Search for a rare η-decay in pp-reactions at E_{kin}=3.5 GeV

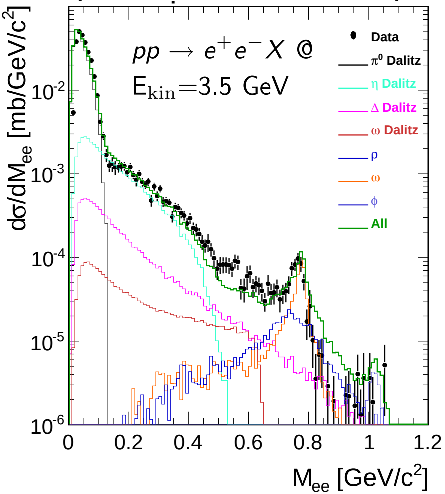
P. Huck
for the HADES-Collaboration

The rare Decay $\eta \to \pi^+\pi^-e^+e^-$

Physics Aspects:
CP-Violation, QCD-Anomalies
see *D. Coderre* (HK 26.7) & *T. Petri* (HK 54.5)

HADES Aspects:
pp-Data well described by hadronic Cocktail (*Pluto*)
[arXiv:0905.2568]
$\Downarrow$
rel. η-production from fit
$\Downarrow$
independent measurement:
– $pp \to pp\eta$ Missing Mass
– $\eta \to \pi^+\pi^-e^+e^-$ full reconstruction

[A. Rustamov priv. comm., see also HK 17.3]



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⇓

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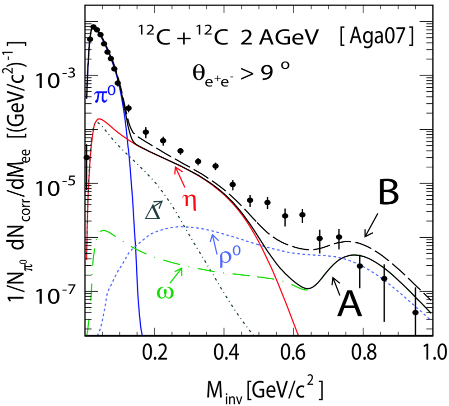
[PRL (2007) 98(5):052302] 50$^+$



- try to pin down η-contribution in HI collisions

The rare Decay $\eta \to \pi^+\pi^- e^+ e^-$

Physics Aspects:
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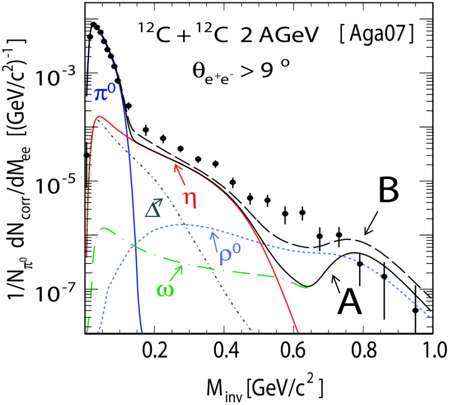
see *D. Coderre* (HK 26.7) & *T. Petri* (HK 54.5)

η as reference

$\eta \to \gamma\gamma$	39,31%
$\eta \to \pi^0\pi^0\pi^0$	32,56%
$\eta \to \pi^+\pi^-\pi^0$	22,73%
$\eta \to \pi^+\pi^-\gamma$	4,60%
$\eta \to e^+e^-\gamma$	0,68%
$\eta \to \pi^0\pi^0\gamma\gamma$	$<$ 0,12%
$\eta \to \pi^0\gamma\gamma$	0,044%
$\eta \to \pi^+\pi^- e^+ e^-$	0,042%
$\eta \to e^+e^-$	$<$ 0,0077%

[PRL (2007) 98(5):052302] 50+



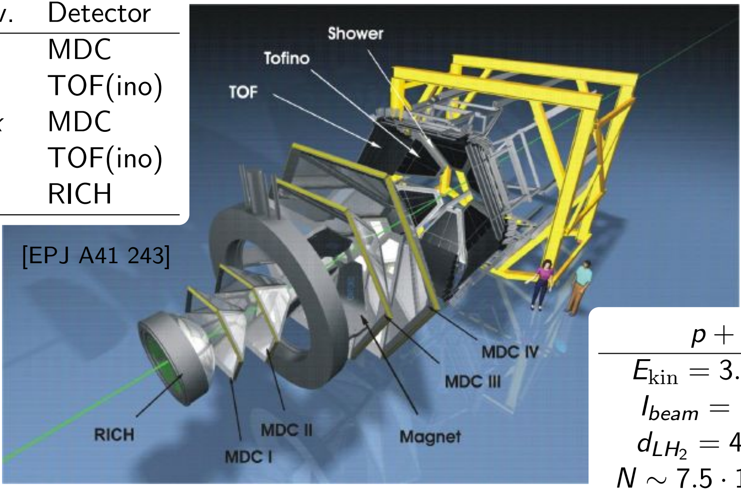
- try to pin down η-contribution in HI collisions

Existing Data

	Year	Authors	BR [10^{-4}]	# η's	# $\eta \rightarrow \pi^+\pi^-e^+e^-$
Theory	1967	Jarlskog, Pilkuhn [NP B1 264]	3.1		
	1993	Picciotto, Richardson [PR D48 3395]	3.2±0.3		
	1999	Faessler, Fuchs, Krivoruchenko [PR C61 035206]	3.6		
	2007	Borasoy, Nissler [NP A740 362]	$2.99^{+0.08}_{-0.11}$		
Experiment	1966	Grossmann, Price, Crawford [PR 146 993]	13^{+12}_{-8}		1
	2001	CMD-2 [PL B501 191]	$3.7^{+2.5}_{-1.8}$		4
	2006	CELSIUS/WASA (*pp*) [PL B644 299]	$4.3^{\pm 1.3}_{\pm 0.4}$	75 k	16
	2008	KLOE (e^+e^-) [PL B675 283]	$2.68^{\pm 0.09}_{\pm 0.07}$	72 M	1555
	2009	HADES (*pp*)	Can we see some of them?	4-7 M	10–20

Hades - Experiment

Observ.	Detector
p	MDC
β	TOF(ino)
dE/dx	MDC
	TOF(ino)
$e^{\pm}$	RICH



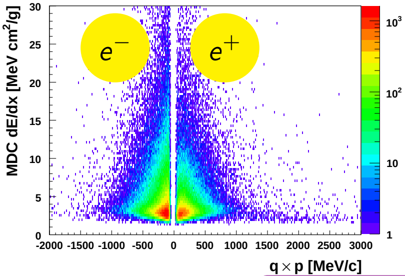
$p + p$
$E_{\mathrm{kin}} = 3.5$ GeV
$I_{beam} = 10^7/s$
$d_{LH_2} = 4.4\ cm$
$N \sim 7.5 \cdot 10^9$ evts

Particle Identification - Sim./Exp.

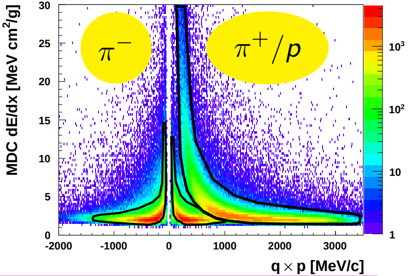
- Hadron ID: MDC dE/dx vs p for PID
- 42% of e^+ do not reach TOF ($p < 100\ MeV/c$)
  Lepton-Hadron-Discrimination by RICH Ring-Signal only
- tuned cuts on $e^+e^-/\pi^+\pi^-$-vertices

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

good Ring + $p < 1000\ MeV/c$



explic. no Ring + graph. cuts

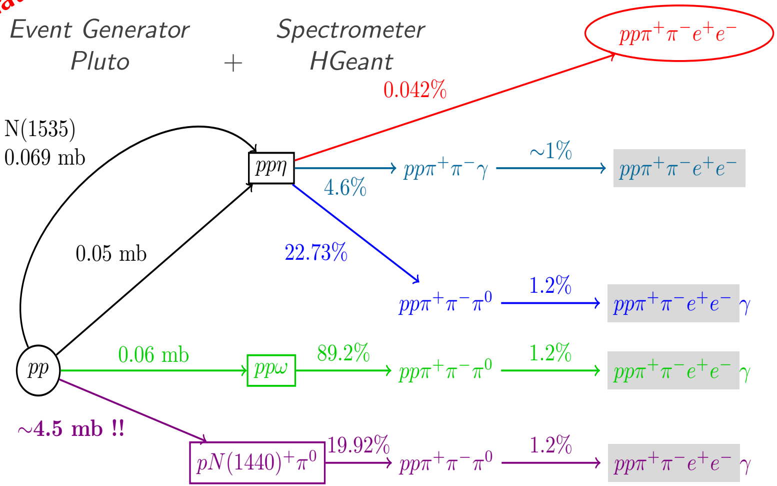


acceptance studies → analysis of $p\pi^+\pi^-e^+e^-$

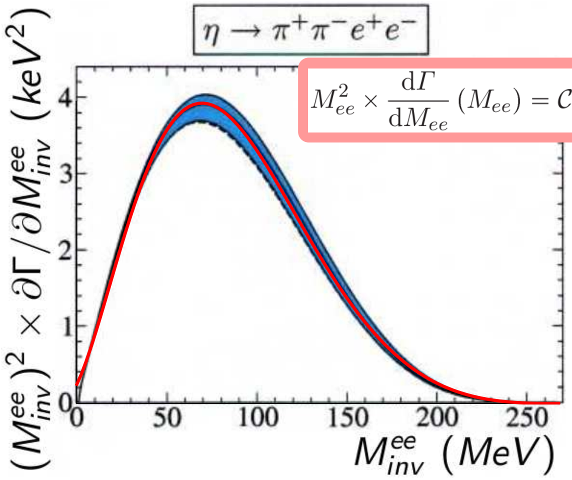
Simulation Input: Cocktail

Full Scale Simulation

Event Generator *Pluto* + *Spectrometer* *HGeant*



Simulation Input: e^+e^- invariant Mass



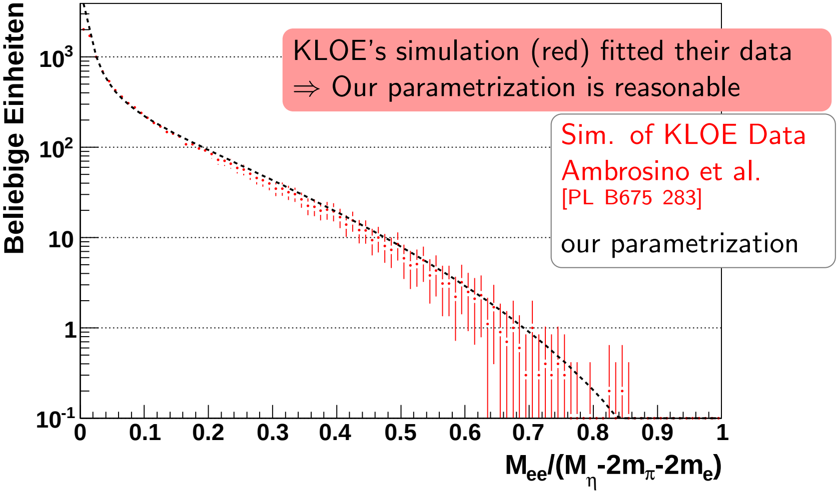
$$M_{ee}^2 \times \frac{\mathrm{d}\Gamma}{\mathrm{d}M_{ee}}(M_{ee}) = \mathcal{C} \cdot \sin^2(a_1 M_{ee} - a_2) \cdot e^{-kM_{ee}}$$

theory:

Borasoy & Nissler
[EPJ A33 95]

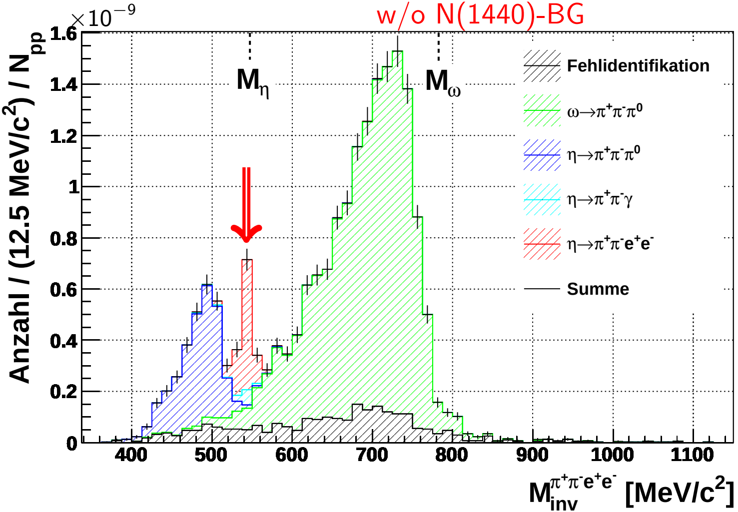
our parametrization

Simulation Input: e^+e^- invariant Mass

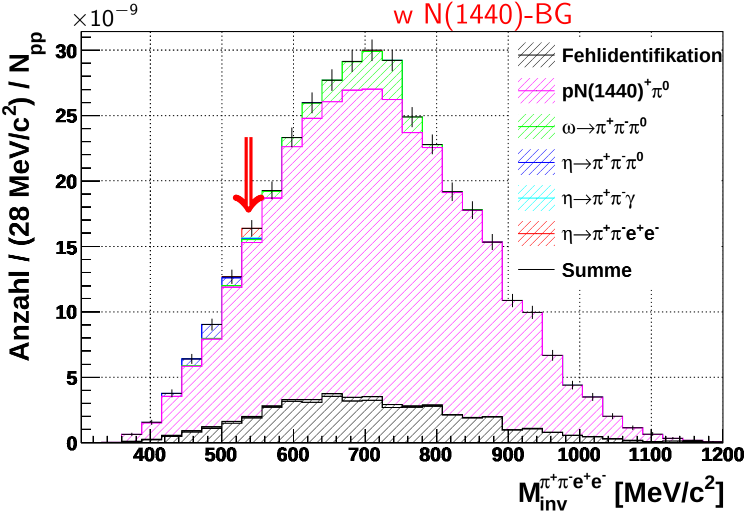


KLOE's simulation (red) fitted their data
$\Rightarrow$ Our parametrization is reasonable

5-Prong - Simulation Cocktail I



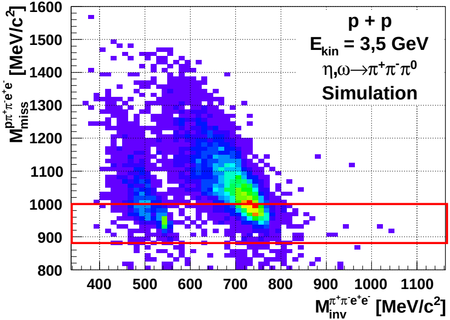
5-Prong - Simulation Cocktail II



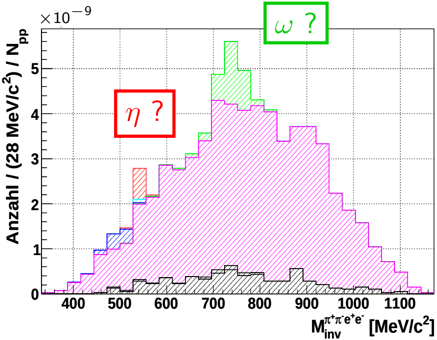
5-Prong - Missing Mass Cut

$pp \to pp\eta/\omega \to p\ p\pi^+\pi^- e^+ e^- (\gamma)$

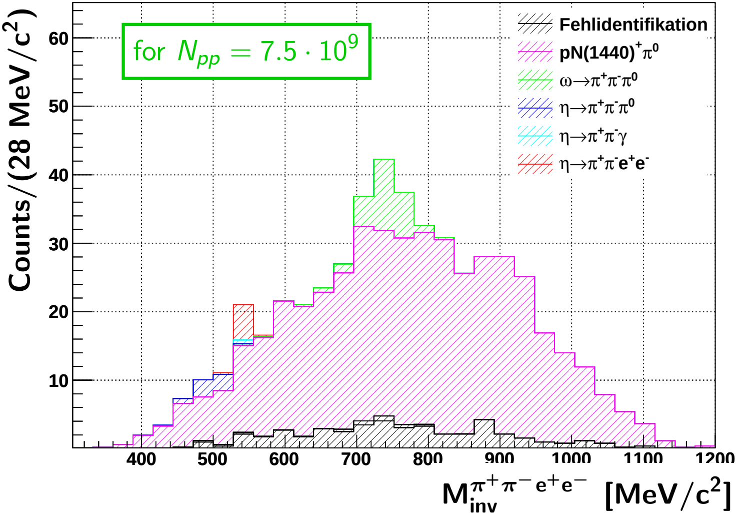
$880\ \mathrm{MeV/c^2} < M_{miss}^{p\pi^+\pi^- e^+ e^-} < 1000\ \mathrm{MeV/c^2}$



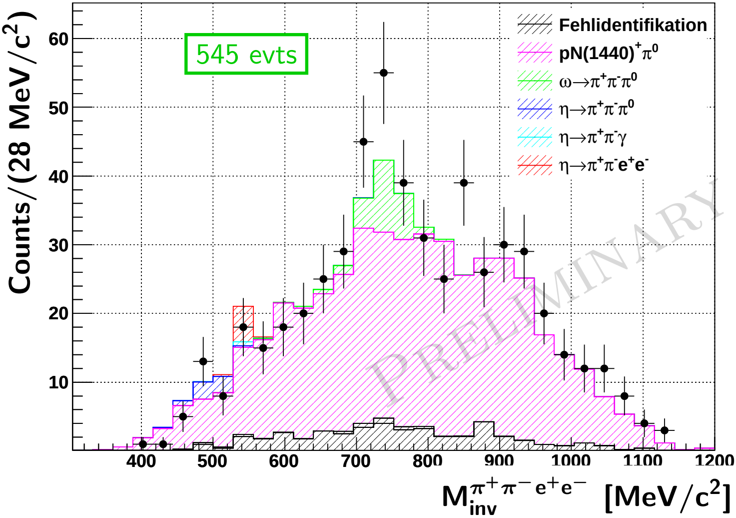
after Missing Mass Cut



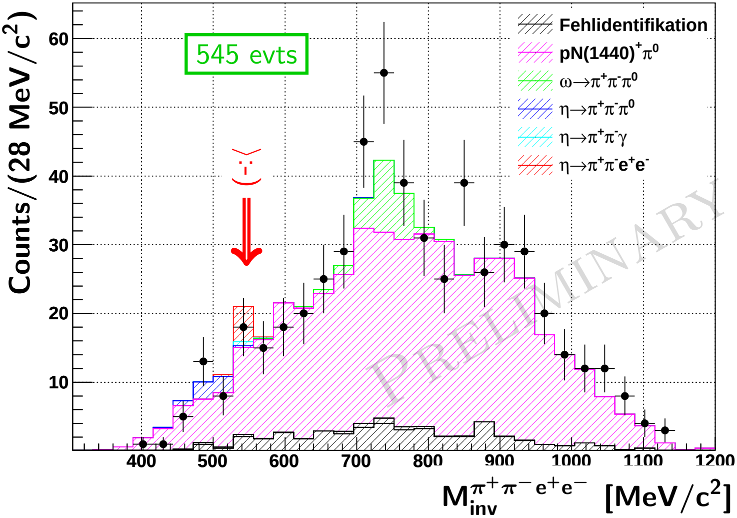
Simulation for $7.5 \cdot 10^9$ events



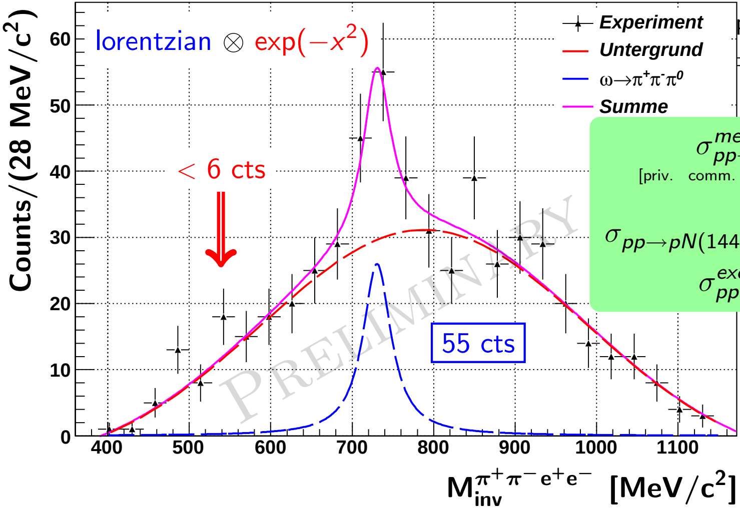
Simulation & Experiment



Simulation & Experiment



Cross Section Limits



preliminary numbers !

$\pm$ 30%

$$\sigma^{meas}_{pp\to pp\omega} = 0.12\ mb$$

[priv. comm. Teilab] HK 17.3

$$\Downarrow$$

$$\sigma_{pp\to pN(1440)^+\pi^0} \approx 4.7\ mb$$

$$\sigma^{excl}_{pp\to pp\eta} \lesssim 0.19\ mb$$

Summary

- GOAL:
  understand η-production in *pp*- & *AA*-collisions at SIS energies
  study rare decay $\eta \to \pi^+\pi^- e^+ e^-$ as reference source
- dominant background by
  $pp \to pN(1440)^+\pi^0 \to pp\pi^+\pi^- e^+ e^- \gamma$
- 5-Prong: Exp + Sim agree well
  Missing Mass Cut: η/ω-decays become visible
- 55 $\omega \to \pi^+\pi^-\pi^0 \to \pi^+\pi^- e^+ e^- \gamma$ detected
- preliminary upper limit for $\eta \to \pi^+\pi^- e^+ e^-$ signal:
  $\sigma^{excl}_{pp\to pp\eta} \lesssim 0.19\ mb.$

HADES-Collaboration

G. Agakishiev, A. Balanda, D. Belver, A. Belyaev, A. Blanco, M. Böhmer, J. L. Boyard, P. Cabanelas, E. Castro, S. Chernenko, J. Díaz, A. Dybczak, E. Epple, L. Fabbietti, O. Fateev, P. Finocchiaro, P. Fonte, J. Friese, I. Fröhlich, T. Galatyuk, J. A. Garzón, A. Gil, M. Golubeva, D. González-Díaz, F. Guber, T. Hennino, R. Holzmann, P. Huck, A. Ierusalimov, I. Iori, A. Ivashkin, M. Jurkovic, B. Kämpfer, I. Koenig, W. Koenig, B. W. Kolb, A. Kopp, G. Korcyl, GK Kornakov, R. Kotte, A. Kozuch, A. Krása, F. Krizek, R. Krücken, H Kuc, W. Kühn, A. Kugler, A. Kurilkin, P. Kurilkin, P.K. Kählitz, V. Ladygin, J. Lamas-Valverde, S. Lang, K. Lapidus, T. Liu, L. Lopes, M. Lorenz, L. Maier, A. Mangiarotti, J. Markert, V. Metag, B. Michalska, J. Michel, C. Müntz, L. Naumann, Y. C. Pachmayer, M. Palka, Y. Parpottas, V. Pechenov, O. Pechenova, J. Pietraszko, W. Przygoda, B. Ramstein, A. Reshetin, J. Roskoss, A. Rustamov, A. Sadovsky, P. Salabura, A. Schmah, J. Siebenson, Yu.G. Sobolev, T. Solovieva, S. Spataro, B. Spruck, H. Ströbele, J. Stroth, C. Sturm, M. Sudol, A. Tarantola, K. Teilab, P. Tlusty, M. Traxler, R. Trebacz, H. Tsertos, V. Wagner, M. Weber, J. Wüstenfeld, S. Yurevich, and Y. Zanevsky —

Thank you !

Backup Slides

5. **Theory**
   - CP-Violation
   - CP Qu.Numbers
   - QCD-Anomalies
6. **SimInput**
   - principle
   - fits
7. **PID**
   - No TOF
   - PID - Exp.
8. **Vert.**
   - sketch
   - γ-Conversion
   - Pair Vertices - Exp.
9. **Accept.**
10. **N(1440)**
    - Missing Mass - Sim.
    - dominant bg-source
11. **5-Prong**
    - exp. 5-prong uncut
    - missing mass cut
    - ee inv. mass
12. **6-Prong**
    - missing mass
    - sim - exp

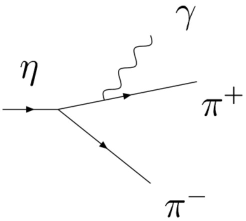
Matter-Antimatter-Asymmetry

Theories

- CP violation
- super-symmetry
- leptogenesis

CP violation in standard model (weak decays) does not explain $\frac{N_\gamma}{N_p} \sim 10^9$.

Motivates search for unknown sources.



$\eta \to \pi^+\pi^- e^+ e^-$

$\eta \to \pi^+\pi^-\gamma$

$$\mathrm{CP}(\eta) = \mathrm{CP}(\pi^+\pi^-) \cdot \mathrm{CP}(\gamma)$$

$$-1 = +1 \cdot \begin{cases} +1 & \mathrm{E1} \quad ✗ \\ -1 & \mathrm{M1} \quad ✓ \end{cases}$$

E1 by bremstrahlung of $(\pi^+\pi^-)^*$ intermediate state

Matter-Antimatter-Asymmetry

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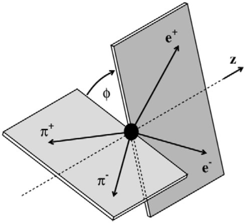


Additional variable to nEDM !

Excursus: CP Quantum Numbers

Photon

parity: results from parities of spherical harmonics $Y_{lm}(\theta, \phi)$.

$$P(El) = (-1)^l$$
$$P(Ml) = (-1)^{l+1}$$

charge conjugation:

$$C^\dagger \mathscr{L}_{\text{int}} C \stackrel{!}{=} \mathscr{L}_{\text{int}} \qquad \mathscr{L}_{\text{int}} \propto j^\mu A_\mu$$
$$C^\dagger A_\mu C \stackrel{!}{=} -A_\mu$$

$$\boxed{CP(\gamma) = \begin{cases} (-1)^{l+1} & El \\ (-1)^l & Ml \end{cases}}$$

η-Meson

pseudoscalar: $J^P = 0^-$

$C(\eta) = C(2\gamma) = (-1)^2 = +1$

$$\boxed{CP(\eta) = -1}$$

$\pi^+\pi^-$-Pair

$P(\pi) = P(\eta) = -1$

intrinsic $\times$ extrinsic

$$P(\pi^+\pi^-) = (-1)^2 \times (-1)^L$$

$C(\pi^+\pi^-) = +1$

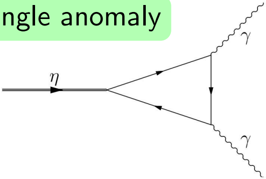
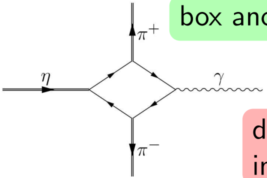
$$\boxed{CP(\pi^+\pi^-) = +1}$$

QCD Anomalies

Divergences in Feynman-Amplitudes of PV-coupling:

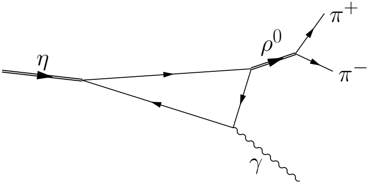
triangle anomaly

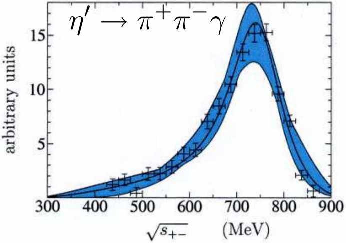
box anomaly

$\mathscr{L}_{\mathrm{WZW}} =$  $+$ 

disentangle by internal conversion

resonant decay via triangle:





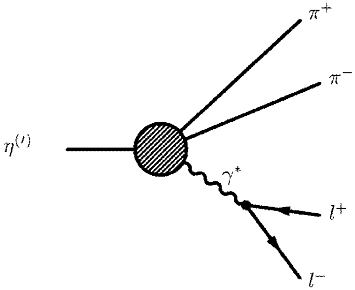
Rare Decay in PLUTO

$pN(1535)$ — 100% → $pp\eta$

pp — 58% → $pN(1535)$; 42% → $pp\eta$

η-production

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

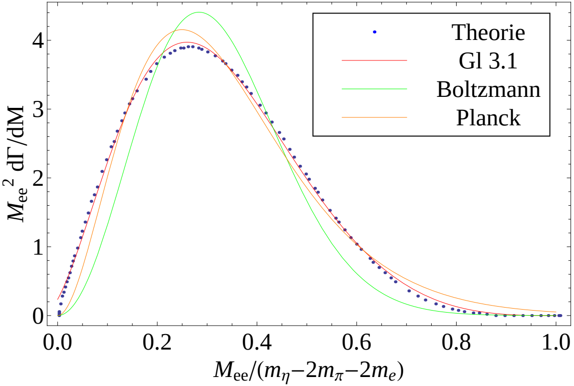


Differential Decay Width:

$$d\Gamma\left(\eta \rightarrow \pi^+\pi^- e^+ e^-\right) = \underbrace{\Gamma\left(\eta \rightarrow \pi^+\pi^-\gamma^*\right)}_{\text{determined by } M_{inv}^{ee}} \times \frac{1}{M^4}$$

$$\times \underbrace{M\Gamma\left(\gamma^* \rightarrow e^+e^-\right)}_{\gamma^*-\text{width}} dM^2$$

Rare Decay in PLUTO



$$M_{ee}^2 \times \frac{\mathrm{d}\Gamma}{\mathrm{d}M_{ee}}(M_{ee}) = \mathcal{C} \cdot \sin^2(a_1 M_{ee} - a_2) \cdot e^{-kM_{ee}}$$

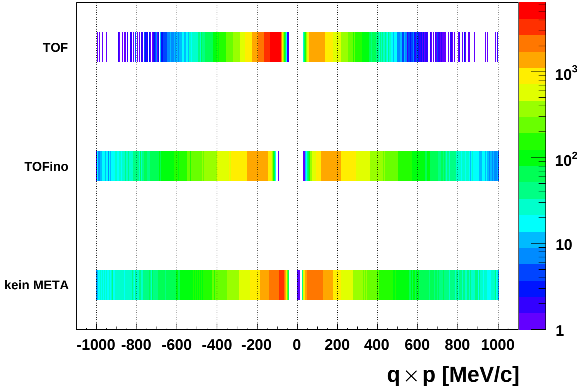
kinematic range:

$2m_e = 1.022\ \mathrm{MeV}/c^2$

$M_\eta - 2m_\pi - 2m_e = 267.7\ \mathrm{MeV}/c^2$

Particle Identification

Can β be used for PID in the case of $\eta \rightarrow \pi^+\pi^-e^+e^-$?



Independent variables $p, dE/dx$ and RICH Signal have to be used

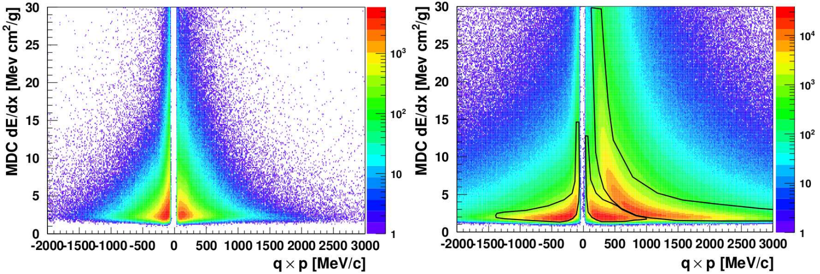
Particle Identification - Exp.

Electrons

good Ring

Hadrons

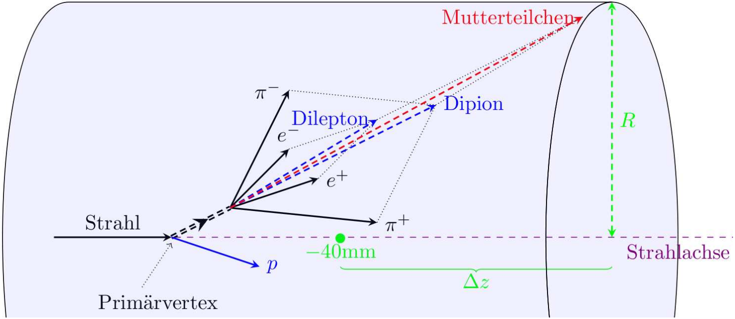
no Ring Correlation



$p < 1000\ GeV/c$

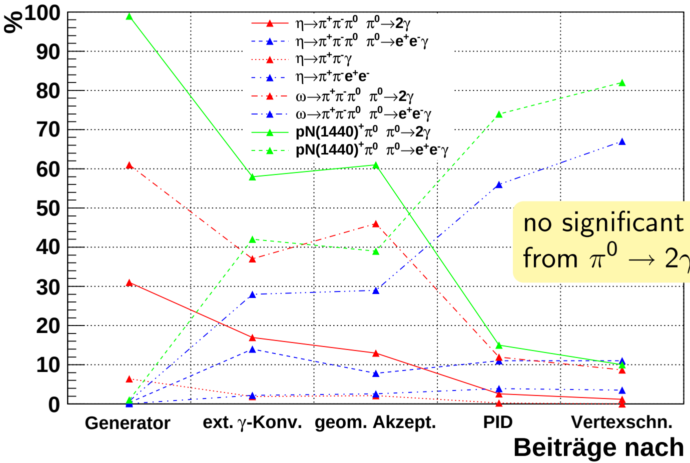
graphical cuts

Cuts on Pair-Vertices



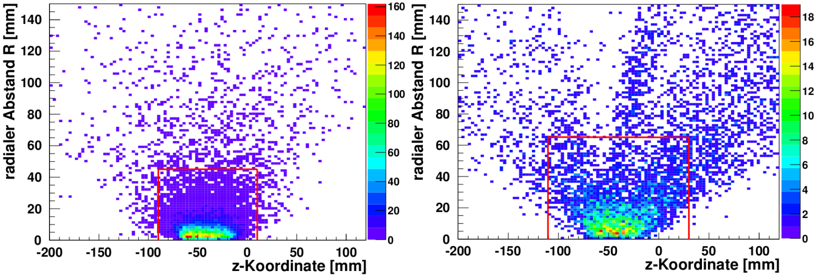
Vertex	R [mm]	z [mm]
$\pi^+\pi^-$	<45	-90 ... 10
e^+e^-	<65	-110 ... 30

External γ-Conversion



no significant contribution from $\pi^0 \to 2\gamma$

Cuts on Pair-Vertices - Exp.



(a) $\pi^+\pi^-$ (b) e^+e^-

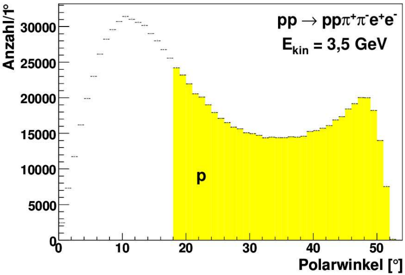
Cuts on pair-vertices determined by simulation fit the experimental data. Diffuse e^+e^--vertex due to higher curvature in MDC and boundary fields. Majority of γ-conversion in surrounding radiator material can be suppressed.

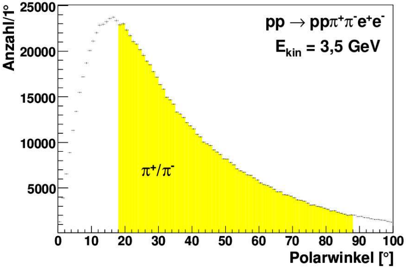
$\eta \to \pi^+\pi^- e^+ e^-$

Geometrical Acceptance

Analyse	Name	Akzeptanz
e^+e^-		16%
$\pi^+\pi^-e^+e^-$	4-Prong	3,4%
$p\pi^+\pi^-e^+e^-$	5-Prong	2,5%
$pp\pi^\pm e^+e^-$		1,9%
$pp\pi^+\pi^-e^+e^-$	6-Prong	0,55%

- slow electrons
- missing p instead of $\pi^\pm$
- 5-prong: essential info gain
- 6-prong: statistics too low



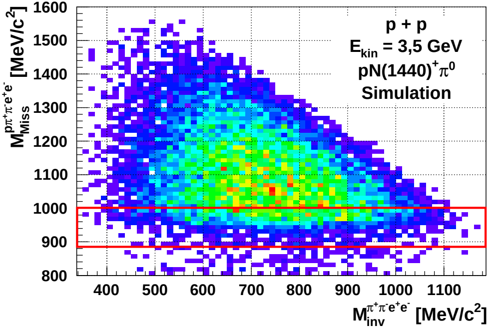


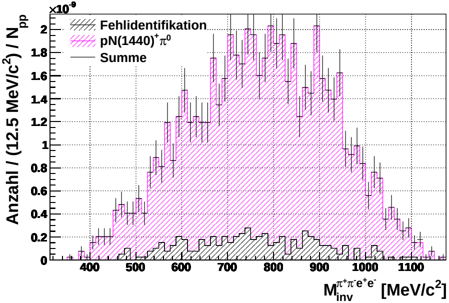
5-Prong - Missing Mass - $pN(1440)^{+}\pi^{0}$ Bg

$pp \rightarrow pN(1440)\pi^{0} \rightarrow p\ p\pi^{+}\pi^{-}e^{+}e^{-}\ \gamma$

$880\ \mathrm{MeV}/c^2 < M_{miss}^{p\pi^{+}\pi^{-}e^{+}e^{-}} < 1000\ \mathrm{MeV}/c^2$

80% BG reduction
no significant change in shape

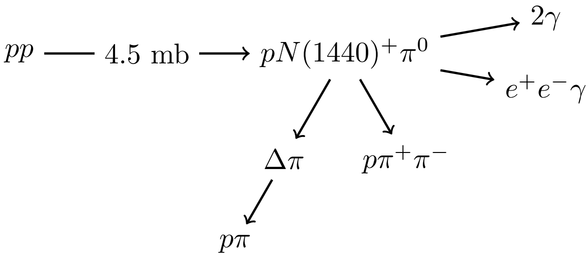




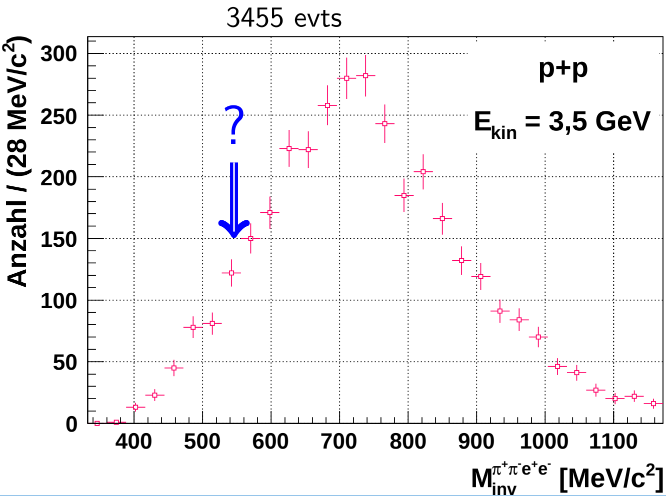
Background Source

Produktionskanal	σ [mb]
pp	17,8
$p\Delta^+$	3,756
$pN(1440)^+$	5,511
$n\Delta^{++}$	10,928
$p\Delta^{++}\pi^-$	1,226
$p\Delta^0\pi^+$	2,933
$pN(1440)^+\pi^0$	4,462
$pN(1535)^+$ (η resonant)	0,155
$pp\eta$ (η nicht-resonant)	0,05
$pp\eta\pi^0$	0,029
$pn\eta\pi^+$	0,029
$pp\eta\pi^+\pi^-$	0,0069
$pp\eta\pi^0\pi^0$	0,0069
$pp\rho^0$ (nicht-resonant)	0,06
$pp\omega$ (nicht-resonant)	0,06

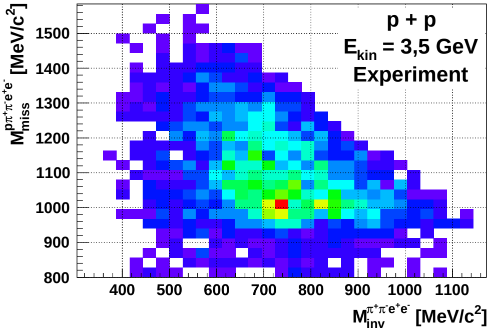
From the listed production channels which contribute to M_{inv}^{ee} esp. $pN(1440)^+\pi^0$ can result in $pp\pi^+\pi^-e^+e^-$ in the final state:



Experimental 5-Prong-Spectrum



5-Prong - Missing Mass - Experiment

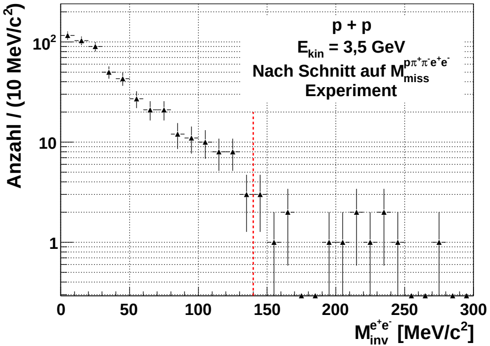


- form and abundances comparable with simulation
- no prominent structure from η or ω decays visible

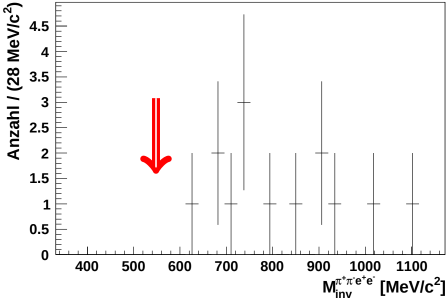
5-Prong - e^+e^- Invariant Mass

Majority of e^+e^--pairs from $\pi^0 \to e^+e^-\gamma$

$$m_{\pi^0} = 135\,\mathrm{MeV}/c^2 < M_{\mathrm{inv}}^{e^+e^-} < 268\,\mathrm{MeV}/c^2$$



14 evts



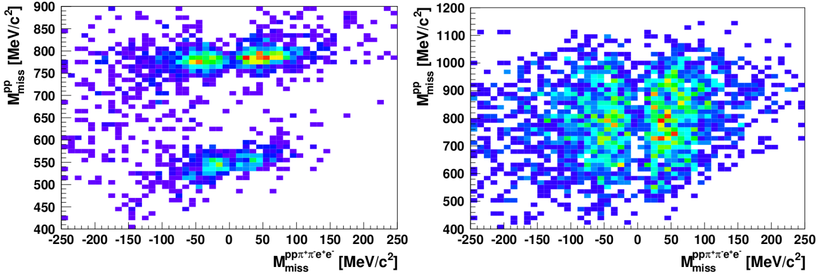
6-Prong - Missing Mass

Additional Missing Mass combinations:

$500\,\mathrm{MeV}/c^2 < M^{pp}_{\mathrm{miss}} < 600\,\mathrm{MeV}/c^2$

$740\,\mathrm{MeV}/c^2 < M^{pp}_{\mathrm{miss}} < 820\,\mathrm{MeV}/c^2$

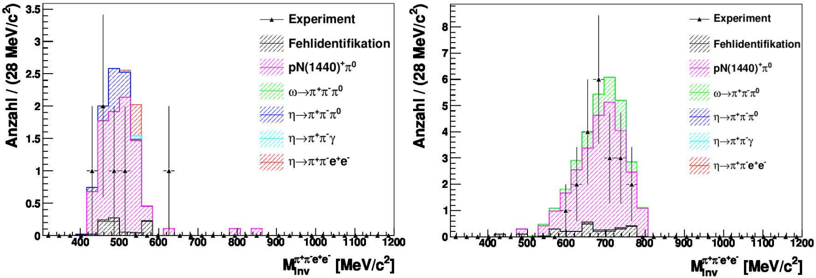
$M^{pp\pi^+\pi^-e^+e^-}_{\mathrm{miss}} \sim 0\,\mathrm{MeV}/c^2$



(a) η/ω-Quellen (b) $pN(1440)^+\pi^0$

6-Prong - Comparison

- good separation of η and ω but very low statistics (404 evts)
- cut into continuous BG generates peak structure
- 5-Prong analysis is to be preferred



(a) η-Bereich von M^{pp}_{miss} (Gl. 5.3)   (b) ω-Bereich von M^{pp}_{miss} (Gl. 5.4)