cLFV and New Physics Searches at BESIII

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CLFV2016@UVA, Jun 22 2016

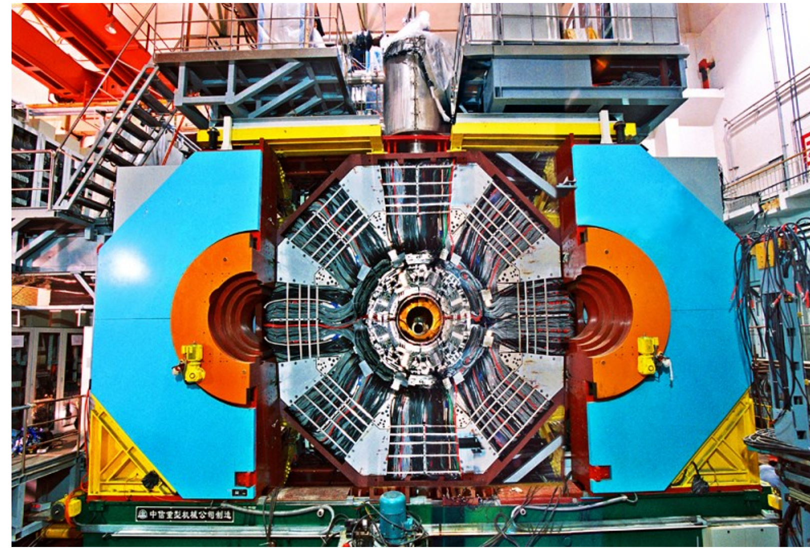
Outline

- About BESIII Exp
- $J/\psi \to e\mu$ Analysis
- Ongoing and Potential cLFV Studies
- Other New Physics searches
- Summary

About BESIII Exp

- Introduction
- BEPCII and BESIII
- Data sets and Physics Scope

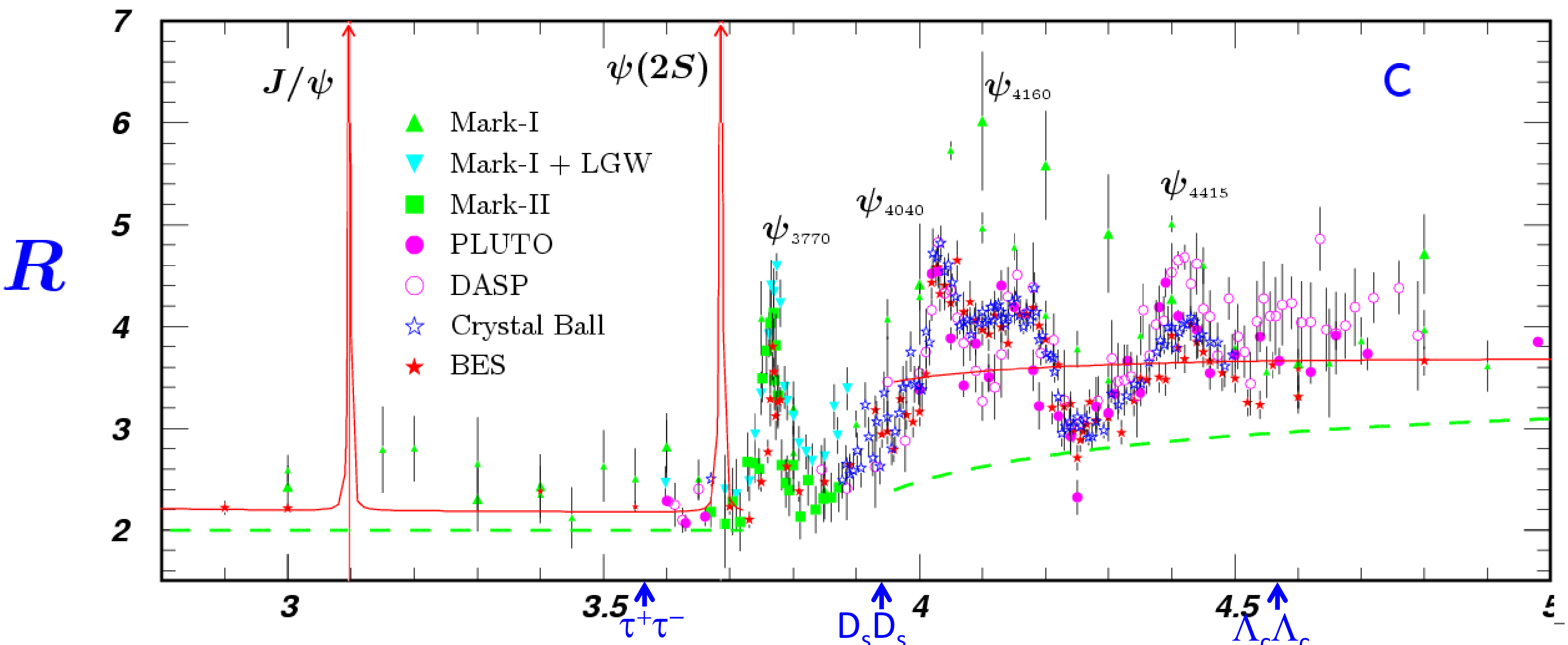
BEPCII and BESIII Exp



- BEPCII is the only collider currently running at τ-charm energy
- First collision in 2008, physics run started in 2009
- BEPCII reached peak lumi of $1 \times 10^{33}\ cm^{-2}s^{-1}$@1.89GeV in April 2016
- BESIII collaboration includes 31 Chinese institutes , 13 European ones , 6 US ones and 6 from other Asian countries, ~300 collaborators

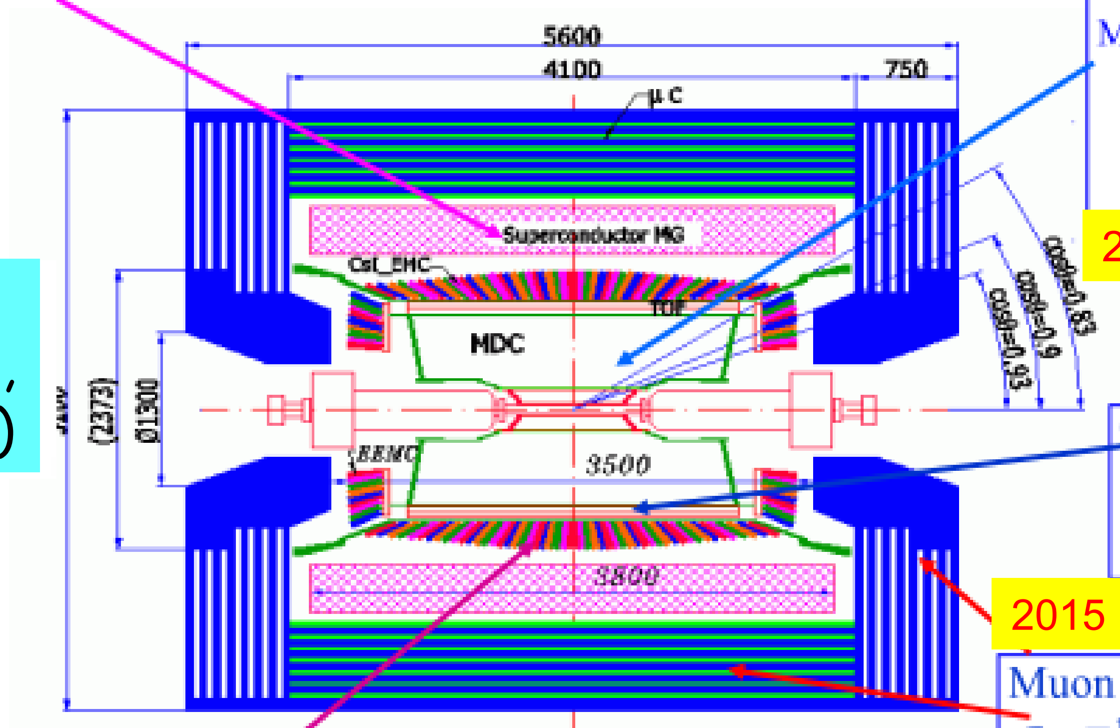
BEPCII: a τ-c Factory

- Rich of resonances, charmonia and charmed mesons.
- Threshold characteristics (pairs of τ, D, D_s, charmed baryons…).
- Transition between perturbative and non-perturbative QCD.
- New hadrons: glueballs, hybrids, multi-quark states
- New Physics: high lumi, large datasets, hermetic detector with good performance



BESIII Detector

Solenoid Magnet: 1 T Super conducting



MDC: small cell & He gas

σ_{xy}=130 μm

$\delta p/p$ = 0.5% @1GeV

dE/dx=6%

2017-18: Inner upgrade

Ref:
NIM A614, 345 (2010)

TOF:

σ_T = 90 ps Barrel

110 ps Endcap

2015 ETOF upgrade: 70ps

Muon ID: 8~9 layer RPC

$\sigma_{R\Phi}$=1.4 cm~1.7 cm

EMCAL: CsI crystal

$\Delta E/E$ = 2.5% @1 GeV

$\sigma_{\varphi,z}$ = 0.5~0.7 cm/$\sqrt{E}$

Data Acquisition:

Event rate = 3 kHz

Throughput ~ 50 MB/s

Trigger: Tracks & Showers

Pipelined; Latency = 6.4 μs

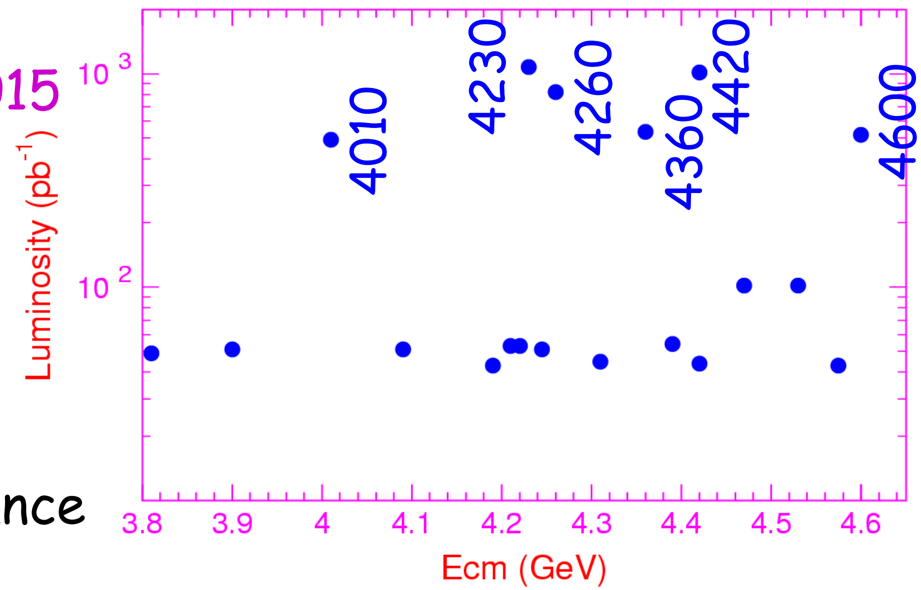
Clean environment and high luminosity at BESIII are helpful for indirect probe of new physics

BESIII data samples

~ 0.5 B	$\psi(3686)$ events	~ 24×CLEO-c
~ 1.3 B	J/ψ events	~ 21×BESII
~ 2.9/fb	$\psi(3770)$	~ 3.5×CLEO-c
~5/fb	**XYZ** states above 4 GeV	Unique

- 20 points for R &QCD Scan: 500/pb finished in May 1st, 2015
- Y(2175) resonance: 100 /pb : finished in June 15, 2015

2016: just finish 3/fb Ds data at 4170 MeV ~ 5×CLEO-c



~ other data sets: tau, Λ_c, resonance scan and continuum, etc.

$J/\psi \rightarrow e\mu$ Analysis

PRD87, 112007 (2013)

- Event selection
- Background estimation
- Systematics
- Results

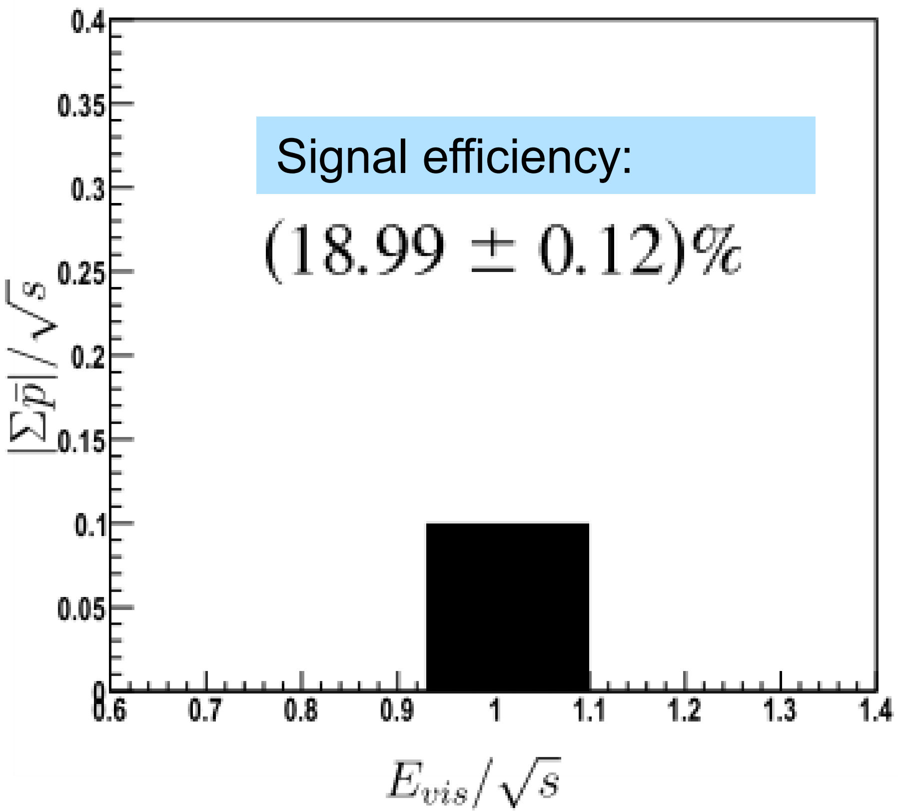
Motivation for $J/\psi \to e\mu$

- With finite neutrino masses included, Lepton Flavor Violation (LFV) is allowed, but the smallness of the mass leads to the predicted branching fraction well beyond current experimental sensitivity.
- However, there are various theoretical models such as SUSY may enhance LFV effects up to a detectable level.
- Any detection of a LFV decay indicates the existence of new physics.
- The LFV decay have been searched in lepton decay, pseudoscalar meson decay and vector meson decay. It is equally important to search it in heavy quarkonium decays.

Signal box definition based on MC

$$|\Sigma\bar{p}|/\sqrt{s} \pm 2\sigma \text{ and } E_{vis}/\sqrt{s} \pm 2\sigma$$

$$0.93 \le E_{vis}/\sqrt{s} \le 1.10 \text{ and } |\Sigma\bar{p}|/\sqrt{s} \le 0.1$$



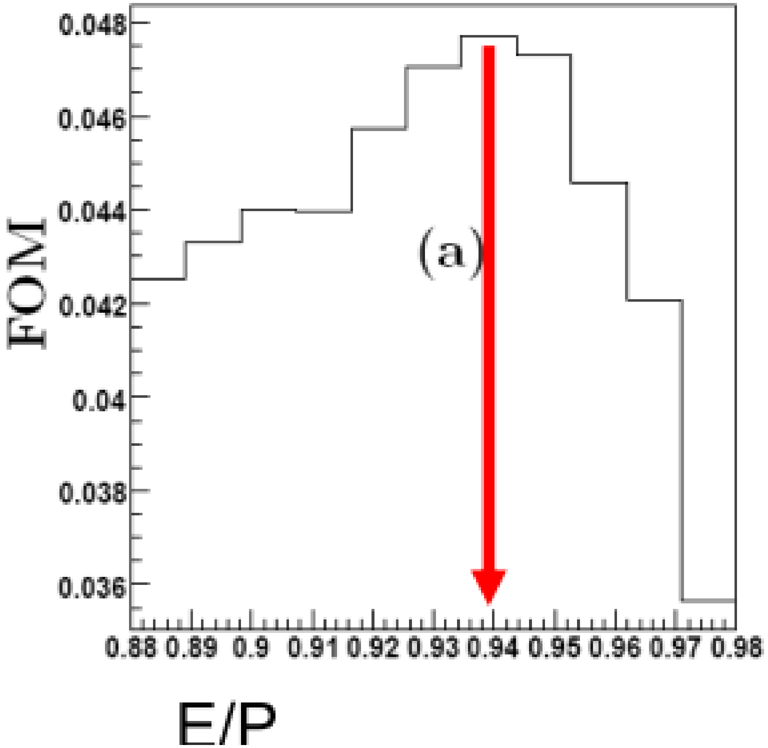
Event Selection Optimization

- ## The optimization method

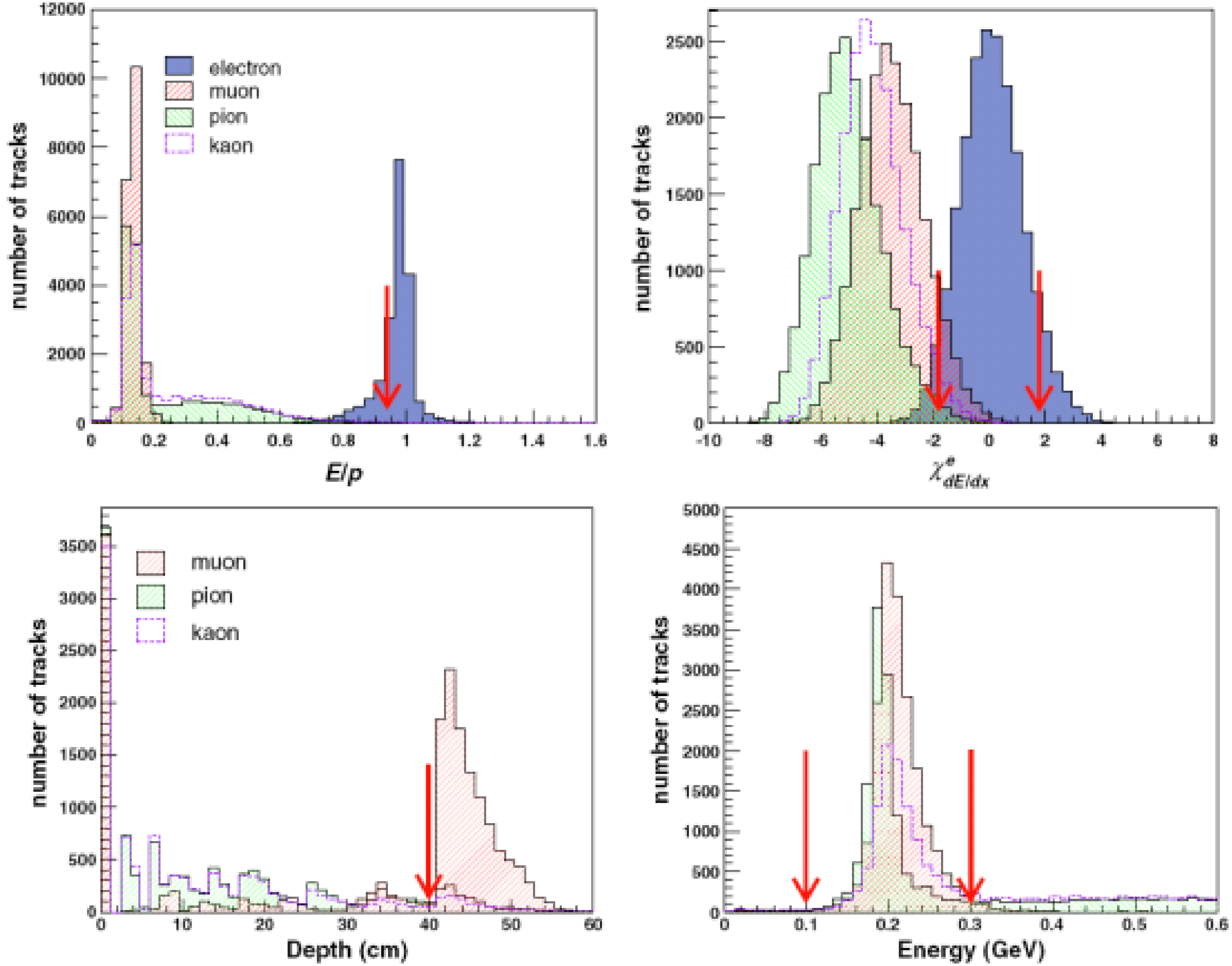
$$\mathrm{FOM} = \frac{\epsilon}{\sum_{N_{\rm obs}=0}^{\infty} P(N_{\rm obs}|N_{\rm exp}) \cdot UL(N_{\rm obs}|N_{\rm exp})}$$

The optimized cuts after maximizing the FOM

Criteria	optimized value
$\|\Delta\theta\| <$	0.9°
$\|\Delta\phi\| <$	1.4°
egam <	15 MeV
egam1 <	50 MeV
egam2 <	15 MeV
for e: $E/P >$	0.94
for e: $\|\chi^e_{dE/dx}\| <$	1.8
for μ: $\chi^e_{dE/dx} <$	-1.8
for μ: Depth >	40 cm

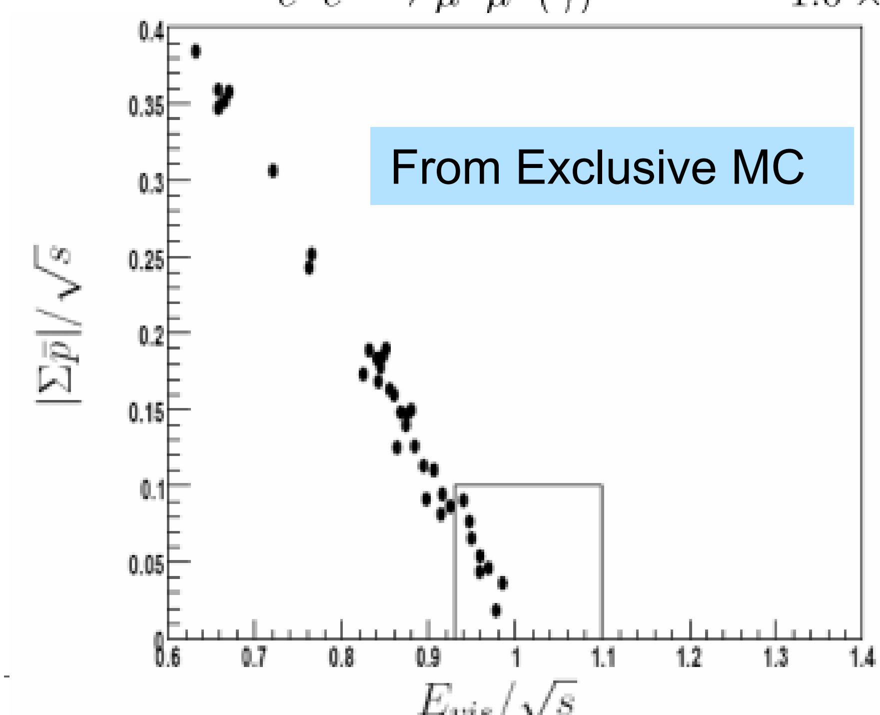


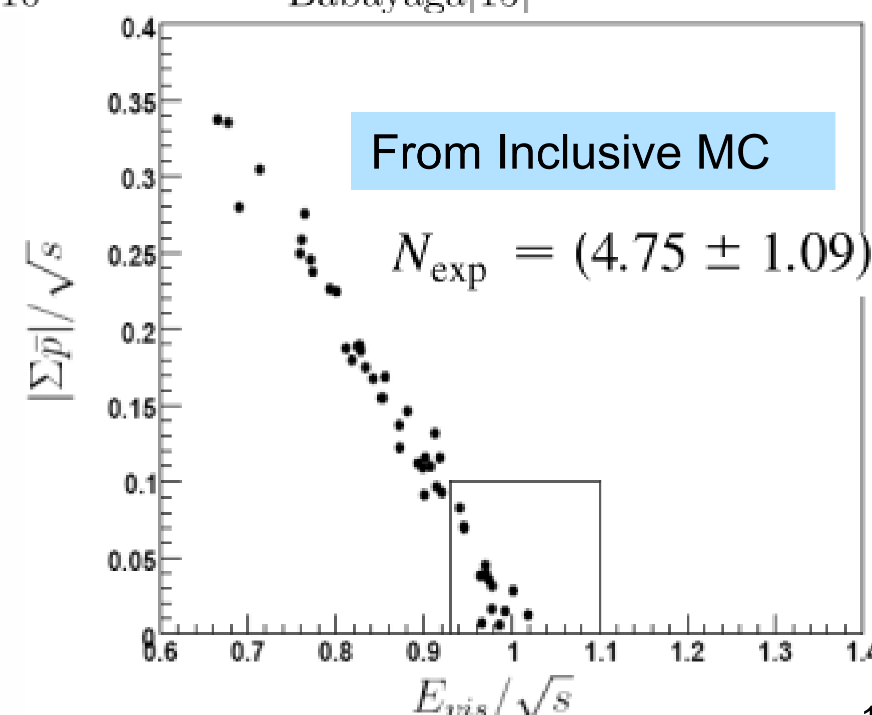
Variable Distributions



Background study

Background channel	normalized number	Model
$J/\psi \to e^+e^-$	2.7×10^7	PHOTOS and VLL[13]
$J/\psi \to \mu^+\mu^-$	2.7×10^7	PHOTOS and VLL[13]
$J/\psi \to \pi^+\pi^-$	1.0×10^5	PHSP[13]
$J/\psi \to K^+K^-$	7.0×10^4	PHSP[13]
$e^+e^- \to e^+e^-(\gamma)$	2.7×10^7	Babayaga[15]
$e^+e^- \to \mu^+\mu^-(\gamma)$	1.0×10^5	Babayaga[15]





$N_{exp} = (4.75 \pm 1.09)$

Systematic Uncertainties

Sources	Error
$e^{\pm}$ tracking	1.00
$\mu^{\pm}$ tracking	1.00
$e^{\pm}$ ID	0.62
$\mu^{\pm}$ ID	0.04
Acollinearity, acoplanarity	5.36
Photon veto	1.19
$N_{J/\psi}$	1.24
Total	5.84

$\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to e^+e^-$, $\mu^+\mu^-$

$J/\psi \to ee$

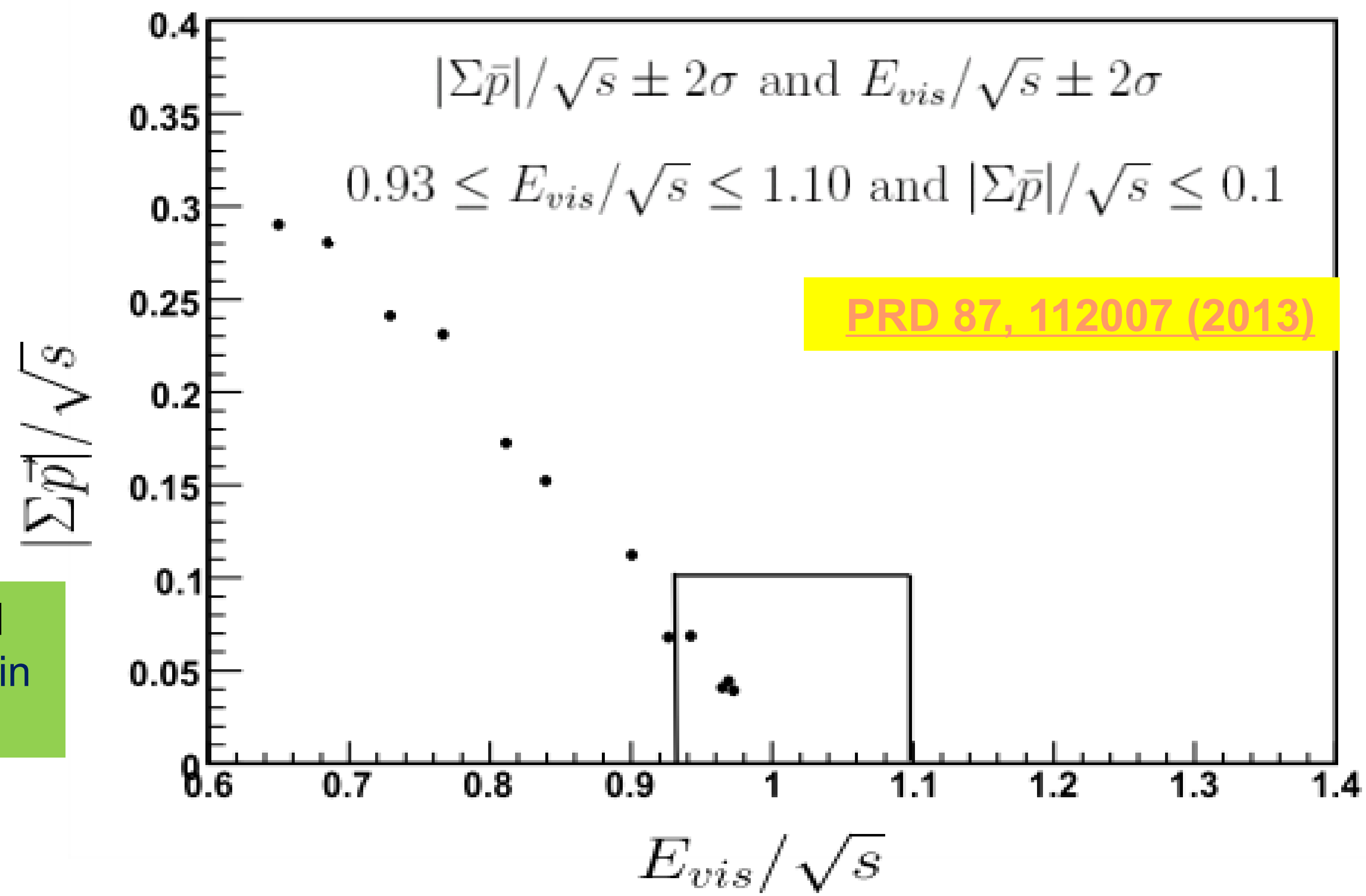
$J/\psi \to \mu\mu$

$J/\psi \to \mu\mu$

$J/\psi \to \pi\pi$

Relative, most from control samples, in percentage

J/ψ → eμ: Unblinded Data and Results



Among 225M J/ψ, 4 events in the signal box

$$\mathcal{B}(J/\psi \to e\mu) < 1.6 \times 10^{-7} \ (90\% \text{ C.L.})$$

Ongoing and Potential cLFV Studies

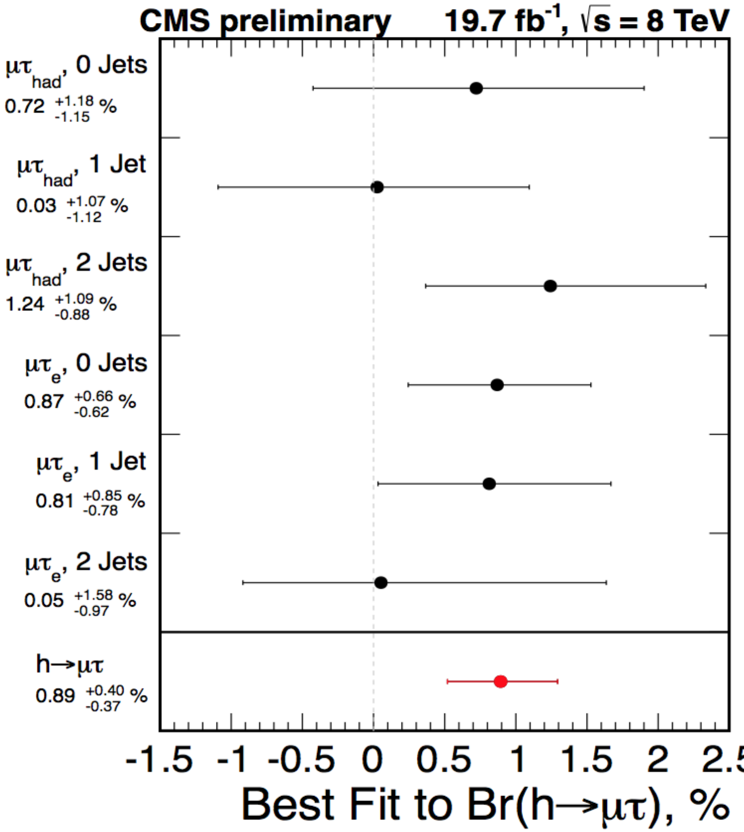
- $\psi \to e\tau/\mu\tau$ (going on)
- $\psi \to \gamma e\tau/\gamma\mu\tau$ (started)
- FLV in mesons: D, η, η' (to be further investigated)

$\Psi(1S,2S) \to e\,\tau / \mu\tau / \gamma e\tau / \gamma\mu\tau$

Could non-trivial Yukawa Coupling be a new interaction?
=>Flavor Changing rates be enhanced

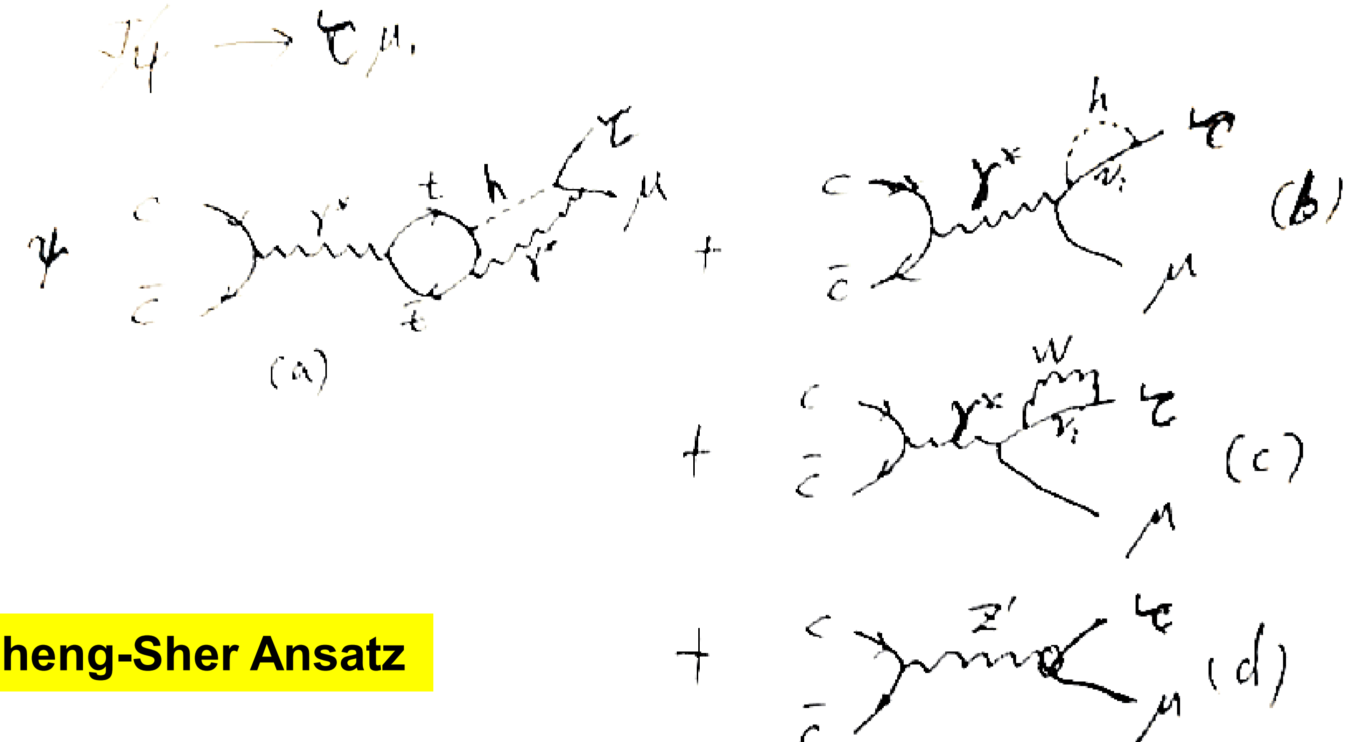
$$BR(h \to \tau^{\pm}\mu^{\mp}) < 1.57\% \text{ (95\% C.L.)}$$
$$|y_{\tau\mu}| \leq 3.6 \times 10^{-3}$$

$$BR(h \to \tau^{\pm}\mu^{\mp}) = 0.89 \begin{matrix}+0.40\\-0.37\end{matrix} \%(2.46\sigma)$$
$$|y_{\tau\mu}| \simeq 2.7 \times 10^{-3}$$
$$\sim \sqrt{y_{\tau} y_{\mu}} = 2.48 \times 10^{-3}$$



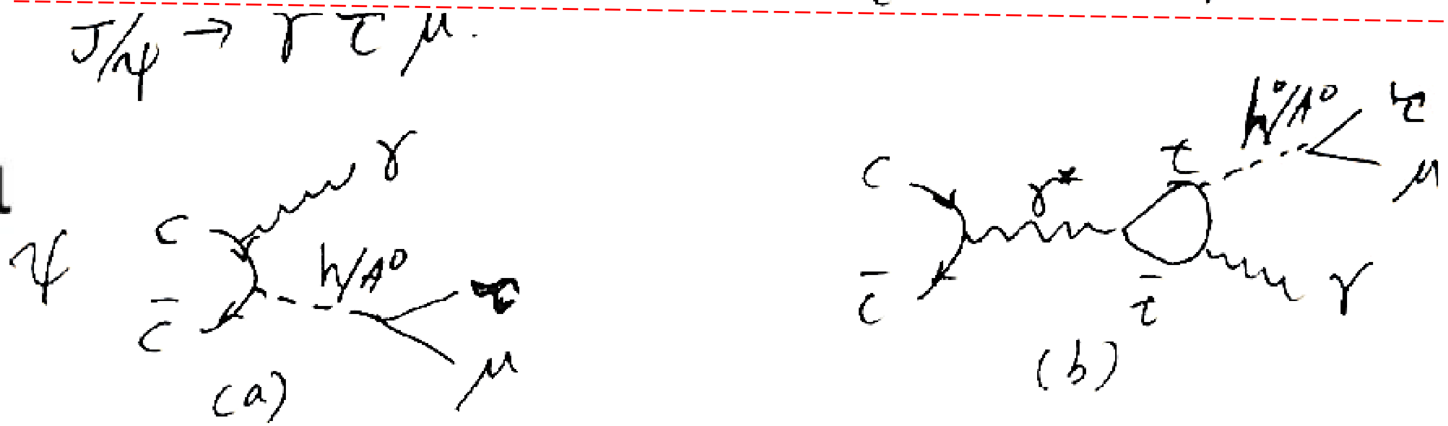
Possible Enhancements

Ψ→τμ



Inspired by Cheng-Sher Ansatz

Ψ→γτμ



cLFV beyond eμ: estimations

$$J/\psi \to e^+\tau^- \quad \tau^- \to \mu^-\overline{\upsilon}_\mu\upsilon_\tau + cc.$$

$$J/\psi \to \mu^+\tau^- \quad \tau^- \to e^-\overline{\upsilon}_e\upsilon_\tau + cc.$$

$$J/\psi \to \gamma e^+\tau^- \quad \tau^- \to \mu^-\overline{\upsilon}_\mu\upsilon_\tau + cc.$$

$$J/\psi \to \gamma\mu^+\tau^- \quad \tau^- \to e^-\overline{\upsilon}_e\upsilon_\tau + cc.$$

- ✓ From preliminary MC studies, the efficiencies could reach ~30-35%, and the BR sensitivity could be in the level of 1E-8 to 1E-7
- ✓ Better up limit could be achieved if QED description & PID on muons improved

- ✓ **Detailed analysis with data without photons is going on (J/ψ-> e τ/μτ)**
- ✓ **Further study on the channel with photons is started (J/ψ-> γeτ/γμτ)**

Symmetry breaking process: More possibilities

In Both Charmonium and Charm meson decays

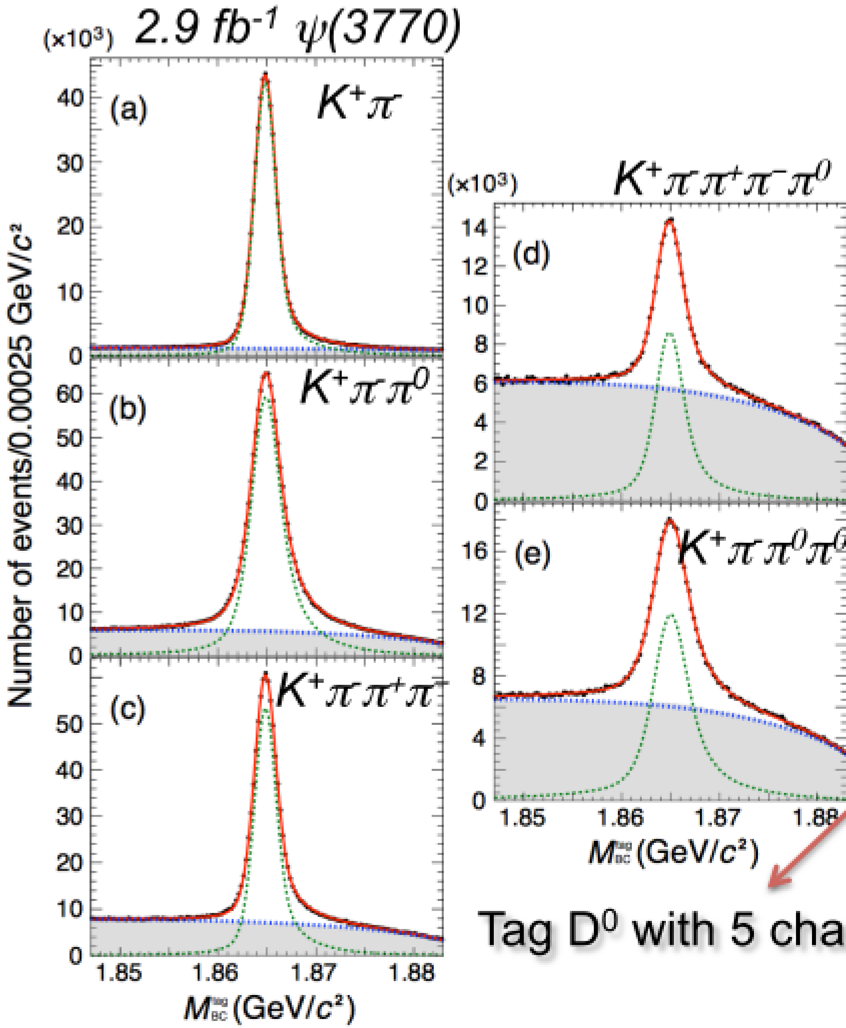
- Lepton Flavor Violation (LFV) processes
- Lepton Number Violation (LNV) processes
- Baryon Number Violatoin (BNV) processes

BESIII is more competitive in channels with low energy electron/photons, neutrons, pi0's

cLFV processes from D, η and η′ decays are also possibly to search at BESIII, esp for final datasets

$\mu^\pm e^\mp$	LFV
$\pi^0 e^\pm \mu^\mp$	LFV
$\eta e^\pm \mu^\mp$	LFV
$\pi^+\pi^- e^\pm \mu^\mp$	LFV
$\rho e^\pm \mu^\mp$	LFV
$\omega e^\pm \mu^\mp$	LFV
$K^+K^- e^\pm \mu^\mp$	LFV
$\phi e^\pm \mu^\mp$	LFV
$\bar{K}^0 e^\pm \mu^\mp$	LFV
$K^-\pi^+ e^\pm \mu^\mp$	LFV
$\bar{K}^{*0} e^\pm \mu^\mp$	LFV
$\pi^\mp\pi^\mp e^\pm e^\pm$	LNV
$\pi^\mp\pi^\mp \mu^\pm \mu^\pm$	LNV
$K^\mp\pi^\mp e^\pm e^\pm$	LNV
$K^\mp\pi^\mp \mu^\pm \mu^\pm$	LNV
$K^\mp K^\mp e^\pm e^\pm$	LNV
$K^\mp K^\mp \mu^\pm \mu^\pm$	LNV
$\pi^\mp\pi^\mp e^\pm \mu^\pm$	LNV
$K^\mp\pi^\mp e^\pm \mu^\pm$	LNV
$K^\mp K^\mp e^\pm \mu^\pm$	LNV
pe^-	BNV+LNV
$\bar{p}e^+$	BNV+LNV

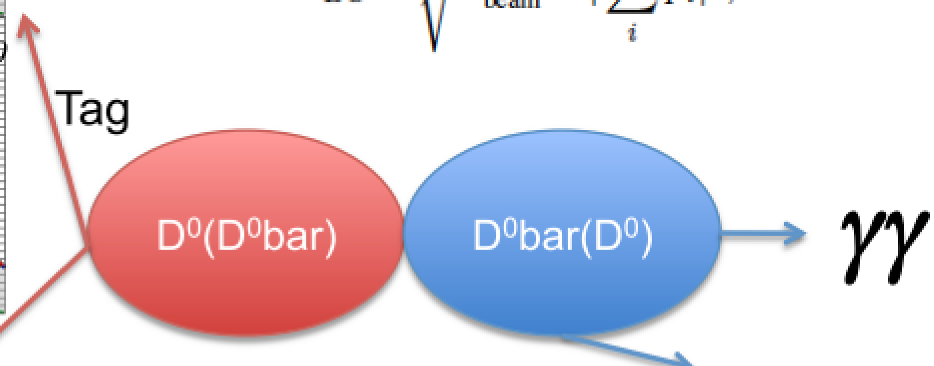
$D^0 \to \gamma\gamma$: analysis method



The $\psi(3770)$ resonance is below the threshold for $D\bar{D}\pi$ production, so the events from $e^+e^- \to \psi(3770) \to D\bar{D}$ have D mesons with energies equal to the beam energy ($E_{\rm beam}$) and known momentum. Thus, to identify $\bar{D}^0$ candidate, we define the two variables ΔE and $M_{\rm BC}$, the beam-constrained mass:

$$\Delta E \equiv \sum_i E_i - E_{\rm beam},$$

$$M_{\rm BC} \equiv \sqrt{E_{\rm beam}^2 - |\sum_i \vec{p}_i|^2},$$



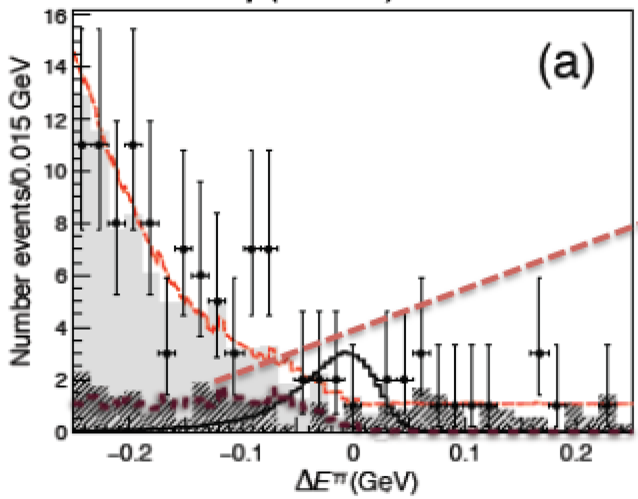
Tag D^0 with 5 channels on tag side.

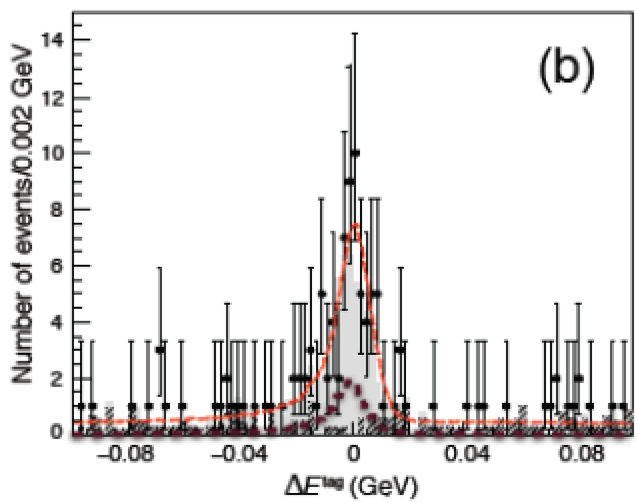
Cut on M_{BC} on the tag side, and search for $\gamma\gamma$ in $\Delta E_{\gamma\gamma}$ on the recoiling side

We could use similar technique to perform the D(Ds) LFV search, and estimate the sensitivity

$D^0 \to \gamma\gamma$ Results

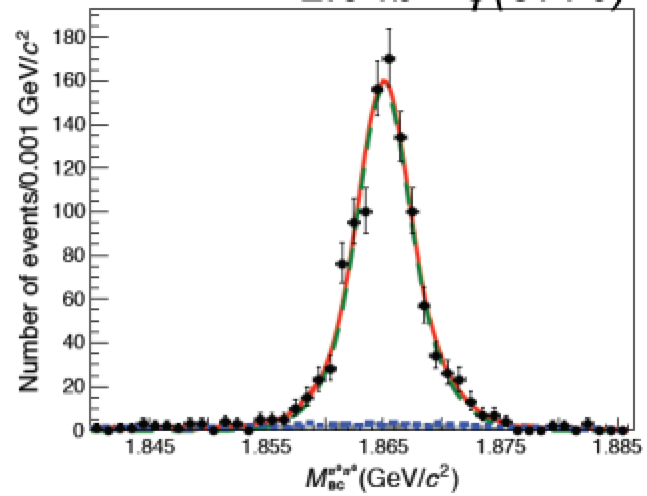
2.9 fb^{-1} $\psi(3770)$





Major background $D^0 \to \pi^0\pi^0$ is determined in data with similar double-tag method.

2.9 fb^{-1} $\psi(3770)$



$B(D^0 \to \pi^0\pi^0) = (8.24 \pm 0.21 \pm 0.30) \times 10^{-4}$

2-D fit to ΔE in both tag side and $\gamma\gamma$ sides to determine $D^0 \to \gamma\gamma$ yield.

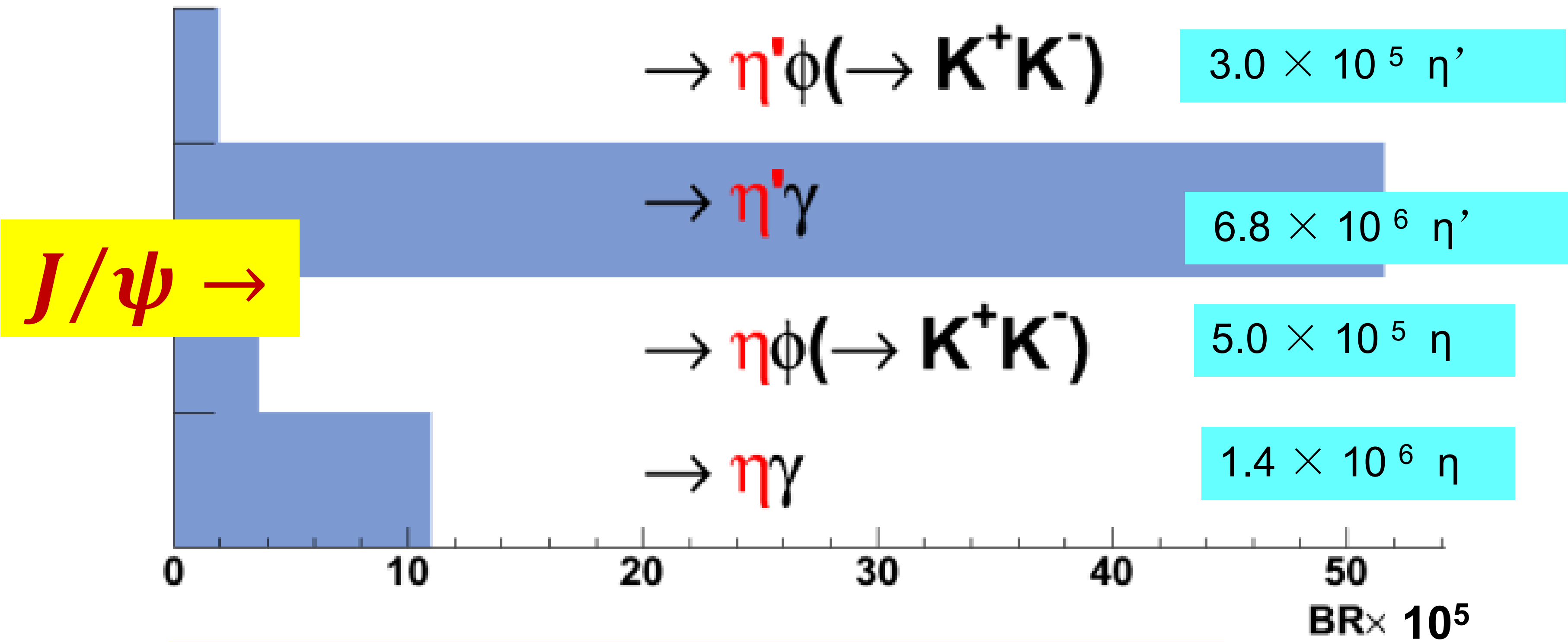
$$B(D^0 \to \gamma\gamma) < 3.8 \times 10^{-6}$$

consistent with BaBar result, will update with a 4X larger sample.

PRD91, 112015 (2015)

η and η′ yields with J/ψ data set

In 1.3B Jpsi(09+12)



We could use same phi tag to perform the study, the sensitivity could be estimated similarly

Other New Physics Searches

- Charmonium weak decays
- Charm FCNC and LNV rare decays
- Search for meson invisible decays
- Search for CP-odd Light Higgs
- Search for Dark Photons

Rare Decays to probe NP

- **Rare Charmonia Decays**
  - Semileptonic weak decays
  - Two-body weak hadronic decays
  - C/P violation decays
  - Invisible decays
  - LFV, INV, BNV decays

$$Br(J/\psi \to D_s^- e^+ \nu_e + c.c.) < 1.3\times10^{-6}$$

$$Br(J/\psi \to D_s^{*-} e^+ \nu_e + c.c.) < 1.8\times10^{-6}$$

$$Br(J/\psi \to D_s^- \rho^+) < 1.3\times10^{-5}$$

$$Br(J/\psi \to \overline{D}^0 \overline{K}^{*0}) < 2.5\times10^{-6}$$

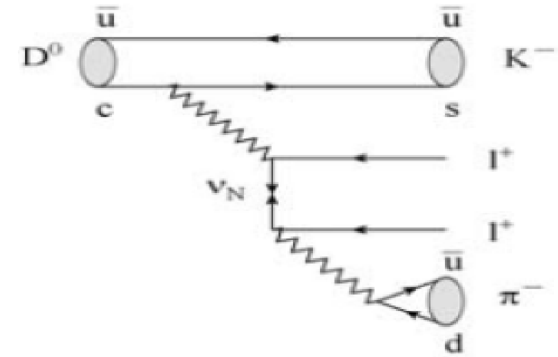
$$Br(J/\psi \to \gamma\gamma) < 2.7\times10^{-7}$$

$$Br(J/\psi \to \gamma\phi) < 1.4\times10^{-6}$$

- **Rare Charm decays**

- LNV : $c \to u\mu^+\mu^+$ forbidden in SM
  - ✓ Majorana neutrino: ~ $10^{-30\sim-23}$ level, PRD64 (2001) 114009
  - ✓ May be greatly enhanced: ~$10^{-5\sim-6}$ with EPJC71 (2011) 1715)

H.R. Dong, F. Feng and H.B. Li, Chin, Phys. C **39** 013101 (2015)

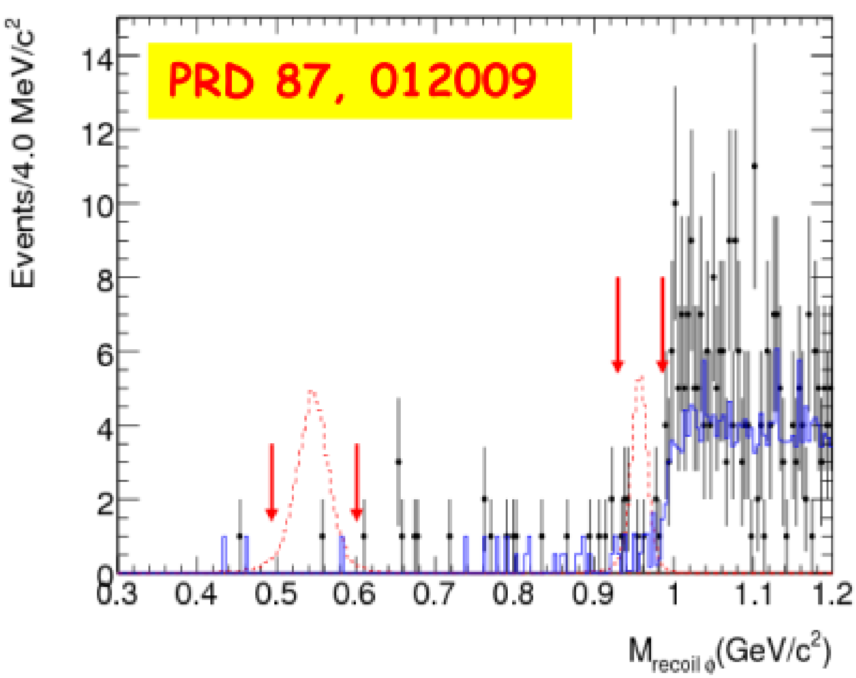


(a) $D^0 \to K^- \ell^+ \ell^+ \pi^-$ (CF)

- FCNC : $c \to u\mu^+\mu^-$ highly suppressed in SM by GIM mechanism BF_{th}~10^{-9} [PRD64 (2001) 114009] while can be enhanced by physics BSM [PRD 76 (2007) 074010]
- Rare FCNC: $D^0 \to \gamma\gamma$

Search for η/η' invisible decays

- η/η' decay play special role in low energy scale QCD theory.
- Invisible and radiative decays offer a window for new physics beyond the SM.
- The observation of the invisible final states provide information for light dark matter states χ, spin-0 axions, and light spin-1 U bosons.
- Huge J/ψ sample, large branching fraction of $J/\psi \to (\gamma/\phi)\eta/\eta'$ and narrow intermediate meson widths provide clean, large η/η' sample.



$Br(\eta' \to invisible)/Br(\eta' \to \gamma\gamma) < 2.39\times10^{-2}$
$Br(\eta \to invisible)/Br(\eta \to \gamma\gamma) < 2.58\times10^{-4}$

$Br(\eta' \to invisible) < 5.21\times10^{-4}$ @90%C.L.
$Br(\eta \to invisible) < 1.01\times10^{-4}$ @90%C.L.
Improved PDG Values

PDG : $Br(\eta' \to invisible) < 9\times10^{-4}$ @90%C.L
$Br(\eta \to invisible) < 6\times10^{-4}$ @90%C.L.

Theory : $Br(\eta' \to \chi\chi) \sim 8.1\times10^{-7}$
$Br(\eta \to \chi\chi) \sim 7.4\times10^{-5}$
B. McElrath, PRD 72, 103508 (2005)

light Higgs search:Motivation

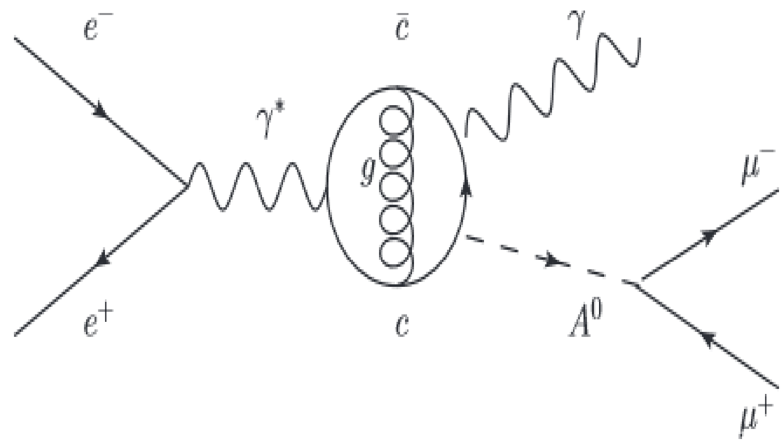
➢ Coupling of fermions and the CP-odd Higgs A^0 in the NMSSM:

$$L_{\rm int}^{f\bar{f}} = -\cos\theta_A \tan\beta \frac{m_f}{v} A^0 \bar{d}(i\gamma_5)d,$$

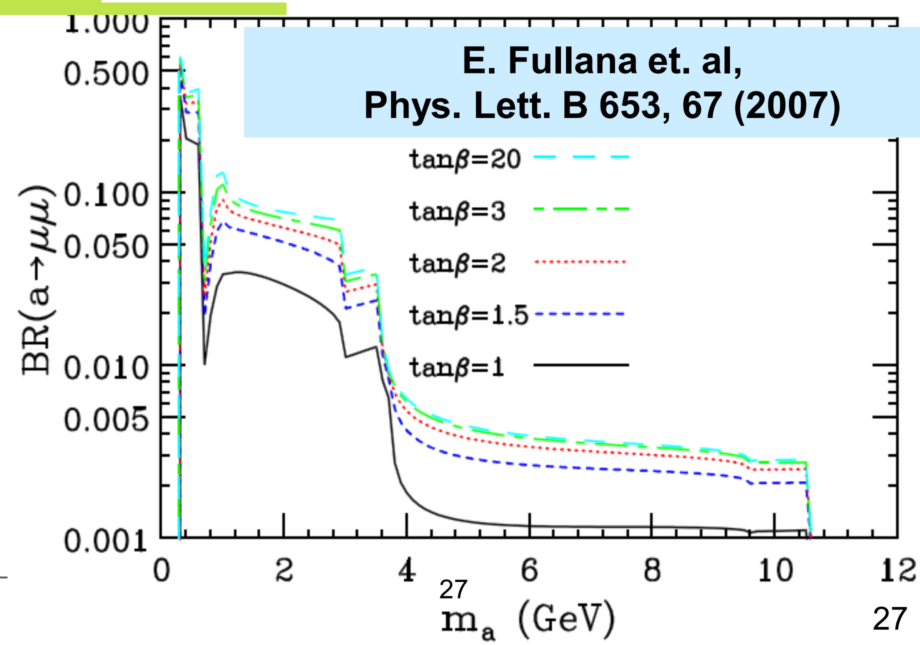
d = d, s, **b**, e, μ, τ

$$L_{\rm int}^{f\bar{f}} = -\cos\theta_A \cot\beta \frac{m_f}{v} A^0 \bar{u}(i\gamma_5)u,$$

u = u, **c**, t, ν_e, ν_μ, ν_τ



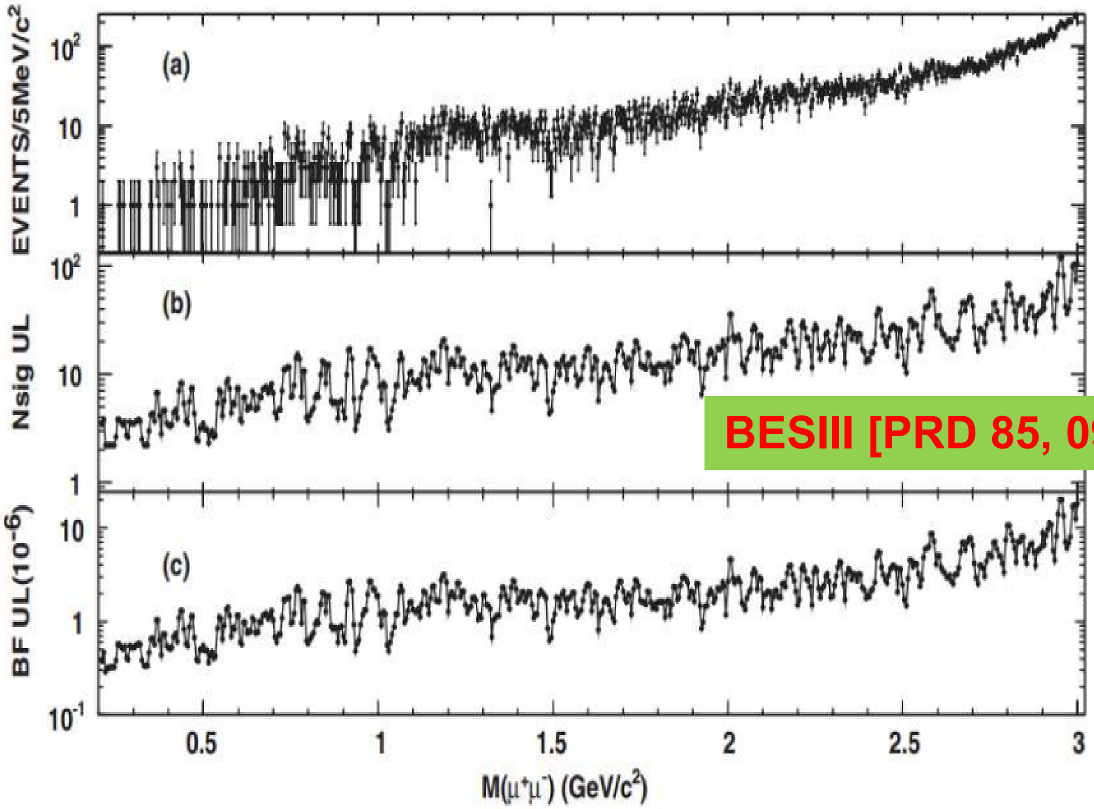
$$\tan\beta = \frac{v_u}{v_d}$$



E. Fullana et. al,
Phys. Lett. B 653, 67 (2007)

Results with ψ' data in published in 2012

ψ'->pipi J/ψ, J/ψ→γA^0, A^0→$\mu^+\mu^-$



BESIII [PRD 85, 092012 (2012)]

Coupling of c-quark to the A^0

Expected BF: 10^{-7} -10^{-9}

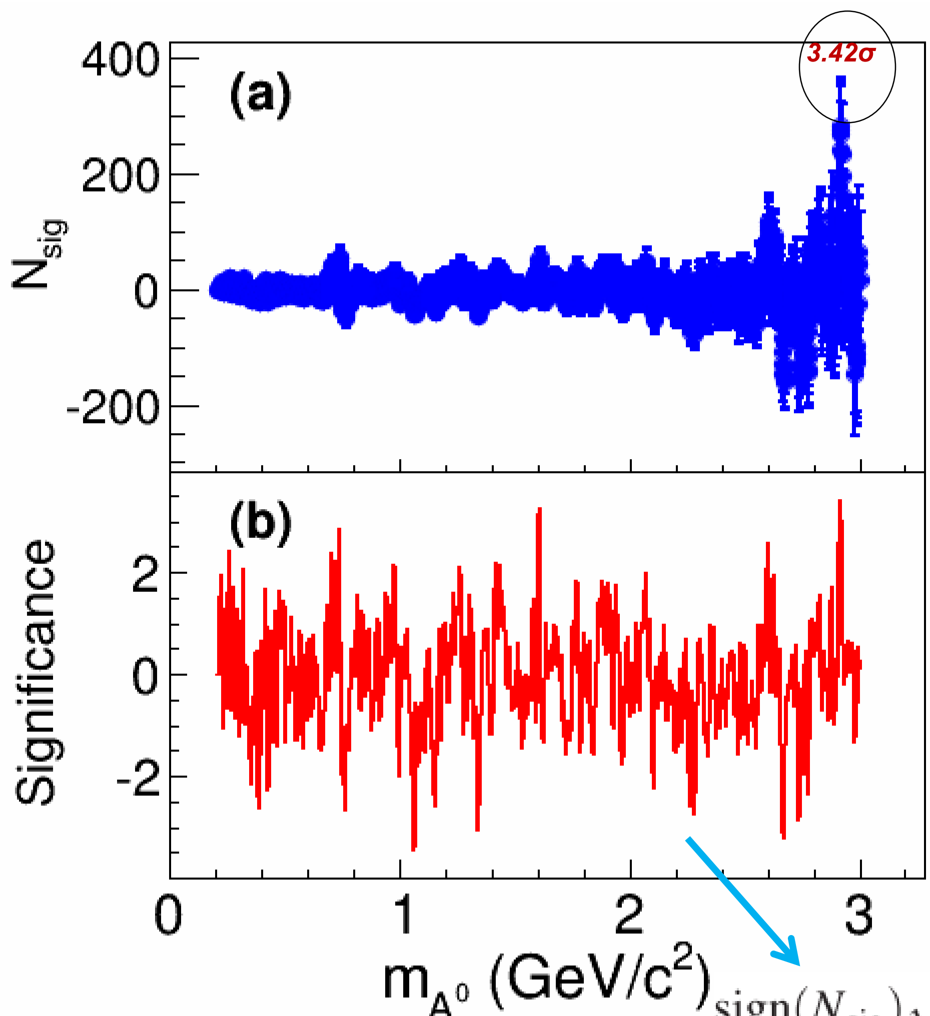
[PRD 76, 051105 (2007)]

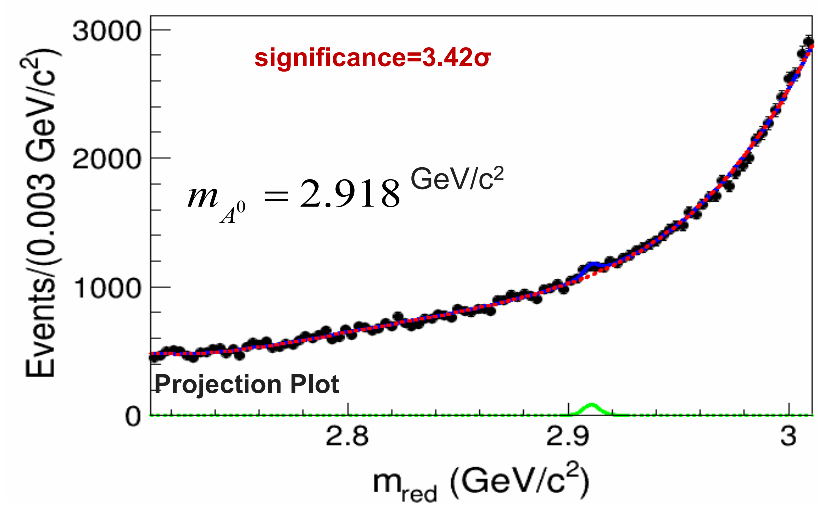
106M psi' data

BESIII exclusion limit ranges from 4×10^{-7} - 2.1×10^{-5} depending on A^0 mass points.

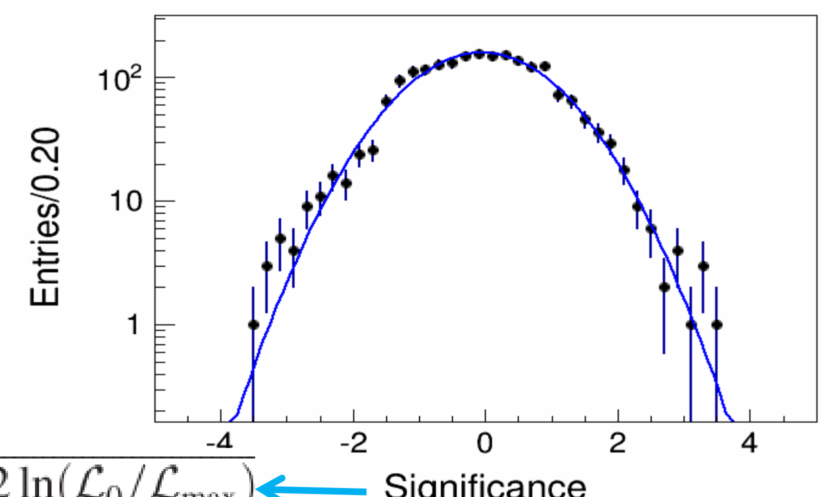
J/ψ -> $\gamma\mu^+\mu^-$: Fit Results

- Perform the ML fit to the m_{red} distribution at 2035 mass points in the steps of 1-2 MeV/c^2.



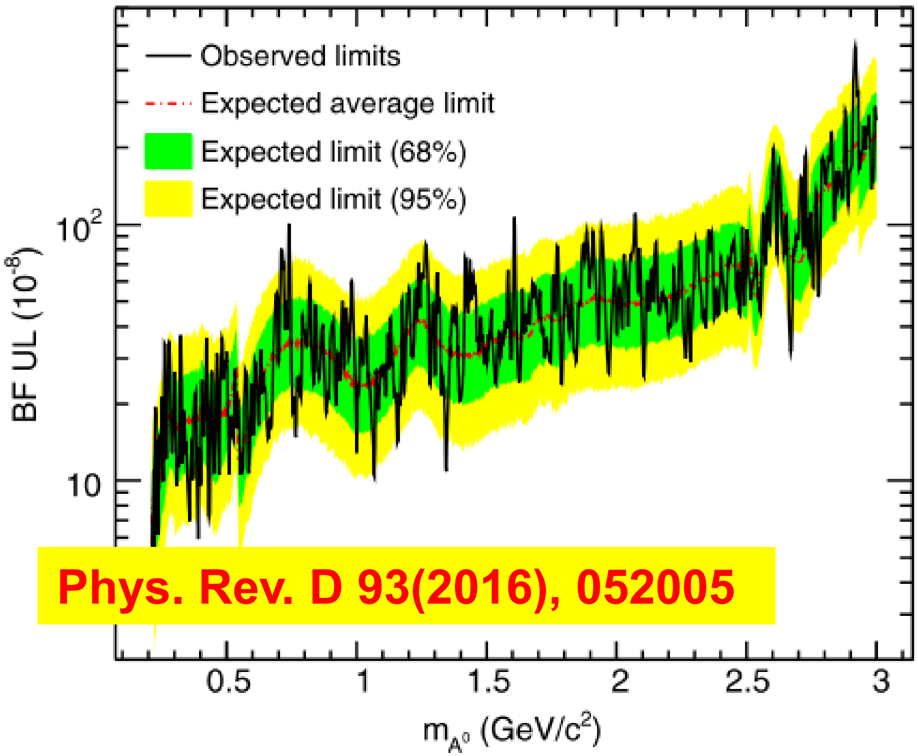


✓Significance distribution: consistent with unit-width Gaussian

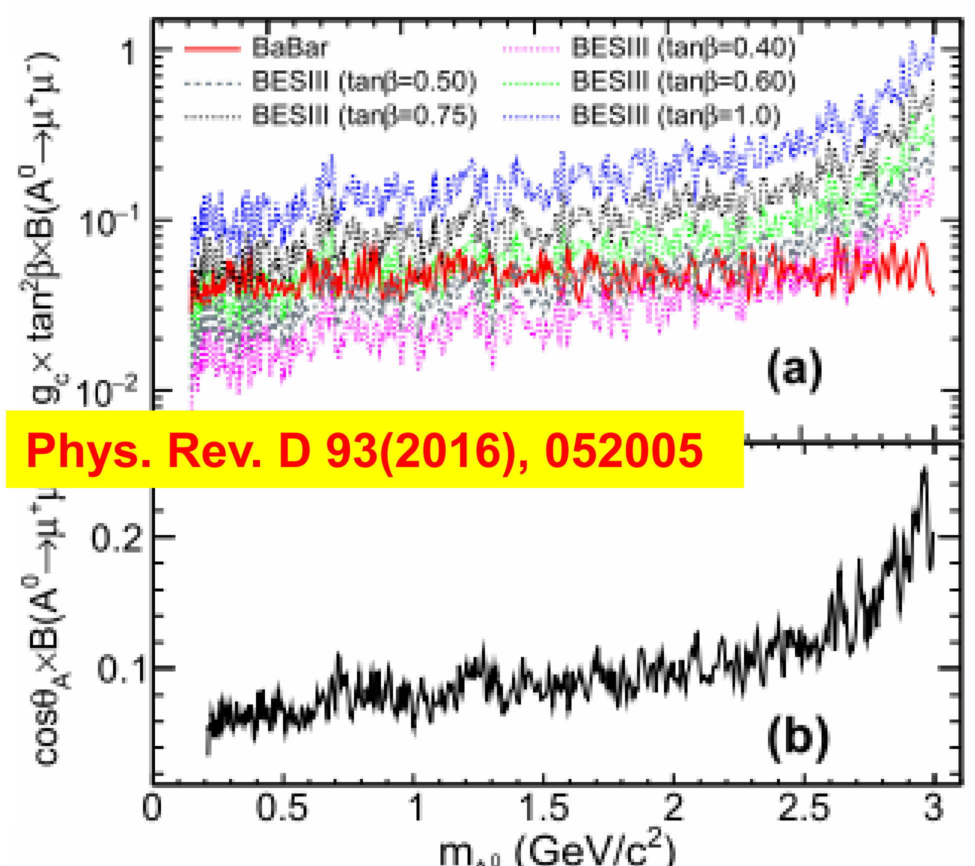


$$\text{sign}(N_{sig})\sqrt{-2\ln(\mathcal{L}_0/\mathcal{L}_{max})}$$

New BESIII Results(225M J/ψ)



Phys. Rev. D 93(2016), 052005



Phys. Rev. D 93(2016), 052005

PRD 87, 031102 (R) (2013) (BaBar experiment)

The new limits are five times below our previous results (2012, Psip)

BESIII vs. BaBar measurements comparison and combination,A0 is mostly singlet

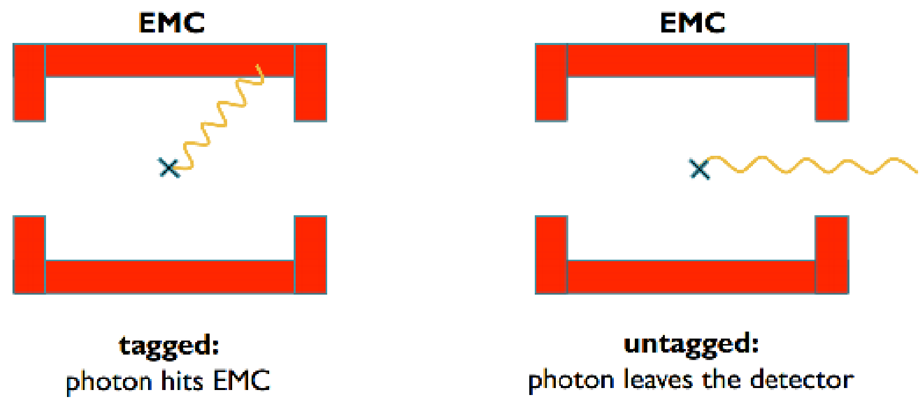
Dark photon search with ISR

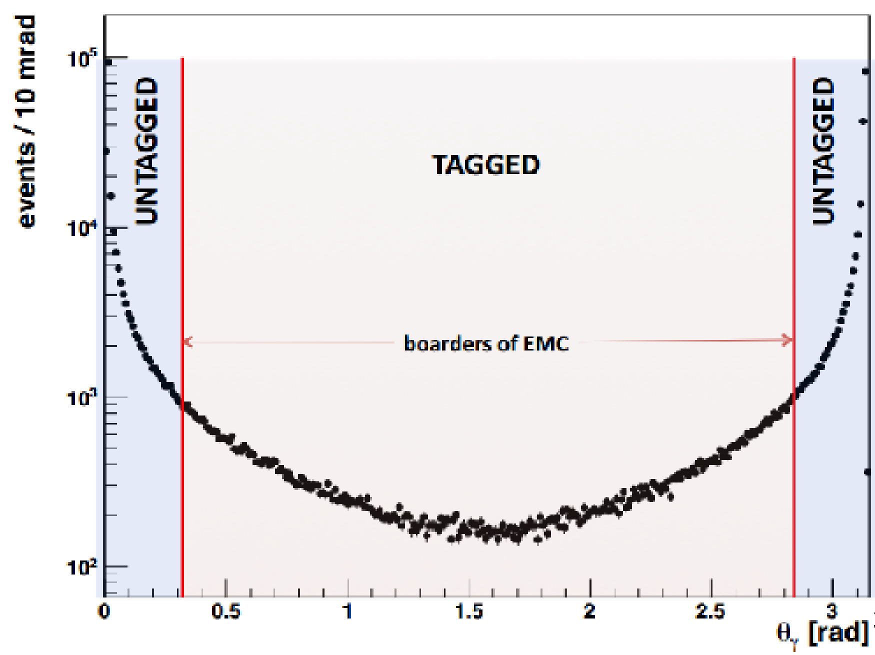
Dark Photon (A') as dark-force carrier is EM-equivalent expected in the dark sector. It couples to SM particles via kinetic mixing. The idea sparked world-wide efforts

- Use an untagged photon method to perform this analysis.

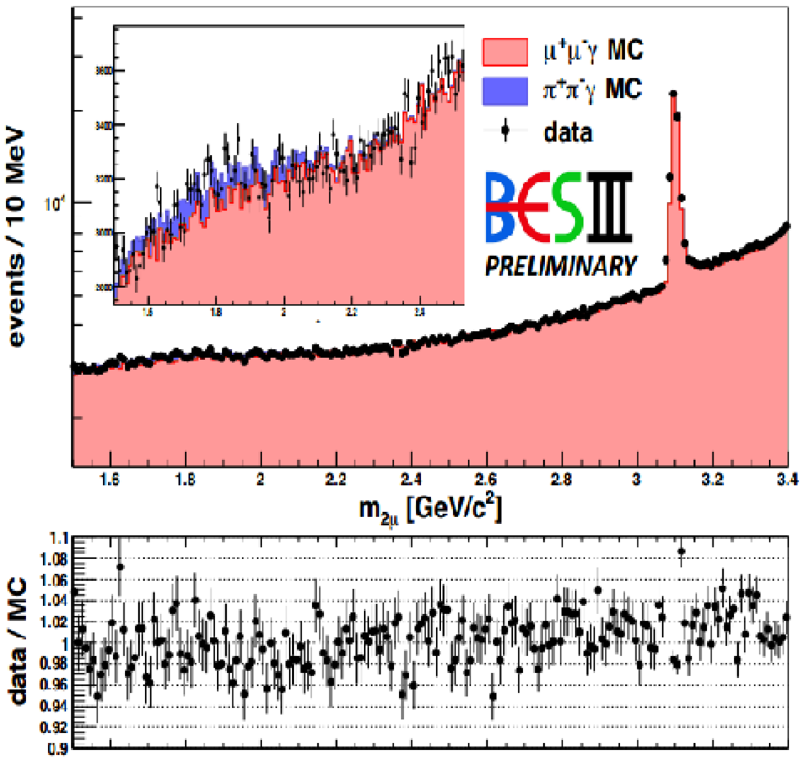
Event selection: $e^+e^- \rightarrow \mu^+\mu^-\gamma_{ISR}$ and $e^+e^- \rightarrow e^+e^-\gamma_{ISR}$

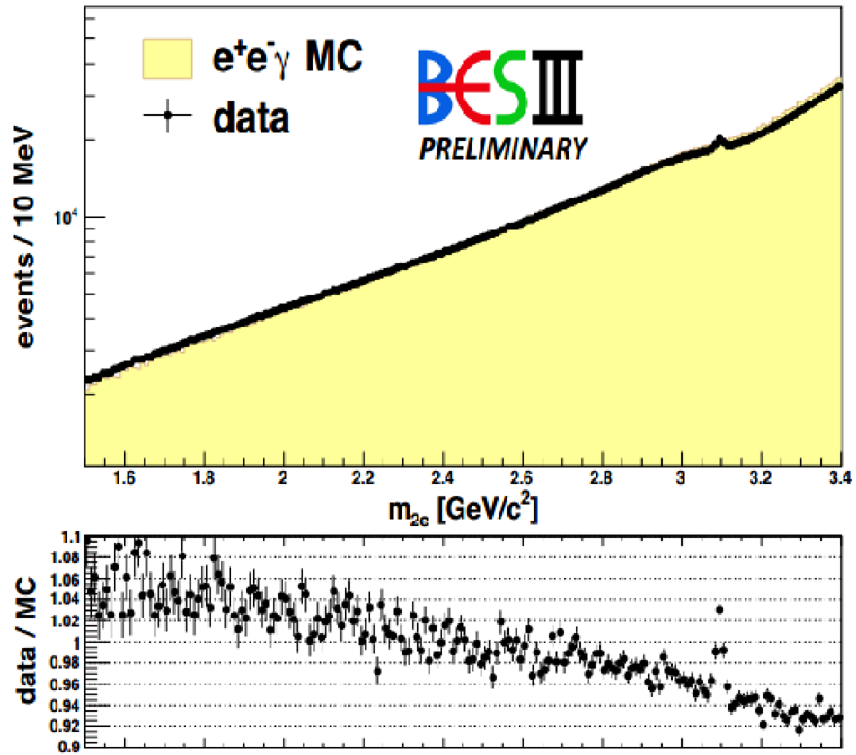
distance to interaction point	$R_{xy} < 1.0$ cm $R_z < 10.0$ cm
acceptance	0.4 rad < θ < π – 0.4 rad
to supress background	PID
# charged tracks	= 2
total charge	= 0
# photons	= 0 (untagged analysis)
missing photon angle	< 0.1 rad or > π – 0.1 rad
1C kinematic fit	$\chi^2_{1C} < 20$





Spectrum of ee and mumu channel



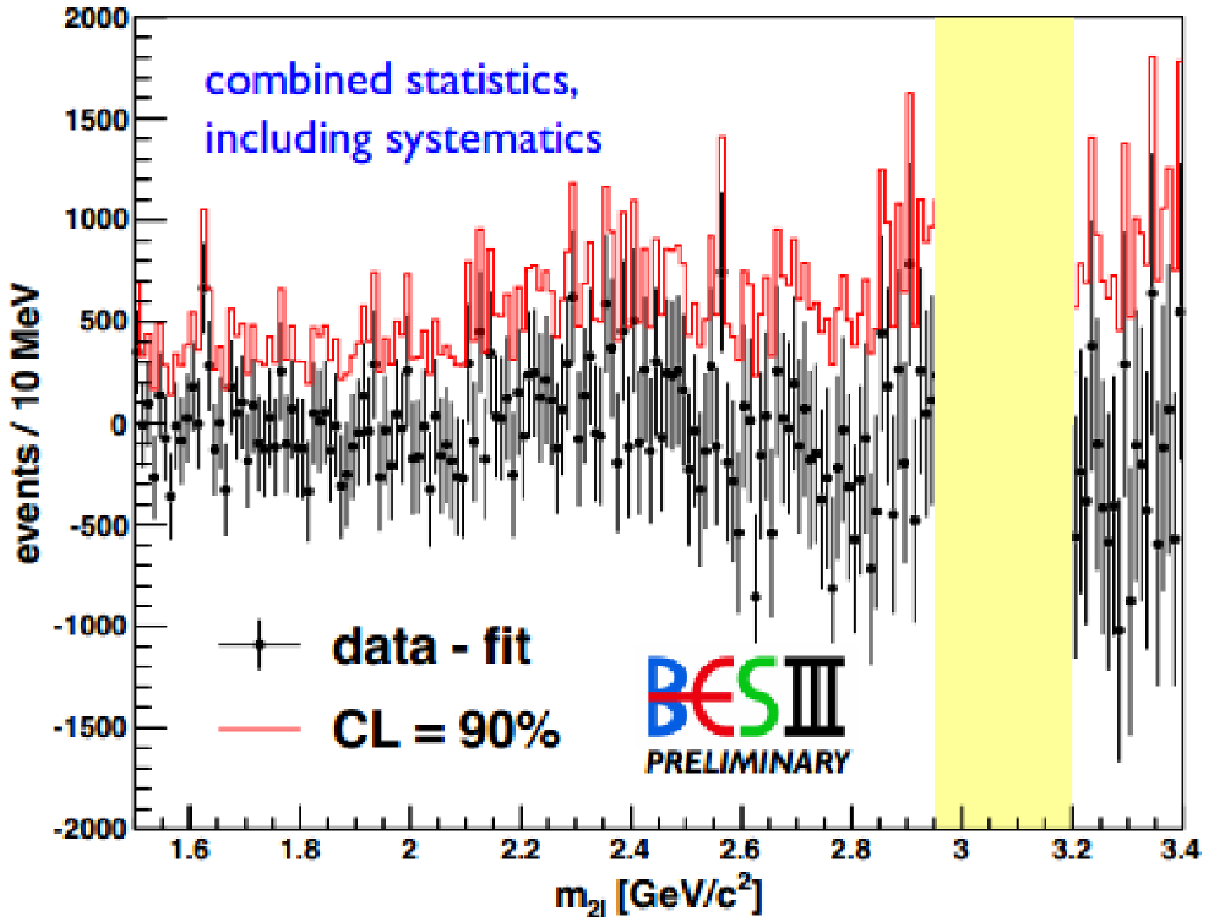


2.9fb-1 psi"

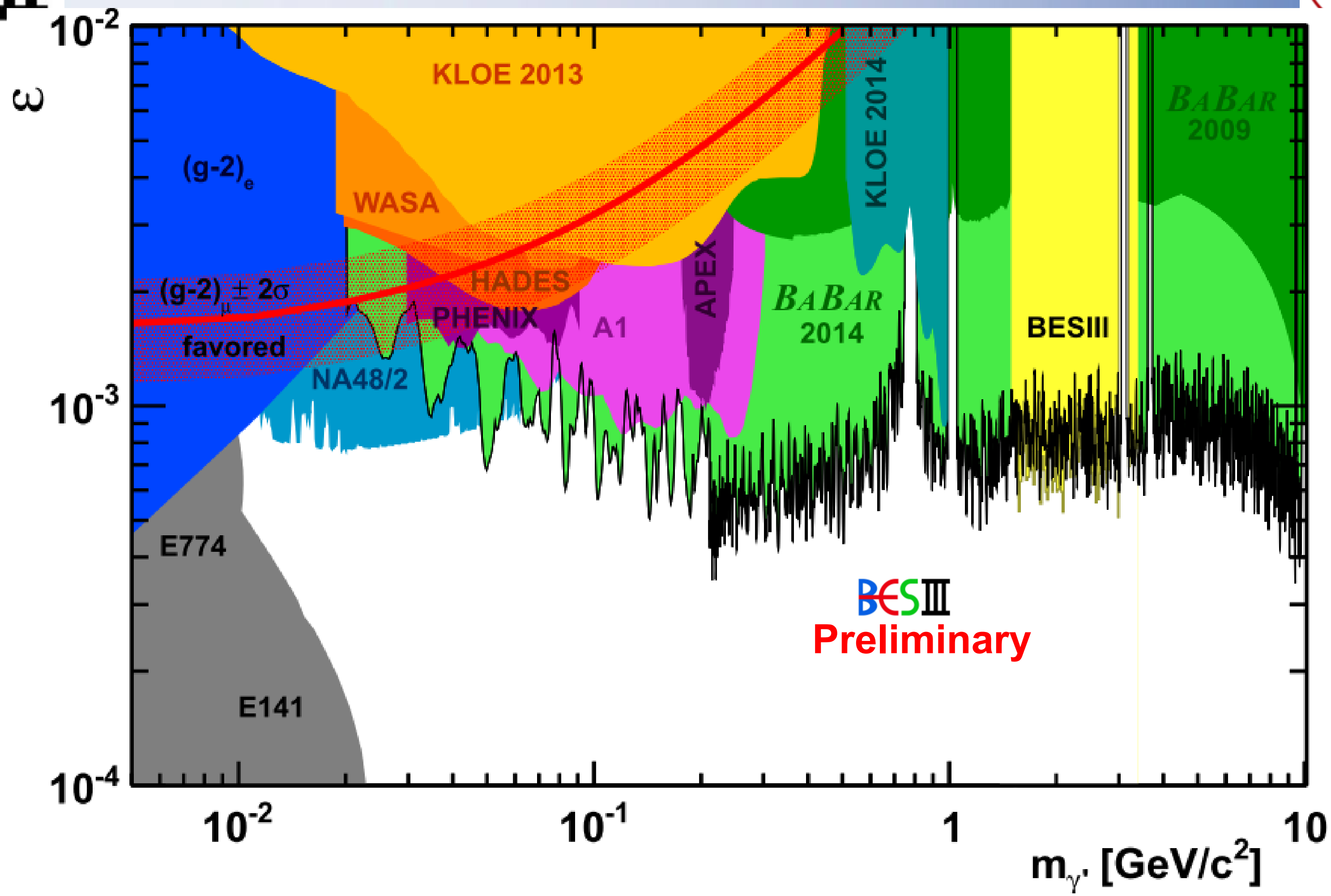
Upper limit setting

- Set the 90% C.L. upper limit using TRolke method.

Nucl.Instrum.Meth., A551, 493-503 (2005)



BESIII ISR search results



Some searches with meson decays are also going on with BESIII data, but less competitive

Summary

- High lumi and good detector enables BESIII sensitive to LFV in meson decays
- The published results on $J/\psi \to e\mu$ yield the best limit from Heavy Quarkonium decays
- LFV J/ψ decays involving τ are going on, would be more close to probe some models
- FLV in other mesons: D, Ds, eta, eta', V's are also possible, to be further investigated
- Other New Physics searches from BESIII are also active, more to come

Thanks!

Extra slides…

Lepton flavour violation

$$\mathcal{B}(\tau^- \to \mu^- \mu^+ \mu^-) \quad < \quad 4.6 \times 10^{-8} \text{ at } 90\% \text{ CL}$$

$$\mathcal{B}(B^0 \to e^\pm \mu^\mp) < 2.8 \times 10^{-9} \text{ at } 90\% \text{ CL}$$

$$\mathcal{B}(B_s^0 \to e^\pm \mu^\mp) < 1.1 \times 10^{-9}$$

$$\mathcal{B}(D^0 \to e^\pm \mu^\mp) < 1.5 \times 10^{-8} \text{ at } 90\% \text{ CL}$$

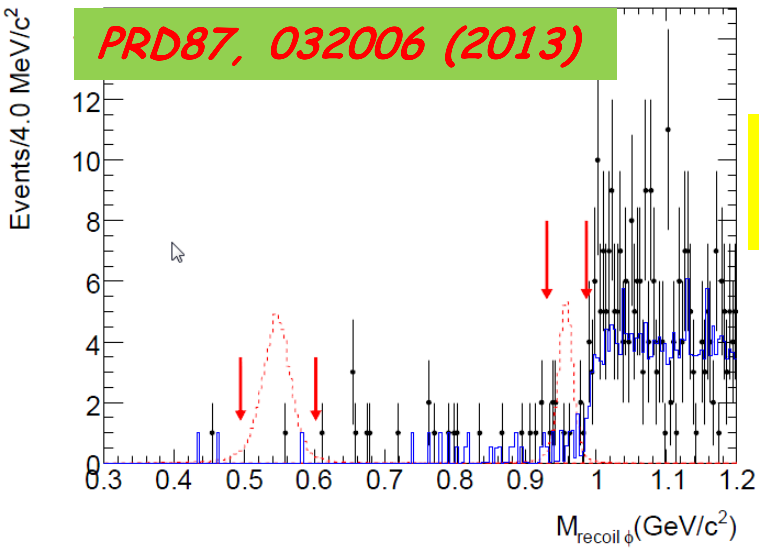
$$\mathcal{B}(D^+ \to \pi^- \mu^+ \mu^+) < 2.2 \cdot 10^{-8}$$

$$\mathcal{B}(D_s^+ \to \pi^- \mu^+ \mu^+) < 1.1 \cdot 10^{-8}$$

at 90% CL

Probing NP with Charmonia and Charmed mesons

Symmetry breaking, Invisible decays, FCNC …



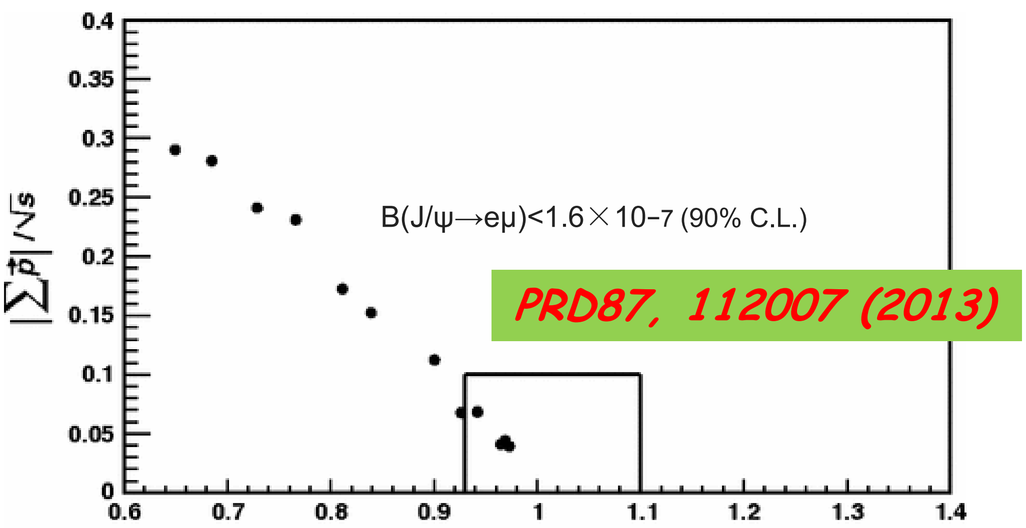
$B(\eta \to \text{invisible}) < 1.0\times 10^{-4}$
$B(\eta' \to \text{invisible}) < 5.3\times 10^{-4}$

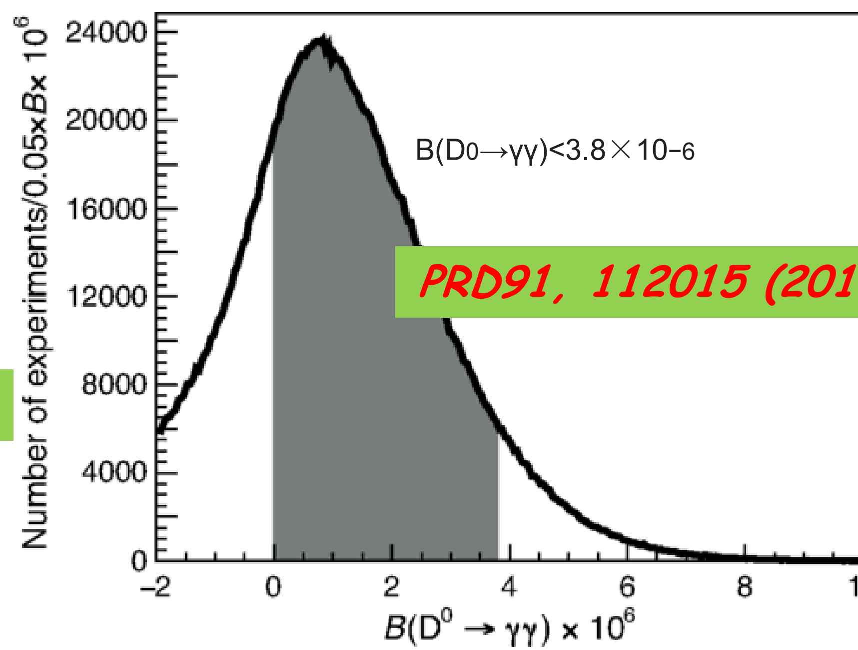
@90%C.L.

Theory:
PRD 72, 103508(2005)

$BR(\eta \to \chi\chi) \sim 7.4 \times 10^{-5}$

$BR(\eta' \to \chi\chi) \sim 8.1 \times 10^{-7}$





$D^0 \to \gamma\gamma$: Motivation

- FCNC mode, forbidden at tree level

→ Larger GIM suppression

→ Short distance: BF~10^{-11} [PRD66 (2002) 014009]

→ Long distance due to VMD: BF~10^{-8} [PRD66 (2002) 014009]

→ MSSM up to BF~10^{-6} [PLB500(2001)304], i.e. $c \to u\gamma$ via gluino exchange

- BaBar (PRD85, 091107(R) (2012)):
  - Reconstruct through $D^{*+} \to D^0(\to \gamma\gamma)\pi^+$, normalized by $D^{*+} \to D^0(\to K_S\pi^0)\pi^+$.
  - Peaking background from $D^0 \to \pi^0\pi^0$.
  - $B(D^0 \to \gamma\gamma) < 2.2\times10^{-6}$ @ 90% C.L.

Phys. Rev. D 85 (2012) 091107R