light meson decays
- experiments with WASA-at-COSY -

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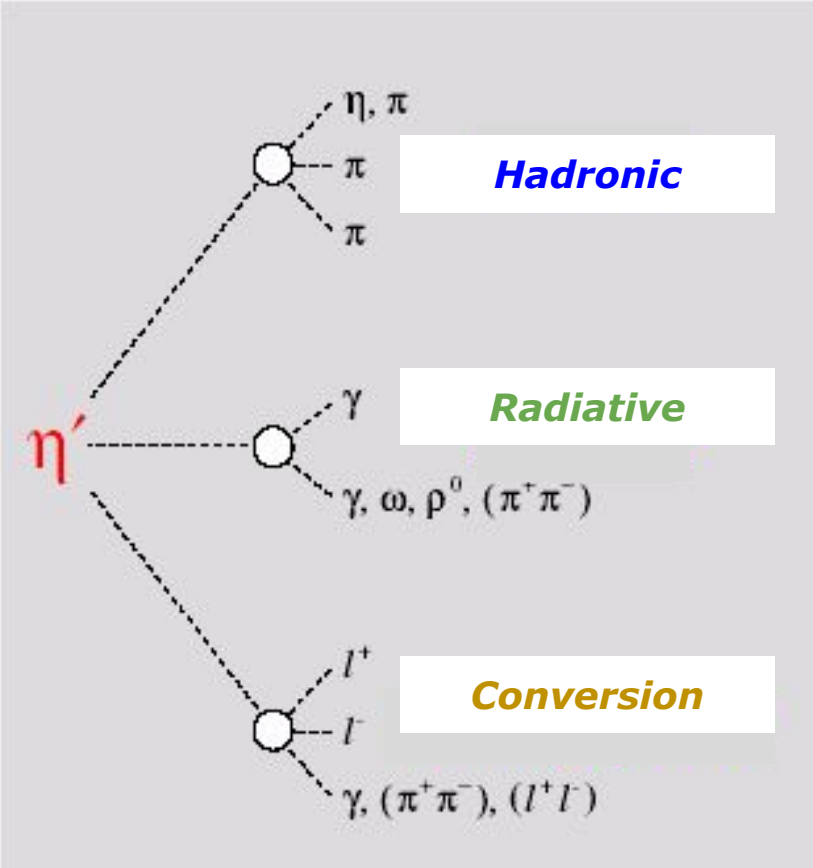
workshop WASA at GSI/FAIR
27-28 Nov 2017

WASA-at-COSY physics

- η-mesic nuclei → yesterday: Pawel Moskal
- meson production → today: Nils Hüsken
- **light meson decays** → today: Joanna Stepaniak, and this talk
- charge symmetry breaking → today: Maria Zurek
- dibaryons (ABC effect) → today: Heinz Clement

light meson decays



decay dynamics: **Dalitz plot analysis**

quantum anomalies

transition form factors: **dileptons**

Standard Model: **rare decays**

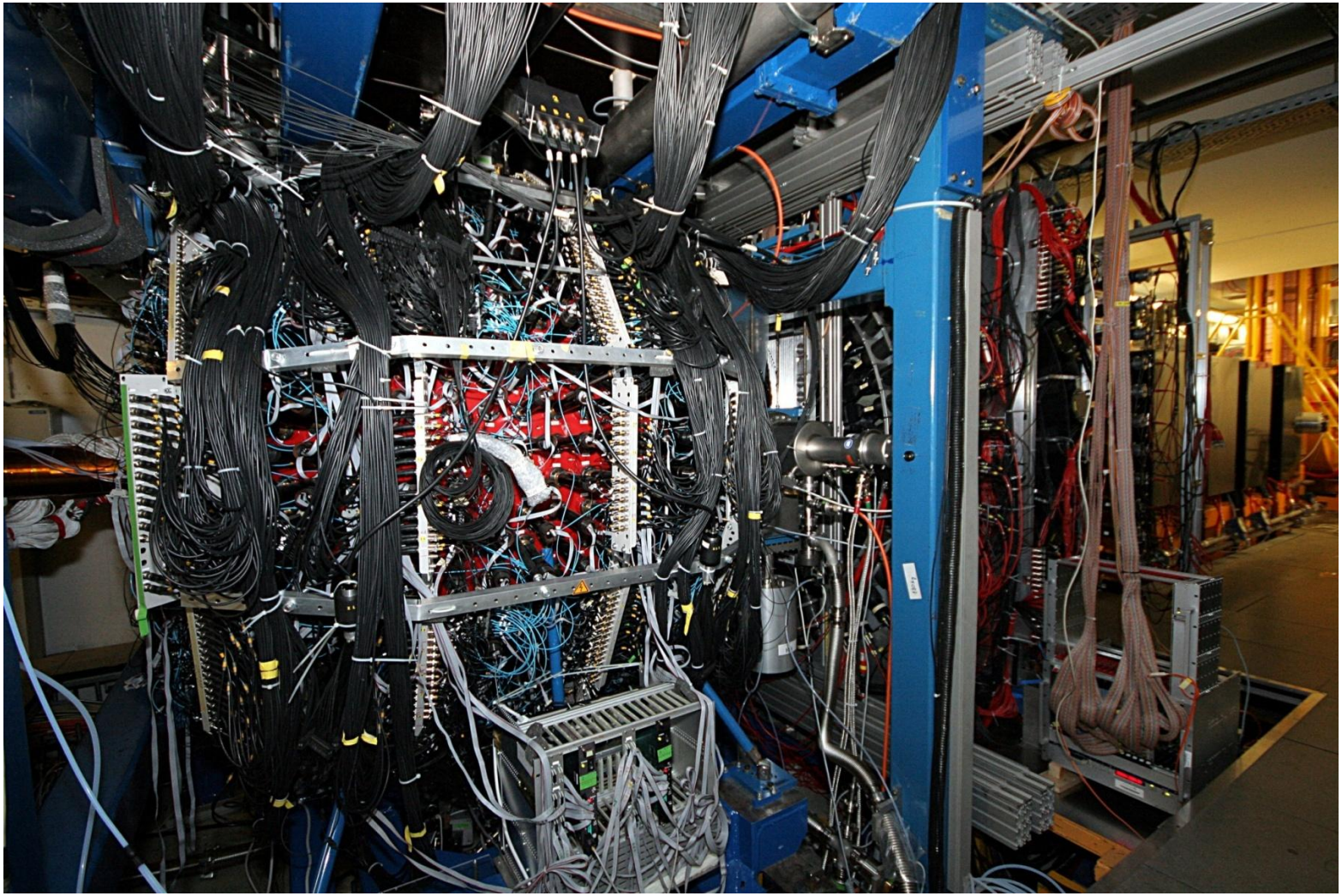
CP and C violation, new physics?

WASA-at-COSY: π, η, ω decays

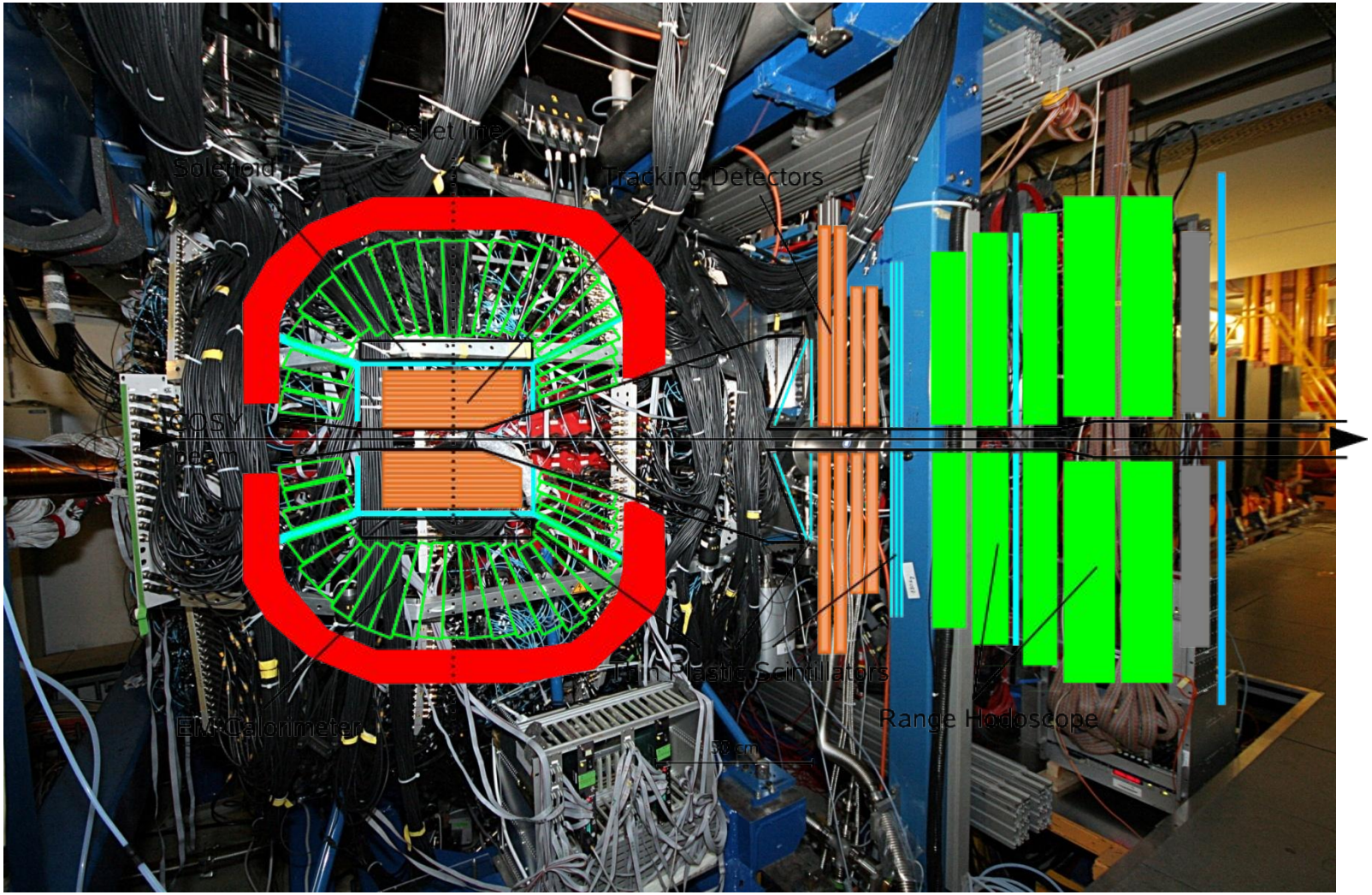
the orginal proposal for bringing WASA to COSY :

Proposal for the wide angle shower apparatus (WASA) at COSY-Julich: WASA at COSY
WASA-at-COSY Collaboration, e-Print: **nucl-ex/0411038**

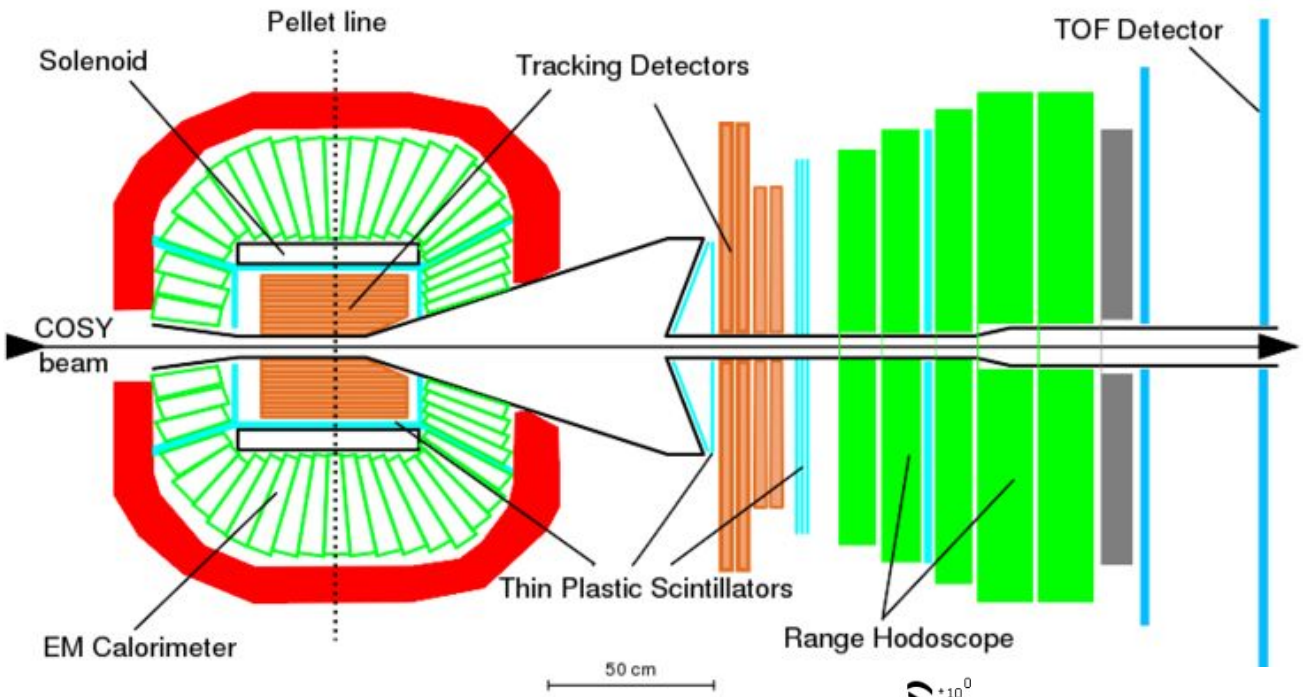
experimental approach

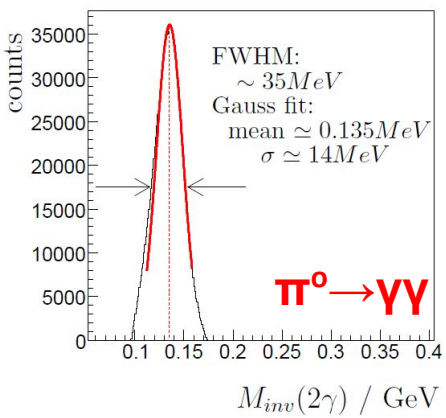


experimental approach

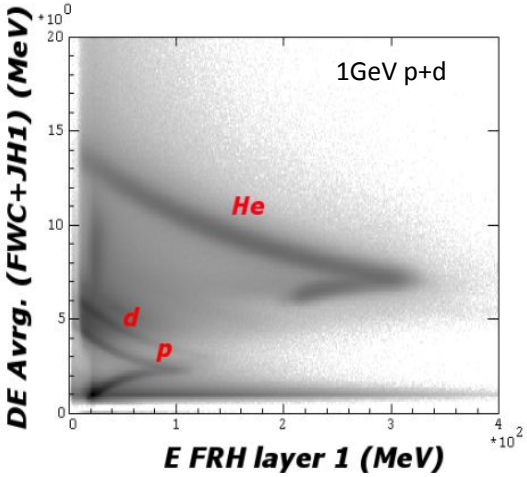


experimental approach





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



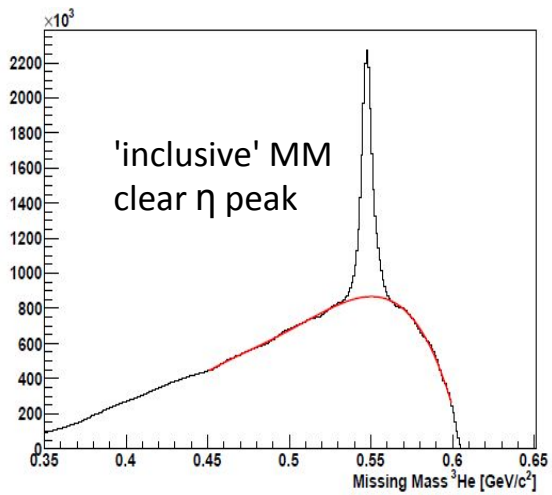
η meson tagging with forward detector

pd $\rightarrow {}^3$He η and pp→ppη

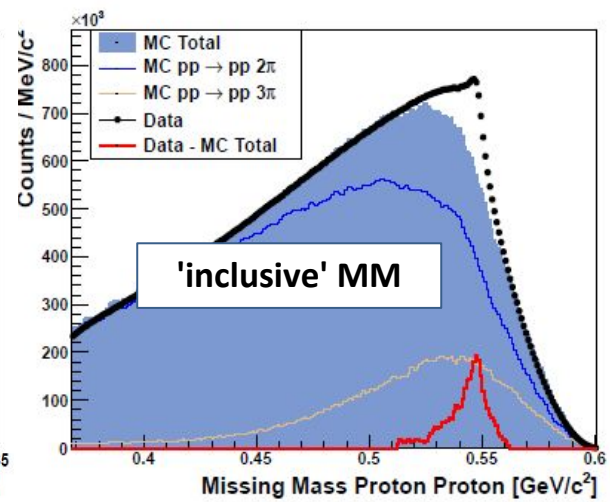
- missing mass method: meson tagging
- detection of all decay products

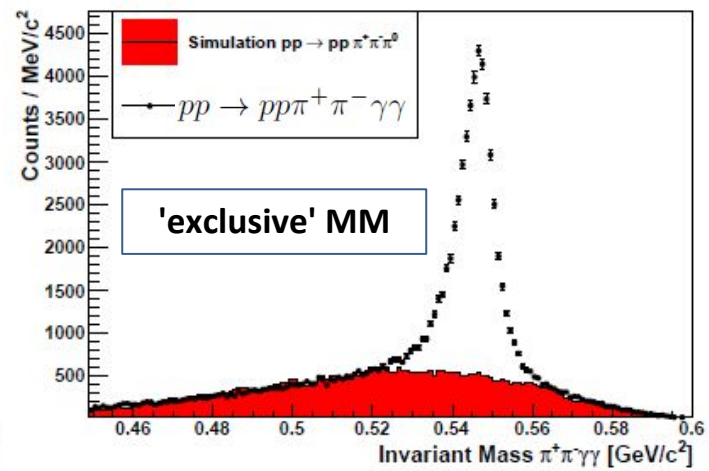
$$MM = \sqrt{(E_{initial} - E_{recoil})^2 - (\vec{P}_{initial} - \vec{P}_{recoil})^2}$$

1.0GeV p+d $\rightarrow {}^3$HeX



1.4GeV p+p $\rightarrow$ppX$_{trig}$ triggered on charged decay products





pd $\rightarrow {}^3$He η ***$3\cdot10^7$ ^{3}Heη tagged***
abundant decays, analysis training

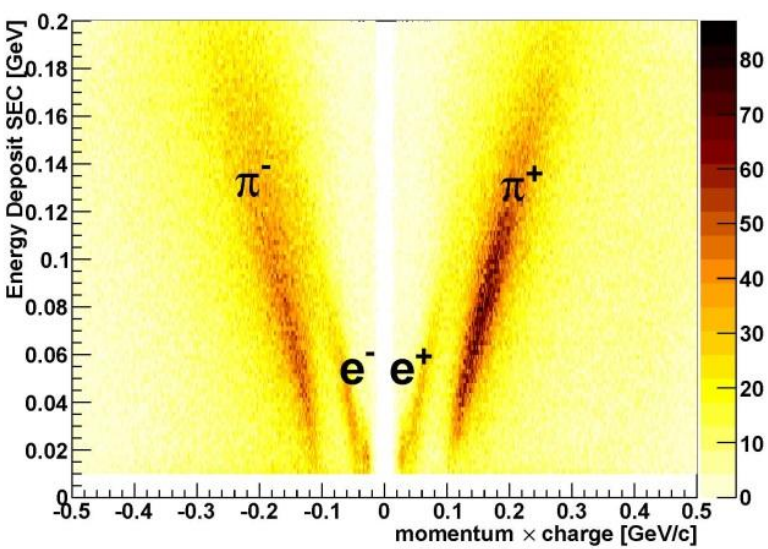
pp→ppη ***5×10^8 η produced***
rare decays

particle identification in central detector

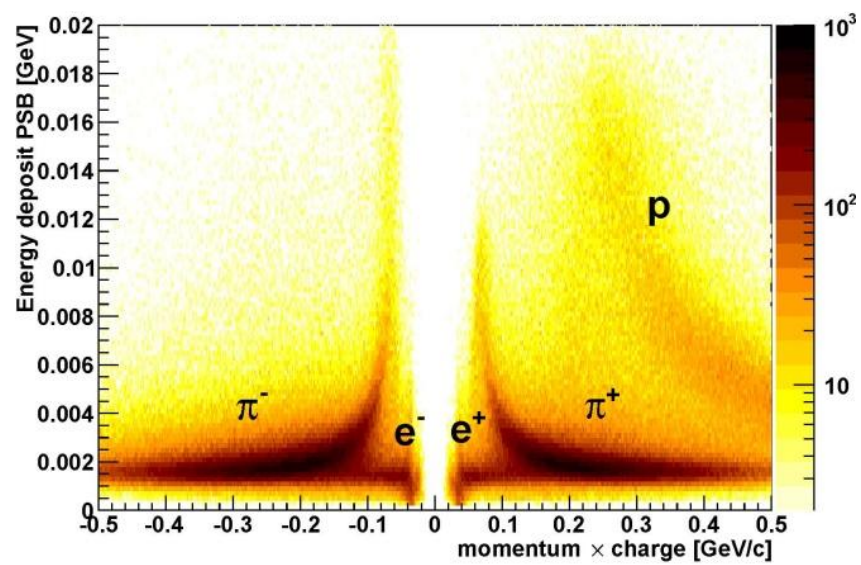
example PID:
analysis of p + d → ^{3}He + η

- ^{3}He selected in WASA forward detector
- low-energy proton background visible (in thin plastic scintillator)

calorimeter vs signed momentum



plastic scintillator vs signed momentum



Measurements of branching ratios for η decays into charged particles
Physical Review C, 94(6), 65206

experimental challenge

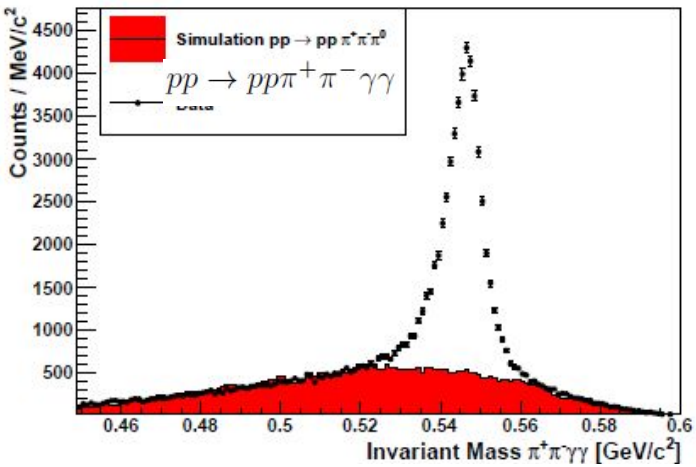
method:

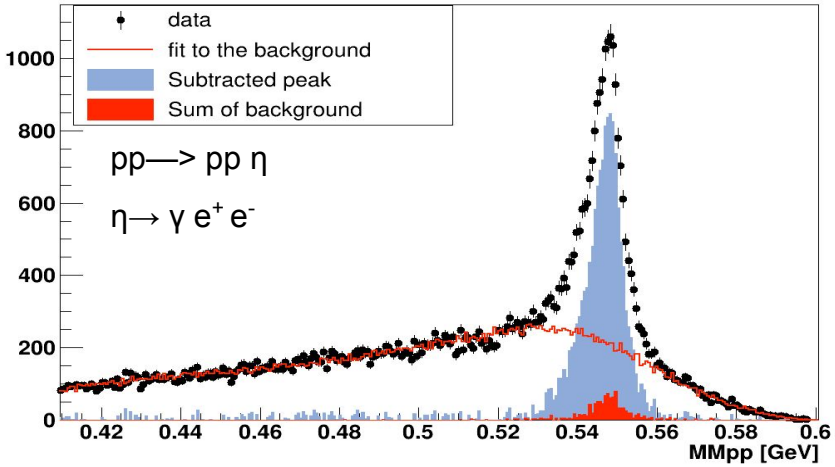
reconstruct meson mass peak, use full final state information

2 types of background:

1.) multi-pion background
meson production cross sections
→ smooth background under meson mass peak
example:
- signal $\eta \to \pi^+\pi^-\pi^0$ decay
- background direct $\pi^+\pi^-\pi^0$ production

2.) competing meson decays
relative branching ratios
→ peaked background at the meson mass peak
subtract via simulations
example:
- signal $\eta \to e^+e^-\gamma$ decay
- background (eg) from $\eta \to \gamma\gamma$ decay



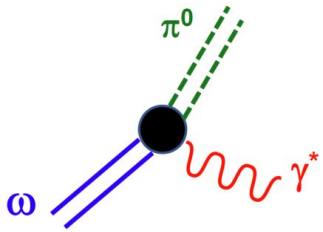


light meson decay analyses *('charged')*

decay mode	branching ratio	physics	analysis / publication
$\eta \to \pi^+\pi^-\pi^0$	$(22.74 \pm 0.28) \times 10^{-2}$	ChPT: Dalitz plot parameters	**PRC 90 (2014) 4** - pd (Adlarsson *2012). pp[1] (Zielinski *2012), *pp (Bardan)*
$\omega \to \pi^0\pi^+\pi^-$	$(89.2 \pm 0.7) \times 10^{-2}$		**PLB 770 (2017) 418** - pd (Heijkenskjöld *2016), pp (Sawant *2017).
$\eta \to \pi^+\pi^-\gamma$	$(4.60 \pm 0.16) \times 10^{-2}$	ChPT: box anomaly decay dynamics	**PLB 707 (2012) 243** - pd (Redmer *2010). *pp (Lersch *2014)*
$\eta \to \gamma\, e^+e^-$	$(7.0 \pm 0.7) \times 10^{-3}$	transition form factor	**PRC 94 (2016) 65206** - pd (Hodana *2012). pp[1] (Bhatt *2011), *pp (Goswami)*
$\eta \to e^+e^-e^+e^-$	$(2.4 \pm 0.2) \times 10^{-5}$	double transition form factor	**PRC 94 (2016) 65206** - pd[1] (Yurev *2011), pd (Wurm *2012). *pp (Su)*
$\eta \to \pi^+\pi^-e^+e^-$	$(2.68 \pm 0.11) \times 10^{-4}$	Standard Model: CP	pd[1] (Janusz *2010), **PRC 94 (2016) 65206** pd (Coderre *2012). *pp (NN)*
$\eta \to \pi^0e^+e^-$	$<4 \times 10^{-5}$	Standard Model: C	pd[1] (Winnemöller *2011), ***paper draft*** *pd (Bergmann *2017). pp (Demmich)*
$\eta \to (\gamma)e^+e^-$	$\eta \to e^+e^-$ $<2.7 \times 10^{-5}$	Standard Model: new physics? (dark?) U boson?	pp[1] (Berlowski *2013) , *pp[1] (Pszczel *2017)*
$\pi^0 \to (\gamma)e^+e^-$	$\pi^0 \to e^+e^-$ $(6.46 \pm 0.33) \times 10^{-8}$		**PLB 726 (2013) 187** pp (Güllstrom, Zlomanzcuk)

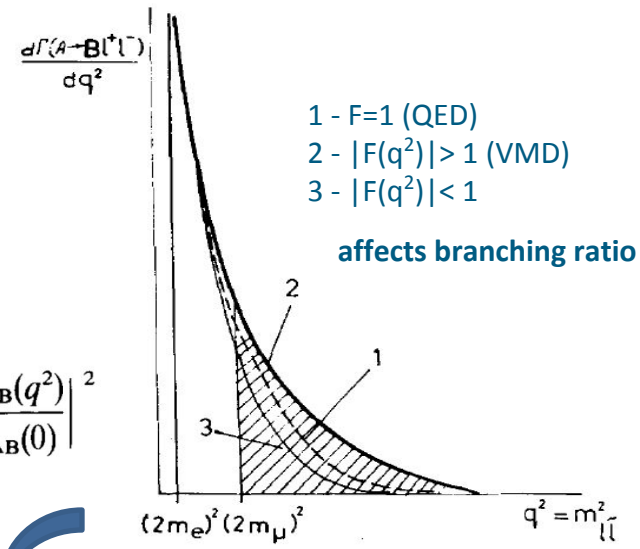
* www.collaborations.fz-juelich.de/ikp/wasa/theses.shtml
[1] partial data set

Dalitz (conversion) decays of mesons

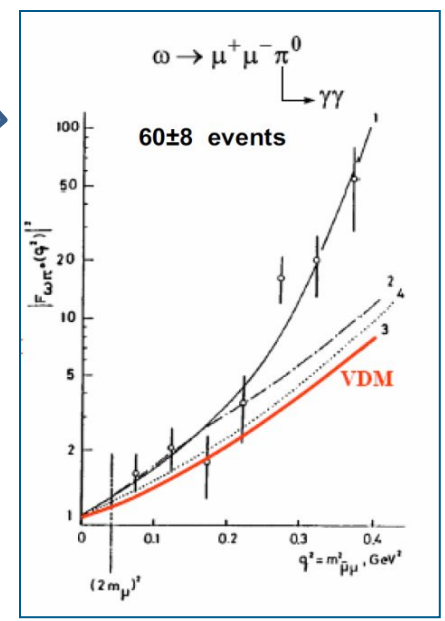


$$\frac{d\Gamma(A\to B\ell^+\ell^-)}{dq^2\cdot\Gamma(A\to B\gamma)} = \frac{\alpha}{3\pi}\left[1-\frac{4m_\ell^2}{q^2}\right]^{1/2}\left[1+2\frac{m_\ell^2}{q^2}\right]\frac{1}{q^2}$$
$$\times\left[\left(1+\frac{q^2}{m_A^2-m_B^2}\right)^2-\frac{4m_A^2q^2}{(m_A^2-m_B^2)^2}\right]^{3/2}\left|\frac{f_{AB}(q^2)}{f_{AB}(0)}\right|^2 = [\mathrm{QED}]\cdot\left|\frac{f_{AB}(q^2)}{f_{AB}(0)}\right|^2$$

L.G. Landsberg, Electromagnetic decays of light mesons



procedure: divide experimental q^2 distribution by QED



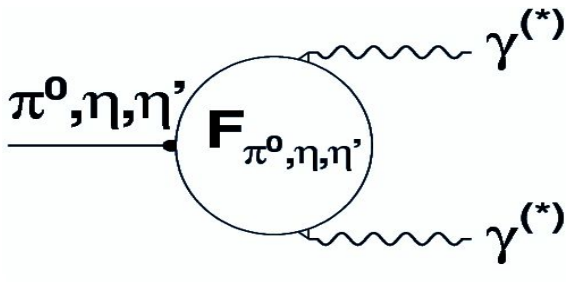
$$F_{AB}(q^2)\simeq 1+q^2[dF_{AB}/dq^2]|_{q^2\simeq 0} = 1+q^2b_{AB} = 1+\tfrac{1}{6}q^2\langle r^2_{AB}\rangle$$

slope parameter
b~ 1/m(rho)
(1.7 GeV^{-2}) 'standard VMD'

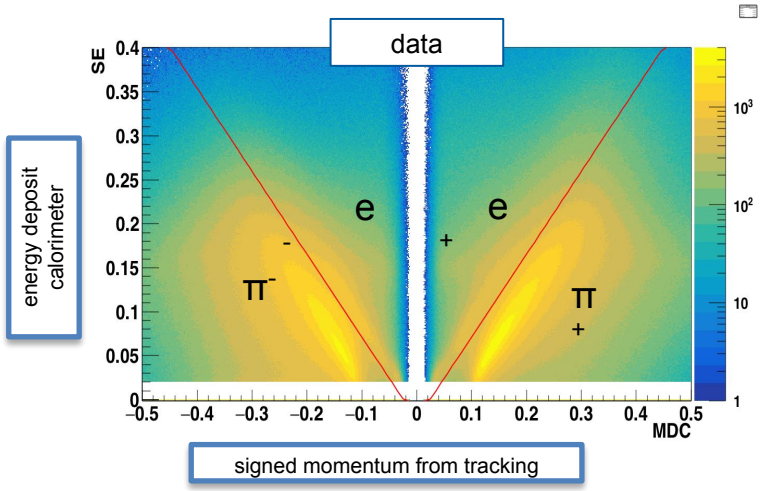
conversion decay $\eta \rightarrow \gamma\, e^+ e^-$

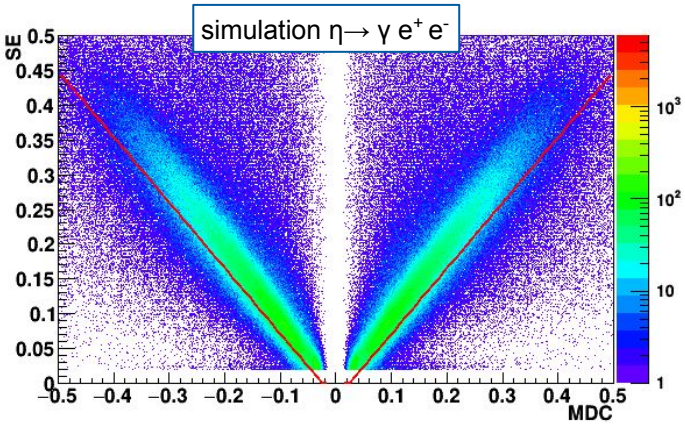
Electromagnetic Transition Form Factor

- intrinsic structure of mesons
- pseudoscalar mesons: size of the meson
- observable: dilepton mass distribution

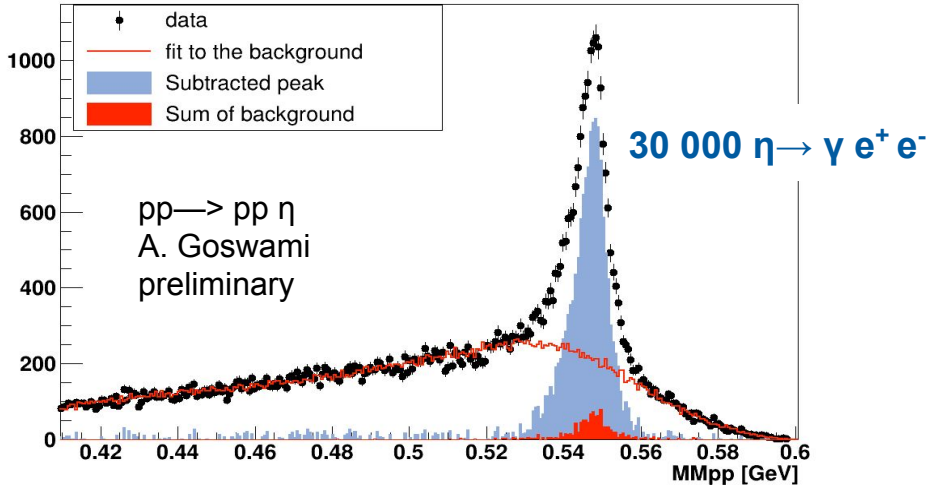


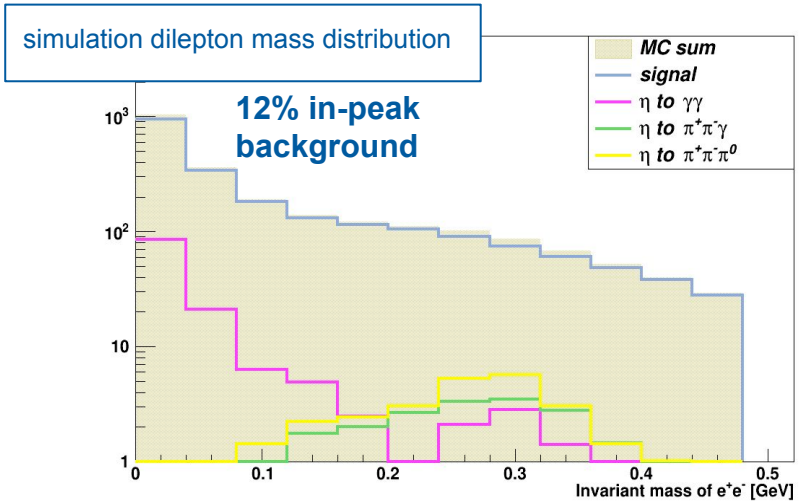
cut-based analysis:
cuts on particle identification, photon conversion (beam pipe), kinematic variables





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





outlook:

analysis: new base class for pp eta analyses

- full particle multiplicities
- improved particle id (neural networks)
- kinematic fit

→ can improve the efficiency and signal/background

- in parallel, look at η→ eeee

further: *study in γ p—> p η(') and ω with CLAS/JLab*

light meson decay publications

- **Search for C violation in the decay $\eta \rightarrow \pi^0 + e^+ + e^-$ with WASA-at-COSY**
  to be submitted PLB
- **Measurement of the $\omega \rightarrow \pi + \pi - \pi 0$ Dalitz plot distribution**
  Phys.Lett. B770 (2017) 418
- **Measurements of branching ratios for η decays into charged particles**
  Physical Review C, 94 (2016) 65206
- **Measurement of the $\eta \rightarrow \pi + \pi - \pi 0$ Dalitz plot distribution**
  Phys.Rev. C90 (2014) 4
- **Search for a dark photon in the pi0 --> e+e-gamma decay**
  Phys.Lett. B726 (2013) 187
- **Exclusive Measurement of the eta --> pi+ pi- gamma Decay**
  Phys.Lett. B707 (2012) 243
- **Measurement of the eta->3pi0 Dalitz Plot Distribution with the WASA Detector at COSY**
  Phys.Lett. B677 (2009) 2