$\Upsilon(10753)$ results from Belle II

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南开大学

第十届XYZ研讨会，长沙，2025年4月13日

Discovery of Upsilon

January, 1976

Fermi Lab, E288, $ee1$

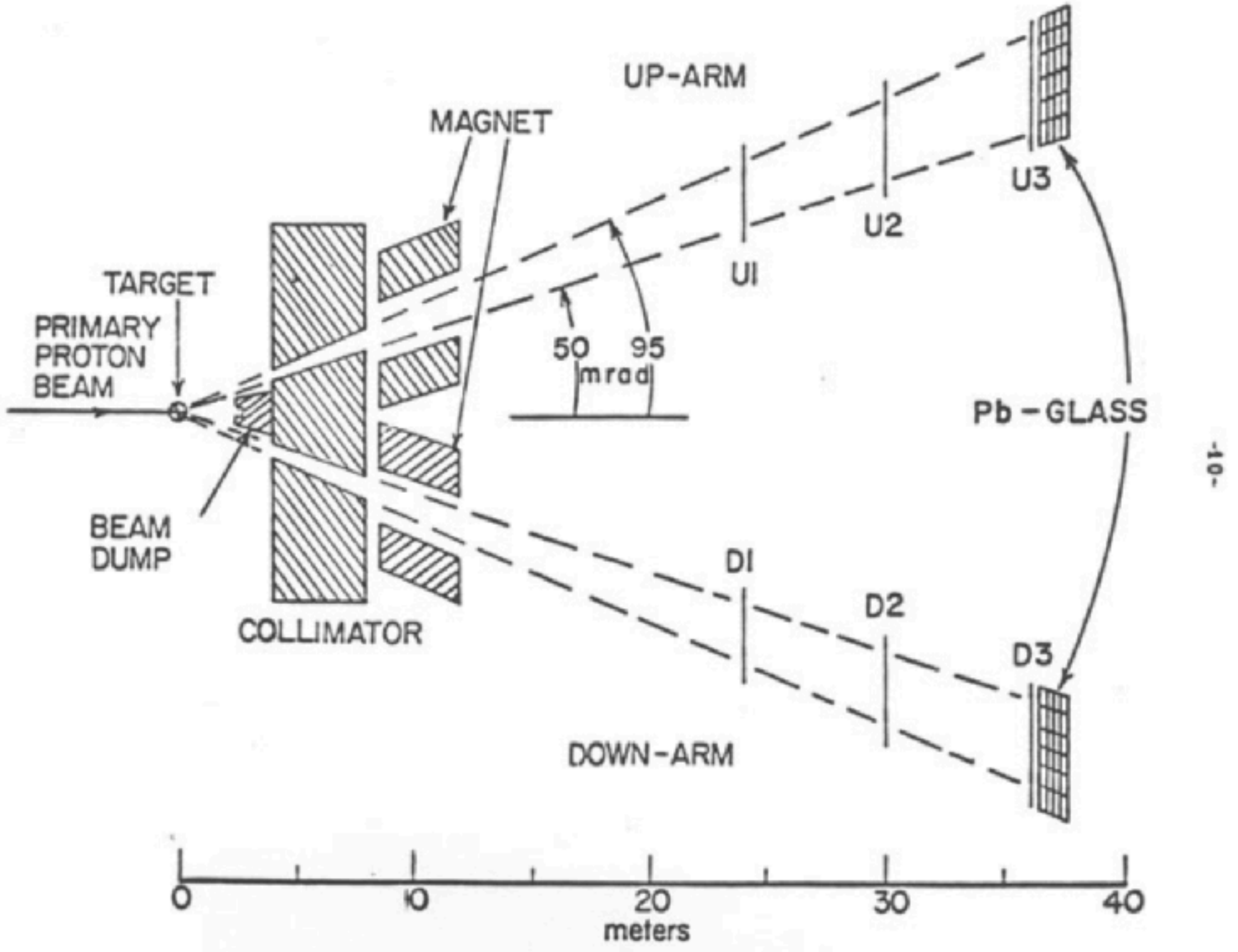


Fig. 1: Schematic Diagram of the Apparatus: U1-3 and D1-3 are sets of scintillation trigger counters, proportional wire chambers, and scintillation hodoscopes.

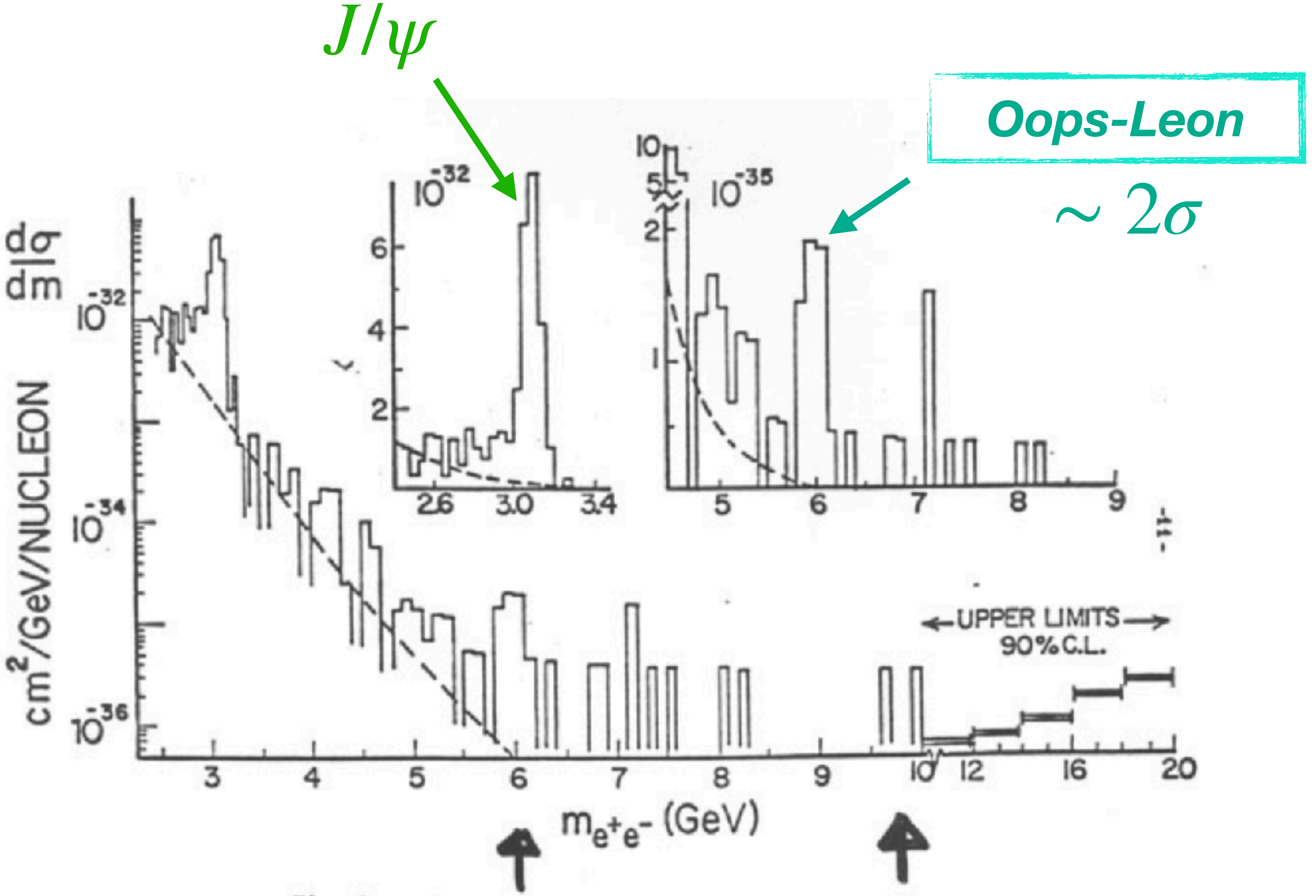
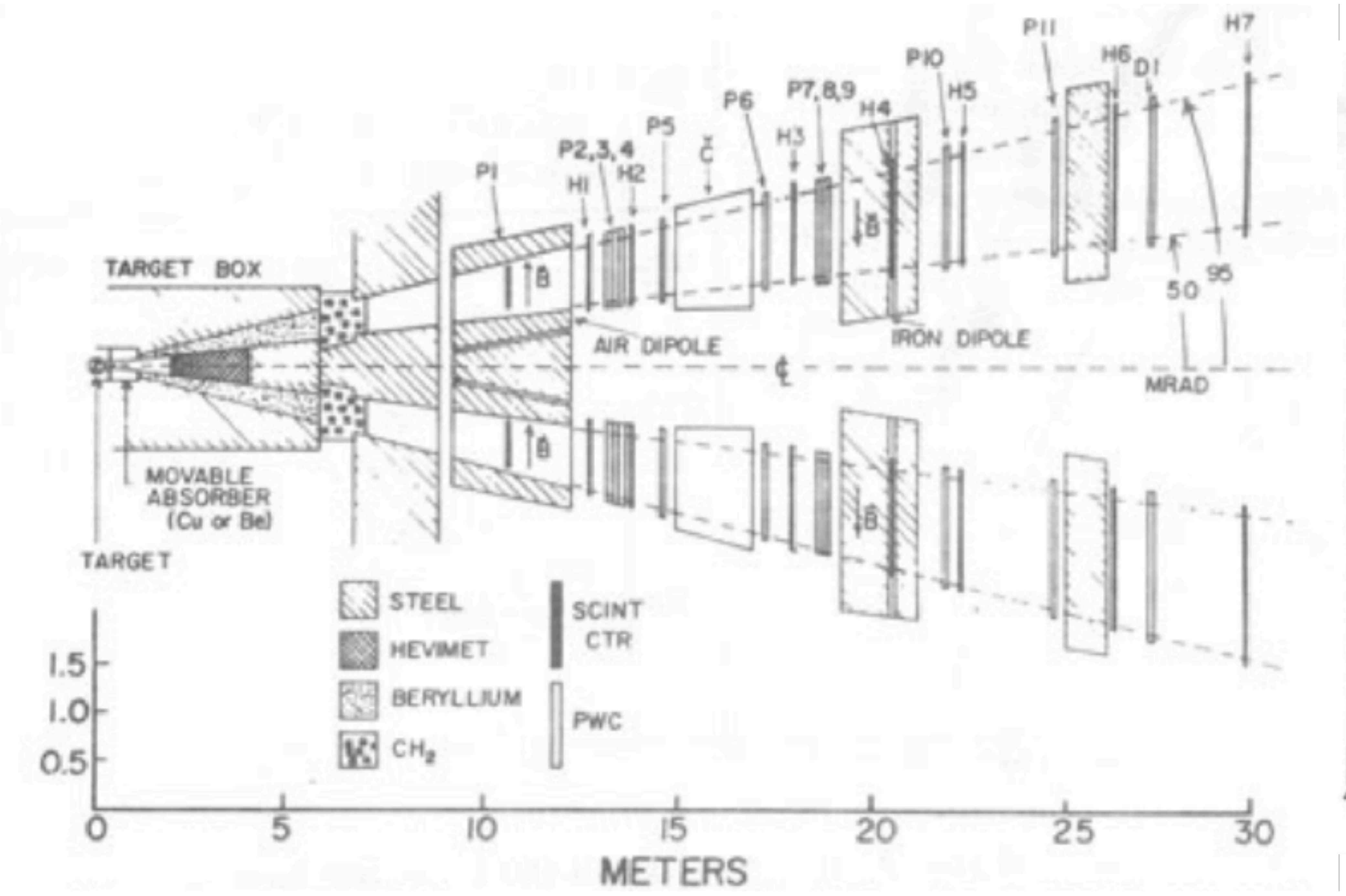
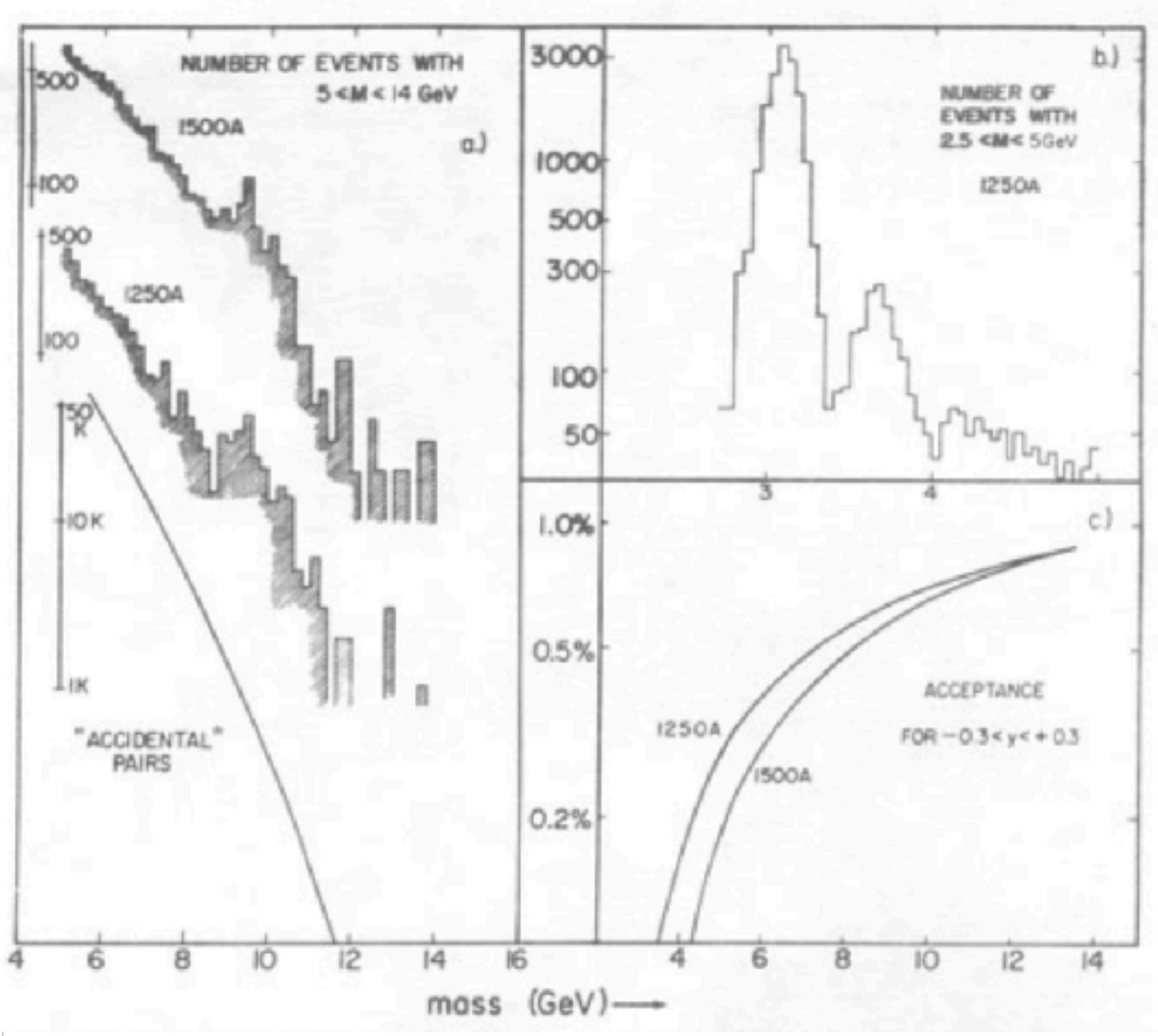


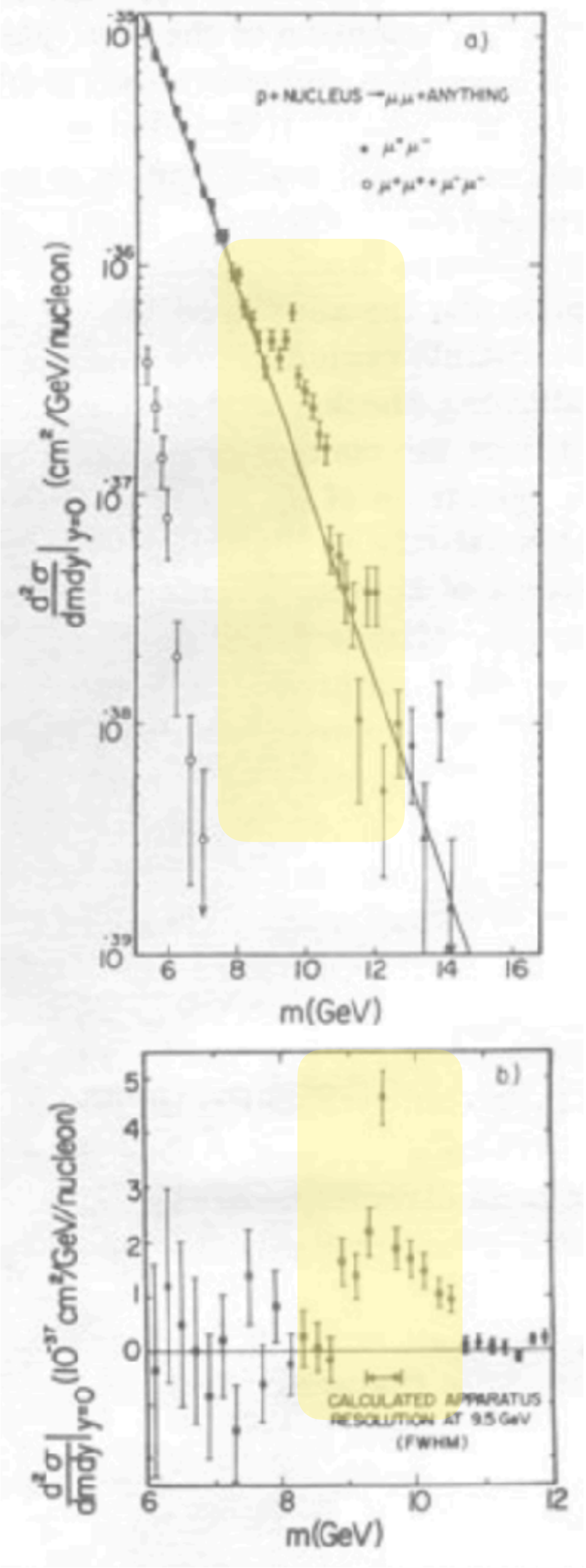
Fig. 2: Electron-Positron Mass Spectrum: dσ/dm per nucleon versus the effective mass. A linear A-dependence is assumed. Note bin width changes.

Discovery of Upsilon

Fermi Lab, E288, $\mu\mu 2$

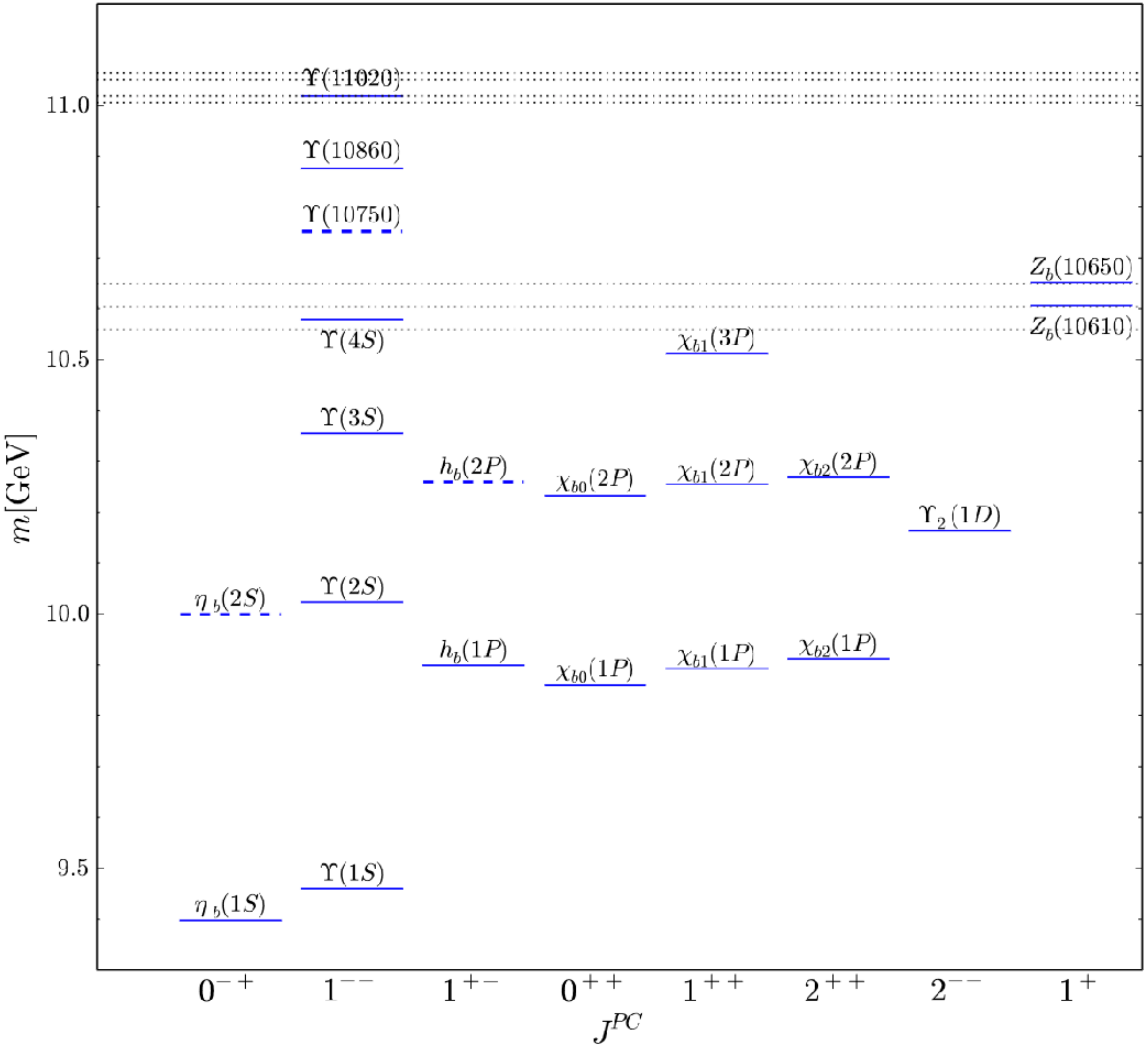




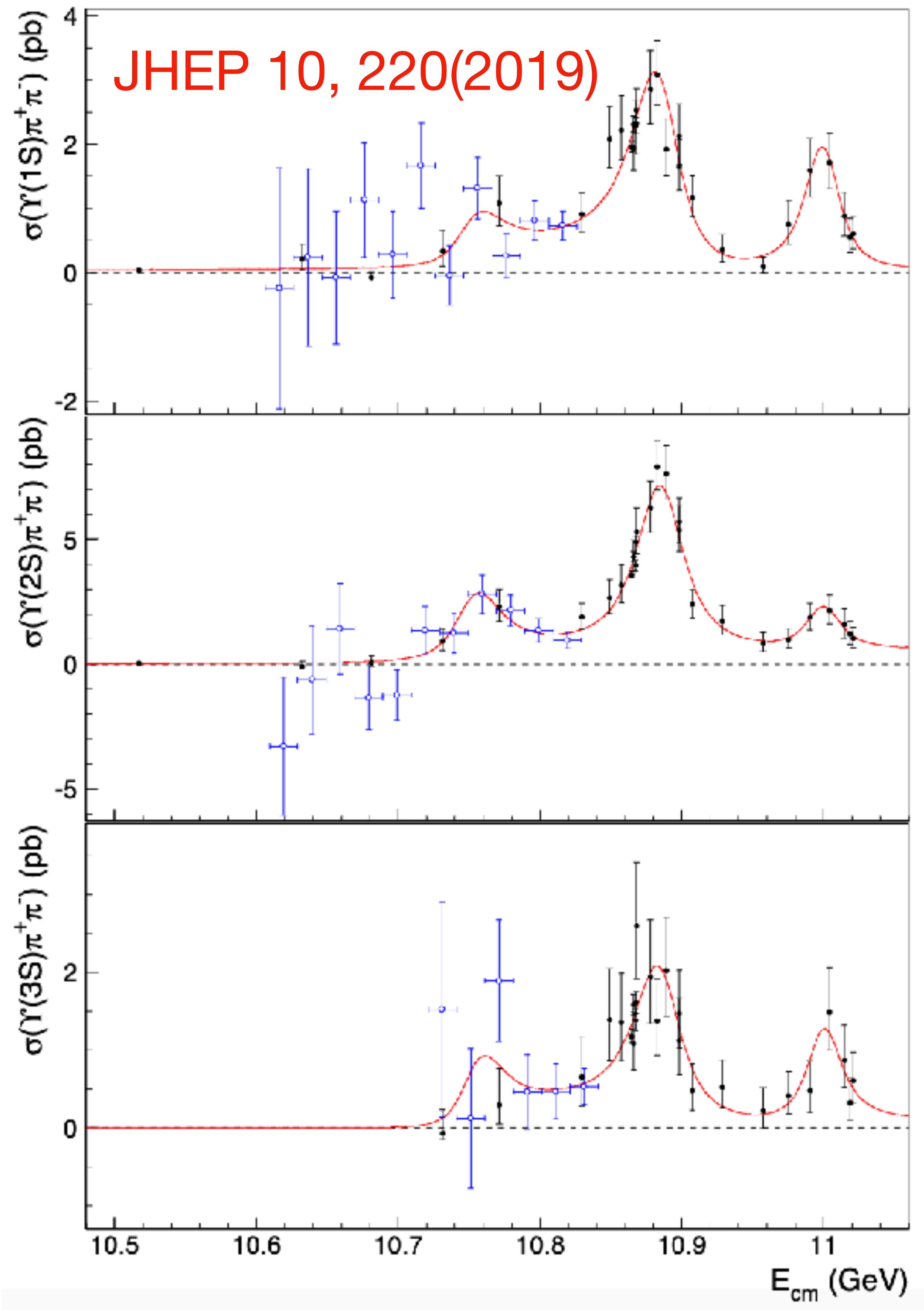


3 years after November revolution

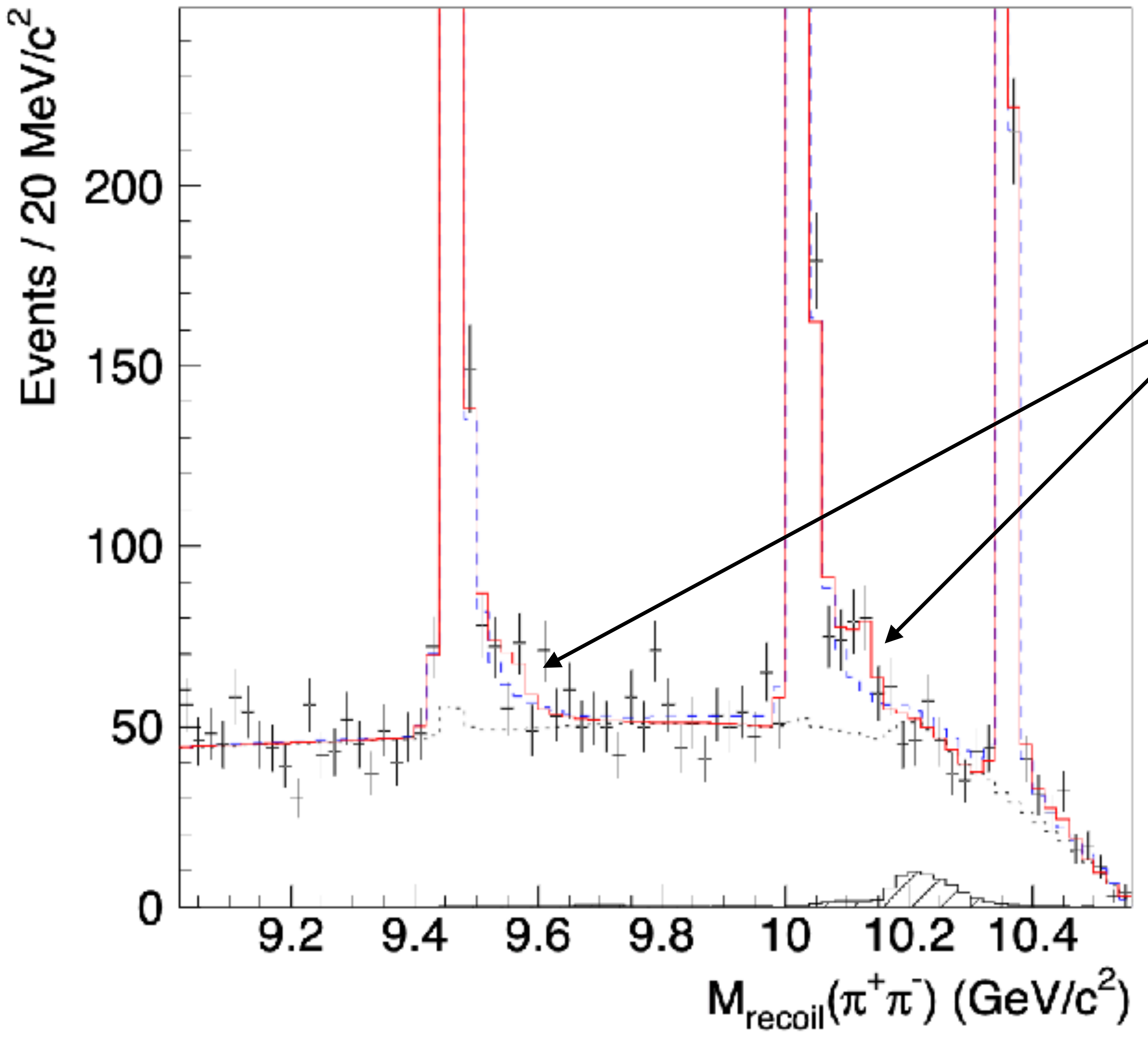
July 1, 1977


$\Upsilon(11020)$
$\Upsilon(10860)$
$\Upsilon(10750)$
$Z_b(10650)$
$Z_b(10610)$
$\Upsilon(4S)$
$\chi_{b1}(3P)$
$\Upsilon(3S)$
$h_b(2P)$
$\chi_{b0}(2P)$
$\chi_{b1}(2P)$
$\chi_{b2}(2P)$
$\Upsilon_2(1D)$
$\eta_b(2S)$
$\Upsilon(2S)$
$h_b(1P)$
$\chi_{b0}(1P)$
$\chi_{b1}(1P)$
$\chi_{b2}(1P)$
$\Upsilon(1S)$
$\eta_b(1S)$
11.0
10.5
10.0
9.5
m[GeV]
0^{-+} 1^{--} 1^{+-} 0^{++} 1^{++} 2^{++} 2^{--} 1^{+}
J^{PC}

$\Upsilon(10753)$ — discovery and studies



- The $\Upsilon(10753)$ was firstly observed in the process of $e^+e^- \to \Upsilon(nS)\pi^+\pi^-(n=1,2,3)$ by Belle.
- Simultaneous fit to cross sections and $M_{\mathrm{recoil}}(\pi\pi)$

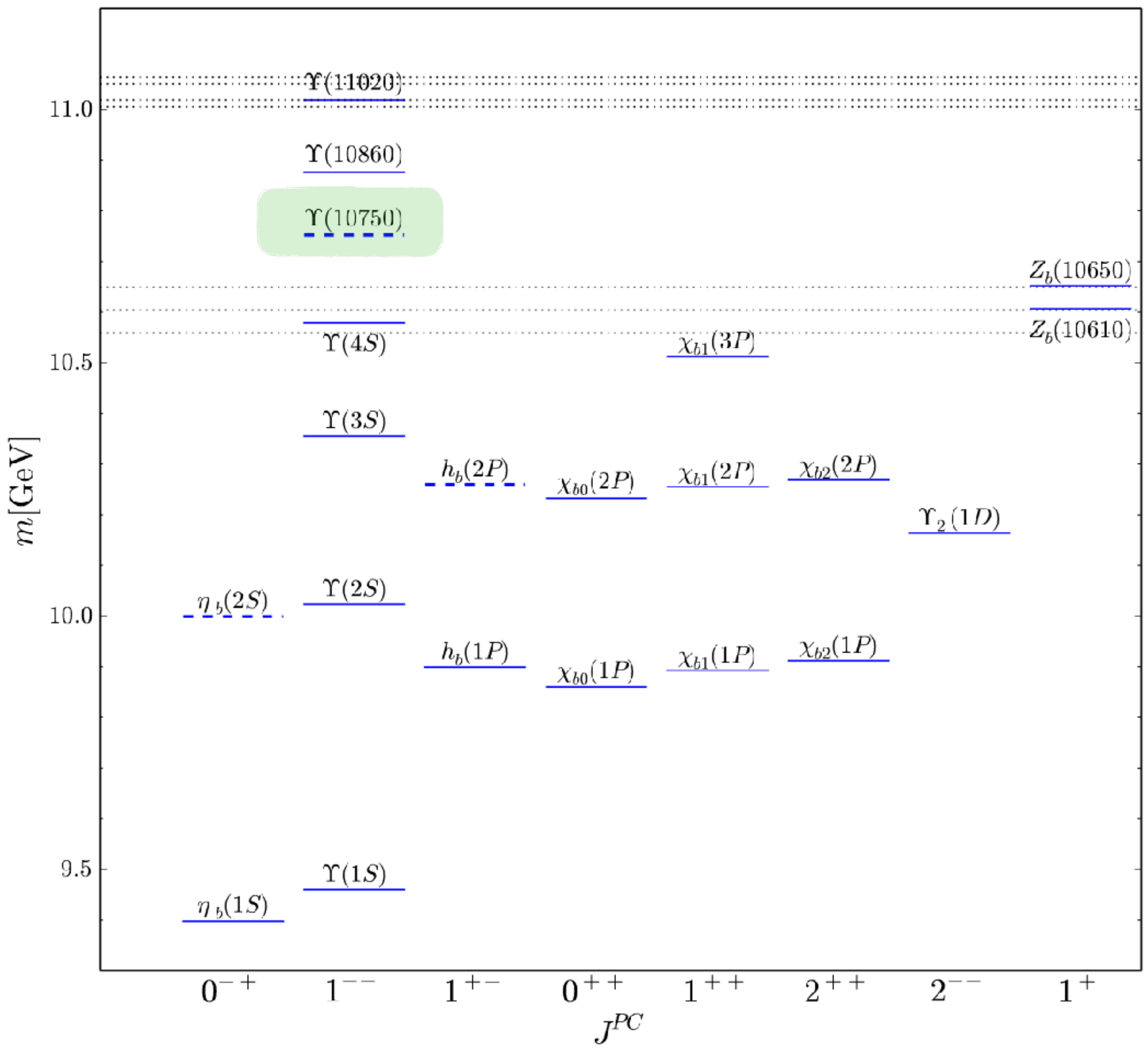


Existence of $\Upsilon(10753)$

Computed as blue dots in left plot

$M = (10752.7 \pm 5.9^{+0.7}_{-1.1})\ \mathrm{MeV}/c^2$

$\Gamma = (35.5^{+17.6}_{-11.3}\ {}^{+3.9}_{-3.3})\ \mathrm{MeV}$



Bottomonium?

Phys. Rev. D 101, 014020 (2020)

Phys. Lett. B 803, 135340 (2020)

Eur. Phys. J. C 80, 59 (2020)

Phys. Rev. D 102, 014036 (2020)

Prog. Part. Nucl. Phys. 117, 103845 (2021)

Phys. Rev. D 104, 034036 (2021)

Phys. Rev. D 105, 074007 (2022)

etc…

Hybrid?

Phys. Rept. 873, 1 (2020)

Phys. Rev. D 104, 034019 (2021)

etc…

Tetraquark?

Phys. Lett. B 802, 135217 (2020)

Chin. Phys. C 43, 123102 (2019)

Phys. Rev. D 103, 074507 (2021)

Phys. Rev. D 107, 094515 (2023)

etc…

$$\Upsilon(10753) \to \pi^+\pi^-\Upsilon(1,2,3S)$$

$$\Upsilon(10753) \to \eta\Upsilon(1,2S)$$

$$\Upsilon(10753) \to \omega\chi_{bJ}$$

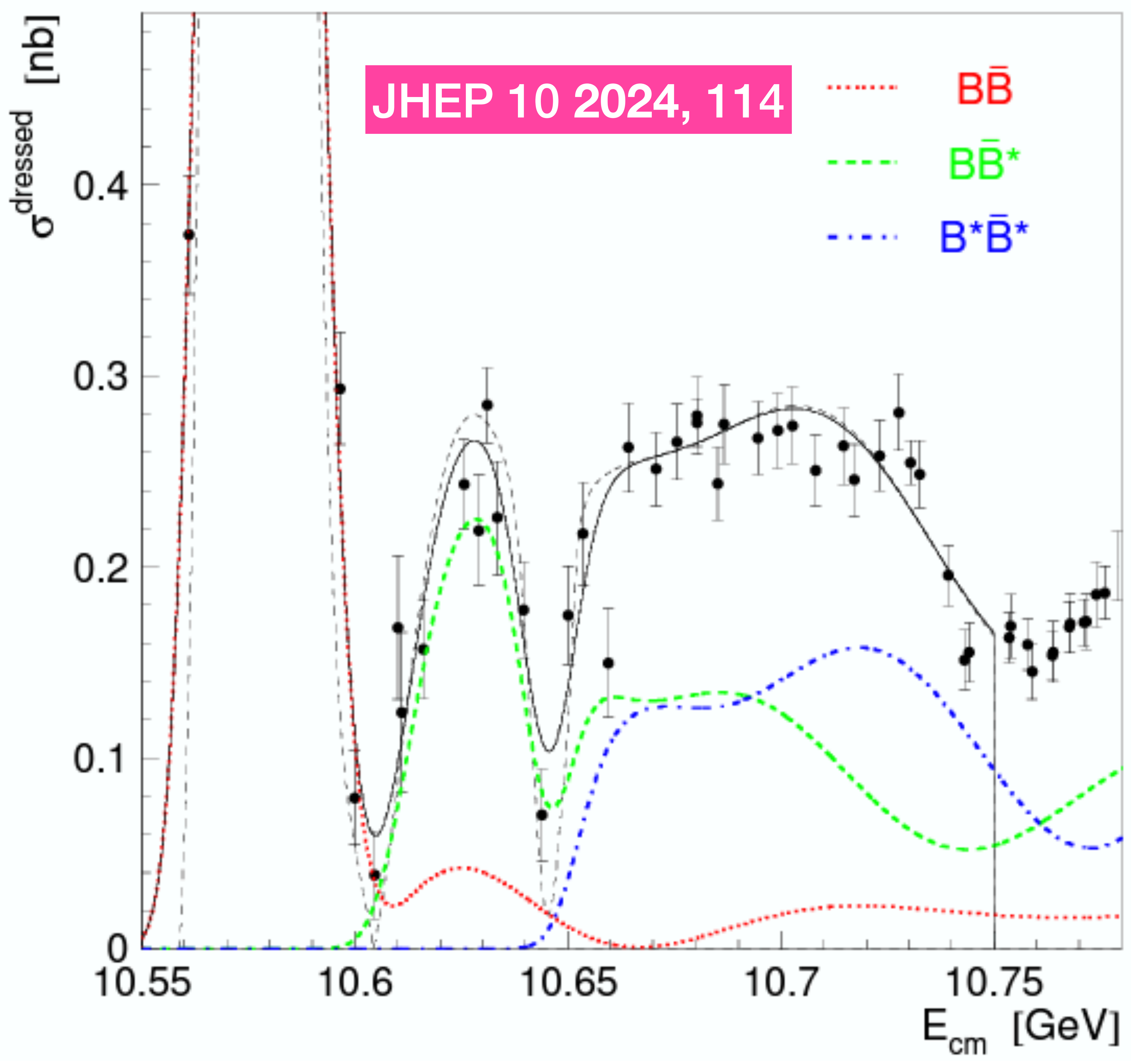
$$\Upsilon(10753) \to \gamma X_b$$

$$\Upsilon(10753) \to \omega\eta_b$$

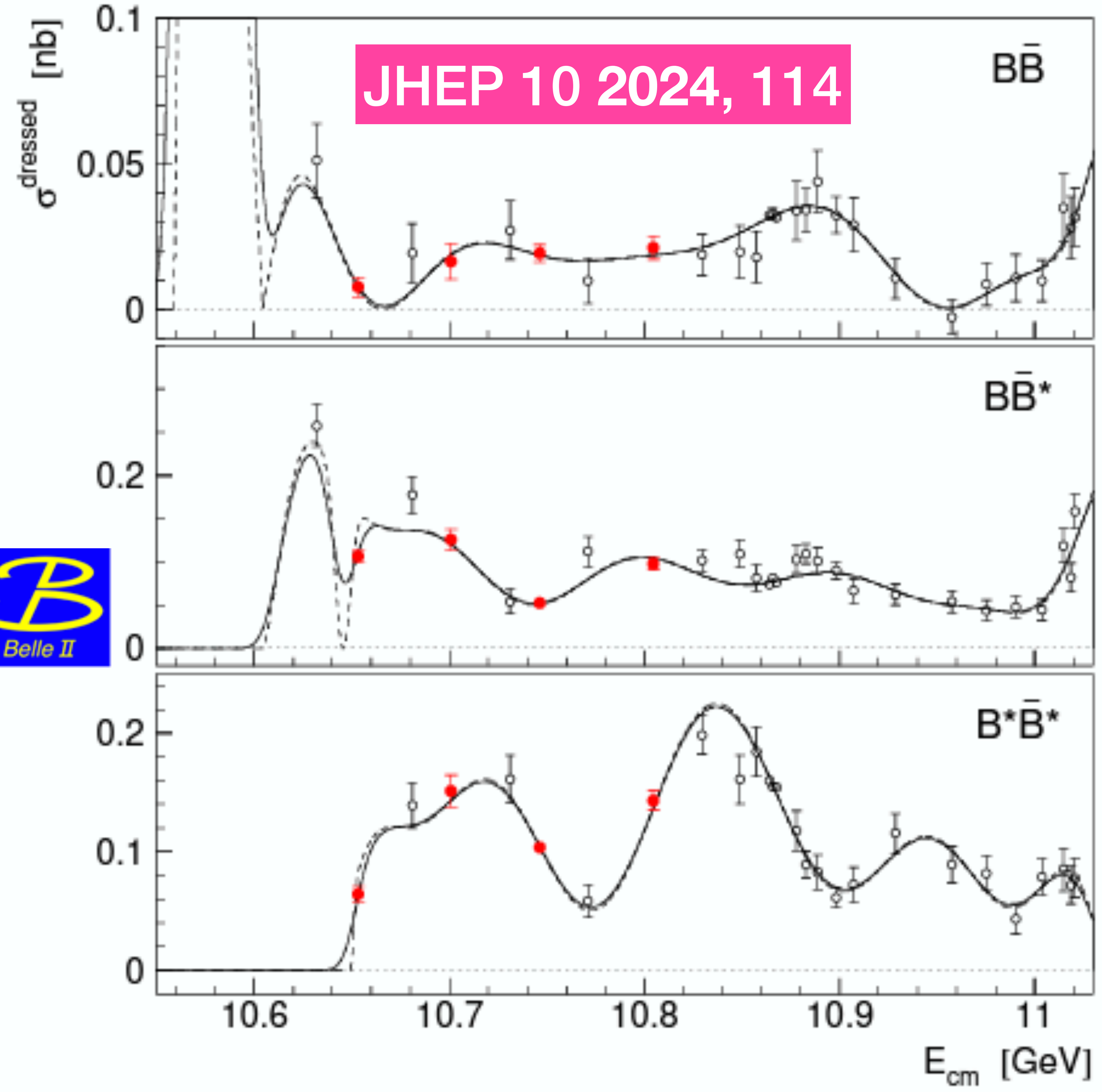
$$\Upsilon(10753) \to B^{(*)}\bar{B}^{(*)}$$

$e^+e^- \to B^{(*)}\bar{B}^{(*)}$

total cross-section



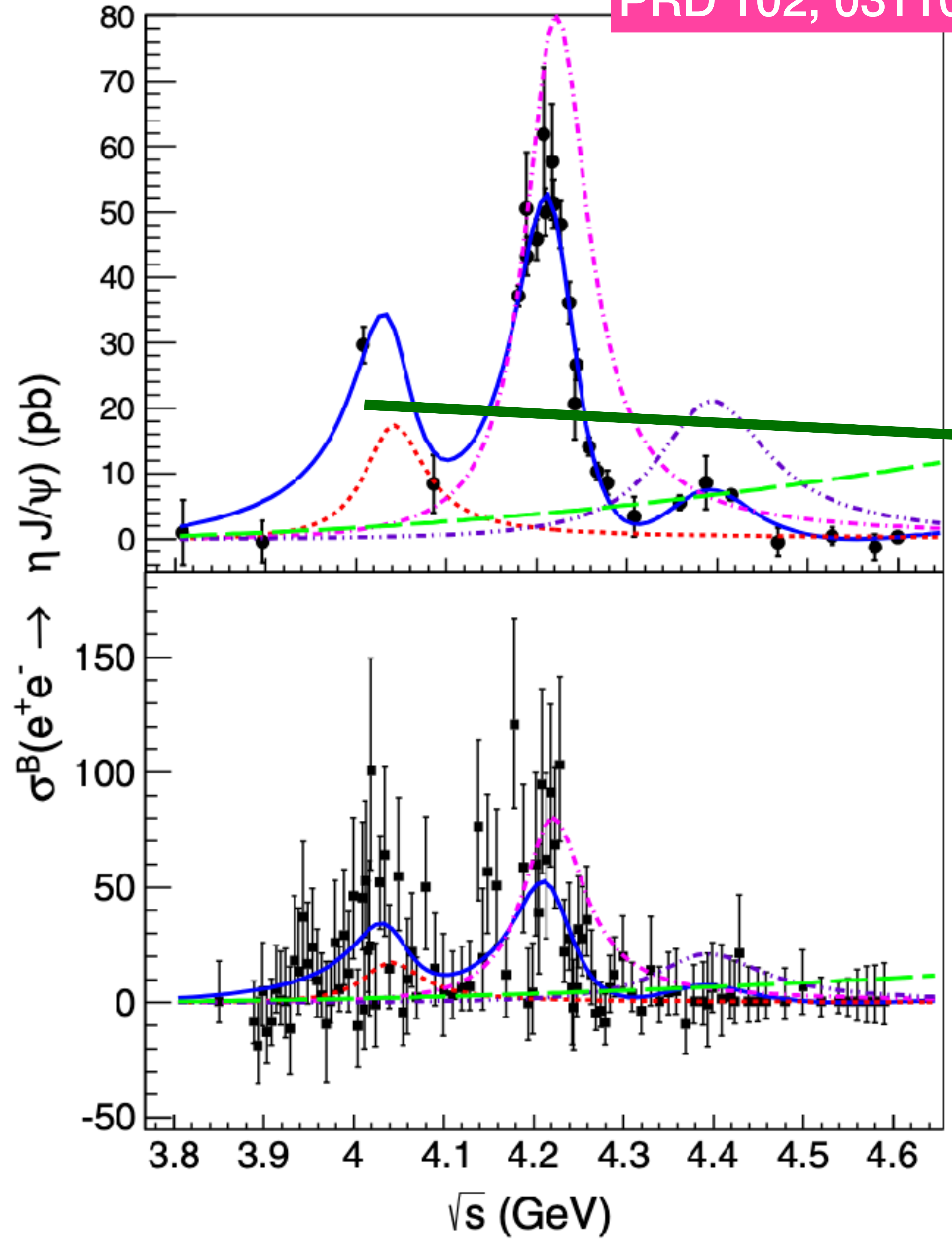
exclusive cross-section



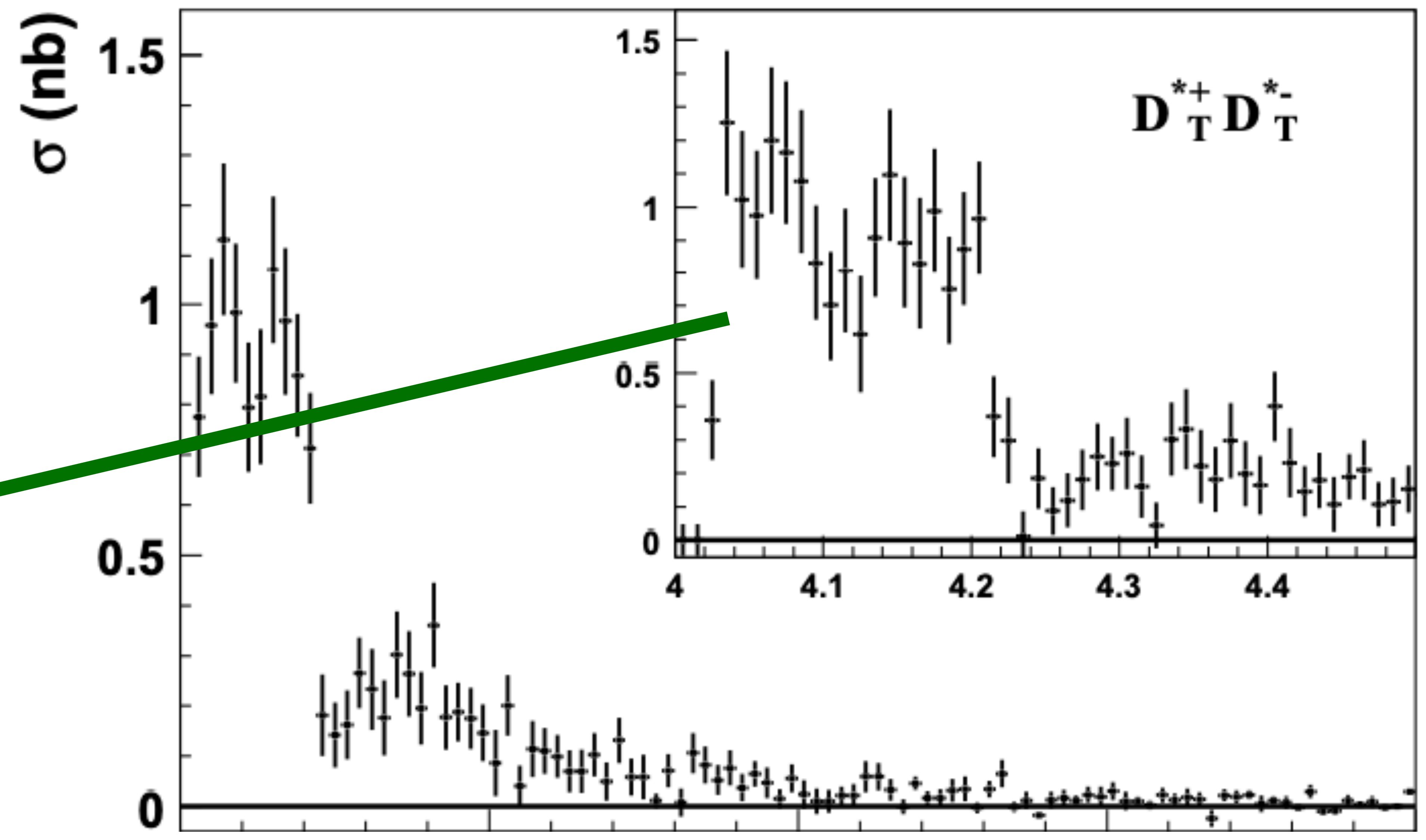
Belle+Belle II

Shape increase at $B\bar{B}^*$ threshold.
Suggestive of something?

PRD 102, 031101 (2020)



$\psi(4040)$



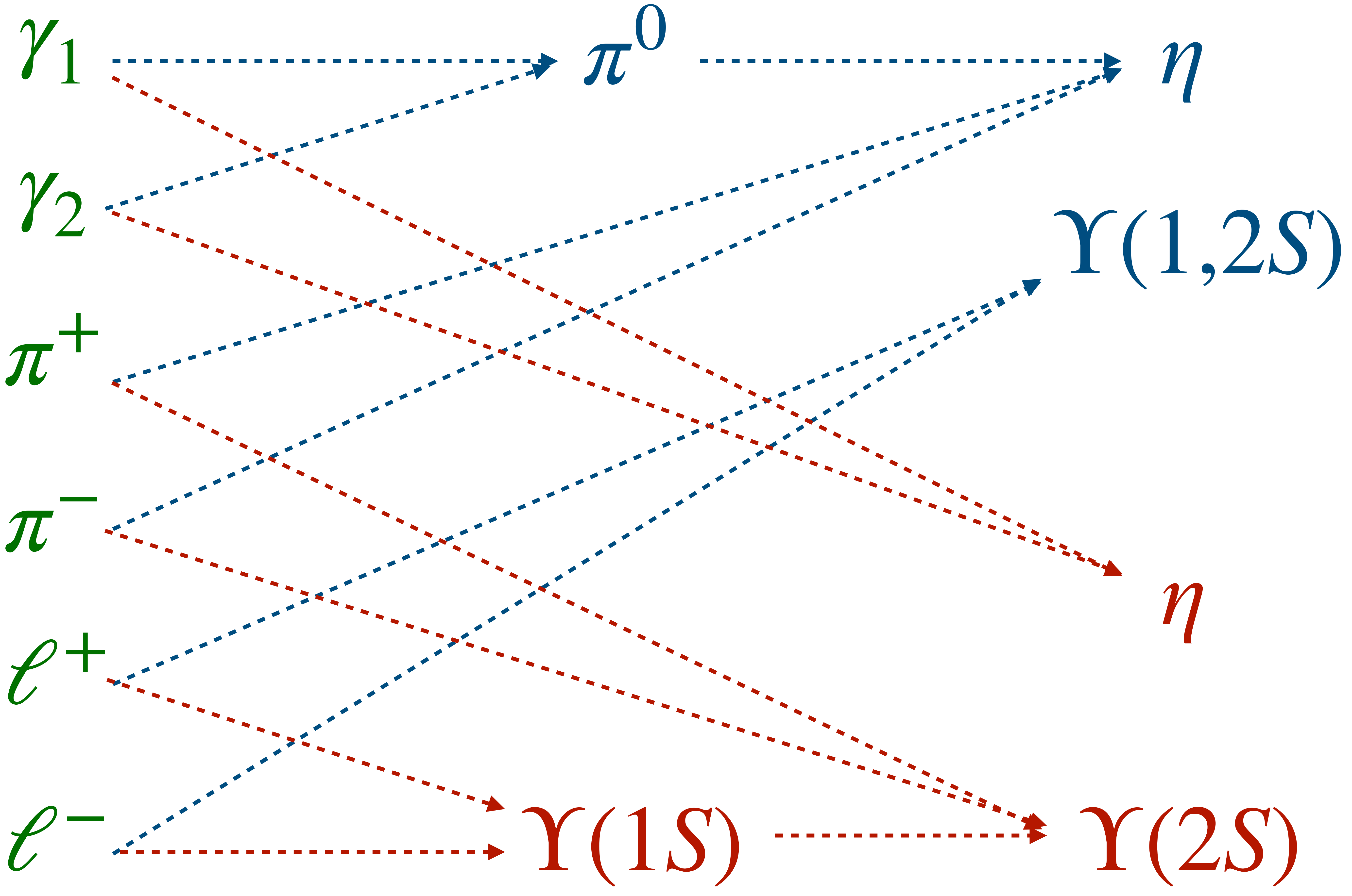
Considerable BR of $\psi(4040) \to \eta J/\psi$

Γ_{17}	$J/\psi(1S)$ hadrons	seen
Γ_{18}	$J/\psi\pi^+\pi^-$	$< 4 \times 10^{-3}$
Γ_{19}	$J/\psi\pi^0\pi^0$	$< 2 \times 10^{-3}$
Γ_{20}	$J/\psi\eta$	$(5.2 \pm 0.7) \times 10^{-3}$
Γ_{21}	$J/\psi\pi^0$	$< 2.8 \times 10^{-4}$
Γ_{22}	$J/\psi\pi^+\pi^-\pi^0$	$< 2 \times 10^{-3}$

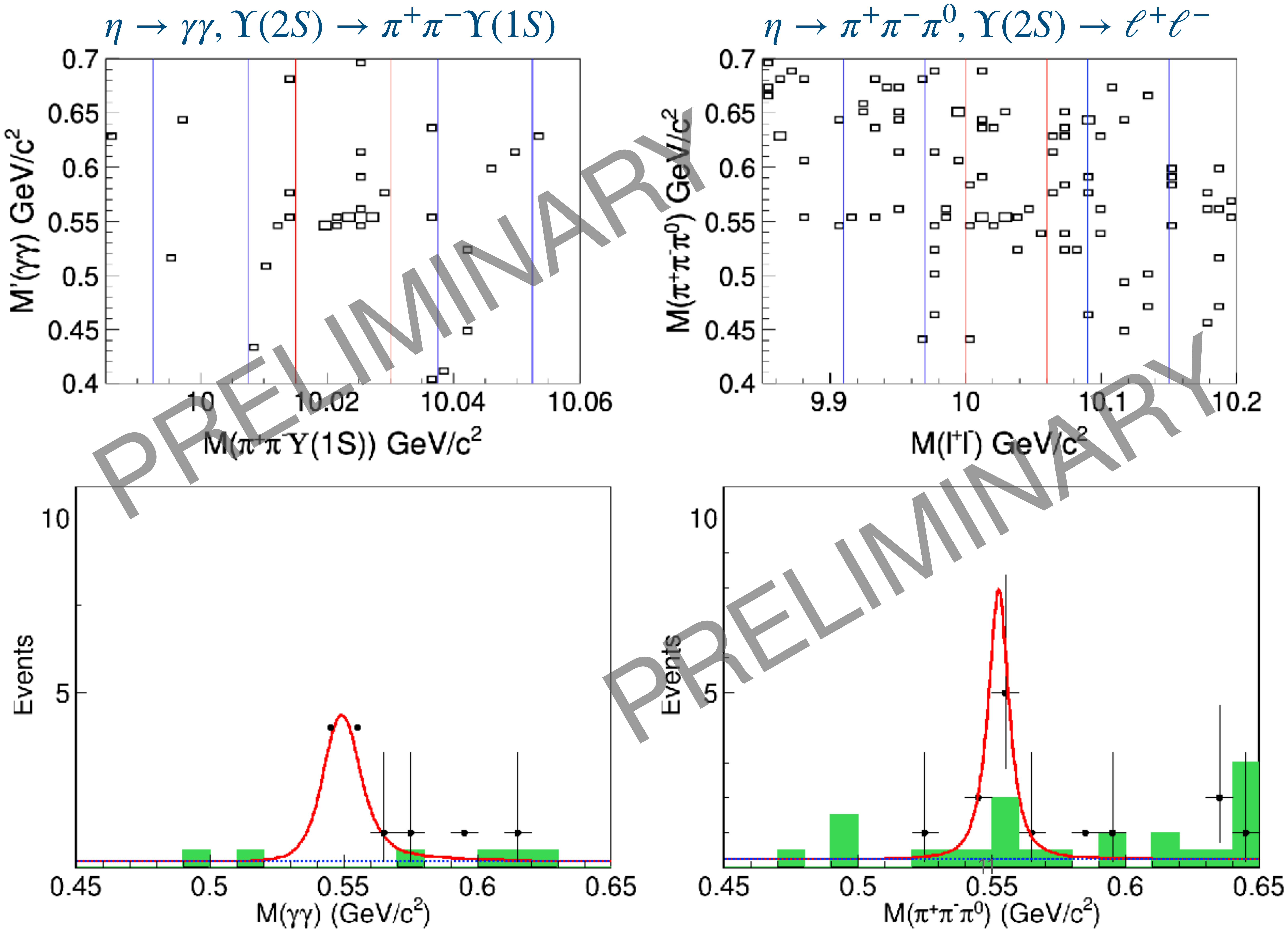
$E > 20(22.5)$ MeV from barrel and FW endcap (BW endcap)

Tracks with $p < 1$ GeV, at least one with eID<0.1, $\cos\theta_{\pi\pi} < 0.98$.

Tracks with $p > 3$ GeV, $E/p > 0.7(< 0.3)$ to identify $e(\mu)$



$\Upsilon(10753) \to \eta\Upsilon(2S)$

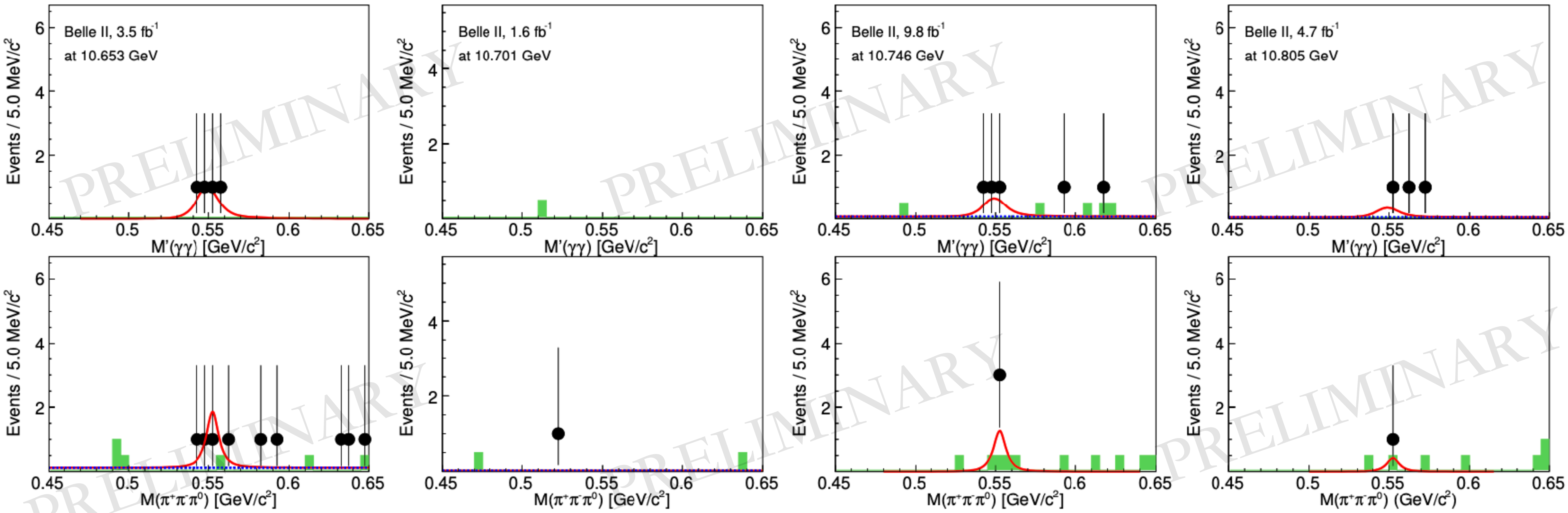


Clear signal is seen.

Project to $M(\eta \to \gamma\gamma/\pi^+\pi^-\pi^0)$

Fit to $M(\eta \to \gamma\gamma/\pi^+\pi^-\pi^0)$ simultaneously.

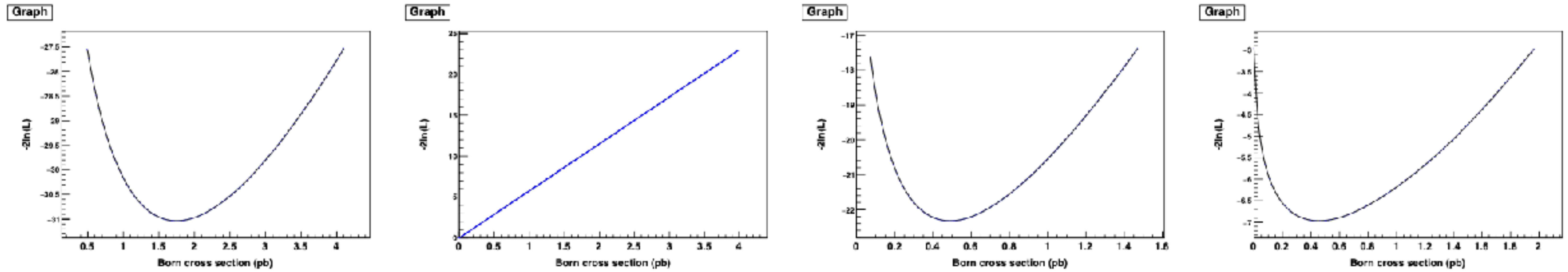
Significance: 6.4σ



For $\sqrt{s} = 10.701$ GeV, we count the signal instead of fit. $N_{\text{sig}} = N_{\text{fit}}/(\mathscr{B}\epsilon)$

E	N_{sig}	significance	ϵ_2/ϵ_3	$(1+\delta)$	$\|1-\Pi\|^2$	σ_B (pb)
10.653	$(3.71^{+1.6}_{-1.3}) \times 10^3$	4.2σ	0.192/0.151	0.881	0.929	$1.11^{+0.49}_{-0.39}$
10.701	$(0.00^{+1.0}_{-0.0}) \times 10^3$	-	0.130/0.070	1.834	0.928	$0.00^{+0.31}_{-0.00}$
10.745	$(3.25^{+1.6}_{-1.2}) \times 10^3$	4.8σ	0.171/0.140	0.687	0.930	$0.45^{+0.22}_{-0.17}$
10.805	$(1.52^{+1.4}_{-0.9}) \times 10^3$	2.8σ	0.166/0.147	0.848	0.931	$0.36^{+0.32}_{-0.21}$

Profiled likelihood distributions from the fit/count results to individual energy point.



Unbinned maximum likelihood fit to the σ^{Born} together with Belle measurement.

Likelihood obtained from simultaneous fits to $M(\eta_{2/3})$.

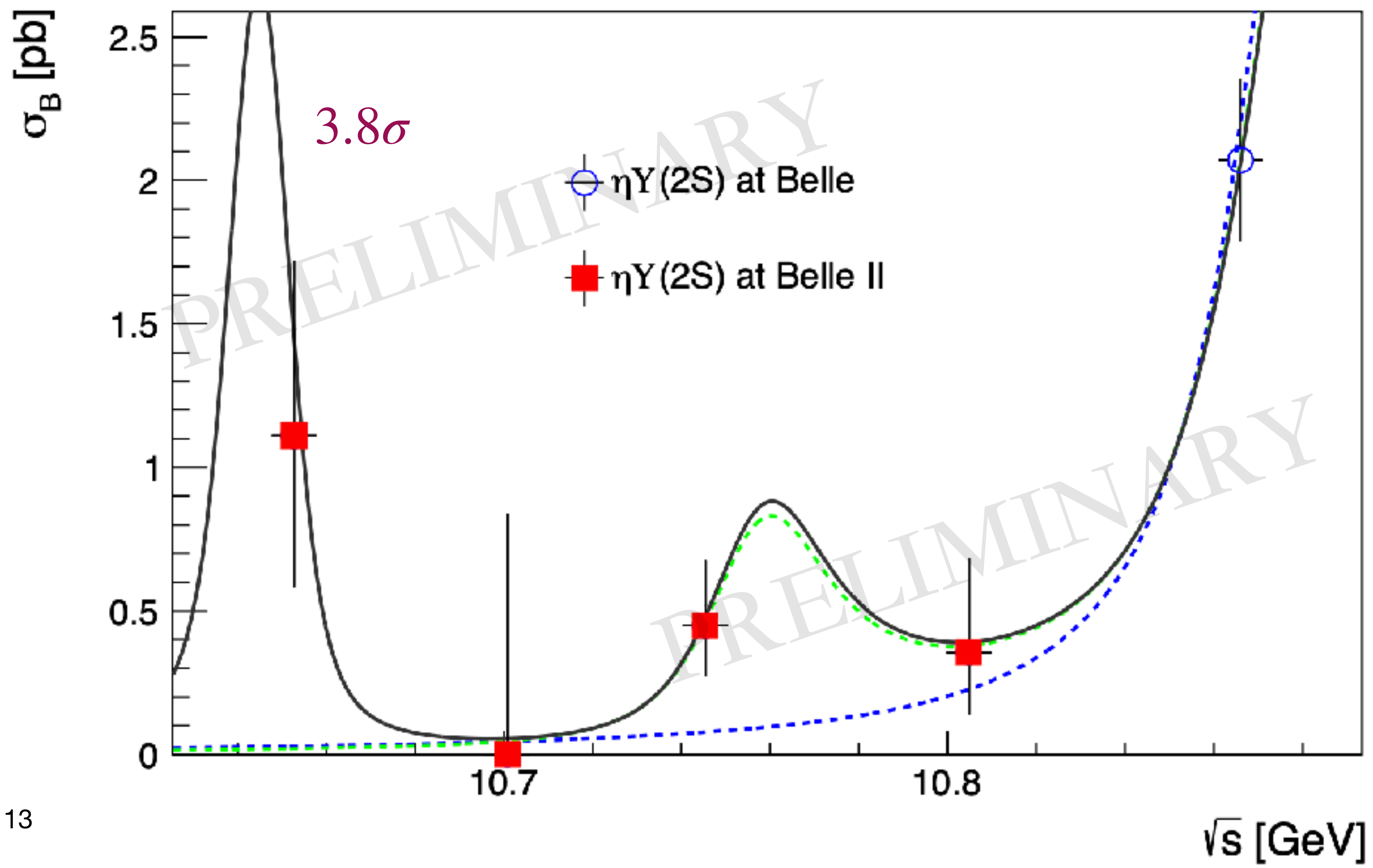
Fit the with 3 different hypotheses:

1. $\Upsilon(5S)$ only;
2. $\Upsilon(5S) + \Upsilon(10753)$
3. $\Upsilon(5S) + \Upsilon(10753) + \Upsilon_{\mathrm{new}}$, *default*

Parameters of Υ_{new} fixed to:

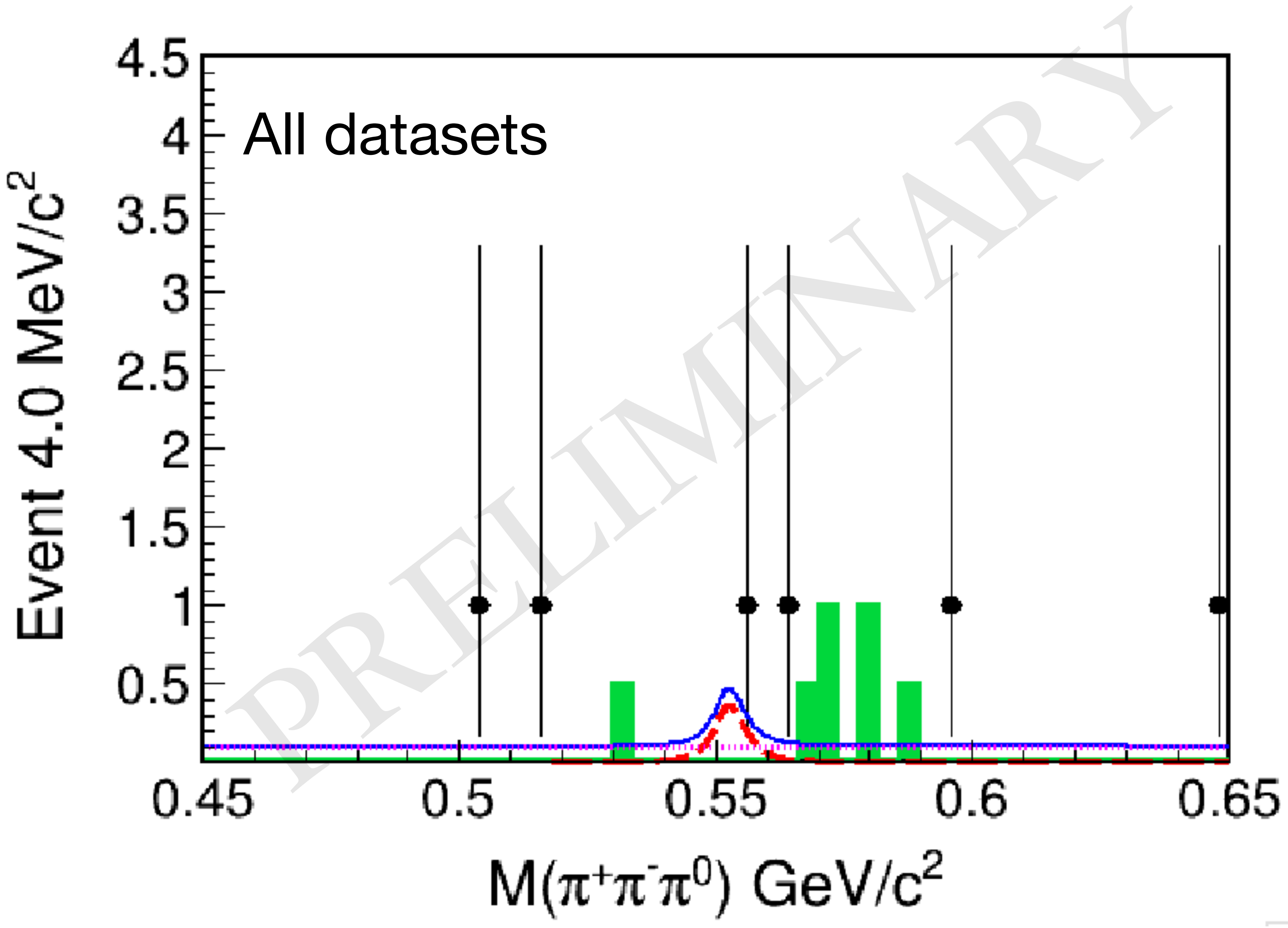
$m = 10645\ \mathrm{MeV}/c^2, \Gamma = 9\ \mathrm{MeV}$

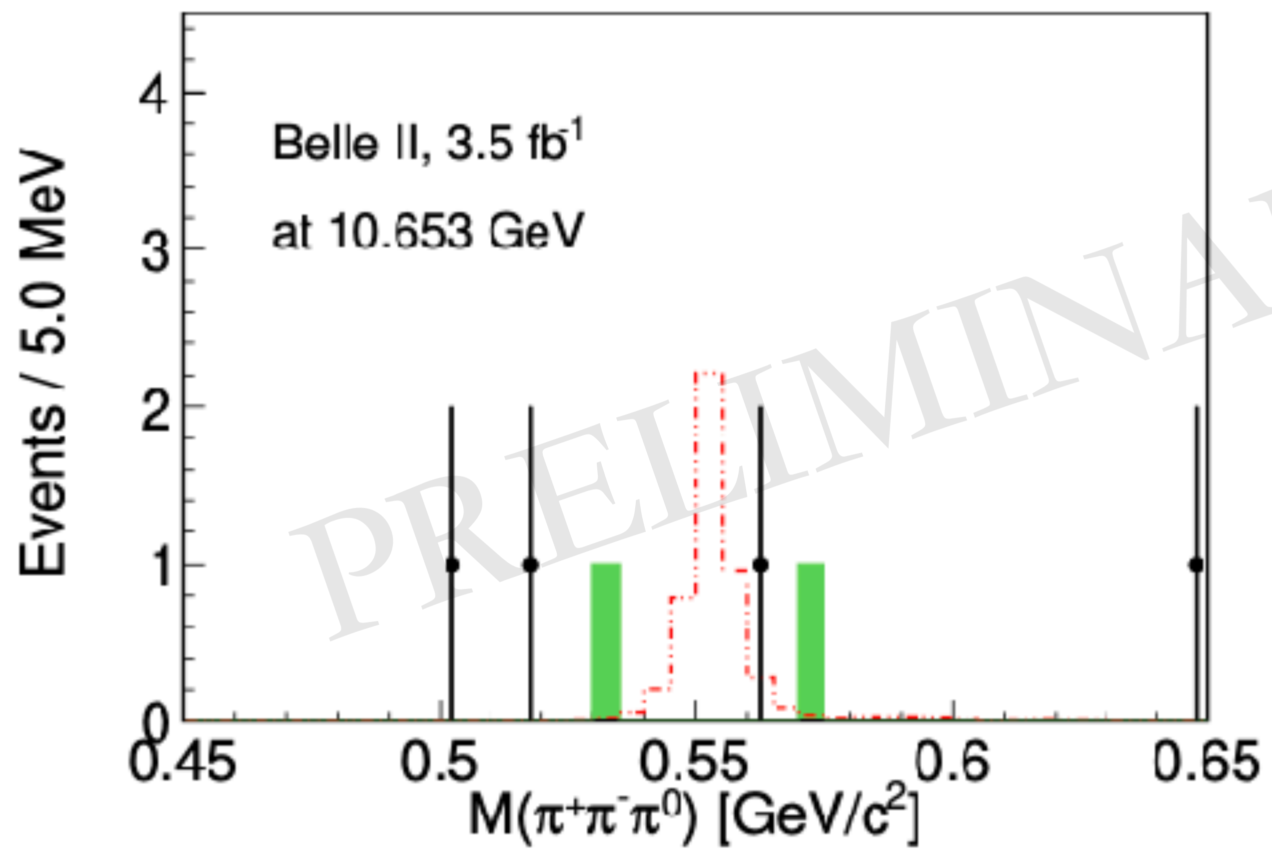
obtained from $e^+e^- \to B^{(*)}\bar{B}^{(*)}$ measurement

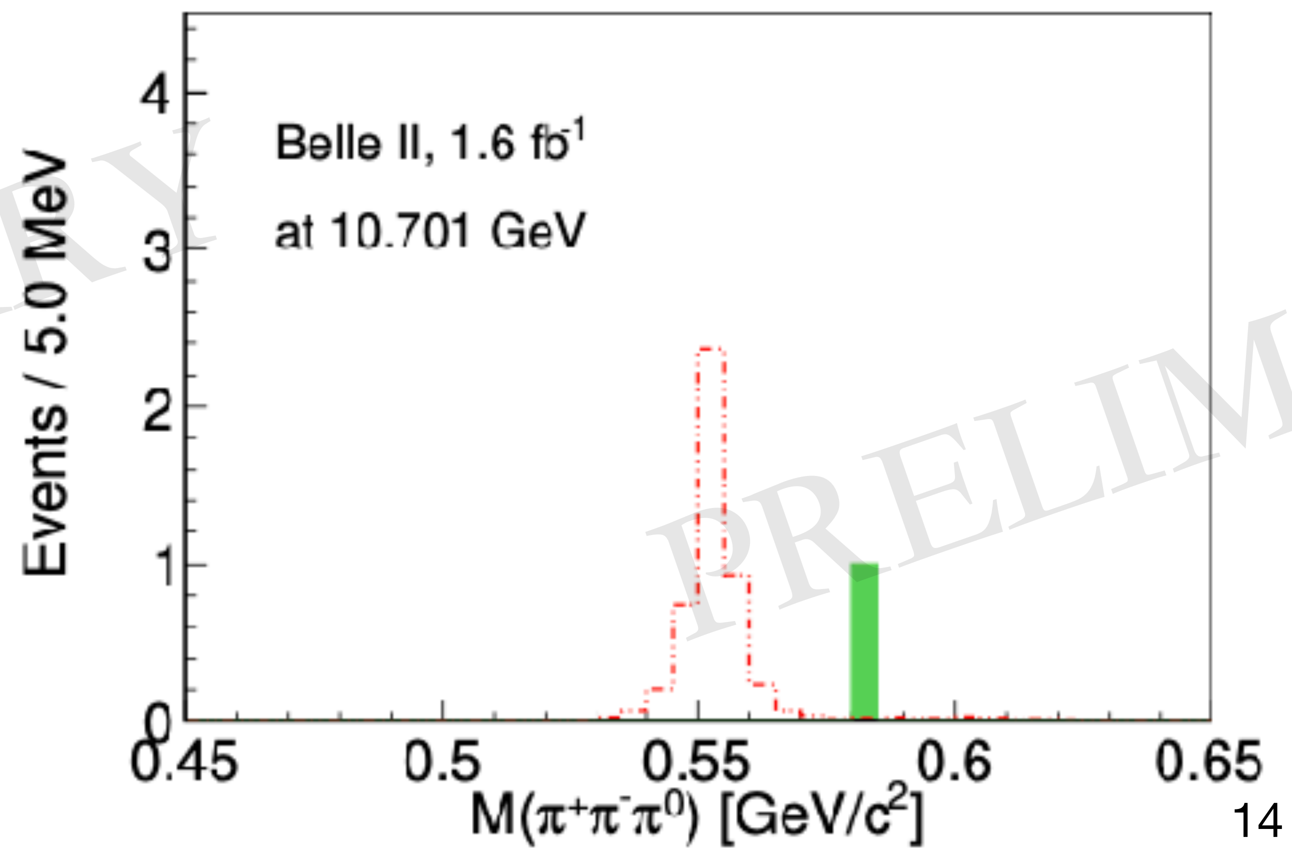


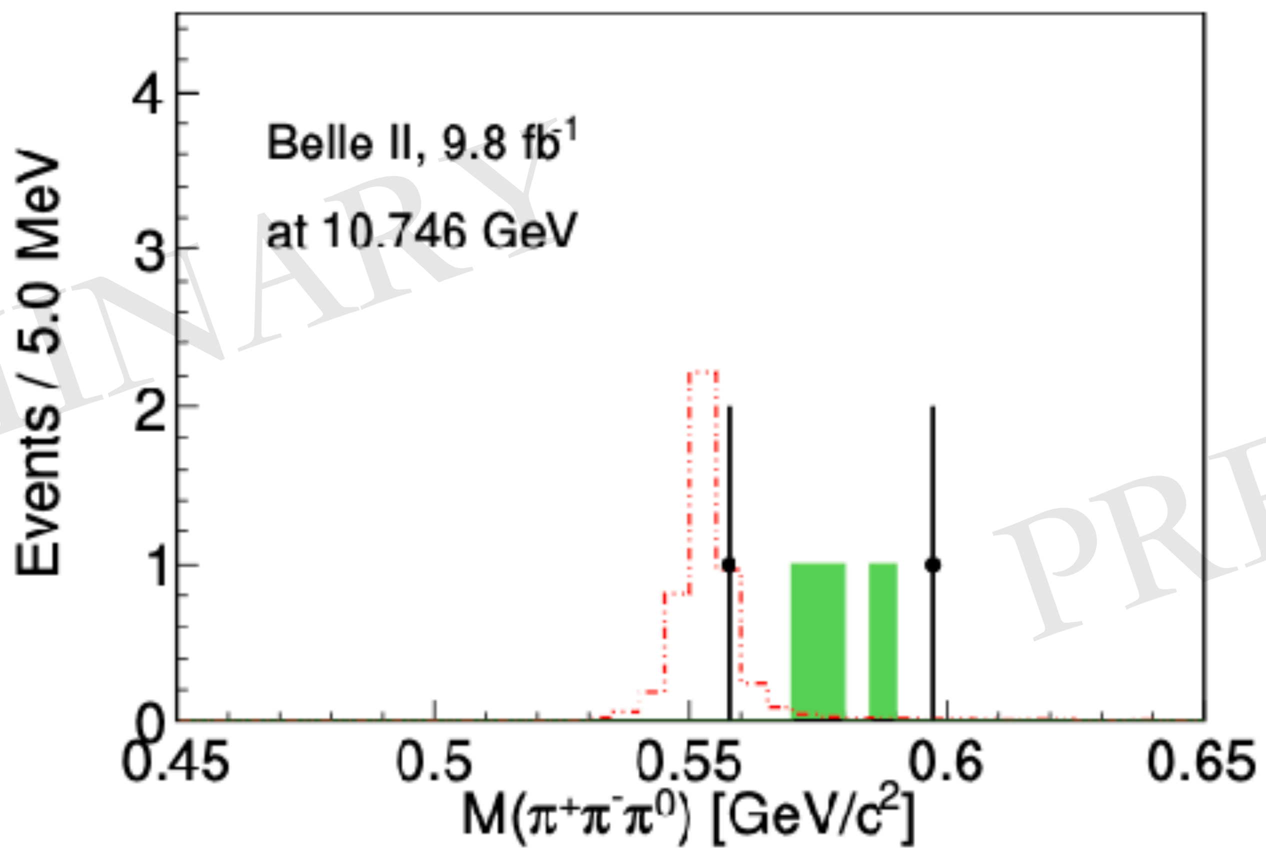
$e^+e^- \to \eta\Upsilon(1S)$

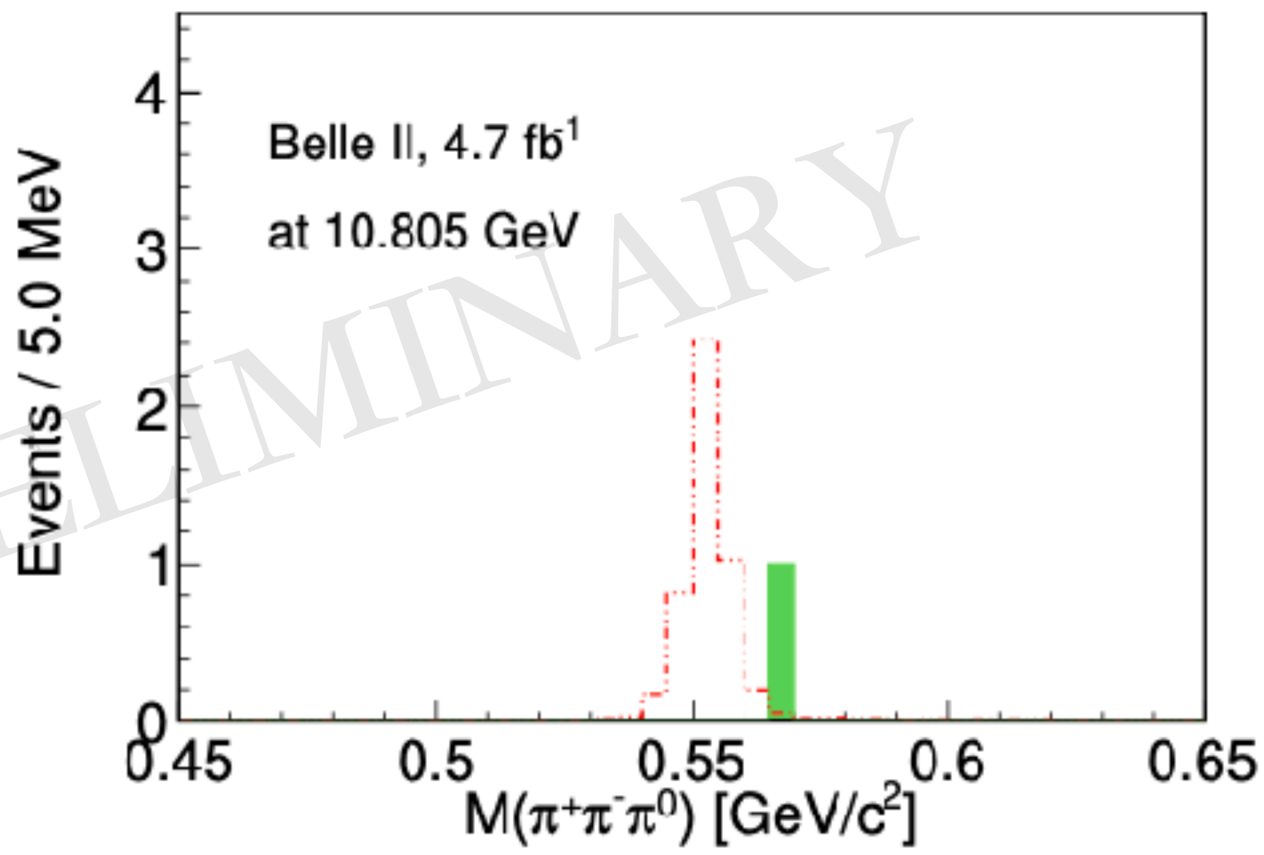
- An extended unbined maximum likelihood 1-D fit:
  - Signal: PDF obtained from MC simulation
  - Background: Chebychev polynomial
- No evident signal











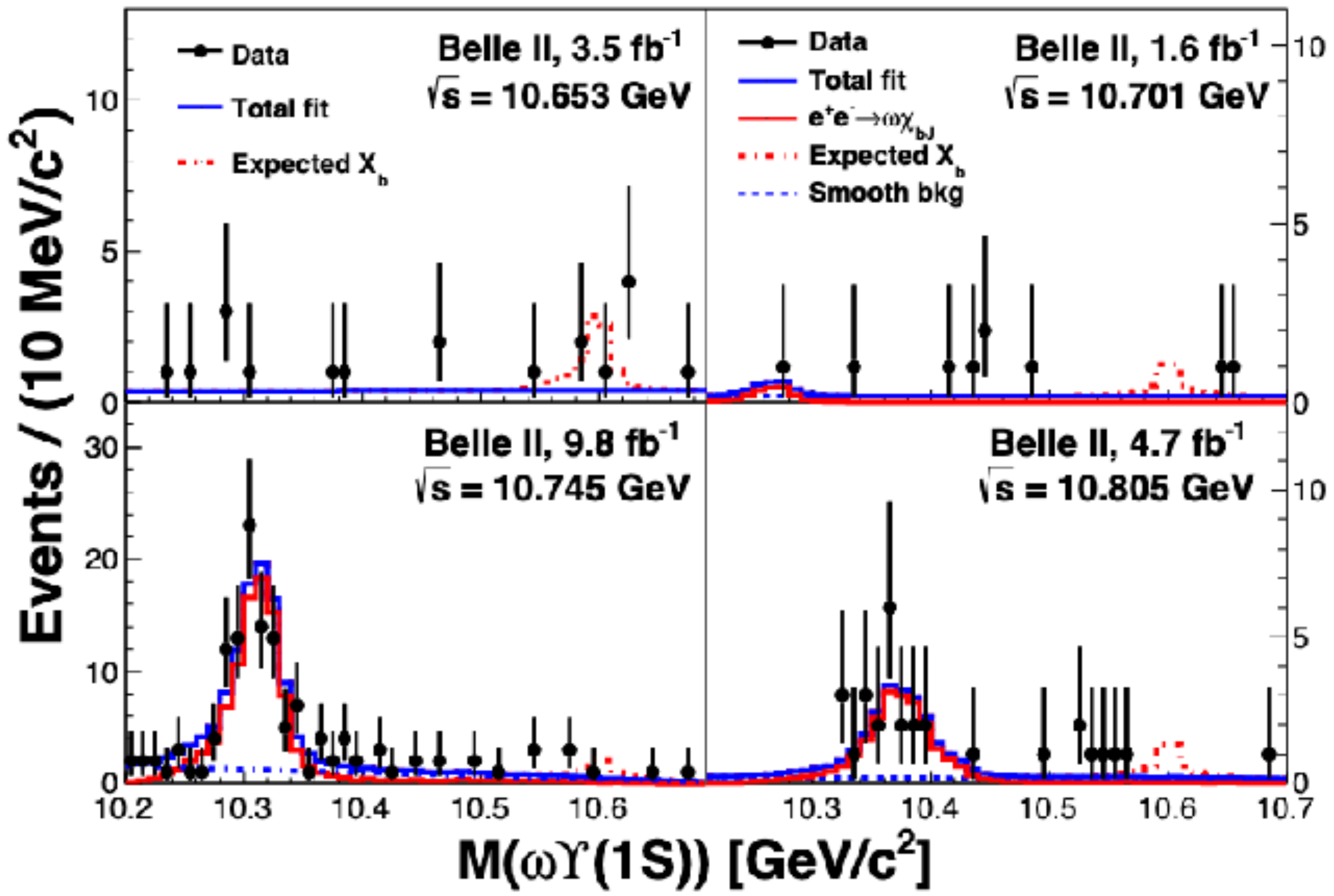
- Count #signal with $N_{\text{signal}} = N_{\text{SR}} - N_{\text{SB}}$
    - Upper limits estimated with Feldman-Cousin method
- Estimate the efficiency in the assumption of $\sigma \propto 1/s$
- Born cross sections and their upper limits:

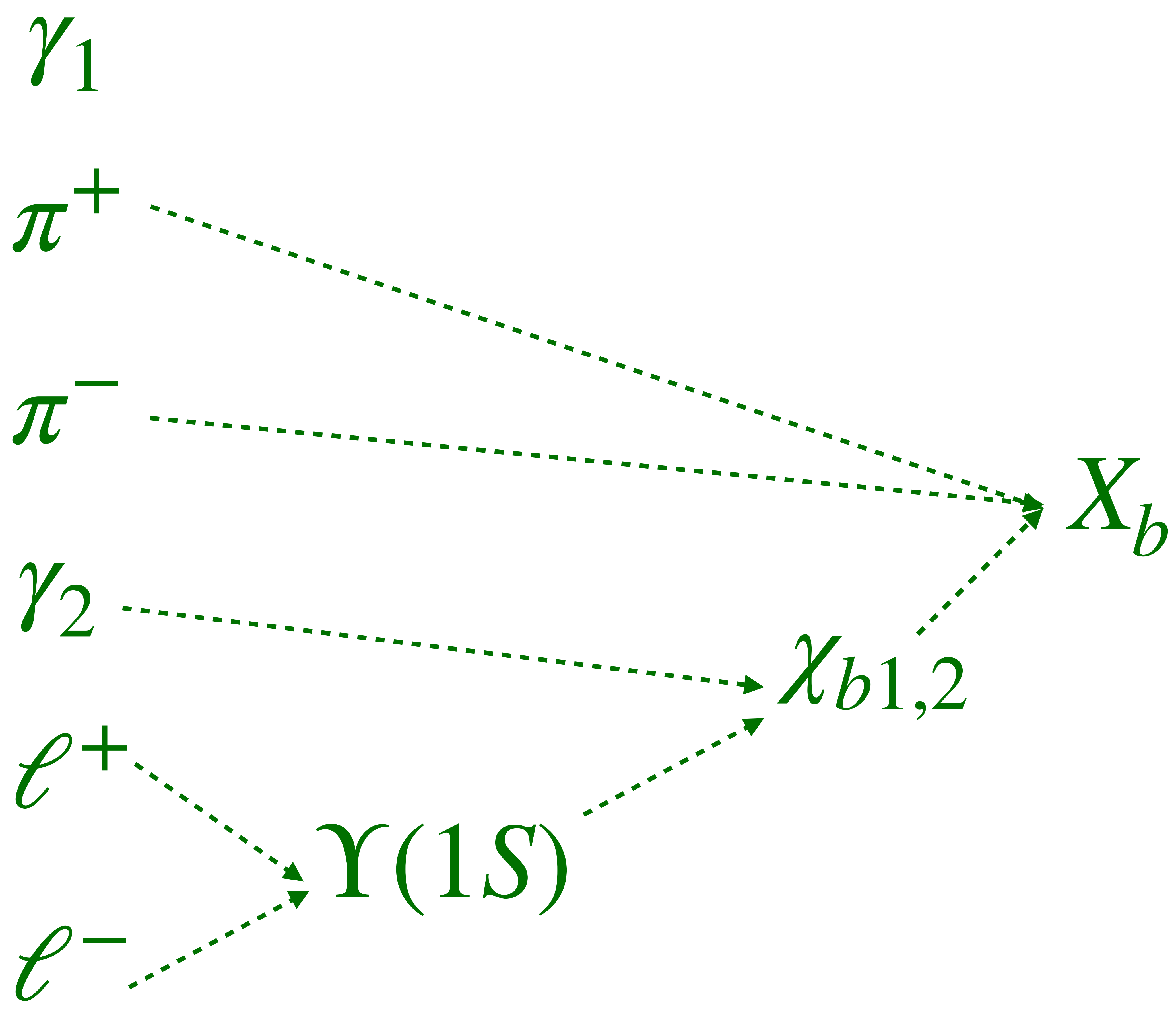
E	N_{SR}	N_{SB}	N_{signal}	ϵ	$(1+\delta)$	$\|1-\Pi\|^2$	σ_B (pb)
10.653	$0.0^{+1.0}_{-0.0}$	$0.0^{+1.0}_{-0.0}$	$0.0^{+1.0}_{-0.0}$ (< 2.0)	$(23.9 \pm 0.4)\%$	0.895	0.929	$0.00^{+0.10}_{-0.00}$ (< 0.26)
10.701	$0.0^{+1.0}_{-0.0}$	$0.0^{+1.0}_{-0.0}$	$0.0^{+1.0}_{-0.0}$ (< 2.0)	$(24.0 \pm 0.5)\%$	0.901	0.928	$0.00^{+0.22}_{-0.00}$ (< 0.56)
10.745	$1.0^{+1.4}_{-0.7}$	$0.0^{+1.0}_{-0.0}$	$1.0^{+1.4}_{-0.7}$ (< 3.6)	$(23.8 \pm 0.2)\%$	0.906	0.930	$0.04^{+0.05}_{-0.03}$ (< 0.18)
10.805	$0.0^{+1.0}_{-0.0}$	$0.0^{+1.0}_{-0.0}$	$0.0^{+1.0}_{-0.0}$ (< 2.0)	$(24.6 \pm 0.3)\%$	0.912	0.931	$0.00^{+0.08}_{-0.00}$ (< 0.18)

Search for $e^+e^- \to X_b\gamma$

In [EPJC 74, 3063(2014)], X_b was predicted to decay to

- $\gamma\Upsilon(1S)$, too difficult
- $\omega\Upsilon(1S)$, searched in [PRL 130, 091902 (2023)]
- $\pi^+\pi^-\chi_{bJ}$

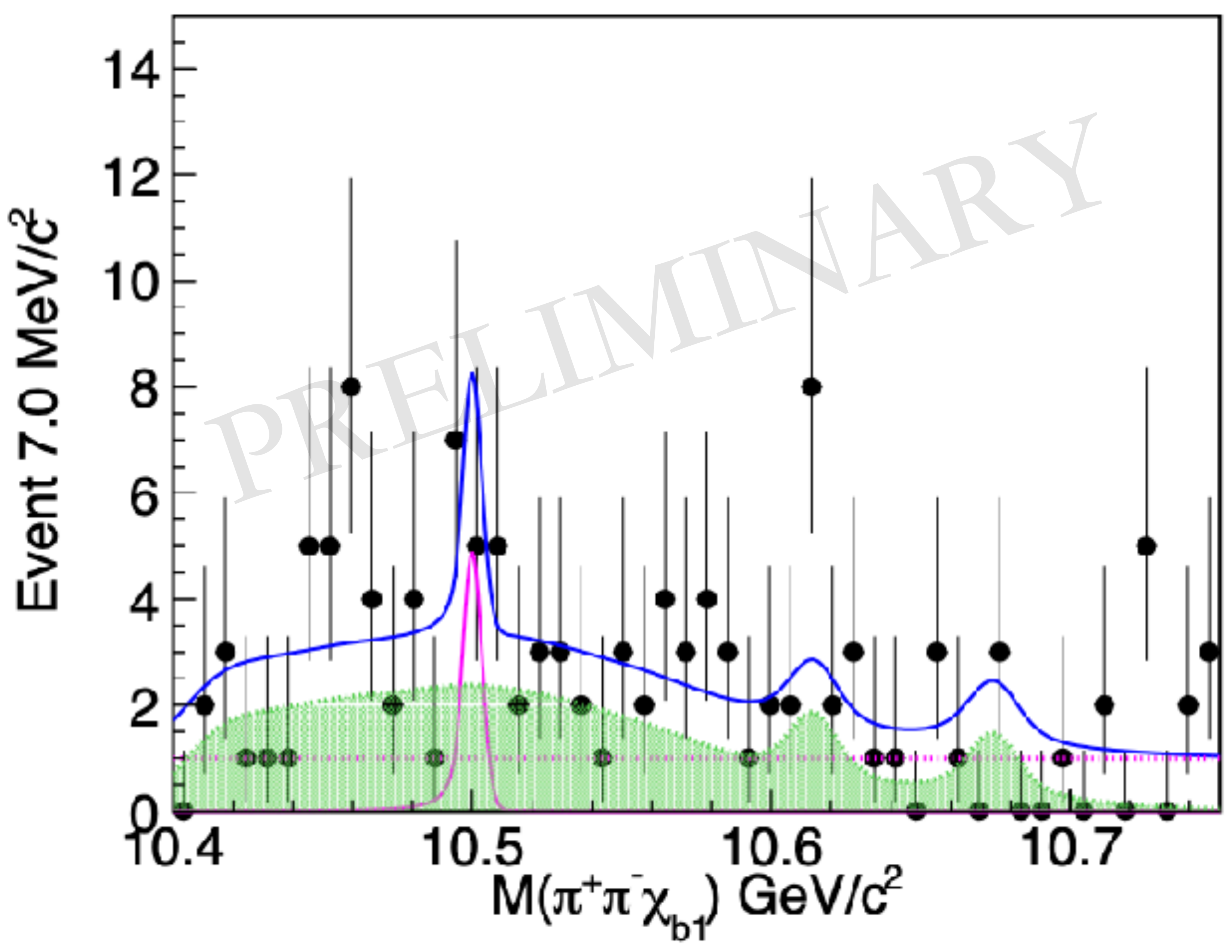


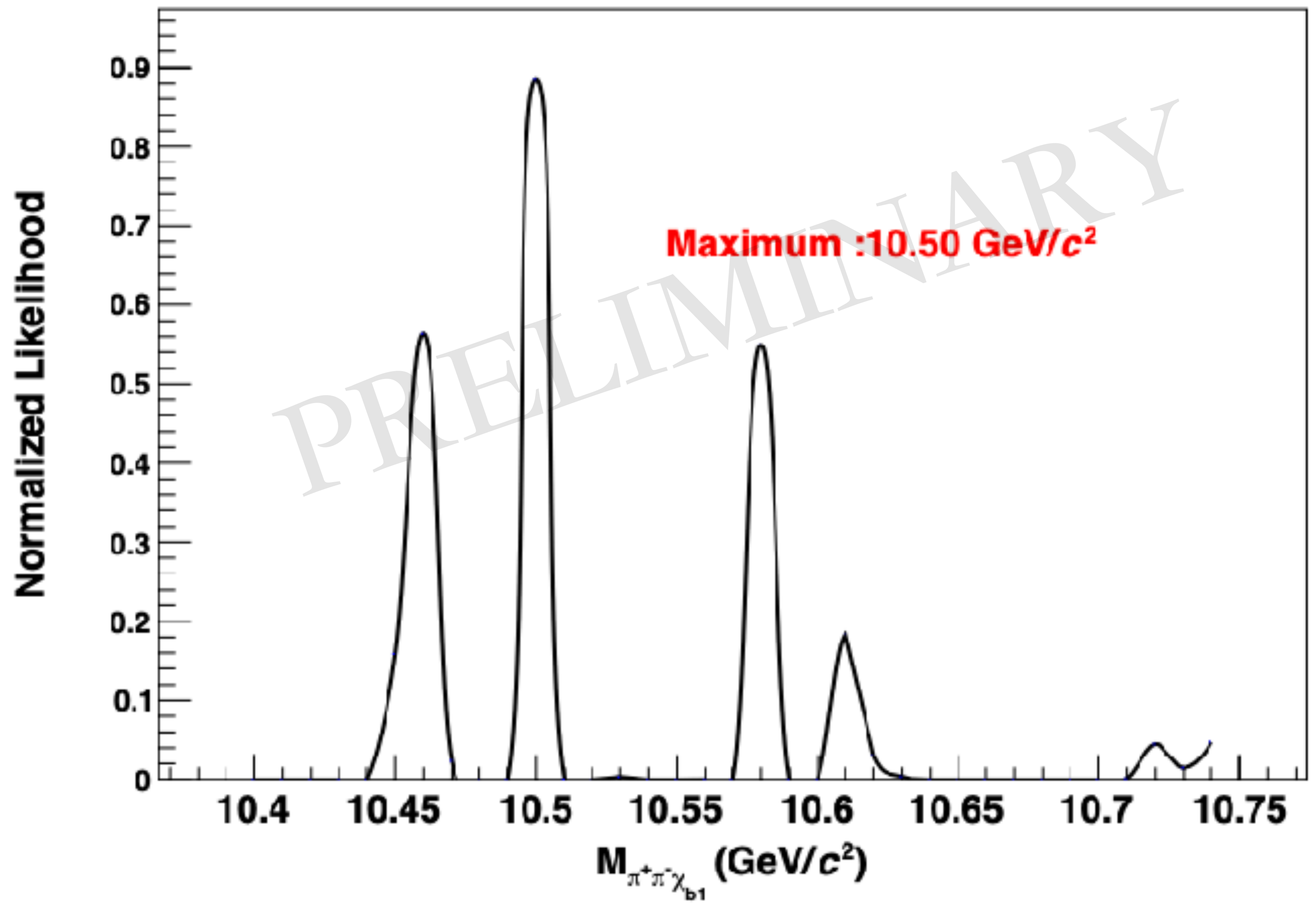


No evident signal with $X_b \to \omega\Upsilon(1S)$

Fit with four components:

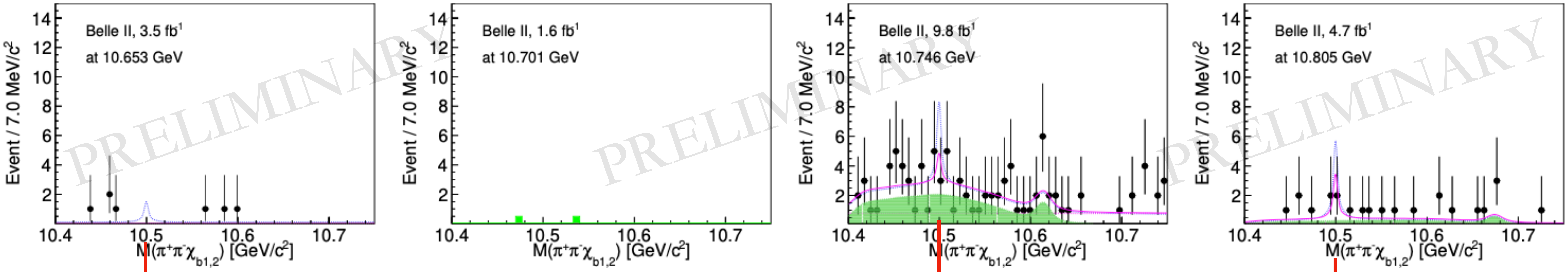
1. signal
2. normal background
3. fixed $\pi\pi\Upsilon(2S)$
4. fixed $\omega\chi_{bJ}$





No X_b signal is found.

Scan $m(X_b)$ to find where X_b most likely placed, which is $m(X_b) = 10.50\ \mathrm{GeV/c^2}$



90% C.L.

Summary

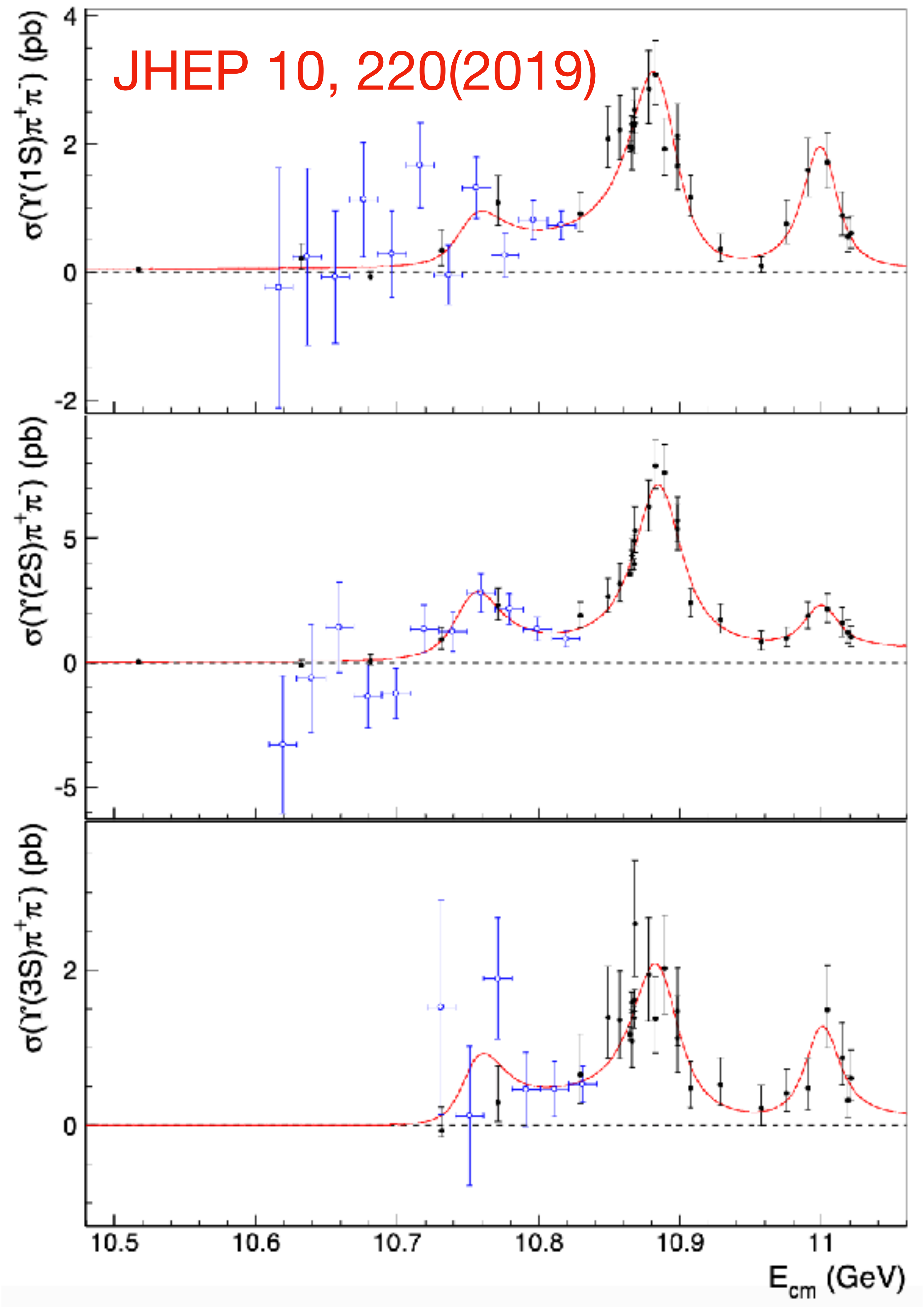
- With 20/fb $\Upsilon(10753)$ data collected with Belle II detector, we observe clear $e^+e^- \to \eta\Upsilon(2S)$ signal.
  - Not likely from $\Upsilon(10753)$
  - Higher cross section at 10.653 GeV
  - An extra resonance near $B^*\bar{B}^*$ threshold is favored by ~3.8σ, but with parameters fixed
- No signal of $e^+e^- \to \eta\Upsilon(1S)$ nor $e^+e^- \to \gamma X_b[\pi\pi\chi_{bJ}]$
  - Upper limits estimated.

Mode	$N_{\rm prod}$ ($\times 10^3$)	$(1+\delta)$	$\epsilon(\%)$	$\sigma_{\rm B}^{\rm (UL)}$ (pb)
(10653.30 ± 1.14) MeV				
$\eta\Upsilon(2S)$	$(3.7^{+1.6}_{-1.3}), 4.3\sigma$	0.881	19.2/15.1	$1.11^{+0.49}_{-0.39} \pm 0.36$
$\eta\Upsilon(1S)$	< 0.4	0.895	23.9	< 0.10
γX_b	< 0.3	0.784	32.0	< 0.14
(10700.90 ± 0.63) MeV				
$\eta\Upsilon(2S)$	$(0.0^{+1.0}_{-0.0})$	1.832	12.9/7.0	$0.00^{+0.31}_{-0.00} \pm 0.53$
$\eta\Upsilon(1S)$	< 0.4	0.901	24.0	< 0.22
γX_b	< 0.1	0.803	31.3	< 0.09
(10746.30 ± 0.48) MeV				
$\eta\Upsilon(2S)$	$(3.3^{+1.6}_{-1.2}), 4.2\sigma$	0.687	17.1/14.0	$0.45^{+0.22}_{-0.17} \pm 0.05$
$\eta\Upsilon(1S)$	< 0.9	0.906	23.8	< 0.09
γX_b	< 1.4	0.817	29.8	< 0.17
(10804.50 ± 0.70) MeV				
$\eta\Upsilon(2S)$	$(1.5^{+1.4}_{-0.9}), 2.8\sigma$	0.848	16.6/14.7	$0.36^{+0.32}_{-0.21} \pm 0.04$
$\eta\Upsilon(1S)$	< 0.4	0.912	24.6	< 0.08
γX_b	< 1.3	0.833	28.2	< 0.32

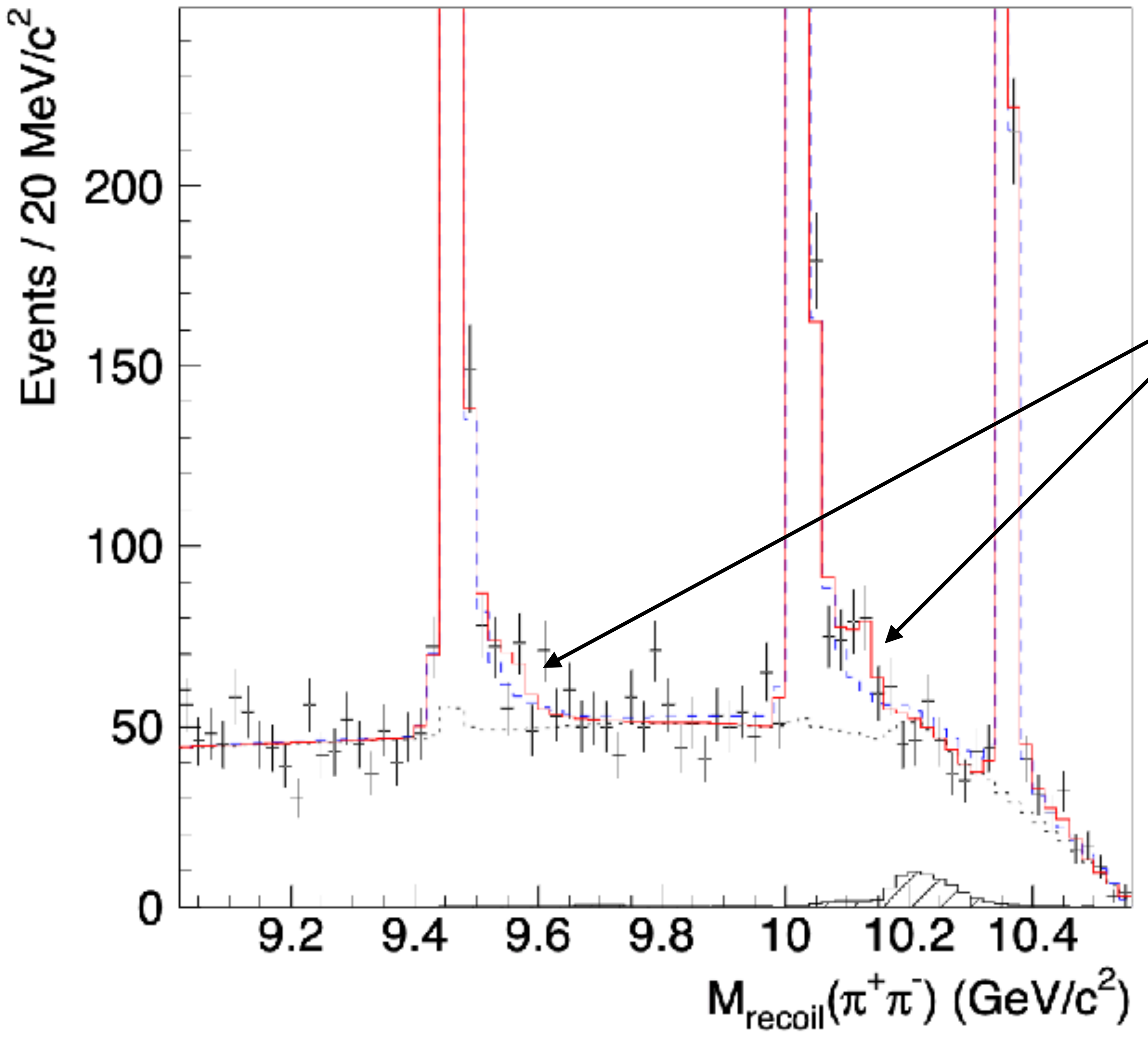
Thanks!

backup

$\Upsilon(10753)$ — discovery and studies



- The $\Upsilon(10753)$ was firstly observed in the process of $e^+e^- \to \Upsilon(nS)\pi^+\pi^-(n = 1,2,3)$ by Belle.
- Simultaneous fit to cross sections and $M_{\text{recoil}}(\pi\pi)$



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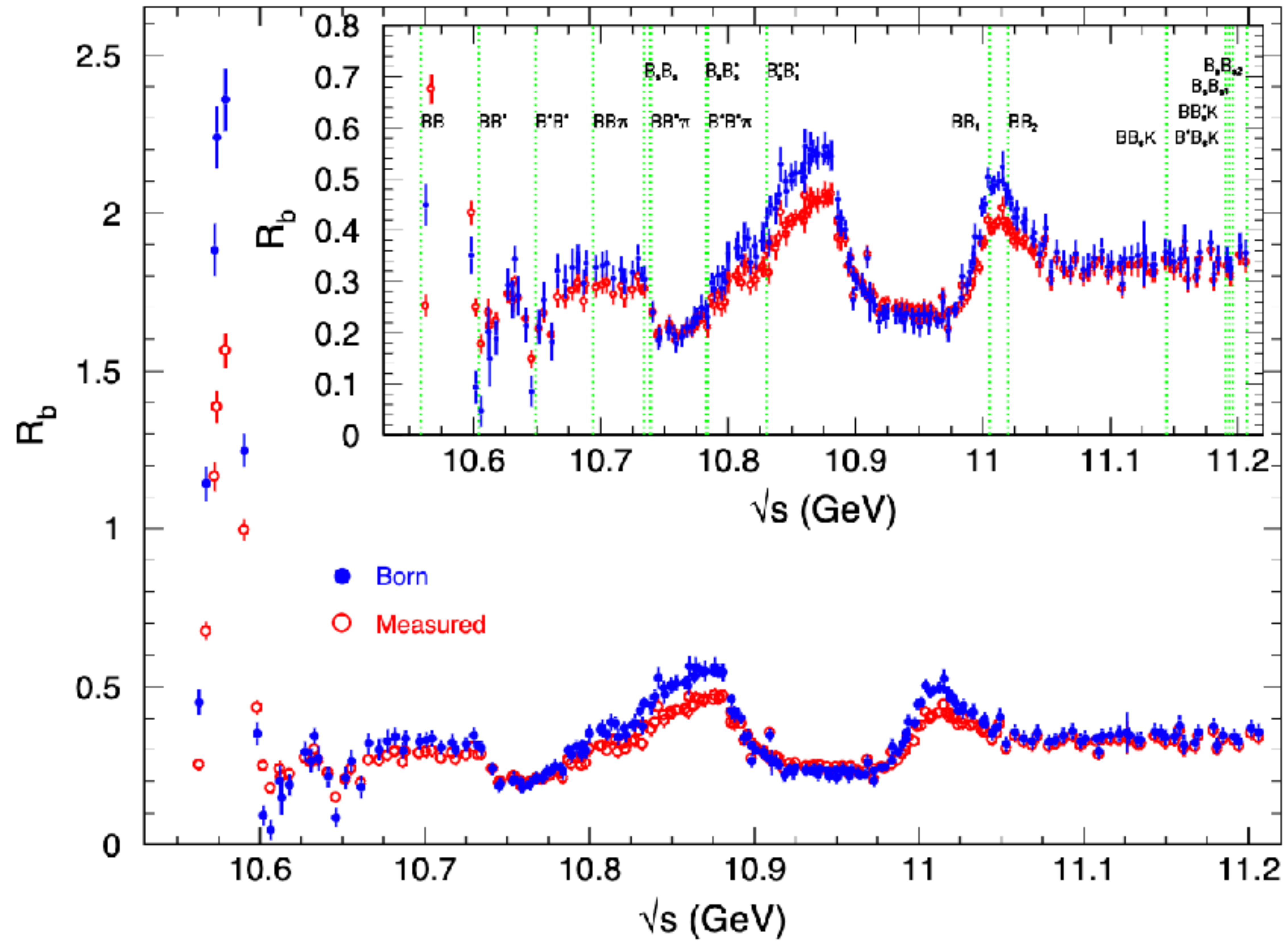
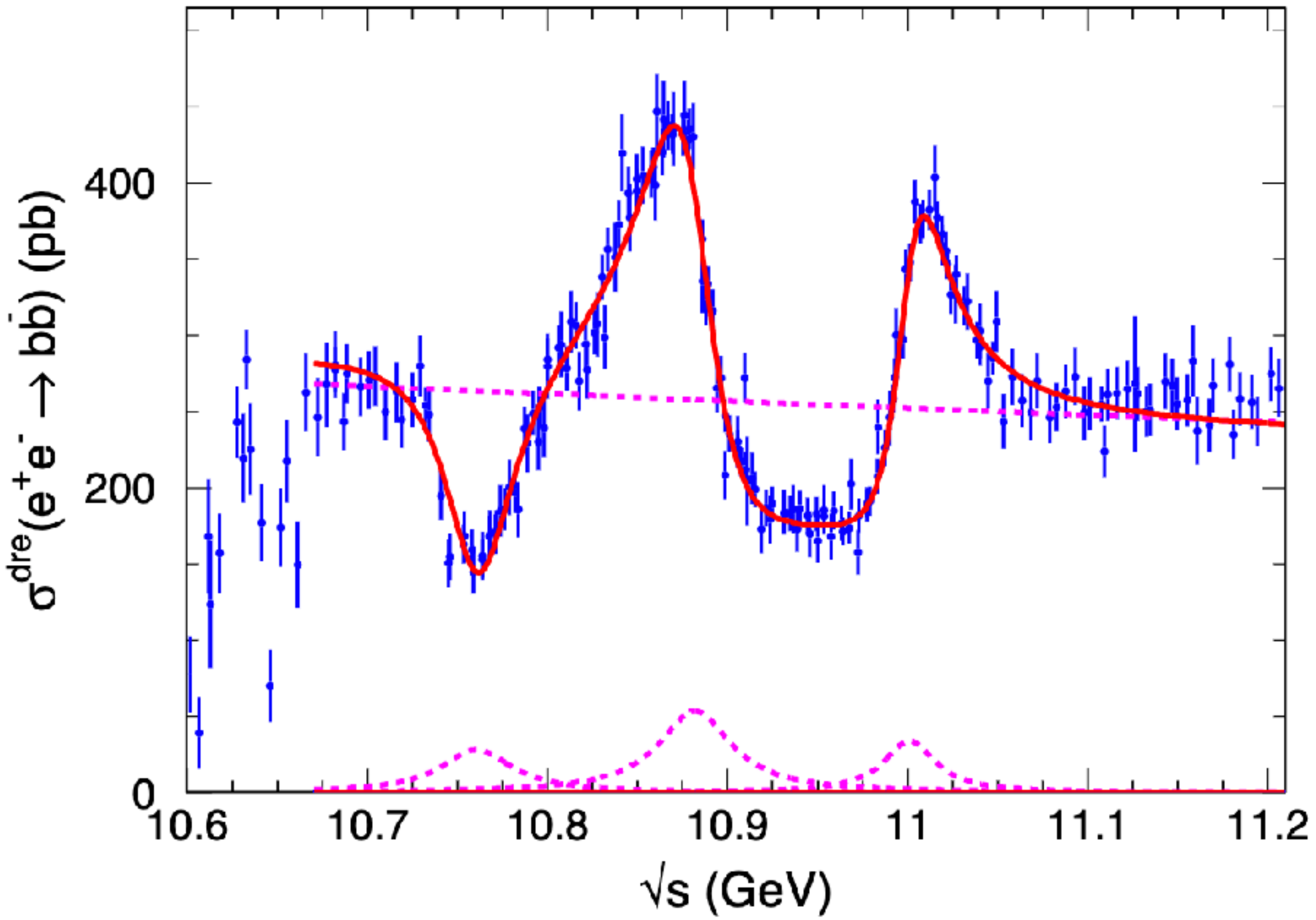




$M = (10761 \pm 2)\ \mathrm{MeV}/c^2$

$\Gamma = (48.5 \pm 3.0)\ \mathrm{MeV}$

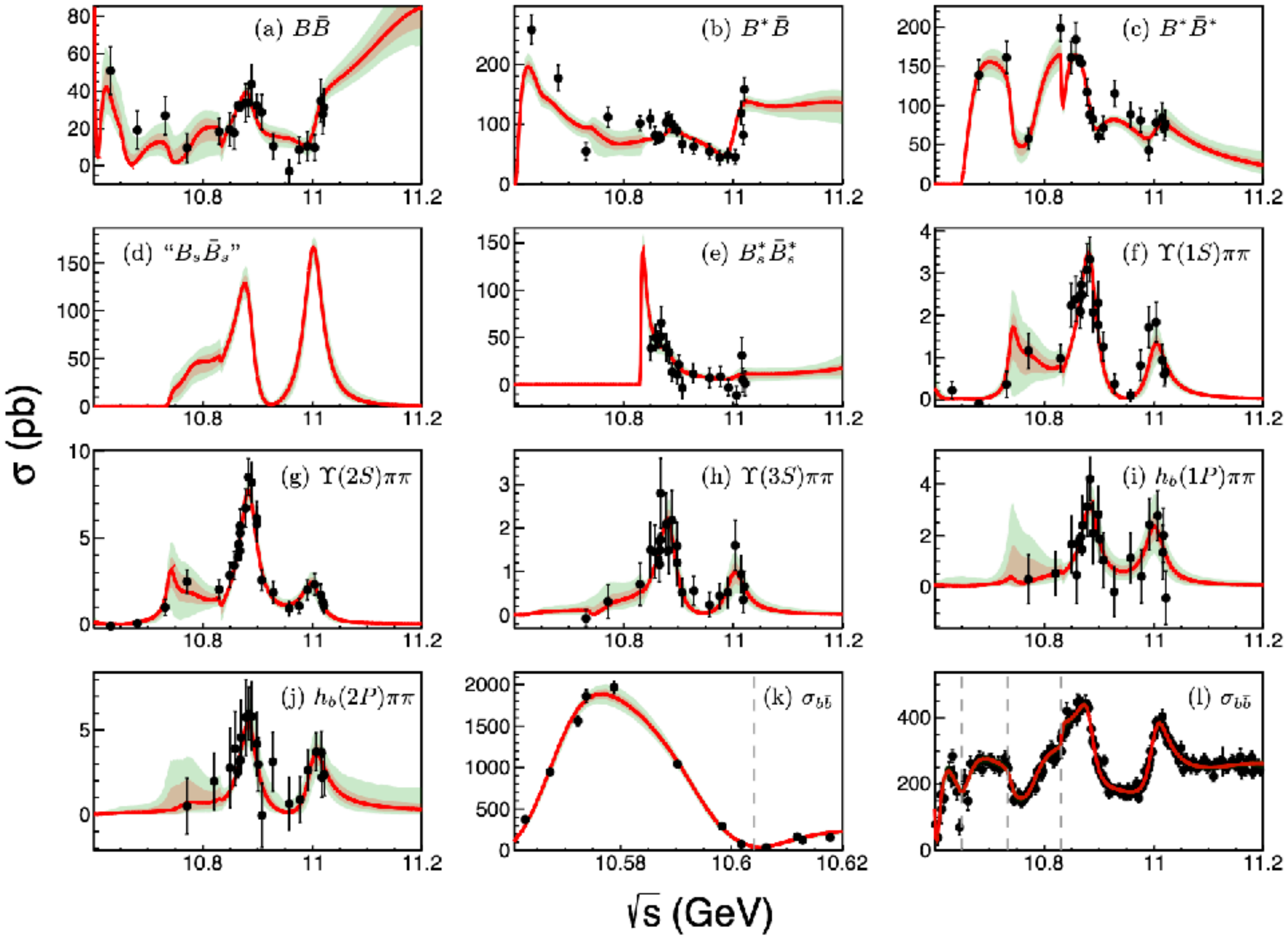
- A dip in the R_b distribution near $10.75\ \mathrm{GeV}$
- Fit to dressed cross section of $b\bar{b}$ with three BWs.

“The results from these fits may change dramatically by including more information on each exclusive mode. ”

K-matrix Analysis of e^+e^- Annihilation in the Bottomonium Region

N. Hüsken,[1,2] R.E. Mitchell,[1] and E.S. Swanson[3]

Phys.Rev.D 106 (2022) 9, 094013



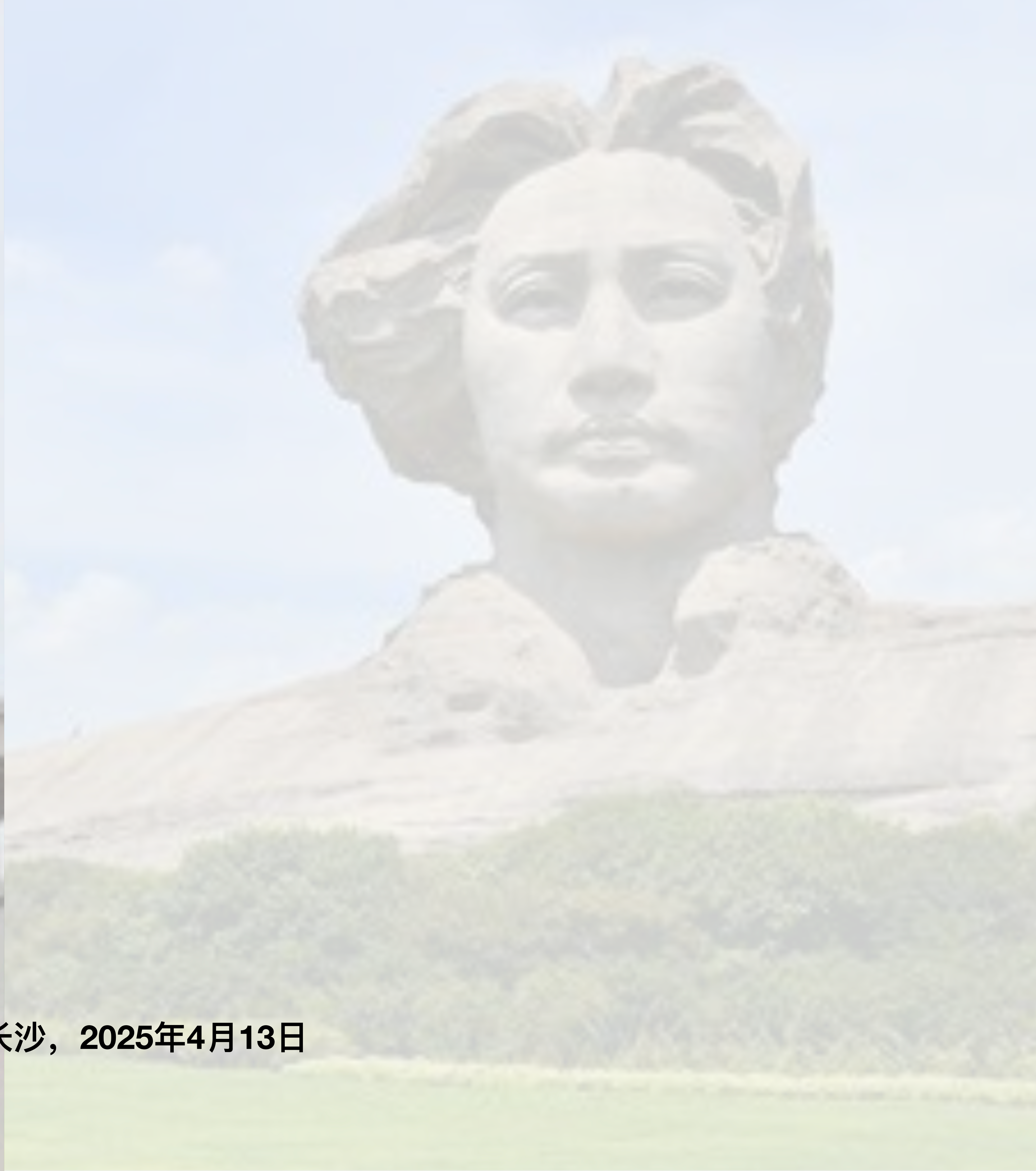
Strong evidence for $\Upsilon(10753)$ with significance $>10\sigma$

Pole locations varies with models.

state	RPP	our estimate	GM	ARM	NR	bbg	SOEF	LGT
1^3S_1	9460		9465	9444	9454	9445	9502	9419.1(4)
2^3S_1	10023		10003	10029	10010	10002	10015	9981(4)
3^3S_1	10355		10354	10374	10344	10339	10349	10384(12)
4^3S_1	10579	(10590 - 10610)	10635	10641	10614	10610	10607	
5^3S_1	10885	(10878 - 10884)	10878	10865	10849	10848	10818	
6^3S_1	11000	(11000 - 11008)	11102	11065	11064	11064	10995	
1^3D_1			10138	10156	10146	10148	10117	10191(9)
2^3D_1			10441	10453	10432	10435	10414	10718(33)
3^3D_1			10698	10697	10679	10684	10653	
$\Upsilon(10750)$	10753	(10630 - 10780)						
hybrid						11093		10952(33)

TABLE IV. Experimental and Theoretical Vector Bottomonium Masses (MeV).

Coupled channel analysis of high energy scan data using the K-matrix formalism shows four poles: $\Upsilon(4S)$, $\Upsilon(10753)$, $\Upsilon(5S)$, $\Upsilon(6S)$.

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