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The Lund-York-Cologne Calorimeter (LYCCA): Concept, Design and Prototype Developments for a FAIR-NUSTAR Detector System to Discriminate Relativistic Heavyion Reaction Products

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The Lund-York-Cologne Calorimeter (LYCCA): Concept, design and prototype developments for a FAIR-NUSTAR detector system to discriminate relativistic heavy-ion reaction products

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Abstract

The concept, design and prototype developments for the Lund-York-Cologne CAlorimeter (LYCCA) is presented. LYCCA is a modular device for the NUclear STructure, Astrophysics and Reactions (NUSTAR) science pillar of the Facility for Antiproton and Ion Research (FAIR) at Darmstadt, Germany. LYCCA is designed to discriminate heavy ions produced in nuclear reactions induced by relativistic radioactive ion beams. Measurements of energy loss, total energy, and time-of-flight allows the derivation of proton number, Z, and mass number, A, of the reaction products. LYCCA-inherent tracking of the flight paths of the reaction products enables coincident HIgh-resolution in-beam γ -ray SPECtroscopy (HISPEC) of atomic nuclei far from the line of β -stability.

Keywords: relativistic heavy ions, nuclear structure, time of flight, energy loss, total energy, A and Z identification

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1. Introduction and Requirements

The NUclear STructure, Astrophysics and Reactions 2 (NUSTAR) science pillar [1] of the Facility for Antipro-3 ton and Ion Research (FAIR) at Darmstadt, Germany awaits beams of relativistic radioactive ions with un-5 precedented intensities. The major incentive is to study the atomic nucleus at its extremes of proton-to-neutron ratio, which is of immediate relevance towards and motivated by heavy-element production in the course of 9 stellar evolution. 10 The HIgh-resolution in-beam SPECtroscopy (HIS-11 PEC) [2] experiment within NUSTAR addresses nuclear 12 structure questions by using radioactive beams to be de-13 livered by the new, super-conducting FRagment Sepa-14 rator (Super-FRS) [3]. The beam energies are typically

rator (Super-FRS) [3]. The beam energies are typically
 some 100-300 MeV/u. Single-step Coulomb excitation

- and nuclear fragmentation reactions at these intermedi-
- ¹⁸ ate energies as well as inelastic scattering, transfer and
- ¹⁹ knock-out reactions are envisaged. The experiments

will provide information relevant for the shell structure of atomic nuclei far from the line of β -stability, and more specifically low-lying excitation energies, transition probabilities, or single-particle spectroscopic factors, to name but a few.

The core of HISPEC is the use of high-resolution Ge detectors at one of the focal planes of the Super-FRS, i.e. to perform high-resolution in-beam spectroscopy of excited nuclear quantum states via their γ -ray decay; therefore, the HISPEC set-up foresees at its core the European Advanded GAmma-ray Tracking Array (AGATA) [4], surrounding the secondary target position. To enable event-by-event correlations of the γ rays with the nuclear residues, HISPEC will comprise a new generation of beam tracking and identification detectors placed in front of and behind the secondary target. Here, the Lund-York-Cologne CAlorimeter (LYCCA) has the central role of determining both proton number, Z, and mass number, A, of the final reaction products; by itself or in conjunction with a magnetic spectrometer. Until HISPEC becomes operational, a subset of LYCCA detectors is being commissioned and used for

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the PRESPEC-AGATA [5] physics campaign at the ex-

⁴³ isting FRS facility [6] at the GSI Helmholtzcentre for

⁴⁴ Heavy Ion Research in Darmstadt, Germany.



Figure 1: Sketch of the detection concept of LYCCA. LYCCA-related items are drawn in black. See text for details.

HISPEC-type experiments have also been performed 45 already within the Rare Isotope Spectroscopic IN-46 vestigations at GSI (RISING) Fast-Beam campaign 47 2003–2005 [7]. Here, γ -ray spectroscopy with fifteen 48 former EUROBALL Cluster detectors [8] was per-49 formed in conjunction with the CAlorimeter TElescope 50 (CATE) [9], which at the time provided discrimination 51 between nuclear reaction products. Both the experience 52 with CATE and extensive simulations within the 53 LYCCA collaboration [10] show that several items are 54 essential for an improved HISPEC calorimeter system: 55 56

- A physical segmentation of both ΔE and E elements is useful for both rate considerations and active tracking.
- To achieve a proper mass separation, a highprecision time-of-flight system (better than 50 ps FWHM resolution [10]) needs to be integrated.
- LYCCA should be able to deal with rather light nuclei, $A \sim 30$, at energies up to 300 MeV/u, likewise heavy nuclei, $A \sim 200$, down to about 100 MeV/u.

The resulting LYCCA detection concept within the 118 66 HISPEC framework is sketched in Fig. 1: Up front, the 119 67 definition of the tracked position and proton number, Z_{120} 68 as well as mass number, A, of the incoming relativistic 121 69 radioactive ion beam is subject to either future Super- 122 70 FRS or existing FRS detection systems. A double-sided 123 71 silicon strip detector (DSSSD) at the secondary target 124 72 position together with those forming the downstream 125 73 LYCCA wall ensure precise (x,y)-tracking of the reac-74 tion products. At the same time, the DSSSD wall ele-127 75

ments provide an energy-loss signal, ΔE , which in conjunction with the measurement of the residual energy, $E_{\rm res}$, of the recoiling reaction products aims at determining their proton number, Z, by means of the established ΔE - $E_{\rm res}$ technique. E_{res} is determined by LYCCA wall CsI(Tl) detector elements. The DSSSD position measurement also has the capacity to improve CsI energy resolution through straightforward corrections of possible CsI light-collection dependencies on the impact position of the ions.

To determine the mass number, A, of the reaction products, E_{res} is being correlated with time-of-flight (ToF) information (cf. Ref. [10]), in particular by measuring ToF_{out} over the distance d_{out} between the LYCCA ToF Target and LYCCA ToF Stop detectors. The thickness of the secondary target used in previous in-beam campaigns seriously limited the envisaged mass resolution of the CATE spectrometer. This was especially worsened in fragmentation reactions due to the momentum spread induced by the reaction process. Therefore, available flight-paths and required solid-angle coverage call for a high-precision timing measurement. Simulations indicate [10] that a timing resolution of 50 ps (FWHM) or better is required, though this number depends on recoil energies and the mass regimes of interest. The ToF Target detector is placed near the secondary target inside the target chamber, the ToF Stop detector close to the LYCCA wall DSSSD elements. In addition, the individual velocities of incoming beam particles can be re-determined with ToFin between the LYCCA ToF Start and LYCCA ToF Target detector over the distance d_{in} .

Based on the LYCCA simulations [10] and anticipated typical HISPEC experiments and experimental conditions, the following design goals concerning *A* and *Z* resolution of LYCCA have been defined in the LY-CCA Technical Design Report [11]:

DSSSD energy resolution (FWHM) at 0.1 GeV:

 $\Delta E/E < 1$ %, projected goal $\Delta E/E < 0.5$ %

CsI(Tl) energy resolution (FWHM) at 10 GeV:

 $\Delta E/E < 1$ %, projected goal $\Delta E/E < 0.5$ %

ToF resolution (FWHM):

 $\Delta t < 100 \text{ ps}, \text{ projected goal } \Delta t < 50 \text{ ps}$

In principle, these numbers are considered initial guidelines, while the actual LYCCA performance depends strongly on the available flight paths and experimental parameters, namely the mass regimes to be studied, secondary target thickness, or the focussing scheme of a relevant (Super-)FRS setting.

Section 2 details the various detector components of LYCCA. A brief description of the mechanical housing of the LYCCA wall ΔE -E_{res} telescopes in Sec. 3 is fol-

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lowed by a brief overview of hitherto used processing
 and read-out electronics in Sec. 4. Section 5 illustrates
 very first in-beam commissioning spectra of LYCCA,
 thereby confirming the achievement of the design goals
 indicated above. The paper concludes with an outlook
 towards LYCCA as a FAIR-NUSTAR detection device.

134 2. The LYCCA Detector Components

135 2.1. The Target DSSSD

Double sided silicon strip detectors (DSSSD) are 136 common in physics experiments as an apparatus to mea-137 sure the energy loss, ΔE , and position, (x,y), of particles 138 passing through the silicon bulk of the detectors. The 139 silicon wafers used as LYCCA target DSSSDs are ion 140 implanted, silicondioxide (SiO₂) passivated, and oper-141 ated totally depleted with floating guard rings. They are 142 obtained from RADCON Limited. 143

181 The nominally 300-320 μ m thick wafers are square 144 182 shaped, 60.1 mm ×60.1 mm in size with an active 145 183 area of 58.5 mm ×58.5 mm. The active area is sub-146 184 divided into 32 strips on both front (junction) p-side 147 185 and rear (ohmic) n-side in orthogonal directions pro-148 viding two dimensional position information. With 149 186 58.5 mm/32=1.83 mm, the pitch of the p-side strips is 150 1.80 mm with an interstrip SiO₂ isolation of 30 μ m. To 187 151 improve interstrip capacitive and resistive isolation from 152 188 the adjacent n-strips on the ohmic side, a so-called p-153 189 type zone or p-stop structure surrounding n-strips was 154 190 implanted. Thus the pitch size on the ohmic side is 155 191 1.63 mm with interstrip distances of 200 μ m. 156 192



Figure 2: Photograph of a target DSSSD detector.

¹⁵⁷ Leakage currents, upon delivery, range between 5- ²⁰⁶ ¹⁵⁸ 10 nA per strip with modest capacities of 33 pF per strip ²⁰⁷ ¹⁵⁹ at full depletion voltage, which is typically reached at ²⁰⁸ ¹⁶⁰ 50 V. The energy resolution and crosstalk was measured ²⁰⁹ ¹⁶¹ by scanning detectors with collimated ²²⁸Th and ²⁴¹Am ²¹⁰ ¹⁶² α -particle sources. A typical spectrum for this type of ²¹¹ DSSSD, obtained in a test chamber using standard LY-CCA vacuum feedthrough, cabling, and electronics (see Secs. 3 and 4), is shown in Fig. 5(a).

The thickness of the dead layers on both sides of detectors was determined by measuring the energy loss of the α particles by irradiating the detector from different incident angles. They are found to be ~ 1.0 μ m Si-equivalent on the junction side and ~ 2.0 μ m on the ohmic side. To optimize charge collection on the rear side of the detector the full depletion voltage was measured by injecting α particles into the ohmic side and maximizing detector response as a function of applied bias voltage.

The target DSSSD is mounted on a printed circuit board made of FR4 together with connectors and gold plated pads for strips bonding. Due to possible harsh radiation damage all components and material used for detector packaging allow temperature annealing at lowto-medium temperature for few days. The detector frame is mechanically compatible for mounting into the secondary reaction chamber together with the ToF Target detectors (cf. Secs. 2.3.2 and 2.3.3) and various secondary reaction targets.

2.2. The LYCCA ΔE - E_{res} Wall Telescope

The requirements described in Sec. 1 call for the use of telescopes based on segmented semiconductor detectors backed by segmented inorganic scintillators readout by photodiodes (PD). Such a device presents a powerful tool for charged particle identification in a wide range of charge, mass, and energy, the latter if being used to stop the particles. Due to the very broad range of experimental conditions for which LYCCA is constructed, a modular design was deemed necessary.

All modules are identical telescopes where particle identification is obtained through $\Delta E \cdot E_{res}$ measurements. In addition, internal segmentation of the telescope components provides the capability to sustain sufficiently high counting rates as well as multiple particle detection even within one single telescope. In the following subsections the design, construction, test results, and performance of LYCCA telescopes are presented.

2.2.1. The DSSSD Frame

For energy loss, ΔE , measurements, each LYCCA telescope comprises a 300-320 μ m DSSSD as detailed in Sec. 2.1. To minimize physical dead areas surrounding each DSSSD, a very close packing of telescopes into the full LYCCA array is of high importance, thus a minimal amount of material for the DSSSD frame was a central design goal. The LYCCA solution is to mount

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the silicon wafer into a thin frame made out of FR4 242 212 printed circuit board (PCB) material with the help of 243 213 custom made tools and a bonding assembly [12] based 244 214 on epoxy rubber CAF4 [13], which ensures the neces- 245 215 sary mechanical stability and elasticity for possible me-246 216 chanical tensions on the frames. Only 0.2 mm of the de- 247 217 tector frame extends beyond the wafer on the two con- 248 218 nector free sides, and 2.0 mm on the two sides where 249 219 signal multipin connectors are mounted. The frame has 250 220 gold plated pads for bonding and pin-like connectors 251 221 (BLX-1-056-40G) soldered for signal extraction. 252 222

The challenge of minimal dead space of the tele-253 223 scope front face and signal read-out combined with 254 224 mechanical stability for the subsequent heavy-weight 255 225 block of CsI(Tl) scintillators (see below) is overcome by 256 226 specially designed signal transportation boards. These 257 227 boards fabricated out of FR4 PCB material are equipped 258 228 at one edge with connectors (SLX-1-053-30G) to be at- 259 229 tached to the thin DSSSD frame. At the another end 260 230 of the signal transportation board multipin connectors 261 231 (KEL 8831E-068-170) are mounted for further DSSSD 262 232 signal transportation towards the feedthrough boards of 263 233 the LYCCA vacuum chamber. A closeup view of a 264 23 DSSSD mounted on its PCB frame and in combination 265 235 with the signal transportation boards assembly is shown 266 236 in Figs. 3(a) and (b), respectively. 267



 Figure 3: LYCCA module elements: (a) A DSSSD wafer mounted in
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 its thin PCB frame and (b) coupled to the signal transport boards. (c)
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 A photodiode mounted in its ceramic plate and CsI 'short' and 'long'
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 crystals wrapped in the ESR reflecting foil. (d) A 9-element CsI-block
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 in the brass frame.
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238 2.2.2. The CsI Block

Each LYCCA telescope is equipped with an array of $_{291}$ nine CsI(Tl) crystals being placed 10 mm behind the $_{292}$ DSSSD wafer to measure the full residual energy, E_{res} , $_{293}$ of the particles. The front face of all CsI(Tl) crystals has the dimension $19.4 \times 19.4 \text{ mm}^2$ and there are two different lengths of crystals available: a 'long' version of 33.0 mm in depth plus 7.0 mm of pyramidal lightguide and a 'short' version of 10.0 mm in depth with 5.0 mm pyramidal lightguide. The dimensions of the back end of the pyramidal light guide are $10.4 \times 10.4 \text{ mm}^2$ matching the size of the read-out PDs.

The choice of CsI(Tl) is dictated by its high stopping power, high light output, and the relatively easy handling of this type of inorganic scintillator. One of the important characteristic of the CsI(Tl) crystal for highresolution charged-particle spectroscopy is light output variations arising from possible gradients or local fluctuations of the Tl concentration. To achieve optimal light uniformity all crystals were machined from a single ingot. The typical Tl concentration is 0.08-0.10 mol%. All crystals were supplied by Amcrys-H Ltd., Kharkov, Ukraine [14].

The achievable resolution of total energy measurement depends first of all on non-uniformities of light collection across the active volume of a CsI crystal. Secondly, it depends on the position of energy deposition but also on the deposited energy density. Such aspects are detailed in Refs. [15, 16, 17]. For example, light output depends strongly upon the reflecting material used for wrapping. ESR film was proposed [18] and also tested for LYCCA and found to be most optimal for wrapping all sides of the crystals except for the front face. The ESR foil is partially transparent in the blue region of scintillation light. To achieve optical isolation of a crystal from its neighbours each crystal was additionally wrapped into 12μ m thin Al-foil. The same foil was used to cover front face of the crystal to maximize light collection from the scintillation process and at the same time minimize dead layer for incoming particles. Following a number of cross checks, no additional lapping to compensate for potential light non-uniformity along the crystals appears needed, not least due to the relatively small dimensions of the LYCCA CsI(Tl) crystals.

The scintillation light produced in the CsI(Tl) crystals is read-out by photodiodes (PD). The PDs are 10.6 mm ×11.6 mm ×0.3 mm in size and supplied by RADCON Ltd., Zelenograd, Russia. The PDs are mounted into custom-made application specific ceramic frames and glued directly onto the light guide of the crystal by means of Epo-Tek 302 optical epoxy. The chosen PD has a very good matching for the CsI(Tl) scintillator emission light: the quantum efficiency is as high as ~ 82-86% at 560 nm, which is the peak position in the emission spectrum of the CsI(Tl). The total spectral response of the PD ranges from 320 nm up to

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1060 nm with a maximum at some 920 nm. At nominal non nal operating voltage 35 V the leakage current is on the
 level of 1-2 nA and the capacitance is 38-40 pF at full
 depletion.

Nine CsI(Tl)-PD units are packed into a 3×3 ar- 326 298 ray into a brass frame which allows for proper relative 327 299 alignment of all active elements of a LYCCA telescope 328 300 (see below). A FR4 PCB CsI(Tl)-PD signal distribu- 329 301 tion board is soldered directly onto the nine PD's pins. 330 302 This board is also equipped with MMCX connectors, 331 303 and shielded coaxial cables are used for PD signal trans-304 portation towards the feedthrough boards of the LYCCA 333 305 vacuum chamber to guarantee noise immunity and neg- 334 306 ligible signal cross talk. Figs. 3(c) and (d) provide pho- 335 307

tographs of various CsI(Tl) detector components.



Figure 4: A LYCCA telescope (a) in its three-dimensional CAD drawing stage and (b) in its LYCCA-1 realization.

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309 2.2.3. The LYCCA Module

The single LYCCA telescope module is made up of 310 one DSSSD mounted on its thin frame connected to 311 the signal transportation boards, with the brass frame 312 of a CsI scintillator block mechanically attached. Ad-313 ditionally, a custom-made mechanical locking system 314 for mounting the telescope into LYCCA chamber (see 315 Sec. 3) is linked to the brass frame and the signal trans-316 339 portation boards. The detachable nature of the CsI 317 340 block allows easy access to both telescope components 318 341 and active elements for exchange, service or repair. 319 342 Figs. 4(a) and (b) provide both the technical drawing 320 343 and a photograph of a real LYCCA telescope. 321 344

2.2.4. Bench Tests

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A test vacuum chamber has been configured to enable high-resolution test measurements and overall performance tests for LYCCA detectors. The test chamber is equipped with mechanics, cables, connectors and front-end electronics identical to items used in the real LYCCA chamber. Various radioactive sources can be mounted inside the chamber to provide possibilities for comprehensive detector testing.

The energy resolution and crosstalk for each DSSSD was measured by scanning detectors with collimated ²²⁸Th and ²⁴¹Am α -particle sources in the test chamber. A typical spectrum, obtained using standard LY-CCA electronics (cf. Sec. 4), vacuum feedthrough and cabling is provided in Fig. 5(a). The pixel resolution has a typical value of less than 50 keV FWHM at 9 MeV α energy, which comprises also significant uncertainties from source as well as deadlayer thicknesses.



Figure 5: Energy calibration spectra for a bare photodiode (b), a CsI(Tl)-PD detector (b,c), and a LYCCA DSSSD detector (d). Energy resolutions are indicated and there are labels for the respective radioactive source used.

Standard γ -ray sources (⁶⁰Co, ¹³⁷Cs, ²⁴³Am) have been used for various energy resolution measurements of bare photodiodes, single CsI(Tl)-PD units, and complete CsI block assemblies, respectively. Figs. 5(b)-(d) show some of these γ -ray spectra. For example, the

energy resolution measured at $E\gamma = 1.3$ MeV yields 345 6.2% FWHM for the 'short' crystal version. Taking 346 into account the well known $R \sim 1/\sqrt{E}$ power law re-347 lation for energy resolution dominated by statistical ef-348 fects one can anticipate that the projected goal is eas-349 ily reached for an expected minimum deposited energy 350 of at least several GeV in CsI(Tl) crystals in real PRE-351 SPEC or HISPEC experiments. Following the modules' 352 use in real experiments, spectra such as those displayed 353 in Fig. 5 serve as reference spectra for quality assess-35 ment and maintenance procedures [19]. 355

Successful tests of the first LYCCA prototype telescope inside the test chamber performed with a proton beam delivered by the Tandem Accelerator of the University of Cologne are summarized in Ref. [20].

Further calibration aspects for $\Delta E - E_{res}$ telescopes are addressed in Refs. [21, 22] followed by in-beam tests during the R&D phase of related DSSSD-CsI(Tl) telescope arrangements [23].

364 2.3. The LYCCA ToF Detectors

The R&D of LYCCA ToF detectors has followed es-365 sentially two lines (cf. Ref. [11]): A new class of large-366 area scintillation membranes [24] and the development 367 of polycrystalline, chemical vapour deposited diamond 368 detector wafers [25]. In-beam commissioning experi-369 ments have been successfully performed with both sys-370 tems, while availability, performance, and also cost-per-371 performance issues favour the scintillator concept, at 372 least within the LYCCA framework. 373

374 2.3.1. The ToF Start and ToF Stop Elements

The ToF Start and ToF Stop detectors follow a new 375 design approach for large-area plastic scintillation de-376 tectors: A circular membrane of Saint-Gobain BC-420 377 with 27 cm diameter is read out by 32 Hamamatsu 378 R7400U photomultiplier tubes. The R&D, components, 394 379 construction, and the in-beam result of an intrinsic de- 395 380 tector resolution of $\Delta t \ll 50$ ps FWHM is detailed in 396 381 Ref. [24]. In brief, the unusually good timing resolution 397 382 for plastic scintillator systems is achieved through col-398 383 lecting the light in 32 independent measurements. Tak- 399 38 ing an average, i.e. to first order by means of the factor 400 385 $1/\sqrt{32} \sim 0.2$, results in a better effective ToF resolution 401 386 than other fast materials with a better intrinsic resolu-402 387 tion such as, for example, diamond detectors. 403 388

2.3.2. The ToF Target Scintillation Detector

Based on the achievements of the large membrane 406 scintillators, a smaller Target ToF scintillation detec- 407 tor with an active diameter of 73 mm has been de- 408 signed and built recently. This dimension follows (*i*) the 409



Figure 6: (a) Drawing of the LYCCA ToF Target detector and (b) photograph of its realization.

need for typical beam spot sizes of relativistic radioactive ion beams at the secondary target position, namely $\sigma_x \sim \sigma_y \sim 1.5$ cm, and (*ii*) the constraints by the size of the HISPEC-AGATA vacuum chamber surrounding the secondary target. Figure 6 provides a drawing and photograph of this detector. Simulations based on the studies in Refs. [24, 26] indicate that despite the necessarily smaller number of only 12 photomultiplier tubes a time resolution similar to the above can be achieved by using quenched Saint-Gobain BC422Q(0.2%) instead of BC-420 and by replacing the former Hamamatsu R7400U tubes with the latest generation of Hamamatsu R9880-210. A detailed performance characterisation of this new detector is going to be a part of a comprehensive subsequent publication on LYCCA in-beam measurements [27].

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Figure 7: Photograph of the prototype of the LYCCA Target ToF diamond detector.

410 2.3.3. The ToF Target Diamond Detector

Any LYCCA ToF detector placed at the target posi-41 463 tion is required to cover the full area of the secondary 412 target. This necessity led to the development of what we 413 believe to be one of the largest area diamond detectors 464 414 tested to date. As can be seen in figure 7, the detector 415 can accommodate nine $20 \times 20 \times 0.3 \text{ mm}^3$ polycrystalline 465 416 diamond wafers formed by chemical vapour deposition, 466 417 although only six were used for this experiment. Five 467 418 of the wafers are segmented into four strips measur- 468 419 ing 18×4.5 mm². These wafers were mounted onto 469 420 a custom-made PCB, allowing for separate biasing and 470 421 signal extraction for each strip. The signals were am- 471 422 plified using 2.3 GHz broadband DBAIV preamplifiers 472 423 [28], specially designed for fast pulses from diamond. 473 424 Further details on the fabrication and development re- 474 425 sults from an earlier version of this diamond detector 475 426 can be found in Ref. [25]. 427 476

In-beam measurements were made with the large- 477 428 area plastic start and stop scintillators, as well as the 478 429 target diamond detector to enable detailed comparisons 479 430 of their timing performance. The precision of the dia- 480 431 mond - plastic stop ToF measurements were compared 481 432 with the plastic start - plastic stop ToF measurements, 482 433 which had flight paths of $d_{out} = 3.61(1)$ m and $d_{tot} = 483$ 434 4.31(3) m, repectively. Details of the latter can be found 484 435 in Sec. 5. The same procedure applied to the diamond 485 436 indicates a resolution of 193 ps (FWHM). This com- 486 437 pares with the best result of 103 ps (FWHM), obtained 487 438 at Texas A&M University [25] using the same configu- 488 439 ration of diamond wafer. 489 440

Further analysis has concluded that this worsening of 490 the resolution is likely to be caused by the necessarily 491 large length of cable (2.5 m compared with 1 m at Texas 492 A&M University) present between the diamond detector and the DBAIV, which significantly increased the 494 capacitance on the input of the preamplifier. The charge 495 collection from the detector was also found to be smaller 496

during the commissioning experiment. These factors would be expected to have adverse effects on the noise contribution to the final amplified signal, and the timing resolution would become worse as a result. Indeed, it should be noted that where diamond has demonstrated especially good timing resolution, the custom built electronics have always been adjacent to the detector [29].

From this is can be concluded that it will be challenging for diamond to meet the optimum resolution required for LYCCA without significant redesign of the signal processing arrangements. This, coupled to the better final resolution demonstrated by the the plastic scintillators (cf. Sec. 5) has led the LYCCA collaboration to decide that the LYCCA ToF measurements for the final NUSTAR device should be undertaken using the plastic scintillation detectors.

3. The LYCCA Chamber

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The mechanical construction to hold the LYCCA ΔE_{res} modules (see Sec. 2.2.3 and Fig. 8(a)) is compatible with the final full LYCCA setup and flexible to be placed at any suitable position along the Super-FRS and HISPEC beamlines, provided rather trivial coupling flanges being manufactured in the future. In addition, the mechanical construction allows for a relatively easy replacement of single LYCCA $\Delta E - E_{\text{res}}$ modules if deemed necessary from an experimental point of view.

The LYCCA-chamber itself is based on a cylindrical vacuum vessel with a diameter of 800 mm and a depth of 400 mm. The upstream side has an open circular entrance with a diameter of 450 mm for the incoming particles. The vacuum chamber is designed to host up to the anticipated 26 LYCCA ΔE - E_{res} detector modules in 5 rows of 4, 6, 6, 6, and 4 modules each. The photograph on the right hand side of Fig. 8 shows the realization of the LYCCA vacuum chamber with 3 × 4 LYCCA modules mounted. This represents the configuration used for the first PRESPEC experiments in 2010 and 2011. For the PRESPEC-AGATA experiments in 2012 and 2014, 4 additional modules were implemented, namely 2 in the centre of the top and 2 in the bottom row, respectively.

While fixed on top of a support table, the LYCCA vacuum vessel has a standard flange to connect to a vacuum pumping system at its bottom. Radially, some 70 vacuum feedthroughs are foreseen to carry the signals from detector elements inside the vacuum chamber into custom-made 32-channel preamplifiers (cf. Sec. 4.2) via glued-in printed circuit boards. Until 2014, this scheme is followed for both CsI and DSSSD detectors



Figure 8: (a) Technical 3D drawing of the holding structure for LY-CCA modules inside the LYCCA Wall vacuum chamber. (b) Photograph of the LYCCA Wall vacuum chamber as seen by the beam with 543 twelve LYCCA modules mounted inside the holding structure.

545 (cf. Secs. 4 and 5). The preamplifiers connect via 68-497 546 pin high-density connectors and are mechanically ori-498 547 ented and held in place by means of a dedicated 'plug-499 548 and-play' mechanism. Hence, both electrical contacts 500 549 and mechanical stability are secured while keeping the 501 550 distance between detectors and preamplification stage 502 551 minimal. Vacuum feedthroughs are also provided for 503 552 temperature and pressure read-out. 50

553 For the complete PRESPEC experimental campaign 505 554 2010-2014, the LYCCA ToF Stop detector (cf. Sec. 2.3) 506 555 is also contained in the main LYCCA Wall vacuum 507 556 chamber. In fact, some of its signal- and high-voltage 508 vacuum feedtroughs can be seen in Fig. 8(b). For HIS-509 557 PEC, a revised and further optimized LYCCA ToF Stop 510 558 plastic scintillation detector, covering the complete area 511 of all 26 ΔE - E_{res} modules, is being manufactured. This 559 512 detector is going to be inside a separate vacuum housing 560 513 in front of the existing LYCCA Wall vacuum chamber. 514 More comprehensive information on the LYCCA 515 vacuum chamber is provided in Refs. [11, 20, 30, 31].

4. LYCCA Electronics 517

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4.1. Processing of LYCCA ToF Detector Signals 518

The processing of the signals of the photomultiplier 519 tubes of the LYCCA ToF system based on plastic scin-520 tillators is detailed in Ref. [24]. In short, the outputs 521 of the photomultiplier bases are directly plugged into 5-522 channel Phillips Scientific Model 715 constant fraction 523 discriminators [32]. Commercial time-to-digital con-524 verters CAEN V1290A, providing 21-bit dynamic range and 25-ps time bins, are used to digitize the individ- 562 526 ual timing signal with respect to a common reference, 563 527 namely the accepted event trigger signal of the complete 564 528 PRESPEC data acquisition system. Once in place, the 565 529 12 timing signals of the Target ToF detector are also put 566 530 into a logic OR unit to provide an optional 'Target ToF' 567 531

trigger input signal. The remotely controllable highvoltage supply to the photomultiplier bases comprises four 16-channel ISEG EH160-30n305SHV modules in a common main frame [33].

A similar electronics scheme was also used for the target diamond detector. The outputs of the DBAIV preamplifiers were fed into Phillips Scientific Model 708 leading edge discriminators [32], and then converted into ECL signals and passed into the same CAEN V1290A TDC. Each strip on the diamond detector was biased to 395 V, which was applied via the DBAIV preamplifiers. Further details can be found in Ref. [25].

4.2. The 32-channel LYCCA preamplifier

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Within the framework of the LYCCA project, the CSP-32(X) series of highly compact, charge-sensitive preamplifiers was developed at the University of Cologne. The underlying design is such that in principle a wide energy range of the signals from both DSSSDs and PDs is covered, with an easily reconfigurable amplification stage up to a 10 GeV range. For LYCCA the model CSP-32(4.1GeV) is selected from this series [11], which foresees a switchable dynamic range between 1.3 GeV and 4.1 GeV. An overview of the main components of the CSP-32(4.1GeV) is presented in Fig. 9. It consists of the following stages:

- · a charge-sensitive loop with frequency compensations,
- a passive pole-zero cancellation and attenuation stage, and
- a balanced differential output buffer.



Figure 9: Block diagram of one channel of the front-end electronics for DSSSD and photodiode processing of LYCCA modules. Fall times of $\tau_F \sim 55 \ \mu s$ after the first amplification stage and $\tau_0 \sim 15 \ \mu s$ following pole zero compensation are indicated.

The charge sensitive loop has a conversion factor of 50 pC/V. It comprises an input stage with a very low noise jFET transistor, a current feedback operational amplifier, a passive feedback circuitry and a rather complex frequency compensation network. The use of a large feedback capacitance was mandatory to achieve

the large dynamic range but moreover to account for 600 568 placement of the detectors in a relatively large reaction 601 569 chamber, which implies long wiring between detector 602 570 elements and the charge sensitive preamplifier input cir-603 57 cuitry. In order to cope with these adverse conditions 604 572 and to get a transfer function with a flat amplitude re- 605 57 sponse at the highest possible bandwidth, a multiple fre-574 quency compensation network was designed and imple- 607 57 mented. 576 608



Figure 10: Simplified block diagram of the equivalent transimpedance amplifier stages and frequency compensation networks.

628 The connection of the detector elements to the 577 629 charge-sensitive loop input stage is AC (10 nF/400 V). 578 630 This is imposed by the required detector bias voltage 579 631 of up to 200 V. The choice of the preamplifier input 580 632 jFET type is one critical issue of such developments. 581 633 After some tests performed, we have found that the n-582 634 channel jFET models BF861A and BF861C manufac-583 635 tured by NXP Semiconductor represent the most ade-636 quate choice. In fact, both provide a very low-noise with 585 637 a working point at a drain voltage of only $\sim 2.0-2.5$ V 586 638 and a drain current of less than 4 mA, i.e. a power con-587 639 sumption of only $\sim 8-10$ mW. 588 640

The transimpedance amplifier of the charge sensitive 589 641 loop is built around a miniature current feedback oper-590 642 ational amplifier (AD8005ART; RT-5 package) which 591 643 is showing a wide signal bandwidth (270 MHz), very 592 644 low quiescent current (typically 400 μ A) and at the 593 645 same time very low input voltage noise $(4.0 \text{ nV}/\sqrt{\text{Hz}} \text{ at})$ 594 10 MHz). To match the different detector requirements 646 595 the feedback network values can vary for different con-596 figurations: For LYCCA DSSSD detectors, the default 647 597 values are $C_F = 56 \text{ pF}$ and $R_L = 10 \text{ M}\Omega$, respectively 598

599 $\tau_F \sim 56 \,\mu s$ (Fig. 9).

The frequency compensation circuit is implemented in the charge sensitive loop and it is similar to the AGATA FEE design [34]. It comprises three main components, namely one high-pass filter (as the Miller effect like internal compensations of the equivalent operational amplifiers), one lead-lag filter, and finally one dominant-pole compensation circuit. The lead-lag compensation with a time constant of $\sim 3-5$ ns is a rather high frequency compensation without sacrificing the close-loop gain performance.

The dominant pole frequency compensation circuit detailed in Fig. 10 compensates the pole existing in the more complex feedback network of the charge sensitive stage [35]. One takes advantage of the very large open loop gain of the charge sensitive stage and its quite small output impedance, Z_0 , capable to drive the rather large output capacitor of 10-20 pF. This network has a time constant of ~ 1.0-1.5 ns and acts efficiently as a dominant pole compensation without causing instabilities in interaction with the intrinsic equivalent operational amplifier pole.

The rise time, t_{rise} , of the charge sensitive stage is ~ 13 ns for zero input capacitance, $C_{in} = 0$ pF, with the rise-time slope being 0.3 ns/pF with almost no overshoot or undershoot over the whole dynamic range. A typical transfer function in time domain for $C_{in} \sim 60$ pF and a step function as input test signal with $t_{rise} \sim 1$ ns is shown in Fig. 11(a).

To obtain similar fall-time characteristics of the output signals for different dynamic range configurations of the CSP-32(X) series, a pole-zero cancellation network is also required, as shown in Fig. 9. By default the fall time of the output signals is $\sim 15 \,\mu$ s.

A differential signal transmission mode is chosen to enhance the rejection to common-mode noise and potential disturbances picked up along the output cable. A balanced differential output stage has been designed around the AD8012AR dual operational amplifier which features low noise, low power, and wide bandwidth. Only ± 6 V power supply has been chosen due to the overall power consumption limitation of the 32 channels packed in a relatively small metal case of 80 mm ×40 mm ×120 mm in size. A photograph of an open case is provided in Fig. 11(b).

The main specifications of the CSP-32(4.1GeV) can be summarized as follows:

- conversion gain of the CSP stage 800 mV/GeV(Si),
- noise ~ 2.8 keV FWHM ($C_{\text{detector}} \sim 0 \text{ pF}$),
- noise slope 11 eV/pF,

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Figure 11: (a) Transfer function in time domain for a test with a step function as input signal with $t_{rise} \sim 1$ ns. (b) View of the CSP-32 charge-sensitive preamplifier (box opened). 8 boards are visible, each equipped with 4 channels.

- rise time $\sim 10 \text{ ns}$,
- rise-time slope 0.3 ns/pF,
- fall time ~ 15 μ s by default, while it can optionally be factory adjusted in the range of 10-50 μ s, 698
- a switchable coarse gain of 1/1 or 1/3 is implemented, 700
- differential output signals (with 100 Ω differential output impedance and a dynamic range of ± 4.5 Vterminated, here corresponding to the 4.1 GeV range), 706
- overshoots/undershoots less than 2.5% over the whole dynamic range.
- the 32 output signals can be directly digitized with ⁷¹⁰
 two GSI-EE 16-channel FEBEX3 sampling ADC ⁷¹¹
 modules [38]

Last but not least, cross talk between detector channels has to be considered in a complex detector system where the sensor itself is highly segmented. Special care has been taken to minimize the cross talk between 717

segments and between detectors at the level of the reaction chamber ensemble set-up. To avoid additional crosstalk between LYCCA detector elements, separated return ground paths for each individual segment are provided, while the inductivities to the segment electrode within the detectors wiring cannot be omitted.

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4.3. Processing of LYCCA DSSSD and CsI Elements

Until the final LYCCA read-out scheme based on highly integrated and fully digitized preamplifier signals [11] becomes operational within the FAIR-NUSTAR data acquistion environment, an intermediate path based on readily available and reasonably affordable integrated electronics modules has been followed.

Each of the 32 signals from the p-side and the n-side of the Target DSSSD are handled by one 32-channel preamplifier box described in the previous Sec. 4.2. Sixteen channels of differential preamplifier output are carried by shielded twisted pair cable towards a total of four single-unit NIM, 16-channel analogue shapers of type Mesytec STM16 or MSCF16 [36]. The in total 64 energy channels are subsequently digitized by two CAEN 785 peak-sensing analogue-to-digital converters (ADC), the corresponding times of the 32 p-side channels measured by a CAEN 775 time-to-digital converter (TDC) relative to the accepted event trigger. A logic OR of all 64 timing channels can be used as an optional 'Target DSSSD' trigger input signal.

During the 2010-2011 PRESPEC experimental campaign the four DSSSDs in the centre row of LY-CCA modules [cf. Fig. 8(b)] were processed in an almost identical fashion: 8 custom-made preamplifiers (cf. Sec. 4.2), hence 16 analogue shapers coupled to 8 ADCs were used, while the 128 timing signals of the psides were digitized by a 128-channel CAEN 767 TDC. The signals of the remaining 8 DSSSDs were combined in units of four strips inside the LYCCA vacuum chamber, which gives rise to additional 8*(32+32)/4=128 silicon channels, i.e. four more preamplifiers, eight more analogue shapers, four more ADCs, as well as a second CAEN 767 TDC.

During the 2012-2014 PRESPEC-AGATA experimental campaign, a total of 16 LYCCA $\Delta E \cdot E_{res}$ modules are in use. Here, two neighbouring signals of all DSSSDs are joined inside the LYCCA vacuum chamber, which yields a total of 16*(32+32)/2=512 silicon channels. These 512 channels are handled by 16 preamplifiers, 32 analogue shapers, 16 ADCs, and two CAEN 767 TDCs, since still only the times of the p-sides of the DSSSDs are being recorded. In both configurations, a logic OR of all DSSSD p-side timing channels could or

can be used as an optional 'Wall DSSSD' trigger input 749
 signal. 750

The photodiode read-out of the CsI detectors in 751 720 the LYCCA modules is handled very similarly: The 752 721 modules are grouped together in units of three, such 753 722 that 3*9=27 photodiodes can be processed by one 32-723 channel preamplifier (identical to the one used for the 724 DSSSDs, cf. Sec. 4.2), two analogue shapers, one ADC, 725 and 32 channels of either a CAEN 775 TDC or part of 726 a CAEN 767 TDC. A logic OR of all timing signals 727 could or can be used as an optional 'Wall CsI' trigger 728 input signal. 729

The high-voltage bias supply to both DSSSDs and photodiodes is provided by a set of four 4-channel Mesytec MHV4 NIM modules [36]. Remote control of MHV4 voltages as well as STM16/MSCF16 gain and threshold settings are enabled by two Mesytec MRC1

⁷³⁵ slow-control units [36].



Figure 12: Energy loss vs. energy plot showing the Z distribution measured in one LYCCA ΔE - E_{res} module. The Z = 26 selection for Fe fragments is shown.

736 5. First In-beam Commissioning Results

The first in-beam commissioning experiment for LY-737 CCA took place in September 2010, which aimed to de-738 termine the performance of the LYCCA detectors for 739 nuclei around $A \sim 60$. A 550 MeV/u ⁶⁴Ni beam was in-740 cident upon a 4 g/cm² thick ⁹Be production target at the 741 entrance window to the FRS [6]. A secondary beam of 742 ⁶³Co was selected and allowed to pass through a num-743 ber of FRS detectors, the LYCCA ToF start scintilla-744 tor and the LYCCA target detectors, which consistet of 763 745 the target diamond prototype detector and a DSSSD. A 764 746 0.4 g/cm² thick ¹⁹⁷Au secondary target followed these 765 747

⁷⁴⁸ detectors. The energy of the ⁶³Co beam at this point was ⁷⁶⁶

approximately 165 MeV/u. The beam continued to pass through the remaining LYCCA ToF Stop scintillator and LYCCA telescopes before coming to rest in the LYCCA wall CsI detectors. The flight distances (cf. Fig. 1) were $d_{in} = 700(5)$ mm and $d_{out} = 3.61(1)$ m.



Figure 13: ToF_{tot} vs. energy E_{res} plot showing Fe fragments from the commissioning data.

In order to get an idea of the performance of LYCCA, the mass resolution of Fe fragments, primarily produced by secondary beam interactions with the diamond detector and DSSSD at the target position, was evaluated. Using this measurement and knowledge of the energy resolution, the timing resolution was extracted and all resolution values were compared with those used in the LYCCA simulations [10] and outlined in the LYCCA TDR [11].



Figure 14: Fe fragment masses calculated on an event-by-event basis. The mass resolution of $\Delta A = 0.55$ (FWHM) was determined from the average width of the six peak Gaussian least squares fit shown.

A Z = 26 selection was made using $\Delta E - E_{res}$ data from the LYCCA wall DSSSDs and CsI detectors respectively, as can be seen in Fig. 12. Isotopic identification of the Fe fragments could then be provided by

the ToF_{tot} measurements between LYCCA start and stop 819 767 scintillators, as well as the $E_{\rm res}$ measurements from the 820 768 LYCCA wall detectors. Only one central ΔE - E_{res} wall 769 module was used throughout the analysis to guarantee 770 that partially insufficient calibration data did not com-771 promise the mass resolution measurements. Projectile 772 tracking using the target and wall DSSSDs allowed po-773 sition corrections to be made to the LYCCA scintilla-77 tors, which improved the accuracy of the timing mea-775 surements [24]. 776

The resulting ToF_{tot} vs. E_{res} histogram is shown in 777 Fig. 13, and can be compared with the simulated plot 778 for fragments ⁵⁰Fe to ⁵³Fe in Ref. [10], i.e. in a sim-779 ilar Z and A regime and comparable particle energies 780 and flight distances. At least four Fe isotopes can be 781 identified from the experimental data in Fig. 13. The 782 separation between neighbouring 'diagonal lines', i.e. 783 neighbouring isotopes, is topologically very similar to 784 expectations from the simulations in Ref. [10]. 785

The time-of-flight between the target and the LYCCA 786 wall, ToFout, and total energy measurements were used 787 to calculate fragment masses on an event-by-event ba-788 sis. ToFout was determined from ToFtot using knowl-789 edge of the beam velocity β at various points along the 790 beamline, and LYCCA tracking information was used to 79 correct for different particle trajectories along the flight 792 path. The total energy measurement also required cor-793 rection to ensure that energy losses in the stop scintilla-794 tor and the shielding foil were taken into consideration. 795 The result of these calculations for the Z = 26 se-796 lection can be seen in Fig. 14, which also includes a 797 restrictive gate on incoming fragments from the FRS. 798 An average measurement of the six most prominent 799 peaks produced a mass resolution of $\Delta A = 0.55(3)$ 821 800 (FWHM). A timing resolution for the LYCCA ToF sys-822 801 tem could only be determined by working backwards 823 802 from this mass resolution and taking a known energy 824 803 resolution, which was measured using a ⁶⁴Ni beam with 825 804 minimal matter in the FRS beamline. This reduced the 826 805 energy straggling of the beam, allowing an upper limit 827 808 of 0.69(2) % (FWHM) to be assigned to the energy res-807 olution. With this knowledge, a lower limit to the effec- 829 808 tive timing resolution of $\Delta t = 72(4)$ ps (FWHM) was 830 809 extracted for the LYCCA timing system, which corre- 831 810 sponds to $\Delta t = 51(3)$ ps (FWHM) for each timing de-811 tector. Due to coarse position corrections in the present 833 812 analysis and additional energy and position straggling 834 813 of the ⁶³Co fragmentation beam, this number is about a 835 81 factor of two worse compared to the number achieved in 836 815 a dedicated test with a primary ⁶⁴Ni beam in Ref. [24]. ⁸³⁷ 816 Nevertheless, it still suffices for proper mass resolu- 838 817 tion (cf. Fig. 14). More details of the analysis proce- 839 818

dure of this commissioning experiment are presented in Ref. [37].



Figure 15: (a) LYCCA $\sqrt{\Delta E} - E_{tot}$ plot and (b) charge Z distribution derived from the energy loss ΔE after the secondary target for the ⁸⁴Kr fission fragment beam.

In another experiment, a secondary ⁸⁴Kr beam was produced by relativistic fission of a ²³⁸U primary beam at 650 MeV/u on a ⁹Be target. This FRS setting on stable ⁸⁴Kr was chosen for calibration purposes prior to a Coulomb excitation experiment of the unstable isotope ⁸⁸Kr. The experimental set-up was identical to the one of the ⁶³Co test experiment described above, but with one exception: the prototype diamond ToF detector element was removed.

In Fig. 15(a) the square root of the energy loss in the DSSSD $\sqrt{\Delta E}$ is plotted versus the total kinetic energy E_{tot} deduced from the sum of the energy loss ΔE in the DSSSD and the energy E_{res} deposited in the CsI. The different nuclear charges from bare ions after the secondary target are clearly separated in this plot. Figure 15(b) shows the *Z* distribution obtained from ΔE after applying a momentum correction and a *Z* calibration (for more details see Ref. [30]) together with a least-square fitted multiple gaussian function. From this fit

the charge resolution is calculated to be $\Delta Z = 0.55$.



Figure 16: (a) LYCCA E_{tot} versus γ_{LYCCA} plot and (b) mass A distribution obtained from the distribution (a) by applying a momentum correction, a calibration, and background subtraction. Both plots are in prompt coincidence with incoming Z = 35 fragments using the preceding FRS ion identification.

Masses are determined from the correlation between 887 841 total kinetic energy and the time-of-flight. Figure 16(a) 888 842 shows the mass identification plot $E_{\rm tot}$ versus γ_{LYCCA} . 889 843 The relativistic Lorentz factor γ_{LYCCA} is calculated from 890 844 the ToF measured with LYCCA after the secondary tar- 891 845 get. As a by-product of the ⁸⁴Kr beam also bromine iso-846 topes can be selected from the incoming beam cocktail 893 84 with a gate on Z = 35 imposed on the FRS ion iden-848 tification. Following a Z = 35 selection in LYCCA 895 849 as well, the capability of LYCCA to separate the dif-850 ferent Br isotopes after the secondary target is demon- 897 85 strated. The two-dimensional distribution displayed in 898 852 Fig. 16(a) is transformed into the mass spectrum shown 899 853 in Fig. 16(b) by employing a momentum correction, a 900 854 mass calibration, and subtraction of background. For 901 855 a detailed description see Ref. [30]. The distribution 902 856 is least-squares fitted with a multiple gaussian function 903 857 with equal width values. The resulting mass resolution 904 858 (FWHM) for masses $A \sim 80-85$ yield $\Delta A = 1.02$. 905 859

The preceding – and to some extent still preliminary 906 – analyses provide the proof-of-principle of the LYCCA 907

detection scheme. Both energy and timing resolutions of the various LYCCA detector elements have to work according to or even better than specifications to achieve the main characteristics of the set-up, namely

• $\Delta Z/Z \lesssim 0.022 \ (Z \lesssim 26).$

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- $\Delta Z/Z \lesssim 0.015 \ (Z \lesssim 36).$
- $\Delta A/A \lesssim 0.010 (A \lesssim 60).$
- $\Delta A/A \lesssim 0.012 (A \lesssim 80).$

In the framework of the presently ongoing PRESPEC-AGATA campaign at GSI, a comprehensive performance commissining experiment has been performed recently, complemented with extensive pulser calibration data. This data is presently being analysed. Results concerning LYCCA performance will be subject to a forthcoming paper, detailing analysis procedures as well as achieved detector, proton number, and mass number resolutions [27].

6. Summary and outlook towards HISPEC at FAIR-NUSTAR

The concept, design and prototype developments for the FAIR-NUSTAR detector system LYCCA have been described. LYCCA aims to discriminate relativistic heavy-ion reaction products at typical energies of 100-300 MeV/u. Valuable and timely feedback on the LY-CCA design concept has been achieved during its early PRESPEC implementation of 12- and 16-module prototype versions of LYCCA at the GSI Helmholtzcentre for Heavy Ion Research in the years 2010-2014. With the basic LYCCA particle identification concept proven (cf. Sec. 5), further optimization on data analysis software algorithms is ongoing [27], and additional detectors and detector modules as well as electronics upgrades are foreseen towards the anticipated implementation of the complete LYCCA device for HISPEC experiments.

Concerning detectors, a very-large area plastic scintillator is being built to cover the approximate full 40cm diameter of the downstream HISPEC beam pipe, i.e. the anticipated 26-module version of the LYCCA Wall. Concerning these telescopes of the LYCCA Wall, the aim is to be able to provide up to 30 CsI blocks each of the 'short' and 'long' version.

In terms of read-out and processing electronics, the LYCCA Wall telescopes are going to be upgraded to already existing and commissioned sampling electronics modules: for the CsI(Tl)-PD part, the preamplifier

- signals are going to be digitized with some twenty 16-908
- channel GSI-EE FEBEX3 cards [38] based on 14-bit 909
- 50 MHz sampling ADCs. The DSSSDs are going to 910
- be handled by custom made front-end electronics de-911
- veloped in the United Kingdom. It is based on a ap-912
- plication specific integrated circuit design for the AIDA 913
- project [39]. Revised CFD-TDC concepts for the PMT 914 signal processing of the large-area scintillators are to be 915 investigated.
- 916
- Finally, LYCCA is going to be readily available to 917
- support physics-driven Super-FRS commissioning to-918
- wards FAIR-NUSTAR, either stand-alone or together 919
- with other FAIR-NUSTAR detectors and activities. 920

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