Ferrara activity in 2013 and plan for 2014

The Ferrara group is actively involved in the study of the 3D nucleon structure, in particular the transverse momentum dependent parton distributions (TMDs). Based on the experience gained with the HERMES experiment, the group is promoting this field of research for the 12 GeV upgrade of JLab. In particular the group is involved in the physics program definition, both in the feasibility studies and proposals of new experiments and in the R&D of the required apparatus.

Members of the Ferrara group are co-spokespersons of 3 experiments approved (C1) by the JLab PAC39 in June 2012, which are based on the use of a transversely polarized target. Moreover members of the Ferrara group are proponents and co-spokespersons of approved experiments that require the hadron identification by a RICH detector. Therefore the activity in Ferrara concentrates on two main topics:

Ring Imaging Cherenkov for CLAS12

The group takes care of the procurement and characterization of the aerogel radiator, of the MC simulations (accounting for optical effects) for the definition of the geometry and materials of the final detector and the RICH prototype, and of the single-photon detection tests with SiPM;

Magnet system for the transverse HD-Ice target

The group has studied the conceptual design of the magnet system to hold the transverse polarization of the HD-Ice target in the CLAS12 central detector.

RICH

The goal of the RICH detector is to identify hadrons in the momentum range from 3 to 8 GeV/c. Since the pion flux is about an order of magnitude larger than that of kaons and protons, a rejection factor of several hundreds is required. Early MC studies showed that a proximity-focusing RICH, based on aerogel and photomultipliers, can do the job. Since this technology is expensive, a strong effort is devoted to contain the costs by exploring different alternatives, listed in the following.

The first is to use relatively cheap photomultipliers (PMTs), as the large area and high packing-factor Hamamatsu H8500 multi-anode PMT. During the CERN 2011 test-beam, the expected number of photo-electrons (of the order of 10) was verified experimentally. This demonstrated that the H8500 PMT is suitable for the CLAS12 RICH, despite it is not designed for single-photon detection.

The second is the use of mirrors to reduce the photo-detection area. Given the peculiar geometry of CLAS12, this solution is non-conventional as it requires a multiple passage of the Cherenkov photons through the aerogel. A necessary condition is therefore the use of aerogel tiles with high transparency. A collaboration has been established with the Russian Budker Institute of Novosibirsk to produce aerogel tiles of 2-3 cm thickness and high transmittance with the so-called pinhole drying technique. The plan is to perform some test productions by varying certain effective parameters in the catalysis process, to be tested in Ferrara.

The third is the use of different photon detectors. The silicon photomultiplier (SiPM) devices have in principle several advantages. They have higher quantum efficiency and are insensitive to magnetic fields, are pretty compact and robust devices. The known sensitivity to radiation damage would not be a problem at CLAS12, due to the limited integrated radiation dose (of the order of 10^9 neutron/cm^2/year at maximum luminosity). The high dark count (of the order of MHz) can be in principle controlled by tight time coincidences or by cooling the device. SiPM are in fast development: in the last two years both the typical dark count and the price halved, thus representing a promising future alternative to the standard multi-anode PMTs.

RICH conceptual design: simulations and performances

In 2013 the RICH simulations have been refined to account for specific optical effects, i.e. mirror reflectivity, aerogel Rayleigh scattering, chromatic dispersion and forward scattering due to the aerogel surface roughness. A reconstruction algorithm has been implemented based on a likelihood analysis of the hit pattern.

These same tools have been used to define the geometry of the real-scale prototype tested at CERN. Figure 1. shows the real-scale prototype used in the two 2012 CERN test-beam. The prototype had a flexible geometry and allowed to test not only the direct light configuration, in which the Cherenkov ring is directly detected by the PMTs array, but also the reflected light case, in which the Cherenkov photons are first reflected back by a spherical mirror, and then focalized onto the PMT plane after a second reflection on the planar mirrors. The reflected case is more challenging as it requires a multiple passage of the photons through the radiator material, resulting in a partial absorption of the Cherenkov light, and thus in a smaller number of photoelectrons.

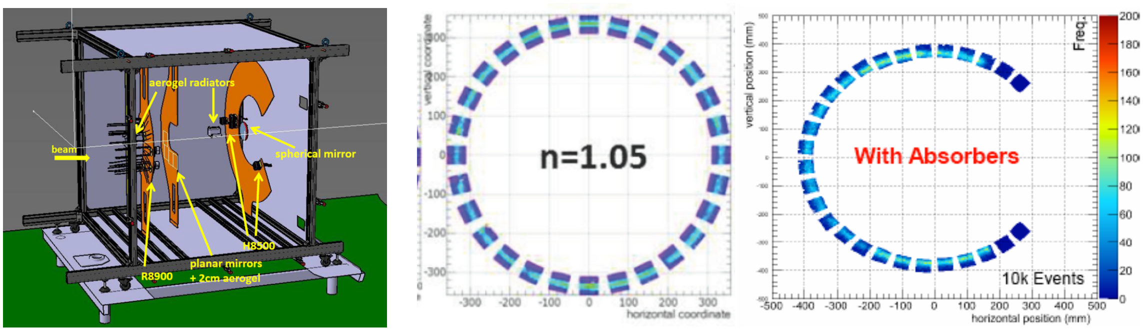

Fig. 1 Overview of the real-scale RICH prototype used in the two 2012 CERN test-beam. Event-display showing the Cherenkov ring detected by the array of H8500 PMTs for direct (center) and reflected (right) light case.

During 2013 the analysis of the CERN data has been carried out (now almost finalized) in collaboration with the Frascati group. Figure 2 shows the pion-kaon separation for different beam momenta for the direct light configuration.

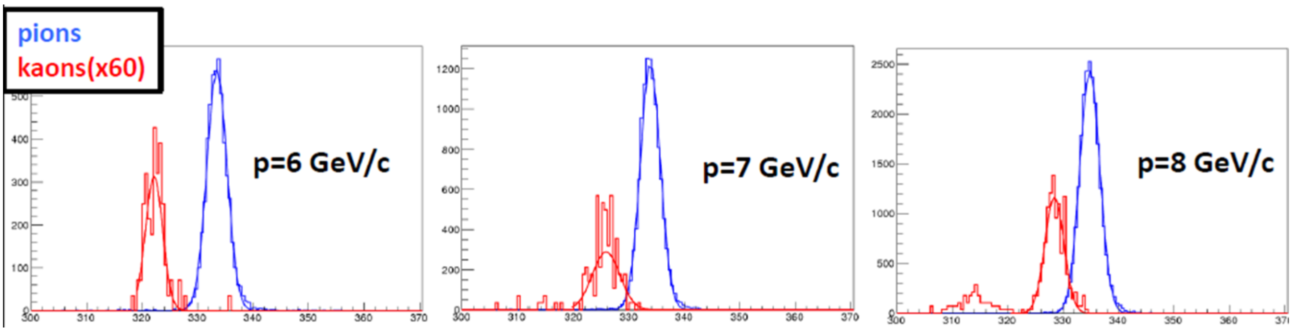

Fig. 2 Pion-kaon separation for different beam momenta momenta for the direct light configuration. The kaon yields are enhanced by a factor of 60 for better visualization.

A full simulation of the prototype geometry and response has been developed in order to validate the detailed description of the optical properties of the various materials (radiator, mirror, PMTs). Figure 3 shows the MC is able to reproduce the ring radius resolution, a quantity directly related to the basic Cherenkov angle resolution, in different experimental conditions.

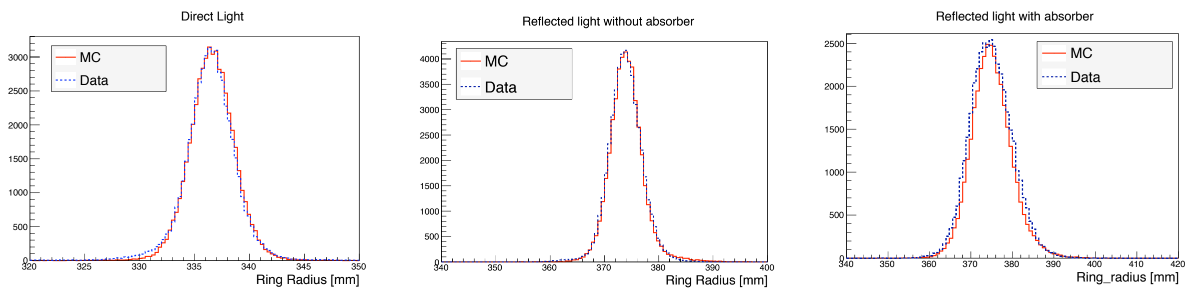

Fig. 3 Pion-kaon separation for different beam momenta momenta for the direct light configuration. The kaon yields are enhanced by a factor of 60 for better visualization.

After being tuned by the prototype results, the simulations can be used to estimate the expected pion-kaon and proton-kaon contaminations at CLAS12, including the available information on the TOF and HTCC (High Threshold Cherenkov Counter) detectors. The studies were performed in a 2-dim space spanned by the hadron momenta and polar angles. The results reported in Fig. 4 shown that the RICH is an essential tool for the hadron PID at CLAS12 as it limits the pion contamination in the kaon sample to the level of few percents.

The simulations are extended the the study of the particle fluence (radiation damage due to the integrated flux of slow neutrons), Moeller background and influence of the RICH material budget on the downstream detectors (time-of-flight and calorimeter).

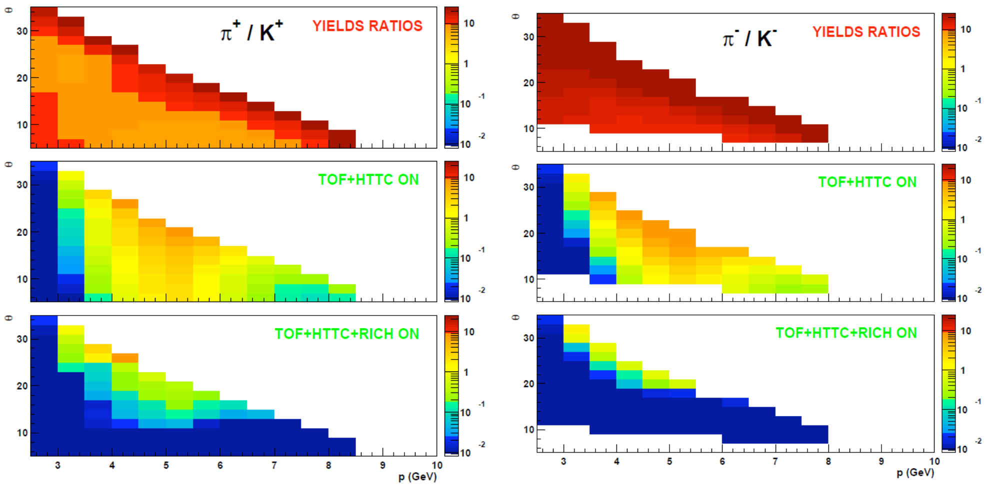

Fig. 4 π^+/K^+ (left) and π^-/K^- (right) yield ratios within CLAS12 acceptance in a 2-dim binning in hadron momentum and polar angle. The upper panels show the pion/kaon yield ratios, the middle panels show the pion contamination after the TOF and the HTCC PID, and the bottom panels show the pion contamination after the TOF+HTCC+RICH PID, indicating the crucial role of the RICH detector.

RICH radiator: Aerogel

In 2012 a small laboratory has been commissioned in Ferrara for aerogel characterization. Le laboratory equipment includes a Perkin-Elmer Lambda 650 S spectrophotometer (fig.5 left), an dry-atmosphere cabinet for aerogel storage (fig.5 right), an optical bench and several lasers with different wavelength.

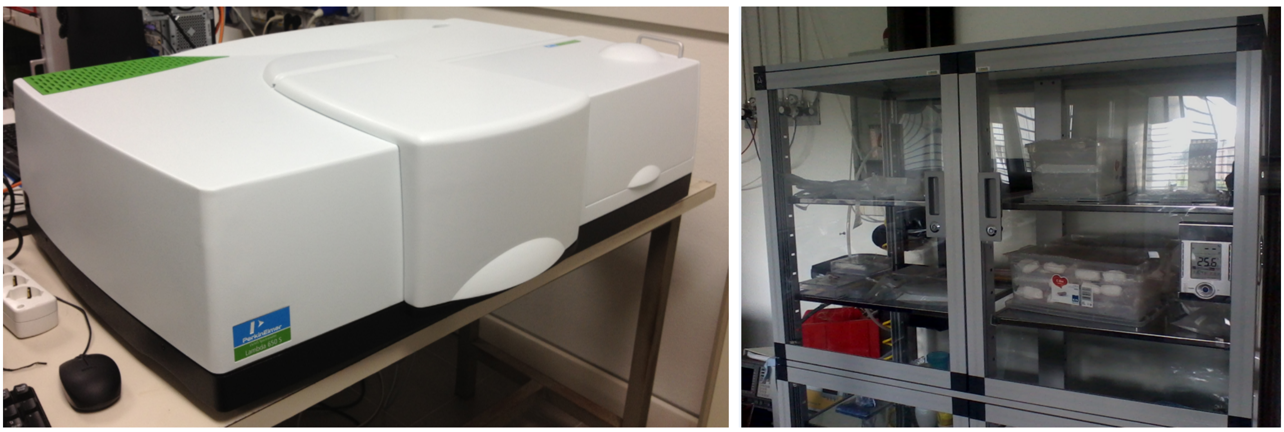

Fig.5 The Perkin-Elmer Spectrophotometer in use at Ferrara (left) and the dry-atmosphere cabinet used to store the aerogel samples (right).

During 2013 the laboratory has been intensively used for the systematic characterization of the optical properties of the various aerogel tiles: the chromatic dispersion, the transmittance and the absorption and scattering lengths.

Scattering lengths as large as 53 mm at λ=400 nm have been recently obtained in collaboration with the Budker Institute, but further improvements are envisaged. Figure 6 shows the increase of the scattering length of the aerogel tiles produced by Novosibirsk over time. There is a clear trend showing that the production technique and the resulting quality of the aerogel has significantly improved in time following the requirements of the project. The achieved clarity (0.005 $\mu m^4/cm$ at n=1.05) is higher than the aerogel produced for LHCb (0.0064 $\mu m^4/cm$ at n=1.03), despite the higher refractive index.

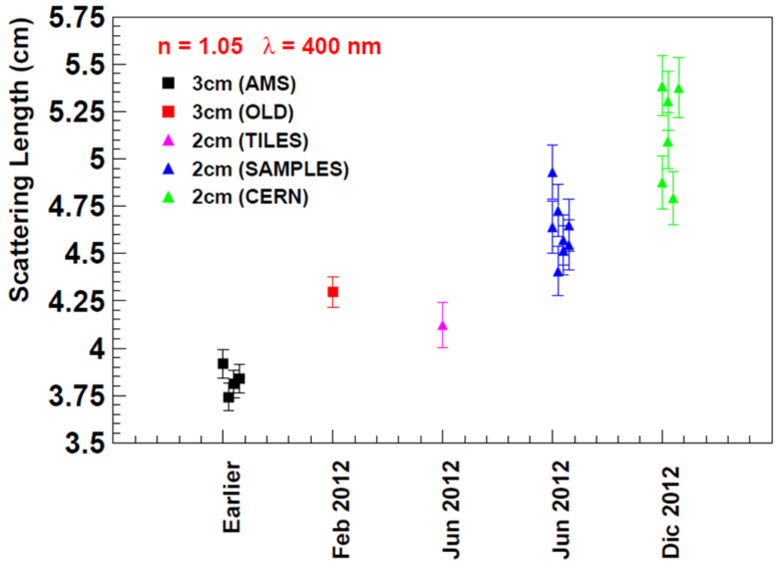

Fig.6 Scattering length at λ = 400 nm for the Novosibirsk aerogel tiles versus the production time.

The Japanese aerogel is for the moment not an option, since Panasonic is not producing the BELLE aerogel for public yet. Only available from Panasonic are large productions of aerogel based on a standard technique, with short scattering length (37 mm) and small thickness (1 cm). Also the US aerogel from Aspen, recently tested in Ferrara, is for the moment not an option for the CLAS12 RICH due to its limited performances in terms of transmittance and scattering length.

The transmission length is measured with the spectrophotometer. It is a Perkin-Elmer Lambda 650 S instrument, completed with a integrating sphere and a large compartment for samples suitable for the aerogel tiles. Examples of the measurements done so far on eight Novosibirsk samples with n=1.05, based on the Hunt formula,

Transmittance — Hunt formula

$$T(\lambda) = e^{-\frac{t}{\Lambda_{tot}}} = e^{-t\left(\frac{1}{\Lambda_A}+\frac{1}{\Lambda_S}\right)} = e^{-\frac{t}{\Lambda_A}} \cdot e^{-\frac{t}{\Lambda_S}} = A \cdot e^{-\frac{Ct}{\lambda^4}}$$

are shown in Figure 7. Similar measurements were performed for all the aerogel samples purchased so far.

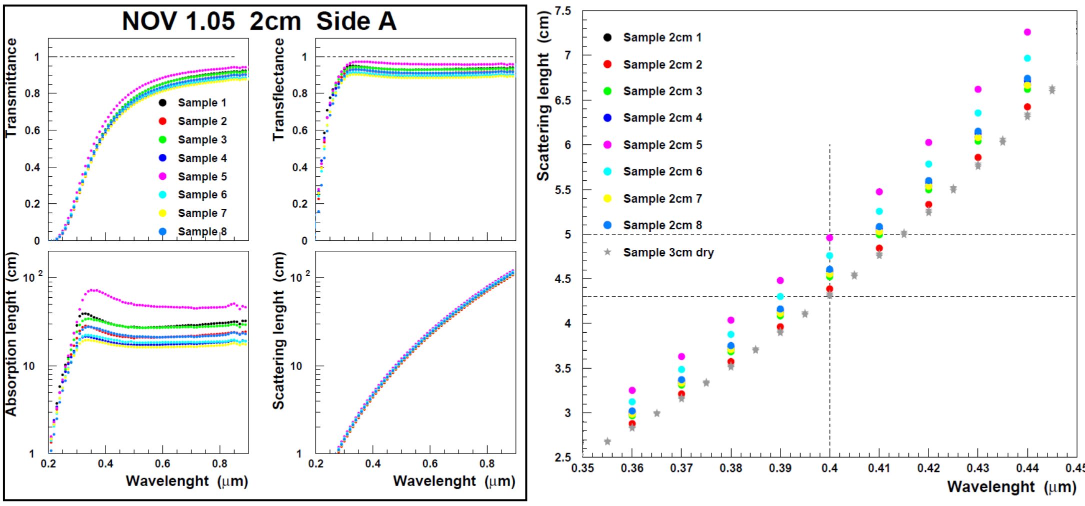

Fig.7 The aerogel transmittance measurement and the absorption and scattering length as extracted from the Hunt formula. Comparison of scattering length at 400 nm wavelength for 8 different aerogel tiles of n=1.05 refractive index and 2 cm thickness. The values range from 43 mm (standard) up to 50 mm.

The chromatic dispersion is one of the main sources of uncertainty of the Cherenkov angle. In literature there are several measurements for n=1.03 refractive index, but none for the n=1.05, to be used at CLAS12. The measurements are based on the prism method and require the use of three lasers: red (λ=633 nm), green (λ=532 nm) and blue (λ=405 nm). A preliminary validation of the input to the CLAS12 simulations is shown in Figure 8. The preliminary measurements indicate a smaller than expected dispersion for the Russian aerogel. Refined laboratory tests and test-beam measurements with optical filters are ongoing, as this could reflect in better RICH performances.

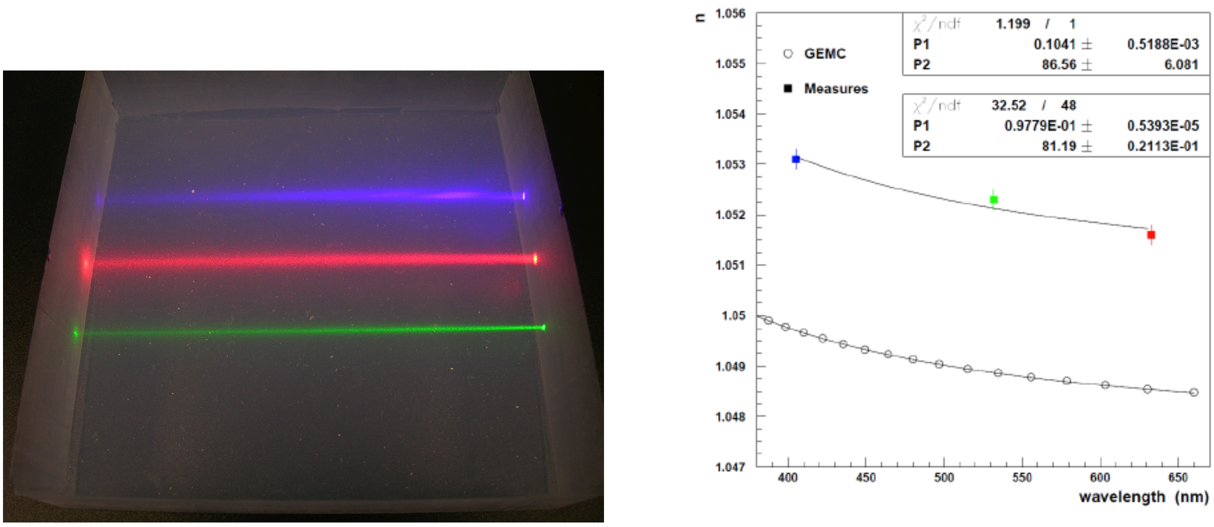

Fig.8 (Left) The three laser beams used for the dispersion measurement passing through the aerogel. The attenuation of the beam intensity, which is decreasing with the wavelength, is visible. (Right). Dispersion measurement based on the Snell-Descartes law for laser light of known wavelength passing through a prism (corner of an aerogel tile). The measured curve (over the colored dots) is consistent with the one in input to the simulations (black dots) besides the irrelevant offset.

The foreseen activity in the second half of 2013 and 2014 is

- the continuation of the collaboration with the Budker Institute to improve the optical properties of the aerogel radiator: since high values of clarity has been achieved, the interest now is to improve the optical surface of the radiator to minimize;
- the commissioning of the test-bench for aerogel characterization;
- the starting of the massive production for the first RICH sector.

The fund request for 2014 are 80k euros of "Apparati" for aerogel production. This is the largest request. It is mandatory we start the production early next year in order to achieve the goal of the 1st RICH sector installation at beginning of 2016, in time for the physics run. The fund request accounts for 4k euros of "Consumo" for the services of the test-bench (i.e lens, mirrors, holders and black boxes) and 2.5 k euros for a CCD camera for precise optical characterizations.

RICH photo-detector: SiPM

Since SiPMs were never used in a working RICH detector, a R&D work has been planned to test their performances for single photon detection, following the seminal work of the Lubiana group. During the first of the two CERN test-beams in 2012, three SiPM matrices were used to detect the Cherenkov light, with the aim to test their single-photon detection capabilities.

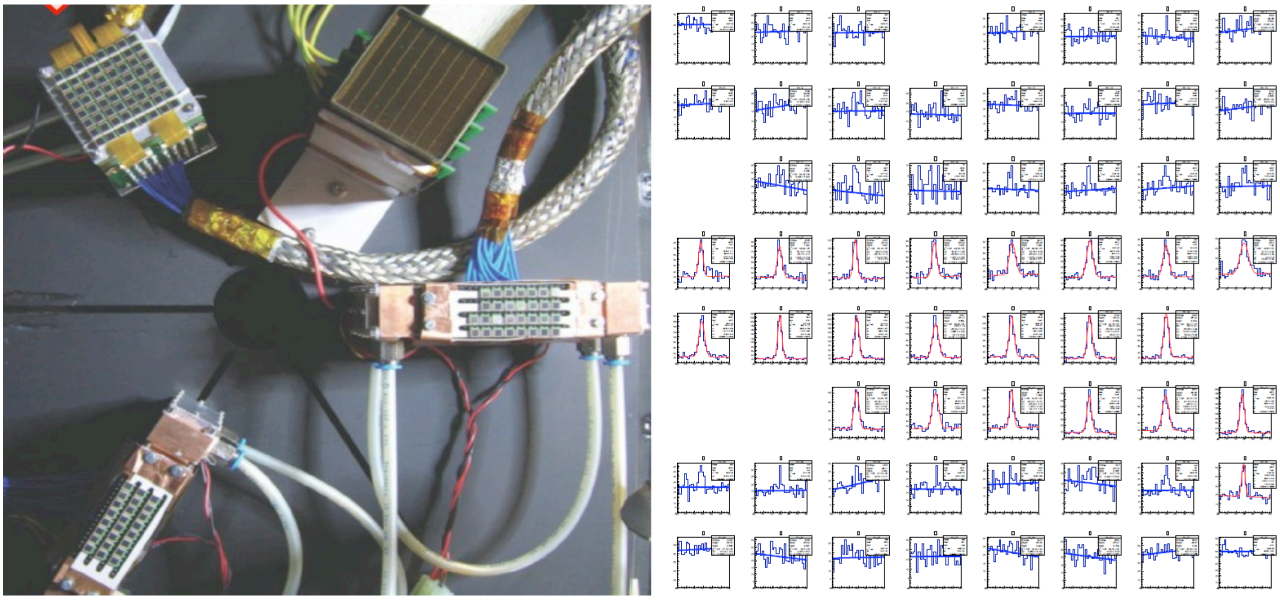

Fig.9 (Left) The three SiPM matrix used in the test-beam in summer 2012. They are sitting on a Peltier cell for temperature control and read-out by a front-end card developed for SuperB muon detector. Also shown is a H8500 PMT, used as a reference. (Right) The spectra collected with the Hamamatsu SiPM matrix: single-photon signals are very clear signals (peaks) in the central pixels, illuminated by the Cherenkov ring. The missing pixels were not connected or dead.

One of the matrices is a recent product of Hamamatsu, completed by read-out kapton foils and temperature sensor. The other ones are custom matrices made from single SiPMs.

The DAQ is based on a front-end card developed for SuperB muon detector and a standard VME TDC. Figure 9 show the SiPM array used at the CERN test-beam (left) and an example of acquired spectra (right). The spectra show very clear signals (peaks) in the central pixels, illuminated by the Cherenkov ring.

The foreseen activity in the second half of 2013 and 2014 is

- realization of custom SiPM matrices with new types of SiPM (monolithic devices);
- study of the performances with a laser test-bench.

Being the group activity concentrated in the 1st RICH sector realization, the SiPM activity will be limited to the R&D with innovative devices already purchased (to stay updated on cost-effective options for additional RICH sectors). No specific found are therefore planned.

HD-Ice

A transversely polarized target allows unique measurements related to the quest for the 3D nucleon structure. Among the accessible parton functions, there are the transversity (the last collinear missing piece), the Sivers TMD function and the generalized parton distribution function E, which are related to the elusive orbital motion of the partons.

The HD-Ice is a new type of frozen-spin target with minimal dilution of not-polarizable material and nuclear effects. It does not require strong holding magnets, matching the large acceptance of the CLAS12 detector and the approved physics program. The preliminary test with electron beam indicates the radiation damage, a potential show-stopper, is not the limiting factor for the Hydrogen component. However it also showed the cooling system is not suitable for charged beams and R&D works is required. Three experiments has been approved by JLab PAC39 with maximum rating A, with the condition that the target can run long enough in an electron beam. Beam tests are foreseen in 2015, before CLAS12 operation, when a new test-beam facility with low-energy electrons will be operative at JLab.

HD-Ice activity in 2013 and plan for 2014.

To insert a transversely polarized target in the CLAS12 central detector, which is embedded in a superconducting solenoid, is a difficult task. A compensating magnetic system has to be designed in Ferrara to provide a region of zero-field in the target volume. The proposed solution is a counter solenoid, able to compensate the external 2T longitudinal field down to 5 mT within the target, complemented by a saddle coil for a 0.5T transverse field. The system is a powered version of the already existing HD-Ice magnet system and can be accommodated in the HD-Ice cryostat, with no impact on the CLAS12 detector. A sketch of the proposed solution is shown in Fig.10.

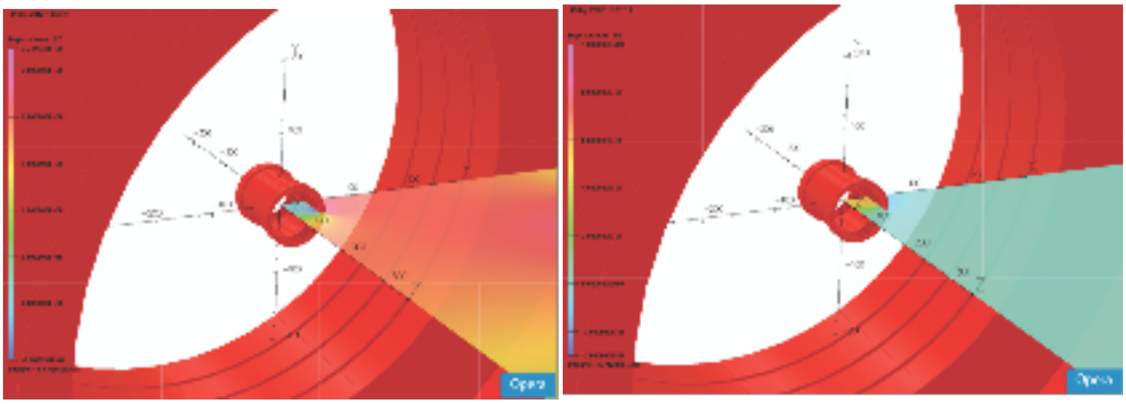

Fig.10 Longitudinal (left) and transverse (right) field components inside the CLAS12 solenoid magnet with at the center the compensating and saddle HD-Ice coils.

During 2012 a preliminary feasibility study was done, showing the Moeller background is under control, the critical current and the static forces are not critical and a standard solution for quench protection is available. This study was presented at the JLab PAC39 supporting the proposals based on HD-Ice. The study is now being extended to account for higher transverse fields, as requested by the JLab target groups: up to 1T to contrast the depolarization effects of the charged beam on HD-ice target or up to 2T to allow a dynamical polarization of the NH_3 target as possible (more standard) alternative.

The foreseen activity in the second half of 2013 and 2014 is:

- optimize the magnet design accounting for the commercially available superconducting wires and constraints from the new HD-Ice cryostat for CLAS12;
- test the wiring of the saddle coil, the less trivial element in the project.

The fund request for 2014 is 20k euros of "Apparati" for superconducting wire and wiring tests (aluminum mold, G10 epoxy, …). Note in Ferrara there is expertise in superconductivity and cryogenics and there are dedicated tools available, i.e. a 700 A power supply and a test-bench for small superconducting magnet mapping at working temperature.

Milestones for 2014.

The proposed milestones for the major RICH activity are:

1. Inizio produzione aerogel (30/06/2014);
2. Conclusione R&D specchi (31/12/2014).