Snowmass Advanced Polarized Positron Source Discussion

P. Musumeci

January, 20th 2022 – Future US Collider workshop

Snowmass polarized positron workshop: last week of Feb. , 3 hrs 5-8 am pacific time

Topics: ILC polarized positron plans, advanced concepts for polarized positron sources

Organizers: P. Musumeci, G. Moortgat-Pick, A. Lankford, K. Yokoya, A. Faus-Golfe

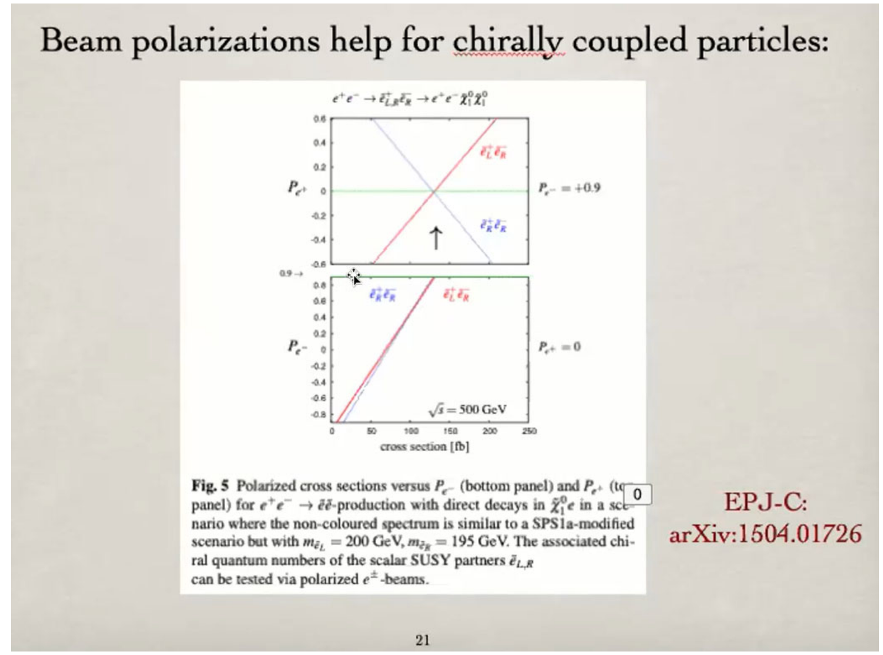
Motivations for polarized positrons

References:

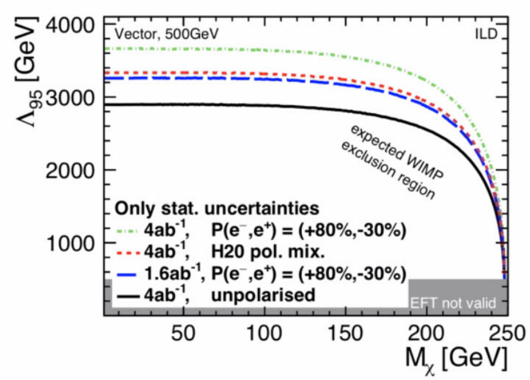
T. Han - Snowmass Agora Dec 15th

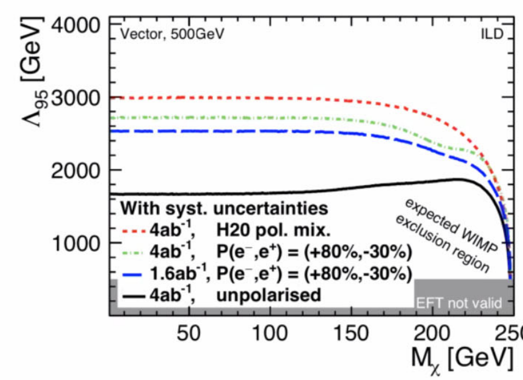
F. Dietrich et al. arXiv:1902.07744

ILC Snowmass report. Chapter 5

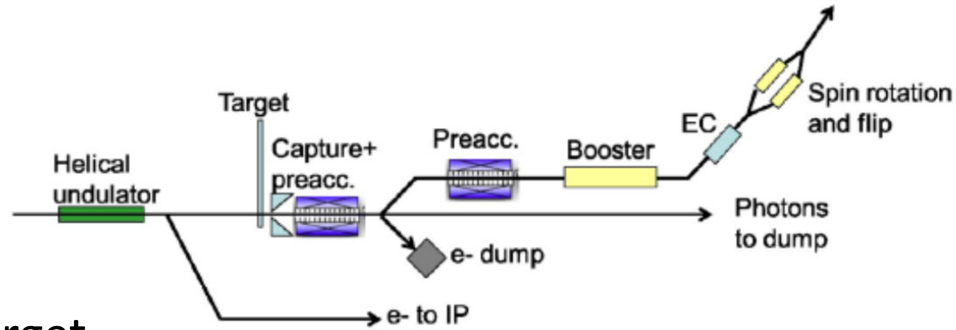


- Effective increase in luminosity with the correct helicity of both beams
- Decrease in background
- Uncover new BSM chiral physics





ILC polarized positron source

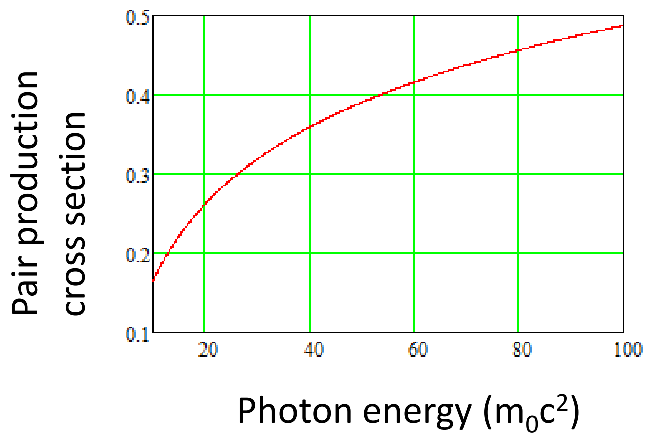


- 231 m SC undulator with period 1.15 cm
- 125 GeV e-beam -> 7 MeV photons
- 1 mm transverse spot size on 0.2 X_0 Ti-alloy target
- 100 m/s 50 cm radius rotating wheel to distribute incident power
- High field flux concentrator
- 1.5 e+/e- yield
- 30 % polarized beams

- Alternative conventional source in preparation based on 3 GeV e-beam on 3 X_0 W target
  - If source is independent, the format of positron bunch train has some freedom exploiting the damping ring to reshape the temporal structure (Omori et al.)

Some issues with current design

- Very long, small gap superconducting undulator (230 m). Need to limit energy deposition.
- As CoM energy drops the undulator needs to get longer and the photon energy suffers (@125 GeV, 1.1 cm -> 7 MeV photons)
- Angular divergence is very small and this complicates the design of the target (1 mm spot size)
- Not-independent source: requires yield e+/e- to be larger than 1 since 125 GeV bunch is the main collider beam.

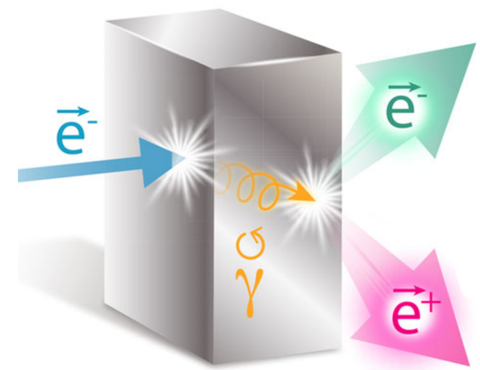


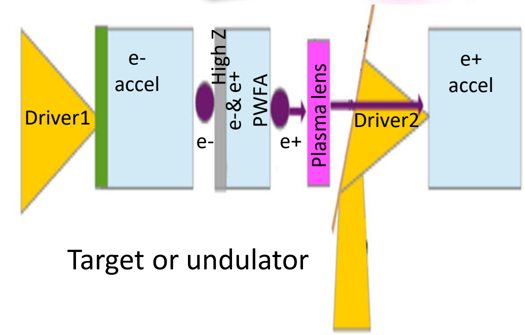
Advanced accelerator technology for polarized positron sources

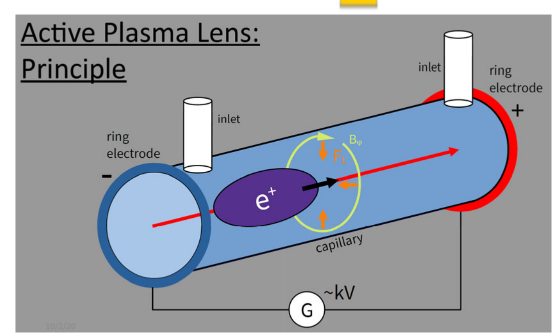
- Motivation for R&D on this topic – Snowmass white paper to be submitted
  - Complement the more mature ILC pre-lab design efforts
  - Increase flux, increase polarization, match compact collider format

- Laser-based undulator. Inverse Compton Scattering for PPP originally proposed in 90's. (Snowmass LOI AF6-079. Murokh et al.)
- PEPPO scheme – JLAB. PRL 116,214801 (2016)
- Alternative applications of low-energy polarized positrons

- SC-undulators (Interest from US National labs, ANL, LBNL)
- Advanced targets (FNAL)
- FCC-ee SC solenoids as flux concentrator. PSI
- Plasma-lens for positron capture. High field for increasing collection

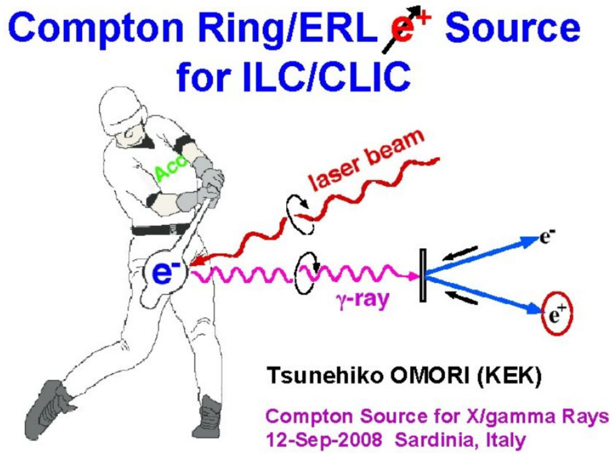






An Inverse-Compton-Scattering-based circularly polarized gamma ray source for positron production

- High photon energy (1 GeV + 515 nm) -> 34 MeV
  - Increase in yield and final polarization
- Larger spot size at the target as angular divergence is 125 times $\theta_{undulator}$ and for example it can be expanded to 5 mm at 10 m distance
- Number of initial e- is independent of number of positrons. Can be much larger than collision beam.

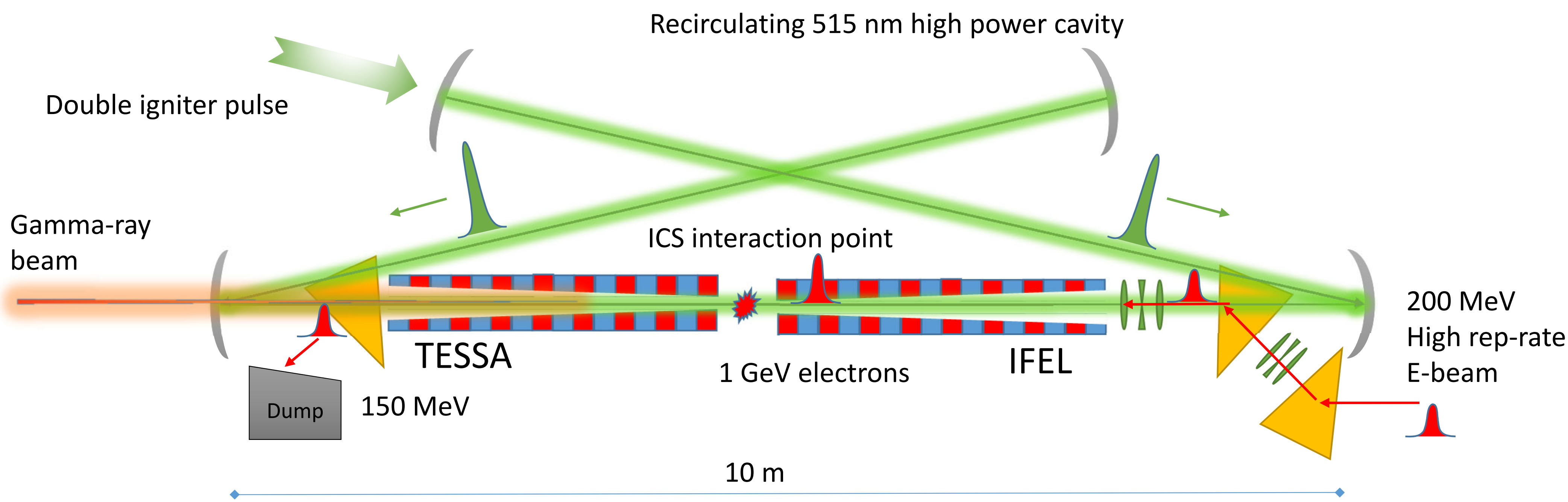


- Smaller number of circularly polarized photons per electron from ICS interaction. (Typically ~ 1 vs. undulator yield of 300 γ/e-)
- Where do we get MW-class laser system for ICS collisions ?

❖ Key observation: Due to small cross section, most of laser and e-beam energy remain in beams after ICS interaction

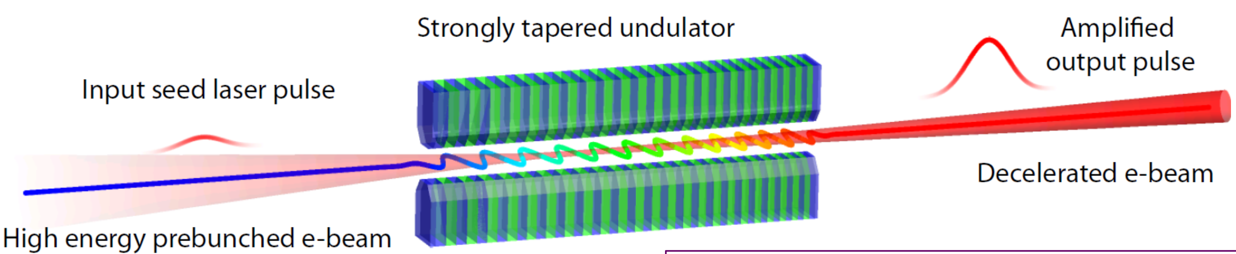
Solution: laser energy recirculator

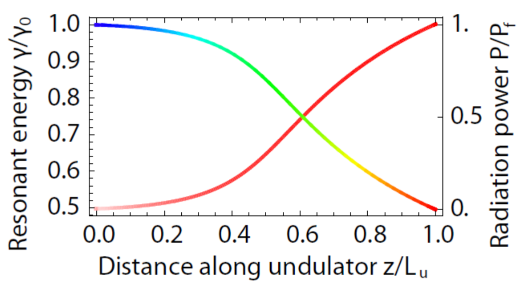
- Use high power laser + IFEL to boost energy from SRF linac to 1 GeV
- ICS collisions to generate gamma-ray photons
- Reversing the acceleration process, laser energy is replenished + some extra to compensate for losses in cavity
- Repeat as many times as necessary (main limit is optical power in the cavity)



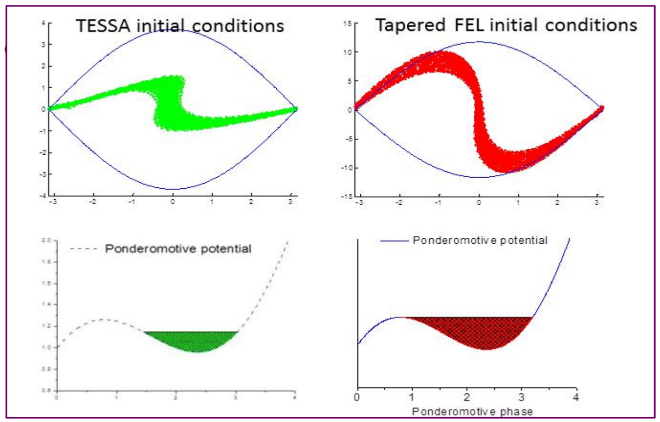
TESSA: Tapering Enhanced Stimulated Superradiant Amplification

- Reversing the laser-acceleration process, we can extract a large fraction of the energy from an electron beam provided:
  - A high current, microbunched input e-beam
  - An **intense input seed**
  - High gain regime: strong tapering matches decelerating gradient to growing radiation field amplitude





J. Duris et al. New Journal of Physics, 17 (2015)



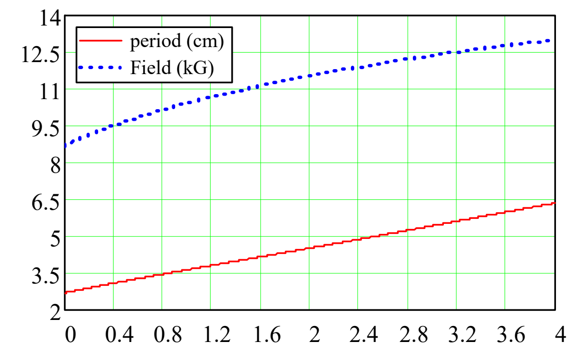
- ❖ Essentially a tapered FEL with favorable initial conditions
- ❖ Initial experiments @ 10 um showed 35 % energy conversion at 10 um. N. Sudar et al. PRL, 117, 174801 (2016)
- ❖ Exploring combination of the TESSA concept with high-rep rate SC linac (FNAL – FASTGREENS)

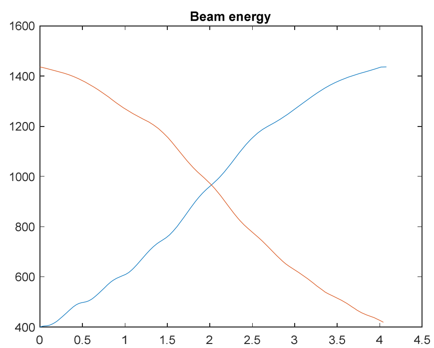
Laser-energy recovery

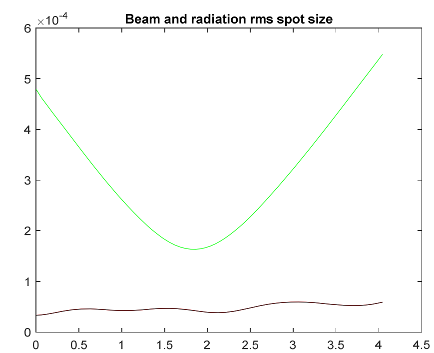
- Assuming 4 m of tapered helical undulator with an average K = 5.0, the minimum power required to go from 200 MeV to 1 GeV is 5 TW (assuming refocusing optics)
- 6 J -> 1.2 ps bunch length. Adding 0.15 J per pass from additional TESSA deceleration
- Self-consistent 3D Genesis simulations

$$P_{IFEL3D} := 0.1 \cdot \frac{1}{K_{ave}^{2}} \cdot 693 \cdot MW \cdot \Delta\gamma 2^{2} \cdot \frac{\lambda}{L_u} = 4.837 \cdot TW$$

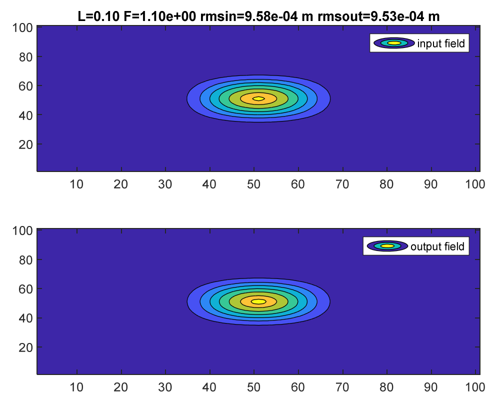
Duris, J. P., P. Musumeci, and R. K. Li. "Inverse free electron laser accelerator for advanced light sources." *Physical Review Special Topics-Accelerators and Beams* 15.6 (2012): 061301.



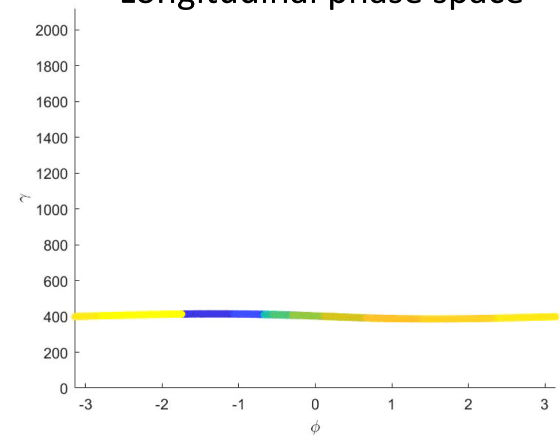




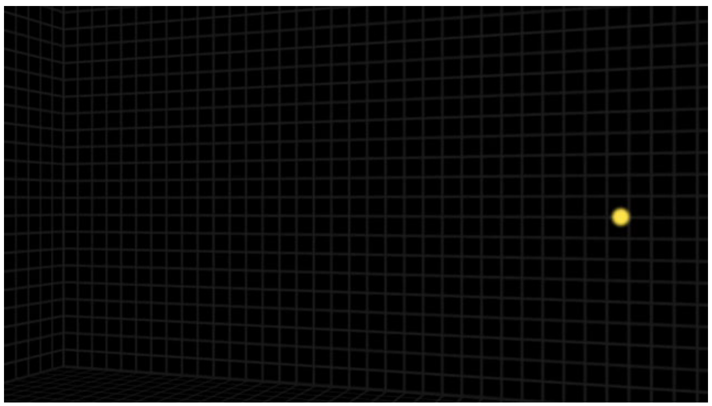
Laser profile IFEL and TESSA sections



Longitudinal phase space

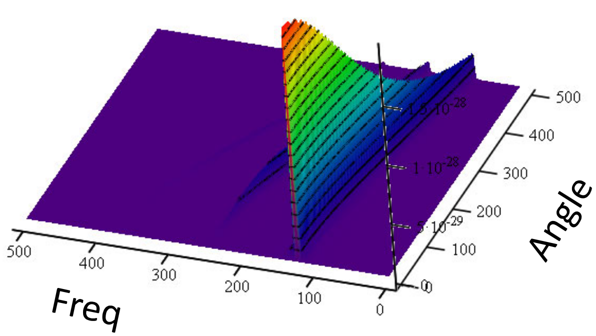


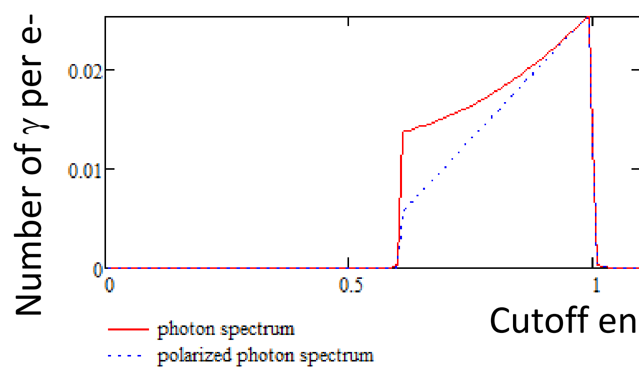
Some parameters: ICS interaction



Ebeam energy	1 GeV
Ebeam/laser pulse duration	1.2 ps
Ebeam charge	3.2 nC
Laser wavelength	515 nm
Laser energy	6 J
Laser spot size (1/e2)	10 um
E-beam spot size (rms)	5 um
Integrated photon yield	0.8 γ/e-

Double-differential spectrum



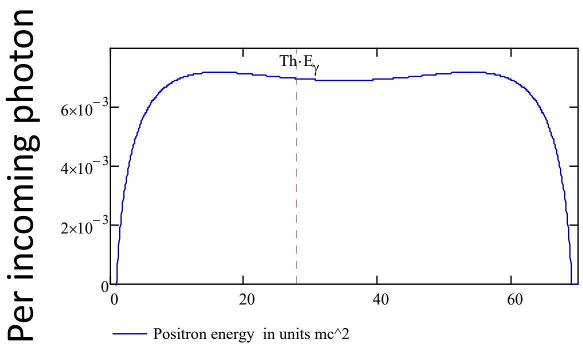


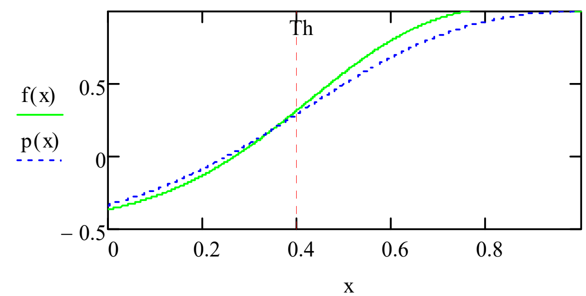
Angular cutoff 0.5 mrad

Cutoff energy for ICS: 35 MeV

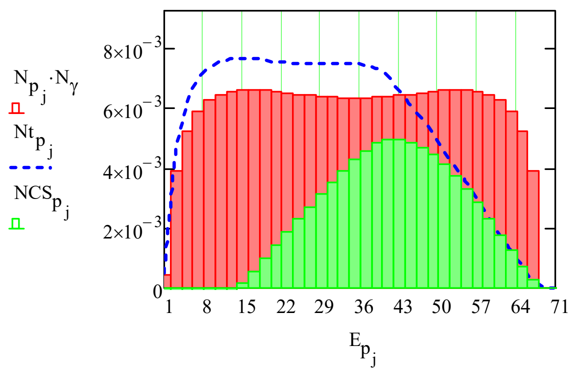
Polarized positron generation

- Pair production cross-section *Motz, Olsen, Kock, RMP 41 581 (1969)*
  - Consider 0.8 rad length thick target (3 mm for tungsten)
- Polarization of positrons vs. cut-off energy (x = 1 -> 34 MeV)
  - Michailichenko - *LC02, Proceedings, SLAC-WP-21*.
  - Olsen and Maximon - *Physical Review* 114.3 (1959): 887.





Using actual photon spectrum from ICS source



Assume a capture threshold at 14 MeV
0.1 polarized e+ per incoming e-
0.14 total e+ per e-
Polarization 0.7 (neglecting depolarization in target)

Polarized positron flux

- $2 \cdot 10^{14}$ e+/s are required by ILC
- Start with $2 \cdot 10^{15}$ e-/s or 320 μA average current
- Can be packaged/divided in different time-format depending on damping ring and optical recirculation cavity. For the sake of discussion let us consider a 100 KHz repetition rate (9 MHz bursts with 0.011 duty cycle)
- Average e-beam power of SRF linac to 200 MeV -> 65 kW
- IFEL acceleration to 1 GeV (Using linear collider 3.2 nC e-bunch absorb 2.5 J laser energy or 40 % of 6 J circulating laser energy in cavity). TESSA deceleration back to 100 MeV (give back to laser 3J to compensate for cavity losses)
- Laser intra-cavity average power 600 kW

- Also Compton-ring + stacking laser cavity and other solutions should be considered !
- Overlap with gamma-gamma program