Preliminary study of the $e^+e^- \to \pi^+\pi^-\Upsilon(nS)$ at 10.58 GeV

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Nov. 19, 2026

Contributions of each group member

- Wandi Sun: Give the report, drawing
- Hongjian Zhou: MC generation,drawing and fit
- Yue Lu: Drawing, prepare the report
- Zhen Sun: Drawing, prepare the report

All members study and discuss with the details of this study

Motivation

- Dipion transitions **$\Upsilon(mS) \to \pi^+\pi^-\Upsilon(nS)$** are a classic probe of the QCD multipole expansion: their partial widths are directly related to the Y radial wave function [1];
- BaBar observed these transitions in $\Upsilon(4S)$ decays first (230×10^6 $\Upsilon(4S)$, 211 fb^{-1}) [1]:

  $\mathcal{B}(\Upsilon(4S) \to \pi^+\pi^-\Upsilon(1S)) \cdot \mathcal{B}(\Upsilon(1S) \to \mu^+\mu^-) = (2.23 \pm 0.25 \pm 0.27) \times 10^{-6}$

  $\mathcal{B}(\Upsilon(4S) \to \pi^+\pi^-\Upsilon(2S)) \cdot \mathcal{B}(\Upsilon(2S) \to \mu^+\mu^-) = (1.69 \pm 0.26 \pm 0.20) \times 10^{-6}$
- In e^+e^- annihilation the same $\pi^+\pi^-\Upsilon(nS)$ system is produced through a **virtual photon**, $e^+e^- \to \gamma^* \to \pi^+\pi^-\Upsilon(nS)$, with no $\Upsilon(4S)$ in the final state;
- **This work: $e^+e^- \to \gamma^* \to \pi^+\pi^-\Upsilon(2S)$ and $e^+e^- \to \gamma^* \to \pi^+\pi^-\Upsilon(1S)$, with $\Upsilon(nS) \to \mu^+\mu^-$**

[1] B. Aubert et al. (BaBar Collaboration), Observation of $\Upsilon(4S)$ decays to $\pi^+\pi^-\Upsilon(1S)$ and $\pi^+\pi^-\Upsilon(2S)$, Phys. Rev. Lett. 96, 232001 (2006).

Data and MC Samples

Sample	Content	Energy / GeV
Data	/belle/collection/Data/Moriond2023_prompt_all_4S_v1	10.58
Private MC	[vpho->pipi [Y2S ->mumu]]	10.58
	[vpho->pipi [Y1S ->mumu]]	
	[vpho->gamma[Y3S->pi+pi-[Y1S->mu+mu-]]]	
	[vpho->gamma[Y3S->pi+pi-[Y2S->mu+mu-]]]	
	[vpho->gamma[Y2S->pi+pi-[Y1S->mu+mu-]]]	

- The table lists the available 10.58 GeV data and private MC samples.
- **Generic MC production is pending; Moriond 2023 data is used as a temporary reference sample.**

Event Selection Criteria

Event level

- $4 \leq N_{trk} \leq 5$; all four objects inside the CDC acceptance

Lepton pair $Y(nS) \rightarrow \mu^+\mu^-$

- μID > 0.9 at least one;
- $4.2 < p^* < 5.3$ GeV/c (lepton momentum in the CM frame)
- $|d_r| < 2$ cm, $|d_z| < 4$ cm

Pion pair $\pi^+\pi^-$

- $p_T > 0.06$ GeV; μID < 0.75 and eID < 0.75
- $|d_r| < 2$ cm, $|d_z| < 4$ cm
- $\cos\theta(\pi^+\pi^-) < 0.9$

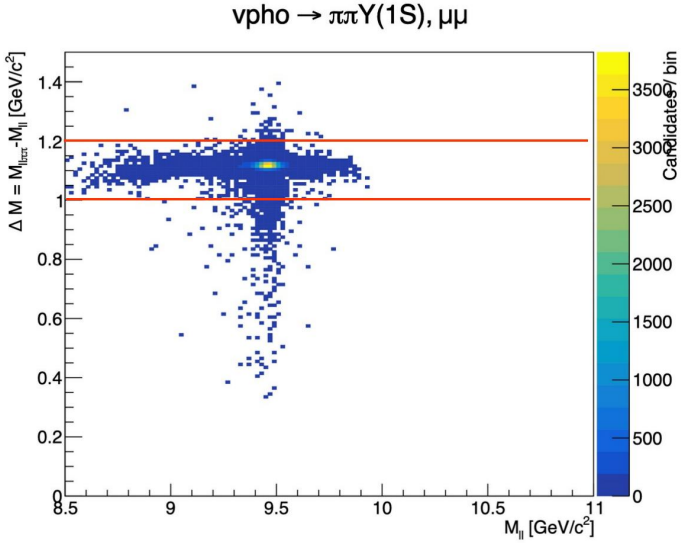
Vertex fits

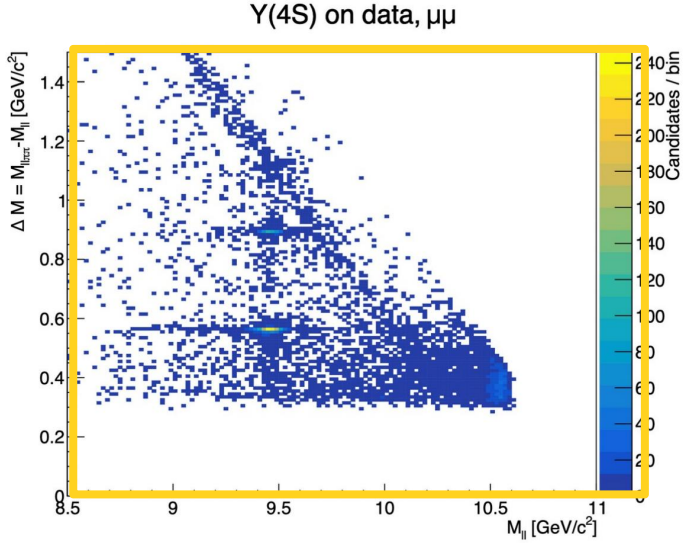
- χ^2 probability > 0.01 for the $\pi\pi$, $\mu\mu$ and 4-track vertex fits
- the four tracks are fitted to one common vertex

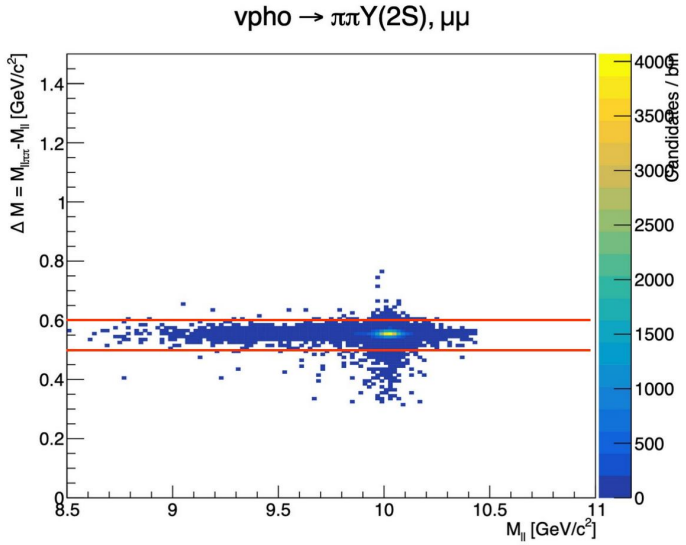
Signal region and sideband, together with the five Δm boxes, are defined on the next page.

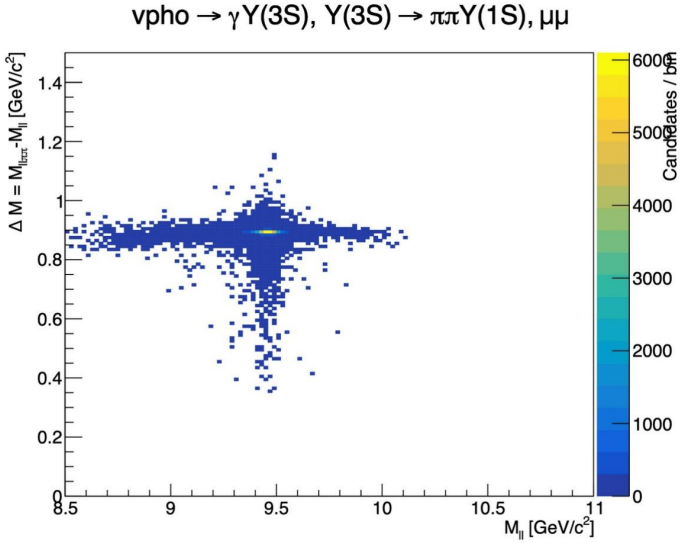
Kinematic Distributions: Mll vs ΔM

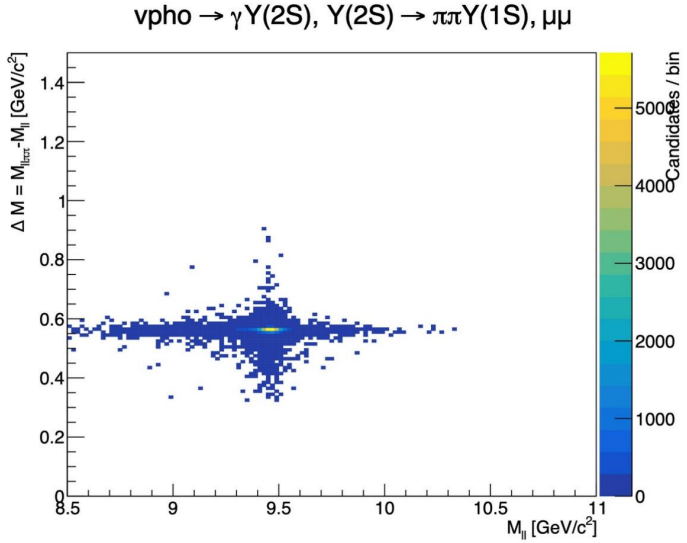
Red lines indicate the current ΔM windows.

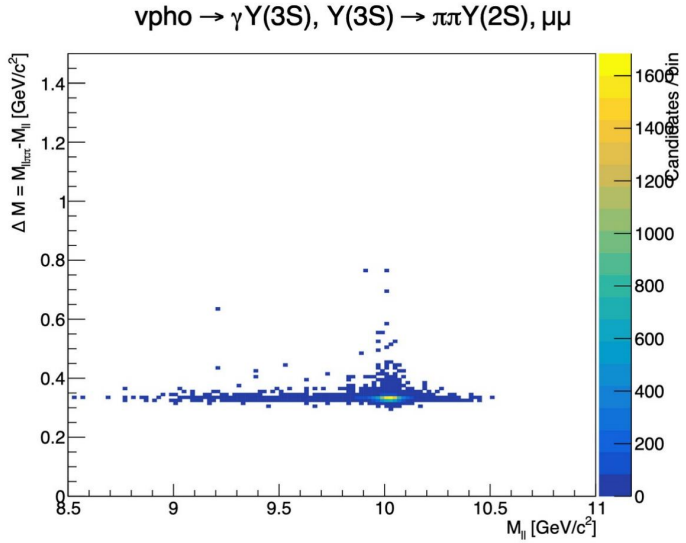








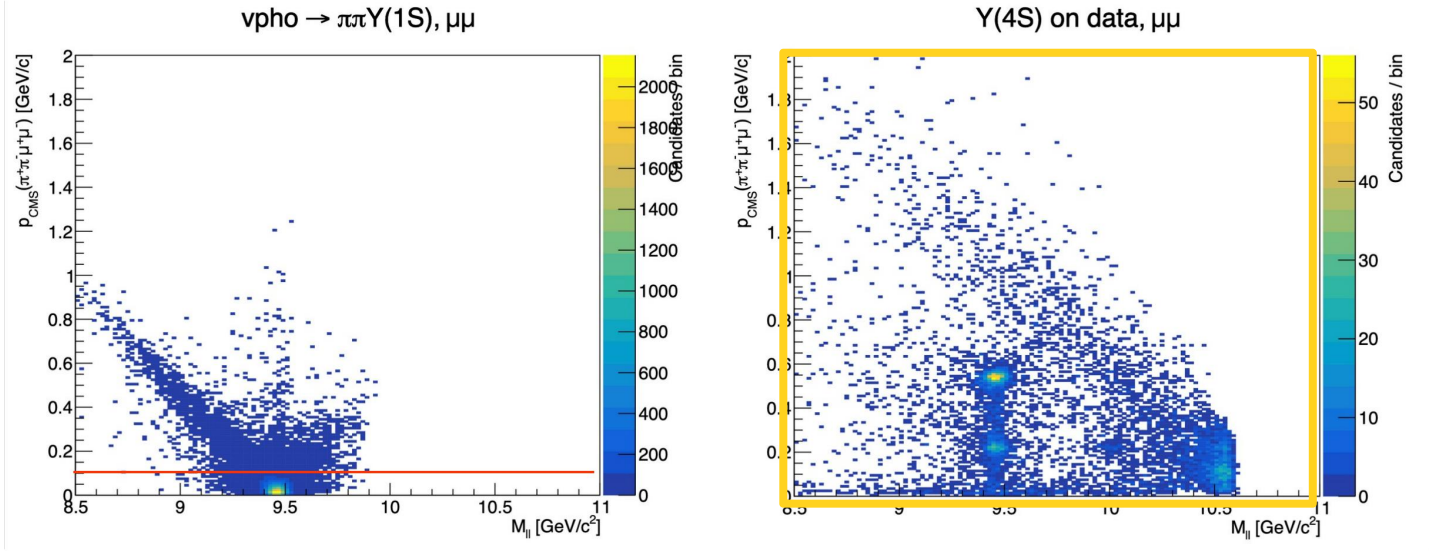


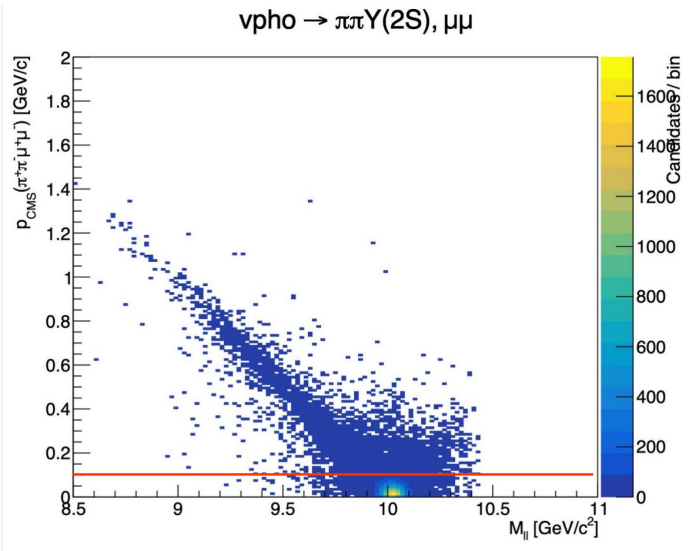


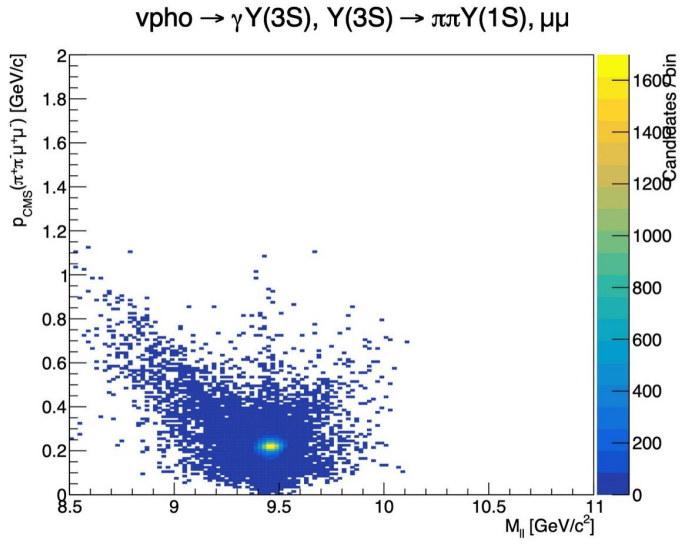
- Mll = M(μ⁺μ⁻)
- ΔM = M(π⁺π⁻μ⁺μ⁻) − M(μ⁺μ⁻)

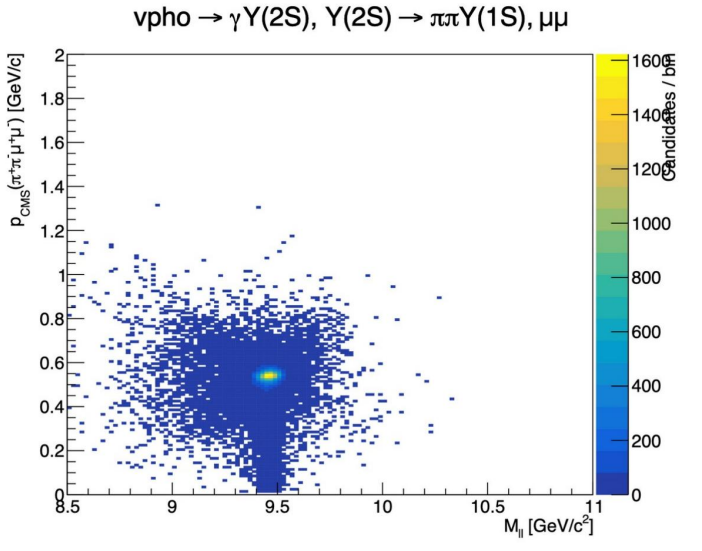
Candidate Momentum vs Mll

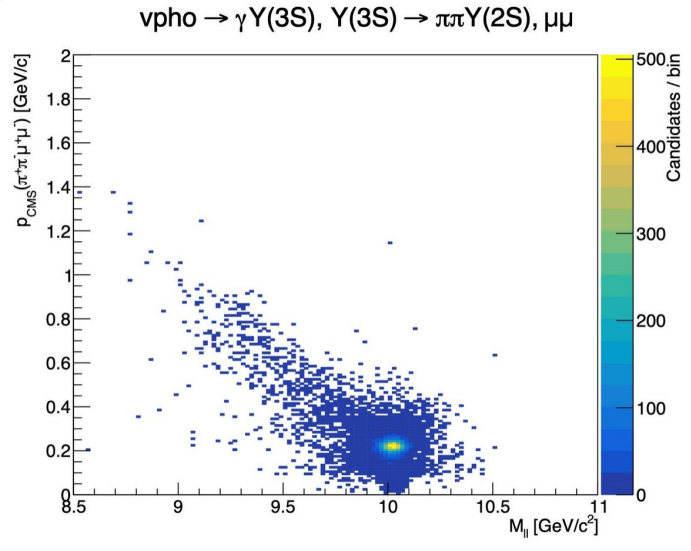
The red line marks pcms < 0.1 GeV/c.





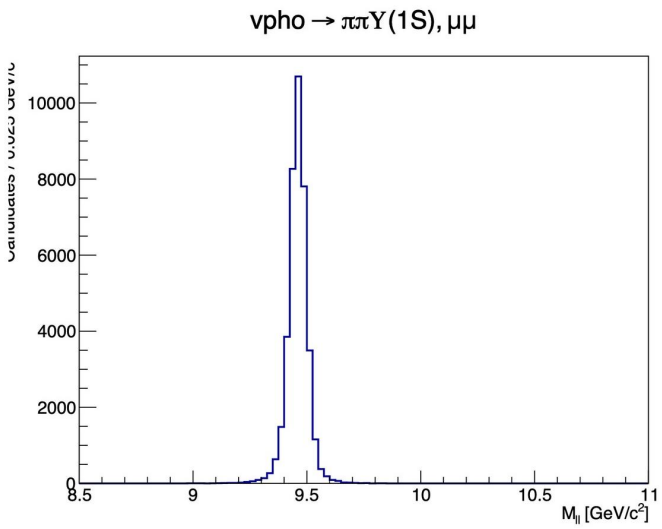


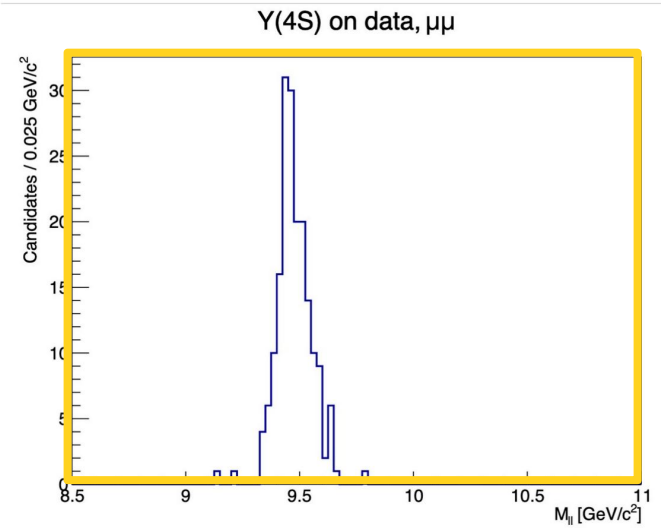


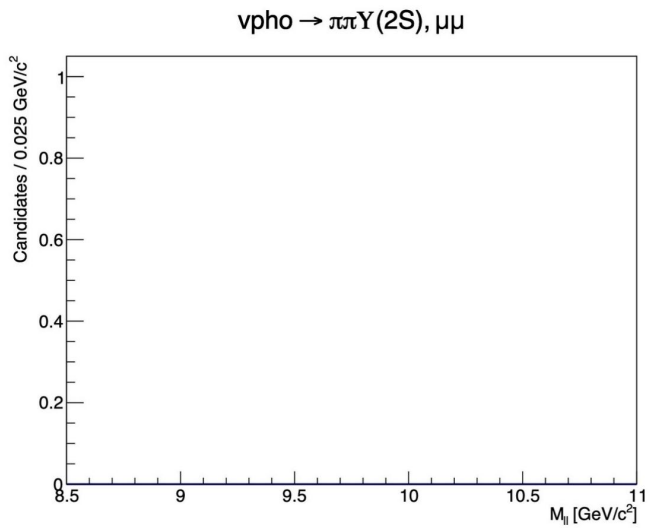


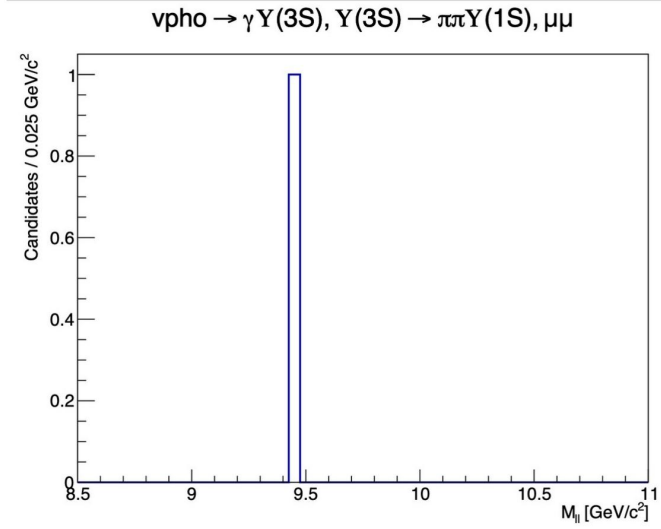
Y(1S) Candidates in the Y(4S) Sample

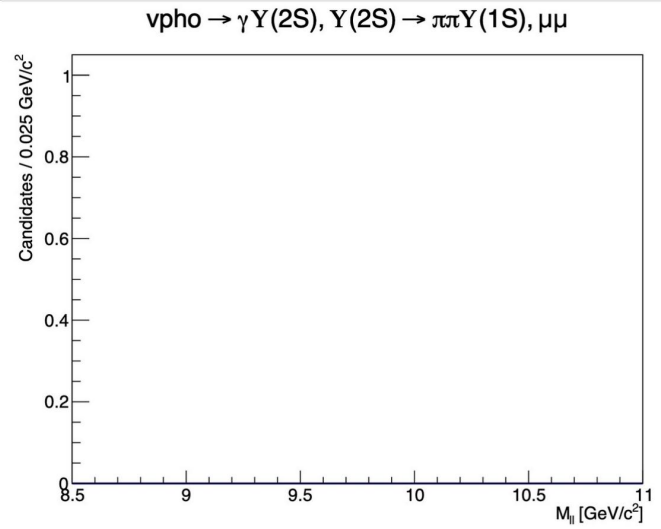
Mll after pcms < 0.1 GeV/c and 1.0 < ΔM < 1.2 GeV.

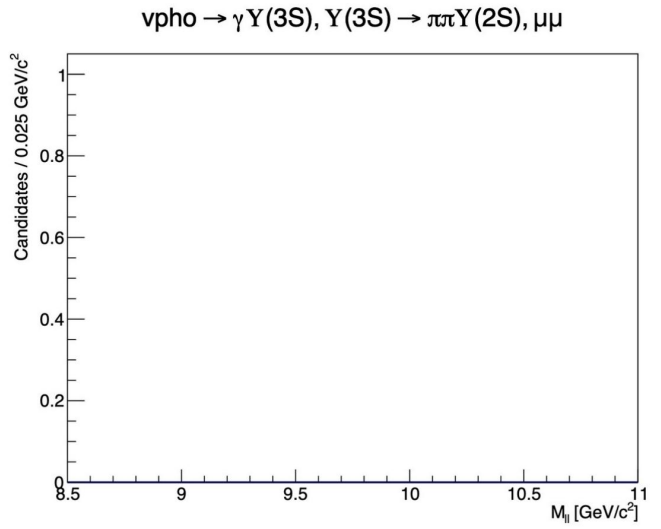






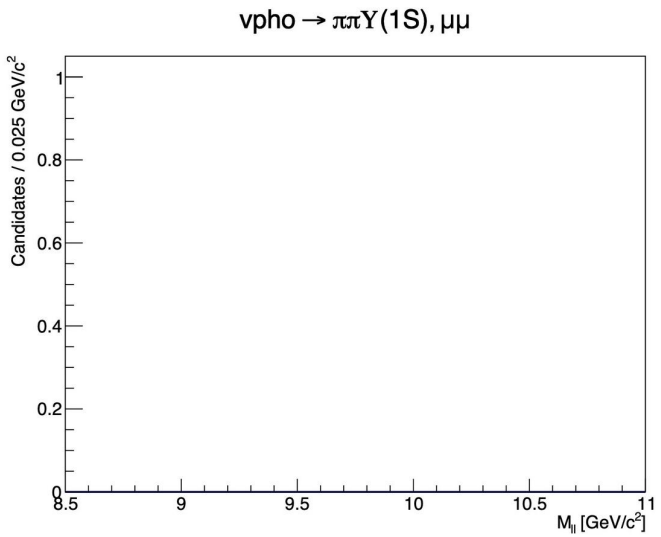


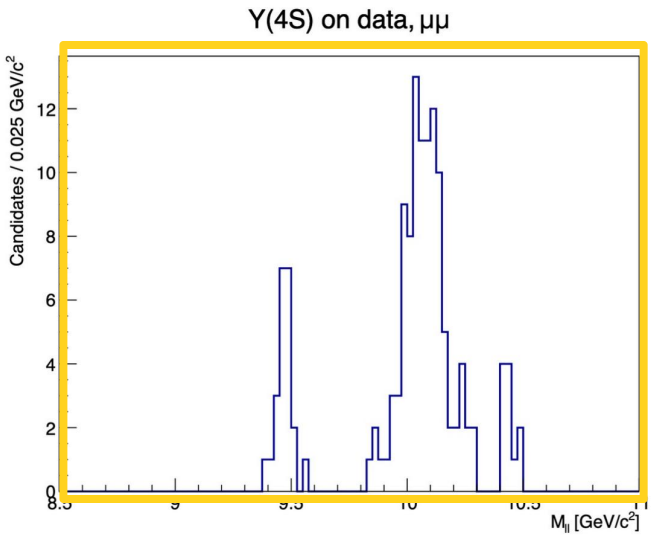


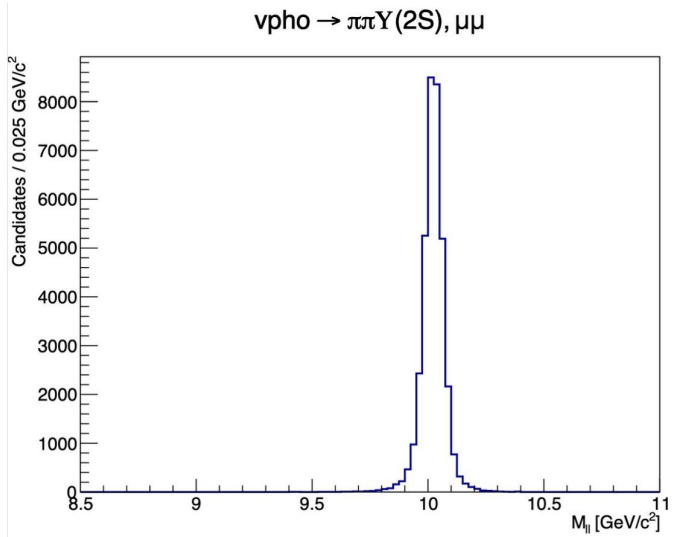


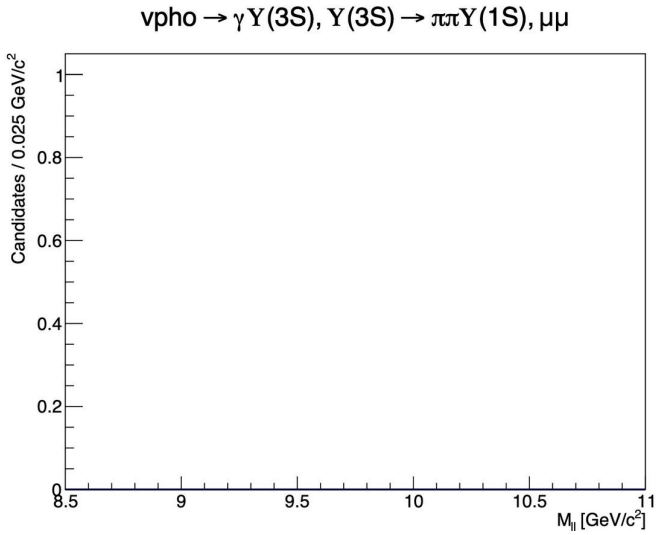
Y(2S) Candidates in the Y(4S) Sample

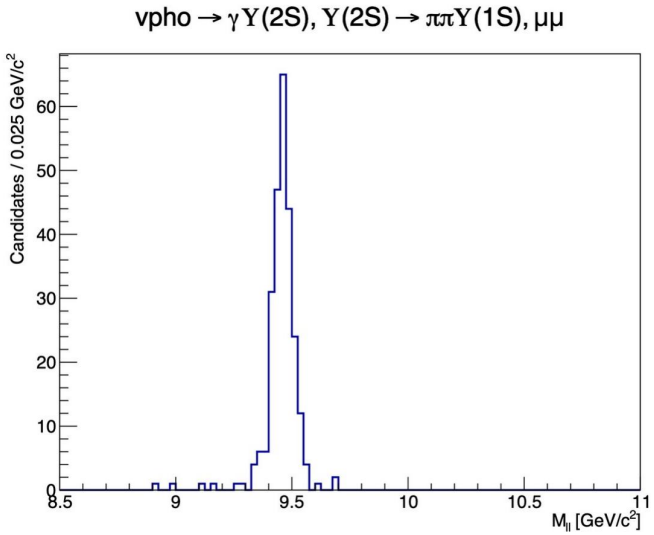
Mll after pcms < 0.1 GeV/c and 0.5 < ΔM < 0.6 GeV.

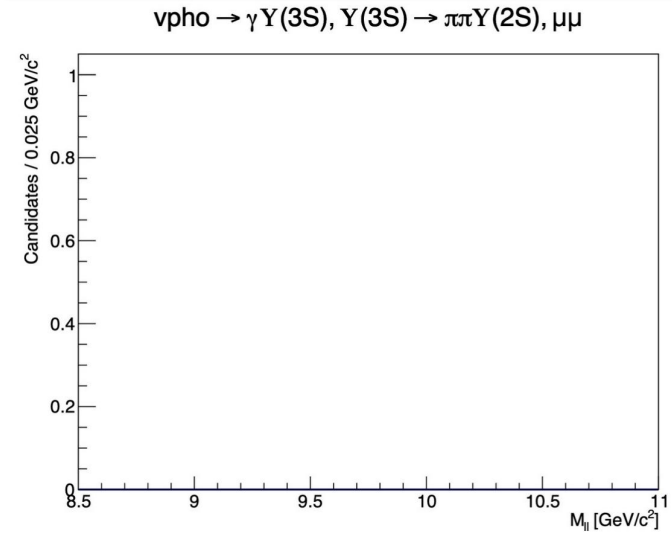






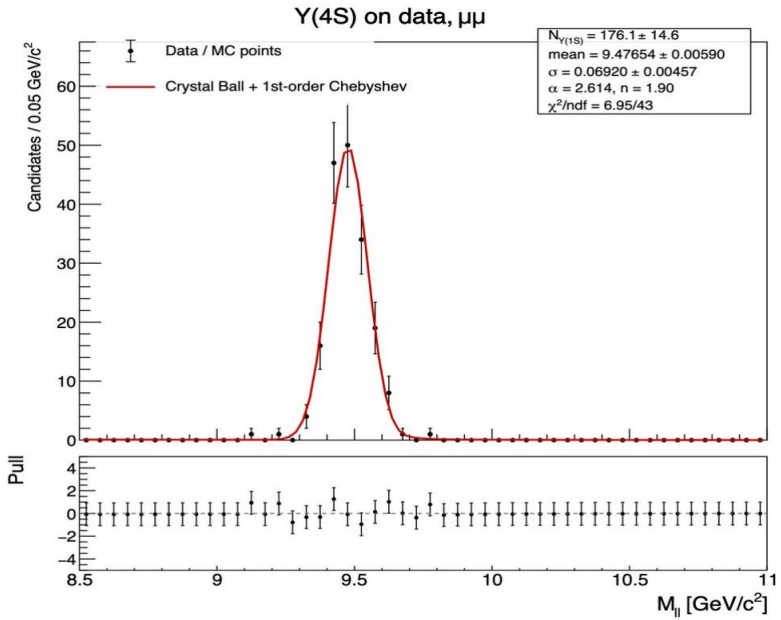






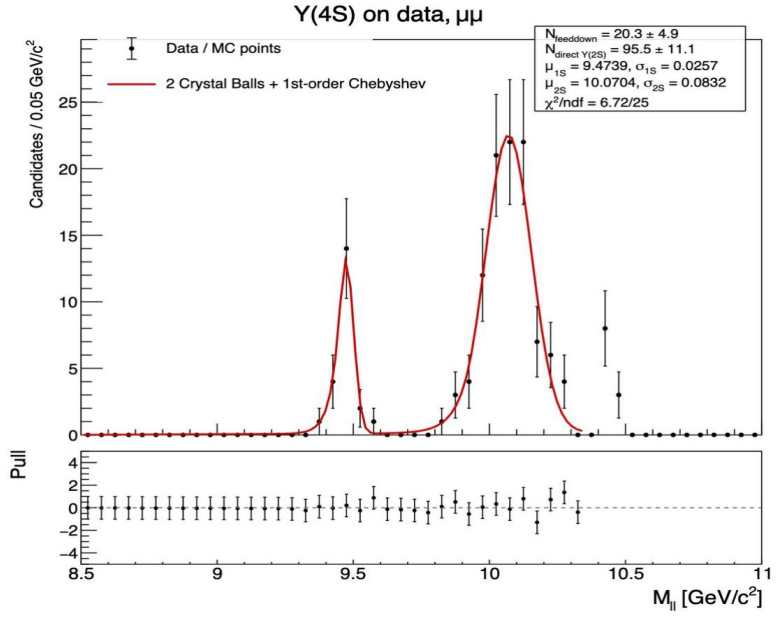
Preliminary Fits to the μμ Mass Spectra

Fit workflow demonstration; yields are preliminary.



Direct: $e^+e^- \rightarrow \pi^+\pi^- Y(1S)$

N = 176.1 ± 14.6 candidates



Direct Y(2S) + Y(2S) $\rightarrow \pi^+\pi^- Y(1S)$

N(Y(2S)) = 95.5 ± 11.1; N(feed-down) = 20.3 ± 4.9

Summary and Next Step

Current scope: $Y(4S) \to \pi^+\pi^- Y(nS)$, $Y(nS) \to \mu^+\mu^-$.

Completed

- Prepared five exclusive signal/feed-down MC samples
- Compared Mll, ΔM and pcms distributions
- Applied preliminary windows and completed fit-workflow studies

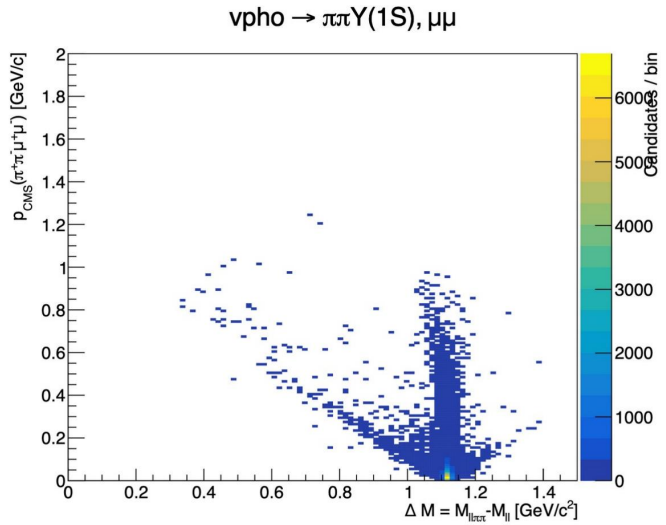
In progress / next

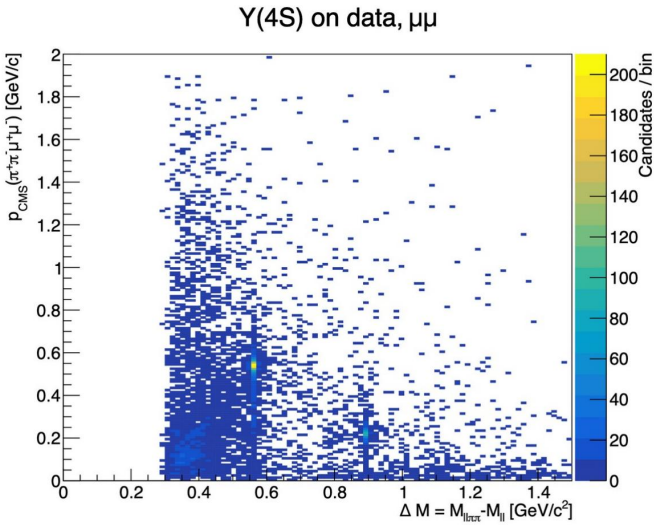
- Grid submission was unavailable until yesterday; Generic MC is not ready
- Moriond 2023 data from Prof. Yin is used temporarily as a reference sample
- Generate and process Generic MC, then revisit background modeling
- Validate selections and fits; determine efficiencies with matching MC
- Consider extending the study to the 5S scan energies

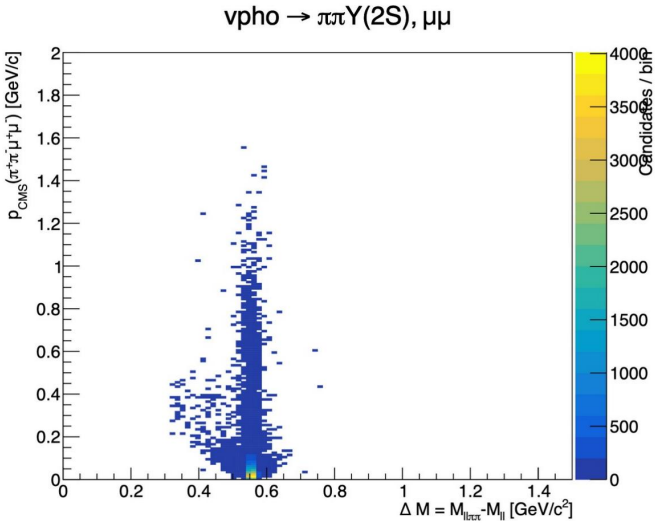
Current fits are exploratory; signal yields and purity are not yet final.

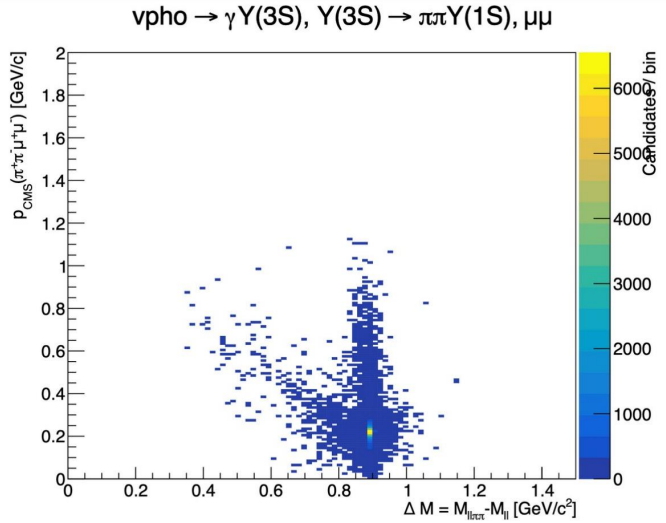
Thanks!

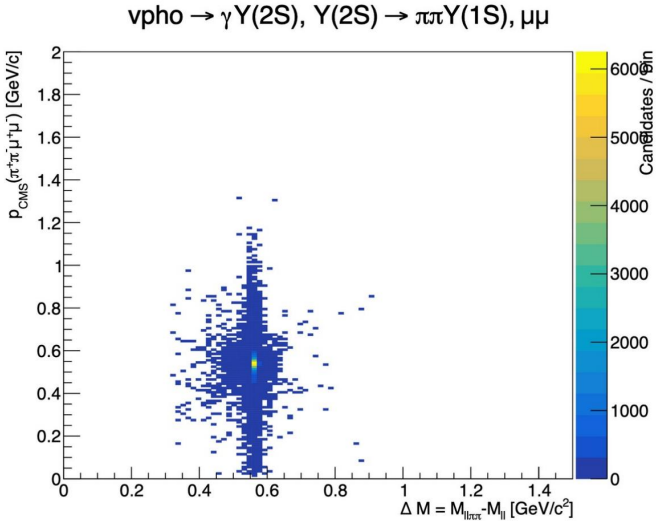
Back up

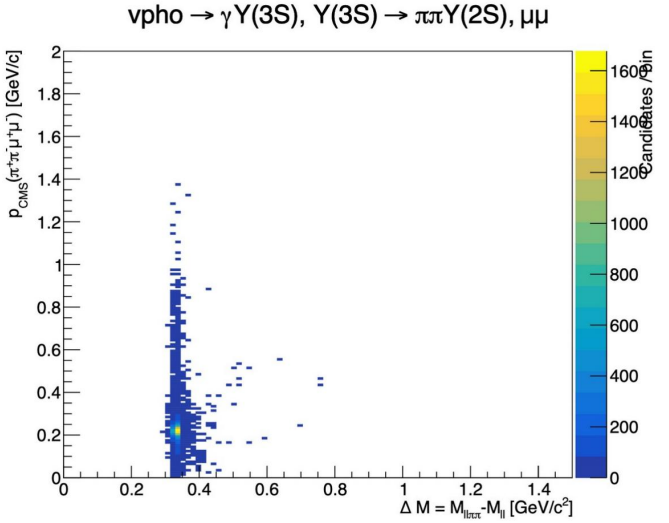

vpho → ππY(1S), μμ
$p_{CMS}(\pi^+\pi^-\mu^+\mu^-)$ [GeV/c]
$\Delta M = M_{l\nu\tau\tau} - M_{ll}$ [GeV/c^2]
Candidates / bin


Y(4S) on data, μμ
$p_{CMS}(\pi^+\pi^-\mu^+\mu^-)$ [GeV/c]
$\Delta M = M_{l\nu\tau\tau} - M_{ll}$ [GeV/c^2]
Candidates / bin


vpho → ππY(2S), μμ
$p_{CMS}(\pi^+\pi^-\mu^+\mu^-)$ [GeV/c]
$\Delta M = M_{l\nu\tau\tau} - M_{ll}$ [GeV/c^2]
Candidates / bin


vpho → γY(3S), Y(3S) → ππY(1S), μμ
$p_{CMS}(\pi^+\pi^-\mu^+\mu^-)$ [GeV/c]
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Candidates / bin


vpho → γY(2S), Y(2S) → ππY(1S), μμ
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