Bunch-by-Bunch Luminosity Monitor For STCF

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Outline

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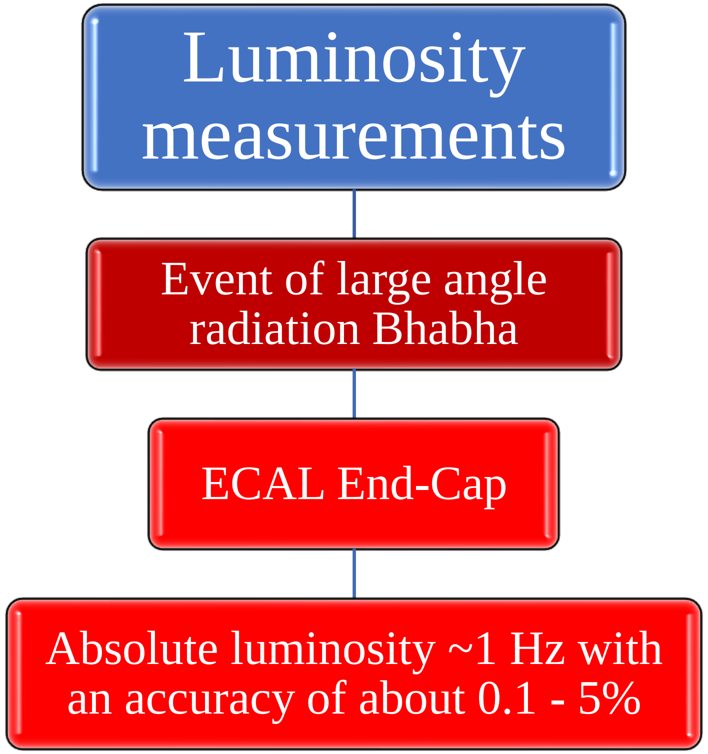
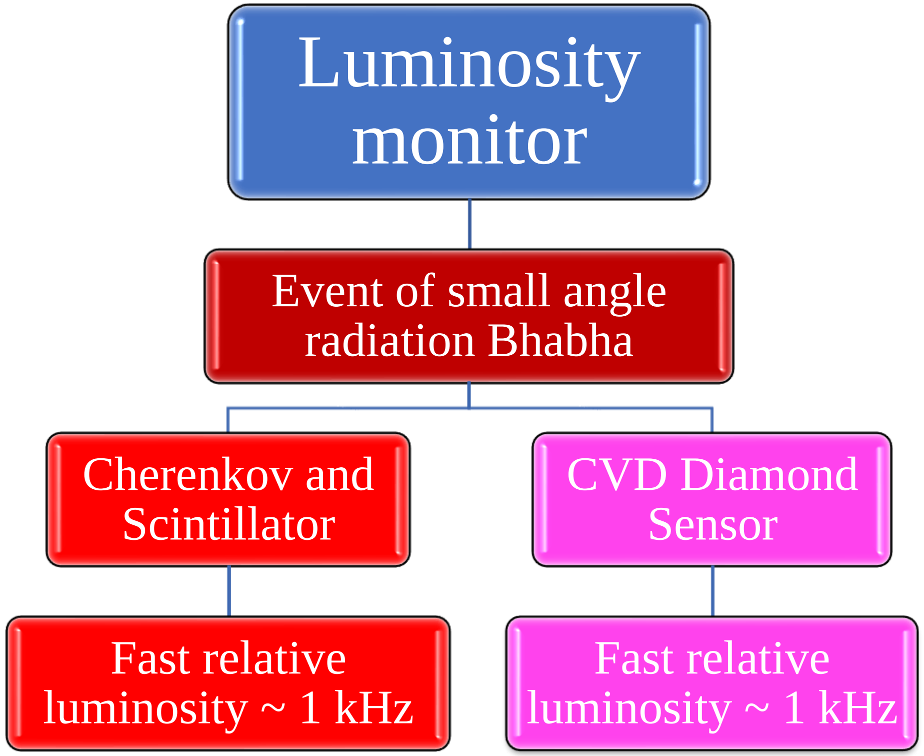
1. Motivation

Bunch-by-Bunch Luminosity monitor

- **Luminosity:** an important physical quantity about the event rate for a collider. It is a key factor of the performance of the collider.
- **Bunch-by-Bunch Luminosity monitoring :** an important technique for tuning the beam current, helping to keep the luminosity of each bunch (4 ns) to be consistent.





Radiation Bhabha Process

Radiation Bhabha Process：

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

- Large cross-section, ~ 97 mb at 4 GeV (with a photon cutoff energy of 200 MeV).
- The emission angle of photon is focused within 1 mrad.

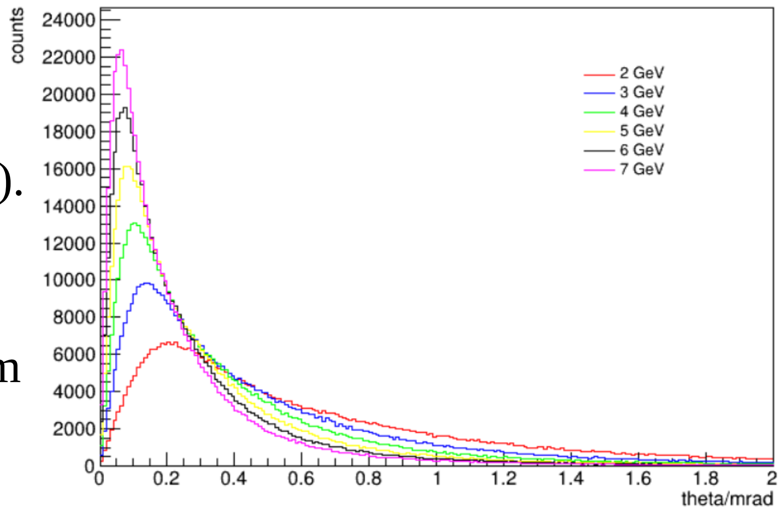
➢ For example, the acceptance (polar angle) is ~1 mrad, Ecm = 4 GeV, the minimum cutoff energy of photon = 200 MeV.

$$R = L \times \sigma \qquad R{=}10^{35}cm^{-2}s^{-1} \times 9.7 \times 10^{-26}cm^2{=}9.7 \times 10^9 s^{-1}$$

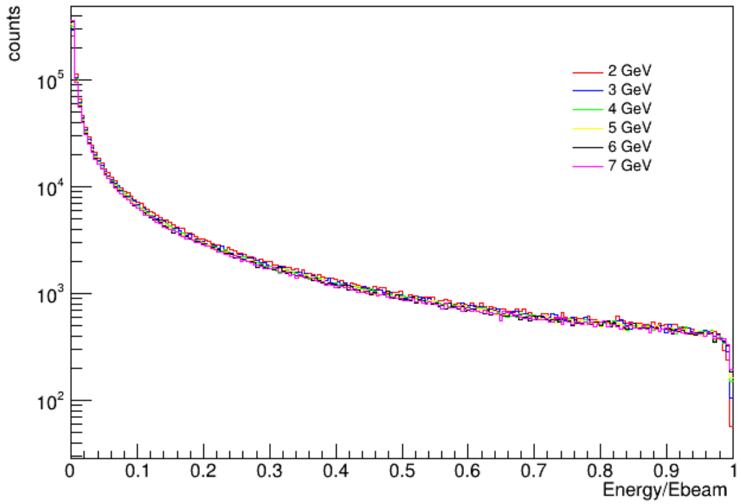
- R： Single photon count rate (Hz)
- L： Peaking luminosity ($cm^{-2}s^{-1}$)
- σ： Cross section of Single photon Bhabha (cm^2)

Rate of Single photon per bunch： $R_{single}{=}R \times T/N{\approx}0.08$ / bunch

❖ Photon angular distribution



❖ Photon energy spectrum distribution



Current Operational Luminosity Monitor

BESIII

BLM

Measurement of small-angle radiation Bhabha photon

- ❑ Tungsten converter, fused silica and PMT

- ➢ **Provides relative luminosity measurements at 0.5 Hz with 0.8% accuracy.**
- ➢ **Lower background**

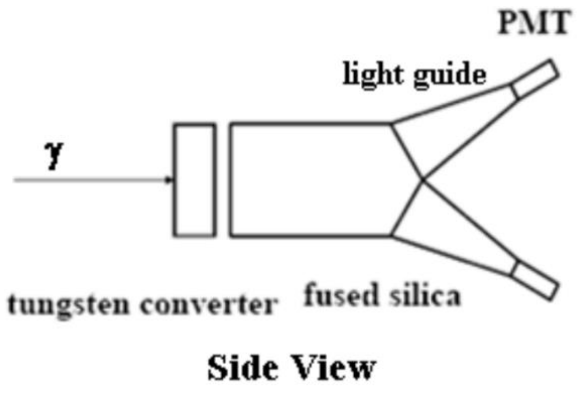
BelleII

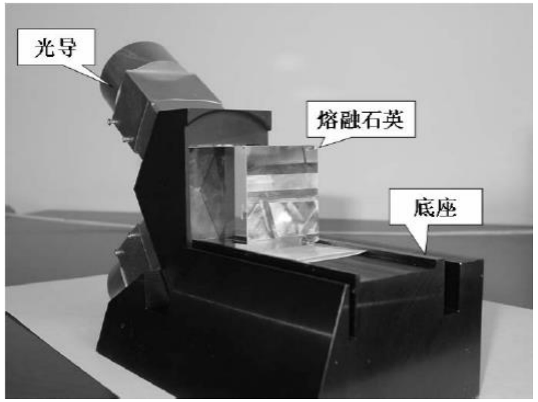
LumiBelle2

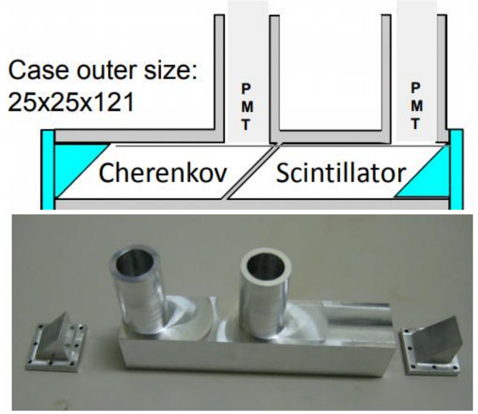
Measurement of photons and positrons/electrons in the small-angle radiation of the Bhabha process

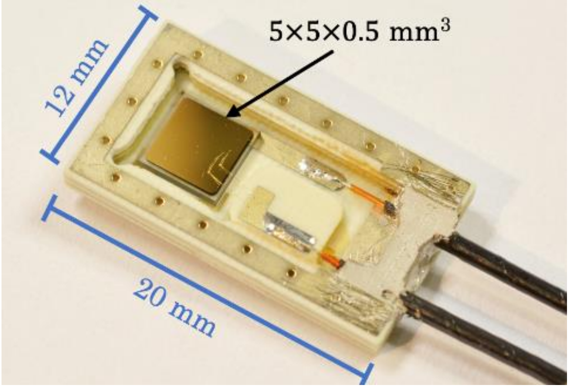
- ❑ Silica Cherenkov detector
- ❑ Single crystal diamond detector
- ❑ LGSO Crystal Scintillator Detector

- ➢ **Provides relative luminosity measurements at 1 kHz with about 1% accuracy;**
- ➢ **a wide luminosity range ($10^{30} - 10^{36} cm^{-2} s^{-1}$)**









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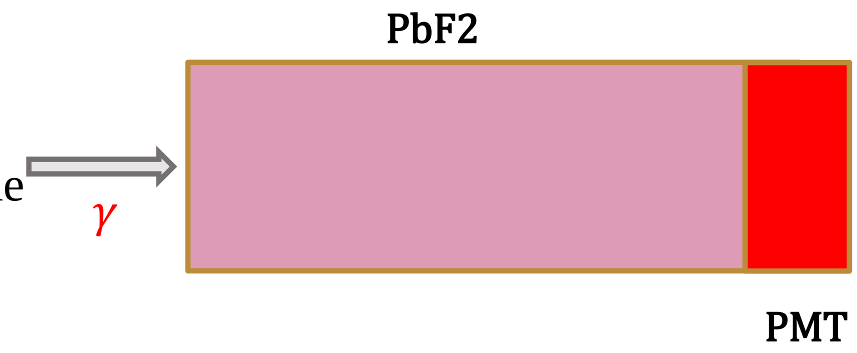
2. Conceptual Design of Luminosity Monitor By Cherenkov Detector

Cherenkov Detector Design

Cherenkov radiator: PbF_2 (Lead fluoride) crystals



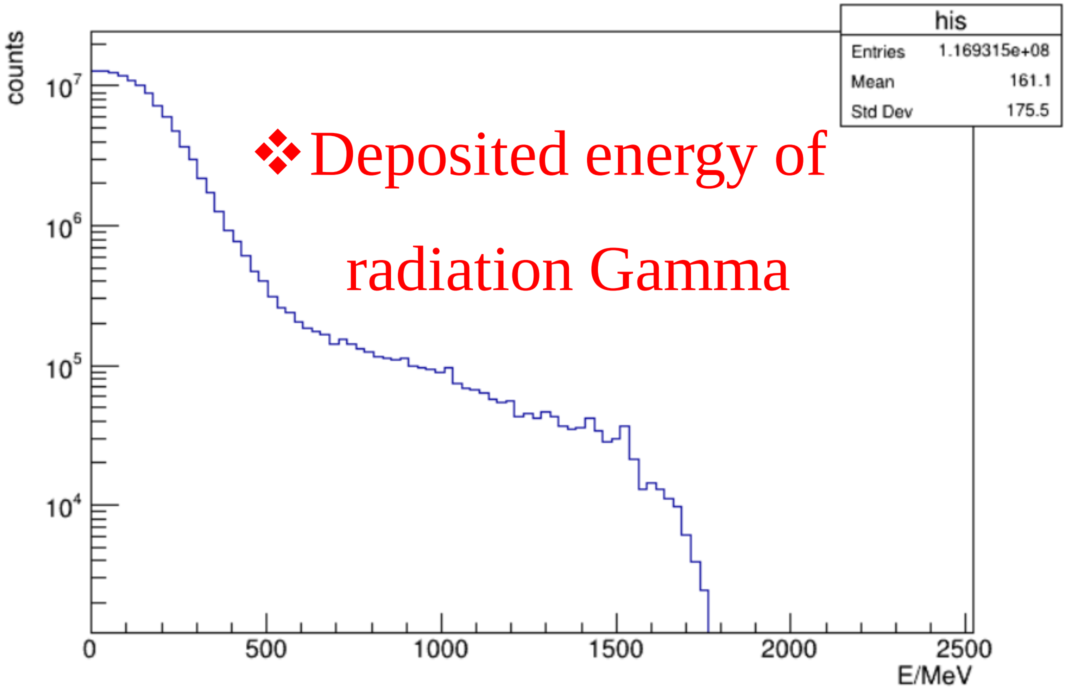
- **Advantages：**
  - Short X_0=0.93 cm : Allows the detector to be smaller. It is suitable for the limited installation space.
  - Higher index of refraction : more light produced.
  - Faster time response : < 1ns.
  - Hard radiation resistance.
- **Disadvantages：**
  - Compared to scintillators, lead fluoride crystals have a lower light yield.

表 4.1 PbF2 与一些较耐辐照闪烁体的性能比较

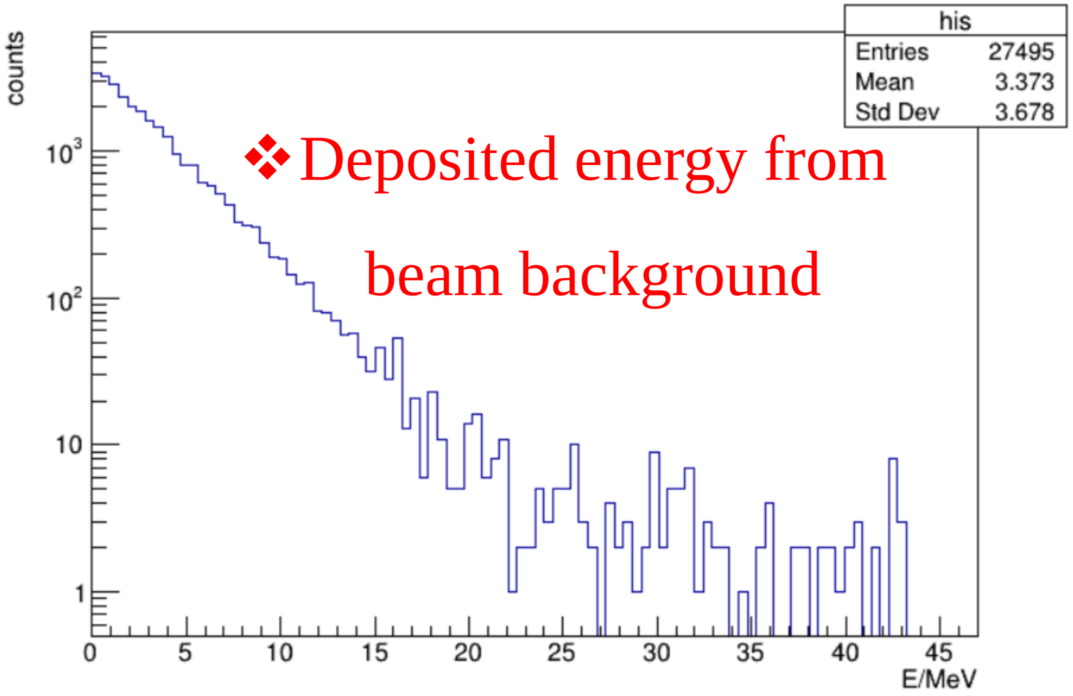
material	PbF2	BGO	LYSO	BaF2	GSO	PbWO4
Radiation length(cm)	0.93	1.1	1.1	2.1	1.4	0.89
Moliere radius(cm)	2.2	2.7	1.9	4.4	2.2	2.2
Refractive index	1.82	2.15	1.82	1.47	1.8	2.16
Decay constant(ns)	1	300	40-44	0.6,620	30	6,30

Deposited energy in the radiator

- Energy threshold for γ : large than 100 MeV



❖Deposited energy of radiation Gamma

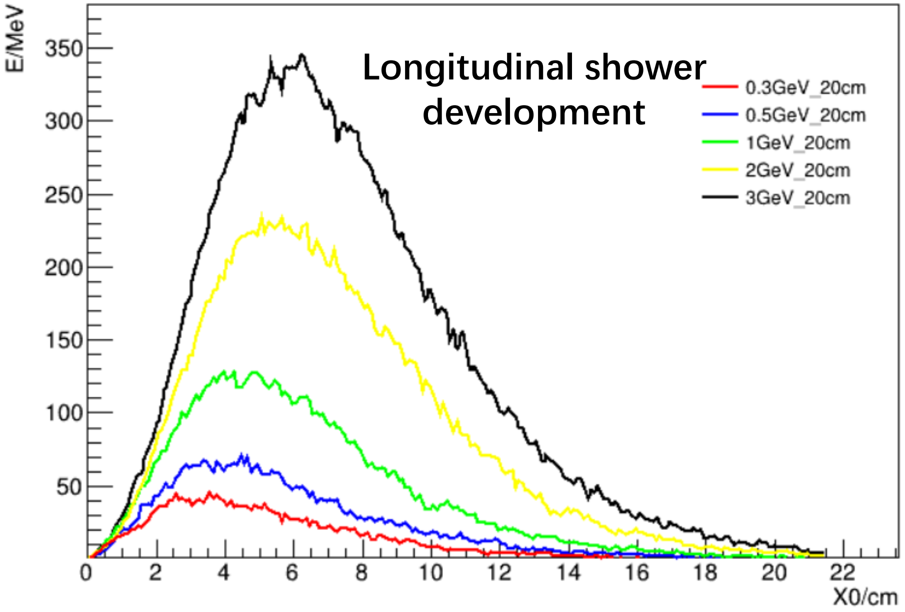


❖Deposited energy from beam background

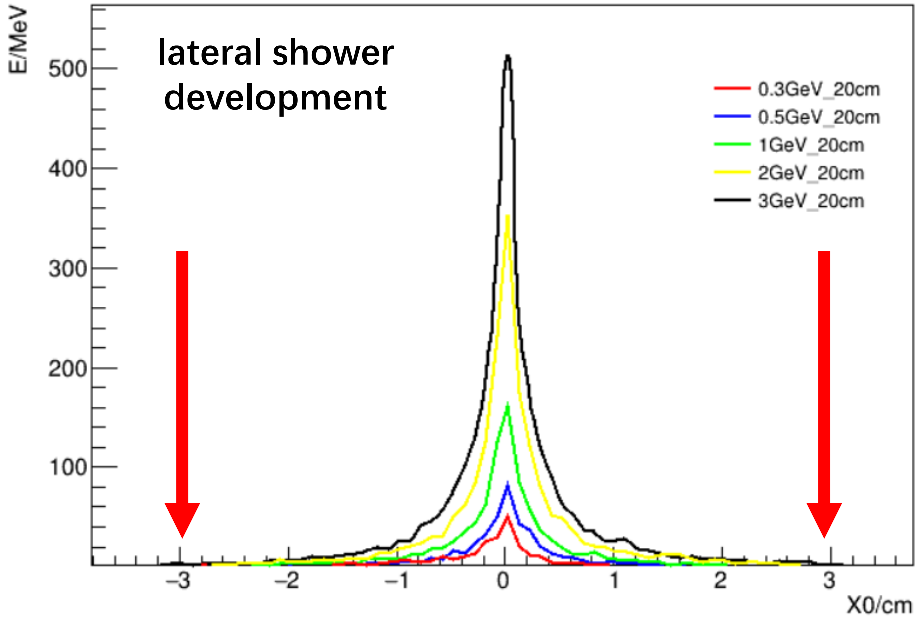
Cherenkov Detector: Size

- Optimize size：
  - Deposited energy in different crystal depth with different initial energies (0.3, 0.5, 1, 2, and 3 GeV) , where the maximum energy deposited at [4, 6]X_0.
  - Lateral deposited energy is focused within 3 X_0.
- The width and length of crystal are optimized to be: Φ4×14cm^2.

❖ Deposited energy distribution along the Z-direction



❖ Deposited energy distribution along the X-direction



Cherenkov Detector: PMT

☐ Selection of the PMT

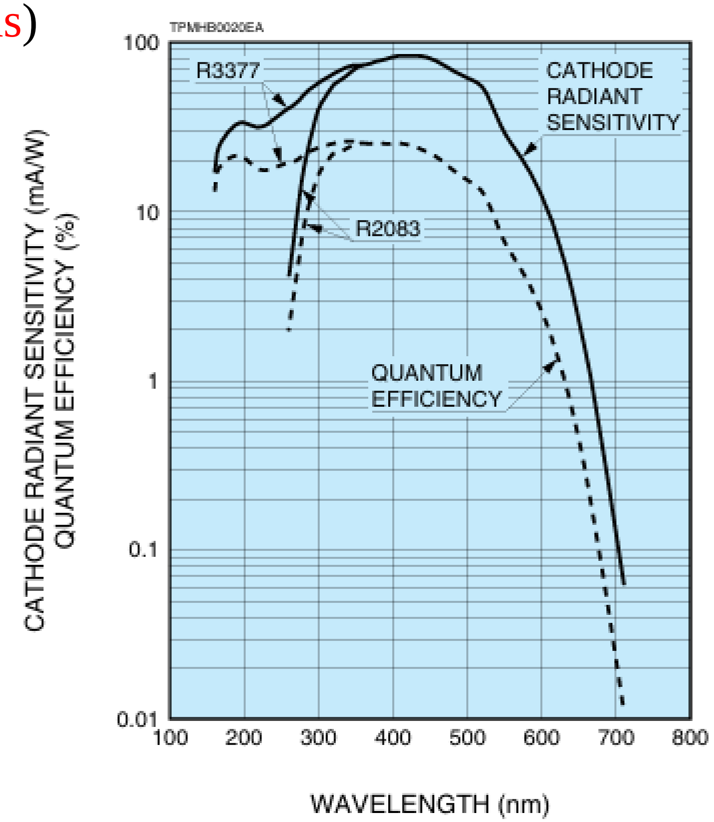
- The R2083 model PMT made by HAMAMATSU with a fast rise time (0.7 ns) and response to blue light.

HAMAMATSU R2083 performance

GENERAL

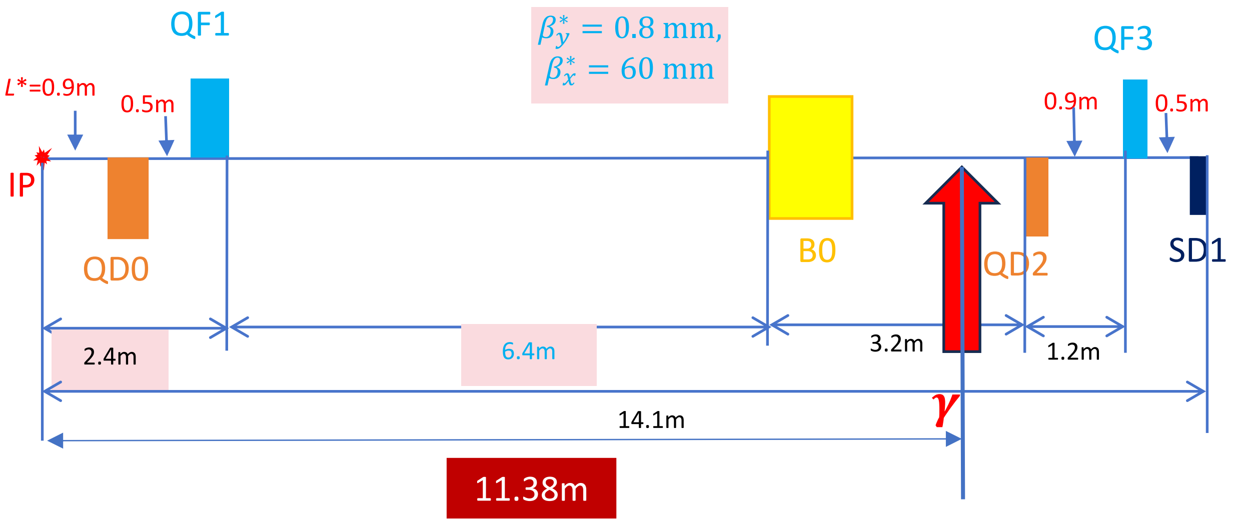
Parameter		Description / Value			Unit
Spectral Response	R2083	300 to 650			nm
	R3377	160 to 650			nm
Wavelength of Maximum Response		420			nm
Photocathode	Material	Bialkali			—
	Minimum Effective Area	ϕ46			mm
Window Material	R2083	Borosilicate glass			—
	R3377	Synthetic silica glass			—
Dynode	Structure	Linear focused type			—
	Number of Stages	8			—
Operating Ambient Temperature		-30 to +50			°C
Storage Temperature		-30 to +50			°C
Base		19-pin glass base with SMA output connector			—
Suitable Socket		E678-19J (supplied)			—
Time Response	Anode Pulse Rise Time	—	0.7	—	ns
	Electron Transit Time	—	16	—	ns
	Transit Time Spread	—	0.37	—	ns

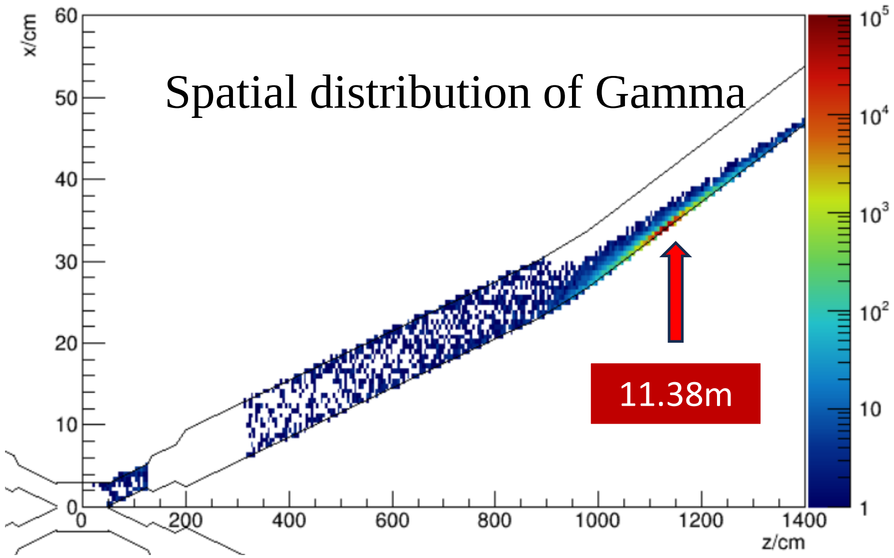
Figure 1: Typical Spectral Response

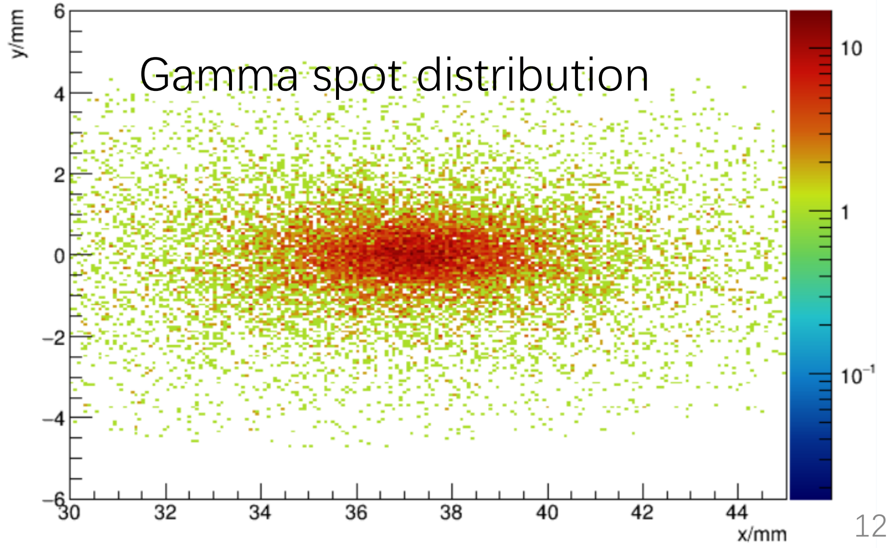


γ Signal Location

- Spatial distribution of Gamma.
  - Most Gamma accumulated at 11.38 m;
- We propose location of the detector at 11.38 m according to spatial distribution of Gamma.

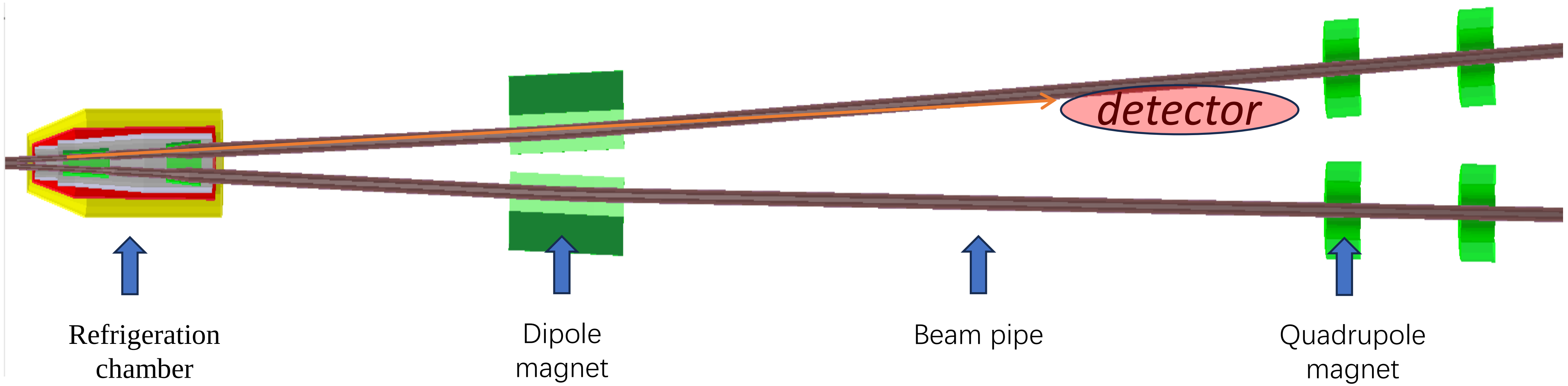






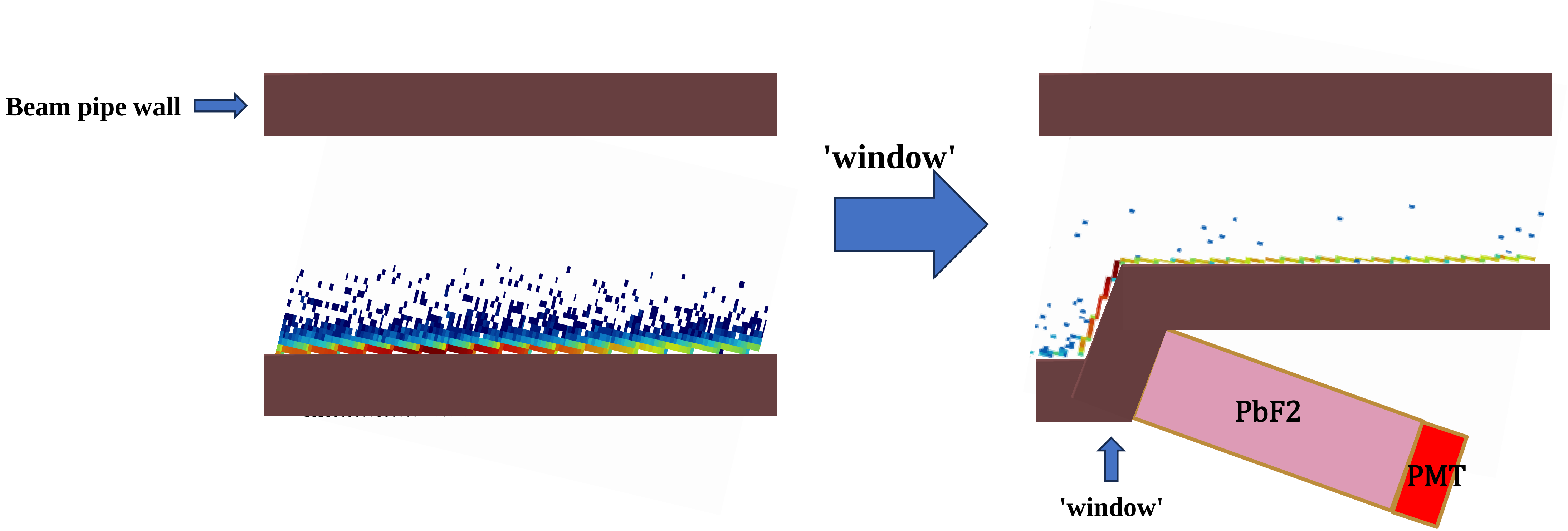
Location of Cherenkov Detector on Site

- Over 90% of the radiation Gamma travel along the direction of the incoming positron and electron, escaping from the beam pipe after the first layer of the dipole magnet.
- Radiation Gamma detection: at 11.38 m along the beam pipe.



Requirement of the 'window' on the beam pipe

- Radiation Gamma interact strongly with the material of the beam pipe in small angles . The 'window' on the beam pipe helps to reduce the radiation Gamma at the beam pipe wall.
- 'window' (The shape change of the beam pipe wall): angle 45°.
- Location of the radiation Gamma window : z = 1138 cm.



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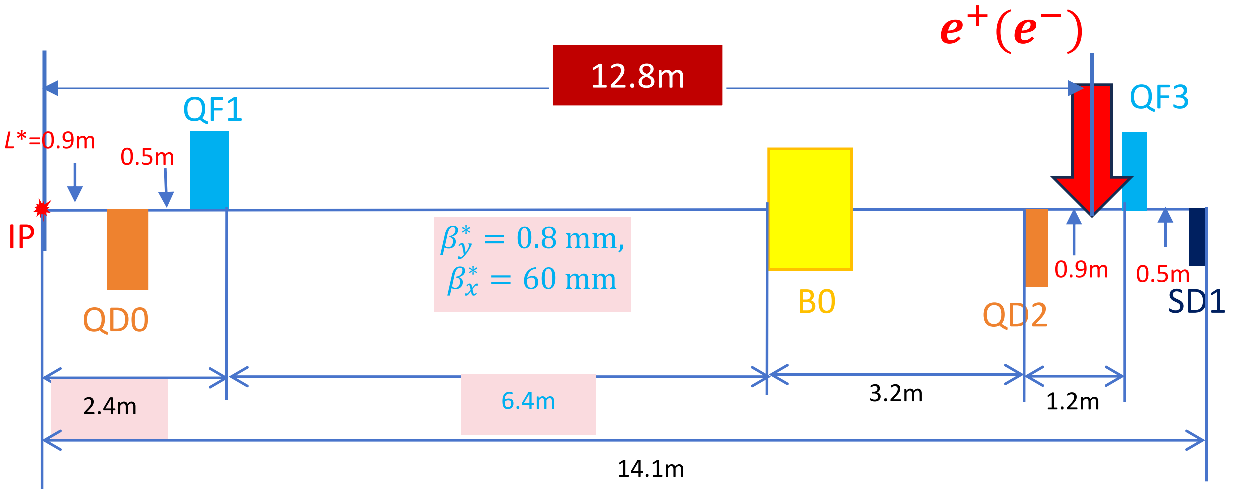
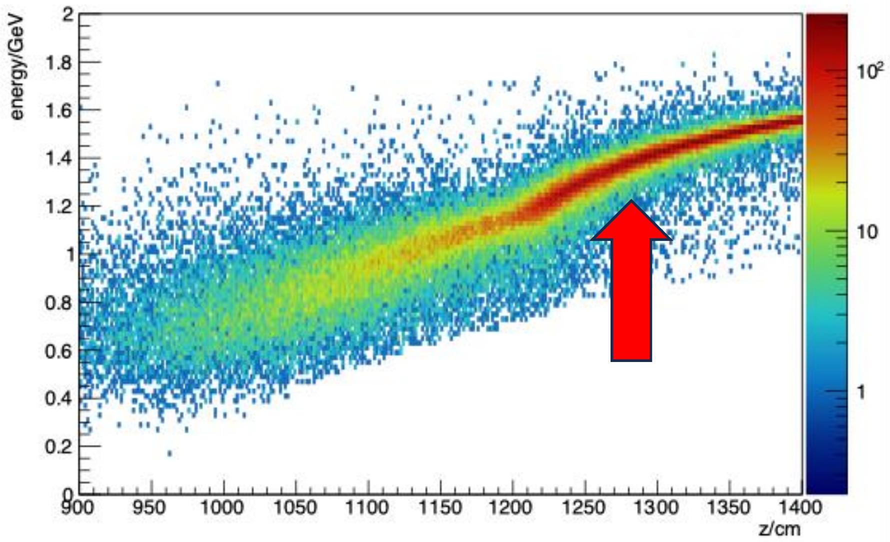
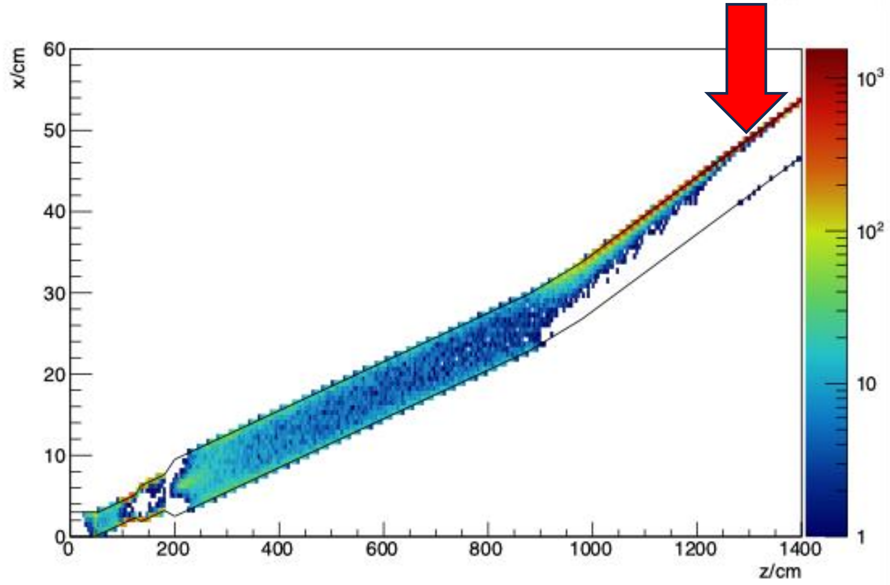
3. Conceptual Design of Luminosity Monitor By Diamond Detector

e^{+}/e^{-} Signal

- Measures luminosity by collecting recoil e^+/e^-
- Low energy e^{+}/e^{-} will be bent in B0 downstream of the IP point (like in Belle II). After passing through QD2 (defocused in x, focused in y), e^{+}/e^{-} will be bent again in the x direction
  - Need more radiation shields because of large mass materials like QD2.
- The distribution of position is related to particle energy

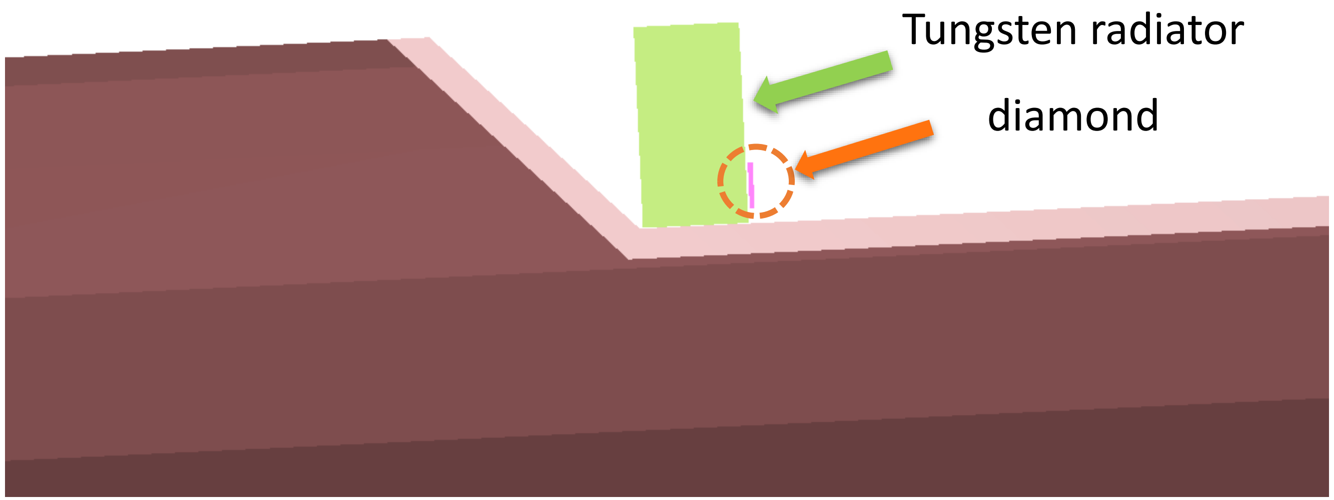


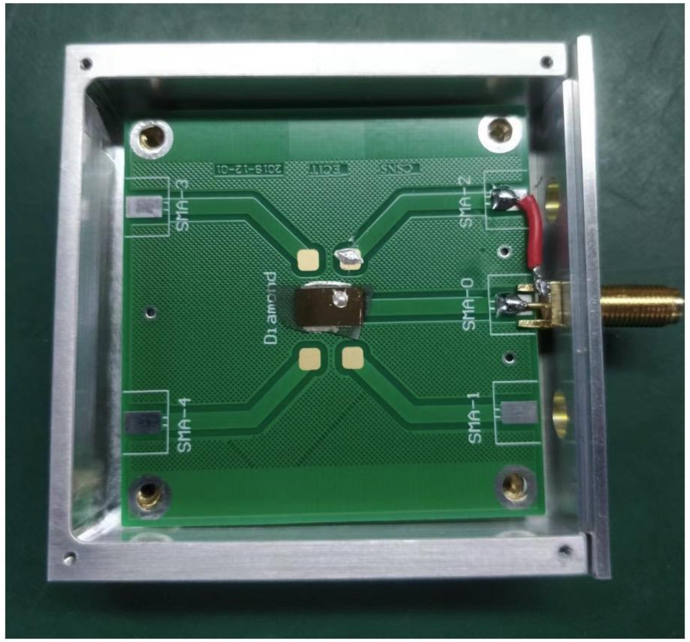




Conceptual Design: sCVD Diamond

- sCVD (Single crystal Chemical Vapor Deposition) diamond detector
  - Good radiation tolerance, fast signal collection, average ionization energy of 13 eV
  - diamond size: $4.5 \times 4.5 \times 0.5$ mm^3
  - Using broadband current amplifier, turn ionization energy to the current signal
- Tungsten radiator length: $3X_0$
  - Generated more secondary e^-, thereby increasing the energy deposition and event rate on diamond

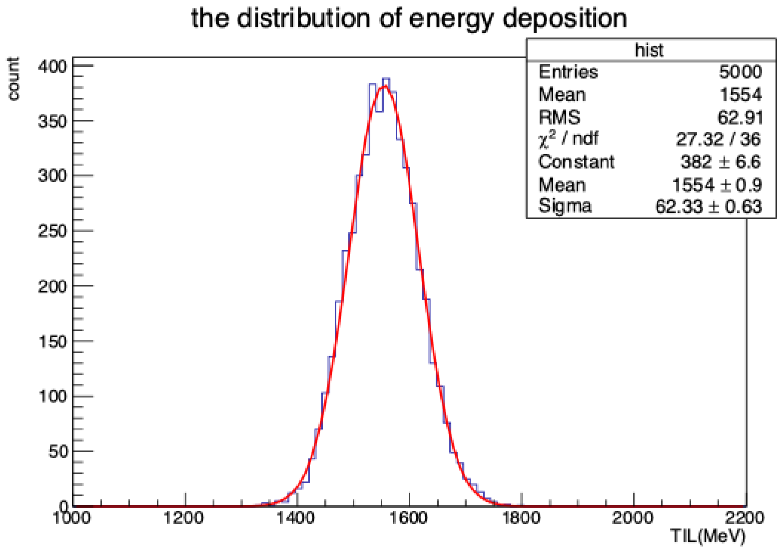


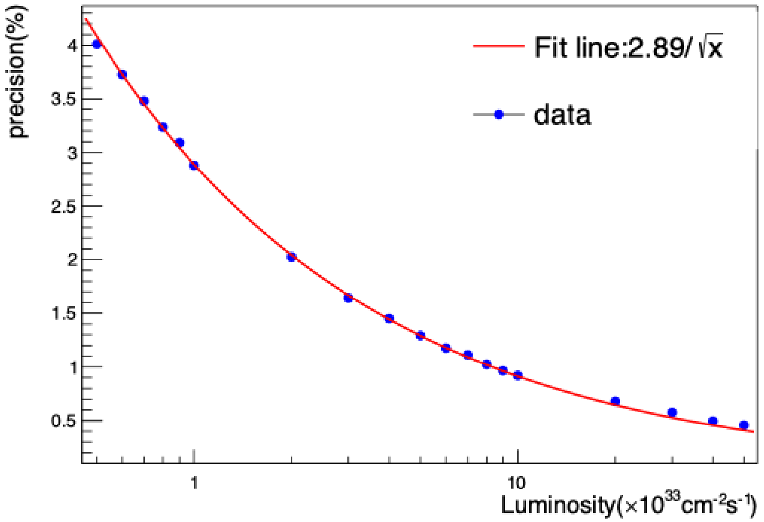


Preliminary Luminosity Simulation

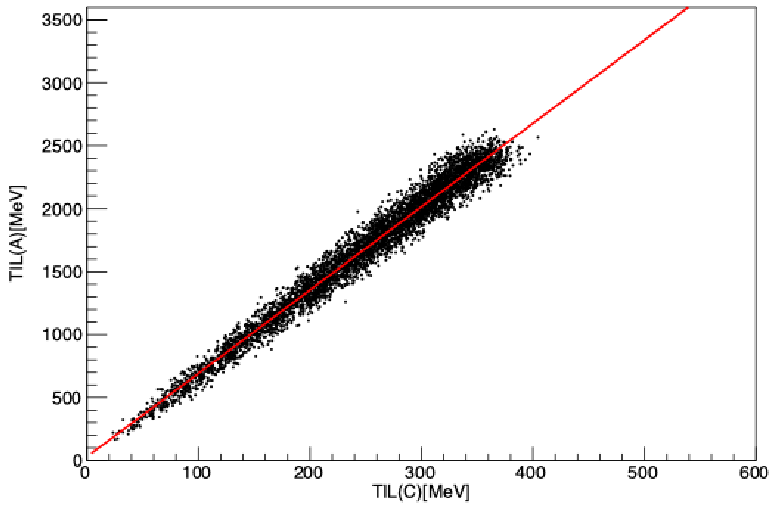
- Train Integrated Luminosity signals(TIL)： integrate the deposition energy signal over all the bunches in 1 ms.
- According to Geant4 simulation, the TIL is 1554 MeV at 1kHz when the luminosity reaches $0.5 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$.

  The relative precision will reach 1% when luminosity reaches $0.5 \times 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.
- Set multiple diamond to calibrate each other. The TIL on different diamond has good linear relationship.



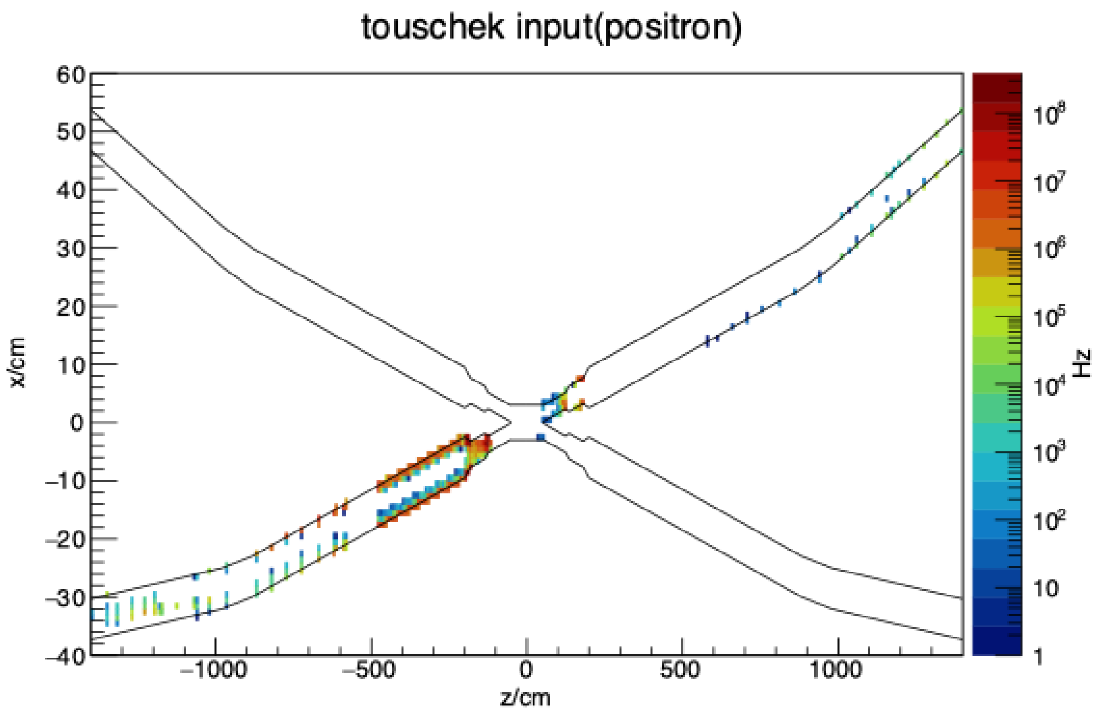


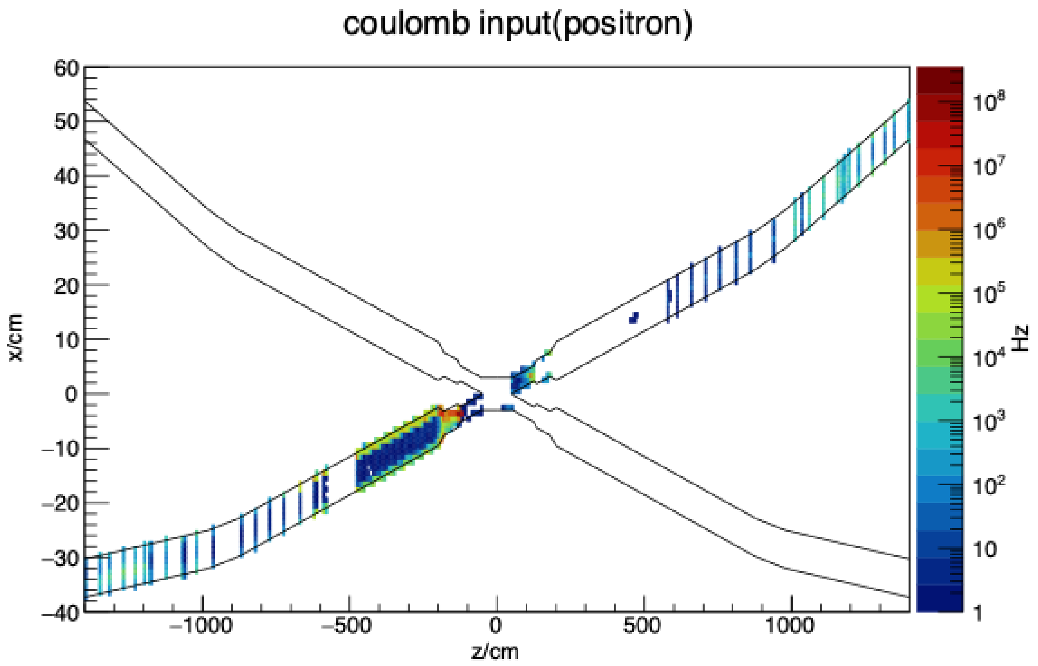
Luminosity signals from diamond A against diamond C



Preliminary Background Simulation

- Beam background: Touschek effect, beam-gas interaction(coulomb scattering and bremsstrahlung)
- The background along the beam pipe at 12m: TID ~ $200\mathrm{Gy/y}$, NIEL ~ $2 \times 10^{10}(\mathrm{n_{eq}cm^{-2}y^{-1}})$
- Considering Touschek effect and beam-gas interaction, the Preliminary Background result(on diamond) is less than 20 MeV at 1kHz.





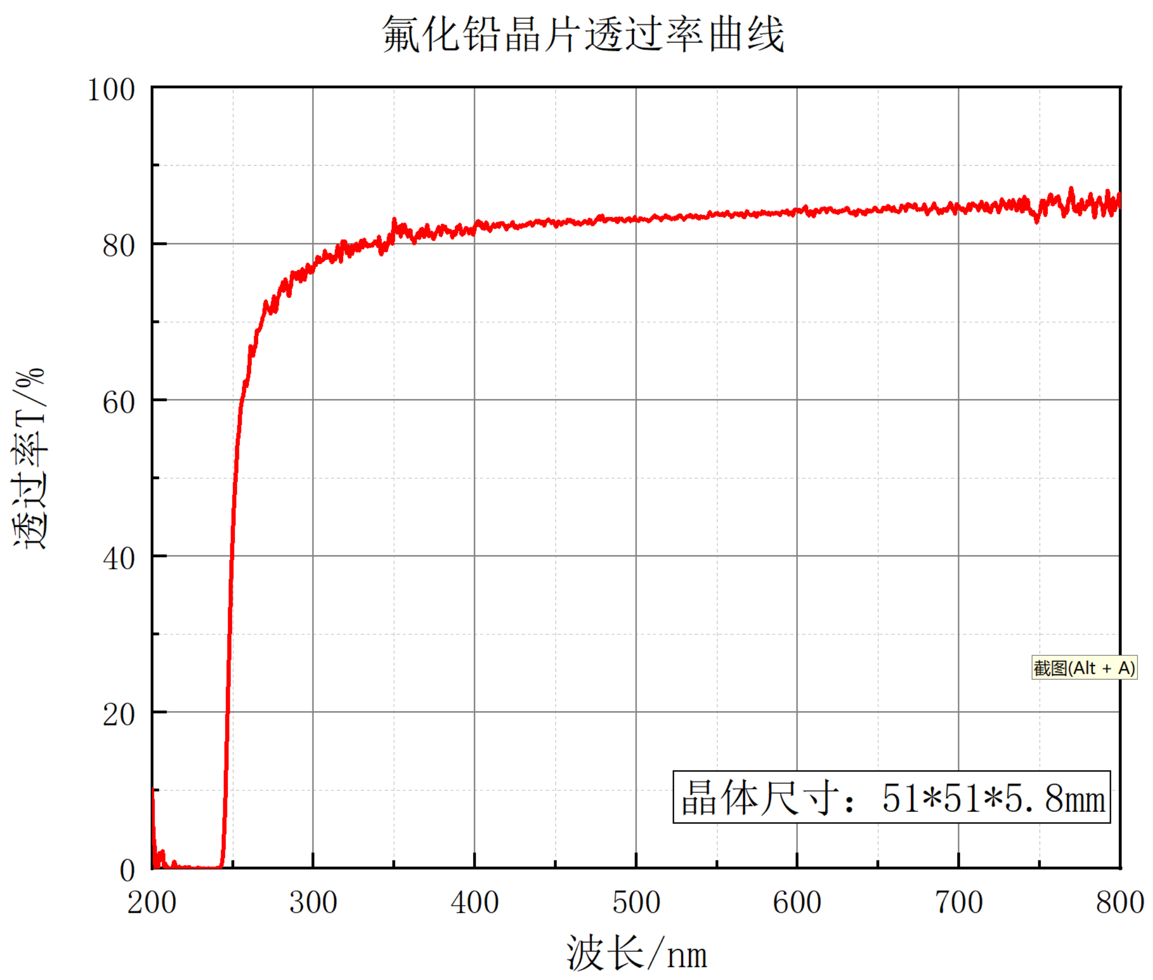
Summary

- Bunch-by-Bunch luminosity monitoring is of significant helpful for beam tuning.
- A Cherenkov detector is preliminary proposed for STCF, and the key technologies are also studied.
- The diamond luminosity detector have been carried out for STCF.
- Next, we will proceed with the hardware development.

Thanks

Backup

Lead fluoride crystal transmittance curve



Hard radiation resistance

The radiation damage resistance of PbF_2 crystals has been tested.

Experiments show that the light output only decreases by ~15% after nearly 4 hours of continuous irradiation(10^6 rad).

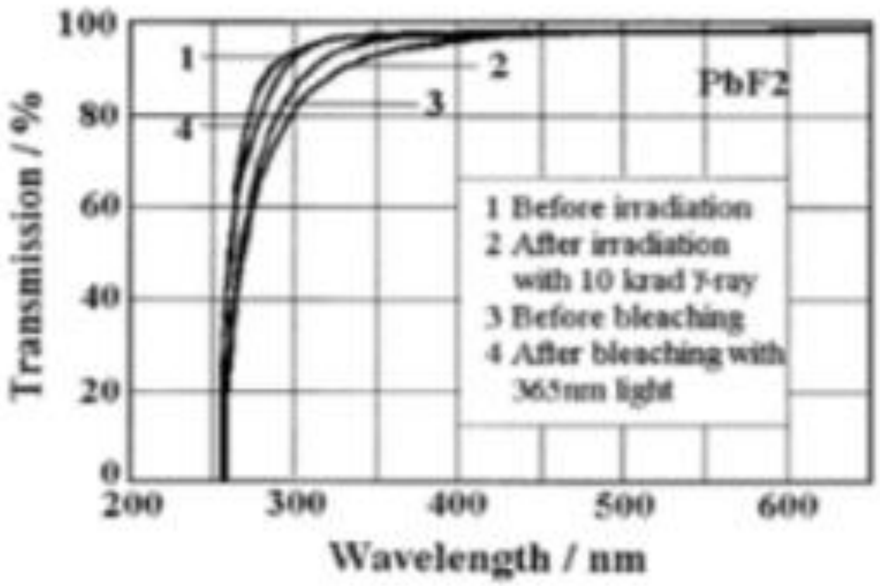


Fig. 10. Transmission of PbF_2 crystals before and after irradiation with 10 krad γ-rays as well as before and after annealing with 365 nm filtered light.

PbF2 scintillator crystal strengths:

- High stopping power: High Density - 7.77 g/cm³, Radiation Length - 0.93 cm, Moliere Radius -2.2 cm
- Fast: Decay Times - 6 and 30 ns
- Radiation Hard: No damage up to 10^5 Gy