The 14th International Conference on Meson-Nucleon Physics and the Structure of the Nucleon

July 25-30, 2016 in Kyoto, Japan

Hadron Physics at KLOE-2

C.Bloise

on behalf of the KLOE-2 Collaboration

INFN Frascati Laboratory, Italy

Outline

- Status Report on KLOE-2 at Daϕne
- Precision measurements in hadron physics
- Form factor of $\phi \to \eta\, e^+e^-$ transitions
- Form factor of $\phi \to \pi^0 e^+e^-$ transitions
- Analysis of the $\phi \to \pi^+\pi^-\pi^0$ Dalitz plot
- $\gamma\gamma$ physics
- Conclusions

The KLOE experiment

The KLOE experiment, at the Frascati φ–factory Daφne took data in 2001-2002 and 2004-2006

2.5 fb^{-1} integrated at 1.02 GeV; 250 pb^{-1} at 1 GeV

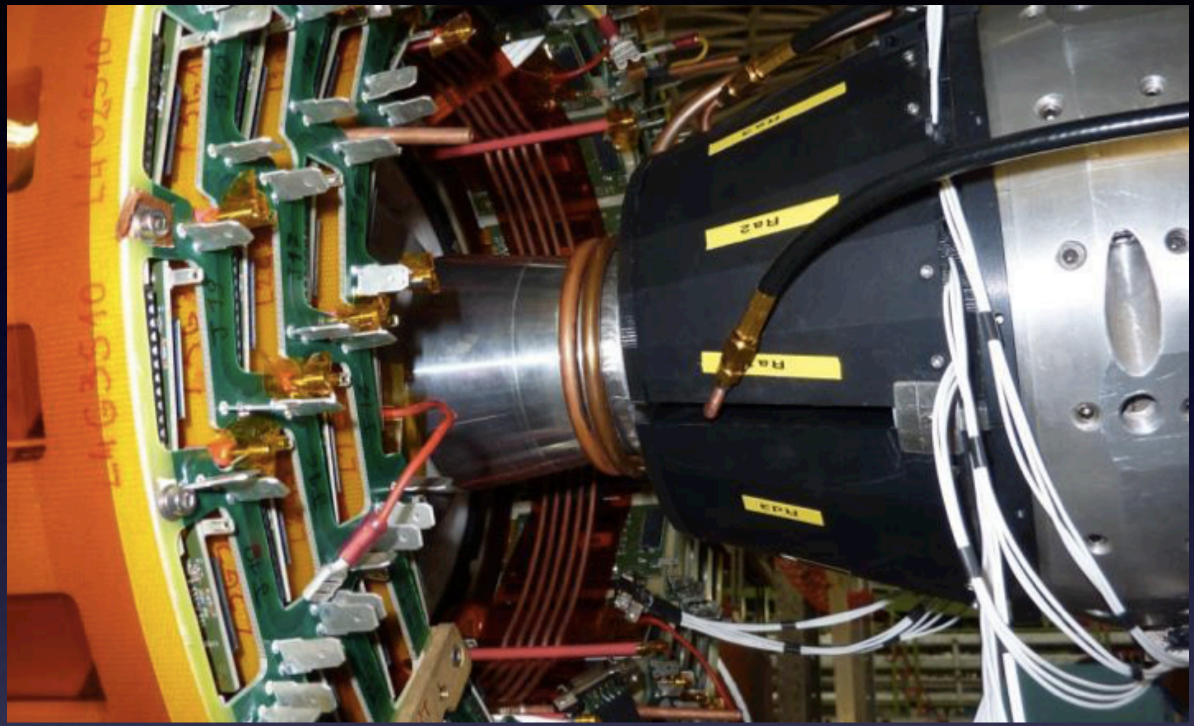
Excellent-quality data set for precision measurements of

CKM unitarity
QM, and CPT invariance;
CP in kaons;
QCD models based on ChPT;
isospin-violating decays for the measurement of the light quark masses ratio;
hadronic cross section for the calculation of HVP
γγ physics

New data taking to integrate 5 fb^{-1} during 2014-17
G. Amelino-Camelia et al., EPJ C68, 619 (2010)

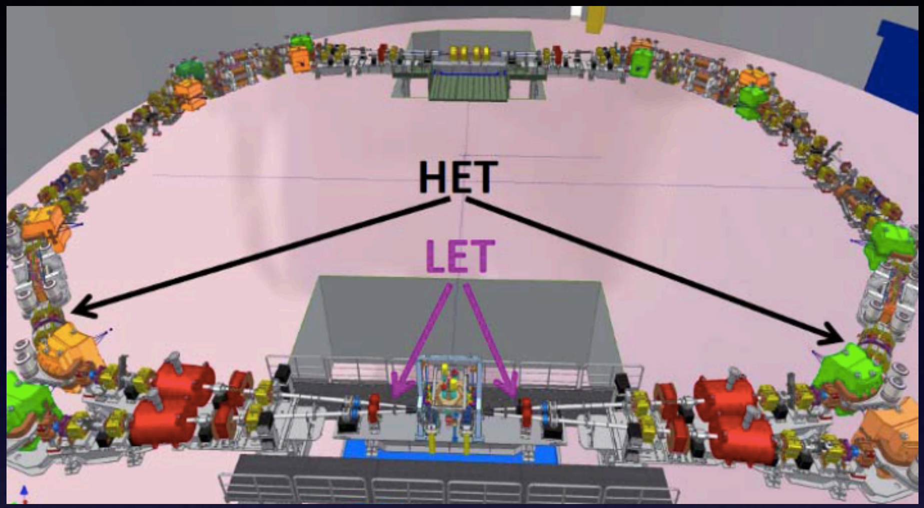
KLOE-2 Run follows
the upgrade of Daφne interaction region with crab-waist
the KLOE upgrade with the installation of IT, calorimeters at low angle, taggers for γγ physics
consolidation works on Daφne

Detector upgrades



Installation of the upgrades and the IR in Dafne completed on 12 July 2013

Tagging system for γγ physics



Two stations have been installed

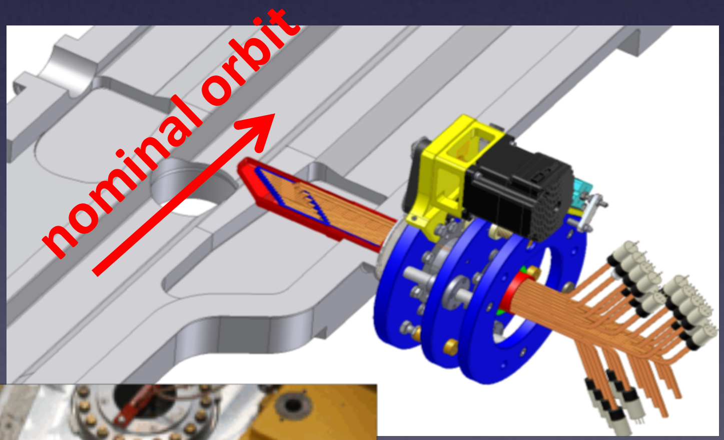
HET station (scintillator strips) @ 11 m from the IP
DAFNE bending dipoles used as spectrometer

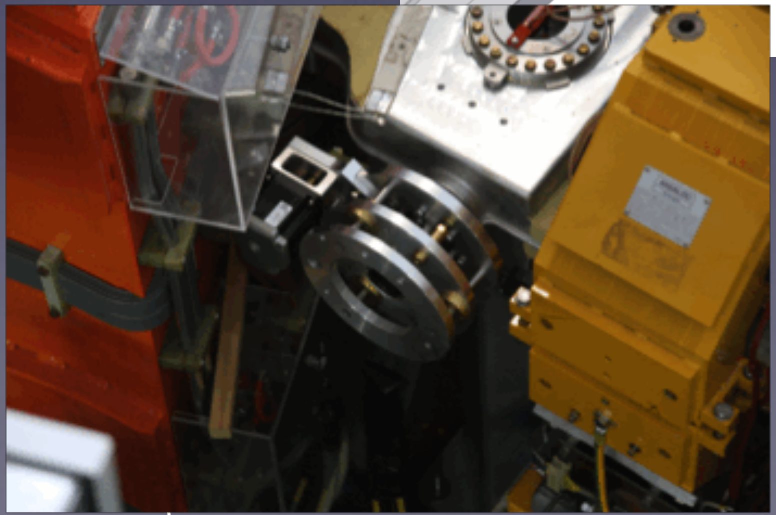
Energy acceptance for final-state particles expected in the range 410-490 MeV

LET station (LYSO crystals) @ 2 m from the IP, in one of the QCALT wedges

It should detect final-state particles of about 200 MeV

With taggers, on-peak data could be used for γ–γ study





Daφne operation

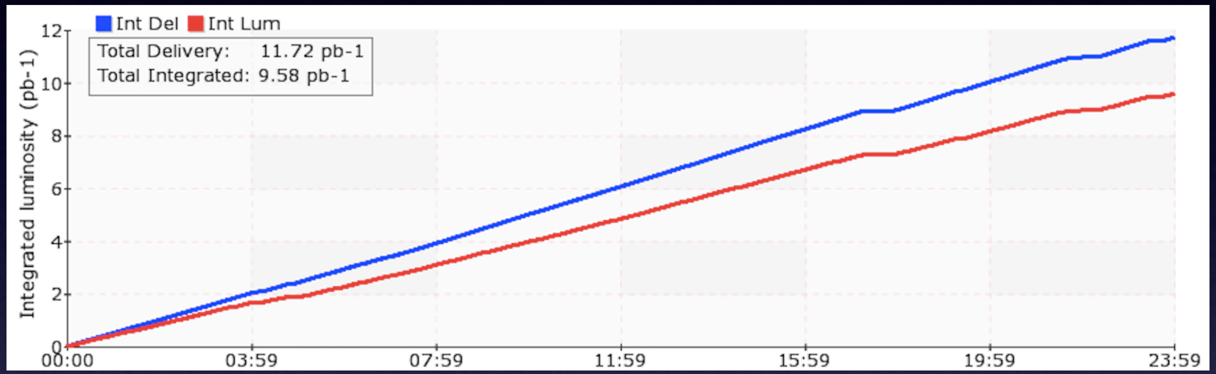
The accelerator complex was consolidate in 2013-14 to substantially improve the uptime

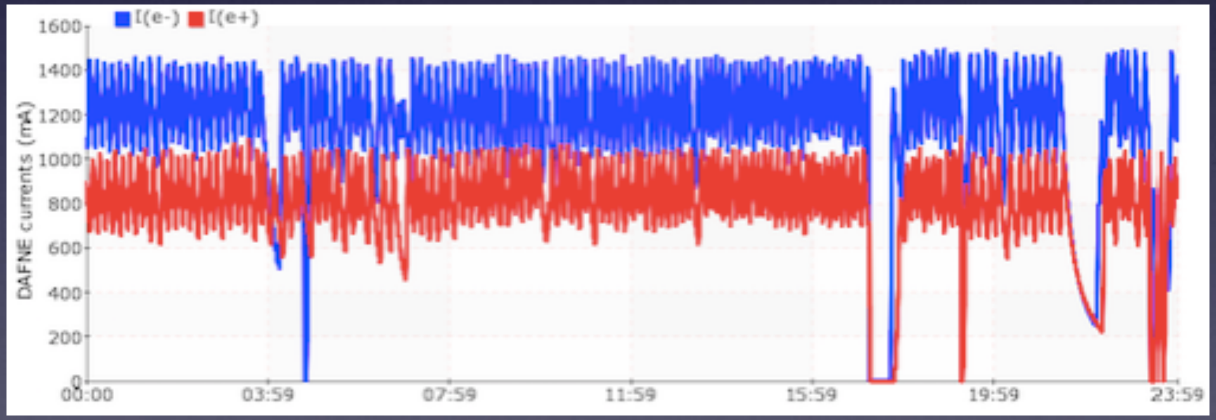
It is able to routinely deliver 12 pb^{-1} per day

Electron and positron beam currents in excess of 1.4 (e^-) and 1 (e^+) A in 105 bunches stored

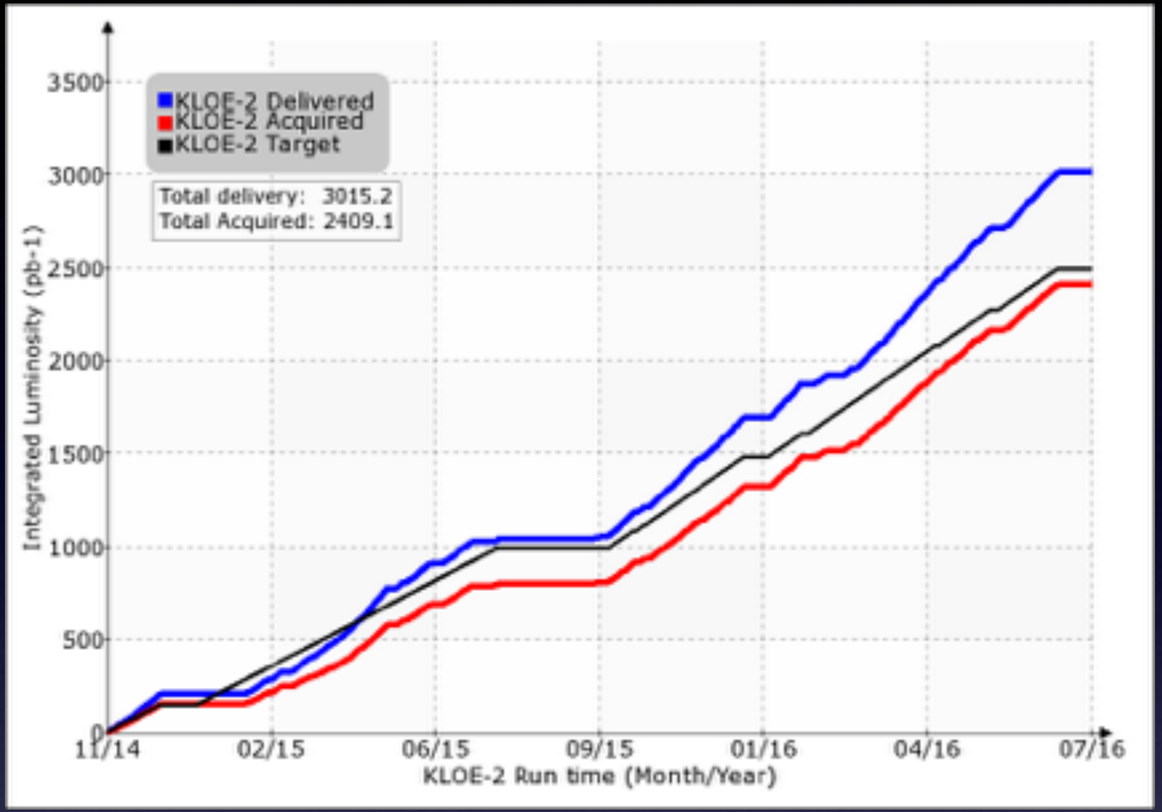
Continuous alternate injections of electron and positron beams on a time basis of 10 min

Average luminosity exceeds 1.5 10^{32} cm^{-2} s^{-1}





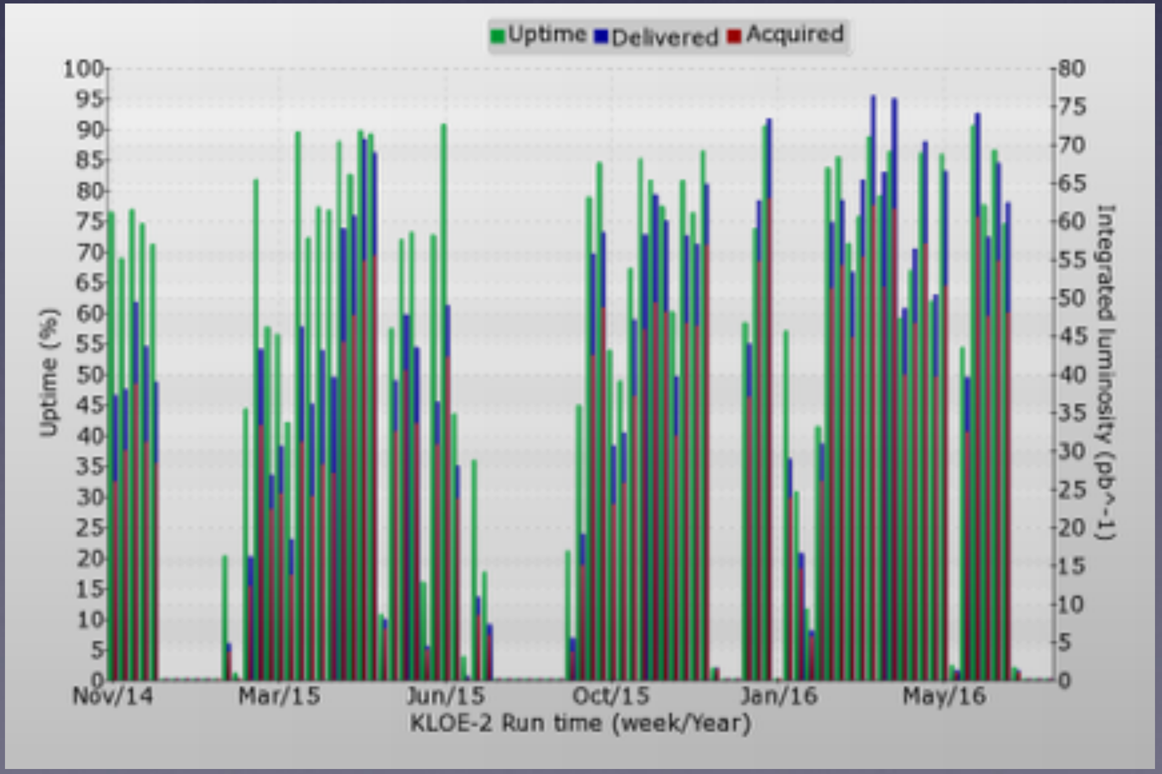
The KLOE-2 Run



From Nov 2014 KLOE-2 recorded 2.4 out of 3 fb^{-1} delivered by Daϕne closely following data taking plans

Performance and operation stability still improving

The goal is to achieve 5 fb^{-1} by the end of 2017



Transition form factors

Meson to photon coupling and the transition form factors, TFF, are fundamental measurements in hadron physics, relevant to

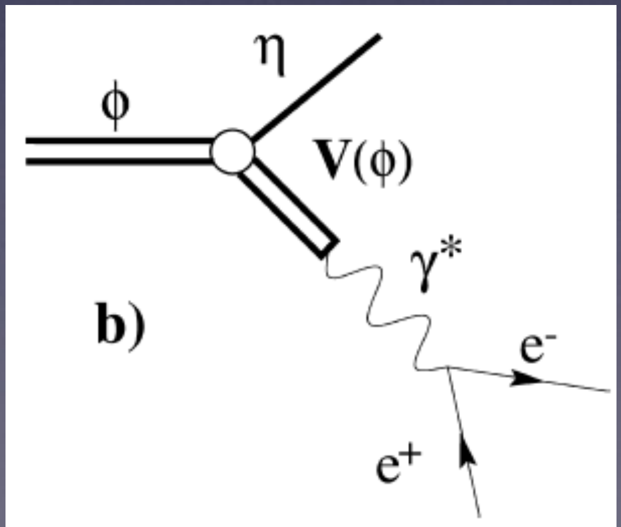
ChPT and its low-q^2 extensions
the analytic extrapolations of ChPT Lagragian to resonances region
the treatment of the transition regime from soft, non-perturbative QCD, to hard processes (pQCD)

They are measured from

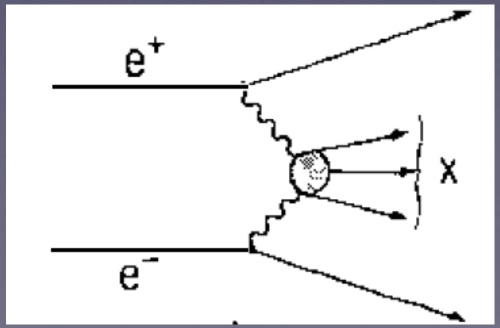
i) meson decays, with $P \to V \gamma^{(*)}$ transitions, as $\eta \to \pi^0 e^+ e^-$

ii) radiative meson production in $e^+ e^-$ interactions, as $\phi \to \pi^0 e^+ e^-$ or $\phi \to \eta e^+ e^-$

$$\frac{d}{dq^2}\Gamma\left(\phi \to \eta e^+ e^-\right) = \frac{\alpha}{3\pi}\Gamma(\phi \to \eta\gamma)\frac{\left|F_{\phi\eta}\left(q^2\right)\right|^2}{q^2}\sqrt{1-\frac{4m^2}{q^2}}\left(1+\frac{2m^2}{q^2}\right)\left[\left(1+\frac{q^2}{m_\phi^2-m_\eta^2}\right)^2-\frac{4m_\phi^2 q^2}{\left(m_\phi^2-m_\eta^2\right)^2}\right]^{3/2}$$



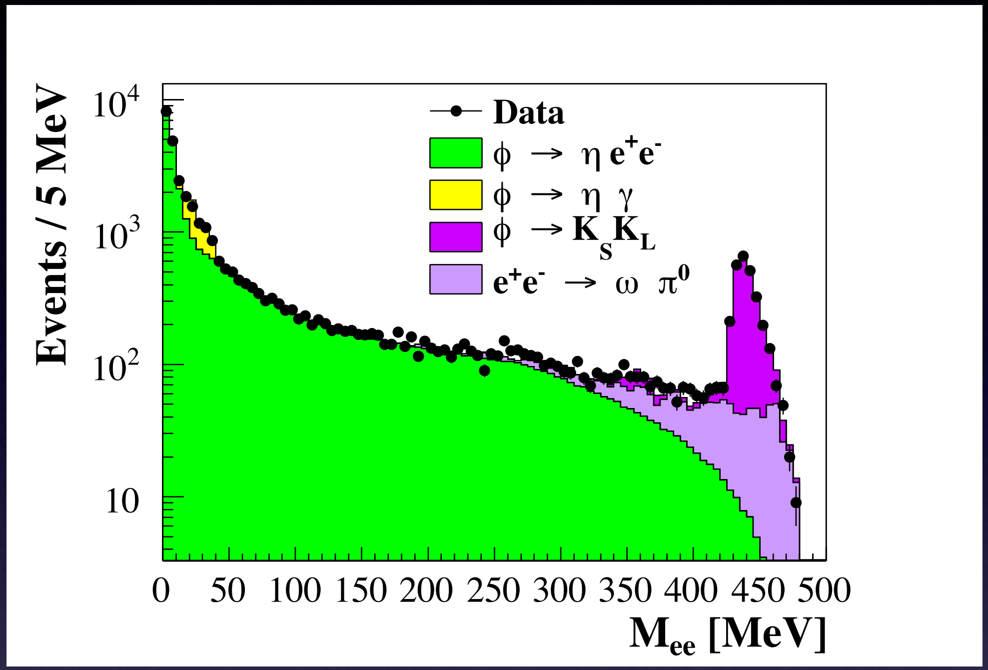
iii) meson production in γ-γ interactions



$\Phi \rightarrow \eta\, e^+e^-$

Phys.Lett. B742 (2015) 1

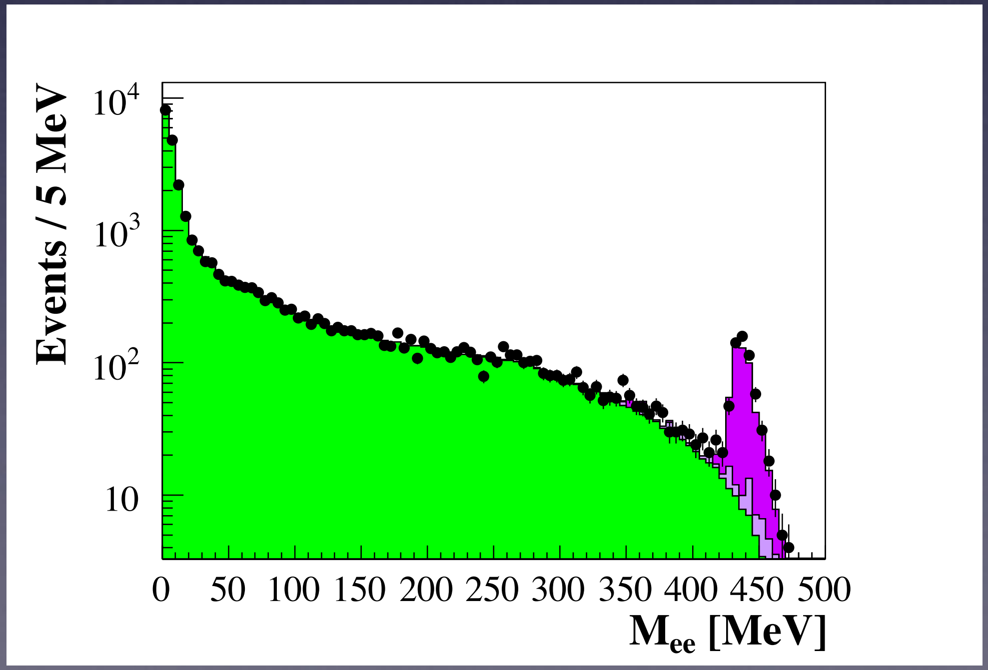
$\eta \rightarrow \pi^0\, \pi^0\, \pi^0$ decays have been selected for the purity of the sample obtained



3x10^4 events selected

15.5% global efficiency

3% residual background



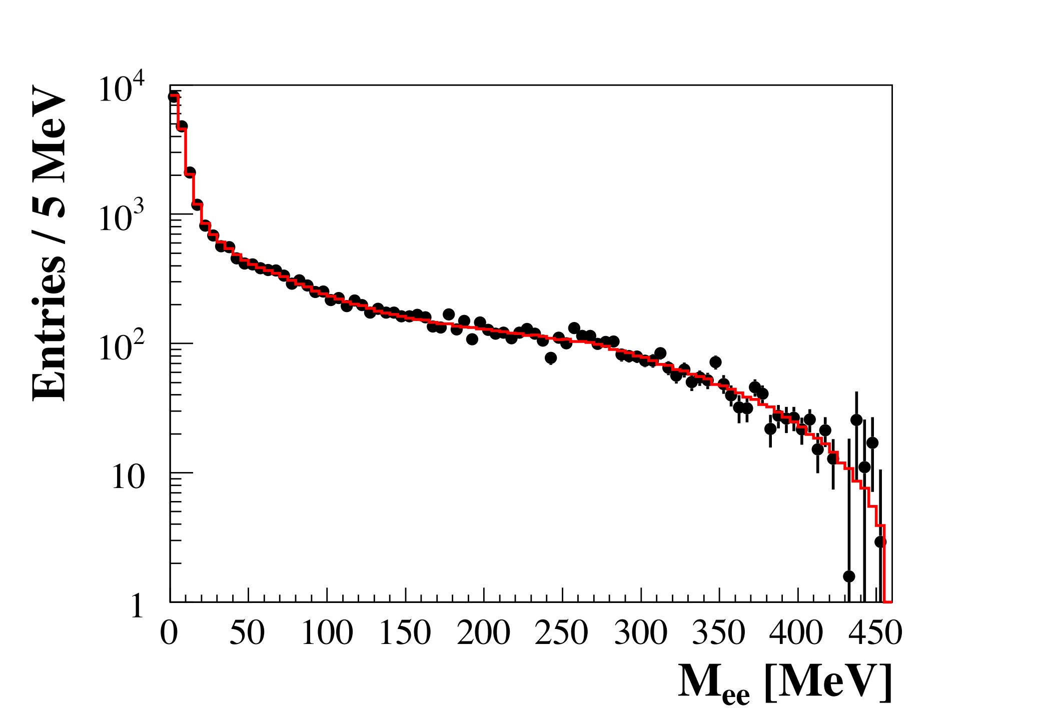
The $TFF_{\phi\to\eta}$

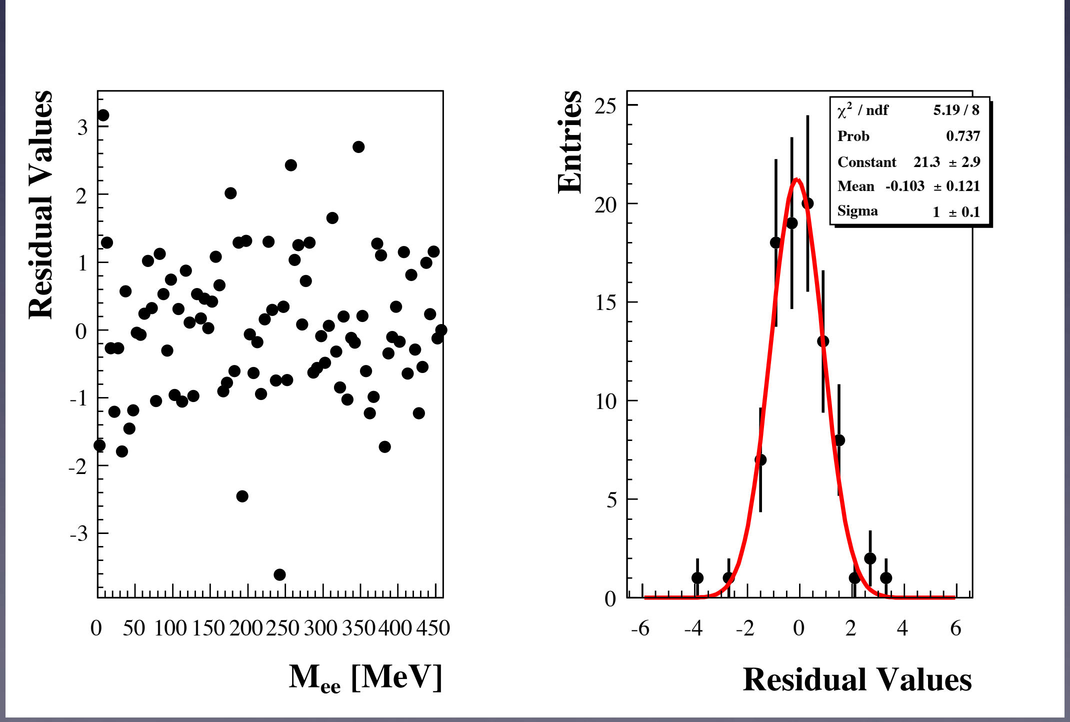
The results are in agreement with VMD predictions and with previous measurements from SND and CMD-2

The transition form factor slope is a factor of five more precise than previous measurement

$BR(\phi \to \eta\, e^+ e^-)=(1.075 \pm 0.007 \pm 0.038)\times10^{-4}$

$b_{\phi\to\eta} = (1.17 \pm 0.10^{+0.07}_{-0.11})\ \mathrm{GeV}^{-2}$





$\Phi \rightarrow \pi^0 e^+e^-$

Phys.Lett. B757 (2016) 362

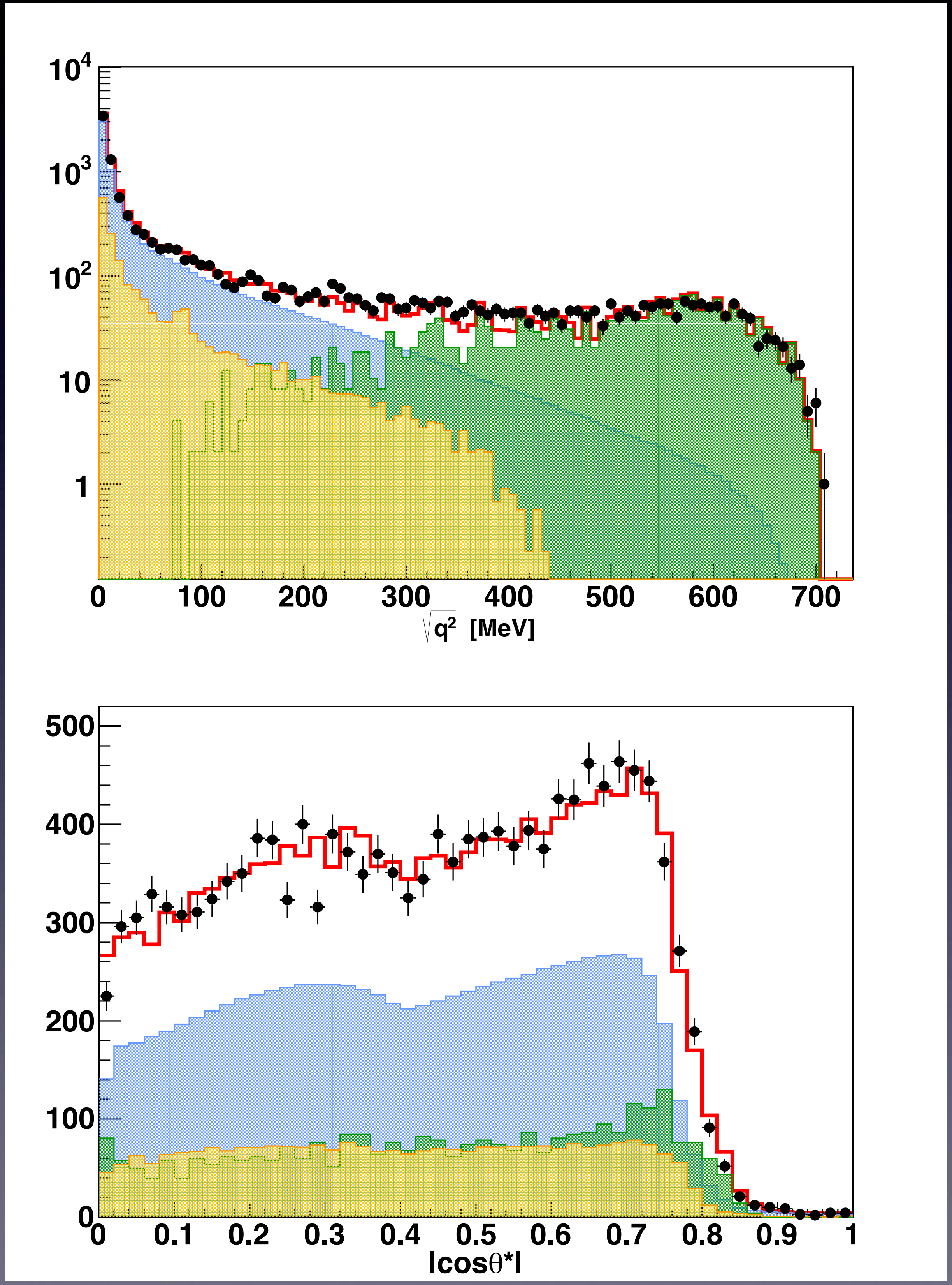
It is the first analysis of the transition form factor

Background from radiative Bhabha and $\phi \rightarrow \pi^0 \gamma$ is relevant

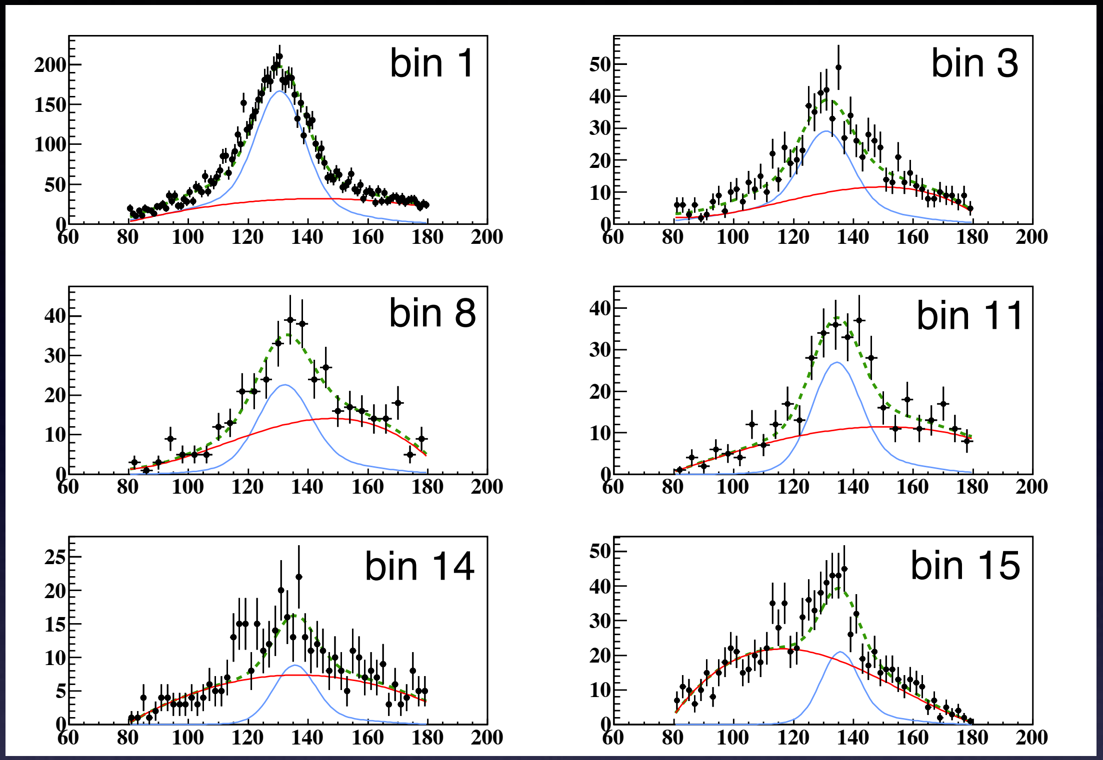
Background subtraction has been obtained separately in different q^2 windows

Global efficiency from 15% at low M_{ee} to 2% at 0.6 GeV

9500 events selected (background-subtracted)



Systematics



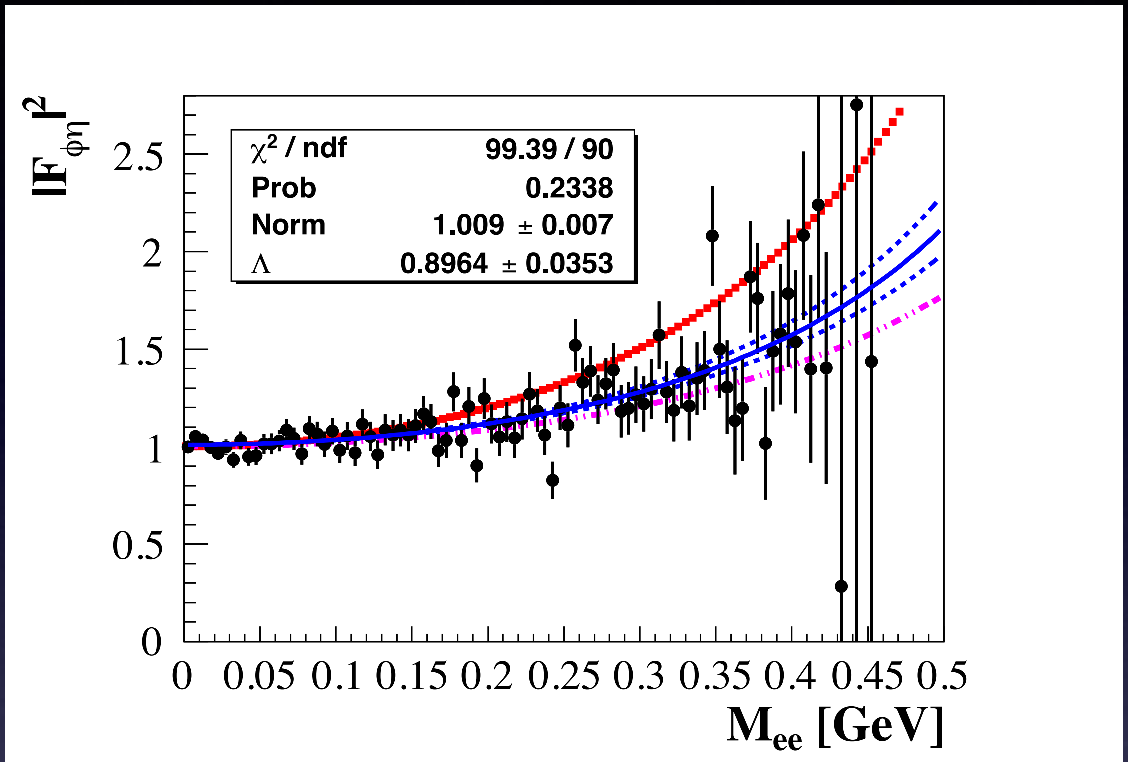
The systematic error receive equal contribution from the control of the analysis cuts and from the procedure of background subtraction

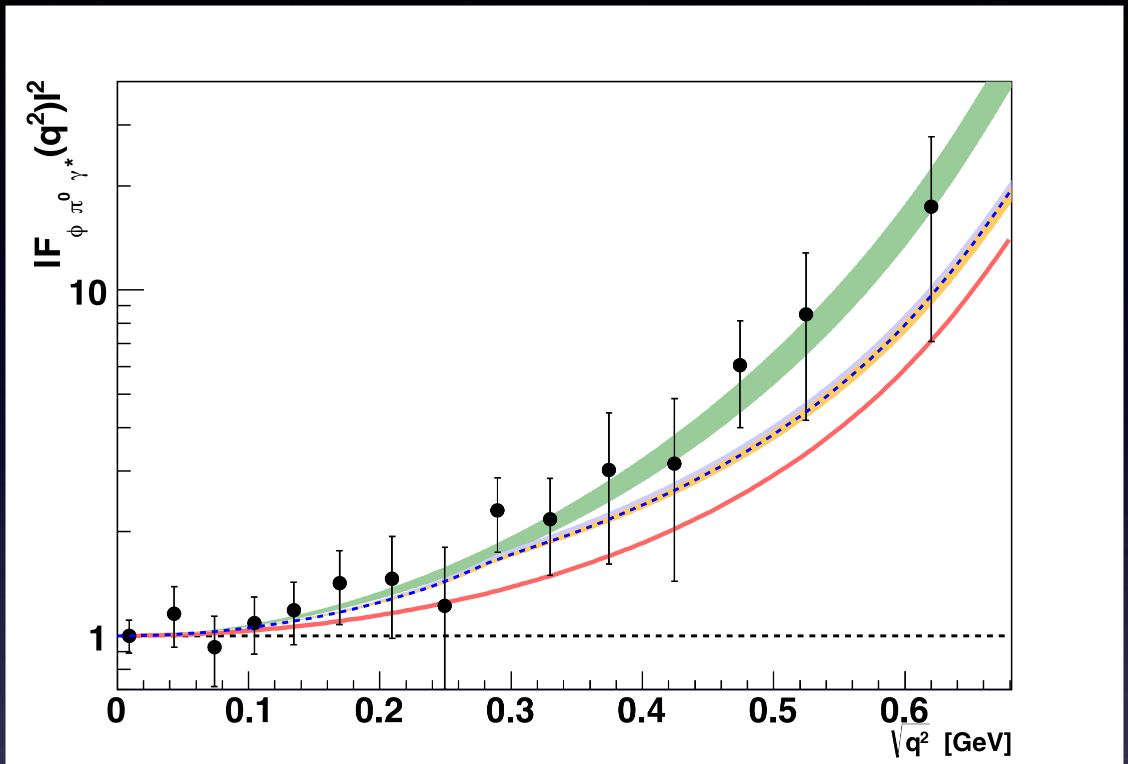
$BR(\phi \rightarrow \pi e^{+} e^{-}) = (1.35 \pm 0.05 {}^{+0.05}_{-0.07}) \times 10^{-5}$

$b_{\phi \rightarrow \pi} = (2.02 \pm 0.11)\ \mathrm{GeV}^{-2}$

		$BR\ (\phi \to \pi^0 e^+ e^-) \times 10^5$
Experiment	SND	$1.01 \pm 0.28 \pm 0.29$
	CMD-2	$1.22 \pm 0.34 \pm 0.21$
Theory	Schneider et al. [5] ("once")	$(1.39 \ldots 1.51)$
	Schneider et al. [5] ("twice")	$(1.40 \ldots 1.53)$
	Danilkin et al. [7]	1.45

The results on TFFs





Comparison with different models

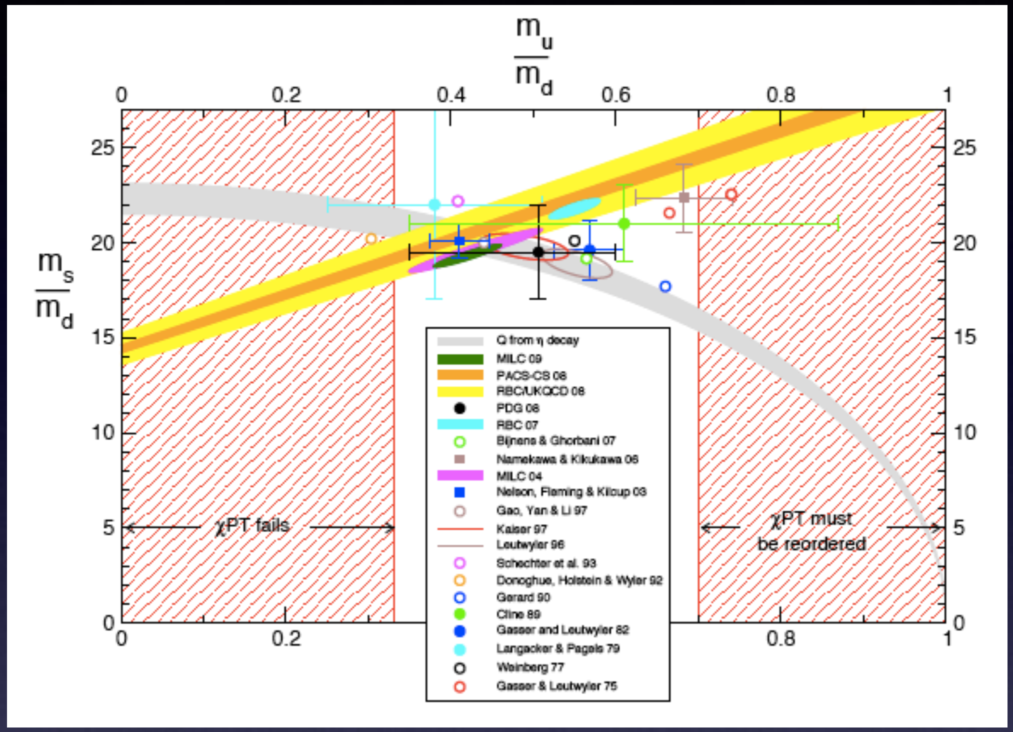
C. Terschlusen and S. Leupold, Phys. Lett. B 691, 191-201 (2010)
One-pole approximation with KLOE data
One-pole approximation - VMD

S. Ivashyn, Prob. Atomic Sci. Technol. 2012N1, 179-182 (2012)
S. P. Schneider, B. Kubis, F. Niecknig, Phys. Rev. D 86 (2012) 054013
I. Danilkin, et al., Phys. Rev. D 91 (2015) 094029
One-pole approximation - VMD

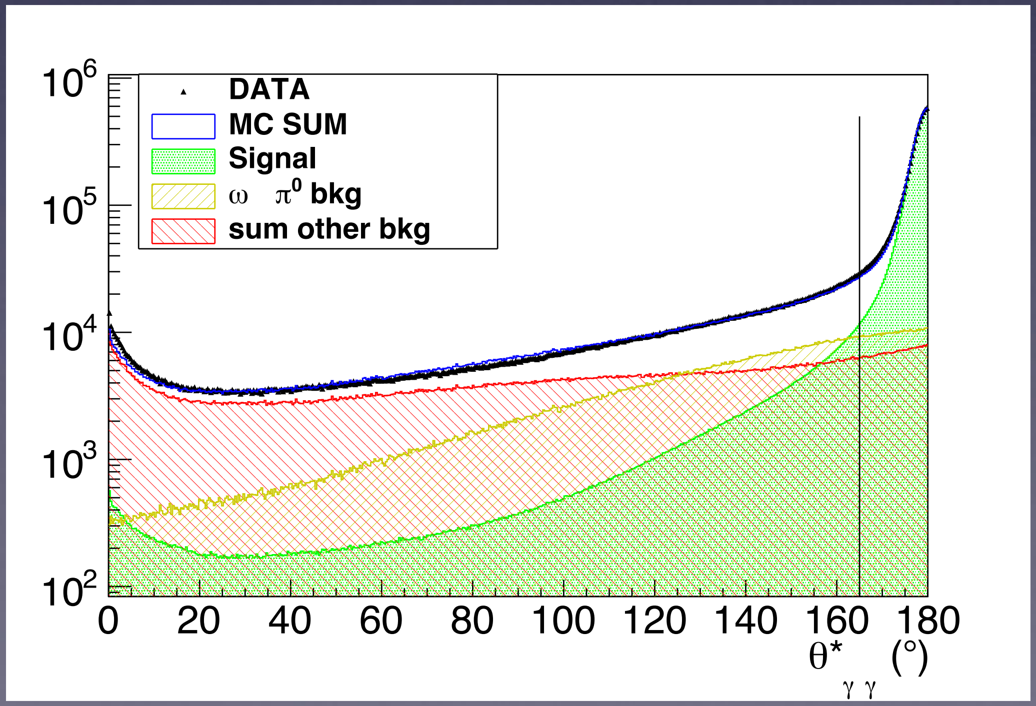
$\eta \rightarrow \pi^0 \pi^+\pi^-$

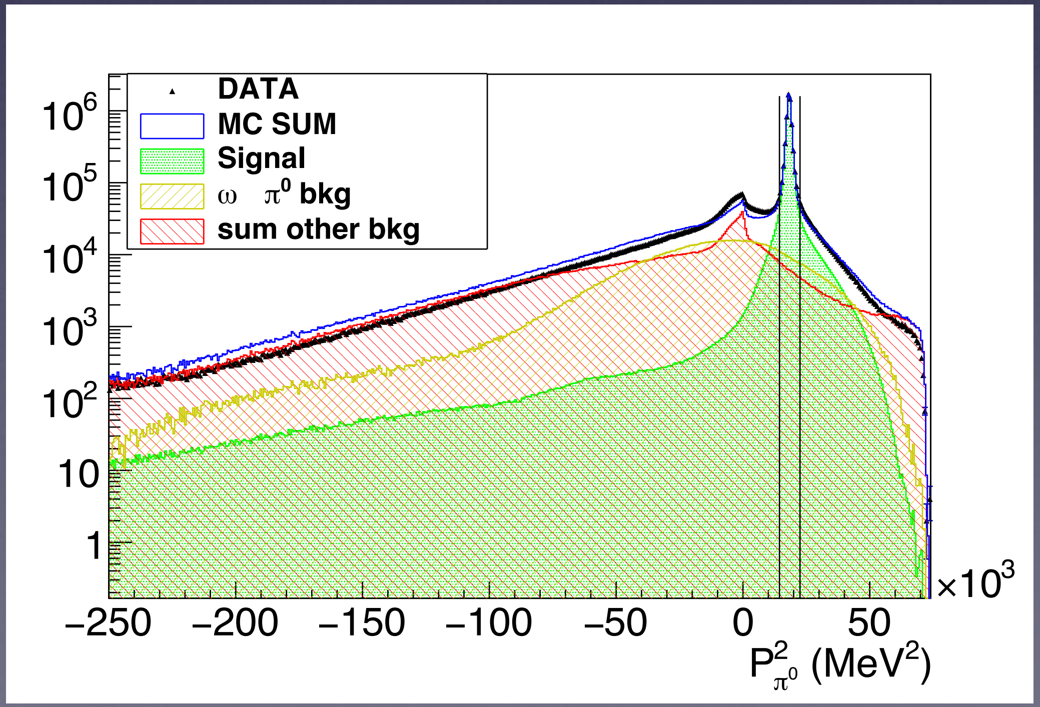
JHEP 1605 (2016) 019

The interest to improve on the precision of the measurement of the density of the Dalitz plot is related to the development of dispersive techniques to derive more powerful constraints on the light quark masses
H. Leutwyler 0911.1416



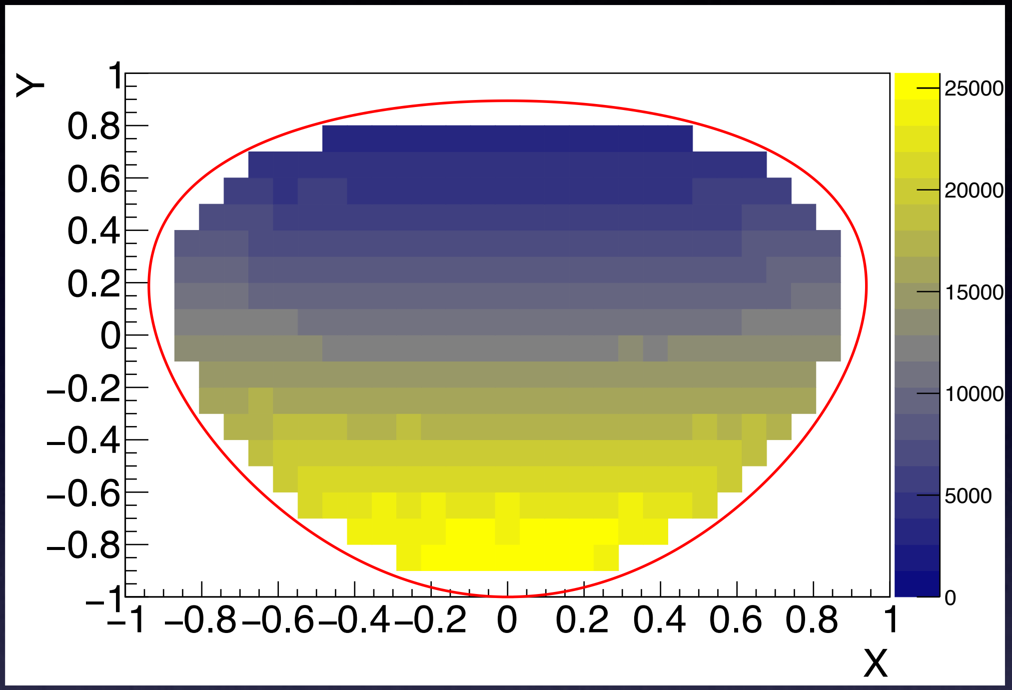
The Dalitz plot density has been obtained with an high-purity sample (15% global efficiency) and corrected to take into account the residual background





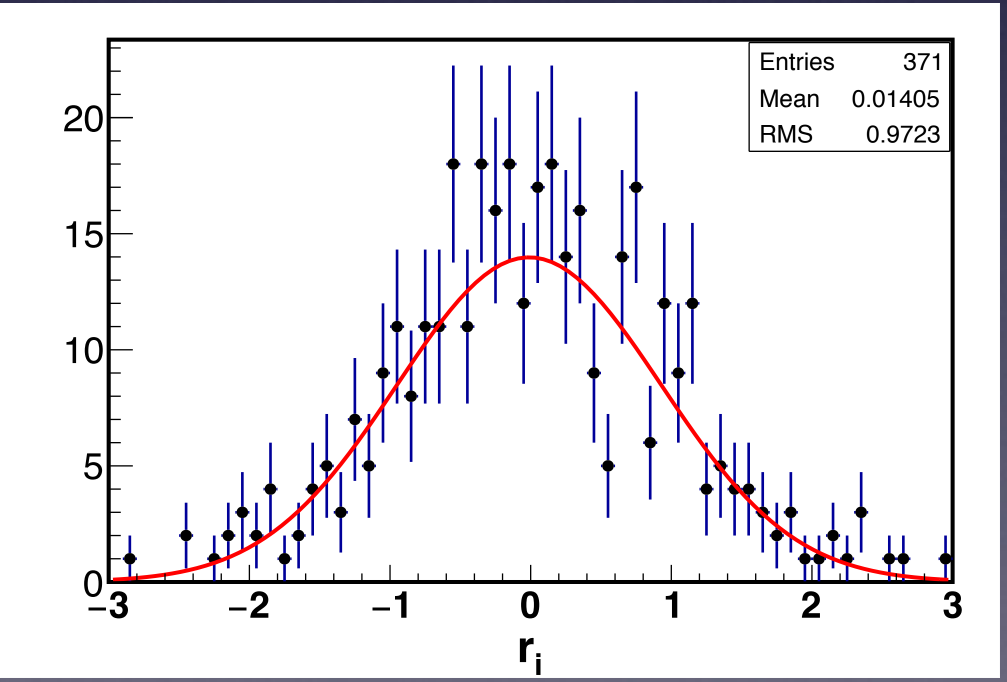
Results on $\eta \to \pi\,\pi^{+}\pi^{-}$

The decay amplitude has been parametrised by a polynomial expansion around the Dalitz plot centre



The results improve the precision on the parameters by a factor of 2

Systematics also improved using control data sample for the efficiency measurement

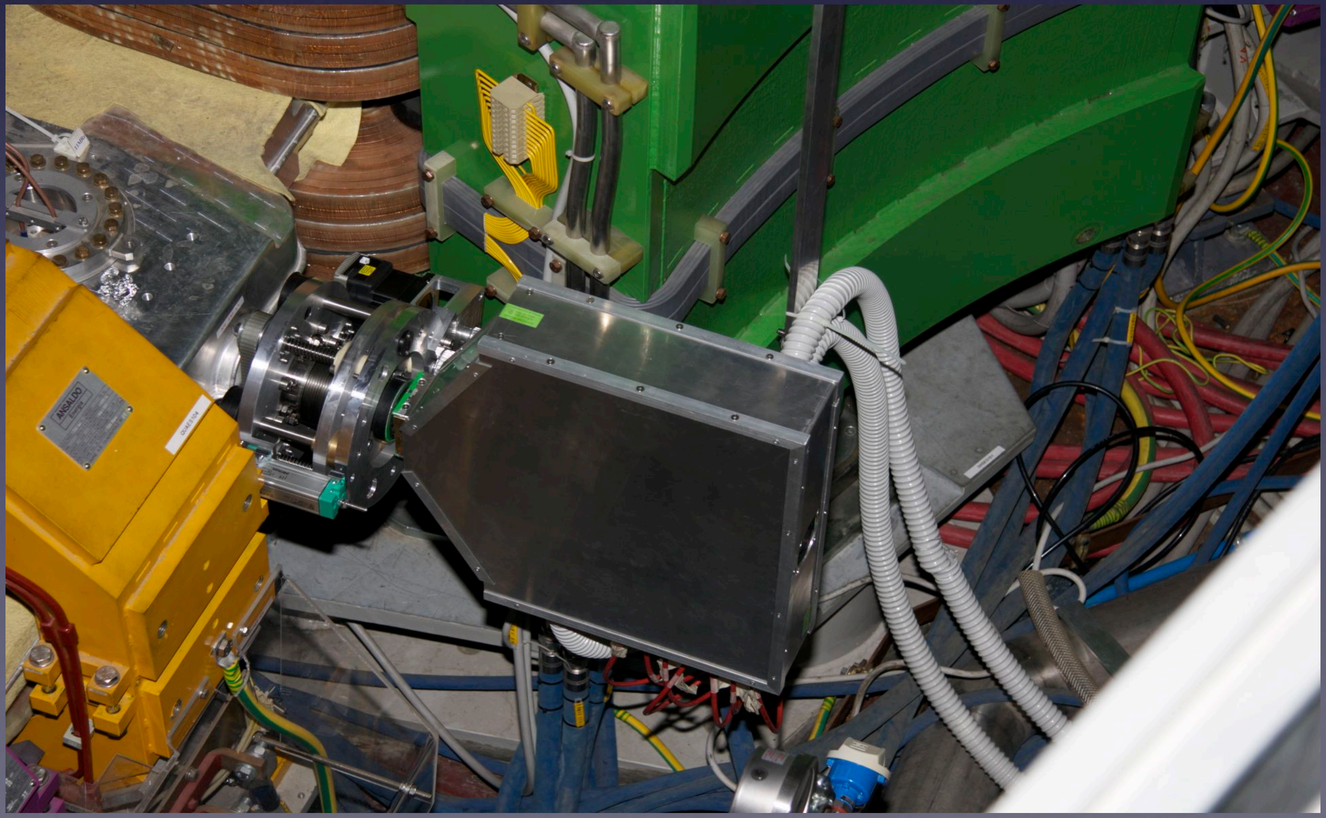


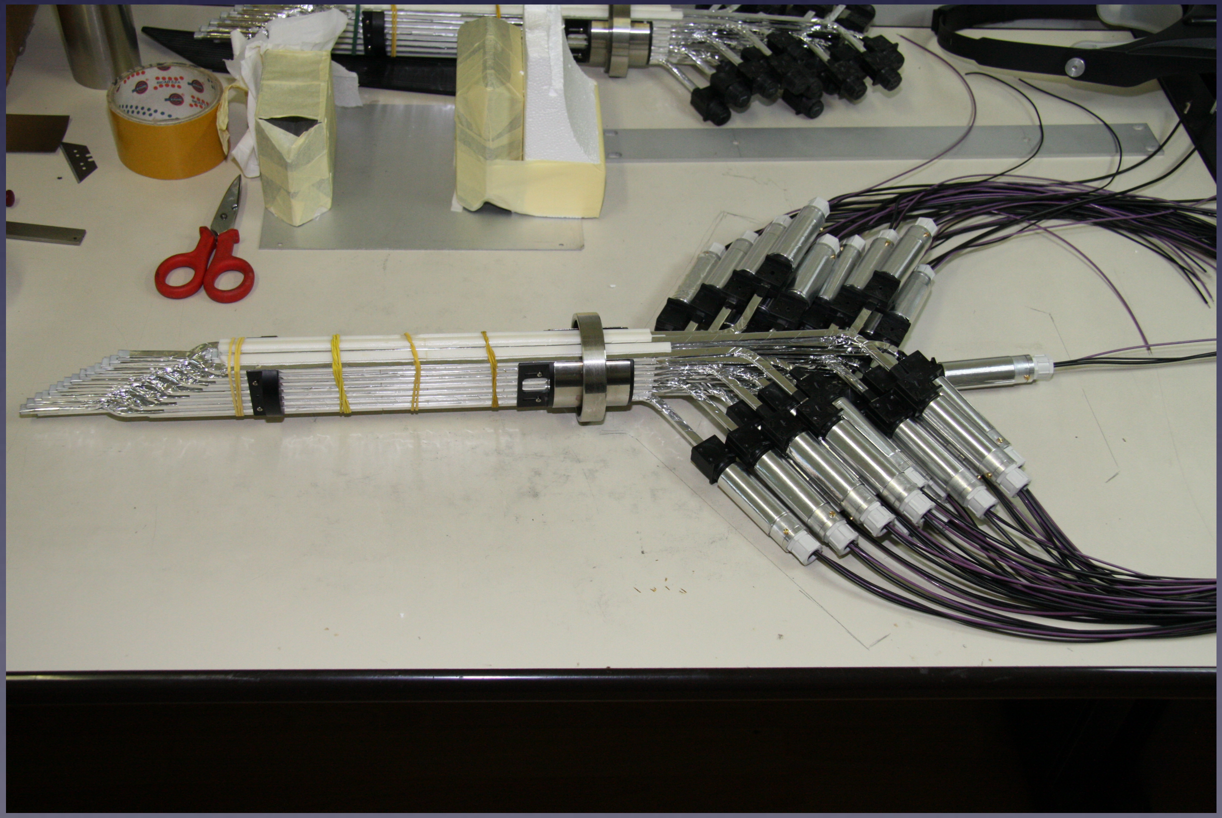
	a	b	d	f
JHEP0805,006	-1.090(5)($^{+8}_{-19}$)	0.124(6)(10)	0.057(6)($^{+7}_{-16}$)	0.140(20)
JHEP160.019	-1.104(3)(2)	0.142(3))($^{+5}_{-4}$)	0.073(3))($^{+4}_{-3}$)	0.154(6))($^{+4}_{-5}$)

The HET tagger

Main goal at present is the precision measurement of the π^0 width [Bernstein, Rev.Mod.Phys. 85 (2013) 49] using meson production γγ from scattering
O(10^4) π^0 expected with 5 fb^{-1}

HET stations installed after bending dipoles, 11 m from the IP
28+1 scintillators of different length
Operational since the very beginning of the KLOE-2 data taking
Energy acceptance from 425-490 MeV. MC validation needed



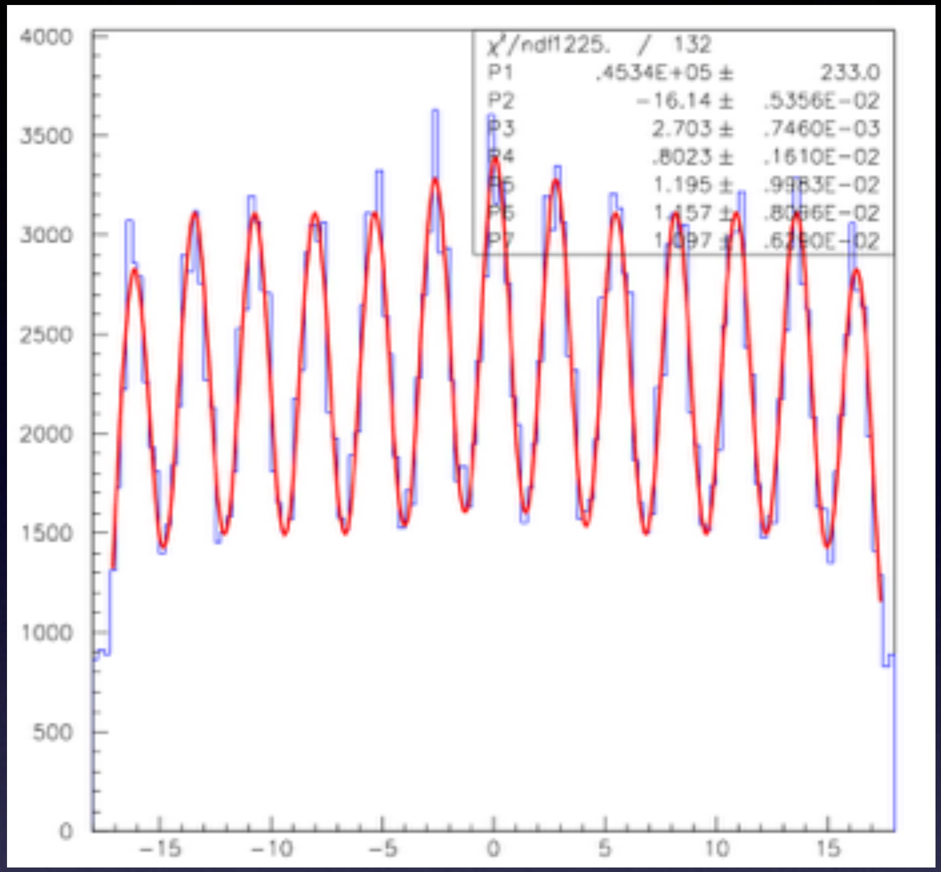


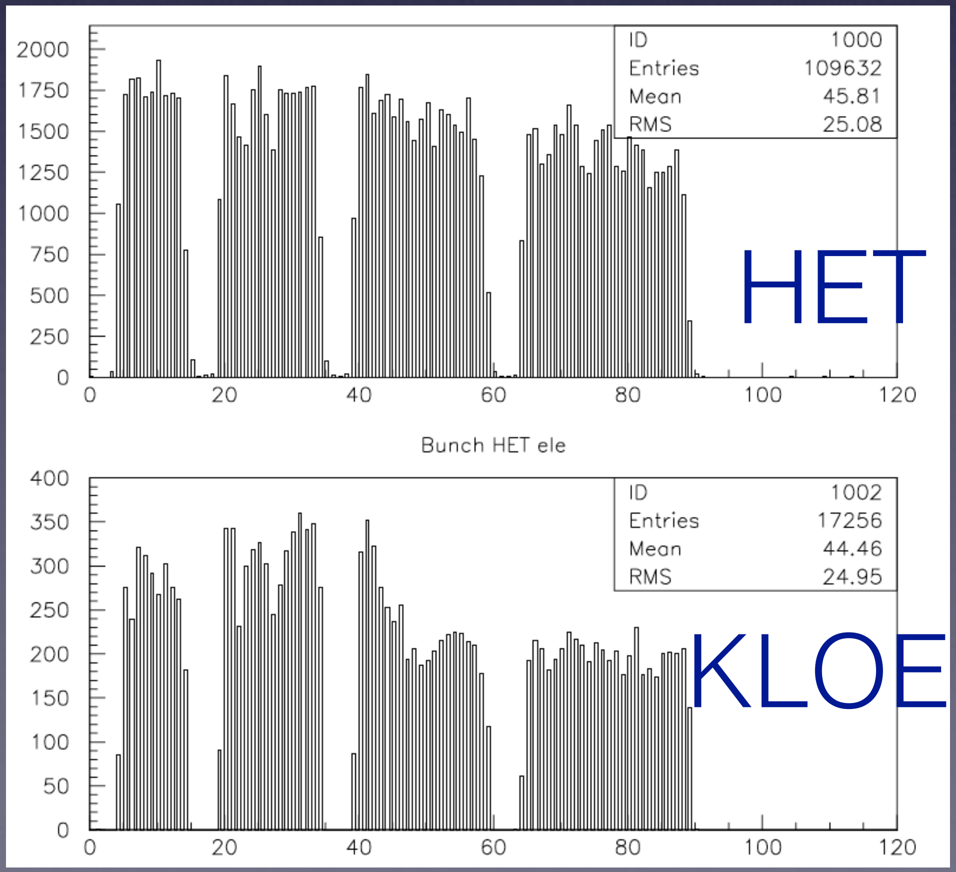
Time resolution

Time difference between electron and positron stations in agreement with uncorrelated events

Time resolution of 550 ps measured

Bunch structure in Daφne measured separately by both, HET and KLOE





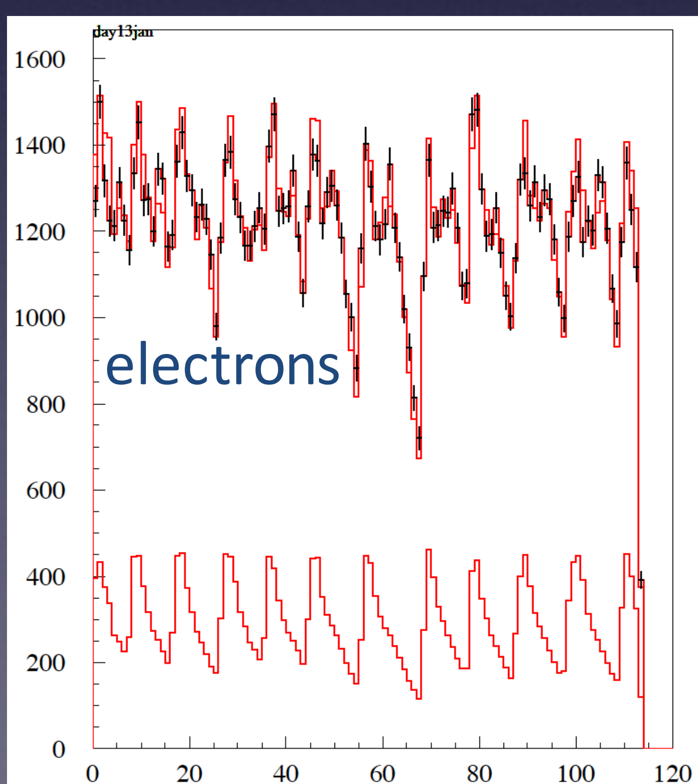
HET rates

HET rates are dominated by single-arm Bhabha's . Particles from intra-bunch scattering give a 24% (4%) contribution to the e^- (e^+) rates (average, Jan 2016)

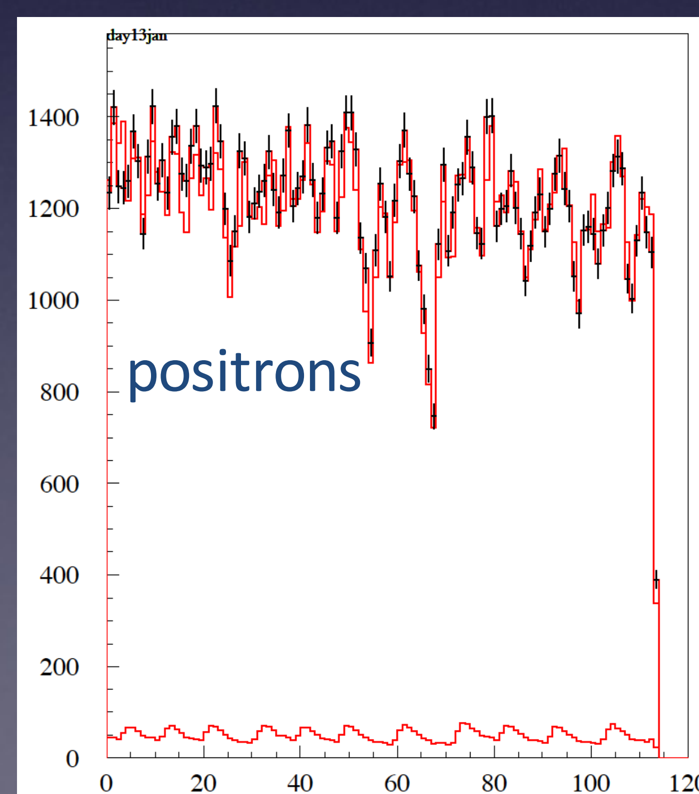
It is the ideal device to provide fast, reliable feedbacks on the machine operation

Timeline of the rates

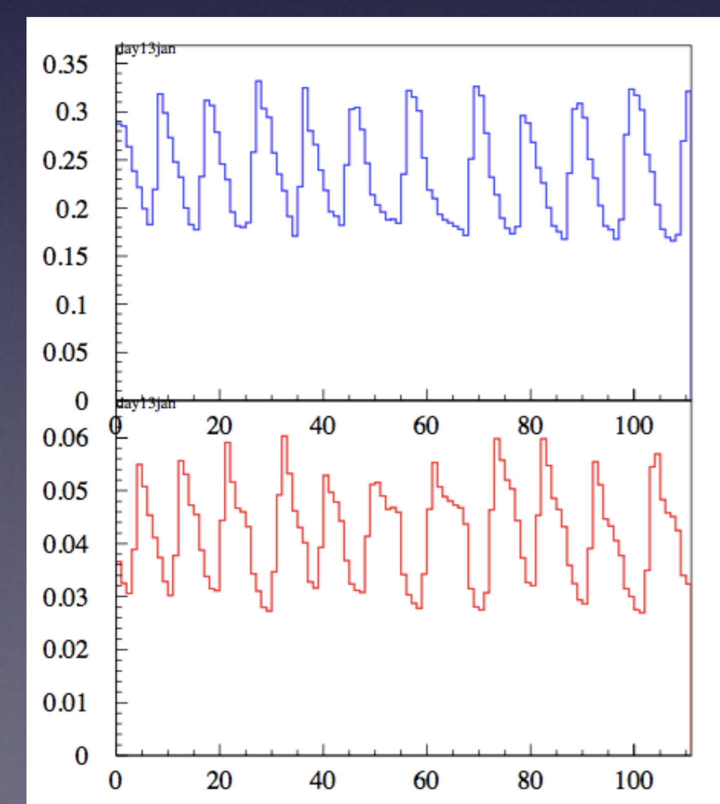
Timeline of the T/(B+T) ratio



min



min



min

Tagger data analysis

HET stations are completely noiseless

The timeline of the counting rate for electron AND positron stations shows only 2 visible contributions : from luminosity and from Touschek particles
Machine background reaches a maximal relative contribution of 30% for electron and 6% for positron beams

The total rate dominated by Bhabha scattering is at the level of 500-600 kHz

The rate of uncorrelated time-coincidences between KLOE and HET requires full reconstruction of a large fraction of the KLOE triggers

We have pre-filtered candidates of single-π^0 production from $\gamma\gamma$ scattering
A total of 450 pb^{-1} are being analysed

Conclusions

The large data sample of light mesons recorded at the ϕ factory and the sensitivity of the KLOE detector provide a unique opportunity for precision measurements in hadron physics

Precision measurements of $V \rightarrow P\gamma^*$ transitions from $\Phi \rightarrow \eta e^+e^-$ and $\Phi \rightarrow \pi^0 e^+e^-$ have been obtained

The Dalitz plot density of the isospin-violating $\eta \rightarrow \pi\pi\pi$ decays, sensitive to the light quark mass ratio, has been studied at KLOE and both statistical and systematic accuracy have been improved

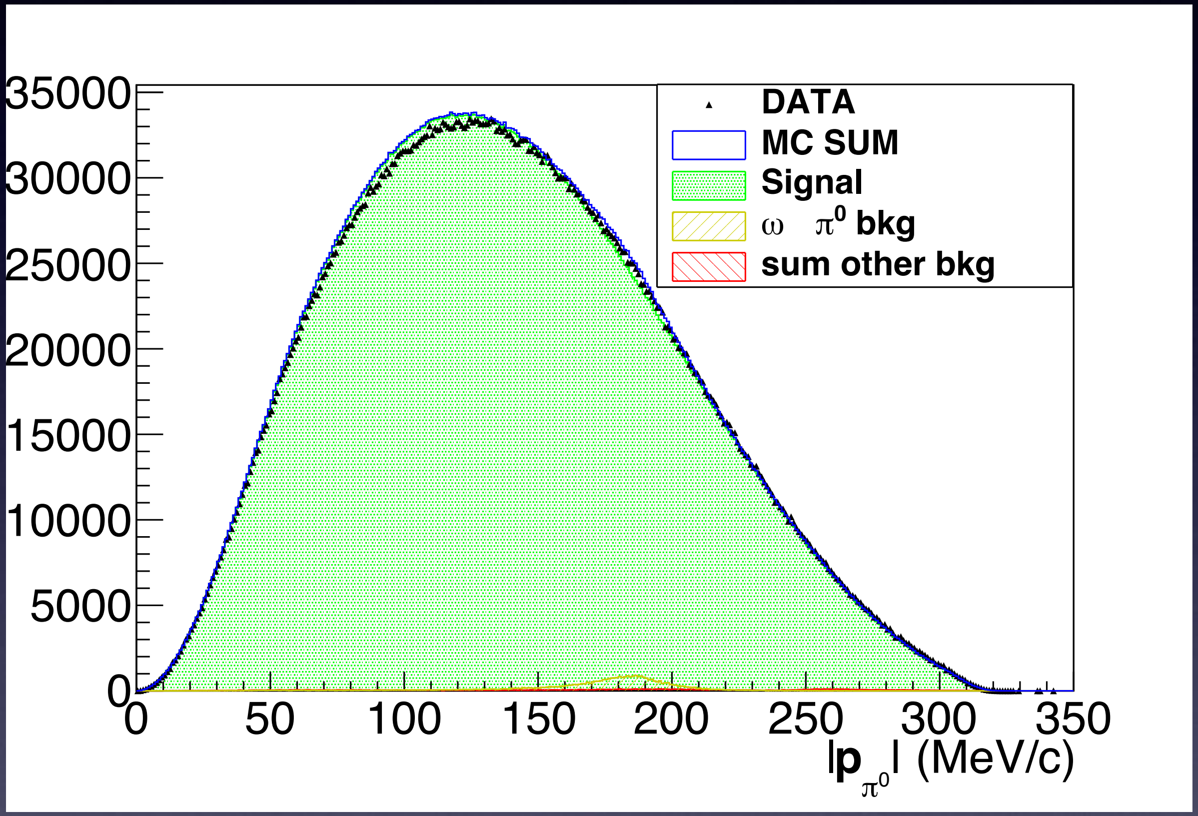
Daϕne is currently operating with a novel beam crossing scheme and good operational stability providing stable beams in continuous injection mode. More than 12 pb^{-1} per day are routinely delivered.

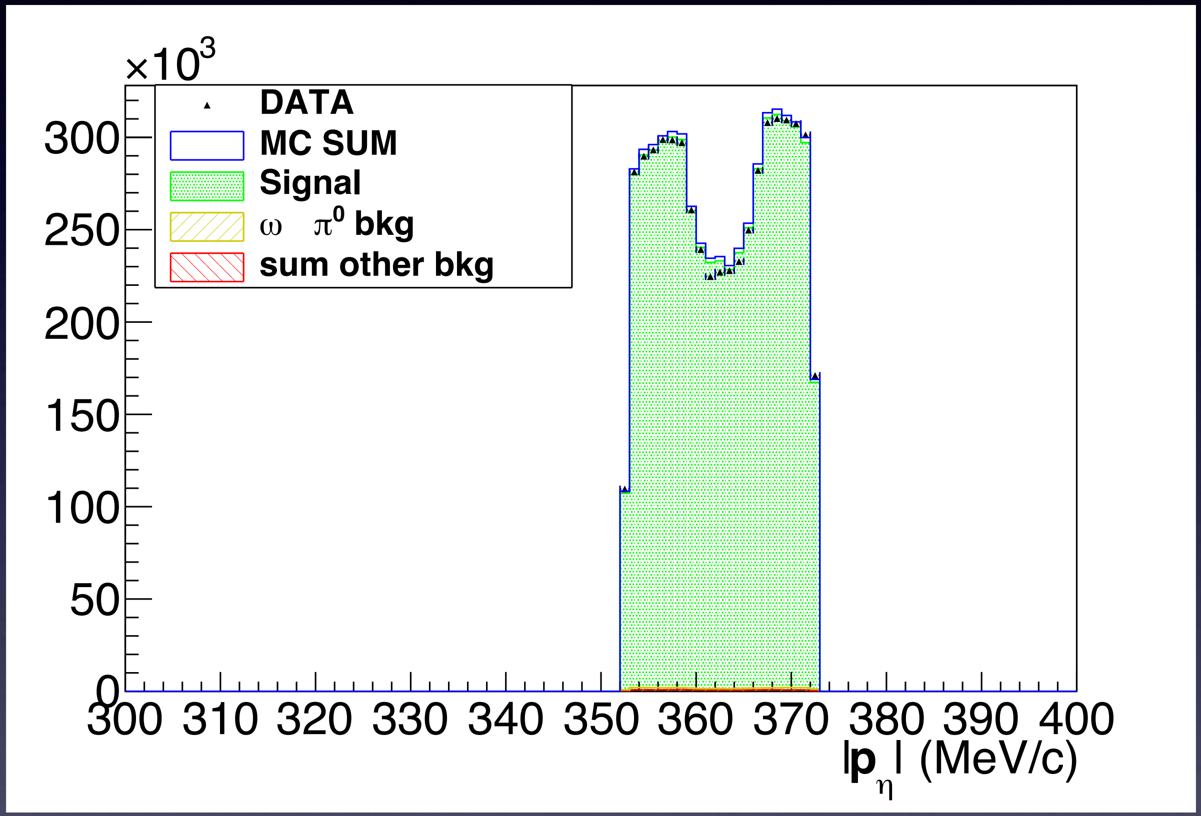
The upgraded detector, KLOE-2, has already collected 2.4 fb-1 demonstrating the feasibility of the goal to record 5 fb^{-1} by the end of 2017.

The KLOE-2 physics program is mainly focused on the study of low energy hadrons and on neutral kaon interferometry

The analysis of meson production from γγ exploiting the KLOE-2 tagging system has been started. The goal is to improve to the percent level the precision of the p0 radiative width and obtain the first measurement of the TFF at low momentum transfer

$\eta \to \pi^0 \pi^+\pi^-$: data-MC comparison



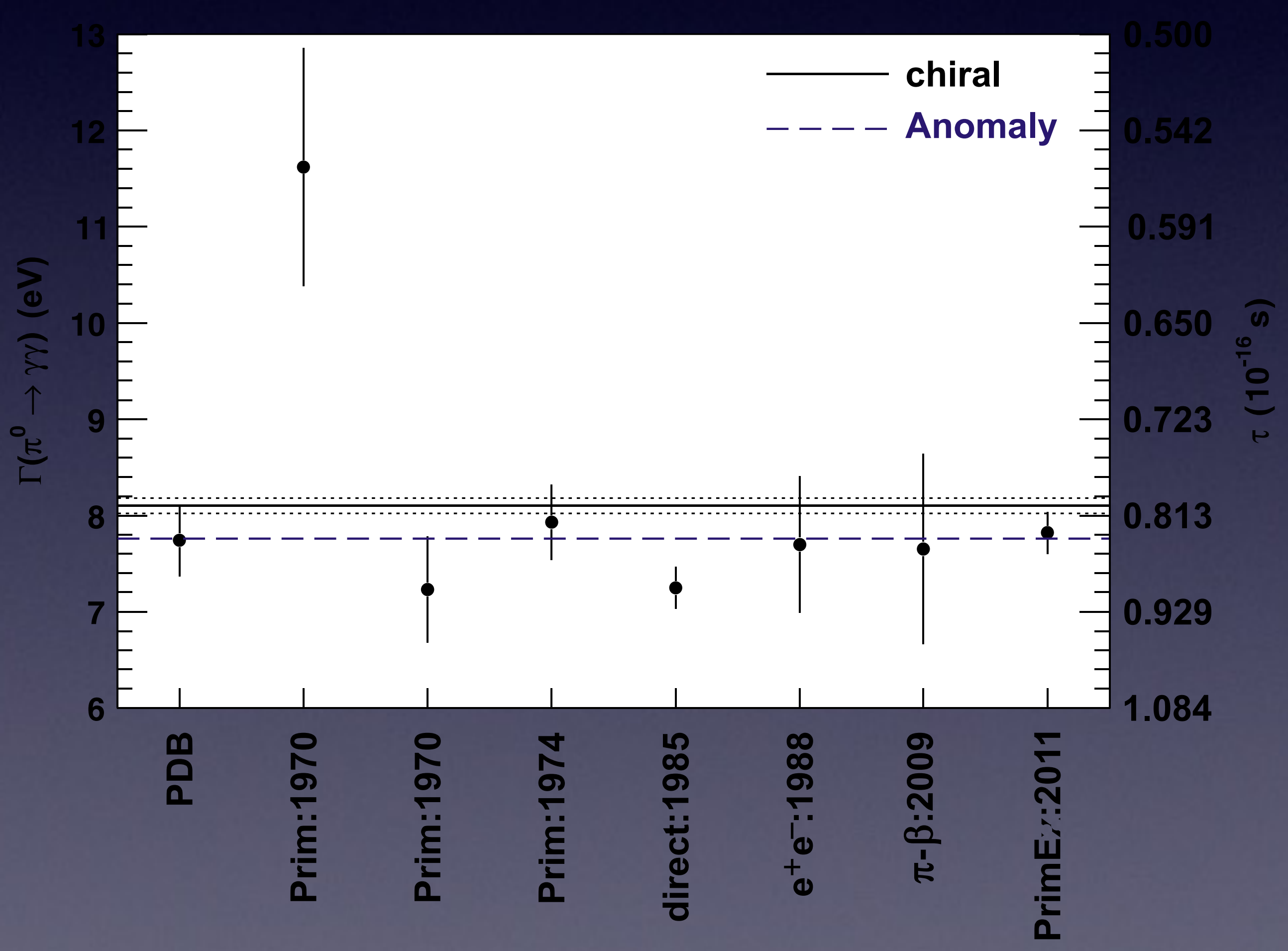


$\eta \to \pi^0 \pi^+\pi^-$: theory

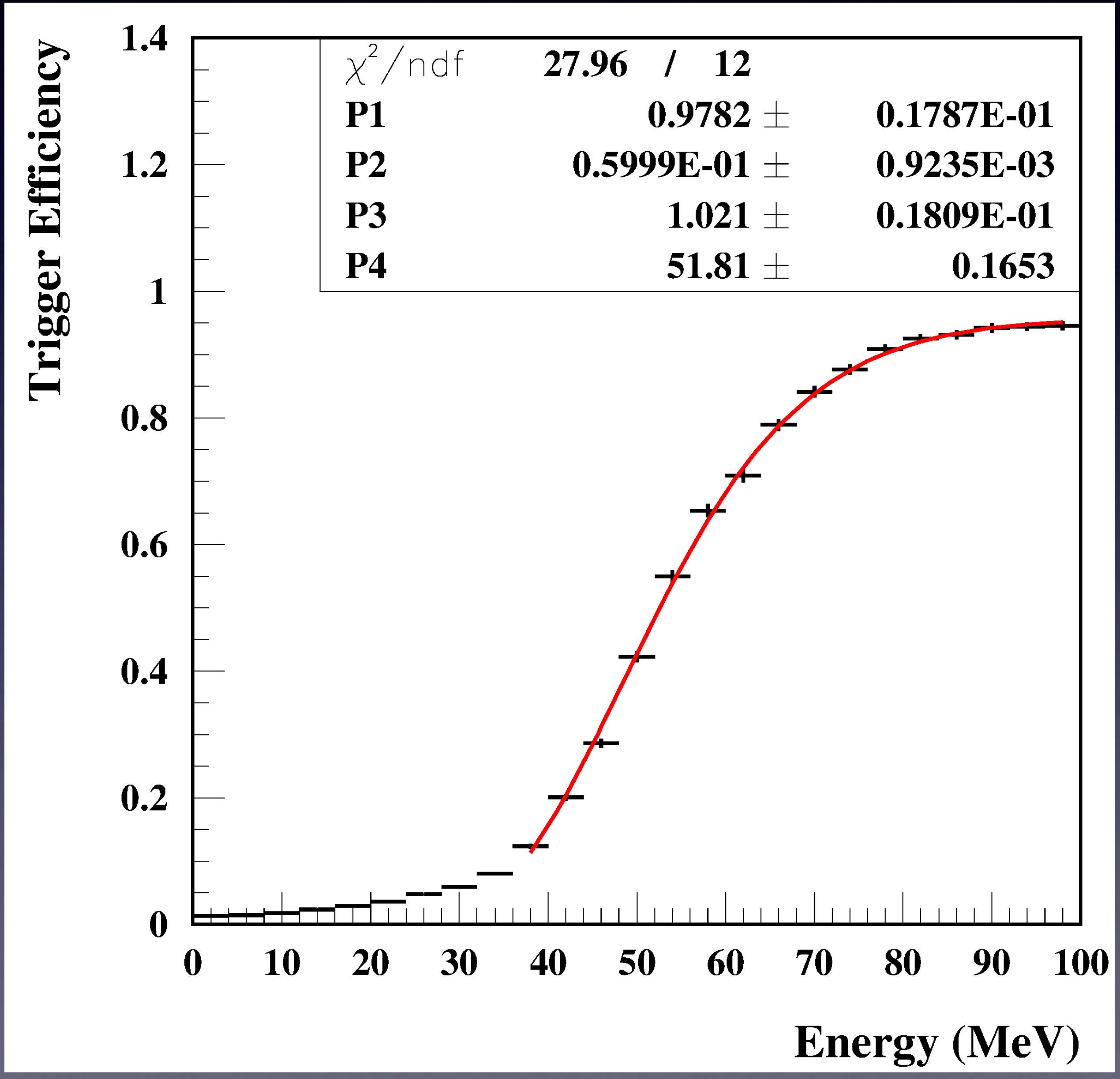
TABLE I: Summary of Dalitz plot parameters from experiments and theoretical predictions.

Experiment	$-a$	b	d	f	$-g$
Gormley(70) [16]	1.17 ± 0.02	0.21 ± 0.03	0.06 ± 0.04	–	–
Layter(73) [17]	1.080 ± 0.014	0.03 ± 0.03	0.05 ± 0.03	–	–
CBarrel(98) [18]	1.22 ± 0.07	0.22 ± 0.11	0.06(fixed)	–	–
KLOE(08) [19]	$1.090 \pm 0.005^{+0.019}_{-0.008}$	$0.124 \pm 0.006 \pm 0.010$	$0.057 \pm 0.006^{+0.007}_{-0.016}$	$0.14 \pm 0.01 \pm 0.02$	–
WASA(14) [20]	1.144 ± 0.018	$0.219 \pm 0.019 \pm 0.047$	$0.086 \pm 0.018 \pm 0.015$	0.115 ± 0.037	–
BESIII(15) [21]	$1.128 \pm 0.015 \pm 0.008$	$0.153 \pm 0.017 \pm 0.004$	$0.085 \pm 0.016 \pm 0.009$	$0.173 \pm 0.028 \pm 0.021$	–
Calculations					
ChPT LO [10]	1.039	0.27	0	0	–
ChPT NLO [10]	1.371	0.452	0.053	0.027	–
ChPT NNLO[10]	1.271 ± 0.075	0.394 ± 0.102	0.055 ± 0.057	0.025 ± 0.160	–
dispersive [22]	1.16	0.26	0.10	–	–
simplified disp [5]	1.21	0.33	0.04	–	–
NREFT [12]	1.213 ± 0.014	0.308 ± 0.023	0.050 ± 0.003	0.083 ± 0.019	0.039 ± 0.002
UChPT [11]	1.054 ± 0.025	0.185 ± 0.015	0.079 ± 0.026	0.064 ± 0.012	–

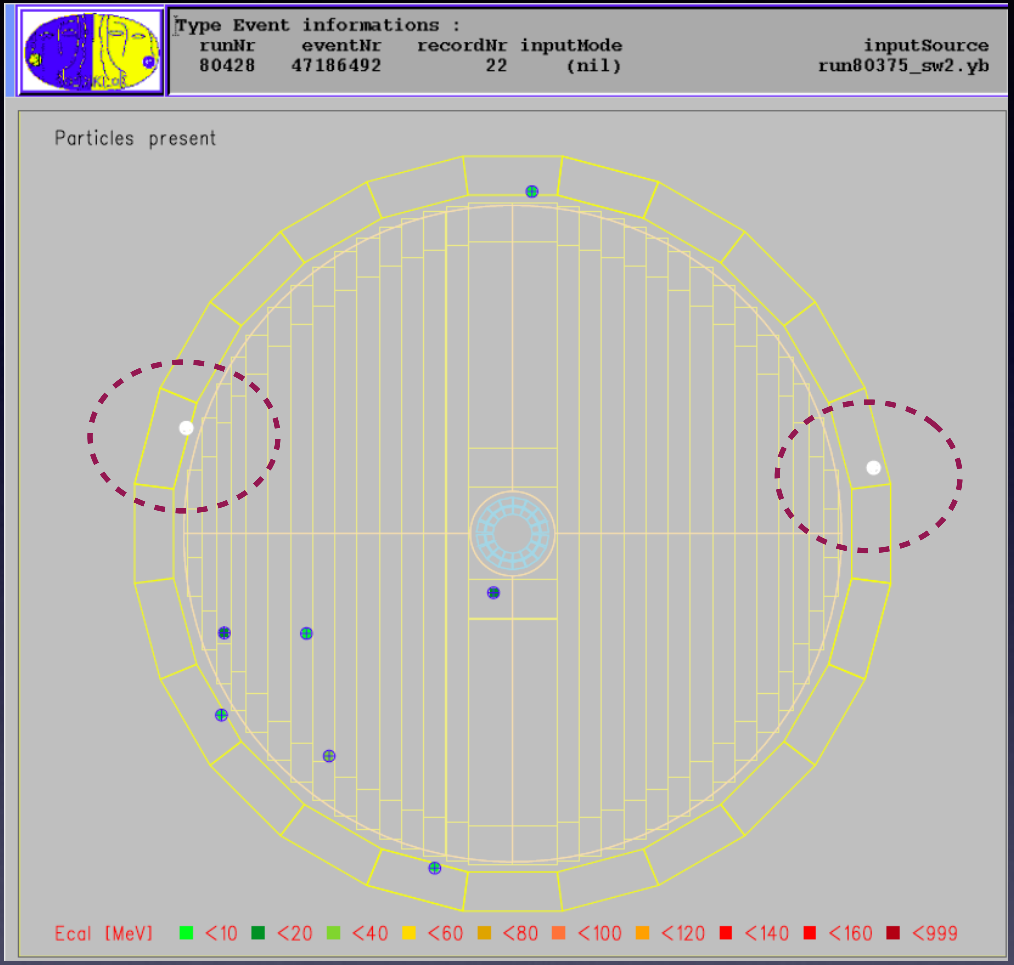
π^0 radiative width

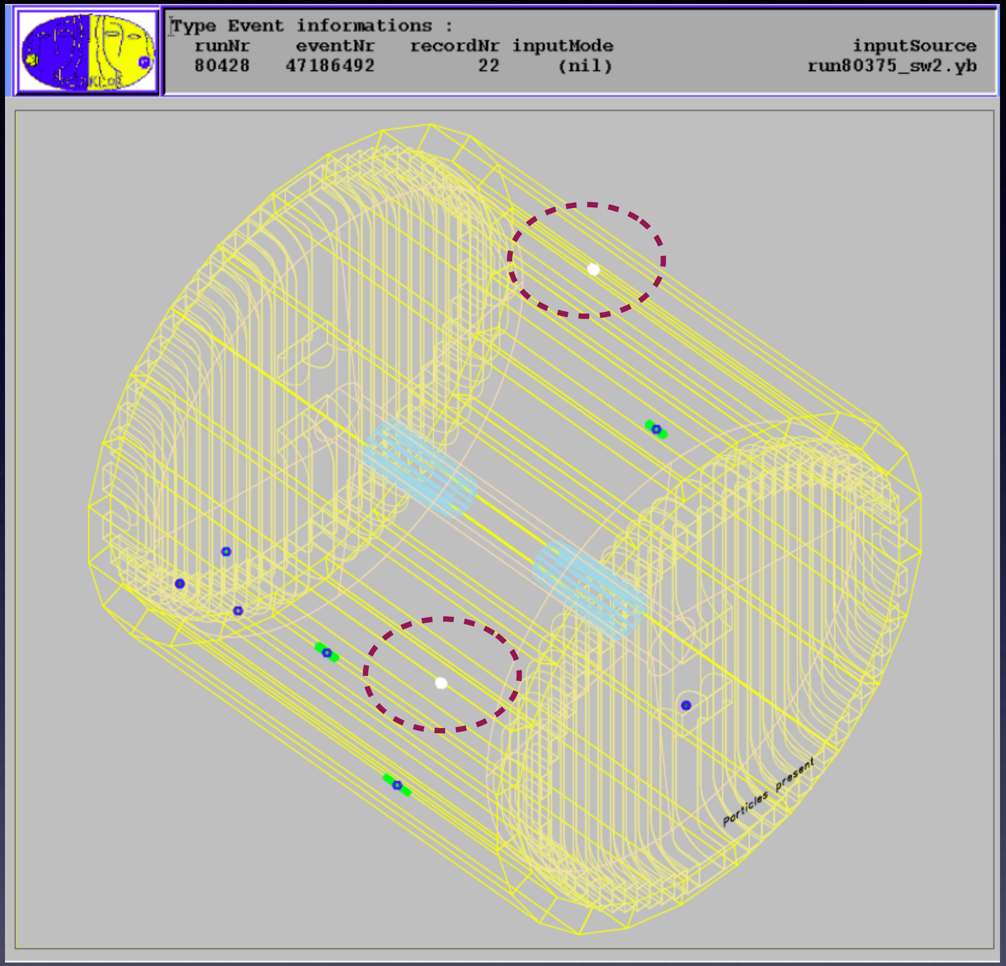


KLOE trigger thresholds



π^0 candidates





CLPS informations (9 objects) :

#	cluster	x	y	z	Energy	time
1	1	-11.2542	-34.8853	202.006	52.8381	-25.8356
2	2	-192.418	62.4433	125.599	76.165	7.10808
3	3	212.916	38.9161	-119.271	68.7743	7.45317
4	4	-45.8829	-197.008	-141.324	7.09928	15.2842
5	5	-171.69	-107.213	58.4166	7.329	47.0982
6	6	11.4123	202.107	148.161	9.18299	69.0268
7	7	-108.216	-131.431	-172.477	22.5101	88.3781
8	8	-121.543	-58.9879	-171.709	5.29586	95.9757
9	9	-170.027	-58.6804	-171.91	13.5686	98.1629