CHIRAL DYNAMICS AT KLOE, MAINZ, ELSA AND OTHER LABS

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Chiral Dynamics

- Study of (pseudo)Goldstone bosons dynamics: pions, kaons etas

- The most interesting observables *vanish* in the Chiral limit $m_u = m_d = m_s = 0$

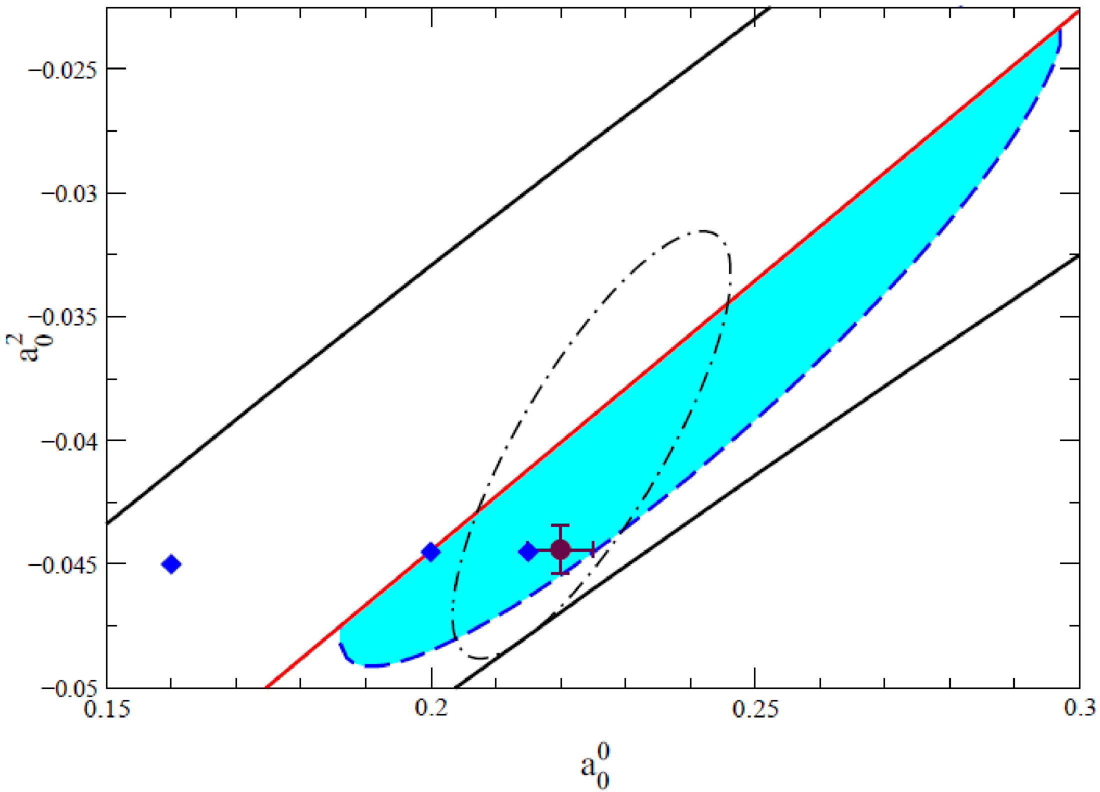
  - $\pi\pi$ scattering lengths
  - $\eta \rightarrow 3\pi$
  - πN scattering, photoproduction at threshold
  - …

- This talk: a *personal* choice in a vast field….

- N. B. the speaker spent last 5 years or so in measuring η->3π at KLOE…

ππ scattering lengths

- An enormous and successful effort from experiments, ChPT and lattice calculations during last 10 years.



H Leutwyler @
Chiral Dynamics 2000

ππ scattering lengths

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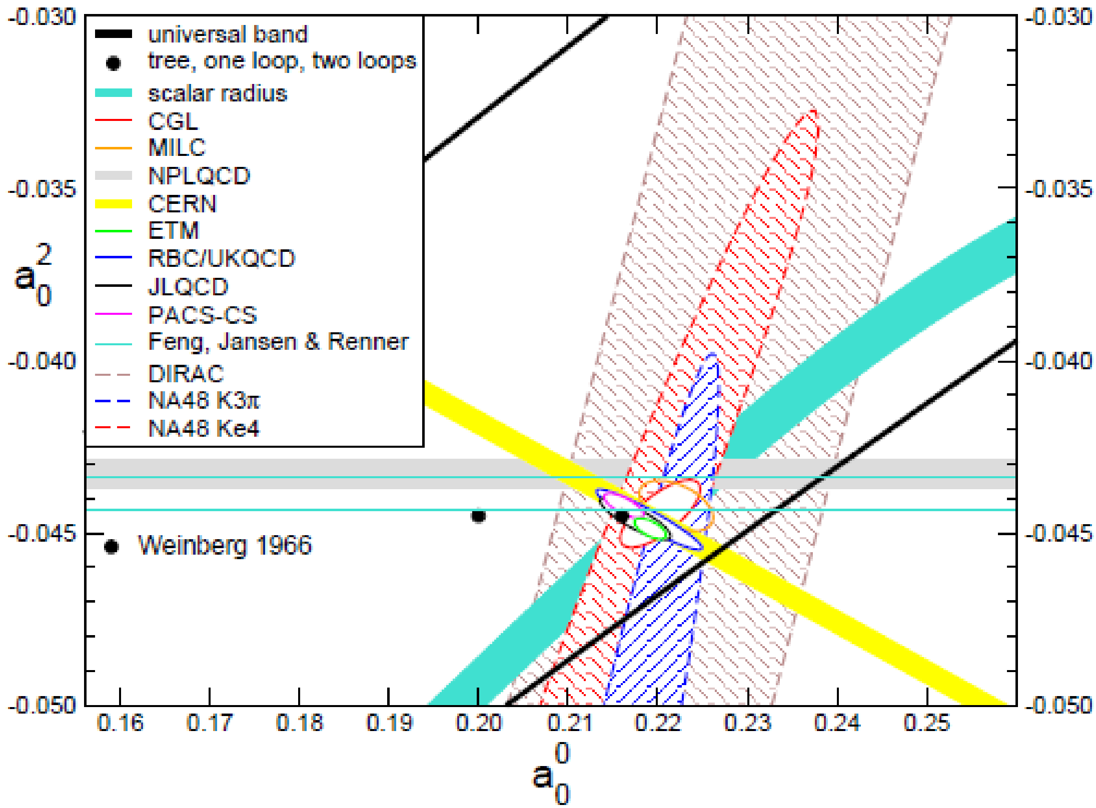
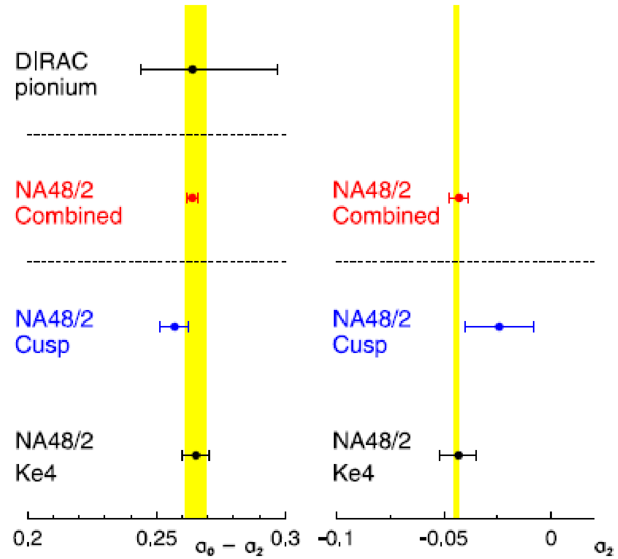


H Leutwyler @ Confinement 2008

(See also M. Piccini's talk, this conf.)



$\eta \rightarrow 3\pi$: motivations

- G parity violating → Isospin breaking effects
- EM amplitude vanish at LO (Sutherland's theorem)

…and is still small at higher orders…

[Baur et al. Nucl. Phys.. B460 (1996)]
[Ditsche et al. Eur. Phys. J. C60 (2009)]

- *So it can be used to constrain the light quark masses !*

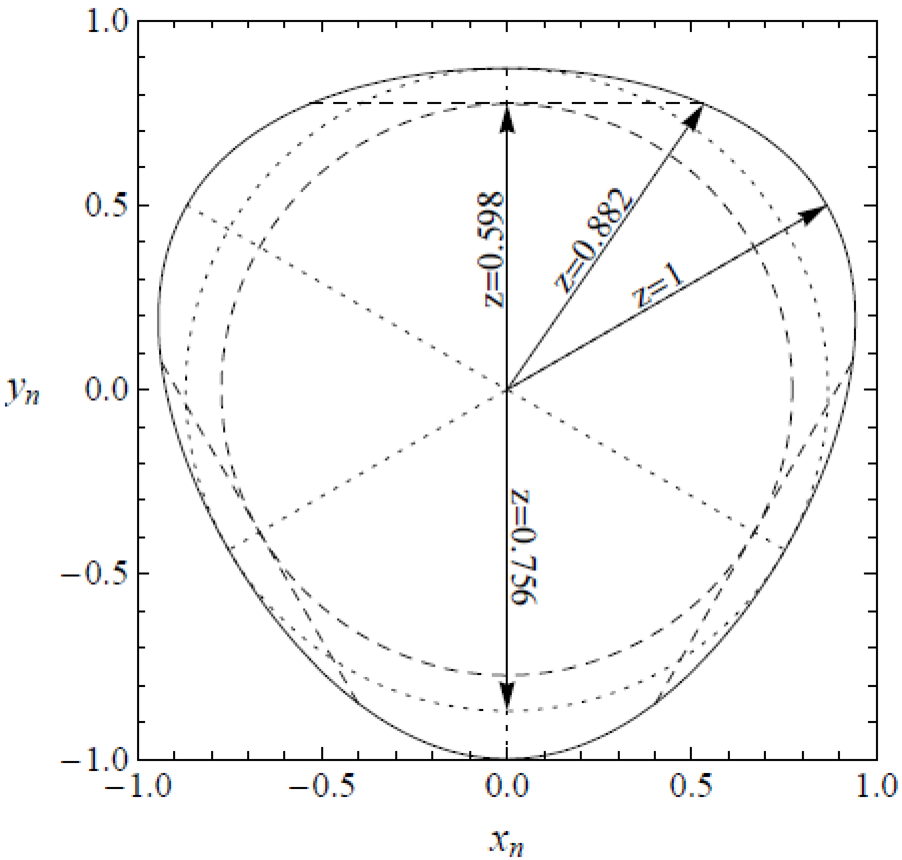
$$A(s,t,u) \propto \frac{m_d - m_u}{(m_s - \hat{m})}$$

$\eta \to 3\pi^0$

- Fit to the symmetrized Dalitz plot:

$$|A(s,t,u)|^2 \propto 1 + 2\alpha z$$

$$z = \frac{\rho^2}{\rho^2_{max}}$$

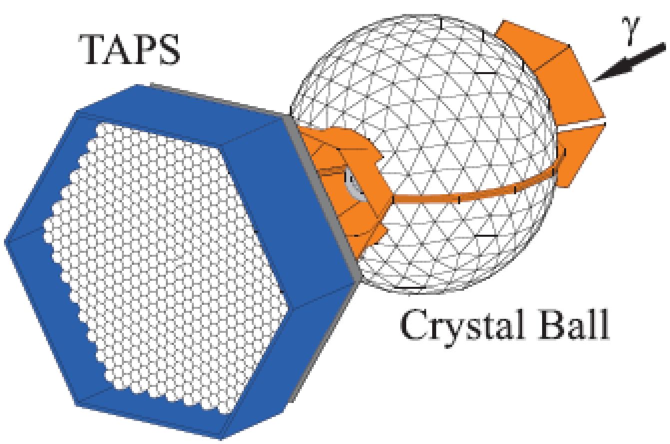


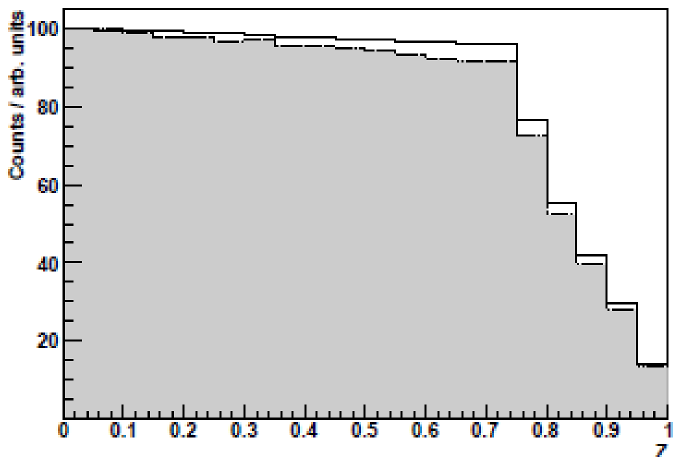
$\eta \to 3\pi^0$ results

- Intense and widespread experimental activity
- MAMI-B (1.8 Mevts)

  [M. Unverzagt et al. Eur. Phys. J. A39 (2009)]

  $$\alpha = -0.032 \pm 0.02 \ \pm 0.02$$

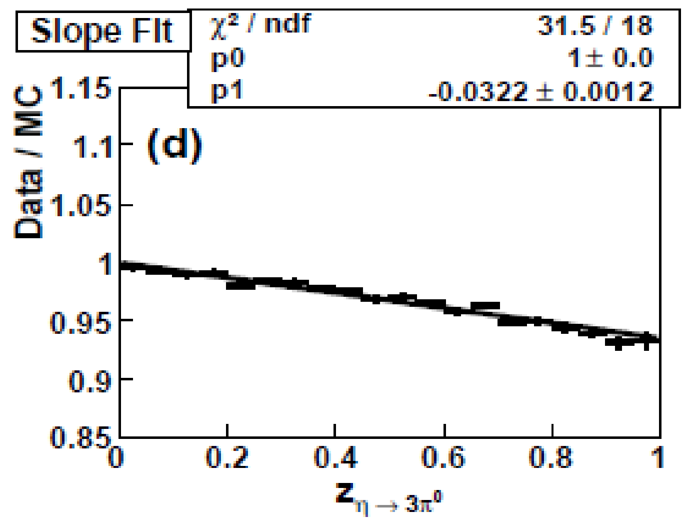




- MAMI-C (3 Mevts)

  [S. Prakhov et al. Phys. Rev. C79 (2009)]

  $$\alpha = -0.0322 \pm 0.012 \pm 0.022$$

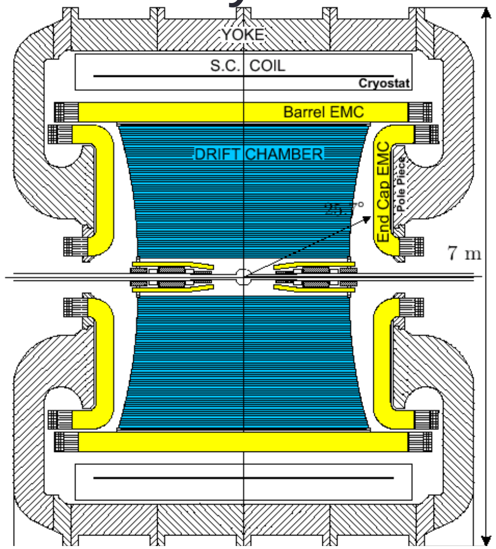


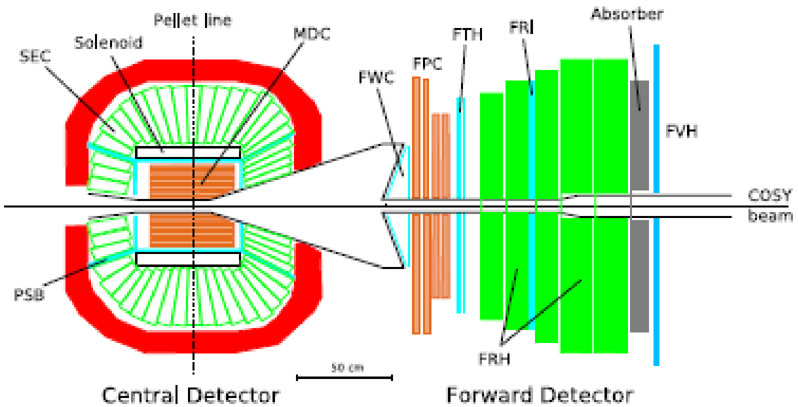
$\eta \to 3\pi^0$ results

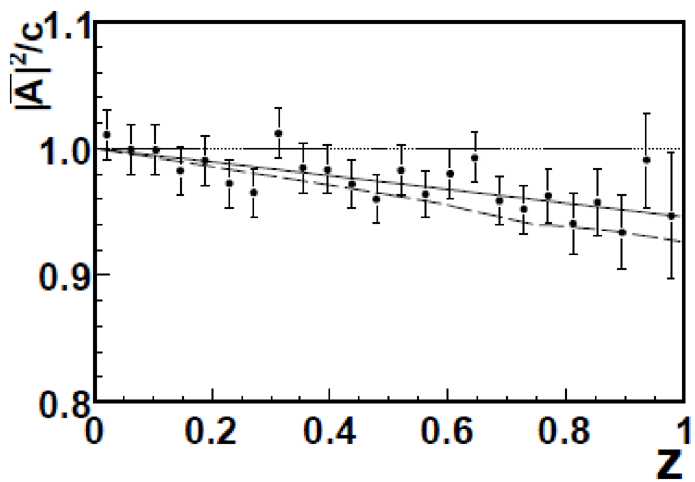
- Intense and challenging experimental activity
- KLOE (600 kevts)

  [F. Ambrosino et al. Phys. Lett. B694 (2010)]

$$\alpha = -0.0301 \pm 0.035 \;{}^{+0.022}_{-0.0035}$$







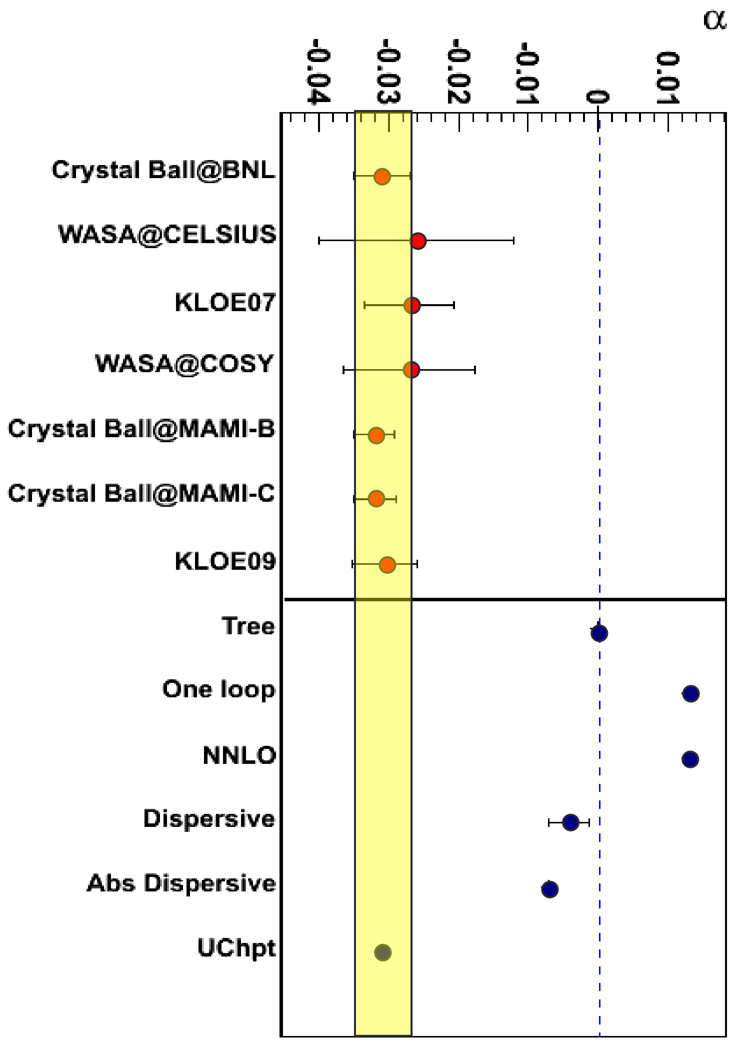
- WASA@COSY (120 kevts)

[C. Adolph et al. Phys. Lett. B677 (2009)]

$$\alpha = -0.027 \pm 0.008 \pm 0.005$$

$\eta \rightarrow 3\pi^0$ summary

- An experimental success !
- Remarkable agreement of all experiments
- But…measured value far from Chiral predictions: how reliable is a quark mass extraction from the width ?
- New results using dispersive or NREFT approach -> see later



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

- Fit to the full 2D Dalitz plot:

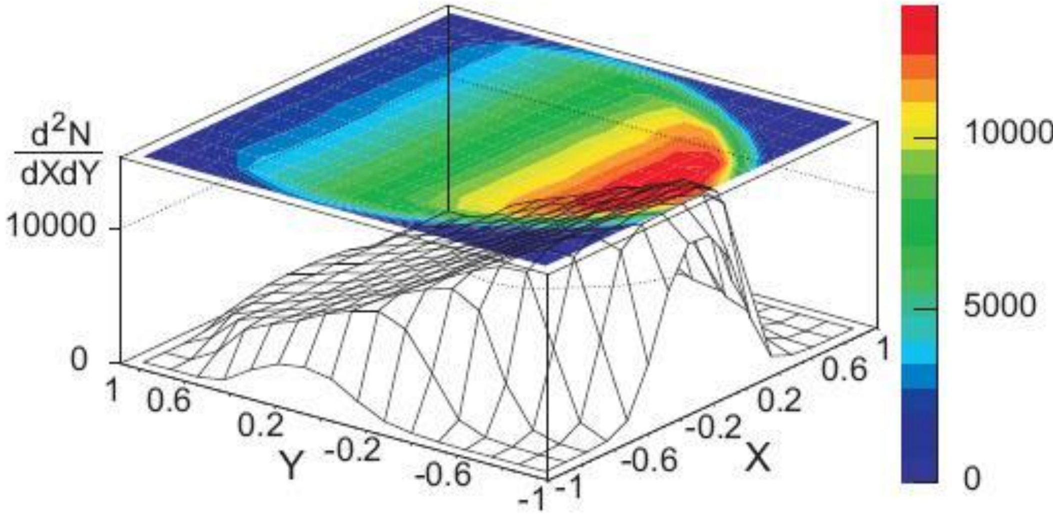
$$|A(s,t,u)|^2 \propto 1 + ay + by^2 + cx + dx^2 + exy + fy^3 + \cdots$$

$$x = \sqrt{3}\,\frac{T_+ - T_-}{Q} \quad ; \quad y = \frac{3T_0}{Q} - 1$$

- Only one precision measurement by KLOE (1.3 Mevts)

[F. Ambrosino et al. JHEP 05(2008)006]

a	-1.090 (5) (+ 8) (-19)
b	0.124 (6) (10)
c	0.002 (3) (1)
d	0.057 (6) (+7) (-16)
e	-0.006 (7) (5) (-3)
f	0.14 (1) (2)
$P(\chi^2)$	0,73



- *c*, *e* compatible with zero (C violation)
- fit without cubic term (fY^3) $\Rightarrow P(\chi^2) \sim 10^{-6}$

$\eta\to\pi^+\pi^-\pi^0$ vs $\eta\to3\pi^0$

- Assuming I = 1 final state, in the first order in isospin breaking the two processes can be related. An important relation is found between the Dalitz parameters:

$$\alpha = \frac{1}{4}\left(b + d - \frac{a^2}{4}\right) - \frac{(Im\,\bar{a})^2}{4}$$

[J. Bijnens and K. Ghorbani JHEP 11(2007)030]

where $\bar{a}$ is the linear complex coefficient of the expansion of the amplitude for the charged mode:

$$A(s,t,u) \propto (1 + \bar{a}y + \bar{b}y^2 + \bar{d}x^2 + \ldots)$$

- Exploiting this relation between the amplitudes, and considering $\pi\pi$ rescattering effect at LO KLOE finds an indirect determination of α :

$$\alpha = -0.038 \pm 0.03\,(stat.)\ {}^{+0.012}_{-0.008}(\mathrm{syst})$$

[F. Ambrosino et al. JHEP 05(2008)006]

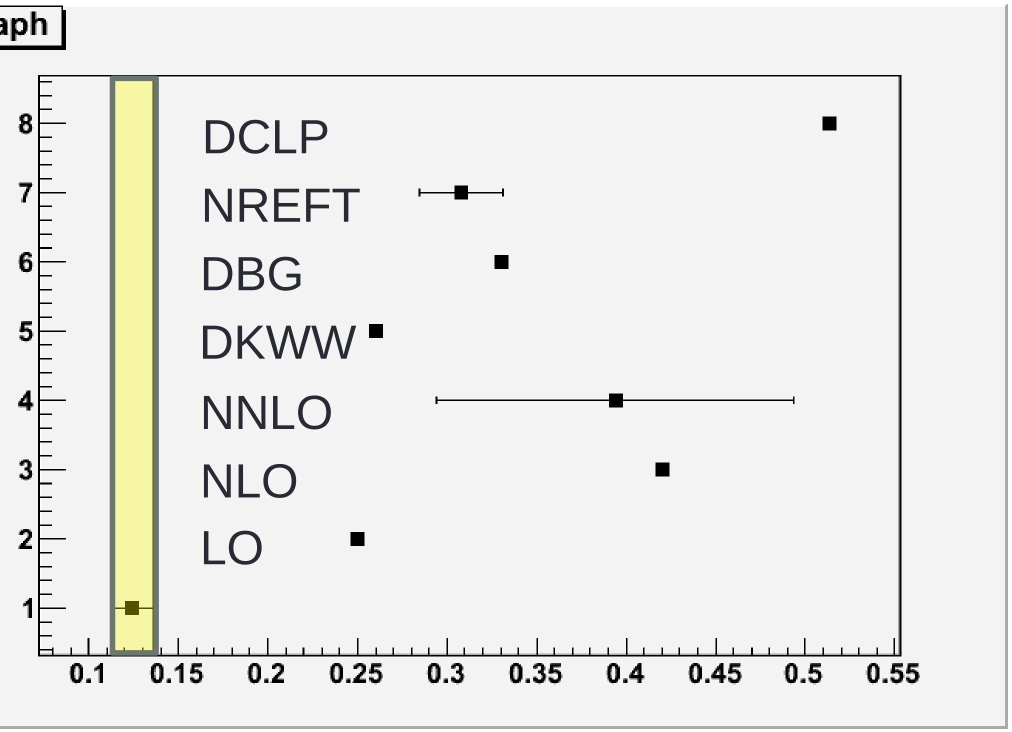
A puzzle ?

- It has been recently argued, in the NREFT approach that using $\pi\pi$ rescattering at NLO the charged result by KLOE would imply α = -0.062(7), in contrast with experimntal evidence. [S.P. Schneider et al. JHEP 1102(2011)028]

- The KLOE data agree very well with Im $(\bar{a})$ = 0 which is incompatible with NREFT calculation of pion rescattering at NLO. This *is* a puzzle !

- However, the NREFT approach, which finds a quite reasonable value for α = -0.025, fails in the quadratic slope in y, i.e. b

Is b the true villain ?



NLO: [Gasser and Leutwyler Nucl. Phys.B250 (1985)]
NNLO: [Bijnens and Ghorbani JHEP 11(2007)030]
DKWW: [Kambor et al. Nucl. Phys B 465 (1996)]
DBG: [Bijnens and Gasser Phys. Scripta T99 (2002)]
NREFT: [S.P. Schneider et al. JHEP 1102(2011)028]
DCLP:[G. Colangelo et al. arXiv:1102.4999]

- The problem in reproducing the value of α (and even its sign) is pretty evident.

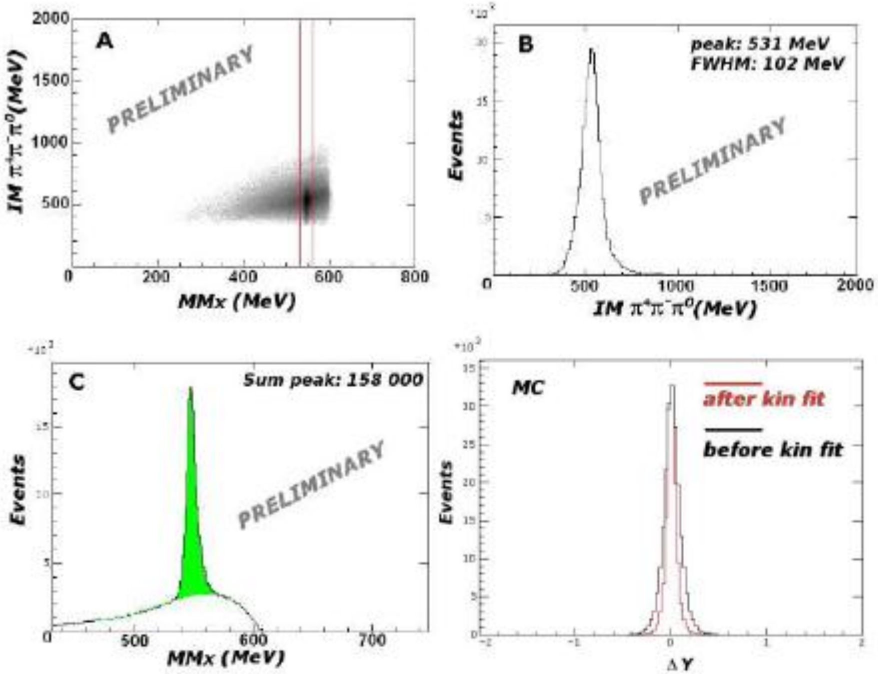
- This is strictly linked to the fact that
  - ChPT (LO, NLO, NNLO)
  - Dispersive (matched to ChPT)
  - NREFT

are always far from experiment for b

- The only precision measurement, disagrees with CHPT calculations:

new precise measurements welcome ….

New measurements on the way…



WASA@COSY
Two independent channels

- pd→^{3}He η 200 kevts

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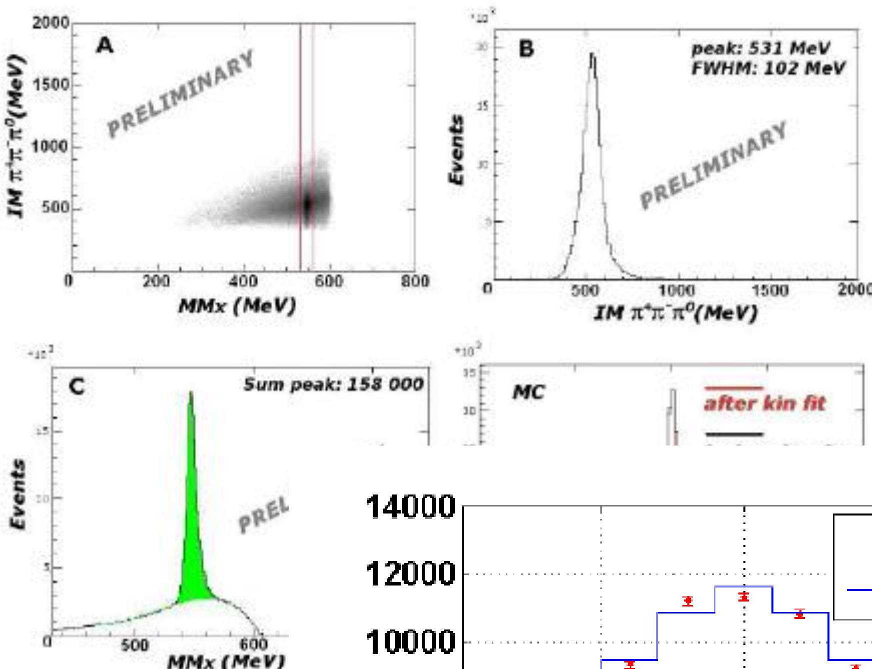

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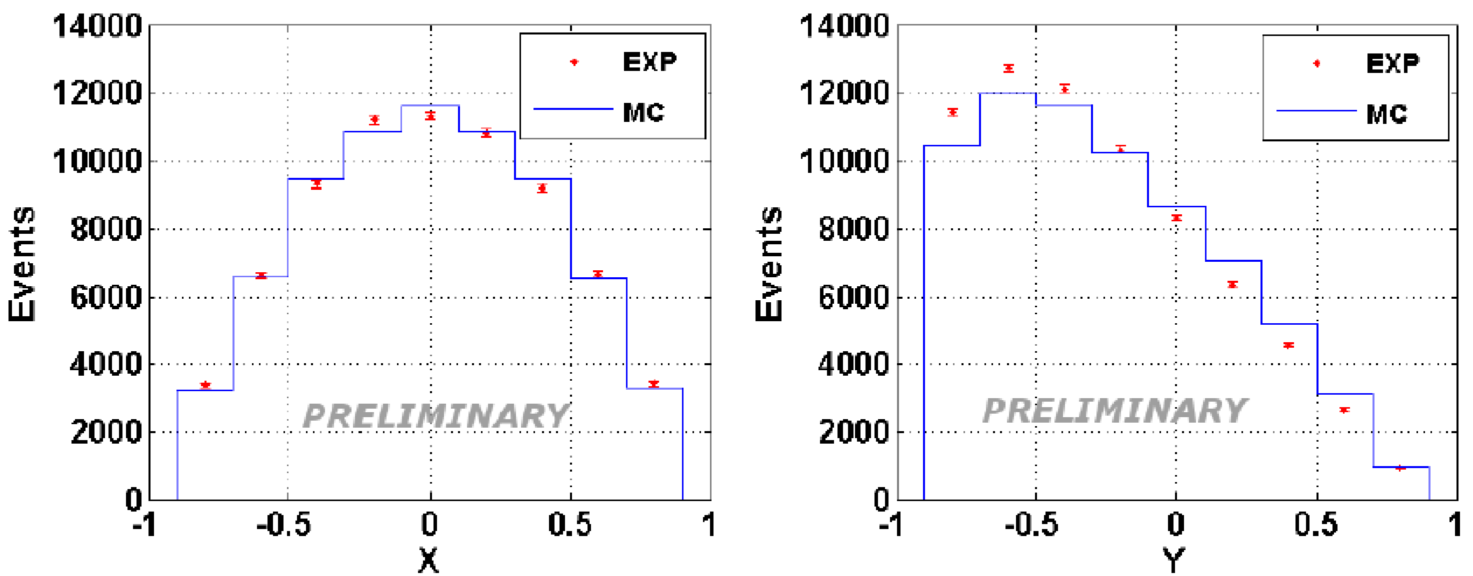

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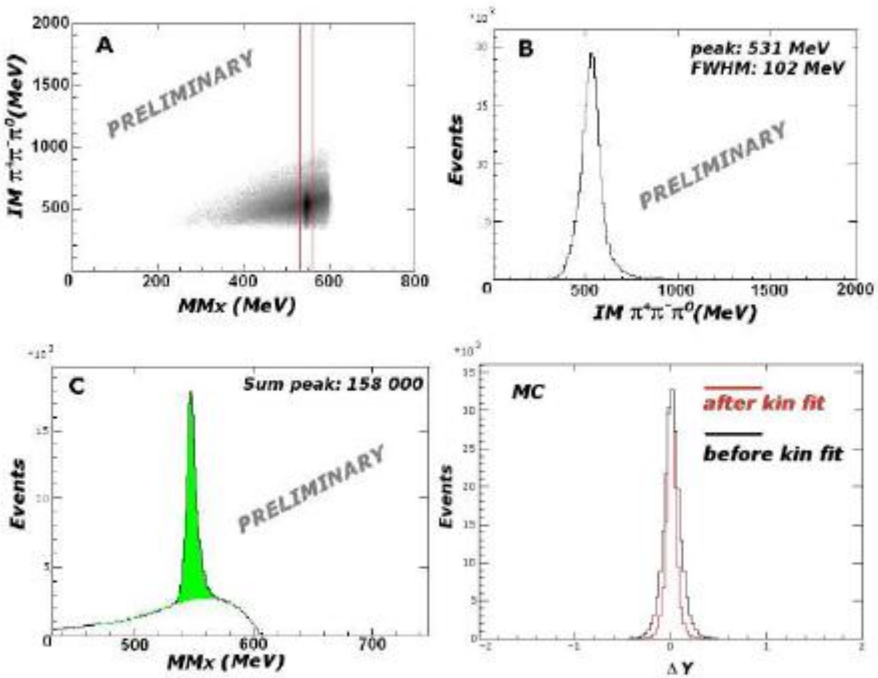

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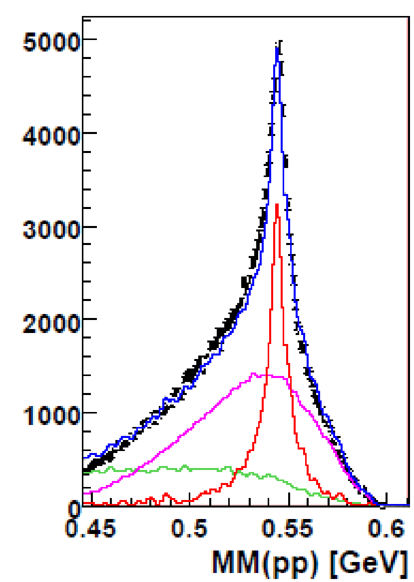
- pd→^{3}He η 200 kevts
- pp →pp η 10 Mevts (!)



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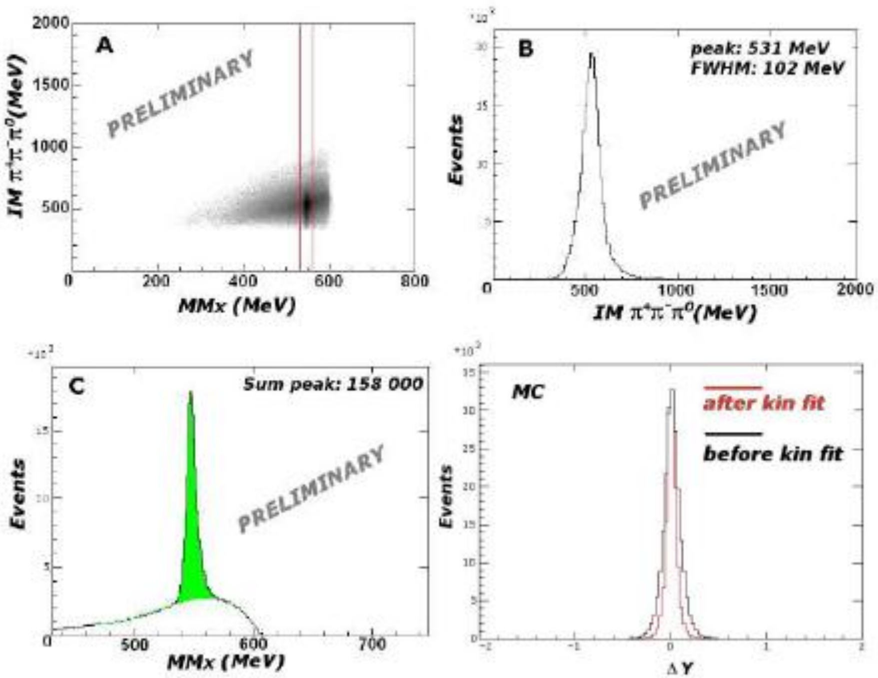

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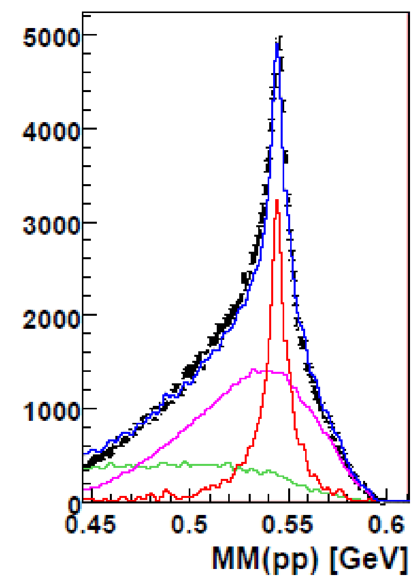

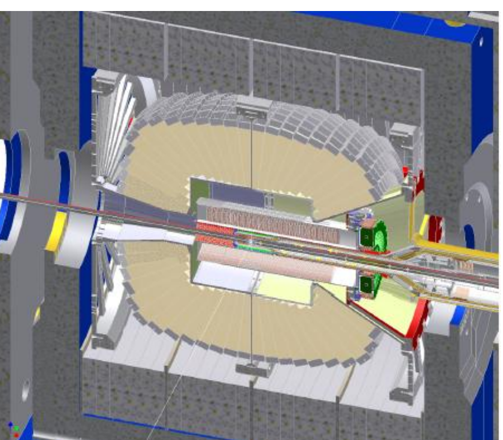

..and after the upgrade ELSA and MAMI can enter the game, too…

…but do not forget the old ones !

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- It is usual to refer to old measurement in the charged channel as follows:

Exp.	a	b	d
KLOE [50]	$-1.090 \pm 0.005^{+0.008}_{-0.019}$	$0.124 \pm 0.006 \pm 0.010$	$0.057 \pm 0.006^{+0.007}_{-0.016}$
Crystal Barrel [51]	-1.22 ± 0.07	0.22 ± 0.11	0.06 ± 0.04 (input)
Layter et al. [52]	-1.08 ± 0.014	0.034 ± 0.027	0.046 ± 0.031
Gormley et al. [53]	-1.17 ± 0.02	0.21 ± 0.03	0.06 ± 0.04

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  2. So is Crystal Barrel with only 3kevts. When fitting only linear slope they get a = -1.10(4)
  3. Gormley only uses full 2D fit to look for xy effects…

…but c

- It is usua
  channel

Exp.	
KLOE [5	$^{+0.007}_{-0.016}$
Crystal Barr	nput)
Layter et al	)31
Gormley et a	)4

The results of Table I indicate that we can integrate the matrix element over the Dalitz x coordinate and obtain a function which depends only upon y. To study the y dependence of the Dalitz-plot density, we have fitted the π^0 energy spectrum to

$$M(y) = 1 + \alpha y. \qquad (9)$$

We find that

$$\mathrm{Re}\,\alpha = -0.58 \pm 0.01, \quad \mathrm{Im}\,\alpha = 0.00 \pm 0.08,$$

and $\chi^2 = 51$ for 29 degrees of freedom.

Although these values of $\mathrm{Re}\,\alpha$ and $\mathrm{Im}\,\alpha$ agree with the results of previous experiments,[7] the value of χ^2 suggests that a higher-order expansion of the matrix element is required to represent our data.

The simplest Dalitz-plot density resulting from a nonlinear matrix element is

$$|M(y)|^2 = 1 + ay + by^2, \qquad (10)$$

where a and b are independent real coefficients. Fitting the π^0 energy spectrum to Eq. (10) yields

$$a = -1.15 \pm 0.02, \quad b = 0.16 \pm 0.03,$$

with $\chi^2 = 36.8$ for 29 degrees of freedom. The π^0 energy

- This is in … very
  controve … inal
  papers…
  1. Layte
  2. So is … ar
     slope
  3. Gorm

Old vs new results

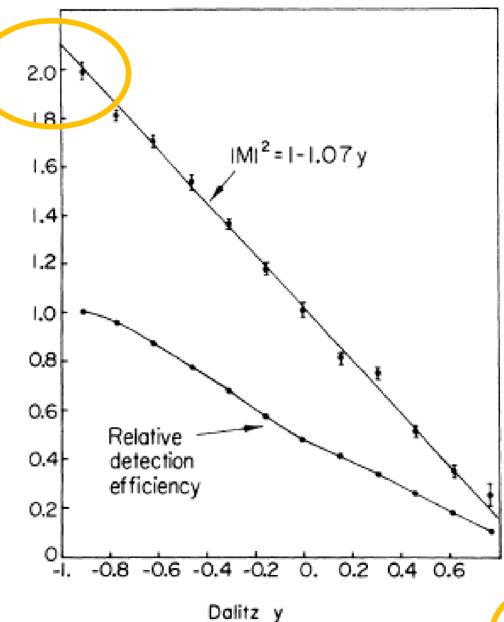
- I believe that a more coherent way to compare results on the charged channel is:

Exp	a	b	d
KLOE	-1.090(-20)(+9)	0.124 (12)	0.057 (+9)(-17)
Crystal Barrel	-1.10 (4)	-	-
Layter	-1.08 (14)	-	-
Gormley	-1.15 (2)	0.16 (3)	-

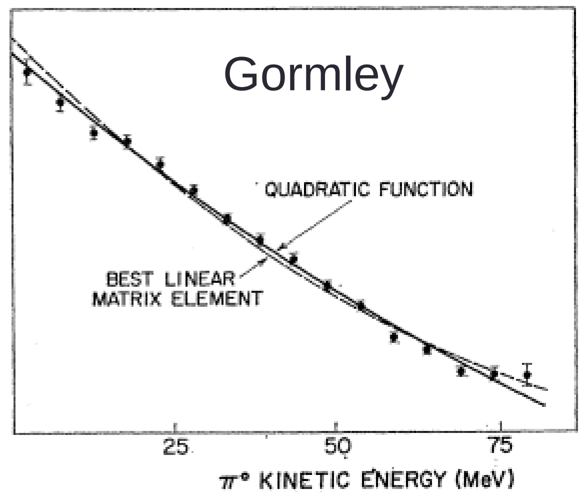
- This is reflected in the quite similar behaviour of all data…

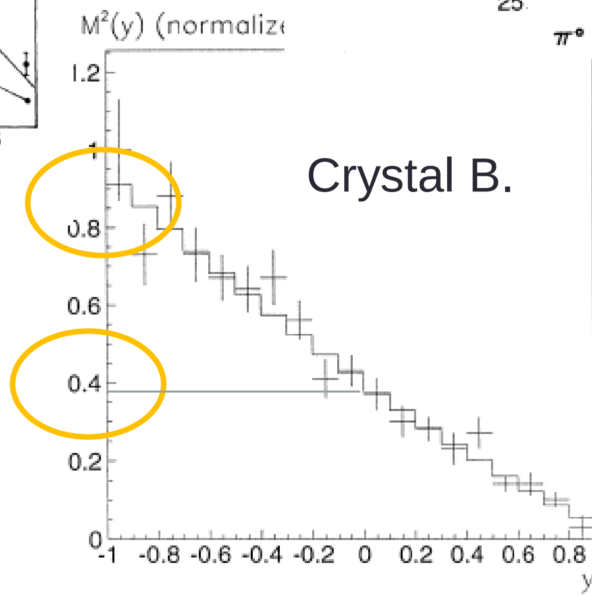
Old vs new results

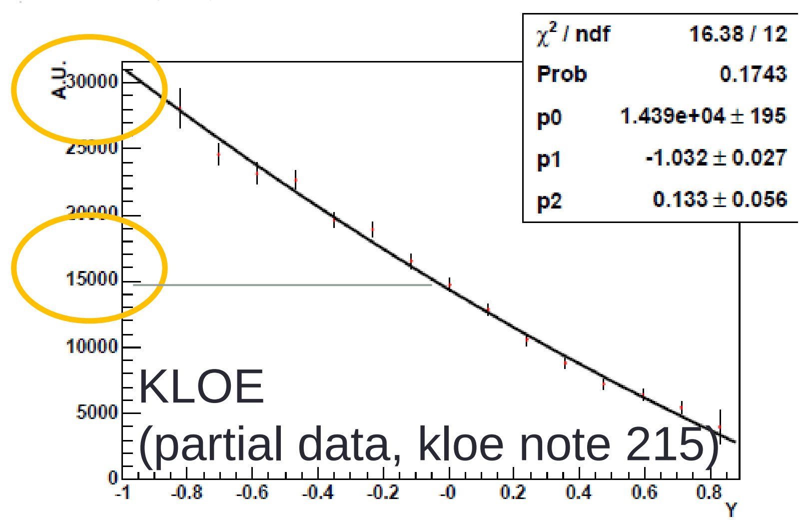
- The 1D projections along y agree reasonably…



Layter

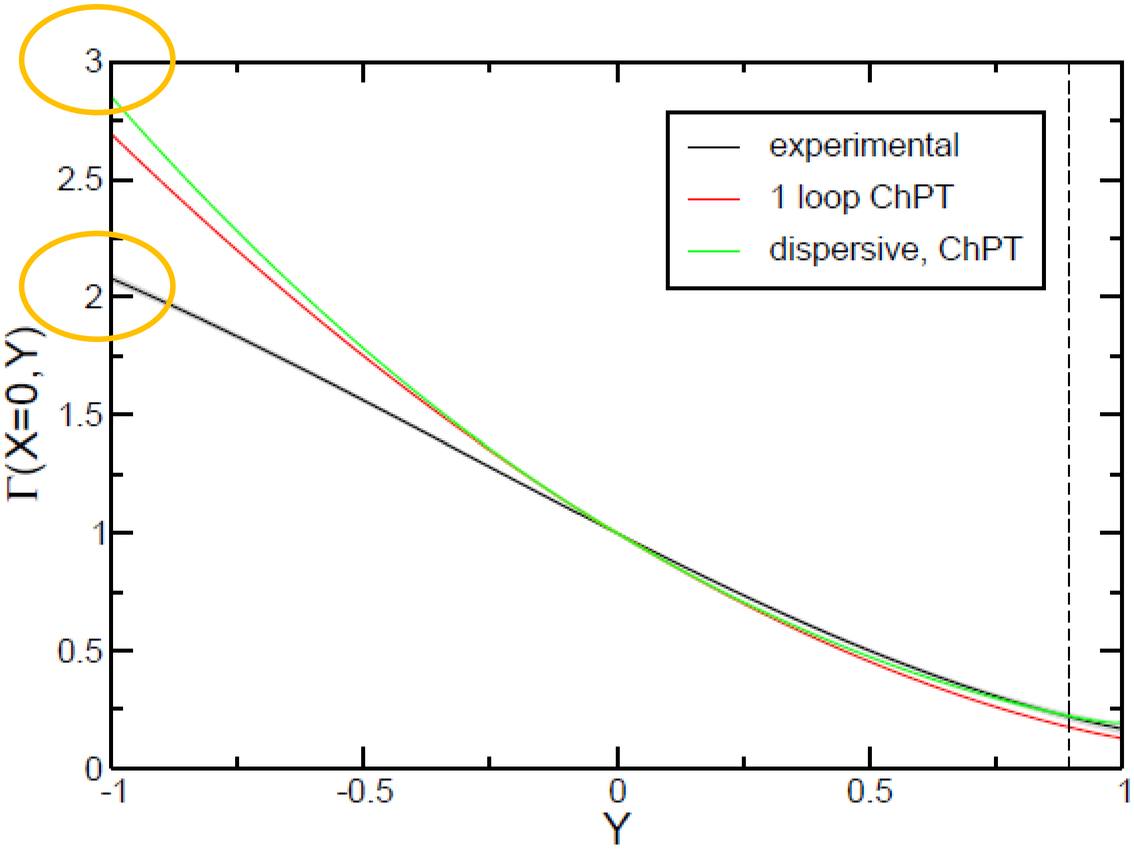






Old & new results vs theory

- A quad slope of 0.2-0.3 would have a dramatic effect on y projected event count ! Very difficult to account for a large quadratic slope from the current experimental picture…



S. Lang@PrimeNet Workshop (2010)

What really matters..

- ..is obviously the value of quark mass ratio $Q^2 = \left(\frac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2}\right)$

- New approaches: *fit* dispersive parametrizations to KLOE data with normalization from ChPT (e.g. at the Adler zero) and extract quark mass ratios.

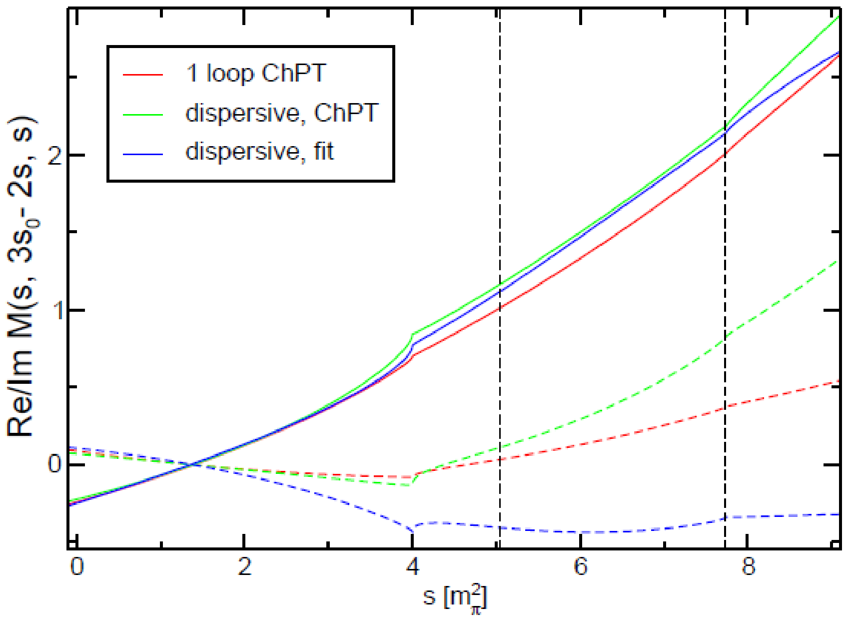
- They obtain:

$Q = 22.0 \pm 0.4$

[G. Colangelo, et al. arXiv:0910.0765; arXiv:1102.499

$Q = 23.3 \pm 0.8$

[K. Kampf, et al. arXiv: 1103.0982]



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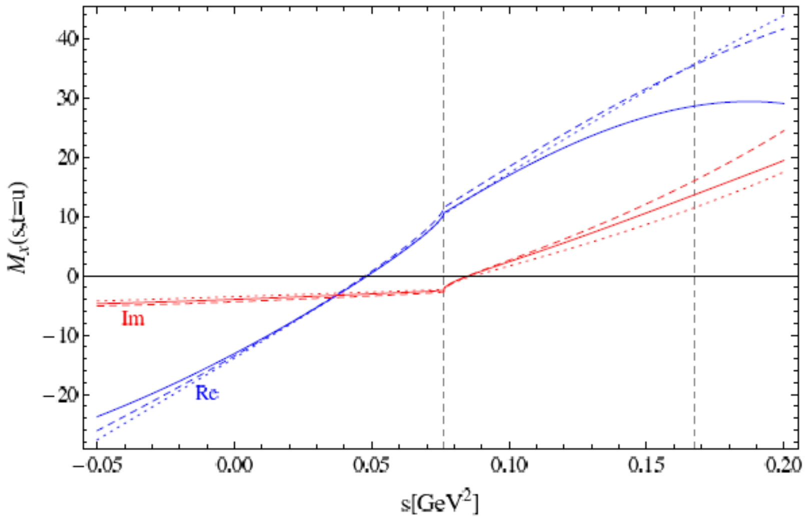

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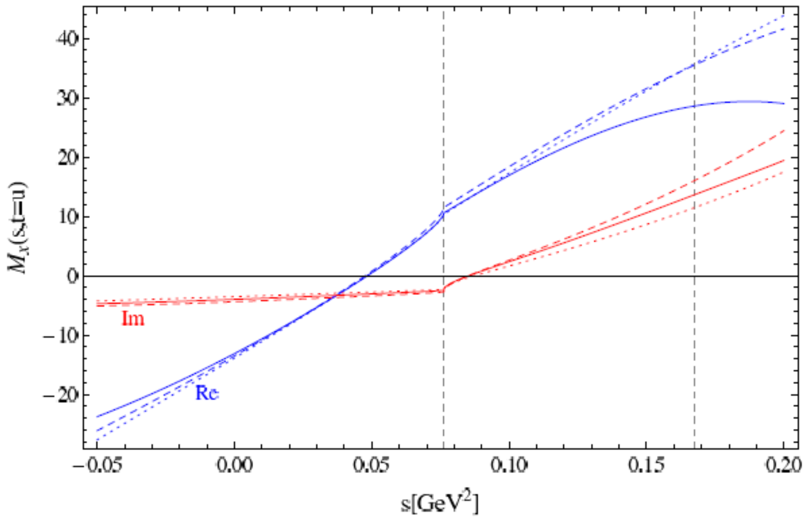
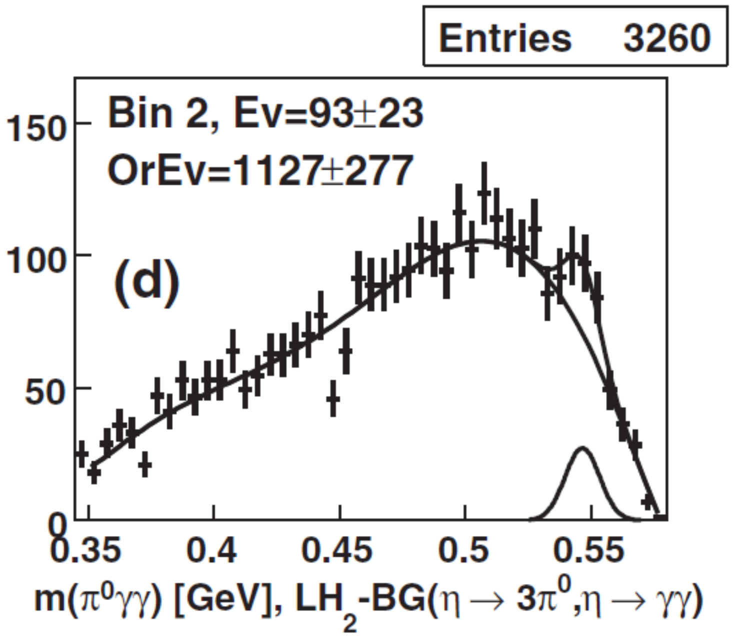
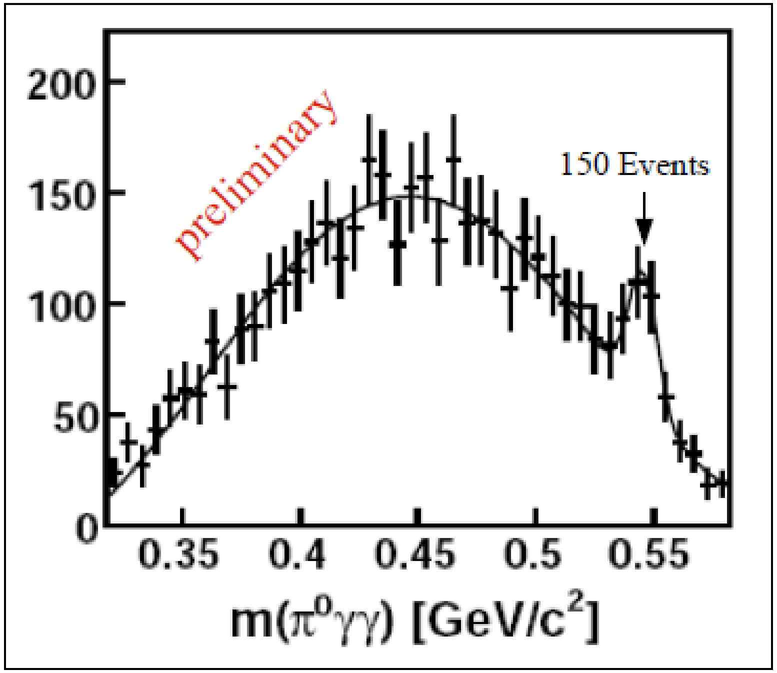


$\eta \rightarrow \pi^0\gamma\gamma$

- $\eta \rightarrow \pi^0\gamma\gamma$ is a pure p^6 process
- Very very hard from the experimental point of view
- Recent reanalysis of CB@BNL and preliminary result from new data from MAMI:

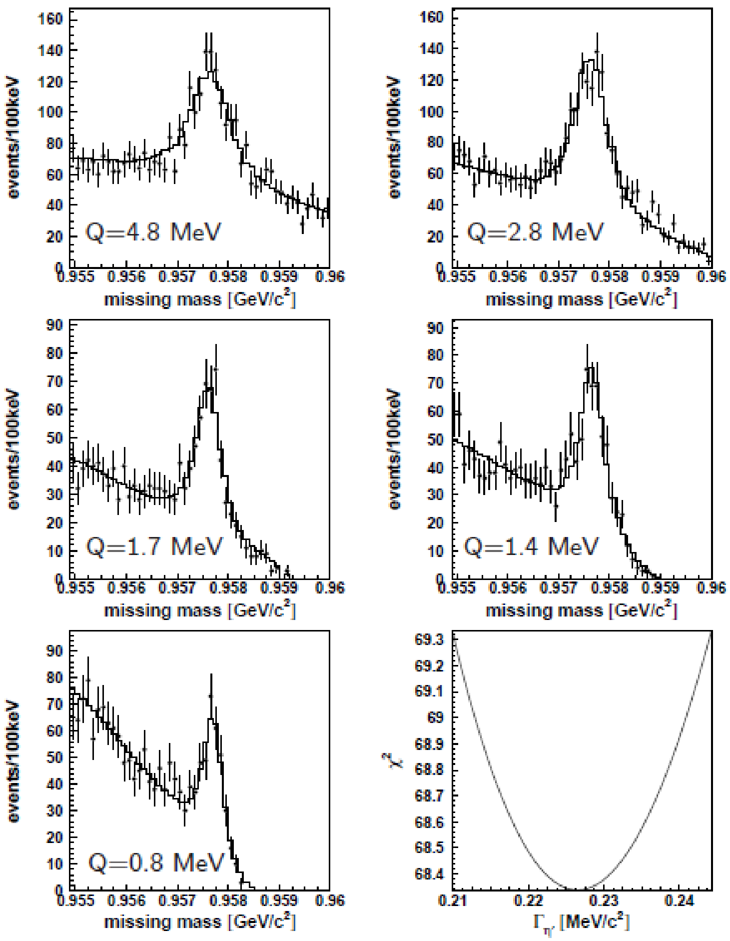
$$BR(\eta \rightarrow \pi^0\gamma\gamma) = (2.21 \pm 0.24_{stat} \pm 0.47_{syst}) \times 10^{-4}$$





$$BR(\eta \rightarrow \pi^0\gamma\gamma) = (2.25 \pm 0.46_{stat} \pm 0.17_{syst}) \cdot 10^{-4}\,(preliminary)$$

η' properties



- Recently very interesting result for the η' total width from COSY-11 without relying on intermediate BR
- Will be useful to improve understanding of the gluonium content and to extract information from the Dalitz plot analyses:

$$\Gamma_{\eta'} = 0.226 \pm 0.017\,(stat.) \pm 0.014(syst.)\,MeV/c^2$$

[E. Czerwinski et al. Phys. Rev. Lett. 105 (2010)]

η’ dynamics

- BESIII has measured with unprecedented accuracy the Dalitz plot parameters of $\eta' \to \eta\pi\pi$ using 40k events showing again the inadequateness of the so-called linear parameterization.

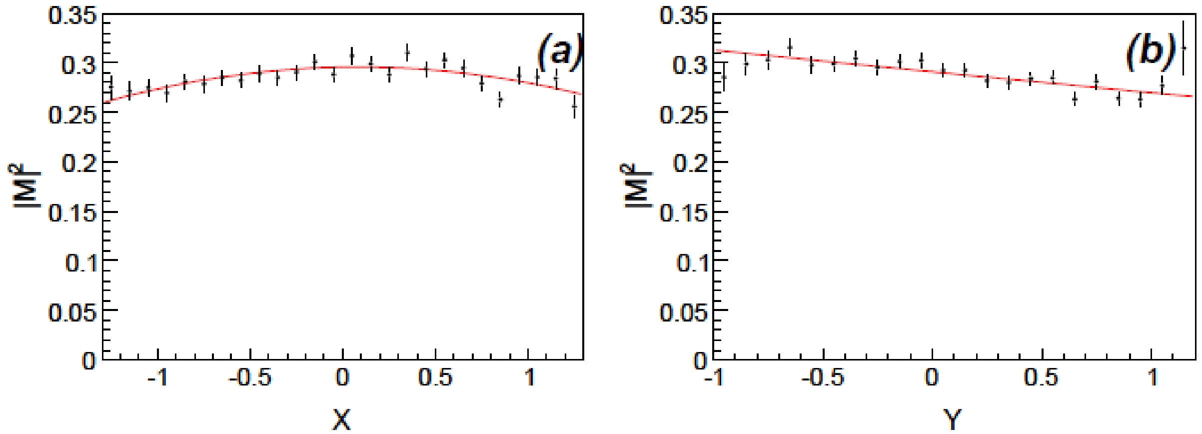
[M.Ablikim et al. Phys. Rev. D83 (2011)]

$$a = -0.047 \pm 0.011 \pm 0.003$$

$$b = -0.069 \pm 0.019 \pm 0.009$$

$$c = +0.019 \pm 0.011 \pm 0.003$$

$$d = -0.073 \pm 0.012 \pm 0.003$$



η' dynamics

- BESIII has measured with unprecedented accuracy the Dalitz plot parameters of $\eta' \to \eta\pi\pi$ using 40k events showing again the inadequateness of the so-called linear parameterization.

  [M.Ablikim et al. Phys. Rev. D83 (2011)]

- The value of the linear coefficient a is not in good agreement with previous measurement by VES

  [V. Dorofeev et al.Phys. Lett. B 651(2007)]

$a = -0.047 \pm 0.011 \pm 0.003$

$b = -0.069 \pm 0.019 \pm 0.009$

$c = +0.019 \pm 0.011 \pm 0.003$

$d = -0.073 \pm 0.012 \pm 0.003$

Par.	VES
a	-0.127 ± 0.018
b	-0.106 ± 0.032
c	$+0.015 \pm 0.018$
d	-0.082 ± 0.019

η' dynamics

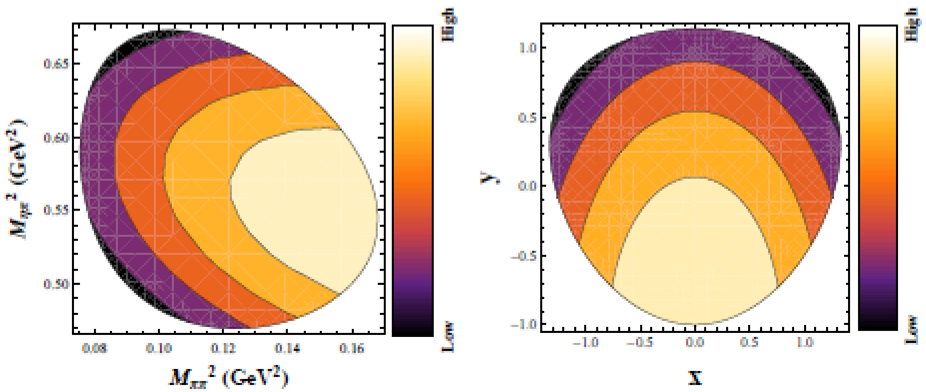


Figure 1: Dalitz plot distribution of $\eta' \to \eta\pi\pi$ using Eq. (3.12) supplemented by rescattering effects through Eq. (3.18), in terms of the invariant masses $M^2_{\pi\pi}$ and $M^2_{\eta\pi}$ (left) and the kinematical variables X and Y (right). Larger values are shown lighter.

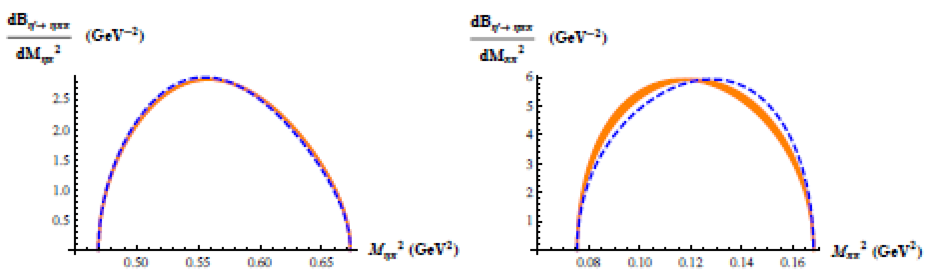


Figure 2: $M^2_{\eta\pi}$ (left) and $M^2_{\pi\pi}$ (right) invariant mass spectra for the differential branching ratio. The tree-level large-N_C ChPT prediction from Eq. (3.12) —blue dashed line— is compared to its unitarized counterpart via Eq. (3.18) —solid orange band.

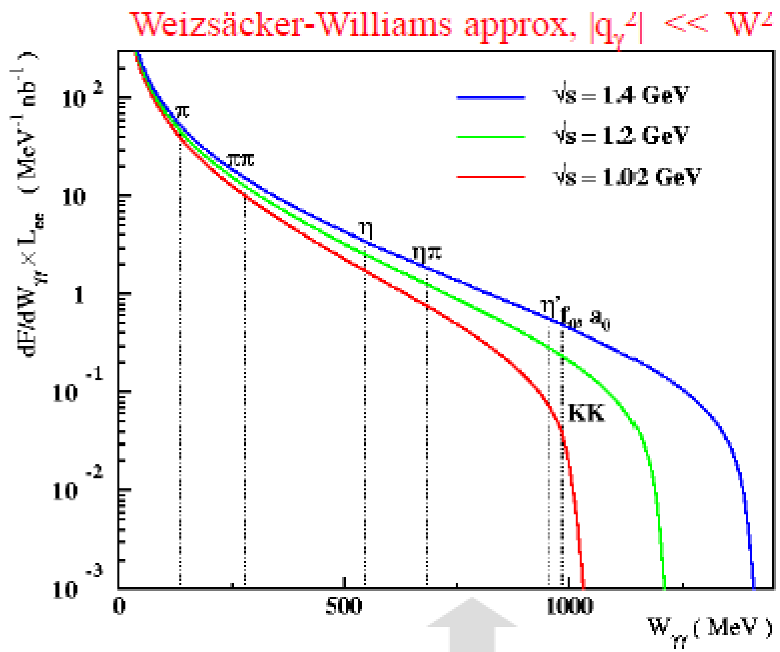
- A new detalied study of the system has been performed in the framework of large Nc and RChPT including also X^2Y and X^4 terms of the expansion

[R. Escribano et al. JHEP 1105 (2011)094]

η' dynamics :prospects

- A lot of experimental activity is planned in the next future:

- KLOE/KLOE2 (tagger, γγ fusion, see C. Di Donato's talk)

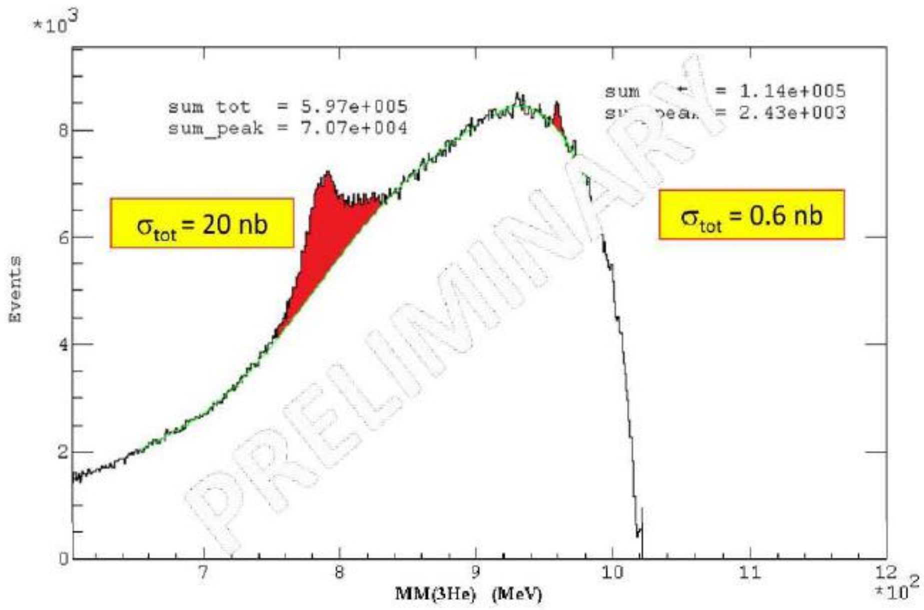


$L_{int} = 1\ fb^{-1}$

$\sqrt{s}$ (GeV)	π^0	η	η'
1.02	4.1×10^5	1.2×10^5	1.9×10^4
2.4	7.3×10^5	3.7×10^5	3.6×10^5

η' dynamics :prospects

- A lot of experimental activity is planned in the next future:
- KLOE/KLOE2 (tagger, γγ fusion, see C. Di Donato's talk)
- WASA@COSY (in pp->ppη')



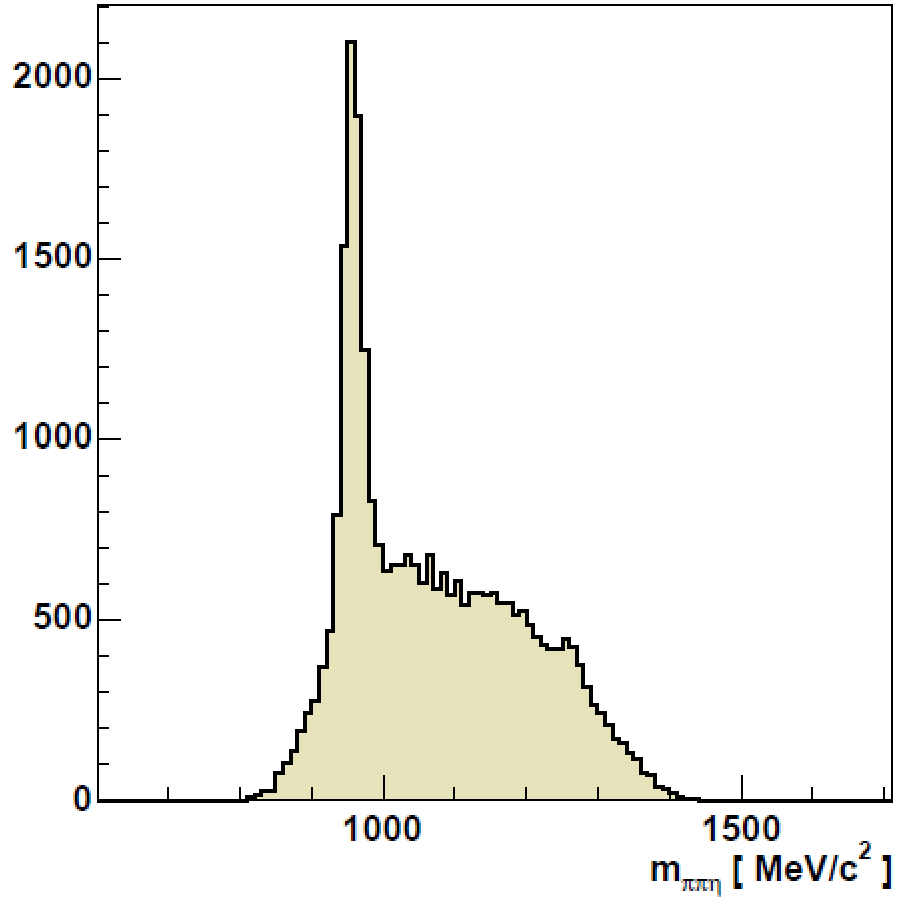
η' dynamics :prospects

- A lot of experimental activity is planned in the next future:

- KLOE/KLOE2 (tagger, γγ fusion, see C. Di Donato's talk)

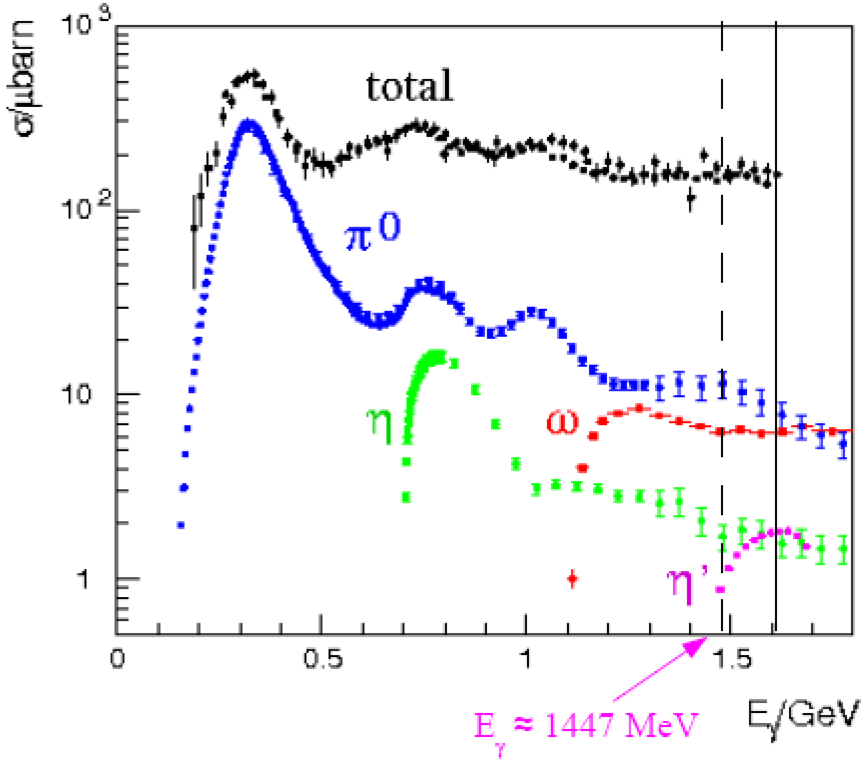
- WASA@COSY (in pp->ppη')

- ELSA (TPC inner tracker + fast trigger upgrade)



η' dynamics :prospects

- A lot of experimental activity is planned in the next future:
- KLOE/KLOE2 (tagger, γγ fusion, see C. Di Donato's talk)
- WASA@COSY (in pp->ppη')
- ELSA (TPC inner tracker + fast trigger upgrade)
- MAMI (new end point trigger + TPC inner tracker)



Chiral Dynamics and SM tests

- Extending the domain of precise calculations and measurements for hadronic observalbles is crucial for interpreting results of next generation precision experiments and challenge the SM
- One example is the success of Vus precise determination
- Another important example:

$$R_K = \frac{\Gamma\left(K^{\pm} \to e^{\pm}\nu_e\right)}{\Gamma\left(K^{\pm} \to \mu^{\pm}\nu_{\mu}\right)} = \frac{m_e^2}{m_{\mu}^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_{\mu}^2}\right)^2 \left(1 + \delta R_{QED}\right) = \left(2.477 \pm 0.001\right) \cdot 10^{-5}$$

[M. Finkemeier, Phys. Lett. B 387 (1996)]

[V. Cirigliano and I Rosell, JHEP 0710:005 (2007)]

- To be compared with the recent measurement by NA62 collaboration:

$$R_K = (2.487 \pm 0.013) \cdot 10^{-5}$$

[C. Lazzeroni et al. Phys. Lett. B 98 (2011)]

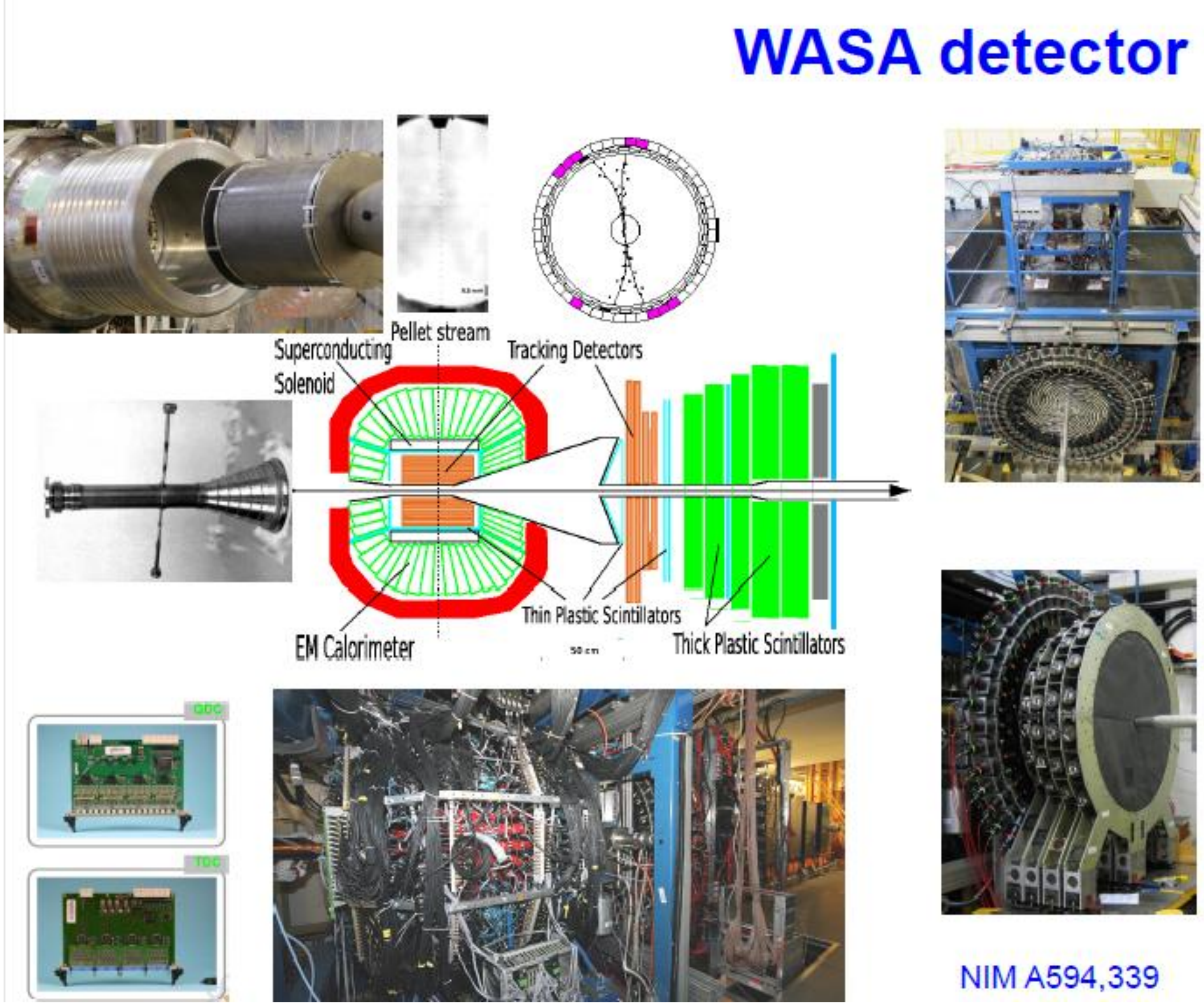
Conclusion

- $\pi\pi$ scattering show us the potential of Chiral Dynamics as a precision framework
- The determination of η dynamics is entering the precision era: this is a challenge for both theory and experiments, but is worth the fee
- More measurements next to come, with the η' playing an increasingly important role in the near future

THANK YOU

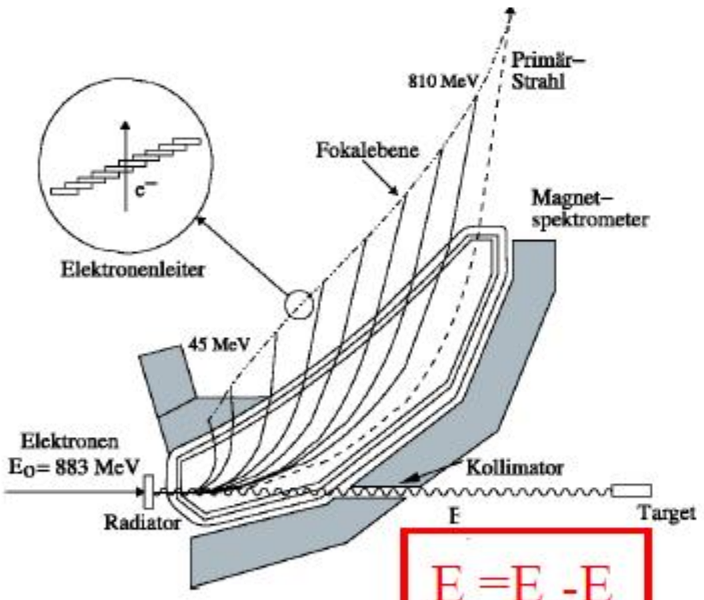
SPARE SLIDES

WASA @ COSY


WASA detector
Pellet stream
Superconducting
Solenoid
Tracking Detectors
Thin Plastic Scintillators
Thick Plastic Scintillators
EM Calorimeter
NIM A594,339

MAMI

MAMI-C Parameters:
1604 MeV σ_E<0.1 MeV
High current (110μA)
High polarisation (80%)
Duty factor 100%
~7000 h/year running experiments

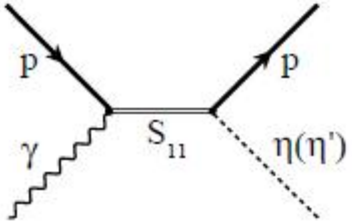


$E_\gamma = E_0 - E_{e-}$

High energy resolution: $\Delta E_\gamma \approx$2MeV at E_{e-}=883 MeV

$\Delta E_\gamma \approx$4MeV at E_{e-}=1604 MeV

Tagging range: 4.7 to 93% of E_γ



CB + TAPS @ MAMI

Crystal Ball:

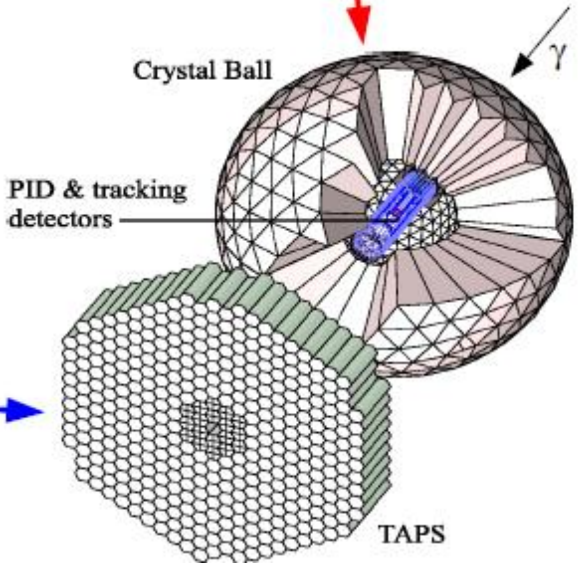
672 NaI(Tl) crystals

93,3% of total solid angle

Each crystal equipped with PMT

$$\frac{\sigma}{E_\gamma} = \frac{2\%}{(E_\gamma/GeV)^{0.25}} \qquad \sigma(\theta) = 2^\circ \ldots 3^\circ$$

$$\Delta t = 2.5 \text{ ns FWHM} \qquad \sigma(\phi) = \frac{2^\circ \ldots 3^\circ}{\sin(\theta)}$$



TAPS:

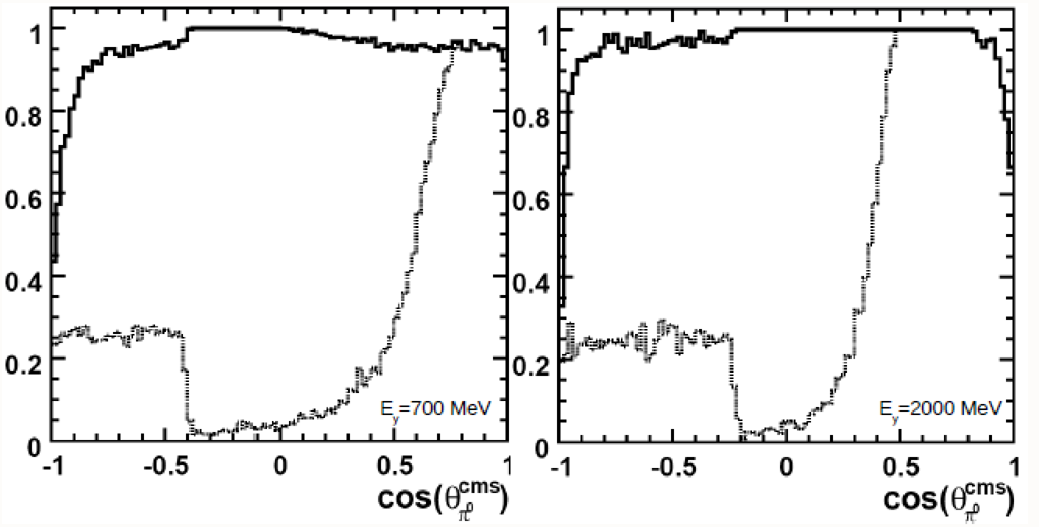
Up to 510 BaF_2 crystals

Polar acceptance: 4-20°

$$\Delta t = 0.5 \text{ ns FWHM} \qquad \frac{\sigma}{E_\gamma} = \frac{0{,}79\%}{\sqrt{E_\gamma/GeV}} + 1{,}8\%$$

CB-ELSA

Trigger efficiency of the Crystal Barrel Detector for
$\gamma p \rightarrow p\pi^0$ (solid) and $\gamma n \rightarrow n\pi^0$ (dashed)



- Crystal Barrel detector 1230 CsI crystals with photodiode readout
- Inner-detector, cylinder of 513 scintillating fibres
- Forward detector 90 CsI crystals with photomultiplier readout, 12°-30°
- MiniTAPS calorimeter covering 1.2°-12° with 216 BaF crystals