B E S III

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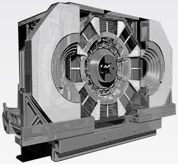
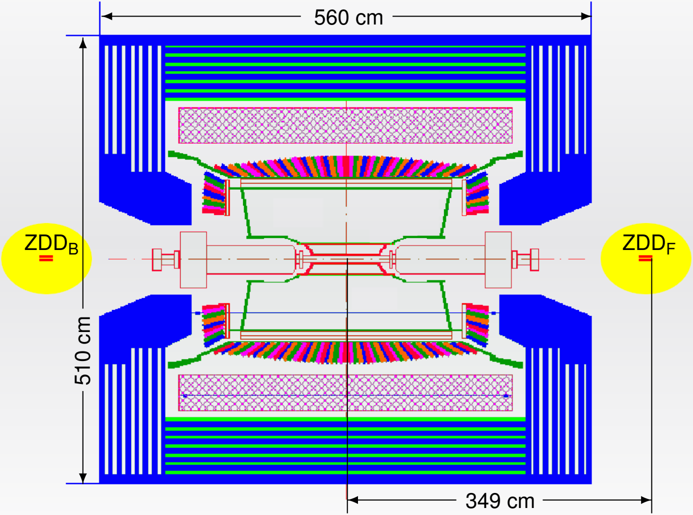
Commissione Scientifica Nazionale 1



17-19 maggio 2010, Torino

Design and Installation

BESIII and ZDD



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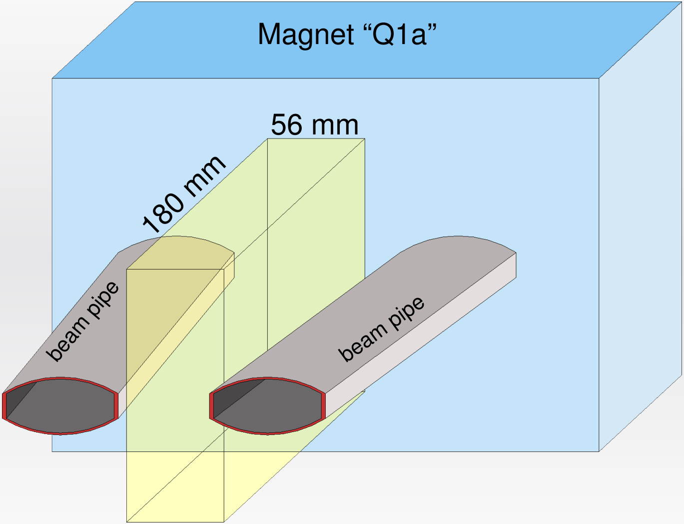

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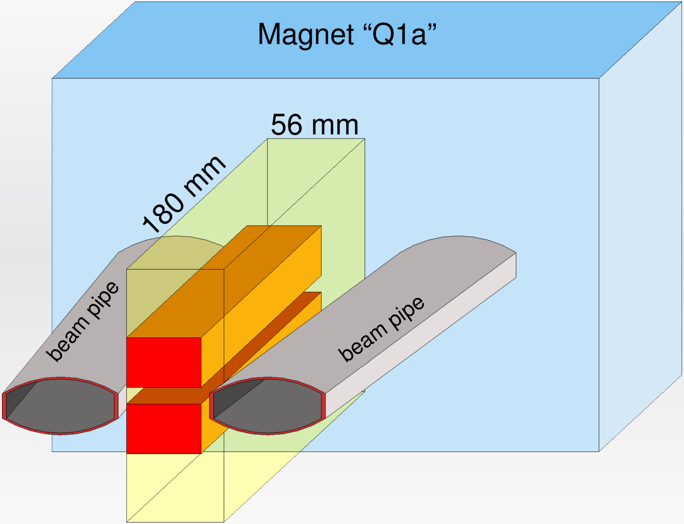
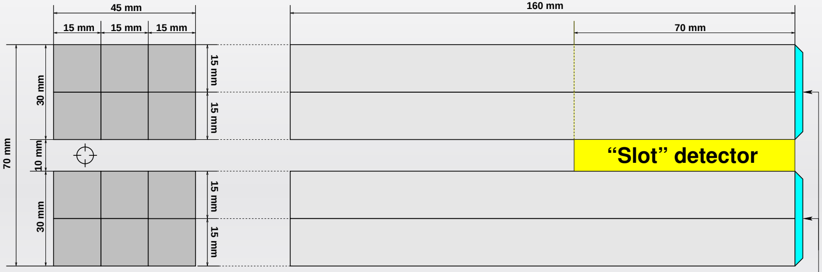
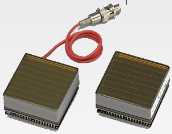


LYSO design

Front view
(cross section)

Side view

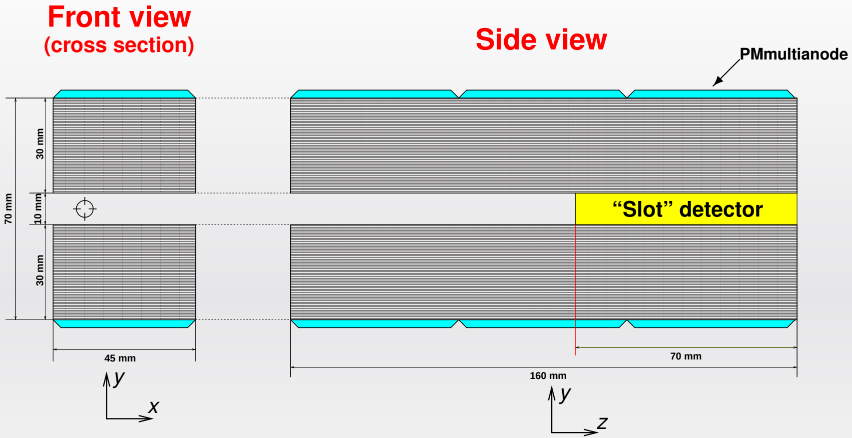




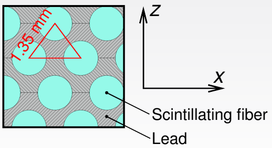
PMmultianode

- Two 3×2 matrices of 1.5×1.5×16 cm^3 of LYSO bars
- Total volume 864 cm^3
- Readout with 4 PMmultianode
- Possible Luminosity-monitor “Slot” detector in the last 7 cm

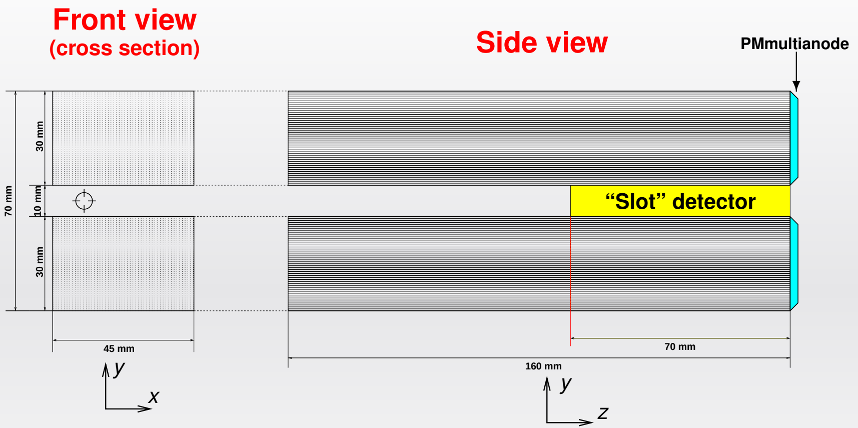
Pb-Scintillator design à la Kloe



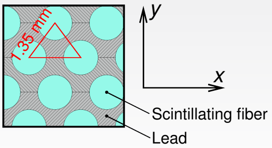
- Along *z* axis:
  320 grooved 0.5 mm thick lead foils
  alternated with layers of cladded
  1 mm diameter scintillating fibers
- Readout with PMmultianode



Pb-Scintillator “Spaghetti” design



- Along *y* axis:
  120 grooved 0.5 mm thick lead foils
  alternated with layers of cladded
  1 mm diameter scintillating fibers
- Readout with PMmultianode

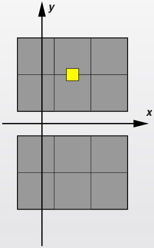


Physical properties of materials

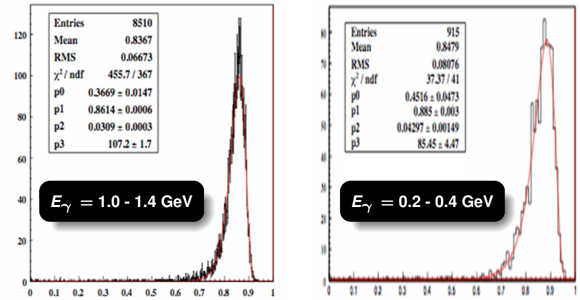
Material	LYSO	Pb-Scint
Density (g/cm^3)	7.4	5.3
Radiation Length (cm)	1.1	1.6
Molière Radius (cm)	1.9	2.9
Decay Constant (ns)	40-44	2.4
Peak Emission (nm)	428	460
Radiation Hardness (rad)	$\sim 10^8$	$\sim 10^6$

Energy Resolution

LYSO GEANT4 simulation$_1$



Deposited energy/E_γ



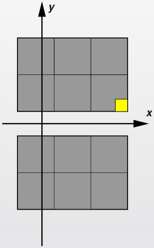
Log-normal distribution

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

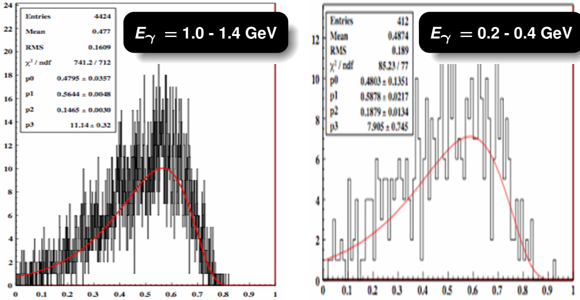
$$\sigma_0 = \frac{2}{2.35}\ln\left[\eta\frac{2.35}{2}+\sqrt{1+\left(\eta\frac{2.35}{2}\right)^2}\right], \quad \sigma_E = \frac{\text{FWHM}}{2.35}$$

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

LYSO GEANT4 simulation$_2$

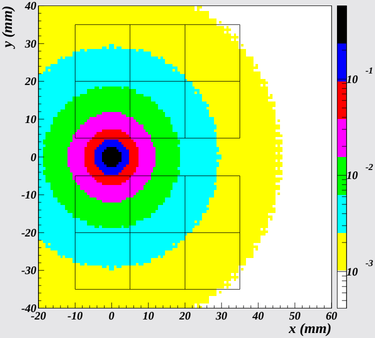


Deposited energy/E_γ



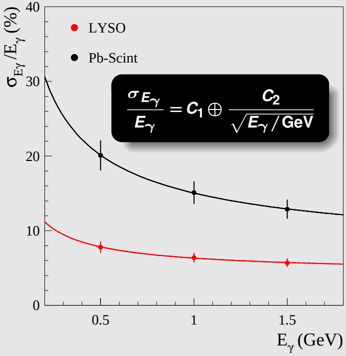
E_γ (GeV)	$\sigma_{E_\gamma}/E_\gamma$ Central (yellow square)
1.0 - 1.4	26.0%
0.2 - 0.4	32.0%

ISR angular distribution on ZDD



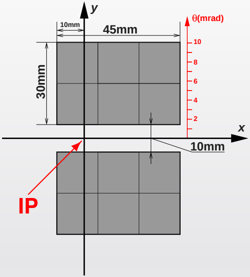
	LYSO	Pb-Scint
E_γ (GeV)	$\sigma_{E_\gamma}/E_\gamma$	$\sigma_{E_\gamma}/E_\gamma$
1.5	5.7%	12.9 %
1.0	6.4%	15.1 %
0.5	7.8%	20.1 %

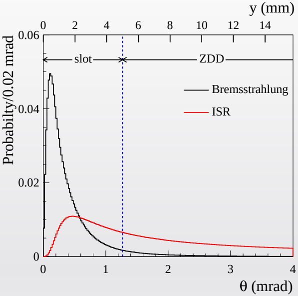
Energy resolution for ISR



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

Bremsstrahlung simulation





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

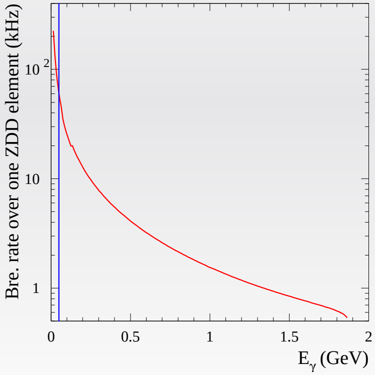
- ISR in ZDD 13.7% of total solid angle
- Bremsstrahlung in ZDD 2.8% of total solid angle
- Bremsstrahlung rate in a single ZDD element (upper or lower):

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}

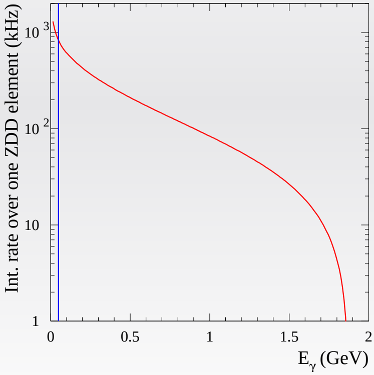
Bremsstrahlung rate

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

Bremsstrahlung rate in 10 MeV E_γ intervals



Integrated Bremsstrahlung rate



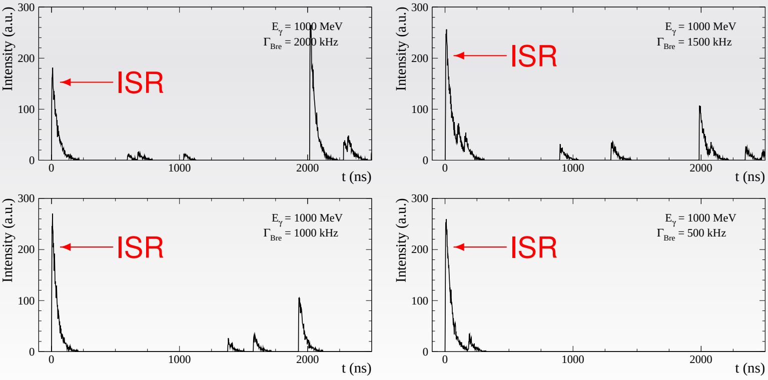
Pileup effect$_1$: signal generation

Maximum Bremsstrahlung rate expected 2.1 MHz (ZDD/4)

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

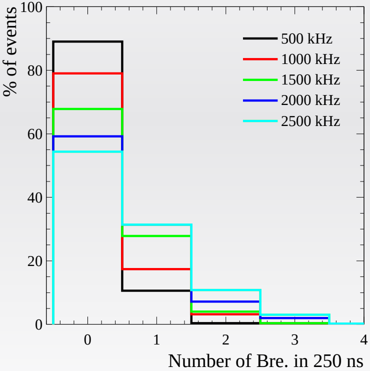
$$\textbf{Intensity} = e^{-t/\tau_d}(1 - e^{-t/\tau_r})$$

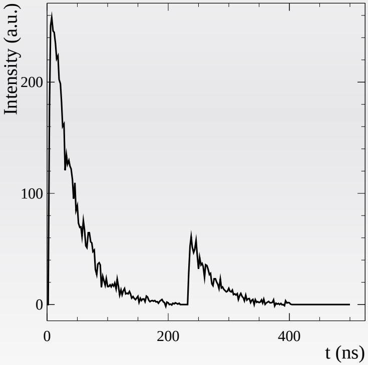
rising time $\tau_r = 2$ ns, decay time $\tau_d = 40$ ns



Pileup effect$_2$: probability

Probability of pileup as a function of the Bremsstrahlung rate





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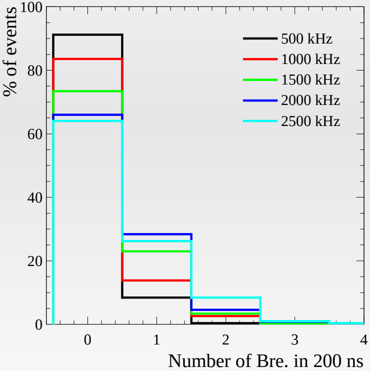

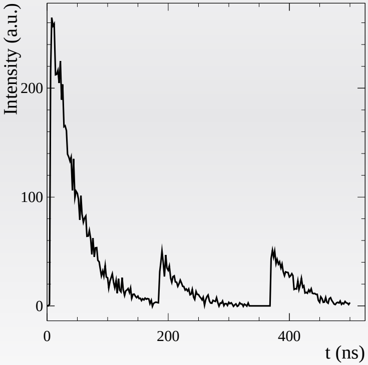

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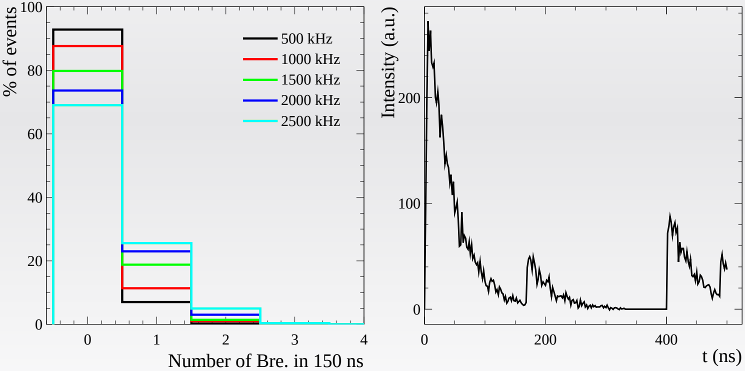

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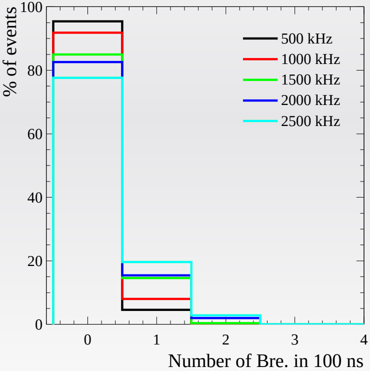
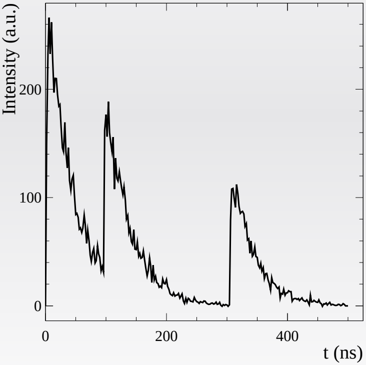
Pileup effect$_2$: probability

Probability of pileup
as a function of the Bremsstrahlung rate





Probability of pileup
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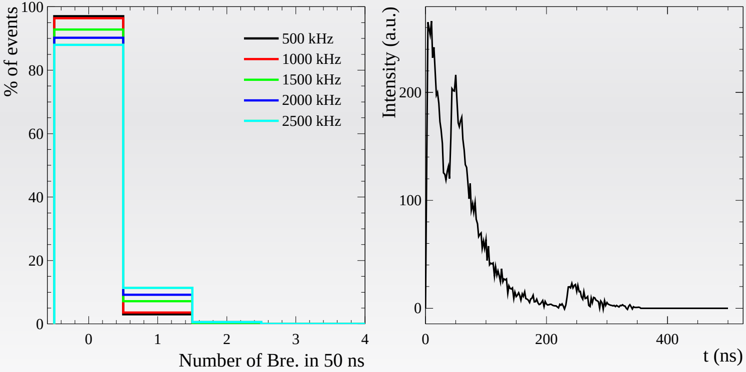
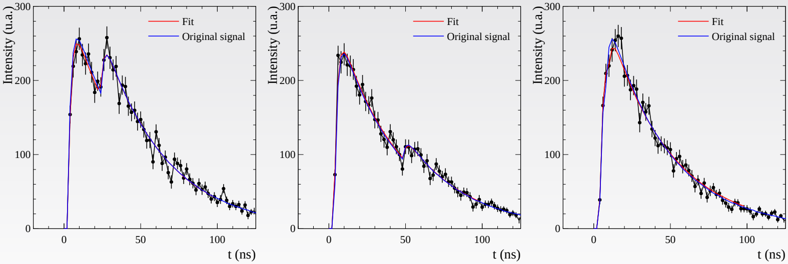


Pileup effect$_3$: evaluation

- **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

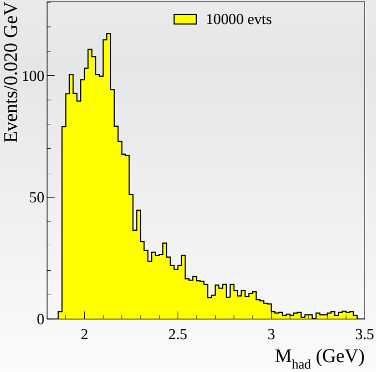
- The fit goodness is expressed as $(\sigma_E/E)_{\text{fit}} = (E_{\text{gen}} - E_{\text{fit}})/E_{\text{gen}}$, where E_{gen} is the generated ISR amplitude and E_{fit} is its fitted value
- We consider as a reference accuracies: $\begin{cases} 7\% \sim \frac{\sigma_E}{E} & \text{LYSO} \\ 15\% \sim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

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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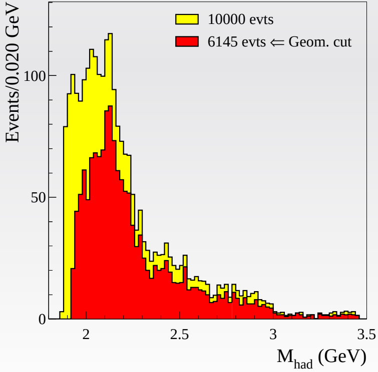

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- Geometrical cut:
  - $\bar{n} \longrightarrow$ BESIII
  - No constraint in n

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

Inputs (6)

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

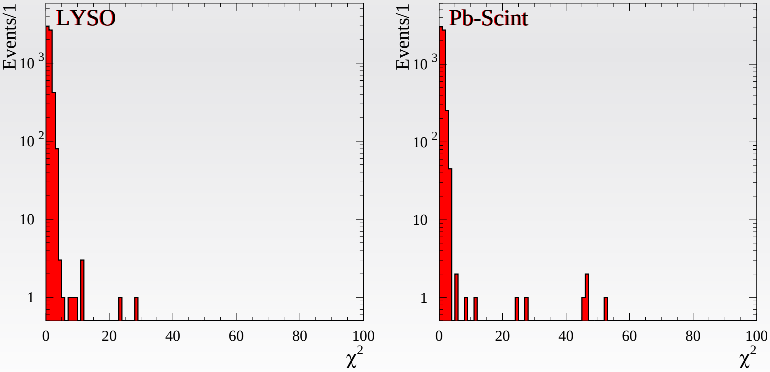
Constraints (4)

- 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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Inputs (6)
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- γ_{IS} 3-momentum (ZDD)

Constraints (4)
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Unknowns (3)
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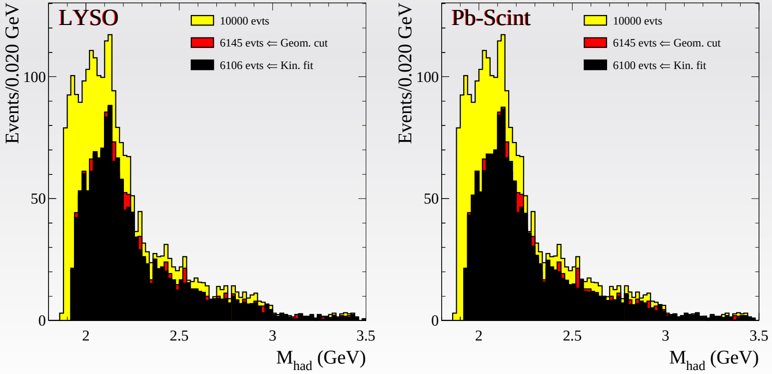


The $n\bar{n}\pi^0$ background

- $e^+e^- \to n\bar{n}\pi^0$ 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:

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

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

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

$$\frac{2\cdot(2\cdot 4.5\cdot 3/349^2)}{4\pi \cos\theta_{\min}} = 3.8\cdot 10^{-5}$$

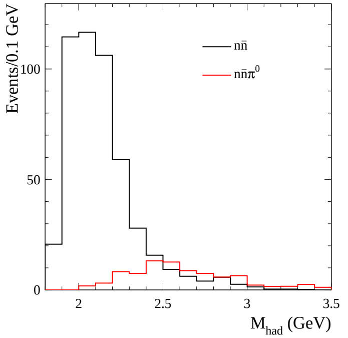
$\Rightarrow$

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

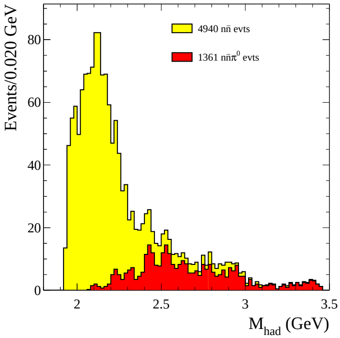
The $n\bar{n}\pi^0\gamma_{IS}$ background

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

Yields from *BABAR*

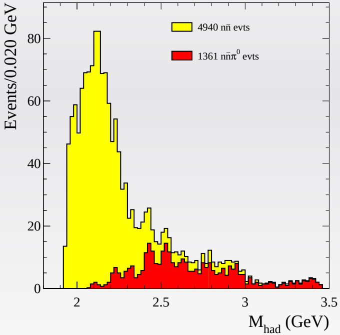


- After geometrical cut
- High contamination at high M_{had}



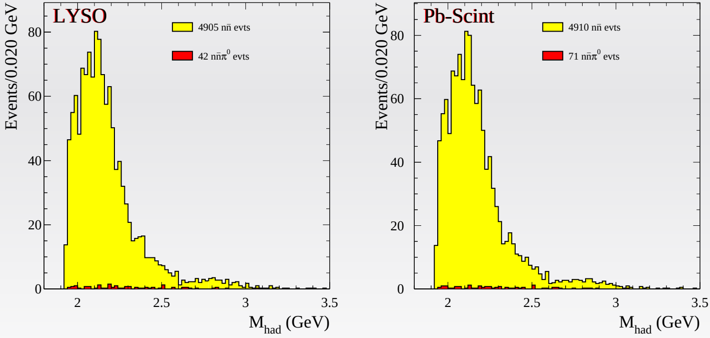
The $n\bar{n}\pi^0\gamma_{IS}$ background reduction

- **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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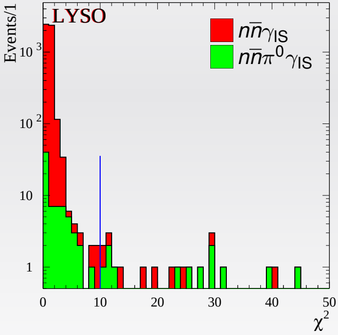
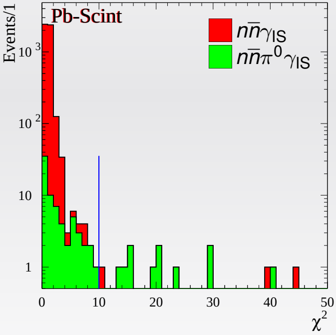
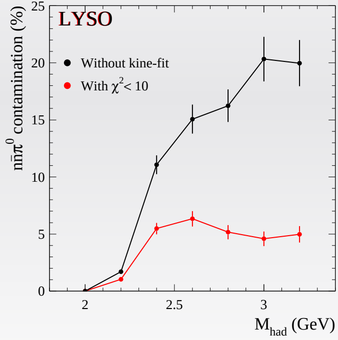
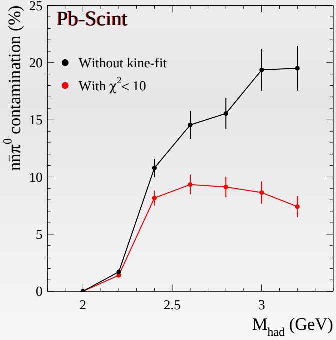




The $n\bar{n}\pi^0\gamma_{IS}$ background reduction

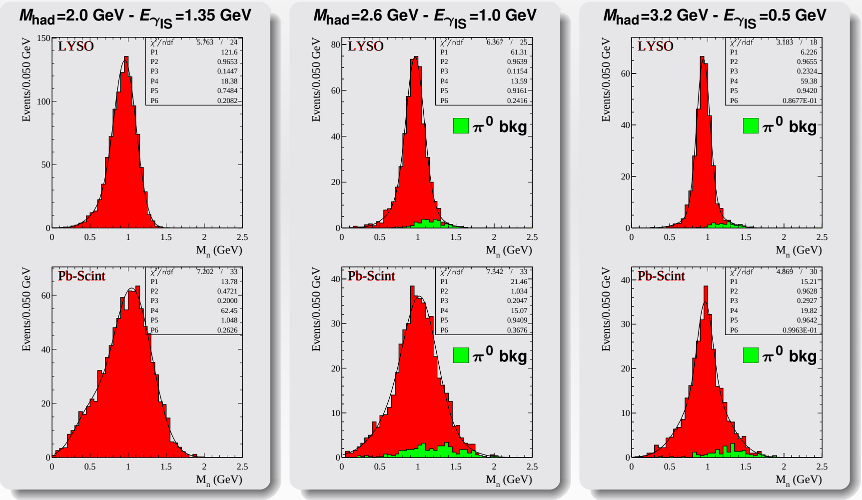
- **π^0 detection in BESIII**: at least one of the π^0 photons with $E_\gamma > 50$ MeV in BESIII not in a 200 mrad cone around $\bar{n}$ direction
- **Kinematic fit**: $\chi^2 \leq 10$





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

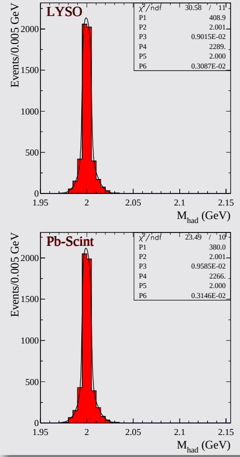
- Events are generated with fixed value of $M_{had} = E_{c.m.}\sqrt{1 - 2E_{\gamma_{IS}}/E_{c.m.}}$
- The $\overline{n}\gamma_{IS}$ missing mass is obtained only from experimental data



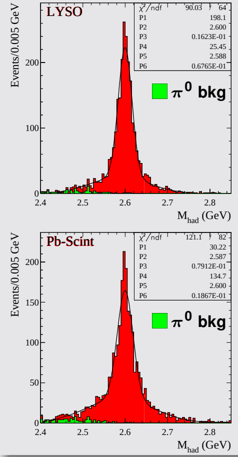
Energy resolution in M_{had} slices

- 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

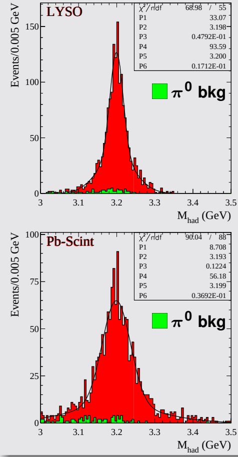
M_{had}=2.0 GeV - $E_{\gamma_{IS}}$=1.35 GeV



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



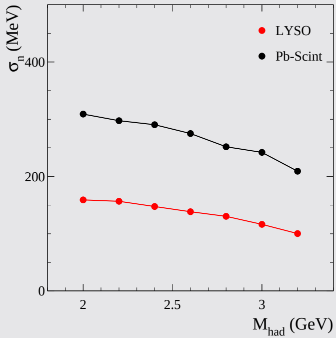
M_{had}=3.2 GeV - $E_{\gamma_{IS}}$=0.5 GeV



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

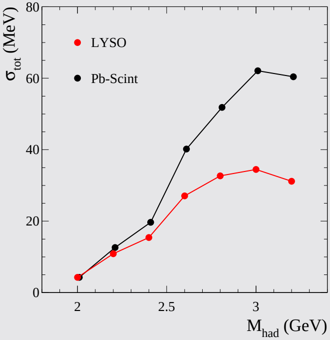
Width of the $\bar{n}\gamma_{IS}$ miss. mass



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

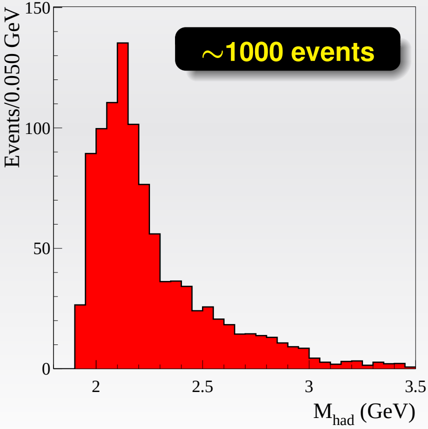


σ_{tot} is dominated by $\delta E_{\gamma IS}$

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

Expected events

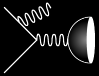
- One year of data taking: $T = 1.5 \times 10^7$ s
- Average luminosity: $\overline{\mathcal{L}} = 1.5 \times 10^{32}$ cm^{-2}s^{-1}
- Detection efficiency: $\epsilon = 0.5$
- Center of mass energy: $E_{c.m.} = 3.77$ GeV



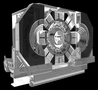
Other possible physics items
R_{had} in the 1-3 GeV region

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

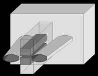
- ISR: small systematic error versus E_{had}
- ISR on ZDD: negligible π^0 background



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



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



Radiation hardness

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

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

Declared hardness

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

Costs and agenda

Costi e richieste per il 2010

LYSO

Componente	quantità	costo (KEuro)
LYSO SICCAS	24 + 4	**30**
PMmultianode	4	**10**
TDC (24 ch)	1	**5**
FADC (8 ch)	3	**15**
Crate CAEN	1	**5**
HV supply	1	**10**
	Totale	**75**

Richieste per il 2010

- LYSO . . . . **30 KEuro**
- Consumo . . . . **2 KEuro**
- PMmultianode in prestito da Kloe

Totale . . . . **32 KEuro**

Pb-Scint

Componente	quantità	costo (KEuro)
Pb-Scint	Kloe modulo zero	
PMmultianode	12	**30**
ADC (24 ch)	1	**5**
TDC (24 ch)	1	**5**
Crate CAEN	1	**5**
HV supply	1	**10**
	Totale	**55**

Richieste per il 2010

- Taglio e fresatura . . . . **2 KEuro**
- Sviluppo elettronica . . . . . **2 KEuro**
- Consumo . . . . **1 KEuro**
- PMmultianode in prestito da Kloe

Totale . . . . **5 KEuro**

Pro/contro

	LYSO	Pb-Scint
Time decay	slow	fast
Rad. hardness	ok	limit
ΔM_{had} (MeV)	150	350
Feasibility	easy	Kloe modulo zero
Costs (KEuro)	74	55 (if Kloe modulo is working)

Milestones

LYSO Option

- **Agosto 2010**:
  consegna cristalli
- **Settembre 2010**:
  assemblaggio
- **Ottobre 2010 ?**:
  test rate e PM (Kloe2)
- $\leq$ **Dicembre 2010**:
  definizione elettronica
- **Gennaio-Febbraio 2011**:
  consegna PM Hamamatzu
- **Febbraio 2011**:
  consegna elettronica CAEN
- **Marzo-Giugno 2011**:
  test
- **Agosto 2011**:
  installazione a BESIII

Pb-Scint Option

- **Luglio 2010**:
  taglio modulo zero
- **Giugno-Settembre 2010**:
  assemblaggio
- $\leq$ **Dicembre 2010**:
  definizione elettronica e test BTF per Pb-Scint
- **Gennaio-Febbraio 2011**:
  consegna PM Hamamatzu
- **Febbraio 2011**:
  consegna elettronica CAEN
- **Marzo-Giugno 2011**:
  test
- **Agosto 2011**:
  installazione a BESIII