EXOTIC SEARCHES (VISIBLE DECAY) AT BESIII

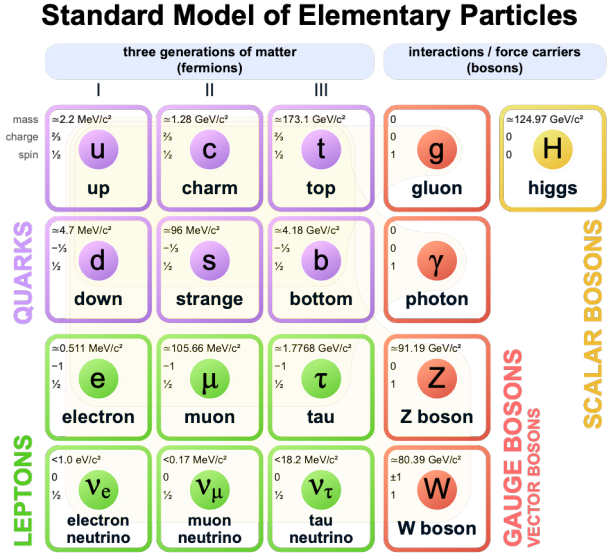
Houbing Jiang（姜候兵）

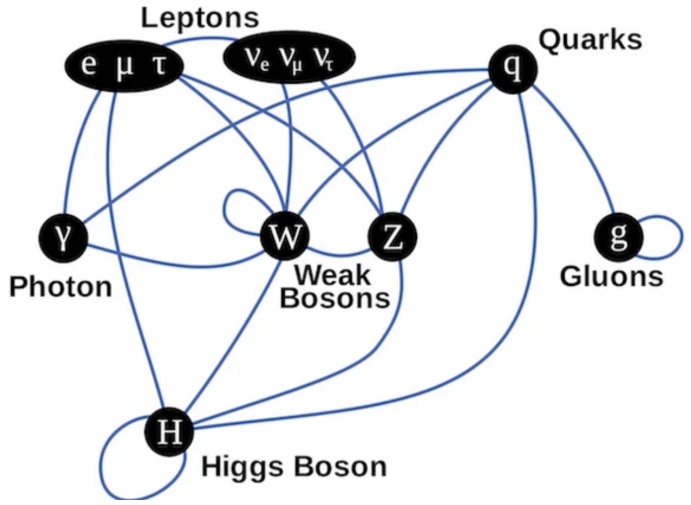
(Shandong University)

The Standard Model and Beyond

- With the discovery of the Higgs boson in 2012, the Standard Model (SM) has been firmly established. No any signal of New Physics was established;

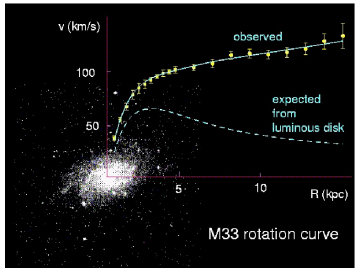
- "The Standard model is not the final answer"
  1. Theory motivations: Such as Hierarchy problem(s), origin of SM symmetries, particle mass hierarchies, too many free parameters …..
  2. Experimental `issues': strong CP problem, neutrino oscillations, dark matter, dark energy, matter-antimatter asym ….



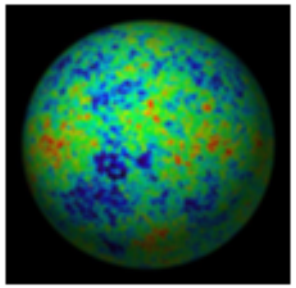


Motivation of "dark sector"

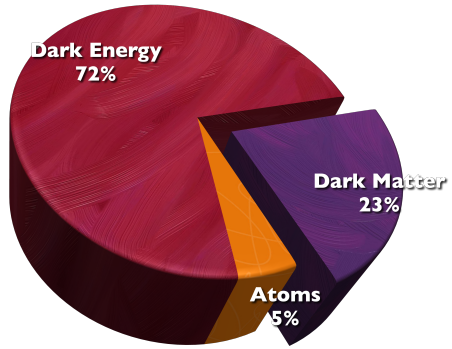
The presence of cold DM



Rotation curves

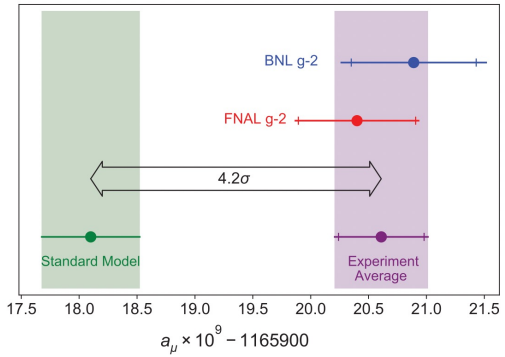


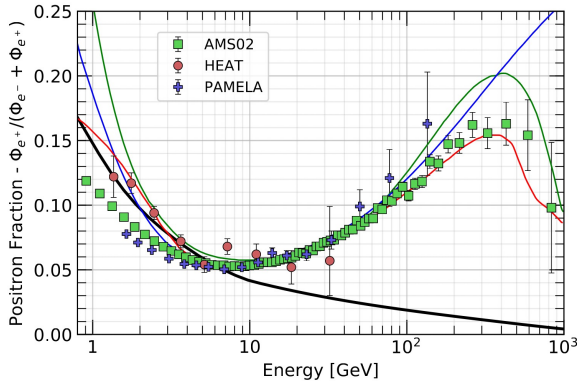
CMB

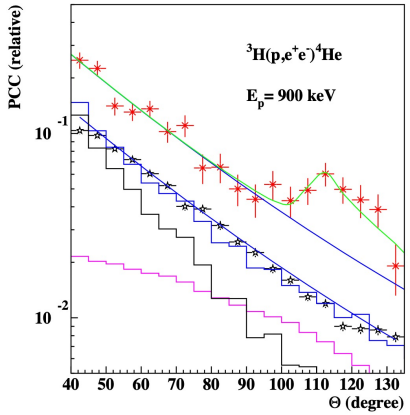


...

Anomalies in experiment







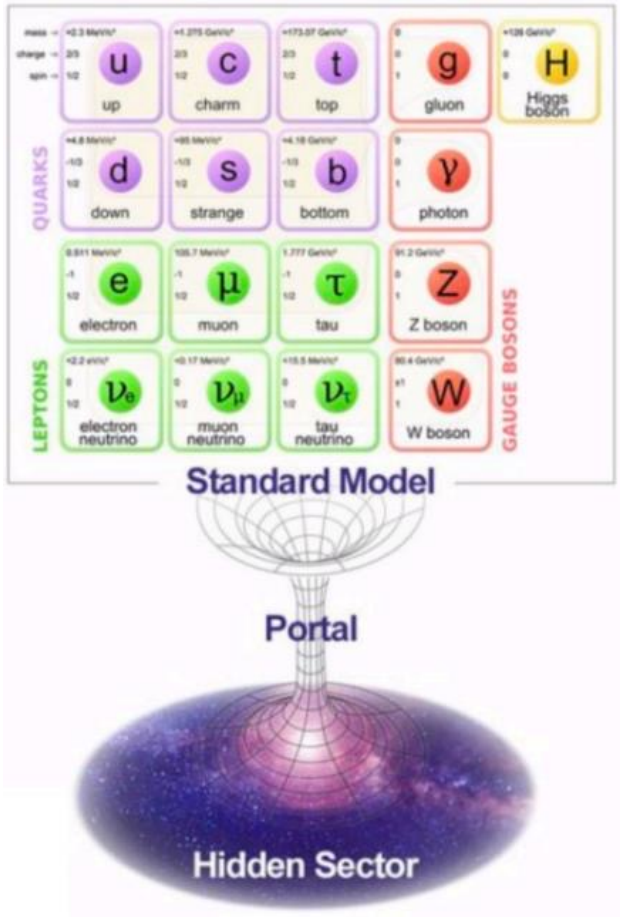
...

- *Its existence provides a strong hint that there may be a dark sector, consisting of particles do not interact with the known strong, weak, or electromagnetic forces.*

"Portals" between Standard Model and dark sector

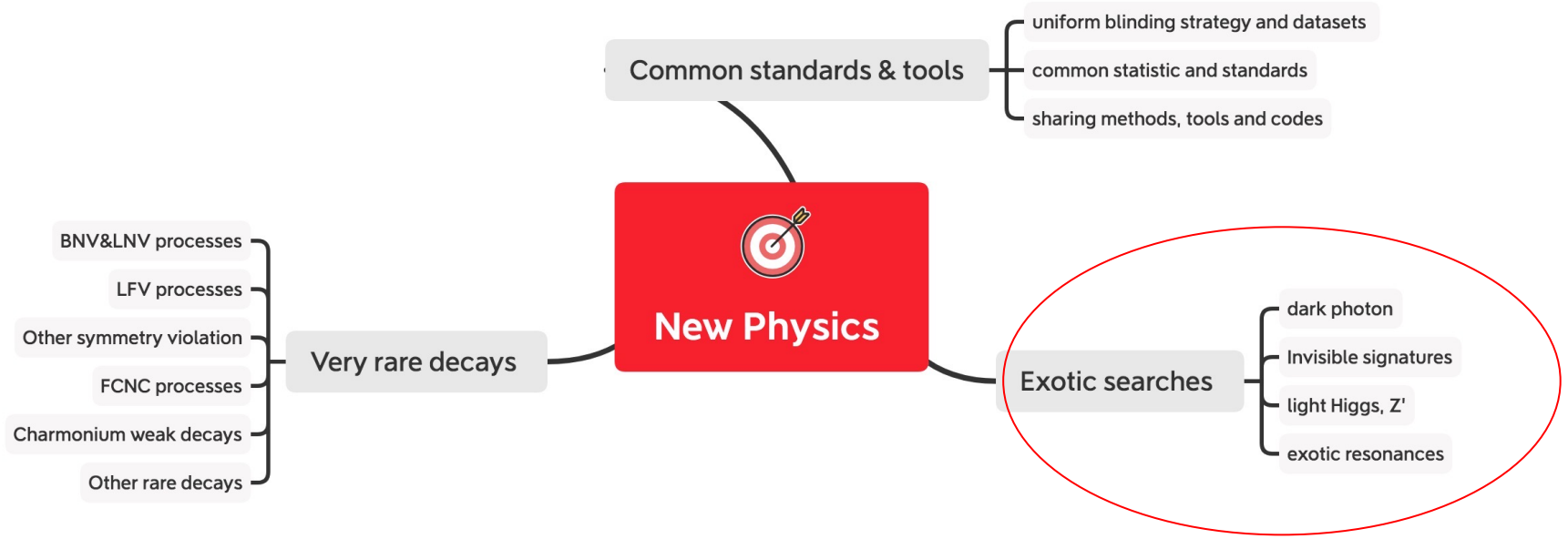
- Dark sectors typically include one or more mediator particles coupled to the SM via a portal.

Portal	Particles	Operator(s)
"Vector"	Dark photons	$-\frac{\epsilon}{2\cos\theta_W} B_{\mu\nu} F'^{\mu\nu}$
"Axion"	Pseudoscalars	$\frac{a}{f_a} F_{\mu\nu}\widetilde{F}^{\mu\nu}$, $\frac{a}{f_a} G_{i\mu\nu}\widetilde{G}_i^{\mu\nu}$, $\frac{\partial_\mu a}{f_a}\overline{\psi}\gamma^\mu\gamma^5\psi$
"Higgs"	Dark scalars	$(\mu S + \lambda S^2) H^\dagger H$
"Neutrino"	Sterile neutrinos	$y_N L H N$



•These new particles can be accessible by high intensity e^+e^-collider experiments, such as BESIII experiment, if their masses are in the MeV-GeV range.

Exotic searches at BESIII



- We focus on the visible decay of (dark photon and light higgs) searches in this talk;
- Electron-positron colliders are suitable for exotic via either the direct production or decays of mesons.

Topics in this talk

- A review of the exotic visible decay at BESIII

✓ Dark photon (γ') search:

1. via $J/\psi \to \gamma'\eta, \gamma' \to e^+e^-$;
2. via $J/\psi \to \gamma'\eta', \gamma' \to e^+e^-$;
3. via $e^+e^- \to \gamma'\gamma_{ISR}, \gamma' \to l^+l^-$;

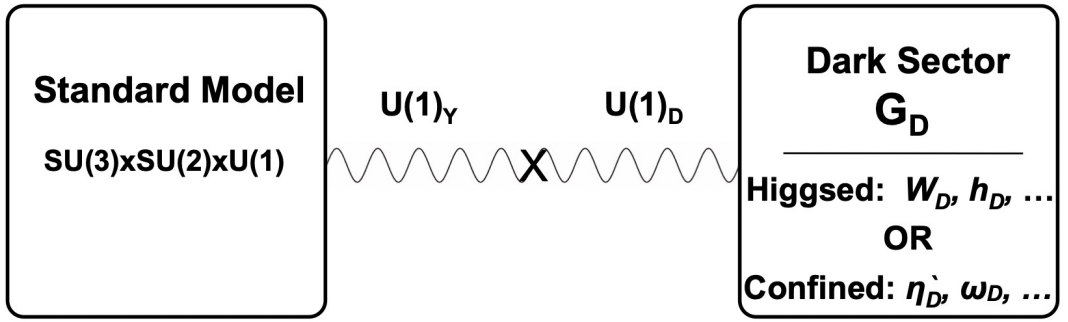
✓ Light Higgs boson (A^0) search:

1. via $J/\psi \to \gamma X(X \to \mu^+\mu^-)$ in $\psi' \to \pi^+\pi^- J/\psi$;
2. via $J/\psi \to \gamma A^0$, $A^0 \to \mu^+\mu^-$;

An introduction to the "dark photon"

- As a "Portals" between Standard Model and dark sector, the dark photon field V_μ couples to the SM photon A_μ via kinetic mixing:

$$\epsilon e A'_\mu J^\mu_{\mathrm{EM}}$$



- ε values in the $10^{-12} - 10^{-3}$ range have been predicted in the literature; PRD80 015003

- A GeV scale dark photon could explain the features of astrophysical observations, and the anomaly of $(g-2)_\mu$……

Dark photon search via $J/\psi \to \gamma'\eta, \gamma' \to e^+e^-$

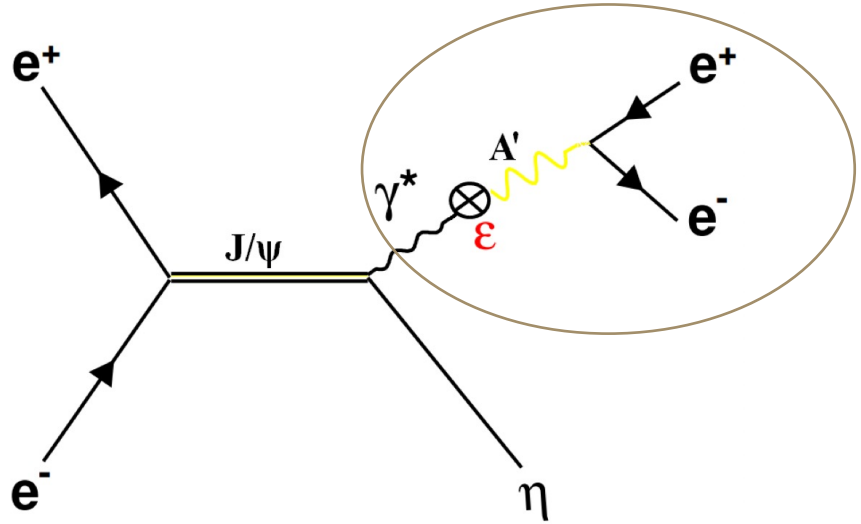
PRD 99, 012006 (2019)/ arXiv:1810.03091

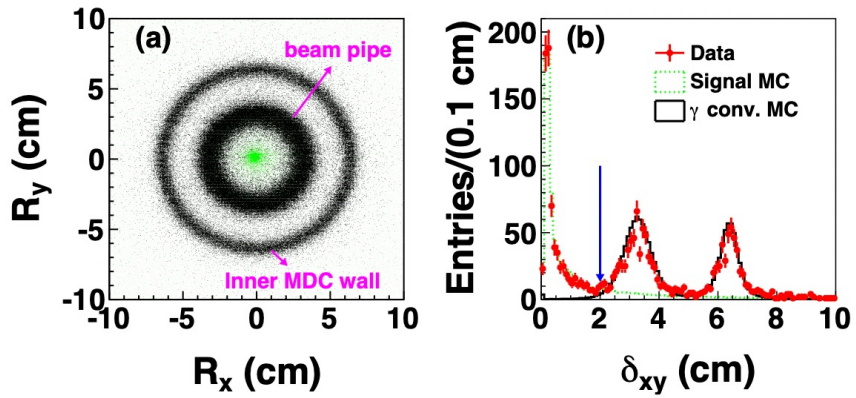
- **Data:** *1310.6* $\pm$ *7.0* $\times 10^6$ J/ψ *events;*

- *Search for dark photon via electromagnetic dalitz decay, where* $\epsilon = \alpha'/\alpha$ *and* α' *is the fine structure constant in the dark sector.*

- η **Reconstruction:** $\eta \to \gamma\gamma$ *and* $\eta \to \pi^+\pi^-\pi^0$;

- ***Event selection*:**
  1. *Two /four charged tracks with zero net charge;*
  2. *PID algorithm is performed to identify electron;*
  3. *4C kinematic fit;*
  4. *Suppression of gamma conversion events;*
  5. $\eta \to \gamma\gamma$ *mode:* $|\cos\theta_{helix}| < 0.9$;
  6. …



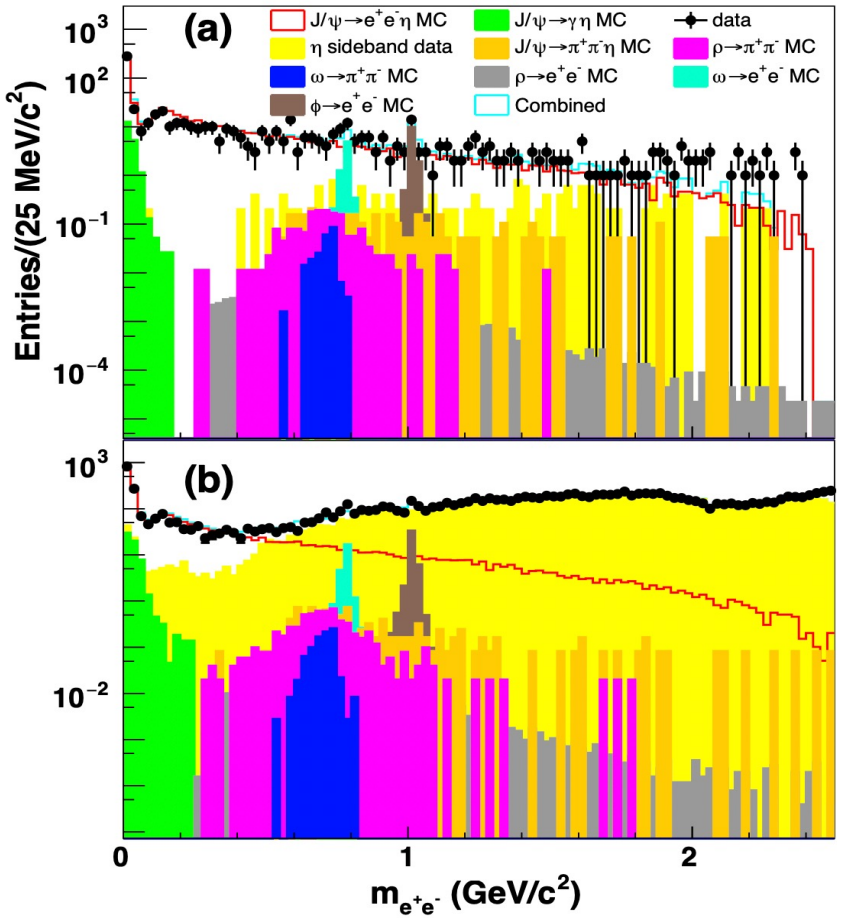


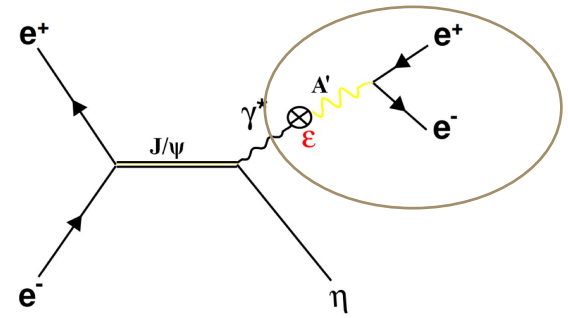
Dark photon search via $J/\psi \to \gamma'\eta, \gamma' \to e^+e^-$

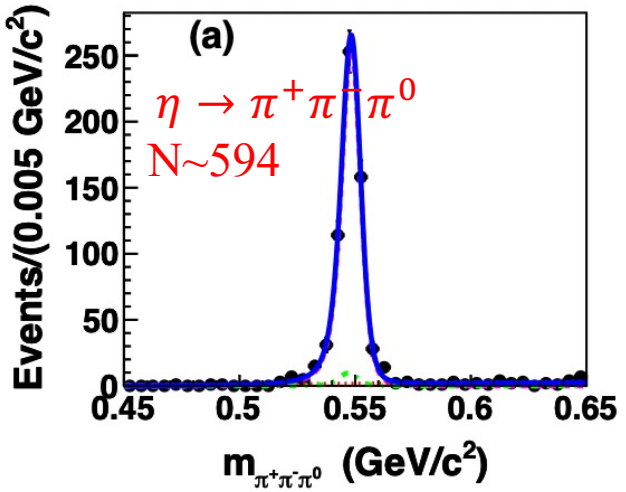
PRD 99, 012006 (2019)/ arXiv:1810.03091

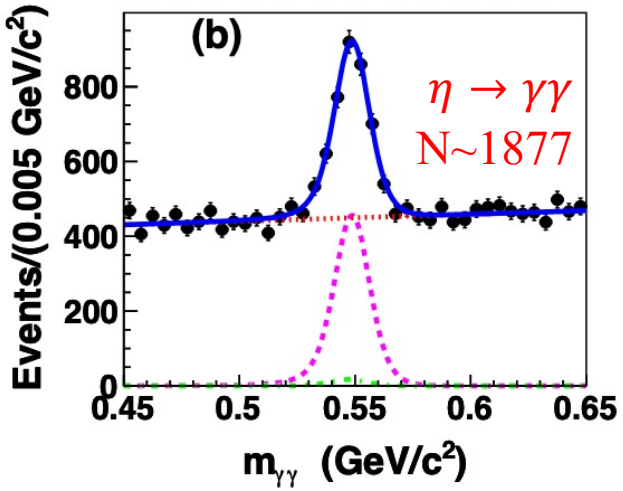
- *m (e^+e^-) and η signal:*

within the η signal region





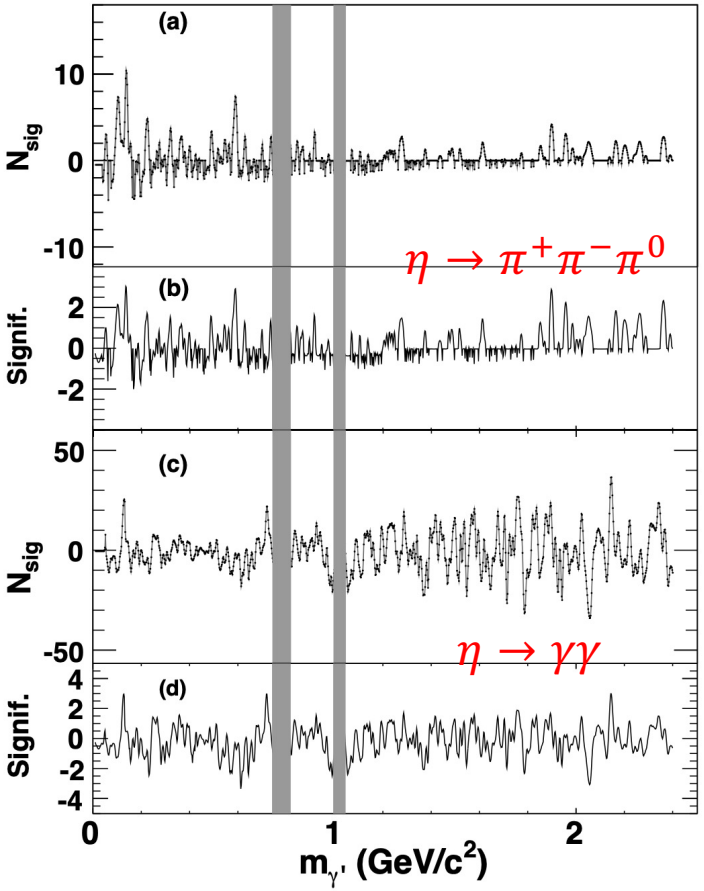


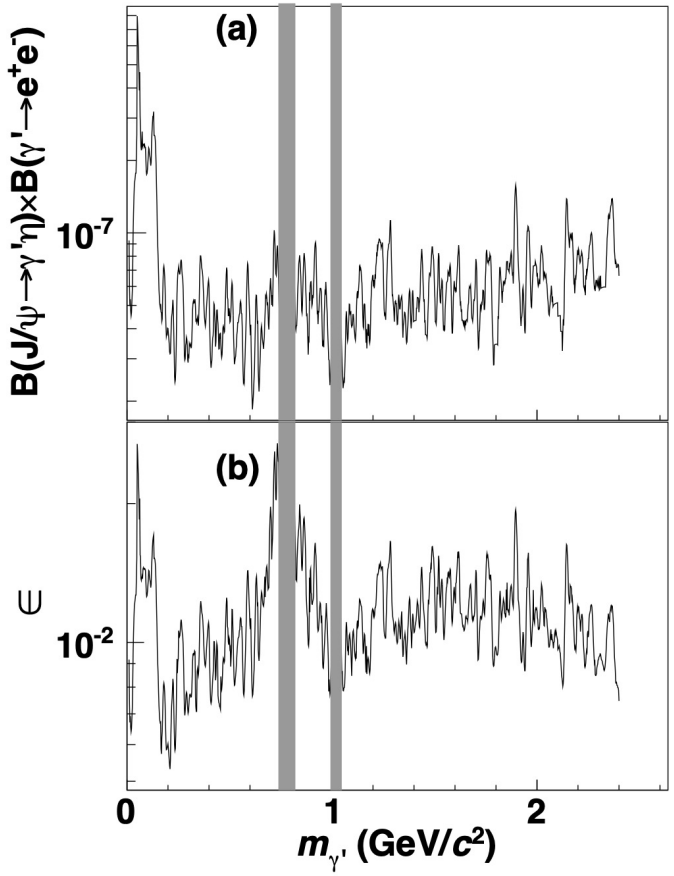


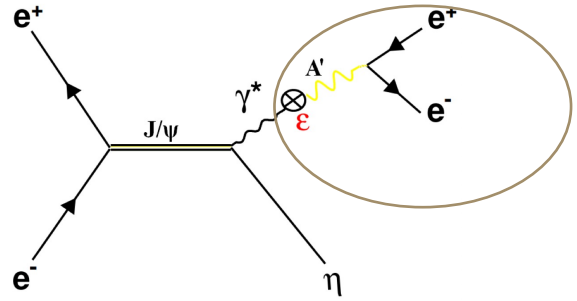
Dark photon search via $J/\psi \to \gamma'\eta, \gamma' \to e^+e^-$

PRD 99, 012006 (2019)/ arXiv:1810.03091

- *Search for dark photon signal:*
  1. *Search for a narrow structure in the $m(e^+e^-)$ spectrum;*
  2. *Exclude the ω and φ mass regions for the γ′ searches;*







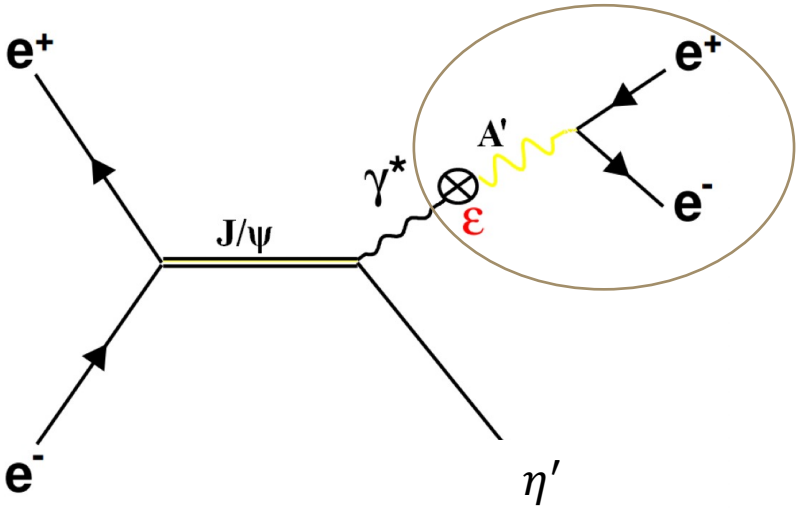
- *The largest local significance is 2.98σ, no evidence of dark photon γ′ production is observed;*
- *The upper limits on the $\mathcal{B}(J/\psi \to \gamma'\eta) \times \mathcal{B}(\gamma' \to e^+e^-)$ vary in range of $(1.9 - 91.1) \times 10^{-8}$;*
- *The upper limits on ε vary in range of 10^{-2}- 10^{-3};*

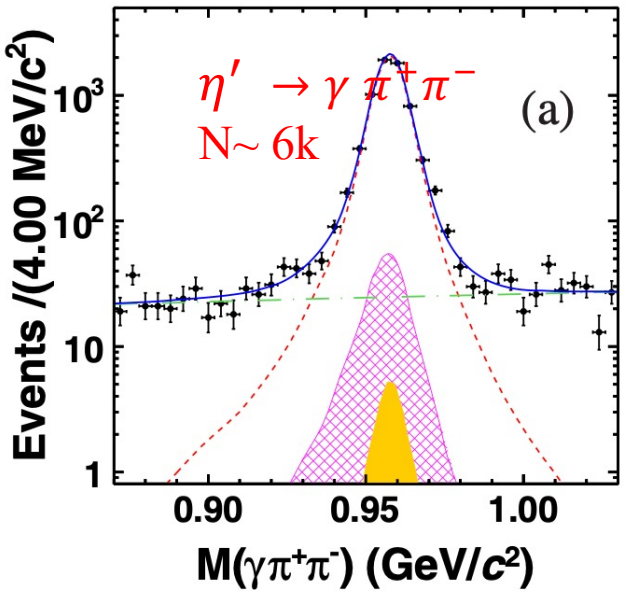
$\mathcal{B}(\gamma' \to e^+e^-)$ *from*
PRD 79, 115008 (2009)
JHEP 0907, 051 (2009)

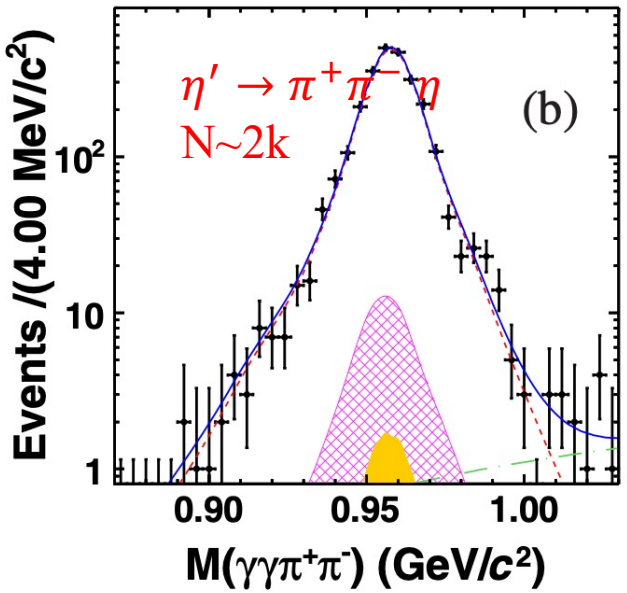
Dark photon search via $J/\psi \to \gamma'\eta', \gamma' \to e^+e^-$

PRD.99.012013(2019)

- ***Data:*** *1310.6 ± 7.0 × 10⁶ J/ψ events;*
- ***The event selection*** *criteria is similar to* $J/\psi \to \gamma'\eta$ *work;*
- ***η' Reconstruction:*** $\eta' \to \gamma\,\pi^+\pi^-$ *and* $\eta' \to \pi^+\pi^-\,\eta$*;*
  Signal of ***η'***



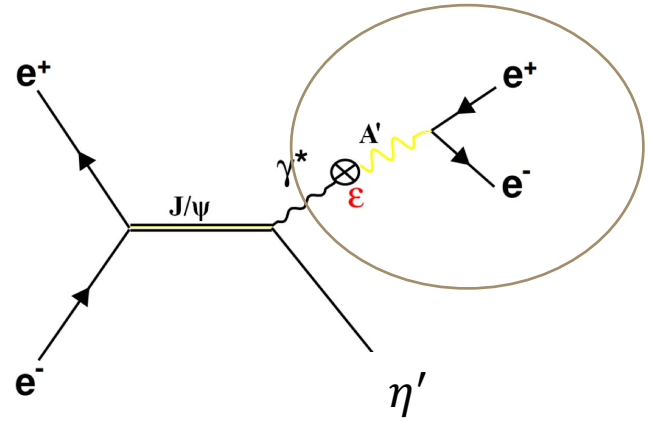




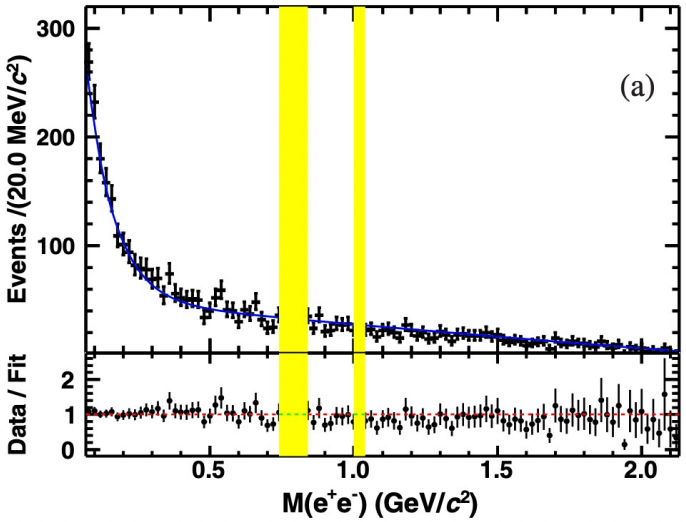
Dark photon search via $J/\psi \to \gamma'\eta', \gamma' \to e^+e^-$

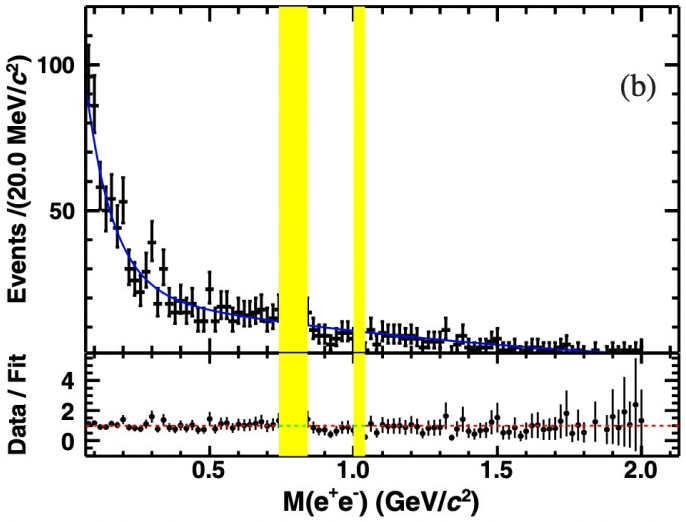
PRD.99.012013(2019)

- ***Search for the dark photon signal*** :
  1. *The dark photon is searched for by looking for a narrow resonance peaking on $M(e^+e^-)$spectrum ;*
  2. *Without the γ conversion veto criteria $(m(e^+e^-)>70\ MeV/c2)$;*
  3. *Peaking background region (ω,ϕ) are excluded;*



within the η' signal region



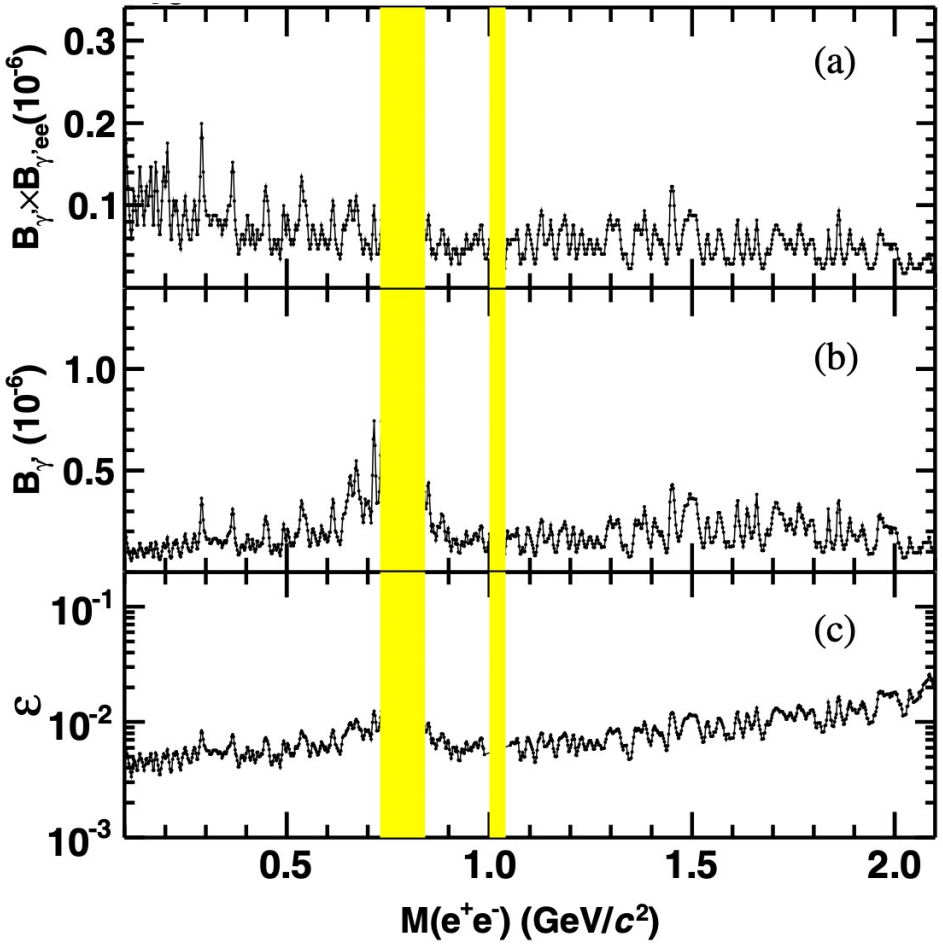


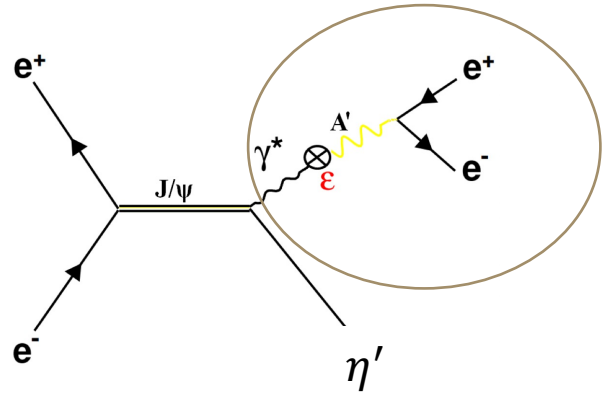
- *The maximum local significance is 3.1σ at 0.204 GeV/c^2. The corresponding global significance is less than 1σ; PRD 93, 052005 (2016)*
- *No significant dark photon signal!!!*

Dark photon search via $J/\psi \to \gamma'\eta', \gamma' \to e^+e^-$

PRD.99.012013(2019)

- ***Dark photon search result :***





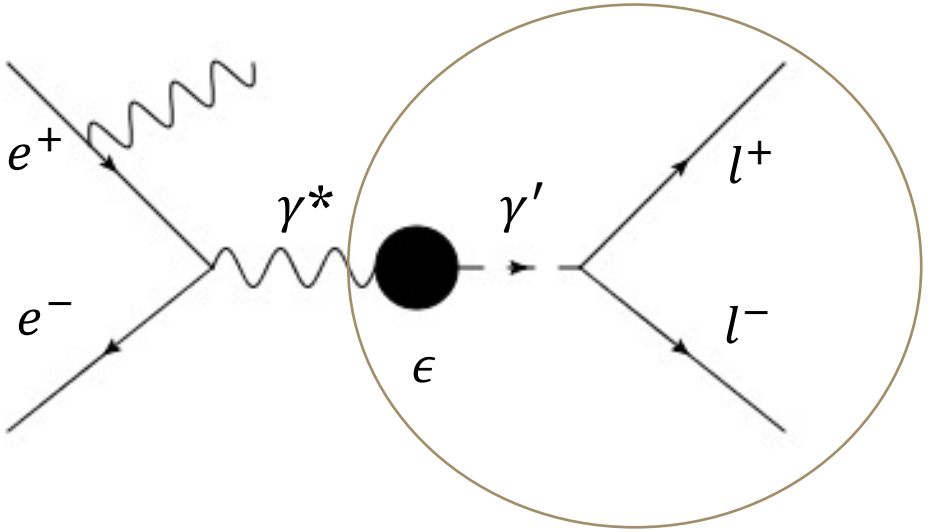
- *The upper limits on the* $\mathcal{B}(J/\psi \to \gamma'\eta') \times \mathcal{B}(\gamma' \to e^+e^-)$ *vary in range of* $(1.8 - 20.0) \times 10^{-8}$;
- *The upper limits on* ε *vary in range of* 3.4×10^{-3} - 2.6×10^{-2};

$\mathcal{B}(\gamma' \to e^+e^-)$ *from*
PRD 79, 115008 (2009)
JHEP 0907, 051 (2009)

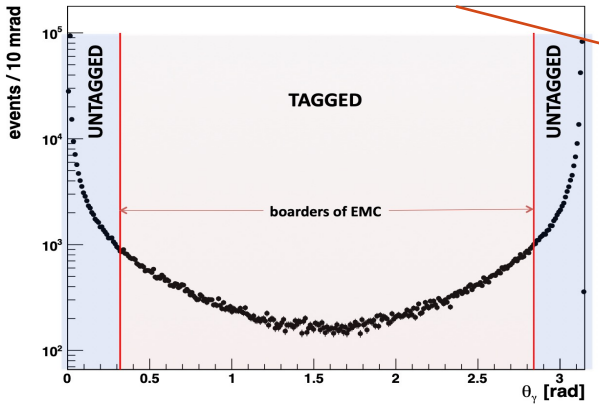
Dark photon search via $e^+e^- \to \gamma'\gamma_{ISR}, \gamma' \to l^+l^-$

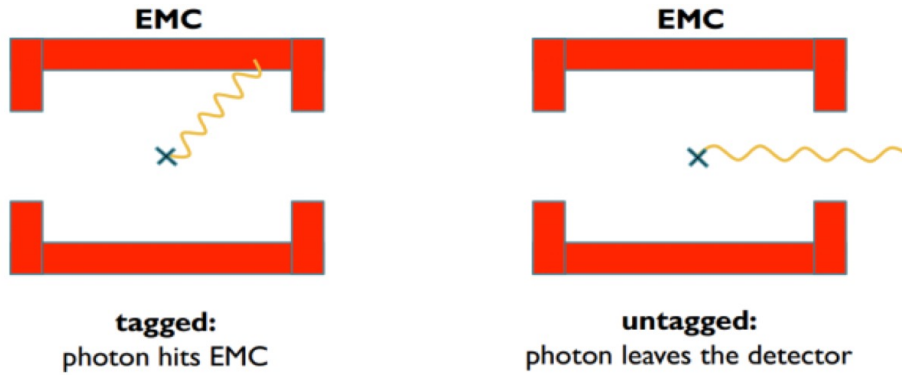
PLB 774, 252 (2017)

- ***Data:*** *2.93fb^{-1} data taken at $\sqrt{S}$ = 3.773 GeV ;*
- *Both of $e^+e^- \to \gamma_{ISR}\ e^+e^-$ and $\gamma_{ISR}\ \mu^+\mu^-$ are studied;*
- ***Event selection*:**
  1. *Two charged tracks with zero net charge;*
  2. *Tracks are required to be* $0.4 < \theta < \pi - 0.4$;
  3. *Pt of each tracks above 300 MeV/c;*
  4. *PID for muon : P(μ)>P(e); Electron: E/p>0.8c;*
  5. *Use an untagged photon ISR photon method to increase statistics ;*
  6. *1C fit ….;*



Polar angle of leading order ISR photon.

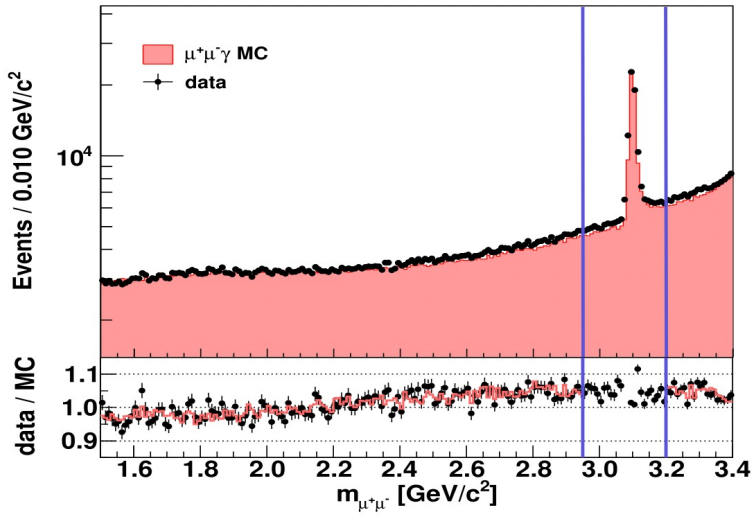


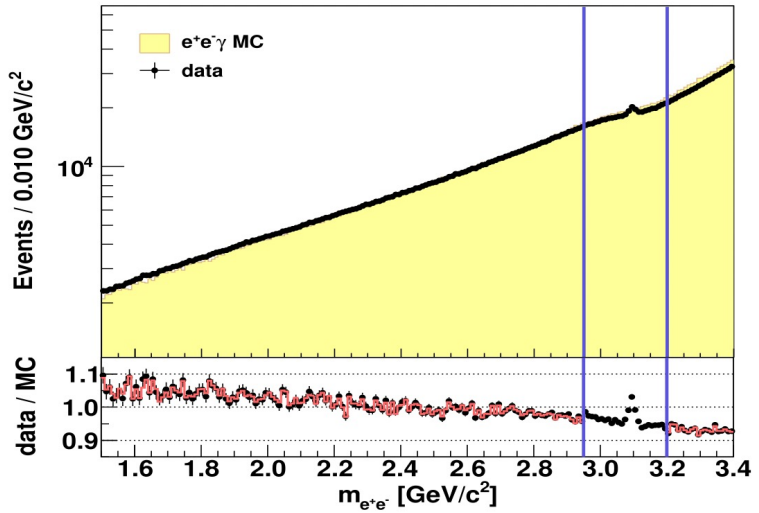


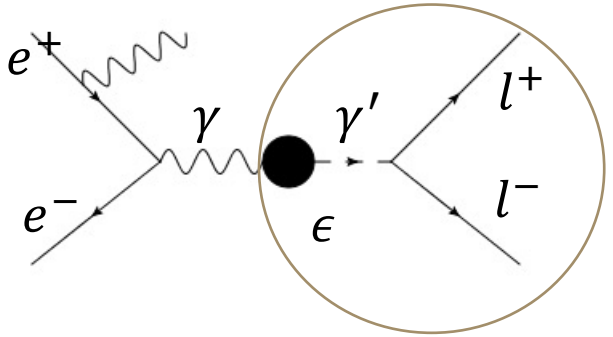
Dark photon search via $e^+e^- \to \gamma'\gamma_{ISR}, \gamma' \to l^+l^-$

PLB 774, 252 (2017)

- ***$m(e^+e^-)$ and $m(\mu^+\mu^-)$ distributions:***







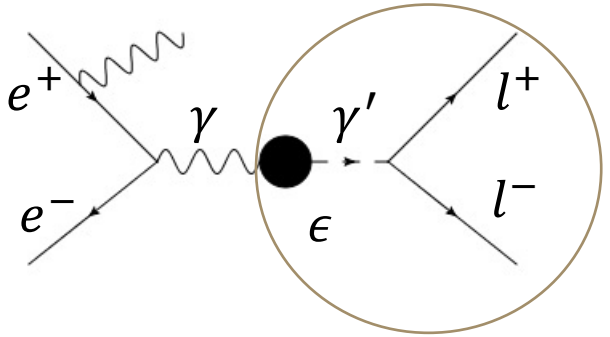
- *Dominant QED backgrounds*: $e^+e^- \to \gamma_{ISR}\, l^+l^-$;

- *Below 1.5 GeV/c^2 the $\pi^+\pi^-\gamma_{ISR}$ cross section with muon misidentification dominates the $m(\mu^+\mu^-)$ spectrum. Above 3.4 GeV/c 2 the hadronic $q\bar{q}$ process can not be suppressed sufficiently by the χ^2_{1c} requirement.*

- *The mass range around the narrow J/ψ resonance between 2.95 and 3.2 GeV/c^2 is excluded.*

Dark photon search via $e^+e^- \to \gamma'\gamma_{ISR}, \gamma' \to l^+l^-$

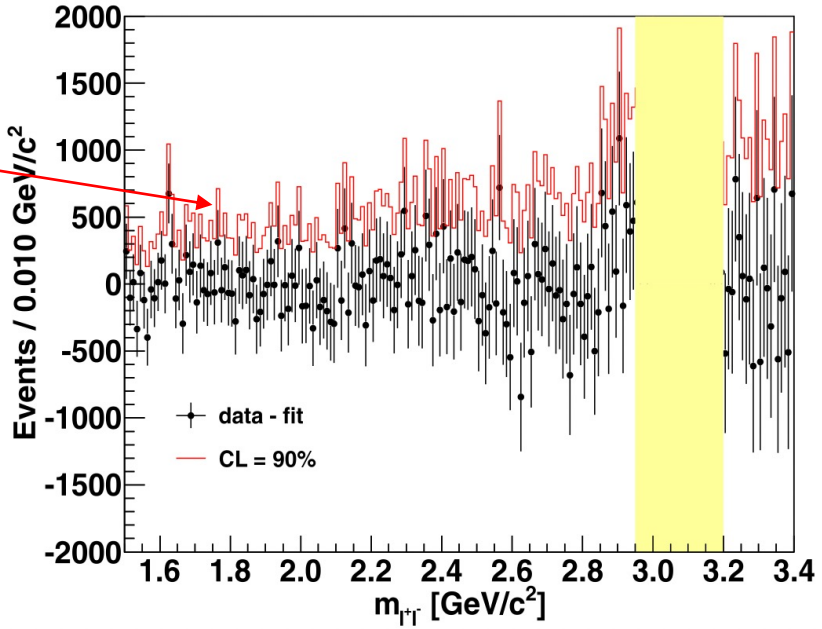
PLB 774, 252 (2017)



- ***Search for A narrow structure in m(l^+l^-) spectrum:***

- *The combined differences between the γ_{ISR} e^+e^- and γ_{ISR} $\mu^+\mu^-$ event yields, and their respective fit results;*

Upper Limit



- *The observed statistical significances are less than 3σ everywhere in the explored region.*

Dark photon search via $e^+e^- \to \gamma'\gamma_{ISR}, \gamma' \to l^+l^-$

PLB 774, 252 (2017)

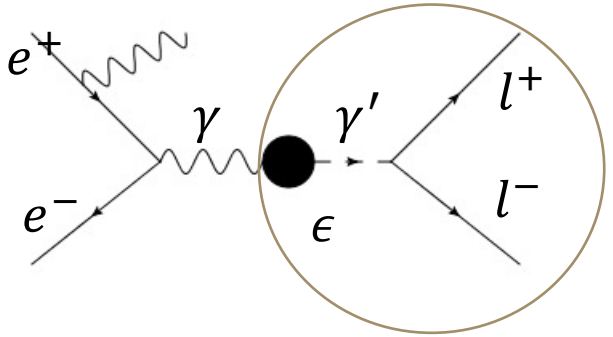
- ***Calculation of mixing strength ε :***

$$\frac{\sigma_i(e^+e^- \to \gamma'\gamma_{ISR} \to l^+l^-\gamma_{ISR})}{\sigma_i(e^+e^- \to \gamma^*\gamma_{ISR} \to l^+l^-\gamma_{ISR})} = \frac{3\pi \cdot \varepsilon^2 \cdot m_{\gamma'}}{2N_f^{l^+l^-}\alpha \cdot \delta_m^{l^+l^-}},$$

$$N_f^{l^+l^-} = \Gamma_{tot}/\Gamma_{ll}$$

$$\Gamma_{ll} = \frac{\alpha\varepsilon^2}{3m_{\gamma'}^2}(m_{\gamma'}^2 + 2m_l^2)\sqrt{m_{\gamma'}^2 - 4m_l^2}$$

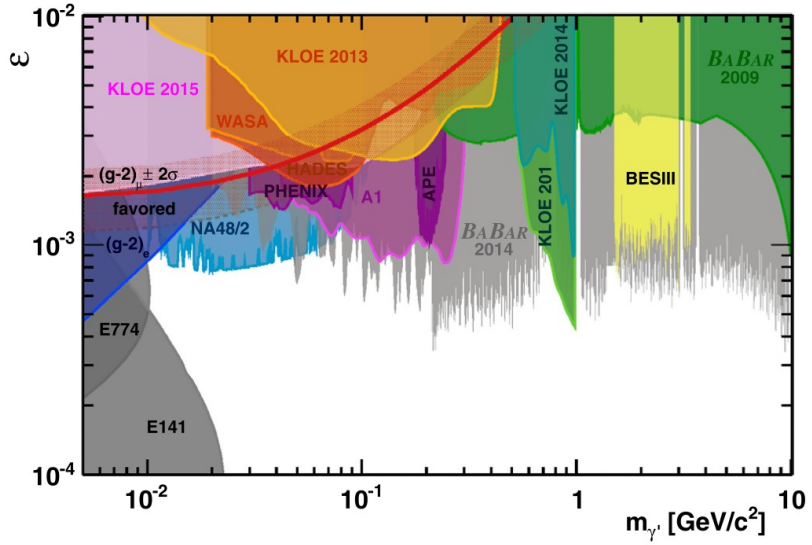
$$\Gamma_{tot} = \Gamma_{ee} + \Gamma_{\mu\mu} \cdot (1 + R(\sqrt{s})) ,$$



PRD 80 (2009) 075018

Phys. Rev. D 88 (2013) 015032.

the mixing strength ε



- *This is a competitive limit in this dark photon mass range.*

An introduction to the light higgs boson

- *A light Higgs boson is predicted by many extensions of Standard Model, such as Next-to-Minimal Supersymmetric Standard Model (NMSSM).* PRL 95 041801 PRD 76, 051105

- *NMSSM contains a total of three CP-even, two CP-odd and two charged Higgs bosons, which can alleviate the so-called "hierarchy problem" ;* Phys. Lett. B 710, 460

- *The lighter state of the A_0 is defined as:*

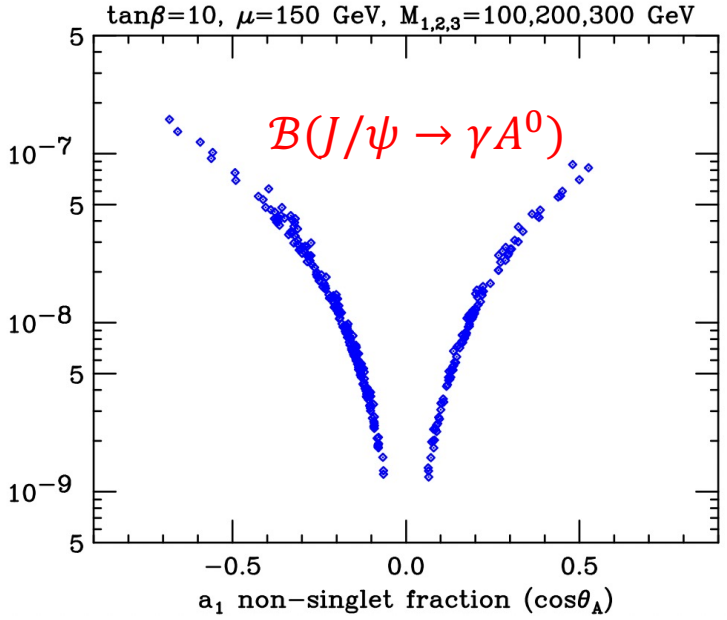
$$A_0 = \cos\theta_A A_{MSSM} + \sin\theta_A A_S$$

Non-singlet Singlet

- If m(A_0) *is smaller than two charmed quark,* $J/\psi \to \gamma A^0$ is access

$$\frac{\mathcal{B}(V \to \gamma A^0)}{\mathcal{B}(V \to l^+l^-)} = \frac{G_F m_q^2 g_q^2 C_{\mathrm{QCD}}}{\sqrt{2}\pi\alpha}\left(1 - \frac{m_{A^0}^2}{m_V^2}\right),$$

where $g_c = \cos\theta_A / \tan\beta \ (q = c)$



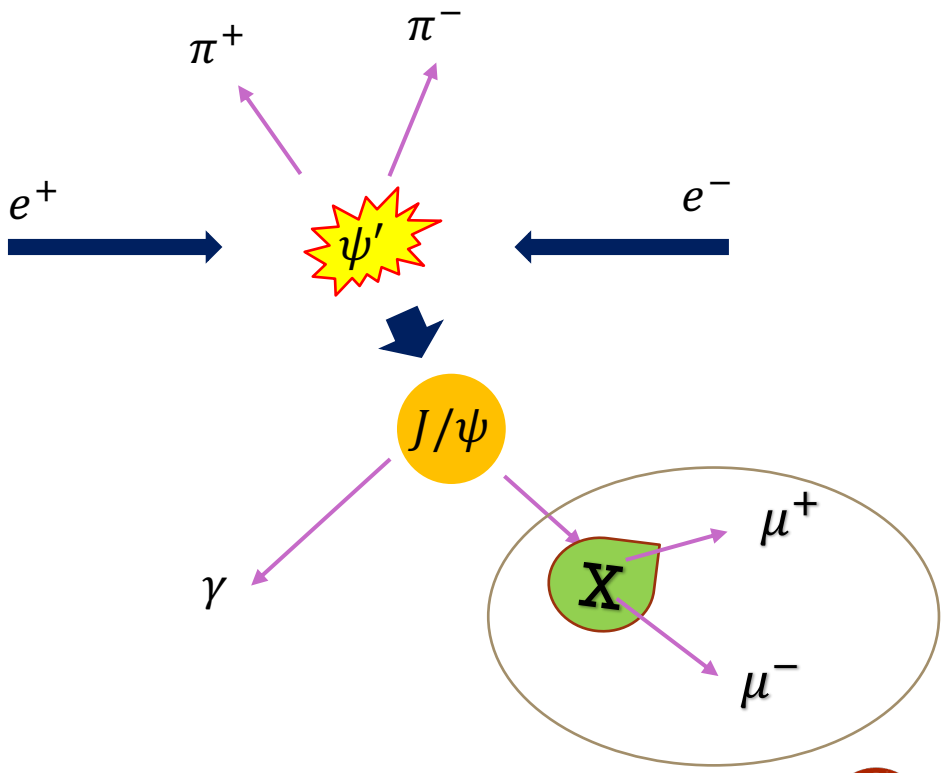
eConf C070805 19

Search for light exotic particle $J/\psi \to \gamma X(X \to \mu^+\mu^-)$

PRD 85, 092012 (2012)

X could be "Higgs-like boson A^0", "a spin-1 U boson"

- ***Data:*** *1.06×10^8 ψ' events;*
- ***Decay:*** $\psi' \to \pi^+\pi^- J/\psi, J/\psi \to \gamma X(X \to \mu^+\mu^-)$;
- ***Prediction:*** $\mathcal{B}(J/\psi \to \gamma A^0) = 10^{-9} \sim 10^{-7}$; PRD 76, 051105
- ***Event selection*:**
  1. *Two positive and two negative charged tracks;*
  2. *Muons within the active area of the barrel MUC ($|\cos\theta| < 0.75$) ;*
  3. *EMC, MUC information is used to identified the mouns;*
  4. *Veto π^0 (for $J/\psi \to \pi^+\pi^-\pi^0$) ;*
  5. *$\pi^+\pi^-$ recoil mass in the J/ψ mass window;*
  6. *4C kinematic fit ....*

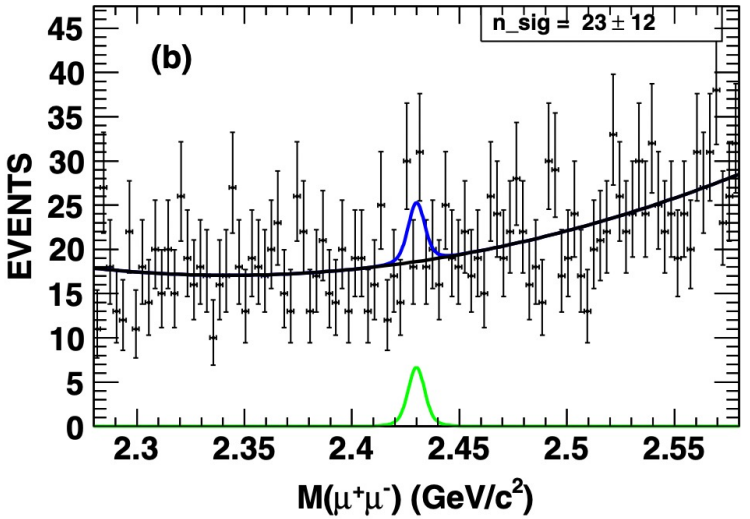


Search for light exotic particle $J/\psi \to \gamma X(X \to \mu^+\mu^-)$

PRD 85, 092012 (2012)

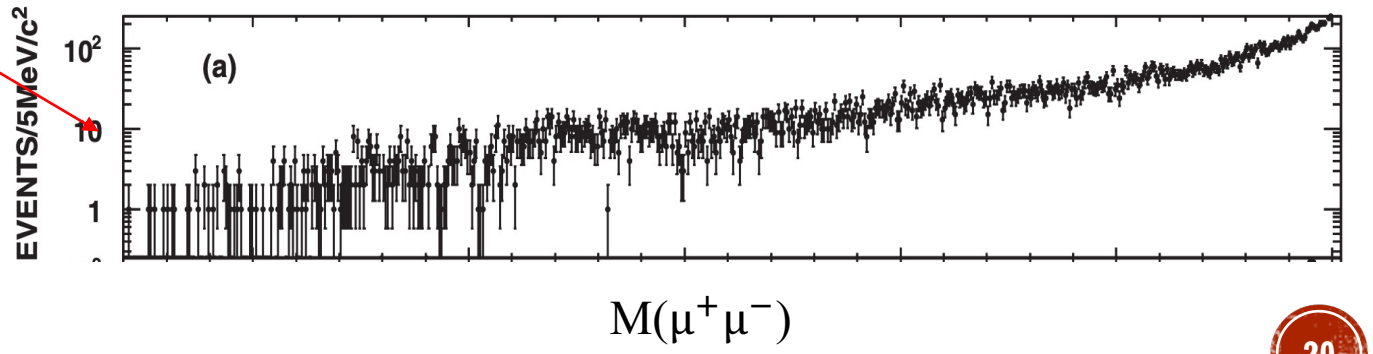
X could be "Higgs-like boson A^0", "a spin-1 U boson"

- ***X Search*:**
  1. *MC simulation: $\Gamma(A^0)$ is set to be 0;*
  2. *Search for a narrow resonance in the $M(\mu^+\mu^-)$ mass spectrum;*
  3. *MC shape for A^0 signal and polynomial for background;*
  4. *Unbinned maximum-likelihood fits is performed;*



$M(\mu^+\mu^-)$

there is no evident narrow peak ! !



light exotic particle search $J/\psi \to \gamma X(X \to \mu^+\mu^-)$

PRD 85, 092012 (2012)

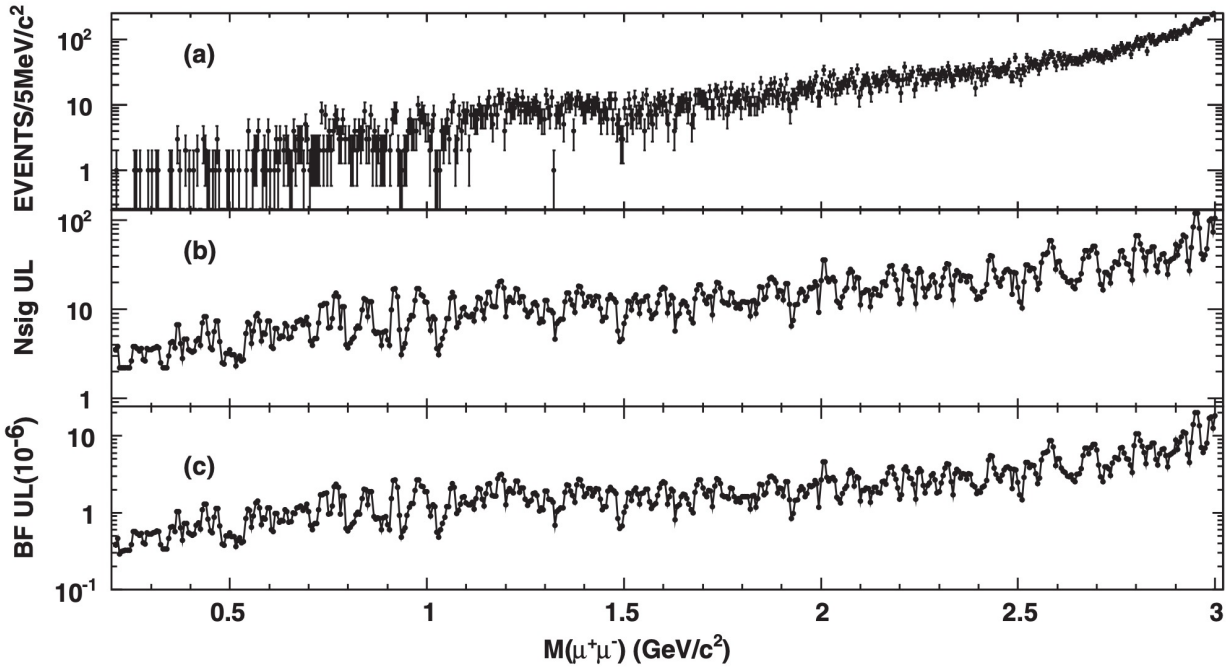
X could be "Higgs-like boson A^0", "a spin-1 U boson"

- ***Upper Limit*:**
  $J/\psi \to \gamma A^0, A^0 \to \mu^+\mu^-$:

$$\mathcal{B} < \frac{\text{Nsig(UL)}/\varepsilon}{N(\psi') \times \mathcal{B}(\psi' \to \pi^+\pi^- J/\psi) \times (1-\sigma)},$$

- *The resulting $\mathcal{B}(J/\psi \to \gamma A^0) \times \mathcal{B}(A^0 \to \mu^+\mu^-)$ upper-limit values range from 4×10^{-7} to 2.1×10^{-5};*

- *Spin-0 particle, they are the same, to within a few percent, for a spin-1 particle;*

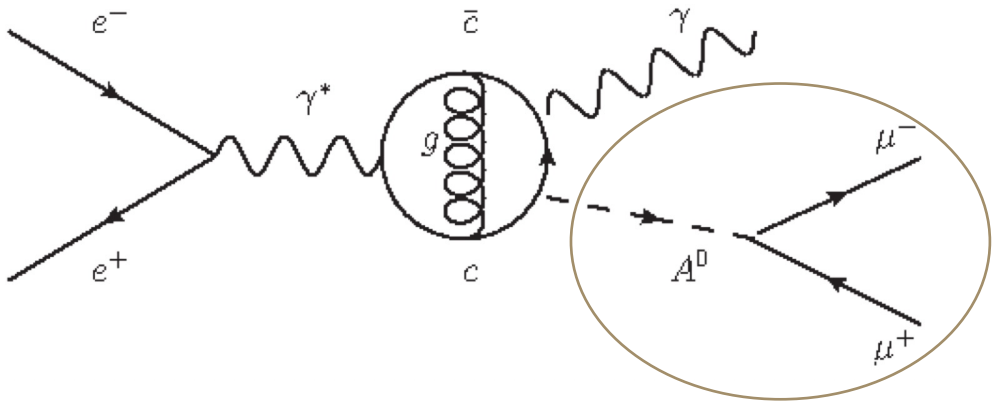


Light Higgs boson search via $J/\psi \to \gamma A^0,\ A^0 \to \mu^+\mu^-$

arXiv: 2109.12625

New!!!

- ***Data***: *9 billion J/ψ events ;*
- *$\mathcal{B}(J/\psi \to \gamma A^0)$ is predicted to be in $10^{-9} - 10^{-7}$;*
- ***Event selection***:
  1. *Two charged tracks with zero net charge;*
  2. *$E_{EMC}/P < 0.9c$, $0.1 < E_{EMC} < 0.3$ GeV;*
  3. *MUC information to identify muon track;*
  4. *4C kinematic fit;*
  5. *Reject fake photon by requiring $m(\mu^+\mu^-) < 3.04$ GeV/c^2;*
  6. *…*



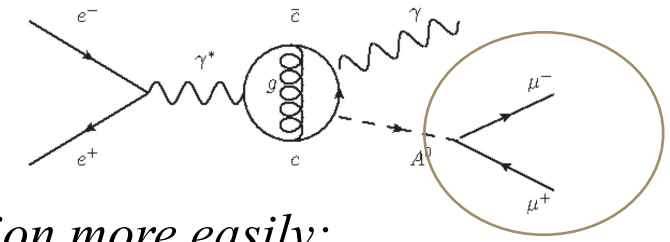
Light Higgs boson search via $J/\psi \to \gamma A^0,\ A^0 \to \mu^+\mu^-$

arXiv: 2109.12625

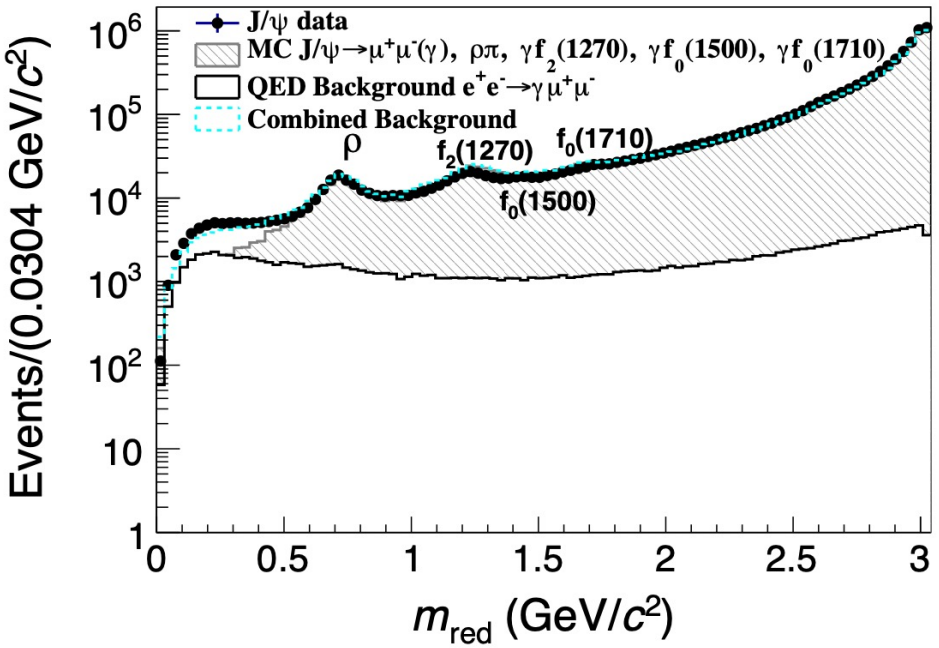
New!!!

- ***m_{red} distribution:***

$$m_{\rm red} = \sqrt{m^2_{\mu^+\mu^-} - 4m^2_{\mu}},$$



m_{red} is used to model the non-peaking background across the entire $m(A_0)$ region more easily;



- *The background is dominated by:*

  $e^+e^- \to \gamma\mu^+\mu^-, J/\psi \to (\gamma)\mu^+\mu^-;$

  Several peaking background:

  $J/\psi \to \gamma\rho/\omega\ \pi;$

  $J/\psi \to \gamma f_2(1270)/\ f_0(1500)/\ f_0(1710);$

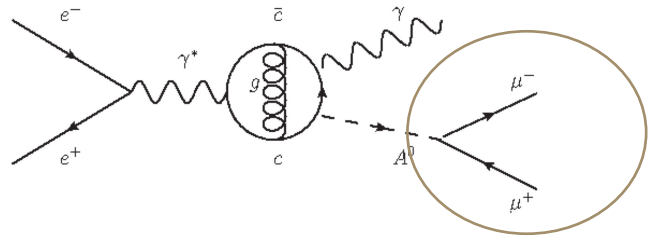
Light Higgs boson search via $J/\psi \to \gamma A^0,\ A^0 \to \mu^+\mu^-$

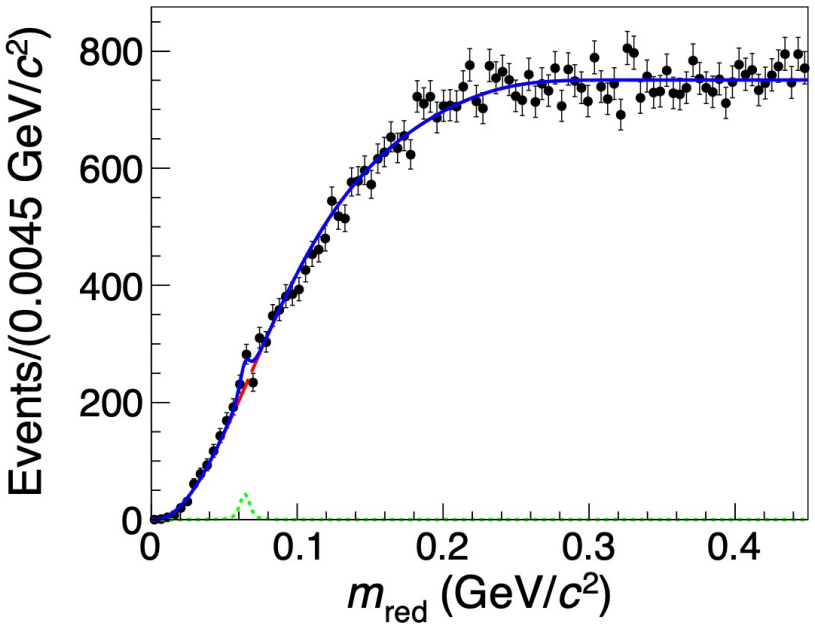
arXiv: 2109.12625

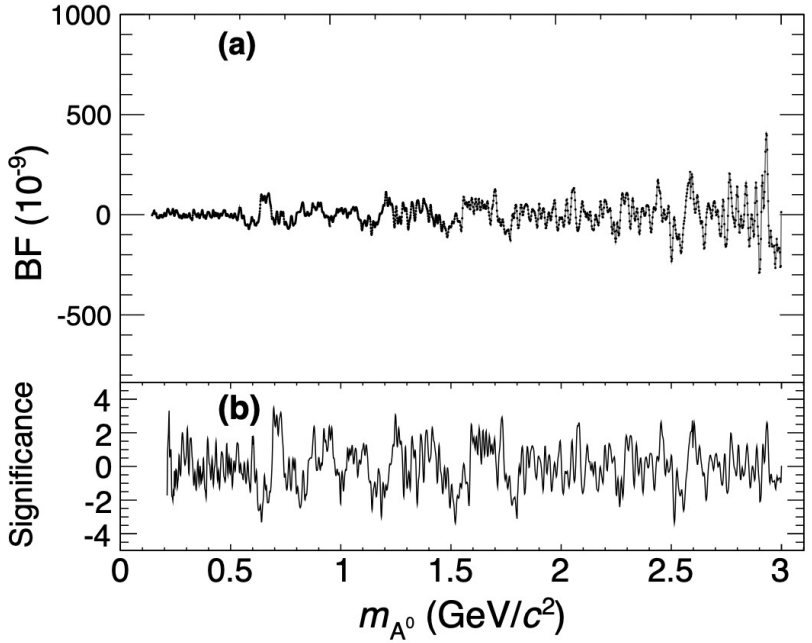
New!!!

- ***A_0 Search:***

  A series of one-dimensional unbinned extended maximum likelihood fits to the m_{red} distribution;







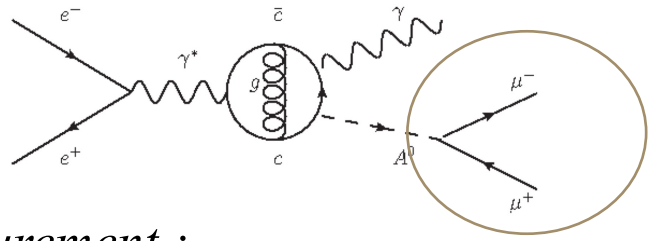
- *The largest local significance is 3.5σ at $m(A_0)$= 0.696 GeV/c^2. The corresponding global significance is 1σ.* ***No evidence of light Higgs !!!***

Light Higgs boson search via $J/\psi \to \gamma A^0,\ A^0 \to \mu^+\mu^-$

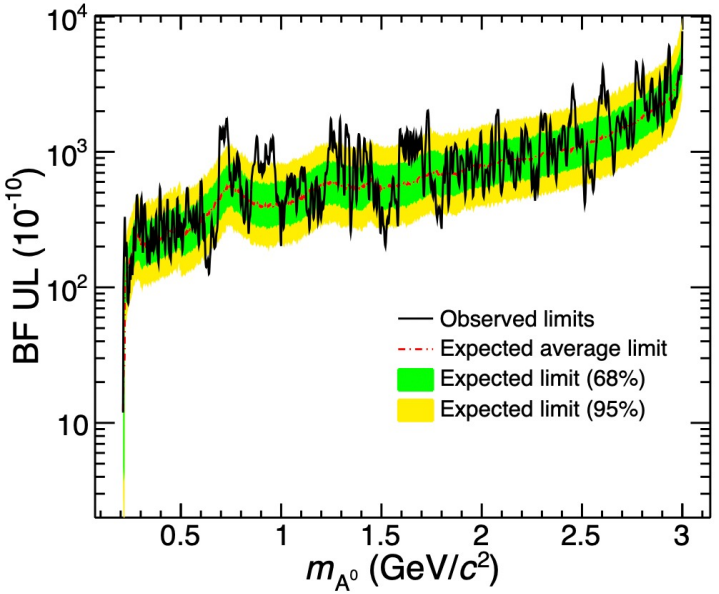
arXiv: 2109.12625

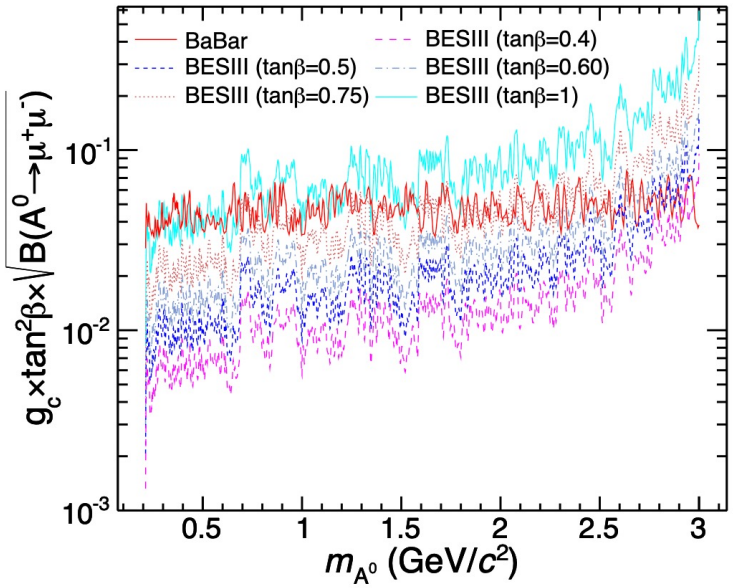
New!!!

- ***Result of light higgs search:***



- *90% C.L. Upper limits of* $\mathcal{B}(J/\psi \to \gamma A^0) \times \mathcal{B}(A^0 \to \mu^+\mu^-)$ *is set to be* $(1.2 - 778.0) \times 10^{-9}$;
- *This result has an improvement by a factor of 6-7 over the previous BESIII measurement ;*





- *The is slightly better than the BaBar measurement in the low-mass region for tan* $\beta = 1.0$.

Summary

1. *BESIII performed wide range study of exotic decays and new physics via J/ψ decay or e^+e^- annihilation;*

2. *We review the search of exotic (γ' , A_0) visible decay (lepton pair) ;*

3. *More data is coming ,* ***looking forward to more sensitive results and the first signal of NP !!***

Energy	Physics motivations	Current data	Expected final data	T_C / T_U
1.8 - 2.0 GeV	R values Nucleon cross-sections	N/A	0.1 fb^{-1} (fine scan)	60/50 days
2.0 - 3.1 GeV	R values Cross-sections	Fine scan (20 energy points)	Complete scan (additional points)	250/180 days
J/ψ peak	Light hadron & Glueball J/ψ decays	3.2 fb^{-1} (10 billion)	3.2 fb^{-1} (10 billion)	N/A
$\psi(3686)$ peak	Light hadron & Glueball Charmonium decays	0.67 fb^{-1} (0.45 billion)	4.5 fb^{-1} (3.0 billion)	150/90 days
$\psi(3770)$ peak	$D^0/D^{\pm}$ decays	2.9 fb^{-1}	20.0 fb^{-1}	610/360 days
3.8 - 4.6 GeV	R values XYZ/Open charm	Fine scan (105 energy points)	No requirement	N/A
4.180 GeV	D_s decay XYZ/Open charm	3.2 fb^{-1}	6 fb^{-1}	140/50 days
4.0 - 4.6 GeV	XYZ/Open charm Higher charmonia cross-sections	16.0 fb^{-1} at different $\sqrt{s}$	30 fb^{-1} at different $\sqrt{s}$	770/310 days
4.6 - 4.9 GeV	Charmed baryon/XYZ cross-sections	0.56 fb^{-1} at 4.6 GeV	15 fb^{-1} at different $\sqrt{s}$	1490/600 days
4.74 GeV	$\Sigma_c^+\bar{\Lambda}_c^-$ cross-section	N/A	1.0 fb^{-1}	100/40 days
4.91 GeV	$\Sigma_c\bar{\Sigma}_c$ cross-section	N/A	1.0 fb^{-1}	120/50 days
4.95 GeV	Ξ_c decays	N/A	1.0 fb^{-1}	130/50 days

谢谢！！