BESIII

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1 The BESIII experiment

The BESIII experiment is successfully taking data since 2009 at the Beijing Electron Positron Collider BEPC-II, at the Institute of High Energy Physics, IHEP, and it will continue taking data until at least 2024. The BESIII detector is designed to study τ- charm physics and collected the world largest samples of J/ψ, $\psi(3686)$, $\psi(3770)$, $\psi(4040)$, $Y(4260)$ and $Y(4360)$. BESIII discovered the first unambiguous four-quark states, the charged $Zc(3900)^+$ and $Zc(4020)^-$.

In 2015 the experiment has taken data in the low-energy range (between 2.0 and 3.1GeV) for the R-scan and the maximum instantaneous luminosity reached in 2015 is $\mathcal{L} = 0.9 \times 10^{33}$ cm^{-2} s^{-1}.

In 2012 the LNF group started to work on the proposal of upgrading the inner BESIII traking chamber, which is suffering early ageing due to the increase of the luminosity, with a new Cylindrical GEM (CGEM) detector. The project has gone ahead, a Conceptual Design Report has been drafted in 2014 with the contribution of the whole Italian BESIII group. The project, that since 2014 also includes groups from Mainz, Uppsala and IHEP, has been recognized as a Great Relevance Project within the Executive Program for Scientific and Technological Cooperation between Italy and P.R.C. for the years 2013-2015 and it has been selected as one of the projects funded by the European Commission within the call H2020-MSCA-RISE-2014.
The group is involved in the analysis of physics processess mainly involving nucleons and light hadrons.

2 Measurement of the relative phase between strong and electromagnetic vector charmonium decay amplitudes

As already stated in last years'reports the INFN component of the BESIII Collaboration, represented by the LNF, Torino, Ferrara and Perugia groups, proposed and obtained a data taking based on an energy scan below, above and at the J/ψ to measure the phase Φ between strong and electromagnetic (e.m.) decay amplitudes in a model independent way, from the interference between the J/ψ and the continuum for as much as possible processes. In a model dependent way, Φ in modulus (i.e., apart the sign) is close to $|90^0|$, at odd with the expectation that both the decay and the continuum amplitudes should be real, as it has been shown in last year Activity Report.
The scan data analysis turned out to be more problematic than foreseen, in particular concerning ISR simulation. Different approaches have been considered, in the end they essentially agree with each other and the effect is a component of the systematic error. In the following some results are reported.

In Fig.1(a) the scan data for $e^+e^- \rightarrow \mu^+\mu^-$ are shown [1] black dots are the data, the red line is the prediction, according to QED for the continuum and to PDG-2014 value for the $J/\psi \rightarrow \mu^+\mu^-$ branching ratio. There is an excellent agreement and a full interference is found, i.e. the phase angle between e.m. amplitudes from J/ψ decay and direct e^+e^- decay is measured to be $\Phi_{\gamma,cont} = (-5.0 \pm 9.7)^0$. This is a good check, since $J/\psi \rightarrow \mu^+\mu^-$ is a pure e.m. decay and a full interference (0^0) is expected. It also allows a calibration of the beam energy scale and of the beam energy spread, which is close to 900 KeV.
In Fig.1(b) the scan data and the relative prediction are reported, concerning a typical process where the J/ψ strong decay is an important one, namely $e^+e^- \rightarrow 2\pi^+2\pi^-\pi^0$. This time there is no interference, pointing out a $\simeq 90^0$ phase. This is the first attempt to measure such a phase directly from the J/ψ Q^2 behaviour and to make use of multi-hadron final state. However more decay channels have to be studied before drawing a conclusion about the phase Φ.

The process $e^+e^- \rightarrow \eta\pi^+\pi^-$ does not have a strong contribution, due to G-parity violation, therefore this channel can provide more information on $\Phi_{\gamma,cont}$ and in fig.1(c) one can see that the lineshape is similar to that of $\mu^+\mu^-$(a), but different from that of 5π(b). From the fit we measure:$\Phi_{\gamma,cont} = (-2.0 \pm 39)^0$ for the first time and $Br(J/\psi \rightarrow \eta\pi^+\pi^-) = (3.6 \pm 0.7)X10^{-4}$ with a better precision than the PDG value.

3 Measurement of $e^+e^- \rightarrow \Lambda_c^+\overline{\Lambda}_c^-$ and $e^+e^- \rightarrow \Lambda\overline{\Lambda}$ cross sections close to their production thresholds

As already mentioned , many unexpected features has been observed, mostly by BaBar [3] by means of the initial state radiation technique, in the measurement of $e^+e^- \rightarrow p\bar{p}$ cross section close to the production threshold: a sudden jump in the total cross section, likely related to a Coulomb enhancement, followed by a flat behavior and a form factor at threshold close to unity [3]. Actually the interpretation of BaBar data is controversial.

A measurement of $e^+e^- \rightarrow \Lambda_c^+\overline{\Lambda}_c^-$ cross section in the e^+e^--center of mass can be performed exactly at threshold, because of the weak decay into lighter particles. Hence BESIII can check and eventually confirm these features in the case of a heavy baryon. For this reason we have proposed [2] to the BESIII Collaboration to perform the measurement of the $e^+e^- \rightarrow \Lambda_c^+\overline{\Lambda}_c^-$ cross section close to the production threshold and in part has been performed by BESIII at the end of the 2014 data taken, and it can be anticipated that similar features have indeed been observed. However before making any statement, a higher amount of integrated luminosity has been requested, hopefully to be delivered in the 2016-2017 data taken.

In particular the measurement at $\Lambda_c^+\overline{\Lambda}_c^-$ at threshold depends on the c.m. energy resolution σ_w, which is not well known. In principle it can be derived by the ψ(2S) apparent width, assuming as usual that it is increasing as the square of the c.m. total energy. Unfortunately the extrapolation is a big one and the ψ(2S) apparent width during that data collection was not reliable. A method to get indepedently σ_w has been developed in 2015: the c.m. energy, as achieved by means of $\Lambda_c^+\overline{\Lambda}_c^-$ fully reconstructed events, at threshold, will be shifted roughly by a $\sim \sigma_w$ amount. Present data suggest $\sigma_w \sim 3$ MeV, quite more than expected. Unfortunately a better statistics is needed to apply this method and that is an additional reason to ask for more integrated luminosity.
For a neutral baryon the standard expectation is that the cross section at threshold should be vanishing, lacking the Coulomb interaction considered responsible of a non zero cross section at threshold, for charged baryons. Conversely BESIII has found that $e^+e^- \rightarrow \Lambda\overline{\Lambda}$ cross section at threshold is different from zero [4], as shown in Fig. [?](a) and (b), in terms of Λ effective form factor. Coulomb interaction at quark level might be the explanation. Data from other baryons, already collected and under analysis, are needed to draw a conclusion.

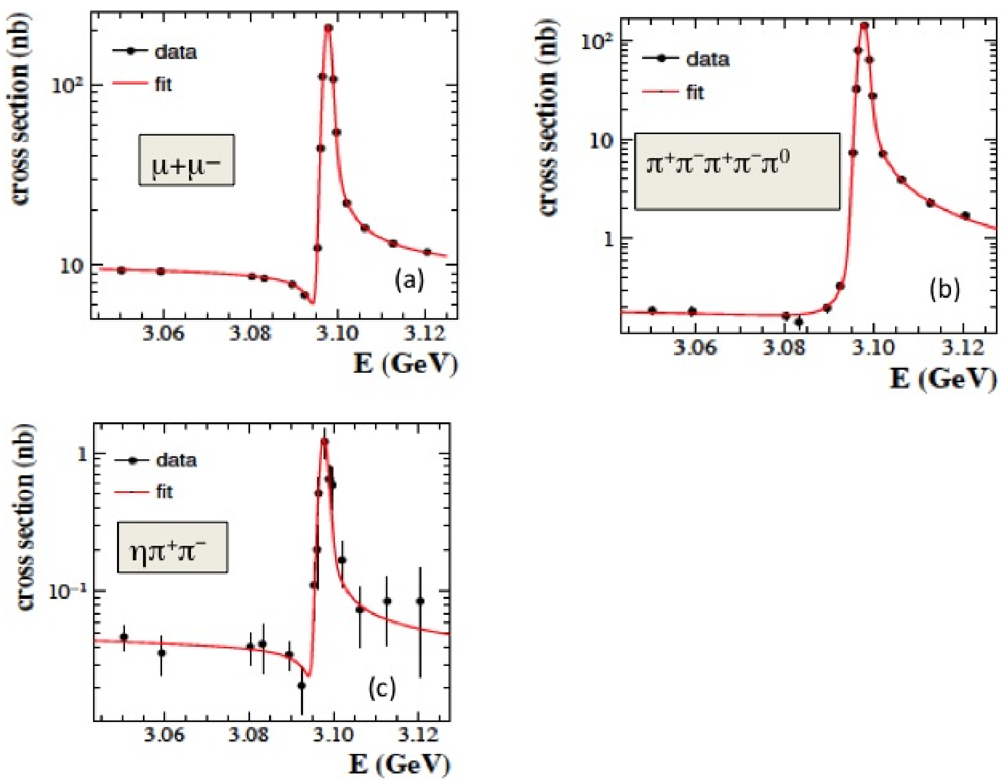

Figure 1: (a) Fit result of J/ψ lineshape from $e^+e^- \to \mu^+\mu^-$: the phase obtained is consistent with 0^0; (b)e$^+e^- \to 2\pi^+2\pi^-\pi^0$ J/ψ lineshape: there is no interference pattern, since the strong amplitude is large and Φ is fully consistent with a $|90^0|$ phase; (c) J/ψ lineshape from $\eta\pi^+\pi^-$ with a full interference pattern as in (a).

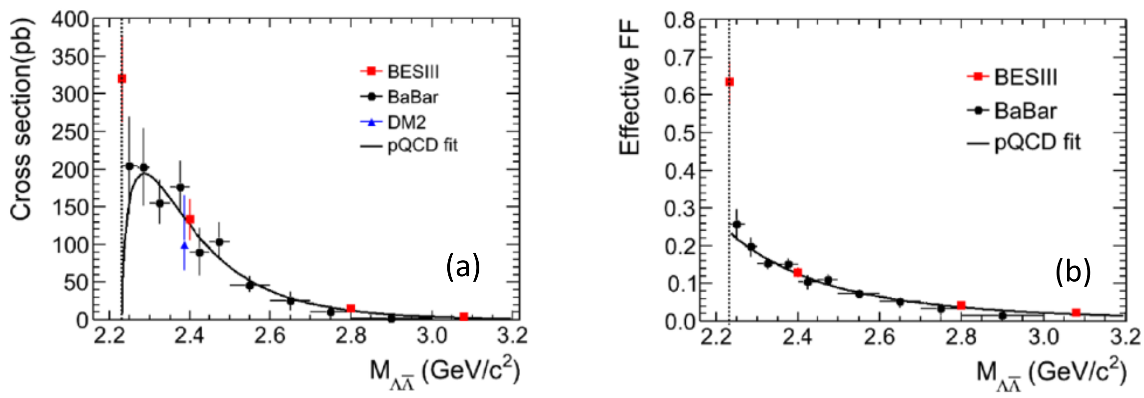

Figure 2: (a)$e^+e^- \to \Lambda\overline{\Lambda}$ cross section, the solid line is a phenomenological fit with a $1/\beta$ behaviour at threshold and the high energy slope is the one foreseen by pQCD; (b) Λ time-like effective form factor $|G_\Lambda$. The BESIII result strongly suggests a $1/\beta_\Lambda$ behaviour. The dotted line in (a) and (b) indicates the threshold.

3.1 Measurement of $\psi(3686) \to N\overline{N}$

Furthermore, using the full sample of 10^8 events the branching ratio $B(\psi(3686) \to n\overline{n})$ has been measured for the first time [5], together with the branching ratio B($\psi(3686) \to p\overline{p}$) with unprecedented accuracy. It turns out that the two branching ratios are very close, coherently with a phase difference beween strong and e.m. $\psi(3686)$ in these decays very close to 90^0. The angular distributions $(1 + \alpha cos(\theta)^2)$ turn out to be very peculiar: $\alpha_{n\overline{n}} = 0.53 \pm 0.2$, barely consistent with $\alpha_{p\overline{p}} = 1.03 \pm 0.07$, very closet to the limiting value, since it should not exceed 1.

4 The BESIII CGEM Inner Tracker

The BESIII group has completed in 2015 the third year of the Program of Great Relevance PGR00136, a 3-year joint project of INFN, IHEP, and the Italian Ministry of Foreign Affairs. The objective of this program, started in 2013, is a prototype of a cylindrical layer of detector, built with the technique of Cylindrical Gas Electron Multiplier (CGEM) developed in Frascati for the KLOE2 Inner Tracker but with an analog readout technique.

This prototype layer has 2 roles: it will help the BESIII group to understand and test construction details differing from KLOE, and it will be finally incorporated, once proven functional, in the 3-layer Inner Tracker for the BESIII experiment at IHEP, whose Inner Drift Chamber is starting to show signs of degradation by excessive backgrounds. This second requirement has complicated much the task, because the connections for all services, HV, gas, anchoring points, needed an ampunt of planning that usually may be overlooked in a prototype.

The Inner Tracker [6] will be composed by three layers of triple cylindrical GEM with an angular coverage of 93% of the solid angle. Each layer is assembled with five cylindrical structures: the cathode, three GEMs and the anode readout. A new rohacell based technique is used to manifacture the structure of anode and cathode in order to minimize the material budget [7] with respect to the state of the art.

The anode configuration is also be innovative: a jagged strips layout has been developed to minimize the capacitance coupling. The design has been optimized by means of Maxwell and Garfield simulations and with a small scale planar prototype. The readout is two-dimensional: X-strips, 570μm-wide parallel to the CGEM axis which provide $\rho\phi$ coordinates, and V-strips, 130μm-wide and with a stereo angle with respect to the X-strip, giving the z coordinate. The strip pitch is 650μm for both X- and V-strips, and the space between the readout and the ground plane is filled by a Rohacell structure. The anode design (performed by LNF-SEA) has been quite difficult both because the foil dimension and the requirement to minimize the cross-talk between X and V strips.

The relatively strong BESIII magnetic field (1T) requires an innovative readout based on analogue information which can allow identifying the charge centroid. The charge will be measured by a time-over-threshold technique and the new dedicated ASIC chip, is beeing designed and will be produced for optimal data collection.

4.1 Construction of the first BESIII CGEM layer

The large GEM foils needed for construction are manufactured by the CERN TS-DEM-PMT laboratory at CERN and were delivered to LNF in 2014, where here they have been tested, and identified a few defects, that have been corrected at CERN.

At the beginning of 2015 construction of the first cylinders for the second CGEM layer has started. The cylindrical electrodes have all been constructed in a class 1000 clean room. The controlled environment is mandatory for these electrodes since the presence of dust in the multiplication channels can produce discharges during the detector operation. Moreover the tolerances with which the moulds and the GEM foils are produced require a very powerful control of the room temperature. The limits on the GEM foil dimensions are such that in order to realize a cylindrical electrode it's necessary to glue together two GEMs [8]. The construction procedure is based on the KLOE-2 Inner Tracker experience [9]: the foils are spliced together on a rectified aluminum table, carrying precisely drilled holes for the positioning of the GEM foils. Beside the long edges of the GEM active area we have 3 mm wide kapton used for the overlap where the epoxy is spread. A vacuum bag, realized on the same planar table (fig. 3a), ensures a uniform pressure on the gluing area. Each so obtained large GEM is then rolled on a cylindrical aluminum mould wrapped with a very precisely machined 400 m teflon film. Again the electrode is realized with the vacuum bag technique (fig. 3b) and then it is ready for the final assembly. Similar technique has been used for the cylindrical readout and for the cathode, but we would like to point out the difference with respect to the CGEM case. In order to give robustness to the whole detector, two rohacell rolls have been realized to support both cathode and readout cylinder. The rohacell surface for cathode has been precisely rectified with a precision of 100 m (fig. 3e). The readout is moreover completed with a ground plane (fig. 3f) that is then connected to the FEE ground. This is a very schematic description of how all of the five electrodes (readout, 3 GEMs (fig. 3d) and cathode) have been realized in 2015. The final assembly of the detector, meant as the procedure of inserting all the electrodes one into the other, is performed with the usage of the Vertical Insertion Machine already employed for the KLOE-2 Inner Tracker triple-CGEMs [10]. Because of the different length with respect to the KLOE-2 layers, the machine has been modified: its height has been increased in order to host the longer BESIII moulds. The procedure starts placing the mould with the readout cylinder on the base of the machine. The base is a round plate with four degrees of freedom to allow the best alignment of the center of the mould with respect to a vertically sliding flange. The increase of the machine height lets the flange have a longer path, reducing the risks for the electrodes during the moulds handling. The flange is the "active" element of the machine since it carries the holes where the delrin pins are inserted to catch the electrode on the mould. As the flange lifts up, the readout cylinder is removed from its mould (fig. 3g) and hanged only in the upper part. The assembly goes on replacing the naked mould with the one wrapped with the electrode with the closest diameter. The machine allows also a 180° rotation (fig. 3h) to seal with glue both sides of the detector. Due to the relatively small gaps between each electrodes (3 and 2 mm) the misalignment between the mould axis and the sliding direction of the flange must be at most 100 m for a length of 1 m. The assembly of the prototype of the BESIII Inner Tracker layer 2 has been completed and the detector is now on test(fig. 3i).

4.2 Beam test on planar prototypes

In June 2015 we have run a 2-weeks beam test at SPS H4 beam line at CERN, within the RD51 Collaboration, with a setup similar to the one used last year: the two planar (10cmx10cm) test chambers having different gap size ((3 and 5 mm) and different analog readout configuration. Tracks were reconstructed by a telescope composed of additional four planar GEM chambers kept outside the magnetic field. The main purpouse of the test was the test of the analog readout with and without and in magnetic field, measurement of the efficiency at different gains ans different gas mixtures (Argon/CO2 70/30 and Ar/Isobutane 90/10), of cluster size and resolution as function of the magnetic field, signal to noise ratio have also been studied . The H4 beam line at the SPS has a secondary extracted beam of muons and pions with momentum up to 400GeV/c, the facility has a dipole magnet (GOLIATH) capable of reaching B field values of 1.5T. A schematic drawing and a picture of the setup are shown in fig.4 (a). To exploit the features of the GEM detectors fully analog readout, both the tracking and the test chambers have been instrumented by means of a front-end chain based on the APV25 hybrid boards and a FADC-SRS card readout through a GBD transceiver. The HV was provided by commercial CAEN system instrumented with CAEN A1550 power supply and distributed to the GEM electrodes by a custom distribution system. Singular current monitoring was provided by a nano-amperometer. APV boards provide a 25 ns sampling of the input signals then allowing a coarse reconstruction of the signal shape. The output data can be used for simple charge centroid measurements or, by means of a more complex analysis, to define the arrival time of the signals then allowing to implement the so called "micro-TPC"(μTPC) readout. The μTPC method is very powerful as it allows to avoid the worsening of spatial resolution measurements carried out by means of the charge centroid method in presence of strong (1 T) magnetic fields.

With the charge centroid method, which exploits the charge values of the readout strips , at B=1T, the efficiency plateau of about 97% starts at a gain of about 6000 as shown in fig.4 (b), and an unprecedented resolution of about $190\mu m$ has been achieved at 1 Tesla with Ar/Isobutane (90/10) gas mixture at high drift field, fig. 4 (c).

The effect of the magnetic field to the electron avalanche has been studied with Garfield simulation:the Lorentz force diplays the electron avalanche, the effect is a heavy smearing and a deformation of the electron cloud shape at the anode. The shape of the charge distribution is no longer gaussian and the charge chentroid method reduces its performance. Studies have been performed to exploit the single strip time information to operate GEM in the μTPC mode which allows to perform a local track reconstruction in the few-mm wide drift gap. This is possible if the time resolution of the detector is good enough to distinguish the arrival time of the electron avalanche on different strips, and with a highly segmented readout plane. The μTPC reconstruction technique has been successfully developed and tested by the ATLAS Micromegas group [11]. The performance of the algorithm, even if still preliminary and not optimized, with a drift gap of 5mm, 1Tesla magnetic field and with Ar/Isobutan (90/10) gas mixture is very promizing: the results on the spatial resolution vs the track incident angle, is compared with the charge centroid method is shown in fig. 4 (d): spatial resolution below $150\mu m$ is achievable.

Next year a new test beam with optimized drift field values and a system of three-GEM-layers

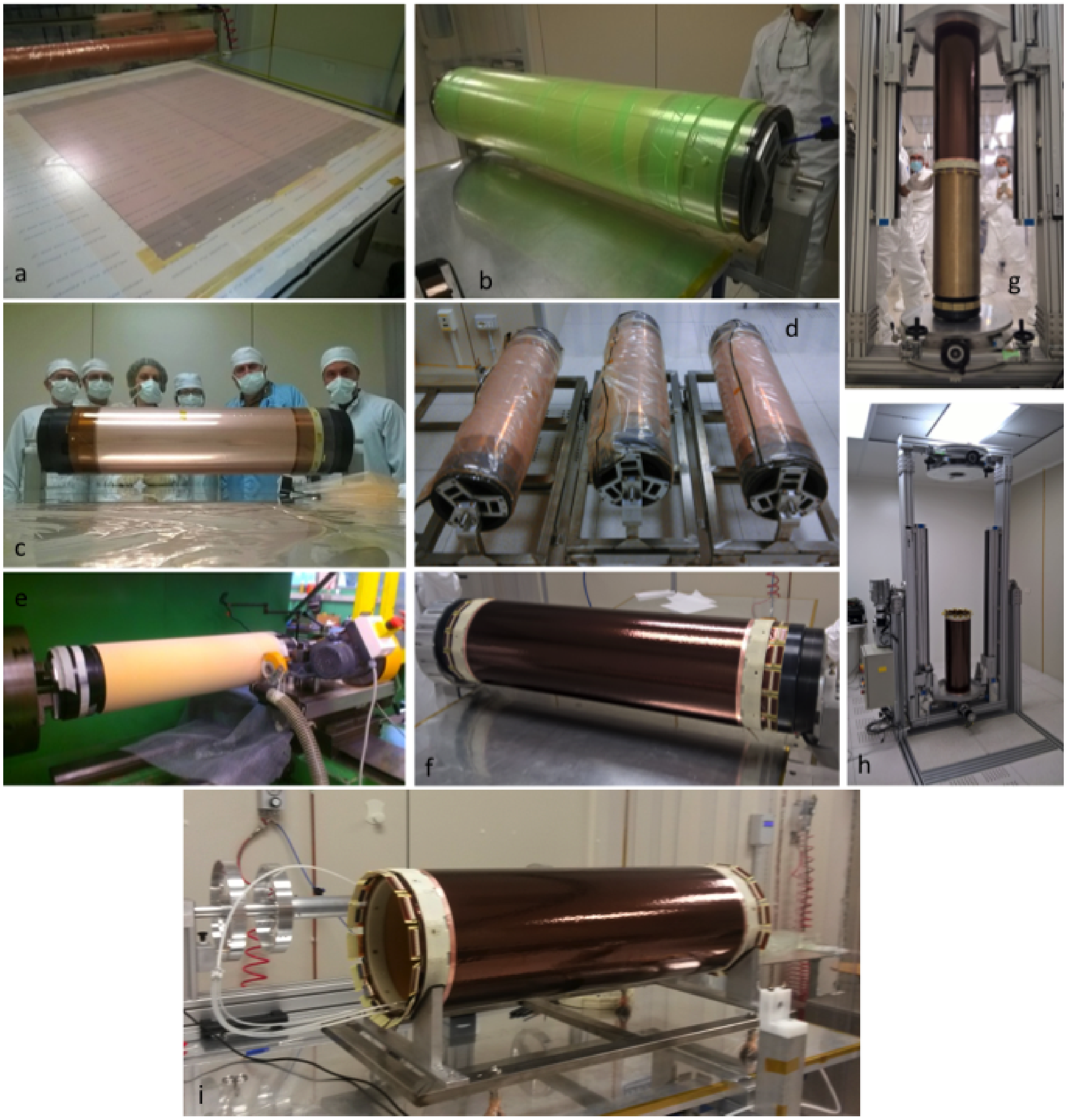

Figure 3: A summary of the construction: planar gluing of two GEM foils (a), the vacuum bag technique applied for the cylindrical gluing (b), a completed cylindrical GEM (c), the three CGEM used for the prototype (d), the machining of the rohacell surface for the cathode construction (e), the readout with its ground plane (f), the removing of the anode from its mould on the machine (g) the machine rotated of 180° (h), finally the detector completed and under test (i).

μTPC tracking system will be performed, and a combined method of charge chartroid and μTPC will be studied to optimize the resolution in the full angle range.

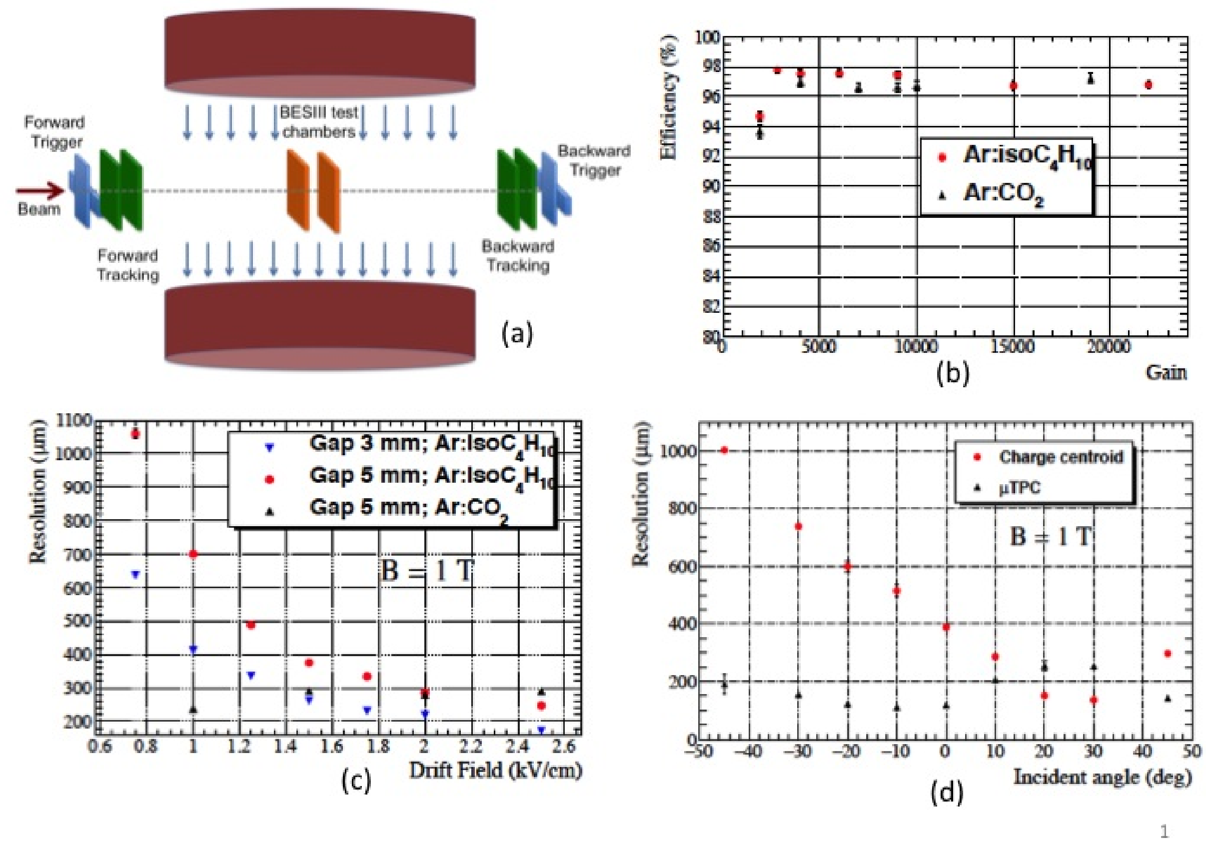

Figure 4: (a) drawing of the Beam Test setup, particles going from left to right. The two BESIII test chambers (yellow) inbetween the four trackers (green) the four trigger bars (blue). The whole setup is placed in the magnet (purple).(b) Dtection fficiency vs Gain at B=1T, (c) spatial resolution as a function of the drift field for diffferent gas mixtures and detector geometries, B=1T ; (d) spatial resolution with the charge centroid (red) and μTPC (black) vs the incident angle of the track for Ar/isobutane (90/10) gas mixture at B=1T.

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