Results on Light Higgs(Belle&BaBar)

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2013/6/27 @NTHU

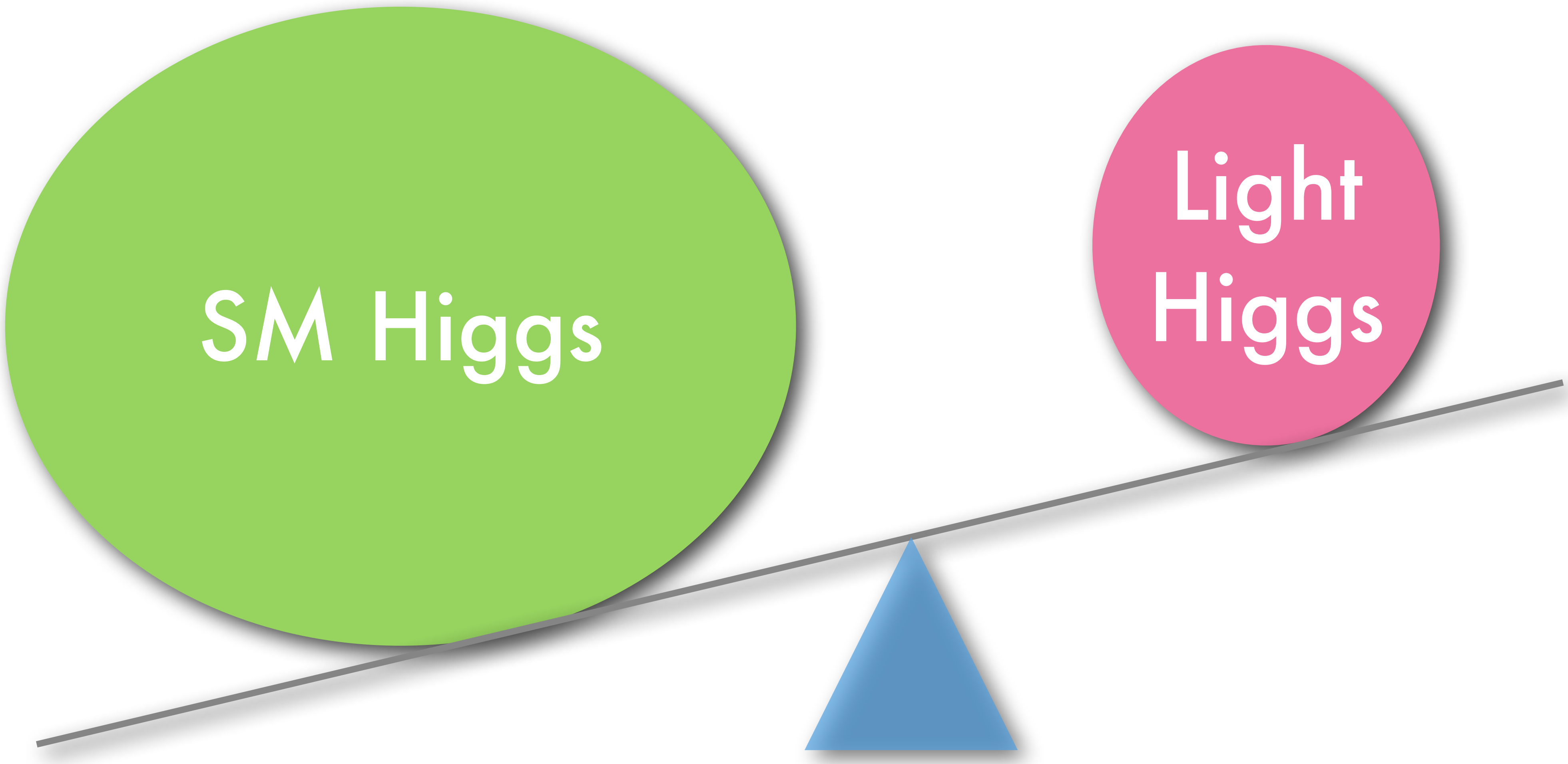
Outline

1. Light Higgs

2. Belle&BaBar Results

Light Higgs

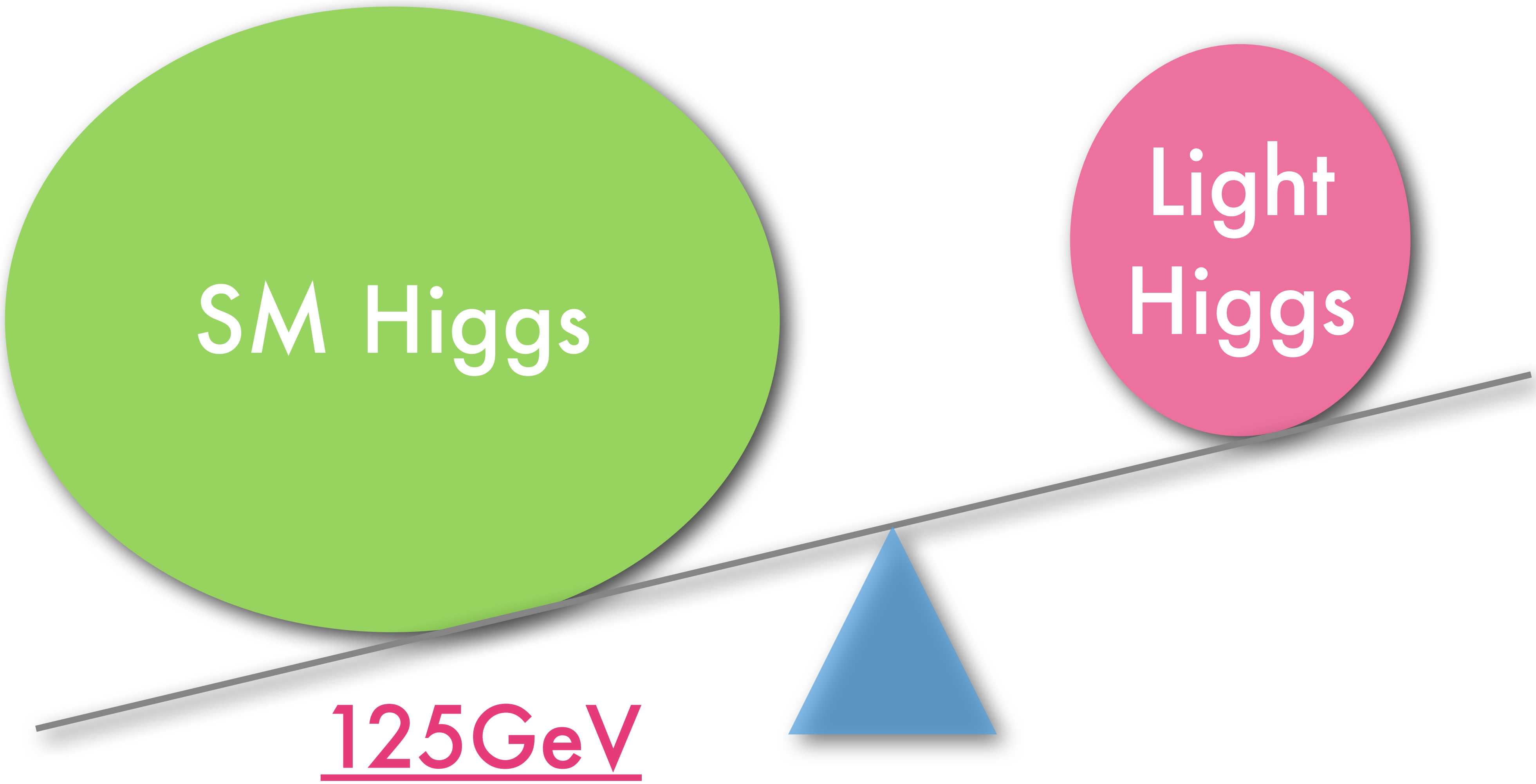
First



SM: Standard Model

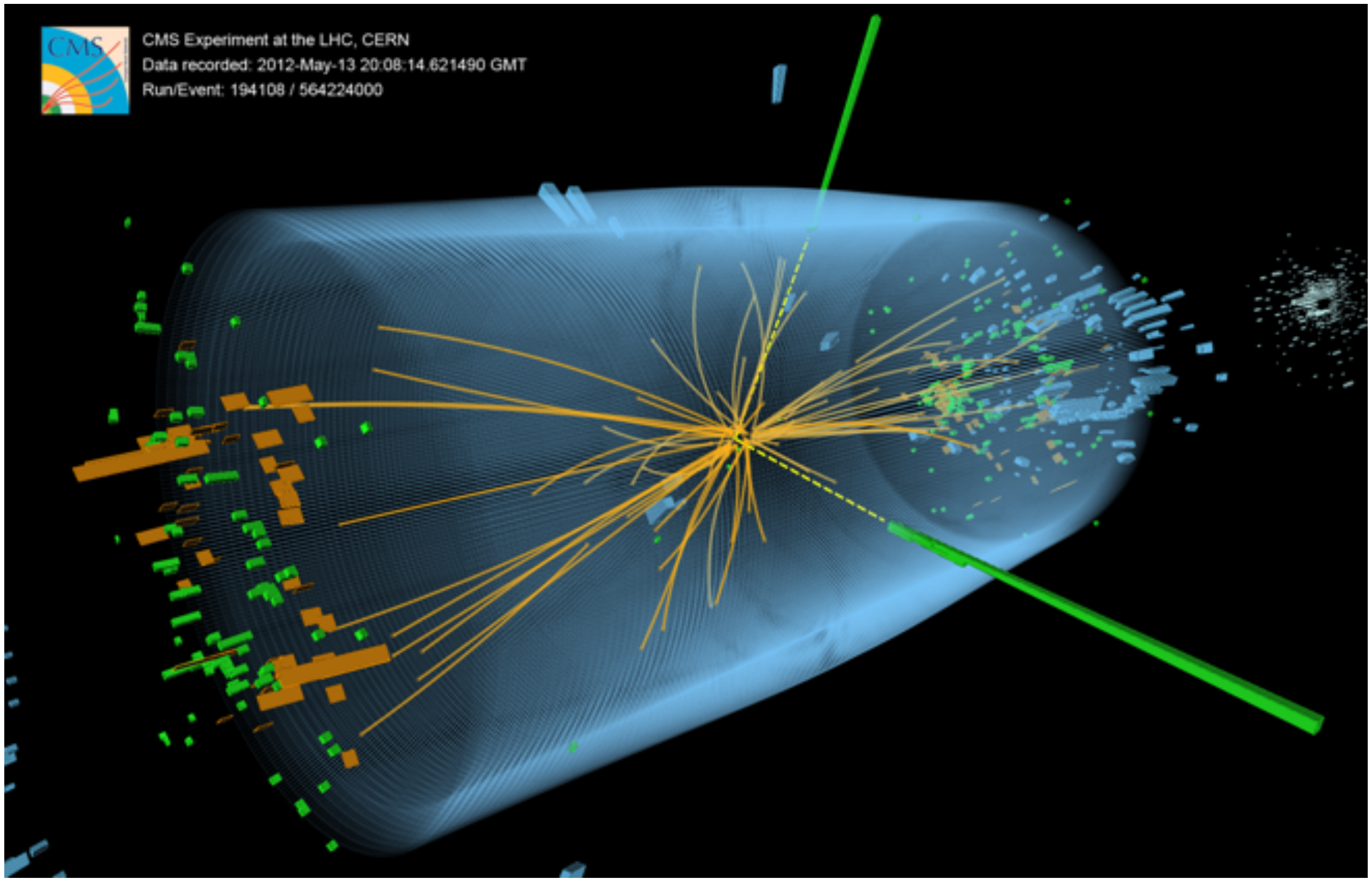
First

July, 2012.



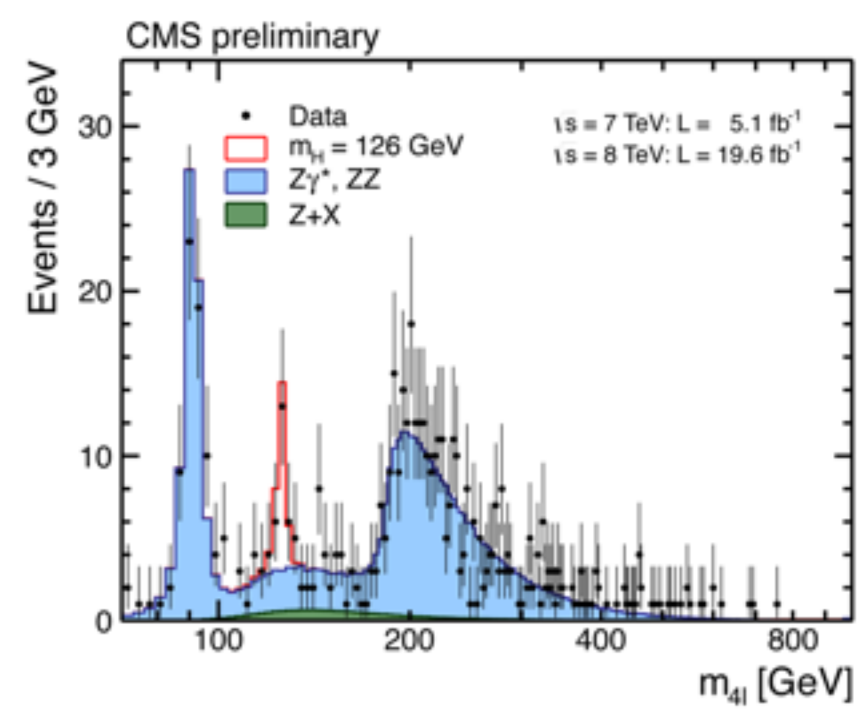
SM: Standard Model

Discover by ATLAS and CMS group @CERN
Higgs-like particle



proton-proton centre-of-mass energy of 8 TeV, 2012

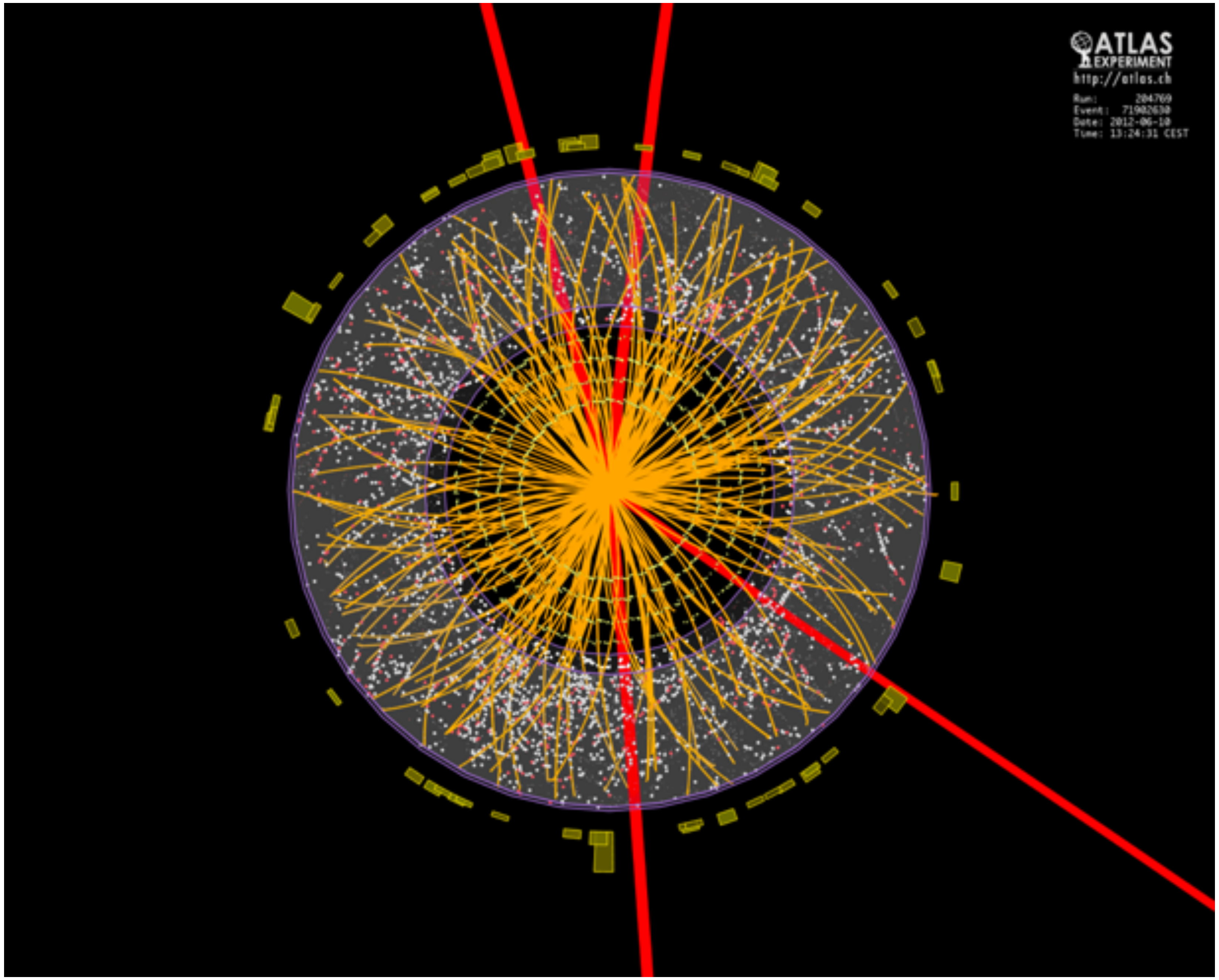
CMS
Higgs Candidate



New CMS results 2013

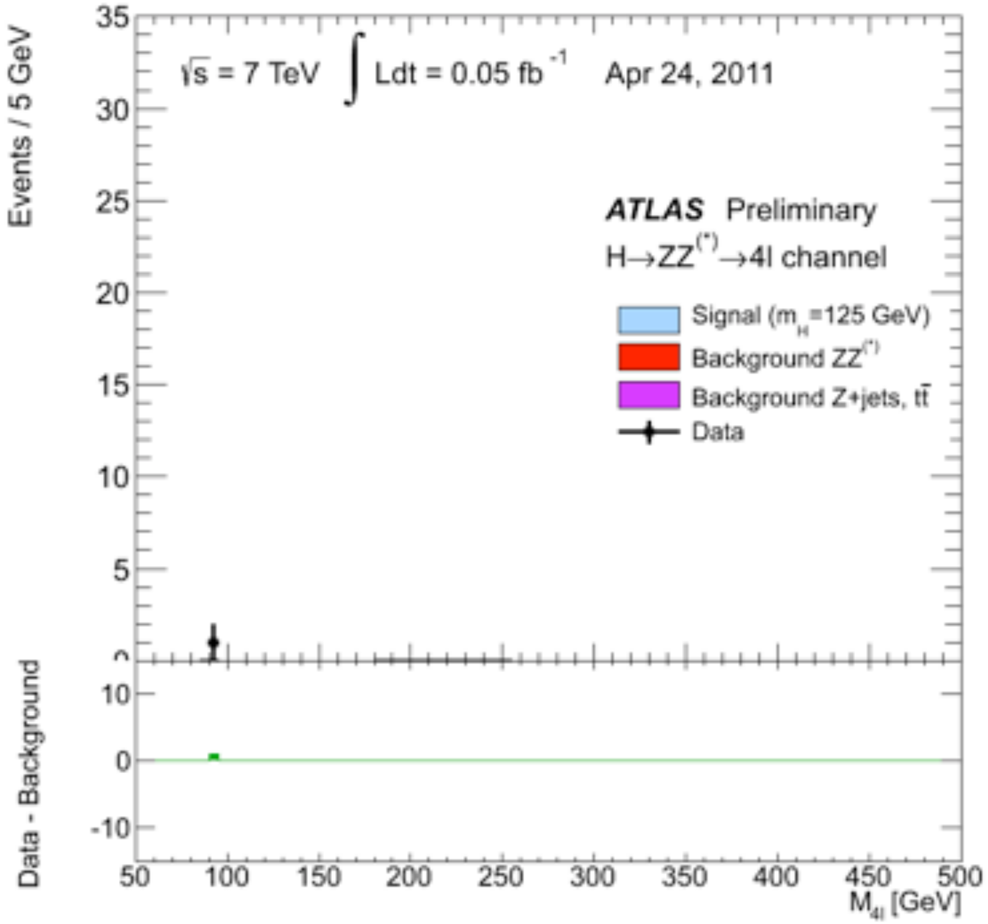
Discover by ATLAS and CMS group @CERN

Higgs-like particle

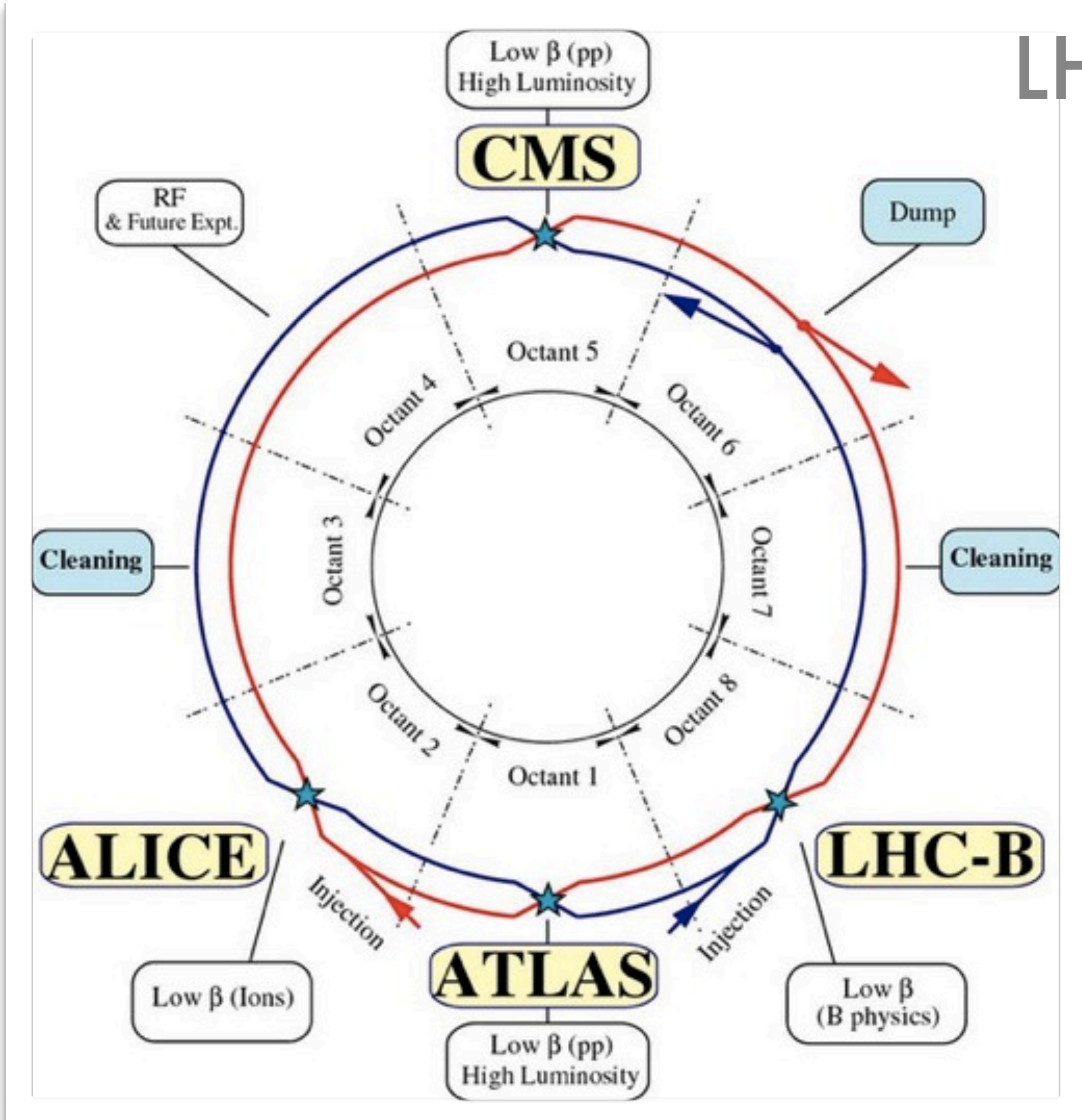


ATLAS

Higgs Candidate

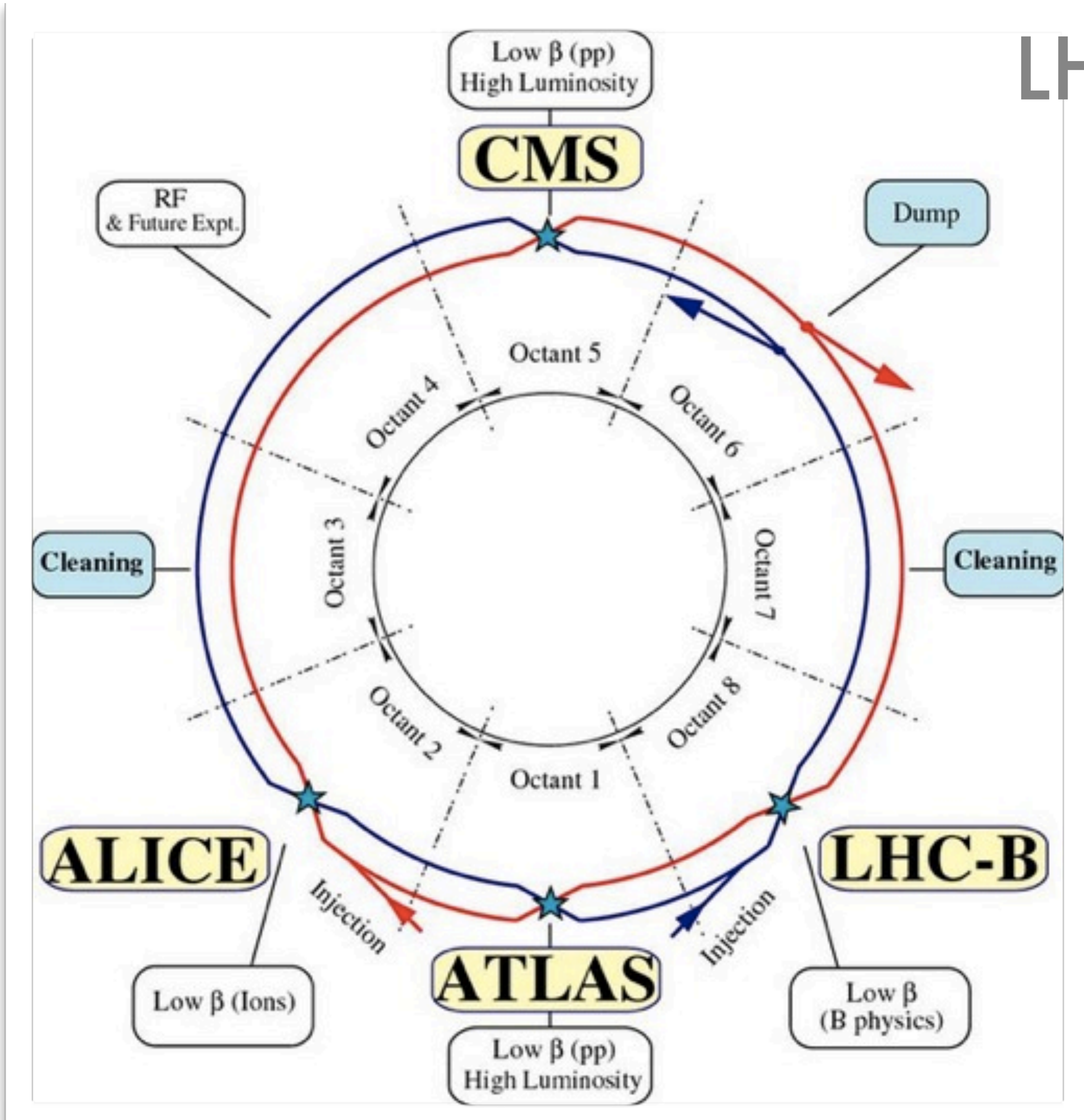


Discover by ATLAS and CMS group @CERN
Higgs-like particle



LHC(Large Hadron Collider)

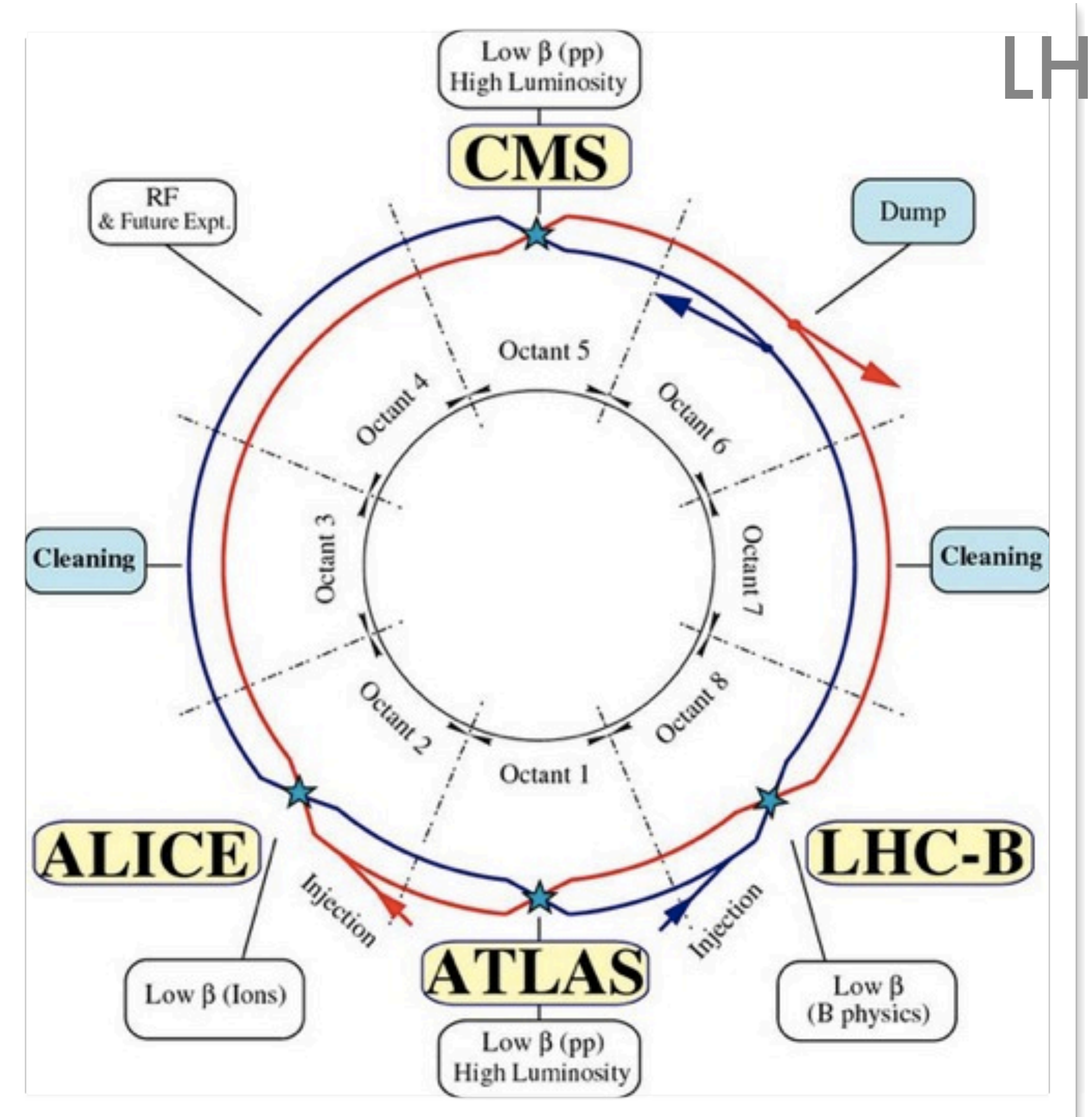
Discover by ATLAS and CMS group @CERN
Higgs-like particle



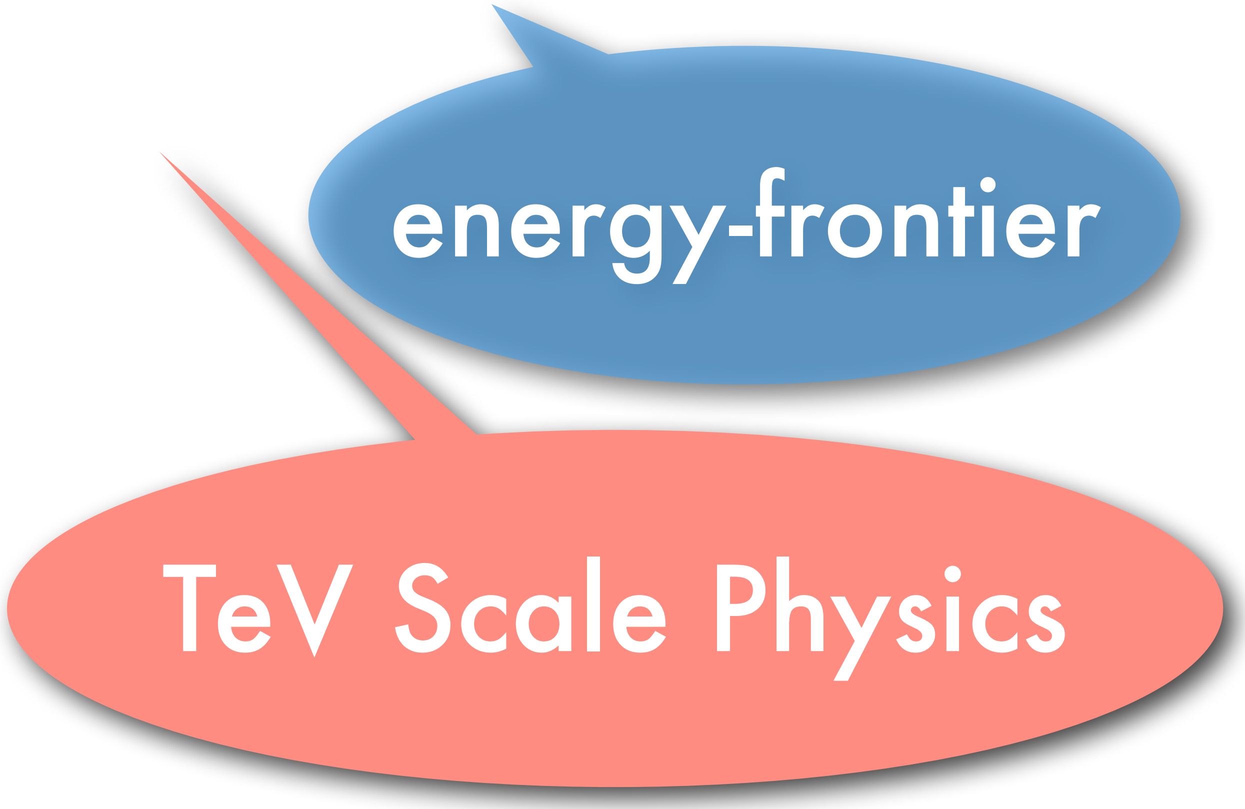
LHC(Large Hadron Collider)

energy-frontier

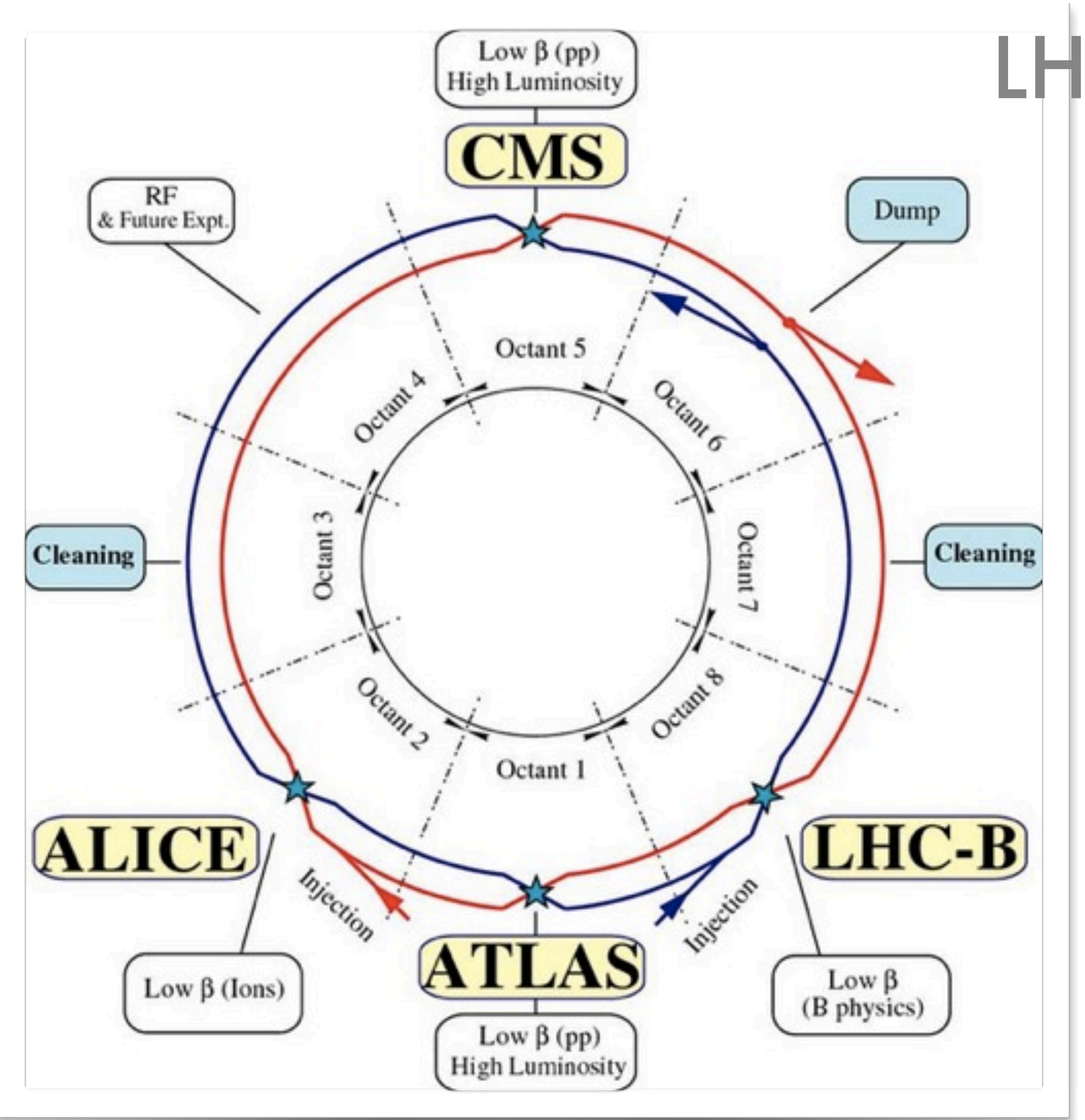
Discover by ATLAS and CMS group @CERN
Higgs-like particle



LHC(Large Hadron Collider)



Discover by ATLAS and CMS group @CERN
Higgs-like particle



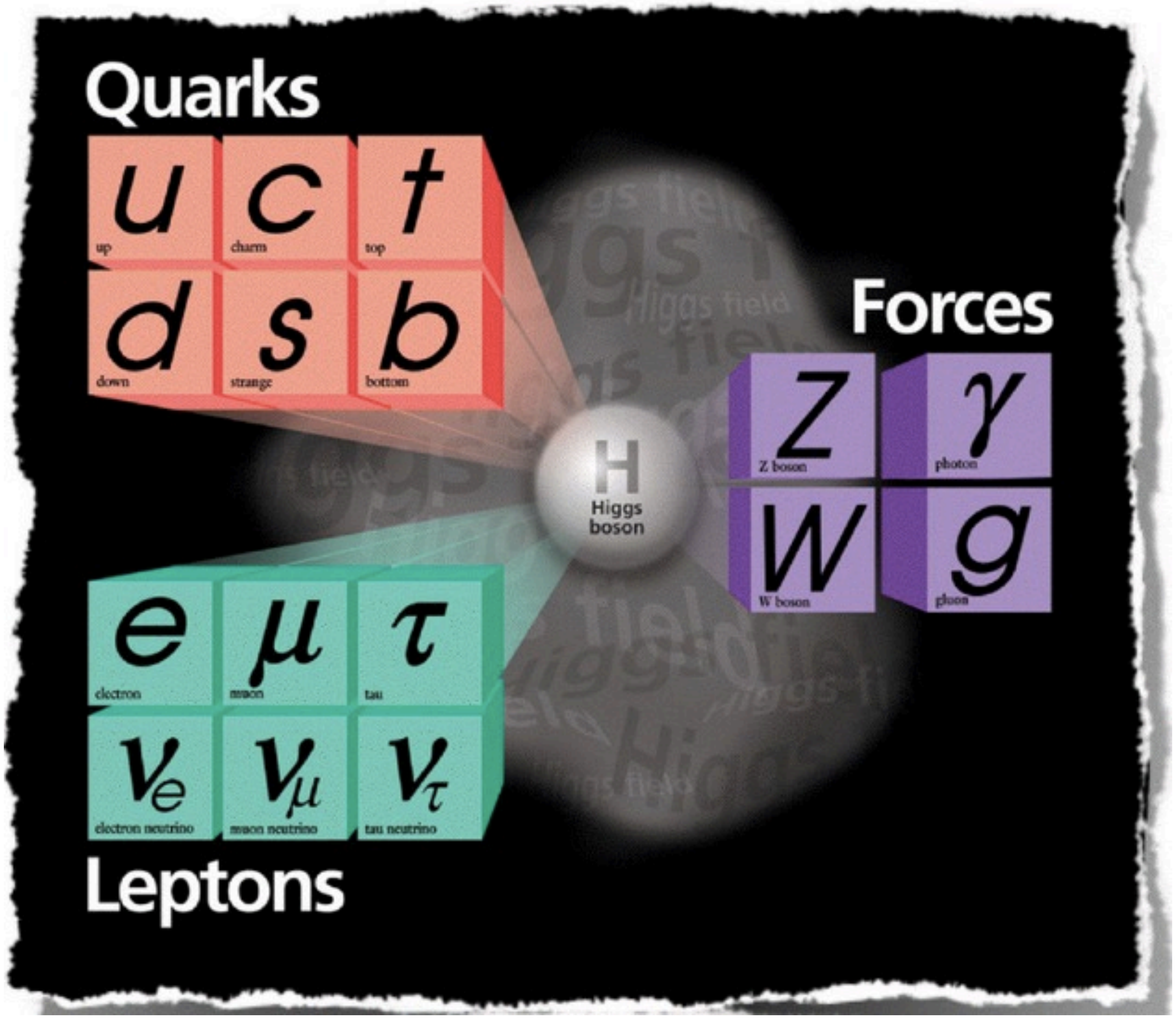
LHC(Large Hadron Collider)

energy-frontier

TeV Scale Physics

<u>125GeV</u>

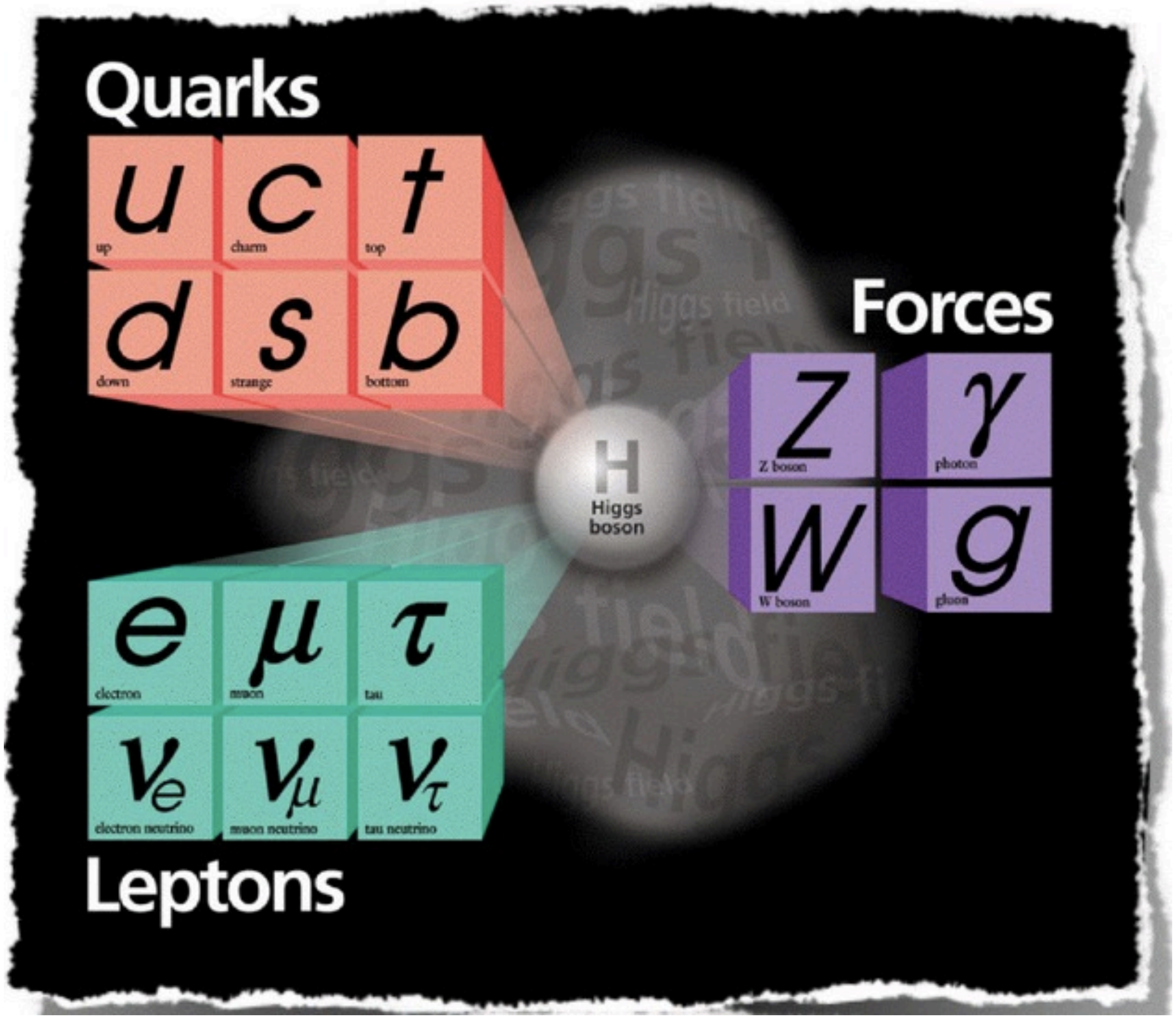
Standard Model(SM) complete?



Question:

1. Yes
2. No

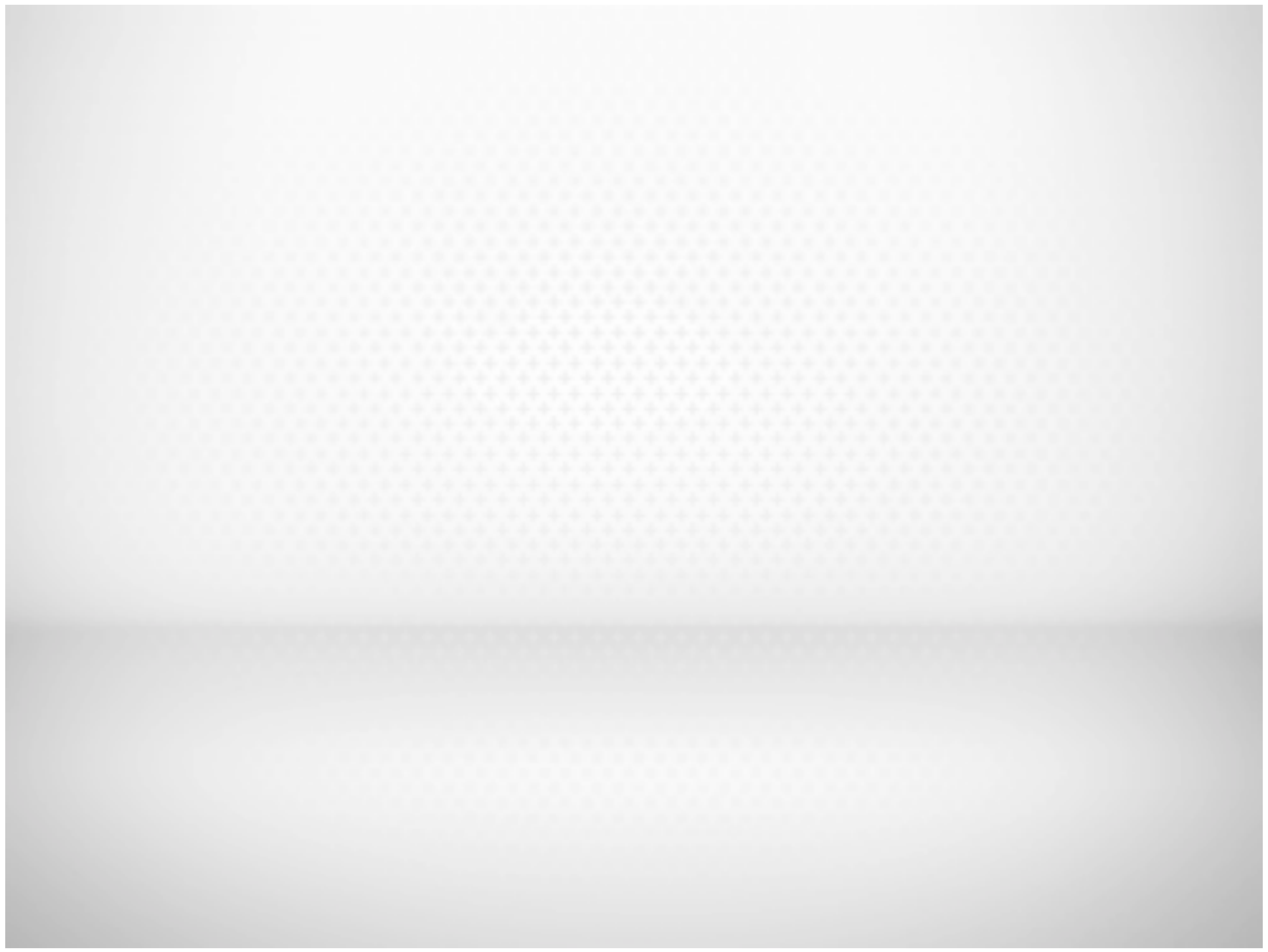
Standard Model(SM) complete?



Answer:

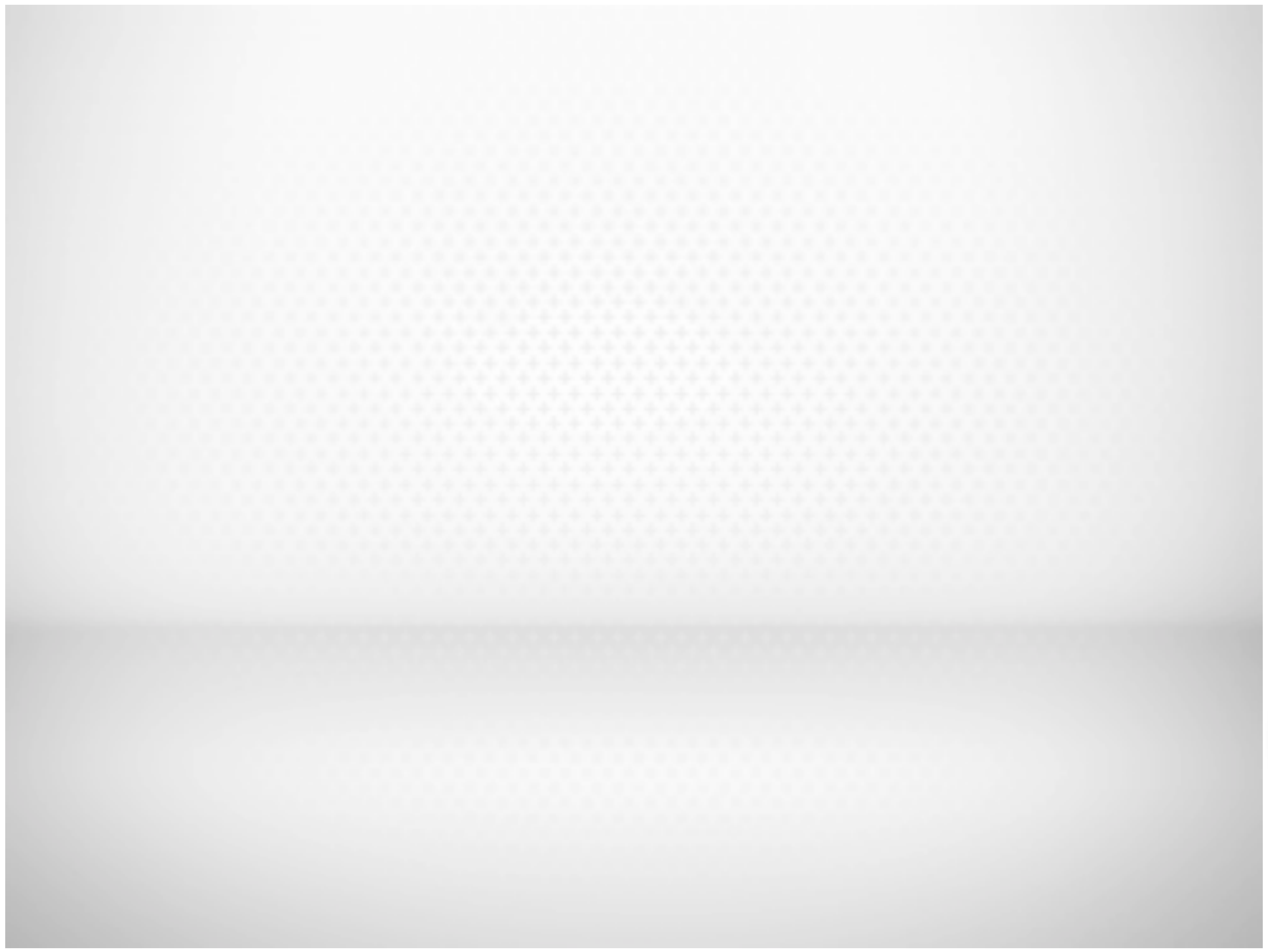
1. Yes
2. No

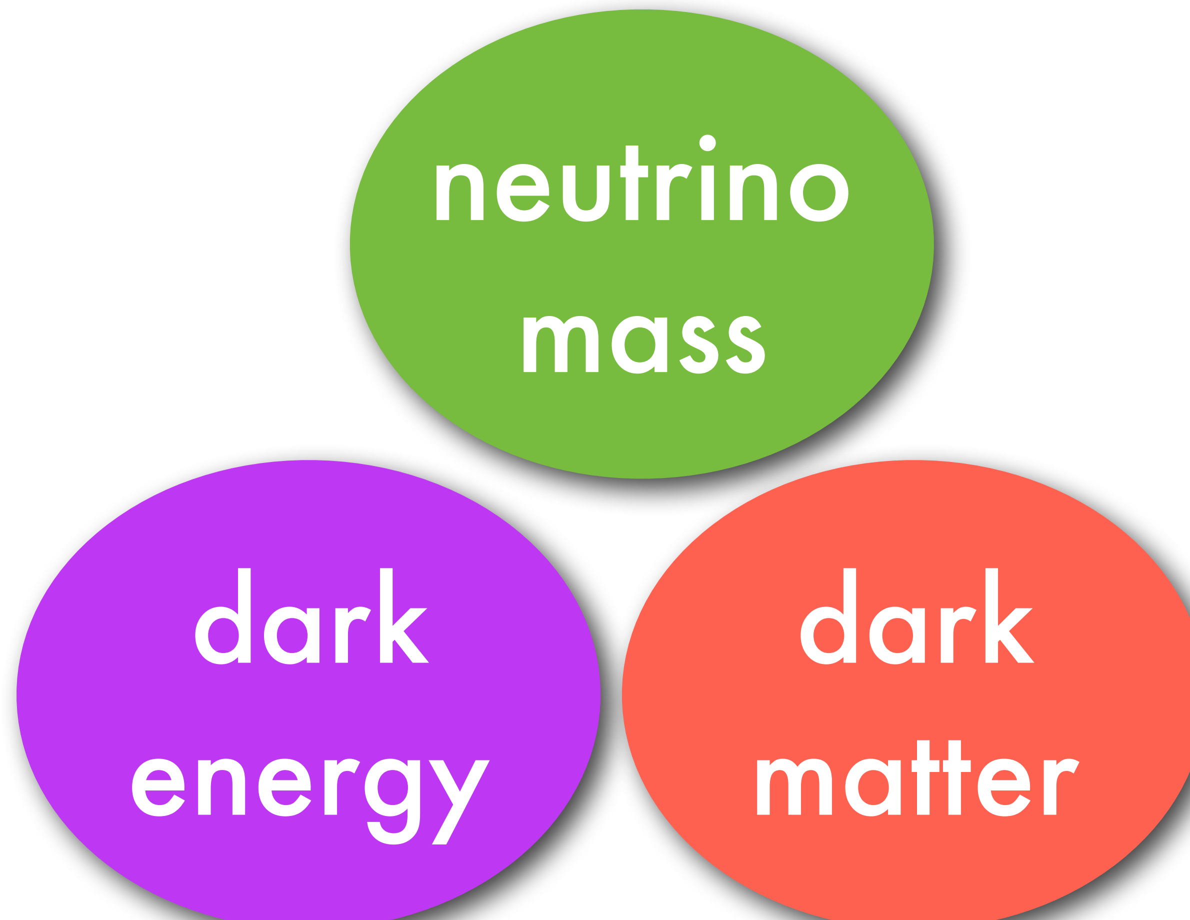
Standard Model(SM) complete?



Something Beyond Standard Model...

Standard Model(SM) complete?





Something Beyond Standard Model...

Standard Model(SM) complete?

neutrino mass

dark energy

dark matter

Something Beyond Standard Model...

Beyond Standard Model

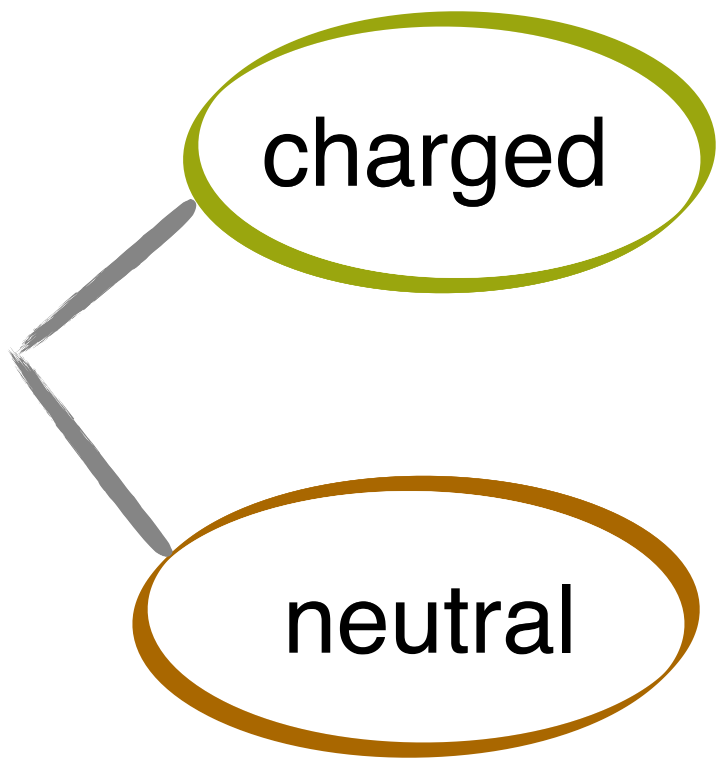
Let’s Check

SUSY

Next-to-Minimal Supersymmetric Standard Model (nMSSM)

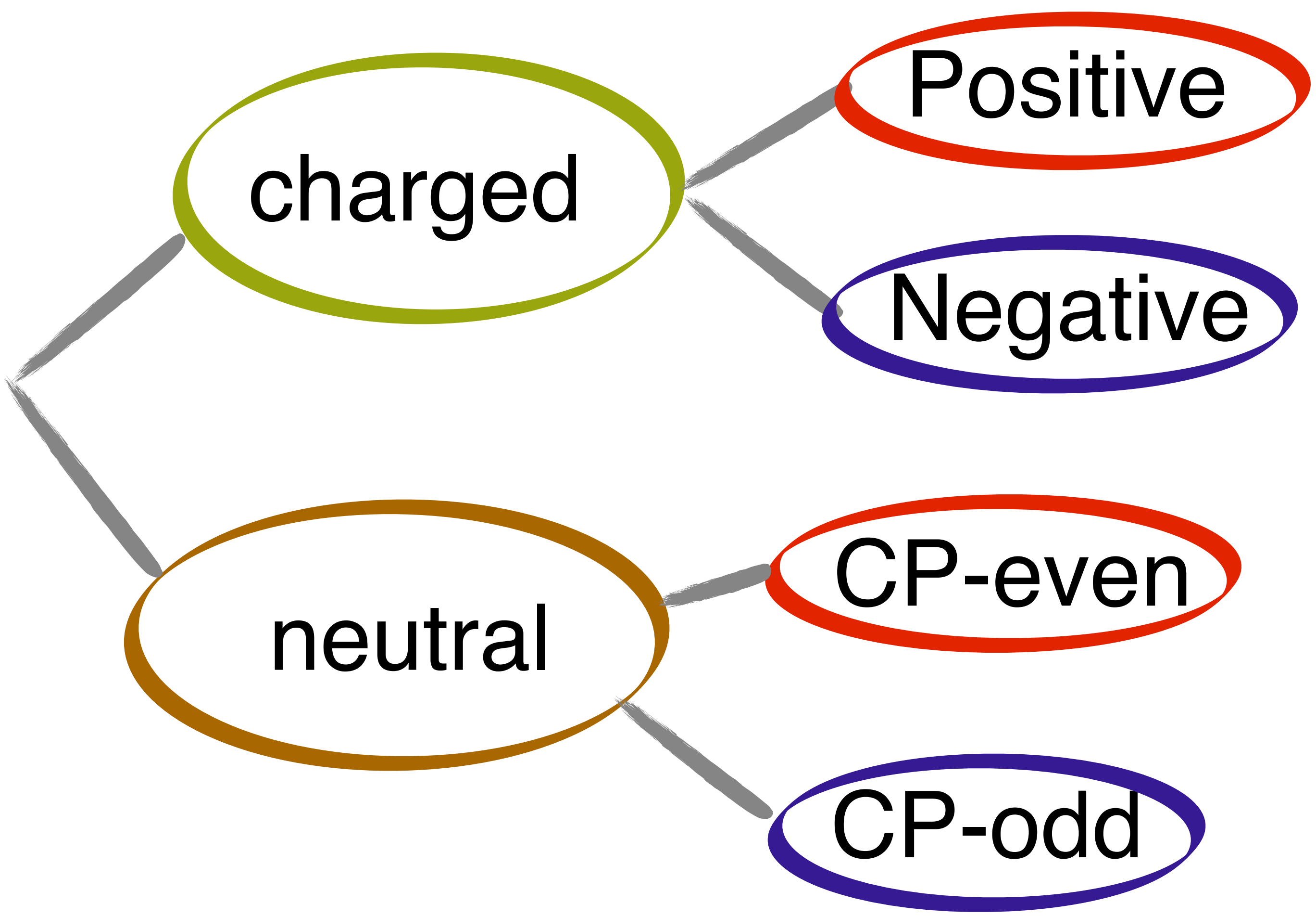
nMSSM

SUSY



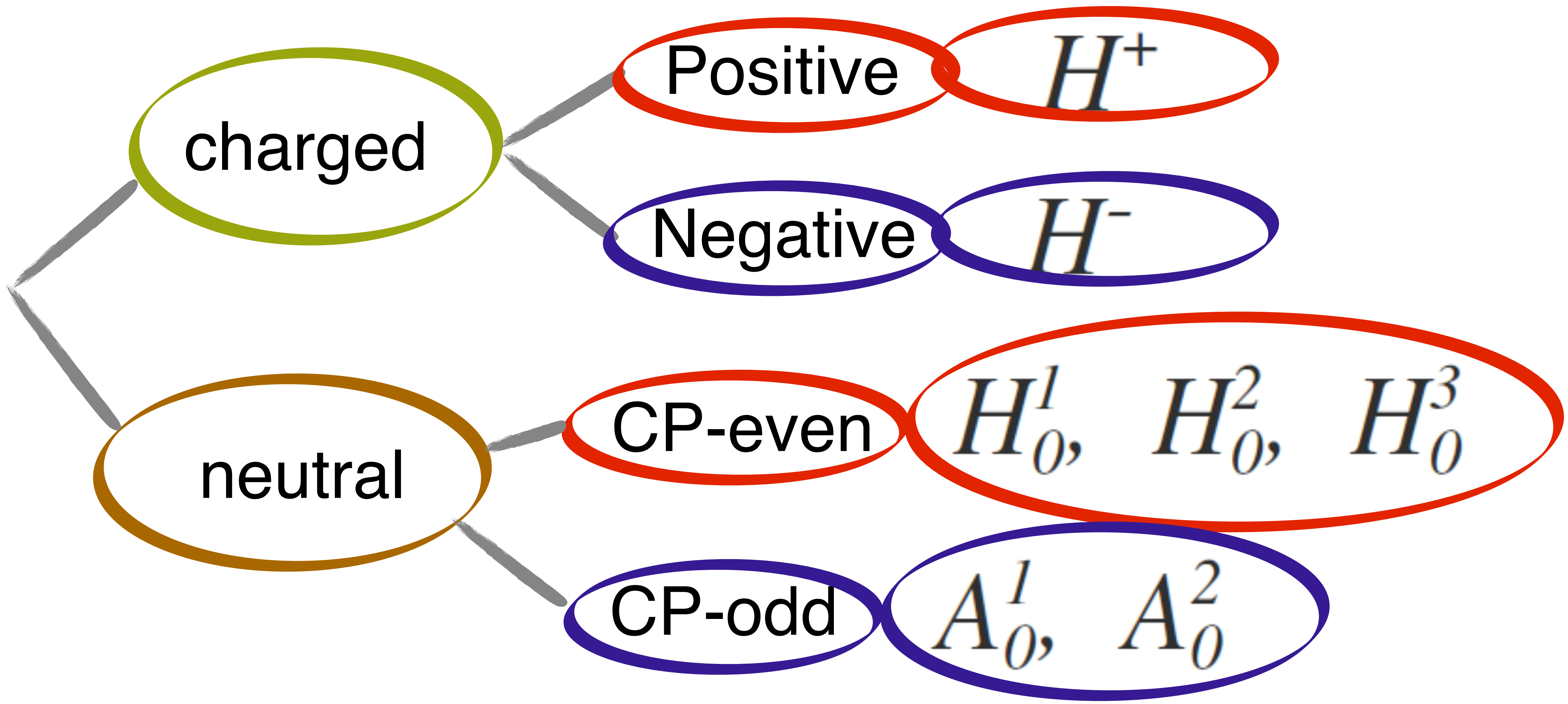
nMSSM

SUSY



nMSSM

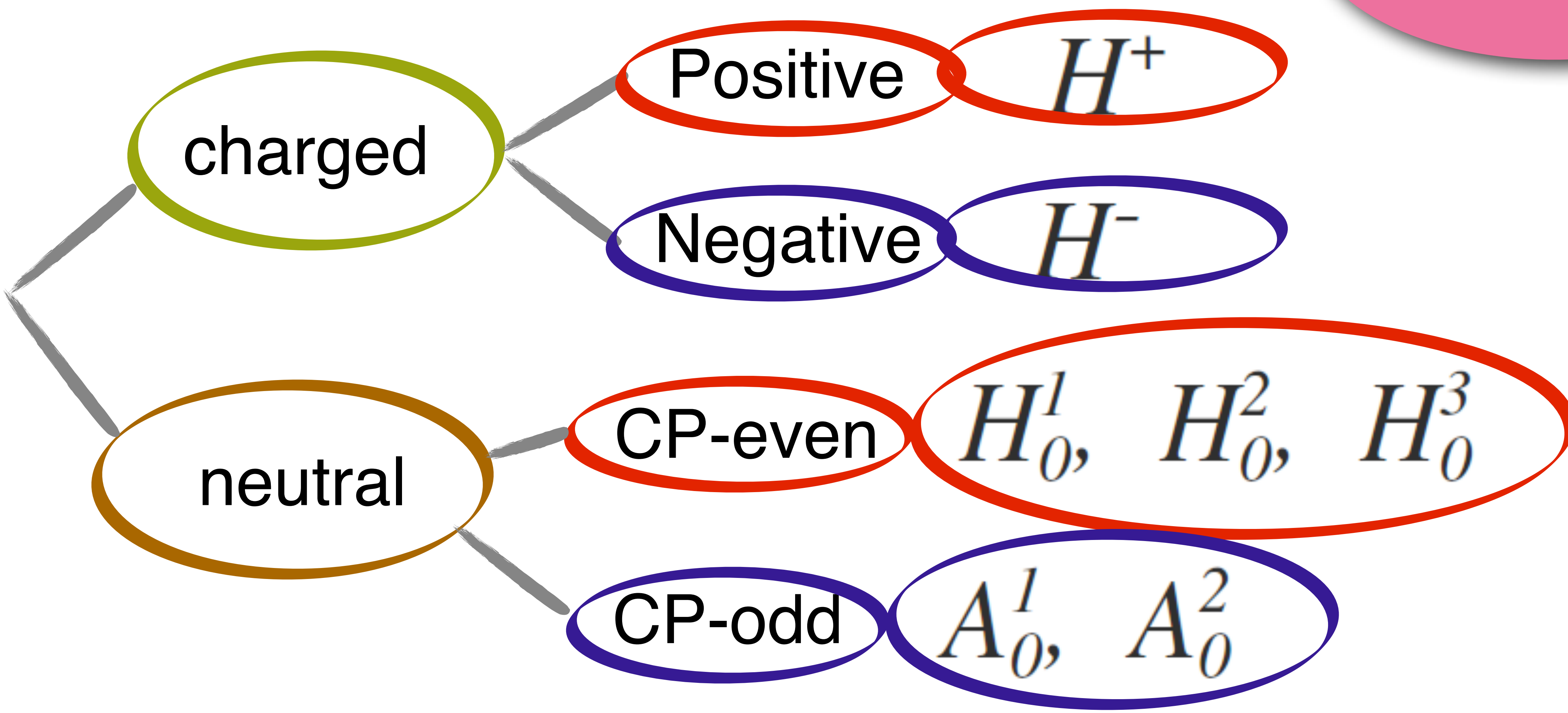
SUSY


charged
neutral
Positive
Negative
CP-even
CP-odd
H^+
H^-
H_0^1, H_0^2, H_0^3
A_0^1, A_0^2

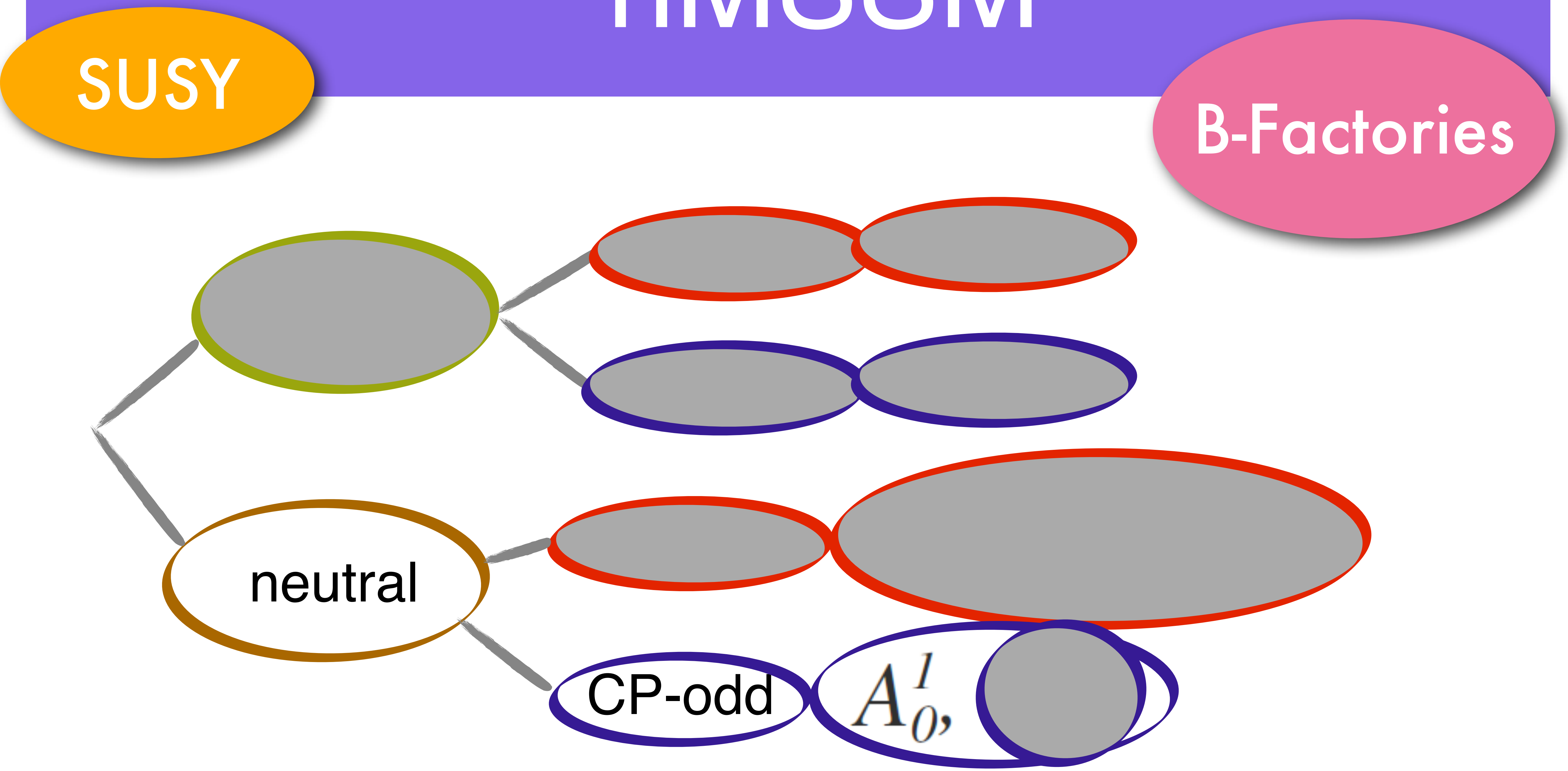
nMSSM

SUSY

B-Factories



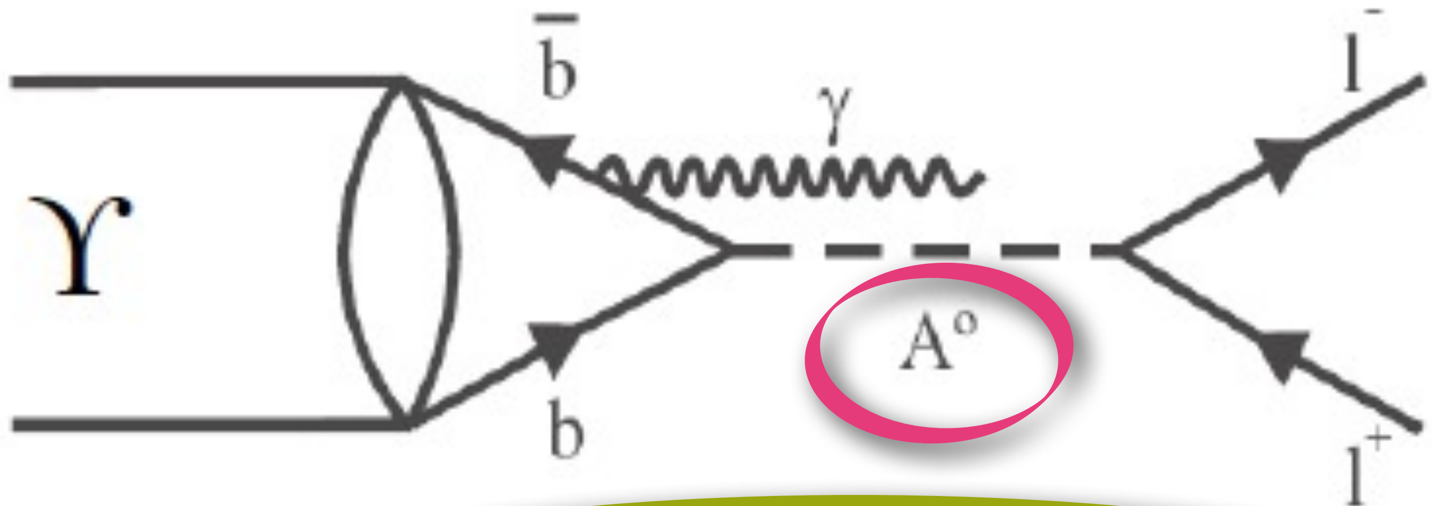
nMSSM



<u>light Higgs</u>: A_0^1

Searching for a CP-odd light Higgs

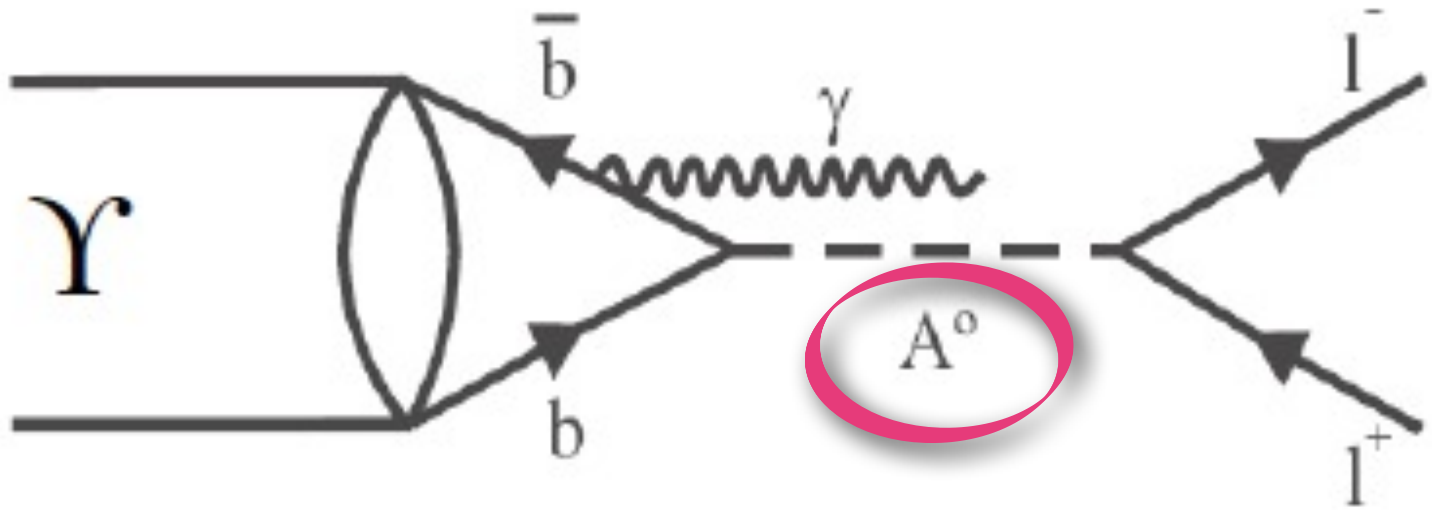
B-Factories



proposed by Dermíšek, Gunion, & McElrath in 2007

Searching for a CP-odd light Higgs

B-Factories



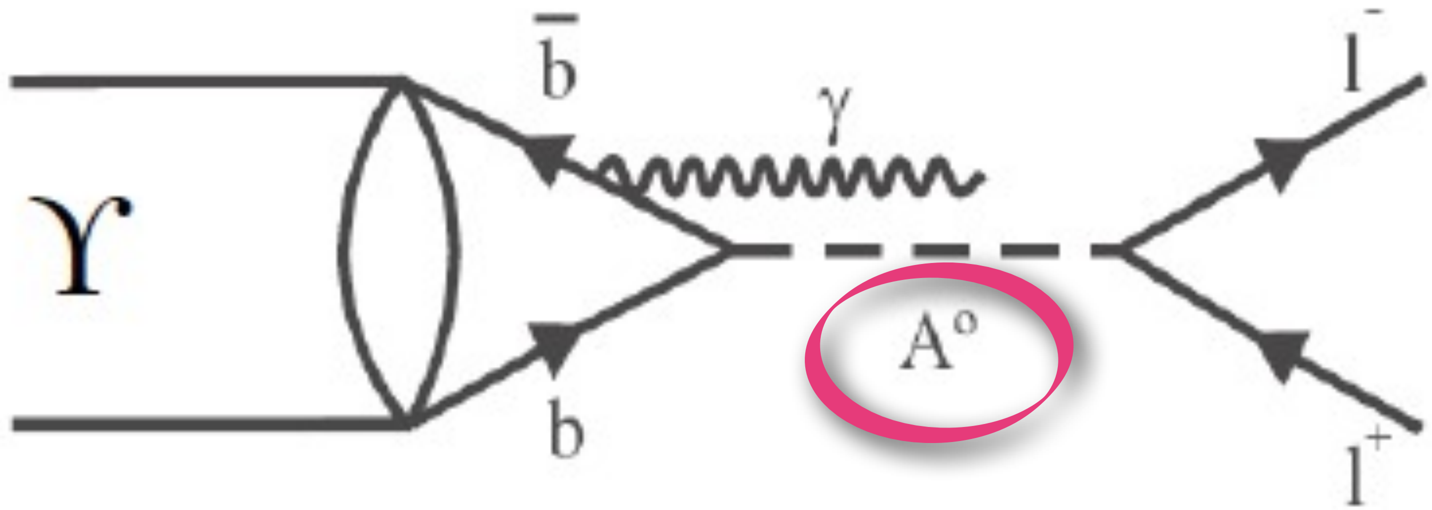
At e+e- colliders

Directly

in cascades

Searching for a CP-odd light Higgs

B-Factories



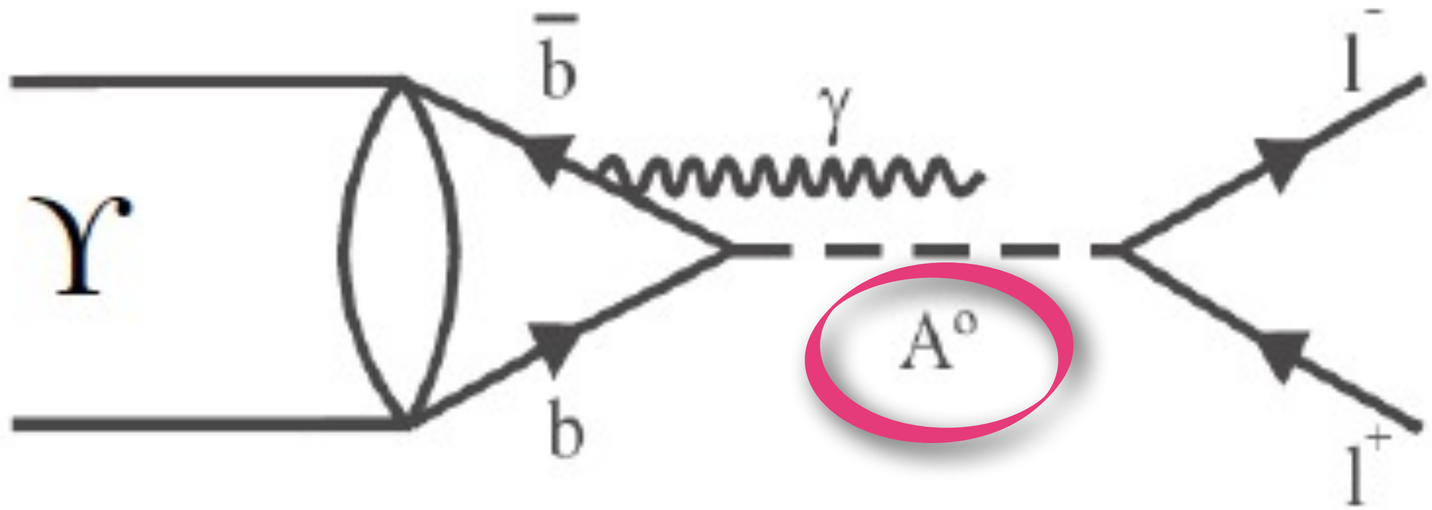
Directly

in cascades

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

Searching for a CP-odd light Higgs

B-Factories



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

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

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

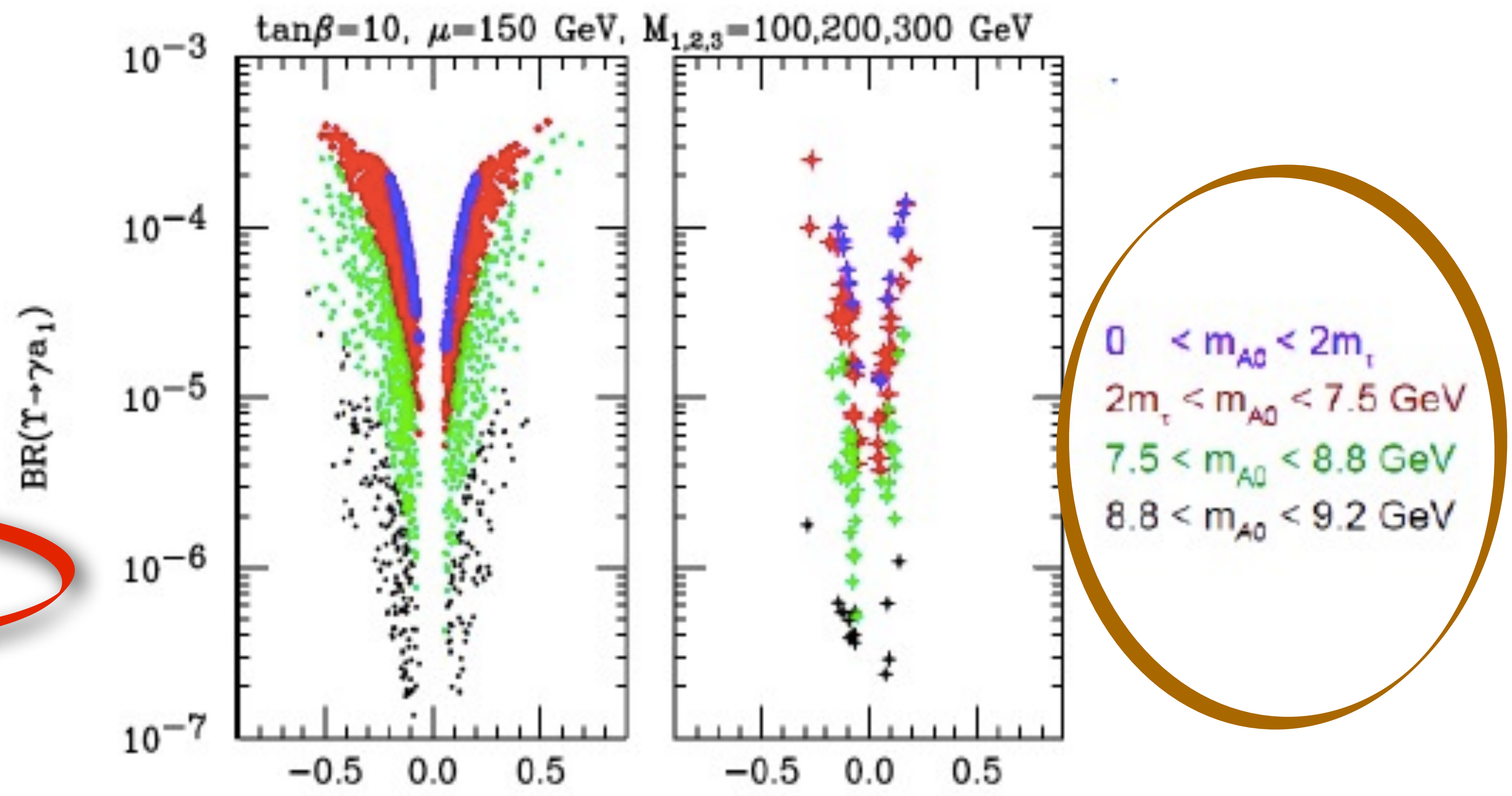
Searching for a CP-odd light Higgs

$$BR(\Upsilon \to \gamma A^0)$$

can be large

- up to 10^{-4}

Directly



two models, different parameter setting

Phys.Rev.D76:051105,2007

arXiv:hep-ph/0612031

Searching for a CP-odd light Higgs

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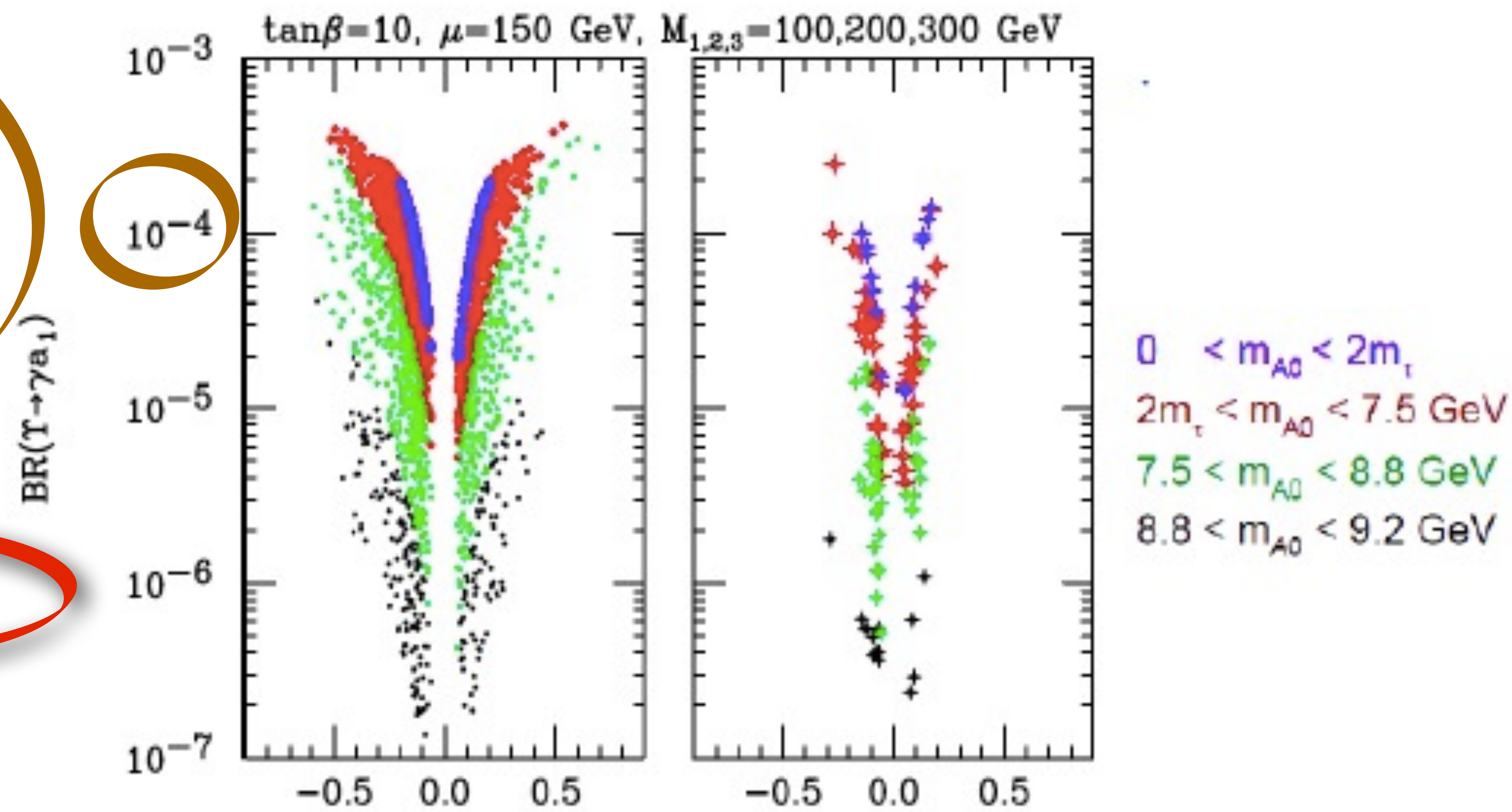
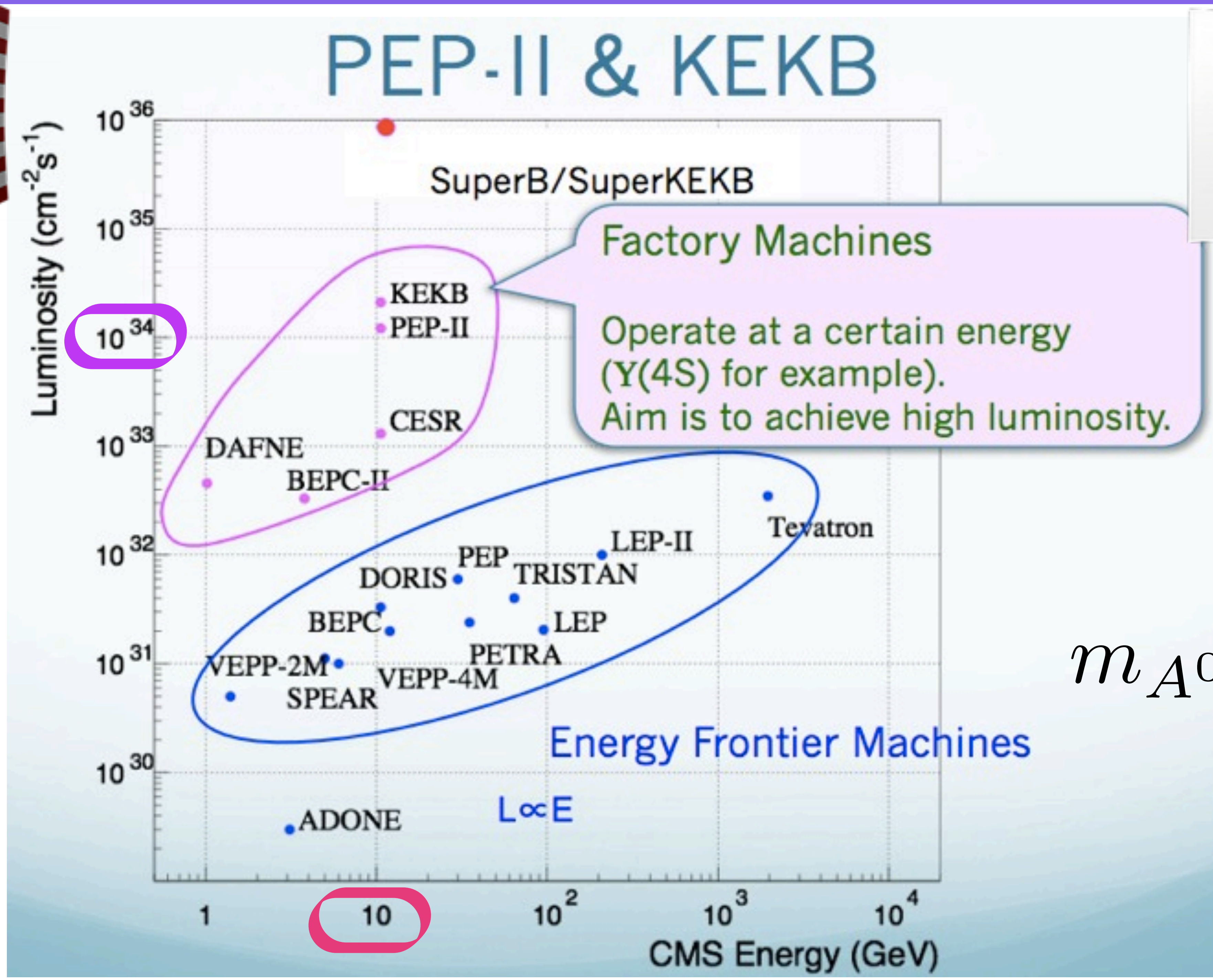


two models, different parameter setting

Phys.Rev.D76:051105,2007

arXiv:hep-ph/0612031

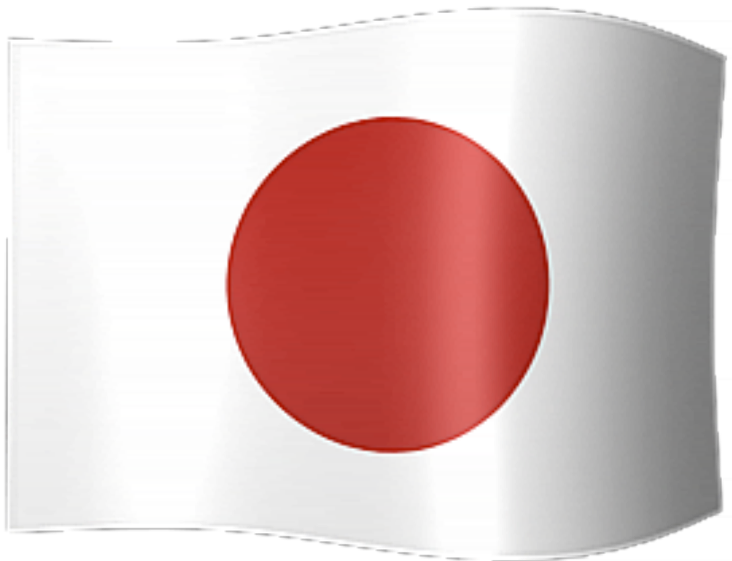
Accelerator of B-Factories



Light Higgs

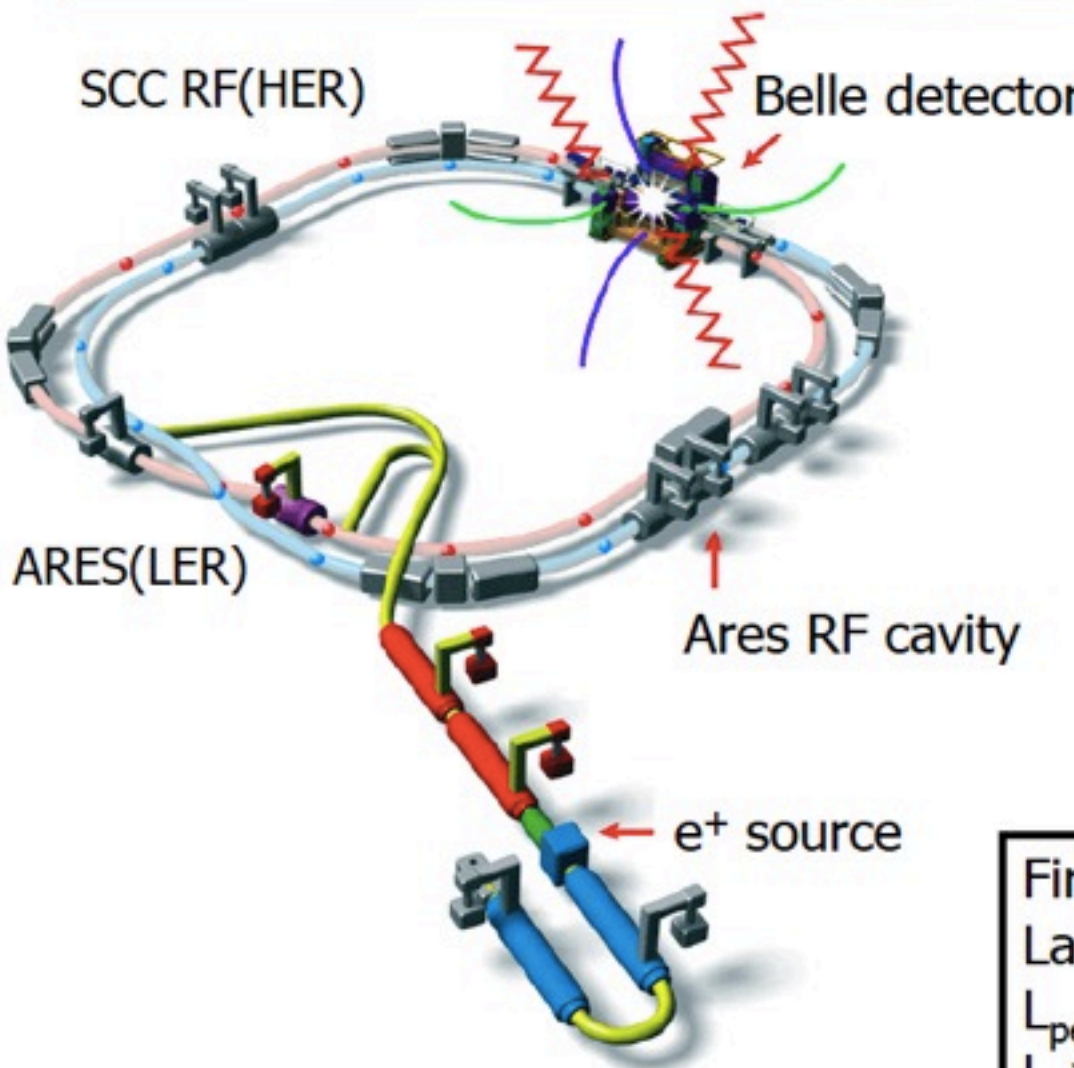
$$m_{A^0} < 2m_B$$

Detector of B-Factories



Belle

The KEKB Collider & Belle Detector



- e^- (8 GeV) on e^+(3.5 GeV)
  - $\sqrt{s} \approx m_{\Upsilon(4S)}$
  - Lorentz boost: $\beta\gamma=0.425$
- 22 mrad crossing angle
- Operating since 1999

Peak luminosity (WR!) :

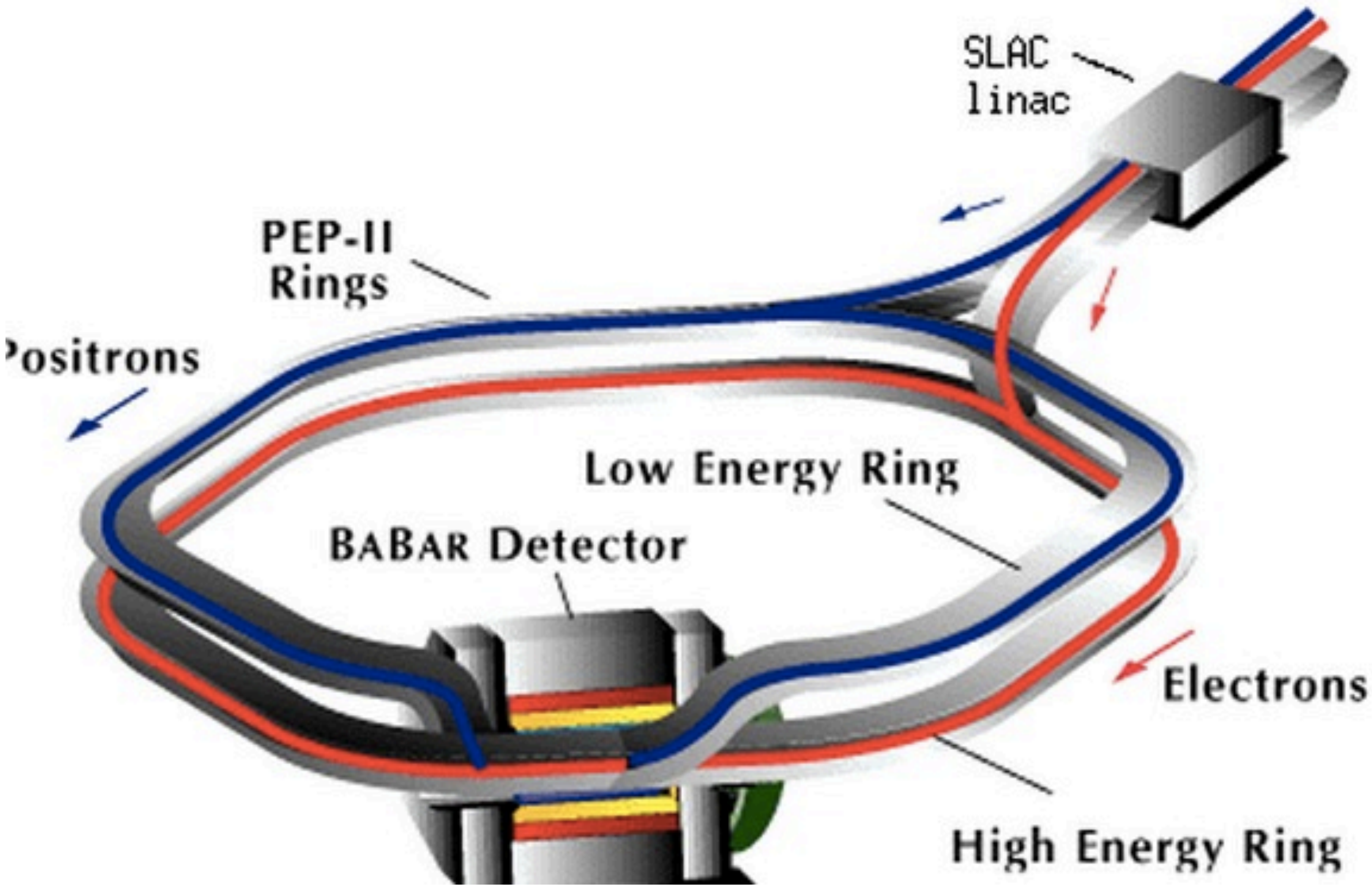
$2.1 \times 10^{34}\ cm^{-2}s^{-1}$

=2x design value

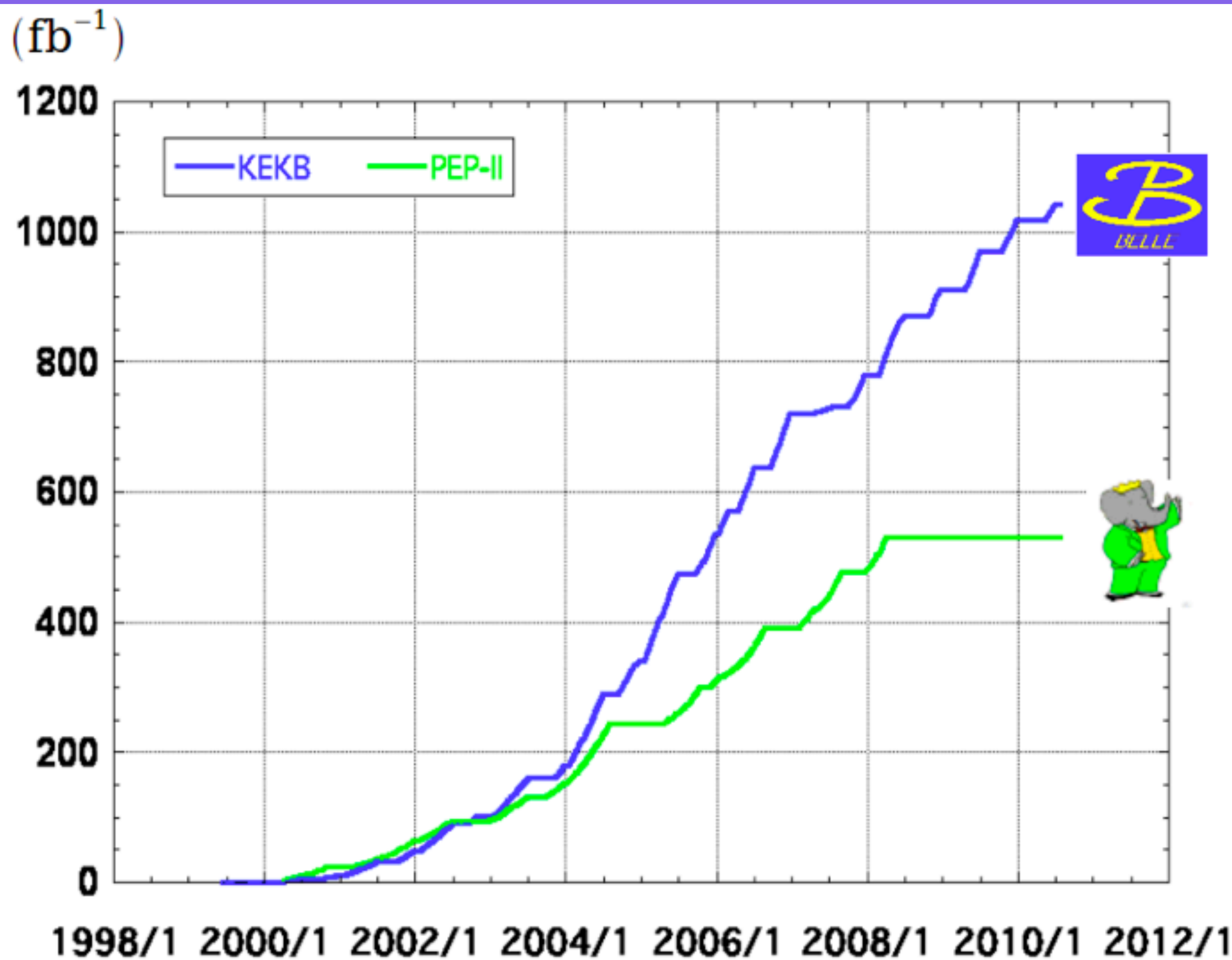
First physics run on June 2, 1999
Last physics run on June 30, 2010
$L_{peak} = 2.1\text{x}10^{34}/cm^2/s$
$L > 1ab^{-1}$

Detector of B-Factories

BaBar



Samples at B factories



> 1 ab^{-1}

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 25 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan:

$\sim$ 100 fb^{-1}

~ 550 fb^{-1}

On resonance:

$\Upsilon(4S)$: 433 fb^{-1}

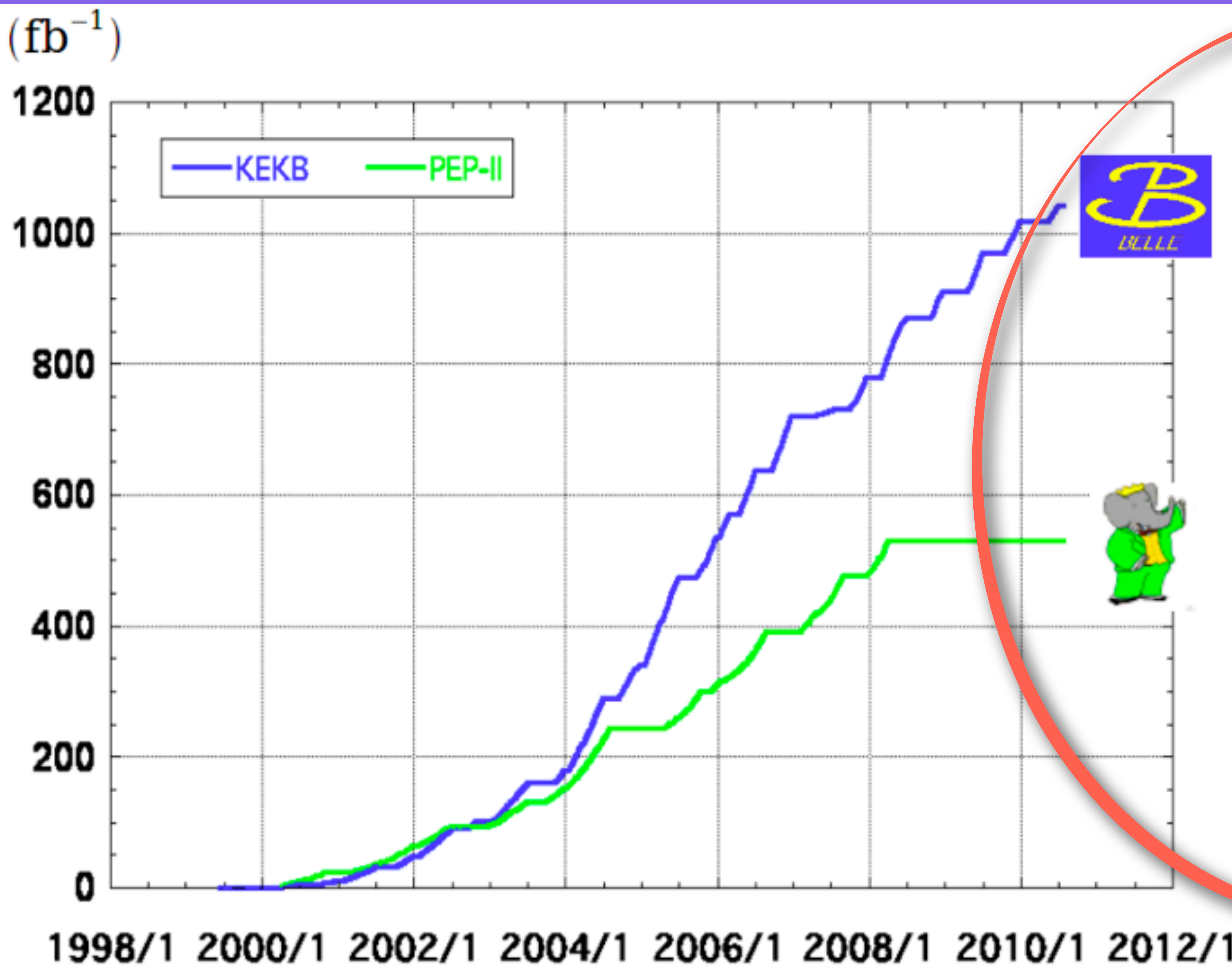
$\Upsilon(3S)$: 30 fb^{-1}

$\Upsilon(2S)$: 14 fb^{-1}

Off resonance:

$\sim$ 54 fb^{-1}

Samples at B factories



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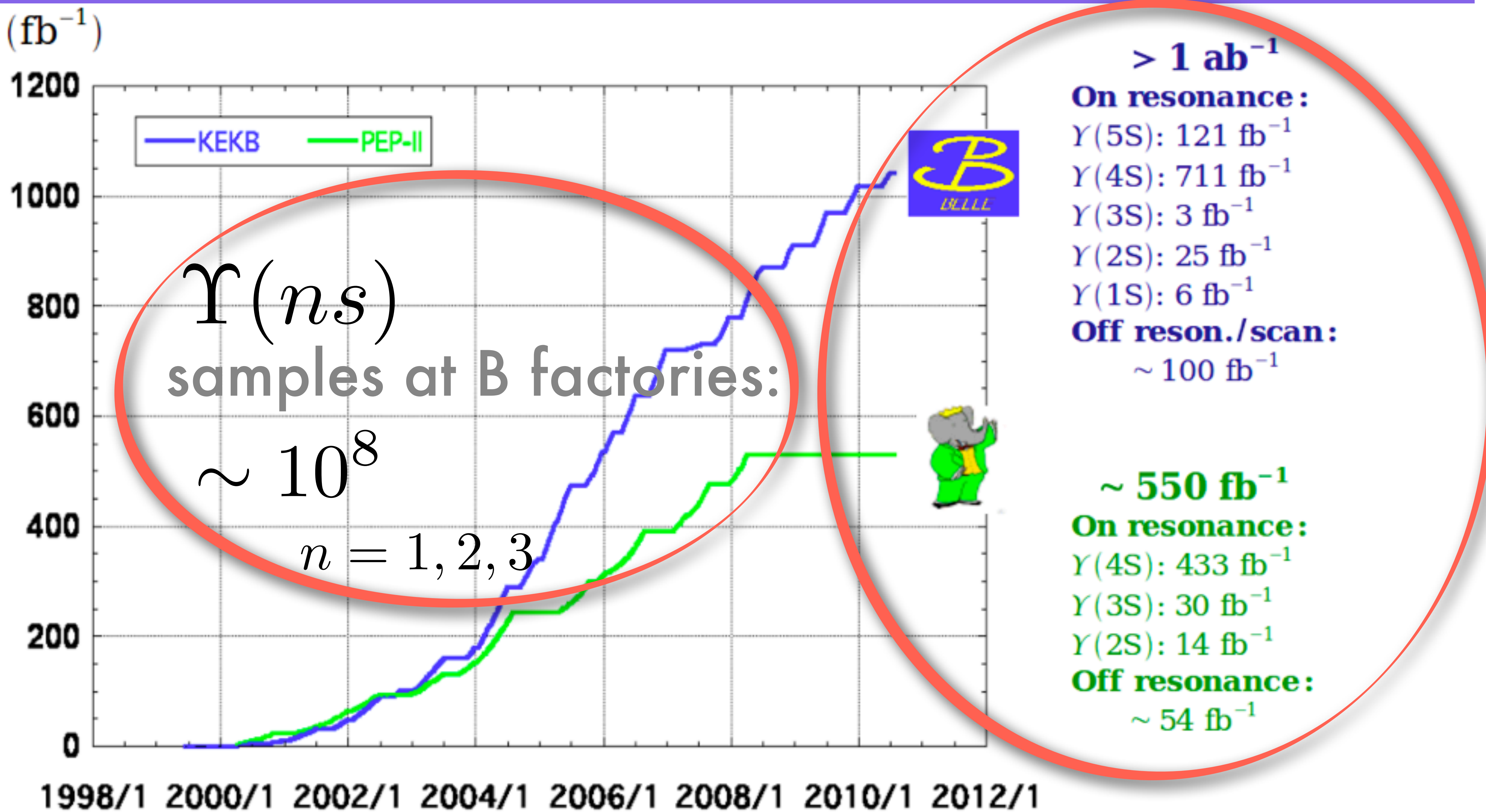
Off resonance:

~ 54 fb^{-1}

Samples at B factories

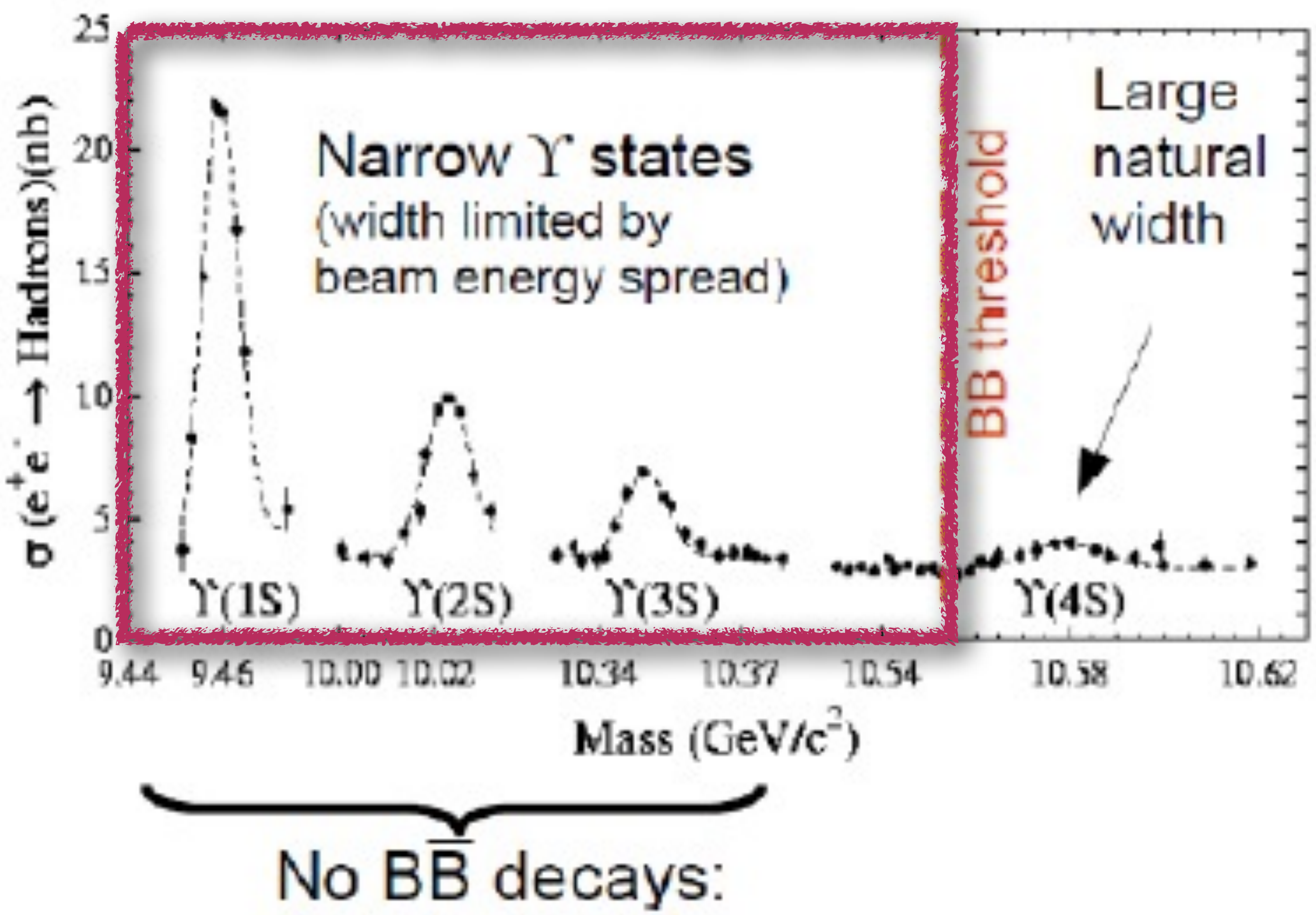


$\Upsilon(ns)$ samples at B factories:

$\sim 10^8$

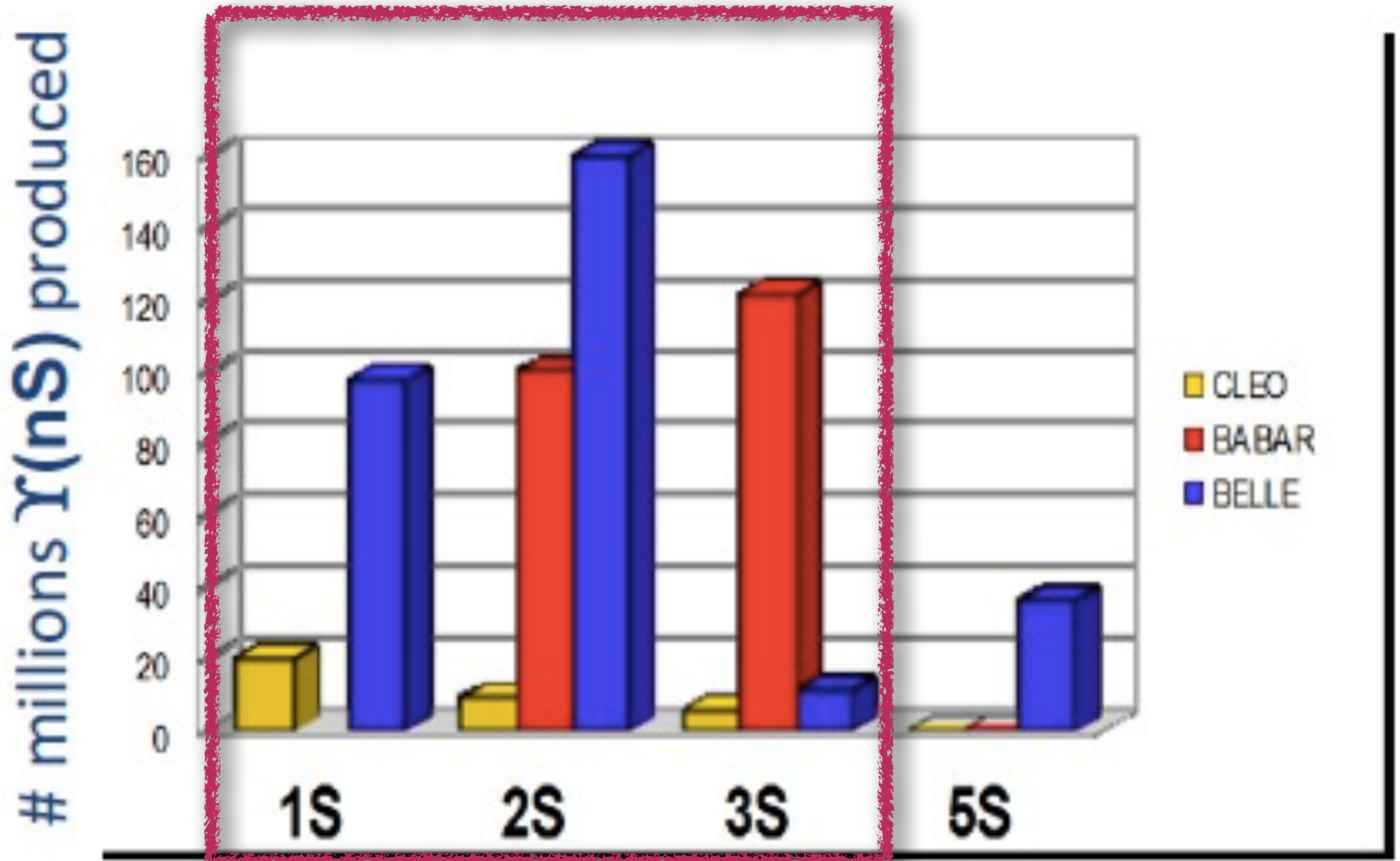
$n = 1, 2, 3$

Upsilon 1S, 2S, 3S samples



Selections

Upsilon 1S, 2S, 3S samples



Selections

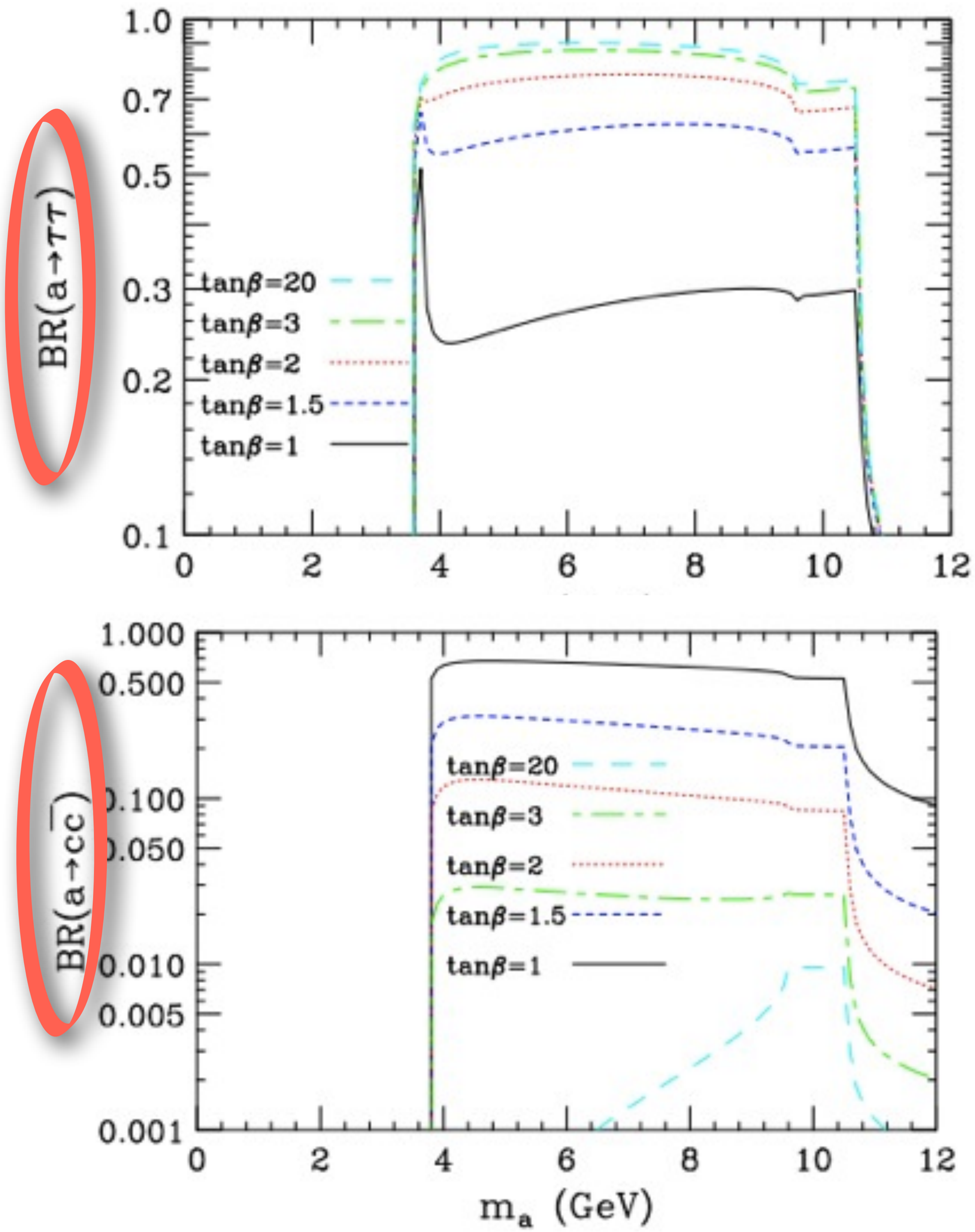
Expected A^0 Decays in nMSSM

Preferred decays
depend on A^0 mass &
model parameters

Phys.Rev.D81:075003,2010
arXiv:1002.1971

Expected A^0 Decays in nMSSM

$for\ m_{A^0} > 2m_\tau,$
$\tau\tau\ and\ hadronic$
$c\bar{c}$



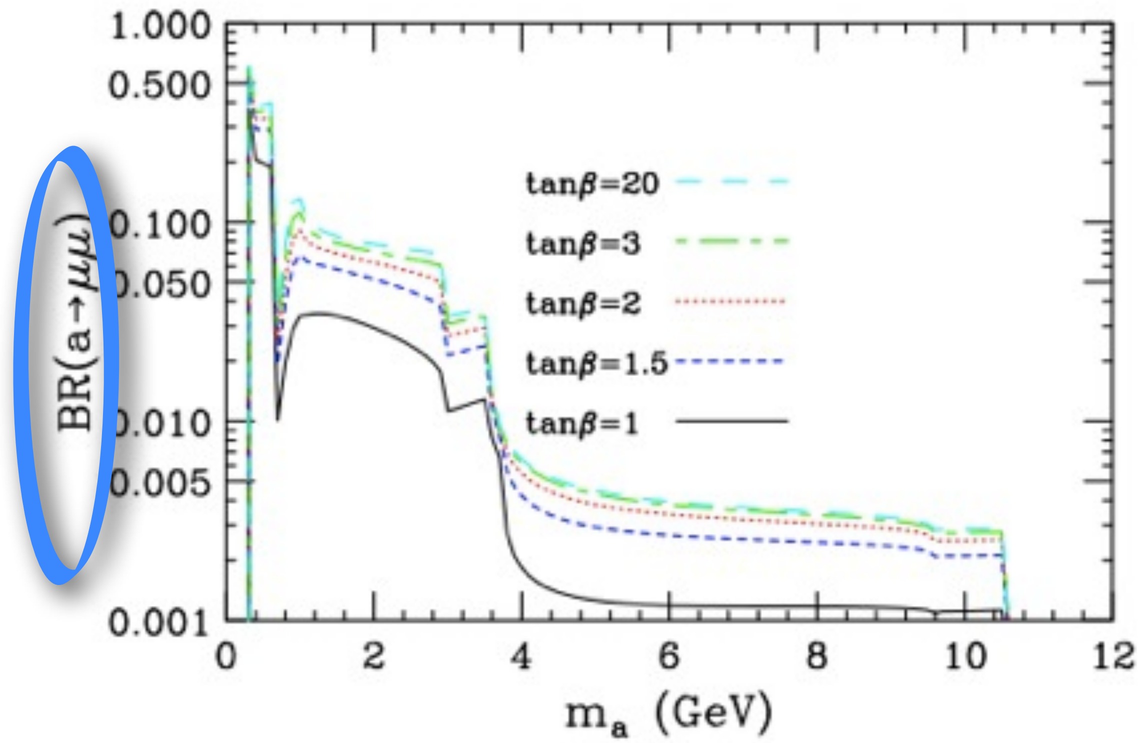
Phys.Rev.D81:075003,2010
arXiv:1002.1971

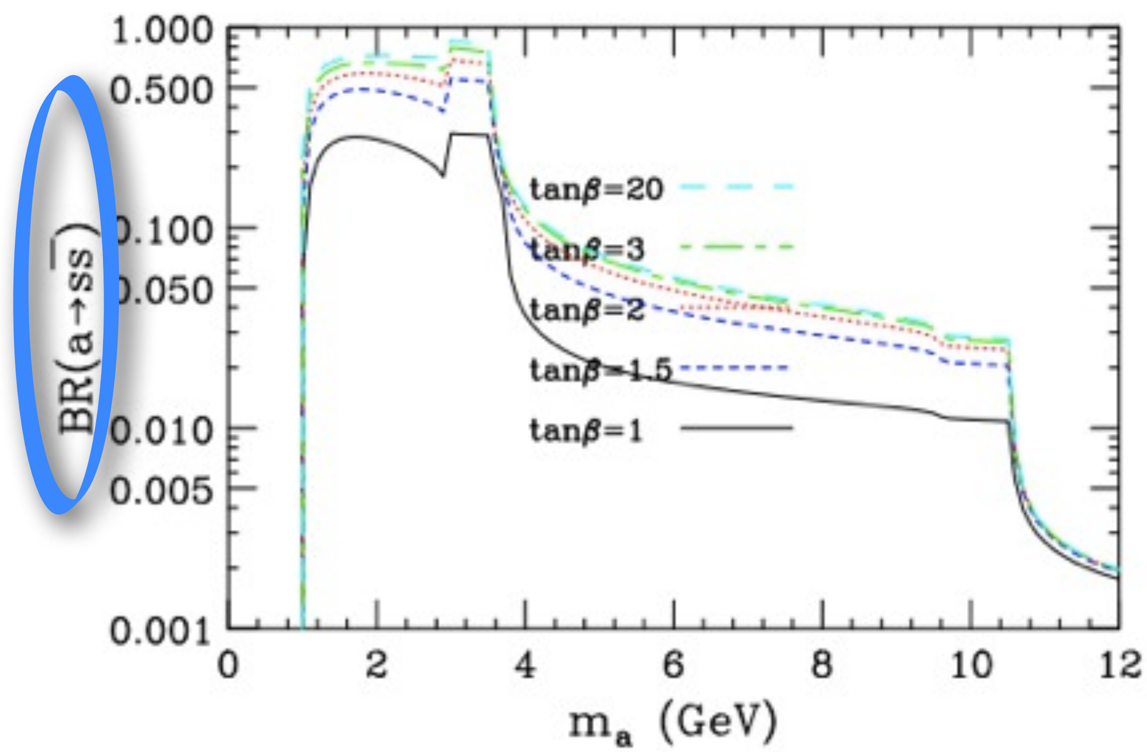
Expected A^0 Decays in nMSSM

$for \ m_{A^0} > 2m_\tau,$
$\tau\tau \ and \ hadronic$
$c\bar{c}$

$for \ lower \ m_{A^0},$
$\mu\mu \ and \ hadronic$
$s\bar{s}$

Phys.Rev.D81:075003,2010
arXiv:1002.1971





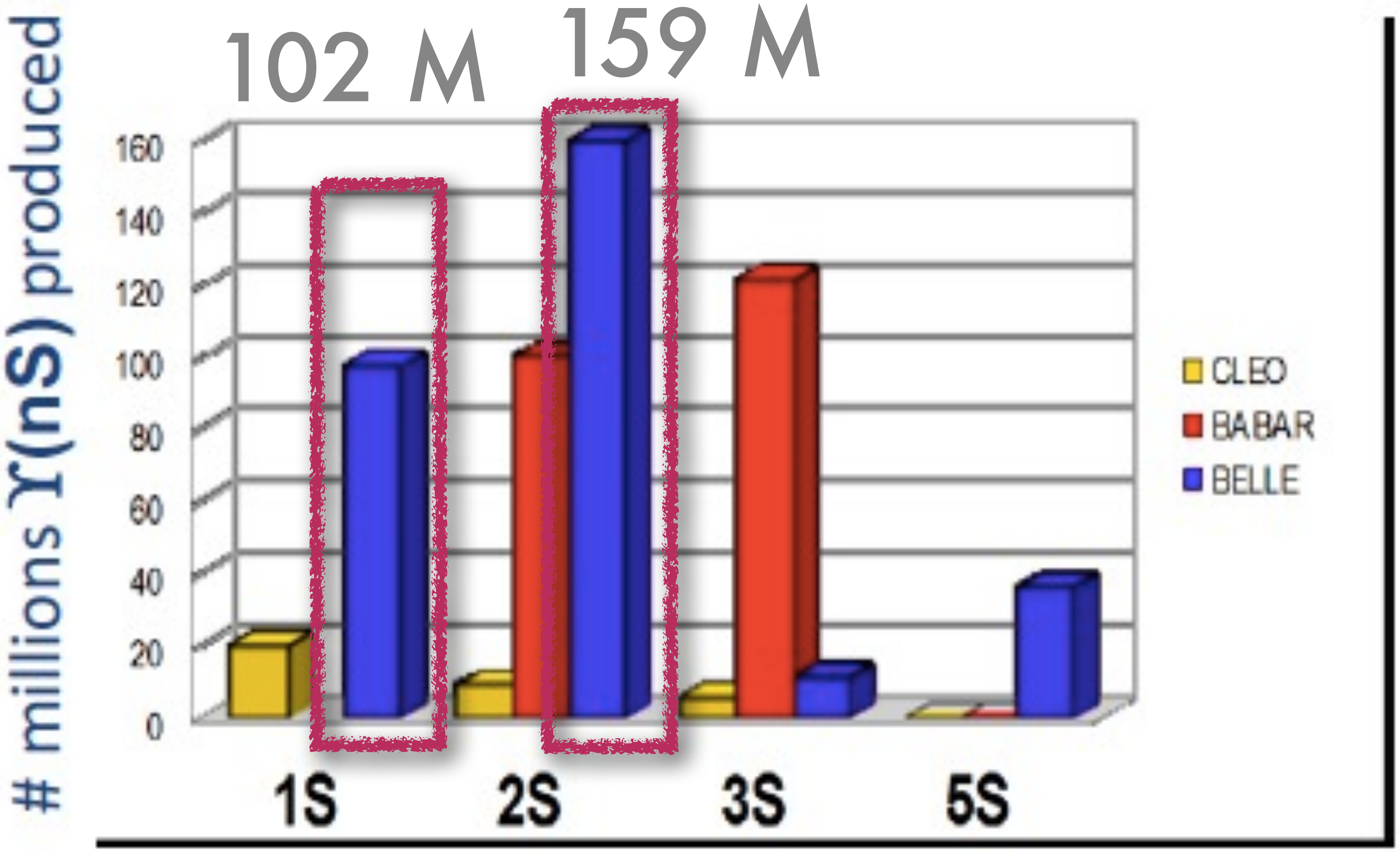
Belle & BaBar

Belle Preliminary

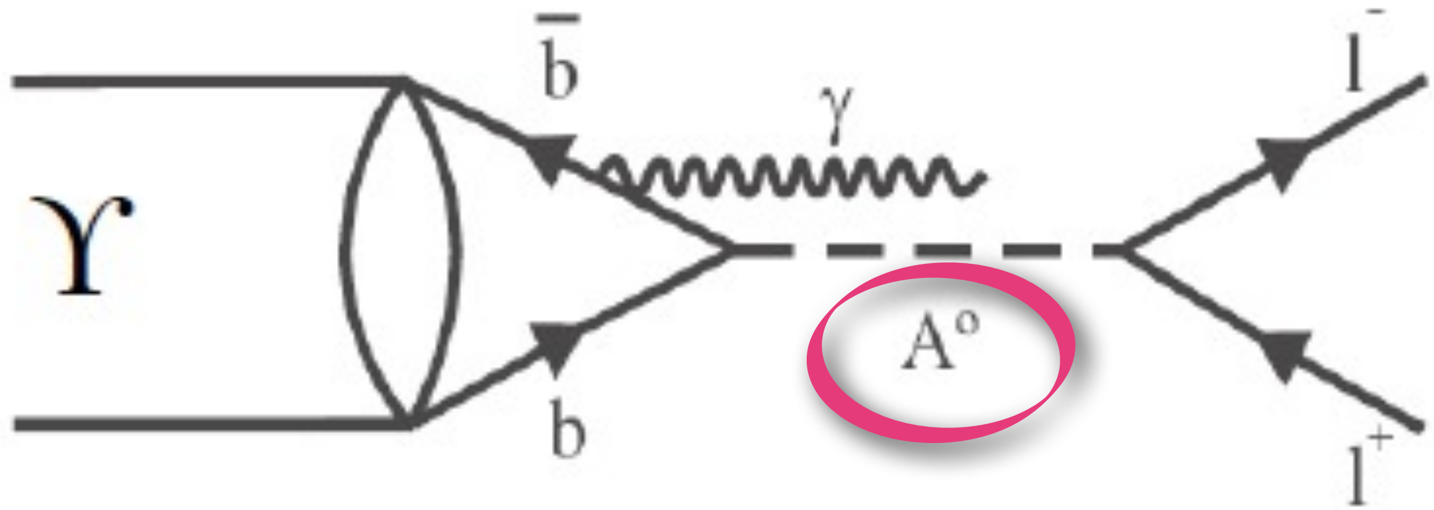
Samples at Belle

$\Upsilon(1s)$ $\Upsilon(2s)$

102 M 159 M



Belle Preliminary



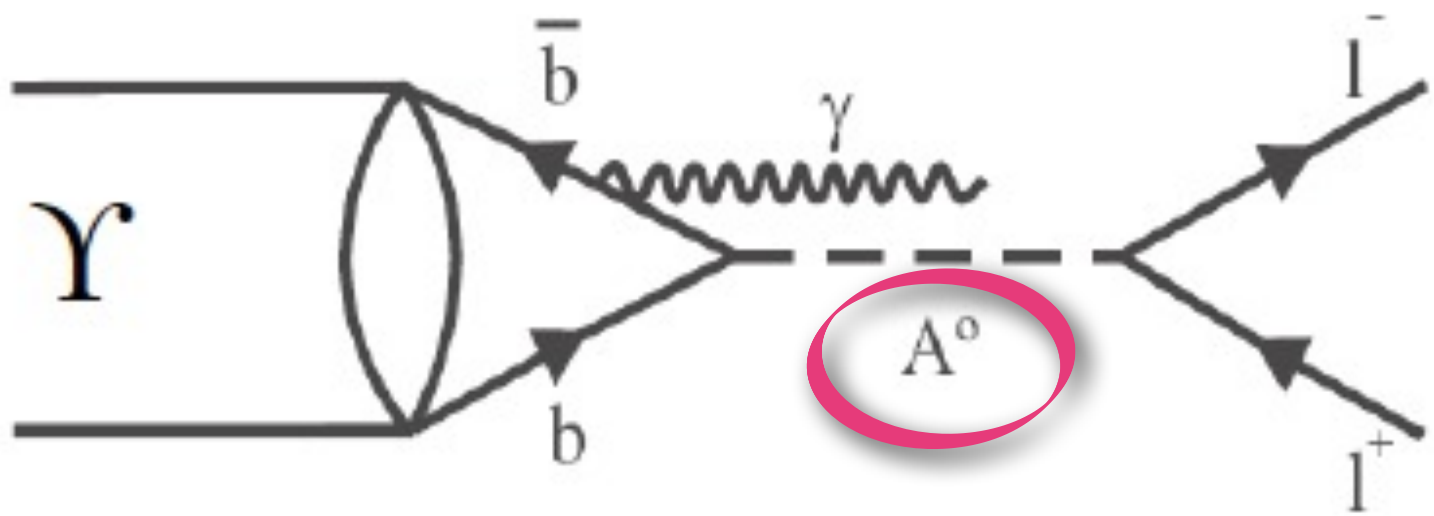
At e+e- colliders

Directly

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

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

Belle Preliminary



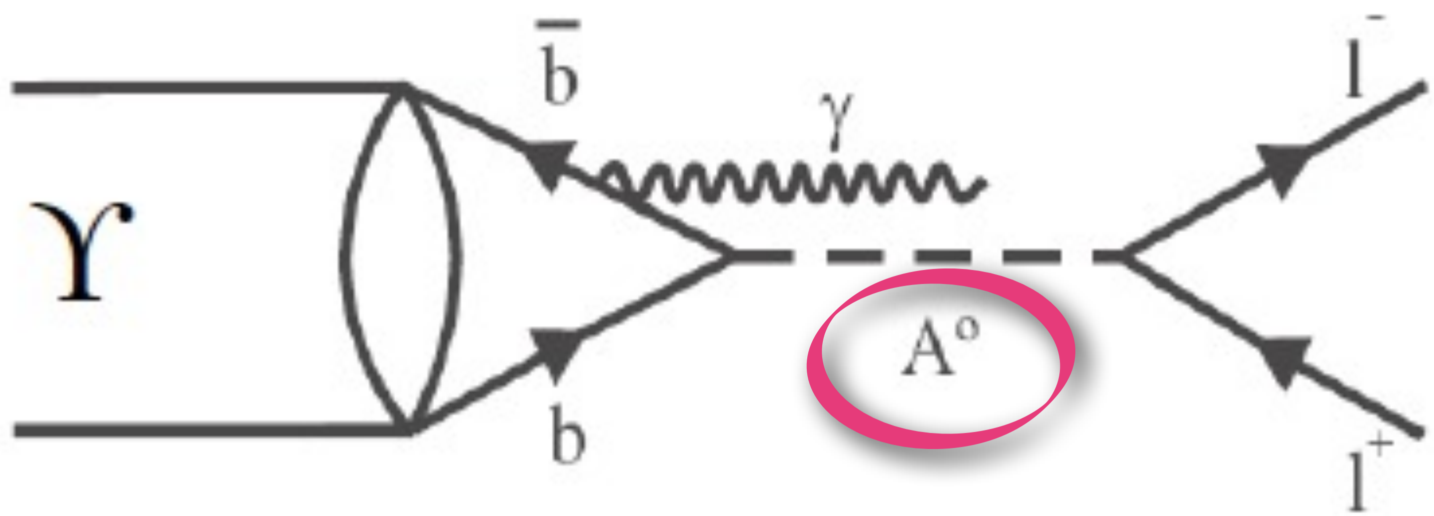
Directly

At e+e- colliders

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

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

Belle Preliminary



At e+e- colliders

in cascades

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

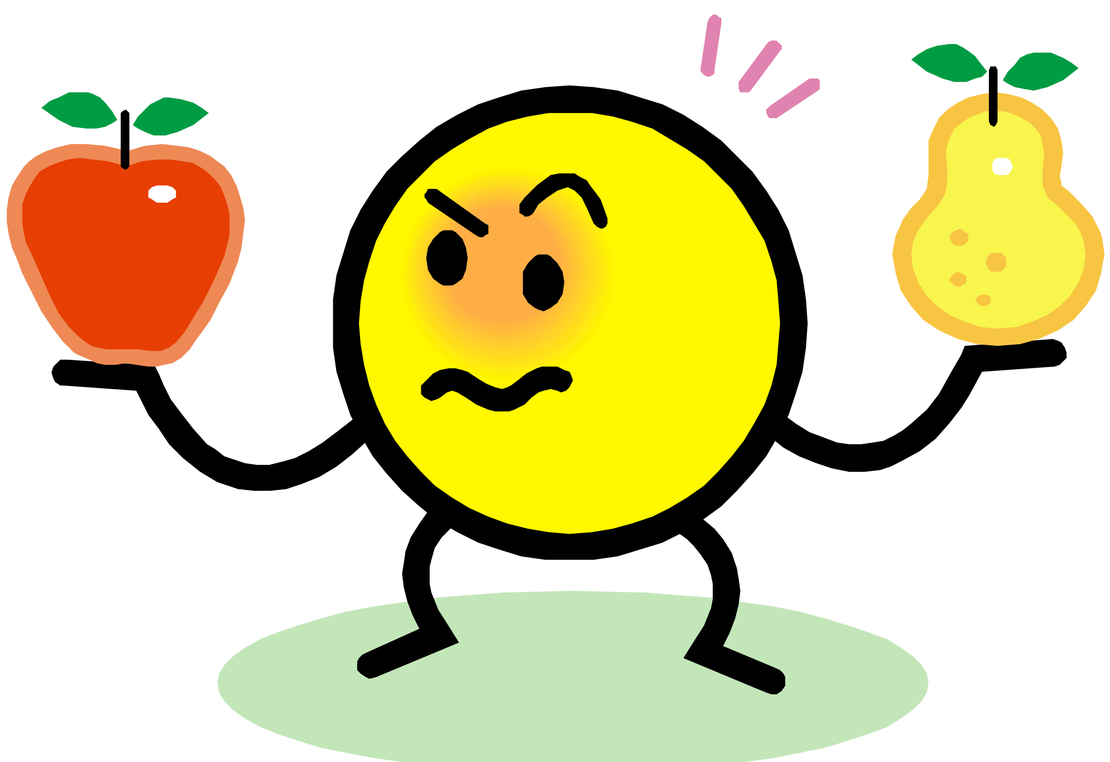
$$\Upsilon(1s) \to \gamma A^0 (A^0 \to \tau^+\tau^- or \to \mu^+\mu^-)$$

Belle Preliminary I

$e^+e^- \rightarrow \Upsilon(1s) \rightarrow \gamma A^0(\rightarrow \tau^+\tau^-)$ Directly

Data Analysis

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



Event Selections

Optimization

For Example

FOM: figure-of-merit

$$FOM = \frac{signal}{\sqrt{signal + background}}$$

7.2. List of Tuned e,μ Cuts.

(1) Tau Skim B: evt_cls.flag(4)>0
(2) Trigger: RecTRG_summary3.final(0) + final(1) != 0
(3) Two Charged Tracks w/ Balance
(4) $N_\mu = N_e = 1$
(5) Lepton Probability cut: $P(e) > 0.05$ and $P(\mu) > 0.8$
(6) KB Cut: KB Parameter > $20GeV^2$
(7) Missing Energy Cut: $1.5GeV \leq E_{missing} \leq 7.5GeV$ in CM frame
(8) Missing Angle Cut: $-0.9 < Cos(\theta_{Missing}) < 0.96$ in CM frame
(9) Gamma Quantity: $N_\gamma > 0$
(10) π^0 Cut: $110MeV < M_{\gamma\gamma} < 160MeV$
(11) Bremsstrahlung: $\alpha_{Brem} > 0.2$ radians in CM frame
(12) CM θ Distribution Cut: $-0.9 < Cos(\theta_{CM}) < 0.9$

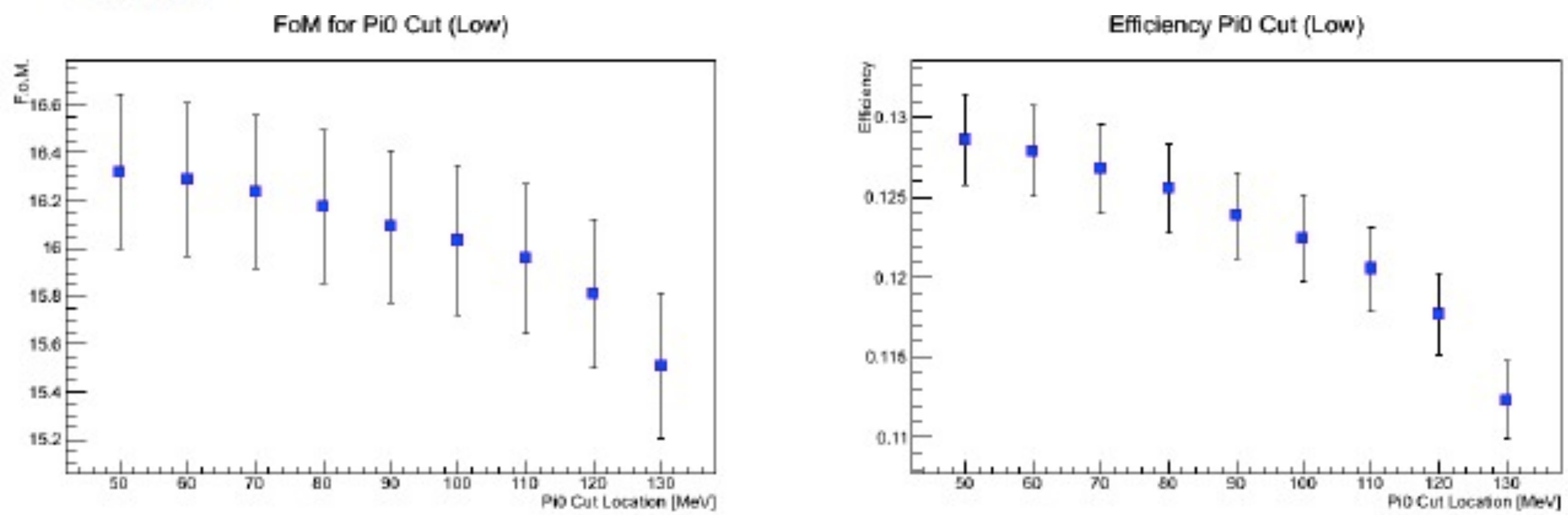
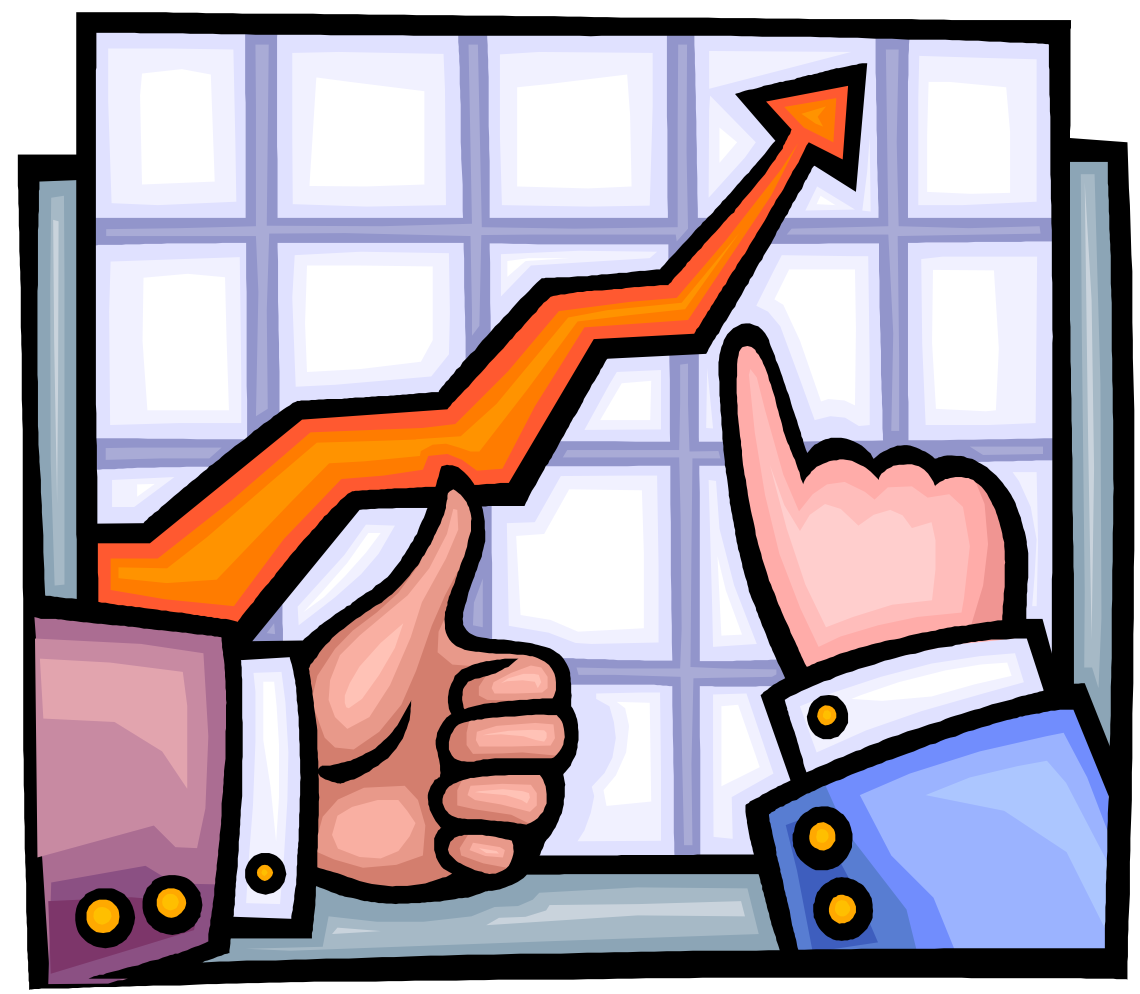


FIGURE 32. Figure of merit and efficiency for π^0 low-side cut, 3.6 GeV A^0 mass, e, μ cuts

Data Analysis

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

background survey

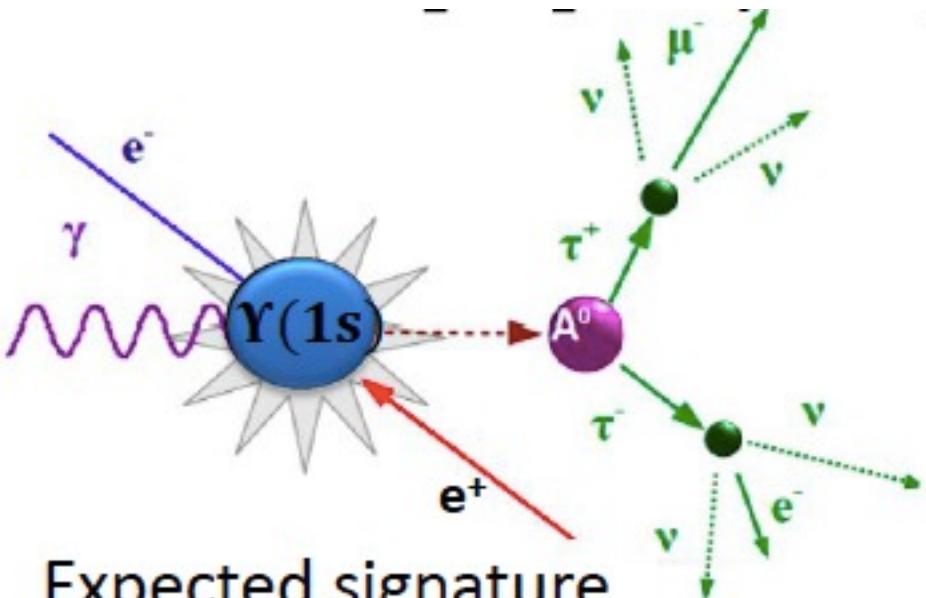


fitting and limit

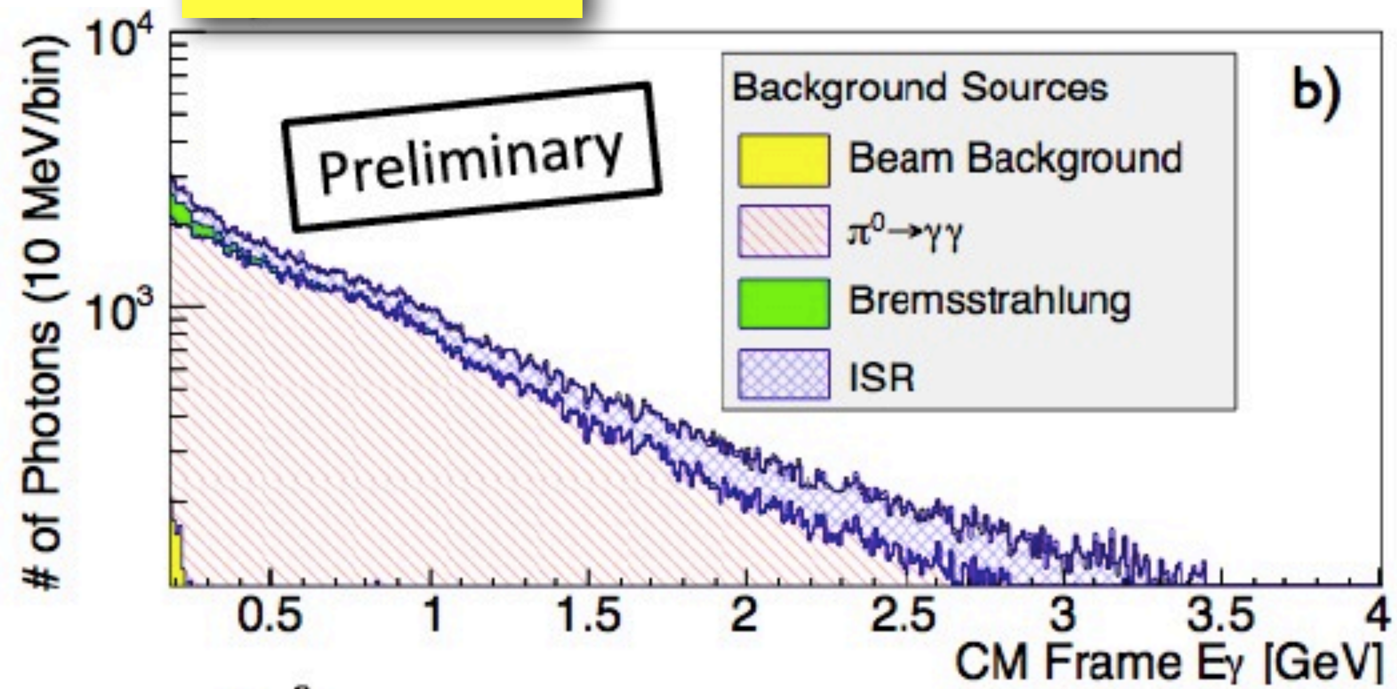
Belle Preliminary I

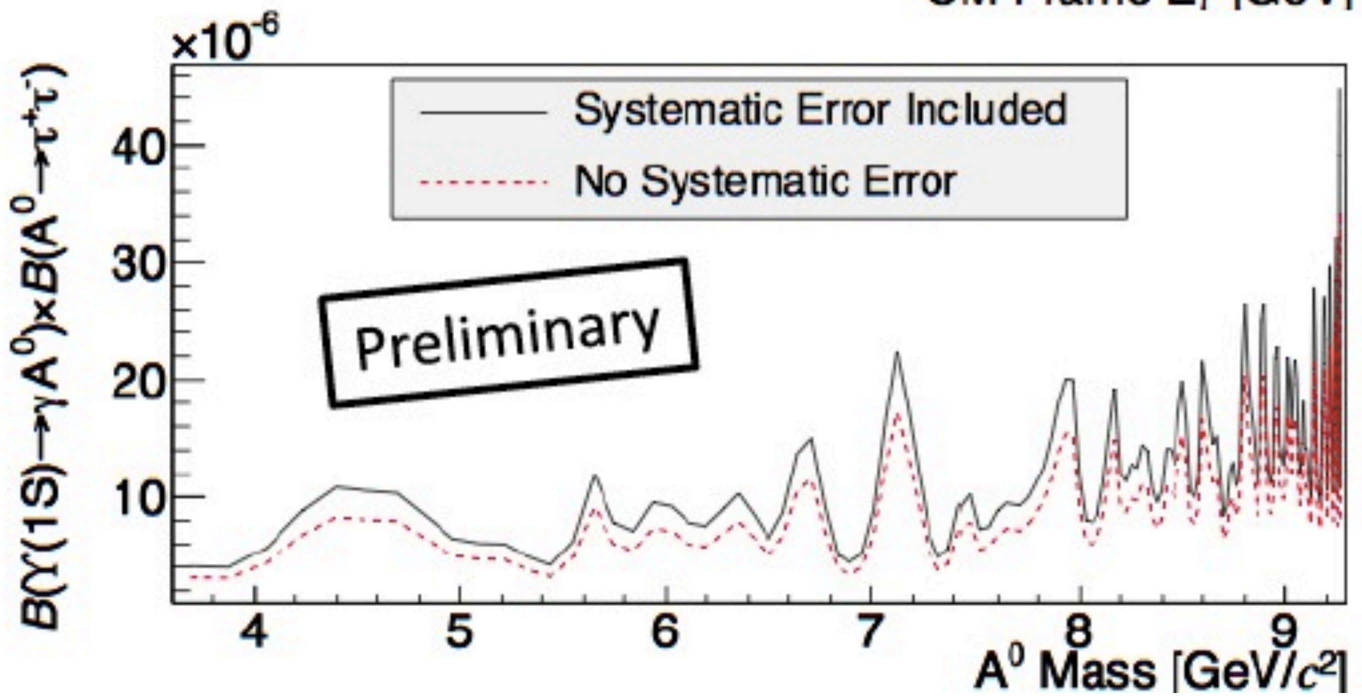
$e^+e^- \rightarrow \Upsilon(1s) \rightarrow \gamma A^0(\rightarrow \tau^+\tau^-)$

new



- Expected signature
  - mono-energetic photon line
  - products of two Tau decays
- Event selection
  - two charged tracks only, at least one with positive μ or e ID
  - Missing energy
  - veto Bremsstrahlung and π^0
- Fit for peak in E_γ spectrum
- None observed → set limit





Belle Preliminary I

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

Factor of 2 improvement over previous world limit by CLEO

Belle Preliminary I

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

Factor of 2 improvement over previous world limit by CLEO

Sensitivity scales with 1/sqrt(L), due to large BG.

If background could be greatly reduced, limits might scale like 1/L instead...

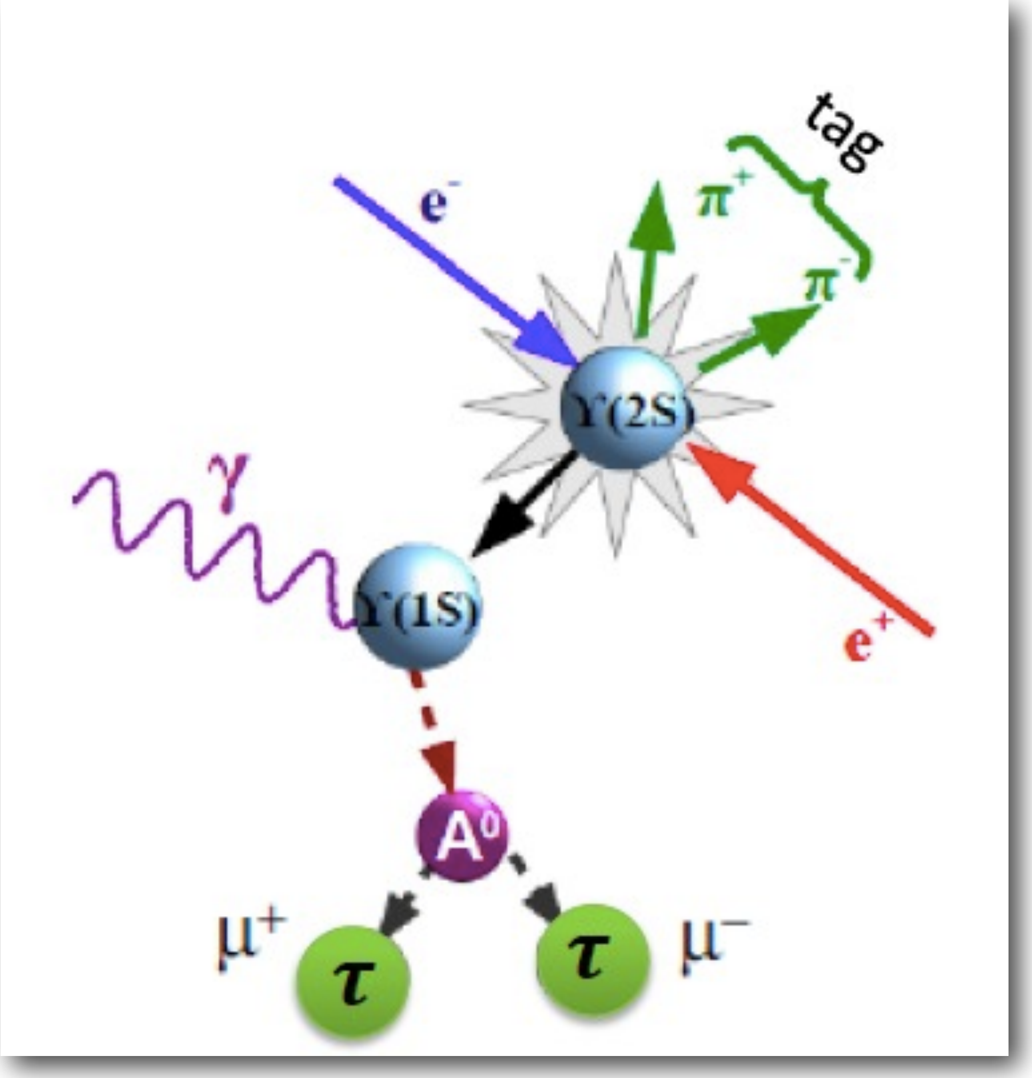
Belle Preliminary I

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

POSSIBLE SOLUTION

pion Tag

reduce BG



Belle Preliminary II

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

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

$$A^0 \rightarrow \mu^+\mu^-$$

Belle Preliminary II

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

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

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

$$e^+e^- \to \Upsilon(2s) \to \Upsilon(1s)\pi^+\pi^-; \Upsilon(1s) \to \gamma A^0 \ \ (cascade)$$

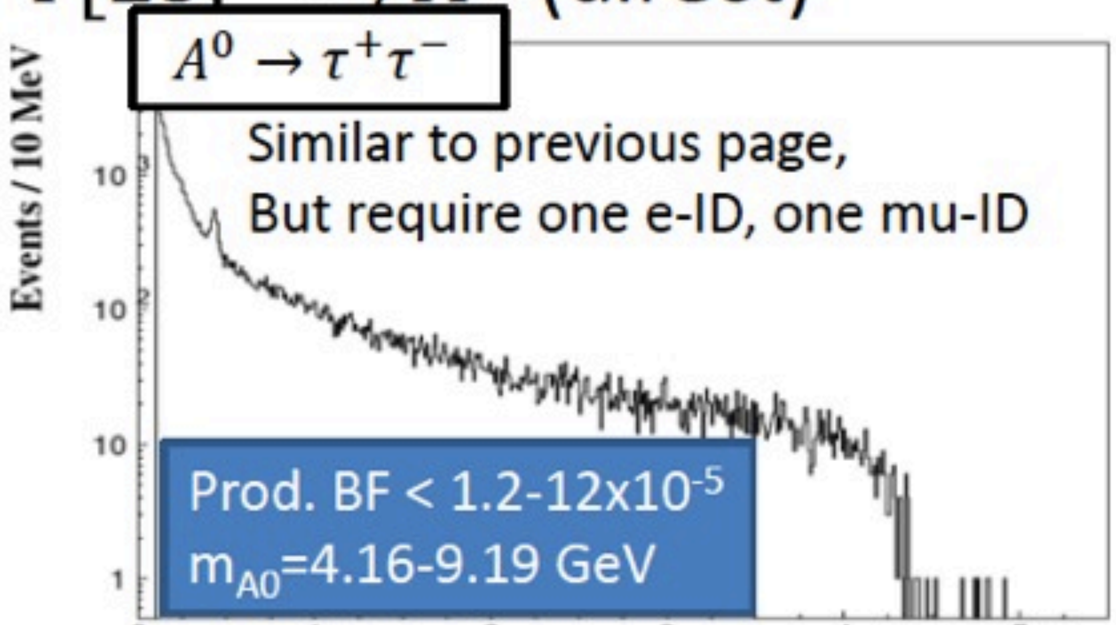
$$A^0 \to \tau^+\tau^-$$

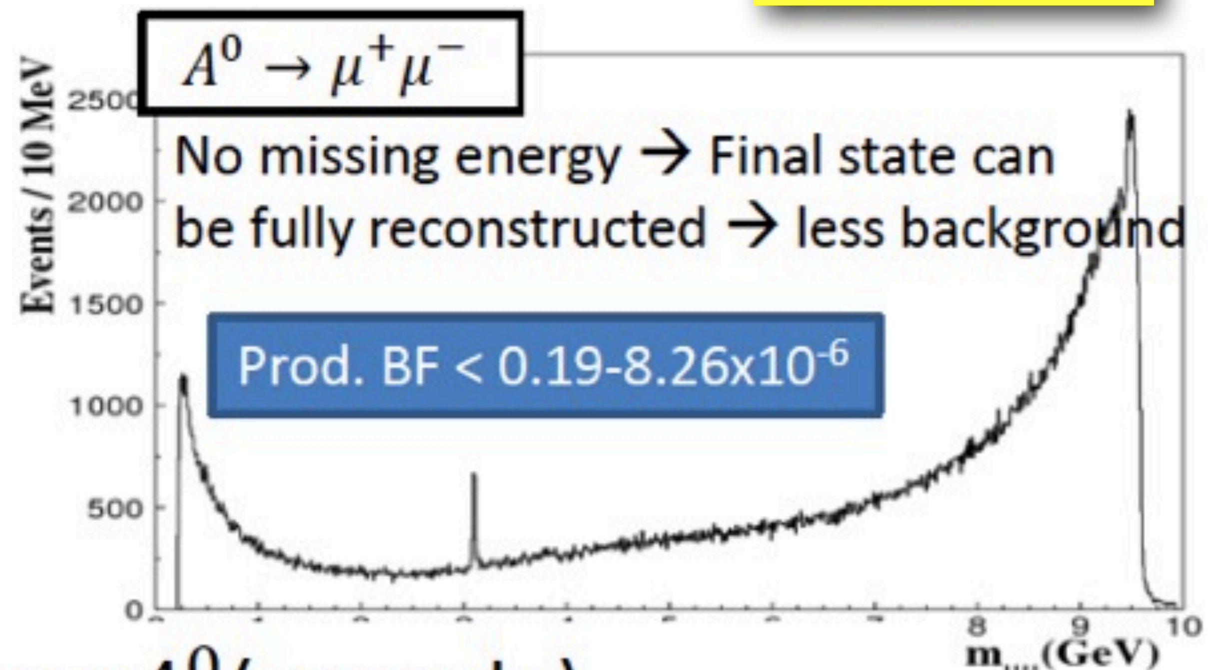
$$A^0 \to \mu^+\mu^-$$

Belle Preliminary II

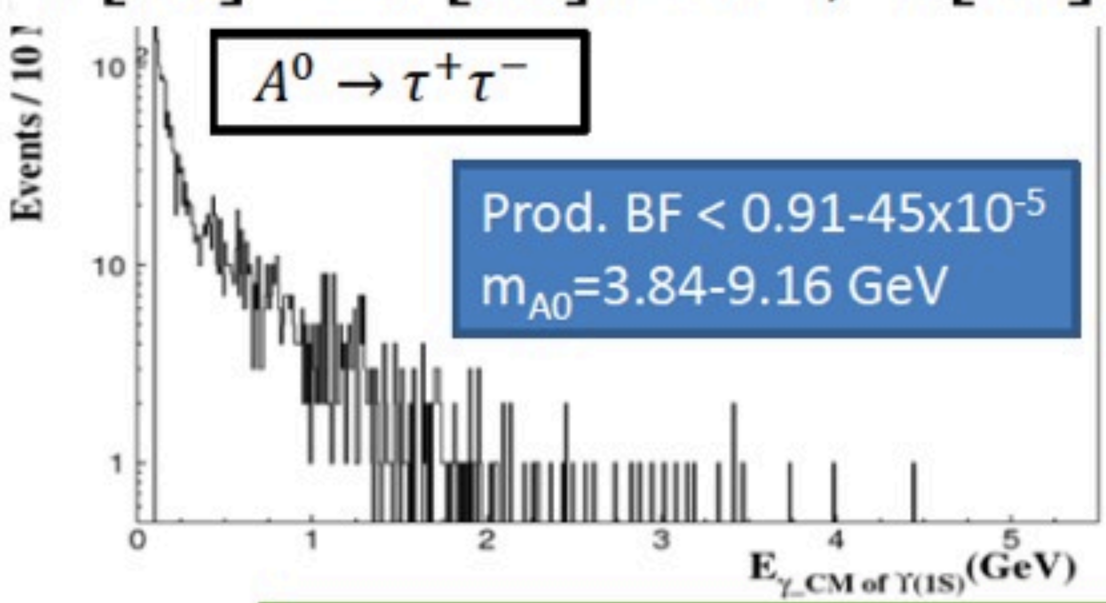
new

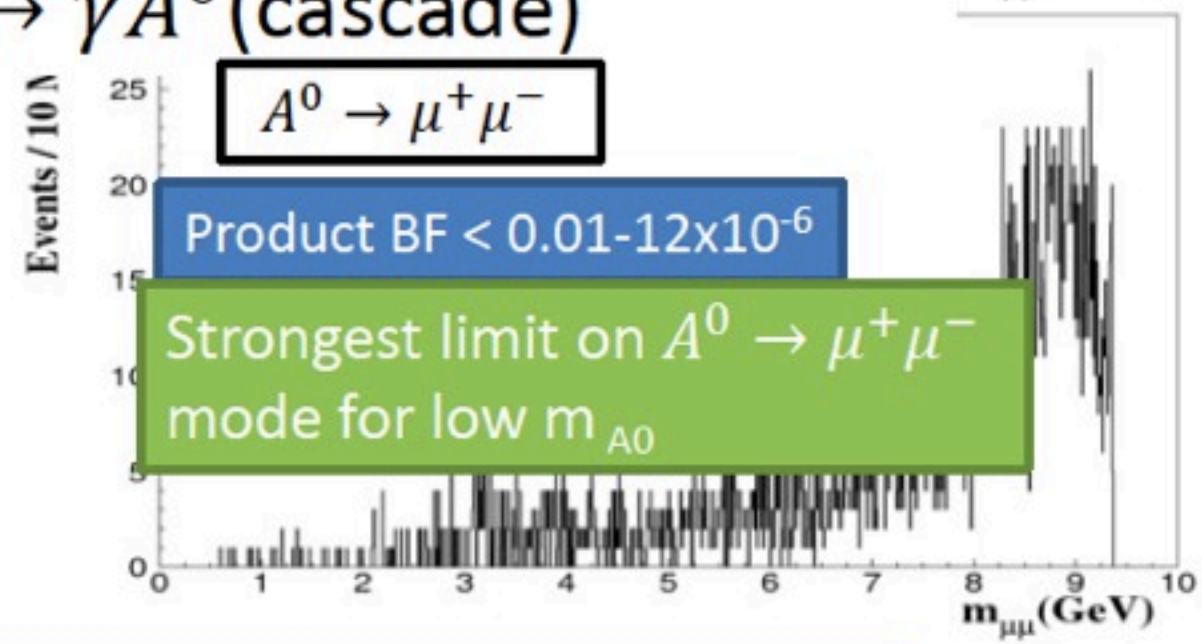
$\Upsilon[2s] \rightarrow \gamma A^0$ (direct)





$\Upsilon[2s] \rightarrow \Upsilon[1s]\pi^+\pi^-$; $\Upsilon[1s] \rightarrow \gamma A^0$(cascade)





- Modes with the π+π- tag have lower BG, but also lower statistics…

BaBar results I

$$e^+e^- \rightarrow \Upsilon(2s) \rightarrow \Upsilon(1s)\pi^+\pi^-; \Upsilon(1s) \rightarrow \gamma A^0 \ \ (\rightarrow \tau^+\tau^-)$$

BaBar results I

new

$$e^+e^- \rightarrow \Upsilon(2s) \rightarrow \Upsilon(1s)\pi^+\pi^-; \Upsilon(1s) \rightarrow \gamma A^0 \ (\rightarrow \tau^+\tau^-)$$

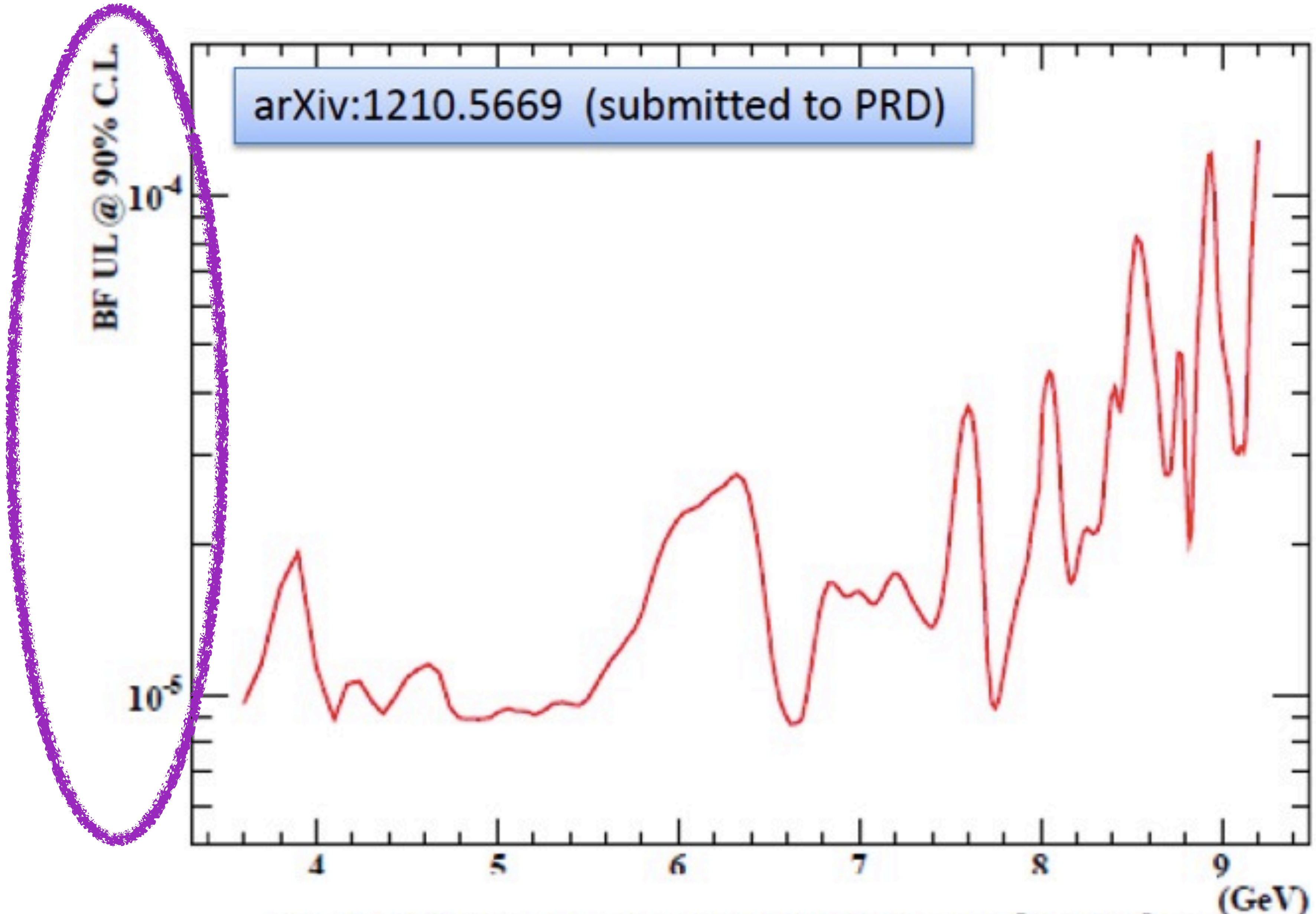


FIG. 3: 90% C.L. upper limits for $\mathcal{B}(\Upsilon(1S) \rightarrow \gamma A^0) \times \mathcal{B}(A^0 \rightarrow \tau^+\tau^-)$.

Belle (preliminary) limit just slightly stronger.

BaBar results I

new

$$e^+e^- \rightarrow \Upsilon(2s) \rightarrow \Upsilon(1s)\pi^+\pi^-; \Upsilon(1s) \rightarrow \gamma A^0 \ (\rightarrow \tau^+\tau^-)$$

combine limits, red solid line, from different Υ resonances by plotting limit on Yukawa coupling x BF

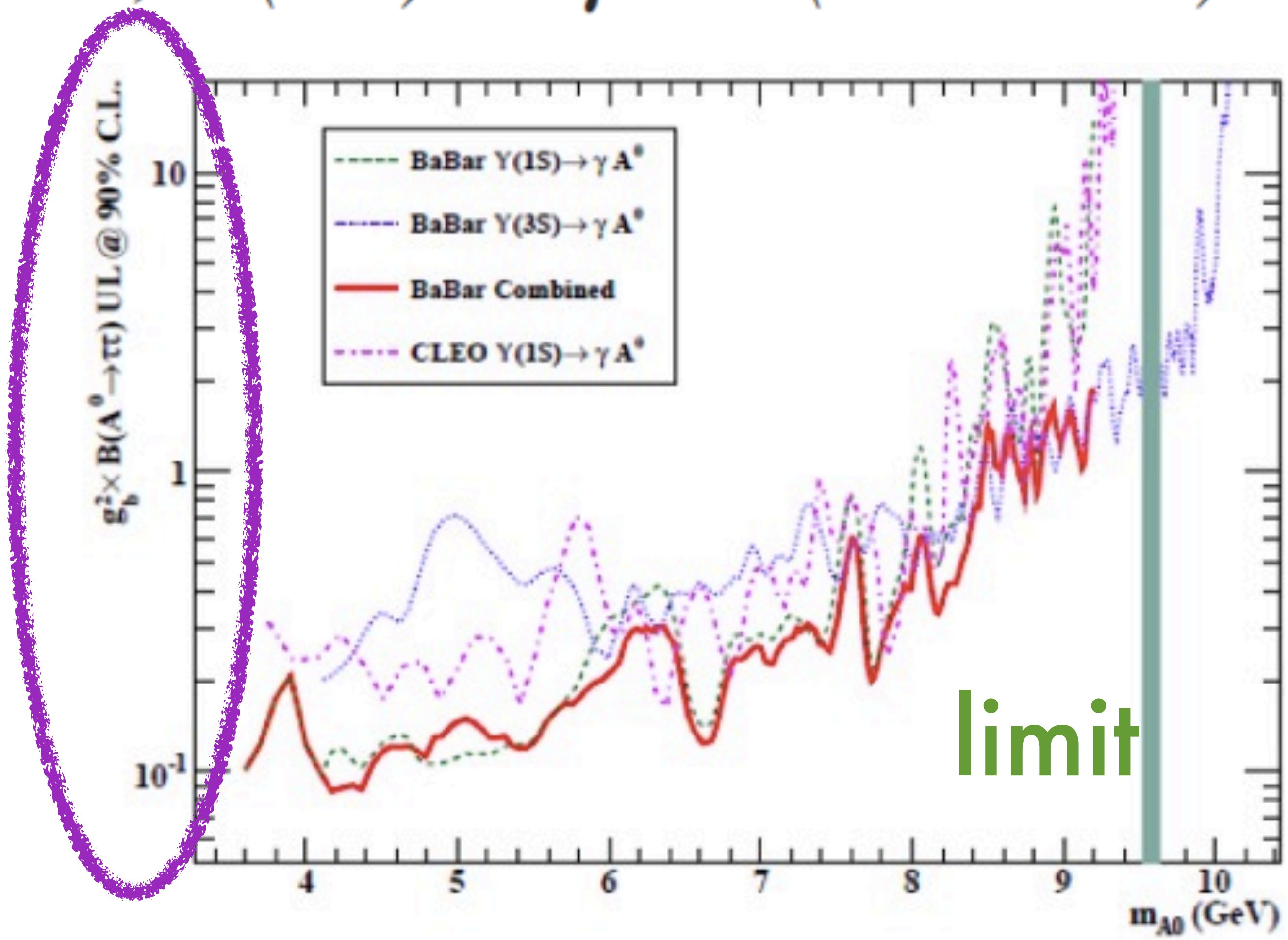


FIG. 4: 90% C.L. upper limits for Yukawa coupling $g_b^2 \times \mathcal{B}(A^0 \rightarrow \tau^+\tau^-)$. Shown are combined *BABAR* results (red solid line), results from this analysis only (dashed green line), the previous *BABAR* measurement [9] (dotted blue line), and results from the CLEO experiment [12] (dot-dashed black line). The shaded vertical bar shows the region around $\chi_b(2P)$ mass excluded from Ref. [9].

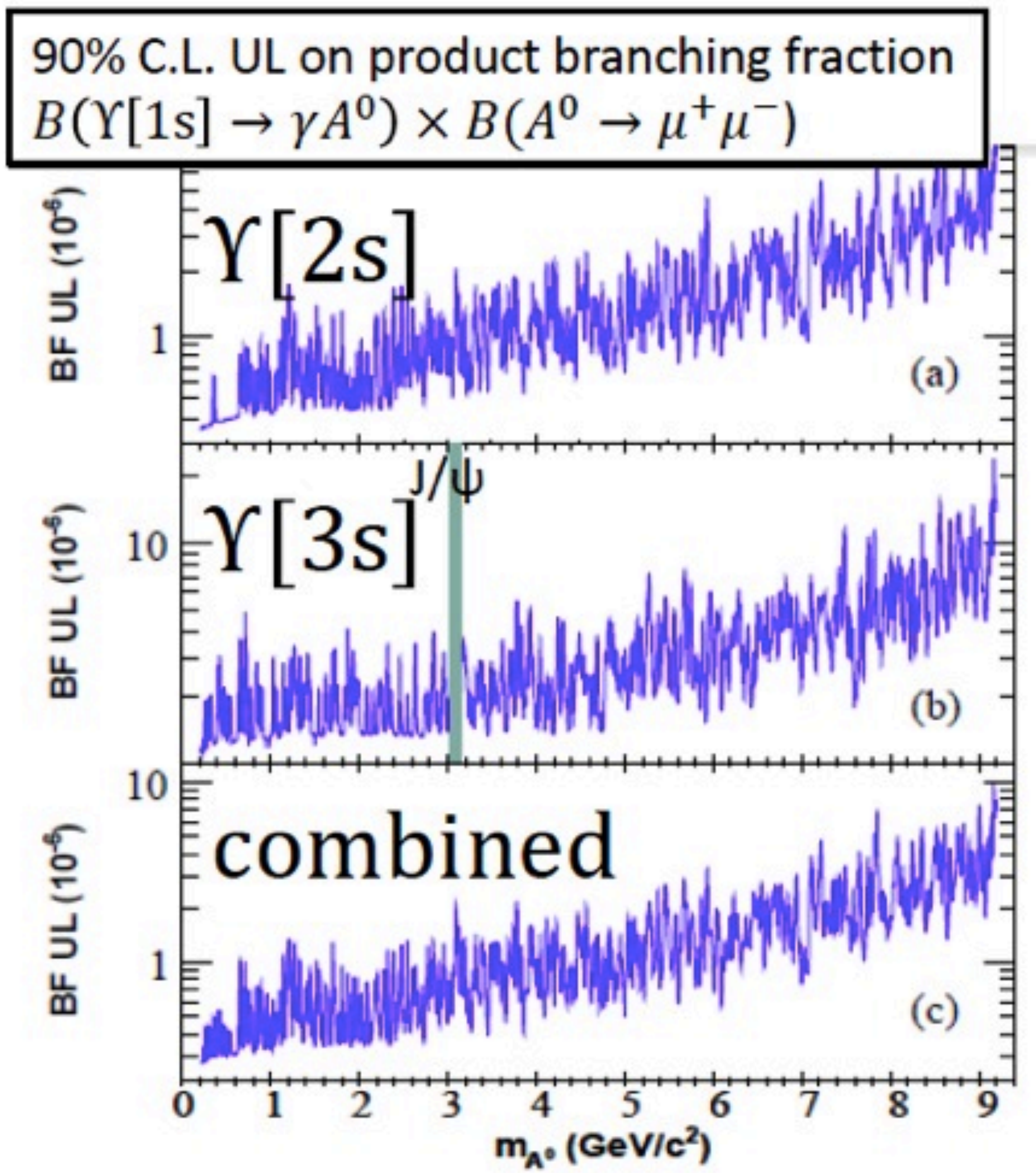
BaBar results II

$$e^+e^- \rightarrow \Upsilon(2s,3s) \rightarrow \Upsilon(1s)\pi^+\pi^-;\Upsilon(1s) \rightarrow \gamma A^0 \ \ (\rightarrow \mu^+\mu^-)$$

BaBar results II

new

$$e^+e^- \rightarrow \Upsilon(2s,3s) \rightarrow \Upsilon(1s)\pi^+\pi^-; \Upsilon(1s) \rightarrow \gamma A^0 \ (\rightarrow \mu^+\mu^-)$$



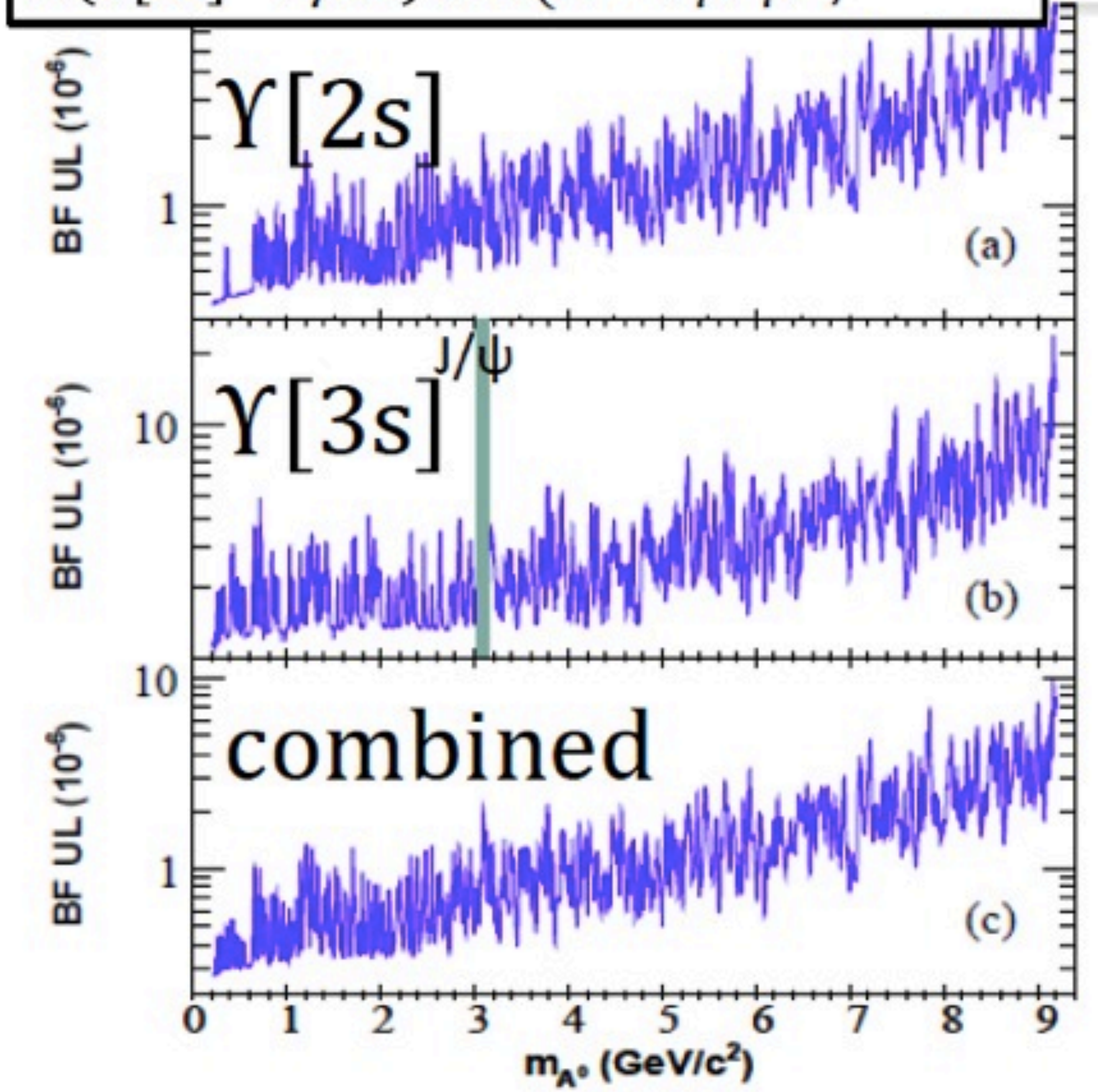
BaBar results II

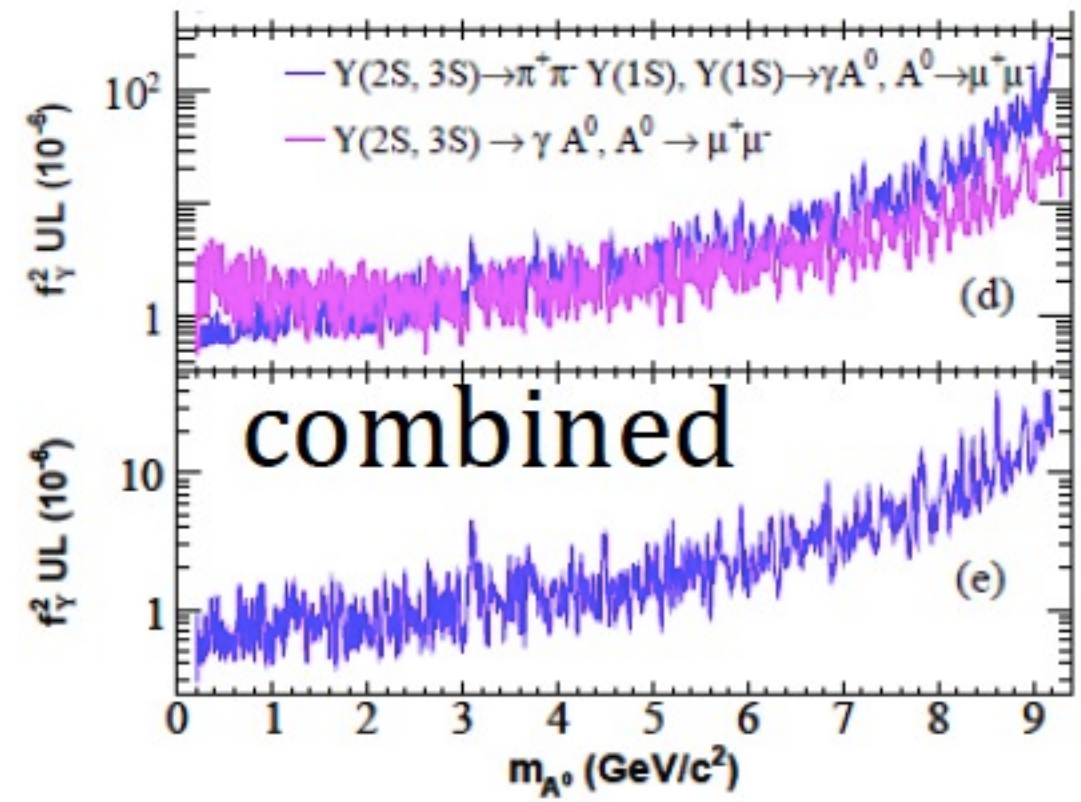
new

$$e^+e^- \rightarrow \Upsilon(2s,3s) \rightarrow \Upsilon(1s)\pi^+\pi^-; \Upsilon(1s) \rightarrow \gamma A^0 \ (\rightarrow \mu^+\mu^-)$$

90% C.L. UL on product branching fraction
$B(\Upsilon[1s] \rightarrow \gamma A^0) \times B(A^0 \rightarrow \mu^+\mu^-)$

PRD-RC 87,031102,2013

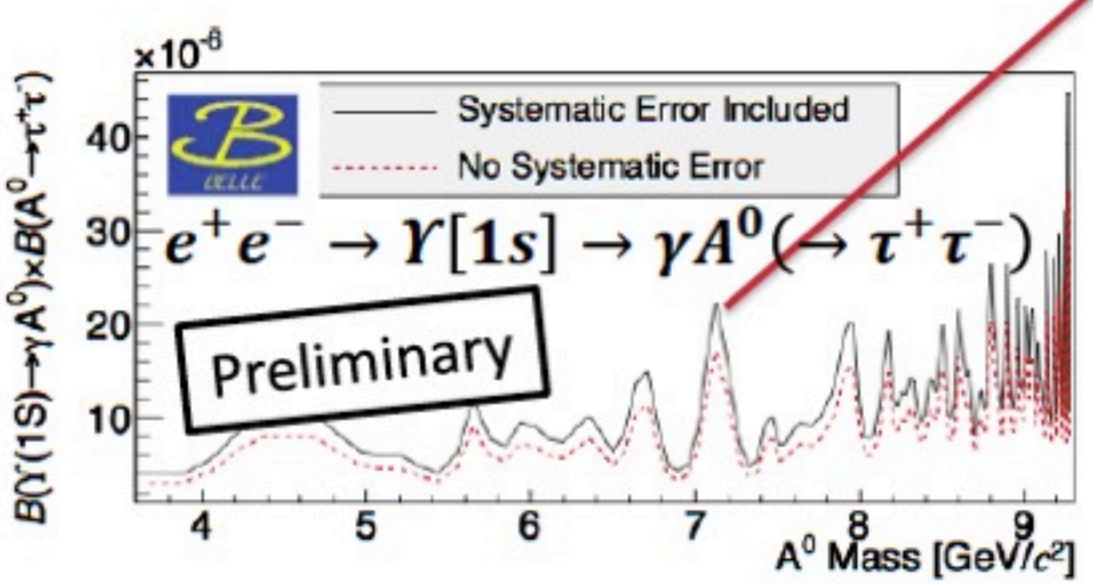


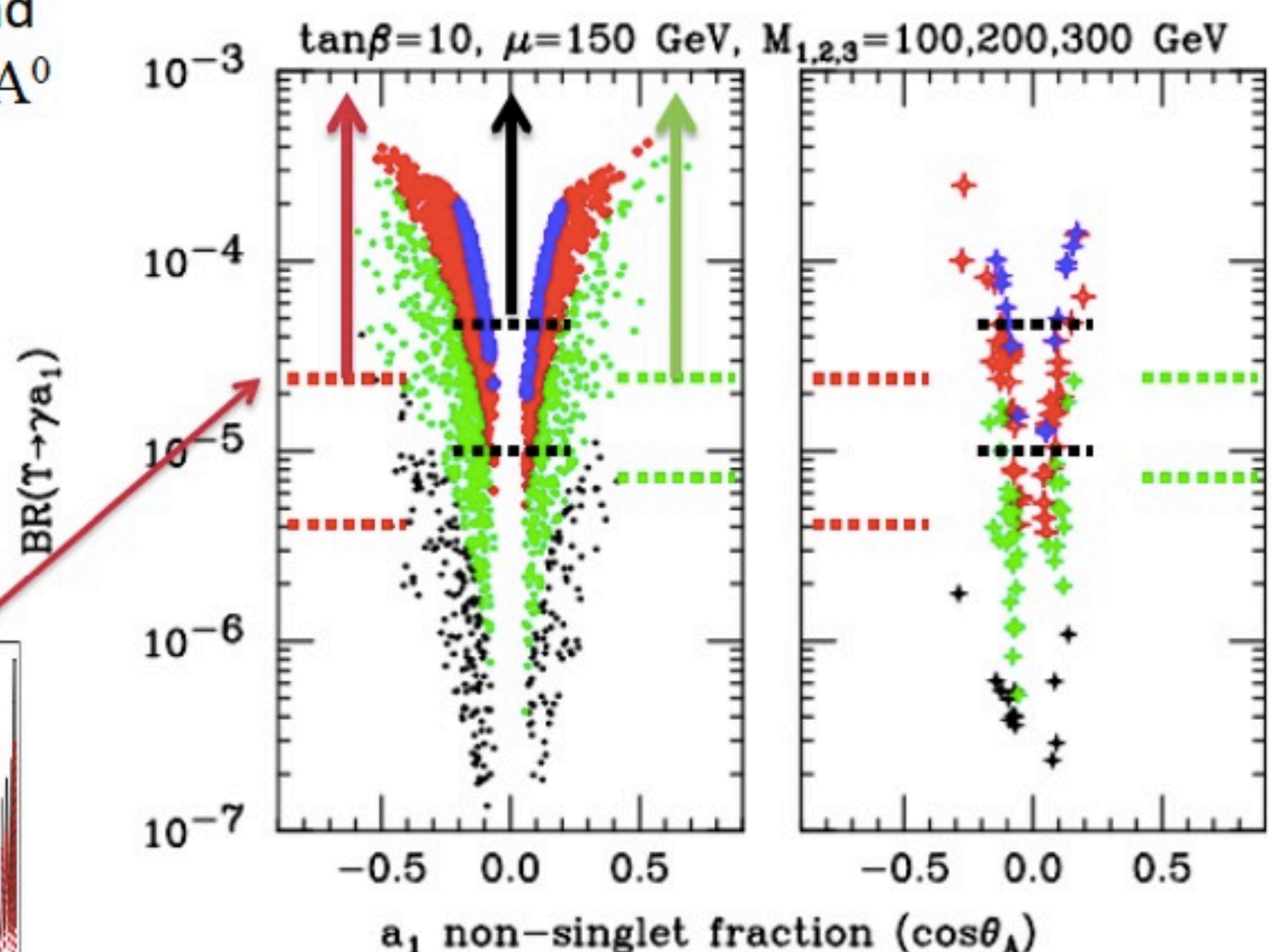


Limit on the Light Higgs vs nMSSM

- Assume $BR(A^0 \to \tau^+\tau^-)=1$
- Dashed lines to show highest and lowest upper limits in different A^0 mass regions

$A^0 < 2M_\tau$
$2M_\tau < A^0 < 7.5\ \text{GeV}/c^2$
$7.5\ \text{GeV}/c^2 < A^0 < 8.8\ \text{GeV}/c^2$
$8.8\ \text{GeV}/c^2 < A^0 < 9.2\ \text{GeV}/c^2$

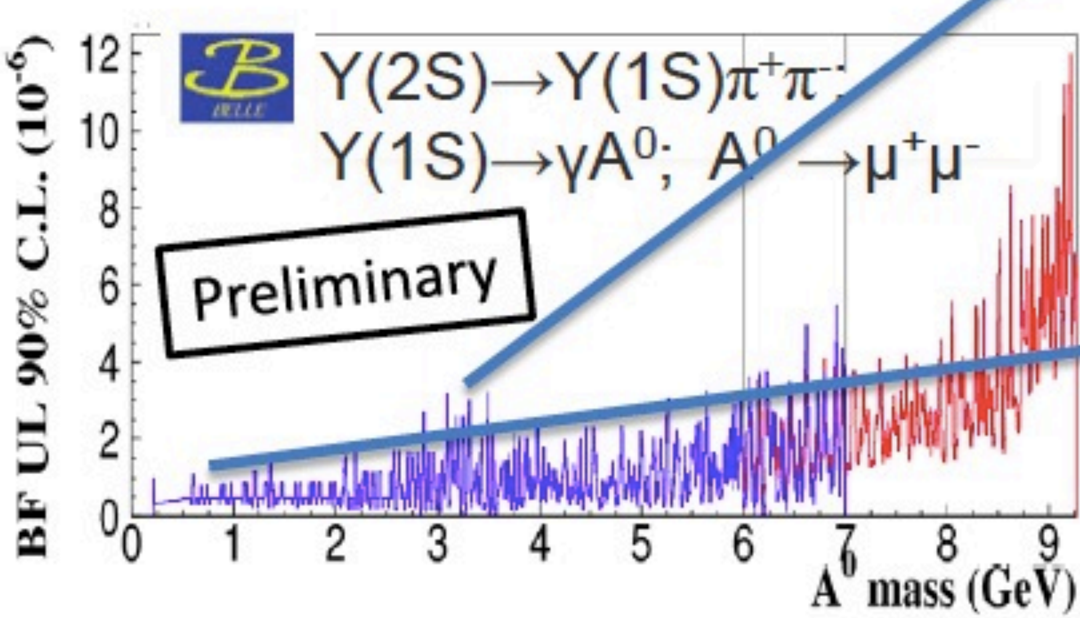


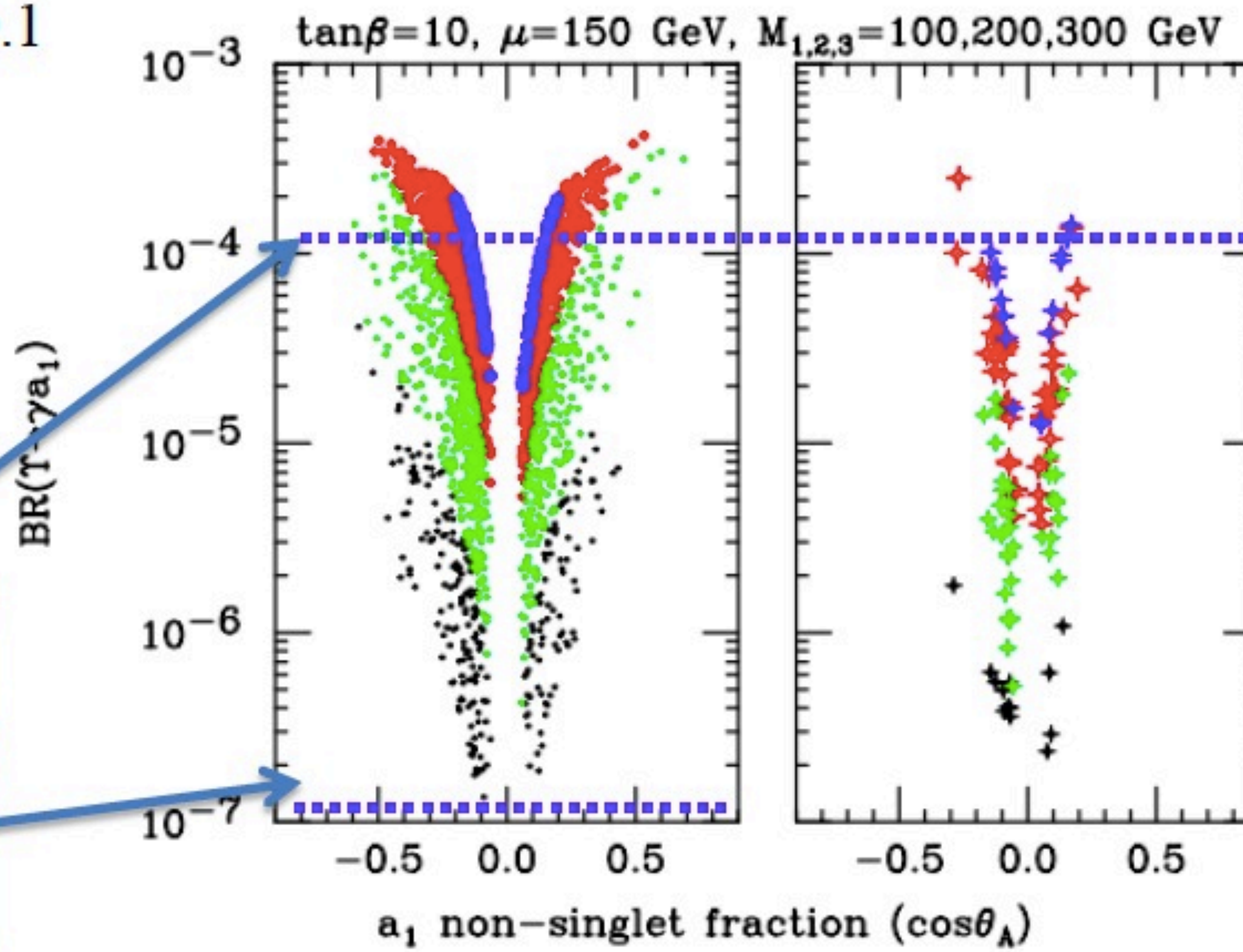


Limit on the Light Higgs vs nMSSM

- Repeat for muon final state
- Assume $BR(A^0 \to \mu^+\mu^-)=0.025\text{-}0.1$

$A^0<2M_\tau$
$2M_\tau<A^0<7.5$ GeV/c^2
7.5 GeV/$c^2$$<A^0<8.8$ GeV/c^2
8.8 GeV/$c^2$$<A^0<9.2$ GeV/c^2





*PRD **76** 051105(R) (2007)

Belle & BaBar Results

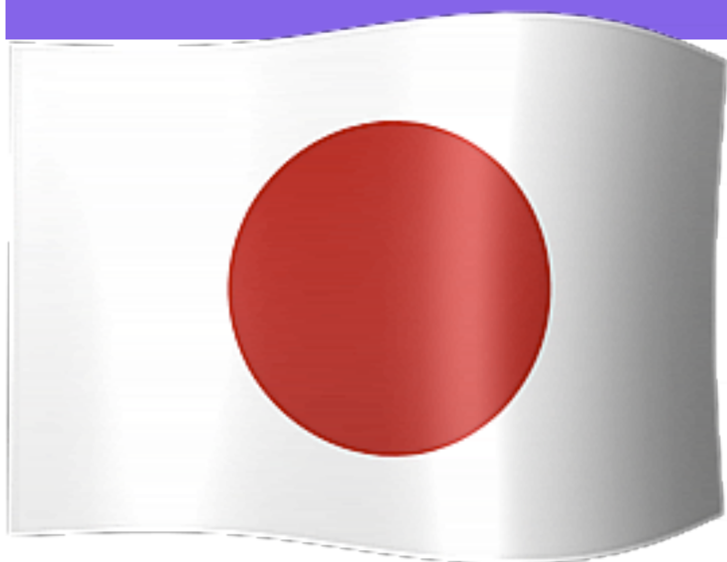
No significant signals observed

BaBar

Shown at FPCP 2012. Also 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	$0.3 < m_A < 7.0$	$(0.1 - 8) \times 10^{-5}$
$\Upsilon(1S) \to \gamma A^0, A^0 \to \chi\bar{\chi}$	$m_\chi < 4.5\,\text{GeV}$	$(0.5 - 24) \times 10^{-5}$
$\Upsilon(1S) \to \gamma A^0, A^0 \to$ invisible	$m_A < 9.2\,\text{GeV}$	$(1.9 - 37) \times 10^{-6}$
$\Upsilon(3S) \to \gamma A^0, A^0 \to$ invisible	$m_A < 9.2\,\text{GeV}$	$(0.7 - 31) \times 10^{-6}$

Belle & BaBar Results



No significant signals observed

Belle

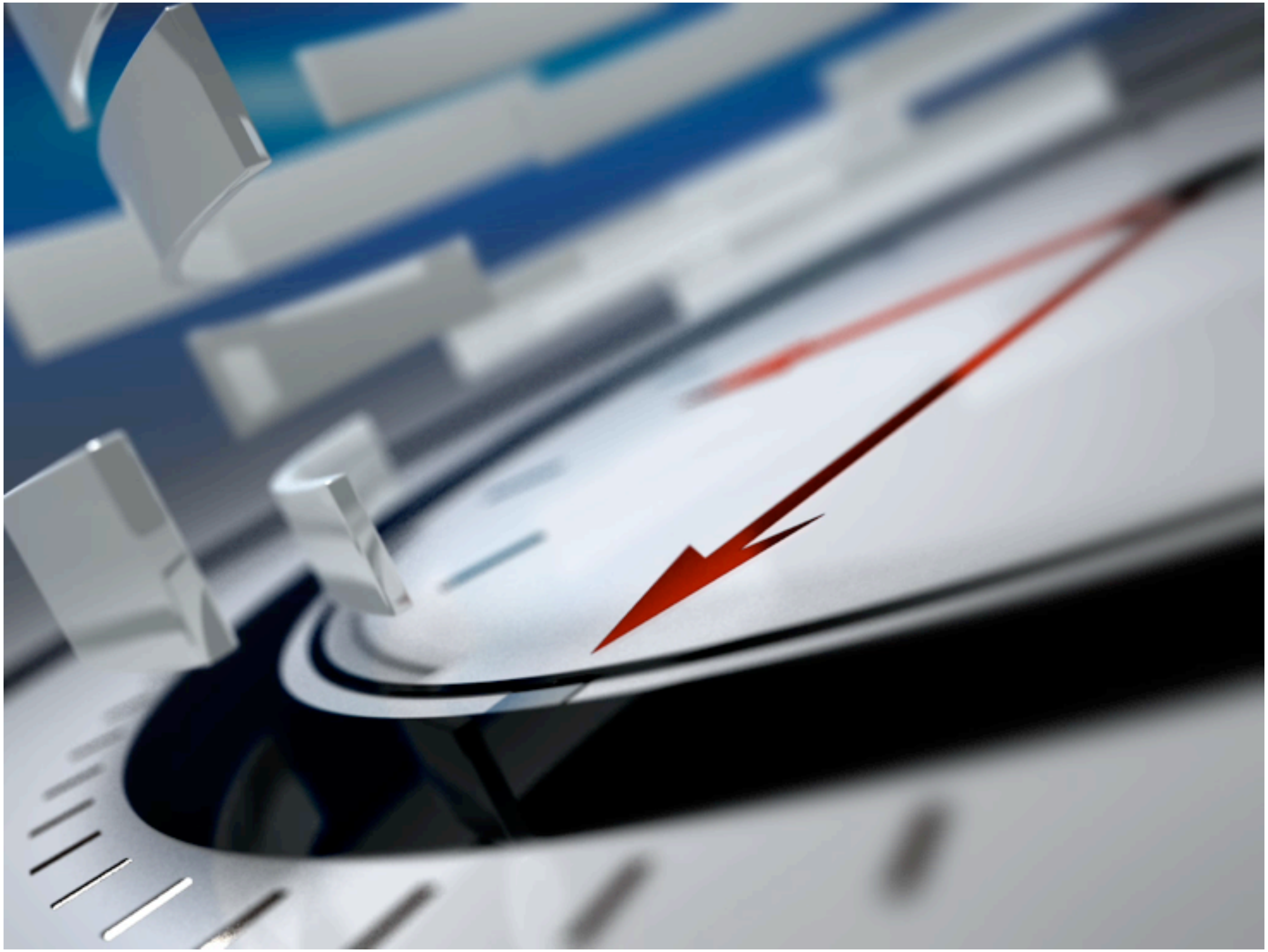
<u>New searches since then</u>

- $e^+e^- \rightarrow \Upsilon[1s] \rightarrow \gamma A^0(\rightarrow \tau^+\tau^-)$
- $e^+e^- \rightarrow \Upsilon[2s] \rightarrow \gamma A^0(\rightarrow \tau^+\tau^-\,,\ \mu^+\mu^-)$
- $e^+e^- \rightarrow \Upsilon[2s] \rightarrow \Upsilon[1s]\pi^+\pi^-;\ \Upsilon[1s] \rightarrow \gamma A^0(\rightarrow \tau^+\tau^-\,,\ \mu^+\mu^-)$

Belle Preliminary

- $e^+e^- \rightarrow \Upsilon[2s] \rightarrow \Upsilon[1s]\pi^+\pi^-;\ \Upsilon[1s] \rightarrow \gamma A^0(\rightarrow \tau^+\tau^-)$
- $e^+e^- \rightarrow \Upsilon[2s,3s] \rightarrow \Upsilon[1s]\pi^+\pi^-;\ \Upsilon[1s] \rightarrow \gamma A^0(\rightarrow \mu^+\mu^-)$

Summary



Summary

Much activity, but nothing found to date…

Summary

Light Higgs

Light-CP odd Higgs

most, but not all, BaBar/Belle samples are exploited

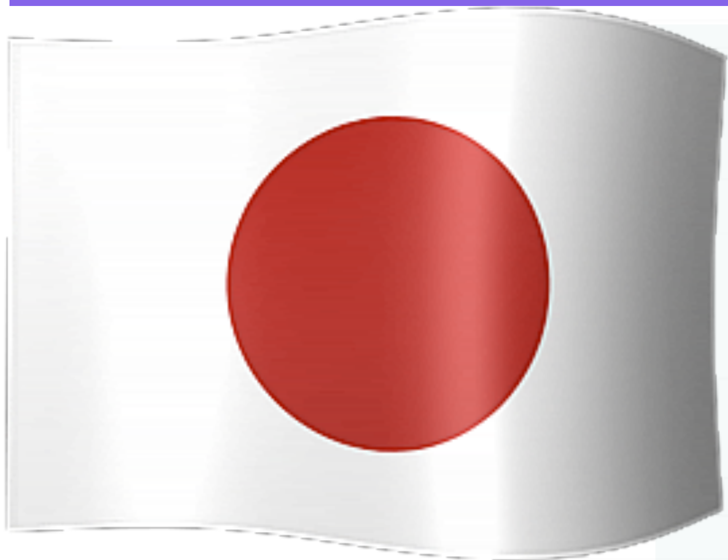
Thank you for your listening

Backup

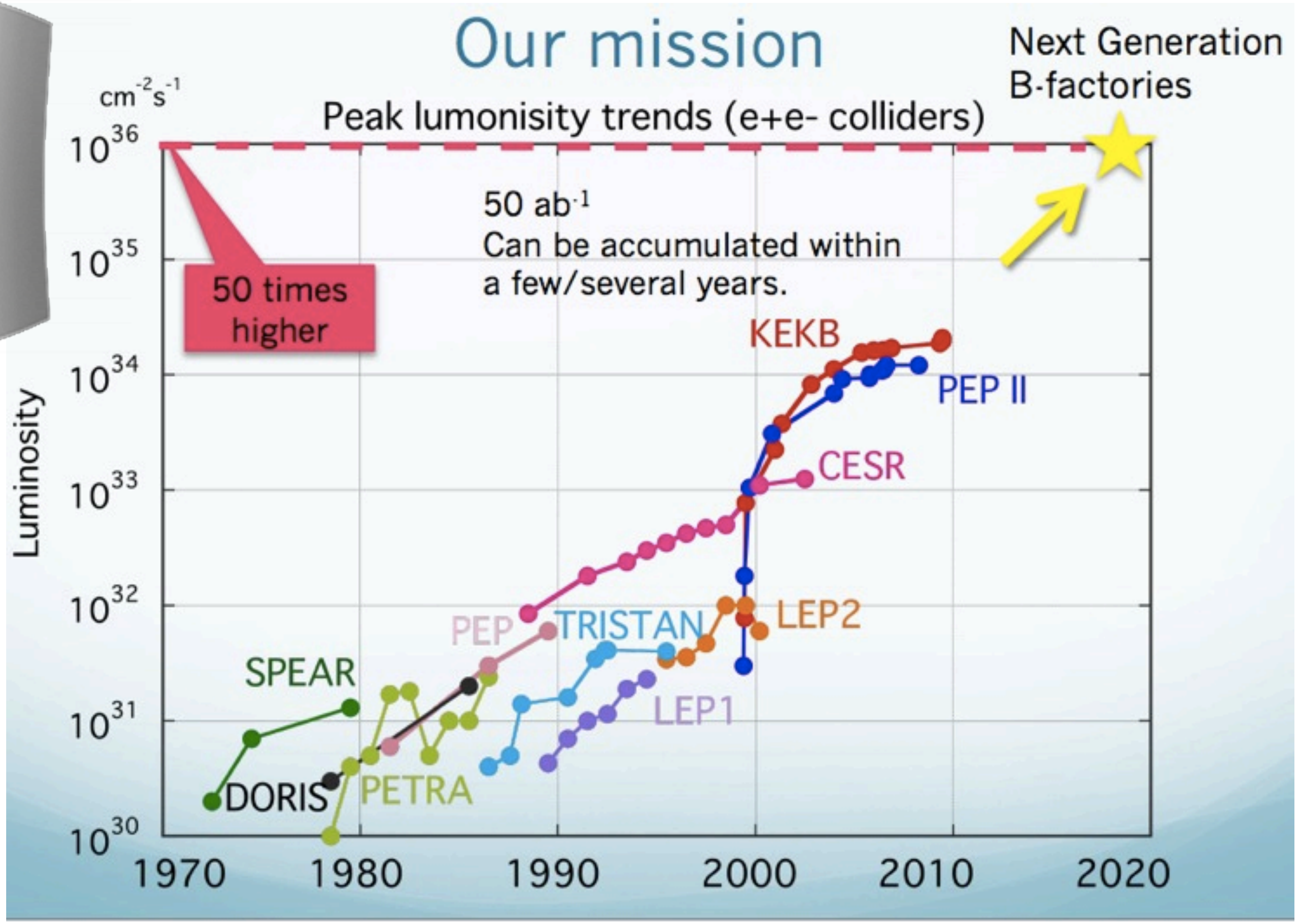
SuperKEKB & Belle-II

2011.11.18

SuperKEKB & Belle-II



2015 start



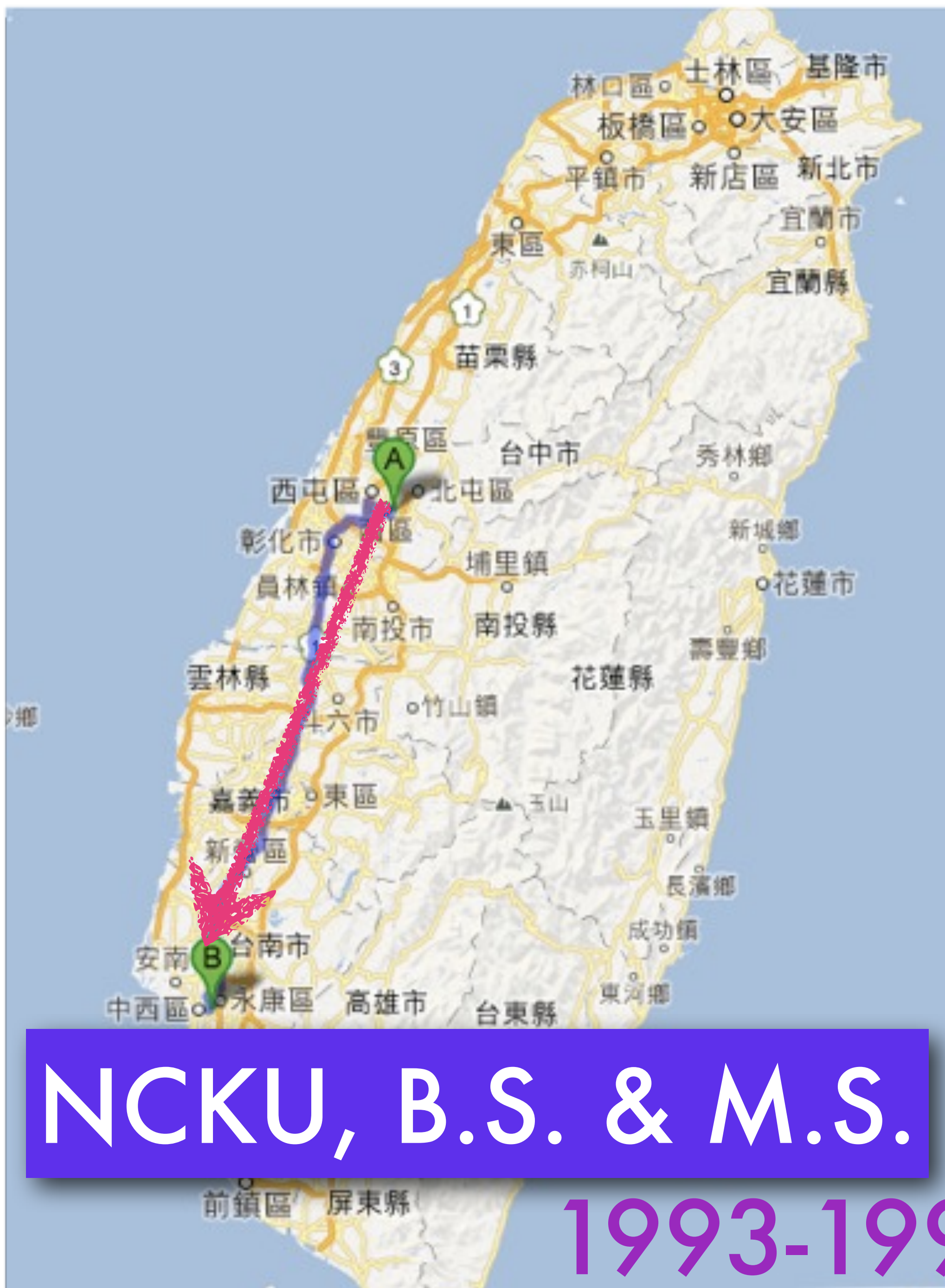
Why SuperKEKB?

SuperKEKB $\xrightarrow{\text{5 years}}$ $10^{36}/cm^2 s^{-1}$

KEKB $\xrightarrow{\text{167 years}}$ $10^{36}/cm^2 s^{-1}$

Next Generation B-factories

About Me



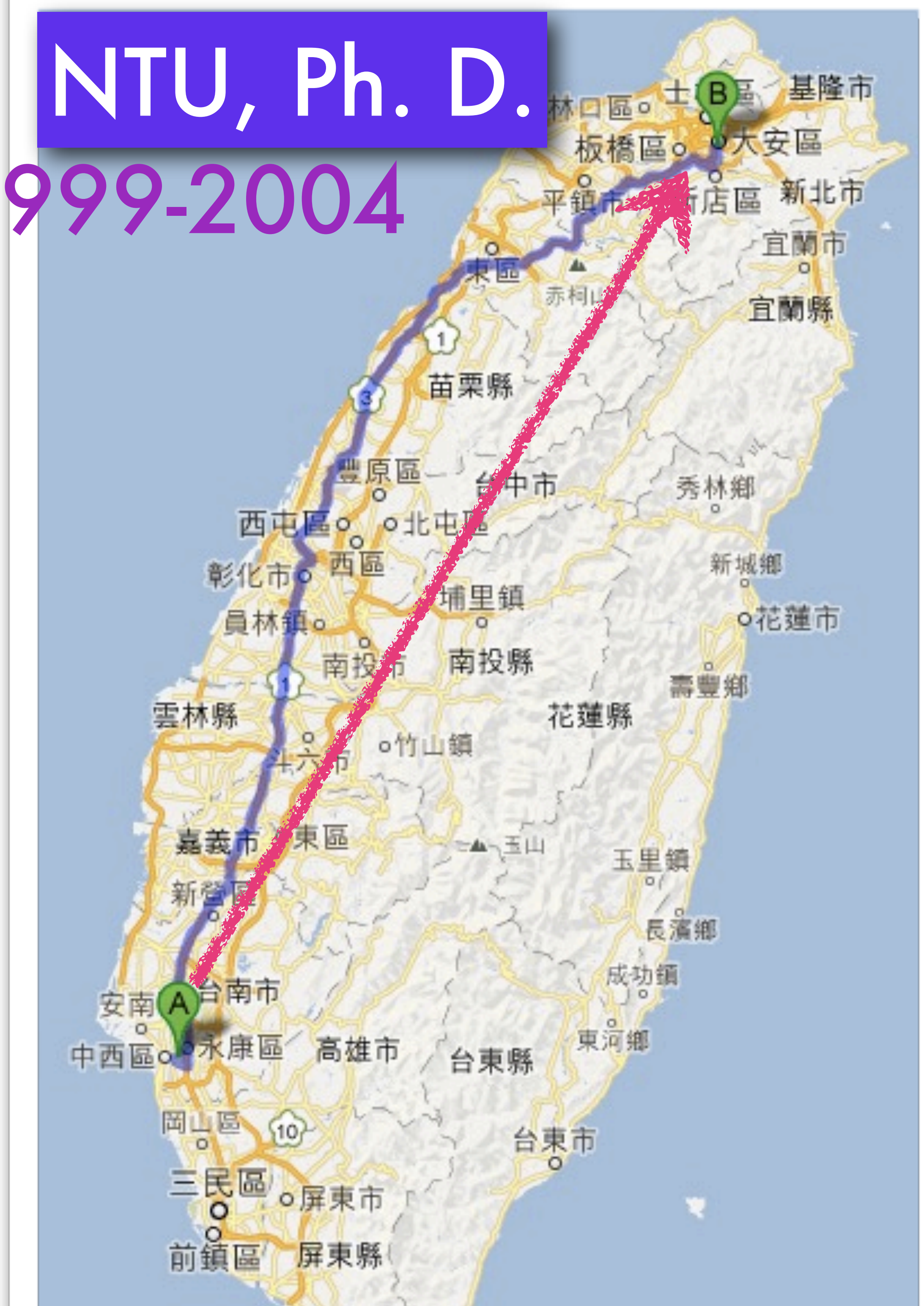
NCKU, B.S. & M.S.

1993-1999

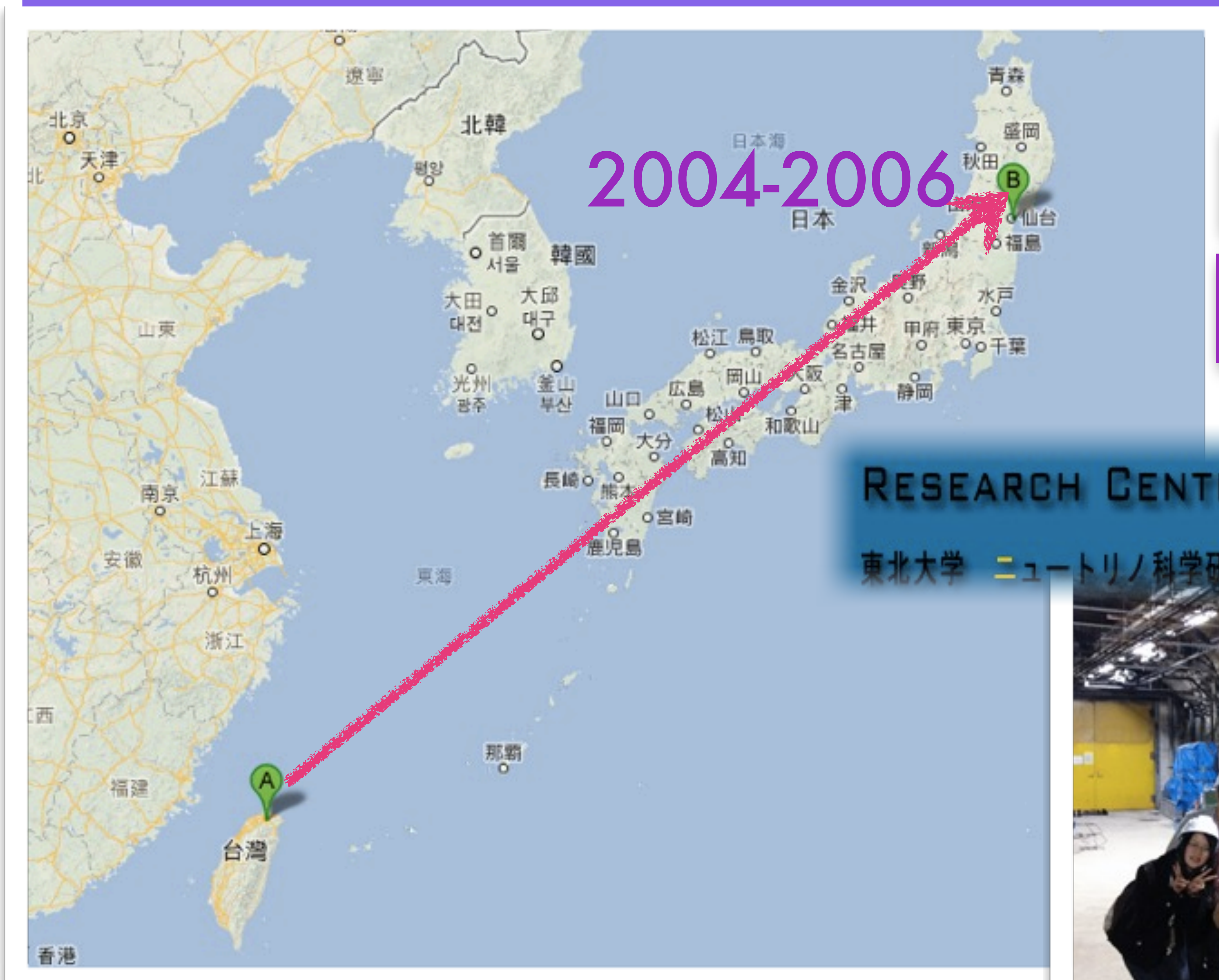
PHYSICS

NTU, Ph. D.

1999-2004



About Me



My first job

Tohoku University

RESEARCH CENTER FOR NEUTRINO SCIENCE

東北大学　ニュートリノ科学研究センター

About Me

2006-2040(?)

My 2nd job

Fu Jen Catholic University

天主教教宗方濟(Pope Francis) (資料照片/AFP)

Associate Professor 2013.08.-

PHYSICS Assistant Professor 2006-2013

My Students in FJU

2013