Dark searches at (super)-B factories

- Dipion tagging of invisible bottomonium decays
- Dark photon and dark higgs to leptons
- Strongly interacting DM ? H-dibaryon in Y decays

Neutralino annihilation to SM particles

Relic density is denoted as follows

$$\Omega h^2 \cong \frac{0.1 \text{ pb} \cdot \text{c}}{\langle \sigma(\chi\chi \rightarrow SM)\, v \rangle}$$

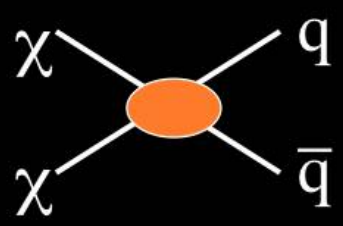
Ω : relic density

h : Hubble constant

v : 1/20 ~ 1/25

$\Omega h^2 = 0.113$ ← WMAP

$\sigma(\chi\chi \Diamond SM) \sim 18$ pb



see PDG

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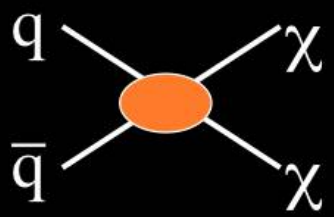


see PDG

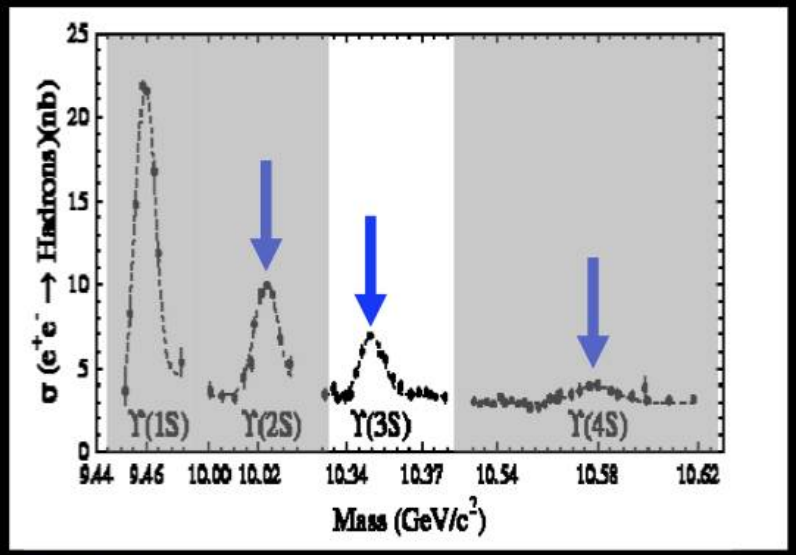
$\sigma(SM \rightarrow \chi\chi) \cong \sigma(\chi\chi \rightarrow SM)$, $\Gamma(\Upsilon(1S) \rightarrow \chi\chi) = f_\Upsilon^2 M_\Upsilon \sigma(b\bar{b} \rightarrow \chi\chi)$

Br($\Upsilon(1S) \rightarrow \chi\chi$) ~ 6×10^{-3} ($m_\chi < 4.73\ \text{GeV}/c^2 \sim m_b$)

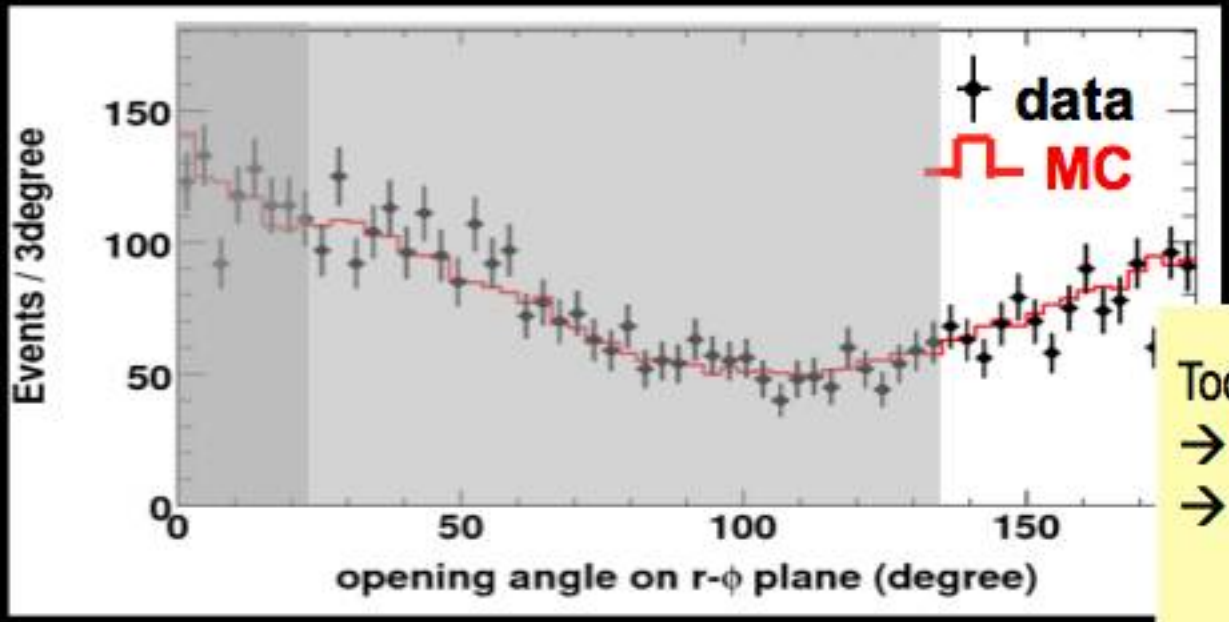
PRD 72, 103508 (2005) , B.McElrath, "Invisible quarkonium decays as a sensitive probe of dark matter"

Past Best limit < 23×10^{-3} (90% CL) by ARGUS (1986)

Searches of DM using dipion tagging



Slow dipion trigger for Dark Matter searches

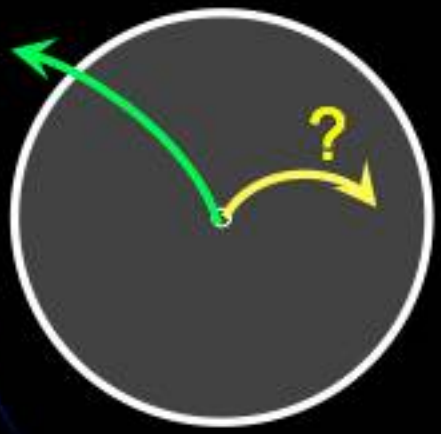


Control sample

$\Upsilon(3S) \rightarrow \pi^+\pi^-\Upsilon(1S)$

$\Upsilon(1S) \rightarrow \mu^+\mu^-$

Too low efficiency with usual condition (>135°)
→ Higher efficiency with looser condition
→ Special trigger condition was implemented
(~850 Hz, twice rate as usual)

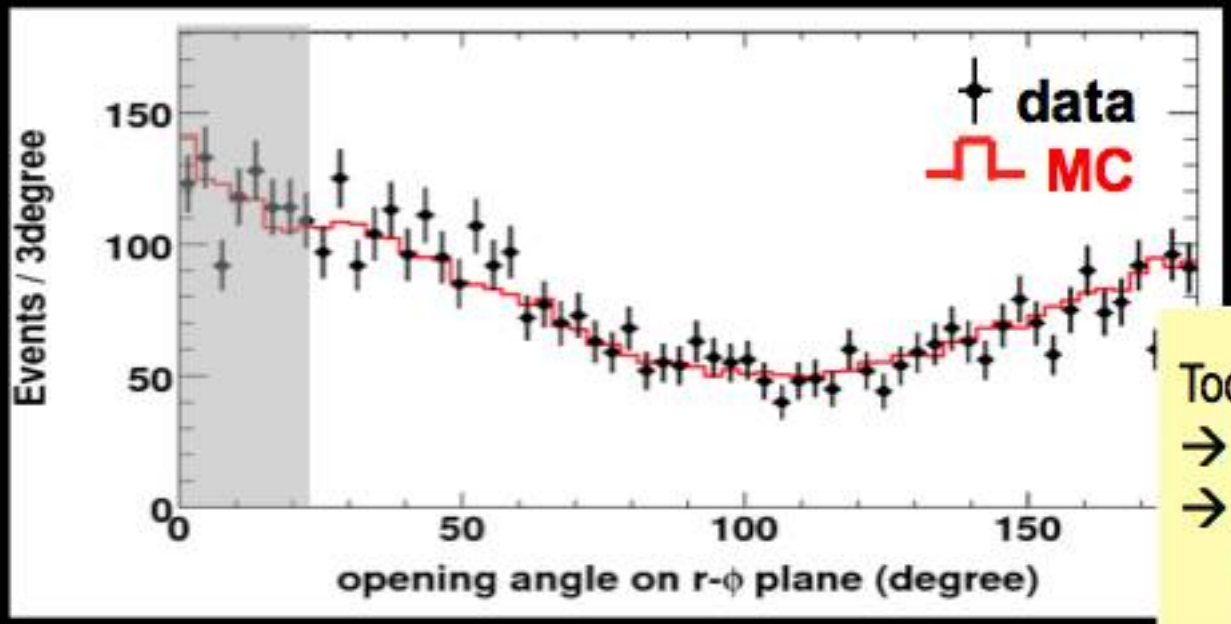


Single track trigger was implemented, too with 1/500 pre-scale rate (pt>250 MeV/c)

$$\frac{\text{2-track trigger \& 1-track trigger}}{\text{1-track trigger}}$$

for efficiency monitoring

Slow dipion trigger for Dark Matter searches



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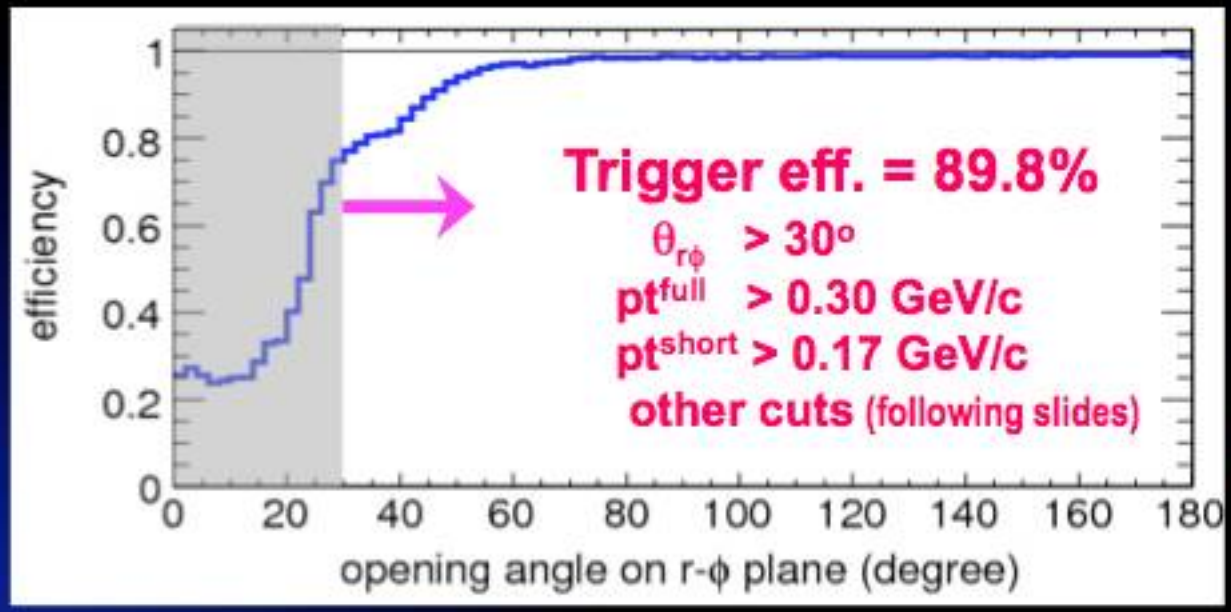


Single track trigger was implemented, too with 1/500 pre-scale rate (p_t>250 MeV/c)

$$\frac{\text{2-track trigger \& 1-track trigger}}{\text{1-track trigger}}$$

for efficiency monitoring

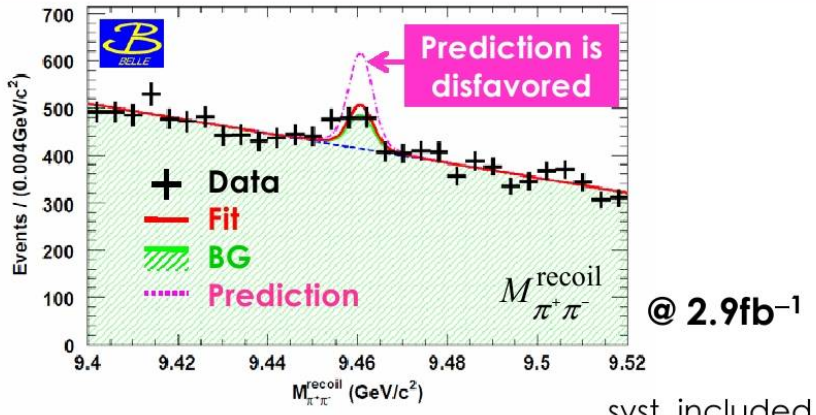
244 events predicted

$Br(\Upsilon(1S) \rightarrow \text{invisible}) = 6 \times 10^{-3}$

Dark matter searches in Y(1S) decays: results

Belle: Y(3S) → ππ + NOTHING

N_{sig} = 38 □ 39(stat) ⇔ 0 consistent

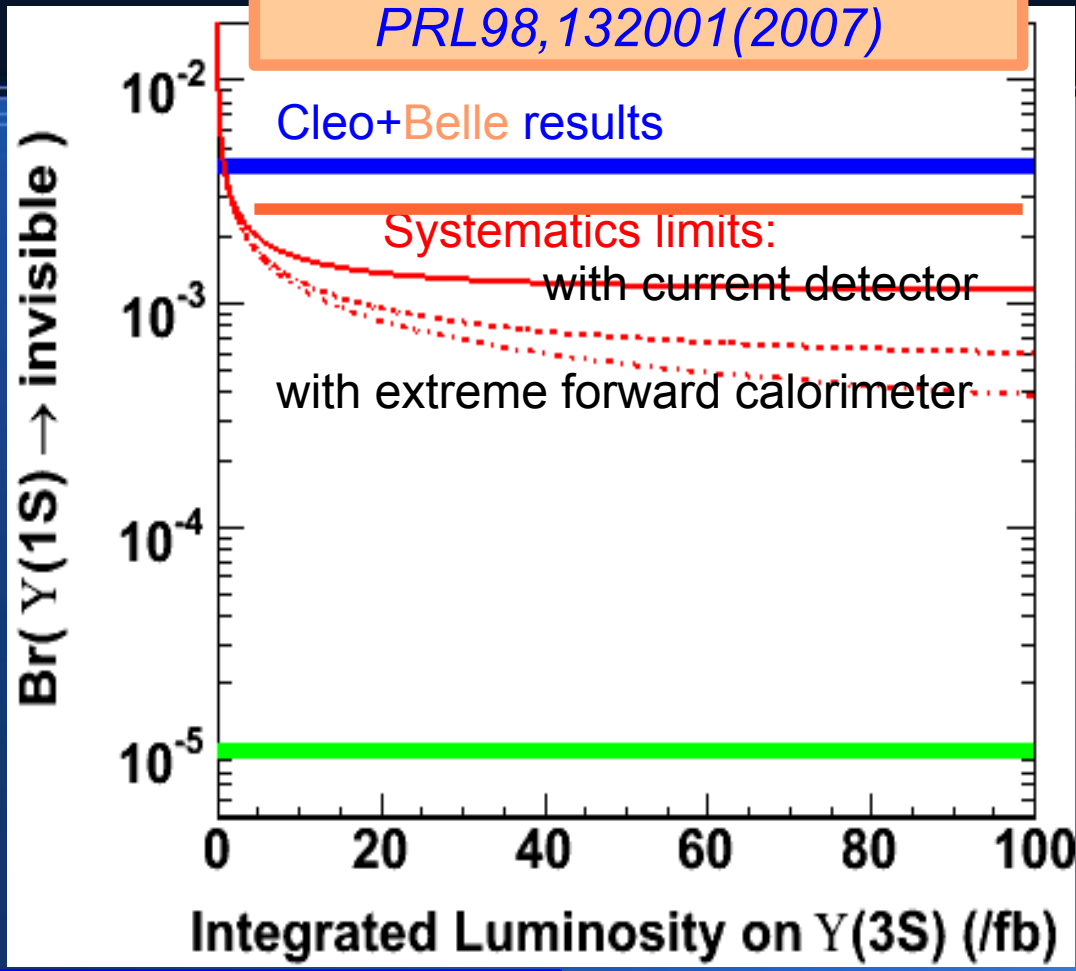


@ 2.9fb^{-1}

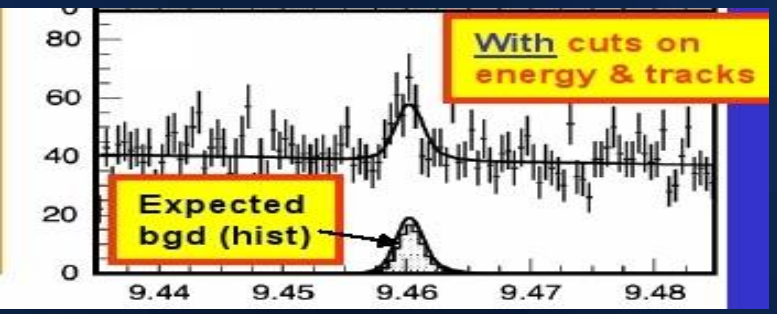
syst. included

Br(Y(1S) → invisible) < 2.5 x 10^{-3} (@90%C.L.)

2.9 fb^{-1}.11 M Y(3S)
PRL98,132001(2007)



CLEO: Y(2S) → ππ + NOTHING

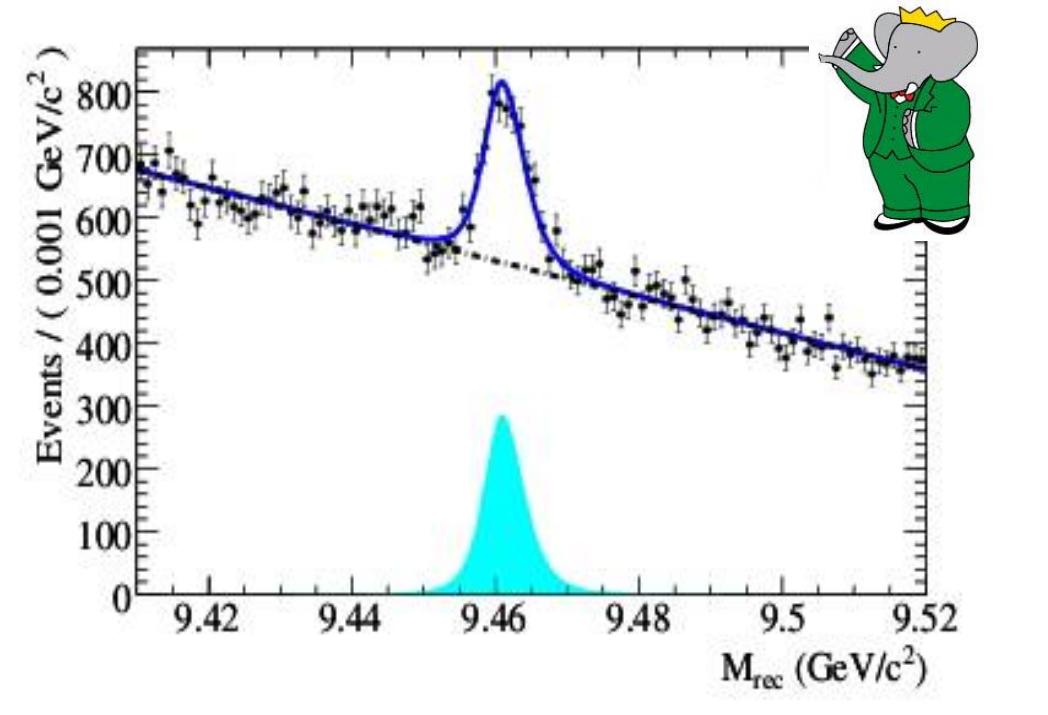


1.46 fb^{-1}, 6M Y(3S)
PRD75,031104(2007)

BR(Y(1S) → invisible) < 3.9*10^{-3} (90% CL)

Dark matter searches in Y(nS) decays : results

Babar: Y(3S) → ππ + NOTHING



BR(Y(1S) → invisible) < $3*10^{-4}$ (90% CL)

From MC simulations:

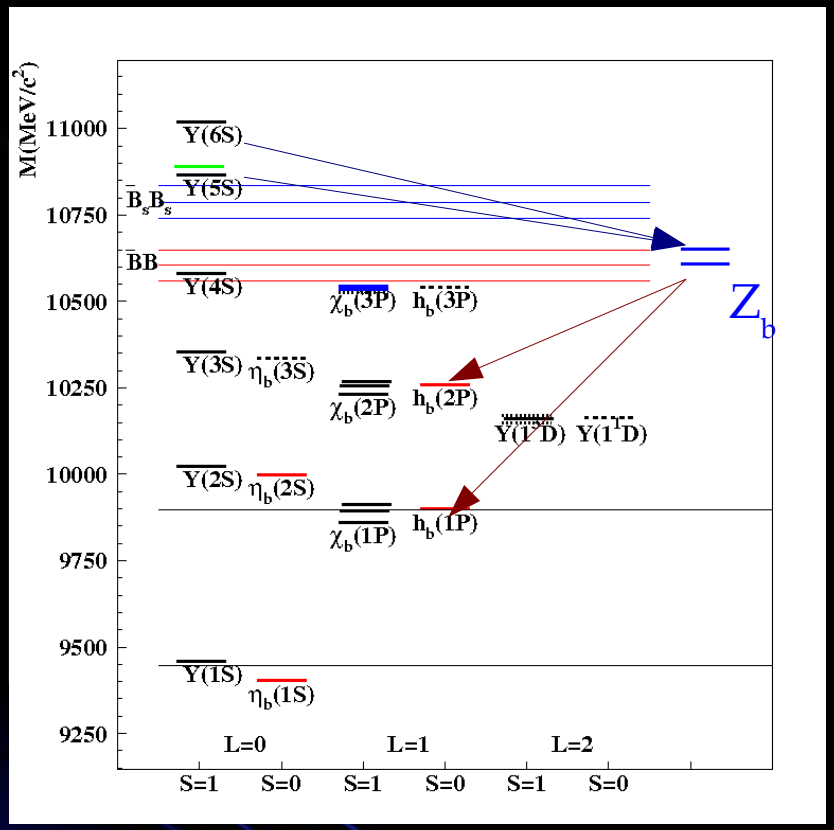
Belle	Babar	
50.3	1019	Y(1S) → ee
77.3	1007	Y(1S) → μμ
5.2	92	Y(1S) → ττ
	3	Y(1S) → hadrons
	2122	events tot exp.

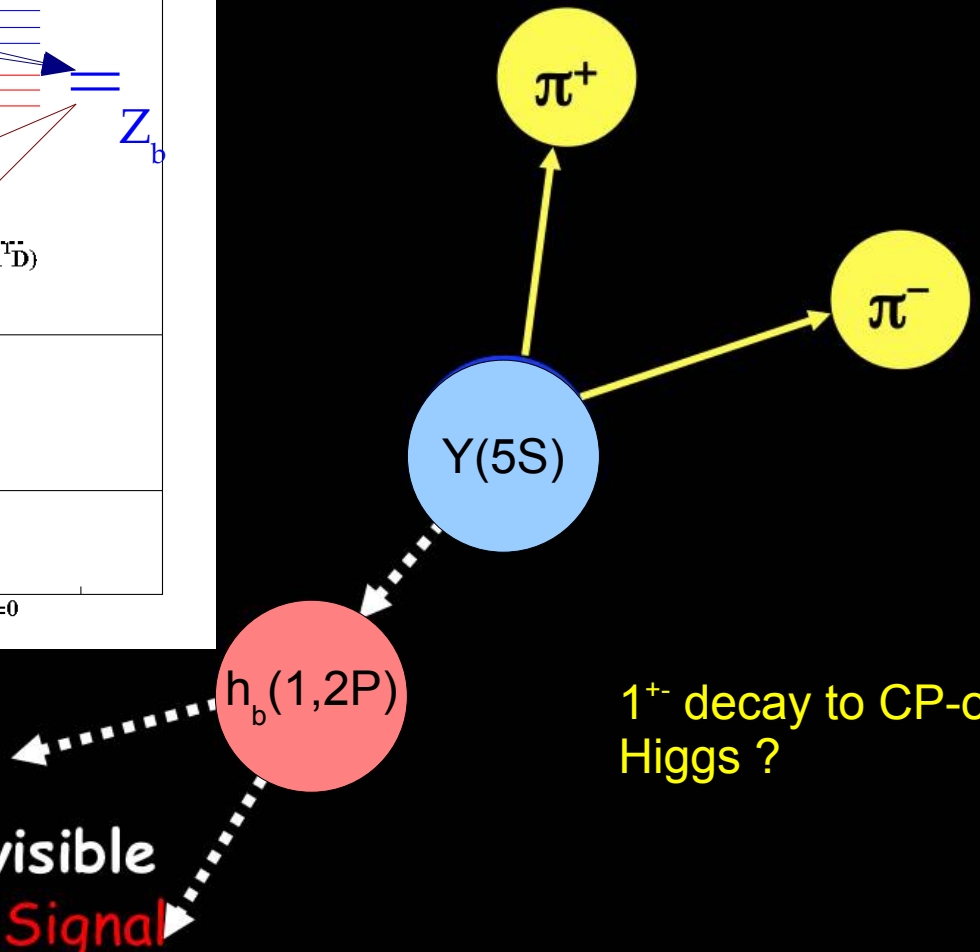
Renormalized from analysis of 3 and 4 track events:

$133.2^{+19.7}_{-14.7}$	2451+/- 38	total exp
38±39	2326+/-105	total obs

BABAR: 30 *fb*$^{-1}$. *91.4M Y(3S)*
Phys.Rev.Lett. 103 (2009) 181801

Further opportunities: dipion tagging of parabottomonia



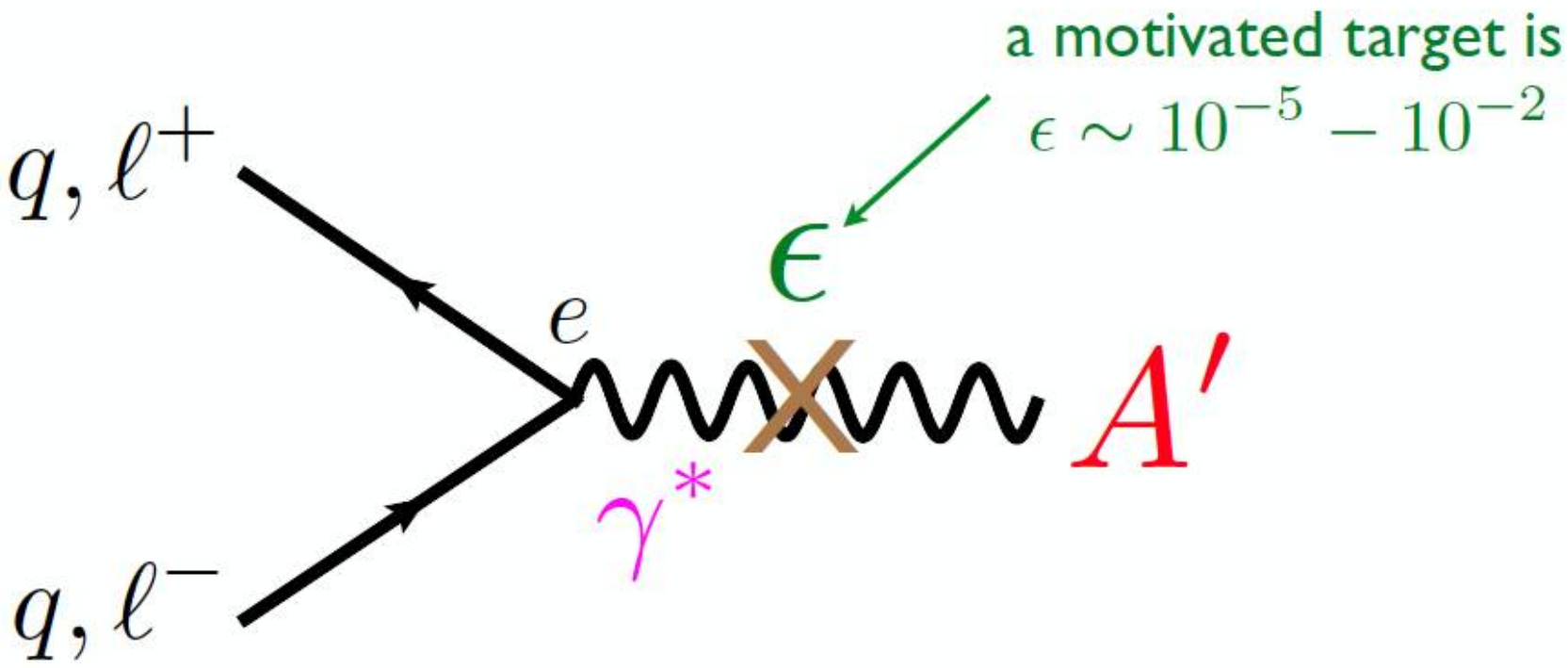


1^{+-} decay to CP-odd (dark) Higgs ?

Portals to the "Dark Sector"

- "Vector" $\epsilon F^{Y,\mu\nu} F'_{\mu\nu}$ dark photon A'
- "Axion" $\frac{1}{f_a} F_{\mu\nu} \tilde{F}^{\mu\nu} a$ axions & axion-like particles (ALPs)
- "Higgs" $\lambda H^2 S^2 + \mu H^2 S$ exotic Higgs decays?
- "Neutrino" $\kappa (HL) N$ sterile neutrinos?

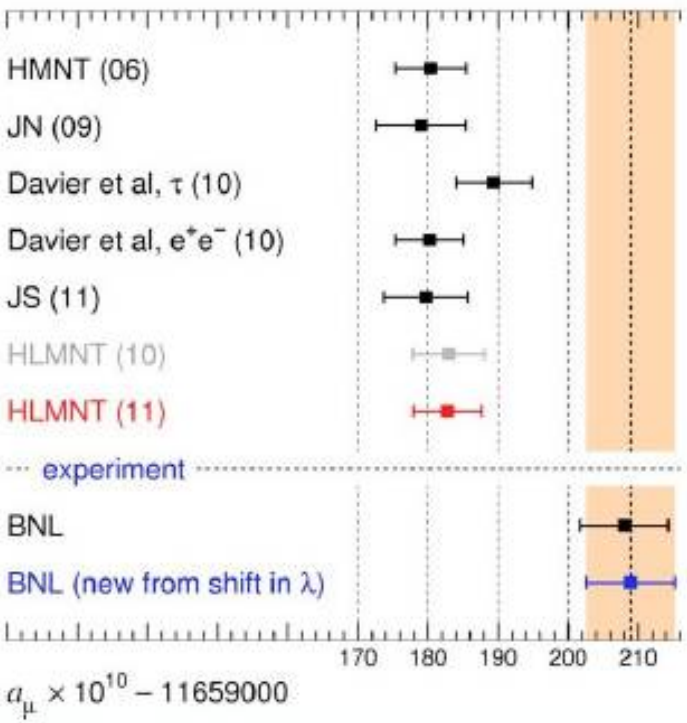
The “Dark Photon”

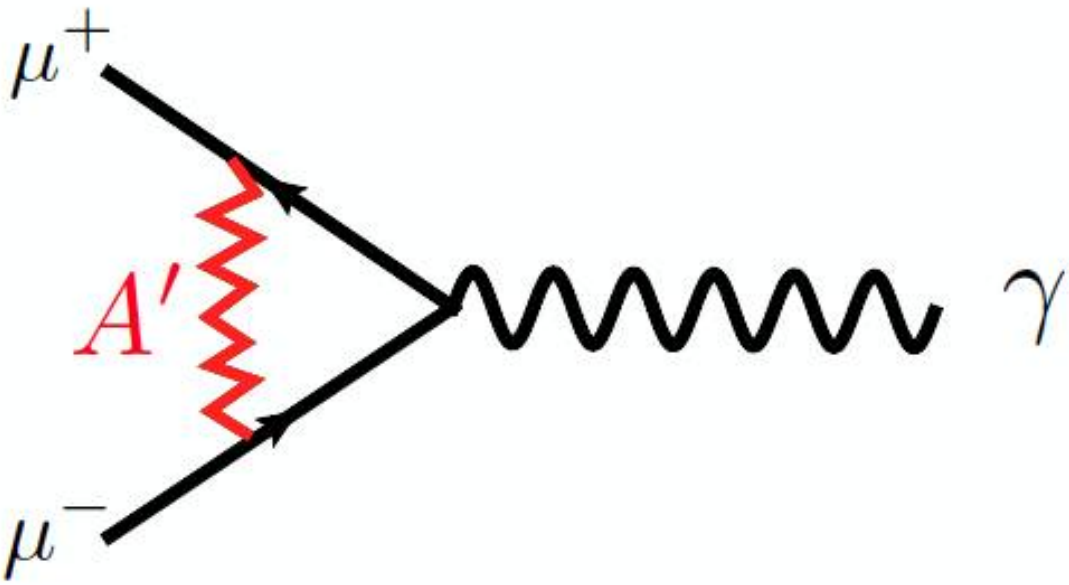


focus on $m_{A'} \sim 1$ MeV – 10 GeV

(theoretically natural, motivated from data)

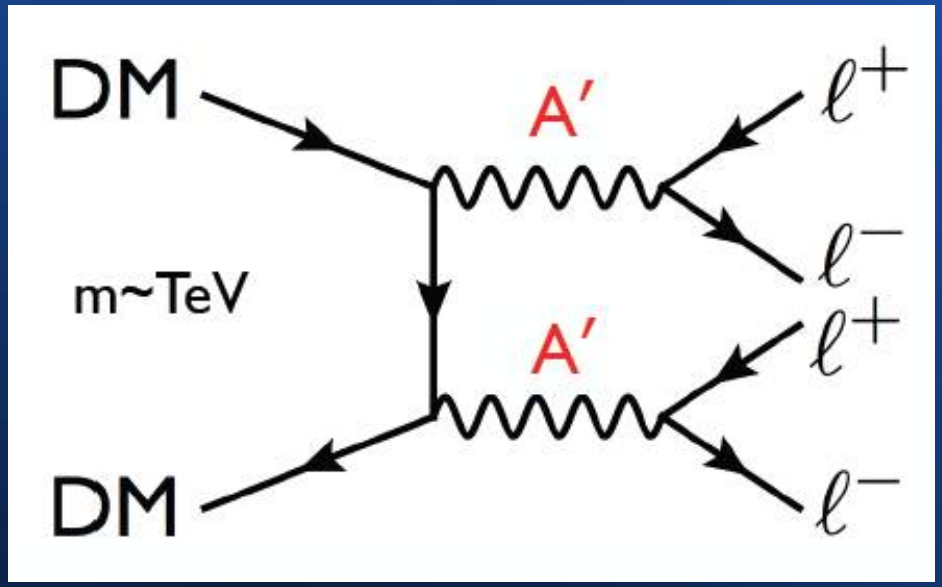
The “Dark Photon” and muon (g-2)



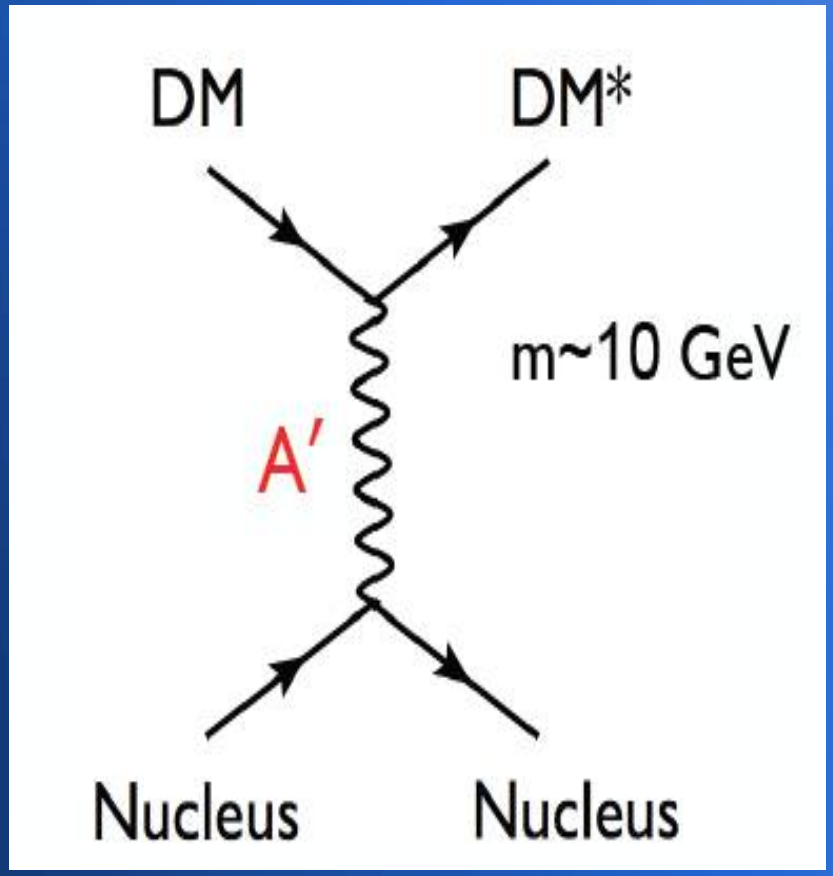


A′ may explain observed $(g_s - 2)_\mu$

The “Dark Photon” in Astroparticle Physics

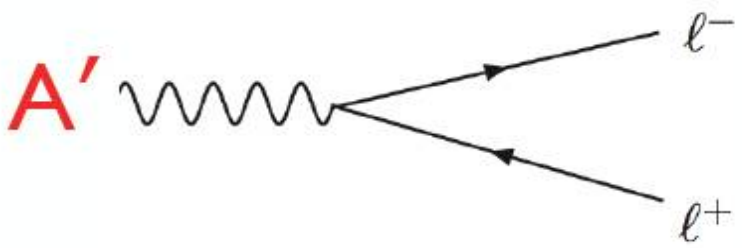


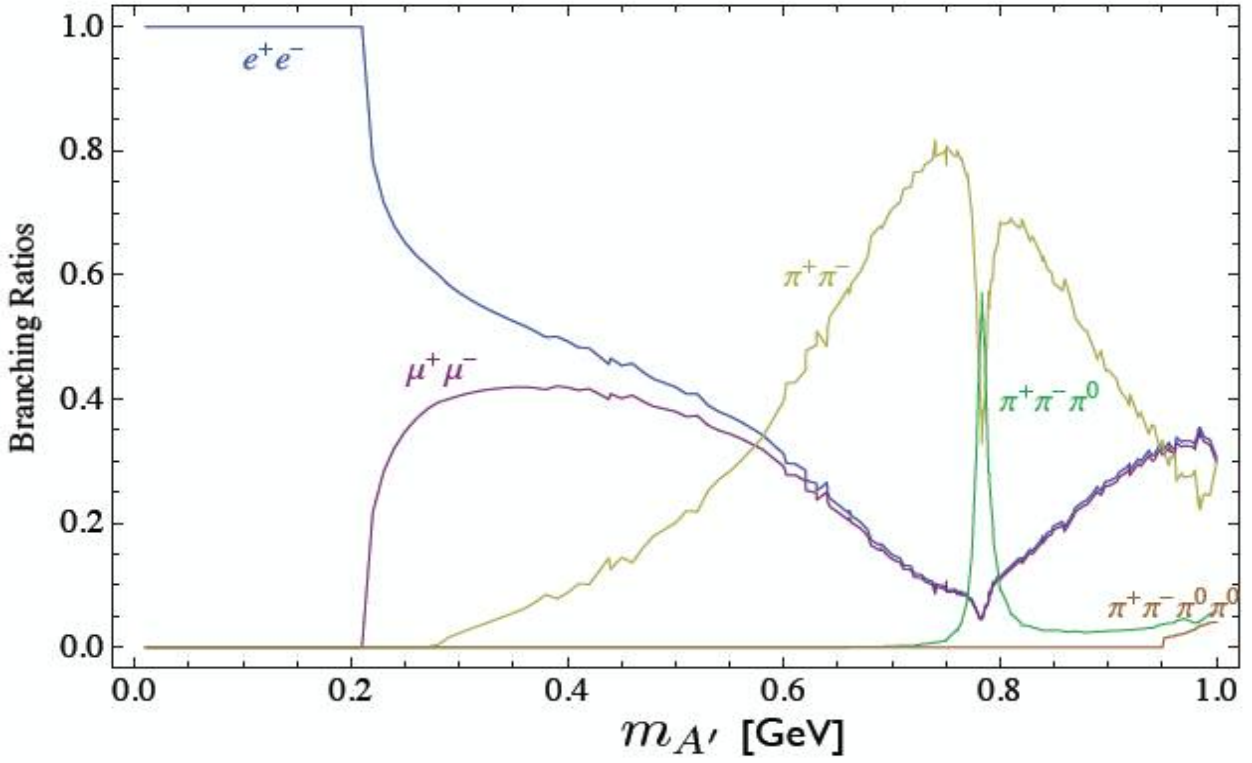
e+e- excess in Pamela, Fermi, AMS2



DAMA, CoGENT, CRESST, CDMS-Si

“Dark Photon” coupling to light hadrons and leptons

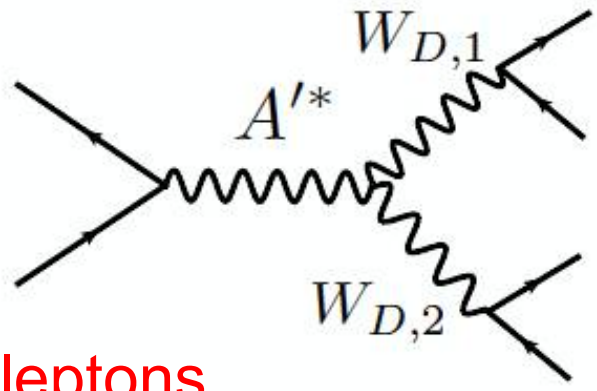




Higher order perversions: “Dark Ws” and “Dark Higgs”

non-Abelian
(many gauge bosons)

0908.2821 (BaBar)



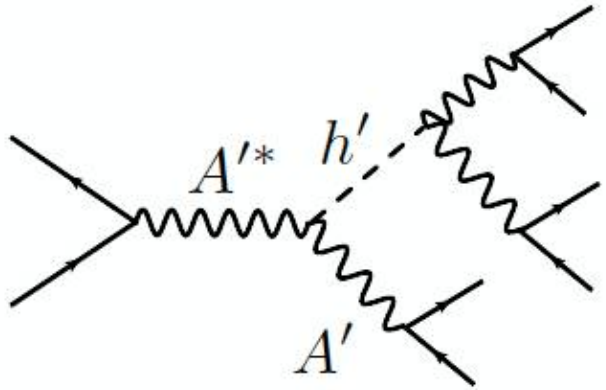
e+e- → 4 leptons

e+e- → 6 leptons

Dark Higgs boson

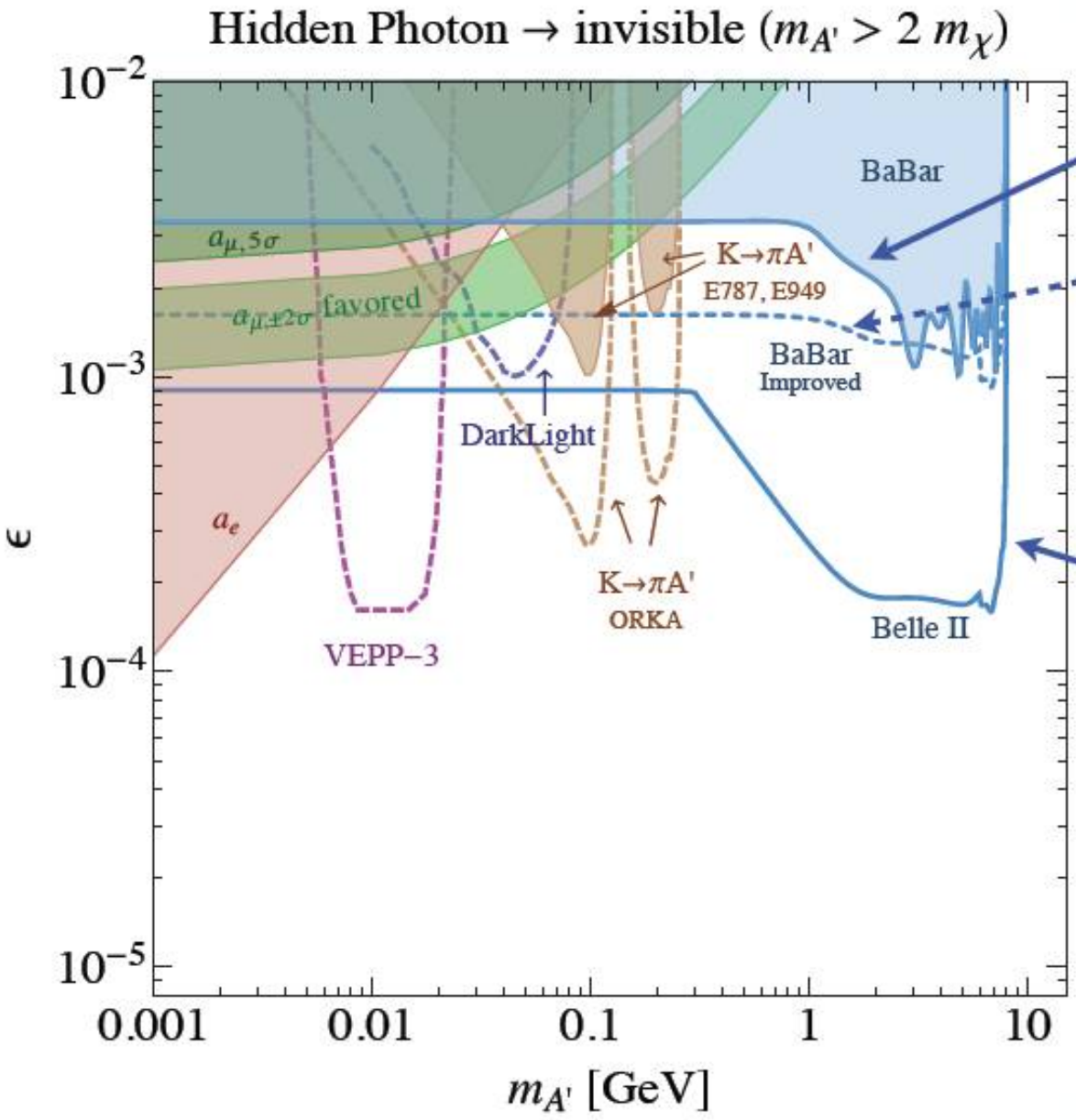
1202.1313 (BaBar)

In progress by Belle
(Igal Jaegle)



e+e- → γ + A'; A' to invisible

RE, Mardon, Papucci, Volansky, Zhong



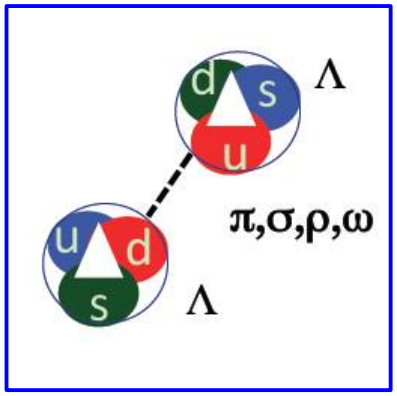
- existing data
- potential improvement from reducing $\gamma\gamma$ background (private communication)
- projected Belle II
  50/ab + better resolution

Planning single photon trigger at Belle-II (threshold: depends on actual backgrounds)

DM candidate from QCD ?

SLAC-PUB-1828
October 1976
(T/E)

PERHAPS A STABLE DIHYPERON*



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Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

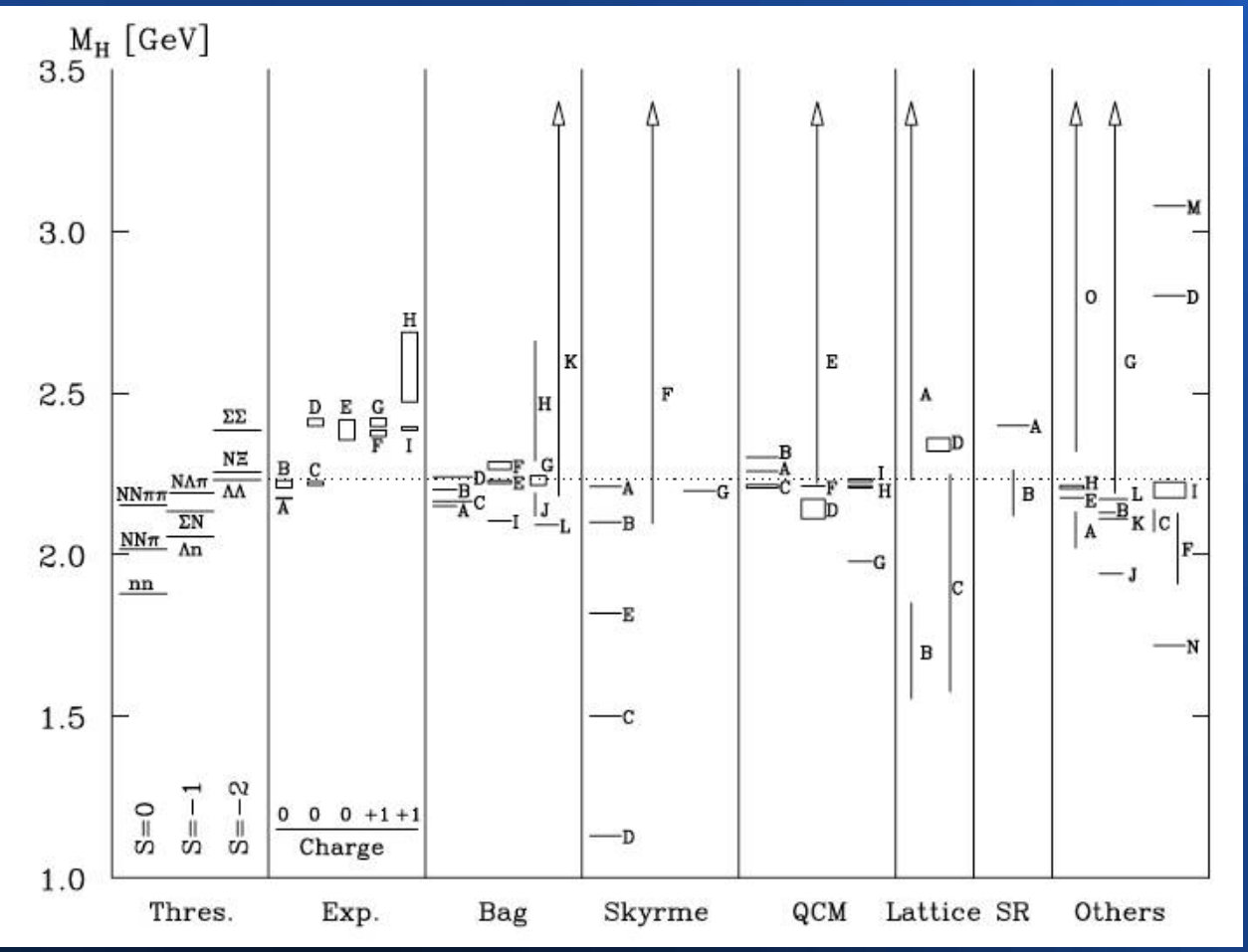
ABSTRACT

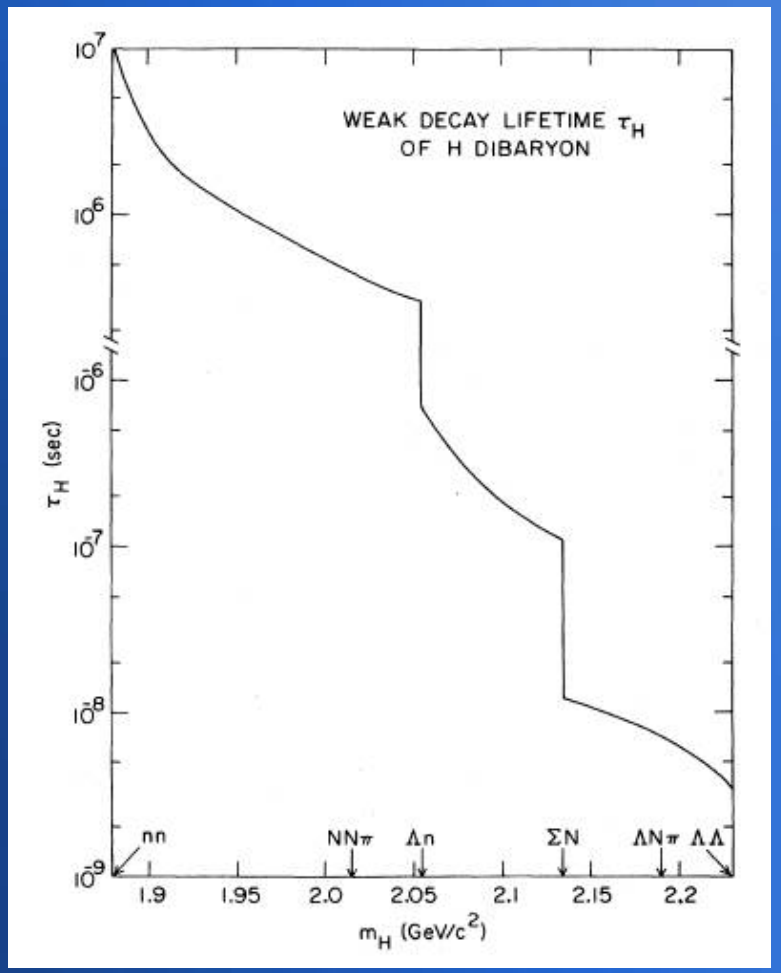
In the quark bag model the same gluon exchange forces which make the proton lighter than the Δ(1236) bind 6 quarks to form a stable, flavor singlet (strangeness -2) $J^P = 0^+$ dihyperon (H) at 2150 MeV. Another isosinglet di-hyperon (H*) with $J^P = 1^+$ at 2335 MeV should appear as a bump in ΛΛ invariant mass plots. Production and decay systematics of the H are discussed.

H-dibaryon Mass and Lifetime

Sakai et al.,Prog.Theor.Phys.Suppl. **137 (2000),121**

Dover et al.,PRC 40 (1989), 115





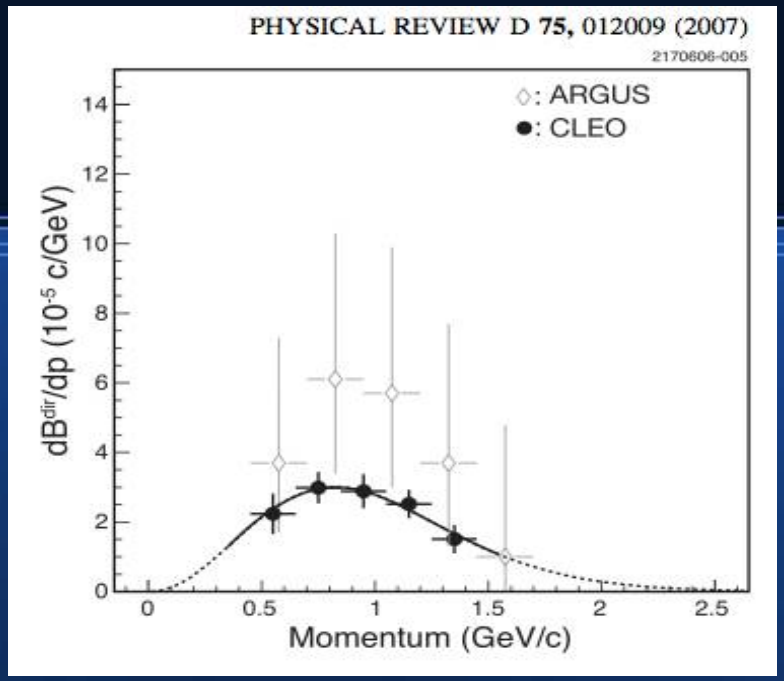
H-dibaryon as DM?

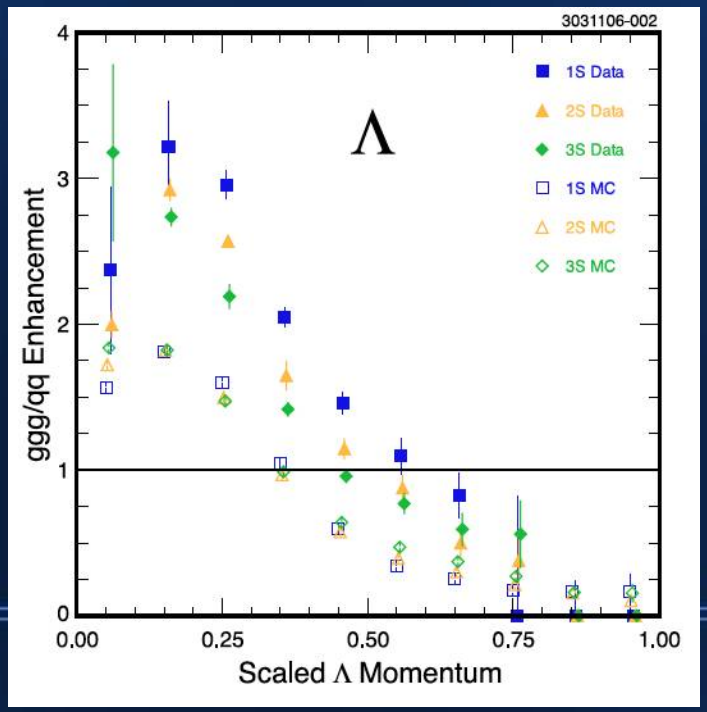
Kochelev 1999: JETP Lett. 70 (1999) 491, hep-ph/9905333
M = 1.7 GeV for QCD induced instanton effects (even LIGHTER than deuteron?)

Farrar-Zaharijas 2003-4: **Int.J.Theor.Phys. 42 (2003) 1211, Phys.Rev. D70 (2004) 014008**
"If very compact ($r_H < r_N/4$) , a H dibaryon would not lead to matter instabilities and maybe candidate for cold dark matter. Data from Uranus internal energy exclude DM made of *equal amounts of H and anti-H dibaryons.*"

Shuryak 2005: **J.Phys.Conf.Ser. 9 (2005) 213-217, ArXiV: hep-ph/0505011**
Deeply bound diquarks formed by QCD instantons
"However if one considers the quantum numbers of the famous H dibaryon, one can also make those out of diquarks […] The resulting wave function is overall flavor antisymmetric with all diquarks in S-states. Thus there is no need for P-wave or
tensor diquarks for the H dibaryon. Our schematic model would then lead to a light H never seen"

H-dibaryon in bottomonium decays





Former observations by ARGUS (Z.Phys. C39 (1988) 177) and CLEO (Phys.Rev. D76 (2007) 012005)

- Inclusive production of (anti)deuteron in Y(1,2S) decays :

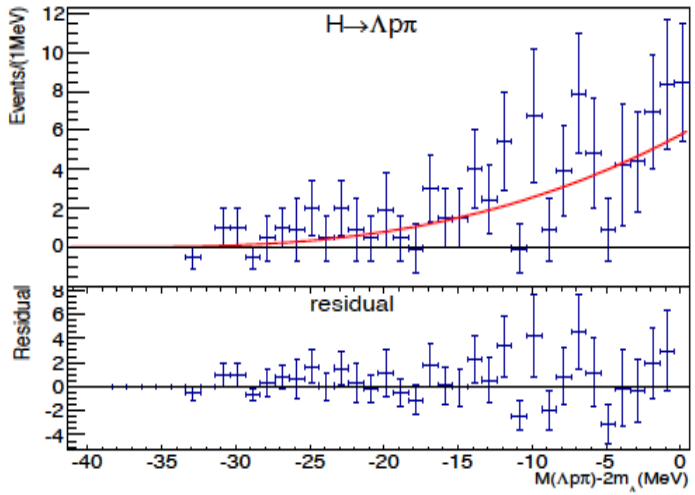
$$\mathcal{B}^{\mathrm{dir}}(\Upsilon(1S) \to \bar{d}X) = (3.36 \pm 0.23 \pm 0.25) \times 10^{-5}.$$

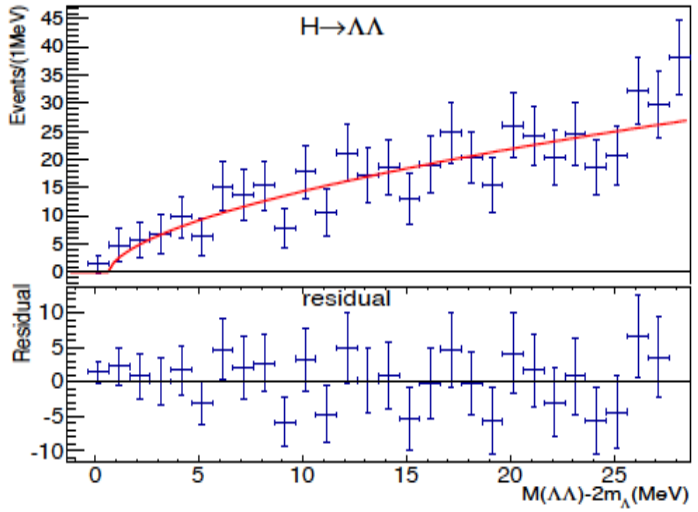
$$\mathcal{B}(\Upsilon(2S) \to \bar{d} + X) = (3.37 \pm 0.50 \pm 0.25) \times 10^{-5}.$$

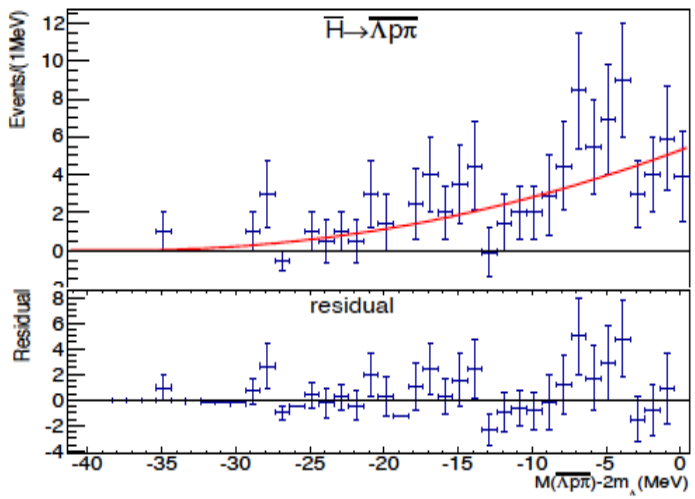
- Enhanced (3x) production of low momentum hyperons in hadronic events from bottomonium decays w/respect to continuum.

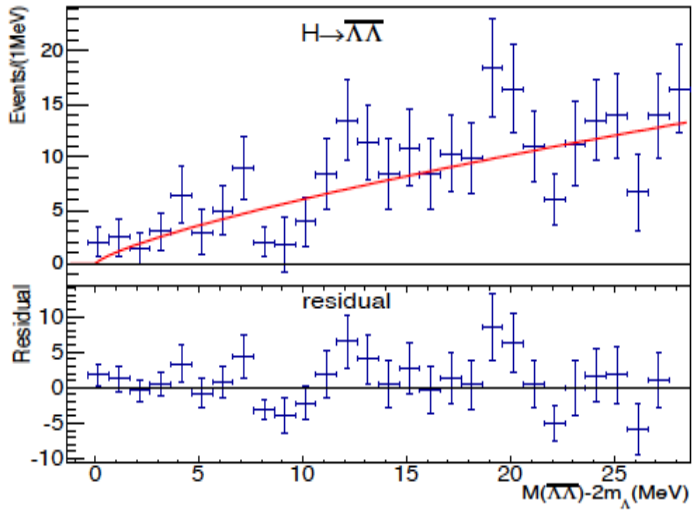
BELLE has exploited the Y(1,2S) record samples to search for the long sought H-dibaryon

Searches for H-dibaryon at BELLE









Searches for H-dibaryon at BELLE

Belle has searched for H dibaryon in the folllowing channels:

- $\Lambda\pi p$ (+cc) PRL 110, 222002 (2013)
- $\Lambda\Lambda$ (+cc)
- Ξ p (+cc) [preliminary]

More to come from Y(1,2,...S) decays (+cont):

- Λp and $\Lambda\Lambda$ (+cc) correlations
- antideuteron spectra (and more)
- antideuteron-deuteron production
- searches for H in missing mass