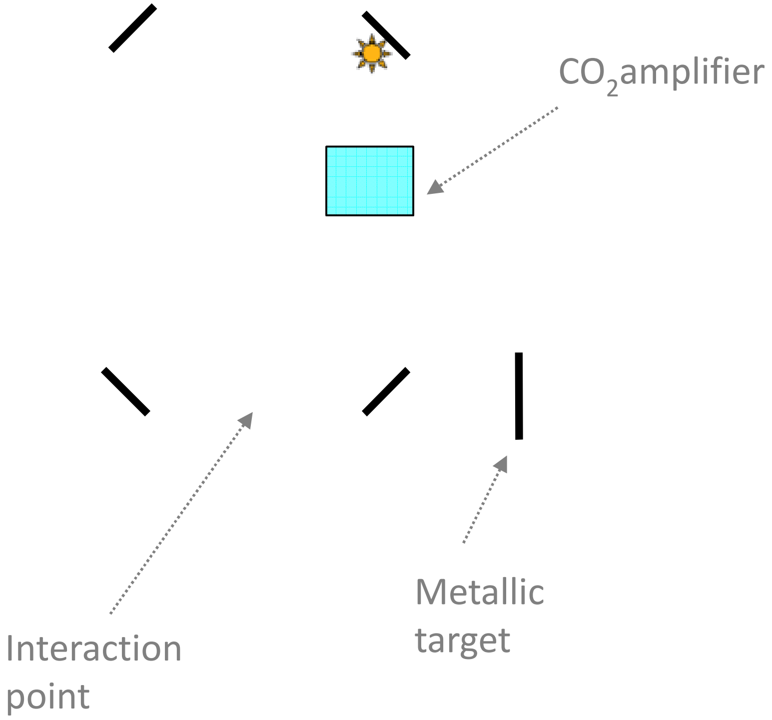
Compton Linac for Polarized Positrons

V. Yakimenko, I. Pogorelsky,
M. Polyanskiy, M. Fedurin
BNL

CERN, October 15, 2009

Polarized positron source: the concept



Pulse duration:	5 ps
Pulse energy:	1J
Repetition:	3-12 ns
Pulses/bunch:	100

- *A picosecond CO_2 laser pulse circulates in a ring cavity*

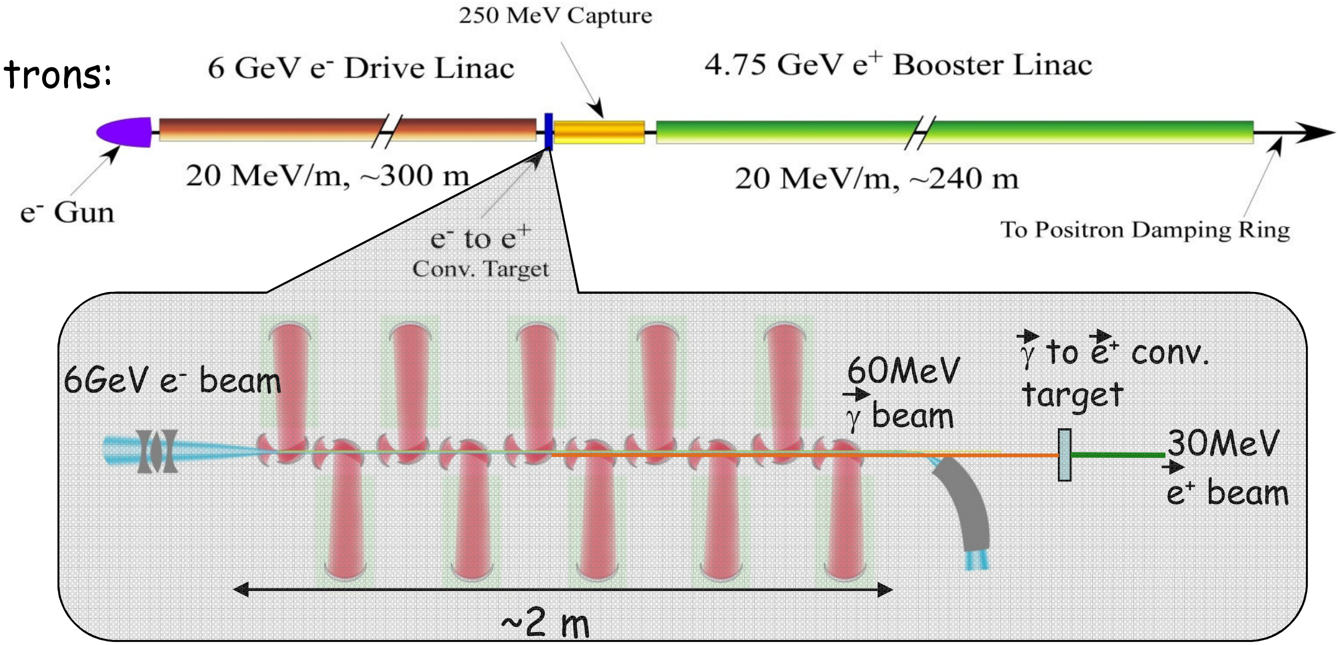
- *At each pass through the cavity the laser pulse interacts with a counter-propagating electron pulse generating γ-quanta* via *Compton scattering*

- *Optical losses are compensated by intracavity amplifier*

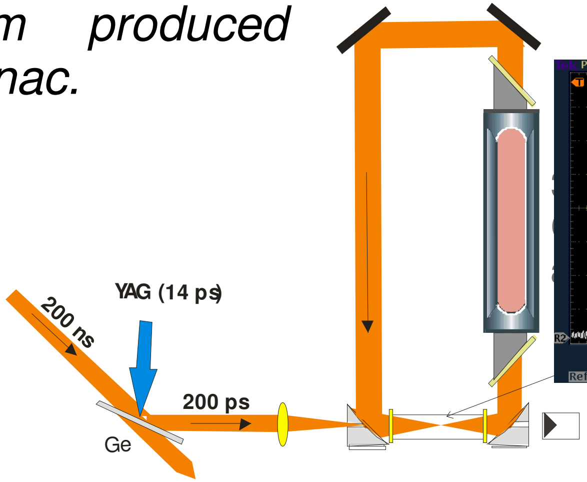
- *The λ-proportional number of photons per Joule of laser energy allows for higher γ-yield (compared to solid state lasers)*

Polarized positron source

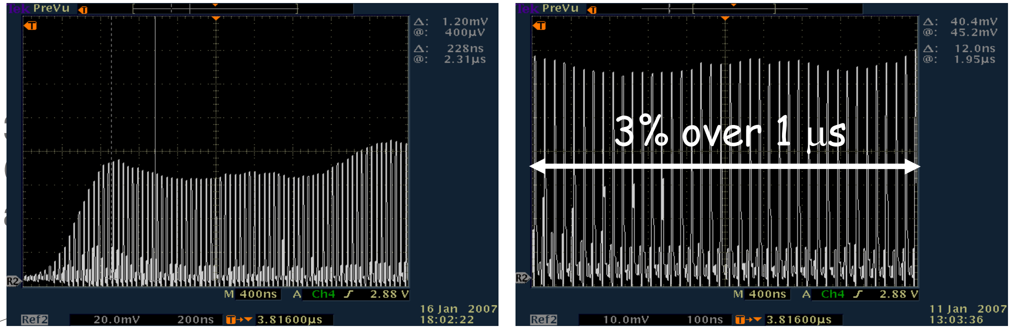
Conventional
Non-Polarized Positrons:



Polarized γ-ray beam is generated in the Compton back scattering inside optical cavity of CO_2 laser beam and 6 GeV e- beam produced by linac.



First tests of the laser cavity



Linac Compton Source (LCS): Numbers

	ILC	CLIC
Positron beam requirement	$2\ 10^{10}$/3 nc	$4\ 10^{9}$/0.6 nc
	2656@5Hz	312@50Hz
e- beam energy	4 / 6 GeV	
e- bunch charge	15 / 10 nC	6 / 4 nC
RMS bunch length (laser & e$^-$ beams)	3ps	
Number of laser IPS	10	5
Total Nγ/Ne$^-$ yield (in all IPs)	10	5
Ne$^+$/Nγ capture	2 / 3 %	
Ne$^+$/Ne$^-$ yield	20 / 30 %	10 / 15%
Total e$^+$ yield	3 nC	0.6 nC
# of stacking	No stacking	
Normalized e+ emittance	6 / 4 mm rad	3 / 2 mm rad

Computer simulations: Model

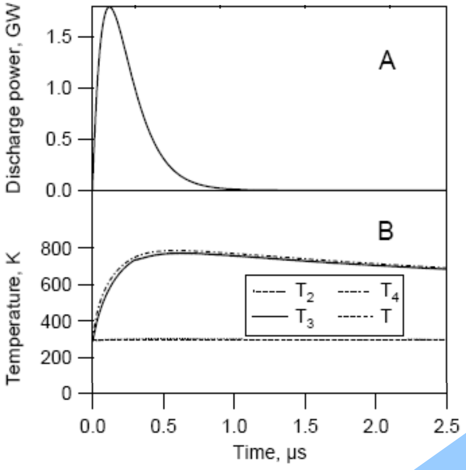
$$2ik\frac{\partial}{\partial z}E = -\nabla_{\perp}E - 4\pi\frac{\omega^2}{c^2}P,$$

$$\frac{\partial}{\partial t}p_J = i(\omega-\omega_J)p_J - \frac{p_J}{\tau_2} - \frac{Ed_J^2}{2i\hbar}\Delta n_J,$$

$$\frac{\partial}{\partial t}\Delta n_J = -\frac{2}{i\hbar}(Ep_J - c.c.) - \frac{\Delta n_J - \Delta n_J^0}{\tau_r}$$

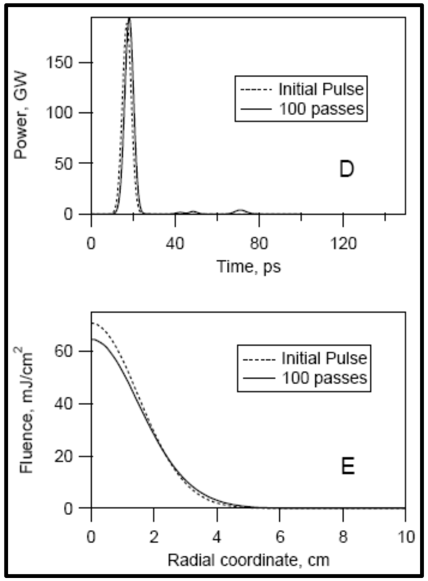
Beam Propagation
(diffraction, optics, losses)

Amplification & Rotational relaxation
(fast time-scale)



Vibrational relaxation
(slow time-scale)

Pumping
(slow time-scale)



Boltzmann equations
(discharge energy distribution)

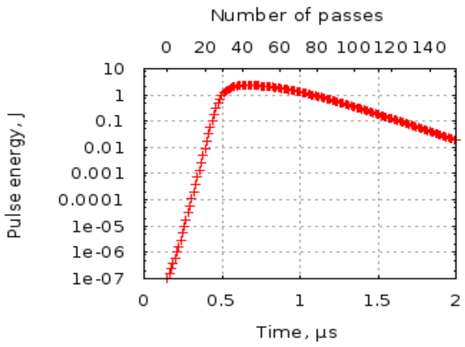
Discharge dynamics

Spectra
(amplification band)

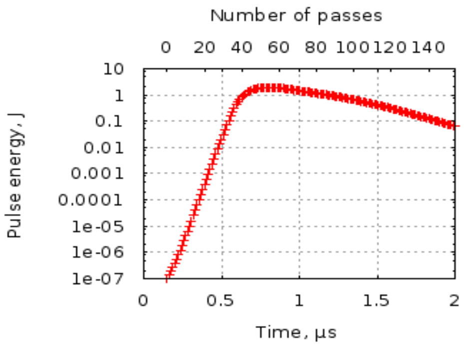
Using data from HITRAN2008

Simulation results

Pulse energy dynamics



Natural CO_2



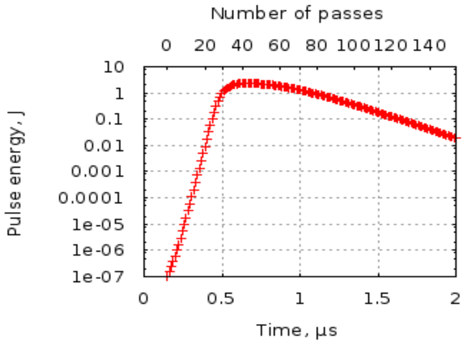
O^{16}:O^{18} = 50:50

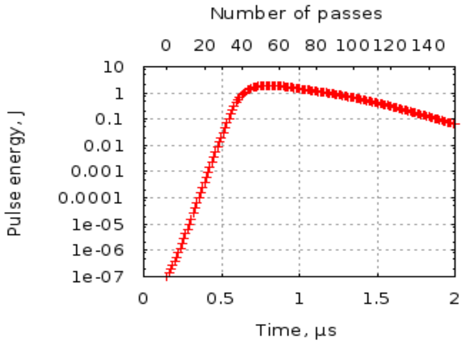
Simulation results

Natural CO_2

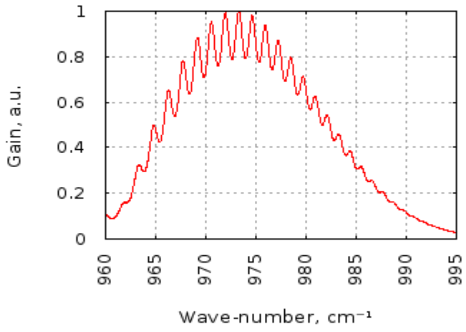
$O^{16}:O^{18}$ = 50:50

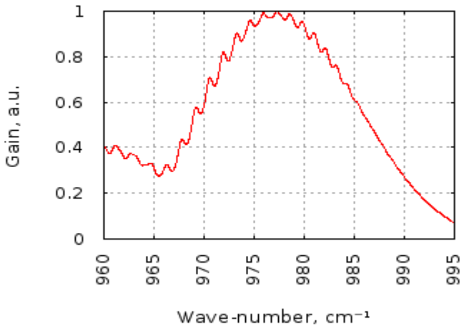
Pulse energy dynamics





Gain spectra



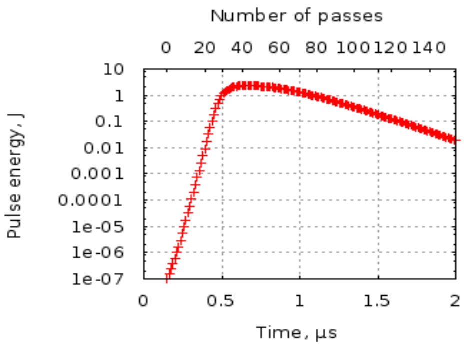


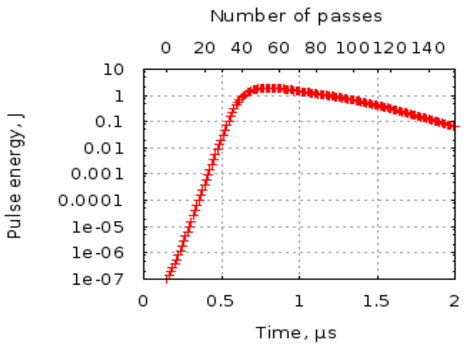
Simulation results

Natural CO_2

O^{16}:O^{18} = 50:50

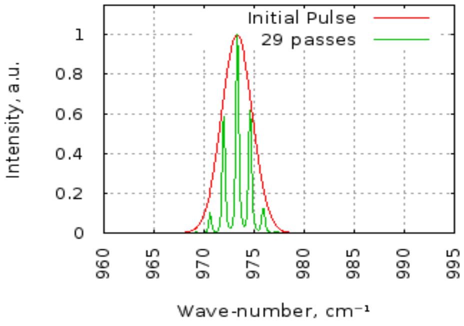
Pulse energy dynamics

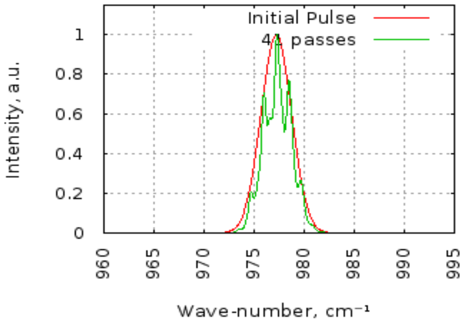




Pulse spectra

(initial and after reaching 1 J)



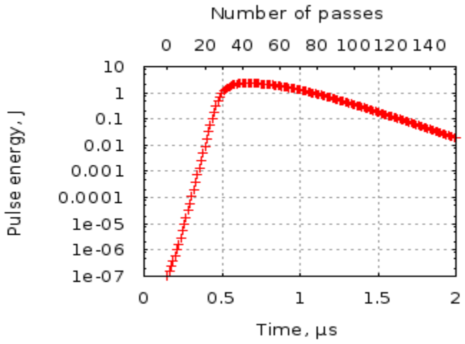


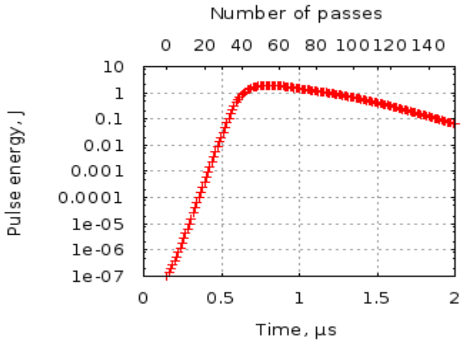
Simulation results

Natural CO_2

O^{16}:O^{18} = 50:50

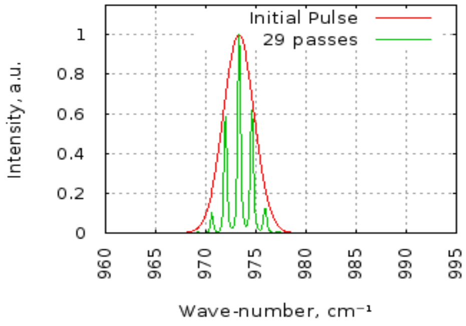
Pulse energy dynamics

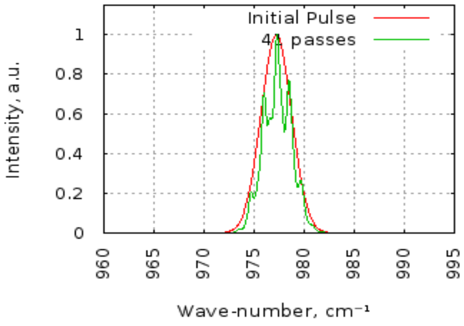




Pulse spectra

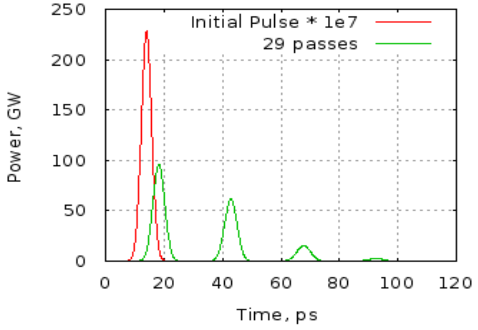
(initial and after reaching 1 J)

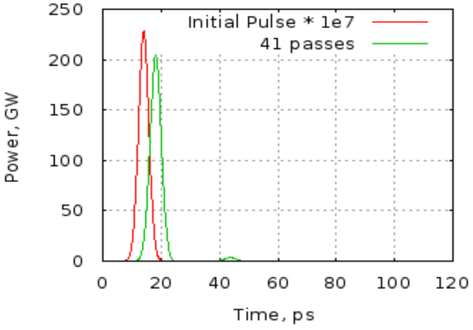




Temporal pulse profile

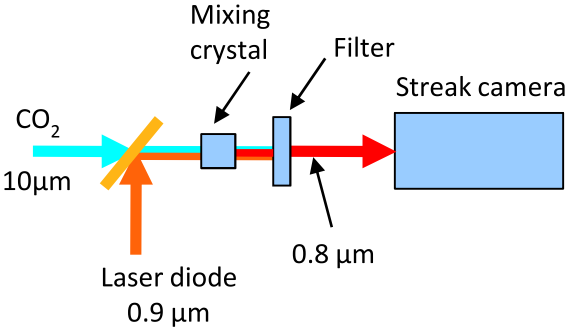
(initial and after reaching 1 J)

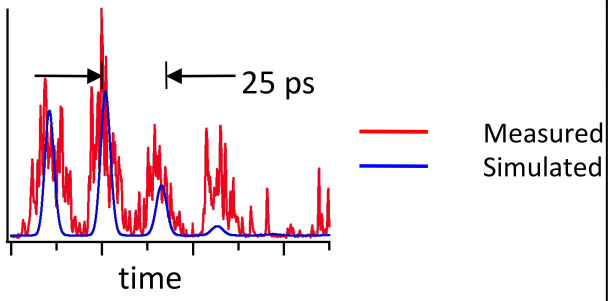




Pulse diagnostics

"Streak camera"



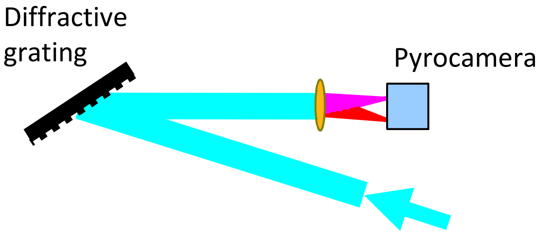


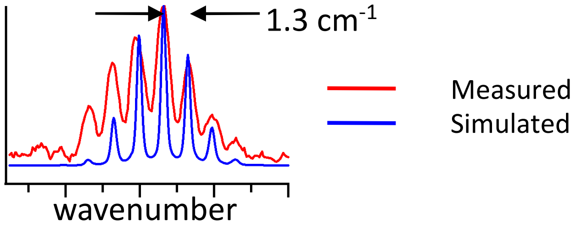
:) Single-shot

:(Low resolution (~10 ps)

:) Train measurements

"Spectrometer"





Fourier transform

Total bandwidth <=> Individual pulse
sub-ps resolution

Individual lines <=> Train
resolution improvement needed

:) Single-shot

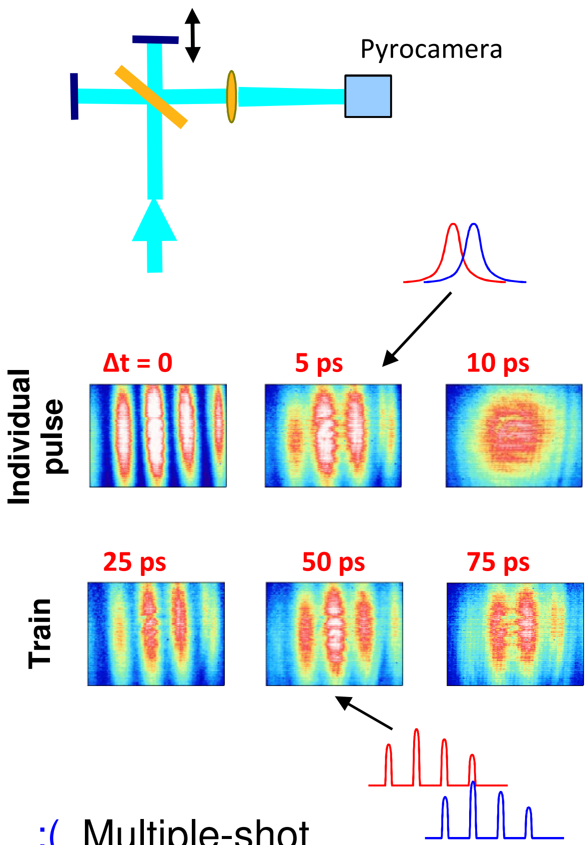
:) Simple = reliable

:) Indiv. pulse measurements

... Train measurements (?)

:(Indirect method

"Interferometer"



:(Multiple-shot

:) Indiv. pulse measurements

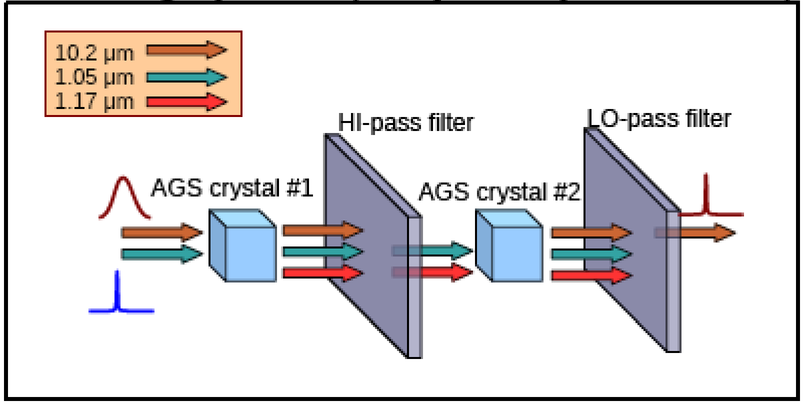
:) Train measurements

:(Complicated data analysis

Laser system

CO_2 laser system
(**10 µm, 80 ns, 120 Hz**)

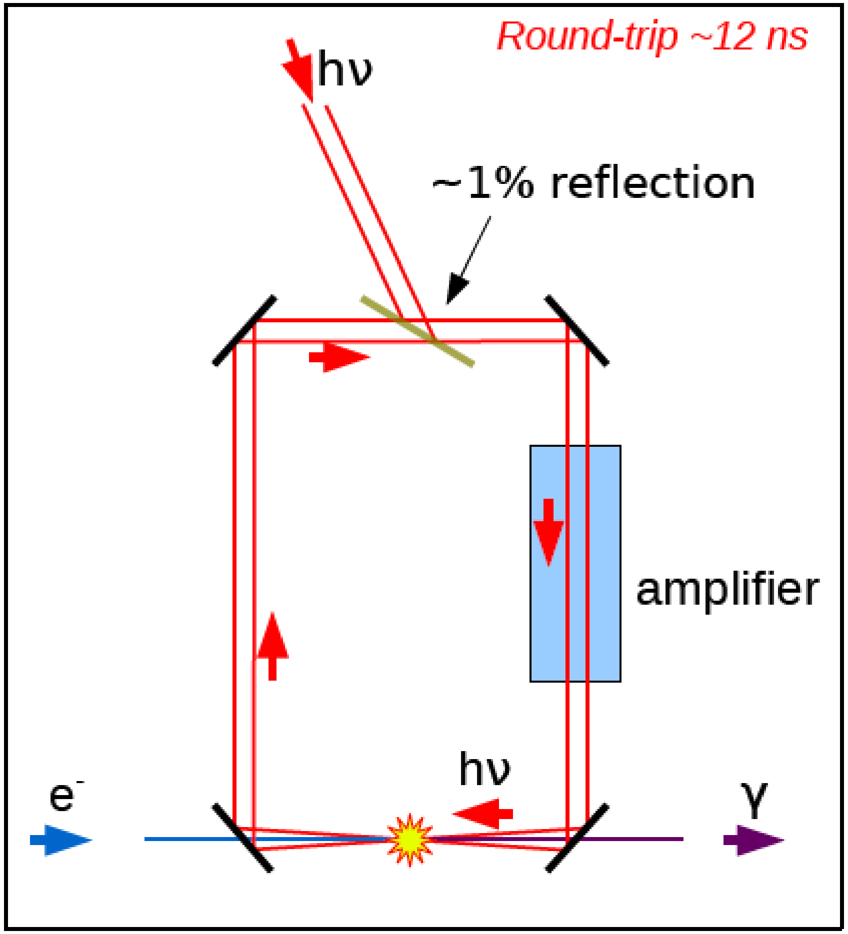
Pulse forming system (**10 µm, 3 ps, 120 Hz**)



Solid state laser system
(**1 µm, 3 ps, 120 Hz**)

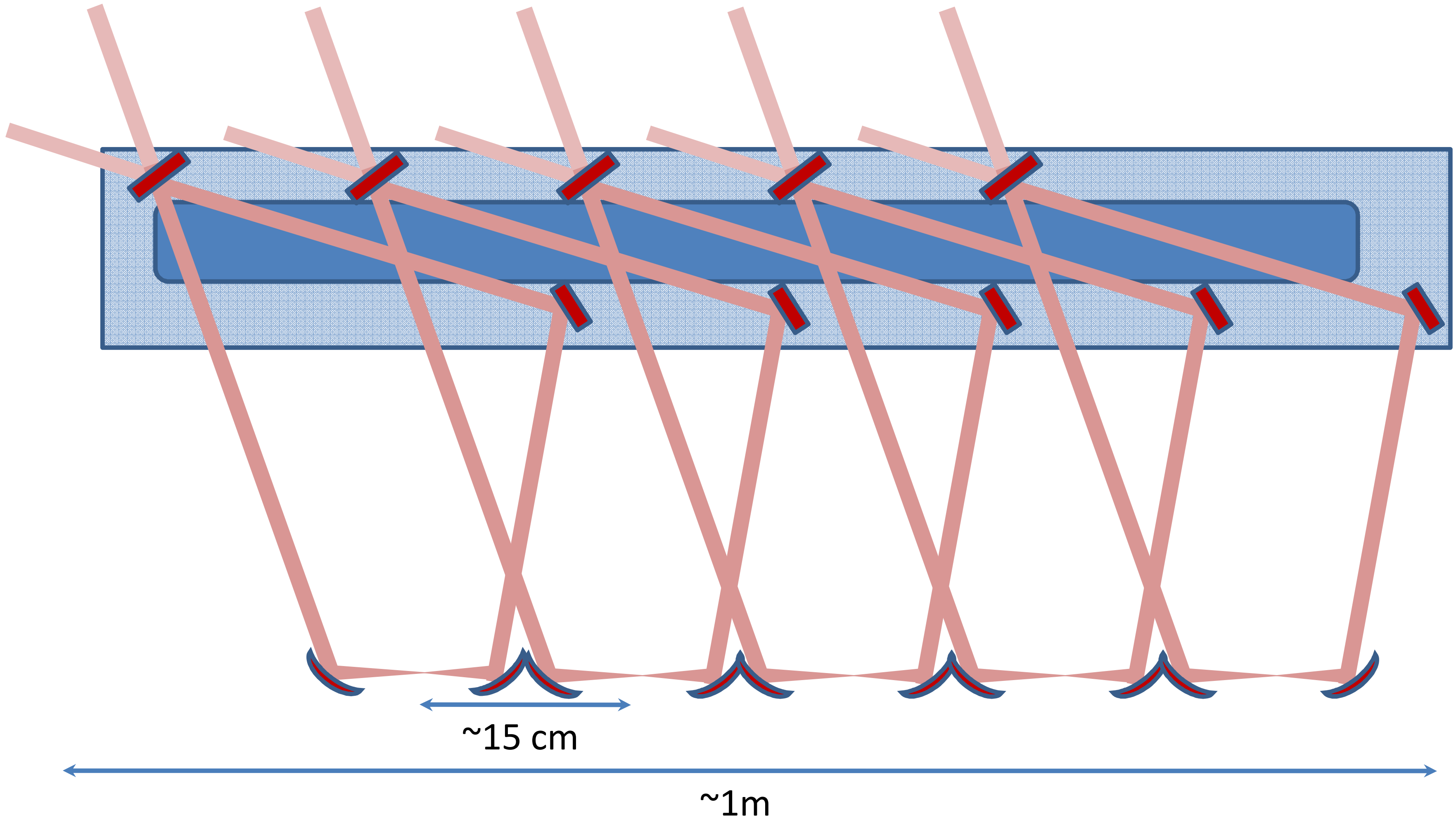
120 Hz

Recirculating cavity



Realistic goal:
Trains: 25~50 pulses @ 120 Hz
(effective repetition rate: 3~6 kHz)
Pulse energy: 0.5~1.0 J
Pulse duration: 3~5 ps (fwhm)

Possible configuration with 5 IPs and 1 laser amplifier

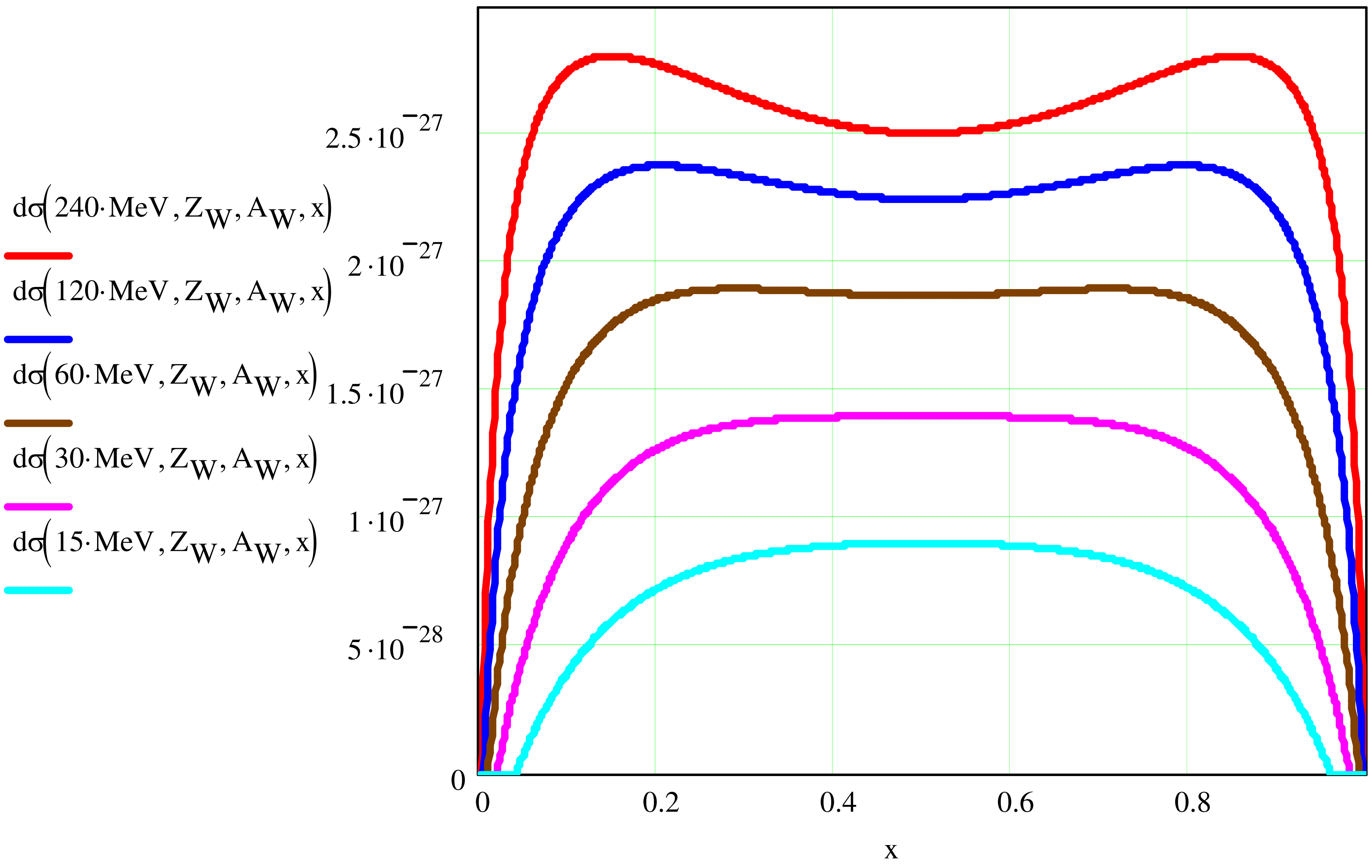


Wall plug power consideration

- ILC:
  - 3 10^{14} positrons/second;
  - 2% γ - > e^+ efficiency for 60 MeV γ

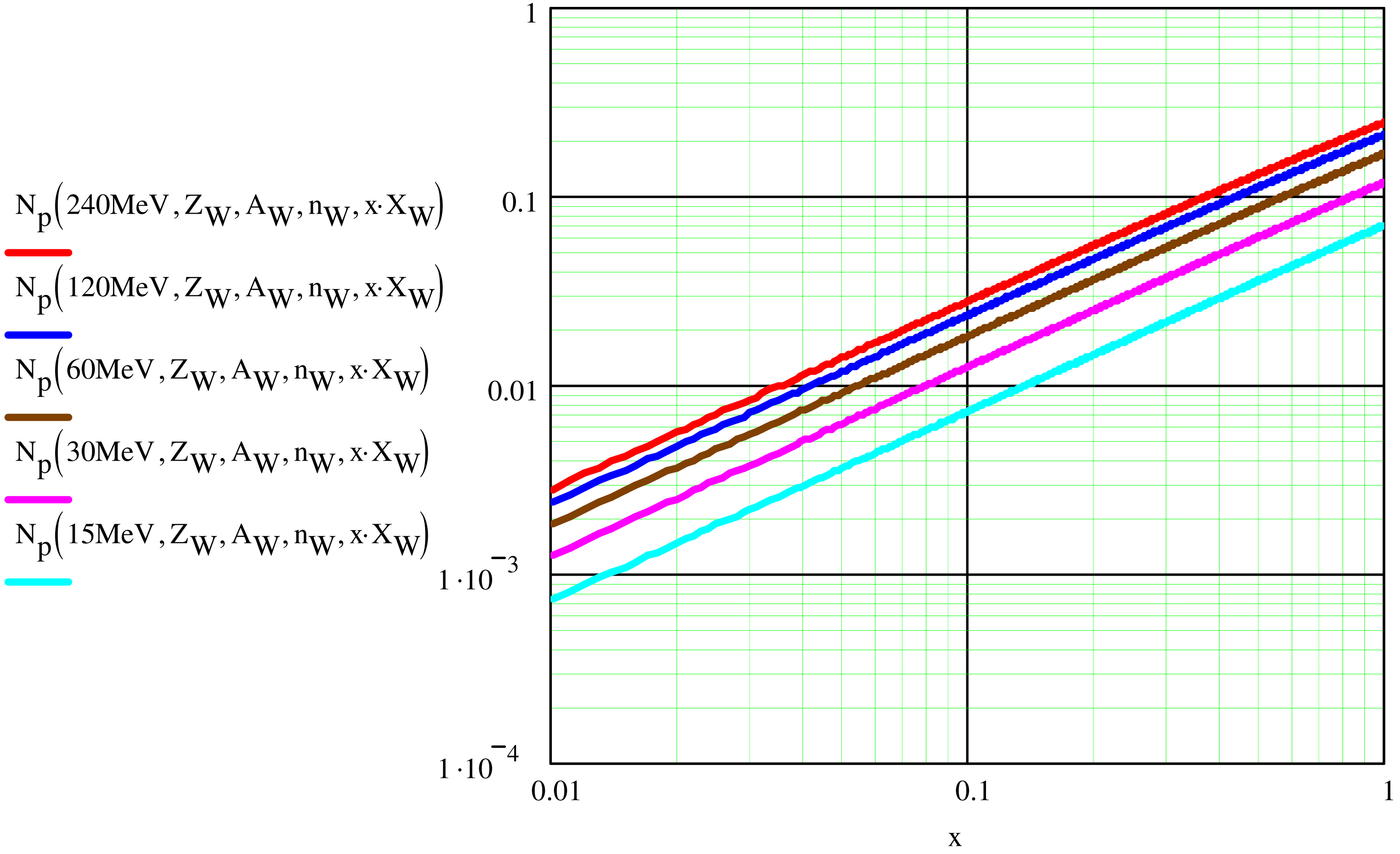
  => 150 kW γ beam
- Wall plug to γ for warm linac/CO2 is expected ~5-10%

Cross section for Pair production



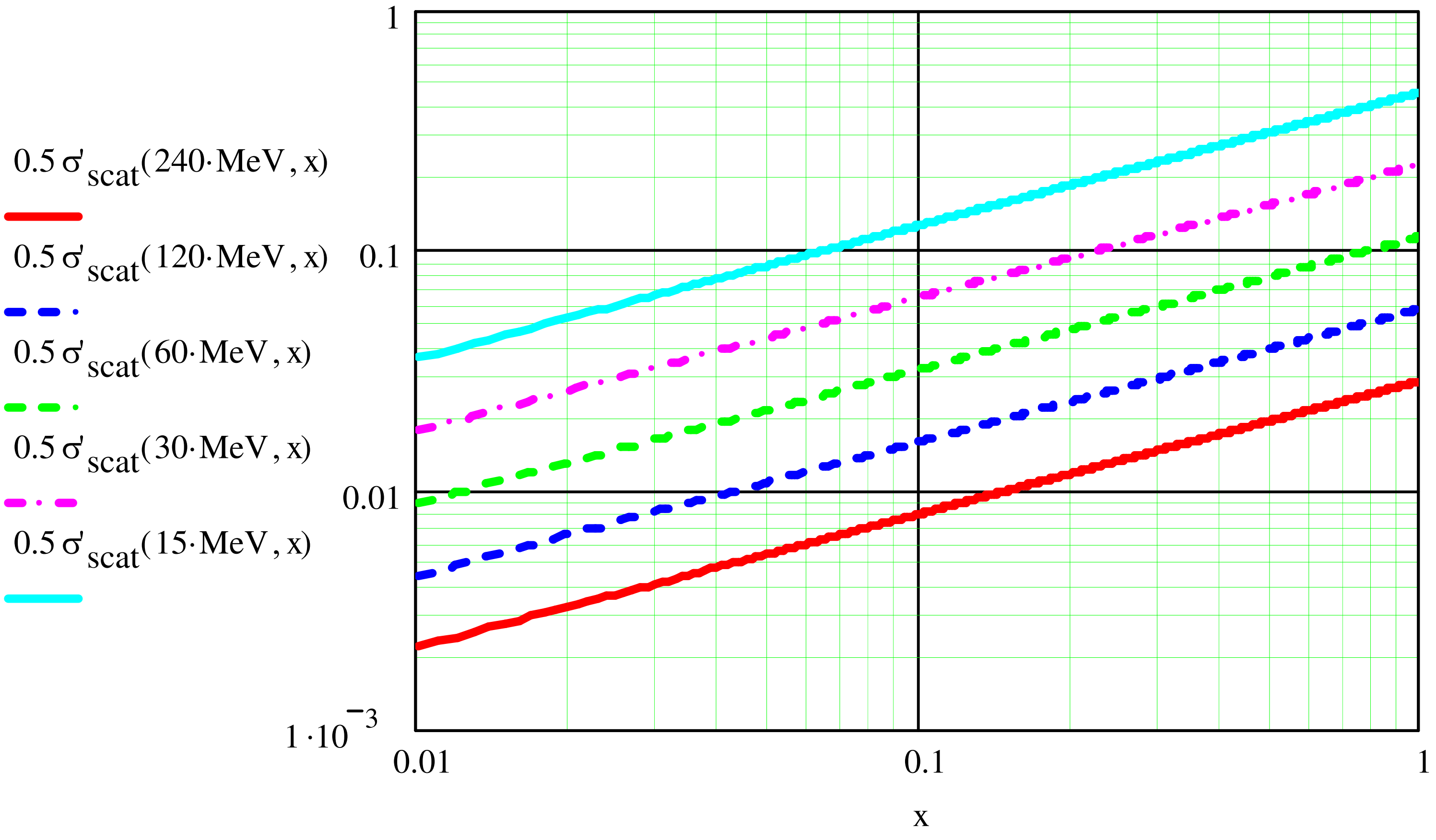
Positron generation efficiency

$$N_p(E\gamma, Z, A, n, L) := 1 - \exp\left(-n\cdot L\cdot \int_{0.5}^{1} d\sigma(E\gamma, Z, A, x)\, dx\right)$$



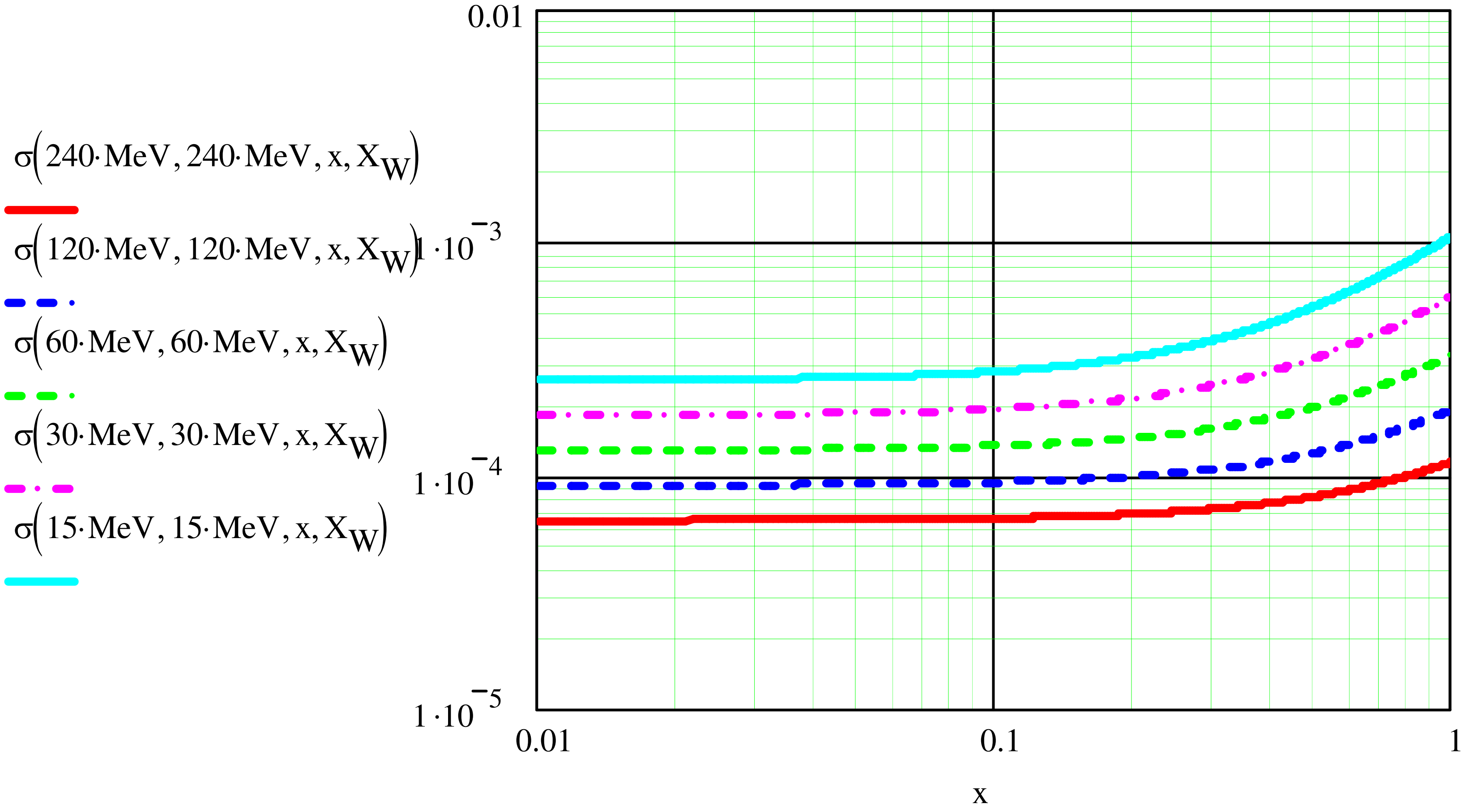
Angular spread of positron beam

$$\sigma'_{scat}(Ep, L\_X_0) := \frac{13.6\,MeV}{Ep\cdot\left[1-\left(\frac{m_e\cdot c^2}{Ep}\right)^2\right]}\cdot(L\_X_0)^{0.555}$$



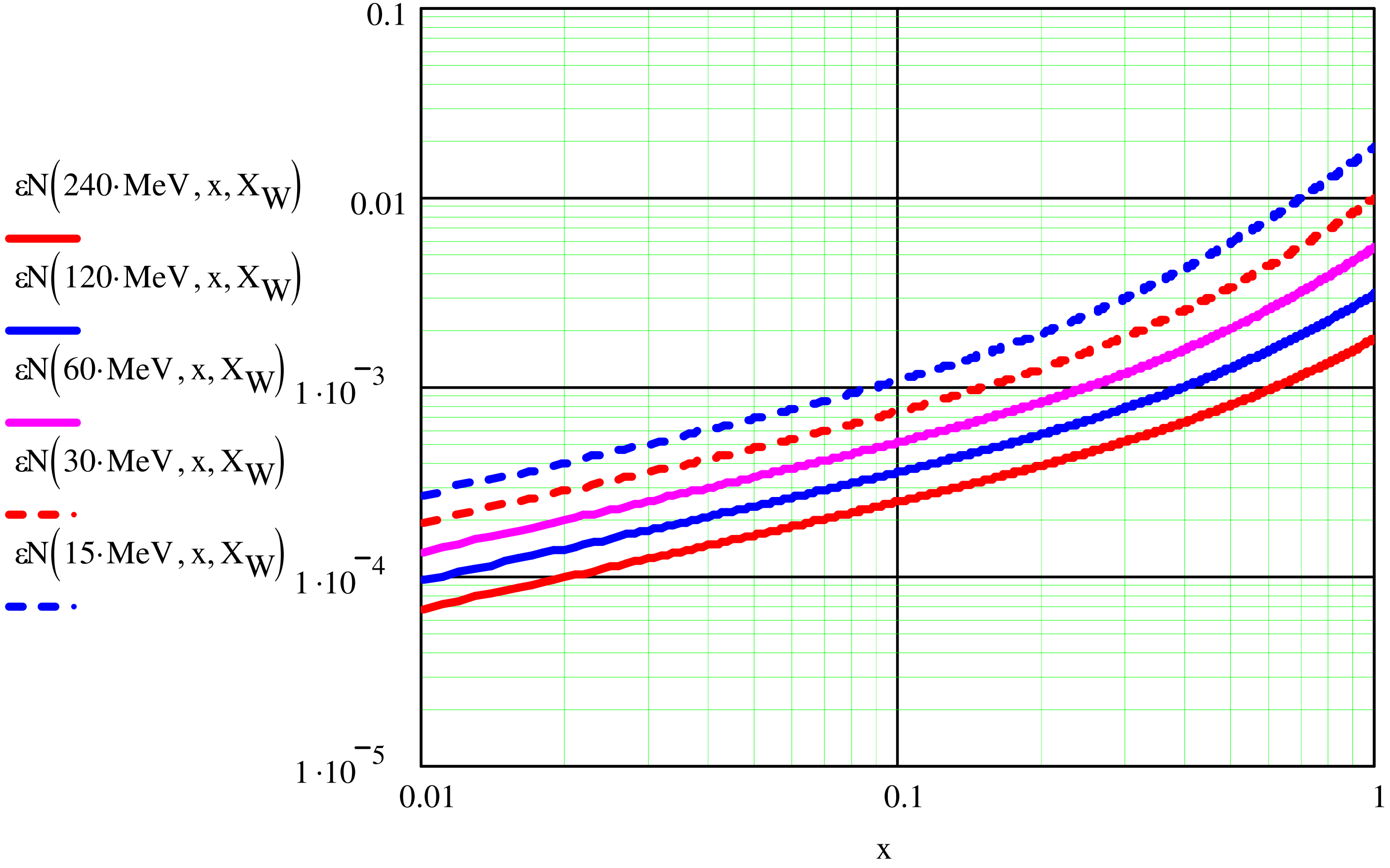
Positron beam size at the target exit

$$\sigma\left(Ep, E\gamma, L\_X_0, X_0\right) := \sigma\gamma\left(E\gamma\right) + \int_0^1 \sigma'_{scat}\left[Ep, L\_X_0\cdot(1-x)\right]\cdot L\_X_0\cdot X_0\cdot x\,dx$$



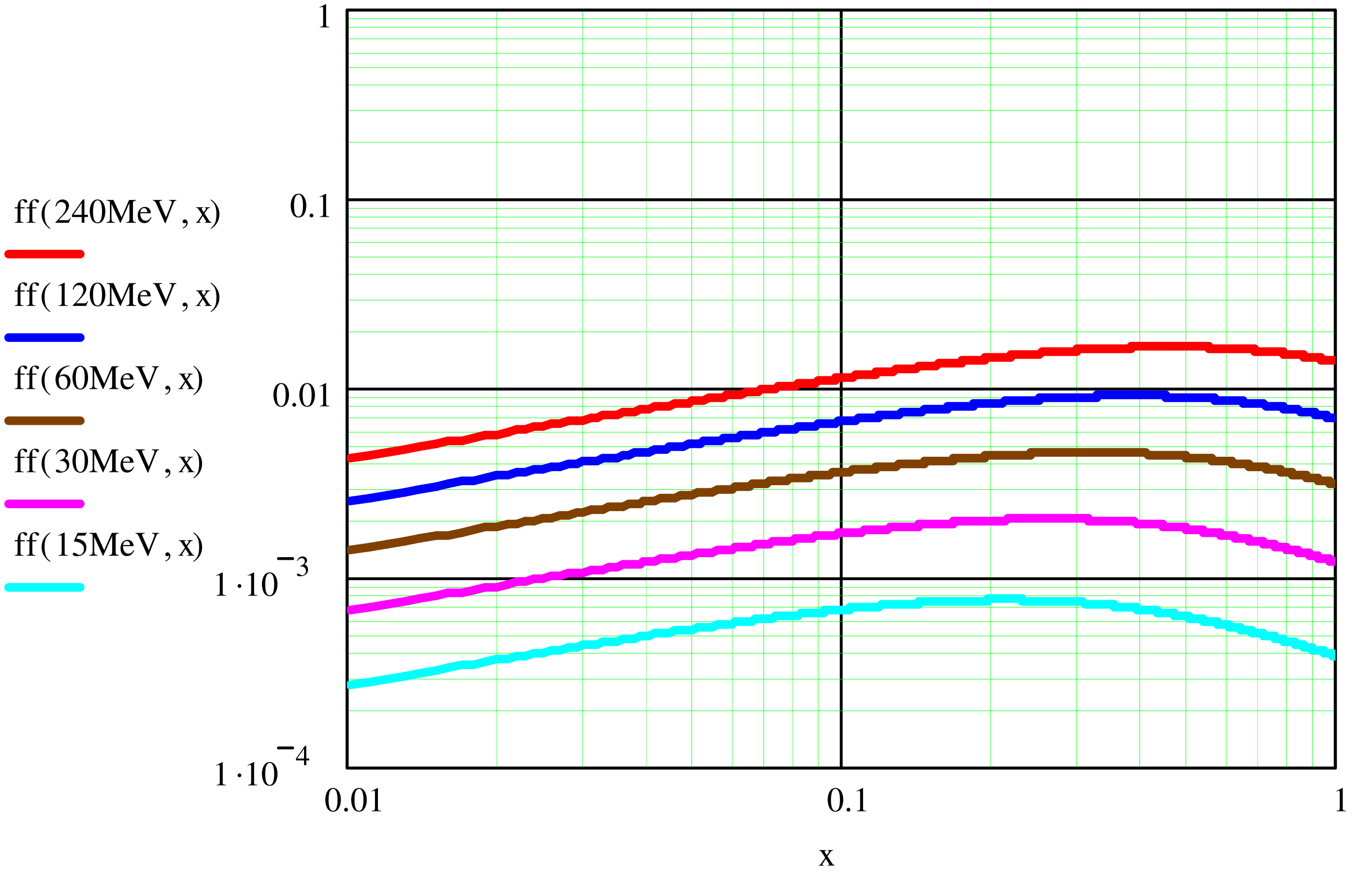
Normalized emittance at the target exit

$$\varepsilon N\left(E\gamma, L\_X_0, X_0\right) := 2\cdot\int_{0.5}^{1} \frac{x\cdot E\gamma}{m_e\cdot c^2}\cdot\sigma\left(x\cdot E\gamma, E\gamma, L\_X_0, X_0\right)\cdot\frac{1}{2}\cdot\sigma'_{scat}\left(x\cdot E\gamma, L\_X_0\right)\,dx$$



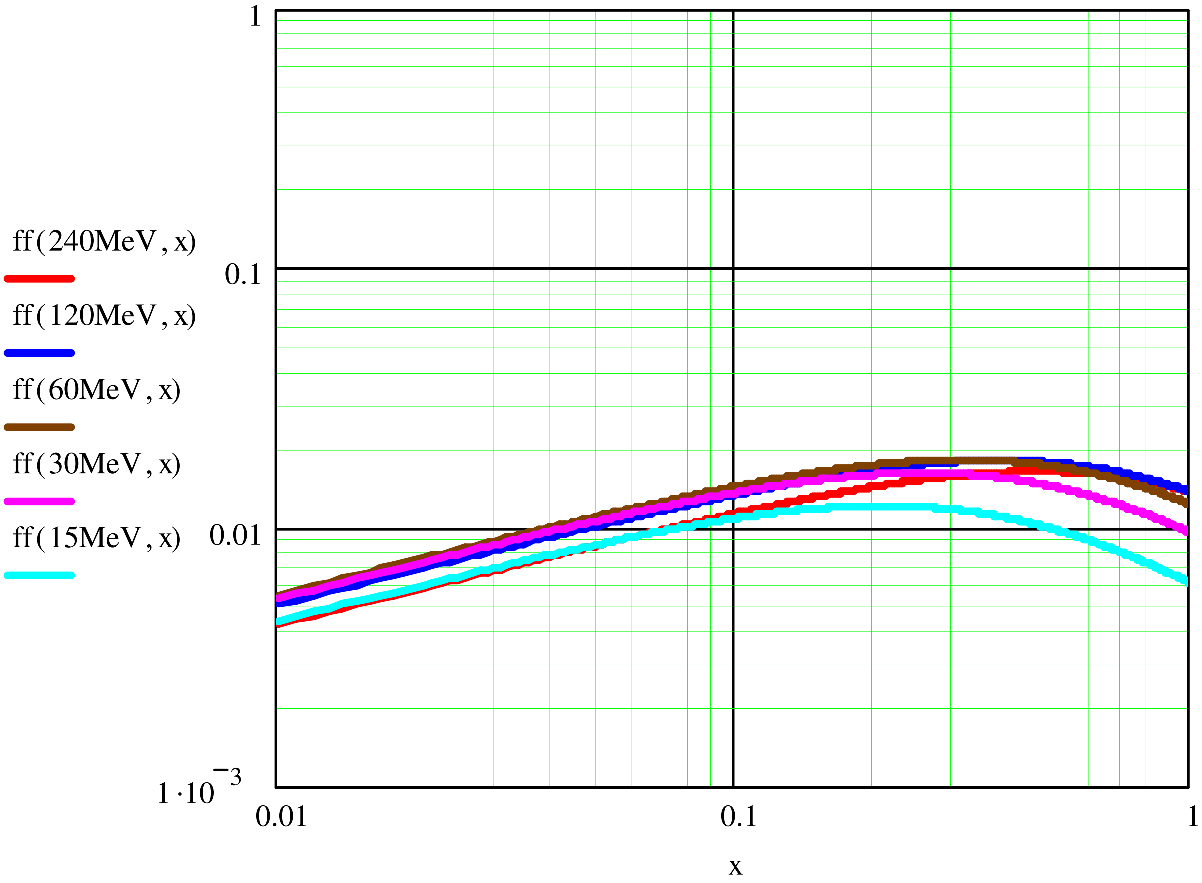
Positron generation efficiency normalized by emittance

$$ff(E\gamma, x) := N_p(E\gamma, Z_W, A_W, n_W, x\cdot X_W)\cdot\left(\frac{0.1\text{mm}}{\varepsilon N(E\gamma, x, X_W)}\right)$$



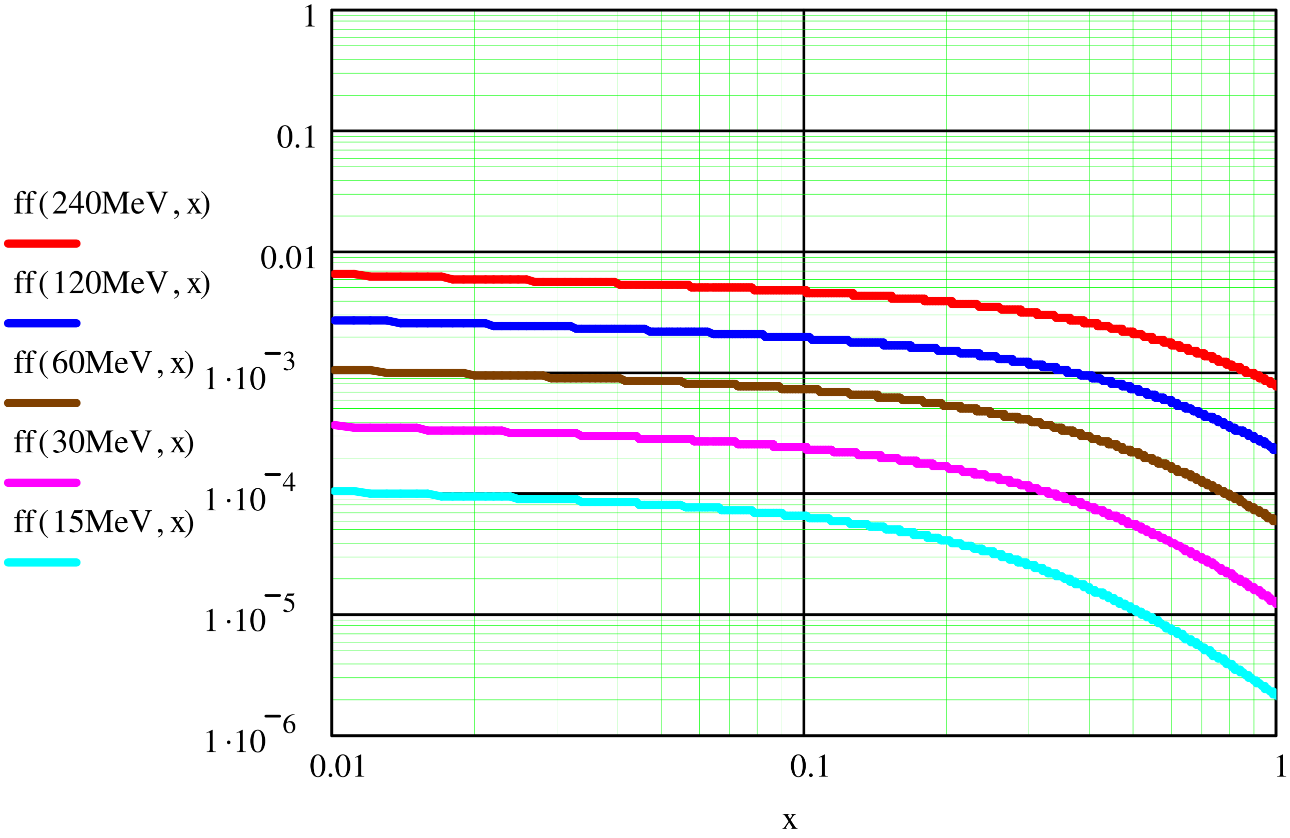
Positron generation efficiency normalized by emittance and gamma beam power

$$ff(E\gamma, x) := N_p\left(E\gamma, Z_W, A_W, n_W, x \cdot X_W\right) \cdot \left(\frac{0.1 \cdot mm}{\varepsilon N\left(E\gamma, x, X_W\right)}\right) \cdot \frac{240MeV}{E\gamma}$$



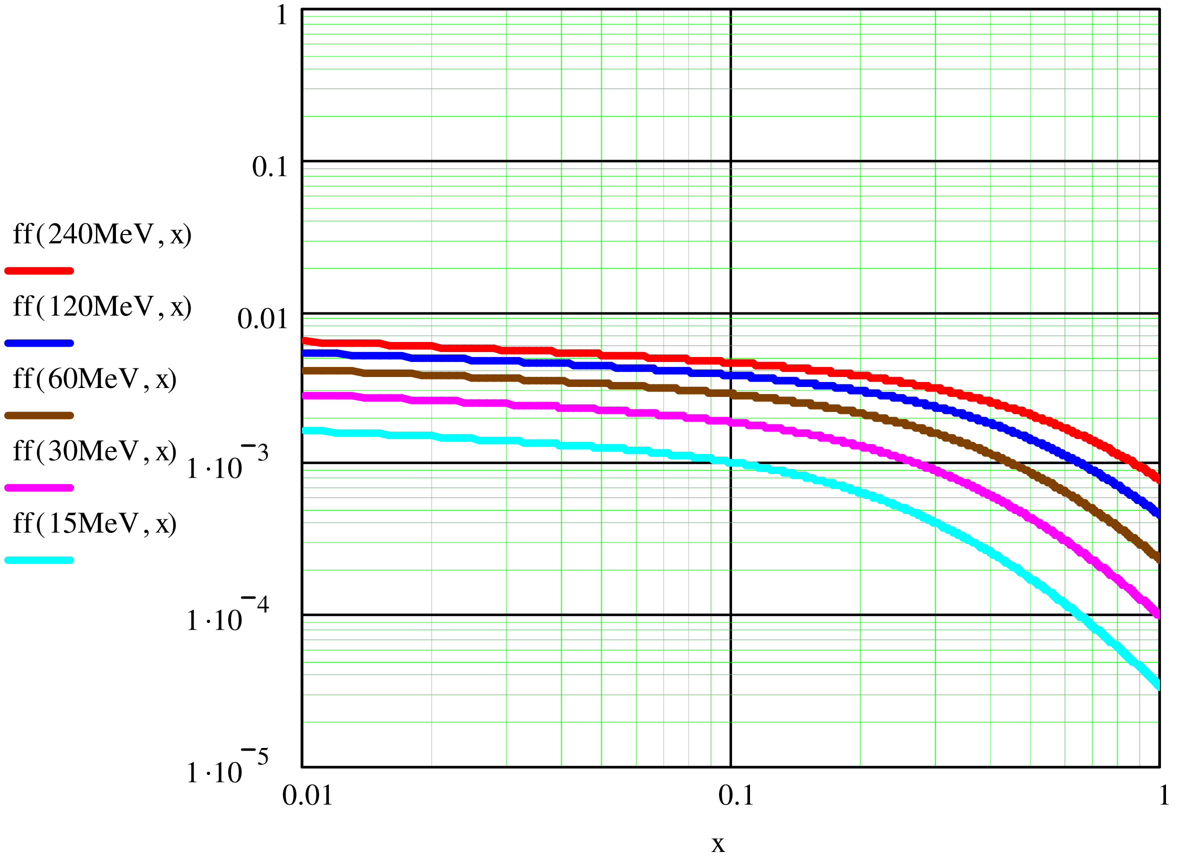
Positron generation efficiency normalized by transverse phase space

$$ff(E\gamma, x) := N_p\left(E\gamma, Z_W, A_W, n_W, x \cdot X_W\right) \cdot \left(\frac{0.1\text{mm}}{\varepsilon N\left(E\gamma, x, X_W\right)}\right)^2$$



Positron generation efficiency normalized by transverse phase space and gamma beam power

$$\mathrm{ff}(E\gamma, x) := N_p(E\gamma, Z_W, A_W, n_W, x\cdot X_W)\cdot\left(\frac{0.1\cdot \mathrm{mm}}{\varepsilon N(E\gamma, x, X_W)}\right)^2\cdot\frac{240\mathrm{MeV}}{E\gamma}$$



Conclusion

- Polarized positron beam requirement for CLIC can be satisfied with Compton CO2/LINAC based gamma source
- Higher energy gamma beam is preferential for the thermal load on the target
- Shorter target is preferential when low emittance after target is needed (CLIC, LeHC …)
- Total power consumption should be part of optimization for high positron demands (LeHC)
- Amplification in Isotope mixture will be tested shortly at ATF
- Seed pulse generation using solid state laser will be tested at ATF in ~year
- There is no funding/activity for regenerative cavity test