Beam Energy Measurement System at BEPCII

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On behalf of the BEMS group:

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Motivation

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

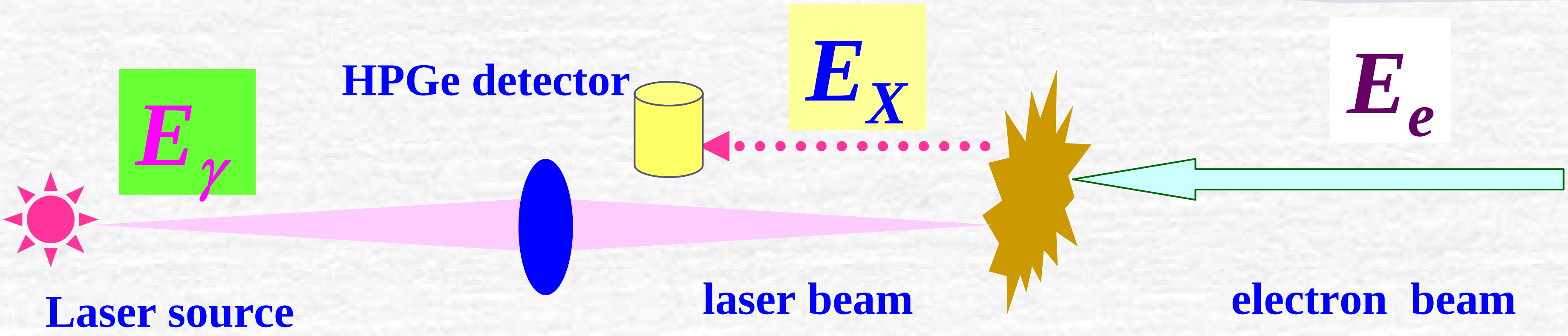
- The τ-lepton mass determination

  $M_\tau = 1776.82 \pm 0.16$ MeV/c^2

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

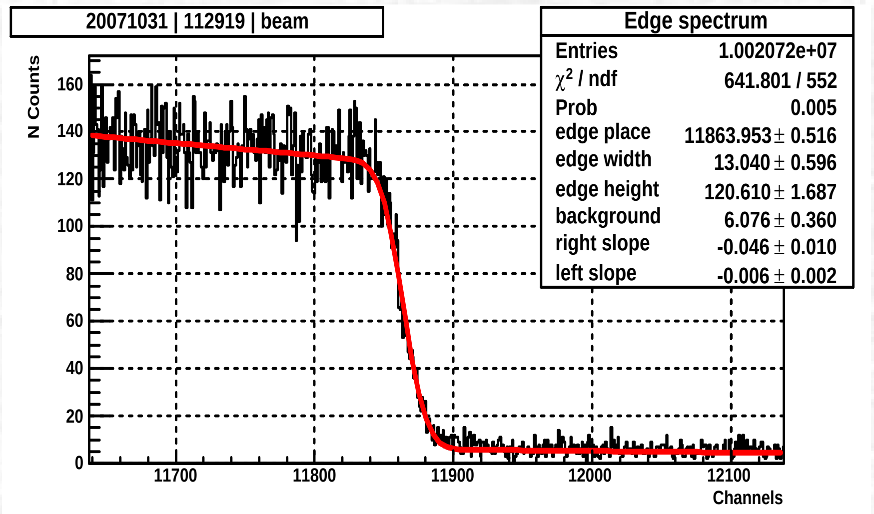
- The masses of ψ and D mesons are of interest.
- Useful tool to monitor the collider.

Compton Backscattering

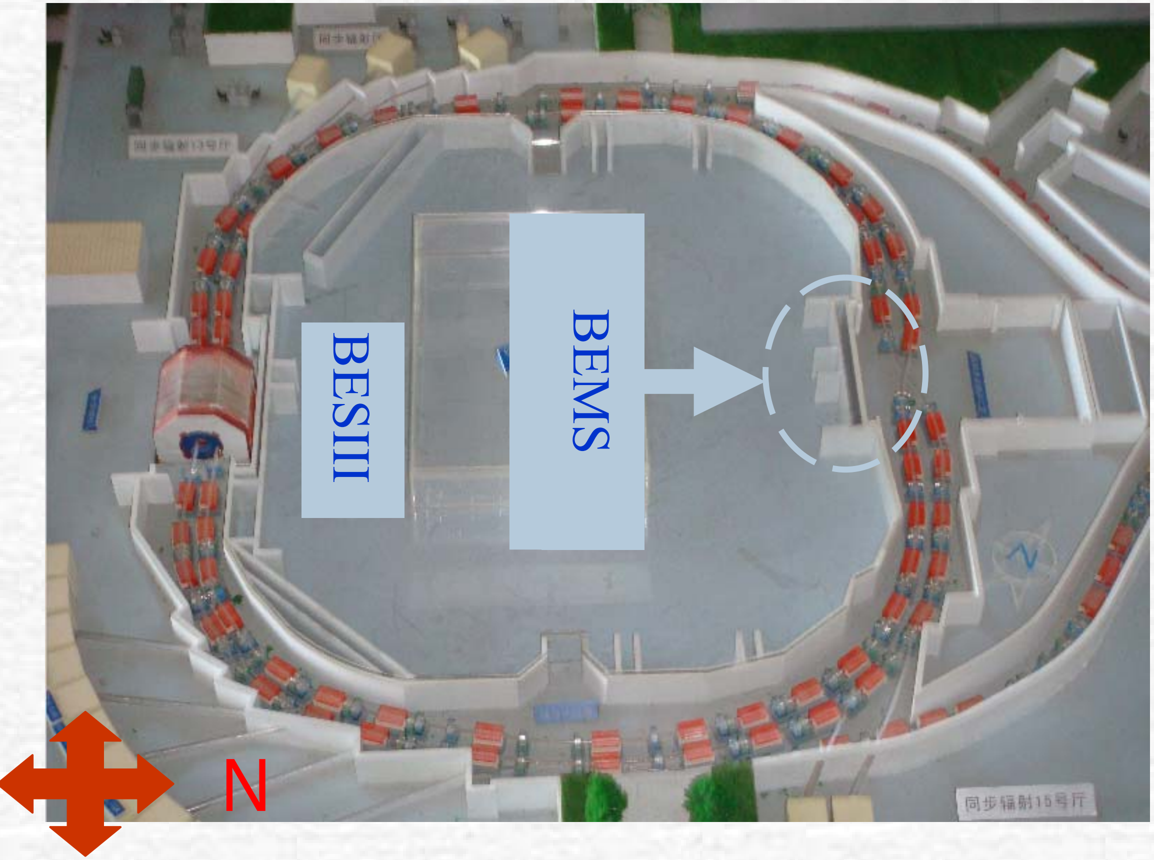


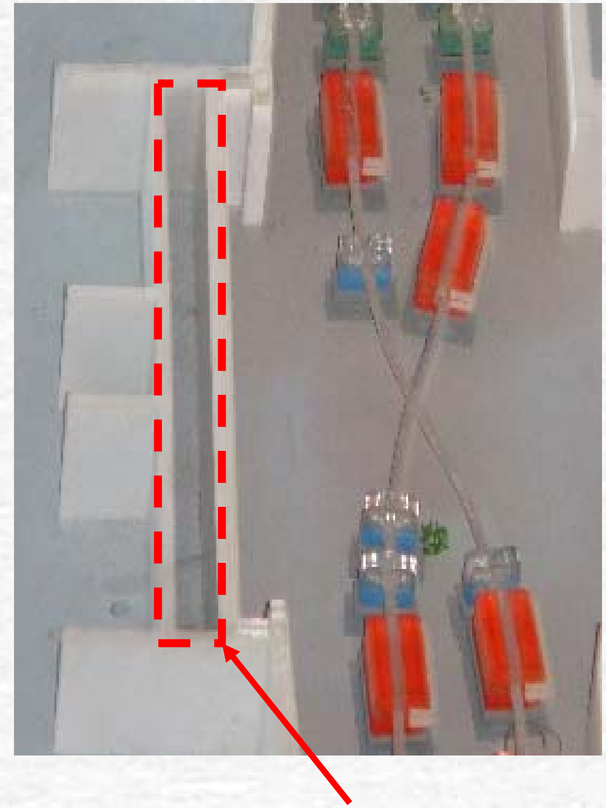
The beam energy E_e is determined by the maximum energy E_x

$$E_e = \frac{E_X}{2}\left[1 + \sqrt{1 + \frac{m_e^2}{E_\gamma E_X}}\right]$$



BEPC-II electron-positron storage ring

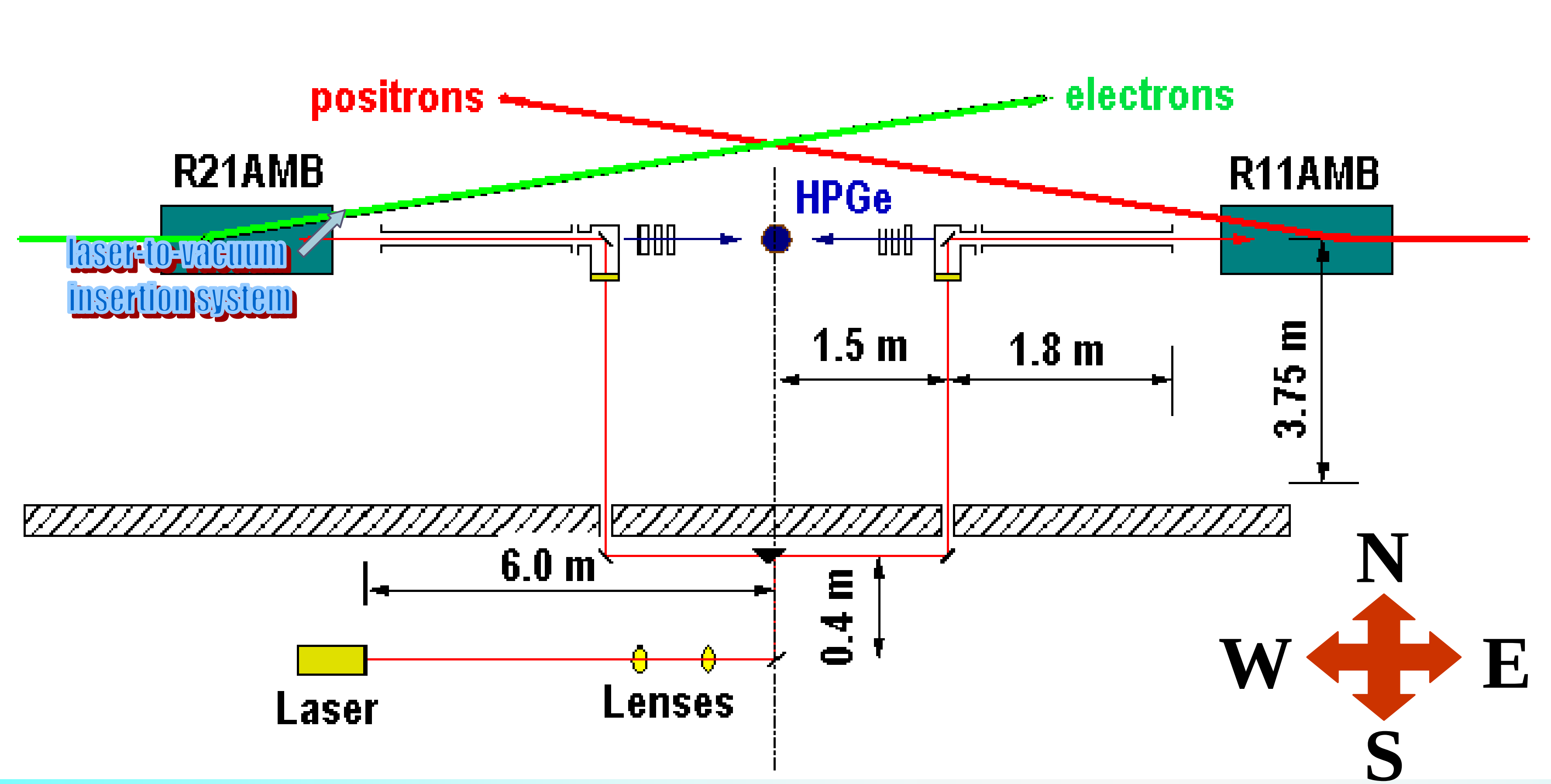




Corridor where optics system located

The beam energy measurement system locates at the north crossing point.

Sketch map of BEMS



Laser and optics system

Laser to beam interaction system

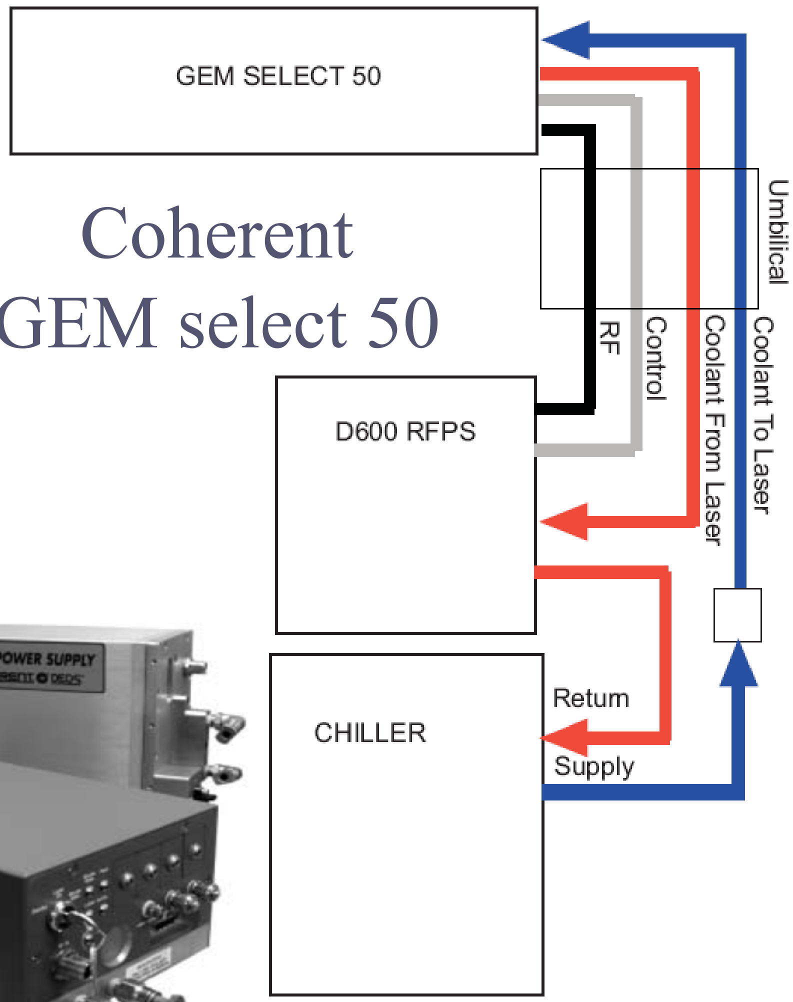
HPGe detection system

Data acquisition system

Coherent CO_2 laser

λ=10.835 μm

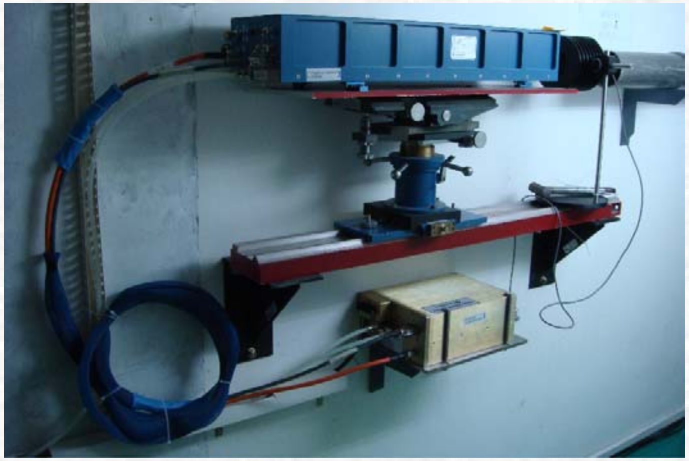
Agilent 6573A power supply



Coherent GEM select 50

Lytron CR011H03BC circulating chillers

Laser and Optics system

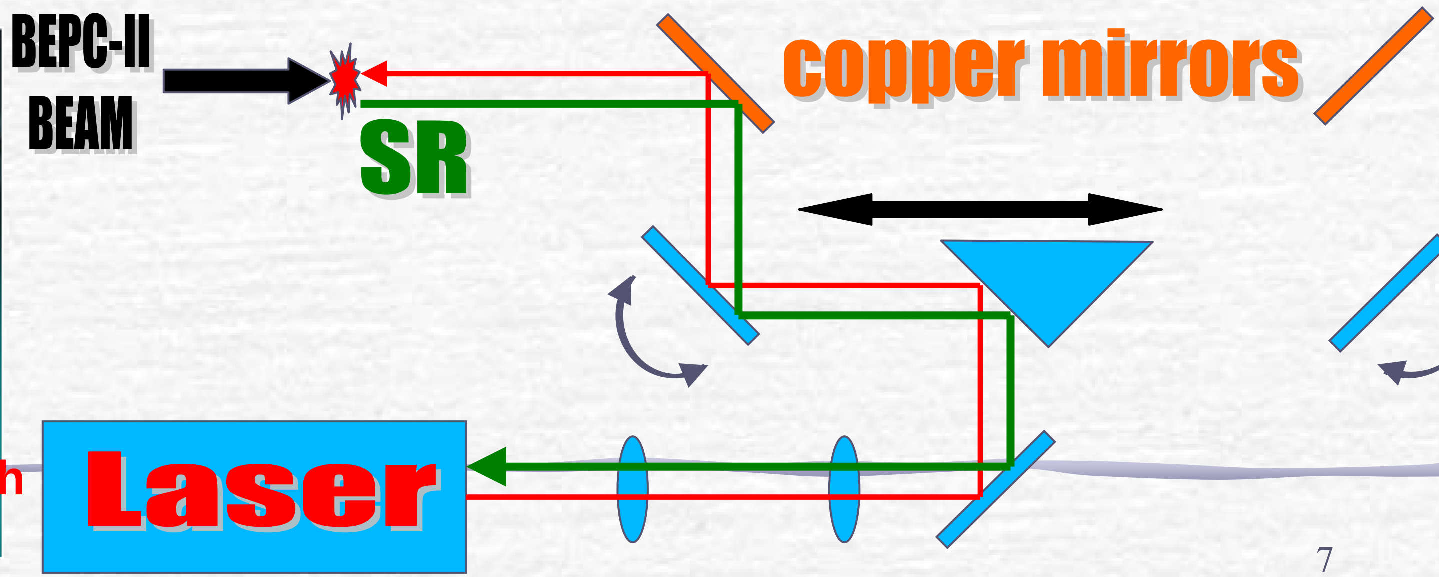


wavelength λ=10,835231 μm
power P = 25 W.

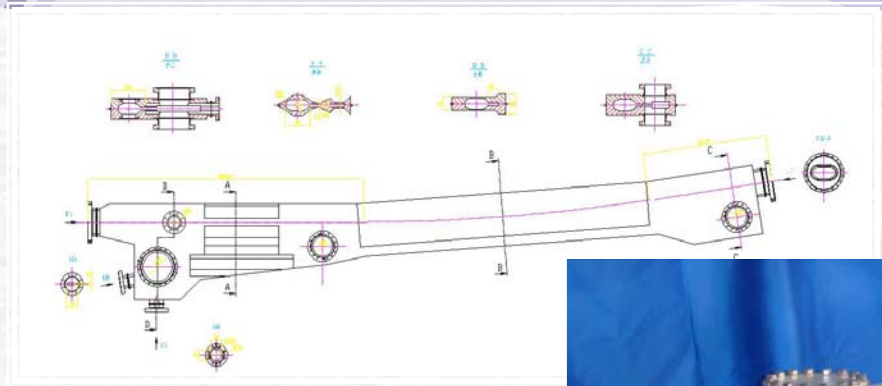
Two ZnSe lenses
focal length f = 40 cm

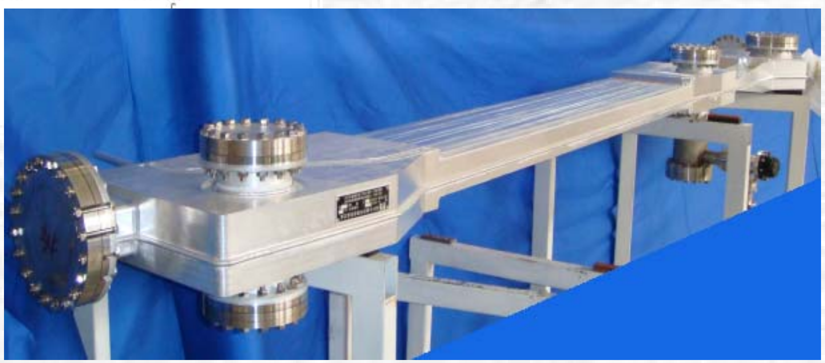
Movable reflector prism

Two mirrors with step motors



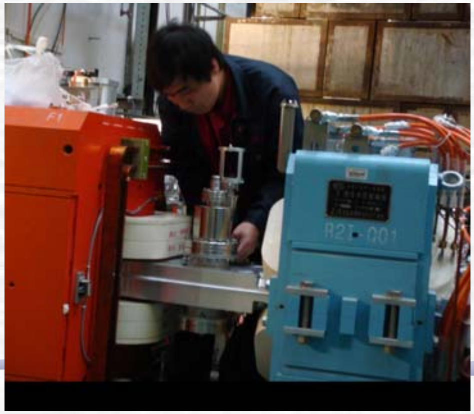
Reformed vacuum chamber



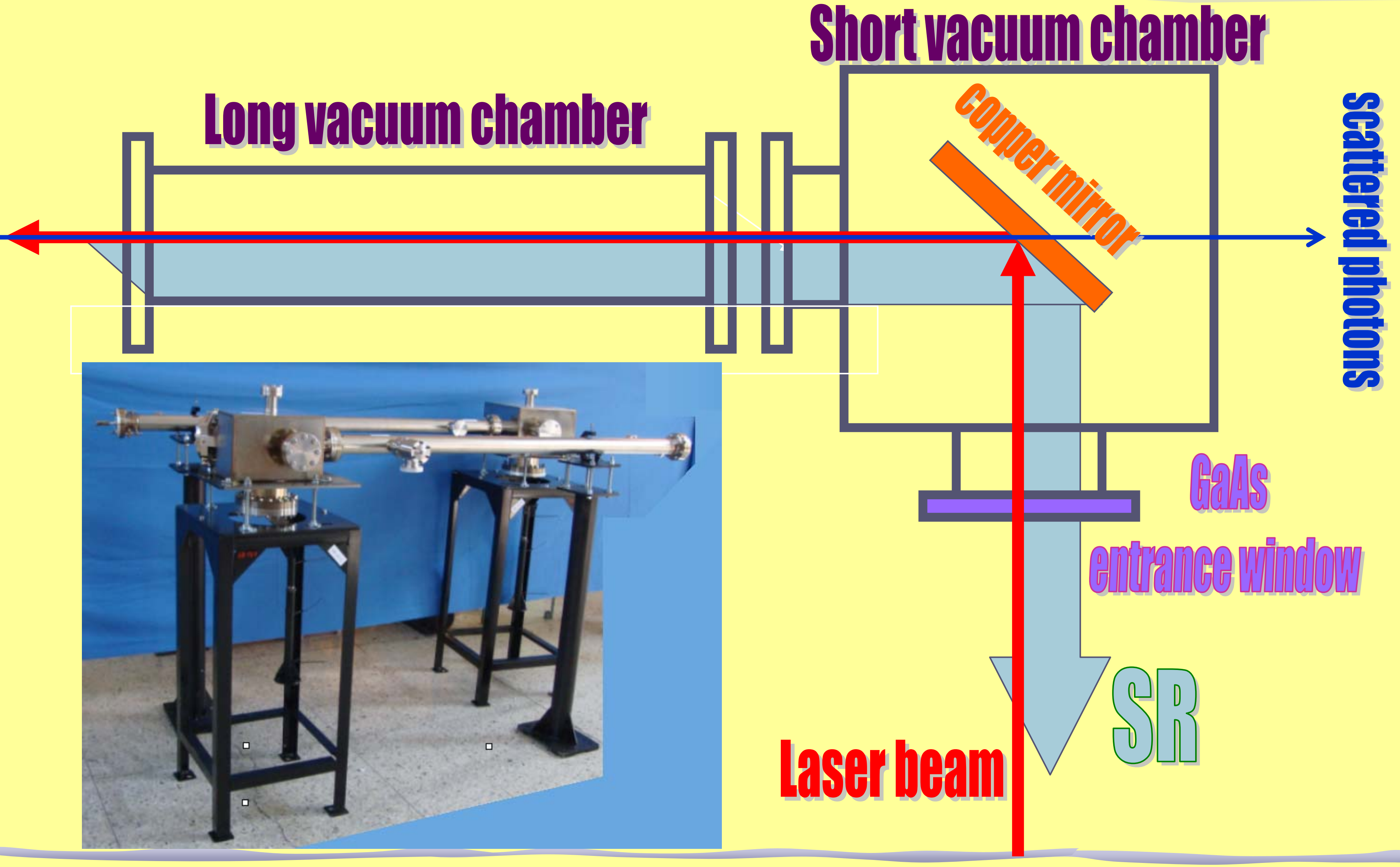


Installation

Alignment

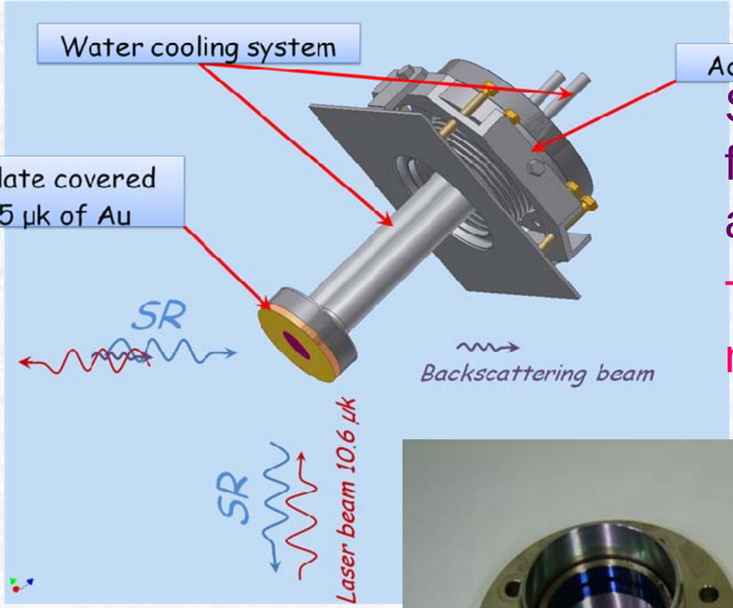


laser-to-vacuum insertion part



Pressure less than 5×10^{-10} mbar

Copper mirror and High vacuum GaAs viewport

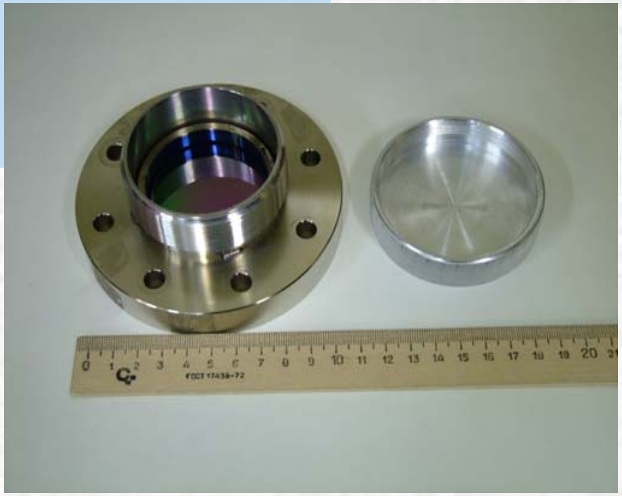


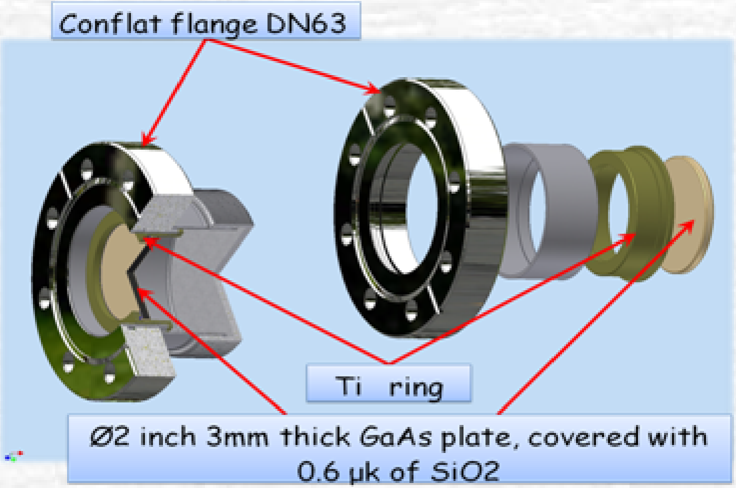
The mirror is mounted to the support.

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 light falls on the mirror and heats the mirror. Water cooling system is used.

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





GaAs plate was covered with 0.6 μ m 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 ºC, has transparency ~66% at λ =10.6 μm .

laser-to-vacuum insertion part

chamber installation

Pump Installation

Alignment

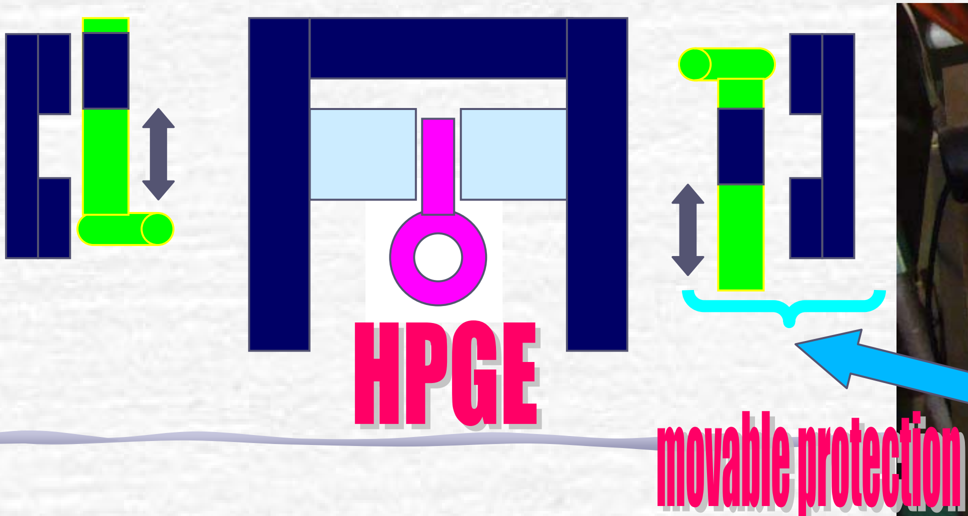
Baking 24 hours
Pressure:
$1.5\sim4.5\times10^{-10}$ Torr

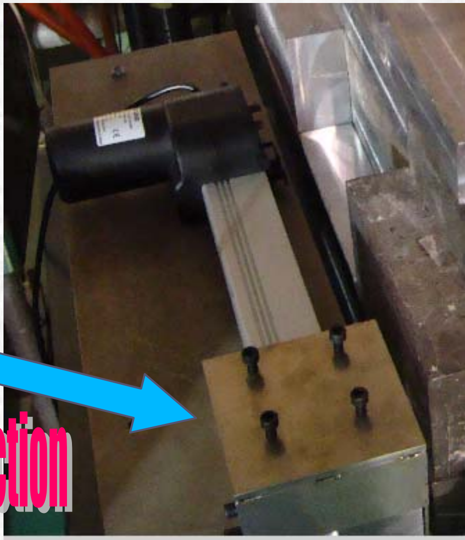
Coaxial HPGe detector (ORTEC GEM10P4-70)

Size: Ø 57.8 mm, height 52.7 mm
detection efficiency : about 10%
energy resolution ~ 10^{-3}

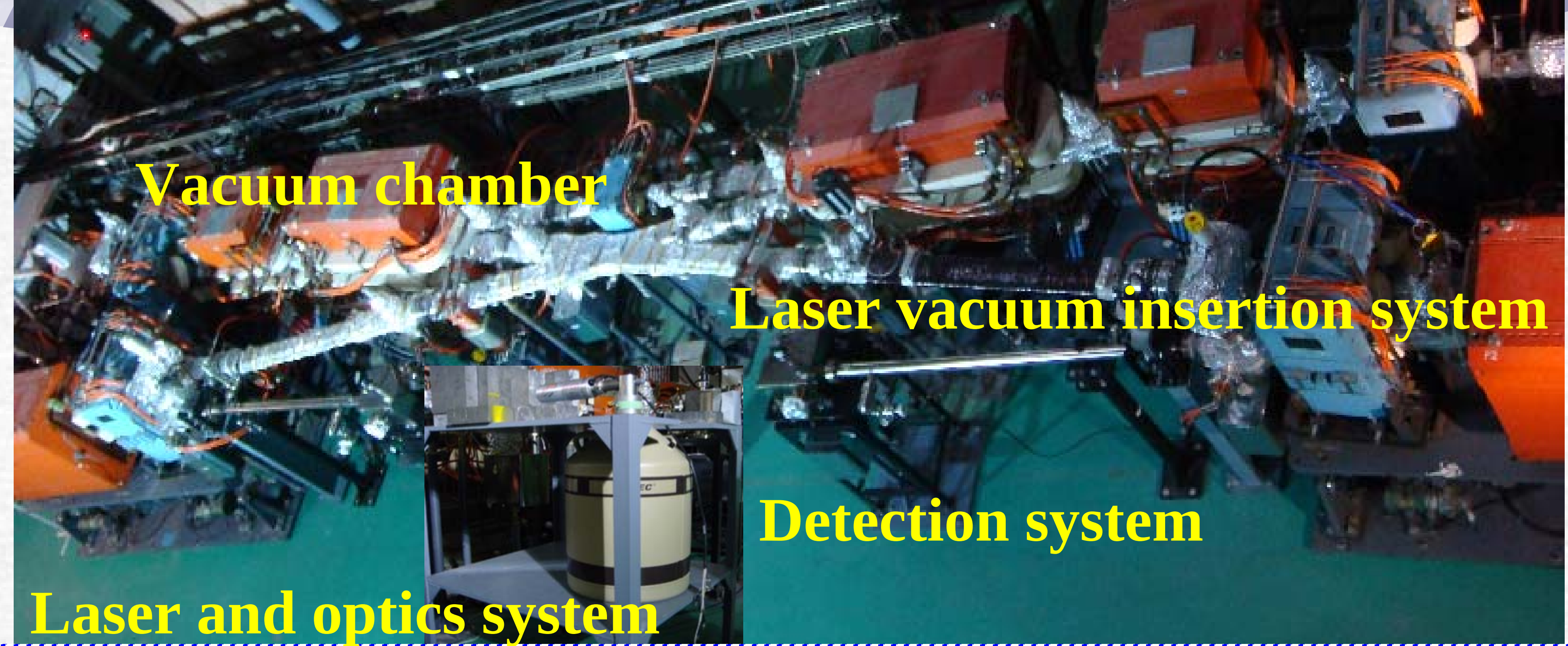
lead and paraffin are added to suppress the low energy photons.

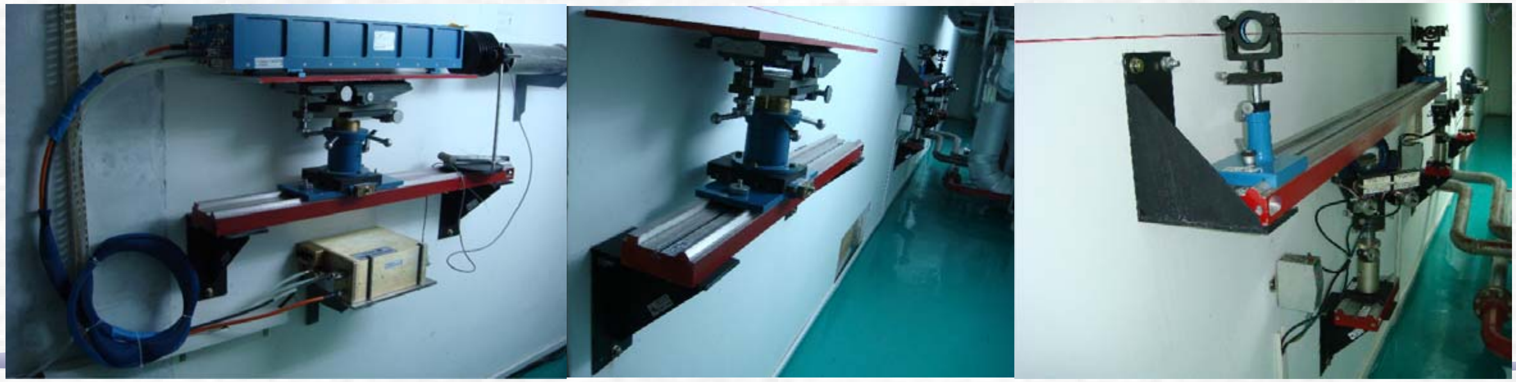
Movable protection is used at the other side of beam direction to reject the high energy photons.



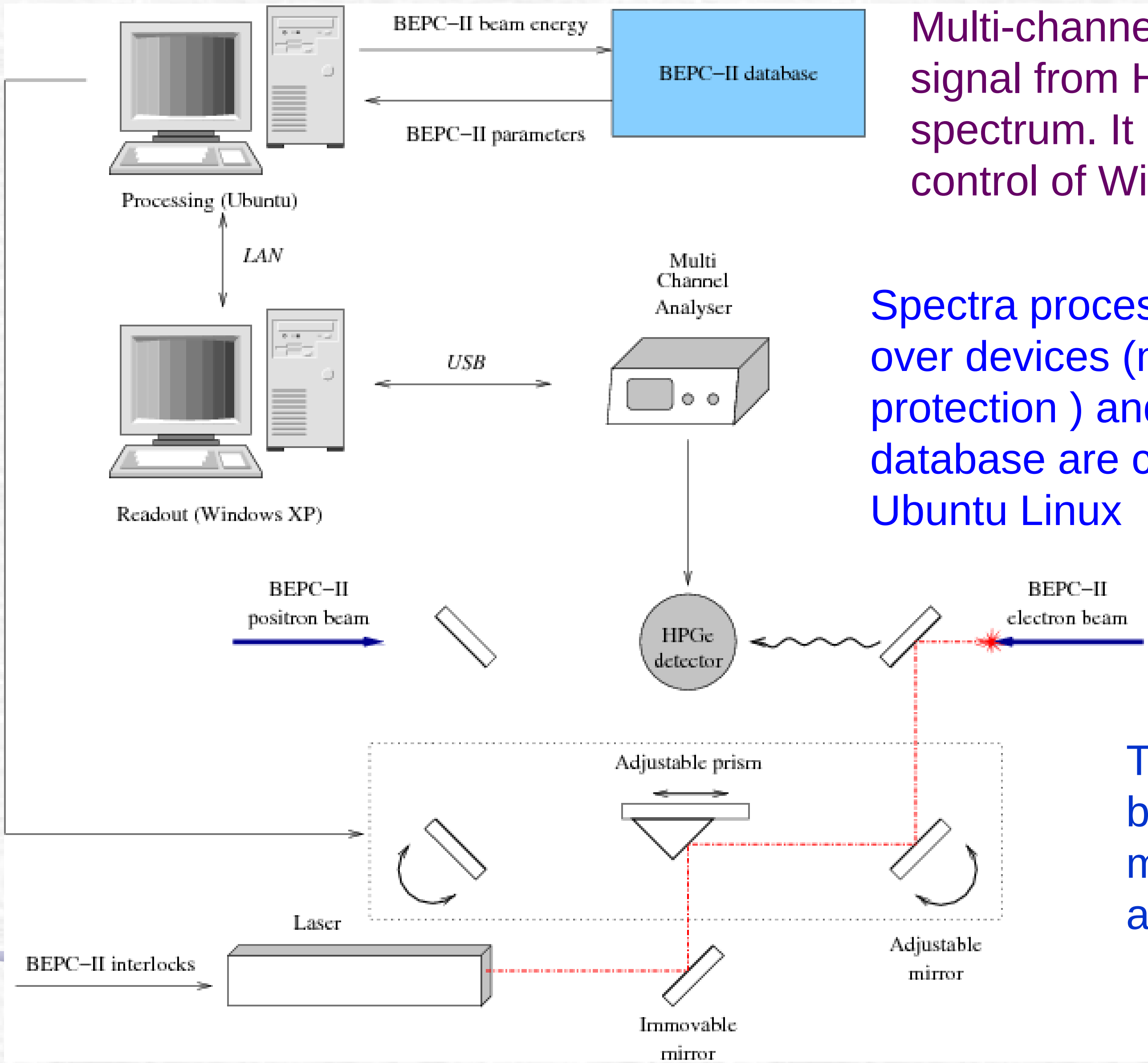


Installation of BEMS





Data acquisition system



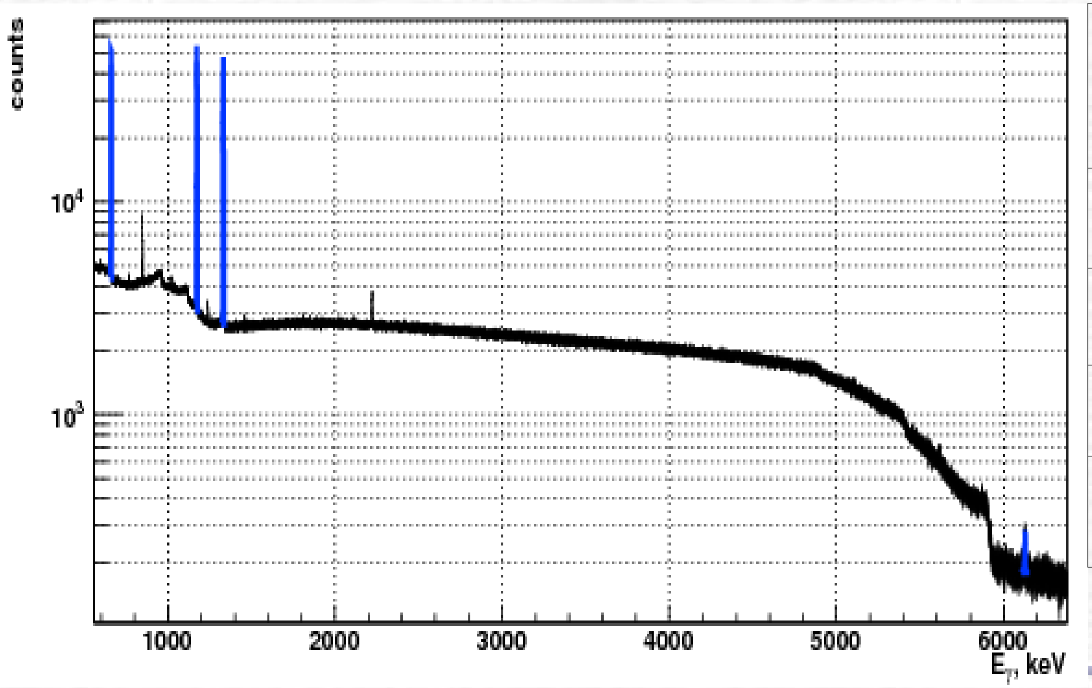
Multi-channel analyser digitises the signal from HPGe and converts it to spectrum. It is connected to PC under control of Windows XP

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

Data processing

- HPGe energy scale calibration;
- Fitting of the Compton edge
- calculation of the beam energy



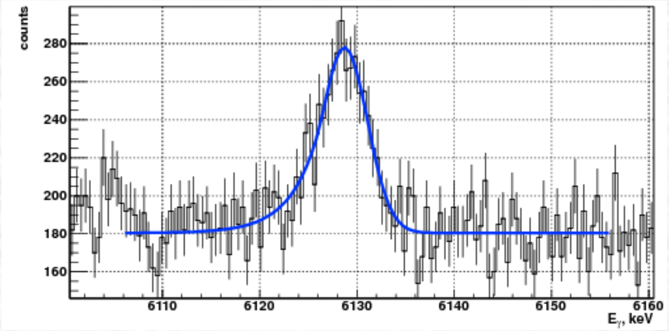
Lines used for calibration.	
^{137}Cs	E_γ=661.656 MeV
^{60}Co	E_γ=1173.228 MeV
^{60}Co	E_γ=1332.492 MeV
$^{16}O^*$	E_γ=6129.226 MeV

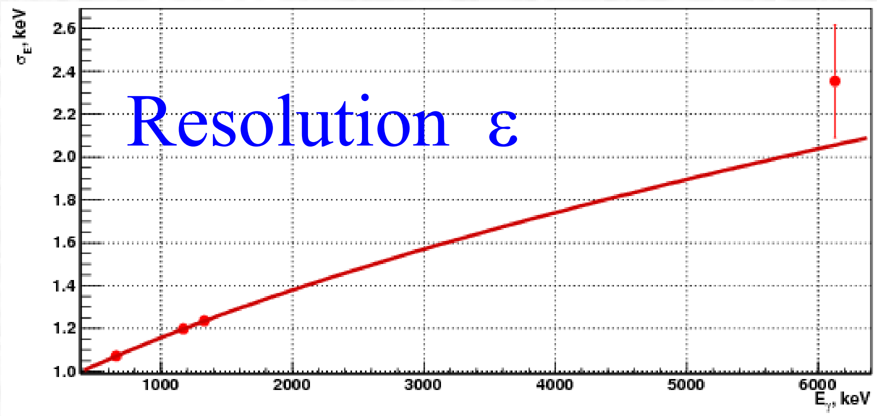
HPGe scale calibration procedure

1) The peaks searching and identification

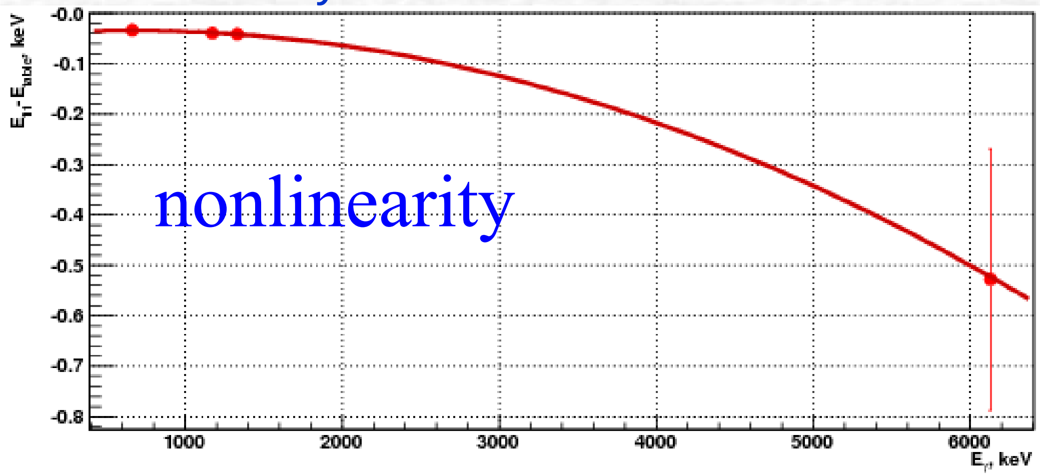
2) Peaks which correspond to calibration lines are fitted by response function:

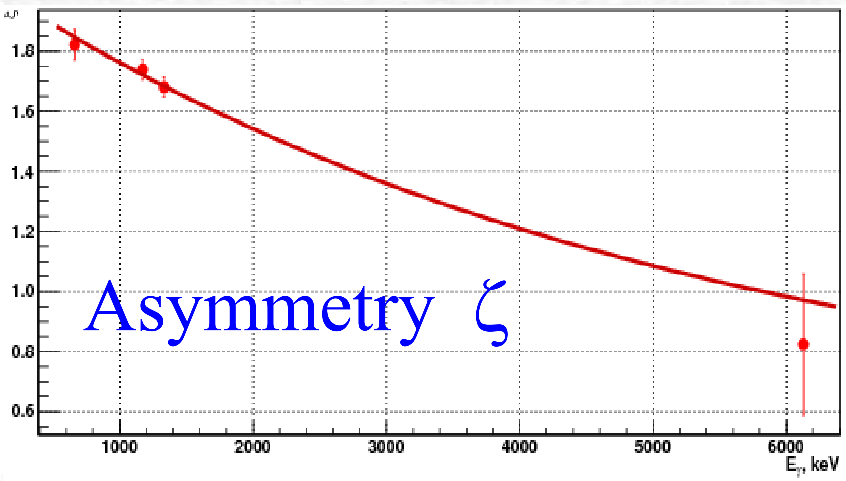
$$f(x, x_0, \sigma, \xi) = \frac{N}{\sqrt{2\pi}\sigma} \begin{cases} \exp\left\{-\dfrac{(x-x_0)^2}{2\sigma^2}\right\}, x > x_0 - \xi\sigma \\ \exp\left\{\dfrac{\xi^2}{2} + \dfrac{(x-x_0)^2}{2\sigma^2}\right\}, x < x_0 - \xi\sigma \end{cases}$$





3) Using the results of the fits the energy dependence of the response function parameters and HPGe detector scale nonlinearity are obtained

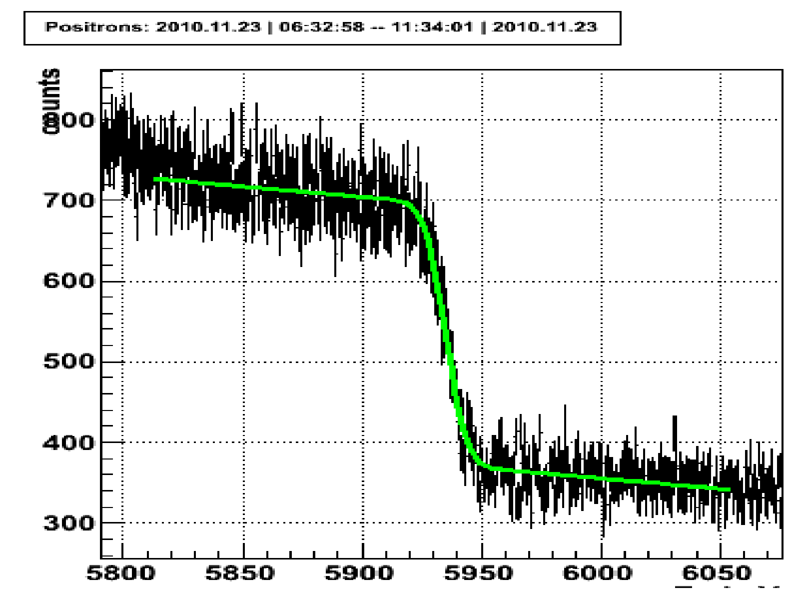




Fit of Compton edge

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 the fit.

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

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

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

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

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

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

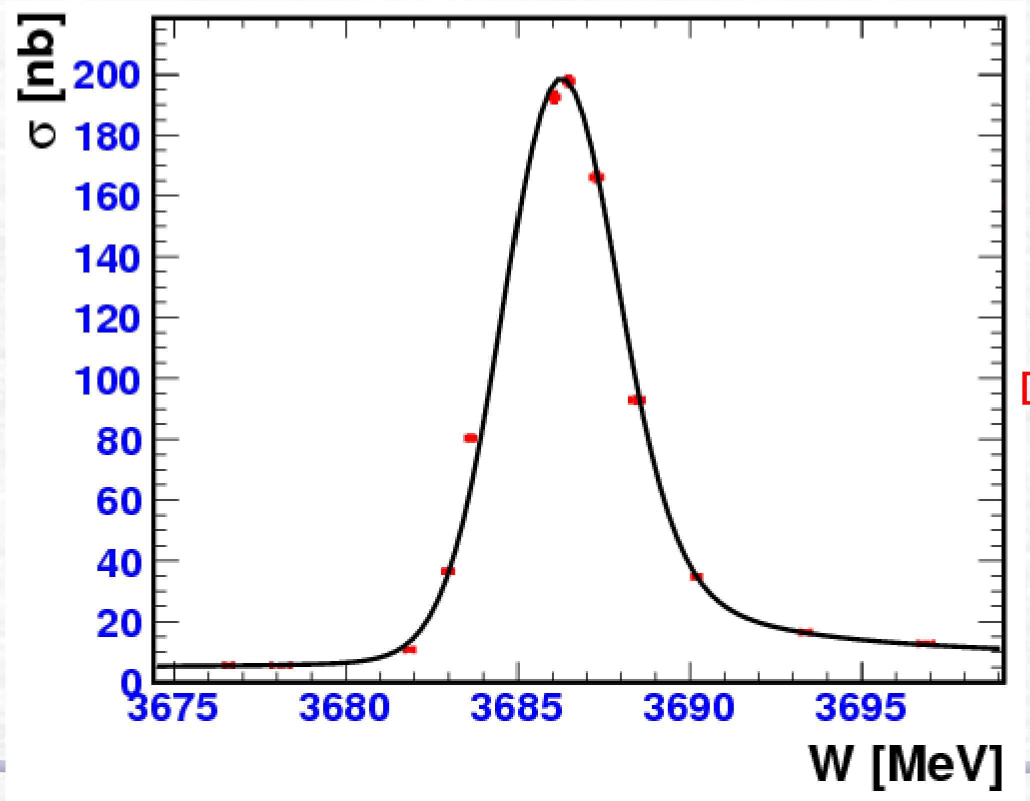
Taking into account the energy losses due to SR:

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

Beam energy in the south interaction point

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:

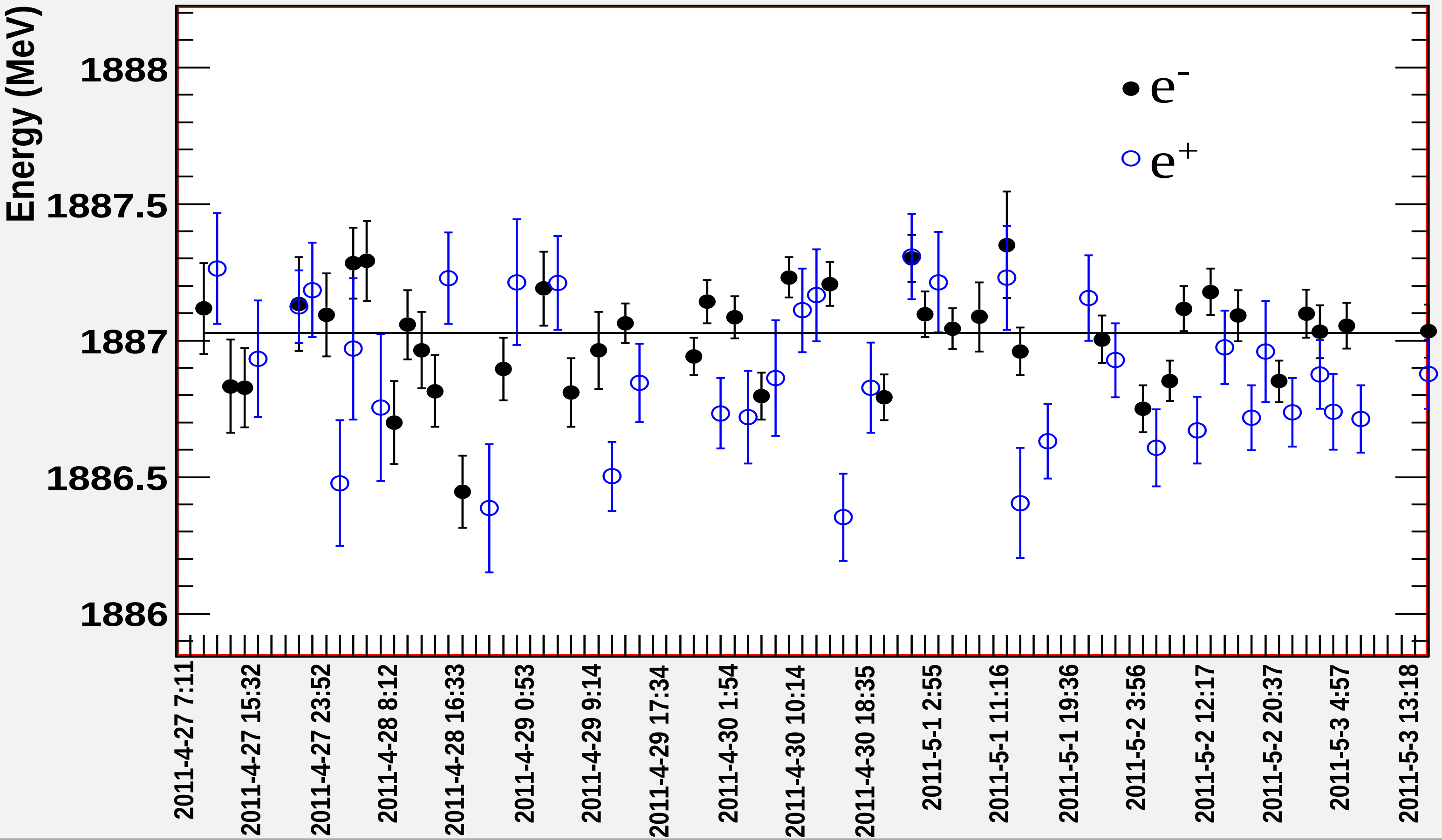
$$\Delta m = m - m_{\psi} = 0.02 \pm 0.05 MeV$$

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: $\delta\varepsilon/\varepsilon \sim 2\times10^{-5}$

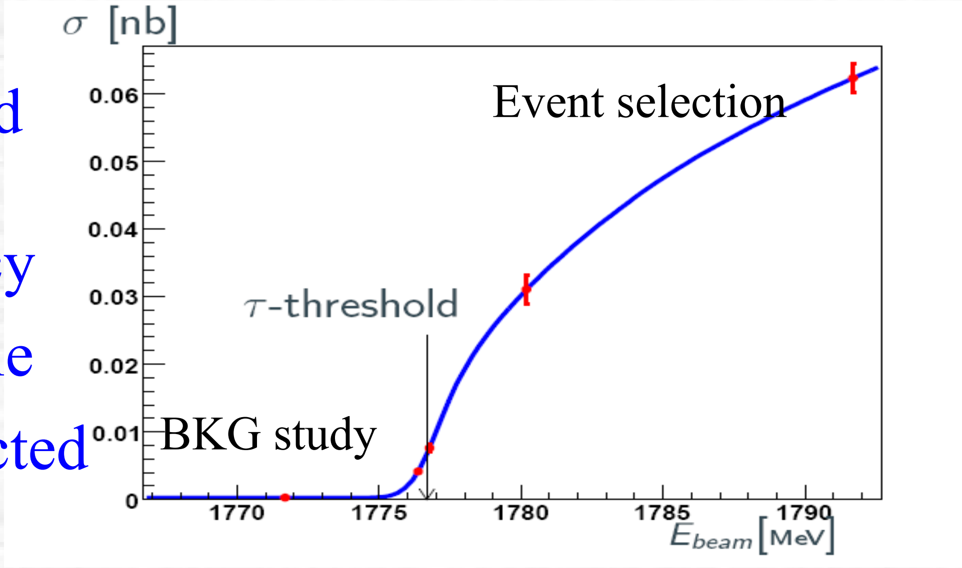
Stable performance

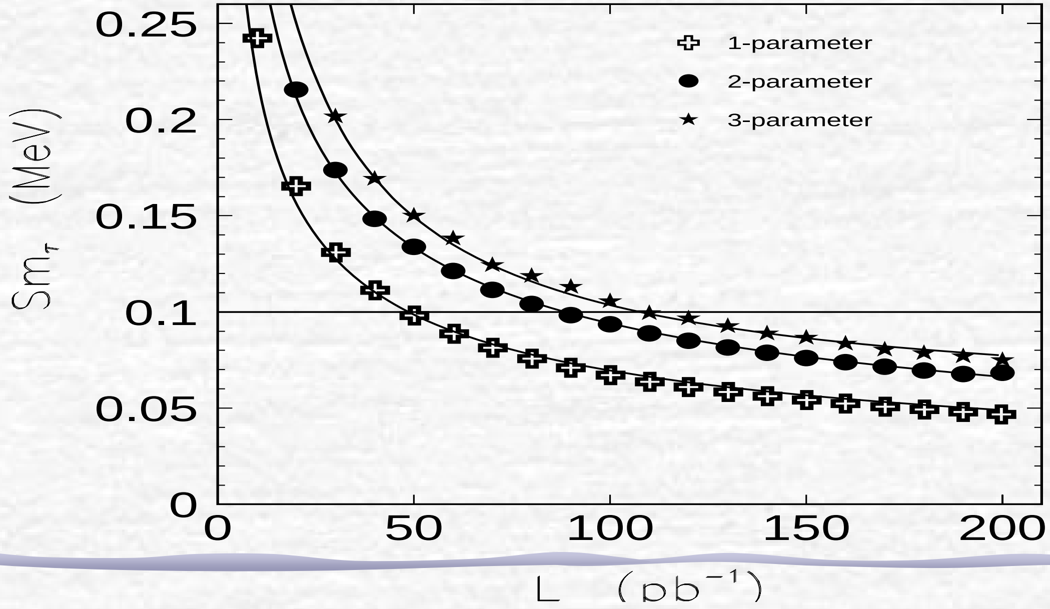


Data taking design

The τ mass scan will be performed

Considering the possible efficiency and background variations, reliable χ^2 check, 5 points design are selected





Luminosity allocation:

Background: 10%

Threshold: 70%

High energy region: 20%

Conclusions

The BEMS was designed, constructed and put into operation

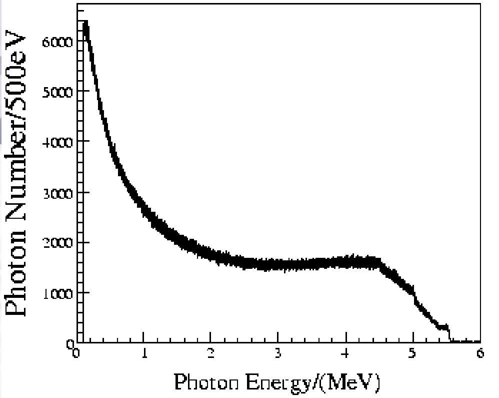
The commission of BEMS is fine. The systematical accuracy of the beam energy measurement is about 2×10^{-5} estimated by analysis of ψ' scan data

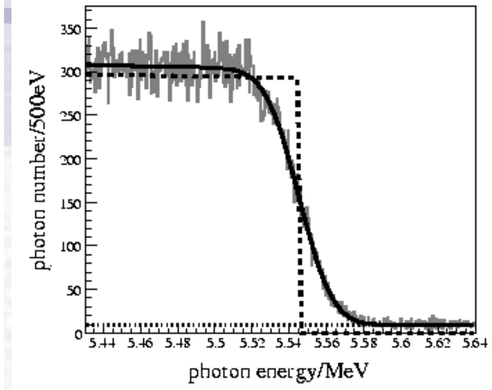
The BEMS plays an important role in the BES physics analysis and will play important role in the future

The BEMS also become a useful tool for the improvement of the running status of BEPCII

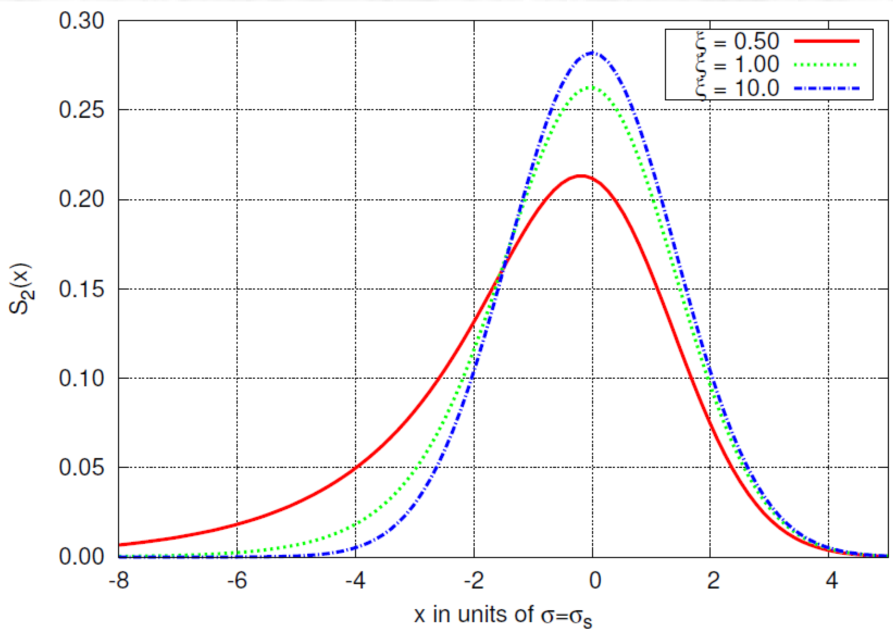
Thank you !

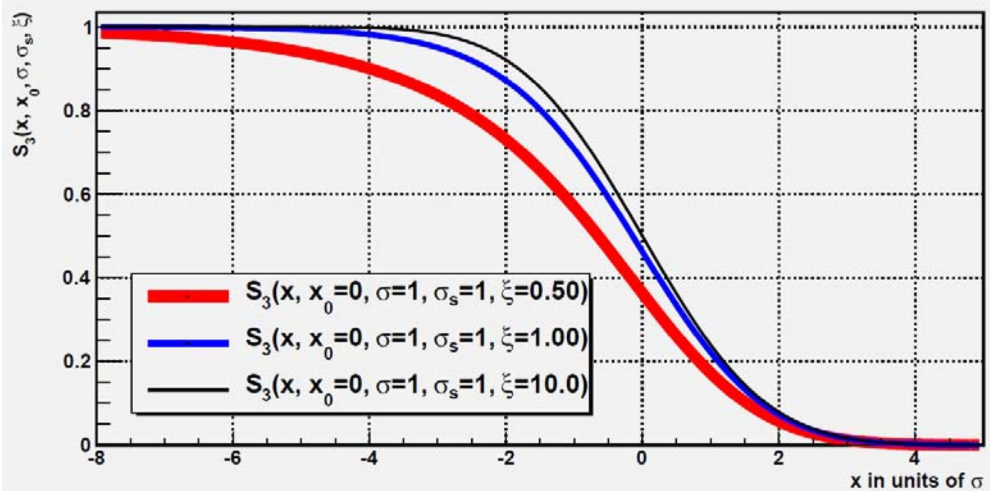
Backup





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





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

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

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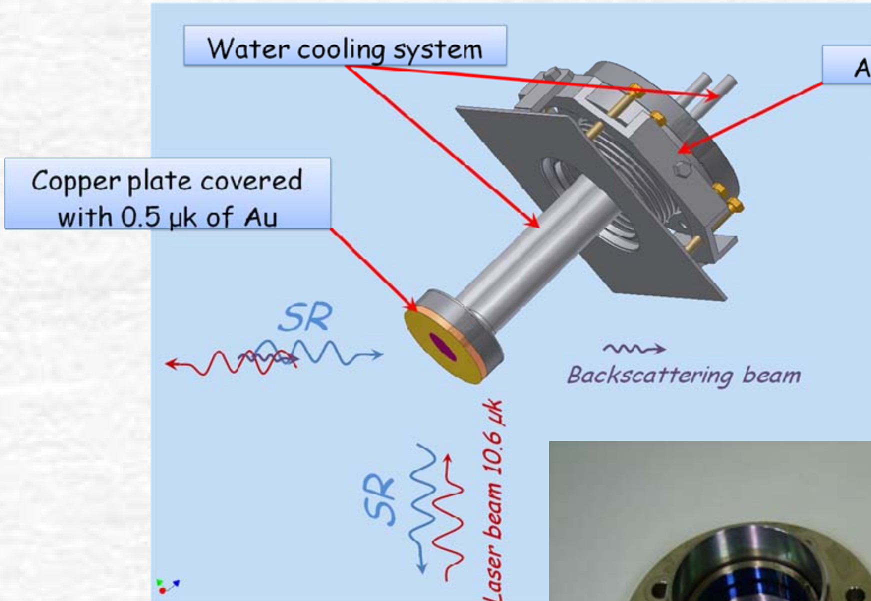
$$S_3(x, \sigma, \sigma_s, \xi) = \int_x^{+\infty} S_2(y)\, dy$$

Copper mirror and High vacuum GaAs viewport



The mirror is mounted to the support.

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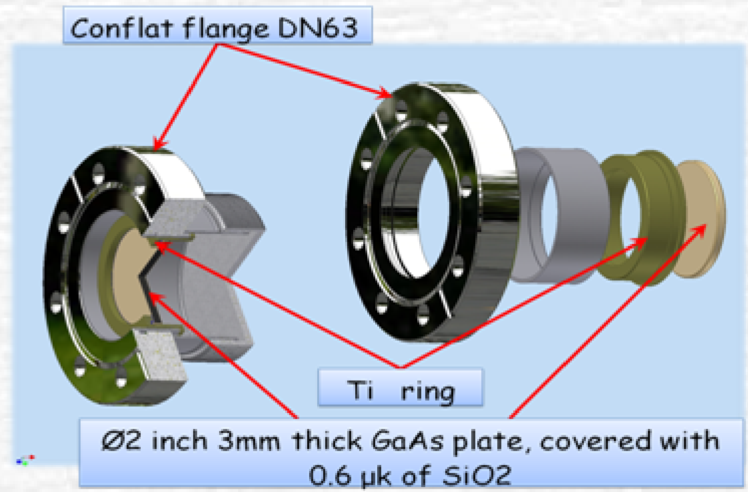
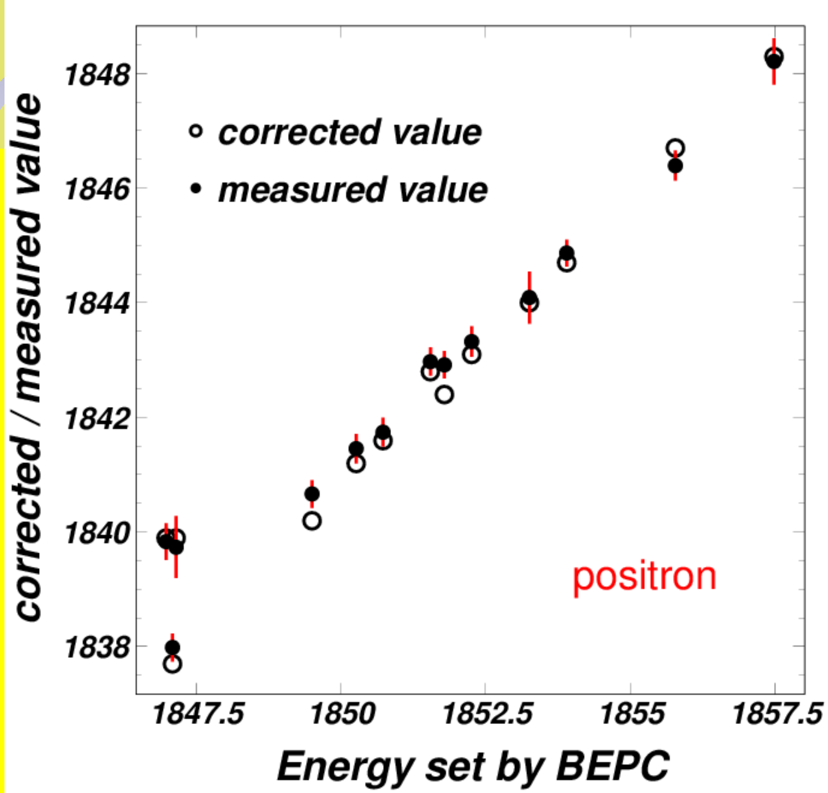
The SR is absorbed by the mirror. The extraction of heat is provided by the water cooling system.

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

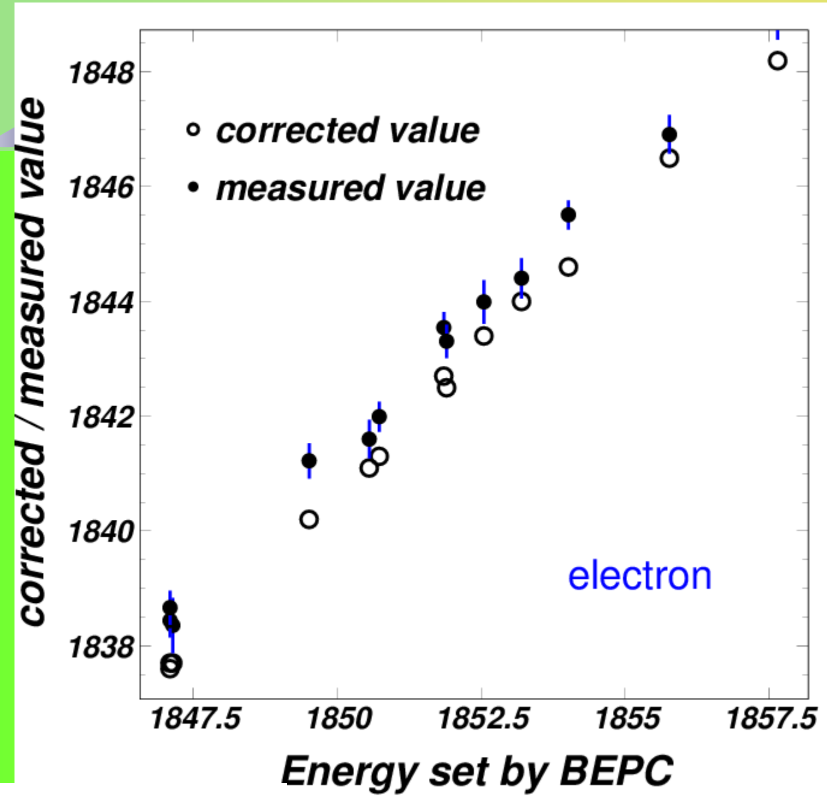


GaAs plate was covered with 0.6 μ m of SiO_2 and brazed with lead alloy to titanium ring. The titanium ring was brazed with *AgCu* alloy to the stainless steal ring. The steal ring was welded to stainless steel DN40 flange.

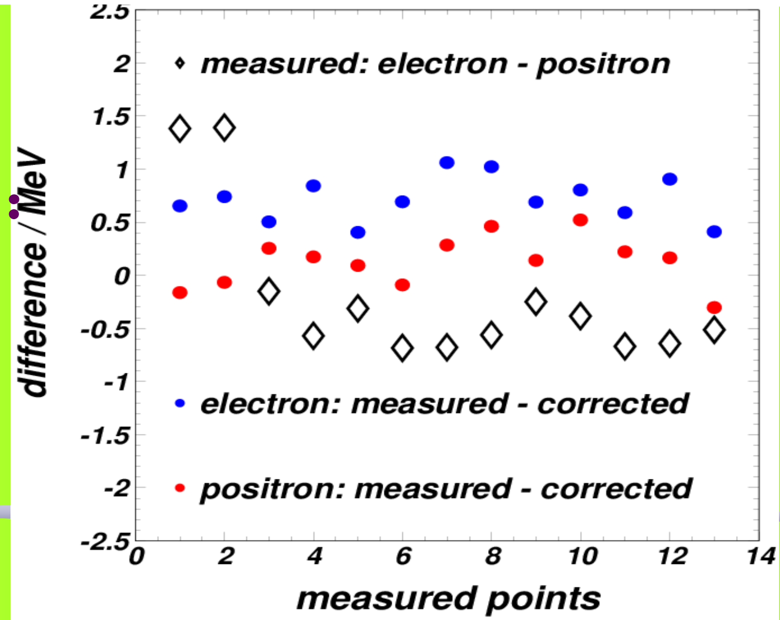
The viewport can be heated up to 250 ºC, has transparency ~66% at λ =10.6 μm .



Energy diff.

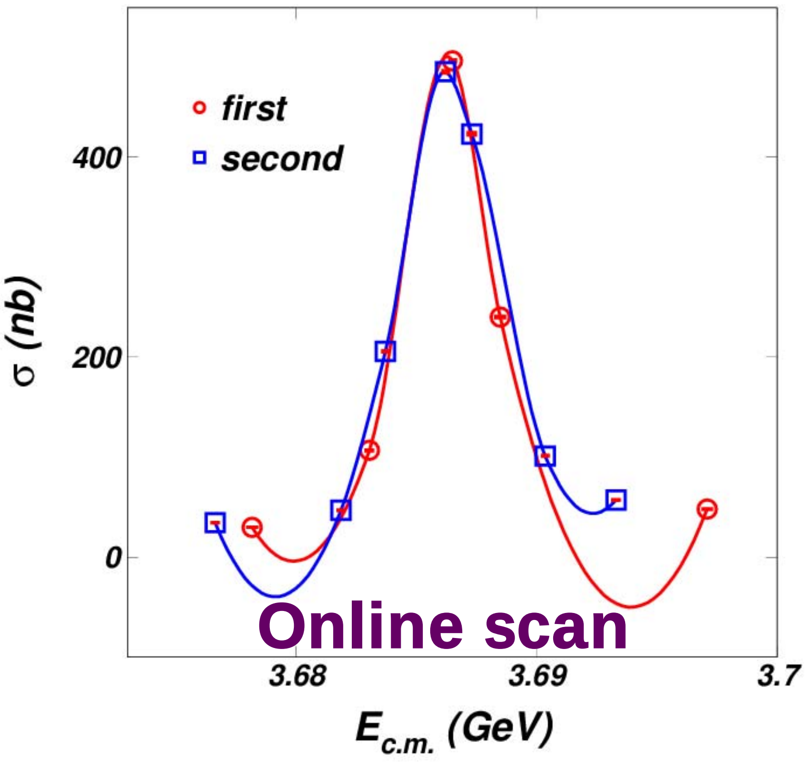


Corrected BEPCII:
Measured BEMS:

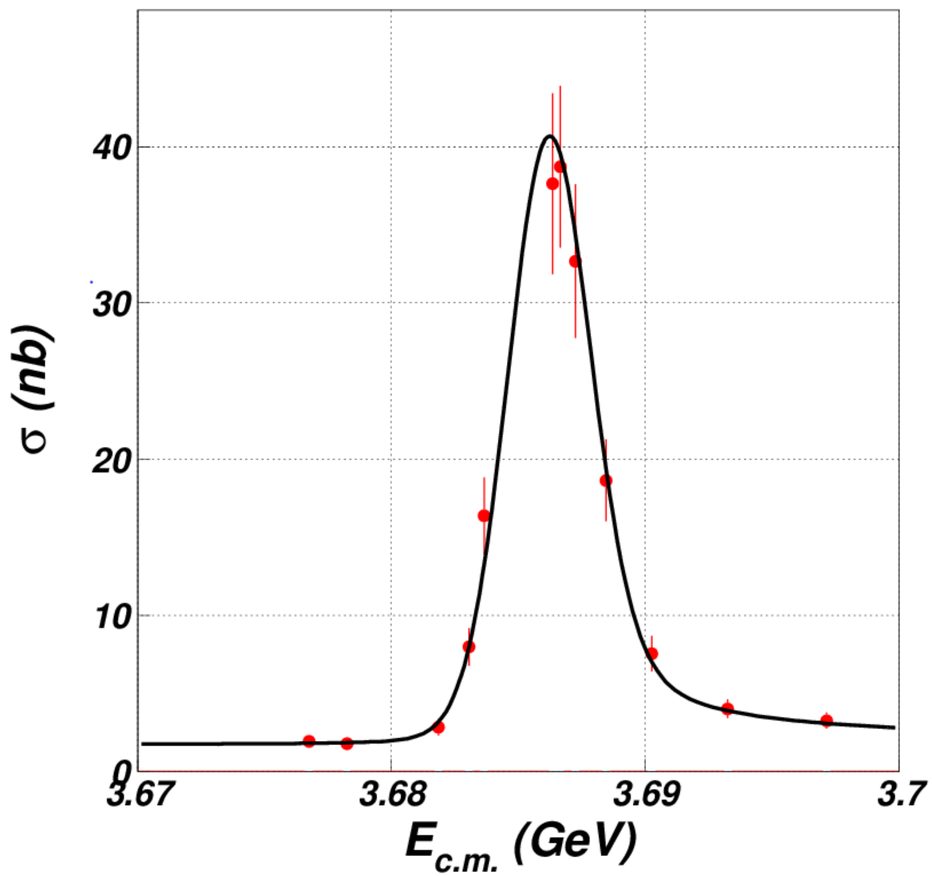


Energy error determined by BEMS is enlarged 3 times

Results of ψ(3686) scan by

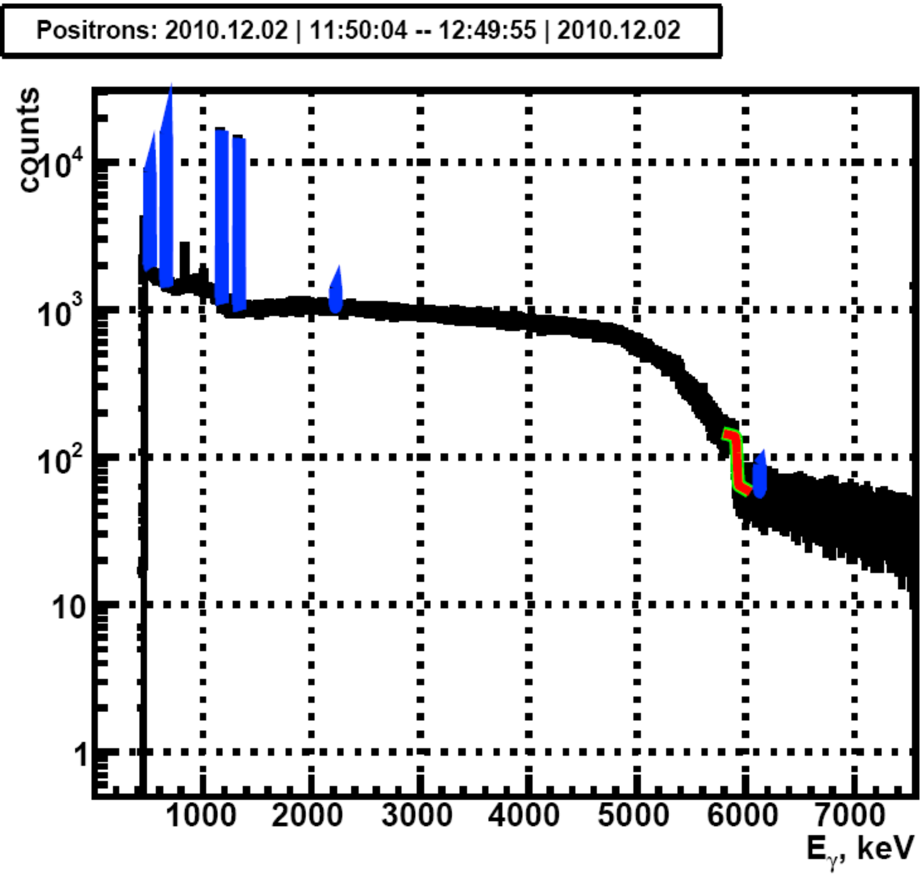


Offline fit:
3686.08 ± 0.02 MeV
PDG2010:
3686.09 ± 0.04 MeV



- ❖ 无效率修正;
- ❖ 截面含任意倍数因子;
- ❖ 统计误差放大十倍.

No.	Positron (MeV)	error (MeV)	relat. Err. (10^{-5})	Electron (MeV)	error (MeV)	relat. Err. (10^{-5})
1.	1839.740	0.180	9.784	1838.355	0.160	8.703
2.	1839.835	0.108	5.870	1838.443	0.098	5.331
3.	1841.455	0.086	4.670	1841.604	0.112	6.082
4.	1842.976	0.083	4.504	1843.545	0.092	4.990
5.	1844.095	0.151	8.188	1844.405	0.118	6.398
6.	1848.212	0.136	7.358	1848.895	0.112	6.058
7.	1837.987	0.081	4.407	1838.663	0.099	5.384
8.	1840.664	0.081	4.401	1841.224	0.103	5.594
9.	1841.742	0.084	4.561	1841.990	0.088	4.777
10.	1842.922	0.081	4.395	1843.305	0.096	5.208
11.	1843.324	0.088	4.774	1843.992	0.127	6.887
12.	1844.867	0.079	4.282	1845.508	0.086	4.660
13.	1846.398	0.087	4.712	1846.911	0.113	6.118

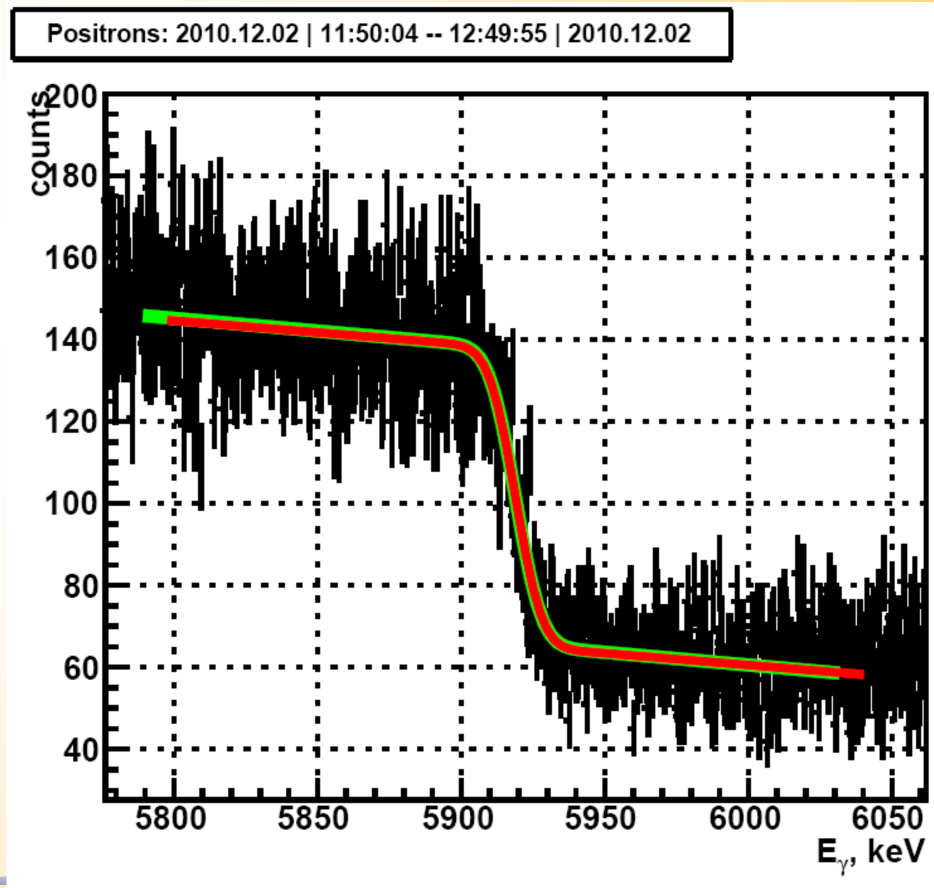


$E_{edge} = 5919.332 \pm 0.519$ keV

$\sigma_{E_{edge}} = 6.83 \pm 0.85$ keV

$E_{beam} = 1840.664 \pm 0.081$ MeV

$\sigma_{E_{beam}} = 1062.1 \pm 131.5$ keV



Uncertainty:

measured: 4.4×10^{-5}

designed: 5×10^{-5}

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

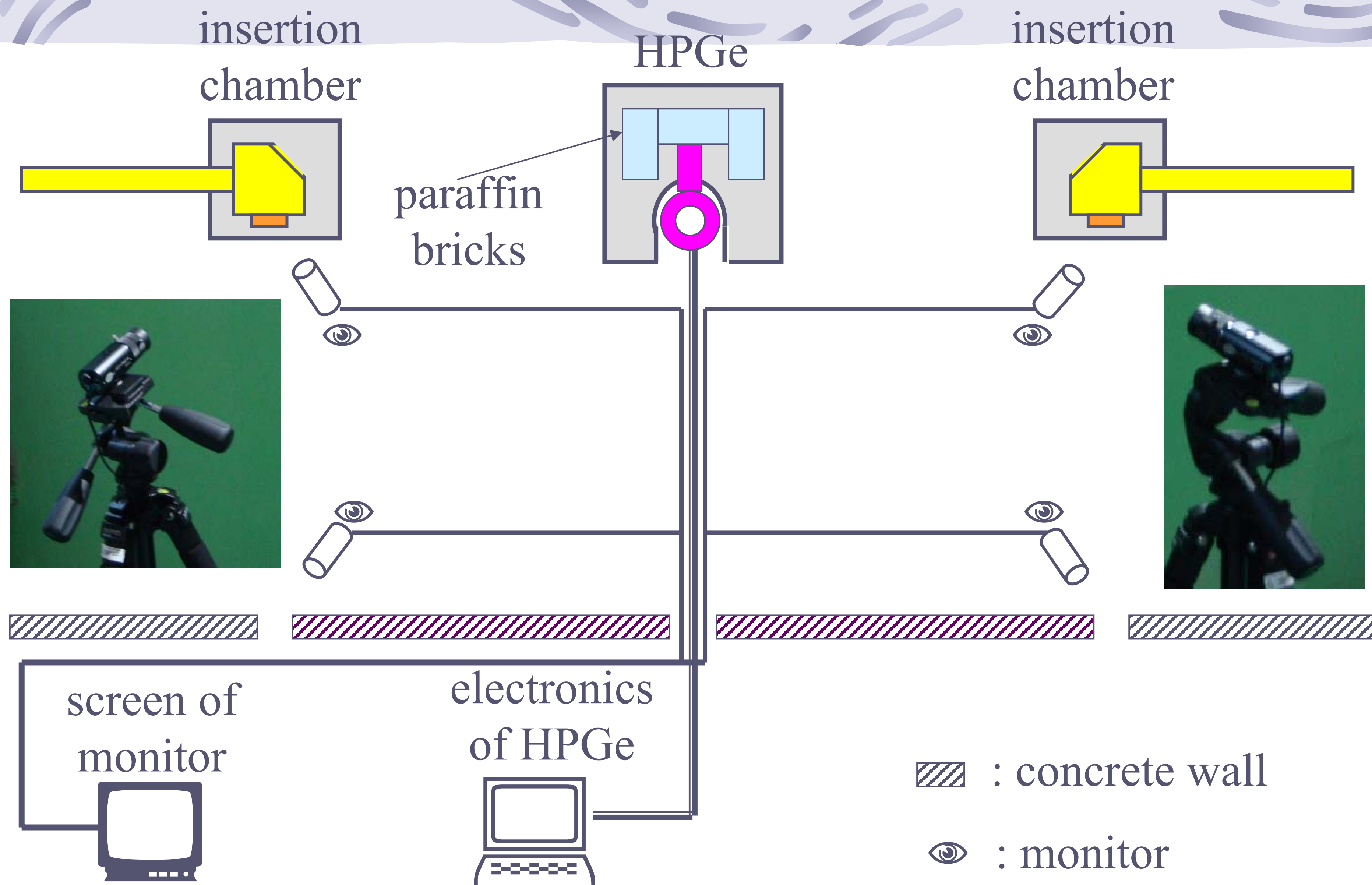
Laser system finished in 2010.1

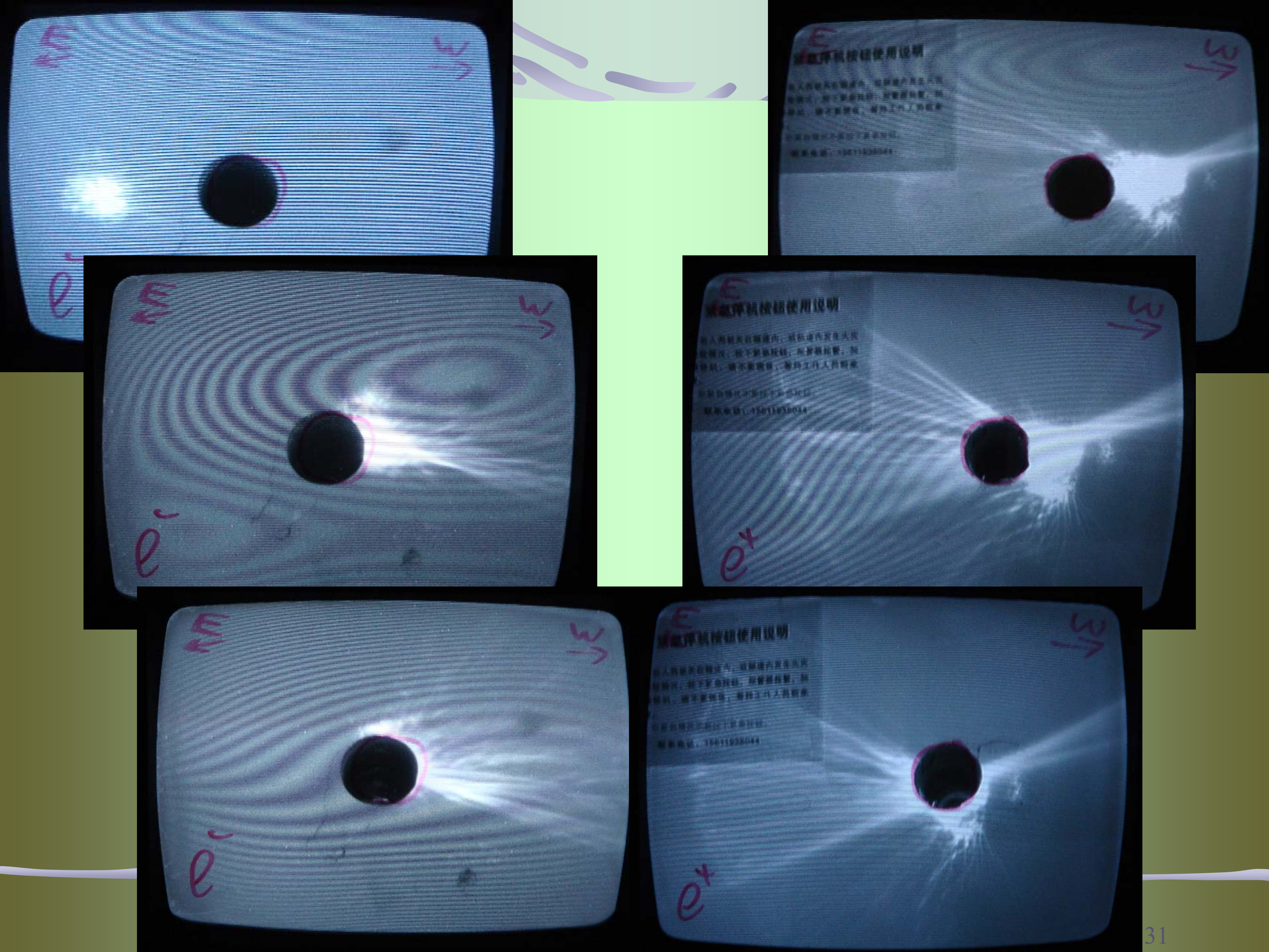
HPGe detector arrived in 2010.4

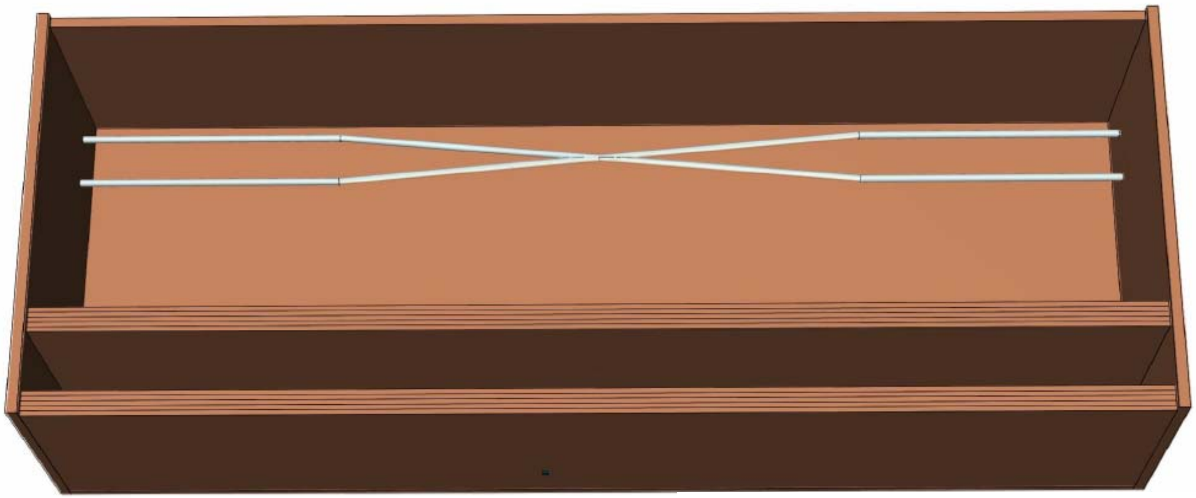
GaAs windows replacement finished in 2010.8

Laser alignment finished in 2010.9

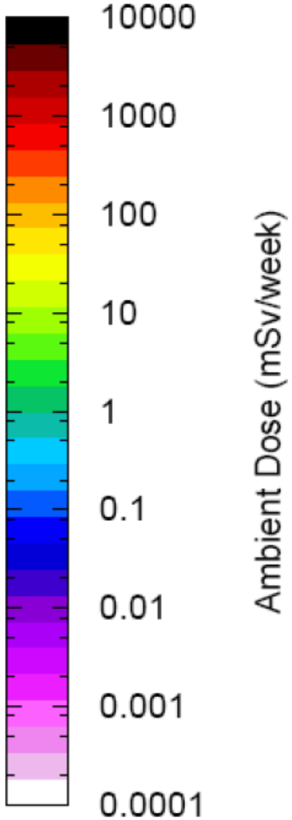
Total monitor system finished in 2010.9

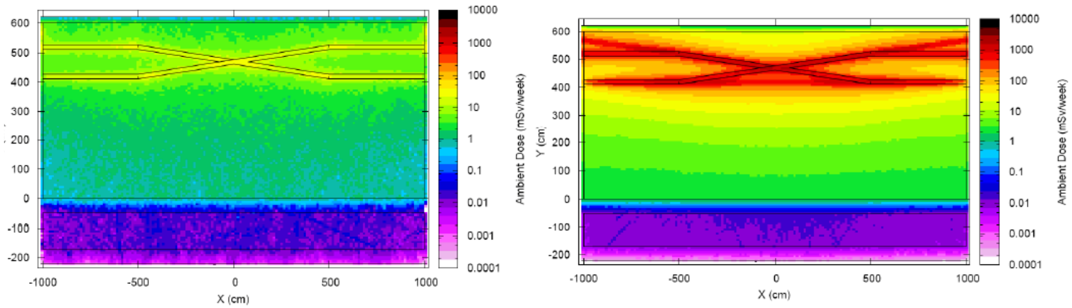

insertion chamber
HPGe
insertion chamber
paraffin bricks
screen of monitor
electronics of HPGe
: concrete wall
: monitor


E
W
e^-
e^+

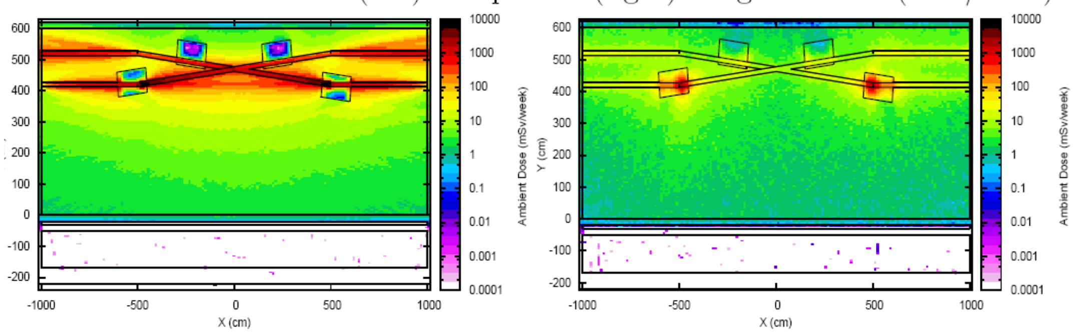


FULKA:
Construction geometry model of BEPCII north crossing point





Neutron (left) and photon (right) integrated dose (mSv/week).



Neutron (left) and photon (right) cumulative dose normalized to one week if magnets and point lose mechanism considered.

5-points scenario

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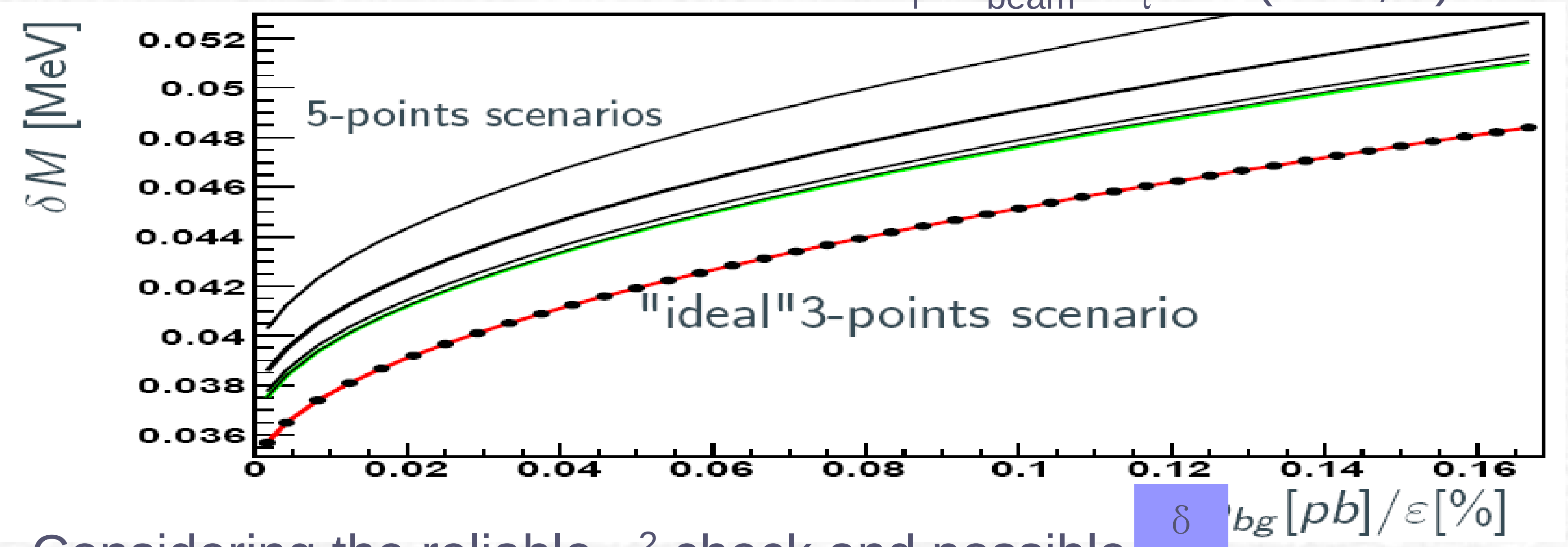
Energy points	ΔE_1	ΔE_2	ΔE_3	ΔE_4	ΔE_5
Energy value (MeV)	-5.	-0.325	-0.075	+3.5	+15
Luminosity(percent)	14	39	26	7	14

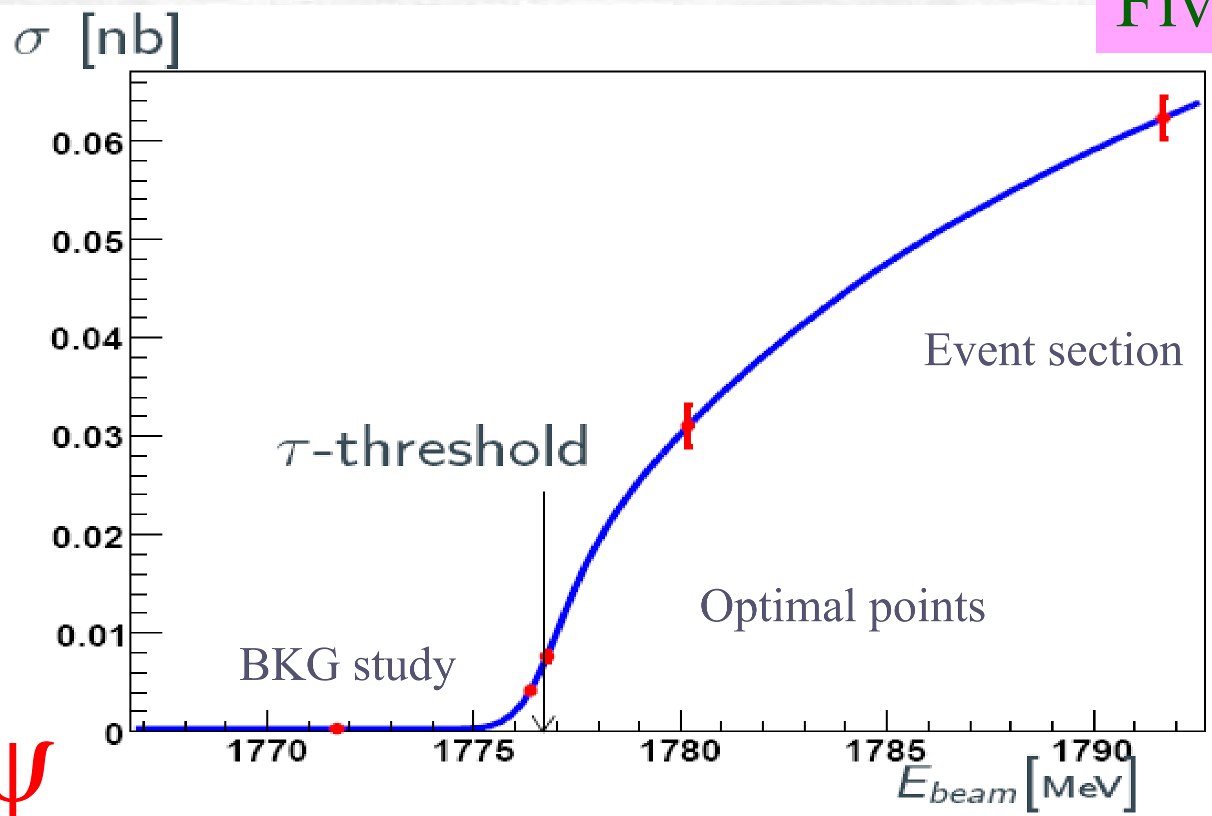
$\Delta E_i = E_{beam} - m_\tau^{PDG}$ (i = 1, 5)



Considering the reliable χ^2 check and possible efficiency and background variations

Data taking design

Five-points proposal



J/ψ

ψ′

Min. Luminosity requirement

J/ψ :1×10^{31}cm^{-1} s^{-1}

τ :1×10^{32} cm^{-1} s^{-1}

ψ′ :3×10^{32} cm^{-1} s^{-1}

① ② ③ ④ ⑤ ⑥ ⑦

⑧ ⑨ ⑩

Energy points for Mτ scan:

Mtau=1776.82 ± 0.16 MeV (PDG2010)

Ecm(MeV)= [J/ψ scan]; 3543.68, 3553.03, [3553.3], 3553.53, 3560.68, 3583.68; [ψ′ scan].

Ebeam(MeV)= [J/ψ scan]; 1771.84, 1776.52, [1776.65], 1776.77, 1780.34, 1791.84; [ψ′ scan].

Point order: [1,8]; 2, 3, [9], 4, 5, 6; [7,10].

12days, for τ mass scan; 2 days for J/ψ &ψ′ scan

Final uncertainty (sta. ⊕ sys.)< 100keV