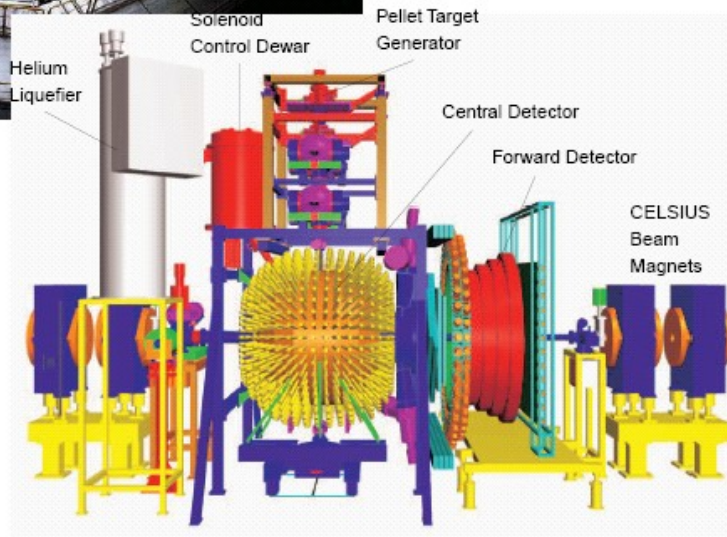
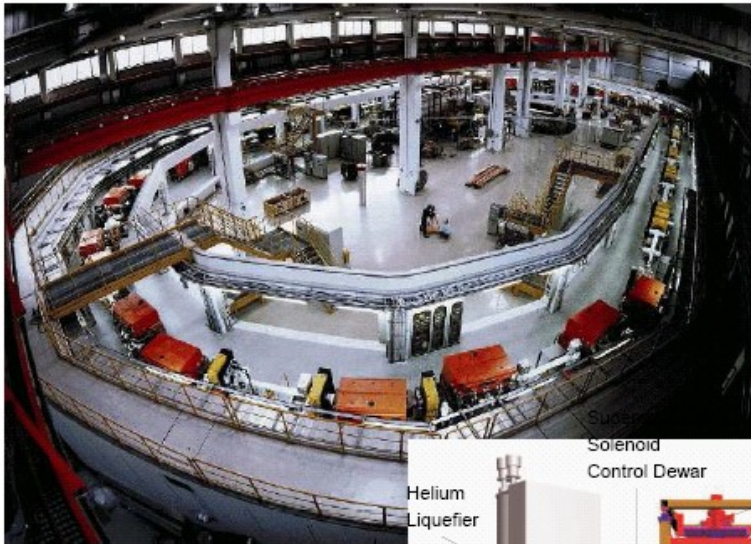


Dlaczego badamy mezony i

’?

Joanna Stepaniak
Warszawa, 13.01.2006

Wide Angle Shower Apparatus (WASA) at COSY-Jülich



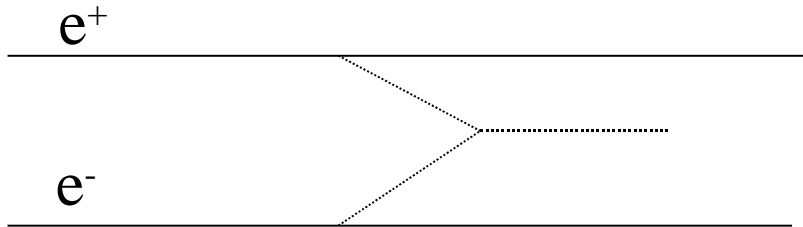
Plan

- ~~W~~ ~~mezonów~~ i'
→ ~~ak~~ kwarkowy, domieszka gluonów
- ~~D~~ ~~dzia~~ $-N$
→ ~~W~~ ~~S~~ $_{11}(1535)$, spektroskopia rezonansów barionowych
- ~~D~~ ~~dzia~~ eta-j
→ Nowa forma materii?
- ~~R~~ ~~ozpady~~ mezonów i'
→ Testy C,CP
- ~~K~~ ~~nomalie~~ w rozpadach B ~~K~~ B $'X$

$(547), \rho(958) \quad I^G(J^{PC}) \quad 0^+(0^{-+})$

~~Średnia~~ Średnia szeroko

$\Gamma(\rho) = 1.2 \text{ keV} \quad \Gamma(\rho') = 202 \text{ keV}$



~~Średnia szeroko~~ Średnia szeroko
z tego procesu + BR dla innych kana
rozpadu

~~Średnia szeroko~~ Średnia szeroko $\Gamma(\rho) = 0.542 \pm 0.031 \text{ keV}$

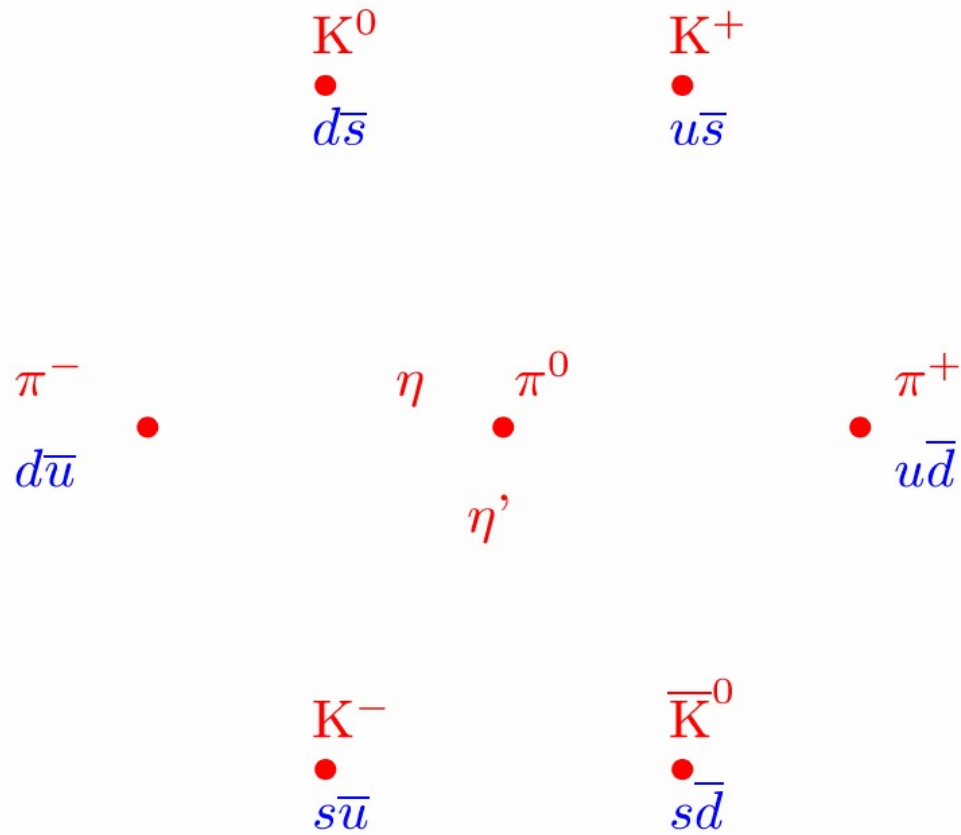
$\Gamma(\rho') = 4.59 \pm 0.27 \text{ keV}$

~~Średnia szeroko~~ Średnia szeroko rozpadu

emerytalnego, a wi

jak bardzo

MESONS $J^P = 0^-$



- $SU(3)_{\text{flavour}}$ nonet of pseudoscalar mesons

$$\eta_0 = \frac{1}{\sqrt{3}} (|u\bar{u}\rangle + |d\bar{d}\rangle + |s\bar{s}\rangle),$$

$$\eta_8 = \frac{1}{\sqrt{6}} (|u\bar{u}\rangle + |d\bar{d}\rangle - 2|s\bar{s}\rangle),$$

~~Źródło~~ wyja

~~Źródło~~ w stan mieszaj

$$\eta = \eta_8 \cos \theta - \eta_0 \sin \theta$$

$$\eta' = \eta_8 \sin \theta + \eta_0 \cos \theta$$

Wyniki na podstawie rozpadów 2, $J/\psi \rightarrow (\psi')$, formfaktorów,

siły kwarkowych daj -12° do -22° $\psi' = -20^\circ$

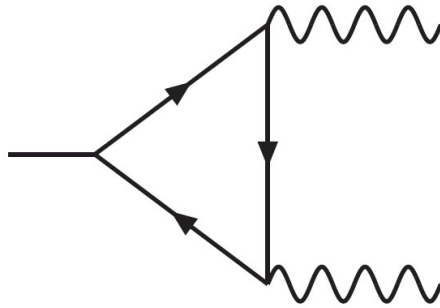
$$\eta \approx \frac{1}{\sqrt{3}} (|u\bar{u}\rangle + |d\bar{d}\rangle - |s\bar{s}\rangle)$$

$$\eta' \approx \frac{1}{\sqrt{6}} (|u\bar{u}\rangle + |d\bar{d}\rangle + 2|s\bar{s}\rangle)$$

Obserwowana masa ~~Źródło~~ si

Main decay channels:

$\eta \rightarrow \gamma\gamma$	39%	α^2
$\eta \rightarrow \pi^0\pi^0\pi^0$	32%	$(m_u - m_d)$
$\eta \rightarrow \pi^+\pi^-\pi^0$	23%	$(m_u - m_d)$
$\eta \rightarrow \pi^+\pi^-\gamma$	5%	



i^0 w rozpadach mezonu B

$$BR(B \rightarrow i^0) (70.8 \pm 3.4) 10^{-6} > BR(B \rightarrow i^0) (12.1 \pm 0.8) 10^{-6}$$

Ważna, znacznie mniejsza przestrze

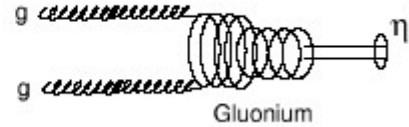
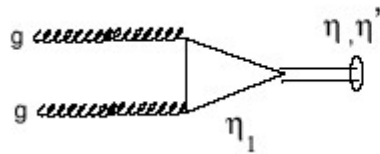
Ważna, znacznie mniejsza przestrze

Ważna, znacznie mniejsza przestrze

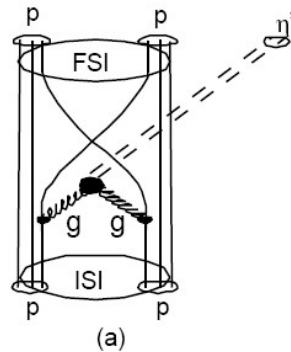
Ważna, znacznie mniejsza przestrze

Ważna, znacznie mniejsza przestrze

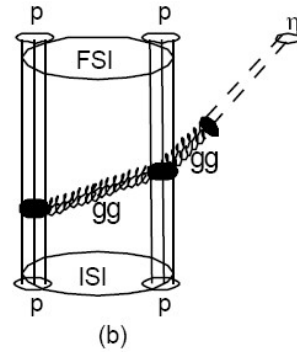
Coupling of η and η' to two gluons



Gluon fusion



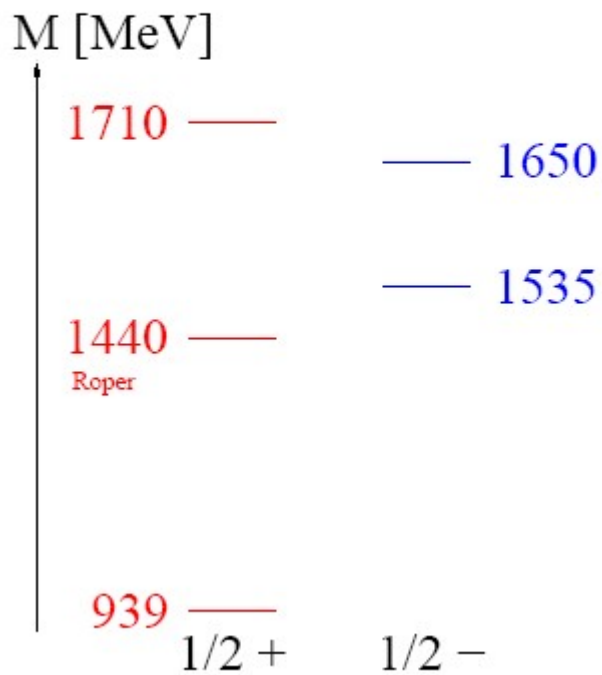
Exchange and rescattering of colour-singlet object



Jak produkowano mezony eta?

- W produkcji pionów π i kaonów K
pierwsza obserwacja (1961)
- W fotoprodukcji CLAS, GRALL, MAMI, CEBAF
- W zderzeniach nukleon-nukleon – zderzenia centralne
przy progu, WA102 przy 450 GeV : fuzja gluonowa?
- W zderzaczach ee , z rozpadów mezonu Φ (KLOE -Dafne, Nowosybirsk)

Baryon spectroscopy



Naiwny model kwarkowy
nie opisuje dobrze widma
kałtanów. Si
od zapachu (Glozman, Riska)?
moleku

Energy dependence of $\eta N \rightarrow \eta N$ amplitude most sensitive to S_{11} molecular component (Baru et al. (2004))

What do we know?

PDG 2004: Mass: 1520–1555 MeV ($m_\eta + M_N = 1486$ MeV)
Width: 100–200 MeV

Hadronic decay channels:

πN 35 – 55%

ηN 30 – 55%

$\pi\pi N$ 1 – 10%

$\pi\Delta$ < 1%

ρN < 4%

σN < 3%

$\pi N(1440)$ < 7%

two pion channels neither well determined nor big

Can we get away without them?

Szerkesztés

11(1535)

$$\sigma(\pi N \rightarrow \pi N) \sim \Gamma_{\pi} \Gamma_{\pi}$$

$$\sigma(\pi N \rightarrow \eta N) \sim \Gamma_{\pi} \Gamma_{\eta}$$

$$\sigma(\gamma N \rightarrow \pi N) \sim \Gamma_{\gamma} \Gamma_{\pi}$$

$$\sigma(\gamma N \rightarrow \eta N) \sim \Gamma_{\gamma} \Gamma_{\eta}$$

Odległa eta-nukleon

istnienie?

$$a_N = 0.91 \pm 0.06 + i(0.27 \pm 0.02)$$

Analiza reakcji $N \rightarrow N$, $N \rightarrow N$, $N \rightarrow N$

Green, Wycech

Batinic

$$a_N = 0.717 \pm 0.03 + i(0.263 \pm 0.025)$$

Wieloletnia historia – eta mo

→

niejasności

$N^*(1535)$

N

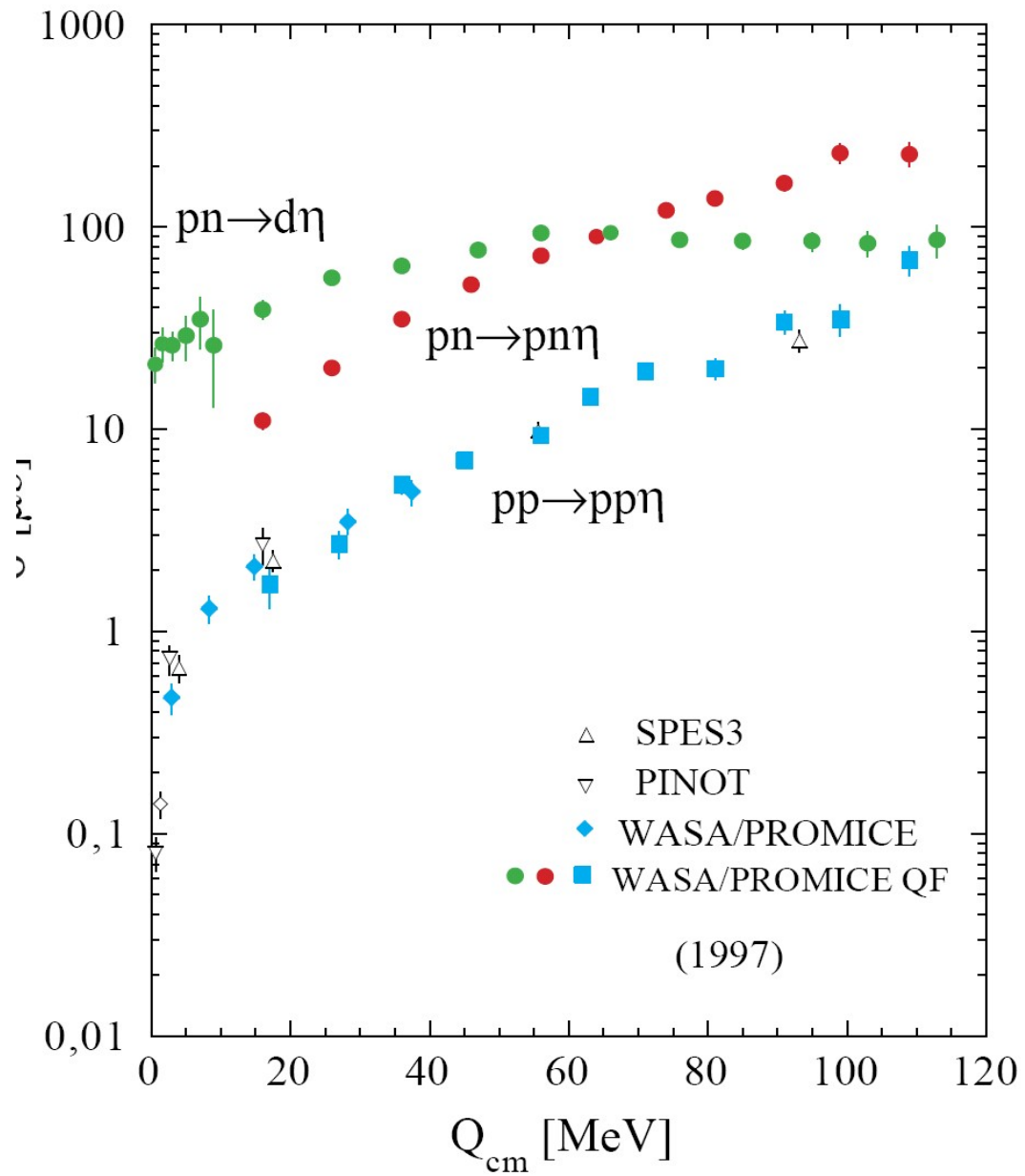
o energii 50 MeV

Reakcje z minimalnego A j

Reakcje d+d

$3p+d$

wzmocnienie w stosunku do oczekiwa



Łączny prógowej produkcji mezonów

	$p[\text{MeV}]$	$p[\text{fm}^{-1}]$	$R[\text{fm}]$
	370	1.9	0.53
	770	3.9	0.26
'	1060	5.4	0.19

Centrum kinematyki protonów
i mezonów produkowane cz

TESTS OF DISCRETE SPACE-TIME SYMMETRIES

CHARGE CONJUGATION (C) INVARIANCE

$\Gamma(\pi^0 \rightarrow 3\gamma)/\Gamma_{\text{total}}$	$<3.1 \times 10^{-8}$, CL = 90%
η C-nonconserving decay parameters	
$\pi^+ \pi^- \pi^0$ left-right asymmetry parameter	$(0.09 \pm 0.17) \times 10^{-2}$
$\pi^+ \pi^- \pi^0$ sextant asymmetry parameter	$(0.18 \pm 0.16) \times 10^{-2}$
$\pi^+ \pi^- \pi^0$ quadrant asymmetry parameter	$(-0.17 \pm 0.17) \times 10^{-2}$
$\pi^+ \pi^- \gamma$ left-right asymmetry parameter	$(0.9 \pm 0.4) \times 10^{-2}$
$\pi^+ \pi^- \gamma$ parameter β (<i>D</i> -wave)	-0.02 ± 0.07 ($S = 1.3$)
$\Gamma(\eta \rightarrow 3\gamma)/\Gamma_{\text{total}}$	$<5 \times 10^{-4}$, CL = 95%
$\Gamma(\eta \rightarrow \pi^0 e^+ e^-)/\Gamma_{\text{total}}$	[a] $<4 \times 10^{-5}$, CL = 90%
$\Gamma(\eta \rightarrow \pi^0 \mu^+ \mu^-)/\Gamma_{\text{total}}$	[a] $<5 \times 10^{-6}$, CL = 90%
$\Gamma(\omega(782) \rightarrow \eta \pi^0)/\Gamma_{\text{total}}$	$<1 \times 10^{-3}$, CL = 90%
$\Gamma(\omega(782) \rightarrow 3\pi^0)/\Gamma_{\text{total}}$	$<3 \times 10^{-4}$, CL = 90%
$\Gamma(\eta'(958) \rightarrow \pi^0 e^+ e^-)/\Gamma_{\text{total}}$	[a] $<1.4 \times 10^{-3}$, CL = 90%
$\Gamma(\eta'(958) \rightarrow \eta e^+ e^-)/\Gamma_{\text{total}}$	[a] $<2.4 \times 10^{-3}$, CL = 90%
$\Gamma(\eta'(958) \rightarrow 3\gamma)/\Gamma_{\text{total}}$	$<1.0 \times 10^{-4}$, CL = 90%
$\Gamma(\eta'(958) \rightarrow \mu^+ \mu^- \pi^0)/\Gamma_{\text{total}}$	[a] $<6.0 \times 10^{-5}$, CL = 90%
$\Gamma(\eta'(958) \rightarrow \mu^+ \mu^- \eta)/\Gamma_{\text{total}}$	[a] $<1.5 \times 10^{-5}$, CL = 90%

Przebiegi przemiany ładunkowego

$$C |\eta\rangle = + |\eta\rangle$$

$$\eta \rightarrow 3\gamma$$

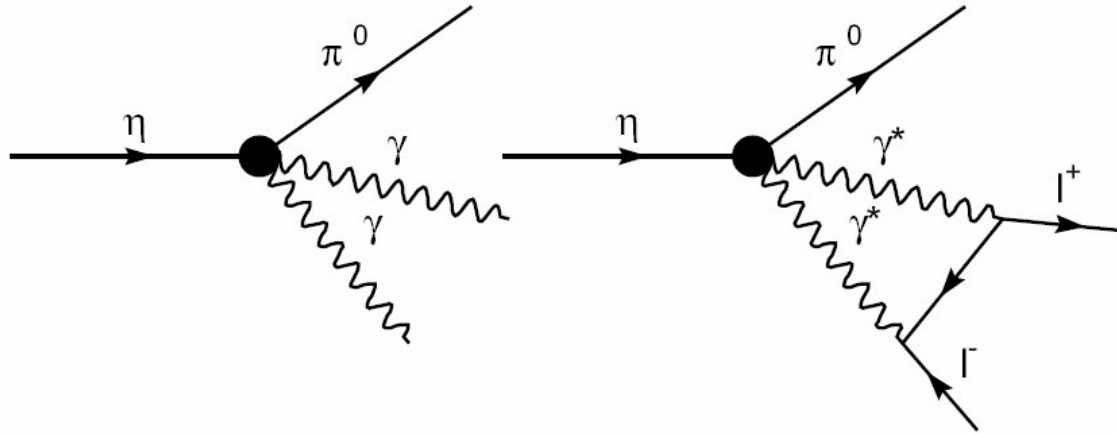
$$\eta \rightarrow 2\gamma$$

Składowe przesunięcia fazowe),
każda wartość

$$\frac{\eta \rightarrow \pi^0 e^+ e^-}{\eta \rightarrow \text{cokolwiek}} < 4 \cdot 10^{-5}$$

Decays $\eta \rightarrow \pi^0 l^+ l^-$

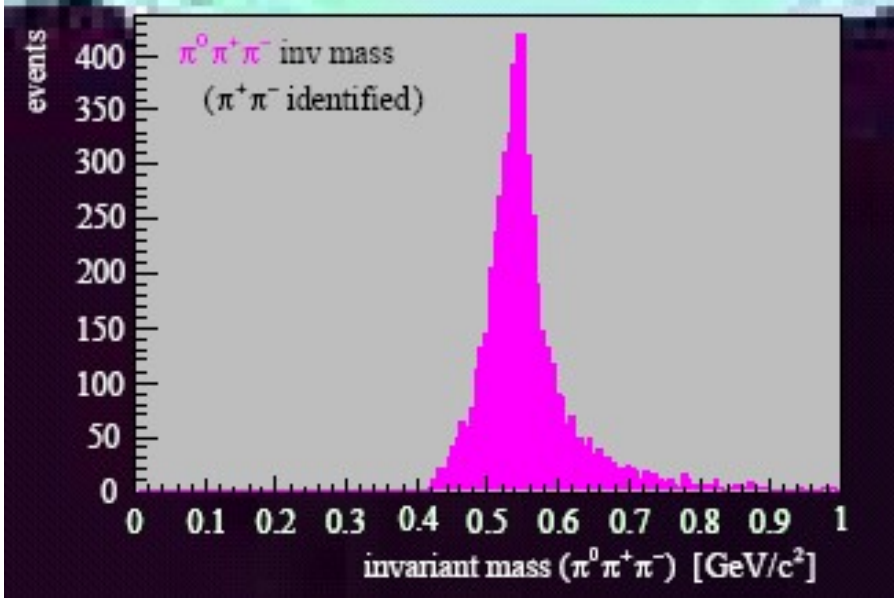
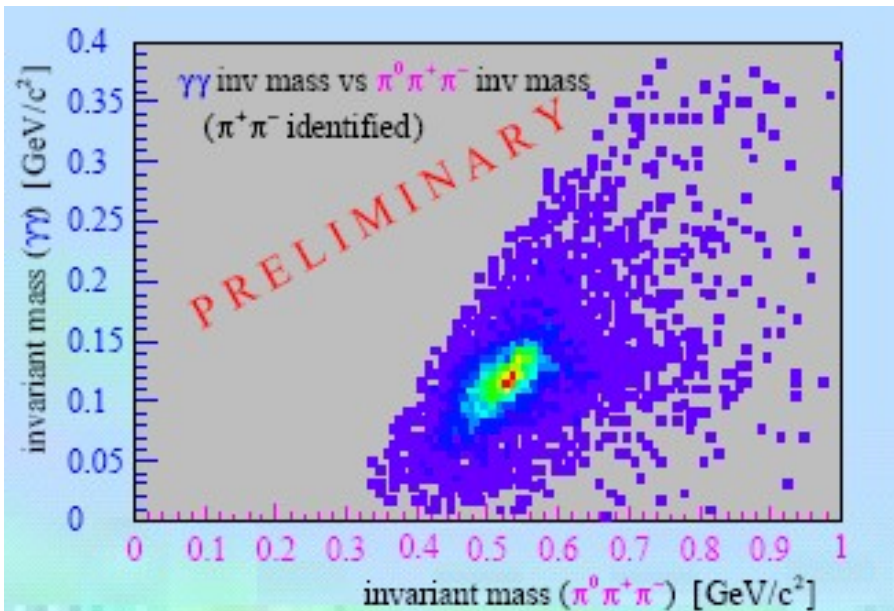
Decay	BR(<i>exp</i>) PDG	BR(th)
\mathcal{C} if single-photon process:		
$\pi^0 \mu^- \mu^+$	$< 5 \times 10^{-6}$	3×10^{-9} [NG93]
$\pi^0 e^+ e^-$	$< 4 \times 10^{-5}$	3×10^{-9} [NG93]

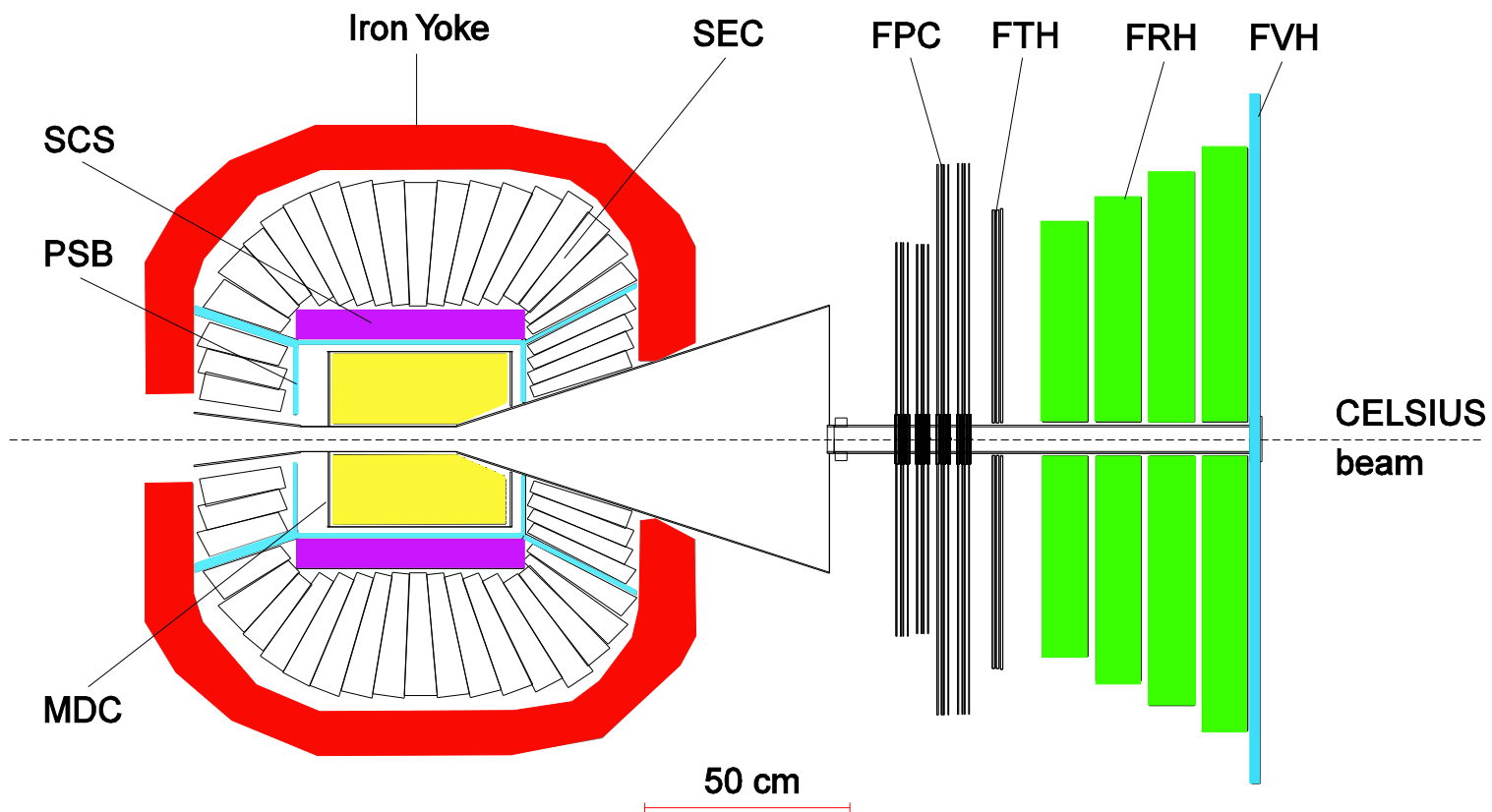


Present CP violation limits from eta decays (flavour conserving sector)

$\Gamma(\eta \rightarrow \pi^+ \pi^-) / \Gamma_{\text{total}}$	$< 3.3 \times 10^{-4}$, CL = 90%
$\Gamma(\eta \rightarrow \pi^0 \pi^0) / \Gamma_{\text{total}}$	$< 4.3 \times 10^{-4}$, CL = 90%
$\Gamma(\eta \rightarrow 4\pi^0) / \Gamma_{\text{total}}$	$< 6.9 \times 10^{-7}$, CL = 90%
$\Gamma(\eta'(958) \rightarrow \pi^+ \pi^-) / \Gamma_{\text{total}}$	$< 2 \times 10^{-2}$, CL = 90%
$\Gamma(\eta'(958) \rightarrow \pi^0 \pi^0) / \Gamma_{\text{total}}$	$< 9 \times 10^{-4}$, CL = 90%

WASA at CELSIUS → 3





Central Detector

Forward Detector



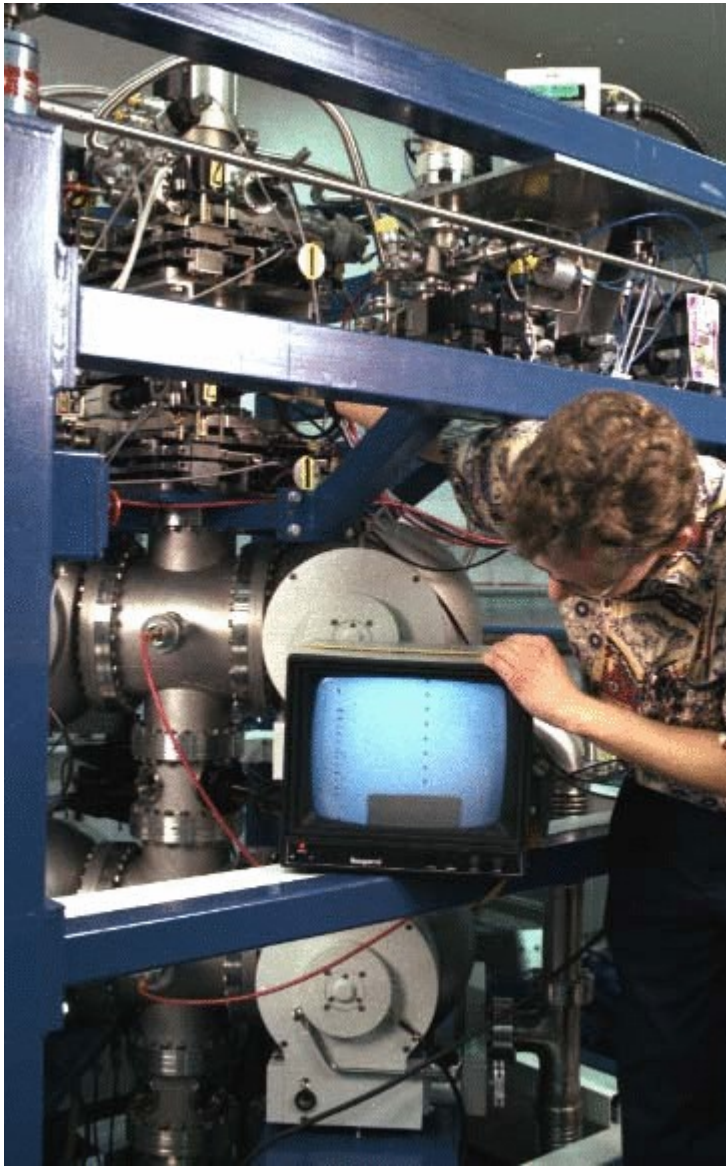
File written by Adobe Photoshop® 4.0

Album 3.2





File written by Adobe Photoshop® 4.0

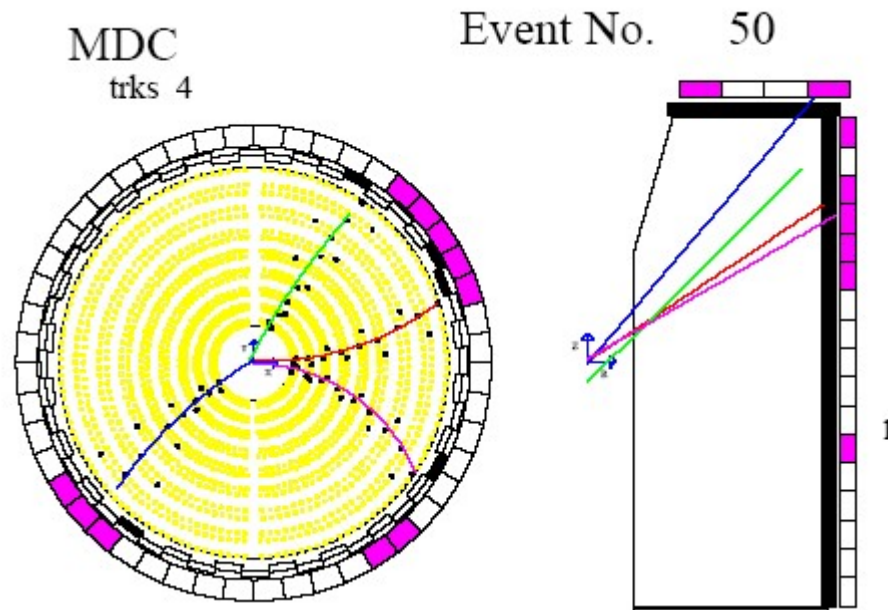


Album 3.2



File written by Adobe Photoshop' 4.0

→ $\mu^- e^- e^+$ candidate



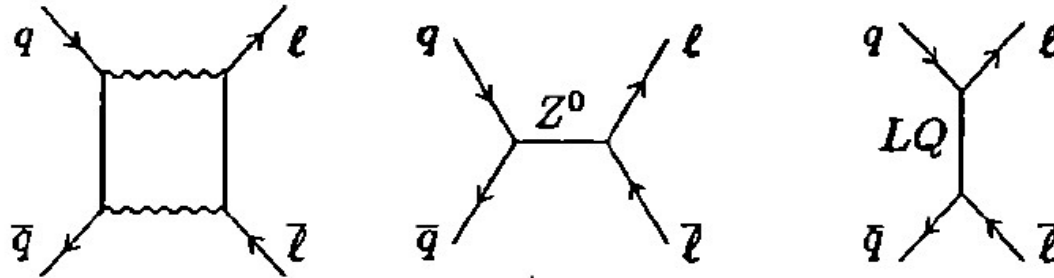
Decays $\mathcal{P}^0 \rightarrow l^+l^-$

Decay	BR(<i>exp</i>) PDG	Unitary bound
$\pi^0 \rightarrow e^+e^-$	$7.04 \pm 0.53 \times 10^{-8}$	4.8×10^{-8}
$\eta \rightarrow e^+e^-$	$< 7.7 \times 10^{-5}$	1.8×10^{-9}
$\eta' \rightarrow e^+e^-$	$< 2.1 \times 10^{-7}$	
$\eta \rightarrow \mu^+\mu^-$	$5.8 \pm 0.8 \times 10^{-6}$	4.3×10^{-6}
$K_L \rightarrow \mu^+\mu^-$	$7.15 \pm 0.16 \times 10^{-9}$	6.8×10^{-9}
$K_L \rightarrow e^+e^-$	$9_{-4}^{+6} \times 10^{-12}$	3.0×10^{-12}

Table 1: Counting rate estimates including detector efficiencies for η (η') decays with WASA at COSY based on a luminosity of $10^{32} \text{ cm}^{-2} \text{ s}^{-1}$, with a $20 \mu\text{b}$ (300 nb) cross section in $pp \rightarrow pp\eta(\eta')$ at 2.250 GeV/c (3.350 GeV/c) beam momentum.

	Decay mode	Branching fraction Γ_i/Γ_{tot} [74]	Existing data [events]	Counting rate [evts/day]
η (semi)-leptonic	$e^+e^-\pi^+\pi^-$	$4. \begin{smallmatrix} +14.0 \\ -2.7 \end{smallmatrix} \cdot 10^{-4}$	5	xx
	$e^+e^-e^+e^-$	$< 6.9 \cdot 10^{-5}$	-	850 ²
	e^+e^-	$5. \cdot 10^{-9}$	-	1/6 ³
	$\pi^0e^+e^-$	$0.2\text{-}1.3 \cdot 10^{-8}$	-	xx ⁴
η' hadronic	$\pi^+\pi^-\eta$	$44.3 \pm 1.5 \%$	8200	18000
	$\pi^0\pi^0\eta$	$20.9 \pm 1.2 \%$	5400	14500
	$3\pi^0$	$1.56 \pm 0.26 \cdot 10^{-3}$	130	145
	$\pi^+\pi^-\pi^0$	$< 5. \%$	-	85 ⁵
η' radiative	$\rho^0\gamma$	$29.5 \pm 1.0 \%$	8300	44000 ⁶
	$\omega\gamma$	$3.03 \pm 0.31 \%$	160	1200
	$\gamma\gamma$	$2.12 \pm 0.14 \%$	2767	17100
η' semi-leptonic	$\mu^+\mu^-\gamma$	$1.04 \pm 0.26 \cdot 10^{-4}$	33	15
	$e^+e^-\gamma$	$< 9. \cdot 10^{-4}$	-	45 ⁷

$$\mathcal{P}^0 \rightarrow l^+ l^-$$



- α^4 process (BR 10^{-8})
 - Z^0 contribution negligible (BR 10^{-11})
- \Rightarrow Sensitive to new interactions (leptoquarks)
- $\eta(\eta') \rightarrow e^+ e^-$ unmeasured
 - More precise BR values needed to test exotic contributions

