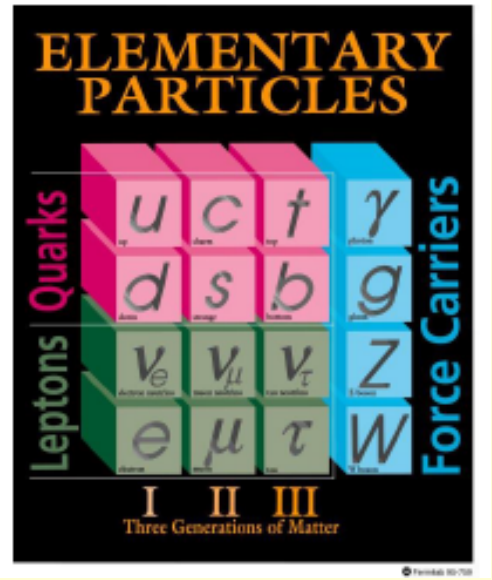
Search for a Leptophobic Gauge Boson via η Decay at JLab

Liping Gan
University of North Carolina Wilmington

Outline

- Motivation
- JLab Eta Factory (JEF) experiment
- Projected experimental reach
- Summary

Search for Dark Forces

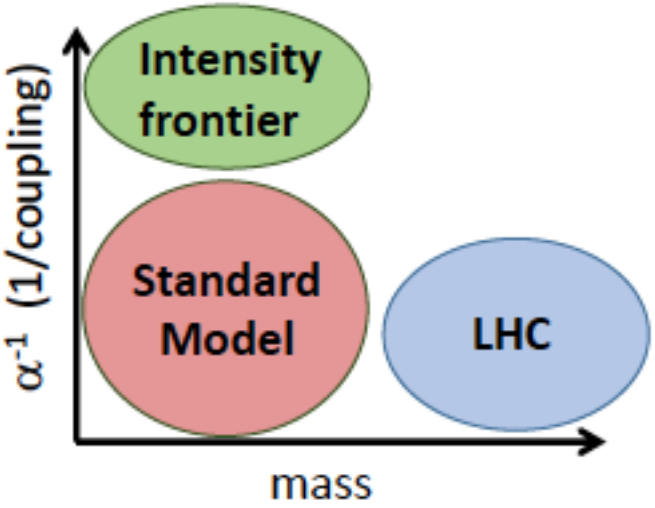


SM based on $SU(3)_C \times SU(2)_L \times U(1)_Y$ gauge symmetry. Are there any additional gauge symmetries? Look for new gauge bosons.

Motivations:

1. **Grand unified theories:** Generically have additional gauge bosons, but typically very heavy (10^{16} GeV).
2. **Dark matter:** Stability of dark matter related to new gauge symmetry?

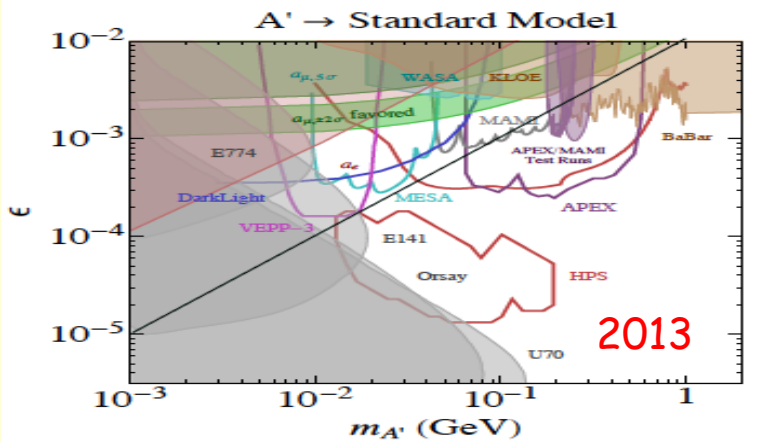
   Can also give the right relic density.

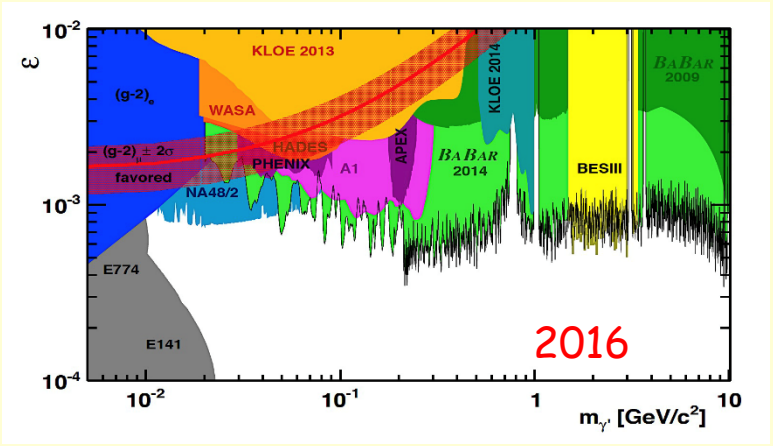


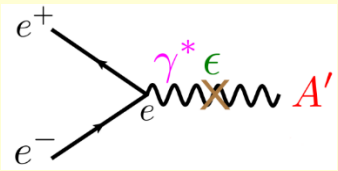
"Vector Portal" to Dark Sector

1. Dark photon A'

$-\frac{1}{2}\varepsilon F^{\mu\nu}F'_{\mu\nu}$ Kinetic mixing and U(1)'







Most A' searches look for $A' \to l^+l^-$, relying on the leptonic coupling of new force

2. Dark leptophobic B-boson (dark ω, γ_B , or Z'):

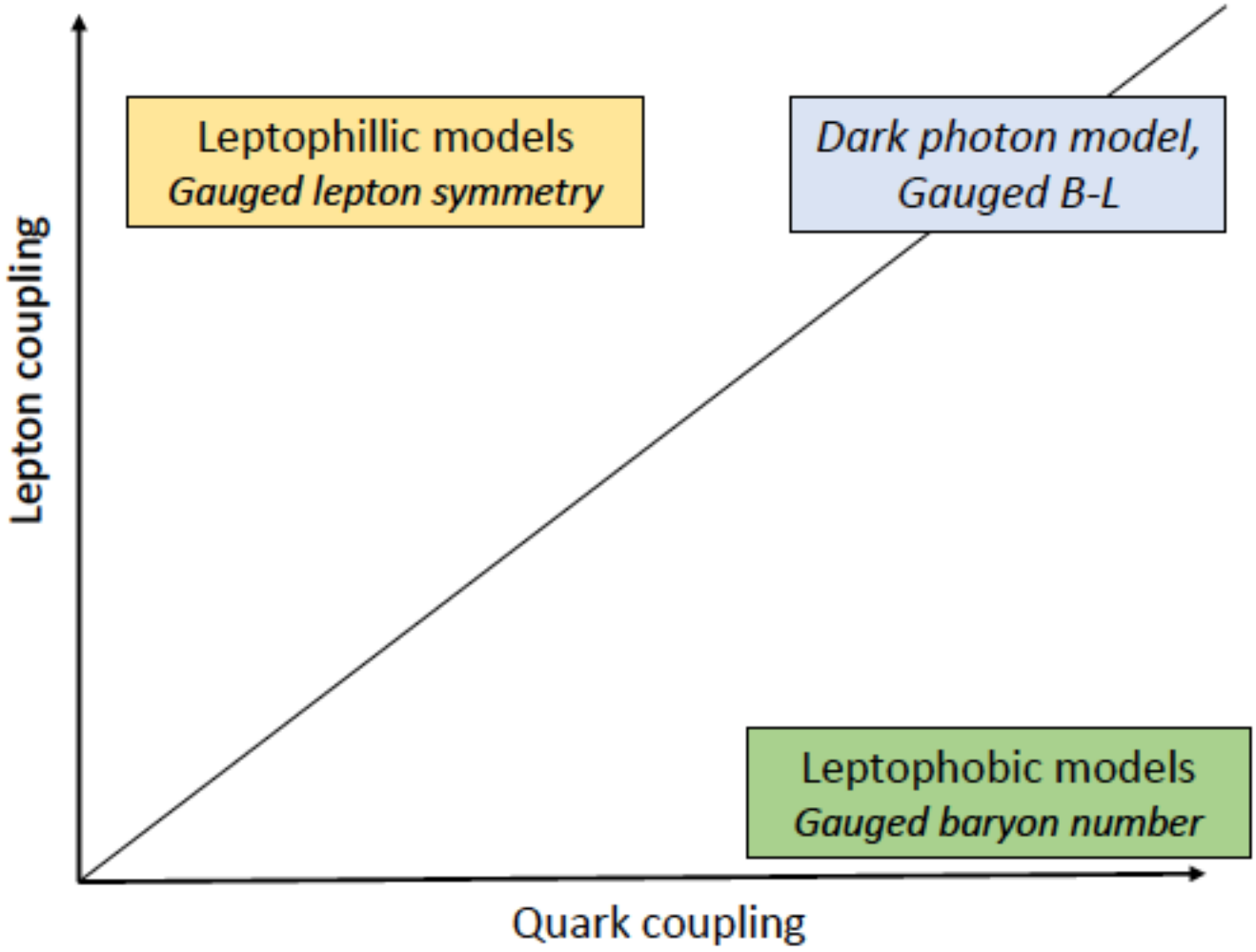
$$\frac{1}{3}g_B\bar{q}\gamma^\mu qB_\mu$$

Gauged baryon number symmetry $U(1)_B$

T.D. Lee and C.N. Yang, Phys.Rev.,98, 1501 (1955)

- the stability of baryonic and dark matter
- a unified genesis of baryonic and dark matter M.Graesser, I. Shoemaker and L. Vecchi, arXiv:1107.2666
- a natural framework for resolving "Strong CP problem" in QCD

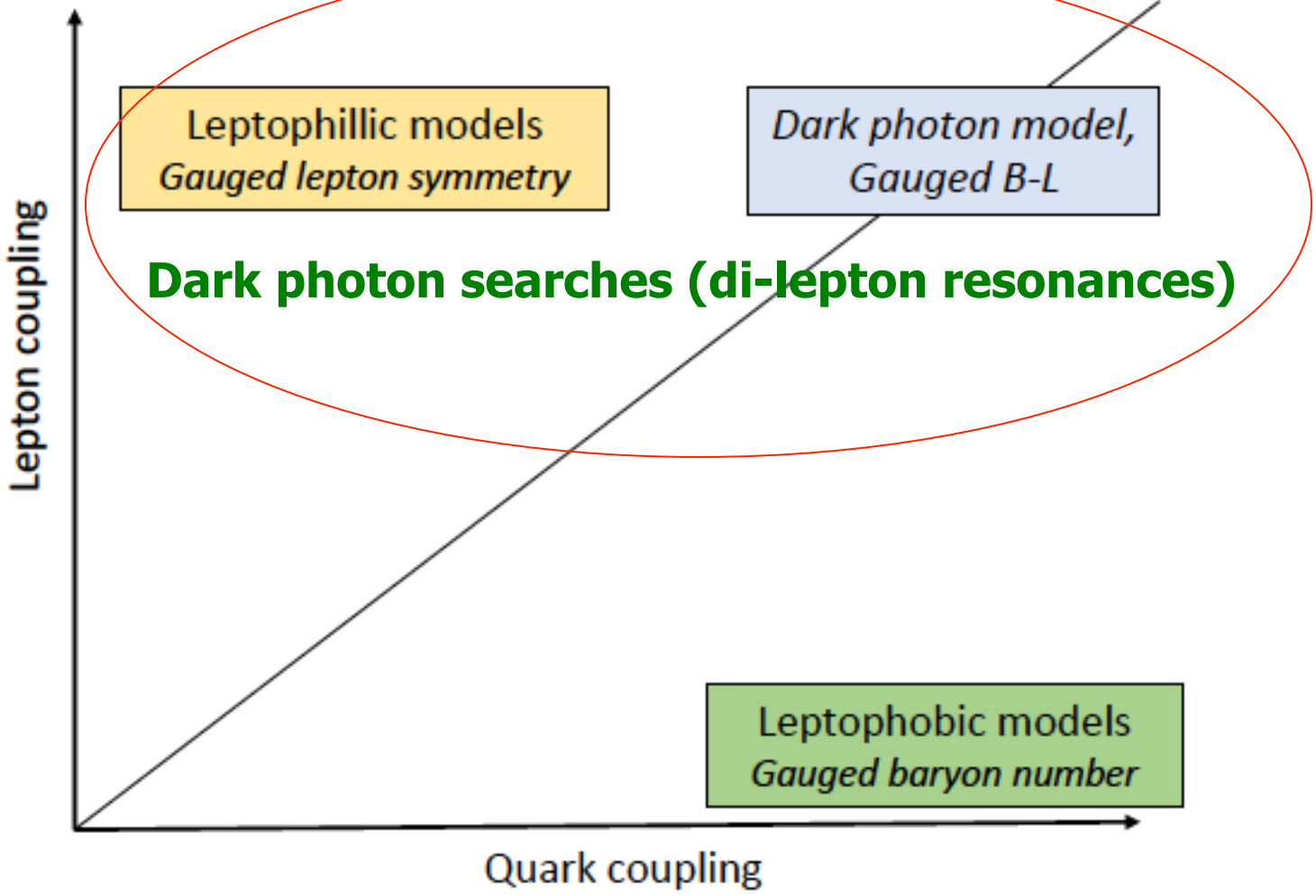
Landscape of new GeV-scale forces



Also a third axis: decays to invisible states (neutrinos, light dark matter)

Davoudiasl et al (2012), Batell et al (2009), deNiverville et al (2011,2012)

Landscape of new GeV-scale forces



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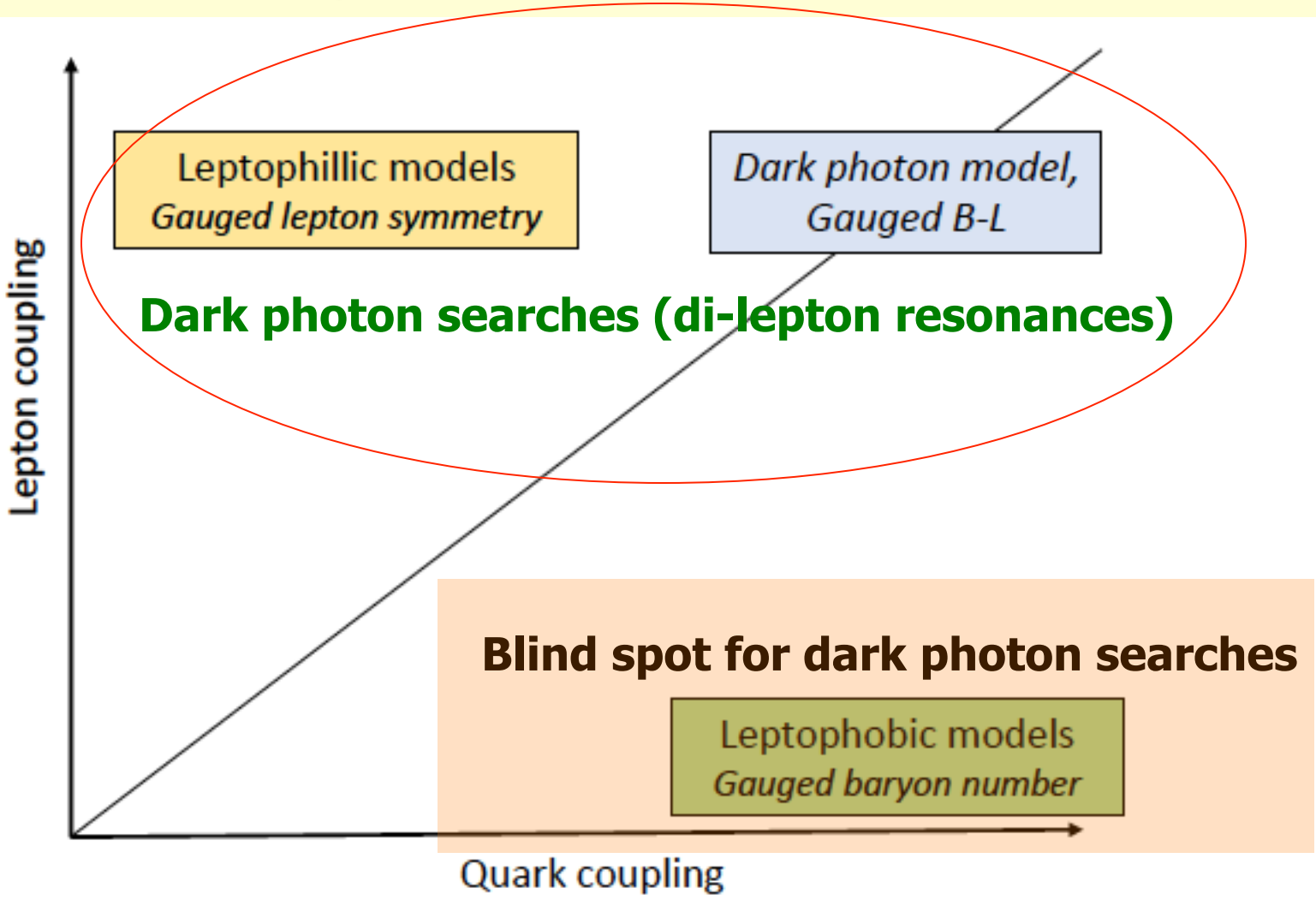

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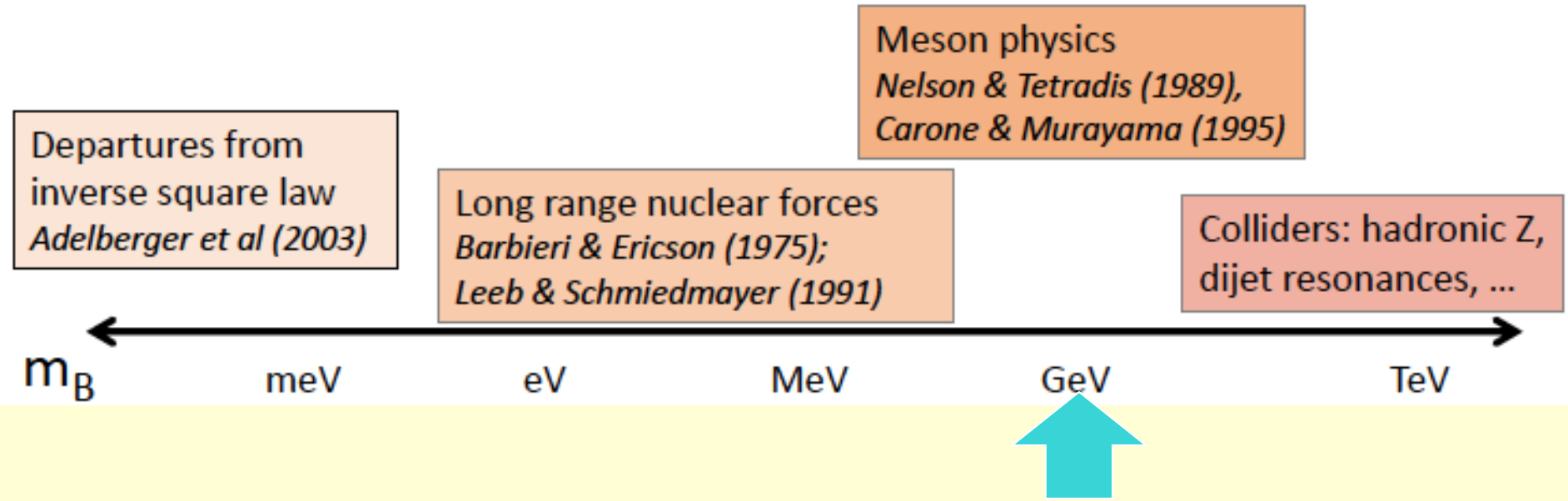
Davoudiasl et al (2012), Batell et al (2009), deNiverville et al (2011,2012)

Experimental probes for B-boson

Discovery signals depend on the B mass:

- the $m_B < m_\pi$ region is strongly constrained by long-range forces search and nuclear scattering experiments.
- the $m_B > 50GeV$ region has been investigated by the collider experiments.
- GeV-scale domain is nearly untouched.

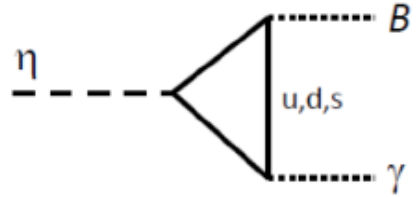


a discovery opportunity hiding in nonperturbative QCD regime!

Striking signature for B-boson in $\eta \to \pi^0\gamma\gamma$

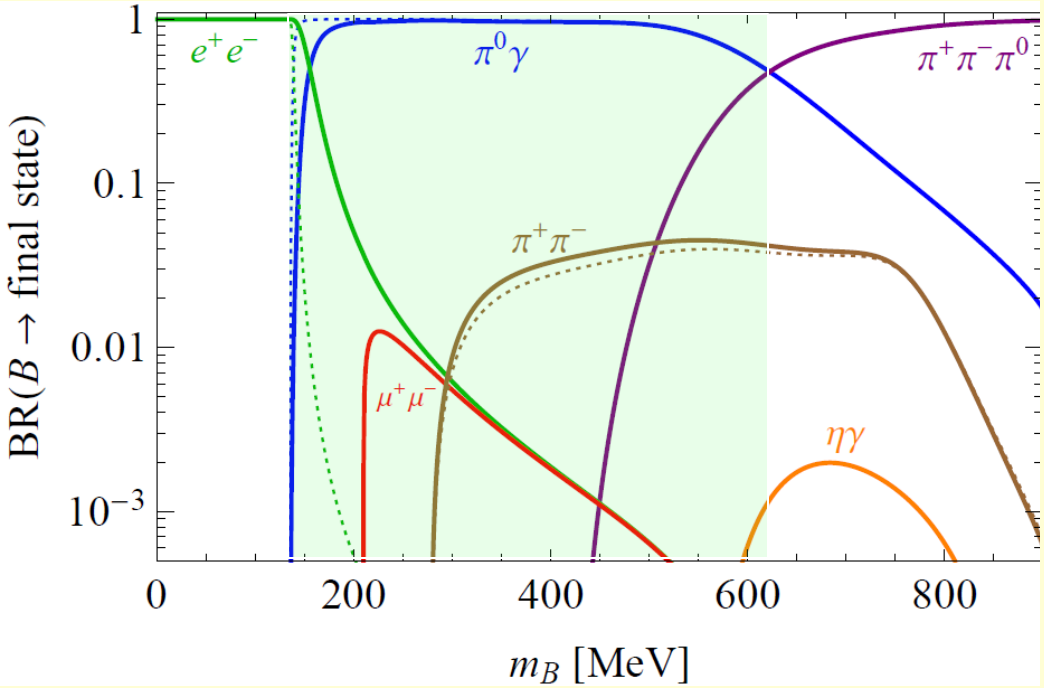
- B production: **A.E. Nelson, N. Tetradis, Phys. Lett., B221, 80 (1989)**

$\eta \to B\gamma$ decay ($m_B < m_\eta$)



Triangle diagram

- B decays: $B \to \pi^0\gamma$ in 140-620 MeV mass range



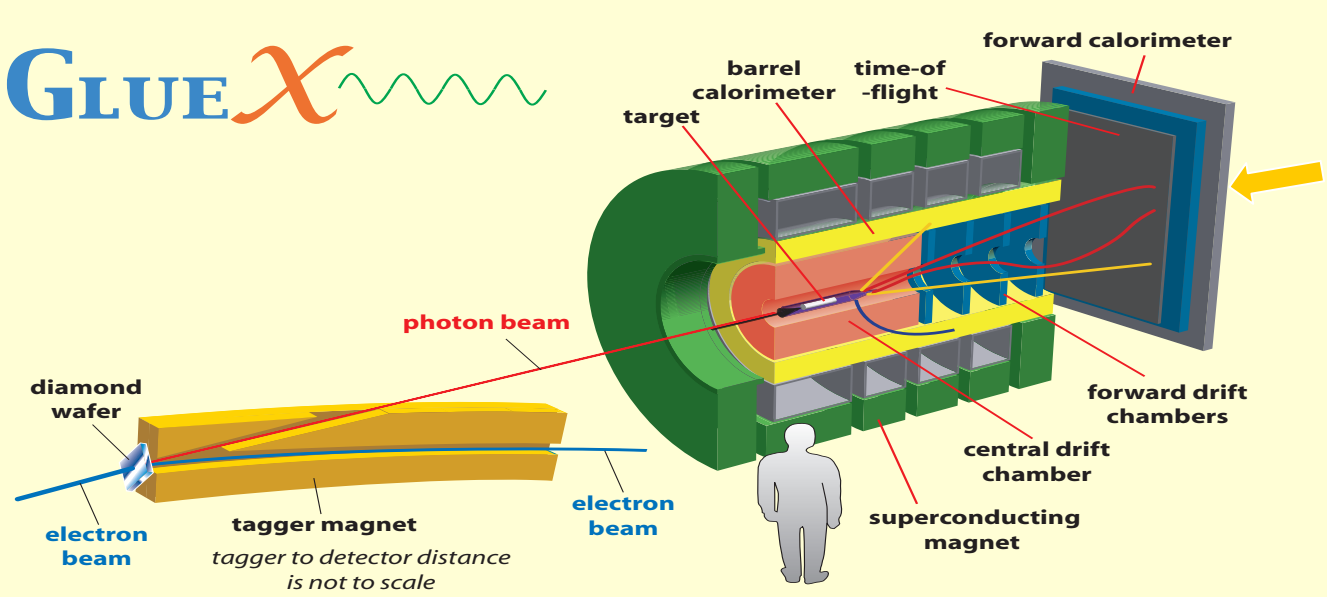
$\eta \to \gamma B \to \gamma + \pi^0\gamma$

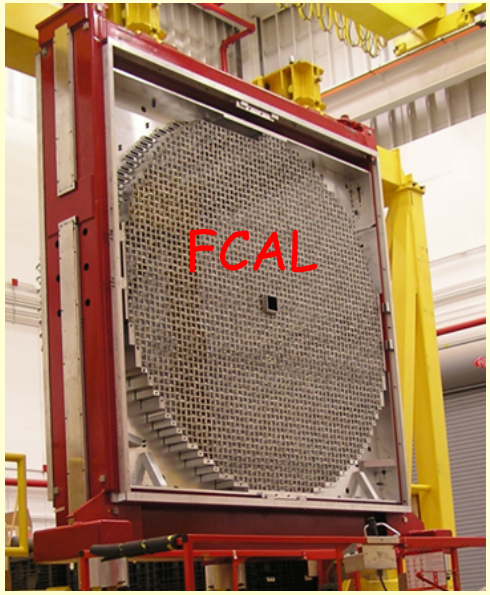
Search for a resonance peak of $\pi^0\gamma$ for m_B ~140-550 MeV

S. Tulin, Phys.Rev., D89, 14008 (2014)

- $\Gamma(\eta \to \pi^0\gamma\gamma) \sim 0.3eV$ ➡ highly suppressed SM background

JLab Eta Factory (JEF) experiment





Simultaneously measure η decays: $\eta \to \pi^0\gamma\gamma$, $\eta \to 3\gamma$, and …

- η produced on LH_2 target with **9-11.7 GeV tagged photon beam:**

  $\gamma + p \rightarrow \eta + p$

- Reduce non-coplanar backgrounds by **detecting recoil p's** with GlueX detector ($\varepsilon \sim 75\%$)

- Upgraded Forward Calorimeter with **High resolution, high granularity** $PbWO_4$ insertion (**FCAL-II**) to detect multi-photons from rare η decays

Overview of the JEF project

Mode	Branching Ratio	Physics Highlight	Photons
priority:			
$\pi^0 2\gamma$	$(2.7 \pm 0.5) \times 10^{-4}$	χPTh at $\mathcal{O}(p^6)$	4
$\gamma + B$	beyond SM	leptophobic dark boson	4
$3\pi^0$	$(32.6 \pm 0.2)\%$	$m_u - m_d$	6
$\pi^+\pi^-\pi^0$	$(22.7 \pm 0.3)\%$	$m_u - m_d$, CV	2
3γ	$< 1.6 \times 10^{-5}$	CV, CPV	3
ancillary:			
4γ	$< 2.8 \times 10^{-4}$	$< 10^{-11}$[112]	4
$2\pi^0$	$< 3.5 \times 10^{-4}$	CPV, PV	4
$2\pi^0\gamma$	$< 5 \times 10^{-4}$	CV, CPV	5
$3\pi^0\gamma$	$< 6 \times 10^{-5}$	CV, CPV	6
$4\pi^0$	$< 6.9 \times 10^{-7}$	CPV, PV	8
$\pi^0\gamma$	$< 9 \times 10^{-5}$	CV, Ang. Mom. viol.	3
normalization:			
2γ	$(39.3 \pm 0.2)\%$	anomaly, η-η' mixing PR12-10-011	2

Main physics goals:

1. Search for a leptophobic dark boson (B).

2. Directly constrain CVPC new physics

3. Probe interplay of VMD & scalar resonances in ChPT to calculate $O(p^6)$ LEC's in the chiral Lagrangian.

4. Determine the light quark mass ratio

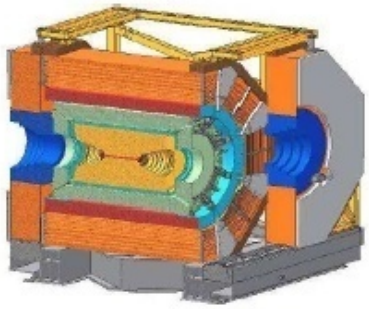
FCAL-II is required for the rare decays

World competition in η decays

e^+e^- Collider

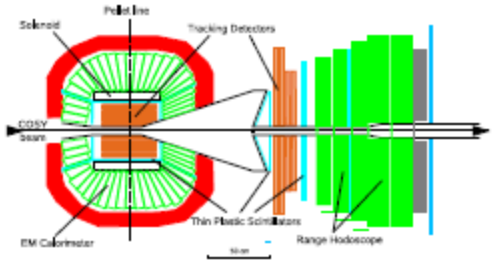
KLOE-2 at DAϕNE

BESIII at BEPCII



Fixed-target

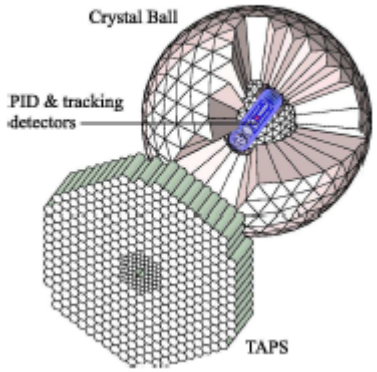
WASA at COSY



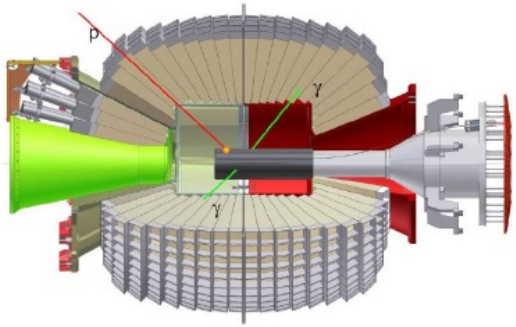
hadroproduction

photoproduction

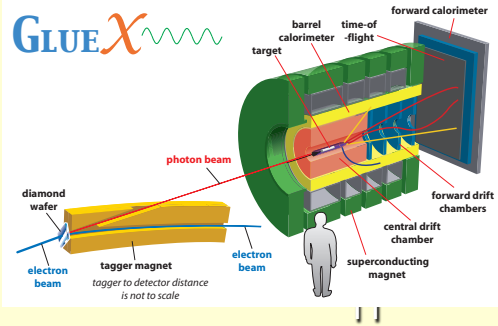
Crystall Ball at MAMI



CBELSA/TAPS at ELSA



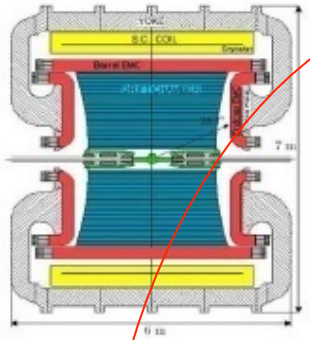
JEF at Jlab



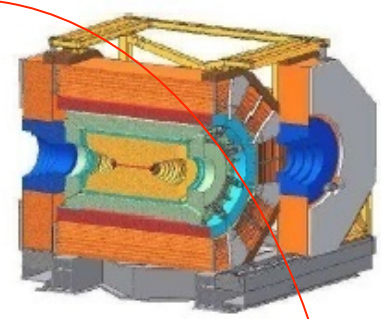
World competition in η decays

e^+e^- Collider

KLOE-2 at DAϕNE



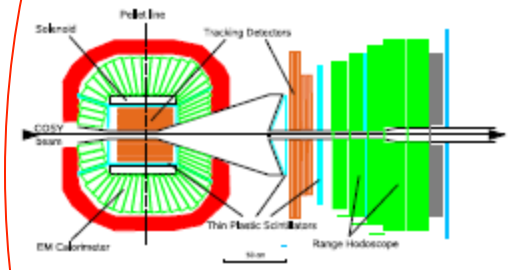
BESIII at BEPCII



Low energy η-facilities

Fixed-target

WASA at COSY



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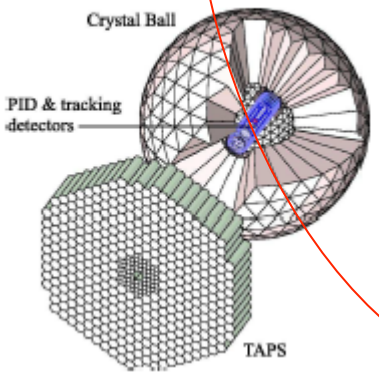

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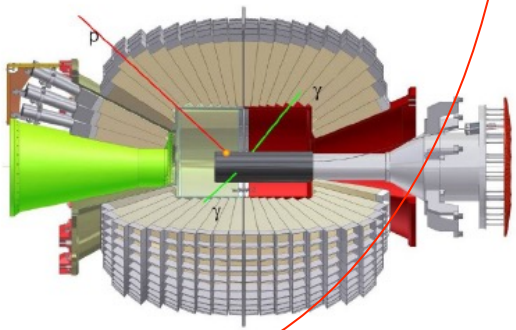
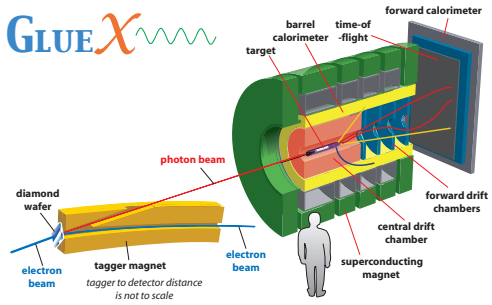


JEF at Jlab



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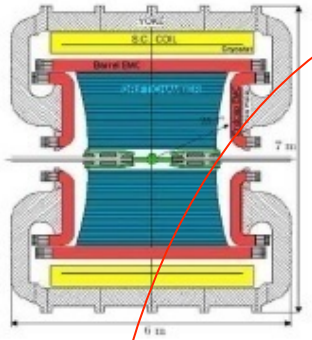

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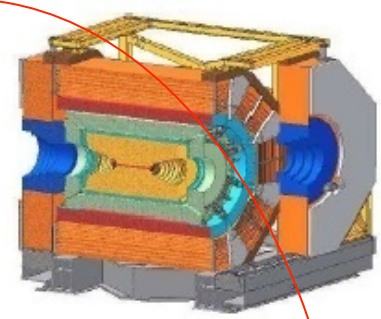

Low energy η-facilities

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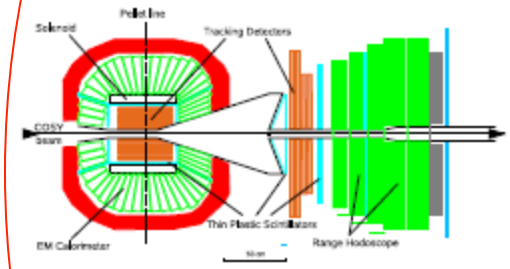

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High energy η-facility

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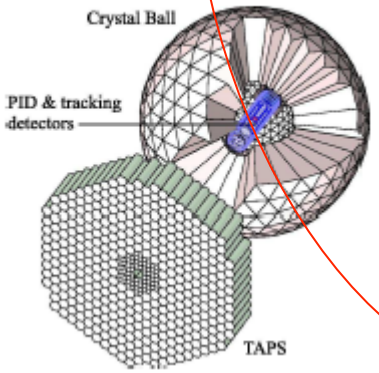

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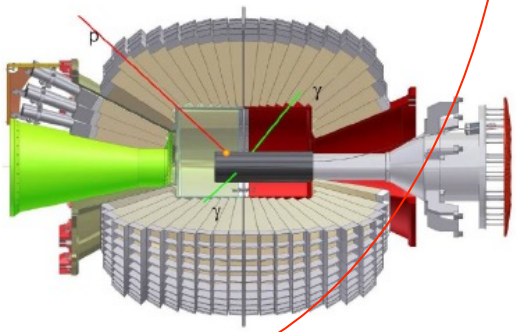
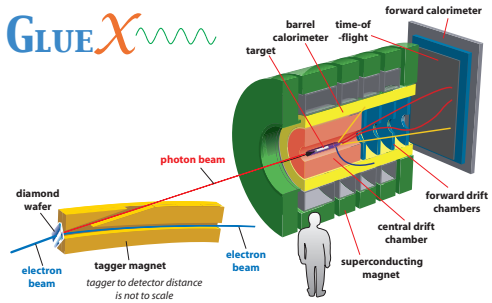
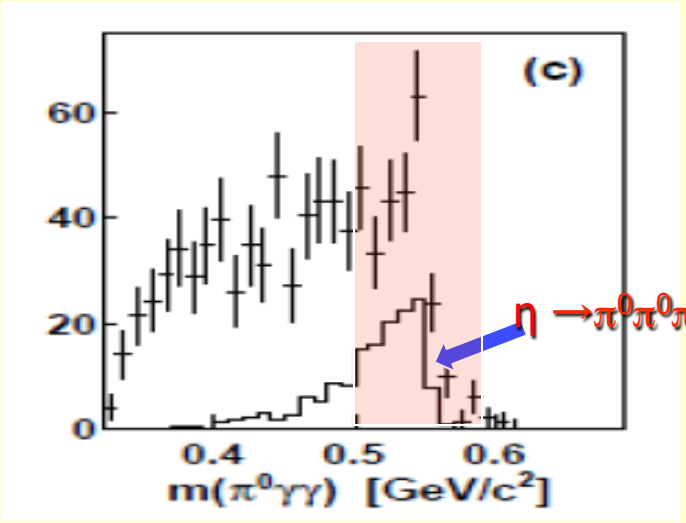


JEF at Jlab

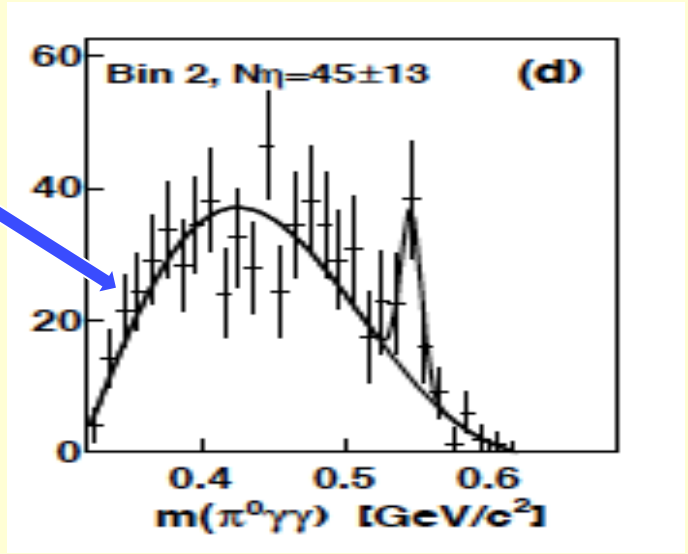


Filter Background with η Energy Boost ($\eta \to \pi^0\gamma\gamma$)

A2 at MAMI (Phys.Rev. C90 (2014) 025206): $\gamma p \to \eta p$ (E_γ=1.5 GeV)

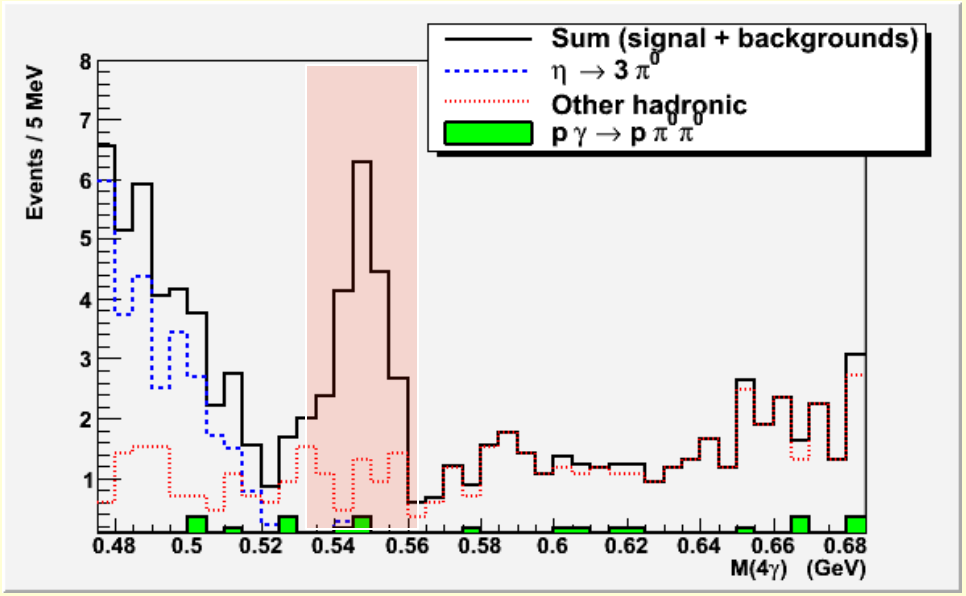


$\gamma p \to \pi^0\pi^0 + p$

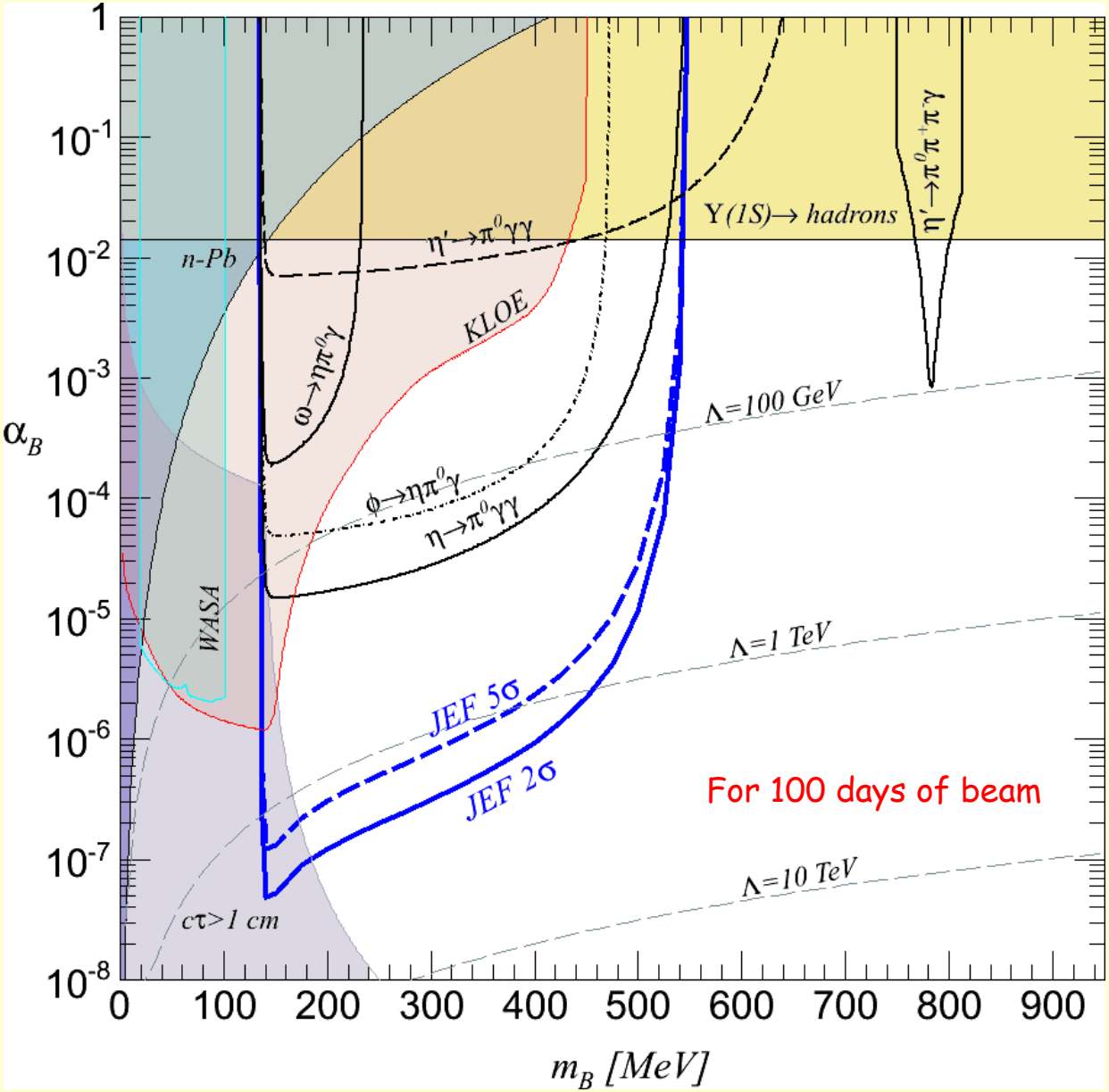


Jlab:

$\gamma p \to \eta p$ (E_γ = 9-11.7 GeV)



JEF Experimental Reach ($\eta \to B\gamma \to \pi^0\gamma\gamma$)

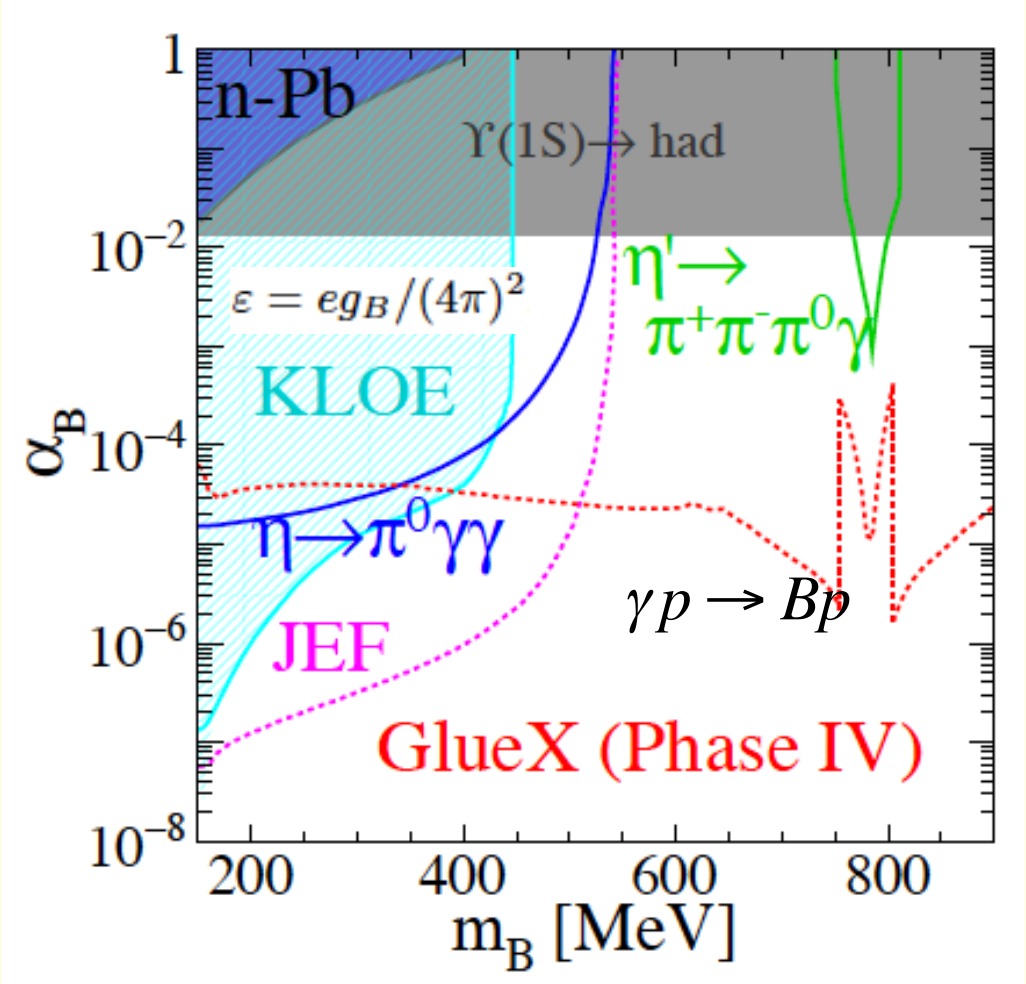


- A stringent constraint on the leptophobic B-boson in 140-550 MeV range.
- A positive signal of B in JEF will **imply a new fermion with a mass up to a few TeV** due to electro-weak anomaly cancellation.
- Future η' experiment will extend the experimental reach up to 1 GeV

Constraints from A' search (KLOE and WASA) assumed:

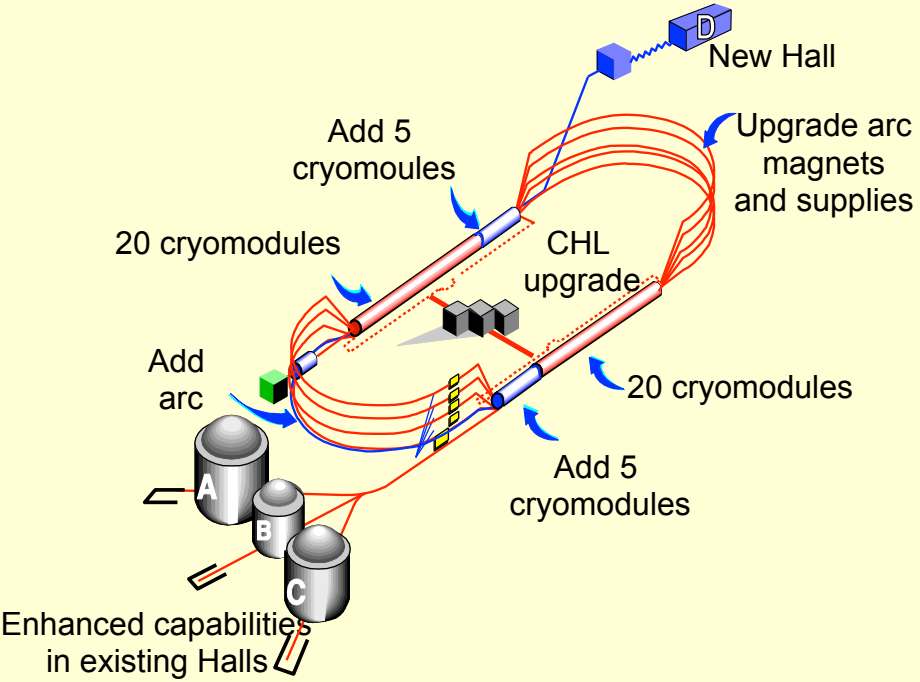
$$\varepsilon \sim 0.1 \times e g_B / (4\pi)^2$$

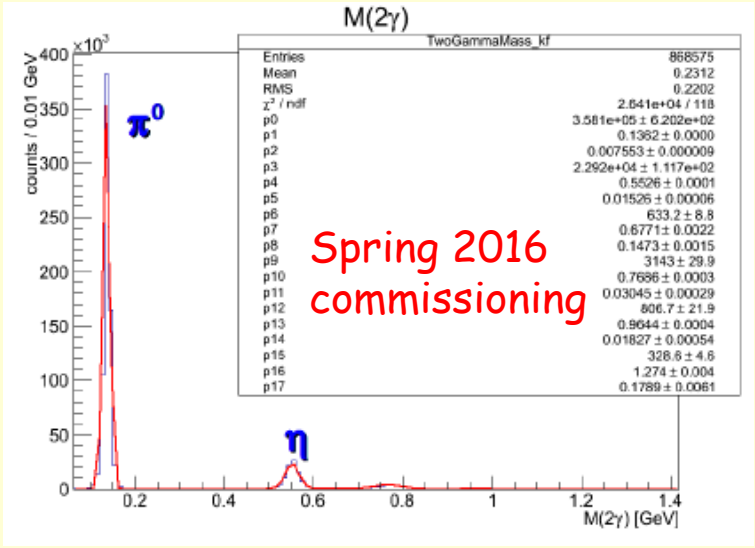
Search for B-boson in direct photo-production with GlueX



C. Fanelli and M. Williams, arXiv:1606.07161

JLab and GlueX





Summary

- 12 GeV tagged photon beam with GlueX setup offers a unique opportunity for discovering weakly-coupled new forces in **neutral mode**. It provides **two orders of magnitude in background reduction** in the neutral rare η decays compared to other facilities in the world.

- The JEF experiment will probe a leptophobic dark B-boson in 140-550 MeV range via $\eta \rightarrow B\gamma \rightarrow \pi^0\gamma\gamma$ (**complementary to ongoing A' search**), with sensitivity to the baryonic fine structure constant α_B as low as 10^{-7}.

- B-boson searches in η' decays or in direct photo-production may extend the experimental reach for the B mass up to 1 GeV

This project is supported in part by US NSF award PHY-1206043 and PHY-1506303 awards.