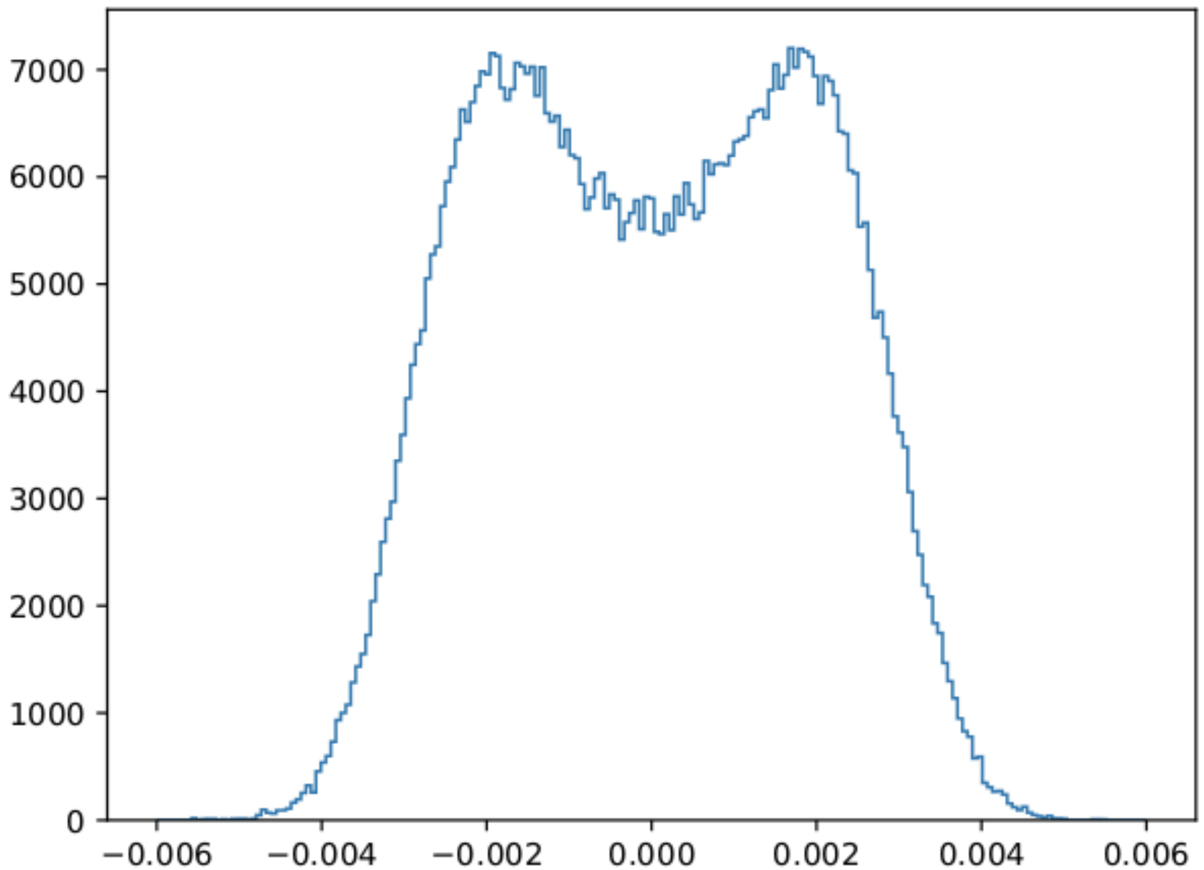
ptarmigan v0.11 (LP, ξ_{nom}=10)



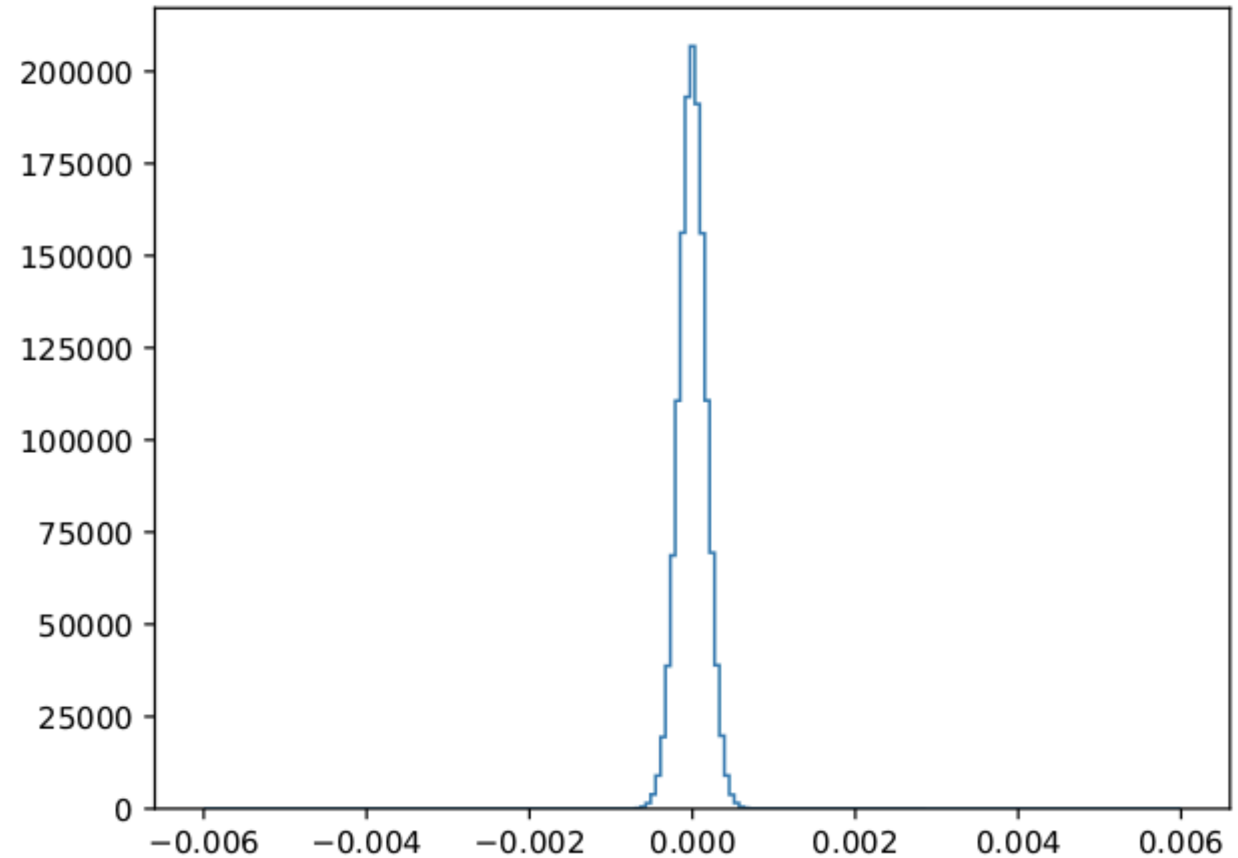
Momentum in y

- Double peak structure in CP not seen in LP. Much narrower distribution.

ptarmigan v0.8.1 (CP, ξ_{nom}=7)



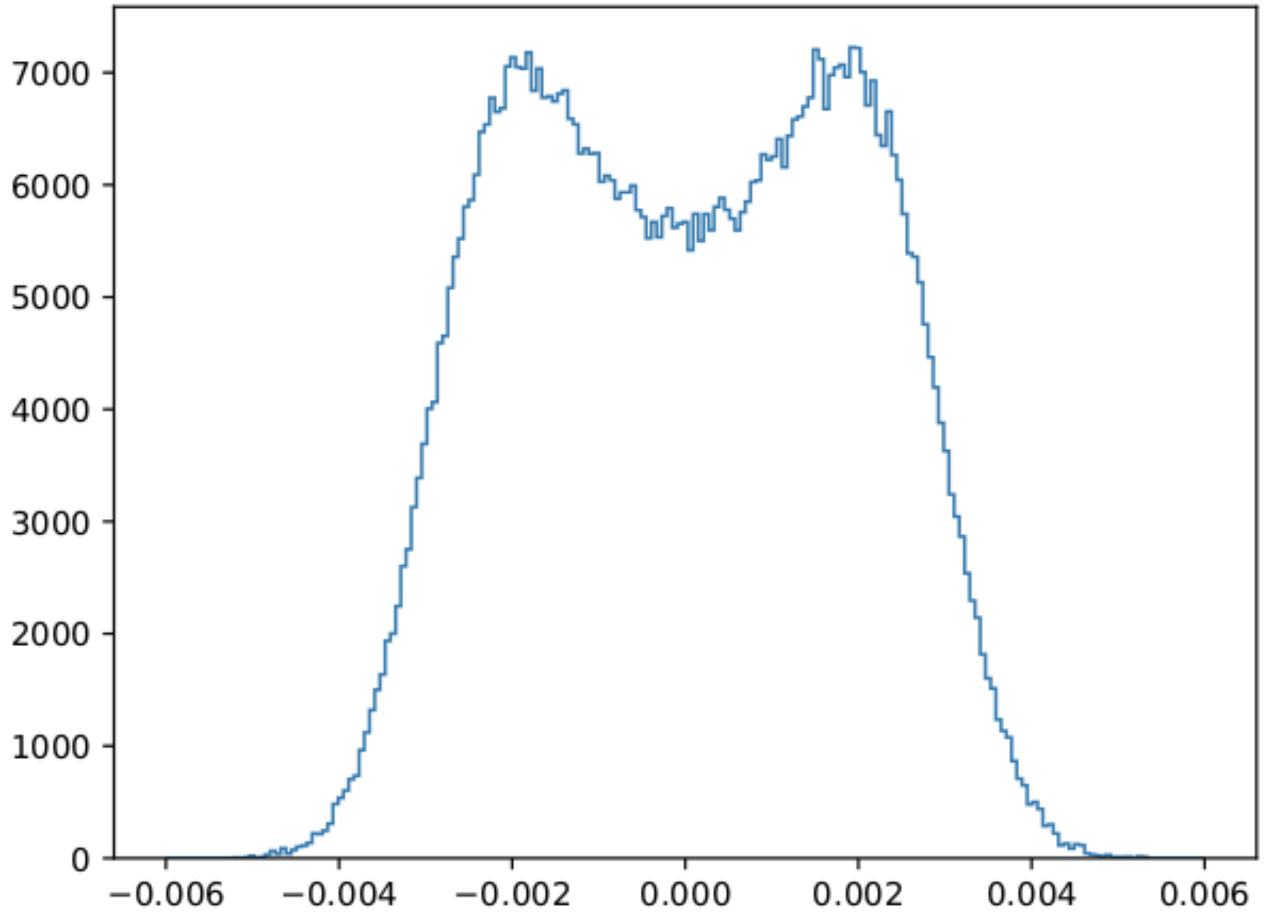
ptarmigan v0.11 (LP, ξ_{nom}=10)



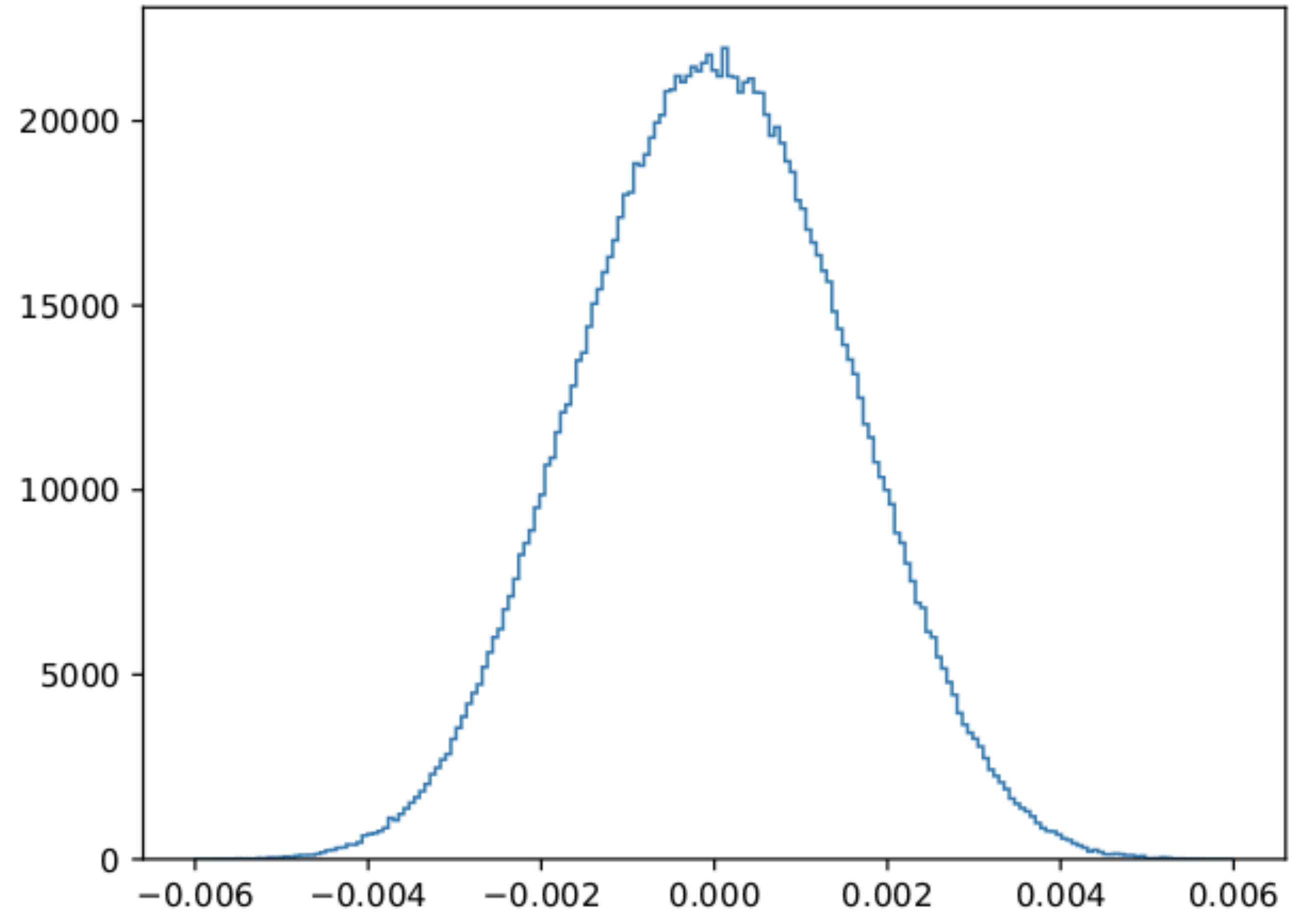
Momentum in x

- CP is symmetric, while LP has much broader distribution in x than in y.

ptarmigan v0.8.1 (CP, ξ_{nom}=7)

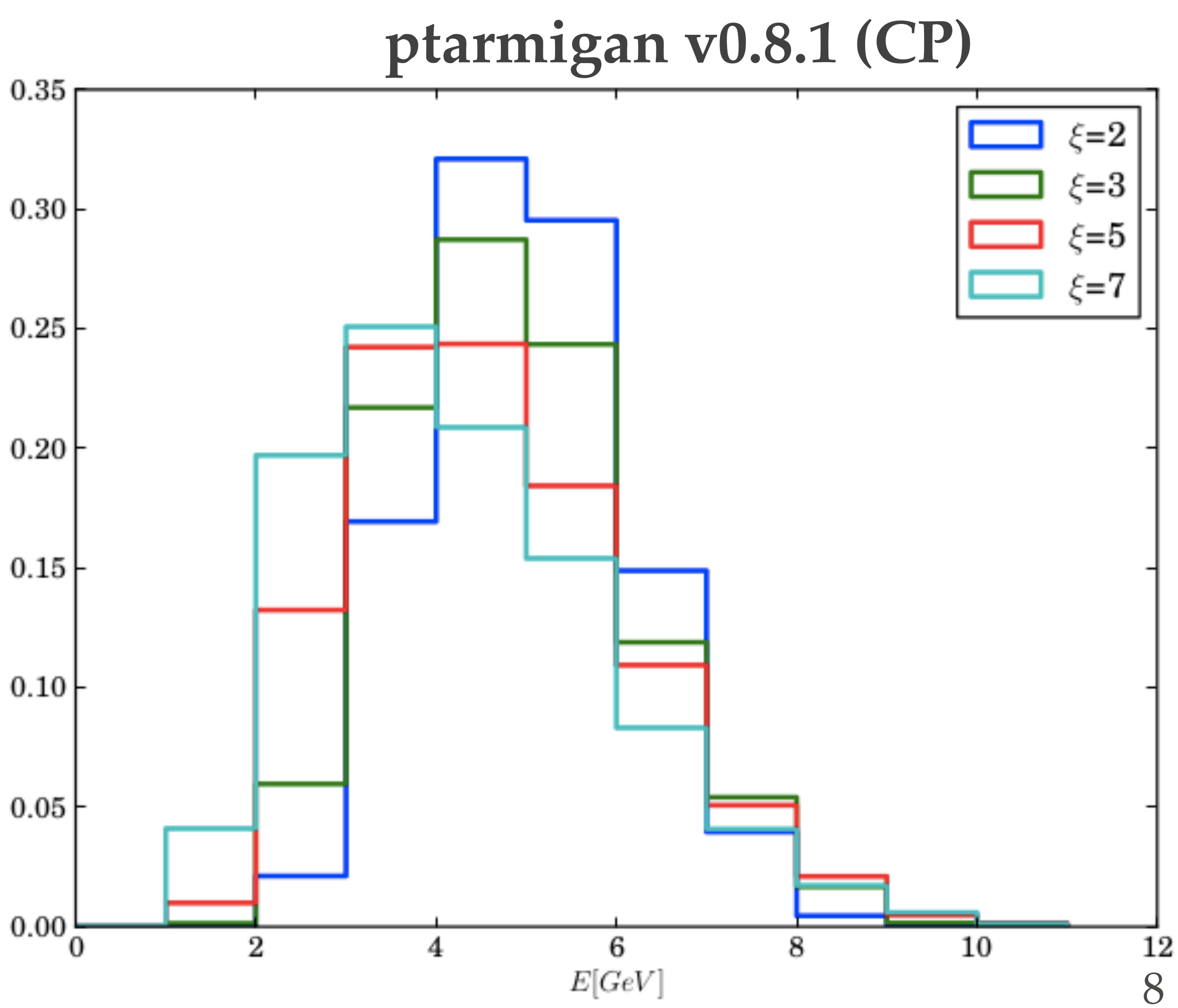


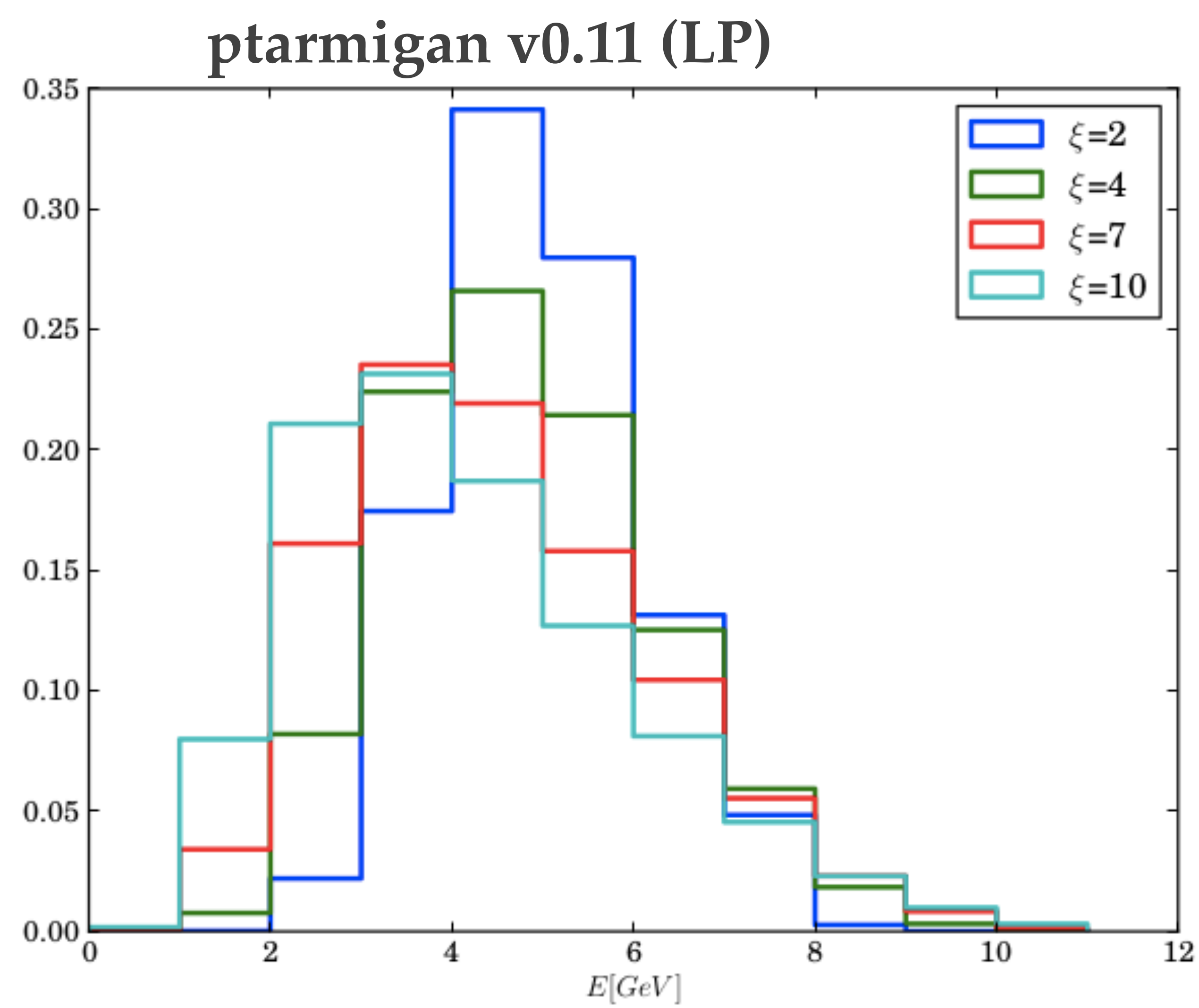
ptarmigan v0.11 (LP, ξ_{nom}=10)



ξ dependence

- Now look at dependence on ξ. Use samples with weight biasing for statistics. Only 1 BX per ξ, plots normalised to unity.
- Positron energy tends to be lower and broader as ξ increases.

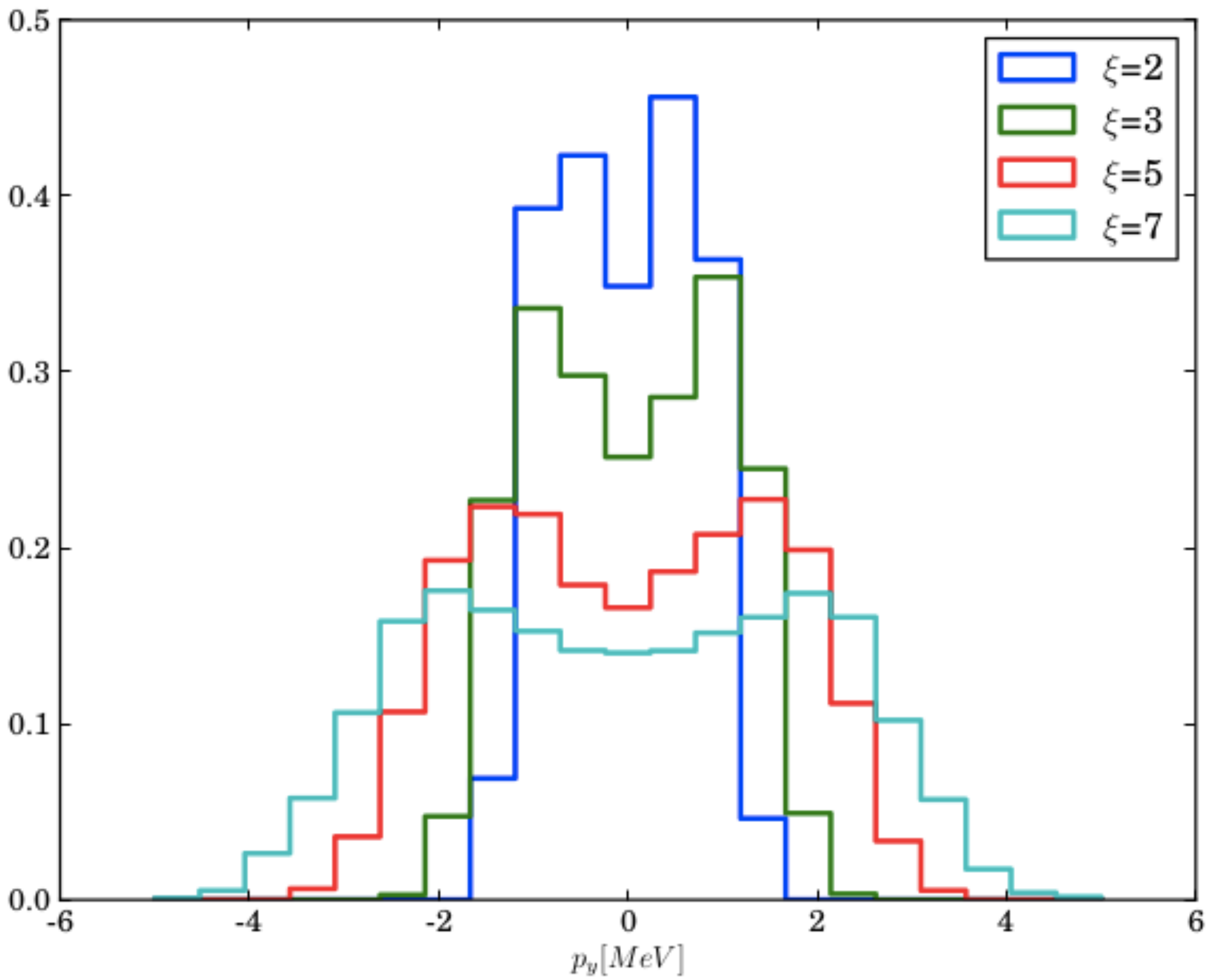




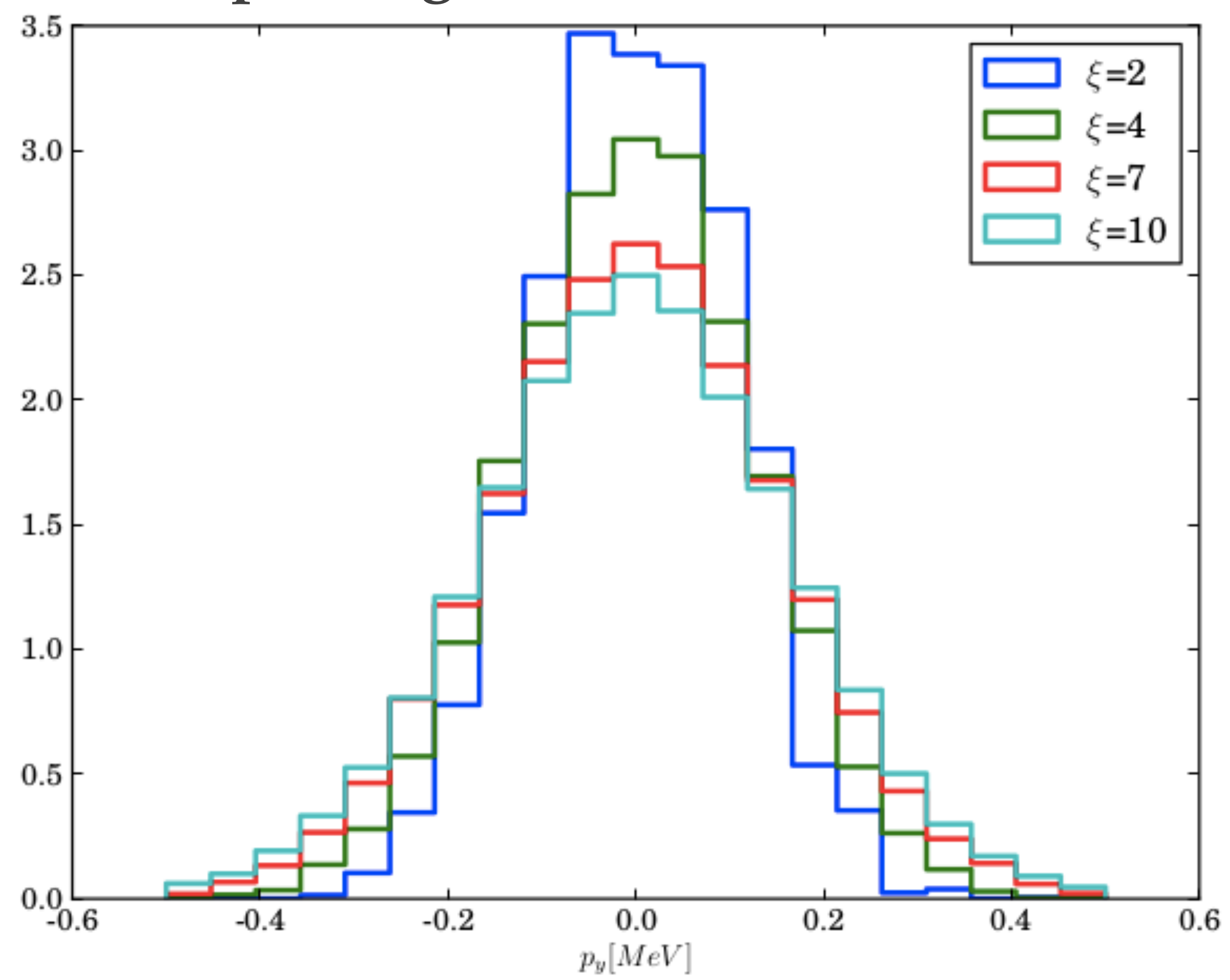
p_y dependence on ξ

- Broadens with ξ.
- Note the different x-axis scale.

ptarmigan v0.8.1 (CP)



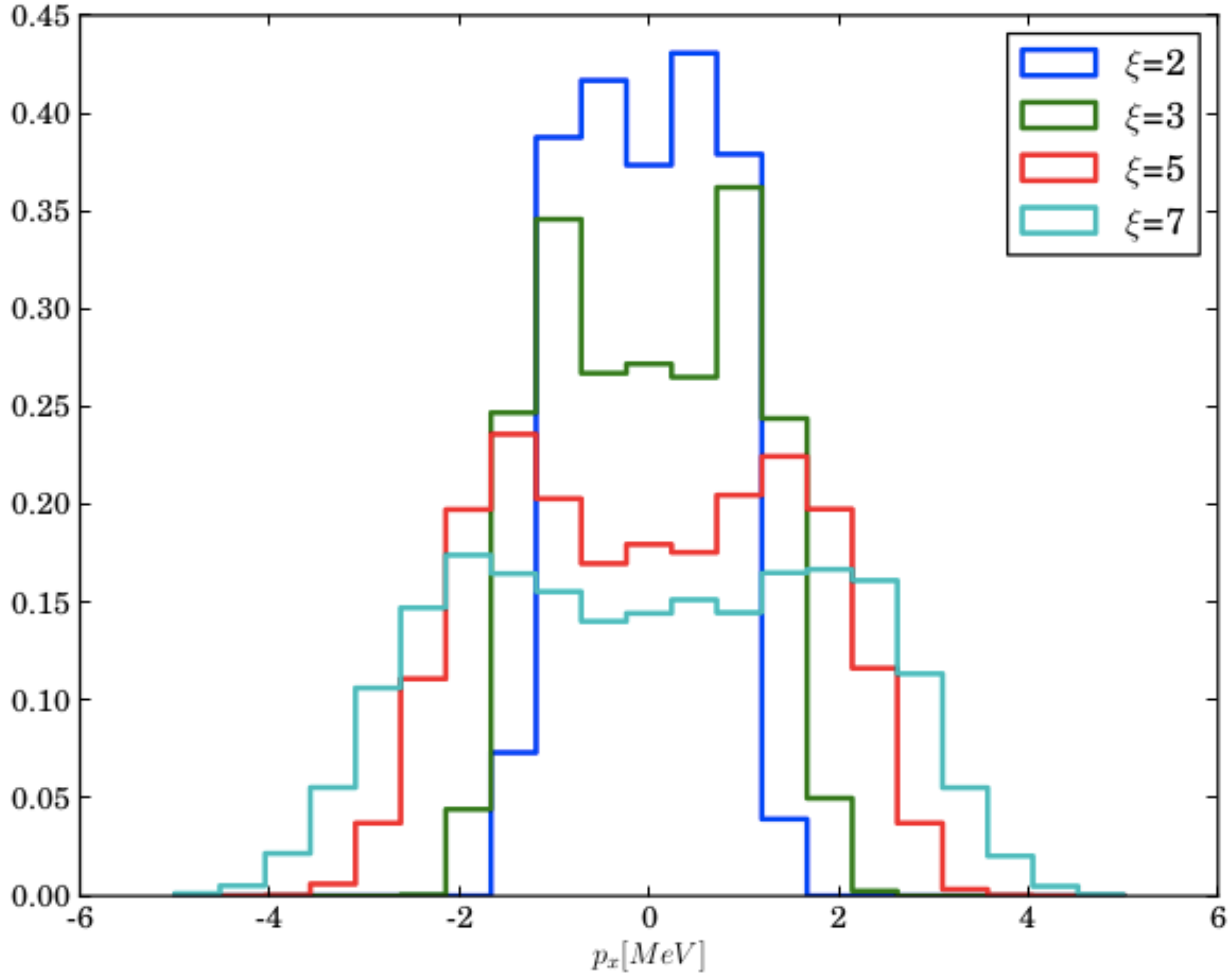
ptarmigan v0.11 (LP)



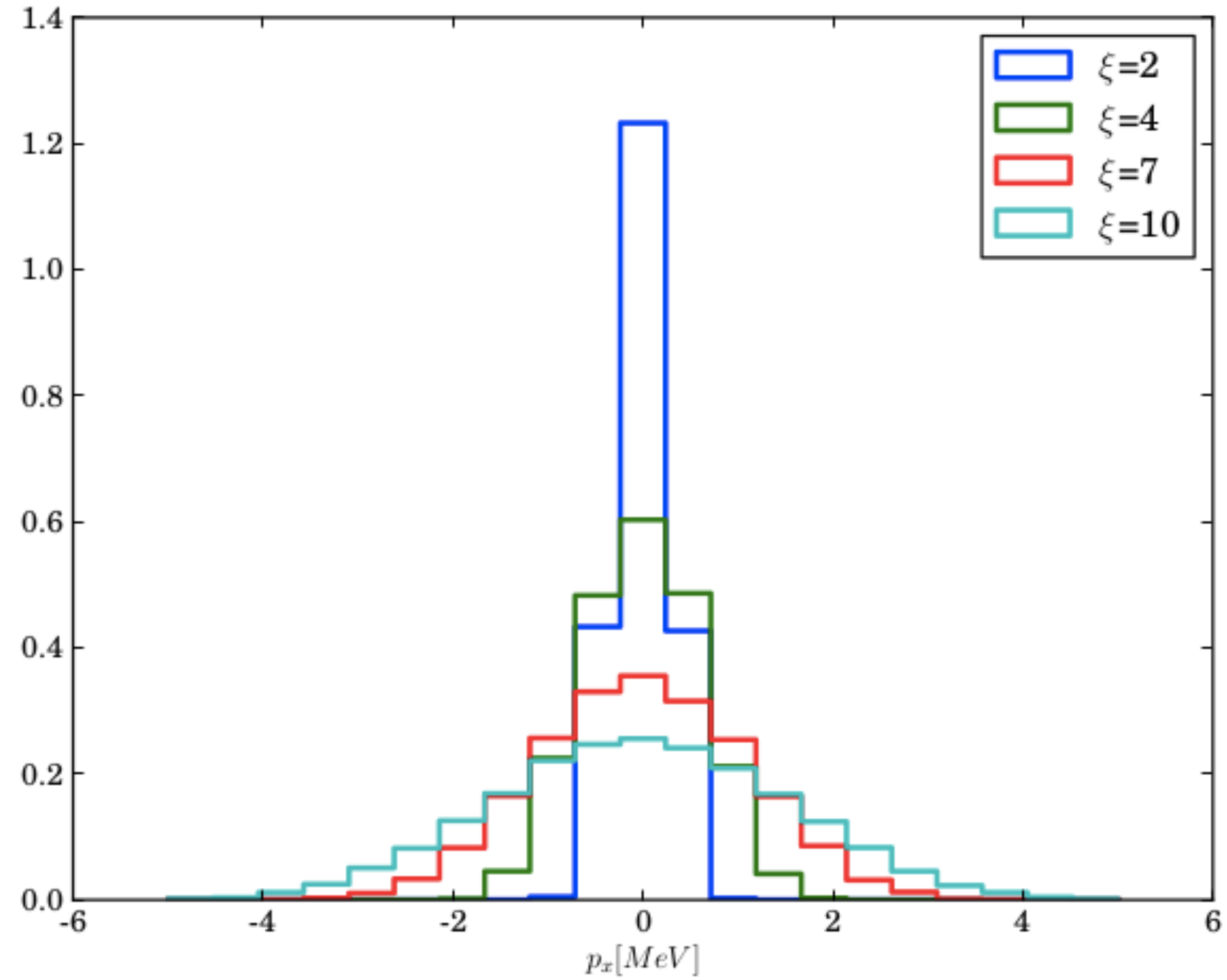
p_x dependence on ξ

- More pronounced broadening in x than in y for linear polarisation (polarisation along x).

ptarmigan v0.8.1 (CP)



ptarmigan v0.11 (LP)



Check: resolved polarisation

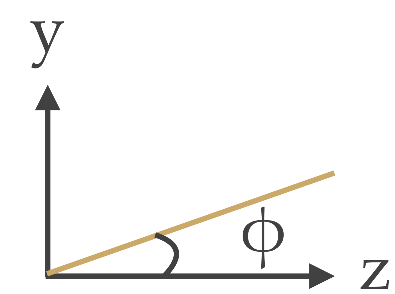
- Photon polarisation not resolved. See T. Blackburn's talk at e.g. collaboration meeting.
  - B-polarised (polarised perpendicular to laser E field) photons more likely to create e^+e^- pairs, but radiated photons are mostly E-polarised.
  - ~15-20% correction to the rate for LP, mostly unchanged for CP.
- To verify, run with latest ptarmigan version (1.3.3) and ask specifically for photon polarisation to be resolved.
- No obvious change in dispersion.

Phase-0	# positrons (weighted) from 1 BX	
	Not resolved	Resolved
ξ=7 CP	68692 (v0.8.1)	69204 (v1.3.3)
ξ=10 LP	141600 (v0.11)	129289 (v1.3.3)

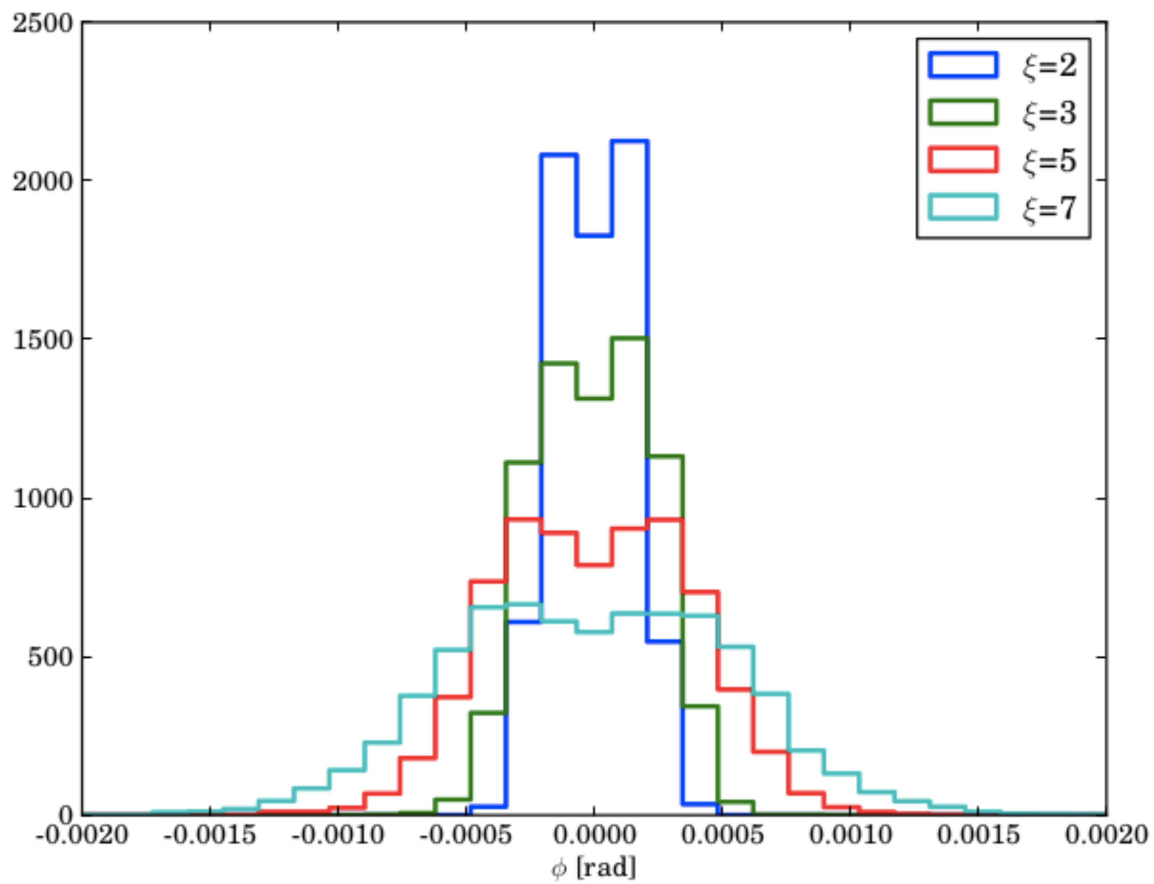
Tracking

- What does this mean for tracking?
- Is this ξ dependence measurable in the tracker?
- What kind of tracking performance can we expect for linear polarisation?
  - For linear polarisation, the higher ξ reach in phase-0 results in double the number of positrons than studied so far tracking.
  - However, the lack of dispersion in y means we can expect significantly higher than double the peak occupancy!

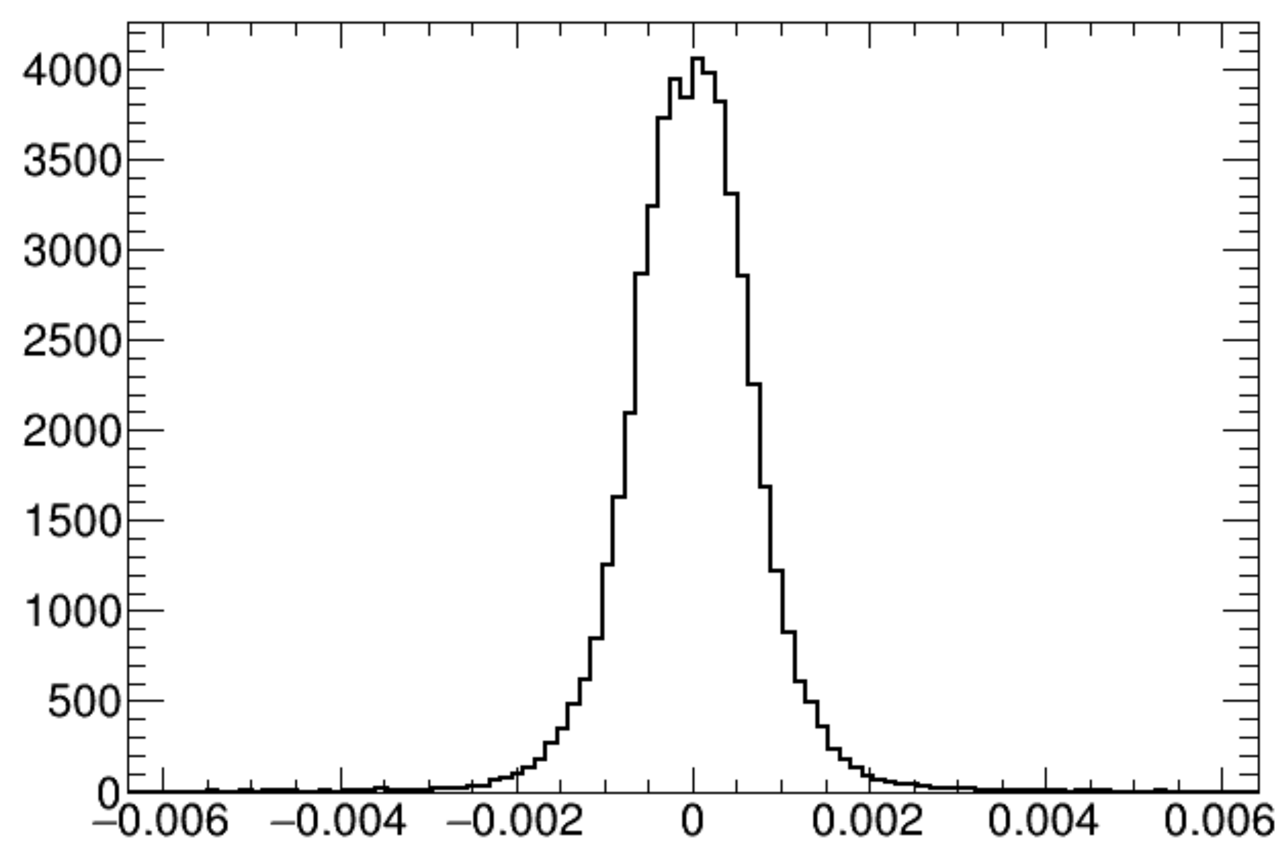
Track ϕ (CP)



- ϕ is a measure of p_y. ϕ measured from track fitting is quite smeared.
- However, width still shows a dependence on ξ.
  - Gaussian width = 0.065±0.002 (ξ=7), 0.046±0.004 (ξ=5), 0.038±0.006 (ξ=4). Statistical uncertainty only.



True ϕ at IP



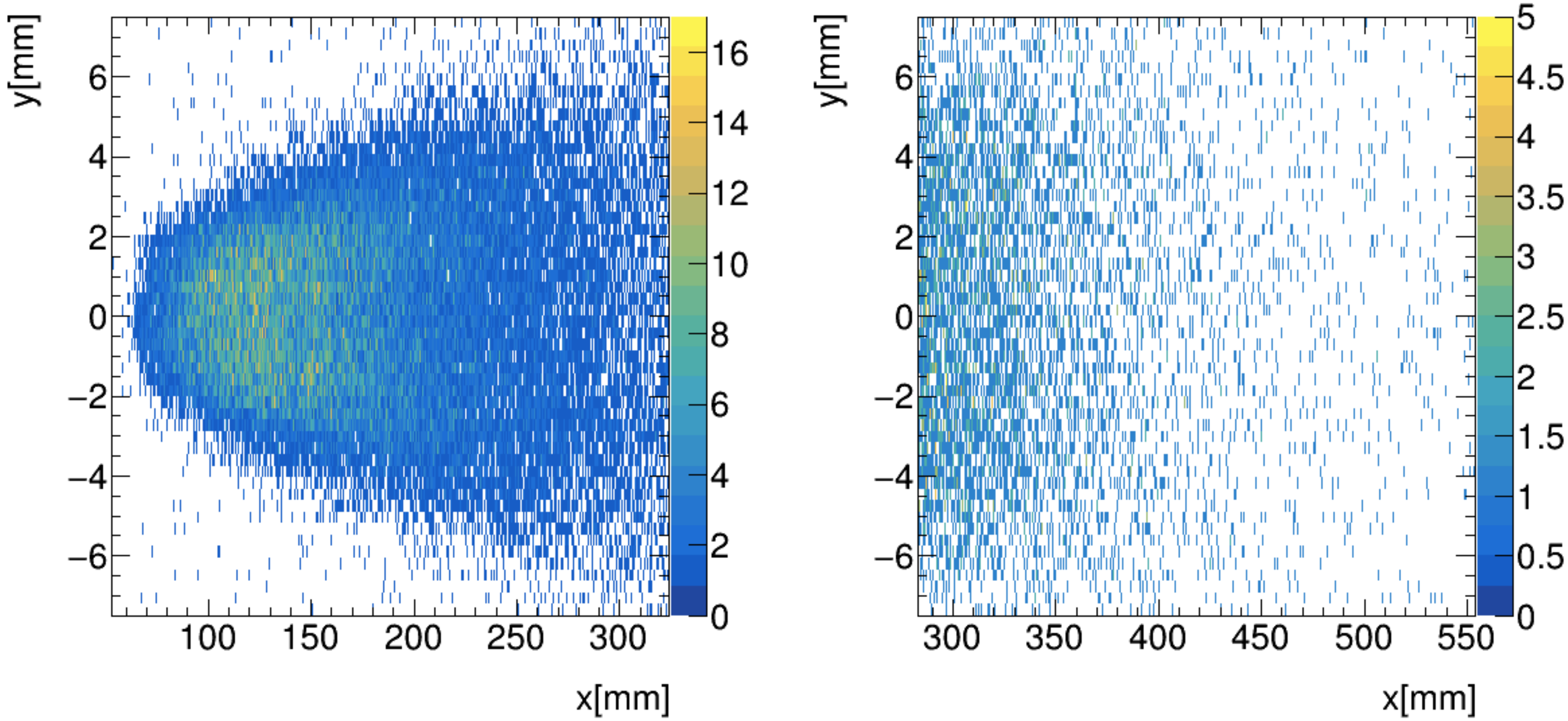
Measured ϕ for ξ=7

Occupancy

- For best estimate of occupancies, need:
  - Positron weight=1
  - Run full digitisation to get detector response, since a particle usually results in ≳2 pixel hits.
- This is not available, so I get an estimate using extrapolation.
- Compare highest ξ reach in phase-0 for circular (ξ_{nom}=7) vs linear (ξ_{nom}=10) polarisation.
- Run tracker simulation using DDsim. Divide detector into roughly 10x10 pixels and count the number of particles to get occupancy map.
- Note: slightly different samples shown than before, use only 1 BX.

Occupancy (CP)

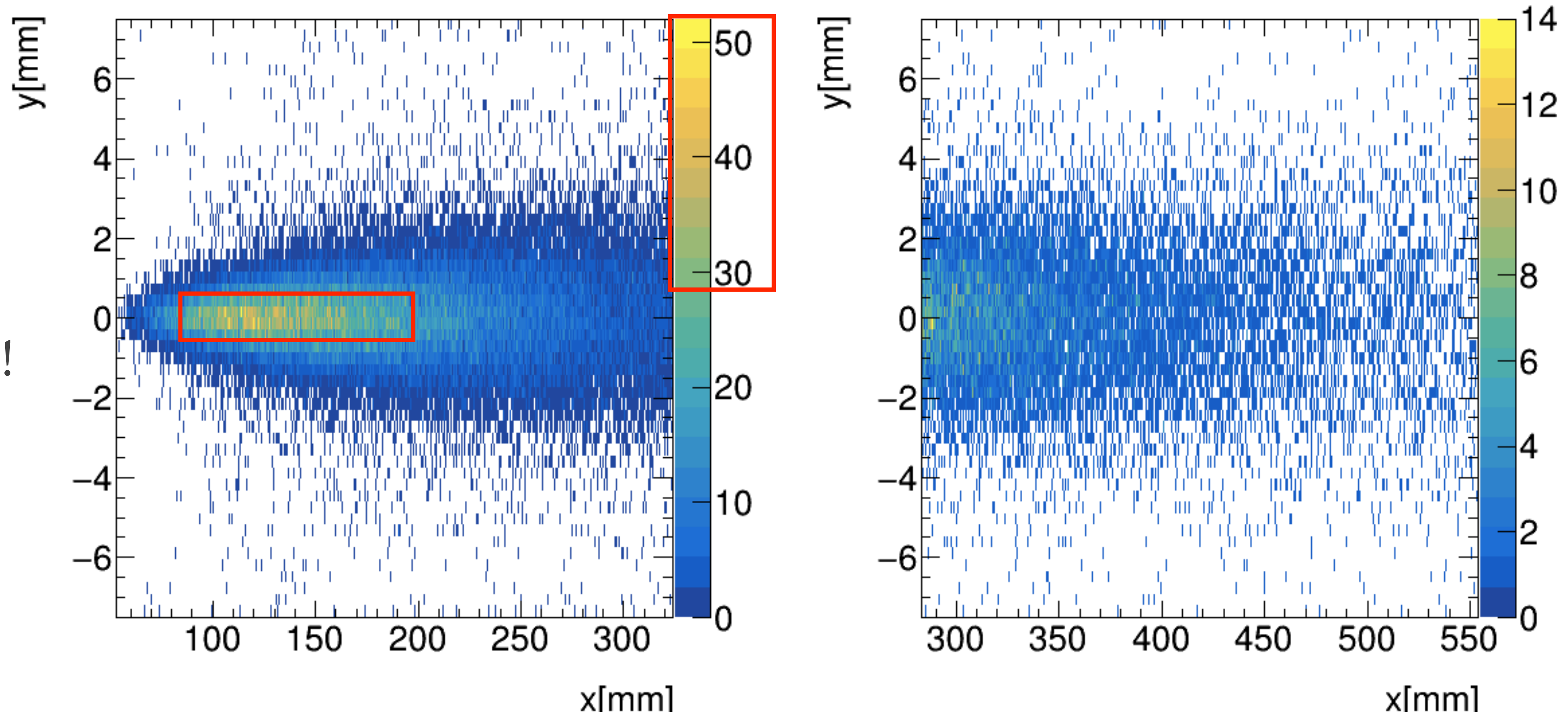
- ptarmigan v0.8.1 (CP, ξ_{nom}=7) custom weight=1 sample. # positrons (raw)= 67442.
- Assuming ≳2 pixel hits per particle (2.6 pixels to be exact, from the average found in digitised samples): **peak occupancy ~45%**.



Occupancy (LP)

- ptarmigan v0.11 (LP, ξ_{nom}=10) average weight=1.3 sample. # positrons (raw)=108759.
- Hits concentrated at middle of detector. Assuming ≥2 pixel hits per particle and fixed weight -> **peak occupancy 100%**.

100% occupancy!



Summary

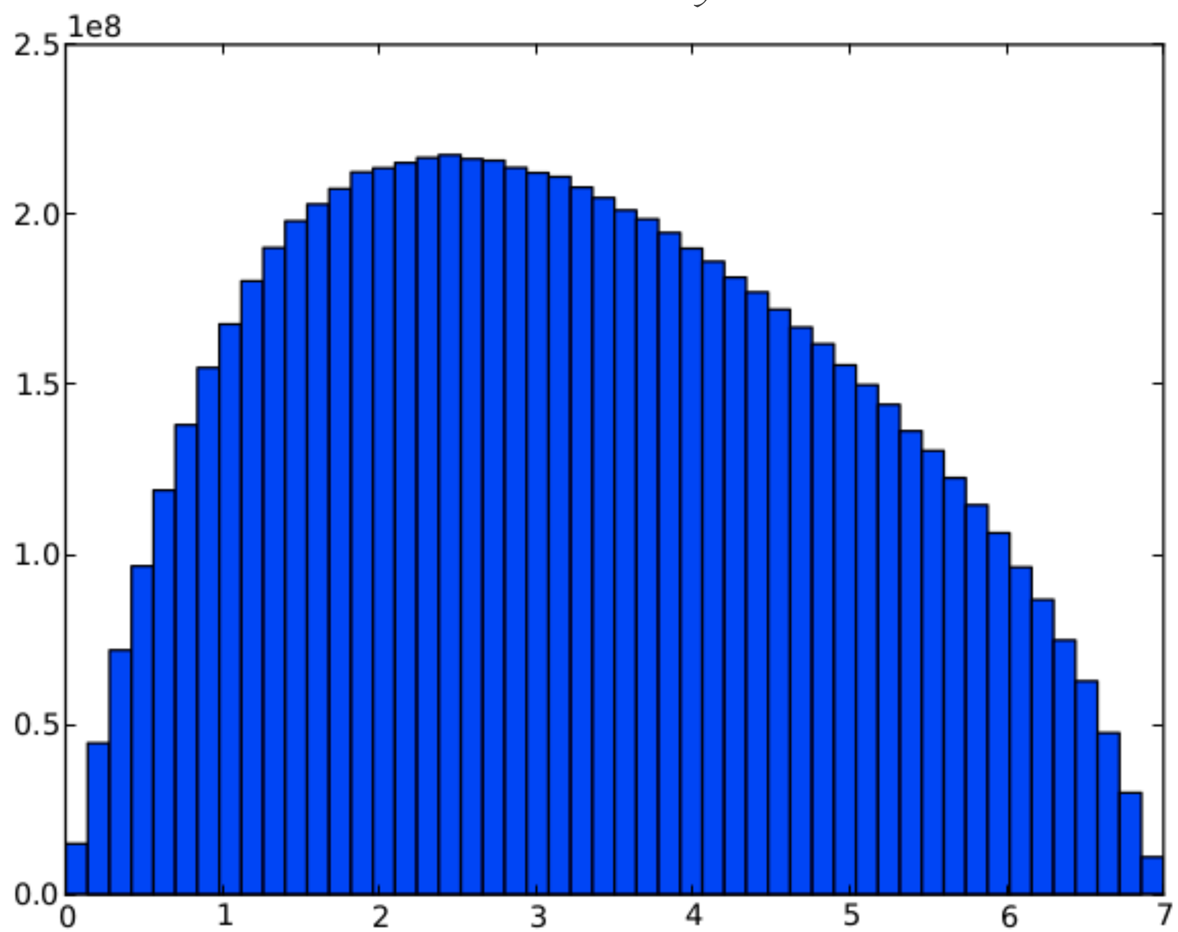
- Polarisation has a strong effect on the particle yields as well as their properties.
- The dispersion carries information about ξ.
- With linear polarisation (along x), tracking is impossible for part of the detector at highest ξ already in phase-0.
- What if the polarisation is along y direction?

Back-up

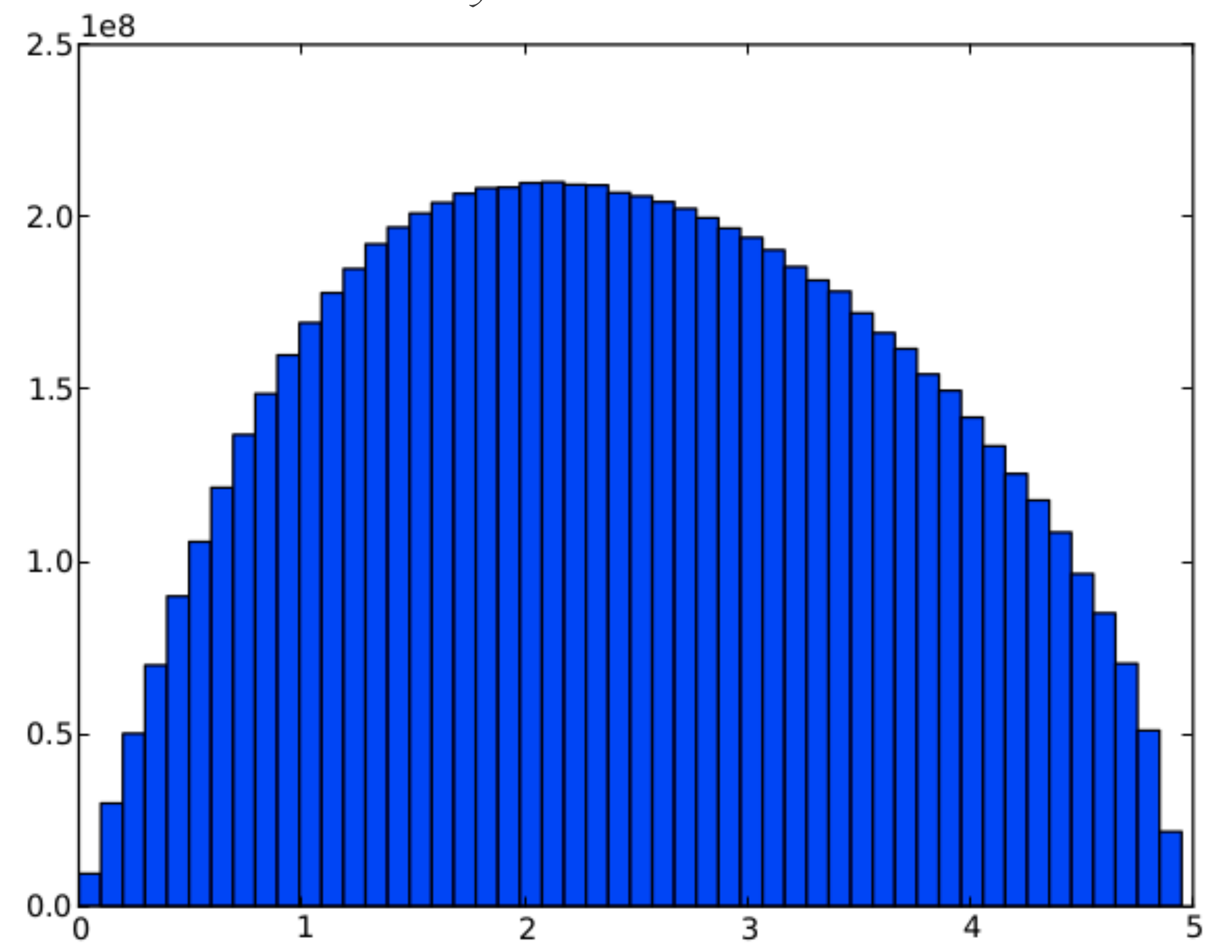
I compare both with $\xi_{nom}=7$ here, but one should normally compare same max ξ.

- Left: ptarmigan v0.8.1 (CP, $\xi_{nom}=7$). Right: ptarmigan v0.11 (LP, $\xi_{nom}=7$).
- Summed over 10 BX

Max $\xi = \xi_{nom}$ (7)
$\langle\xi\rangle=3.25$

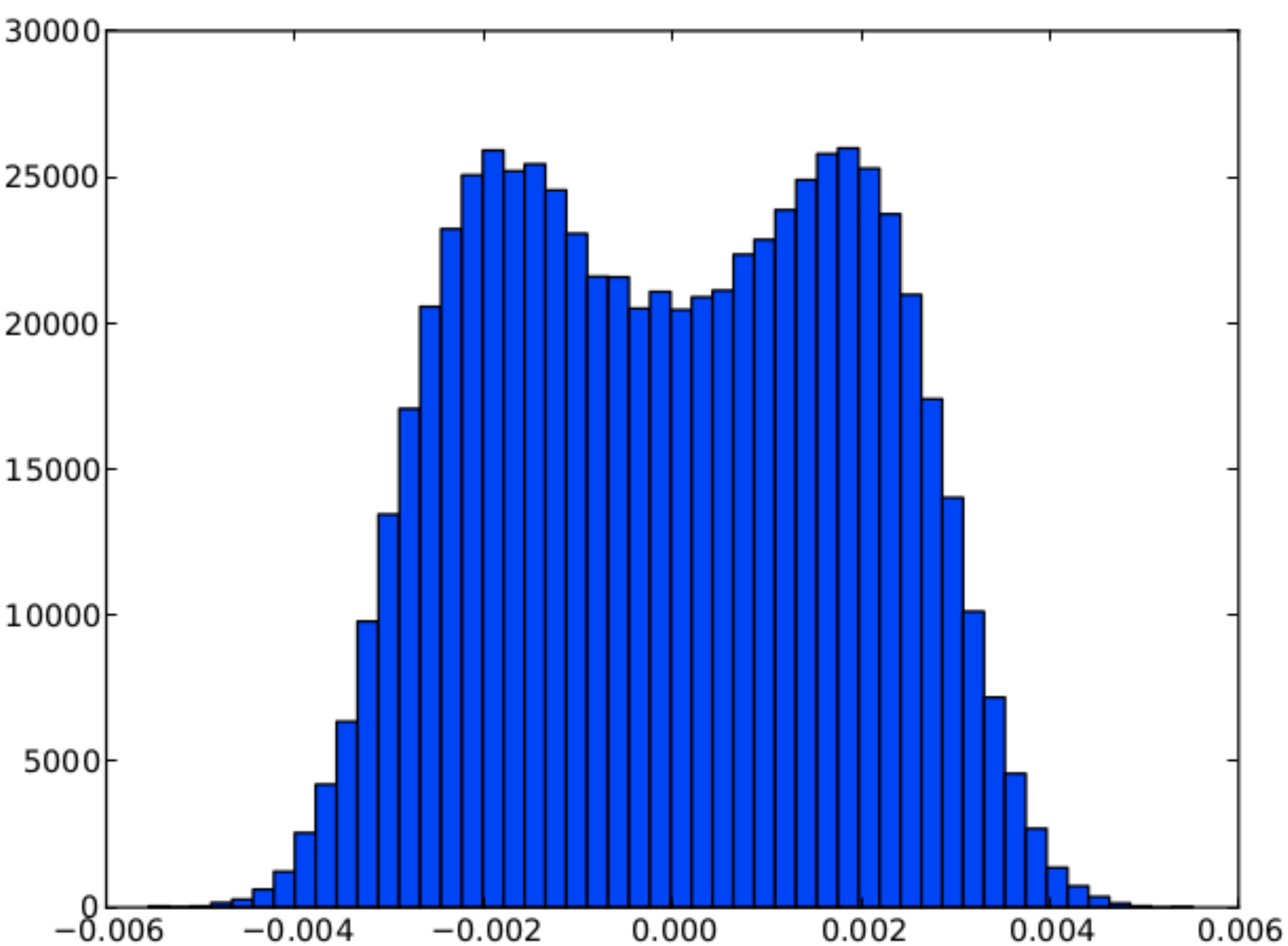


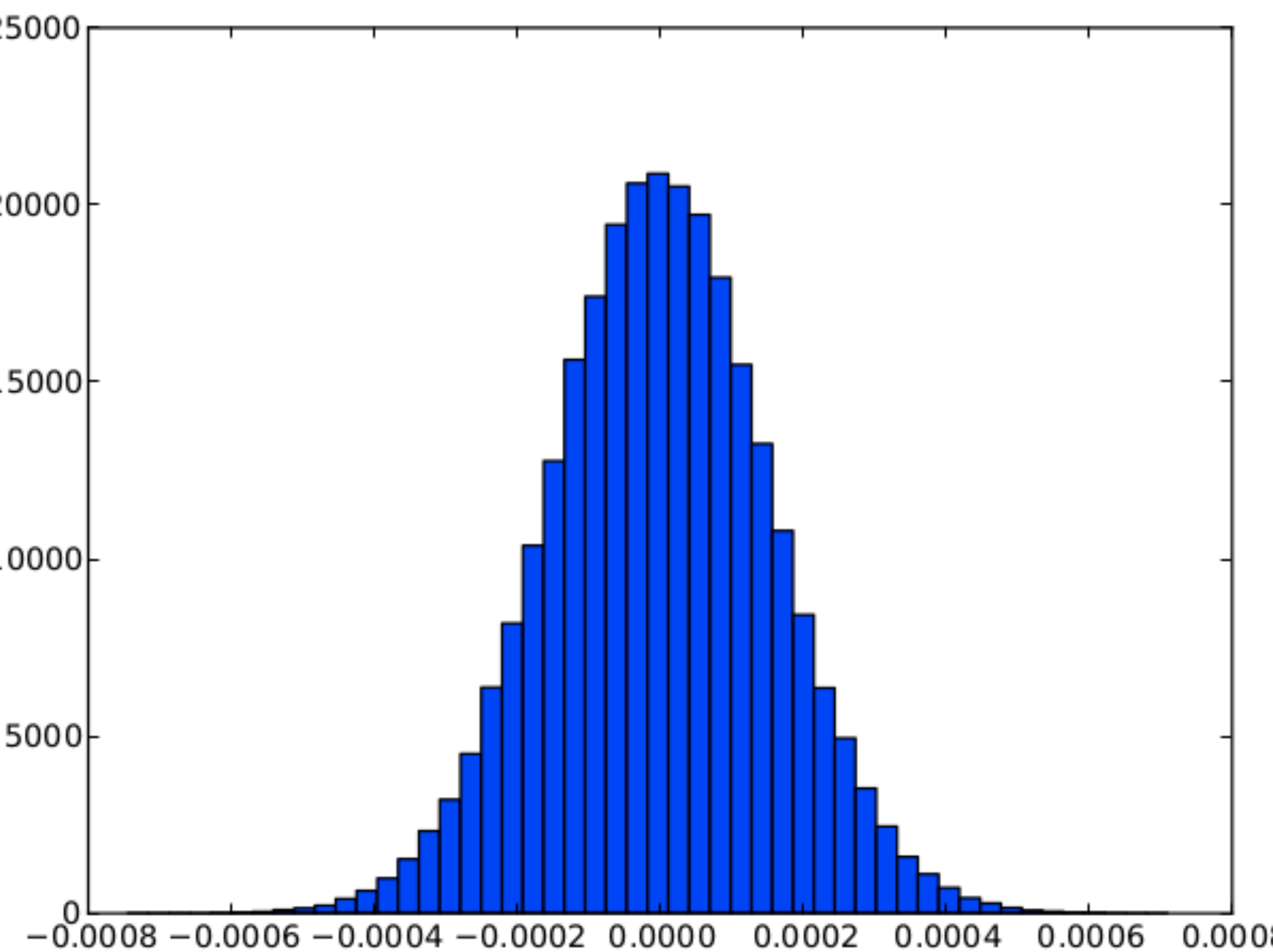
Max $\xi = \xi_{nom}/\sqrt{2}=4.95$
$\langle\xi\rangle=2.46$



Momentum in y

- Left: ptarmigan v0.8.1 (CP, ξ_{nom}=7). Right: ptarmigan v0.11 (LP, ξ_{nom}=7)
- Note the scale in x-axis, momentum spread is 10x larger on the left.





Momentum in x

- Left: ptarmigan v0.8.1 (CP, ξ_{nom}=7). Right: ptarmigan v0.11 (LP, ξ_{nom}=7).
- The spread in x is of the same scale but shows the same single vs double peak structure.