The crystal Zero Degree Detector (cZDD) at BESIII

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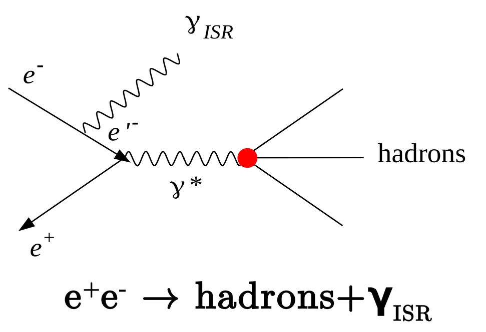
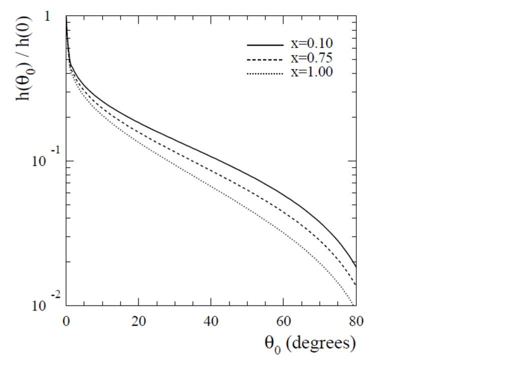
Physics motivation





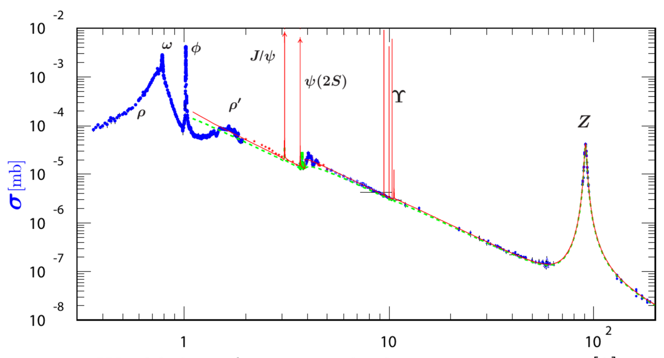
Relative probability to emit ISR within $\theta_0<\theta<180°-\theta_0$, for different fraction x of total energy carried by the ISR photon

- Measurements for **different effective center of mass s' at a fixed beam energy** possible
- Initial State Radiations (ISR) mainly emitted at **small polar angles** [1] → ~80 % emitted below θ=20°

- Input for calculations of [2]

  → running of the fine structure constant α_{QED}

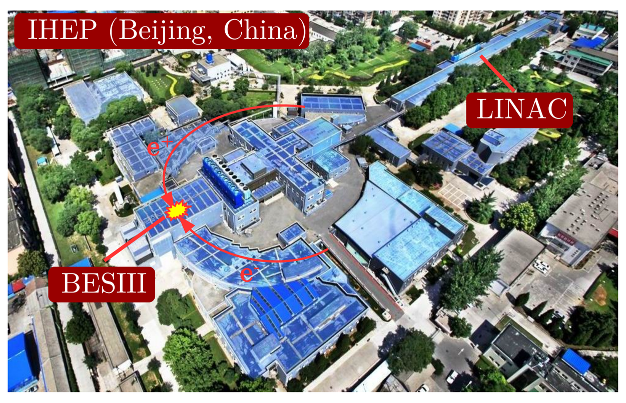
  → anomalous magnetic moment of the muon a_μ



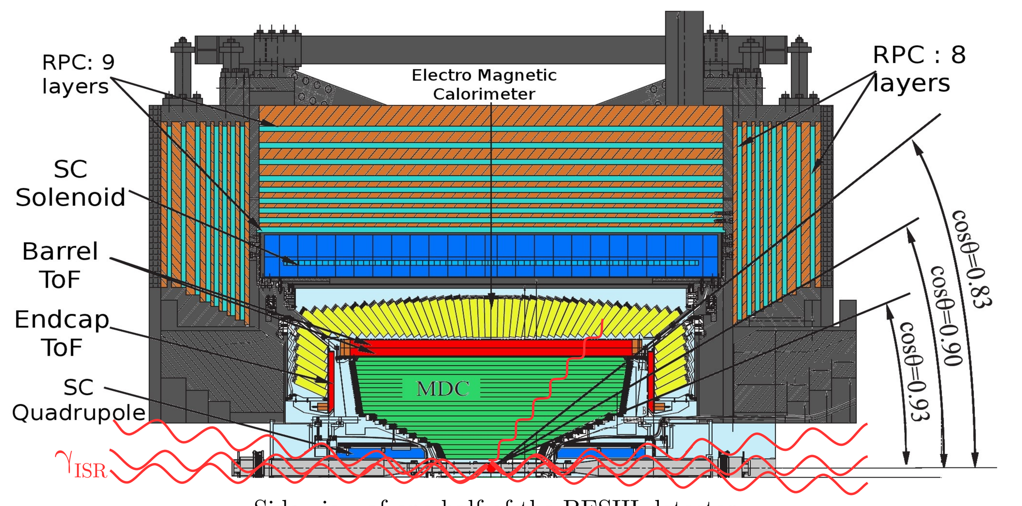
World data for $e^+e^- \to$ hadrons cross section [3]

- Neutron Form Factors ($e^+e^- \to n\bar{n}\gamma_{ISR}$)

The BESIII experiment



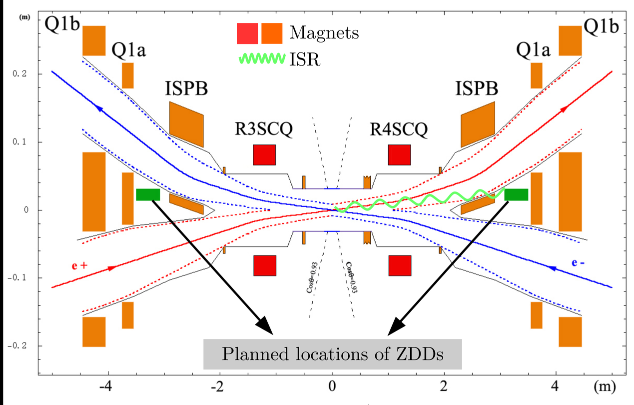
- BEPCII : Symmetric double ring, multi-bunch e^+e^- collider
- Center of mass energy = 2 - 4.6 GeV (Charm-τ) [4]
- Design luminosity achieved : 10^{33} cm^{-2}.s^{-1} at E_{CM}=3.773 GeV

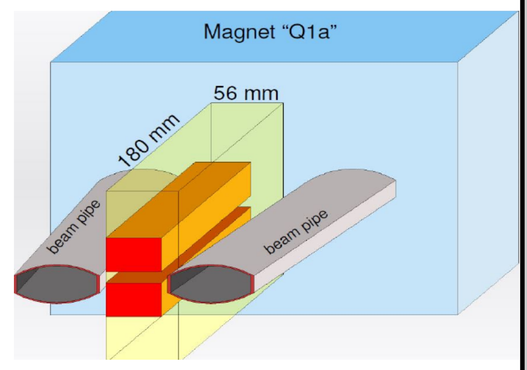


Side view of one half of the BESIII detector
MDC : Multilayer Drift Chamber, RPC : Resistive Plate Counter
SC : Superconducting Solenoid, ToF : Time of Flight

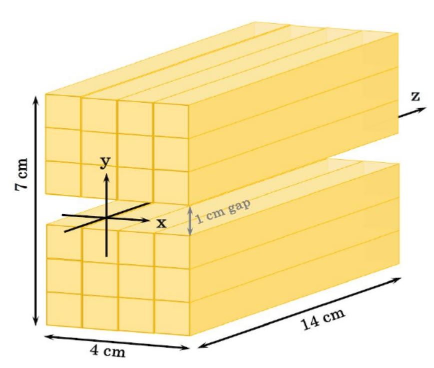
- Large fraction of **ISR outside of BESIII detection region** → Addition of **photon detectors** in the **beam pipe** region

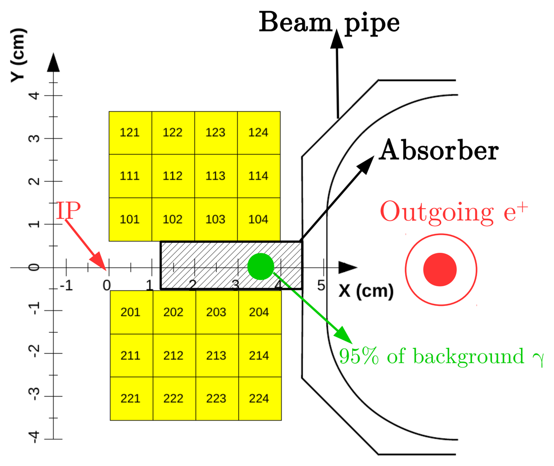
The cZDD



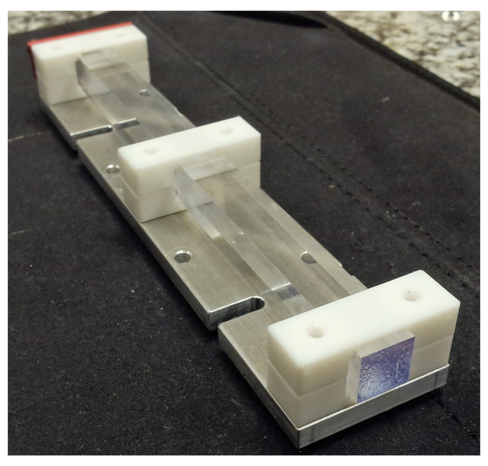


- Placed in the front/backward regions of BESIII, 335 cm away from the Interaction Point (IP)
- 2 blocks separated by a **1 cm gap** to limit background
- **Tungsten absorber** in the gap region to suppress background
- **24 LYSO crystals** (1x1x14 cm³ each)
- Each crystal readout by a **Silicon Photomultiplier.**
- **Data acquisition**: Waveform analyzing sampling ADC (**sADC**) to reduce data bandwidth and pile-up



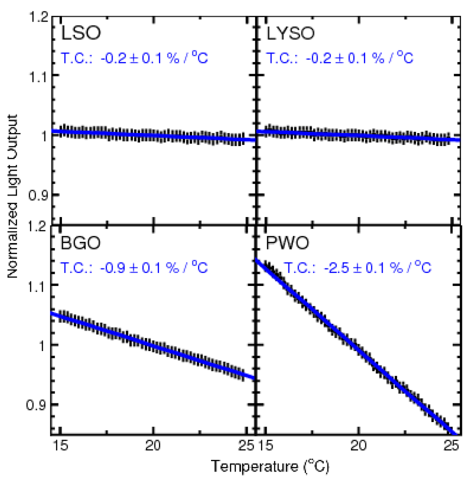


The LYSO crystal



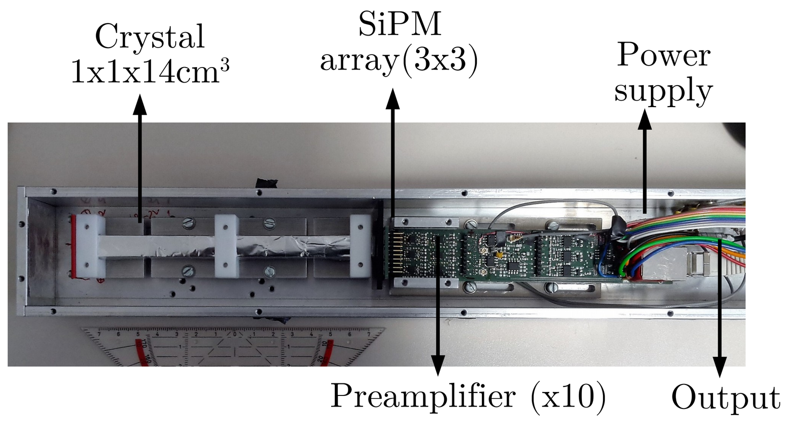
Density (g/cm³)	7.15
Radiation Length(cm)	1.16
Decay Constant (ns)	<47
Peak Emission (nm)	410
Light Yield (10³ ph/MeV)	24.7-28.5
Energy Resolution (%)	8.9
Molière Radius (cm)	2-2.2

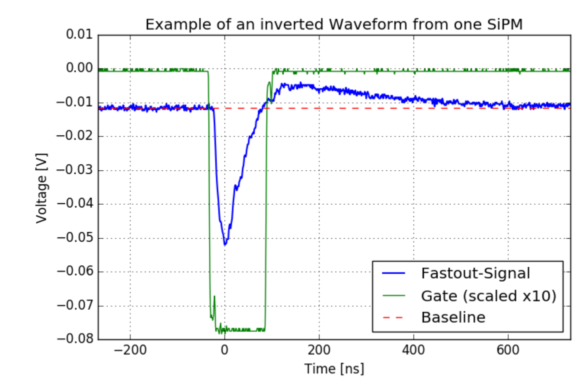
- $Lu_{1.8}Y_{0.2}SiO_5$:Ce (EQ Photonics)
- High density inorganic crystal → Short radiation length.
- Radiation hardness
- Short decay constant → Limits pile-up from scintillations
- High light-yield → Low gain readout can be used.
- Stable light-yield at ambient temperature → High temperatures expected
- Radioactive → Self-emission of scintillation light



Test with single crystal prototype [5]

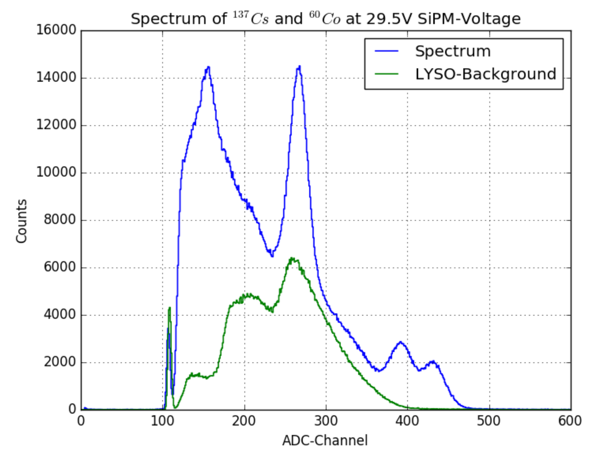
The test setup



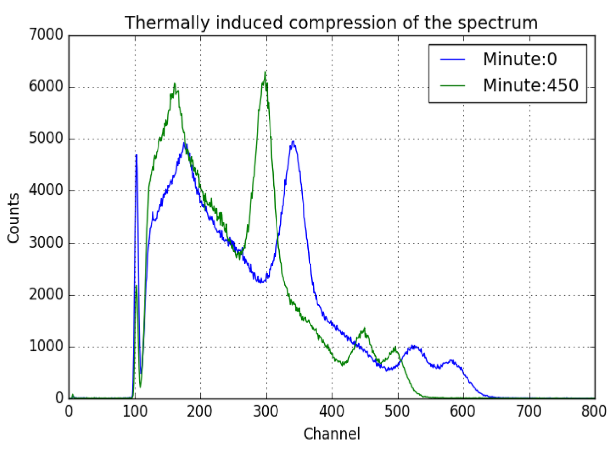


- Self-triggered acquisition by an ADC
- **Undershoot** of the fast out signal
  → Signal is partly integrated
  → Gate has to be adjusted
  → Baseline offset needed

Measurements with ^{137}Cs and ^{60}Co

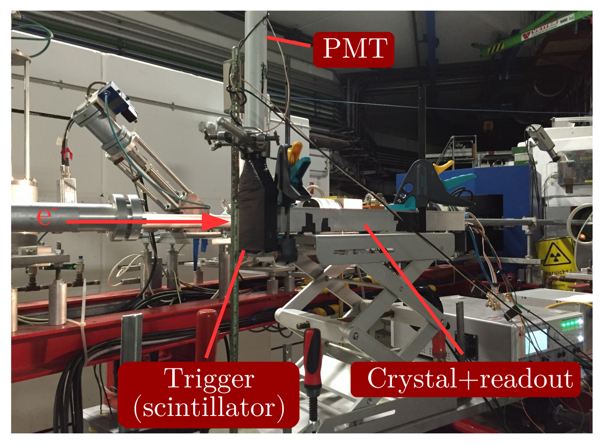


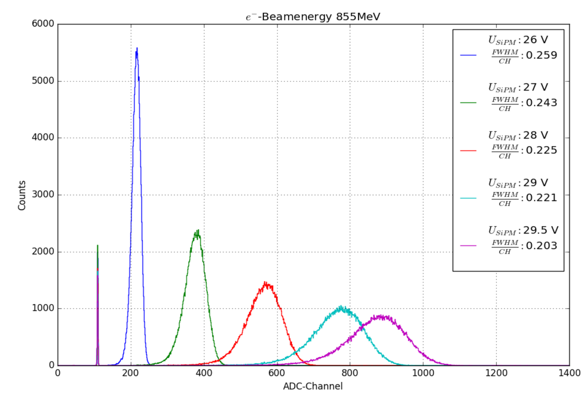
- ^{137}Cs and ^{60}Co peaks **clearly visible**
- Background from LYSO to be subtracted.



- Warm-up of the setup during measurements due to the readout board (T=25°C to 40°C)

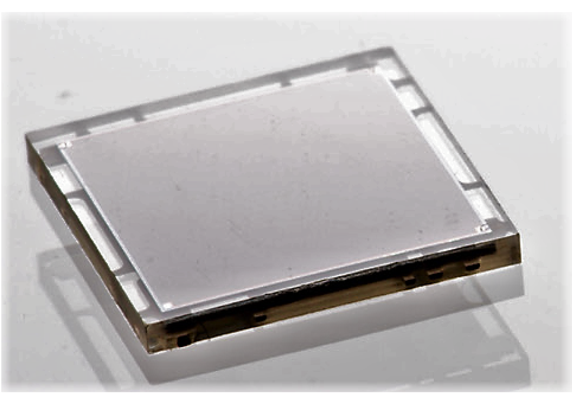
Beam test at MAMI facility

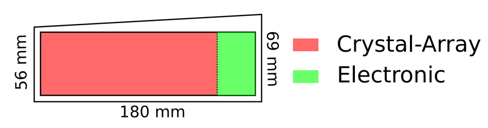




- Electron beam : f=1 kHz, E=195/855 MeV
- Relative resolution improved with higher SiPM voltage

Silicon Photomultipliers (SiPMs)

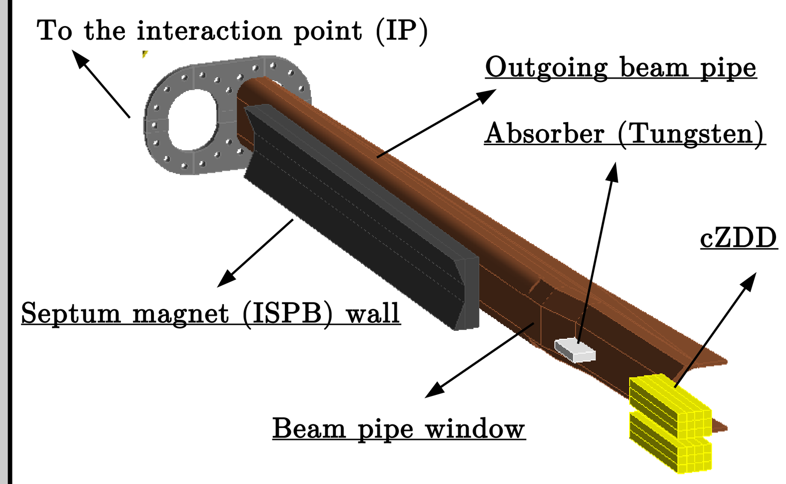




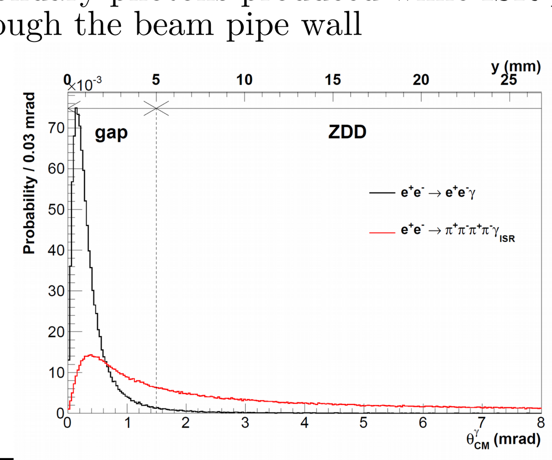
- SiPM used : SensL C series
- Advantages of SiPMs :
  → Compact
  → Insensitive to magnetic field
- Two outputs with different pulse width :
  → Slow (FHWM~200 ns)
  → Fast (FWHM~3 ns)

Sensor Size (mm²)	6x6
Breakdown Voltage U_{br} (V)	24.2-24.7
Recommend overvoltage (V)	1.0-5.0
Peak Wavelength (nm)	420
No. of pixels	18980
Gain (Fast Output) at U_{br} + 2.5V	4.3x10⁶

Simulations

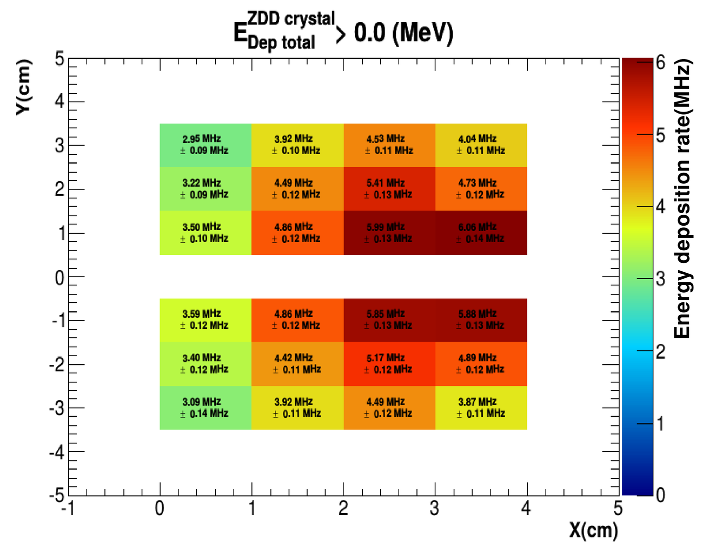


- Geant4-based simulation of BESIII and the two beam pipes region.
- Simulation of cZDD includes geometry, propagation of the scintillation light and digitization of the signal [6].
- ISR photons pass from IP to the ZDD through the beam window.
- Secondary photons produced while ISR passes through the beam pipe wall



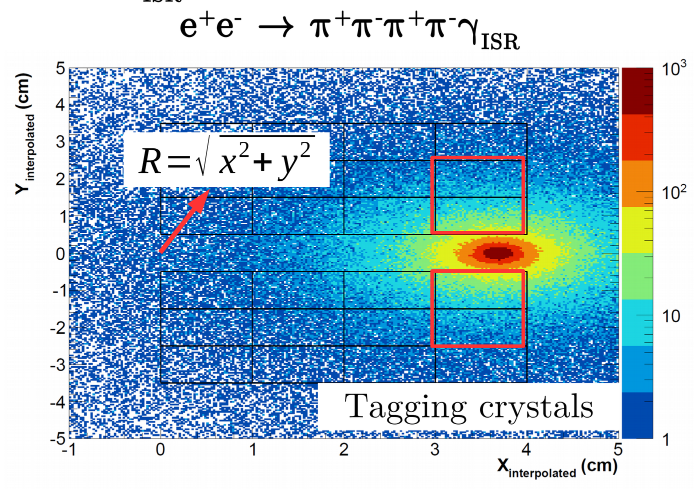
$e^+e^- \to e^+e^-\gamma$ background study

- Main contributing background at low polar angle
- σ=440 mb (E_{CM}=3.773 GeV, E_γ>50MeV) [7]

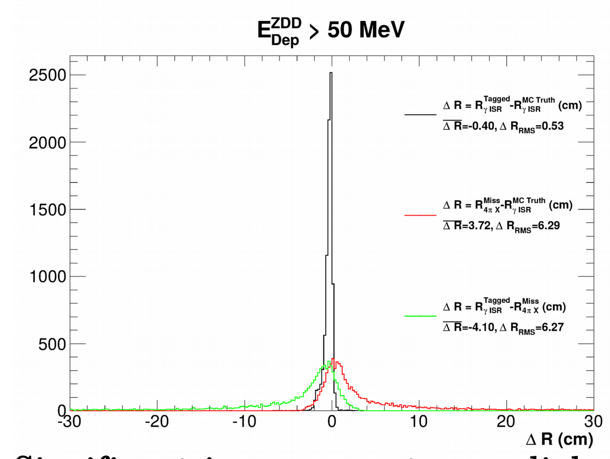


- The gap limits radiative Bhabha ($e^+e^-\to e^+e^-\gamma$)
  → More than 95 % background γ in the gap.
- Maximal energy deposition rate in one crystal :
  → Without absorber :
  f_{max}=20 MHz
  → With absorber :
  f_{max}=6 MHz < 1/$\tau_{Scintillation}$~25 MHz

γ_{ISR} hit reconstruction in $e^+e^- \to \pi^+\pi^-\pi^+\pi^-\gamma_{ISR}$



True angular distribution of γ_{ISR} at ZDD



- **Significant improvement on radial position** with tagged photon over the missing 4 vector.

Summary and outlooks

- Improvement on ISR coverage
- Significant improvement on the resolution of ISR kinematics
- Beam pipe materials limits the tagging coverage
- Test of the prototype with full DAQ chain using high intensity photon beam at MAMI A2

References

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