Undulator Based Positron Sources for Future Colliders

Simulations with 'Realistic' Photon Spectra

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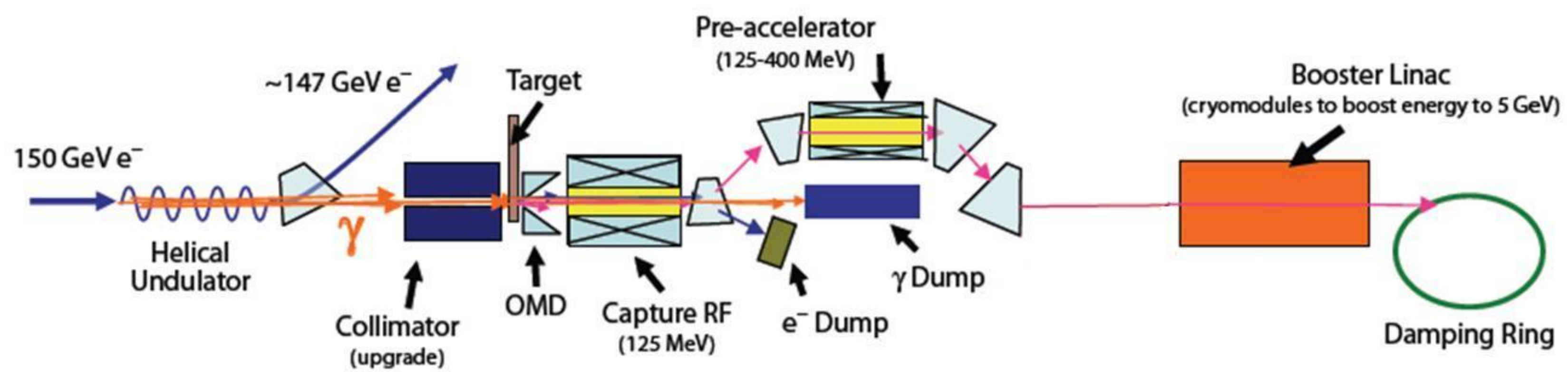
Presentation Overview

- Positron source requirements of future colliders
- A multi-target undulator based positron source
- ‘Realistic’ undulator spectra
- Simulation results
  - Yield and polarization results
  - Comparisons of ideal and ‘realistic’ spectra

Requirements of a Positron Source

	SLC	CLIC (3TeV)	ILC (RDR)	LHeC (ERL)
e^+ / bunch @ IP	4×10^{10}	3.72×10^{9}	2×10^{10}	2×10^{9}
Bunches per pulse	1	312	2625	n/a
Pulse rep rate (Hz)	120	50	5	CW
Bunches per second	120	15600	13125	2×10^{8}
Positrons per second	6×10^{12}	1.1×10^{14}	3.9×10^{14}	4×10^{16}

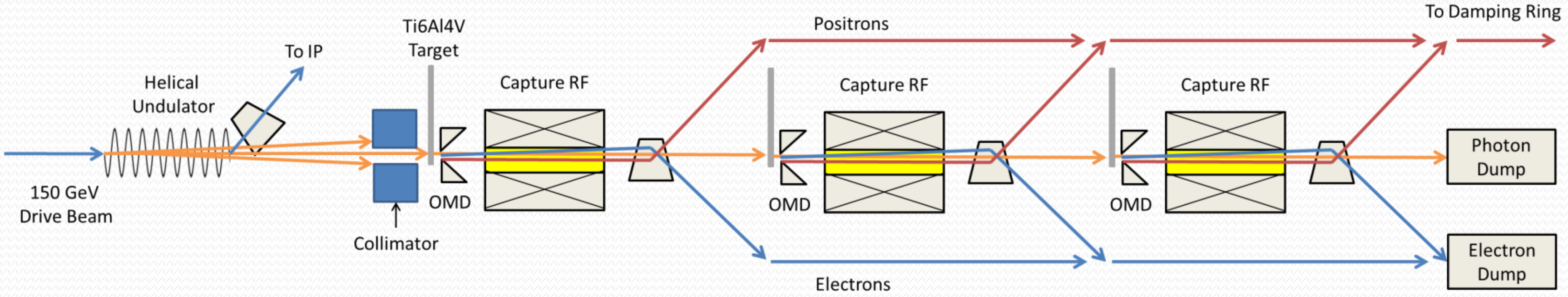
Undulator Based Positron Source



Schematic of ILC RDR Positron Source

Length of Undulator	Number of γ / e^-	Heat Load on Target	Number of e^+ / e^-
~150m to 250m	200	~20 kW (beam) Up to 20 kW (eddy currents)	2

A Multi-Target Positron Source



Length of Target and OMD	Length of Capture RF	Length between Targets
~1m	2.5 to 15.5m	10 to 25m

Realistic Undulator Spectra

- Analytical expression used by most simulations
- E.g. PPS-Sim uses Kincaid76
- Codes to generate 'Realistic' Spectrum developed at Cockcroft Institute by
  - David Newton
  - Duncan Scott

Realistic Undulator Spectra

- The analytical expression for the ideal undulator photon spectra is:

$$\frac{dN_\gamma}{dE} = \frac{2\pi N e^2 K^2 r}{h\omega c\varepsilon_0} \sum_n \left[J_n'^2(x_n) + \left(\frac{\alpha_n}{K} + \frac{n}{x_n}\right)^2 J_n^2(x_n) \right] H(\alpha_n^2)$$

$$x_n = 2Kr\alpha_n$$

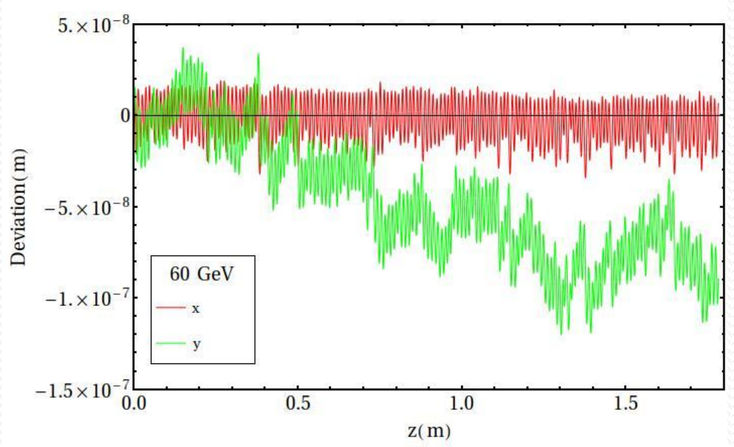
$$\alpha_n^2 = \frac{n}{r} - 1 - K^2$$

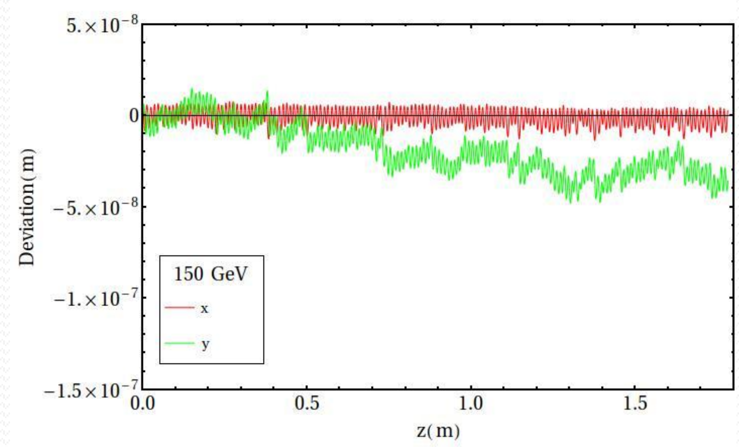
$$r = \frac{\omega}{2\gamma^2\omega_0}$$

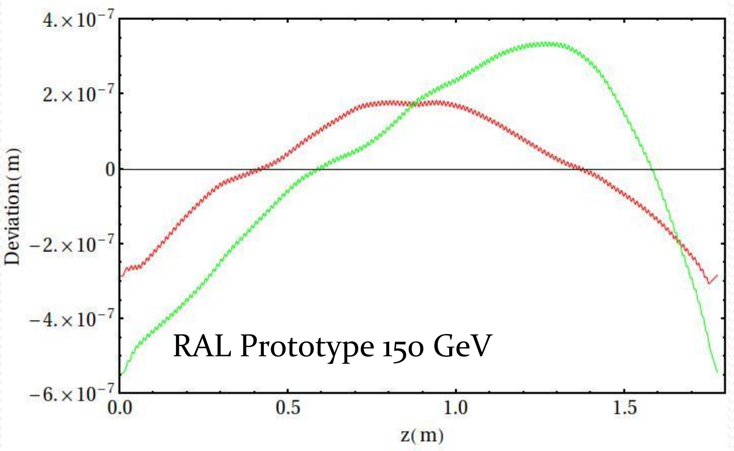
Realistic Undulator Spectra Simulations

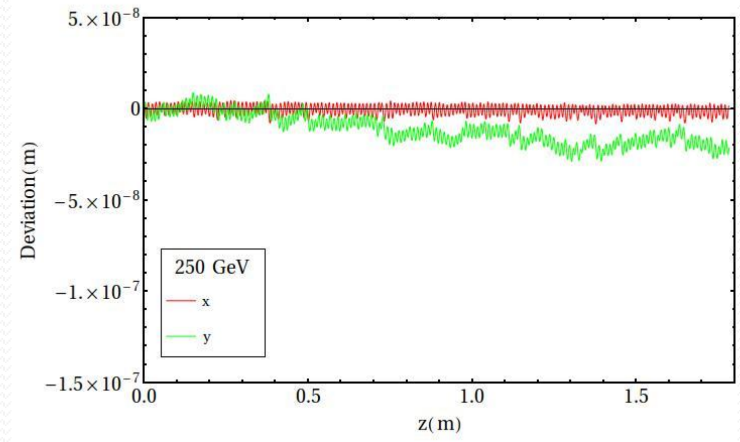
- David Newton's code generates a photon spectra for a given magnetic field map:
  - The code tracks particles through field map
  - Photon flux calculated by integrating along track
- To produce 'realistic' undulator photon spectra use:
  - Non-ideal field maps
  - Field map errors similar to field errors in the RAL prototypes

Tracking Particle Through 'Realistic' Field Maps

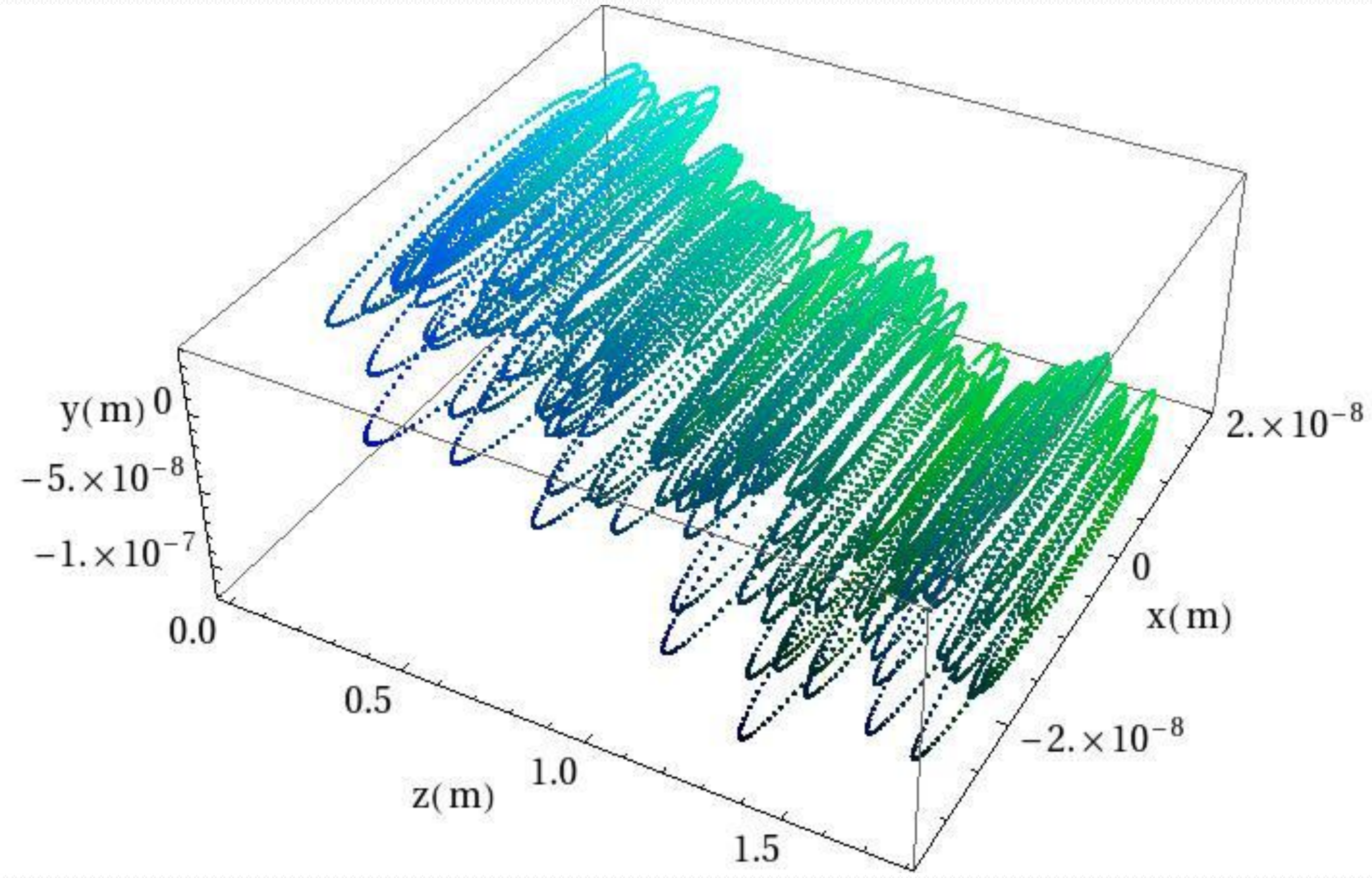




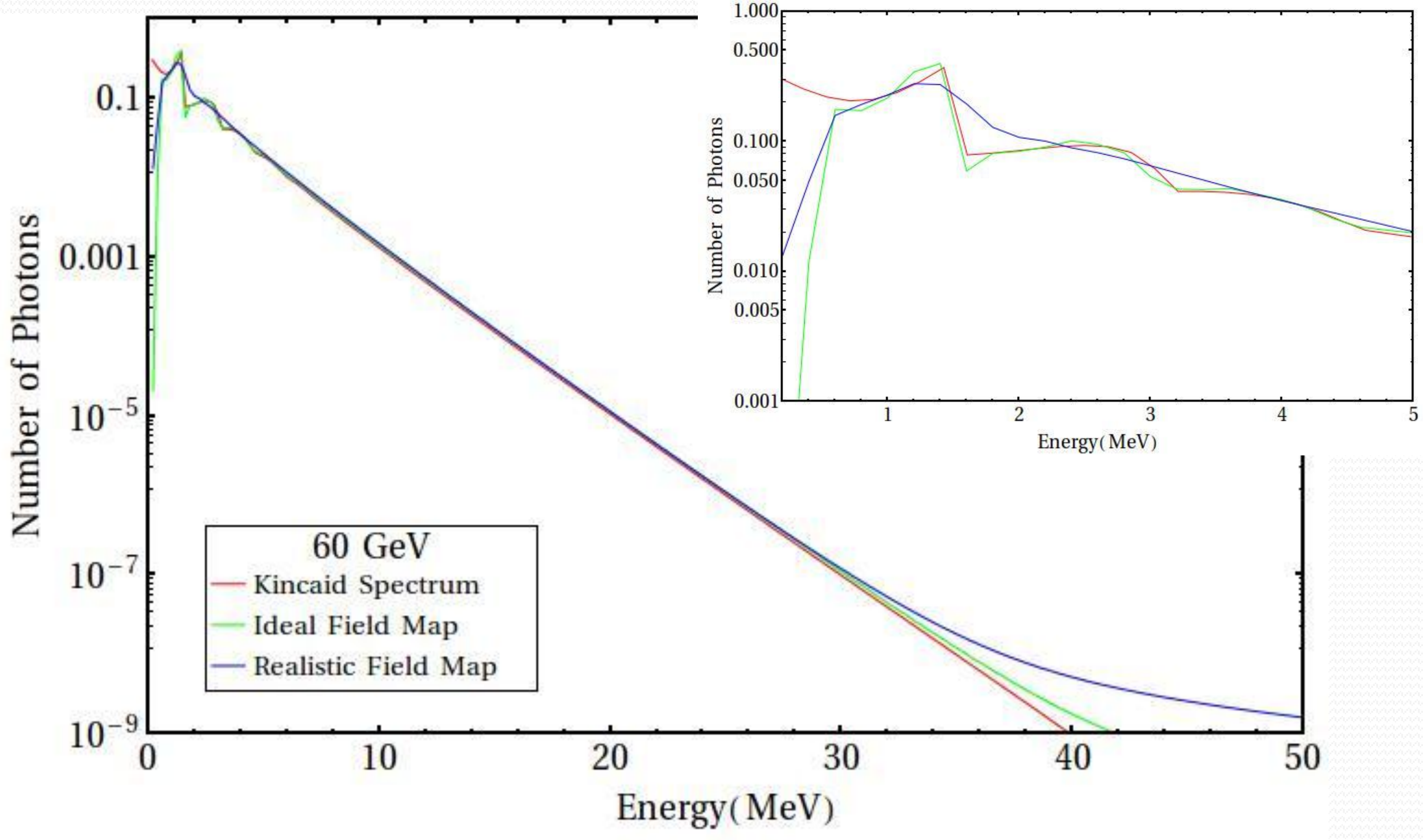




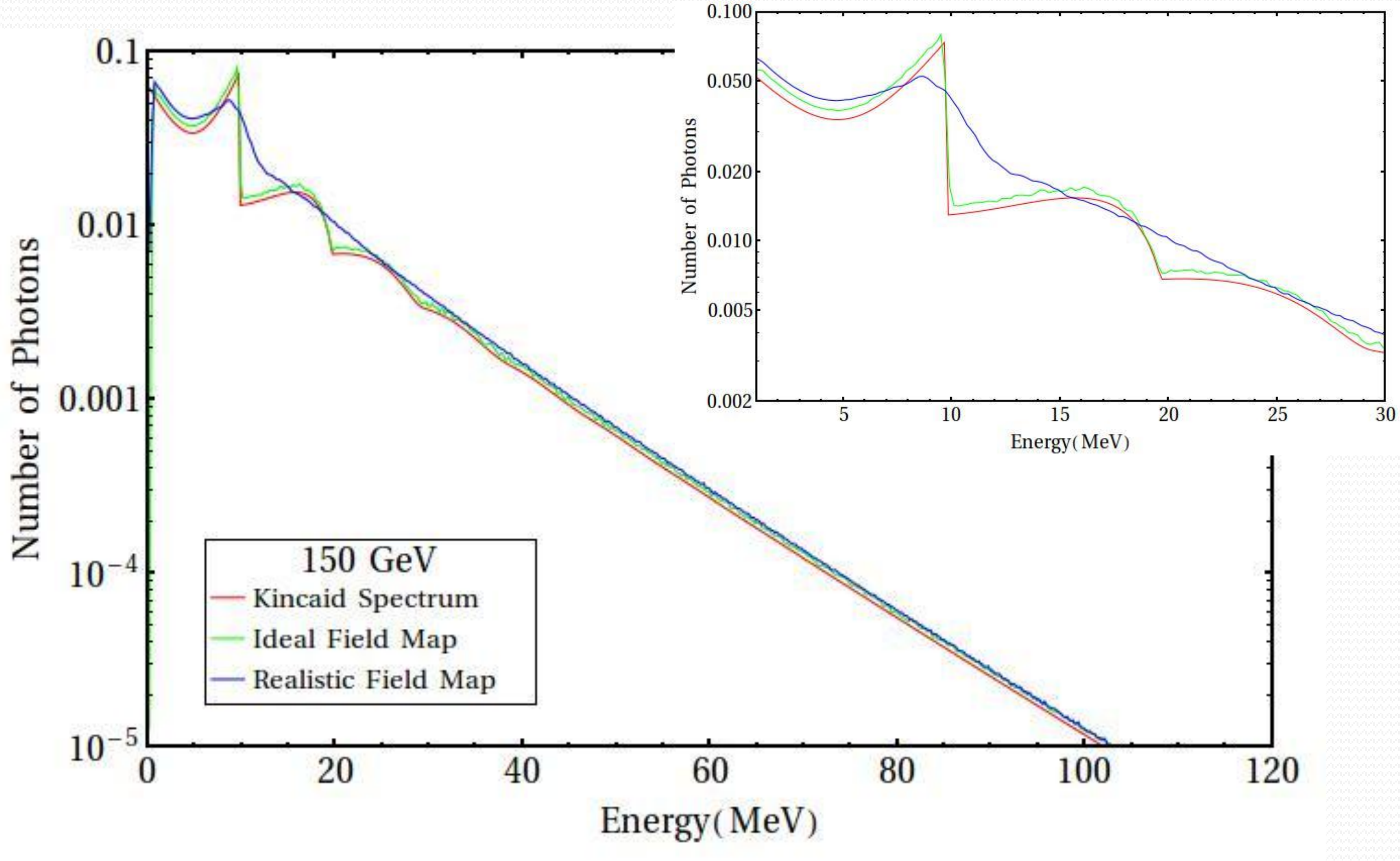
Tracking Particle Through 'Realistic' Field Maps: 60 GeV e^-



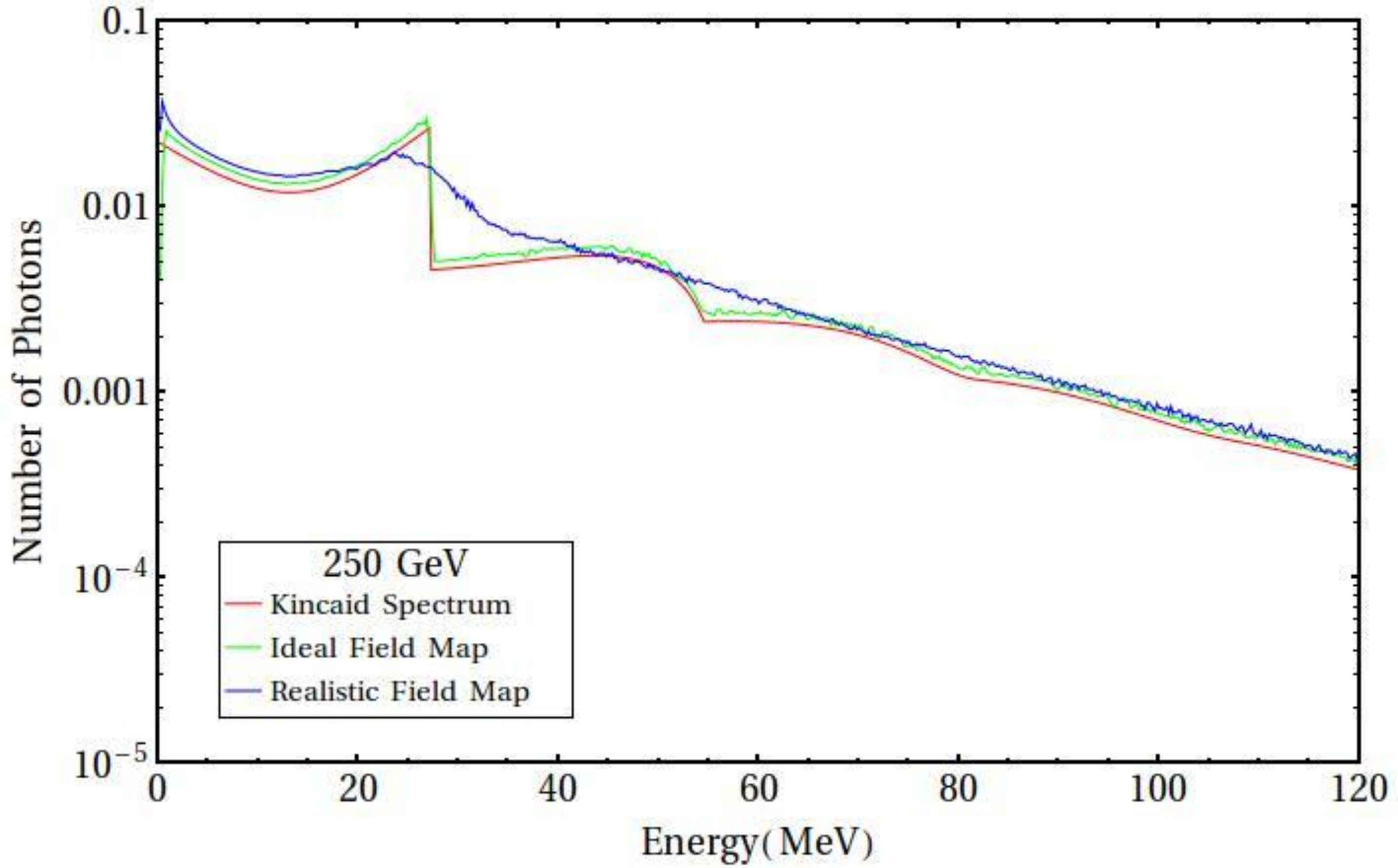
‘Realistic’ Undulator Spectra 60 GeV



'Realistic' Undulator Spectra 150 GeV

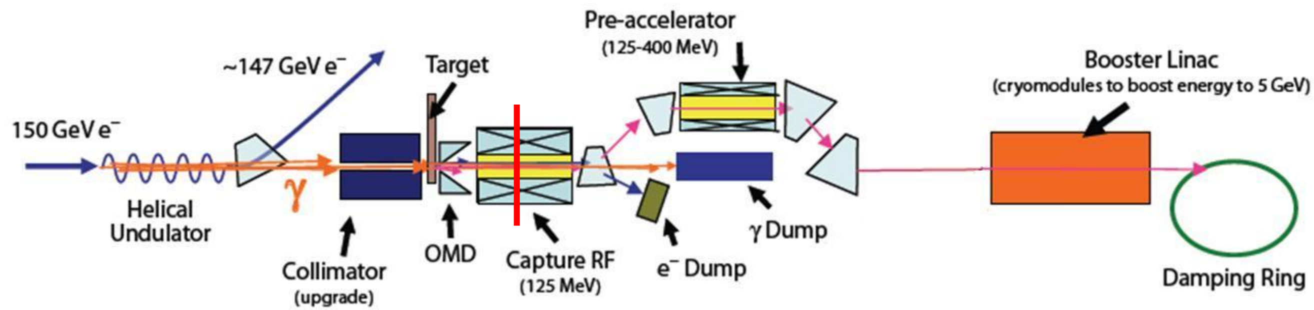


‘Realistic’ Undulator Spectra 250 GeV



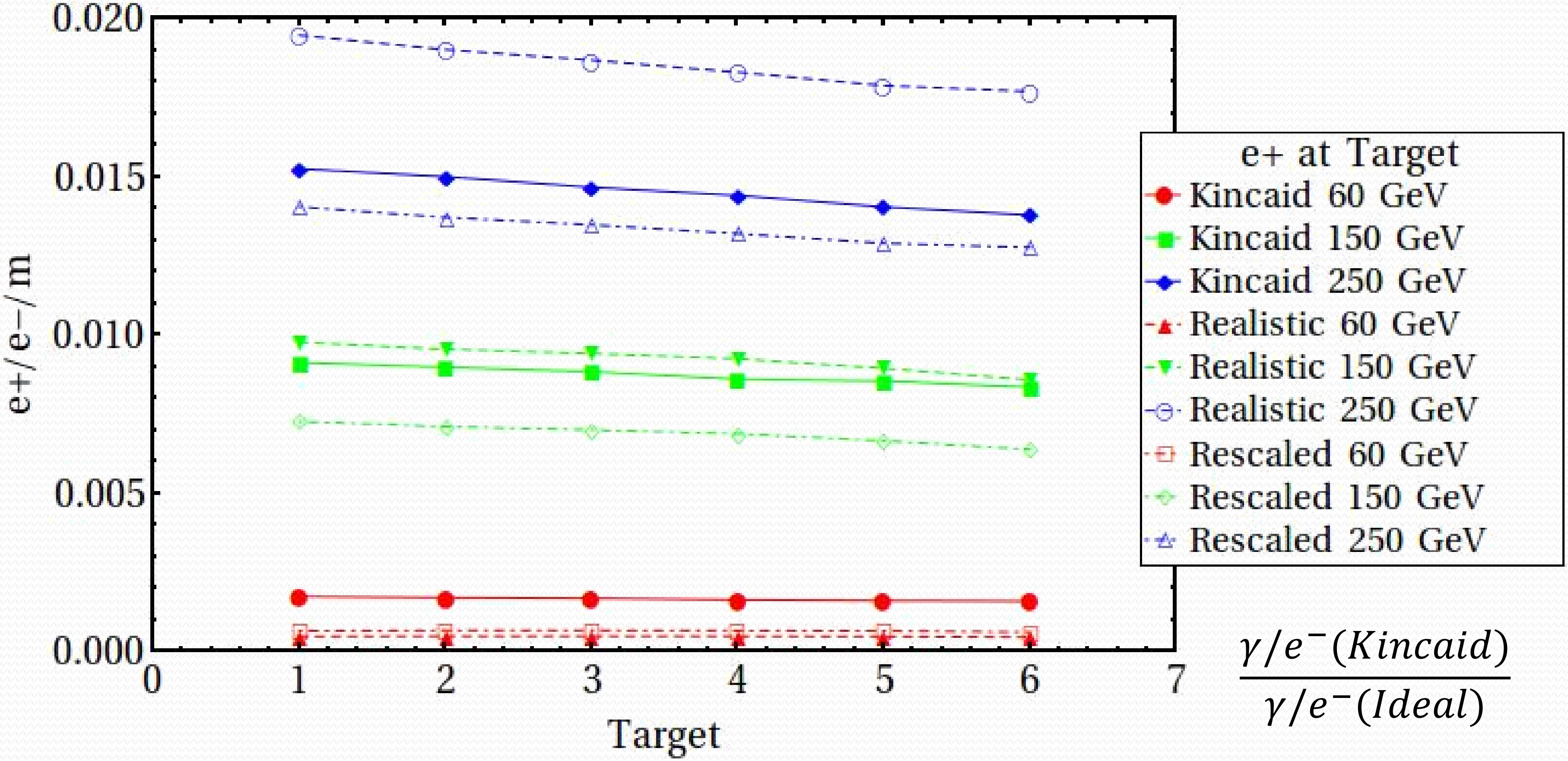
PPS-SIM

- PPS-SIM is a code originally developed at DESY that utilizes Geant4 to simulate the ILC positron source http://pps-sim.desy.de
- PPS-SIM currently simulates from the undulator to the first Capture RF cavity
- Simulations of a 6 target positron source have been carried out with PPS-Sim (K=0.92, λ_u=1.15cm, L=1.7825m, $r_{collimator}$=10mm)



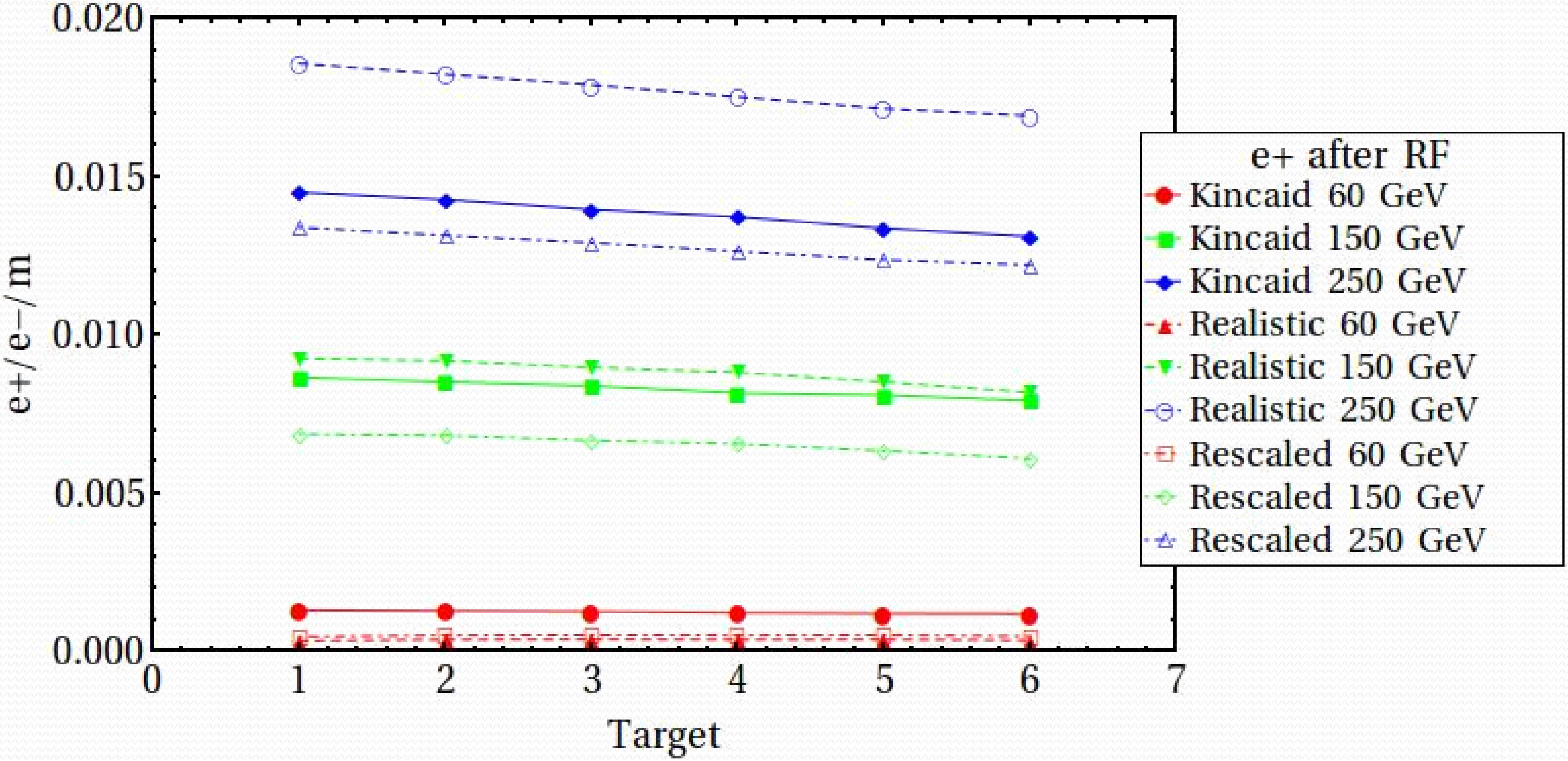
Schematic of ILC RDR Positron Source

Simulations of a Multi-Target Positron Source – Yield after Target



$$\frac{\gamma/e^-(Kincaid)}{\gamma/e^-(Ideal)}$$

Simulations of a Multi-Target Positron Source – Yield after RF



Simulations of a Multi-Target Positron Source – Yield Summary

e^+/e^- /100m@ Target: 60 GeV	Kincaid	Realistic	Rescaled
Target 1	0.17	0.048	0.066
Total	1.00	0.288	0.395

e^+/e^- /100m@ End: 60 GeV	Kincaid	Realistic	Rescaled
Target 1	0.13	0.035	0.048
Total	0.75	0.225	0.309

e^+/e^- /100m@ Target: 150 GeV	Kincaid	Realistic	Rescaled
Target 1	0.91	0.98	0.73
Total	5.25	5.56	4.14

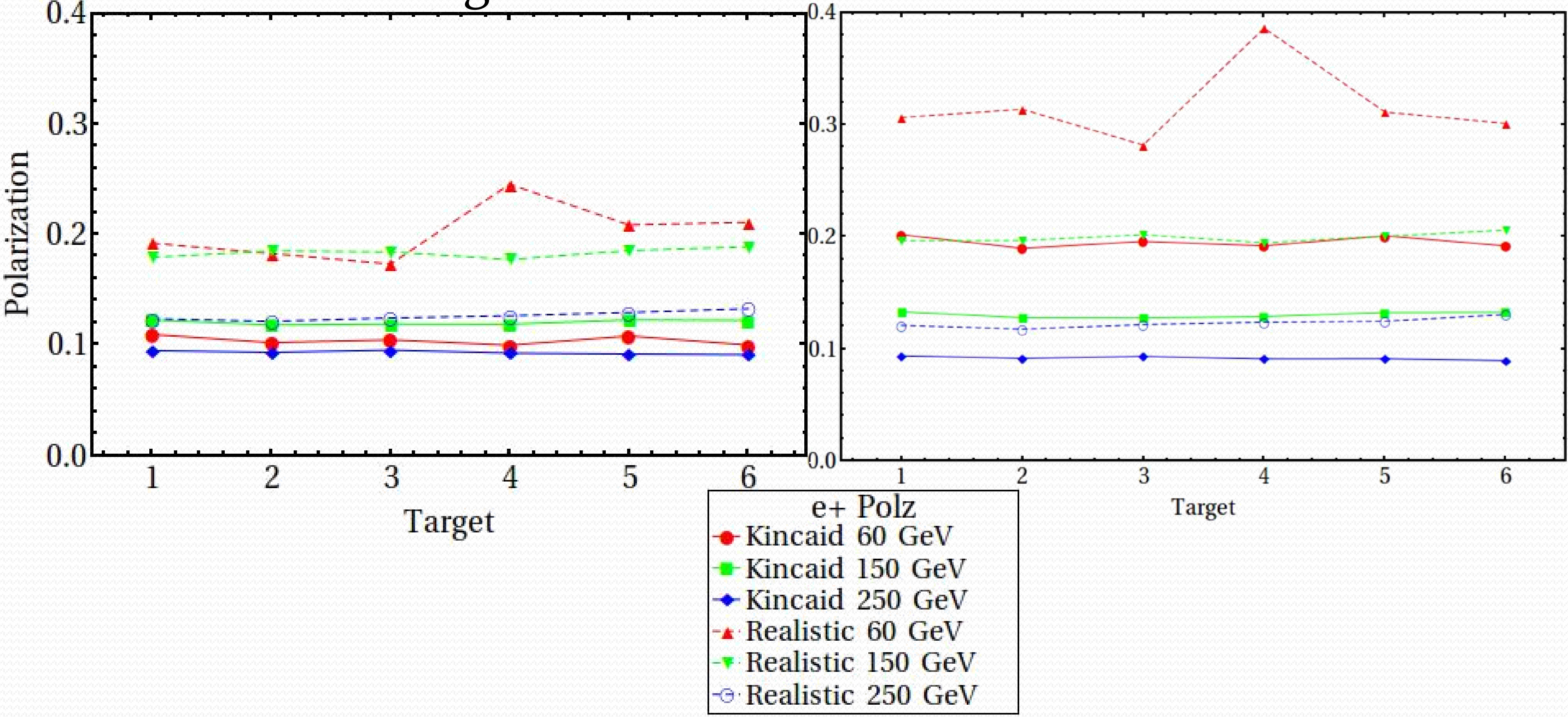
e^+/e^- /100m@ End: 150 GeV	Kincaid	Realistic	Rescaled
Target 1	0.87	0.93	0.69
Total	4.99	5.30	3.94

e^+/e^- /100m@ Target: 250 GeV	Kincaid	Realistic	Rescaled
Target 1	1.5	1.9	1.4
Total	8.7	11.1	8.0

e^+/e^- /100m@ End: 250 GeV	Kincaid	Realistic	Rescaled
Target 1	1.5	1.9	1.3
Total	8.3	10.6	7.7

Simulations of a Multi-Target Positron Source - Polarization

At Target | After RF



Simulations of a Multi-Target Positron Source – Polarization

PolZ 60 GeV	Kincaid	Realistic
At Target	0.11	0.19
At End	0.20	0.31

PolZ 150 GeV	Kincaid	Realistic
At Target	0.12	0.18
At End	0.13	0.20

PolZ 250 GeV	Kincaid	Realistic
At Target	0.09	0.12
At End	0.09	0.12

Simulation Conclusions

- At high energies yield appears to increase when a 'realistic' spectrum is used
- Uncertainty in simulation scaling implies possible drop in yield of ~10% (?)
- At low energies (60 GeV) yield drops when 'realistic' spectrum is used
- Polarization increases when 'realistic' spectrum is used

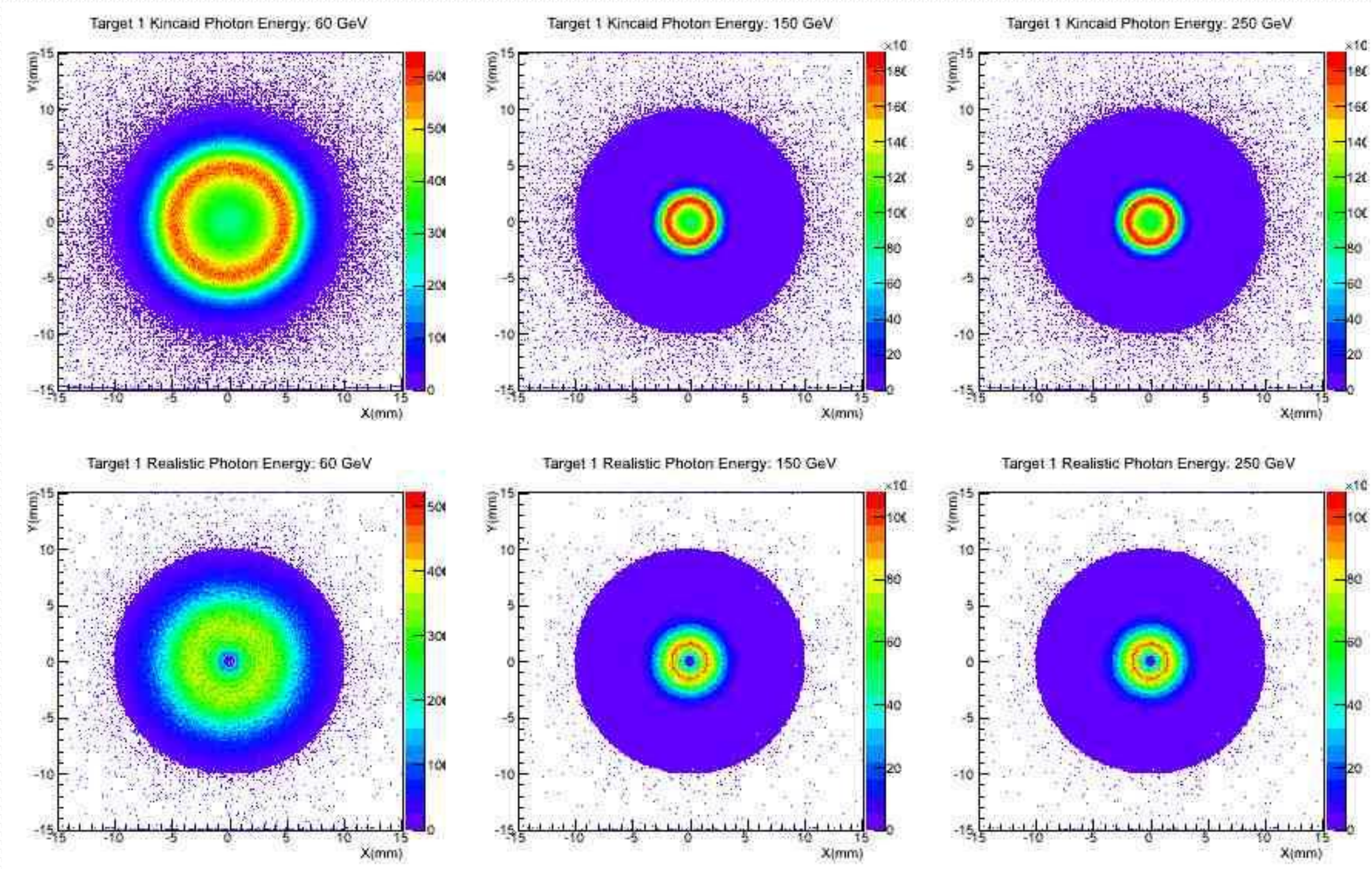
Comparison of Ideal and ‘Realistic’ Distributions

- Current positron capture optics have been optimised using ideal spectrum
- Comparisons of the ideal and ‘realistic’ spectra and the photons produced may indicate further possible optimisations

Comparison of Ideal and 'Realistic' Spectra: Photon Energy

Kincaid

'Realistic'

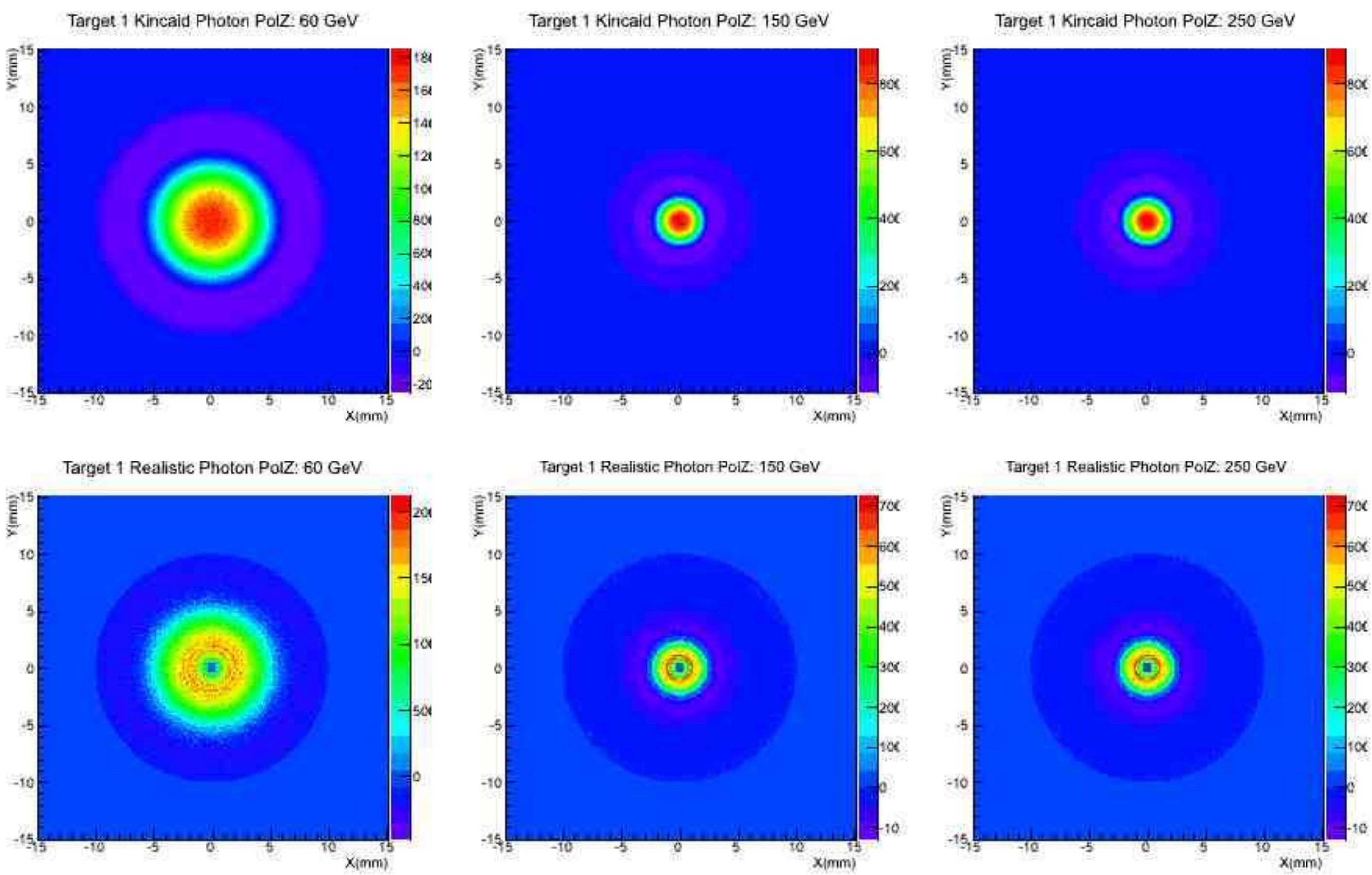


60 GeV 150 GeV 250 GeV

Comparison of Ideal and 'Realistic' Spectra: Photon PolZ

Kincaid

'Realistic'

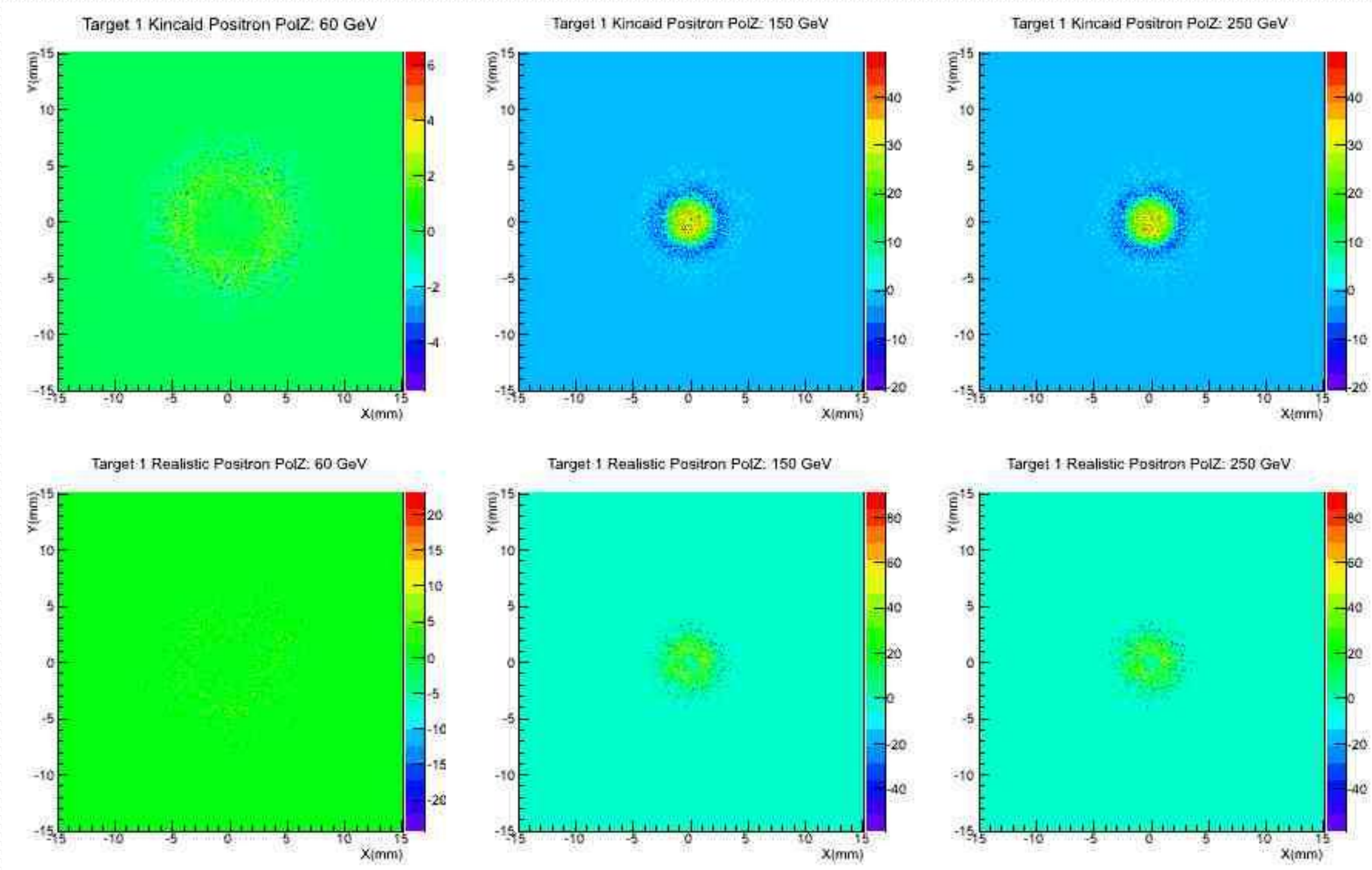


60 GeV 150 GeV 250 GeV

Comparison of Ideal and 'Realistic' Spectra: Positron PolZ at Target

Kincaid

'Realistic'



60 GeV

150 GeV

250 GeV

Conclusions

- Target stations in series may be an approach to increase yield
  - More work is needed on tracking
- Comparing a 'realistic' undulator spectra to the ideal spectra shows:
  - $e^+/e^-/m$ is not reduced and may increase
  - With large aperture collimator polarization from realistic spectra is higher than polarization from ideal
  - Collimator needs to take into account change in photon distribution due to field errors, as well as module misalignments

Conclusions

- Work is ongoing to produce a ‘realistic’ spectra from:
  - Long undulator
  - Multiple particles
- Effects of different collimator apertures on the yield and polarization of positrons produced from a ‘realistic’ spectra need to be simulated
- Work needed to simulate with ILC parameters and crosscheck with Andriy and Wanming

Thank you for listening, are there any questions

Back Up Slides

Implementation of Tracking Code

Taken from talk by D. Newton, Synchrotron Radiation Output from the ILC Undulator, ILC Positron Source Workshop 2010

Analytic Tracking Code

- Characterise an arbrtrary magnetic field in terms of it's multipole expansion and generalised gradients to produce an analytical description of field as a fuction of the longitudinal coordinate [a]
- Use the analytical expression in differential algebra or Lie algebra code to generate a Taylor or Lie (symplectic) map for the dynamics in the magnet.
- Evaluate the analytical expressions to perform a numerical integration giving a fast particle tracking code to describe the evolution of the canonical coordinates within the magnet.
- The C++ code that has been has been written has a modular structure which facilitates extending the code
- A Synchrotron Radiation Module is being implemented which calculates the synchrotron emission from a particle into an arbitrary observation point
- eg ILC Helical undulator

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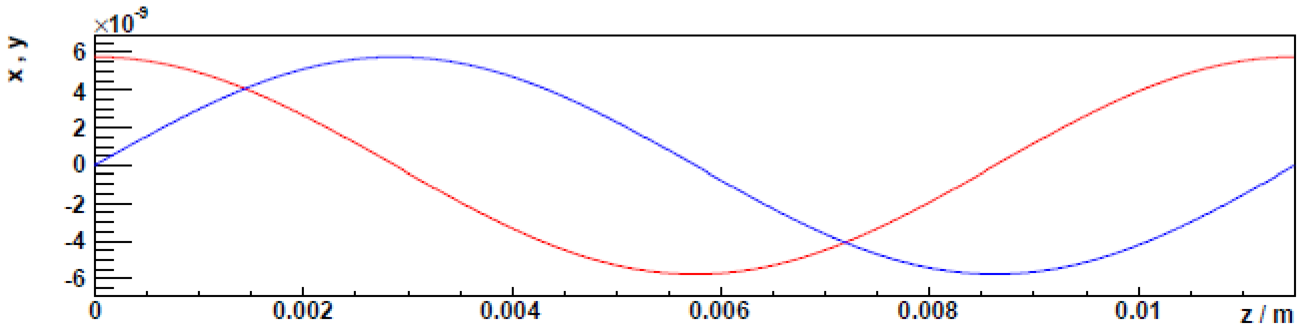
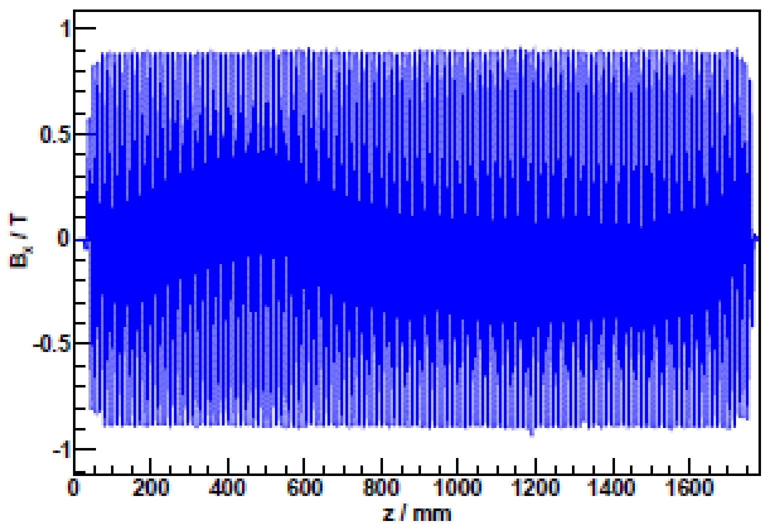
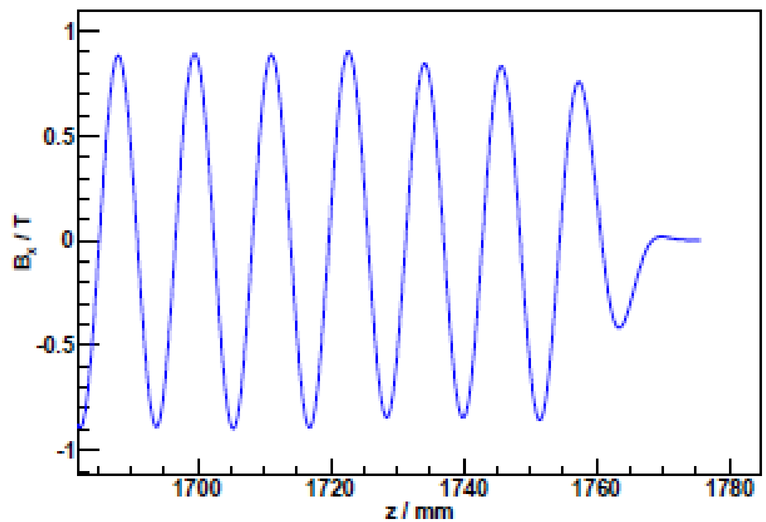
[a]Venturini and Dragt

Tracking through Field Maps

Taken from Synchrotron Radiation Output from the ILC undulator talk by D. Newton at ILC Positron Source Workshop 2010







Tracking through Field Maps

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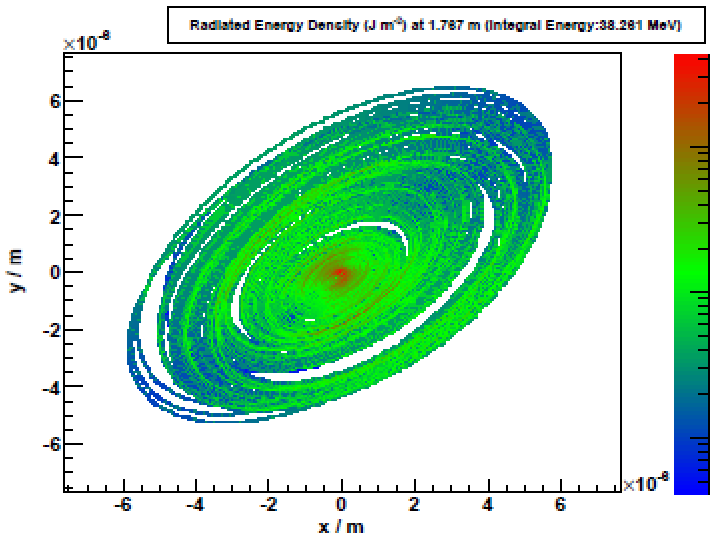
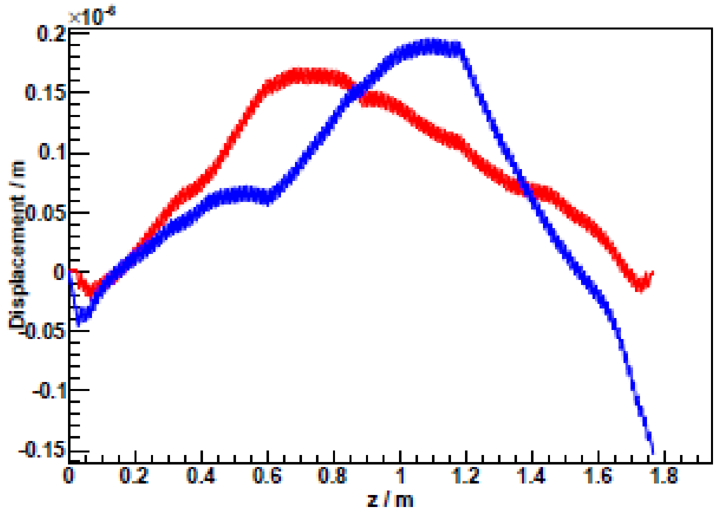




- These plots are for one of the 2m undulator prototypes constructed at RAL
- One shows the power radiated at the end and the other shows the trajectory through the undulator in x and y for a beam that enters at a correction angle
- The angular deviations off axis are of the order 1 μrad which when compared with k/γ (3.13 μrad for a drive beam energy of 150 GeV) are significant

Simulations of a Multi-Target Positron Source

e^+ / e^- at Target

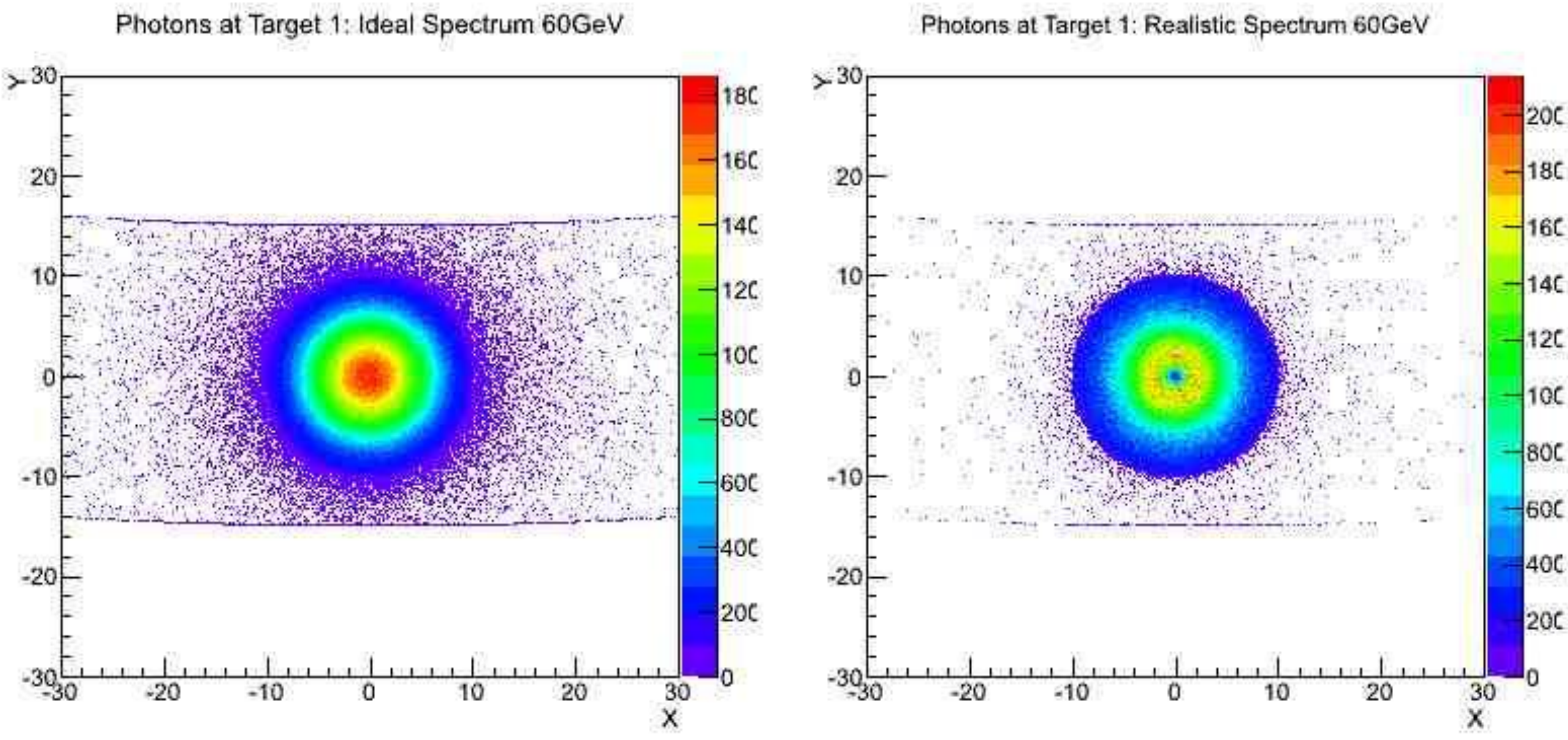
	Kincaid 60 GeV	Realistic 60 GeV	Rescaled 60 GeV	Kincaid 150 GeV	Realistic 150 GeV	Rescaled 150 GeV	Kincaid 250 GeV	Realistic 250 GeV	Rescaled 250 GeV
1	0.0017	0.00048	0.00066	0.0091	0.0098	0.0073	0.015	0.019	0.014
2	0.0017	0.00049	0.00067	0.0090	0.0096	0.0071	0.015	0.019	0.014
3	0.0017	0.00049	0.00067	0.0089	0.0094	0.0070	0.015	0.019	0.013
4	0.0016	0.00049	0.00067	0.0086	0.0093	0.0069	0.014	0.018	0.013
5	0.0016	0.00048	0.00066	0.0086	0.0090	0.0067	0.014	0.018	0.013
6	0.0016	0.00045	0.00062	0.0084	0.0086	0.0064	0.014	0.018	0.013
Total	0.0100	0.00288	0.00395	0.0525	0.0556	0.0414	0.087	0.111	0.080

Simulations of a Multi-Target Positron Source

e^+ / e^- at End

	Kincaid 60 GeV	Realistic 60 GeV	Rescaled 60 GeV	Kincaid 150 GeV	Realistic 150 GeV	Rescaled 150 GeV	Kincaid 250 GeV	Realistic 250 GeV	Rescaled 250 GeV
1	0.0013	0.00035	0.00048	0.0087	0.0093	0.0069	0.015	0.019	0.013
2	0.0013	0.00038	0.00052	0.0085	0.0092	0.0068	0.014	0.018	0.013
3	0.0013	0.00039	0.00054	0.0084	0.0090	0.0067	0.014	0.018	0.013
4	0.0012	0.00038	0.00052	0.0082	0.0088	0.0066	0.014	0.018	0.013
5	0.0012	0.00038	0.00053	0.0081	0.0085	0.0063	0.013	0.017	0.012
6	0.0012	0.00036	0.00050	0.0079	0.0082	0.0061	0.013	0.017	0.012
Total	0.0075	0.00225	0.00309	0.0499	0.0530	0.0394	0.083	0.106	0.077

Comparison of Ideal and Realistic Spectra: Photon Position



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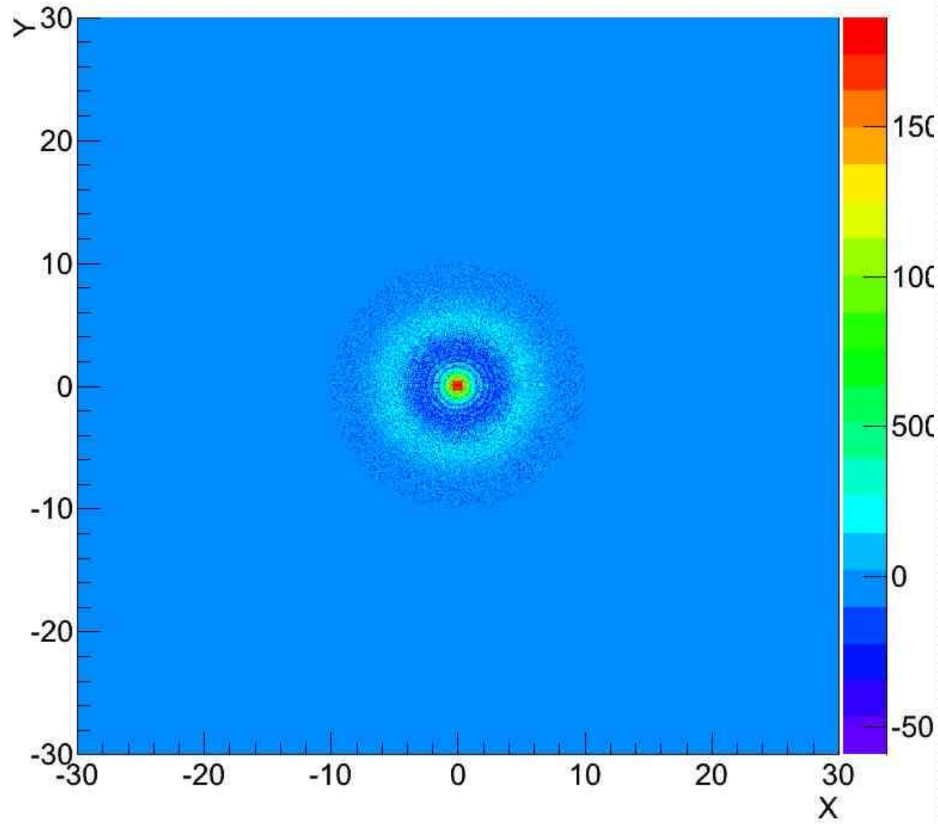
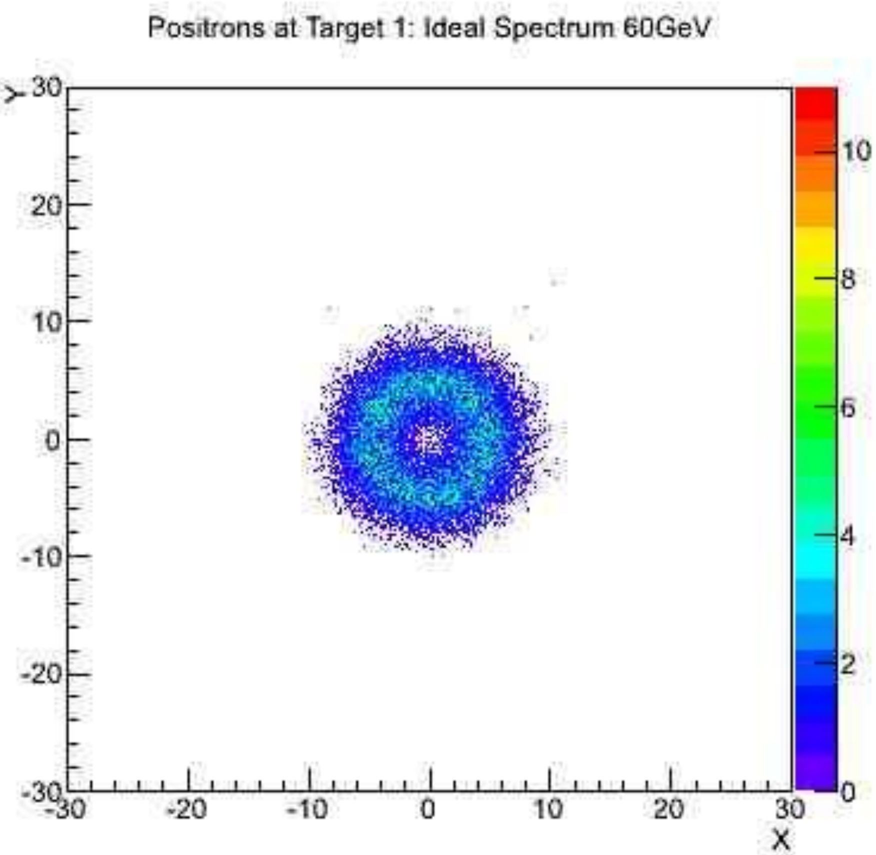
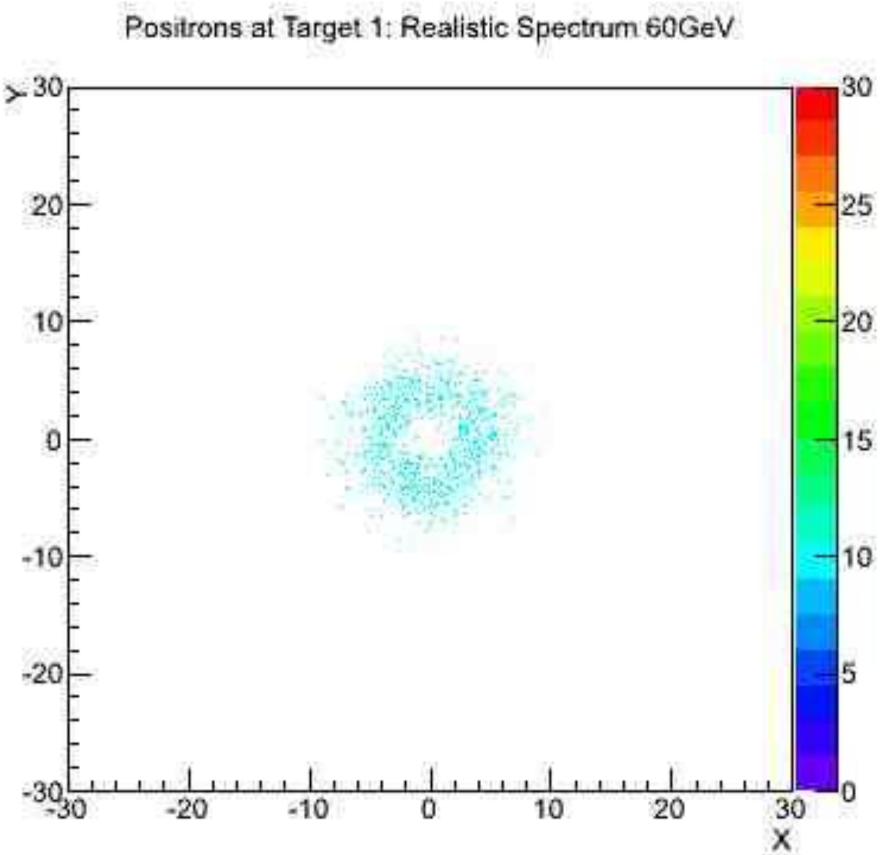


Comparison of Ideal and Realistic Spectra: Positron Position at Target





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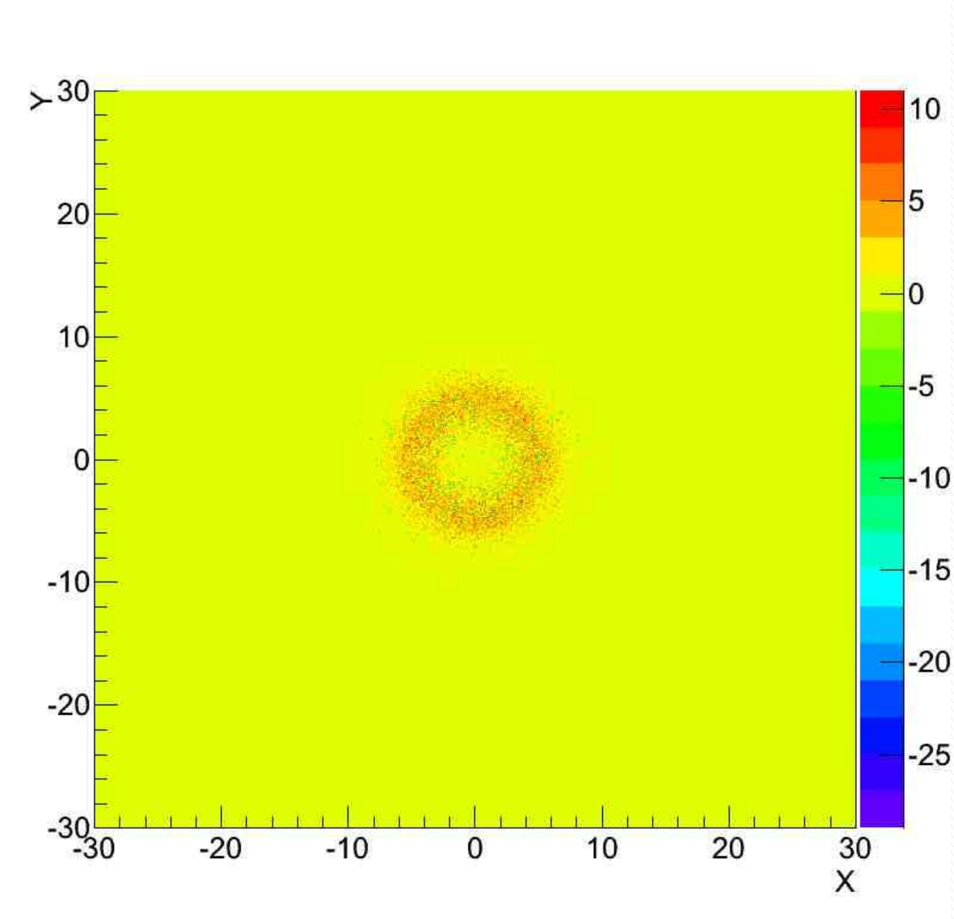

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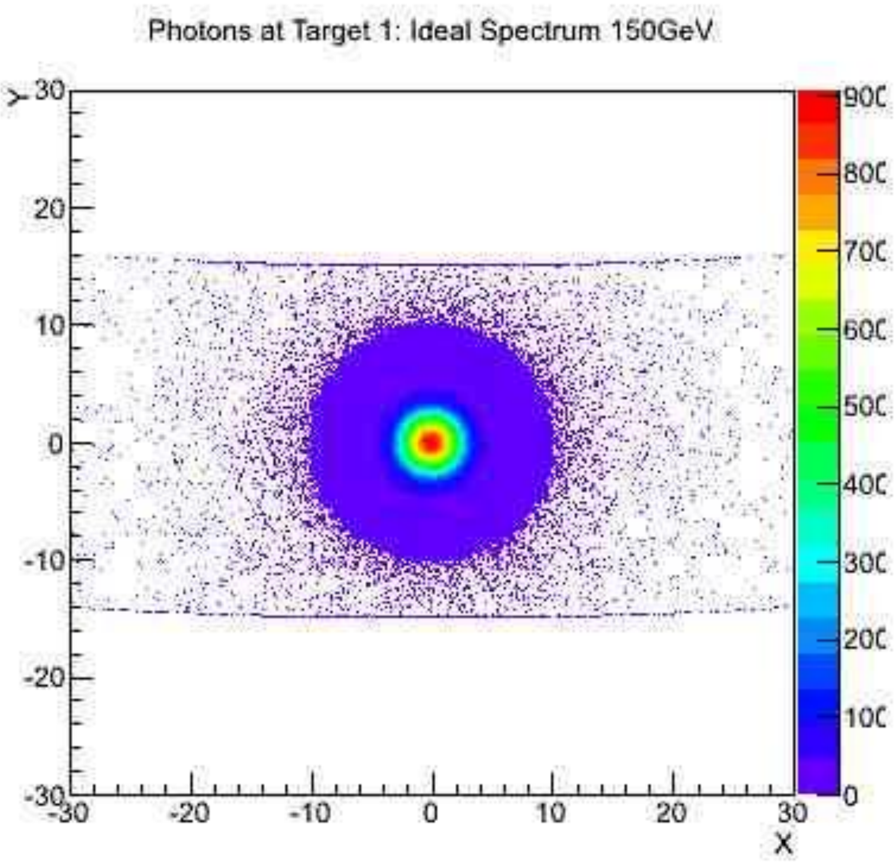

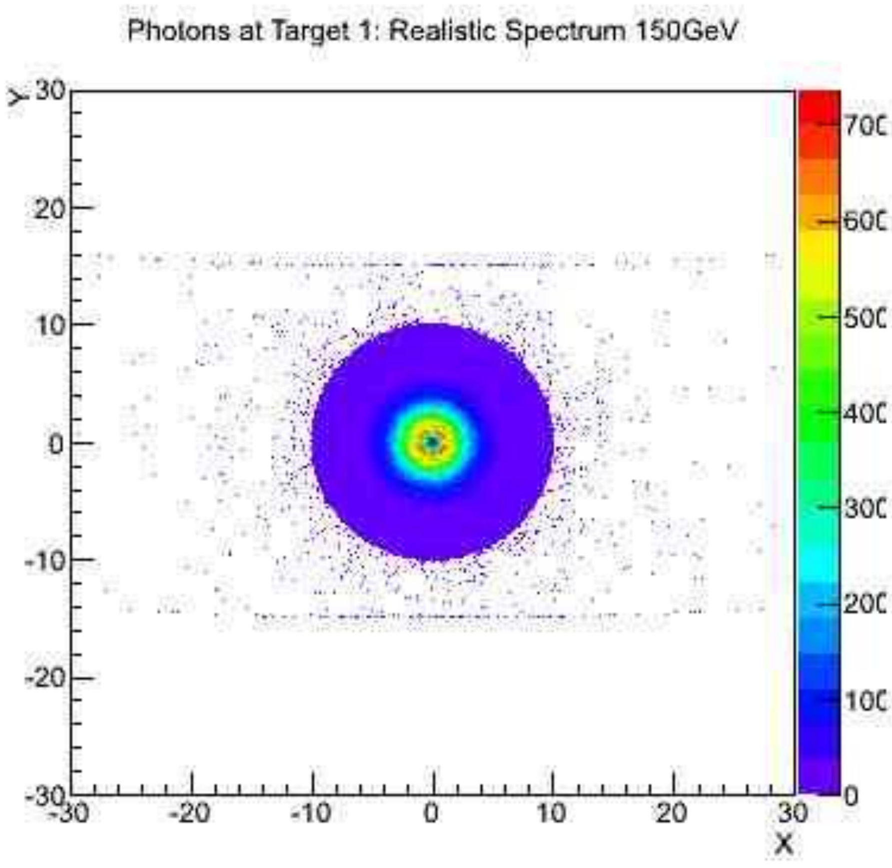

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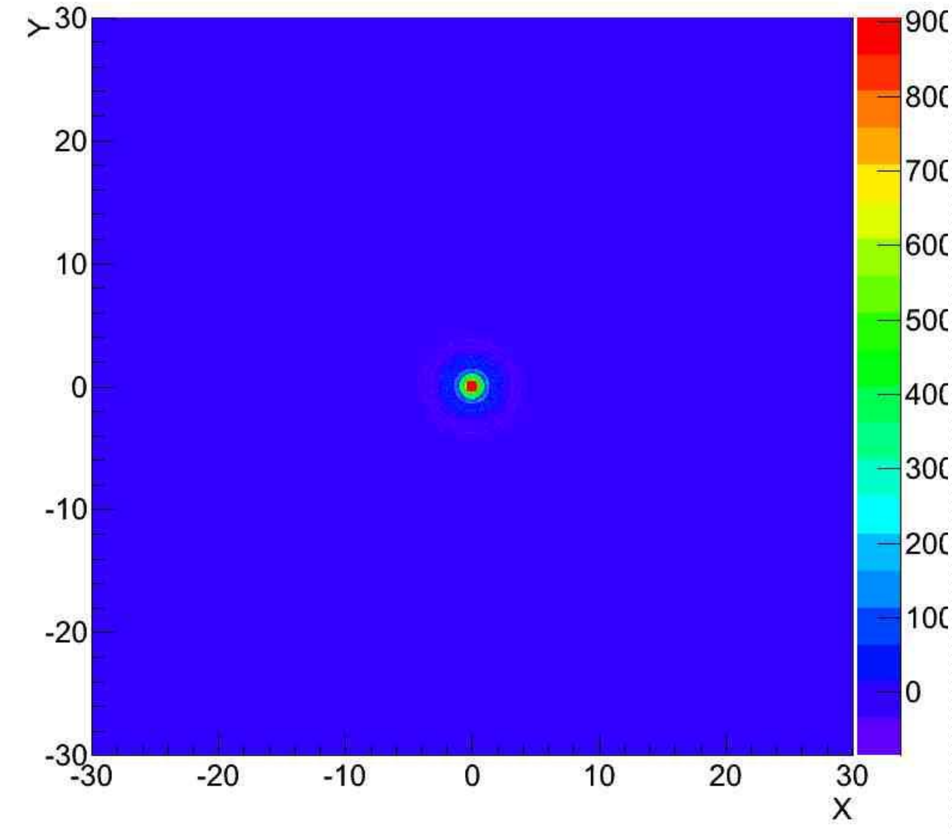

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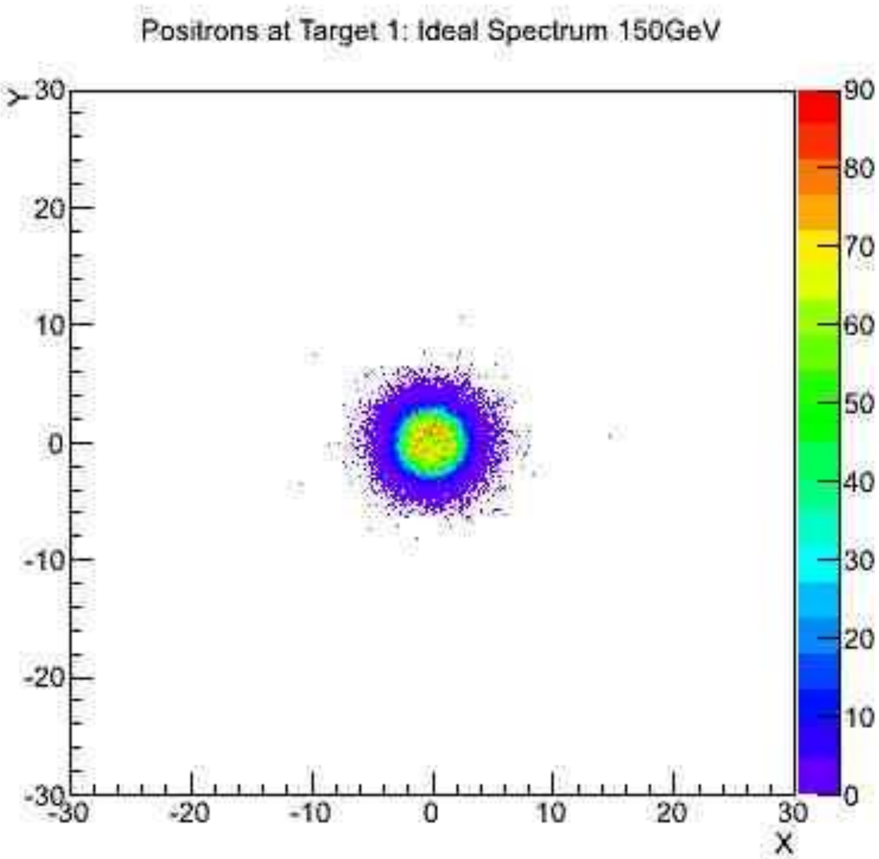

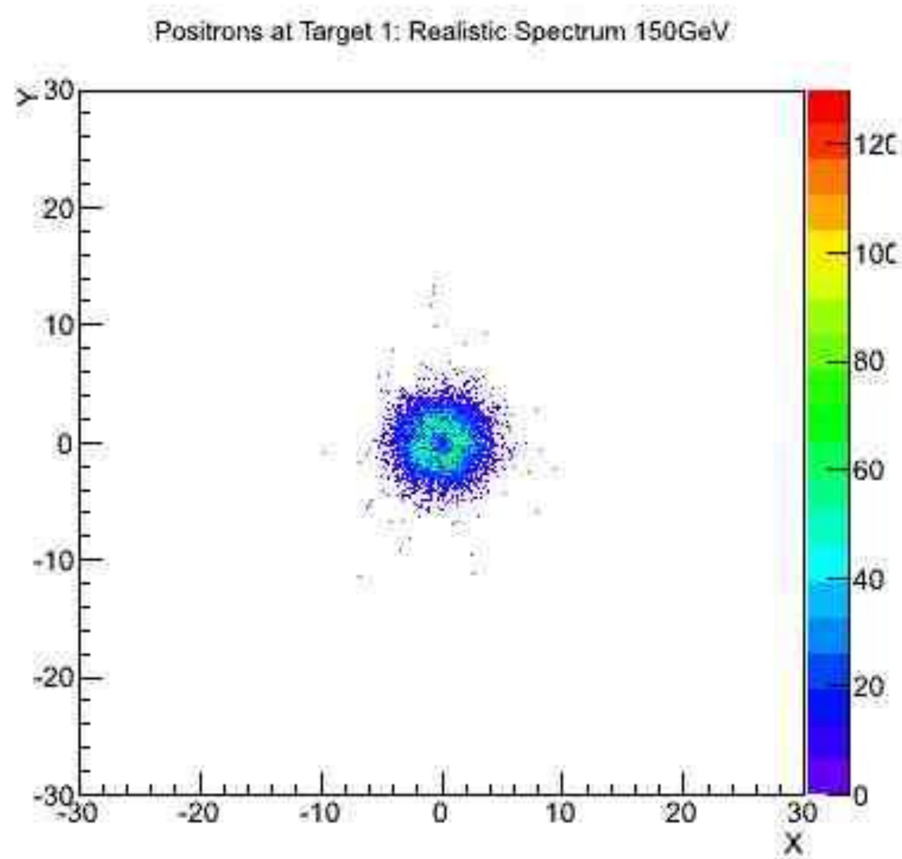

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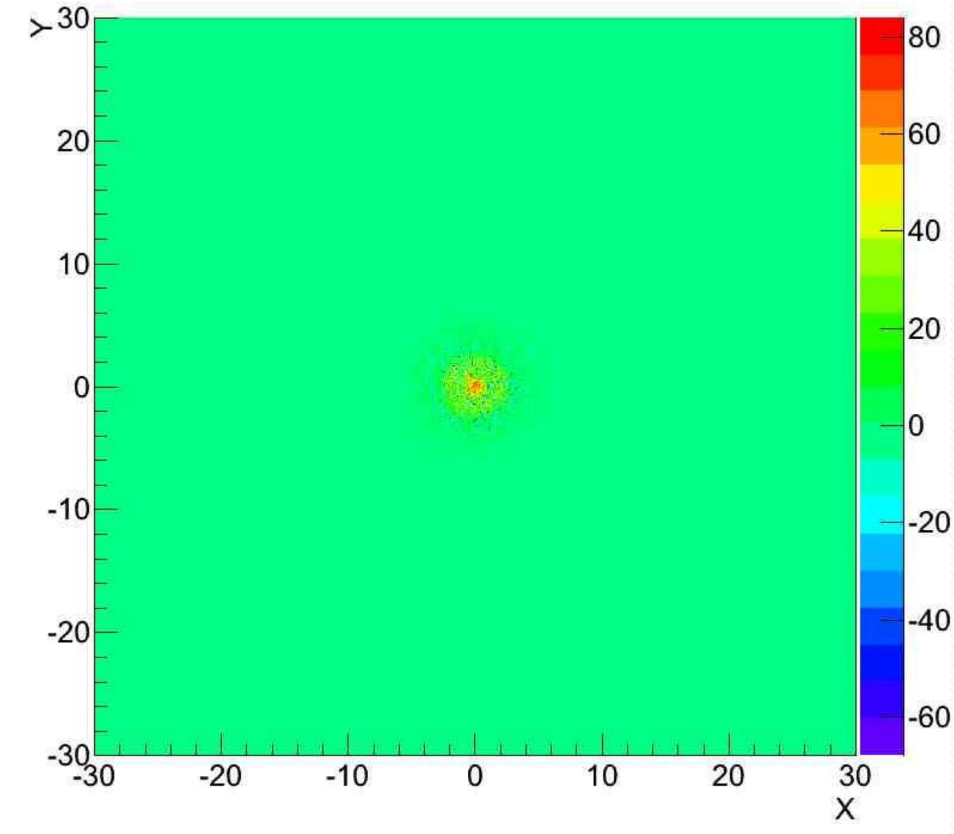
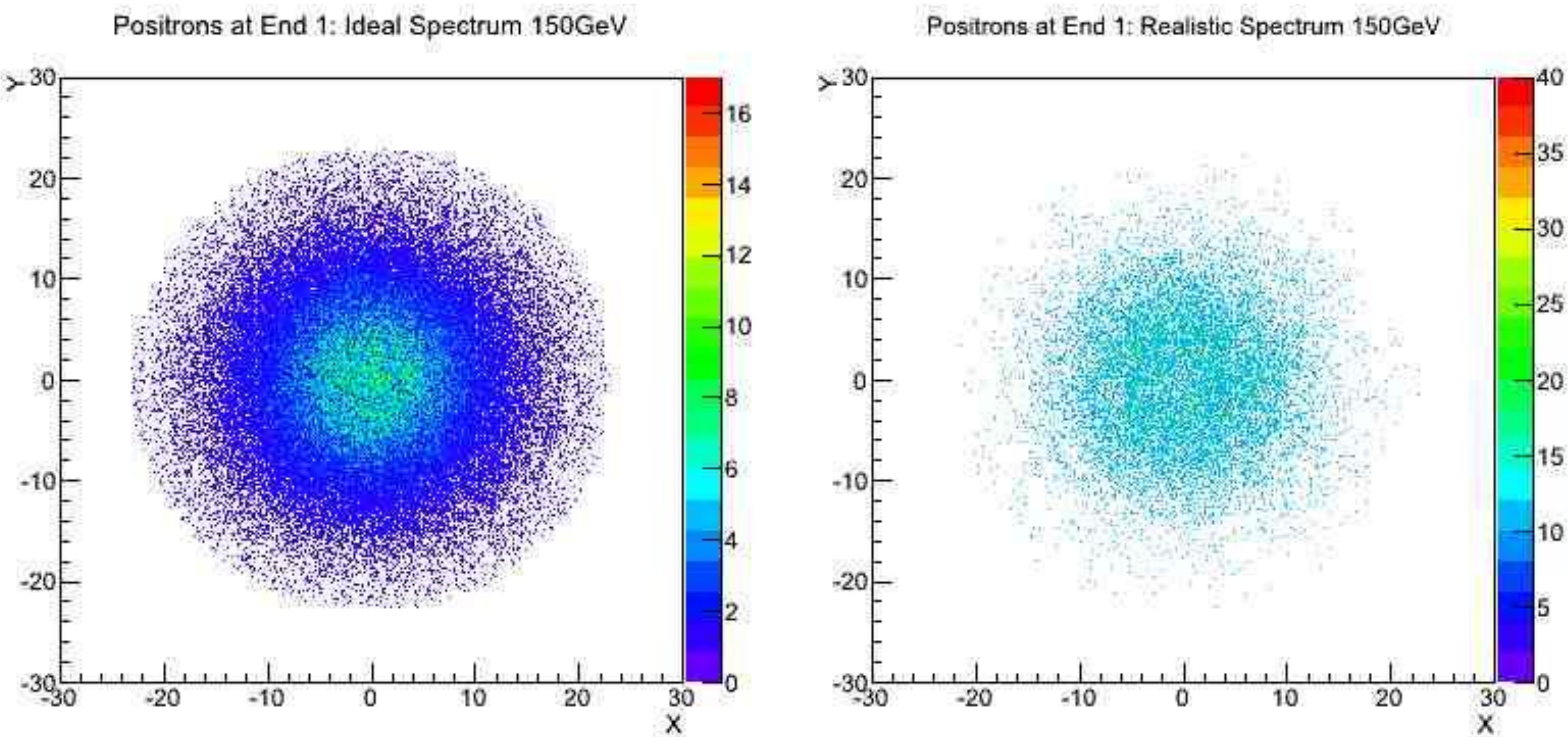


Comparison of Ideal and Realistic Spectra: Positron Position at End



Comparison of Ideal and Realistic Spectra: Positron Position at End