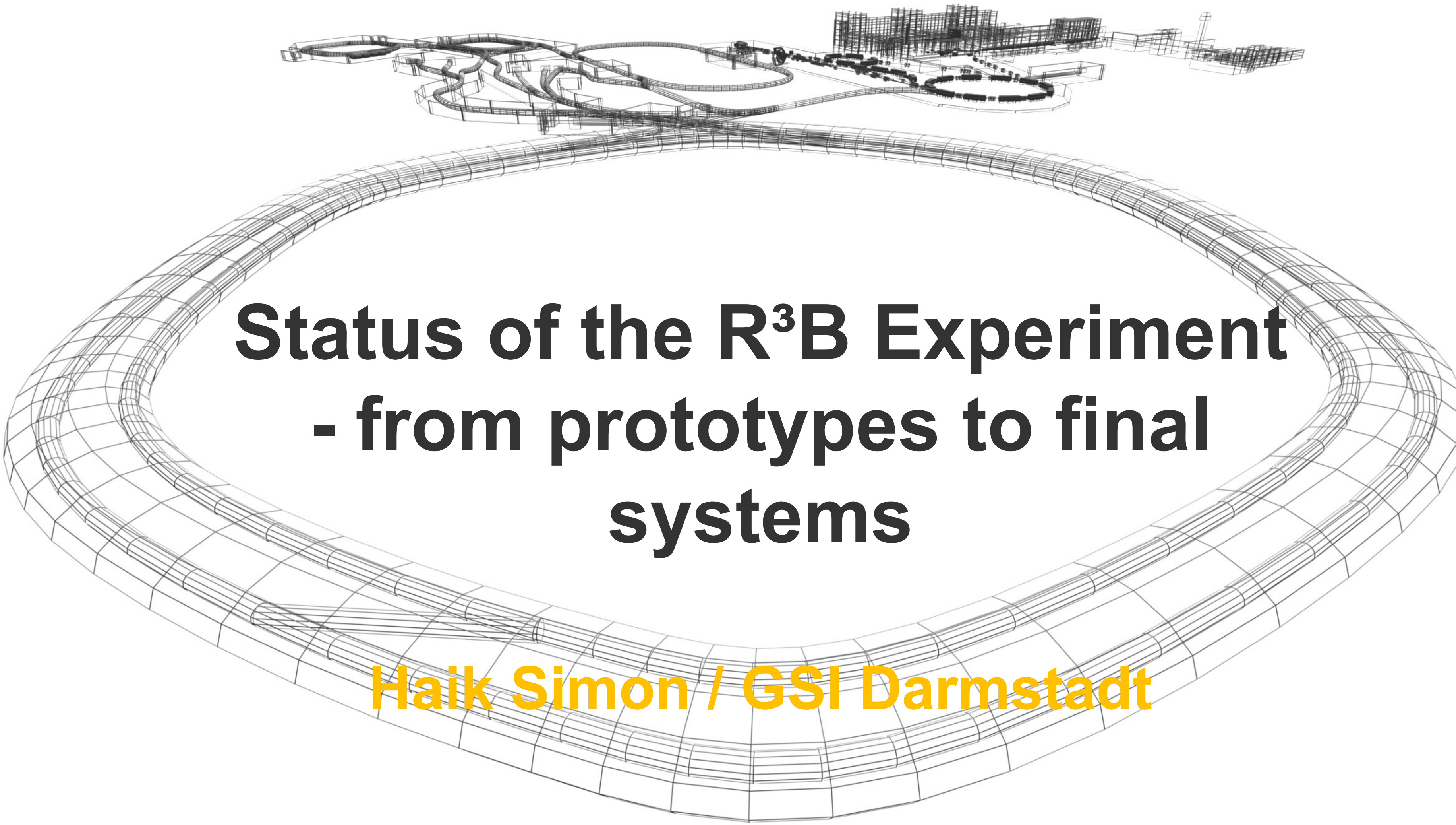
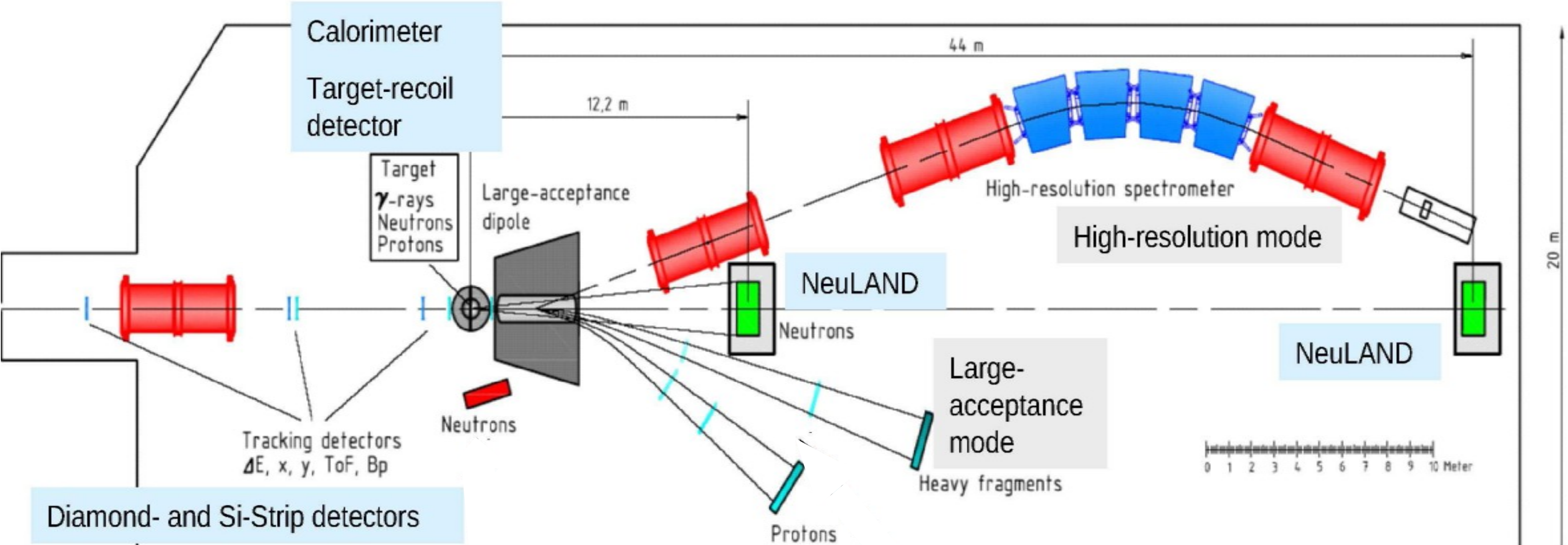


Status of the R³B Experiment - from prototypes to final systems

Haik Simon / GSI Darmstadt

Reactions with Relativistic Radioactive Beams
- A versatile and flexible setup



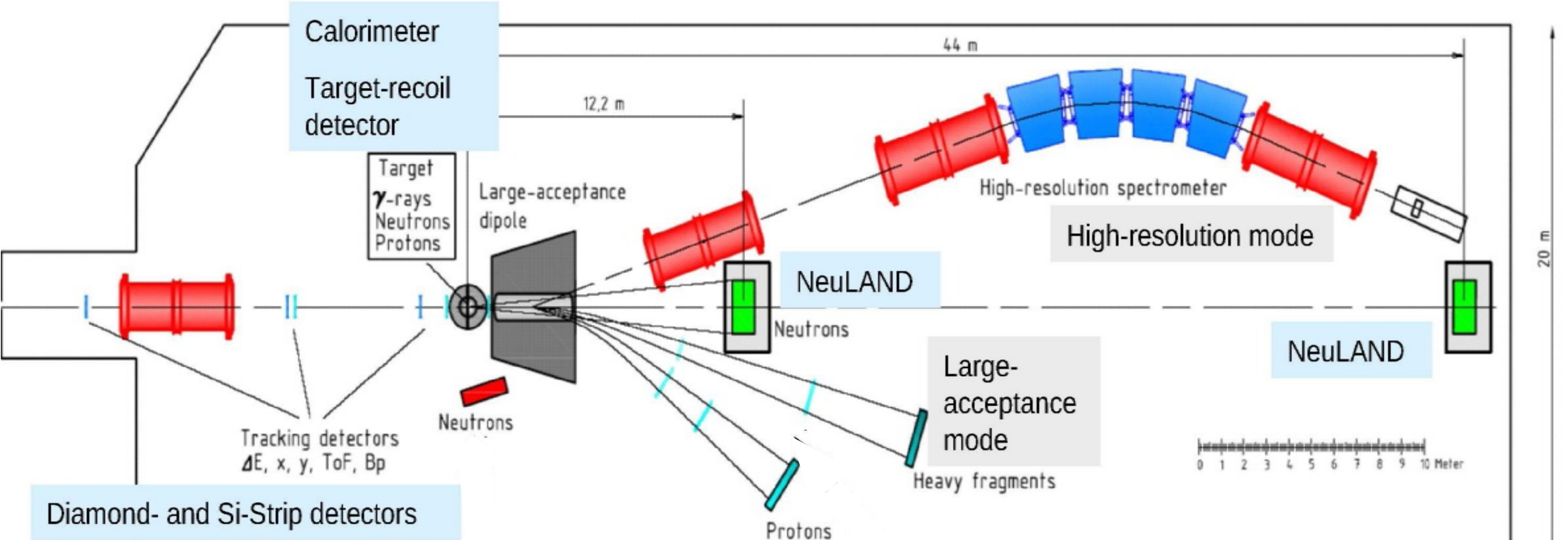
- High enery branch of the SuperFRS

  Beam energies: ~ 100 MeV/u – 1 GeV/u
- Overdetermined Measurement
  - Kinematically Complete
  - Target Calorimetry
  - Target Recoil Protons/Neutrons

Objectives:

- Reaction Studies
- Structure of (exotic) Nuclei
- Nuclear Astrophysics
- Neutron-rich Matter

Reactions with Relativistic Radioactive Beams
- A versatile and flexible setup

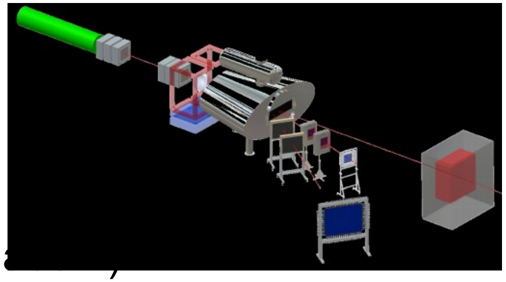


Major Components:
- Large Acceptance Dipole (GLAD)
- Neutron ToF Spectrometer (NeuLAND)
- Target Calorimeter and Recoil Detector (CALIFA + Si Tracker)
- Beam Tracking system

Additional Systems:
- High Resolution Spectrometer
- Active Target
- Low-energy Neutron Detector

Schedule and first experiments

2014	Installation of 20% detectors NeuLAND and CALIFA Commissioning run in Q3/2014
2015/16	Construction and installation of detector components
2017/18	Commissioning of full R3B setup (Cave C)
2018-202x	Physics runs at GSI (Cave C) (phase 0)
202x-202x+1	Move to High-Energy Branch building
202x+1 →	Commissioning and first experiments at Super-FRS (ph)



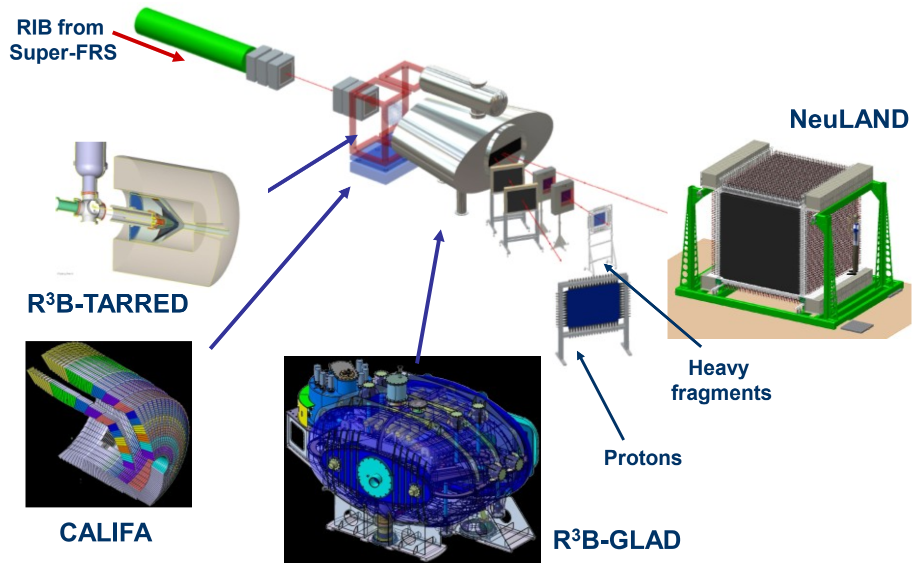
Experiments will make use of uniqueness of R^{3}B:

- Reactions at high beam energies up to 1 GeV/nucleon
- Tracking and identification capability even for the heaviest ions
- Multi-neutron tracking capability, high-efficiency calorimeter

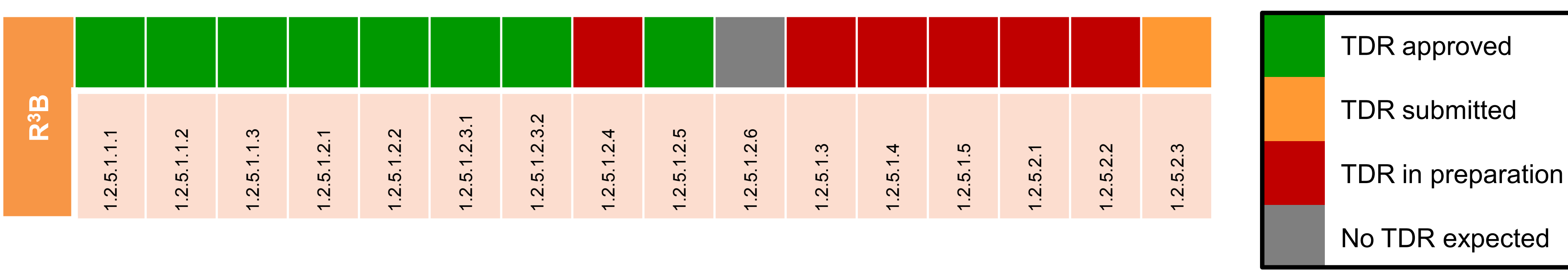
Experiments possible for the first time:

- 4 neutron decays beyond the drip-line and for heavier n-rich isotopes
- Kinematically complete measurements of quasi-free nucleon knockout reactions
- Electric dipole and quadrupole response of Sn nuclei beyond N=82,
  and of neutron-rich Pb isotopes (polarizability, symmetry energy)
- fission barriers from (p,2p) reactions (→ r-process)

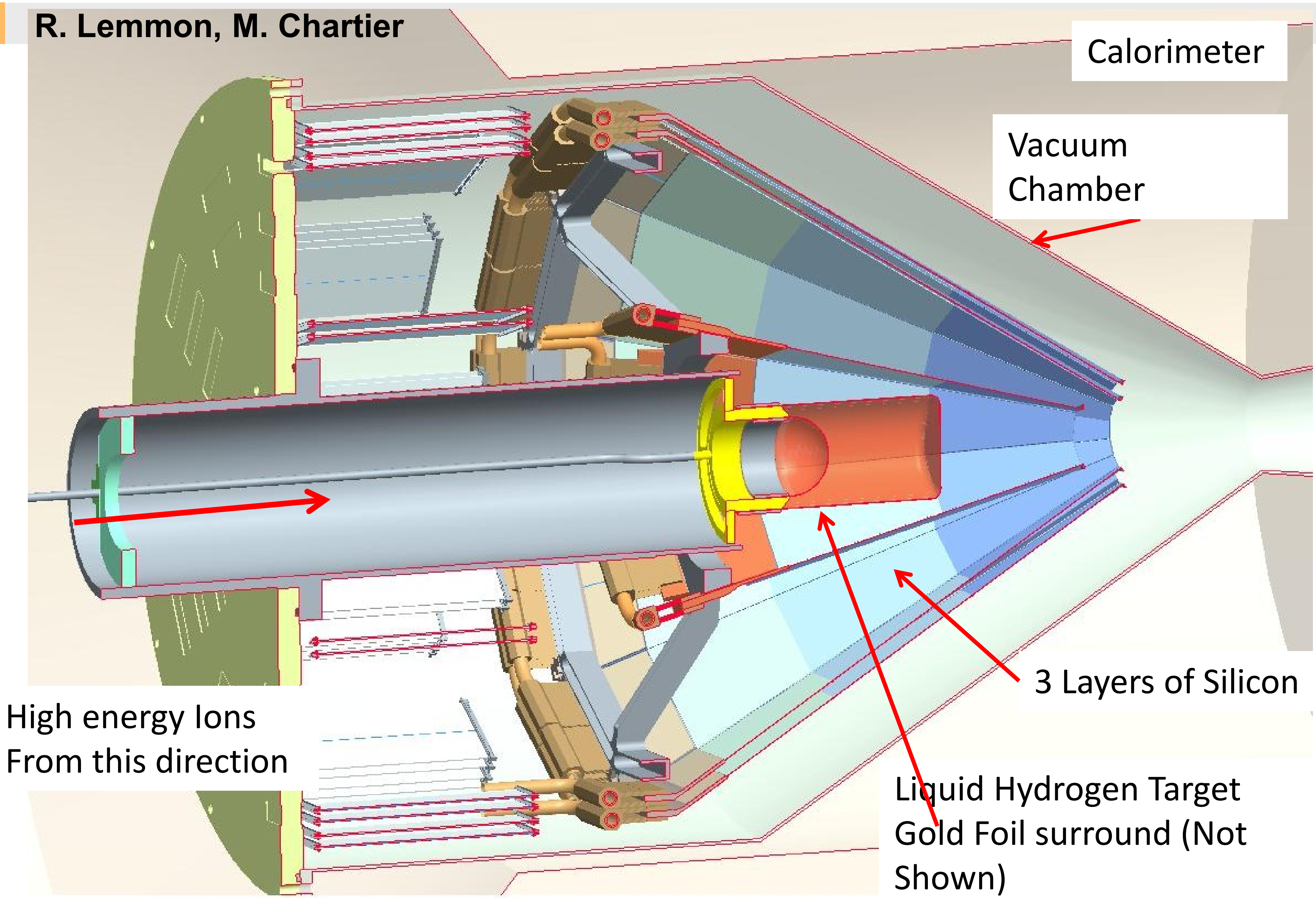
Status of the Experiment



- NeuLAND, CALIFA-barrel & forward endcap, GLAD, tracking detectors, Multiplett TDRs are **accepted**
- Submitted: Active Target
- **Submission this year: NUSTAR Common EDAQ (Draft circulating)**
- Missing: Si tracker, Vacuum / Installations for High Energy Cave@FAIR & High Resolution Spectrometer

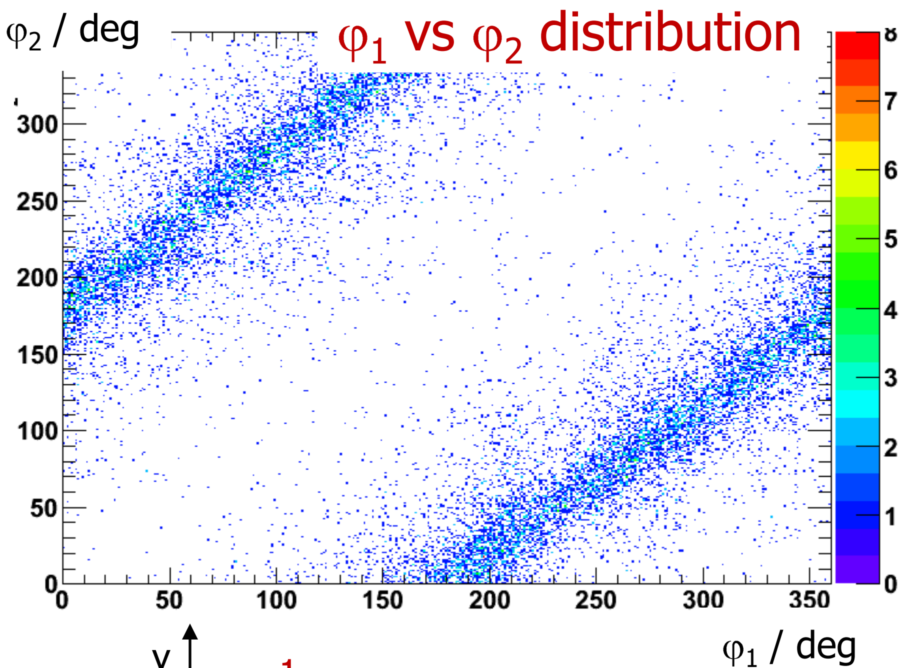


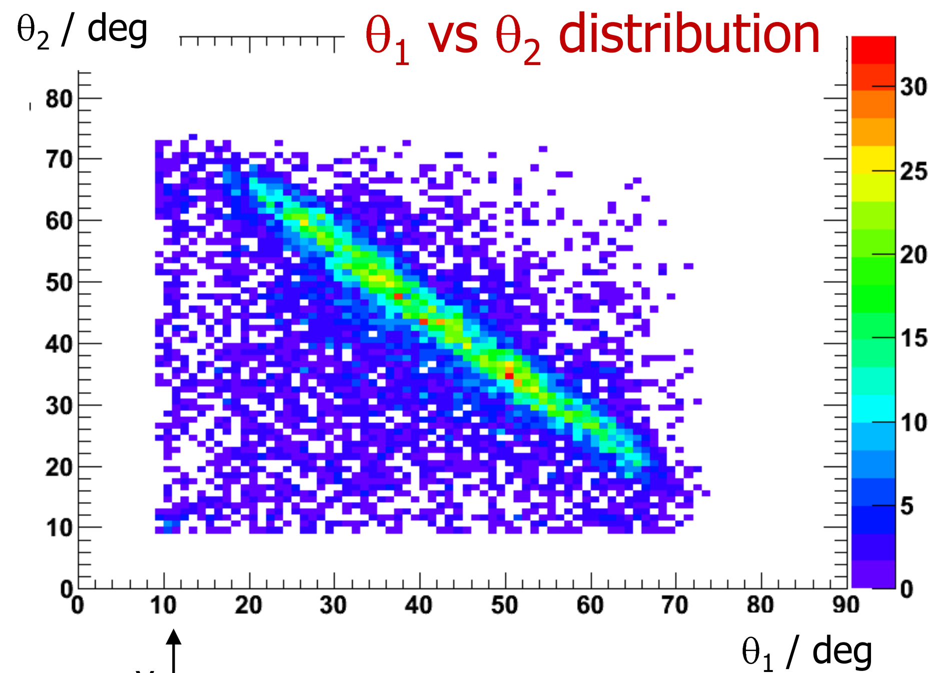
R3B Si Tracker

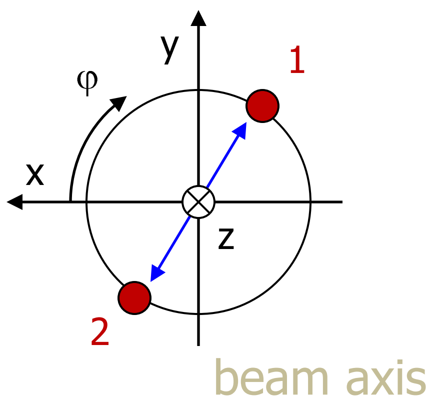


Target Recoil Detection

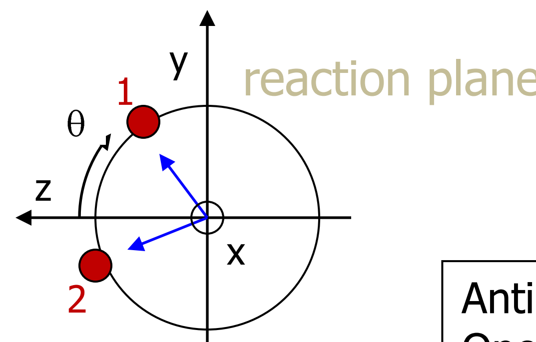
Data: F. Wamers $^{17}Ne(p,2p)$ @ 500MeV/u, CH_2







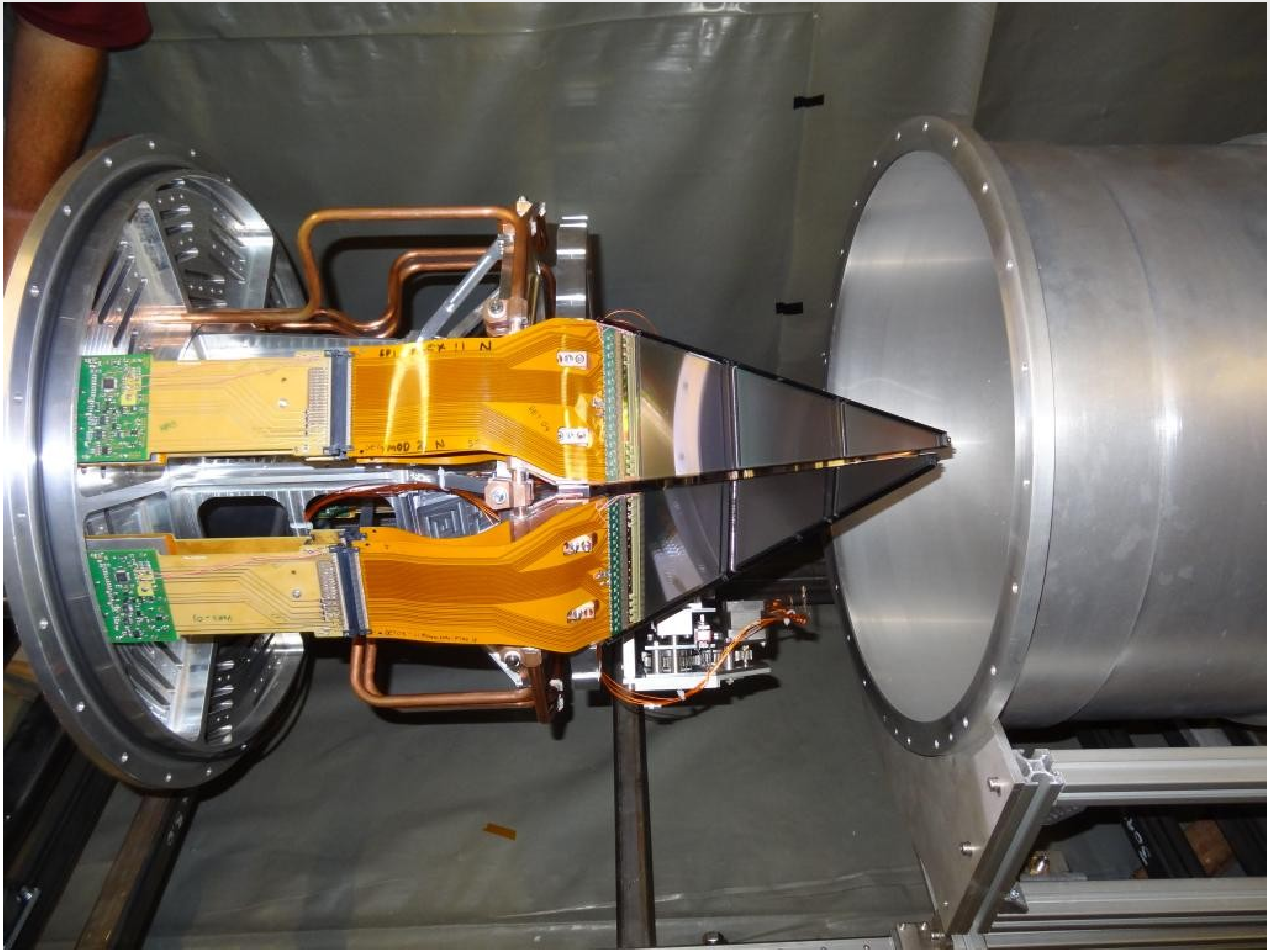
Correlation in φ:
$\Delta\varphi$ = 180°



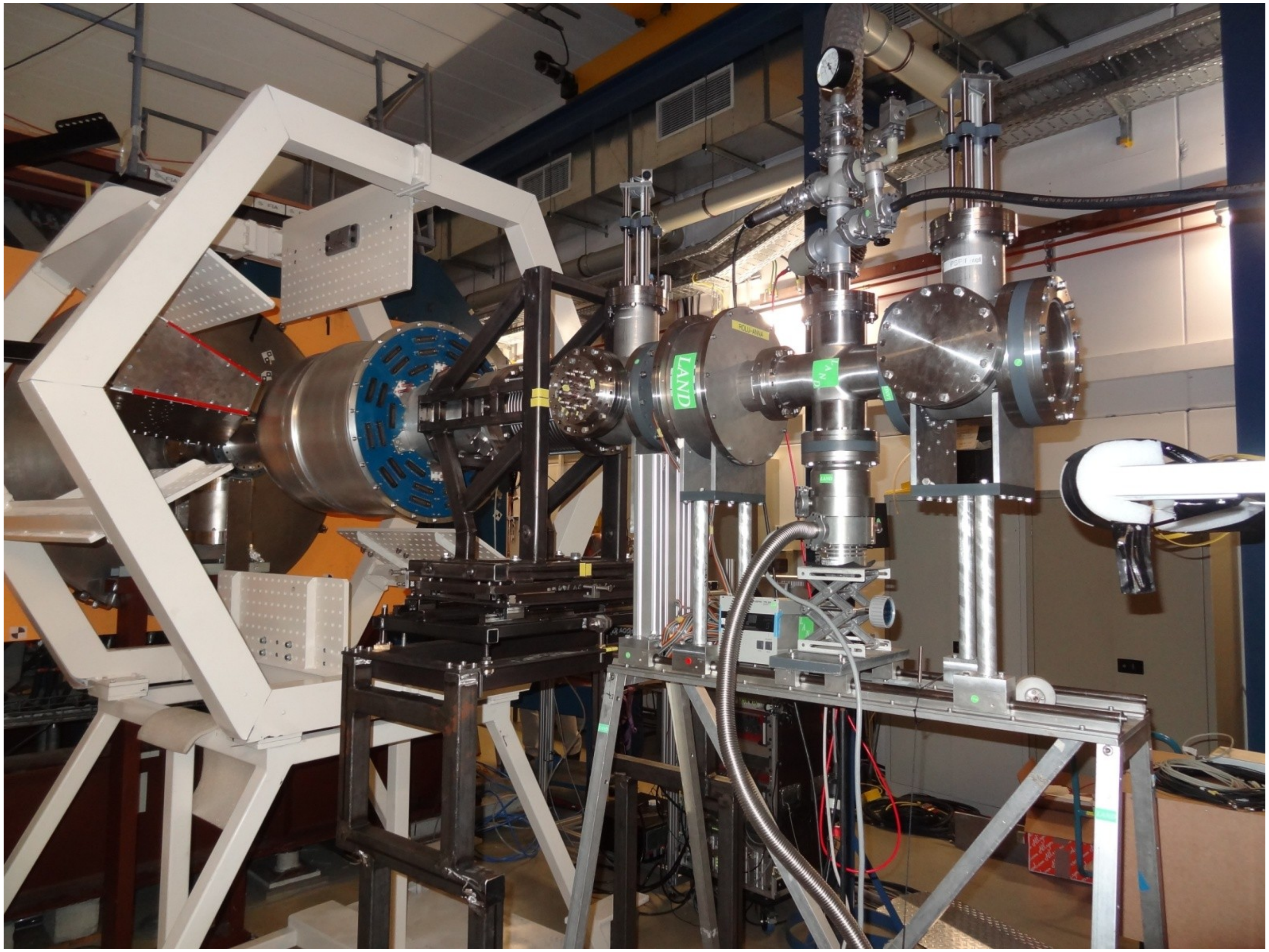
Anti-correl. in θ:
Opening angle ≈ 83°

➔ Clear signature for (p,2p) reactions

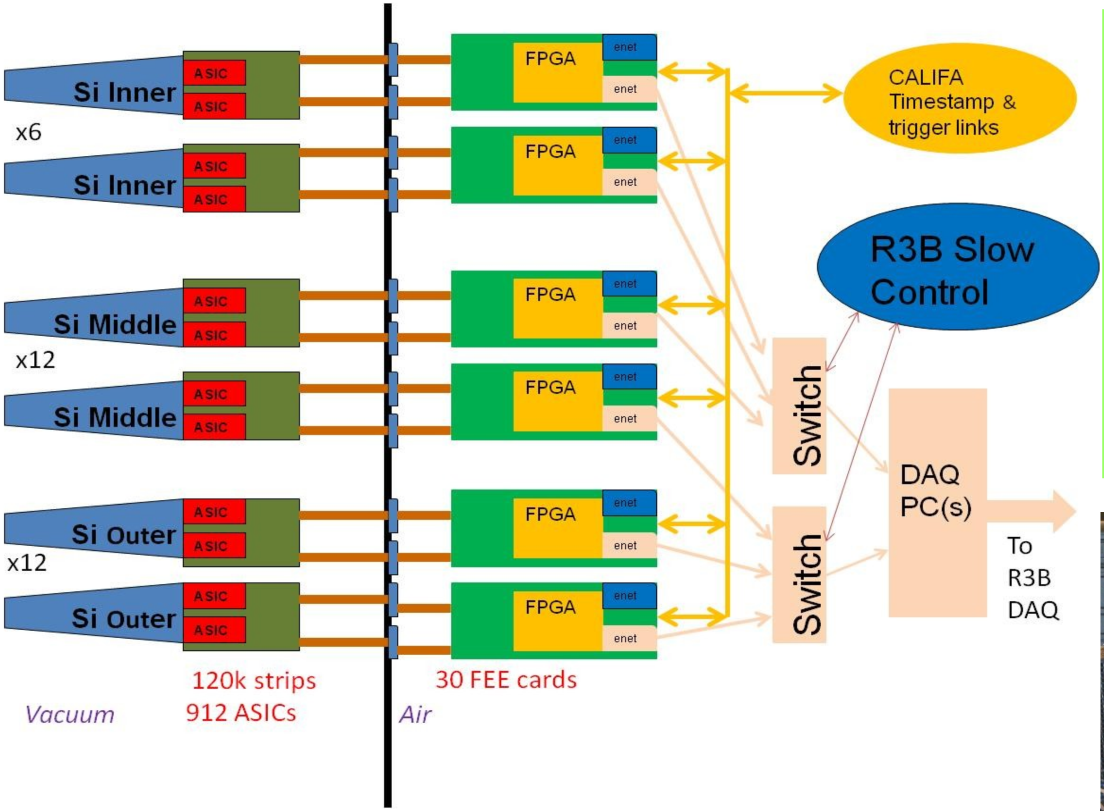
R3B Si Tracker – Test Beam @ GSI

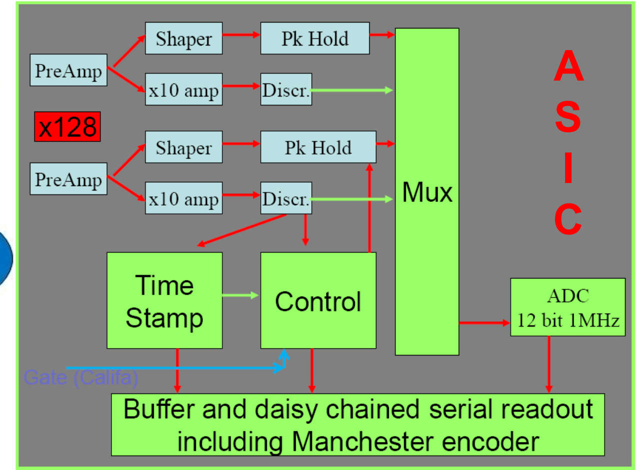


R3B Si Tracker – Test Beam @ GSI



R3B Si Tracker Schematic FEE/DAQ System





- Resolution 10keV – Threshold to be measured in situ
- Dyn. range 40 keV to 50MeV – Counting Rate max 5kHz/channel.

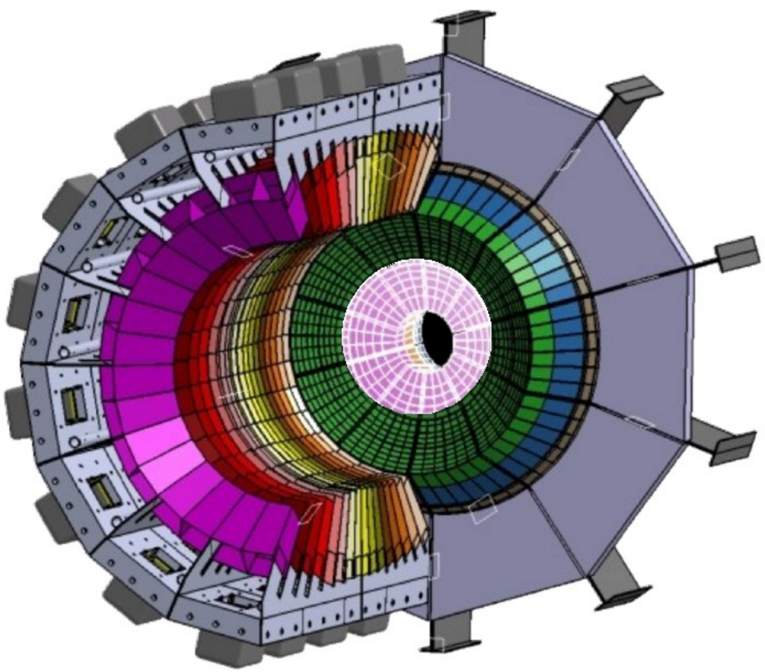
- **Revisions & Improvements (ASIC readout) ongoing ➔ Grant: ...04/2016: 14/24 ladders will be finished by the end of November 2015.**
- **From December on inner layer will be produced.**

STFC DL & RAL, Liverpool

Scientific requirements for CALIFA

D. Cortina,USC

CALIFA is one of the key detectors in R3B. It will be used in many of the experimental proposed at R3B. The required functionality will vary greatly from one experiment to another.



- Granular detector
- Performant scintillator materials and photosensors
- Minimum dead volume: compact arrangement
- Digital electronics

USC-IEM-UVigo

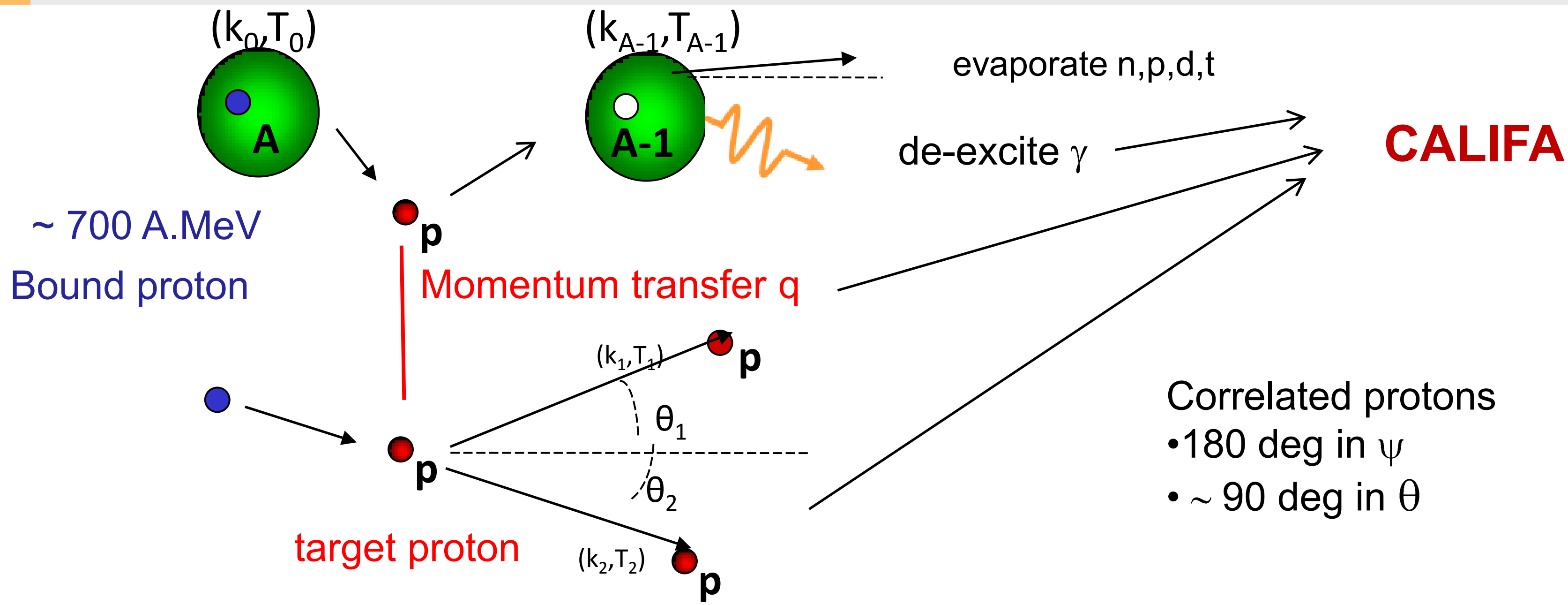
GSI-TUM EMMI-TUD

Chalmers Lund

CFNUL

JINR - NRC

Challenging R³B physics case for CALIFA: Quasi Free Scattering (p,2p)



deg)	E_p (MeV)	CsI(Tl) range (cm)	Efficiency (%)
7	686	71,8	15%
20	592	59,7	…
40	356	26,4	50%

Physics imposes the scientific requirements

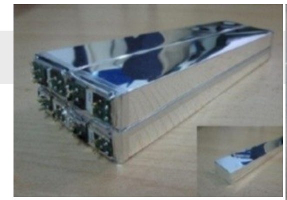
•Huge dynamic range
100keV γ-rays – 700 AMeV charged particles
•high efficiency, good resolution
•high granularity → Doppler correction
•particle identification

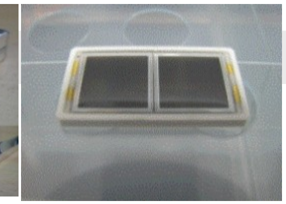
Scientific requirements for CALIFA

- Spectroscopic properties
- Calorimetric properties
- Fast response

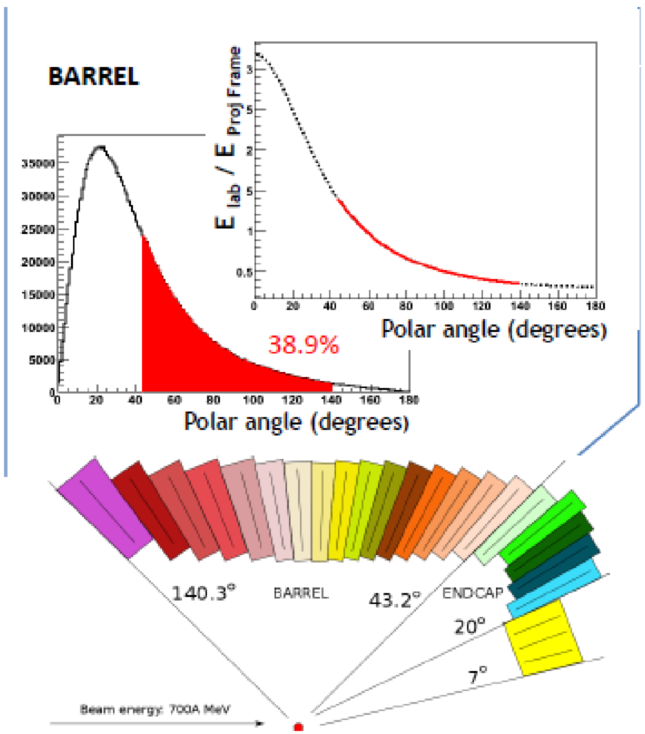
Intrinsic photopeak efficiency	40% (up to Eγ=15 MeV projectile frame)
Gamma sum energy resolution D($E_\gamma$sum)/<($E_\gamma$sum)>	< 10% for 5 γ rays of 3 MeV
Calorimeter for high energy Light charged particles	200-700 MeV in lab system
Gamma energy resolution	~5-6% (FWHM at Eγ=1 MeV) ~ 3% for very forward angles
Light charged particles resolution	~2% (stopped particles) ~ 5% (punch through particles)
Proton-γ ray separation	For 1 to 30 MeV

CALIFA BARREL



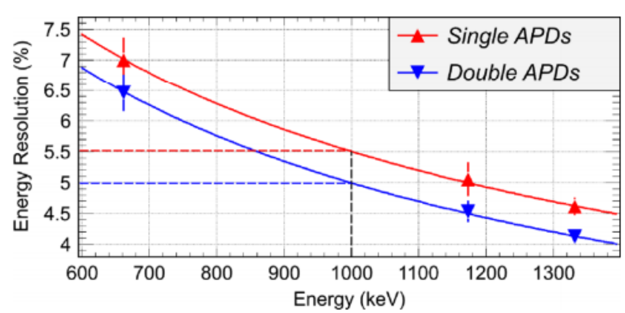


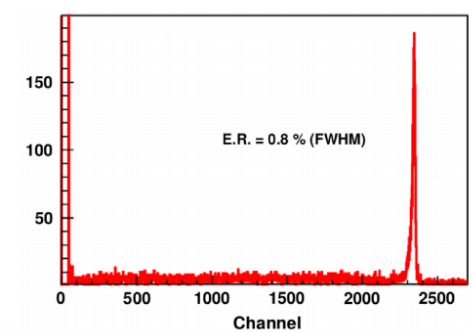
- CsI(Tl) crystals readout by customized LAAPD
- Up to 22 cm long crystals
- The entrance shape of each detection unit varies with θ to keep constant the ΔE/E



Inner radius	30 cm
Numb. of crystals	1952
Diff. crystal geometries	11
Av. crystal volume (CsI(Tl))	≈ 285.000 cm^3
Av. crystal weight (CsI(Tl))	≈ 1300 kg
Full operation system weight	≈ 6100 kg

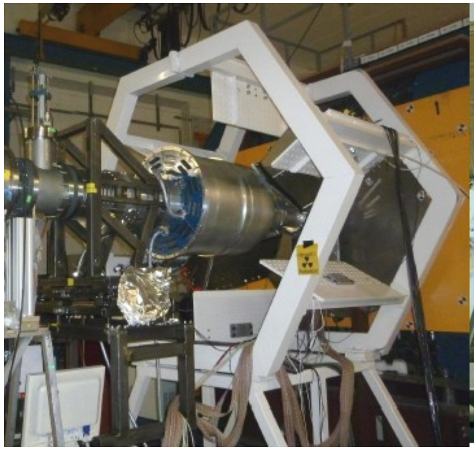
Good energy resolution for γ (~ 5% at 1 MeV γ) and fully stoped protons (up to 320 MeV)





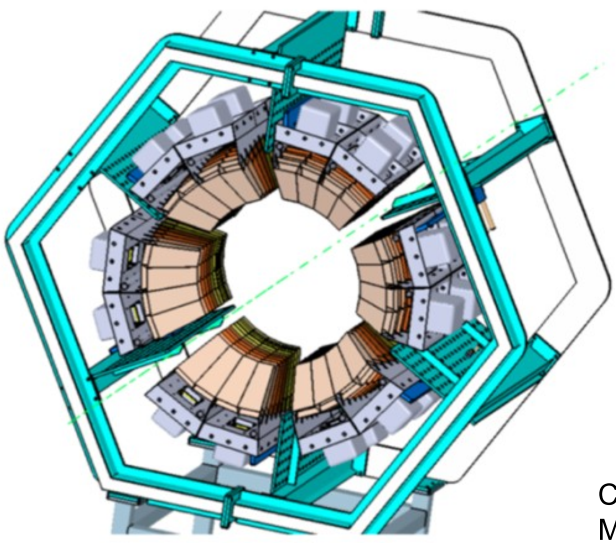
TDR accepted by January 2013 → in construction

CALIFA Barrel constructiom



- The first 128 detection channels were tested with protons (up to 280 MeV) at CCB Krakow and high energy γ×s in NEPTUN and TUM tandem

- Integration test of all CALIFA Barrel parts and syncronization with other R3B detectors was done.



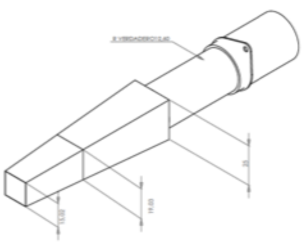
- The construction of other 640 detection channels is foreseen fo the next 12 months. They will complete the Barrel Demonstrator.

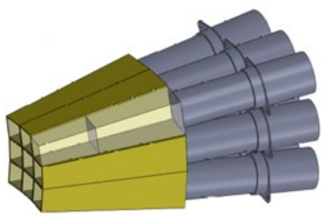
CALIFA Barrel TDR
M. Gascón PhD Thesis USC (2012)
M. Gascón et al JINST 8 (2013) P1004
B: Pietras et al. NIM A 729 (2013) 77
…..

CEPA4: a bigger phoswich array

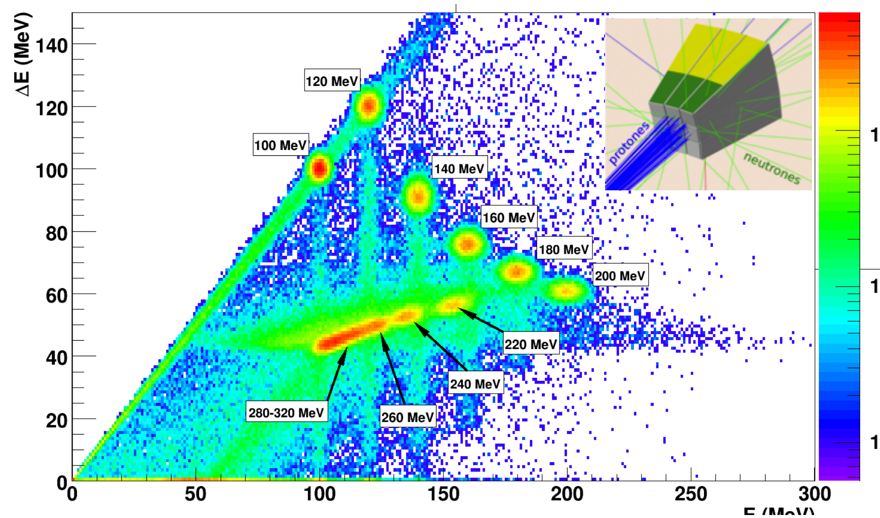
E. Nacher, O. Tengblad CSIC

- What we wanted…

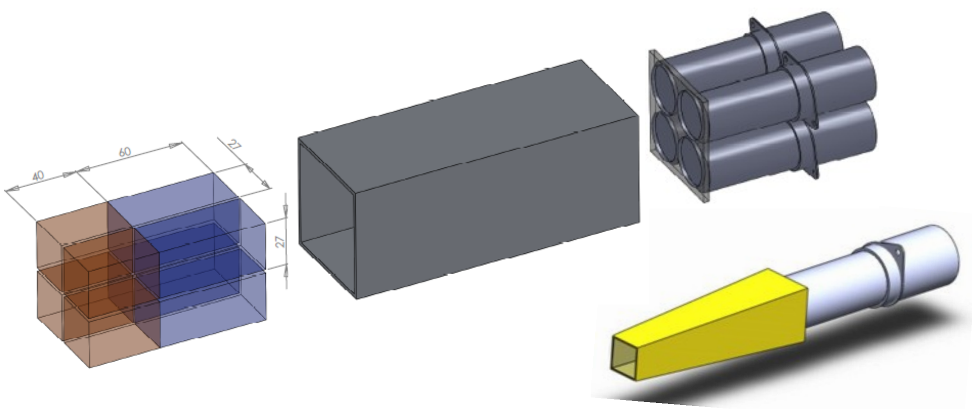




Simulations



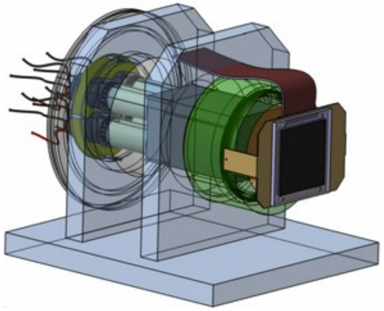
- What we got… CEPA4

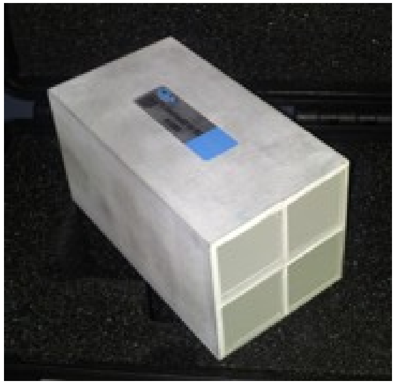


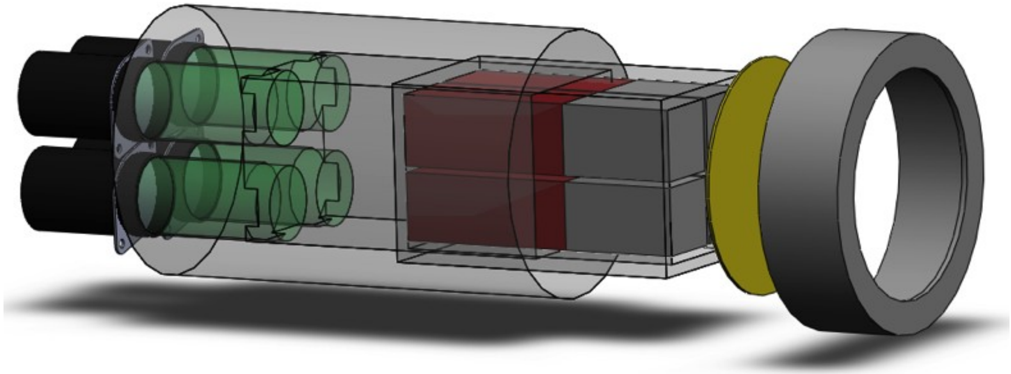
- 4 phoswich units in an Al (0.5mm) can
- $LaBr_3$ (4 cm) + $LaCl_3$ (6 cm) and 27 x 27 mm^2 entrance window
- No Al between the crystals, just 1 mm of Teflon (waterproof?)
- Test the optical insulation and the addback procedure

CEPA4: a bigger phoswich array

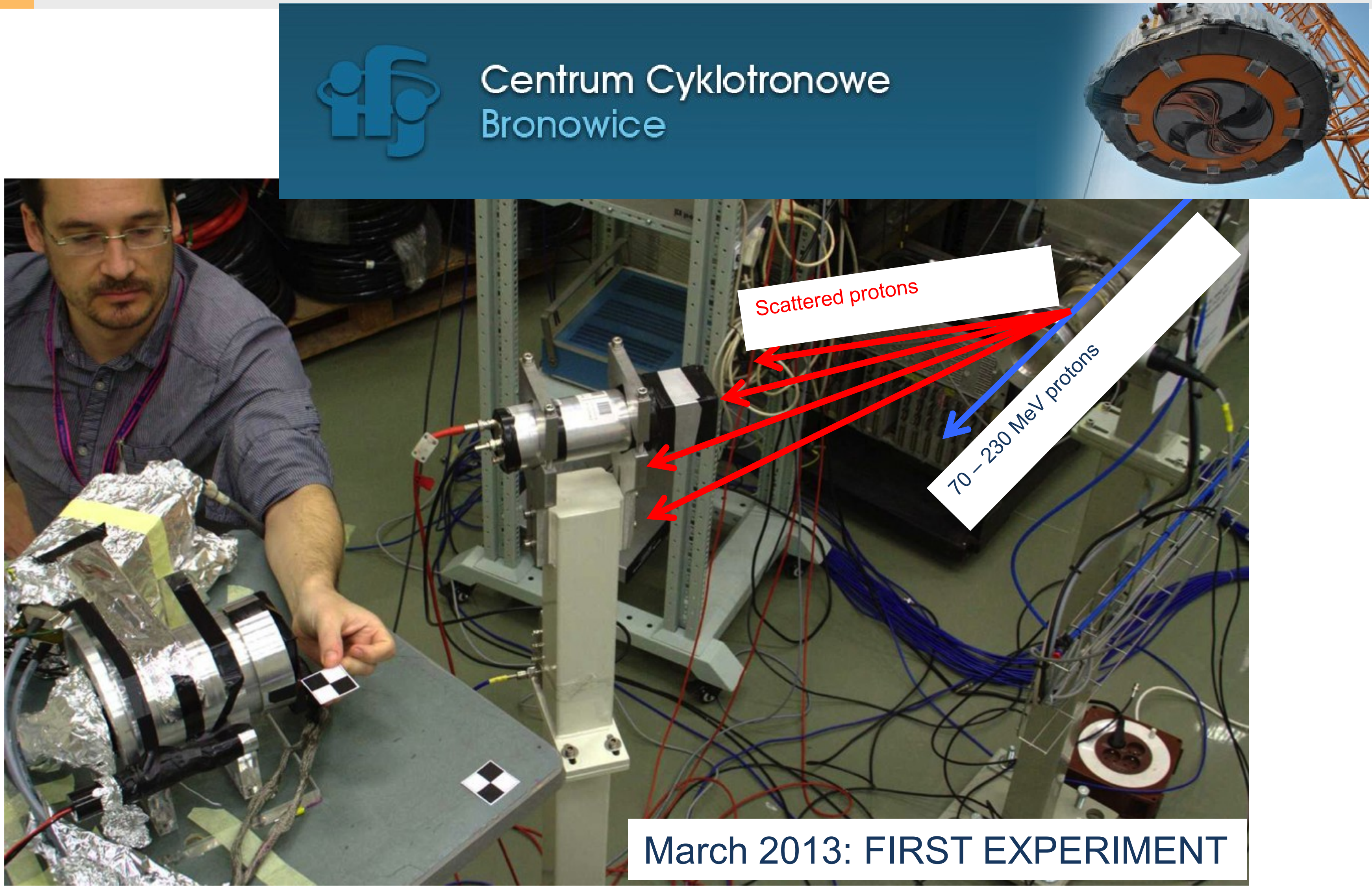
- Readout: 4 Hamamatsu 8-stage PM Tubes R5380 (changed to R7600U-200: shorter & square-shaped)
- A DSSD detector (5x5 cm^2) at the entrance face (in vacuum if necessary) to measure the entrance point of the protons.
- A VME CAEN Flash ADC (V1742) to digitize the signals.



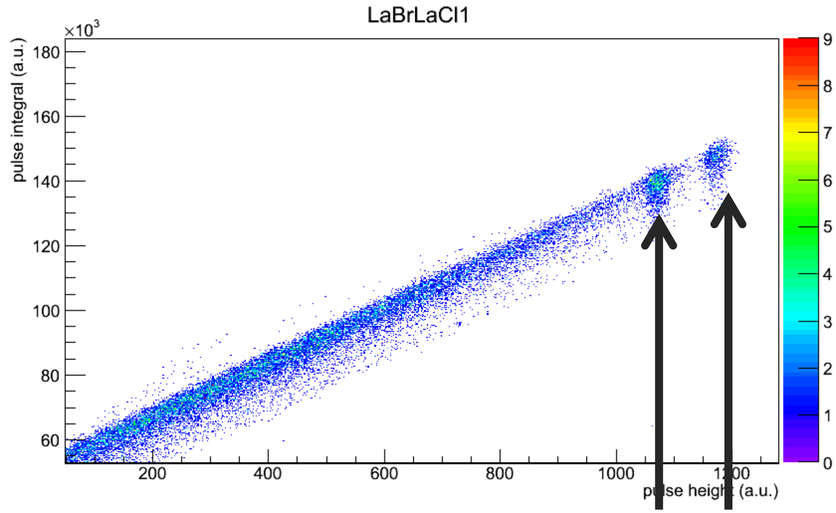




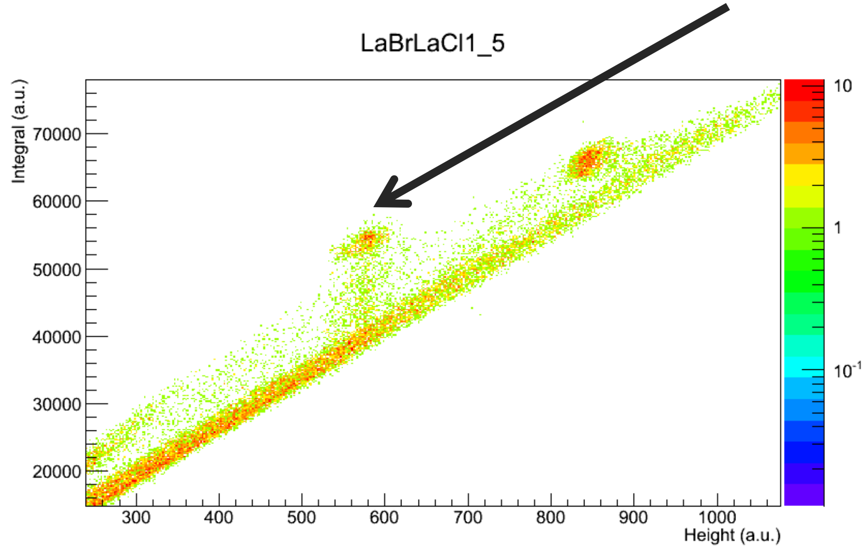
CEPA4: response to protons



CEPA4: response to protons



On-line pulse-shape analysis (120, 130 MeV)
Xtal5 (shorter): Energy beyond punch through



Energy resolution 2.0 – 2.5 % ok
(@ nominal beam resolution: 0.7%)
➔ … … …

FAIR

Inti Lehmann, FAIR GmbH, Planckstr. 1, D-64291 Darmstadt, Germany

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Email: inti.lehmann@fair-center.eu

Authors of the
Technical Design Report for FAIR:
NUSTAR R^{3}B CALIFA Endcap

25 August 2015

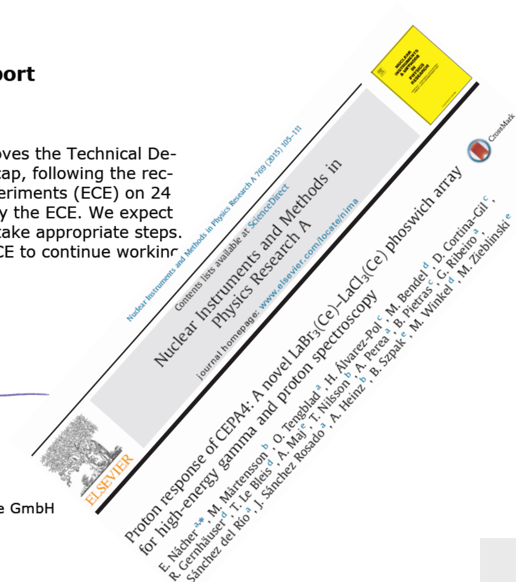
Approval of Technical Design Report

Dear colleagues,

We are happy to inform you that FAIR approves the Technical Design Report of the NUSTAR R^{3}B CALIFA Endcap, following the recommendation by the Expert Committee Experiments (ECE) on 24 July 2015. Please find attached comments by the ECE. We expect that you consider all of those seriously and take appropriate steps. In addition, please accept the offer of the ECE to continue workin[g] together to follow up the process.

Yours sincerely,

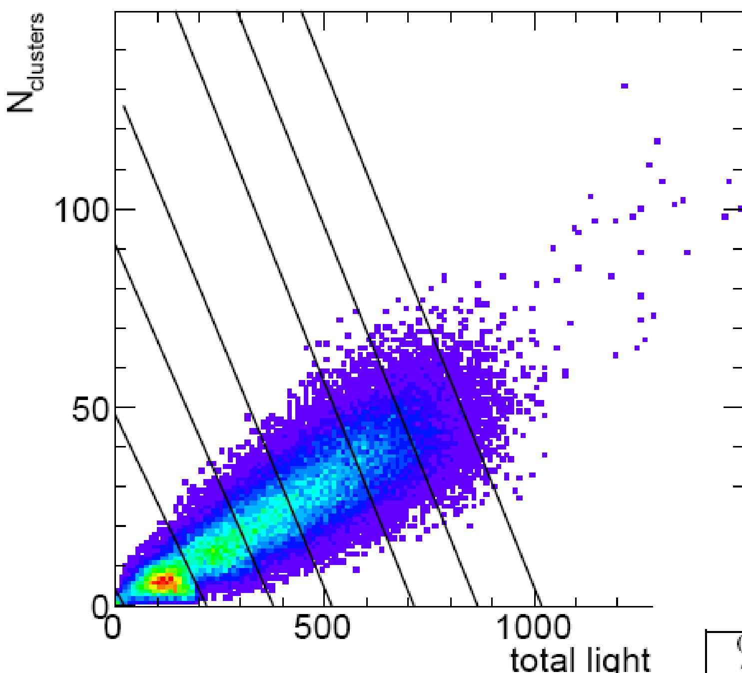
Inti Lehmann
Deputy Research Director
Head of Experiment Office
Facility for Antiproton and Ion Research in Europe GmbH

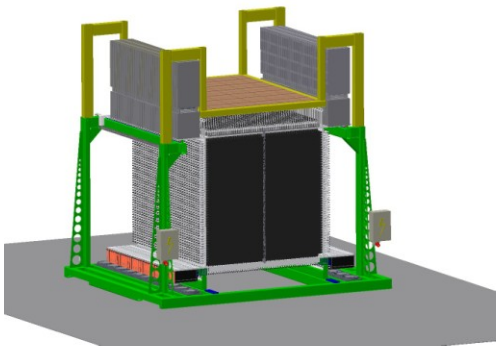


Novel Neutron Detector: NeuLAND

K. Boretzky

Fully active neutron detector based on scintillators (calorimetry & tracking)





	1000 MeV generated					
	%	1n	2n	3n	4n	5n
detected	1n	89	12	1	0	0
	2n	7	78	23	3	0
	3n	0	8	63	26	5
	4n	0	0	12	63	40
	5n	0	0	0	7	46
	6n	0	0	0	0	8

Previously < 50%

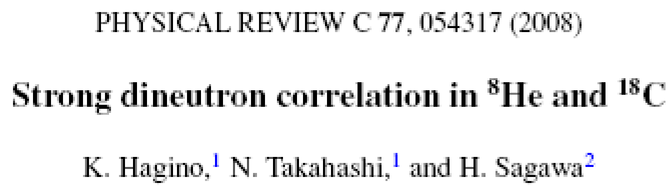
Previously <5% !

30 double planes
2 x 50 paddles each
5 x 5 x 250 cm³
RP408 / R8619ASSY

FPGA TDC readout

Incredients for the ^{7}H case

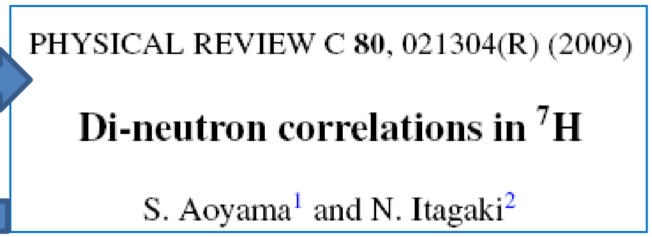
- t + n + n + n + n


PHYSICAL REVIEW C 77, 054317 (2008)

Strong dineutron correlation in ^{8}He and ^{18}C

K. Hagino,[1] N. Takahashi,[1] and H. Sagawa[2]

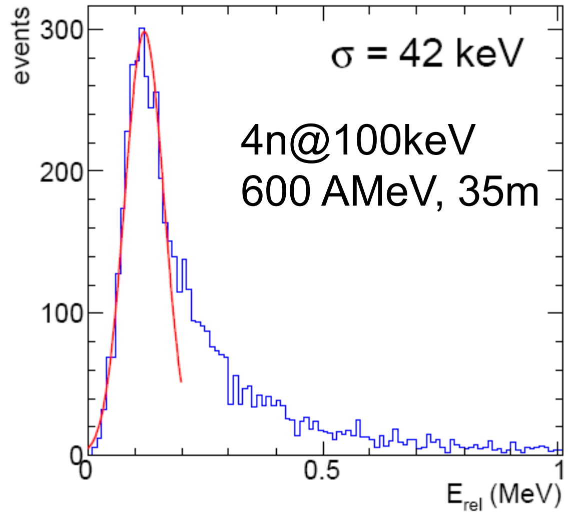
Core +4n (HFB)


PHYSICAL REVIEW C 80, 021304(R) (2009)

Di-neutron correlations in ^{7}H

S. Aoyama[1] and N. Itagaki[2]

Core +4n
AMD selected snapshots

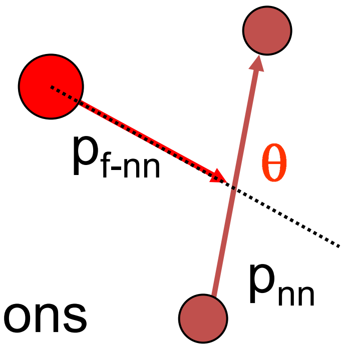


NeuLAND Simul.

- t + 2n + 2n

^{11}Li - α → ^{7}H + 2n + 2n
^{8}He – p → ^{7}H + 2n + 2n

→ Analysis of three body correlations



NeuLAND status as of today

4 double-planes at

SAMURAI@RIKEN:

participation in several beam times within next years together with NEBULA,

starting October 2015.

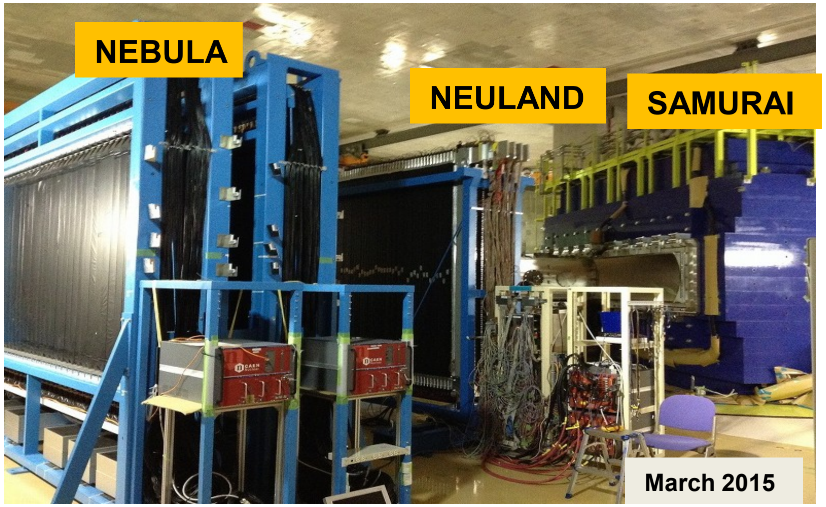
construction ongoing @ GSI:

- modular design →

    continuous production and commissioning

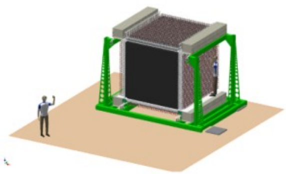
- quality control procedures established:

    e.g. via cosmic ray measurements



construction by a collaborative consortium of the University groups of **Darmstadt, Frankfurt, Köln, GSI RB team**

double-plane Nr. 8 under construction → 25% of NeuLAND existing!



Example NeuLAND Response for ^{136}Sn

NeuLAND detector parameters:

- full active detector using RP/BC408
- face sice 250x250 cm^2
- active depth 300 cm
- 3000 scintillator bars
- 6000 PM / readout channels
- 32 tons

GDR

E_m = 15.5 MeV,

Γ = 4 MeV

100% TRK SR

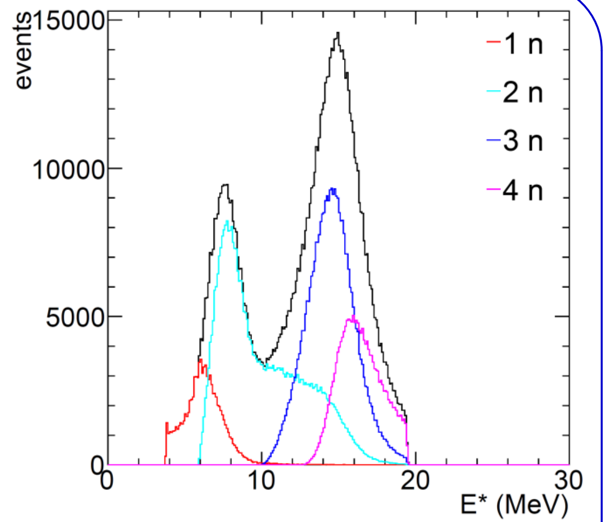
PDR

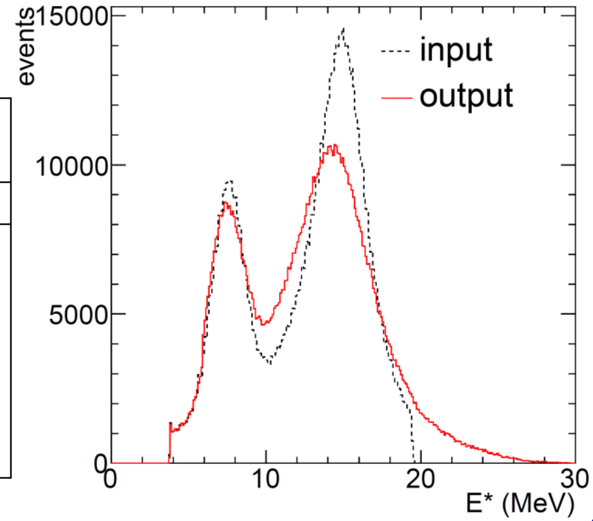
E_m = 8 MeV

σ = 1 MeV

5% TRK SR

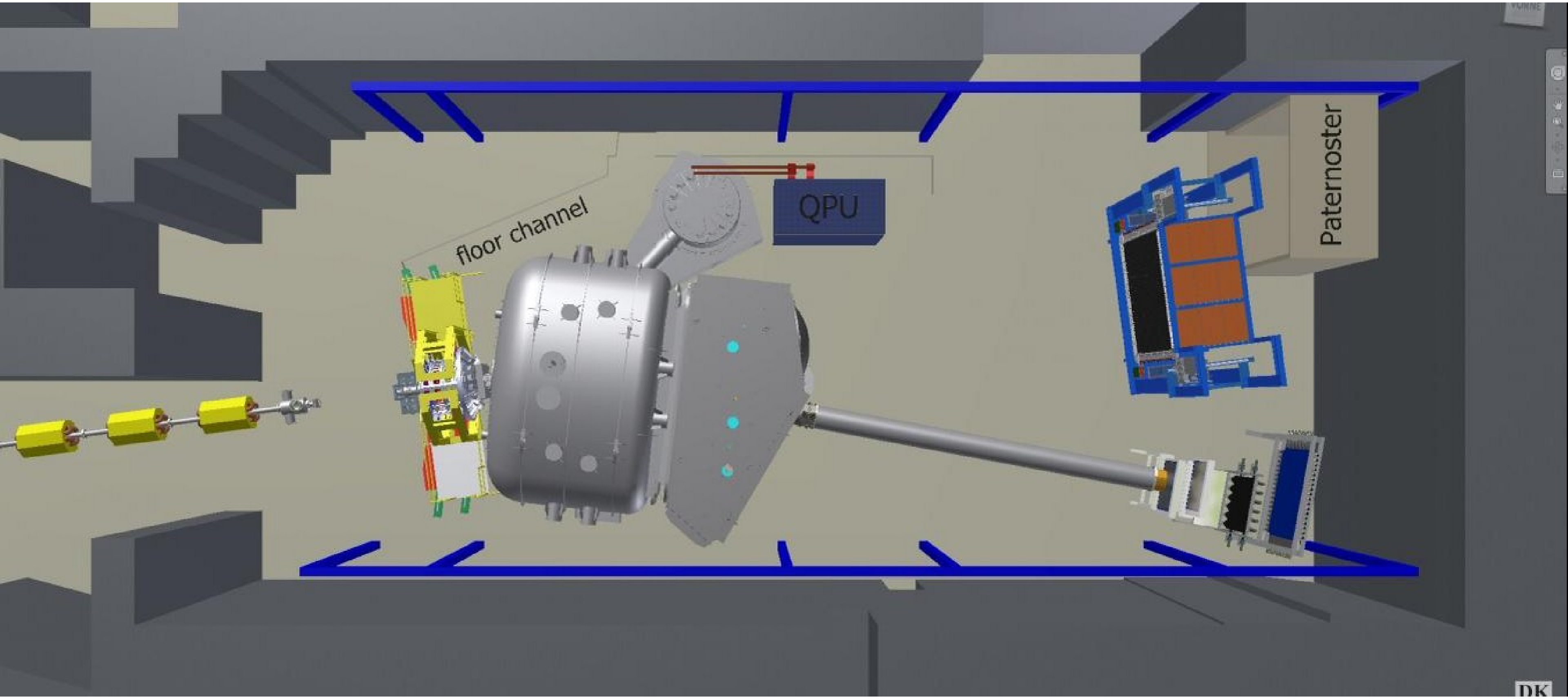
	%	1000 MeV generated 1n	2n	3n	4n	5n
detected	1n	**89**	12	1	0	0
detected	2n	7	**78**	23	3	0
detected	3n	0	8	**63**	26	5
detected	4n	0	0	12	**63**	40
detected	5n	0	0	0	7	**46**
detected	6n	0	0	0	0	8



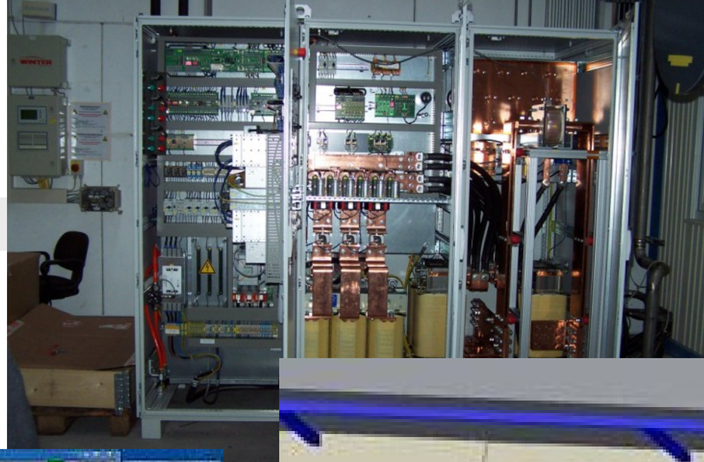


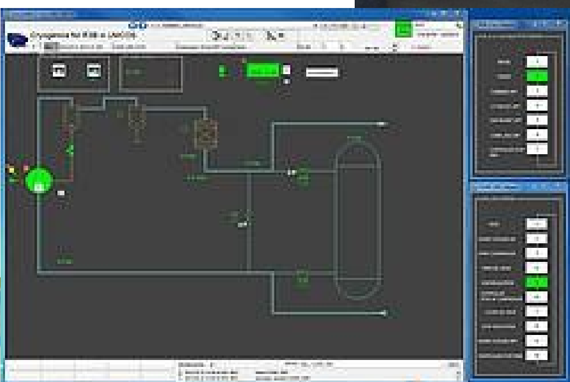
GLAD @ Cave-C

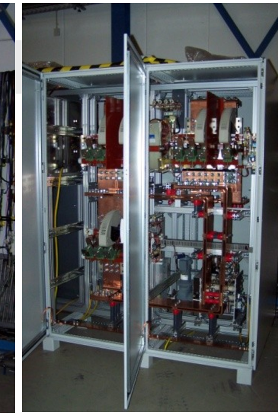
Short Spec.:
$B\ell$ = 4.8 Tm
Opening angle: 80 mrad
20 mT field @ target position

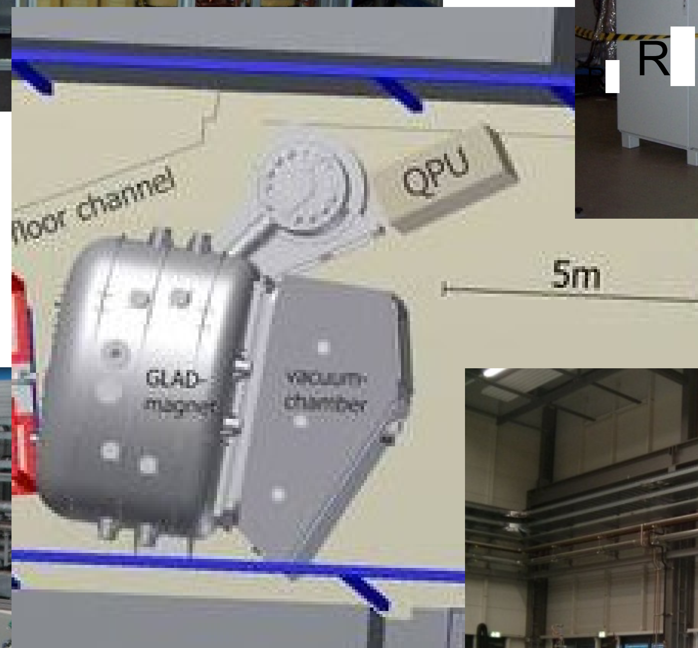


2013/14









… GLAD Infrastructure @ GSI

The magnet is ready
… for travel

- Production
(and revision) finalized.
- FAT passed 23.9.2015
- Transport to GSI
  calendar week 43

➔Tightness test
➔Installation in Cave-C
➔Full system operation
  & quench training
➔„Test bench“ operation
➔Preparation for FAIR

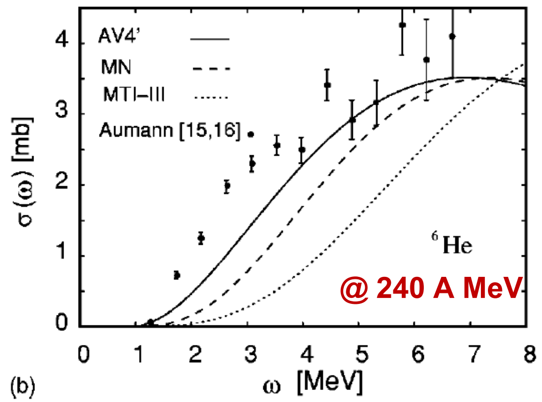
August 2015

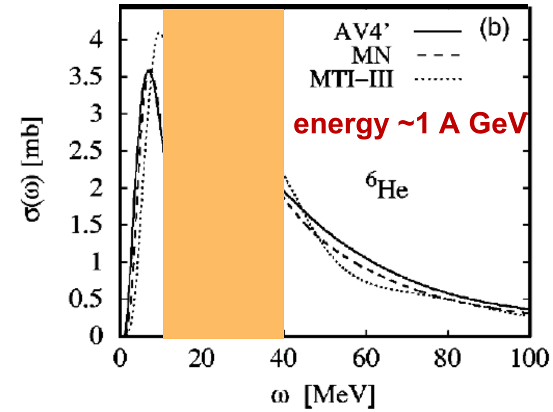
September 2015

Transport to GSI
October 2015
SATa Test Q1/2016
Installation Cave-C
Q2/2016
Operation ready
Q1 /2017

Dipole strength Distributions in heavy neutron-rich nuclei

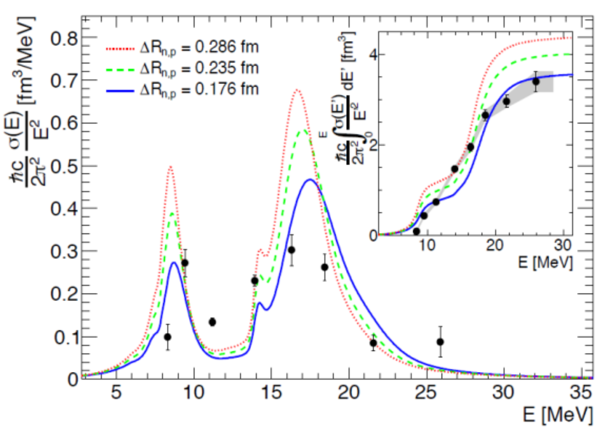
- core vs. neutron skins & halos → density / asymmetry





S. Bacca et al.
PRL **89** (2002) 052502
PRC **69** (2004) 057001

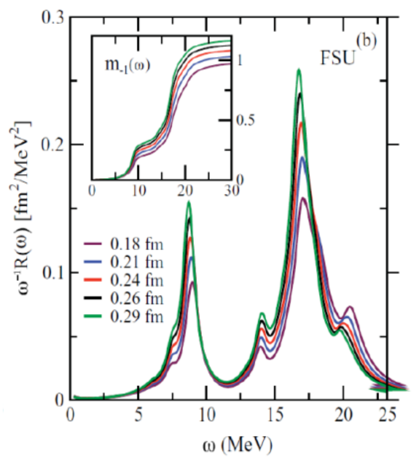
- access to EoS (e.g. neutron star) & low lying E1 strength (r-process)



$$\alpha_D = \frac{\hbar c}{2\pi^2}\int_0^\infty \frac{\sigma(E)}{E^2}dE$$

D. Rossi et al.
PRL **111** (2013) 242503

skin thickness ^{68}**Ni**
0.175(21) fm



Pb chain & N=126 isotones

~1 A GeV →
bare ions
Fragment identification

J. Piekarewicz, PRC **83** (2011) 034319

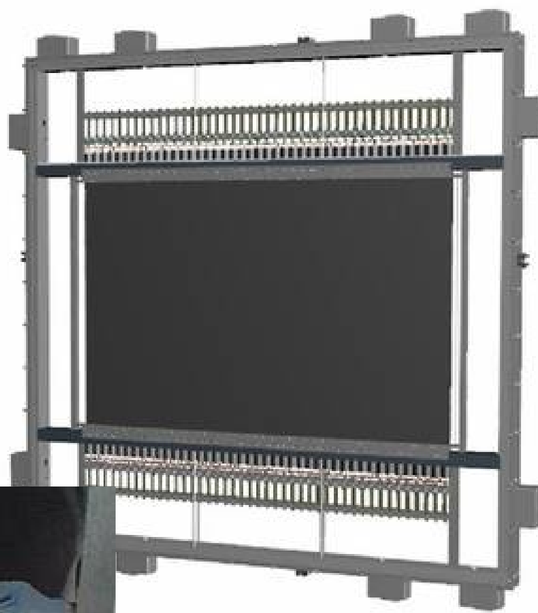
Fragment arm:
Time-of-flight detector prototyping

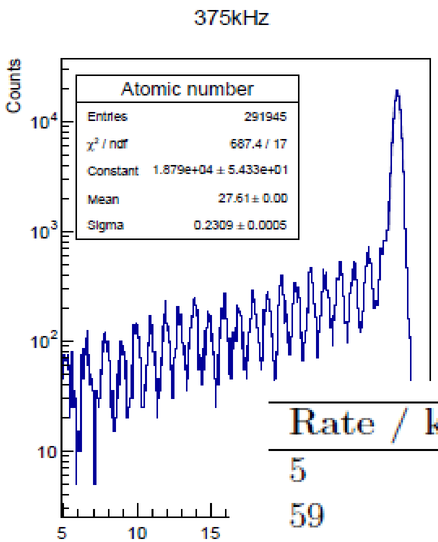
M. Heil

Performance goals:

- Time resolution σ_t/t = 2E-4
  (⇔ σ_t =20 ps for 20 m flight path at 1 *A*GeV)
- Energy resolution σ_E /E = 1%
- High-counting rate capabilities (~1 MHz)
- Large dynamic range (up to Pb-U).
- FPGA based TDC readout (ΔE via ToT Techniques)

Detector layout





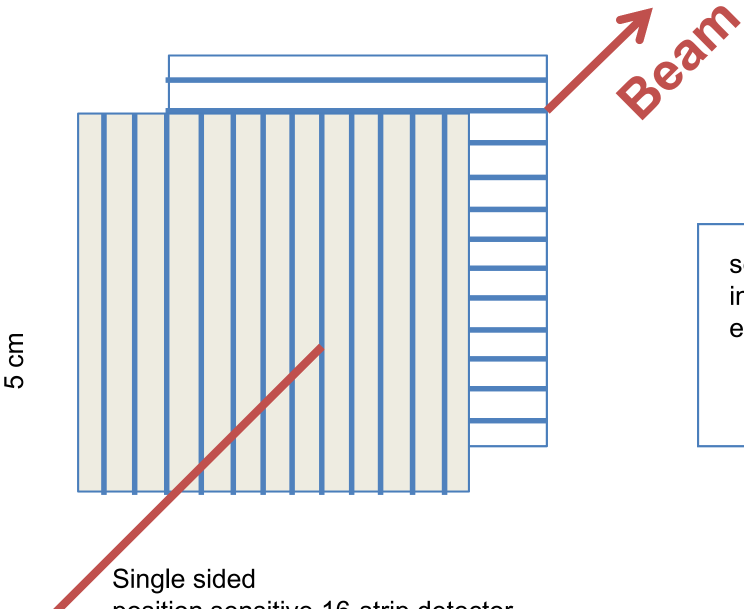
Excellent time and energy resolution at high rates

Rate / kHz	σ_t / ps	σ_t^{det} / ps
5	41	14
59	41	14
375	45	16
1000	64	23

Prototype studies @ Cave-C 08/2014 10/2014

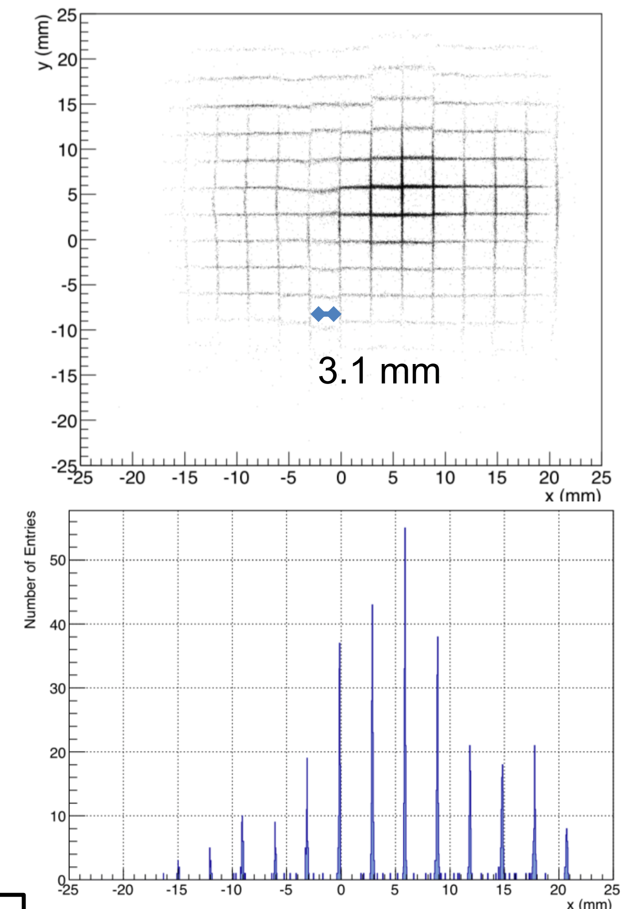
Beam tracking:
Si detector: in-beam position calibration

S. Paschalis



Single sided
position sensitive 16-strip detector
300 um thick
MPR-16 Mesytec preamp
FEBEX digitizer

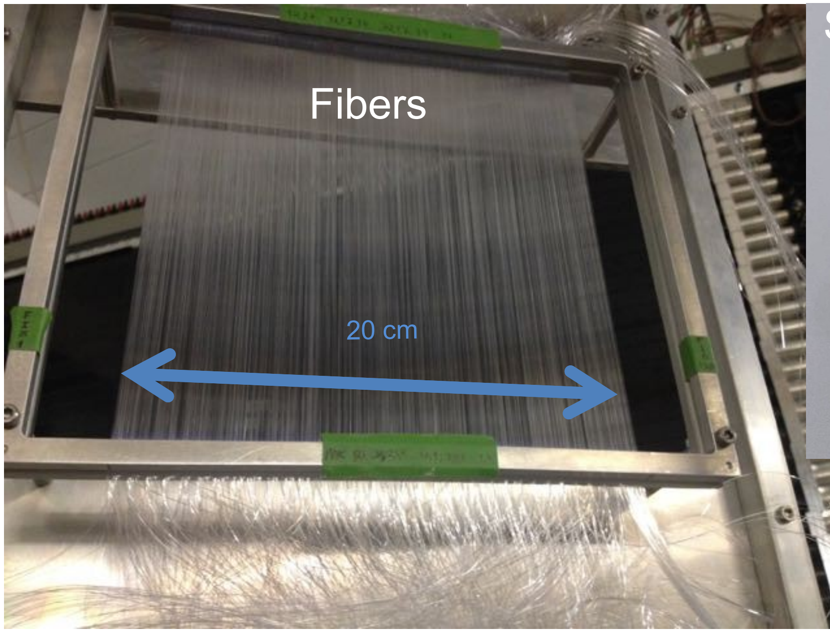
selecting
interstrip
events

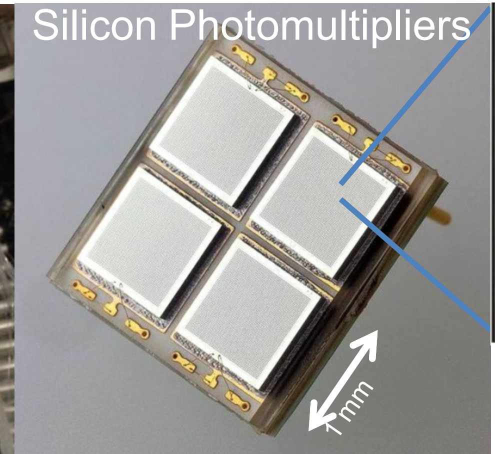


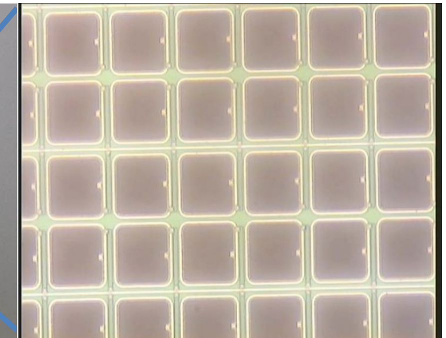
^{48}Ca @ 500MeV/u

demonstrates < 80 um resolution and enables online position self-calibration !!

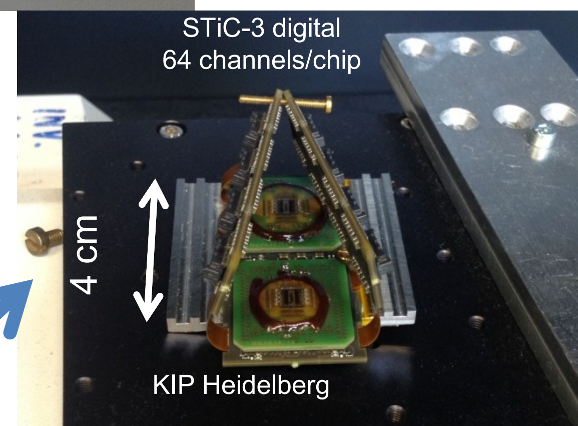
Fragment arm:
Plastic scintillating fiber detector







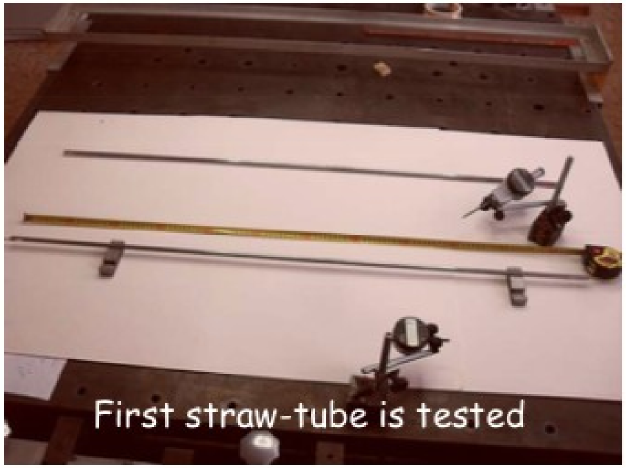
25 µm

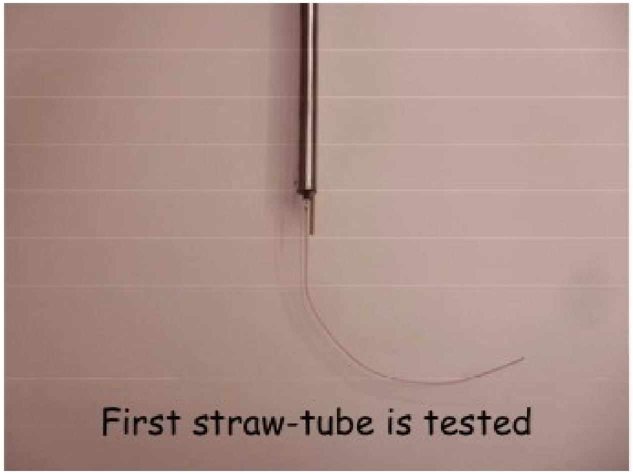


square fibers 0.2x0.2 mm^2
position resolution: 60 µm
material budget: X/X_0 ~ 0.05%
thousands of electronic channels

Application Specific Integrated Circuits (ASICs)

Proton arm:
Strawtube prototype detector construction





Technical Design Report for the R^{3}B In-beam Tracking Detectors

Just Approved !!

FAIR

Inti Lehmann, FAIR GmbH, Planckstr. 1, D-64291 Darmstadt, Germany

Authors of the
Technical Design Report for FAIR:
NUSTAR Tracking Detectors for R^{3}B

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30 July 2015

Approval of Technical Design Report

Dear colleagues,

We are happy to inform you that FAIR approves the Technical Design Report of the NUSTAR Tracking Detectors for R^{3}B, following the recommendation by the Expert Committee Experiments (ECE) on 24 July 2015. Please find attached comments by the ECE. We expect

Summary

- All major components for first experiments with the R^3B experiment are in production or get finalized.
- Particular system just leave the R&D phase.
- Integration work started and ongoing.
- First commissioning without beam 2016/17
- Beam tests of single detector components at different facilities including GSI.
- Beam tests with full experiment/system 2018-20

➔ Viable physics programme with restricted beam performance

Move to High energy Cave possible within ~1year.