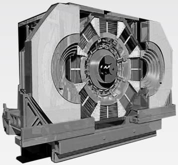
ZDD at BESIII

R. Baldini Ferroli and A. Zallo

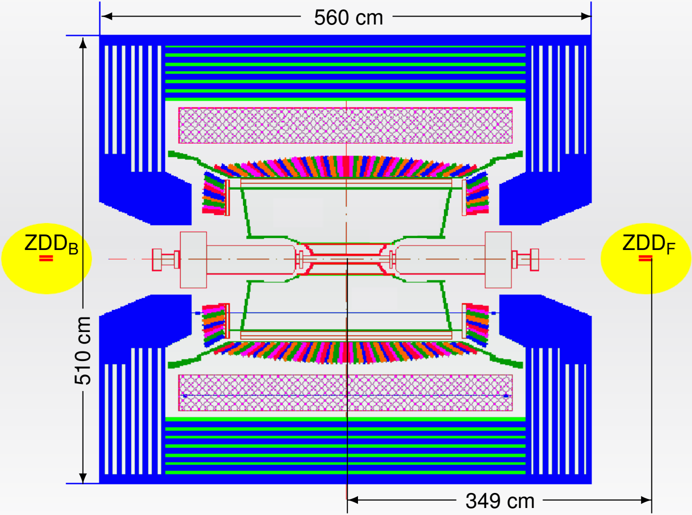
for the Italian BESIII Group



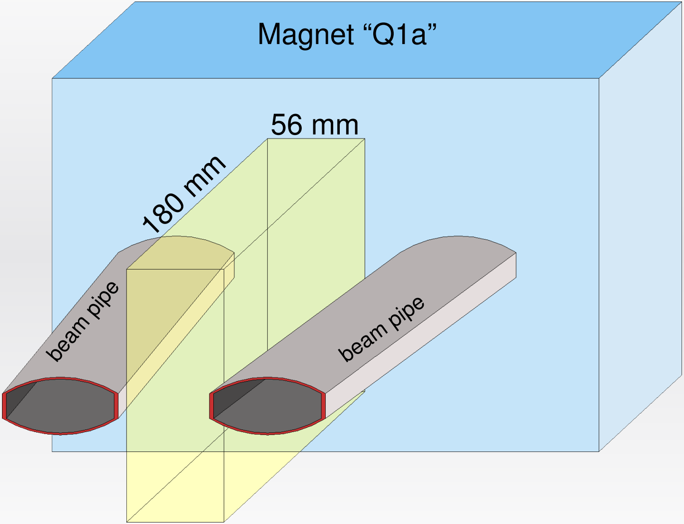
December 17, 2010 - Giessen, Germany

Design and Installation

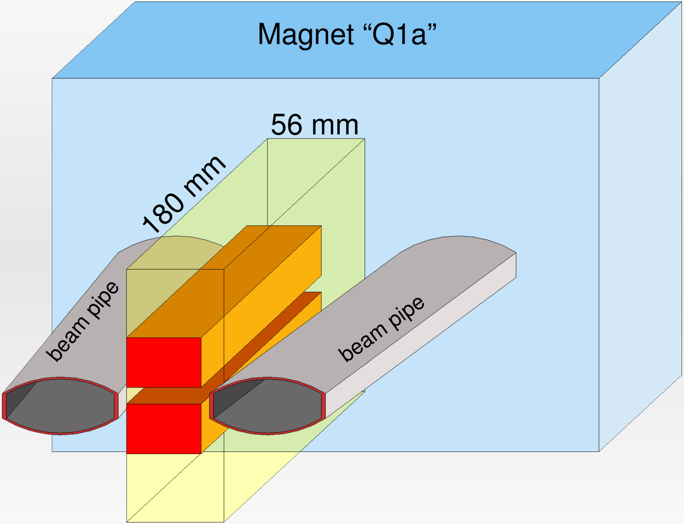
BESIII and ZDD



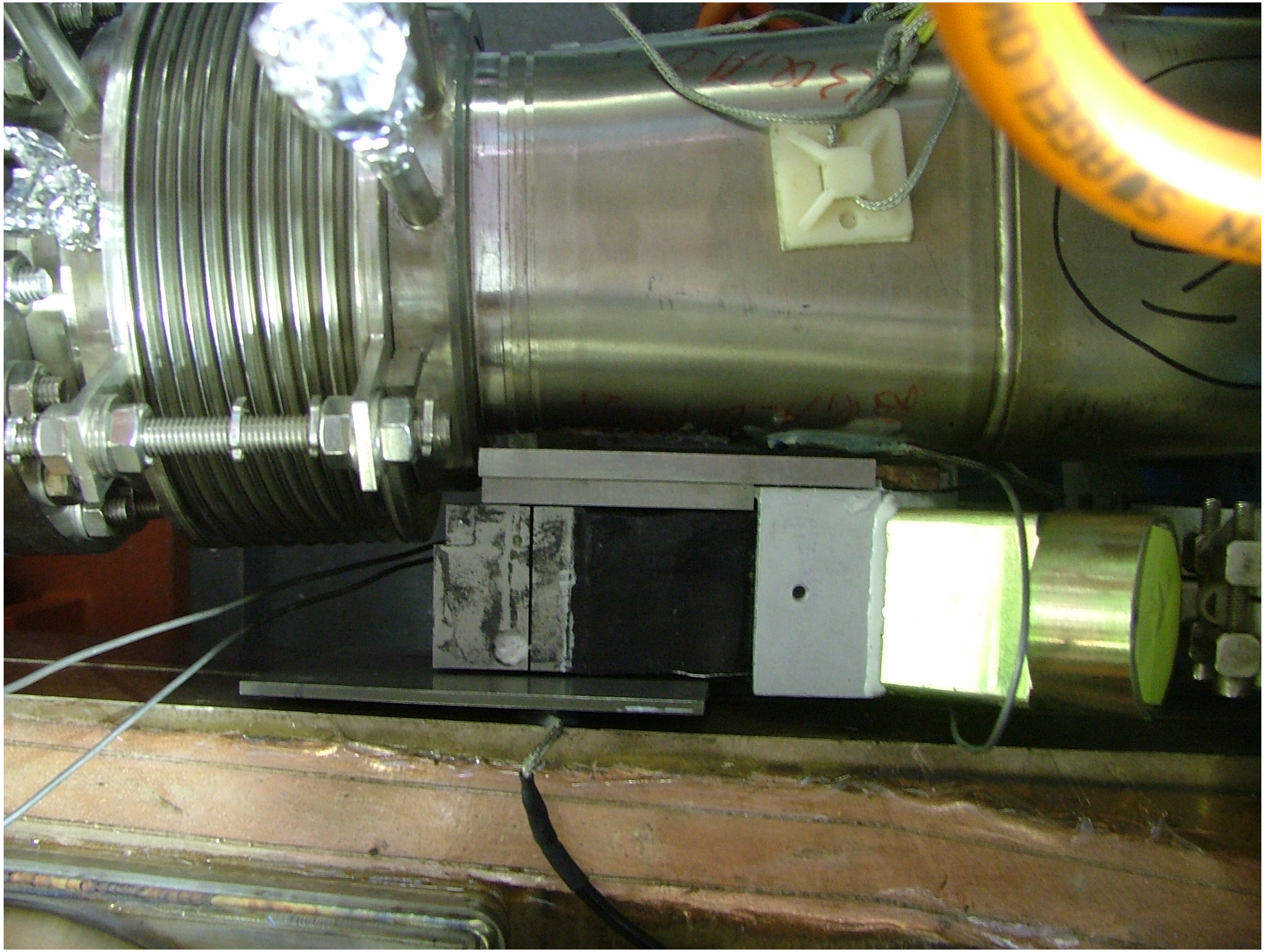
Available space



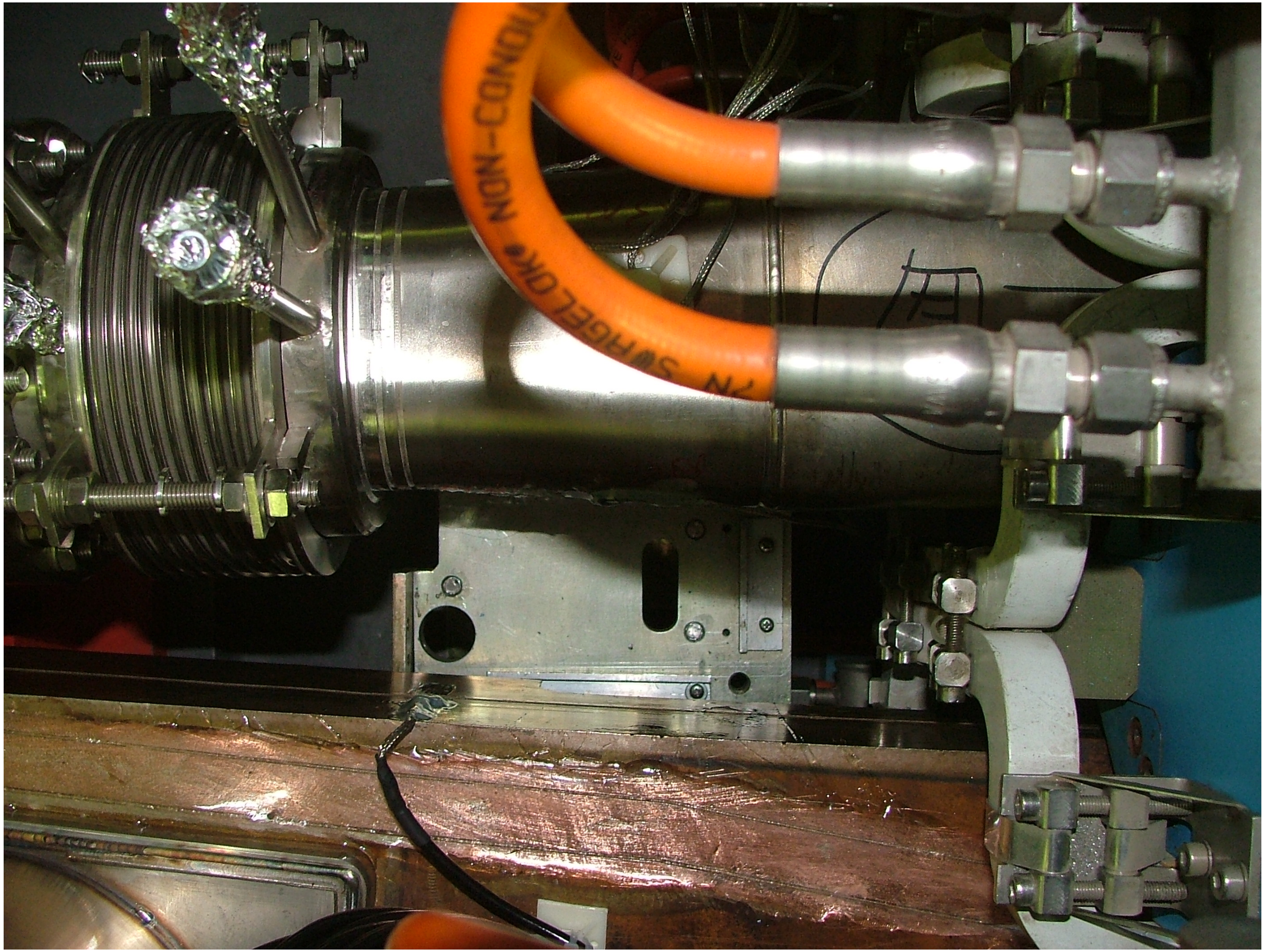
Available space



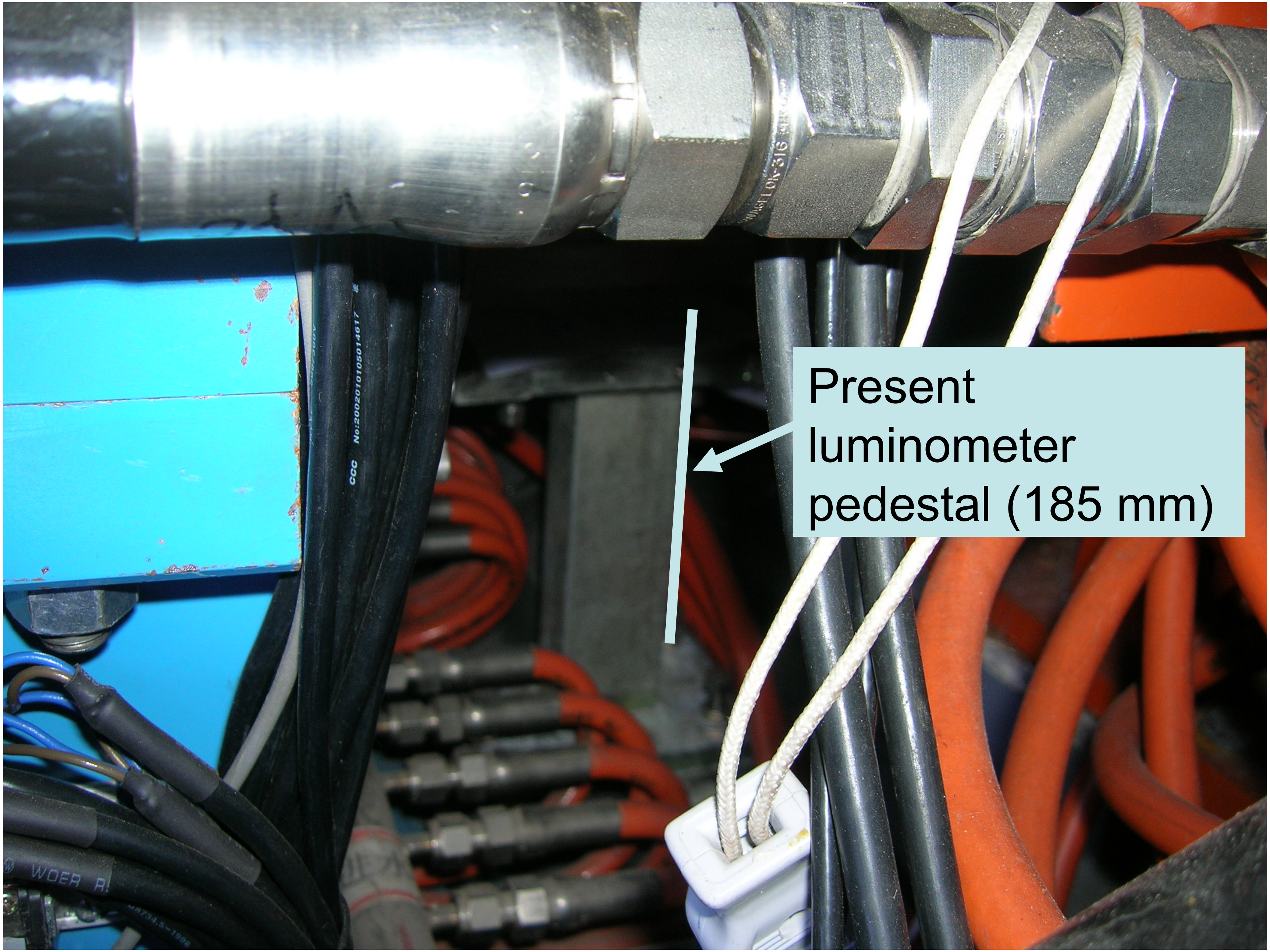
BESIII Lumi detector



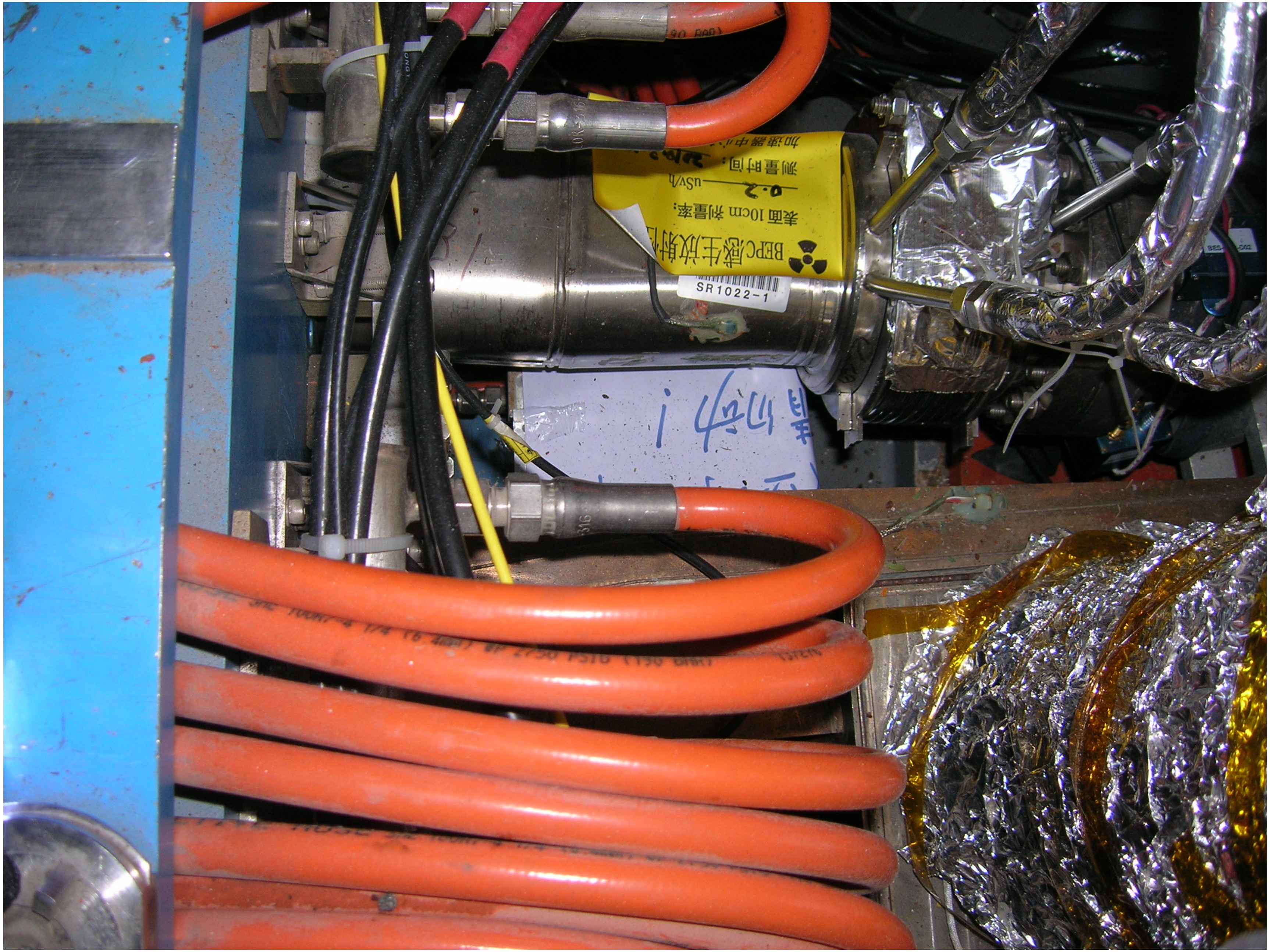
BESIII Lumi detector



August survey of the region, no Lumi detector

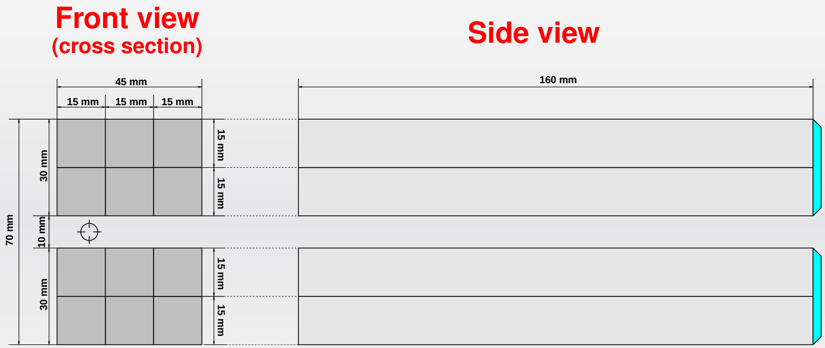


August survey of the region, no Lumi detector, top view



Two options:
LYSO and Pb-Scint

LYSO design

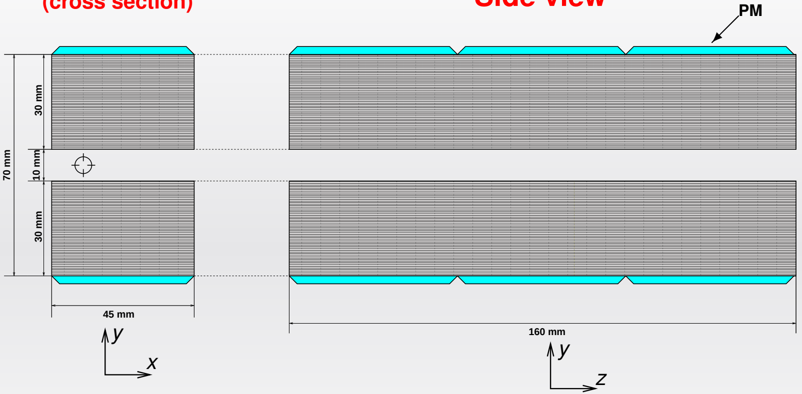


- Two 3×2 matrices of $1.5 \times 1.5 \times 16$ cm^3 of LYSO bars
- Total volume 864 cm^3

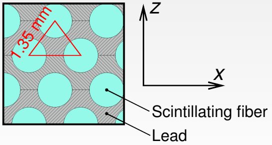
Pb-Scintillator design à la Kloe

Front view
(cross section)

Side view



- Along *z* axis:
  320 grooved 0.5 mm thick lead foils
  alternated with layers of cladded
  1 mm diameter scintillating fibers
- Readout with PM



Physical properties of materials

Material	LYSO	Pb-Scint
Density (g/cm^3)	7.4	5.3
Radiation Length (cm)	1.1	1.6
Molière Radius (cm)	1.9	2.9
Decay Constant (ns)	40-44	2.4
Peak Emission (nm)	428	460
Radiation Hardness (rad)	$\sim 10^8$	$\sim 10^6$

Radiation hardness

- Radiation damages mostly due to Bremsstrahlung: $\sigma_{\text{Bre}}(\text{ZDD}/4) = 2.6$ mb
- One year of data taking: $T = 1.5 \times 10^7$ s
- Average luminosity: $\overline{\mathcal{L}} = 1.5 \times 10^{32}$ cm^{-2}s^{-1}
- Center of mass energy: $E_{c.m.} = 3.77$ GeV

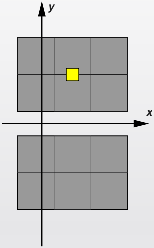
$$\frac{\text{Dose absorbed}}{\text{year}} = \frac{\text{energy deposited}}{\text{year} \cdot \text{mass}} = \begin{cases} \dfrac{3\times 10^{21}\ \text{eV}}{0.12\ \text{kg}} = 4\times 10^5\ \dfrac{\text{rad}}{\text{year}} & \text{LYSO} \\ \dfrac{3\times 10^{21}\cdot \frac{2}{13}\ \text{eV}}{1.8\times 10^{-2}\ \text{kg}} = 10^6\ \dfrac{\text{rad}}{\text{year}} & \text{Scint} \end{cases}$$

Declared hardness

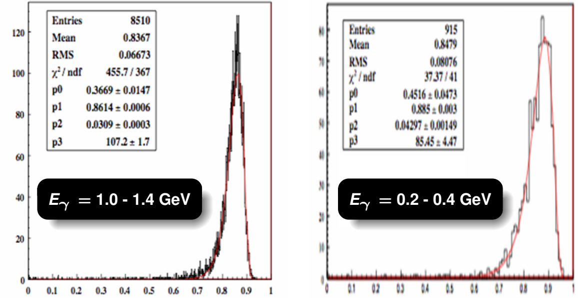
- LYSO $\sim 10^8$ rad
- Scint. $\sim 10^6$ rad

Energy Resolution

LYSO GEANT4 simulation$_1$



Deposited energy/E_γ

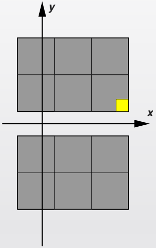


Log-normal distribution

$$\frac{df}{dE} = \frac{\eta}{\sqrt{2\pi}\sigma_E\sigma_0} e^{-\frac{1}{2}\left[\frac{\ln^2\left(1-\frac{\eta(E-E_0)}{\sigma_E}\right)}{\sigma_0^2}+\sigma_0^2\right]}$$

$$\sigma_0 = \frac{2}{2.35}\ln\left[\eta\frac{2.35}{2}+\sqrt{1+\left(\eta\frac{2.35}{2}\right)^2}\right], \quad \sigma_E = \frac{\text{FWHM}}{2.35}$$

E_γ (GeV)	$\sigma_{E_\gamma}/E_\gamma$ Central (yellow square)
1.0 - 1.4	3.6%
0.2 - 0.4	4.9%



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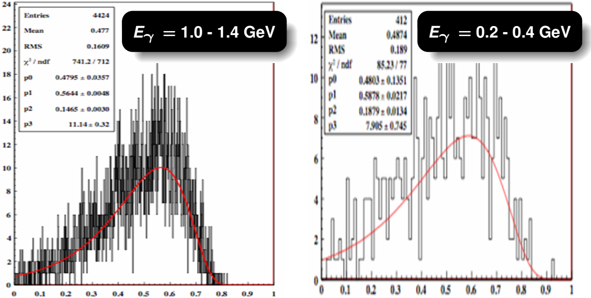
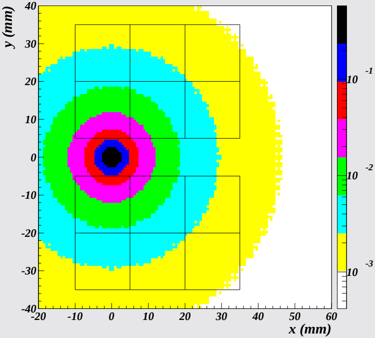


E_γ (GeV)	$\sigma_{E_\gamma}/E_\gamma$ Central (yellow square)
1.0 - 1.4	26.0%
0.2 - 0.4	32.0%

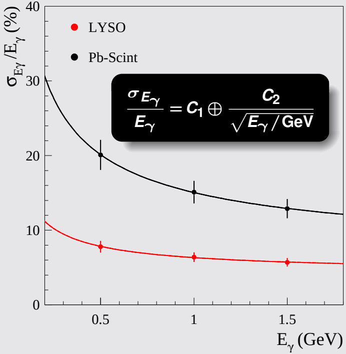
Energy resolution, the ISR case

ISR angular distribution on ZDD



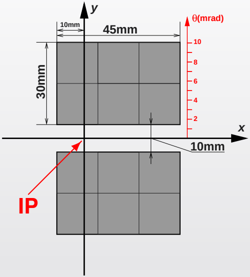
E_γ (GeV)	LYSO $\sigma_{E_\gamma}/E_\gamma$	Pb-Scint $\sigma_{E_\gamma}/E_\gamma$
1.5	5.7%	12.9 %
1.0	6.4%	15.1 %
0.5	7.8%	20.1 %

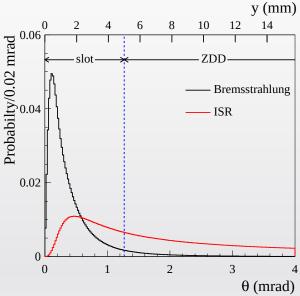
Energy resolution for ISR



	LYSO	Pb-Scint
C_1	4.3%	6.9 %
C_2	4.6%	13.4 %

Bremsstrahlung simulation





- $E_{\rm beam} = 1.89$ GeV
- $E_\gamma^{\rm min} = 50$ MeV
- $\sigma_{\rm Bre}(4\pi) = 353$ mb
- $\sigma_{\rm Bre}(\rm ZDD) = 10$ mb
- $\mathcal{L} = 8 \times 10^{32}$ cm^{-2} s^{-1}

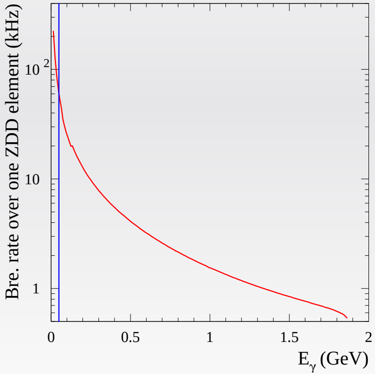
- ISR in ZDD 13.7% of total solid angle
- Bremsstrahlung in ZDD 2.8% of total solid angle
- Bremsstrahlung rate in a single ZDD element (upper or lower):

800 kHz at $\mathcal{L} = 3 \times 10^{32}$ cm^{-2} s^{-1}
2.1 MHz at $\mathcal{L} = 8 \times 10^{32}$ cm^{-2} s^{-1}

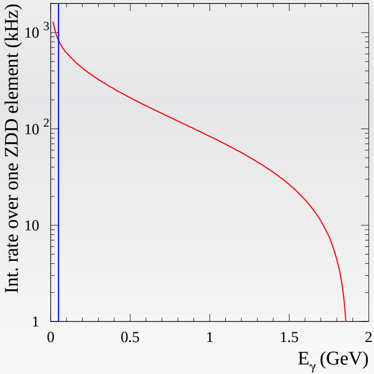
Bremsstrahlung rate

$$\mathcal{L} = 3 \times 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

Bremsstrahlung rate in 10 MeV E_γ intervals



Integrated Bremsstrahlung rate

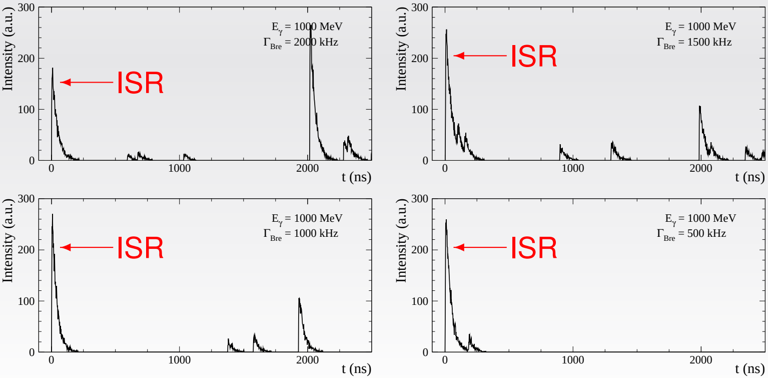


Maximum Bremsstrahlung rate expected 2.1 MHz (ZDD/4)

- Flash ADC: 500 MS/s, 8-bit resolution
- LYSO signal:

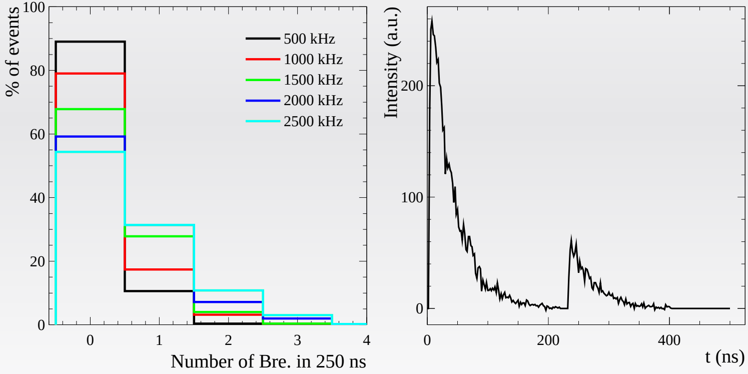
$$\text{Intensity} = e^{-t/\tau_d}(1 - e^{-t/\tau_r})$$

rising time $\tau_r = 2$ ns, decay time $\tau_d = 40$ ns



Pileup effect$_2$: probability

Probability of pileup
as a function of the Bremsstrahlung rate



Pileup effect$_2$: probability

**Probability of pileup
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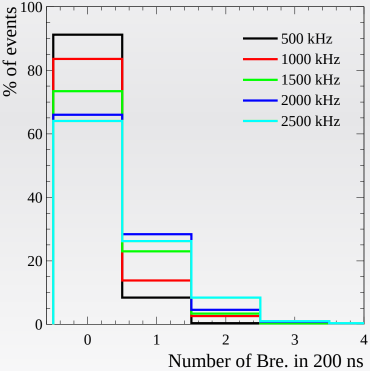
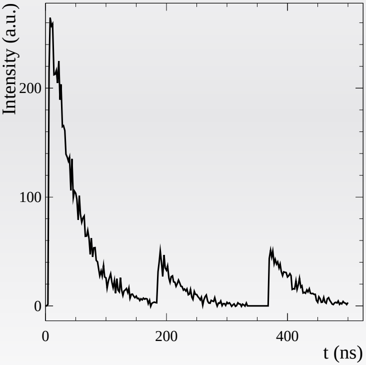
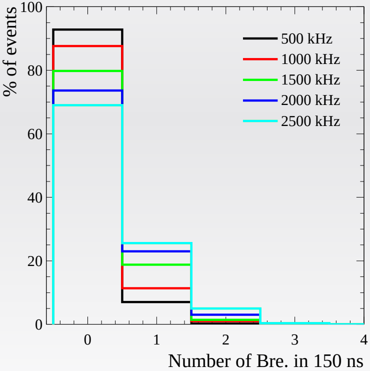
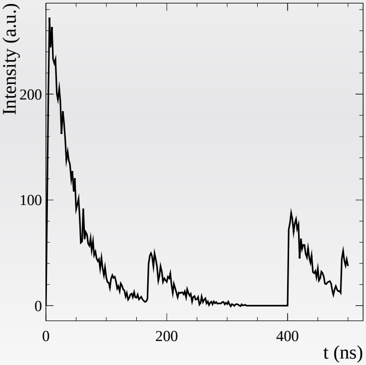




Probability of pileup as a function of the Bremsstrahlung rate





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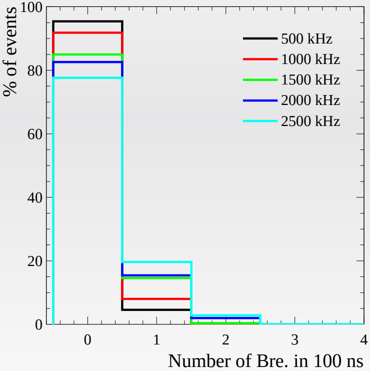

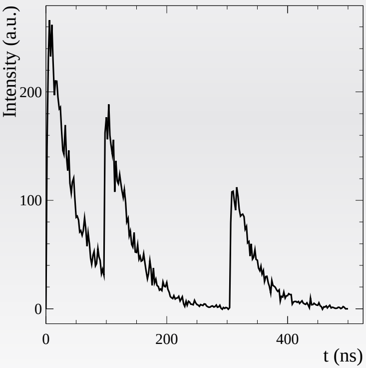

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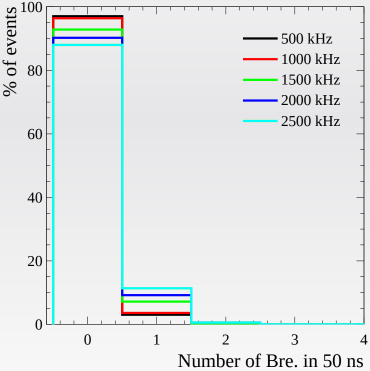
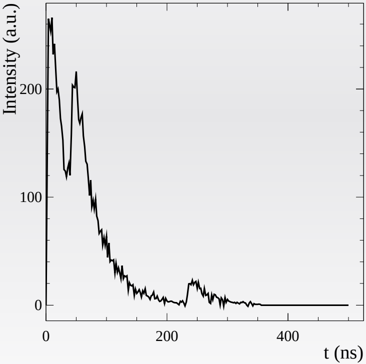
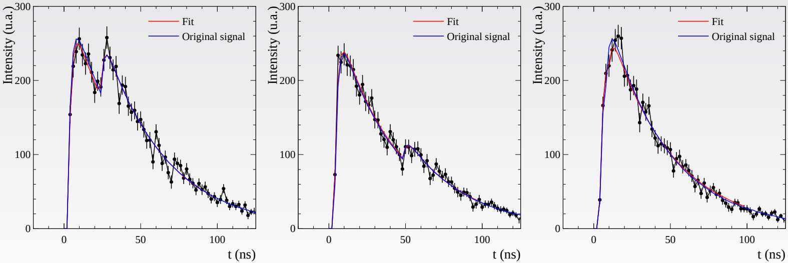




- **500 events have been generated at various rates**
- **E.g. at 2500 kHz:**
  158 (31.6%) have $\Delta t_{ISR} < 160$ ns $\sim$ 4 decay times
- **We fit these signals to verify our capability to distinguish ISR and Bremsstrahlung contributions**

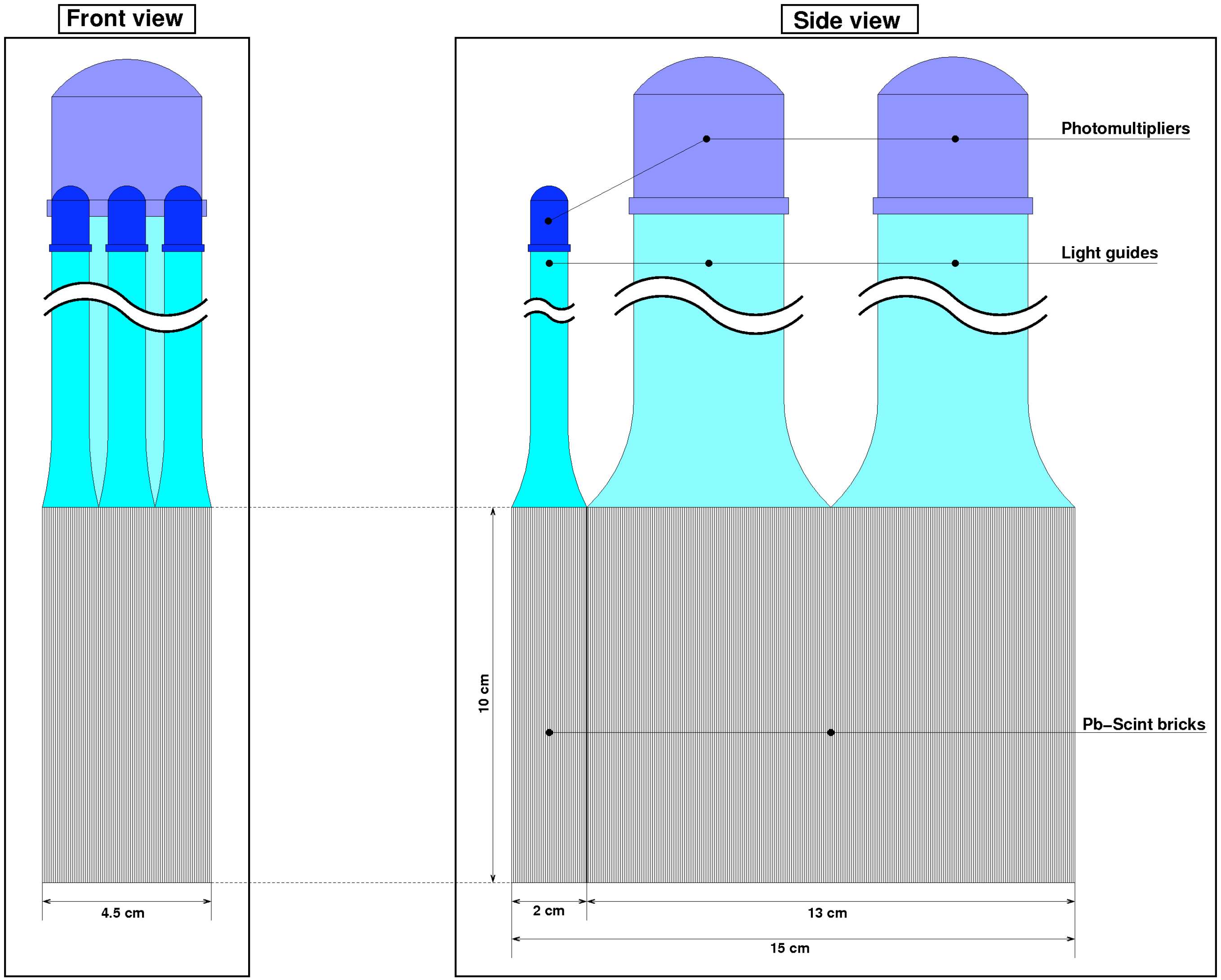


Pileup effect$_4$ in $T = 160$ ns

- The fit goodness is expressed as $(\sigma_E/E)_{\text{fit}} = (E_{\text{gen}} - E_{\text{fit}})/E_{\text{gen}}$, where E_{gen} is the generated ISR amplitude and E_{fit} is its fitted value
- We consider as a reference accuracies: $\begin{cases} 7\% \sim \frac{\sigma_E}{E} & \text{LYSO} \\ 15\% \sim \frac{\sigma_E}{E} & \text{Pb-Scint} \end{cases}$
- $E_{\gamma_{\text{IS}}} \in [0.5\,\text{GeV}, 1.5\,\text{GeV}]$, mild dependence on $E_{\gamma_{\text{IS}}}$

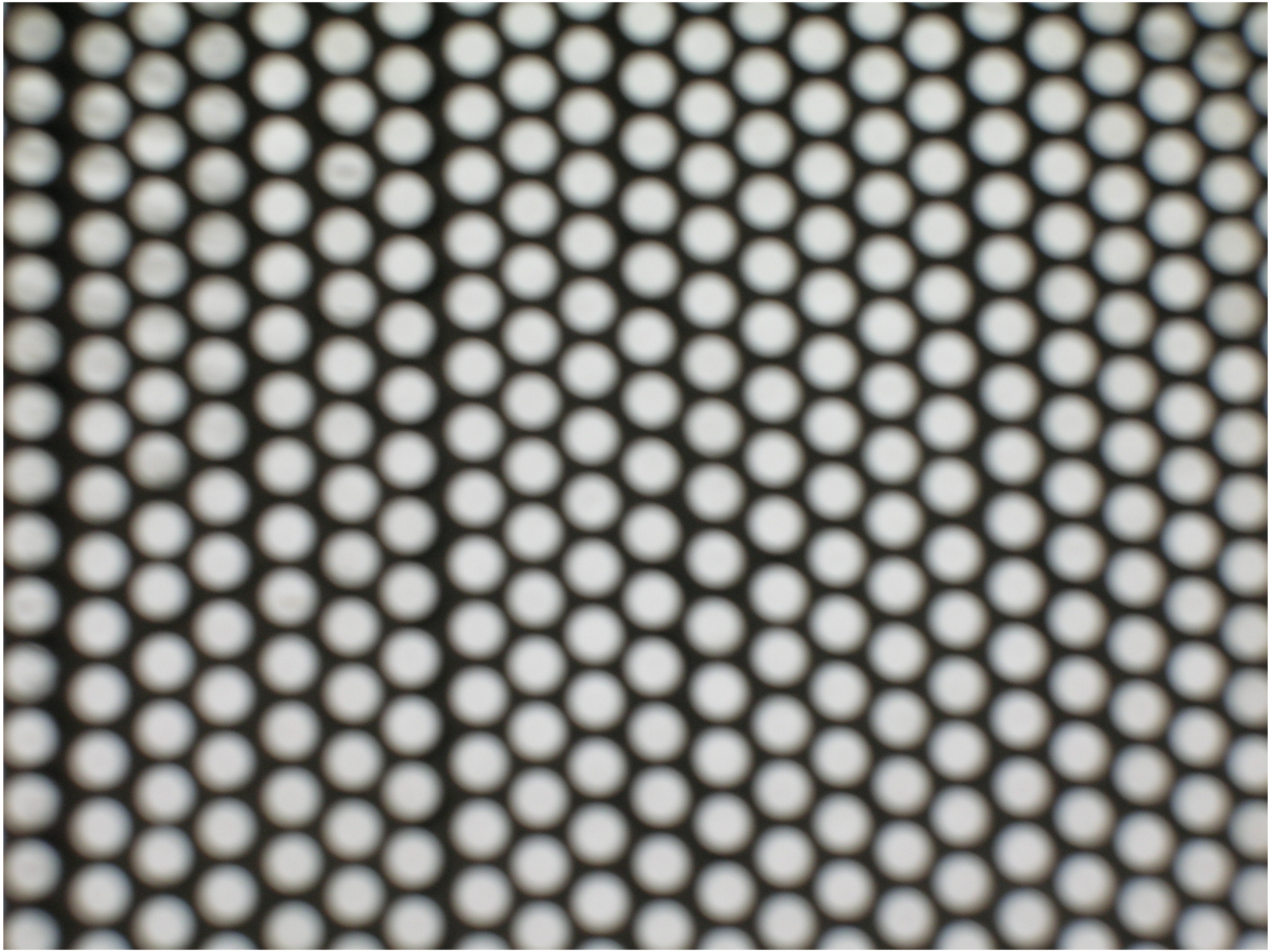
rate (kHz)	Pileup in 160 ns (%)	$(\sigma_E/E)_{\text{fit}} > 7\%$ (%)	$(\sigma_E/E)_{\text{fit}} > 15\%$ (%)
2500	30	9.4	4.8
2100	26	8.1	4.2
1000	14	4.3	2.2
800	10	3.2	1.6

Present ZDD Design

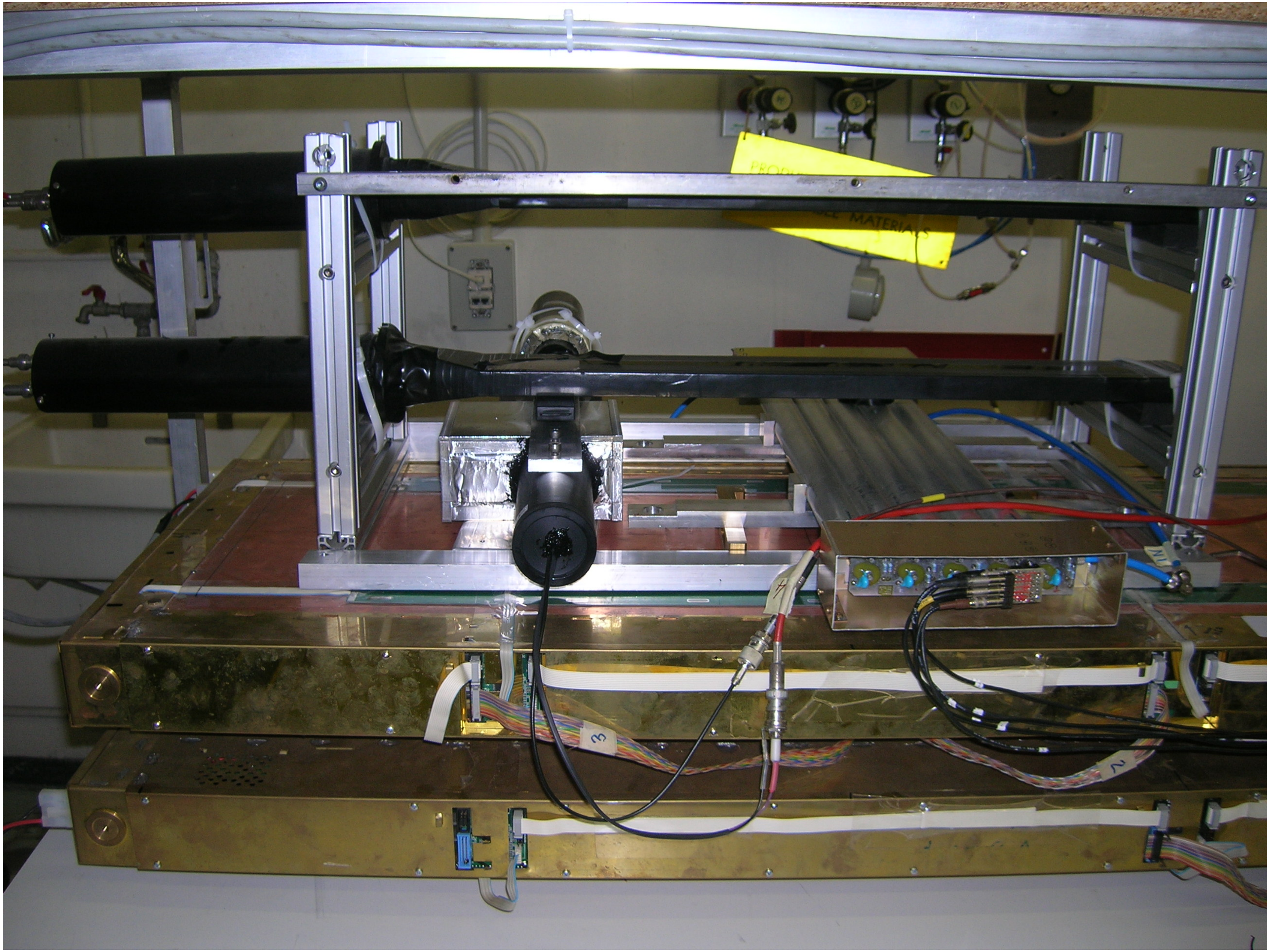


First ZDD prototype, September 2010

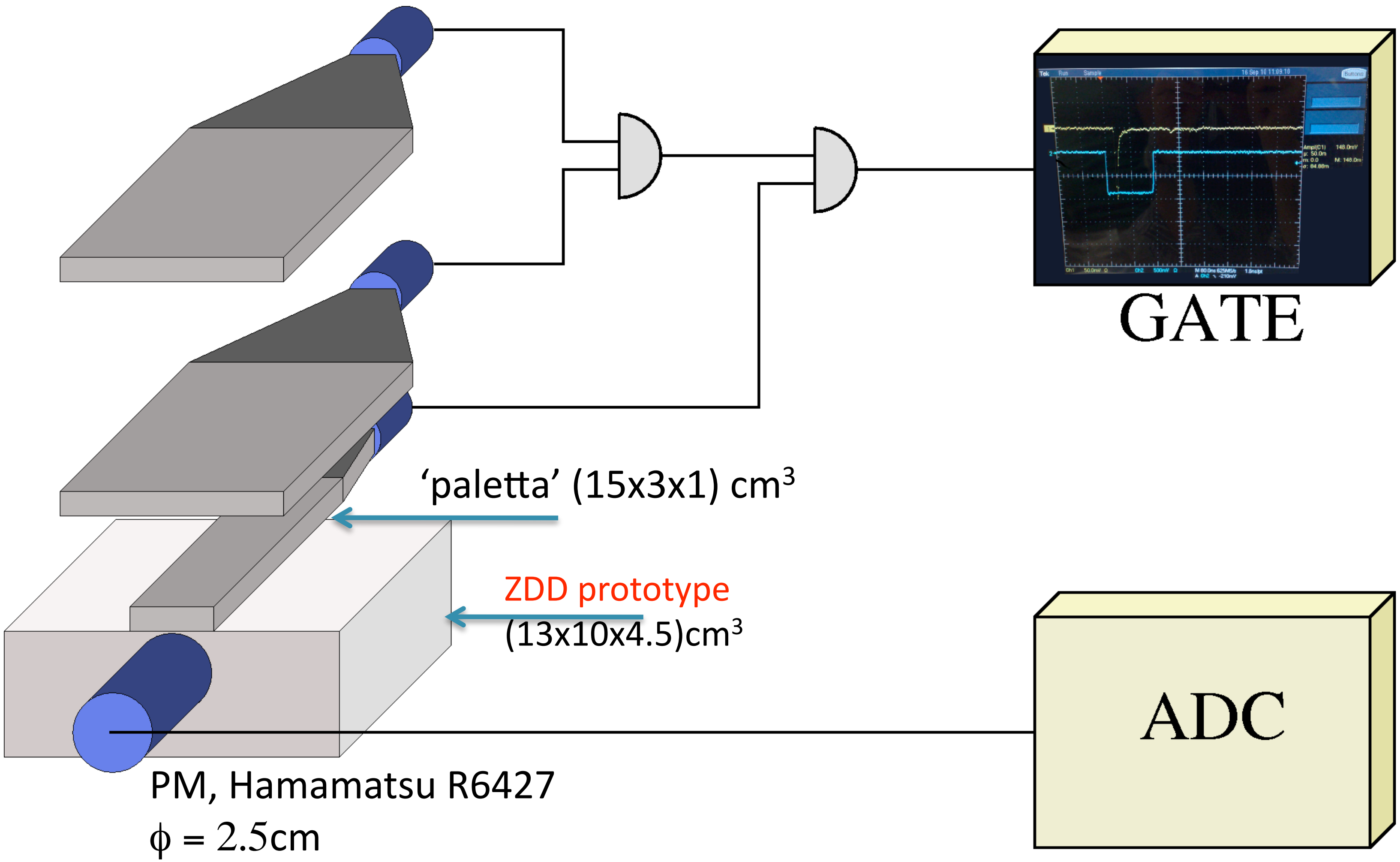
First prototype,September 2010



Cosmic rays test for first prototype

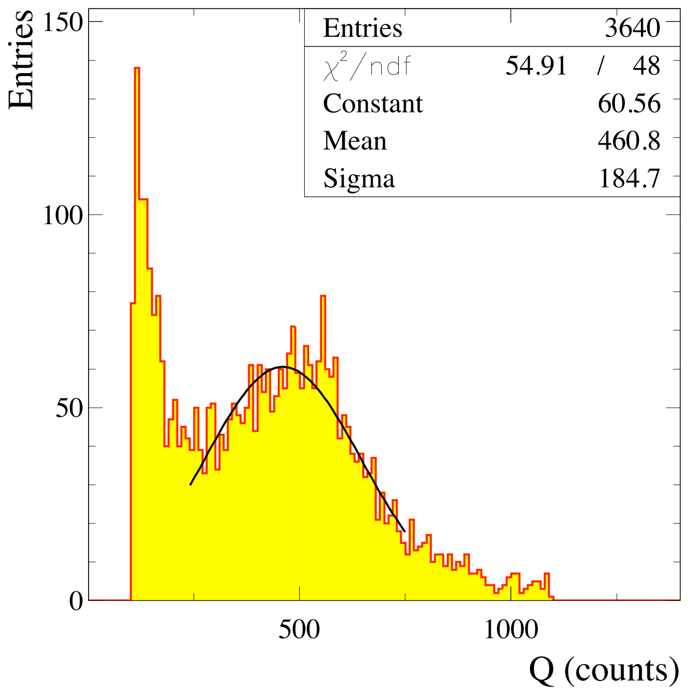


Cosmic ray setup @ LNF

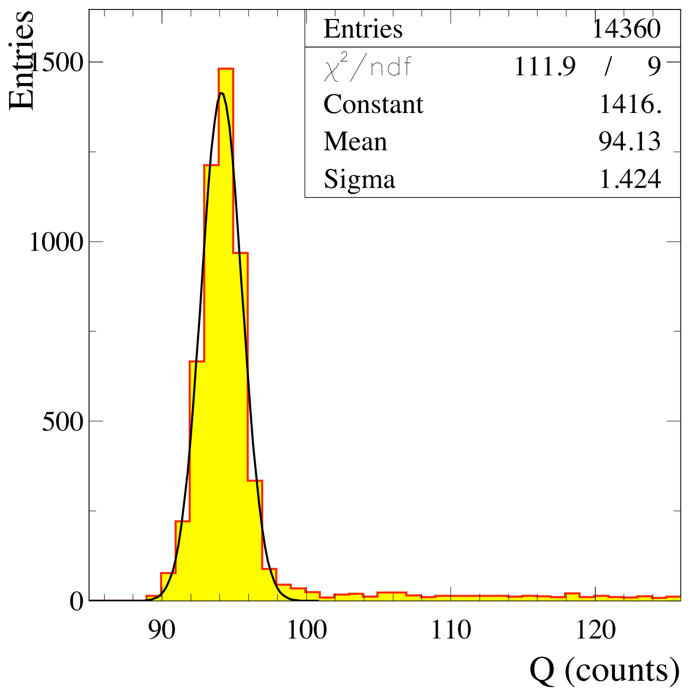


Cosmic ray test: preliminary results

ADC Counts

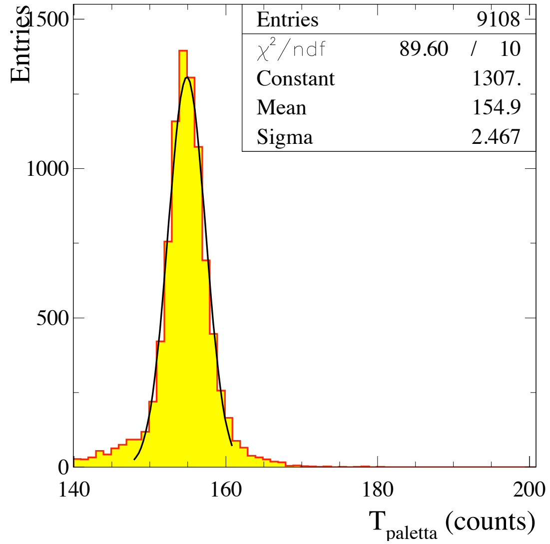


ADC pedestal

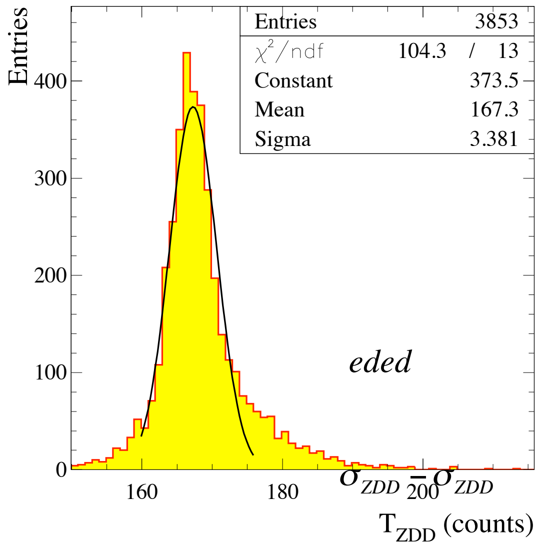


Cosmic ray test: preliminary results

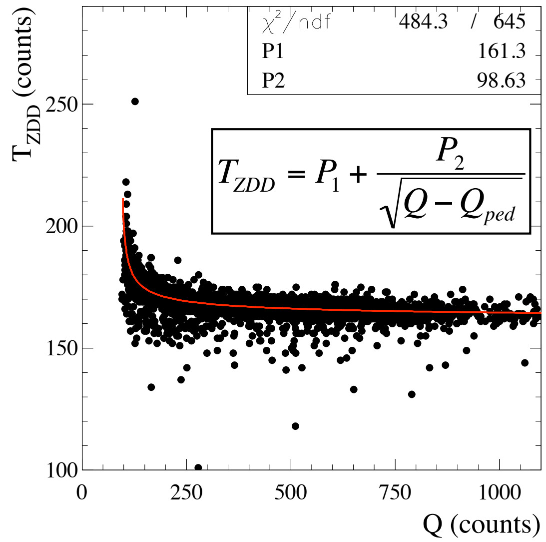
'Paletta': TDC Counts



ZDD: TDC Counts



ZDD: TDC vs ADC Counts



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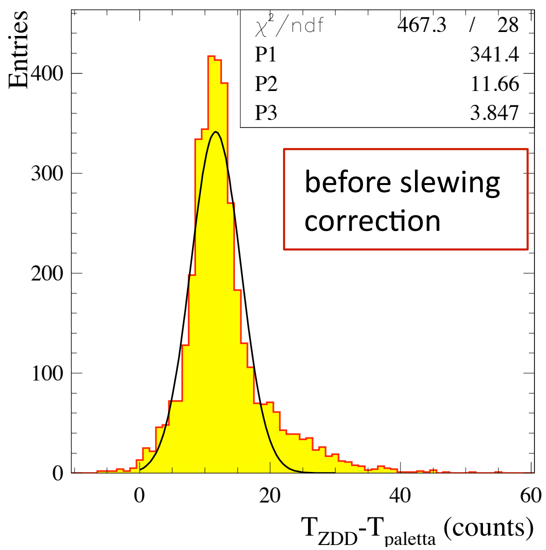
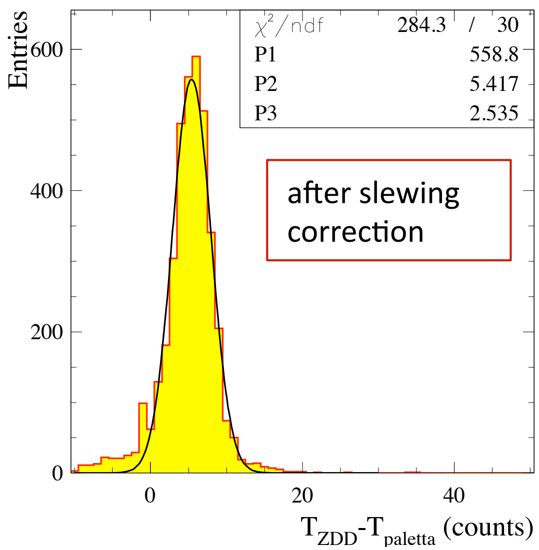


TDC Counts 'Paletta'



$$\sigma_{ZDD} - \sigma_{paletta} = \frac{\tau_{ZDD}}{\sqrt{N_{p.e.}}}$$

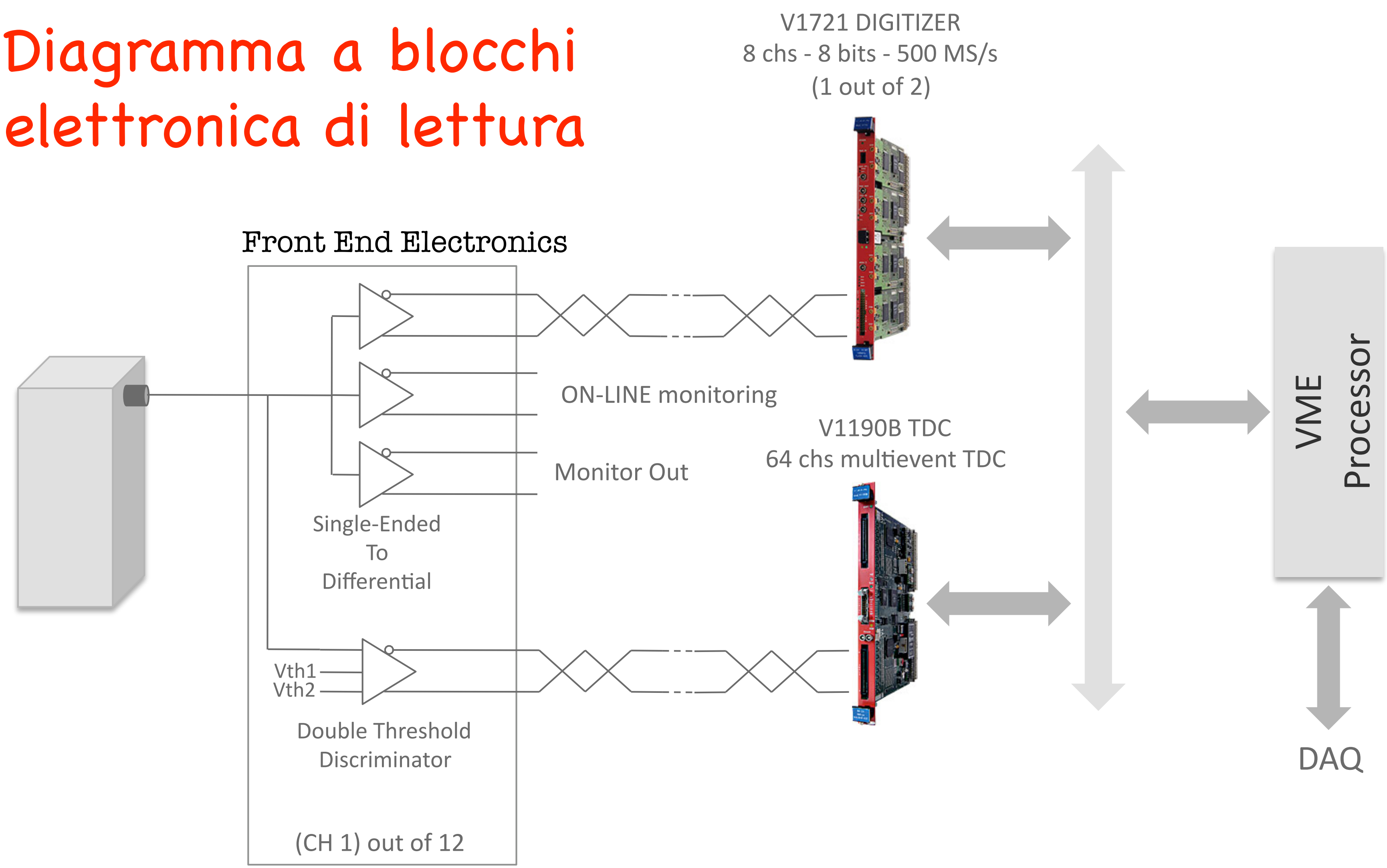
$$\tau_{ZDD} = 2.2ns$$

@17MeV:

$$N_{p.e.} = \left(\frac{\tau_{ZDD}}{\sigma_{ZDD} - \sigma_{paletta}}\right)^2 = 20$$

$$N_{p.e.} = 20/17 \geq 1 p.e./MeV$$

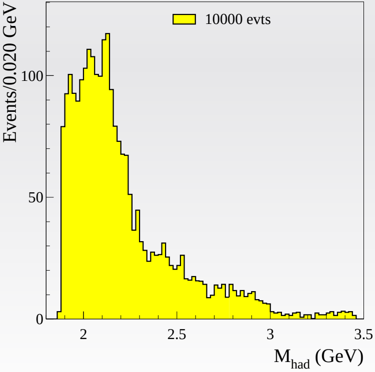
Diagramma a blocchi elettronica di lettura



Physics

The $n\bar{n}\gamma_{IS}$ physics case

- $e^+e^- \longrightarrow n\bar{n}\gamma_{IS}$ at a center of mass energy: $E_{c.m.} = 3.77$ GeV
- Initial state photon energy range: $50\text{ MeV} \leq E_{\gamma_{IS}} \leq \frac{E_{c.m.}}{2}\left(1 - \frac{4M_n^2}{E_{c.m.}^2}\right)$
- Beam pipe suppresses sinc. rad. bkg. and γ_{IS} with $E_{\gamma_{IS}} < 50$ MeV
- γ_{IS} in ZDD and only antineutron detected in BESIII



- 10000 events with $\gamma_{IS} \longrightarrow$ ZDD
- $M_{had} = E_{c.m.}\sqrt{1 - \frac{2E_{\gamma_{IS}}}{E_{c.m.}}}$
- Geometrical cut:
  - $\bar{n} \longrightarrow$ BESIII
  - No constraint in n

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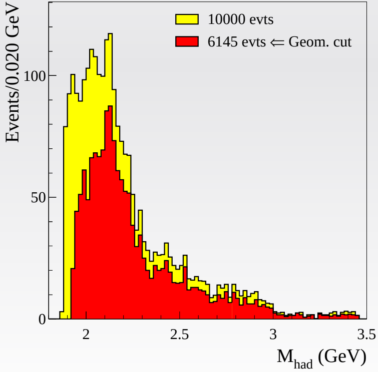

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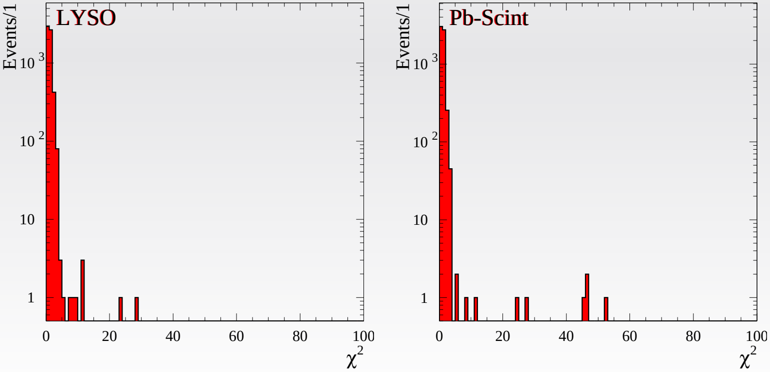
The $n\bar{n}\gamma_{IS}$ physics case: kinematic fit

Inputs (6)
- $\bar{n}$ 3-momentum (TOF)
- γ_{IS} 3-momentum (ZDD)

Constraints (4)
- 4-momentum cons.

Unknowns (3)
- n 4-momentum

$$\chi^2 = \sum_{\text{tracks}} \sum_i \frac{\left(p_i^{\text{exp}} - p_i^{\text{fit}}\right)^2}{\sigma_{p_i}^2}$$



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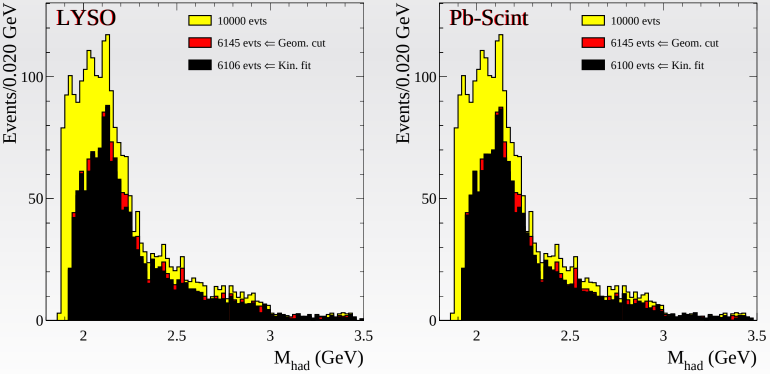


The $n\bar{n}\pi^0$ background

- $e^+e^- \longrightarrow n\bar{n}\pi^0$ is one of the main backgrounds
- Assuming $\sigma(e^+e^- \to n\bar{n}\pi^0) \simeq \sigma(e^+e^- \to p\bar{p}\pi^0)$:

$$\frac{\text{Ev}(n\bar{n}\pi^0)}{\text{Ev}(n\bar{n}\gamma)}\left[M_{\Upsilon(4S)}\right] \simeq R_{BABAR} = \frac{\text{Ev}(p\bar{p}\pi^0)}{\text{Ev}(p\bar{p}\gamma)}\left[M_{\Upsilon(4S)}\right] = 0.06$$

- In **BESIII**, directly at the $\psi(3770)$ mass:

$$R_{\text{BESIII}} = 0.06 \times \underbrace{\left(\frac{0.012}{3 \times 10^{-6}}\right)}_{p\bar{p}\pi^0 \text{ cross section ratio}} \times \underbrace{\left(\frac{1}{10.7}\right)}_{\text{Lum. ratio}} = 22.4$$

$\gamma_{IS} \longrightarrow$ **ZDD**

$$\frac{\text{ZDD solid angle}}{\text{BESIII solid angle}}$$

$$\frac{2\cdot(2\cdot4.5\cdot3/349^2)}{4\pi\cos\theta_{\min}} = 3.8\cdot10^{-5}$$

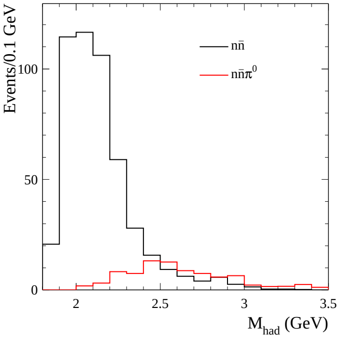
$\Rightarrow$

$$\frac{\text{Ev}(n\bar{n}\pi^0,\ \pi^0 \to 0^o)}{\text{Ev}(n\bar{n}\gamma,\ \gamma \to 0^o)} = 0.0008$$

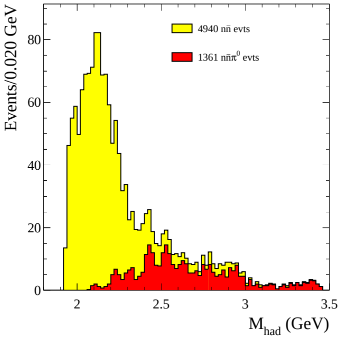
The $n\bar{n}\pi^0\gamma_{IS}$ background

$e^+e^- \longrightarrow n\bar{n}\pi^0\gamma_{IS}$ is a severe background having the IS photon

Yields from *BABAR*

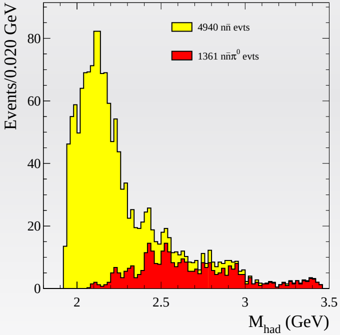


- After geometrical cut
- High contamination at high M_{had}



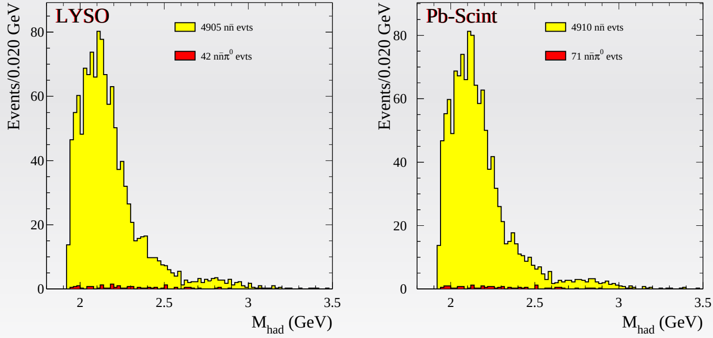
The $n\bar{n}\pi^0\gamma_{IS}$ background reduction

- **π^0 detection in BESIII**: at least one of the π^0 photons with E_γ>50 MeV in BESIII not in a 200 mrad cone around $\bar{n}$ direction
- **Kinematic fit**: $\chi^2 \leq 10$



The $n\bar{n}\pi^0\gamma_{IS}$ background reduction

- **π^0 detection in BESIII**: at least one of the π^0 photons with $E_\gamma > 50$ MeV in BESIII not in a 200 mrad cone around $\bar{n}$ direction
- **Kinematic fit**: $\chi^2 \leq 10$



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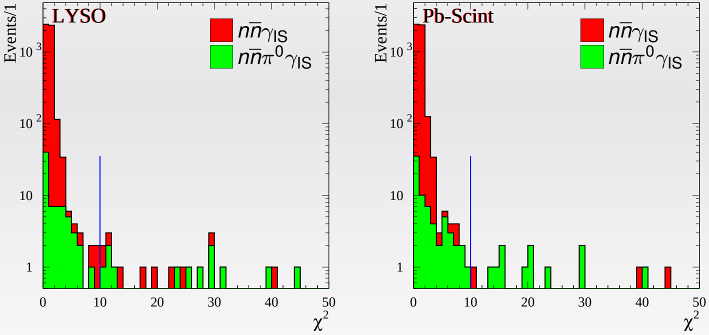

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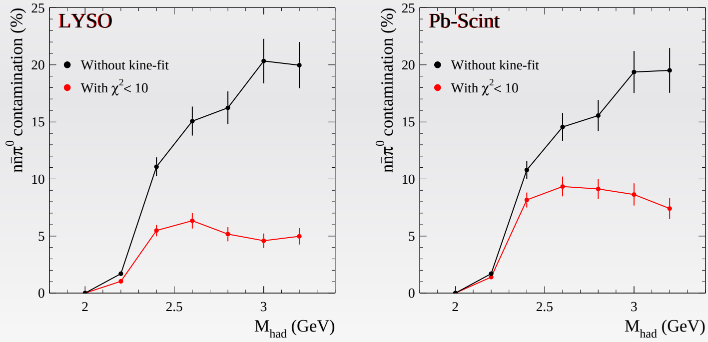
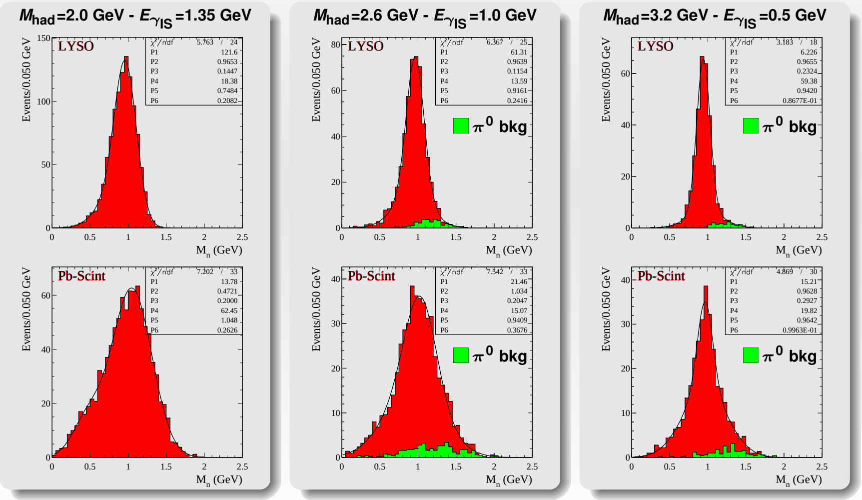


Energy resolution in $\overline{n}\gamma_{IS}$ missing mass

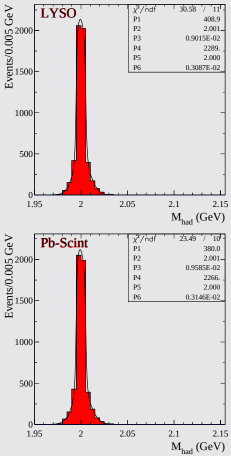
- Events are generated with fixed value of $M_{had} = E_{c.m.}\sqrt{1 - 2E_{\gamma_{IS}}/E_{c.m.}}$
- The $\overline{n}\gamma_{IS}$ missing mass is obtained only from experimental data



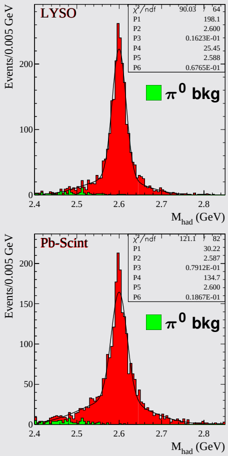
Energy resolution in M_{had} slices

- Events are generated with fixed value of $M_{had} = E_{c.m.}\sqrt{1 - 2E_{\gamma_{IS}}/E_{c.m.}}$
- M_{had} is reconstructed using the kinematic fit procedure

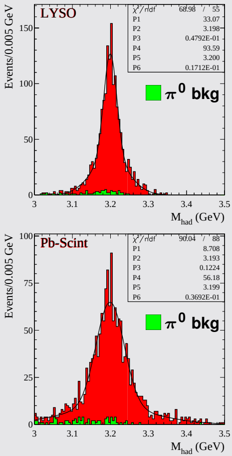
M_{had}=2.0 GeV - $E_{\gamma_{IS}}$=1.35 GeV



M_{had}=2.6 GeV - $E_{\gamma_{IS}}$=1.0 GeV



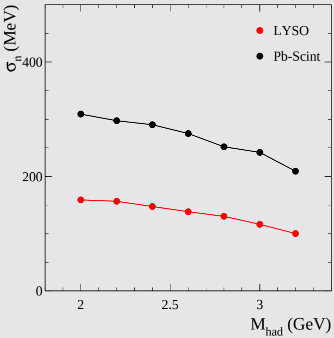
M_{had}=3.2 GeV - $E_{\gamma_{IS}}$=0.5 GeV



Energy resolutions

- Two-gaussian fit: σ = half width of the area, symmetric w.r.t. the center of mass of the distributions, which contains the 68% of events

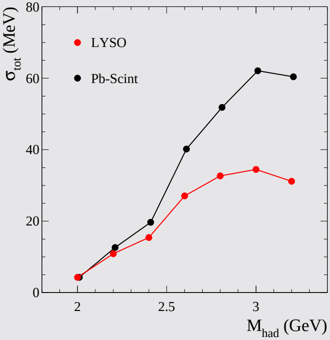
Width of the $\bar{n}\gamma_{IS}$ miss. mass



σ_n is dominated by $\delta p_{\bar{n}}$

small $M_{had} \Rightarrow$ large $E_{\gamma IS} \Rightarrow$ small $\delta E_{\gamma IS}$

Energy resolution in M_{had} bins

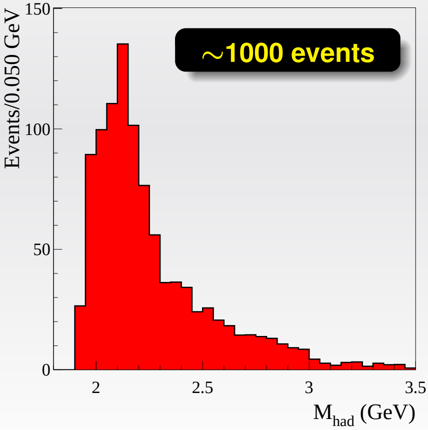


σ_{tot} is dominated by $\delta E_{\gamma IS}$

large $M_{had} \Rightarrow$ small $E_{\gamma IS} \Rightarrow$ large $\delta E_{\gamma IS}$

Expected events

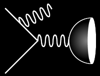
- One year of data taking: $T = 1.5 \times 10^7$ s
- Average luminosity: $\overline{\mathcal{L}} = 1.5 \times 10^{32}$ cm^{-2}s^{-1}
- Detection efficiency: $\epsilon = 0.5$
- Center of mass energy: $E_{c.m.} = 3.77$ GeV



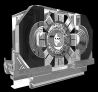
Other possible physics items
$R_{\rm had}$ in the 1-3 GeV region

- Accessible had-CoM energy: $E_{\rm had} = \sqrt{E_{\rm coll}^2 - 2E_{\rm coll}E_{\gamma_{\rm IS}}}$
- PDG: $\gamma\gamma$2 and BESII (2-3 GeV) only

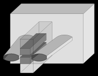
- ISR: small systematic error versus $E_{\rm had}$
- ISR on ZDD: negligible π^0 background



- $|\Delta E_{\rm had}| = |\Delta E_{\gamma_{\rm IS}}| E_{\rm coll}/E_{\rm had}$:
  feasible only if $E_{\rm coll}/E_{\rm had} \sim 1$ (not for *B*-factories)
- BESIII: $E_{\rm coll} \sim 3.5$ GeV $\Rightarrow E_{\rm had} \simeq 1-3$ GeV



- LYSO: $|\Delta E_{\rm had}| \simeq 150$ MeV
- Pb-Scint: $|\Delta E_{\rm had}| \simeq 300$ MeV
- $|\Delta E_{\rm had}|$ reduced by deconvolution techniques



Radiation hardness

- Radiation damages mostly due to Bremsstrahlung: $\sigma_{\mathrm{Bre}}(\mathrm{ZDD}/4) = 2.6\ \mathrm{mb}$
- One year of data taking: $T = 1.5 \times 10^{7}\ \mathrm{s}$
- Average luminosity: $\overline{\mathcal{L}} = 1.5 \times 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Center of mass energy: $E_{c.m.} = 3.77\ \mathrm{GeV}$

$$\frac{\text{Dose absorbed}}{\text{year}} = \frac{\text{energy deposited}}{\text{year}\cdot\text{mass}} = \begin{cases} \dfrac{3\times 10^{21}\ \mathrm{eV}}{0.12\ \mathrm{kg}} = 4\times 10^{5}\ \dfrac{\mathrm{rad}}{\mathrm{year}} & \text{LYSO} \\ \dfrac{3\times 10^{21}\cdot \frac{2}{13}\ \mathrm{eV}}{1.8\times 10^{-2}\ \mathrm{kg}} = 10^{6}\ \dfrac{\mathrm{rad}}{\mathrm{year}} & \text{Scint} \end{cases}$$

Declared hardness

- LYSO $\sim 10^{8}$ rad
- Scint. $\sim 10^{6}$ rad