

Detector studies for 10 TeV wakefield-based lepton/photon colliders

Simone Pagan Griso, **Angira Rastogi**
Lawrence Berkeley National Laboratory

Beam-beam and MDI working group meeting #13

<https://indico.slac.stanford.edu/event/10443/>

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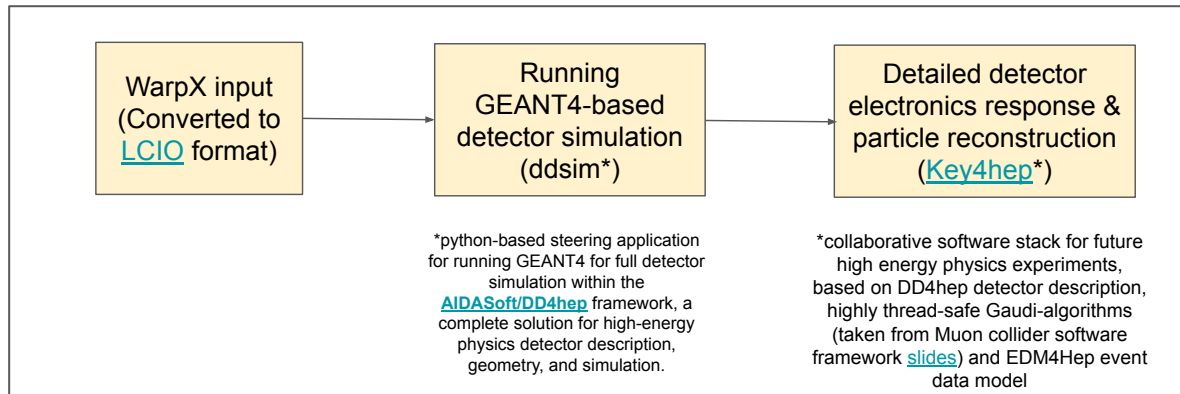


Outline

- Introduction & workflow
- Software framework
- Initial detector geometry
- Preliminary results with WarpX beam-beam simulation
- Conclusion

Introduction & workflow

- Software framework needed to study the environment created by the high energy electron or photon collisions along with their background radiations.
- Important to come up with a proposal for the detector layout as well as the required technology needed for wakefield-based colliders.
- Using the latest WarpX beam-beam simulation as input, provided by A. Formenti
 - Includes incoherent and coherent pairs production, beam-beam as well as beamstrahlung e+/e- and photons
 - Missing hadron photoproduction ($\Upsilon\Upsilon \rightarrow qq$) for now

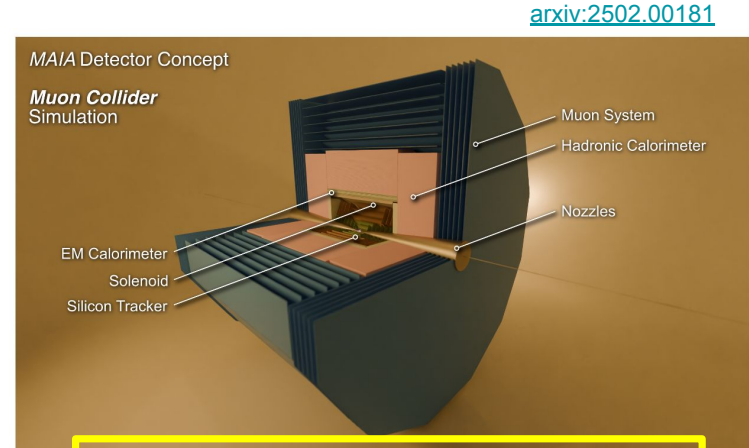
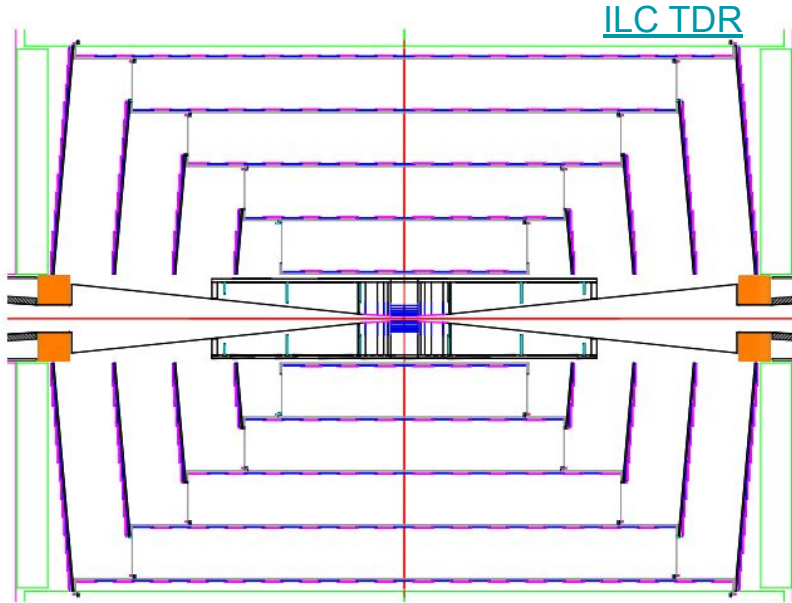


Software setup

- Fully containerized! One stop repository for everything: <https://github.com/wfa-detector>
- Docker image (with all the necessary libraries for entire workflow) available to download “docker pull angirar/wcd:main-gaudi-alma9”
- Starting a docker container or shifter container with docker image, instructions here: [wcd-gaudi-docker](#)
- To convert WarpX beam-beam output to LCIO format: [WarpX to slcio.py](#)
 - Simple script to plot 4-vec of initial beam-beam particles: [plot_mc_particles.py](#)
- Workspace to perform detector R&D studies (simulation, detector digitization & reconstruction): [WakefieldBeamStudiesGaudiWorkspace](#)
 - Setup instructions and steps to run provided in [README](#)
 - Need detector description (next slide)

Initial detector geometry

- Starting point: ILC SiD ([o3_v02](#)) beam pipe (2.45 cm) + vertex + tracker detector, immersed in 5T field from solenoid; ECAL + HCAL + Muon detector from [MAIA_v0](#)

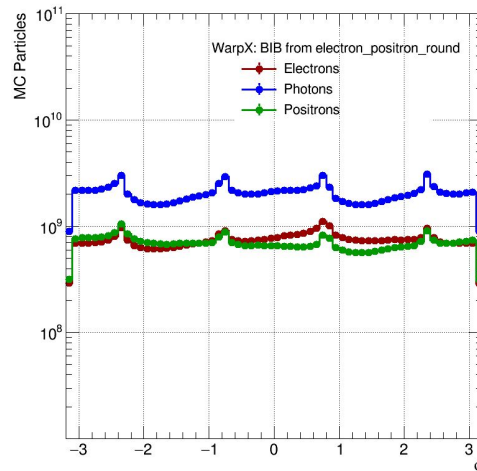
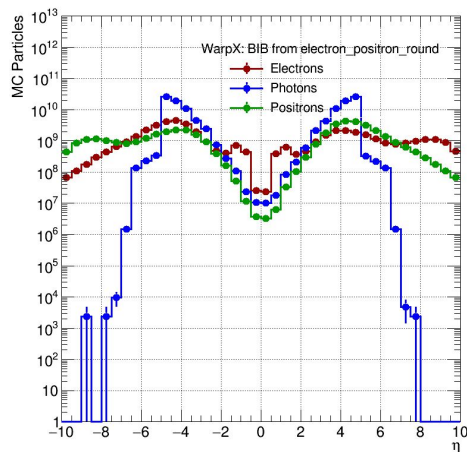
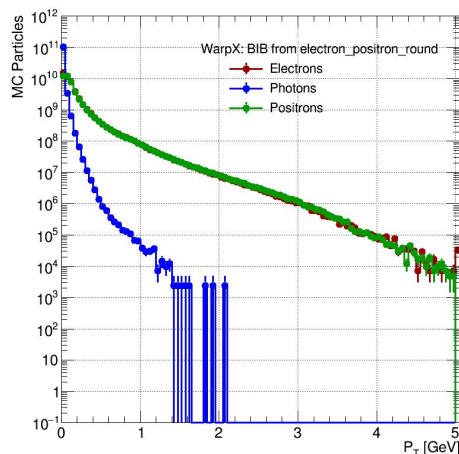


Solenoid	Barrel	150.0 – 185.7	230.7	Al
ECAL	Barrel	185.7 – 212.5	230.7	W + Si
	Endcap	31.0 – 212.5	230.7 – 257.5	W + Si
HCAL	Barrel	212.5 – 411.3	257.5	Fe + PS
	Endcap	30.7 – 411.3	257.5 – 456.2	Fe + PS
Muon Detector	Barrel	415.0 – 715.0	456.5	Air + RPC
	Endcap	44.6 – 715.0	456.5 – 602.5	Air + RPC

- Present in the workspace: [Wakefield_v0](#)

Preliminary results

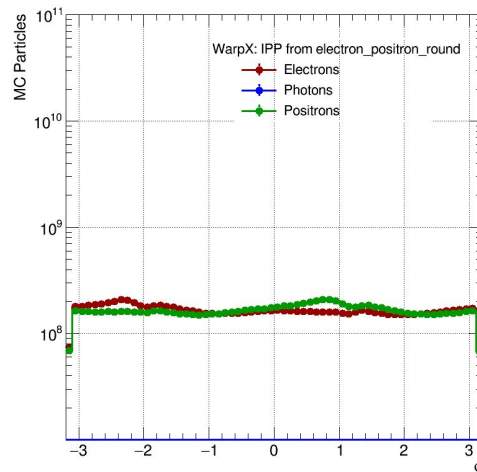
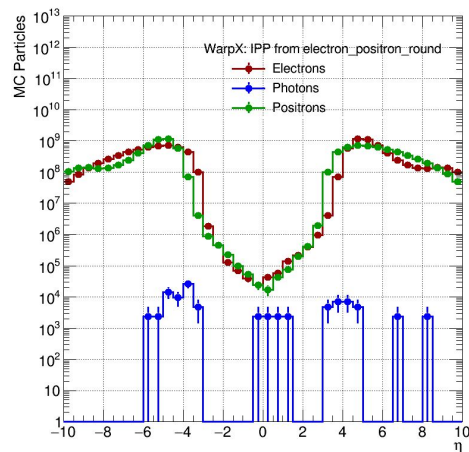
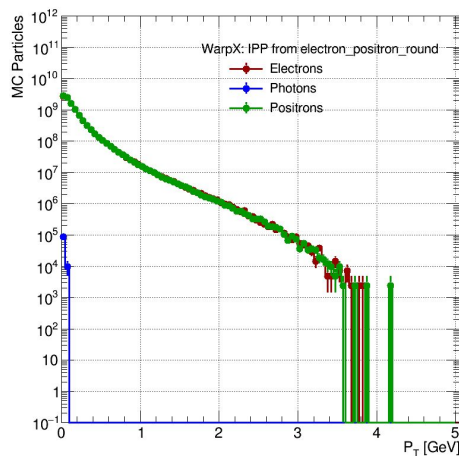
Particle-level distributions: Beam-beam background from WarpX



Number of electrons = $O(10^{11})$
Number of positrons = $O(10^{11})$
Number of photons = $O(10^{12})$

(No selections applied)

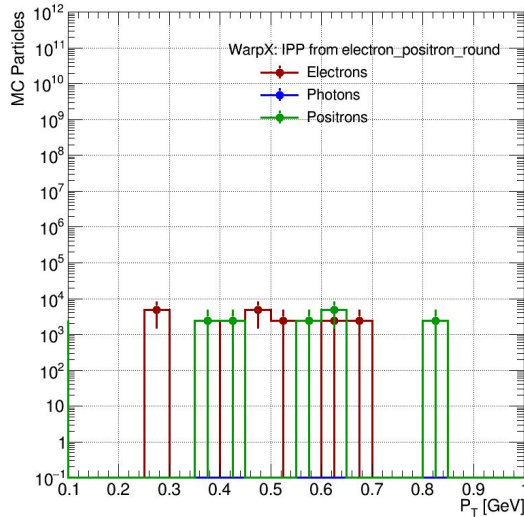
Particle-level distribution - Incoherent pairs from WarpX



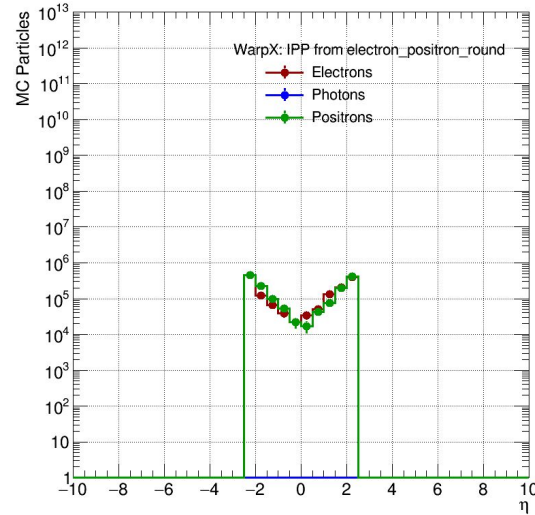
Number of electrons = O(e10)
Number of positrons = O(e10)
Number of photons = O(e6)

(No selections applied)

With detector fiducial cuts...



Number of electrons = $O(e6)$
Number of positrons = $O(e6)$
Number of photons = 0

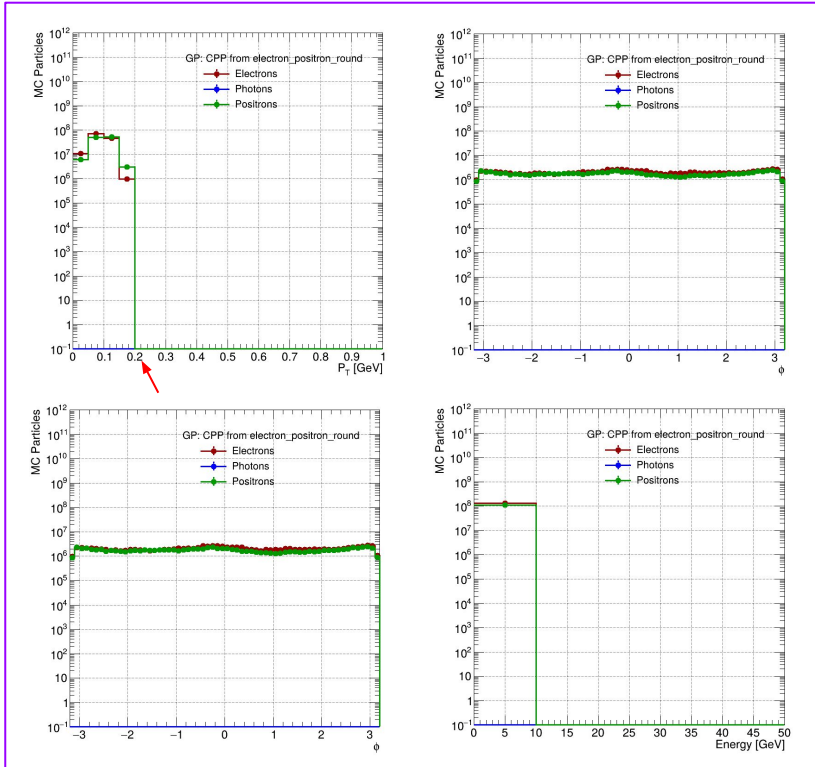


$e^+/e^- p_T > 10$ MeV, $|\eta| < 2.5$
Photon $|\eta| < 5$

Very few incoherent pairs left after p_T , η cuts
(with mean of $p_T \sim 20$ -30 MeV).

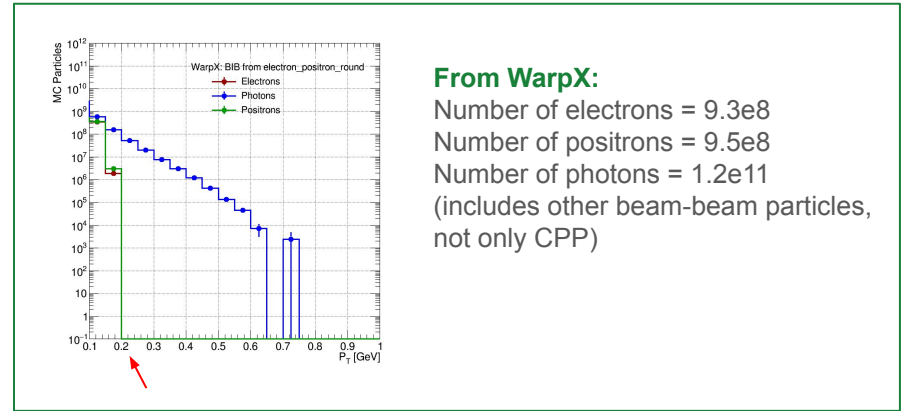
Particle-level distributions - Coherent pairs

$e^+/e^- p_T > 10 \text{ MeV}$, $|\eta| < 2.5$,
Photon $|\eta| < 5$



From Guinea-pig:

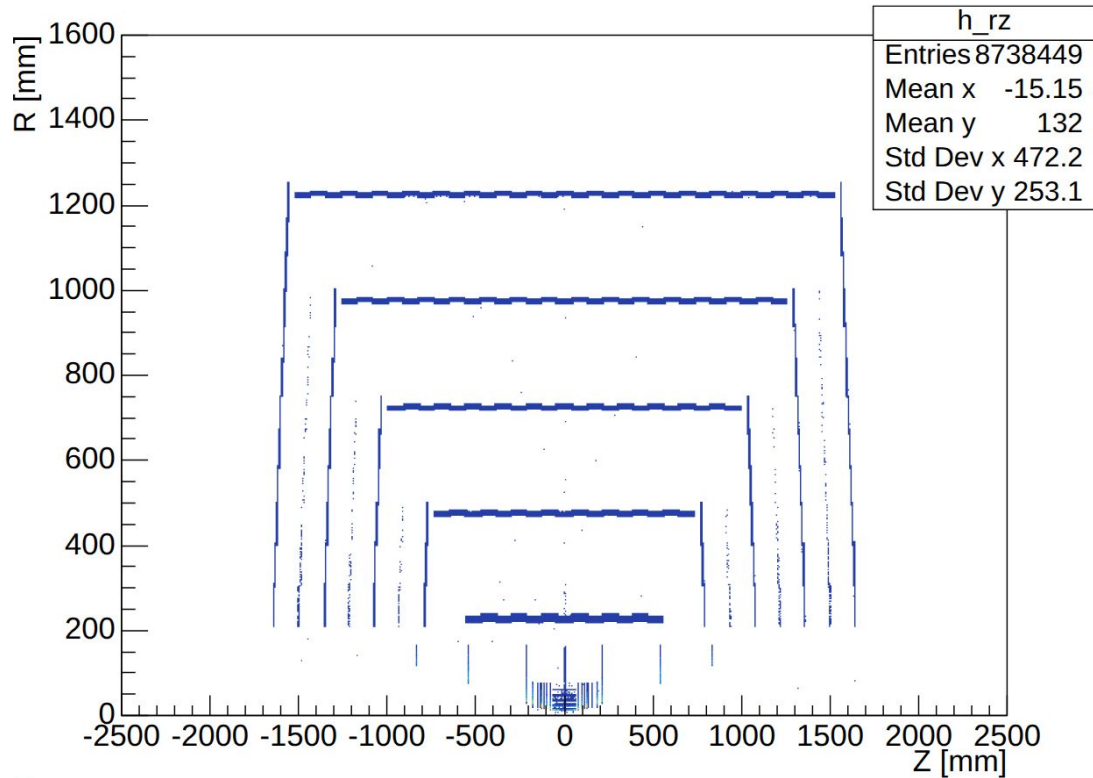
Total $e^- = 1.3e8$
Total $e^+ = 1.1e8$
Total photons = 0
(including macroparticle weight=2400)



From WarpX:

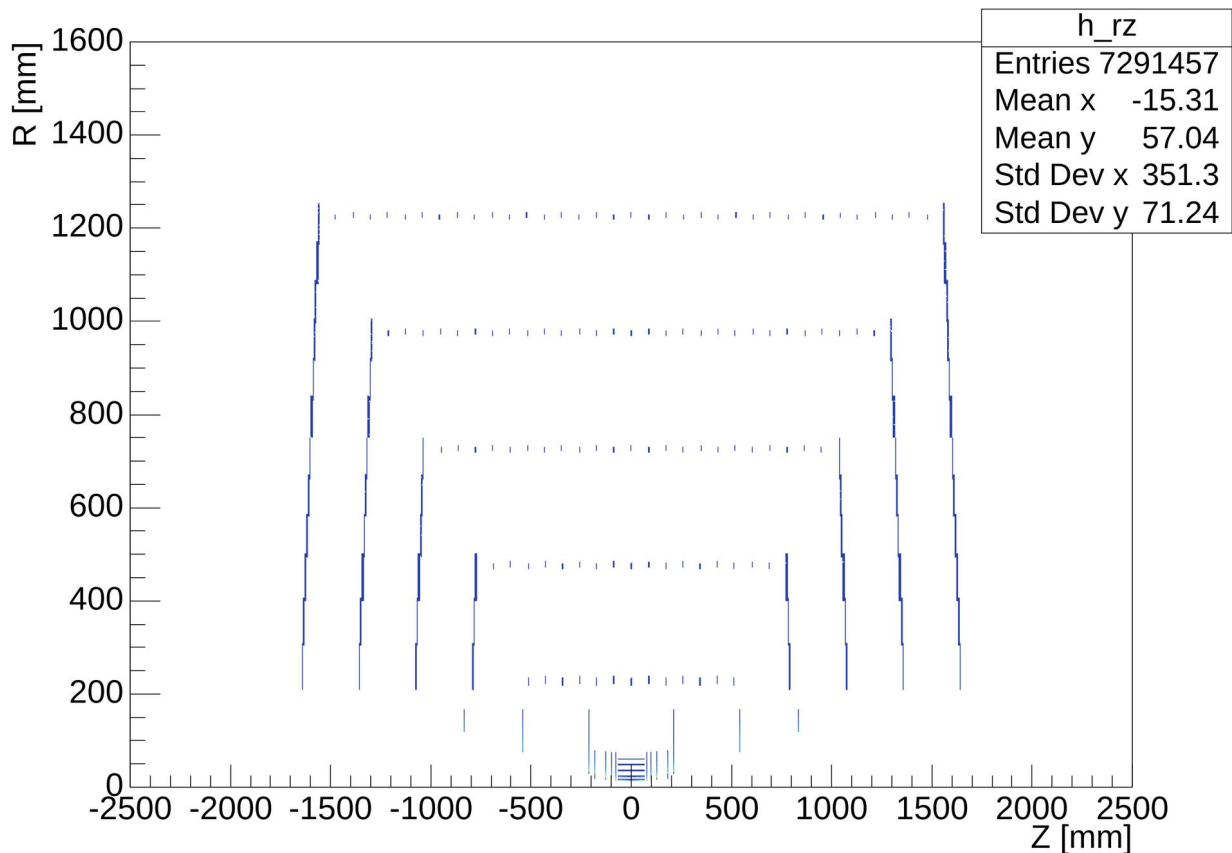
Number of electrons = $9.3e8$
Number of positrons = $9.5e8$
Number of photons = $1.2e11$
(includes other beam-beam particles, not only CPP)

Detector simulation



- Using GEANT4 based simulation of the detector via DD4HEP.
- Initial geometry well-reproduced.
- Some extra simulated hits seen in between the tracker layers, and also around $z=0$, probably from failed conversion to detector cell ID
 - Will debug this

Detector-level detailed modeling (digitization)



- Using [DDPlanarDigi](#) to simulate the response of tracking detectors, specifically silicon-based planar sensors.
- Transforms simulated energy deposits from Geant4 (with position & energy information) into digital, reconstructed hits via gaussian smearing based on expected resolution of the detector.
 - Some issue with translating surface position in tracker barrel layers, debugging this
- More realistic detector digitization model ([MuonCVXDDigitiser](#)) with pixel-by-pixel level energy map will be available to run soon !

Conclusion

- Software pipeline to analyze WarpX output and perform detector R&D studies for 10 TeV wakefield-based collider is in place now: [wfa-detector](#)
 - Should add documentation in <https://10tev-wakefield-collider.github.io/> ?
- This helps us in initial validation and gaining an understanding of the collision environment by looking at:
 - Individual (macro)particles
 - Interaction with detector material (GEANT4)
 - Interaction with detector electronics
- Developed initial detector geometry based on ILC SiD tracking with 5T magnetic field and calorimetry from 10 TeV muon collider detectors (included in the workspace)
 - Need to explore for benchmark signal scenarios as well (e.g. disappearing tracks)

- Plenary talk at ALEGRO 2026 on more detailed detector studies next week ([link](#))