Sensitivity study of τ decays with an η meson at the Belle II experiment

Michel Hernández Villanueva
Department of Physics
CINVESTAV

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Outline:

- The $\tau \to \eta\pi\nu$ decay
  - Second class currents.
  - Previous results.
  - Reconstruction and cuts.
- The $\tau \to \eta\pi\pi^0\nu$ decay
  - Previous measurements.
  - Reconstruction and cuts.

$\tau \to \eta \pi \nu$

Second Class Currents

- Currents can be classified by their transformation properties under *G*-parity[1], $G = Ce^{i\pi I_2}$.

  - First-class currents: $J^{PG} = 0^{++}, 0^{--}, 1^{-+}, 1^{+-}, ...$

  - Second-class currents **(SCC)**:

$$J^{PG} = 0^{+-}, 0^{-+}, 1^{++}, 1^{--}, ...$$

- Unsuccessful searches of SCC in nuclear Physics.

- Another possibility:
  Search in tau decays, using the channel[2]

$$\tau^- \rightarrow \eta\pi^-\nu_\tau$$

$$G|\bar{d}\gamma^\mu u\rangle = +|\bar{d}\gamma^\mu u\rangle$$

$$G|\pi\rangle = -|\pi\rangle$$
$$G|\eta\rangle = +|\eta\rangle$$

[1]Weinberg, S. (1958). Physical Review, 112 (1978)
[2]Leroy, C., & Pestieau, J. (1978). Physics Letters B, 72(3), 398-399.

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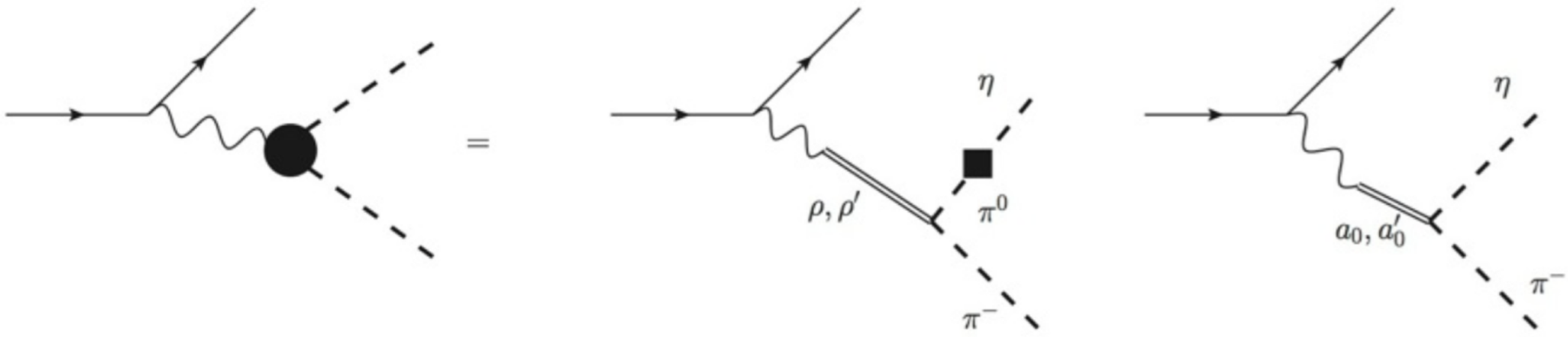
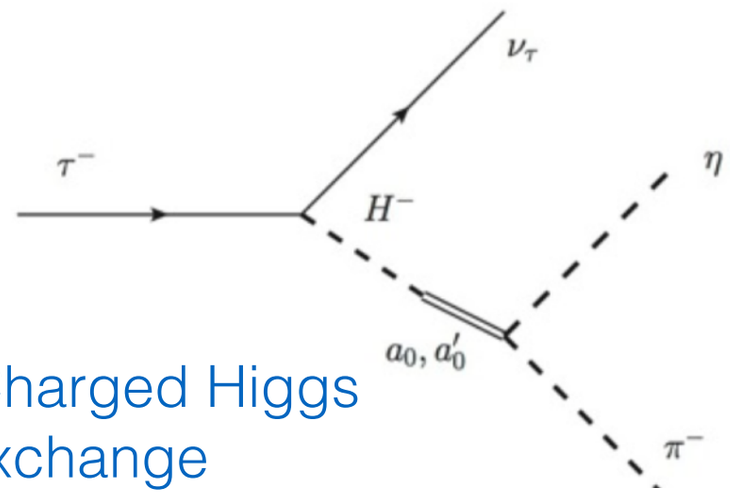
The $\tau \to \eta\pi\nu$ decay

- Mechanisms in the SM: Isospin violation



- BR($\tau \to \eta\pi\nu$) ~ 10^{-5} ⟵ Accesible at Belle II luminosity. [1]

- The corresponding suppression of the SM contribution can make new physics visible.



Charged Higgs exchange

[1] R. Escribano, S. Gonzalez, P. Roig; Phys.Rev. D94 (2016) no.3, 034008

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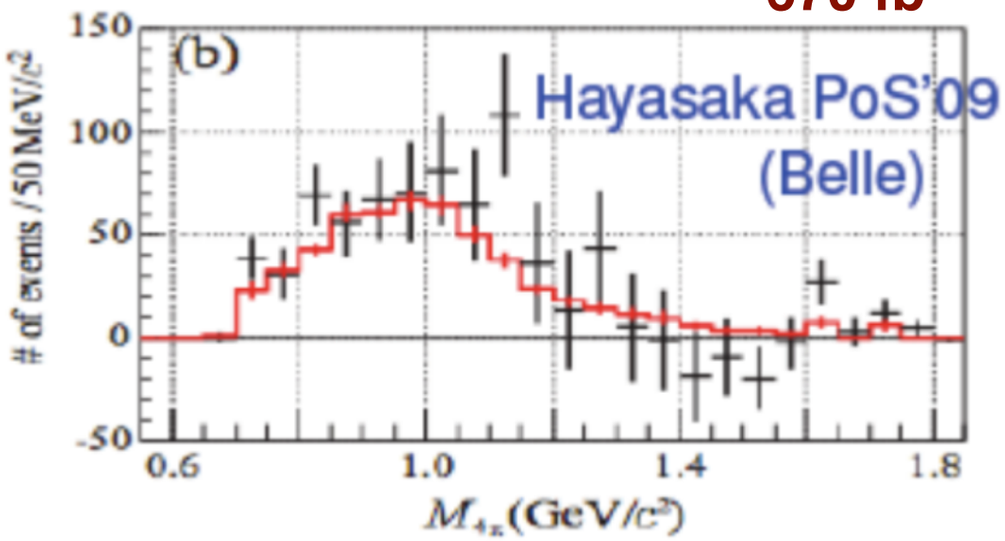
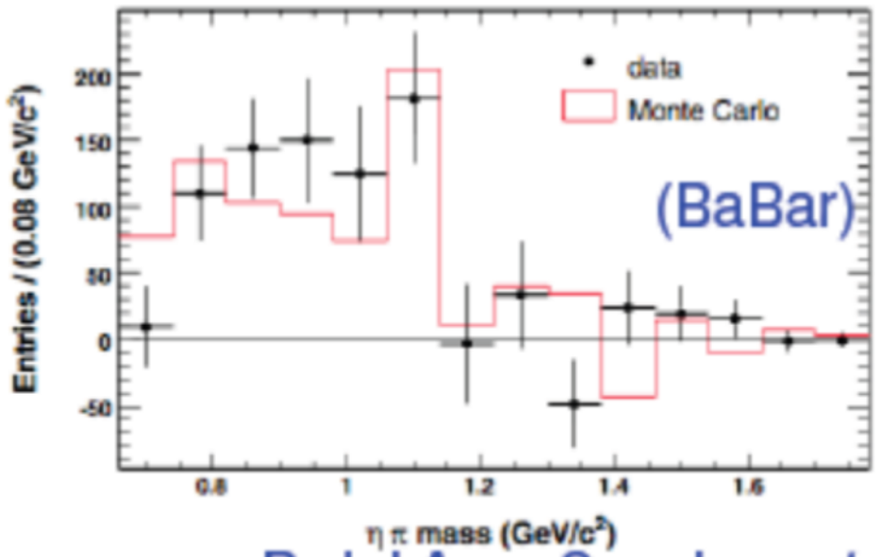
Previous Results

670 fb^{-1}



$BR^{Belle}_{exp} < 7.3 \cdot 10^{-5}$ 90%CL

470 fb^{-1}



P. del Amo Sanchez *et.al*
(PRD 83 032002 '11)

$BR^{BaBar}_{exp} < 9.9 \cdot 10^{-5}$ 95%CL

- This decay mode should have already been discovered if there were no strong background.

- <u>Control of the background is essential.</u>

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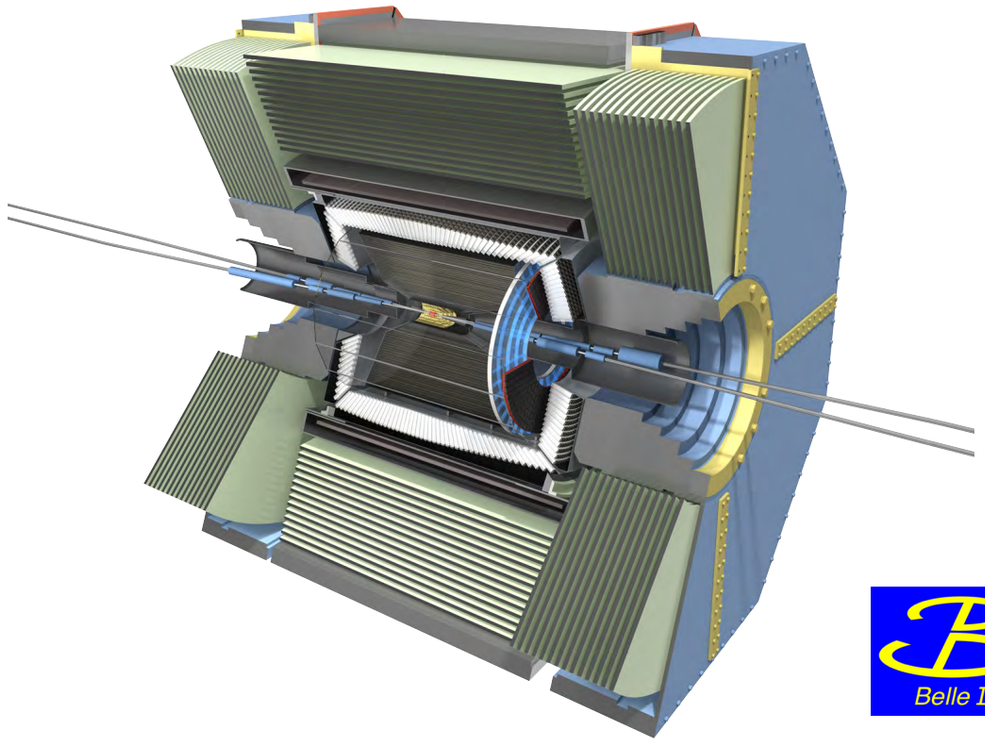
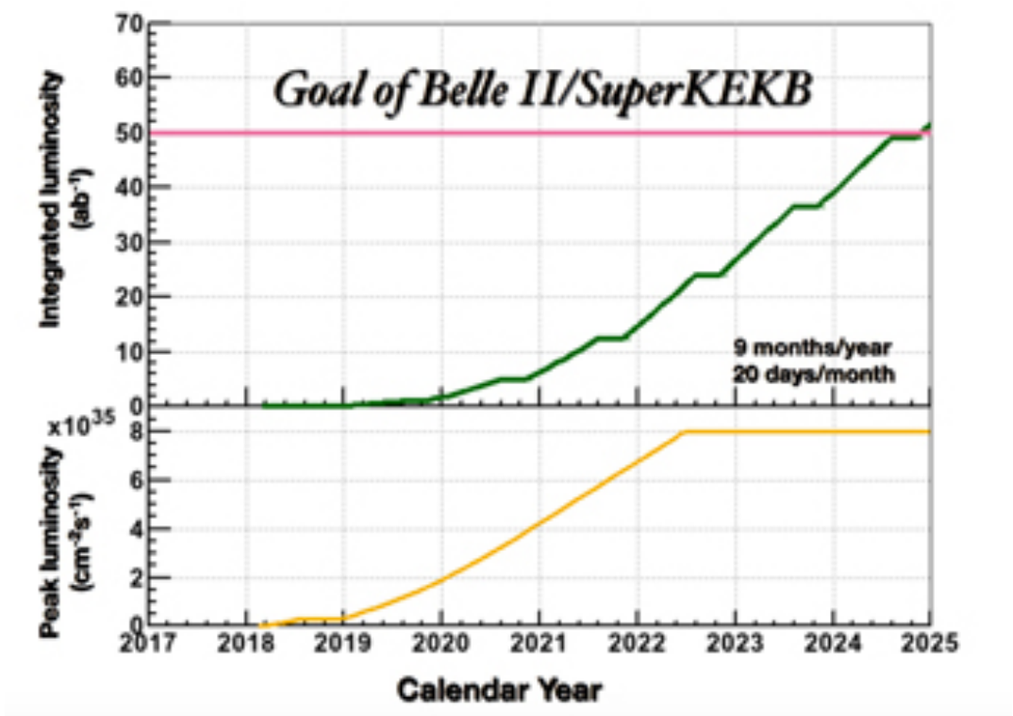
Belle II





- Super B-Factory
  (And τ factory too!)

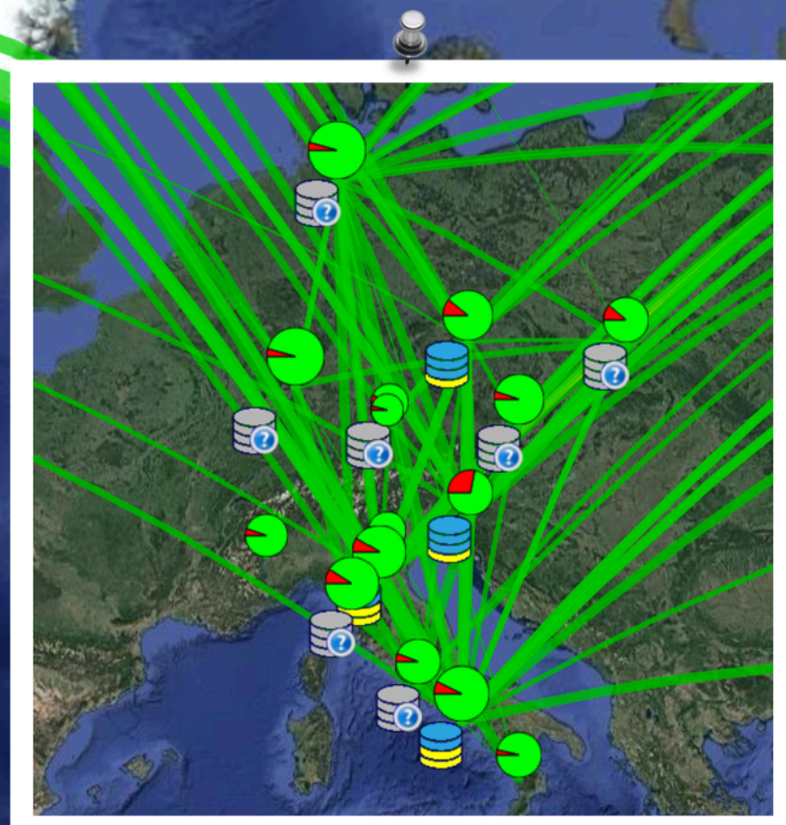
  $\sigma(e^+e^- \rightarrow \Upsilon(4s)) = 1.2$ nb
  $\sigma(e^+e^- \rightarrow \tau\,\tau) = 0.8$ nb

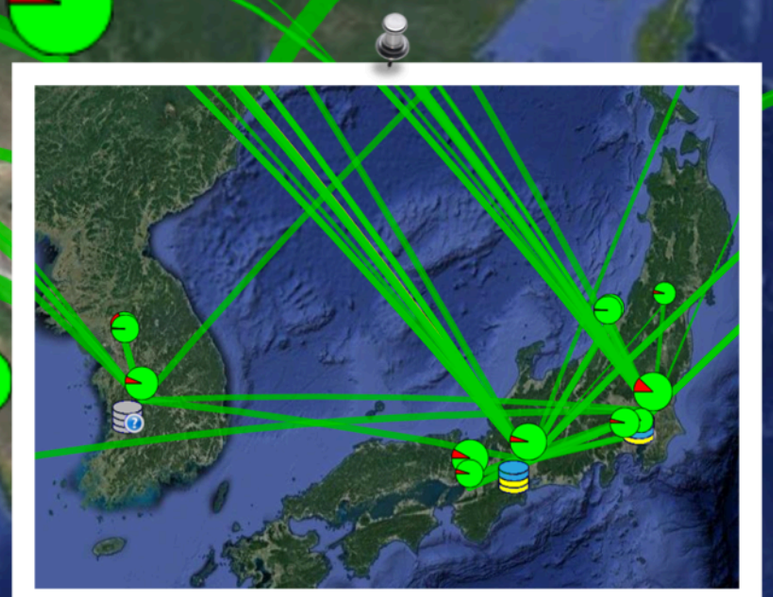
- Integrated luminosity expected: **50 ab^{-1}**

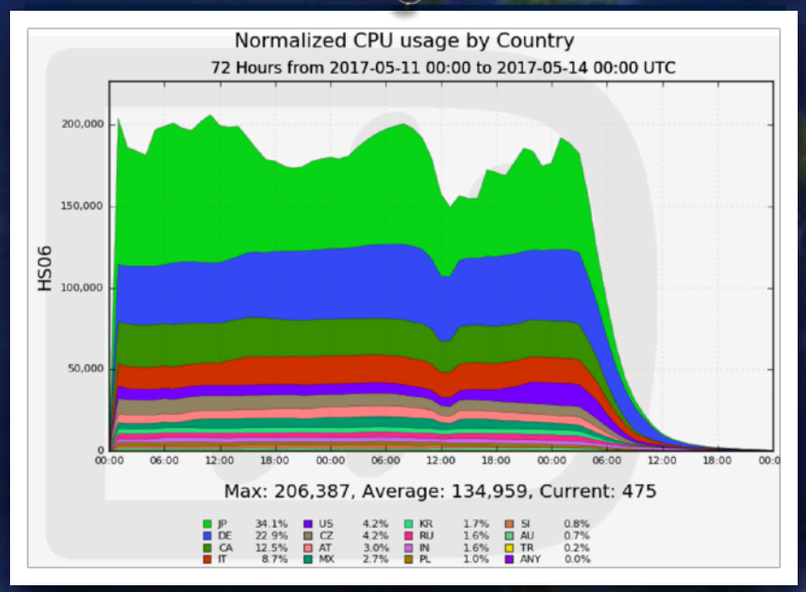
- Full physics program: late 2018

Belle II MC samples

MC Sample:
~ 2 ab^{-1}
(1 ab^{-1} for training,
1 ab^{-1} for analysis).







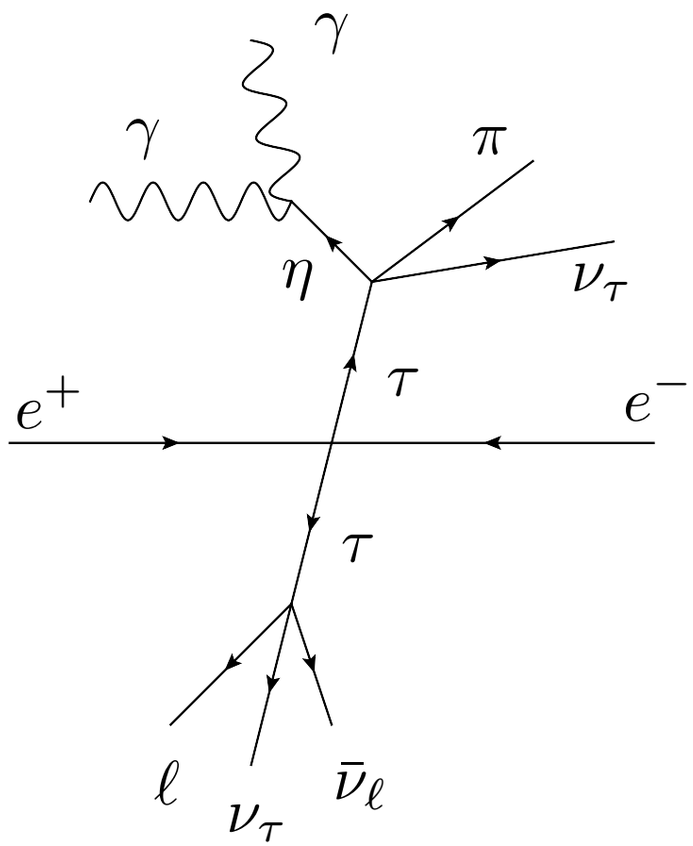
2 ways to reconstruct η

- Thrust axis: $\hat{n}_{thrust}$ such that V_{thrust} is maximum.

$$V_{thrust} = \frac{\sum_i |\vec{p}_i{}^{cm} \cdot \hat{n}_{thrust}|}{\sum_i |\vec{p}_i{}^{cm}|}$$

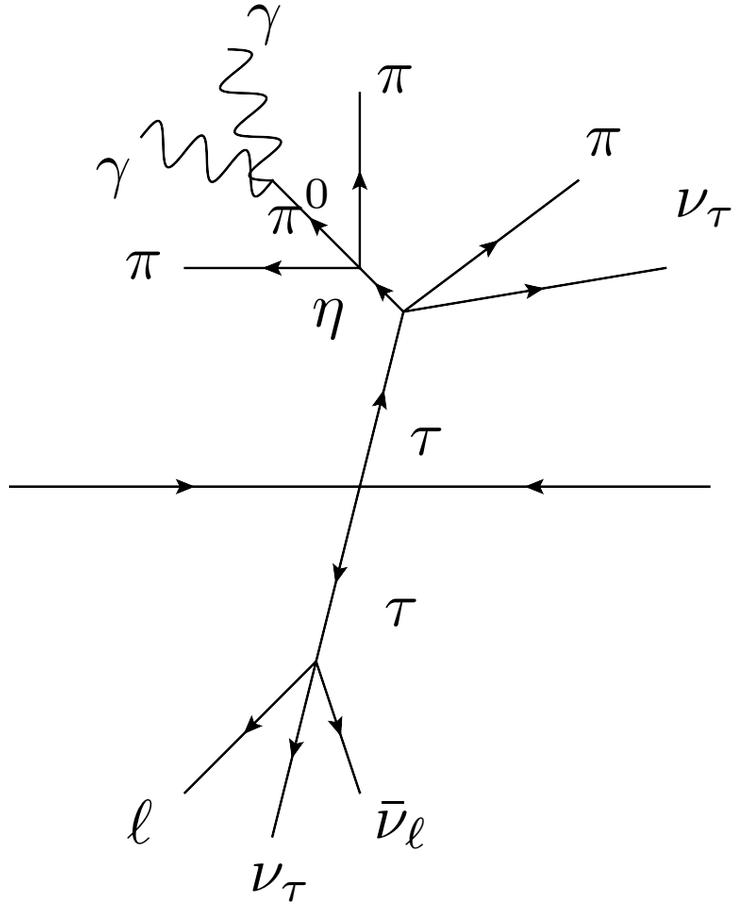
1-prong

BR(η —> $\gamma\gamma$) = 39.41%



3-prong

BR(η —> $\pi\pi\pi^0$) = 22.92%



Signal side

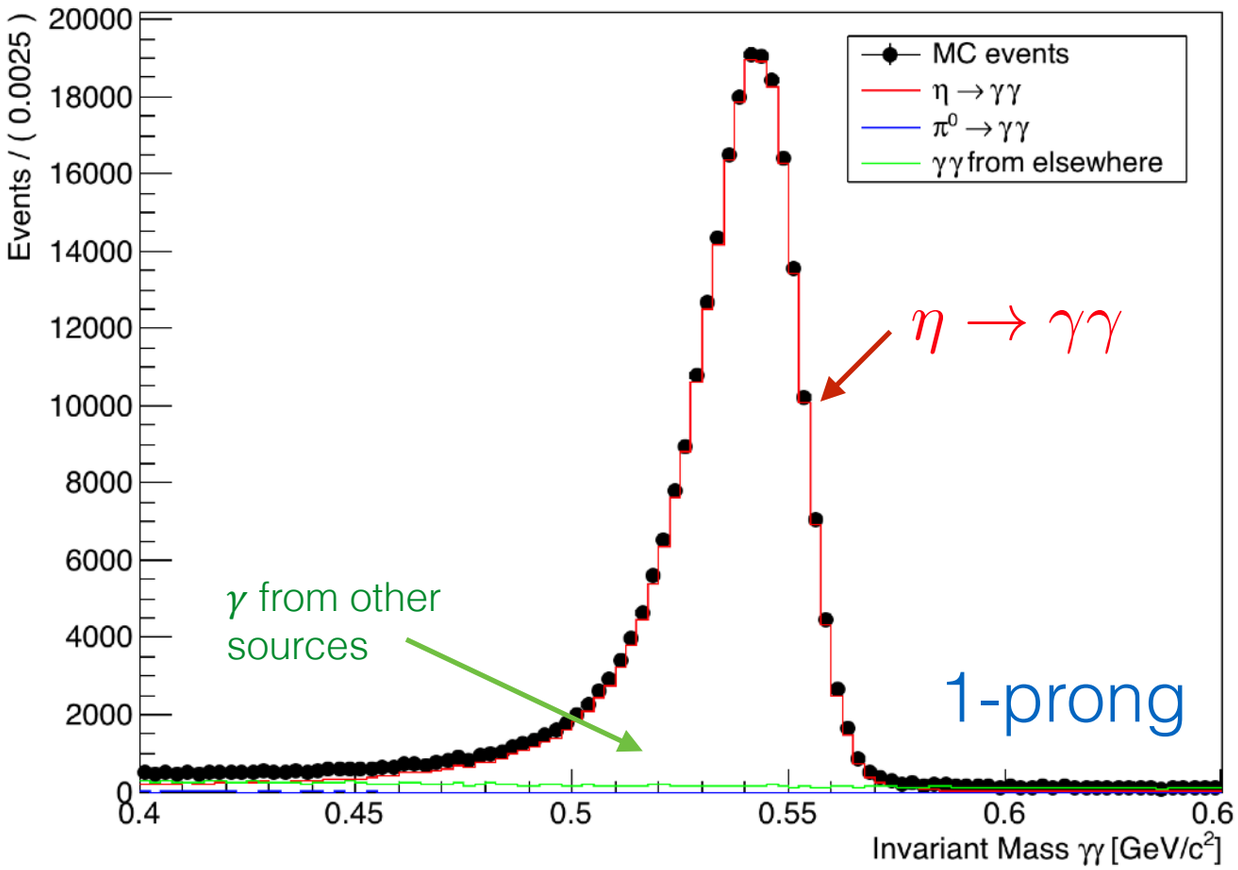
Tag side

$\tau \to \eta\pi\nu$ signal events

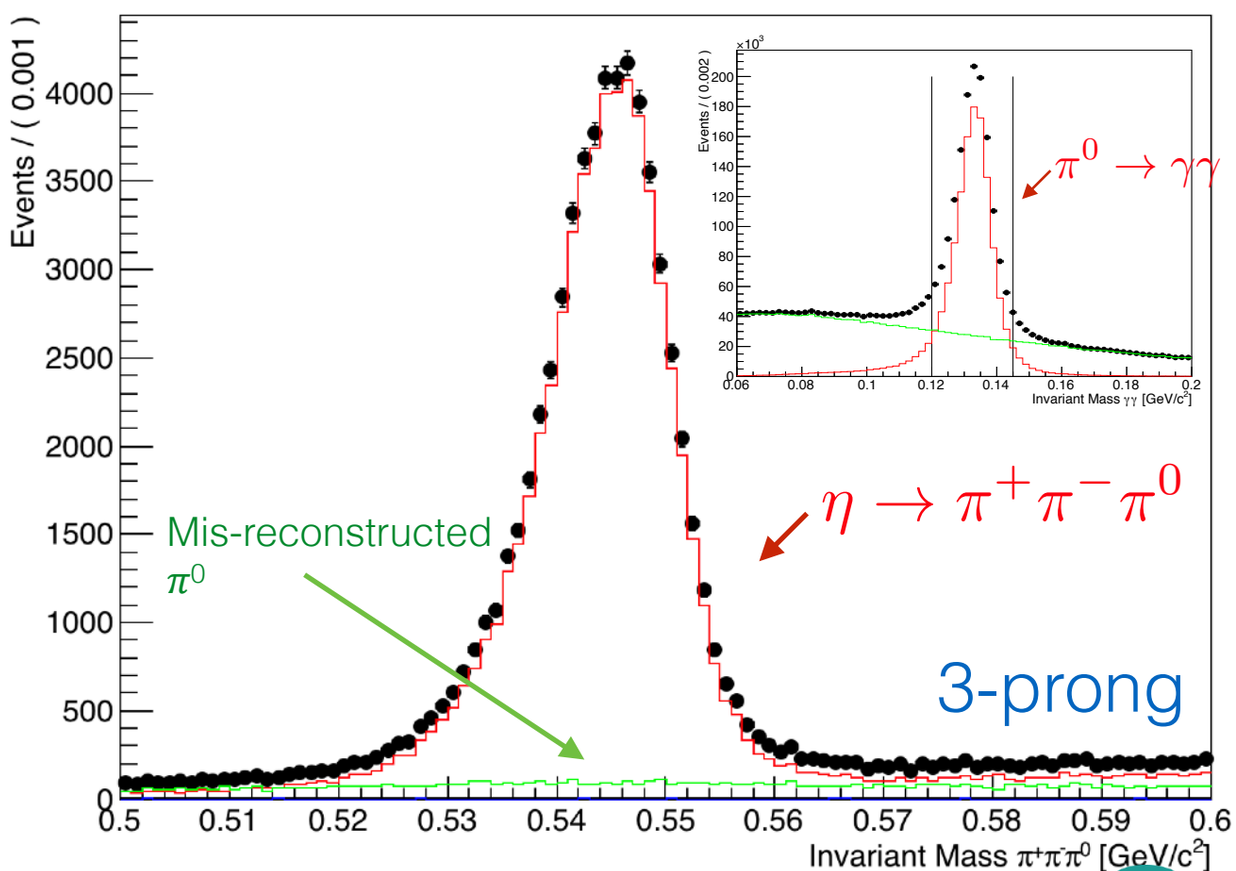
- With simple selection criteria (tag + 1 or 3 charged + 2 or 3 γ), it's possible to reconstruct η mesons.

- Signal events generated: 2M

Eff: 13.56%



Eff: 3.70%

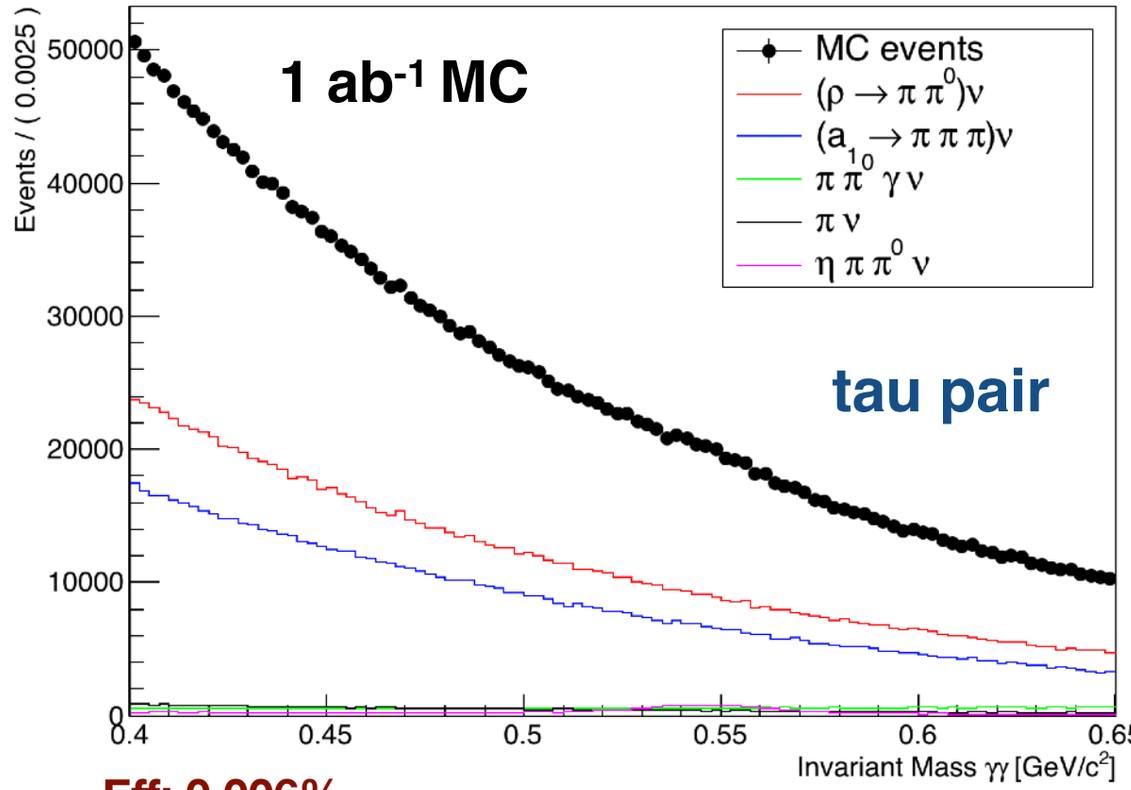


$\tau \to \eta\pi\nu$ bkg events

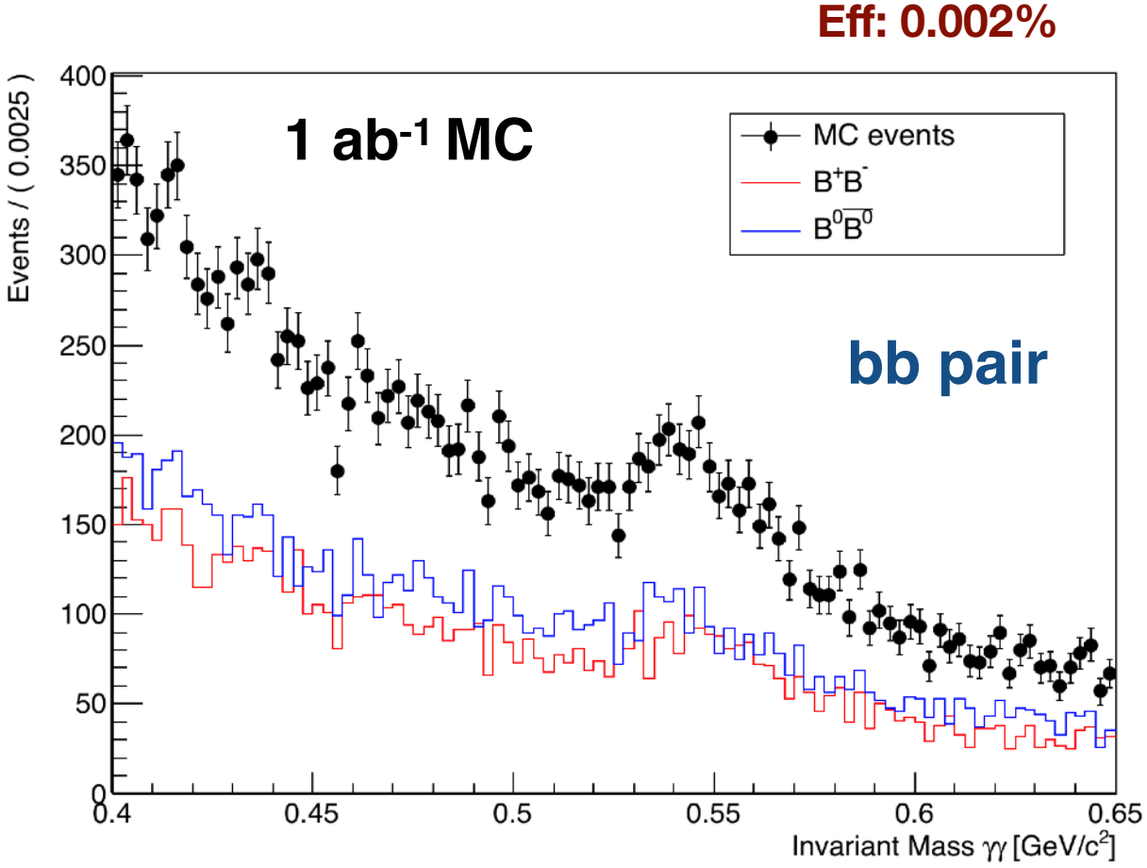
1-prong

- Background sources:
  - $\boldsymbol{\tau\tau}$ pair
  - bb pair
  - qq pair

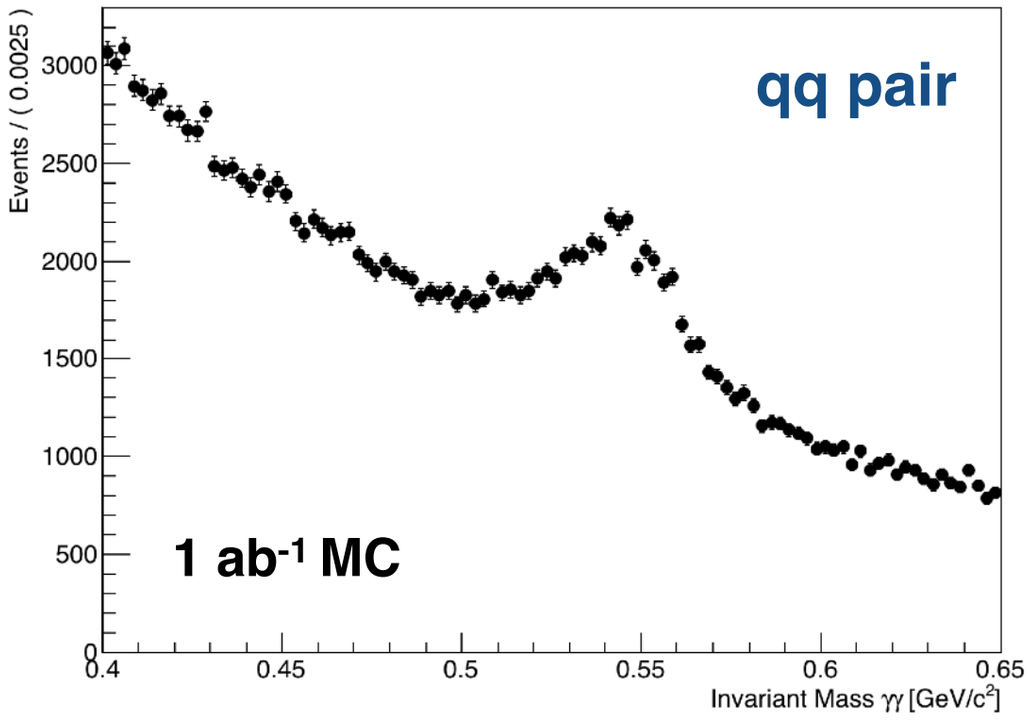
Eff: 0.34%



Eff: 0.002%



Eff: 0.006%



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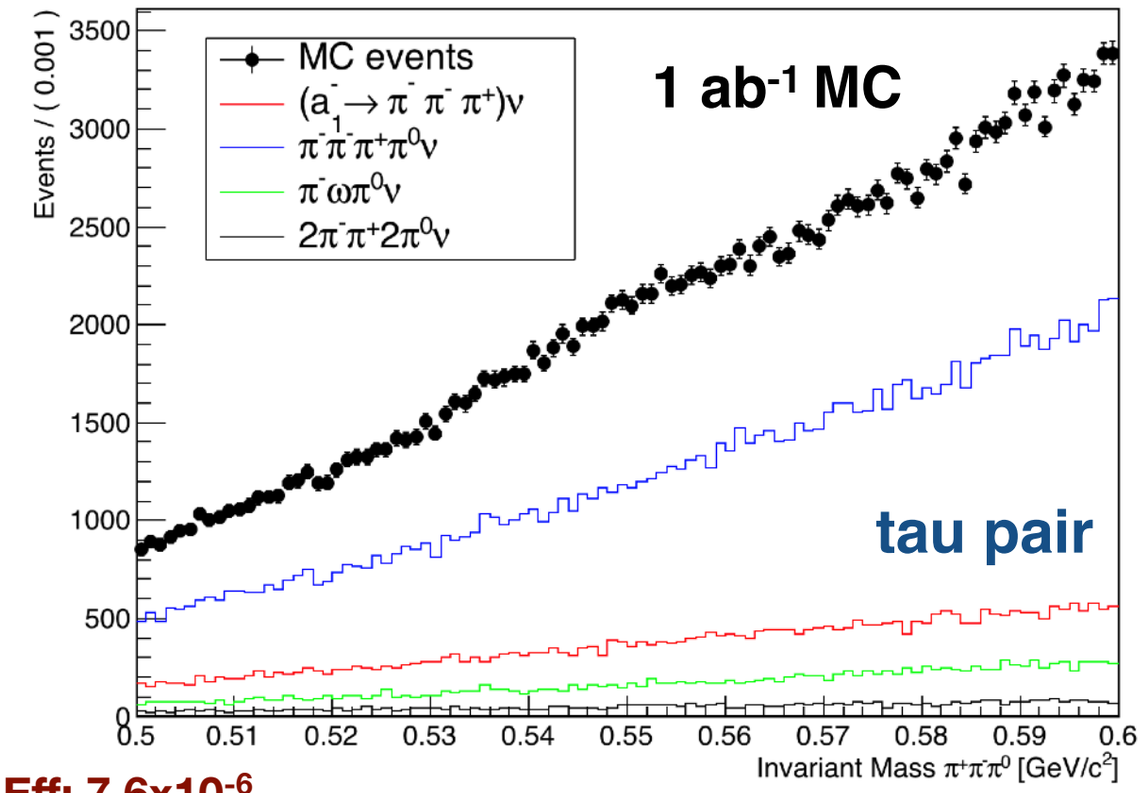
$\tau \to \eta\pi\nu$ bkg events

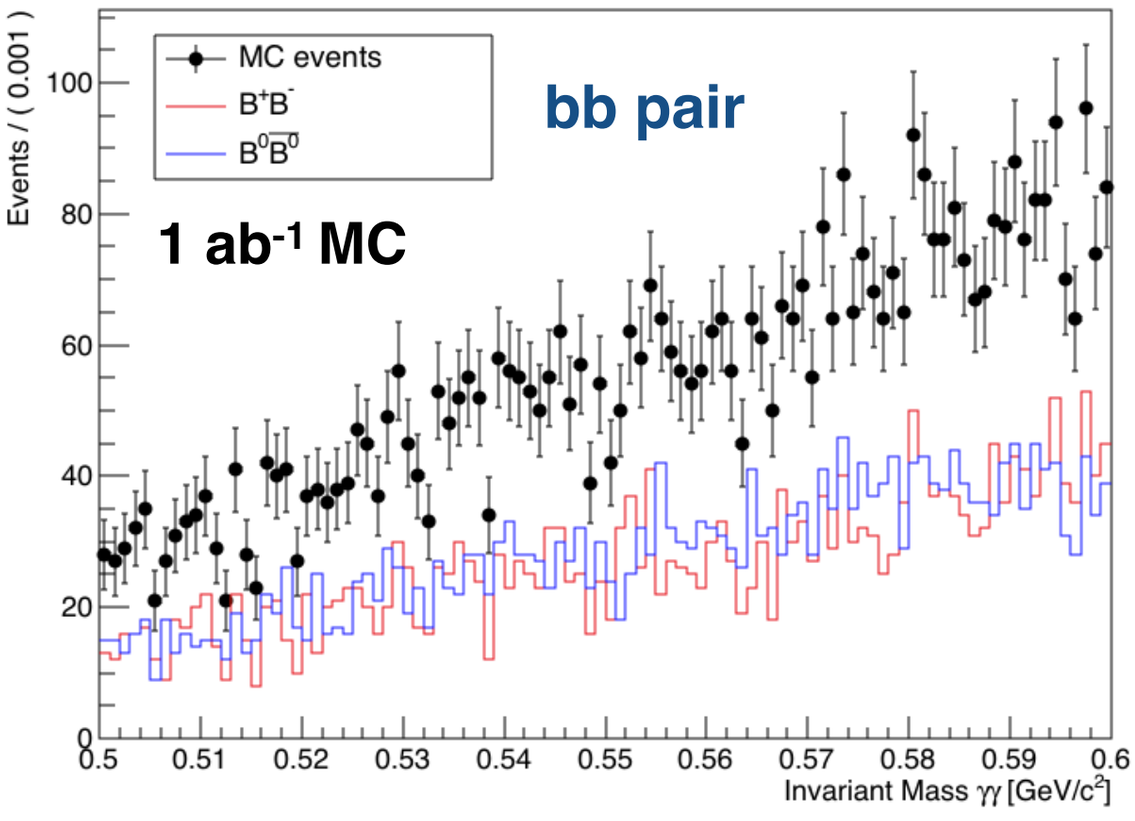
3-prong

- Background sources:
  - $\tau\tau$ pair
  - bb pair
  - qq pair

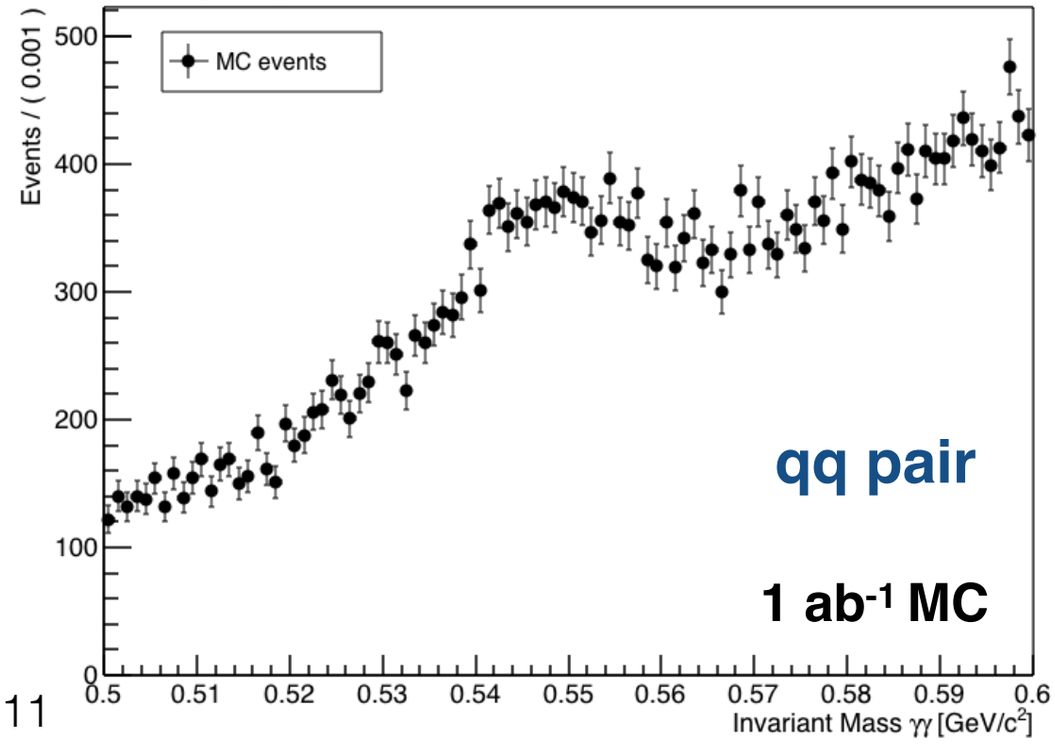
Eff: 0.028%



Eff: 5.6x10^{-6}



Eff: 7.6x10^{-6}



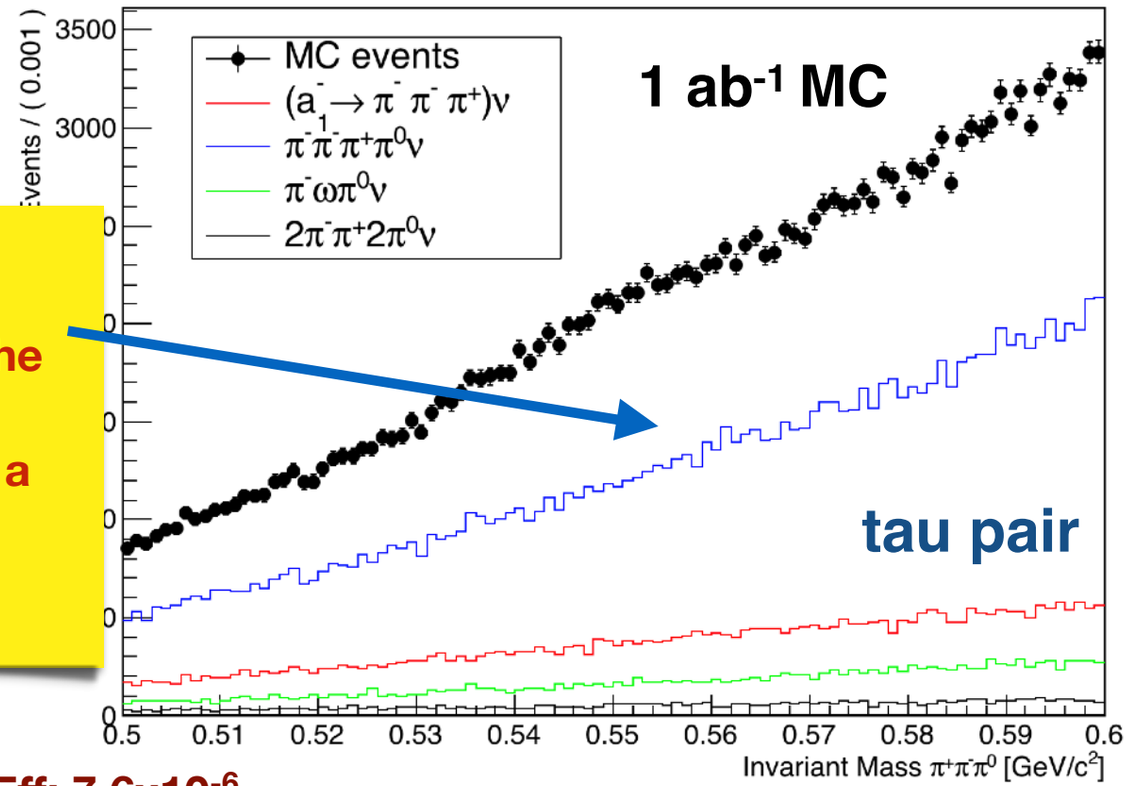
$\tau \to \eta\pi\nu$ bkg events

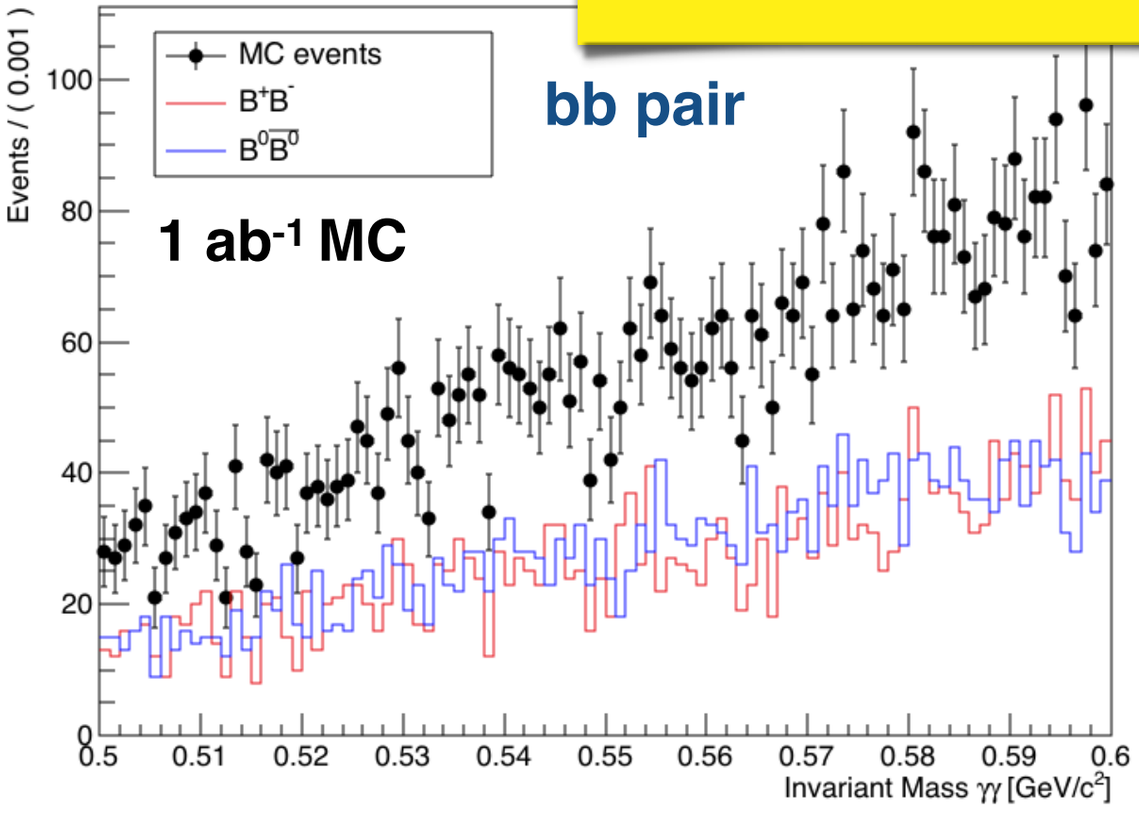
3-prong

- Background sources:
  - $\tau\tau$ pair
  - bb pair
  - qq pair

$3\pi\pi^0$ is the mayor issue. (Warning! This depends of the hadronic input in the generation of MC. Requires a revision in the model.)

Eff: 0.028%





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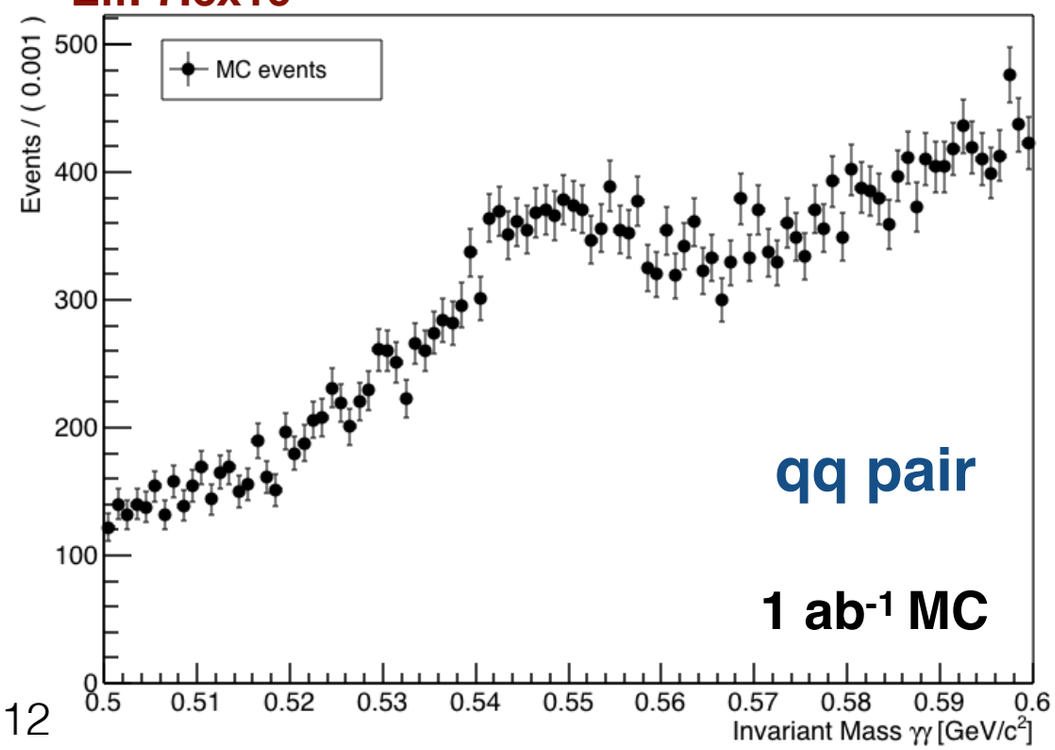
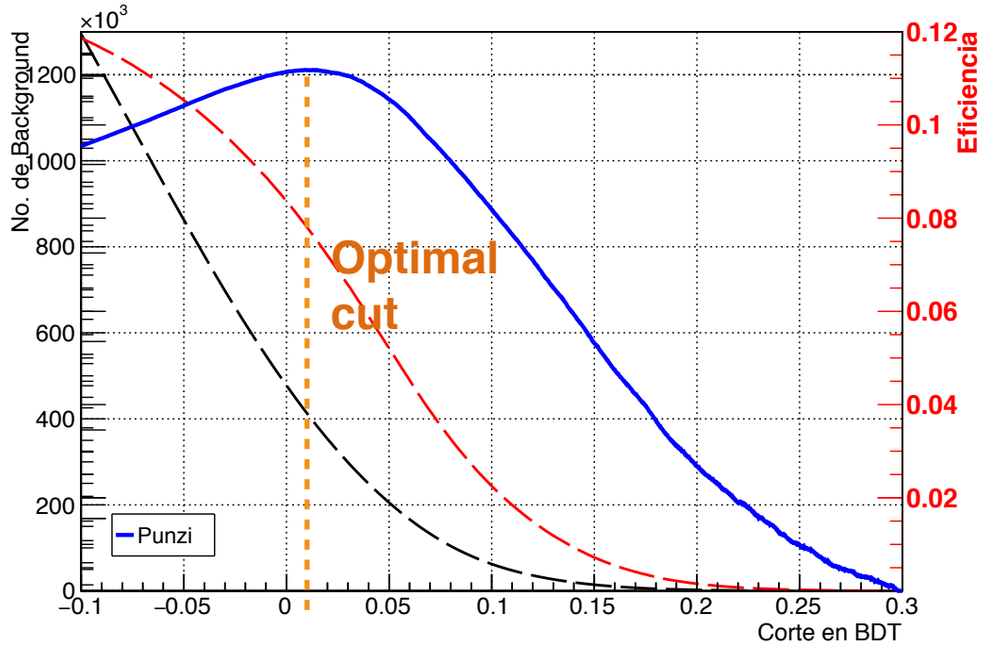
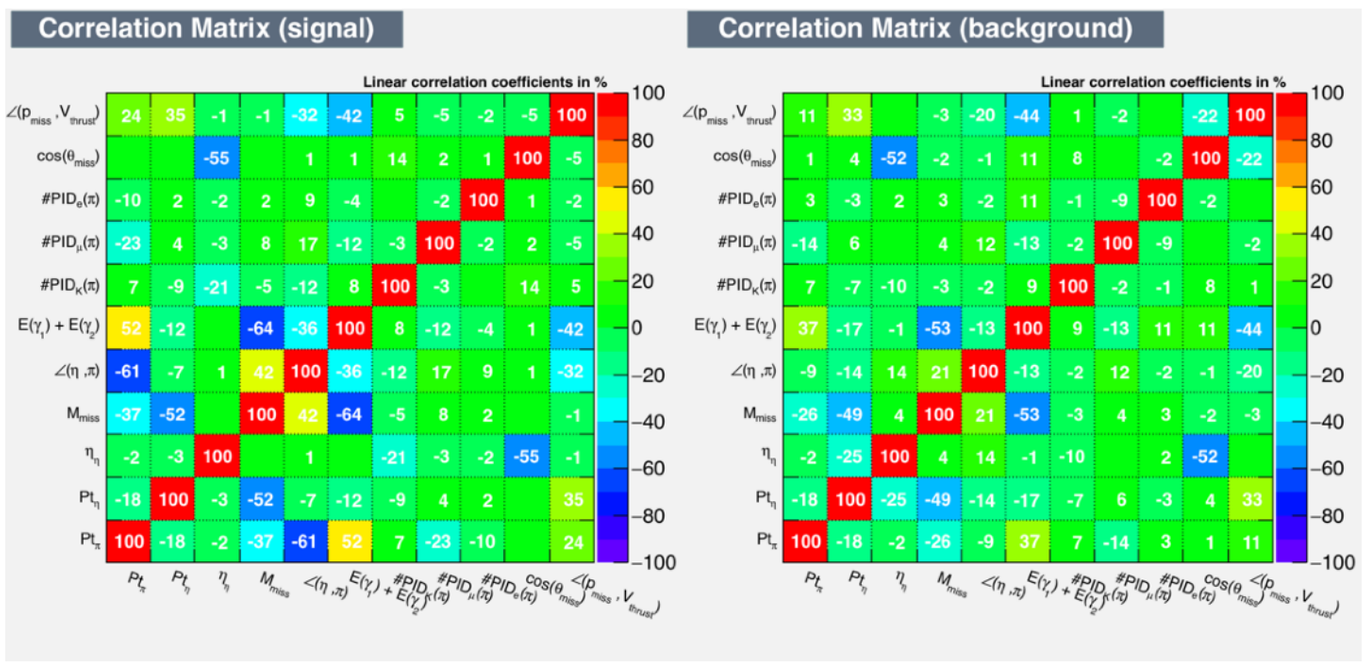


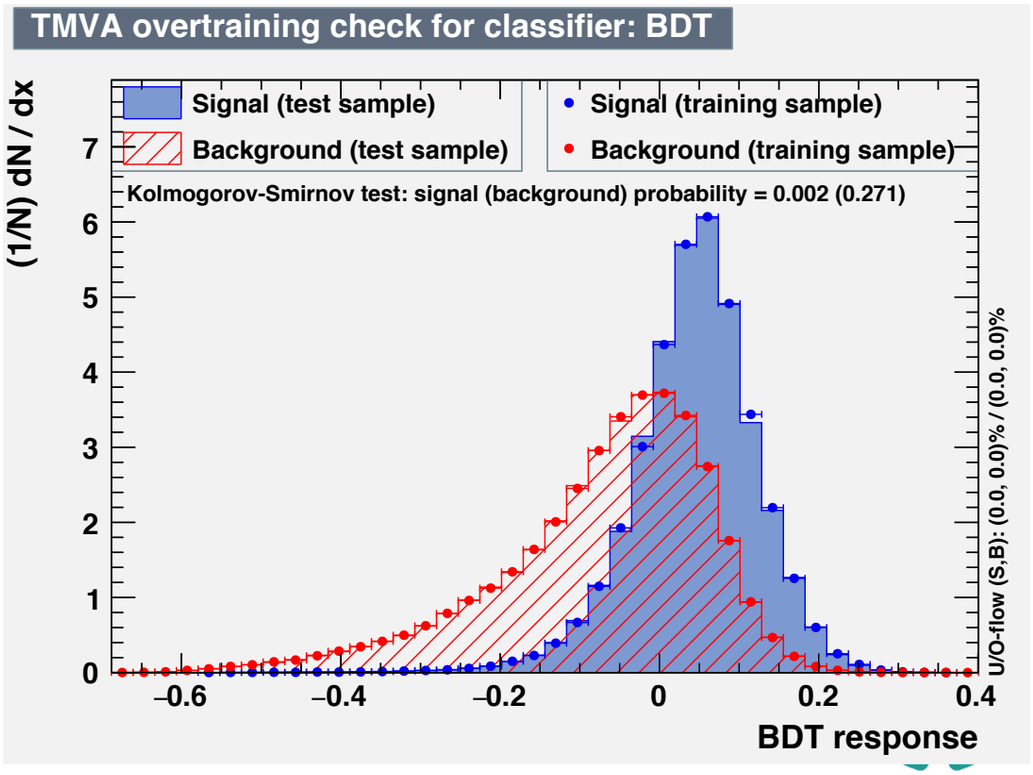
BDT variables

TMVA used for this test.

- $\angle(\eta,\pi)$
- $\angle(p_{miss}, V_{thrust})$
- $P_t(\eta)$
- $P_t(\pi)$
- $\eta(\eta)$
- $\cos(\theta_{miss})$
- $PID_e(\pi)$
- $PID_\mu(\pi)$
- $E(\gamma)$
- M_{miss}







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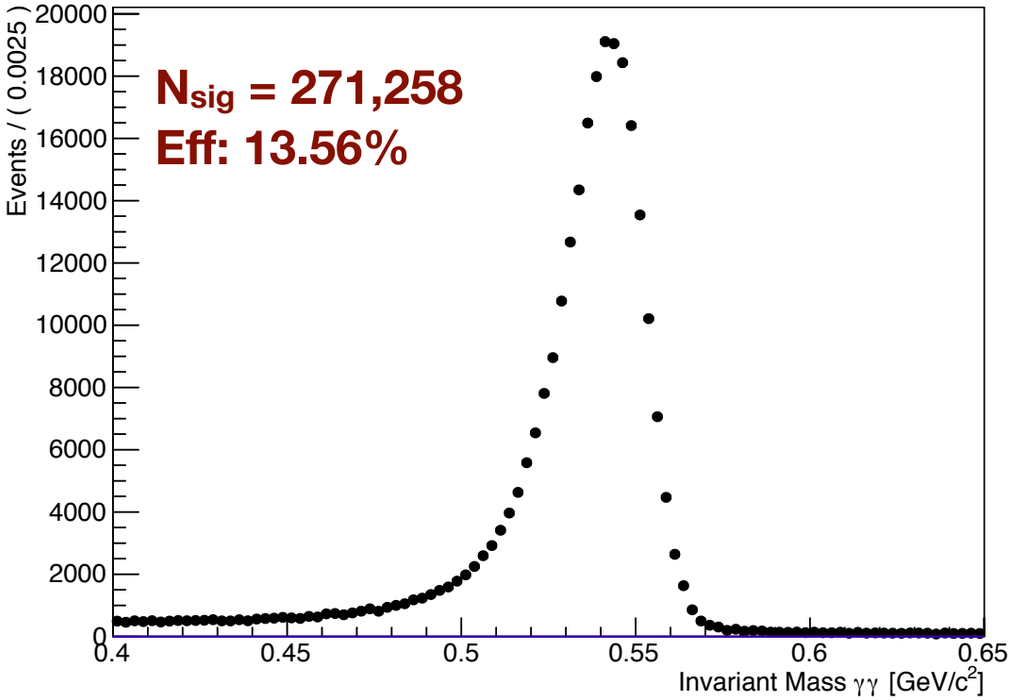
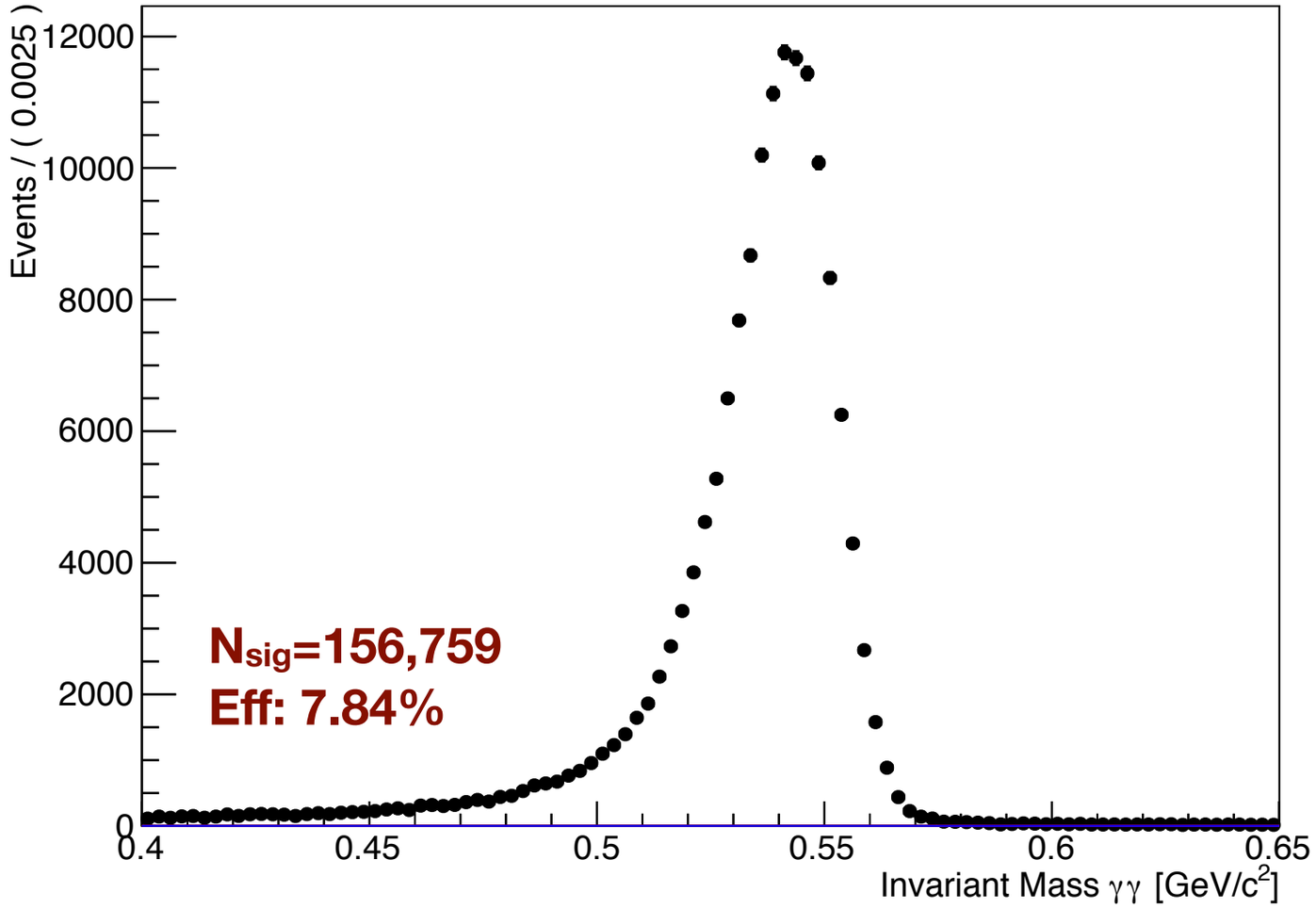
Optimal BDT cut

Signal
1-prong



Eff_{cut} = 42.21%



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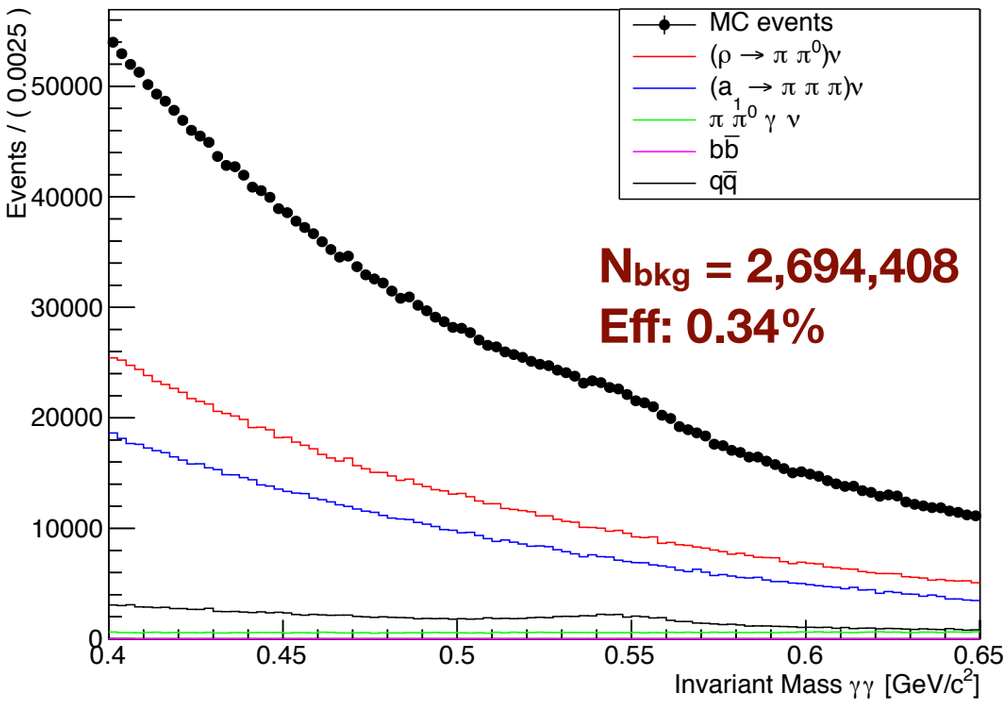
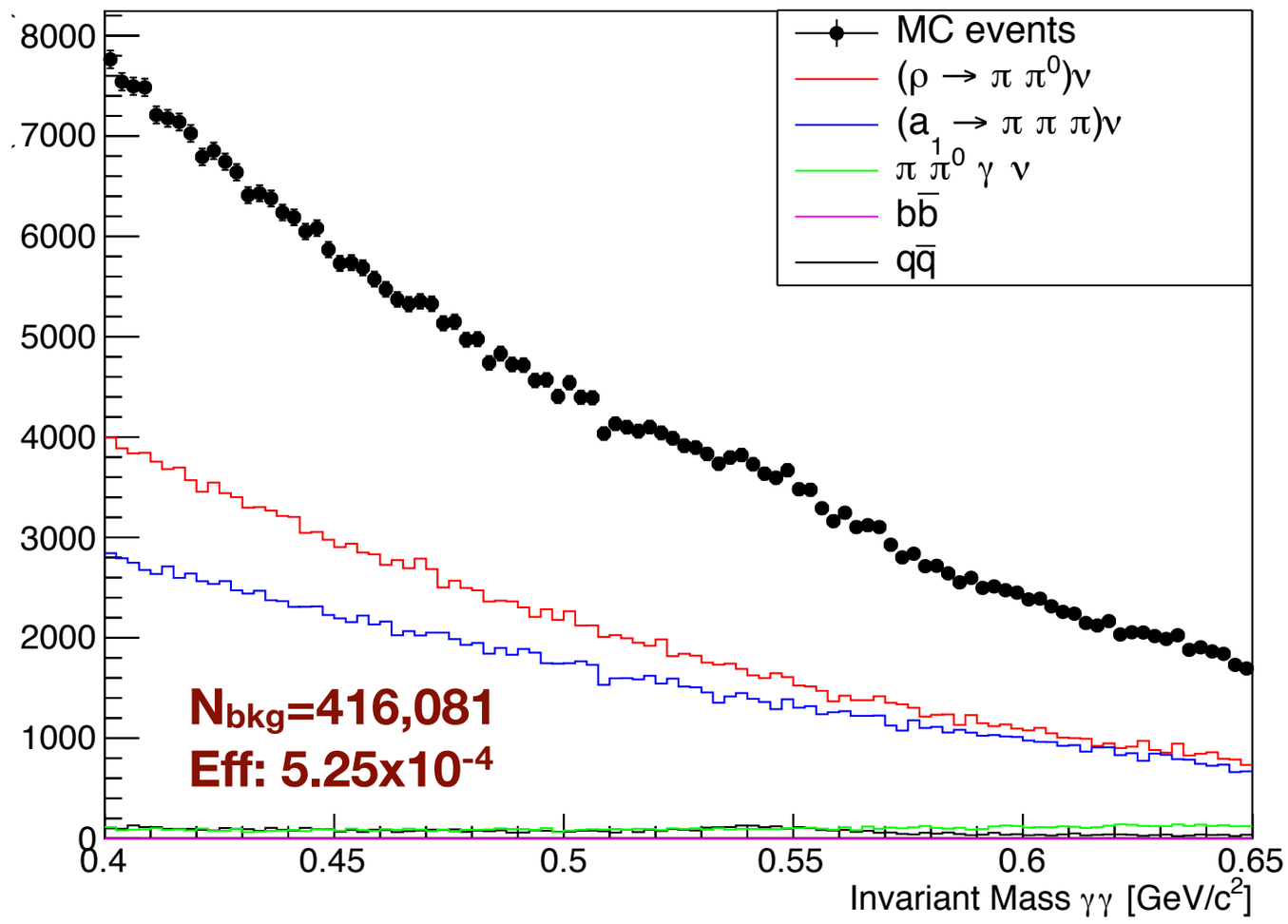
Optimal BDT cut

Background 1-prong



$Eff_{cut} = 84.56\%$



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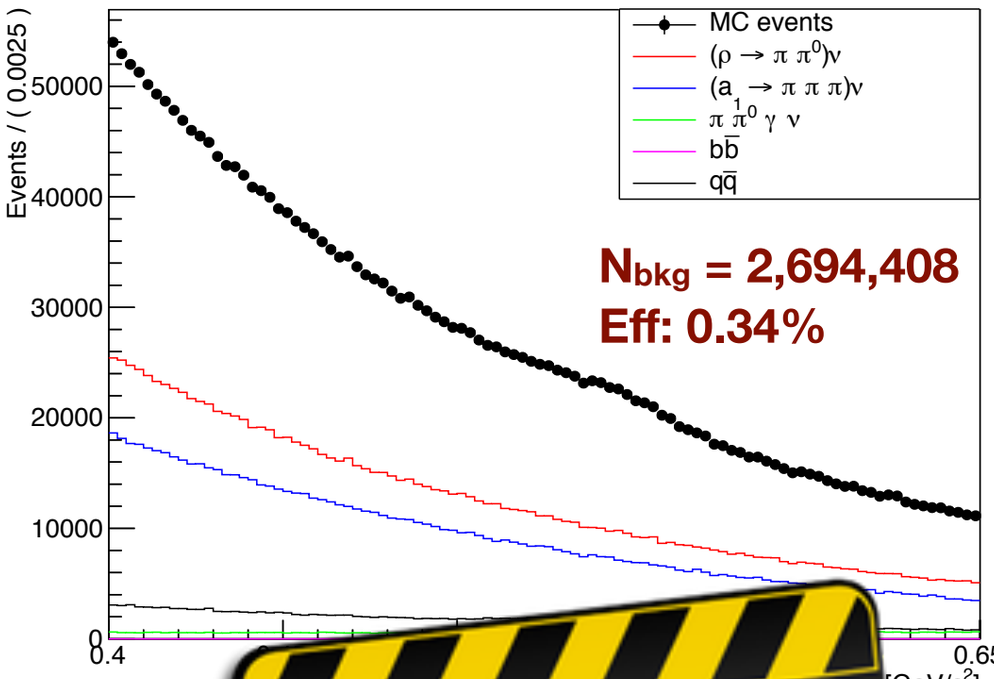
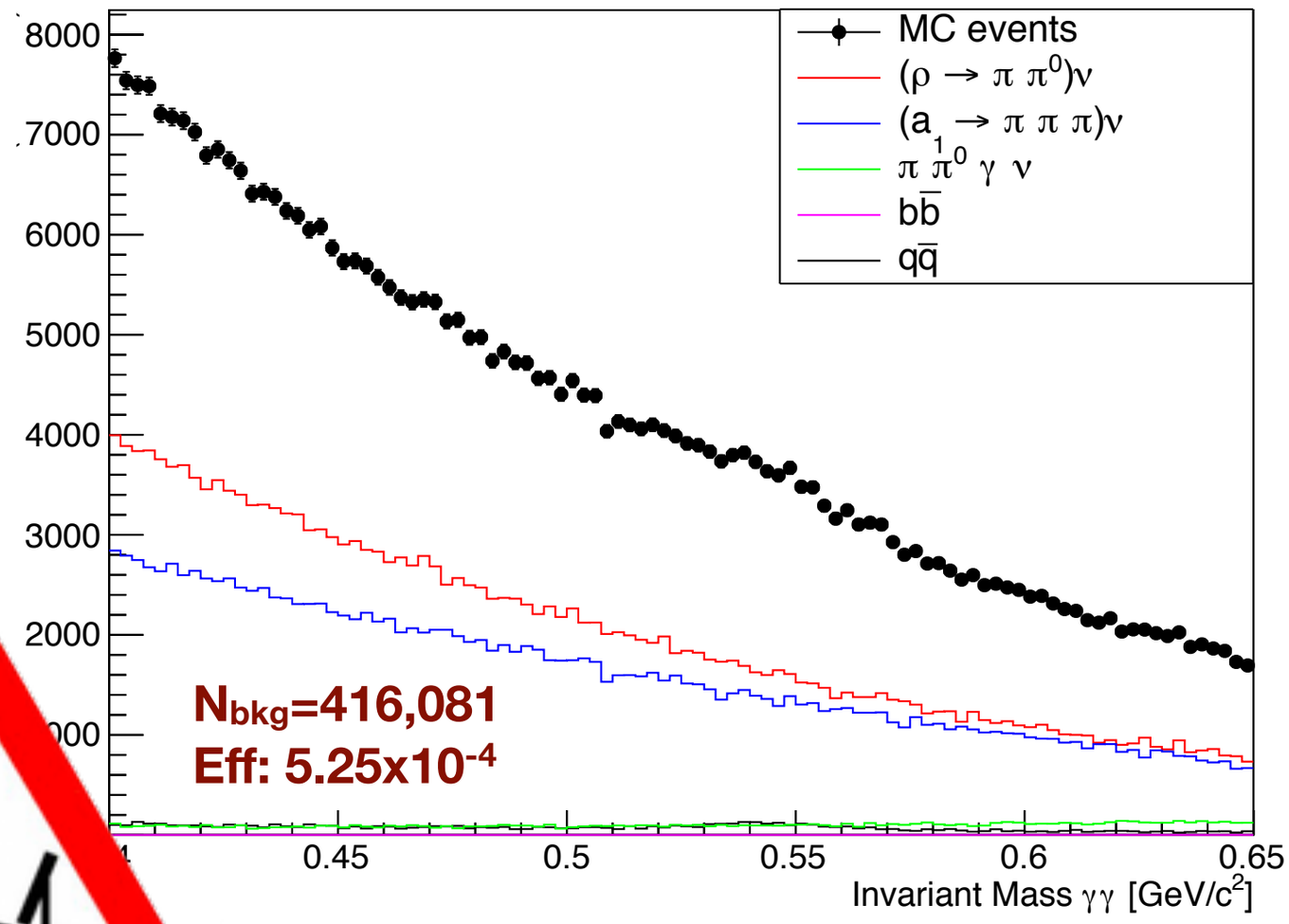
Optimal BDT cut

Background 1-prong



N_{bkg} = 2,694,408
Eff: 0.34%

Eff_{cut} = 84.56%



N_{bkg}=416,081
Eff: 5.25×10^{-4}

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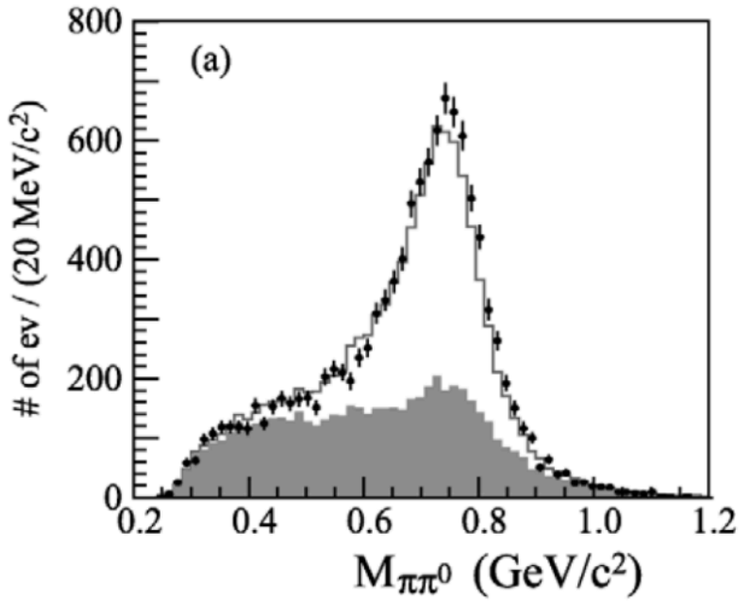
$\tau \to \eta \pi \pi^0 \nu$

The $\tau \to \eta\pi\pi^0\nu$ decay

- Previously measured by BELLE, ALEPH and CLEO.
  BR(τ —> $\eta\pi\pi^0\nu$) = (1.39 ± 0.07) x10^{-3}

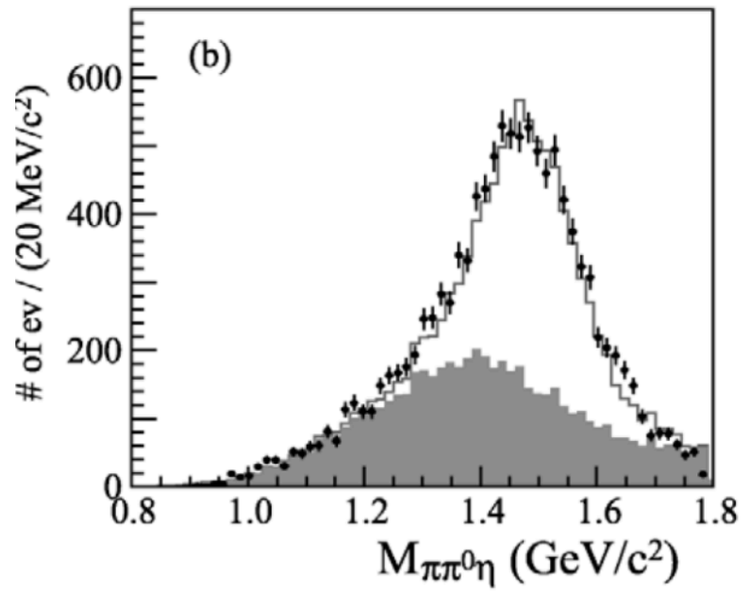
- The contributions of scalar and pseudoscalar resonances are expected to be negligible.
  So, the corresponding amplitudes are driven by the vector current, allowing a precise study of the couplings in the odd-intrinsic parity sector.



- In the limit of the SU(2) isospin symmetry, is a good cross-check of consistency with
  $\sigma(e^+e^- \text{—>} \eta\pi^+\pi^-)$ in the low energy region [1]

$$\frac{d\Gamma(\tau^- \to \eta\pi^-\pi^0\nu_\tau)}{\mathrm{d}Q^2} = 2\, f(Q^2)\sigma(e^+e^- \to \eta\pi^+\pi^-)$$

- For the hadronic contributions to the theoretical value of a_μ, experimental input from the measurement of the cross section $\sigma(e+e- \to hadrons)$ dominates. [2]



K. Inami et.al (BELLE)
Phys.Lett. B672 (2009)

[1] D. Gómez Dumm and P. Roig; Phys. Rev. D 86, 076009 (2012)
[2] Waldi, R (BaBar Collaboration); PoS ICHEP2016 (2016) 682.

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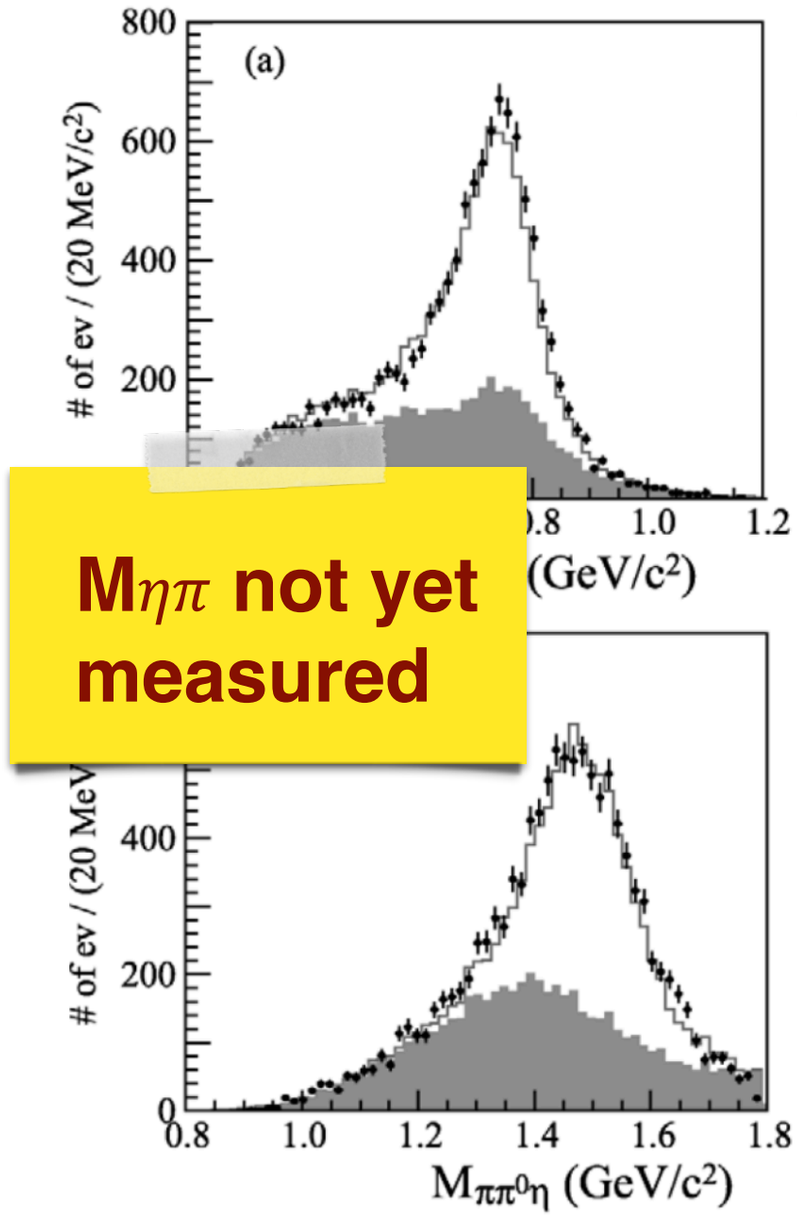

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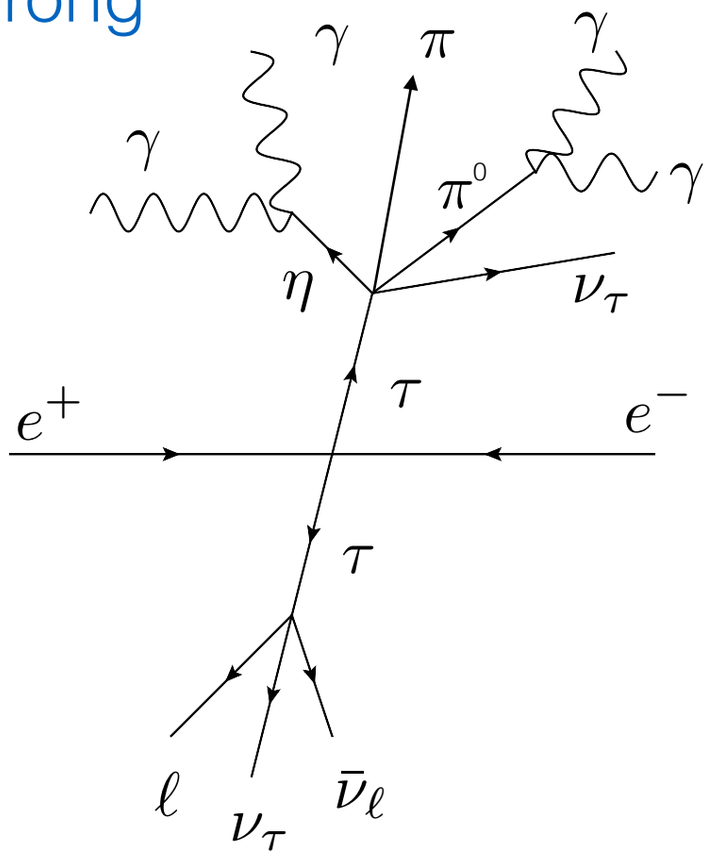
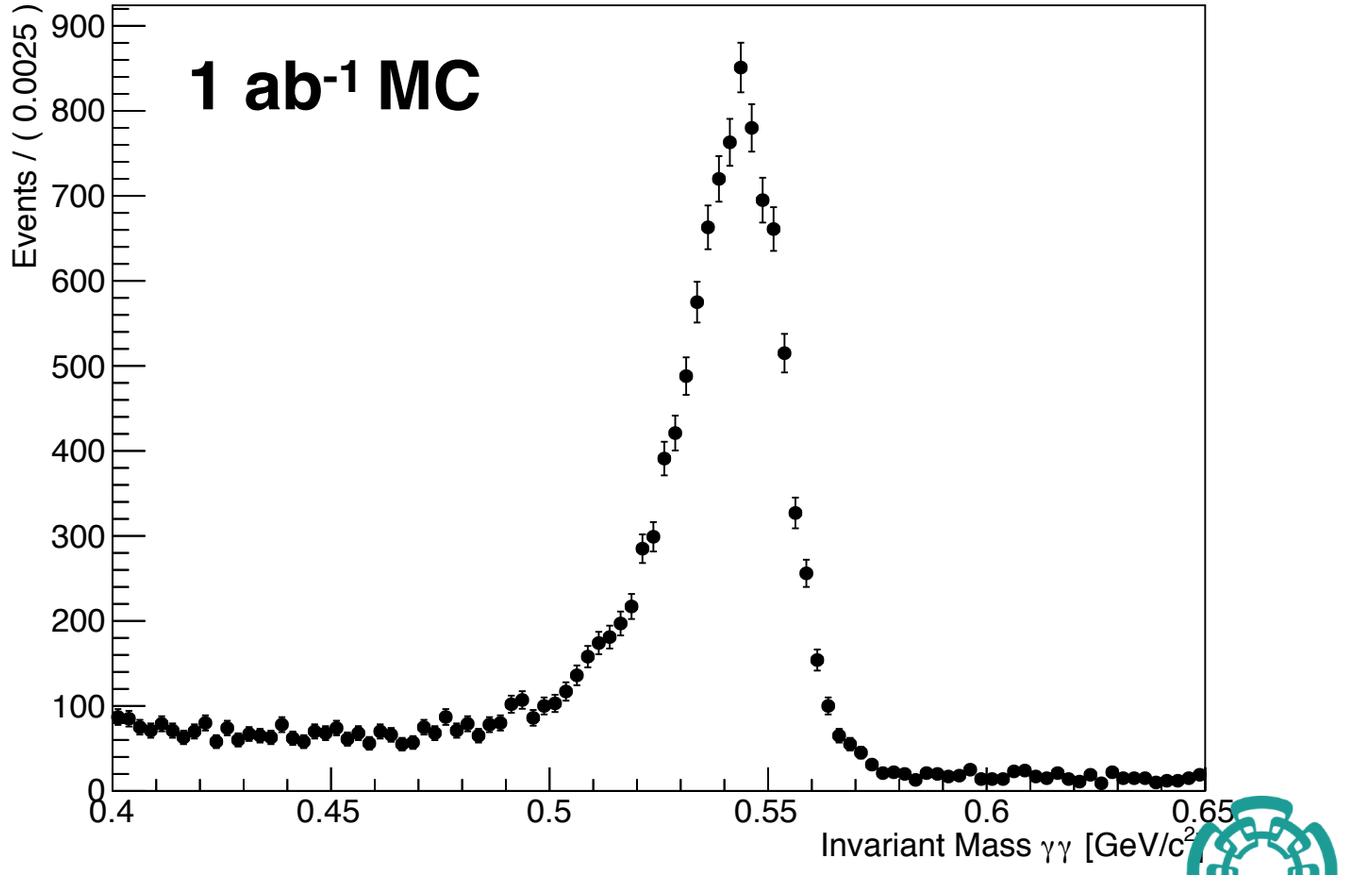
$\tau \rightarrow \eta\pi\pi^0\nu$

- η mesons reconstructed from $\gamma\gamma$ (1-prong) **BR(τ —> $\eta\pi\pi^0\nu$) = 1.39 x10^{-3}**
- Selection: tag + 1 charged + 4 or 5 γ
- Signal events generated: 1x10^6.

Eff: 1.38%

1-prong





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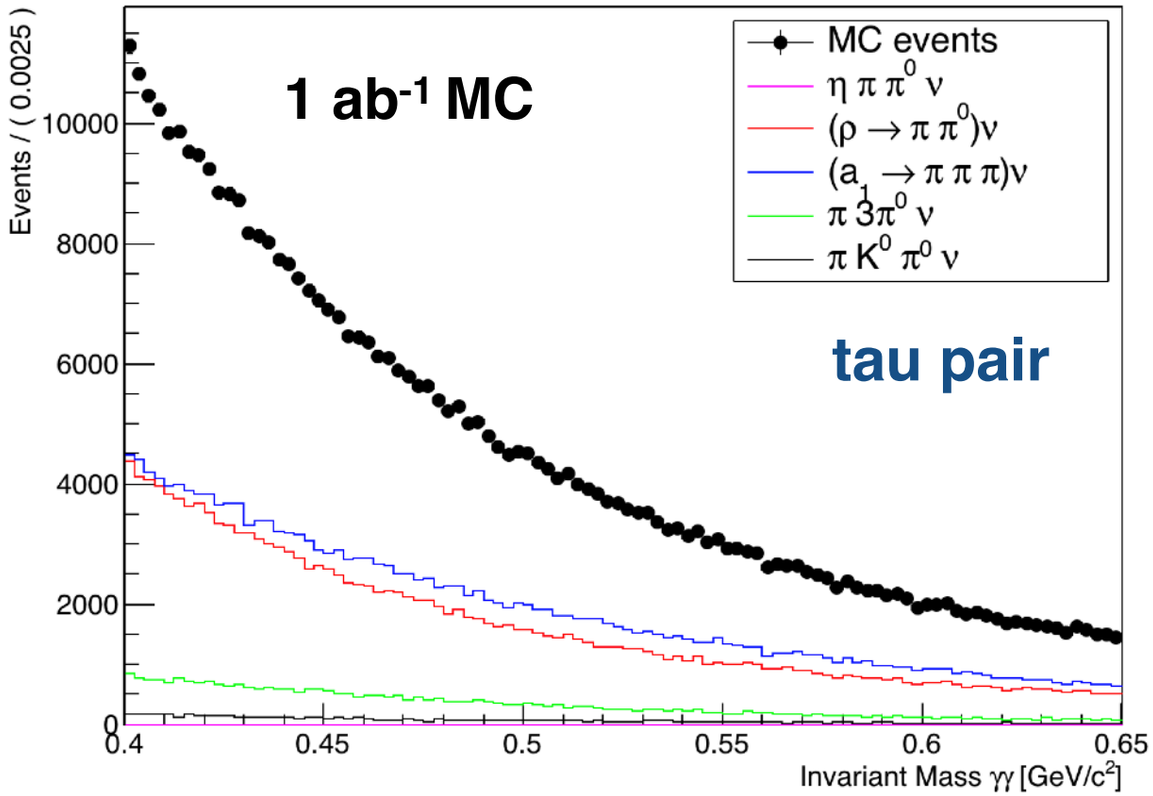
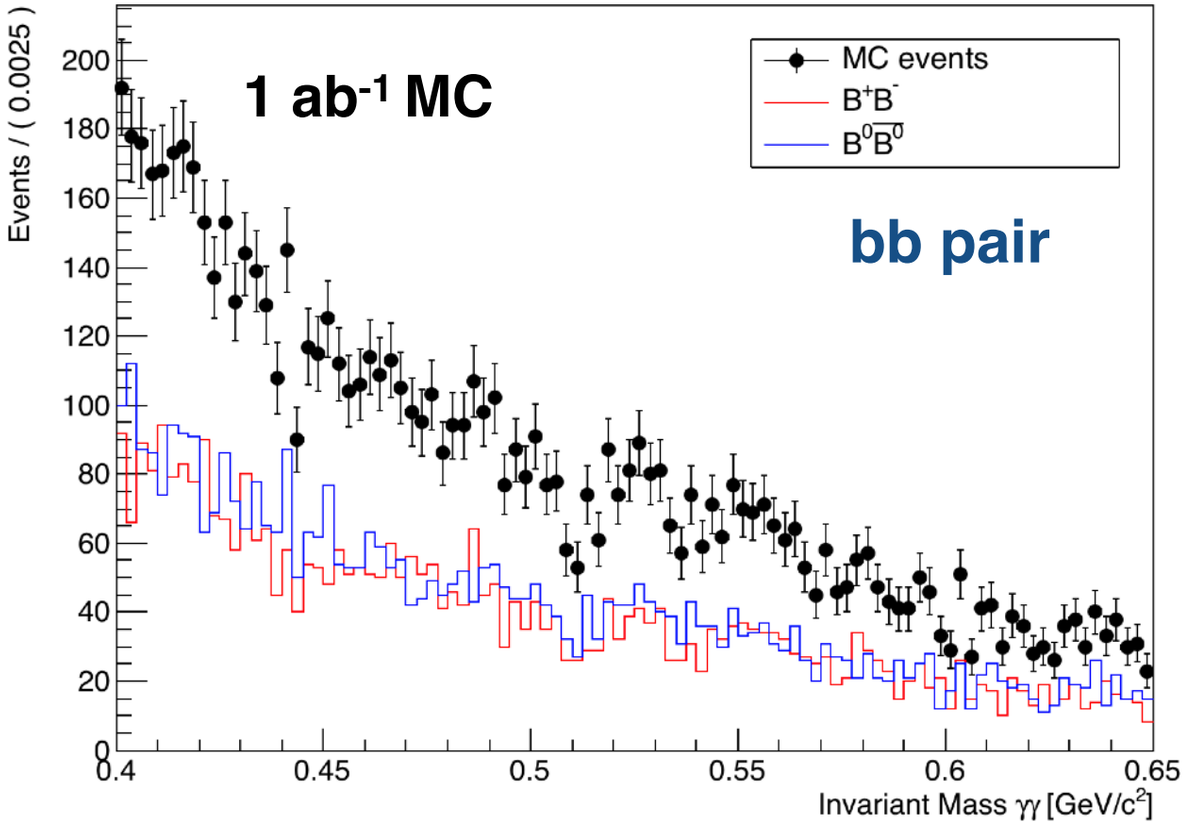
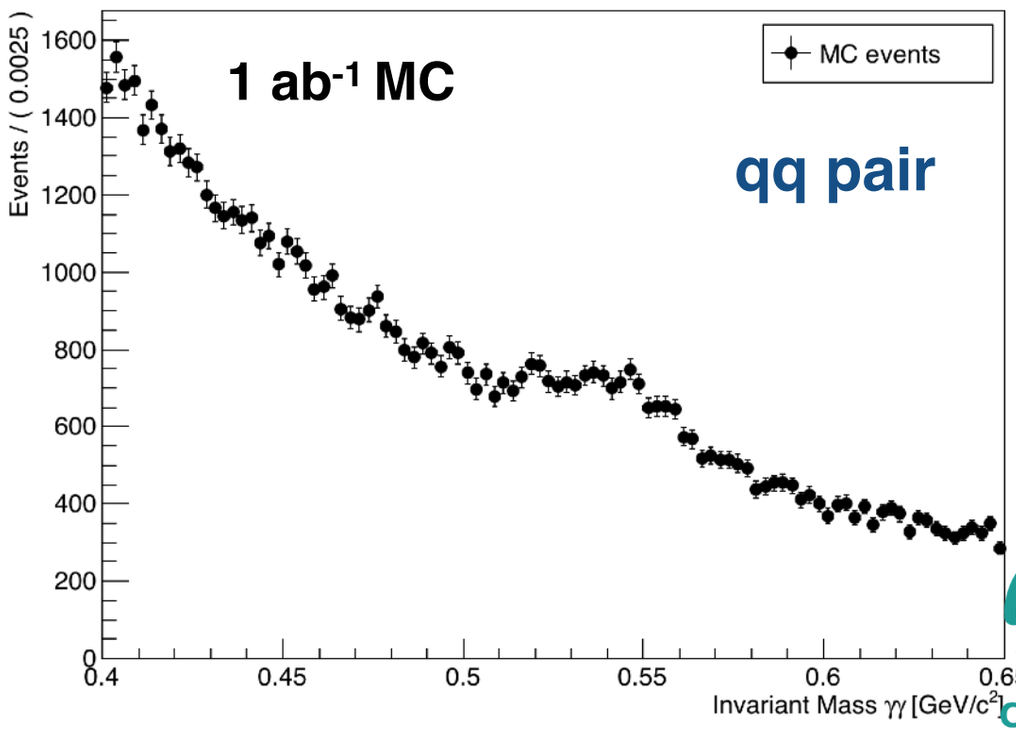
$\tau \to \eta\pi\pi^0\nu$ bkg events

- Background sources:
  - $\boldsymbol{\tau\tau}$ pair
  - bb pair
  - qq pair

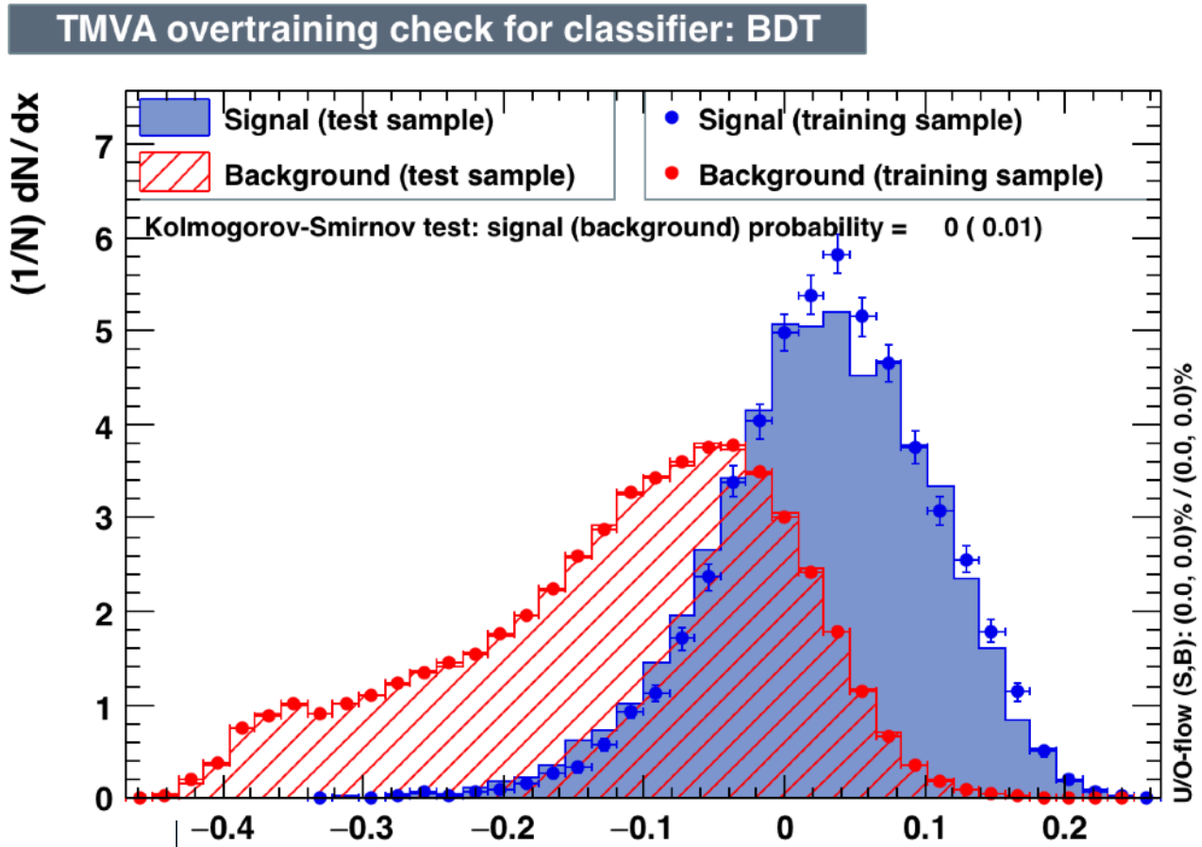


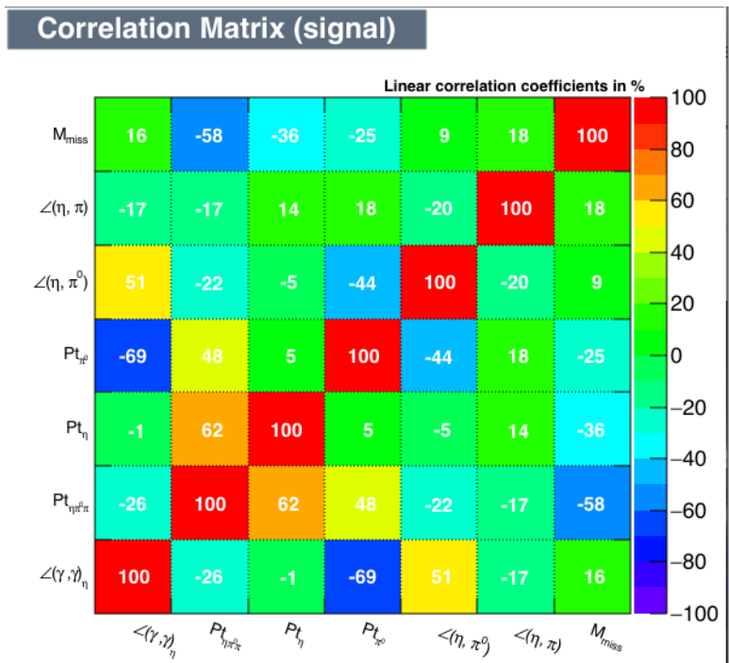


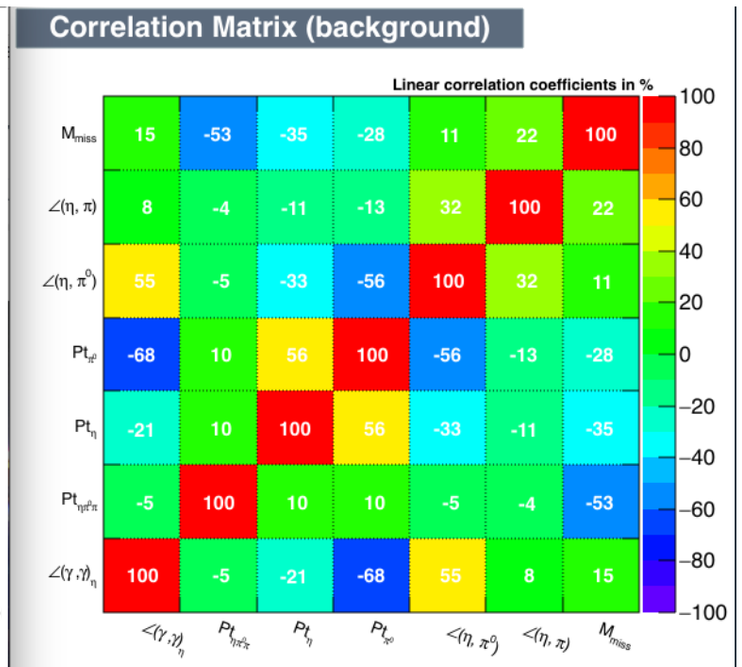


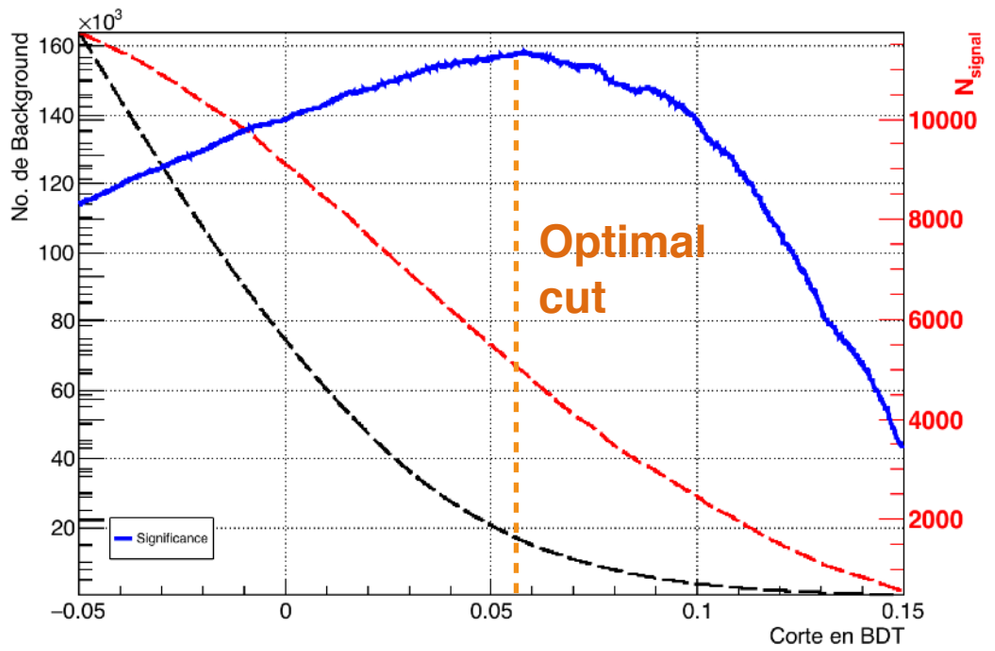
BDT variables

- $\angle(\gamma,\gamma)_\eta$
- $P_t(\eta\pi\pi^0)$
- $P_t(\pi^0)$
- $P_t(\eta)$
- M_{miss}
- $\angle(\eta,\pi)$
- $\angle(\eta,\pi^0)$





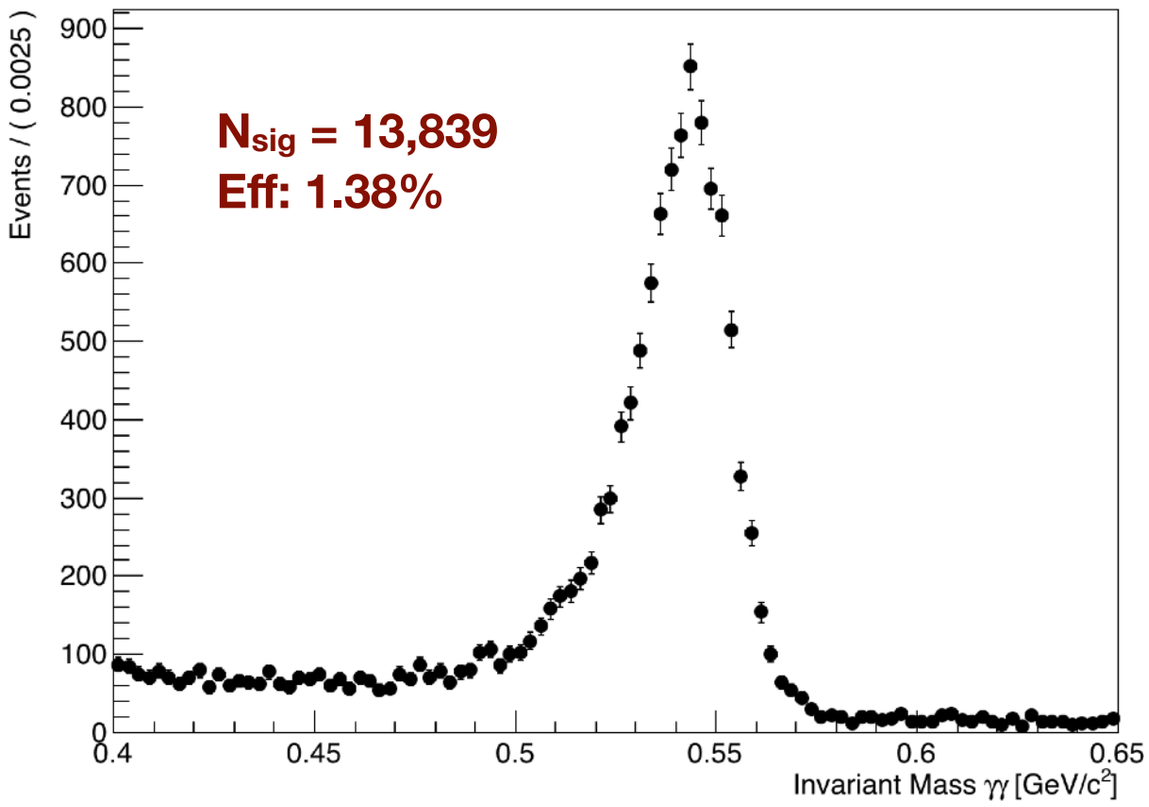


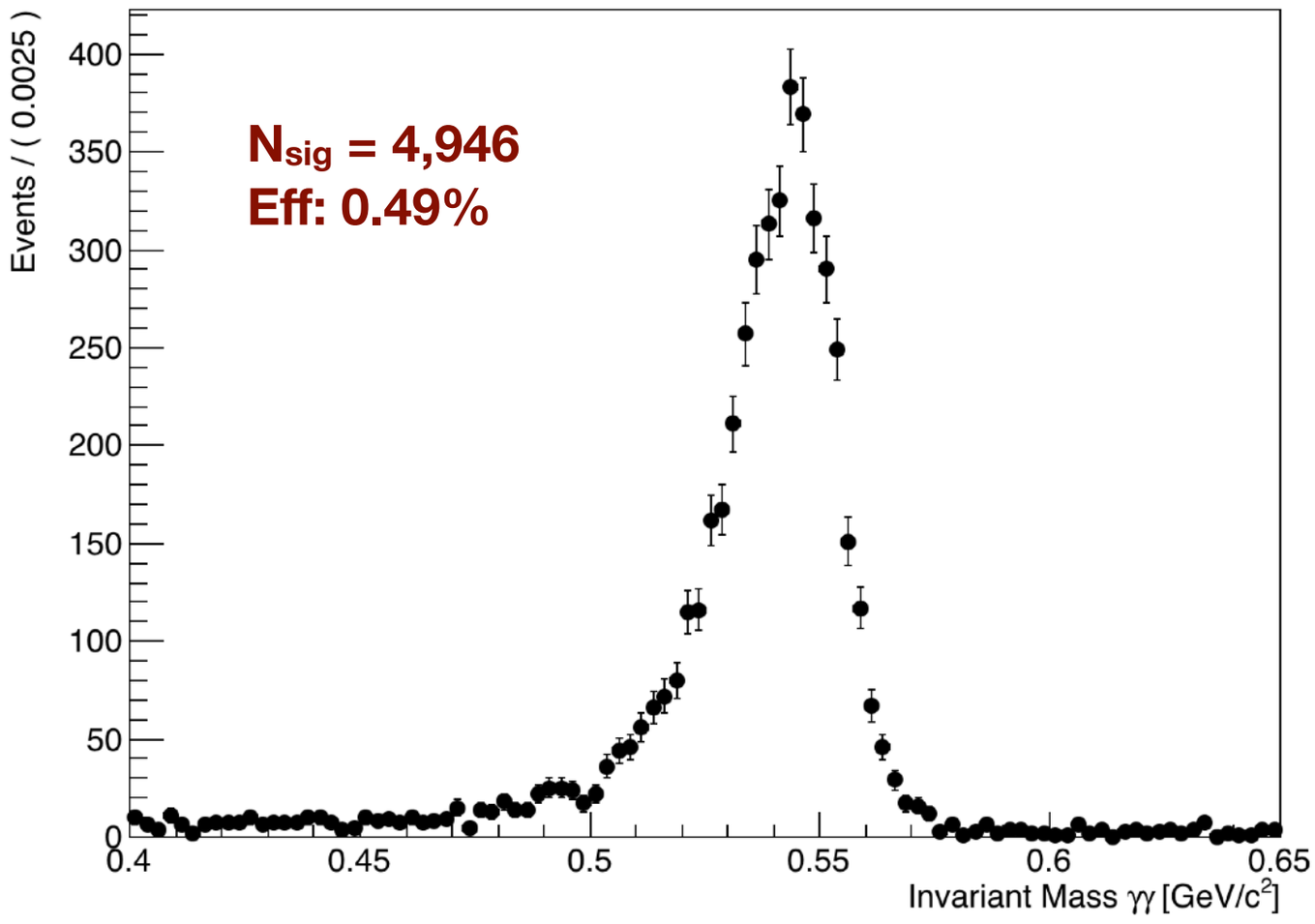


Optimal BDT cut

Signal

$\text{Eff}_{\text{cut}} = 64.26\%$





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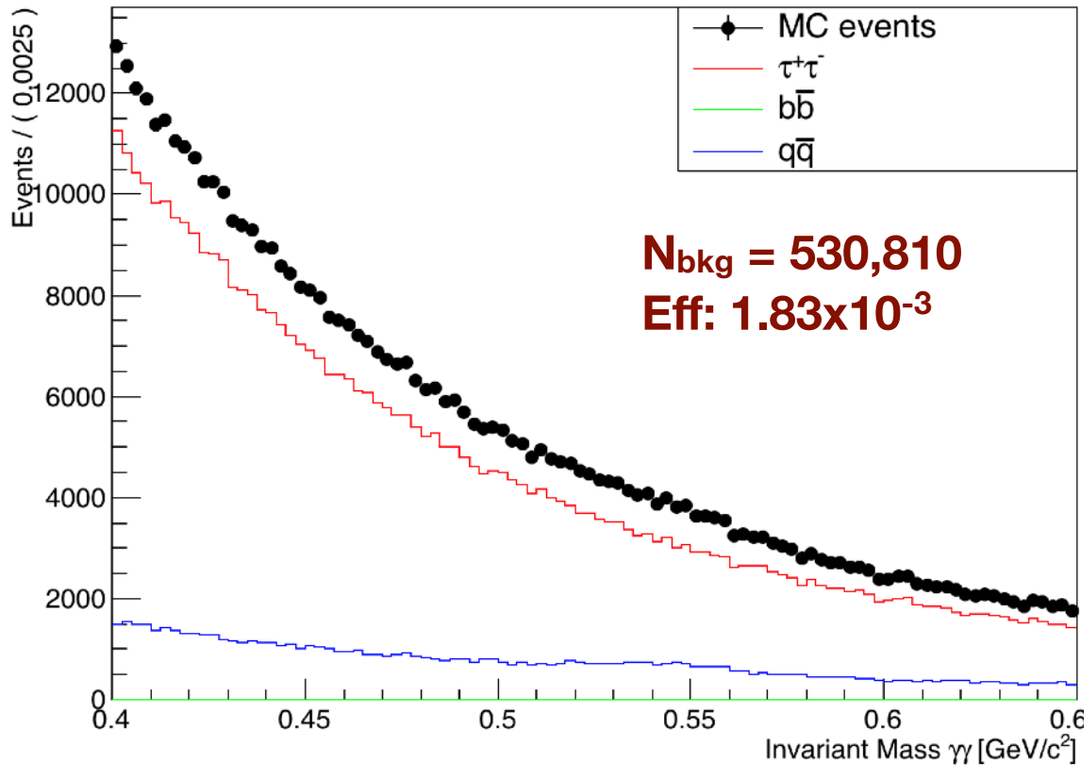
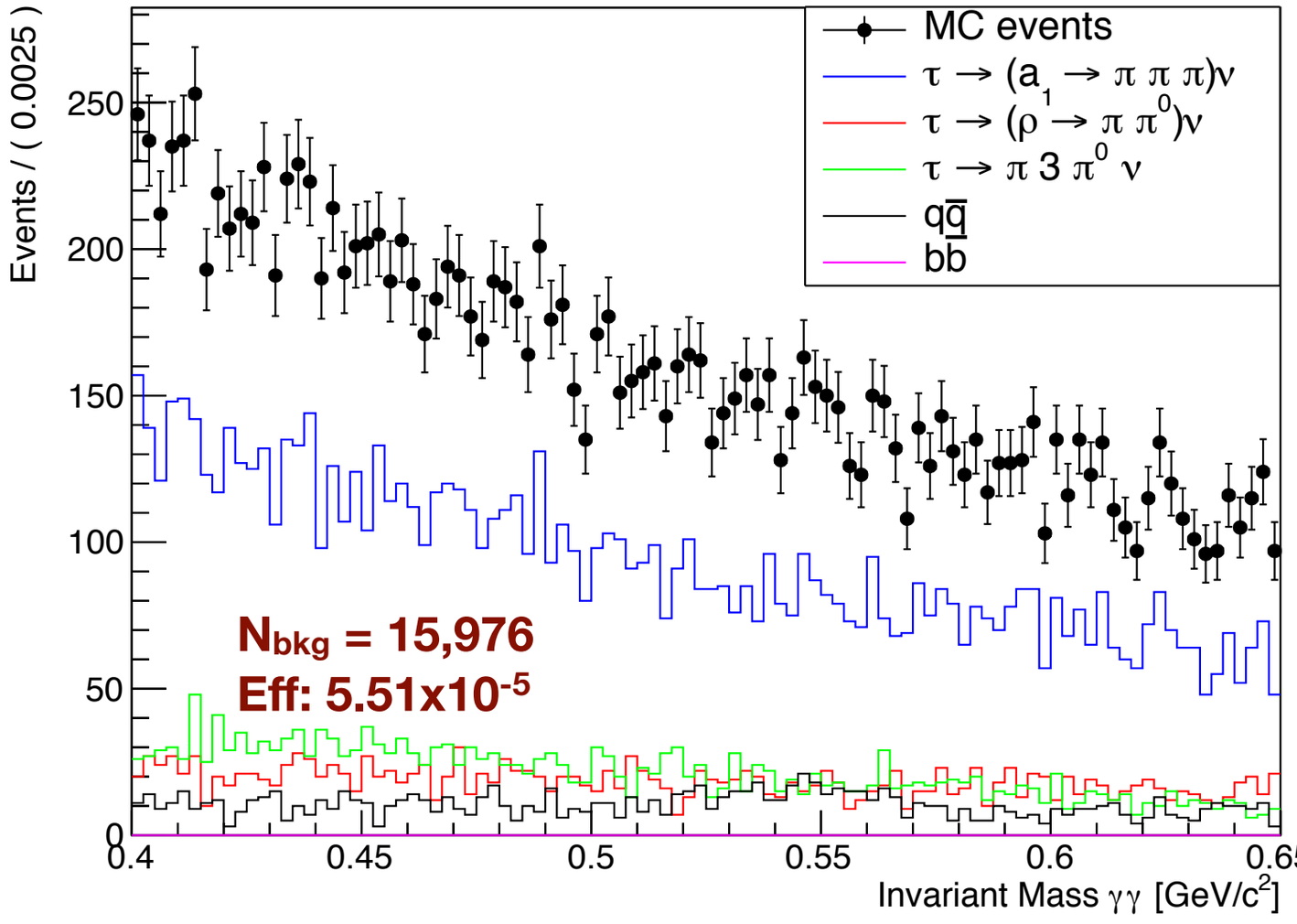
Optimal BDT cut

Background



$$\frac{S}{\sqrt{S+B}} = 34.19$$

$\text{Eff}_{\text{cut}} = 97.0\%$



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Outlook

- All bkg sources should be included in the sensitivity analysis (two photon, $\tau \to \eta\pi\gamma\nu$, etc).

- Besides BDT and TMVA, we can test other MVA software packages and techniques (FANN, FastBDT, TensorFlow, etc).

- Once the MVA determines the optimum cuts, we will use RooFit to estimate efficiencies.

- BR measurement, invariant mass of $\eta\pi$, $\eta\pi\pi^0$ and form factors will be very important to disentangle models.

- The implementation of channels in TAUOLA, with the most recent decay models, is important to control the bkg.

Thank you

Backup

G - Parity

- G-parity is defined by $G = Ce^{i\pi I_2}$

- Is a good symmetry of the strong interactions

  $[H_{str}, I_i] = 0; \qquad [I_i, I_j] = i\epsilon_{ijk} I_k$

  Convenient to analyze process where the initial or final state contains only mesons

$$G|\pi\rangle = -|\pi\rangle$$
$$G|\eta\rangle = +|\eta\rangle$$
$$G|\rho\rangle = +|\rho\rangle \qquad \rho \to \pi\pi, 4\pi; \quad \not\to 3\pi, \eta\pi$$
$$G|\omega\rangle = -|\omega\rangle \qquad \omega \to 3\pi, \rho\pi; \quad \not\to 2\pi, 4\pi$$
$$G|a_0\rangle = -|a_0\rangle \qquad a_0 \to \eta\pi; \quad \not\to 2\pi$$

- However, G-Parity is not exact. $[H_{tot}, I_i] \neq 0;$

- Some recent theoretical predictions

Ref	BR_V (x10^5)	BR_S (x10^5)	BR_{V+S} (x10^5)	Model
[8]	0.36	1.0	1.36	MDM, 1 resonance
[9]	[0.2, 0.6]	[0.2, 2.3]	[0.4, 2.9]	MDM, 1 and 2 resonances
[10]	0.44	0.04	0.48	Nambu-Jona-Lasinio
[11]	0.13	0.20	0.33	Analiticity, Unitarity
[12]	0.26	1.41	1.67	3 coupled channels

[8] S. Nussinov + A. Soffer, PRD78, (2008)

[9] N. Paver + Riazuddin, PRD82, (2010)

[10] M. Volkov D. Kostunin, PRD82, (2012)

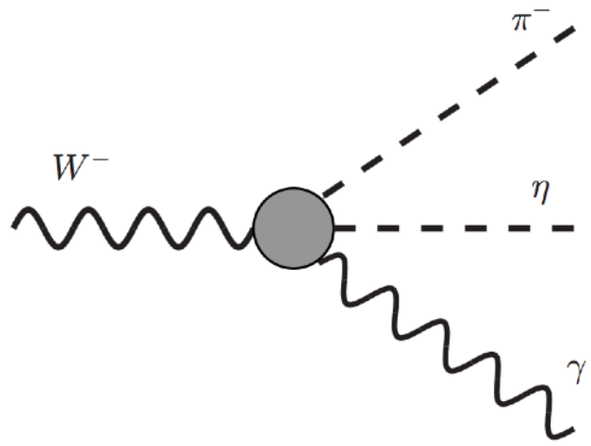
[11] S. Descotes-Genon+B. Moussallam, EJPC74, (2014)

[12] R. Escribano, S. Gonzalez, P. Roig; Phys.Rev. D94 (2016) no.3, 034008

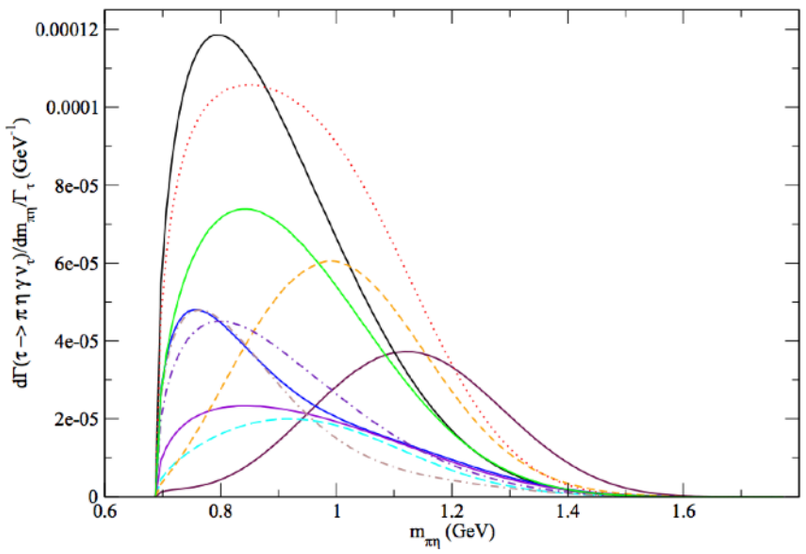
- $BR(\tau \to \eta\pi\nu) \sim 10^{-5}$ ⟵ Accesible at Belle II luminosity.

A new bkg source[1]

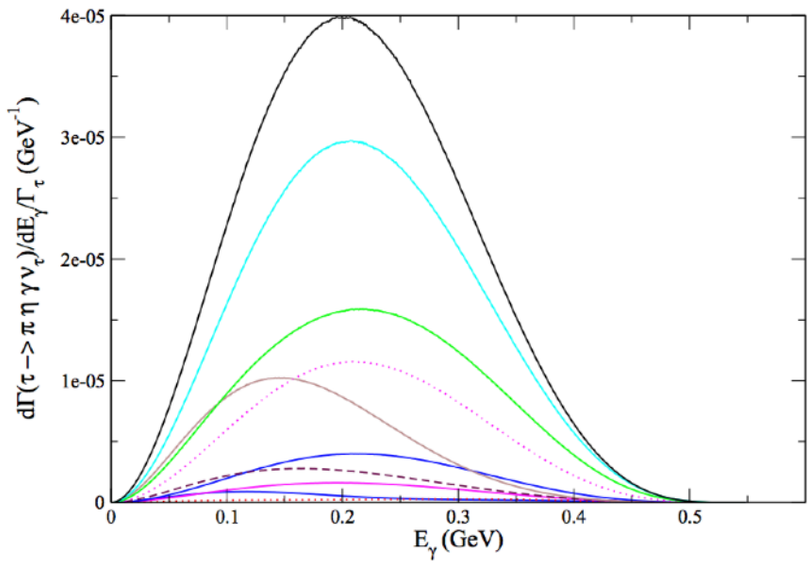
- $\tau^- \to \eta\pi^-\nu_\tau\gamma$



- BR ~ 10^{-5} !
  (Not suppressed by G-parity, unlike the channel without photon.)



(a) Normalized spectra in the invariant mass of the $\eta\pi^-$ system are plotted for some characteristic points in fig. 14(a).



(b) For the same points as in (a), the normalized spectra in E_γ are drawn.

Figure 16: Normalized spectra of the $\tau^- \to \eta\pi^-\nu_\tau\gamma$ decays according to $R\chi L$.

- Veto of photons with Eγ > 100 MeV should get rid of this background.

[1]A. Guevara, G. López-Castro, P. Roig (2016). arXiv:1612.03291. To be published in PRD.

TinyDST

- For tau physics study, roughly TinyDST (tdst) is designed[1].

- Events having:

  - Less than 6 charged tracks with |dr|<0.5 cm, |dz|<3.0 cm, p_t>0.1 GeV/c and -0.8660<cos θ<0.9535.

  - Less than 10 photons with E_γ>50 MeV and -0.8660<cos θ<0.9535.

- Thrust vector information contained.

- To squeeze the size, one lepton is required.

  - In SM precise measurement, to avoid qq BG, usually, leptonic decay is required for tag tau (tau with non-signal decay).

- 50MBytes for 200k events. (In original mdst, 50MBytes for 20k events.)