JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Transition Form Factors (experimental overview - 2)

Patrik Adlarson
A2 collaboration

MesonNet 2014 – Sep 29 – Oct 1, 2014

Outline

Motivation

WASA results

A2 results

BESIII results

Motivation

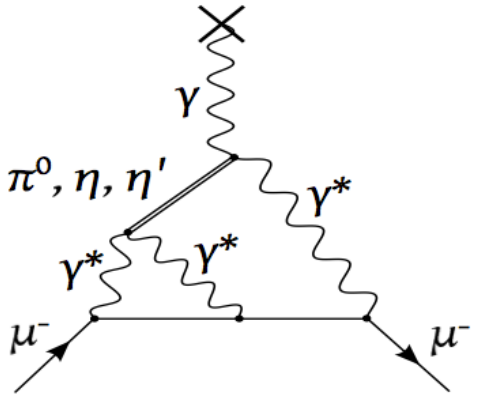
EM TFF allow us access to intrinsic structures of Pseudoscalar mesons (P)

Possible gluonic contribution to η and η' can be studied

The leading hadronic contribution to anomalous magnetic moment given by exchange of light hadrons coupled to two photons

Light by light contribution expected to scale as m_{had}^{-2}

MesonNet Workshop on MTFF
arXiv:1207.6556v2 [hep-ph]



e.g. Dalitz decay

$$P \longrightarrow \gamma^*\gamma \longrightarrow e^+e^-\gamma$$

…but also other anomalous decays involving TFF.

Motivation

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Off-shell P form factors not accessible experimentally

Any aspiring model should be able to correctly describe the on-shell scenario

Lowest time like region studied in

$$4m_l^2 < q^2 < m_P^2$$

MesonNet Workshop on MTFF
arXiv:1207.6556v2 [hep-ph]

$$P \longrightarrow \gamma^{(*)}\gamma^{(*)}$$

Photons either real or virtual

Motivation: π^0 Dalitz Decay

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Observable: slope parameter a_π
$FF = (1 - a_\pi x)^{-1} \sim 1 + a_\pi x$ for small a_π

Theory

VMD	+0.031
ChPT 2 –loop	+0.029(5)

Kampf, Knecht, Novotný, EPJ C46 (2006) 191

Experiment

SINDRUM-I Coll. $+0.025(14)_{stat}(26)_{syst}$ 54k
Drees *et al* Phys.Rev.D 45 (1992) 1439

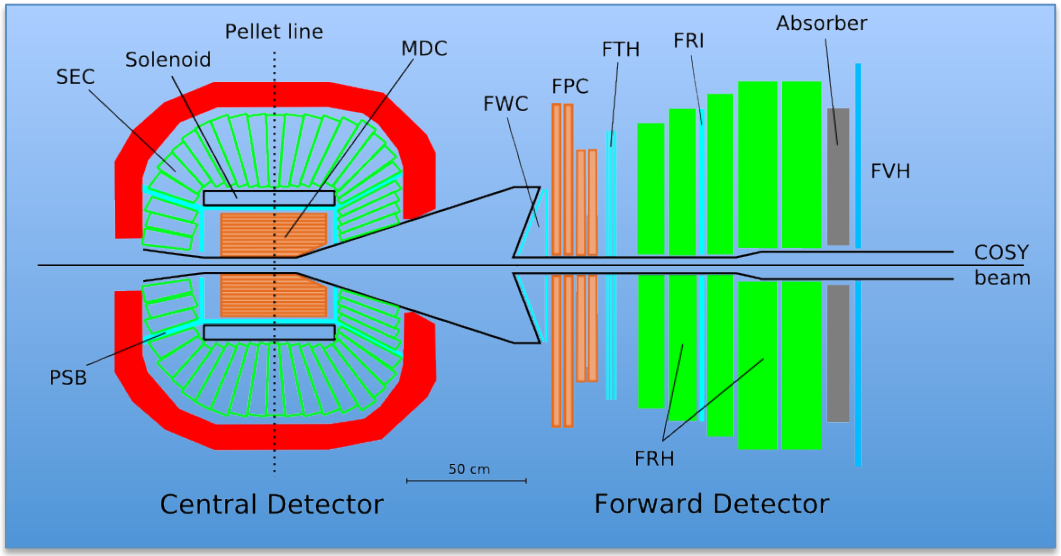
"...we think that a precise measurement of a_π which would not rely on any kind of extrapolation remains an interesting issue."

Extrapolation from space-like region

CELLO +0.0326(26)stat(26)syst
Behrend *et al* (CELLO) Z. Phys.C 49 (1991) 401

CLEO +0.0303(8)stat(9)syst(12)
Gronberg *et al* (CLEO) Phys.Rev.D 57 (1998) 33

WASA at COSY



pp → pp π^0 550 MeV (2010)

pd → ^{3}He η 1 GeV (2008-2009)

Central Detector:

- **Superconducting Solenoid**
- **Plastic Barrel**
- **Wire Chamber**
- **Calorimeter**

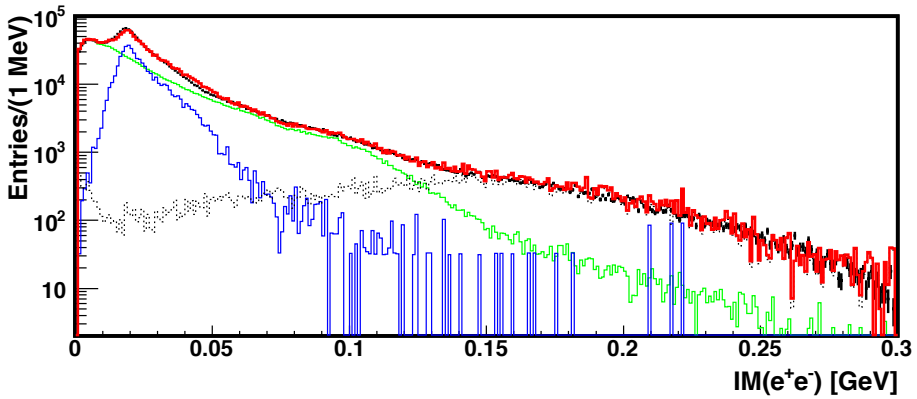
Forward Detector:

- **Plastic Scintillators**
- **Tracker**

π^0 Dalitz Decay

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Phys. Lett. B 726, 187 (2013)



DATA **MC SUM**

$\pi^0 \rightarrow e^+e^- \gamma$

$\pi^0 \rightarrow \gamma\gamma$

coincidentals

In search of a dark photon in $\pi^0 \rightarrow \gamma U \rightarrow e^+e^- \gamma$

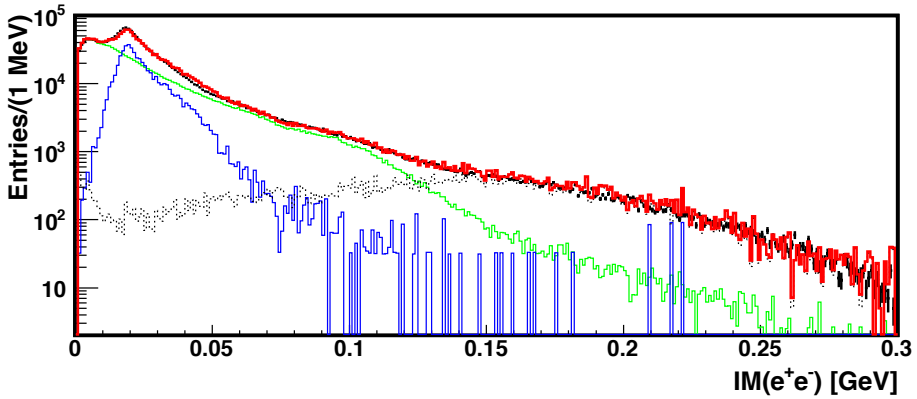
Focus of paper was to set an upper limit on U-γ mixing parameter, ε, 20-100 MeV

Data sample collected can be used to determine π^0 TFF

π^0 Dalitz Decay

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Phys. Lett. B 726, 187 (2013)

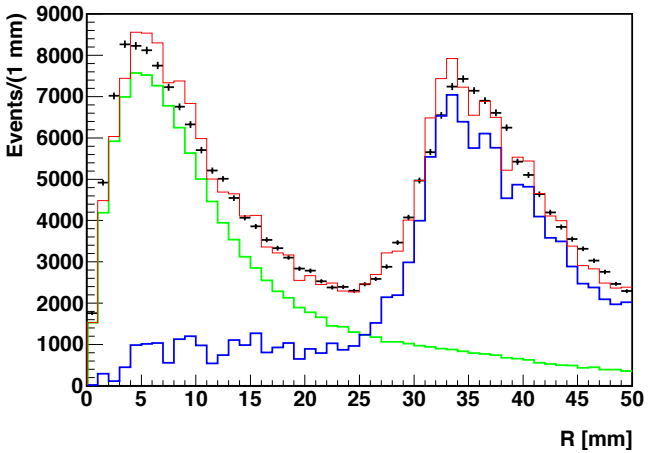


DATA **MC SUM**

$\pi^0 \rightarrow e^+e^-\gamma$

$\pi^0 \rightarrow \gamma\gamma$

coincidentals

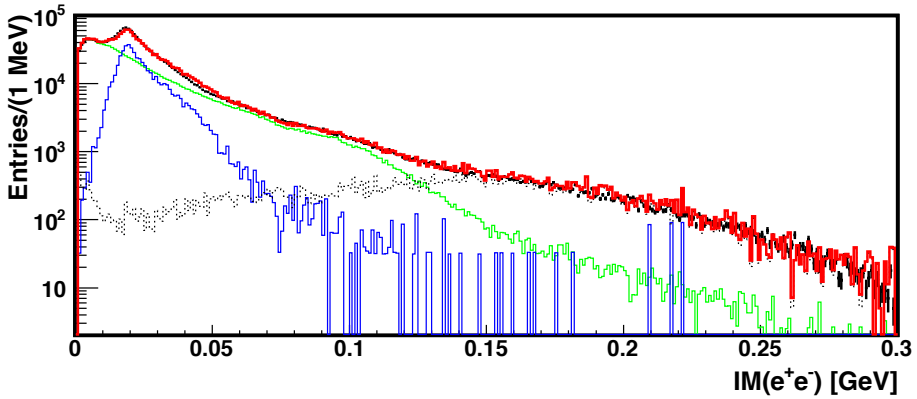


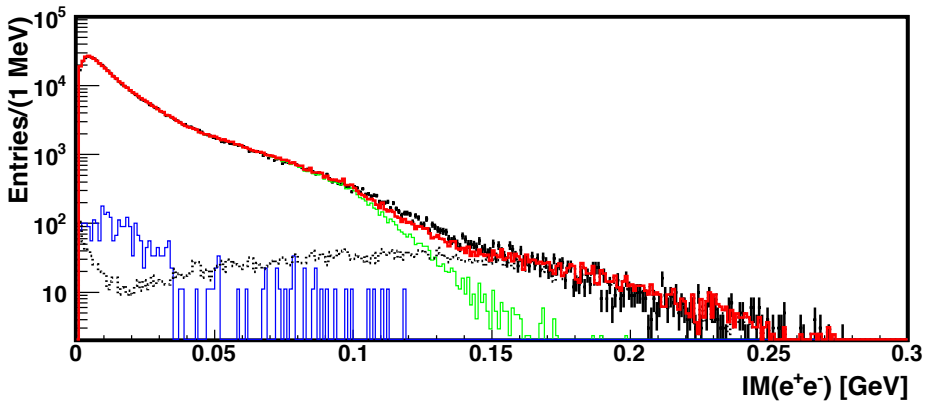
Reconstructed vertex used to remove conversion decays

π^0 Dalitz Decay

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Phys. Lett. B 726, 187 (2013)





Also prel. results π^0 - e+e- available

DATA **MC SUM**

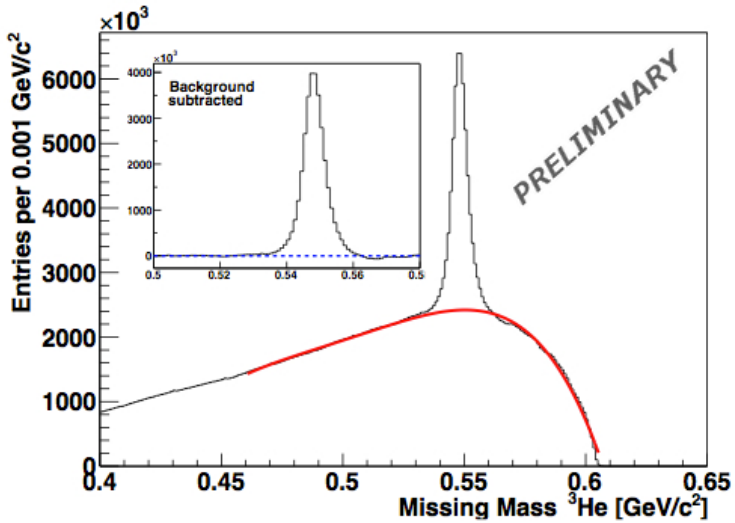
$\pi^0 \rightarrow e^+e^-\gamma$

$\pi^0 \rightarrow \gamma\gamma$

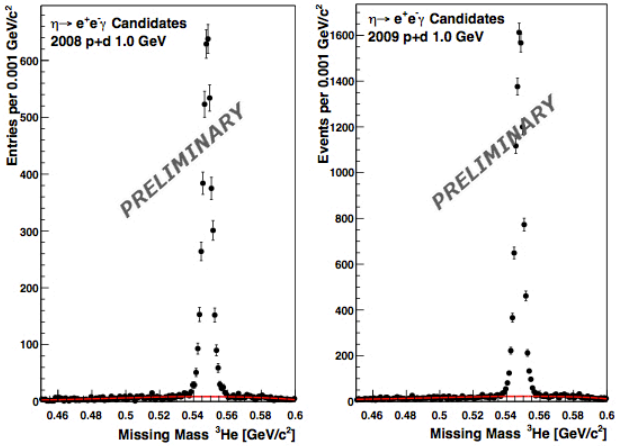
coincidentals

~5.0 x 10^5 events in final event sample
Still to be analysed
~8.0 x 10^6 π^0 Dalitz decays

See also talk by Evgueni Goudzovski NA48/2 NA62 (Mon Sep 29, 17.00)



3.0 x 10^7 η MM(^{3}He)



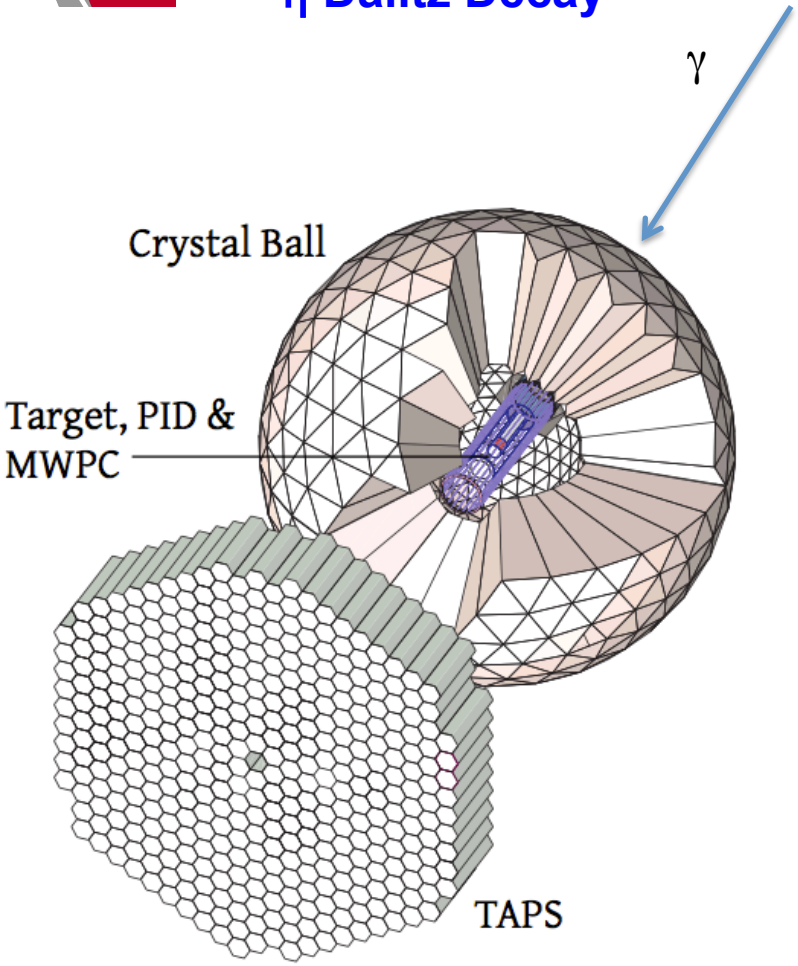
1.4 x 10^4 η ➡ e+e- γ

Several anomalous η decay channels analysed with same analysis scheme
Norm. to η➡ $\pi^+\pi^-\pi^0$

PRELIMINARY RESULTS BR

Channel	Branching Ratio
$\eta \to \pi^+\pi^-\gamma$	$(4.68 \pm 0.07_{stat/fit} \pm 0.19_{sys}) \times 10^{-2}$
$\eta \to e^+e^-\gamma$	$(6.75 \pm 0.06_{stat/fit} \pm 0.29_{sys}) \times 10^{-3}$
$\eta \to \pi^+\pi^-e^+e^-$	$(2.7 \pm 0.2_{stat} \pm 0.1_{sys}) \times 10^{-4}$
$\eta \to e^+e^-e^+e^-$	$(3.2 \pm 0.9_{stat} \pm 0.4_{sys}) \times 10^{-5}$

η Dalitz Decay



CB - NaI(Tl) crystals
TAPS - BaF_2
PID - discr. charged/neutrals

$$\frac{\Delta E}{E_{\text{dep}}} = \frac{2\%}{(E[\text{GeV}])^{0.36}} \quad \text{(CB)}$$

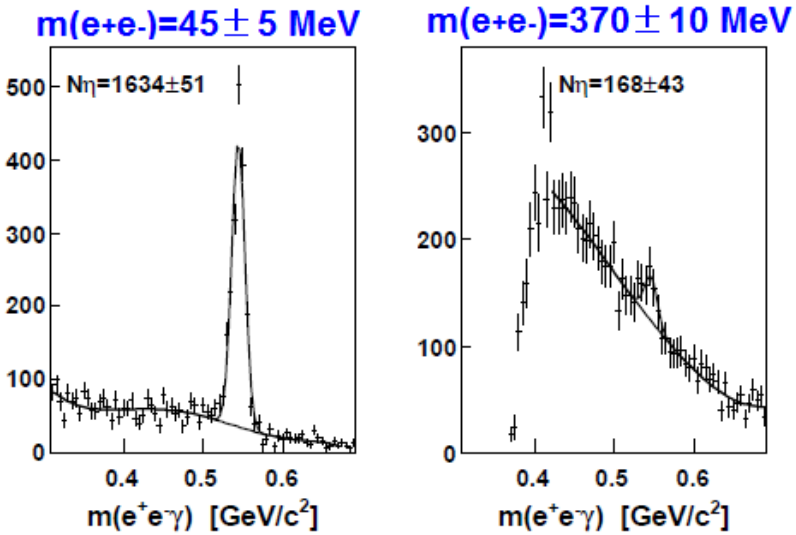
$$\frac{\Delta E}{E_{\text{dep}}} = 1.8\% + \frac{0.8\%}{(E[\text{GeV}])^{0.5}} \quad \text{(TAPS)}$$

$\gamma p \rightarrow p \eta$

η Dalitz Decay

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Phys. Rev. C 89 (2014) 044608



Matches NA60 $\eta \rightarrow \mu^+\mu^-\gamma$ result

Better accuracy for low m(l^+l^-)
Assumes $F_\eta = 1$ in fit

2.2×10^4 $\eta \rightarrow$ e+e- γ, (based on 3×10^7 η decays)

1.3×10^3 in previous measurement A2
Berghäuser et al. (A2-Collaboration) Phys. Rev. B 701 (2011) 562

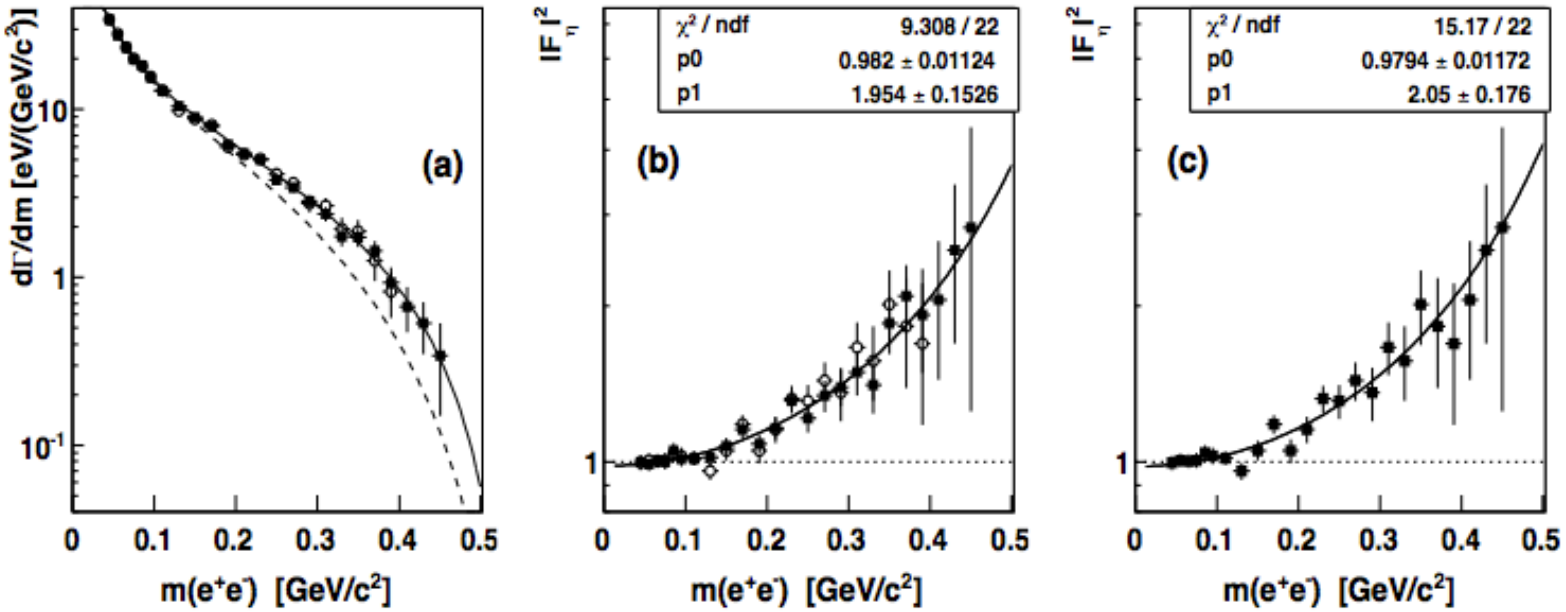
New analysis based on kinematic fit
3 x more data in final event sample

η Dalitz Decay

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Phys. Rev. C 89 (2014) 044608

Most precise measurement of $\eta - e^+e^- \gamma$ to date



$\Lambda^{-2} = 1.95\ (15)_{stat}\ (10)_{syst}\ GeV^{-2}$ Reflects FF slope at $m_{ll} = 0$

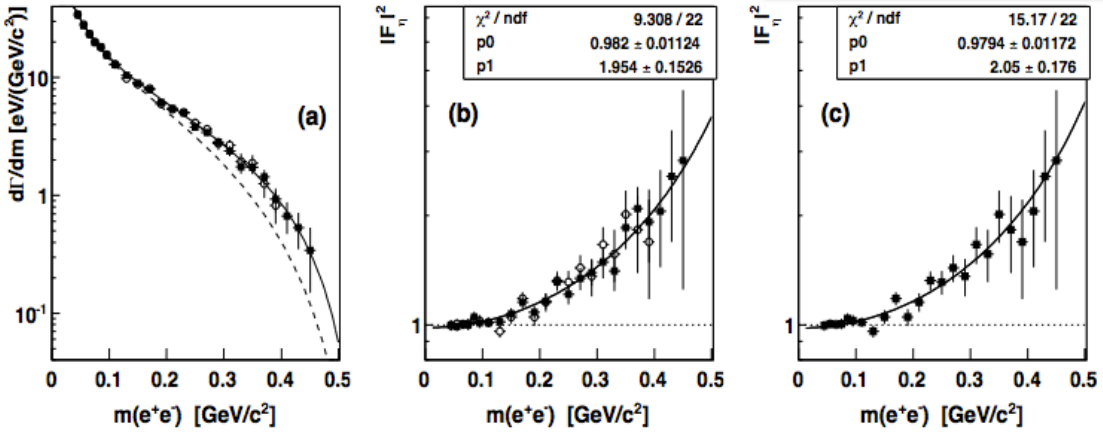
$|F_\eta|^2 = 0.982(11)$ ⟹ compatible to 1 within 2σ

η Dalitz Decay

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Phys. Rev. C 89 (2014) 044608

Most precise measurement of $\eta - e^+e^- \gamma$ to date

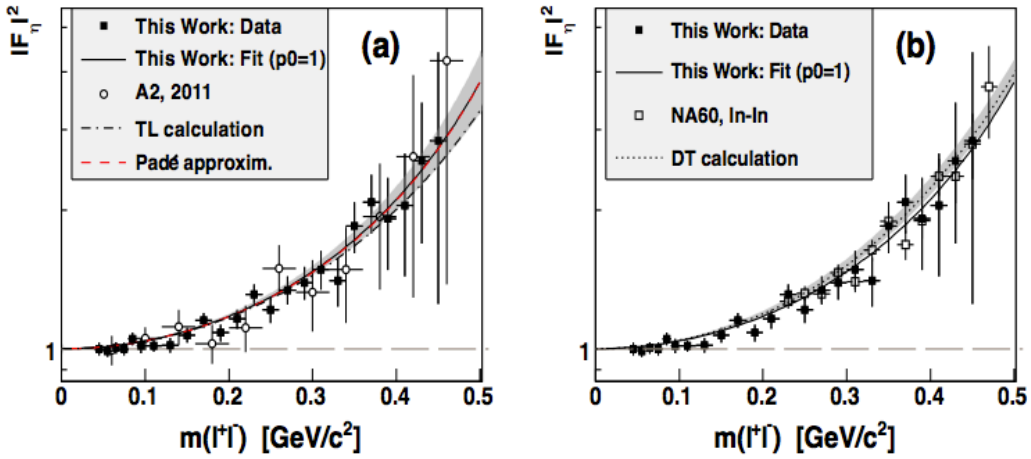


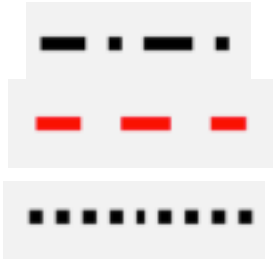
$$\Lambda^{-2} = 1.95\ (15)_{stat}\ (10)_{syst}\ GeV^{-2}$$

Good agreement with NA60 result (l = μ)
G.Usai (NA60 Coll.) Nucl. Phys. A 855, 189(2011)

$$\Lambda^{-2} = 1.950(59)_{stat}\ (42)_{syst}\ GeV^{-2}$$

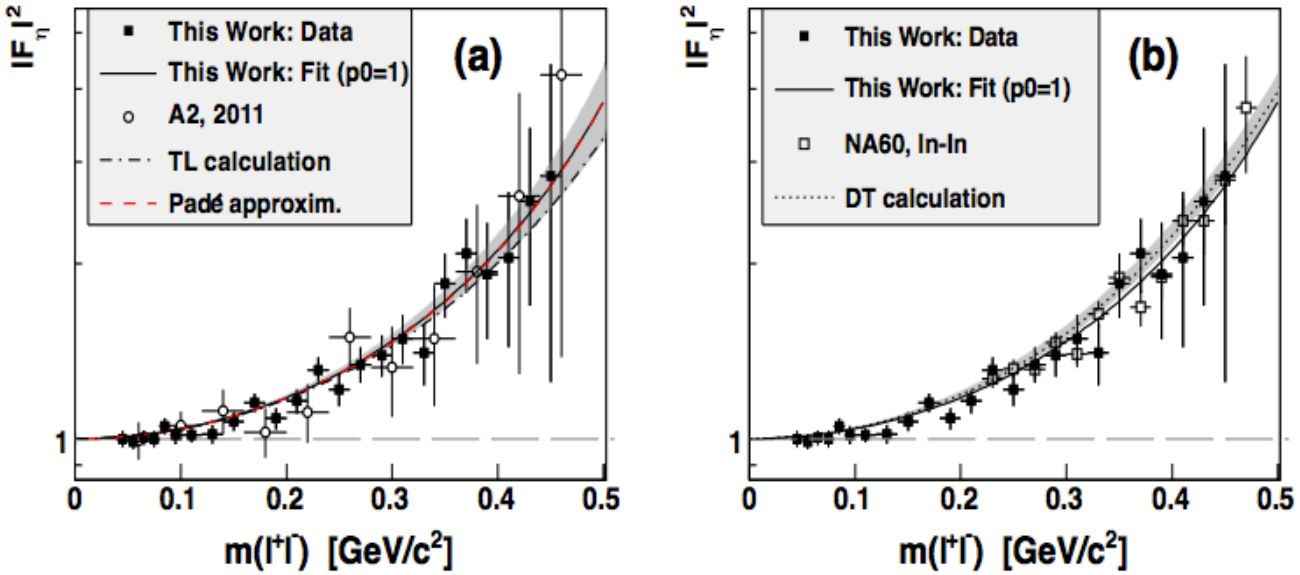
Phys. Rev. C 89 (2014) 044608





TL calculation: C. Terschlüsen, Diploma thesis, University Gießen, 2010.
Padé-approximants: R. Escribano, P. Masjuan, P. Sanchez-Puertas, Phys. Rev. D 89 (2014) 034014. (poster by S. Gonzàlez-Solíz)
DT calculation: C. Hahnhart, A. Kupśc, U.-G. Meißner, F. Stollenwerk, A. Wirzba, Eur. Phys. J. C73 (2013) 2668. (talk by A. Wirzba, mon sep 29, 15.30)

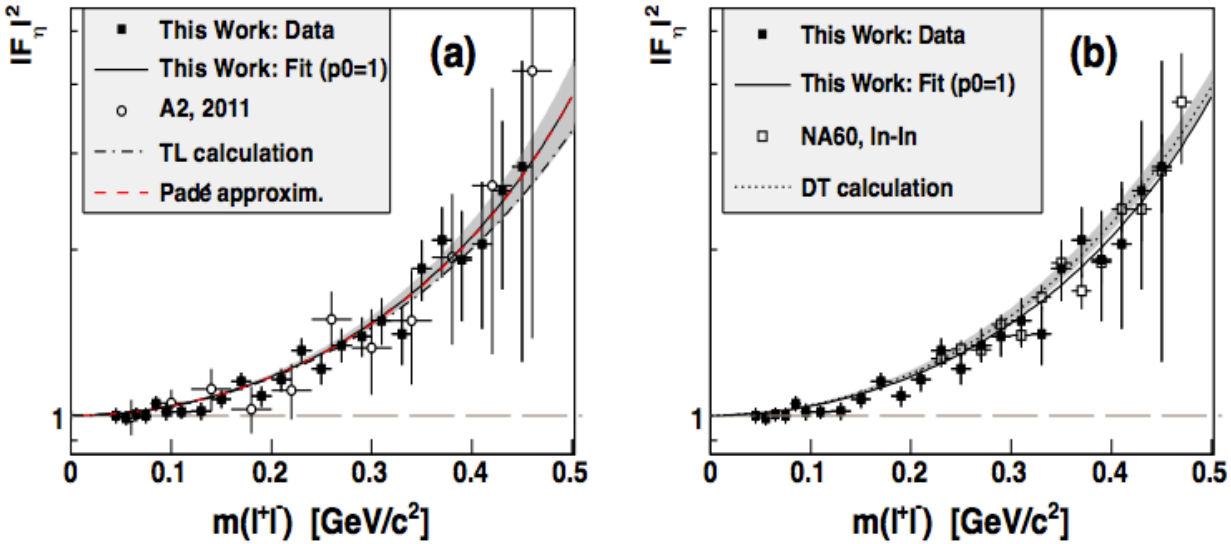
Phys. Rev. C 89 (2014) 044608



TL calculation: C. Terschlüsen, Diploma thesis, University Gießen, 2010.
Padé-approximants: R. Escribano, P. Masjuan, P. Sanchez-Puertas, Phys. Rev. D 89 (2014) 034014. (poster by S. Gonzàlez-Solíz)
DT calculation: C. Hahnhart, A. Kupść, U.-G. Meißner, F. Stollenwerk, A. Wirzba, Eur. Phys. J. C73 (2013) 2668. (talk by A. Wirzba, mon sep 29, 15.30)

Result agrees best with Pade, all within statistical uncertainty

Phys. Rev. C 89 (2014) 044608

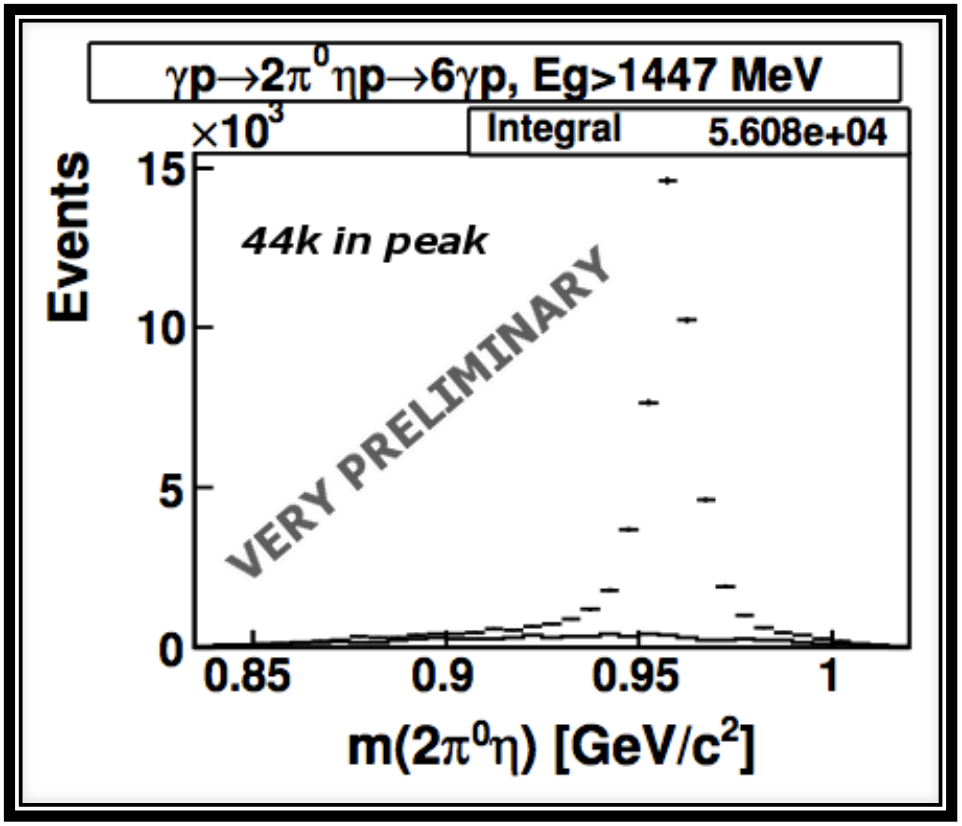


VMD models used to calculate hadr. LbL with Λ = 774(29) MeV

Result of this work Λ = 716(33) MeV

Smaller effective vector-meson masses ought to be used in VMD like models

Outlook



η' Dalitz decay with A2

η' production run ends dec 2014.
(2012) 1.2x10^6 η' on disk

(2014) 3.3x10^6 (July-Aug) –improved DAQ

Projected nr of η' on disk ~ 8 x 10^6

Experience from η Dalitz decay

Motivation

EM Dalitz decays of light unflavored mesons have been studied by many experiments
Experimental input needed for how charmonium states interact with EM field.

Theoretical prediction assuming simple pole approximation available
J. Fu, H.B. Li, X. Qin, M.Z. Yang, Mod. Phys. Lett. A 27 1250223 (2012)

$\Lambda = m_{\psi'} = 3.686$ GeV

$$F_{\psi P}(q^2) = \frac{1}{1 - \frac{q^2}{\Lambda^2}}$$

Decay mode	e^+e^-	$\mu^+\mu^-$
$\psi \to \pi^0 l^+ l^-$	$(3.89^{+0.37}_{-0.33}) \times 10^{-7}$	$(1.01^{+0.10}_{-0.09}) \times 10^{-7}$
$\psi \to \eta l^+ l^-$	$(1.21 \pm 0.04) \times 10^{-5}$	$(0.30 \pm 0.01) \times 10^{-5}$
$\psi \to \eta' l^+ l^-$	$(5.66 \pm 0.16) \times 10^{-5}$	$(1.31 \pm 0.04) \times 10^{-5}$

Motivation

EM Dalitz decays of light unflavored mesons have been studied

No experimental input previously available on how charmonium states interact with EM field.

Theoretical prediction assuming simple pole approximation available

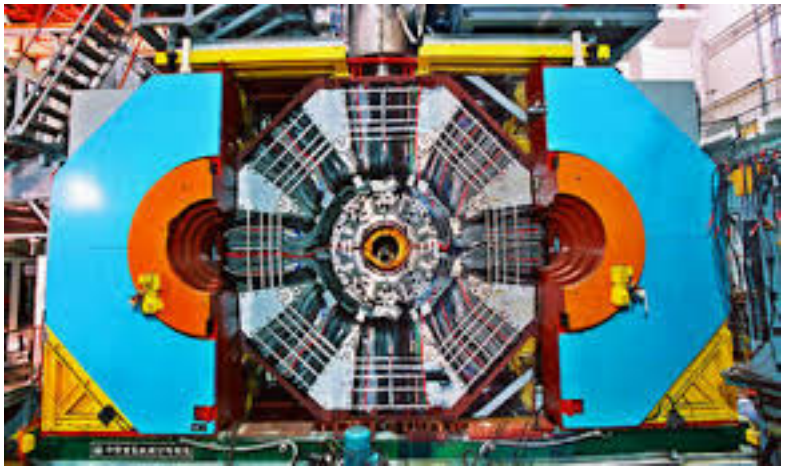
J. Fu, H.B. Li, X. Qin, M.Z. Yang, Mod. Phys. Lett. A 27 1250223 (2012)

$$F_{\psi P}(q^2) = \frac{1}{1 - \frac{q^2}{\Lambda^2}}$$

$\Lambda = m_{\psi'} = 3.686$ GeV

Decay mode	e^+e^-		$\mu^+\mu^-$
$\psi \to \pi^0 l^+ l^-$	$(3.89^{+0.37}_{-0.33}) \times 10^{-7}$	(	$1^{+0.10}_{-0.09}) \times 10^{-7}$
$\psi \to \eta l^+ l^-$	$(1.21 \pm 0.04) \times 10^{-5}$	(0	$\pm 0.01) \times 10^{-5}$
$\psi \to \eta' l^+ l^-$	$(5.66 \pm 0.16) \times 10^{-5}$	(1	$\pm 0.04) \times 10^{-5}$

General information



BESIII four main components

MDC	
Resolution @1 GeV/c	0.5%
$\sigma_{dE/dx}$	6%
EMC	
E Resolution Barrel	2.5%
E Resolution End Cap	5%
TOF	
Barrel	80 ps
End caps	110 ps
Muon chambers	
Position resolution	~ 2 cm

Phys. Rev. D 89, 092008 (2014)

First measurement of rare charmonium decays : J/ψ → P e+e-
Based on 225 million J/ψ

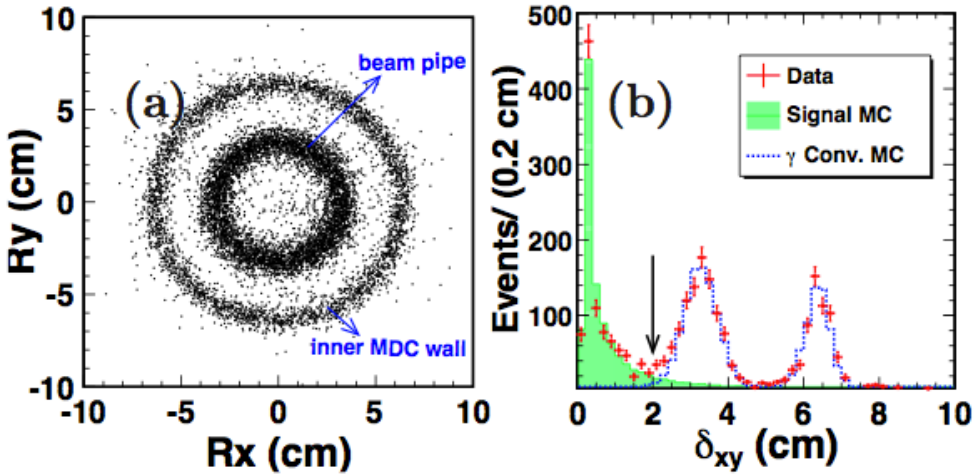
a)	J/ψ	→	η' e^+e^-	→ $\pi^+\pi^-\gamma$	e^+e^-
b)				$\pi^+\pi^-\eta$	e^+e^-
c)	J/ψ	→	η e^+e^-	→ $\pi^+\pi^-\pi^0$	e^+e^-
d)				$\gamma\gamma$	e^+e^-
e)	J/ψ	→	π^0 e^+e^-	→ $\gamma\gamma$	e^+e^-

Phys. Rev. D 89, 092008 (2014)

First measurement of rare charmonium decays : J/ψ → P e+e-
Based on 225 million J/y

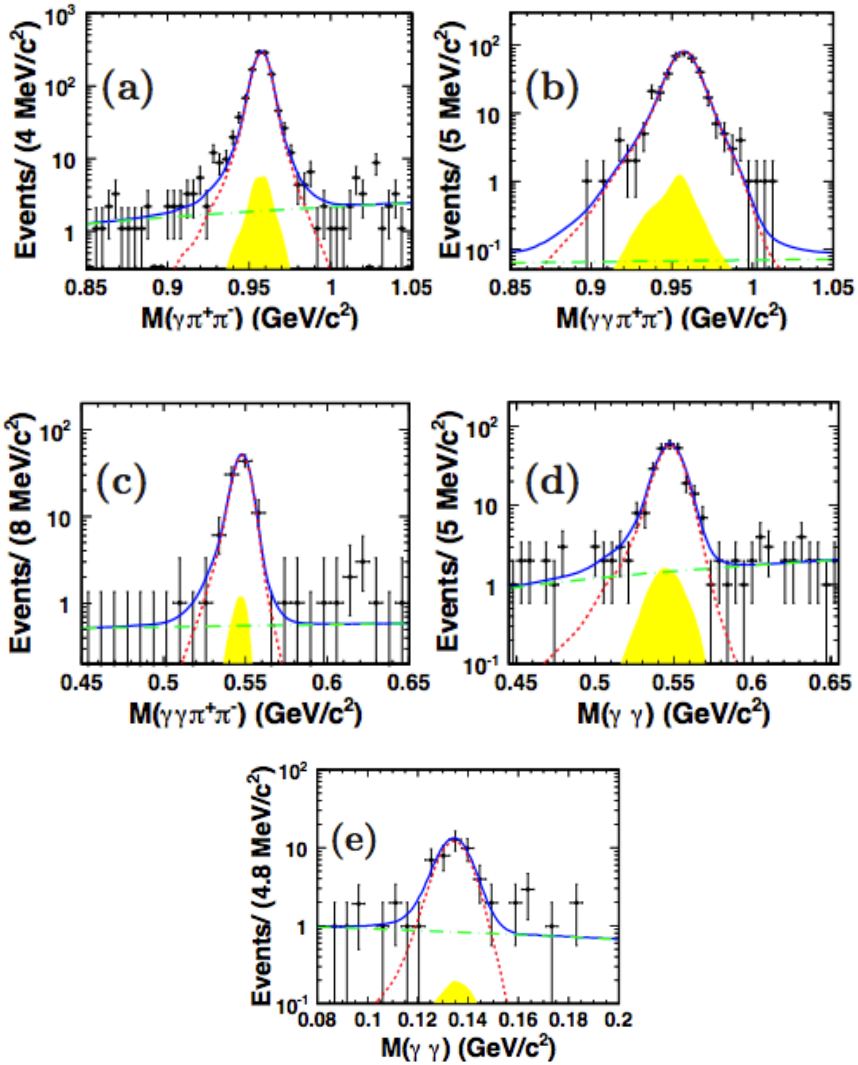
a)	J/ψ →	η' e^+e^- →	$\pi^+\pi^-\gamma$	e^+e^-
b)			$\pi^+\pi^-\eta$	e^+e^-
c)	J/ψ →	η e^+e^- →	$\pi^+\pi^-\pi^0$	e^+e^-
d)			$\gamma\gamma$	e^+e^-
e)	J/ψ →	π^0 e^+e^- →	$\gamma\gamma$	e^+e^-

MC BKG: J/ψ --> η' γ −−> $\pi^+\pi^-\gamma\ \gamma$



Internal conversion main source of background-
cut on radius removes 98% of background and 20% of signal.

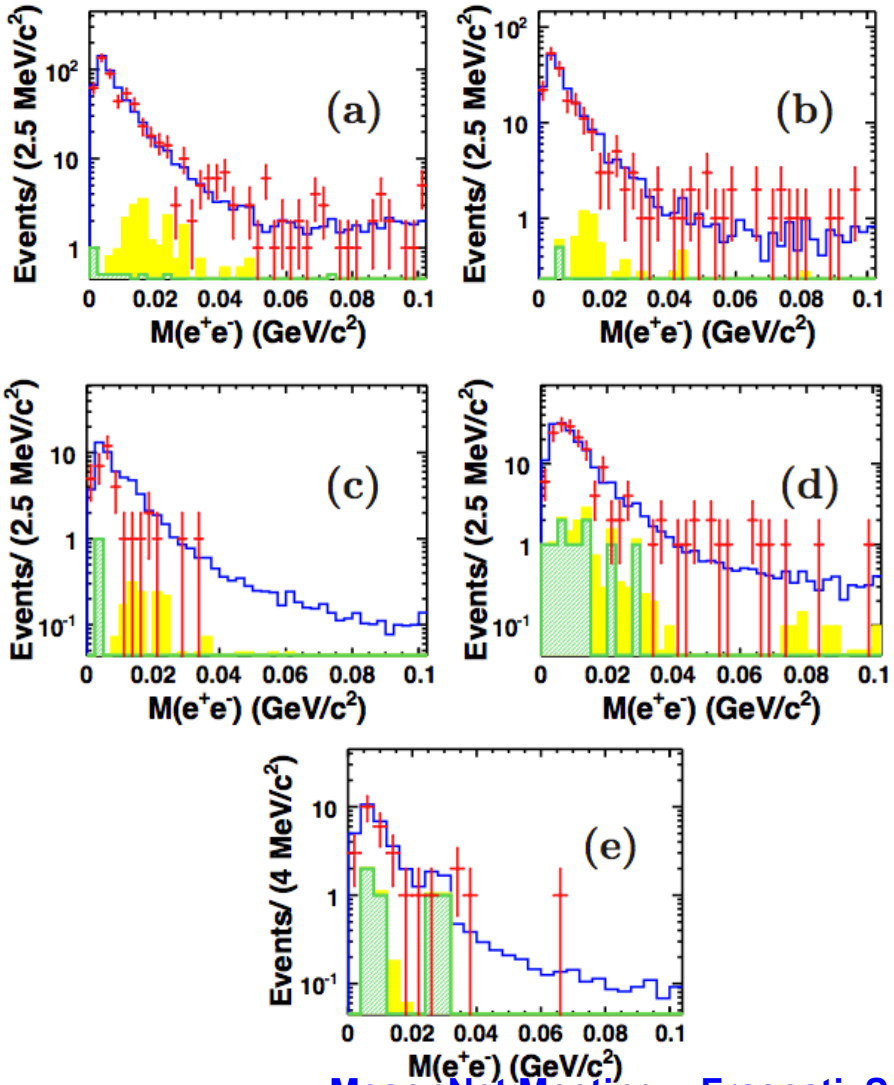
Phys. Rev. D 89, 092008 (2014)



	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%

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

Phys. Rev. D 89, 092008 (2014)



	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)

$$\mathcal{B}(J/\psi \to Pe^+e^-) = \frac{N_S}{N_{J/\psi} \cdot \mathcal{B}(P \to F) \cdot \epsilon}$$

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

Good agreement between theory and experiment for P = η, η'
2.5 σ cf. theory and experiment when P = π^0

Λ_{fit} = 3.0(1.0) GeV (from P = η') used for BR uncertainty

Result based on 1/5 of full statistics

Summary TFF from decays

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

π^0 Dalitz decay large statistics available
Outlook: BR of anomalous η decays, paper in progress
Large ppη data sample available (5 x 10^8 η tagged)

New improved result of η Dalitz decay (*l* = *e*)
Outlook: η'

First results on BR J/ψ ➡ P e+e-
Outlook: More J/ψ available, η' Dalitz decay

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

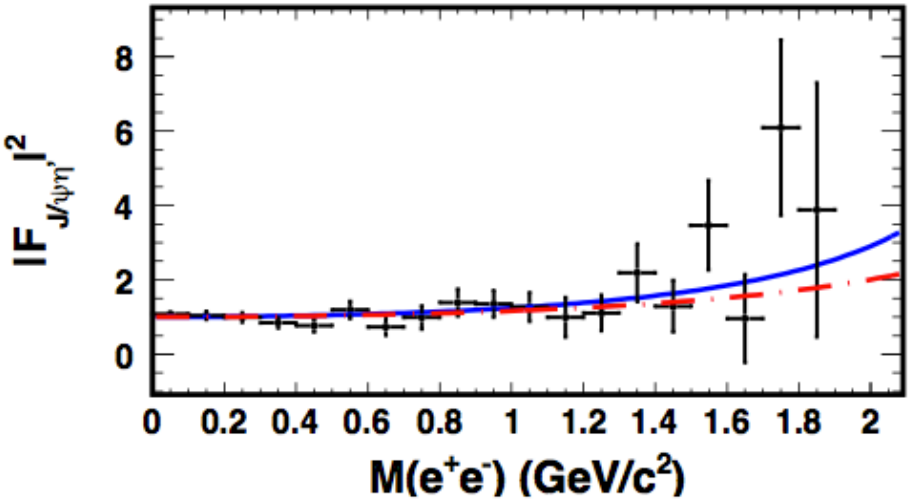
Thank you

Phys. Rev. D 89, 092008 (2014)

Λ_{MC} = 3.686 GeV/c^2

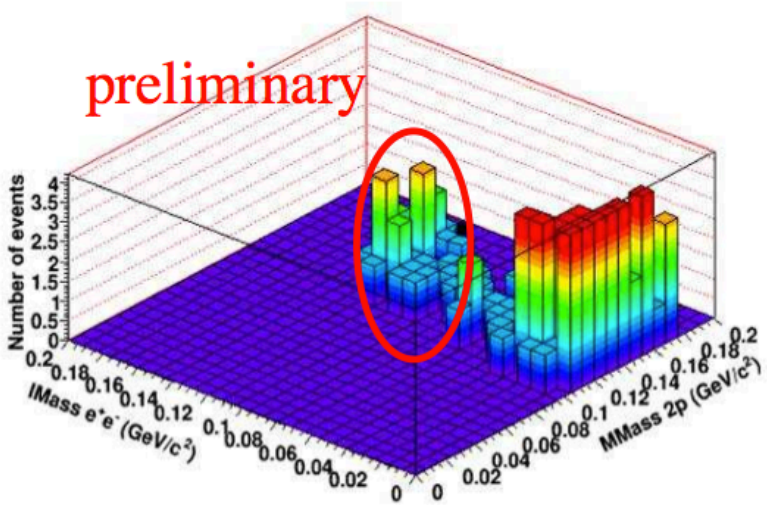
Λ_{fit} = 3.1 (1.0) GeV/c^2

Test on Λ included in systematical uncertainty of BR

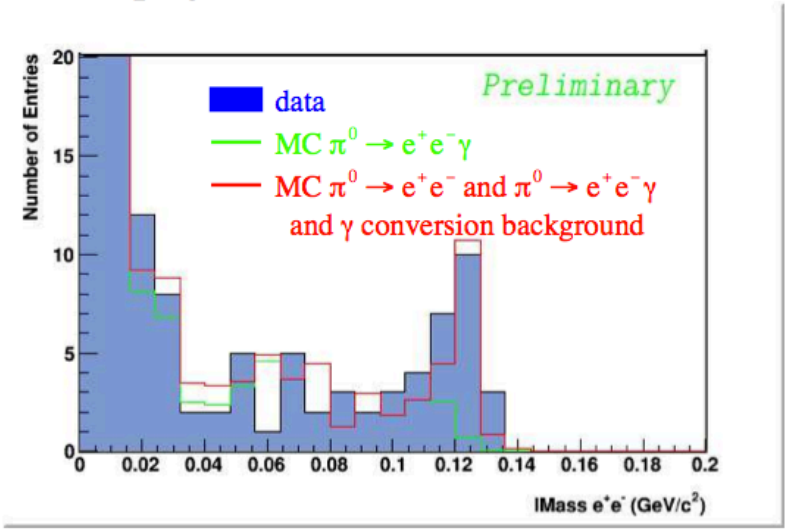


Mode	Branching fraction	Combined Result	Theoretical prediction
$J/\psi \to \eta' e^+ e^- (\eta' \to \gamma\pi^+\pi^-)$	$(6.01 \pm 0.20 \pm 0.34) \times 10^{-5}$		
$J/\psi \to \eta' e^+ e^- (\eta' \to \pi^+\pi^-\eta)$	$(5.51 \pm 0.29 \pm 0.32) \times 10^{-5}$	$(5.81 \pm 0.16 \pm 0.31) \times 10^{-5}$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

inv mass (e^+e^-) vs miss mass (pp)



projection on inv mass (e^+e^-)



15 event candidates in 4 day data taking. 8 more weeks available