

# Muon Pair Production

Koichiro Shimomura (KEK IMSS)\*

T. Yamazaki (KEK IMSS)

N. Kawamura (KEK IMSS)

D. Nomua (KEK IPNS)

Y. Kawashima (RCNP)

\* Koichiro.shimomura@kek.jp

# Possible way from ILC to muon collider

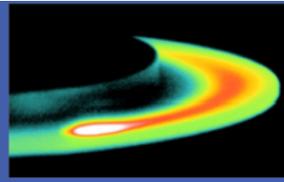
Need efficient muon pair production

- 45 GeV positron beam on fix target
- Use Laser Compton gamma

# Possible way from ILC to muon collider

Need efficient muon pair production

- 45 GeV positron beam on fix target
- Although emittance is good  $O(10^{-4})$   
Intensity is not so large  $2 \times 10^7/s$
- Use Laser Compton gamma

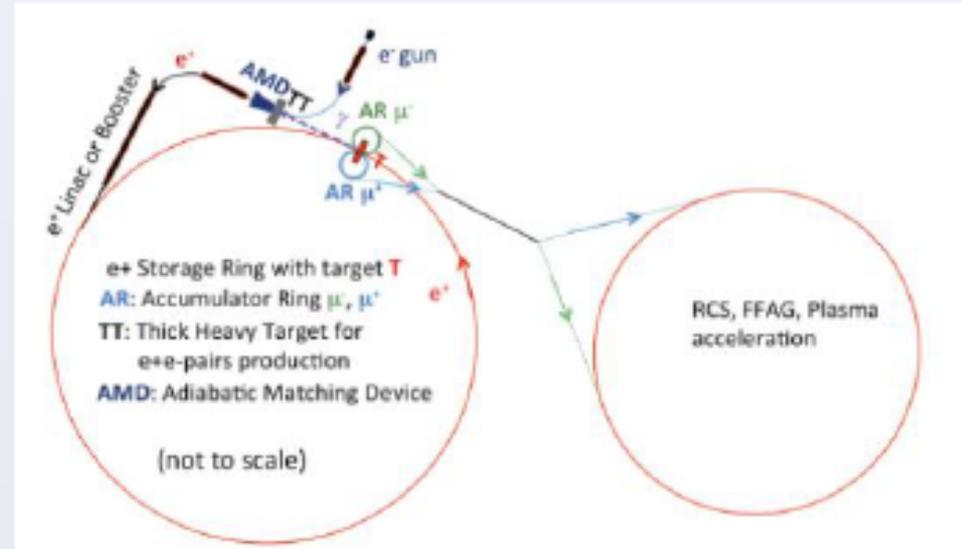


Matteo Iafrati<sup>1,2</sup>, Mario Antonelli<sup>2</sup>, Oscar Roberto Blanco Garcia<sup>2</sup>, Manuela Boscolo<sup>2</sup>, Francesco Collamati<sup>3</sup>, Marco Dreucci<sup>2</sup>, Francesco Edemetti<sup>4</sup>, Susanna Guiducci<sup>2</sup>, Roberto Li Voti<sup>3</sup>, Emanuela Martelli<sup>4</sup>, Luigi Pellegrino<sup>2</sup>, Lorenzo Peroni<sup>5</sup>, and Martina Scapin<sup>5</sup>

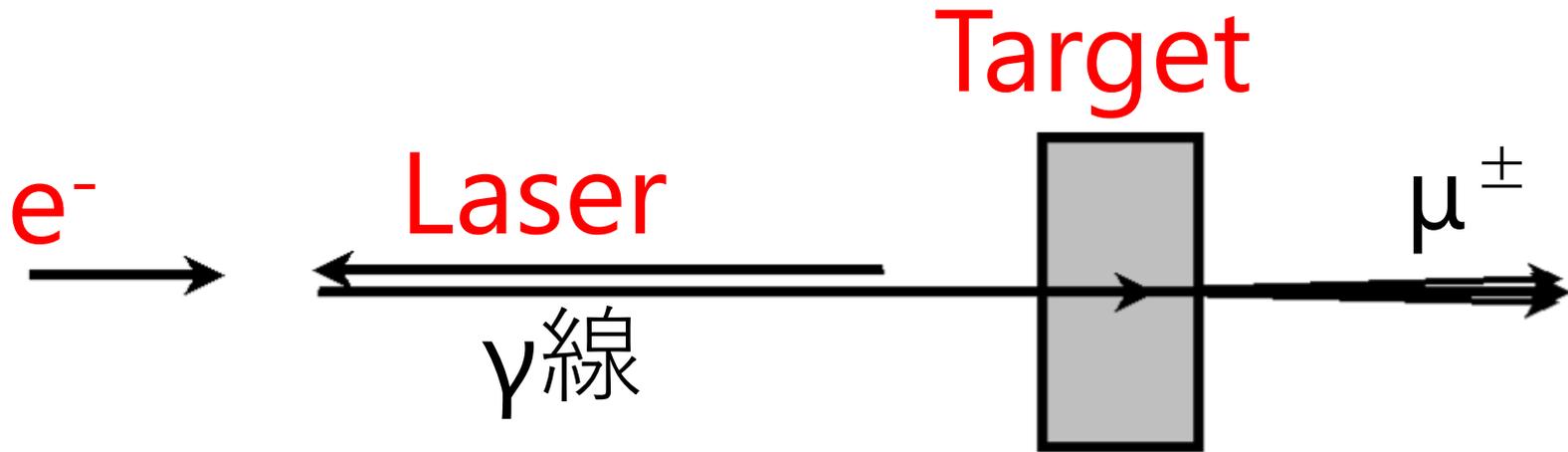
<sup>1</sup>ENEA - Frascati, <sup>2</sup>INFN - LNF, <sup>3</sup>INFN - Roma, <sup>4</sup>Univerita di Roma - La Sapienza, <sup>5</sup>PoliTo - Torino

## Positron beam, interacting with electrons in a target material:

- 45GeV
- $3 \cdot 10^{11} e^+$  per bunches
- 200ns time bunches space
- beam dimension  $O(10 \mu\text{m})$



# Muon pair production



## Study Items

**Electron beam energy from ILC**     5GeV and 125GeV

**Laser choice**

**Muon pair production target**

# Laser Compton

$E_\gamma$  [eV]  $\gamma$  energy  $F_\gamma$  [/s] Flux

$$E_\gamma = \frac{4\gamma^2 E_L}{1 + (\gamma\theta)^2 + 4\gamma E_L/m_e}$$

$$F_\gamma = 2f \frac{\sigma}{A} N_e N_L$$

$\gamma$  : electron  $\gamma$  factor  
 $E_L$  [eV] : Laser photon energy  
 $\theta$  [rad] : scattering angle ( $\sim 1/\gamma$ )  
 $m_e$  [eV] : electron mas  
 $f$  [/s] : collision frequency  
 $\sigma$  [m<sup>2</sup>] : Thomas sc. Cross section  
 $A$  [m<sup>2</sup>] : Area size of larger beam  
 ※ normally laser size  
 $N_e$  : number of electron per pulse  
 $N_L$  : number of photon per pulse

- Assume pulsed laser simultaneously excited ILCに同期したパ  
 $P$  [W], Laser power  $\lambda$  [m], laser wave length

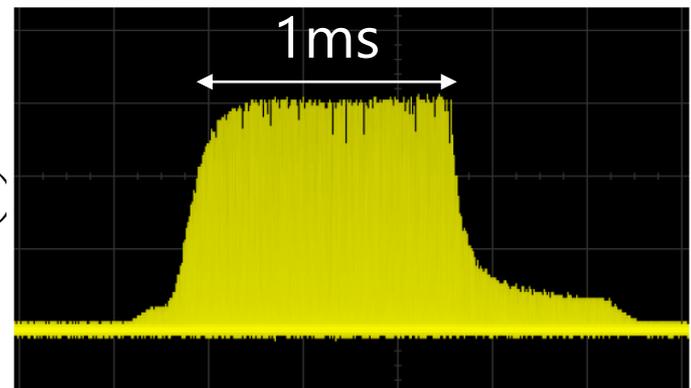
$$F_\gamma \propto f N_L / A \propto P \lambda / A \propto P / \lambda$$

→ High power, Shor wave length

# About Laser Example

- ILC 1 pulse structure 1312 bunch of 0.3mm length, 554ns interval
- Repetition rate 5Hz
- Laser developed by AMPHOS Co.
  - ✓ 1 $\mu$ m wavelength
  - ✓ 200W power
  - ✓ 20J macro pulse (width 1ms) with 10Hz
  - ✓ 20mJ micro pulse  $\sim$ 1MHz in macro pulse
  - ✓ Pulse width  $\sim$ 500ps  
compression with grating  
 $\rightarrow$ 1ps=0.3mm (94% efficiency)
  - ✓  $M^2 < 1.25$  (focusing factor  
focusing size  $\sim$ 1.25 times of wavelength)

Assume every laser pulse interacts with electron beam.

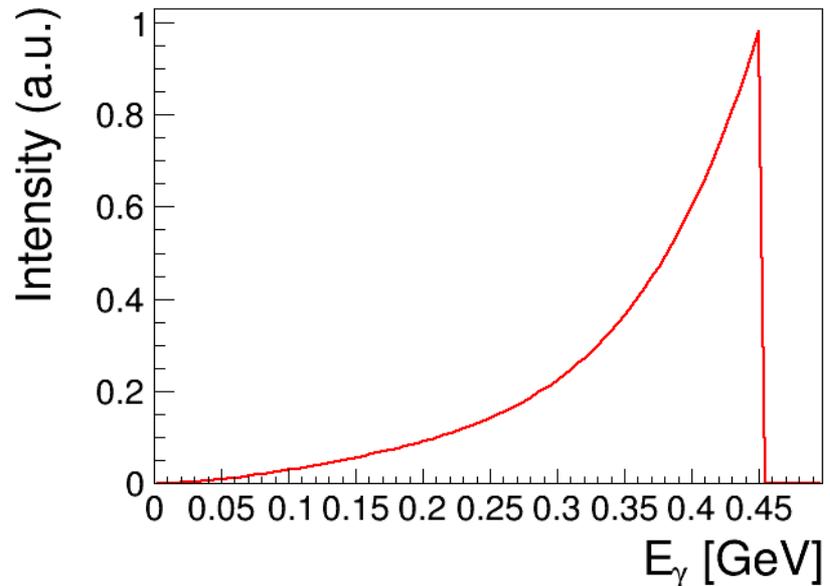


# Beam Dump Specification

Name	Use of the dump	E GeV	PB max kW	W kW
E-1	Commissioning of electron injector	5	100	60
E-2	Extraction from electron DR	5	100	60
E-3	Just before electron bunch compression	5	100	60
E-4	tune-up of electron main linac	125	2500	400
E-5	Electron main dump	125	2500	17000
E-6	Just after electron bunch compression	15	300	60
E-7	Emergency dump just after electron main linac (protect undulator)	125	2500	60
E-8	Spent electron after producing positron (foe 5+5Hz)	150	3000	8000
E+1	Commissioning of positron production system]	5	100	60
E+2	Extraction from positron DR	5	100	60
E+3	Just before positron bunch compression	5	100	60
E+4	tune-up of positron main linac	125	2500	400
E+5	Positron main dump	125	2500	17000
E+6	Just after positron bunch compression	15	300	60
E+7	Dump of photons from undulator	~0.008	60	300

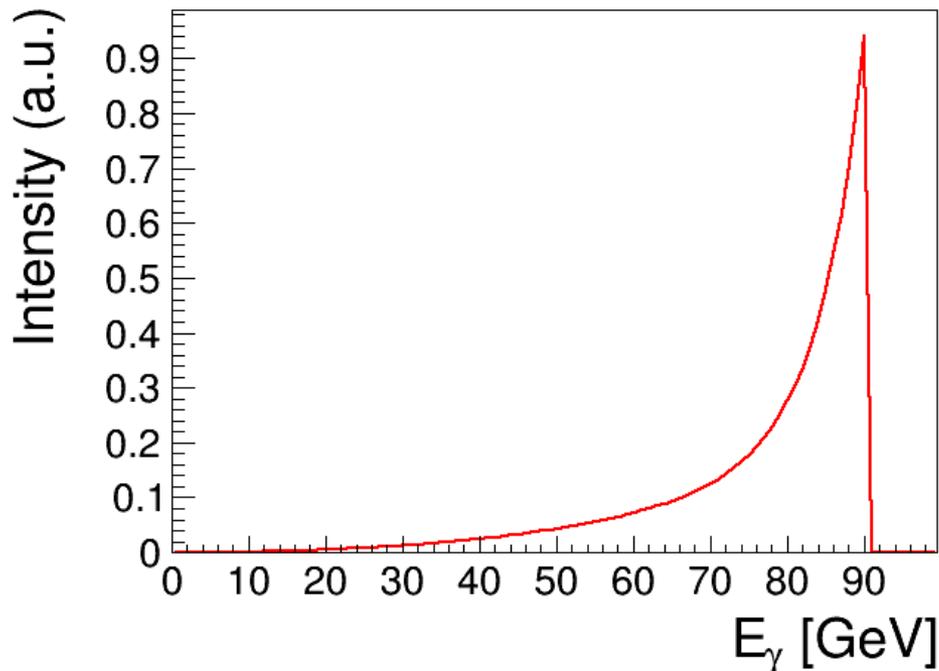
# Case1 5GeV Dump (E-1)

- Beam Power at Dump max=100kW
- Dump  $W=60\text{kW}$ 
  - Assume 50kW (10 $\mu\text{A}$ ) →  $1.25 \times 10^{13}$  e<sup>-</sup>/pulse (10<sup>10</sup> e<sup>-</sup>/bunch)
- $M^2 < 1.25$  however we assume  $w_0 = 10\mu\text{m}$ .
  - Because electron beam bunch length 0.3mm
  - $\lambda = 1\mu\text{m}$
  - $w_0 = 10\mu\text{m}$  Layleigh length  $z_R = \pi w_0^2 / \lambda = 0.3\text{mm}$
- Use P. 3 formula
  - $E_\gamma = 450\text{MeV}$  (max)
  - $F = 8.4 \times 10^{12}$  photons/s
  - Divergence 0.1mrad



# Case2 125GeV Dump (E-5)

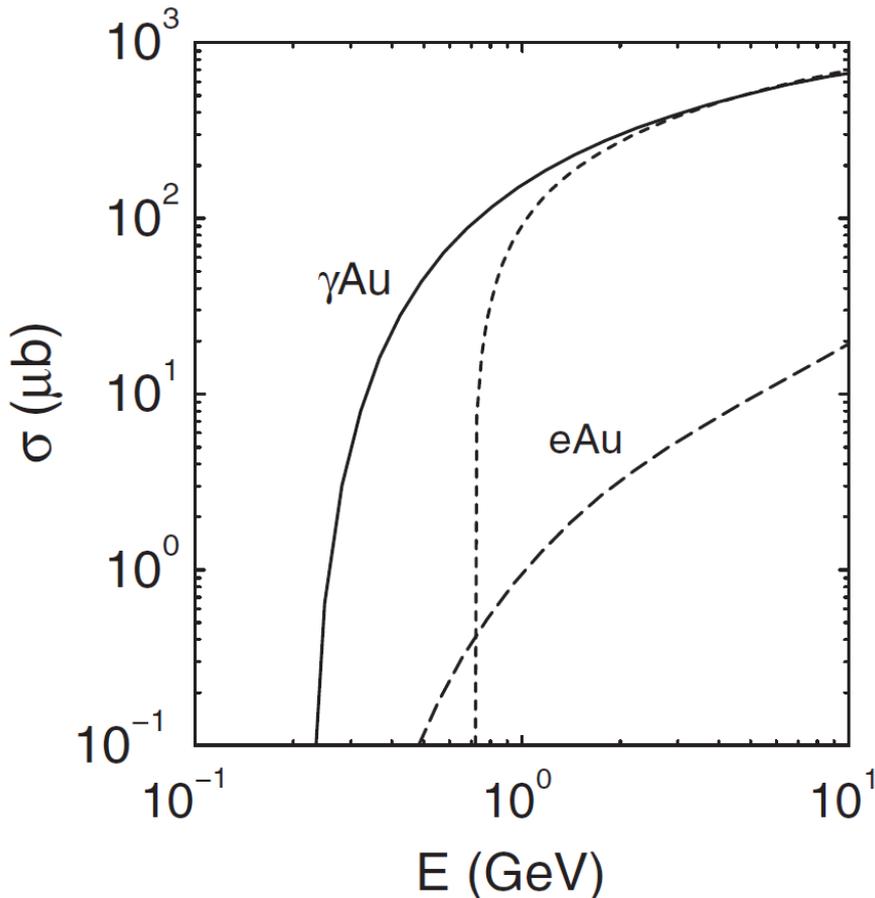
- Beam Power at Dump max= PB max=2500kW
- Dump W=17000kW  
Assume 2500kW (20μA)  $2.5 \times 10^{13}$  e<sup>-</sup>/pulse ( $2 \times 10^{10}$  e<sup>-</sup>/bunch)
- $w_0=10\mu\text{m}$
- Use P. 3 formula,
  - $E_\gamma = 90\text{GeV}$  (Max)
  - $F = 1.7 \times 10^{13}$  photons/s
  - Divergence  $4\mu\text{rad}$
- $\gamma \rightarrow \infty$  で  $E_\gamma \rightarrow E_e$   
→ Better than 5GeV dump



# muon pair production via. $\gamma A \rightarrow \mu^+ \mu^- A$

$\gamma A \rightarrow \mu^+ \mu^- A$  Total cross section

c.f. Phys. Rev. ST Accel. Beams **12**, 111301 (2009)



- Dotted line is approximate

$$\sigma \simeq \frac{28}{9} Z_A^2 \alpha r_0^{\mu 2} \left( \ln \frac{2E_\gamma}{\mu} - \frac{109}{42} \right)$$

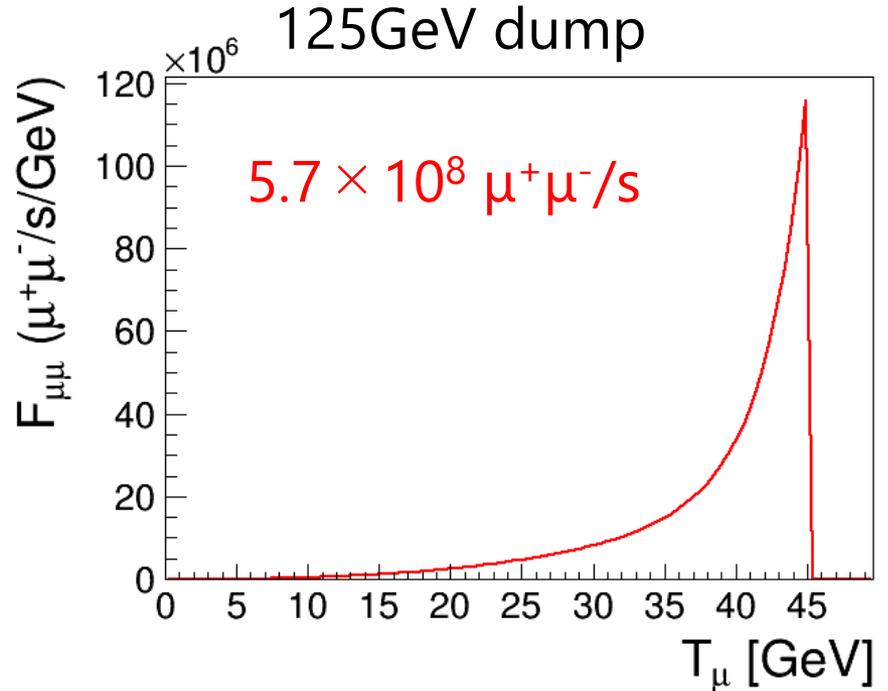
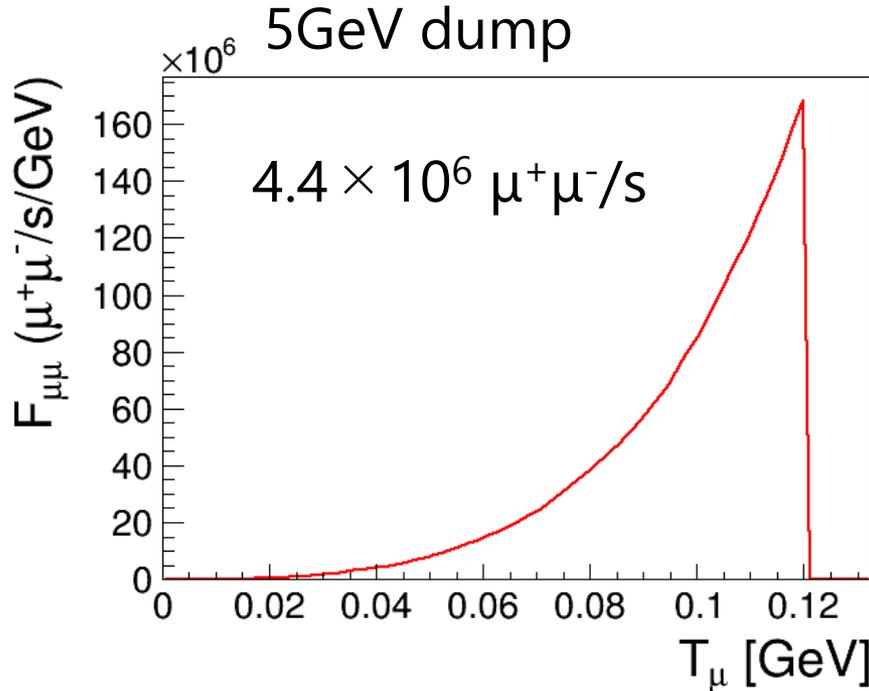
$r_0^\mu$  : classical muon radius

$\mu$  : muon mass

- Au ( $Z=79$ ,  $\rho=19\text{g/cc}$ )  
thickness 1cm
  - 5GeV dump,  $E_\gamma = 450\text{MeV}$
  - $\sigma \sim 30\mu\text{b}$
  - 125GeV dump,  $E_\gamma = 90\text{GeV}$
  - $\sigma \sim 1300\mu\text{b}$

# Muon Beam Intensity

- Au ( $Z=79$ ,  $A=197$ ,  $\rho=19.3\text{g/cm}^3$ )



- 125GeV dump  $\theta \sim 2m_\mu/E_\gamma = O(1)$  mrad
- Beam size
- 5GeV dump 1mm
- 125GeV dump 40 $\mu\text{m}$

# Comparison

Production method	~1GeV p	45GeV e <sup>+</sup>	5GeV e <sup>-</sup>	125GeV e <sup>-</sup>
K.E (GeV)	10 <sup>-3</sup> ~10 <sup>-2</sup>	22	0.1	45
Energy width (%)	10	20	20	10
emittance (mm*mrad)	O(10 <sup>3</sup> )	O(10 <sup>-4</sup> )	O(10 <sup>3</sup> )	O(0.1)
Intensity (/s)	O(10 <sup>8</sup> )	2 × 10 <sup>7</sup>	4 × 10 <sup>7</sup>	6 × 10 <sup>8</sup>
		μ <sup>+</sup> μ <sup>-</sup>	μ <sup>+</sup> μ <sup>-</sup>	μ <sup>+</sup> μ <sup>-</sup>

- Suitable for muon collider !

# Improvement

- How about 500GeV, 1TeV case ?
- Other particle pair production ( $\pi$ ,  $K$ ,  $B$ ,  $\tau$  etc.)
- Any other photon source ?
- Cavity enhancement ? (c.f. H. Shimizu, et al., NIMA **745** (2014) 63-72)