Introduction to Muon Collider & $\gamma\gamma$ Collider

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Outline

- A brief history of particle accelerators and colliders

- Muon collider
  - $\mu^+\mu^-$ collider vs $e^+e^-$ collider
  - “Traditional” muon collider
  - Muon collider for Higgs factory
  - New idea for a muon collider

- $\gamma\gamma$ collider
  - Principle
  - $\gamma\gamma$ collider for Higgs factory
  - Example – How to build a low energy $\gamma\gamma$ collider
1919: Ernest Rutherford discovered the nuclear disintegration by bombarding nitrogen with alpha particles from natural radioactive substances. Later he called for “a copious supply” of particles more energetic than those from natural sources. The particle accelerator era was born.
First Accelerators

1928: Rolf Wideröe, 88 cm glass tube linac

1929: Van de Graaff generator

1930: Ernest Lawrence, 4” cyclotron

1932: Cockcroft-Walton electrostatic accelerator
First Colliders

1961: AdA first lepton collider

1969: ISR first proton collider
World’s Largest Collider – LHC (27 km)
Tens of Thousands Accelerators were built

Light Sources

Neutron Sources

Medical Accelerators

Industrial Accelerators
• Started in 1960s, first 3 colliders: AdA in Italy, CBX in the US and VEP-1 in Russia (then Soviet Union).
• Since then, we have built more than 20 ee colliders.
• We have also built 5 pp and ion-ion colliders as well as one ep collider.
• **However, we have never built a muon collider, nor a \( \gamma\gamma \) collider** because technically it is very difficult.
• But things are changing – there is a new idea about muon collider, and today’s advanced laser technology makes \( \gamma\gamma \) collider immediately possible.
Comparison of Four Particles

A collider requires the following properties of particles:

- Copious supply
- Small emittance
- Stable
- Charged

<table>
<thead>
<tr>
<th>Particle</th>
<th>Copious supply</th>
<th>Small emittance</th>
<th>Stable</th>
<th>Charged</th>
</tr>
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<tbody>
<tr>
<td>p</td>
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<td>✓</td>
<td>✓</td>
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<tr>
<td>e</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td>μ</td>
<td>✓</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>γ</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✗</td>
</tr>
</tbody>
</table>
μ⁺μ⁻ Collider vs e⁺e⁻ Collider

- **Advantages:**
  - Synchrotron radiation $\propto E^4/m^4$, $m(\mu) = 207 \times m(e)$
    - $\Rightarrow$ high energy muon collider ring possible
  - A TeV muon collider ring is small and can fit to the size of existing labs (e.g., Fermilab)
  - Beamstrahlung (synchrotron radiation as two beams collide) also $\propto E^4/m^4$, which is suppressed in a muon collider ring
  - In a Higgs factory, the s-channel ($\mu^+\mu^- \rightarrow H$) cross section $\propto m^2$, $[m(\mu)/m(e)]^2 \approx 43,000$

- **Disadvantages:**
  - In a “traditional” muon collider, initial muon beam has large 6D emittance and must be cooled by a factor of $10^7$ ($10^3$ in each of the two transverse directions and 10 in longitudinal)
  - Cooling and acceleration must be fast (lifetime = 2.2 $\mu$s at rest, but increases as $E/E_0$)
  - Ring magnets and detector requires heavy shielding from decay electrons
Relative Size and Energy of Colliders (R. Palmer)

- **LHC** $p+p$ (1.5 TeV)
- **ILC** $e^+e^-$ (0.5 TeV)
- **CLIC** $e^+e^-$ (3 TeV)
- **Mu-Mu** (4 TeV)

10 km
Fermilab Site – Scale of facility (D. Neuffer)

- Proton Ring
- Coolant line
- Linac
- Target $+\pi^{+} \rightarrow \mu$
- Capture
- Collider Ring
"Traditional" Muon Collider Principle

Steps:
1. A proton driver provides high intensity (~4 MW) short pulse (~2 ns) proton beams on target, producing high flux pions.
2. Pion quickly decays to muon and neutrino.
3. Muon is unstable but has a relatively long mean lifetime (2.2 µs), which becomes longer at higher energy ($\propto E/E_0$). Therefore, a series of beam manipulation is possible before it decays (capture, rotation, cooling, acceleration, storage and collision).
Key Technology – Ionization Cooling

- Radiation cooling (for e+, e-), electron cooling (for pbar), stochastic cooling (for pbar) – all too slow for muons

- Ionization cooling appears feasible:
  - Particles passing through an absorber, losing momentum in three coordinates. RF acceleration restores the longitudinal momentum, while transverse momentum remain reduced.
  - This method cannot be applied to protons due to strong nuclear interaction
  - It cannot be applied to electron either due to strong beamstrahlung
  - But for muons this method is ideal:
    - Muons have no strong interaction
    - Muons have negligible beamstrahlung
    - Ionization cooling is fast
Schematic of “Traditional” Muon Collider (R. Palmer)
Description of Technical Systems (R. Palmer)

1) Proton driver: protons of high power (4 MW), high bunch intensity, short bunch length (2 ns)
2) Mercury jet target and capture solenoid (20 T, SC)
3) Chicane and Be proton absorber (to get rid of protons)
4) Phase rotation (to reduce energy spread by increase bunch length)
5) Charge separation (to form two beams: $\mu^+$ and $\mu^-$)
6) 6D cooling – the most critical stage, ionization cooling, using absorber (gas or liquid hydrogen, or lithium) and rf acceleration
7) Bunch merging (combining multiple bunches into a single bunch)
8) 6D cooling
9) 30-40 Tesla 4D cooling (final cooling, rf cavities inside a 3T solenoid)
10) Recombination
11) Acceleration (recirculating linac, or rapid cycling synchrotron, or FFAG)
12) Collider ring
13) Detectors
s-channel production of Higgs boson (Han and Liu)

- s-channel Higgs production cross section in a muon collider is \(~43,000\) times larger than in an \(e^+e^-\) collider
  \[
  \sigma(\mu^+\mu^- \rightarrow H) \cong 43,000 \times \sigma(e^+e^- \rightarrow H)
  \]
  \(\sigma(\text{peak}) = 70\ \text{pb}\), which should be compared to \(\sigma(e^+e^- \rightarrow ZH) = 0.2\ \text{pb}\)
- This high cross section can compensate the low luminosity of muon collider
- Muon collider can measure the decay width \(\Gamma\) directly without any theoretical assumption (a unique advantage) – if the muon beam energy resolution is sufficiently high
- But the required energy resolution is very demanding
126 GeV $\mu^+\mu^-$ Collider (D. Neuffer)

- **8 GeV, 4MW Proton Source**
  - 15 Hz, 4 bunches $5 \times 10^{13}$/bunch

- **$\pi \rightarrow \mu$ collection, bunching, cooling**
  - $\varepsilon_{\perp,N} = 400 \pi$ mm-mrad, $\varepsilon_{\parallel,N} = 2 \pi$ mm
  - $10^{12}$ $\mu$/bunch

- **Accelerate, Collider ring**
  - $\delta E = 4$ MeV, $C = 300$m
  - Detector
  - monitor polarization precession
  - for energy measurement
  - $\delta E_{\text{error}} \rightarrow 0.1$ MeV

---

### Parameters and Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision Beam Energy</td>
<td>$E_{\mu^+}E_{\mu^-}$</td>
<td>63 GeV</td>
</tr>
<tr>
<td>Luminosity</td>
<td>$L_0$</td>
<td>$10^{31}$</td>
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<tr>
<td>Number of $\mu$ bunches</td>
<td>$n_B$</td>
<td>1</td>
</tr>
<tr>
<td>$\mu^+/ -$ bunch</td>
<td>$N_{\mu}$</td>
<td>$10^{12}$</td>
</tr>
<tr>
<td>Transverse emittance</td>
<td>$\varepsilon_{t,N}$</td>
<td>0.0004 m</td>
</tr>
<tr>
<td>Longitudinal emittance</td>
<td>$\varepsilon_{LN}$</td>
<td>0.002 m</td>
</tr>
<tr>
<td>Energy spread</td>
<td>$\delta E$</td>
<td>4 MeV</td>
</tr>
<tr>
<td>Collision $\beta^*$</td>
<td>$\beta^*$</td>
<td>0.05 m</td>
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<tr>
<td>Beam size at collision</td>
<td>$\sigma_{x,y}$</td>
<td>0.02 cm</td>
</tr>
<tr>
<td>Beam size (arcs)</td>
<td>$\sigma_{x,y}$</td>
<td>1.0 cm</td>
</tr>
<tr>
<td>Beam size IR quad</td>
<td>$\sigma_{\text{max}}$</td>
<td>5.4 cm</td>
</tr>
<tr>
<td>Storage turns</td>
<td>$N_t$</td>
<td>1000</td>
</tr>
<tr>
<td>Proton Beam Power</td>
<td>$P_p$</td>
<td>4 MW</td>
</tr>
<tr>
<td>Bunch frequency</td>
<td>$F_p$</td>
<td>60 Hz</td>
</tr>
<tr>
<td>Protons per bunch</td>
<td>$N_p$</td>
<td>$5 \times 10^{13}$</td>
</tr>
<tr>
<td>Proton beam energy</td>
<td>$E_p$</td>
<td>8 GeV</td>
</tr>
</tbody>
</table>
Muon Ionization Cooling Experiment (MICE)

Under construction

Will test 10% 4D emittance reduction (0.1% accuracy)

Single particle experiment

http://www.mice.iit.edu/

Linda Coney, UCR
Status of “Traditional” Muon Collider

- The idea was first proposed by A. Skrinsky et. al and D. Neuffer in early 1980s
- A first schematic design was presented by D. Neuffer and R. Palmer in 1990s
- A complete design of neutrino factory (a facility using the same technology but less demanding) was published in 2000
- An informal collaboration on neutrino factory and muon collider was formed in 2002
- A formal, US DOE initiated and funded Muon Accelerator Program (MAP) was formed in 2012
- However, upon a recommendation of P5, DOE terminated MAP in 2014 and redirected it to a general R&D
- DOE’s support for MICE ended; MICE finished Step IV running in 2017 but will not continue.
- At this moment, “traditional” muon collider is put on the shelf without much activity
New Muon Collider Principle (M. Boscolo)

Steps:
(1) A high intensity high energy (45 GeV) e+ beam hits a thin target (0.01 radiation length), colliding with e- in the target and producing a muon pair just above the threshold ($\sqrt{s} = 212$ MeV), which has small emittance and small energy spread; therefore, no need for cooling.
(2) Muons can be accelerated and stored for collision.

$$e^+e^- \rightarrow \mu^+\mu^-$$
from **e⁺ SOURCE to RING:**
- e⁺ on conventional Heavy Thick Target (TT) for e⁺e⁻ pairs production.
- possibly with γ produced by e⁺ stored beam on T →
- Adiabatic Matching Device (AMD) for e⁺ collection →
- acceleration (linac / booster) , injection →

**e⁺ RING:**
- 6.3 km 45 GeV storage ring with target T for muon production

**from μ⁺ μ⁻ production to collider**
- produced by the e⁺ beam on target T with E(μ) ≈ 22 GeV, γ(μ) ≈ 200 → τ_{lab}(μ) ≈ 500μs
- **AR:** 60 m isochronous and high mom.
  - acceptance rings will recombine μ bunches for ~ 1 τ_{μ}^{lab} ≈ 2500 turns
- fast acceleration
- muon collider

(Not to scale)
Parameters (M. Boscolo)

**Goal:**

@\( T \approx 10^{11} \mu/s \)

Efficiency \( \approx 10^{-7} \) (with Be 3 mm) → 10^{18} e^+/s needed @\( T \) → e^+ stored beam with \( T \)

need the largest possible lifetime to minimize positron source rate

LHeC like e+ source required rate with life\( t(\text{e}+) \approx 250 \) turns [i.e. 25% momentum aperture] \( \rightarrow n(\mu)/n(\text{e}^+ \text{ source}) \approx 10^{-5} \)

<table>
<thead>
<tr>
<th>e+ ring parameter</th>
<th>unit</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference</td>
<td>km</td>
<td>6.3</td>
</tr>
<tr>
<td>Energy</td>
<td>GeV</td>
<td>45</td>
</tr>
<tr>
<td>bunches</td>
<td>#</td>
<td>100</td>
</tr>
<tr>
<td>e^+ bunch spacing = T_{rev} (AR)</td>
<td>ns</td>
<td>200</td>
</tr>
<tr>
<td>Beam current</td>
<td>mA</td>
<td>240</td>
</tr>
<tr>
<td>N(e+)/bunch</td>
<td>#</td>
<td>3 \cdot 10^{11}</td>
</tr>
<tr>
<td>( U_0 )</td>
<td>GeV</td>
<td>0.51</td>
</tr>
<tr>
<td>SR power</td>
<td>MW</td>
<td>120</td>
</tr>
</tbody>
</table>

(also 28 km foreseen to be studied as an option)
New vs “Traditional”

- **Advantage:**
  - No need for cooling

- **Disadvantage:**
  - Much smaller cross section: \( \sigma(e^+e^- \rightarrow \mu^+\mu^-) < 1 \ \mu b \)
    - about 3 orders of magnitude smaller than proton cross section (~mb)
  - Need much higher intensity of e\(^+\) beam
Status of New Muon Collider

- The idea was first proposed by M. Boscolo et. al at IPAC2017
- A collaboration team on Low Emittance Muon Accelerator has been formed
- Study is at an early stage
- Tests with e+ beam was recently performed at CERN
- Being actively pursued right now
Two steps:

1. Inverse Compton Scattering (ICS) $\rightarrow$ high energy $\gamma$
2. $\gamma\gamma \rightarrow H (bb, cc, \tau\tau, \gamma\gamma, e^+e^-)$
\( \gamma \gamma \) Collider as Higgs Factory

\( \gamma \gamma \rightarrow H \) cross section

Dependence of photon spectrum on polarization

Comparable to 240 GeV e+e- \( \rightarrow ZH \) but only need 160 GeV

\[
\omega_m = \frac{x}{x + 1} E_0; \quad x \approx \frac{4E_0 \omega_0}{m^2 c^4} \approx 15.3 \left[ \frac{E_0}{\text{TeV}} \right] \left[ \frac{\omega_0}{\text{eV}} \right],
\]

Figure 1.3.1: Spectrum of the Compton scattered photons for different polarisations of the laser and electron beams.
Various Proposals for Photon Collider

**HFiTT**
- **HFiTT – Higgs Factory in Tevatron Tunnel**
- Goal: 10,000 Higgs/year
- **Diagram**
  - RF (1.3 GHz, 8 sets, 5 cryomodules 1.25 GV/arc)
  - Energy: 80 GeV
  - Total circumference: ~9 km
  - Parameters:
    - 10, 30, 50, 70 GeV for e⁺ (8 arcs)
    - e⁻ (8 arcs)

**SAPPhiRE**
- **Diagram**
  - 500 MeV e⁻ injector
  - 11-GeV linac
  - Parameters:
    - ~0, 20, 40, 60 GeV for e⁺ (8 arcs)

**CLIC-based**
- **Diagram**
  - Laser γ
  - Detector
  - Main linac
  - Drive beam decelerator
  - Drive beam accelerator

**SLC-type**
- **Diagram**
  - 45 GeV, 1.5 km
  - 85 GeV, 3 km
Key Technology – Laser

- Laser can provide very high peak power (TW or even PW), or very high energy (several MJ) at a very low frequency (one shot in several hours).

- But for $\gamma\gamma$ collider, the laser must have:
  - High average power (from hundreds watts to tens of kW)
  - High single pulse energy (J)
  - Short pulse length (ps)
  - High repetition rate (tens Hz to kHz)
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ILC-based $\gamma\gamma$ Collider

Laser Requirements

<table>
<thead>
<tr>
<th>Pulse width</th>
<th>Pulse energy</th>
<th>Pulse spacing</th>
<th>No. pulses in a train</th>
<th>Laser power in a train</th>
<th>Laser average power</th>
<th>Rep rate</th>
<th>Wavelength</th>
<th>Spot size</th>
<th>Crossing angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ps</td>
<td>10 J /Q</td>
<td>370 ns</td>
<td>2640</td>
<td>25 MW /Q</td>
<td>150 kW /Q</td>
<td>5 Hz</td>
<td>1 $\mu$m</td>
<td>120 nm x 2.3 nm</td>
<td>25 mrad</td>
</tr>
</tbody>
</table>

Need an optical cavity with $Q \sim 300$
Multi-Pass Optics (from the DESY TESLA Design)

2-pass scheme

4-pass scheme

multi-pass scheme 1
Pulse Stacking Laser Cavity for ILC (T. Takahashi)

- total length ~100m
- power enhancement ~100
### CLIC-based and X band-based $\gamma \gamma$ Collider

- **Pulse width:** 1 ps
- **Pulse energy:** 5 J
- **Pulse spacing:** 0.5 ns
- **No. pulses in a train:** 354 (5 x 354 = 1770 J per train)
- **Laser power in a train:** 10 GW
- **Laser average power:** 88.5 kW
- **Rep rate:** 50 Hz
- **Wavelength:** 1 $\mu$m
- **Spot size:** 120 nm x 2.3 nm
- **Crossing angle:** 25 mrad

### Laser Requirements

<table>
<thead>
<tr>
<th>Pulse width</th>
<th>Pulse energy</th>
<th>Pulse spacing</th>
<th>No. pulses in a train</th>
<th>Laser power in a train</th>
<th>Laser average power</th>
<th>Rep rate</th>
<th>Wavelength</th>
<th>Spot size</th>
<th>Cross angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ps</td>
<td>5 J</td>
<td>0.5 ns</td>
<td>354 (5 x 354 = 1770 J per train)</td>
<td>10 GW</td>
<td>88.5 kW</td>
<td>50 Hz</td>
<td>1 $\mu$m</td>
<td>120 nm x 2.3 nm</td>
<td>25 mrad</td>
</tr>
</tbody>
</table>

Livermore LIFE fusion project laser beam: 130 kW average power, 8100 J /pulse, 16 Hz (LIFE would have 384 such beams)
Livermore fusion project LIFE will have 384 laser boxes
One would be enough for $\gamma \gamma$ collider
**Figure 2:** Principle of a coherent amplifier network (CAN) based on fiber laser technology. An initial pulse from a seed laser (1) is stretched (2), and split into many fibre channels (3). Each channel is amplified in several stages, with the final stages producing pulses of ~1 mJ at a high repetition rate (4). All the channels are combined coherently, compressed (5) and focused (6) to produce a pulse with an energy of **>10 J** at a repetition rate of **10 kHz** (7). [5]
Two unique experiments:
• $\gamma \gamma \to \gamma \gamma$ scattering: predicted (Halpern) but never observed in the laboratory
• $\gamma \gamma \to e^+e^-$: predicted (Breit-Wheeler) but never observed in the laboratory
$\sigma_u (\mu\text{barn})$

threshold of the Breit-Wheeler process

threshold of the Bethe-Heitler process $\gamma \rightarrow e^+e^-$

integrated luminosity corresponding to a bare minimum of about 100 scattering events (total).

$E_\gamma^6$

$E_{CM} \approx 630 \text{ keV}$

$E_{CM} \approx 880 \text{ keV}$

$E_{CM} \approx 13 \text{ MeV}$

$E_{CM} \approx 140 \text{ MeV}$

$\gamma\gamma \rightarrow \gamma\gamma$

$\gamma\gamma \rightarrow e^+e^-$

1 nb$^{-1}$

10 pb$^{-1}$
### γγ Collider Parameters (11/01/2018)

<table>
<thead>
<tr>
<th>Electron beam</th>
<th>Laser beam</th>
<th>γ Beam / γγ → γγ collision</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>200 MeV</td>
<td>E(c.m., peak) 1 MeV (2 x 0.5)</td>
</tr>
<tr>
<td>Charge</td>
<td>2 nC</td>
<td>N (total) 2 x 10^{11} /s</td>
</tr>
<tr>
<td>σ(x,y)</td>
<td>2 μm</td>
<td>Rep rate 50 Hz</td>
</tr>
<tr>
<td>β*</td>
<td>626 μm</td>
<td>Pulse energy 2 J</td>
</tr>
<tr>
<td>ε</td>
<td>6.4 nm</td>
<td>σ(x,y) 2 μm</td>
</tr>
<tr>
<td>σ(z)</td>
<td>2 ps</td>
<td>Pulse length 1 ps</td>
</tr>
<tr>
<td>Rep rate</td>
<td>50 Hz</td>
<td>L 1 x 10^{27} cm^{-2}s^{-1}</td>
</tr>
<tr>
<td>Crossing θ</td>
<td>0 mrad</td>
<td>Cross section 3 μb</td>
</tr>
<tr>
<td>L (geometric)</td>
<td>1.6 x 10^{28}</td>
<td>Event rate 7 /hr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nonlinear a₀ 0.45</td>
</tr>
</tbody>
</table>

#### Event rate:
- γγ → γγ: L = 1 x 10^{27}, σ = 3 μb ⇒ several events per hour (30,000 events/year)
  *Comparable to the Higgs rate in CEPC, in which the luminosity is higher by 7 orders of magnitude, but cross section is smaller by 7 orders of magnitude*
- γγ → e^+e^-: L = 1 x 10^{27}, σ = 100 mb ⇒ 100 events per second
Electron Linac for $\gamma\gamma$ Collider

- RF GUN
- A0, A1, A2, A3, A4
- 2 e- pulses
  - 200 MeV, 50 Hz
- K1, K2, K3
- $\rho = 3 \text{ m}$
- $B = 2 - 3 \text{ kG}$
- $\gamma\gamma$ collision (1 MeV)
- Laser
  - (1 $\mu$m, 2 J, 50 Hz)
- FFS

W. Chou
CAS, 22/02/2018, Zurich
1 sigma beam size of BEAM Line A (beam energy dispersion effect is not included)
1 sigma beam size of BEAM Line B (beam energy dispersion effect is not included)
Beta function and 1 sigma beam size near the IP.
16-piece Permanent Quadrupole (Y. Chen)

<table>
<thead>
<tr>
<th></th>
<th>d (mm)</th>
<th>G (T/m)</th>
<th>L (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1#</td>
<td>6</td>
<td>590</td>
<td>9.1</td>
</tr>
<tr>
<td>2#</td>
<td>6</td>
<td>590</td>
<td>15</td>
</tr>
<tr>
<td>3#</td>
<td>6</td>
<td>590</td>
<td>25</td>
</tr>
</tbody>
</table>

2.0 T vs. 1.95T @ 3mm
Narrowband power amplifier

- **Extracted energy:**
  - $340 \text{mJ} @ 100 \text{Hz}$

<table>
<thead>
<tr>
<th><strong>Magma 300</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pulse duration</strong></td>
</tr>
<tr>
<td><strong>Average power</strong></td>
</tr>
<tr>
<td><strong>Pulse energy</strong></td>
</tr>
<tr>
<td><strong>Repetition rate</strong></td>
</tr>
<tr>
<td><strong>Wavelength</strong></td>
</tr>
<tr>
<td><strong>Beam quality</strong></td>
</tr>
<tr>
<td><strong>Footprint</strong></td>
</tr>
<tr>
<td><strong>Cooling</strong></td>
</tr>
</tbody>
</table>
Detector (Y. Huang, C. Zhang, J. Lu)

Detector dimension

- Length = 76 cm
- Inner diameter = 40 cm
- Thickness = 6 cm

PS detector

- Attached in front and inner side of the crystal
- Thickness = 1 cm

CsI crystal

- 46 Lines,
- 23 crystals per line
- 966 crystals
Figure 1.3.1: Spectrum of the Compton scattered photons for different polarisations of the laser and electron beams.
Luminosity Calculation (code CAIN)

(L. Takahashi)

$L = 1.1 \times 10^{27} \text{ cm}^{-2} \text{ s}^{-1}$ for $0.9 \text{ MeV} < W$

$L = 3.3 \times 10^{27} \text{ cm}^{-2} \text{ s}^{-1}$ for all energy
Detector Simulation (T. Takahashi, B.H. Sun)

Detection simulations design, resolution, efficiency, background …

Physics simulation $\gamma\gamma \rightarrow \gamma\gamma$, $\gamma\gamma \rightarrow e^+e^-$, $\gamma e^- \rightarrow \gamma e^-$ …

Shielding design and simulation beam Scattering, collimation design…

The study gets under way
$\gamma \gamma \rightarrow \gamma \gamma \quad \sqrt{s} = 1.41 \text{MeV}$

**Back to back photons 0.0019 events/s**
Detector Simulation (T. Takahashi, B.H. Sun)

\[ \gamma \gamma \rightarrow e^+ e^- \sqrt{s} = 1.41 \text{MeV} \quad \Rightarrow \quad p_{e^\pm} \approx 0.48 \text{MeV} \]

Low momentum $e^+ e^-$ not back to back 64 events/s
Challenges

• **Electron beam:**
  * high charge (2 nC)
  * low emittance (6 nm at 200 MeV)

• **Laser beam:**
  * high average power (100 W)
  * high repetition rate (50 Hz)
  * high intensity (2 J)
  * short pulse (1 ps)

• **FFS:**
  * small size, high gradient PMQ (600 T/m)

• **Detector:**
  * to select $\gamma\gamma$ signal from e+e- signal
  * strong background from e$\gamma$ and e-e- collisions

• **Timing:**
  * Jitter requirement: <100 fs
  * between e-beam and laser
  * between two laser beams
Status of $\gamma \gamma$ Collider

- High energy $\gamma \gamma$ collider for Higgs factory:
  There are a number of proposals. However, the timeline to construct a real one appears to be very long – it has to wait until a high energy $e^+e^-$ collier is built (e.g., ILC, CLIC)

- Low energy $\gamma \gamma$ collider:
  Being actively pursued in China, Italy and Japan (part of ELI-NP). The construction of at least one of them is likely to happen soon.

- Medium energy $\gamma \gamma$ collider:
  If a low energy $\gamma \gamma$ collider is successfully built, a medium energy one may quickly follow suit, because it can use existing electron accelerators and also because there are a lot of interesting physics in several GeV range.
Both muon collider and $\gamma\gamma$ collider were proposed in 1980s but have never been built because of technical difficulties.

The “traditional” muon collider had been pursued for more than 20 years but the activity is stalled due to lack of technology breakthrough (e.g., how to solve the problem of RF breakdown in a strong magnetic field) and other reasons.

A new idea about muon collider was recently proposed and appears to gain momentum, because it has no need for muon cooling. But it must find a solution for how to produce a high intensity e+ beam.

From early on, $\gamma\gamma$ collider had been considered as an afterburner of a high energy linear collider and, thus, a remote possibility.

However, interest in a low energy $\gamma\gamma$ collider together with today’s advanced laser technology has changed the game plan. A first $\gamma\gamma$ collider can be built in just a few years.

This field is very challenging and will attract young and talented people who love challenges.

But this field also contains high risk. ROI (return on investment) is uncertain – it could be enormous (success will crown you “world no. 1”), but it might also go nowhere.
Questions?