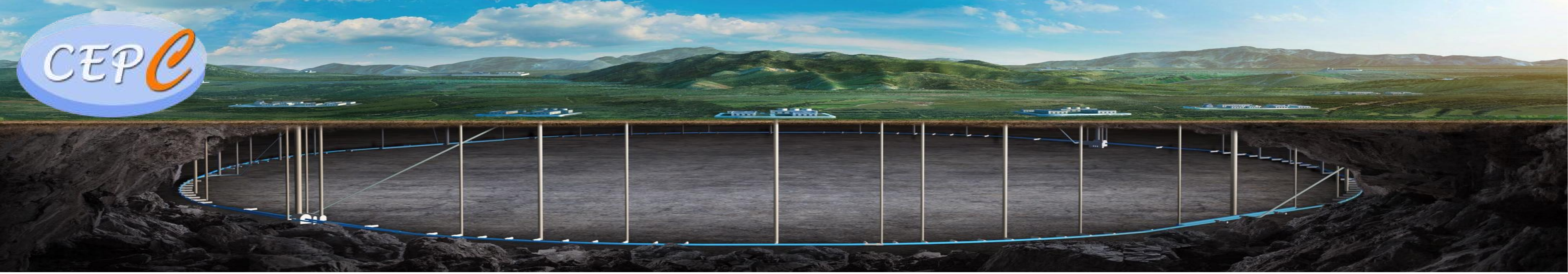

The Study Status of the incoherent pair production simulation

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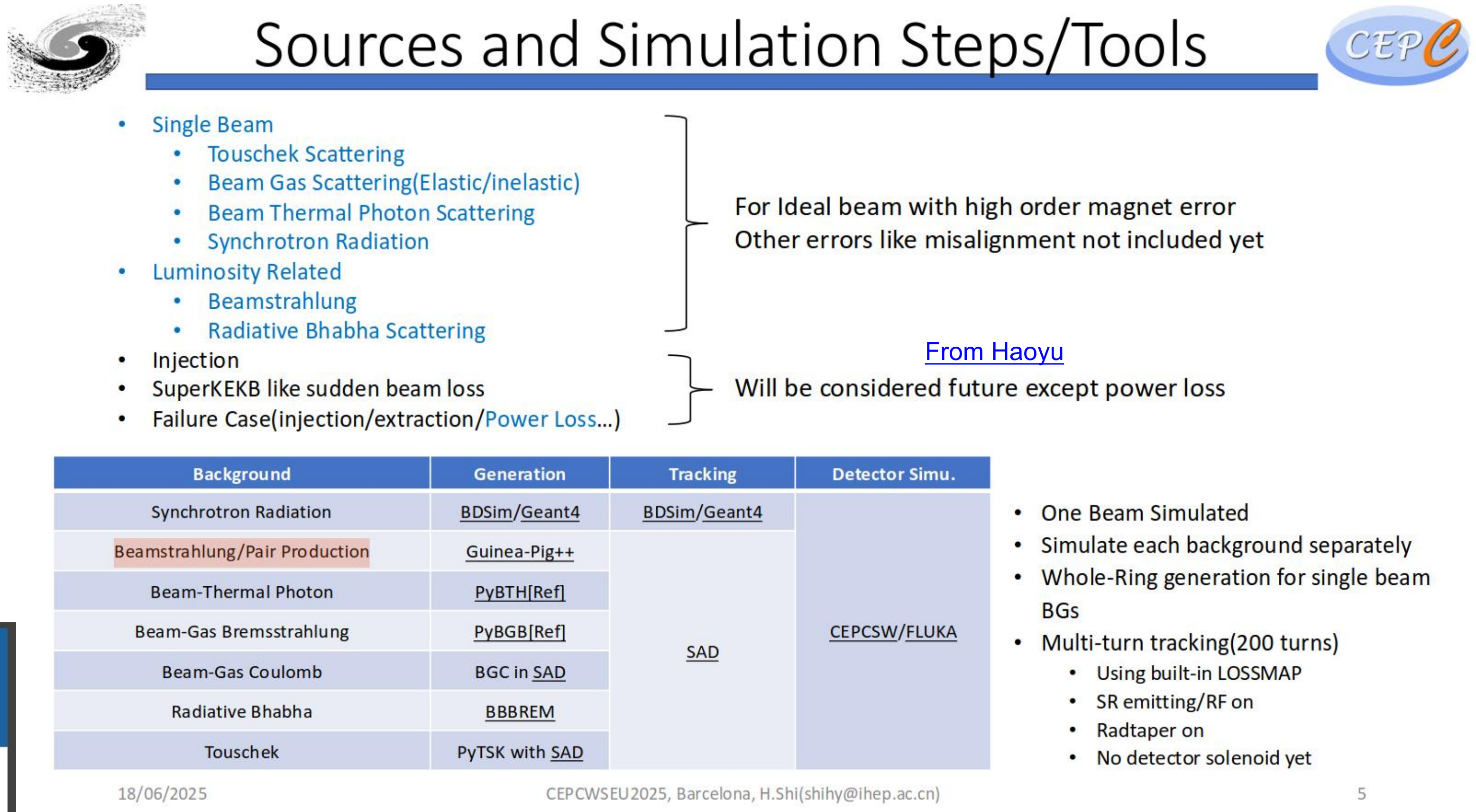
Introduction

- Beam induce background
  - Single beam; Lumi related
- Focus on incoherent pair production
- Dominant background in CEPC
- Simulated by [Guinea-Pig]
  - Ihep-Vinca joint group for the GPig study
  - Led by Ivanka from Vinca
  - Validate this simulation tool



Sources and Simulation Steps/Tools

- Single Beam
  - Touschek Scattering
  - Beam Gas Scattering(Elastic/inelastic)
  - Beam Thermal Photon Scattering
  - Synchrotron Radiation
- Luminosity Related
  - Beamstrahlung
  - Radiative Bhabha Scattering
- Injection
- SuperKEKB like sudden beam loss
- Failure Case(injection/extraction/Power Loss...)

For Ideal beam with high order magnet error
Other errors like misalignment not included yet

From Haoyu
Will be considered future except power loss

Background	Generation	Tracking	Detector Simu.
Synchrotron Radiation	BDSim/Geant4	BDSim/Geant4	CEPCSW/FLUKA
Beamstrahlung/Pair Production	Guinea-Pig++	SAD	
Beam-Thermal Photon	PyBTH[Ref]		
Beam-Gas Bremsstrahlung	PyBGB[Ref]		
Beam-Gas Coulomb	BGC in SAD		
Radiative Bhabha	BBBREM		
Touschek	PyTSK with SAD		

- One Beam Simulated
- Simulate each background separately
- Whole-Ring generation for single beam BGs
- Multi-turn tracking(200 turns)
  - Using built-in LOSSMAP
  - SR emitting/RF on
  - Radtaper on
  - No detector solenoid yet

18/06/2025 CEPCWSEU2025, Barcelona, H.Shi(shihy@ihep.ac.cn) 5

Three processes for pair production

- Breit-Wheeler (BW)
  - Two real photons from beamstrahlung
- Bethe-Heitler (BH)
  - One real photon from beamstrahlung
  - One virtual photon from electron
- Landau-Lifshitz (LL)
  - Two virtual photon from electrons
- Real photons from beamstrahlung: Sokolov-Ternov formula for photon energy spectrum
- GPig: Virtual photon approximation for BH and LL
  - To simplify the simulation
- Compare analytical and simulation result

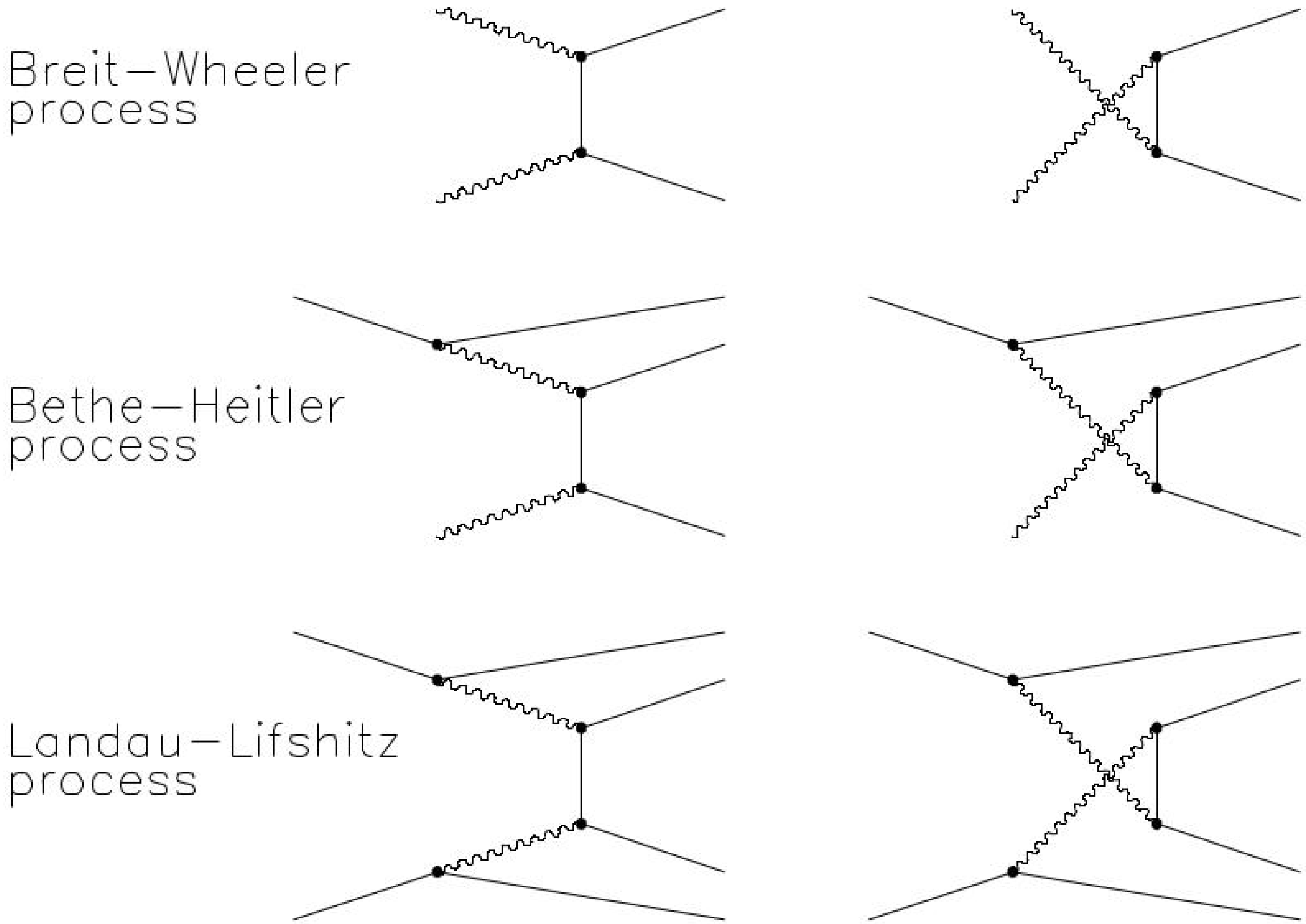
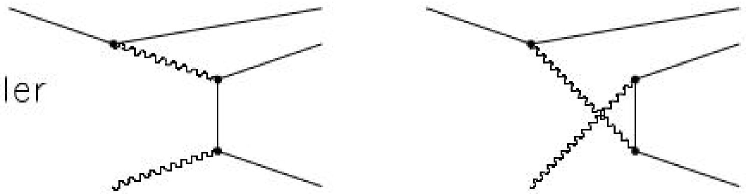
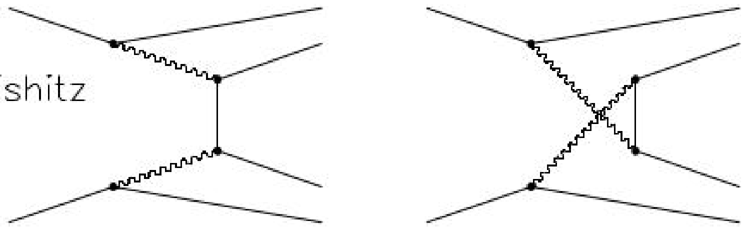


Figure 4.1: The incoherent pair production processes.

TESLA-Report 1997-08 by Daniel Schulte(Authro of Gpig)

Analytical cross section for three processes

- BW: determined by the two real photons from beamstrahlung
- BH: determined by one real photon from beamstrahlung and one electron/positron(120 GeV for higgs mode)
- LL: determined by the electron-positron pair(120 GeV for higgs mode)

Process	Cross section
Breit–Wheeler process 	$\sigma_{BW} = \frac{2\pi r_e^2 m^2}{s}\left[\left(2+\frac{2}{\gamma^2}-\frac{1}{\gamma^4}\right)\ln\frac{1+\beta}{1-\beta}-\left(2+\frac{2}{\gamma^2}\right)\beta\right].$
Bethe–Heitler process 	$\sigma_{BH} = \frac{28\alpha r_e^2}{9}\left(\ln\frac{s}{m^2}-\frac{109}{42}\right)$
Landau–Lifshitz process 	$\sigma_{LL} = \frac{\alpha^2 r_e^2}{\pi}\left(\frac{28}{27}\ln^3\frac{s}{m^2}-6.59\ln^2\frac{s}{m^2}-11.8\ln\frac{s}{m^2}+104\right)$

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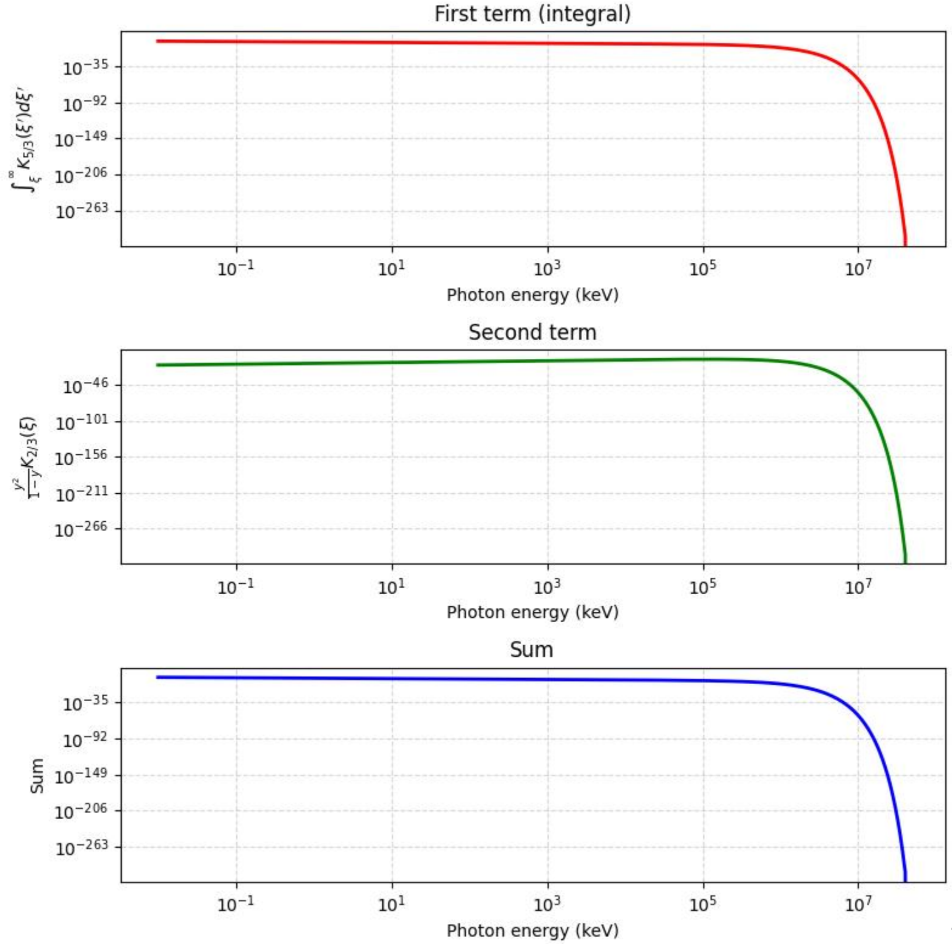
Sokolov-Ternov formula for beamstrahlung

- Real photons from beamstrahlung: Sokolov-Ternov formula(**ST**) for photon energy spectrum
- E: electron energy; ω: photon energy
- x=(ω/ωc)×E/(E-ħω)
- ωc: critical energy (beam property)
  - ωc=3/2×γ^{3}c/ρ; ρ: bending radius of the particle
  - Simulation: calculate the ρ based on EM
  - Analytical: ϒ=2/3×ħωc/E; $\langle \Upsilon \rangle = \frac{5}{6} \frac{N r_e^2 \gamma}{\alpha(\sigma_x + \sigma_y)\sigma_z}$
- The first integral term dominant
- σBW final = ∫σBW×ST 1×ST2 dω1dω2
- σBH final = ∫σBH×ST dω
- σLL final = σLL

The spectrum of the emitted photons is given by the Sokolov-Ternov formula [14]:

$$\frac{\mathrm{d}\dot{w}}{\mathrm{d}\omega} = \frac{\alpha}{\sqrt{3}\pi\gamma^2}\left[\int_x^\infty \mathrm{K}_{\frac{5}{3}}(x')\mathrm{d}x' + \frac{\hbar\omega}{E}\frac{\hbar\omega}{E-\hbar\omega}\mathrm{K}_{\frac{2}{3}}(x)\right] \tag{2.9}$$



Final cross section

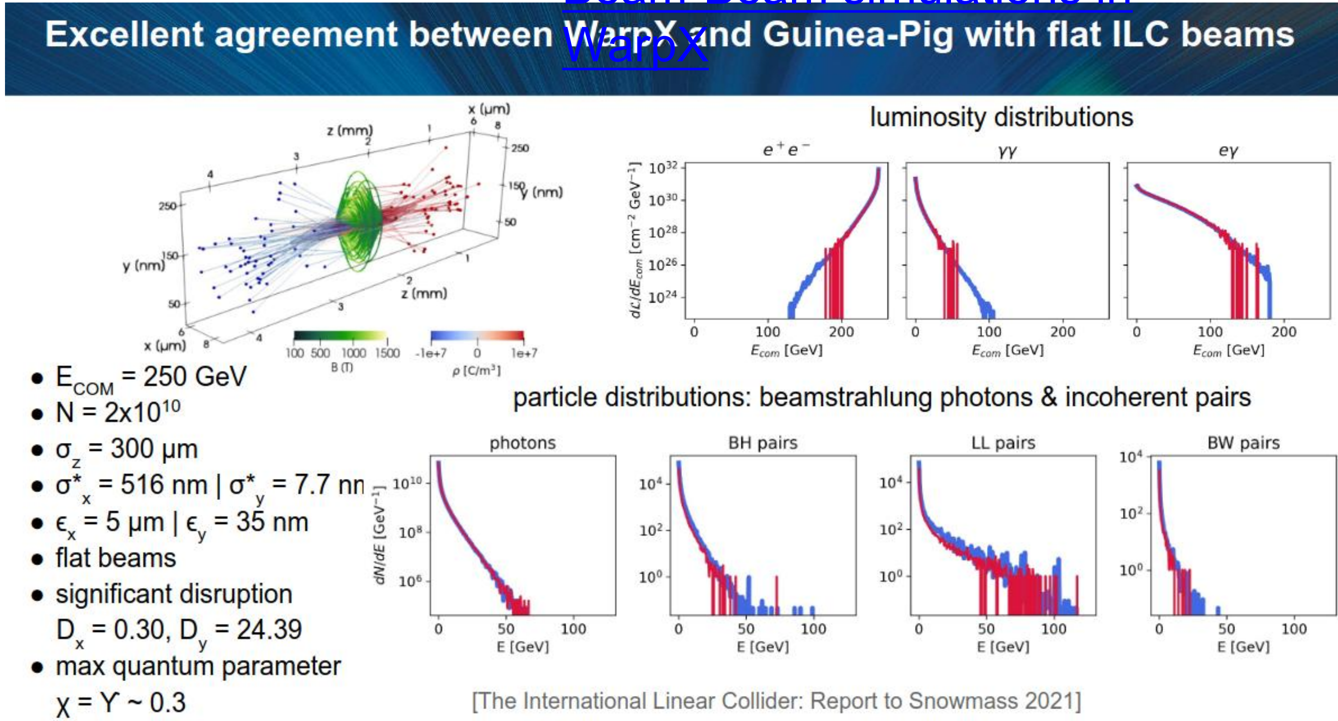
- LL depends only on the beam energy
  - Dominant term
  - Monotonic increasing(very slow)
- BH/BW depends on the beam property
- σLL>σBH>σBW
- Analytical vs simulation:
- LL: analytical ~ simulation
- BH: analytical > simulation
- BW: analytical >> simulation
- CEPC Sum: analytical: 31.7mb; GPig: 20.7
- The difference between the simulation and analytical results for BH and BW may come from their different treatments of the ST formula
  - Next: Compare the real photon energy spectrum between GPig and analytical

	Analytical			GPig			BDK
Xsec	LL(mb)	BH(mb)	BW(mb)	LL(mb)	BH(mb)	BW(mb)	LL(mb)
CEPC (240 GeV)	18.5	9.3	3.9	16.1	4.3	0.31	?
LEP1 (91 GeV)	14.3	0.42	0.0029	15.2	0.38	0.00066	12
LEP2 (208 GeV)	17.9	1.8	0.33	18.5	1.6	0.072	13.5

Next: WarpX

[Beam-Beam simulations in WarpX]

- GPig: no active maintenance
- [WarpX]: an advanced open-source Particle-In-Cell code
  - Multi-physics packages (incl. ionization, atomic, fusion and collisional physics, as well as quantum electrodynamics)
  - Developed by an international multidisciplinary team
  - May be used also for FCC in future



Next: LEP open data

- One LEP(L3) paper measures the cross section for the ee→eeee
  - BDK for generator(only for LL); LL>>BH/BW
  - σLL total = 5×10^6×σLL measure

	Analytical			GPig			BDK
Xsec	LL(mb)	BH(mb)	BW(mb)	LL(mb)	BH(mb)	BW(mb)	LL(mb)
CEPC (240 GeV)	18.5	9.3	3.9	16.1	4.3	0.31	?
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- Try LEP open data
  - To compare the cross section and momentum/angular distribution
  - GPig is a tool for beam collision, not for one electron/positron pair collision
  - Need to modify the source code

ELSEVIER

4 September 1997

PHYSICS LETTERS B

Physics Letters B 407 (1997) 341–350

Production of e, μ and τ pairs in untagged two-photon collisions at LEP

L3 Collaboration

6. Results

The observed numbers of events in the different channels are given in Table 3, together with the predictions of the BDK Monte Carlo generator, including the effects of acceptance and trigger efficiency. The first quoted error on the observed number of events is statistical, the second is systematic. The errors quoted on the predictions are the Monte Carlo statistical errors. In all cases, good agreement is found between the data and the BDK predictions.

The data are then corrected for the detection efficiency and normalized to the integrated luminosity, in order to measure cross sections which can be compared with the QED calculations. For the $e^+e^- \to e^+e^-e^+e^-$ and $e^+e^- \to e^+e^-\mu^+\mu^-$ channels, the comparison is given for the angular range ($44° \leqslant \theta \leqslant 136°$) and for $W_{\gamma\gamma} \geqslant 500$ MeV. For the reaction $e^+e^- \to e^+e^-e^+e^-$, we find

$$\sigma_{\rm data} = 2.56 \pm 0.01\ ({\rm stat.}) \pm 0.05\ ({\rm syst.})\ {\rm nb}$$

to be compared with

$$\sigma_{\rm QED} = 2.57 \pm 0.02\ ({\rm stat.})\ {\rm nb.}$$

Summary

- Compare the analytical and simulation results
  - LL is fine; BH (BW): analytical > (>>)simulation
- Next to do:
  - Compare the real photon distribution for simulation and Gpig
  - Try WarpX
  - Compare with LEP2 data

Backup

Simulation result

- Number of event(electron/positron pair) and Lumi per bunch
- LL>BH>BW
- N = σ×Lumi

	GPig			
Nevent	LL	BH	BW	lumi(m^{-2})
CEPC	876	235	16.8	5.5E32
LEP1	3.87	0.095	0.00017	2.5E30
LEP2	45	3.9	0.17	2.4E31