JÜLICH
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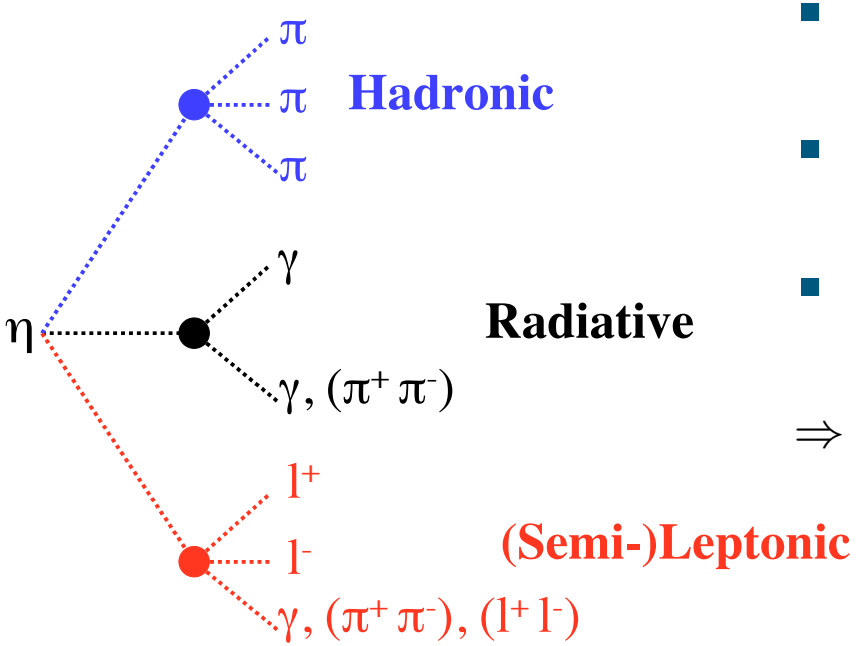
The η-Meson Decay Program at WASA-at-COSY

31.08.2015 | Daniel Lersch for the WASA-at-COSY collaboration

Institute for Nuclear Physics

The η-Meson



- $m_\eta = 0.5478\,\mathrm{GeV/c^2}$, $\bar{\tau} \approx 5 \cdot 10^{-19}\,\mathrm{s}$
  $(\Gamma_\eta = (1.31 \pm 0.05)\,\mathrm{keV})$
- $J^{PC} = 0^{-+} \Longrightarrow \eta$-meson is:
  C-, *P*-, *G*- and *CP*- eigenstate
- All strong and electromagnetic decays are forbidden to first order

$\Rightarrow$ **Access to rare decay processes:**

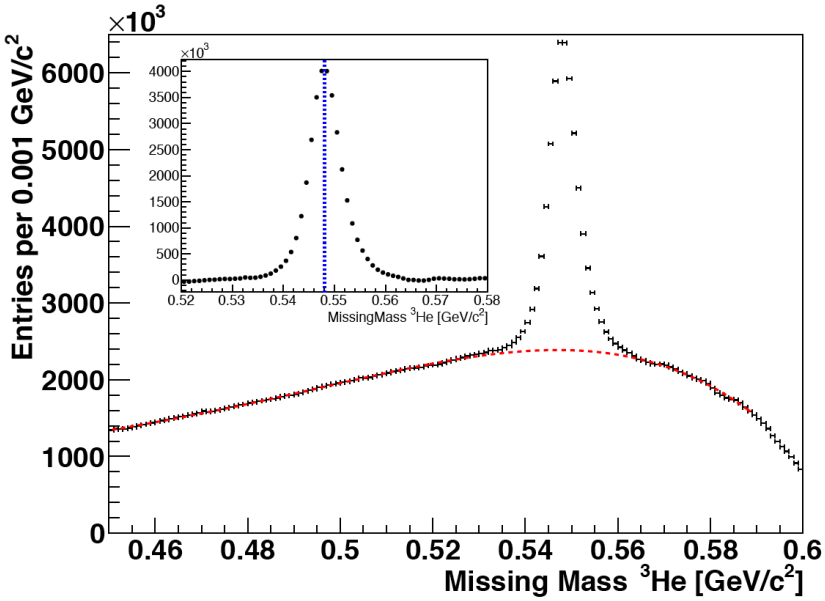
- Explore anomalous sector of QCD
- Determine electromagnetic transition form factors
- Study of symmetry-breaking-phenomena

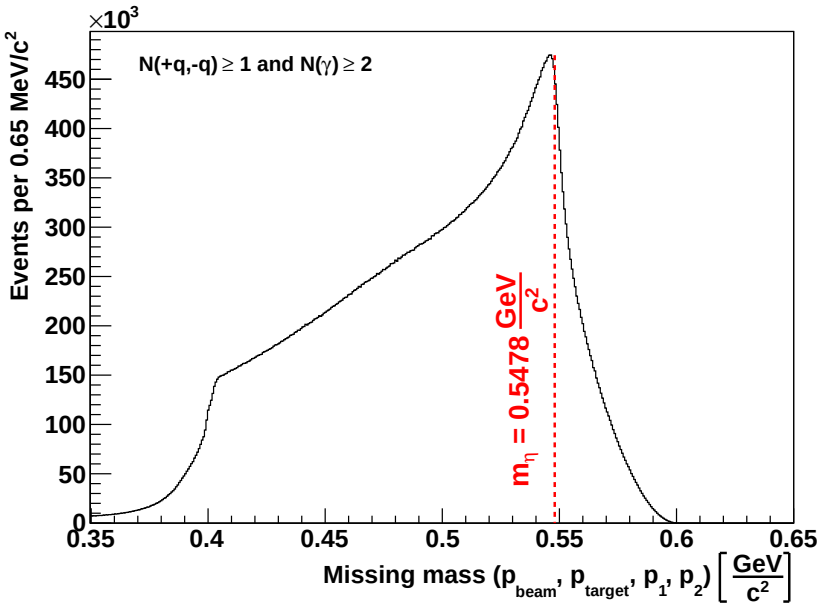
η-Meson production at WASA-at-COSY:

i) $pd \to {}^3\mathrm{He}\eta[\eta \to ...] \parallel \sigma(\eta) = (0.412 \pm 0.016)\,\mu\mathrm{b}$ at $T_{beam} = 1\,\mathrm{GeV}$

ii) $pp \to pp\eta[\eta \to ...] \parallel \sigma(\eta) = (9.8 \pm 1)\,\mu\mathrm{b}$ at $T_{beam} = 1.4\,\mathrm{GeV}$

The data sets



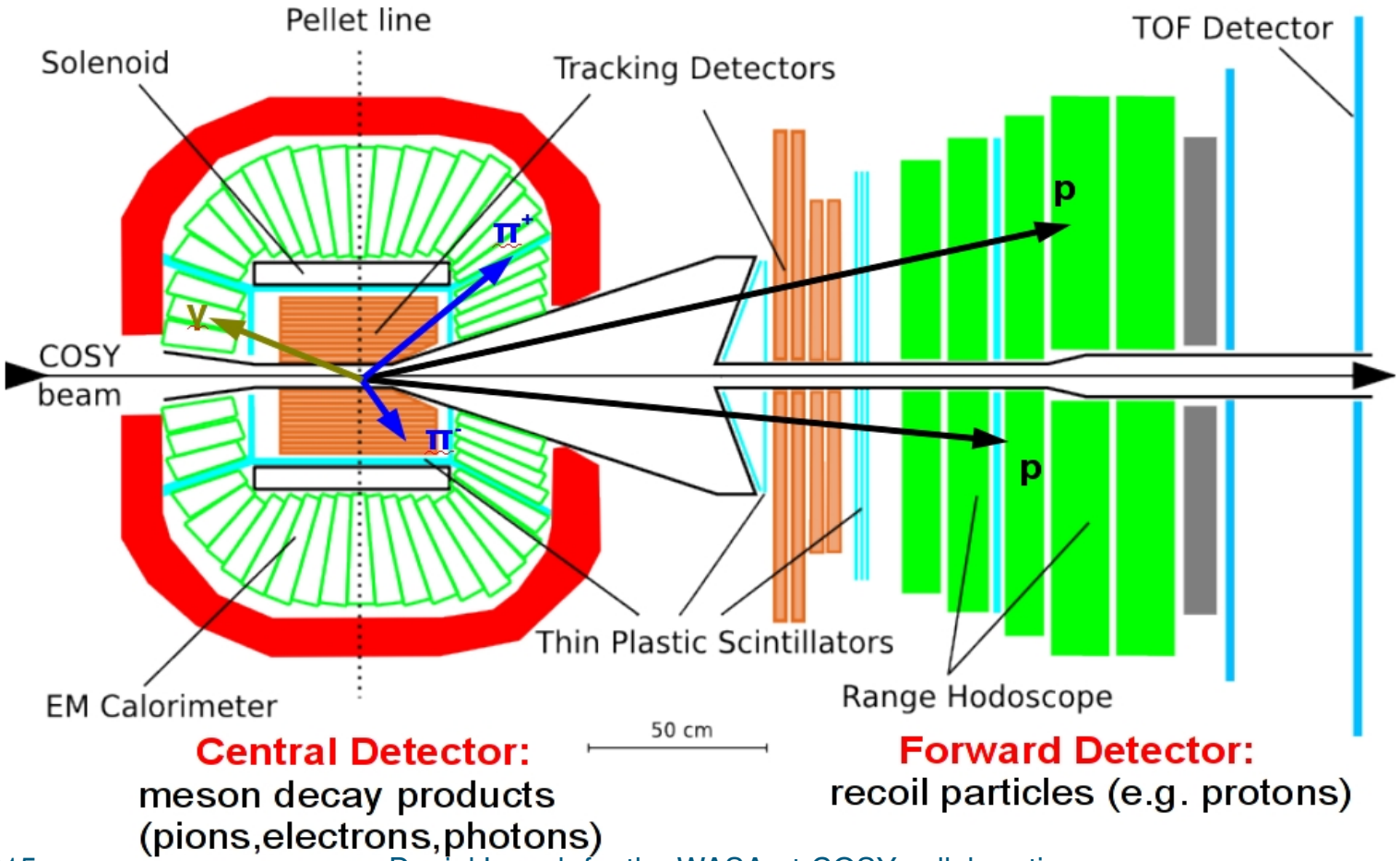


- Background contributions from direct pion production reactions: $pd \rightarrow {}^3\mathrm{He}X$, $pp \rightarrow ppX$
  $X = \pi^+\pi^-$, $X = \pi^0\pi^0$ and $X = \pi^+\pi^-\pi^0$
- Reconstruct η-meson via missing mass: e.g. $|\mathbf{P}_{\mathrm{beam}} + \mathbf{P}_{\mathrm{target}} - (\mathbf{P}_{\mathrm{proton1}} + \mathbf{P}_{\mathrm{proton2}})|$

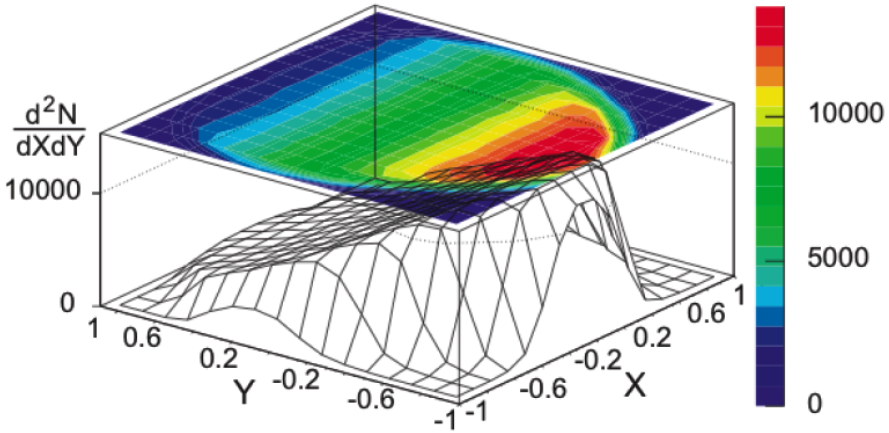
	$pd \rightarrow {}^3\mathrm{He}\eta$		$pp \rightarrow pp\eta$		
Data taken in	2008	2009	2008	2010	2012
Duration of beam time	4 weeks	8 weeks	2 weeks	7 weeks	8 weeks
η-mesons detected / produced	$\sim 1 \cdot 10^7$	$\sim 2 \cdot 10^7$	$\sim 1 \cdot 10^8$	$\sim 4 \cdot 10^8$	$\sim 5 \cdot 10^8$

Wide Angle Shower Apparatus - WASA

Example: $pp \rightarrow pp\eta[\eta \rightarrow \pi^+\pi^-\gamma]$



$\eta \to \pi^+\pi^-\pi^0$: Dalitz plot



(a) KLOE coll., *JHEP*, 05, (2008)

Dalitz plot variables:

$$X = \sqrt{3}\frac{T_{\pi^+} - T_{\pi^-}}{T_{\pi^+} + T_{\pi^-} + T_{\pi^0}}$$

$$Y = \frac{3T_{\pi^0}}{T_{\pi^+} + T_{\pi^-} + T_{\pi^0}}$$

- Decay via strong isospin violation: $\Gamma_{meas} = \left(\frac{Q_D}{Q}\right)^4 \bar{\Gamma}$
- $Q^2 = \frac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2}$ with $\hat{m} = 0.5 \cdot (m_u + m_d)$
- $\bar{\Gamma}$ calculated with ChPT at Dashen limit, $Q_D = 24.2$
- Dalitz plot analysis: $\frac{d\Gamma}{dXdY} \propto (1 + aY + bY^2 + dX^2 + fY^3 + gX^2Y + ...)$
  $\to$ c, e and h would imply C-violation

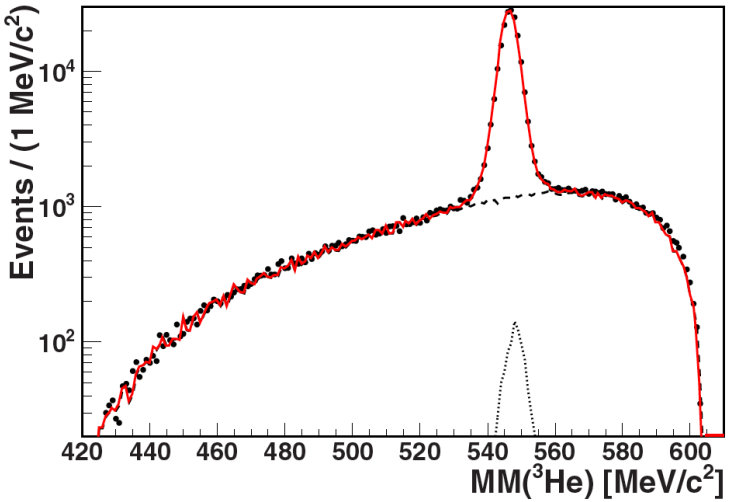
$\eta \to \pi^+\pi^-\pi^0$: Results from $pd \to {}^3\mathrm{He}\eta$

Exp. / Theo.	$-a$	b	d	f
ChPT (NNLO)[a]	1.271(75)	0.394(102)	0.055(57)	0.025(160)
NREFT[b]	1.213(14)	0.308(23)	0.050(3)	0.083(19)
KLOE[c]	$1.090(5)(^{+8}_{-19})$	0.124(6)(10)	$0.057(6)(^{+7}_{-16})$	0.14(1)(2)
WASA[d]	1.144(18)	0.219(19)(47)	0.086(18)(15)	0.115(37)

(a): J. Bijnens and K. Ghorbani., *JHEP*, 11, (2007) (b): S- P. Schneider et al., *JHEP*, 028, (2011)

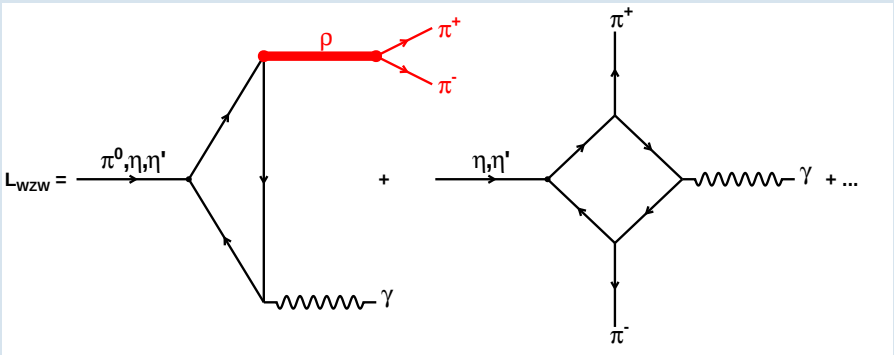
(c): KLOE coll., *JHEP*, 05, (2008) (d): WASA-at-COSY coll., *Phys. Rev.*, C90(045207), 2014

- $\sim 1.2 \cdot 10^5$ $\eta \to \pi^+\pi^-\pi^0$ events selected via a kinematic fit for the final event sample
- Dalitz plot analysis for $pp \to pp\eta[\eta \to \pi^+\pi^-\pi^0]$ in progress



$\eta \to \pi^+\pi^-\gamma$: The box anomaly and $\pi^+\pi^-$ FSI

Beyond chiral limit:



- Include $\pi^+\pi^-$ Final State Interactions
- Modification of decay amplitude:(a)

(a) F.Stollenwerk et al., *Phys. Lett.*, B707:184-190, 2012

$$A_{\eta\to\pi^+\pi^-\gamma} \times [F_{PV}(s_{\pi\pi}) \cdot (1 + \alpha s_{\pi\pi})]$$

$\Rightarrow$ Description of FSI: $\begin{cases} \text{by } F_{PV} & \alpha = 0 \\ \text{reaction specific}^* & \alpha \neq 0 \end{cases}$

*Input from theory

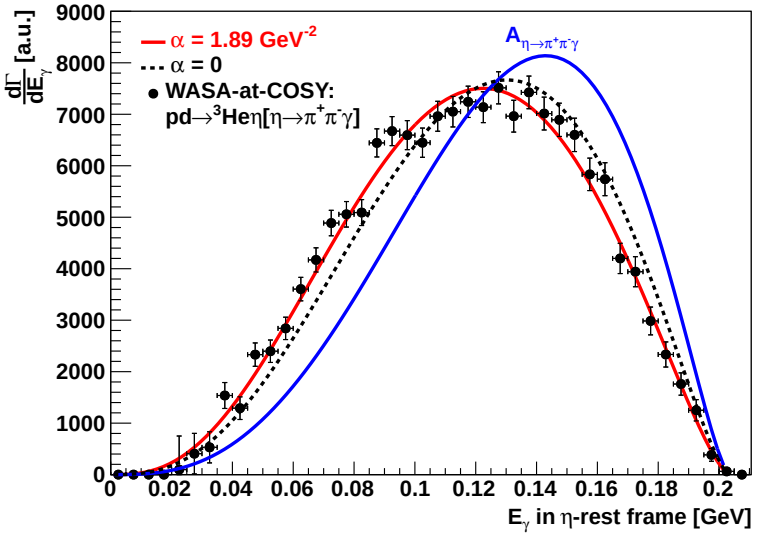
- $\Gamma^{\text{Theory}}(\eta \to \pi^+\pi^-\gamma) = 35.7\,\text{eV}$(b)
- $\Gamma^{\text{Exp.}}(\eta \to \pi^+\pi^-\gamma) = (55.3 \pm 2.4)\,\text{eV}$(c)

(b): B.R. Holstein, *Phys. Scripta*, T99:55-67, 2002

(c): PDG, *Chin. Phys.*, 090001, 2014

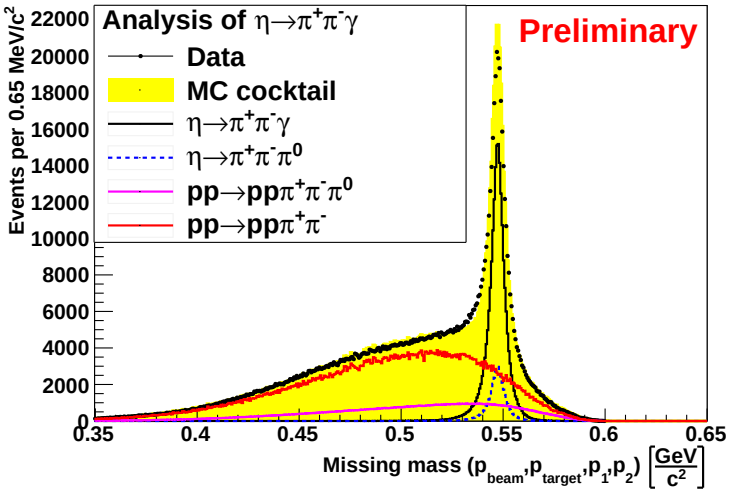
- Photon energy distribution E_γ:(d)

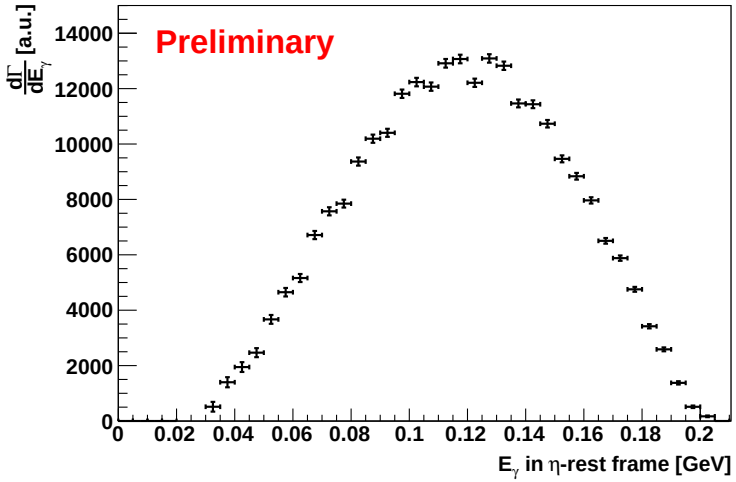
(d) WASA-at-COSY coll. *Phys. Lett.*, B707:243-249, 2012



Goal:Determine $\frac{\Gamma(\eta\to\pi^+\pi^-\gamma)}{\Gamma(\eta\to\pi^+\pi^-\pi^0)}$ and α via E_γ-distribution in $pp \to pp\eta[\eta \to \pi^+\pi^-\gamma]$

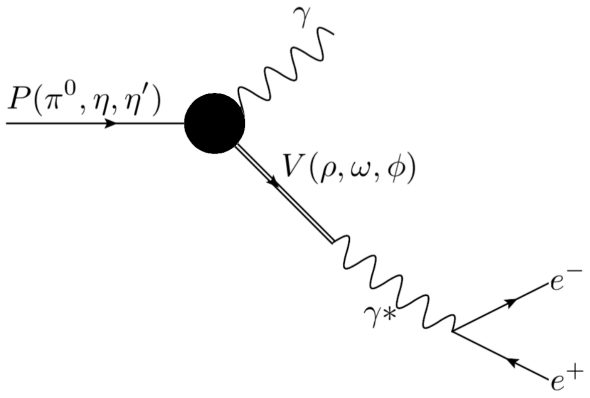
$\eta \to \pi^+\pi^-\gamma$: Status in $pp \to pp\eta$





- $\sim 209\,\mathrm{k}\ \eta \to \pi^+\pi^-\gamma$ events reconstructed
  - i) Rejection of wrongly reconstructed photons $\Rightarrow$ Reduce background from $pp \to pp\pi^+\pi^-$
  - ii) Kinematic fit $\Rightarrow$ Further reduction of multi pion background and improvement of E_γ resolution
- E_γ distribution after background correction from direct pion production
- Next steps (ongoing):
  1.) Include efficiency corrections for different assumptions on α
  2.) Calculate $\frac{\Gamma(\eta\to\pi^+\pi^-\gamma)}{\Gamma(\eta\to\pi^+\pi^-\pi^0)}$ and α

$\eta \to e^+e^-\gamma$ and $\eta \to e^+e^-e^+e^-$: Dalitz decays



Single off-shell transition form factor $F(q^2)$

- $\frac{d\Gamma}{dq^2} = \left[\frac{d\Gamma}{dq^2}\right]_{QED} \cdot |F(q^2)|^2$
- Observables to test: $\frac{\Gamma(\eta \to e^+e^-\gamma)}{\Gamma_\eta}$ and Dilepton invariant mass distribution
- Recent result: $\frac{\Gamma(\eta \to e^+e^-\gamma)}{\Gamma_\eta} = (6.9 \pm 0.4) \cdot 10^{-3}$ (a)

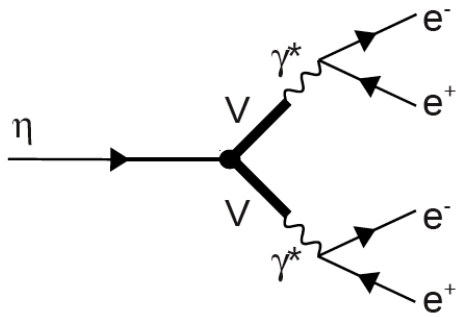
(a) K. Olive et al. *Chin. Phys.*, C38, 090001, 2014

Double off-shell transition form factor $F(q_1^2, q_2^2)$

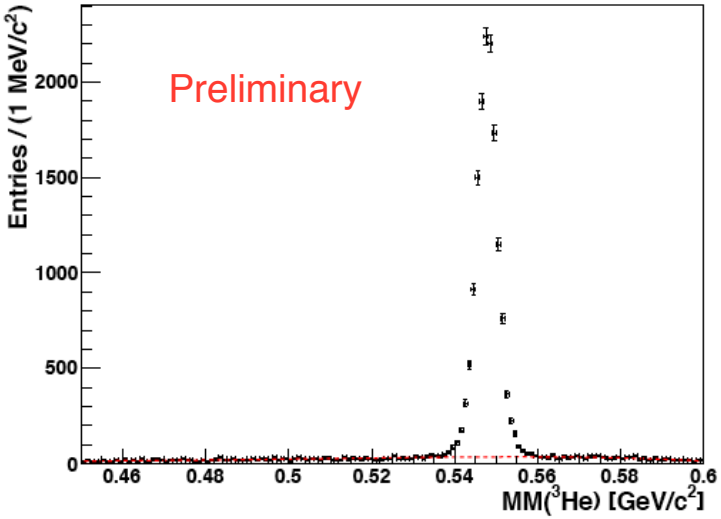
- Different approaches for calculation of F (b)
- Observable to test: $\frac{\Gamma(\eta \to e^+e^-e^+e^-)}{\Gamma_\eta}$
- Current result measured by KLOE: (c)

$$\frac{\Gamma(\eta \to e^+e^-e^+e^-)}{\Gamma_\eta} = (2.4 \pm 0.2_{stat} \pm 0.1_{sys}) \cdot 10^{-5}$$

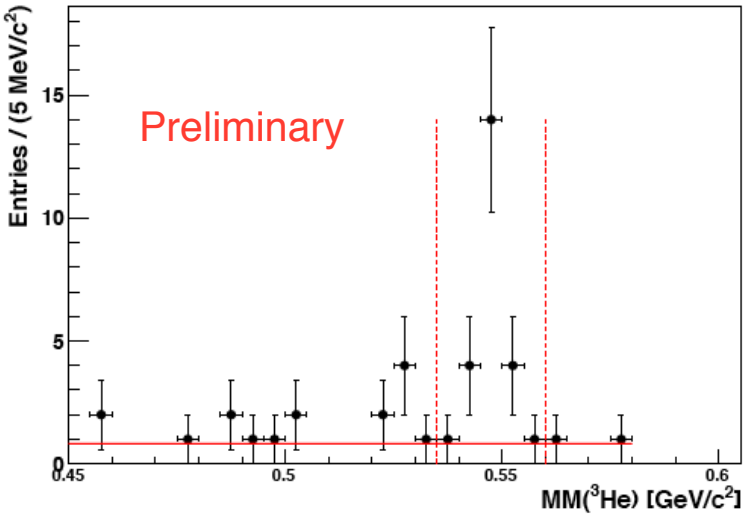
(b) J. Bijnens et al. *arXiv:hep-ph/0106130v1*, 2001 (c) KLOE coll. *Phys. Lett.*, B702:324-328, 2011



$\eta \to e^+e^-\gamma$ and $\eta \to e^+e^-e^+e^-$: Results from $pd \to {}^3\mathrm{He}\eta$



- $14,040 \pm 120$ events $\eta \to e^+e^-\gamma$ events reconstructed
- Preliminary: $\frac{\Gamma(\eta \to e^+e^-\gamma)}{\Gamma_\eta} = (6.72 \pm 0.07_{stat} \pm 0.31_{sys}) \cdot 10^{-3}$

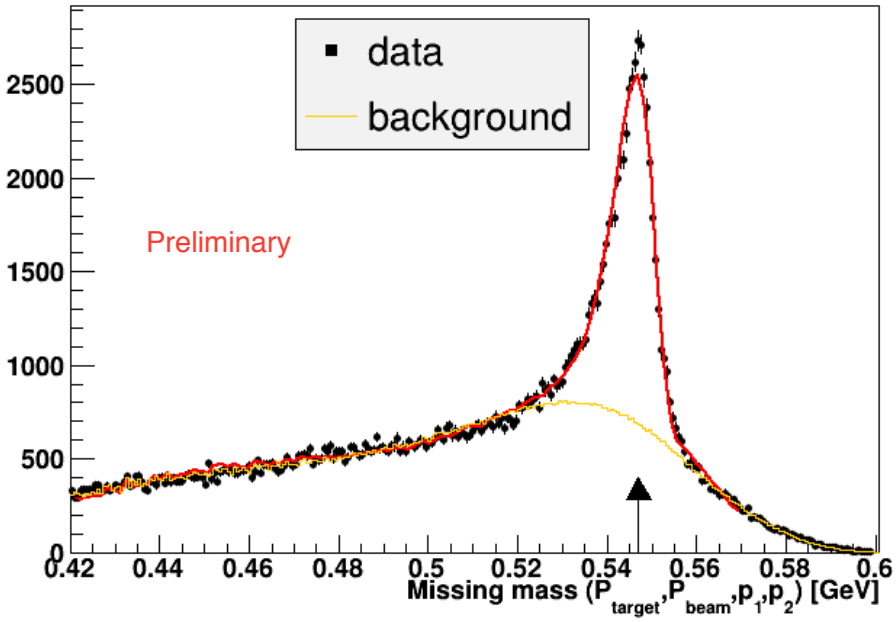


- 18 ± 5 $\eta \to e^+e^-e^+e^-$ events reconstructed
- Preliminary: $\frac{\Gamma(\eta \to e^+e^-e^+e^-)}{\Gamma_\eta} = (3.2 \pm 0.9_{stat} \pm 0.5_{sys}) \cdot 10^{-5}$
- Need more statistics $\Rightarrow$ $pp\eta$ data set

Challenges in analysis:

i) Dilepton pairs from conversion events at the beam pipe
ii) Handling of large pion background

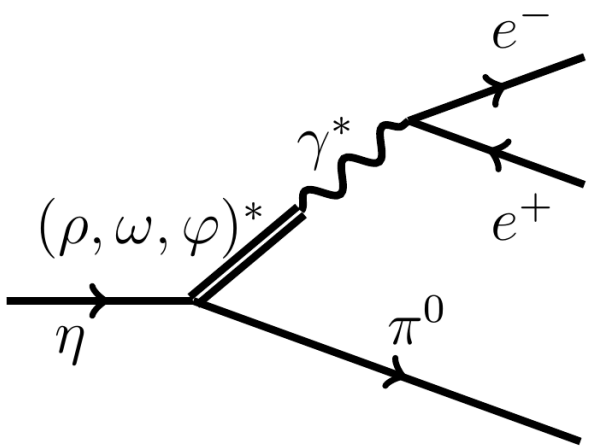
$\eta \to e^+e^-\gamma$: Status in $pp \to pp\eta$

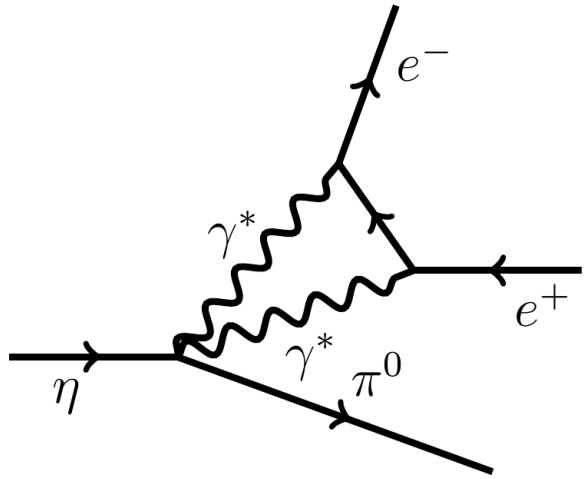


- Reduce uncertainty of $F(q^2)$ at high q^2: Increase statistics $\Rightarrow$ $pp\eta$ data set
- $\sim 29\,\mathrm{k}\ \eta \to e^+e^-\gamma$ events reconstructed in current $pp \to pp\eta[\eta \to e^+e^-\gamma]$ analysis
- In preparation:
  i) Calculation of $\frac{\Gamma(\eta\to e^+e^-\gamma)}{\Gamma_\eta}$
  ii) Dilepton invariant mass distribution $\Rightarrow F(q^2)$

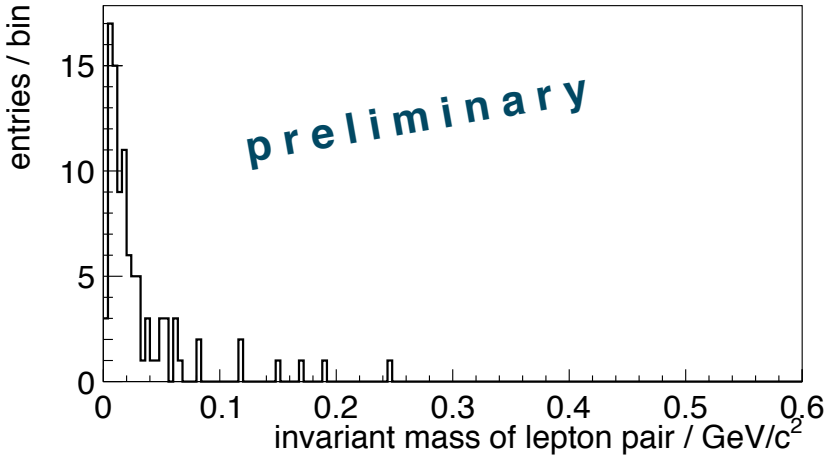
Analysis of $pp \to pp\eta[\eta \to e^+e^-e^+e^-]$ in preparation

$\eta \to \pi^0 e^+ e^-$: C-Violation





- Forbidden by SM:
  $BR(\eta \to \pi^0 e^+ e^-) < 4 \cdot 10^{-5}$ (a)
- Different models for C-violation (e.g. VMD)
- Investigate existing upper limit *BR* with hight statistics $pp \to pp\eta$ data set



(a) K. Olive et al. *Chin. Phys.*, C38, 090001, 2014

Summary and Outlook

- ☑ η-decays measured in $pd \to {}^3\mathrm{He}\eta$ with WASA-at-COSY
  - Published results for: $\eta \to \pi\pi\pi$ (Dalitz plot) and $\eta \to \pi^+\pi^-\gamma$ (E_γ-distribution)
  - Publication for BR of: $\eta \to \pi^+\pi^-\gamma$, $\eta \to e^+e^-\gamma$, $\eta \to e^+e^-e^+e^-$ (and $\eta \to \pi^+\pi^-e^+e^-$) in progress
- ☑ Large statistics $pp \to pp\eta$ data set taken with WASA-at-COSY
- ☑ Start analysis of decays presented above for the 2010 $pp \to pp\eta$ data set:
  - BR and E_γ-distribution for $\eta \to \pi^+\pi^-\gamma$
  - Determination of form factor $F(q^2)$ and BR for $\eta \to e^+e^-\gamma$
  - Upper limit for BR of $\eta \to \pi^0e^+e^-$
- ☑ Analysis of $pp \to pp\eta[\eta \to e^+e^-e^+e^-]$ in preperation
- ☐ Analysis of $pp \to pp\eta[\eta \to \pi^+\pi^-e^+e^-]$
- ☐ Analysis of remaining $pp \to pp\eta$ data set

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Backup

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  - Determining the E_γ-distribution
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  - Results from $pd \to {}^3\mathrm{He}\eta$
  - Outlook for $pp \to pp\eta$
- η Production mechanisms

η-Meson Decays accessible with WASA-at-COSY

Decay mode	$\Gamma(\eta \to \ldots)/\Gamma_\eta$ [a]	Issue
$\eta \to \pi^0\pi^0\pi^0$ [b]	$(32.68 \pm 0.23)\%$	Dalitz plot parameter, quark masses
$\eta \to \pi^+\pi^-\pi^0$ [c]	$(22.92 \pm 0.28)\%$	Dalitz plot parameter, quark masses
$\eta \to \pi^+\pi^-\gamma$ [d]	$(4.22 \pm 0.08)\%$	Box-anomaly, $\pi^+\pi^-$-FSI
$\eta \to e^+e^-\gamma$ [e]	$(0.69 \pm 0.11)\%$	Single-off-shell transition form factor
$\eta \to \pi^0\gamma\gamma$	$(2.7 \pm 0.5) \cdot 10^{-4}$	Test of ChPT
$\eta \to \pi^+\pi^-e^+e^-$ [e]	$(2.68 \pm 0.11) \cdot 10^{-4}$	CP-violation
$\eta \to e^+e^-e^+e^-$ [e]	$(2.40 \pm 0.22) \cdot 10^{-5}$	Double-off-shell transition form factor
$\eta \to \pi^0e^+e^-$	$< 4 \cdot 10^{-5}$	C-violation
$\eta \to e^+e^-$	$< 5.6 \cdot 10^{-6}$	Physics beyond the SM

i) $pd \to {}^3\mathrm{He}\eta[\eta \to \ldots]$
ii) $pp \to pp\eta[\eta \to \ldots]$

(a): PDG, *Chin. Phys.*, 090001, 2014

(b): WASA-at-COSY coll., *Phys. Lett.*, B677:24-29, 2009

(c): WASA-at-COSY coll., *Phys. Rev.*, C90(045207), 2014

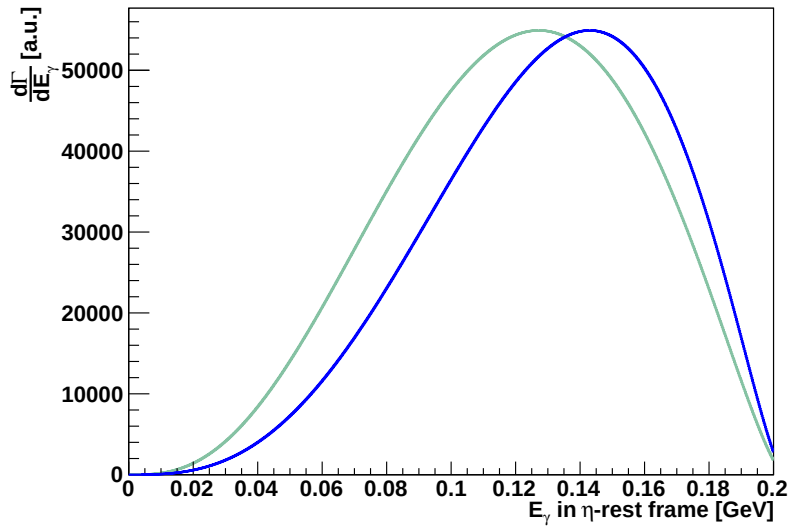
(d): WASA-at-COSY coll., *Phys. Lett.*, B707:243-249, 2012

(e): Publication in preparation

$\eta \to \pi^+\pi^-\gamma$:Theoretical Models

- N/D-Model:[a)]
  - One-loop chiral corrections and VMD
  - Modify $A_{\eta \to \pi^+ \pi^- \gamma}$ with: $\left[\frac{1+0.5 m_\rho^2 s_{\pi\pi}}{D_1(s_{\pi\pi})}\right]$

a) B.R. Holstein, *Phys. Scripta*, T99:55-67, 2002



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- N/D-Model:[a)]
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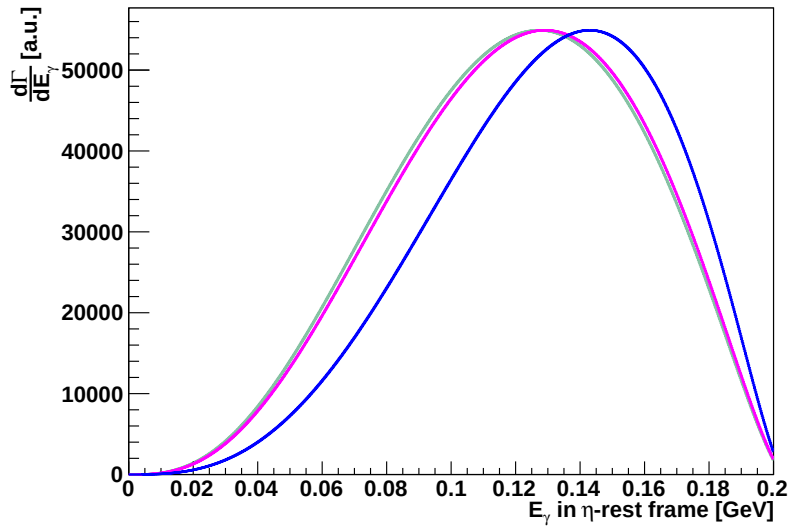
  - Modify $A_{\eta\to\pi^+\pi^-\gamma}$ with: $\left[\frac{1+0.5m_\rho^2 s_{\pi\pi}}{D_1(s_{\pi\pi})}\right]$
- HLS (Hidden Local Symmetries)-Model:[b)]
  - $\gamma - V$ Transitions
  - Modify $A_{\eta\to\pi^+\pi^-\gamma}$ with: $\left[1 + \frac{3m_\rho^2}{D_\rho(s_{\pi\pi})}\right]$

a) B.R. Holstein, *Phys. Scripta*, T99:55-67, 2002

b) M.Benayoun et al., *Europ. Phys. Journal*, C31:525-547, 2003



$\eta \to \pi^+\pi^-\gamma$:Theoretical Models

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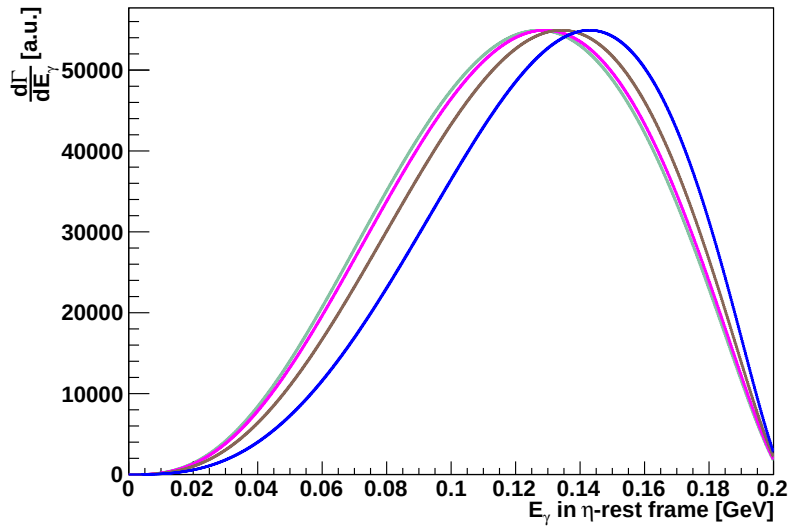
  - Modify $A_{\eta\to\pi^+\pi^-\gamma}$ with: $\left[\frac{1+0.5m_\rho^2 s_{\pi\pi}}{D_1(s_{\pi\pi})}\right]$
- HLS (Hidden Local Symmetries)-Model:[b)]
  - $\gamma - V$ Transitions
  - Modify $A_{\eta\to\pi^+\pi^-\gamma}$ with: $\left[1 + \frac{3m_\rho^2}{D_\rho(s_{\pi\pi})}\right]$
- $O(p^6) + 1 -$ loop-Modell:[c)]
  - Higher momentum orders $O(p^6)$ and one loop chiral corrections
  - Modify $A_{\eta\to\pi^+\pi^-\gamma}$ with: $\left[1 + C^{\text{loops}} + \frac{3}{2m_\rho^2}(p_{\pi^+} + p_{\pi^-})^2\right]$

a) B.R. Holstein, *Phys. Scripta*, T99:55-67, 2002

b) M.Benayoun et al., *Europ. Phys. Journal*, C31:525-547, 2003

c) J.Bijnens et al., *Phys. Lett.*, B237:488-494, 1990



$\eta \to \pi^+\pi^-\gamma$:Theoretical Models

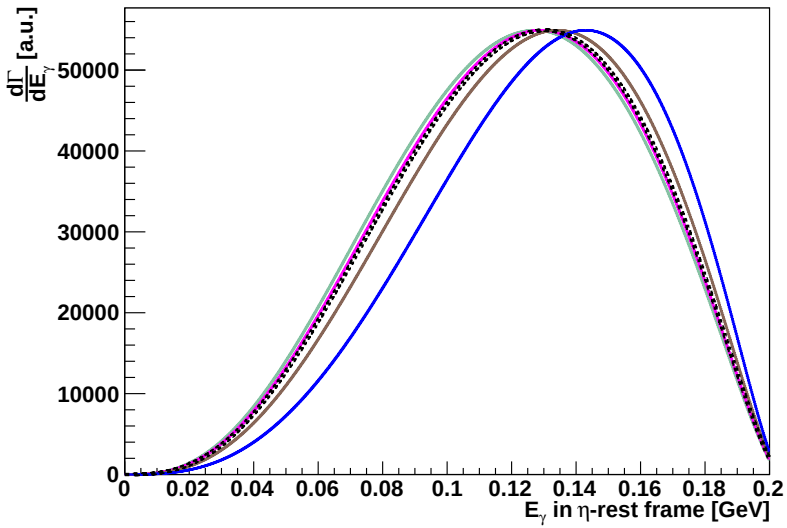
- N/D-Model:[a)]
  - One-loop chiral corrections and VMD
  - Modify $A_{\eta\to\pi^+\pi^-\gamma}$ with: $\left[\frac{1+0.5m_\rho^2 s_{\pi\pi}}{D_1(s_{\pi\pi})}\right]$
- HLS (Hidden Local Symmetries)-Model:[b)]
  - $\gamma - V$ Transitions
  - Modify $A_{\eta\to\pi^+\pi^-\gamma}$ with: $\left[1+\frac{3m_\rho^2}{D_\rho(s_{\pi\pi})}\right]$
- $O(p^6)+1-$loop-Modell:[c)]
  - Higher momentum orders $O(p^6)$ and one loop chiral corrections
  - Modify $A_{\eta\to\pi^+\pi^-\gamma}$ with:
    $\left[1+C^{\text{loops}}+\frac{3}{2m_\rho^2}(p_{\pi+}+p_{\pi-})^2\right]$
- Pion-Vektor-Formfactor:[d)]
  - $\pi^+\pi^-$-interactions (universal)
  - Modify $A_{\eta\to\pi^+\pi^-\gamma}$ with:
    $F_{PV}(s_{\pi\pi}) \approx a\cdot s_{\pi\pi}^3 + b\cdot s_{\pi\pi}^2 + c\cdot s_{\pi\pi} + d$

a) B.R. Holstein, *Phys. Scripta*, T99:55-67, 2002

b) M.Benayoun et al., *Europ. Phys. Journal*, C31:525-547, 2003

c) J.Bijnens et al., *Phys. Lett.*, B237:488-494, 1990

d) F.Stollenwerk et al., *Phys. Lett.*, B707:184-190, 2012



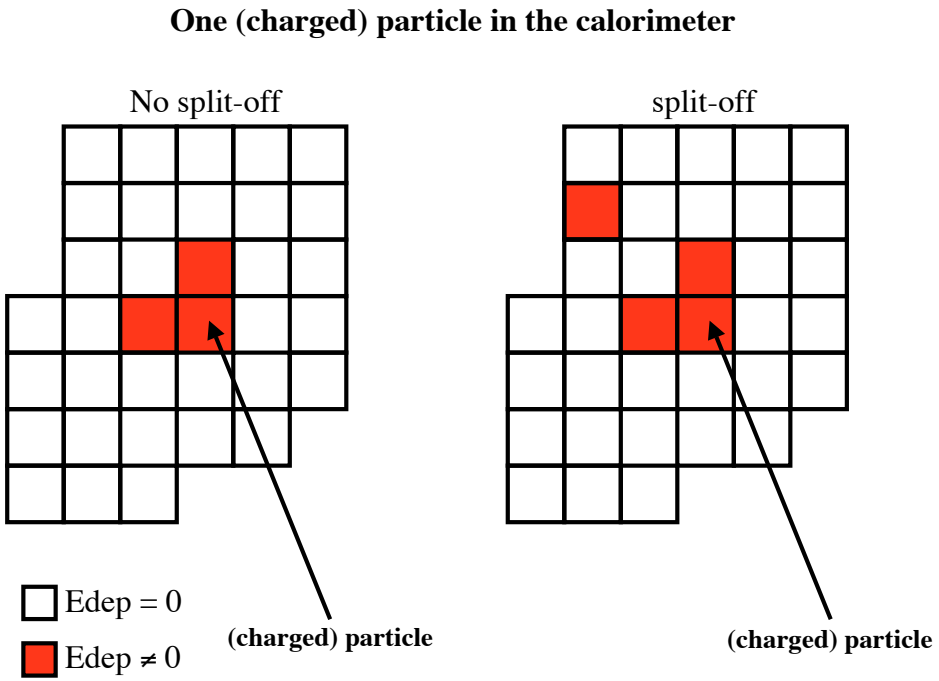
$\eta \to \pi^+\pi^-\gamma$: Theoretical Predictions and Recent Measurements

		$\Gamma(\eta \to \pi^+\pi^-\gamma)/\Gamma(\eta \to \pi^+\pi^-\pi^0)$	$\alpha\ [\mathrm{GeV}^{-2}]$
Experiment	Gormley et al.	0.202 ± 0.006	1.8 ± 0.4
	Thaler et al.	0.209 ± 0.004	-
	Layter et al.	-	-0.9 ± 0.1
	GAMS-200*	-	2.7 ± 0.1
	CRYSTAL BARREL*	-	1.8 ± 0.53
	CLEO	0.175 ± 0.013	-
	WASA-at-COSY	Preliminary: 0.206 ± 0.011	1.89 ± 0.86
	KLOE	0.1856 ± 0.003	1.32 ± 0.2
	CLAS	Analysis ongoing	-
Theory	N/D	0.2188 ± 0.0088	0.64 ± 0.02
	HLS	0.1875 ± 0.0094	0.23 ± 0.01
	$(O(p^6) + 1 - \text{loop})$	0.1565 ± 0.0063	-0.7 ± 0.1
	Box anomaly	0.119 ± 0.0048	-1.7 ± 0.02

*Measured $\eta' \to \pi^+\pi^-\gamma$

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

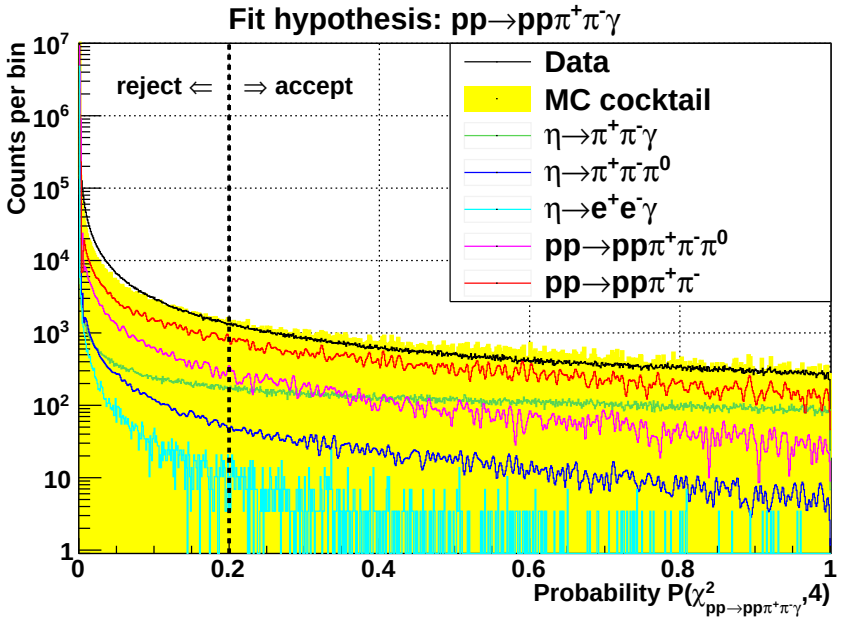
i) Rejection of split-offs



- Hit in calorimeter is assigned to a cluster
- Split-off: Satellite cluster with close distance to primary cluster $\to$ low energy fake photon
- Predominant background: $pp \to pp\pi^+\pi^-(\gamma)$
- Reject low energy fake photons with close distance to primary cluster

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

ii) Kinematic fit



- Least squares fit:

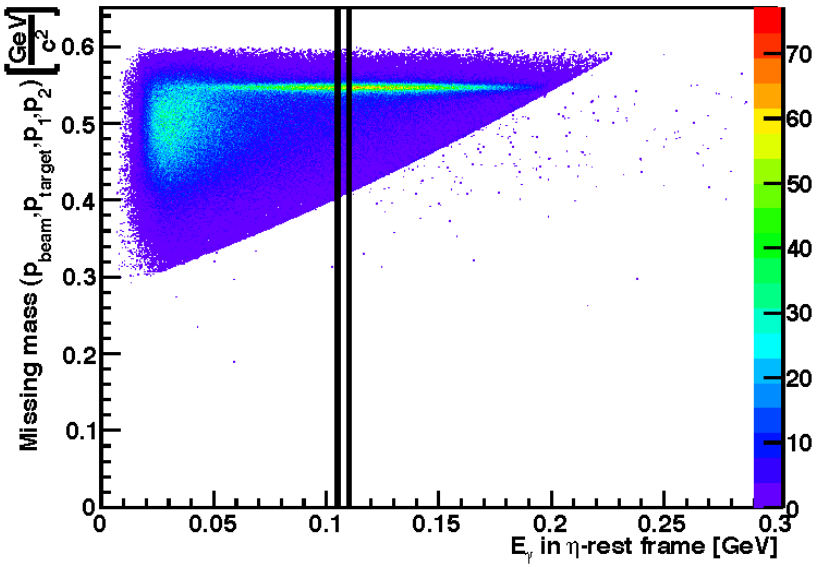
$$\chi^2 = \sum_{i=1}^{N_p}\sum_{j=1}^{N_V}\left(\frac{v_{ij}^{\text{fit}} - v_{ij}^{\text{meas}}}{\sigma_{ij}^{\text{meas}}}\right)^2 + 2\cdot\sum_{\mu}\lambda_\mu F_\mu(v_{11}^{\text{fit}},\ldots,v_{N_pN_V}^{\text{fit}})$$

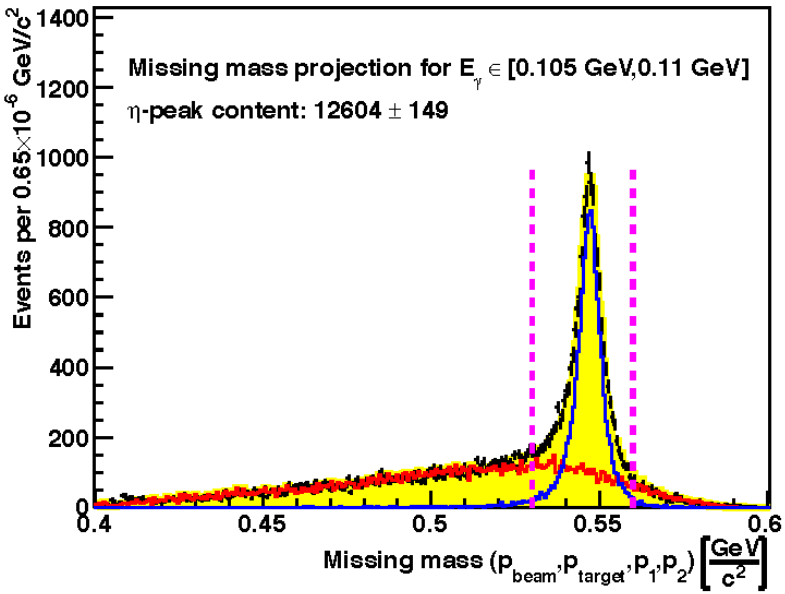
- F_μ: energy and momentum conservation
  $\to$ 4 constraints
- $P(\chi^2, N) = \frac{1}{\sqrt{2^N\cdot\Gamma(\frac{1}{2}N)}}\int_{\chi^2}^{\infty} e^{-\frac{t}{2}}\cdot t^{\frac{1}{2}N-1}dt$

Use kinematic fit to:

a) Improve resolution
b) Suppress background

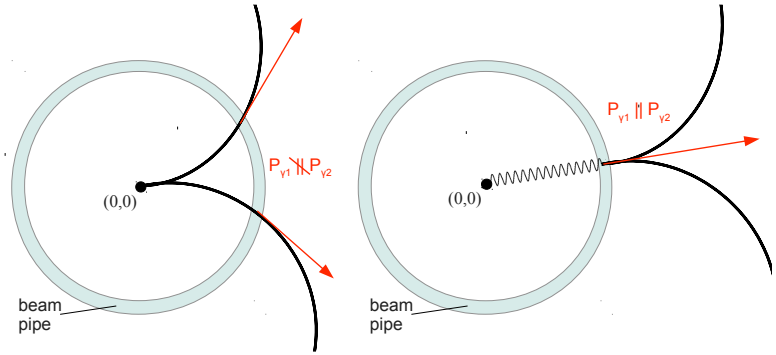
$\eta \to \pi^+\pi^-\gamma$: Determining the E_γ-distribution



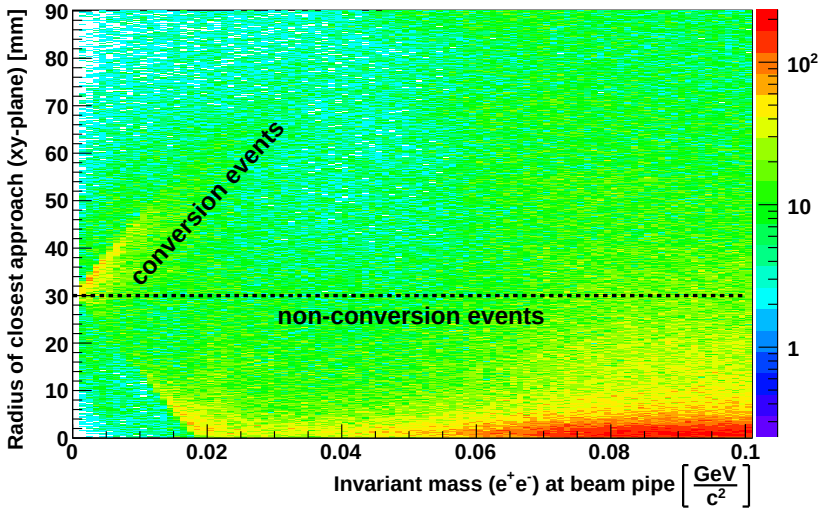


- Scan two proton missing mass distribution in E_γ-intervals
- Subtract background for each E_γ-interval
- Obtain number of $\eta \to \pi^+\pi^-\gamma$ events

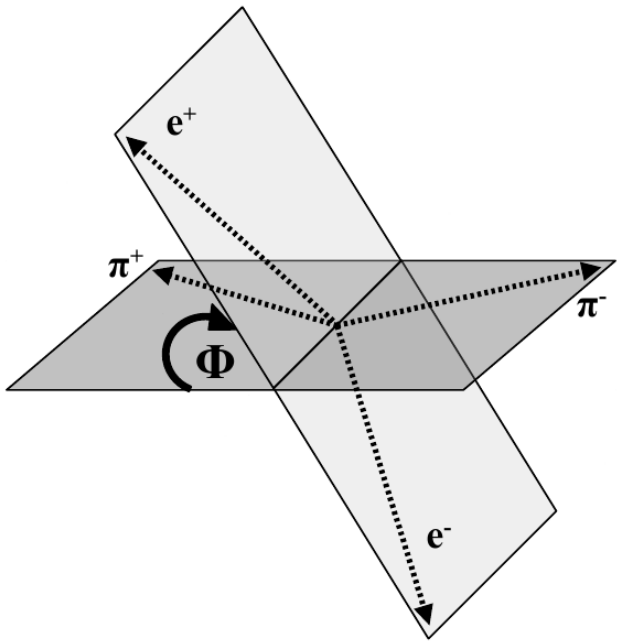
Conversion events



Electrons from Origin Conversion Event



$\eta \to \pi^+\pi^-e^+e^-$: CP-Violation

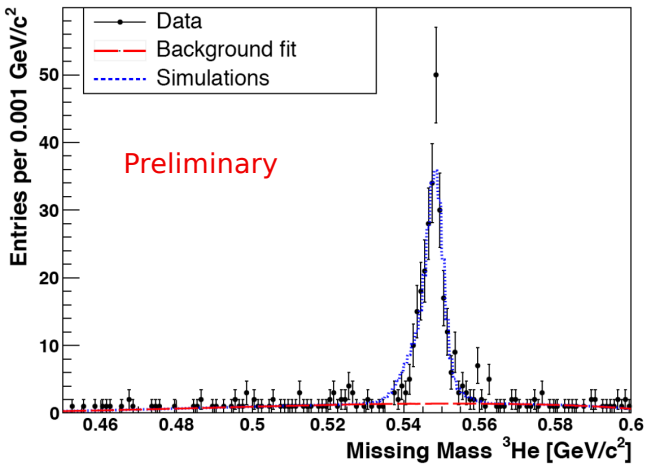


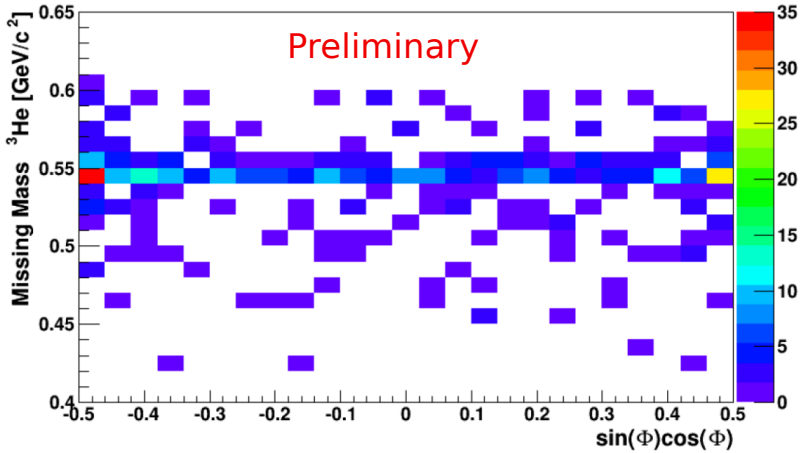
- Decay $\eta \to \pi^+\pi^-\gamma$:
  - CP-conserving for M_1 and E_2 transitions
  - Access to CP-violation $\leftrightarrow$ measure E_1 transition
  - Need information about polarisation of single photon
- Alternative:
  - $\eta \to \pi^+\pi^-\gamma^*$, $\gamma^* \to e^+e^-$
  - Look at asymmetry A_Φ [a] of angle Φ between decay planes of electrons and pions
  - $A_\Phi = \frac{N(\sin[\Phi]\cos[\Phi]>0) - N(\sin[\Phi]\cos[\Phi]<0)}{N(\sin[\Phi]\cos[\Phi]>0) + N(\sin[\Phi]\cos[\Phi]<0)}$

- Upper limit predicted by theory[a]: $\sim 1\%$
- Result found by KLOE[b]: $A_\Phi = (-0.6 \pm 2.5_{stat} \pm 1.8_{sys}) \cdot 10^{-2}$

(a) D. Gao. *Mod. Phys. Lett.*, A17:1583-1588, 2002 (b) KLOE coll. *Phys. Lett.*, B675:283-288-914, 2009

$\eta \to \pi^+\pi^- e^+e^-$: Results from $pd \to {}^3\mathrm{He}\eta$

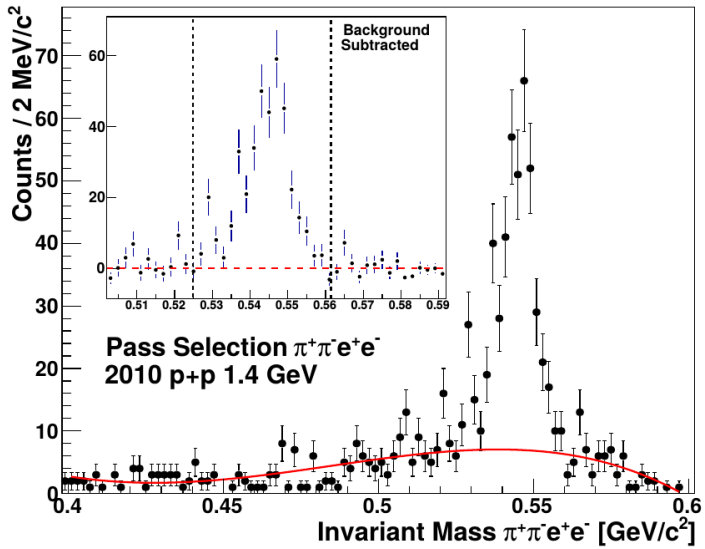




- 251 $\pm$ 17 $\eta \to \pi^+\pi^- e^+e^-$ events in the final sample
  - i) Rejection of photon conversion events $\Rightarrow$ Reduce contributions from $\eta \to \pi^+\pi^-\gamma$ / $\eta \to \pi^+\pi^-\pi^0$
  - ii) Identification of $\pi^\pm$ and $e^\pm$ in the mixed final state $\Rightarrow$ Crucial for the determination of A_Φ
  - iii) Kinematic fit $\Rightarrow$ Reduction of $\eta \to \pi^+\pi^-\pi^0[\pi^0 \to e^+e^-\gamma]$
- Preliminary: $A_\Phi = (-1.1 \pm 6.6_{stat} \pm 0.2_{sys}) \cdot 10^{-2}$

$\eta \to \pi^+\pi^- e^+ e^-$: Outlook for $pp \to pp\eta$

- Analysis procedure shown above done for a fraction of 2010 $pp \to pp\eta$ data set:[(a)]
  - ~ 220 $\eta \to \pi^+\pi^- e^+ e^-$ events reconstructed
  - $\sim 1,000$ events expected for full $pp \to pp\eta$ data sample
- Analysis in $pp \to pp\eta$ needs to be continued



(a) D. Coderre, *PhD Thesis*, 2012

η Production mechanisms

	pd $\rightarrow {}^3\mathrm{He}\eta$	**pp** $\rightarrow$ **pp**η
T_{beam}	$1\,\mathrm{GeV}$	$1.4\,\mathrm{GeV}$
$\sigma(\eta)$[a),b)]	$(0.412 \pm 0.016)\,\mu\mathrm{b}$	$(9.8 \pm 1)\,\mu\mathrm{b}$
Suited for	study of not-so-rare η decays	study of (not-so-) rare η decays
Background	low multi-pion background	high multi-pion background

Reaction	$T_{beam}[\mathrm{GeV}]$	$\sigma[\mu\mathrm{b}]$[b),c)]
$pd \rightarrow {}^3\mathrm{He}\pi^0\pi^0$	0.893	2.8 ± 0.3
$pd \rightarrow {}^3\mathrm{He}\pi^+\pi^-$	0.893	5.1 ± 0.5
$pp \rightarrow pp\pi^+\pi^-\pi^0$	1.36	4.6 ± 1.5
$pp \rightarrow pp\pi^0\pi^0$	1.36	200 ± 30
$pp \rightarrow pp\pi^+\pi^-$	1.36	660 ± 100

a) R. Bilger et al., *Phys. Rev.*, C65(044608), 2002

b) CELSIUS/WASA coll.., *Phys. Lett.*, B649:122-127, 2007

c) M. Bashkanov et al.., *Phys. Lett.*, B637:223-228, 2006