HI JENA
Helmholtz Institute Jena

ICS Simulations

Daniel Seipt
d.seipt@hi-jena.gsi.de

Helmholtz Institute Jena

April 6th, 2021

Introduction

- ICS as alternative option for γ-laser collisions: Narrow bandwidth gives better knowledge of initial state of NBW process $\Rightarrow$ better reconstruction of the strong-field QED interaction
- Need $\chi_\gamma = \frac{1.95\omega\omega_L}{m^2}\xi \sim 1$, thus photon energy $\omega \approx 9\ldots10$ GeV
- Frequency tripled/doubled laser for ICS
- Requires bigger laser $\Rightarrow$ can only be operated in phase-1

$\Rightarrow$ Timescale for important decisions and precise physics simulations?

- At least basic design decisions need to be made until TDR

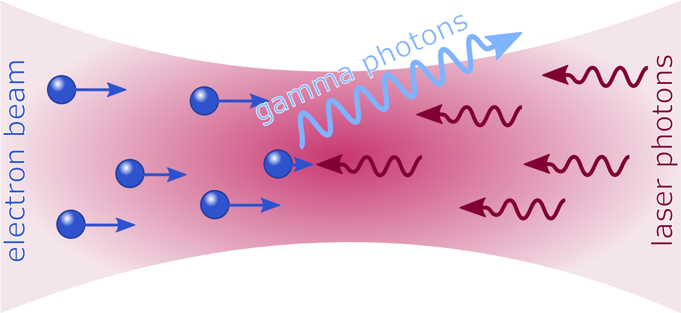
Characteristics of ICS

What are the most important characteristics of the ICS for LUXE?
What is the needed level of accuracy in the simulations?
What needs to be precisely simulated?
What can be estimated/modeled?

- ICS simulations need to provide a gamma-photon-beam which can be used in the IP physics simulations to predict the e^+e^- yields and spectra
- Overlap between gamma-beam and strong-IP laser is essential to get positron yield correct.
- Narrow bandwidth
- Timing and temporal duration of the gamma beam
- Angular distribution: Strong-field IP aperture ($\sim 10^{-6}$) much smaller than $1/\gamma$, thus near on-axis spectrum is what matters most

HI JENA
Helmholtz Institute Jena

Principle of ICS



parameter	value
ω_L	4.65 eV
γ	32290
ξ	< 0.1
η	0.588
$\gamma\theta$	< 0.1
ω	≈ 9 GeV

$$\omega \approx \frac{4\gamma^2\omega_L}{1 + \frac{\xi^2}{2} + \gamma^2\theta^2 + 2\eta}, \qquad \eta \approx \frac{2\gamma\omega_L}{m}$$

HI JENA
Helmholtz Institute Jena

ICS Bandwidth

$$\left(\frac{\Delta\omega}{\omega}\right)^2 = \left(\frac{\Delta\omega_L}{\omega_L}\right)^2 + \left(\frac{\xi^2}{2}\right)^2 + \left(2\frac{\Delta\gamma}{\gamma}\right)^2 + \left(\frac{\gamma^2\Delta\theta_e^2}{4}\right)^2 + (\lceil N_{sc} - 1\rceil\eta)^2 + \dots$$

- Ti:Sa laser 60 nm FWHM bandwidth @ 800 nm: 1×10^{-3}
- $\xi < 0.1$: 2.5×10^{-5}
- $\Delta\gamma/\gamma = 0.1\%$: 4×10^{-6}
- Projected normalized emittance 1.4 mm mrad: 4×10^{-4}
- Number of scatters $N_{sc} = \text{rate} \times \text{pulse duration} < 1$: ≈ 0
- LMA = local monochromatic approximation ⇒ does not correctly describe the laser bandwidth contribution

Photon Beam Timing

- Photon bunch duration determined by ebeam duration: 80 fs
- Why? Laser frequency is Doppler upshifted. Number of electric field oscillations is conserved.
- Thus, pulse duration is Doppler contracted by about $1/4\gamma^2$ for a single electron.
- Assume laser pulse duration of 1 ps, $\gamma \sim 30000 \Rightarrow T < 10^{-22}$ s < 1 zs

Various Levels of Complexity

- ebeam (realistic 6d phase space distribution) + realistic 3d focused laser pulse
- ebeam (Gaussian 6d phase space distribution) + gaussian 3d focused laser pulse

...

- ebeam energy spread/emittance/$\perp$ dist + gaussian 3d focus

...

- 1d temporal electron distribution + plane wave
- single particle + plane wave

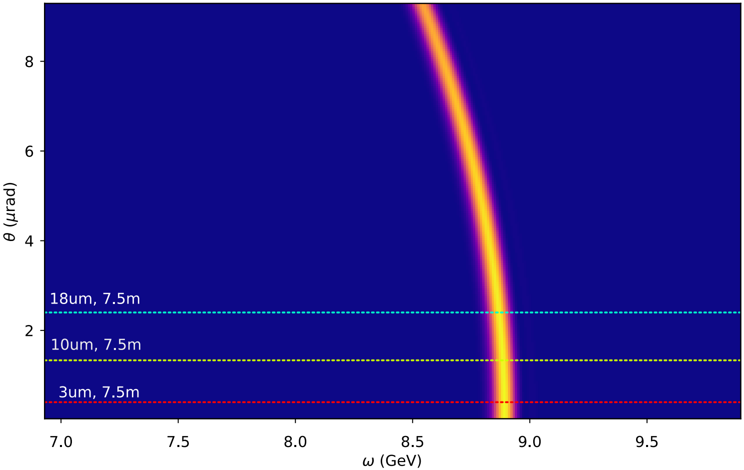
HI JENA
Helmholtz Institute Jena

Simulation Options

Simulation method	recoil	CP/LP	laser focus	ready?
QED matrix element	yes	CP/LP	no	yes
PTARMIGAN/LMA	yes	CP only	yes	yes
Inverse Thomson	**no**	CP/LP	yes	yes
Quasi-classical radiation	yes	CP/LP	yes	devel needed

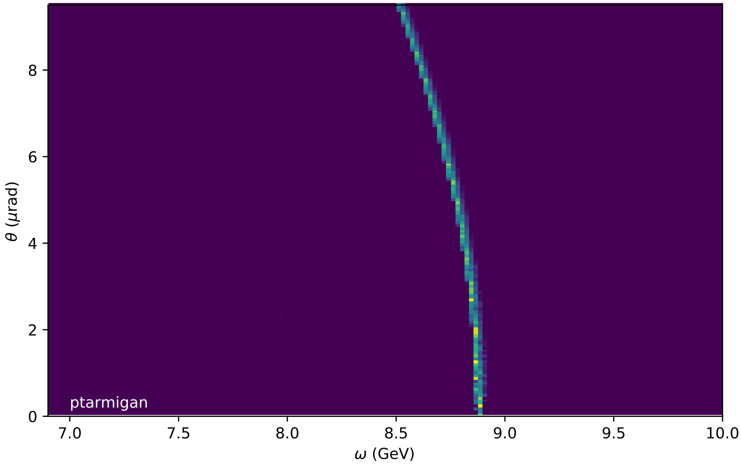
HI JENA
Helmholtz Institute Jena

www.hi-jena.de



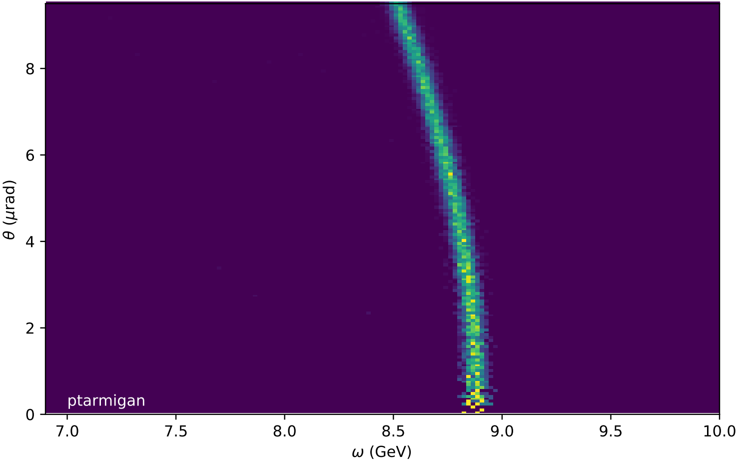
$$1/\gamma \approx 31\mu rad$$

Energy-Angular Spectrum (PTARMIGAN/LMA)



$$1/\gamma \approx 31 \mu rad$$

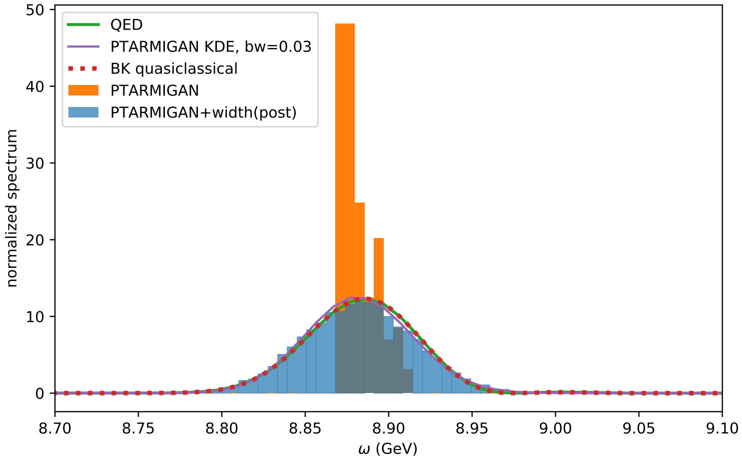
Energy-Angular Spectrum (PTARMIGAN/LMA) + Spectral Width



$$1/\gamma \approx 31\mu rad$$

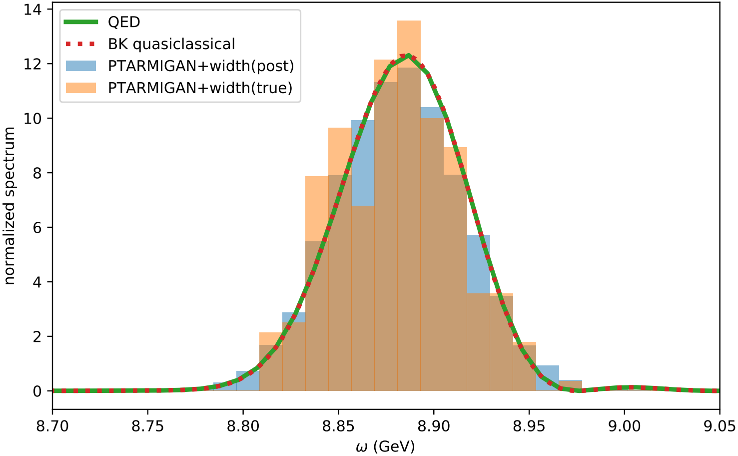
HI JENA
Helmholtz Institute Jena

Comparison of Simulations (Plane Wave)



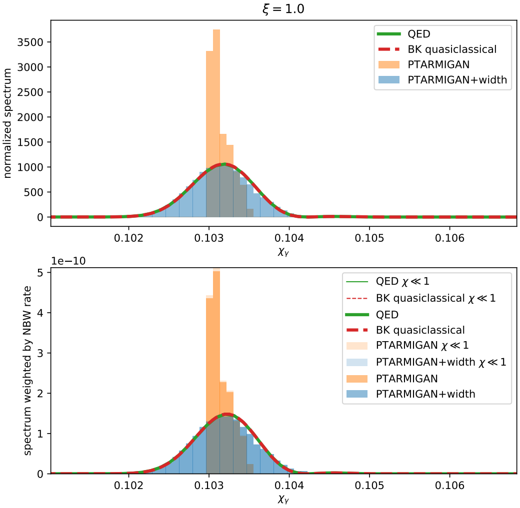
HI JENA
Helmholtz Institute Jena

Comparison of Simulations (Plane Wave)



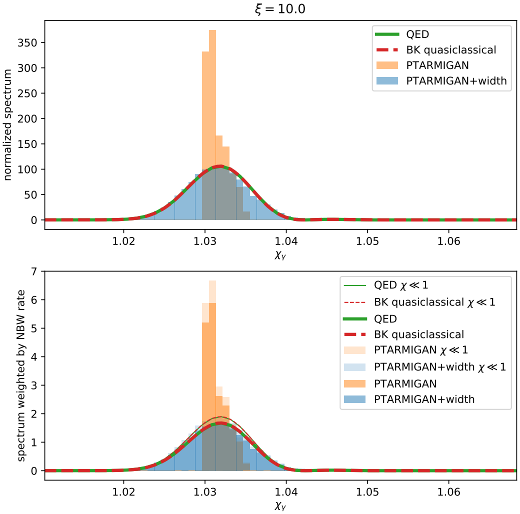
HI JENA
Helmholtz Institute Jena

Photon Spectra Weighted by Pair Production Rate ($\xi = 1$) up to 1 μrad



HI JENA
Helmholtz Institute Jena

Photon Spectra Weighted by Pair Production Rate ($\xi = 10$) up to 1 μrad



HI JENA
Helmholtz Institute Jena

www.hi-jena.de

MISC

- QED and quasiclassical codes calculate spectrum,
- Sample randomly from spectrum to generate photon-beam
- Photon-beam time structure by sampling from spectrum with temporal delay distribution of ebeam

Simulation Plan: PTARMIGAN + QuasiClassical

ICS1: Use PTARMIGAN-CP to generate gamma-photon beams; IP physics simulations of ICS-NBW and tracking of pairs (spring 2021)

ICS2: Some optimiaztion of the ICS in terms of pulse-duration vs. peak intensity (late spring/early summer 2021)

ICS3: Implement limited capacity LP (up to $\xi = 0.1$) into PTARMIGAN (worth it?)

ICS4: Develop quasi-classical ICS simulation code (Baier-Katkov-method, summer/fall 2021)

ICS5: Include gamma-photon polarization (QCBK/PTARMIGAN, 2022)

Notes:

1. ICS sims not independent of PTARMIGAN development plan: Full LP not before 2022
2. Output file format for ICS sims: Mimic PTARMIGAN format for all used codes