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UNIVERSITET

Background

Interesting  
Topics

# An Overview of Issues in $\eta/\eta'$ Physics

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# Outline

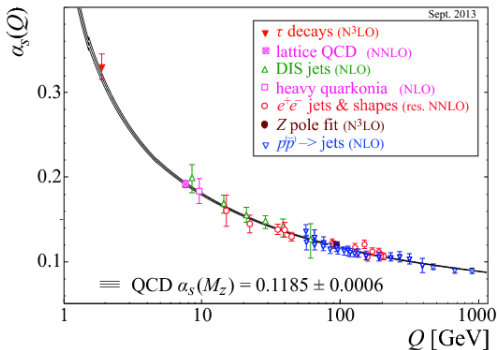
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# Low Energy QCD

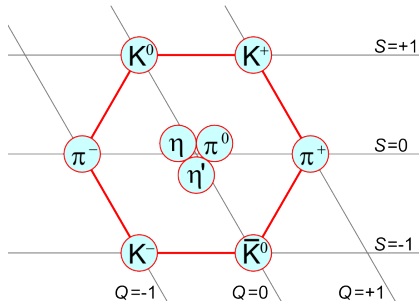
- QCD coupling large at low energies
- Low energy effective field theory, e.g.  $\chi PT$ ,





# Light Mesons

- 8 pseudo-Goldstone bosons == 8 lightest pseudoscalars
- SU(3)-flavor symmetry gives 9 mesons.
- Observable particles are mixes:
  - $\eta = \cos \theta_P \eta_8 - \sin \theta_P \eta_1$
  - $\eta' = \sin \theta_P \eta_8 + \cos \theta_P \eta_1$





# Some Nice Features of $\eta/\eta'$

- Large samples at many experiments
- Narrow width  $\rightarrow$  "easy" reconstruction
- Precision probe for many interesting unanswered questions
  - QCD at low energies
  - Matter-Antimatter disparity
  - Dark Matter?
  - Beyond Standard Model (BSM)

Decays of $\eta$		Decays of $\eta'$	
$\eta \rightarrow \gamma\gamma$	39.41 %	$\eta' \rightarrow \pi^+\pi^-\eta$	42.6 %
$\eta \rightarrow 3\pi^0$	32.68 %	$\eta' \rightarrow \pi^+\pi^-\gamma$	28.9 %
$\eta \rightarrow \pi^+\pi^-\pi^0$	22.92 %	$\eta' \rightarrow \pi^0\pi^0\eta$	22.8 %
$\eta \rightarrow \pi^+\pi^-\gamma$	4.22 %	$\eta' \rightarrow \omega\gamma$	2.62 %
$\eta \rightarrow e^+e^-\gamma$	0.69 %	$\eta' \rightarrow \gamma\gamma$	2.22 %

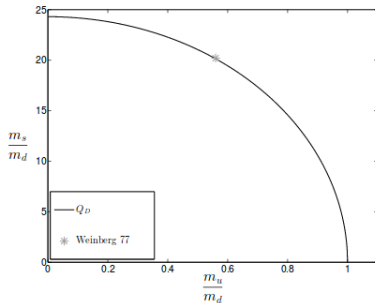


# Quark Mass Difference/Ratio

## ■ $\eta \rightarrow 3\pi$ a sensitive probe

Phys.Lett. 23 (1966) 384-385, Eur.Phys.J.C60:83-105,2009

- Isospin breaking decay
- Strong contribution proportional to  $(m_d - m_u)$

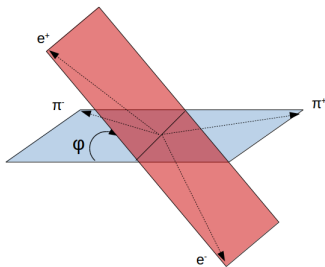


Phys.Lett. B378, 313 (1996)



# CP-violation

- CP-violation discovered in  $K_L \rightarrow 2\pi$
- Analogous test  $\eta^{(\prime)} \rightarrow \pi\pi$ ?
  - Very suppressed!
- Beyond SM contributions may still be large!
  - Look in  $\eta^{(\prime)} \rightarrow \pi^+\pi^-\gamma^* \rightarrow \pi^+\pi^-e^+e^-$   
Mod.Phys.Lett.A17:1583-1588,2002
  - Not dependent on  $\epsilon, \epsilon'$ , or  $\theta$





# Anomalous Muon Magnetic Moment $\mu$ (g-2)

## ■ 3.5 $\sigma$ discrepancy between theory and experiment

C. Patrignani et al. (Particle Data Group), Chin. Phys. C,40, 100001 (2016)

## ■ Hadronic Contribution largest source of theory uncertainty

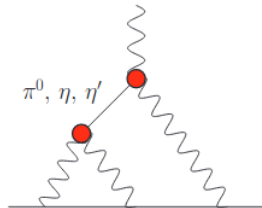
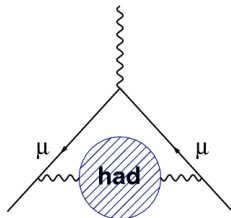
- Hadronic Vacuum Polarization

- ▶  $\frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}$

- ▶  $\frac{1}{s^2}$  dependence. Lighter hadrons more important

- Hadronic Light-by-Light scattering

- ▶ Transition form factors







# Where can we measure these things?



## KLOE-2

- $\sim 2.4 \times 10^{10} \phi$  events
- $3.1 \times 10^8 \eta$
- $1.49 \times 10^6 \eta'$



## BESIII

- $\sim 5 \times 10^9 J/\psi$  events
- $5.5 \times 10^6 \eta$
- $2.6 \times 10^7 \eta'$



## WASA-at-COSY

- $3 \times 10^7 \eta$  from  $pp \rightarrow He\eta$
- $\sim 10^9 \eta$  from  $pp \rightarrow pp\eta$



# WASA: Dark Photon Search



Background

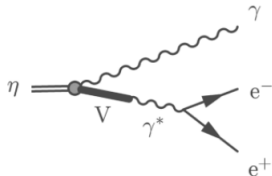
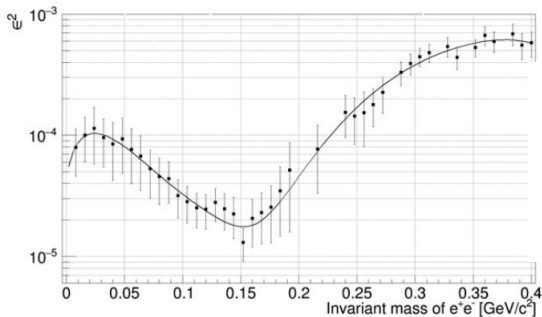
Interesting  
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Summary &  
Outlook

- Dark matter candidate
- Should couple to ordinary photon



Pszczel, D. 2018. Search for a new light boson in meson decays.



# BESIII: Dalitz Plot Analysis



Background

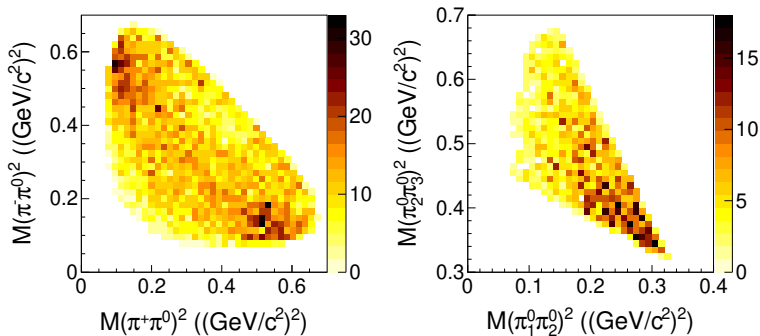
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- Study amplitude of  $\eta' \rightarrow \pi^+ \pi^- \pi^0$  and  $\eta' \rightarrow \pi^0 \pi^0 \pi^0$
- Sizeable contribution from  $\eta' \rightarrow \rho^\pm \pi^\mp$



Phys. Rev. Lett. 118, 012001 (2017)



# Summary & Outlook

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## Summary

- $\eta/\eta'$  are excellent laboratories for:
  - Study of low energy QCD
  - Search for BSM physics

## Outlook

- More  $\eta'$  data opens up study of
  - Rare decays
  - CP-violation
  - Decay Dynamics

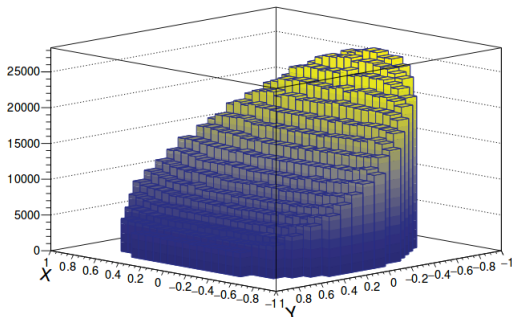
**Thank you for listening!**



# Backup KLOE: Dalitz Plot Analysis



- Precise understanding of the  $\eta \rightarrow \pi^+\pi^-\pi^0$  amplitude
- Better determination of quark mass ratio

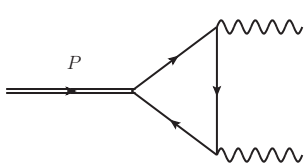


Caldeira Balkeståhl, L. 2015. Measurement of the Dalitz Plot Distribution for  $\eta \rightarrow \pi^+\pi^-\pi^0$  with KLOE. JHEP 1605 (2016) 019

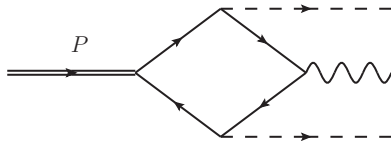


# Backup: Anomalous Decays

- New diagrams from breaking of U(1) axial symmetry
- Test Higher order contributions



$\gamma^{(*)}$



$\gamma^{(*)}$



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## Unprecedented $\eta'$ sample enables study of:

- Rare decays, e.g.
  - $\eta' \rightarrow \pi^+ \pi^- \mu^+ \mu^-$
  - $\eta' \rightarrow \pi^+ \pi^- e^+ e^-$
- CP-Violation
- Decay dynamics