Search for $X_b \to \pi^+\pi^-\Upsilon(1S)$ at Belle and Belle II

Wenpeng Yan[1], Sen Jia[1], Qingping Ji[2] and Chengping Shen[3]

[1]Southeast University, Nanjing
[2]Henan Normal University, Xinxiang
[3]Fudan University, Shanghai

Belle (II) China analysis forum

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yanwp@seu.edu.cn

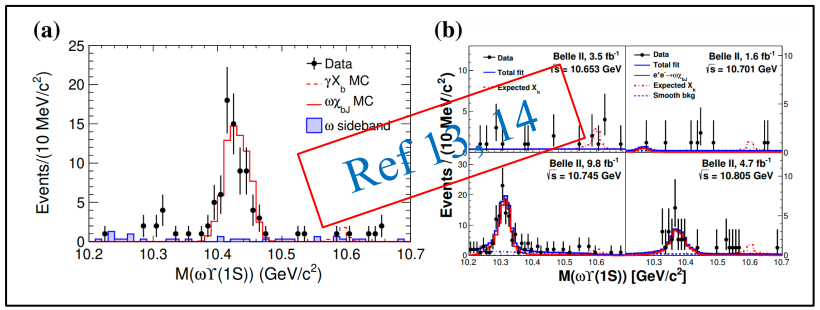
Motivation I

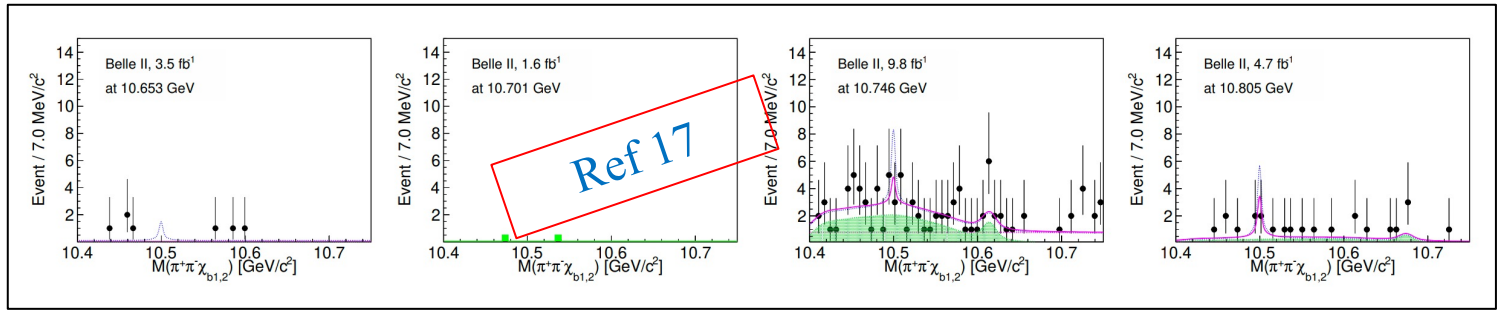
- The X(3872) state was first observed by Belle in 2003 through its decay into $\pi^+\pi^- J/\psi$ in the process $B^+ \to K^+\pi^+\pi^- J/\psi$ [1]. It is natural to search for a similar state with $J^{PC} = 1^{++}$ in the bottomonium system.
- X_b existence has been predicted in molecular [2, 3, 4] and tetraquark models [5, 6, 7], with masses close to the $B\bar{B}$ or $B\bar{B}^*$ threshold [2, 3, 4], or in the 10 to 11 GeV/c^2 [5, 6, 7] range, respectively.
- Using 20.7 fb^{-1} and 16.2 fb^{-1} of pp collision data at C.M. energy $\sqrt{s} = 8$ TeV, CMS and ATLAS searched for $X_b \to \pi^+\pi^-\Upsilon(1S)$, but no evidence for the X(3872) state was found.

[1] S.K. Choi (Gyeongsang Natl. U.) et al. (Belle Collaboration), Phys. Rev. Lett. **91** 262001 (2003)
[2] N.A. Tornqvist, Z. Phys. Rev. D **88**, 054007 (2013).
[3] F.K. Guo, C.H. Duque, J. Nieves, and M.P. Valderrama, Phys. Rev. D 88, 054007 (2013).
[4] M. Karliner and S. Nussinov, J. High Energy Phys. 07, 153 (2013).
[5] D. Ebert, R.N. Faustov, and V.O. Galkin, Phys. Lett. B **634**, 214 (2006).
[6] D. Ebert, R.N. Faustov, and V.O. Galkin, Mod. Phys. Lett. A **24**, 567 (2009).
[7] A. Ali, C. Hambrock, I. Ahmed, and M.J. Aslam, Phys. Lett. B **684**, 28 (2010).
[8] S. Chatrchyan et al. (CMS Collaboration), Phys. Lett. B **727**, 57 (2013).
[9] G. Aad et al. (ATLAS Collaboration), Phys. Lett. B **740**, 199 (2015).

Motivation II

- Belle and Belle II have searched for $X_b \to \omega(\to \pi^+\pi^-\pi^0)\Upsilon(1S)$ using a 118 fb^{-1} data sample at $\sqrt{s} =$ 10.867 GeV and a 19.6 fb^{-1} data sample at $\sqrt{s} = 10.75$ GeV [13, 14].
- Using 3.5, 1.6, 9.8, and 4.7 fb^{-1} data samples at $\sqrt{s}$ = 10.653, 10.701, 10.746, and 10.804 GeV, Belle II search for the X_b with $X_b \to \pi^+\pi^-\chi_{b1,2}$ in $e^+e^- \to \gamma X_b$ [15]. No evident signal of X_b was found.





- In this analysis, we search for the particle X_b corresponding to $X(3872)$ in the bottomonium energy region around 10 GeV. The specific search process is $X_b \to \pi^+\pi^-\ \Upsilon(1S)$, and X_b is found or the strictest upper limit is given.

[13] X. H. He et al. (Belle Collaboration), Phys. Rev. Lett. **113**, 142001 (2014).
[14] I. Adachi et al. (Belle Collaboration), Phys. Rev. Lett. **130**, 091902 (2023).
[15] I. Adachi et al. (Belle II Collaboration), arXiv:2509.01917.

Datasets

➢ **Software environment:** BASF2 release: `light-2505-deimos`

- **Signal MC samples:**

✓ **Generate Signal MC sample for:**

$e^+e^- \to \gamma X_b,\ X_b \to \pi^+\pi^-\Upsilon(1S),\ \Upsilon(1S) \to \mu^+\mu^-(e^+e^-)$

at $\sqrt{s} = 10.751\ \mathrm{GeV}$ **by a combination of PHOKHARA and EvtGen.**

✓ **20000 Events for the sample.**

- **Generic MC samples:**

Run-dependent MC – proc13 + prompt -5S_scan

✓ **Generated these following excMC samples of 20000 each:**

$e^+e^- \to \pi^+\pi^-\Upsilon(\mathrm{nS})\ (\mathrm{n} = 1, 2, 3)$

$e^+e^- \to \omega\chi_{bJ}\ (\mathrm{J} = 0, 1, 2)$

Event type and size of generic MC samples

Mode	Luminosity (fb^{-1})
$u\bar{u}$	76.525
$d\bar{d}$	76.525
$s\bar{s}$	76.525
$c\bar{c}$	76.525
taupair	76.525
ee	1.913
gg	8.262
$\mu\bar{\mu}$	76.525
eeee	19.13
ee$u\bar{u}$	19.13
llXX	19.13
hhISR	19.13
charged	19.13
mixed	19.13
BstarBstar	19.13
BstarB	19.13

Preliminary event selection

- **Charged Tracks:**

✓ $|dr| < 1$ cm; $|dz| < 3$ cm, where *dr* and *dz* are transverse and longitudinal distances in respect to interaction point (IP).

✓ For $e^{\pm}$, perform bremsstrahlung correction:

```
ma.correctBremsBelle(outputListName='e+:corrected',inputListName='e+:uncorrected',ga
mmaListName='gamma:bremsinput',angleThreshold=0.05,path=my_path)
```

✓ $\mathrm{N_{gtrk}} = 4$

✓ For pion identifications, we require $\mathrm{bianaryPID}_{\pi}\_211\_321\mathrm{NN} > 0.6$,
✓ For muon identifications, we require $\mu\mathrm{IDNN} > 0.2$
✓ For electron identifications, we require $\mathrm{electronIDNN} > 0.9$

- $\boldsymbol{\Upsilon(1S) \rightarrow \mu^+\mu^-(e^+e^-)}$

✓ Loose mass window: [9.0, 10.0]

- **Photons:**

✓ $E(\gamma) > 50$ MeV and $E9/E21 > 0.5$.

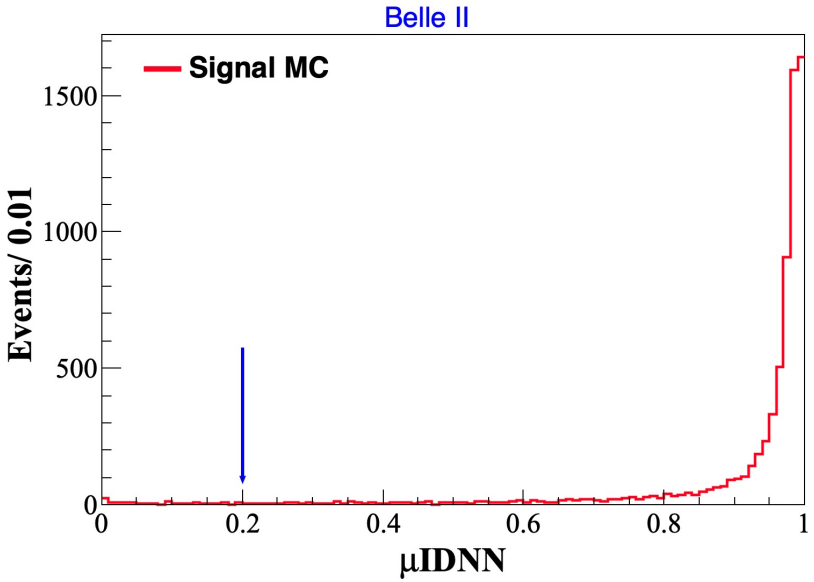
- π^0 veto:
✓ `pi0:veto -> gamma:sig gamma:roe`
✓ require $0.07 < M(\gamma\gamma) < 0.2$

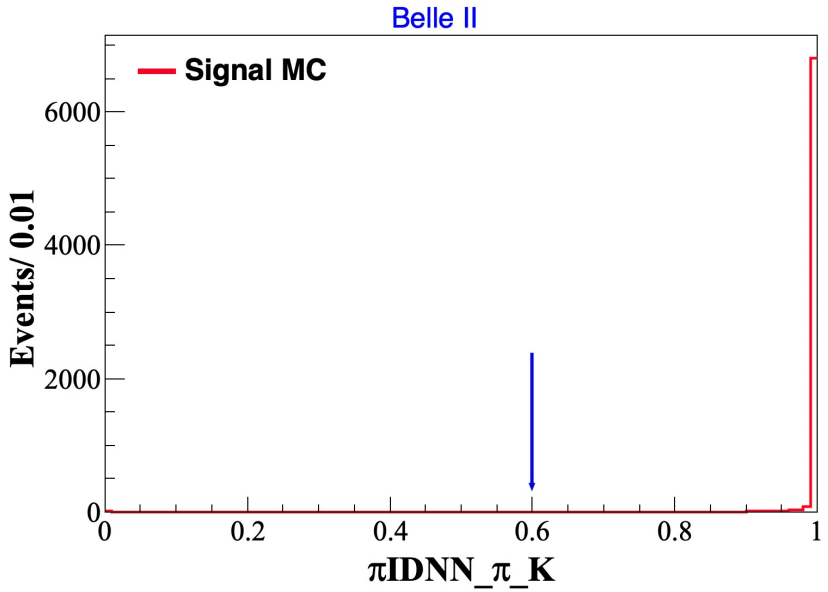
- **Four momentum constraint (4C) fit:**

✓ We perform 4C fit using Kfit for $\gamma\pi^+\pi^-\mu^+\mu^-$ final states. The best candidate is selected with the smallest 4C fit χ^2_{4C}.

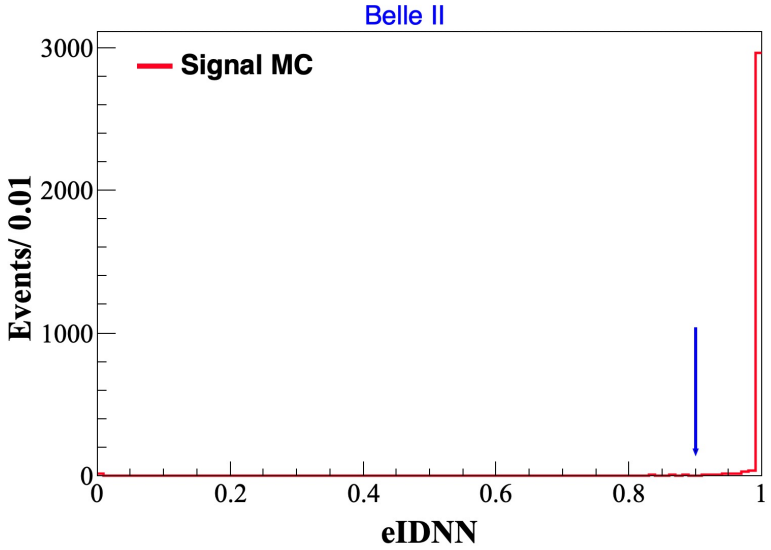
Signal MC Study I

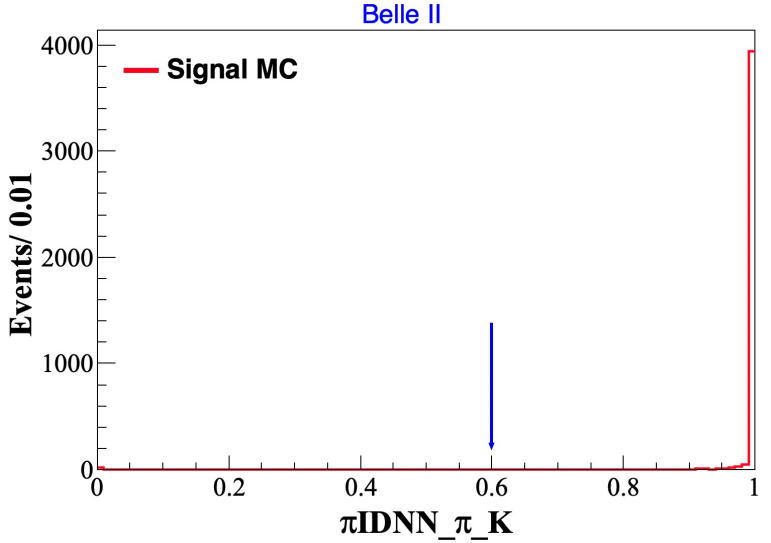
***μμ* chanel**





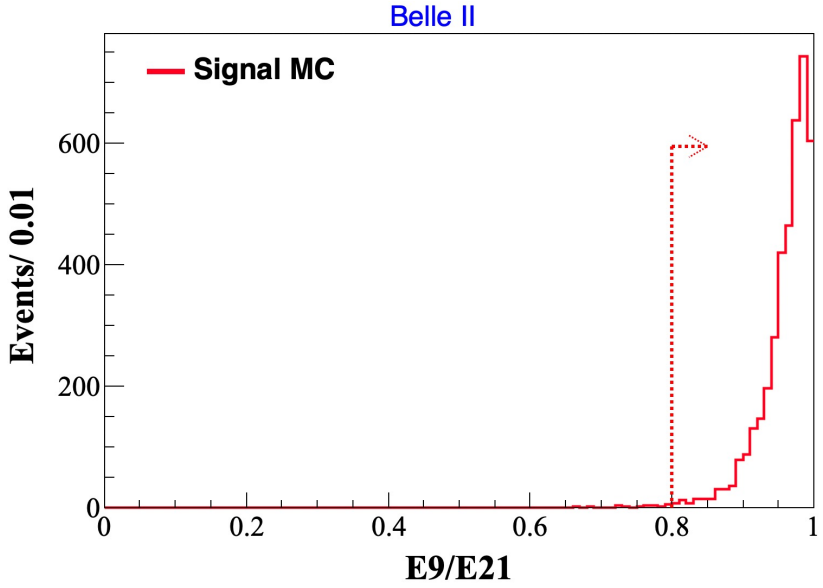
***ee* chanel**

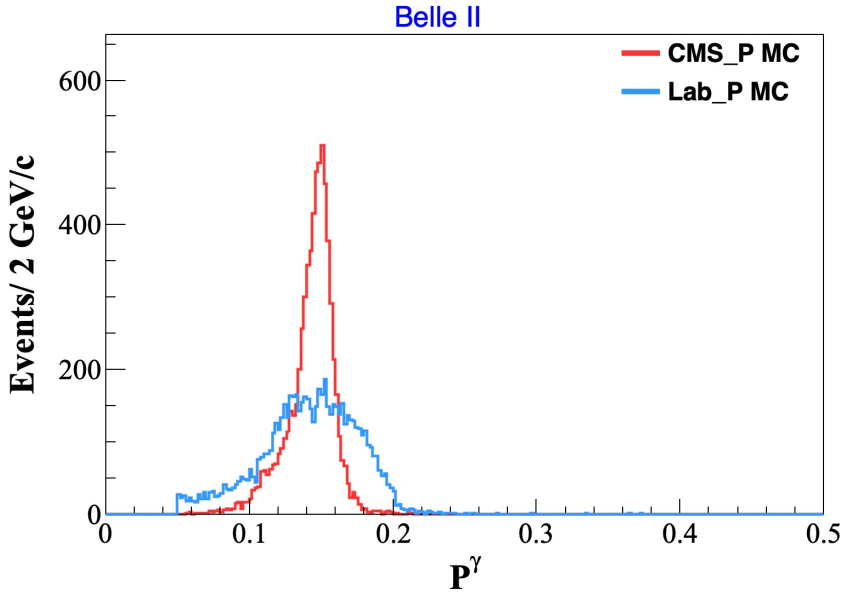




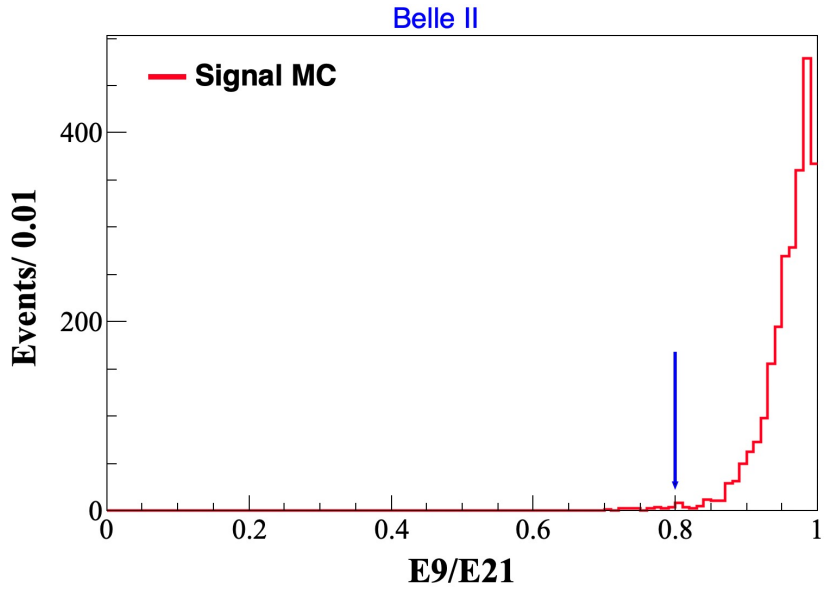
Signal MC Study II

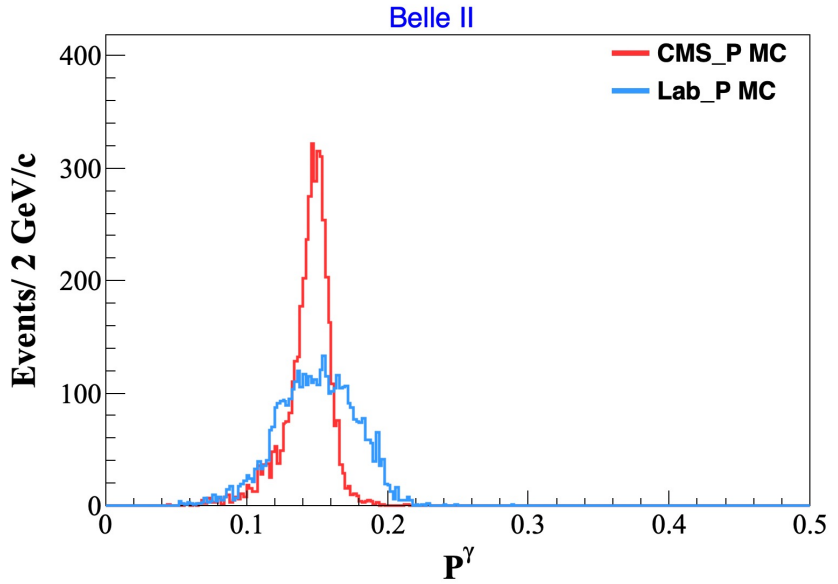
$\mu\mu$ chanel





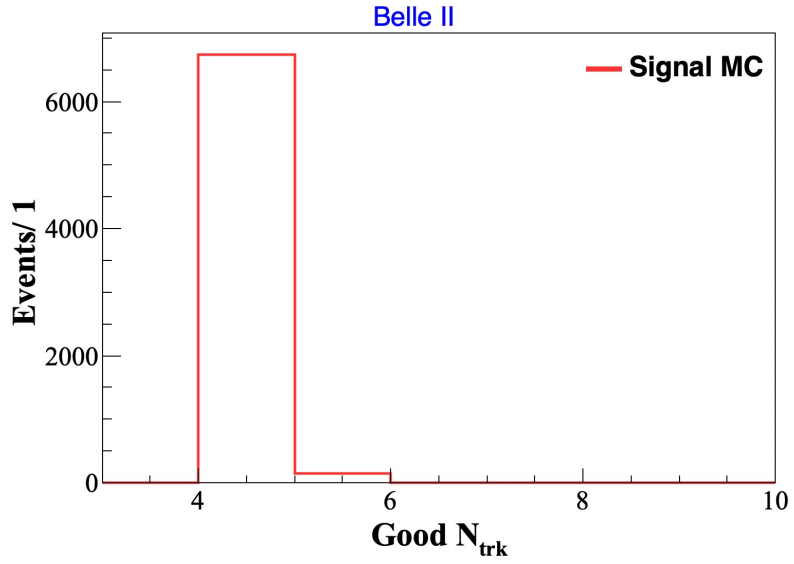
ee chanel

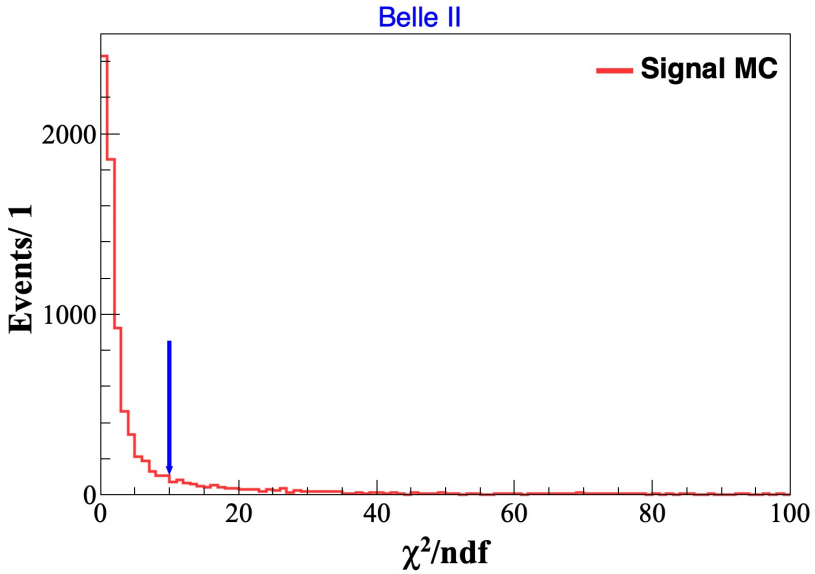




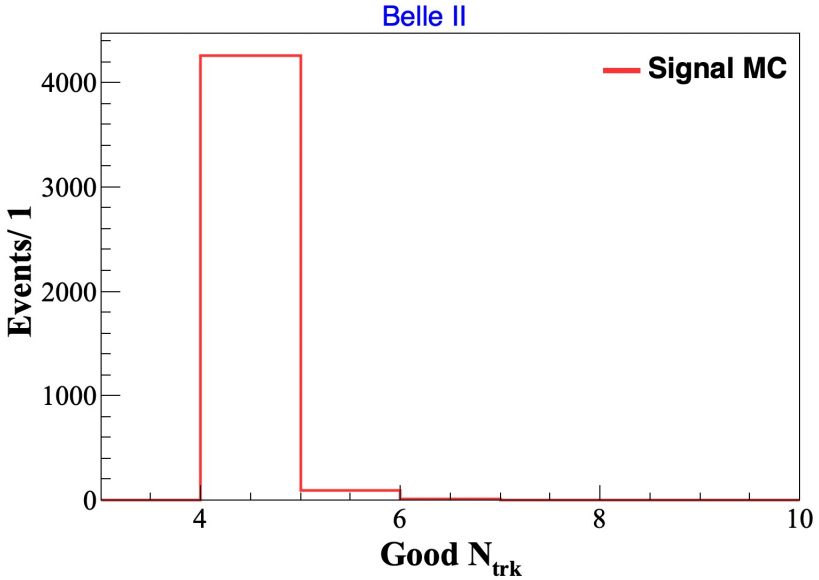
Signal MC Study III

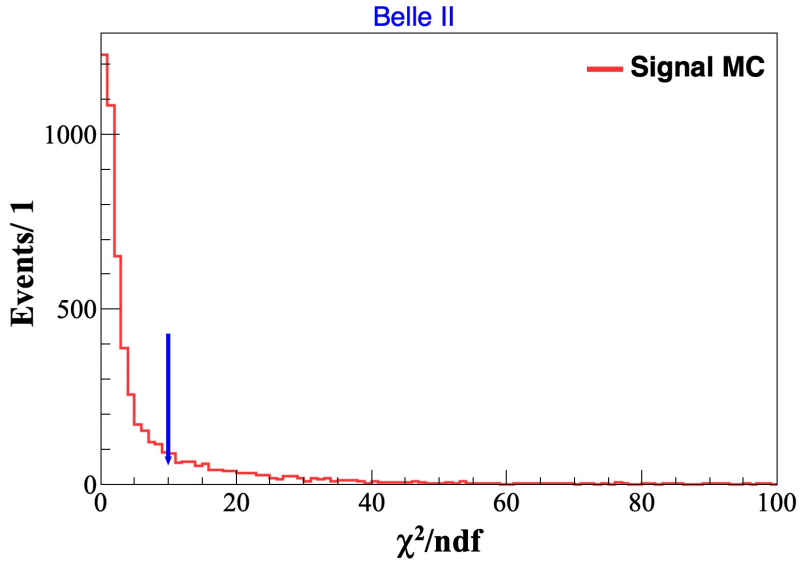
$\mu\mu$ chanel





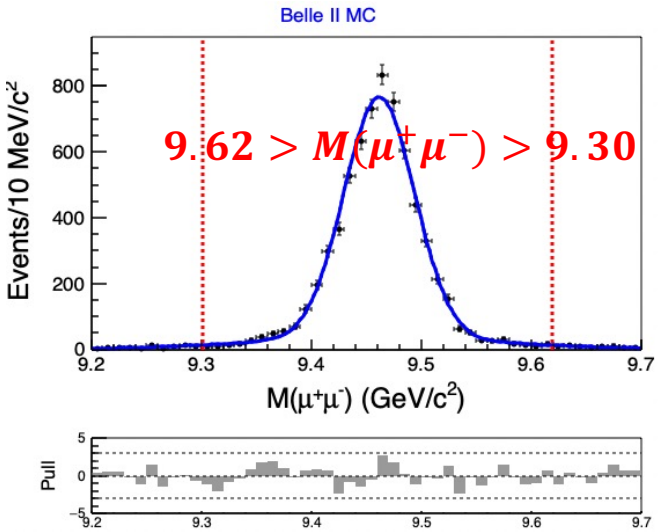
ee chanel

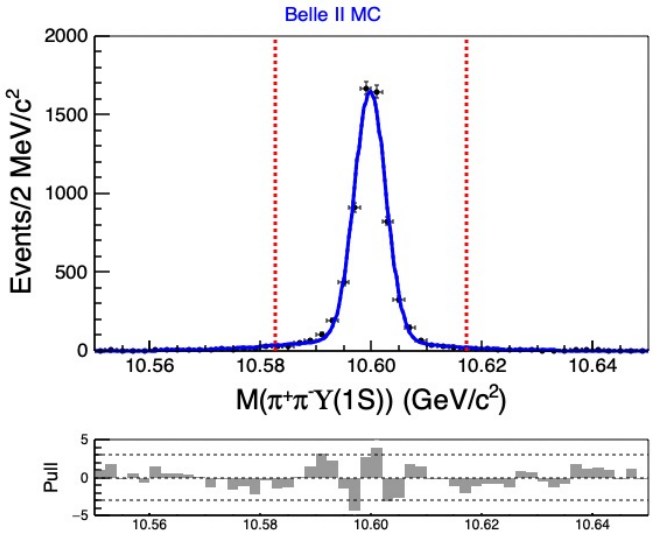




Signal MC Study IV

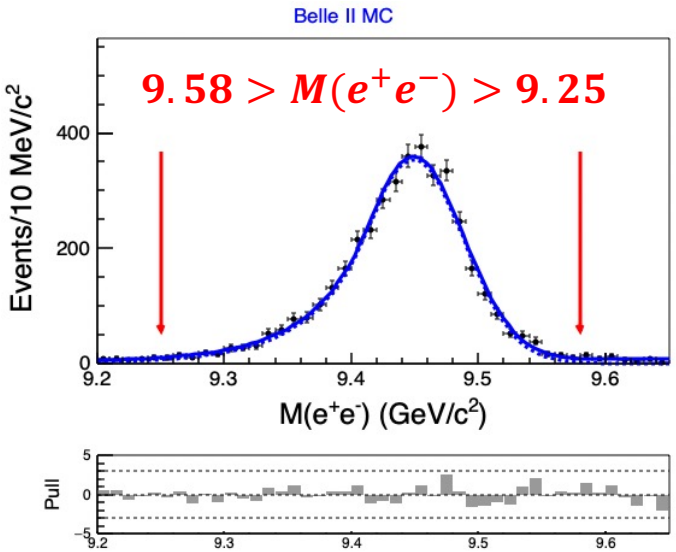
$\mu\mu$ chanel

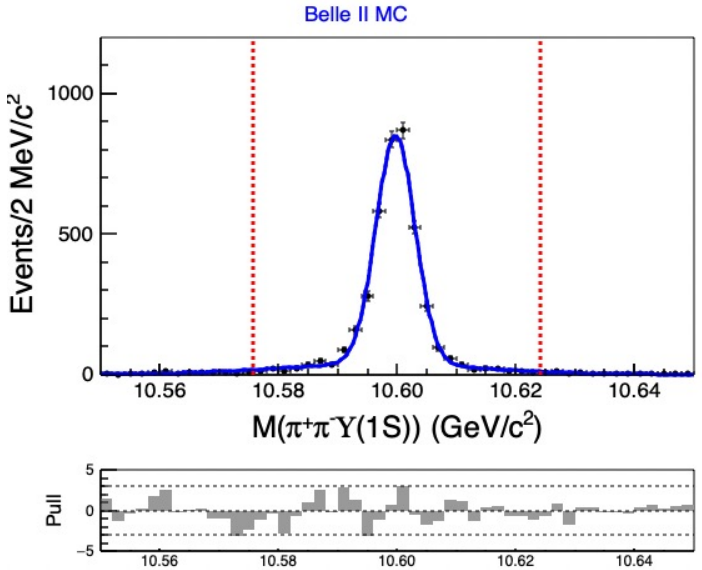




$\varepsilon = 31.07\%$

ee chanel

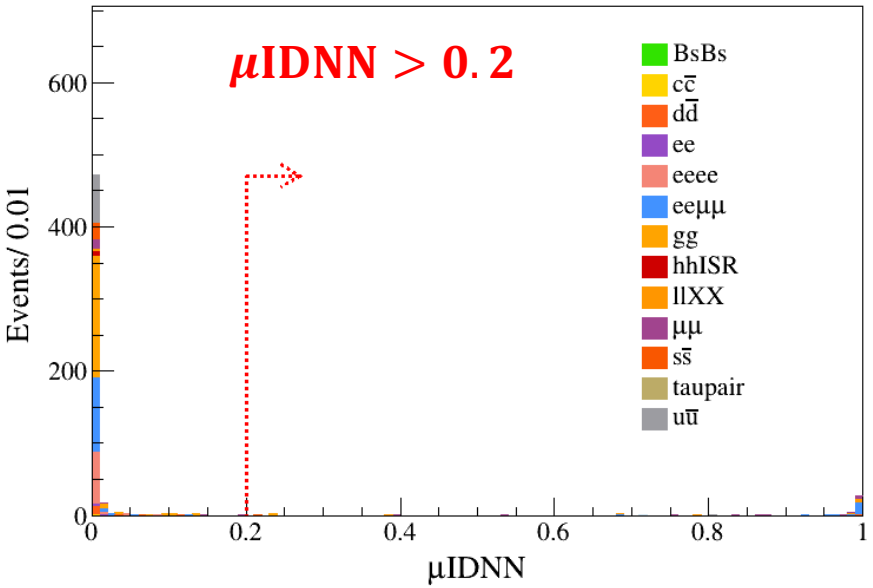


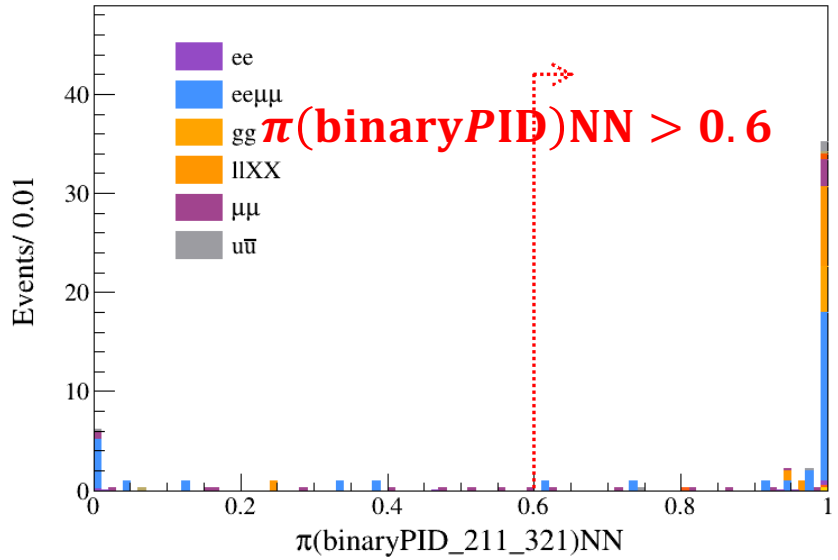


$\varepsilon = 19.28\%$

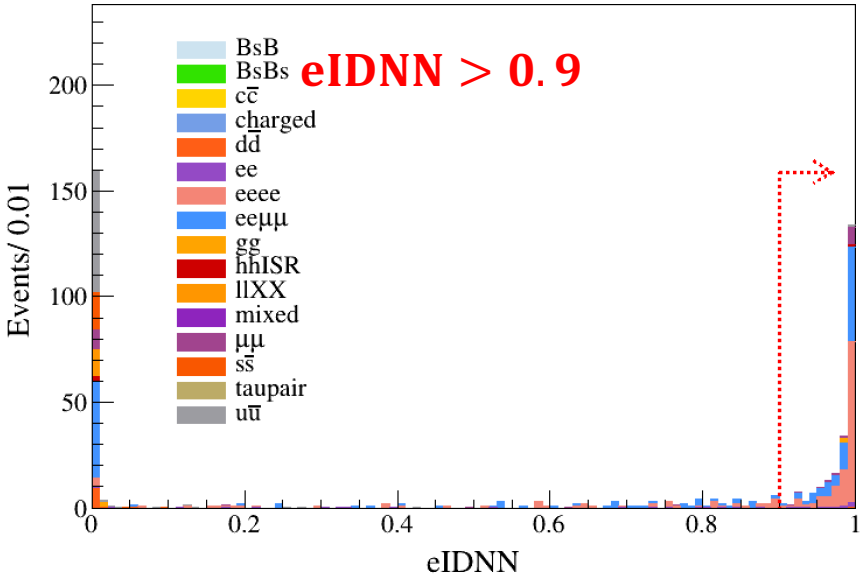
Generic MC Study I

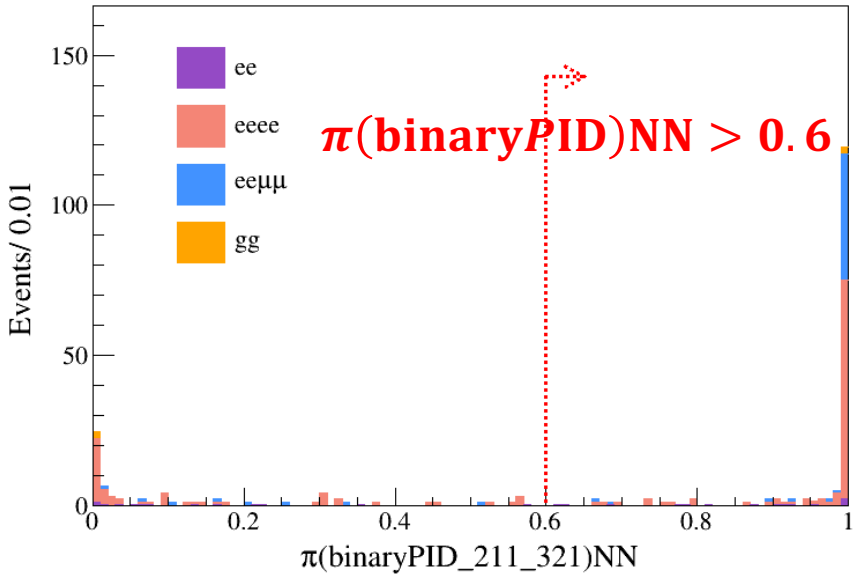
$\mu\mu$ chanel





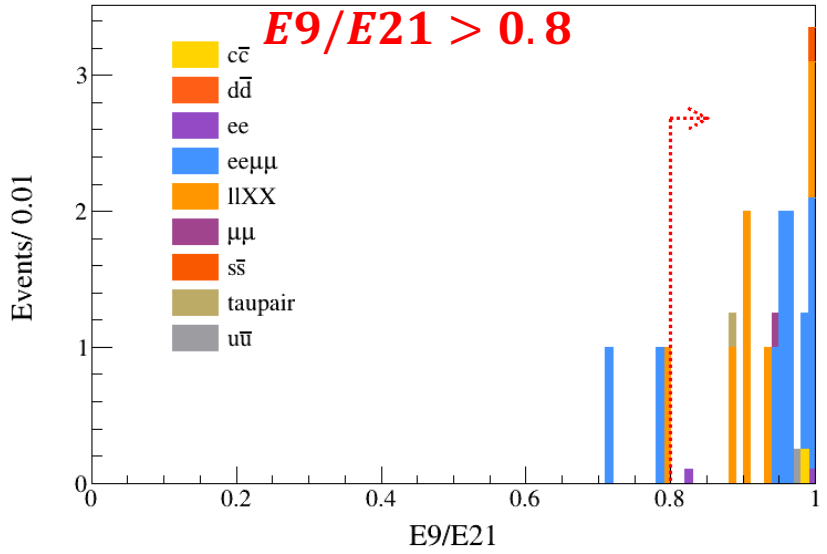
ee chanel

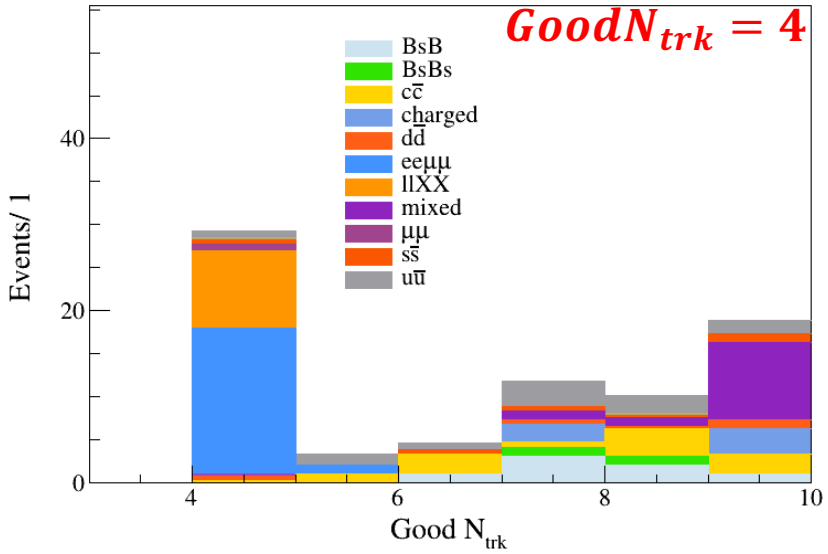




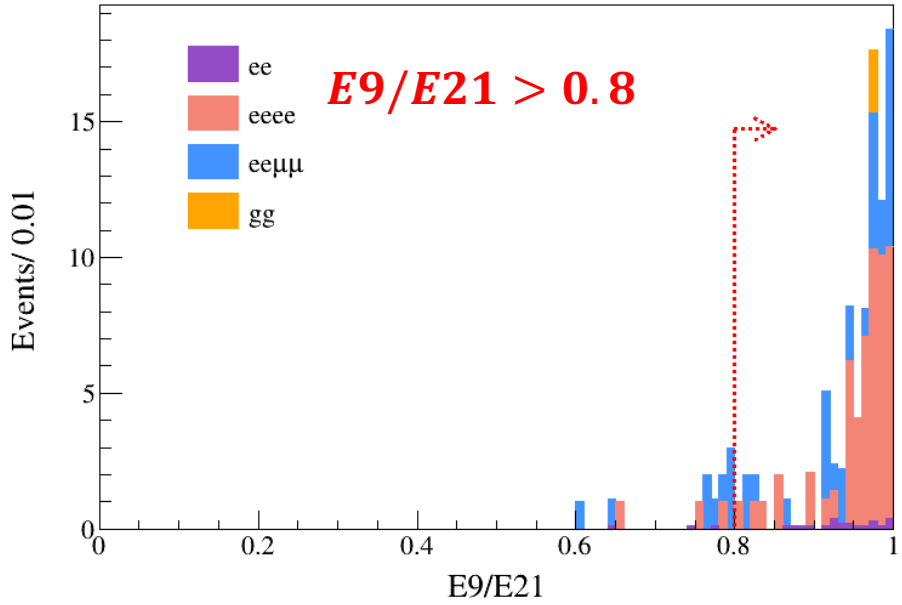
Generic MC Study II

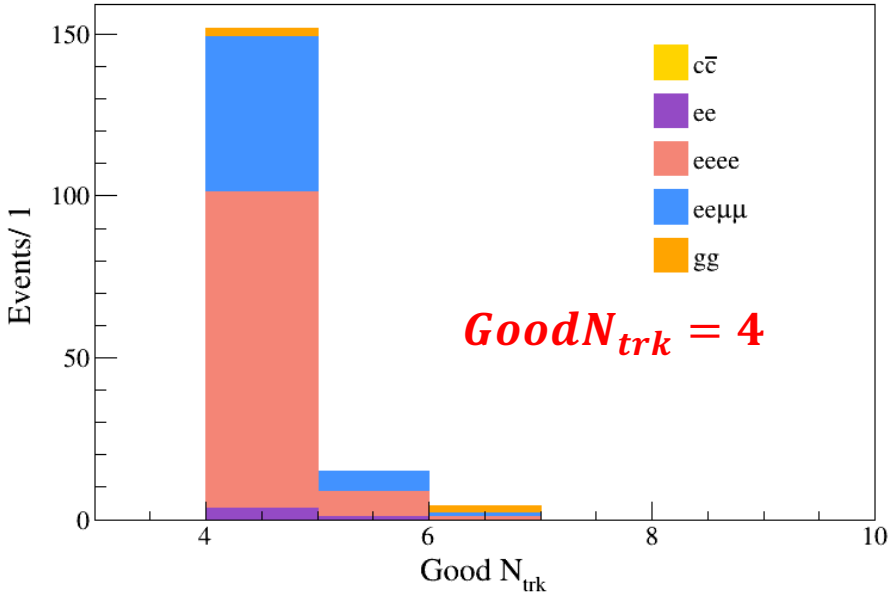
$\mu\mu$ chanel





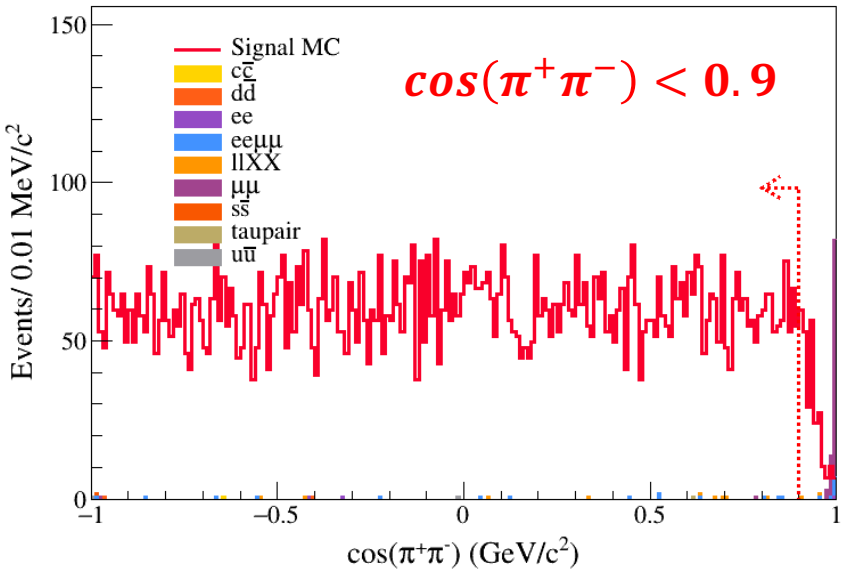
ee chanel

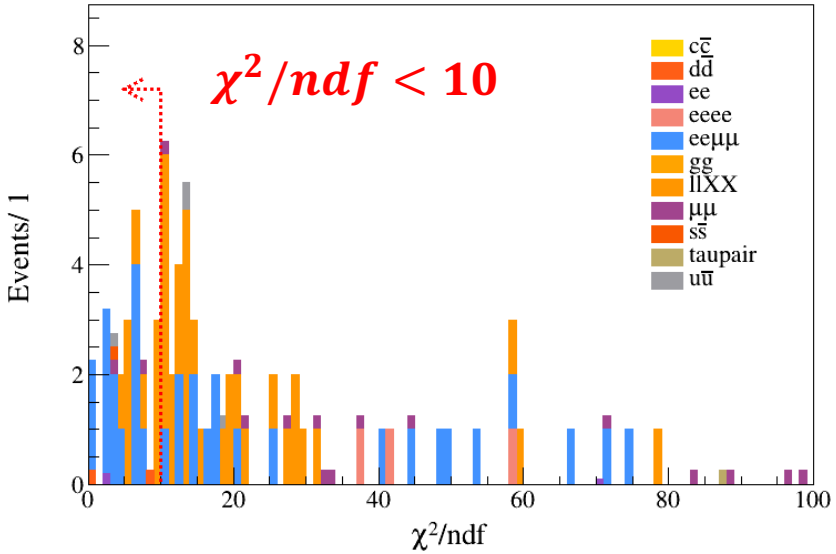




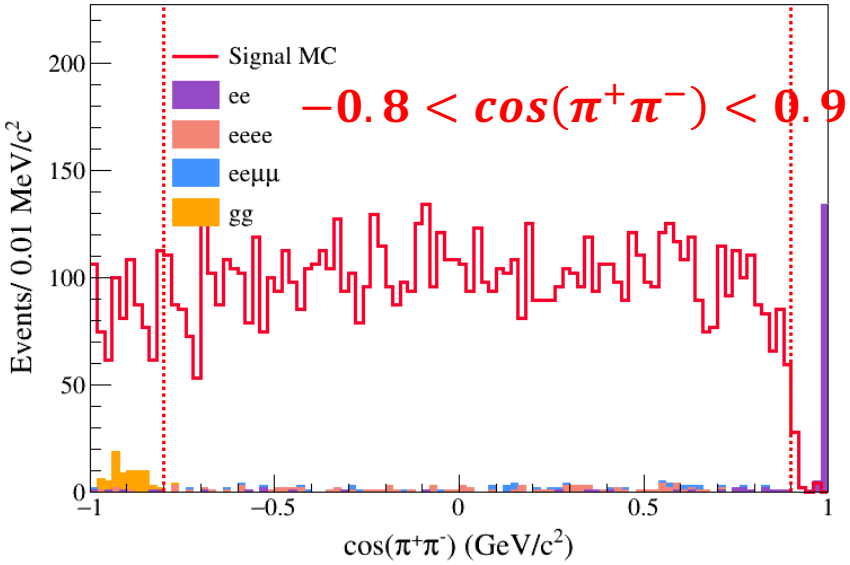
Generic MC Study III

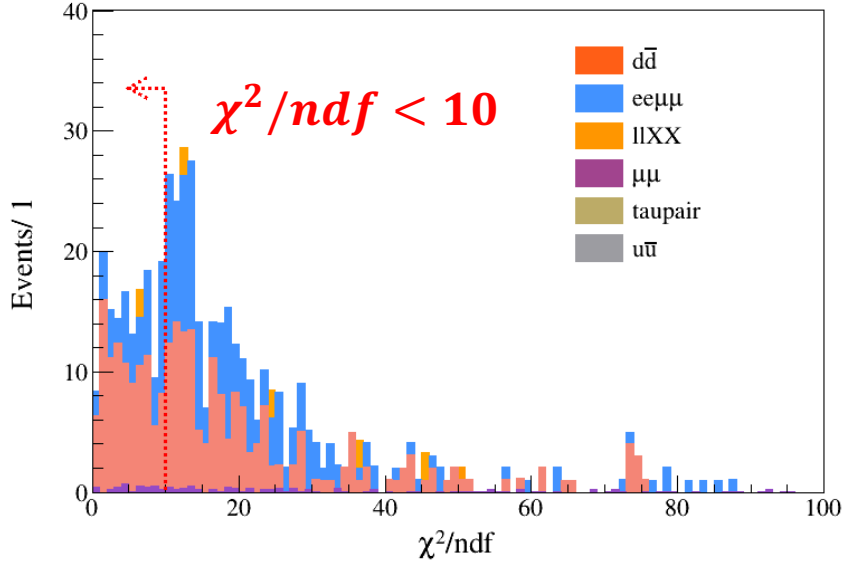
***μμ* chanel**





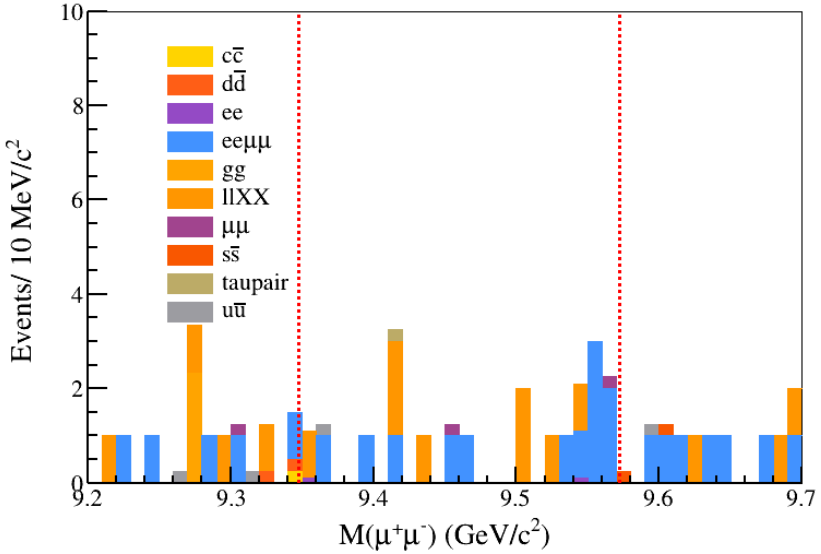
***ee* chanel**

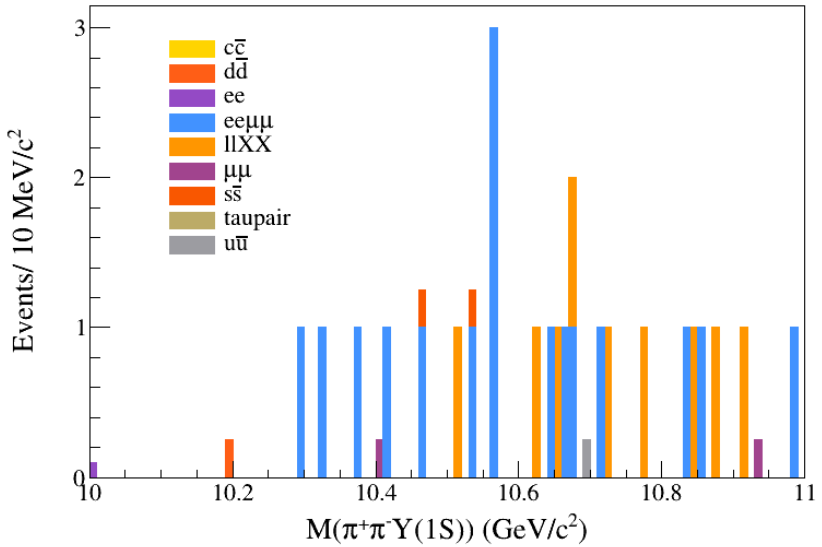




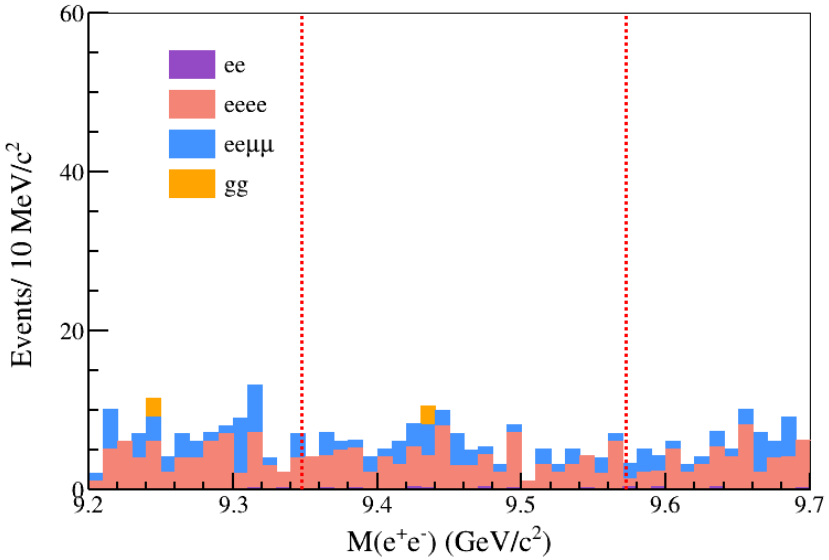
Generic MC Study IV

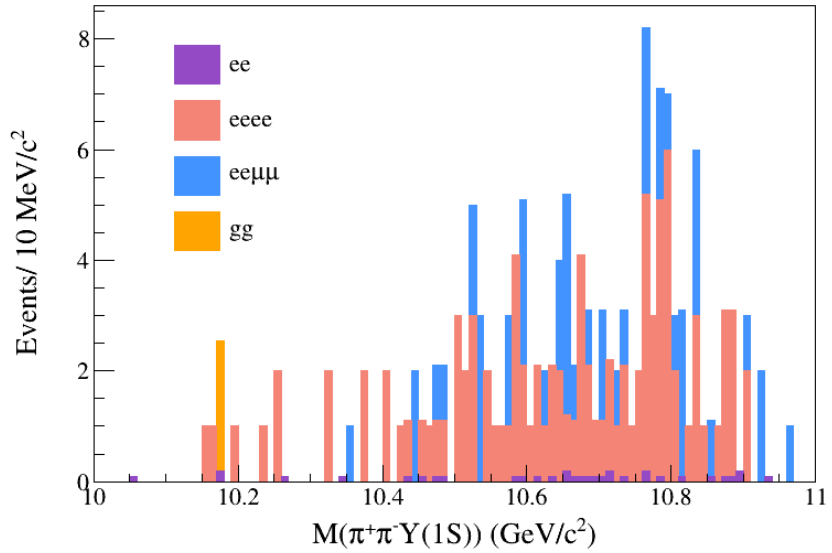
***μμ* chanel**



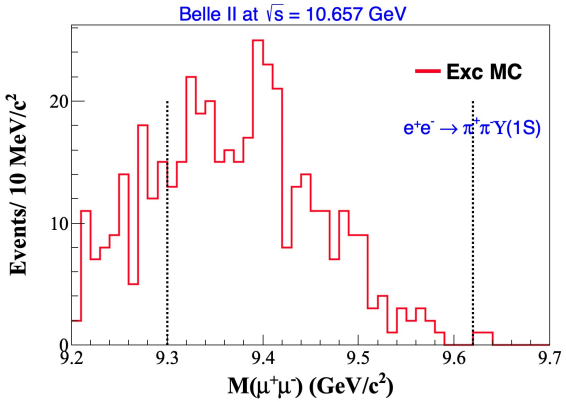


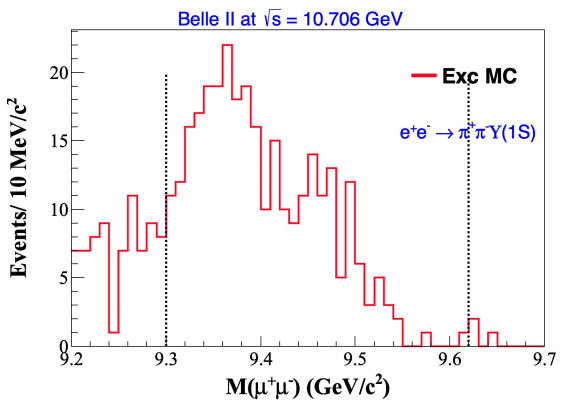
***ee* chanel**

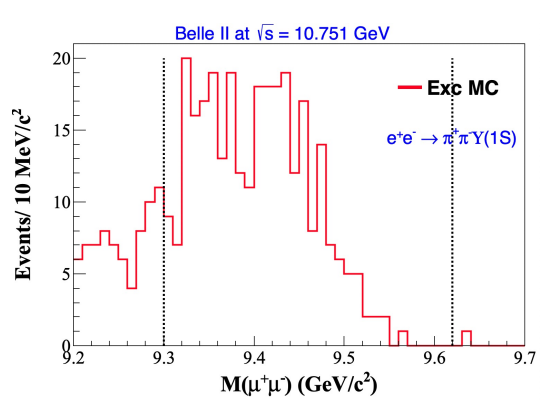


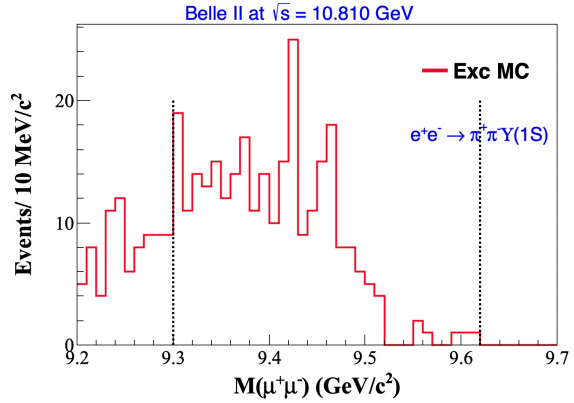


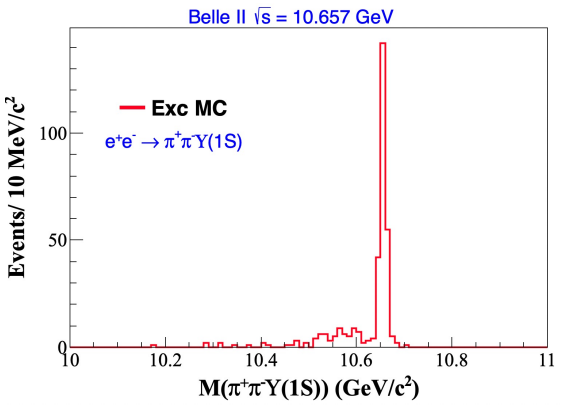
Bkg Study($e^+e^- \to \pi^+\pi^-\Upsilon(1S)(\to \mu^+\mu^-)$)

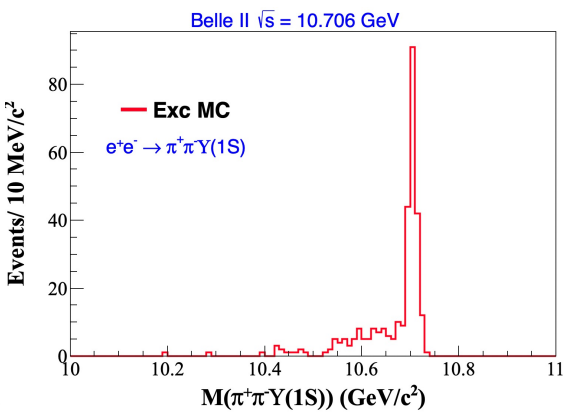


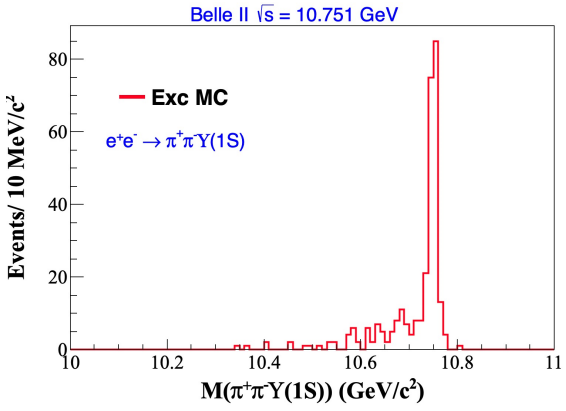


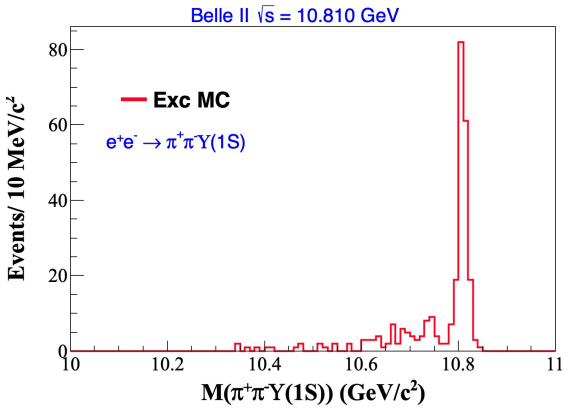






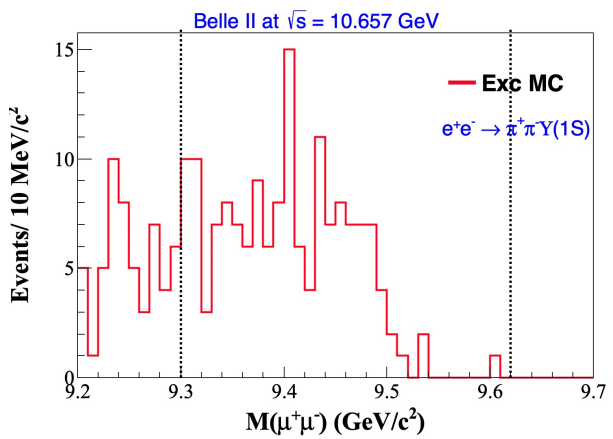


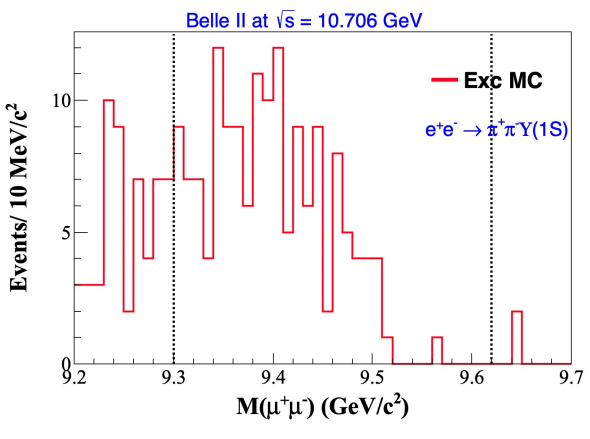


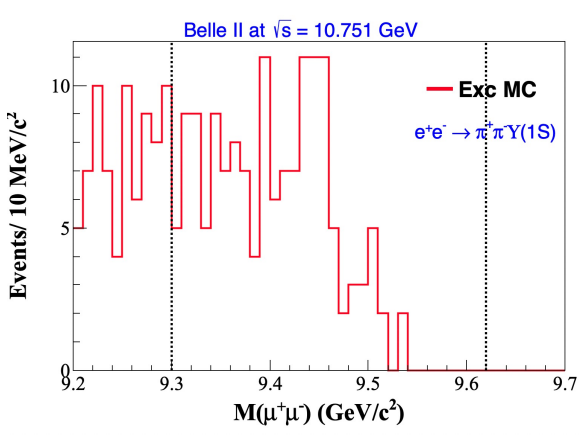


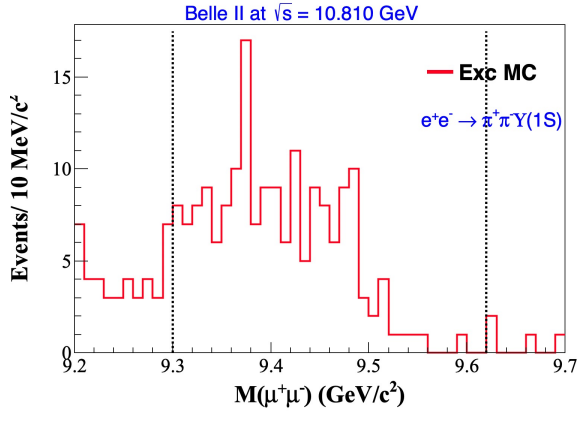
ε =0.0218 ε =0.015 ε =0.01485 ε =0.014

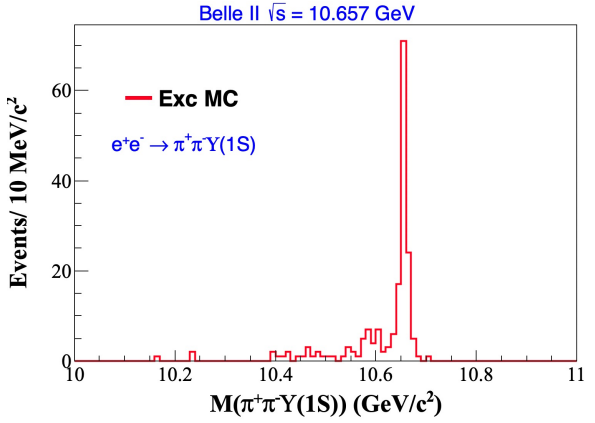
Bkg Study($e^+e^- \to \pi^+\pi^-\Upsilon(1S)(\to e^+e^-)$)

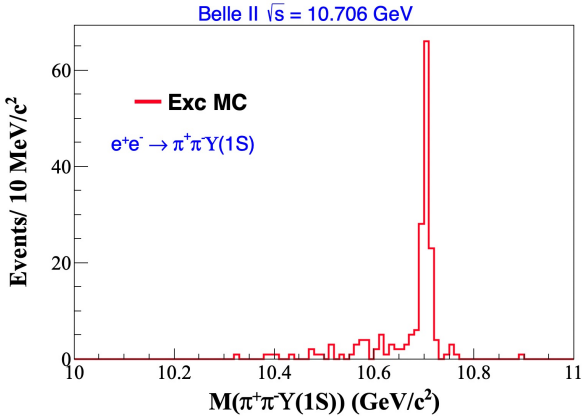


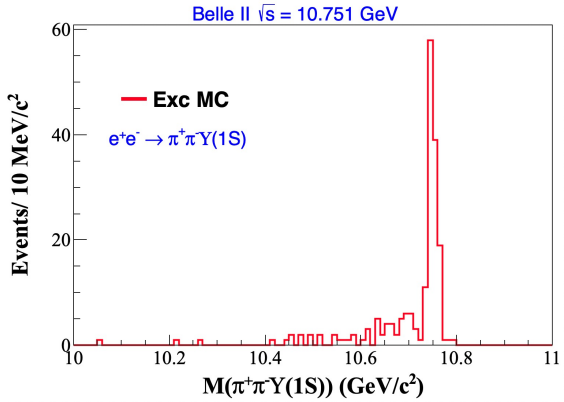


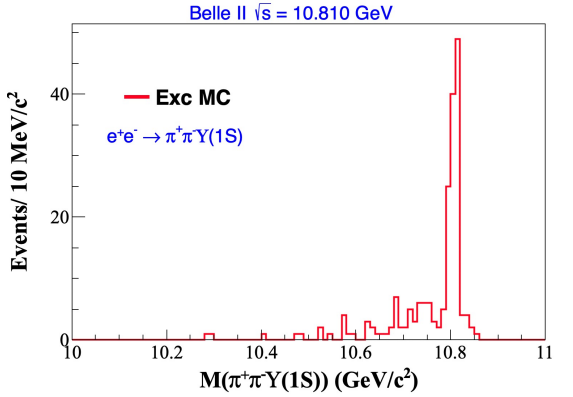










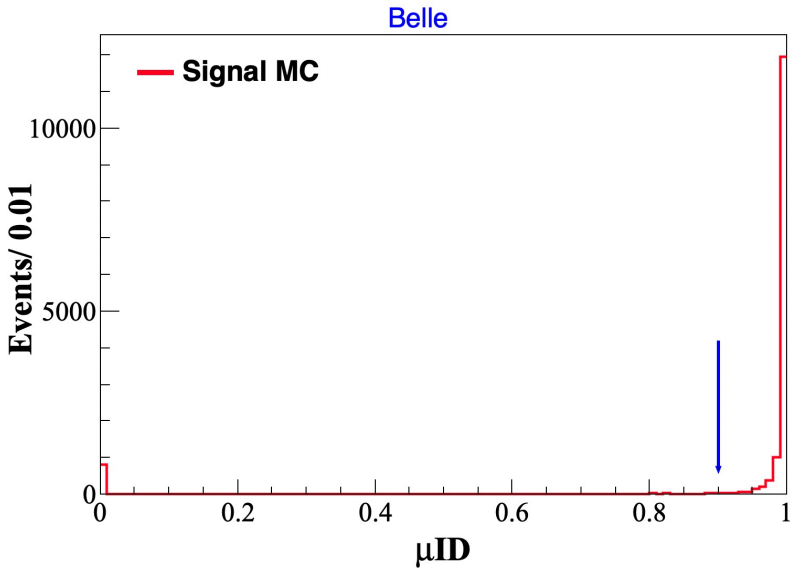


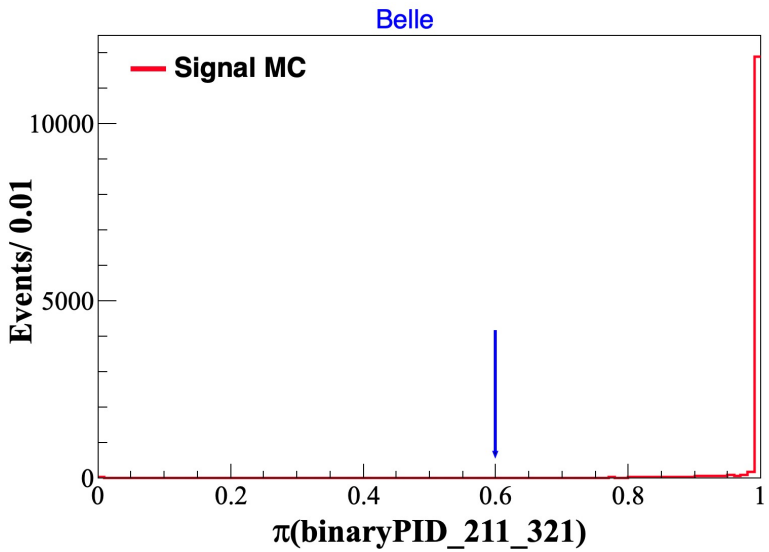
$\varepsilon = 0.009$ $\varepsilon = 0.00905$ $\varepsilon = 0.0096$ $\varepsilon = 0.0098$

Belle Signal MC Sample

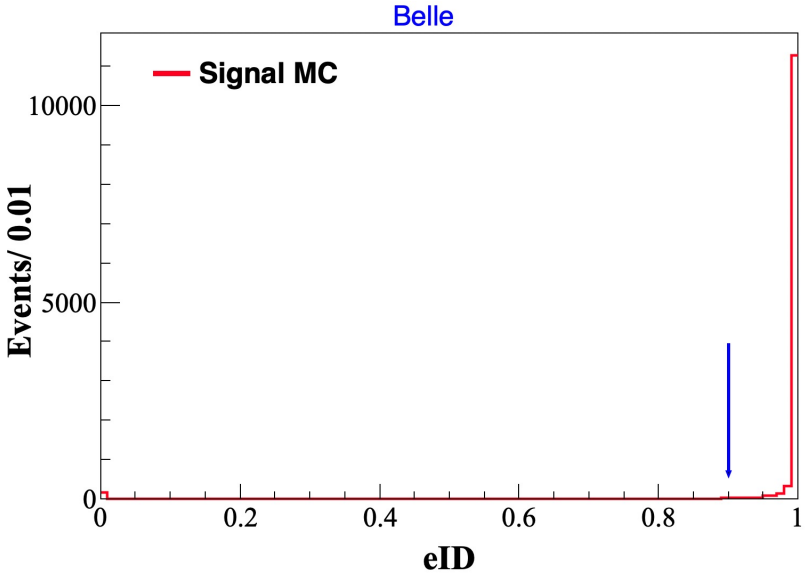
Signal MC Study I

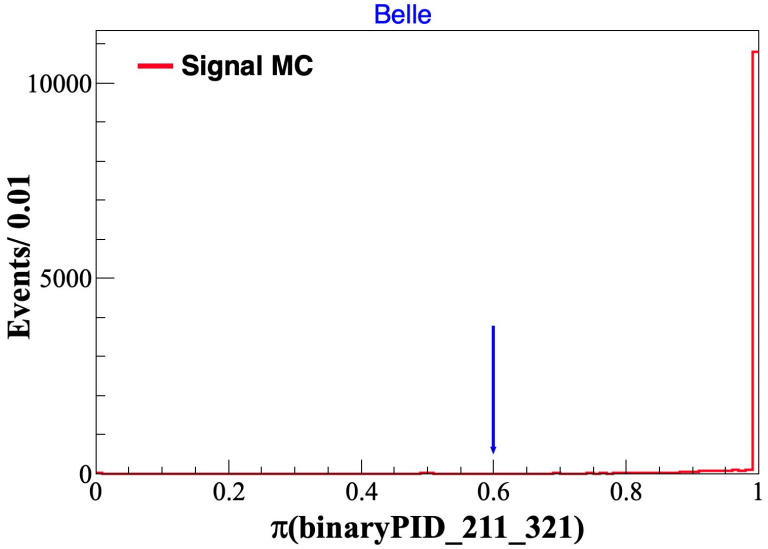
$\mu\mu$ chanel





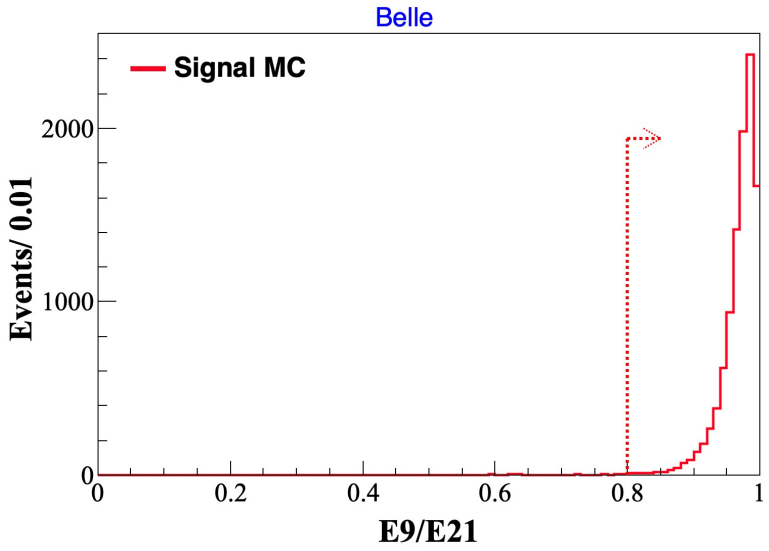
ee chanel

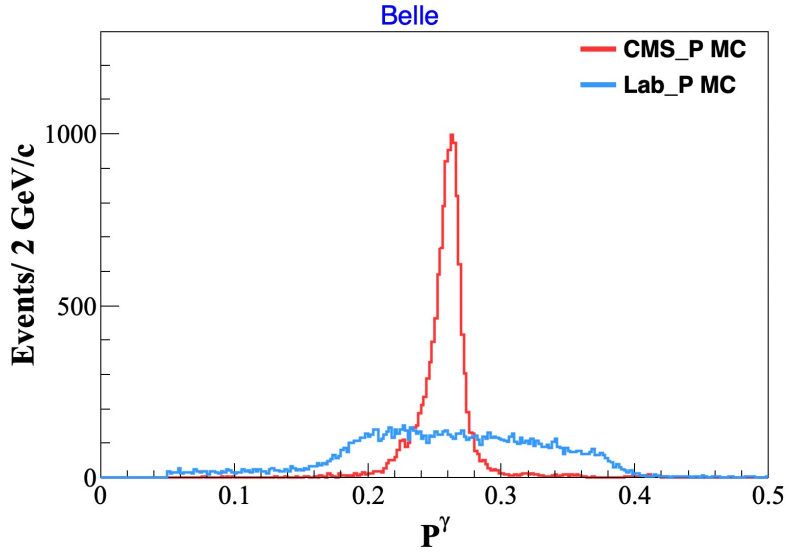




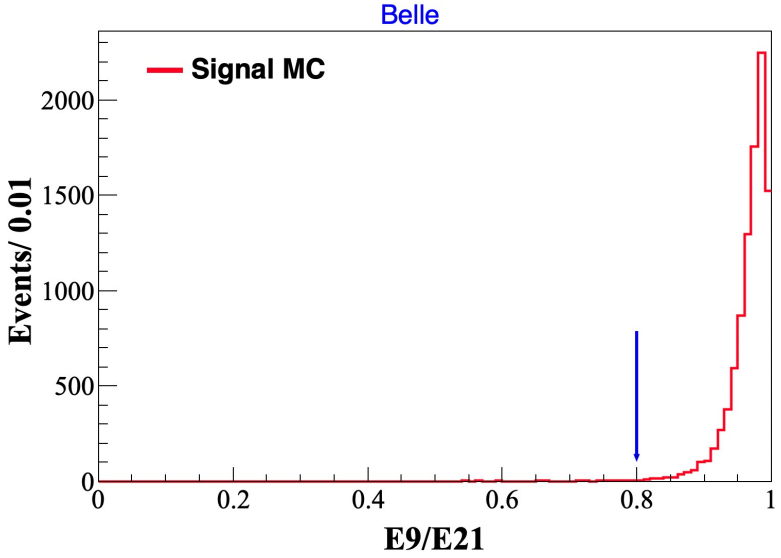
Signal MC Study II

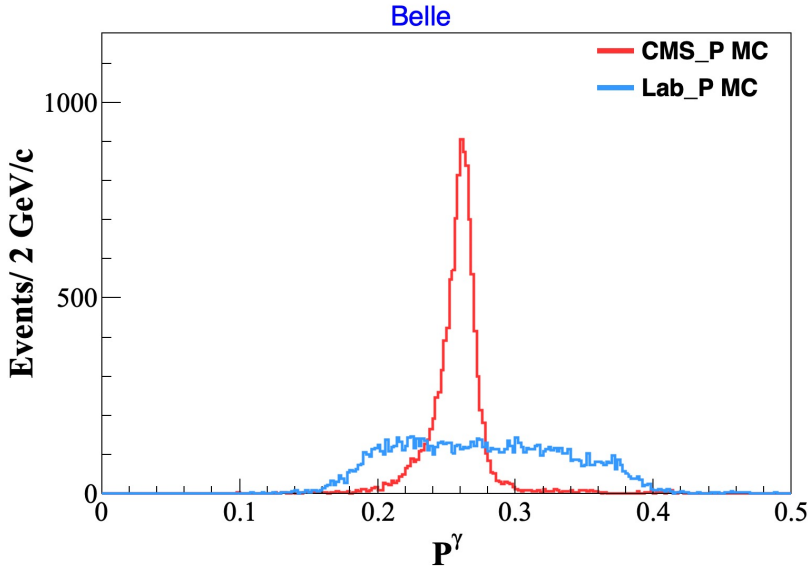
$\mu\mu$ chanel





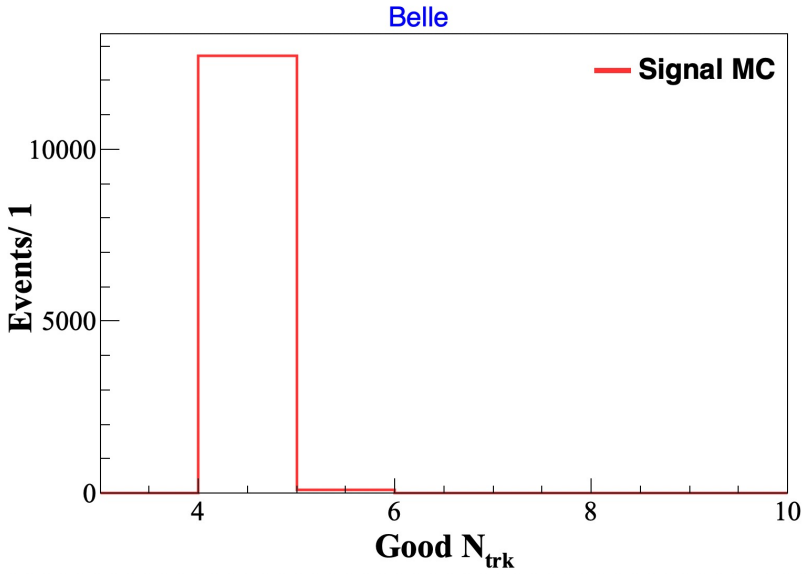
ee chanel

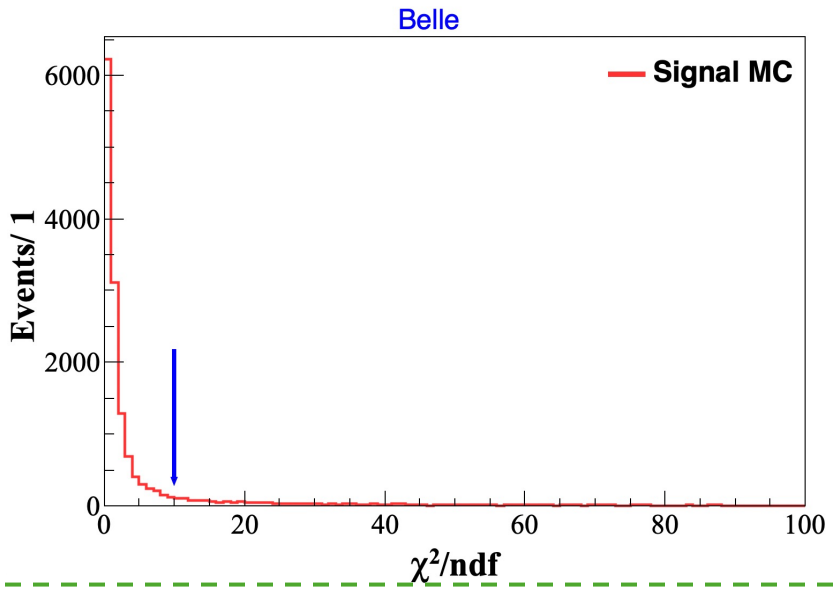




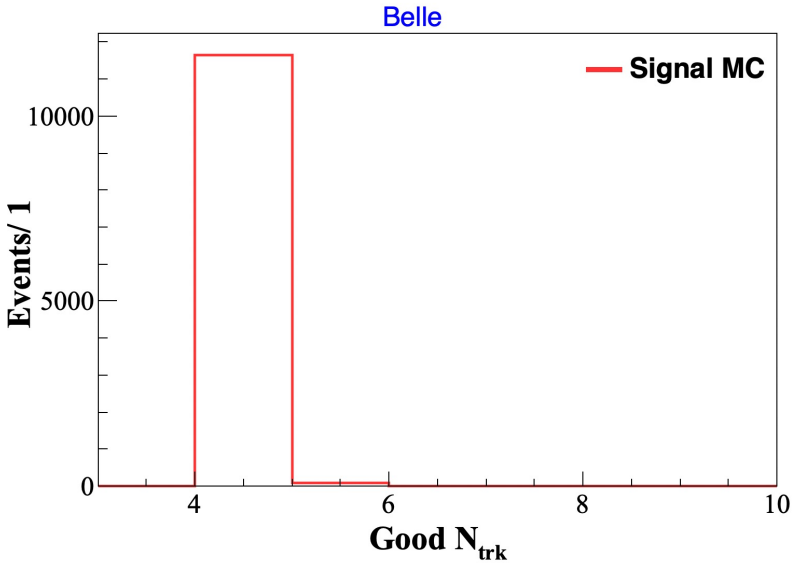
Signal MC Study III

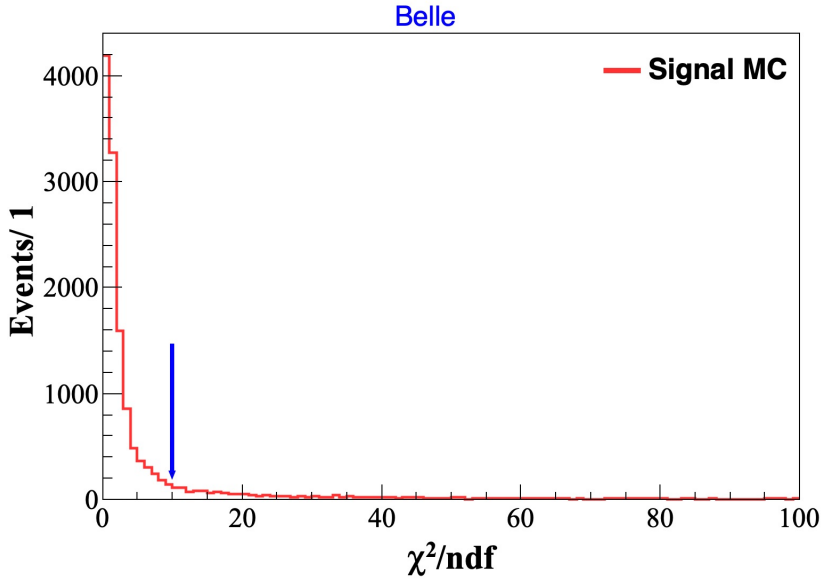
$\mu\mu$ chanel





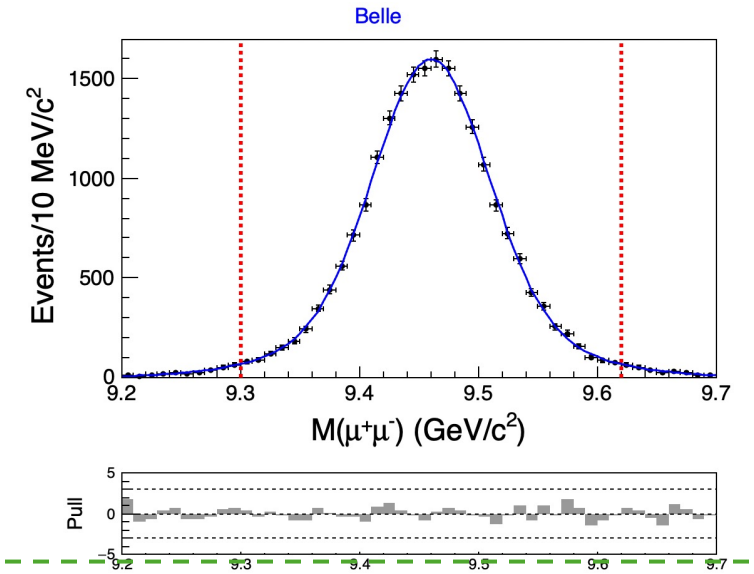
ee chanel

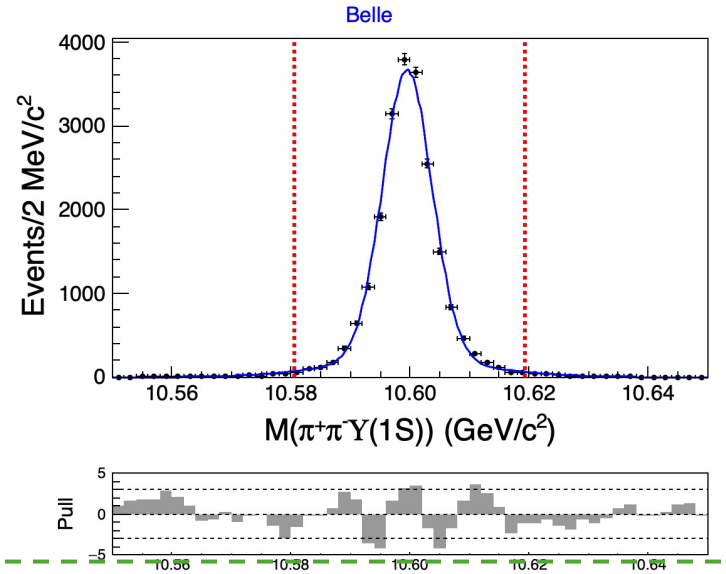




Signal MC Study IV

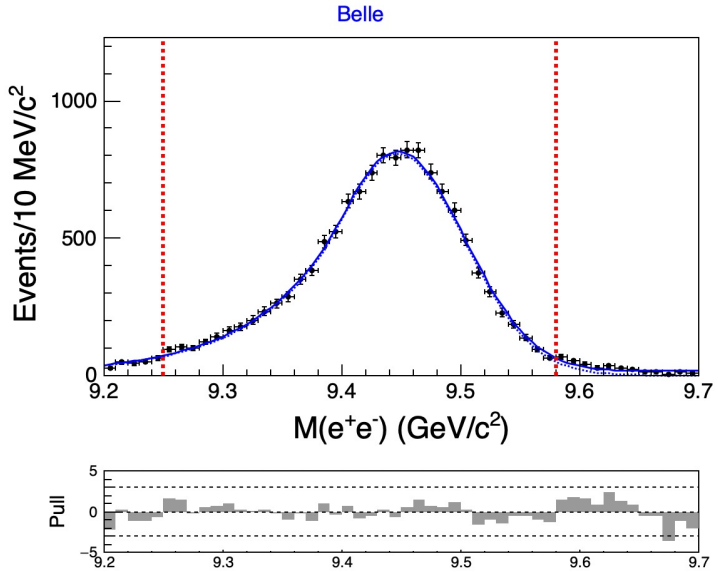
$\mu\mu$ chanel

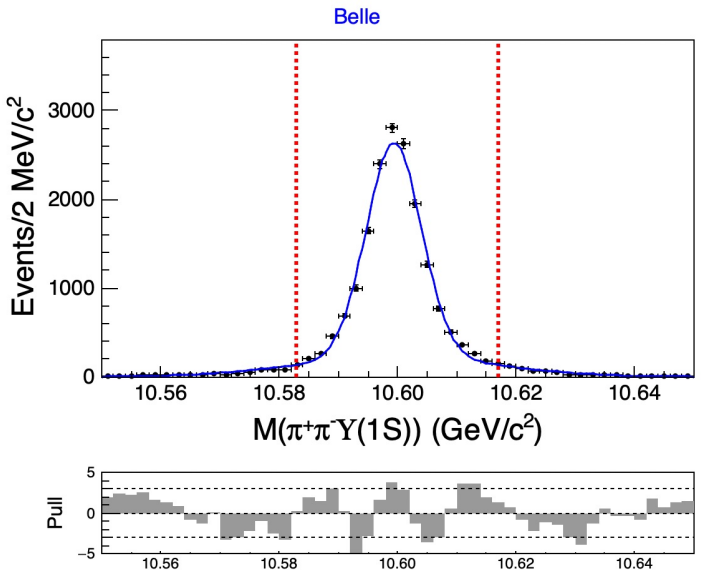




$\varepsilon = 23.16\%$

ee chanel





$\varepsilon = 21.84\%$

Summary and Next to do

- A preliminary study for $X_b \to \pi^+\pi^-\Upsilon(1S)$ is performed.
  - ✓ Generate Belle and Belle II signal MC.
  - ✓ Preliminary determination of signal efficiency.
  - ✓ Preliminary determination of Upsilon signal region.
  - ✓ No obvious background found with Generic MC samples.
- Next to do
  - ✓ Optimize the event selection.
  - ✓ Study GenericMC of Belle.
  - ✓ Estimate systematic uncertainty.

Back Up

Belle II	$\boldsymbol{\varepsilon\,(\Upsilon(1S) \to \mu^+\mu^-)}$	$\boldsymbol{\varepsilon(\Upsilon(1S) \to e^+e^-)}$
$X_b = 10.6$	**31.07%**	**19.28%**

Belle	$\boldsymbol{\varepsilon\,(\Upsilon(1S) \to \mu^+\mu^-)}$	$\boldsymbol{\varepsilon(\Upsilon(1S) \to e^+e^-)}$
$X_b = 10.6$	**23.16%**	**21.84%**

Release-08 recommendations

- The NN-based PID variables are available for all species:

  `electronIDNN, muonIDNN, pionIDNN, kaonIDNN, protonIDNN, deuteronIDNN`

- These are global (i.e. comparing among all 6 hypotheses) variables. If you are interested in binary (e.g. K vs π) or other combinations, you can build your own ratios, like:

  ```
  kaonIDNN_Kpi = kaonIDNN/(kaonIDNN + pionIDNN)
  ```

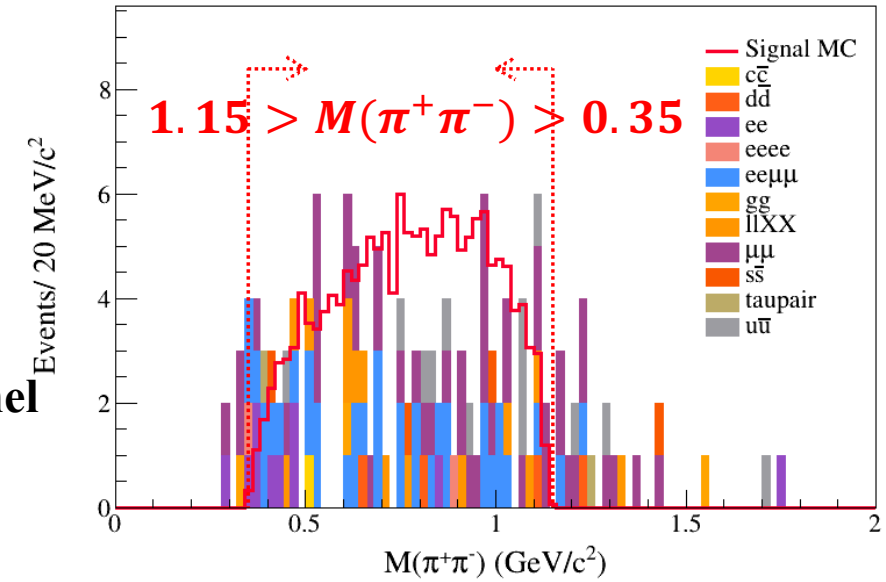
- These require the global tag: `pid_nn_release08_v1`;
- "Standard" likelihood based variables:

  `electronID, muonID, pionID, kaonID, protonID, deuteronID`

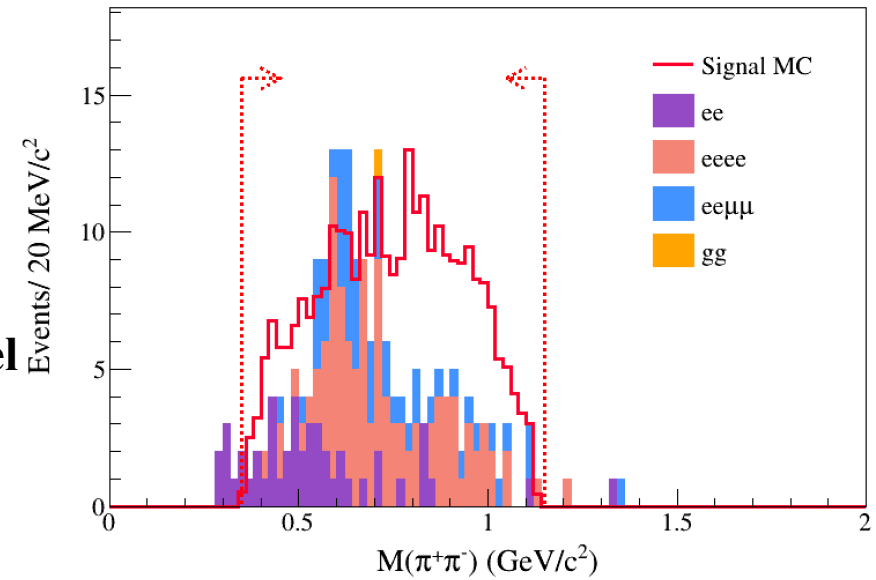
  are still available (and binary variables can be used/built in the usual way);

- "Old" BDT variables (`pidChargedBDTScore_{e,mu}`, `pidChargedBDTScore_{e,mu}_pi`) are no longer maintained.

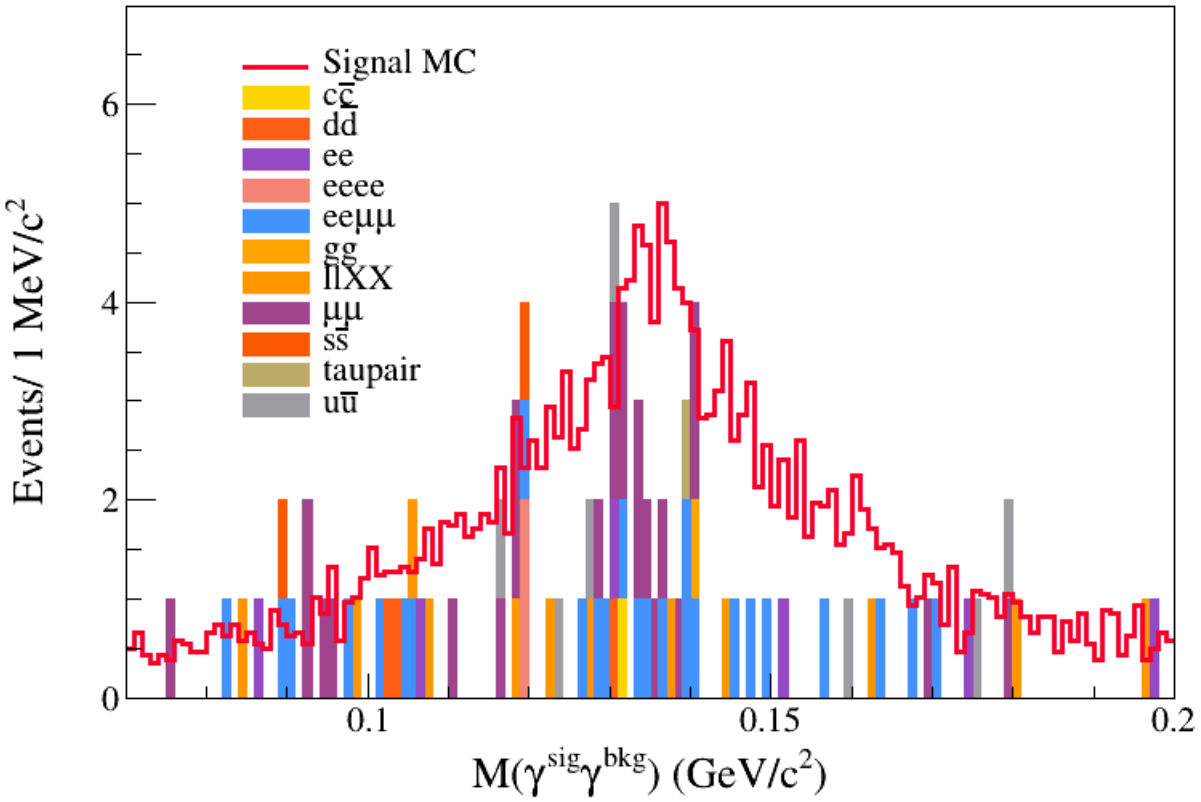
***μμ* chanel**



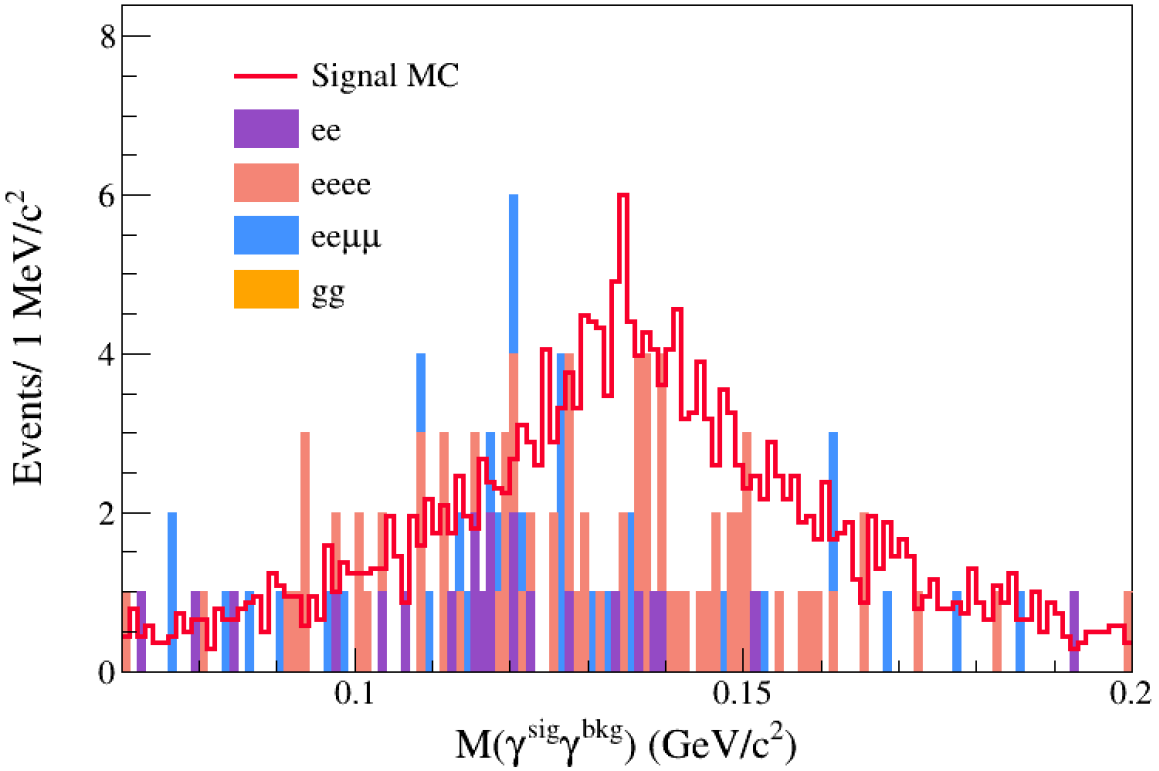
***ee* chanel**



Generic MC Study VI

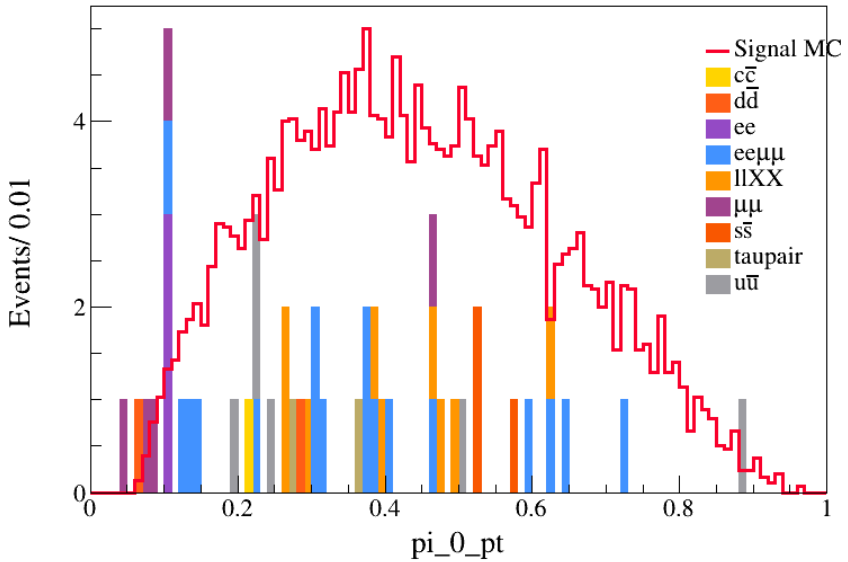


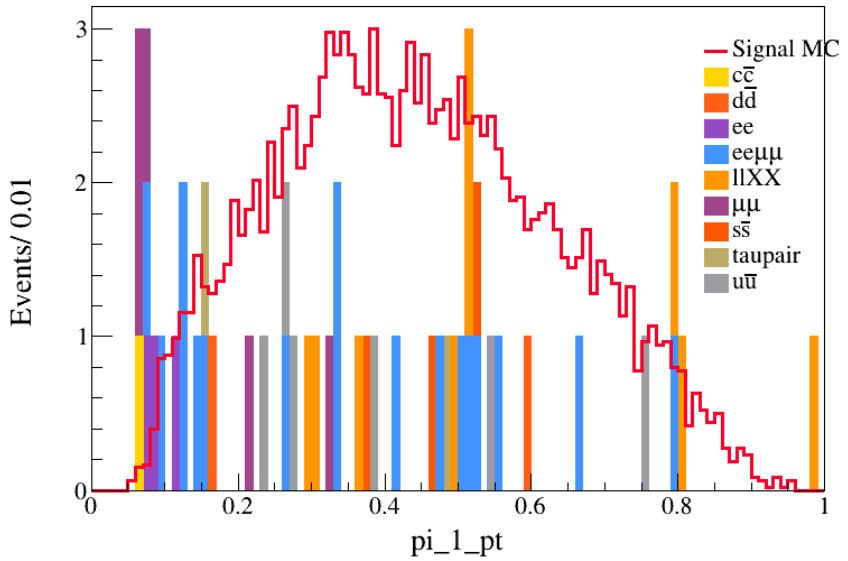
***μμ* chanel**

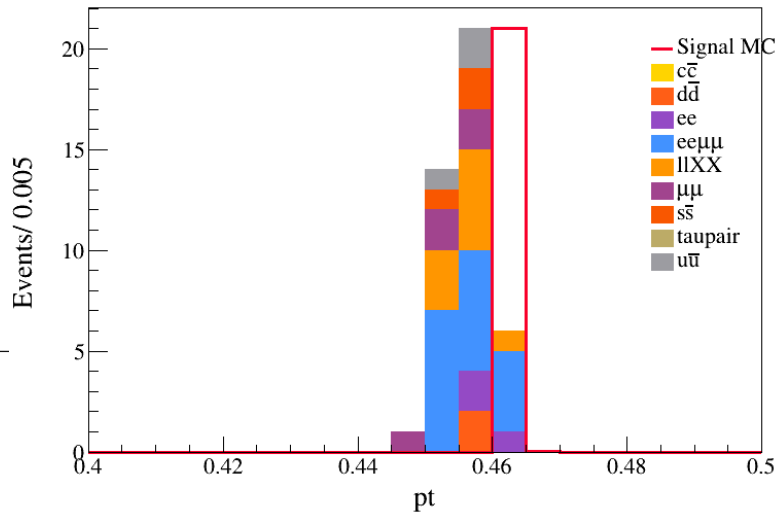


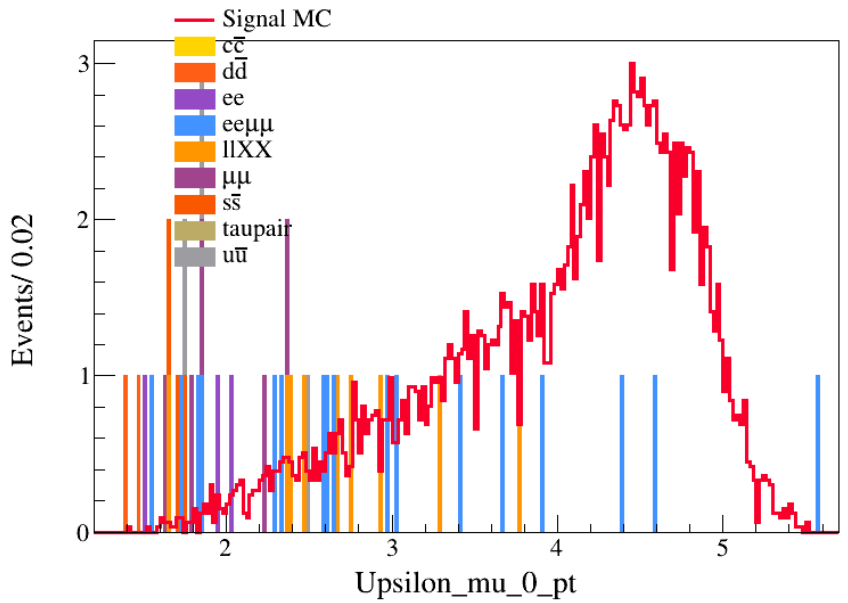
***ee* chanel**

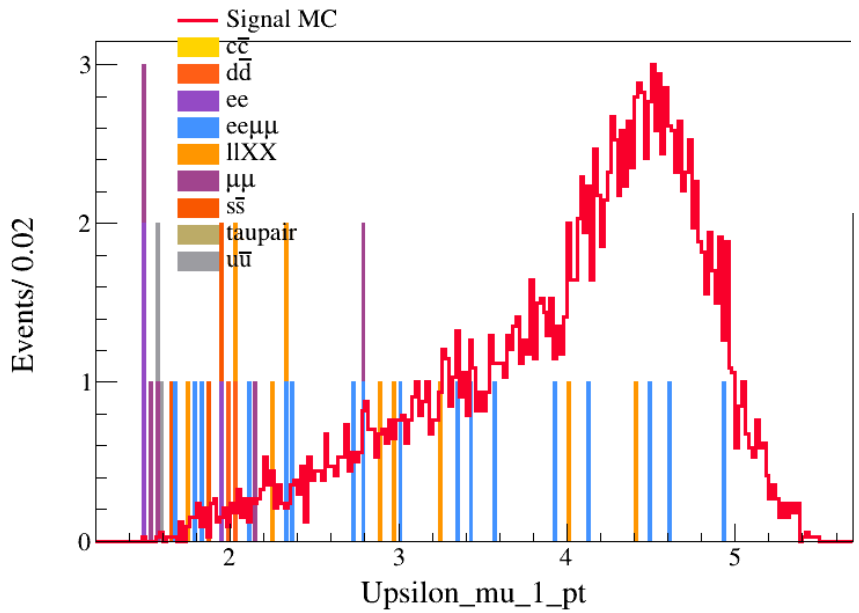
$\mu\mu$ chanel


Signal MC
cc̄
dd̄
ee
eeμμ
llXX
μμ
ss̄
taupair
uū
Events/ 0.01
pi_0_pt

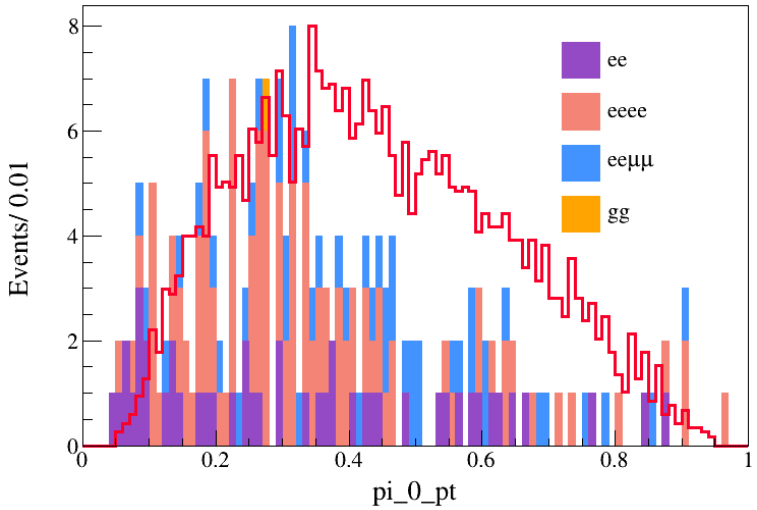

Signal MC
cc̄
dd̄
ee
eeμμ
llXX
μμ
ss̄
taupair
uū
Events/ 0.01
pi_1_pt

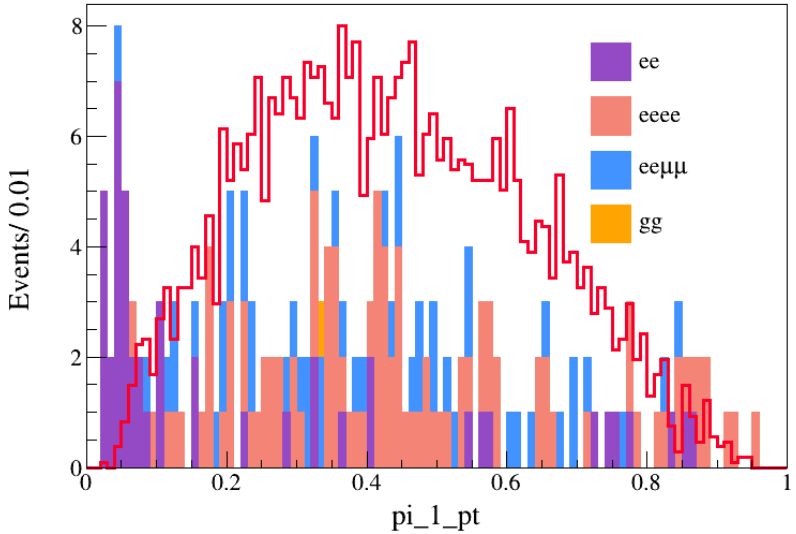

Signal MC
cc̄
dd̄
ee
eeμμ
llXX
μμ
ss̄
taupair
uū
Events/ 0.005
pt

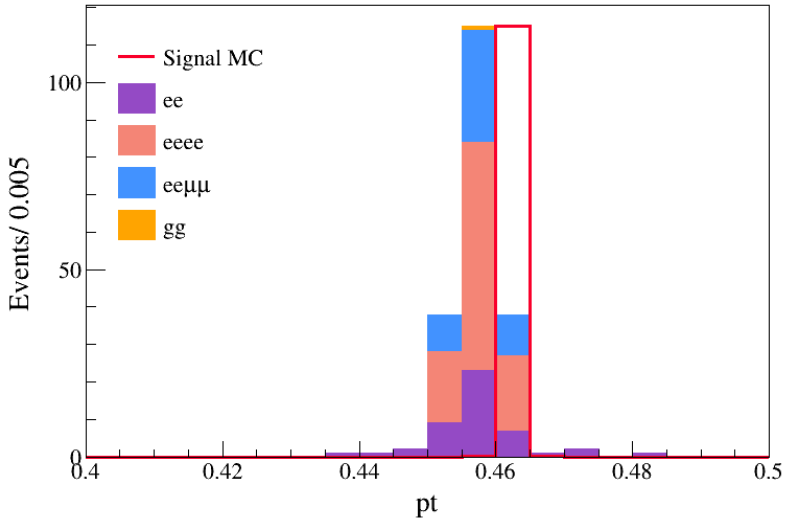

Signal MC
cc̄
dd̄
ee
eeμμ
llXX
μμ
ss̄
taupair
uū
Events/ 0.02
Upsilon_mu_0_pt

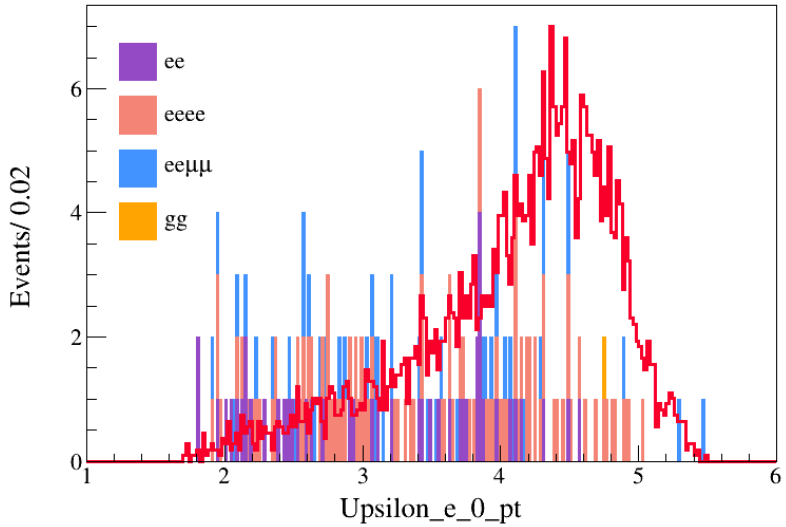

Signal MC
cc̄
dd̄
ee
eeμμ
llXX
μμ
ss̄
taupair
uū
Events/ 0.02
Upsilon_mu_1_pt

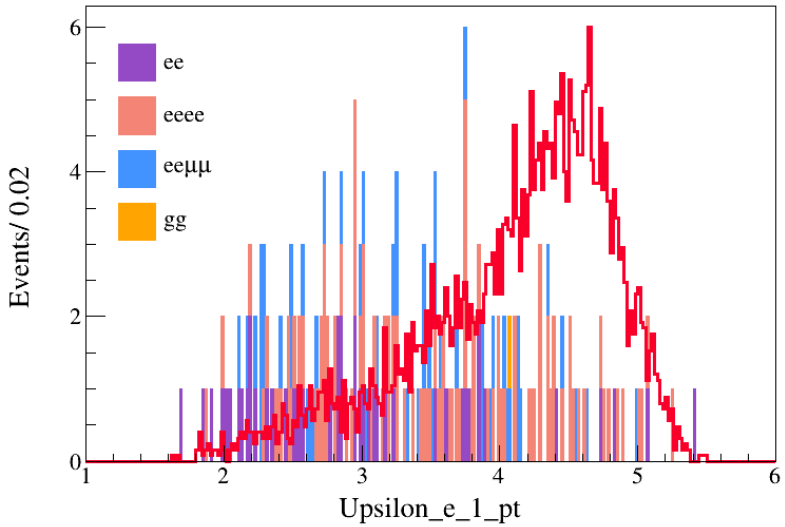
ee chanel


Events/ 0.01
pi_0_pt
ee
eeee
eeμμ
gg


Events/ 0.01
pi_1_pt
ee
eeee
eeμμ
gg


Signal MC
ee
eeee
eeμμ
gg
Events/ 0.005
pt


ee
eeee
eeμμ
gg
Events/ 0.02
Upsilon_e_0_pt


ee
eeee
eeμμ
gg
Events/ 0.02
Upsilon_e_1_pt