WASA at *CELSIUS* and
η′ Decays with WASA@COSY

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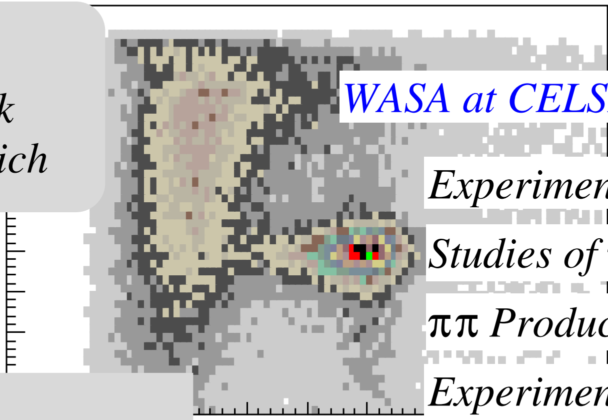
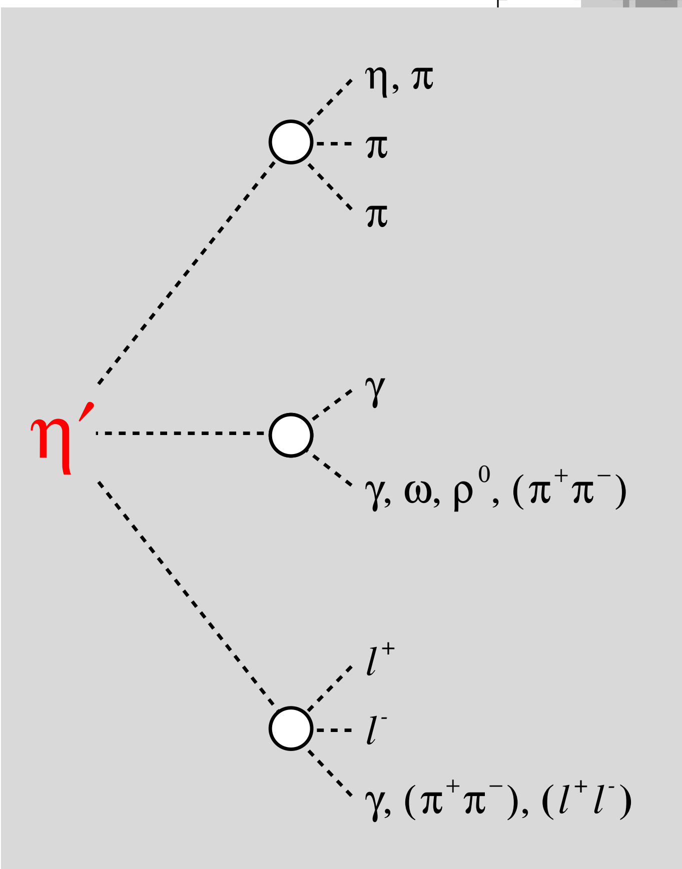


WASA at CELSIUS

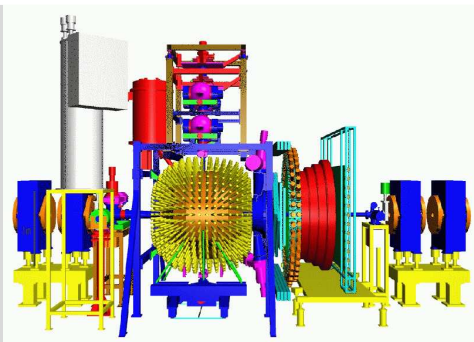
- *Experimental Technique*
- *Studies of η Decays*
- *ππ Production*
- *Experimental Programme*



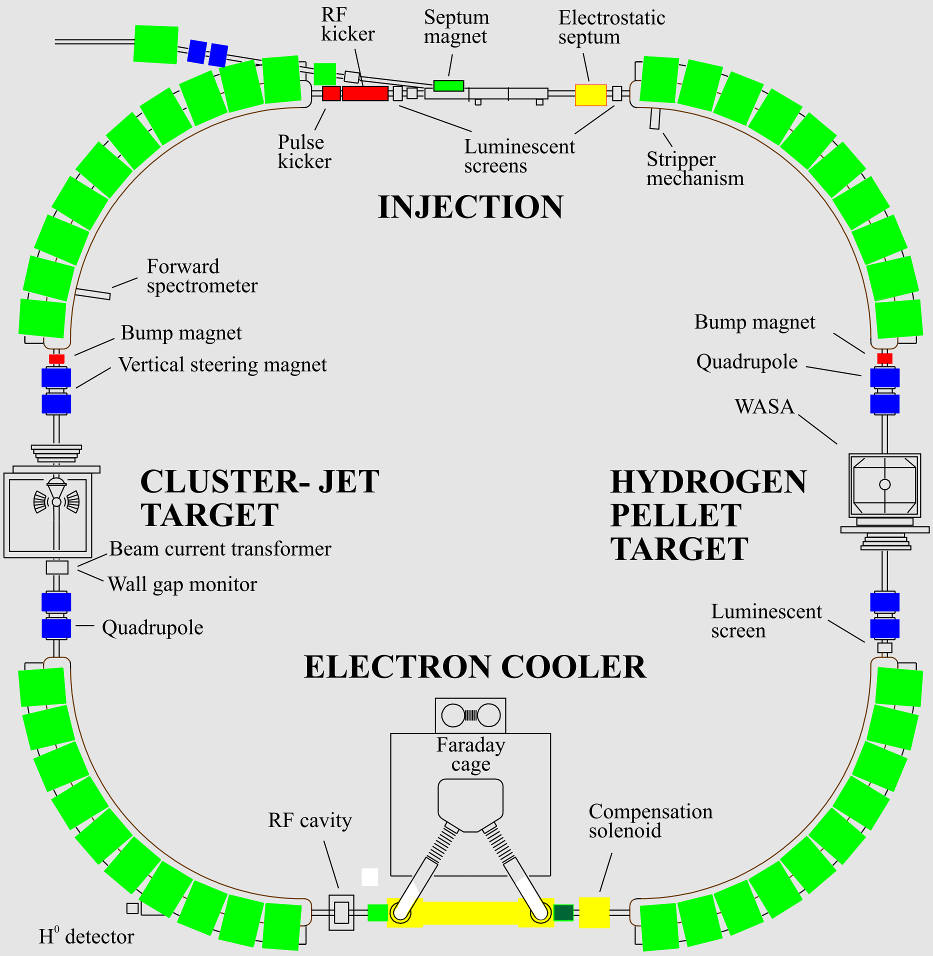
η′ Decays with WASA at COSY

- *Charge Symmetry and Light Quark Masses*
- *Scalar Couplings*
- *Pseudoscalar Singlet-Octet Mixing*
- *QCD Anomalies*
- *Glue Content*
- *Transition Form Factor*

Caucasian-German
School and Workshop on
Hadron Physics
Tbilisi, Aug 30 - Sep 4, 2004



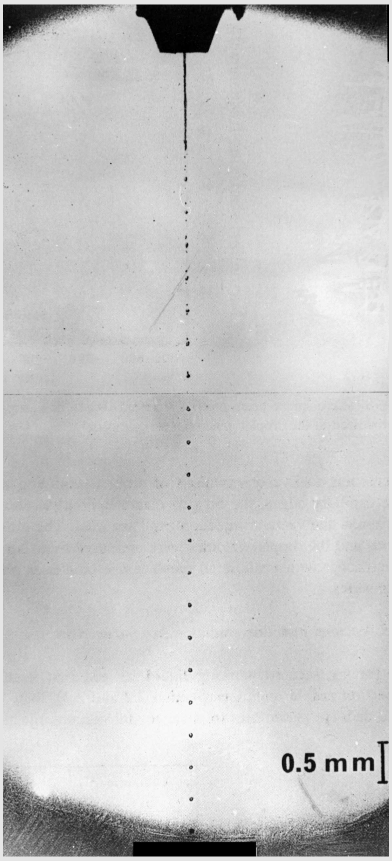
The CELSIUS Cooler Ring

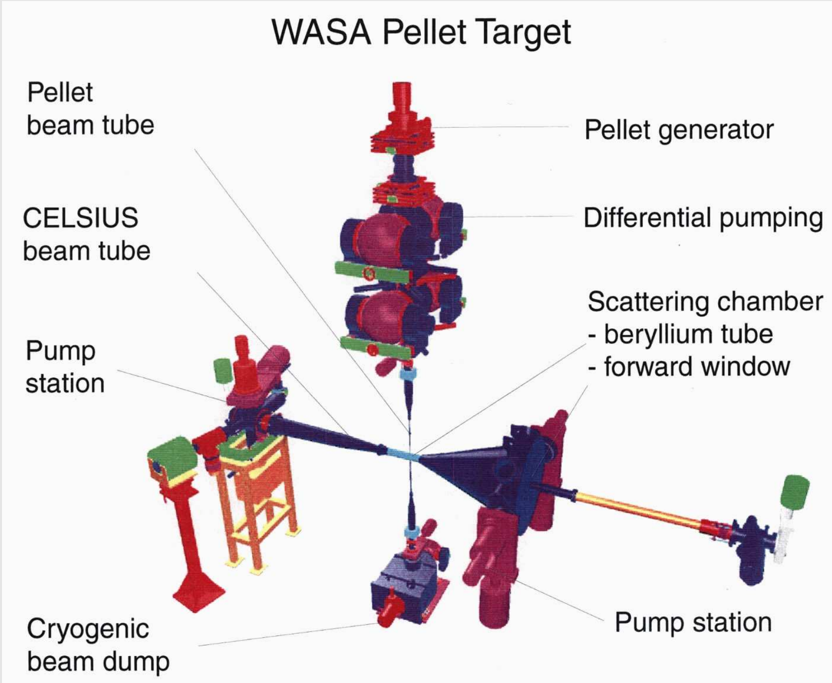


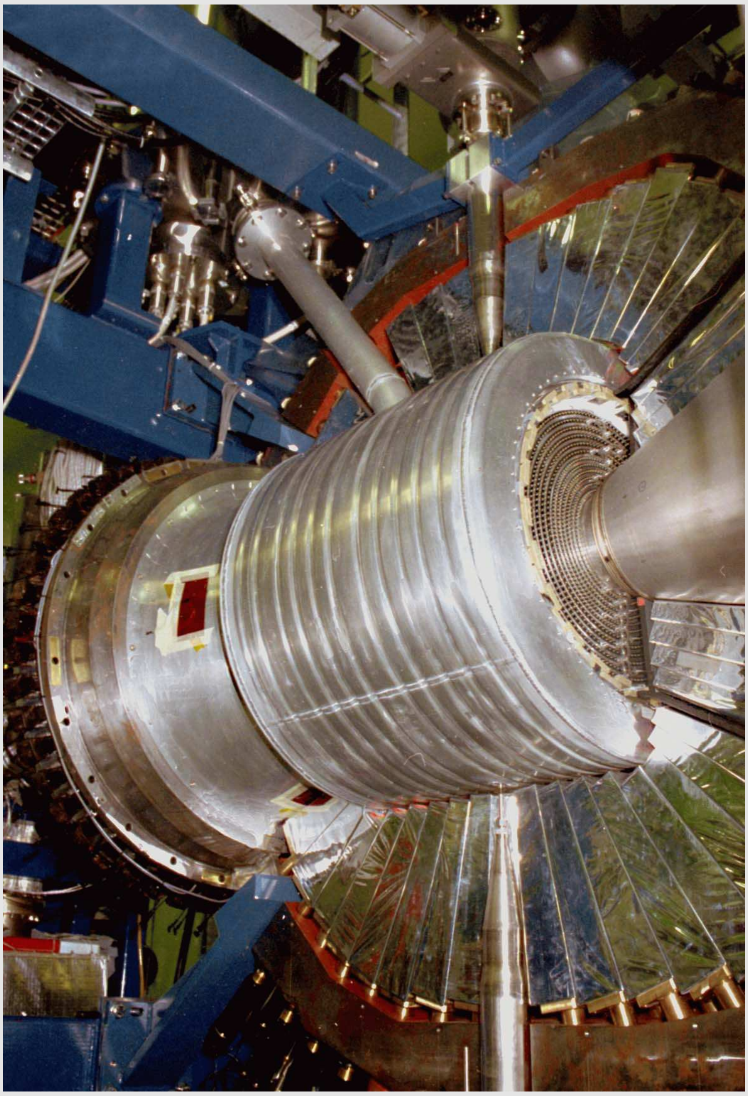
Circumference

81.8 m

Maximum proton energy	Number of stored protons
1450 MeV	$5 \cdot 10^{10}$
Relative momentum spread $\Delta p/p$	**Beam dimensions at target (h/v)**
$1 \cdot 10^{-3}$	5/2.5 mm







Pellet diameter

25 - 35μm

Pellet frequency

5 - 12kHz

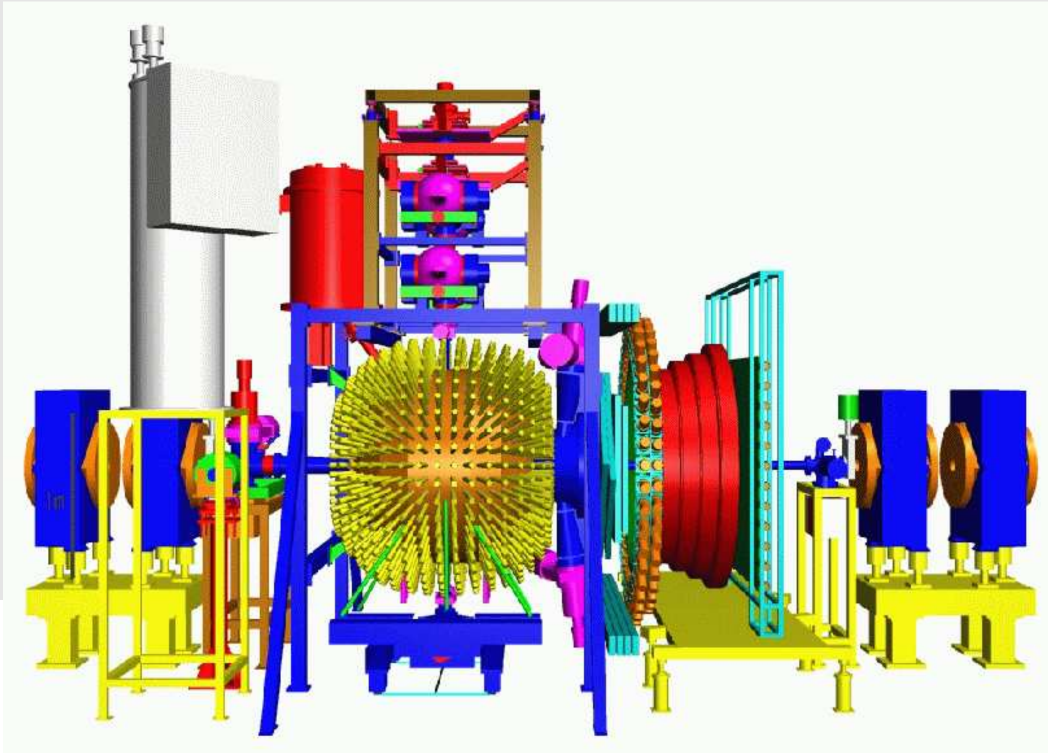
Pellet-pellet distance

9 - 20mm

Effective target thickness

$>10^{15}$ atoms/cm^2

WASA detector



Event identification

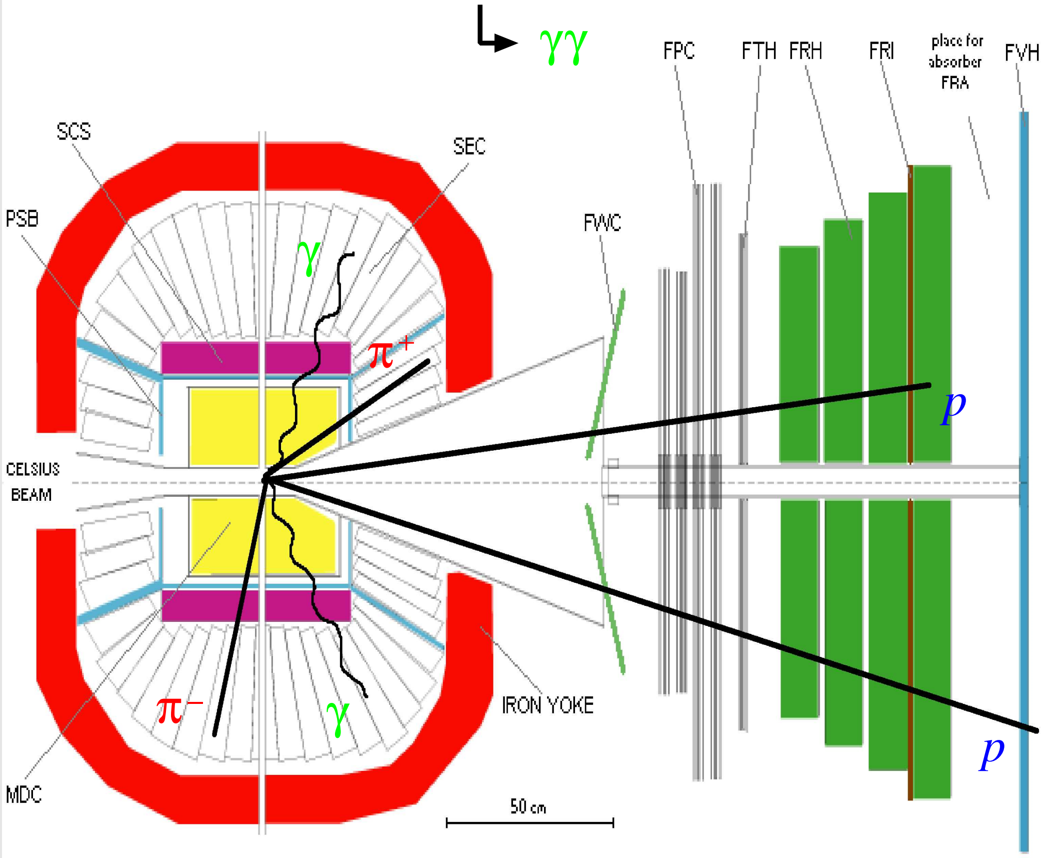
$pp \rightarrow pp\eta$

$\quad \hookrightarrow \pi^+\pi^-\pi^0$

$\qquad \hookrightarrow \gamma\gamma$

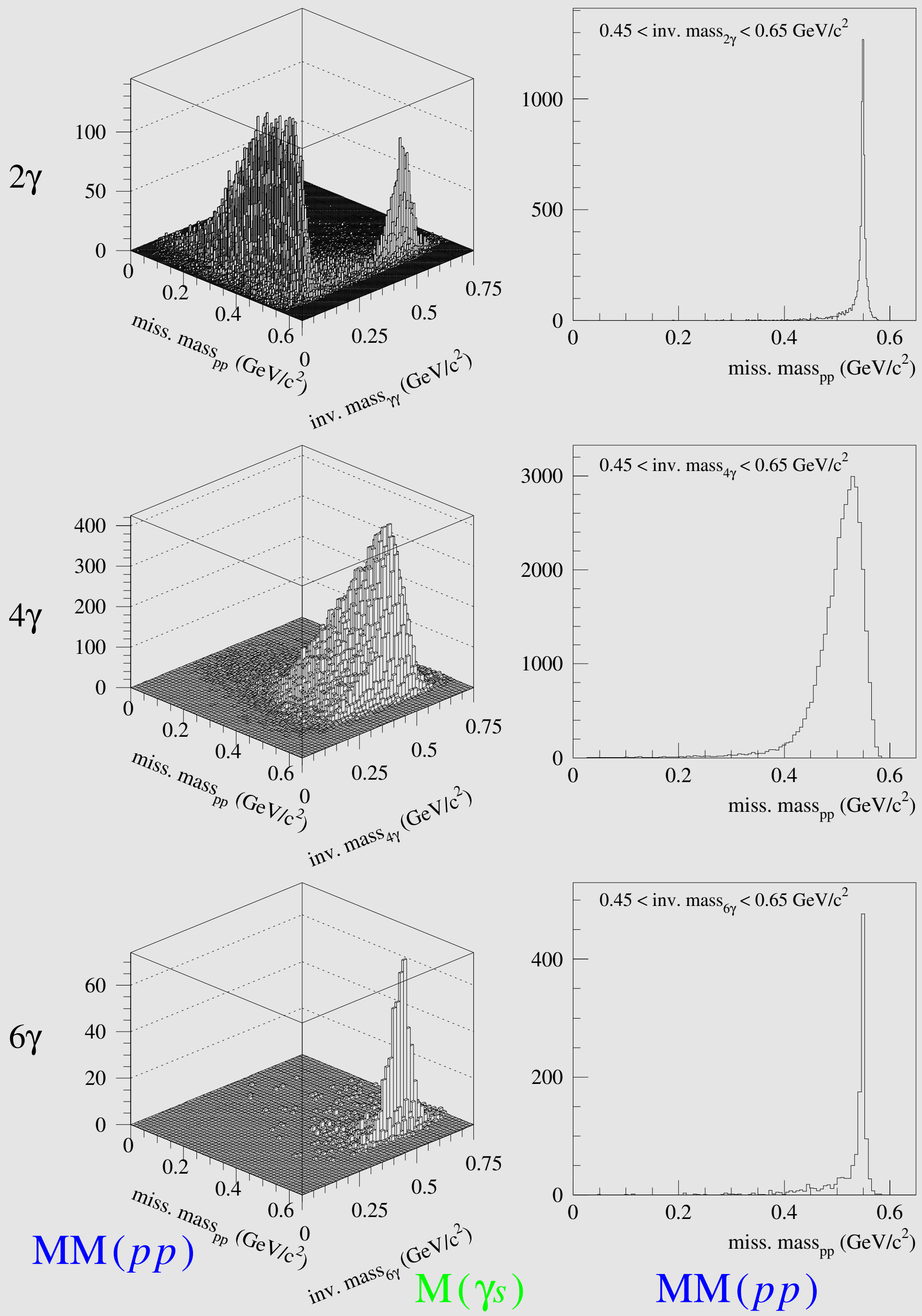
$pp \rightarrow pp\pi^+\pi^-\pi^0$

$\quad \hookrightarrow \gamma\gamma$



$pp \rightarrow pp + \gamma s$ $T_p = 1360\,\mathrm{MeV}$

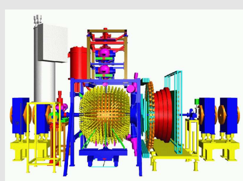
γs *invariant mass* *vs* pp missing mass	pp missing mass	main contribution at high $M(\gamma s)$



$pp \rightarrow pp\eta\ (\rightarrow 2\gamma)$

$pp \rightarrow pp2\pi^0\ (\rightarrow 4\gamma)$

$pp \rightarrow pp\eta\ (\rightarrow 3\pi^0 \rightarrow 6\gamma)$

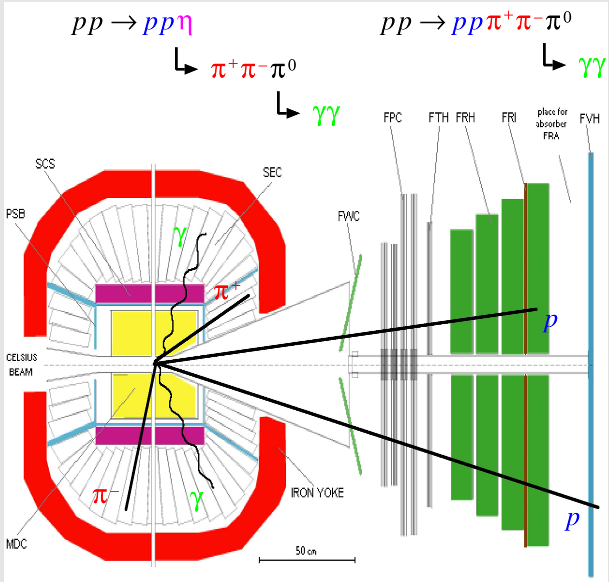


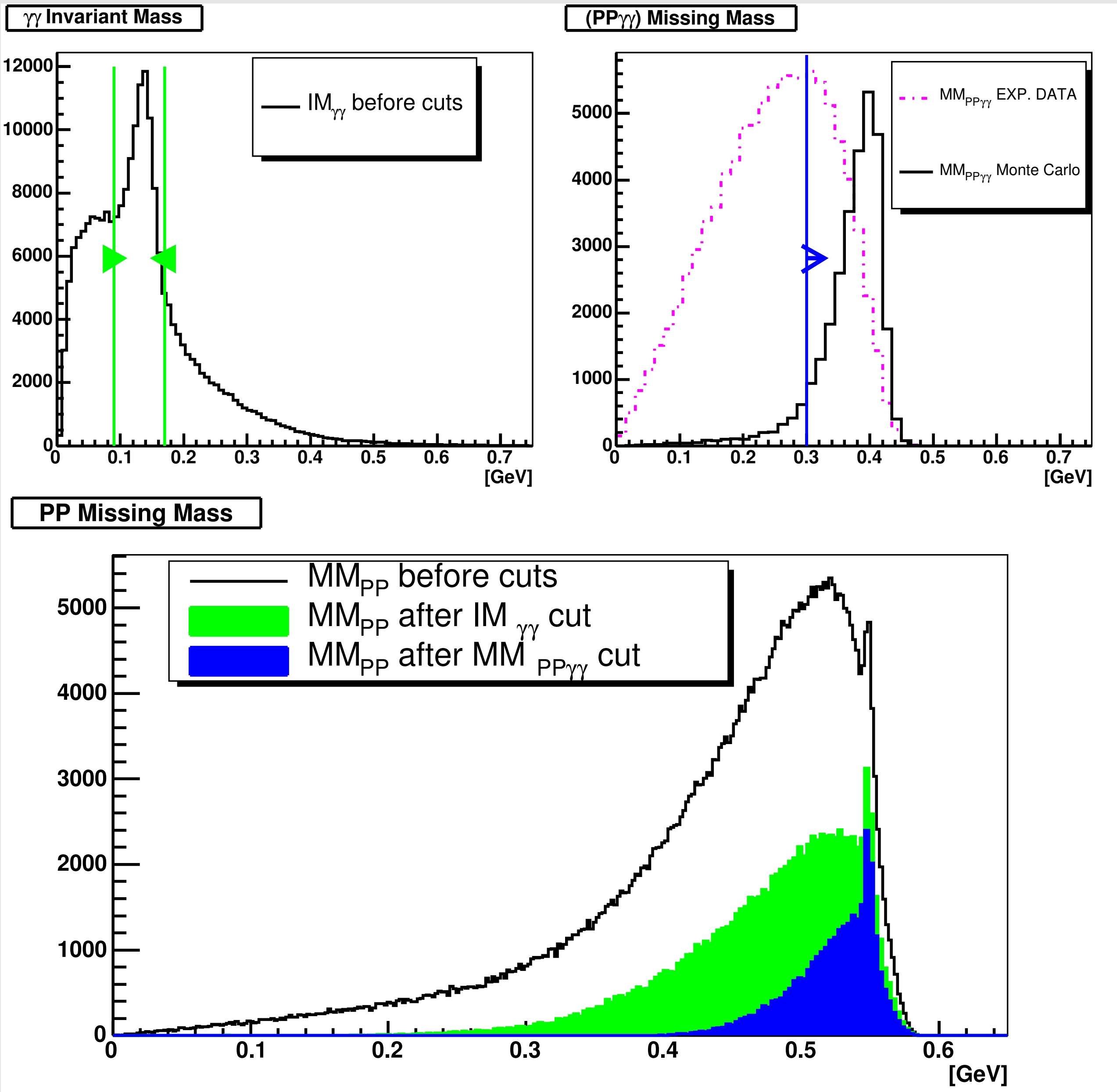
Event identification

$$pp \rightarrow pp(\eta)\pi^+\pi^-\pi^0$$

$$\hookrightarrow \gamma\gamma$$

M. Jacewicz,
PhD thesis, 2004

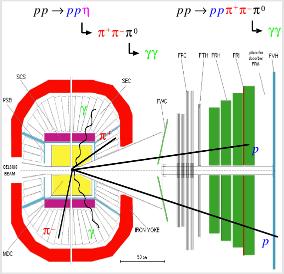




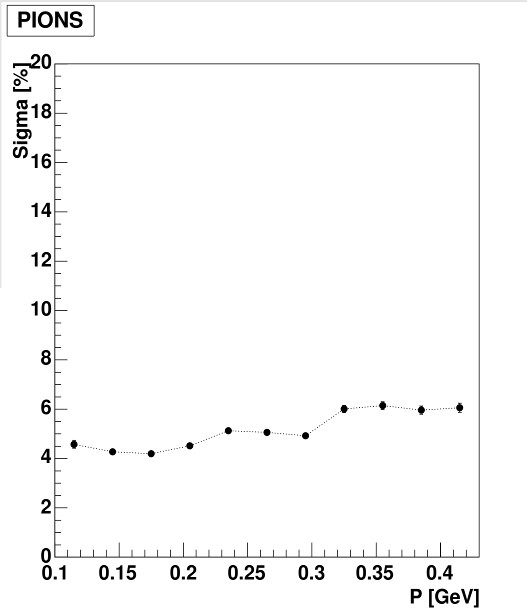
Event identification

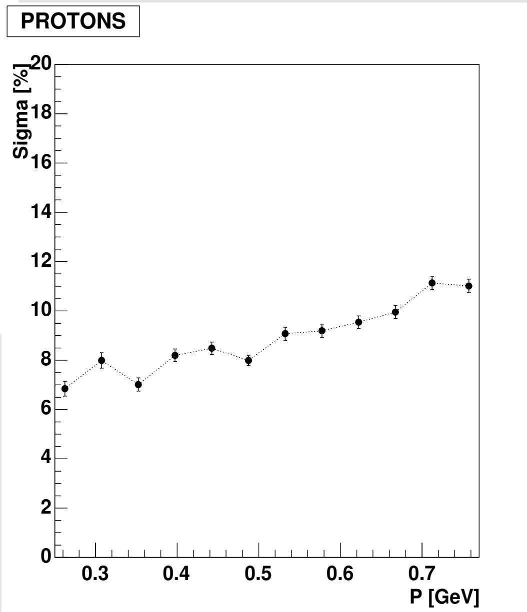
$pp \rightarrow pp(\eta)\pi^+\pi^-\pi^0$, $\pi^0 \rightarrow \gamma\gamma$

M. Jacewicz, PhD thesis, 2004

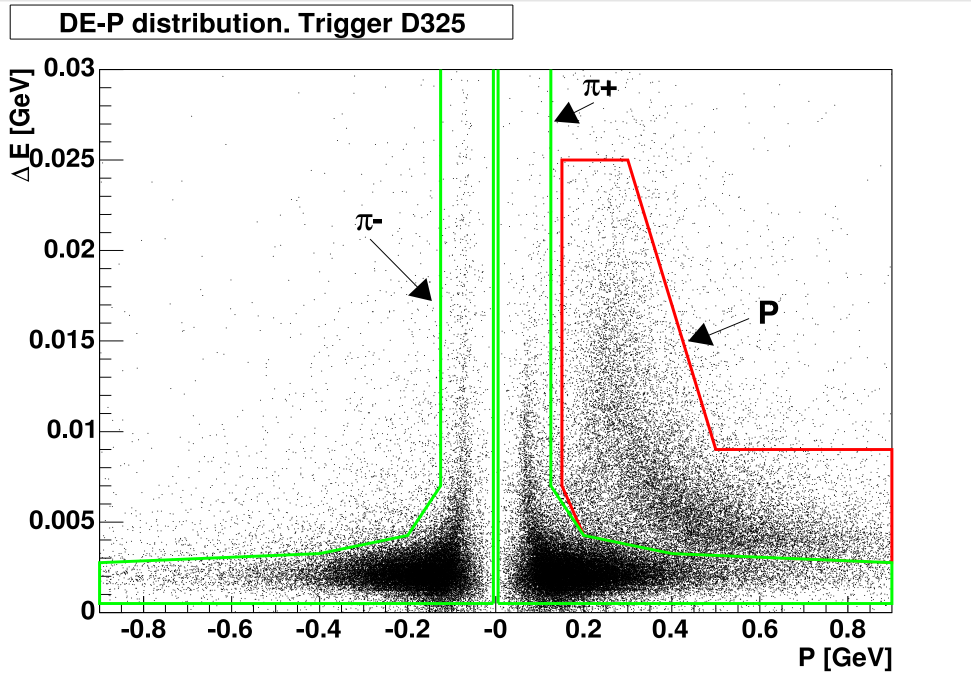


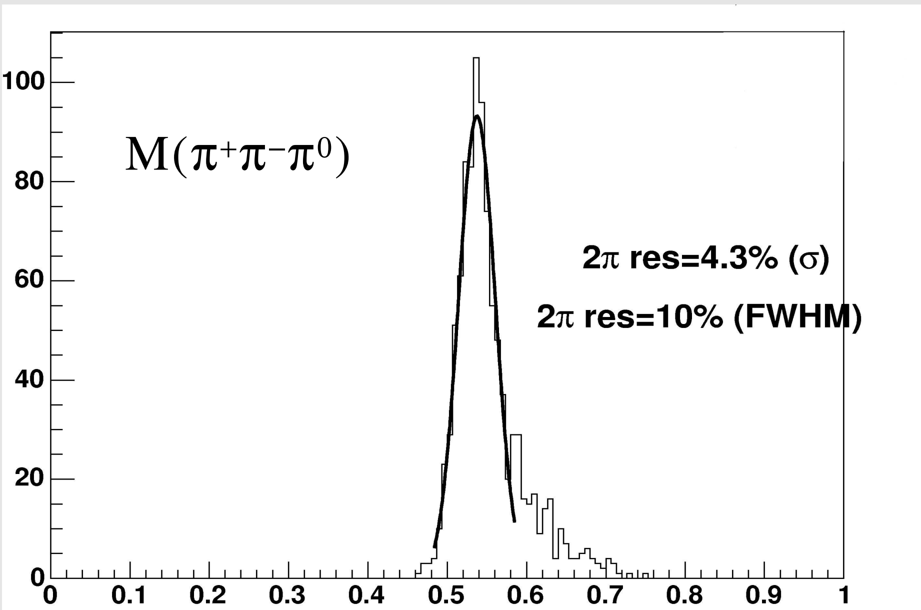
momentum resolution





$\pi^+\pi^-$ identification

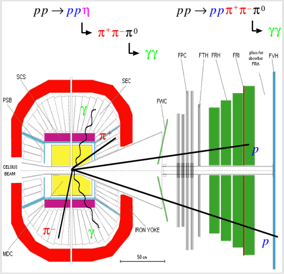


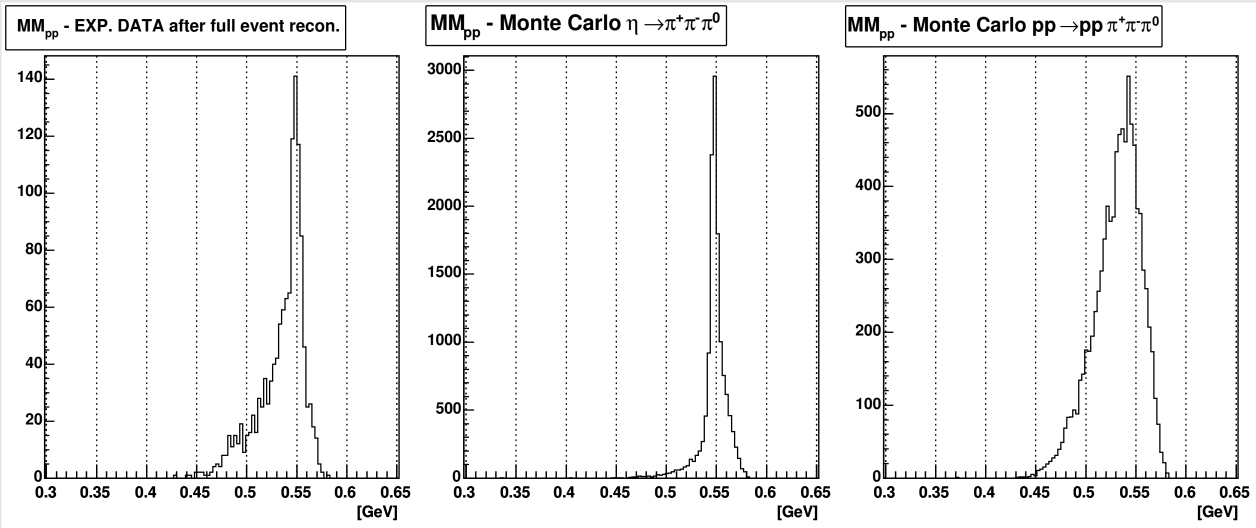


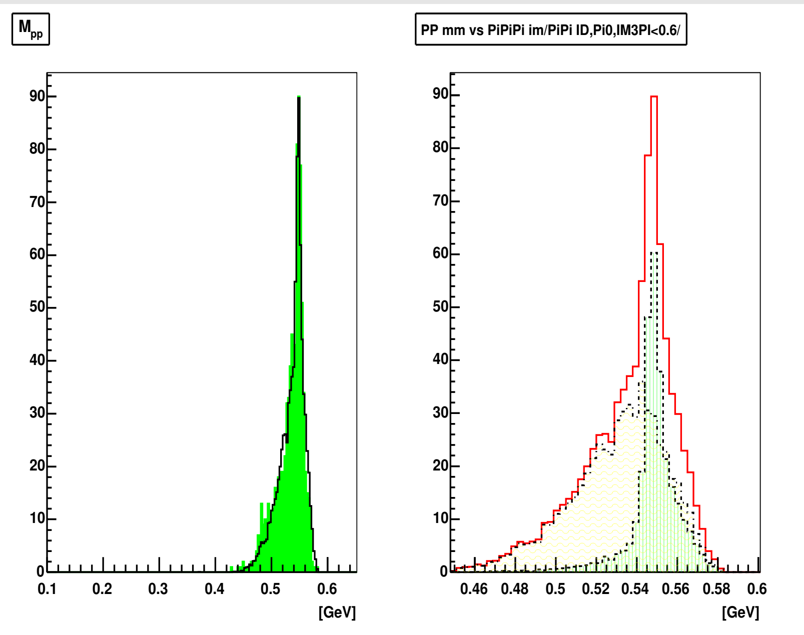
Event identification

$$pp \to pp(\eta)\pi^+\pi^-\pi^0$$
$$\hookrightarrow \gamma\gamma$$

M. Jacewicz,
PhD thesis, 2004







$$\sigma(pp \to pp\pi^+\pi^-\pi^0) = 4.6 \pm 1.2\,^{+0.7}_{-0.9}\,\mu b$$

$$\sigma(pp \to pp\pi^+\pi^-\pi^0)\,/\,\sigma(pp \to pp\eta \to pp\pi^+\pi^-\pi^0) \approx 4$$

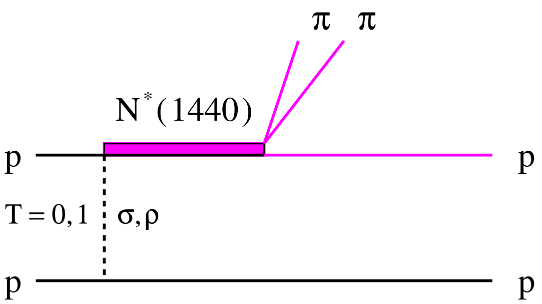
$$\sigma(pp \to pp\pi^+\pi^-\pi^0)\,/\,\sigma(pp \to pp\pi^0\pi^0\pi^0) \approx 3 \neq 8$$

statistical model prediction,
J. Bartke, Herceg-Novi (1970)

Two Pion Production
in Nucleon-Nucleon Collisions

Reaction Mechanism Near Threshold

(L. Alvarez-Ruso, E. Oset, E. Hernández, Nucl. Phys. A 633 (1998) 519)



$T_{2\pi} = 0,\ L_{2\pi} = 0$

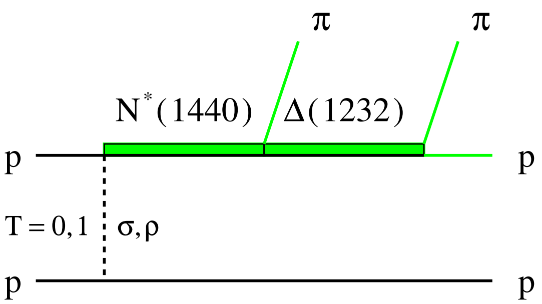
$N^*(1440)\ P_{11}$ s-wave decay

5-10% decay directly to 2π

N^* decay amplitude

$$A_{N^*} \approx 1 + c\,[\mathbf{k}_1 \cdot \mathbf{k}_2\,(3D_{\Delta^{++}} + D_{\Delta^0}) + i\mathbf{s} \cdot (\mathbf{k}_1 \times \mathbf{k}_2)\,(3D_{\Delta^{++}} - D_{\Delta^0})]$$

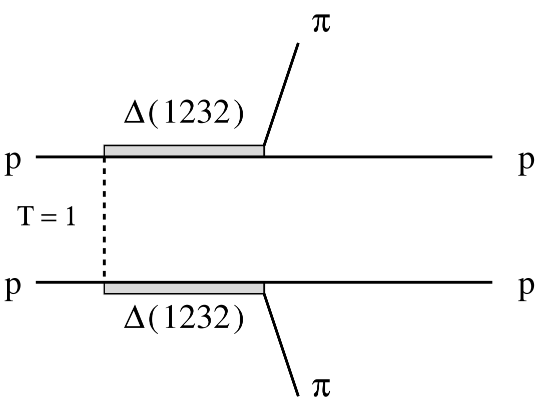
$\mathbf{k}_i$ = π momenta (cms), D_Δ = Δ propagators, $\mathbf{s}$ = nucleon spin



$T_{2\pi} = 0,1$

$N^*(1440)\ P_{11}$ s-wave decay

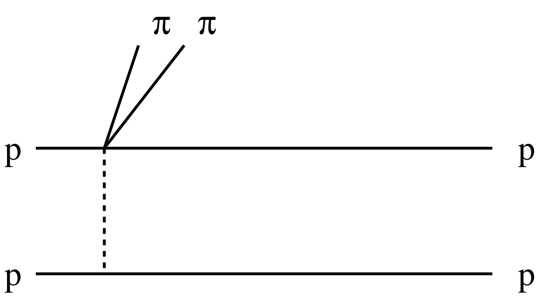
20-30% decay to $\Delta\pi$ $\mathbf{k}_1 \cdot \mathbf{k}_2 \leftrightarrow M_{\pi\pi},\ \delta_{\pi\pi} = <(\mathbf{k}_1, \mathbf{k}_2)>$



$T_{2\pi} = 0,1,2$

dominated by higher partial waves

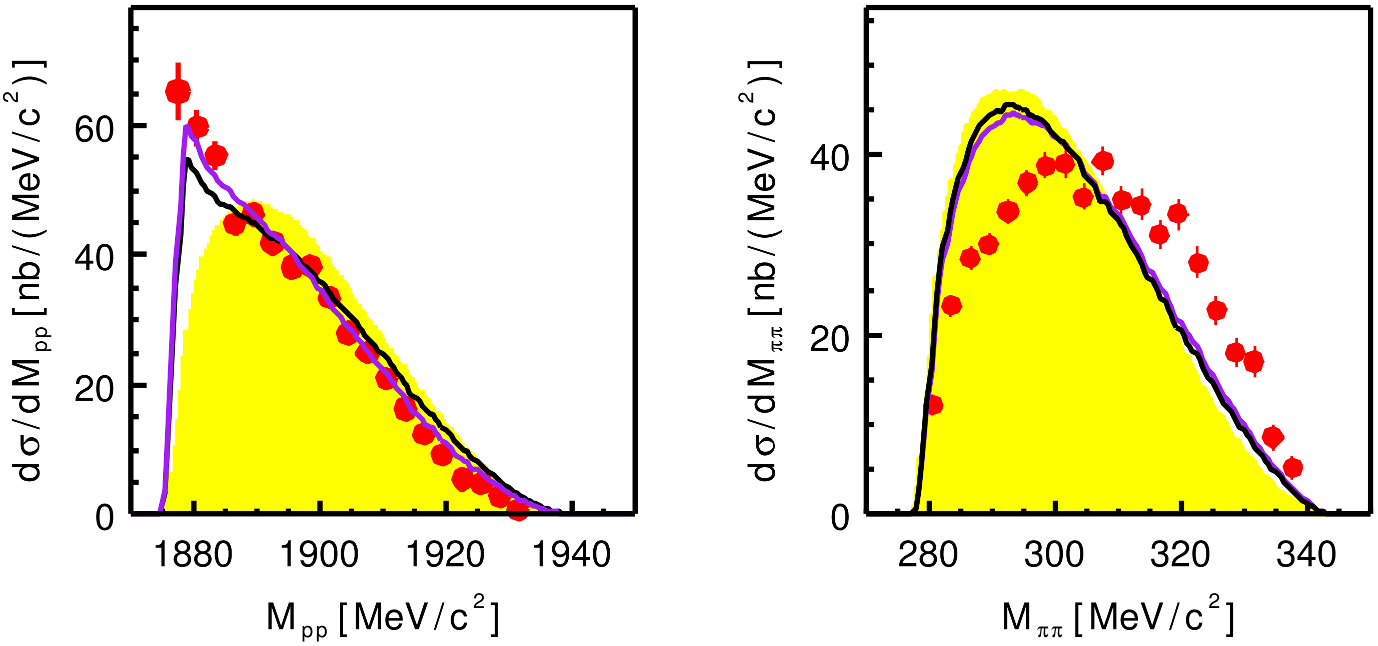
$\sigma(\theta_\pi) \approx 1 + 3\cos^2\theta_\pi$



expected small

$pp \to pp\pi^+\pi^-$ Invariant Mass Distributions

$Q = 64.4\,\text{MeV}$ ($T_p = 750\,\text{MeV}$)



● PROMICE/WASA
(W. Brodowski et al., Phys. Rev. Lett. 88 (2002) 192301)

phase space

phase space + pp FSI

phase space + pp FSI + σ exchange

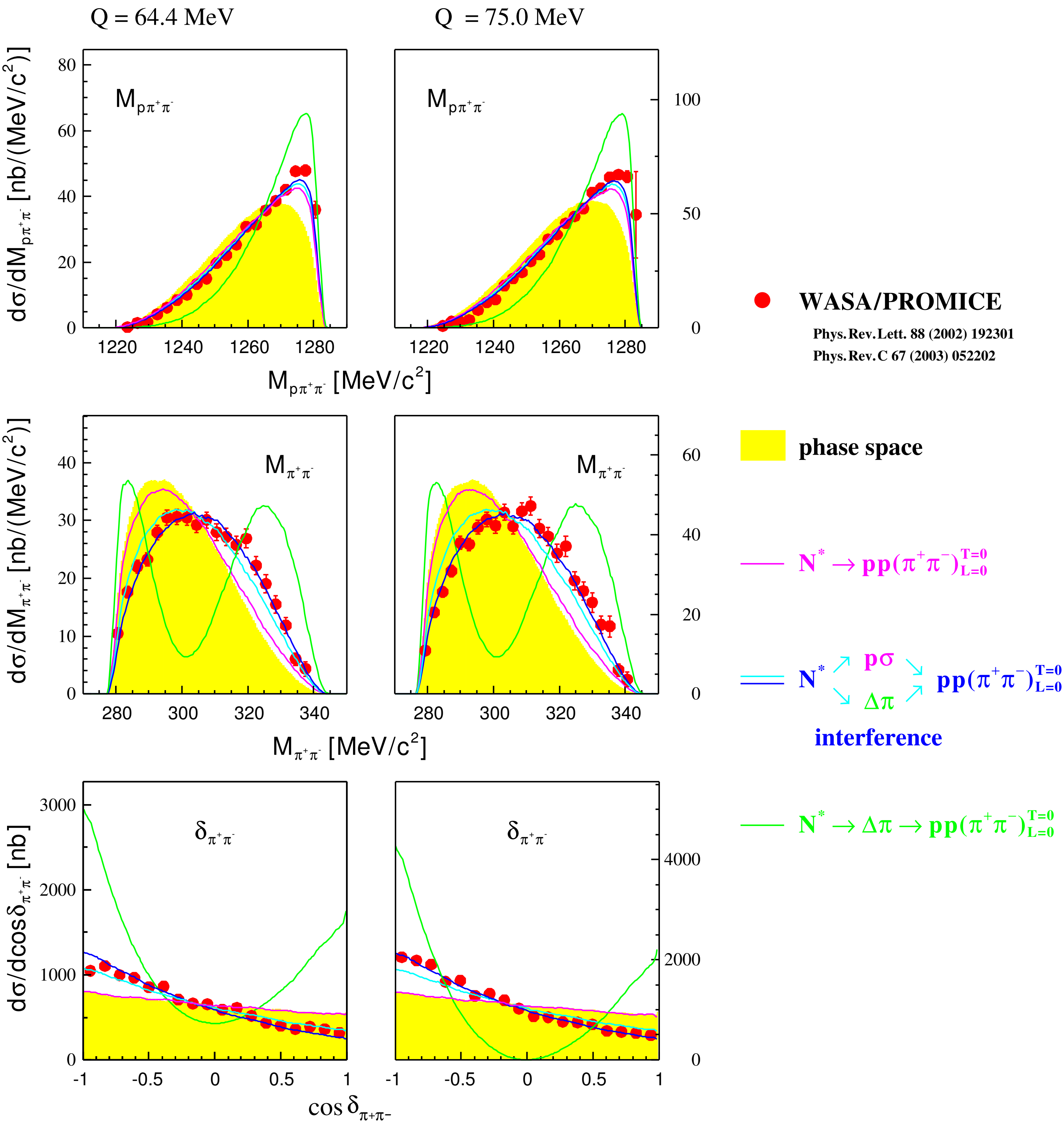
phase space + pp FSI

pp invariant mass is reproduced

additional dynamics of ππ production

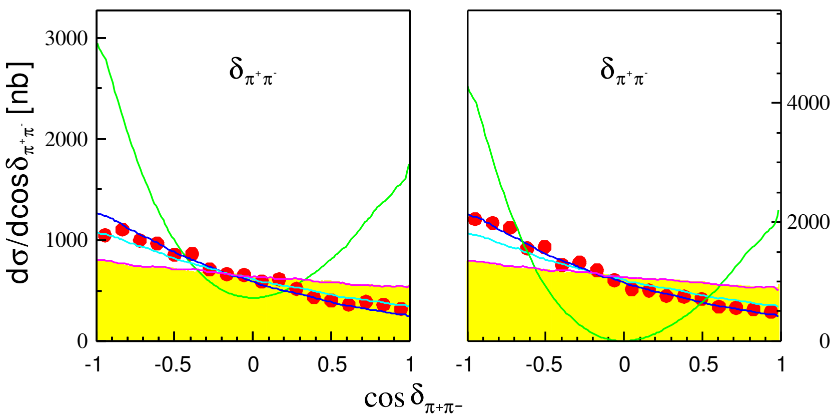
Interference of N^* Decay Routes

$pp \to pN^* \to pp(2\pi)^{T=0}_{L=0}$ $pp \to pN^* \to p\Delta\pi \to pp(2\pi)^{T=0}_{L=0}$



$N^*(1440)$ Partial Decay Widths

$pp \to pN^* \to pp(2\pi)^{T=0}_{L=0}$ $\quad$ $pp \to pN^* \to p\Delta\pi \to pp(2\pi)^{T=0}_{L=0}$



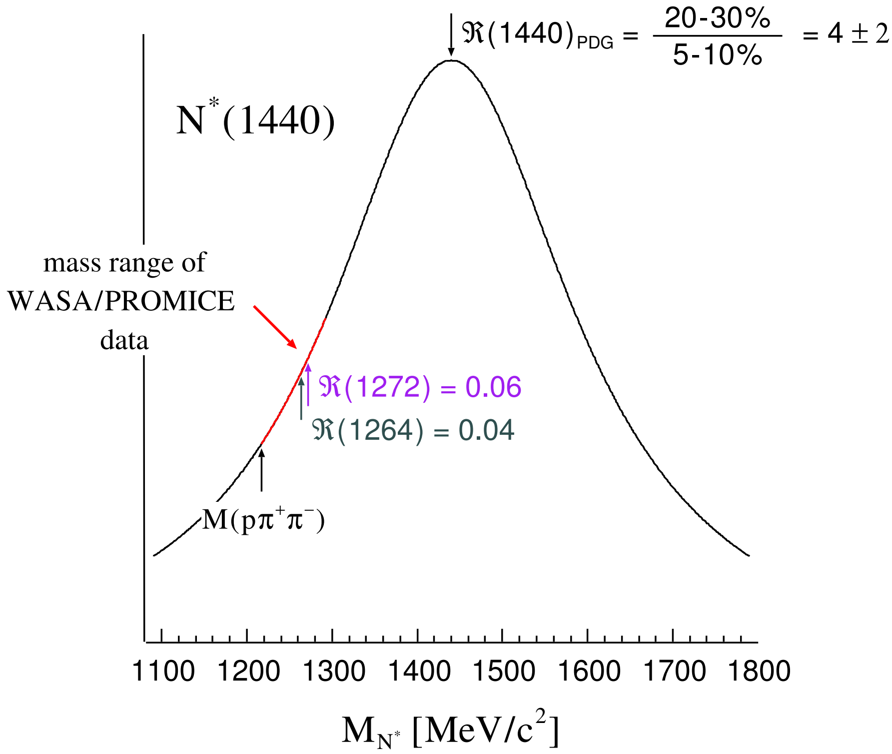
$N^*(1440)$ decay amplitude

$$A_{N^*} \sim 1 + c\cdot[\mathbf{k}_1\cdot\mathbf{k}_2\,(3D_{\Delta^{++}} + D_{\Delta^0})]$$
$$= A_{N^*\to N\sigma} + c\cdot A_{N^*\to\Delta\pi}$$

$\mathbf{k}_i = \pi$ momenta (cms), $D_\Delta = \Delta$ propagators

$$\sigma(\delta_{\pi\pi}) \sim \langle A_{N^*}\rangle^2$$

$$\Re(M_{N^*}) = \frac{\Gamma_{N^*\to\Delta\pi\to N\sigma}(M_{N^*})}{\Gamma_{N^*\to N\sigma}(M_{N^*})} \sim c^2 \cdot \frac{\int |A_{N^*\to\Delta\pi}|^2\, dM^2_{p\pi^+}\, dM^2_{\pi^+\pi^-}}{\int |A_{N^*\to N\sigma}|^2\, dM^2_{p\pi^+}\, dM^2_{\pi^+\pi^-}}$$



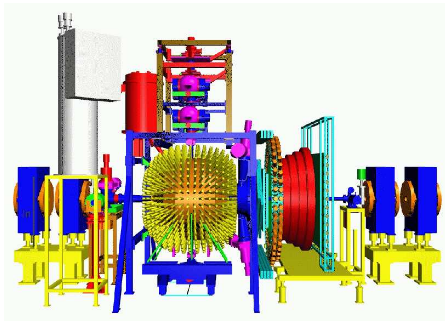
Extrapolation (model dependent!)

$\Re(1440) = 3.4 \pm 0.3$

Experimental programme

Energy Dependence

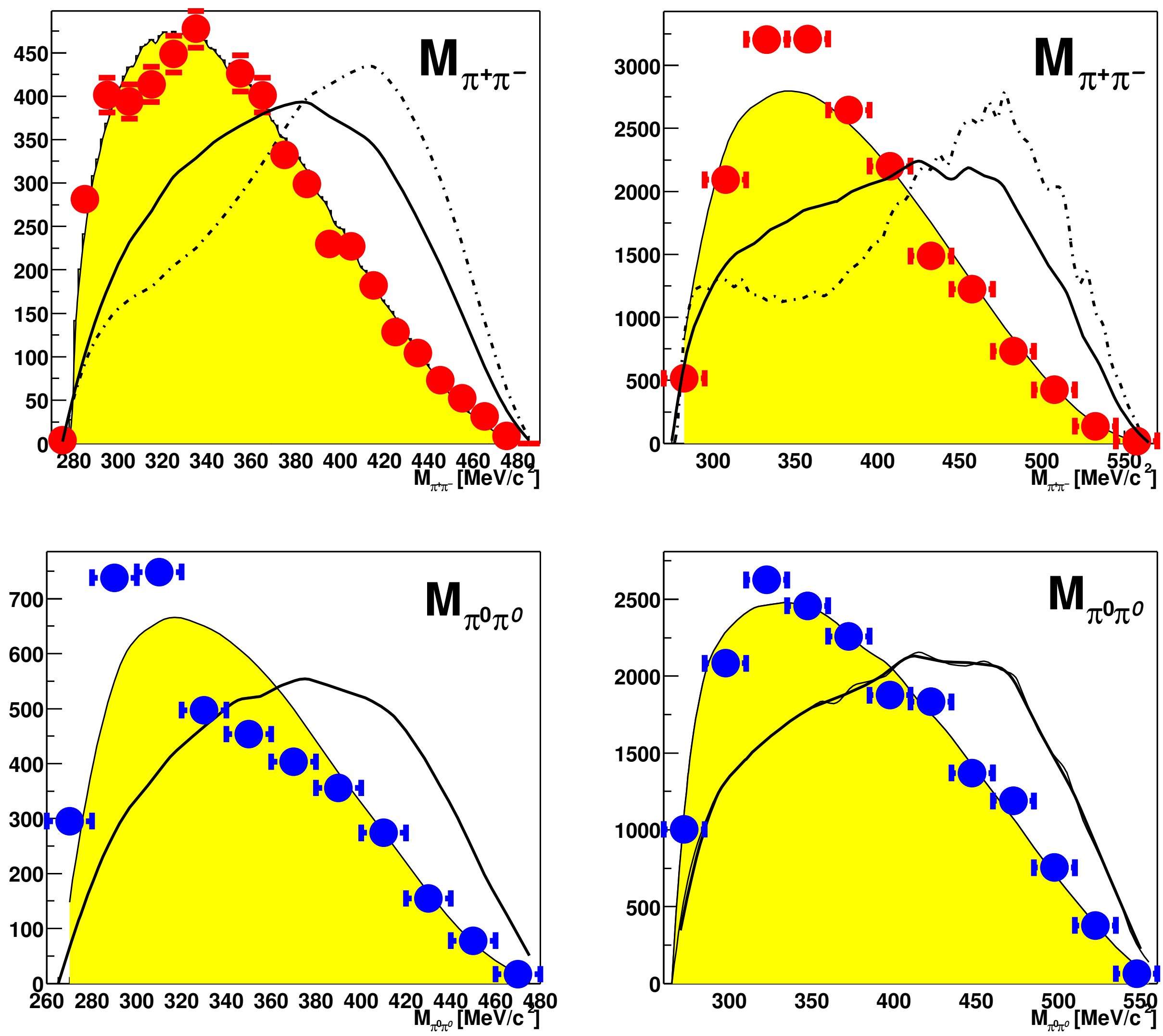
$pp \rightarrow \begin{matrix} pp\pi^+\pi^- \\ pp\pi^0\pi^0 \end{matrix}$ at WASA



preliminary results

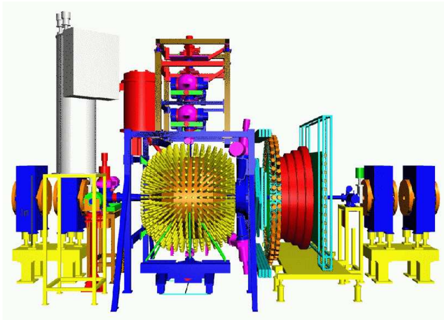
- phase space
- - - - - $\Re(1440) = 3$
- —— $\Re(1440) = 1$
- CELSIUS WASA preliminary $pp \rightarrow pp\pi^+\pi^-$
- CELSIUS WASA preliminary $pp \rightarrow pp\pi^0\pi^0$

$T_p = 1100\,\mathrm{MeV}\ (Q = 208\,\mathrm{MeV})$ $T_p = 1300\,\mathrm{MeV}\ (Q = 286\,\mathrm{MeV})$



Analysis: M. Bashkanov, H. Clement, T. Skorodko,
University of Tübingen

$pp \rightarrow \begin{matrix} pp\pi^+\pi^- \\ pp\pi^0\pi^0 \end{matrix}$ at WASA



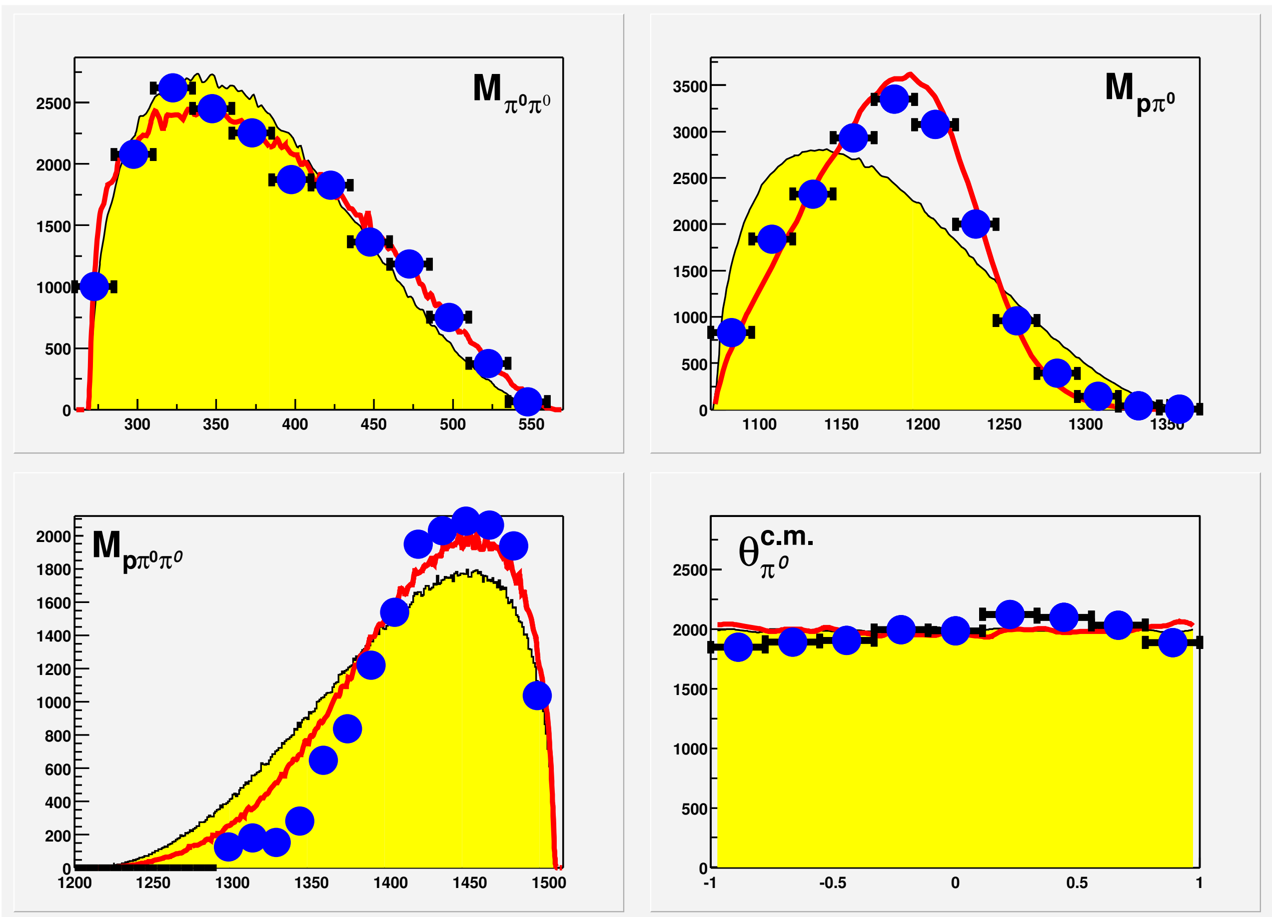
preliminary results

$T_p = 1300\,\text{MeV}\ (Q = 286\,\text{MeV})$

phase space

$pp \rightarrow (\Delta\Delta)_{J(P)=0(+)} \rightarrow pp\pi^0\pi^0$

CELSIUS WASA preliminary $pp \rightarrow pp\pi^0\pi^0$



Analysis: M. Bashkanov, H. Clement, T. Skorodko,
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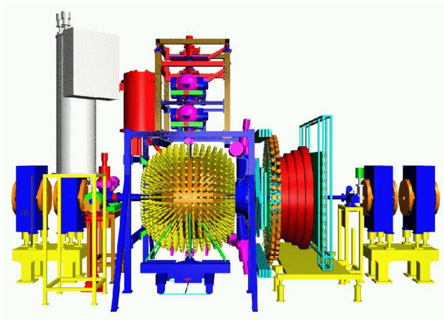
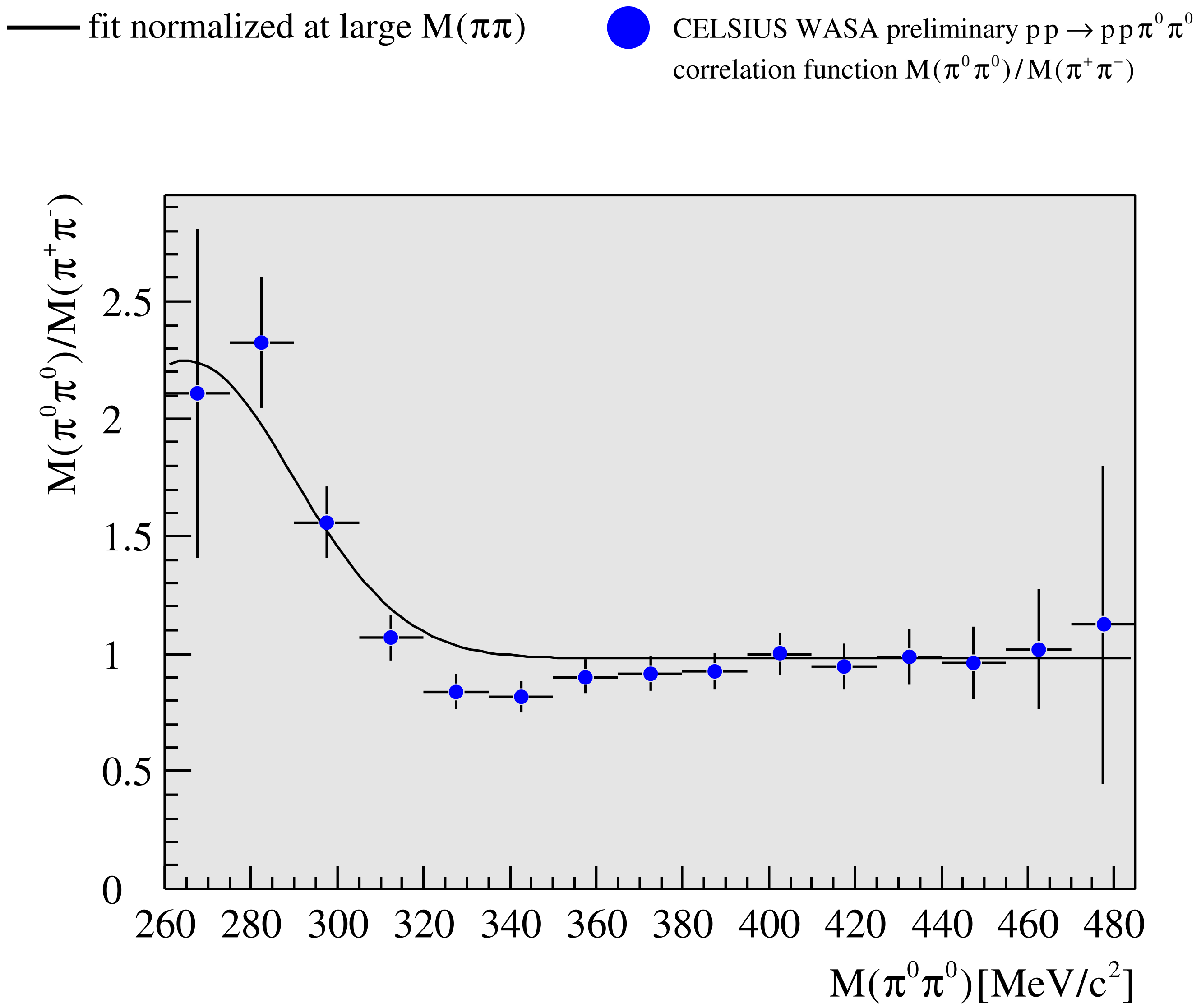
$pp \to \begin{matrix} pp\pi^+\pi^- \\ pp\pi^0\pi^0 \end{matrix}$ at WASA



preliminary results

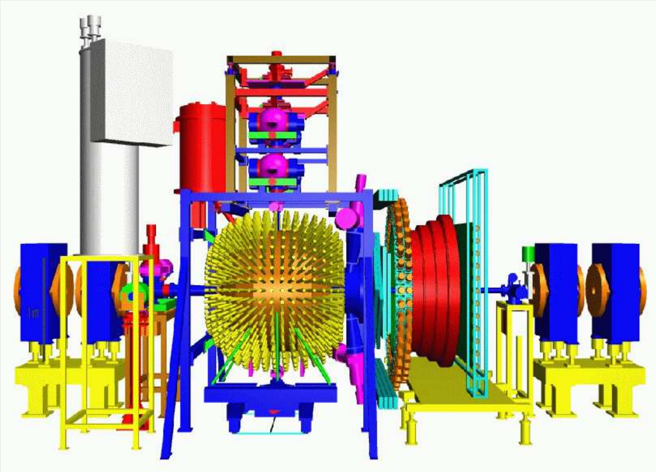
$T_p = 1100\,\text{MeV}$ ($Q = 208\,\text{MeV}$)



Analysis: M. Bashkanov, H. Clement, T. Skorodko,
University of Tübingen

CELSIUS/WASA Experimental Programme

until middle of 2005



Production Experiments

$pd \to {}^3He\pi\eta$	π-η interaction
$pd \to {}^3He\omega$	ω production dynamics
$pd \to {}^3He2\pi^0$	π-π dynamics
$pd \to p\Lambda\Theta^+$	pentaquark search/dynamics
$pd \to pd\eta$	η-d interaction, η production dynamics
$pn \to NNX$	quasifree procuction

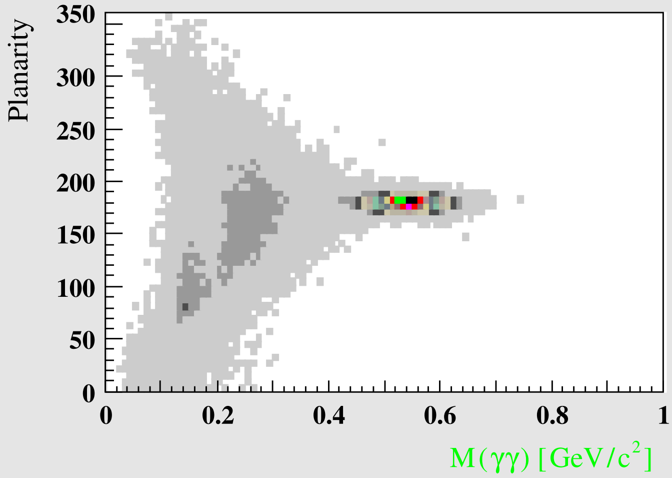
Not so rare η Decays

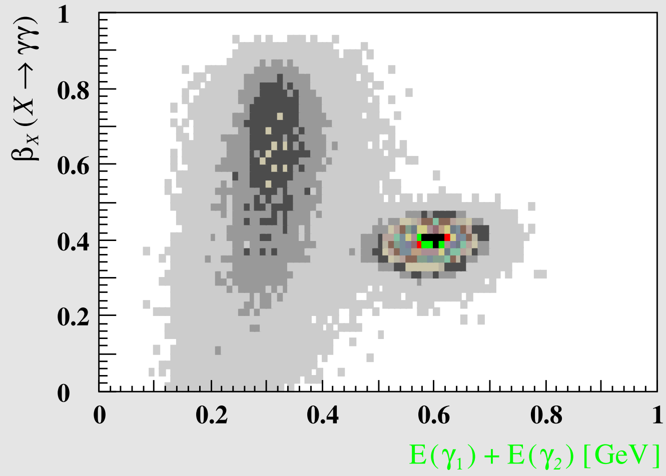
tagging: $pd \to {}^3He\eta$

$\eta \to \pi^+\pi^-\pi^0$	isospin violation
$\eta \to \gamma\gamma^* \to \gamma e^+e^-$	η transition form factor
$\eta \to \pi^+\pi^-\gamma^* \to \pi^+\pi^-e^+e^-$	CP violation test
$\eta \to \pi^0\gamma\gamma$	higher order ChPT terms

η Tagging in $pd \to {}^{3}He\,X$

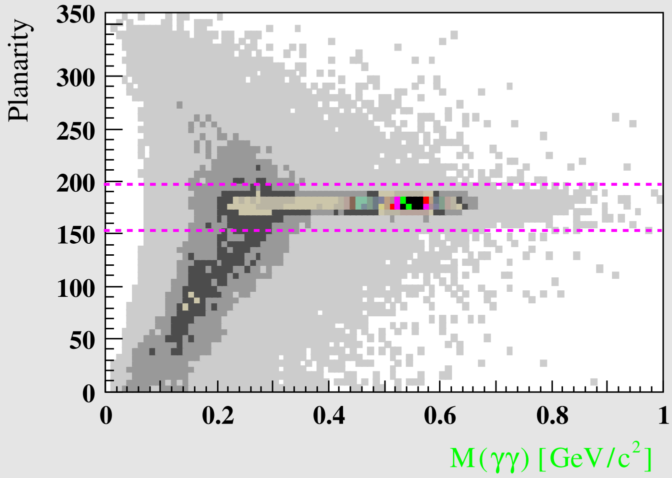
Monte Carlo

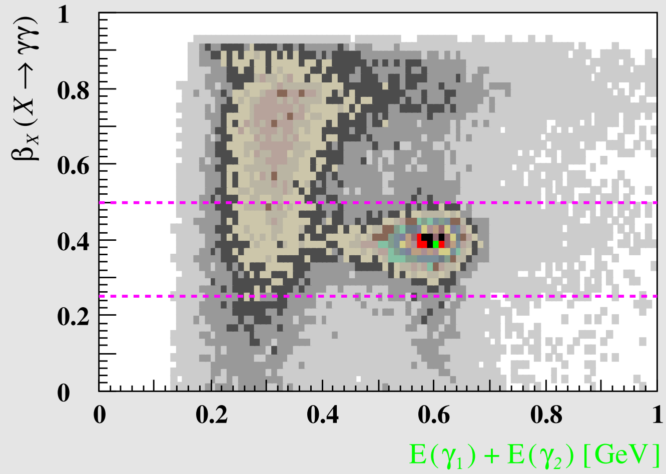


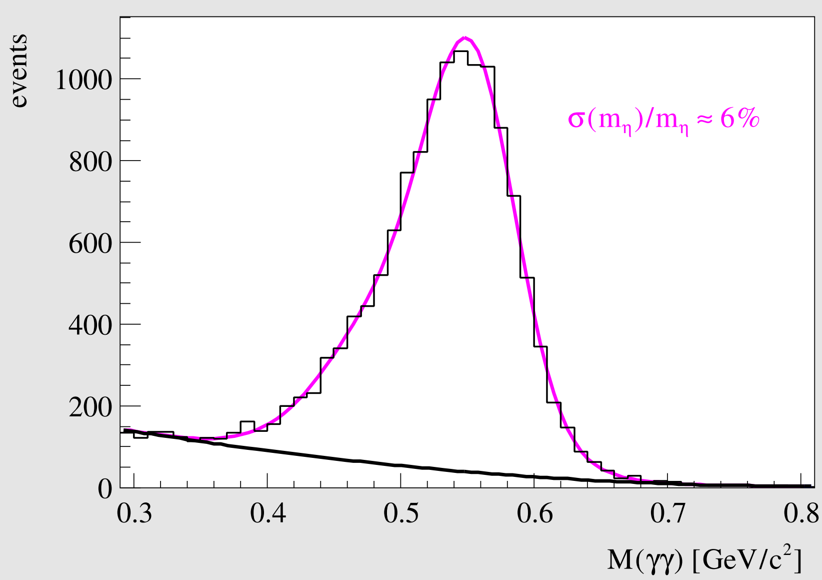


preliminary

Data March/June 2004







η rate on tape:

1/s

Charge Symmetry Breaking

- Difference between u- and d-Quarks -

Origin:
- Mass Difference $m_d - m_u$
- Electromagnetic Energy Differences (charge, magnetic moments)

Approaches:
- Meson Masses (mass formulae, Coulomb estimates)
- Meson Production
- Meson Decay

π-η Mixing In Hadronic η' Decays

H. Machner, A. Magiera,
Workshop FEMC04, Jülich, 26-29 Jan 2004

$(m_d - m_u)$ and $\pi-\eta$ Mixing

SU(3) singlet and octet representations

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

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

bare states without CSB

$$|\tilde{\pi}^0\rangle = \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$$

$$|\tilde{\eta}\rangle = \cos\theta_{PS}\,|\eta_8\rangle - \sin\theta_{PS}\,|\eta_0\rangle$$

$$|\tilde{\eta}'\rangle = \sin\theta_{PS}\,|\eta_8\rangle - \cos\theta_{PS}\,|\eta_0\rangle$$

octet-singlet mixing angle $\theta_{PS} = -20°$ (PDG, $P \to \gamma\gamma$)

$$\langle\tilde{\pi}^0|\,H_m\,|\tilde{\eta}\rangle = \left\langle\frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})\right|\, m_d d\bar{d} + m_u u\bar{u} + m_s s\bar{s}\,\left|\frac{1}{\sqrt{3}}(u\bar{u} + d\bar{d} - s\bar{s})\right\rangle$$

$$= \frac{1}{\sqrt{6}}(m_u - m_d)$$

$\Rightarrow$ π^0,η *mixtures of isospin eigenstates*

$(m_d - m_u)$, $\pi-\eta$ Mixing and η' Decays

π^0, η *mixtures of isospin eigenstates*

$$|\pi^0\rangle = \cos\theta_{\pi\eta}\,|\tilde{\pi}^0\rangle + \sin\theta_{\pi\eta}\,|\tilde{\eta}\rangle$$

$$|\eta\rangle = -\sin\theta_{\pi\eta}\,|\tilde{\pi}^0\rangle + \cos\theta_{\pi\eta}\,|\tilde{\eta}\rangle$$

D.J.Gross, S.B.Treiman, F.Wilczek, Phys. Rev. D19 (1979) 2188

$$\sin\theta_{\pi\eta} = \frac{\sqrt{3}(m_d - m_u)}{4(m_s - \hat{m})}$$

$$\hat{m} = (m_u + m_d)/2$$

$\eta' \to \pi\pi\pi$ *forbidden*

$\eta' \to \eta\pi\pi$ *allowed*

by isospin invariance

$$R_1 = \frac{\Gamma(\eta' \to \pi^0\pi^0\pi^0)}{\Gamma(\eta' \to \eta\pi^0\pi^0)}$$

$$R_2 = \frac{\Gamma(\eta' \to \pi^0\pi^+\pi^-)}{\Gamma(\eta' \to \eta\pi^+\pi^-)}$$

D.J.Gross, S.B.Treiman, F.Wilczek, Phys. Rev. D19 (1979) 2188

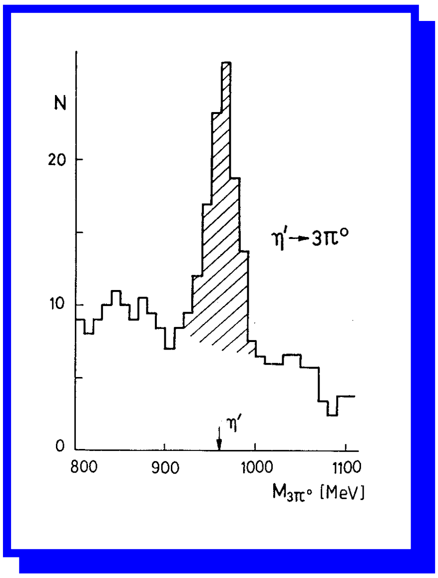
G.Ecker, G.Müller, H.Neufeld, A.Pich, Phys. Lett. B477 (2000) 88

$$R_i = P_i \sin^2\theta_{\pi\eta}$$

P_i = Ratios of Phase Space Volumes

$P_1 = 14.0$, $P_2 = 15.2$

Existing Data $\pi-\eta$ Mixing from η' Decays



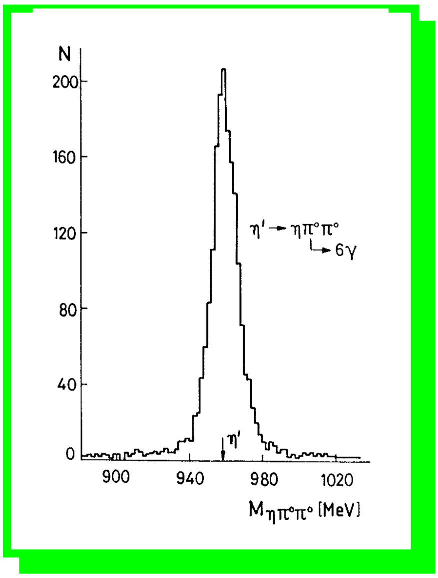
GAMS-2000

D.Alde et al.,
Z. Phys. C 36 (1987) 603
F.Binon et al.,
Phys. Lett. B 140 (1984) 264

$\eta' \to \pi^0\pi^0\pi^0$

$$R_2 = \frac{\Gamma(\eta' \to \pi^0\pi^0\pi^0)}{\Gamma(\eta' \to \eta\pi^0\pi^0)} = (7.4 \pm 1.2) \times 10^{-3}$$

$$\sin\Theta_{\pi\eta} = 0.023 \pm 0.002$$



$\eta' \to \pi^0\pi^+\pi^-$

$$R_1 = \frac{\Gamma(\eta' \to \pi^0\pi^+\pi^-)}{\Gamma(\eta' \to \eta\pi^+\pi^-)} < 0.11$$

π-η Mixing
In Hadronic η' Decays with
WASA@COSY

H. Machner, A. Magiera,
Workshop FEMC04,
Jülich, 26-29 Jan 2004

$\sin\theta_{\pi\eta}$ *Literature:*

0.023 ± 0.002	$\eta' \to 3\pi^0 / \eta\, 2\pi^0$	*F. Binon et al. (GAMS-2000), PL B 140 (1984) 264*
≈ 0.010	*Meson Masses, Dashen's Theorem*	*A.J. Gross, S.B. Treiman, F. Wilczek, PR D 19 (1979) 2188*
0.010	*Meson and Baryon Masses, Dashen's Theorem*	*J. Gasser, H. Leutwyler, Phys. Rep. 87 (1982) 77*
0.034 ± 0.013	*Radiative Decays, Anomalous Ward Identities*	*B. Bagchi, A. Lahiri, S. Niyogi, PR D 41 (1990) 2871*

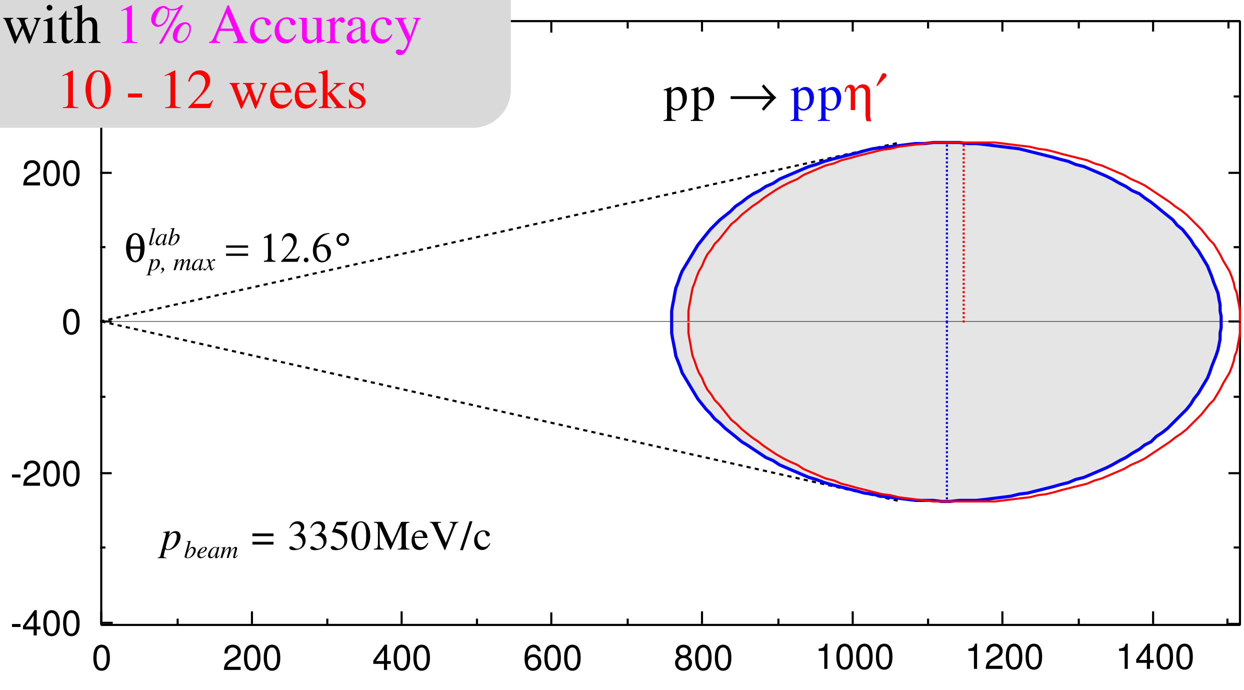
η' *Tagging:* $pp \to pp\eta'$

Beam Momentum: 3350 MeV/c

Cross Section: 300 nb
A. Khoukaz et al. (COSY-11), Eur. Phys. J. A 20 (2004) 345

Luminosity: $10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Beam Time Estimate:
Measurement of $\sin\theta_{\pi\eta}$
with 1 % Accuracy
10 - 12 weeks



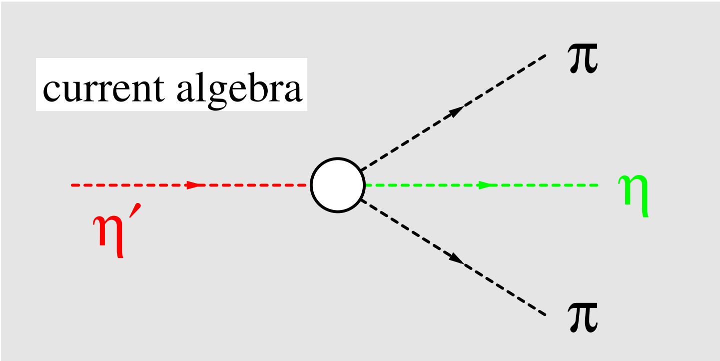
$\eta' \to \eta\pi\pi$

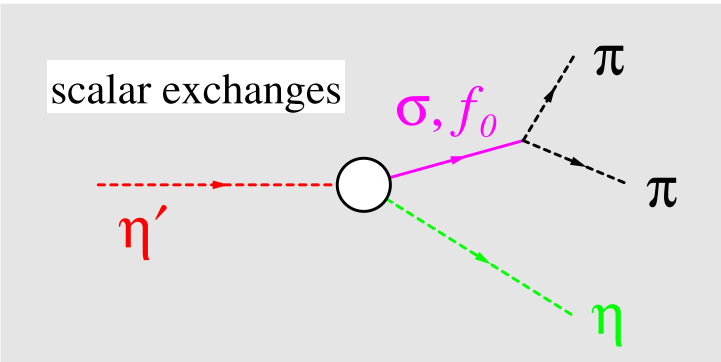
A View on the Scalars I

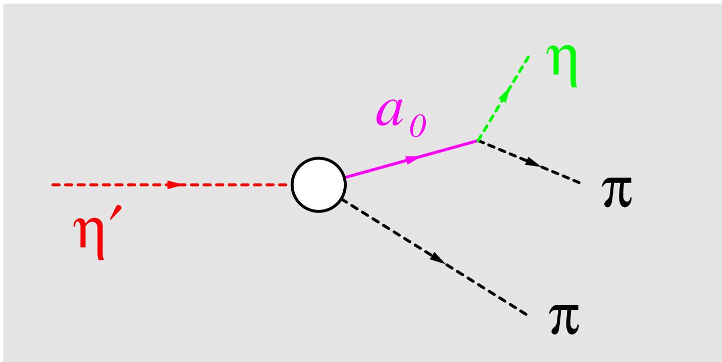
A. H. Fariborz, J. Schechter,
Phys. Rev. D 60 (1999) 034002

effective chiral Lagrangian
including scalar nonet:
$\sigma(560)$, $\kappa(900)$, $f_0(980)$, $a_0(980)$

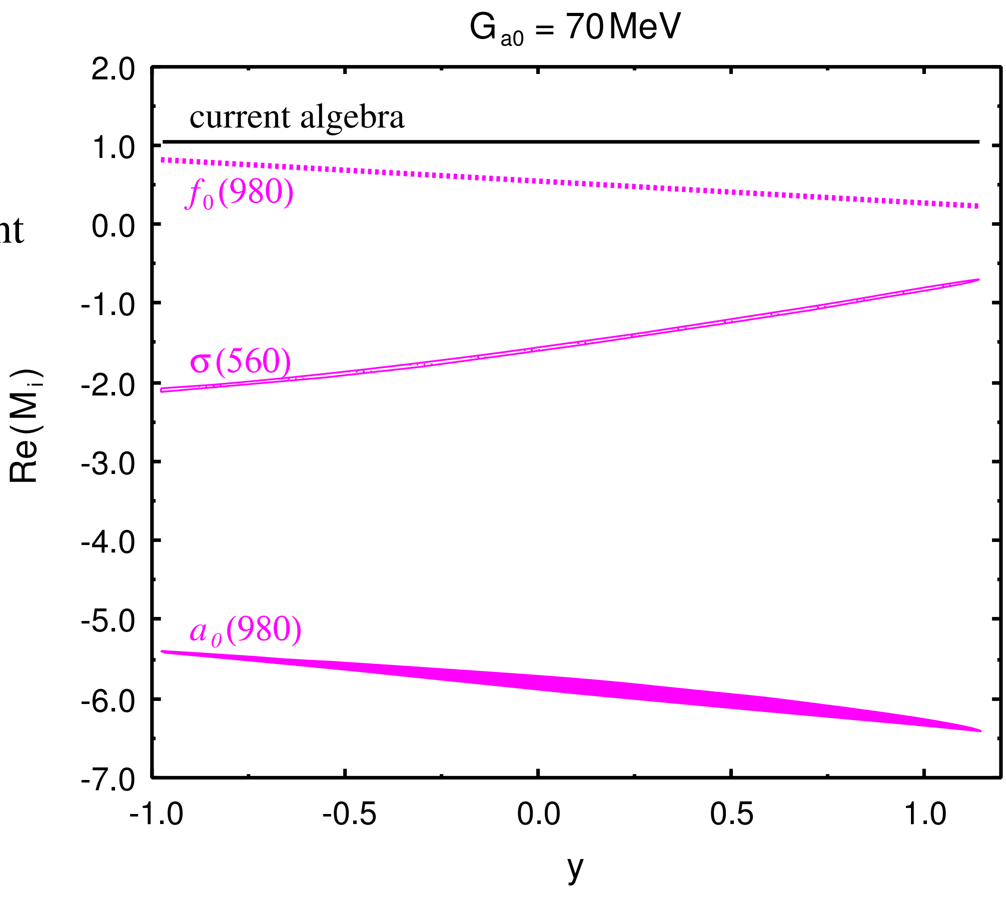
scalar-pseudoscalar-pseudoscalar
interaction parameters:
$\pi\pi$, πK scattering, $\eta' \to \eta\pi\pi$







Scalar Contributions
in
Decay Matrix Element

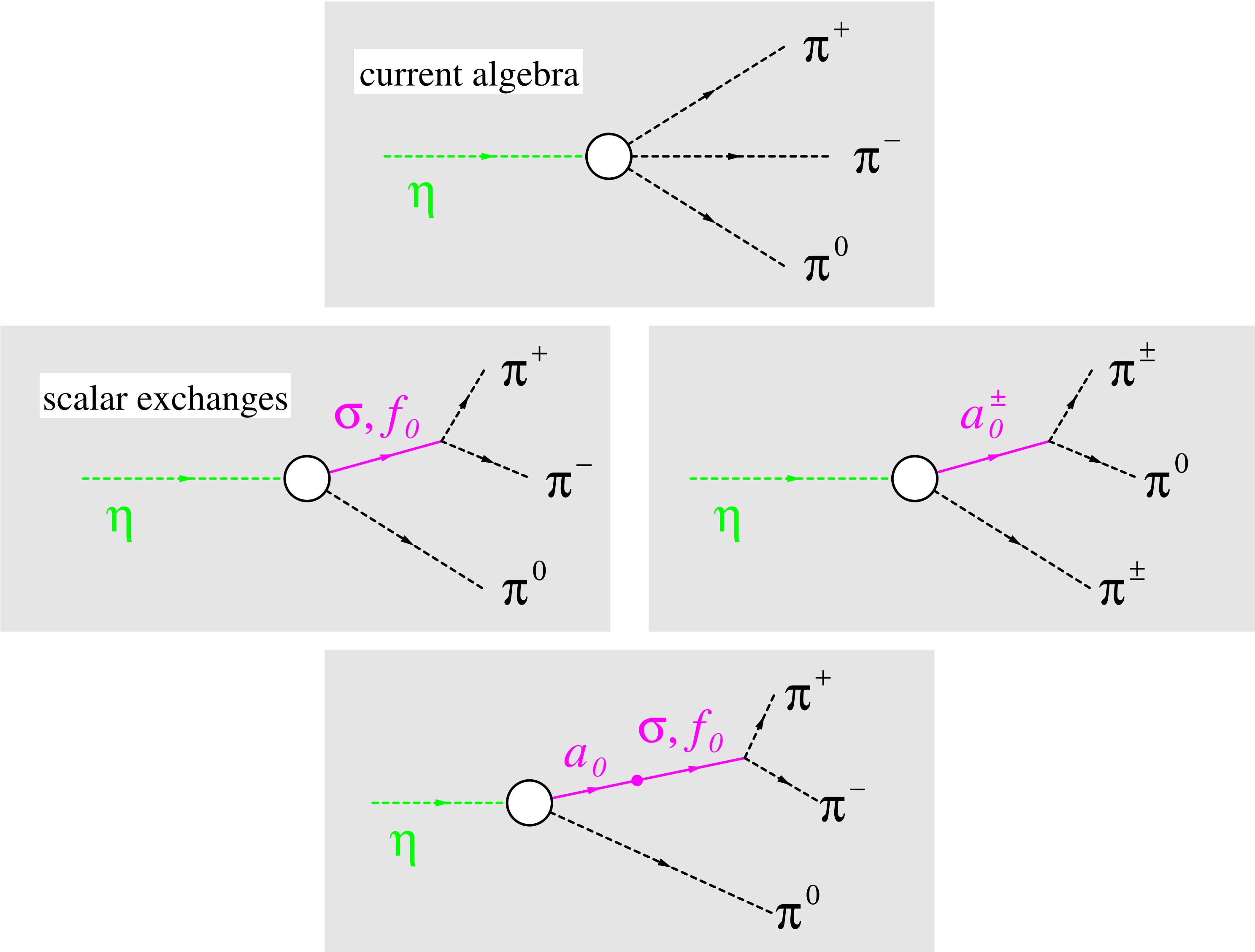


$\eta \to \pi\pi\pi$

A View on the Scalars II

A. Abdel-Rehim, D. Black,
A. H. Fariborz, J. Schechter,
Phys. Rev. D 67 (1003) 054001

effective chiral Lagrangian
including scalar nonet:
$\sigma(560)$, $\kappa(900)$, $f_0(980)$, $a_0(980)$



Scalar Contributions
in
Decay Rate

$< 30\,\%$

for η': a_0, f_0 propagators closer to mass shell

Hadronic Decays of the η'

	Branching Ratio	Existing Data	Count Rate Estimate WASA@COSY **per day**
$\pi^+\pi^-\eta$	44.3 ± 1.5 %	388 / 8090	18000
$\pi^0\pi^0\eta$	20.9 ± 1.2 %	4 / 5400	14500
$3\pi^0$	$5.56 \pm 0.26 \times 10^{-3}$	≈ 70	145
$\pi^+\pi^-\pi^0$	< 5 %		(2700)
$\rho^0\pi^0$	< 4 %		(2100)
$2\pi^+2\pi^-$	< 1 %		(260)
$4\pi^0$	$< 5 \times 10^{-4}$		(8)

Experimental Conditions

Luminosity 1×10^{32} cm^{-2} s^{-1}

Efficiency present WASA setup including reconstruction efficiency

Tagging $pp \to pp\eta'$ 3.350 GeV/c (Q = 45 MeV)

Cross Section 300 nb

Radiative Decays

Ball, Frère, Tytgat
PL B 365 (96) 36

$|\eta'\rangle = |\eta_8\rangle \sin\Theta + |\eta_0\rangle \cos\Theta$

Axial Current "Anomaly"

$$\partial_\mu A_8^\mu = \frac{2}{\sqrt{6}} \left(m_u \bar{u} i\gamma_5 u + m_d \bar{d} i \gamma_5 d - 2 m_s \bar{s} i \gamma_5 s \right)$$

$$\partial_\mu A_0^\mu = \frac{2}{\sqrt{3}} \left(m_u \bar{u} i\gamma_5 u + m_d \bar{d} i \gamma_5 d + m_s \bar{s} i \gamma_5 s \right) + \frac{1}{\sqrt{3}} \frac{3}{4} \frac{\alpha_s}{4\pi} G^A_{\mu\nu} \tilde{G}^{A\mu\nu}$$

Couplings of η to $\partial_\mu A^\mu$

$$\langle 0 | \partial_\mu A_8^\mu | \eta' \rangle = m_{\eta'}^2 f_8 \sin\Theta$$

$$\langle 0 | \partial_\mu A_0^\mu | \eta' \rangle = m_{\eta'}^2 f_0 \cos\Theta$$

$m_u = m_d = 0 \Rightarrow$ matrix element of strong anomaly over vacuum

$$\langle 0 | \frac{3}{4} \frac{\alpha_s}{\pi} G\tilde{G} | \eta' \rangle = \sqrt{\frac{3}{2}}\, m_{\eta'}^2 \left(\underline{f_8} \sin \underline{\Theta} + \sqrt{2}\, \underline{f_0} \cos\Theta \right)$$

$\Rightarrow$ fix $f_8(\Theta), f_0(\Theta)$

$$\Gamma(\eta' \to \gamma\gamma) = \frac{m_{\eta'}^2}{96\pi^3} \alpha^2 \left(\frac{\sin\Theta}{f_8} + \frac{2\sqrt{2}\cos\Theta}{f_0} \right)^2$$

$$\Gamma(\eta \to \gamma\gamma) = \frac{m_\eta^2}{96\pi^3} \alpha^2 \left(\frac{\cos\Theta}{f_8} - \frac{2\sqrt{2}\sin\Theta}{f_0} \right)^2$$

still needed: $\Gamma(P \to V\gamma) = \frac{\alpha}{8} g_{VP\gamma}^2 \left(\frac{m_P^2 - m_V^2}{m_P} \right)$

$$g_{\omega\eta'\gamma} \propto \frac{\cos\Theta}{4 f_8} \left(\sqrt{2} \cos\Theta_V - \sin\Theta_V \right) - \frac{\sin\Theta}{2\sqrt{2} f_0} \sin\Theta_1$$

$g_{\phi\eta'\gamma} \propto$

Radiative Decays of the η'

	Branching Ratio	Existing Data	Count Rate Estimate WASA@COSY **per day**
$\rho^0\gamma$	29.5 ± 1.0 %	1300 + 7000	44000
$\omega\gamma$	3.03 ± 0.31 %	≈ 160	1200
$\gamma\gamma$	2.12 ± 0.14 %	2767	17100
$\pi^0\gamma\gamma$	$< 8 \times 10^{-4}$		(250)

Experimental Conditions

Luminosity	1×10^{32} cm^{-2} s^{-1}
Efficiency	present WASA setup including reconstruction efficiency
Tagging	$pp \rightarrow pp\eta'$ 3.350 GeV/c (Q = 45 MeV)
Cross Section	300 nb

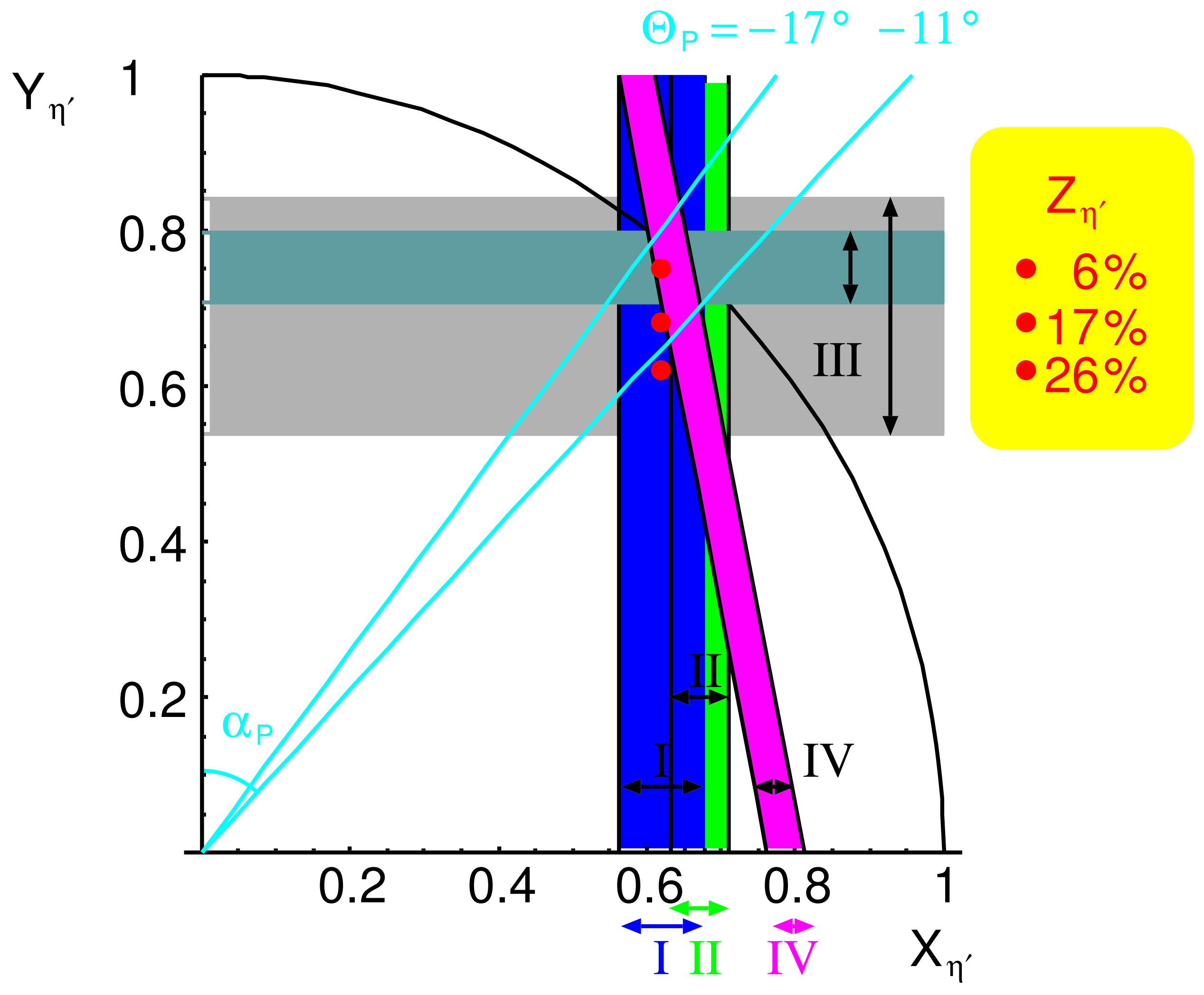
Glue Content of the η'

E. Kou,
Phys. Rev. D63 (2001) 054027

J. L. Rosner,
Phys. Rev. D27 (1983) 1101

$$|\eta\rangle = X_\eta \; |u\bar{u} + d\bar{d}\rangle / \sqrt{2} + Y_\eta \, |s\bar{s}\rangle$$

$$|\eta'\rangle = X_{\eta'} \; |u\bar{u} + d\bar{d}\rangle / \sqrt{2} + Y_{\eta'} \, |s\bar{s}\rangle + Z_{\eta'} \, |\text{gluonium}\rangle$$



I	$\eta' \to \omega\gamma$	$BR = (3.0 \pm 0.3) \times 10^{-2}$	
II	$\eta' \to \rho\gamma$	$BR = (3.0 \pm 0.13) \times 10^{-1}$	
III	$\Phi \to \eta'\gamma$	$BR = (8.2^{+2.1}_{-1.9} \pm 1.1) \times 10^{-5}$	CMD-2
	$\Phi \to \eta'\gamma$	$BR = (8.2^{+2.1}_{-1.9} \pm 1.1) \times 10^{-5}$	KLOE
IV	$\eta' \to \gamma\gamma$	$\Gamma = (0.20 \pm 0.016)$ MeV	

Anomalies in QCD : Triangle and Box

Starting point Wess Zumino Lagrangian

Wess, Zumino Phys Lett B37 (1971) 95

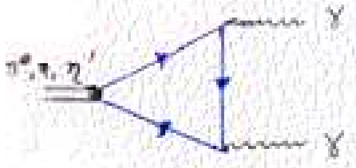
classical triangle anomaly

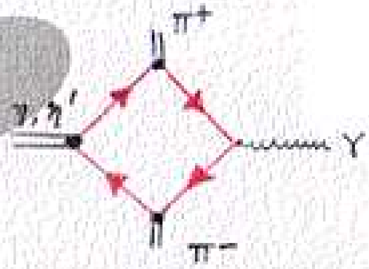
Adler, PR 117 (1969) 2426

Bell, Jackiw NC A60 (1969) 47

higher order anomalies

box anomaly





Amplitudes

$$M(X \to \gamma\gamma) =$$

$$B_X(k_1 k_2)\, \varepsilon_{\mu\nu\rho\sigma}\, k_1^\mu k_2^\nu\, \varepsilon^\rho(\gamma_1)\, \varepsilon^\sigma(\gamma_2)$$

$$M(X \to \pi^+\pi^-\gamma) =$$

$$E_X(p_+ k, p_- k)\, \varepsilon_{\mu\nu\rho\sigma}\, \varepsilon^\mu(\gamma)\, k^\nu p_+^\rho p_-^\sigma$$

Chanowitz Equations

Low Energies

M.S. Chanowitz, Phys Rev Lett 35 (1975) 977

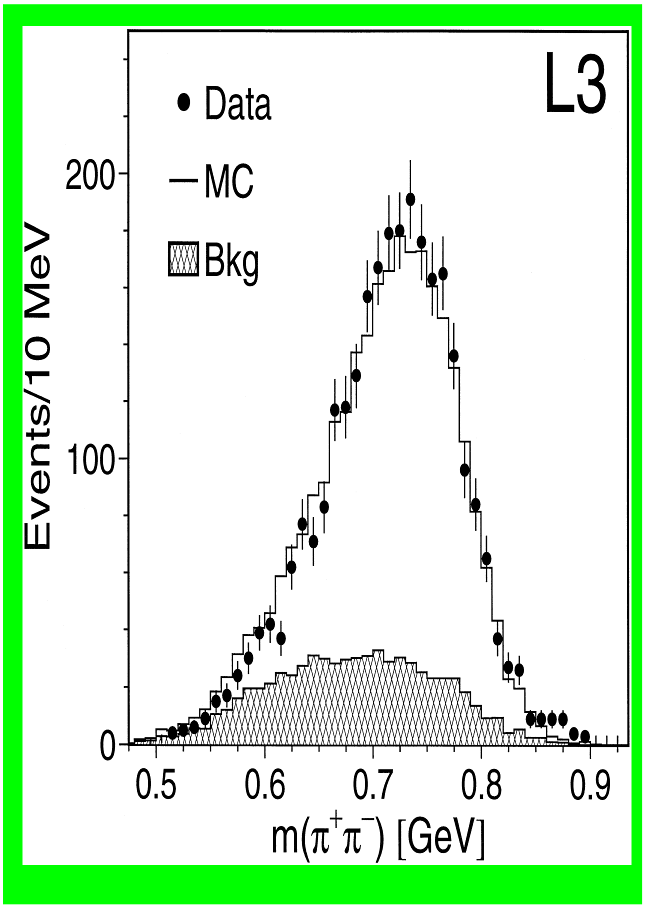
$$B_\eta(0) = -\frac{\alpha_{em}}{\pi\sqrt{3}}\left[\cos\Theta_{PS}/f_8 - 2\sqrt{2}\,\xi\,\sin\Theta_{PS}/f_0\right]$$

$$B_{\eta'}(0) = -\frac{\alpha_{em}}{\pi\sqrt{3}}\left[\sin\Theta_{PS}/f_0 + 2\sqrt{2}\,\xi\,\cos\Theta_{PS}/f_0\right]$$

$$E_\eta(0) = -\frac{e}{4\pi^2\sqrt{3}}\frac{1}{f_\pi^2}\left[\frac{\cos\Theta_{PS}}{f_8} - \sqrt{2}\,\frac{\sin\Theta_{PS}}{f_0}\right]$$

$$E_{\eta'}(0) = -\frac{e}{4\pi^2\sqrt{3}}\frac{1}{f_\pi^2}\left[\sin\Theta_{PS}/f_8 + \sqrt{2}\,\cos\Theta_{PS}/f_0\right]$$

$$\Gamma(X \to \gamma\gamma) = \frac{m_X^2}{32\pi}\,|B_X(0)|^2$$



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

Evidence for Box Anomaly?

⇐ *M. Acciarri et al. (L3),* Phys. Lett. B 418 (1998) 399

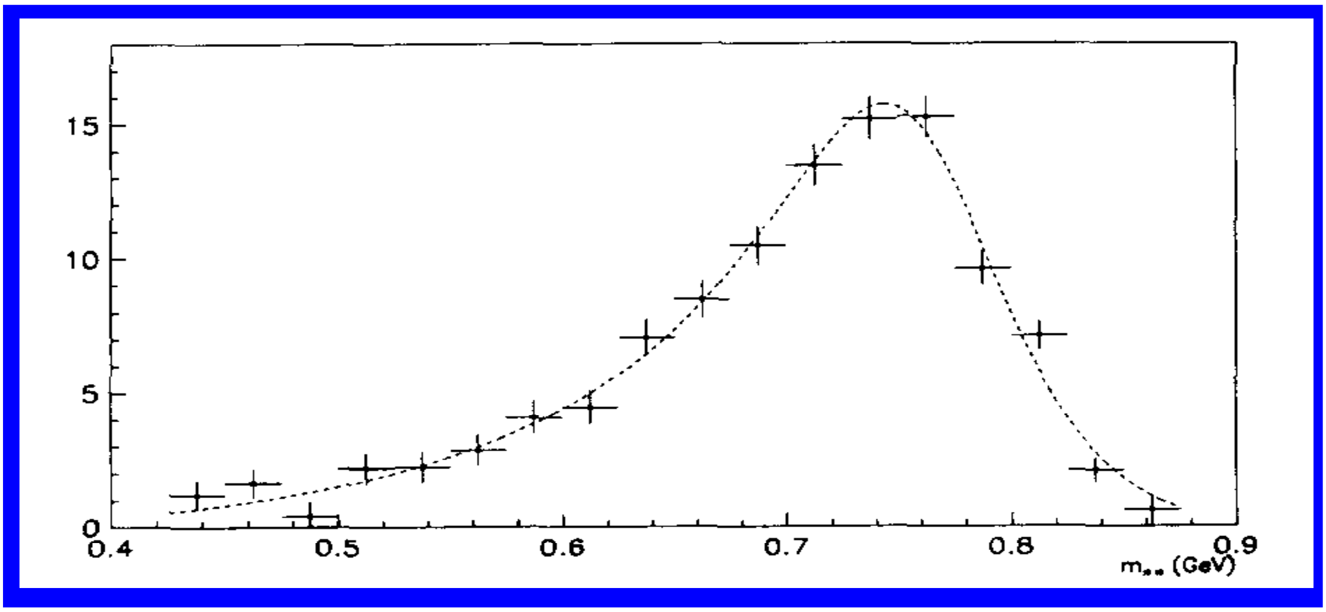
$\xi = 0$ (CL = 37%)

($\xi = 0.4$, $\phi = 3.14 \Rightarrow$ CL = 3%)

$$BW(\rho) = \frac{1}{(m_{12}^2 - m_\rho^2) - i\, m_{12}\, \Gamma_\rho} + \frac{\xi}{m_{\eta'}^2} \exp(i\phi)$$

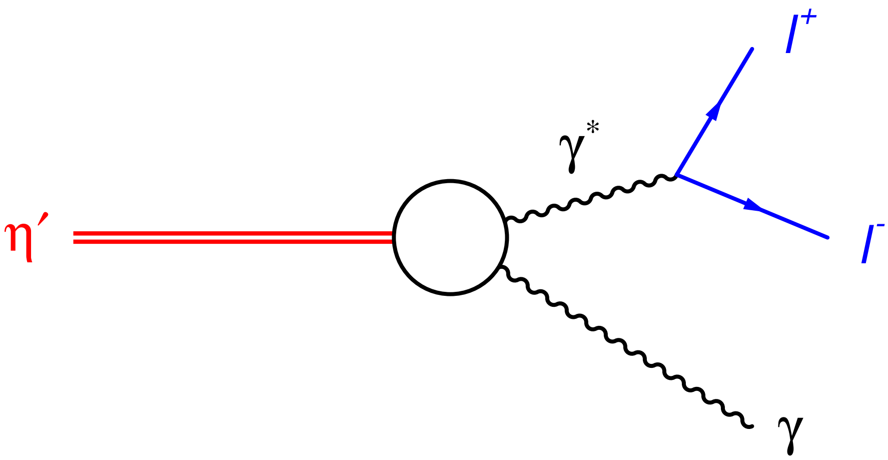
⇓ *A. Abele et al. (Crystal Barrel),* Phys. Lett. B 402 (1997) 195

$\xi = 0.4$, $\phi = 3.14$



η' Transition Form Factor

Conversion Decays

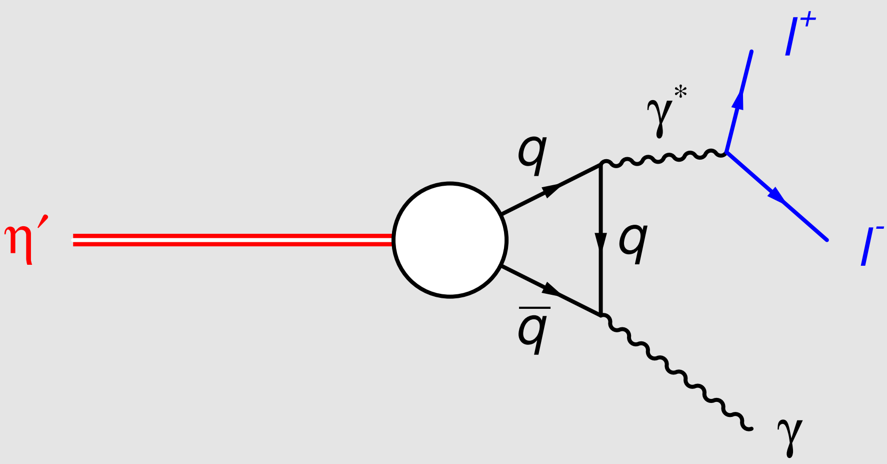


probe
spatial distribution
of meson matter

observable: $l^+ l^-$ mass distribution

for η: J.Stepaniak et al.,
Phys. Scripta T99 (2002) 133

Calculations: VMD | Quark Triangle Loop | ChPT

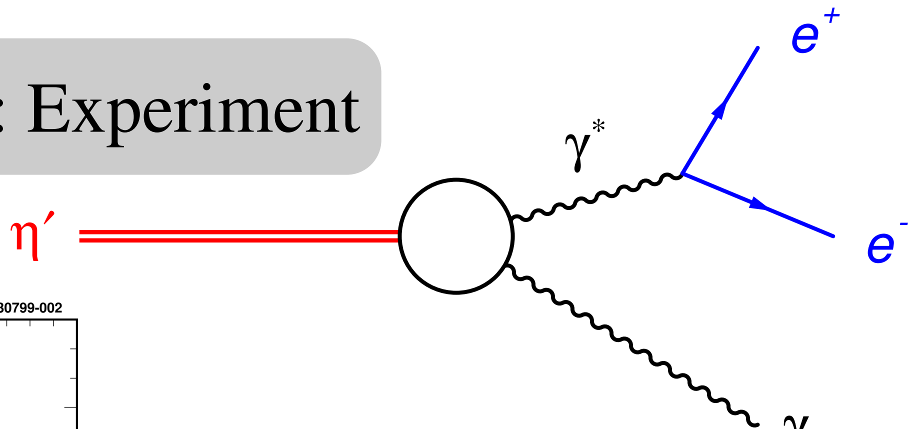


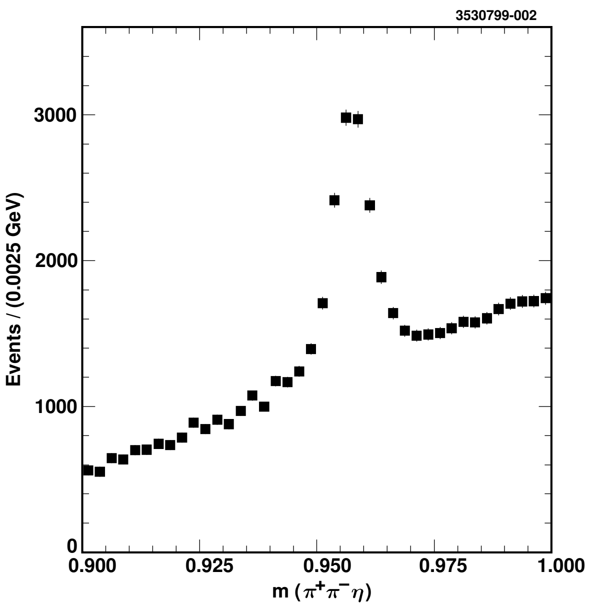
probe
qq coupling of
η′

for η: L. Ametller et al.,
Nucl. Phys. 228 (1983) 301

$$F_\eta(q^2) = \frac{\sum_q (g_{Pq\bar{q}}/m_q)\, Q_q^2\, f(q^2, m_q, m_\eta)}{\sum_q (g_{Pqq}/m_q)\, Q_q^2}$$

η' Dalitz Decay: Experiment

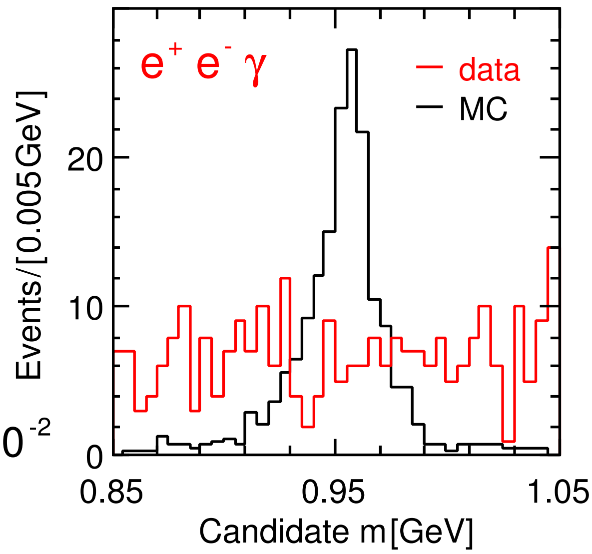




CLEO II (R.A.Briere et al.)
Phys. Rev. Lett. 84 (2000) 26

$\rightarrow$ 6700 events

$\rightarrow$ BR(exp) $< 0.9\times10^{-3}$



expected branching ratio

$$\frac{BR(\eta \rightarrow e^+ e^- \gamma)}{BR(\eta \rightarrow \gamma\gamma)} \approx 0.015 \quad BR(\eta' \rightarrow \gamma\gamma) = 2.1\times10^{-2}$$

$$\rightarrow BR(\eta' \rightarrow e^+ e^- \gamma) \approx 3\times10^{-4}$$

expected counting rate WASA@COSY $\approx$ 130 events/day
(BR = 0.9×10^{-3})

experimental conditions and background

for η: J.Stepaniak et al.,
Phys. Scripta T99 (2002) 133

$e^\pm \leftrightarrow \mu^\pm, \pi^\pm$ misidentification $\approx 10^{-3}$

l^+l^- mass resolution $\approx$ 2.5%

admixture $pp \rightarrow pp\pi^0\pi^0 \rightarrow ppe^+e^-\gamma(\gamma)$ < 1%

admixture $pp \rightarrow pp\eta' \rightarrow pp\gamma\gamma \rightarrow pp\gamma e^+e^-$ negligible

Physics Issues In η′ Decays

Charge Symmetry Breaking

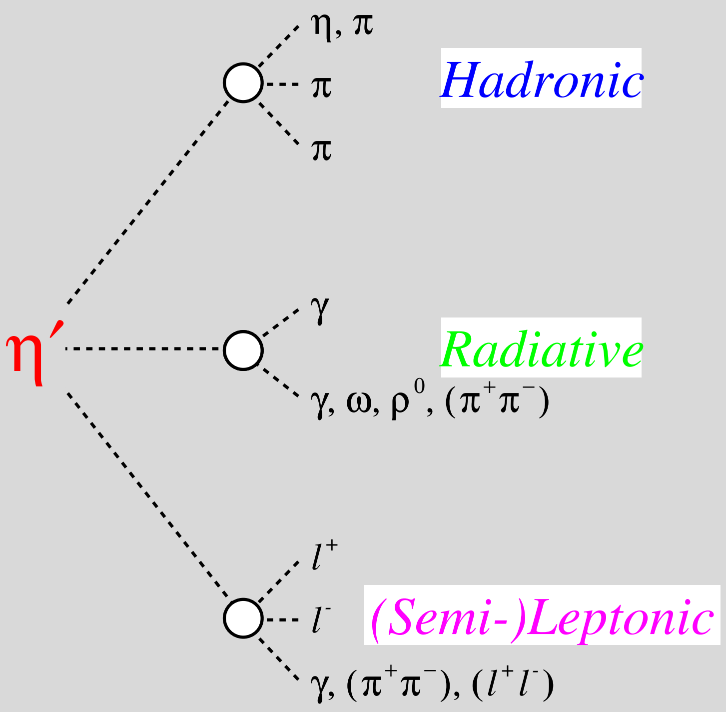
Pseudoscalar Nonet Parameters

Nature of the η′

QCD Anomalies

Scalar Meson Exchange

Tests of ChPT Predictions



at

High Precision

and

High Luminosity

with