BESIII Experiment Results Beyond the Standard Model

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On behalf of the BESIII collaboration

Workshop: A taste of flavour physics

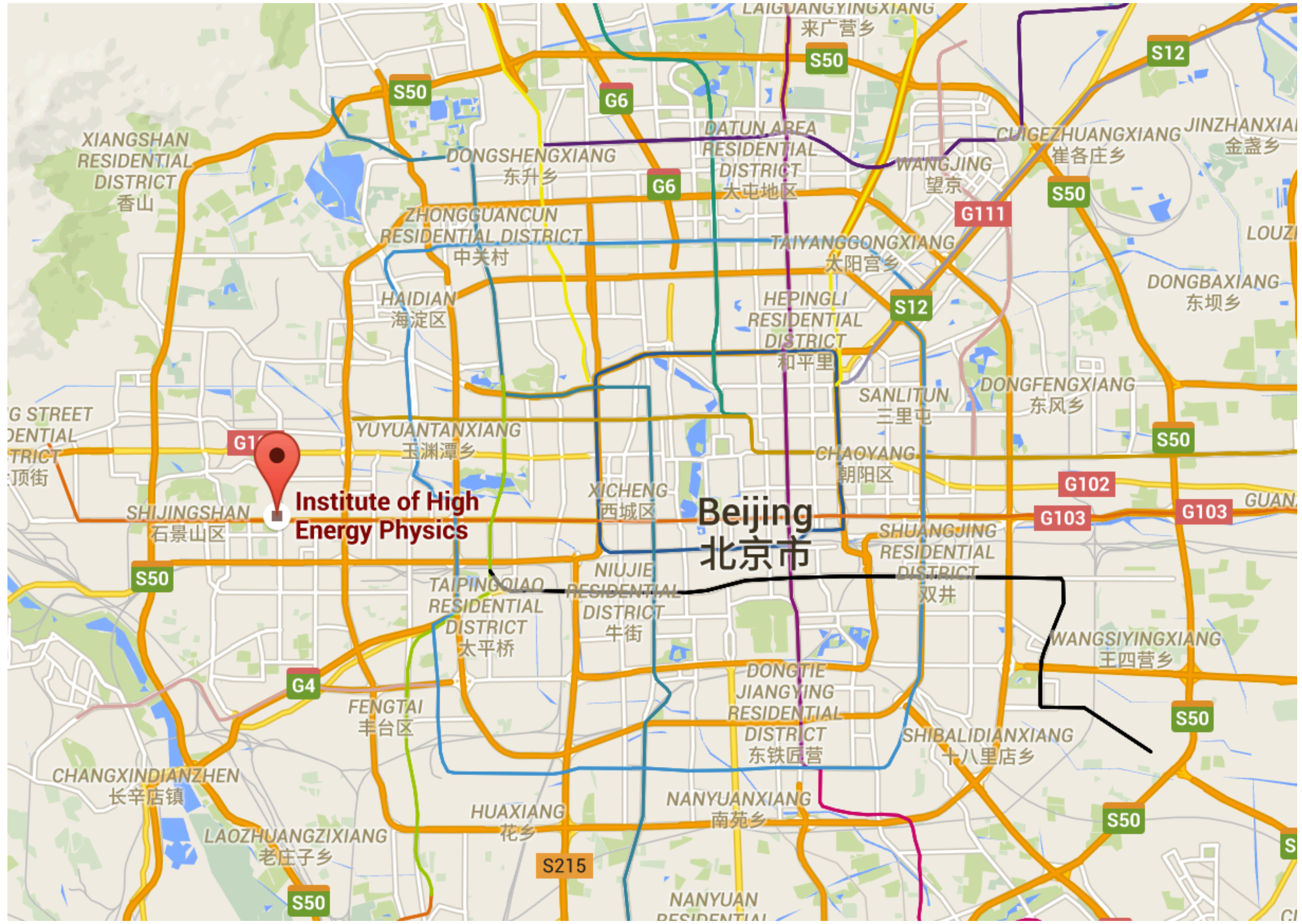
1st March 2016

BESIII

INFN Istituto Nazionale di Fisica Nucleare

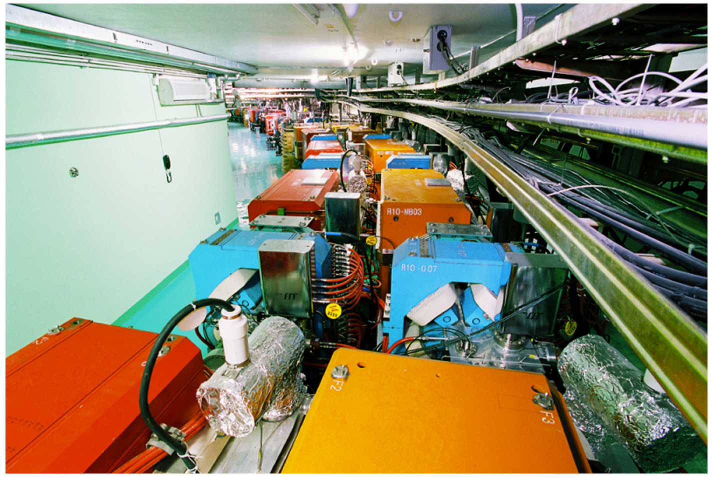
UNIVERSITÀ DEGLI STUDI DI TORINO

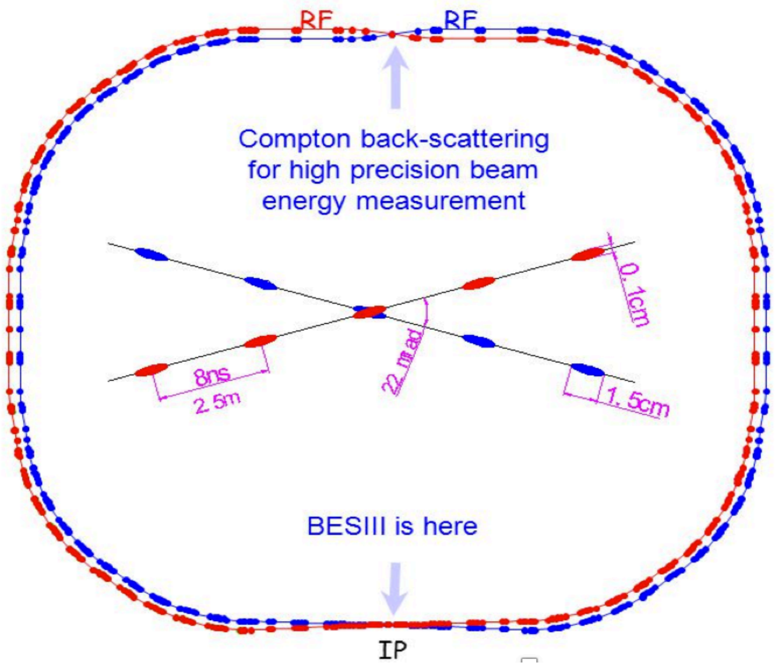
BEPC && BESIII

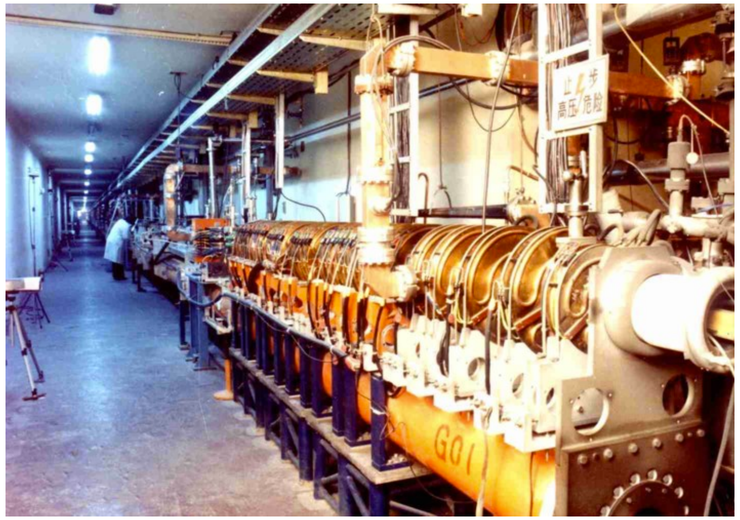


It will take less than 30 mins from the Forbidden City to IHEP by subway.

BECPCII storage rings: a τ-charm factory



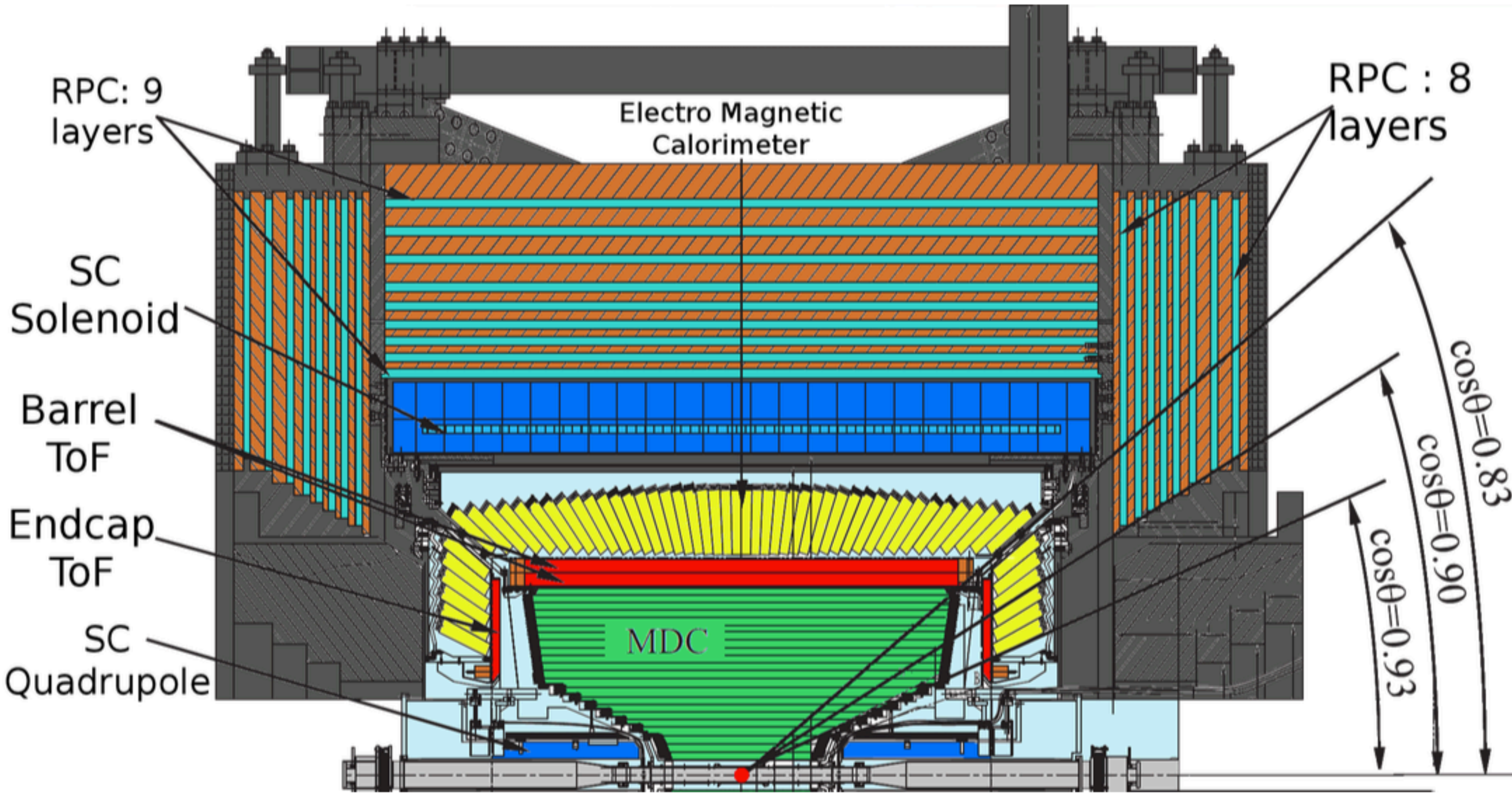




Update of BEPC (started 2004, first collisions July 2008)

Beam energy	1 - 2.3 GeV
Optimum energy	1.89 GeV
Single beam current	0.91 A
Crossing angle	11mrad
Design luminosity	10^{33} cm^{-2} s^{-1}
Achieved	8×10^{32} cm^{-2} s^{-1}

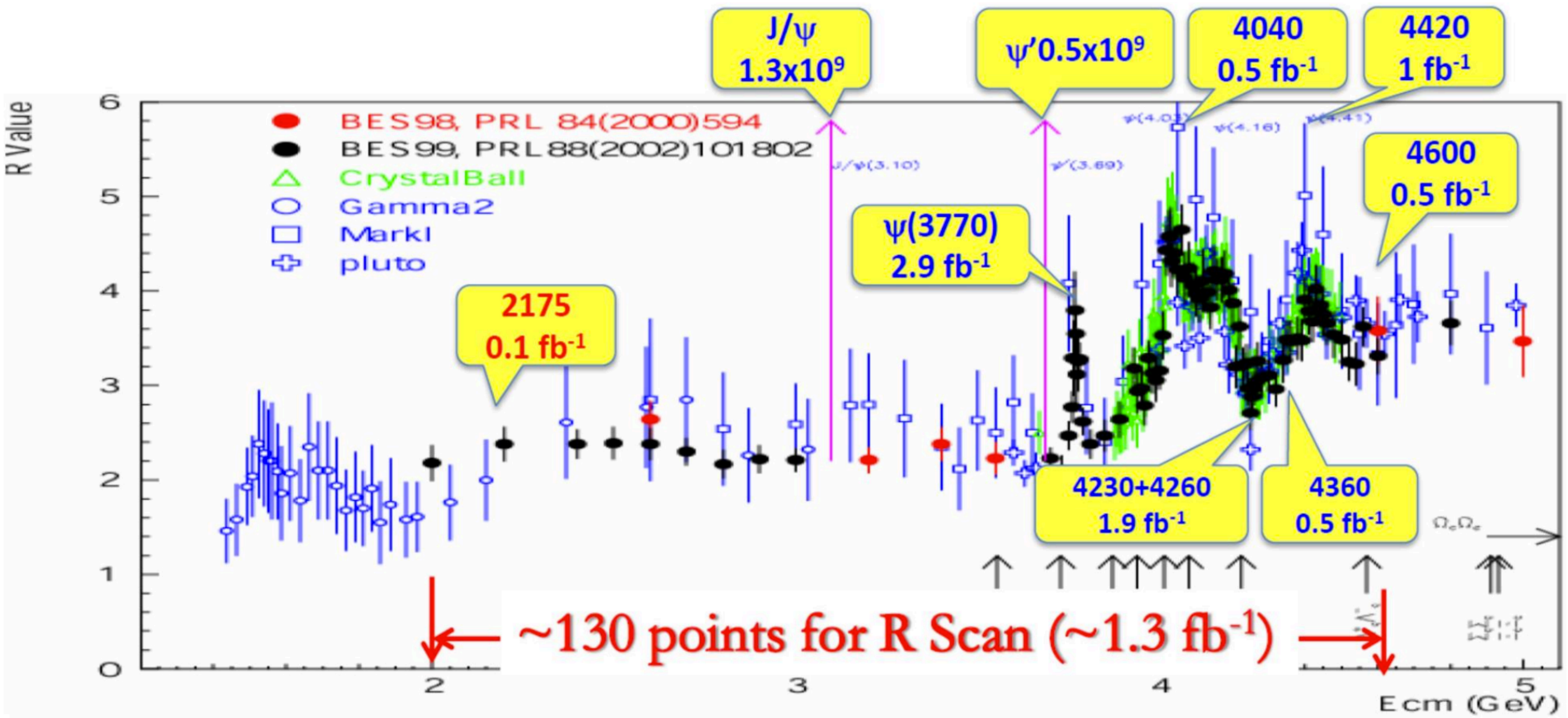
BESIII detectors

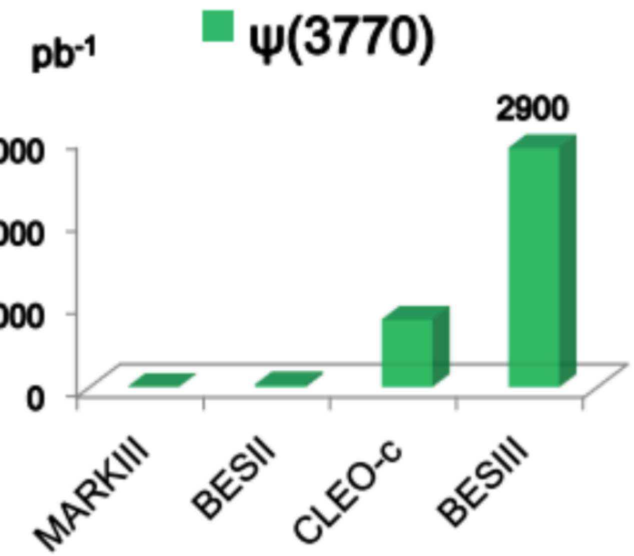


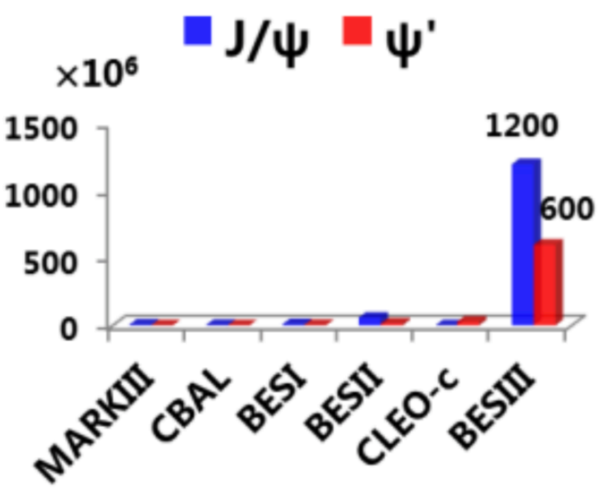
Expt.	MDC Wire resolution	MDC dE/dx resolution	EMC Energy resolution
CLEO	110 μm	5%	2.2 – 2.4%
BABAR	125 μm	7%	2.67%
Belle	130 μm	5.6%	2.2%
BESIII	115 μm	$<$ 5%	2.3%

Expt.	TOF time resolution
CDF	100 ps
Belle	90 ps
BESIII	68 ps (Barrel) 100 ps (ETOF)

BESIII data set

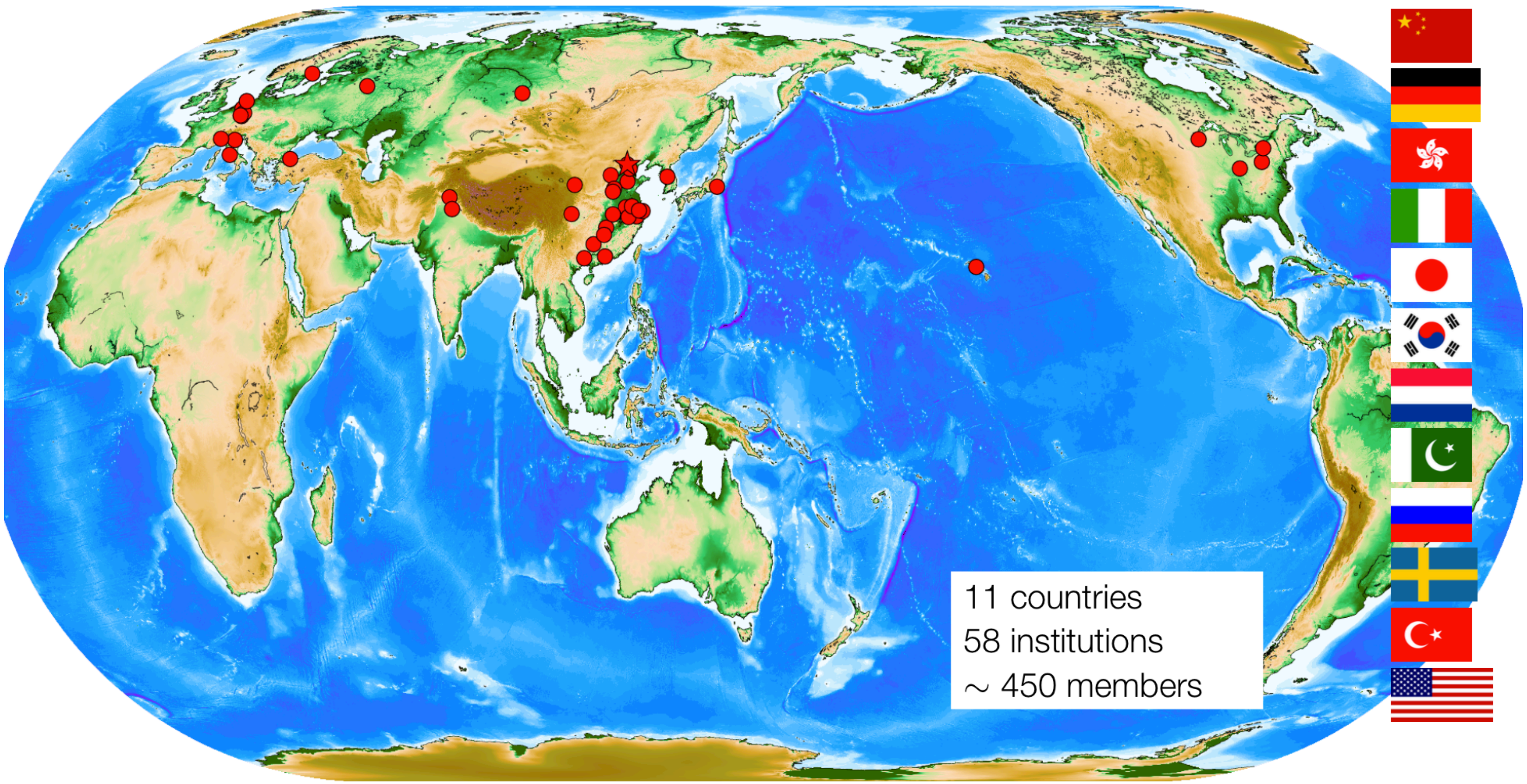






- ✓ World largest data sample on J/ψ, ψ' ψ(3770), Y(4260)… in e^+e^- collisions
- ✓ From light mesons spectroscopy to $\Lambda_c\Lambda_c$
- ✓ Also ISR, photon-photon physics, τ physics…

BESIII collaboration

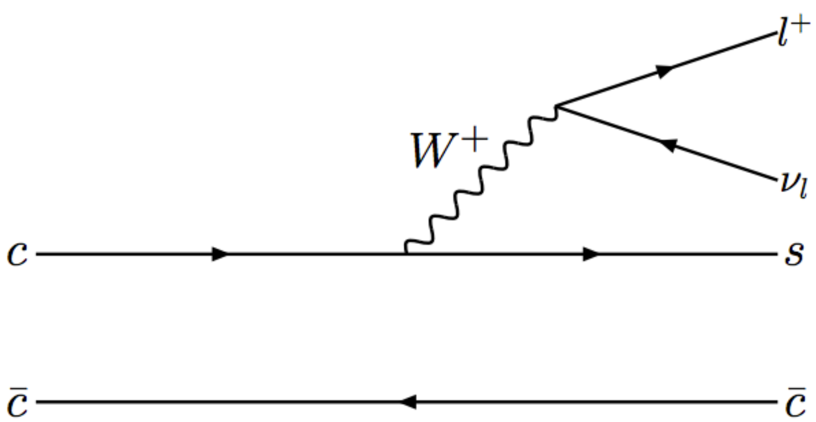


Physics programme in BSM

- Rare decays in J/ψ and ψ';
- Rare and forbidden charm decays;
- Dark matter searching(visible && invisible decays).

Semileptonic decays of charmounium

$$J/\psi \to D_s^{(*)-} e^+ \nu_e + c.c.$$

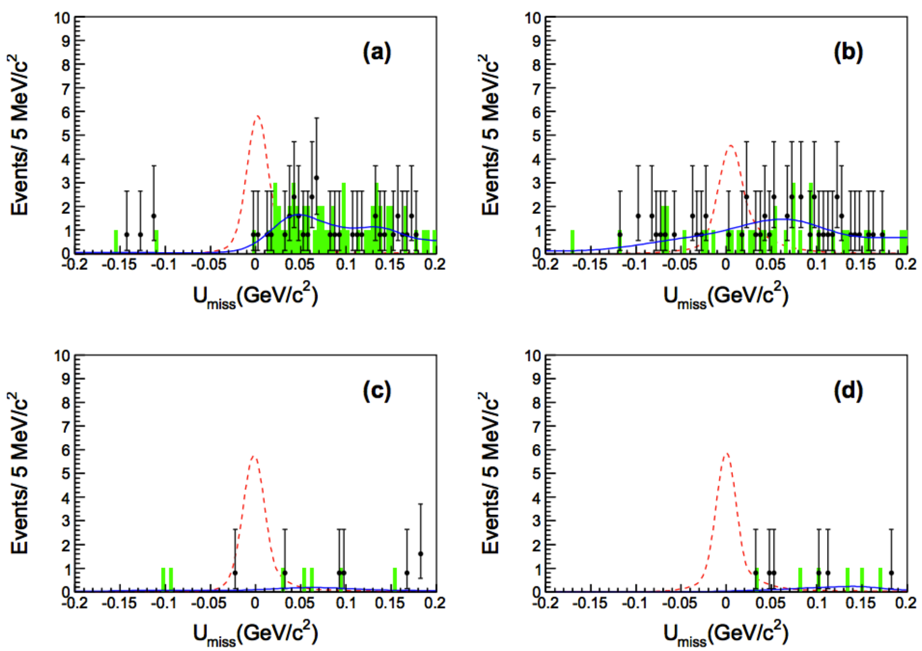


$$D_s^- \to K^+ K^- \pi^-$$
$$D_s^- \to K^+ K^- \pi^- \pi^0$$
$$D_s^- \to K_S^0 K^-$$
$$D_s^- \to K_S^0 K^+ \pi^- \pi^-$$

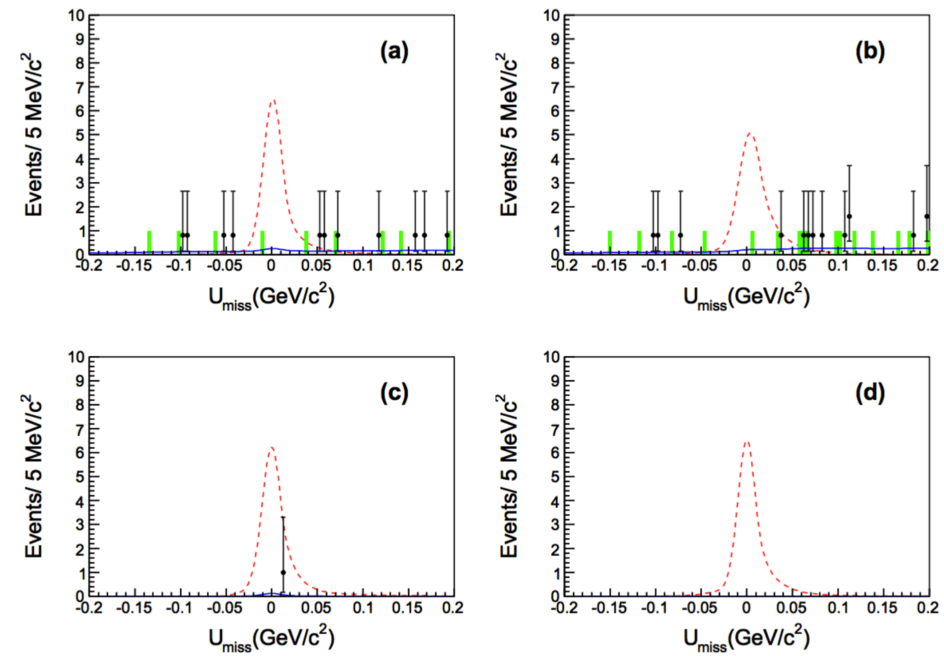
Weak decays of the J/ψ are rare processes, and the inclusive branching fractions of J/ψ decays to single D or D_s mesons are predicted to be of the order of 10^{-8} or less in the Standard Model.
However, it could be enhanced when new interaction couplings are considered, such as in the top-color models, the minimal super-symmetric SM with R-parity violation, or the two-Higgs-doublet model.

BESIII [Phys. Rev. D 90, 112014 (2014)]

Semileptonic decays of charmonium



$U_{\rm miss}$ distributions for $J/\psi \to D_s^- e^+ \nu_e$



$U_{\rm miss}$ distributions for $J/\psi \to D_s^{*-} e^+ \nu_e$

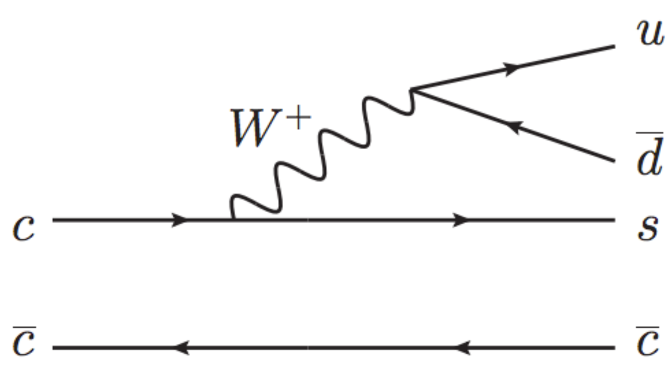
$\mathcal{B}(J/\psi \to D_s^- e^+ \nu_e + c.c.) < 1.3 \times 10^{-6}$ $\mathcal{B}(J/\psi \to D_s^{*-} e^+ \nu_e + c.c.) < 1.8 \times 10^{-6}$

The results are within the SM prediction, but more data will be helpful to test the branching fraction of semileptonic decays of J/ψ to the order of 10^{-8}.

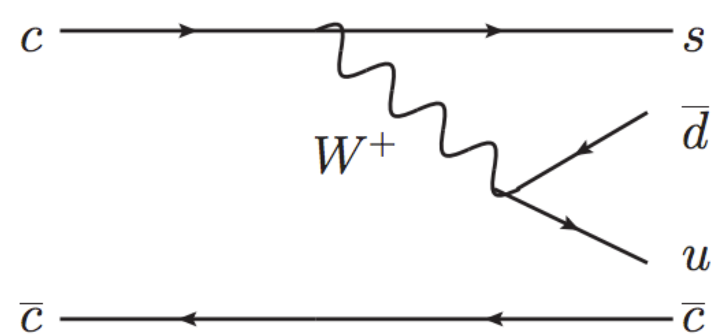
Two-body weak hadronic decays of charmonium

BESIII[Phys. Rev. D 89, 071101(R)(2014)]

$$J/\psi \to D_s^- \rho^+$$



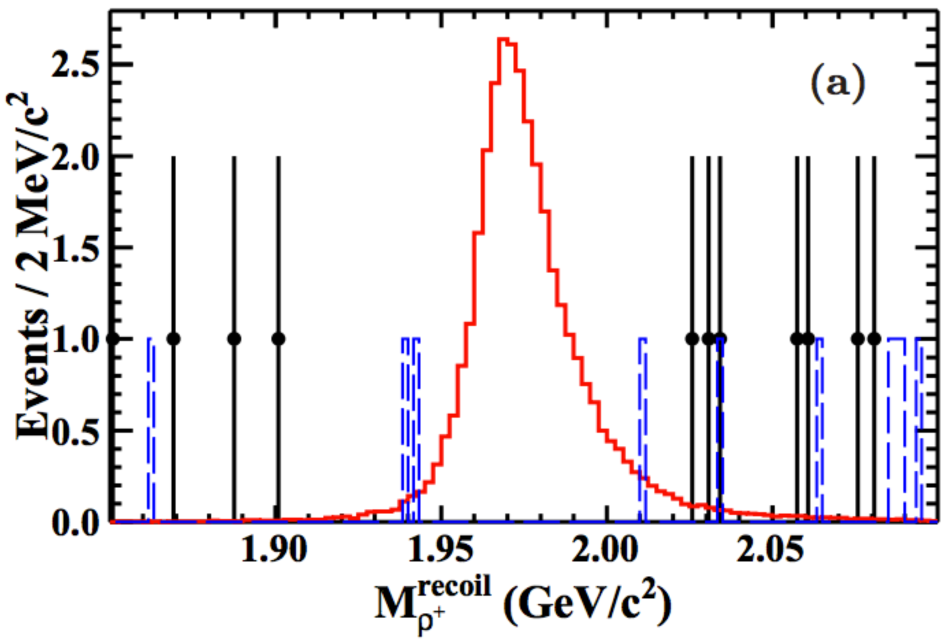
$$J/\psi \to \overline{D}^0 \overline{K}^{*0}$$



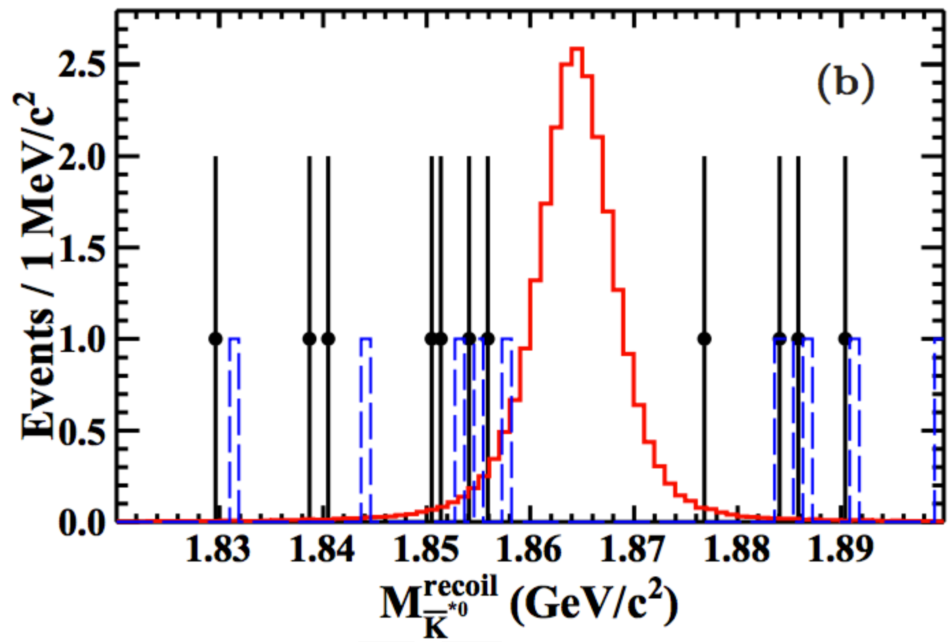
In order to avoid large background of contamination from conventional J/ψ hadronic decays, the $D_{(s)}$ mesons are identified by their semileptonic decays:

$$D_s^- \to \phi e^- \overline{\nu}_e \qquad \overline{D}^0 \to K^+ e^- \overline{\nu}_e$$

Two-body weak hadronic decays of charmonium



$$\mathcal{B}(J/\psi \to D_s^- \rho^+) < 1.3 \times 10^{-5}$$



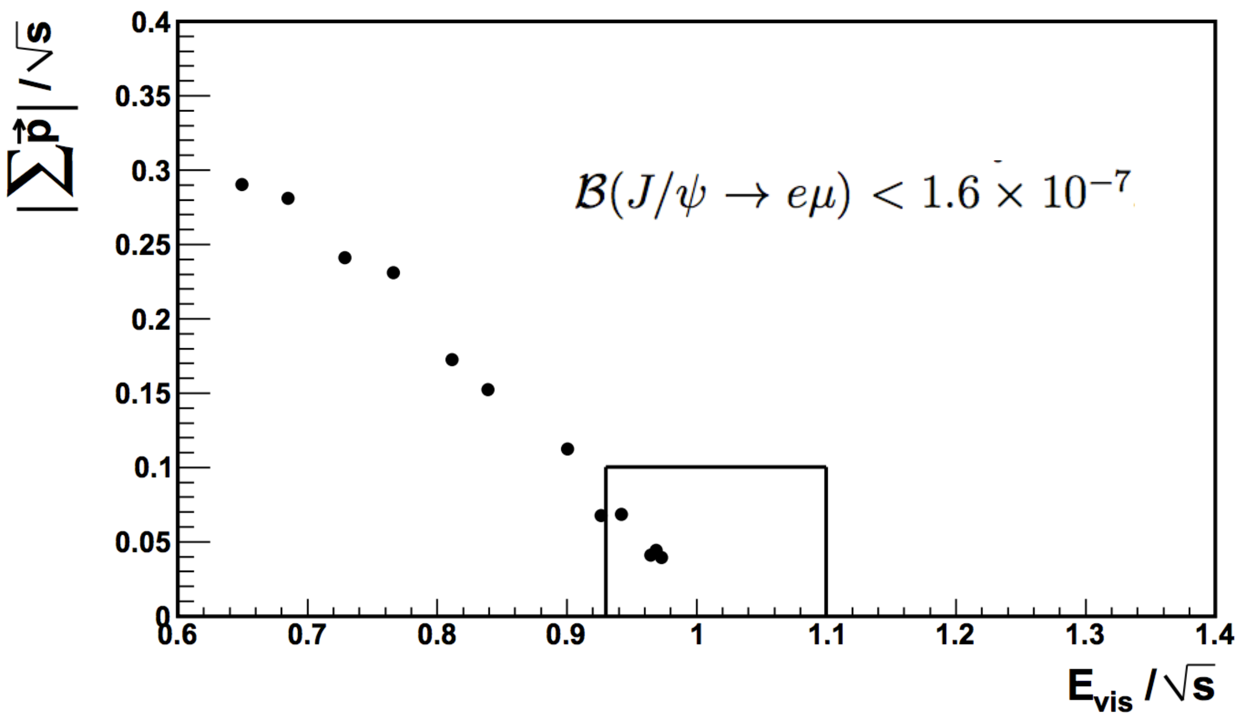
$$\mathcal{B}(J/\psi \to \overline{D}^0 \overline{K}^{*0}) < 2.5 \times 10^{-6}$$

These upper limit exclude new physics predictions which allow flavour-changing processes to occur with branching fractions around 10^{-5}, but are still consistent with the predictions of the SM.

Lepton Flavour Violation

$$J/\psi \to e^{\pm}\mu^{\mp}$$

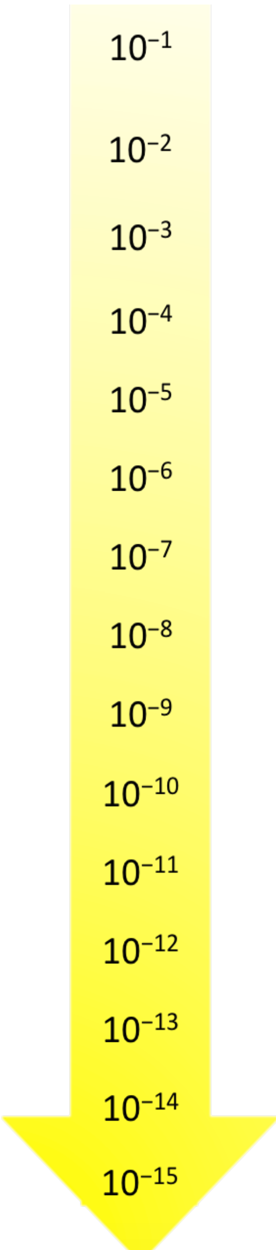
BESIII[Phys. Rev. D 87, 112007 (2013)]



4 candidate events remain in our signal region, and the number of estimated background is 4.75±1.09

With finite neutrino masses included, the SM allows for LFV. Yet the smallness of these masses of leads to a very large suppression, with predicted branching fractions well beyond current experimental sensitivity. The detection of a LFV decay well above SM expectations would be distinctive evidence for new physics

Reaches for rare/forbidden charm decays



Cabibbo favored

Singly Cabibbo suppressed

Doubly Cabibbo suppressed

Radiative decays $D^0 \to \overline{K}^{*0}\gamma / \phi\gamma / \rho\gamma / \omega\gamma$

Long distance: Vector meson Dominance

$$D^0 \to \gamma\gamma / VV'(\to ll) / hV(\to ll) / hh'V(\to ll)$$

Short distance FCNC

$$D^0 / D^+ \to \gamma\gamma / Vl^+l^- / hl^+l^- / hh'l^+l^-$$

$$D^0 \to \mu^+\mu^-$$

$$D^0 \to e^+e^-$$

Forbidden decays: LNV, LFV, BNV

$$D \to (h)\mu^+e^-$$

$$D \to (hh)e^+e^+ / (hh)\mu^+\mu^+$$

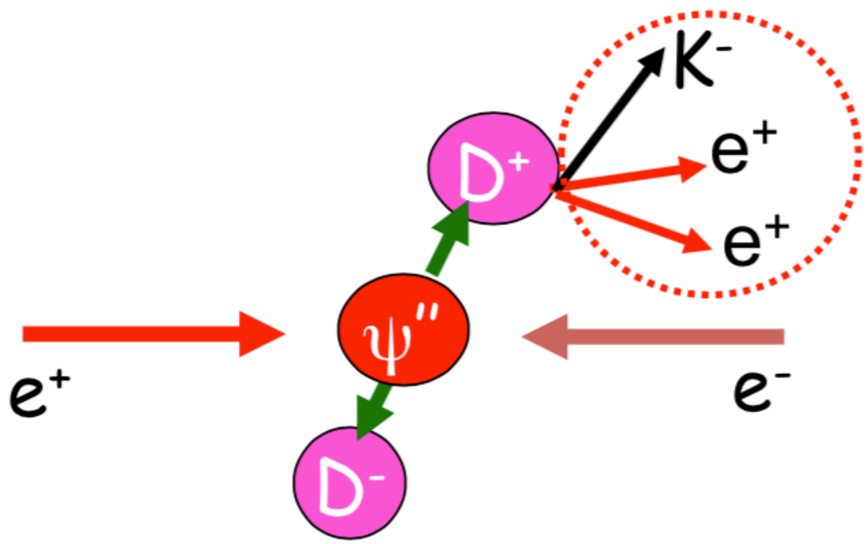
Experimental Reaches

CLEO-c
BESIII
BESIII final/B factory

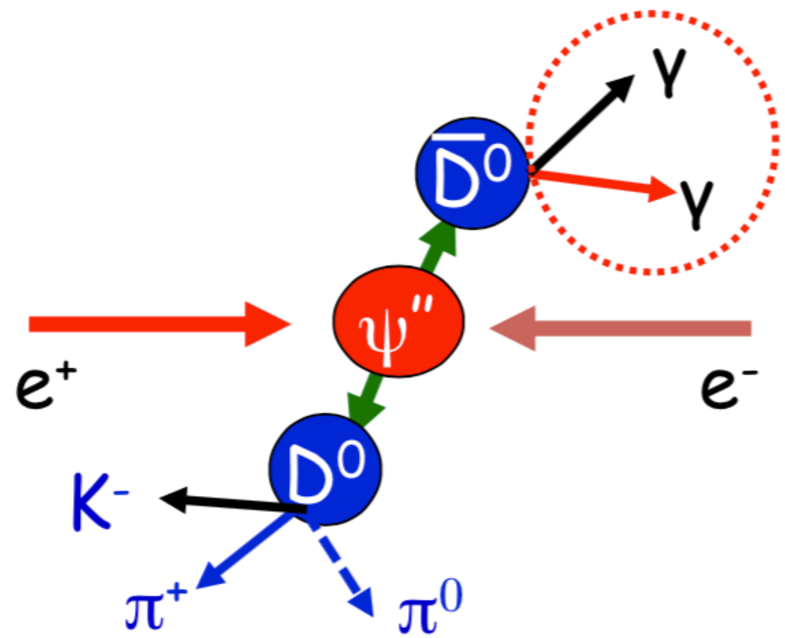
LHCB
Super-B
Super-τ-charm

Two D tag methods in BESIII

Single tag

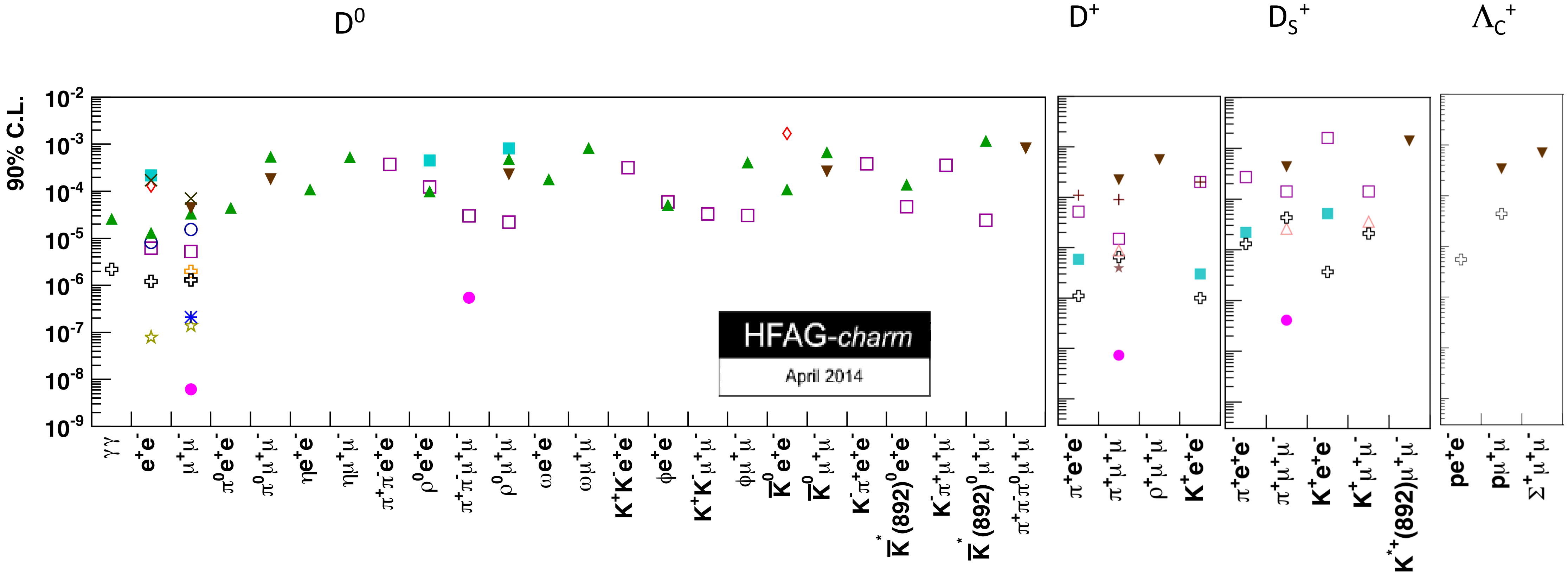


Double tag



Statistic (D^+)	1.7×10^7	1.6×10^6
Statistic (D^0)	2.1×10^6	2.8×10^5

Search for rare decays



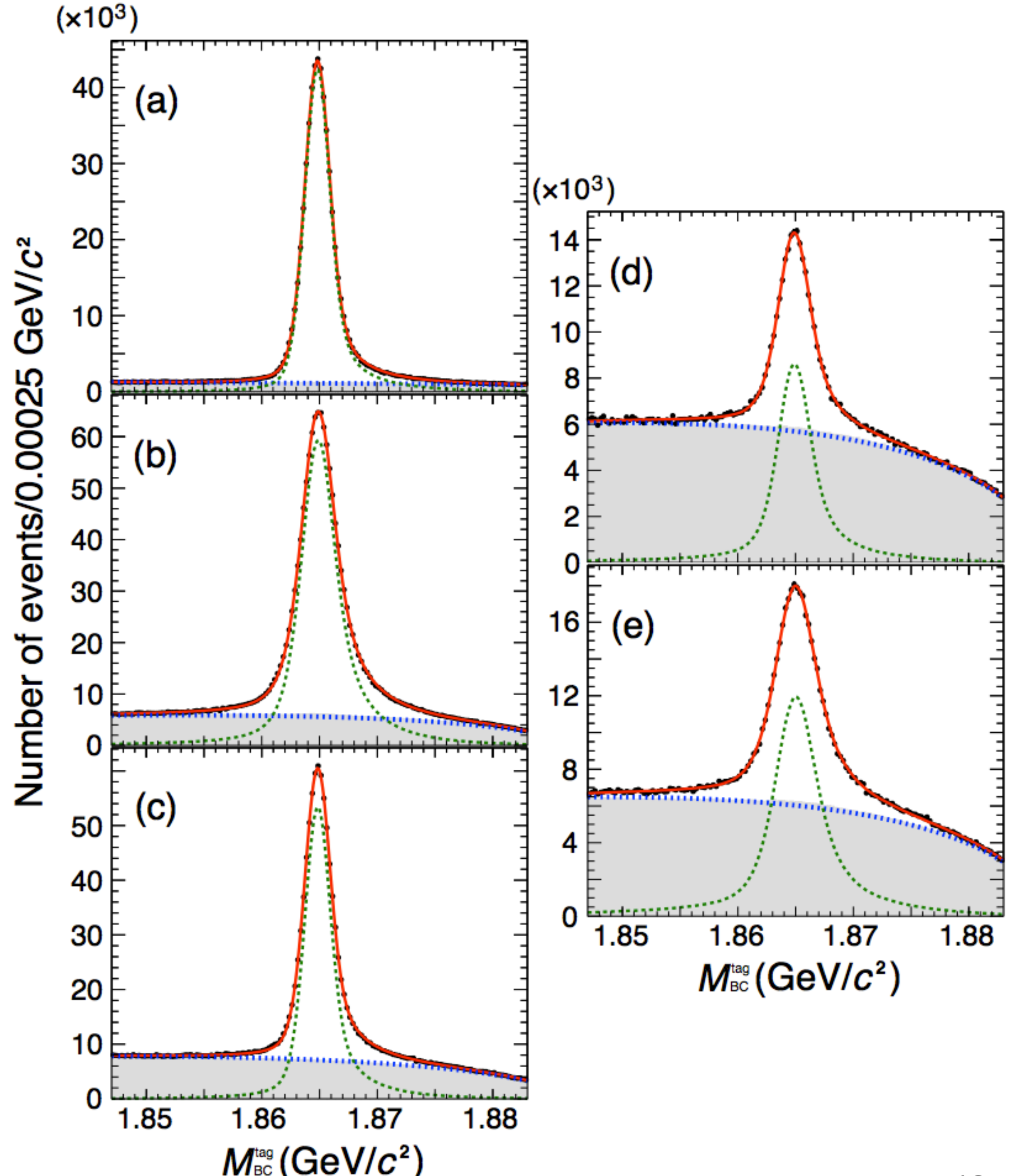
- ✓ Experiments contributed to the FCNC searches:
  Argus, E653, E687, E789, E791, Focus, Mark3, D0, BES, BESII, CLEO, CLEOII, BaBar, Belle, LHCb
- ✓ very few limits below 10^{-6}
- ✓ BESIII could contribute new results in these decay channels

$D^0 \to \gamma\gamma$

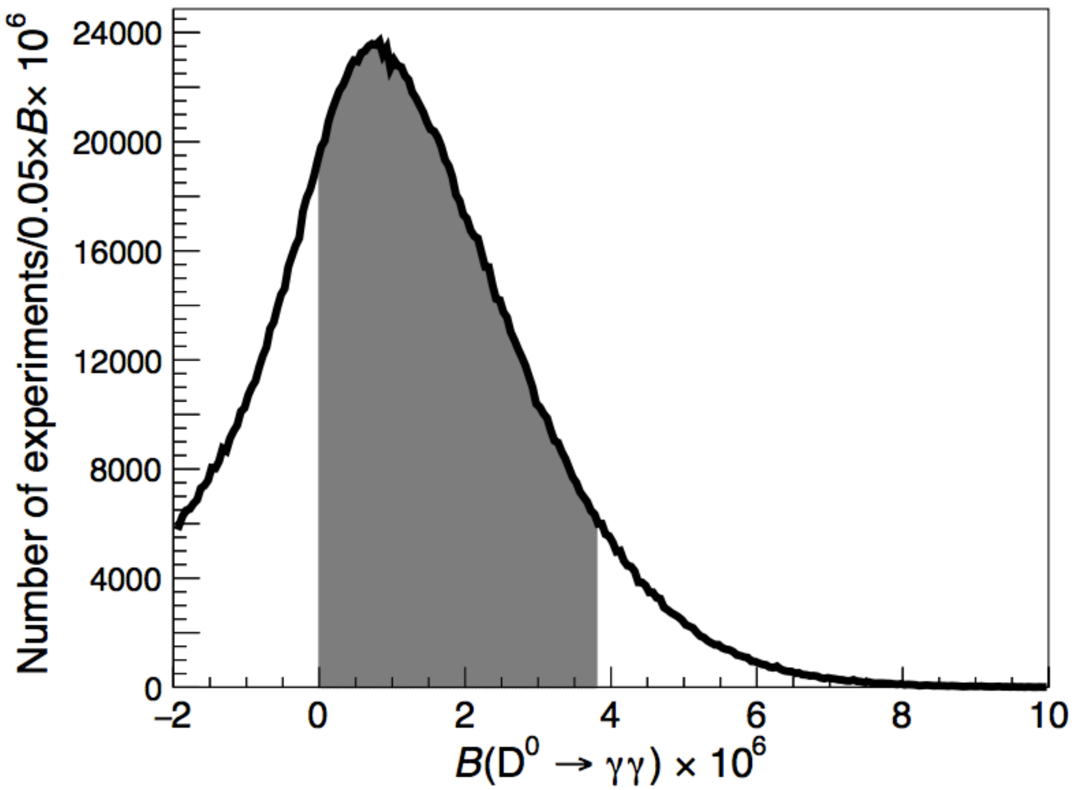
In the SM, dominated by long distance ~10^{-8}
(G. Burdman et al. PRD 66,014009 (2002)
Could be enhanced to 10^{-6} by MSSM
(S. Prelosev and D. Wyler, PLB 500, 304 (2001)

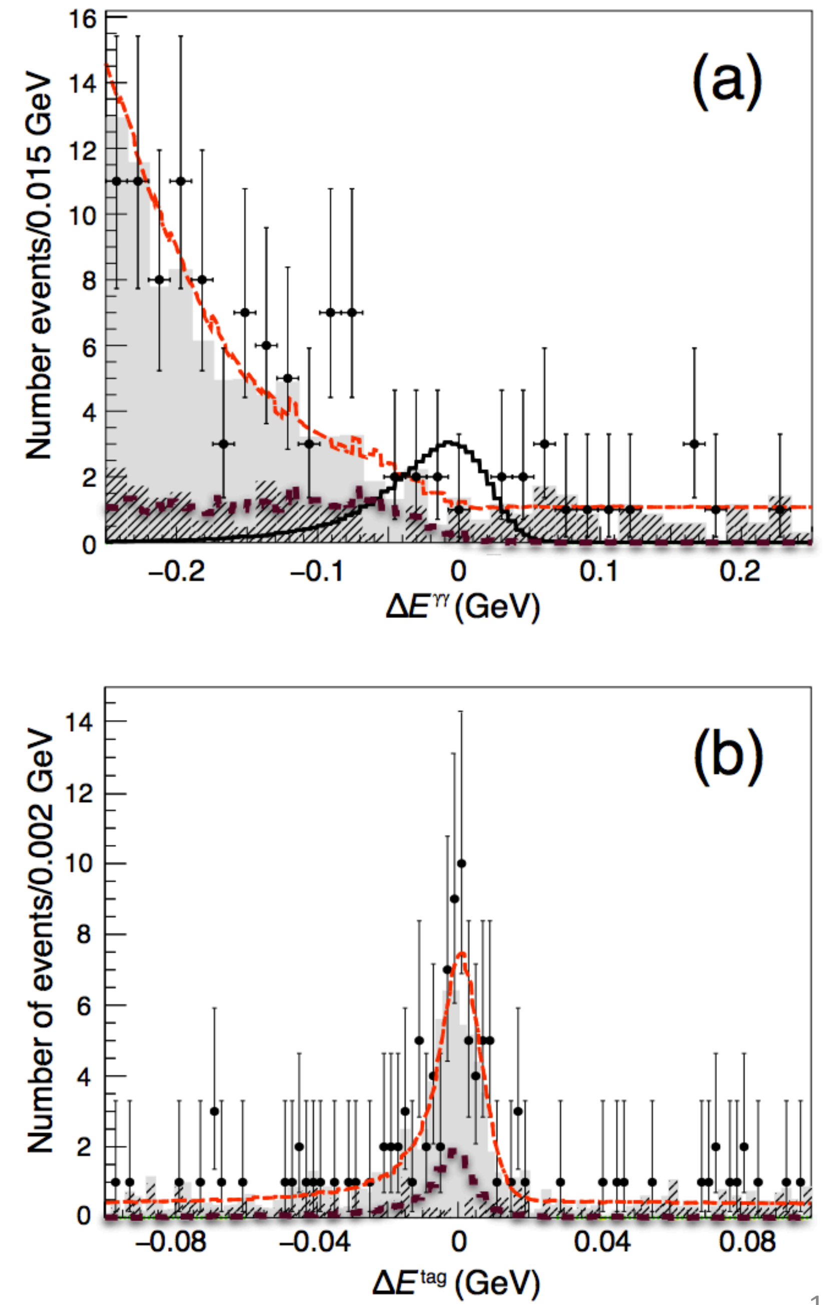
modes	$\epsilon^i_{\rm tag}$ (%)	$N^i_{\rm tag}$	$\epsilon^i_{{\rm tag},\gamma\gamma}$ (%)
$K^+\pi^-$	66.12 ± 0.04	551800 ± 936	44.8 ± 0.4
$K^+\pi^-\pi^0$	35.06 ± 0.02	1097113 ± 1386	24.5 ± 0.1
$K^+\pi^-\pi^+\pi^-$	39.70 ± 0.03	734825 ± 1170	24.7 ± 0.2
$K^+\pi^-\pi^+\pi^-\pi^0$	15.32 ± 0.04	155899 ± 872	9.6 ± 0.1
$K^+\pi^-\pi^0\pi^0$	15.23 ± 0.04	268832 ± 976	8.9 ± 0.1
All Tags		2808469 ± 2425	

BESIII [Phys. Rev. D 91, 112015 (2015)]



$D^0 \to \gamma\gamma$

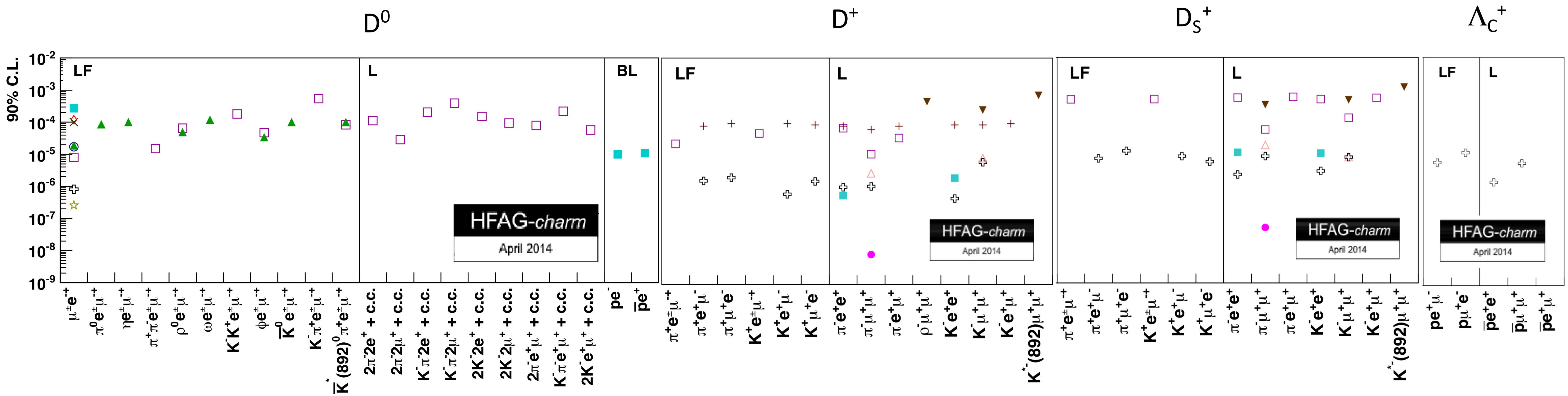




$$\mathcal{B}(D^0 \to \gamma\gamma) < 3.8 \times 10^{-6}$$

which is consistent with the upper limit previously set by the BABAR Collaboration and with the SM prediction.

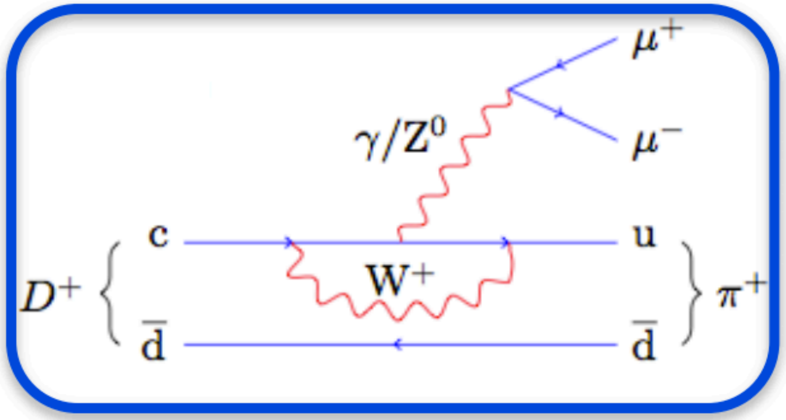
Search for LFV, LNV, BNV

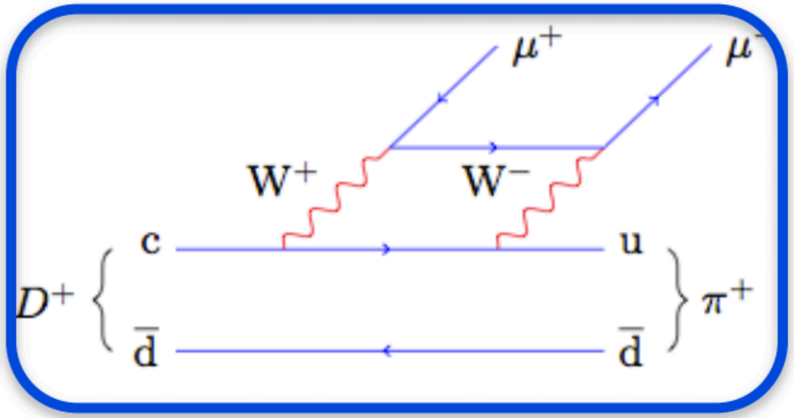


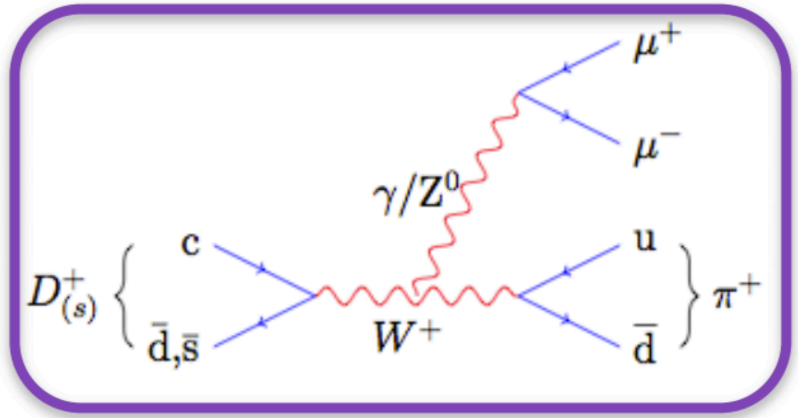
Based on the BESIII data, the upper limit will reach around 10^{-6}.

$D^+ \to h^{+/-} e^+ e^{-/+}$

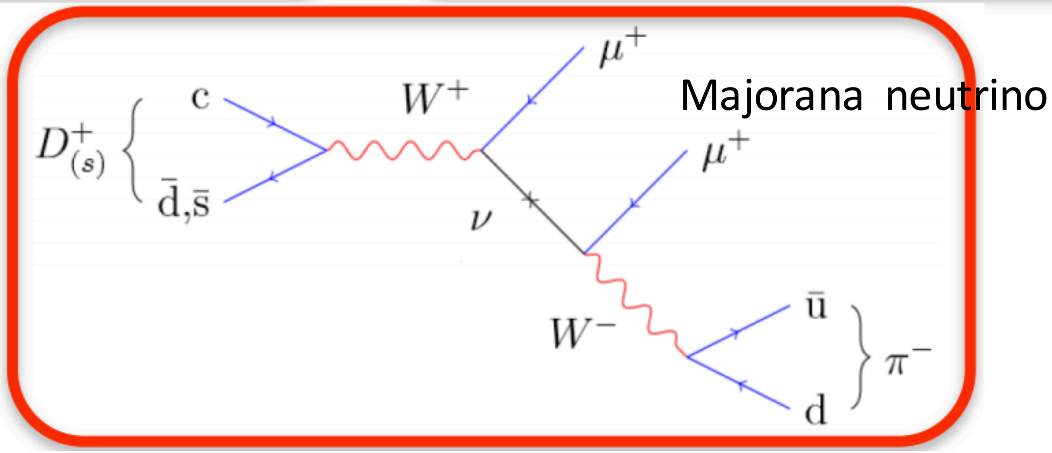
FCNC: $c \to u\, \mu^+\mu^-$ highly suppressed in SM by GIM mechanism BF ~ 10^{-9} [PRD 64, 114009 (2001)]





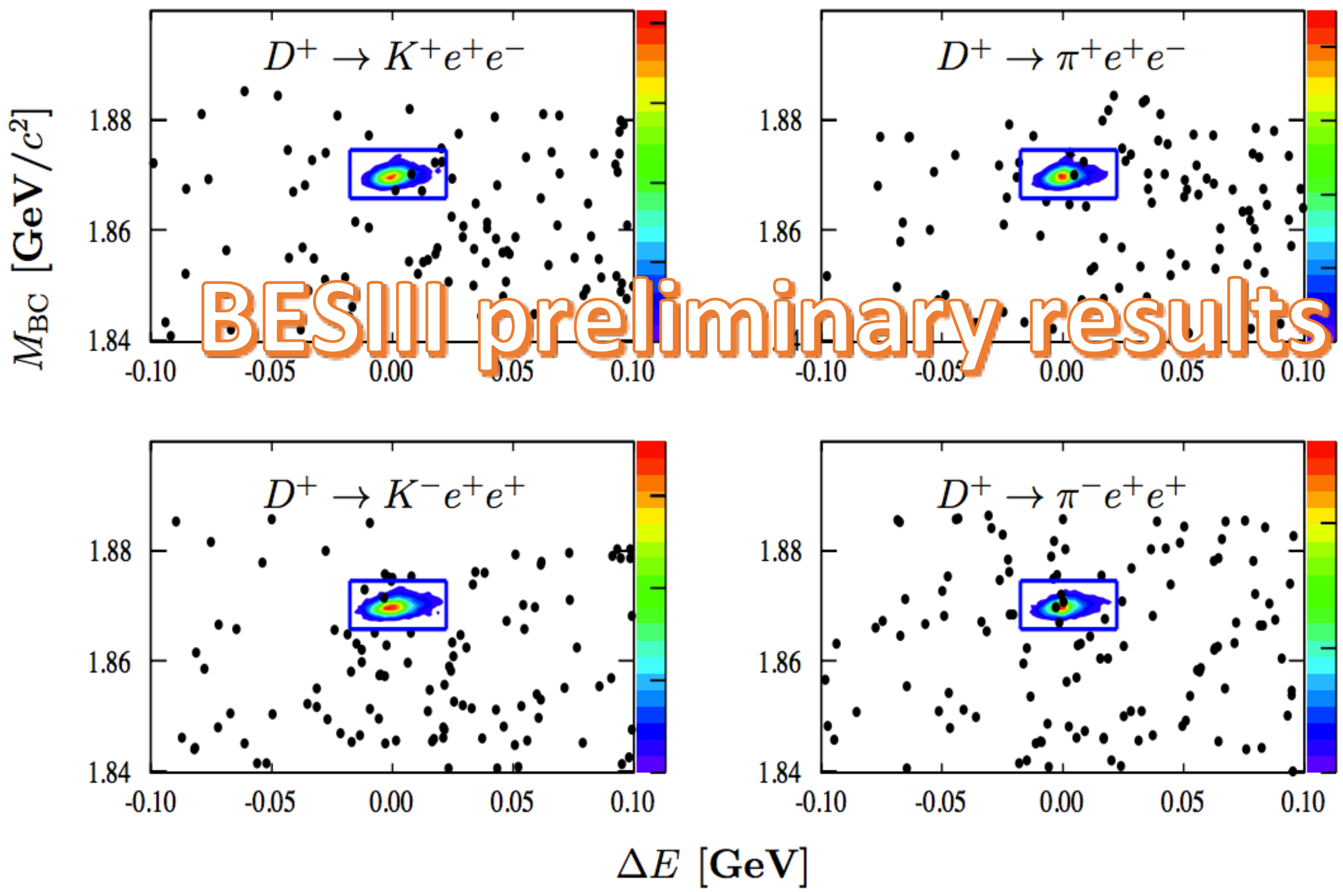


LNV: $c \to u\, \mu^+\mu^+$ forbidden is SM ~$10^{-23\text{-}30}$



Any observation of definite signals would be clear evidence for new physics.

D^+ -> $h^{+/-}$ e^+ $e^{-/+}$ with single tag method



Scatter plots for M_{BC} versus ΔE, where the signal regions are shown as a blue rectangle. The contours are determined from MC simulation to enclose 84% of signal events for each channel

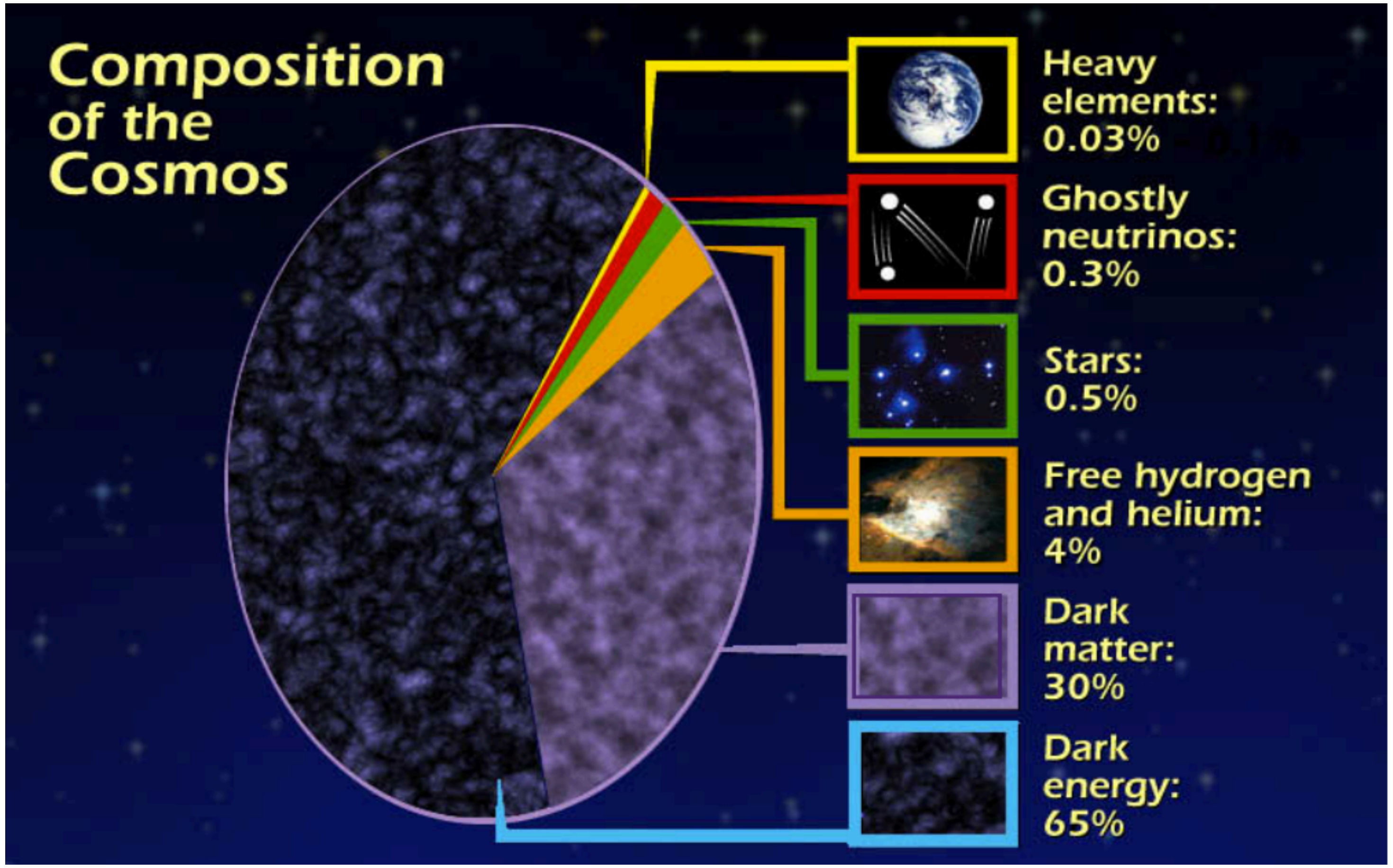
D^+ -> $h^{+/-}$ e^+ $e^{-/+}$ with single tag method

	$N^{\text{data}}_{\text{inside}}$	$N^{\text{data}}_{\text{outside}}$	f_{scale}	ϵ [%]	Δ_{sys} [%]	s_{90}	$\mathcal{B}[\times 10^{-6}]$
$D^+ \to K^+ e^+ e^-$	5	69	0.08 ± 0.01	22.53	5.4	19.4	< 1.2
$D^+ \to K^- e^+ e^+$	3	55	0.08 ± 0.01	24.08	6.1	10.2	< 0.6
$D^+ \to \pi^+ e^+ e^-$	3	65	0.09 ± 0.02	25.72	5.9	4.2	< 0.3
$D^+ \to \pi^- e^+ e^+$	5	68	0.06 ± 0.02	28.08	6.8	20.5	< 1.2

Where s_{90} is estimated with a profile likelihood method, TORLKE program [NIM, A551(2005) 493], incorporating systematic uncertainties and detection efficiencies.

$\mathcal{B}(D^+ \to) \setminus [\times 10^{-6}]$	$K^+ e^+ e^-$	$K^- e^+ e^+$	$\pi^+ e^+ e^-$	$\pi^- e^+ e^+$
CLEO	3.0	3.5	5.9	1.1
Babar	1.0	0.9	1.1	1.9
PDG	1.0	0.9	1.1	1.1
This work	1.2	0.6	0.3	1.2

Search for Dark matter

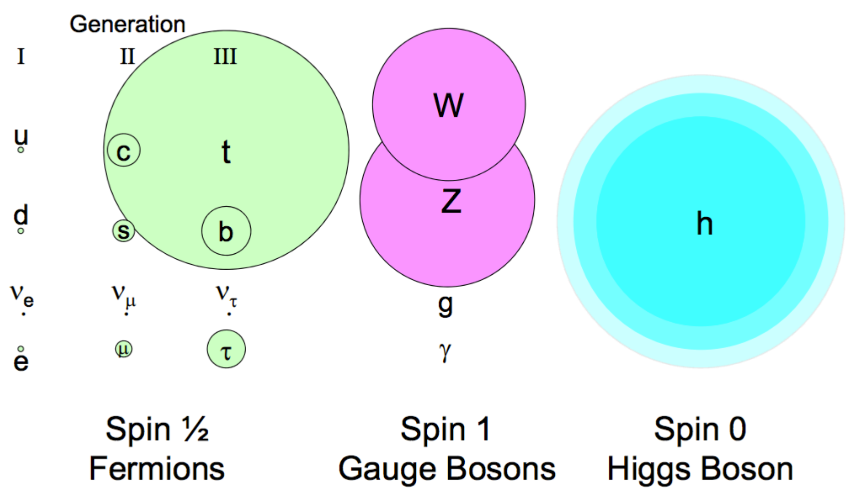


http://hubblesite.org/newscenter/archive/releases/

Many results from astrophysical and cosmology observation have confirmed the existence of dark matter

The particle nature of dark matter is still unknown.

A dizzying list of dark matter candidates



- WIMPs
- Axions
- Gravitinos
- Sterile neutrinos
- Hidden-sector dark matter

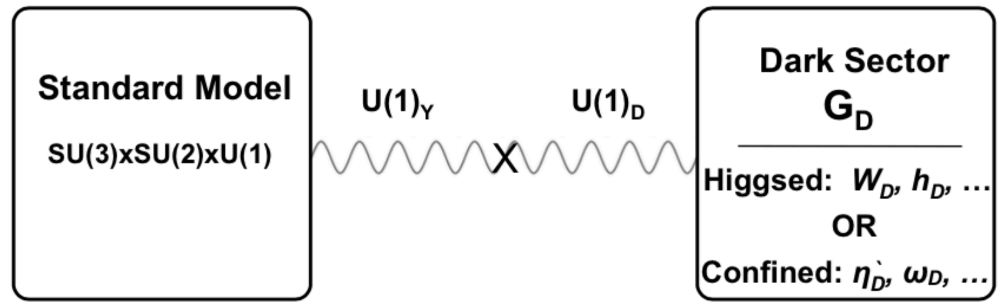
✓ None of these SM particles is a good dark matter candidate;

✓ Recent results from the LHC and direct detection experiments "challenge" the traditional WIMP Paradigm and motivate the exploration of new ideas.

Dark sector model

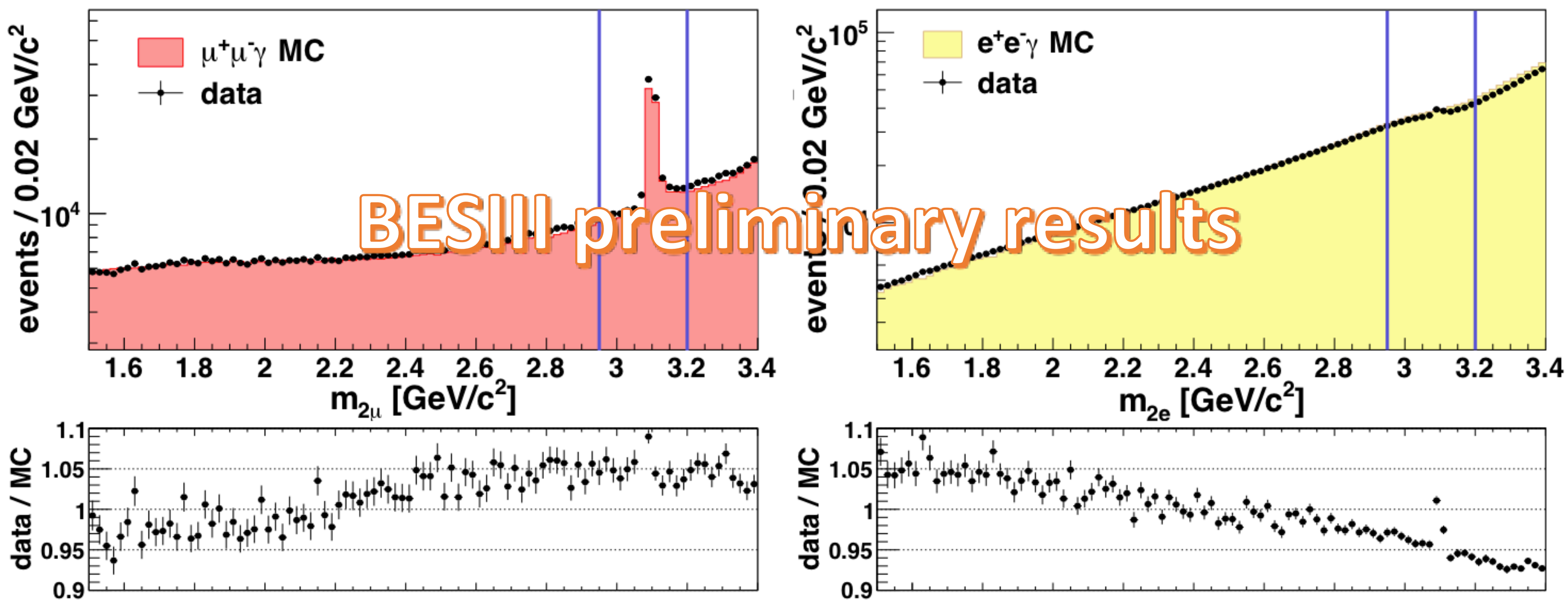
Sectors that have little communication with the Standard Model are called “hidden” or “dark” sectors.

- ✓ Dark sector with a U(1) extension of the Standard Model;
- ✓ Kinetic mixing between dark photon and photon with a mixing strength ε;
- ✓ Mixing strength typically ε~ 10^{-2}~10^{-5}, but could be smaller;
- ✓ Mass scale ~MeV- GeV.



$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$

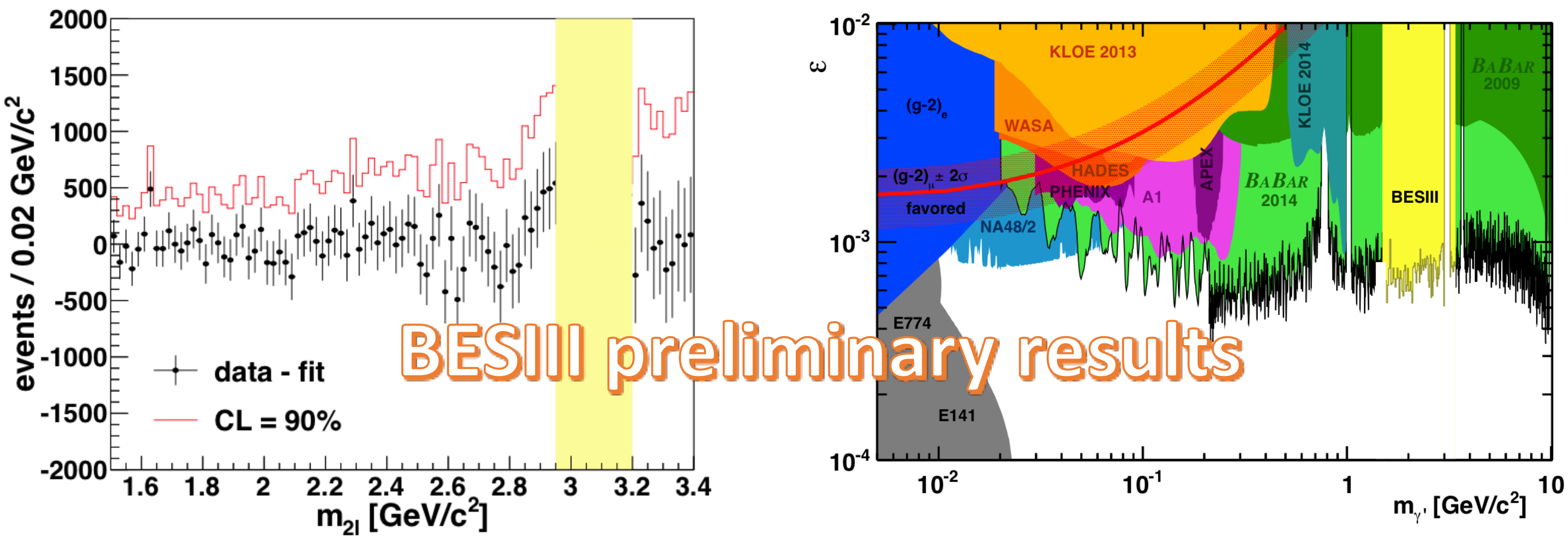
Dark photon Search in BESIII



2.93 fb^{-1} @ 3.773 GeV

Untagged method, for $e^+ e^- \to \gamma_{ISR}\ e^+ e^-$ or $\gamma_{ISR}\ \mu^+ \mu^-$

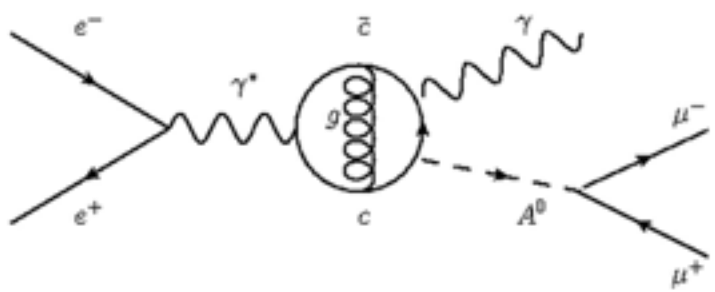
Dark photon Search in BESIII



We performed a dark photon search in the mass range between 1.5 and 3.4 GeV, where we do not observe a significant signal. We set upper limits on the mixing parameter ε between 10^{-3} and 10^{-4} as a function of the dark photon mass with a confidence level of 90%.

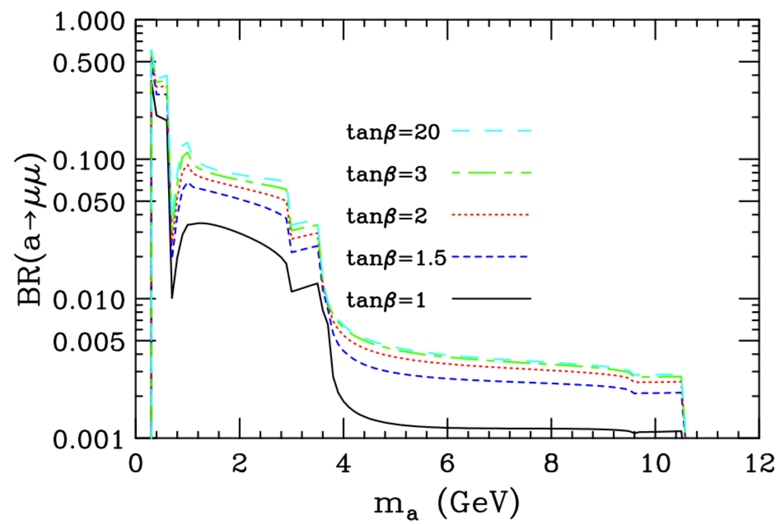
Search for a light CP-odd Higgs boson

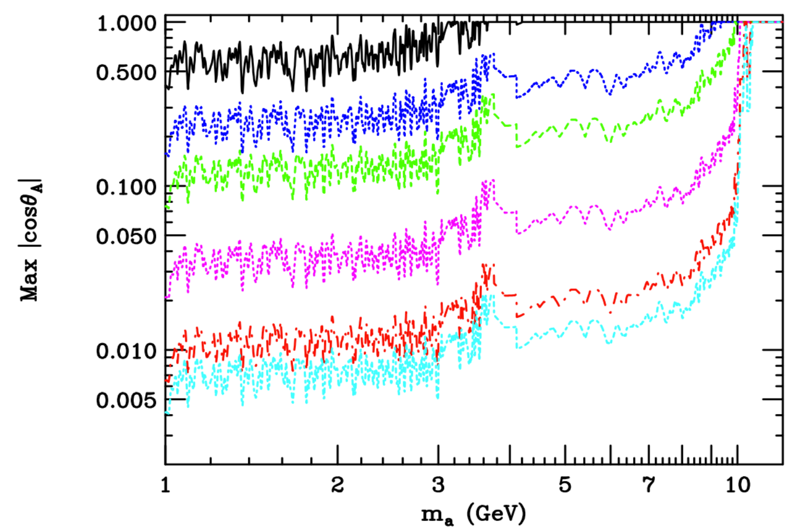
Next-to-Minimal Supersymmetric Standard Model (NMSSM), include a light Higgs boson. the NMSSM Higgs sector contains a total of three neutral CP-even, two neutral CP-odd, and two charged Higgs bosons.



$$\mathcal{L}_{int}^{\bar{f}f} = -X_f \frac{A^0}{v} m_f \bar{f}(i\gamma_5)f$$

The coupling of the A^0 field to up-type (down-type) fermion pairs is proportional to $\cos\theta_A \cot\beta$ ($\cos\theta_A \tan\beta$), where θ_A is the mixing angle between the singlet component and the MSSM component of the A^0, and $\tan\beta$ is the ratio of the vacuum expectation values of the up and down type Higgs doublets.

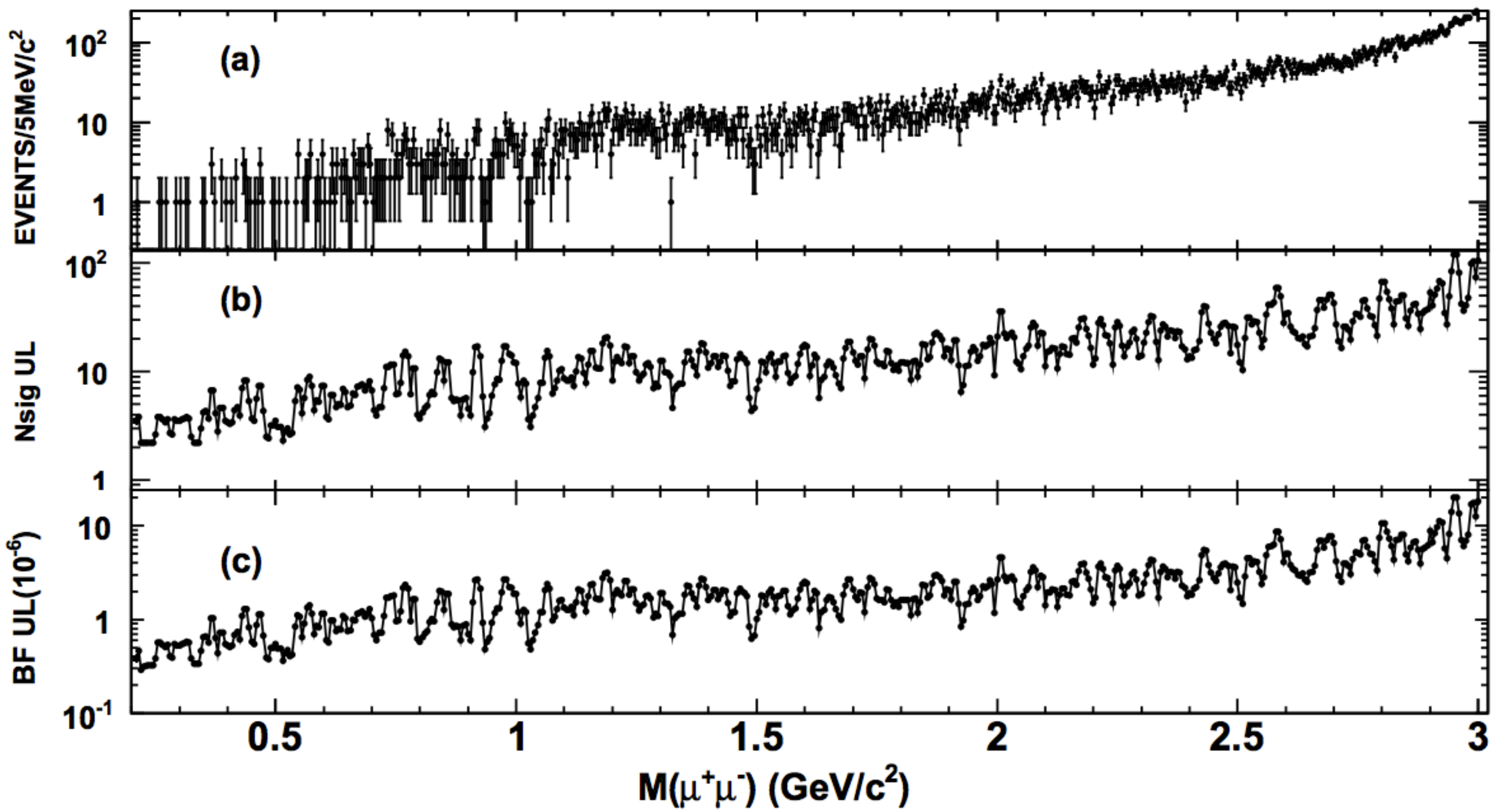




Reference :Phys. Rev. D 81, 075003 (2010)

Results with ψ' data

$\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to \gamma A^0$, $A^0 \to \mu^+\mu^-$



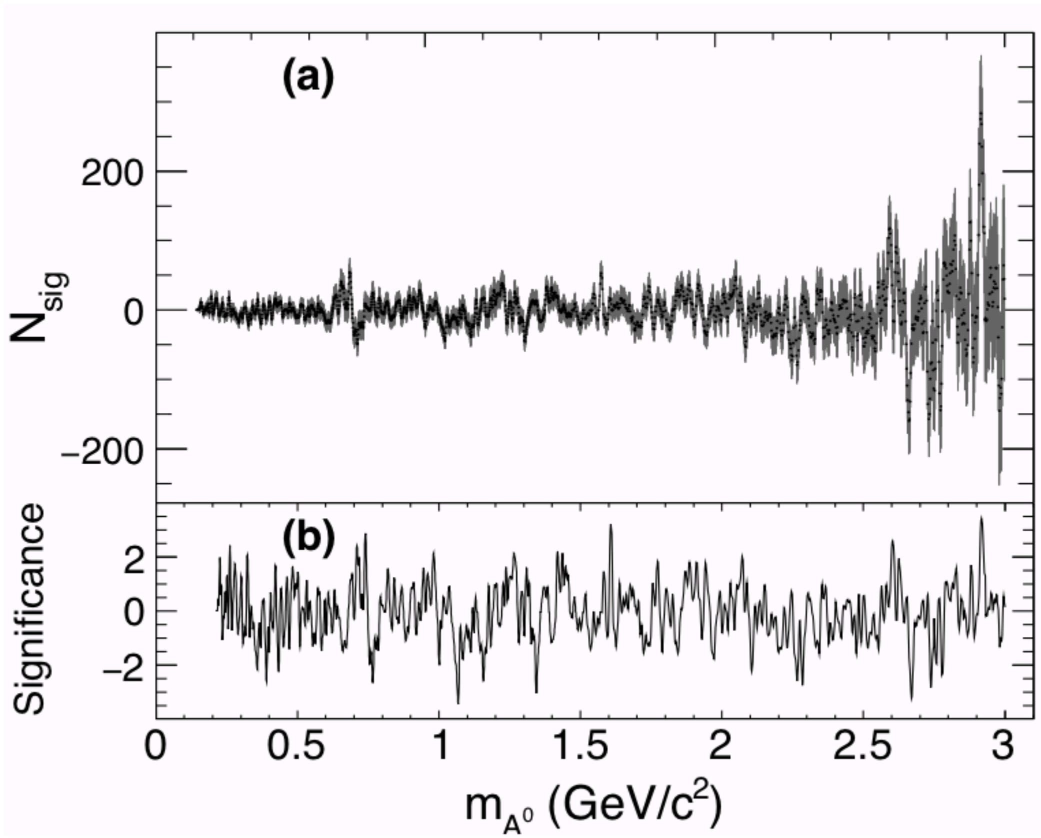
The branching fraction of $J/\psi \to \gamma A^0$ is expected to be around the 10^{-9} to 10^{-7} level. Phys. Rev. D 76, 051105 (2007)

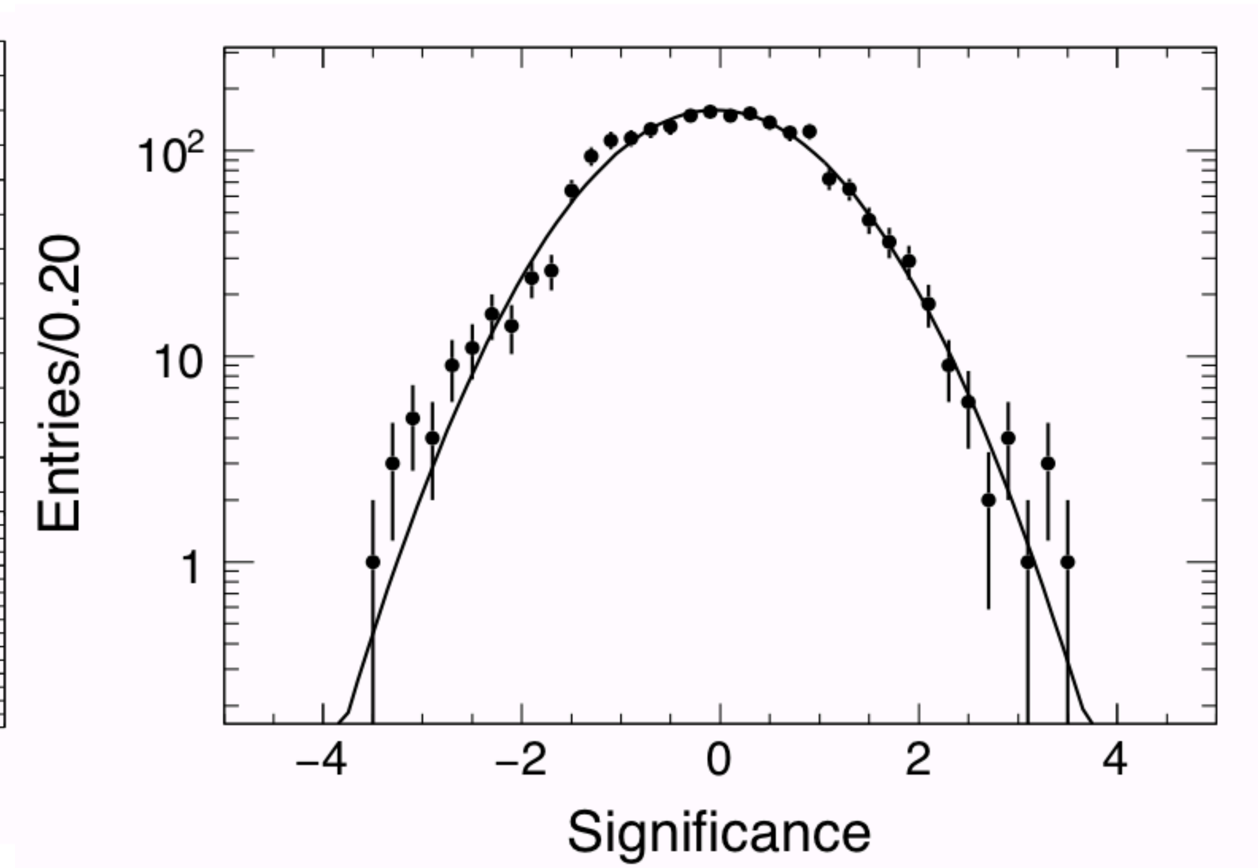
BESIII [PRD 85, 092012 (2012)]

No evidence is observed and upper limits on the product branching fractions for $J/\psi \to \gamma A^0$, $A^0 \to \mu^+\mu^-$ range from 4×10^{-7} to 2.1×10^{-5}, depending on the mass of the A^0, are established.

Results with J/ψ data

$J/\psi \to \gamma A^0,\ A^0 \to \mu^+\mu^-$

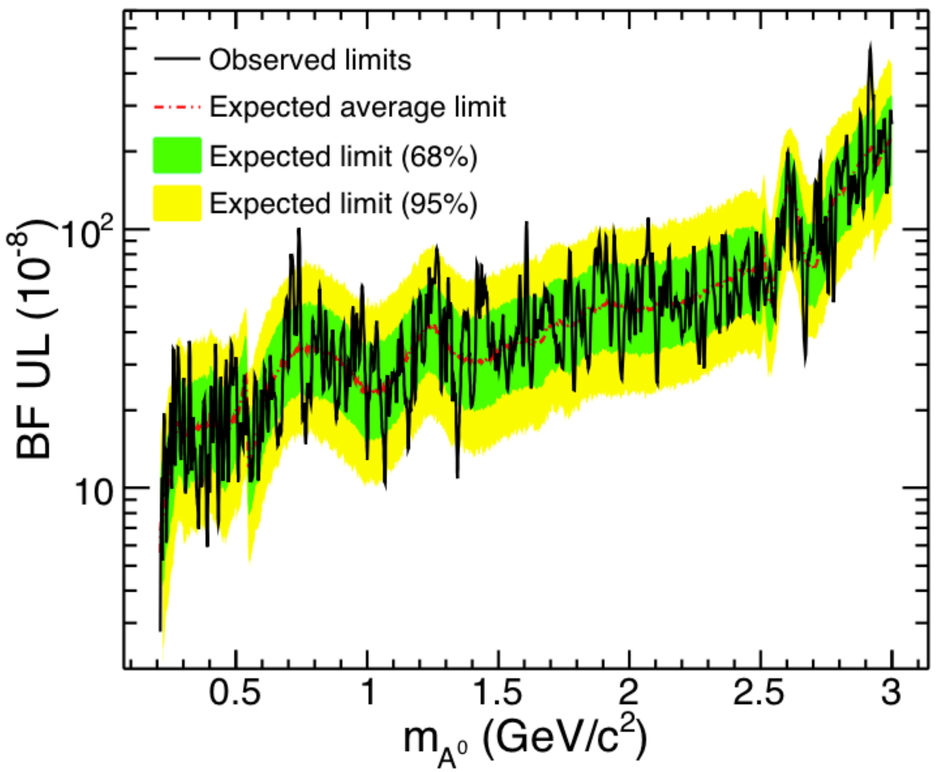


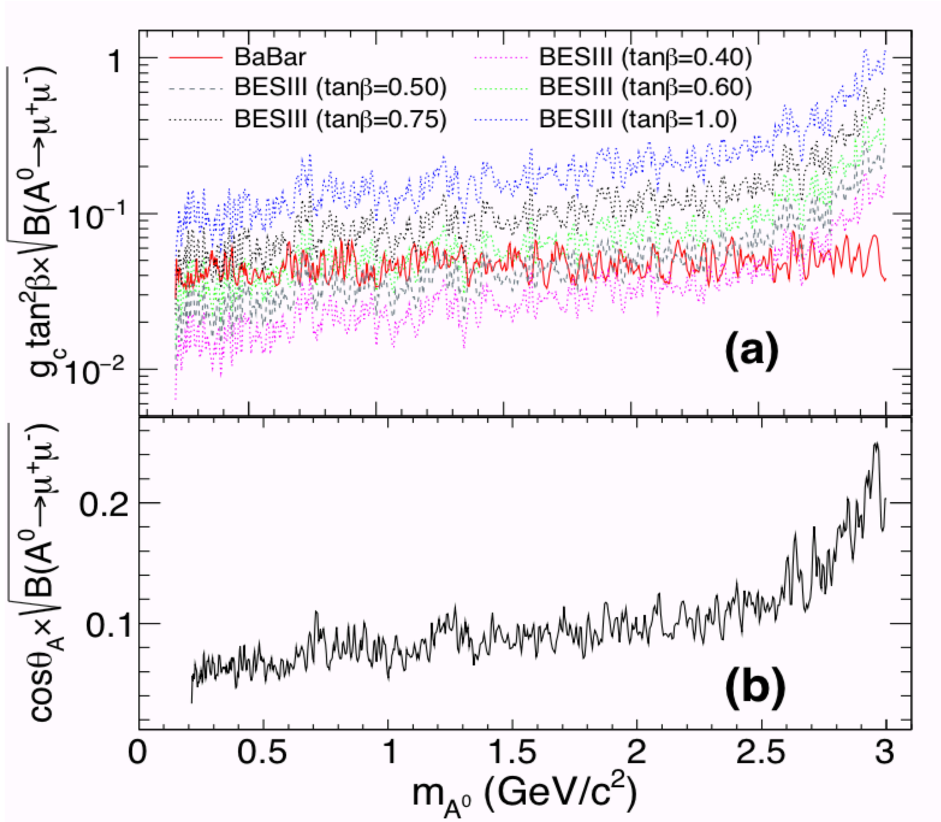


The statistic significance distribution is consistent with the normal distribution under the null hypothesis.

Results with J/ψ data

BESIII [arxiv: 1510.01641]

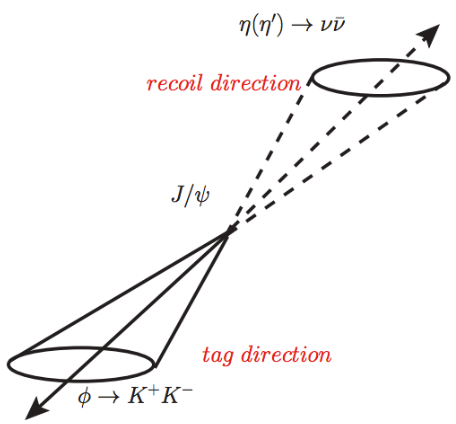


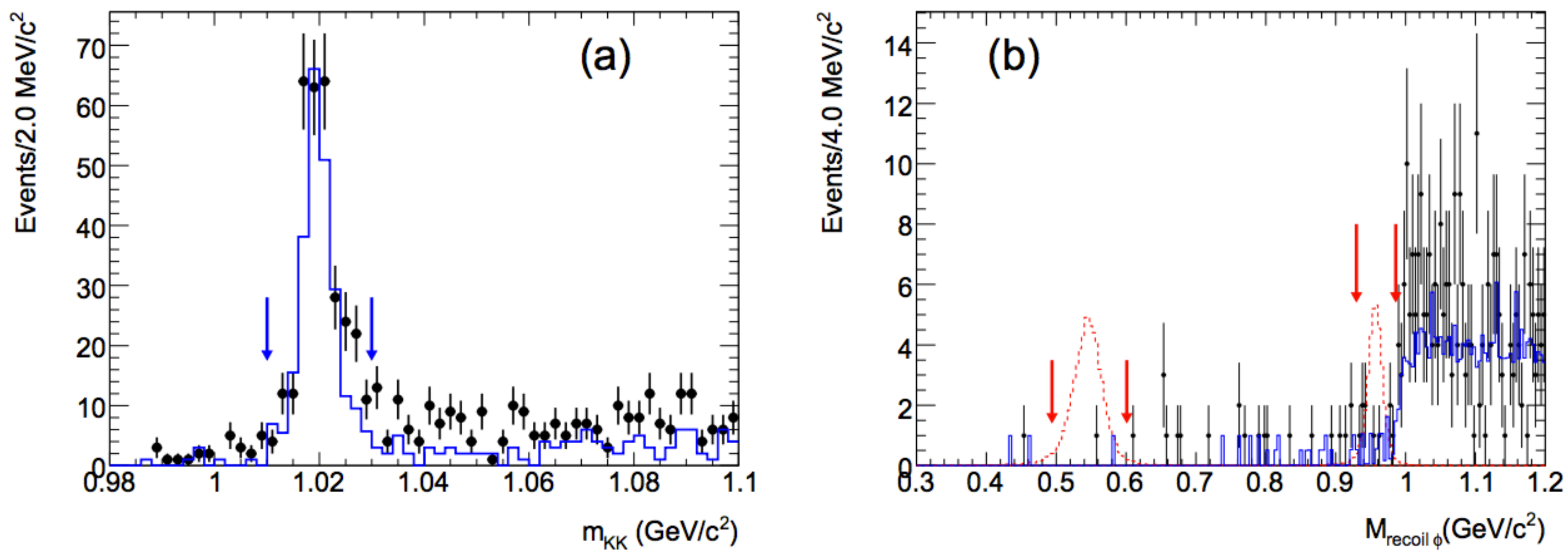


Bottom plot is $\cos\theta_A \times B(A^0 \to \mu^+\mu^-)$ as a function of m_{A0} . We compute $g_c \times \tan^2\beta \times B$ for different values of tanβ to compare our results with BaBar measurement. Then the $\cos\theta_A$ is the square root of the multiplication of g_c and g_b together measured by BESIII and BaBar.

Light meson invisible decay

BESIII [PRD 87, 012009 (2013)]





Within the SM, the invisible decay of η(η′) are tiny due to the helicity suppression.(10^{-10} -10^{-11}).

Phys. Rev. D81 (2010) 117101.

Any enhanced signal of invisible decay may indicate New Physics. Possible decay products could be LDM particles or light neutralinos.

At the 90% confidence level, the invisible decay rates to be
B(η->invisible) < 1.0×10^{-4} and B(η′->invisible) < 5.3×10^{-4} .

J/ψ invisible decay

BESII [Phys. Rev. Lett. **100**, 192001 (2008)]

The SM prediction:

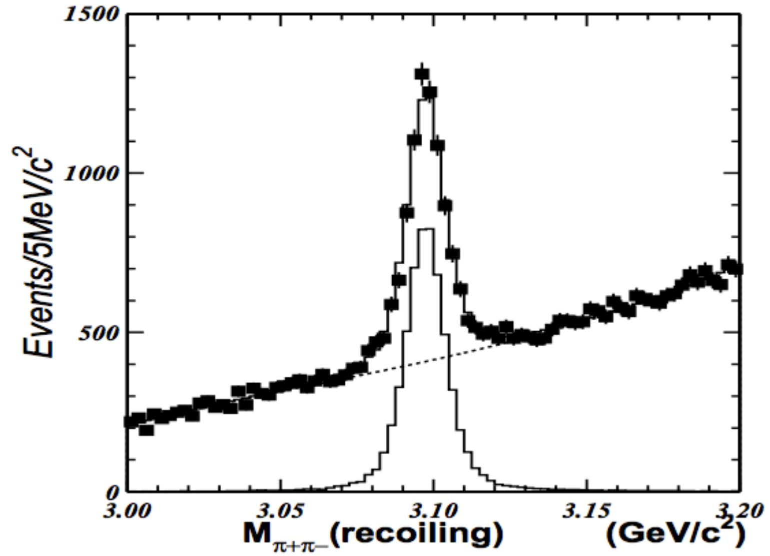
$$\mathcal{B}(J/\psi \to \nu\bar{\nu}) = 4.54 \times 10^{-7} \times \mathcal{B}(J/\psi \to e^+e^-)$$

The predicted BF of the J/ψ decays to a pair of dark matter particles based on model-independent calculation:

$$\mathcal{B}(J/\psi \to \chi\chi) \approx 0.023\%$$

Based on 14.0 million ψ' in BESII, at 90% confidence level,

the ratio $\frac{\mathcal{B}(J/\psi \to \text{invisible})}{\mathcal{B}(J/\psi \to \mu^+\mu^-)}$ < 1.2×10^{-2}



more precise measurement can be obtained in the BESIII experiment.

Summary

- Many rare decays could be searched in BESIII;
- Dark photon, dark Higgs boson and dark light matter are searched in BESIII;
- No evidence of New Physics has been found. Present upper limits are still above SM predictions;
- BESIII will take 3 fb^{-1} data at 4.17 GeV in 2016 and 10 fb^{-1} more data at 3.773 GeV in the future;
- More results can be expected soon.