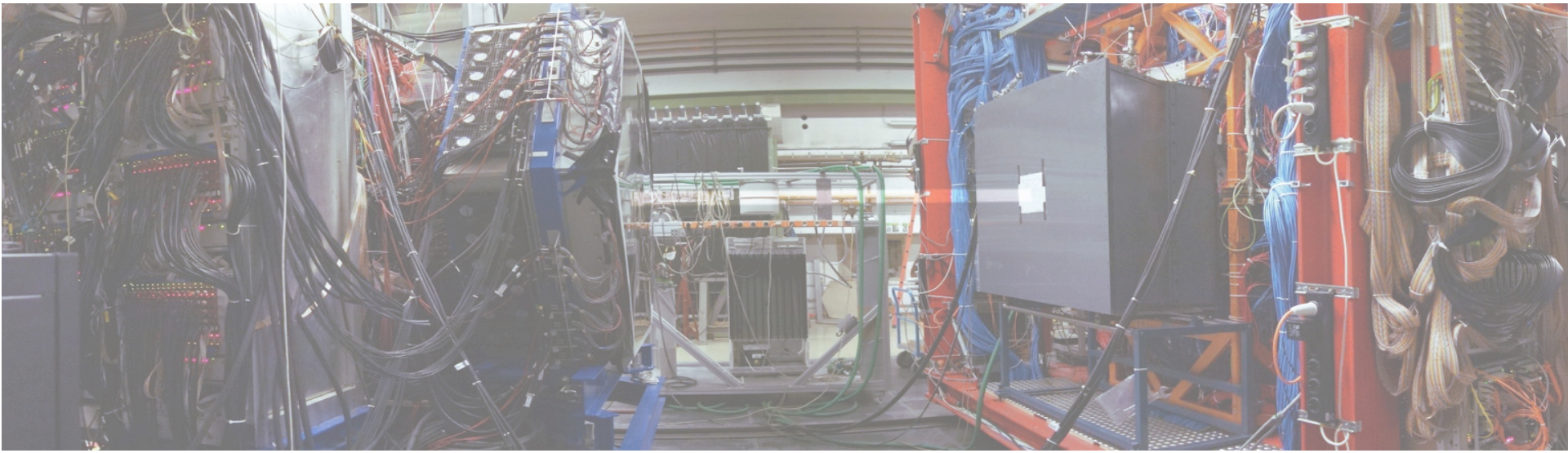


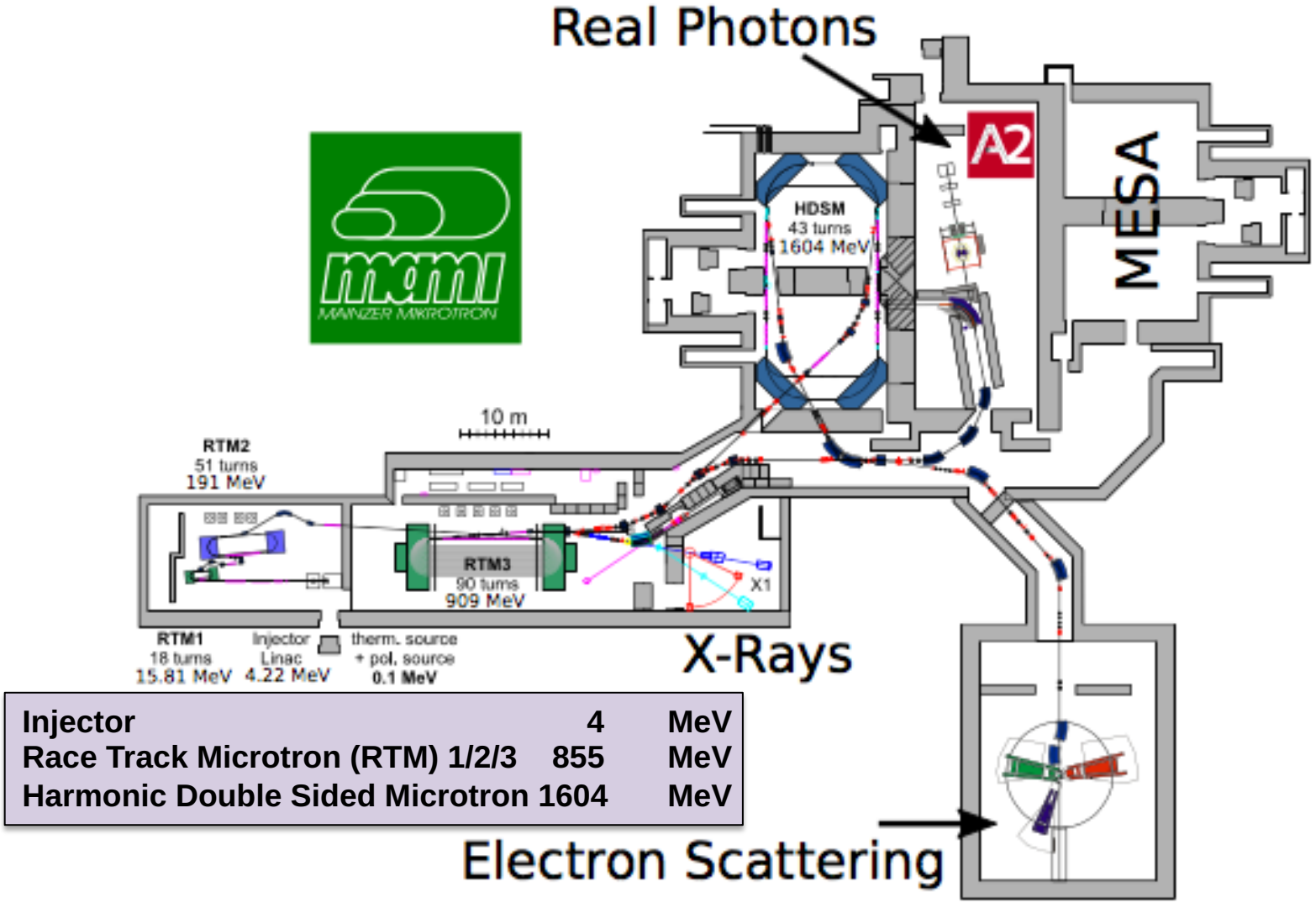
Recent Results on Meson Decays from A2

Patrik Adlarson

on behalf of the A2 collaboration at MAMI

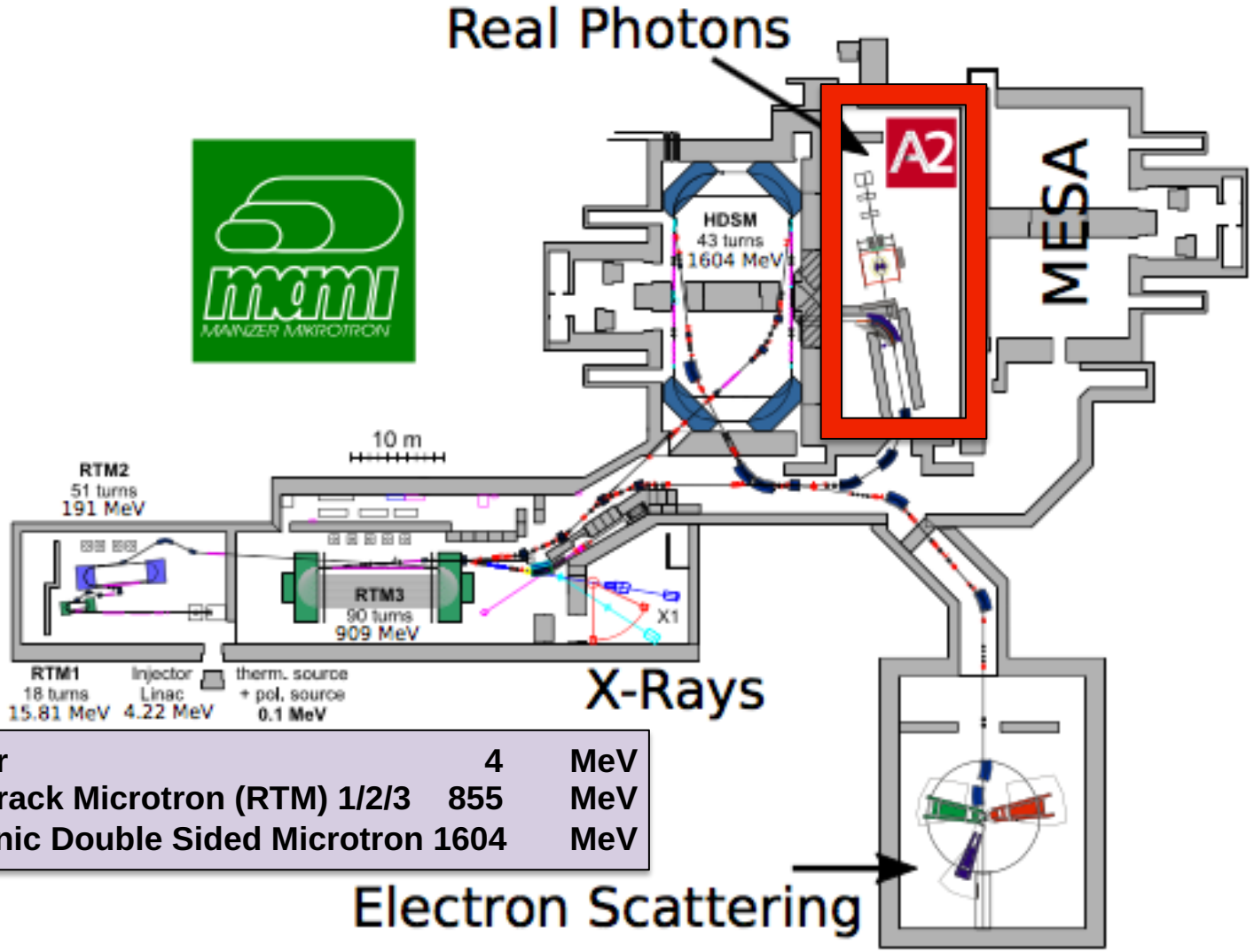
PhiPsi17 Mainz, June 29, 2017

Experiments at MAMI



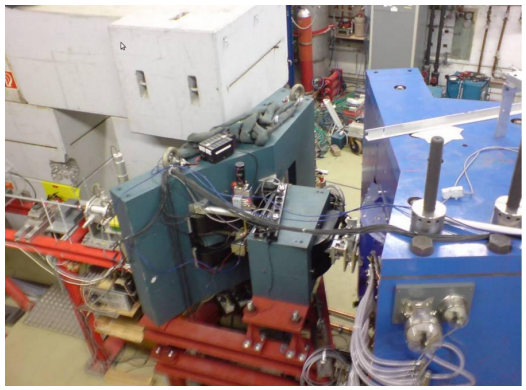
Injector	4	MeV
Race Track Microtron (RTM) 1/2/3	855	MeV
Harmonic Double Sided Microtron	1604	MeV

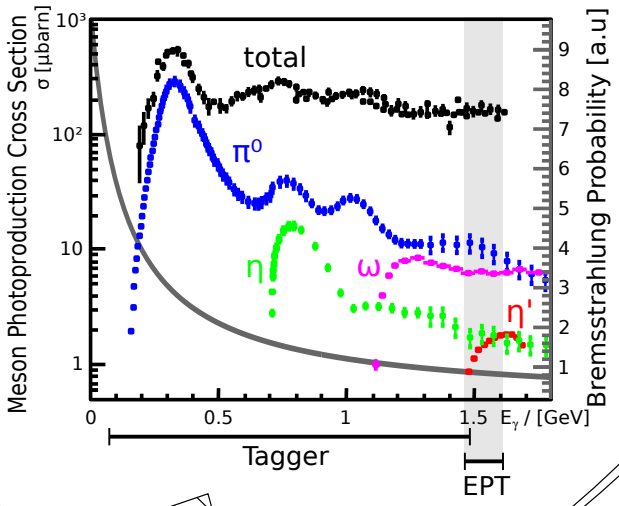
Experiments at MAMI



Injector	4	MeV
Race Track Microtron (RTM) 1/2/3	855	MeV
Harmonic Double Sided Microtron	1604	MeV

Taggers



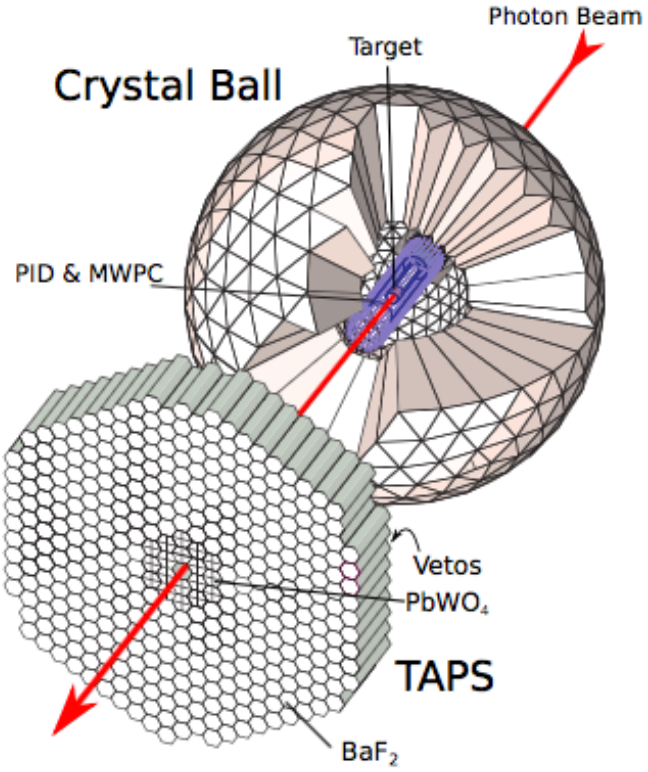


End Point Tagger

$E_\gamma = 1420$ to 1580 MeV

Resolution: 3 MeV

Exp setup CB-TAPS



Typical LH_2 target length 5 or 10 cm

CB – TAPS - 4π detector

Central Part

CB - 672 NaI(Tl) crystals
PID - 24 plastic scintillators

Forward Part

TAPS - 366 BaF_2 , 72 $PbWO_4$ crystals
Veto - 384 plastic scintillators

$$\Delta E / E = 2\ \% / (E[GeV])^{0.36} \quad \text{(CB)}$$
$$\Delta E / E = 1.8\ \% + 0.8\% / (E[GeV])^{0.5} \quad \text{(TAPS)}$$

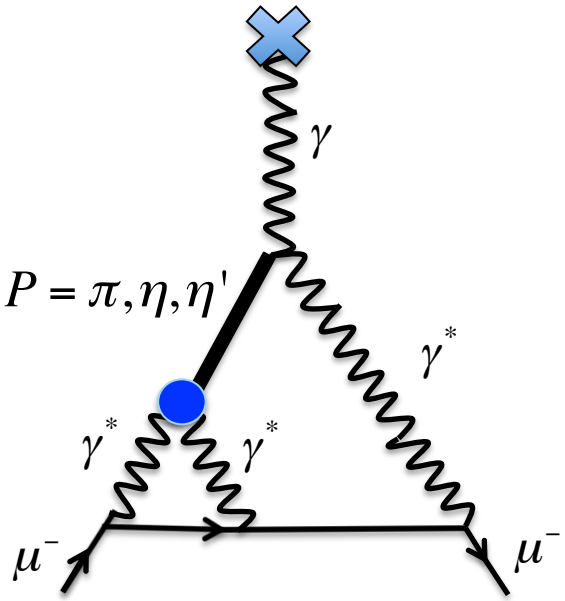
$(g-2)_\mu$ HLbL contribution

$$a_\mu^{hadr} = (692.3 \pm 4.2)\cdot 10^{-10} + (10.5 \pm 2.6)\cdot 10^{-10}$$

J. Prades, E. de Rafael, A. Vainshtein, arXiv:0901.0306

$$(11.6 \pm 3.9)\cdot 10^{-10}$$

F. Jegerlehner and A. Nyffeler, Phys. Rept. 477, 1 (2009)



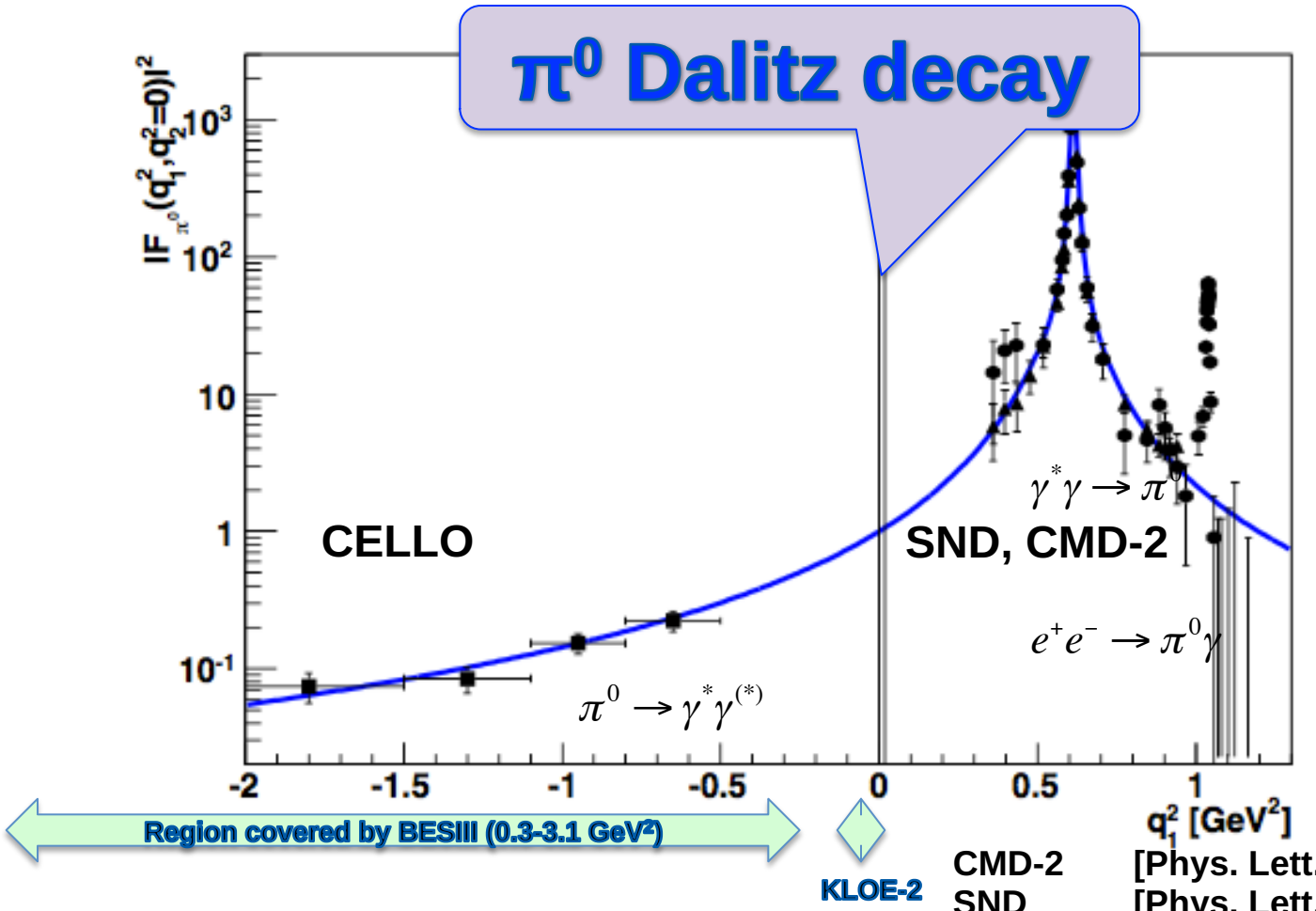
Interaction of virtual mesons with $\gamma^{(*)}$

No direct relation to measureable quantities-model dependence

Off-shell P form factors not accessible experimentally…but any aspiring theory/model should be able to correctly describe also the on-shell scenario

TFF used as experimental input

$\pi^0\gamma$ Transition Form Factor



CMD-2 [Phys. Lett. B 605, 26 (2005)]
SND [Phys. Lett. B 504, 275 (2001)]
CELLO [Z. Phys. C 49, 401 (1991)]

E. Perez (KLOE-2)@11.40; C.Redmer(BESIII) 12.20

π^0 Dalitz Decay

Observable: slope parameter a_π
FF = $(1 - a_\pi x)^{-1} \sim 1 + a_\pi x$ for small a_π

Theory

VMD	+0.031
ChPT 2 –loop	+0.029(5)

Kampf, Knecht, Novotný, EPJ C46 (2006) 191

"...we think that a precise measurement of a_π which would not rely on any kind of extrapolation remains an interesting issue."

Dispersive approach	+0.0307(6)

Hoferichter, *et al*. EPJ C74, 3180 (2014)

Padé approximants	+0.0324(22)

P. Masjuan, Phys. Rev. D 86, 094021 (2012).

Experiment time-like

SINDRUM-I Coll.	$+0.025(14)_{stat}(26)_{syst}$	54k

Drees *et al* Phys.Rev.D 45 (1992) 1439

NA62	$+0.0368(48)_{stat}(18)_{syst}$	1110k

PLB 768 (2017) 38

Extrapolation space-like region

CELLO	+0.0326(26)stat(26)syst

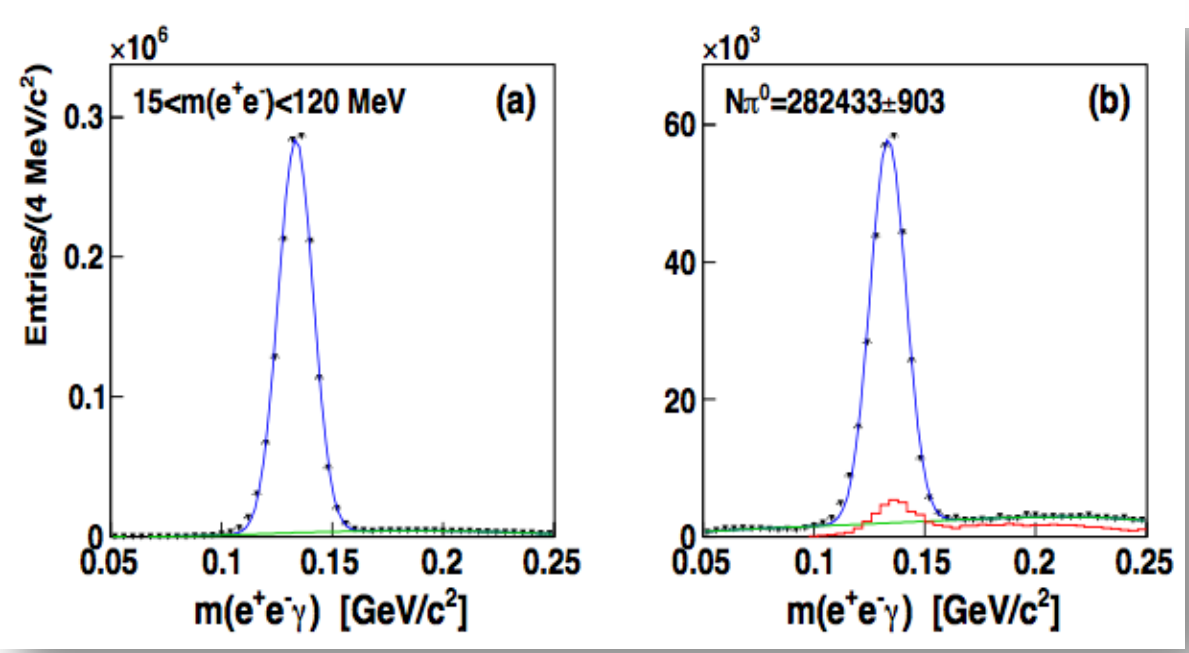
Behrend *et al* (CELLO) Z. Phys.C 49 (1991) 401

CLEO	+0.0303(8)stat(9)syst(12)

Gronberg *et al* (CLEO) Phys.Rev.D 57 (1998) 33

BESIII forthcoming

π^0 Dalitz Decay at A2



A2 result based on 4.0 x 10^5 Dalitz decays from 15-120 MeV in $m(e^+e^-)$ from two different beam times

Low background content, normalization to $\pi^0 \rightarrow 2\gamma$

QED with radiative corrections taken into account

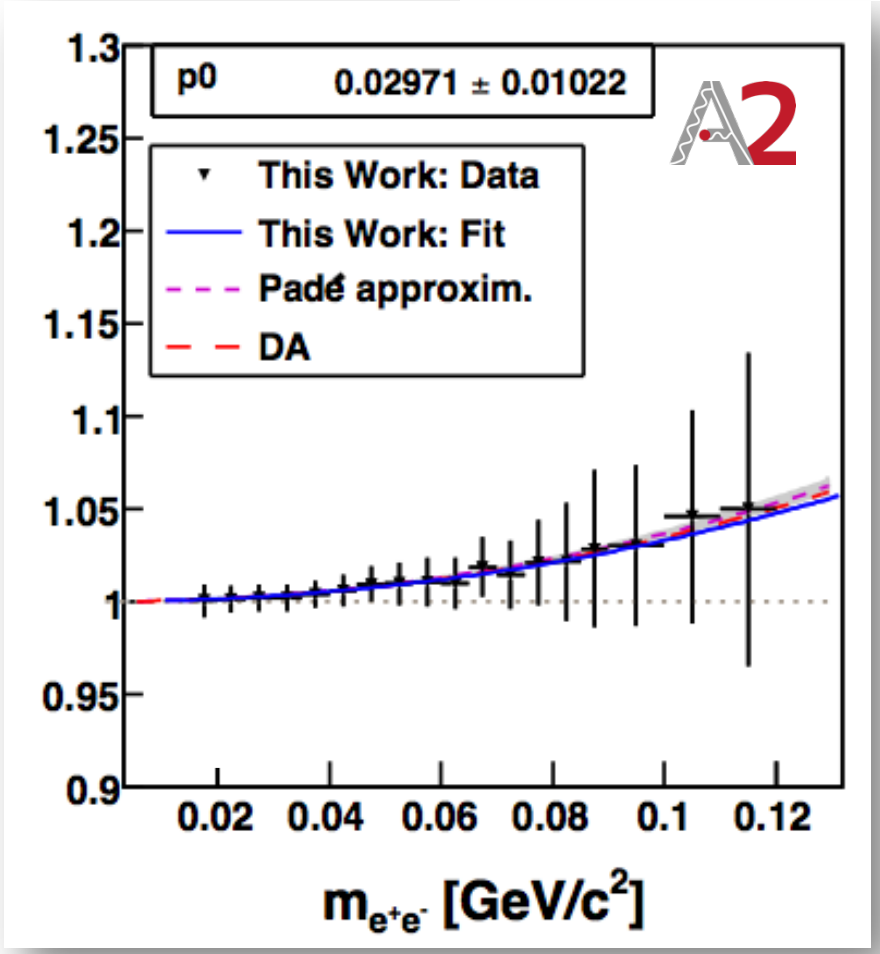
T. Husek, K. Kampf, and J. Novotny , Phys. Rev. D 92, 054027 (2015).

π^0 Dalitz Decay results A2

$a_\pi = 0.030(10)_{tot}$

Dispersive approach +0.0307(6)
Hoferichter, *et al*. EPJ C74, 3180 (2014)

Padé approximants +0.0324(22)
P. Masjuan, Phys. Rev. D 86, 094021 (2012).



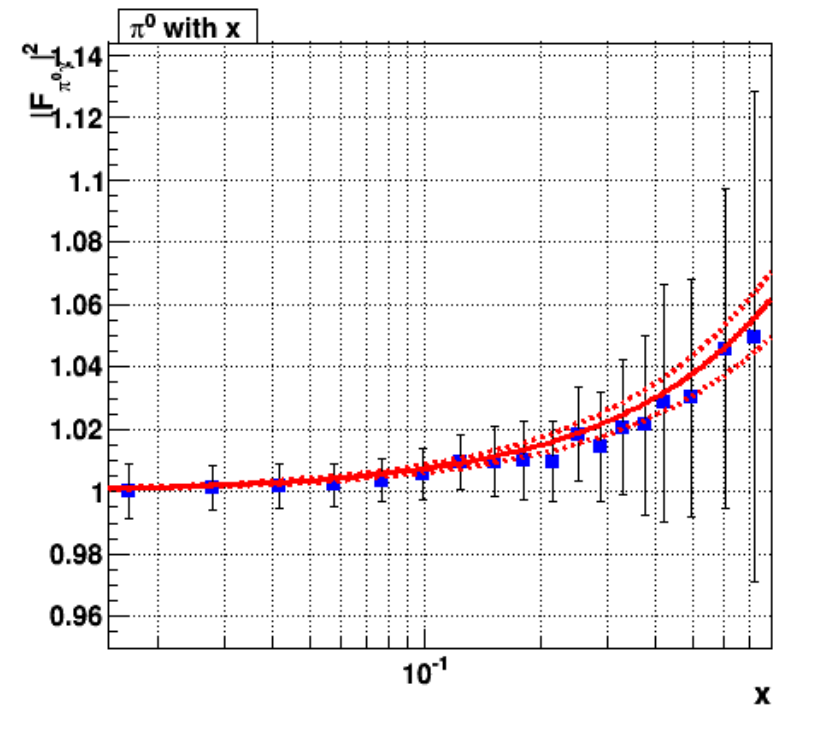
In agreement with current theoretical estimates

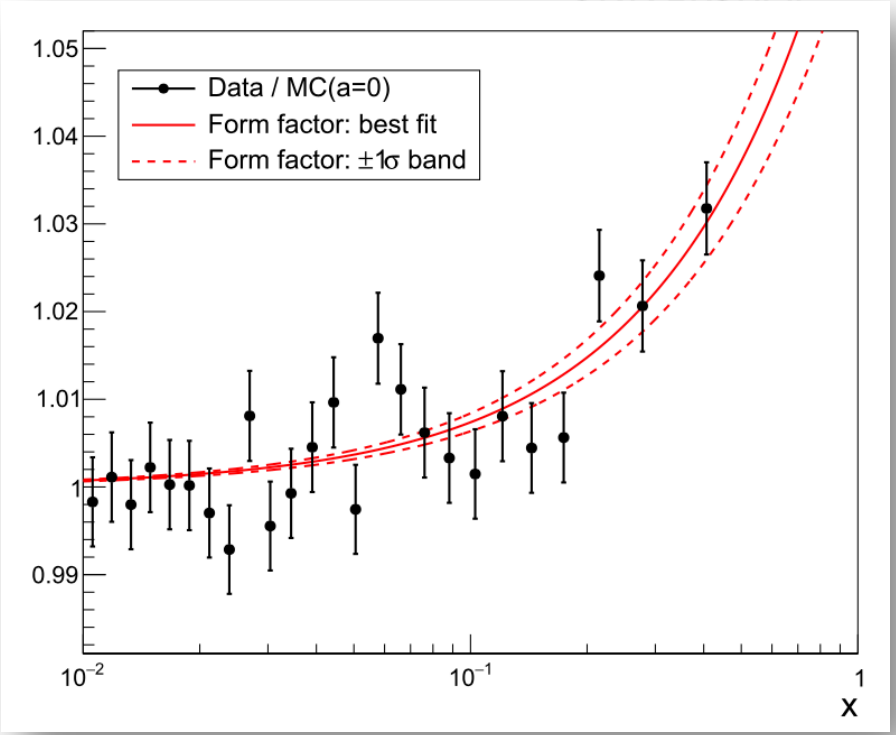
18 data points with total uncertainties provided

Phys.Rev. C 95 no. 2 (2017) 025202

Future plan to further reduce errors

A2 versus NA62 prel





$$a_\pi = 0.030 \pm 0.010_{tot}$$

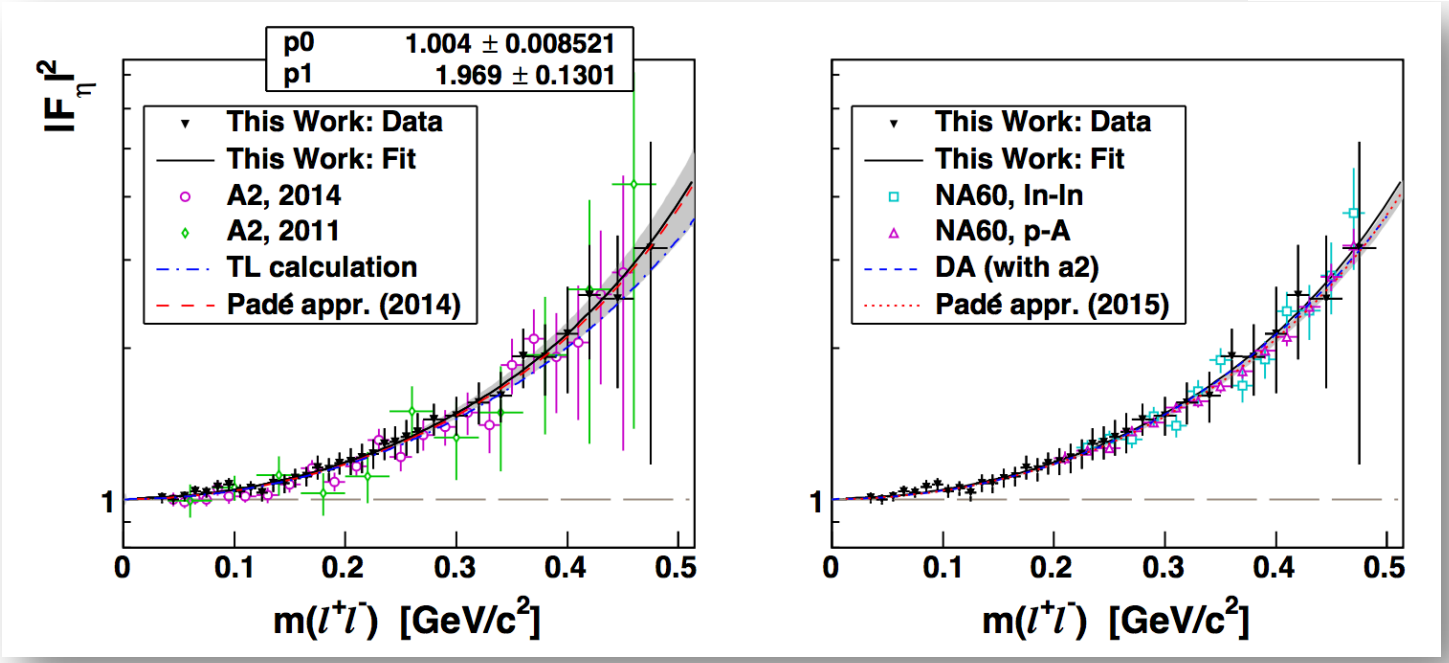
A2 PRC 95 2 (2017) 025202

$$a_\pi = 0.0368 \pm 0.0051_{tot}$$

NA62 PLB 768 (2017) 38

In red- fit parametrization of NA62 onto A2 data (left) and NA62 data (right)

η Dalitz Decay results



A2	Λ^{-2} = 1.97 (13)$_{tot}$ GeV^{-2}		[arXiv:1609.04503 (2016)]
	$\|F_\eta\|^2$ = 1.004(8) compatible with 1 within 1σ		PRC 95 (2017) 035208
NA60	Λ^{-2} = 1.934(67)$_{stat}$ (50)$_{syst}$ GeV^{-2}	($l = \mu$)	[PLB 757 (2016) 437]

Good agreement with theory, NA60 and previous A2 results
Data points with total uncertainties provided

$\omega\pi^0$ TFF and VMD

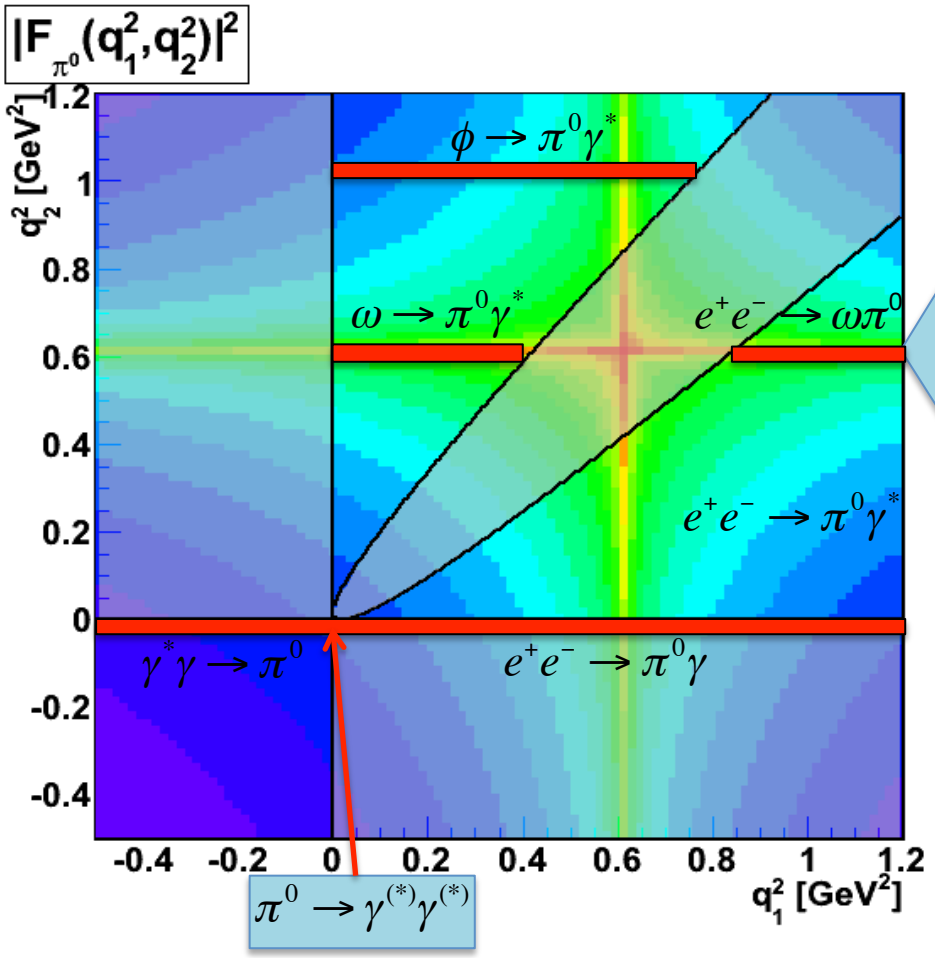


Figure by A. Kupsc, Uppsala University

VMD description fails to reproduce data

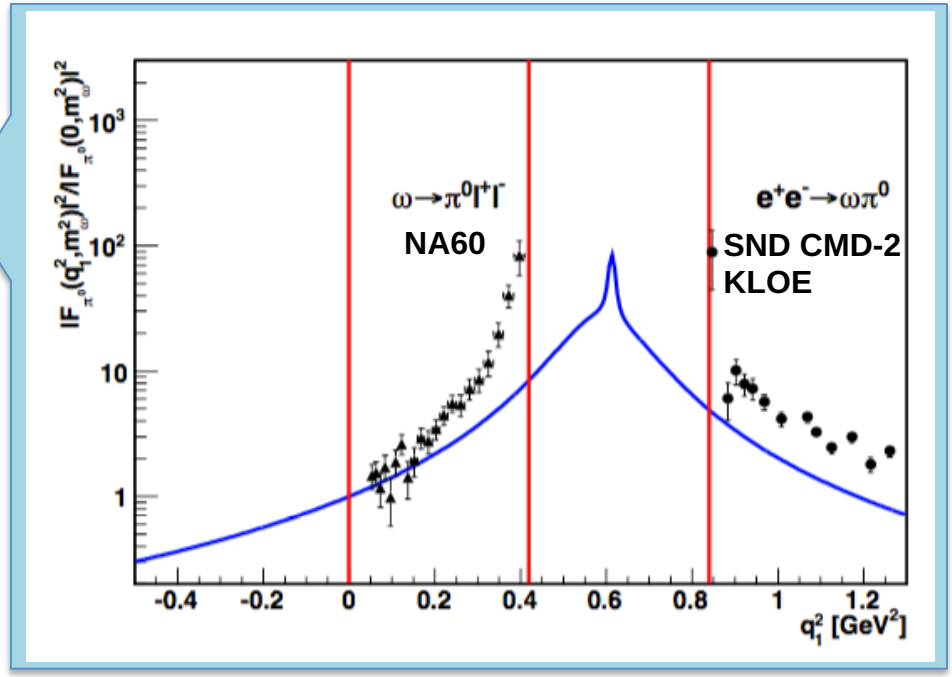
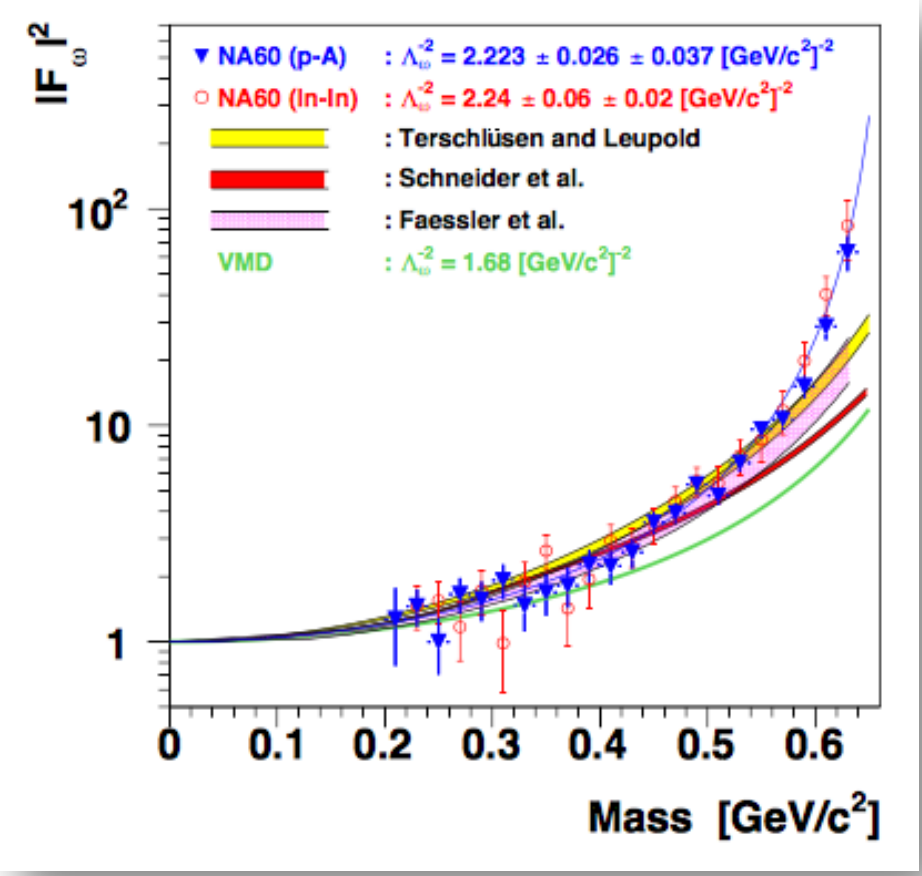


Figure from arXiv:1207.6556

NA60	**[Phys. Lett. B 677 (2009) 260]**
SND	**[Phys. Lett. B 486 (2000) 29]**
CMD-2	**[Phys. Lett. B 562 (2003) 173]**
KLOE	**[Phys. Lett. B 669 (2008) 223]**

$\omega \longrightarrow \pi^0\mu^+\mu^-$ with NA60

NA60 PLB 757 (2016) 437



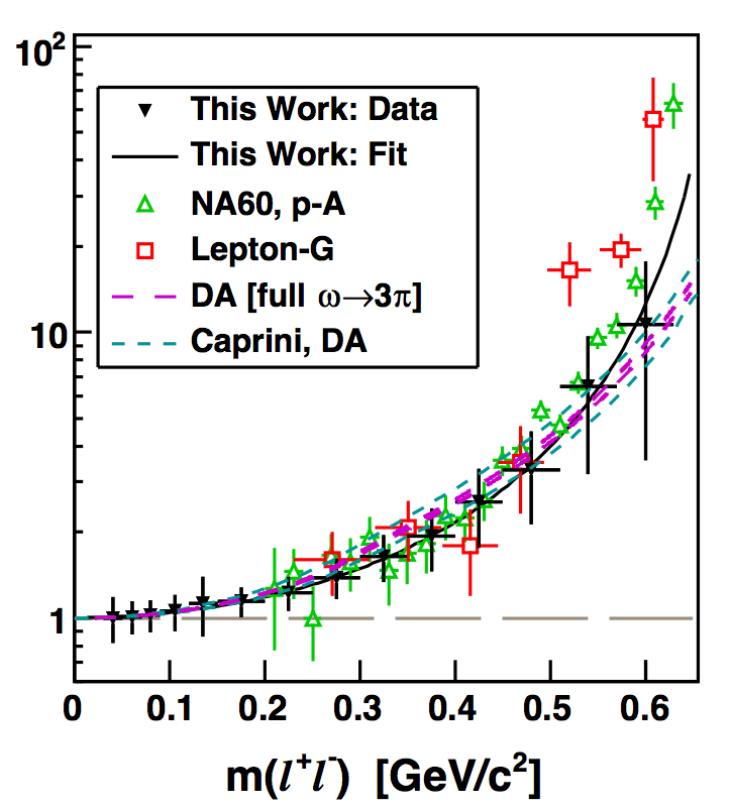
No theoretical approach which reproduce TFF data for η, and other mesons, can describe TFF data based on the ω → π⁰μ+μ⁻ decay at large m(μ⁺μ⁻).

$$\Lambda_{\omega\pi^0}^{-2} = 2.223(26)_{stat}(37)_{syst}\,GeV^{-2}$$

NA60 discrepancy…independent results needed

$\omega \longrightarrow \pi^0 e^+ e^-$ with A2

PRC 95 035208 (2017)



NA60

$$\Lambda^{-2}_{\omega\pi^0} = 2.223(26)_{stat}(37)_{syst}\,GeV^{-2}$$

$$\Lambda^{-2}_{\omega\pi^0} = 1.990(220)_{tot}\,GeV^{-2}$$

PRC 95 035208 (2017)

1100 $\omega \rightarrow \pi^0 e^+ e^-$ decays based off 2.27×10^7 produced ω

In agreement with theoretical descriptions, e.g. dispersive approaches

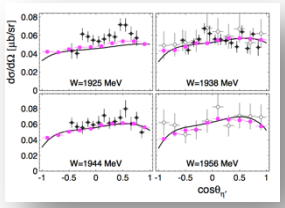
S. P. Schneider, B. Kubis, and F. Niecknig, Phys. Rev. D 86, 054013 (2012).
I. Caprini, Phys. Rev. D 92, 014014 (2015).

Slightly lower compared to NA60 but more experimental data needed

η' with A2

η' campaign 2014- special tagger built for this purpose covering E_γ 1420-1585 MeV
Outcome: 6 x 10^6 η' collected

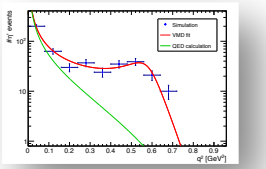
Production mechanism: $\gamma p \rightarrow \eta' p$



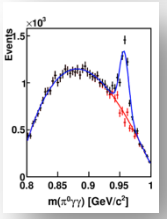
PRL 118 (2017) 2012001

QCD: $\eta' \rightarrow \eta\pi\pi$

Transition Form Factors $\eta' \rightarrow e^+e^-\gamma$



Branching ratios, Chiral EFT $\eta' \rightarrow \omega\gamma$



Forbidden / Suppressed decays $\eta' \rightarrow 2\pi$ $\eta' \rightarrow 4\pi$

Motivation η' ⟶ η $\pi^0\pi^0$

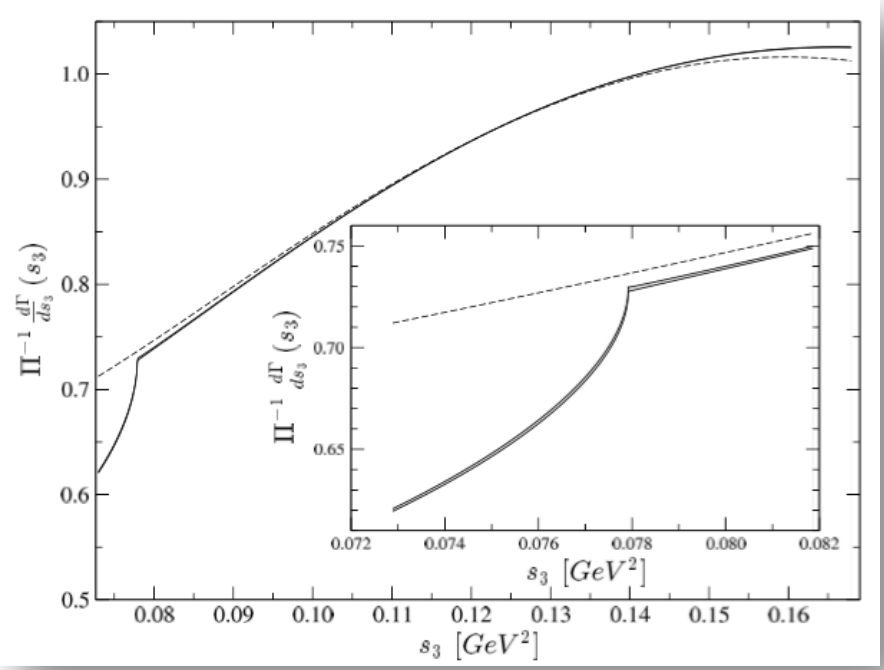


Figure from EPJ C 62 (2009) 511

Cusp effect due to $\pi^+\pi^-$ ➞ $\pi^0\pi^0$ rescattering

First seen in K^+ ➞ $\pi^0\pi^0\pi^+$ by NA48/2 coll

Predicted in η/K_L ➞$3\pi^0$ having few % effect

From study of cusp effect one can extract S-wave ππ scattering lengths NREFT prediction from Kubis, Schneider cusp is 6% < $m_{\pi+\pi-}$ threshold

Motivation η' ⟶ η $\pi^0\pi^0$

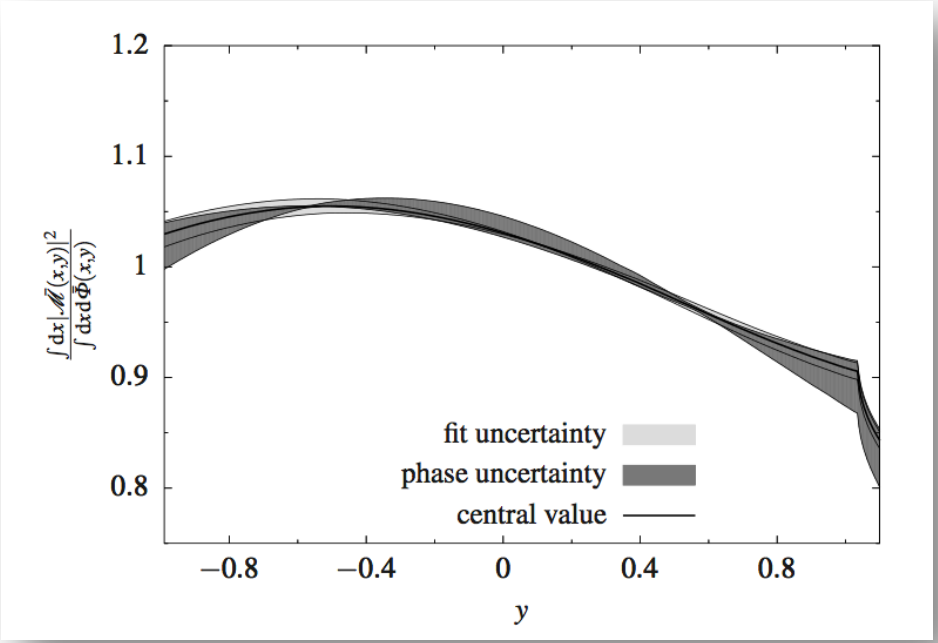


Figure from arXiv:1705.04339, Isken, Kubis, Schneider, Stoffer

Dispersive representation uses Dalitz plot as input. Three or four subtraction constants determined from experimental data. Cusp effect incorporated into effective phase shifts.

Here: BESIII data used for subtraction constants predicting η' ⟶ η$\pi^0\pi^0$

Motivation $\eta' \longrightarrow \eta \pi^0\pi^0$

ChPT is low energy effective field theory of QCD – π, K, η
η' not included as external d.o.f due to axial anomaly. Works well below the resonance region m_σ

large N_C ChPT: axial anomaly absent $U(3)_L \times U(3)_R$ with π, K, η, η' included. Does not include resonances as external states, but in LEC

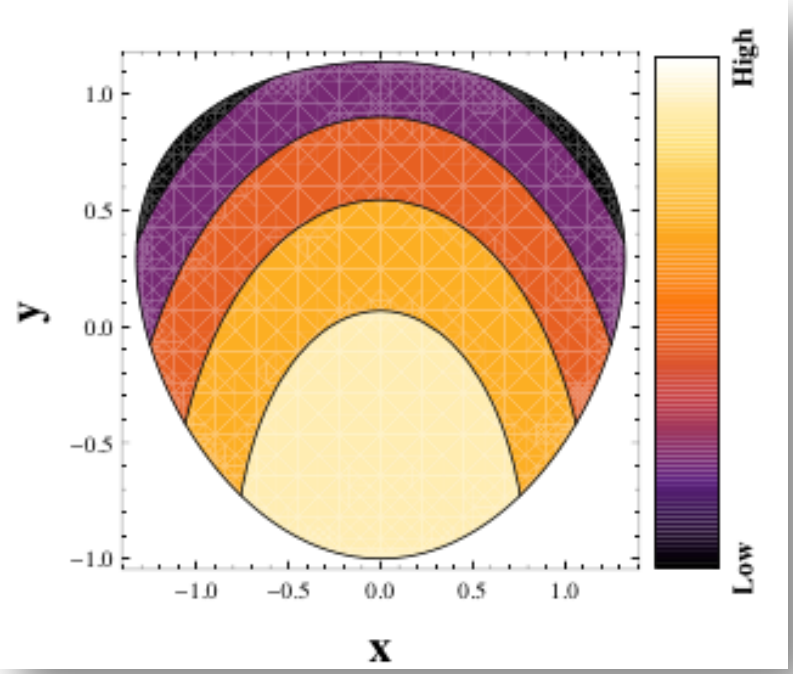
[R. Kaiser and H. Leutwyler, Eur. Phys. J. C 17, 623 (2000)]

Resonance ChPT: takes resonances into account explicitly - ρ, σ, a_1 included

G. Ecker, J. Gasser, H. Leutwyler, A. Pich and E. de Rafael, Phys. Lett. B 223 (1989) 425

Tests ChPT extensions by Escribano, Masjuan, Sanz-Cillero [JHEP 1105 (2011) 094] with $\eta' \Rightarrow \eta\pi\pi$ as probe

Dalitz plot $\eta' \longrightarrow \eta \pi^0\pi^0$



Dalitz plot to compare theory and exp

$$X = \frac{\sqrt{3}(T_{\pi 1} - T_{\pi 2})}{Q} \qquad Y = \frac{(m_\eta + 2m_\pi)}{m_\pi}\frac{T_\eta}{Q} - 1$$

$$Q = T_{\pi 1} + T_{\pi 2} + T_\eta = m_{\eta'} - m_\eta - 2m_\pi$$

$$|A(X,Y)|^2 = |N|^2\left[1 + aY + bY^2 + cX + dX^2\right]$$

Dalitz plot parameters a, b, c, d, …

In isospin-limit neutral and charged decay should give same result

Charged decay BESIII collaboration 4.3×10^4 **[Phys.Rev. D83 (2011) 012003]**

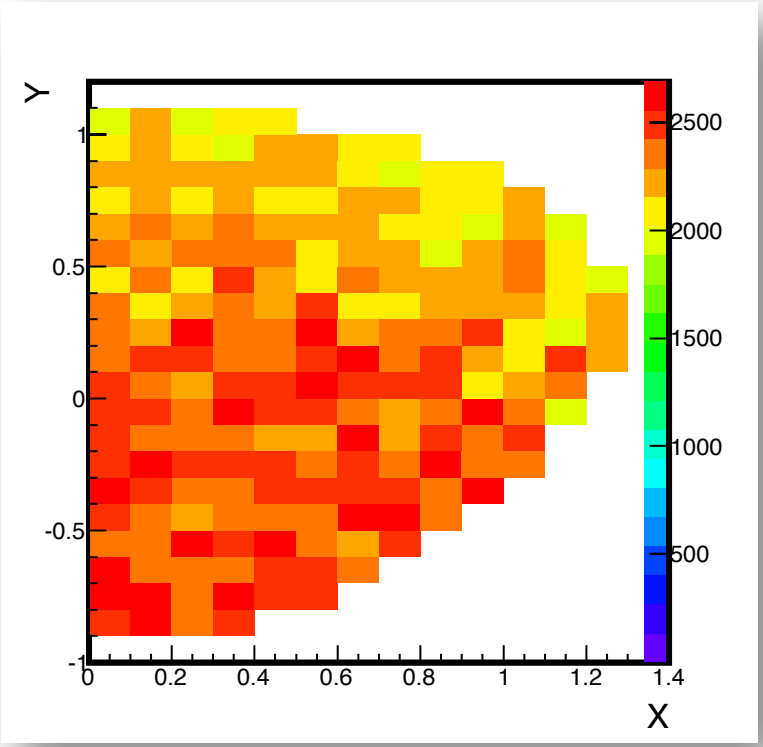
Neutral decay GAMS4π collaboration 1.5×10^4 **[Phys Atomic Nucl, 2009, Vol. 72, 231]**

η' ⟶ η π⁰π⁰ Results A2

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

A2 Preliminary

Exp / Th	a	b	c	d
VES	-0.127(18)	-0.106(31)	-	-0.082(19)
BESIII	-0.047(11)	-0.069(21)	0.019(11)	-0.073(12)
GAMS4π	-0.066(16)	-0.064(29)	-	0.067(20)
LN_C ChPT	-0.098(48)*	-0.050(1)	0	-0.092(8)
RChT	-0.098(48)*	-0.033(1)	0	-0.072(1)
A2 prel	**-0.074(8)(6)**	**-0.063(14)(5)**	**-**	**-0.050(9)(5)**

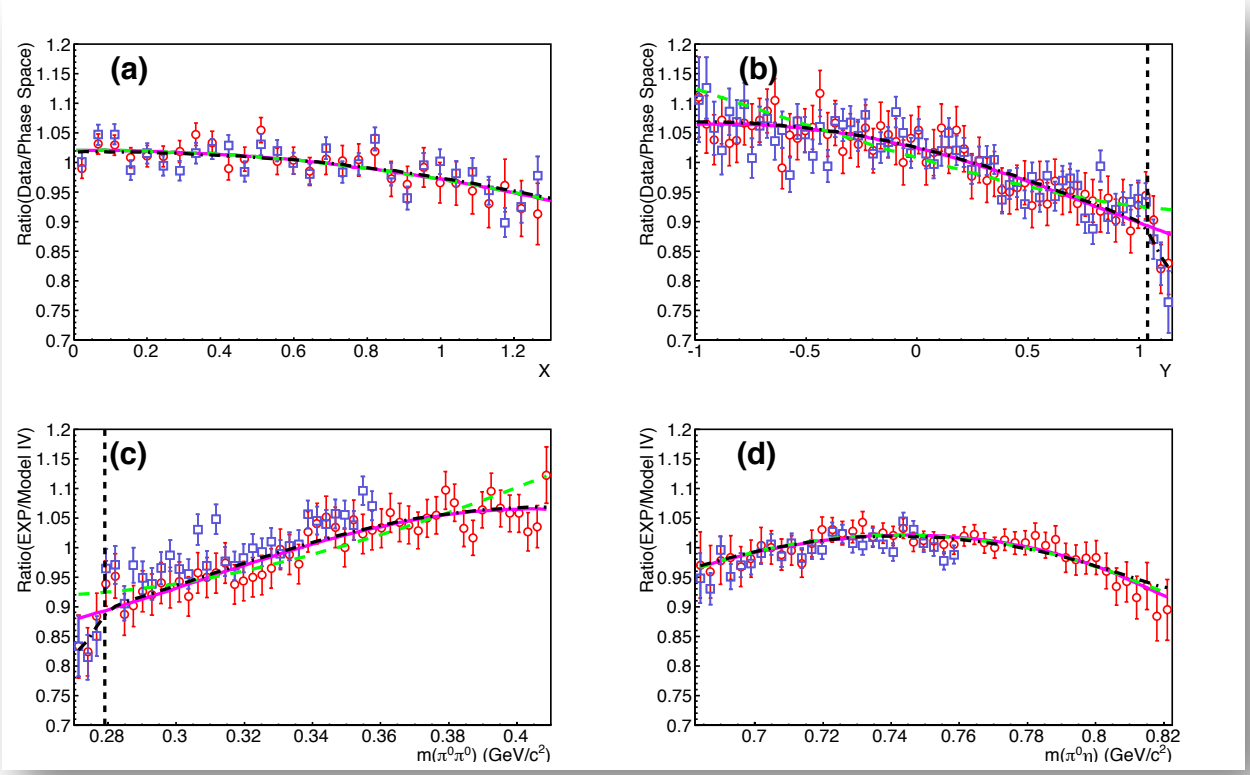


Factor 8 greater statistics compared to GAMS4π, 120 000 events

Results in agreement with GAMS4π but with better precision

η' ⟶ η π⁰π⁰ Results A2

A2 Preliminary

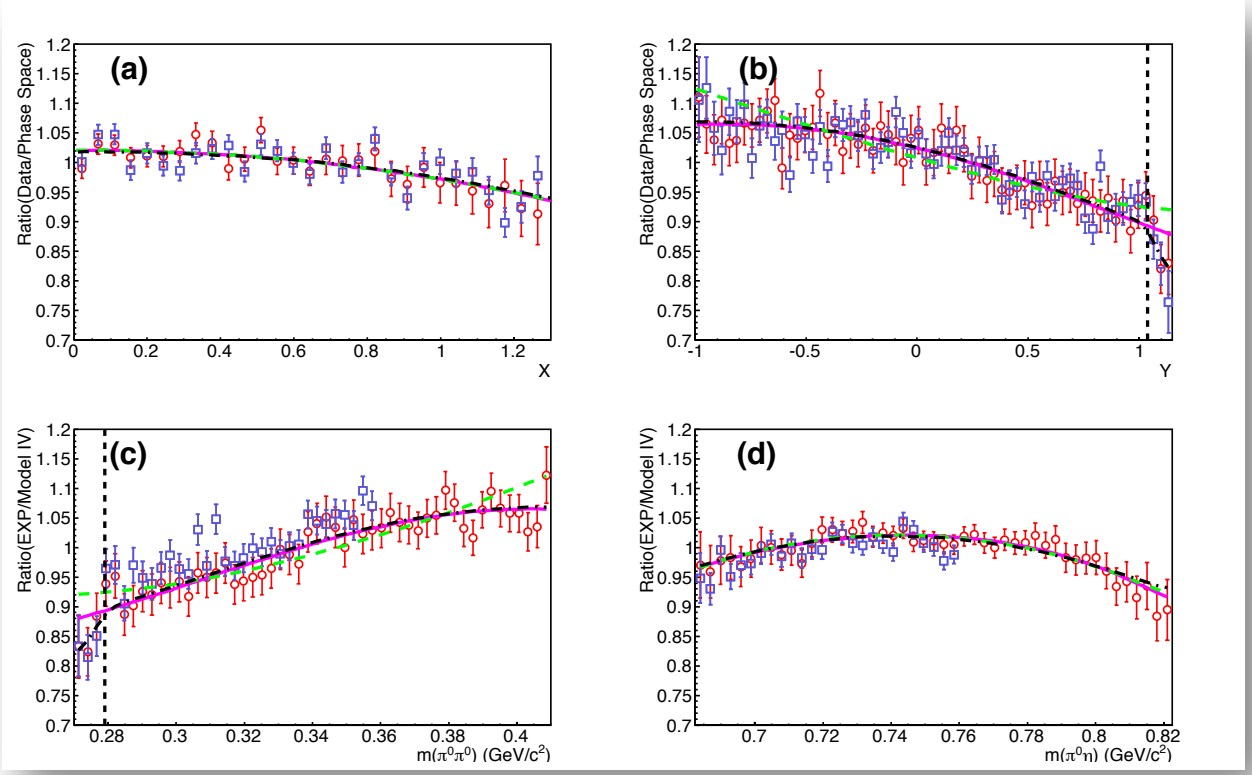


- blue and red data points analysis I and II
- green – linear parametrization
- purple - polynomial black – NREFT

PhiPsi17 Mainz, June 26-29 2017

η' ⟶ η π⁰π⁰ Results A2

A2 Preliminary



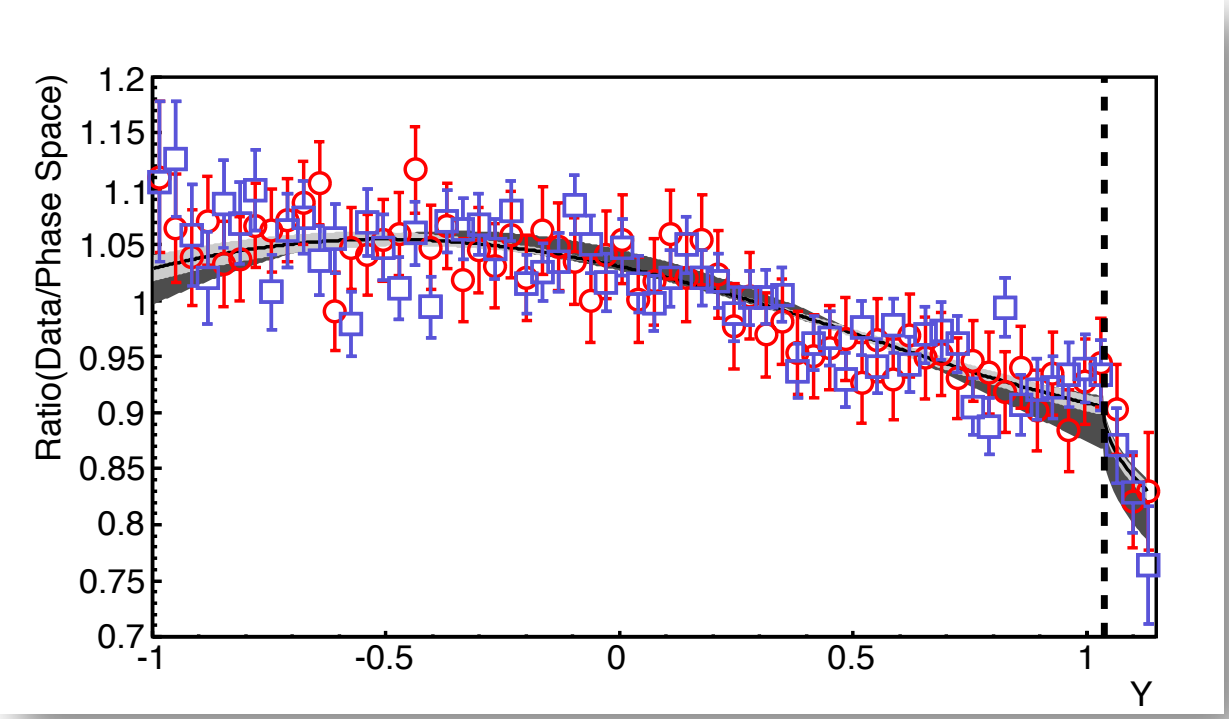
Fit to cusp using NREFT amplitude gives -0.19(8), compatible with a_2-a_0 = -0.2644

Strong indication that sc. lengths can be determined for decays other than K⟶3π!

Paper forthcoming…

η' ⟶ η π⁰π⁰ Results A2

A2 Preliminary



…also data in good agreement with the dispersive representation

…with BESIII data used as input

Summary A2 results

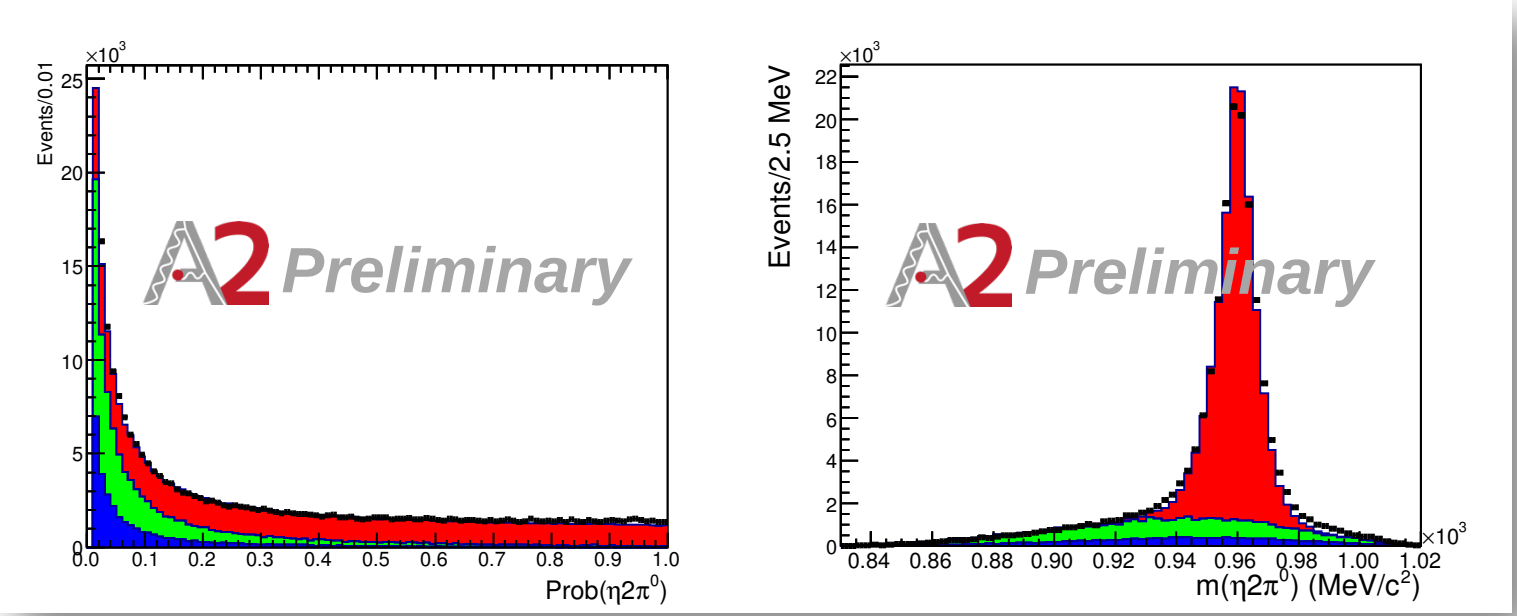
Several new results from A2 collaboration on time-like TFF. Prepared for theoreticians by giving data points with total uncertainties

η' campaign in 2014. Several Ph.D. and post-docs working on the analyses. Preliminary results on $\eta' \rightarrow \eta\, \pi^0\pi^0$ showing indication of cusp in $m_{\pi\pi}$

Outlook: Exciting results from A2 in the upcoming years.

THANK YOU

η' ⟶ η $\pi^0\pi^0$ Results A2



Two analyses conducted on same data sample- results consistent

Removal of background by kinfit with mass constraints

Largest background from $3\pi^0$, $\eta\pi^0$

Factor 8 greater statistics compared to GAMS4π, 120 000 events