Search for Light Higgs and Dark Photons at BaBar and Belle

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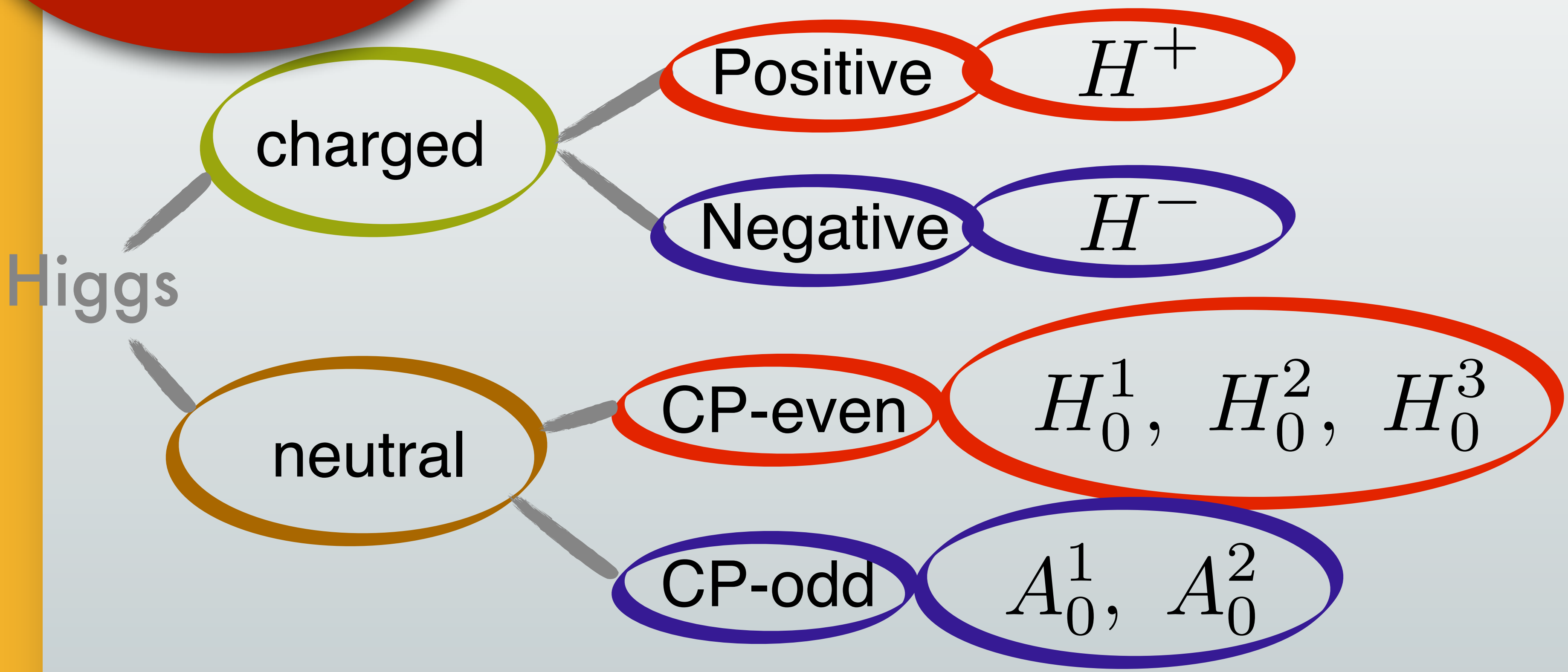
Fu Jen Catholic University
2013/July/19 @EPSHEP2013

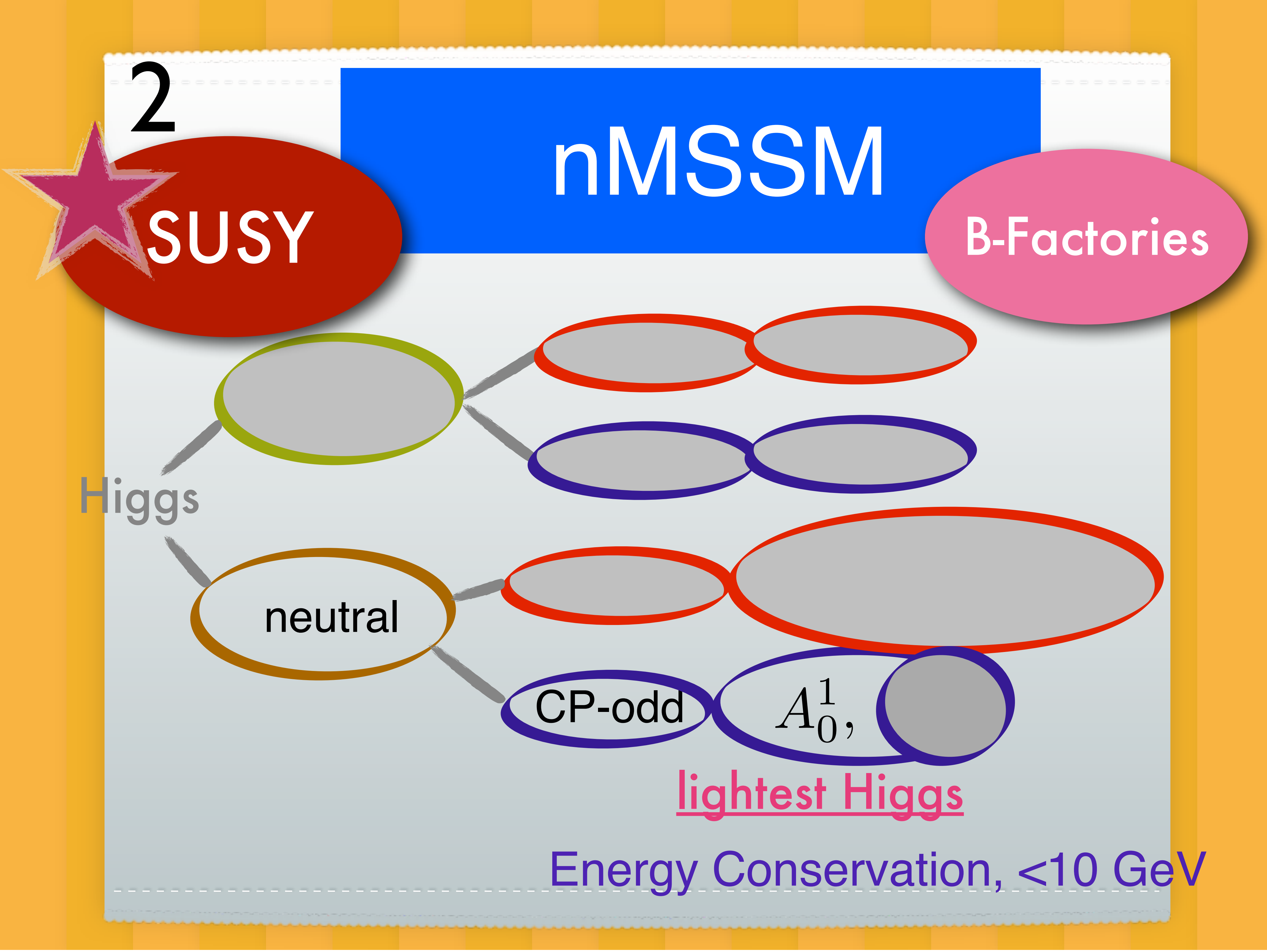
Light Higgs

SUSY

nMSSM

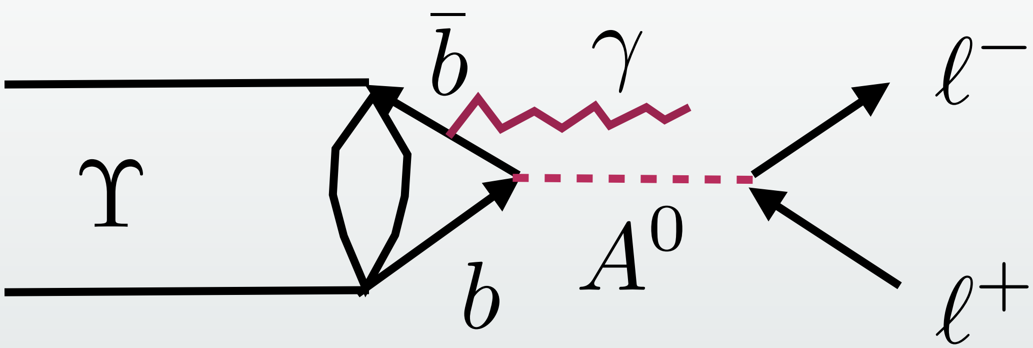


Next-to-Minimal Supersymmetric Standard Model (nMSSM)



2
nMSSM
SUSY
B-Factories
Higgs
neutral
CP-odd
$A_0^1,$
lightest Higgs
Energy Conservation, <10 GeV

3 neutral CP-odd light Higgs



Higgs-Mediated Annihilation

proposed by Dermisek, Gunion, & McElrath in 2007

Phys.Rev.D76:051105, 2007

$Br \sim 10^{-4}$

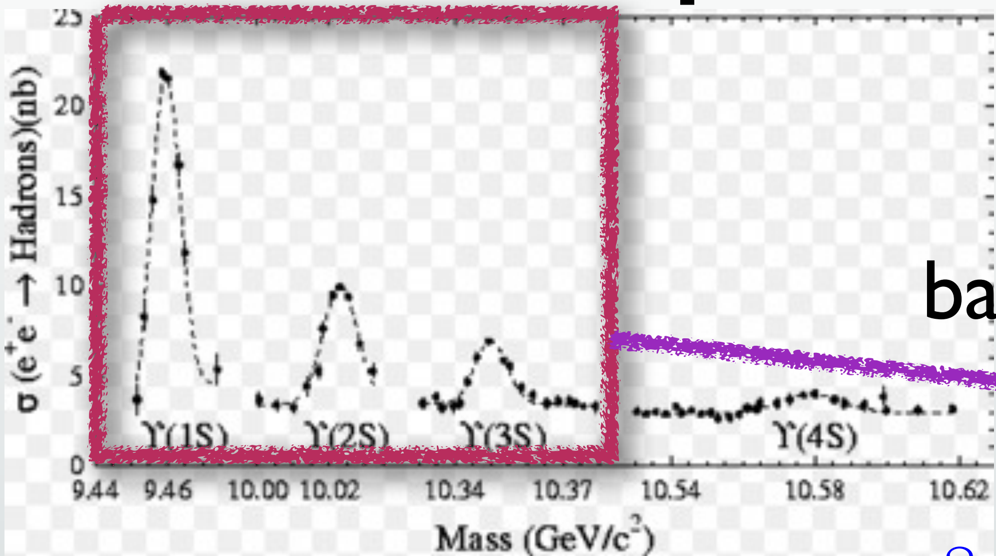
Directly $e^+e^- \to \Upsilon(ns) \to \gamma A^0 \quad (n = 1, 2, 3)$

in cascades $e^+e^- \to \Upsilon(ns) \to \Upsilon(1s)\pi^+\pi^- \quad (n = 2, 3)$

with $\Upsilon(1s) \to \gamma A^0$

B-Factories

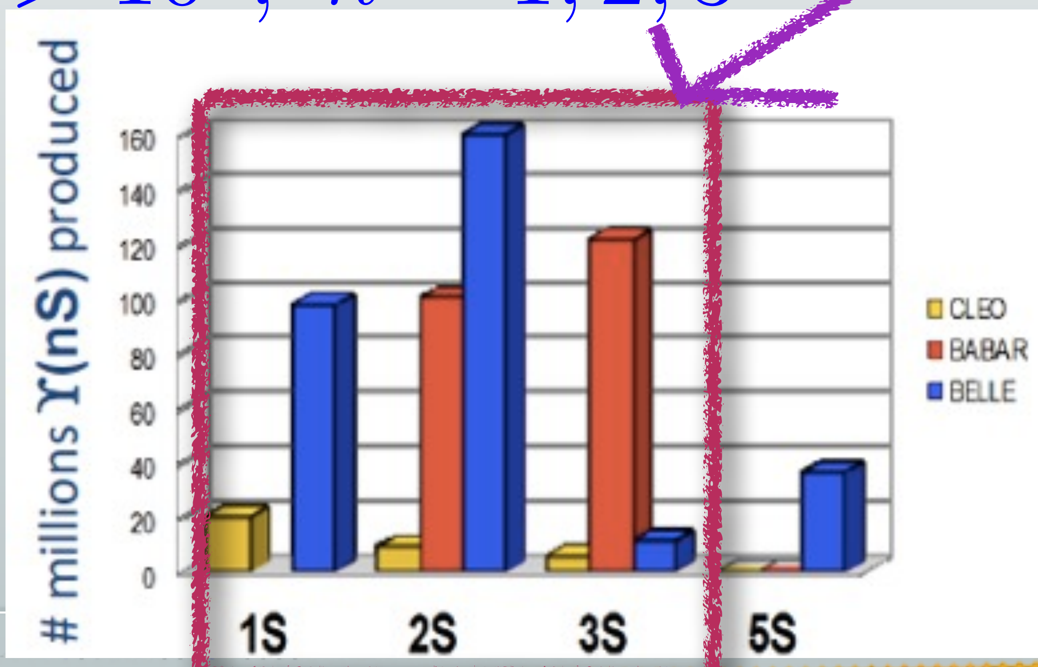
4 Samples at B factories



No $B\bar{B}$ decays.
Cleaner samples for background-limited study.

$m_{A^0} < 2m_b$

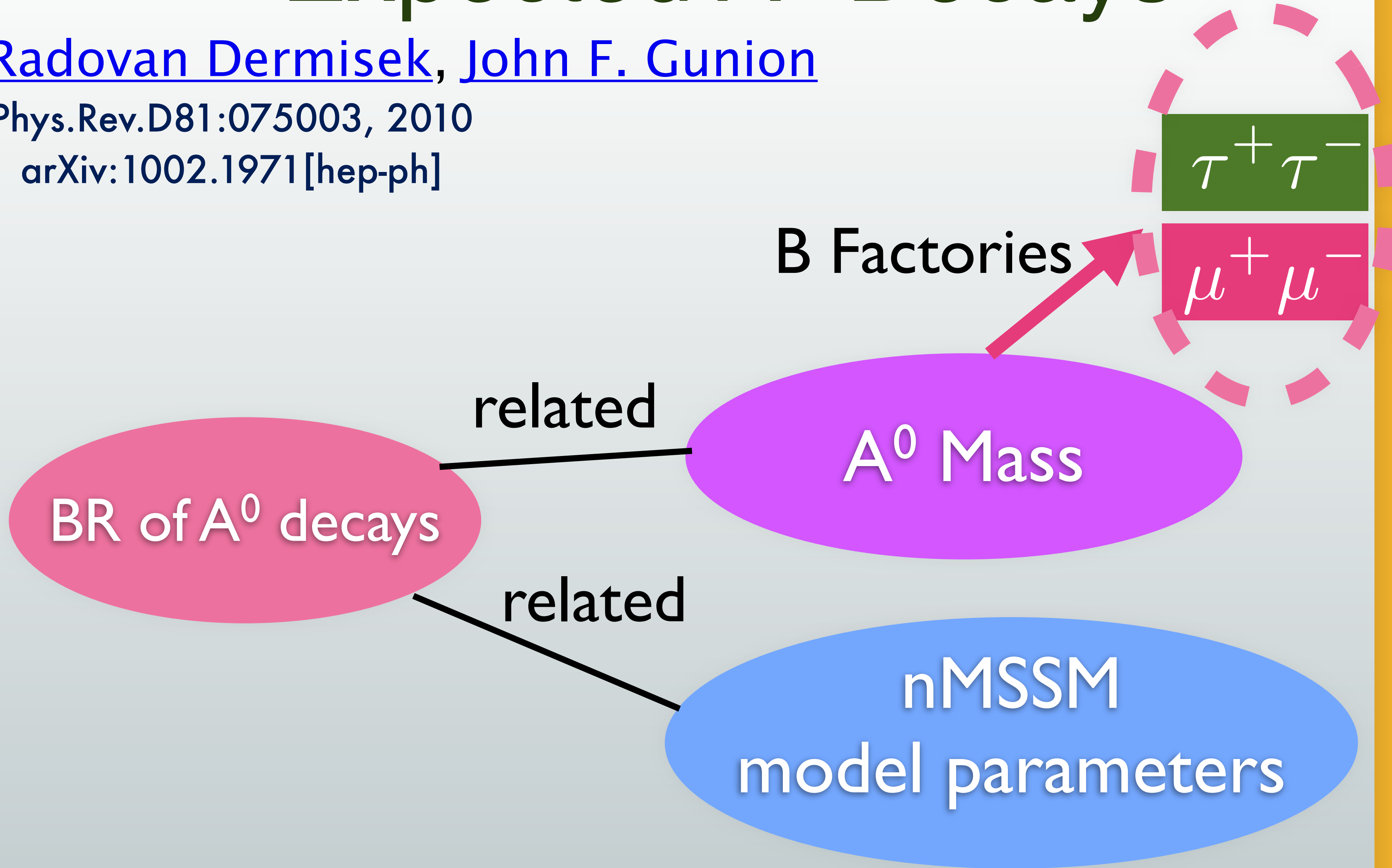
$\Upsilon(nS)\ samples > 10^8,\ n = 1, 2, 3$



5. Expected A^0 Decays

Radovan Dermisek, John F. Gunion

Phys.Rev.D81:075003, 2010
arXiv:1002.1971[hep-ph]

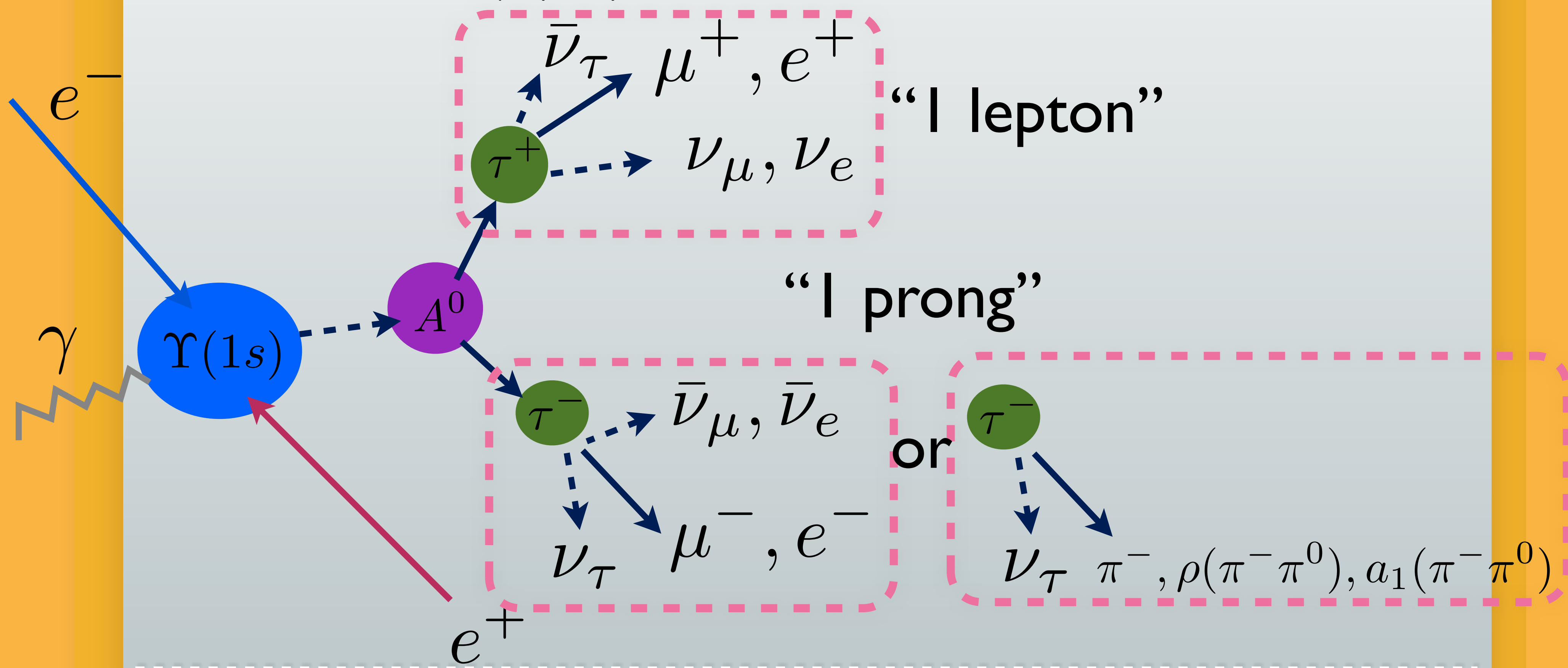


6.1 directly setup $\tau^+\tau^-$

BELLE

$$e^+e^- \to \Upsilon(1s) \to \gamma A^0$$

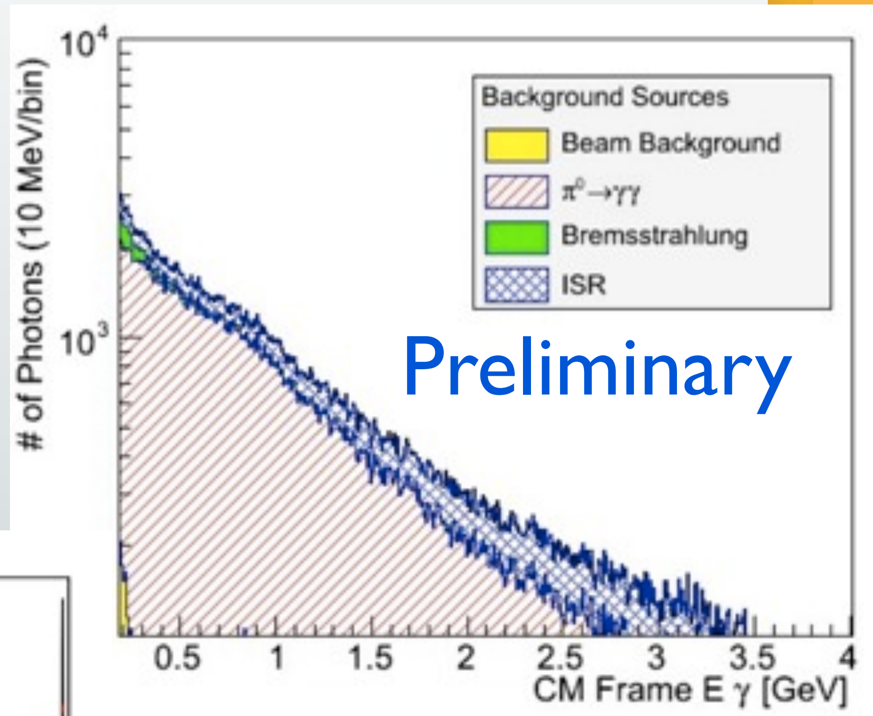
with $A^0 \to \tau^+\tau^-$



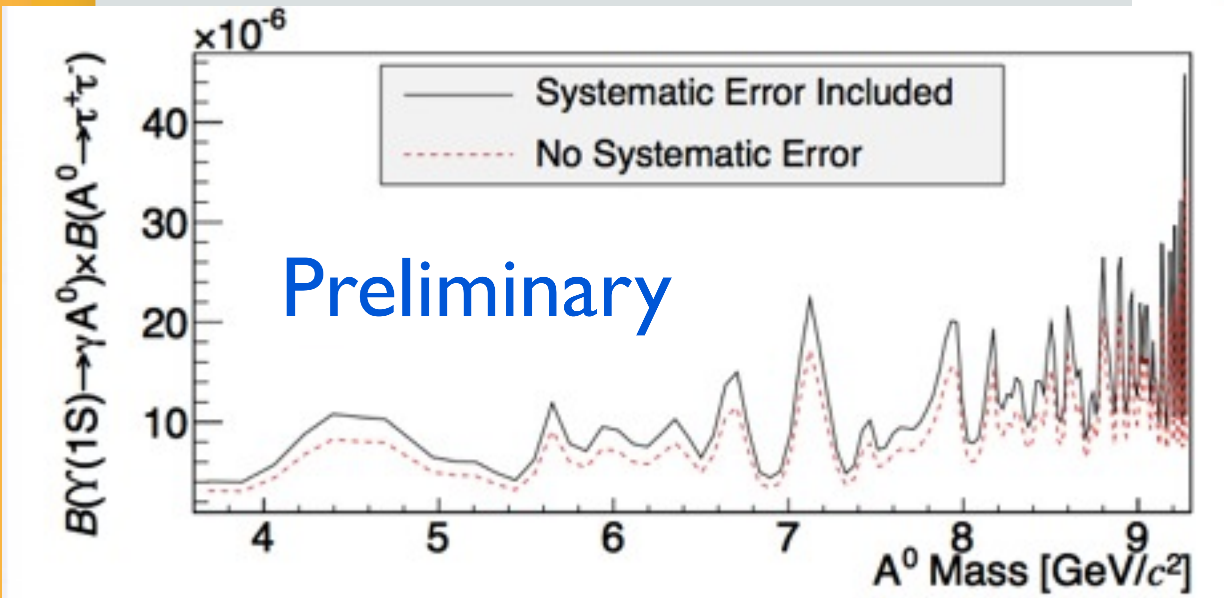
6.1 directly results $\tau^+\tau^-$

$$e^+e^- \to \Upsilon(1s) \to \gamma A^0$$

with $A^0 \to \tau^+\tau^-$



Set Upper Limits on BR



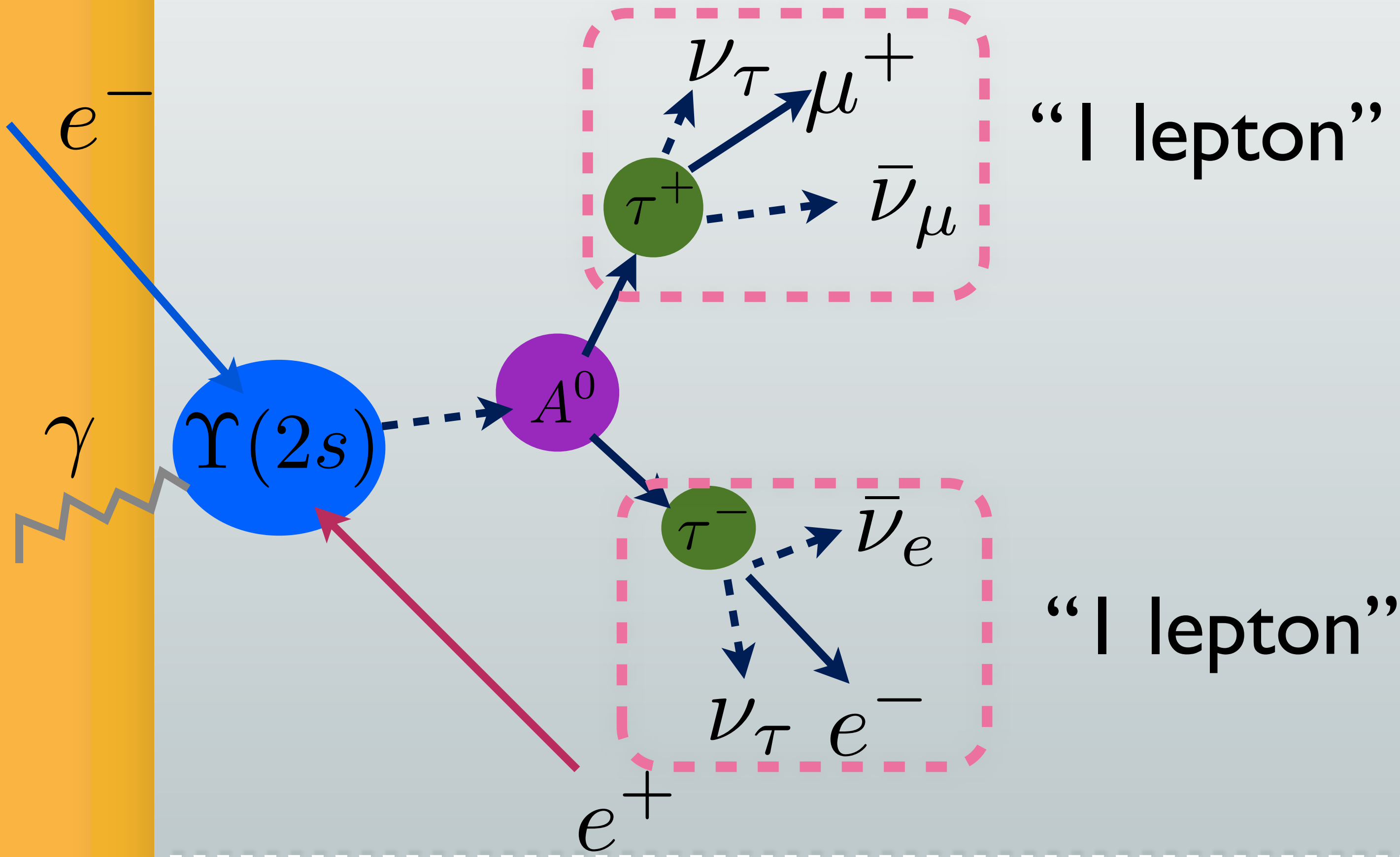
BF 90%CL UL= 4.0×10^{-6} to 4.5×10^{-5}

$$3.6 \leq m_{A^0} \leq 9.3\ GeV$$

6.2 directly setup $\tau^+\tau^-$

$$e^+e^- \rightarrow \Upsilon(2s) \rightarrow \gamma A^0$$

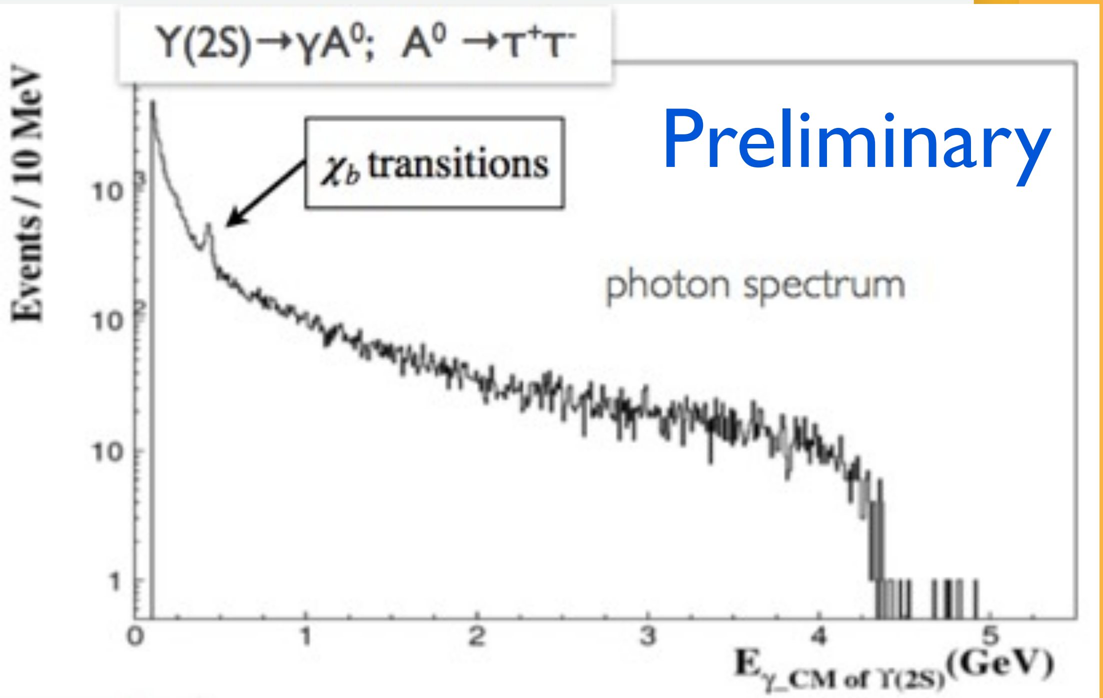
with $A^0 \rightarrow \tau^+\tau^-$



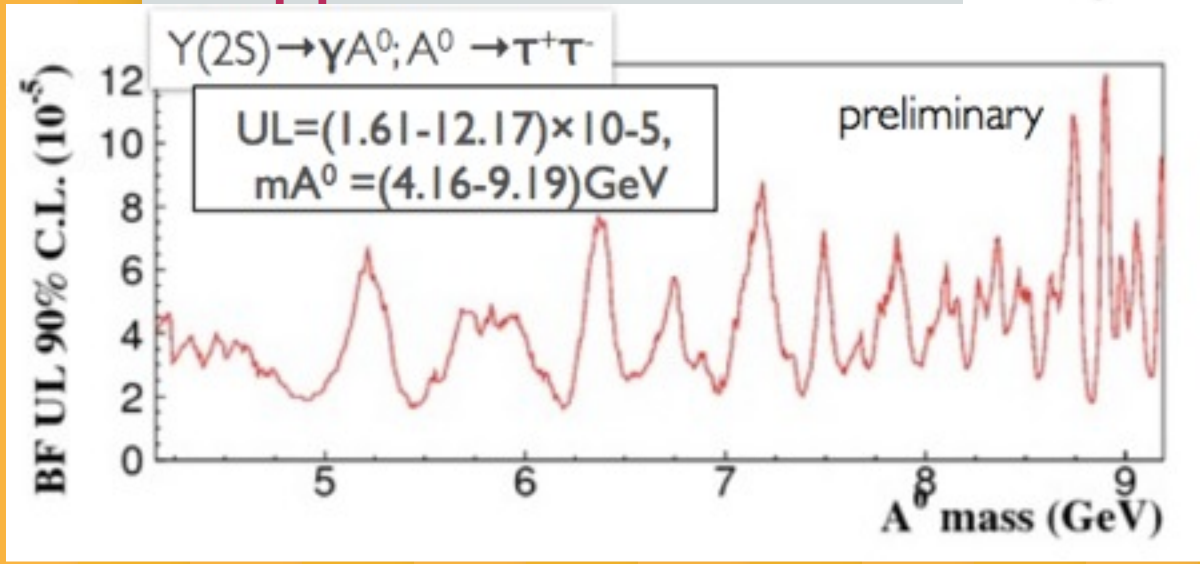
6.2 directly results $\tau^+\tau^-$

$$e^+e^- \rightarrow \Upsilon(2s) \rightarrow \gamma A^0$$

with $A^0 \rightarrow \tau^+\tau^-$



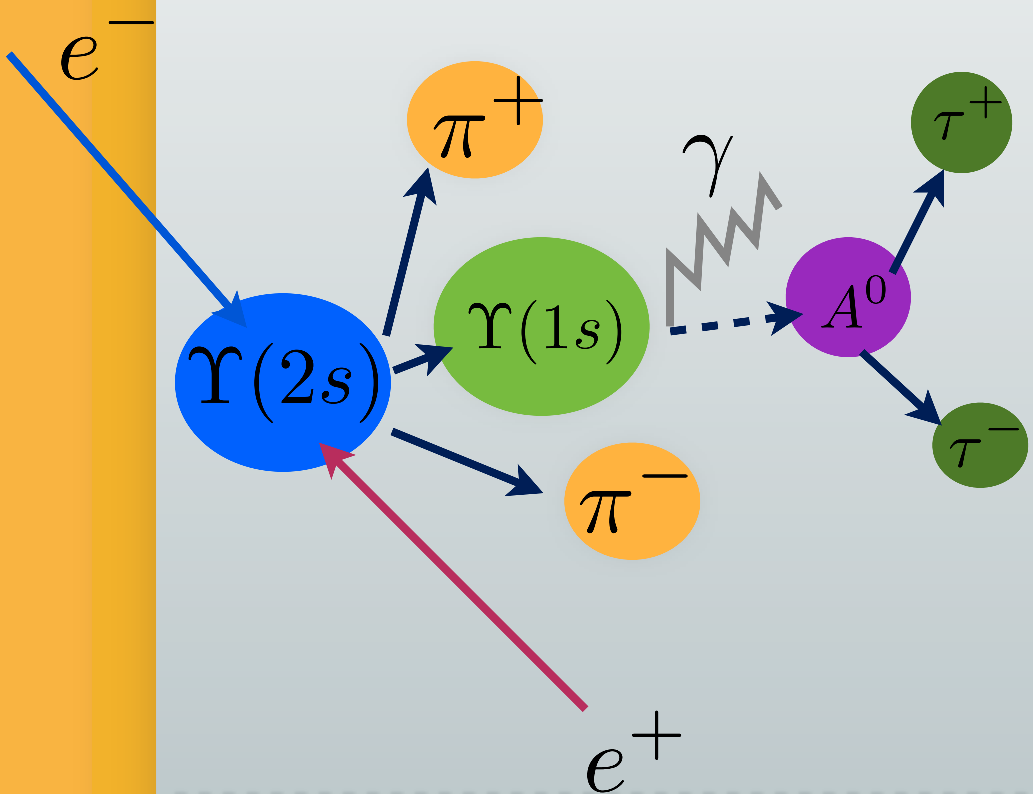
Set Upper Limits on BR



6.3 in cascades | setup | results | $\tau^+\tau^-$

$$e^+e^- \to \Upsilon(2s) \to \Upsilon(1s)\pi^+\pi^-$$

with $\Upsilon(1s) \to \gamma A^0$
$A^0 \to \tau^+\tau^-$



arXiv:1210.5669 [hep-ex], submit to PRD

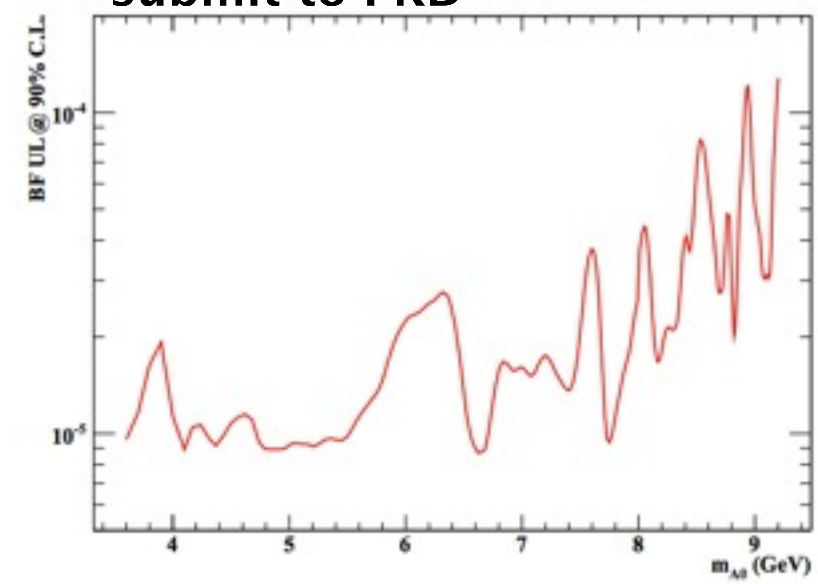


FIG. 3: 90% C.L. upper limits for $\mathcal{B}(\Upsilon(1S) \to \gamma A^0) \times \mathcal{B}(A^0 \to \tau^+\tau^-)$.

Set Upper Limits on BR

BF 90%CL UL= (0.9-13)x10^{-5}

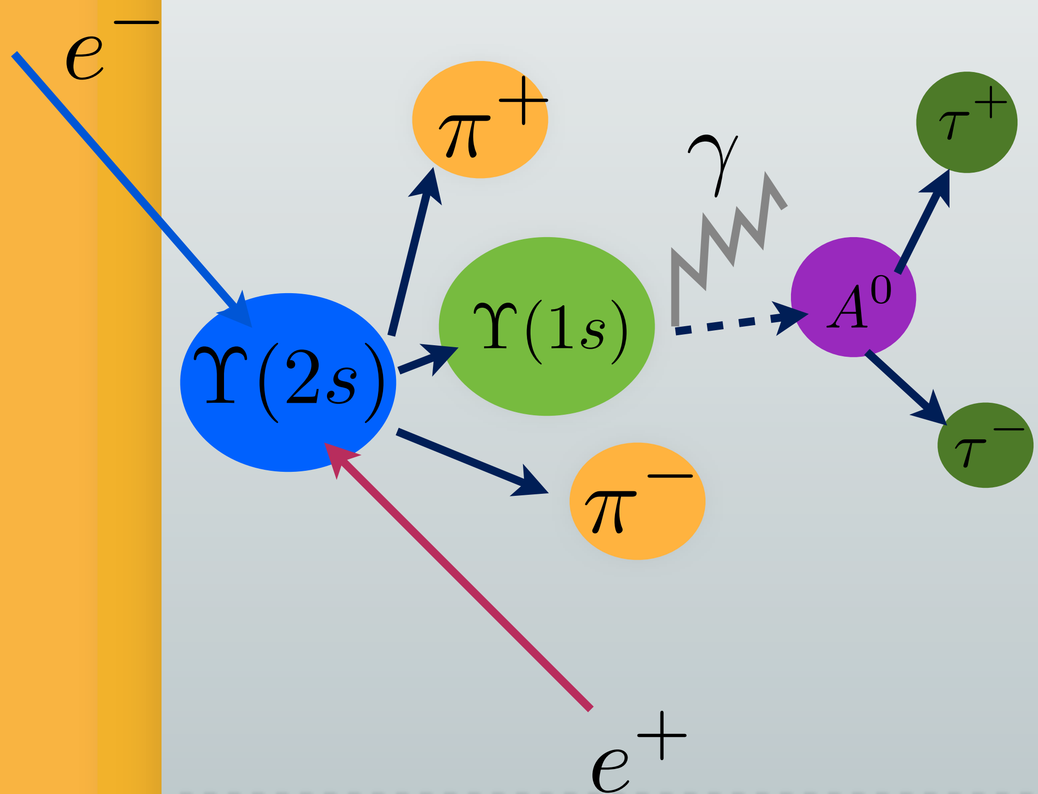
$$3.6 \leq m_{A^0} \leq 9.2\ GeV$$

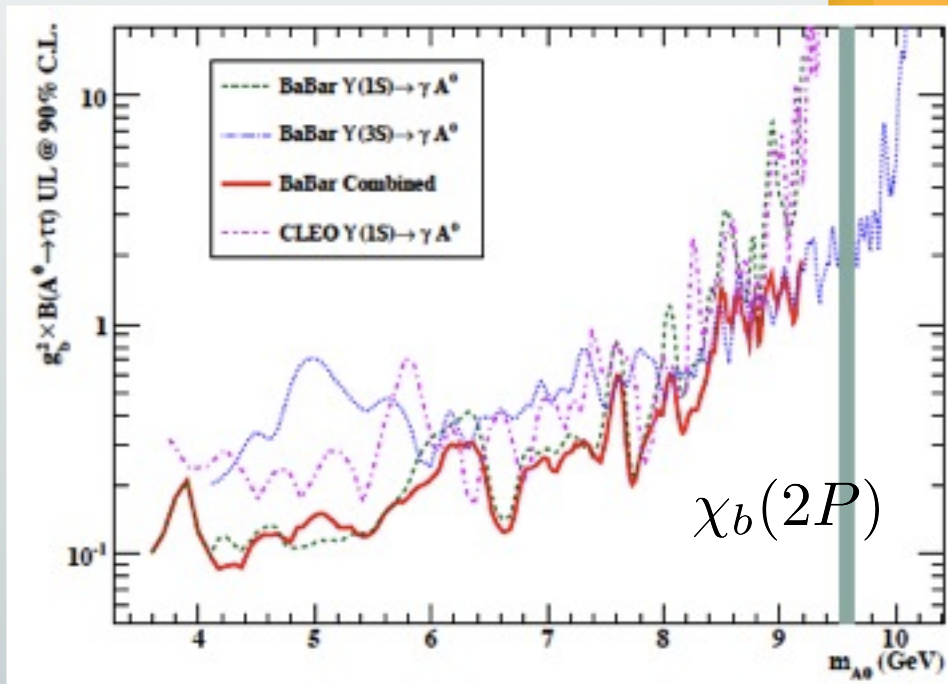
6.3 in cascades | setup | results | $\tau^+\tau^-$

$$e^+e^- \to \Upsilon(2s) \to \Upsilon(1s)\pi^+\pi^-$$

with $\Upsilon(1s) \to \gamma A^0$, $A^0 \to \tau^+\tau^-$

arXiv:1210.5669 [hep-ex], submit to PRD





Set UL on "Effective Yukawa coupling"xBR

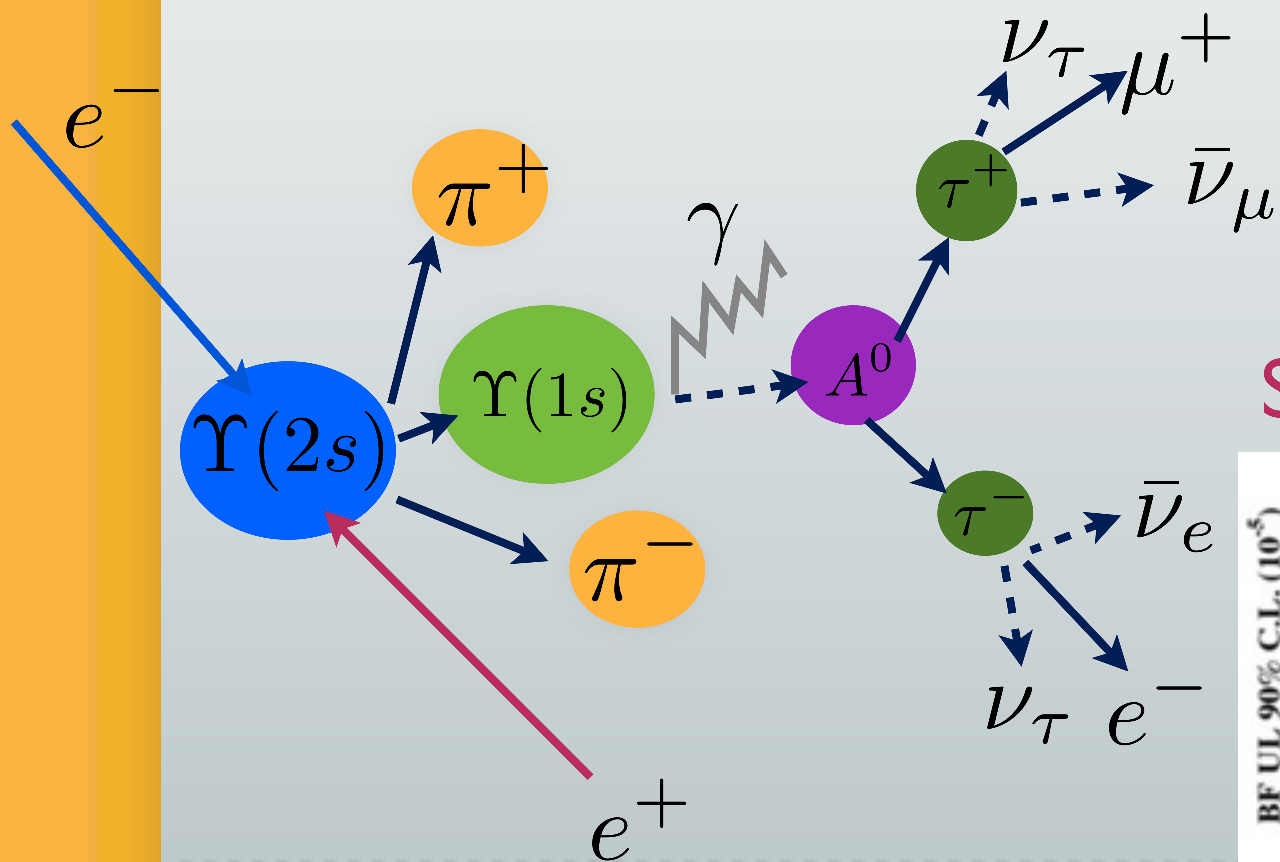
0.09-1.9

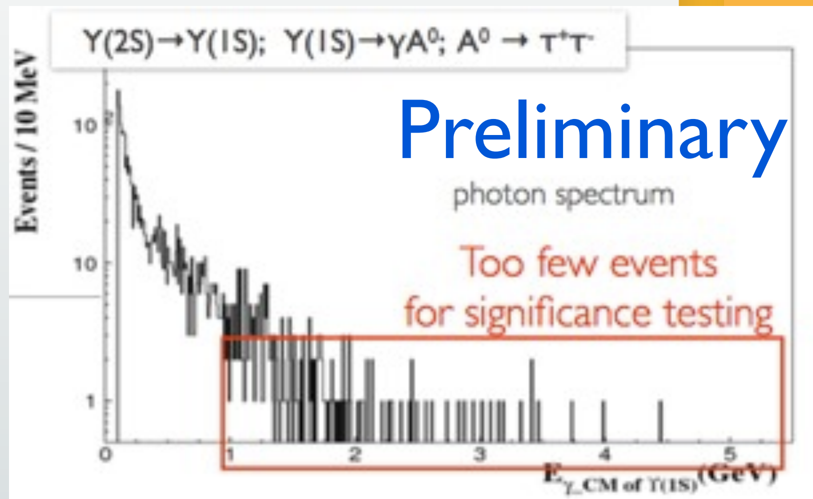
6.3 in cascades | setup | results | $\tau^+\tau^-$

BELLE

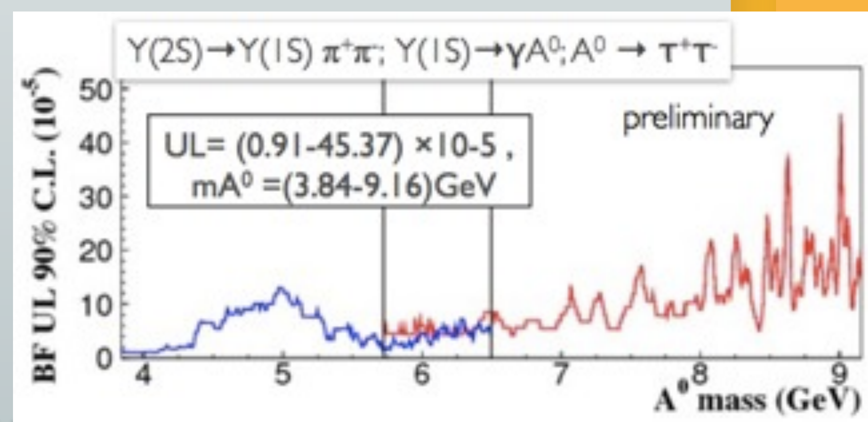
$$e^+e^- \to \Upsilon(2s) \to \Upsilon(1s)\pi^+\pi^-$$

$$\text{with}\quad \begin{array}{l} \Upsilon(1s) \to \gamma A^0 \\ A^0 \to \tau^+\tau^- \end{array}$$





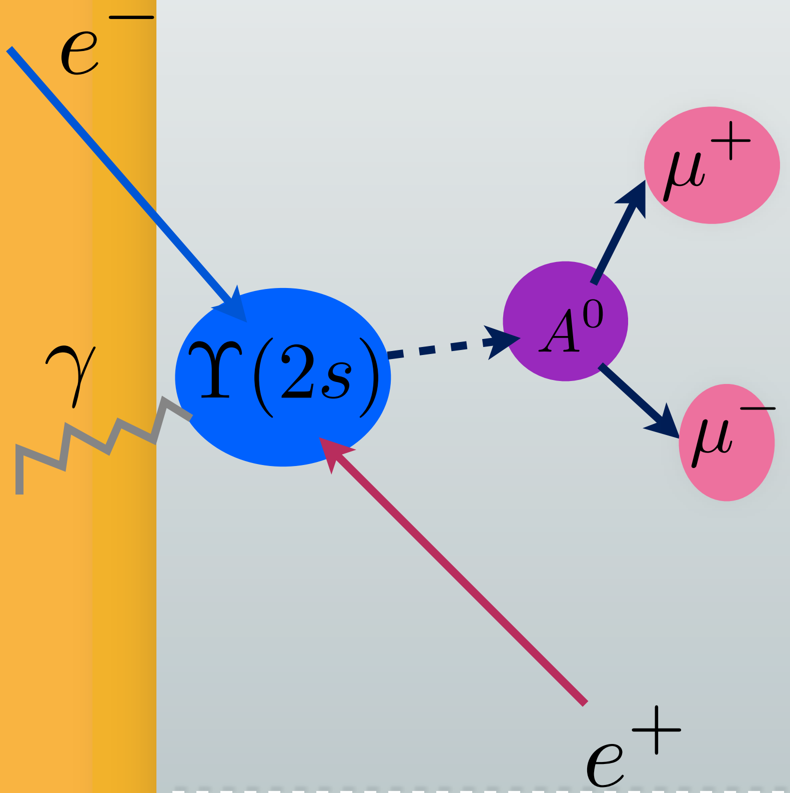
Set Upper Limits on BR

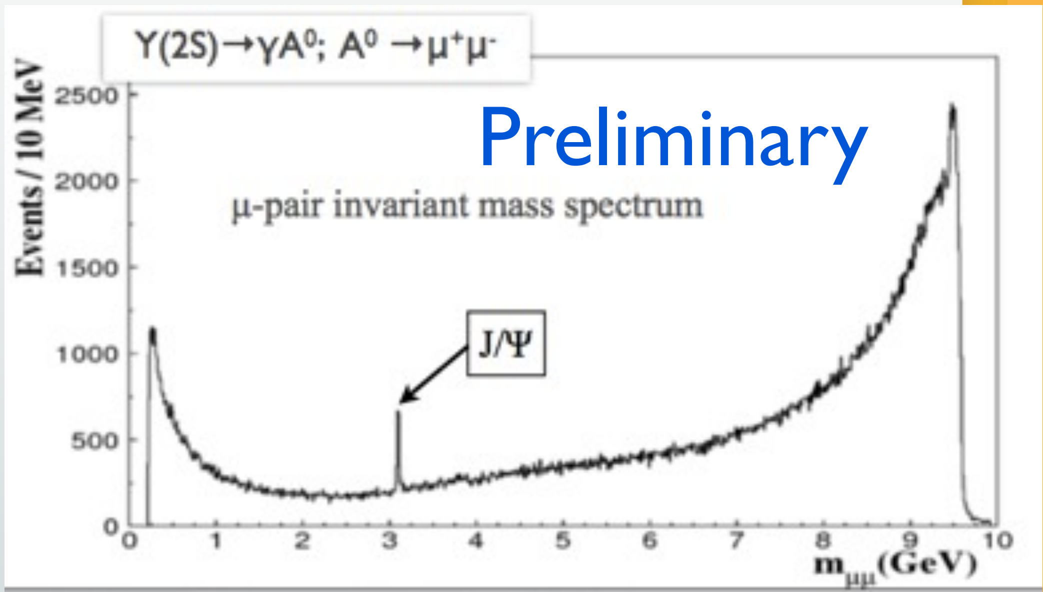


6.4 directly setup results $\mu^+\mu^-$

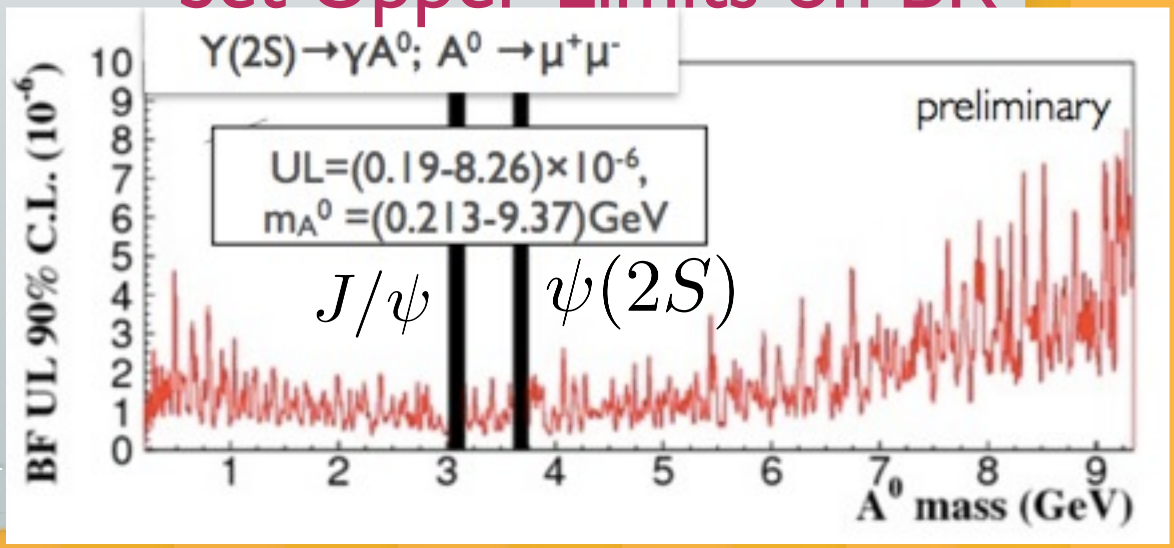
$$e^+e^- \to \Upsilon(2s) \to \gamma A^0$$

with $A^0 \to \mu^+\mu^-$





Set Upper Limits on BR

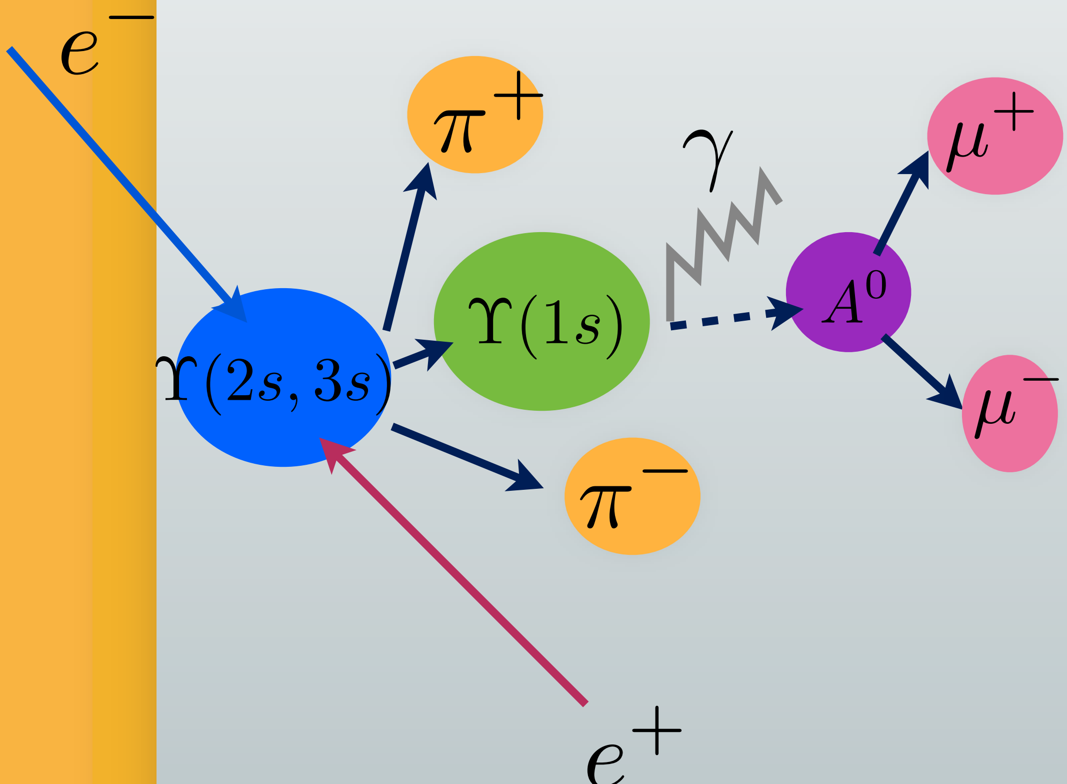


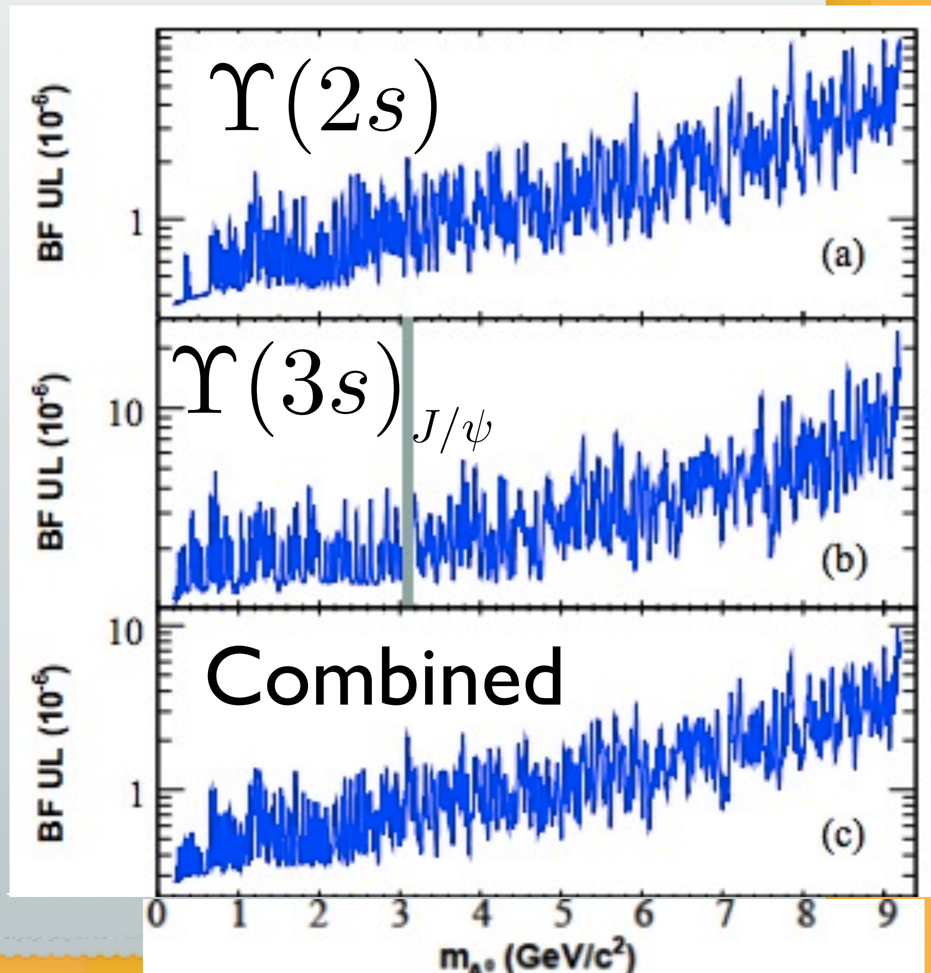
6.5 in cascades | setup | results | $\mu^+\mu^-$

$$e^+e^- \rightarrow \Upsilon(2s,3s) \rightarrow \Upsilon(1s)\pi^+\pi^-$$

with $\Upsilon(1s) \rightarrow \gamma A^0$
$A^0 \rightarrow \mu^+\mu^-$

arXiv:1210.0287
PRD 87, 031102(R), 2013





BF 90%CL UL= $(0.28\text{-}9.7)\times10^{-6}$

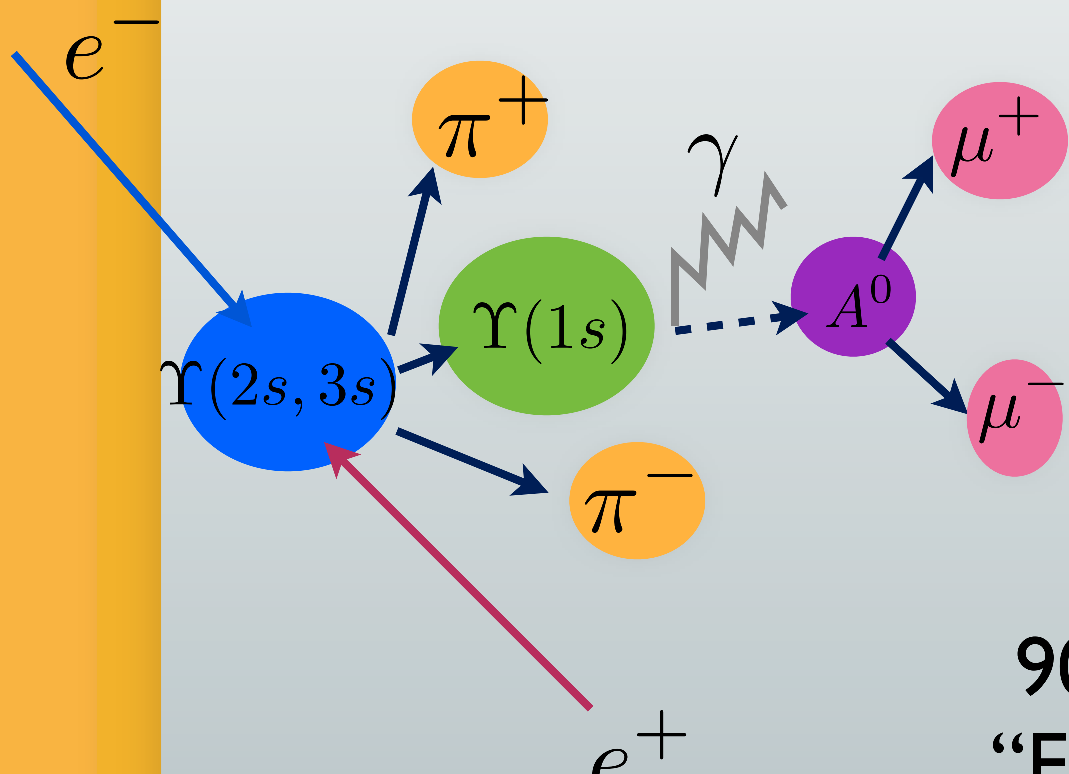
6.5 in cascades | setup | results | $\mu^+\mu^-$

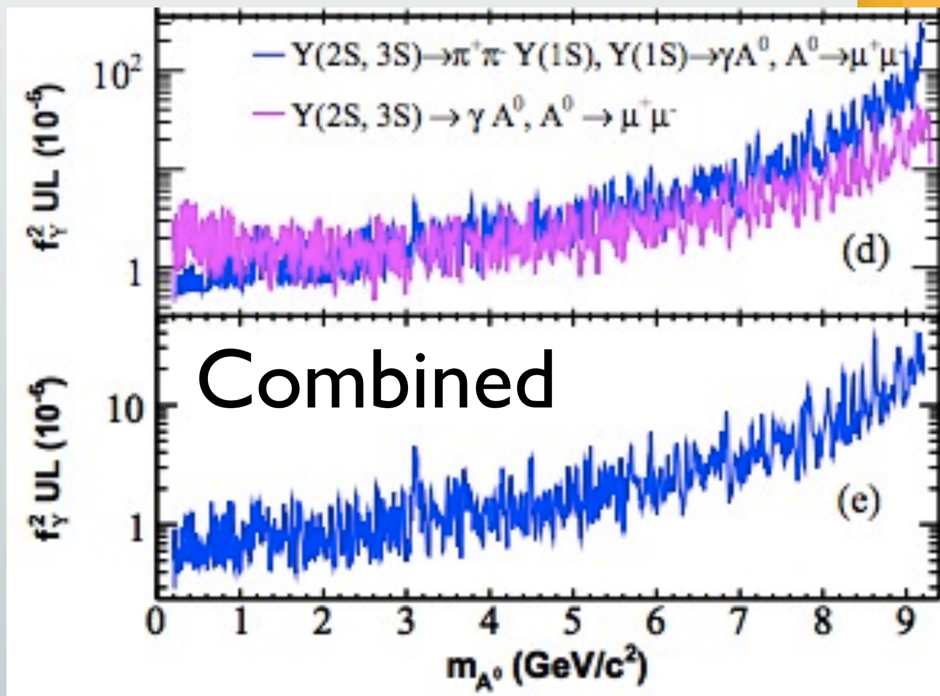
$$e^+e^- \to \Upsilon(2s,3s) \to \Upsilon(1s)\pi^+\pi^-$$

with $\Upsilon(1s) \to \gamma A^0$
$A^0 \to \mu^+\mu^-$

arXiv:1210.0287

PRD 87, 031102(R), 2013





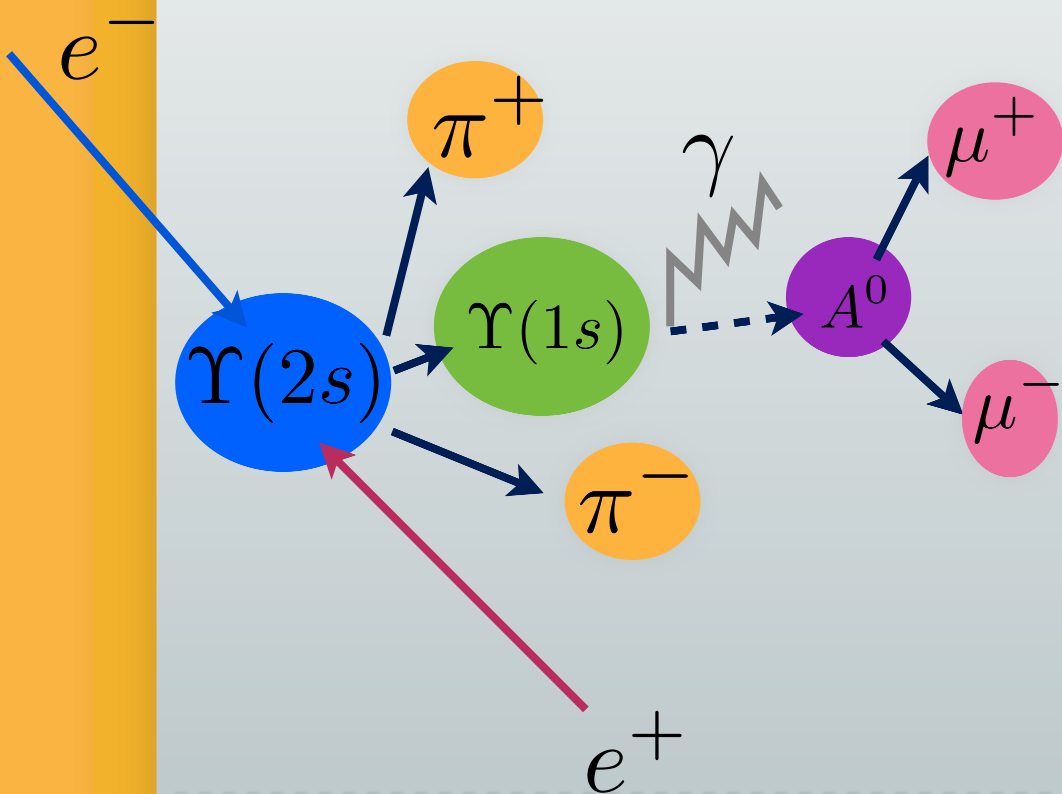
90% C.L. Upper Limits on "Effective Yukawa coupling"

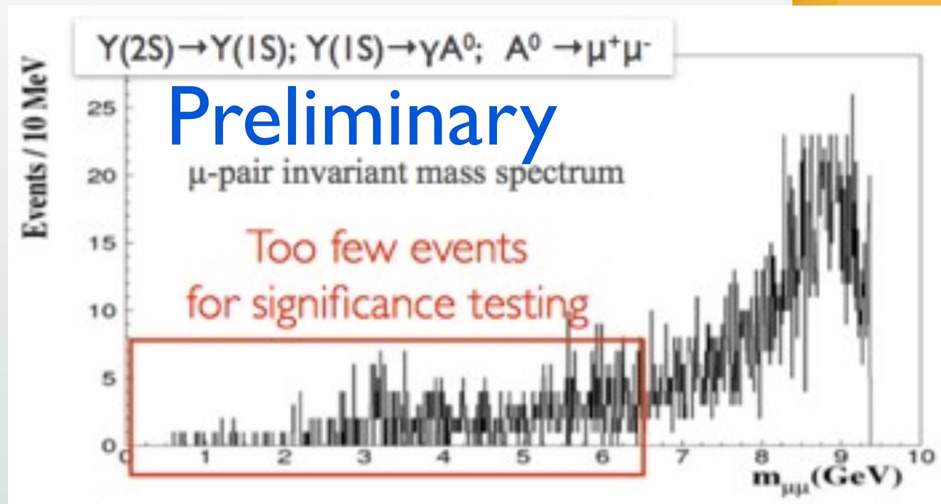
$(0.29\text{-}40)\times10^{-6}$ $\quad m_{A^0} \le 9.2\ GeV$

6.5 in cascades setup results $\mu^+\mu^-$

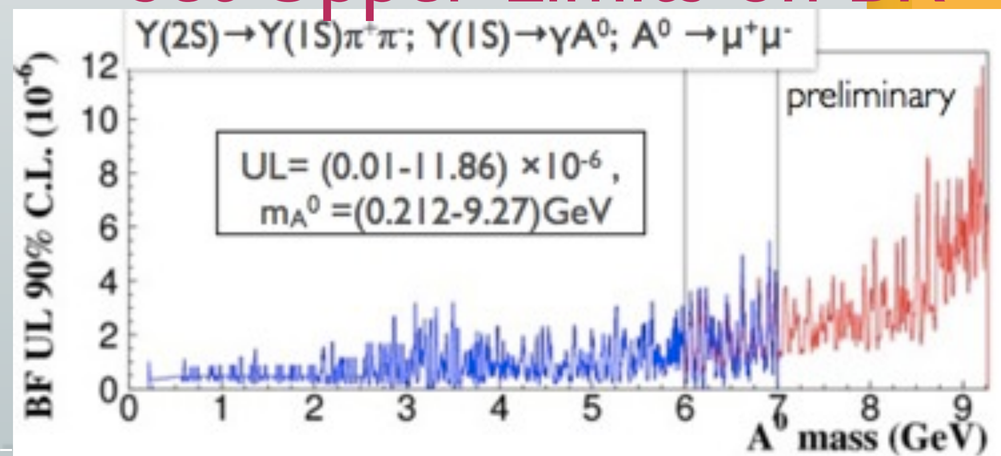
$$e^+e^- \to \Upsilon(2s) \to \Upsilon(1s)\pi^+\pi^-$$

with $\Upsilon(1s) \to \gamma A^0$
$A^0 \to \mu^+\mu^-$





Set Upper Limits on BR



Short Summary for Light Higgs

Set Significant constraints on nMSSM.

Light Higgs

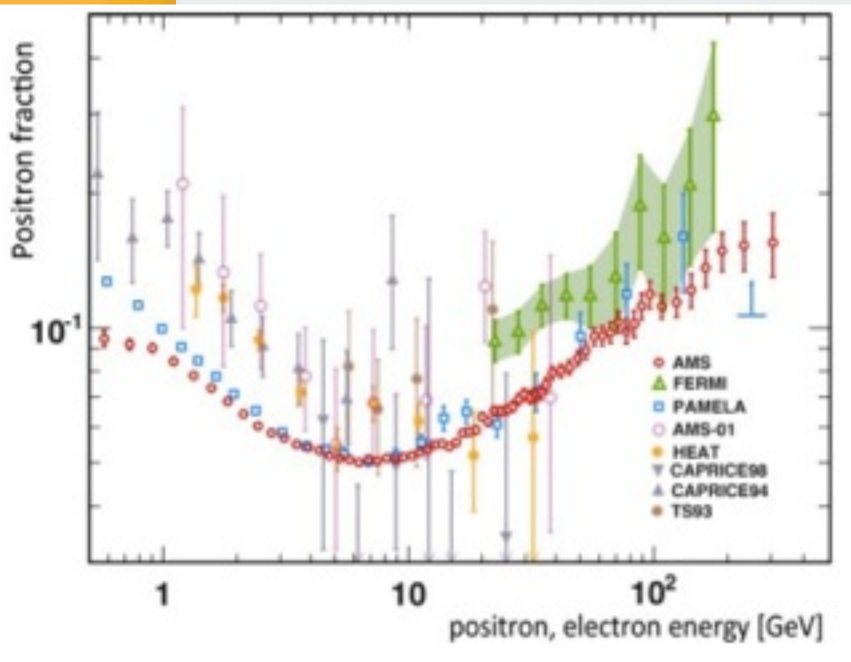
$A^0 \to \tau^+\tau^-$ UL on BF@ 90% C.L. ~10^{-5}

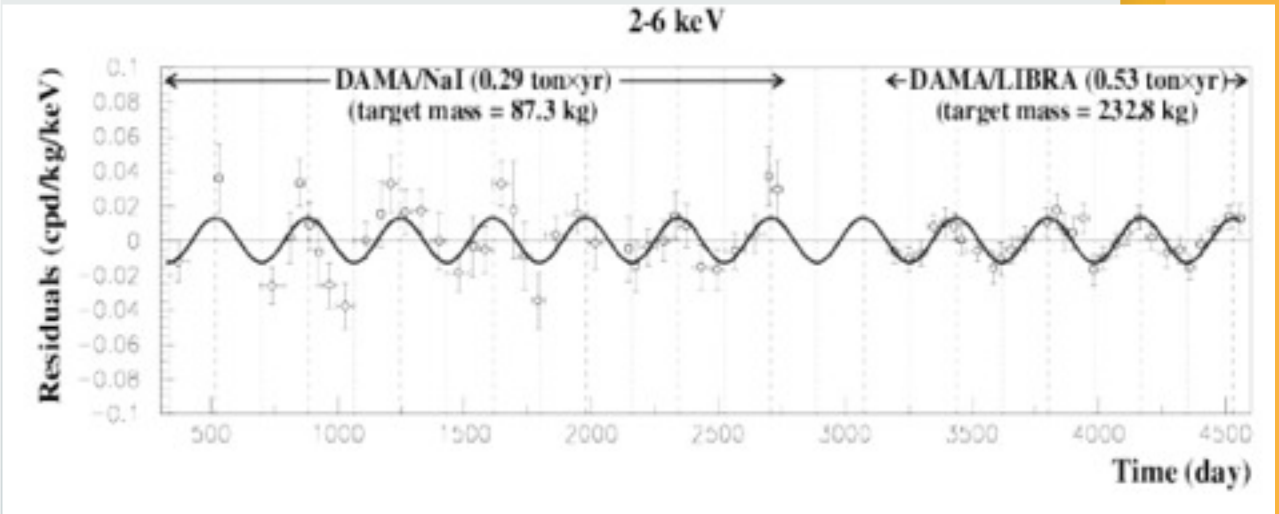
$A^0 \to \mu^+\mu^-$ UL on BF@ 90% C.L. ~10^{-6}

Dark Photon

1. Experimental anomalies

Can Dark Matter explain observed anomalies in astrophysical data and dark matter experiments?





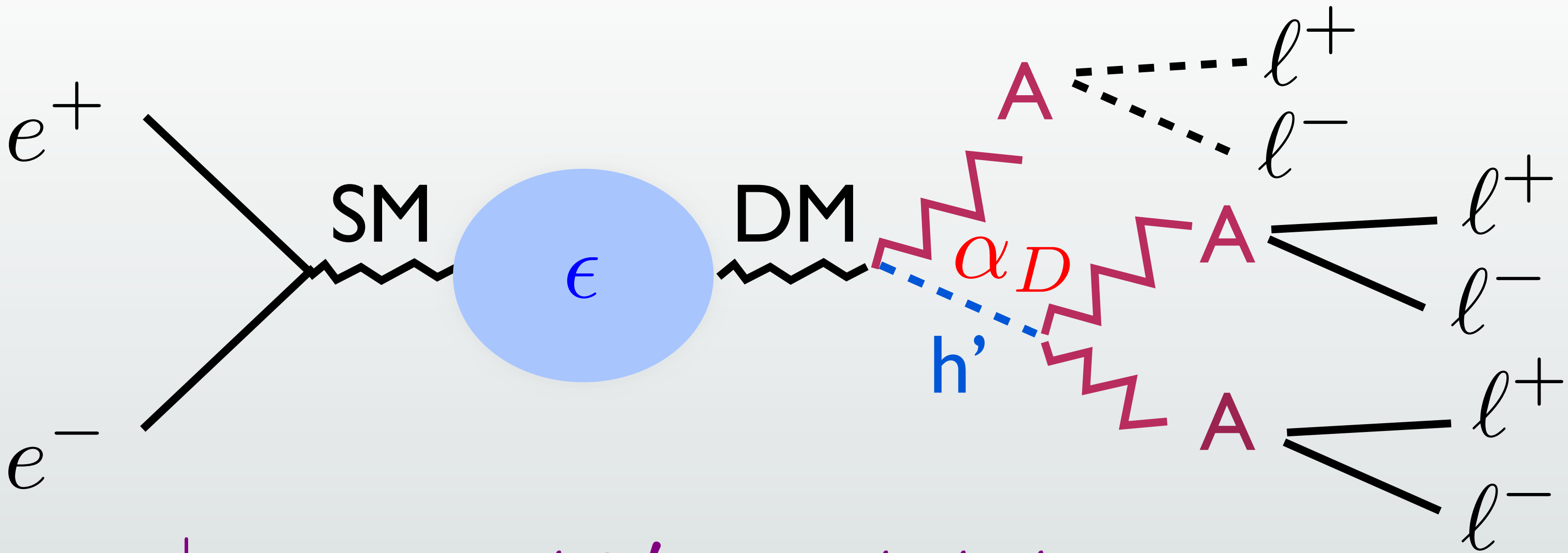
AMS2 PRL 110, 141102 (2013)

positron excess

DAMA/LIBRA, Eur. Phys. J. C 56: 333-355 (2008)

annual modulation

2. Dark Matter at B Factories?



$$e^+e^- \to Ah' \to AAA$$

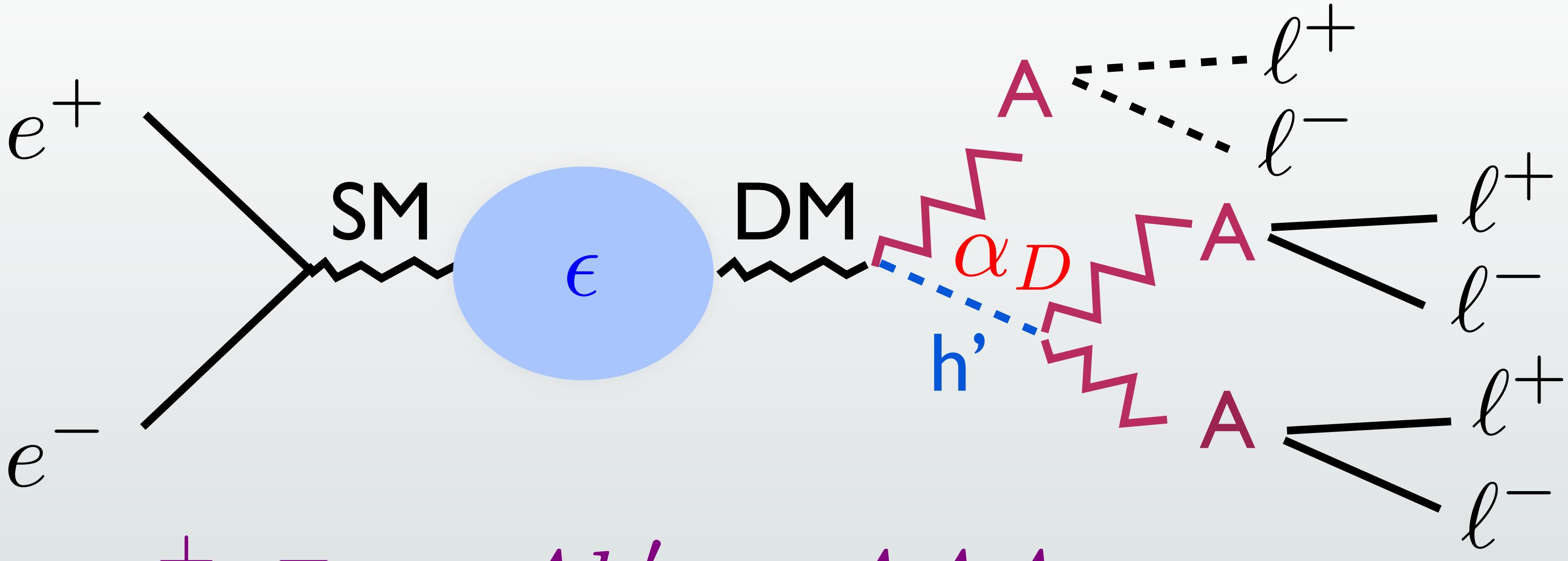
ϵ : kinetic mixing

α_D : dark sector constant

A: Dark Photon

h': Dark Higgs

3. Dark Matter at B Factories



$$e^+e^- \to Ah' \to AAA$$

Phys. Rev. Lett. 108, 211801 (2012)

- ✓ $AAA \to 3(\ell^+\ell^-)$
- ✓ $AAA \to 2(\ell^+\ell^-)\pi^+\pi^-$
- ✓ $AAA \to (\ell^+\ell^-)2(\pi^+\pi^-)$
- ✓ $AAA \to 2(\mu^+\mu^-) + X$
- ✓ $AAA \to \mu^+\mu^-e^+e^- + X$

$\ell = e, \mu$

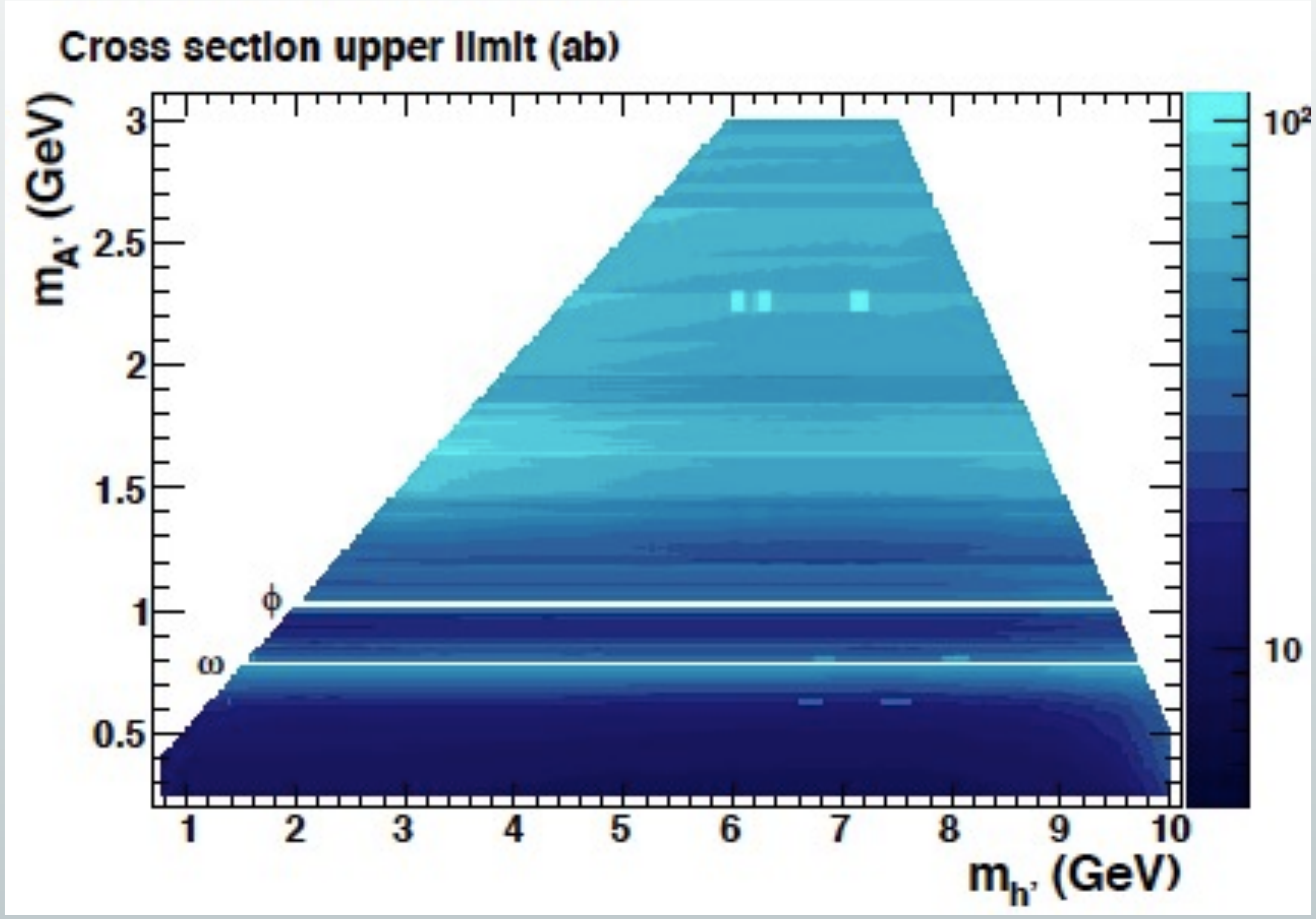
X = any state other than a pair of pions or leptons

3.

Phys. Rev. Lett. 108, 211801 (2012)

Combine all channels

cross section U.L.: 10-100 ab



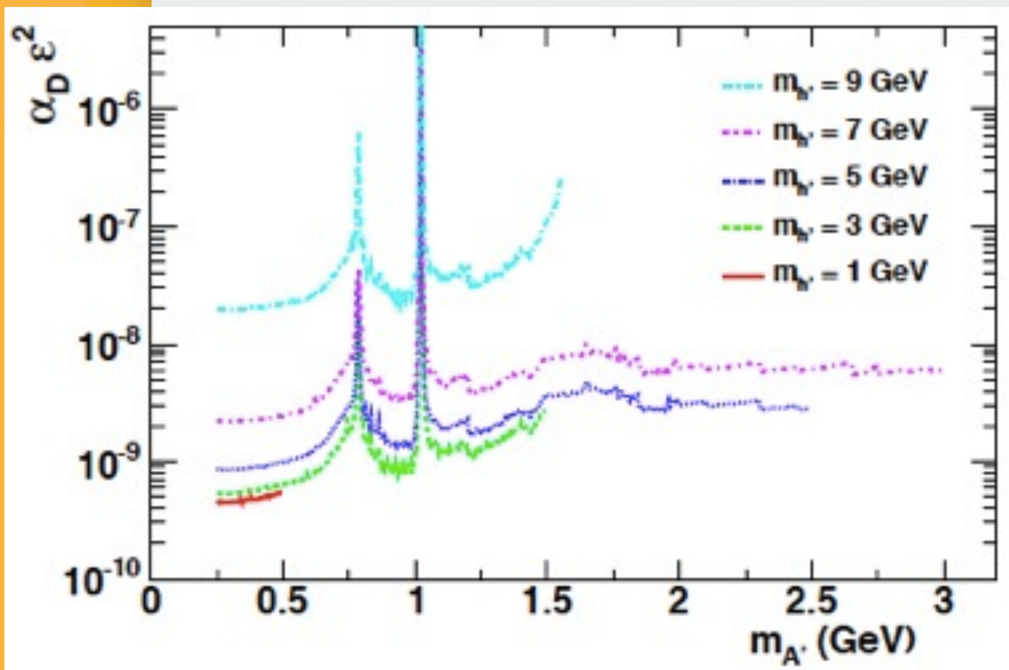
ω, and ϕ regions are excluded to avoid the overflow

3.

Phys. Rev. Lett. 108, 211801 (2012)

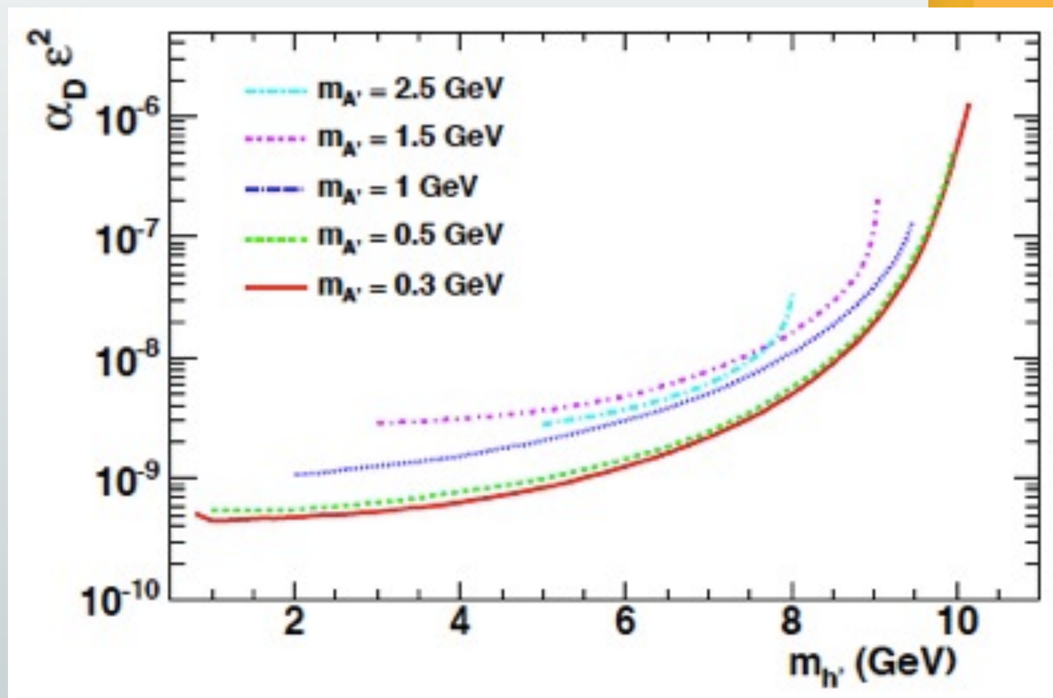
Combine all channels

$\alpha_D \epsilon^2$ U.L. @90% CL



$0.25\ GeV < m_{A'} < 3\ GeV$

$\alpha_D \epsilon^2$ U.L. @90% CL

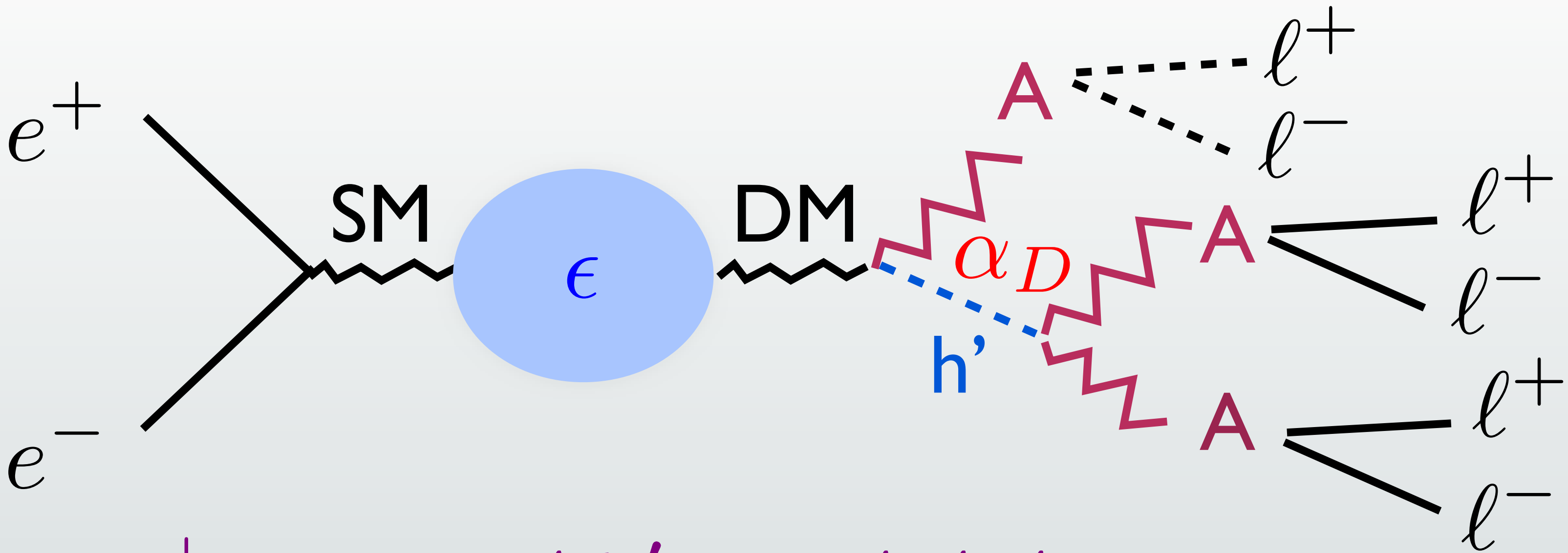


$0.8\ GeV < m_{h'} < 10\ GeV$

no signal has been observed

DM model, predict lower than 10^{-9} level, not preferred

4. Dark Matter at B Factories



$$e^+e^- \to Ah' \to AAA$$

Preliminary

BELLE

✓ $AAA \to 3(\ell^+\ell^-)$

✓ $AAA \to 2(\ell^+\ell^-)\pi^+\pi^-$

✓ $AAA \to (\ell^+\ell^-)2(\pi^+\pi^-)$

✓ $AAA \to 3(\pi^+\pi^-)$

✓ $AAA \to 2(\mu^+\mu^-)e^+e^-$

✓ $AAA \to 2(e^+e^-)\mu^+\mu^-$

✓ $AAA \to (e^+e^-)(\mu^+\mu^-)(\pi^+\pi^-)$

$\ell = e, \mu$

10 channels

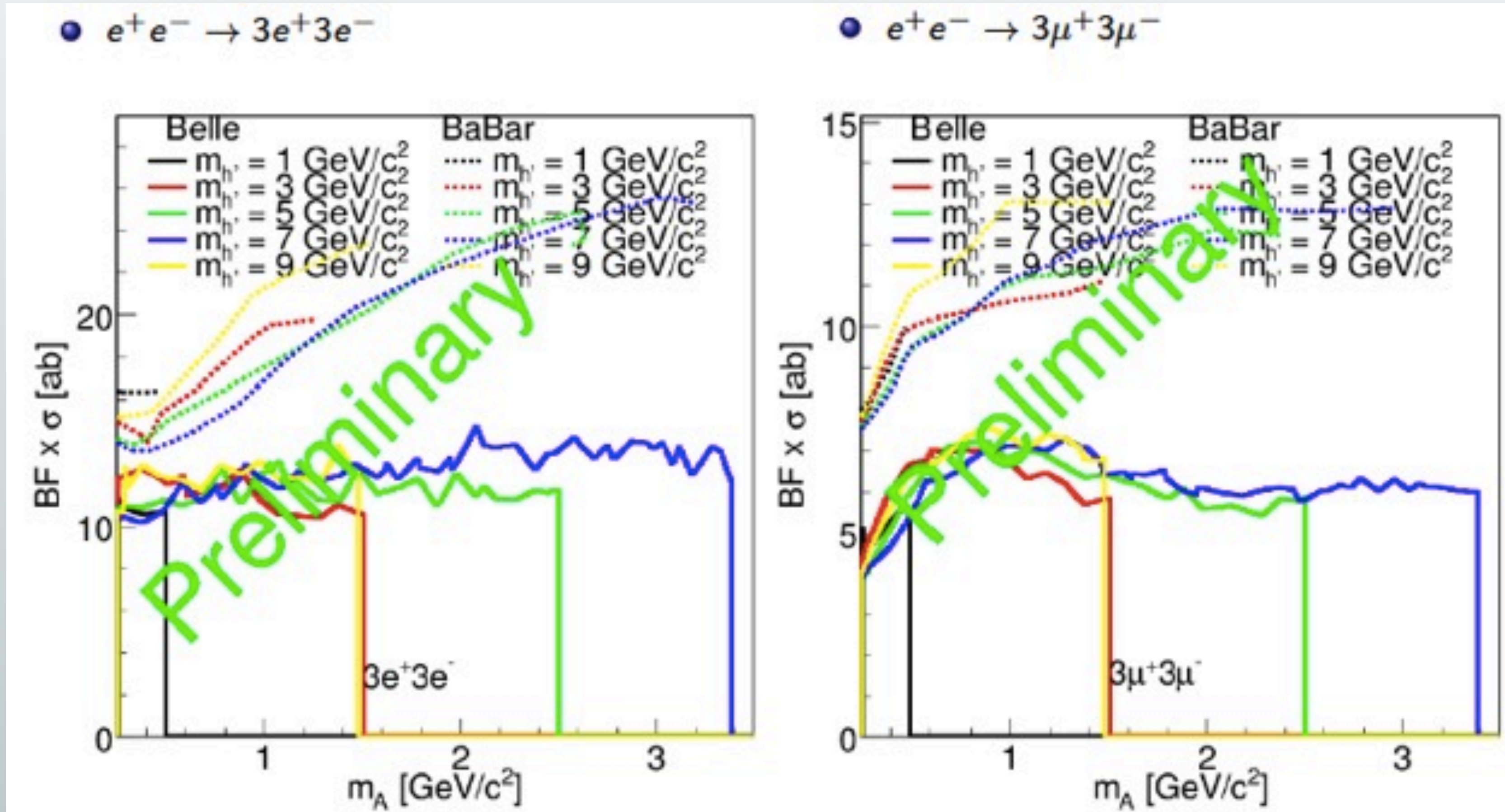
4.

4 channels are opened

$$\checkmark AAA \to 3(\ell^+\ell^-)$$

$$AAA \to (e^+e^-)2(\pi^+\pi^-)$$

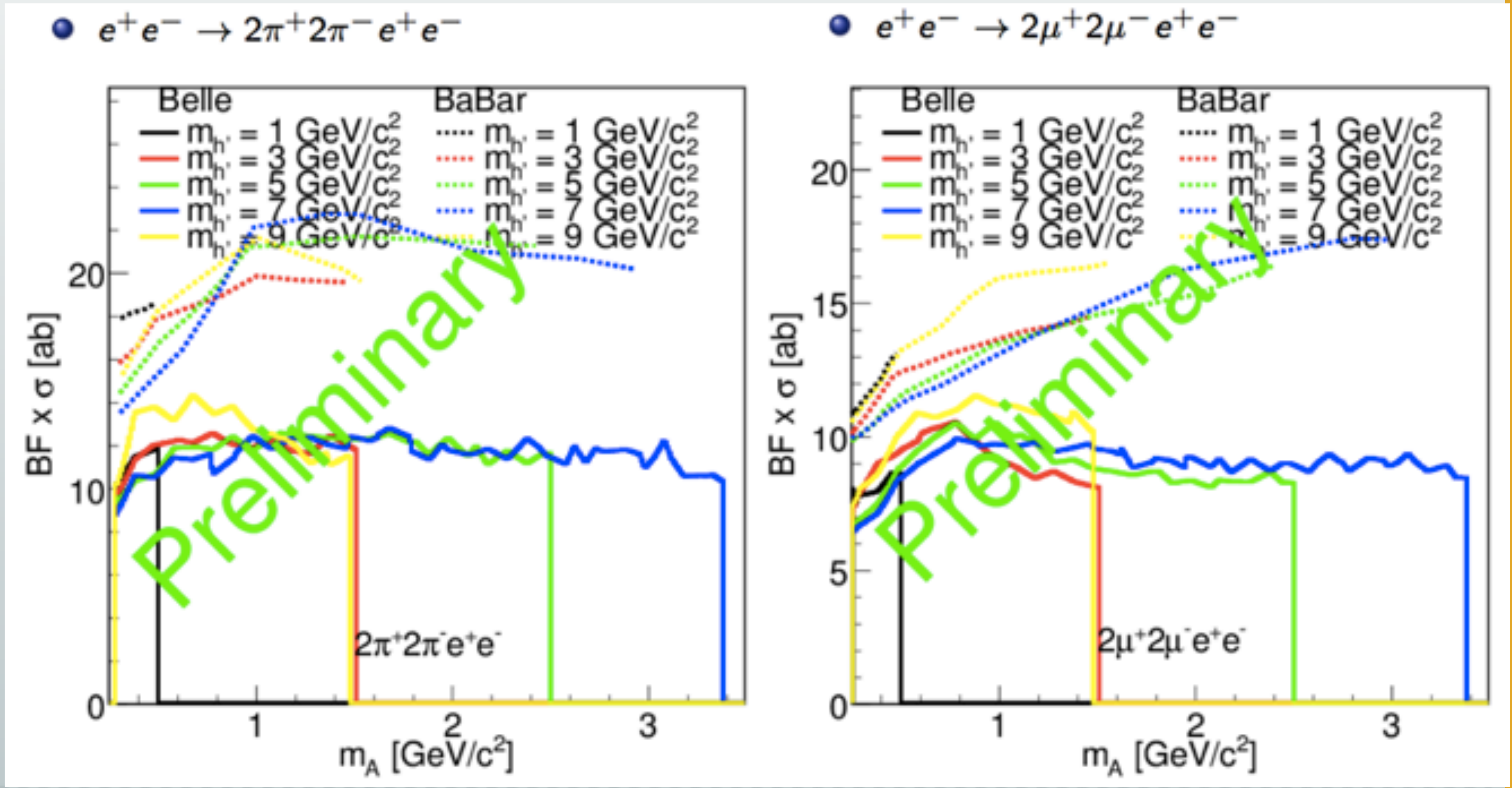
$$AAA \to 2(\mu^+\mu^-)e^+e^-$$



4.

4 channels are opened

$$AAA \to 3(\ell^+\ell^-)$$
$$\checkmark AAA \to (e^+e^-)2(\pi^+\pi^-)$$
$$\checkmark AAA \to 2(\mu^+\mu^-)e^+e^-$$

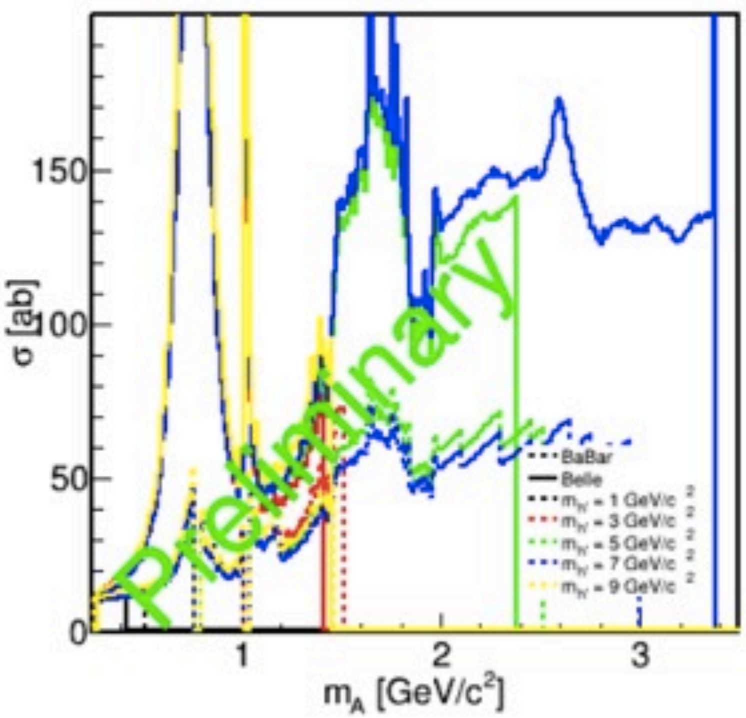


4.

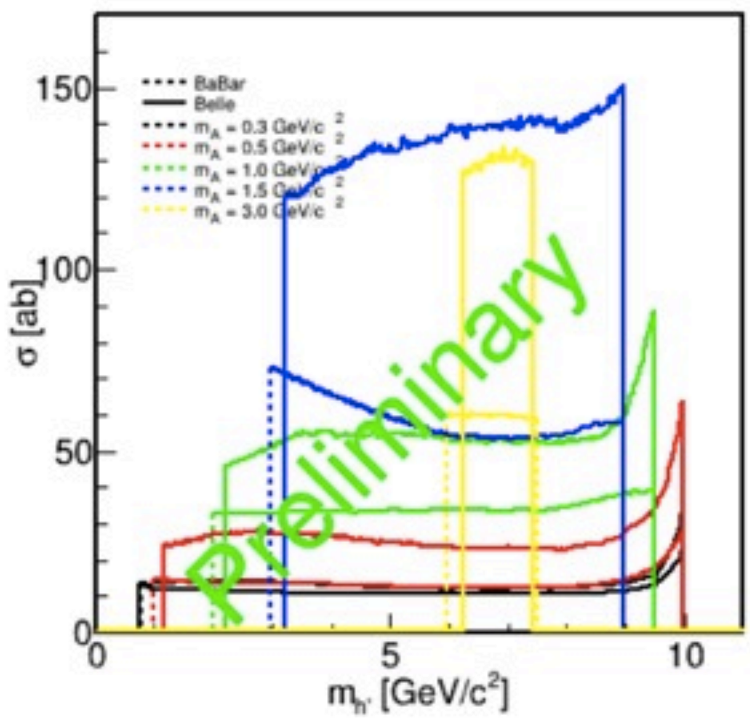
Combine 4 channels

cross section U.L.: 10-200 preferred

- dark photon 90 % CL limit



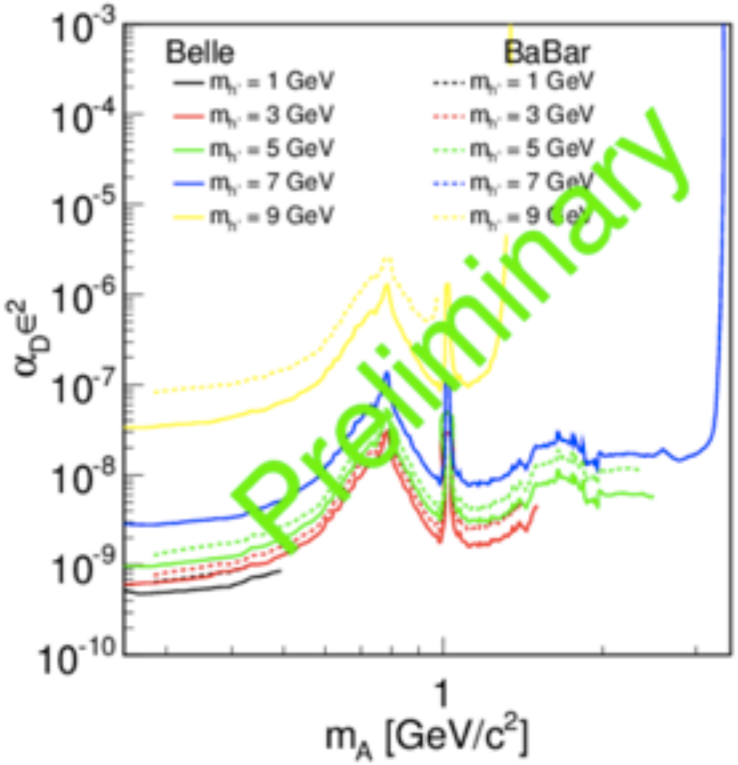
- dark Higgs 90 % CL limit



4.

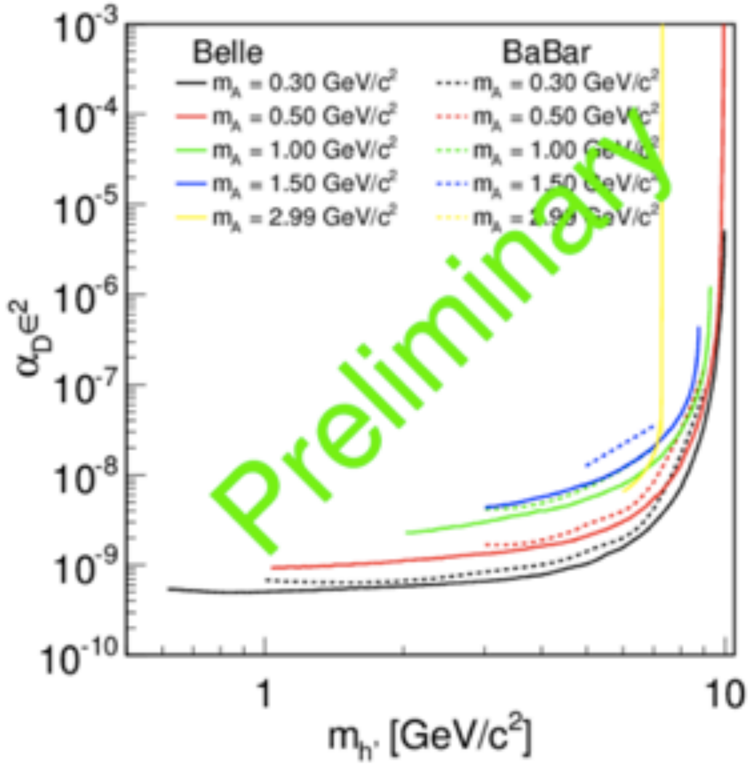
Combine 4 channels

$\alpha_D \epsilon^2$ U.L. @90% CL



$$0.25\ GeV < m_{A'} < 3.5\ GeV$$

$\alpha_D \epsilon^2$ U.L. @90% CL



$$0.5\ GeV < m_{h'} < 10.5\ GeV$$

no signal has been observed

DM model, predict lower than 10^{-9} level, not preferred

Short Summary for Dark Forces

Set Significant constraints on DM.

Dark Photon

Dark Higgs

cross section U.L.: 10-100 ab

$\alpha_D \epsilon^2$ U.L. : >10^{-9}

Summary

No significant excess.

Improve current best limits.

- Light Higgs
- Dark Photon
- Dark Higgs

Thank you very much~

BaBar results, 2012

Shown at FPCP 2012. Summarized in **arXiv:1209.1143 (B. Echenard)**

Mode	Mass range (GeV)	BF upper limit (90% CL)
$\Upsilon(2S,3S) \to \gamma A^0, A^0 \to \mu^+\mu^-$	$0.21 < m_A < 9.3$	$(0.3 - 8.3) \times 10^{-6}$
$\Upsilon(3S) \to \gamma A^0, A^0 \to \tau^+\tau^-$	$4.0 < m_A < 10.1$	$(1.5 - 16) \times 10^{-5}$
$\Upsilon(2S,3S) \to \gamma A^0, A^0 \to$ hadrons	$0.3 < m_A < 7.0$	$(0.1 - 8) \times 10^{-5}$
$\Upsilon(1S) \to \gamma A^0, A^0 \to \chi\bar{\chi}$	$m_\chi < 4.5\,\mathrm{GeV}$	$(0.5 - 24) \times 10^{-5}$
$\Upsilon(1S) \to \gamma A^0, A^0 \to$ invisible	$m_A < 9.2\,\mathrm{GeV}$	$(1.9 - 37) \times 10^{-6}$
$\Upsilon(3S) \to \gamma A^0, A^0 \to$ invisible	$m_A < 9.2\,\mathrm{GeV}$	$(0.7 - 31) \times 10^{-6}$