BEAM ENERGY MEASUREMENT FOR 120GEV BEAM

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BINP-IHEP Seminar

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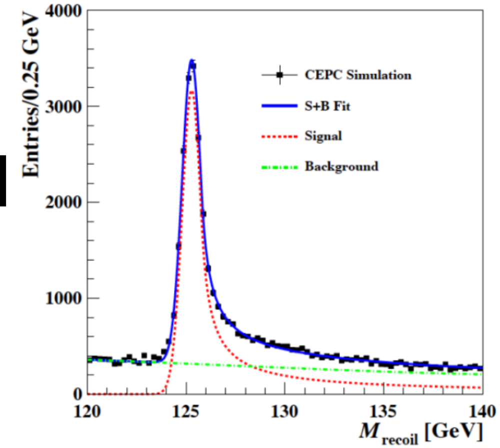
OUTLINE

To study the feasibility of Compton scattering method at CEPC.

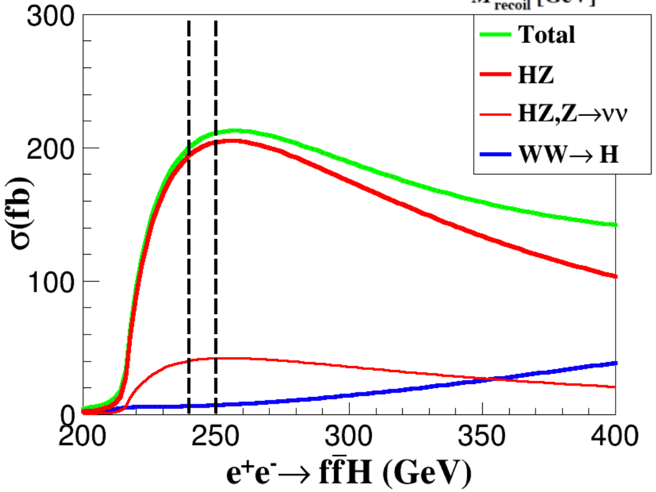
- Introduction
  - general methods
  - experience @BEPCII
- Compton scattering method for 120GeV beam
  - measure scattered photon energy.
  - measure positions of beam and scattered particles.
  - outlooks.
- Summary

PHYSICAL AIM



- Higgs Mass from Recoil Mass method
  - If we require $\delta M_{recoil} < 1\text{MeV}$,

  than, $\delta E_B < 0.25\sim1.35\text{MeV}$.



- No significant impact on other Higgs programs
  - $\sigma(ZH)$ measurement
    - Find Left/Right Shift with 0.5%
      $\sigma(ZH)$ = 200.5fb@240GeV
      200.5f×(1±0.5%)~@240±0.5GeV
      than, $\delta E_{cm} < 500\text{MeV}$.
  - Branching ratio (Br(H->bb)) requires δm_H<130MeV.
  - Event/Background selection efficiency.
- WW threshold & Z pole:

  at least δE_B<1MeV ~ LEP precision 2×10^{-5}
  - Try to do it better, δE_B<100keV.

GENERAL METHODS

- Using $\mu\mu$ events: BESIII, Belle, …
  - Uncertainty ~ 40-50MeV (CM energy)
- Resonant depolarization technique (LEP, VEPP…)
  - Relative uncertainty $< 2 \times 10^{-5}$ ("average" beam energy)
- Compton scattering method.
  - Relative uncertainty $< 2 \times 10^{-5}$ (beam energy at the position where beam and laser scattered)
- Others:
  - J/ψ production with extra beams.
  - …

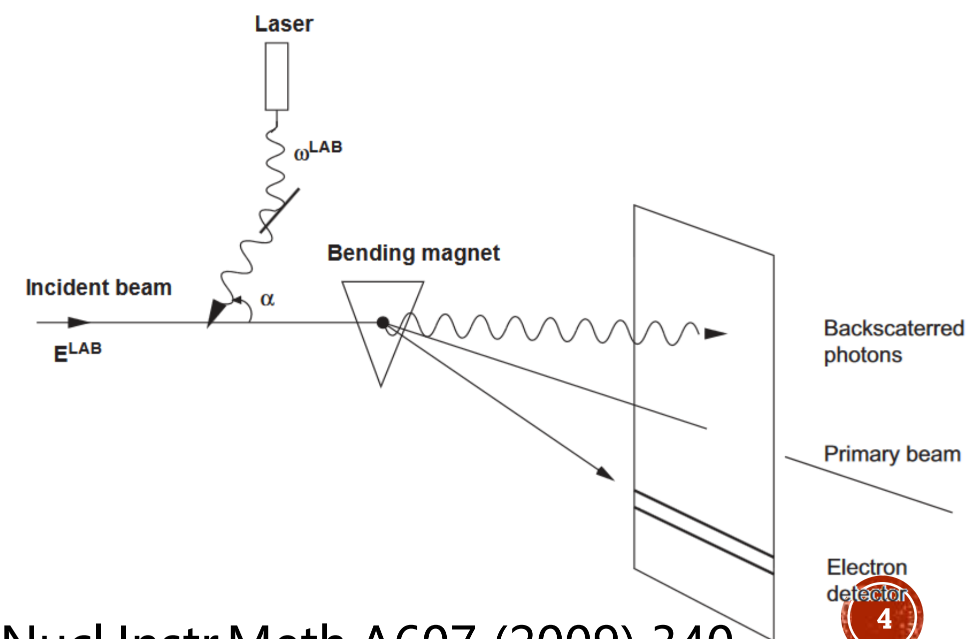


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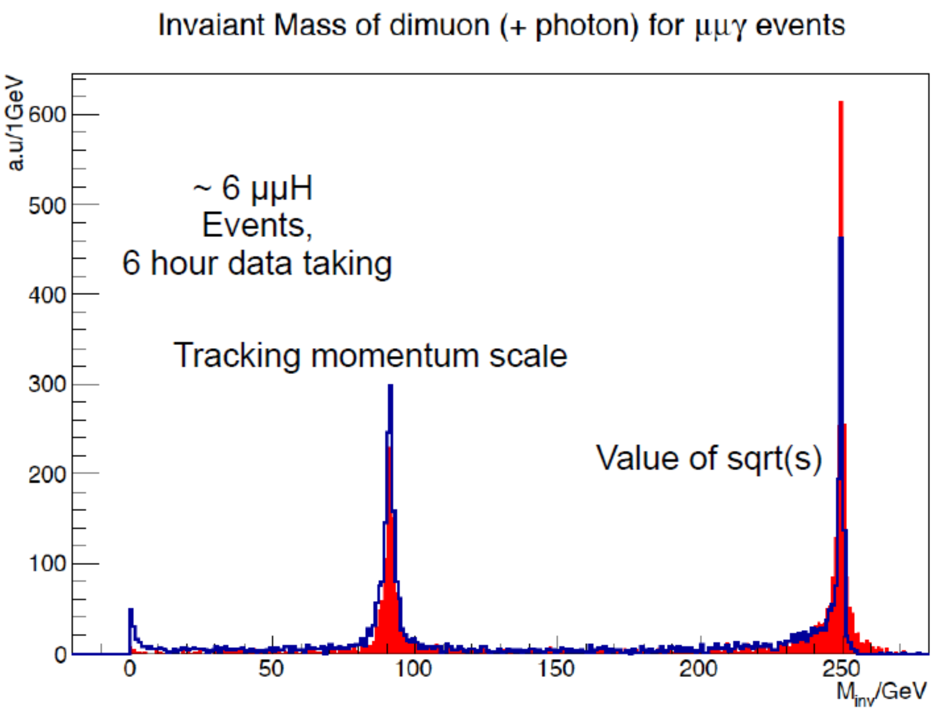
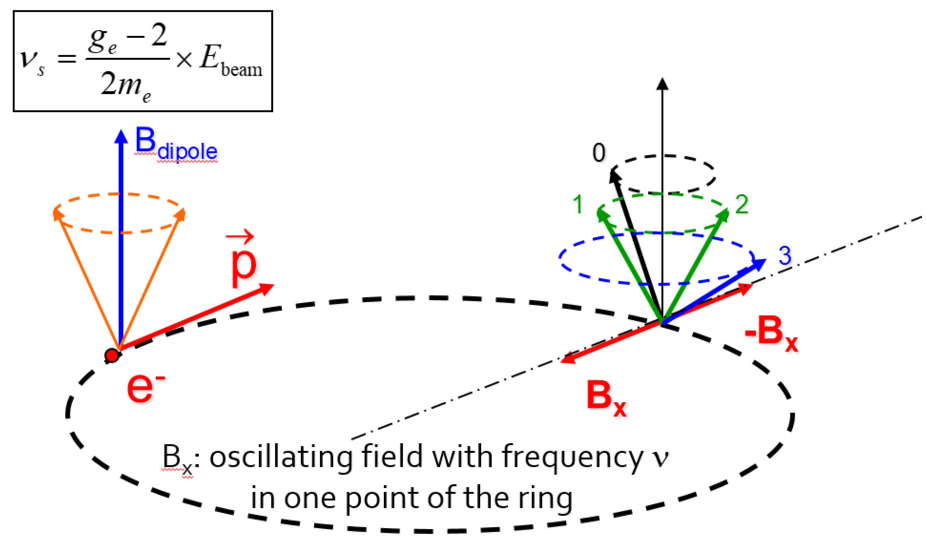
Fig. 8. Scheme of the proposed energy spectrometer based on Compton backscattering.

GENERAL METHODS

- Using $\mu\mu$ events
  - Uncertainty ~ 40-50MeV (CM energy)



- Resonant depolarization technique (@Z-pole, LEP)
  - Uncertainty ~ 2×10^{-5}
- CEPC: @Z-pole√, but @ZH?



Patrick Janot, lecture gave in the 2014 Frascati Spring school

GENERAL METHODS

- Compton scattering method. (beam energy)
  - $E_{beam} \sim f(\alpha, \omega, \omega')$;
  - α: crossing angle; ω: laser photon energy; ω': maximum energy of scattered photon.
  - Or, $E_{beam} = \frac{(mc^2)^2}{4\omega} \frac{\Delta\theta}{\theta_0}$;
- Experiences @BEPCII.

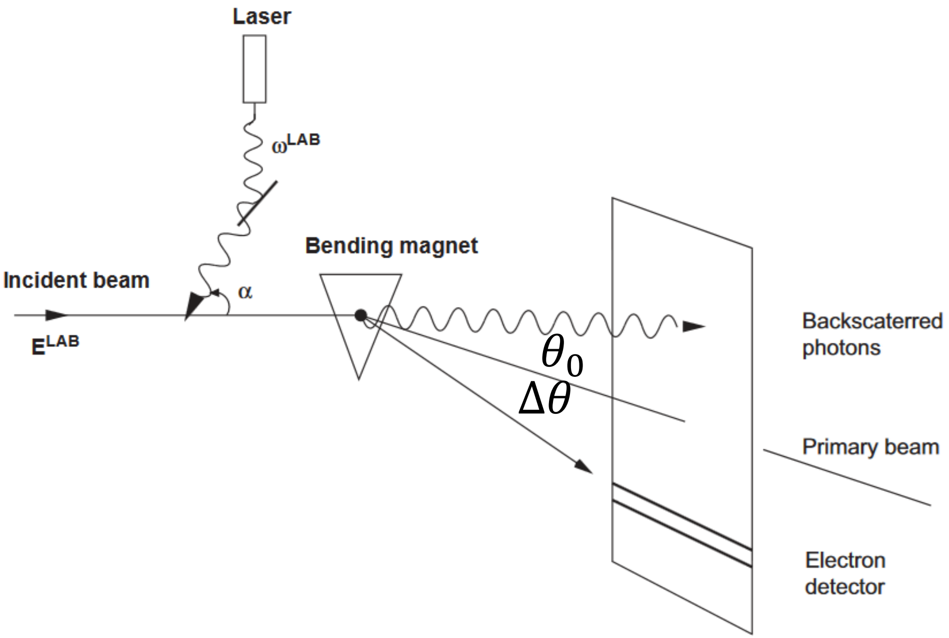


Fig. 8. Scheme of the proposed energy spectrometer based on Compton backscattering.

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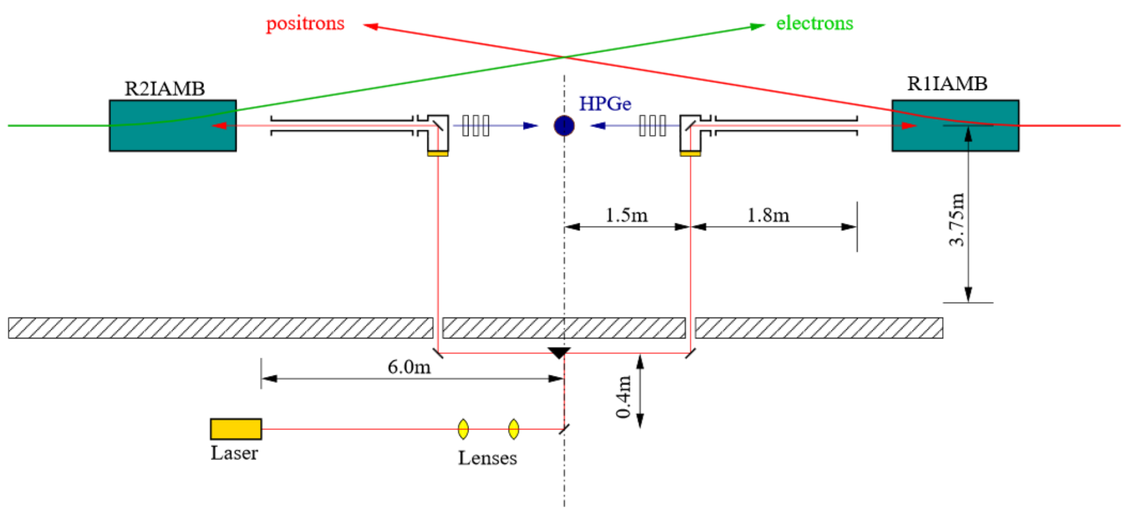
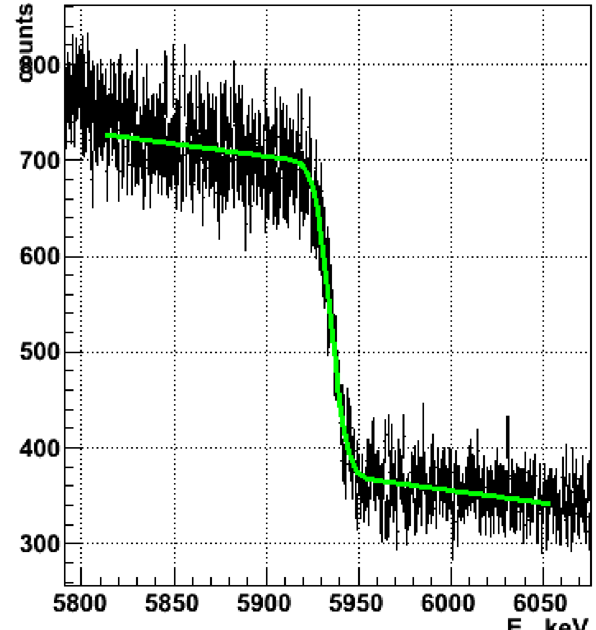
ENERGY MEASUREMENT @BEPCII

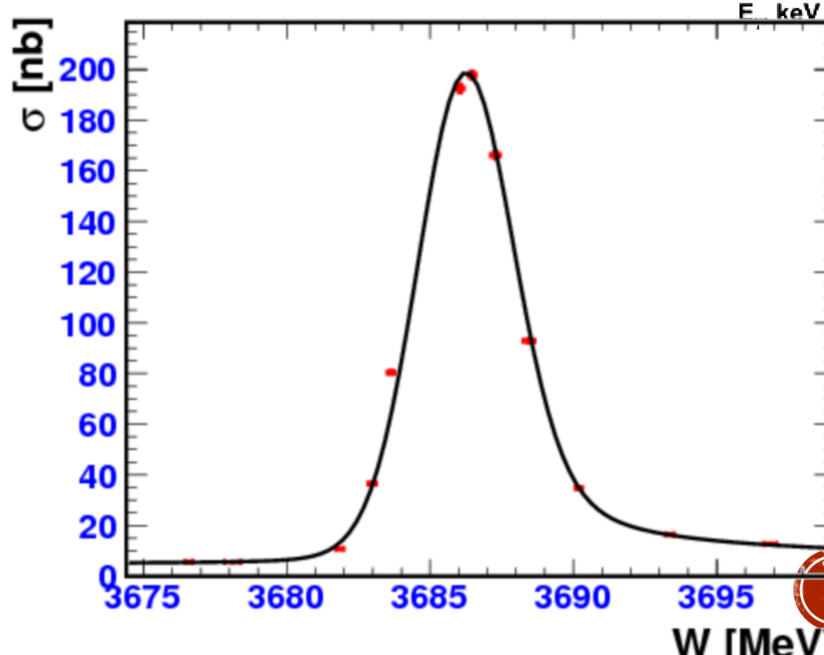
- Compton Back-scattering:
  - $E_{beam} = \frac{\omega'}{2}\sqrt{1 + \frac{m_e^2}{\omega\,\omega'}}$
- Hardware: locate at north IP of BEPCII
  - CO_2 Laser (ω=0.117eV, 50W) and optical system.
  - High purity germanium detector: 16384 channels.
  - Pulse generator and isotopes (Cs, Co, …).
  - Data acquisition system.
- Side-by-side measurement.



ENERGY MEASUREMENT @BEPCII

- Compton Back-scattering:
  - $E_{beam} = \frac{\omega'}{2}\sqrt{1 + \frac{m_e^2}{\omega\,\omega'}}$
- Calibration with isotopes and pulse generator.
- Fit of maximum photon energy (Compton edge).
- Performance studied by comparison of $\psi(2S)$
  - relative uncertainty~2×10^{-5}





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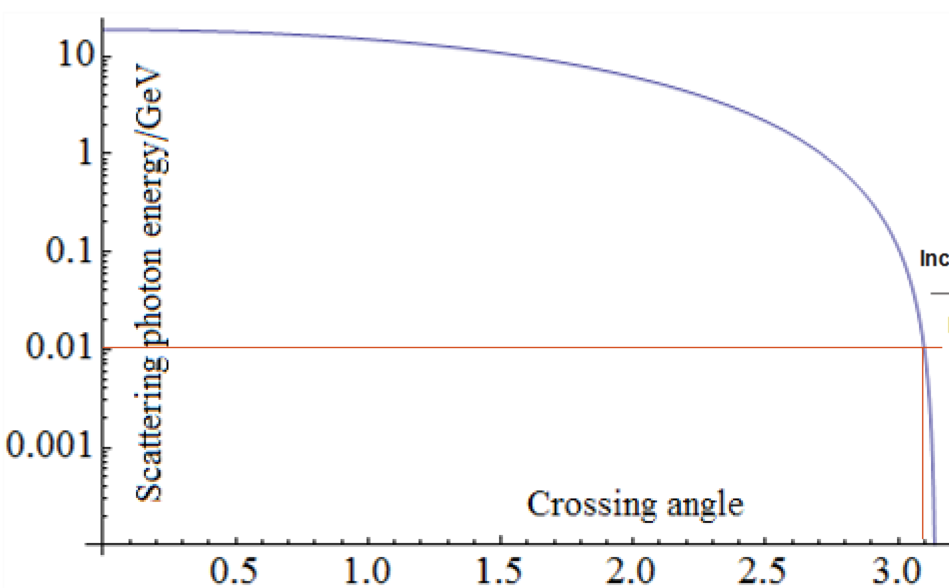
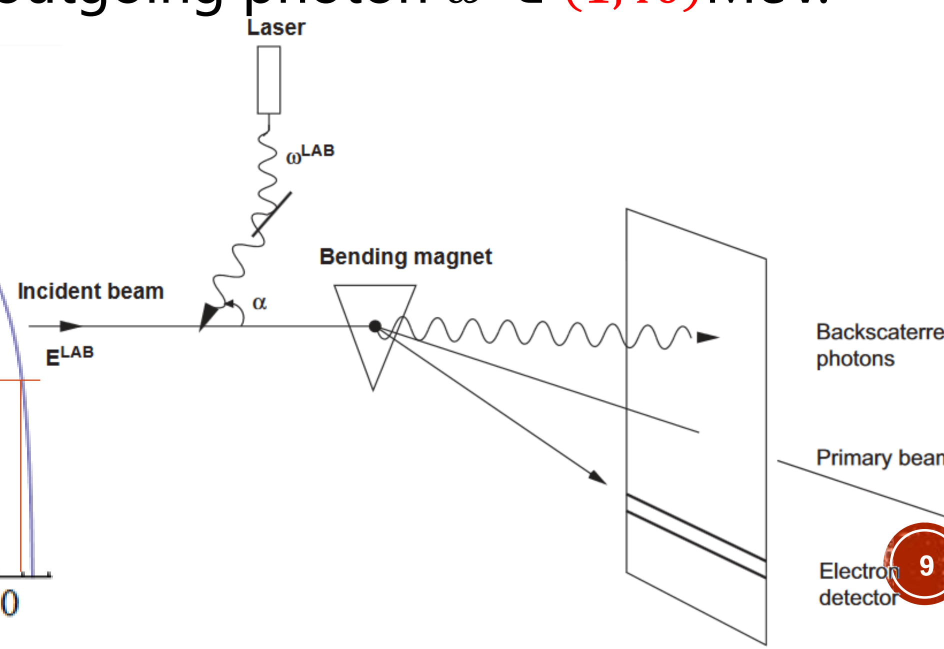
BEAM ENERGY MEASUREMENT

- If we do the same work @CEPC
  - 120GeV(beam) + 0.11eV(CO_2 laser)→20GeV (maximum scattered photon energy). Too large to be measured precisely.
  - Change crossing angle, $\alpha \in (3.06, 3.13)$rad. → Scattering with infrared laser.
  - Or, change the laser frequency ~20GHz. → Scattering with micro-wave.

  - The maximum energy of outgoing photon $\omega' \in (1,40)$MeV.





MEASURE SCATTERED PHOTON ENERGY

- If we do the same work @CEPC
  - 120GeV(beam) + 0.11eV(CO_2 laser)→20GeV (maximum scattering photon energy). Too large to be measured precisely.
  - The maximum energy of outgoing photon $\omega' \in (1,40)$MeV.

1MeV 10MeV 20MeV 40MeV

- Easy to calibrate and detect
- High SR background

- (p, γ) reaction to calibrate

- Difficult to calibrate and detect
- Low SR background

MEASURE SCATTERED PHOTON ENERGY

- Example: crossing angle $\alpha = 3.108\text{rad}$, (scatter 15MeV photon maximum)
  - $\delta E_{beam} \sim \sqrt{(3.5 \times 10^6 \times \delta\alpha)^2 + (4.0 \times 10^3 \times \delta\omega')^2}$
  - If requiring $\delta E_{beam} < 1\text{MeV}$, $\delta\alpha < 2.8 \times 10^{-7}$rad and $\delta\omega' < 2.5 \times 10^{-4}\text{keV}$.
- Impact on $\delta\alpha$:
  - Beam orbit, emittance;
  - Laser alignment.
  - Device vibration.
- Impact on $\delta\omega'$:
  - Detector calibration;
  - Statistic uncertainty.

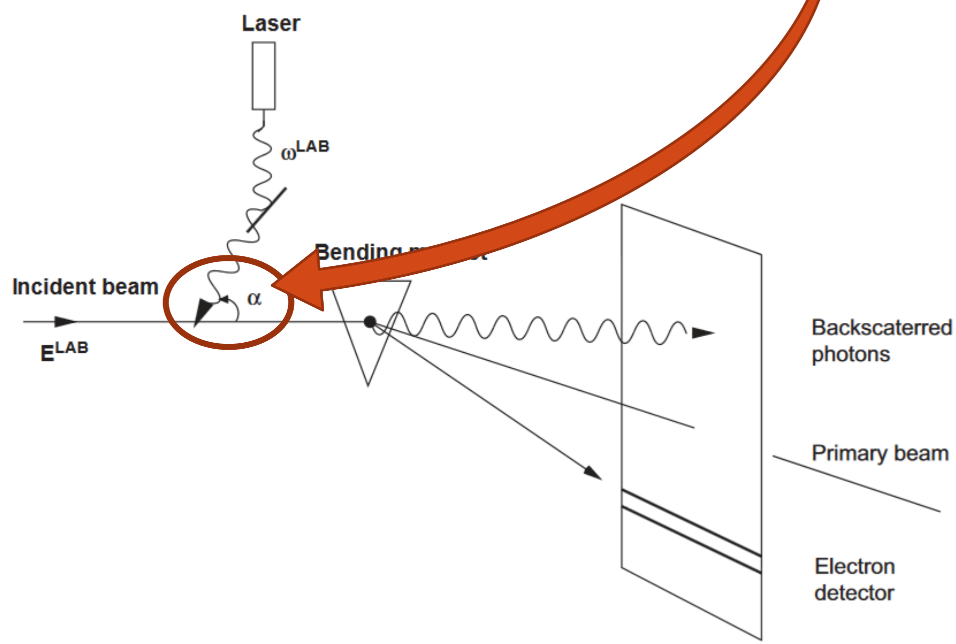


Fig. 8. Scheme of the proposed energy spectrometer based on Compton backscattering.

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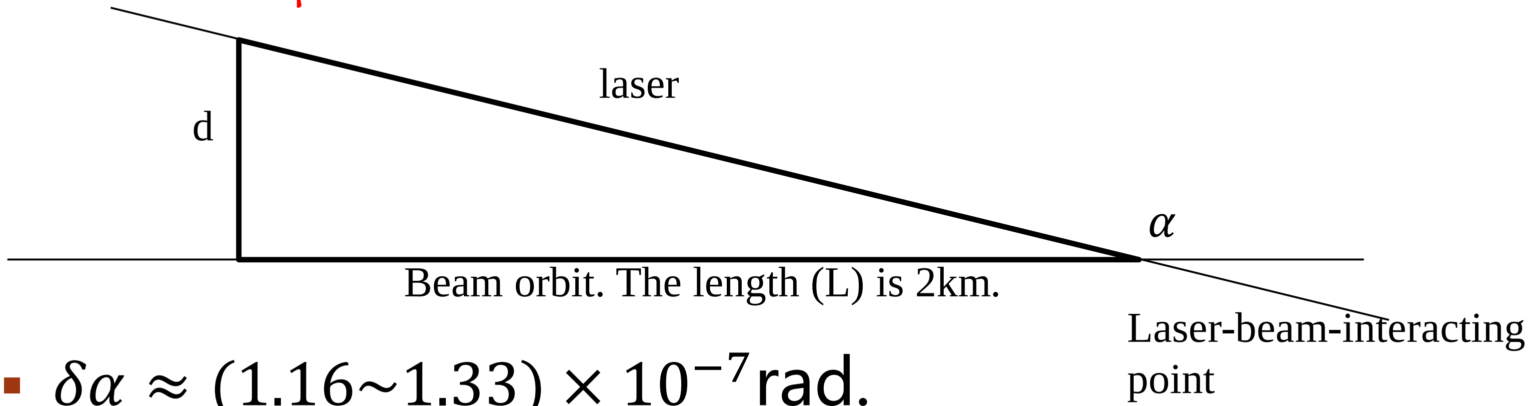
MEASURE SCATTERED PHOTON ENERGY

- Beam position monitor + long linear orbit.

$$\pi - \alpha = \text{ArcTan}(d/L).$$

  - linear orbit 2km; BPM precision 0.1mm; alignment uncertainty 40~100μm.



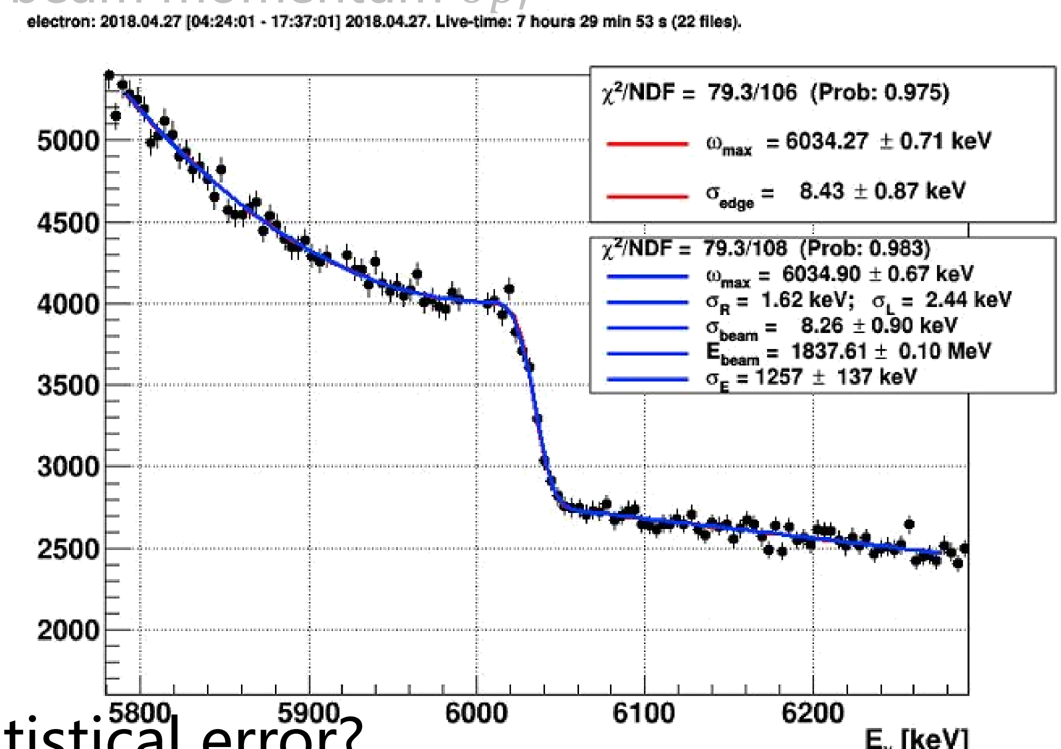
- $\delta\alpha \approx (1.16\sim1.33) \times 10^{-7}$rad.

  $< 2.8 \times 10^{-7}$rad.

- It is crucial to control the incident beam and laser.

MEASURE SCATTERED PHOTON ENERGY

- Example: crossing angle $\alpha = 3.108\text{rad}$, (scatter maximal 15MeV photon)
  - $\delta E_{beam} \sim \sqrt{(3.5 \times 10^6 \times \delta\alpha)^2 + (4.0 \times 10^3 \times \delta\omega')^2}$
  - If $\delta E_{beam} < 1\text{MeV}$, $\delta\alpha < 2.8 \times 10^{-7}$ and $\delta\omega' < 2.5 \times 10^{-4}\text{keV}$.
- Impact on $\delta\alpha$:
  - Beam orbit, variance of beam momentum $\delta\vec{p}$;
  - Laser alignment.
- Impact on $\delta\omega'$:
  - Detector calibration;
  - Statistical error.
- $\frac{\delta\omega'}{\omega'} \sim 10^{-4}$, $\delta\omega' \sim 1.5\text{keV}$
- Total beam energy uncertainty~6.1MeV.



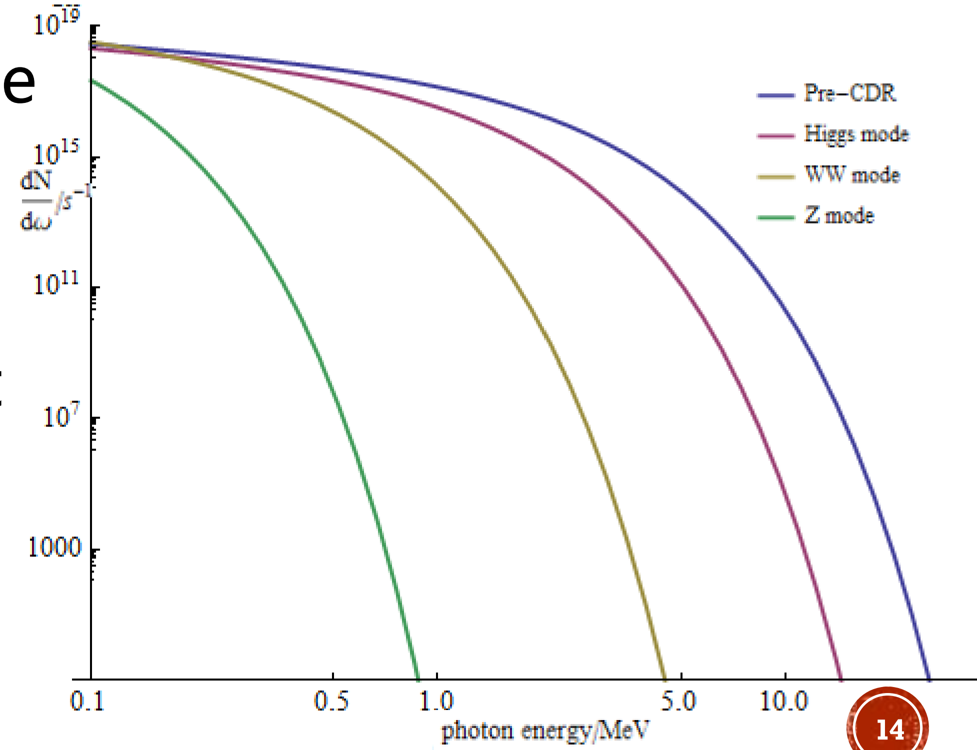
- Signal-noise ratio? Statistical error?

MEASURE SCATTERED PHOTON ENERGY

- Compare between different energy region:

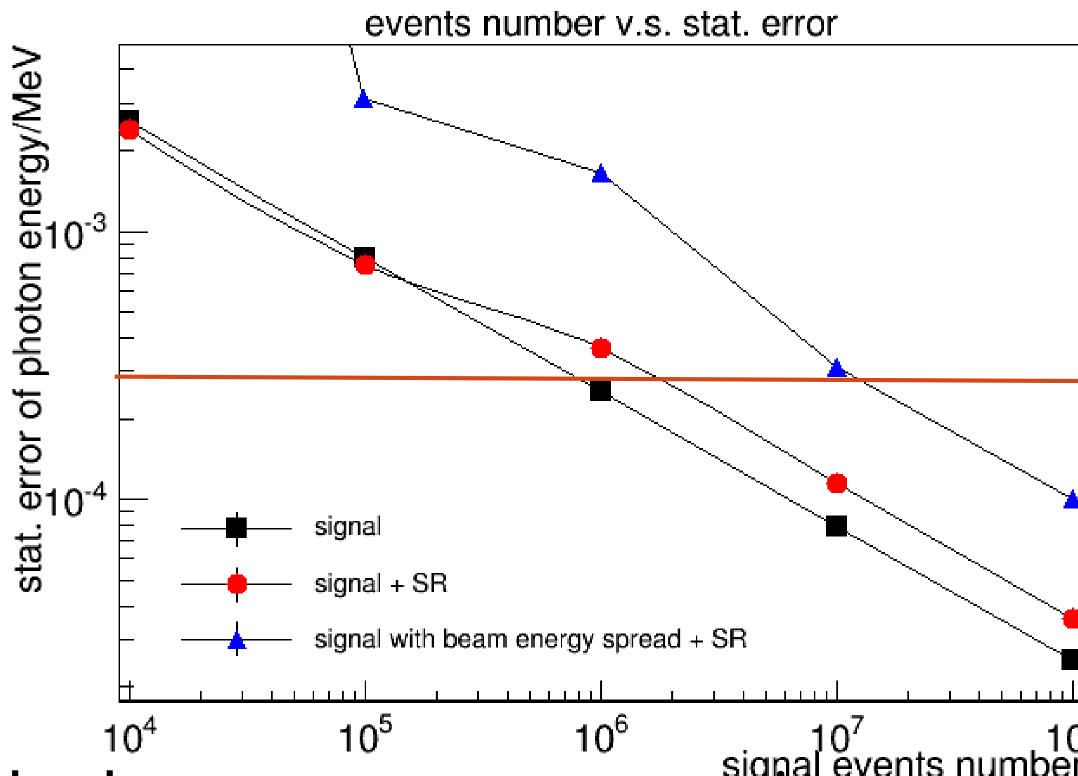
$\frac{dN}{d\omega}/s$		@3MeV	@10MeV	@20MeV	@40MeV
SR	Pre-CDR	10^{15}	10^{10}	2000	10^{-11}
	CDR	10^{13}	10^{4}	10^{-7}	10^{-32}
Compton Scattering		$10^3 \sim 10^4$ (integrated)			

- SR background of double ring is smaller than that of pre-CDR.
- Balance SN ratio against calibration.

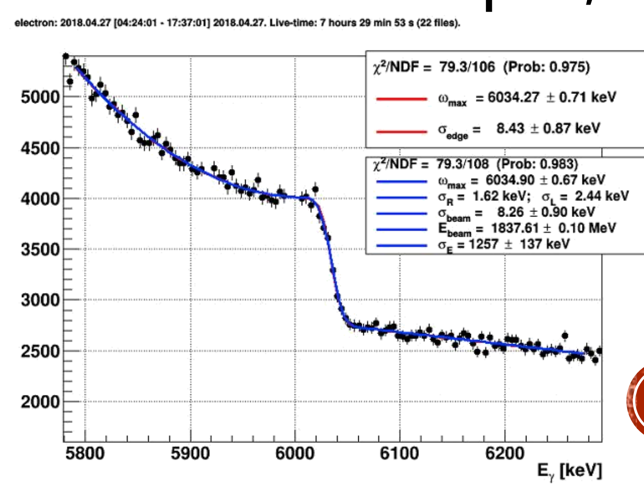


MEASURE SCATTERED PHOTON ENERGY

- The more statistics are, the smaller the statistical error is.
  - Efficiency
  - Laser power
  - Duration
- Depends on the details of fits.



- The more precisely the beam parameters are input, the better fit we obtain.
  - Energy spread, orbit, emittance…



OUTLINE

To study the feasibility of Compton scattering method.

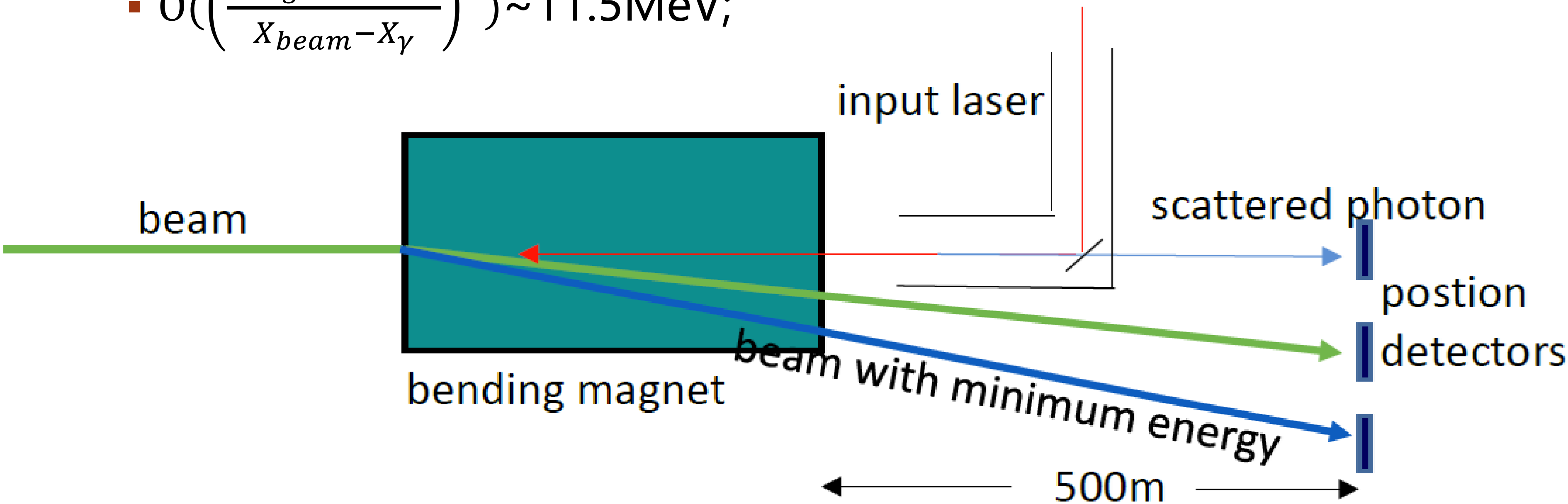
- Introduction
  - Common method
  - Experiences @BEPCII
- Compton scattering method
  - measure scattered photon energy.
  - measure positions of beam and scattered particles.
- summary

MEASURE POSITIONS

- If α=0, and the orbit difference of particles with different energy in dipole and the synchrotron radiation are omitted.

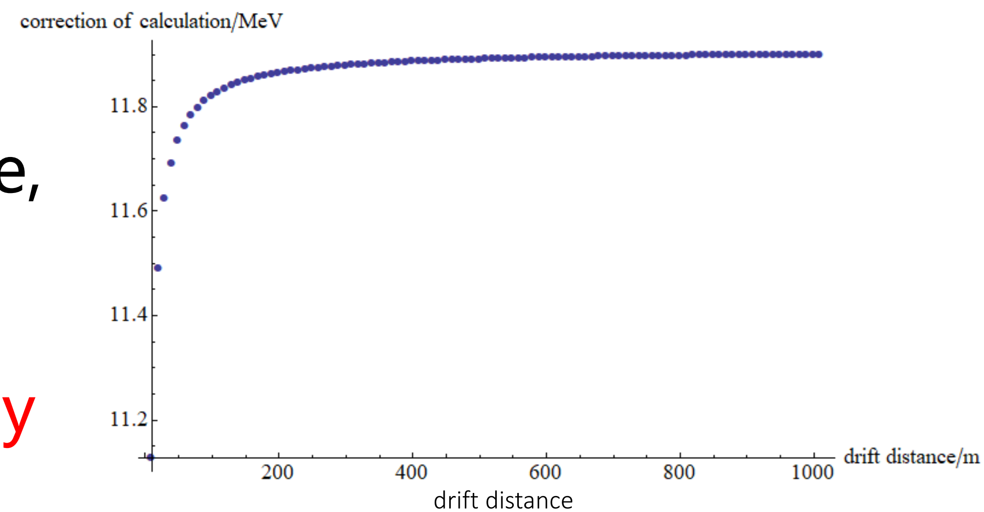
$$E_{beam} \sim \frac{(mc^2)^2}{4\omega}\frac{\Delta\theta}{\theta_0} \sim \frac{(mc^2)^2}{4\omega}\frac{X_{edge}-X_{beam}}{X_{beam}-X_{\gamma}} + \mathrm{O}\left(\left(\frac{X_{edge}-X_{beam}}{X_{beam}-X_{\gamma}}\right)^2\right)\ldots$$

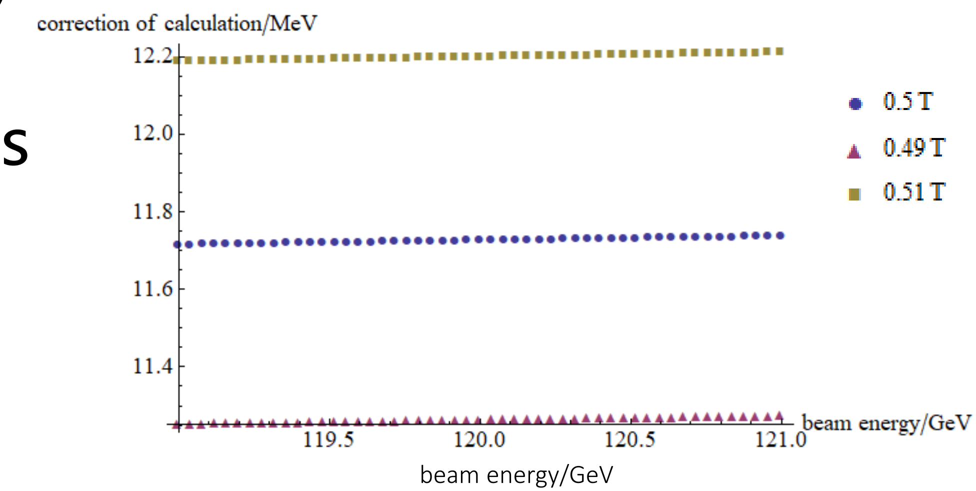
- Magnet field: 0.5T; the length of dipole: 3m; the drift distance between the bending magnet and detector: 500m.
- $\mathrm{O}\left(\left(\frac{X_{edge}-X_{beam}}{X_{beam}-X_{\gamma}}\right)^2\right)$~11.5MeV;



MEASURE POSITIONS

- The correction term, $O\left(\left(\frac{X_{edge}-X_{beam}}{X_{beam}-X_{\gamma}}\right)^2\right)$ is a function of drift distance, magnet and beam energy.
- This term changes slowly while magnet field, drift length and beam energy vary.
- This is true whether SR is considered or not.



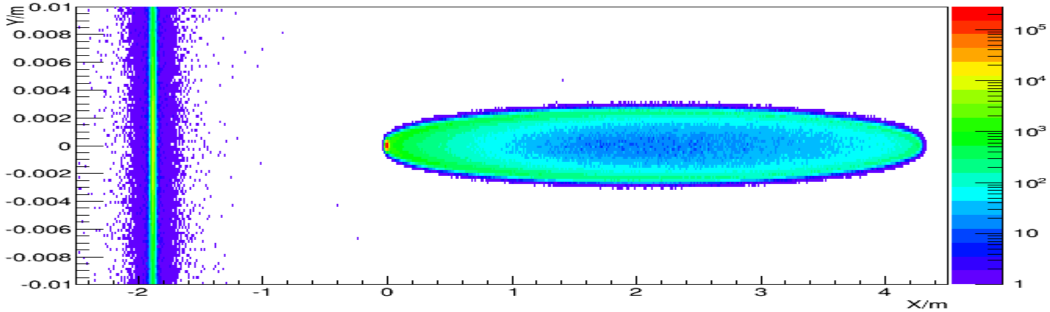


UNCERTAINTY OF POSITIONS MEASUREMENT

- Three positions should be measured:
  - backscattered photon position, X_γ (which is set as the axis origin).
  - the beam position, X_{beam}.
  - the position of the lepton with minimum energy after scattering, X_{edge}.

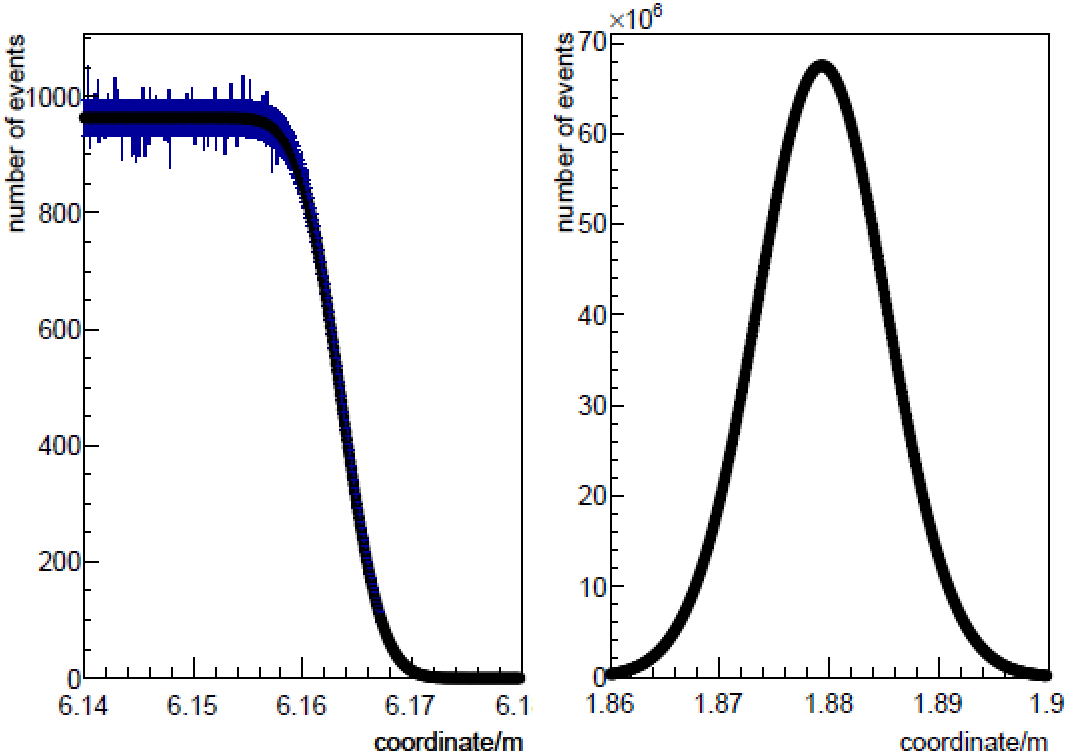
Beam energy	δX_{edge}	δX_{beam}	δX_γ
120GeV	36μm	22μm	32μm

- If requiring δE_{beam}<1MeV, the upper limits of positions measurement are listed above.



I/O CHECK USING GAUSSIAN BUNCH

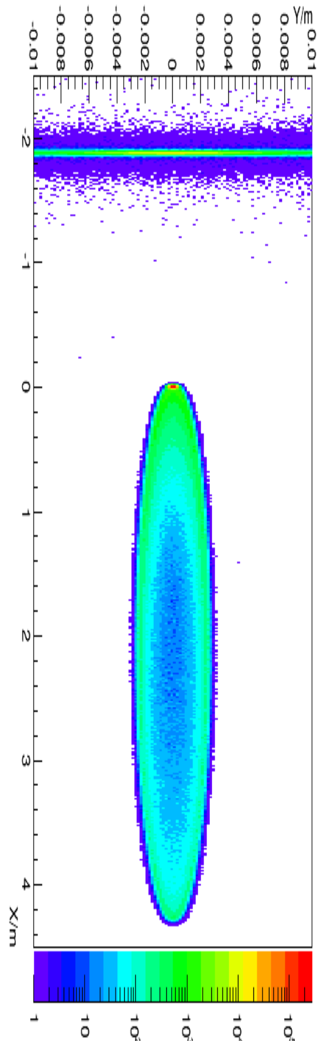
- The energy input is 120GeV.
- Difference between input and output < 1MeV



X_{edge}/m	$6.163503 \pm 2.6 \times 10^{-5}$
X_{beam}/m	$1.879339 \pm 6 \times 10^{-8}$
X_{γ}/m	0 (fixed)
E_{beam}/GeV	119.9993 ± 0.0010

I/O CHECK USING BEAM SIMULATION

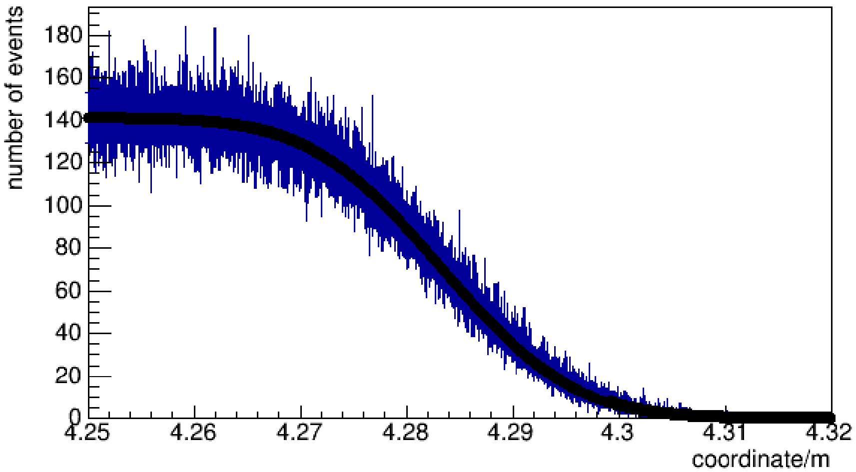
- In the beam simulation program, the bunch is tracked for 500 turns, then goes through a extraction beamline.

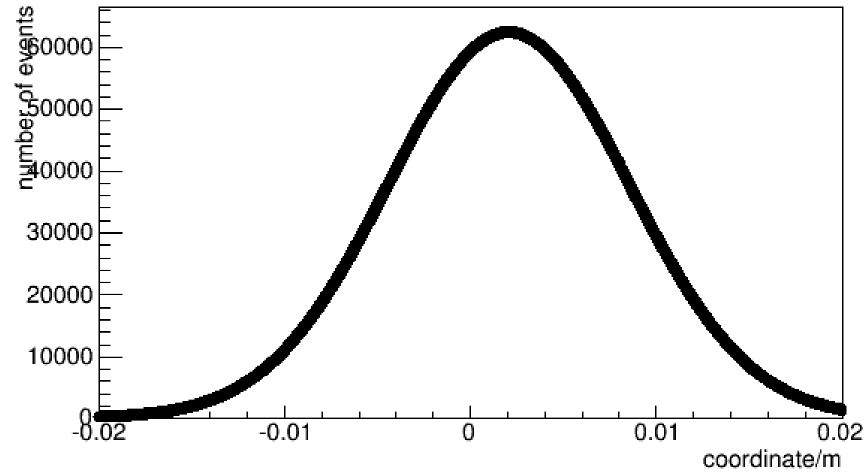


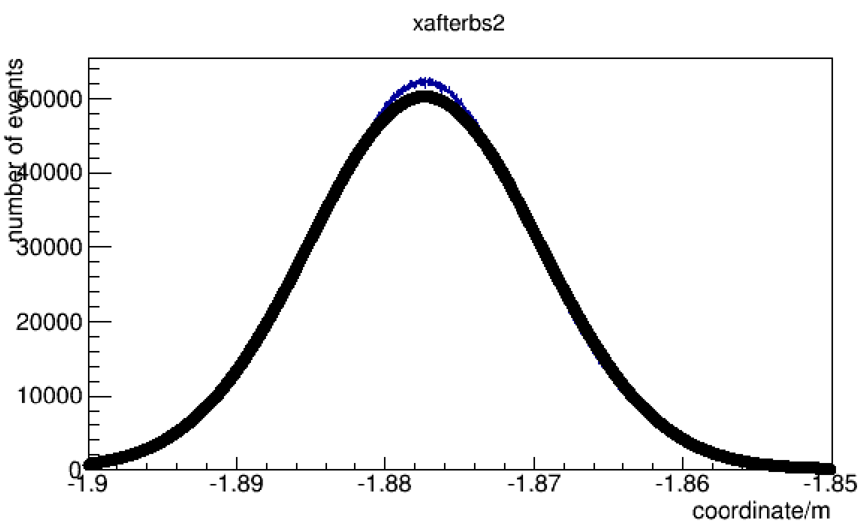
	Truth	10um bins+crystball function	10um bins+double Gaussian
X_{γ}/um	-1877393	+26.8±0.8	+29.4±1.2
X_{beam}/um	1935	+125.1±0.7	+62.9±1.0
X_{edge}/um	4283428	+80±50	+80±50
Beam energy/MeV	119936.9	-7.9±1.5	-2.7±1.4

I/O CHECK USING BEAM SIMULATION

- Difference between input and output >8MeV







mean of edge: 4.2835080
+/-5.0e-05
mean of gauss: 0.0020600
+/-7.e-07
mean of gamma: -1.8773678
+/-8.e-07
energy: 119.9292+/-0.0014

CONCLUSIONS & OUTLOOKS

- Two schemes:
  - Scattering with infrared laser, measure scattered photon energy.
  - Scattering with infrared laser, measure bending angle.
- Systematic error:
  - → ~6 MeV
  - → ~1-8 MeV
- Still more topics should be discussed!!!
  - How to calculate beam energy at IPs?
- Detector selection.
  - Damaged by SR or bunch or not?
  - Alignment and calibration
  - Si, diamond or glass fiber?

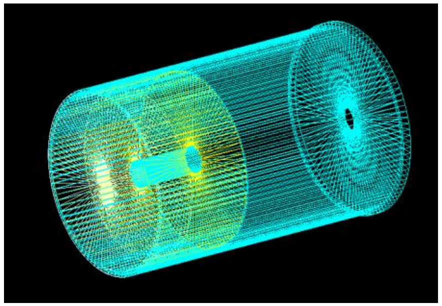
→ study on detectors and simulation.

OUTLOOKS

- Uncertainty of crossing angle α can be handled.
  - beam orbit
  - emittance → understand bunch property.
  - laser alignment → optics system with long light path.
- Additional hardware is compatible with accelerator.
  - Extract bunches
  - Interface between laser and accelerator (beam pipe)
- Statistical error.
  - detector efficiency?
  - fit scheme? → study on detectors and simulation.
  - laser power → pulsed laser, then how to dump it?
- Generator
  - using tree level QED or using simplified kinematics.

OUTLOOKS

- HPGE/diamond detector simulation.



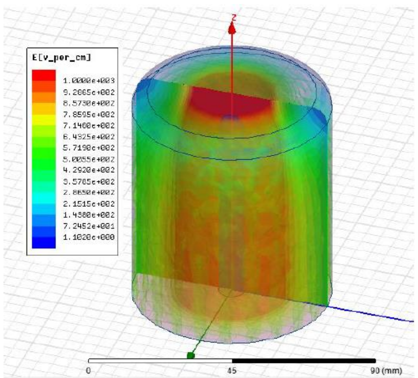
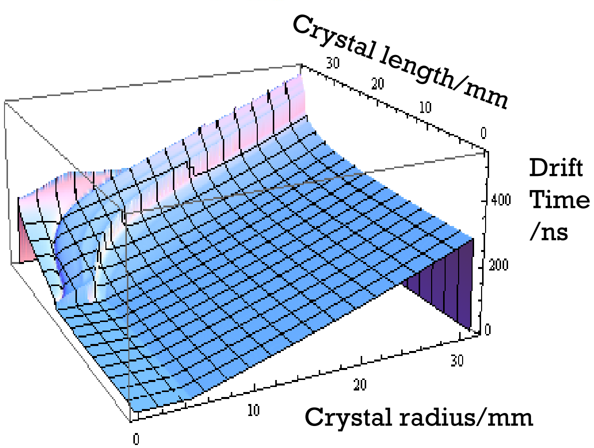


图 3.14 HPGe 探测器电场分布



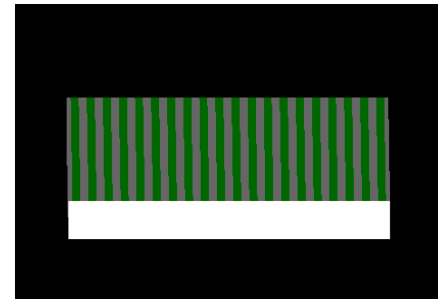
Geant4 detector geometry

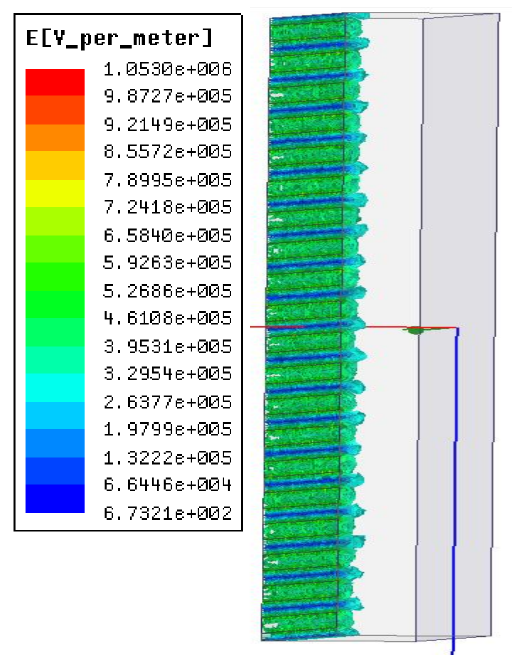
↓

Carriers collection

↓

Electronics





SUMMARY

- The study on CEPC beam energy measurement is going on.
- Compton scattering method may be good.
  - Uncertainty seems to be the order of 1~10 MeV.
  - Possible to work @45.5/80/120/175 GeV.

- From a positive view: we are close to the goal, 1MeV uncertainty.
- Negative view: the closer to the goal we are, the harder the life will be.

Thank you!

Thank you!

Бердь