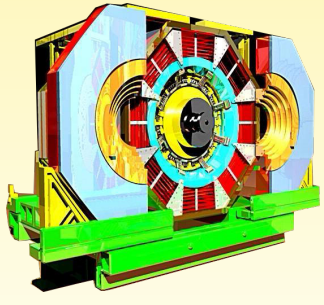
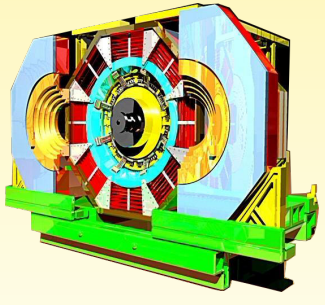
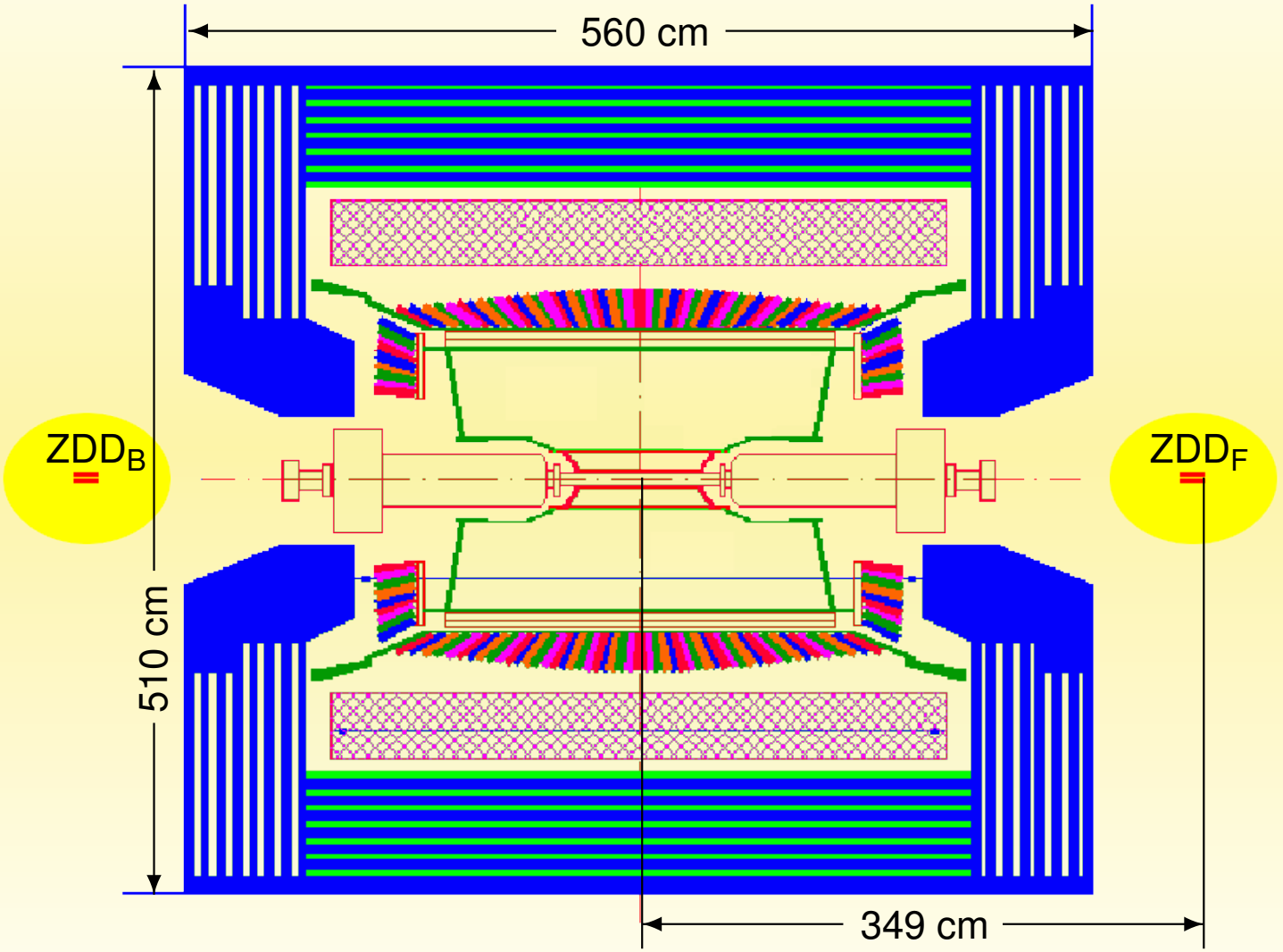
Study of a zero degree radiative photons tagger for ISR events in BESIII



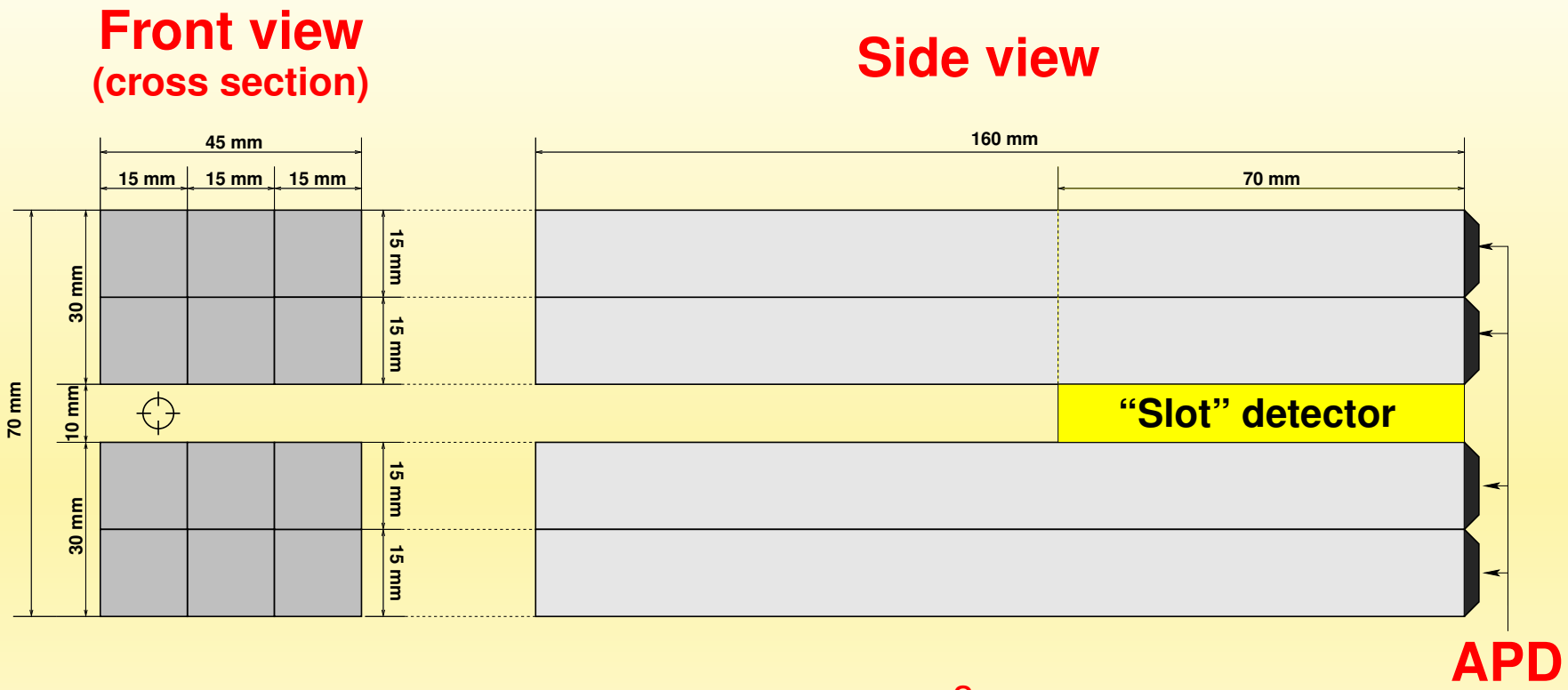
May 13, 2010



BESIII and ZDD

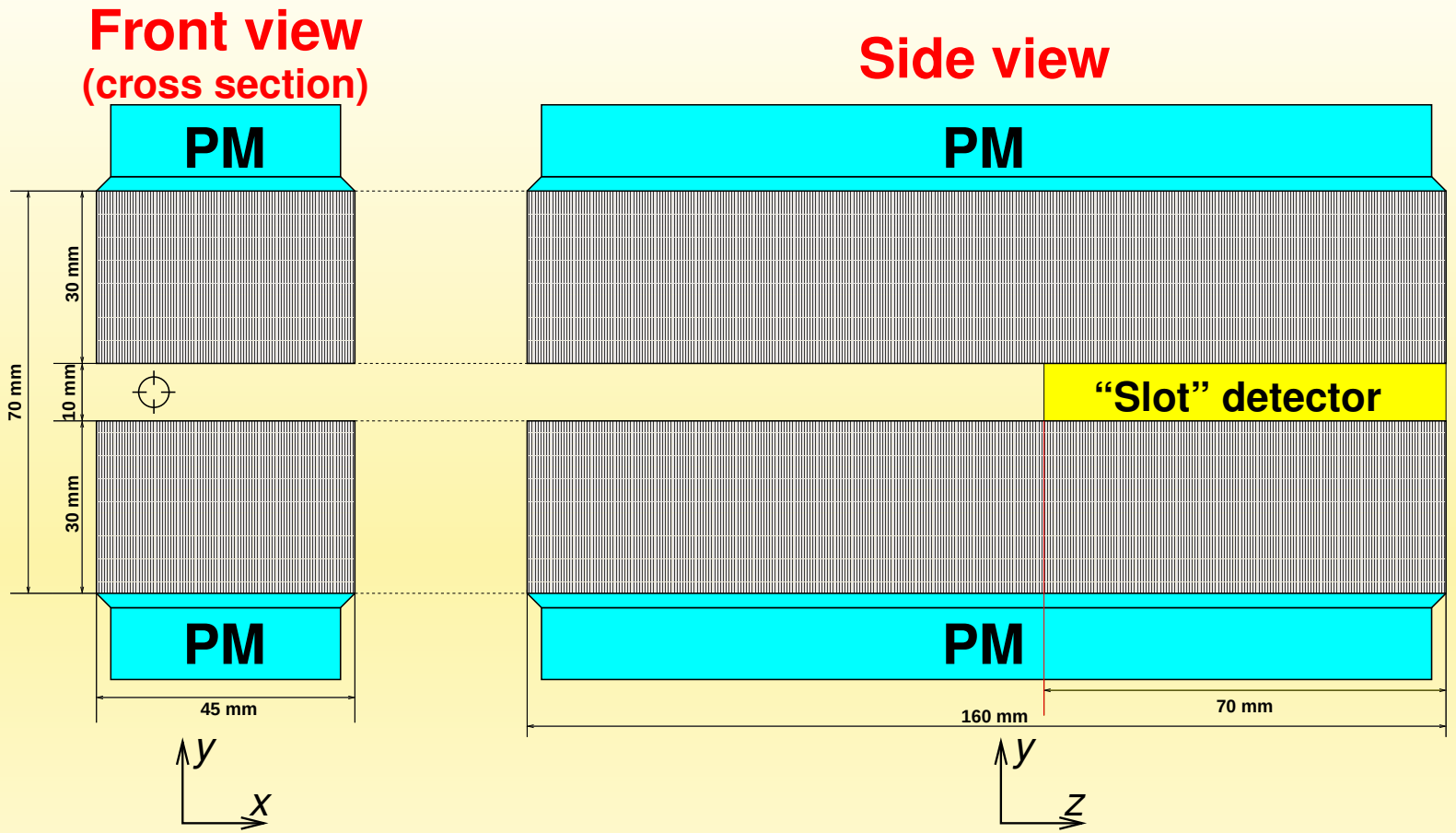


LYSO design

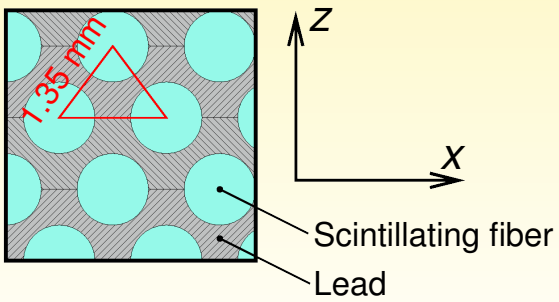


- Two 3×2 matrices of $1.5\times1.5\times16$ cm^3 of LYSO bars
- Total volume 864 cm^3
- Readout with 24 APDs
- Possible Luminosity-monitor "Slot" detector in the last 7 cm

Pb-Scintillator design



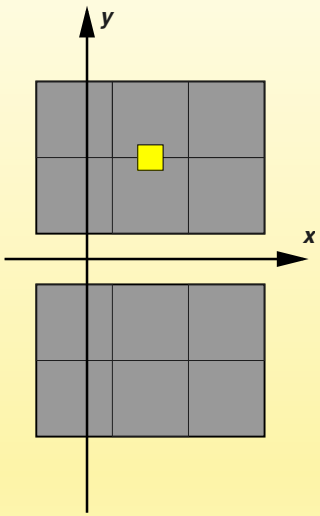
- 320 grooved 0.5 mm thick lead foils alternated with layers of cladded 1 mm diameter scintillating fibers
- Readout with PMs



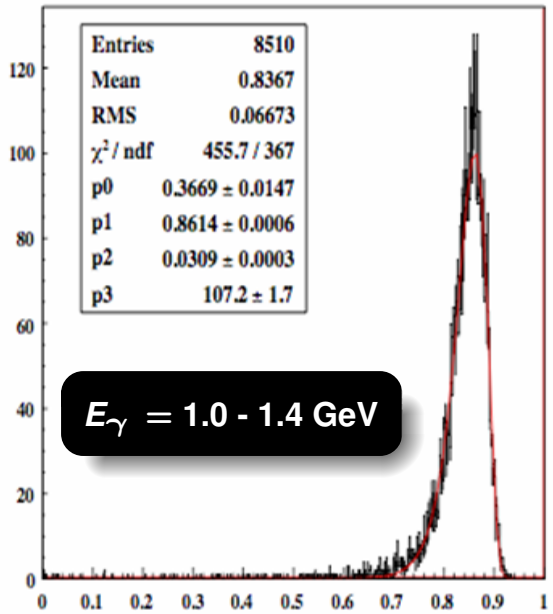
Physical properties of materials

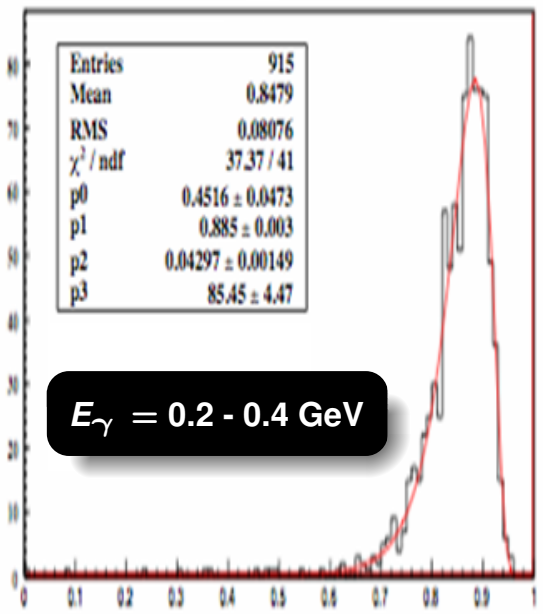
Material	LYSO	Pb-Scint
Density (g/cm^3)	7.4	5.3
Radiation Length (cm)	1.1	1.6
Molière Radius (cm)	2.0	2.9
Decay Constant (ns)	40-44	2.4
Peak Emission (nm)	428	460
Radiation Hardness (rad)	$\sim 10^8$	$\sim 10^6$

LYSO GEANT4 simulation$_1$



Deposited energy/E_γ





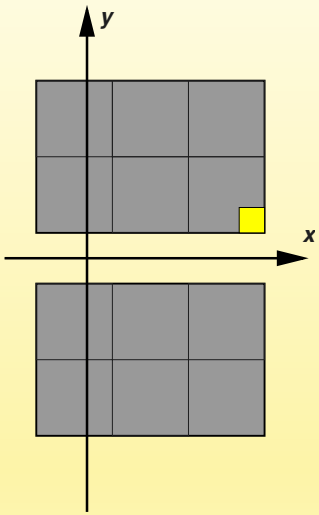
Log-normal distribution

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

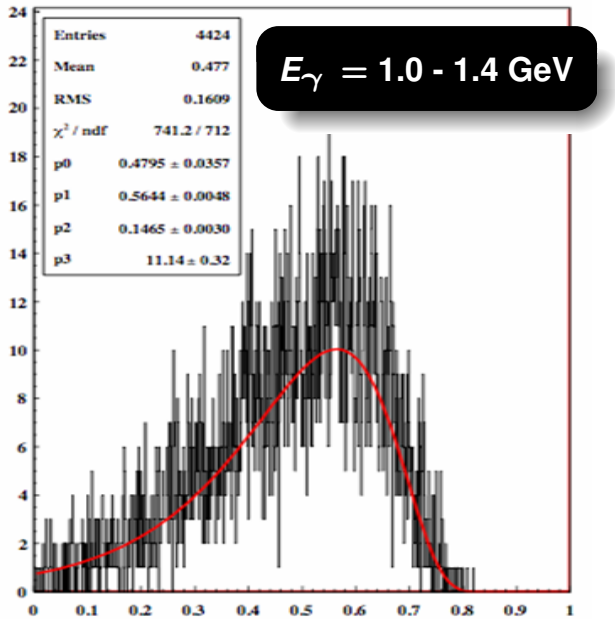
$$\sigma_0 = \frac{2}{2.35}\ln\left[\eta\frac{2.35}{2}+\sqrt{1+\left(\eta\frac{2.35}{2}\right)^2}\right], \quad \sigma_E = \frac{\text{FWHM}}{2.35}$$

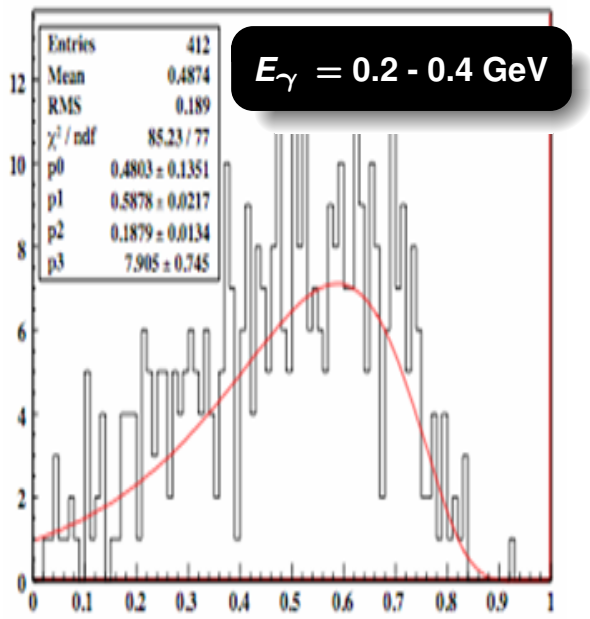
E_γ (GeV)	$\sigma_{E_\gamma}/E_\gamma$ Central (yellow square)
1.0 - 1.4	3.6%
0.2 - 0.4	4.9%

LYSO GEANT4 simulation$_2$



Deposited energy/E_γ

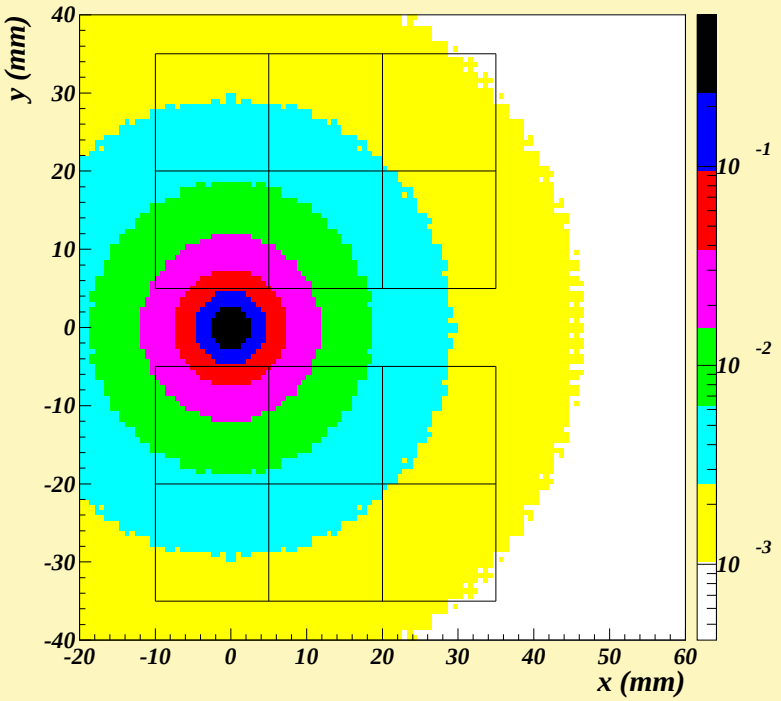




E_γ (GeV)	$\sigma_{E_\gamma}/E_\gamma$ Central (yellow square)
1.0 - 1.4	26.0%
0.2 - 0.4	32.0%

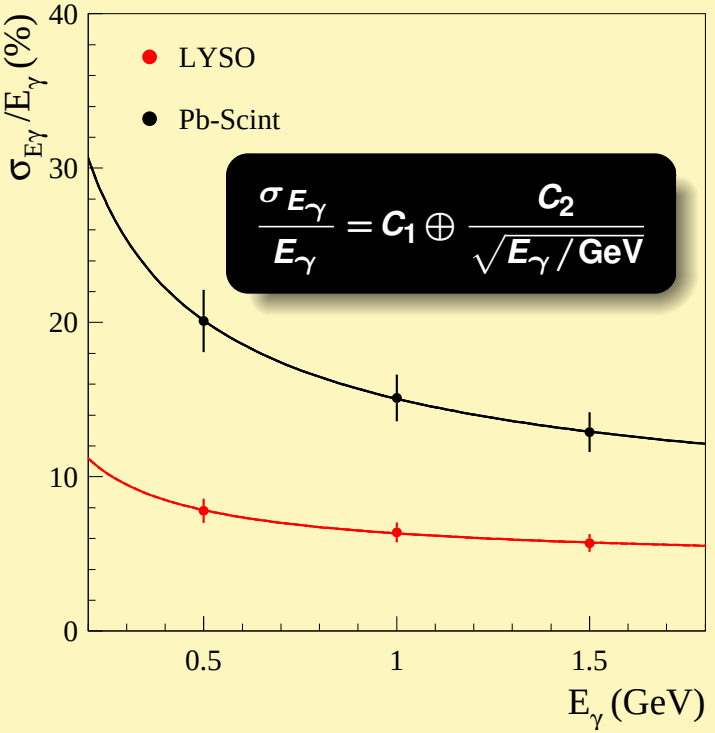
Energy resolution, the ISR case

ISR angular distribution on ZDD



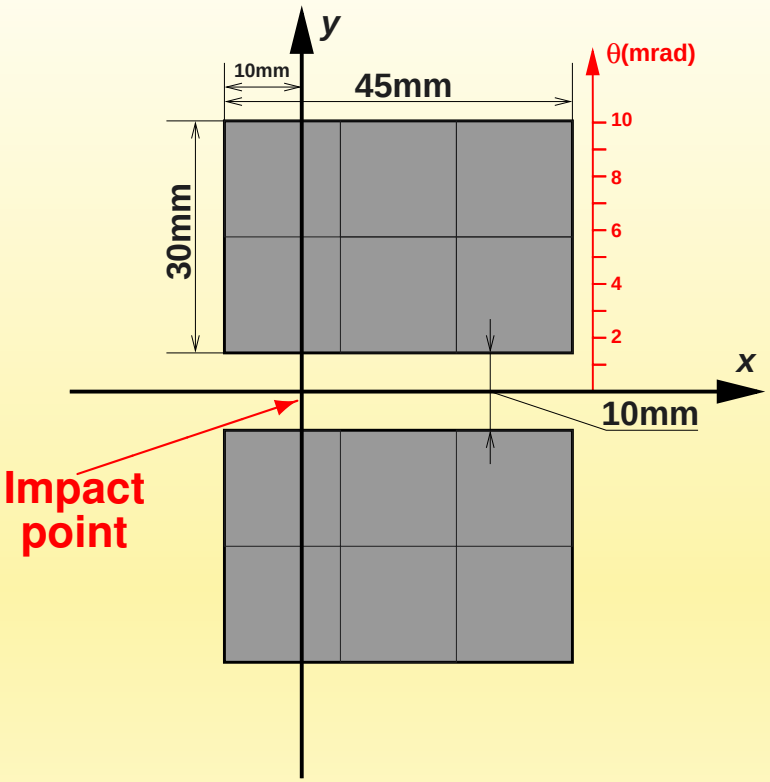
E_γ (GeV)	LYSO $\sigma_{E_\gamma}/E_\gamma$	Pb-Scint $\sigma_{E_\gamma}/E_\gamma$
1.5	5.7%	12.9 %
1.0	6.4%	15.1 %
0.5	7.8%	20.1 %

Energy resolution for ISR



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

Bremsstrahlung simulation



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

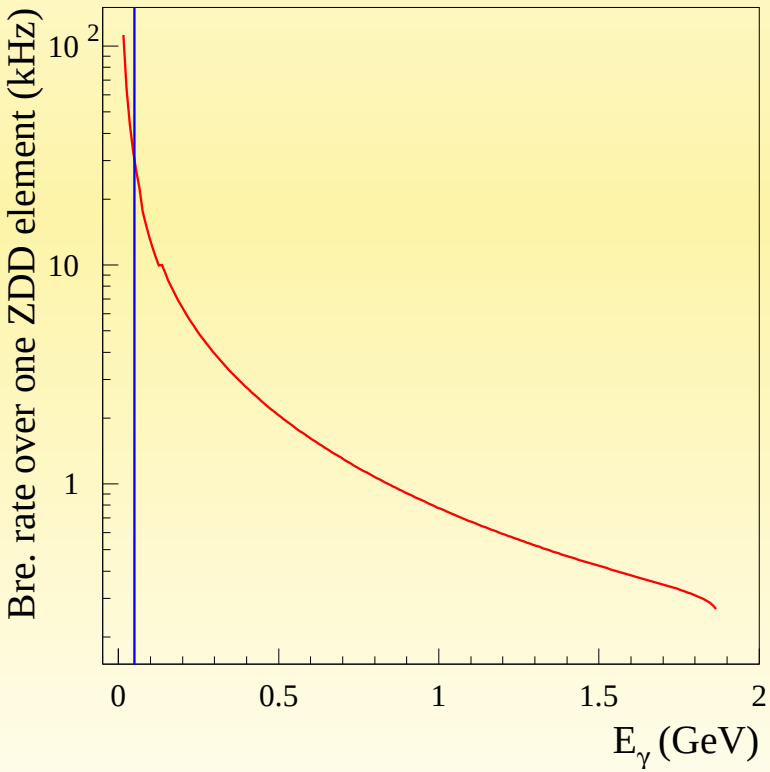
- ISR in ZDD 13.7% of total solid angle
- Bremsstrahlung in ZDD 2.8% of total solid angle
- Bremsstrahlung rate in a single ZDD element (upper or lower):

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

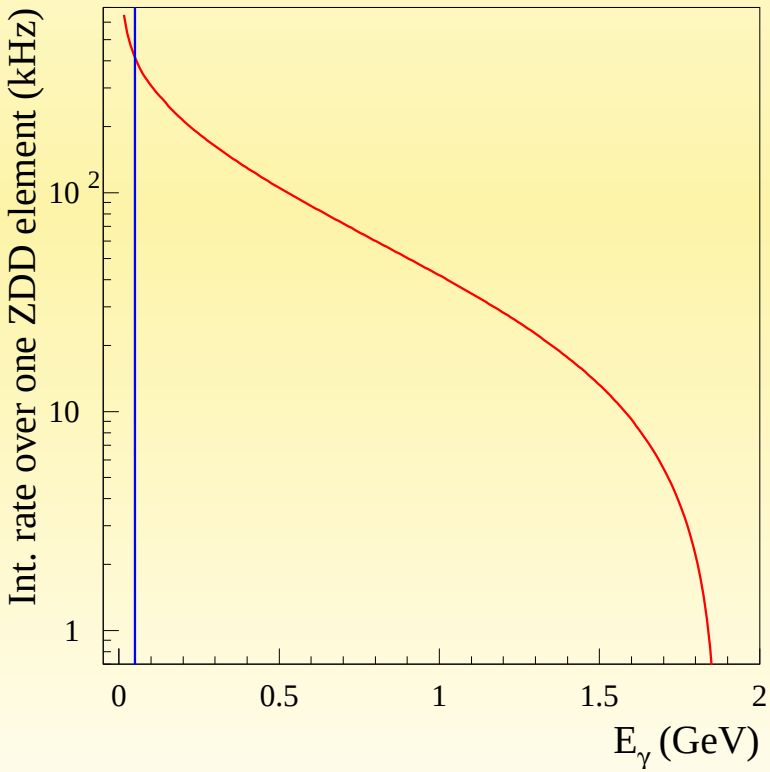
Bremsstrahlung rate

$$\overline{\mathcal{L}} = 1.5 \times 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

Bremsstrahlung rate
in 10 MeV E_γ intervals

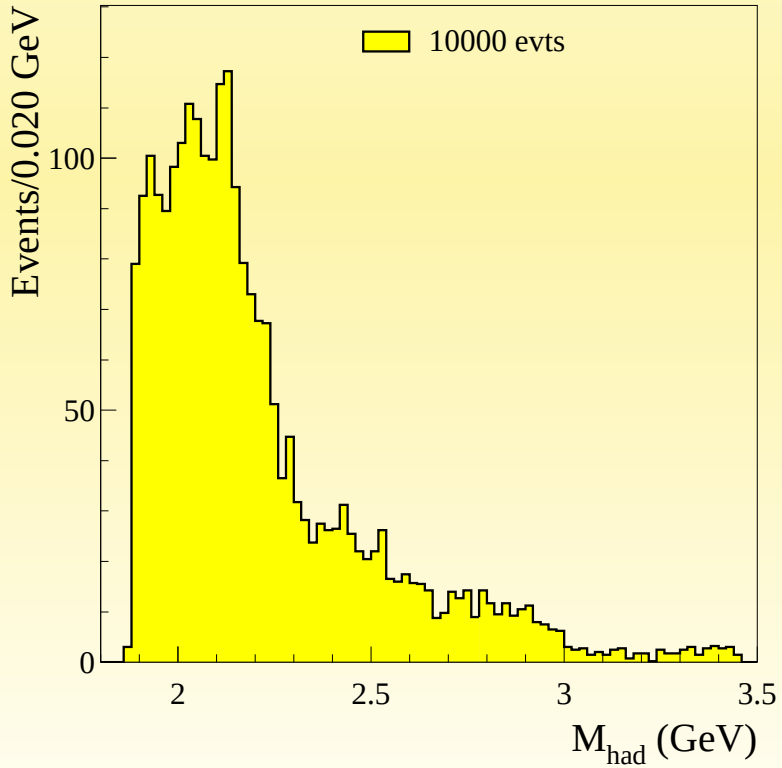


Integrated
Bremsstrahlung rate



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

- $e^+e^- \rightarrow n\bar{n}\gamma_{IS}$ at a center of mass energy: $E_{cm} = 3.77$ GeV
- Initial state photon energy range: $0 \leq E_{\gamma_{IS}} \leq \frac{E_{cm}}{2}\left(1 - \frac{4M_n^2}{E_{cm}^2}\right)$
- γ_{IS} in ZDD and only antineutron detected in BESIII



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

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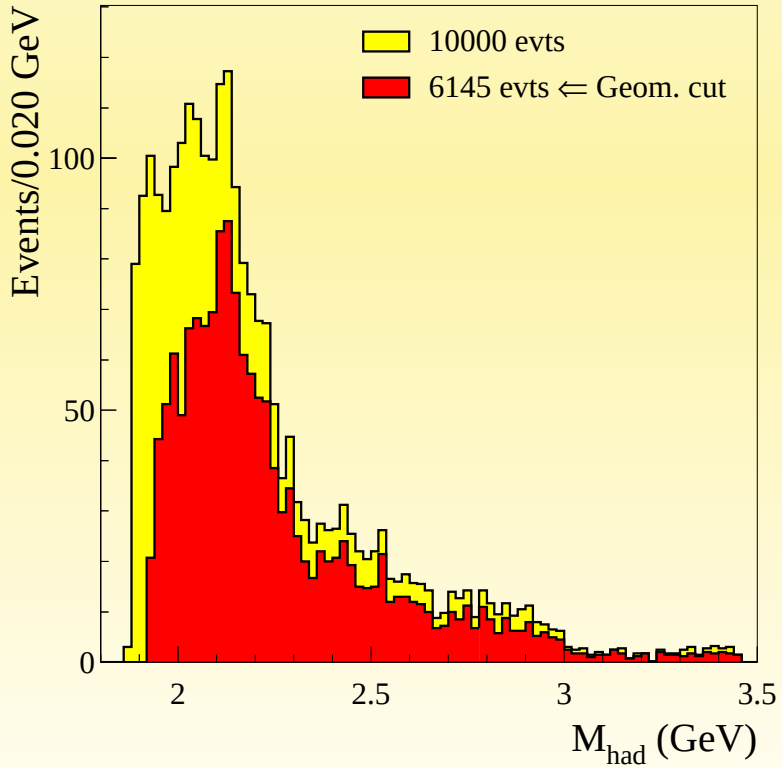

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  - $\bar{n} \rightarrow$ BESIII
  - No constraint in n

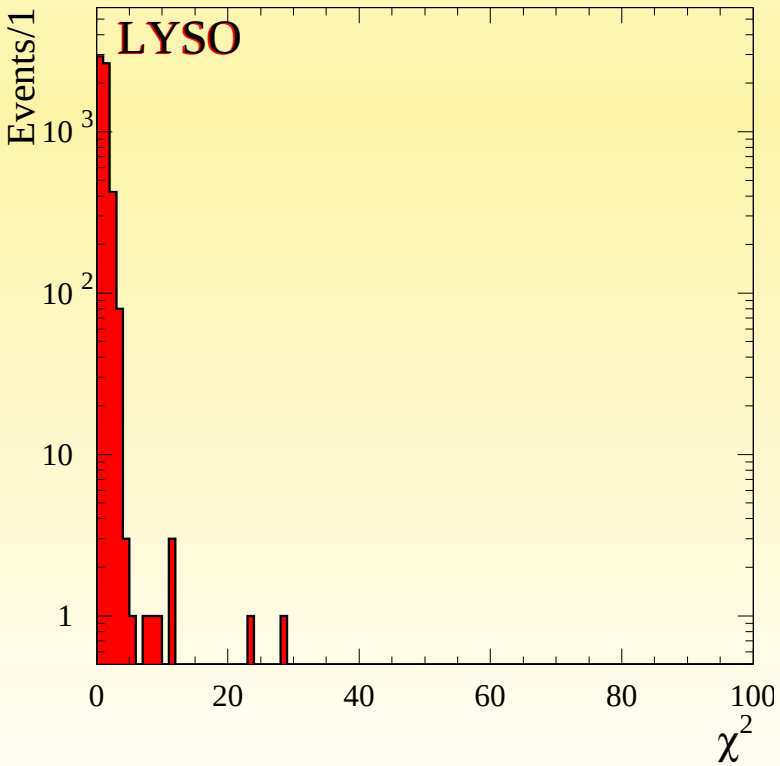
The $n\bar{n}\gamma_{IS}$ physics case: kinematic fit

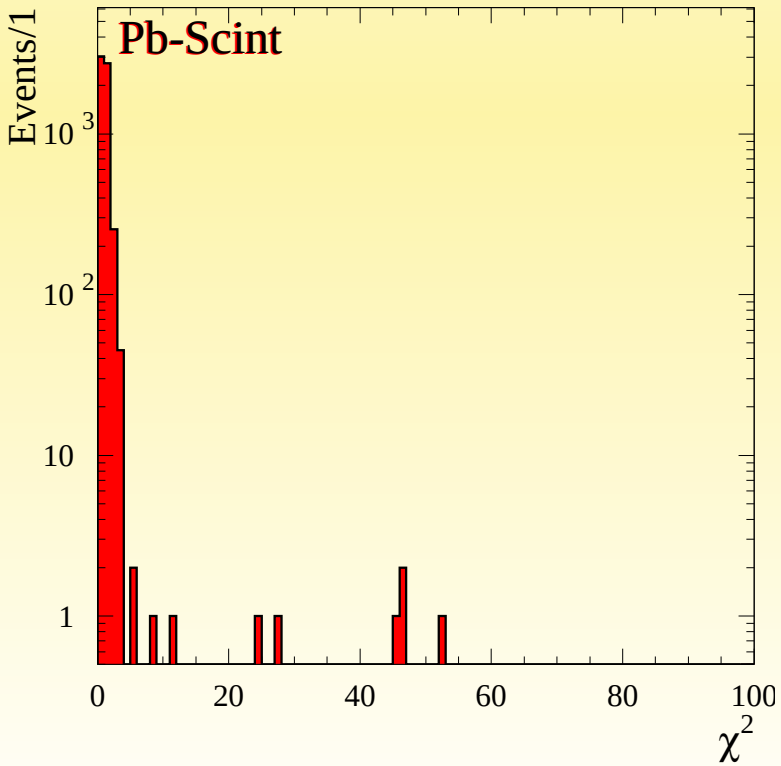
Inputs (6)
- $\bar{n}$ 3-momentum (TOF)
- γ_{IS} 3-momentum (ZDD)

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)
- $\bar{n}$ 3-momentum (TOF)
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Constraints (4)
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Unknowns (3)
- n 4-momentum

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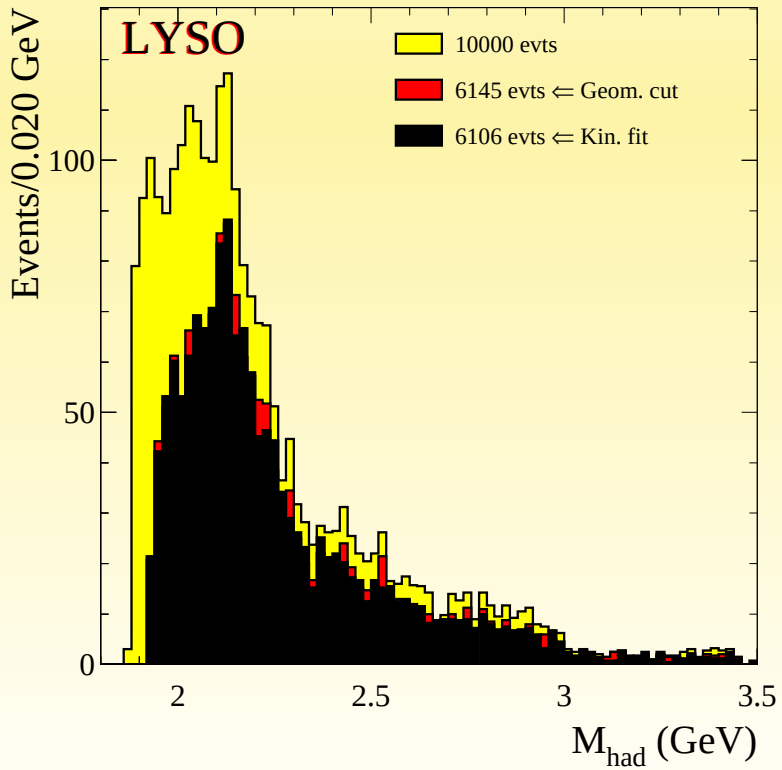
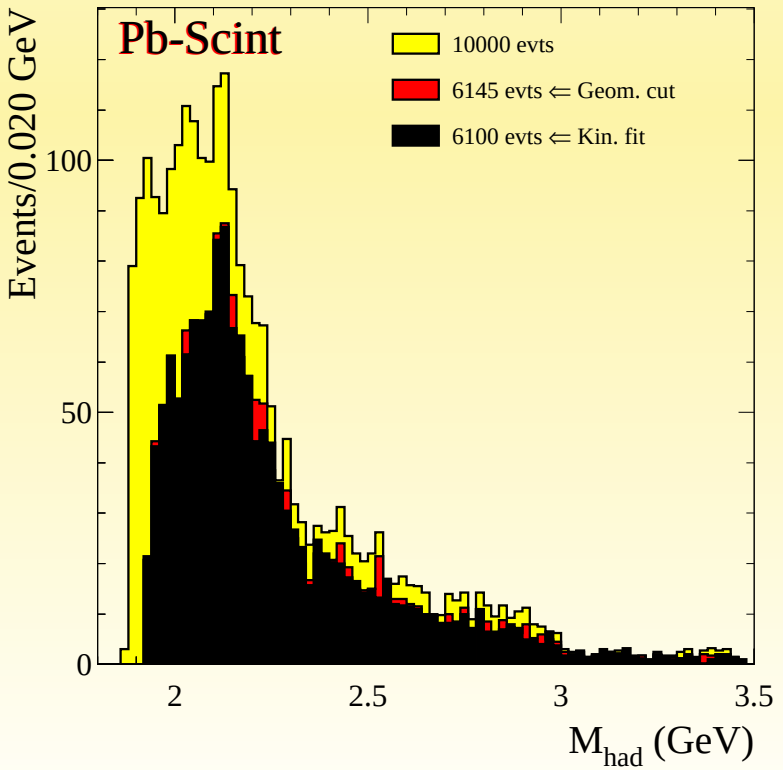
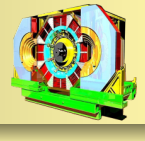




The $n\bar{n}\pi^0$ background



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

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

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

$$R_{BESIII} = 0.06 \times \underbrace{\left(\frac{0.012}{3\times10^{-6}}\right)}_{p\bar{p}\pi^0 \text{ cross section ratio}} \times \underbrace{\left(\frac{1}{10.7}\right)}_{\text{Lum. ratio}} = 22.4$$

$\gamma_{IS} \to$ ZDD

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

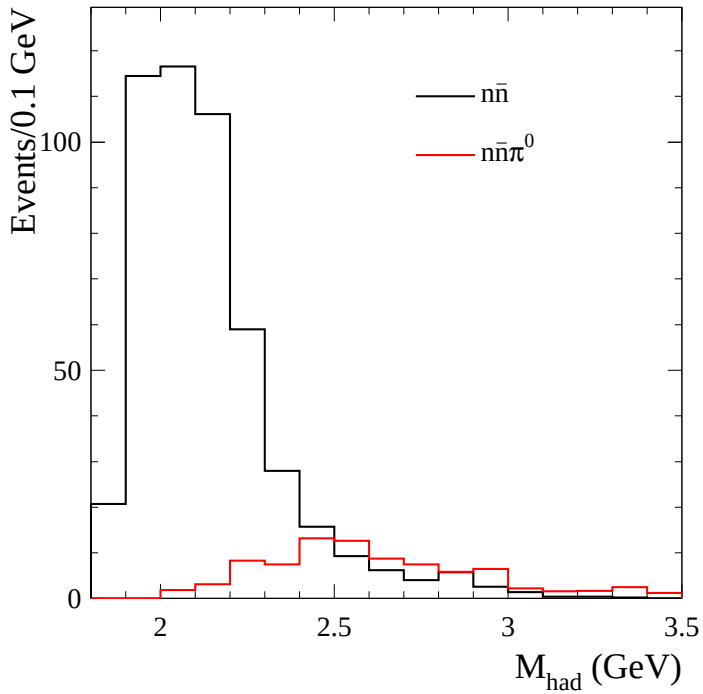
$$\frac{2\cdot(2\cdot4.5\cdot3/349^2)}{4\pi\cos\theta_{\min}} = 3.8\cdot10^{-5}$$

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

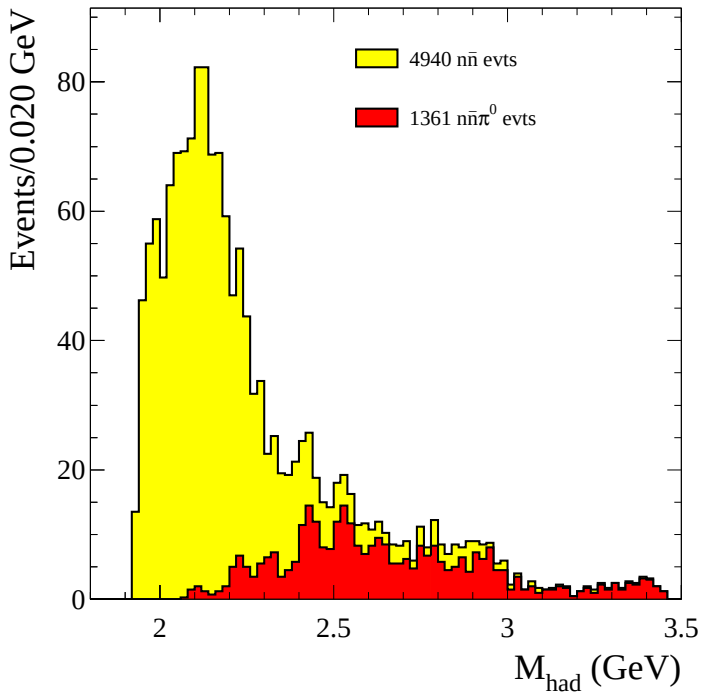
The $n\bar{n}\pi^0\gamma_{IS}$ background

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

Yields from *BABAR*

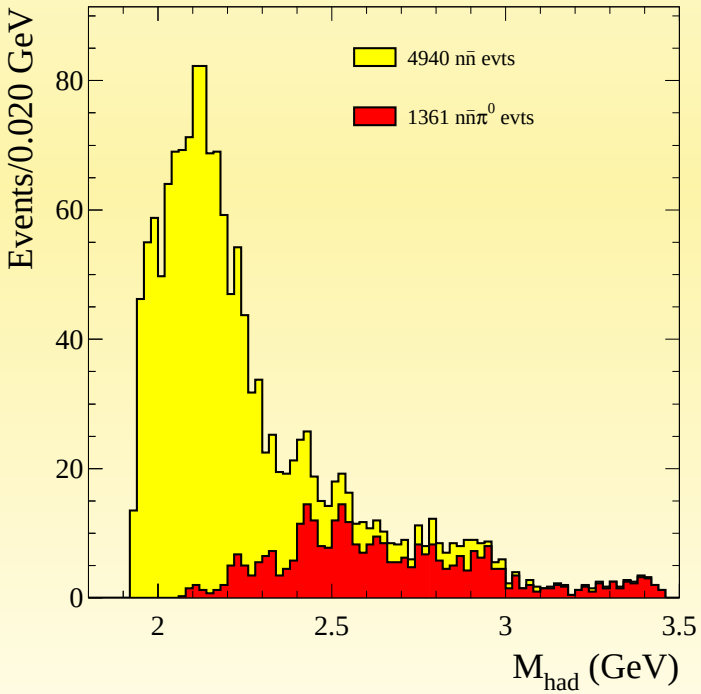


- After geometrical cut
- High contamination at high M_{had}



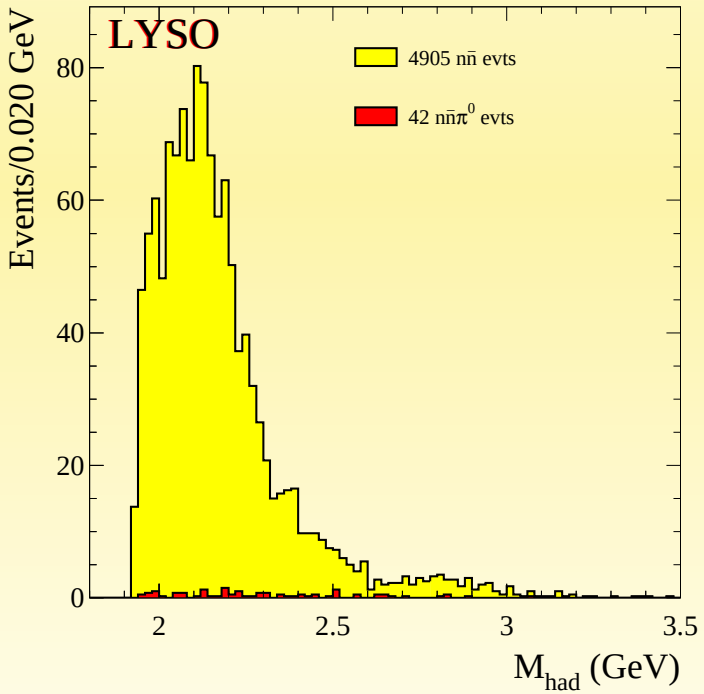
The $n\bar{n}\pi^0\gamma_{IS}$ background reduction

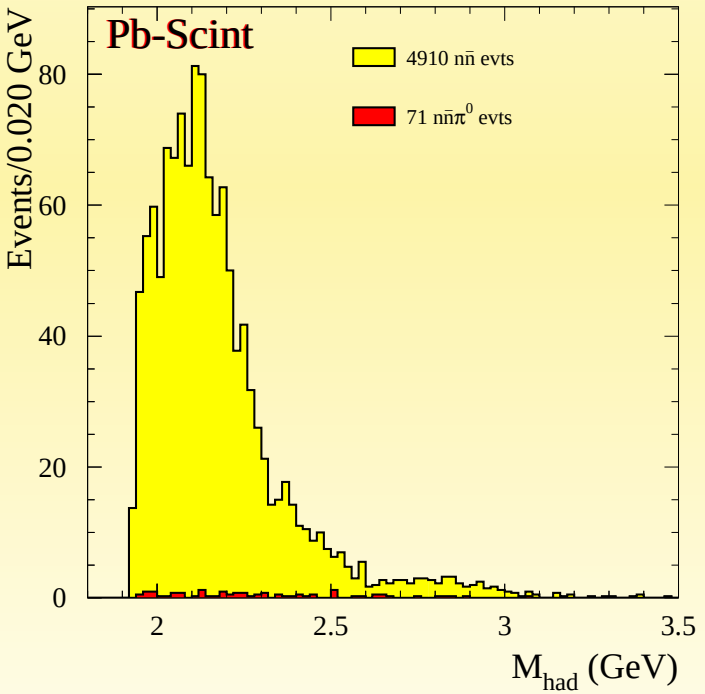
- **π^0 detection in BESIII**: at least one of the π^0 photons with E_γ>50 MeV in BESIII not in a 200 mrad cone around $\bar{n}$ direction
- **Kinematical fit**: $\chi^2 \leq 10$



The $n\bar{n}\pi^0\gamma_{ISR}$ 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
- **Kinematical fit**: $\chi^2 \leq 10$





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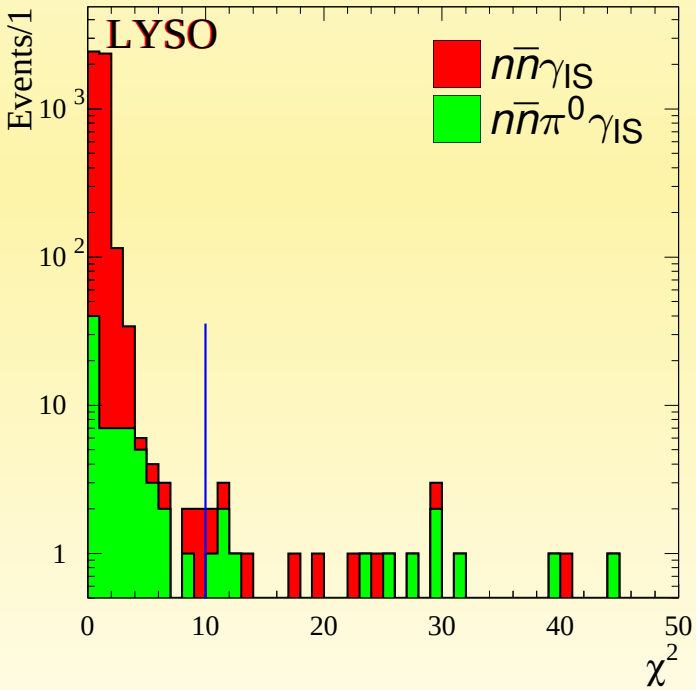

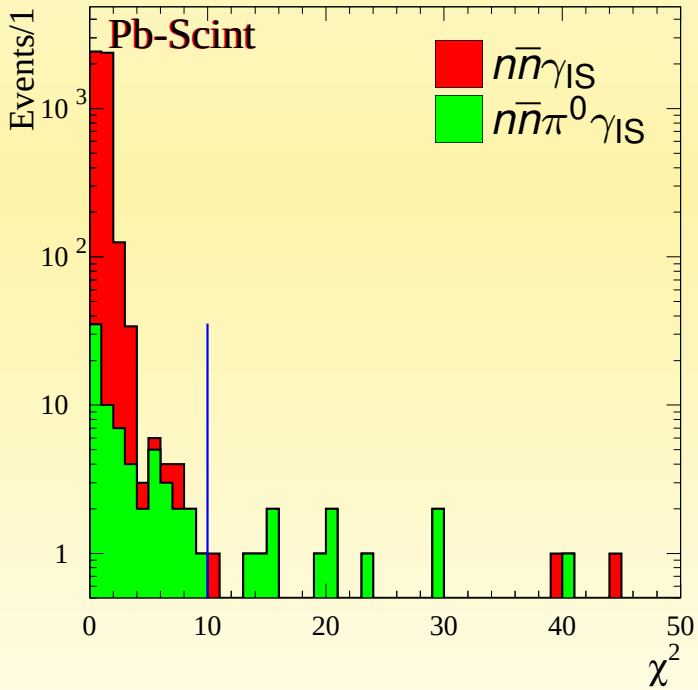

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- **π^0 detection in BESIII**: at least one of the π^0 photons with E_γ>50 MeV in BESIII not in a 200 mrad cone around $\bar{n}$ direction
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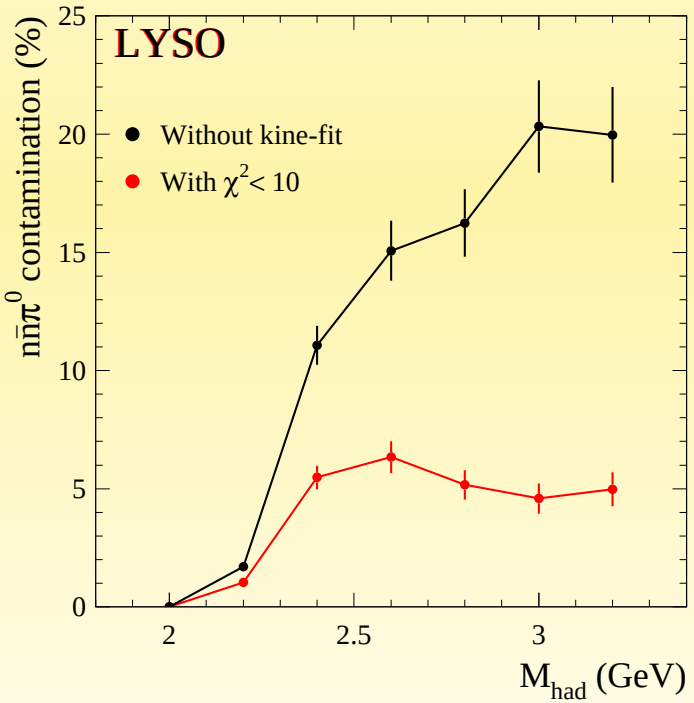
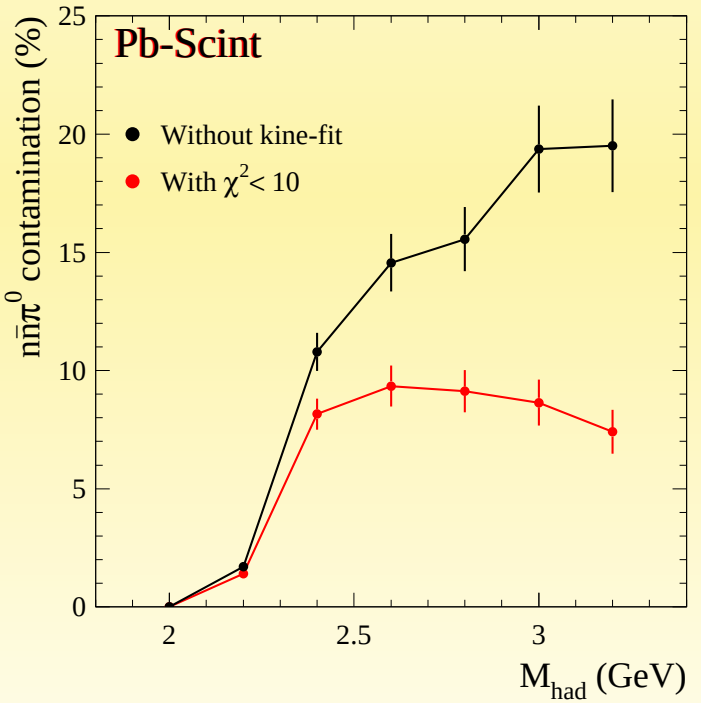
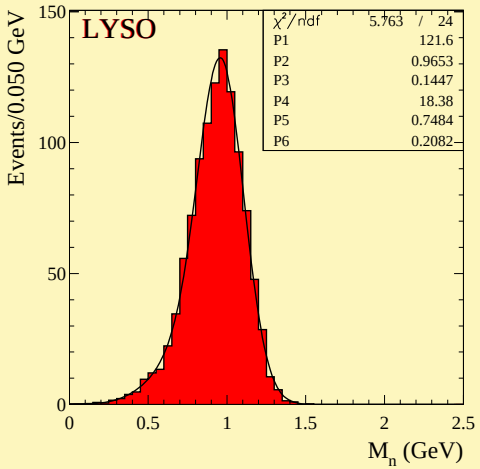


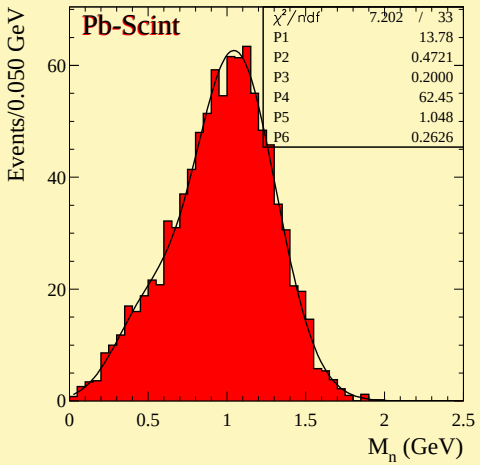


Energy resolution in $\bar{n}\gamma_{IS}$ missing mass

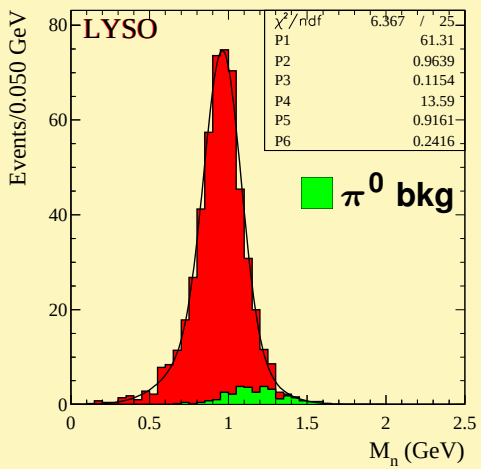
- Events are generated with fixed value of $M_{had} = E_{cm}\sqrt{1 - 2E_{\gamma_{IS}}/E_{cm}}$
- The $\bar{n}\gamma_{IS}$ missing mass is obtained only from experimental data

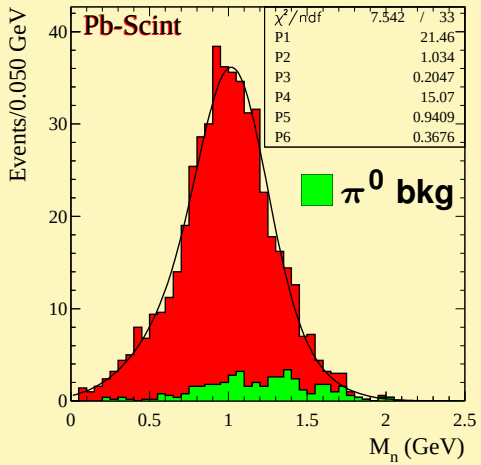
M_{had}=2.0 GeV - $E_{\gamma_{IS}}$=1.35 GeV



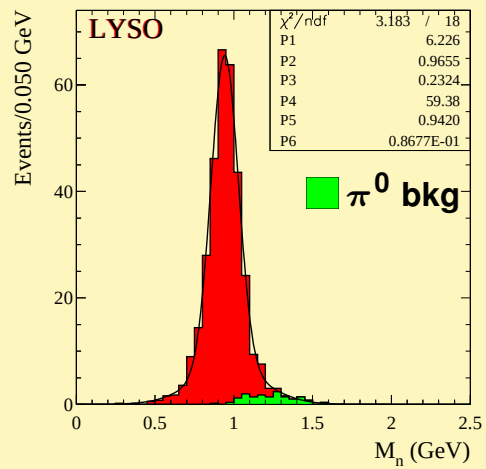


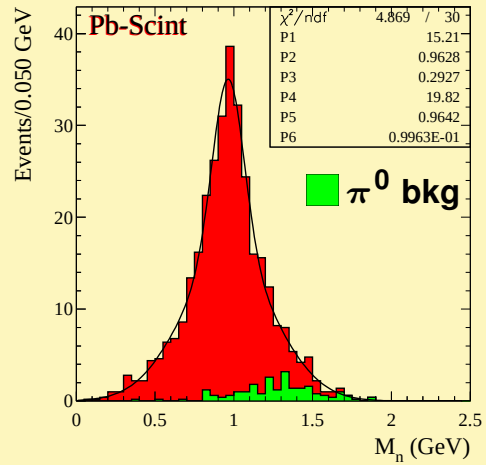
M_{had}=2.6 GeV - $E_{\gamma_{IS}}$=1.0 GeV





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

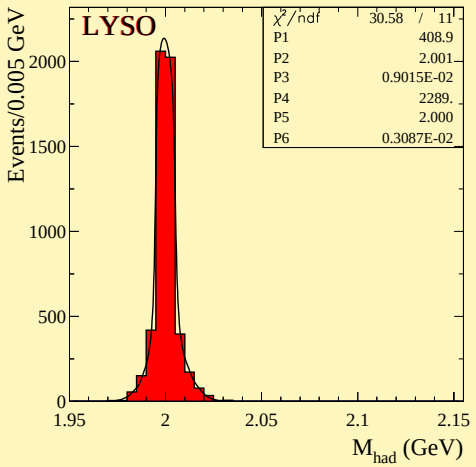


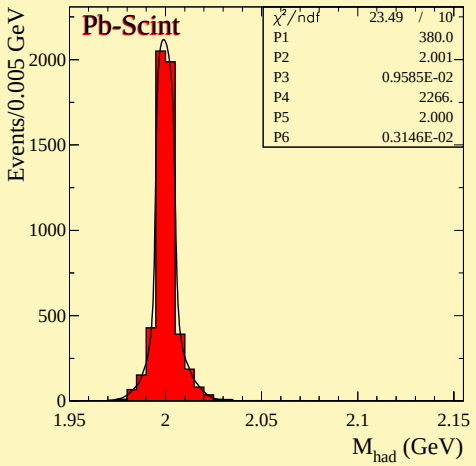


Energy resolution in M_{had} slices

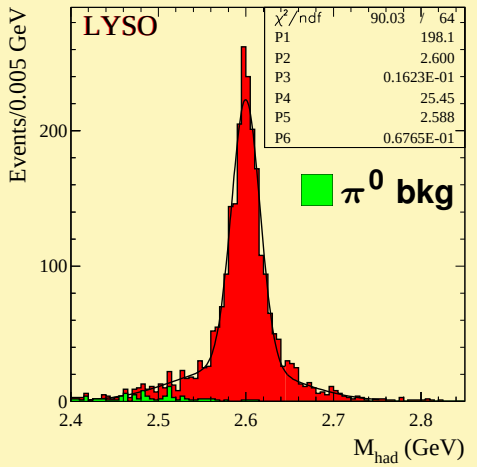
- Events are generated with fixed value of $M_{had} = E_{cm}\sqrt{1 - 2E_{\gamma_{IS}}/E_{cm}}$
- M_{had} is reconstructed using the kinematic fit procedure

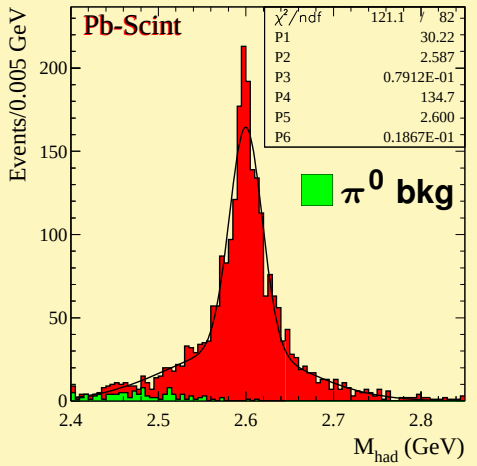
M_{had}=2.0 GeV - $E_{\gamma_{IS}}$=1.35 GeV



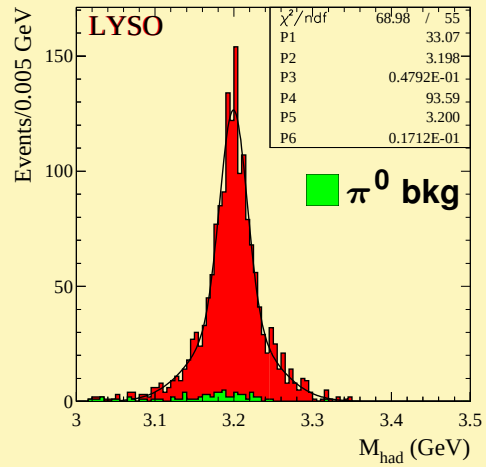


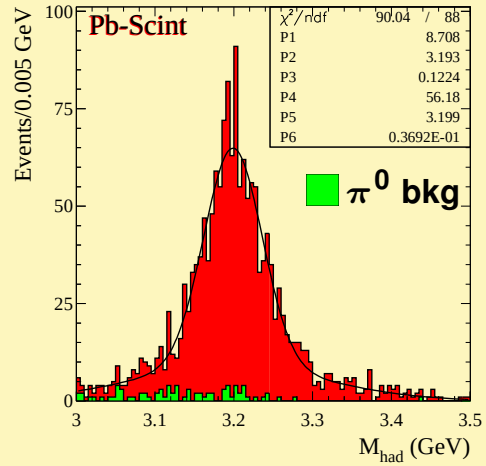
M_{had}=2.6 GeV - $E_{\gamma_{IS}}$=1.0 GeV





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

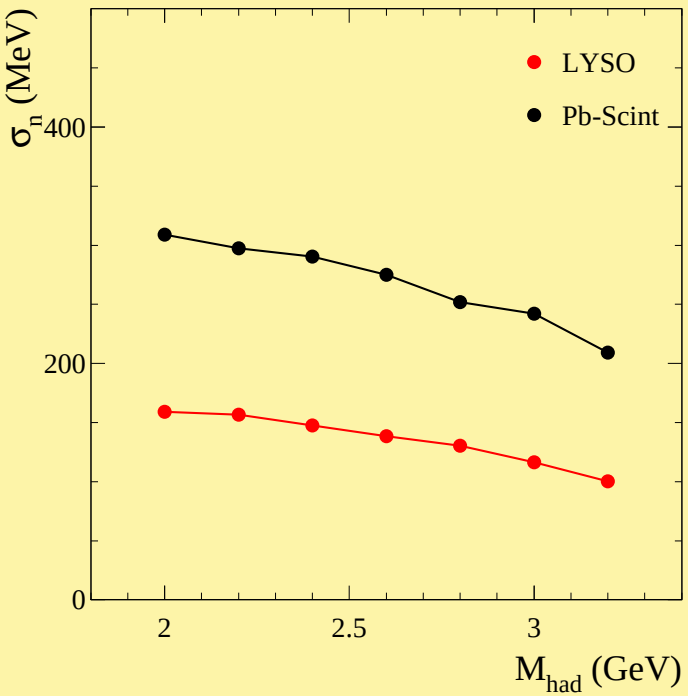




Energy resolutions

- 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

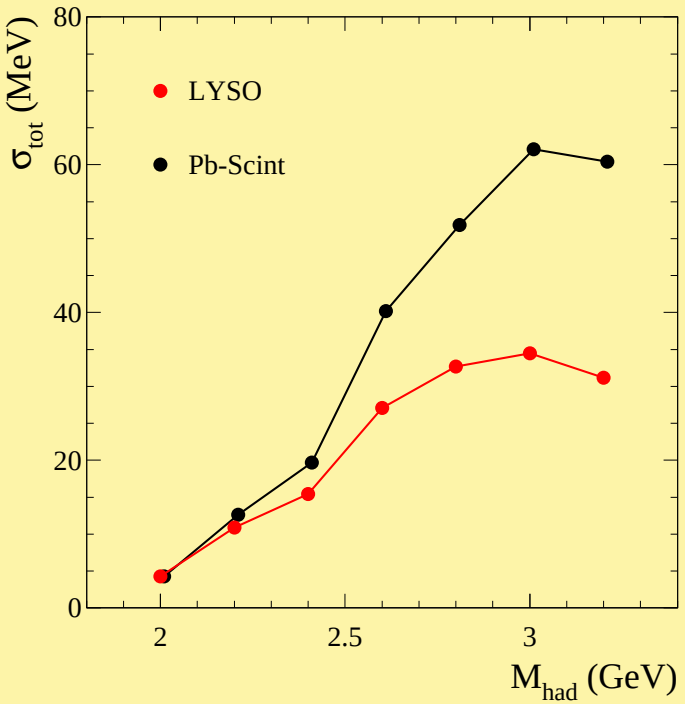
Width of the $\bar{n}\gamma_{IS}$ miss. mass



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

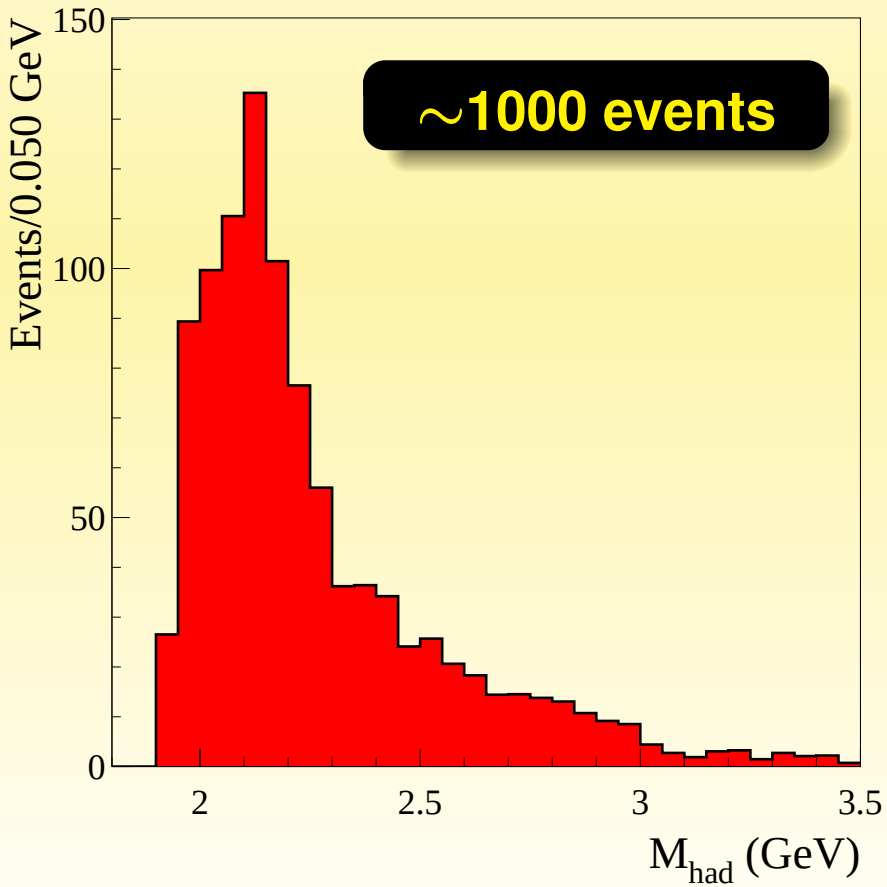


σ_{tot} is dominated by $\delta E_{\gamma_{IS}}$

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: $\overline{\mathcal{L}} = 1.5 \times 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Detection efficiency: $\epsilon = 0.5$
- Center of mass energy: $E_{\mathrm{cm}} = 3.77$ GeV



Radiation hardness

- Radiation damages mostly due to Bremsstrahlung: $\sigma_{Bre}(ZDD/4) = 2.6$ 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: $E_{cm} = 3.77$ GeV

$$\frac{\text{Dose absorbed}}{\text{year}} = \frac{\text{energy deposited}}{\text{year} \cdot \text{mass}} = \begin{cases} \dfrac{3\times10^{21}\ \text{eV}}{0.12\ \text{kg}} = 4\times10^{5}\ \dfrac{\text{rad}}{\text{year}} & \text{LYSO} \\ \dfrac{3\times10^{21}\cdot\frac{2}{13}\ \text{eV}}{1.8\times10^{-2}\ \text{kg}} = 10^{6}\ \dfrac{\text{rad}}{\text{year}} & \text{Scint} \end{cases}$$

Costing and 2010 requests

Material	quantity	Brand	Cost (KEuro)
LYSO crystals	863 cm^3 + 4 spare bars	SICCAS St. Gobain	**26** **52**
APD	28		**28**
TDC	1 + 1 spare		**10**
FADC (8 ch)	3 + 1 spare		**20**
		Total (SICCAS)	**85**
		Total (St. Gobain)	**110**

2010 requests

- LYSO crystals (SICCAS whole quantity, St. Gobain half) ..... **30 KEuro**
- 2 APDs ..... **2 KEuro**
- Consumable materials ..... **2 KEuro**

Total ..... **34 KEuro**