# WP5: PrimeNet -- Meson Physics in Low energy QCD

***A network within Hadron Physics2***

## Outline

- General background and motivations
- Participants, tasks descriptions
- Present activities
- Future plans

The **PrimeNet** network is created to promote exchange of information on the studies of meson physics, in particular the η-η' meson system, at different European accelerator research infrastructures and at university theory centers.

**Crystal Ball at MAMI-C** (upgraded from 800 to 1500 MeV)

**KLOE2 at DAPHNE** (increased luminosity)

**WASA at COSY** (detector performance and higher energy (compared to CELSIUS) )

**Crystal Barrel** together with **TAPS at ELSA** (detector performance and higher luminosity).

**Theory centers** within PrimeNet exist at several universities Barcelona, Bonn, Giessen, Jülich, Lisbon, London, Lund, Uppsala, Valencia, Zagreb.

PrimeNet will bring together and coordinate the different activities to achieve synergetic effects.

**PrimeNet** has a special focus on **η** and **η′** since they are unique mesons in the sense that their decays are perfectly suited to study symmetries and symmetry breakings in QCD. In fact, the simultaneous treatment of both the η and the η' imposes tighter constraints on theoretical approaches than just the η.

Quark masses $\eta, \eta' \to 3\pi$;

ChPT $\eta, \eta' \to 3\pi$; $\eta' \to \eta 2\pi$, $\eta \to \pi^0 \gamma\gamma$

C invariance $\eta, \eta' \to \pi^0\pi^0\gamma$, $\eta' \to \eta e^+e^-$

Chiral anomaly $\eta, \eta' \to 2\gamma$ or $\pi\pi\gamma$

E.M Form Factor $\eta \to e^+e^-\gamma$, $\eta \to e^+e^-\mu^+\mu^-$

CP invariance $\eta, \eta' \to 2\pi, 4\pi^0$

Moreover, η, η′ interactions with nucleons, few body systems and in the nuclear medium, as well as nucleon resonance production will be studied.

Scalar mesons can be studied from the rare decay $\phi \to (f_0, a_0)\gamma \to K\bar{K}\gamma$ and $\phi \to \pi\pi\gamma$ for the $\sigma$.

## PrimeNet institutions

A total number of **32** institutions, from 11 different European countries, participate in this network.
In addition there are 2 associated institutions from Japan and USA.

| **Participant number** | **Organization legal name** | **Short name** | **Activity leaders** *(in **bold** the spokesperson)* | **Person-months (total)** |
|---|---|---|---|---|
| 48 | Uppsala universitet<br>*Uppsala universitet* | UU<br>*UU* | <br>***B. Höistad*** | 384<br>*384* |
| 1 | Istituto Nazionale di Fisica Nucleare<br>*INFN Laboratori Nazionali di Frascati*<br>*INFN Sezione di Pavia*<br>*INFN Sezione di Roma 1*<br>*INFN Sezione di Roma 2* | INFN<br>*INFN–LFN*<br>*INFN–PV*<br>*INFN–RM1*<br>*INFN–RM2* | <br>*C. Bloise*<br>*P. Pedroni*<br>*G. De Zorzi*<br>*R. Messi* | 403<br>*240*<br>*67*<br>*72*<br>*24* |
| 7 | Forschungszentrum Jülich GmbH<br>*Forschungszentrum Jülich* | FZJ<br>*FZJ* | <br>*D. Grzonka* | 288<br>*288* |
| 13 | Ruhr- Universität Bochum | RUB | U. Wiedner | 48 |
| 14 | Rheinische Friedrich-Wilhelms-Universität Bonn<br>*Rheinische Friedrich-Wilhelms-Universität* | UBO<br>*UBO* | <br>*R. Beck* | 144<br>*144* |

| | | | | |
|---|---|---|---|---|
| 18 | Justus Liebig Universität Giessen | PIG-JLU | V. Shklyar | 96 |

| | | | | |
|---|---|---|---|---|
| 20 | Johannes Gutenberg Universität Mainz<br>*University of Mainz* | UMainz<br>*UMainz* | <br>*M. Ostrick* | 144<br>*144* |
| 21 | Westfälische Wilhelms-Universität Münster | WWU | A. Khoukaz | 96 |
| 25 | Universitat de Barcelona | UB | R. Escribano | 24 |
| 27 | Universitat de València | UVEG | E. Oset | 10 |
| 32 | Institut Ruđer Bošković | RBI | A. Svarc | 58 |
| 41 | Jagiellonian University | UJ | P. Moskal | 240 |
| 46 | Lund universitet<br>*Lund universitet* | ULUND<br>*ULUND* | <br>*J. Bijnens* | 10<br>*10* |
| 47 | Stockholms universitet | SU | P-E. Tegner | 72 |

| **Other involved institutions** | **Activity leaders** | **Person-months** |
|---|---|---|
| University of Innsbruck (Austria) | S. Bass | 24 |
| Basel University (Switzerland) | B. Krusche | 240 |
| University Duisburg-Essen (Germany) | H. Machner | 24 |
| Eberhard Karls Universität Tübingen (Germany) | H. Clement | 240 |
| Università e Sezione INFN di Napoli (Italy) | F. Ambrosino | 34 |
| Università e Sezione INFN di Roma 3 (Italy) | A. Passeri | 48 |
| Nara Woman's University (Japan) | S. Hirenzaki | 24 |
| University of Kyoto (Japan) | D. Jido | 24 |
| Lodz IPJ (Poland) | J. Zabierowski | 14 |
| Warsaw IPJ (Poland) | J. Stepaniak | 29 |
| Instituto Superior Técnico, Lisbon (Portugal) | T. Pena | 10 |
| Institute for Theoretical and Experimental Physics (ITEP), Moscow (Russia) | V. Sopov | 36 |
| Budker Institute of Nuclear Physics, Akademgorodok (Russia) | B. Shwartz | 24 |
| London University College (United Kingdom) | C. Wilkin | 14 |
| University of California, Los Angeles (USA) | B Nefkens | 48 |
| University of Georgia, Athens (USA) | K. Nakayama | 24 |

In the final approval PrimeNet got **220 kEUR**. (Compare with the 445 kEUR approved for EtaMesonNet.)

*The time period for HP2 is shortened from 48 months to 30 months*[*)]

**WP5: PrimeNet** Meson Physics in Low-Energy QCD

**REQUESTED EC CONTRIBUTION PER BUDGETARY ITEM AND PER BENEFICIARY**

| Contr. No | Contractor Acronym | Personnel (EUR) | Consumables (EUR) | Travel and workshops (EUR) | Total direct costs (EUR) | Indirect costs (EUR) (7%) | Requested EC contribution (EUR) | OVERHEADS |
|---|---|---|---|---|---|---|---|---|
| 1 | INFN | 0 | 0 | 37 000 | 37 000 | 2 590 | 39 590 | 60,00% |
| | *INFN-LNF* | *0* | *0* | 37 000 | *37 000* | *2 590* | *39 590* | 60,00% |
| 7 | FZJ | 0 | 0 | 37 000 | 37 000 | 0 | 37 000 | 75,00% |
| 14 | UBO | 0 | 0 | 18 000 | 18 000 | 1 260 | 19 260 | 60,00% |
| 20 | UMainz | 0 | 0 | 18 000 | 18 000 | 1 260 | 19 260 | 60,00% |
| 48 | UU | 23 028 | 0 | 75 000 | 98 028 | 6 862 | 104 890 | 60,00% |
| | **TOTAL** | **23 028** | **0** | **185 000** | **208 028** | **11 972** | **220 000** | |

Approximately 40 000 EUR is budgeted for 2 main workshops

**The large overhead makes the budget tough!**

‘) now (Sept 4, 2009) prolonged to 36 months.

# TASK DESCRIPTIONS

**Task 1**: A coordination of the experimental programs at these facilities. In particular, experimental projects will be planned and optimized by utilizing the variety of capabilities of the facilities including their detector systems.
*Taskleader: A. Kupsc (UU)*

**Task 2**: Evaluation of experimental techniques as well as the tools for data analysis and simulations. Assessment of the experimental uncertainties in all experimental data from the detectors Crystal Ball (MAMI), Crystal Barrel (ELSA), KLOE2 (DAPHNE) and WASA (COSY).
*Taskleader: P. Moskal (UJ)*

**Task 3**: Establishment of a common database for all experimental results.
*Taskleader: PrimeNet Post Doc (UU)*

**Task 4**: Development of theoretical models establishing the links between different data and their relationship to basic concepts of hadron physics. Extraction of information from the data concerning properties of resonances, chiral dynamics and the nature of some resonances as well as different light mesons. A coordination of the theoretical model developments.
*Taskleader: T. Peña (Lisbon IST)*

**Task 5**: Establishing the interaction of the η and η' with nucleons and nuclei and the possibility to have η bound states in nuclei. The interaction between other light mesons and nucleons should also be considered.
*Taskleader: C. Hanhart (FZJ)*

**Task 6:** Extension of the techniques of chiral perturbation theory and chiral Lagrangians from a thorough investigation of the η decay modes.
*Taskleader: J. Bijnens (Lund)*

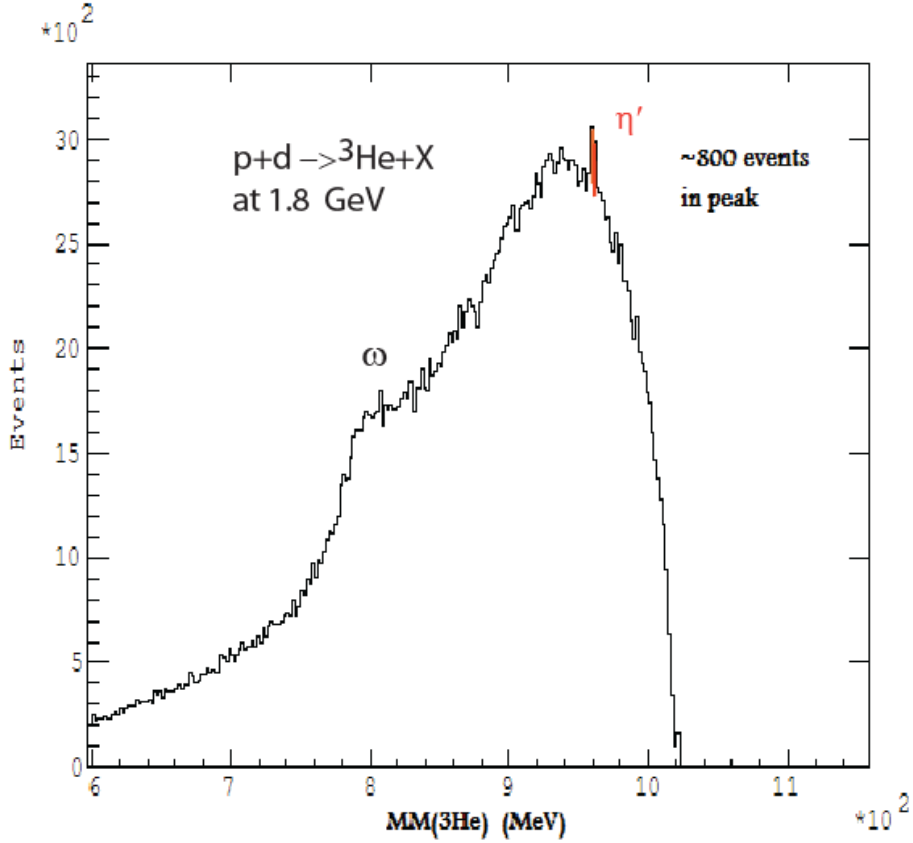
**Task 7**: Two main workshops involving all participants in the network.
*(Program committees)*

- **A first short PrimeNet meeting was held in Frascati April 8, 2009, in which status reports were presented about the experimental situation for η′ studies.**

Some short remarks from this meeting could be made regarding the η' detection possibilities and the Dalitz plot parameters.

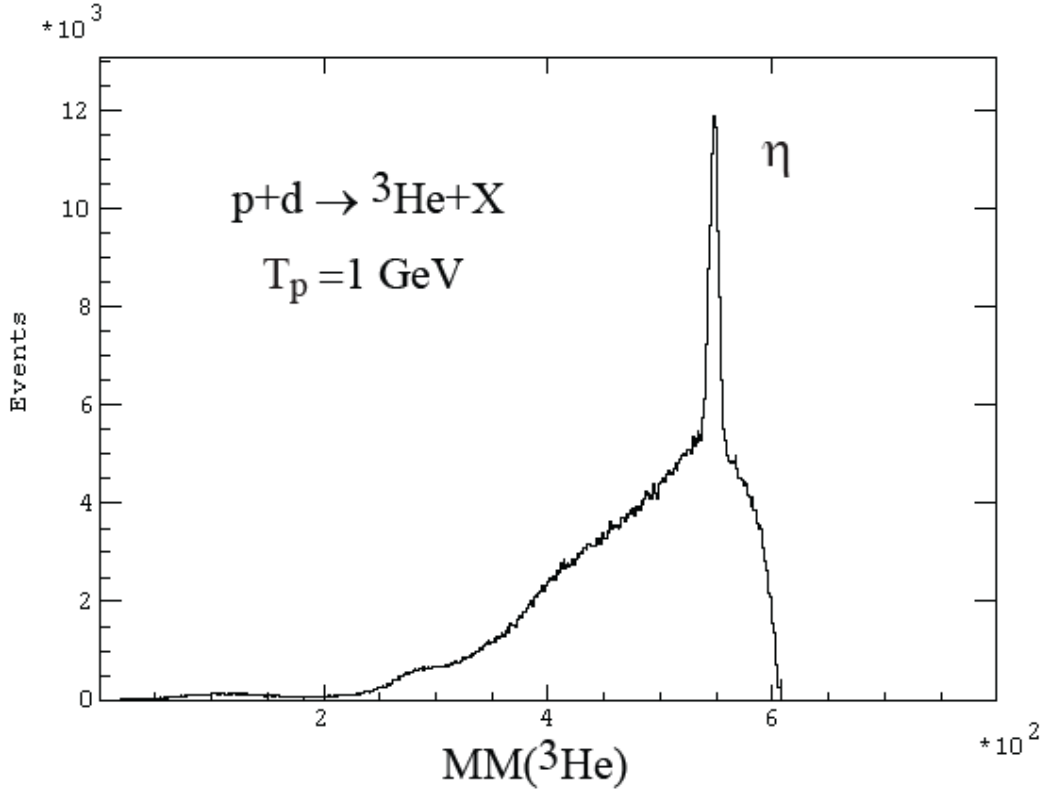
At **WASA** η′ can be produced in p-p collisions. However no success yet to see the η′ in the pp→ppη′ reaction! Too much hadronic background! Moreover, the WASA detector is presently not very good in measuring the high energy protons from the pp→ppη′ reaction. Therefore the missing mass resolution becomes too bad. The forward range hodoscope needs to be completed with a Cherenkov DIRC detector for better proton/pion separation and energy determination. Such a detector is now being developed for WASA.
The pp→ppη′ reaction has great potential to give large samples of η′. With $\sigma \approx 300$ nb and $L=5x10^{31}cm^{-2}s^{-1}$ one has ~50K η′ per hour!

Presently the WASA detector can identify η′ from the two body pd→$^3$Heη′ reaction. Here the $^3$He recoil can easily be identified and determined in energy with the present forward range hodoscope.
Accordingly a η′ peak appears in the missing mass spectrum from the detected $^3$He.
Here, in addition, a very weak constraint is applied on the η′ decay channel, viz the two most energetic photons must be

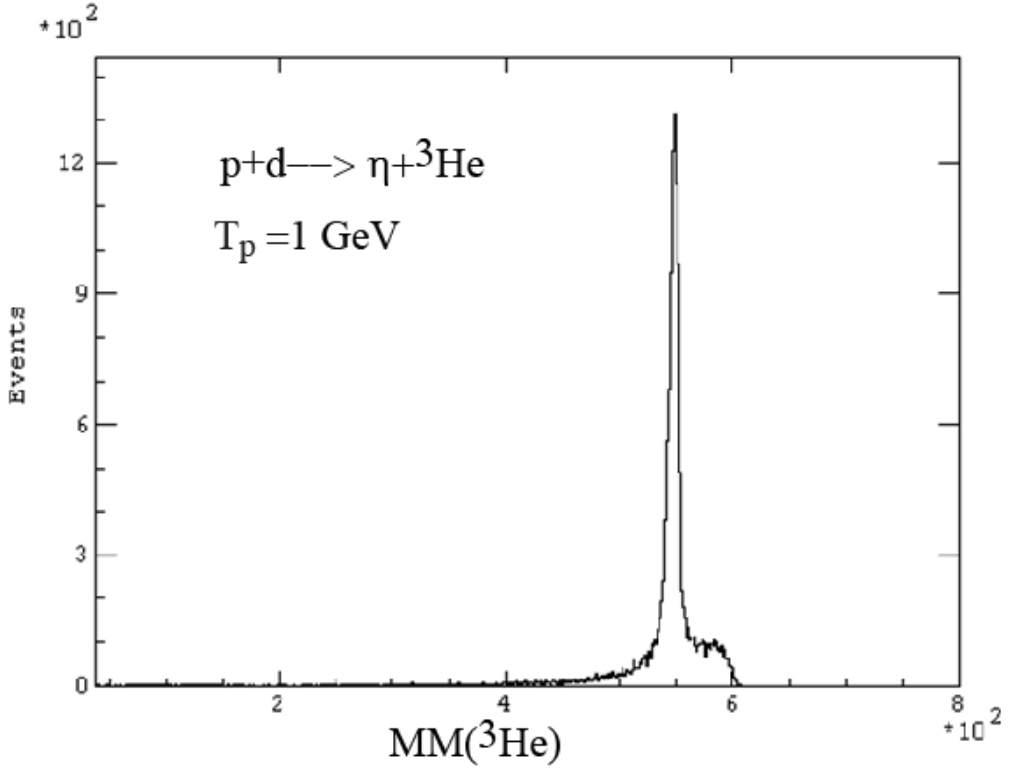


greater than 230 MeV. The hadronic background is still huge. Moreover the η′ cross section is very small in the pd collision (~ 1 nb ⇒ 35 η′ per hour at $L=10^{31}cm^{-2}s^{-1}$) , so this reaction is not very suitable for η′ decay studies.

We can make a comparison with the conditions for η production in the same reaction at 1 GeV. Owing to the larger cross section (~ 400 nb) the η peak stands out clearly.



The signal to background can be improved dramatically by making a strict selection on some of the η decay channels. Here we choose the decay into two photons.

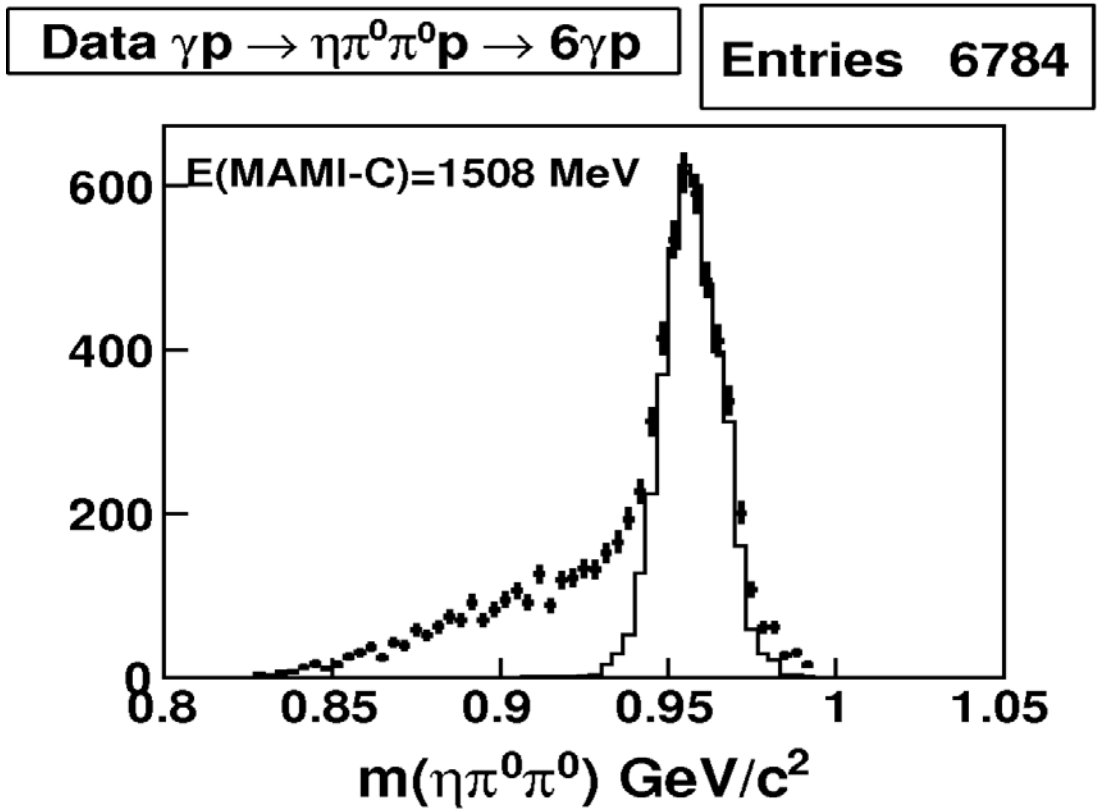



This reaction is presently used to collect high statistics for the $\eta \rightarrow \pi^+\pi^-\pi^0$ decay in order to measure the Dalitz parameters, to be compared with the KLOE result.

The same selection procedure should now be applied to the η′ spectrum with the hope to improve the peak to background ratio significantly.

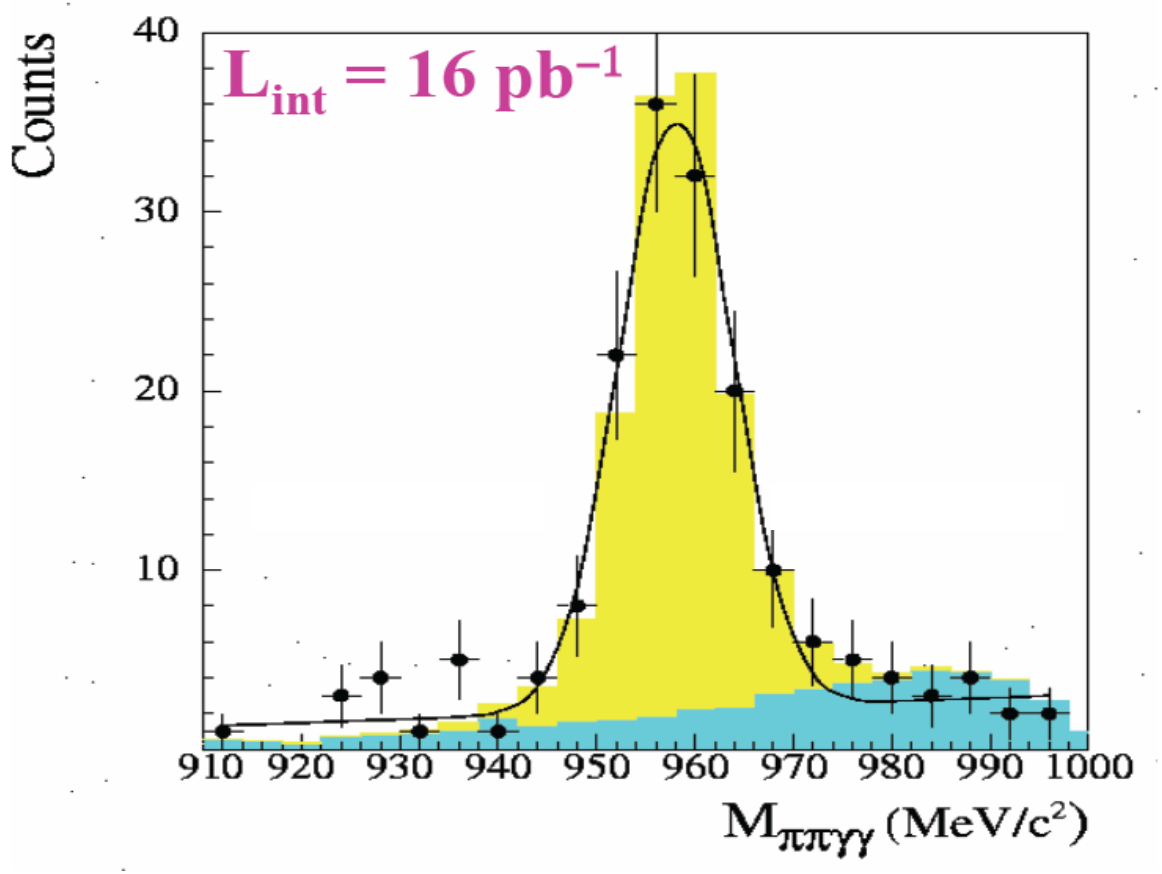
In Mainz the studies with the **Crystal Ball at MAMI-C** involves the photo production $\gamma p \rightarrow \eta' p$. With an average $\sigma \sim 1$ μb, one expects about 15K $\eta'$ per hour. The $\eta'$ can be identified, e.g., from its decay $\eta' \rightarrow \eta\pi^0\pi^0 \rightarrow 6\gamma$.

Kinematic fit is used to select the $\eta' \rightarrow \eta\pi^0\pi^0$. This decay yields ~700 events per hour.
Detection of the recoil proton is required to improve the resolution and background suppression.
The incident-photon energy is unknown since the maximum tagging energy is presently just below the energy of the $\gamma p \rightarrow \eta' p$ threshold 1.45 GeV.




About **10K** events are expected during 2009 at 1557 MeV from the $\eta' \rightarrow \eta\pi^0\pi^0$ process.
A tagged beam energy is needed at this high energy to improve the resolution. Such a tagger is now under construction. Good resolution is particularly needed to get high resolution in the Dalitz plot.

At **KLOE** the η′ is produced via the process $e^+e^- \to \Phi$ (~3μb) followed by $\Phi \to \eta'\gamma$.
The η′ is detected via some of its decay modes. About 500K η′ now on tape from KLOE.
For the $\eta' \to \eta\pi^+\pi^-$ decay channel the following spectrum has been achieved with 23% analysis efficiency, yielding **~21K** events.



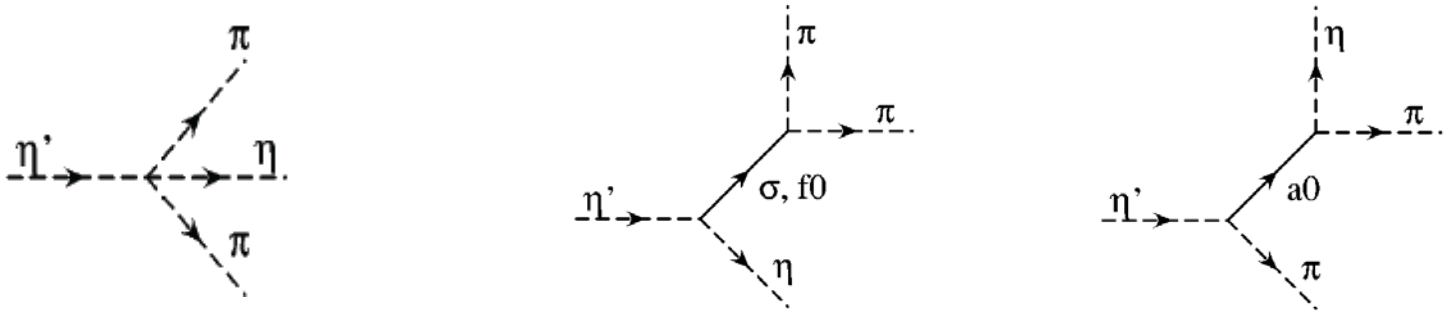

The events are analyzed following the decay pattern
$\Phi \to \eta'\gamma \to \eta\pi^+\pi^-\gamma \to \pi^+\pi^-3\gamma$

As seen the background is very low. These data can now easily be used to determine the Dalitz plot parameters.

The increased luminosity at KLOE2 will open new possibilities for η′ studies. The KLOE2 luminosity will increase to $4.5\times10^{32}$ $cm^{-2}s^{-1}$ from the previous $1.5\times10^{32}$ $cm^{-2}s^{-1}$.

**The Dalitz plot parameters** are introduced to parameterize the energy distribution of the decay products in some specific decay channel.
The Dalitz plot parameters can be calculated in ChPT and are thus subjected to direct comparison with experiment. The Dalitz distributions give a possibility to test the accuracy of the ChPT calculation.

Rough values of the Dalitz plot parameters for the decay $\eta' \to \eta 2\pi$ are available from previous experiments, GAMS, CLEO and VES and very recently also from the updated GAMS-4π. The decay process is expected to be affected by processes like



From the $\eta' \to \eta\pi^0\pi^0$ decay one has used the "linear fit" parameterization of the amplitude

$$|A(x,y)|^2 = |1+\alpha y| + cx + dx^2$$ ($\alpha$ is here allowed to be complex)

with $x = \frac{\sqrt{3}}{Q}\left(T_{\pi^+} - T_{\pi^-}\right)$ and $y = \frac{m_\eta + 2m_\pi}{m_\pi}\frac{T_\eta}{Q}$. T is the kinetic energy in the η′ rest frame and $Q = T_\eta + T_{\pi^+} + T_{\pi^-}$

An early experiment from GAMS gave $\alpha = -0.058 \pm 0.013$ (based on 5400 events).
The $\eta'$ was here produced in a 38 GeV/c $\pi^-$ beam via the reaction $\pi^- p \to \eta' n$.
*Phys. Lett. B 177 (1986) 115.*

In later experiments a more general fit is being used for the amplitude, viz

$$|A(x,y)|^2 = 1 + ay + by^2 + cx + dx^2$$ (c = 0 from symmetry of the wave function for $\eta' \to \eta\pi^0\pi^0$, or C parity for $\eta' \to \eta\pi^+\pi^-$ )

Comparison with the linear fit gives $a = 2\mathrm{Re}(\alpha)$ and $b = \mathrm{Re}^2(\alpha) + \mathrm{Im}^2(\alpha)$. Note that if b becomes negative using the general fit, the two fit expressions are not the same.

A very recent experiment from the improved GAMS detector (GAMS-4π), based on ~15000 events, gave the parameter values, *Phys. Atom. Nucl. 72 (2009) 231*.

| $\eta' \to \eta\pi^0\pi^0$ | | |
|---|---|---|
| Parameters | Fitted values (GAMS-4π) | ChPT + coupled channel<br>Borasoy and Nissler in Eur.Phys.J.A26(2005) |
| *a* | −0.066 ± 0.016 ± 0.003 | –0.127±0.009 |
| *b* | –0.063 ± 0.028 ± 0.004 | 0.003±0.018 |
| *c* | –0.107 ± 0.096 ± 0.003 | 0.019±0.039 |
| *d* | 0.018 ± 0.078 ± 0.006 | |

Note that *b* is negative here and this fit is thus not compatible with the previous linear fit. If a fit is done with the linear amplitude one gets $\alpha = -0.042 \pm 0.008$, which is in agreement with the early measurement from GAMS.

Regarding the $\eta' \to \eta\,\pi^+\pi^-$ decay, there is a result from CLEO yielding $\alpha = -0.021 \pm 0.025$ using the same linear fit as for the neutral decay cannel. The $\eta'$ was produced via resonances produced in $e^+\,e^-$ collisions. The analysis was based on 6700 events. *PRL 84 (2000) 26.*

The general amplitude $|A(x,y)|^2 = 1 + ay + by^2 + cx + dx^2$ has been used to fit the data from VES. For the $\eta'$ production they used the reaction $\pi^- N \to \eta'\pi N$, yielding ~6450 $\eta'$ events, and the $\pi^- p \to \eta' n$ reaction yielding ~13600 $\eta'$ events.

A fit using the combined data sets from VES gave the following parameter values.

| $\eta' \to \eta\ \pi^+\pi^-$ | | | |
|---|---|---|---|
| Dalitz plot Parameters | Fitted value, VES data | ChPT + coupled channel Borasoy and Nissler | Compare with the fitted values for $\eta' \to \eta\pi^0\pi^0$ from GAMS |
| *a* | −0.127 ± 0.016 ± 0.008 | –0.116 ± 0.024 | −0.066 ± 0.016 ± 0.003 |
| *b* | –0.106 ± 0.028 ± 0.014 | 0.000 ± 0.019 | –0.063 ± 0.028 ± 0.004 |
| *c* | +0.015 ± 0.011 ± 0.014 | +0.016 ± 0.035 | –0.107 ± 0.096 ± 0.003 |
| *d* | –0.082 ± 0.017 ± 0.008 | | 0.018 ± 0.078 ± 0.006 |

The values of the Dalitz plot parameters for $\eta' \to \eta\ \pi^+\pi^-$ and $\eta' \to \eta\pi^0\pi^0$ should be the same in the isospin limit.
Note that these values are incompatible with a linear fit since b is found to be negative.

**There is a need for improvement both in experimental data and theory!**

**New measurements of the Dalitz plot parameters are foreseen at KLOE2, Crystal Ball, Crystal Barrel and maybe WASA with improved statistics and a good understanding of the systematical errors.**

Other measurements will focus on:

- $\eta$–$\eta'$ mixing angles.
- The gluon content in $\eta'$.
- Several poorly known $\eta'$ decay channels.
- Investigation of cusp effects in the $\eta'$ decays, in particular $\eta' \to \eta\pi^0\pi^0$ (sensitivity to the $\eta\pi$ and $\pi\pi$ scattering lengths).

**The near future program for PrimeNet will be**

- A general meeting will be held in October 8-9 in Bonn. In this meeting the η′ program at Crystal Barrel at ELSA will be discussed in particular.
In addition the different task groups will make presentations related to their activities.

- The first general workshop will be held in April, 2010, in Lisbon, hosted by Teresa Pena.

- In addition, short exchange visits devoted to the different tasks of PrimeNet will take place when needed.