A proposed γ–γ collider in China

Chuang Zhang and Weiren Chou

For the BggC Study Group

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Russia V. Telnov

A proposed γ–γ collider in China

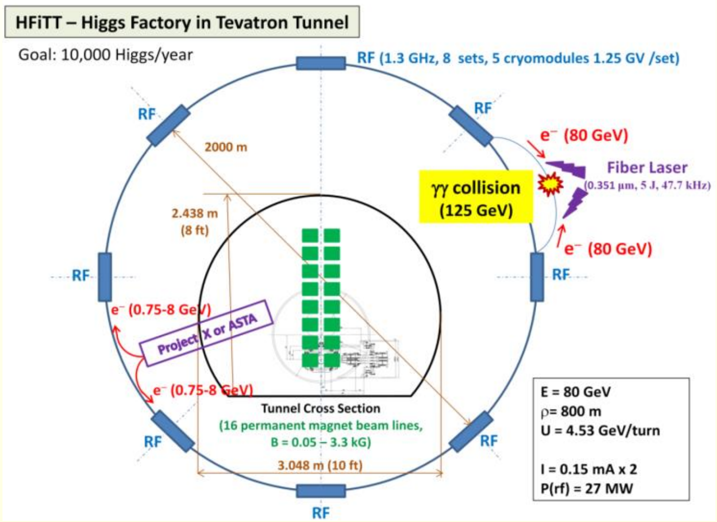
- Introduction
- Scheme and site of BggC
- Parameter optimization
- Design study on BggC
- Summary

ICFA Mini-Workshop on γγ Collider (April, TU)

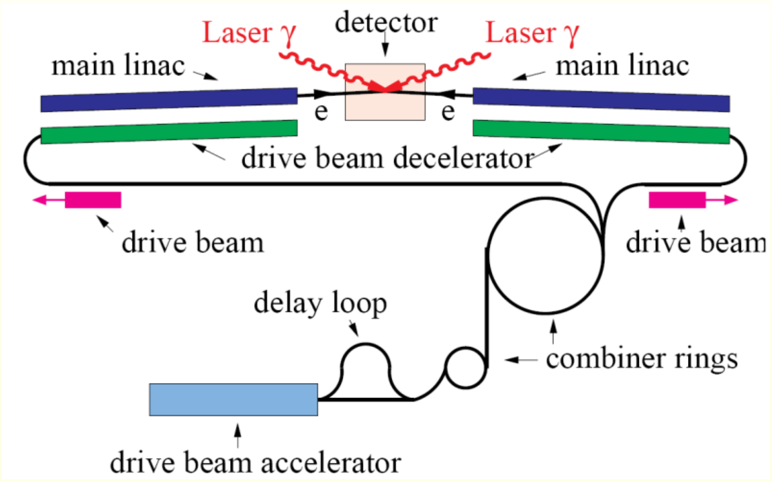
- ~100 participants from 9 countries
- A joint stage of several scientific communities: HEP (γγ) + NP (γ-ray) + accelerator + laser

Various Proposals for Photon Collider

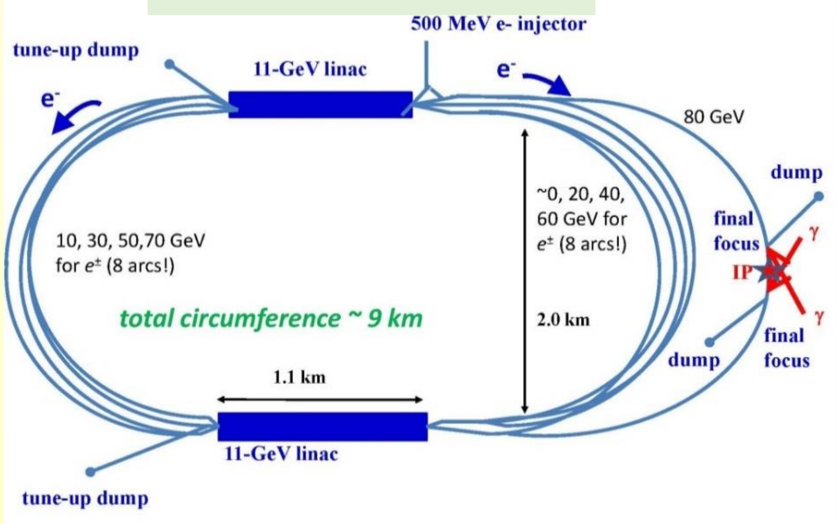
HFiTT



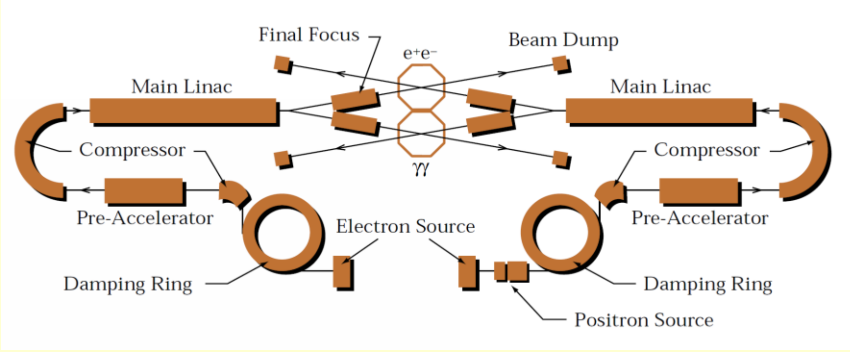
CLIC-based



SAPPHiRE

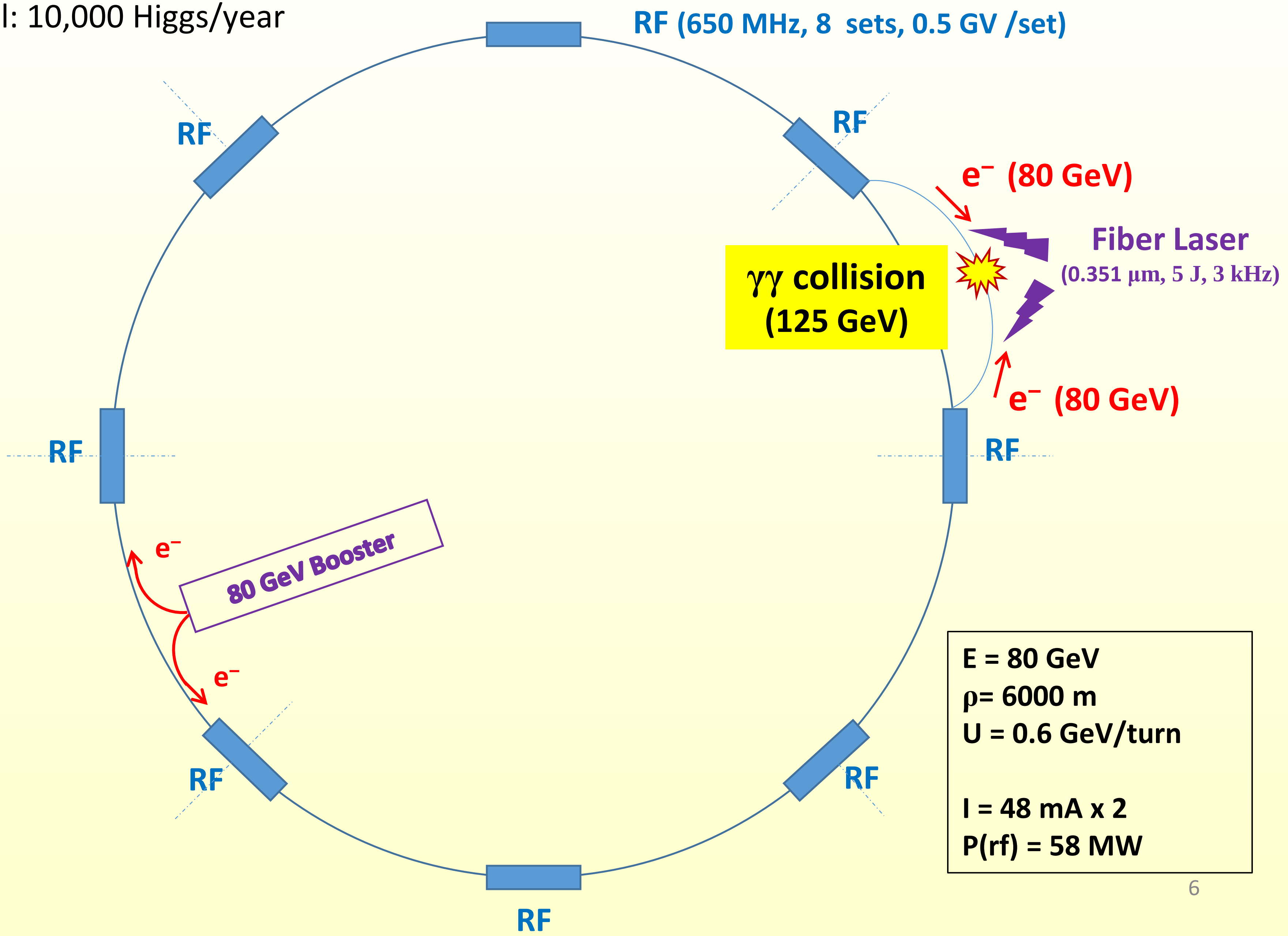


X band-based



CEPC as a γγ Higgs Factory

Goal: 10,000 Higgs/year



$\gamma\gamma \to \eta_b$ (V. Telnov)

Resonance formation from two real photon collisions

$Q = 0$, $C = +$, $J^P = 0^+, 0^-, 2^+, 2^-, 3^+, 4^+, 4^-, 5^+ \ldots (\text{even})^\pm, (\text{odd} \neq 1)^+$

Example: $\gamma\gamma \to \eta_b$.

There was attempt to detect this process at LEP-2 (2E=200 GeV, L=10^{32}, but only upper limit was set.

$$N = \frac{dL_{\gamma\gamma}}{dW_{\gamma\gamma}} \frac{4\pi^2 \Gamma_{\gamma\gamma}(1+\lambda_1\lambda_2)}{M_x^2} \left(\frac{\hbar}{c}\right)^2 t$$

For our collider $\dfrac{dL_{\gamma\gamma} 2E_0}{dW_{\gamma\gamma} L_{ee}} \simeq 0.5$, so

$$N \sim \frac{\pi^2 \Gamma_{\gamma\gamma}(1+\lambda_1\lambda_2)}{E_0 M_x^2} \left(\frac{\hbar}{c}\right)^2 (L_{ee}t) \sim 8 \cdot 10^{-27} \frac{\Gamma_{\gamma\gamma}}{E_0 M_x^2 [\text{GeV}^2]} (L_{ee}t)$$

For $\Gamma_{\gamma\gamma}(\eta_b) = 0.5$ keV, $E_0 = 17.5$ GeV, $M(\eta_b) = 9.4$ GeV, $\lambda_{1,2} = 1, L_{ee} = 1.1 \cdot 10^{33}$ - $\underline{2.2 \cdot 10^{34}}$,

$t = 3 \cdot 10^7 s$ we get $N(\eta_b) \approx 10^5 - 2 \cdot 10^6$ and measure its $\Gamma_{\gamma\gamma}$

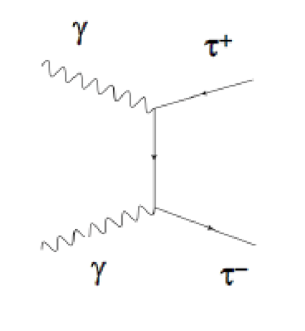
Production rate is higher than was at LEP-2 (in central region) ~ 500 - 10^4 times!

Such photon collider has very rich physics, incl. 4-quark (or molecular) states. Many such states with unclear nature have been discovered recently.

Just for information. η_b is detected in radiative decays of $\Upsilon(nS)$. Babar has detected ~ 30000 η_b, this was not sufficient to detect its decay to $\gamma\gamma$, because Br~$7 \cdot 10^{-5}$. Such decay can be observed at Super-B. LHC with 300 fb^{-1} will produce $5 \cdot 10^9$ η_b.

$\gamma\gamma \rightarrow \tau\tau$ (M. Velasco)

Proposal for $\gamma\gamma$ collider at the $\tau\tau$ threshold



$3.6\ \text{GeV} < E_{\gamma\gamma} < 8\ \text{GeV}$

Or $2m_\tau < E_{\gamma\gamma} < 2m_b$

Away from bb thresholds to avoid contamination from B to τ decays

Indirect search for new physics

1. First precise measurement of the g-2 of the τ (a_τ)
   - $\tau\tau\gamma$ vertex
2. Improve g-2 of the μ (a_μ) *
   - Hadronic decays of the τ like τ to $\nu_\tau\pi^\pm\pi^0$

Direct search for new physics

3. Search for lepton flavor violation (i.e. $\tau \rightarrow \mu\gamma$, $\mu\mu\mu$, etc.) *
4. Search for CP and T -Violation in τ measured from dipole moment and rate, angular and polarization asymmetries from τ decays

** Topics part of the Intensity Frontier program in the USA*

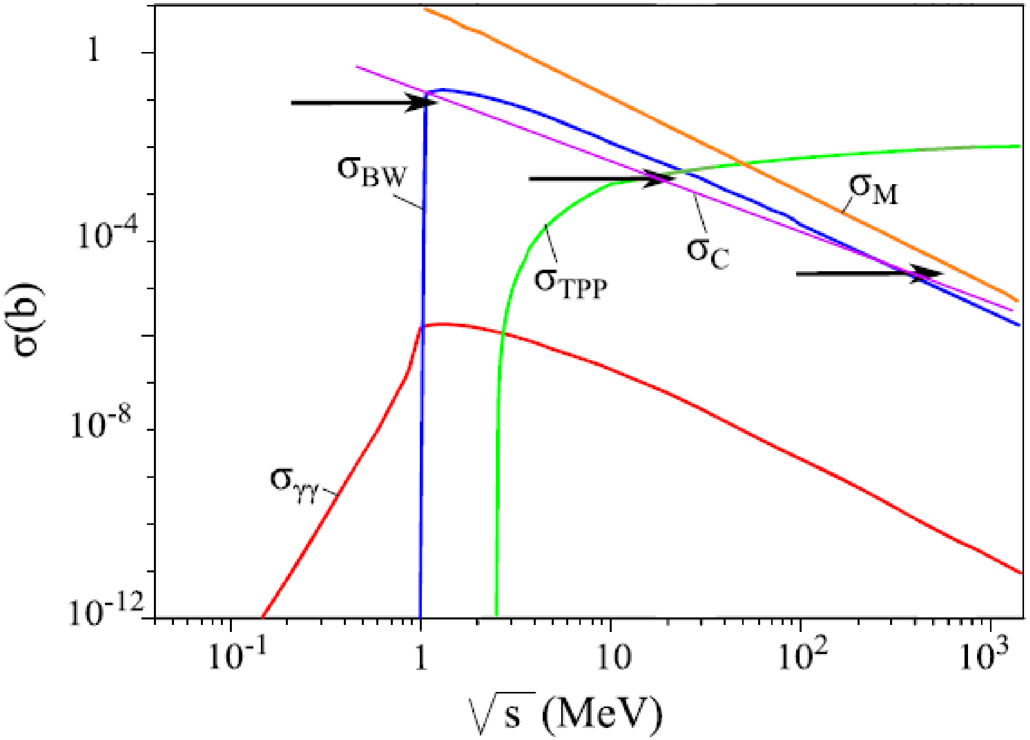


FIG. 3. Total cross section in b for gamma gamma ($\sigma_{\gamma\gamma}$, red line), Breit-Wheeler (σ_{BW}, blue line), TPP (σ_{TPP}, green line), Møller (σ_{M}, orange line) and Compton (violet line) scatterings versus the energy in the center of mass $\sqrt{s}$ (in MeV) of each process. In blue, green, and orange the center of mass energy regions involved in the various processes for electron energy of about 260 MeV. The arrows mark the values of the cross-sections. The Møller cross-section has been evaluated with a cut at $|\cos\theta| < 0.999$.

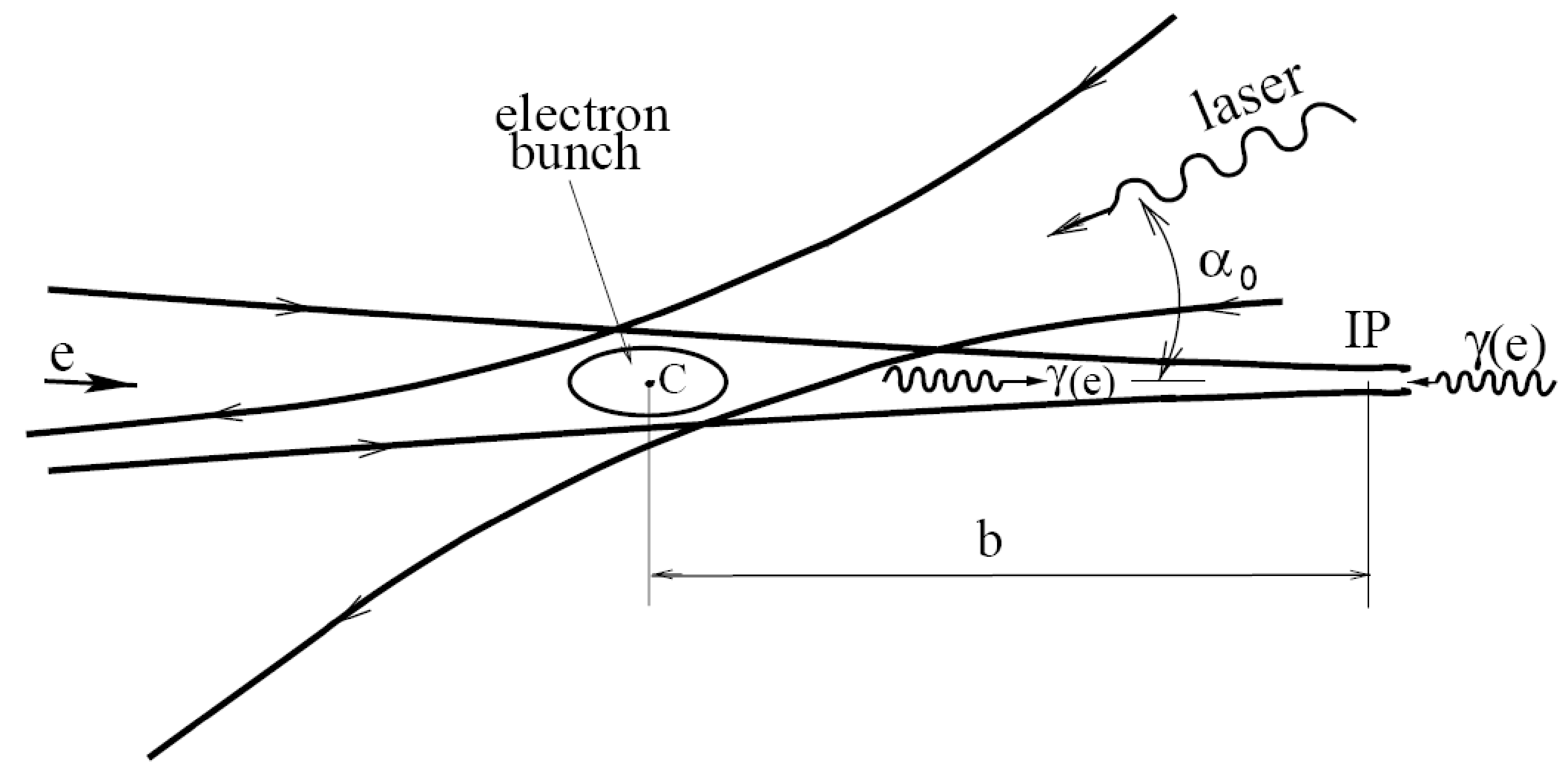
I. Drebot et. al, PRAB 20, 043402 (2017)

$\gamma\gamma$ Collider Principle

Two steps:

(1) Inverse Compton Scattering (ICS) → high energy γ

(2) $\gamma\gamma \rightarrow H$ (bb, cc, $\tau\tau$, $\gamma\gamma$, e^+e^-)



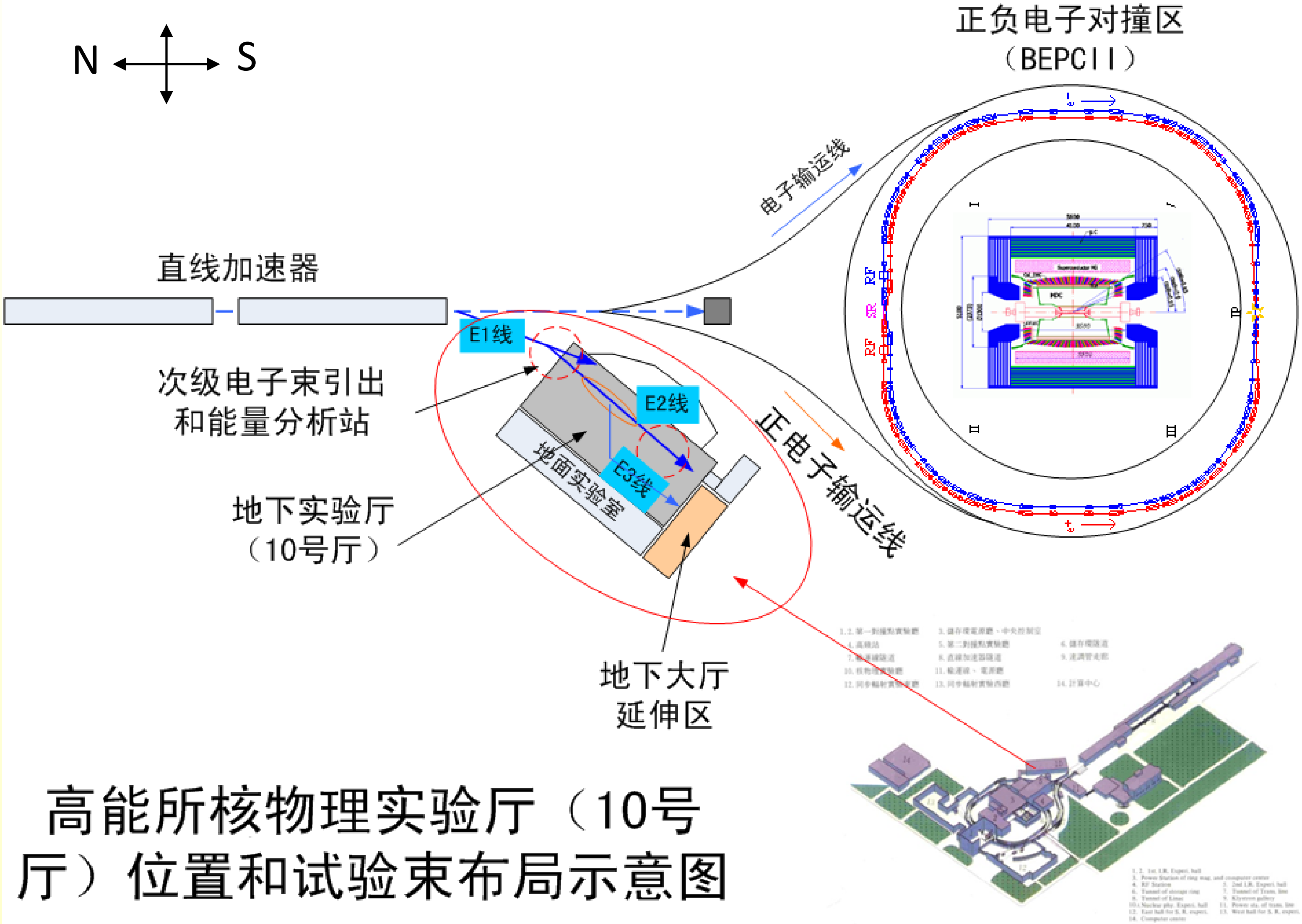
2. Scheme and site of BggC

Machine Candidates in China

Institution	Machine	Energy
IHEP	BEPC linac	0.18 – 2.7 GeV
	HEPS linac	300 MeV
	HEPS ring	6 GeV
Tsinghua U.	TTX	50 MeV
	XGLS photoinjector	130 MeV
	XGLS linac	400 MeV
USTC	Hefei Light Source linac	800 MeV
Shanghai	SSRF linac	150 MeV
	SSRF ring	3.5 GeV
	SXFEL linac	0.8 – 1.3 GeV
	HXFEL linac	8 GeV

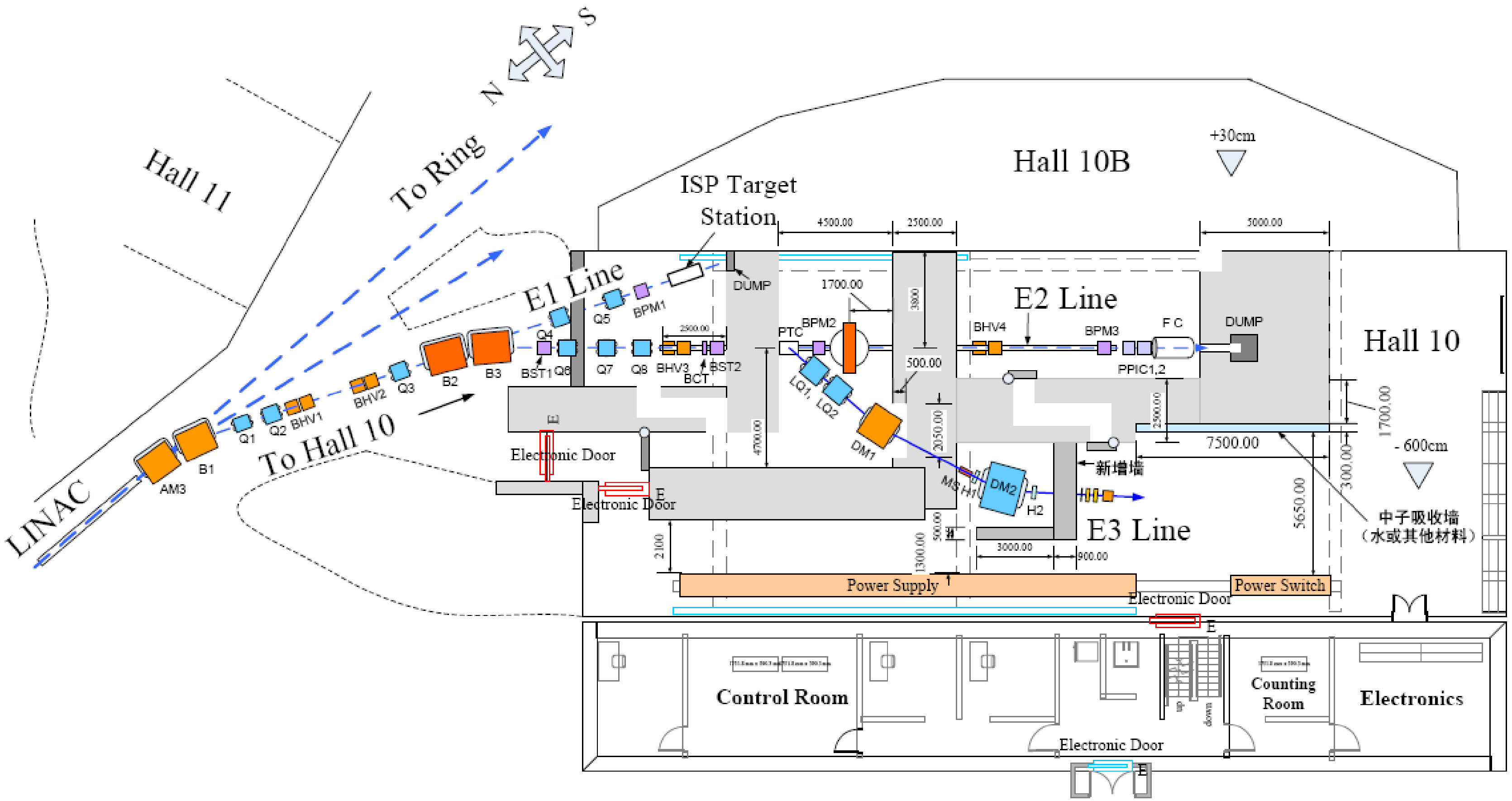
(red: under construction or approved for construction)

BEPC Ring, Linac and Hall #10

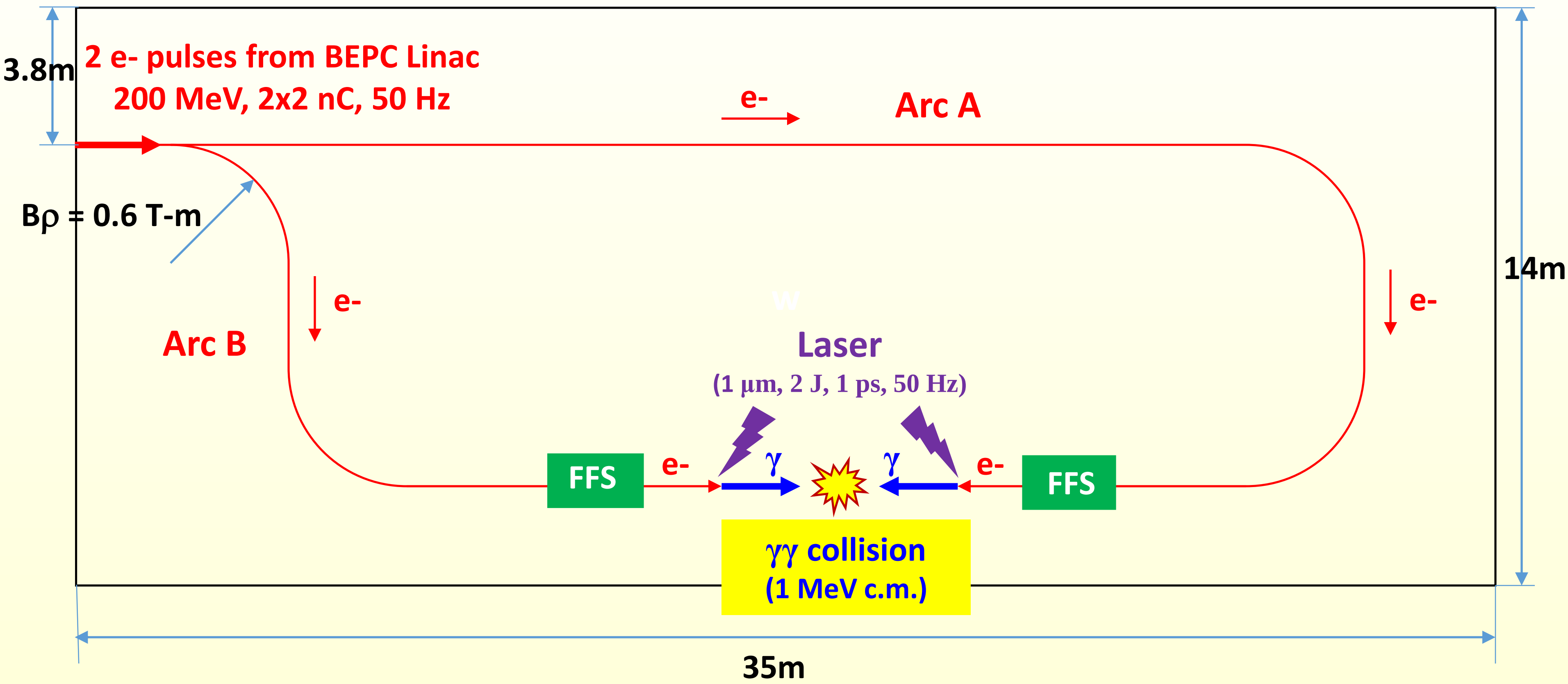


高能所核物理实验厅（10号厅）位置和试验束布局示意图

Hall #10 – Present Layout



How to build a γγ Collider in Hall #10



Two unique experiments:

- γγ → γγ scattering: predicted (Halpern) but never observed in the laboratory
- γγ → e^+e^-: predicted (Breit-Wheeler) but never observed in the laboratory

3. Parameters optimization

- Luminosity and event rate
- Electron beam energy & laser power
- CP-IP distance and crossing angle
- Electron beam size at IP
- Distance between FFS quad to IP

Preliminary Parameters (T. Takahashi)

Laser		Electron	
Wave Length(μm)	1.054	Energy(MeV)	200
Size at focus RMS (μm)	5	Bunch charge(nC)	2
Rayleigh Range(μm)	298	Size at IP (μm)	2
Pulse energy (J)	2	Emittance (nm)	6.39
Pulse Length(μm)	300 (1 ps)	β^* (μm)	626
Repetition (Hz)	50	Bunch length (mm)	0.6
Crossing angle(mrad)	167	Repetition (Hz)	50
IP-CP distance(μm)	313	Crossing angle (mrad)	0
Nonlinear parameter a_0	0.45	Geometric luminosity	1.6×10^{28}cm^{-2}s^{-1}

Event rate:

- $\gamma\gamma \to \gamma\gamma$: L = 1 x 10^{27}, σ = 3 μb $\Rightarrow$ several events per hour (40,000 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*)
- $\gamma\gamma \to e^+e^-$: L = 1 x 10^{27}, σ = 100 mb $\Rightarrow$ 100 events per second

3.1 Luminosity and event rate

$$N_{events} = \varepsilon \cdot \sigma L$$

$$\int \sigma(w) \frac{dL}{dw} dw$$

$$\begin{cases} L_{\gamma\gamma} \\ L_{e\gamma} \\ L_{ee} \end{cases}$$

CAIN simulation

$$\begin{cases} \gamma\gamma \to \gamma\gamma \\ \gamma\gamma \to e^+e^-(\gamma) \\ \gamma e^- \to \gamma e^- \\ e^+e^- \to e^+e^- \end{cases}$$

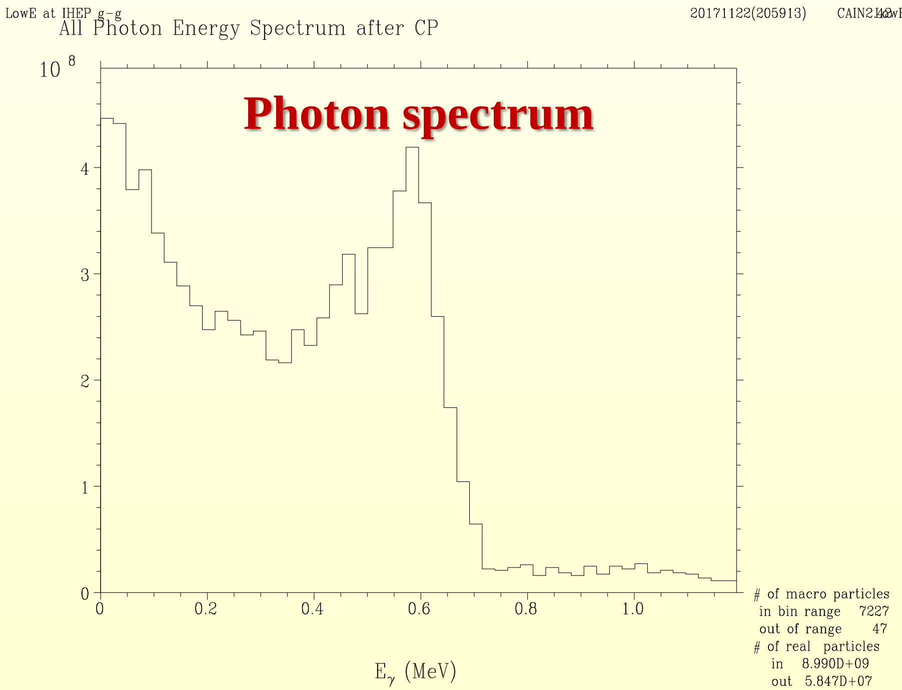
Physics programs
such as Whizard, Grace,
……

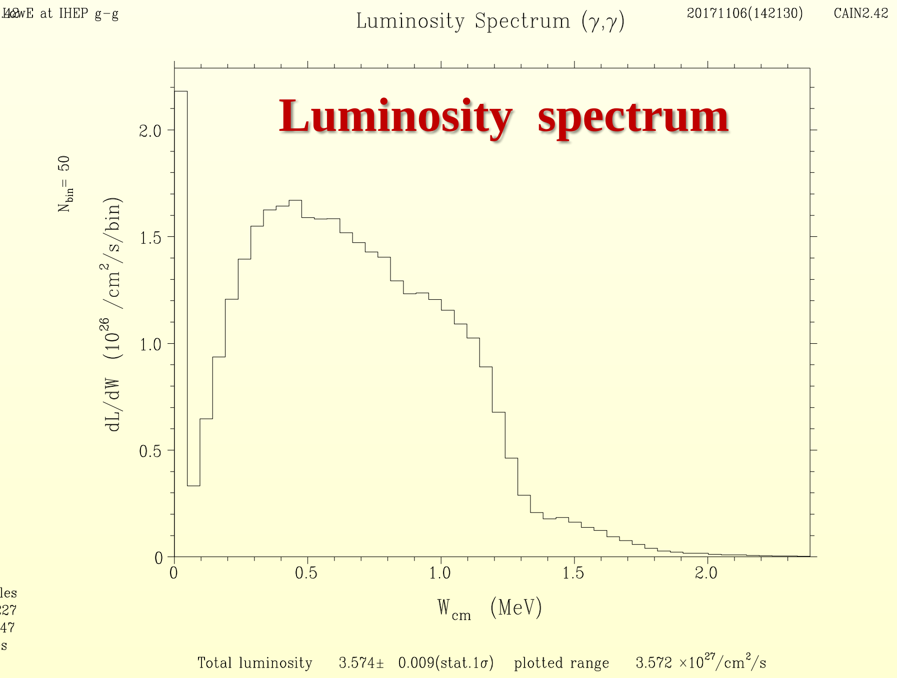
Detector simulation

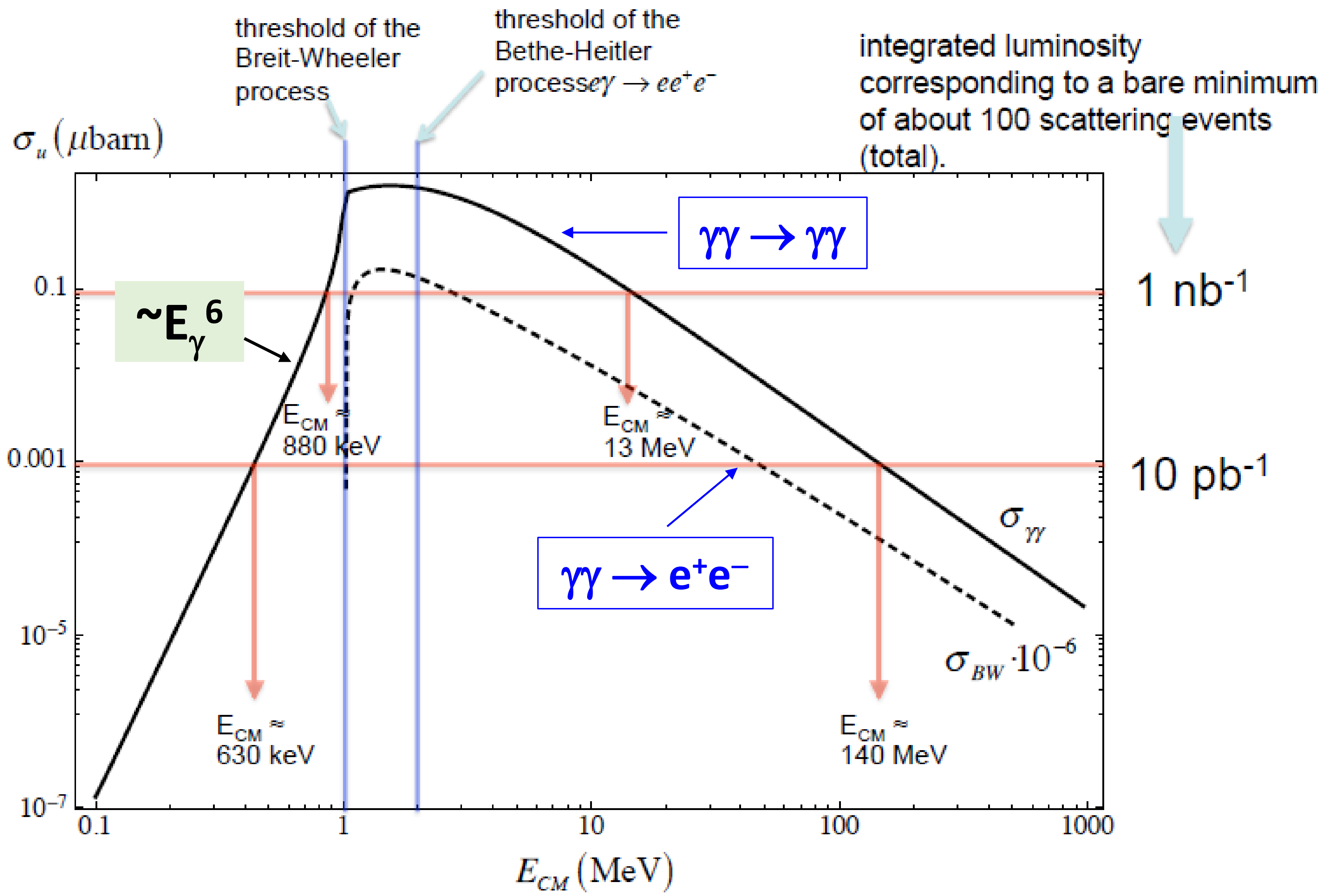
(T. Takahashi, Y. Huang)

CAIN simulation

- Simulations with the code CAIN have been performed for ICS of electron – laser beams.
- Electron beams are with energy of 200-300 MeV, bunch charge of 2pC and length of 0.6mm.
- The laser wave length is 1.054 μm, pulse energy 0.5-1-2 J and size at focus 5 μm.
- Crossing angle=0-167mrad, repetition frequency=50 Hz, IP-CP distance=100–313-1000 μm.



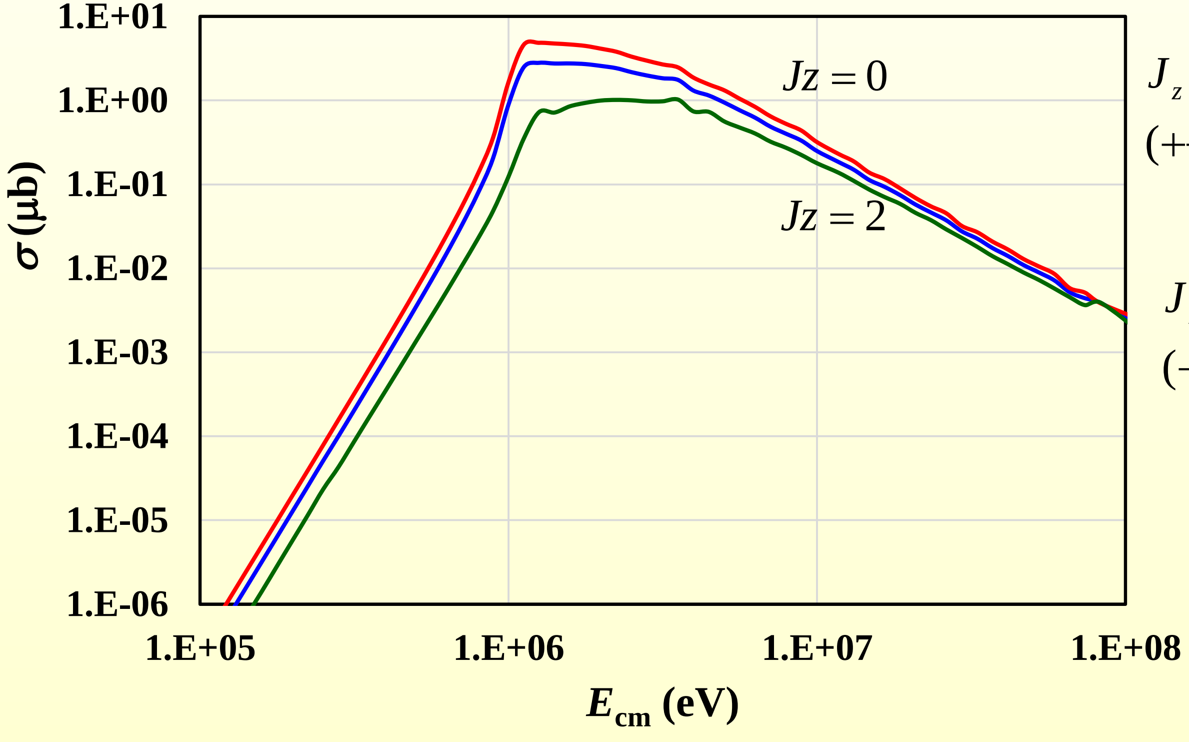


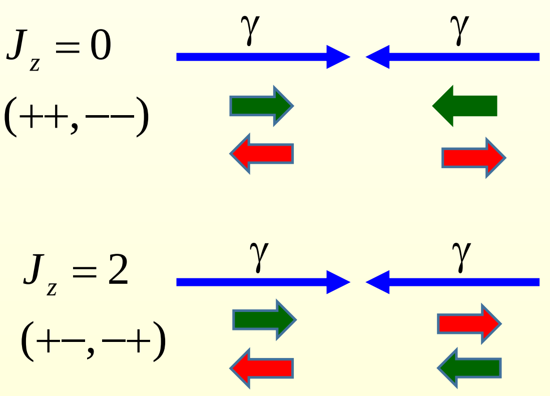


Edoardo Milotti - LNF/IRIDE

(T. Takahashi)

Total cross section for light – light scattering

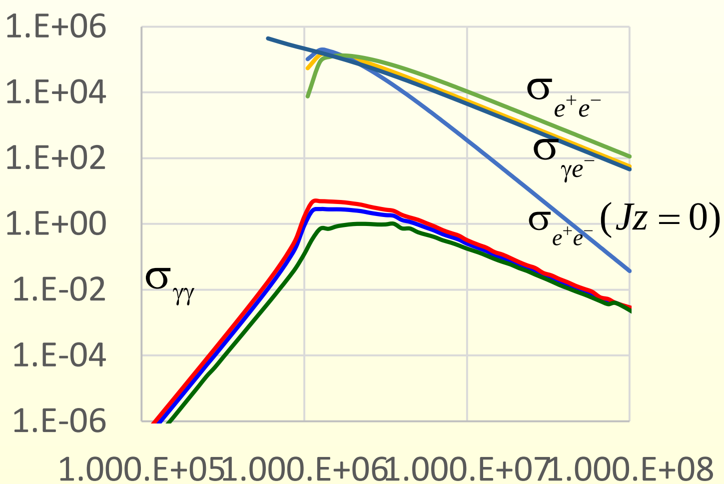




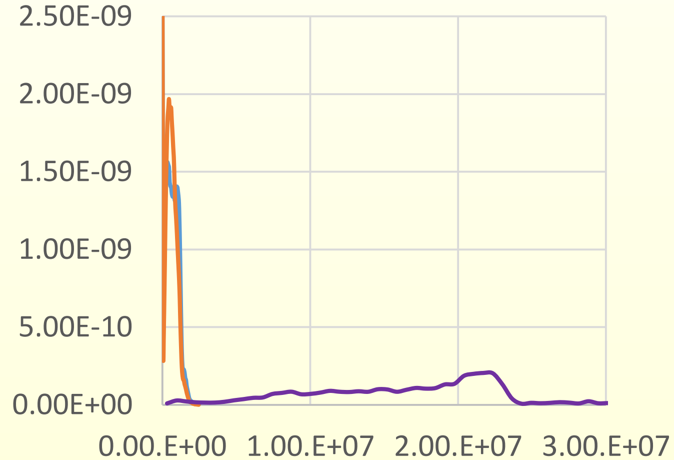
(T. Takahashi)

Event rate calculation

$$\int \sigma(w) \frac{dL}{dw} dw$$



$\times$



$=$

$\sigma_{\gamma\gamma\to\gamma\gamma}(w)$

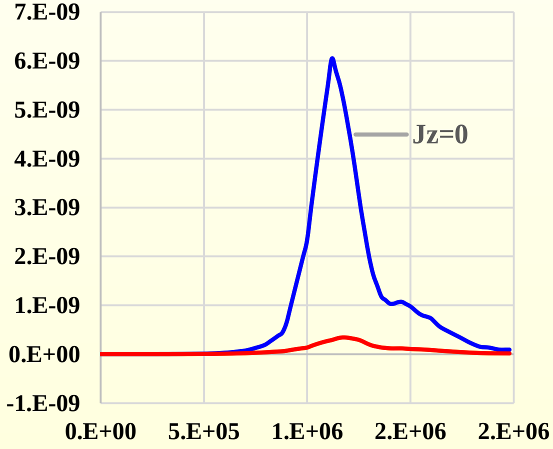
$\sigma_{\gamma\gamma\to e^+e^-}(w)$ } **cal. w/ Whizard** $\times$ $\dfrac{dL}{dw}$ $=$

$\sigma_{\gamma e^-\to\gamma e^-}(w)$

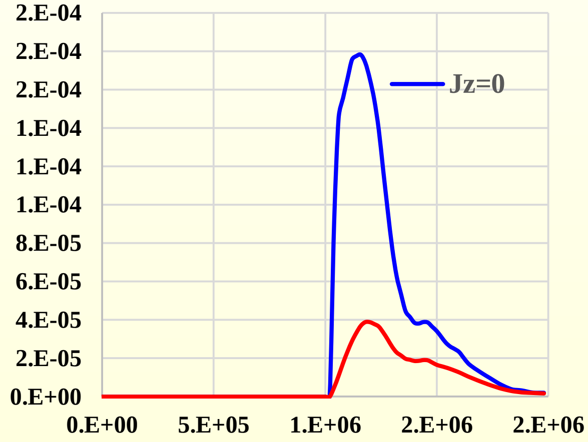
(T. Takahashi)

Number of events per second

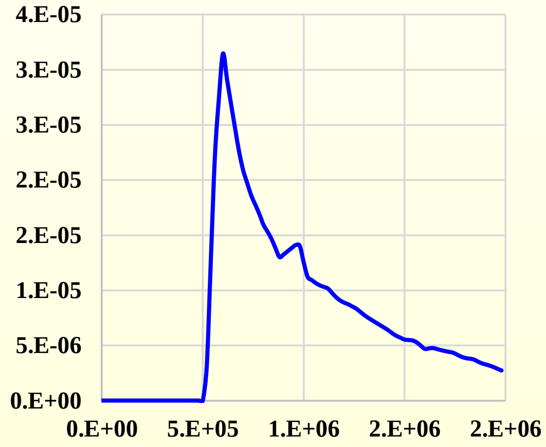
$\sigma_{\gamma\gamma\to\gamma\gamma} L_{\gamma\gamma}(w)$



$\sigma_{\gamma\gamma\to e^+e^-} L_{\gamma\gamma}(w)$



$\sigma_{\gamma e^-\to\gamma e^-} L_{\gamma e^-}(w)$



$$\int \sigma(w) \frac{dL}{dw} dw = 0.0018 (L_z = 0)$$
$$= 0.00014 (L_z = 2)$$
$$= 0.0019 (total)$$

$$\int \sigma(w) \frac{dL}{dw} dw = 51 (L_z = 0)$$
$$= 13 (L_z = 2)$$
$$= 64 (total)$$

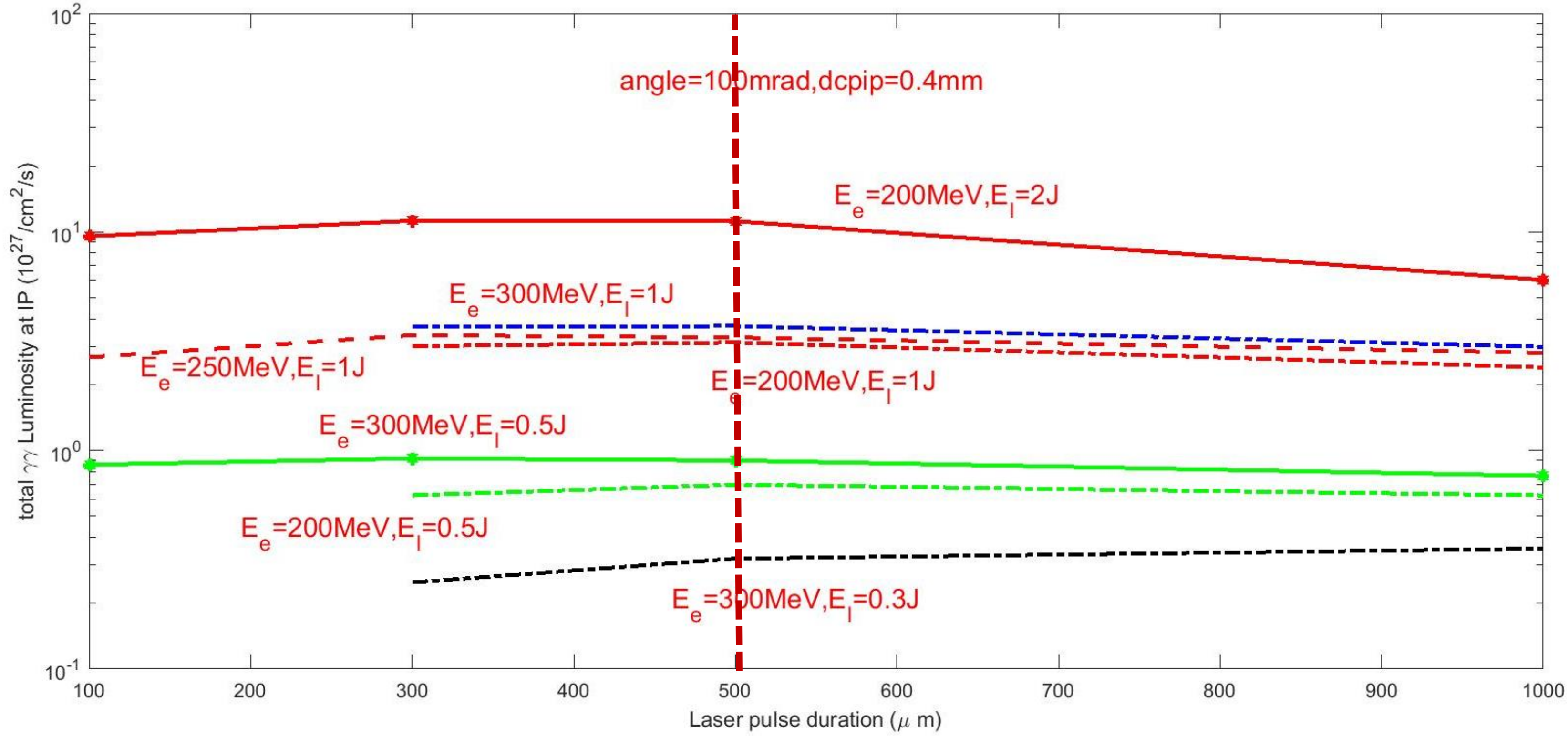
$$\int \sigma(w) \frac{dL}{dw} dw = 6.8$$

The events are highly boosted, and do not enter detector volumes.

(Y. Huang)

3.2 Electron beam energy and laser power

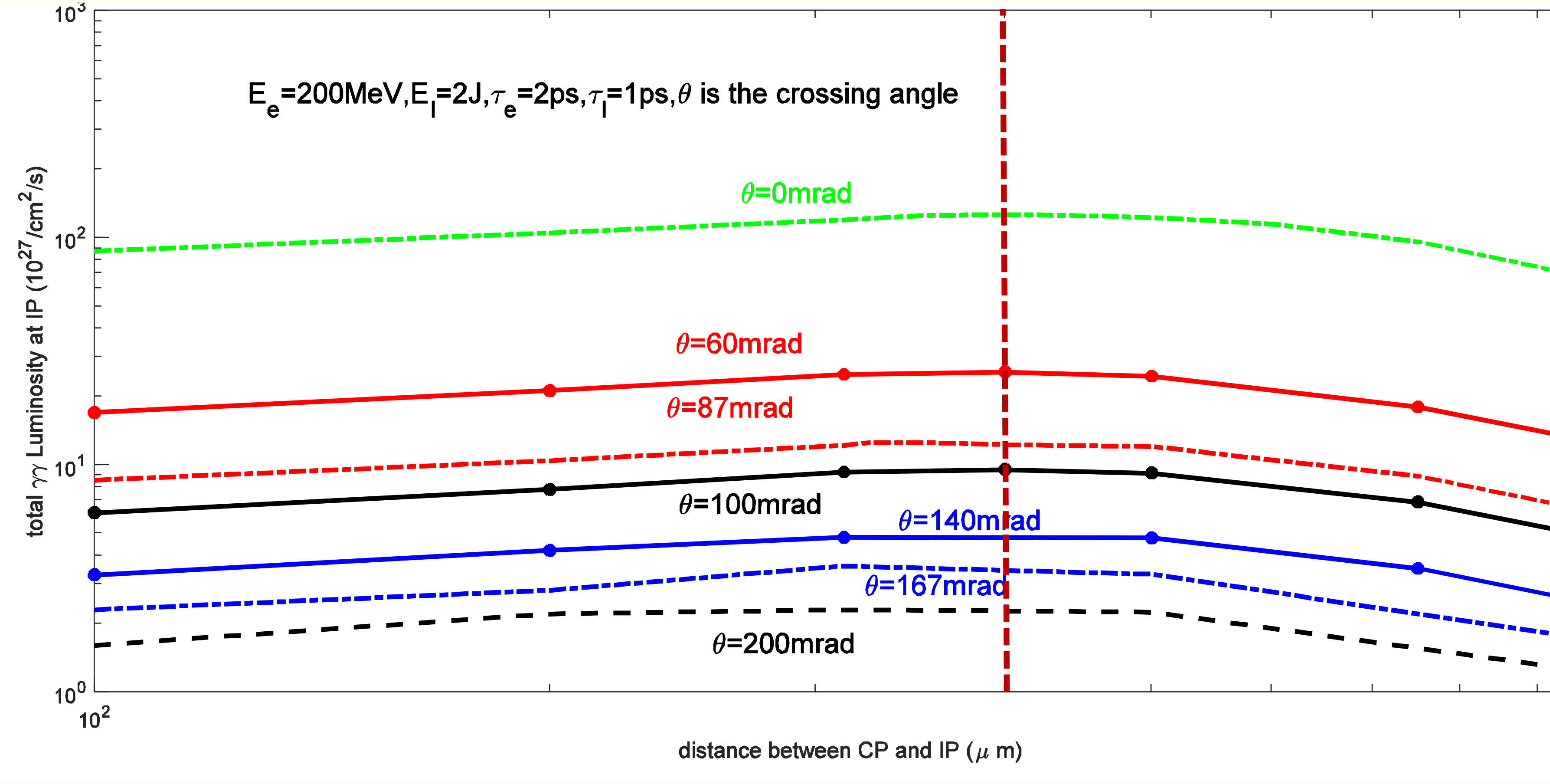
- To increase electron energy towards 300MeV helps luminosity and event rate
- Needs to consider how to identify γγ with e^+e^- pairs and reduce background.
- Laser pulse energy: 2J ➘ 1J ⇨⇨⇨ *L* ➘ 27% (almost same for 1J ➘ 0.5J)



(Y. Huang)

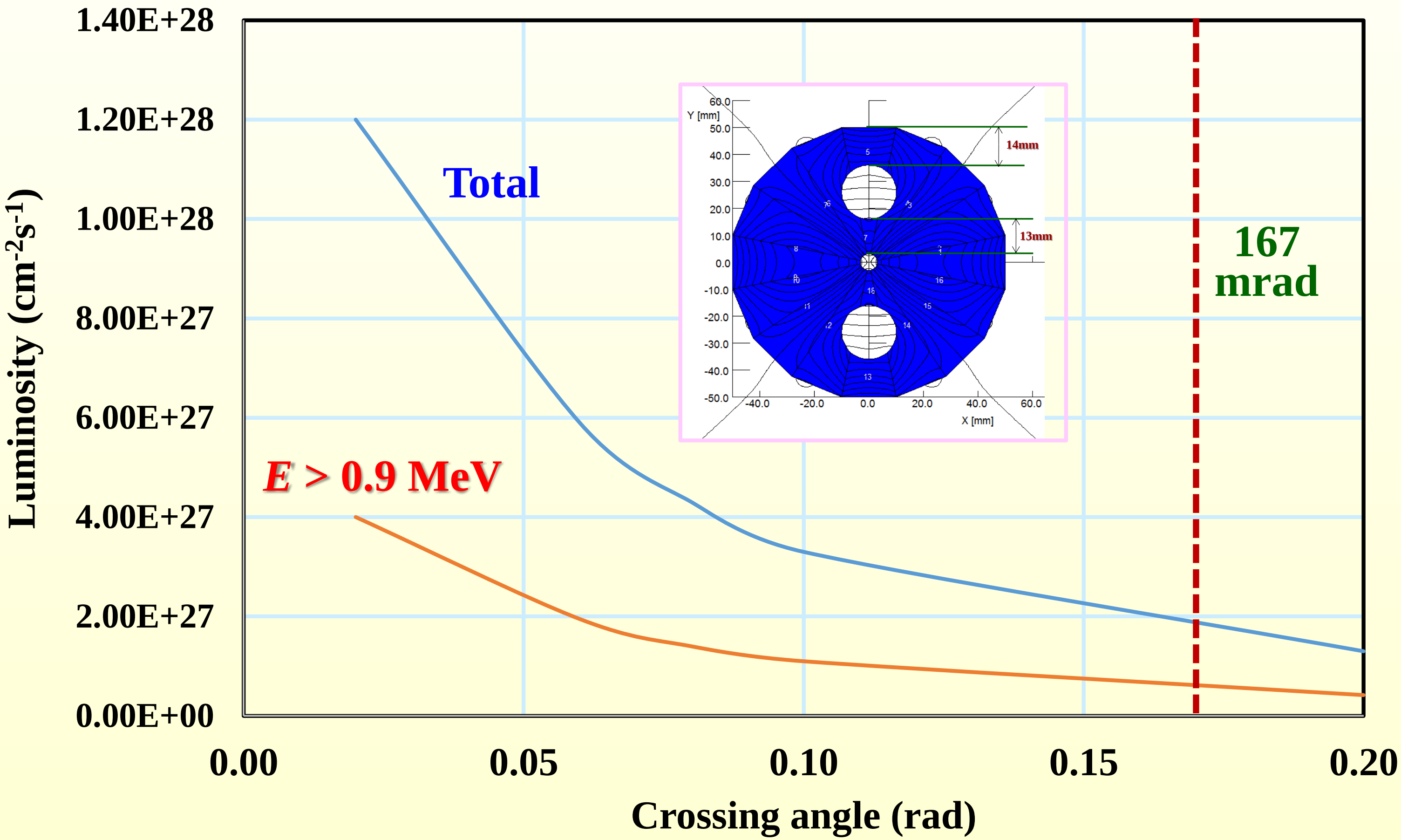
3.3 CP-IP distance and Crossing angle

- Optimized CP-IP distance is around 400 μm.
- The smaller the laser-beam crossing angle, the higher luminosity ⇨⇨⇨
- Choice of *L** + design of FFS quadrupole + using deflection mirrors



(T. Takahashi)

Luminosity vs. crossing angle

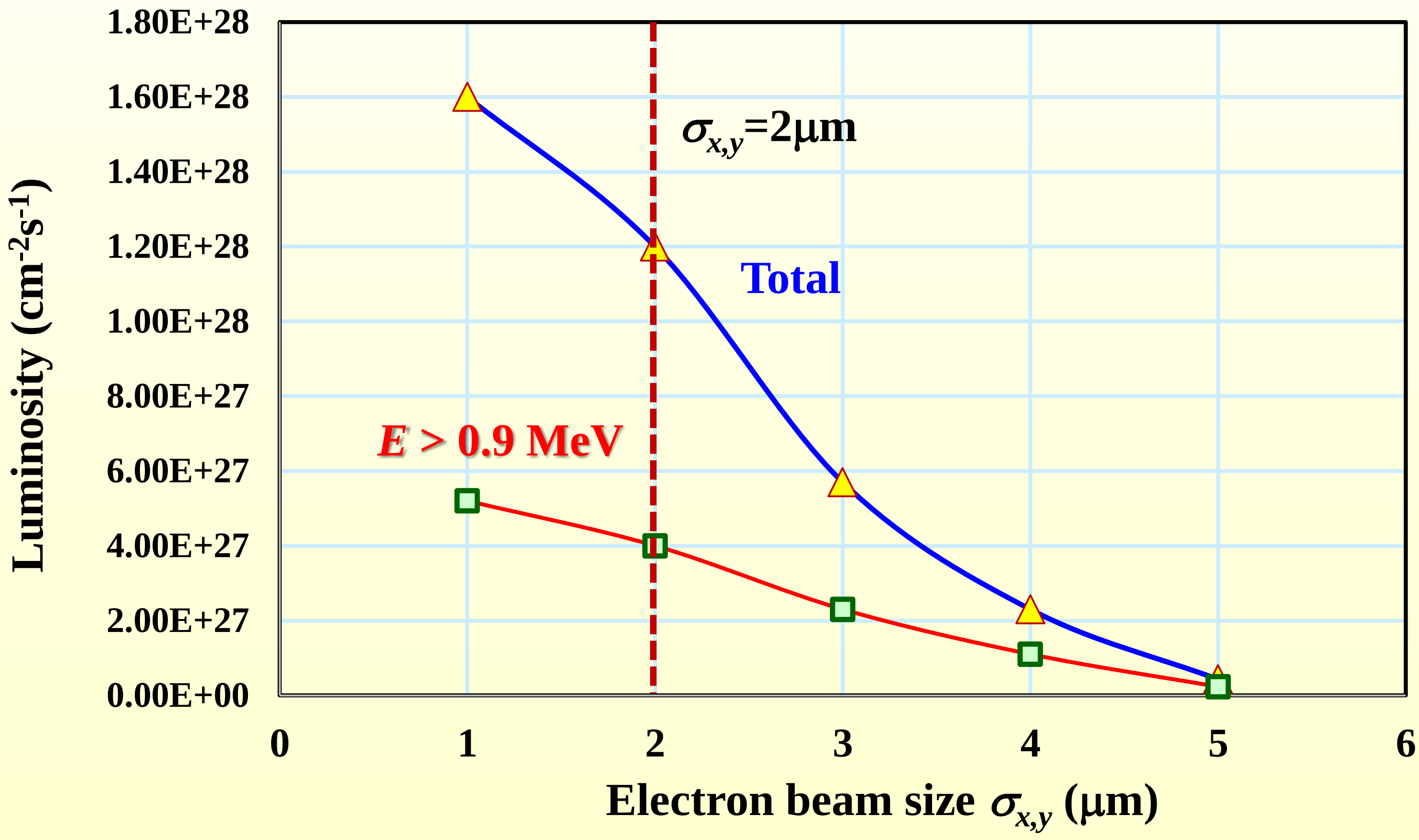


(for ex. 0.1 rad means 1 cm offset at the magnet surface placed 10cm from the IP)

(T. Takahashi)

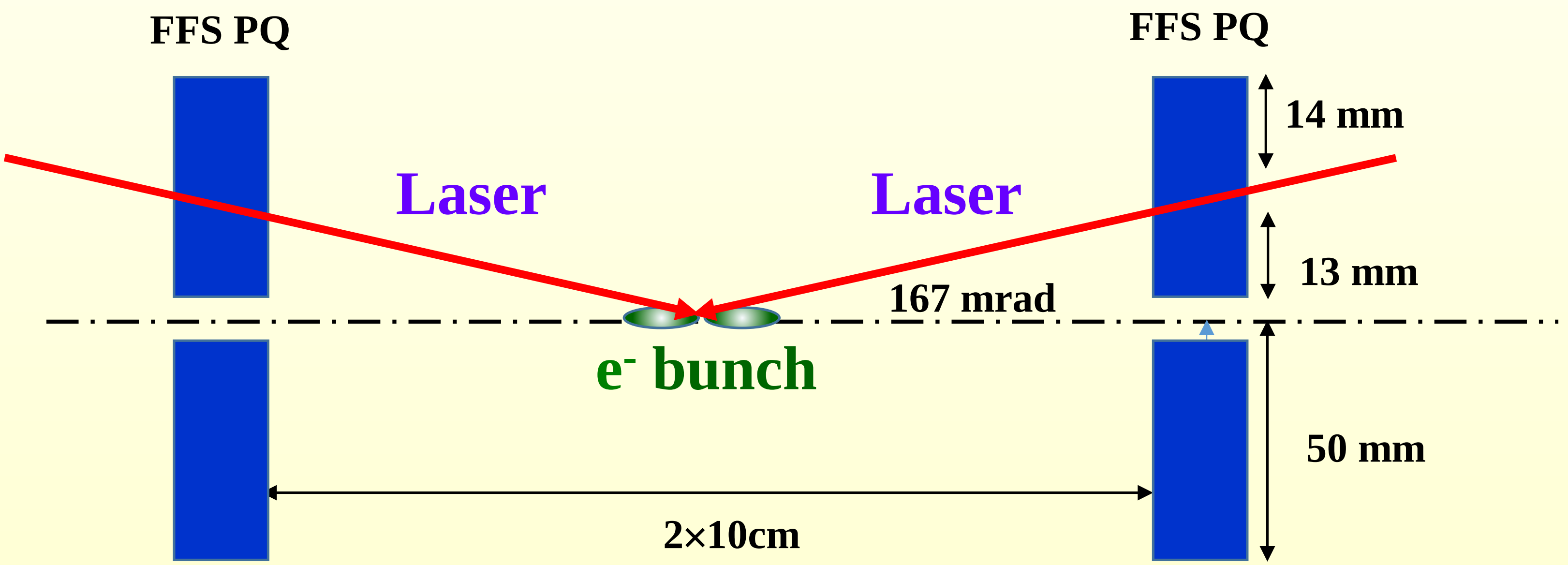
3.4 Electron beam size at IP

- Reduction of electron bean size at IP helps luminosity.
- Need to be optimized together with FFS design.



3.5 Distance between FFS quad to IP

- The distance between FFS quad to IP is chosen as 10 cm for study.
- Needs to be optimized together with crossing angle and FFS design.



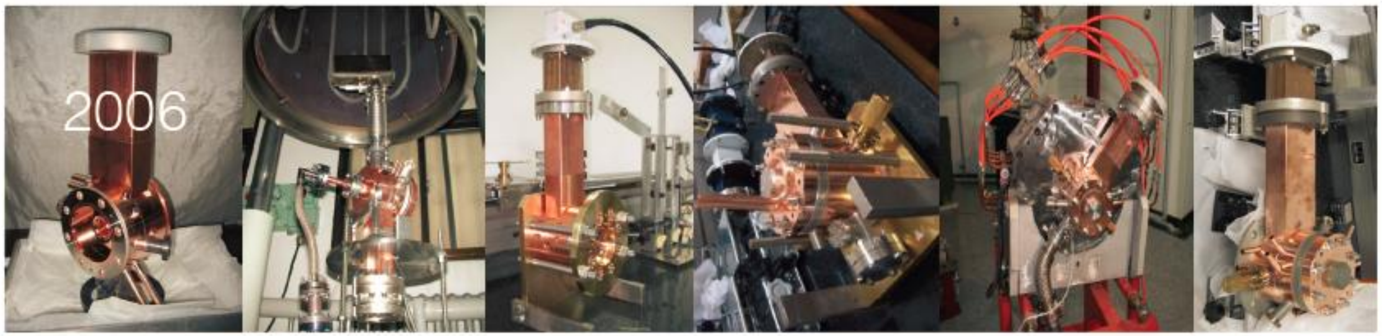
4. Design study on BggC

- Photocathode RF gun
- 200 MeV electron linac
- Electron beam transfer line
- Laser system
- FFS permanent quadrupoles
- Detector

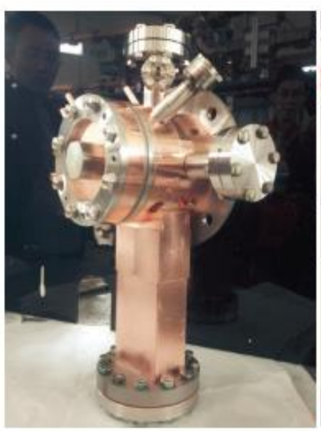
Y.C. Du

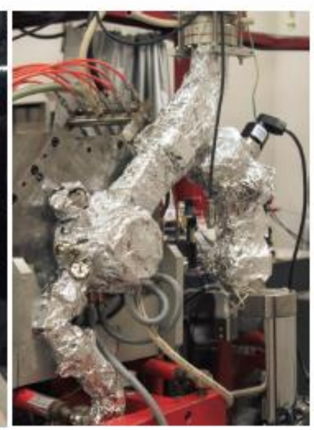
4.1 Photocathode RF gun

Photocathode RF Gun Development at THU



2011

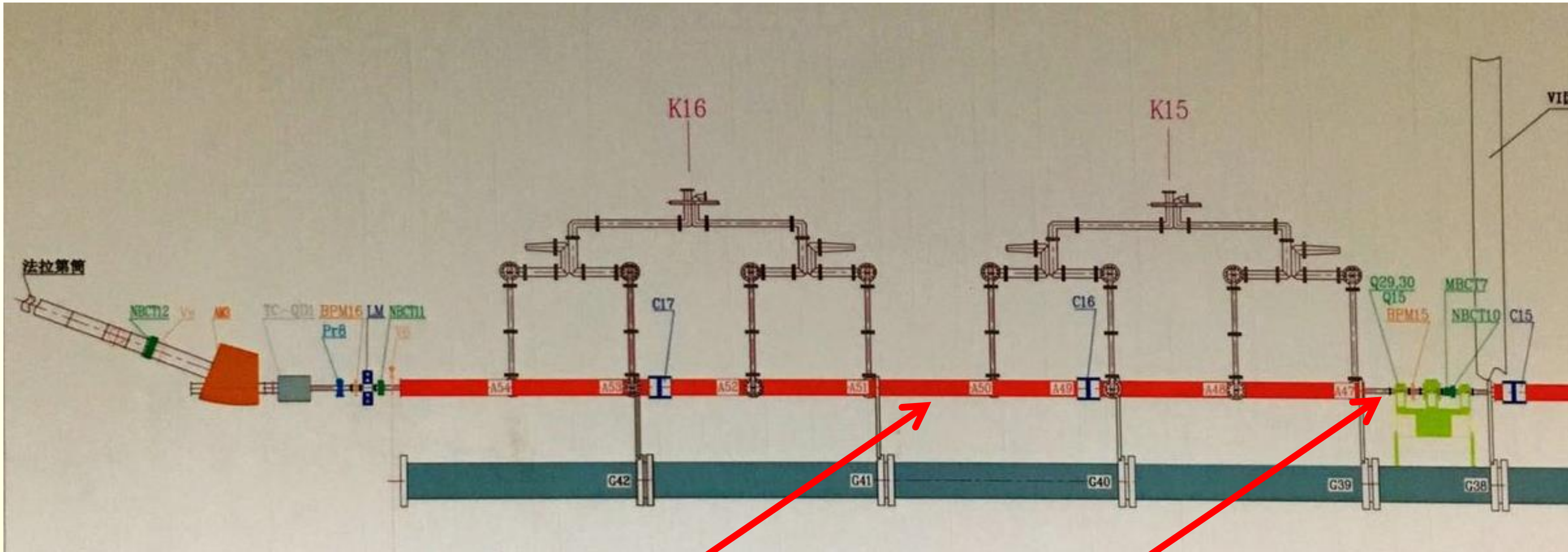




Parameters	Value	Unit
PI mode frequency	2856	MHz
Quality factor Q_0	14000	
Coupling factor β	1.3	
Electric field on cathode	120	MV/m
RF pulse width	1.7	μs
Repetition rate	10	Hz
Peak power of wall heat loss	9.4	MW
Input RF peak power	11.3	MW
Cathode material	Copper	
QE	4×10^{-5}	
dark current at 120 MV/m	< 250	pC/pulse

S. Pei

4.2 200 MeV electron linac

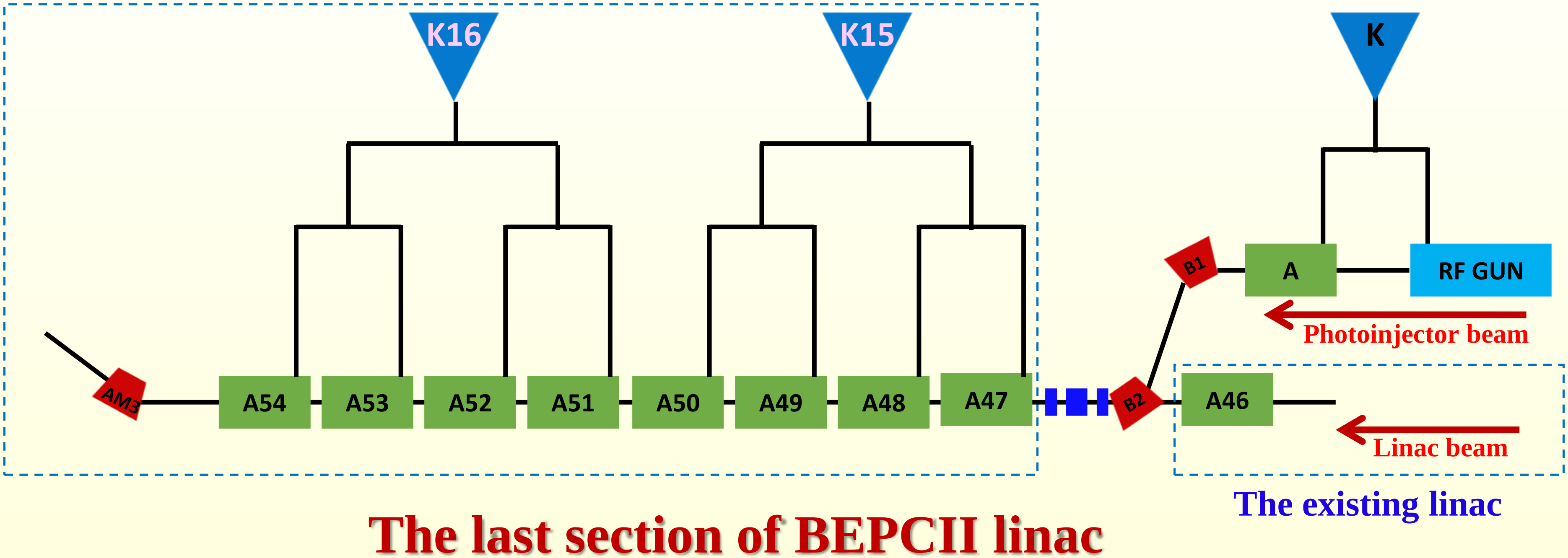


No space at this location!

Possible injection point for the photoinjector beam!

S. Pei

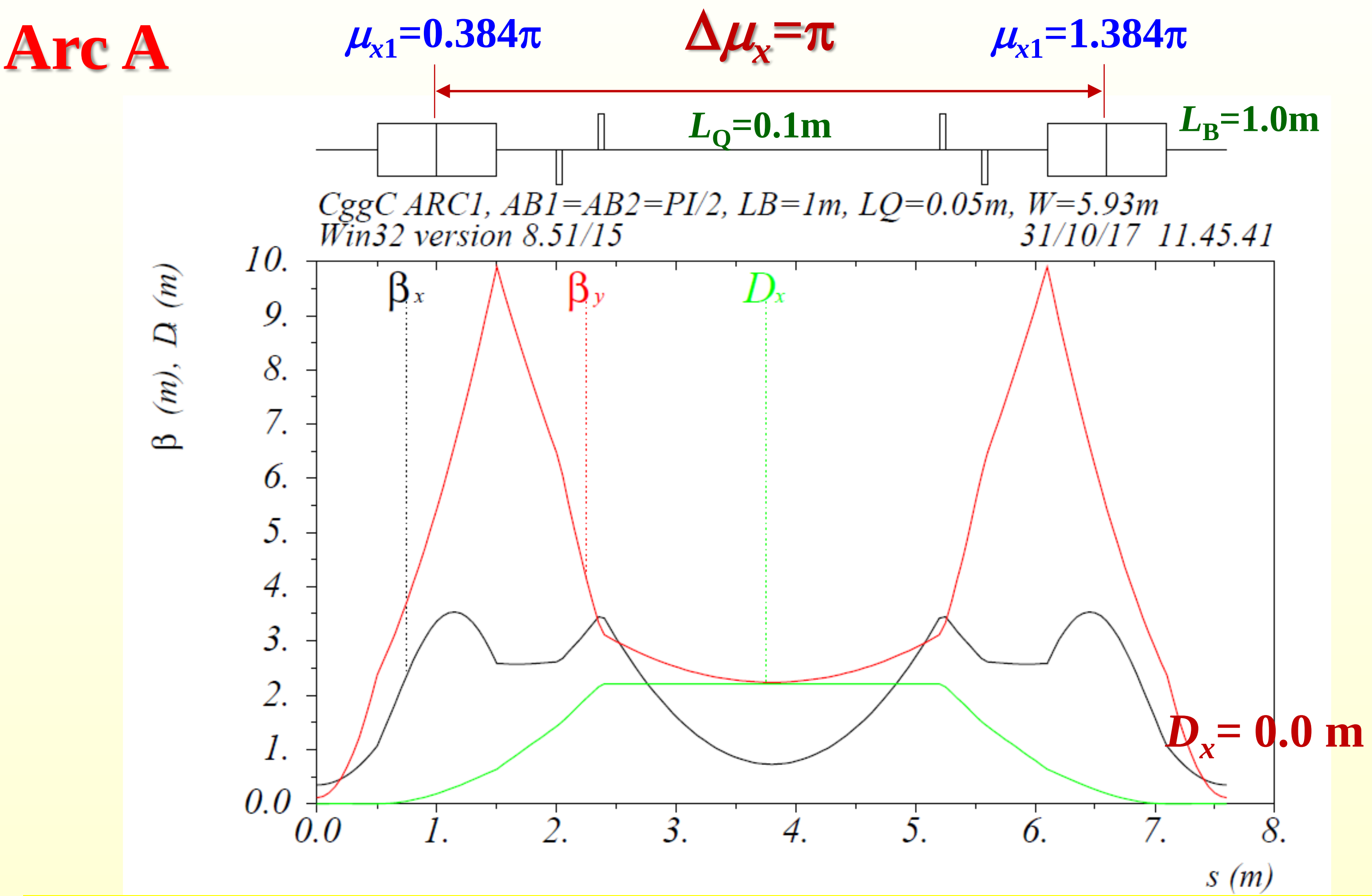
The possible linac layout for the γ–γ collider



- 1 photocathode RF gun
- 1 accelerating structure
- 1 klystron
- 2 bending magnets
- 1 laser system
- 1 solenoid
- new compact triplet
- ……

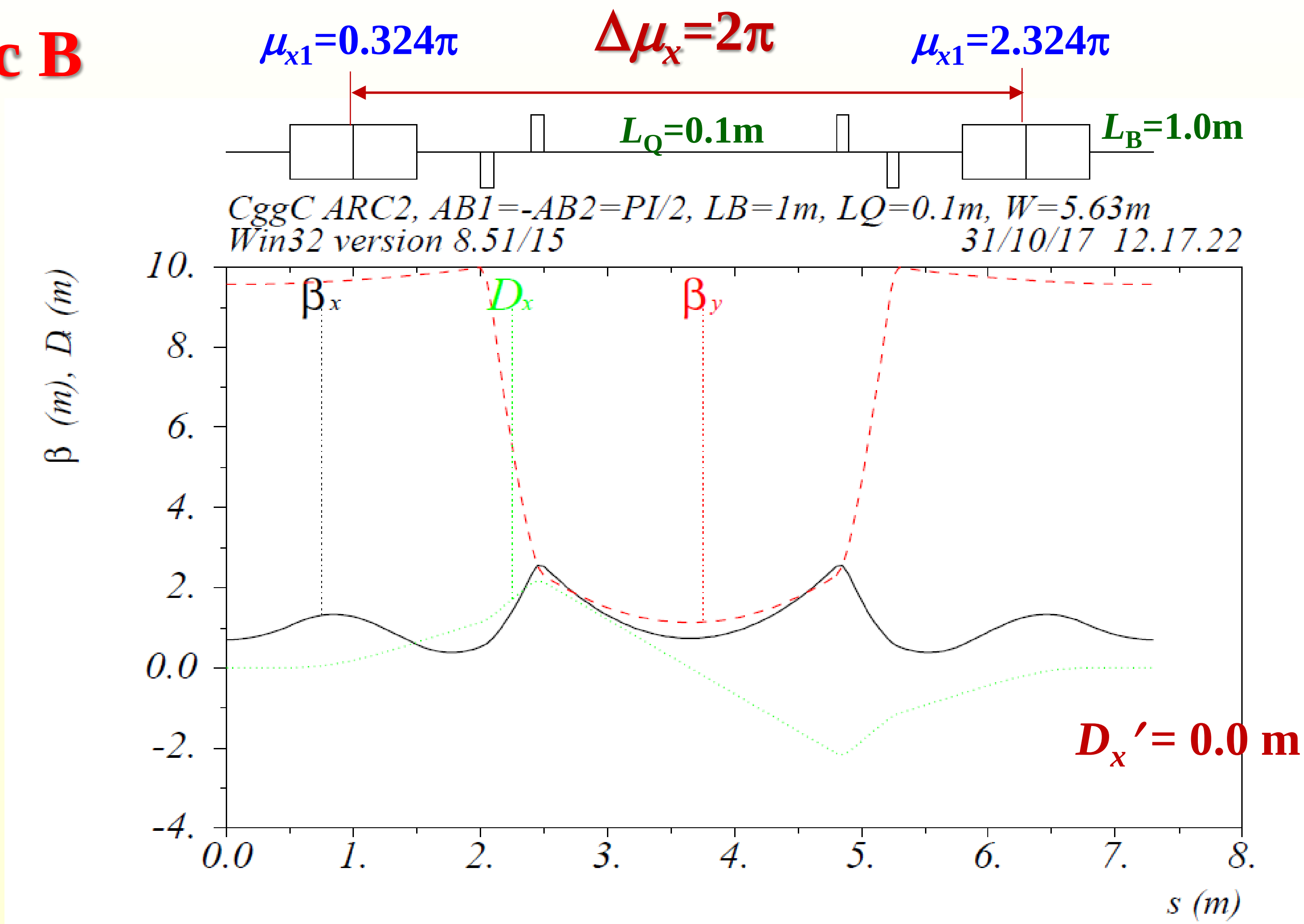
4.3 Electron beam transfer line

Arc A



	L_B (m)	B (T)	EB	k_F (m^{-2})	k_D (m^{-2})	B'_F (T/m)	B'_D (T/m)
Line A	1	1.05	$\theta_B/3$	9.090	-3.445	6.064	-2.299

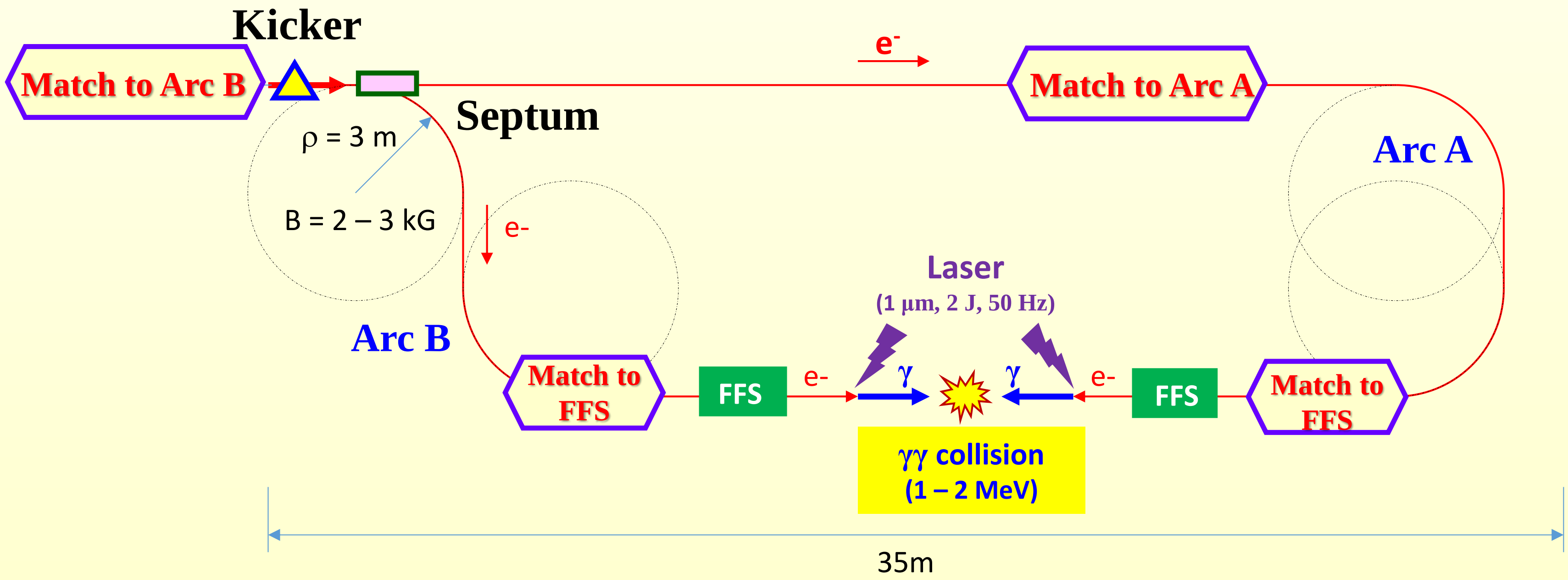
Arc B



	L_B (m)	*B* (T)	*EB*	k_F (m^{-2})	k_D (m^{-2})	B'_F (T/m)	B'_D (T/m)
Arc B	1	1.05	0	20.746	-13.311	13.840	-8.880

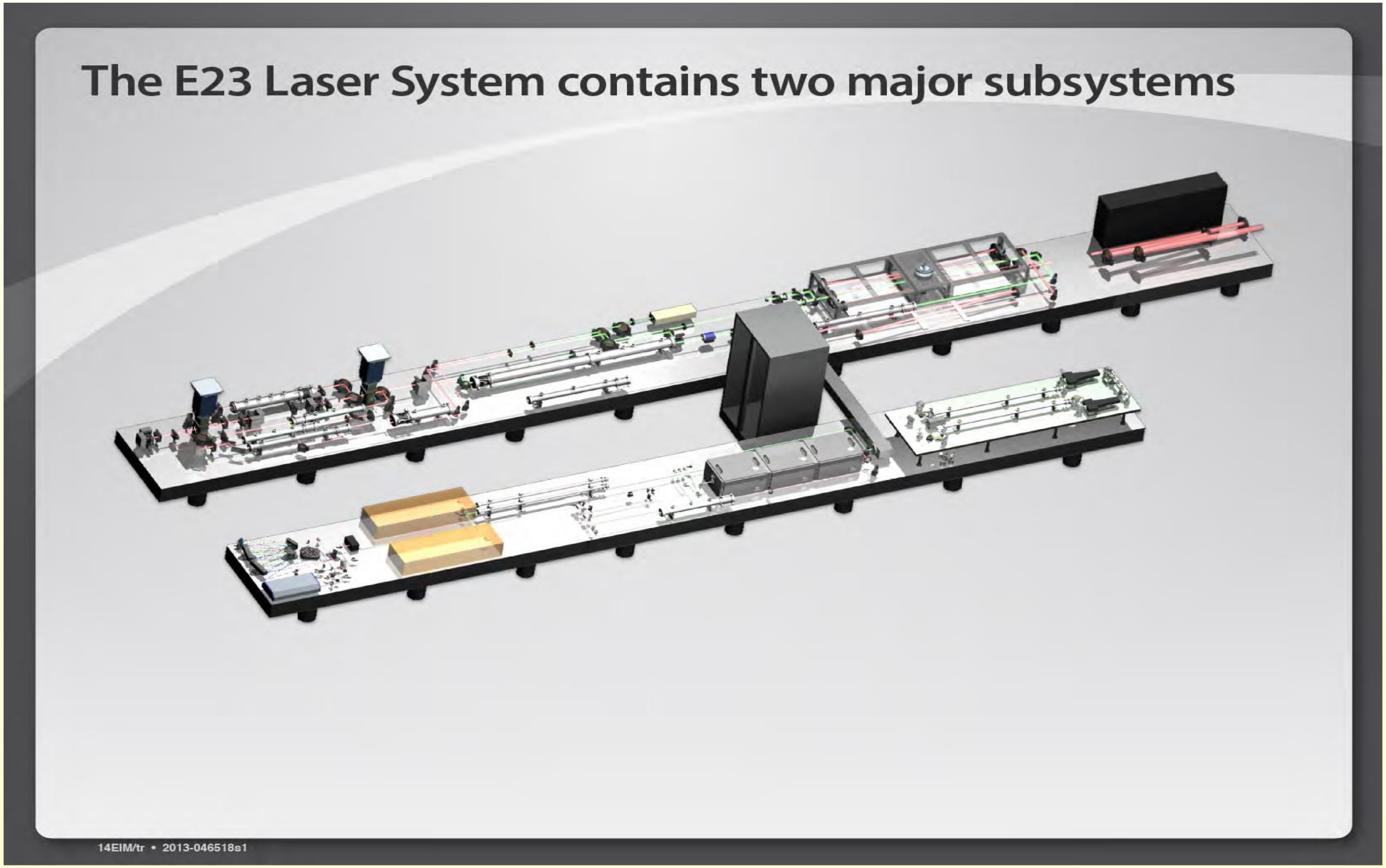
Match from linac and to FFS

- To match Twiss parameters to the arcs and design a kicker / septum system to extract the leading bunch to the Arc B.
- To match Twiss parameters from the end of Arc A and Arc B to the IR;
- To design the final focusing system.



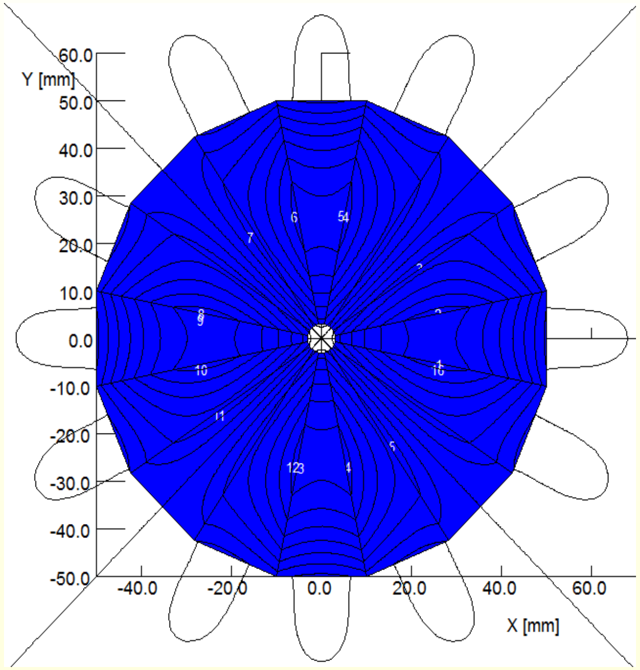
4.4 Laser system

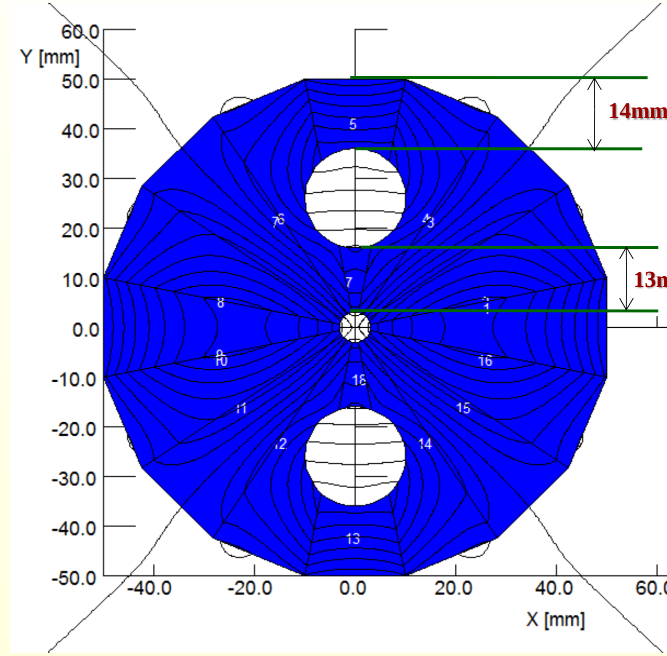
Refer to HAPLS (ELI-E23)



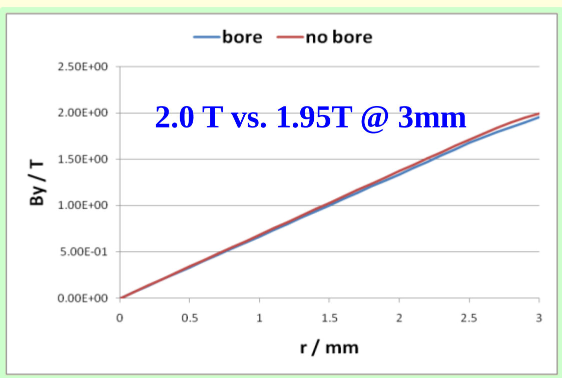
(Y. Huang, Y. Chen)

4.5 The FFS permanent magnets



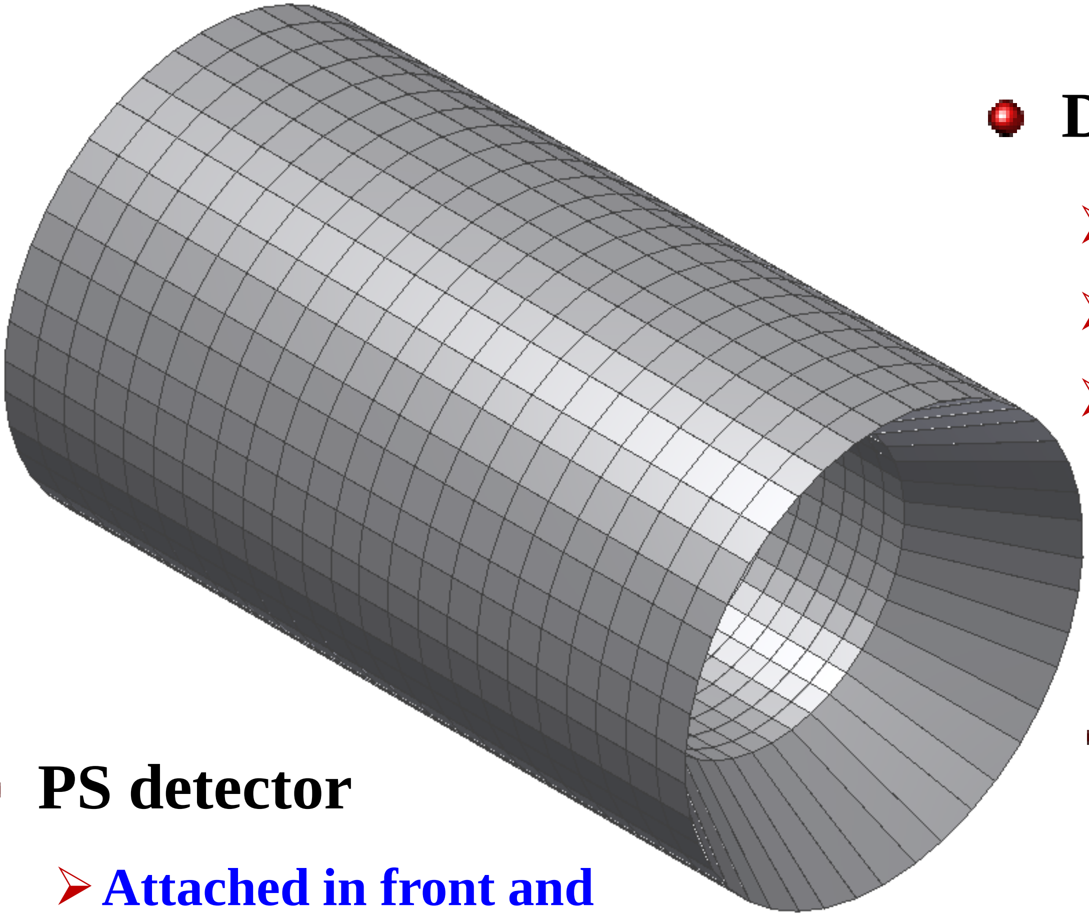


	d（mm）	*G*（T/m）	*L*（mm）
1#	6	590	9.1
2#	6	590	15
3#	6	590	25



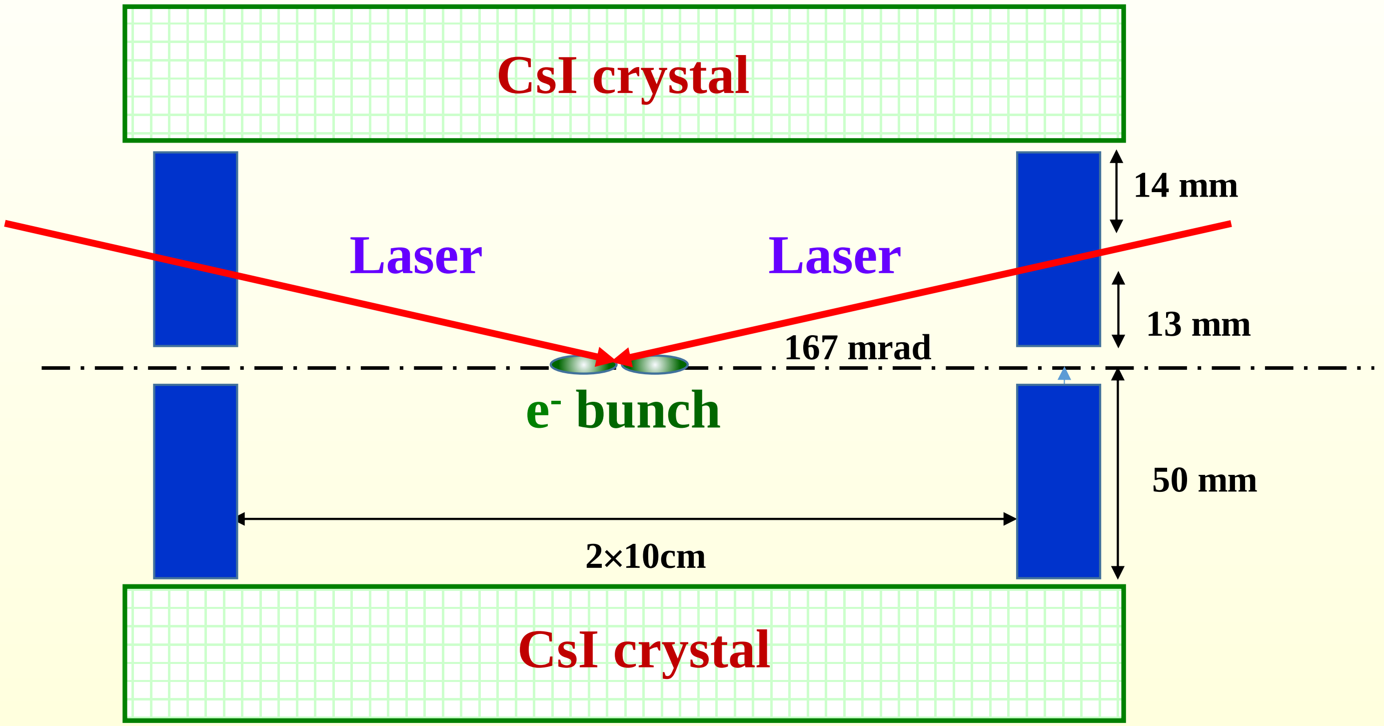
4.5 Detector

(Y. Huang, J. Lu)



- **Detector dimension**
  - Length =76cm
  - Inner diameter = 40cm
  - Thickness = 6cm
- **CsI cristal**
  - 46 Lines,
  - 23 crystals per line
  - 966 crystals
- **PS detector**
  - Attached in front and inner side of the crystal
  - Thickness = 1cm .

Detector simulation



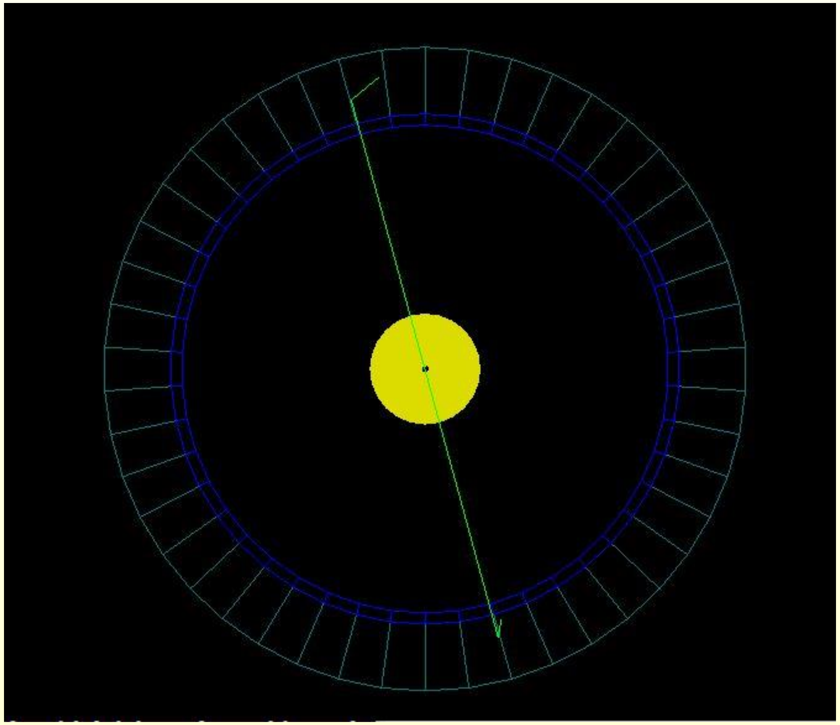
- **Detection simulations** design, resolution, efficiency, background …
- **Physics simulation** $\gamma\gamma \rightarrow \gamma\gamma$, $\gamma\gamma \rightarrow e^+e^-$, $\gamma e^- \rightarrow \gamma e^-$ …
- **Shielding design and simulation** beam Scattering, collimation design…

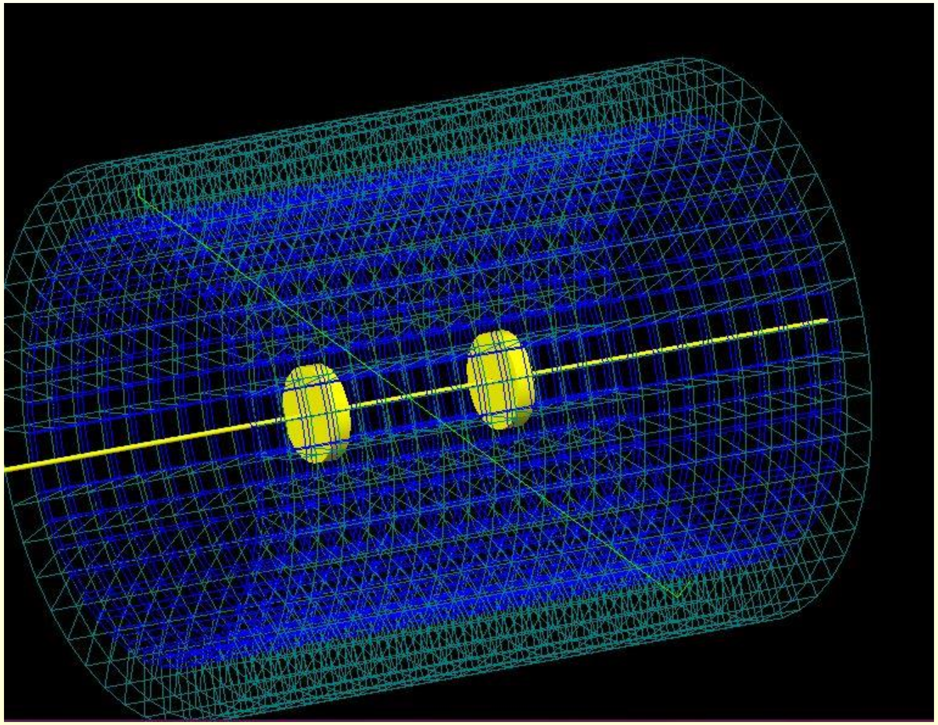
The study gets under way

(T. Takahashi & B.H. Sun)

Detection simulation

$$\gamma\gamma \to \gamma\gamma \quad \sqrt{s} = 1.41 MeV$$



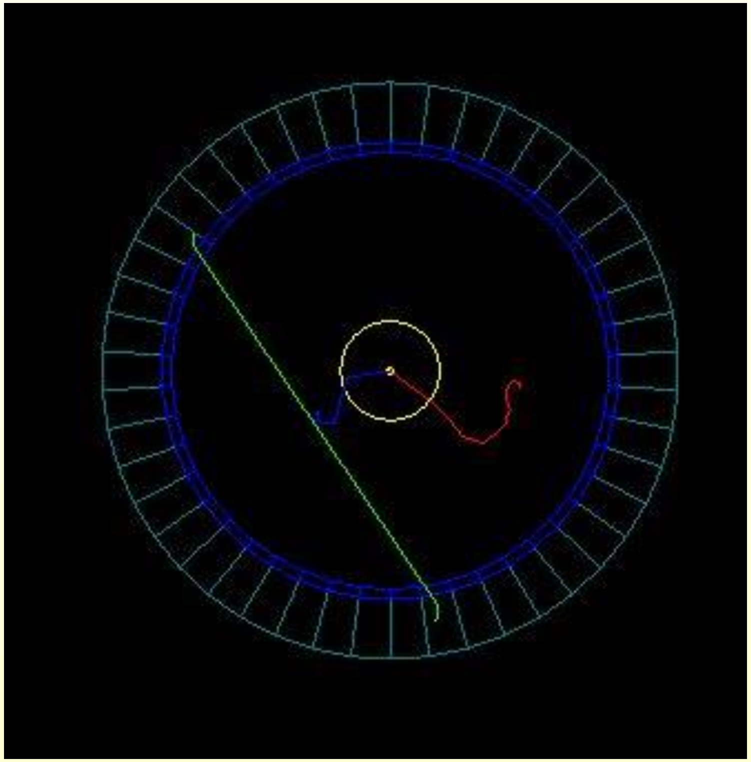


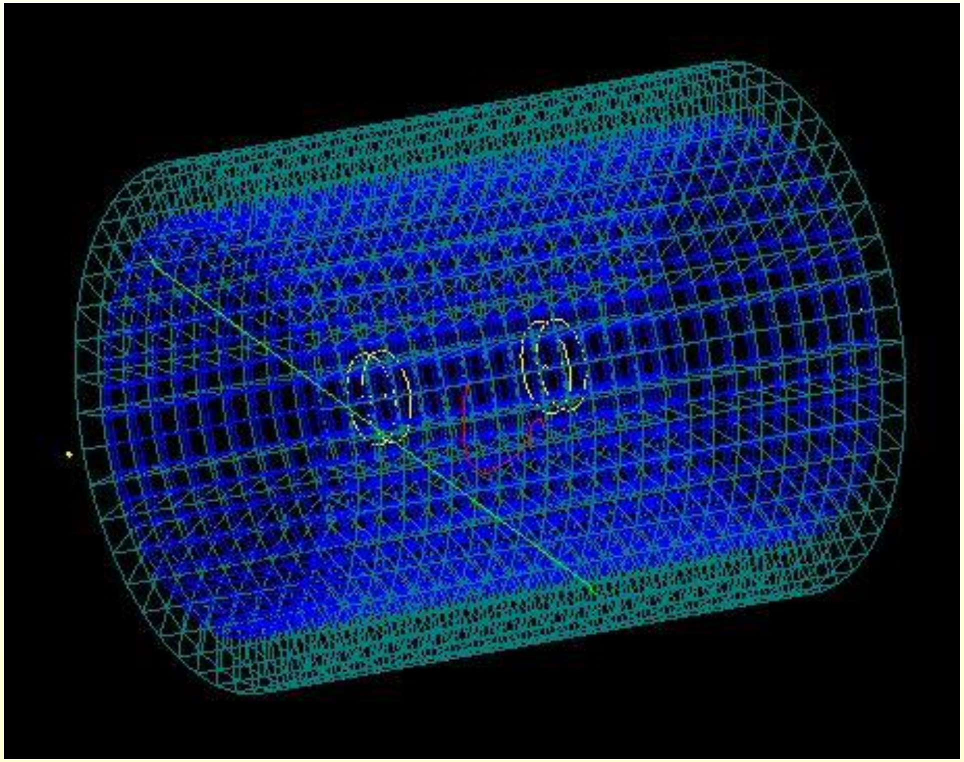
Back to back photons 0.0019 events/s

(T. Takahashi & B.H. Sun)

Detection simulation

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



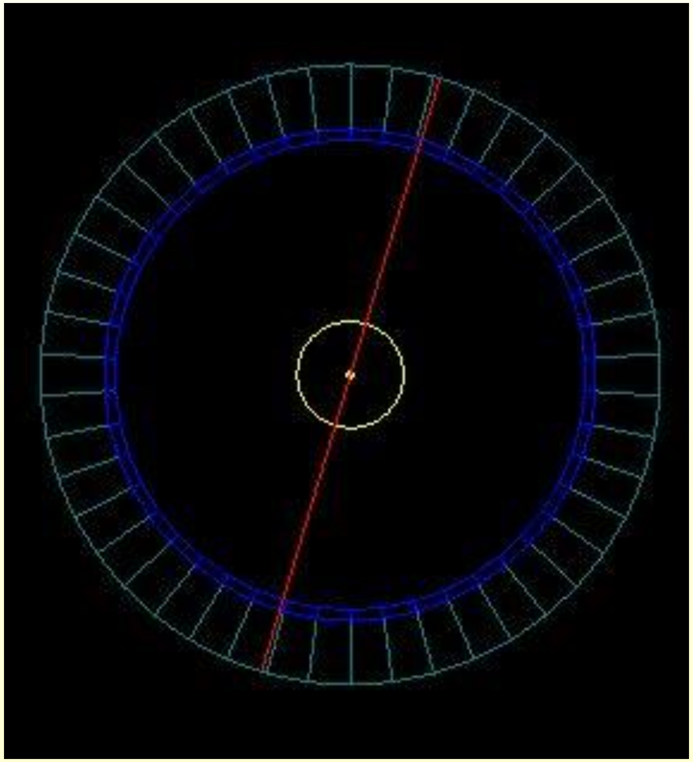


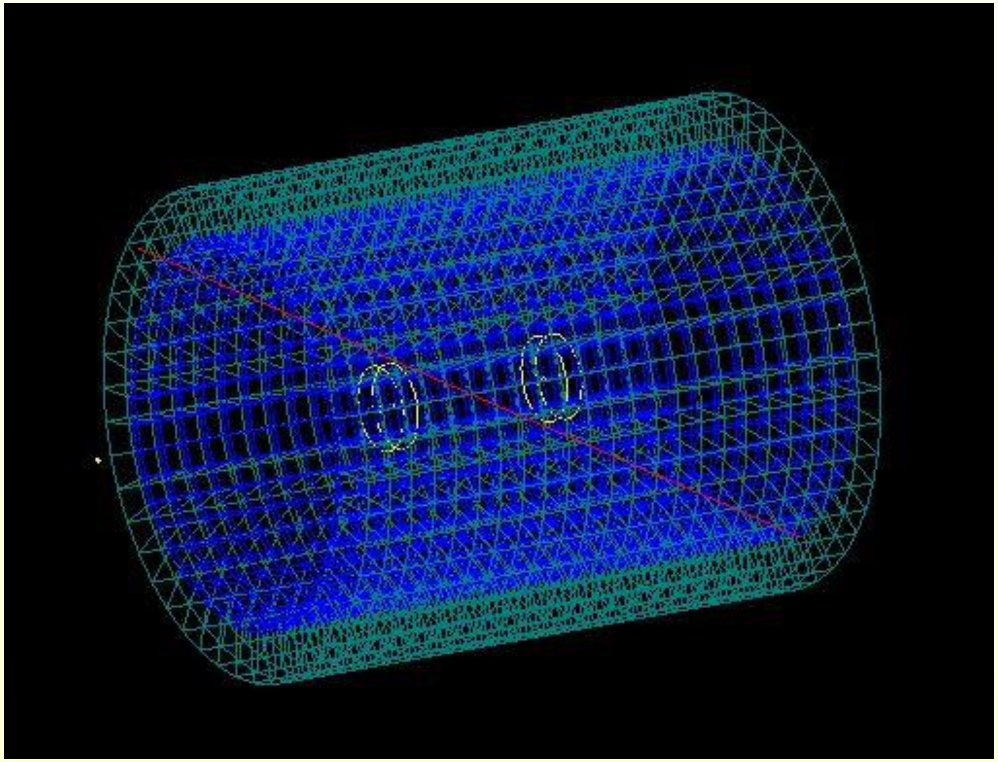
Low momentum e^{+} e^{-} not back to back 64 events/s

(T. Takahashi & B.H. Sun)

Detection simulation

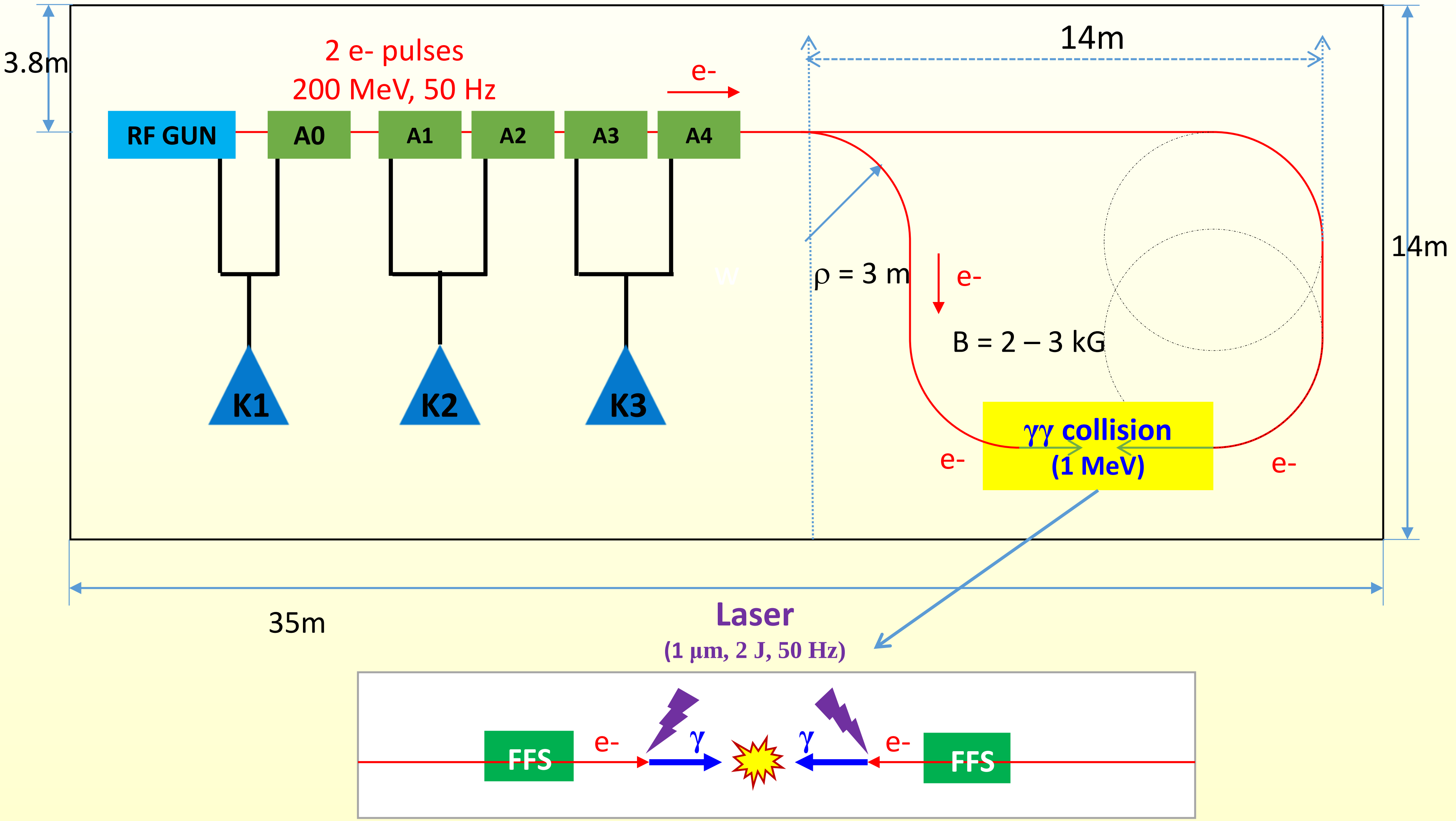
$$e^+e^- \rightarrow e^+e^- \qquad \sqrt{s} = 400\,\text{MeV}$$





Back to back e^- e^- 0.5 events/s

Stand-alone γ-γ Collider



Summary

- A γ–γ collider based on the BEPC injector is proposed;
- The luminosity goal is $1\times10^{27}cm^{-2}s^{-1}$ for the center mass energy above 0.9 MeV.
- About 1 event/hour and 60 events/s are expected for $\gamma\gamma \to \gamma\gamma$ and $\gamma\gamma \to e^+e^-$ respectively.
- The parameter optimization has been performed.
- The design study for the project is in progress.
- The detector simulation is underway.
- The interesting physics and challenging project call for collaboration.

Thank You for Attention