Beam Energy Measurement System at BEPCII

Jianyong Zhang

On behalf of the BEMS group:

BINP (RUSSIA)

Hawaii University (USA)

IHEP(CHINA)

Motivation

Why we build the accurate beam energy measurement system in the "τ–c" energy region ?

- The τ-lepton mass determination

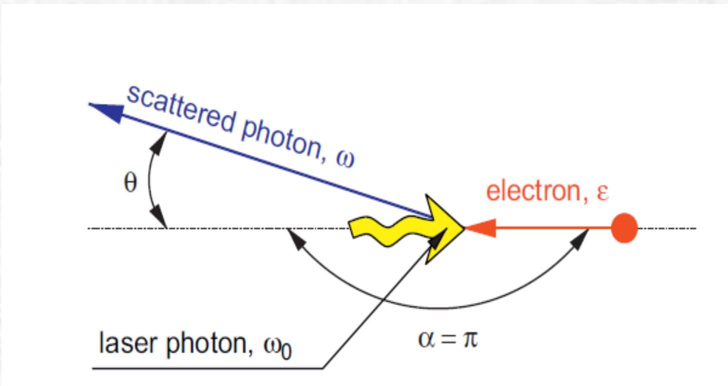
  $M_\tau = 1776.86 \pm 0.12$ MeV/c^2

  τ–lepton is fundamental particle, its mass is an important parameter of the Standard Model.

- The masses of ψ and D mesons are of interest.

- Useful tool to monitor the collider.

BEMS principle：Compton scattering



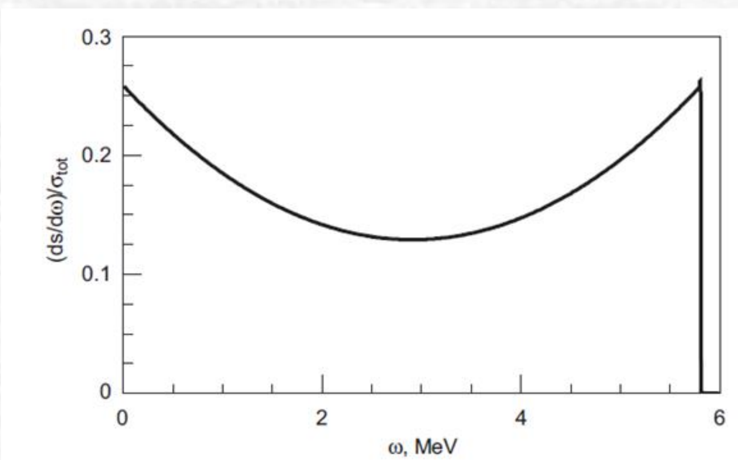


Fig. 3. Energy spectrum of scattered Compton photons. The initial electron and photon energies are $\omega_0 = 0.12$ eV and $\varepsilon = 1770$ MeV, respectively, and $\alpha = \pi$.

Energy of scattered photons：

$$\omega = \omega_0 \frac{1 - \beta\cos\alpha}{1 - \beta\cos\theta + \frac{\omega_0}{\varepsilon}(1 - \cos\Theta)}$$

To head on colliding,

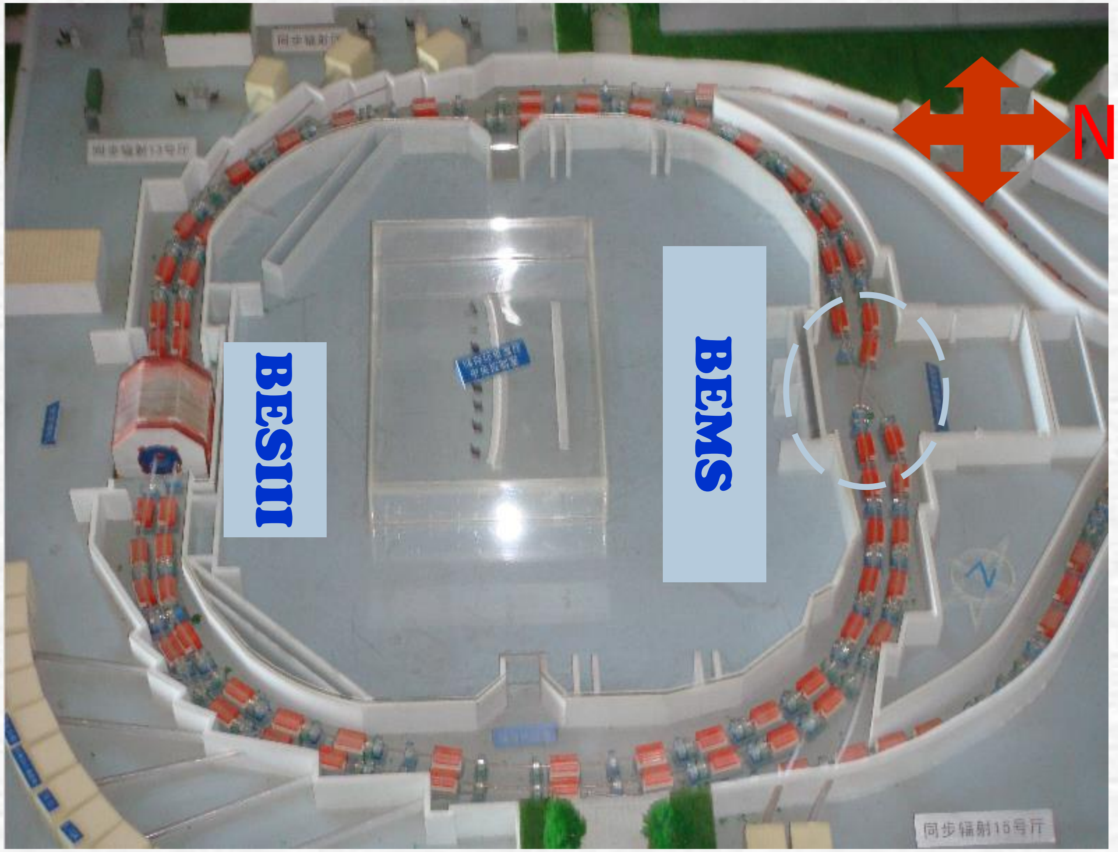
$$\omega_{max} = \frac{\varepsilon^2}{\varepsilon + m_e^2/4\omega_0^2},$$

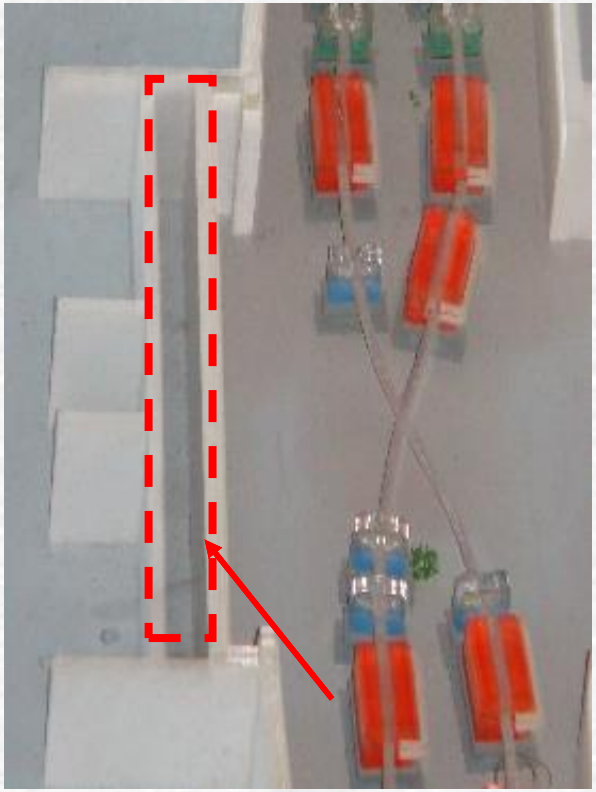
We get the beam energy：

$$\varepsilon = \frac{\omega_{max}}{2}\left[1 + \sqrt{1 + \frac{m_e^2}{\omega_0\omega_{max}}}\,\right].$$

Beijing Electron Positron Collider (II)

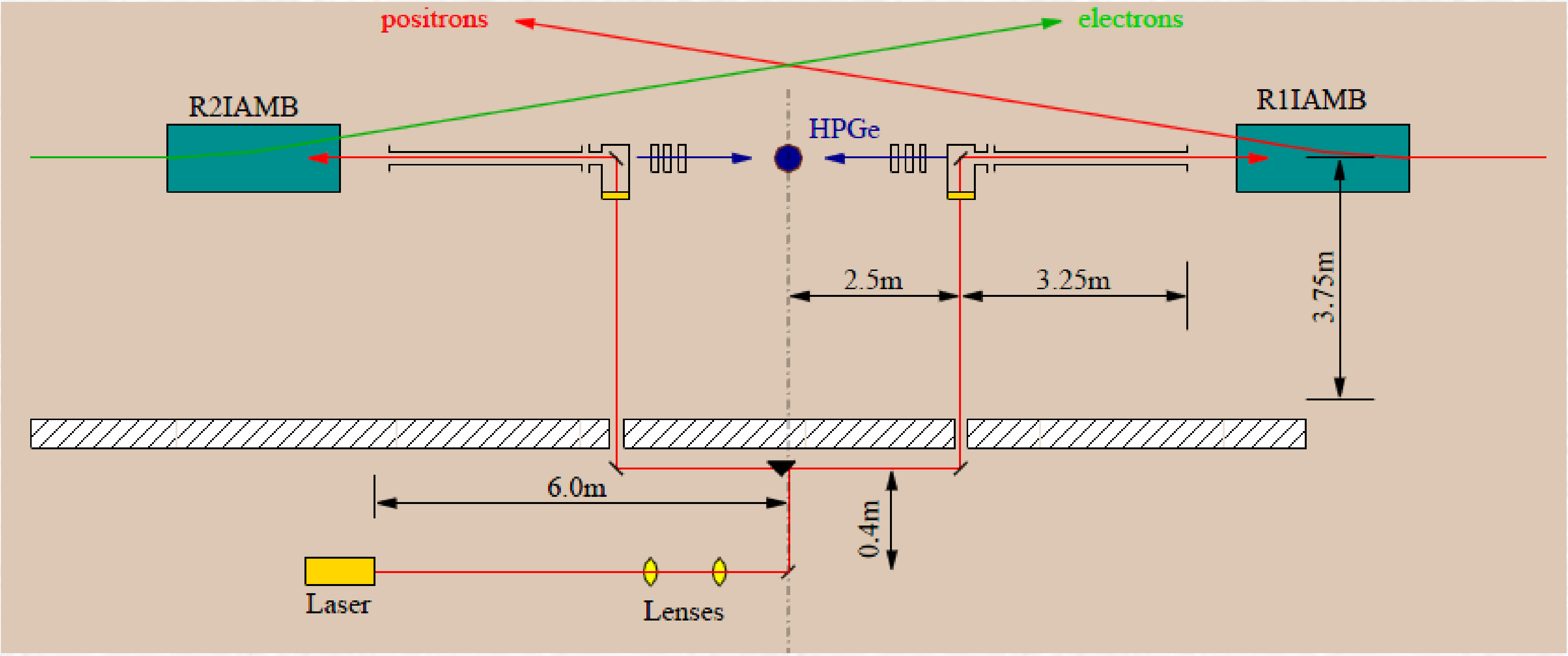
BEMS location





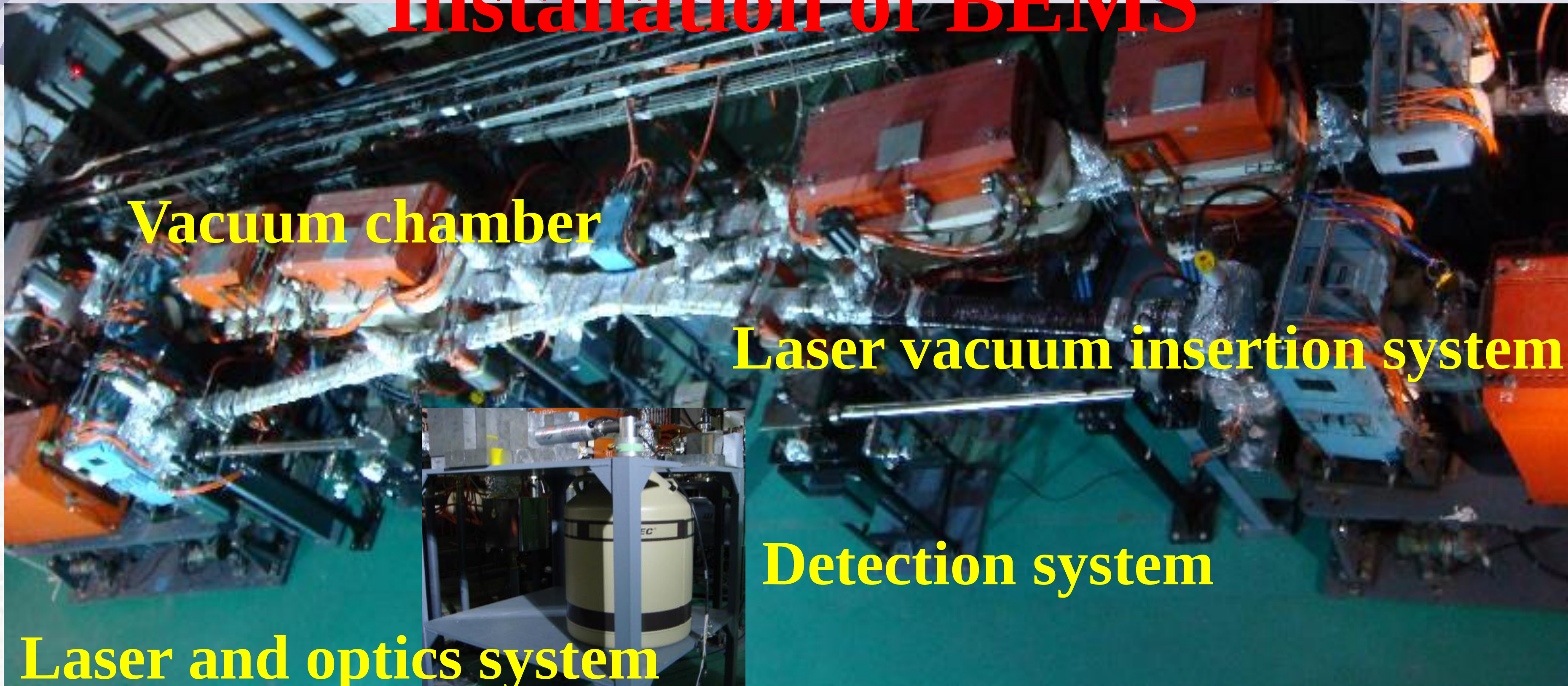
Corridor where optics system located

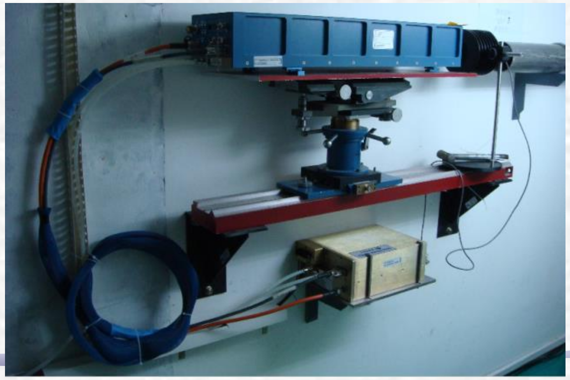
BEMS layout at BEPCII north IP

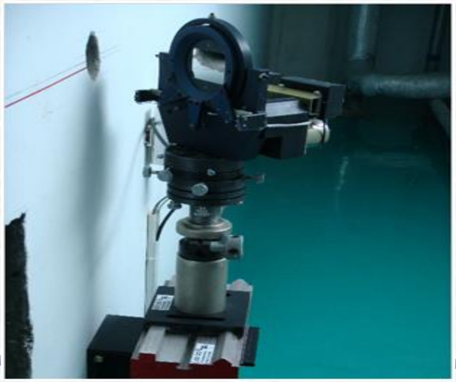


- The size of HPGe detector D ≈ 5 cm
- The distance between HPGe and γ/beam interaction L ≈ 8m
- Beam orbit angle should be zero within D/L ≈ ±3 mrad

Installation of BEMS







BEMS subsystem

- Laser & optics system provides laser transportation and necessary focusing to the interaction area.
- Control system provides change of laser direction to electron or positron beam, control over additional moving shield, tune (maximize) the rate of backscattered photons. It uses DAQ system counting rates as a feedback signal.
- DAQ system reads HPGe data from MCA, saves the raw data to disk. Uses Control system status to distinguish electron/positron records. ALL RAW DATA IS AVAILABLE!
- On-line analysis system provides online beam energy determination results and writes them to the BEPCII database.
- Off-line analysis role is to make various checks and get better results.

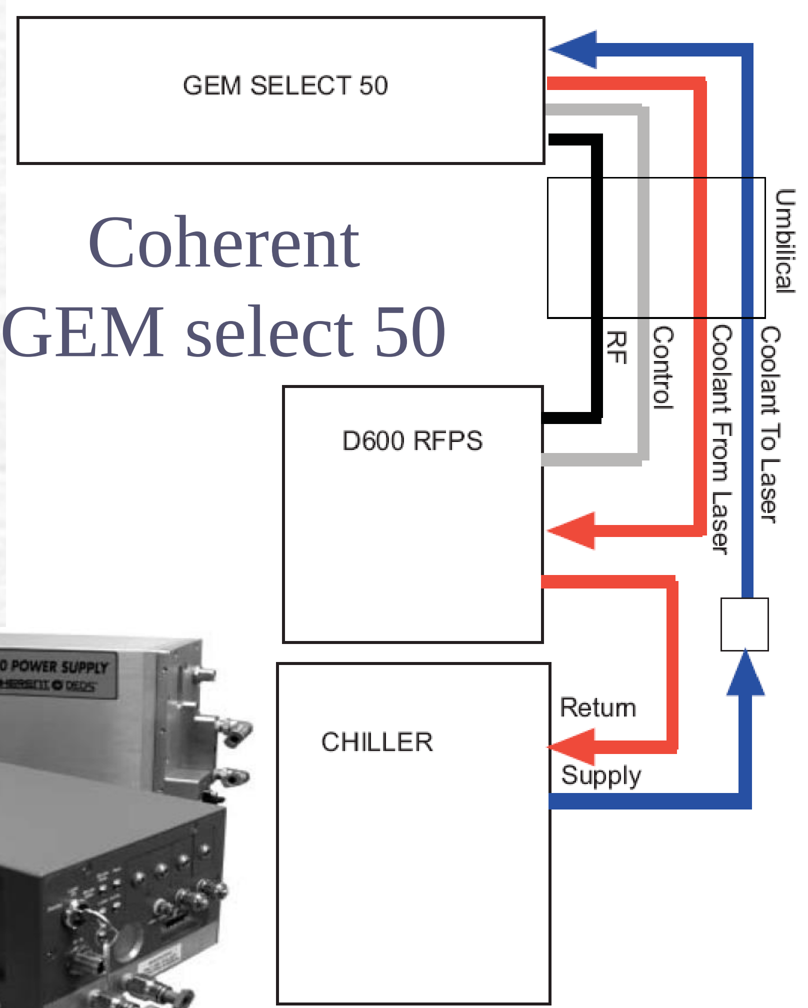
Coherent CO_2 laser

Agilent 6573A power supply

λ=10.835 μm, 20W

λ=10.59 μm, 50W

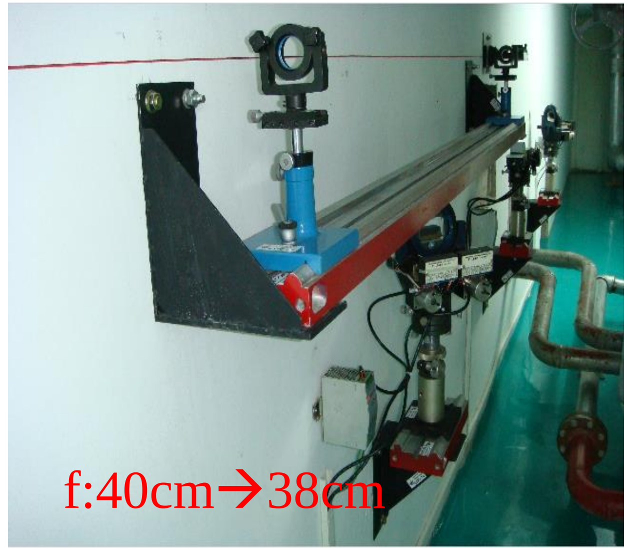
Coherent GEM select 50



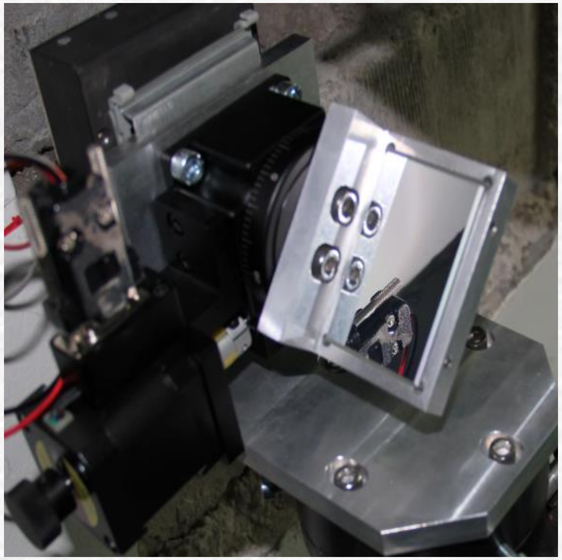
Lytron CR011H03BC circulating chillers

Laser and Optics system

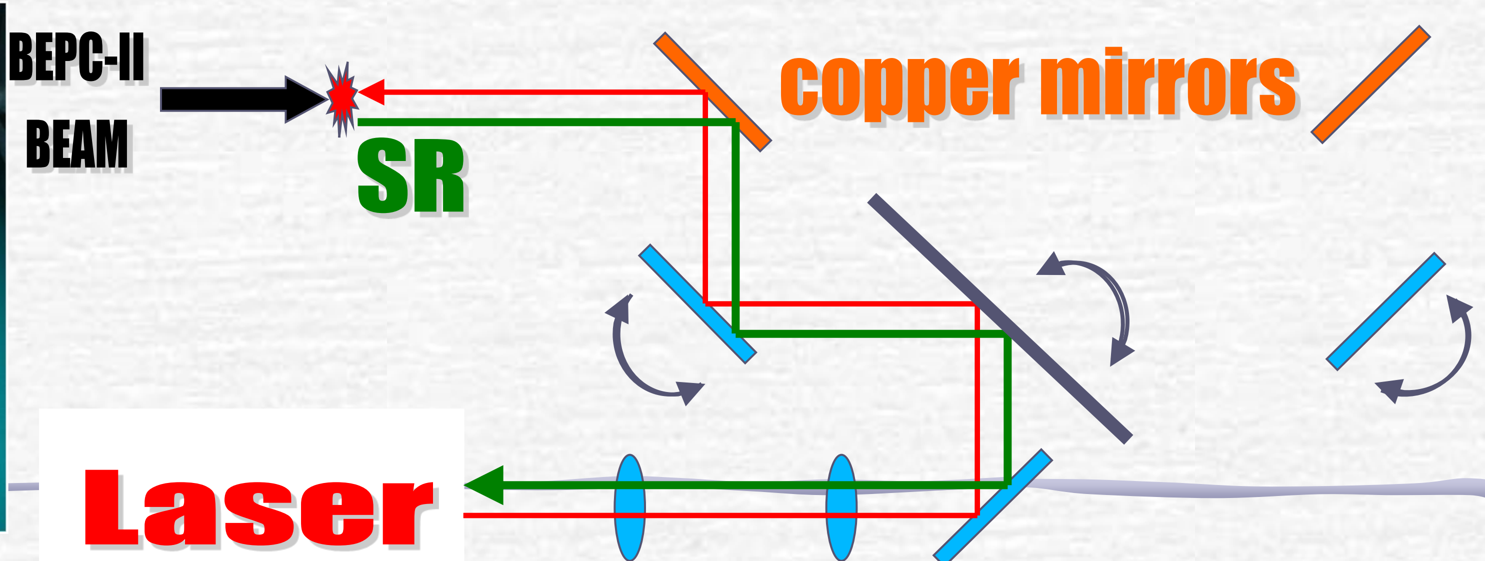
laser



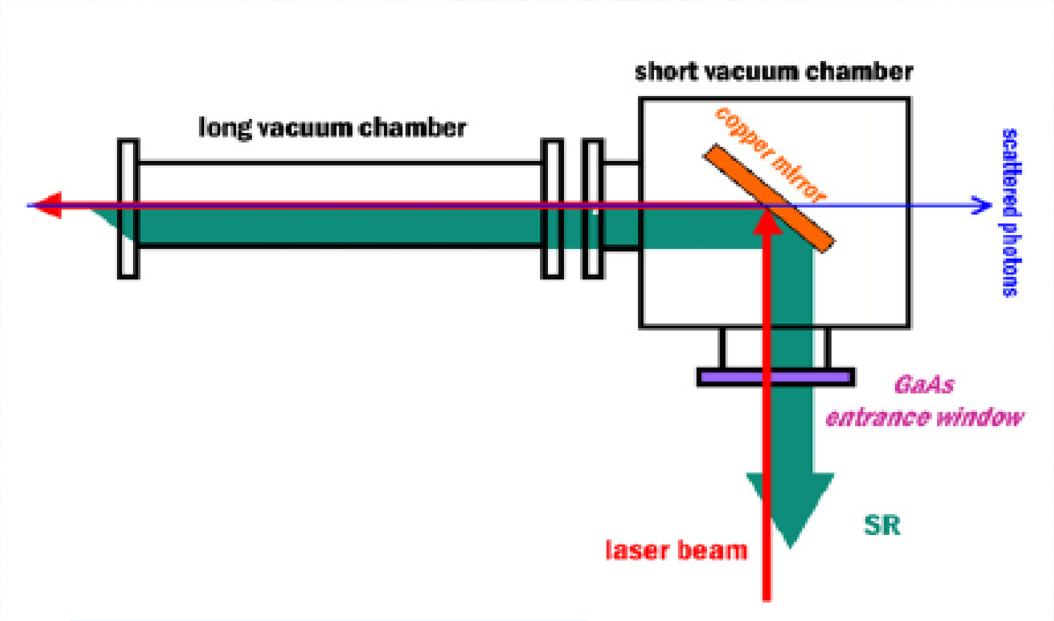
Znse lenses

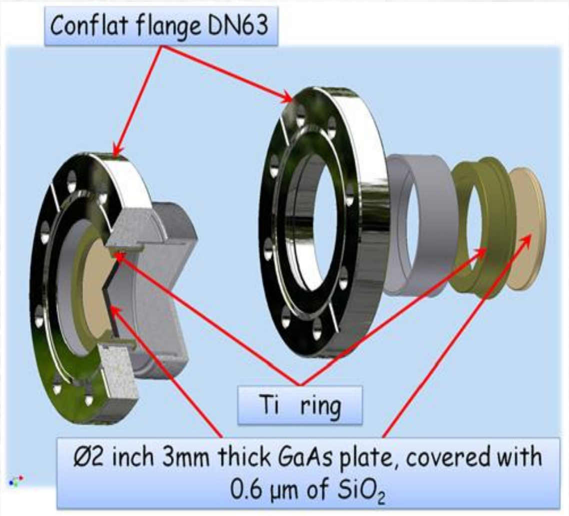


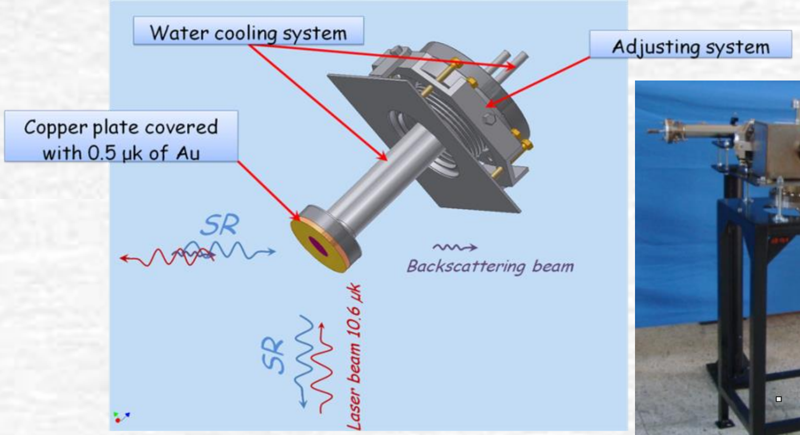
Rotation reflector prism



BEMS-vacuum part







laser-to-vacuum insertion part

chamber installation

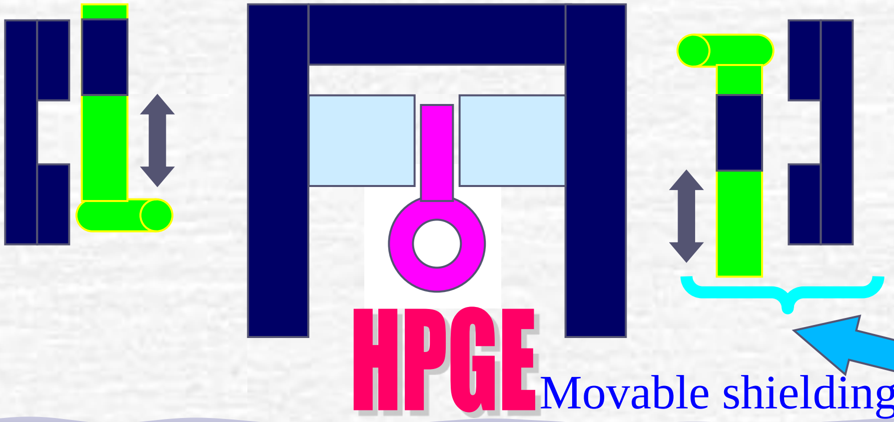
Pump Installation

Baking 24 hours
Pressure:
$1.5\sim4.5\times10^{-10}$ Torr

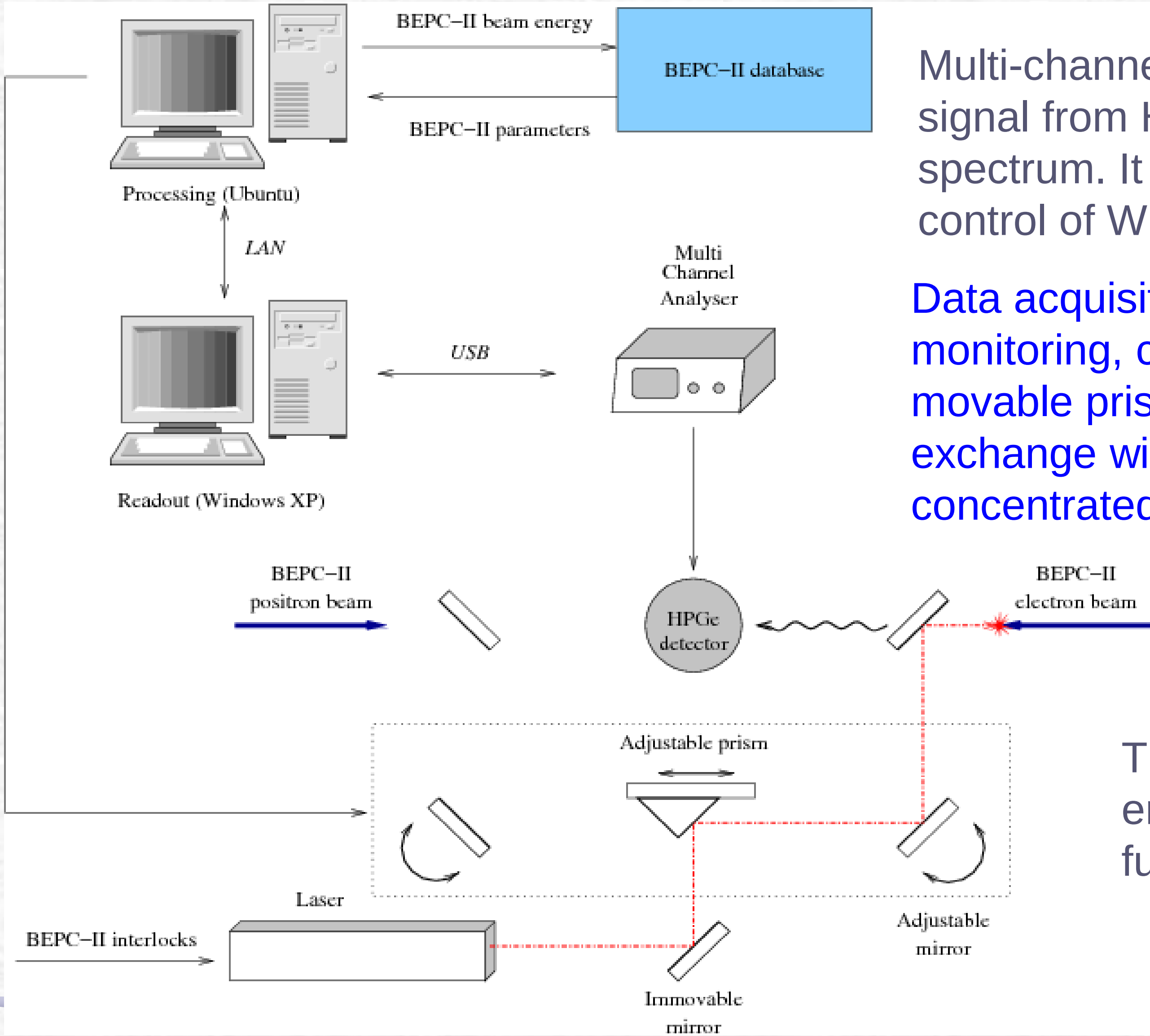
Alignment

Coaxial HPGe detector

- Size: Ø 57.8 mm, height 52.7 mm
  detection efficiency : about 25%
  energy resolution ~ 10^{-3}
- lead and paraffin are added to suppress the low energy photons
- Movable protection is used at the other side of beam direction to reject the high energy photons



Control system



Multi-channel analyser digitises the signal from HPGe and converts it to spectrum. It is connected to PC under control of Windows XP

Data acquisition, spectra processing, monitoring, control over devices (mirrors, movable prism and protection) and exchange with BEPC-II database are concentrated in PC under Ubuntu Linux

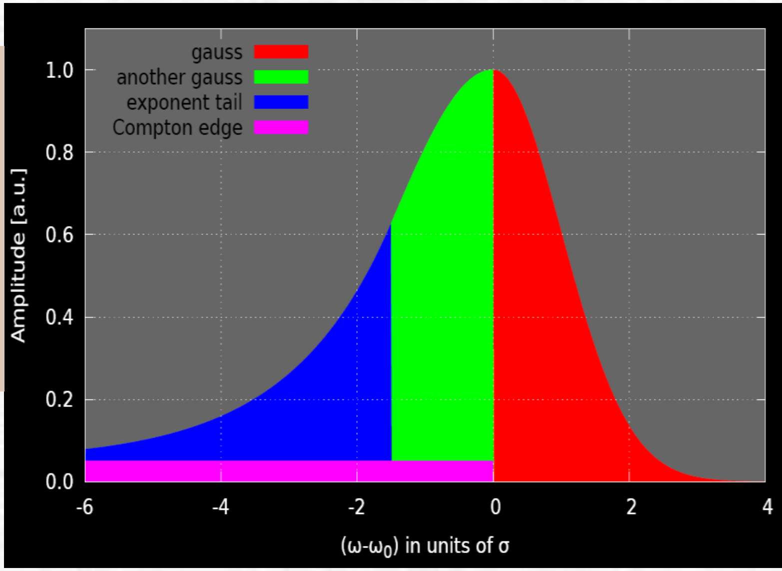
The process of the beams energy measurement is fully automated

HPGe scale calibration

The goals of calibration:

- To obtain the coefficients for conversion of ADC counts to corresponding energy deposition
- Determination of the parameters of the detector response function

$$f(x) = A \times \begin{cases} 0 < x < +\infty : & \exp\left\{-\dfrac{x^2}{2\sigma^2}\right\} \\ -K_0K_1\sigma < x \le 0 : & C + (1-C)\exp\left\{-\dfrac{x^2}{2(K_0\sigma)^2}\right\} \\ -\infty < x \le -K_0K_1\sigma : & C + (1-C)\exp\left\{K_1\left(\dfrac{x}{K_0\sigma} + \dfrac{K_1}{2}\right)\right\} \end{cases}$$



A:amplitude, x=0: line energy, σ: normal width,

K_0: width from-the-left modification,

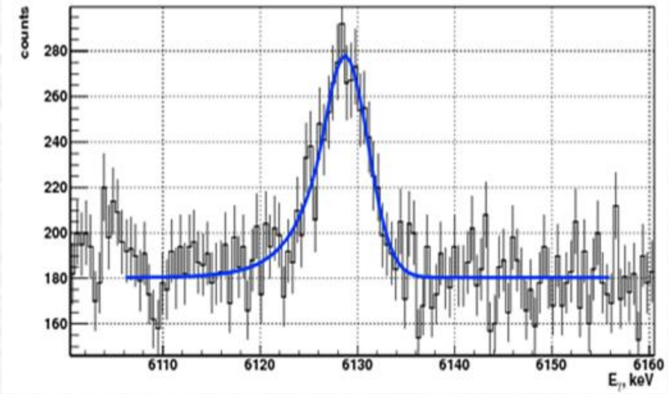
K_1K_0 σ: exponential low-energy tail,

C: is for low-angle scattering of -γs on their way to detector.

Calibration procedure

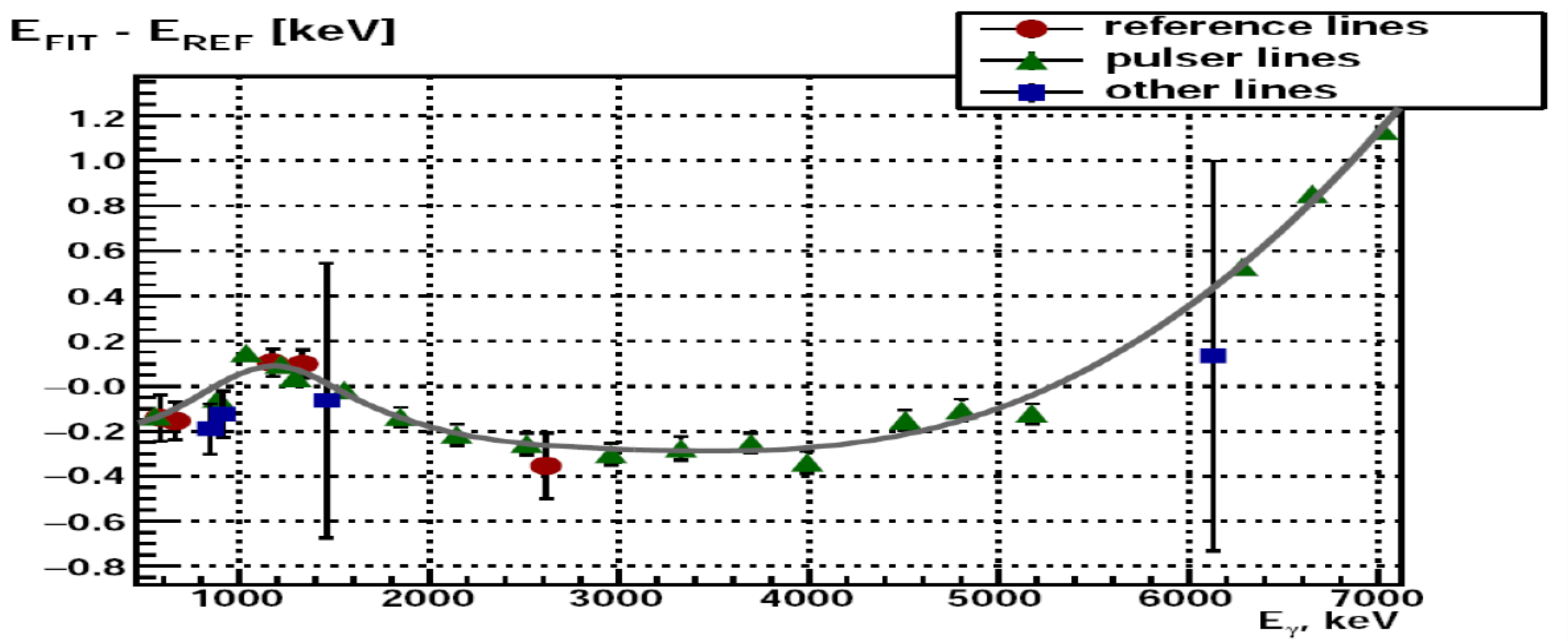
- Peak search and identification of calibration lines
- Fit the calibration lines using response function +bkgd

^{137}Cs	$\tau_{1/2} \simeq 30.07$ y	$E_\gamma = 0661.657 \pm 0.003$ keV
^{60}Co	$\tau_{1/2} \simeq 5.27$ y	$E_\gamma = 1173.228 \pm 0.003$ keV
		$E_\gamma = 1332.422 \pm 0.004$ keV
^{208}Tl	$\tau_{1/2} \simeq 3$ m	$E_\gamma = 2614.511 \pm 0.013$ keV
^{16}O*		$E_\gamma = 6129.266 \pm 0.054$ keV



- Determine the nonlinearity of MCA using pulser BNC-PB5(nonlinearity $\pm$15 ppm jitter $\pm$10 ppm
- Using the results of isotope peak, the energy dependence parameters is determined.

HPGe detector calibration



Green triangles – generator peaks,
Red circles – isotope peaks (used for calibration),
Blue squares – isotop peaks ^{40}K 1460 keV and ^{16}O* 6129 keV (calibration check)
Curve – spline approximation.

Fit of Compton edge

The edge of backscattered photons spectrum is fitted by the function, which tacks into account:

- the “pure” edge shape,
- detector's response function,
- energy spread of backscattered photons due to the energy distribution of the collider beam

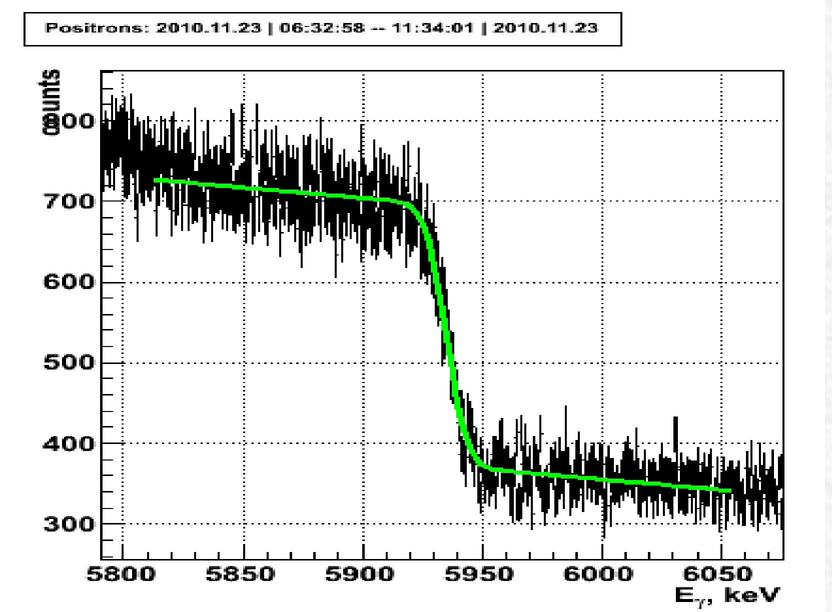
The edge position ω_{max} and the Compton photons energy spread σ_{ω} are obtained from fit

The average beam energy in the north crossing point is calculated as:

$$\varepsilon_{nip} = \frac{\omega_{max}}{2}\left(1+\sqrt{1+\frac{m_e^2}{\omega_{max}\omega_0}}\right)$$

Beam energy in the south interaction point:

$$\varepsilon_{sip}(MeV) = \varepsilon_{nip}(MeV) + 4.75\cdot 10^{-3} \times (0.001\cdot \varepsilon_{nip}(MeV))^4$$



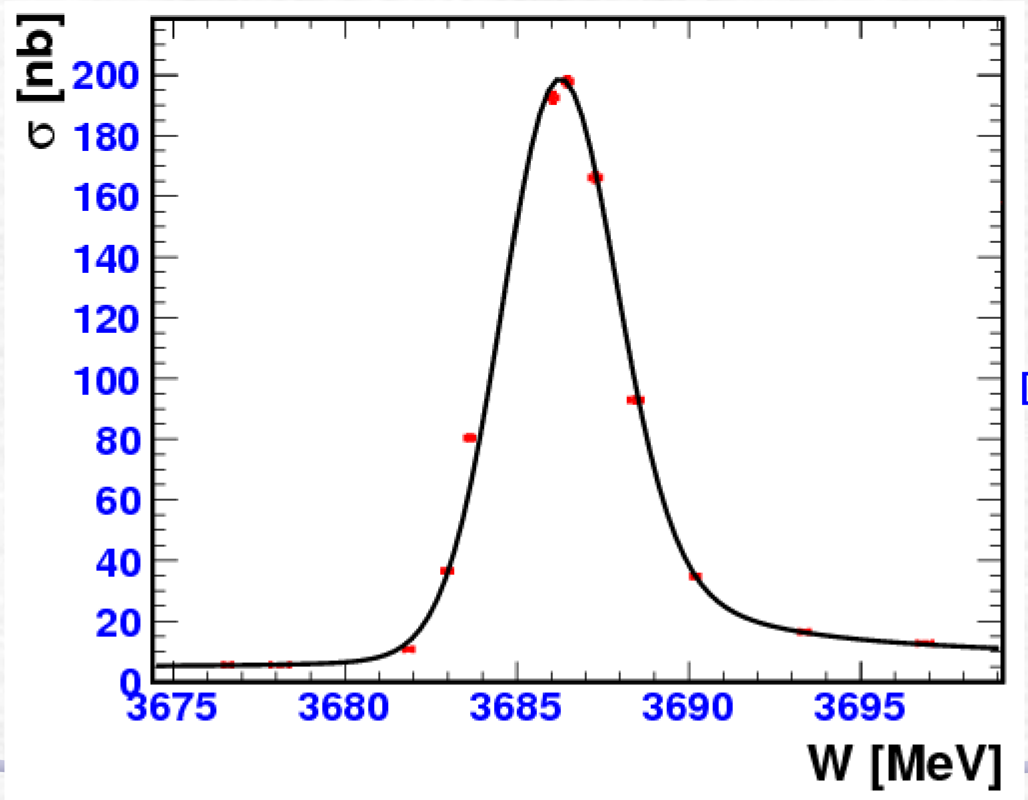
$$S(x) = \frac{1}{2\sqrt{2\pi}}\left\{\frac{1}{\sqrt{\sigma^2+\sigma_s^2}}\exp\left(\frac{-x^2}{2(\sigma^2+\sigma_s^2)}\right)\mathrm{erfc}\left(\frac{-x\sigma}{\sigma_s\sqrt{2(\sigma^2+\sigma_s^2)}}\right)+\right.$$

$$\left.+\frac{C}{\sigma}\mathrm{erfc}\left(\frac{x}{\sqrt{2}\sigma_s}\right)+\frac{(1-C)K_0}{\sqrt{\sigma_m^2+\sigma_s^2}}\exp\left(\frac{-x^2}{2(\sigma_m^2+\sigma_s^2)}\right)\mathrm{erfc}\left(\frac{x\sigma_m}{\sigma_s\sqrt{2(\sigma_m^2+\sigma_s^2)}}\right)\right\}$$

$$E(\omega,\omega_{max}) = \int_{\omega}^{+\infty} S(\omega'-\omega_{max})\,d\omega' \;+\; \text{Background}$$

BEMS performance

The accuracy of beam energy measurement was studied by comparison of ψ(2s) resonance mass 3686.09 ± 0.040 MeV, with its value obtained using the energy obtained using BEMS data.



Two scans of ψ(2s) with integrated luminosity about 4 pb^{-1}.

Mass difference:

$$\Delta m = m - m_{\psi} = 0.02 \pm 0.05 MeV$$

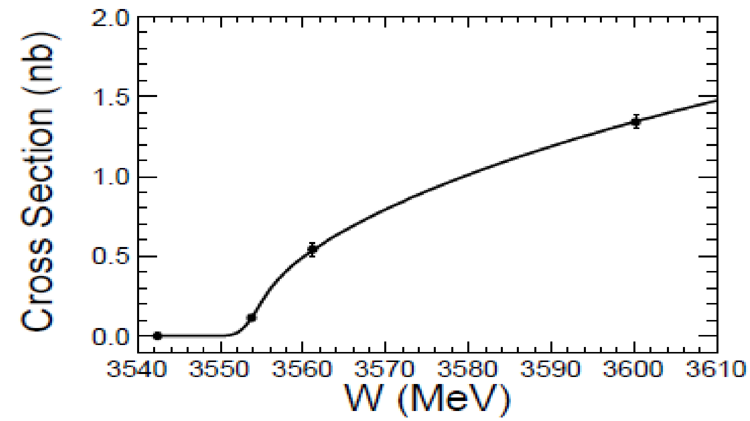
Deviation of the measured beam energy of the beam from true value:

$$\delta\varepsilon = \frac{\Delta m}{2} = 0.01 \pm 0.03$$

Accuracy of the BEMS: **δε/ε** ~ 2×10^{-5}

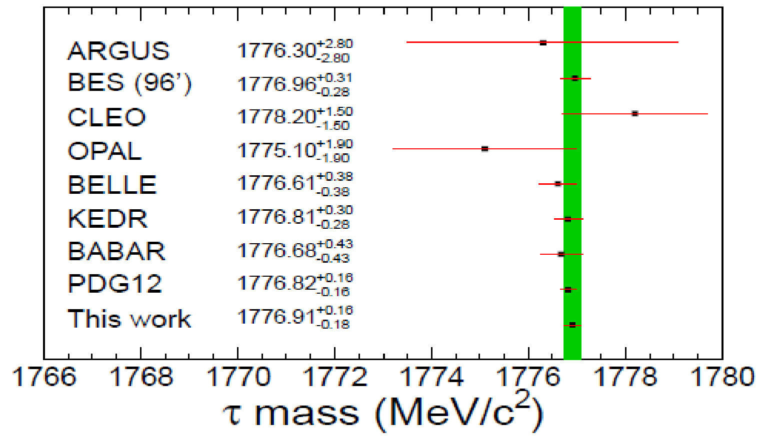
Pre-scan of Tau mass measurement

Scan	E_{CM} (MeV)	$\mathcal{L}(\mathrm{nb}^{-1})$
J/ψ	3088.7	78.5 ± 1.9
	3095.3	219.3 ± 3.1
	3096.7	243.1 ± 3.3
	3097.6	206.5 ± 3.1
	3098.3	223.5 ± 3.2
	3098.8	216.9 ± 3.1
	3103.9	317.3 ± 3.8
τ	3542.4	4252.1 ± 18.9
	3553.8	5566.7 ± 22.8
	3561.1	3889.2 ± 17.9
	3600.2	9553.0 ± 33.8
ψ'	3675.9	787.0 ± 7.2
	3683.7	823.1 ± 7.4
	3685.1	832.4 ± 7.5
	3686.3	1184.3 ± 9.1
	3687.6	1660.7 ± 11.0
	3688.8	767.7 ± 7.2
	3693.5	1470.8 ± 10.3

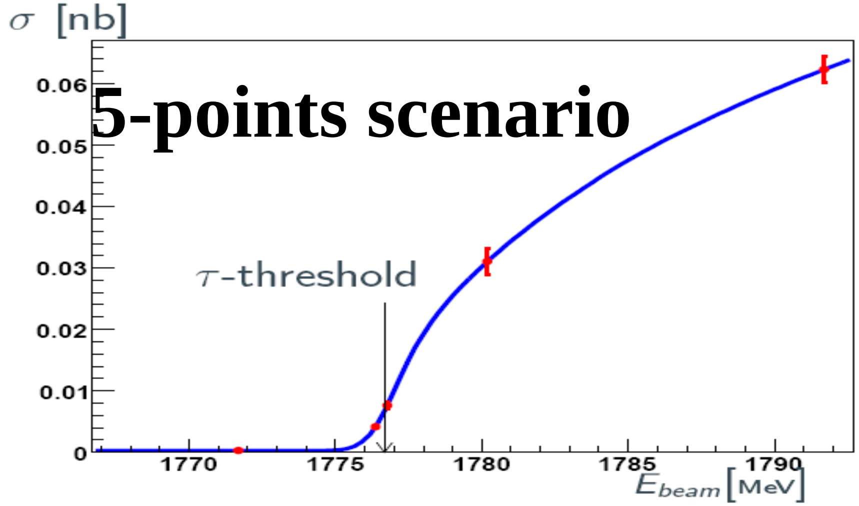


$$m_\tau = (1776.91 \pm 0.12^{+0.10}_{-0.13})\ \mathrm{MeV}/c^2.$$

Phys.Rev.D 90,012001 (2014)



Tau scan plan at BESIII



First scan:

J/ψ scan (7 pts) → τ scan (5 pts) → ψ' scan (7 pts) →

Second scan:

J/ψ scan (7 pts) → τ scan (pt.9&pt.10) → ψ' scan (7 pts)

Final uncertainty
(sta. ⊕ sys.)< 0.1MeV

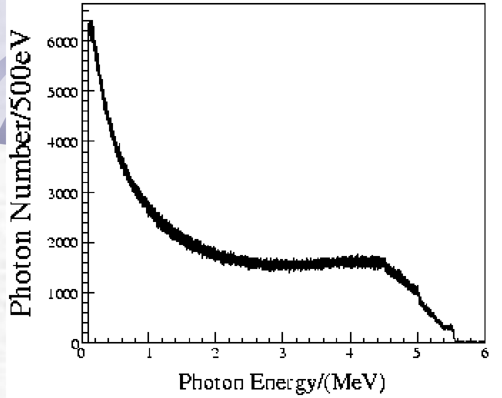
Energy region	order	Beam energy (MeV)	C.M.S energy (MeV)	Integrated lum. (pb^{-1})
Energy points for J/psi scan	1	1544.0	3088.00	
	2	1547.7	3095.40	
	3	1548.1	3096.20	
	4	1548.5	3097.00	
	5	1548.9	3097.80	
	6	1549.3	3098.60	
	7	1552.0	3104.00	
Energy points for tau scan	8	1771.0	3542.00	14
	9	1776.4	3552.80	14+25
	10	1776.65	3553.30	14+12
	11	1780.2	3560.40	7
	12	1792.0	3584.00	14
Energy points for psi' scan	13	1838.0	3676.00	
	14	1841.8	3683.60	
	15	1842.4	3684.80	
	16	1843.0	3686.00	
	17	1843.7	3687.40	
	18	1844.4	3688.80	
	19	1847.0	3694.00	

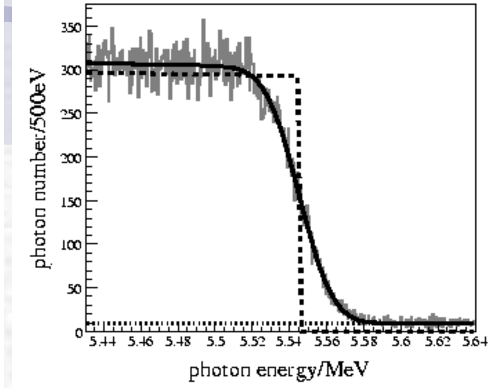
Conclusions

- The systematical accuracy of BEMS is about 2×10^{-5} estimated by analysis of ψ' scan data
- Pre-scan of tau mass measurement was performed. The uncertainty is 0.18 MeV (sta. & sys.) using 23 pb^{-1} scan data. The contribution of uncertainty of beam energy and beam energy spread is 20-80 keV.
- Some upgradations were performed for BEMS
- BEMS is ready for tau mass scan and other new experiments

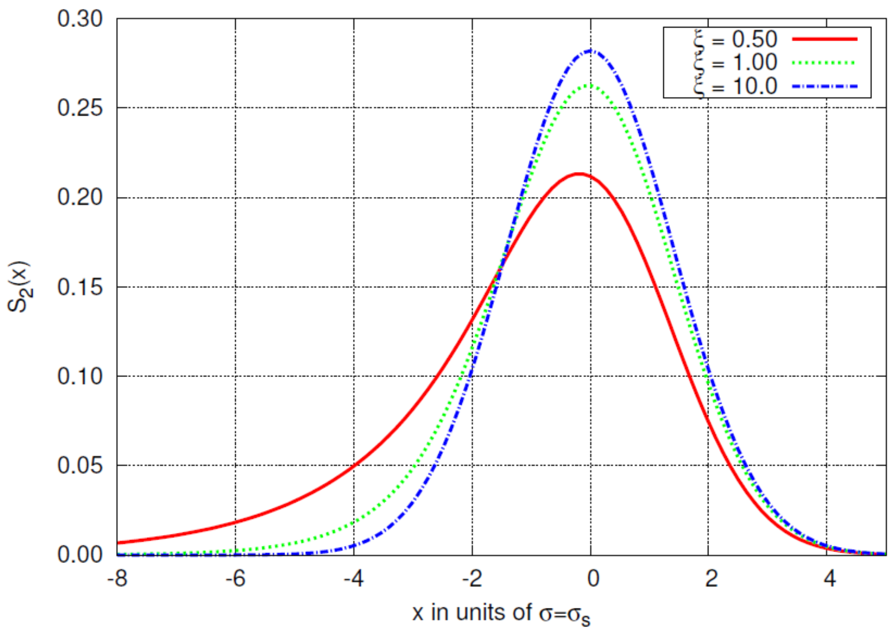
Thank you !

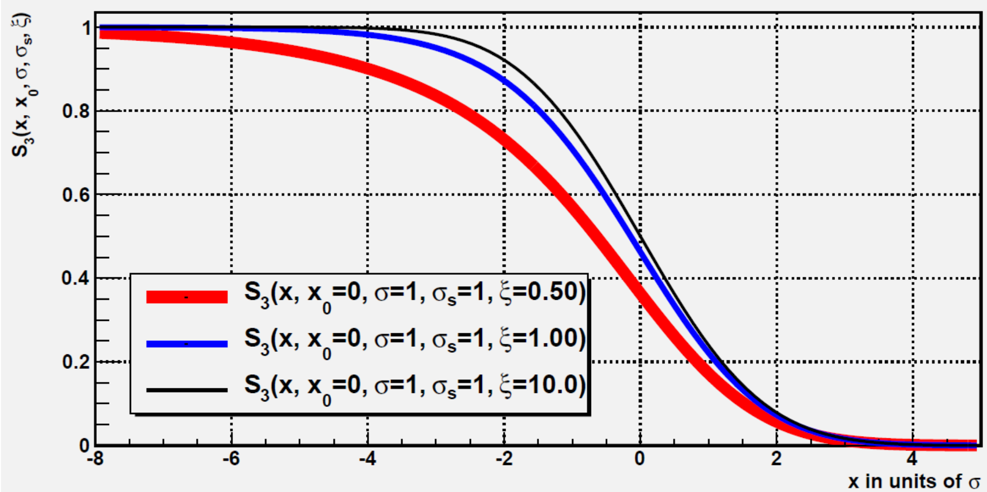
Backup





$$g(x, x_0) = \begin{cases} x < x_0 : & 1 \\ x > x_0 : & 0 \end{cases}$$





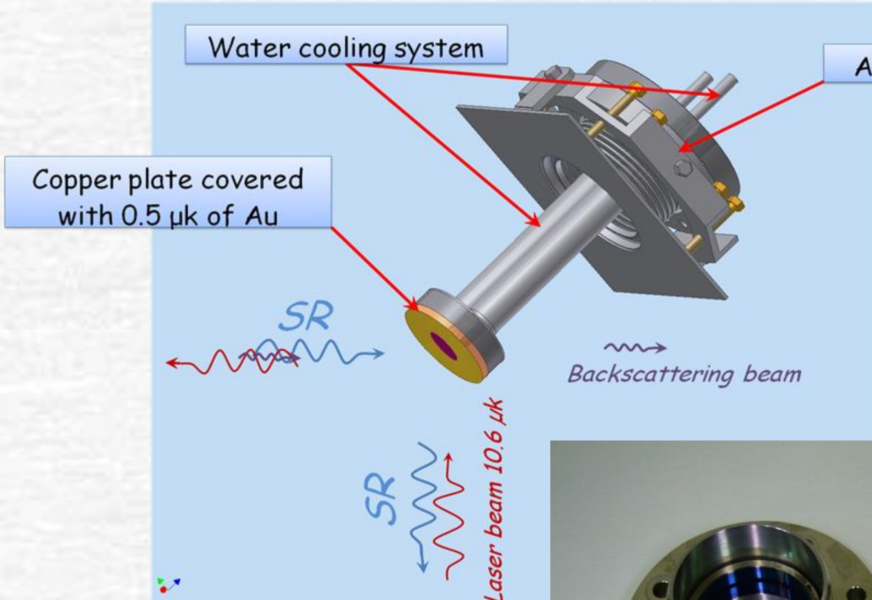
$$S_2(x, x_0, \sigma, \sigma_s, \xi) = \frac{N}{2\sqrt{2\pi}} \times$$

$$\times \left[\frac{1}{\sigma} \exp\left(\frac{\xi^2}{2} \left(1 + \frac{\sigma_s^2}{\sigma^2}\right) + \frac{\xi x}{\sigma} \right) \cdot \mathrm{erfc}\left(\frac{\xi(\sigma^2 + \sigma_s^2) + x\sigma}{\sqrt{2}\sigma\sigma_s} \right) + \right.$$

$$\left. + \frac{1}{\sqrt{\sigma^2 + \sigma_s^2}} \exp\left(-\frac{x^2}{2(\sigma^2 + \sigma_s^2)} \right) \cdot \mathrm{erfc}\left(-\frac{\xi(\sigma^2 + \sigma_s^2) + x\sigma}{\sqrt{2(\sigma^2 + \sigma_s^2)}\sigma_s} \right) \right]$$

$$S_3(x, \sigma, \sigma_s, \xi) = \int_x^{+\infty} S_2(y)\, dy$$

Copper mirror and High vacuum GaAs viewport

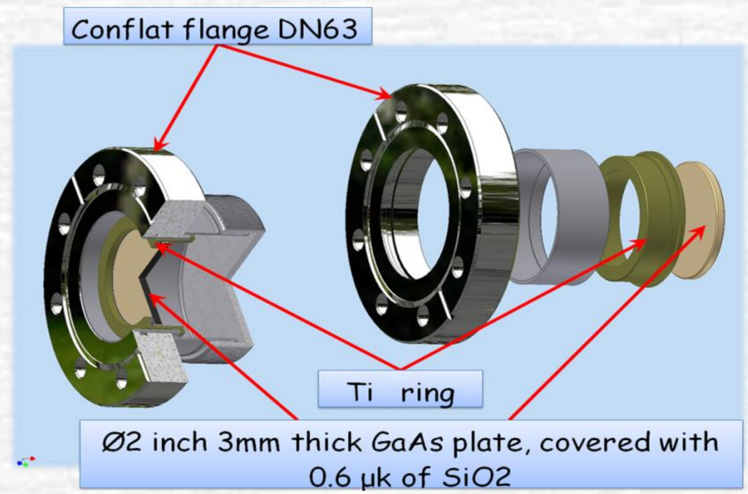


The mirror is mounted to the support.

Support can be turned by bending the vacuum flexible bellow, so the angle between the mirror and the laser can be adjusted as necessary.

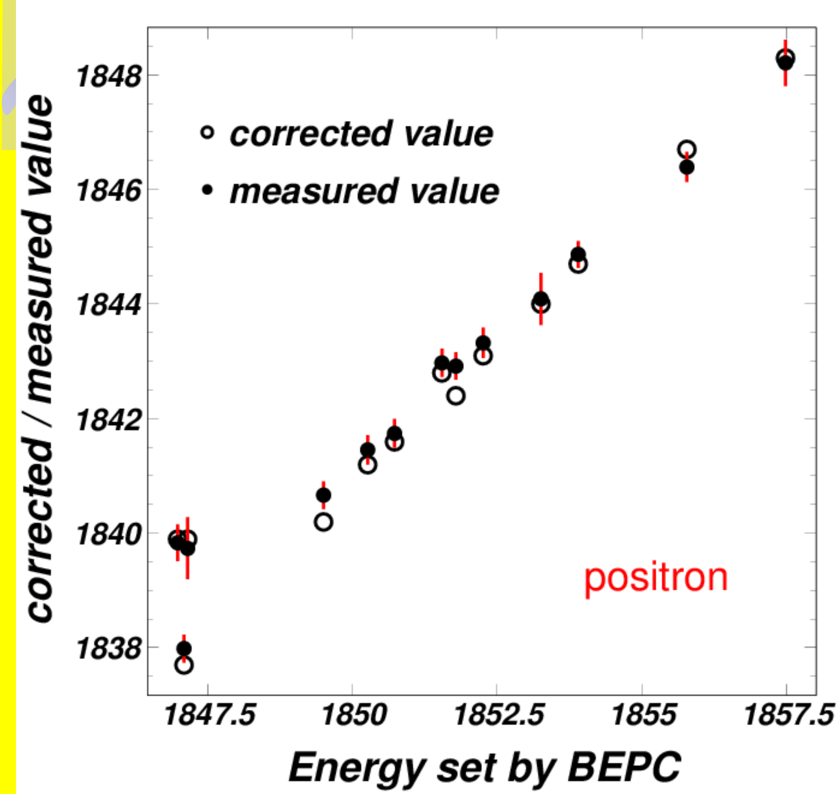
The SR is absorbed by the mirror. The extraction of heat is provided by the water cooling system.

The viewport is *GaAs* crystal plate with Ø2 inch and thickness of 3mm

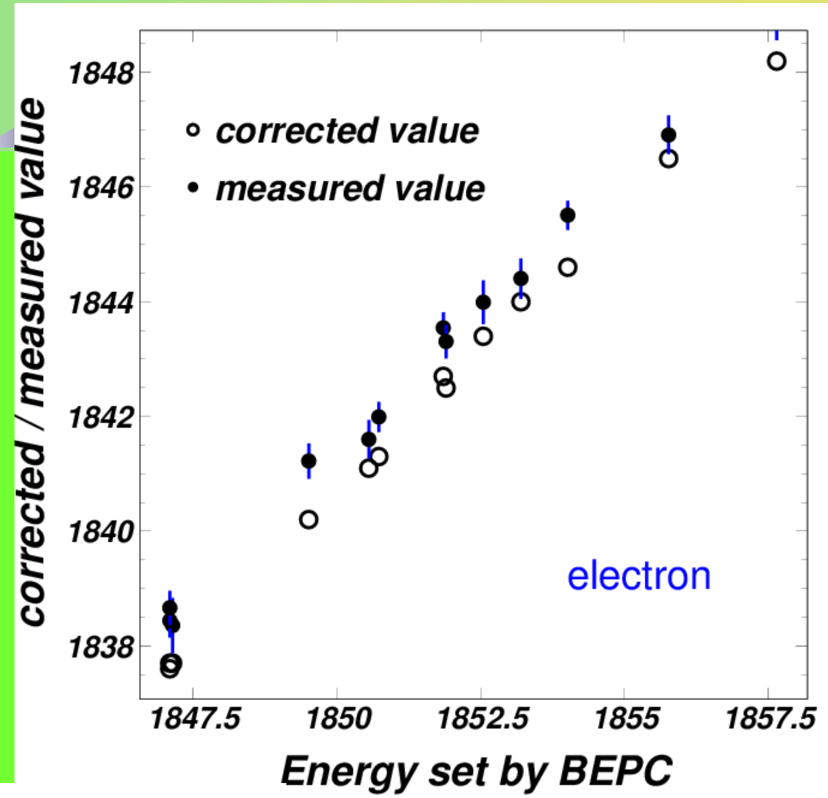


GaAs plate was covered with 0.6μm of SiO_2 and brazed with lead alloy to titanium ring. The titanium ring was brazed with *AgCu* alloy to the stainless steal ring. The steal ring was welded to stainless steel DN40 flange.

The viewport can be heated up to 250 ℃, has transparency ~66% at λ=10.6 μm .

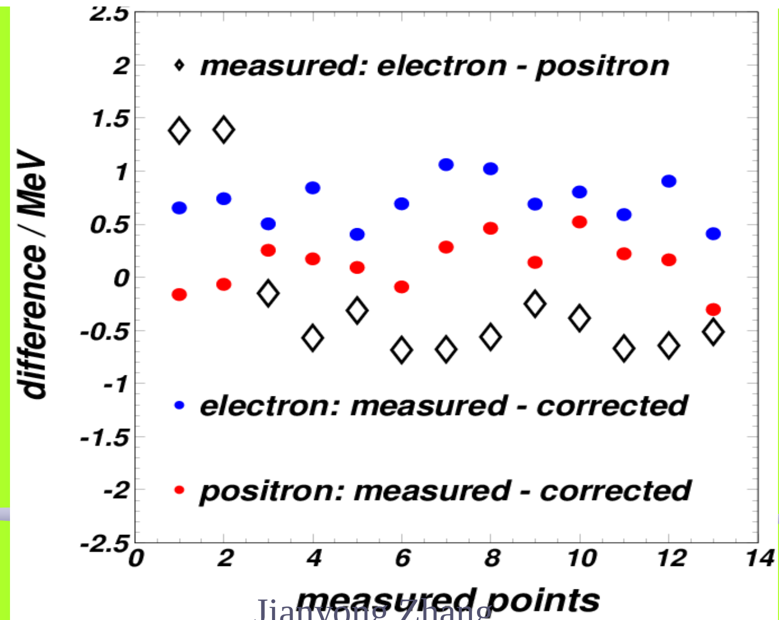


Energy diff.



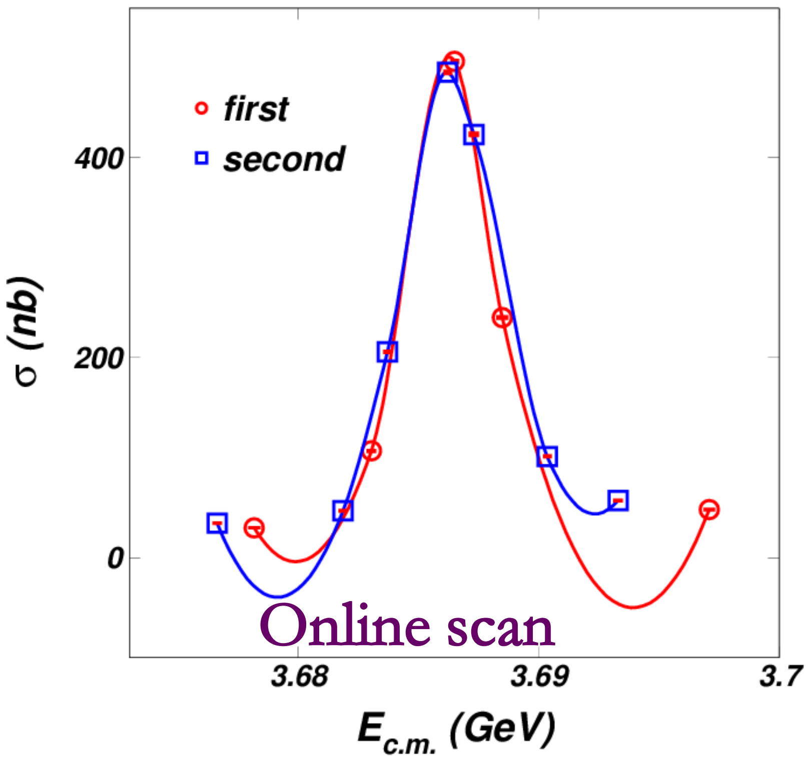
Corrected BEPCII :

Measured BEMS :

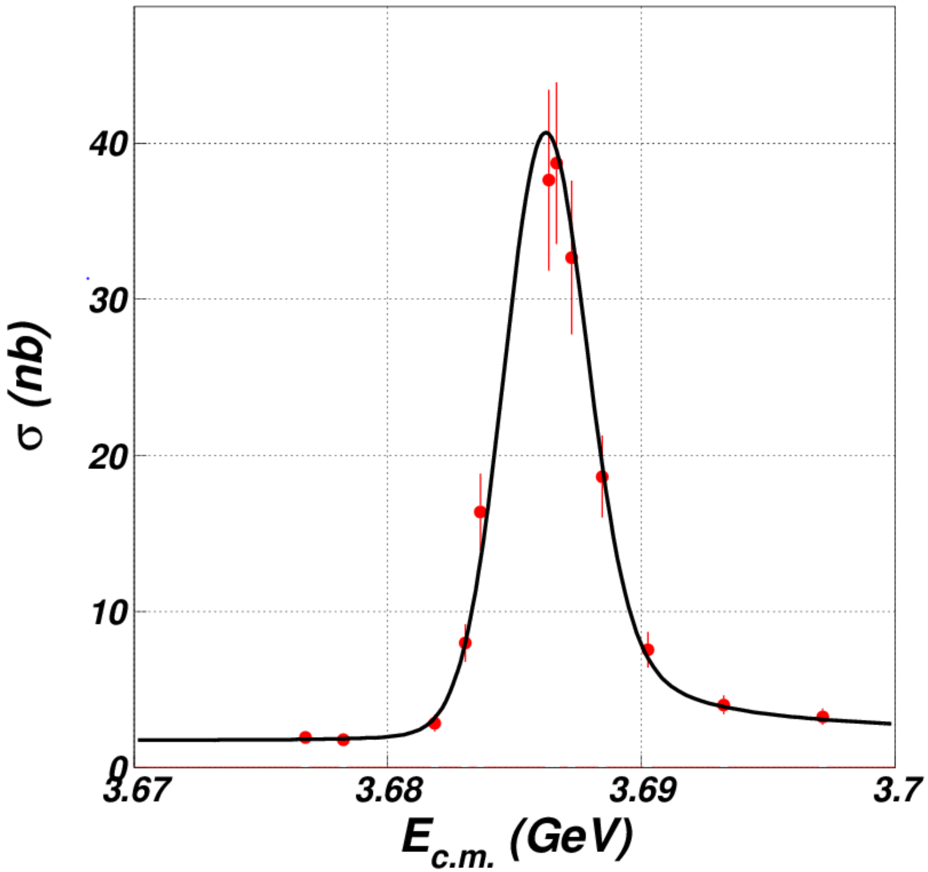


Energy error determined by BEMS is enlarged 3 times

Results of ψ(3686) scan by BEMS



Offline fit:
3686.08 ± 0.02 MeV
PDG2010:
3686.09 ± 0.04 MeV



- 无效率修正;
- 截面含任意倍数因子;
- 统计误差放大十倍.

Important events

Optics system finished in 2008.8

Vacuum tube, connection part finished in 2009.9

Light monitor system finished in 2009.12

DAQ system finished in 2009.12

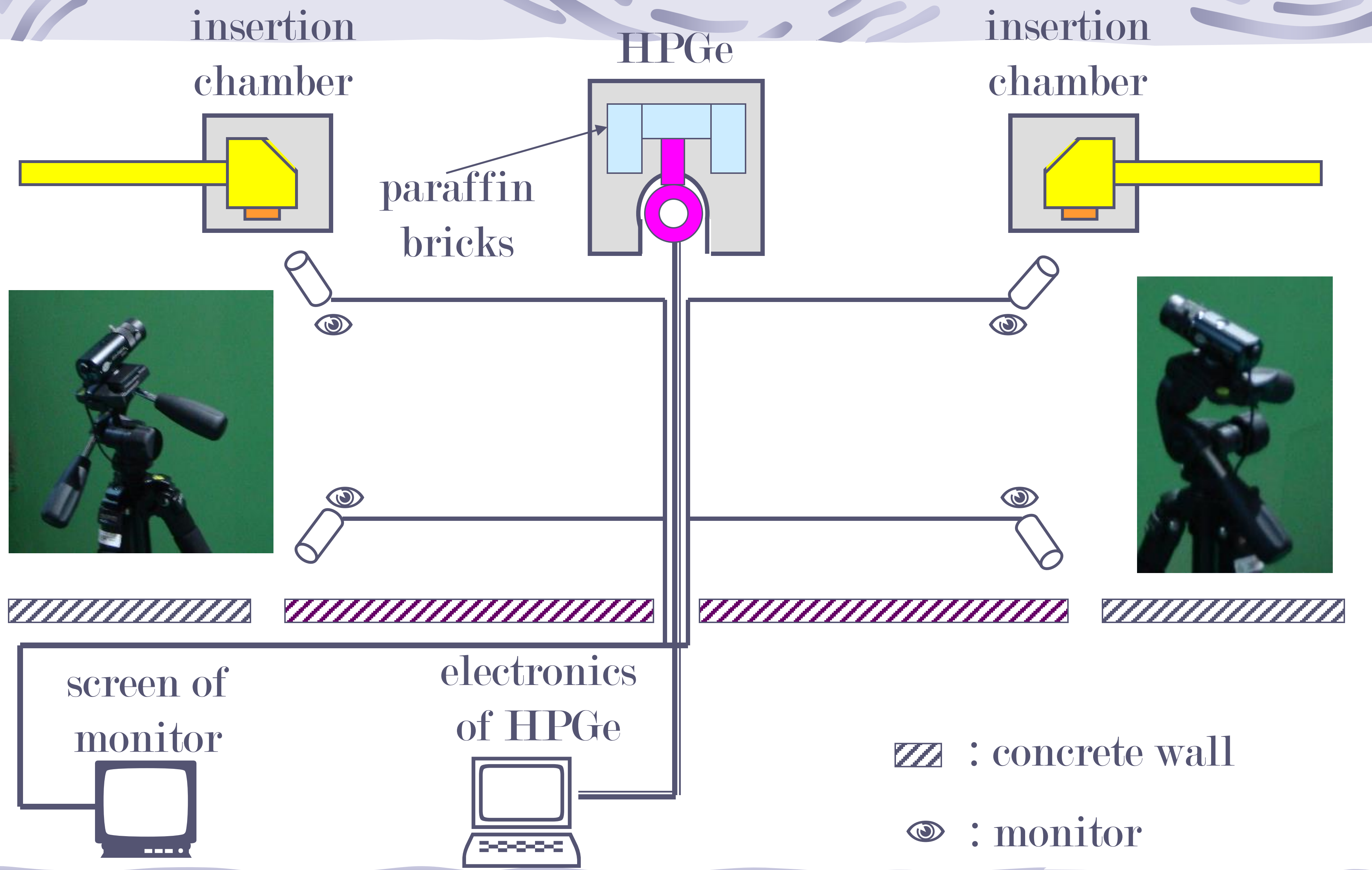
Laser system finished in 2010.1

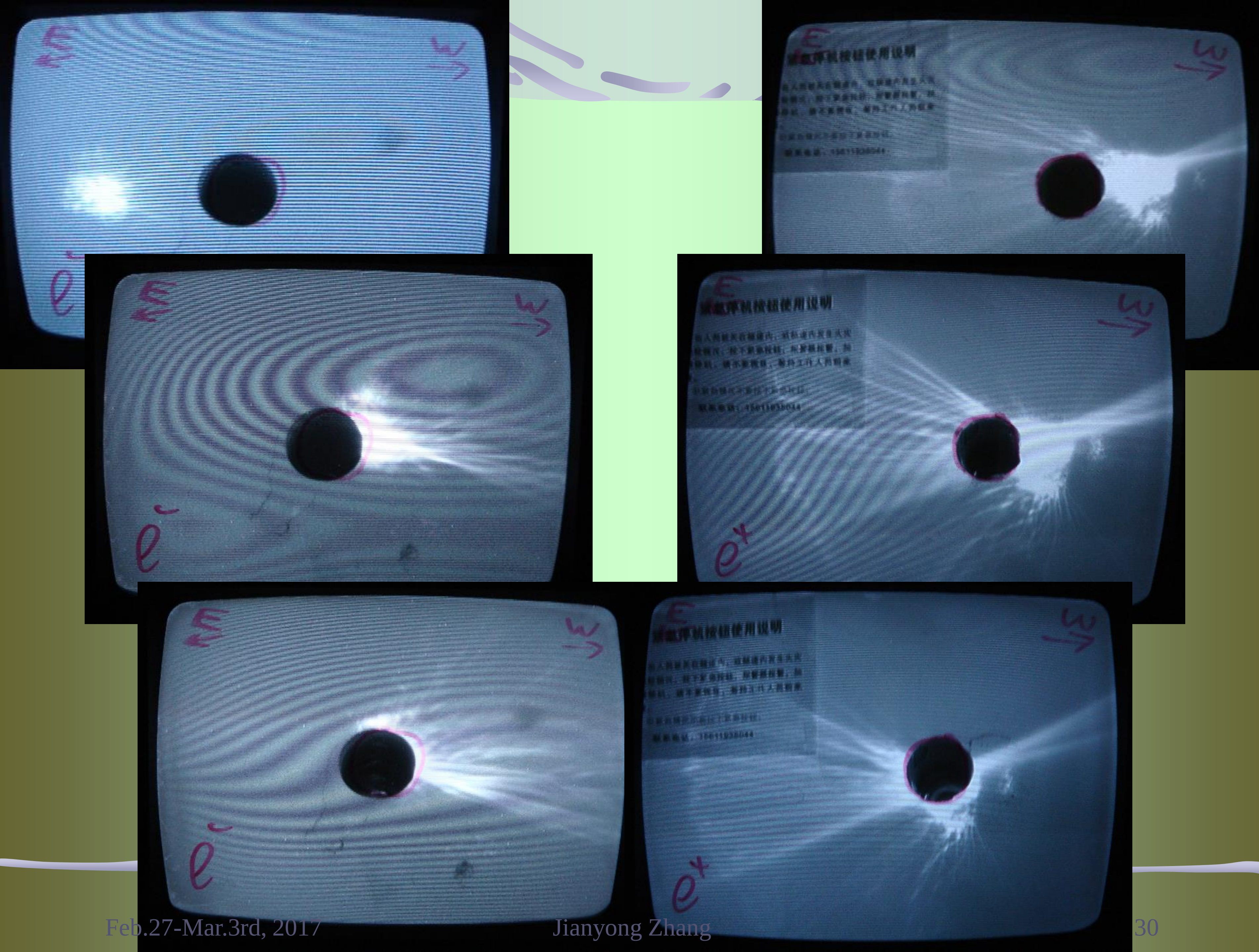
HPGe detector arrived in 2010.4

GaAs windows replacement finished in 2010.8

Laser alignment finished in 2010.9

Total monitor system finished in 2010.9


insertion chamber
HPGe
insertion chamber
paraffin bricks
screen of monitor
electronics of HPGe
: concrete wall
: monitor


E
W
e-
e+