Investigation of the Dalitz decay of the η meson and the determination of the η transition formfactor

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- motivation
- experimental setup
- identification of the $\eta \rightarrow e^+e^-\gamma$ decay; background supression
- experimental results
- comparison to other experiments and calculations
- summary and outlook

HADRON 2011
Munich, June 13-17, 2011

A2 Collaboration

Electromagnetic transition formfactor

hadrons = composite (non-point-like) particles of quarks and gluons
with internal structure

access to internal structure: measurement of formfactors $F(q^2)$

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elastic scattering
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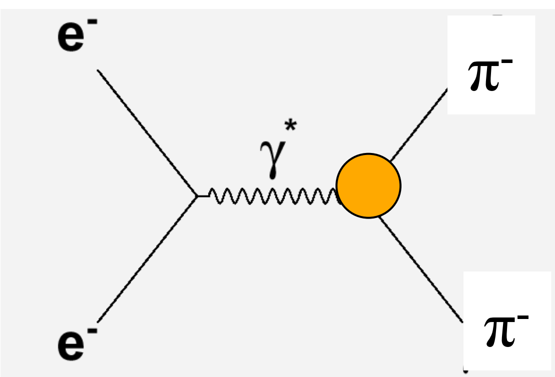
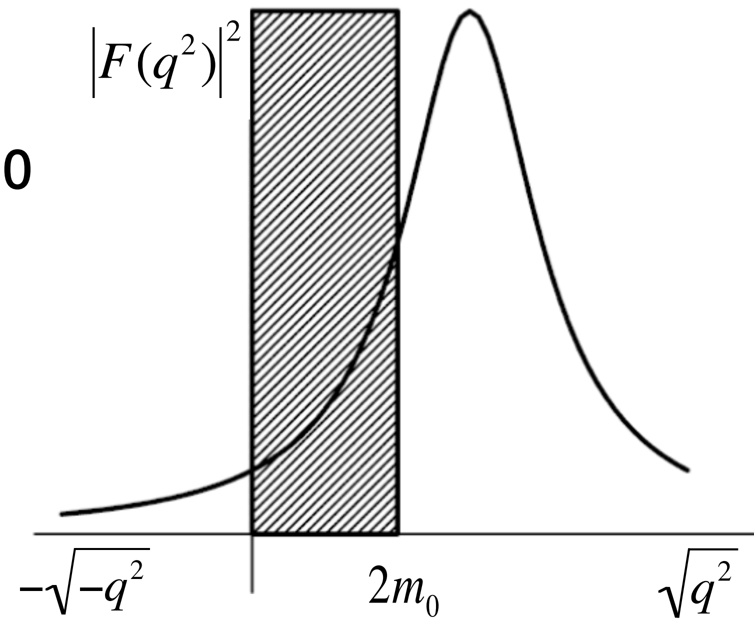
$q^2 = (\Delta E/c)^2 - \Delta p^2 < 0$





annihilation
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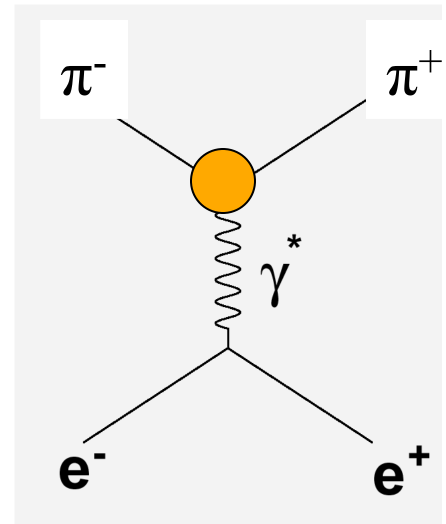
$q^2 = (\Delta E/c)^2 - \Delta p^2 > 0$



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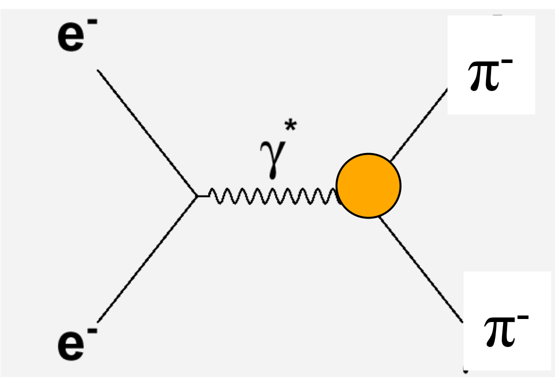

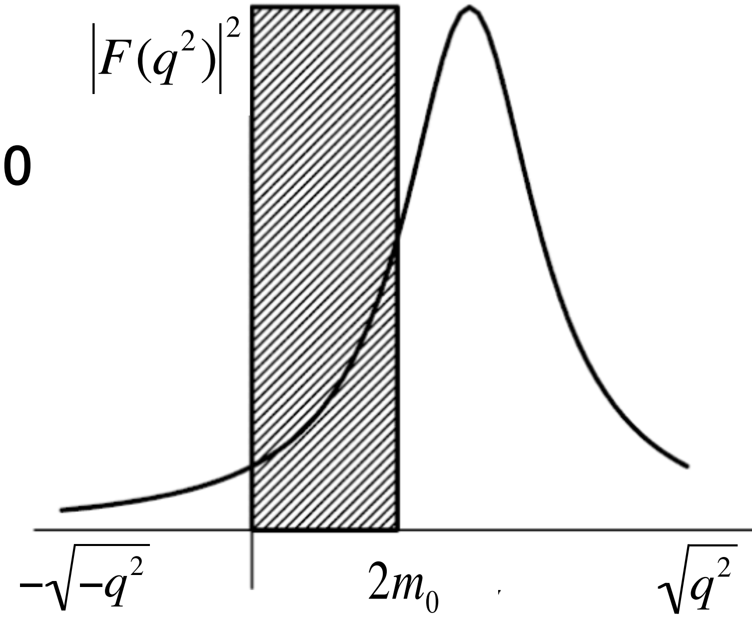

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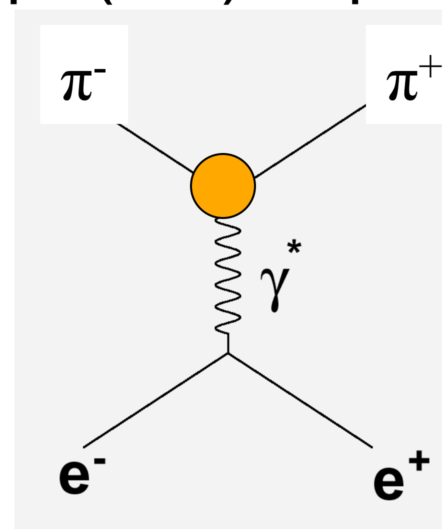
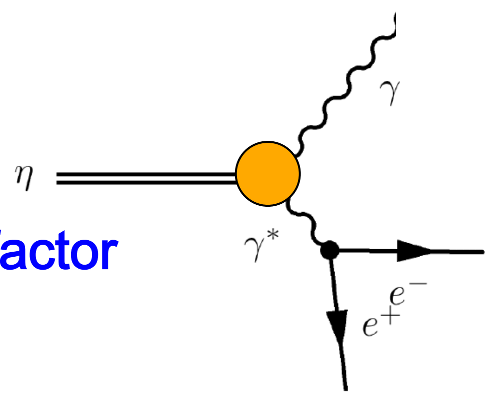


transition form factor



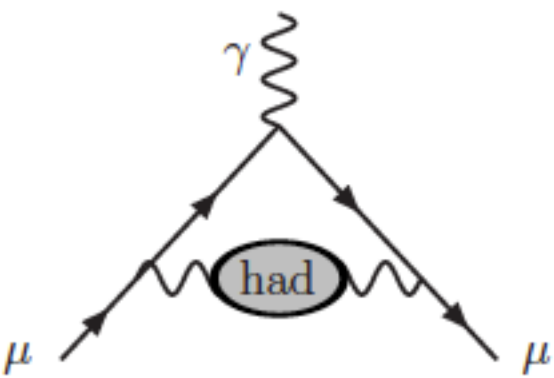
only access for $0 < \sqrt{q^2} < 2m_0$

Search for new physics

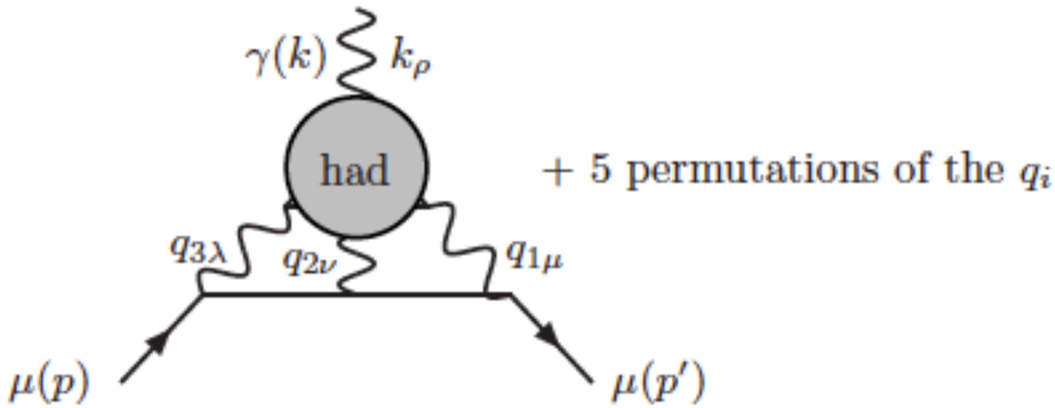
knowledge of lepton-hadron coupling also important in the search for new physics: precision measurement and interpretation of g-2 of the muon.

hadronic corrections:

vacuum polarization



light-by light scattering



transition formfactors

$\eta \rightarrow \gamma\, e^{+}e^{-}$

formfactors in particle decays:

$$\frac{d\Gamma}{dq^2} = \left(\frac{d\Gamma}{dq^2}\right)_{pointlike} \cdot \left|F(q^2)\right|^2$$

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G. Landsberg, Phys.Rep. 128 (1985) 30

$$\frac{d\Gamma\left(P \to e^+e^-\gamma\right)}{dm\, \Gamma\left(P \to \gamma\gamma\right)} = \frac{4\alpha}{3\pi m}\sqrt{1 - \frac{4m_e^2}{m^2}}\left(1 + \frac{2m_e^2}{m^2}\right)\left[1 - \frac{m^2}{m_P^2}\right]^3 \left|F\left(q^2\right)\right|^2;$$

measure $\eta \to \gamma\, e^+e^-$ relative to $\eta \to \gamma\gamma$!!!

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measure $\eta \rightarrow \gamma\, e^+e^-$ relative to $\eta \rightarrow \gamma\,\gamma$!!!

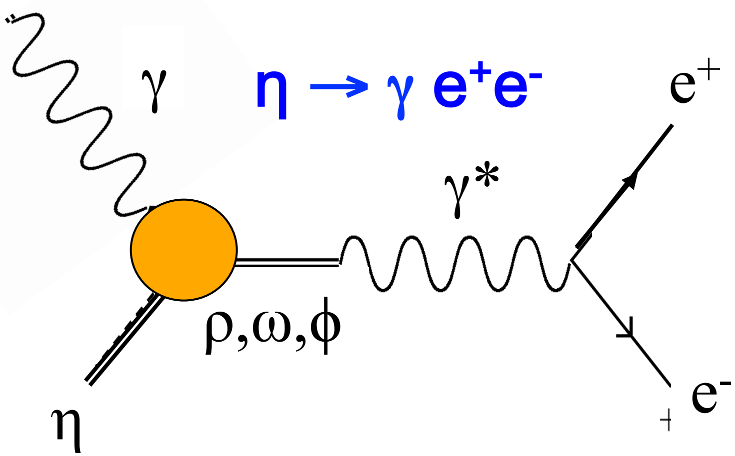
Vector meson dominance (VDM) model:

dileptons couple to hadrons via vector mesons

pole parametrization

$$F(q^2) = \frac{1}{1-\frac{q^2}{\Lambda^2}}$$

$\eta \rightarrow \gamma\, e^+e^-$

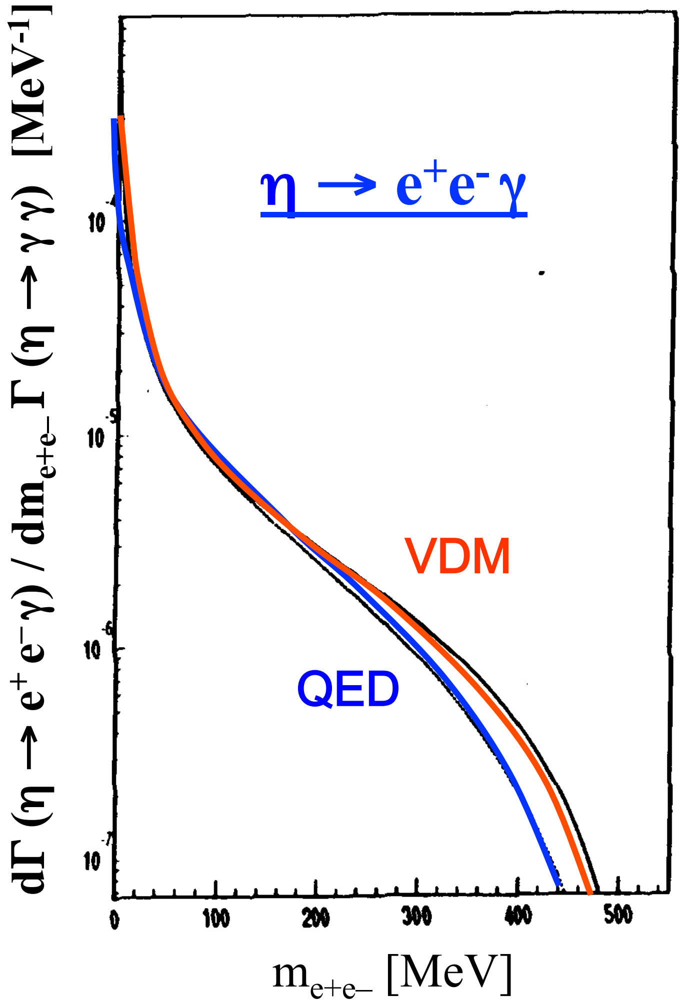


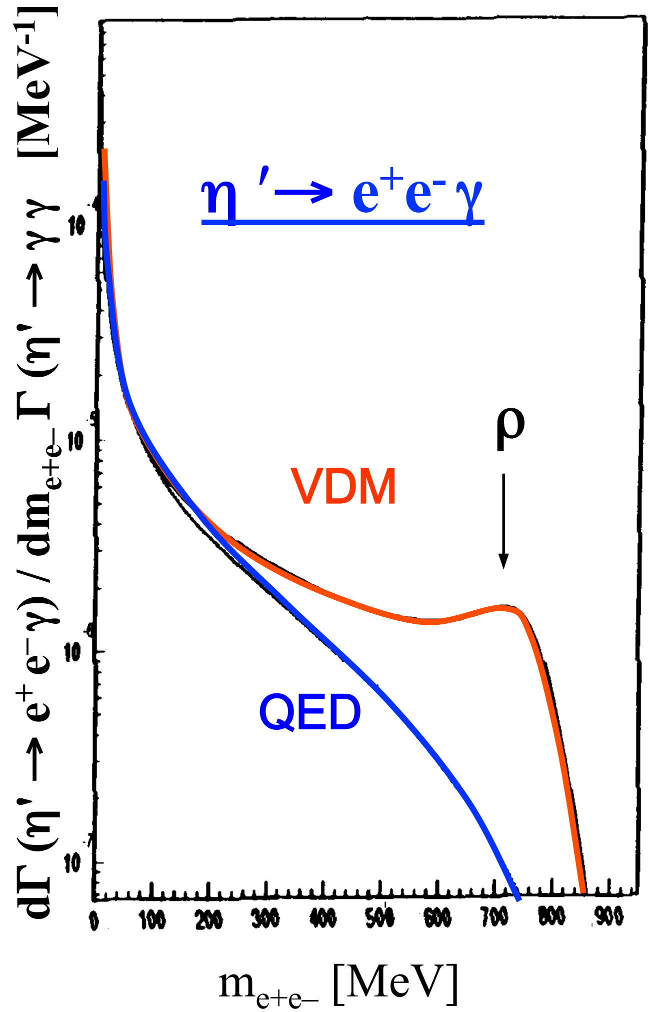
Virtual photon and neutral vector mesons have the same quantum numbers $J^{\pi}=1^-$

electromagnetic transition form factors: comparison QED / VDM

$$\frac{d\Gamma}{dq^2} = \left(\frac{d\Gamma}{dq^2}\right)_{pointlike} \cdot \left|F(q^2)\right|^2$$

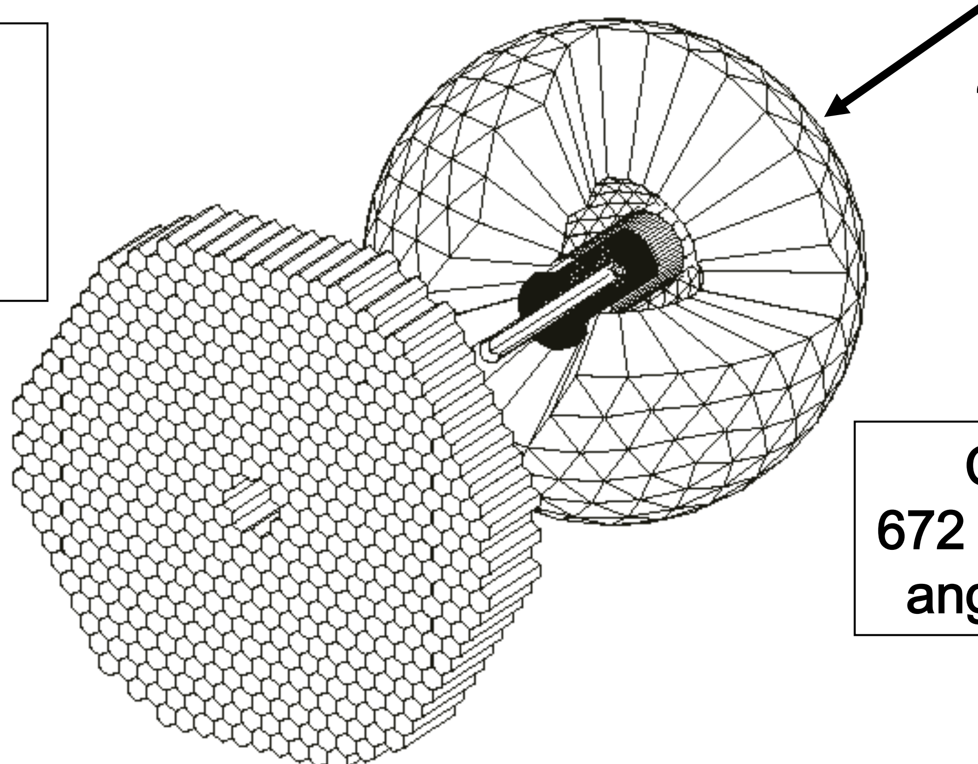
pole parametrization: $F(q^2) = \dfrac{1}{1 - \dfrac{q^2}{\Lambda^2}}$





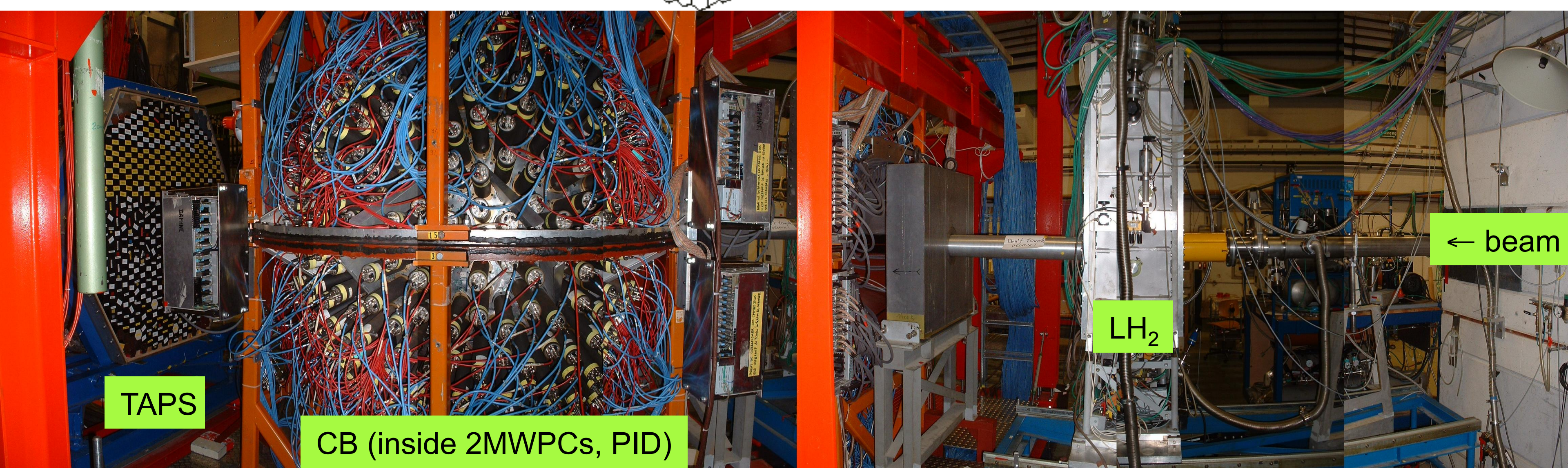
CB/TAPS@MAMI

TAPS forward wall
384 BaF_2 – modules
distance: 150 cm
angles: $1.1^0 – 20.0^0$



Crystal Ball
672 NaI – modules
angles: 21^0 - 155^0

no magnetic field !!



Liquid hydrogen target and beamline

Kapton cell for liquid hydrogen target

<u>material around the target</u>:
125 µm Kapton
8 layers superisolation foil
(8 µm Mylar, 2 µm Alu)
1 mm CFK vacuum tube

Carbon fiber vacuum tube

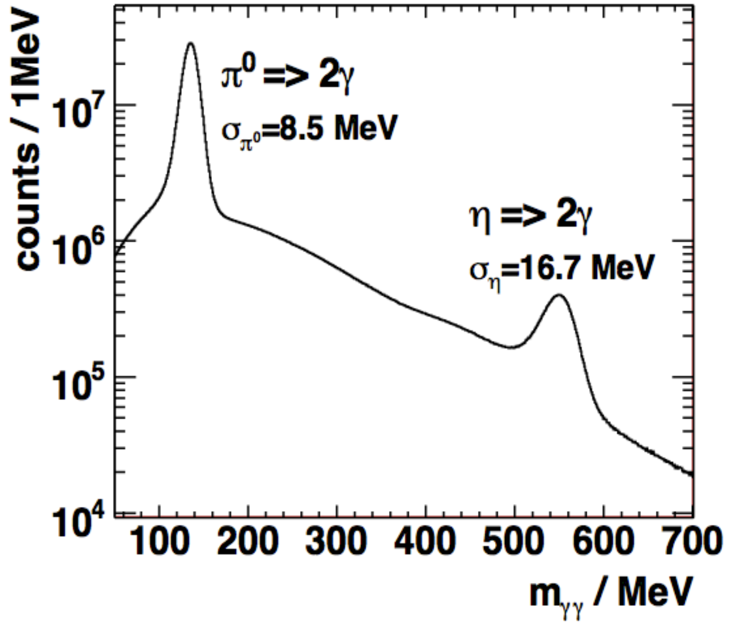
<u>material budget:</u>
alltogether: 0.8% of X_0

low material budget important for suppressing conversion of real photons: $\eta \rightarrow \gamma\gamma \rightarrow \gamma e^+e^-$

particle identification

$\eta \rightarrow e^+e^-\gamma$

neutral particles:
π^0, $\eta \rightarrow \gamma\gamma$



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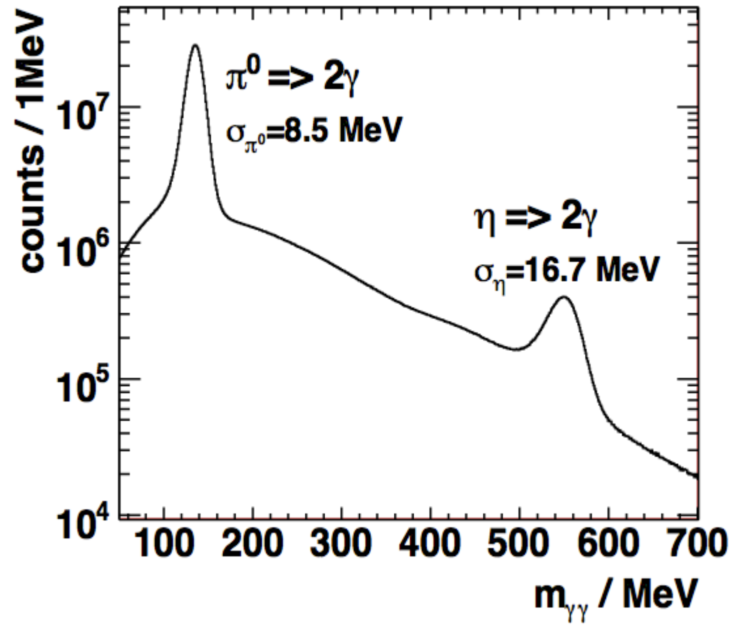
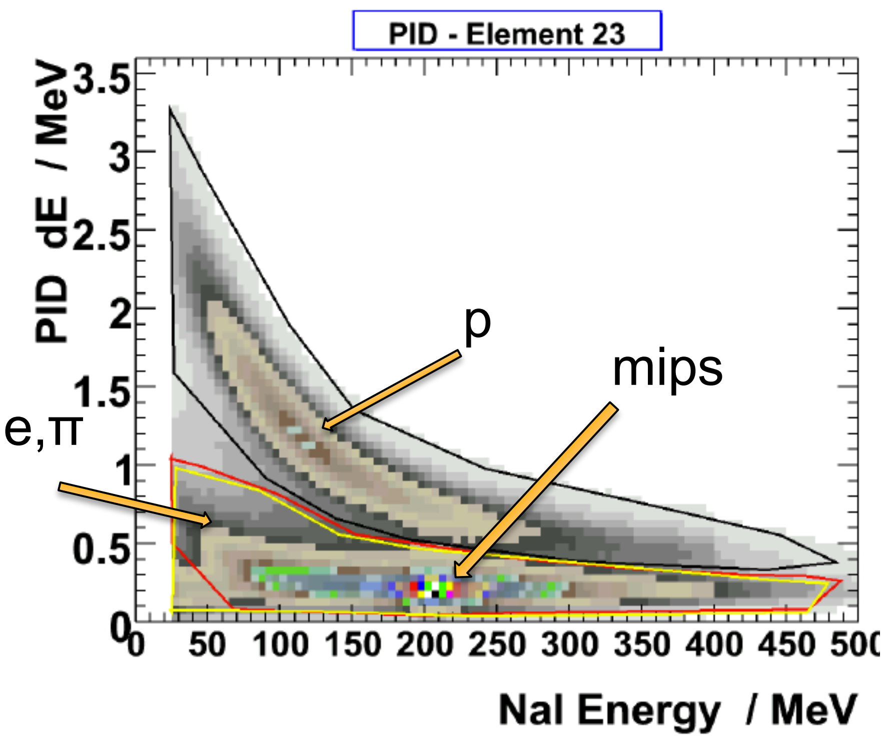
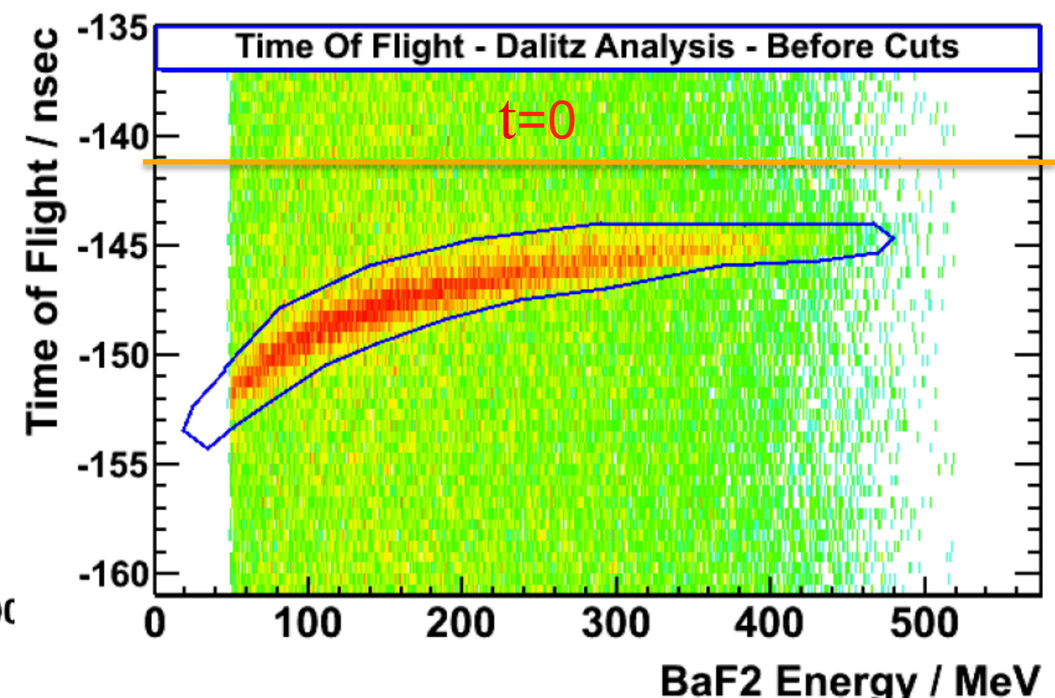


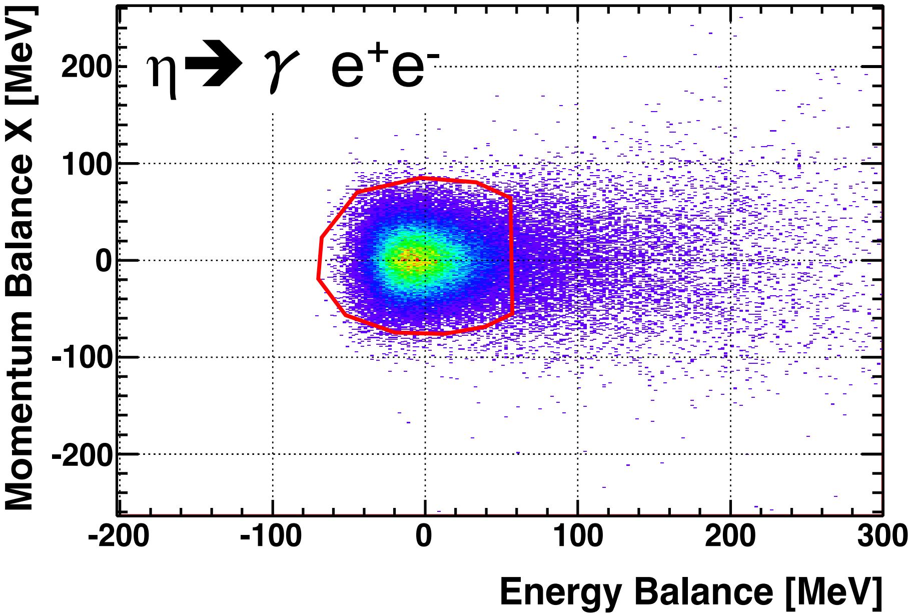
charged particles:
24 plastic scintillators (2 mm thick) in cylindrical arrangement around target
+ veto detectors in front of TAPS
ΔE vs. E; E vs. t (TAPS)

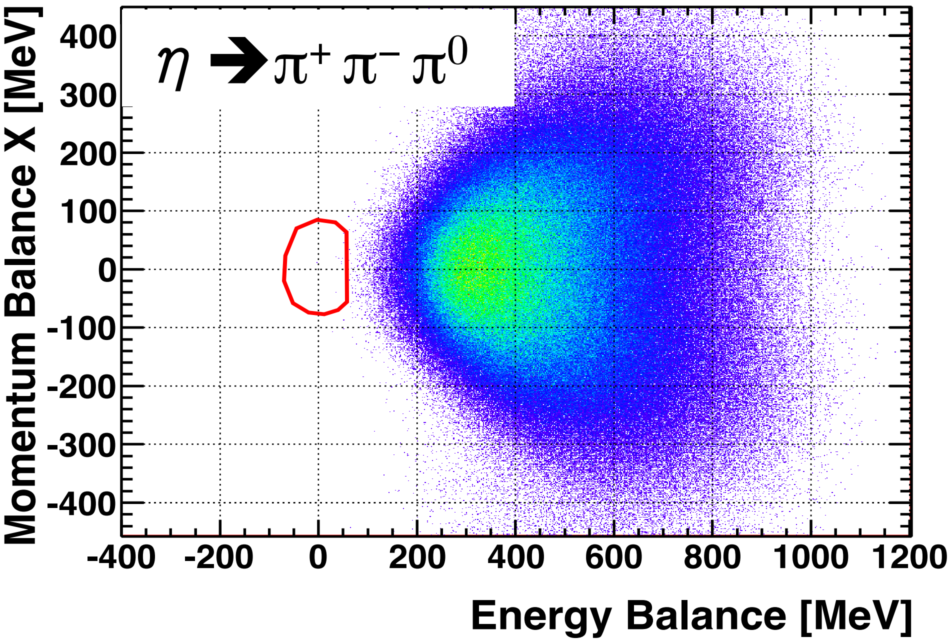




electron / pion misidentification

Simulation: exploiting energy- and momentum- balance for e / π separation





Pions misidentified as electrons

8 counts out of $9.2*10^6$ events in cut range

➔ upper limit for $e^+e^-/\pi^+\pi^-$ misidentification: $1*10^{-6}$

electron / pion misidentification

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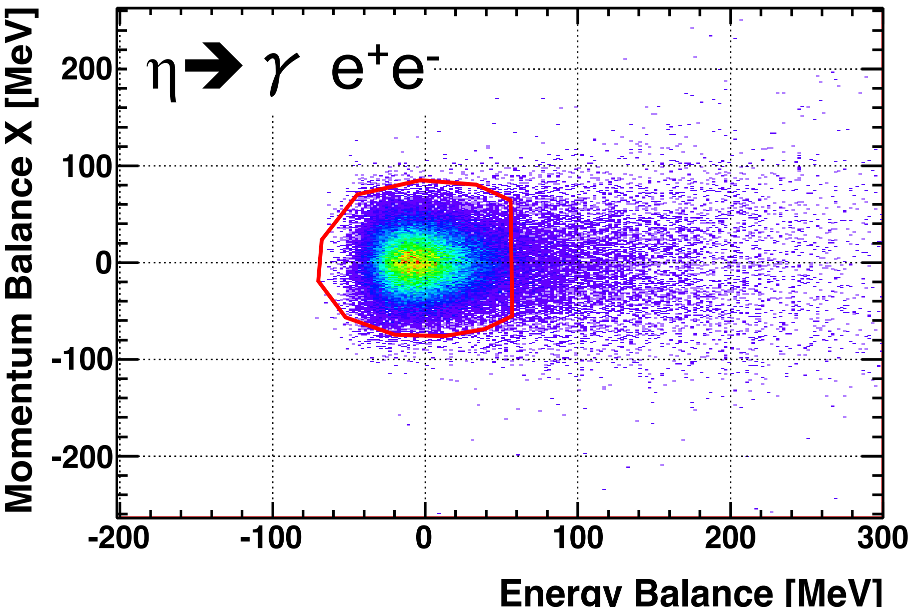

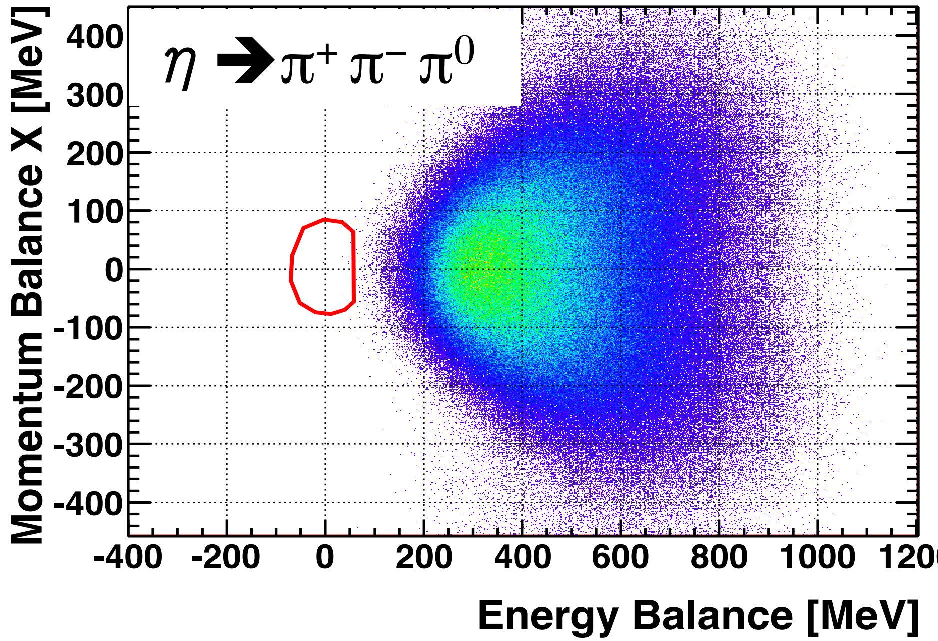

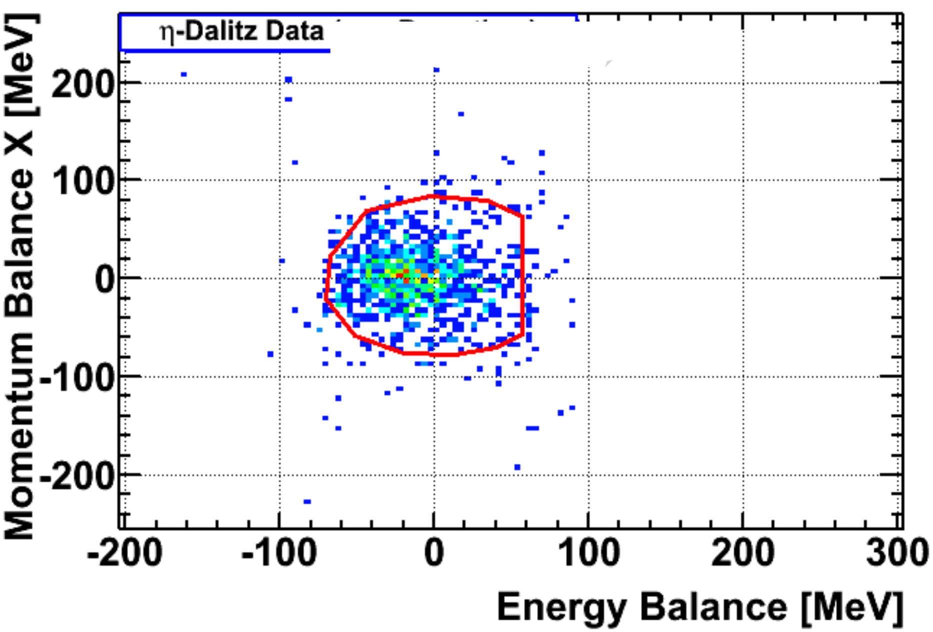

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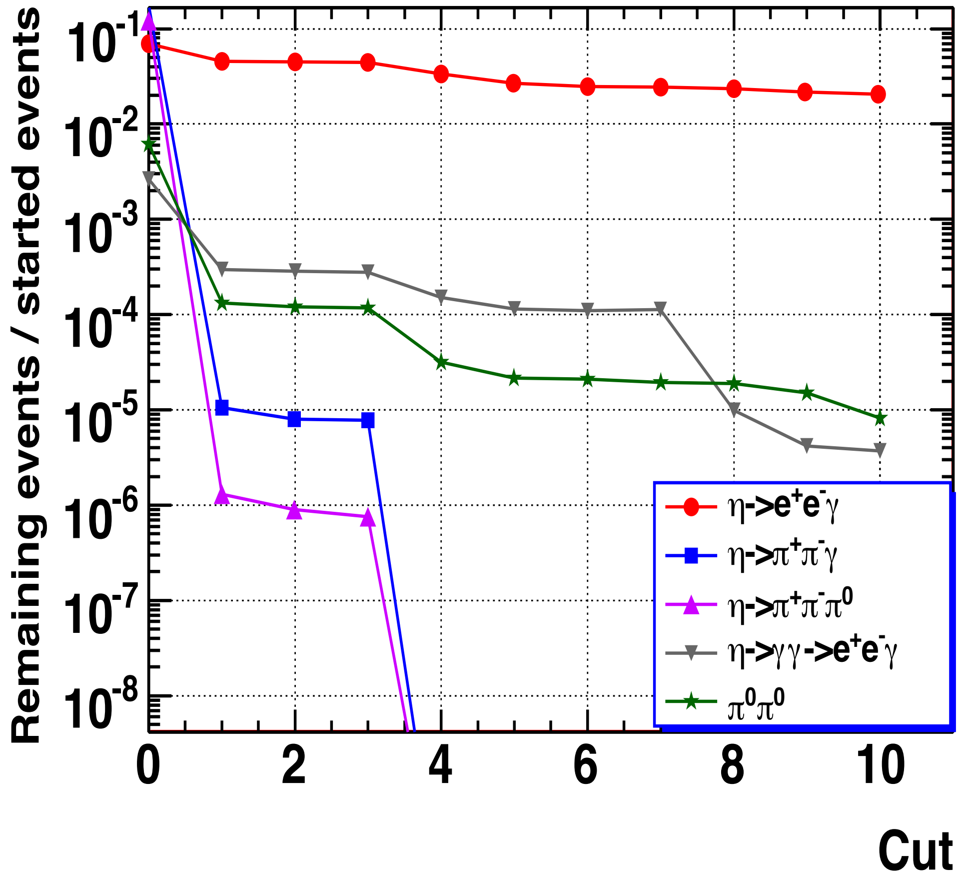
cuts to select reaction of interest: $\gamma p \rightarrow p\eta \rightarrow p\gamma e^+e^-$

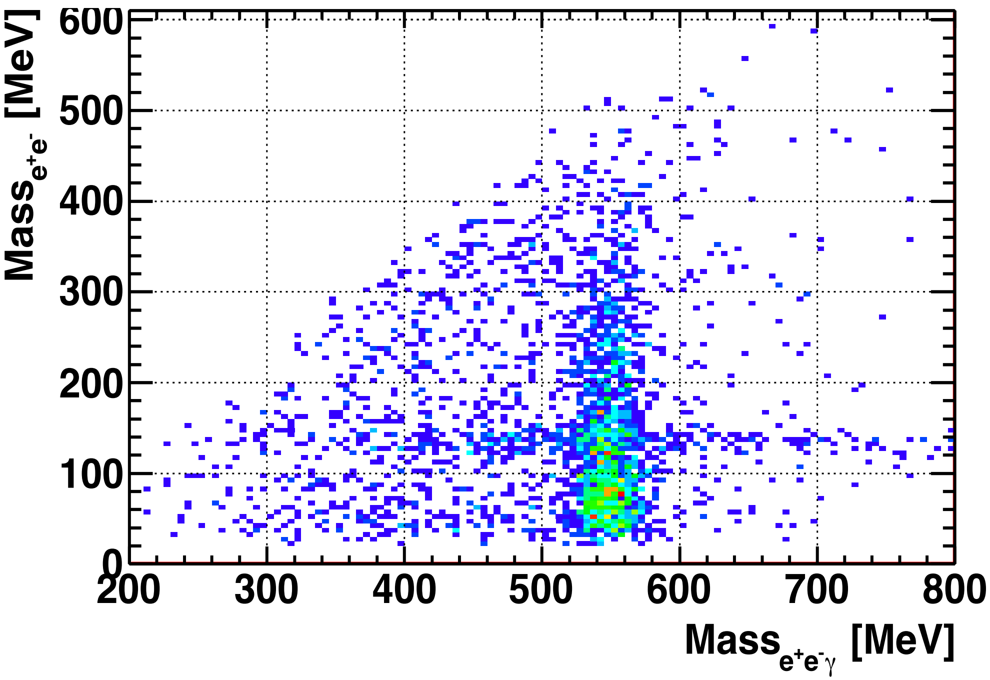
Cut-Nr	Name [Unit]	Limits
1	Momentum Balance X vs. Energy Balance	2D-Cut see Fig. 3
2	Momentum Balance Y vs. Energy Balance	2D-Cut
3	Momentum Balance Z [MeV]	-100.0 to 105.0
4	Missing Mass [MeV]	900 to 960
5	Beam Energy [MeV]	750 to 1210
6	Coplanarity [°]	167 to 193
7	Θ_{proton} [°]	0 to 50
8	opening angle e^+e^- [°]	10 to 140
9	$e^\pm$ Cluster Size	4 to 14
10	Angle $e^\pm\gamma$ [°]	50 to 175



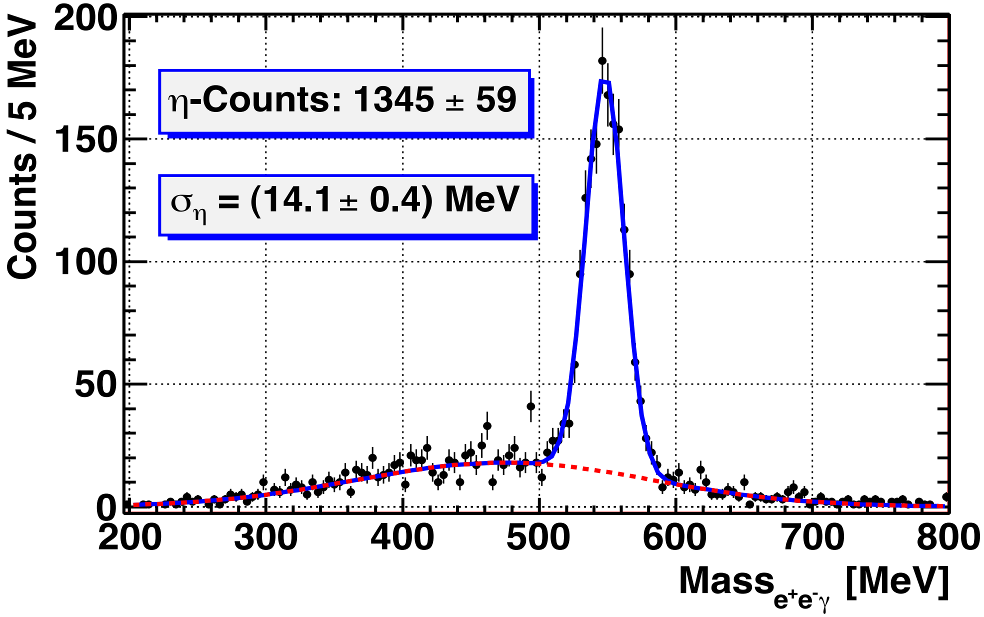
acceptance ($\gamma p \rightarrow p\eta \rightarrow p\gamma e^+e^-$) = (2.0±0.1)%

all other channels suppressed by more than 3 orders of magnitude

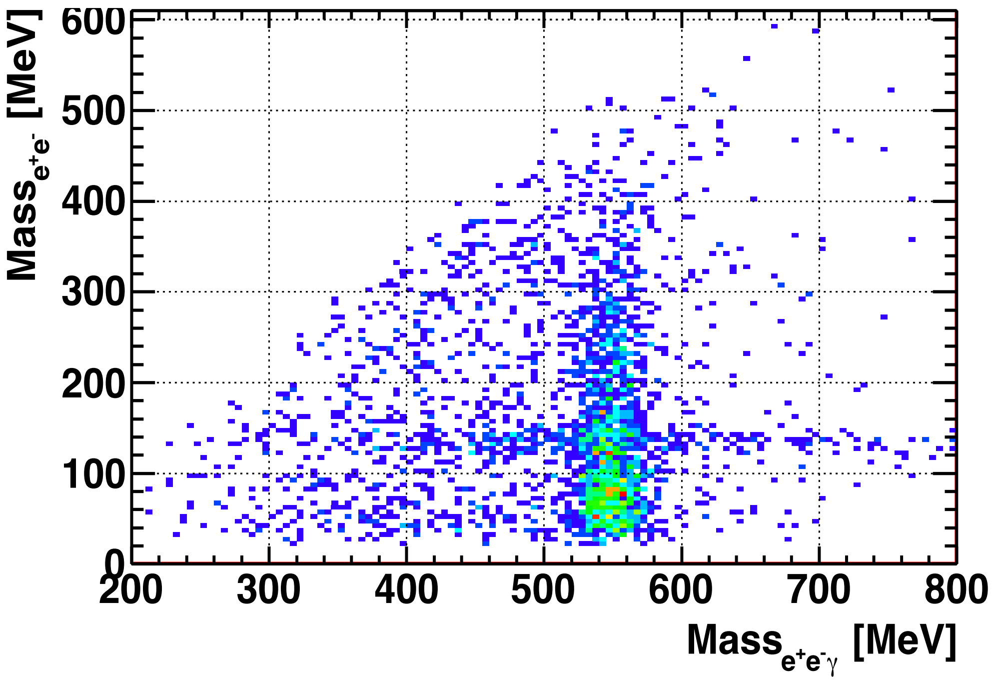
Analysis of η Dalitz decay: $\eta \rightarrow e^+e^-\gamma$

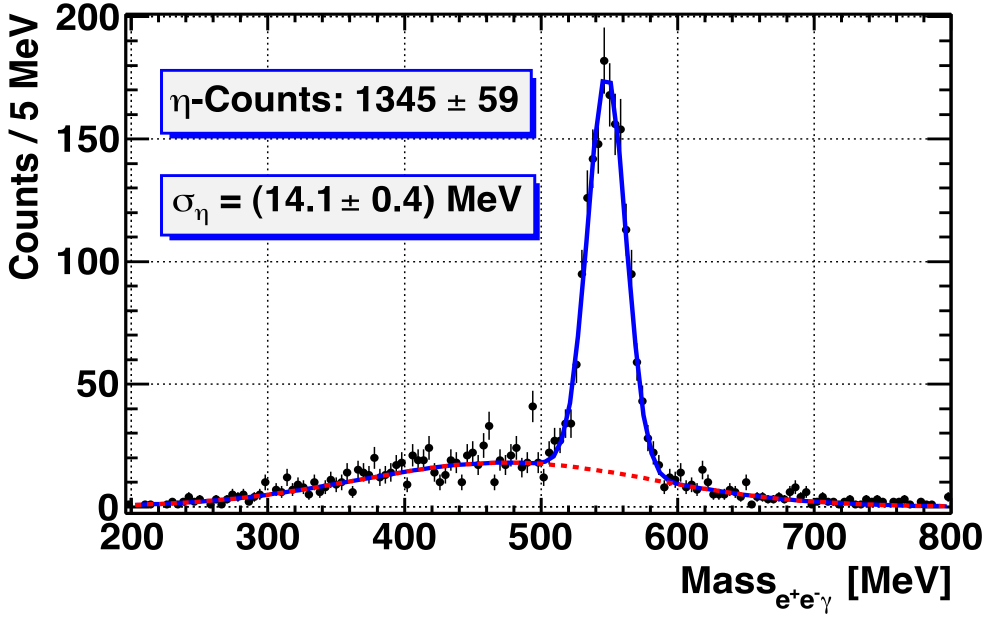


← e/γ mis-identification



Analysis of η Dalitz decay: η ➔ e⁺e⁻ γ





observed: $N(\eta \rightarrow e^+e^-\gamma) = 1345 \pm 49$

$\varepsilon(\gamma p \rightarrow p\eta \rightarrow pe^+e^-\gamma) = (2.0 \pm 0.1)\%$

total $N(\eta \rightarrow e^+e^-\gamma) = (6.72 \pm 0.42) \cdot 10^4$

observed:

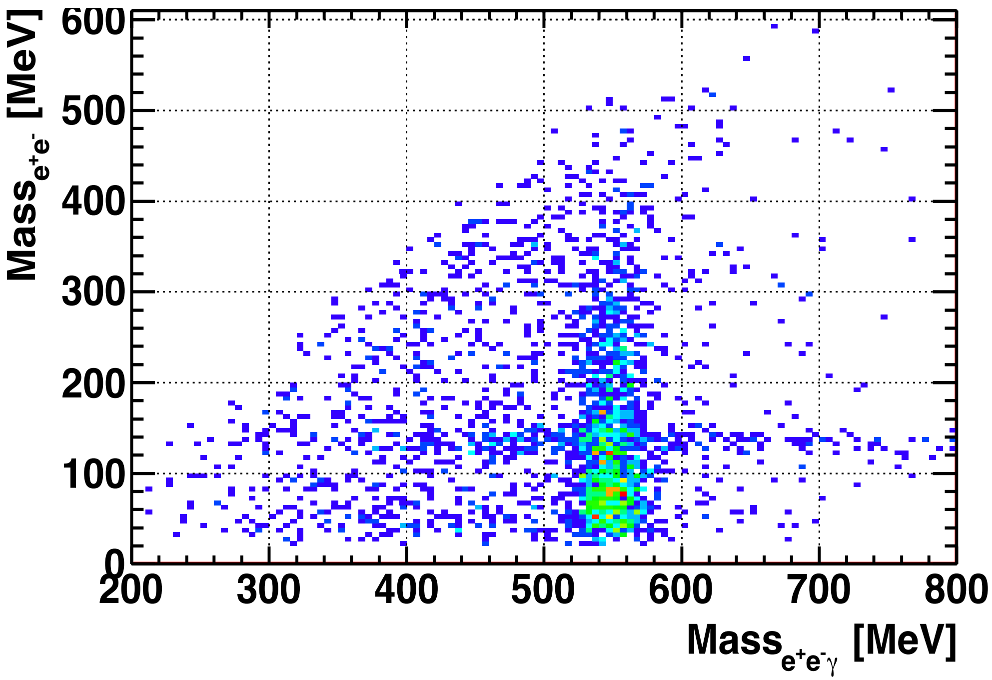
$N(\eta \rightarrow \gamma\gamma) = (4.81 \pm 0.24) \cdot 10^5$

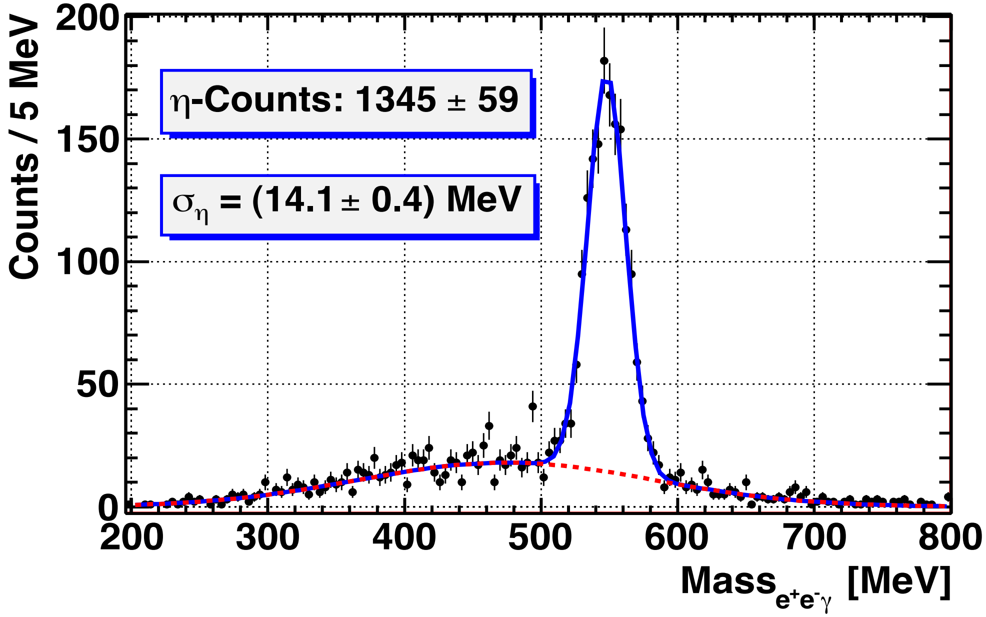
$\varepsilon(\gamma p \rightarrow p\eta \rightarrow p\gamma\gamma) = 12.1\%$

$N(\eta \rightarrow \gamma\gamma) = (4.01 \pm 0.18) \cdot 10^6$

total number of η produced:
$(10.2 \pm 0.45) \cdot 10^6$

Analysis of η Dalitz decay: $\eta \rightarrow e^+e^- \gamma$





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relative branching ratio:

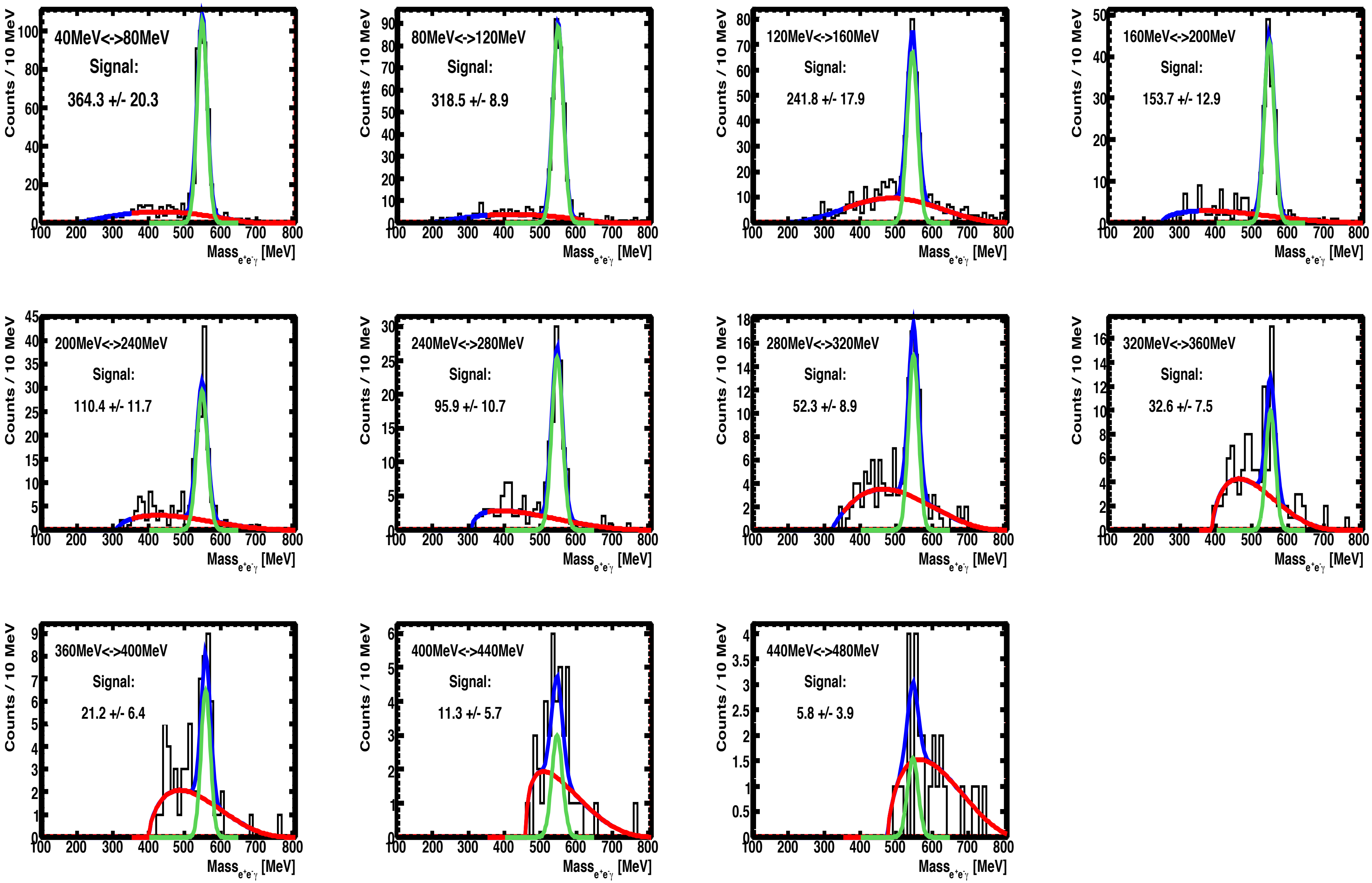
$$\frac{\Gamma_{\eta \rightarrow \gamma e^+ e^-}}{\Gamma_{\eta \rightarrow \gamma\gamma}} = \frac{N_{\eta \rightarrow \gamma e^+ e^-}}{N_{\eta \rightarrow \gamma\gamma}} \cdot \frac{\varepsilon_{\eta \rightarrow \gamma\gamma}}{\varepsilon_{\eta \rightarrow \gamma e^+ e^-}}$$

$= (1.68 \pm 0.10) \bullet 10^{-2}$

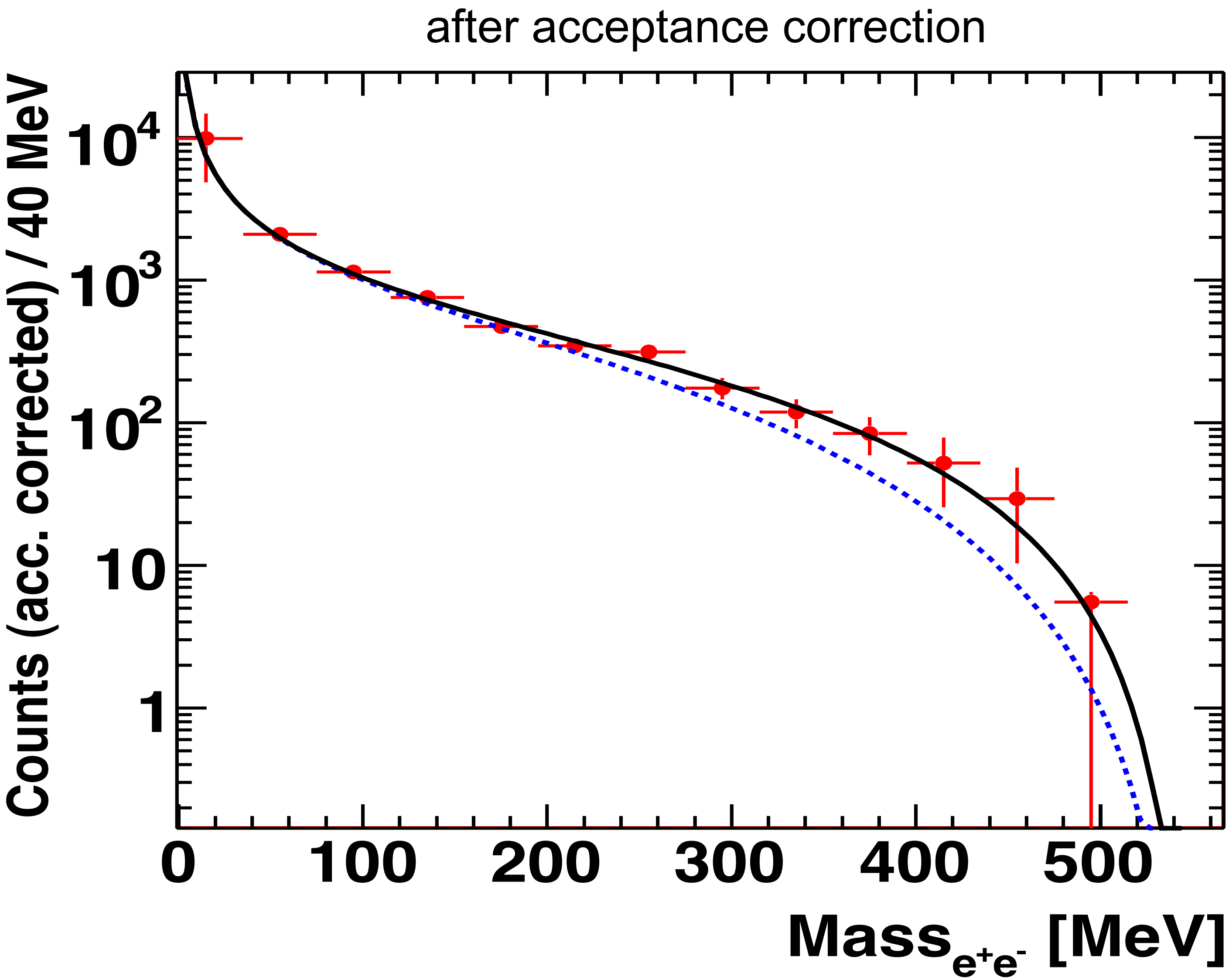
$Br(\eta \rightarrow \gamma e^+e^-) = (6.6 \pm 0.4 \pm 0.4) \bullet 10^{-3}$

PDG: $Br(\eta \rightarrow \gamma e^+e^-) = (7.0 \pm 0.7) \bullet 10^{-3}$

$\eta \rightarrow \gamma\, e^+e^-$ signal for different bins in m_{e+e-}

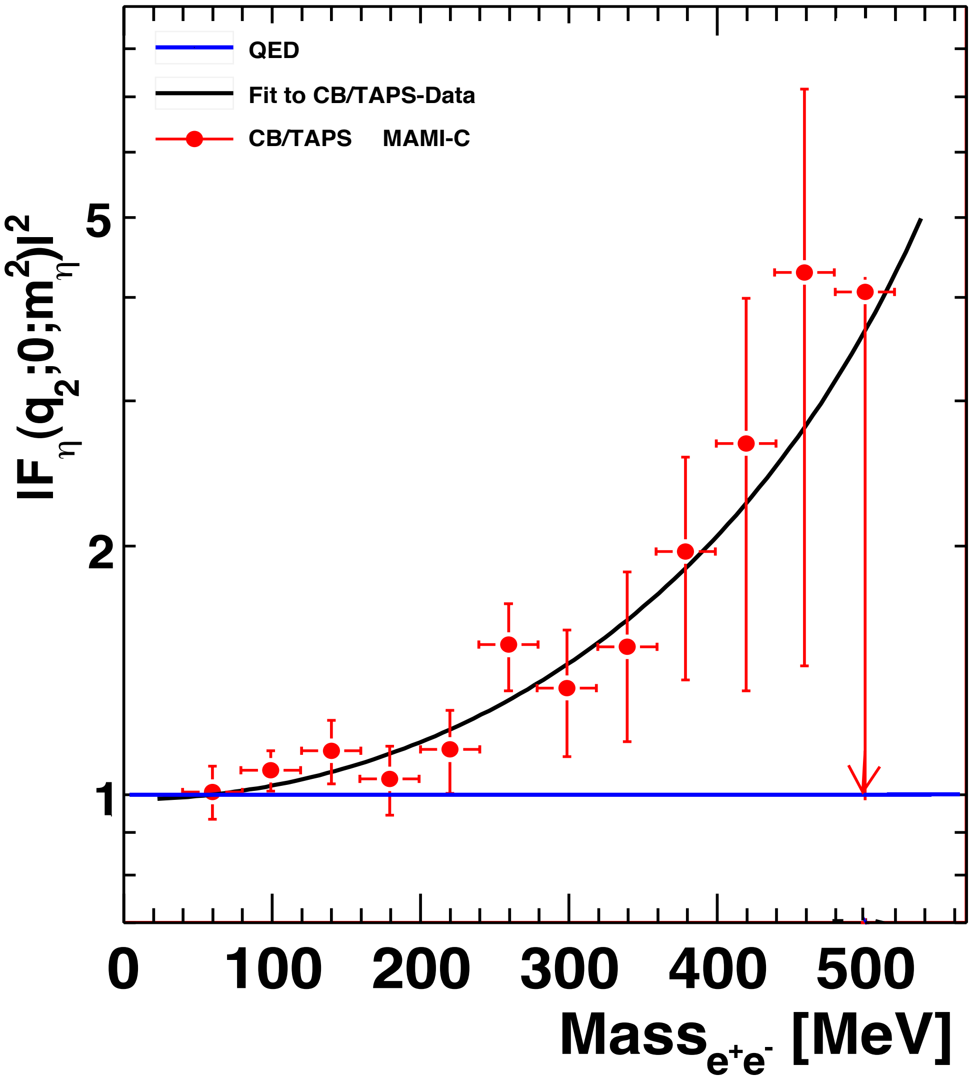


e^+e^- invariant mass distribution for $\eta \rightarrow \gamma e^+e^-$ events



deviation of experimental data from QED prediction ➔ form-factor

electromagnetic transition form-factor of the η meson

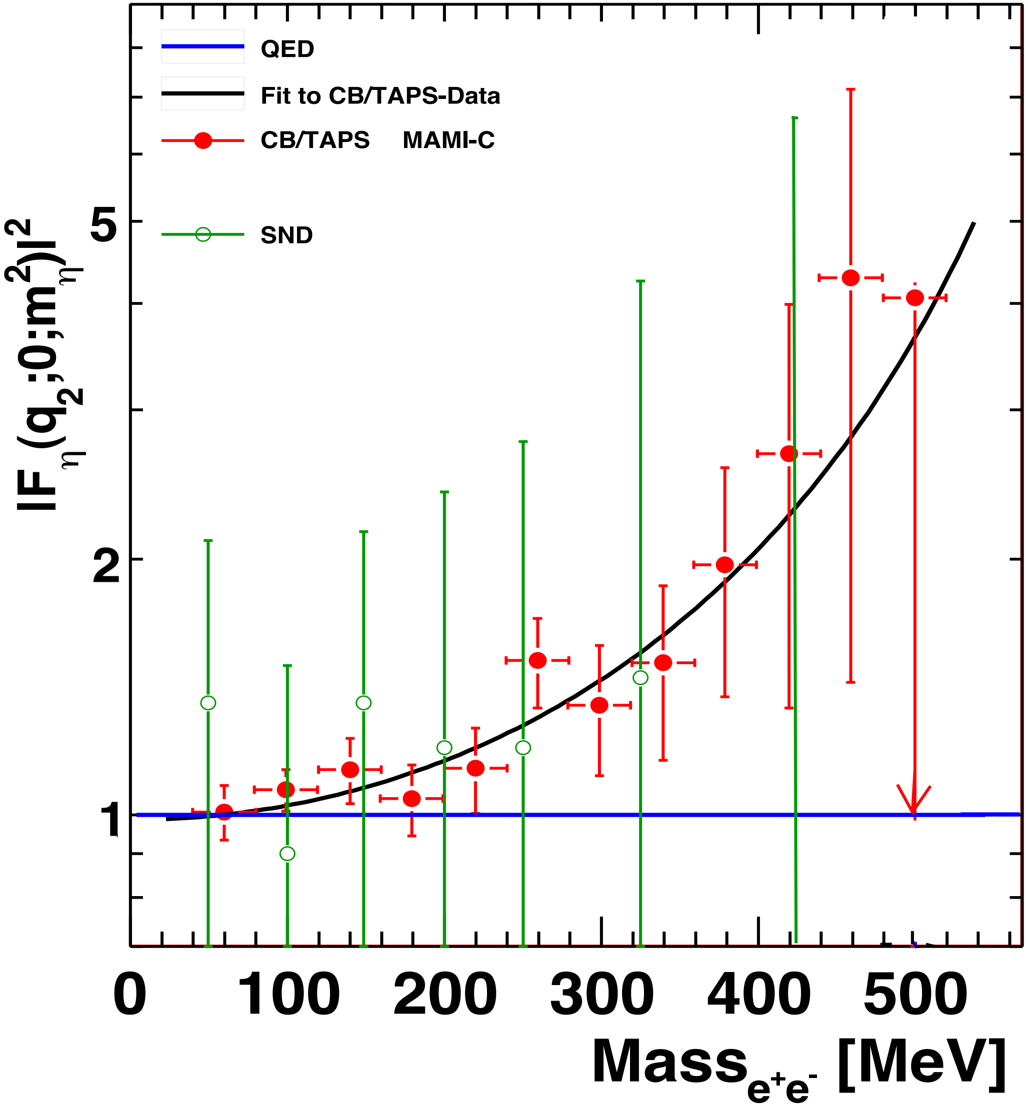


$$F(q^2) = (1 - q^2/\Lambda^2)^{-1}$$

$\eta \rightarrow \gamma e^+e^-$; this work: $b_\eta = \Lambda^{-2} = (1.92 \pm 0.35(\mathrm{stat}) \pm 0.13(\mathrm{syst}))\ \mathrm{GeV}^{-2}$

$\Lambda = (720 \pm 60(\mathrm{stat}) \pm 50(\mathrm{syst}))\ \mathrm{MeV}$

comparsion to SND data



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SND:
M.N. Achasov et al.,
PLB 504 (2001) 275

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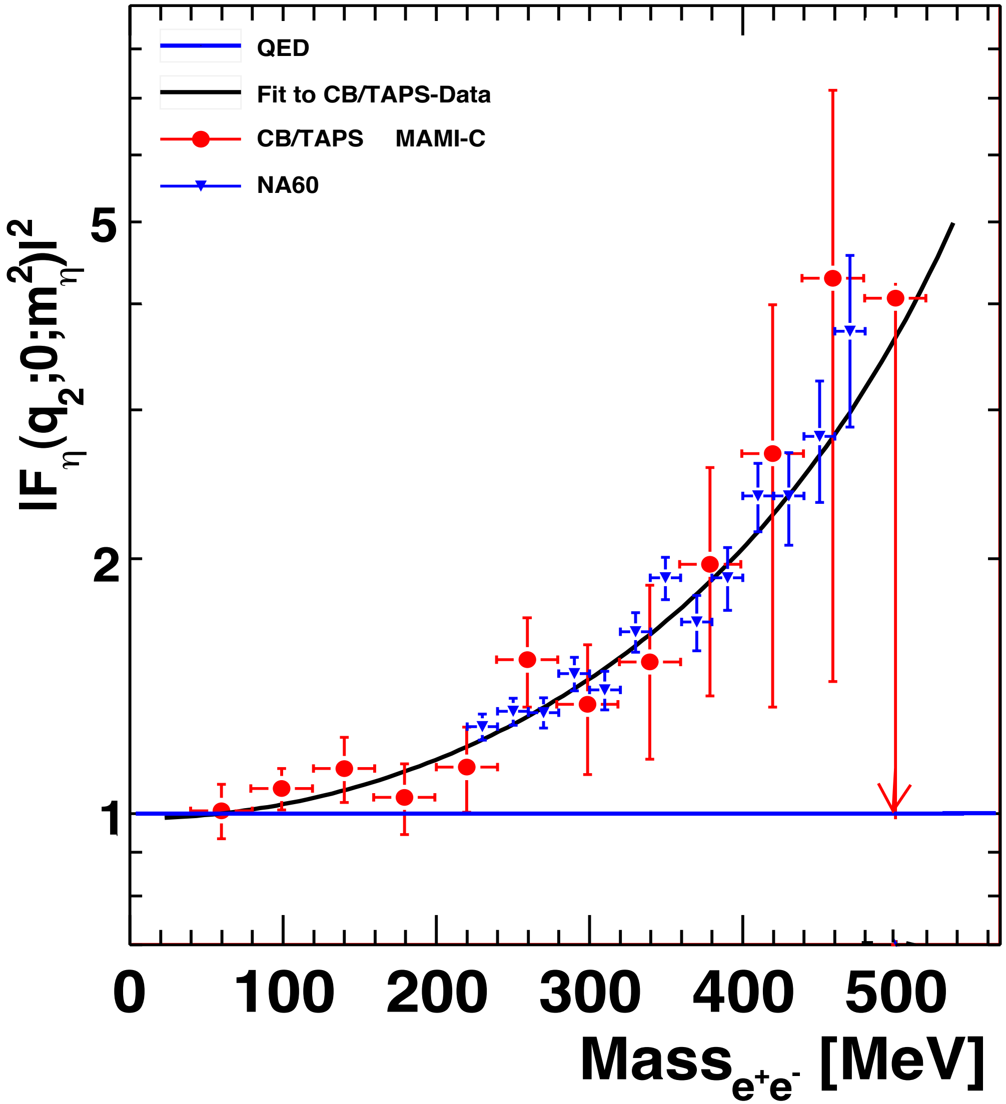
$\eta \rightarrow \gamma\, e^+e^-$; SND: $b_\eta = \Lambda^{-2} = (1.6 \pm 2.0)\ GeV^{-2}$

Comparsion to NA60 data



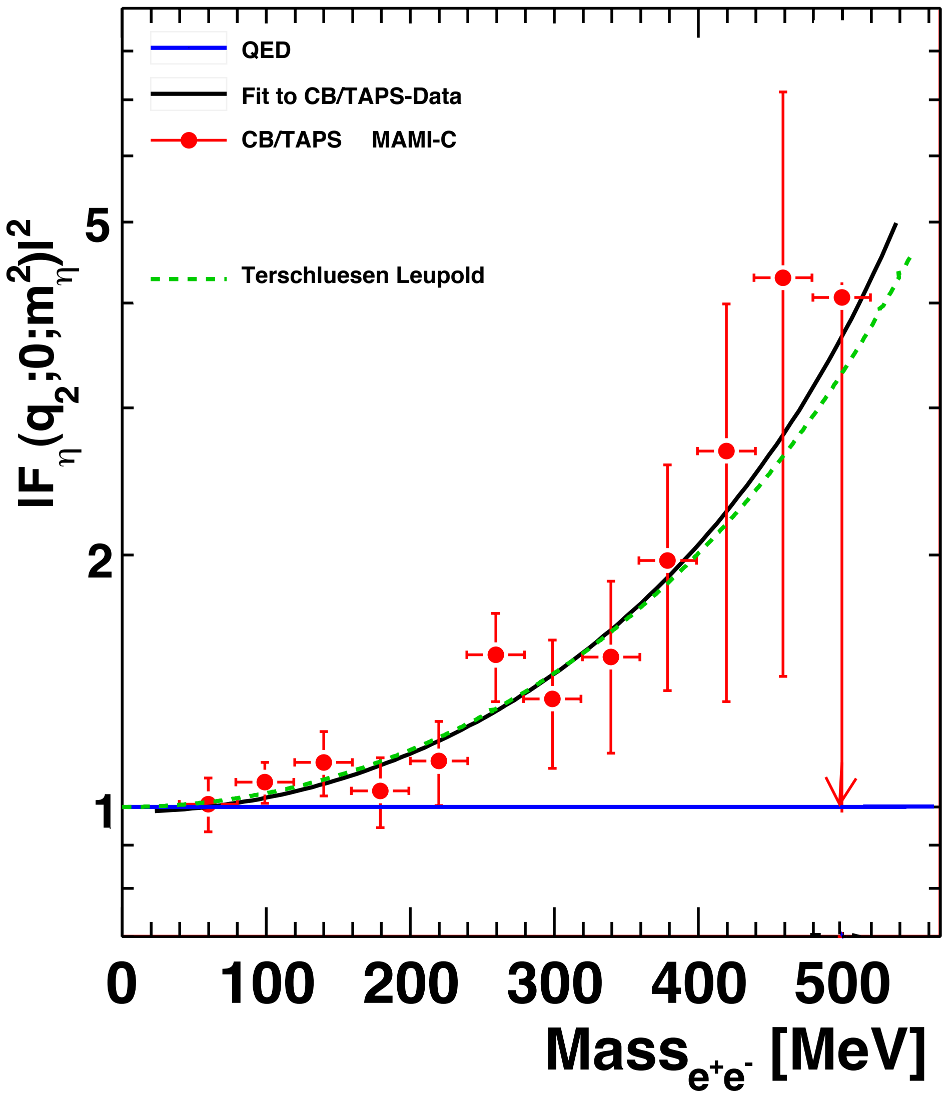
$F(q^2) = (1-q^2/\Lambda^2)^{-1}$

NA60:
no photon detection,
➔ no reconstruction of η meson;
formfactor deduced from unfolding $\mu^+\mu^-$ mass spectrum, starting at $m_{\mu+\mu-} \geq 220$ MeV

$\eta \rightarrow \gamma\, e^+e^-$; this work: $b_\eta = \Lambda^{-2} = (1.92 \pm 0.35(\text{stat}) \pm 0.13(\text{syst}))\ \text{GeV}^{-2}$

$\eta \rightarrow (\gamma)\, \mu^+\mu^-$; NA60: $b_\eta = \Lambda^{-2} = (1.95 \pm 0.17(\text{stat}) \pm 0.05(\text{syst}))\ \text{GeV}^{-2}$

Comparsion to calculations



$F(q^2) = (1-q^2/\Lambda^2)^{-1}$

C. Terschlüsen and S. Leupold, PLB 691 (2010) 191

C. Terschlüsen; Diploma thesis, Univ. Giessen (2010)

$\eta \rightarrow \gamma\, e^+e^-$; this work: $b_\eta = \Lambda^{-2} = (1.92 \pm 0.35(stat) \pm 0.13(syst))\ GeV^{-2}$

$\eta \rightarrow \gamma\, e^+e^-$; theory: $b_\eta = \Lambda^{-2} = 1.79\ GeV^{-2}$; VMD: $b_\eta = \Lambda^{-2} = 1.78\ GeV^{-2}$

summary

- $10.2 \cdot 10^6$ η mesons produced in photo nuclear reaction on LH_2 target

- $\eta \rightarrow e^+e^-\gamma$ Dalitz decay identified in **exclusive reaction** $\gamma\, p \rightarrow p\, \eta$ exploiting the full kinematic information: momentum-, energy balance, missing mass, etc.

- improvement in statistics compared to most recent measurement in the $e^+e^-\gamma$ channel by an order of magnitude.

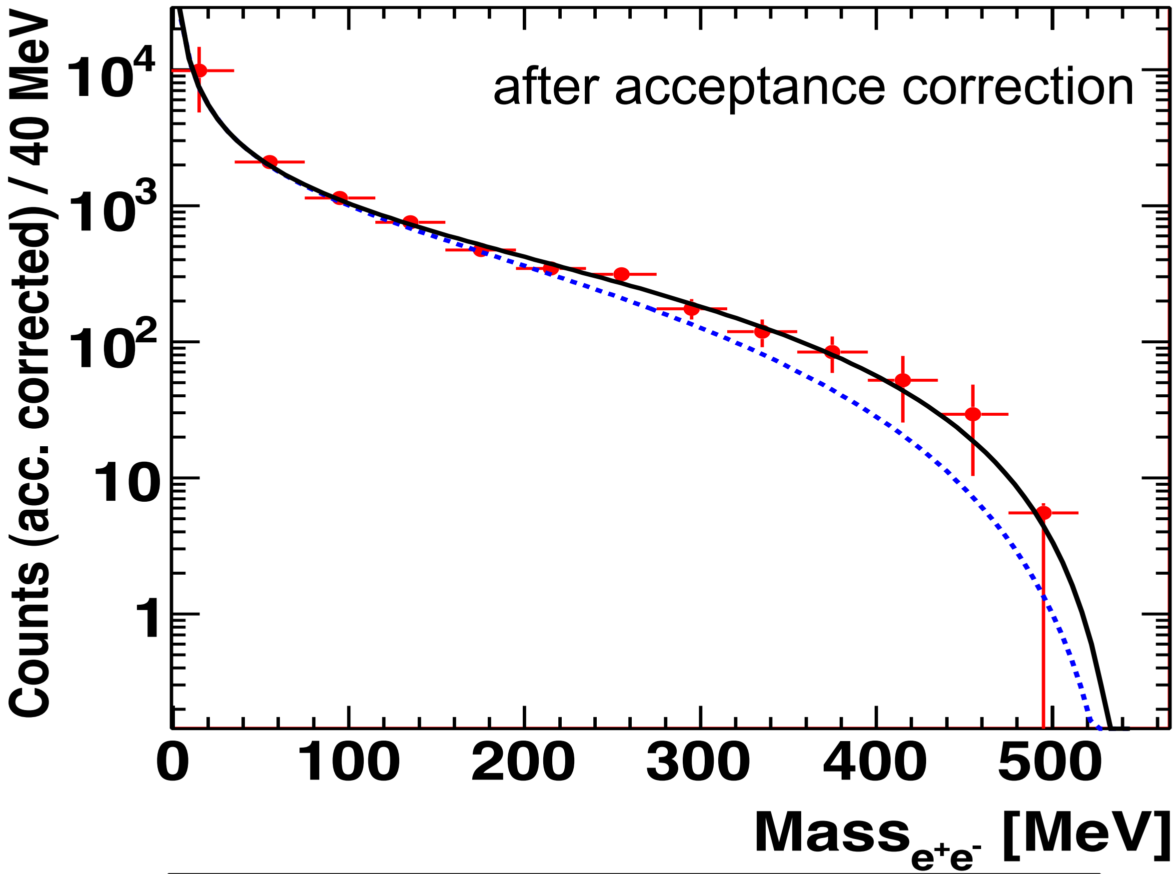
- resulting slope parameter of the form factor:
  $b_\eta = \Lambda^{-2} = (1.92 \pm 0.35(stat) \pm 0.13(syst))\ GeV^{-2}$
  in good agreement with NA60 measurement in $\mu^+\mu^-(\gamma)$ channel

- resulting slope parameter of the form factor in good agreement with calculations by Terschlüsen, Leupold, Lutz within field theoretical approach and with the VMD prediction

- branching ratio for Dalitz decay:
  $Br(\eta \rightarrow e^+e^-\gamma) = (6.6 \pm 0.4(stat) \pm 0.4(syst)) \cdot 10^{-3}$
  PDG: $(7.0 \pm 0.7) \cdot 10^{-3}$

See also poster 13 by Michael Kunkel (CLAS-collaboration) !!

e^+e^- invariant mass distribution for $\eta \rightarrow \gamma e^+e^-$ events



deviation of experimental data from QED prediction

➔ form-factor