Dalitz Decay Studies at BESIII

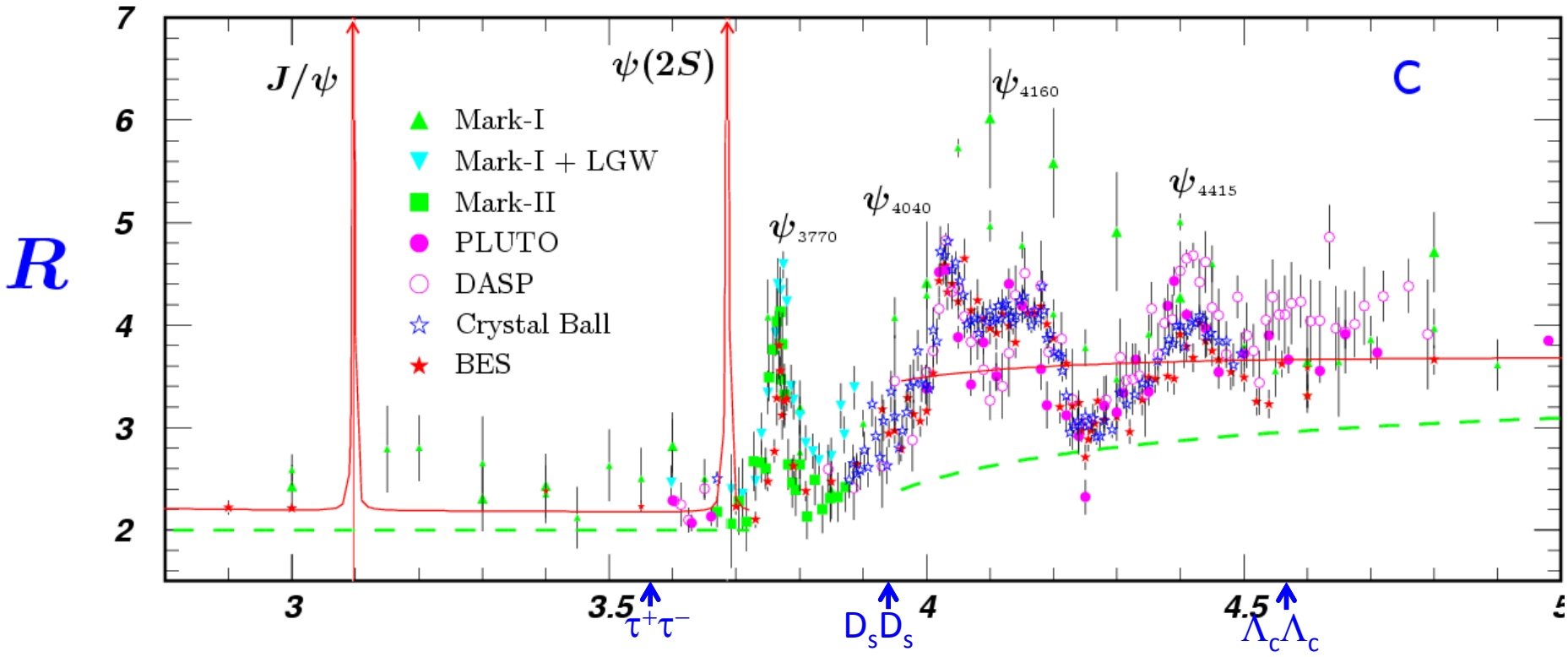
Dayong Wang（王大勇）
(for BESIII Collaboration)

北京大学
PEKING UNIVERSITY

PHIPSI2015, USTC, Sep 25 2015

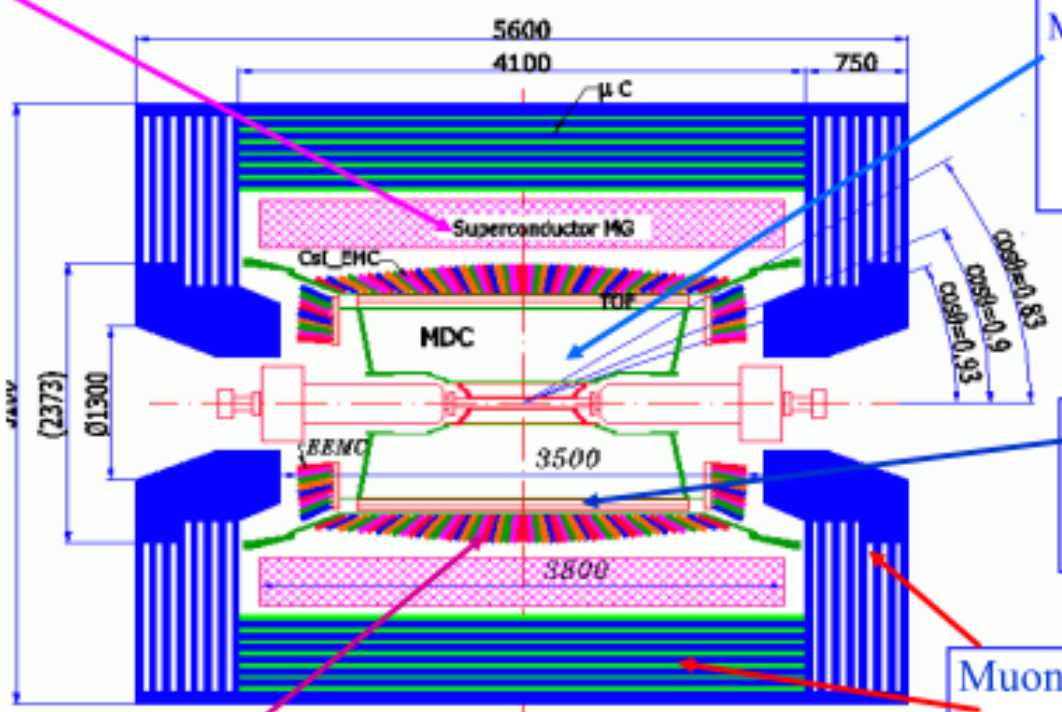
BEPCII: a τ-c Factory

- Rich of **resonances**, charmonia and charmed mesons.
- **Threshold** characteristics (pairs of τ, D, D_s, charmed baryons…).
- **Transition** between perturbative and non-perturbative **QCD**.
- The **hadrons**: states, structures and interactions



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%

Ref:
NIM A614, 345 (2010)

TOF:
σ_T = 90 ps Barrel
110 ps Endcap

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
$\sigma_{\phi,z}$ = 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

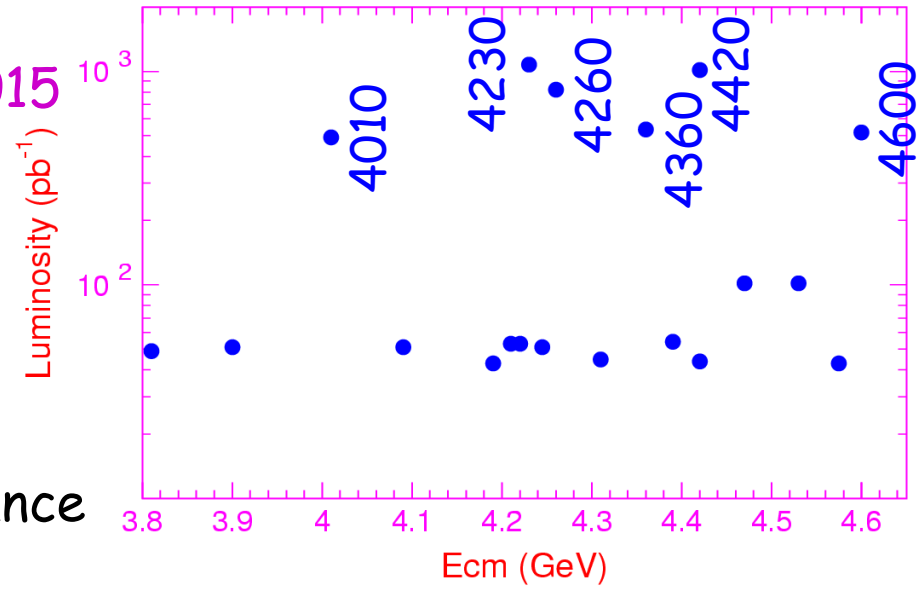
Clean environment and high luminosity at BESIII are helpful to study structure/interaction of hadrons

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

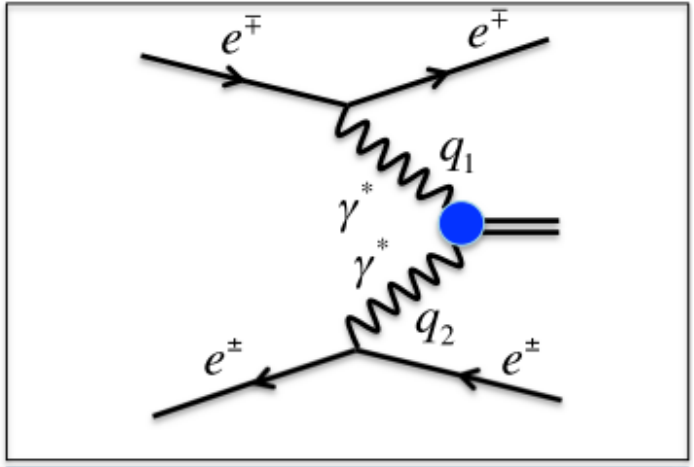
2016: we will take 3/fb Ds data about 4170 MeV ~ 5×CLEO-c



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

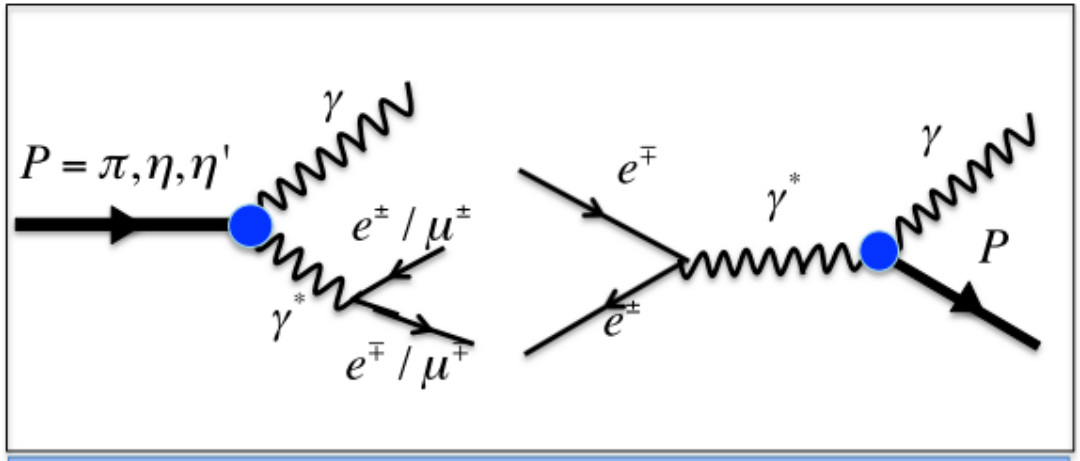
Dalitz-type decays:

- EM probe
- Transition Form Factors
- VMD models



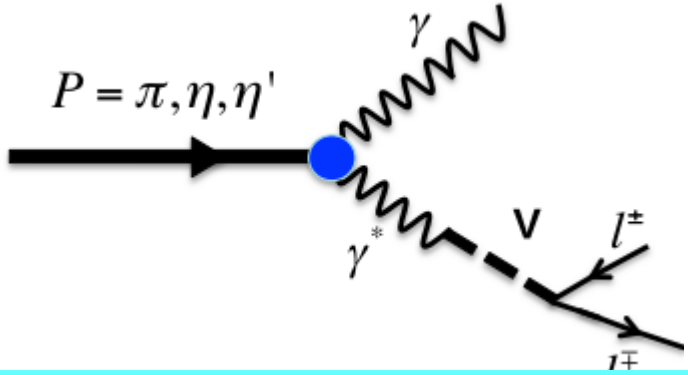
Space-like $q^2 < 0$

Photon-photon fusion
Accessed at e^+e^- colliders



Time-like $q^2 > 0$

Single or double Dalitz decay, $4m_l^2 < q^2 < m_P^2$
Annihilation process, $q^2 > m_P^2$



L. G. Landsberg,
Phys. Rept. 128, 301 (1985)

To better understand $(g-2)_\mu$

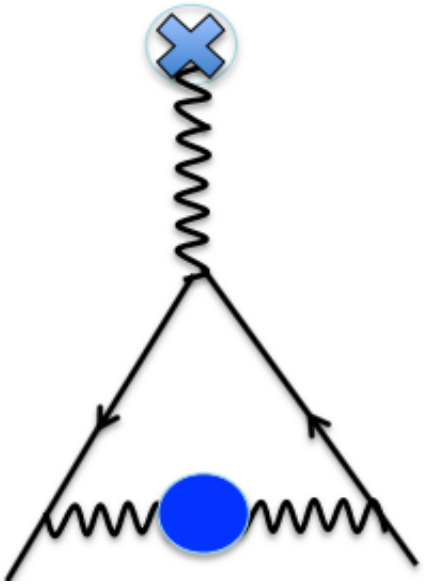
$$\Delta a_\mu^{\exp-SM} = 28.7 \pm 8.0 \cdot 10^{-10}$$

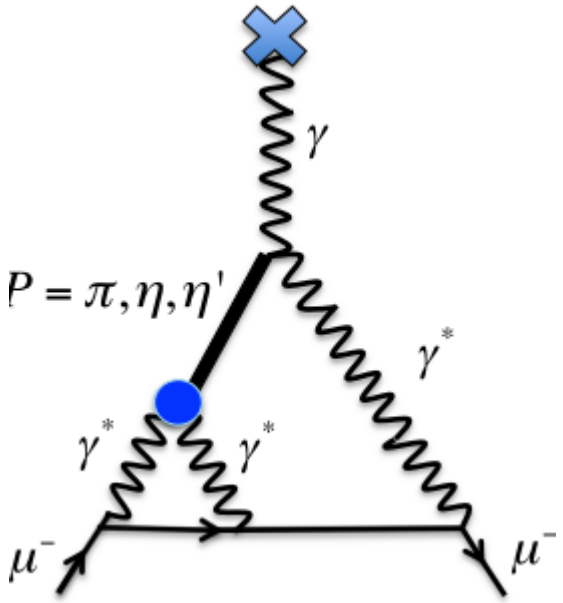
Eur Phys J C71, 1515(2011)

$$a_\mu^{QED} = (11\,658\,471.809 \pm 0.015) \cdot 10^{-10}$$

$$a_\mu^{W,Z} = (15.4 \pm 0.2) \cdot 10^{-10}$$

$$a_\mu^{hadr} = (692.3 \pm 4.2) \cdot 10^{-10} + (10.5 \pm 2.6) \cdot 10^{-10} + \ldots$$

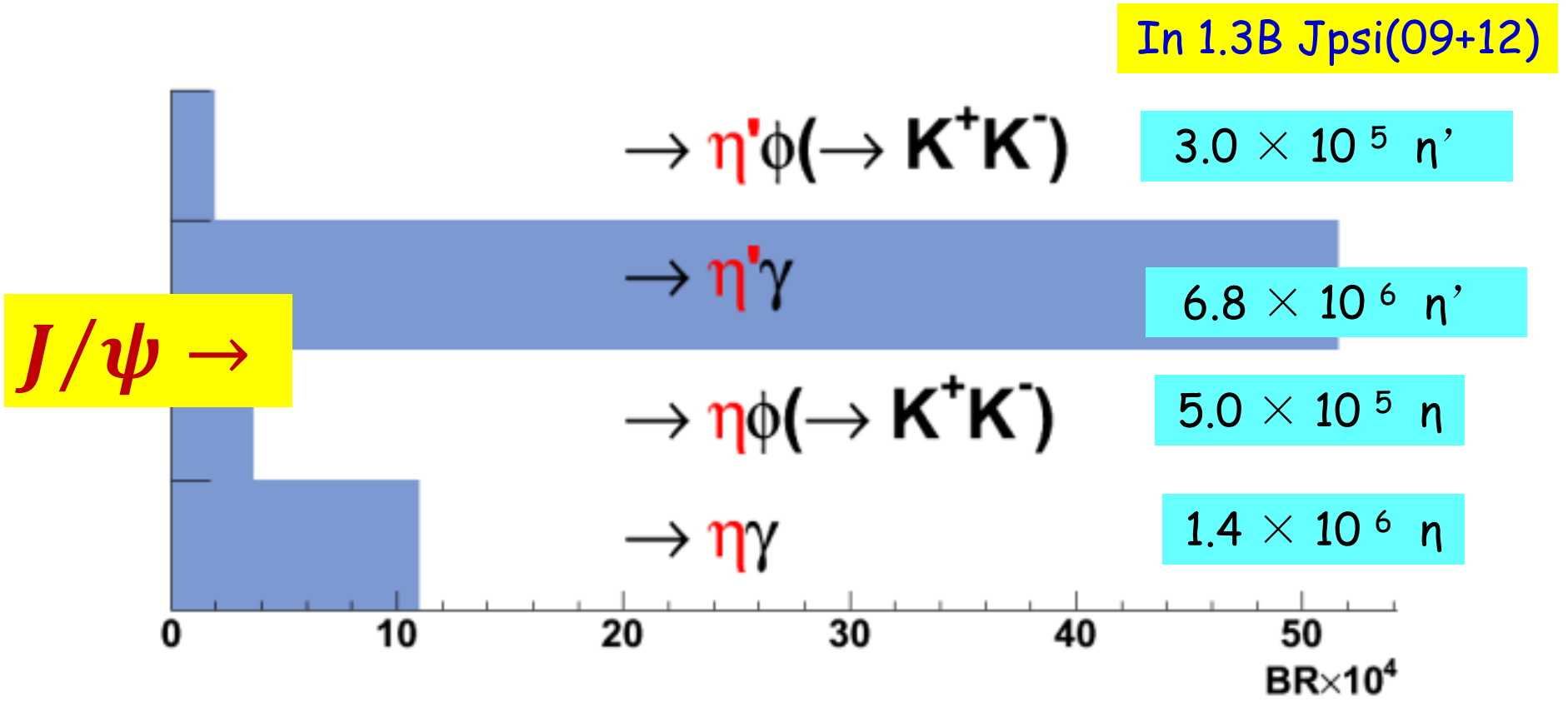




EM Dalitz Decay Studies:
Highlighted topics from BESIII

- $\eta' \to \gamma e^+ e^-$ 1.3B Jpsi(09+12)
- Ref *Phys. Rev. D 92, 012001(2015)* more detail for demo
- $\eta' \to \omega e^+ e^-$ 1.3B Jpsi(09+12)
- Ref Phys. Rev. D 92, 051101(R) (2015), online Sep 14 2015
- $J/\psi \to P e^+ e^- (P = \eta'/\eta/\pi^0)$ 225M Jpsi(09)
- Ref *Phys. Rev. D 89, 092008 (2014)*
- All are the first observations

η and η′ yields with BESIII J/ψ data set



Rich physics programs, rf. S. Fang's talk on Sep 26

Discrimination of gamma conversion

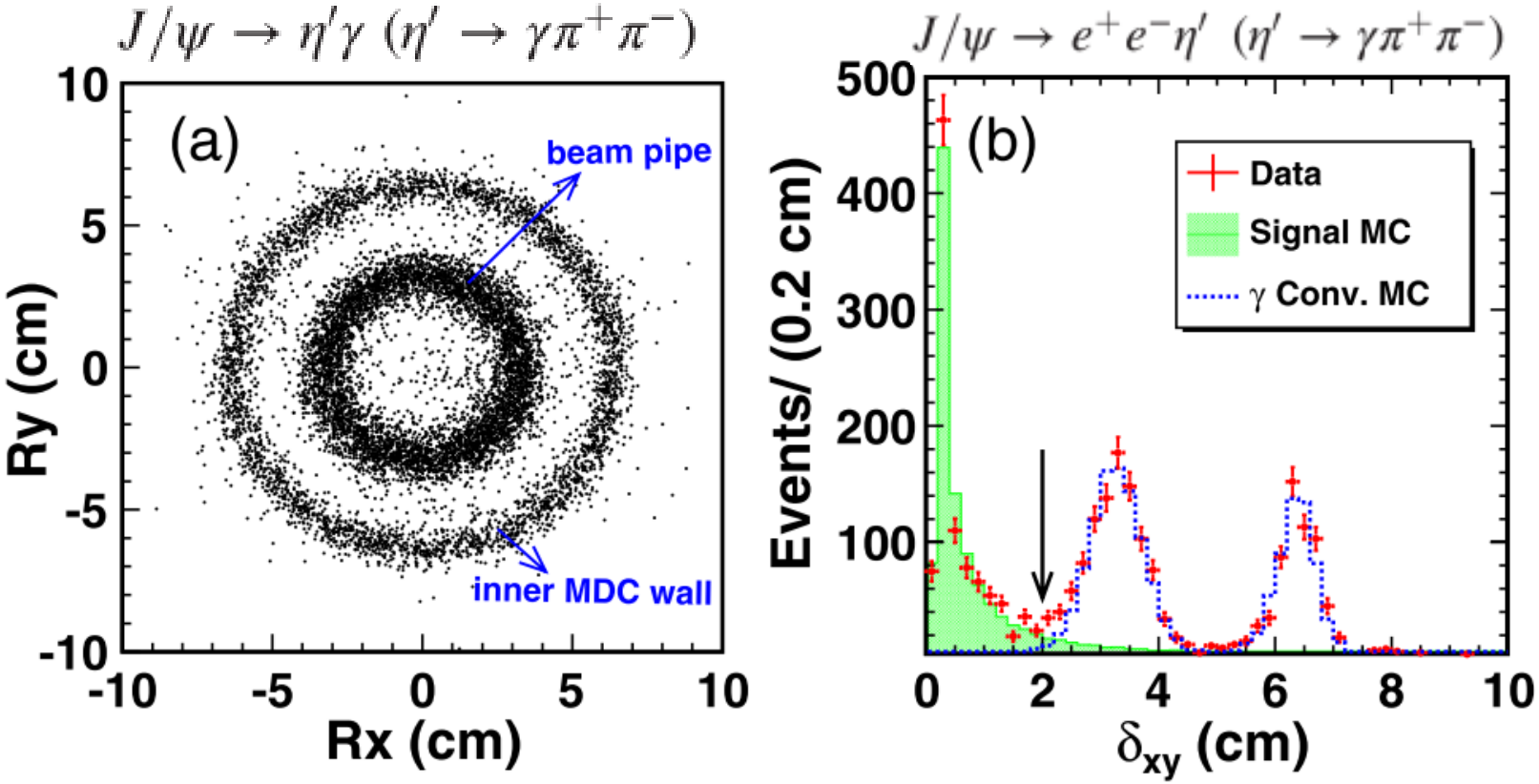


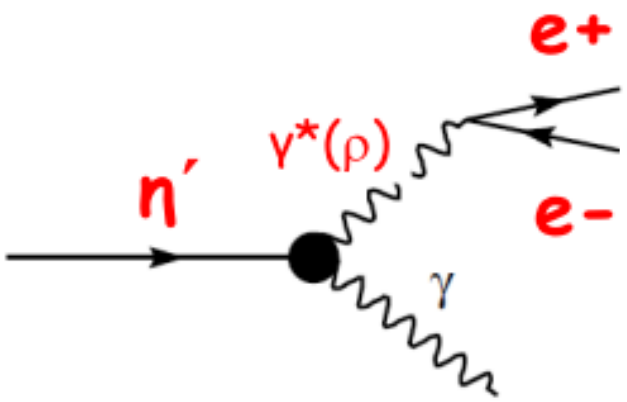
Photo conversion finder

based on common vertex position on the transverse plane

Z. R. Xu and K. L. He, Chin. Phys. C 36, 742 (2012).

$\eta' \to \gamma e^+ e^-$: Motivation

- Investigate the inner structure of the meson
- Transition form factor to better understand the anomalous muon magnetic moment
- VMD multipole FF: $F(q^2) = N \sum_V \frac{g_{\eta'\gamma V}}{2g_{V\gamma}} \cdot \frac{m_V^2}{m_V^2 - q^2 - i\Gamma_V m_V}$



$$\frac{d\Gamma(\eta' \to \gamma l^+ l^-)}{dq^2 \Gamma(\eta' \to \gamma\gamma)} = [\mathrm{QED}(q^2)] \times |F(q^2)|^2$$

$$= \frac{2\alpha}{3\pi} \frac{1}{q^2} \sqrt{1 - \frac{4m_l^2}{q^2}} \left(1 + \frac{2m_l^2}{q^2}\right) \left(1 - \frac{q^2}{m_{\eta'}^2}\right)^3 |F(q^2)|^2$$

Event selections: $\eta' \to \gamma e^+ e^-$ from $J/\psi \to \gamma\eta'$

- Good Charged Tracks
  1. $|V_r| < 1.0cm \quad |V_z| < 10.0cm \quad \cos(\theta) < 0.93$
  2. 2 good charged tracks and 0 total charge
- Good Photons
  1. at least 2 good photons
  2. Barrel ($\cos\theta < 0.8$) $\quad E_\gamma > 25MeV$
  3. Endcap ($0.86 < \cos\theta < 0.92$) $\quad E_\gamma > 50MeV$
  4. $TDC \quad [0, 14] \quad isoAngle > 10^\circ$
- PID
  1. use dE/dx and TOF
  2. $prob(e) > prob(\pi)$
- Vertex Fit e^+e^-
- 4C Kin.Fit $\gamma\gamma e^+e^-$ *candiadate with least* χ^2_{4C}

  $\chi^2_{4C} < 100$

Normalization channel & bkg

Selection of Normalization channel

- At least three good photons
  1. Barrel $(\cos(\theta) < 0.80)$ $E_\gamma > 25MeV$
  2. Endcap $(0.86 < \cos(\theta) < 0.92)$ $E_\gamma > 50MeV$
  3. TDC time window $|T - T0| < 10$
- 4C Kin fit candidate with least χ^2_{4C} $\chi^2_{4C} < 100$

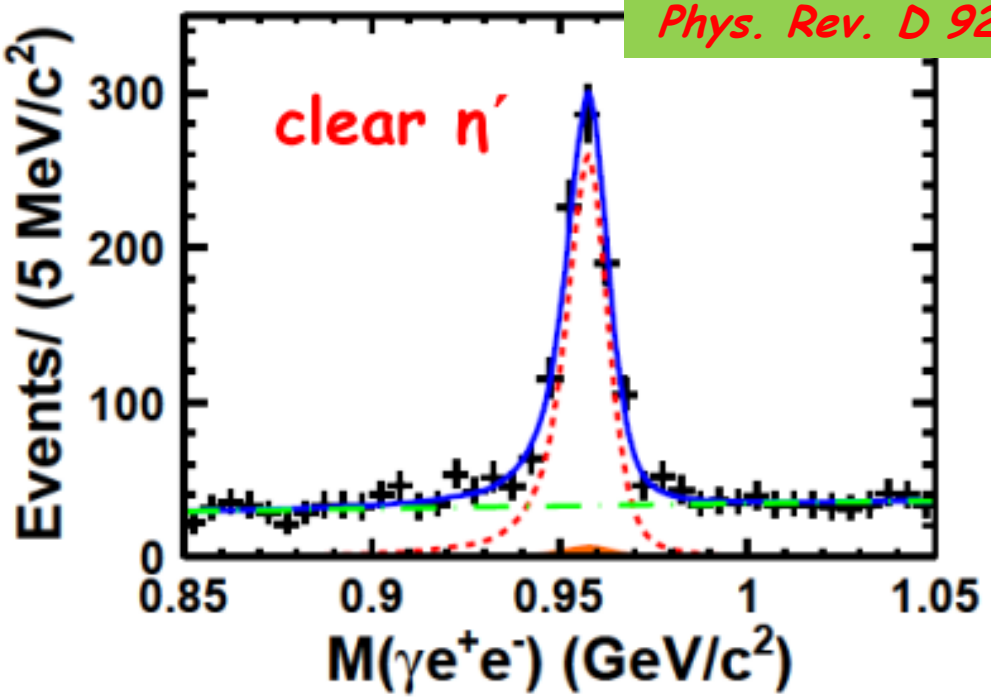
Background studies

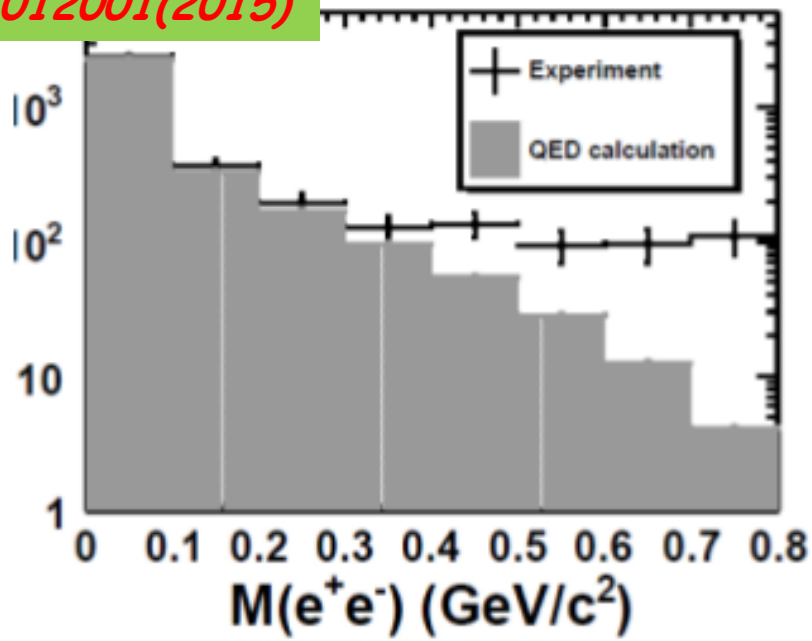
- QED process dominated by $e^+e^- \to e^+e^-\gamma_{FSR}$
- $e^+e^- \to 3\gamma$
- $J/\psi \to e^+e^-\gamma_{FSR}$
- Multi π^0 final states
- Gamma conversion events from $\eta' \to \gamma\gamma$ ⇒ $\delta xy < 2cm$
- Pions misidentified as electrons $\eta' \to \gamma\pi^+\pi^-$

⇒ $prob(e)/(prob(e) + prob(\pi)) > 0.95$

First observation of $\eta' \to \gamma e^+ e^-$

Phys. Rev. D 92, 012001(2015)



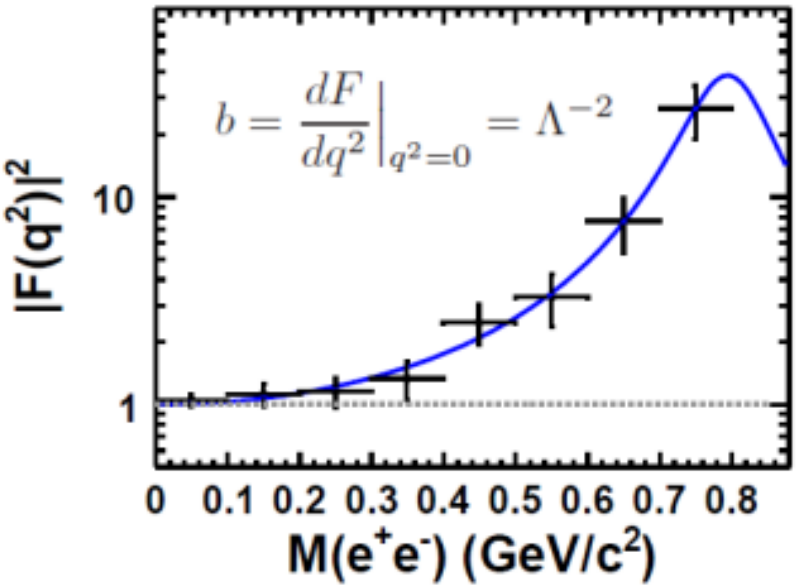


$$\frac{\Gamma(\eta' \to \gamma e^+ e^-)}{\Gamma(\eta' \to \gamma\gamma)} = (2.13 \pm 0.09(\text{stat.}) \pm 0.07(\text{sys.})) \times 10^{-2}$$

$$\mathcal{B}(\eta' \to \gamma e^+ e^-) = (4.69 \pm 0.20(\text{stat.}) \pm 0.23(\text{sys.})) \times 10^{-4}$$

4.2×10^{-4} effective meson theory, PRC61,035206

$\eta' \to \gamma e^+ e^-$: Transition Form Factor



$$|F(q^2)|^2 = \frac{\Lambda^2(\Lambda^2+\gamma^2)}{(\Lambda^2-q^2)^2+\Lambda^2\gamma^2}$$

$$\Lambda_{\eta'} = (0.79 \pm 0.04(\text{stat.}) \pm 0.02(\text{sys.}))\ \text{GeV}$$

$$\gamma_{\eta'} = (0.13 \pm 0.06(\text{stat.}) \pm 0.03(\text{sys.}))$$

$$b_{\eta'} = (1.60 \pm 0.17(\text{stat.}) \pm 0.08(\text{sys.}))\ \text{GeV}^{-2}$$

Phys. Rev. D 92, 012001(2015)

- In agreement with the results of $\eta' \to \gamma\mu^+\mu^-$ from CELLO

$$b_{\eta'} = (1.7 \pm 0.4)\ \text{GeV}^{-2}$$

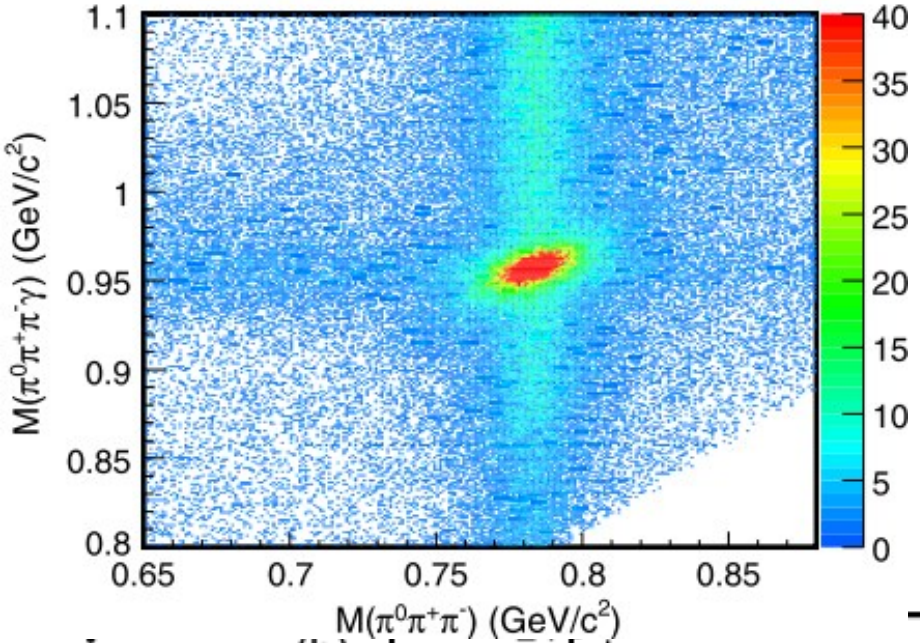
- Theoretical predictions:

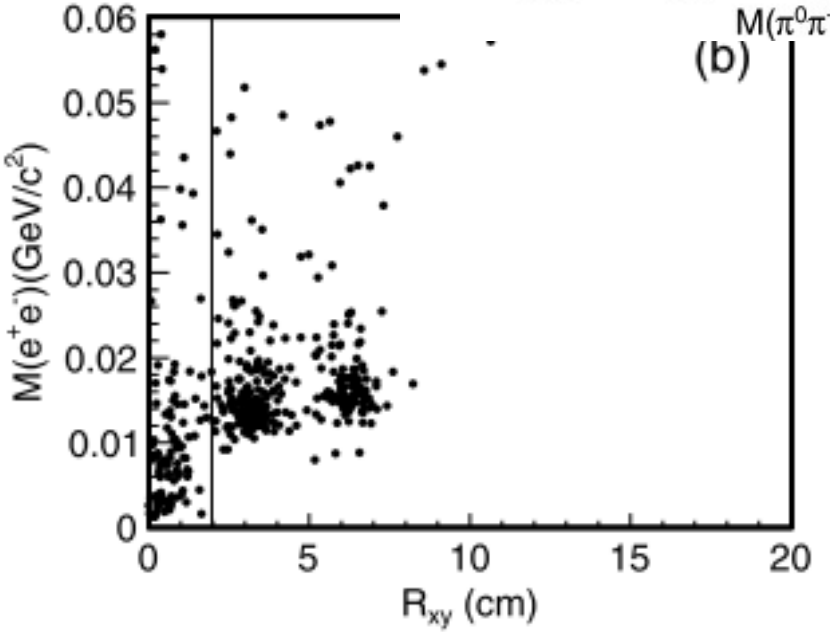
$$b_{\eta'} = 1.45\ \text{GeV}^{-2} \quad \text{VMD}$$

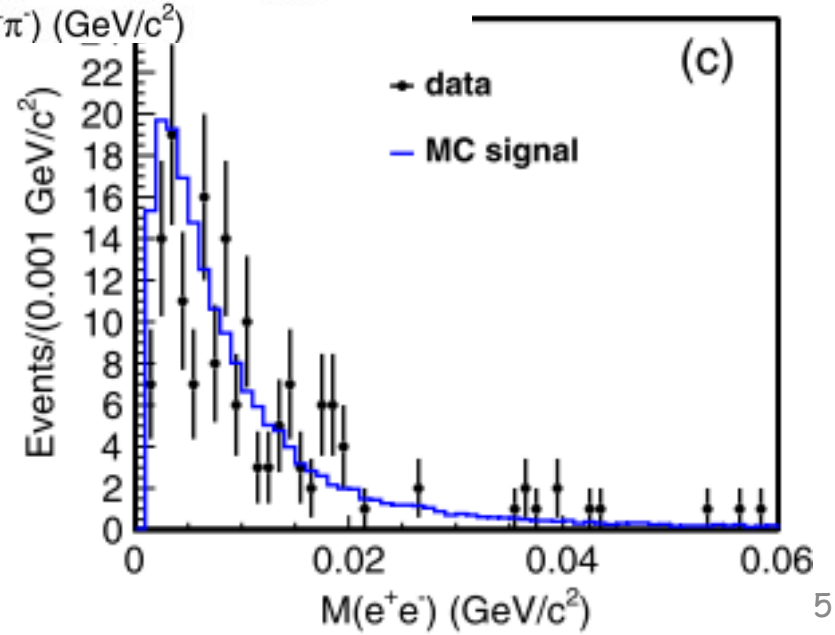
$$b_{\eta'} = 1.60\ \text{GeV}^{-2} \quad \text{ChPT}$$

$$b_{\eta'} = 1.53^{+0.15}_{-0.08}\ \text{GeV}^{-2} \quad \text{Dispersion}$$

$\eta' \to \omega\gamma$ and $\eta' \to \omega e^+e^-$

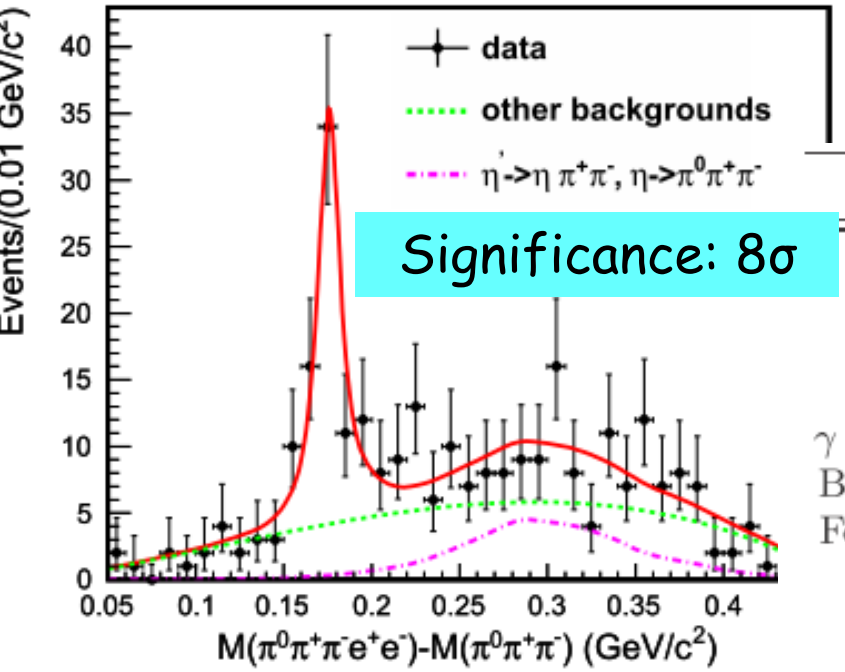






Observation of $\eta' \to \omega e^+ e^-$

Phys. Rev. D 92, 051101(R) (2015)



Significance: 8σ

Sources	$\eta' \to \omega e^+ e^-$	$\eta' \to \omega\gamma$	$\frac{\mathcal{B}(\eta' \to \omega e^+ e^-)}{\mathcal{B}(\eta' \to \omega\gamma)}$
MDC tracking	4.4	2.0	2.4
Photon detection	3.0	4.0	1.0
PID	3.8	–	3.8
Kinematic fit	1.8	0.5	1.9
γ conversion subtraction	1.0	–	1.0
Background uncertainty	3.7	2.9	4.7
Form factor uncertainty	1.3	–	1.3
π^0 mass window	1.4	1.4	–
J/ψ total number	0.8	0.8	–
$\mathcal{B}(J/\psi \to \gamma\eta')$	3.1	3.1	–
$\mathcal{B}(\omega \to \pi^0\pi^+\pi^-)$	0.8	0.8	–
Total	8.7	6.4	7.0

Systematic uncertainties

Results of $\eta' \to \omega\gamma$ and $\eta' \to \omega e^+e^-$

Phys. Rev. D 92, 051101(R) (2015)

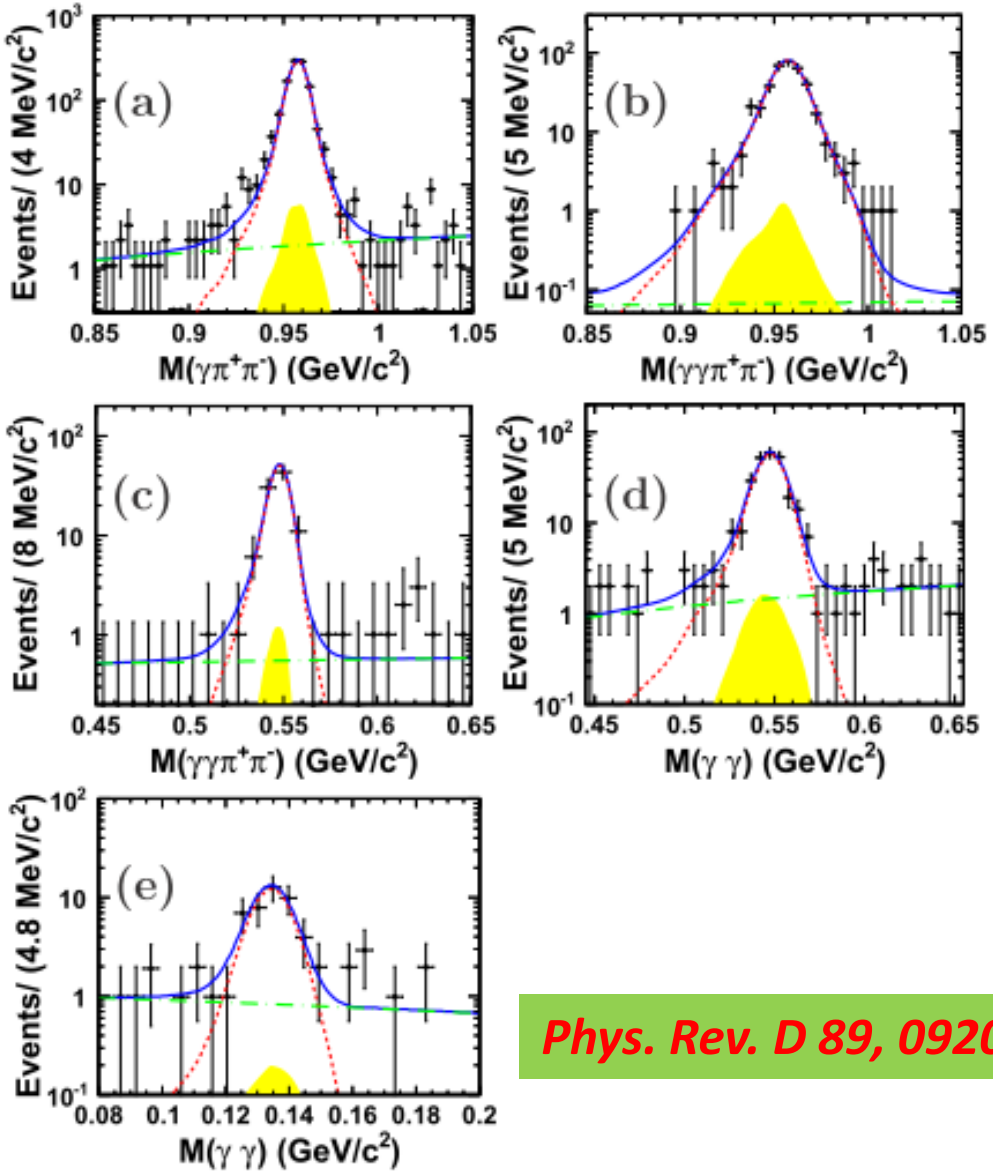
Decay mode	Yield	$\varepsilon(\%)$	Branching fraction
$\eta' \to \omega\gamma$	33187 ± 351	21.87	$(2.55 \pm 0.03 \pm 0.16) \times 10^{-2}$
$\eta' \to \omega e^+e^-$	66 ± 11	5.45	$(1.97 \pm 0.34 \pm 0.17) \times 10^{-4}$

$$\frac{\mathcal{B}(\eta' \to \omega e^+e^-)}{\mathcal{B}(\eta' \to \omega\gamma)} = (7.71 \pm 1.34(\text{stat}) \pm 0.54(\text{syst})) \times 10^{-3}$$

Compatible with theory predictions:

- 2.0×10^{-4}
  - Ref: Faessler, Fuchs, Krivoruchenko, Phys. Rev. C 61, 035206 (2000)
- $1.69 \pm 0.56 \times 10^{-4}$
  - Ref: Terschlüsen, Leupold, Lutz, EPJ. A48 (2012) 190

First observation of $J/\psi \to Pe^+e^-$



	Modes	N_S	N_B	ϵ
a)	$J/\psi \to \eta' e^+e^- (\eta' \to \gamma\pi^+\pi^-)$	983.3 ± 33.0	27.4 ± 1.0	24.8%
b)	$J/\psi \to \eta' e^+e^- (\eta' \to \pi^+\pi^-\eta)$	373.0 ± 19.9	8.5 ± 0.3	17.6%
c)	$J/\psi \to \eta e^+e^- (\eta \to \pi^+\pi^-\pi^0)$	84.2 ± 9.6	5.3 ± 0.3	14.9%
d)	$J/\psi \to \eta e^+e^- (\eta \to \gamma\gamma)$	235.5 ± 16.4	8.7 ± 0.3	22.7%
e)	$J/\psi \to \pi^0 e^+e^- (\pi^0 \to \gamma\gamma)$	39.4 ± 6.9	1.1 ± 0.1	23.4%

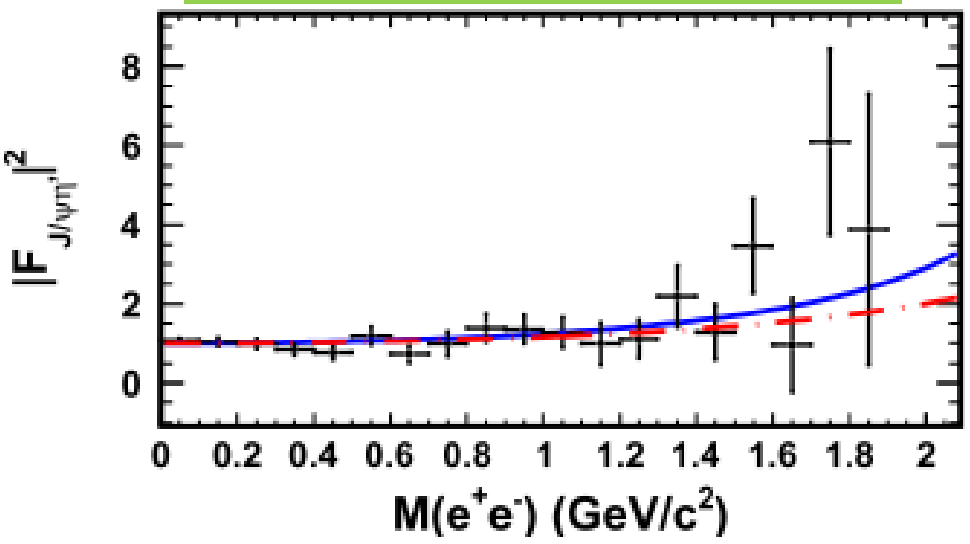
Red	– data points
Blue	– total MC fits
Yellow	– peaking bgd
Green	– non peaking bgd

Phys. Rev. D 89, 092008 (2014)

Results: $J/\psi \to Pe^+e^-$

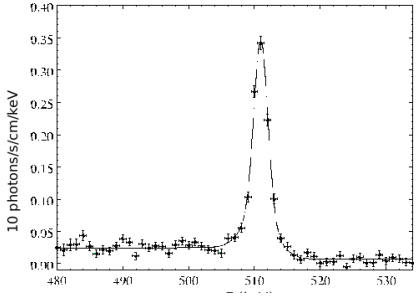
Mode	Branching fraction	Combined result	Theoretical prediction
$J/\psi \to \eta' e^+ e^- (\eta' \to \gamma\pi^+\pi^-)$	$(6.01 \pm 0.20 \pm 0.34) \times 10^{-5}$		
$J/\psi \to \eta' e^+ e^- (\eta' \to \pi^+\pi^-\eta)$	$(5.51 \pm 0.29 \pm 0.32) \times 10^{-5}$	$(5.81 \pm 0.16 \pm 0.31) \times 10^{-5}$	$(5.66 \pm 0.16) \times 10^{-5}$
$J/\psi \to \eta e^+ e^- (\eta \to \pi^+\pi^-\pi^0)$	$(1.12 \pm 0.13 \pm 0.06) \times 10^{-5}$		
$J/\psi \to \eta e^+ e^- (\eta \to \gamma\gamma)$	$(1.17 \pm 0.08 \pm 0.06) \times 10^{-5}$	$(1.16 \pm 0.07 \pm 0.06) \times 10^{-5}$	$(1.21 \pm 0.04) \times 10^{-5}$
$J/\psi \to \pi^0 e^+ e^- (\pi^0 \to \gamma\gamma)$	$(7.56 \pm 1.32 \pm 0.50) \times 10^{-7}$	$(7.56 \pm 1.32 \pm 0.50) \times 10^{-7}$	$(3.89^{+0.37}_{-0.33}) \times 10^{-7}$

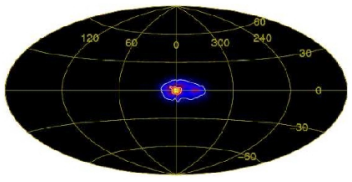
Phys. Rev. D 89, 092008 (2014)



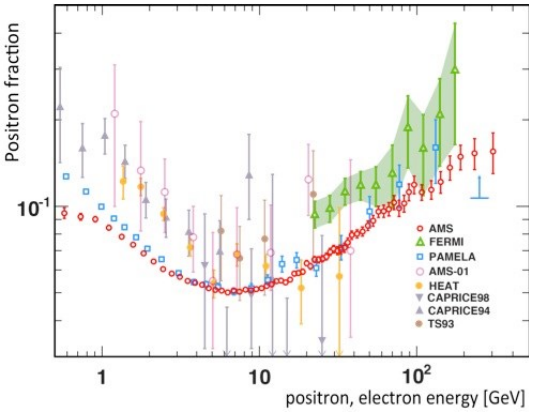
$J/\psi \to PU(e^+e^-)$: Dark photon search with meson decays

- Worldwide endeavor in high intensity frontier (rf: topical session on Sep 26)





511 keV line - sky map
G. Weidenspointner et al., Nature 451 (2008) 159




NEWS IN FOCUS

US POLICY Effort to protect science from politics hits a bump p.15 | SOCIAL SCIENCE Harvard engineers help to police the mean streets p.16 | CLIMATE SCIENCE Monitoring the vital signs of Asian glaciers p.18 | BRAIN IMAGING fMRI is becoming more than a pretty picture p24

The Jefferson Lab's Free-Electron Laser is a low-cost option in the bid to discover dark-sector forces.

PARTICLE PHYSICS

Physicists hunt for dark forces

Cheap colliders probe debris for hint of 'heavy' photon.

NATURE, 2012.4

$$\frac{\Gamma(V \to PU)}{\Gamma(V \to P\gamma)} = \epsilon^2 \left|F_{VP\gamma^*}(m_U^2)\right|^2 \frac{\lambda^{3/2}(m_V^2, m_P^2, m_U^2)}{\lambda^{3/2}(m_V^2, m_P^2, 0)}.$$

Reece& Wang, *J. High Energy Phys.* 051(2009).

Summary

Dalitz type decays to provide more info about meson structure, and plays important role in constraining the uncertainties to $(g-2)_\mu$

- BESIII has studied several Dalitz type decays
- The following processes are first observed and measured

$$\eta' \to \gamma e^+ e^-$$
$$\eta' \to \omega e^+ e^-$$
$$J/\psi \to P e^+ e^- (P = \eta'/\eta/\pi^0)$$

- More to come

Thank you!