DARK SECTOR SEARCH AT BES III

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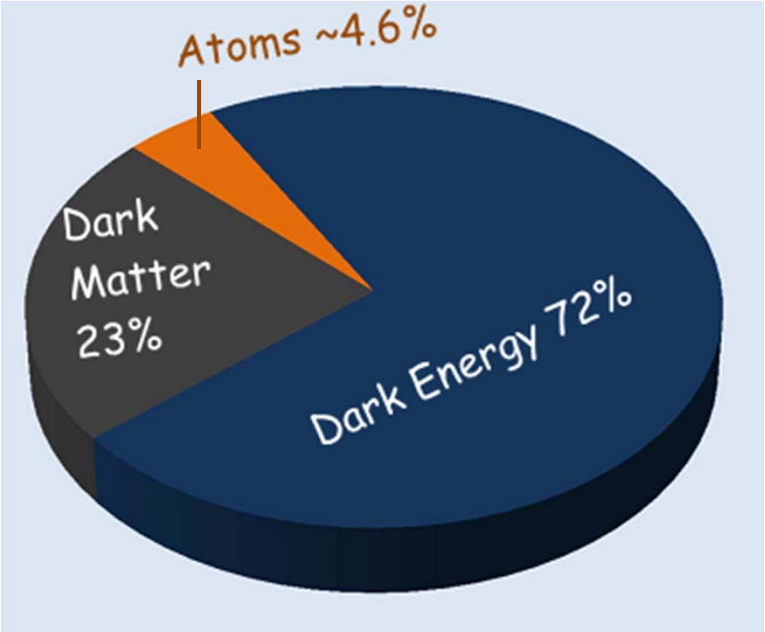
University of Hawaii, on behalf of BESIII collaboration



Heavy Quarks & Leptons
May 22-27, 2016
Virginia Tech, Blacksburg VA

OUTLINE

1) Motivation

2) Experimental technique & event selection

3) Result

4) Summary

DARK SECTOR

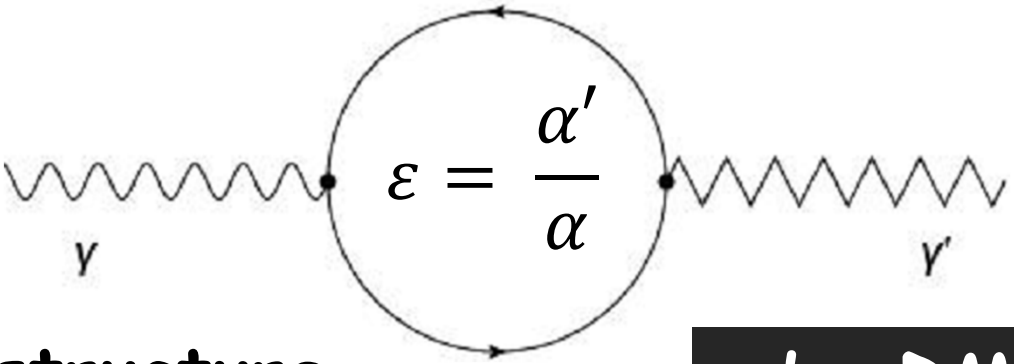
1) Dark Photon (A') is EM-equivalent expected in the dark sector: dark-force carrier▼.
2) Couples to SM particles via kinetic mixing▲.
3) Idea sparked world-wide effort: A'-search at particle accelerators.
4) BESIII can make direct A' contribution and study h -> invisible decays in search for DM.

▼ N. Arkani-Hamad et al. PRD **79**, 015014 (2009)
▲ B. Holdom, Phys. Lett. B **166**, 196 (1986)

A' APPROACH

Measure mixing strength ε:

SM



DM

α -fine structure constant

α' – DM coupling to EM charge

- expected A' mass: MeV/c^2 – GeV/c^2
- could explain e^+ cosmic ray anomaly …
- … also (g_μ-2) deviation from SM.

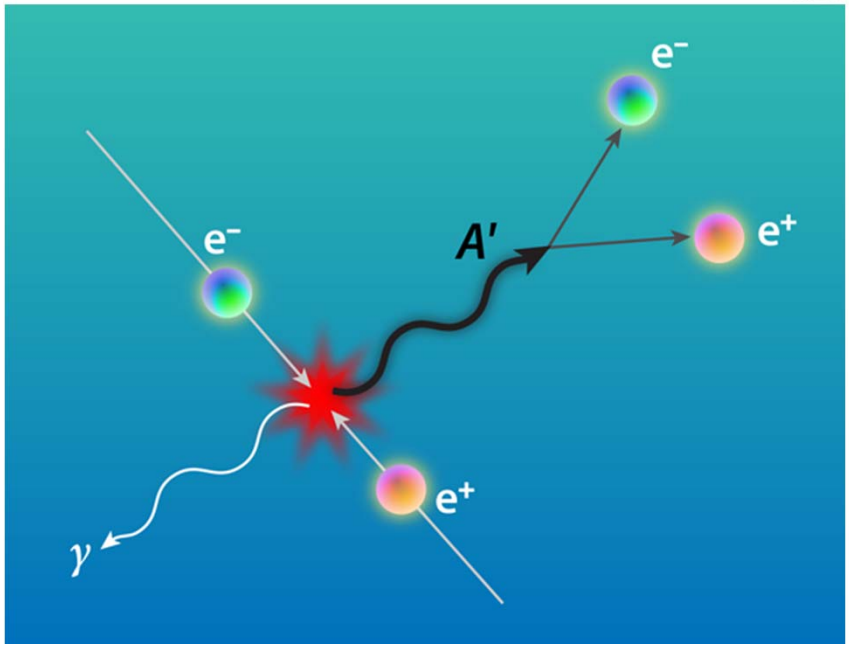
INITIAL STATE RADIATION

ISR processes:

$$e^+e^- \to \gamma_{ISR}\gamma' \to \gamma_{ISR}\mu^+\mu^-$$

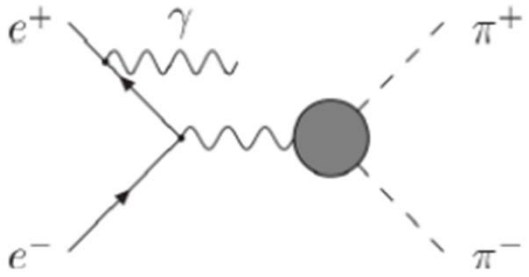
and

$$e^+e^- \to \gamma_{ISR}\gamma' \to \gamma_{ISR}e^+e^-$$



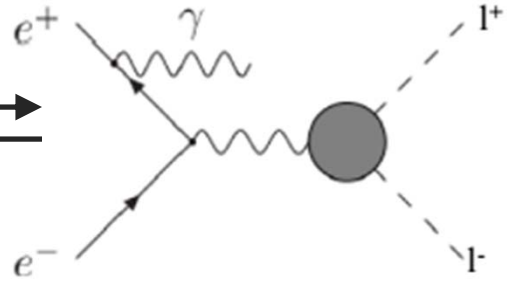
- **Search for peaks in invariant mass of detected particles above 'smooth' background: measure ε (or set limits)**

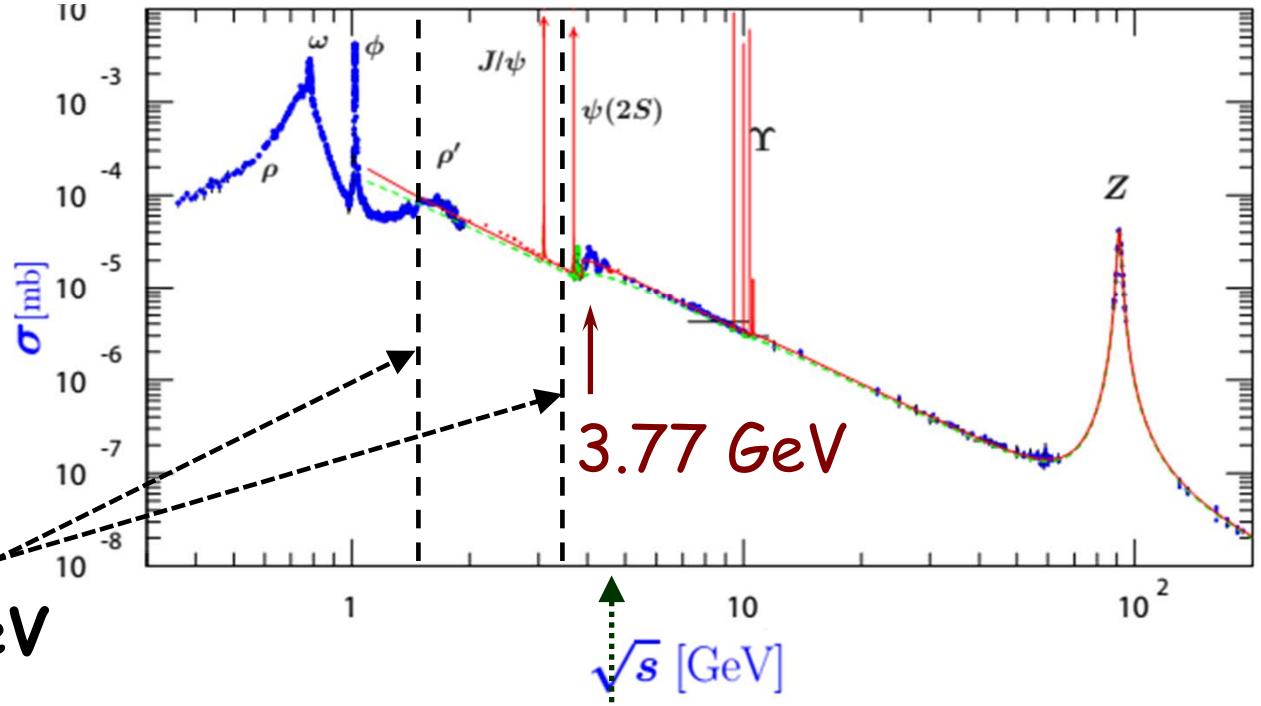
INITIAL STATE RADIATION



background

& vice versa

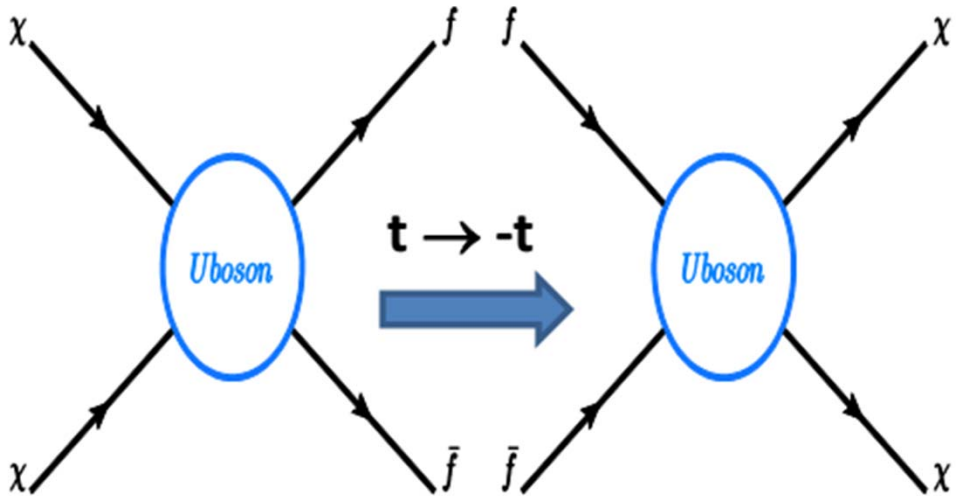




current
A' search
at BESIII
1.5-3.4 GeV

accessible @ BESIII

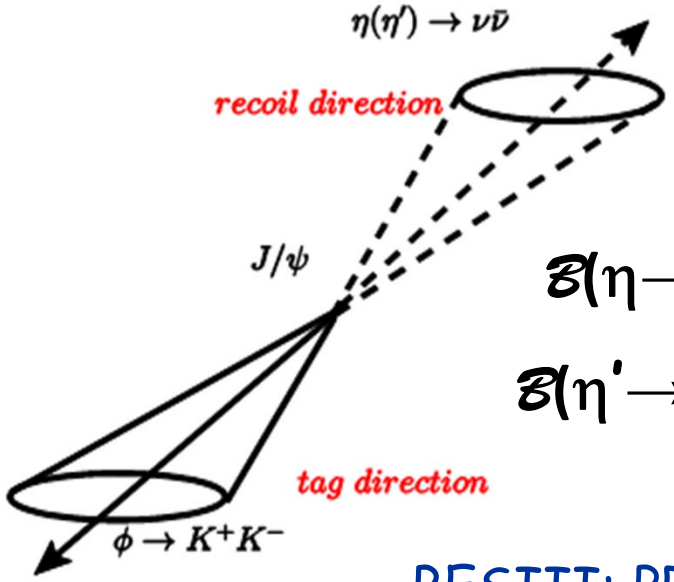
η, η' : INVISIBLE DECAYS



U-boson ⟷ A'

A number of $f\bar{f}$ states to look for Light DM candidates by tagging specific J^{PC}, like:

$$J/\psi \rightarrow \phi\, \eta\, (\eta')$$



223x10⁶ J/ψ

90 C.L.:

$\mathcal{B}(\eta \rightarrow \text{invisible}) < 1.0\times10^{-4}$

$\mathcal{B}(\eta' \rightarrow \text{invisible}) < 5.3\times10^{-4}$

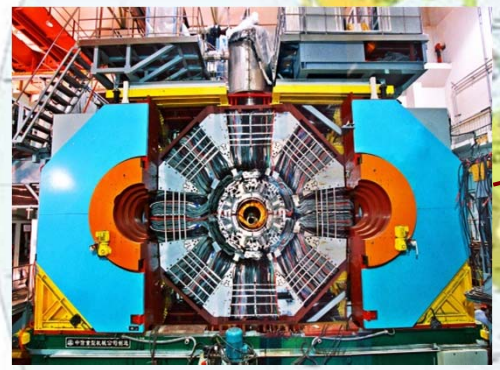
current BESIII DATA:

1.3 B J/ψ

0.5 B ψ(2S)

BESIII: PRD **87**, 012009 (2013)

BESIII COLLABORATION



BESIII@BEPCII

US (5)

Univ. of Hawaii
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Europe (13)

Germany: Univ. of Bochum, Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino, Frascati Lab, Ferrara Univ.
Netherland: KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

Mongolia (1)

Institute of phys. & Tech.

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Pakistan (2)

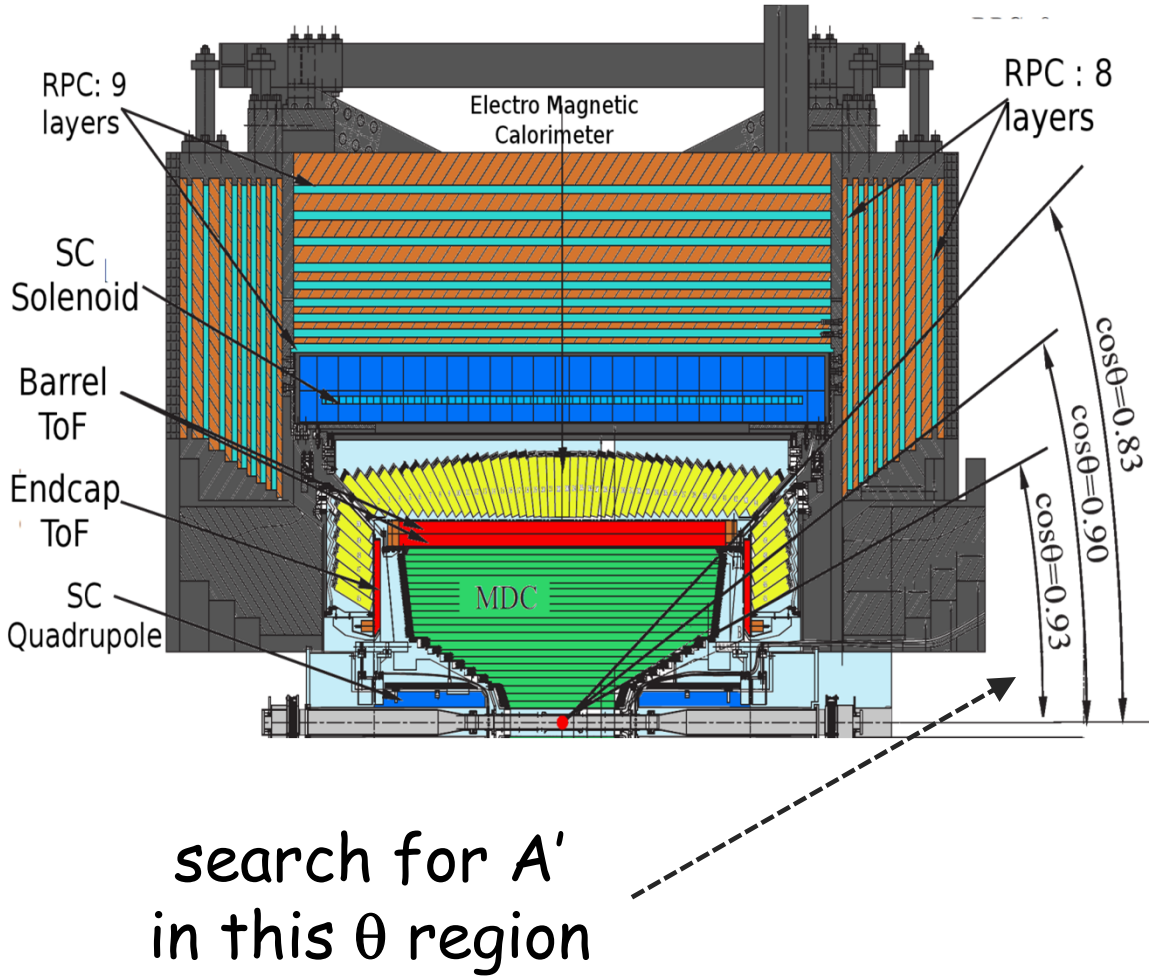
Univ. of Punjab
COMSAT CIIT

China(32)

IHEP, CCAST, GUCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ., Beihang Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Univ. of Sci. & Tech. Liaoning

~400 members
from 55 institutions in 12 countries

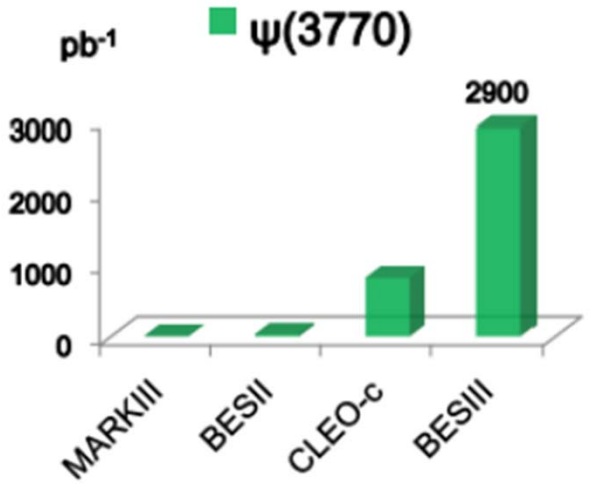
BESIII DETECTOR



search for A′
in this θ region

Data: 2.9 fb^{-1}

@ 3.77 GeV

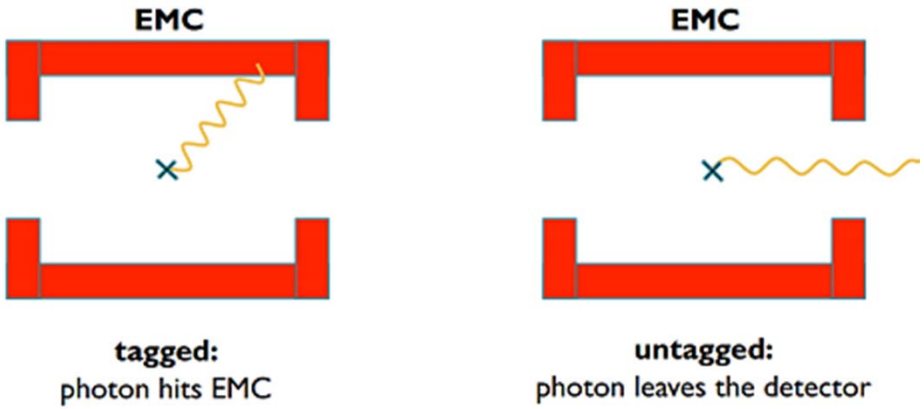


Acquiring in 2016:

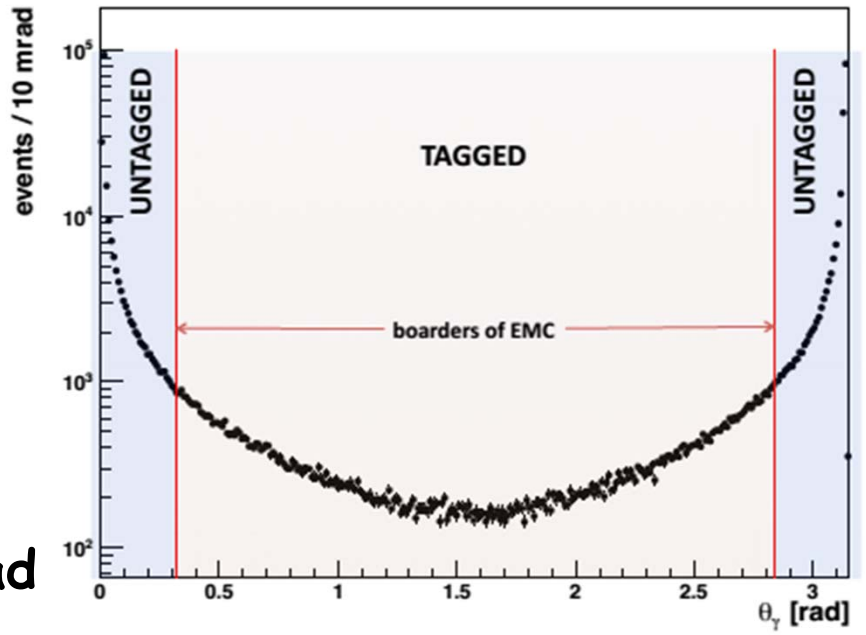
3 fb^{-1} @ 4.17 GeV

EVENT SELECTION

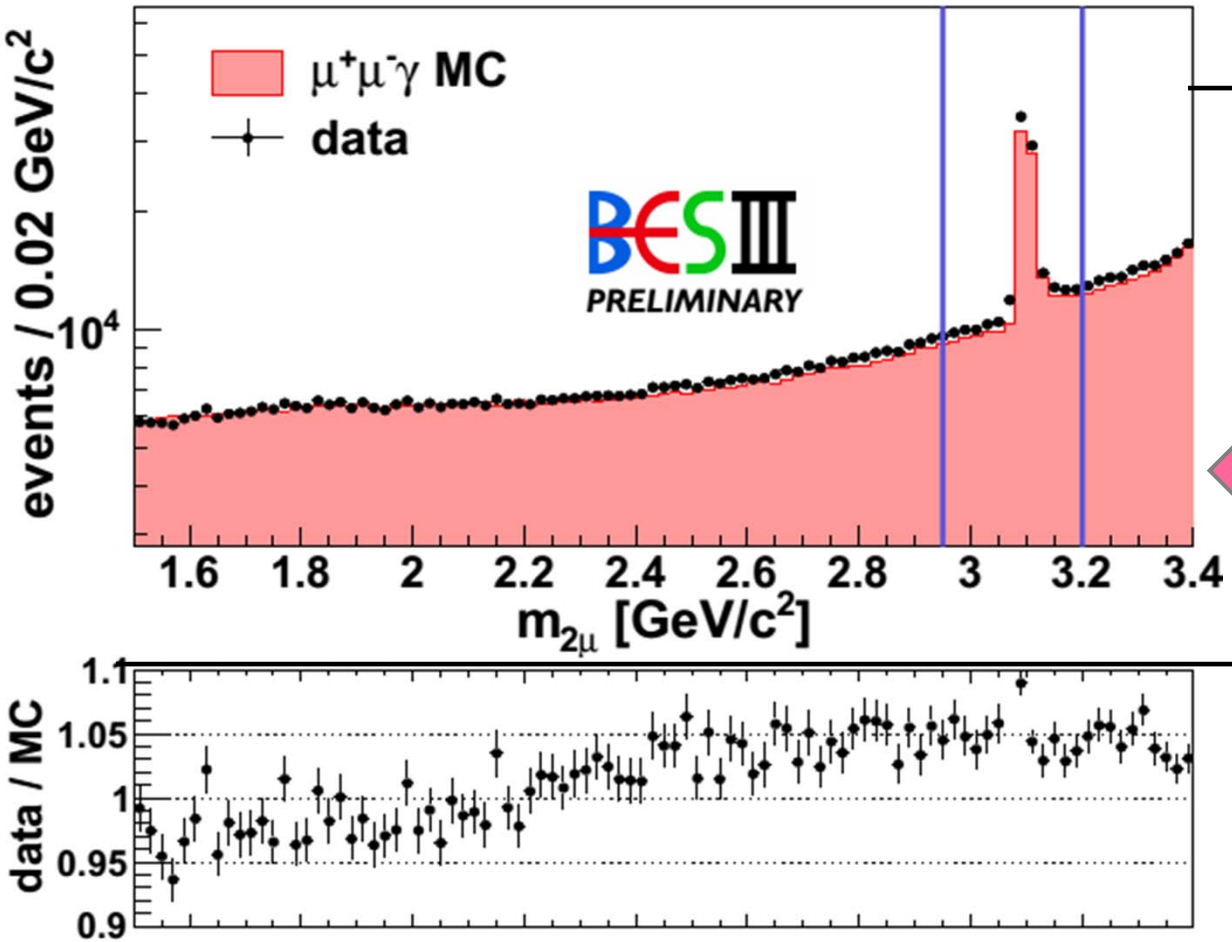
- use untagged region to enhance statistics
- constrain (1C) missing A' and reconstructed $l^- l^+$ to initial e^-e^+ momentum:
  - Require $N\gamma = 0$ and:
    $N_{ch} = 2$; $Q_{tot} = 0$
  - distance to IP:
    R_{xy} (R_z) <1 (10) cm
  - 0.4 rad < θ < π – 0.4 rad
  - missing photon angle: $\theta_{\gamma'}$
    $\mu\mu$: < 0.1 rad or > π - 0.1 rad
    ee: < 0.05 rad or > π - 0.05 rad



1C fits: $\chi 2_{\mu\mu} < 20$; $\chi 2_{ee} < 5$



μμ CANDIDATES



3.4 - 3.77 GeV/c^2
$q\bar{q}$ background
close to beam E

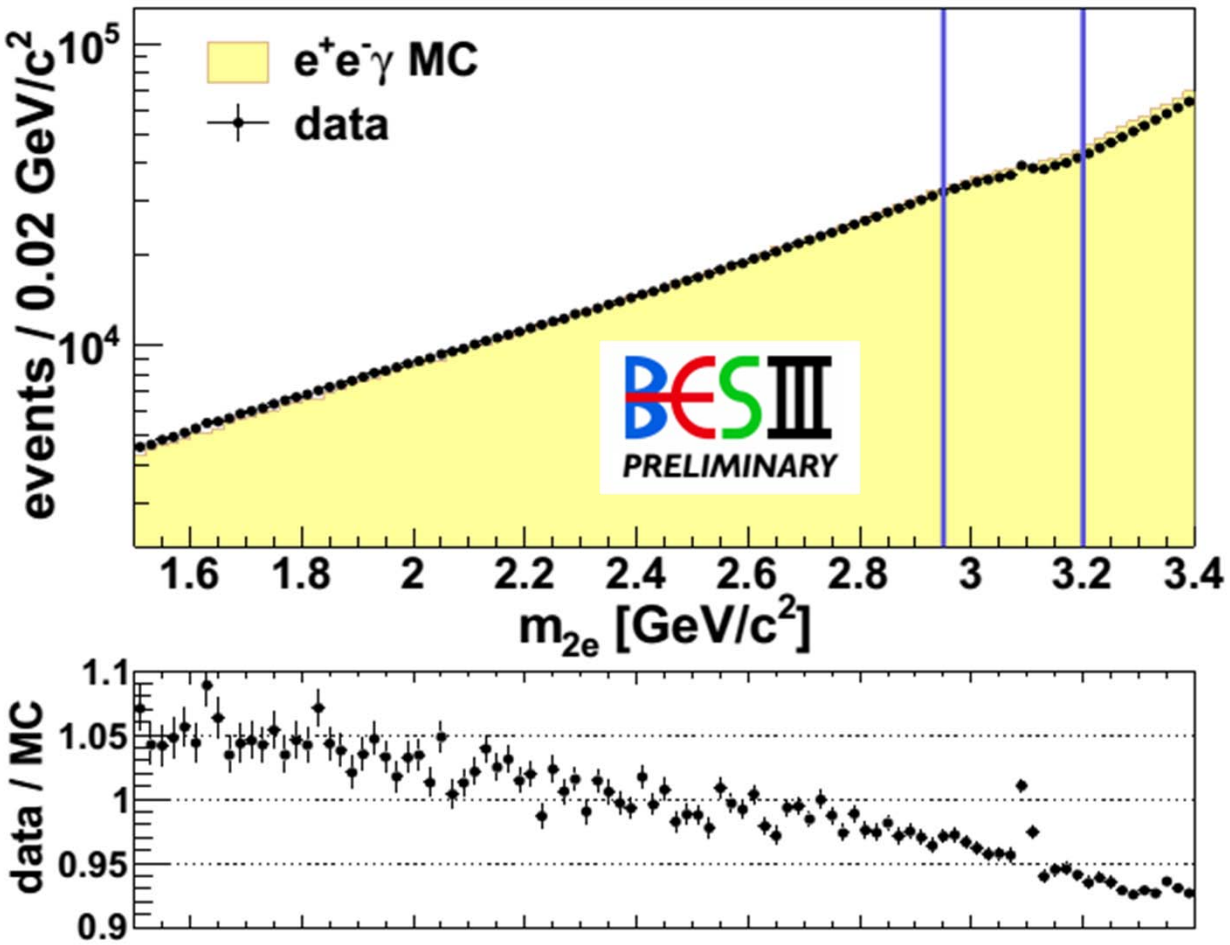
QED background
irreducible

< 1.5 GeV/c^2
$\pi^+\pi^-$ background
dominates

MC simulated with PHOKAHARA

Eur. Phys. J C**24**, 71 (2002)
Phys. Rev. D**77**, 114005 (2008)

e^-e^+ CANDIDATES



$\mu^+\mu^-$ & e^+e^-: **narrow resonant peaks expected, not observed!**

(J/ψ suppressed)

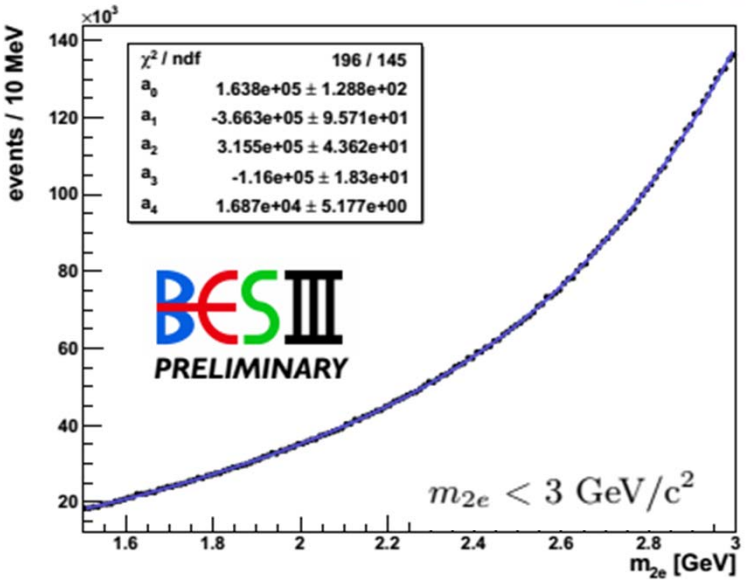
MC simulated with BABAYAGA 3.5

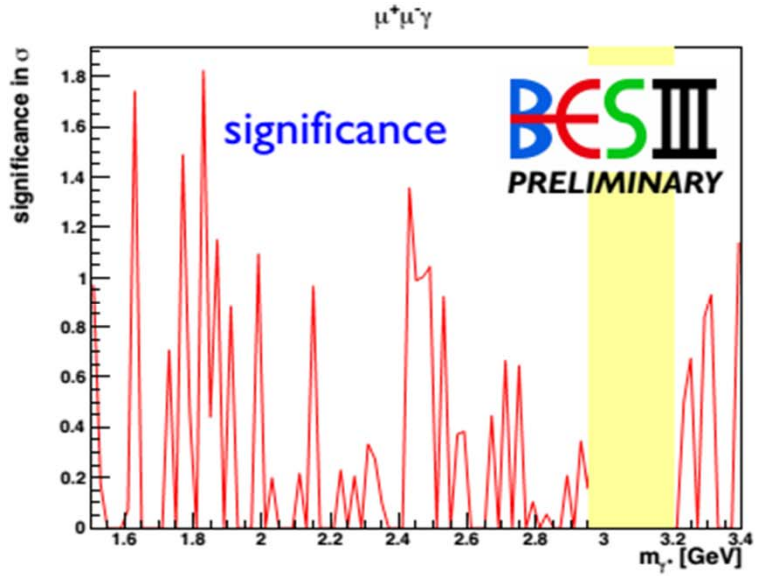
Nucl. Phys. B**758**, 227 (2006)

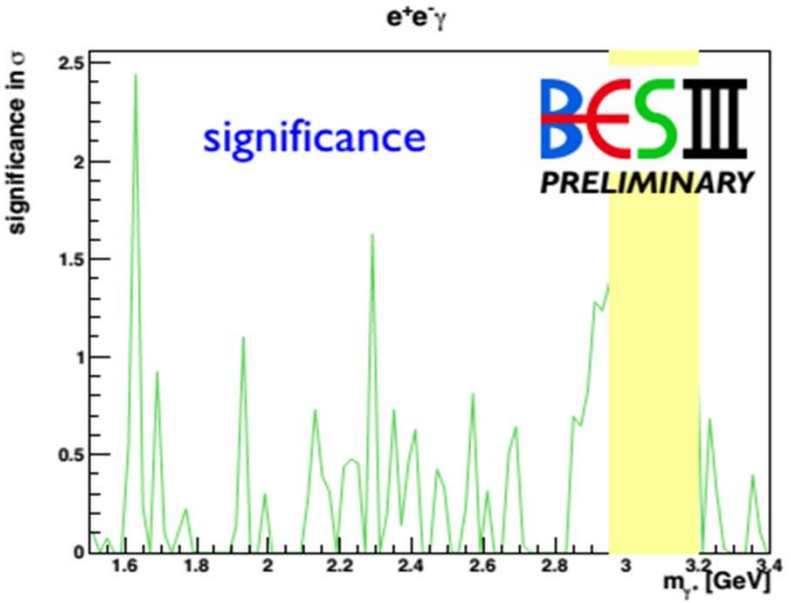
FIT DATA

$$f(x) = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4$$

No peaking structure found in (data-fit) difference!

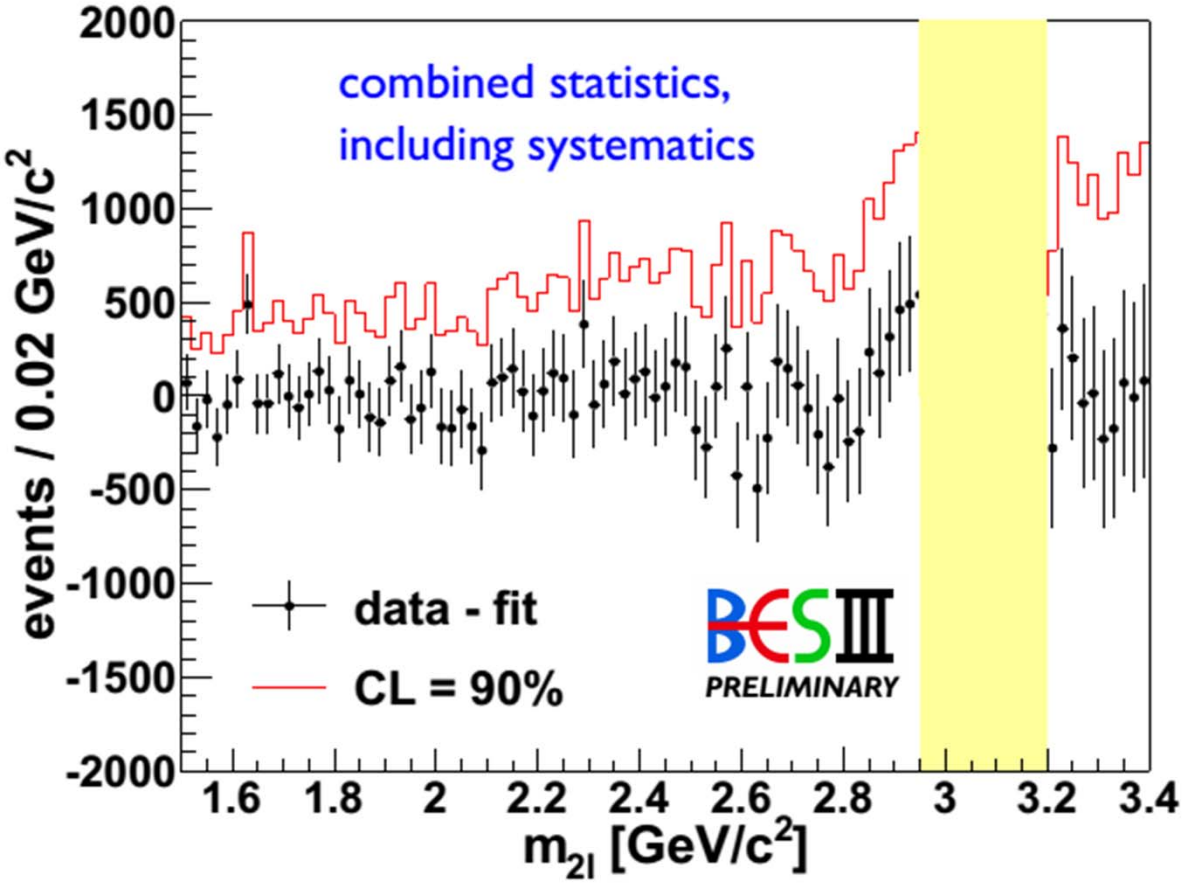






DATA-FIT & 90% CL LIMIT

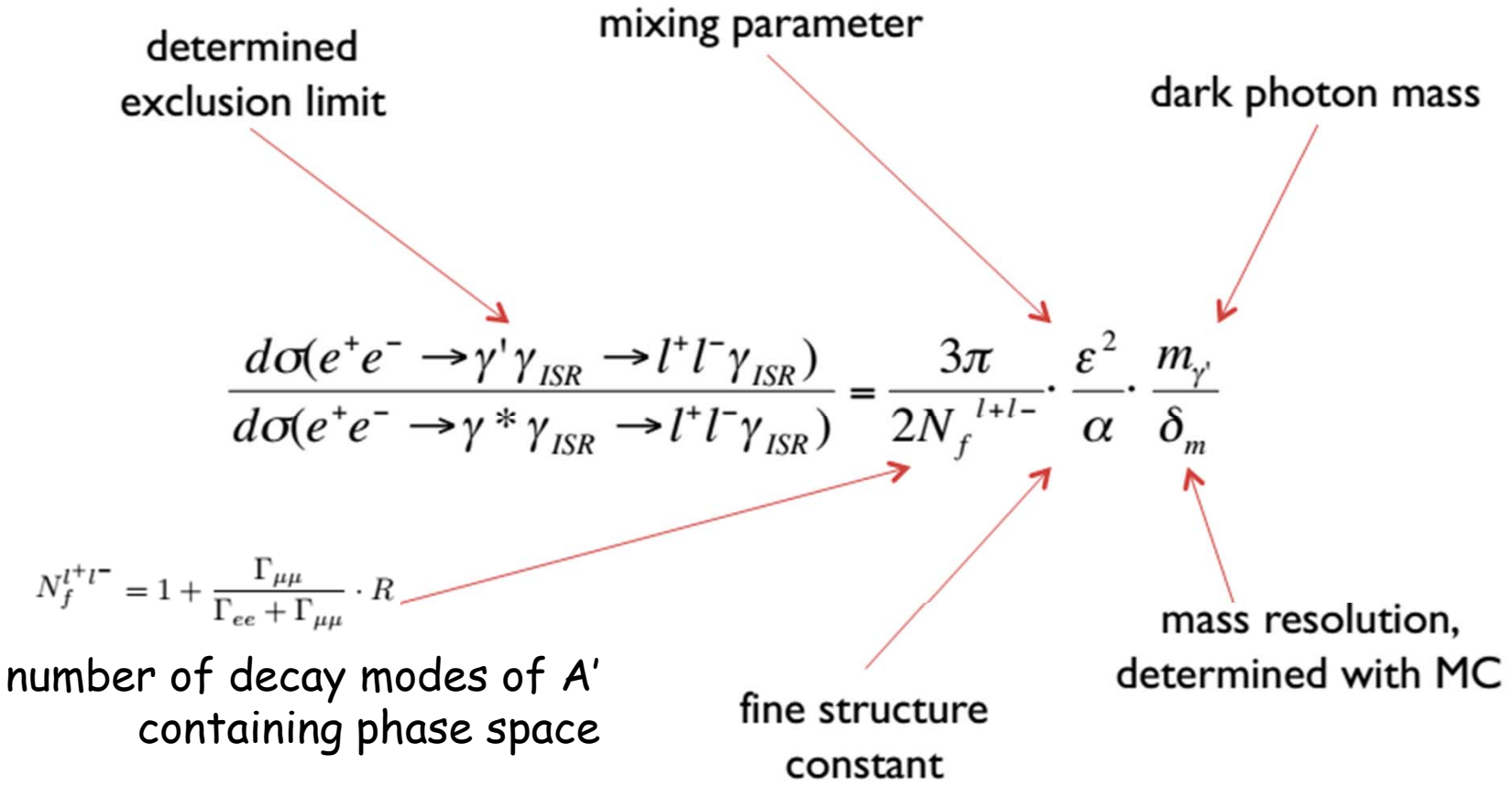
90% confidence level (CL) exclusion limit: profile likelihood approach*



* W. Rolke et al. Nucl. Instrum. Meth. A551, 493 (2005)

ε EXCLUSION LIMITS

calculated in bins of mixing parameter ε



J.D. Bjorken, R. Essig, P. Schuster, and N. Toro, Phys. Rev. D80, 075018 (2009)

SYSTEMATICS

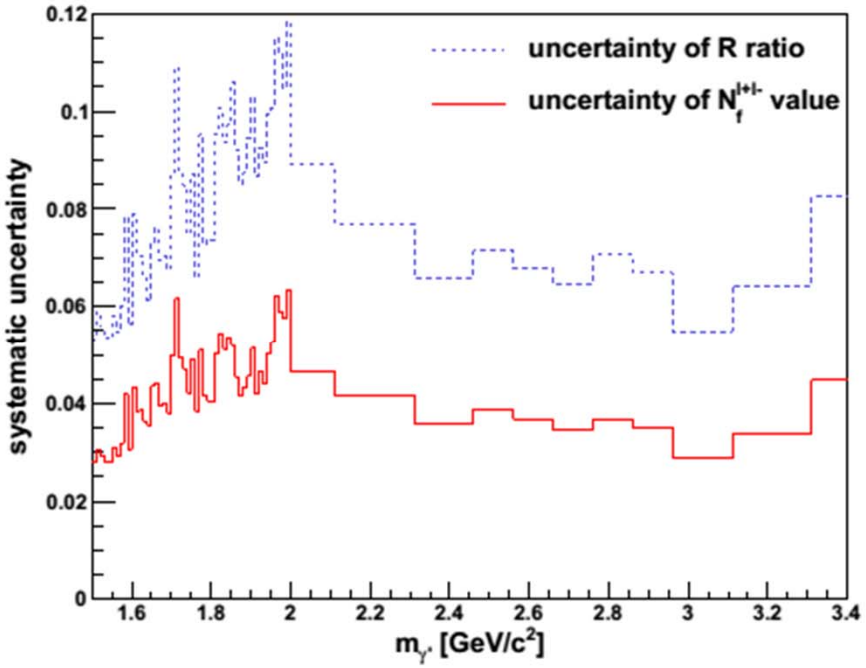
Systematic uncertainty is estimated and implemented bin-by-bin
(possible with TRolke algorithm[1])

Completely dominated by the uncertainty of the R ratio
(everywhere above 5%)

$$R = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

$$\Delta N_f^{l^+l^-} = x \cdot \Delta R$$

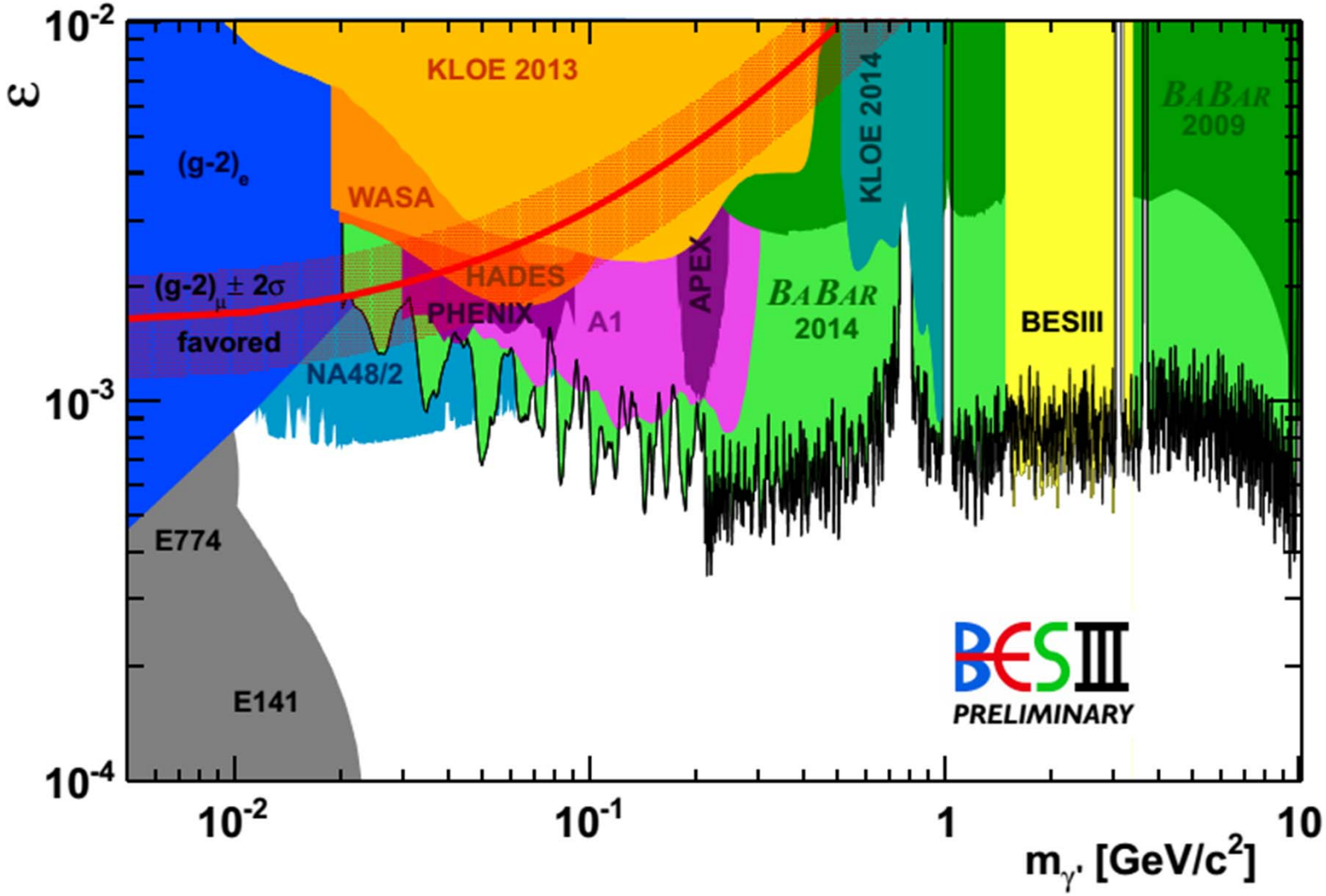
$$x = \frac{\Gamma_{\mu\mu}}{\Gamma_{ee}+\Gamma_{\mu\mu}}$$



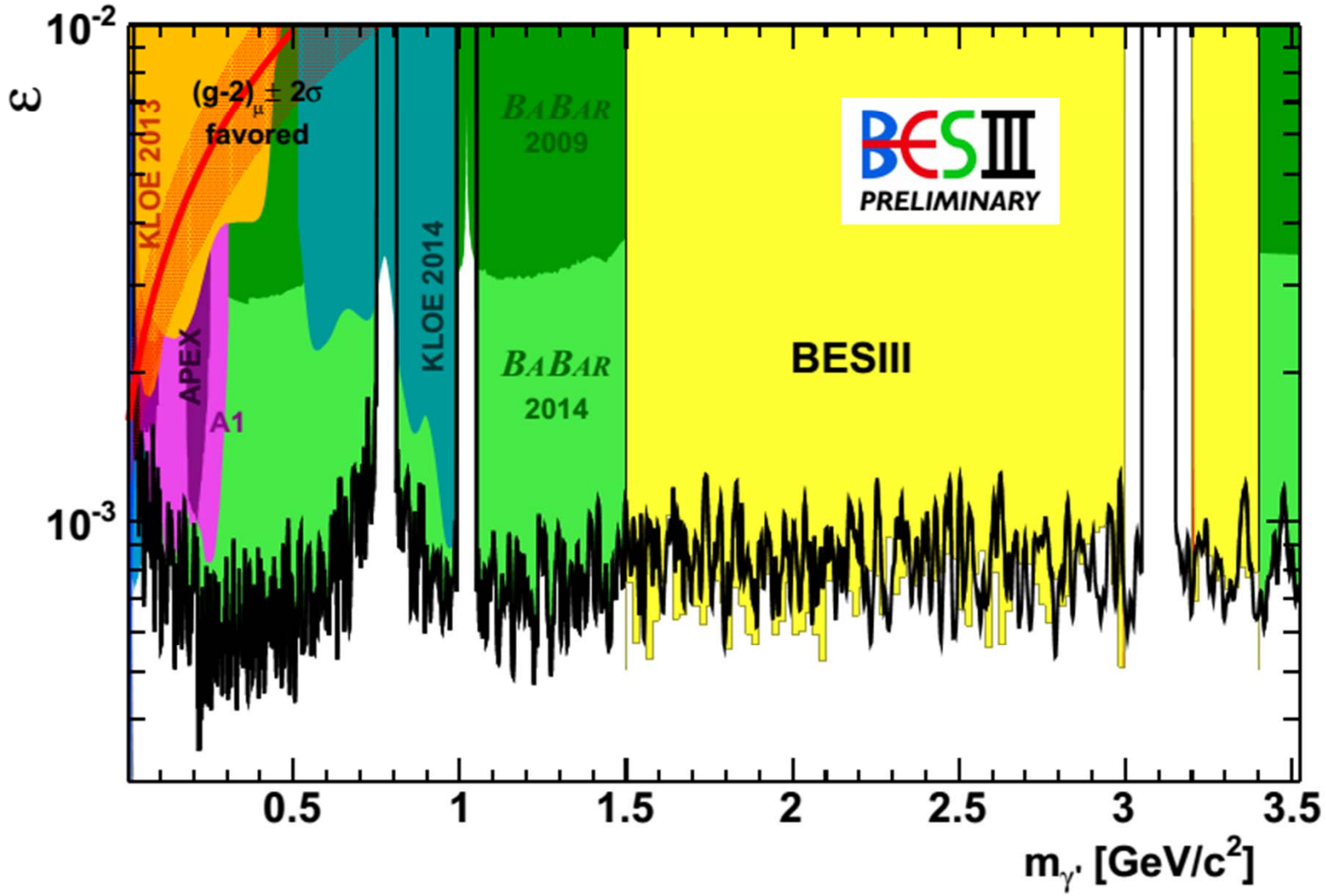
background subtraction	$< 0.5\%$
fitting error	$< 1\%$
mass resolution δ_m	$< 1\%$
$N_f^{l^+l^-}$	3 - 6% (mass dependent)
correction factor for $e^+e^- \to e^+e^-\gamma$	$< 1\%$
sum	3.5 - 6.5% (mass dependent)

[1] see https://root.cern.ch/root/html/tutorials/math/Rolke.C.html

BESIII RESULT VS WORLD



BESIII VS BABAR



SUMMARY

- Search for dark photon A' performed:
  $1.5 < m_{A'} < 3.4$ GeV/c^2

- No DM photon candidates with significance
  $> 3\sigma$ found.

- Obtained competitive limits in accessible mass range, equivalent to **2 year** running …

- … expect more on DM from BESIII:
  3 fb^{-1} @ 4.17 GeV coming this year!

THANK YOU

Number of decay modes N_f

$$N_f^{\,l+l-} = \frac{\Gamma_{tot}}{\Gamma(\gamma' \to l^+ l^-)}$$

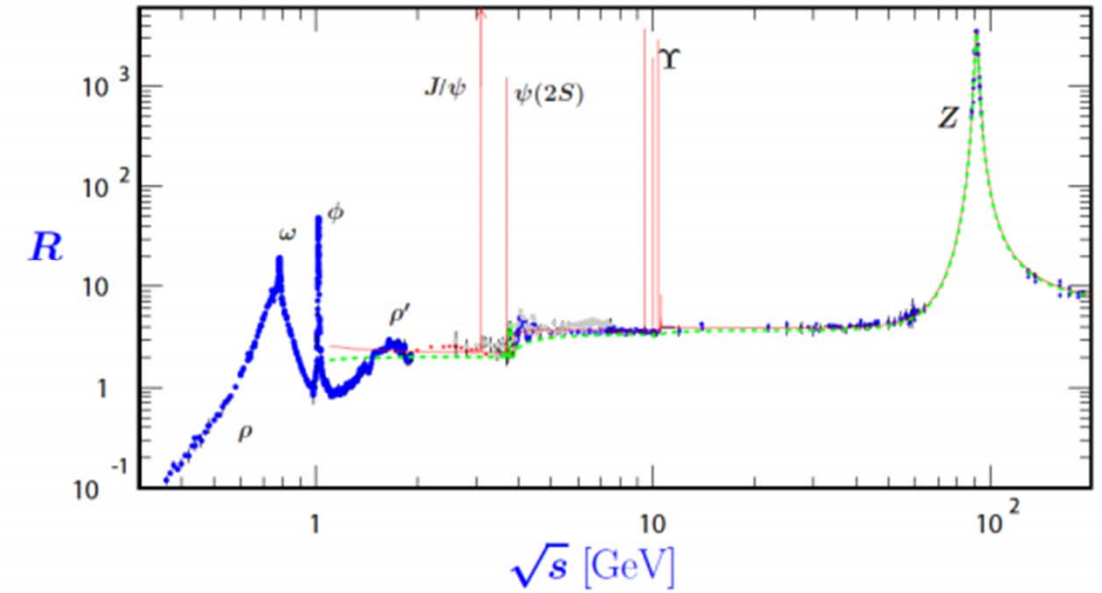
$$\Gamma_{tot} = \Gamma(\gamma' \to e^+ e^-) + \Gamma(\gamma' \to \mu^+ \mu^-) \cdot (1 + R(\sqrt{s}))$$

$$\Gamma(\gamma' \to l^+ l^-) = \frac{\alpha \varepsilon^2}{3 m_{\gamma'}^2} \sqrt{m_{\gamma'}^2 - 4 m_l^2}\,(m_{\gamma'}^2 + 2 m_l^2)$$

Phys. Rev. D88, 015032 (2013)

$$R = \frac{\sigma(e^+ e^- \to hadrons)}{\sigma(e^+ e^- \to \mu^+ \mu^-)}$$

taken from PDG 2014

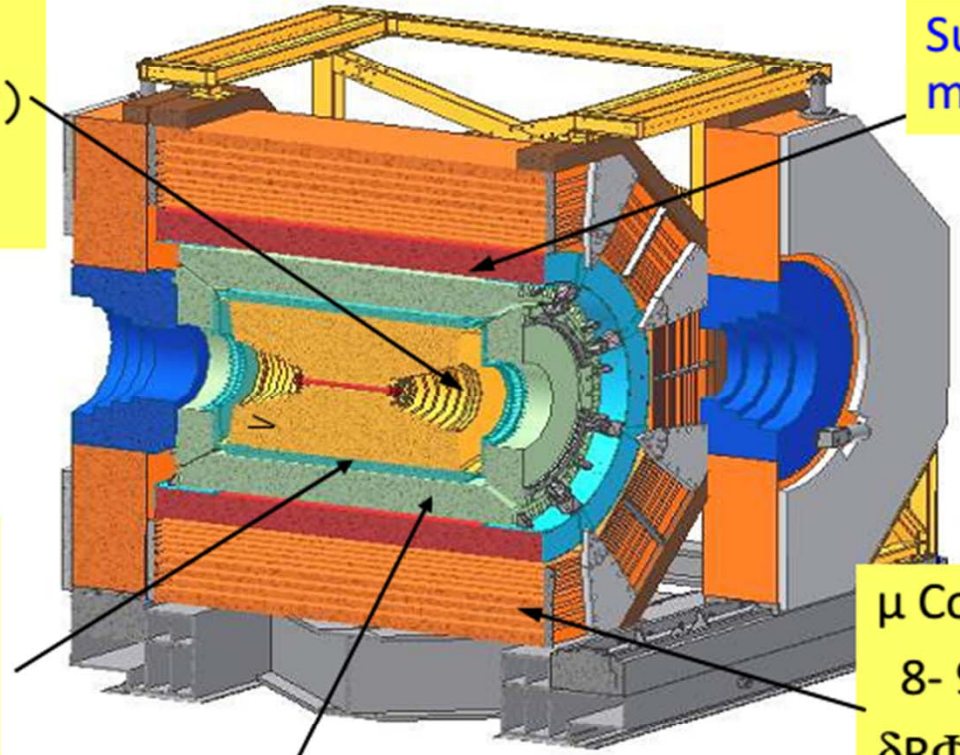


BESIII detector

Drift Chamber (MDC)

$\sigma p/p\ (^0/_0) = 0.5\%(1GeV)$

$\sigma_{dE/dx}\ (^0/_0) = 6\%$



Super-conducting magnet (1.0 Tesla)

Time Of Flight (TOF)

σ_T: 90 ps Barrel

110 ps endcap

μ Counter

8- 9 layers RPC

$\delta R\Phi$=1.4 cm~1.7 cm

EMC: $\sigma E/\sqrt{E}(^0/_0) = 2.5\ \%\ (1\ GeV)$

(CsI) $\sigma_{z,\phi}(cm) = 0.5 - 0.7\ cm/\sqrt{E}$

NIM A614, 345 (2010)