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ICS Simulations Update

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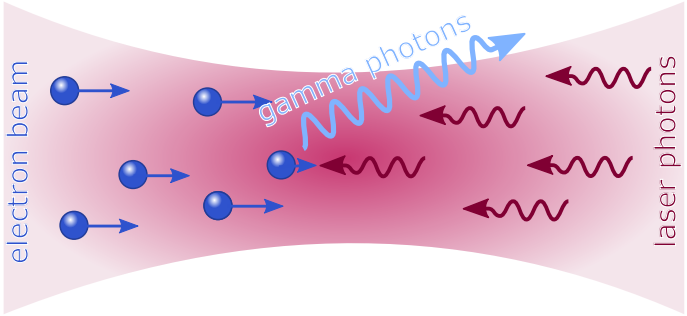
Principle of ICS



parameter	value
ω_L	4.1 eV*
γ	32290
ξ	< 0.1
η	0.518
$\gamma\theta$	$\ll 0.1$
ω	≈ 8.4 GeV

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

* frequency is tripling more efficient at 900 nm, https://indico.desy.de/event/29720/ talk by M. Zepf

ICS Bandwidth

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

- 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}~~ → larger, # incorrect in estimate
- Number of scatters $N_{sc} = \text{rate} \times \text{pulse duration} < 1$: ≈ 0

Curatolo et al,PRAB 20, 080701 (2017)

Simulation Code

Input:

Ebeam: energy spread, emittance, finite size in x, y, z: **Uncorrelated** phase space

Laser: finite transverse size w_0 but with ∞ Rayleigh range, finite pulse duration

Sim:

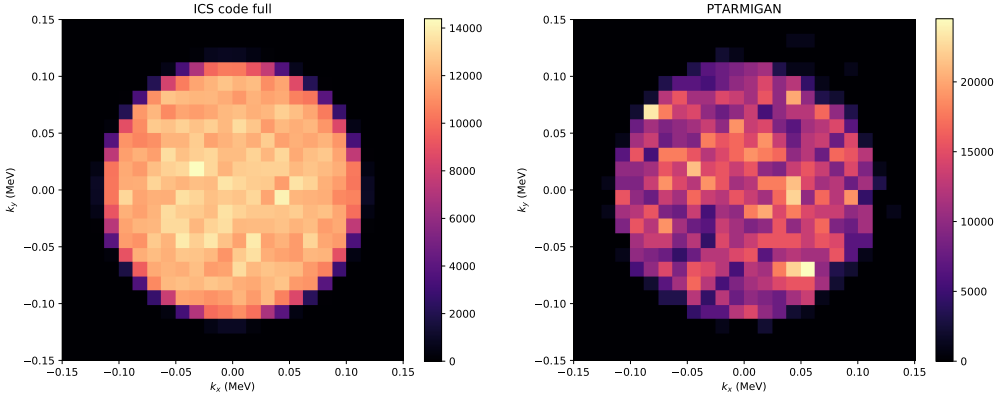
- Determine photon emission probability from (modified) Klein-Nishina cross section
- Spectral shape $\sim$ Fourier transformed temporal pulse duration
- ξ-effects are estimated ($\xi < 0.1$)
- Monte Carlo rejection sampling to generate (macro)photons

Output:

γ-rays: (position, momentum weight) of generated photons in user specified energy range and up to maximum angle

electrons: (position, momentum weight) of electrons that emitted a photon

Benchmark with PTARMIGAN: $\perp$ momentum dist



$$\theta_{\max} = 15\,\mu\text{rad} \Rightarrow \max(k_\perp) \approx 120\ \text{keV}$$

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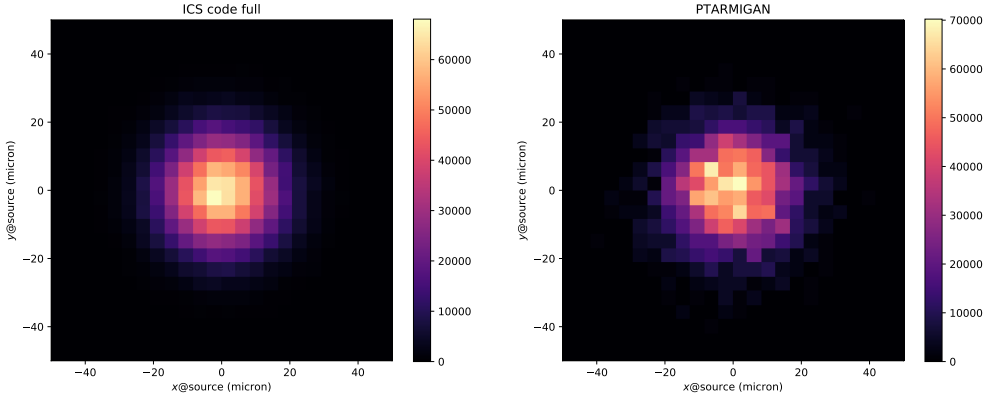
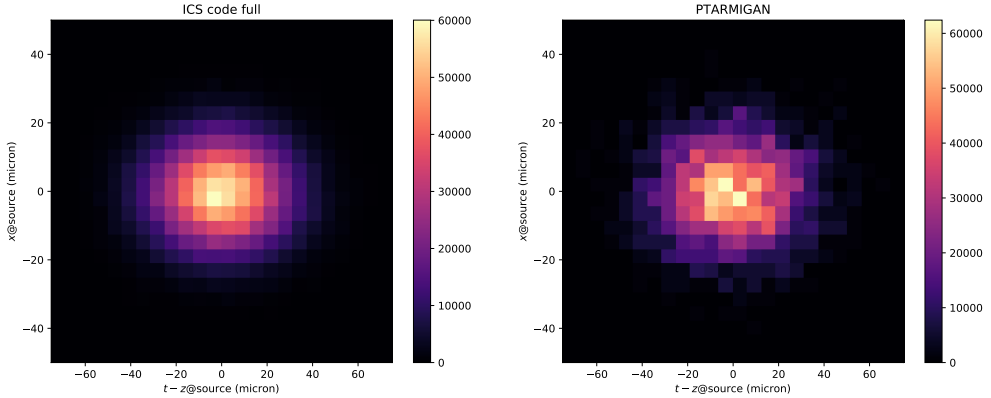
Benchmark with PTARMIGAN: $\perp$ source dist



Benchmark with PTARMIGAN: ‖ source dist



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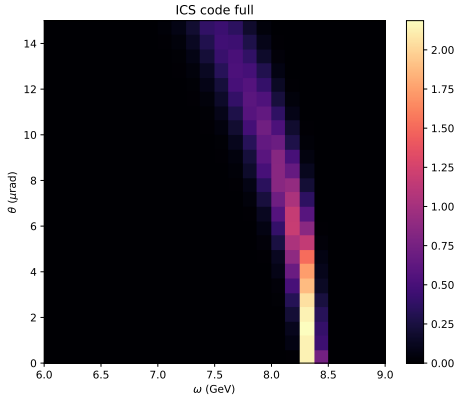
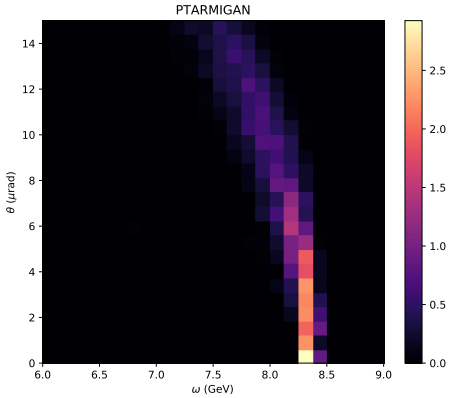
Benchmark with PTARMIGAN: Energy-angle spectrum





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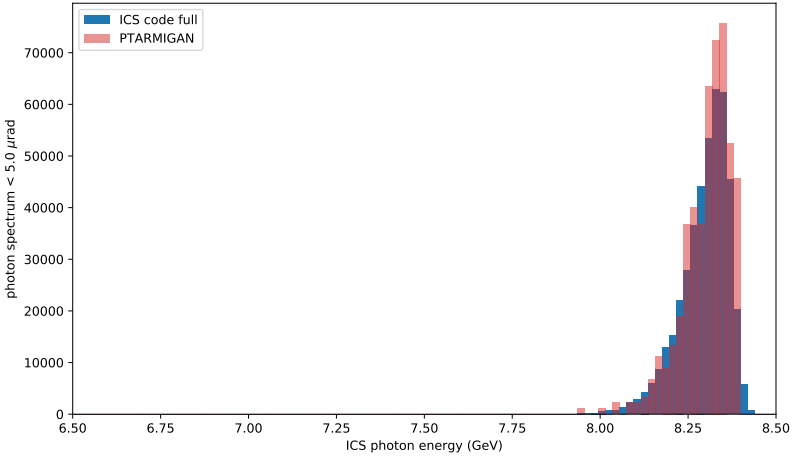
Benchmark with PTARMIGAN: Photonspectrum at IP focus



Benchmark with PTARMIGAN: Photons at IP focus

```
ICS code max mean photon weight          : 3.147
total photon weight                      : 3.1e+05
-------------------------------------------------
PTARMIGAN mean single photon weight      : 111.5
total photon weight                      : 3.174e+05
-------------------------------------------------
photon weight ratio PTARMIGAN/ICS        : 1.024
=================================================
IP-laser spot size: 15.00 micron
baseline          : 7.50 metres
-------------------------------------------------
ICS code, photon weight in spot, zero source size: 7342.24
-------------------------------------------------
PTARMIGAN, photon weight in spot, zero source size: 7913.34
-------------------------------------------------
photon weight ratio PTARMIGAN/ICS : 1.0777
```

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3 Testbeam Simulations

Simulation results for the three testbeams in my public folder on DESY-cluster:
`/afs/desy.de/user/s/seiptdan/public/testbeams`

Params: $\xi = 0.1$, $T_{\mathrm{FWHM}} = 1$ ps, 100 pC beam charge, emittance 1.5 mm mrad

`huge_testbeam.h5`: $w_0 = \sigma_T = 5$ µm
`large_testbeam.h5`: $w_0 = \sigma_T = 25$ µm
`small_testbeam.h5`: $w_0 = \sigma_T = 60$ µm

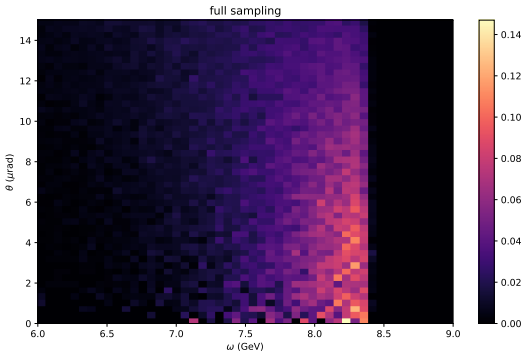
Output file format like PTARMIGAN

```
f['config/input-file']
f['final-state/photon/momentum']
f['final-state/photon/position']
f['final-state/photon/weight']
```

Standard units: [momentum] = eV, [position] = micron, [weight] = 1

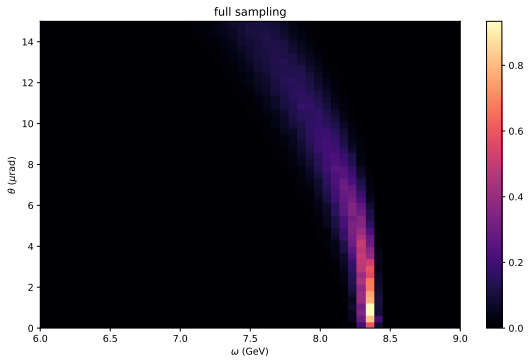
Photon Spectra

small beam



$\theta_e \sim 9.6\,\mu\text{rad}$

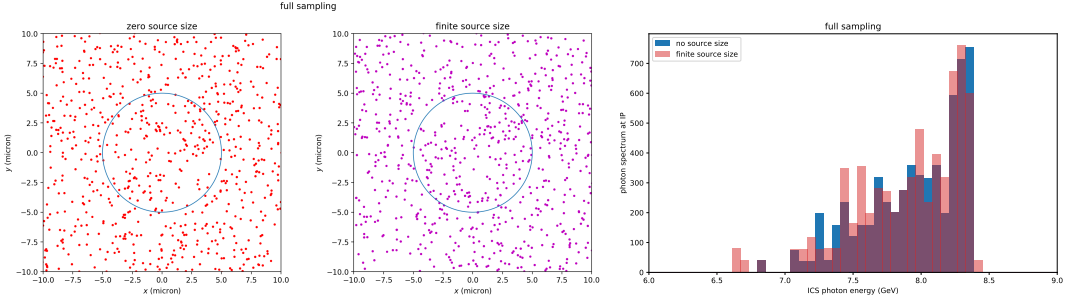
large beam



$\theta_e \sim 1.9\,\mu\text{rad}$

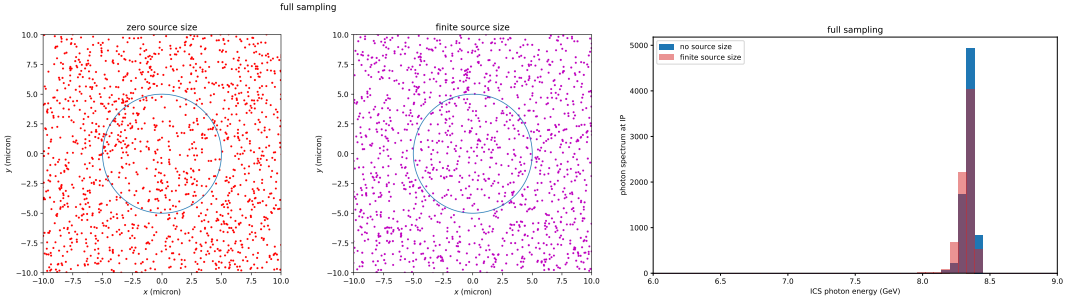
Note: 5 µm IP focus at 7.5 m baseline: $\theta \lesssim 1\,\mu\text{rad}$

Small Testbeam ($w_0 = \sigma_T = 5\,\mu\text{m}$)




```
IP spot size 5 um,
photons at IP, zero   source size        : 5918.76
photons at IP, finite source size        : 6606.77
```

Large Testbeam ($w_0 = \sigma_T = 25\,\mu\text{m}$)




```
IP spot size 5 um,
photons at IP, zero   source size        : 7772.97
photons at IP, finite source size        : 7637.78
```

This case has $(w_{0,large}/w_{0,small})^2 = 25\times$ more laser energy

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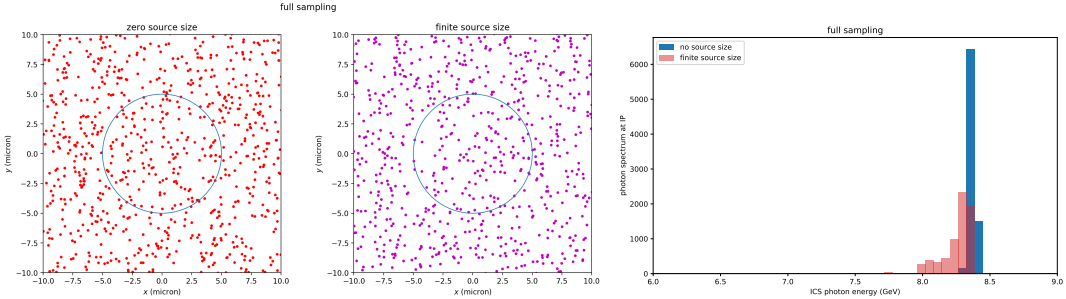
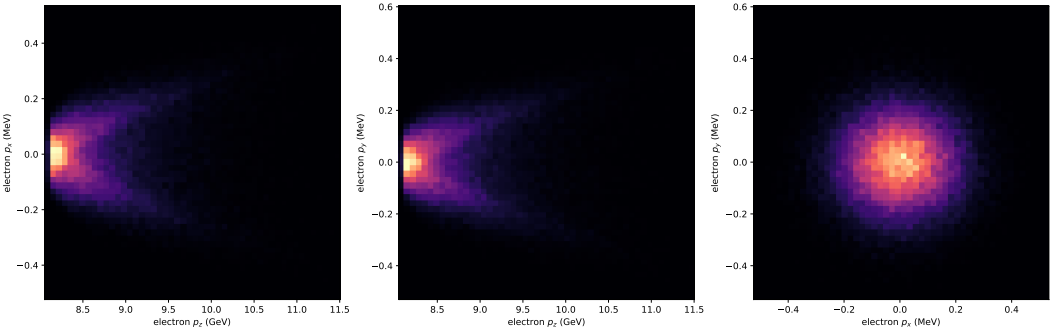
Huge Testbeam ($w_0 = \sigma_T = 60\,\mu\text{m}$)



IP spot size 5 um,
photon weight, zero source size : 8111.78
photon weight, finite source size : 6776.13

Electron Spectra (Small Testbeam)




```
...
f['final-state/electron/momentum']
...
```

Summary & Outlook

- We have a working ICS code that has been benchmarked against PTARMIGAN
- Testbeam simulation results available for further processing: BW pairs, background, ...
  `/afs/desy.de/user/s/seiptdan/public/testbeams`
- Further developments:
  - Correlated electron beam phase space: Ebeam focused to strong-field IP
  - Linear laser polarization
  - Include finite Rayleigh range? Probably not necessary ...
  - Extend to larger $\xi > 0.1$ (using Quasi-Classical Baier-Katkov method)? Probably not necessary ...

Updated ICS Simulation Plan

ICS1: Use PTARMIGAN-CP to generate gamma-photon beams; Development and benchmark of ICS simulation code ☑

ICS1*: IP physics simulations of ICS-NBW and tracking of pairs, background sims (spring 2021)

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

ICS3: Implement LP

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

ICS5: Include gamma-photon polarization (2022?)