Search for a dark photon using initial state radiation at BESIII

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for the BESIII Collaboration

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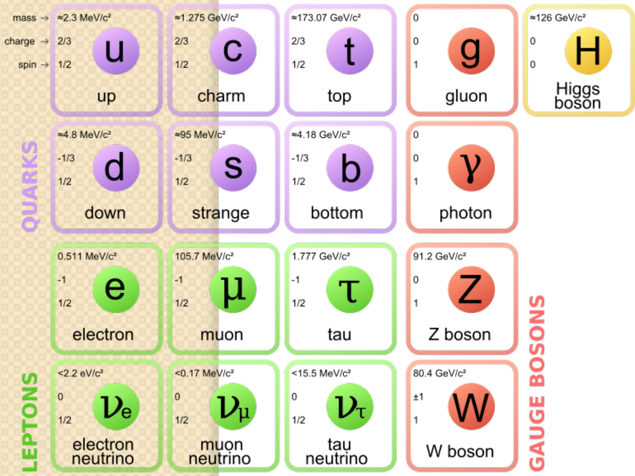
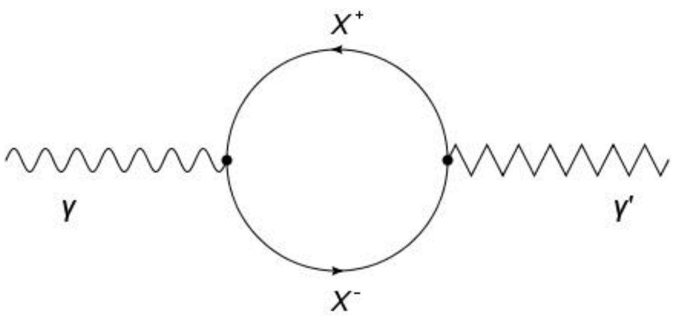
THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

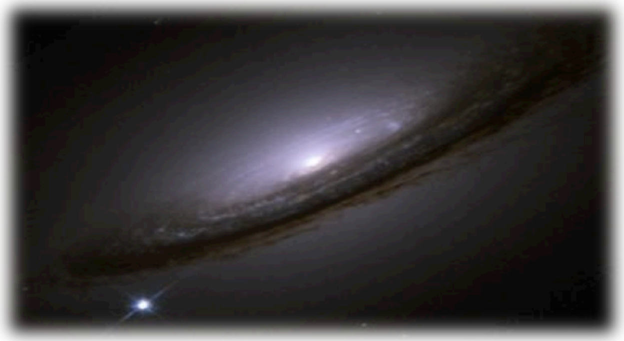
Twelfth Conference on the Intersections of Particle and Nuclear Physics
May 2015, Vail, Colorado

Goal of the analysis

A new U(1) gauge boson γ‘ („dark photon“) might be the connection between the standard model and a dark sector:







standard model kinetic mixing **dark sector**

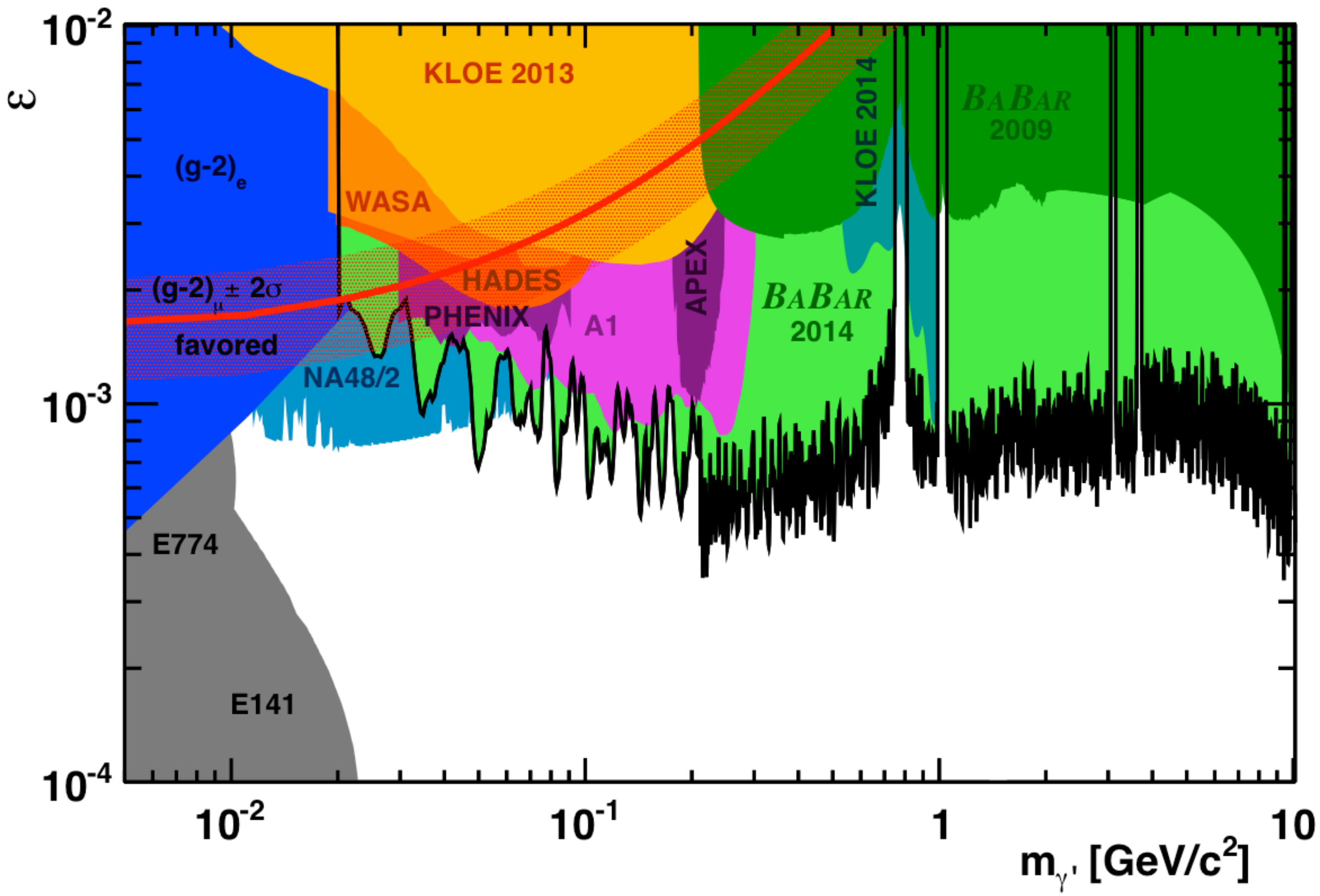
Goal of the analysis

Existing exclusion limits on the dark photon (γ’) mass and mixing parameter (ε):

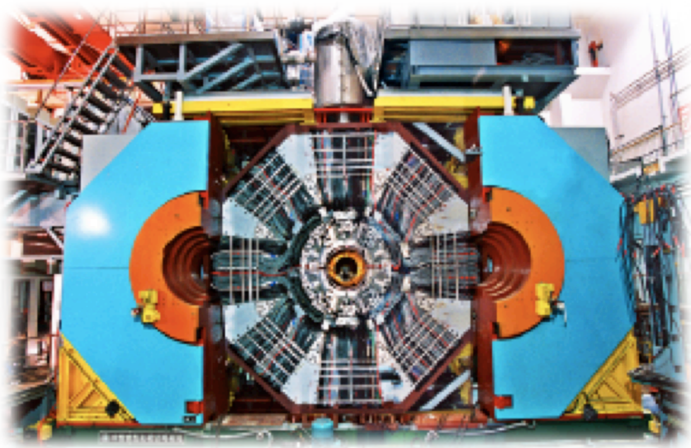
Dark photon coupling strength to SM matter: α'

Mixing parameter: $\varepsilon^2 = \frac{\alpha'}{\alpha}$

GOAL:
make a contribution a



The BESIII experiment



BESIII Collaboration

Political Map of the World, June 1999

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, Univ. of Ferrara, Frascati Lab
Netherland : KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

China(31)

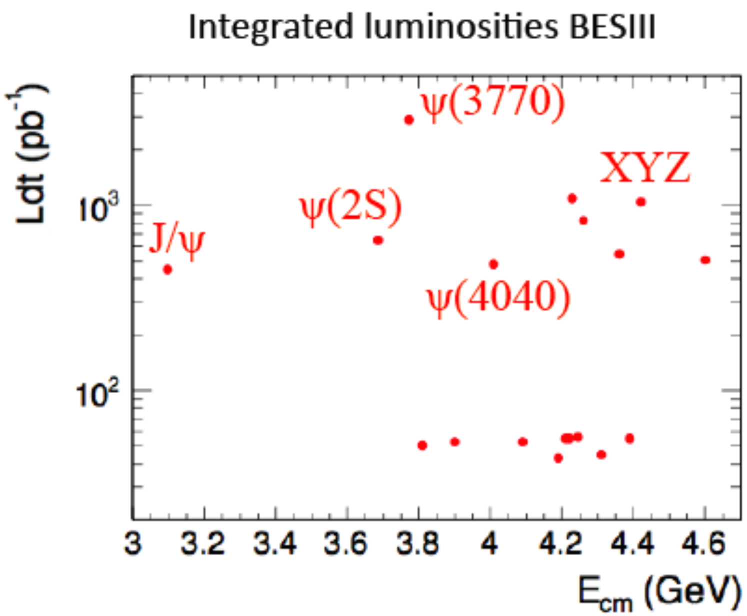
IHEP, CCAST, GUCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning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

BESIII

~400 members
53 institutions from 11 countries

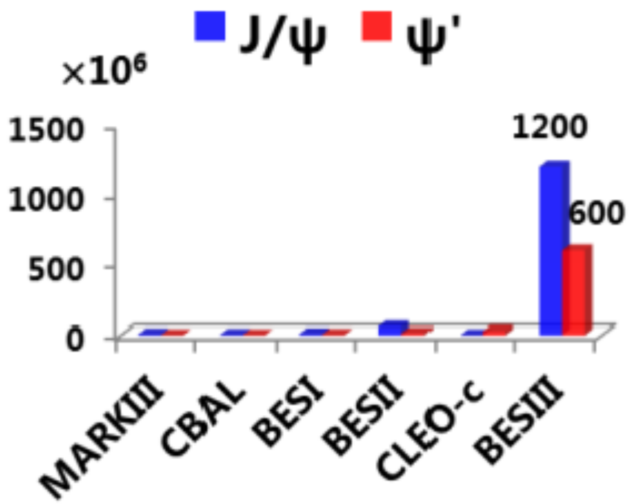
IHEP, Beijing

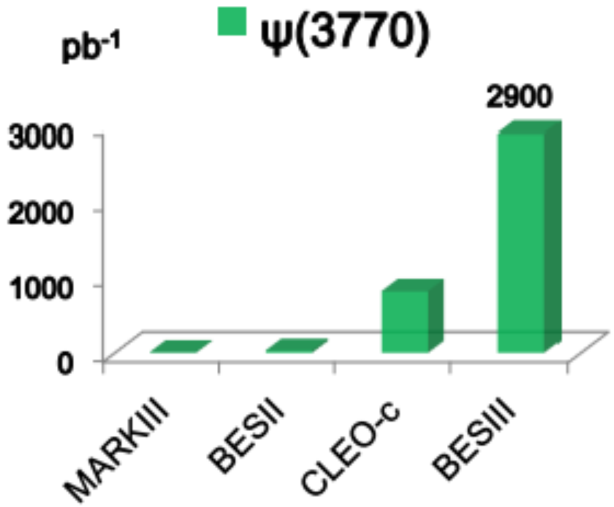
BEPCII



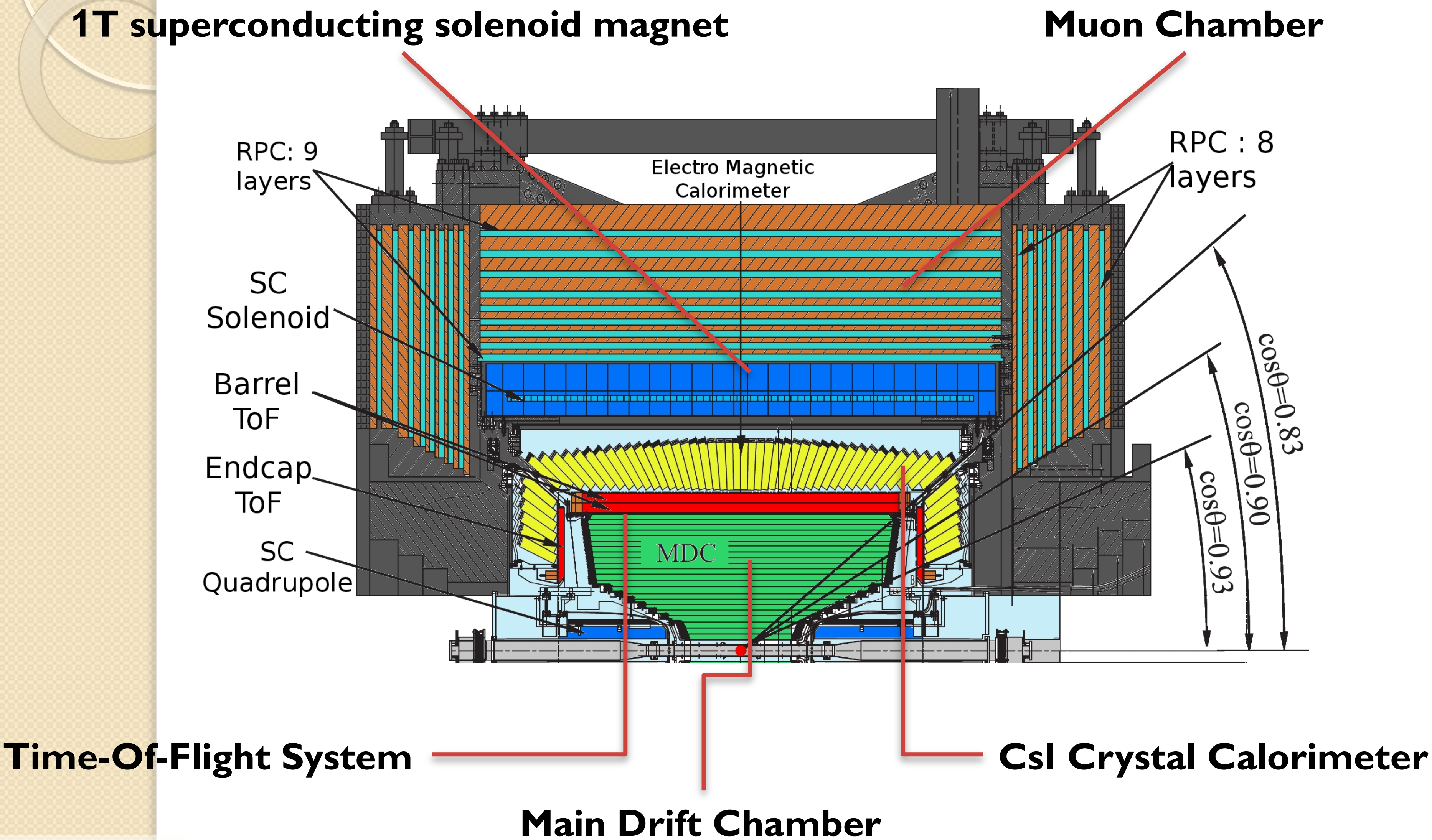
BEPCII Collider:

- located in Beijing, China
- symmetric e+e$^-$ collider
- 2 GeV < E_{CMS} < 4.6 GeV
- data taken at $\sqrt{s} = 3.77\ GeV$: 2.9 fb^{-1}



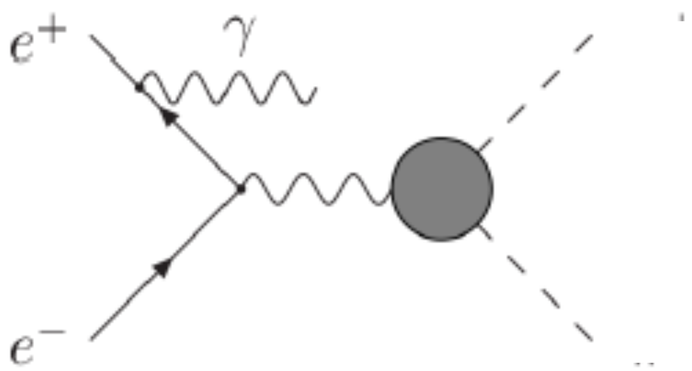


BESIII Detector

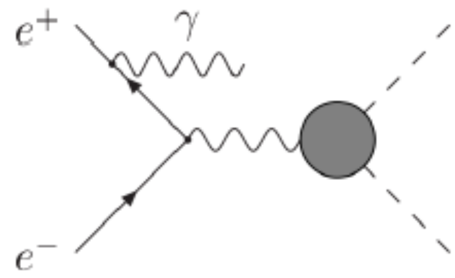


(Graphic produced by Matthias Ulrich, Gießen)

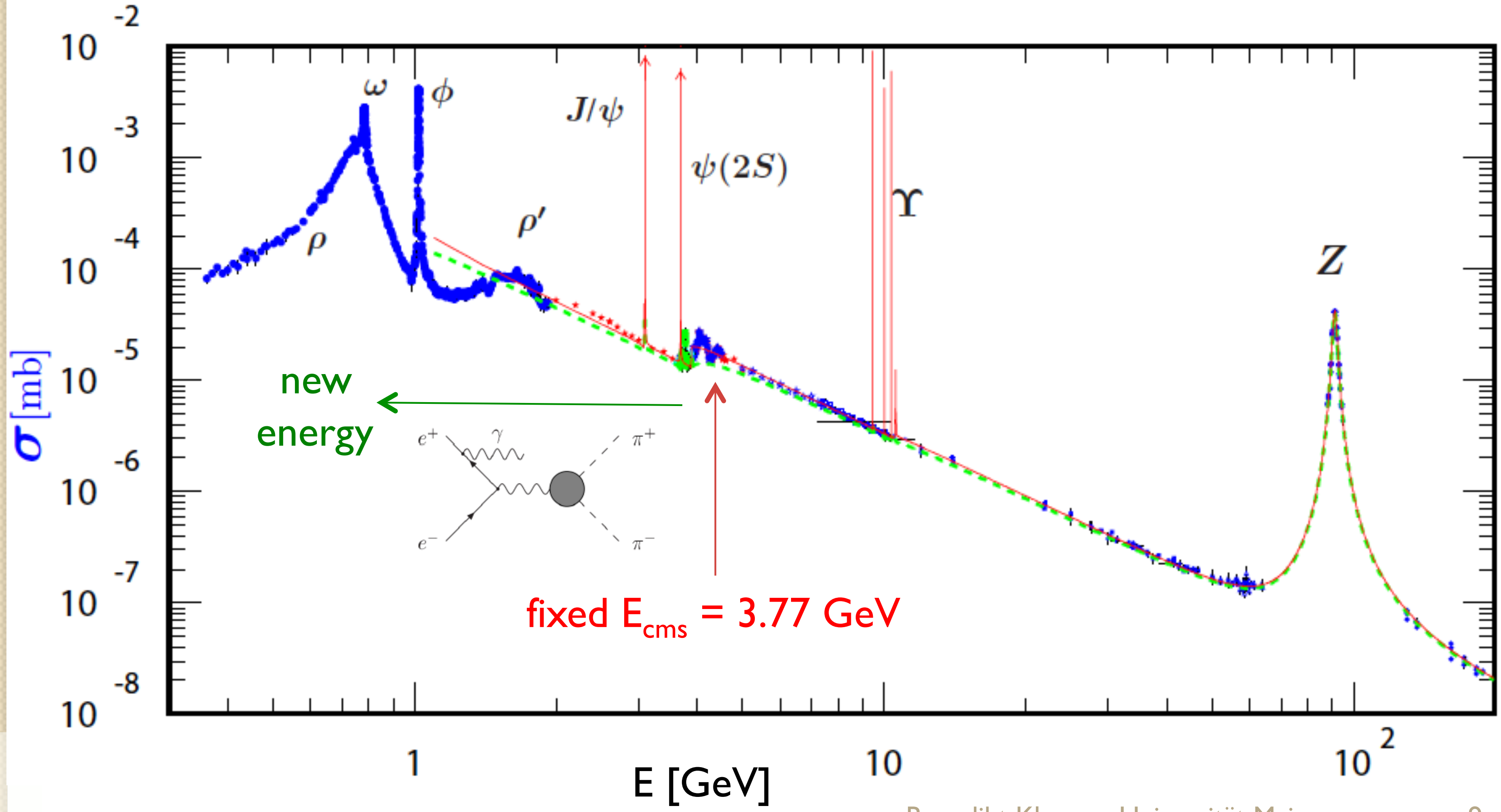
Initial State Radiation



Initial state radiation



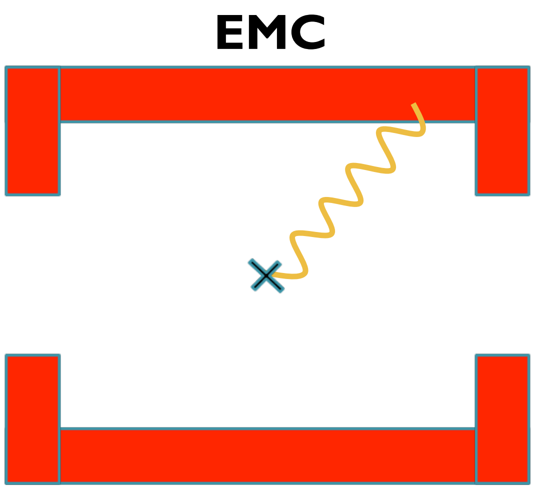
- photon emitted in the initial state
- CMS energy lowered by the energy of the emitted photon
  ⇒ measurements at different energies possible



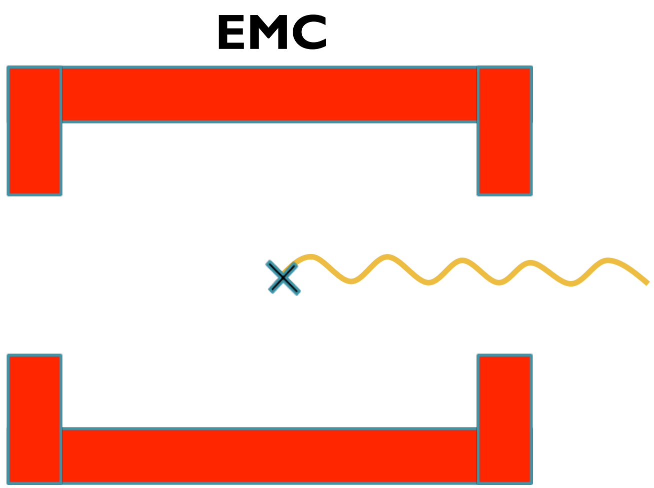
Initial State Radiation

Two different analysis types:

- tagged: photon is detected in the Electromagnetic Calorimeter
- untagged: photon leaves the detector (most probable case)



tagged:
photon hits EMC



untagged:
photon leaves the detector

Initial State Radiation

Two different analysis types:
- tagged: photon is detected in the Electromagnetic Calorimeter
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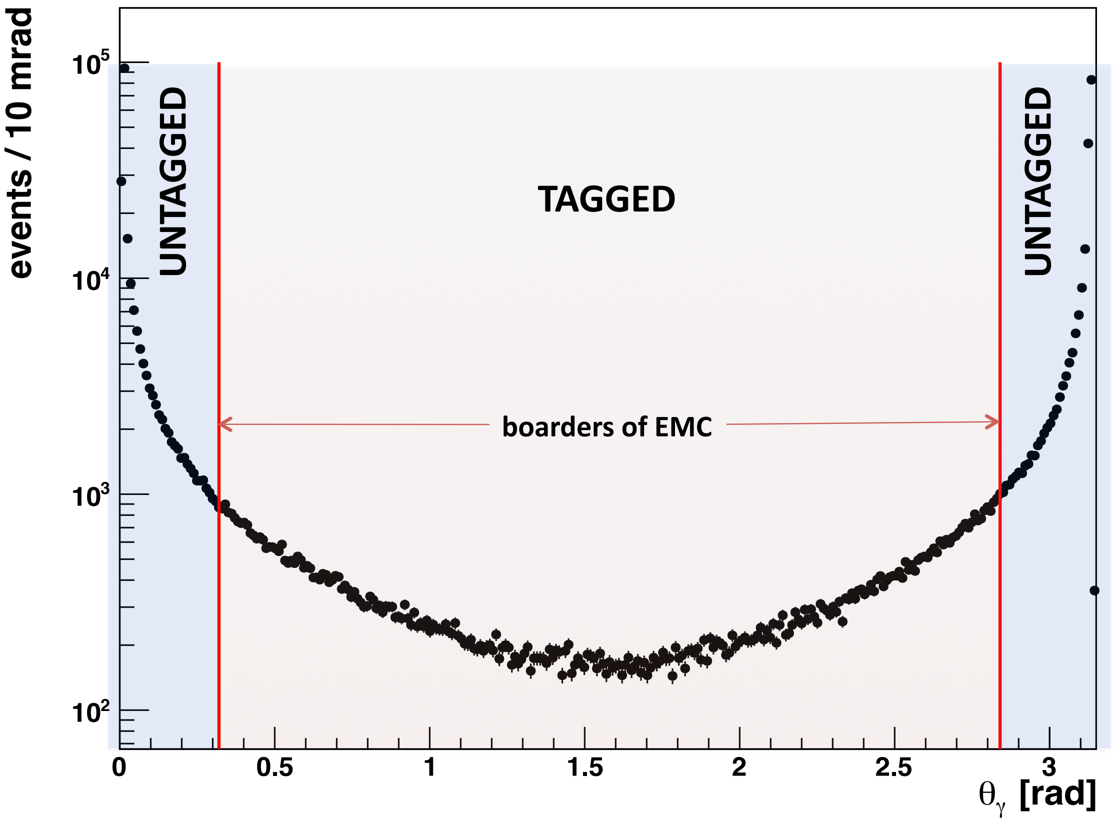


Analysis idea

Idea: Search for the ISR processes

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

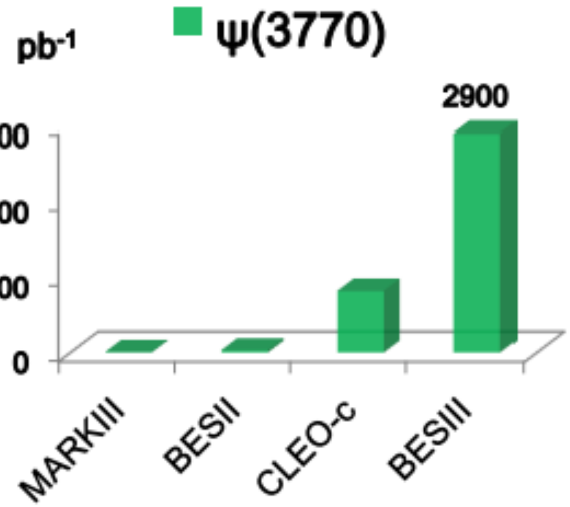
and

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

Use **untagged** ISR events
and 2.9 fb^{-1} data, taken at 3.77 GeV.

at

BESIII



Analysis idea

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and

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Irreducible background:

$$e^+e^- \rightarrow \gamma_{ISR}\gamma^* \rightarrow \gamma_{ISR}\mu^+\mu^-$$

$$e^+e^- \rightarrow \gamma_{ISR}\gamma^* \rightarrow \gamma_{ISR}e^+e^-$$

QED process, same signature in detector!

Dark photon signal would appear as **peak** on the QED background.

⇒ **Peak search!**

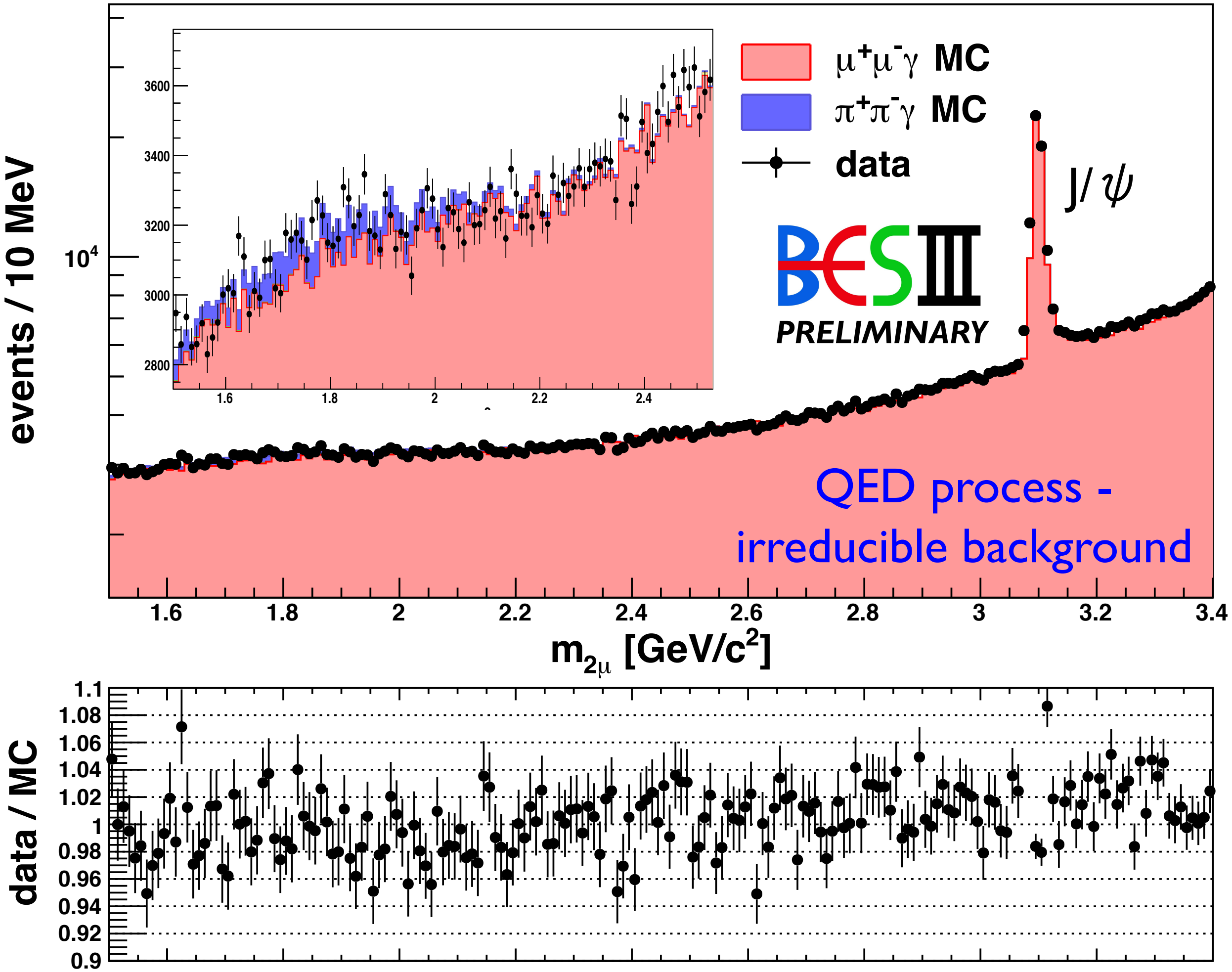
Analysis

Event selection

Event selection: $e^+e^- \to \mu^+\mu^-\gamma_{ISR}$ and $e^+e^- \to e^+e^-\gamma_{ISR}$

distance to interaction point	R_{xy} < 1.0 cm R_z < 10.0 cm
acceptance of charged tracks	0.4 rad < θ < π – 0.4 rad
to supress background	PID to select μ or e
# charged tracks	= 2
total charge	= 0
# photons	= 0 (untagged analysis)
missing photon angle	< 0.1 rad or > π – 0.1 rad
1C kinematic fit	$\chi^2_{1C} < 20$

Data-MC comparison: $\mu^+\mu^-$ case



Data-MC efficiency corrections applied on MC.

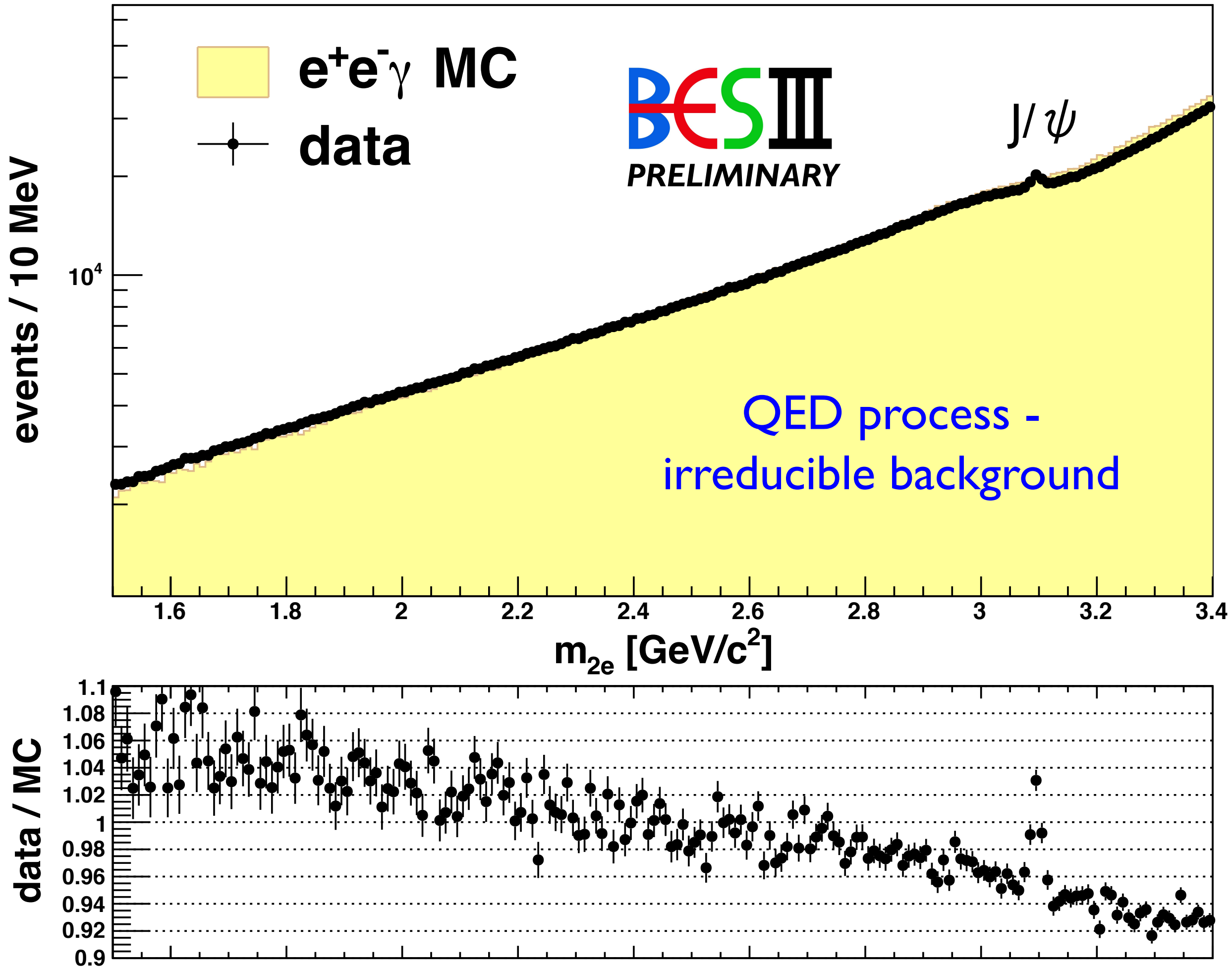
See talk on Wednesday:

"Measurement of the $\pi^+\pi^-$ cross section at BESIII" (PPHI, 16:40)

MC simulated with PHOKHARA

Eur.Phys.J. C**24**, 71-82 (2002)
Phys. Rev. D**77**, 114005 (2008)

Data-MC comparison: e^+e^- case



MC not corrected for data-MC differences.

MC simulated with BABAYAGA 3.5

Nucl. Phys. B**758**, 227-253 (2006)

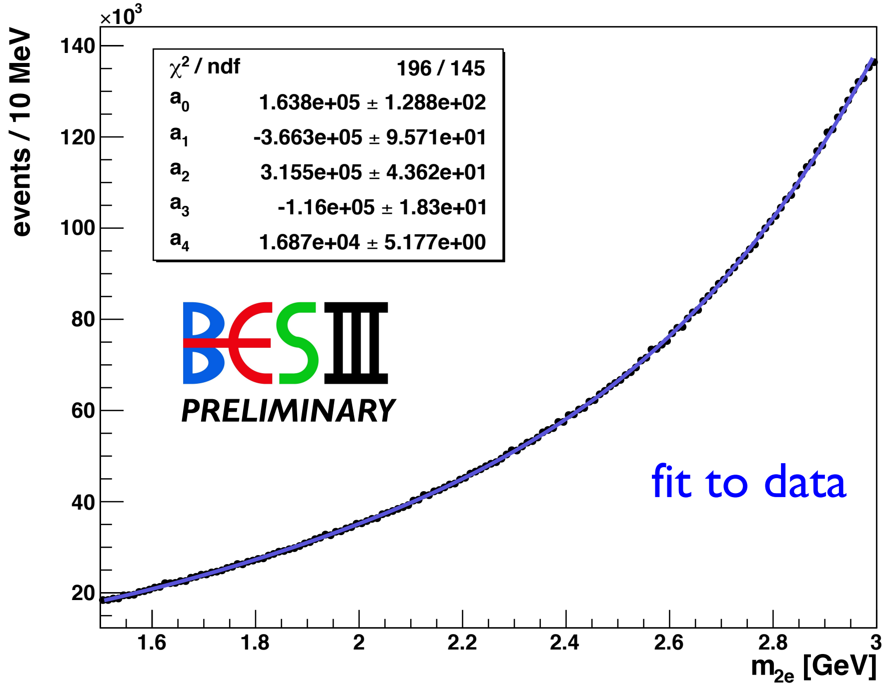
Fit to data

To get rid of the MC prediction:

Fit of the **continouus** mass spectrum in data with a polynomial and look for a peak in data:

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

Spare the region around J/ψ.



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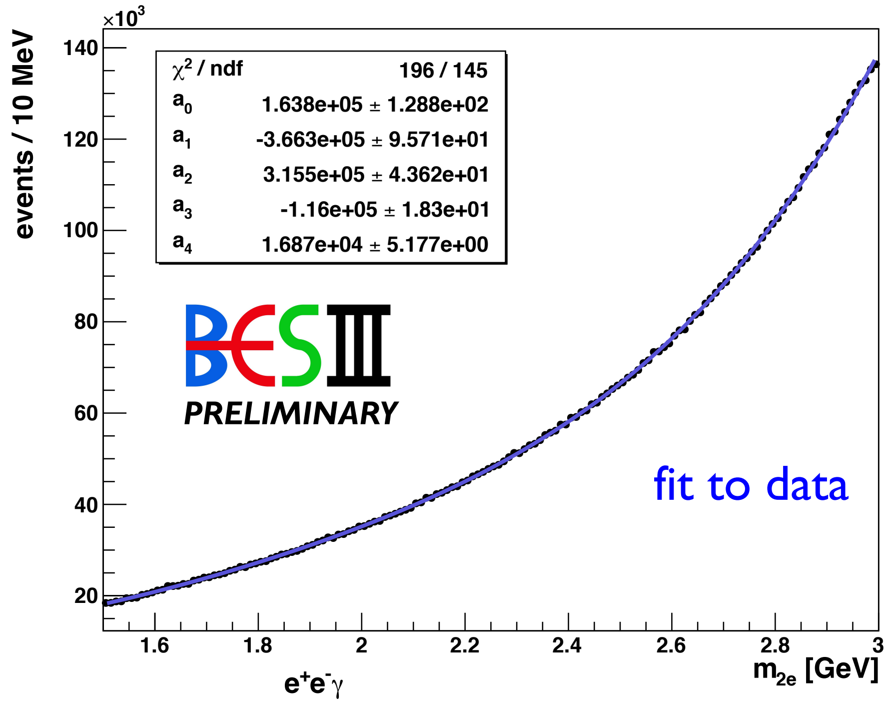
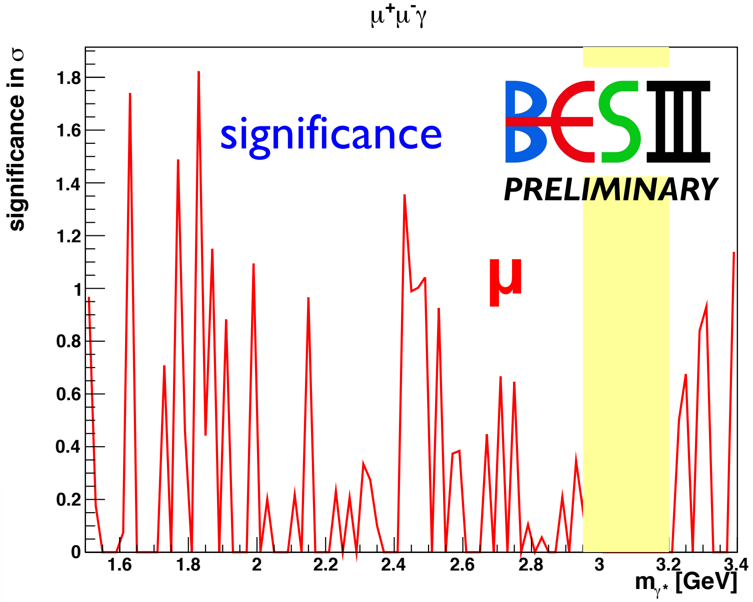
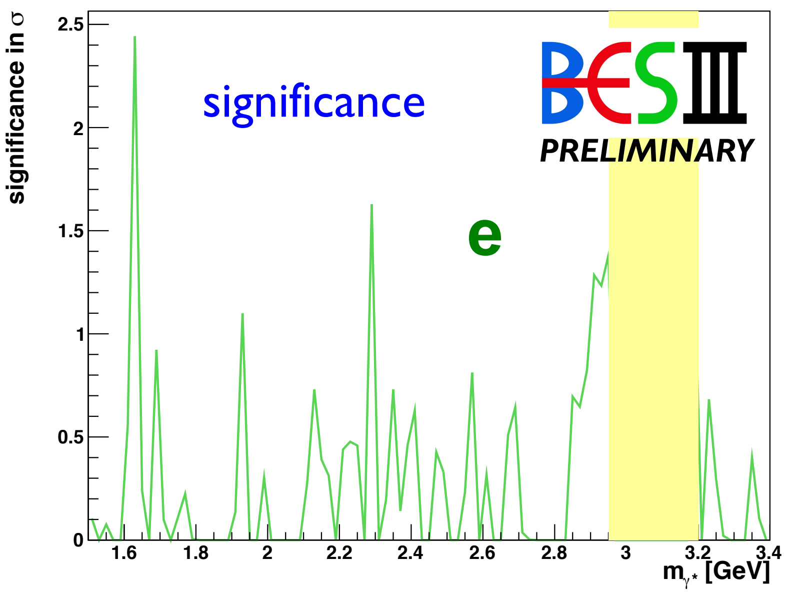
$$p(x) = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4$$

Spare the region around J/ψ.

No peaking structure found.
⇒ Set exclusion limit.







Analysis strategy for the dark photon search

event selection

↓

compare with MC prediction ← check whether huge background is left

↓

fit the invariant mass distribution in data ← get rid of any data-MC comparison in the final result

↓

search for a peaking structure ← none is found

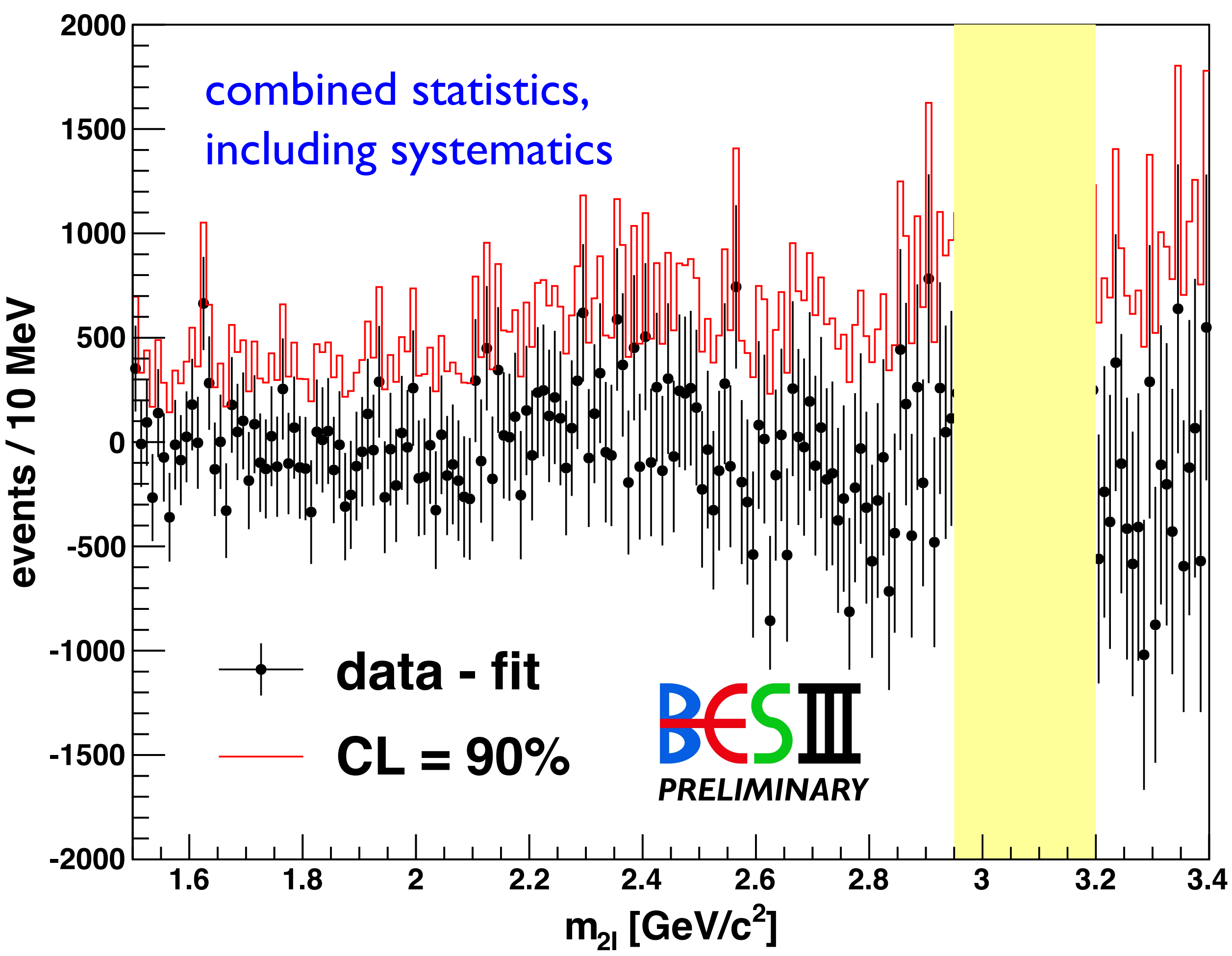
↓

calculate the exclusion limit between $1.5\ \mathrm{GeV}/c^2$ and $3.4\ \mathrm{GeV}/c^2$ ← below $1.5\ \mathrm{GeV}/c^2$: pion background is dominant; above $3.4\ \mathrm{GeV}/c^2$: too close to production threshold

Exclusion limit

90% confidence level (CL) calculated with the algorithm by Rolke et al. (TRolke)

Nucl.Instrum.Meth., A**551**, 493-503 (2005)



Exclusion limit

We want to calculate it in bins of
the mixing parameter ε :

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

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

Exclusion limit

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

- determined exclusion limit: left-hand side ratio
- mixing parameter: ε^2
- dark photon mass: $m_{\gamma'}$
- number of decay modes of dark photon containing phase space (contains R ratio, see next slide): N_f^{l+l-}
- fine structure constant: α
- mass resolution, determined with MC: δ_m

Number of decay modes N_f

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

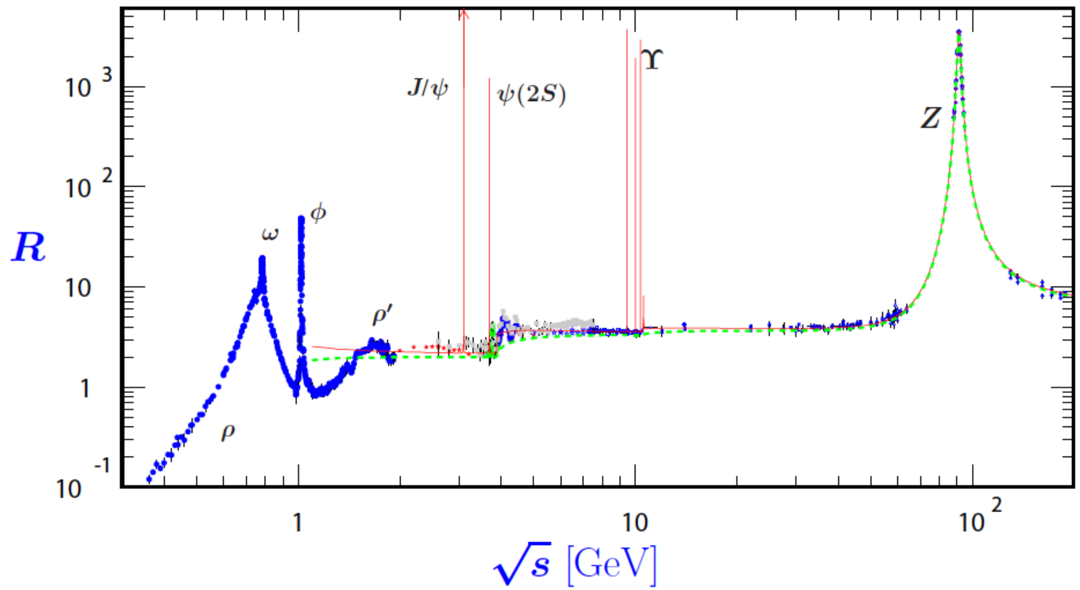
$$\Gamma_{tot} = \Gamma(\gamma' \to e^+ e^-) + \Gamma(\gamma' \to \mu^+ \mu^-) \cdot (1 + R(\sqrt{s}))$$

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

Phys. Rev. D**88**, 015032 (2013)

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

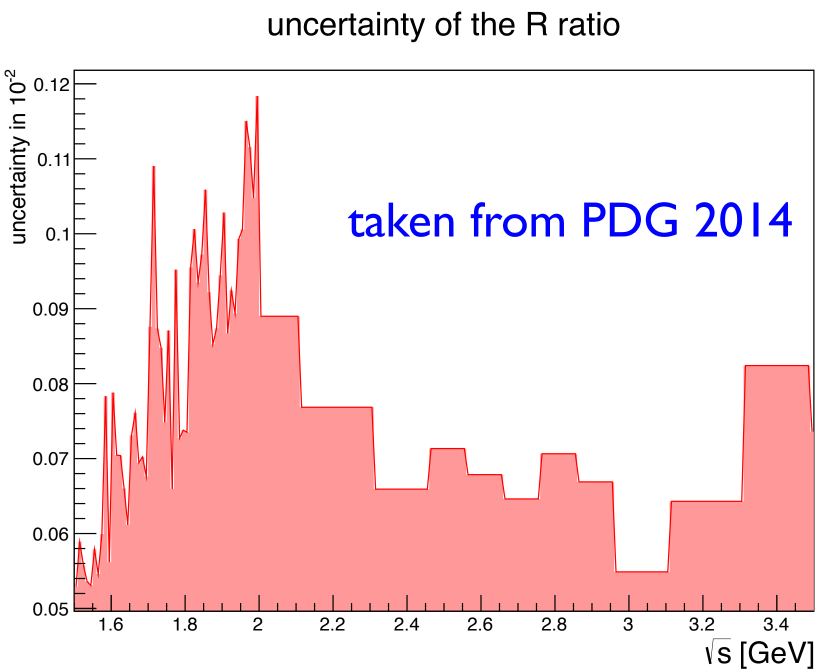
taken from PDG 2014



Systematic uncertainty

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

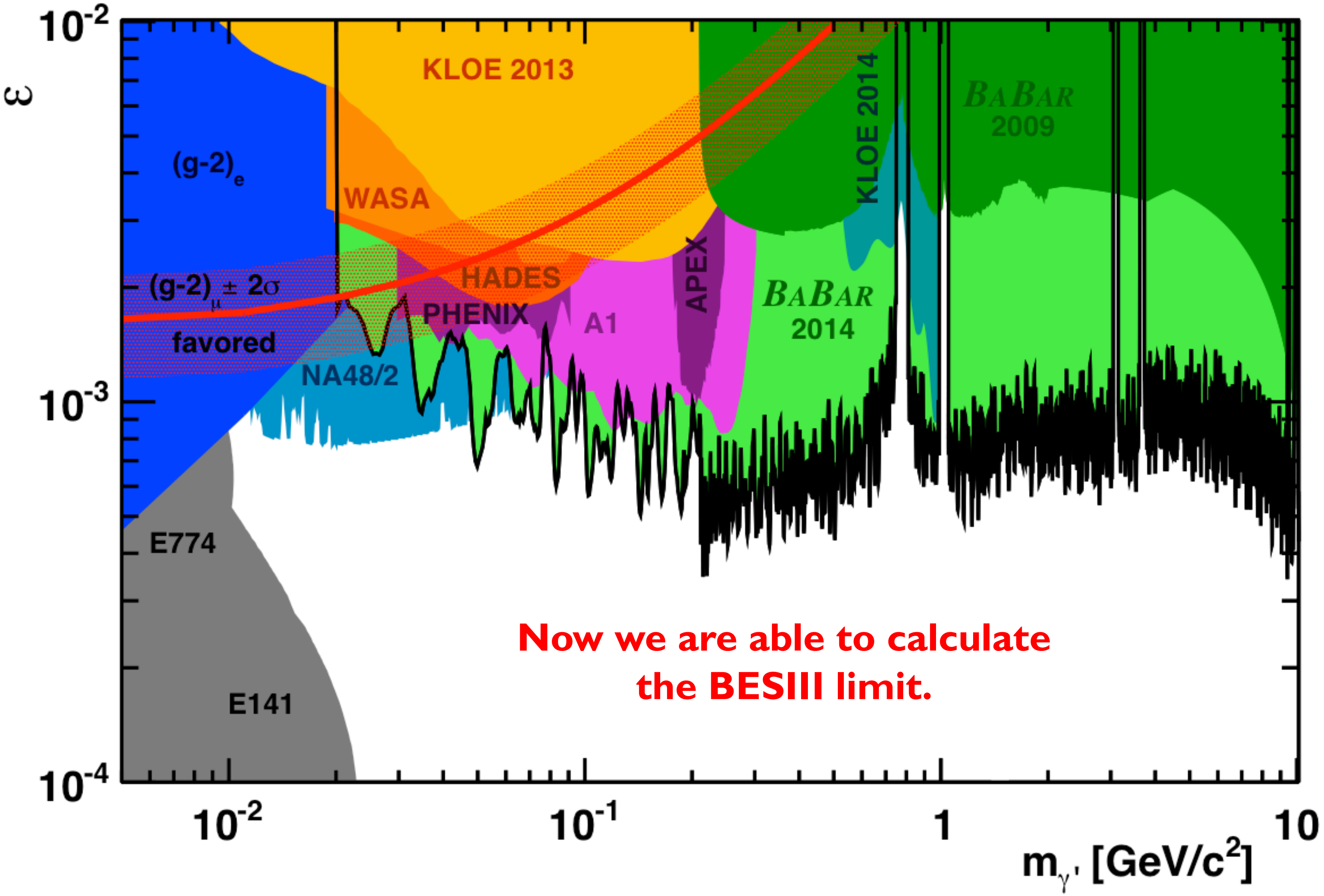
Completely dominated by the uncertainty of the R ratio
(everywhere above 5%)



background subtraction	$< 0.5\%$
fitting error	$< 1\%$
mass resolution	$< 1\%$
R ratio	$> 5\%$
sum	$> 5\%$

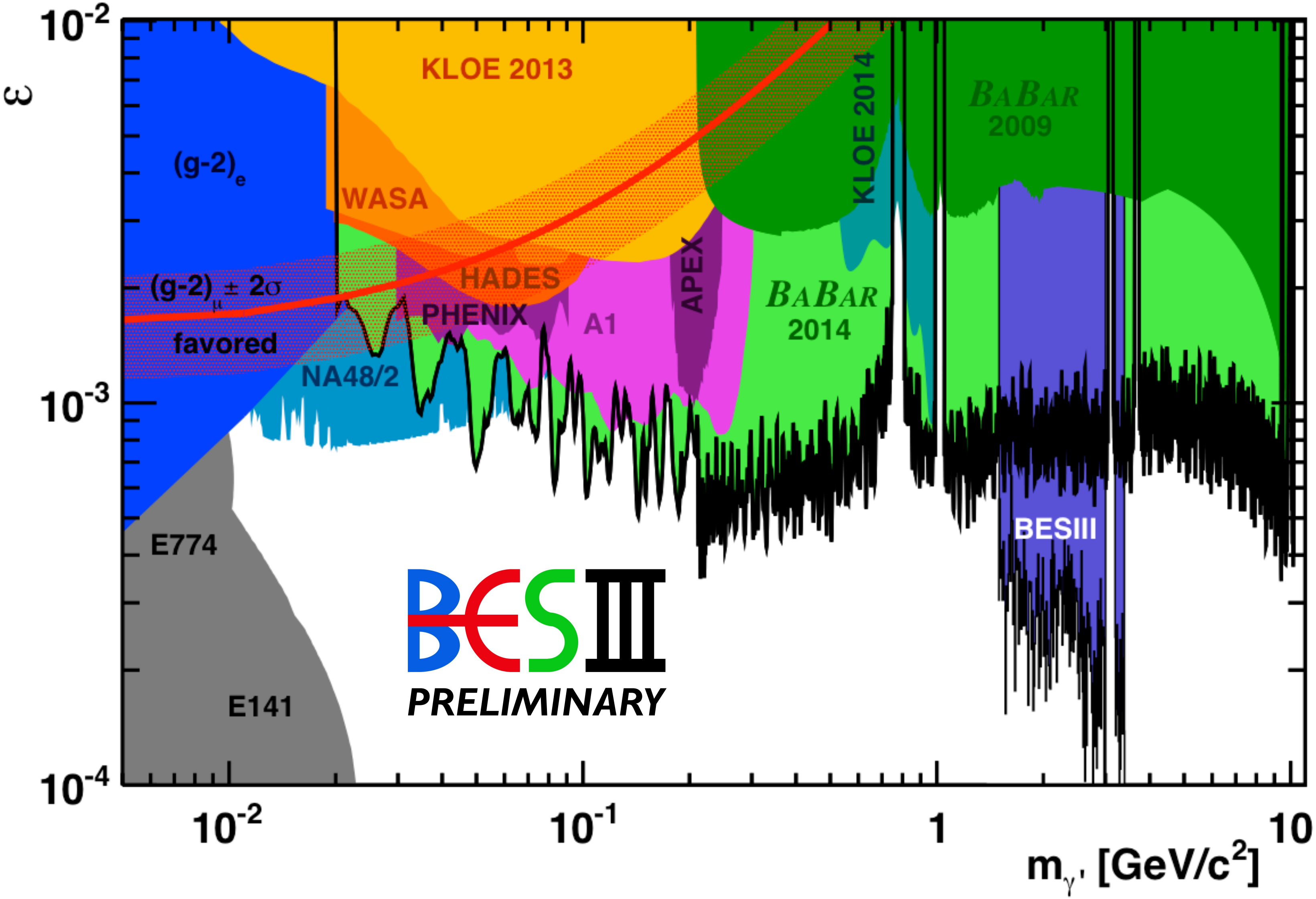
[1] see https://root.cern.ch/root/html/tutorials/math/Rolke.C.html

Result



Now we are able to calculate the BESIII limit.

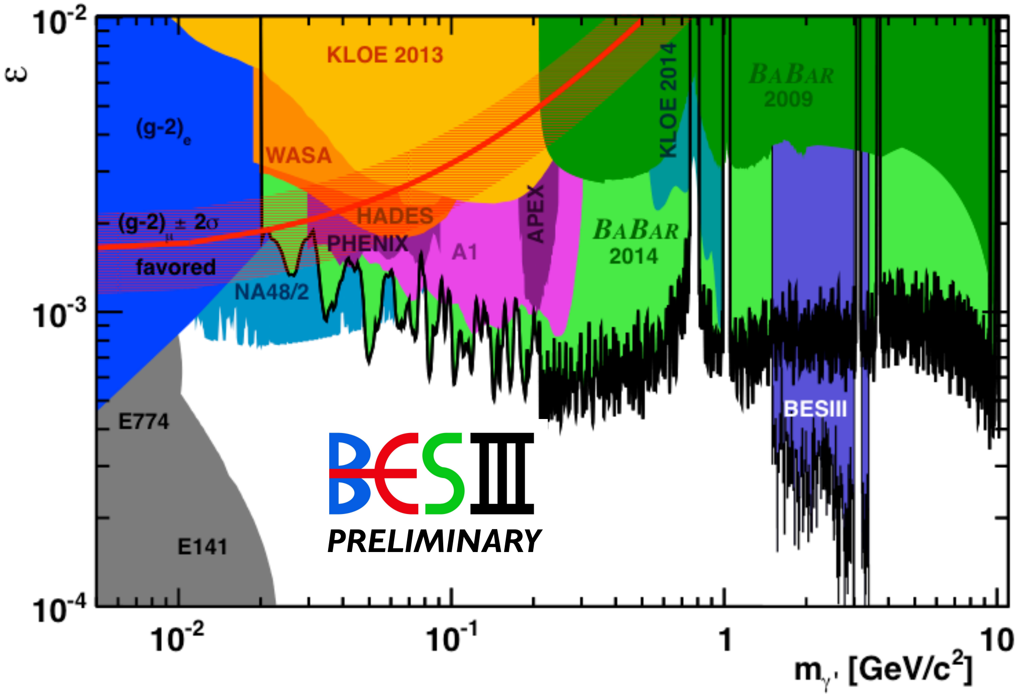
Result



ε
10^{-2}
10^{-3}
10^{-4}
10^{-2}
10^{-1}
1
10
$m_{\gamma'}$ [GeV/c^2]
KLOE 2013
$(g-2)_e$
WASA
$(g-2)_\mu \pm 2\sigma$
favored
HADES
PHENIX
A1
APEX
NA48/2
KLOE 2014
BABAR
2009
BABAR
2014
BESIII
E774
E141
BESIII
PRELIMINARY

Summary

- Goal of the analysis is to search a dark photon signal using $\mu^+\mu^-\gamma_{ISR}$ and $e^+e^-\gamma_{ISR}$ events
- no evidence has been found between 1.5 and 3.4 GeV/c^2
- an exclusion limit with 90% confidence has been calculated with the TRolke algorithm in bins of the mass and mixing parameter of the dark photon
- values down to $\varepsilon < 7 \cdot 10^{-3}$ can be excluded
- best exclusion limit in this mass range



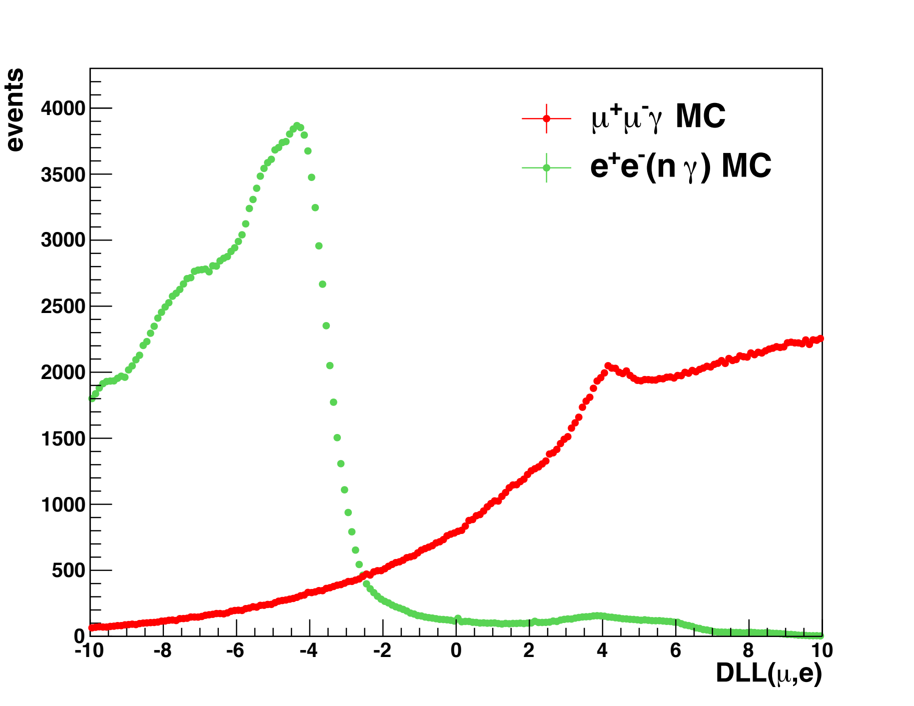
Thank you for your attention!

Backup

Particle identification

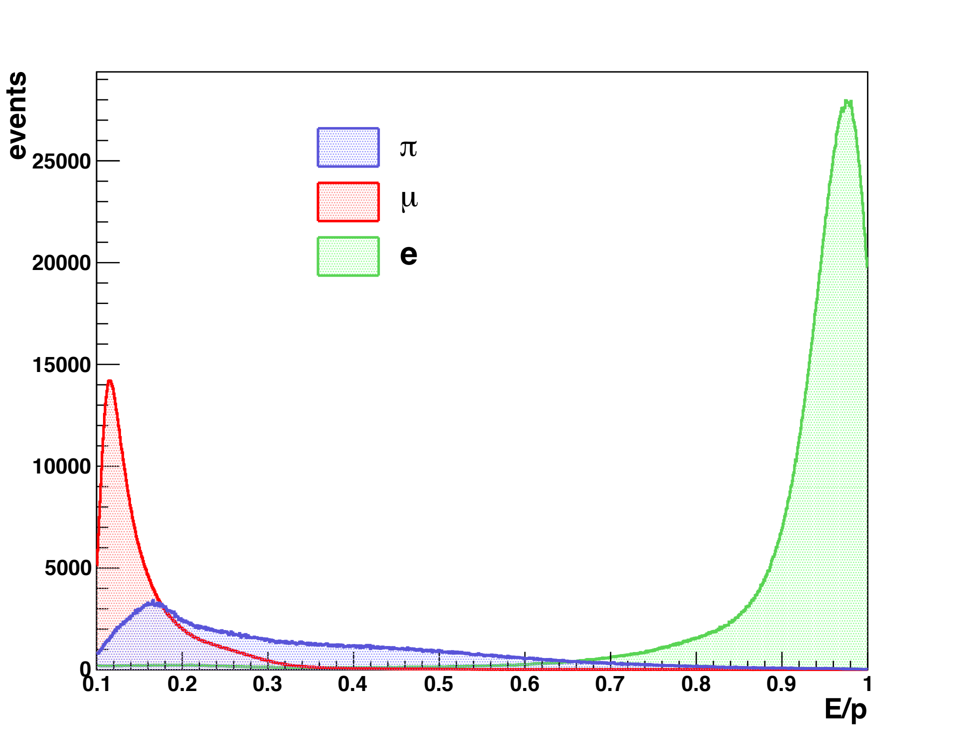
$$e^+e^- \to \mu^+\mu^-\gamma_{ISR}$$

$$DLL(\mu,e) = 2\cdot \log\left(\frac{p(\mu)}{p(e)}\right) > 0$$



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

E / p > 0.8



particle	suppression due to E/p > 0.8
muons	99.95 %
pions	98.01 %
electrons	9.83 %

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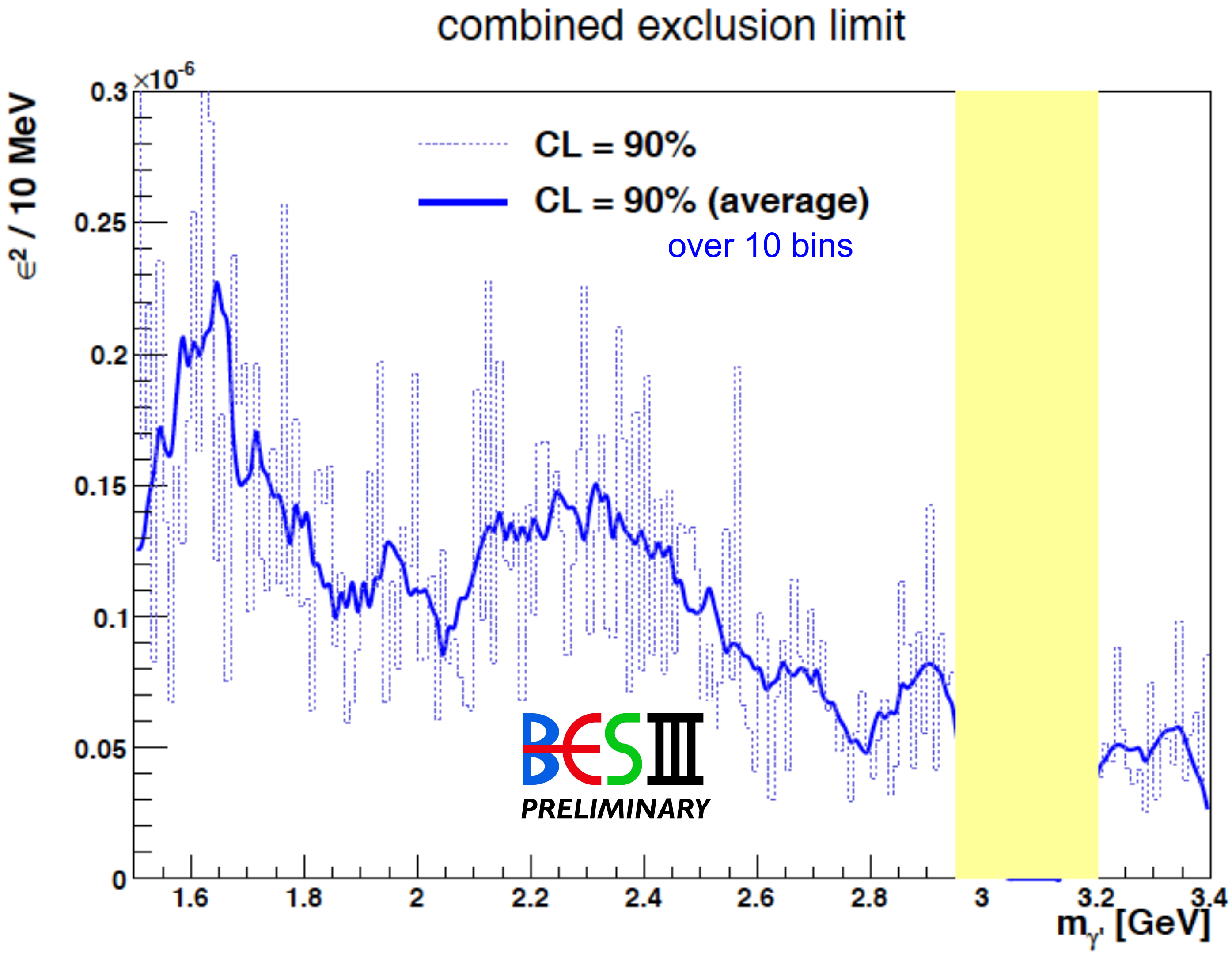
Result



$$N_f^{combined} = \frac{\Gamma_{tot}}{\Gamma(\gamma' \to e^+e^-) + \Gamma(\gamma' \to \mu^+\mu^-)}$$