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Measurement of $B^0_{(s)} \to \eta\eta$ at CEPC

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Status of B→ηη

Channel	DATA	SCET [1]	QCDF	pQCD
$B^0 \to \eta\eta$	< 1 [2]	$0.69 \pm 0.38 \pm 0.13 \pm 0.58$ $1.0 \pm 0.4 \pm 0.3 \pm 1.4$	$0.32^{+0.13+0.07}_{-0.05-0.06}$ [3] $0.16^{+0.03+0.43+0.09+0.10}_{-0.03-0.18-0.03-0.05}$ [4]	0.067 [5]
$B_s^0 \to \eta\eta$	< 1500 [6]	$7.1 \pm 6.4 \pm 0.2 \pm 0.8$ $6.4 \pm 6.3 \pm 0.1 \pm 0.7$	$10.9^{+6.3+5.7}_{-4.0-4.2}$ [7]	$10.4^{+4.9}_{-3.4}$ [8]

Table 1: Experimental mesaurements and theoretical predictions of the branching ratios (in unit of 10^{-6}) of $B \to \eta\eta$ decays. The soft collinear effective theory (SCET), QCD factorization (QCDF), and perturbative QCD (pQCD) are three common theoretical techniques to deal with the hadronic B-meson decays.

$$BR(B^0 \to \eta\eta) \sim 1 \times 10^{-7}$$
$$BR(B_s^0 \to \eta\eta) \sim 1 \times 10^{-5}$$

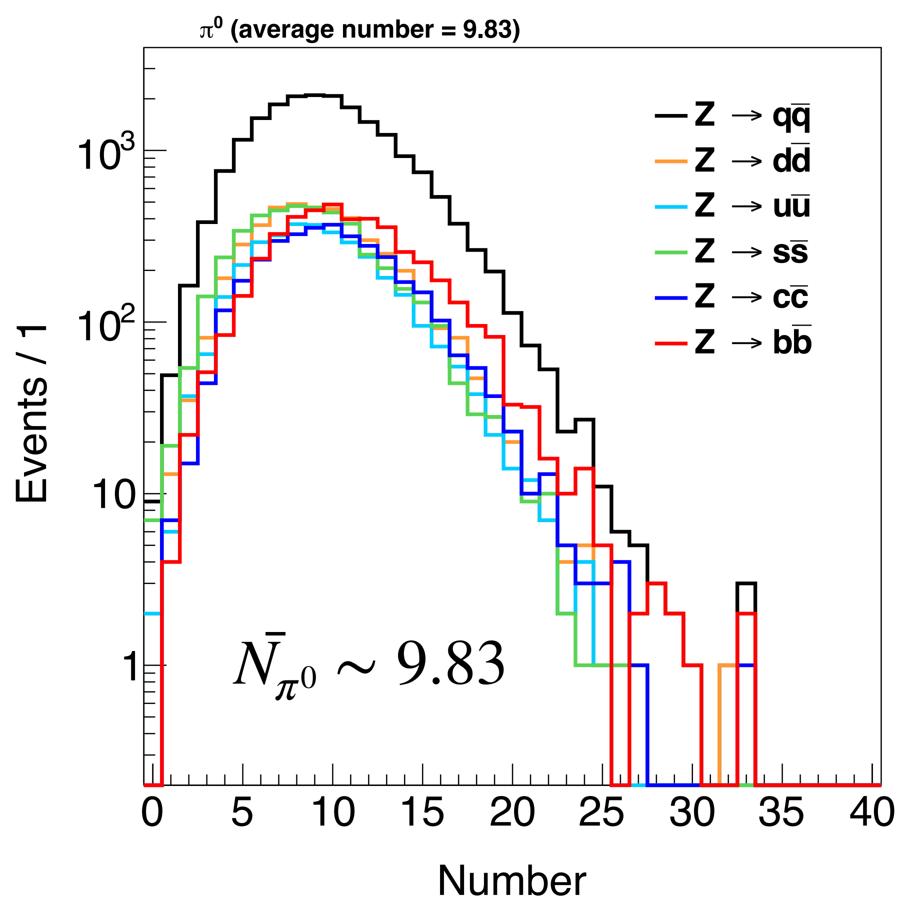
are used in the following analysis

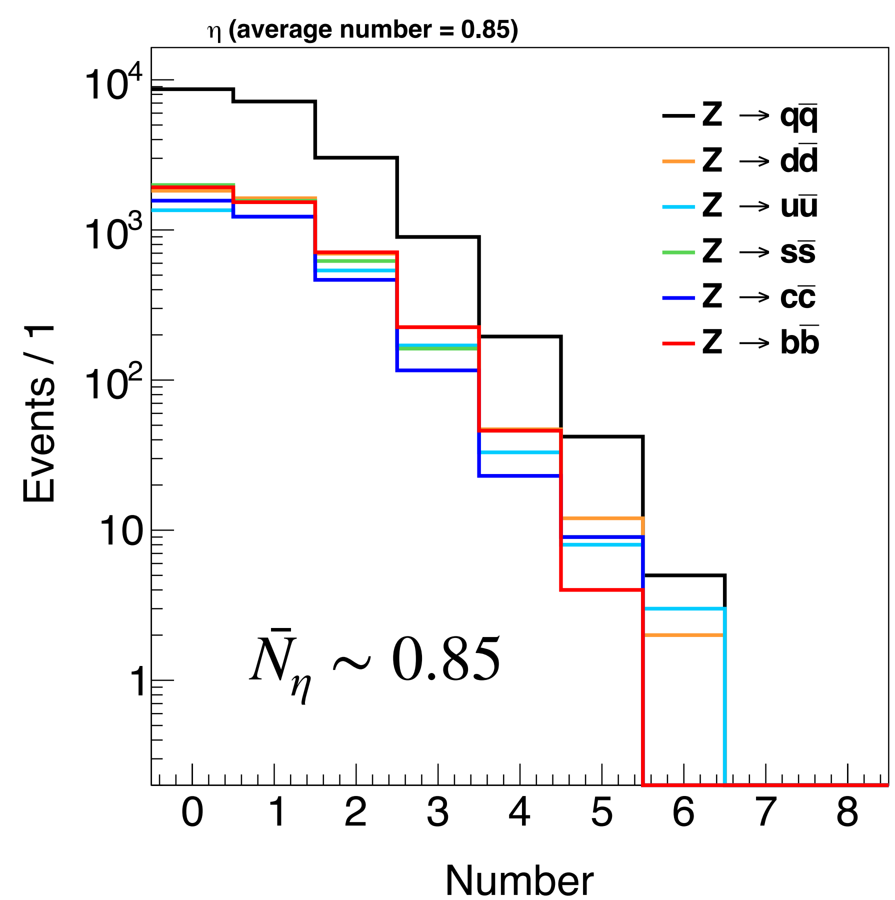
References

[1] A.R. Williamson and J. Zupan, Two body B decays with isosinglet final states in SCET, Phys. Rev. D 74 (2006) 014003 [hep-ph/0601214].
[2] BaBar collaboration, B meson decays to charmless meson pairs containing eta or eta' mesons, Phys. Rev. D 80 (2009) 112002 [0907.1743].
[3] H.-Y. Cheng and C.-K. Chua, Revisiting Charmless Hadronic B(u,d) Decays in QCD Factorization, Phys. Rev. D 80 (2009) 114008 [0909.5229].
[4] M. Beneke and M. Neubert, QCD factorization for B —> PP and B —> PV decays, Nucl. Phys. B 675 (2003) 333 [hep-ph/0308039].
[5] Z.-j. Xiao, D.-q. Guo and X.-f. Chen, Branching Ratio and CP Asymmetry of B0 —> eta-(prime) eta- (prime) Decays in the Perturbative QCD Approach, Phys. Rev. D 75 (2007) 014018 [hep-ph/0607219].
[6] L3 collaboration, Search for neutral charmless B decays at LEP, Phys. Lett. B 363 (1995) 127.
[7] H.-Y. Cheng and C.-K. Chua, QCD Factorization for Charmless Hadronic B_S Decays Revisited, Phys. Rev. D 80 (2009) 114026 [0910.5237].
[8] D.-C. Yan, X. Liu and Z.-J. Xiao, Anatomy of $B_S \to P\,P$ decays and effects of the next-to-leading order contributions in the perturbative QCD approach, Nucl. Phys. B 946 (2019) 114705 [1906.01442].

Reconstruction of Eta

- **Focus on the di-photon final state: BR($\eta\to\gamma\gamma$) = (39.41±0.20)%**
- **Average number of π^0 is significantly larger than that of η in Z→qq events**

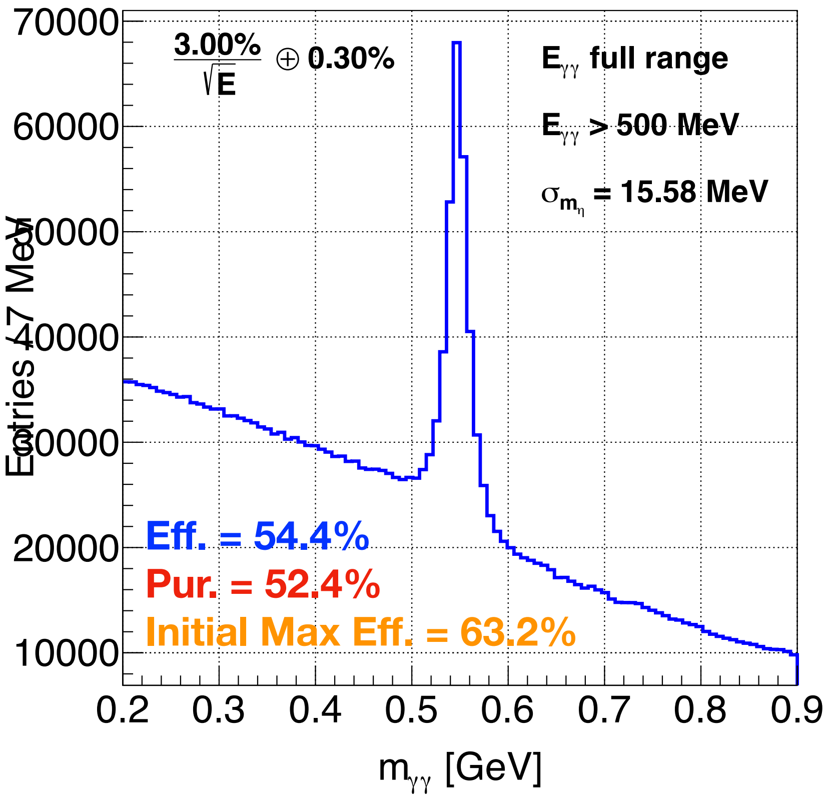


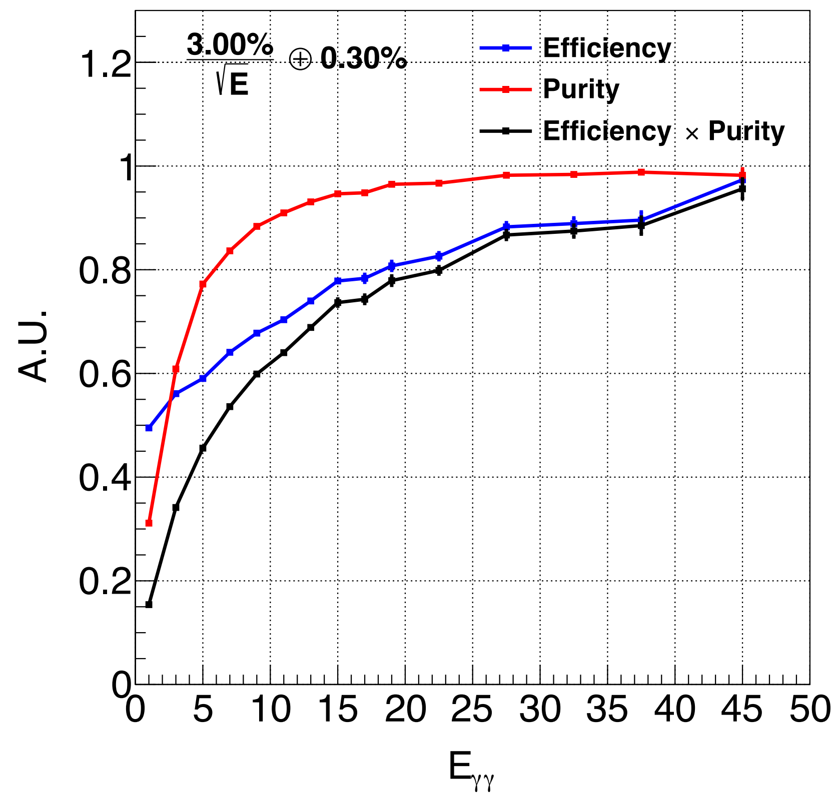


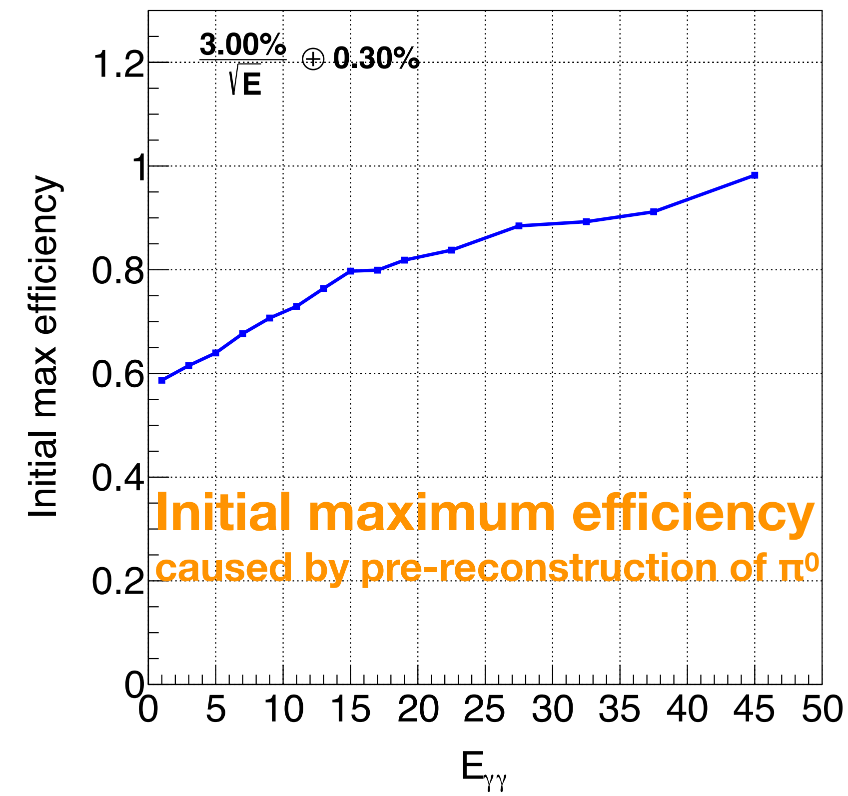
☞***Exclude all photons entering into the π^0 mass window to reduce the combinatorial background related to π^0.***

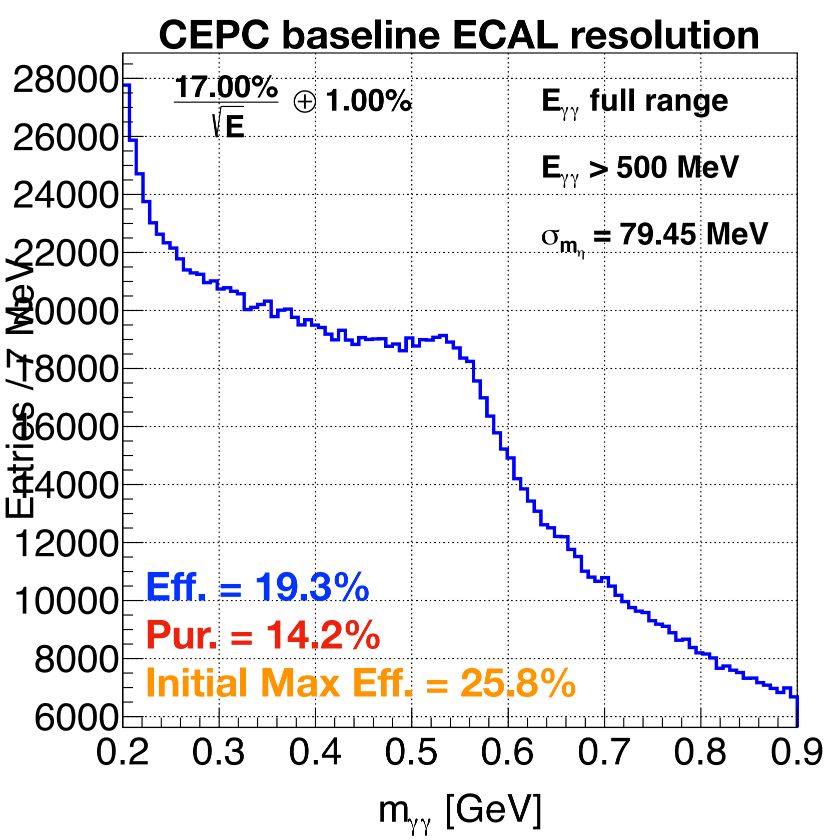
Z→qq @91.2GeV

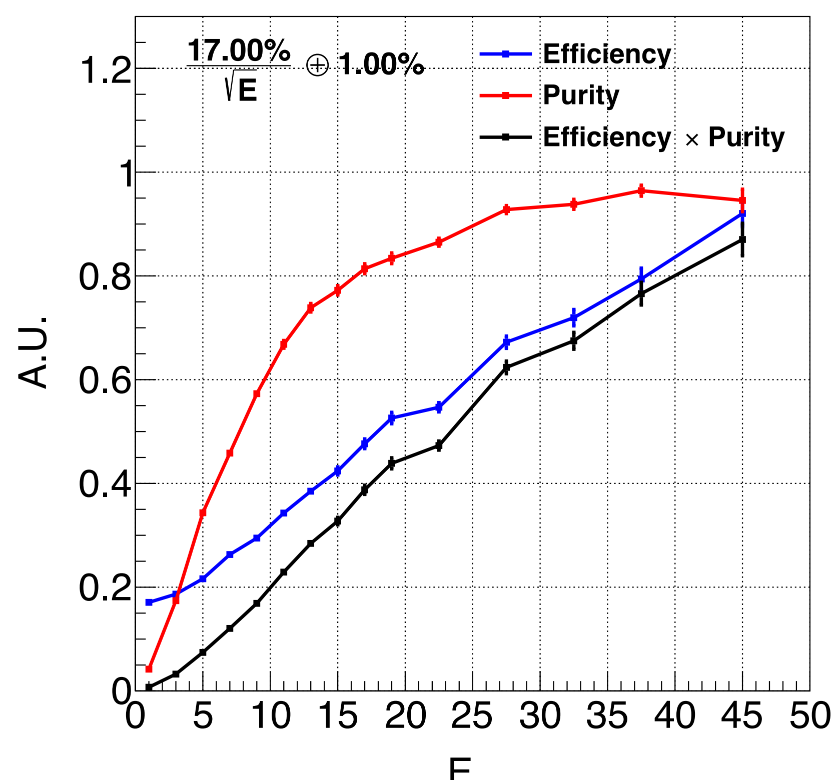
Eta Efficiency & Purity vs Energy

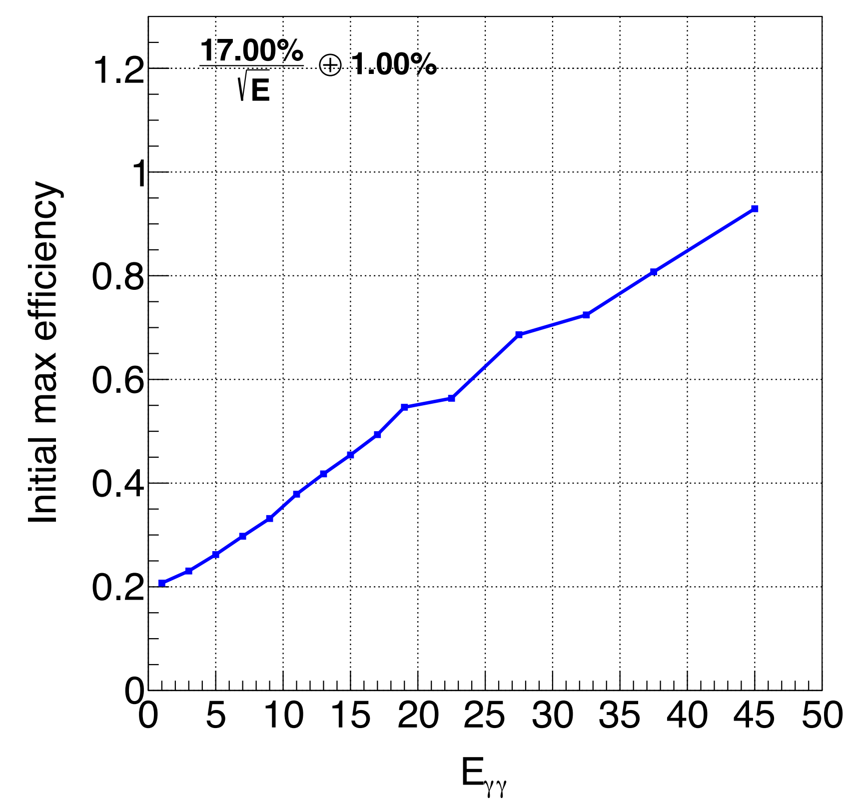




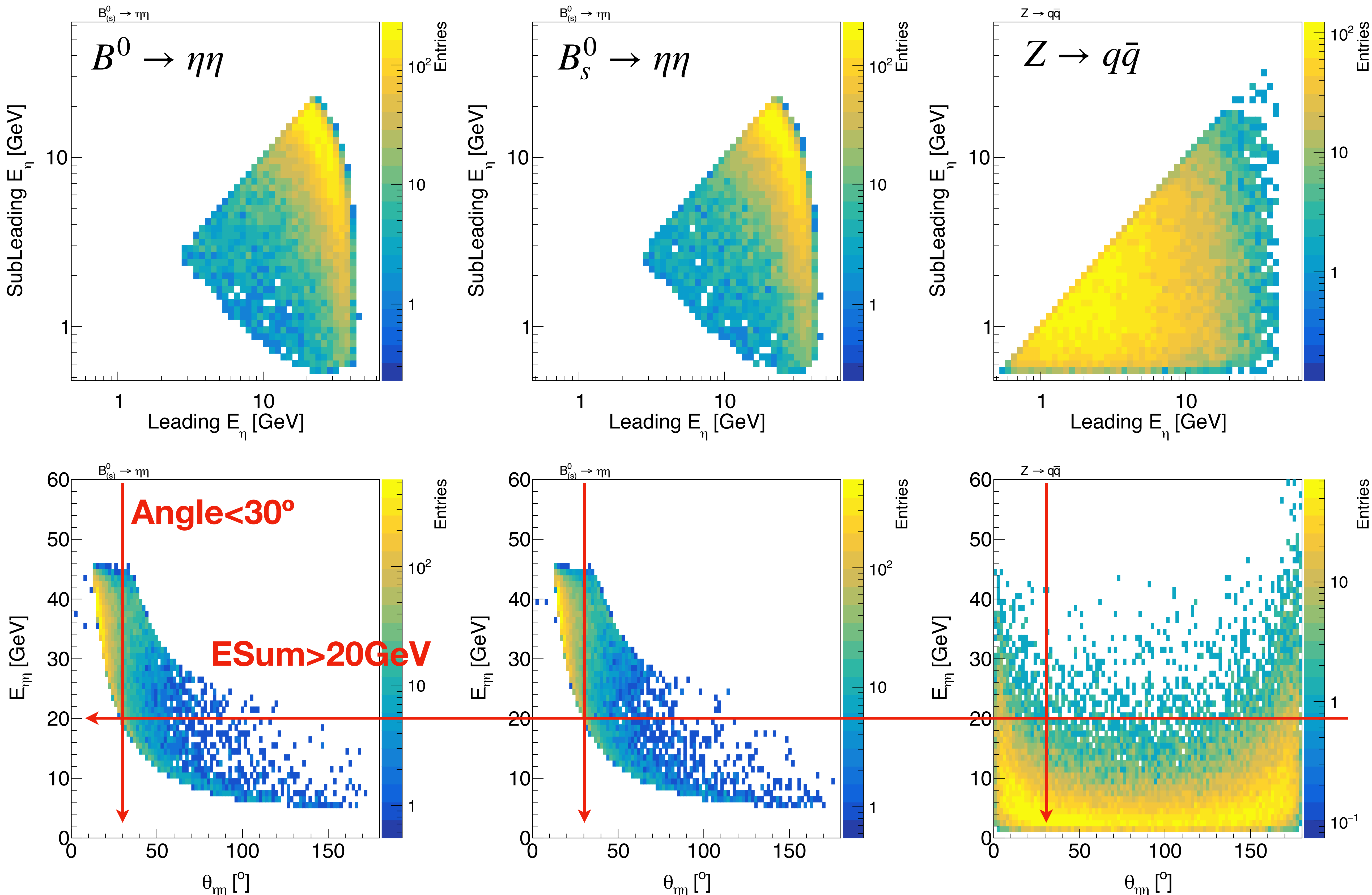






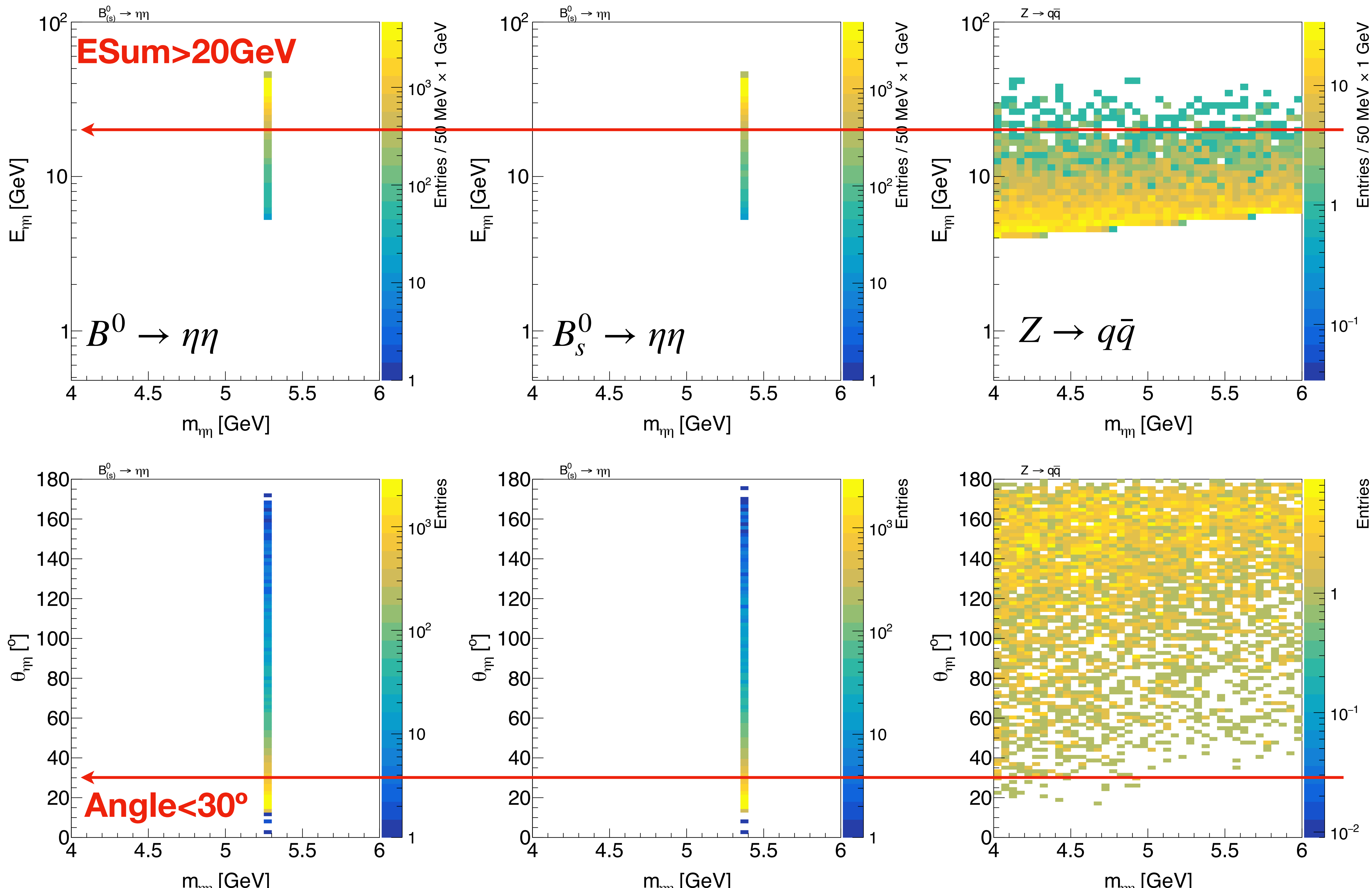


Eta Pair Distributions



MCTruth Level

Eta Pair Distributions



MCTruth Level

Event selection

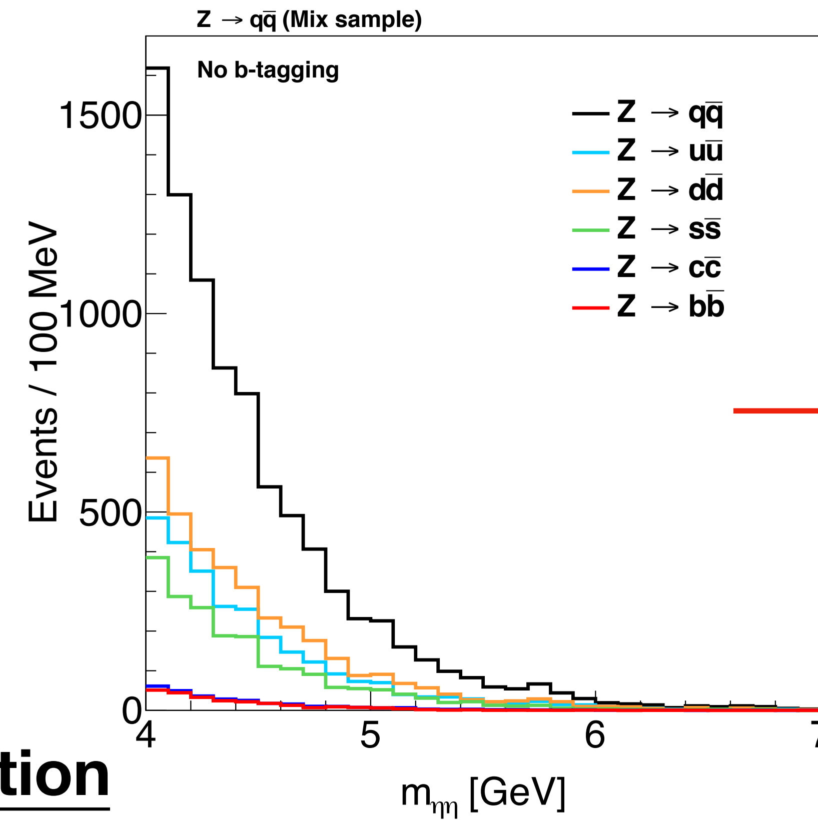
Cut chain:

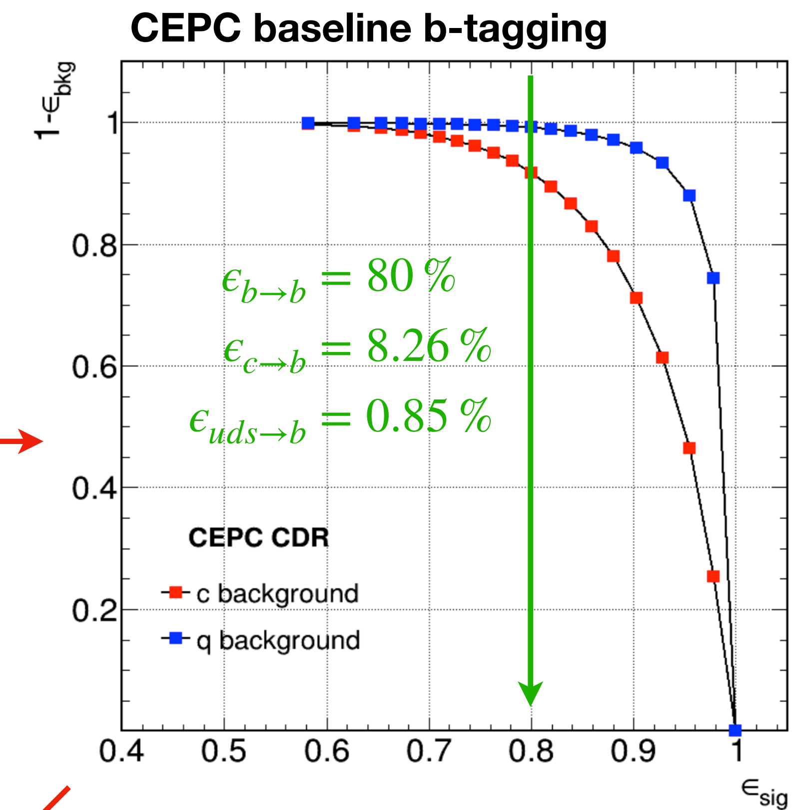
- $E_{\eta\eta} > 20$GeV
- $\theta_{\eta\eta} < 30^{o}$
- $m_{\eta\eta} > 4$GeV

Signal efficiency ~75%

Background model:

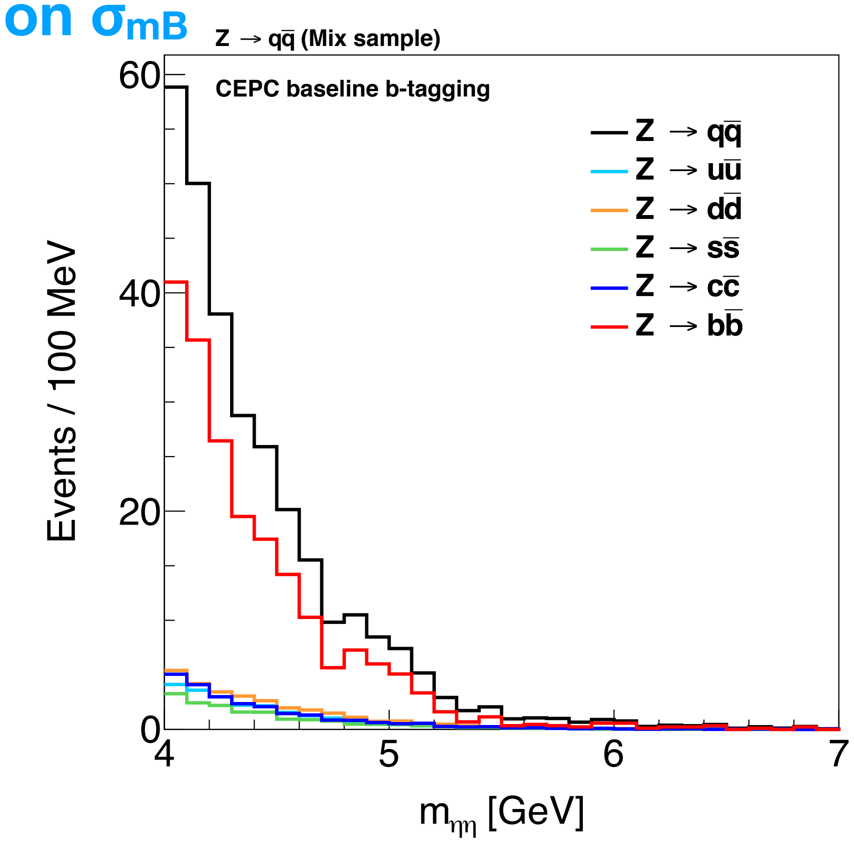
f_{bkg}~Ne^{-ax} (exponential)

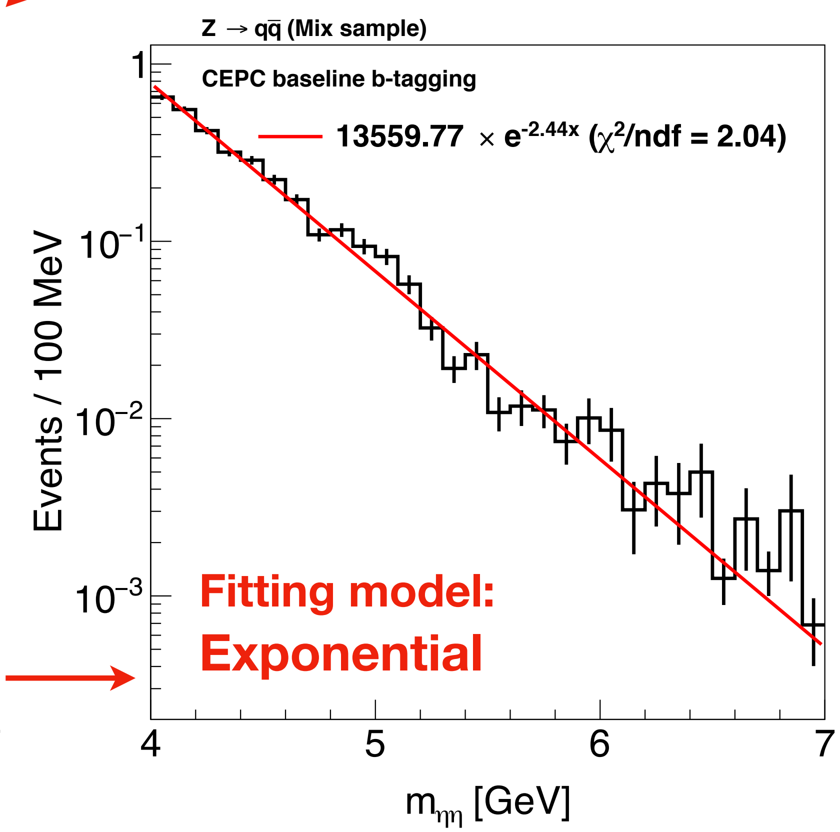




Simple modelling of ECAL resolution

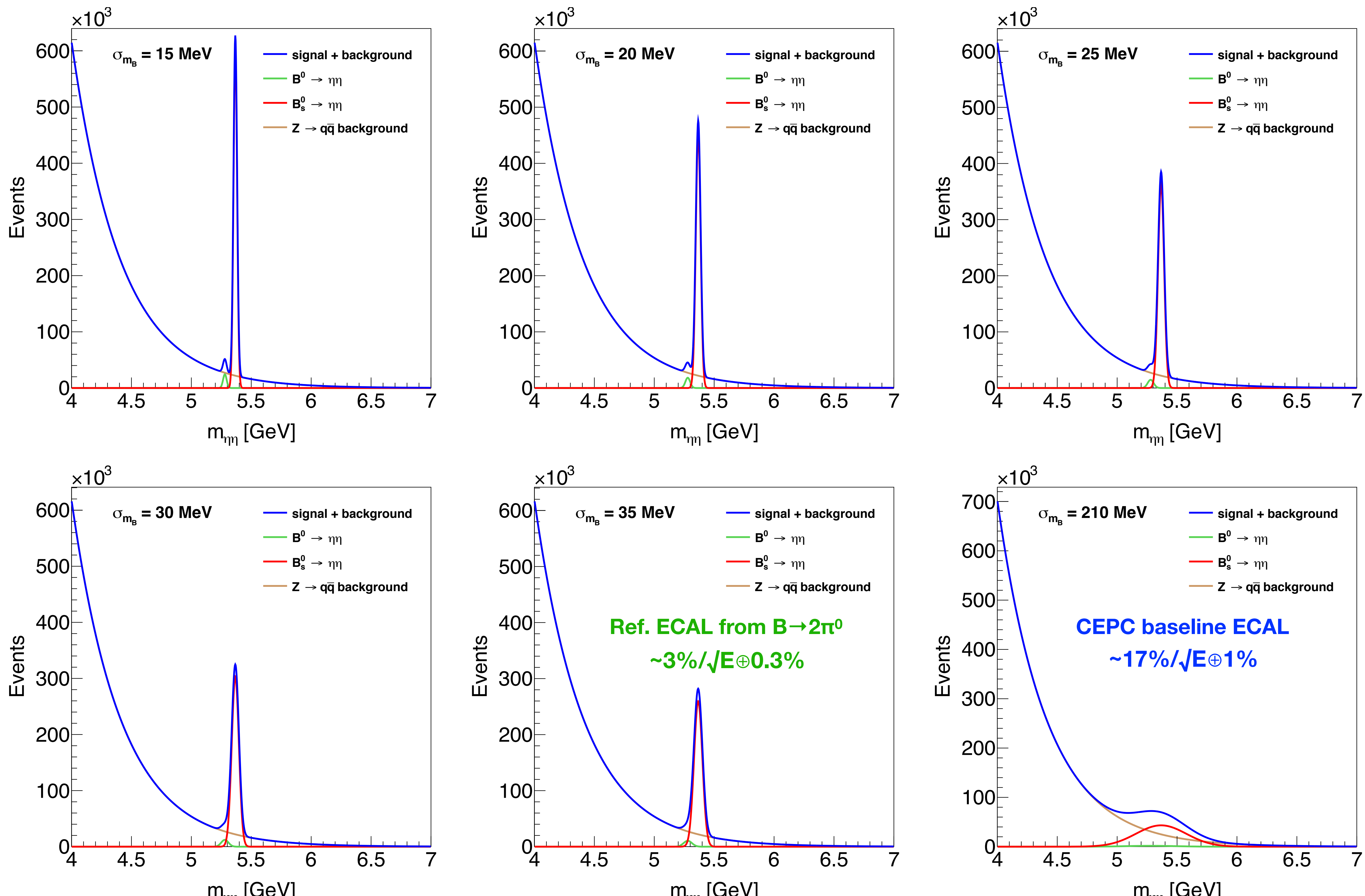
- **Characterized as B mass resolution σ_{mB}**
- **Signal:**
  - **Gaus(m_B,σ_{mB})**
  - **Efficiency**
    - **Event selection (cuts on η)**
    - **Reconstruction of η ~80%**
- **Background:**
  - **f_{bkg} convolve Gaus(0,σ_{mB})**



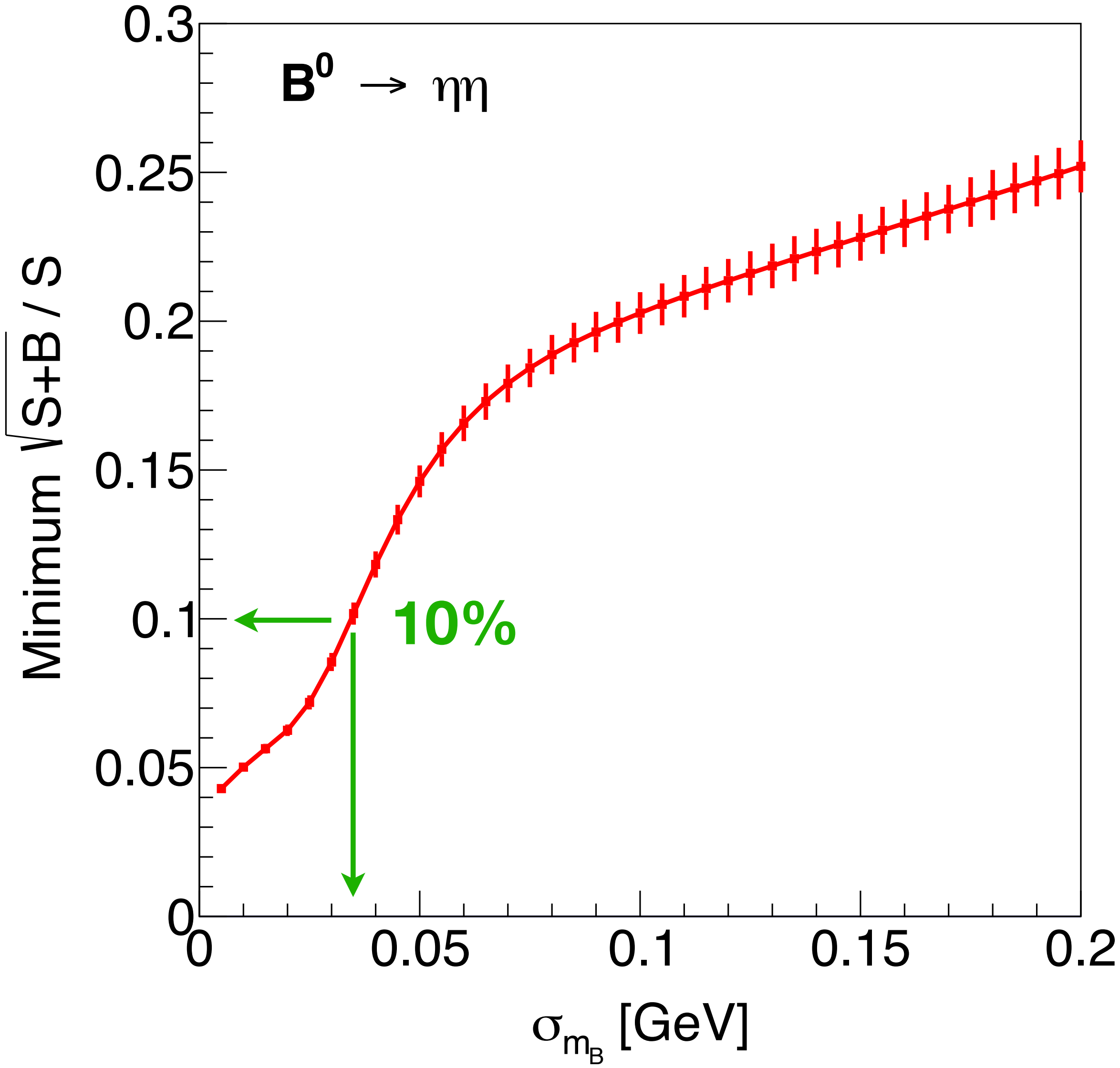


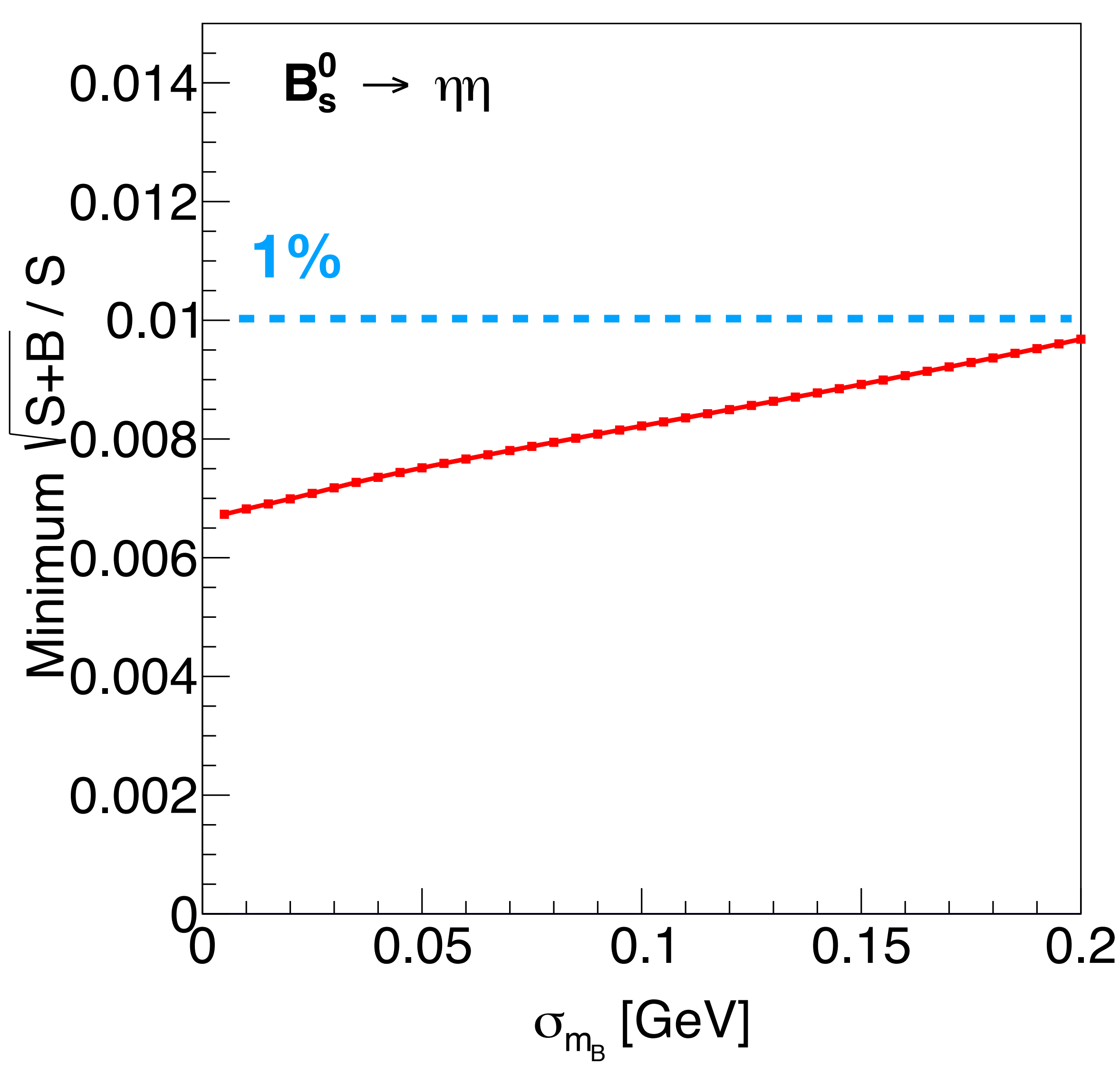
MCTruth Level

$m_{\eta\eta}$ at different B mass resolution



Accuracy





Limitation of the current simple modelling:

- **η reconstruction efficiency is constant → vs ECAL resolution**
- **Not consider the impurity caused by the η reconstruction**

Summary

☞Eta reconstruction efficiency and purity are quantified

- based on the pi0 reconstruction (initial max efficiency < 100%)
- Sample: Z→qq@91.2GeV

ECAL Energy Resolution	Max efficiency	Efficiency	Purity
$17\%/\sqrt{E}\oplus1\%$ (CEPC baseline)	25.8%	19.3%	14.2%
$3\%/\sqrt{E}\oplus0.3\%$ (Ref. ECAL from $B\to2\pi^0$)	63.2%	54.4%	52.4%

☞MCTruth level study

- Event selection
  - Signal efficiency ~75%
  - Background model: exponential
- Simple model of ECAL resolution
  - Characterized as B mass resolution σ_{mB}
  - Background pdf convolve Gaus(0,σ_{mB})
  - Further optimization
    - η reconstruction efficiency as a function of ECAL resolution
    - Model the impurity caused by the η reconstruction

Backup

$B^0_{(s)} \to \eta\eta$

$$\begin{aligned} N_{B^0\to\eta\eta} &= N_Z \times \mathcal{B}(Z\to b\bar{b}) \times 2 \times f(b\to B_d) \times \mathcal{B}(B^0\to\eta\eta) \\ &= 10^{12} \times 15.12\% \times 2 \times 40.7\% \times 1 \times 10^{-7} \\ &\approx 12,308 \end{aligned}$$

$$\begin{aligned} N_{B^0\to\eta\eta\to4\gamma} &= N_Z \times \mathcal{B}(Z\to b\bar{b}) \times 2 \times f(b\to B_d) \times \mathcal{B}(B^0\to\eta\eta) \times \mathcal{B}(\eta\to\gamma\gamma)^2 \\ &= 10^{12} \times 15.12\% \times 2 \times 40.7\% \times 1 \times 10^{-7} \times 39.41\%^2 \\ &\approx 1,912 \end{aligned}$$

$$\begin{aligned} N_{B^0_s\to\eta\eta} &= N_Z \times \mathcal{B}(Z\to b\bar{b}) \times 2 \times f(b\to B_s) \times \mathcal{B}(B^0_s\to\eta\eta) \\ &= 10^{12} \times 15.12\% \times 2 \times 10.1\% \times 1 \times 10^{-5} \\ &\approx 305,424 \end{aligned}$$

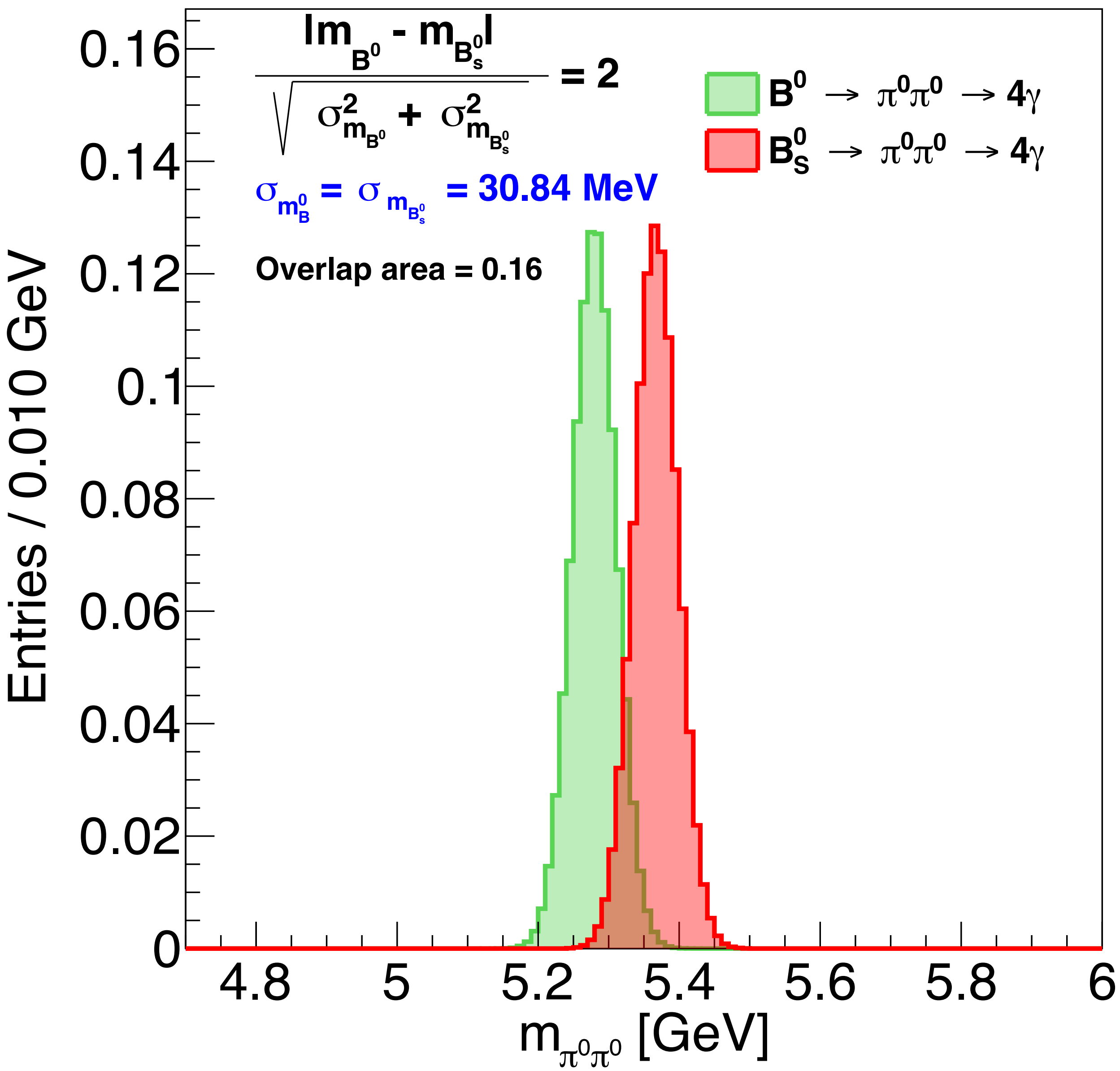
$$\begin{aligned} N_{B^0_s\to\eta\eta\to4\gamma} &= N_Z \times \mathcal{B}(Z\to b\bar{b}) \times 2 \times f(b\to B_s) \times \mathcal{B}(B^0_s\to\eta\eta) \times \mathcal{B}(\eta\to\gamma\gamma)^2 \\ &= 10^{12} \times 15.12\% \times 2 \times 10.1\% \times 1 \times 10^{-5} \times 39.41\%^2 \\ &\approx 47,437 \end{aligned}$$

Separation of B^0 and B^0_s

B meson mass

m_{B^0}	5279.65 ± 0.12 MeV
$m_{B^0_s}$	5366.88 ± 0.14 MeV
$m_{B^0_s}$ - m_{B^0}	87.38 ± 0.16 MeV

$$separation\ power = \frac{|\bar{m}_{B^0} - \bar{m}_{B^0_s}|}{\sqrt{\sigma^2_{m_{B^0}} + \sigma^2_{m_{B^0_s}}}}$$

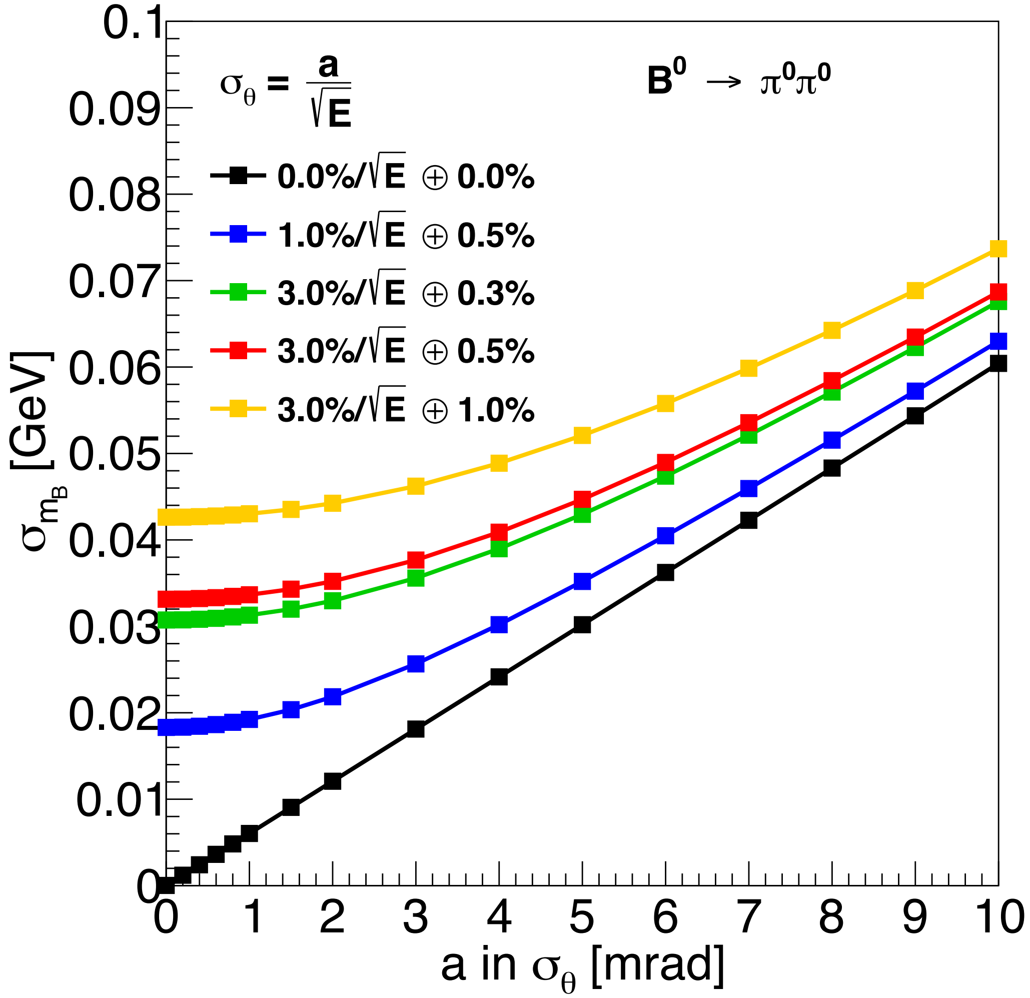


2σ separation requires B mass resolution σ_{mB} better than 30 MeV.

Dependence of B mass resolution on detector performance

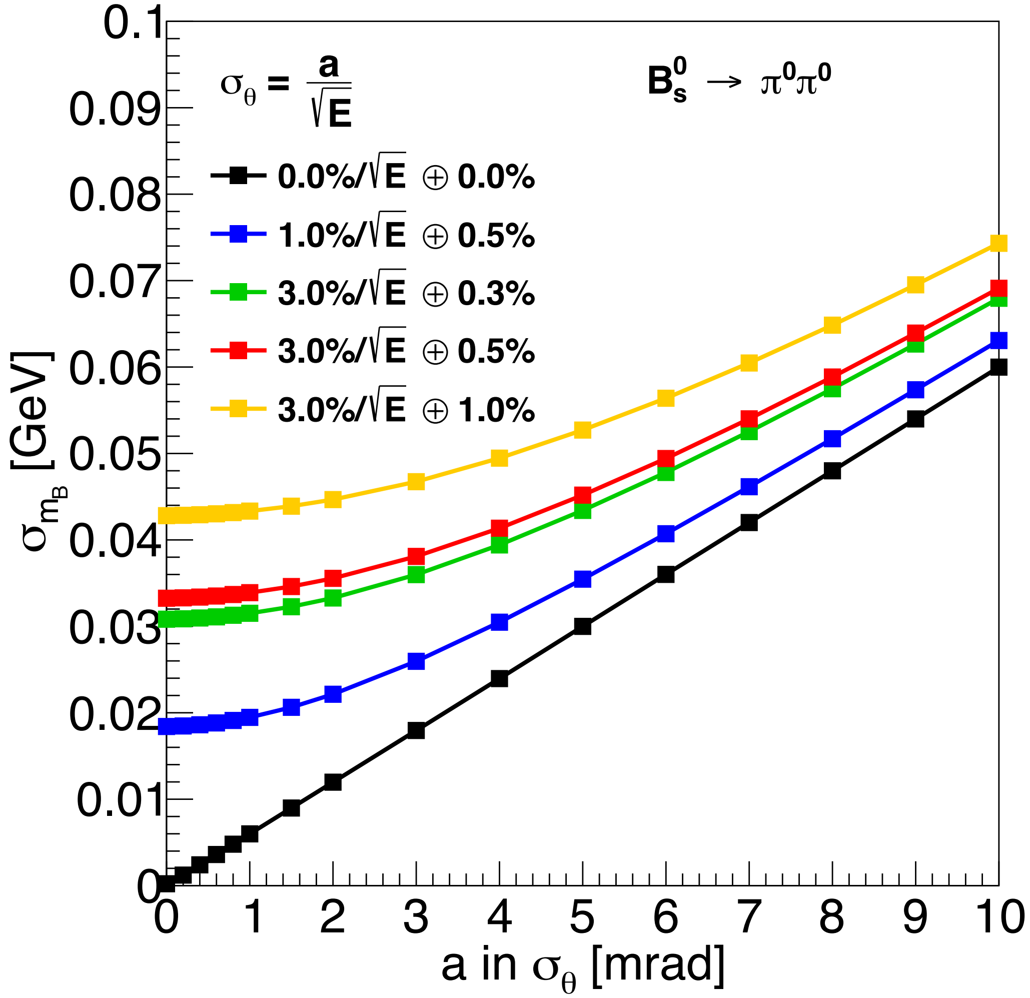
ECAL energy resolution

$$\frac{\sigma_E}{E} = \frac{A}{\sqrt{E}} \oplus C$$



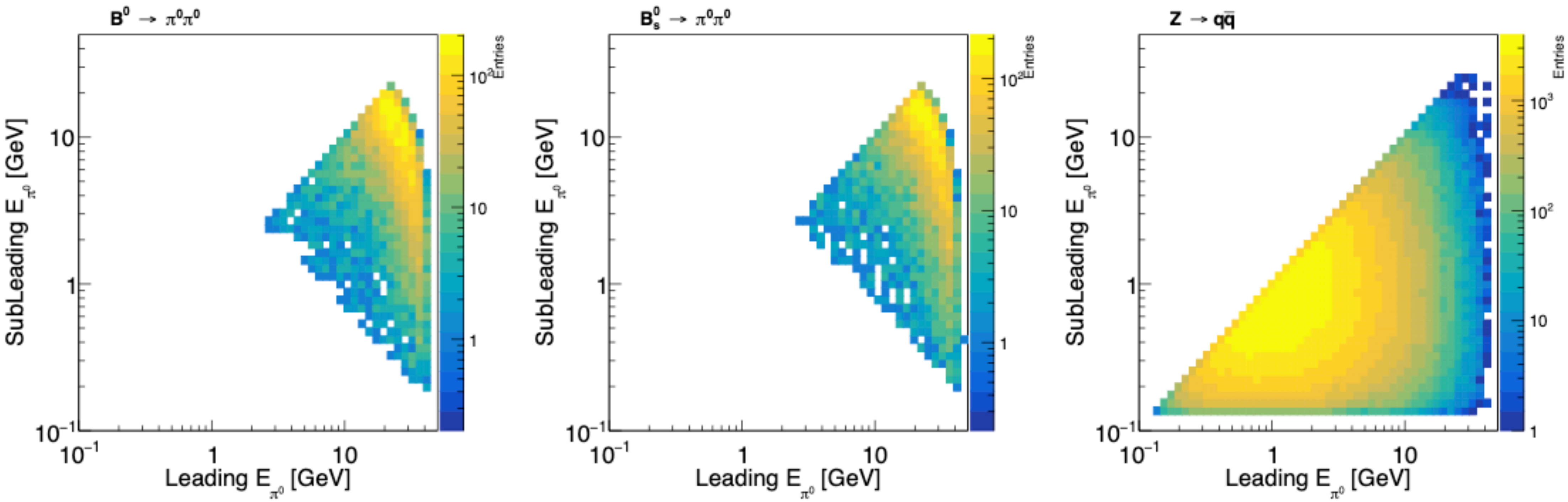
Photon angular resolution

$$\sigma_\theta = \frac{a}{\sqrt{E}},\ \sigma_\phi = \frac{\sigma_\theta}{sin\theta}$$

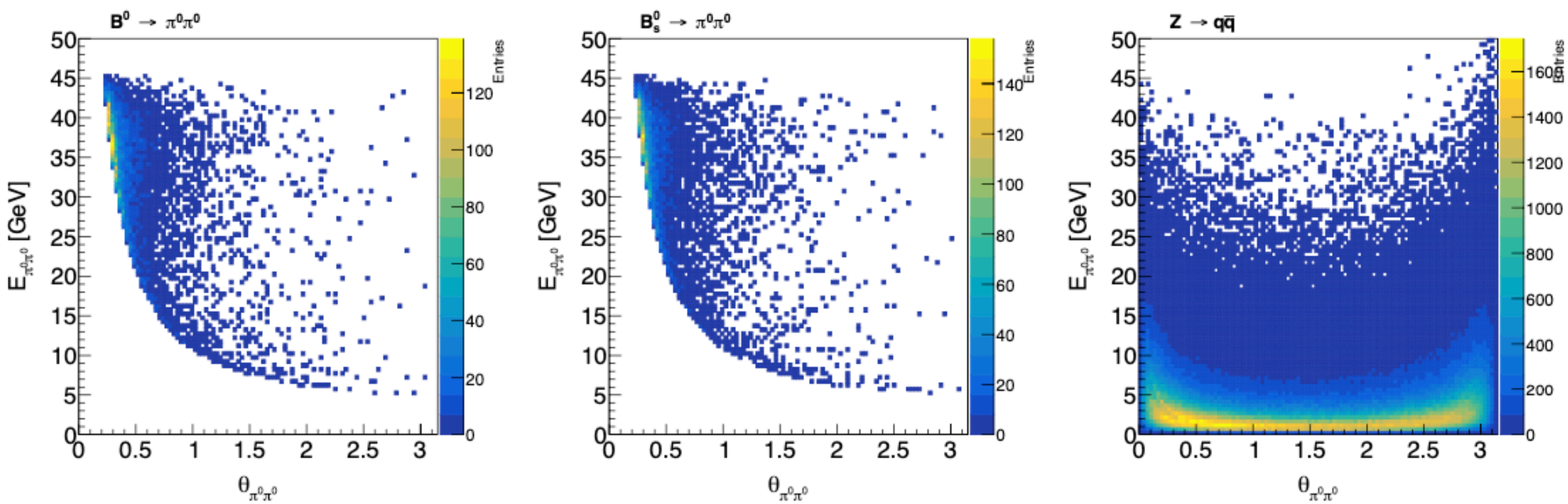


- **CEPC baseline single photon angular resolution ~1mrad/√E**
- **ECAL energy resolution dominates the contribution when σ_θ < 1mrad/√E**
- **The following analysis only takes ECAL energy resolution into account**
- **σ_{mB} ~30 MeV requires ECAL energy resolution ~3%/√E⊕0.3%**

Event Selection



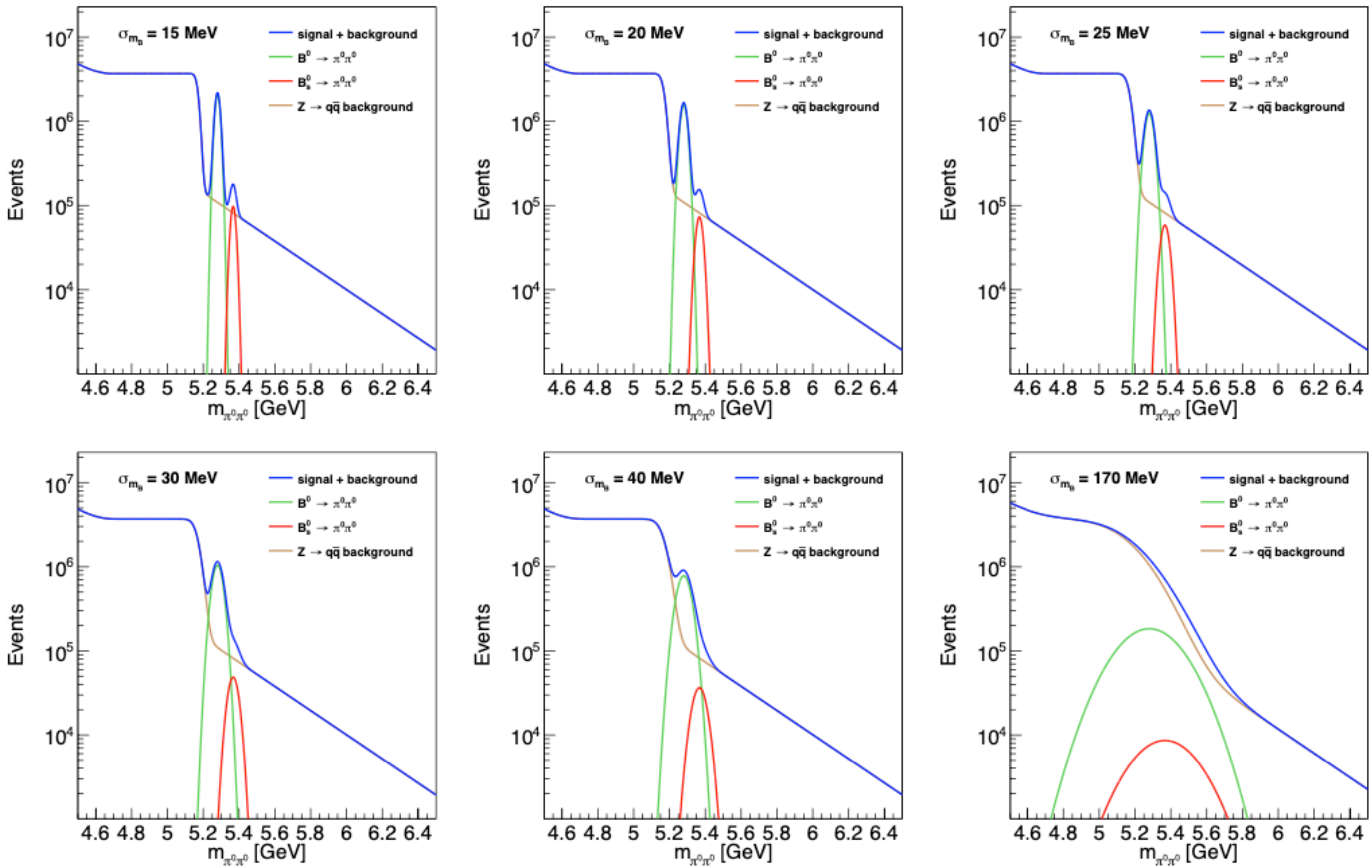
(a) Energy spectrum of π^0 pairs in $B^0 \to \pi^0\pi^0$ (left), $B_s^0 \to \pi^0\pi^0$ (middle), and $Z \to q\bar{q}$ (right) events.



(b) $\theta_{\pi^0\pi^0}$ vs $E_{\pi^0\pi^0}$ in $B^0 \to \pi^0\pi^0$ (left), $B_s^0 \to \pi^0\pi^0$ (middle), and $Z \to q\bar{q}$ (right) events.

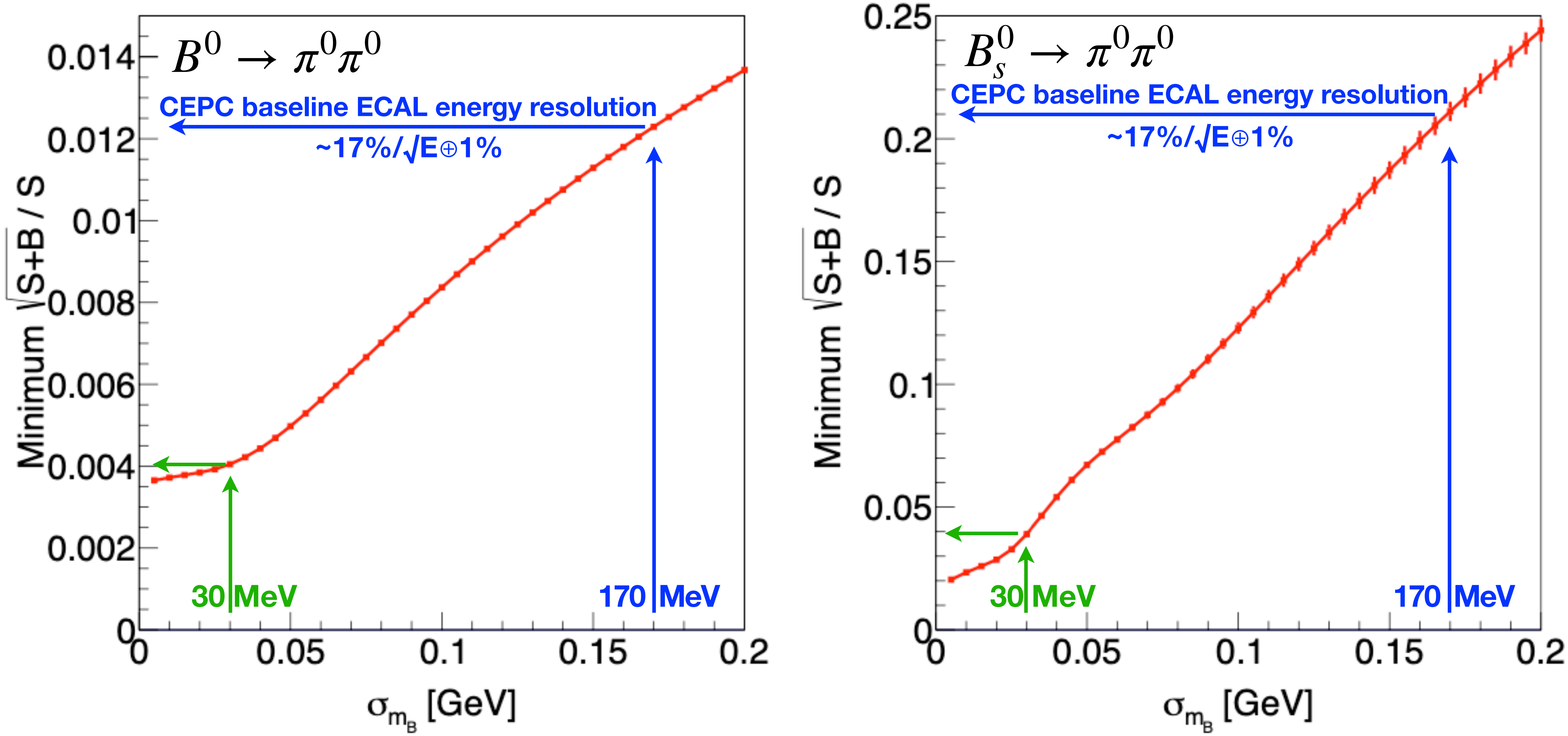
Dependence on B mass resolution

with CEPC baseline b-tagging



Dependence on B mass resolution

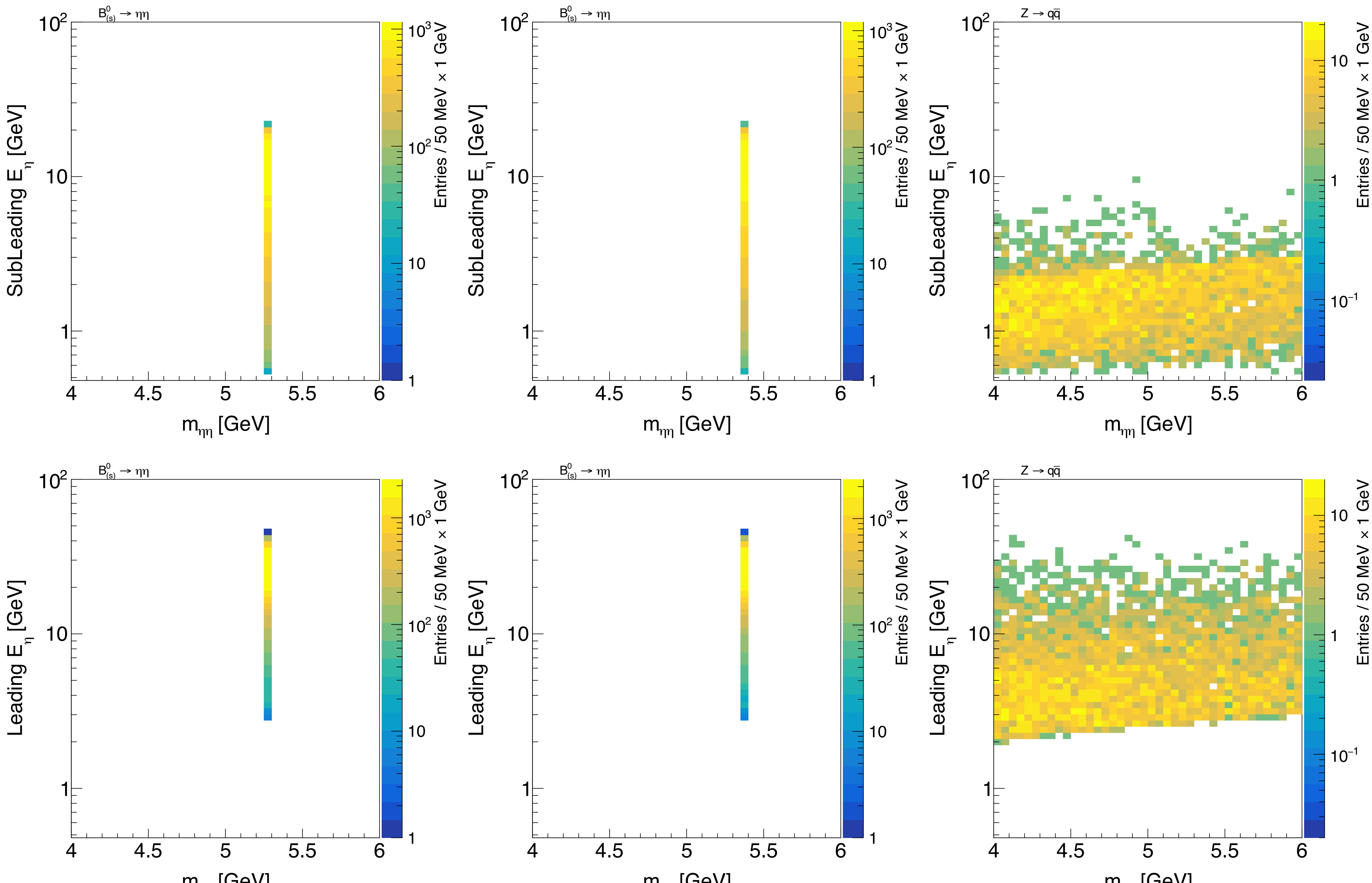
with CEPC baseline b-tagging



Accuracy	$B^0 \to \pi^0\pi^0$	$B^0_s \to \pi^0\pi^0$
17%/√E⊕1% (CEPC baseline)	~1.2%	~21%
3%/√E⊕0.3% (σ_{mB} ~30 MeV)	~0.4%	~4%

3~5 times improvement

Eta Pair Distributions



Bs->2Eta

Eta Efficiency & Purity vs Energy