BEAM ENERGY MEASUREMENT (BEM)

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CEPC workshop @IHEP

Nov 7th, 2017

OUTLINE

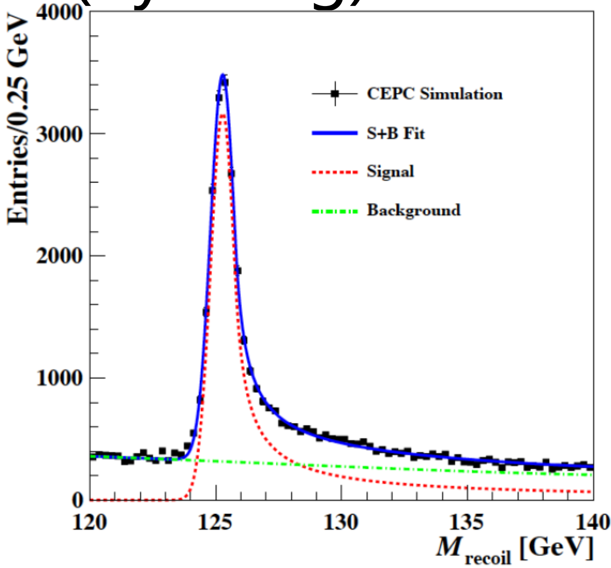
- Introduction
- Compton scattering method
- Summary

To show the feasibility of Compton scattering method.

INTRODUCTION

- Higgs Mass from Recoil Mass method (by Gang)

$$\delta m_{\mu\mu}^{rec} = \begin{cases} (0.31 \sim 0.81)\epsilon = (0.44 \sim 1.14)\delta E_{\rm B} & \text{uncorrelated} \\ 2\epsilon = 4\delta E_{\rm B} & \text{correlated} \end{cases}$$



  - If we require $\delta M_{recoil} \begin{cases} < 5.4\text{MeV} \\ < 1\text{MeV} \end{cases}$,

than, $\delta E_B \begin{cases} < 1.35\sim12\text{MeV} \\ < 0.25\sim2.3\text{MeV} \end{cases}$.

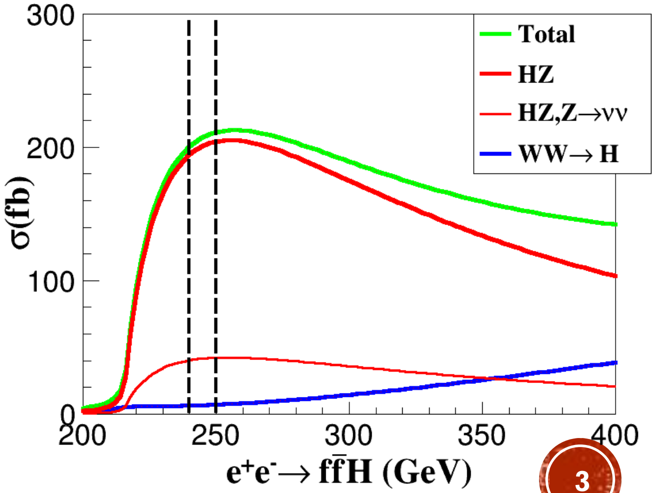
- $\sigma(ZH)$ measurement
  - Find Left/Right Shift with 0.5%

$\sigma(ZH)$ =200.5fb@240GeV

200.5fb*(1.005)~@240.6GeV

200.5fb*(0.995)~@239.5GeV

than, $\delta E_{cm} < 500\text{MeV}$.



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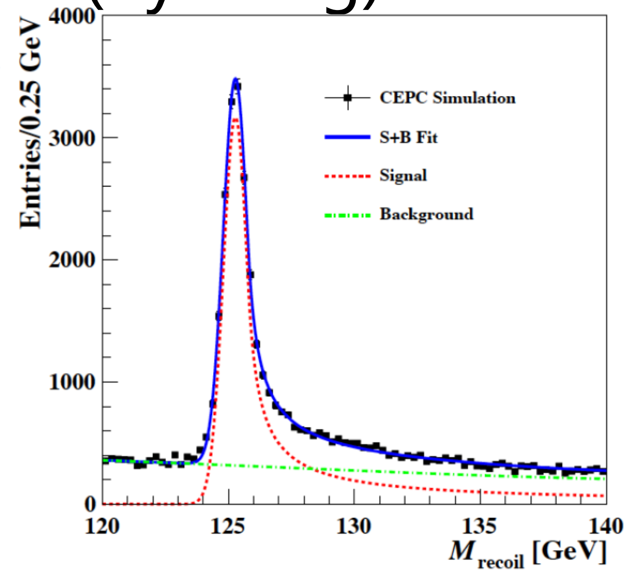

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  than, $\delta E_B \begin{cases} < 1.35\sim12\text{MeV} \\ < 0.25\sim2.3\text{MeV} \end{cases}$.

- No significant impact on other Higgs program
  - Event/Background selection efficiency.
  - $\sigma(ZH)$ measurement requires δE_{cm}<500MeV.
  - Branching ratio (Br(H->bb)) requires δm_H<130MeV.

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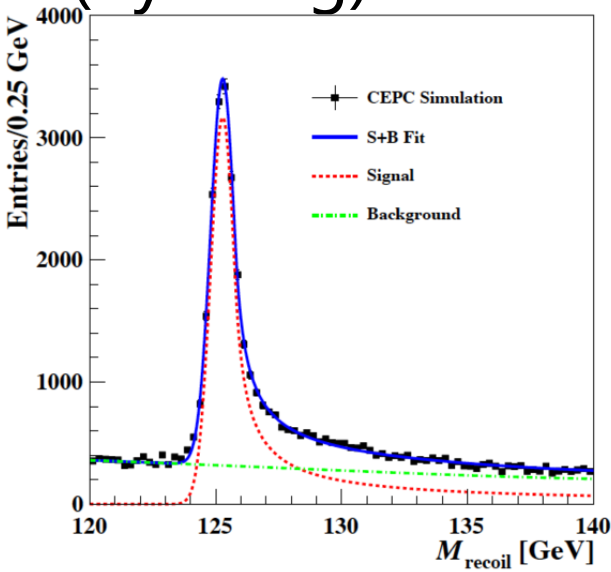

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- WW threshold & Z pole:

at least δE_B<1MeV ~ LEP precision 2×10^{-5}

  - Try to do it better, δE_B<100keV

BEAM ENERGY MEASUREMENT

- $\mu\mu\gamma$ events (by Qinglei)
  - Uncertainty ~ 40-50MeV (CM energy)
- Resonant depolarization technique (@Z-pole, LEP)
  - Uncertainty ~ 2×10^{-5} (relative, beam energy)
- Compton scattering method. (beam energy)
- J/ψ production with other beams. (beam energy)
- …

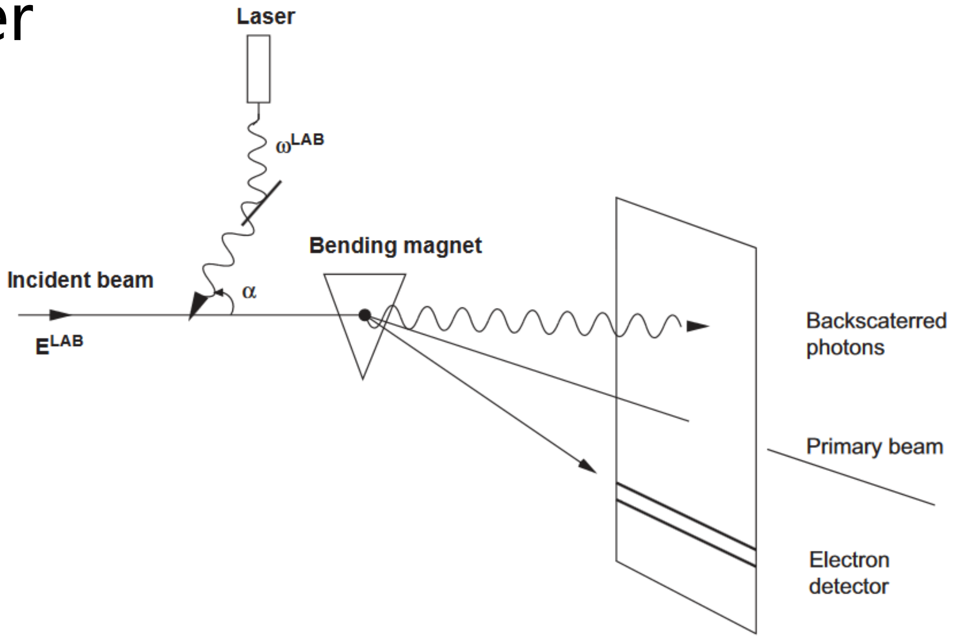

Fig. 8. Scheme of the proposed energy spectrometer based on Compton backscattering.

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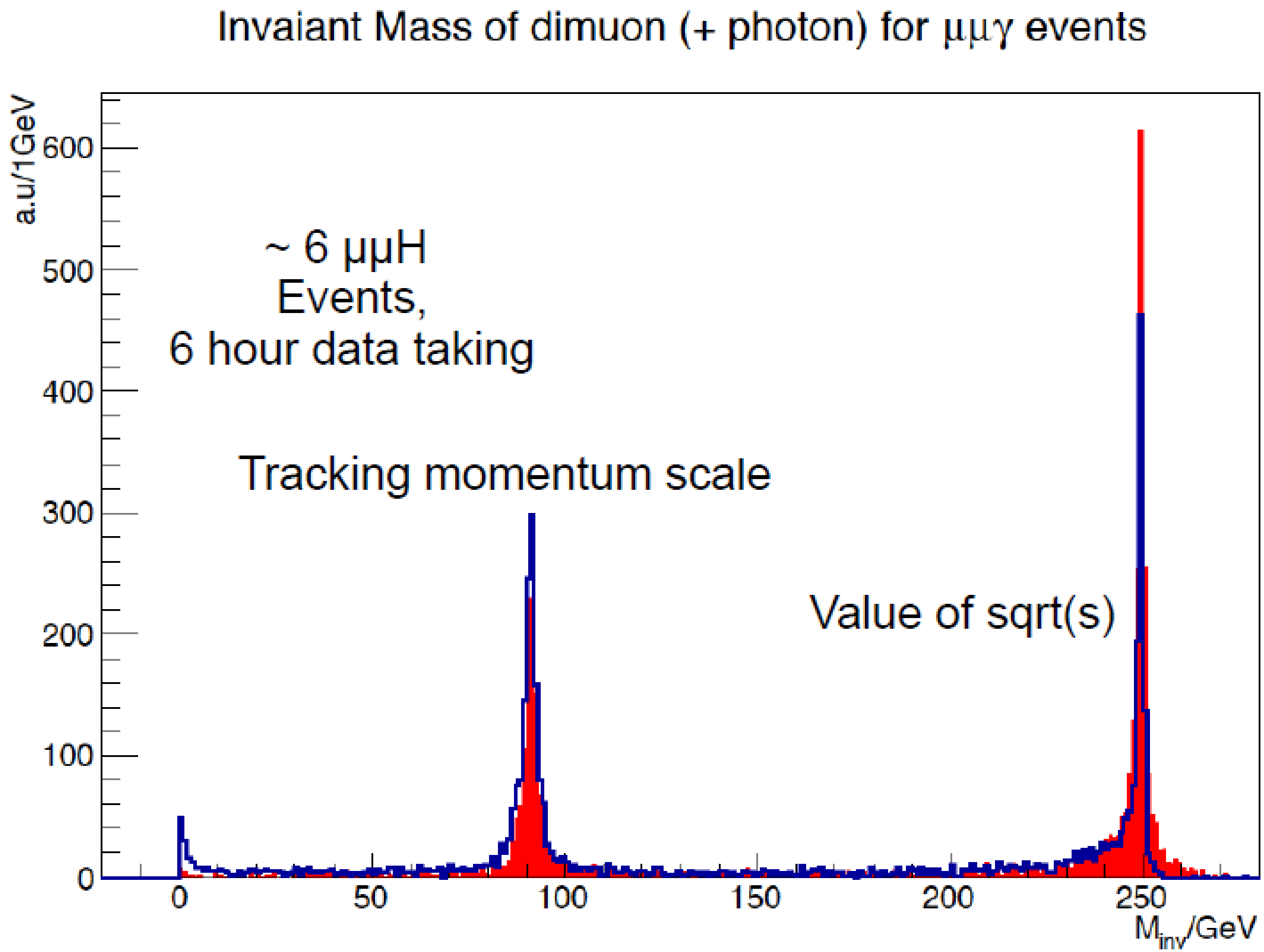

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  - Uncertainty ~ 40-50MeV (CM energy)
- Resonant depolarization technique (@Z-pole, LEP)
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- @CEPC: pre-CDR
  - Typical time to form polarized beam: 21 min
  - Beam lift time: 25 min
  - Feasible or not in this case?

BEAM ENERGY MEASUREMENT

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  - Uncertainty ~ 40-50MeV (CM energy)
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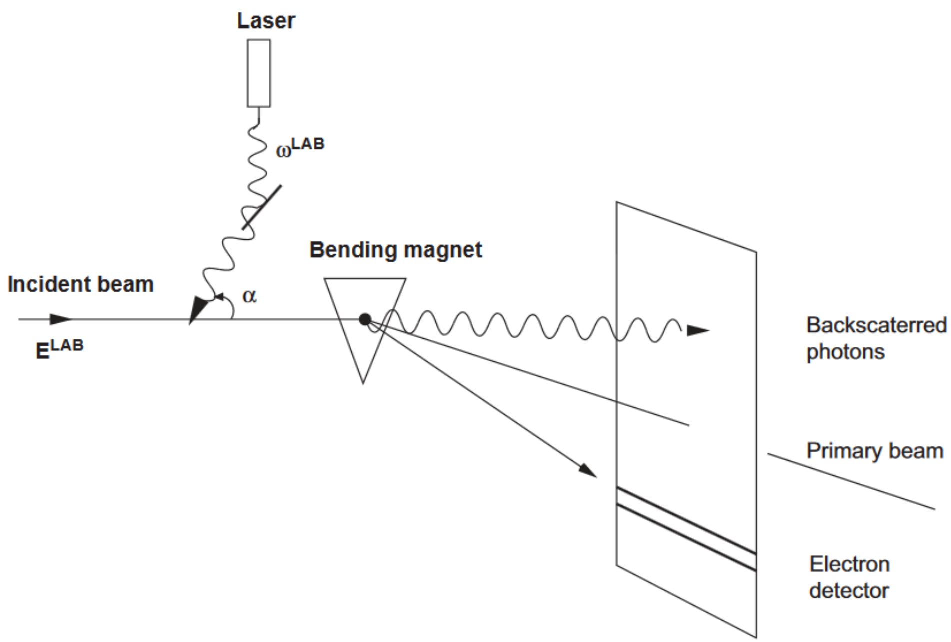
- Compton scattering method. (beam energy)
  - $E_{beam} \sim f(\alpha, \omega, \omega')$;
  - α: crossing angle;
  - ω: laser photon energy;
  - ω': maximum energy of outgoing photon.



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BEM@BEPCII

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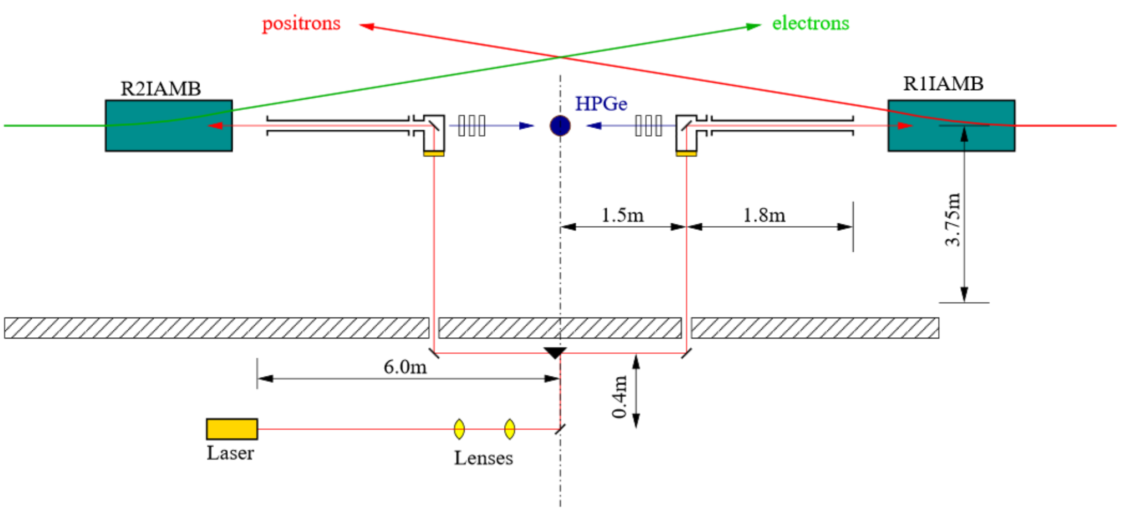
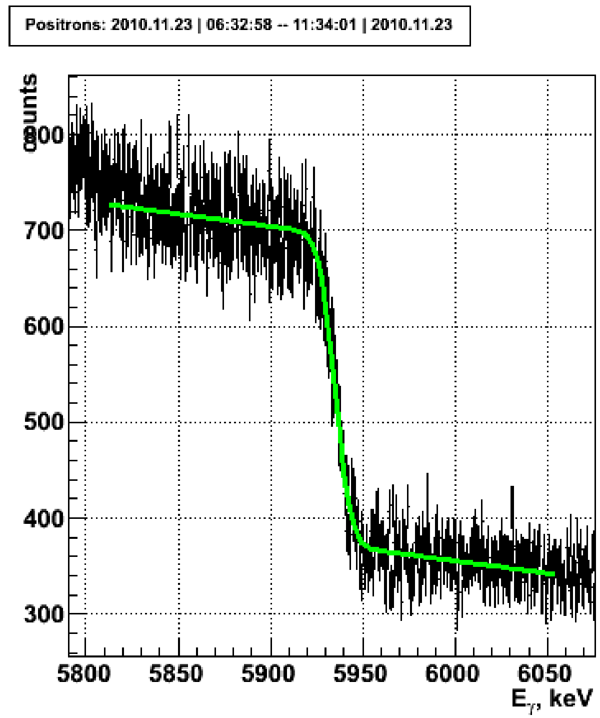
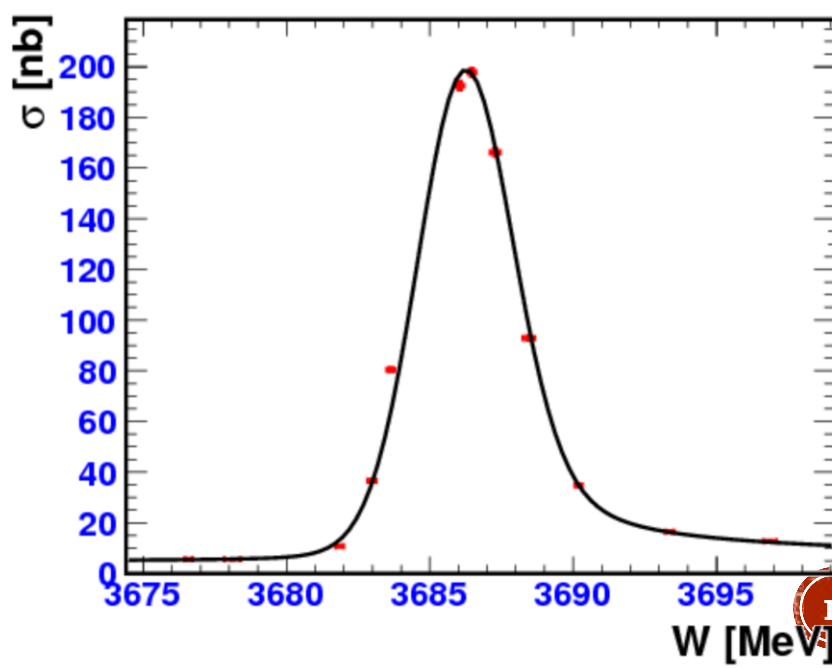
- Compton Back-scattering: (crossing angle $\alpha = 0$)
  - $E_{beam} = \frac{\omega'}{2}\sqrt{1 + \frac{m_e^2}{\omega\,\omega'}}$
- Hardware: locate at north IP of BEPCII
  - CO_2 Laser (ω=0.117eV, 50W) and optical system.
  - High purity germanium detector: 16384 channels.
  - Pulse generator and isotopes (Cs, Co, …).
  - Data acquisition system.
- Side by side measurement.



BEM@BEPCII

- Compton Back-scattering: (crossi
  - $E_{beam} = \frac{\omega'}{2}\sqrt{1 + \frac{m_e^2}{\omega\,\omega'}}$
- 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}



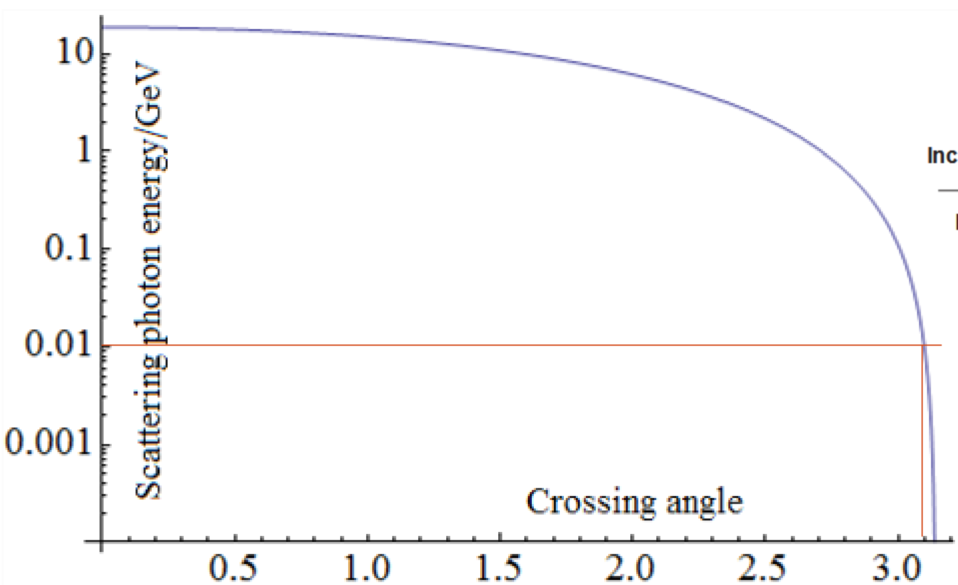


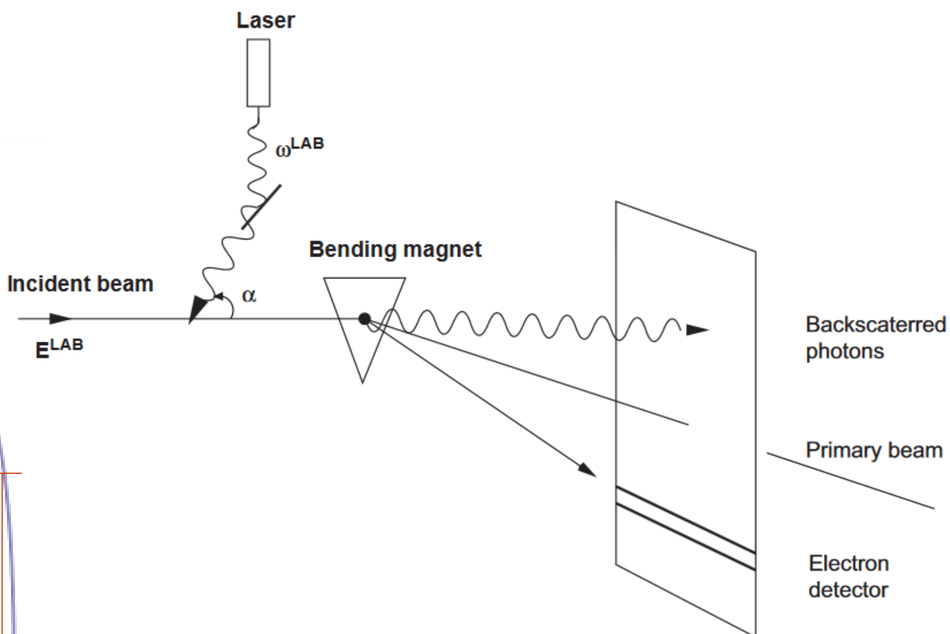
JINST 12 (2017) no.07, C07019

BEAM ENERGY MEASUREMENT

- 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.
  - Change crossing angle, $\alpha \in (3.06, 3.13)$.

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





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

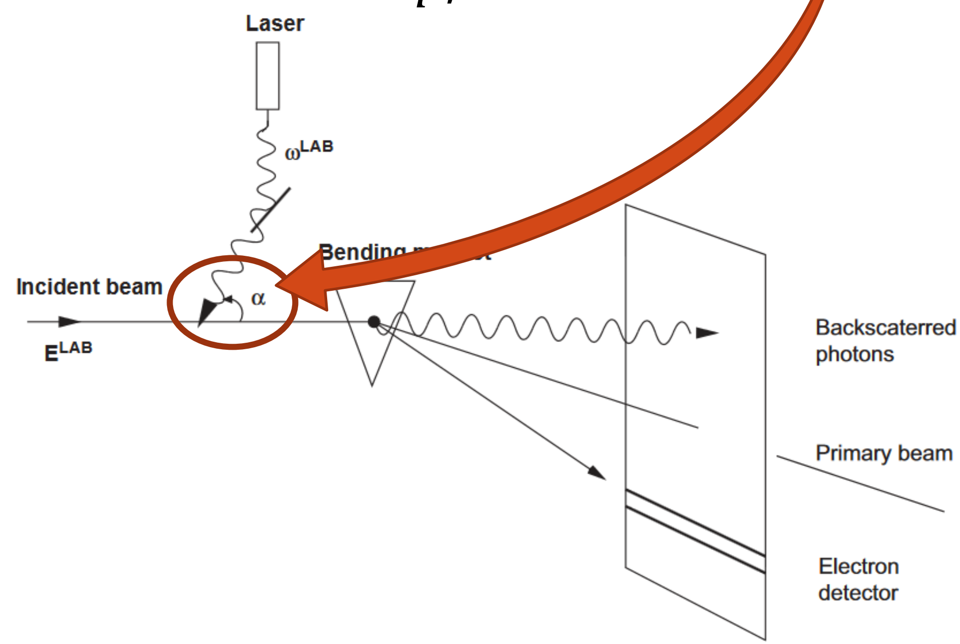
- Easy to calibrate and detect
- High SR background

- Difficult to calibrate and detect
- Low SR background

- Optimize the choice of crossing angle by a full simulation.

ERROR PROPAGATION

- Example: crossing angle $\alpha = 3.086$, (scatter maximum 20MeV photon)
  - $\delta E_{beam} \sim \sqrt{(2.2 \times 10^6 \times \delta\alpha)^2 + (3.0 \times 10^3 \times \delta\omega')^2}$
  - If $\delta E_{beam} < 1\text{MeV}$, $\delta\alpha < 4.2 \times 10^{-7}$ and $\delta\omega' < 3 \times 10^{-4}\text{MeV}$.
- Impact on $\delta\alpha$:
  - Beam orbit, variance of beam momentum $\delta\vec{p}$;
  - Laser alignment.
- Impact on $\delta\omega'$:
  - Detector calibration;
  - Statistic error.



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  - Beam orbit, variance of beam momentum $\delta\vec{p}$;
  - Laser alignment.
- Impact on $\delta\omega'$:
  - Detector calibration;
  - Statistic error.
- Beam position monitor + long linear orbit
- Long laser path

ERROR PROPAGATION

- Beam position monitor + long linear orbit.

  To measure the mean value of α.
  - if BPM precision 0.1mm, 2km linear orbit in needed.
- variance of beam momentum $\delta p_{\perp}$, $\delta p_{\parallel}$
  - If $\frac{\delta p_{\perp}}{\mathrm{p}} < 4.2 \times 10^{-7}$, acceptable systematic error.
  - If $\frac{\delta p_{\perp}}{\mathrm{p}} \geq 4.2 \times 10^{-7}$, the ω' will be smeared. The distribution should be known or estimated to extract ω'.
  - Beam energy spread ($\delta p_{\parallel}$, $\delta p_{\perp}$) ~ 0.1%. Need to know the beam energy distribution. (Maybe Gaussian is a reasonable assumption.)
- It is crucial to input beam parameters to BEM.

ERROR PROPAGATION

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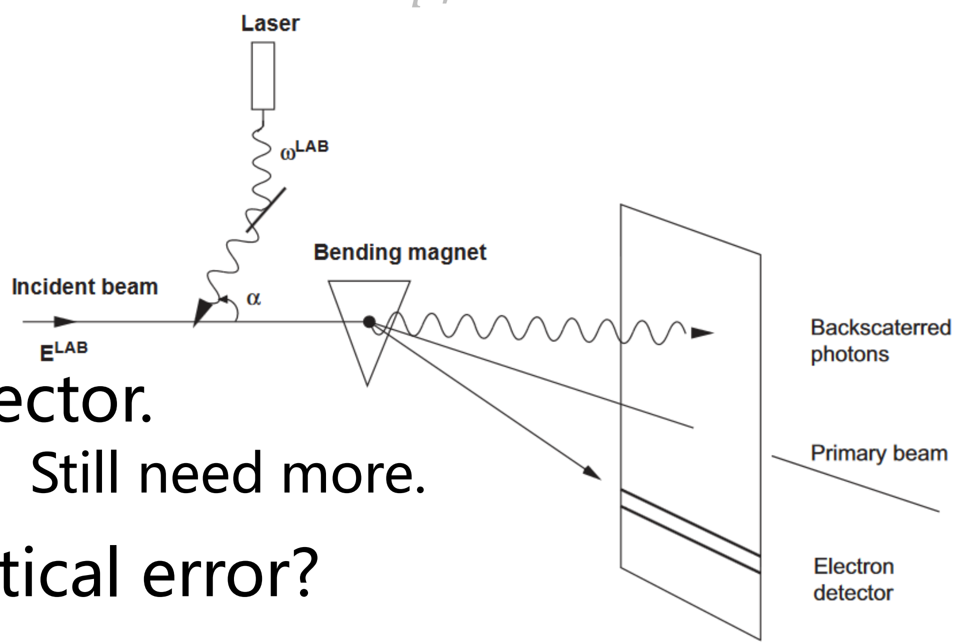
- Impact on $\delta\alpha$:
  - Beam orbit, variance of beam momentum $\delta\vec{p}$;
  - Laser alignment.
- Impact on $\delta\omega'$:
  - Detector calibration;
  - Statistical error.
- Isotopes to calibrate detector.
  - Co, Cs, plutonium-carbon… Still need more.
- Signal-noise ratio? Statistical error?



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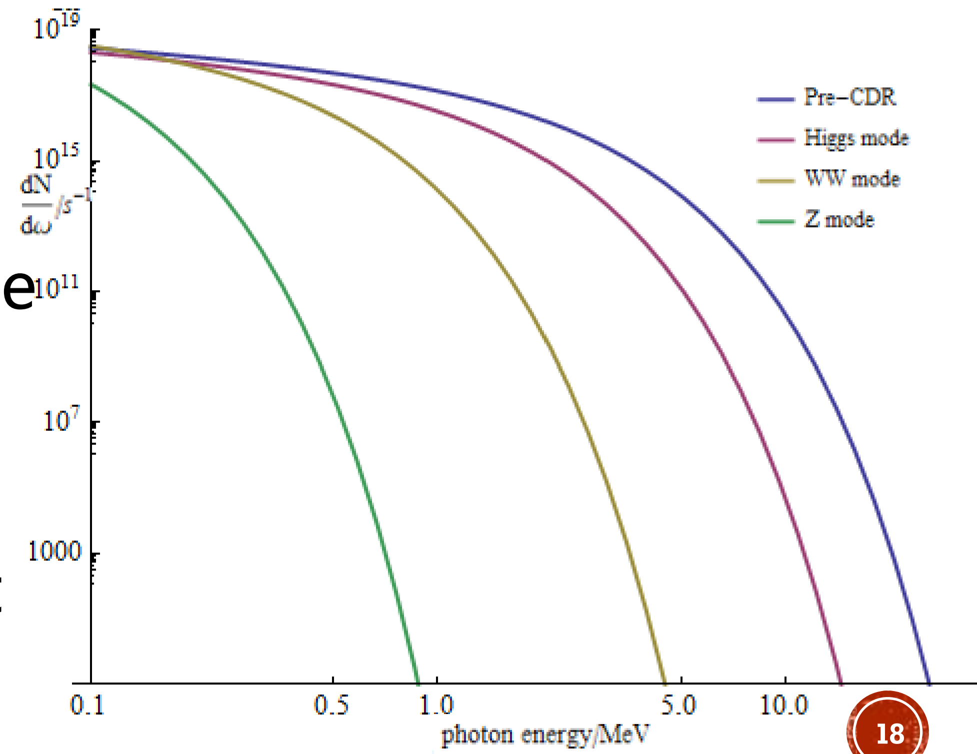
SIGNAL-NOISE RATIO

- Compare between different energy region:

$\frac{dN}{d\omega}/s$		@3MeV	@10MeV	@20MeV	@40MeV
SR	Pre-CDR	10^{15}	10^{10}	2000	10^{-11}
	Double ring	10^{13}	10^{4}	10^{-7}	10^{-32}
CS		$10^{6}\sim10^{7}$ (integrated)			

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



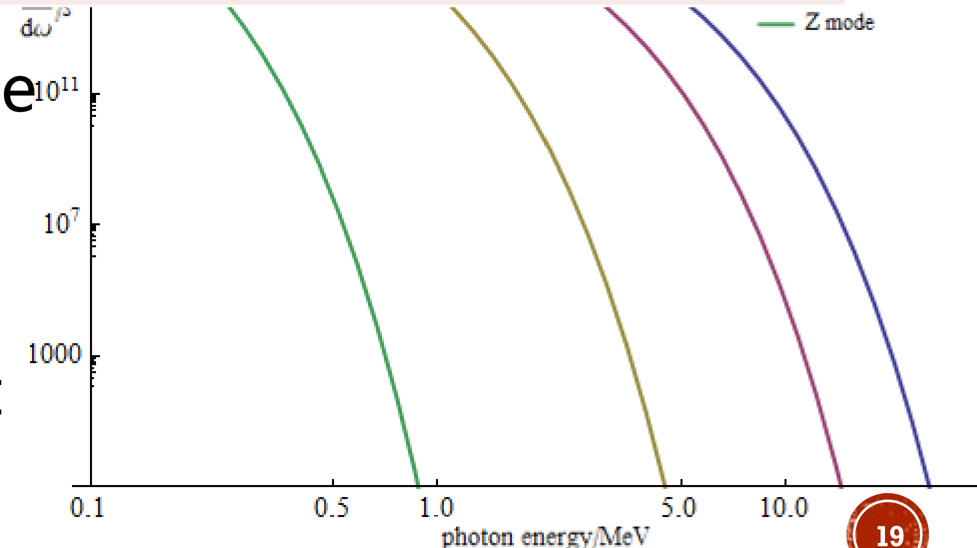
SIGNAL-NOISE RATIO

- Compare between different energy region:

$\frac{dN}{d\omega}/s$		@1MeV	@4MeV	@9MeV	@20MeV
SR	WW mode	10^{12}	10^{-2}	10^{-20}	10^{-54}
CS		$10^{6} \sim 10^{7}$ (integrated)			

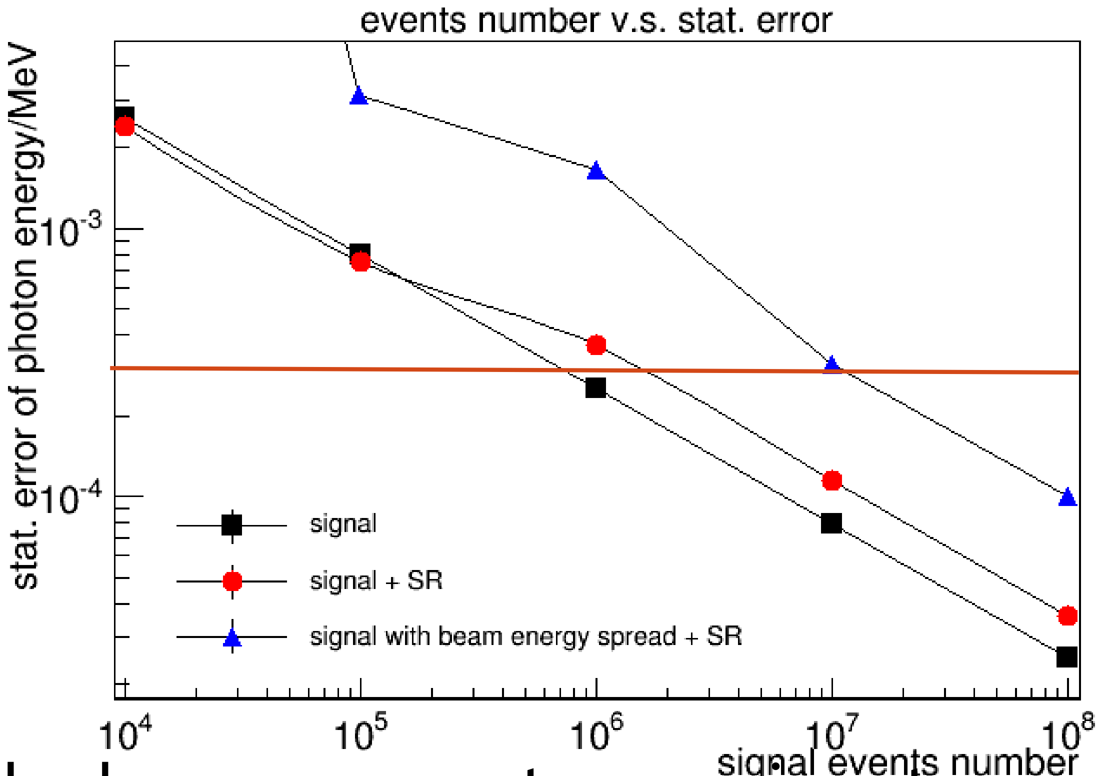
$\frac{dN}{d\omega}/s$		@0.4MeV	@1.4MeV	@2.8MeV	@5.7MeV
SR	Z mode	10^{10}	10^{-14}	10^{-46}	10^{-113}
CS		$10^{6} \sim 10^{7}$ (integrated)			

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



STATISTICAL ERROR

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



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

SUMMARY & OUTLOOK

- We can measure beam energy precisely (error~1MeV, or even smaller),

  if uncertainty of crossing angle α can be handled.
  - beam orbit is under control?
  - variance of beam momentum is clearly known?
  - laser alignment is well?

  if we can calibrate germanium detector.
  - suitable isotopes? (10 ~ 40MeV)
  - detector damage by (SR) radiation?

  if statistical error is small enough.
  - detector efficiency?
  - fit scheme?
  - laser power?

SUMMARY & OUTLOOK

- We can measure beam energy precisely (error~1MeV, or even smaller),

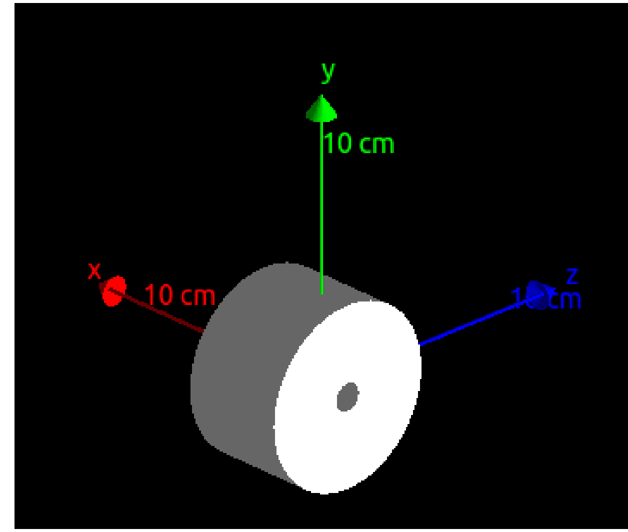
  if uncertainty of crossing angle α can be handled.
  - beam orbit → discuss with accelerator experts
  - beam momentum → to understand beam property.
  - laser alignment → optics system with long light path.

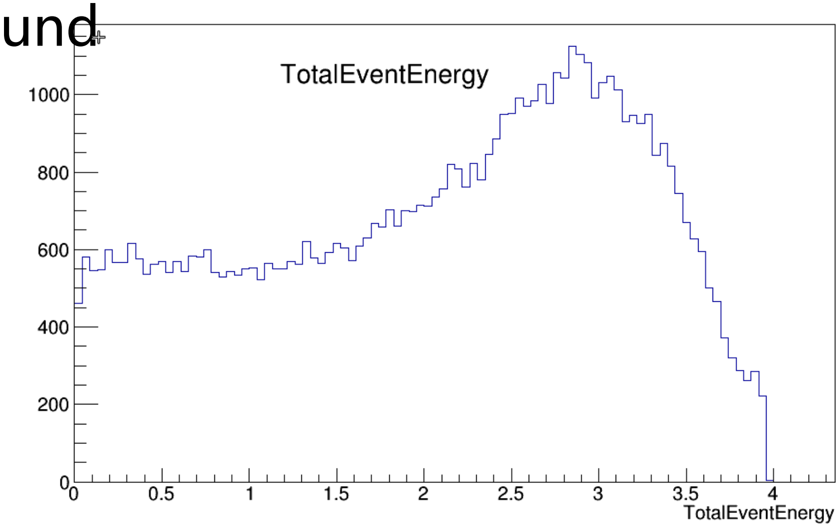
  if we can calibrate detector.
  - isotopes → neutron capture or proton resonance reactions
  - detector damage by (SR) radiation? → study on detector and simulation.

  if statistical error is small enough.
  - detector efficiency?
  - fit scheme? → study on detector and simulation.
  - laser power → pulse laser or multiple reflection

SUMMARY & OUTLOOK

- We have been working on full simulation of BEM system based on Geant4: (by Guangyi Tang, Prof. Wang, Prof. Lou, …)
  - Beam effects;
  - Detector performance and optimization;
  - SR (and other radiative background if exists);
  - Calibration;
  - Fit scheme.
  - …





Thank you!