Progress at BNL

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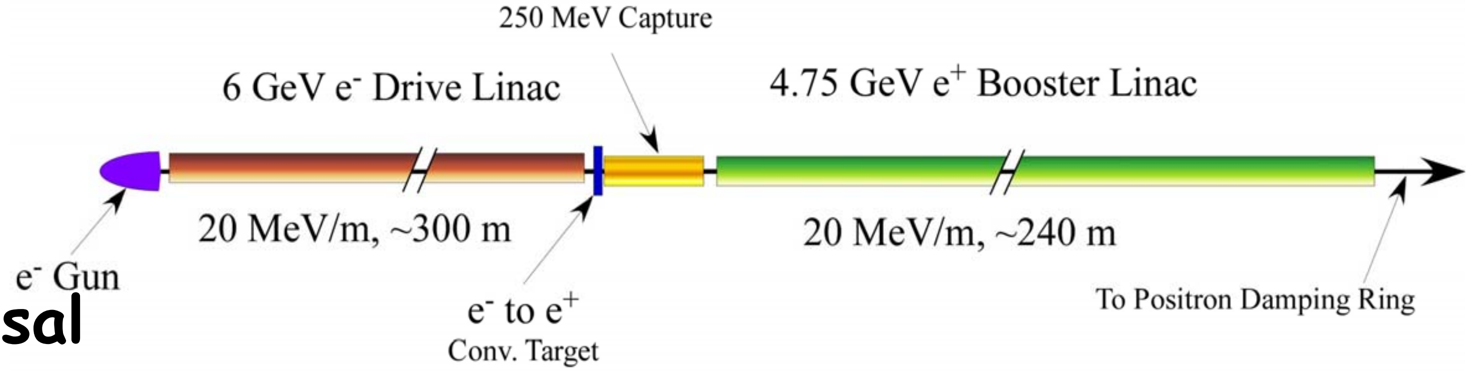
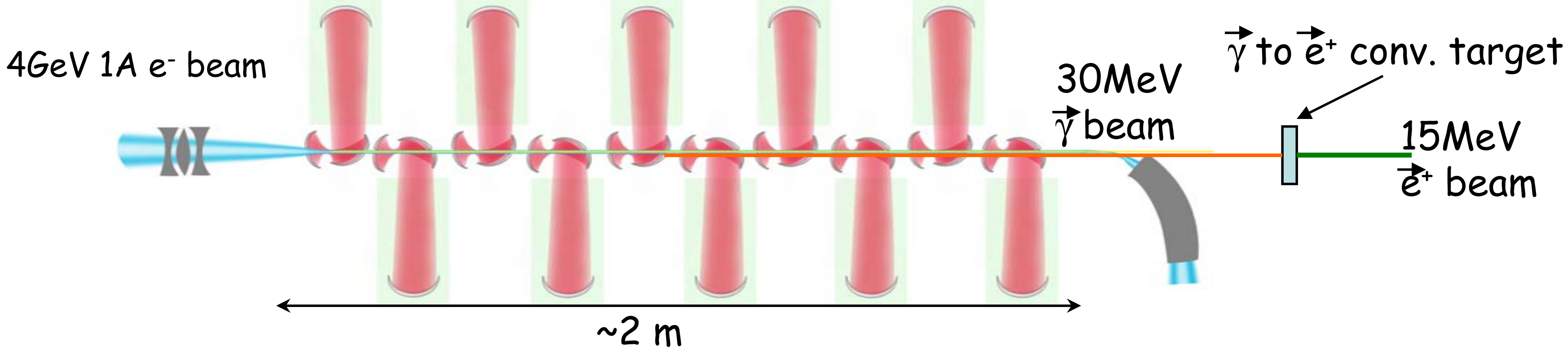
Polarized Positrons Source (PPS for ILC)

Conventional Non-Polarized Positrons:

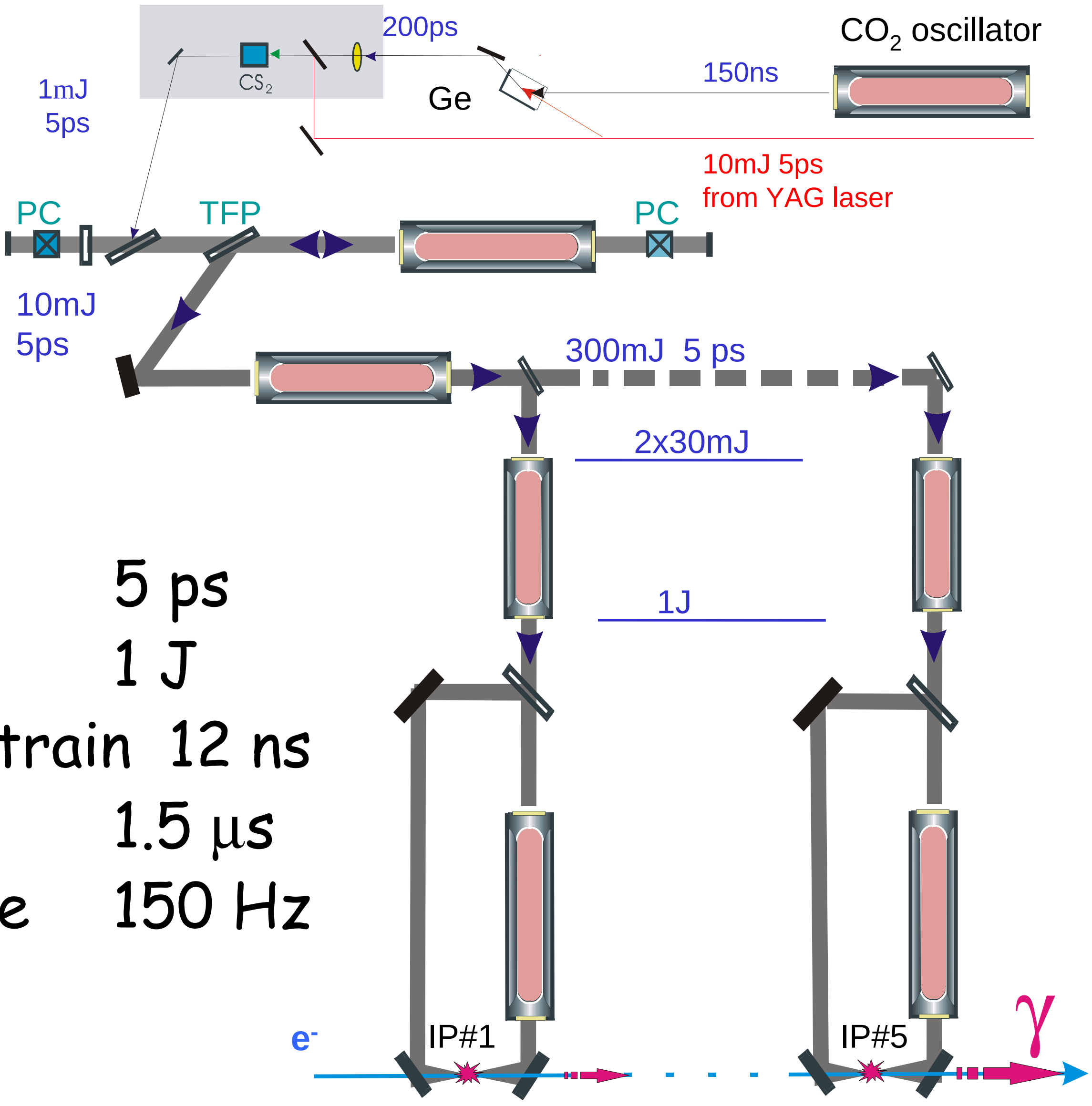


In our proposal

- polarized γ-ray beam is generated in the Compton back scattering inside optical cavity of CO_2 laser beam and 4 GeV e-beam produced by linac.
- The required intensities of polarized positrons are obtained due to 10 times increase of the e-beam charge (compared to non polarized case) and 5 to 10 CO_2 laser system IPs.
- Laser system relies on the commercially available lasers but need R&D for the new mode of operation
- 5ps 10J@0.05 Hz CO_2 laser is operated at ATF



LCS: CO_2 laser system



• pulse length	5 ps
• energy per pulse	1 J
• period inside pulse train	12 ns
• total train duration	1.5 µs
• train repetition rate	150 Hz

CO2 laser developments

- Computer code to simulate propagation and circulation of the short pulse in CO2 media (including Isotopic mixtures is developed).
- Isotopic mixture is needed to low gas pressure and extend live time of the inverse states
- Experimental tests with isotopes are planed for later this year.
- Injection into regenerative amplifier using germanium is planned in next few weeks

Why 100% acceptance of produced positrons (top 50% of the energy) is expected in Compton/Linac source?

- Interaction region is short
- Target is close to Compton source
- Small spot size on the target and high energy of positrons lead to small emittance.

Beam size at the target exit

$$\varepsilon_N = \gamma\sigma\sigma' = \gamma\sqrt{\sigma_\gamma^2 + \left(\sigma' L/2\right)^2}\,\sigma'; \quad \sigma' \approx \frac{14MeV}{E_{e^+}}\sqrt{\frac{L\rho}{X_0}}$$

	WS high K	WS low K	CLS	CRS
Top γ energy [MeV]	10	20	30	30
γ size [mm]	0.5	0.5	0.6	6
e^+ divergence [rad]	1.5	0.75	0.5	0.5
e^+ size Ti/W [mm] (due to scattering)	15/1.5	7.5/0.75	5/0.5	5/0.5
Norm. emittance Ti/W [mm rad]	480/48	240/24	160/16	180/120

Estimates done for the top 50% energy selected
ILC dumping ring acceptance is: 90 mm rad,
(corresponds to ~20 mm rad emittance)

γ beam size on the target

- WS (150GeV, 200m):

$$\sigma_r \approx \frac{L_w}{2\gamma} + \frac{L_d}{\gamma} = \frac{200m}{2\cdot 3\cdot 10^5} + \frac{50..500m}{3\cdot 10^5} = 0.3mm + 0.2..1.6mm$$

  - Long drift is needed to make big enough spot at the target

- CLS (4GeV, 5IPs, 0.3m each)

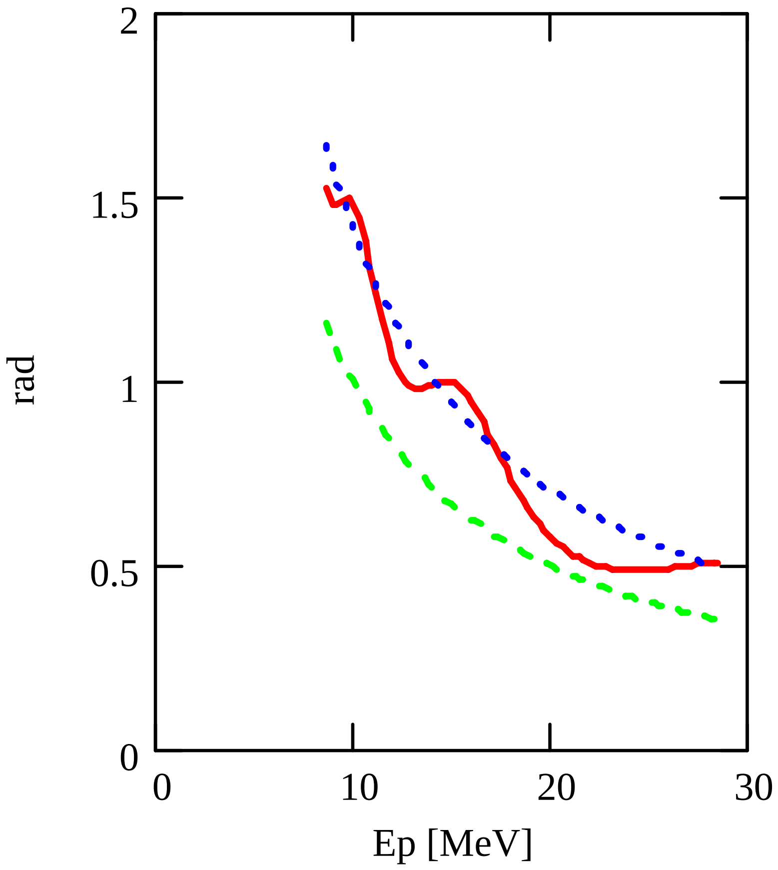
$$\sigma_r \approx \frac{L_{IPs}}{2\gamma} + \frac{L_d}{\gamma} = \frac{3m}{2\cdot 8\cdot 10^3} + \frac{3..15m}{8\cdot 10^3} = 0.2mm + 0.4..1.9mm$$

- CRS (1.2GeV, 5IP, 3m each)

$$\sigma_r \approx \frac{L_{IPs}}{2\gamma} + \frac{L_d}{\gamma} = \frac{15m}{2\cdot 2.5\cdot 10^3} + \frac{3..15m}{2.5\cdot 10^3} = 3mm + 1.5..6mm$$

  - Emittance of the positron beam is limited by the gamma beam spot size on the target

Capture optics



- There is an analytical approximation of the capture dynamics. It is easy to show that ~100% can be captured and transported to DR in the pulsed CLS.
- It is challenging for CW mode of operation of the capture and accelerator for WS and CRS

Analytical estimates for the capture angular acceptance are shown in Red and Blue. Estimated angular spread for CLS is shown in green.

Applications of high intensity gamma ray beam

- (30-60MeV) Polarized Positron Source ILC, CLIC, SuperB

- (15MeV) Rare isotopes production, radioactive waist management

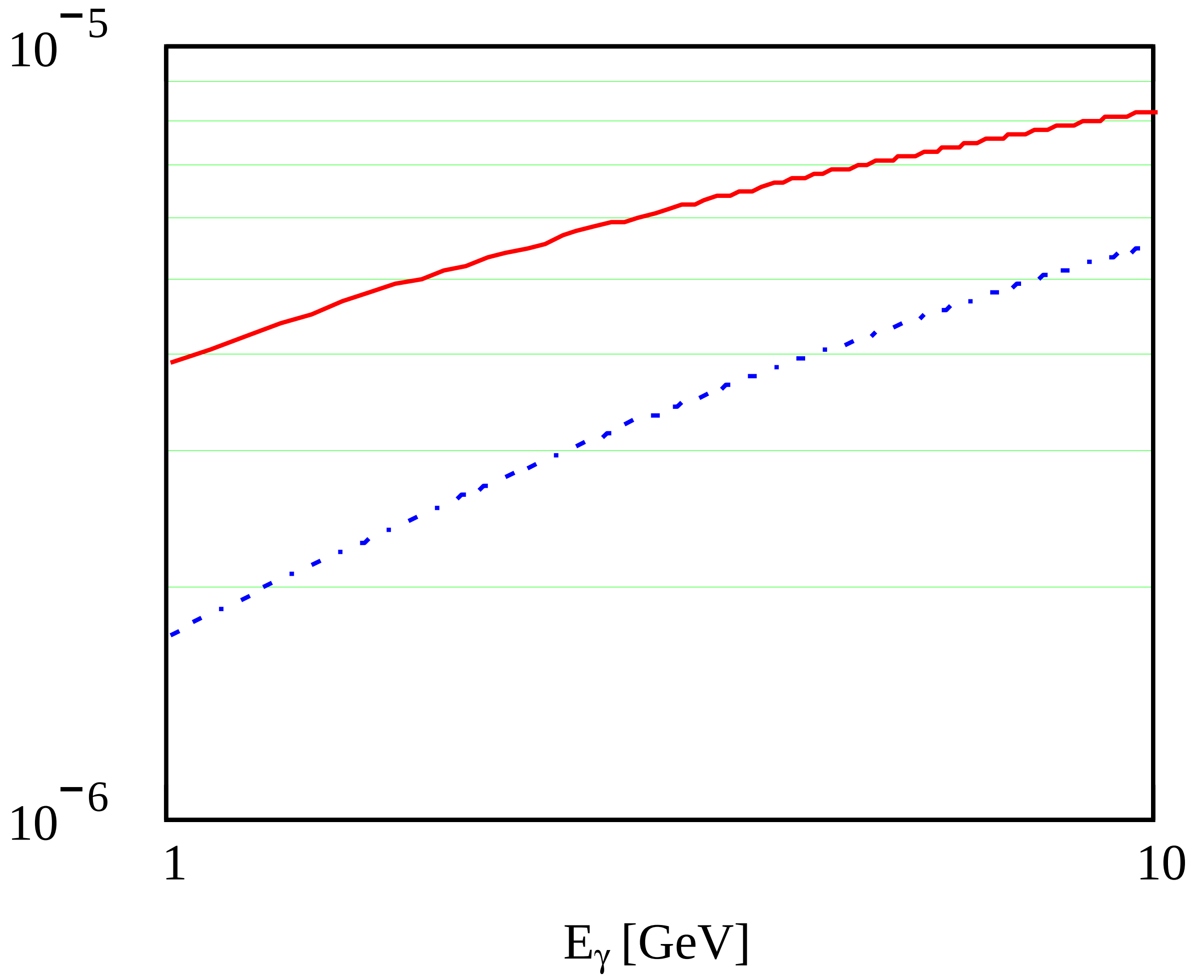
- (2-10GeV) High brightness muon production

Muon beams

- The probability of the formation of a $\mu^+\mu^-$ pair by γ in the field of nuclei is suppressed approximately by a factor of $(m_e/m_\mu)^2$.
- Low emittance from the direct production of the $\mu^+\mu^-$ pair makes this approach competitive with the currently considered production scheme in which a high-power proton beam generates a pion shower, and the pions, in turn, decay into muons.
- Indirect muon production is orders-of-magnitude more efficient in terms of the number of the muons per incident beam power (about 0.2% of the proton beam power is converted into the muon beams),
- yet the brightness of the resulting beam is much less, so that very challenging and complicated cooling schemes must be incorporated into the system in the case of proton driver.
- High-efficiency normal conducting, SC energy-recovering linacs and high-average-power laser cavities offers the opportunity to generate extremely powerful high-energy γ beams through Compton backscattering.

2GeV γ beam	Pulsed Linac	ERL
e-beam energy [GeV]	36	11
Laser wavelength [μm]	10	1
Bunch charge [nC]	10	1.5
Rep. rate [Hz]	200	CW
Bunches per beam	250	
Average current [mA]	0.5	30 / 300
e-beam power [MW]	18	330 / 3300
e-to-γ convers. efficiency	3	1/3
γ-beam power [MW]	3	20 / 200
Total AC-to-γ efficiency	10%	20% / 75%
Peak $\mu^+\mu^-$ [per bunch]	10^6	3 10^4
Average $\mu^+\mu^-$ [per second]	5 10^{10}	3 10^{11} / 3 10^{12}

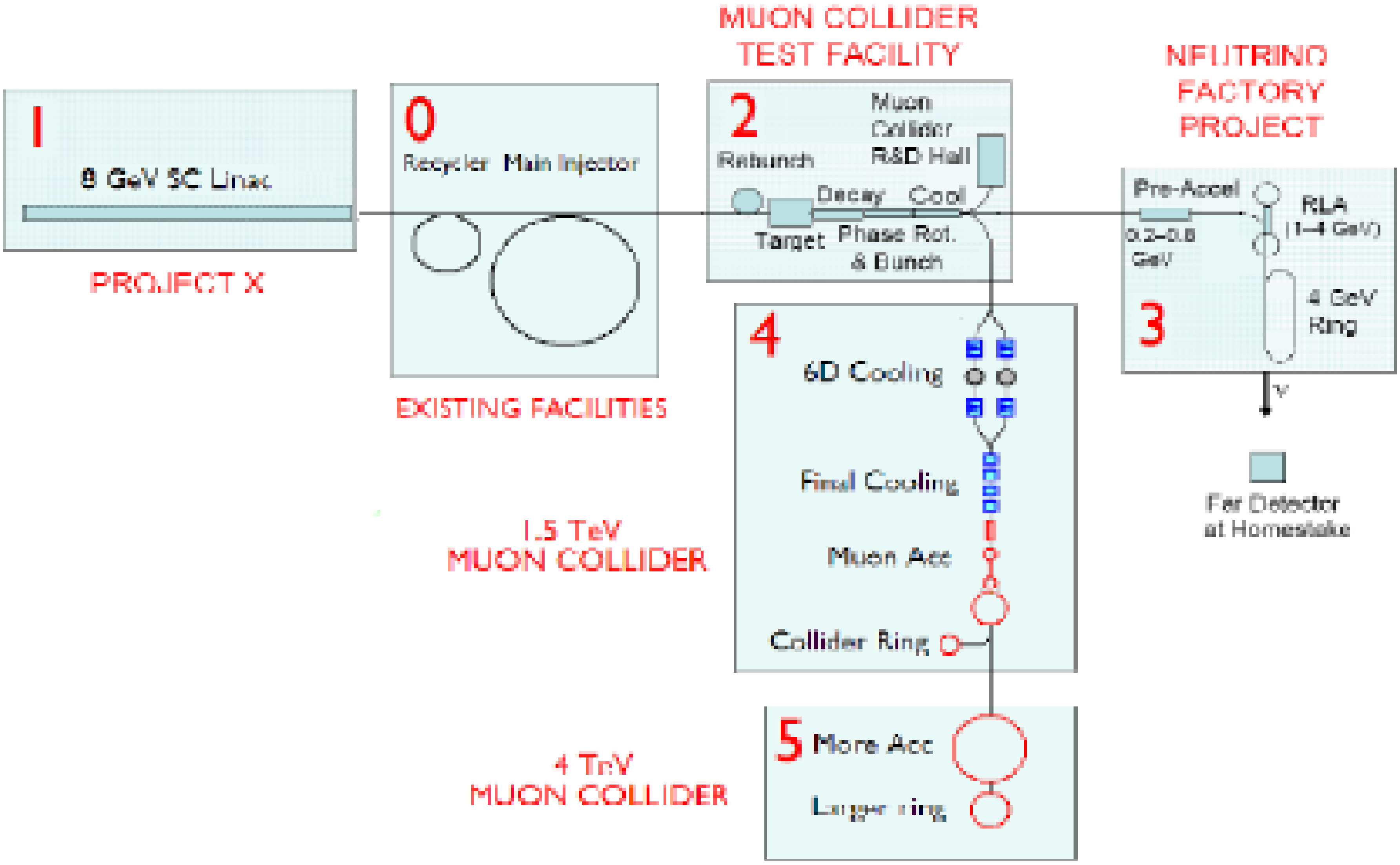
Probability of creating $\mu^+\mu^-$ pairs as a function of the incident photon energy for hydrogen- (solid line) and tungsten (dotted line) targets.



Brightness of muon beams

- The longitudinal and transverse normalized emittances of the $\mu^+\mu^-$ beams produced with a high-intensity 2 GeV γ beam from the tungsten target are calculated as 0.3 mm.
- Transverse emittances can be further reduced by immersing the target into a focusing field thereby limiting the muon beam's size during the gamma ray-beam interaction.
- Focusing will be necessary for a long, targets from light nuclei like liquid-hydrogen.
- It is estimated that the longitudinal and transverse normalized emittances of the captured muon beam produced with proton beams as 20cm and 18 mm, respectively.

Current layout



Conclusion:

- There is good progress at BNL with CO2 laser system.
- High capture efficiency of CLS is investigated.
- Muon source for neutrino factory (1-2B$) project based on Compton source with ERL is suggested.

Target consideration

- For stationary round target cooled through side surface temperature does not depend on the beam size (only ratio of the beam to the target.)

$$\Delta T_{\max} \approx \frac{2P}{L\kappa}\ln\left({R_{target}}\Big/{r_{beam}} \right)$$

- Figure of merit (combination of the heat conductance κ, radiation length ($L=0.3\ X_0$), melting point T_{melt}) is 6.4kW for W and 4kW for T.

$$P_{\max} \approx 4\pi T_{\max}\, 0.3\frac{X_0}{\rho}\,\kappa\left[\ln\left(\frac{R^2}{\sigma_{beam}{}^2}\right)\right]^{-1}$$

Targets election: Rotating VS. stationary

- Rotating target has 10-100 times capture efficiency disadvantage.
- It is due to:
  - bigger spot and bigger output emittance
  - Limited choices of capture optics
- Difficult to build, service

- Stationary target might not survey ILC beam.
- It is likely doable for CLIC
- As small as practically possible target is optimal for "side cooling"
- Liquid target with diamond windows is a better option.