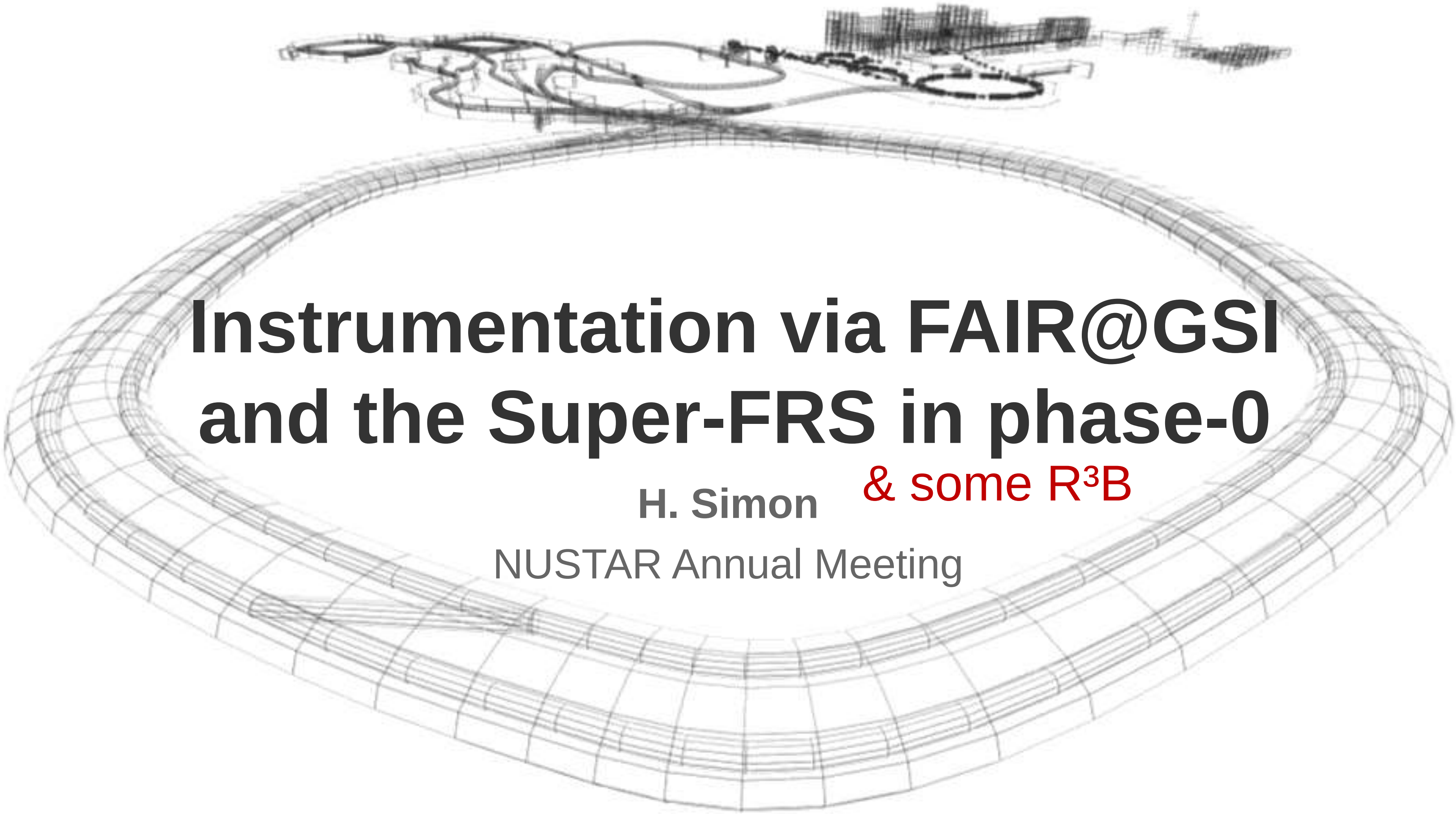
GSI Helmholtzzentrum für Schwerionenforschung GmbH



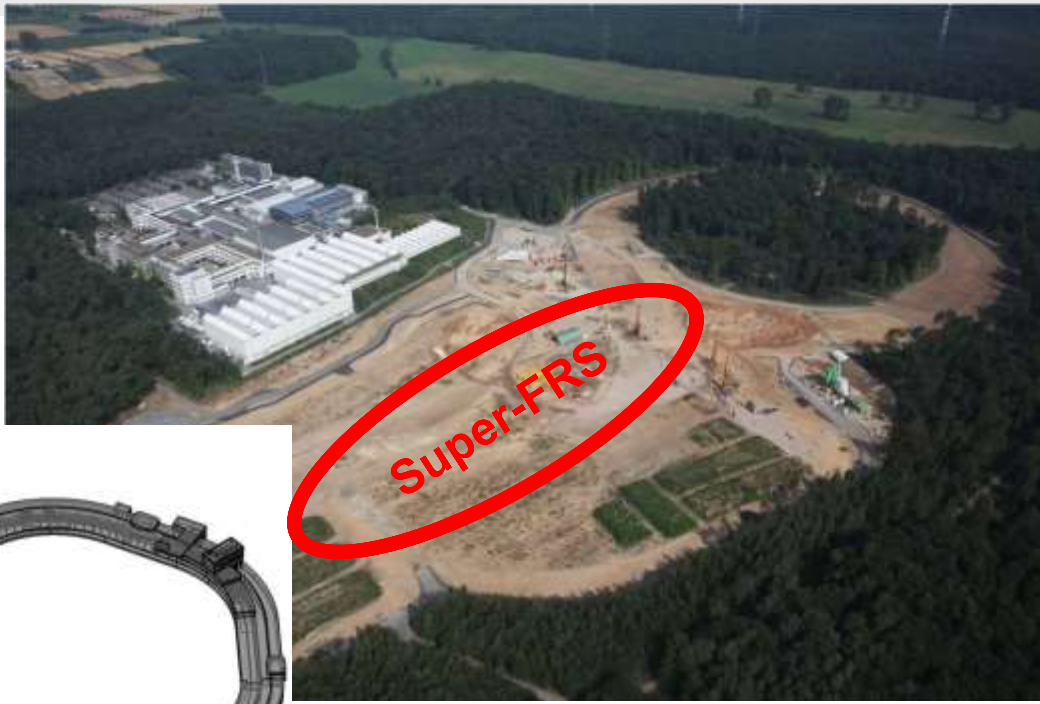
Instrumentation via FAIR@GSI and the Super-FRS in phase-0

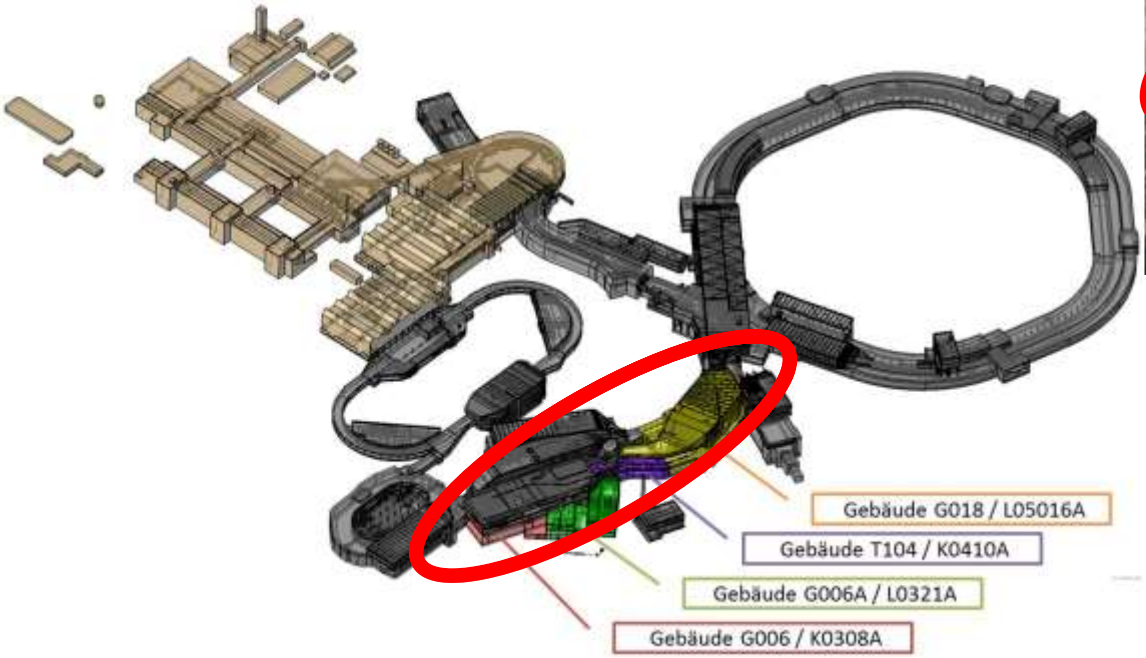
& some R³B

H. Simon

NUSTAR Annual Meeting

Stepping stone towards the facility





Outline from what we've seen this week

- The NUSTAR facilities are progressing!
  - main components are defined and mostly in purchasing process.

- NUSTAR experiments become available (now)
  - major components are being constructed.

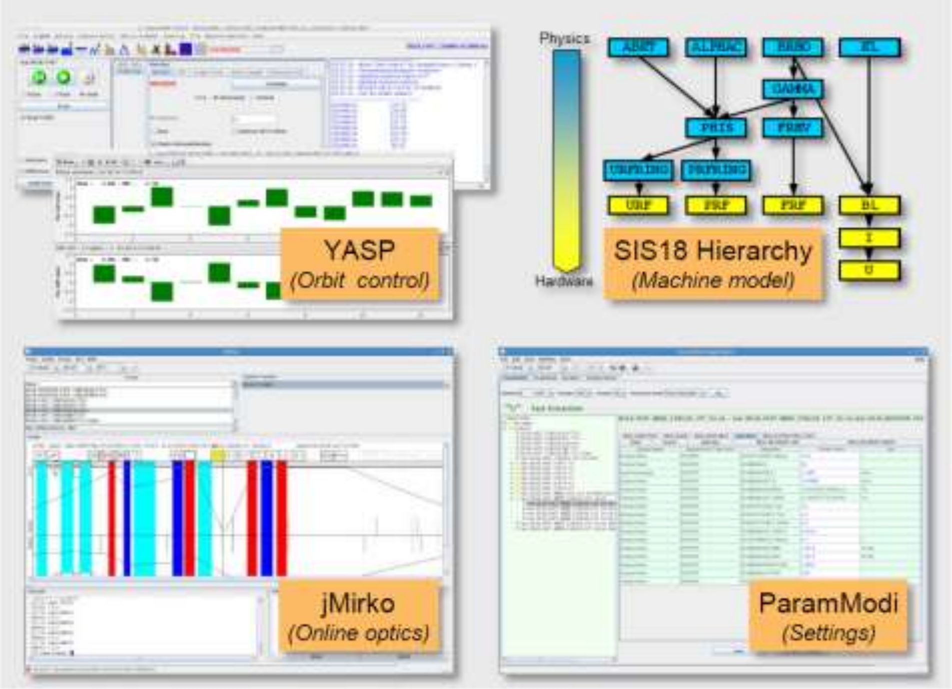
  ➔ Selected Examples

- The facilities @SIS are needed as: (2017+)
  - test bench,
  - for commissioning runs,
  - and viable experiments with already existing novel instrumentation. ➔Selected Examples @ Super-FRS

Controls are being refurbished

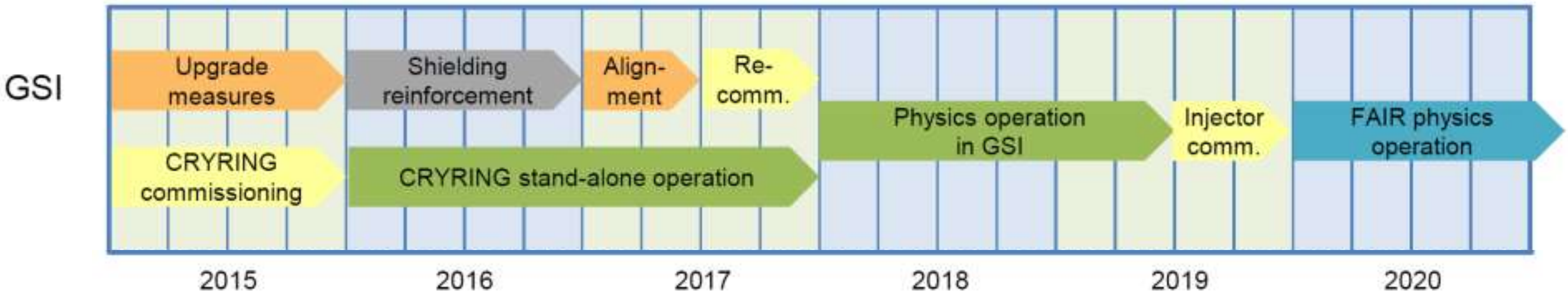
D. Ondreka

- Control system for FAIR
  - Completely new design
  - Collaboration with CERN
    - FESA framework for front-ends
    - LSA framework for settings management
    - Timing system (White Rabbit)
    - User Interfaces
- Prototype systems at SIS18
  - BI: BPMs, Screens
    - Routine use for orbit correction and steering
  - Settings: machine model, applications
    - Commissioning H=2 cavity
    - Resonance compensation
- Operational at CRYRING (2015)
  - Prototype of FAIR control system
  - FESA front-ends for
    - Magnet PCs, RF, HV, RFQ
    - BPMs, Trafos, Screens, Cups, Grids
  - Operating applications
  - Test bench for FAIR operation concepts

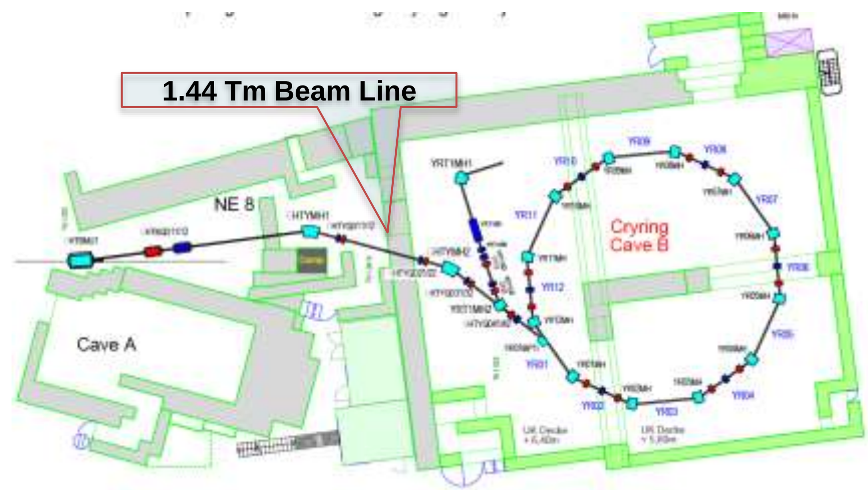


Test benches

D. Ondreka, F. Herfurth



12/2014



➔ Prepare e.g. for ESR operation in the future 2017+

➔ see Yuris talk

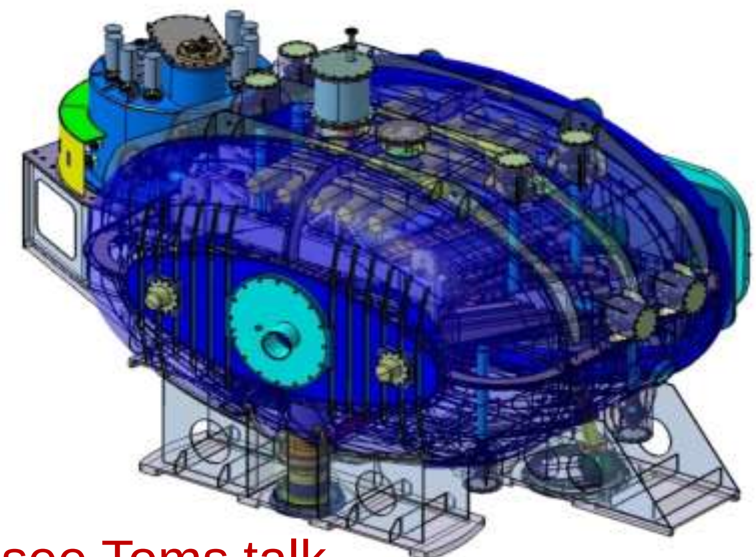
Large-acceptance superconducting dipole magnet GLAD → System study for FAIR

Magnet parameters:

- Large vertical gap ± 80 mrad
- High integrated field of 4.8 Tm
- Fringe field at the target position less than 20 mT
- Operational temperature 4.6 K
- The overall size of the conical cryostat: 3.5 m long, 3.8 m high and 7 m wide.

Challenging Magnet design:

- Collaboration CEA Saclay/GSI
- Tilted coils, ironless design
- Correction Coils
- Lightweight design
- Indirect coil cooling
- Thermosyphon cryo distribution



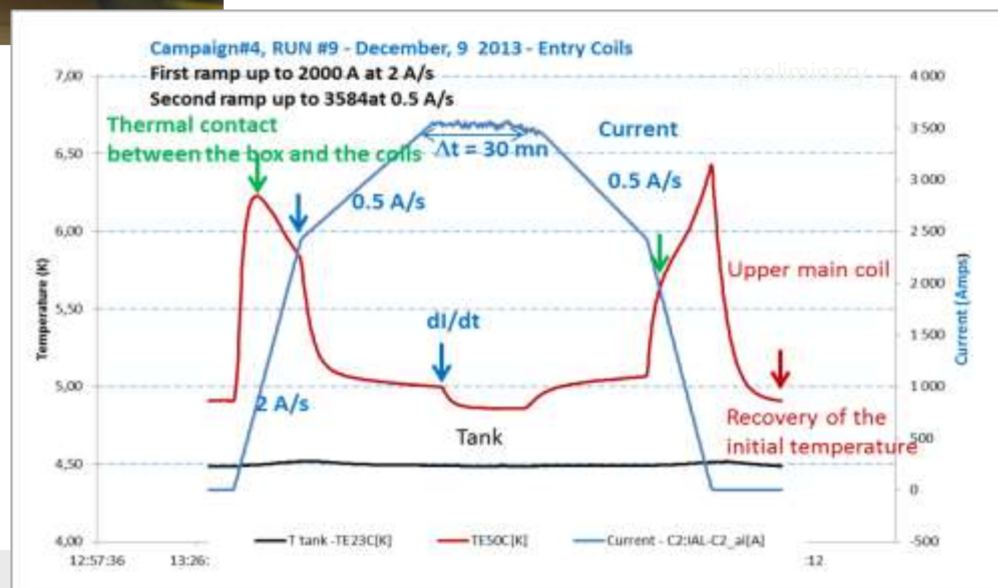
→ see Toms talk

GLAD magnet system Status

@CEA Saclay

- Magnet cold mass ready and tested, December 2013.
- Integration into cryostat mostly done.
- Delivery to GSI expected Q2/2015.

- Cryoplant has been installed **@ GSI**
  Cryolines (33m) on site
  Compressor
  (+ Controls) test Q2/2014.
  Cryoplant operation Q4/2014
  Infastructure installation Q4/2014



GLAD cryosystem
(test bench @ test stand & Fair component)

T. Hackler

- Refurbished TCF50 cryo plant from DESY (new compressor)
- Test stand for R³B/GLAD 2014-
- Later use for Plasma physics

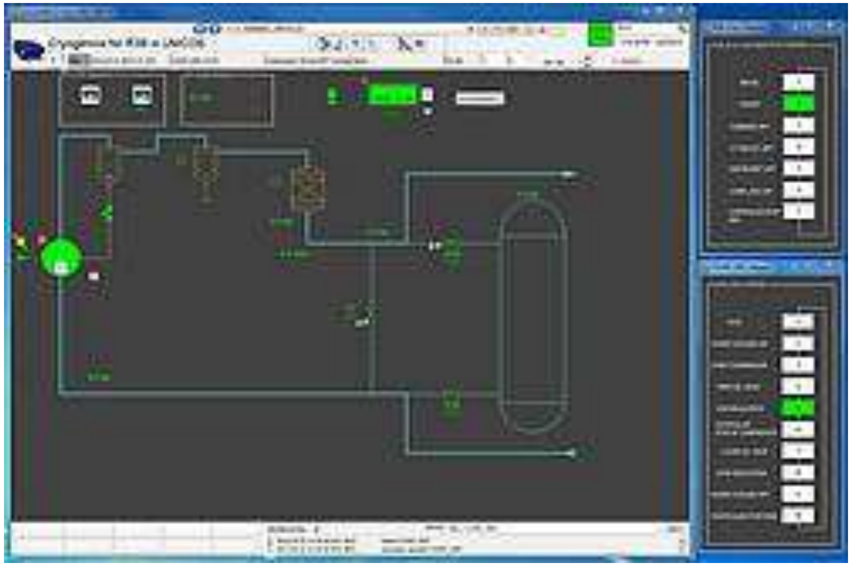
- Prototype for FAIR Cryo plants:
  - UNICOS controls
  - Instrumentation
  - PLC

GLAD Cryo controls (UNICOS)

C. Betz/E. Momper

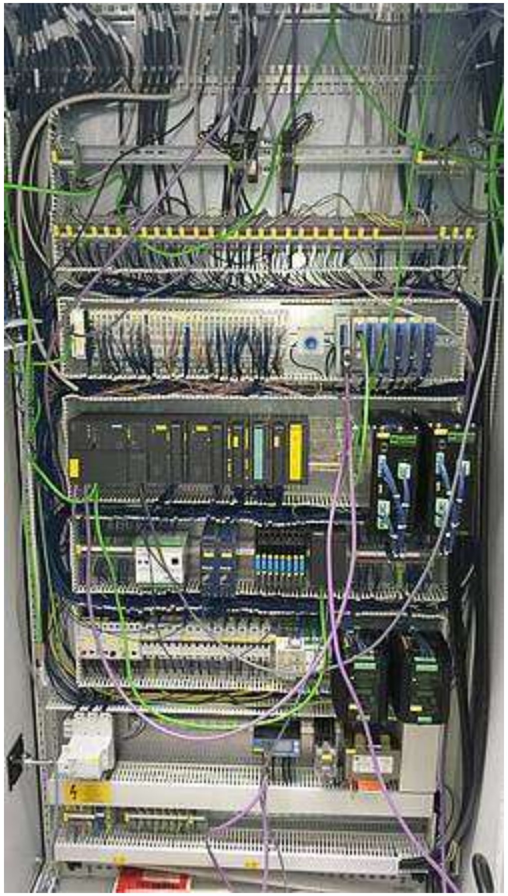
- UNICOS sample system for controlling the GLAD cryo system installed: April 2014
- The compressor of the R3B cryo plant with the new UNICOS control system successfully tested: June 2014
- **Liquid He produced first time (after 25y): December 2014**

Further tests just running in the Cave ...



Sample GUI UNICOS controls GLAD cryosystem.

UNICOS control unit.



GLAD power supply ACU controls

H. Welker, CSCO

GSI Helmholtzzentrum für Schwerionenforschung GmbH

Document Title
Power Converter System for R3B-GLAD Magnet

Document Name
F-DS-PC-04e Power Converters

Date
2013-04-16

Abstract

Document Title: Power Converter System for R3B-GLAD Magnet

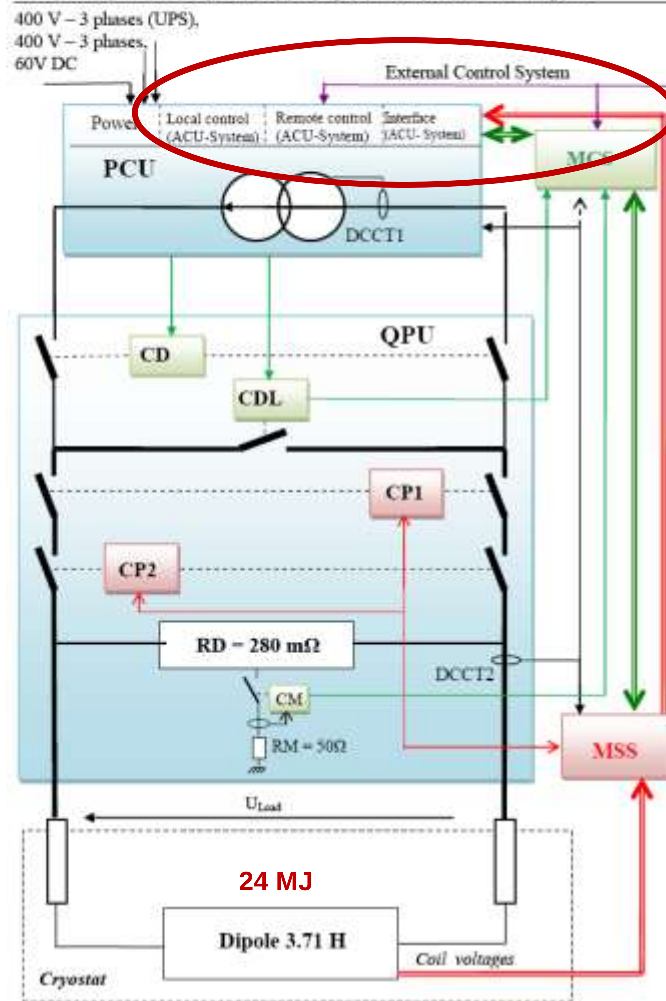
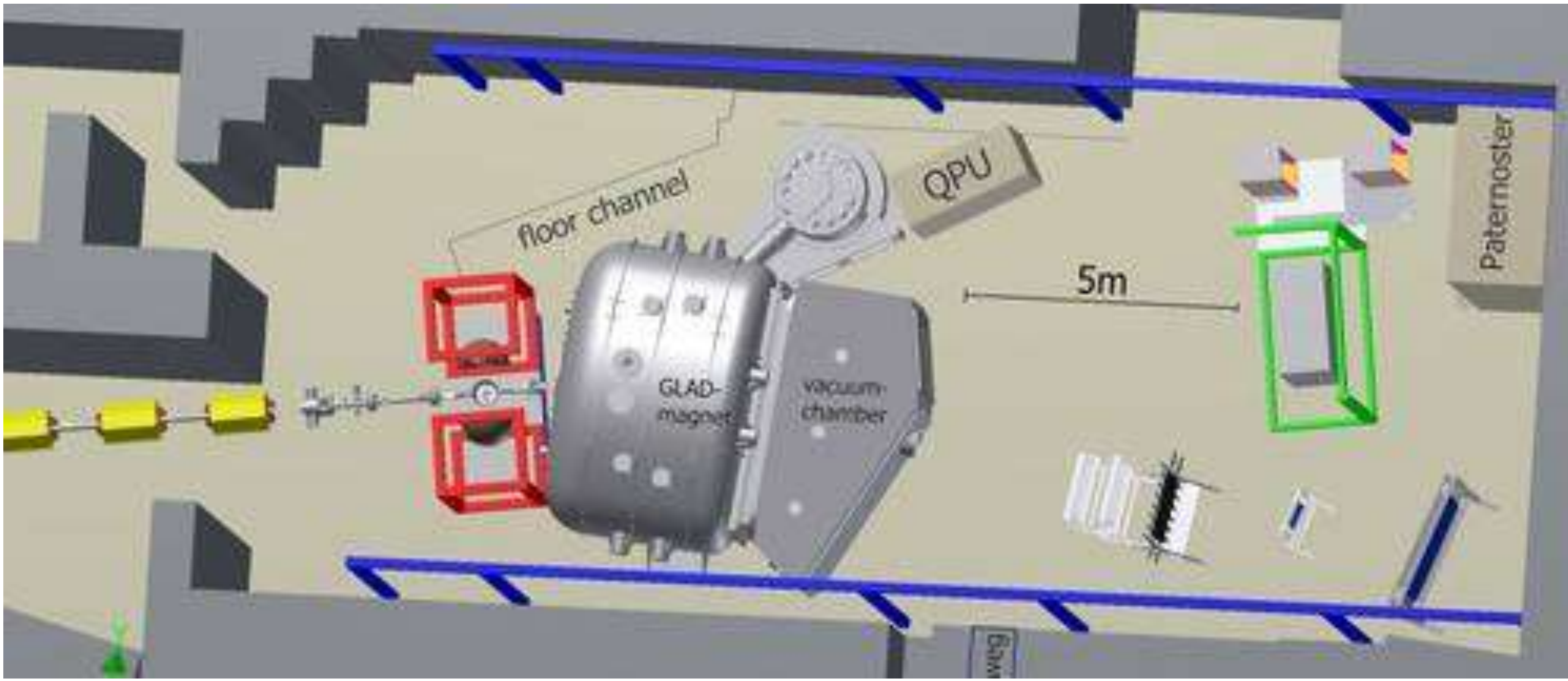


Figure 4 power converter system overview

Currently under test @ Cave-C

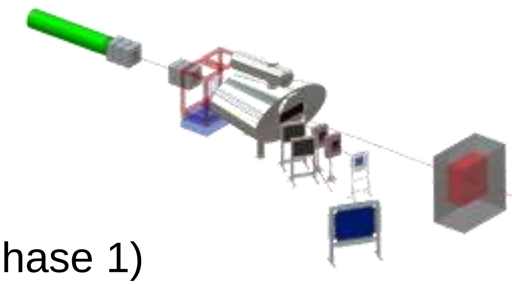
First Ramp implementation in ACU (Frontend)

GLAD @ Cave-C


floor channel
QPU
Paternoster
5m
GLAD-
magnet
vacuum-
chamber

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 (phase 1)



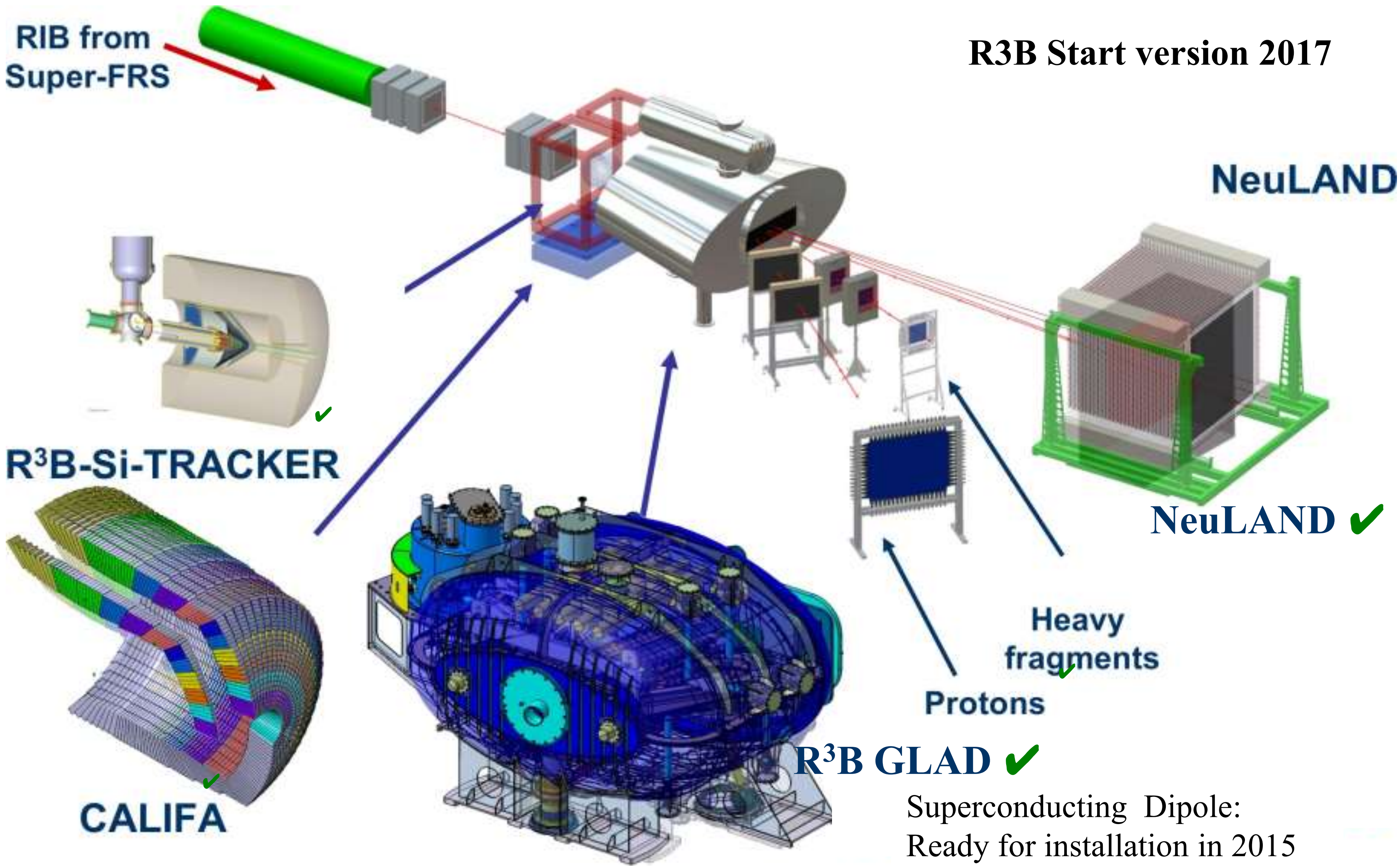
Experiments will make use of uniqueness of R³B:

- 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)

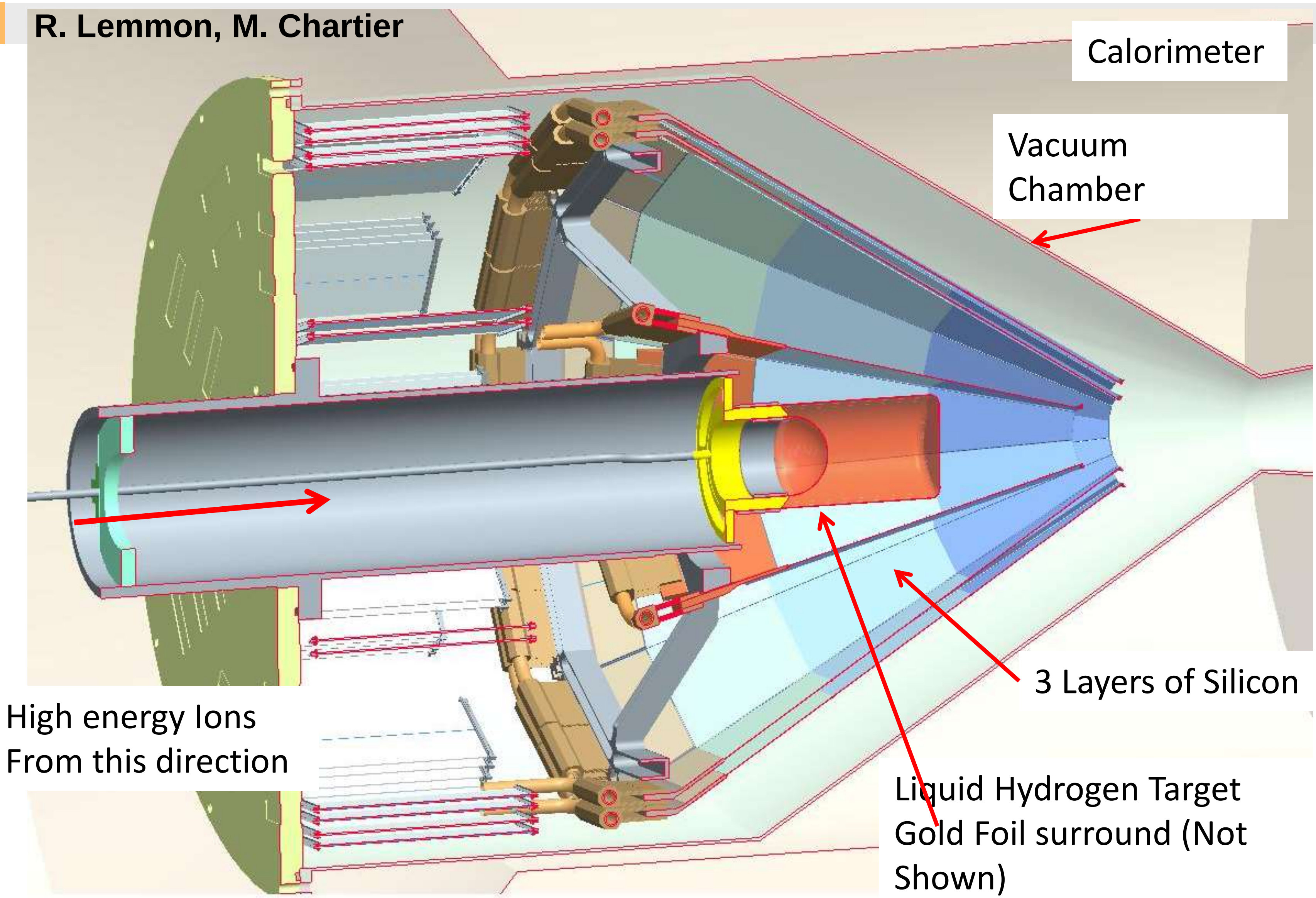
Reactions with Relativistic Radioactive Beams R³B



Superconducting Dipole:
Ready for installation in 2015
Construction by CEA Saclay

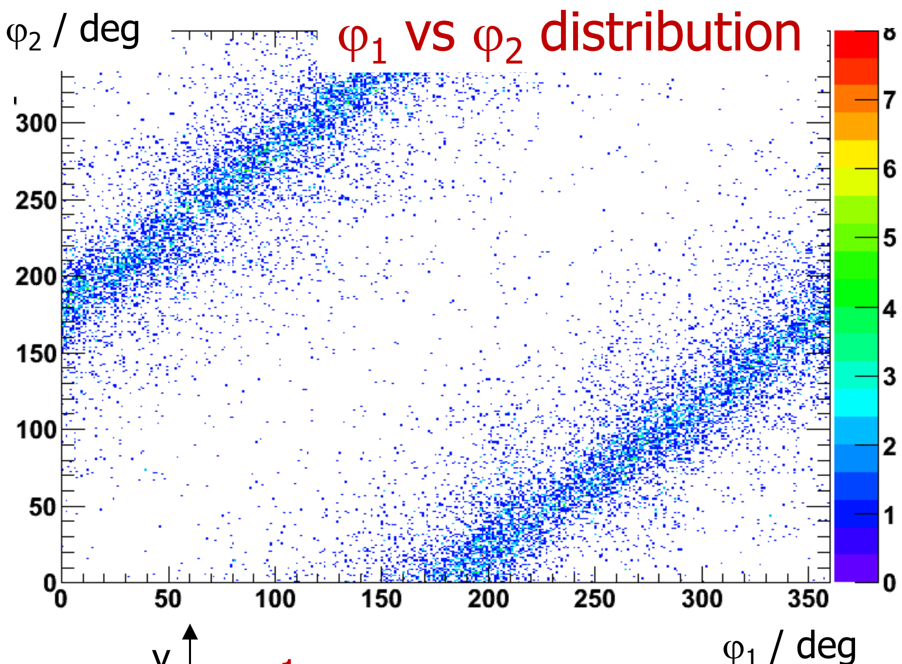
R3B Si Tracker

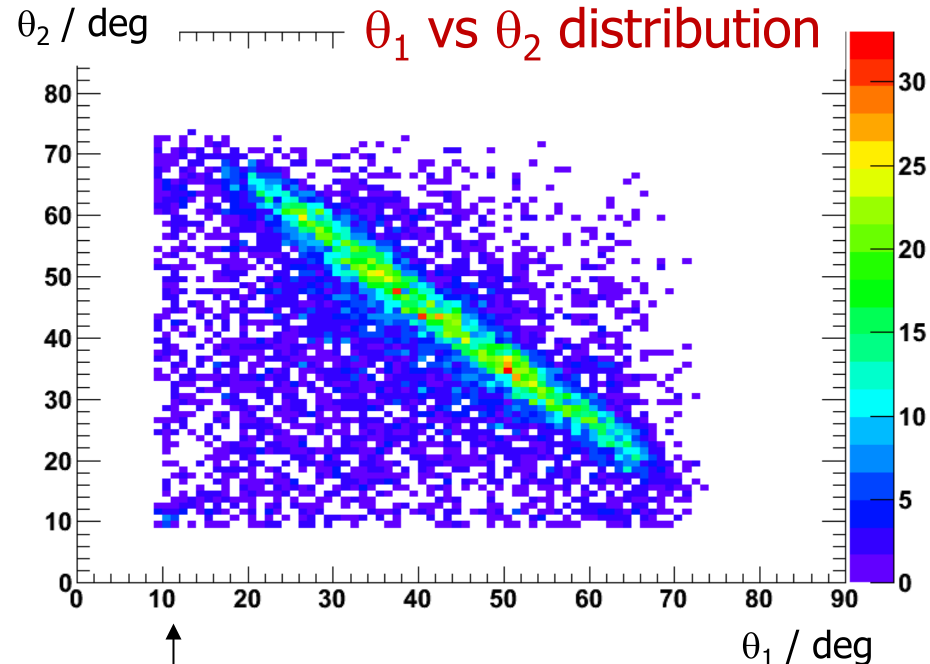
R. Lemmon, M. Chartier

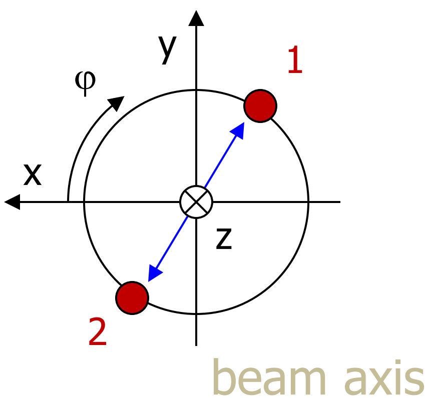


Target Recoil Detection

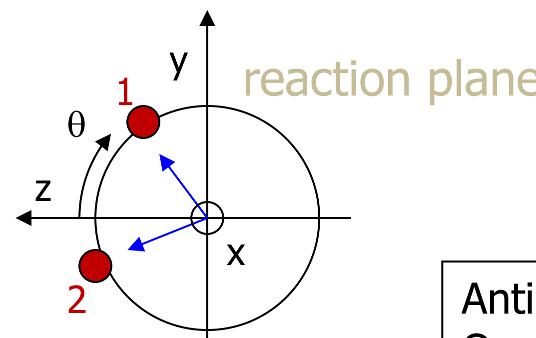
Data: F. Wamers $^{17}Ne(p,2p)$ @ 500MeV/u, CH_2







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



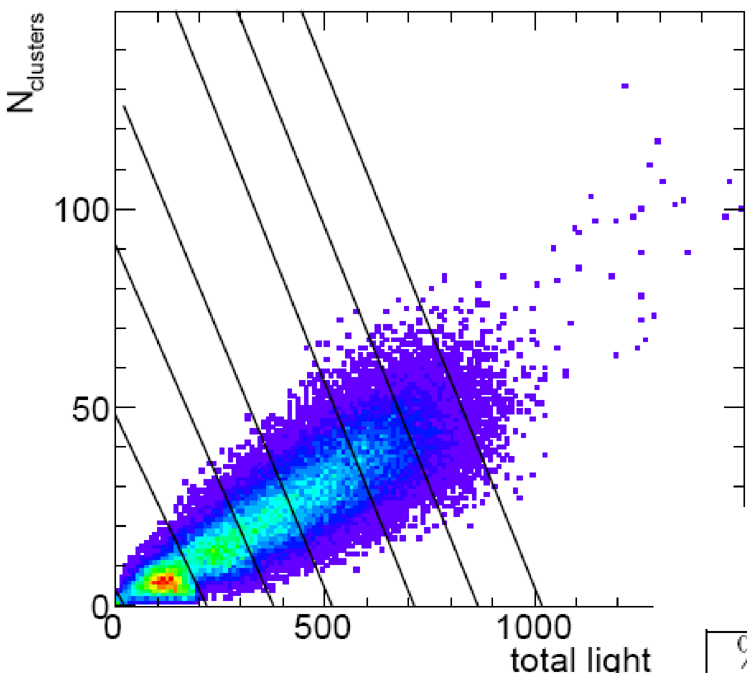
Anti-correl. in θ:
Opening angle ≈ 83°

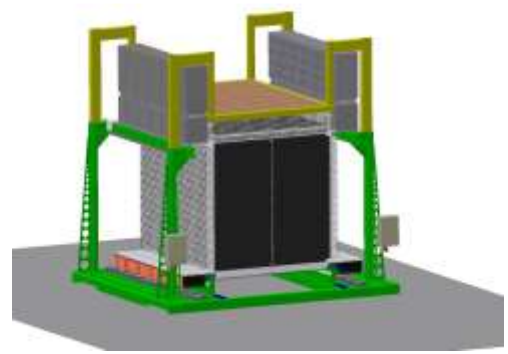
➔ Clear signature for (p,2p) reactions

Novel Neutron Detector: NeuLAND

K. Boretzky

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





Previously < 50%

Previously <5% !

		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

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]

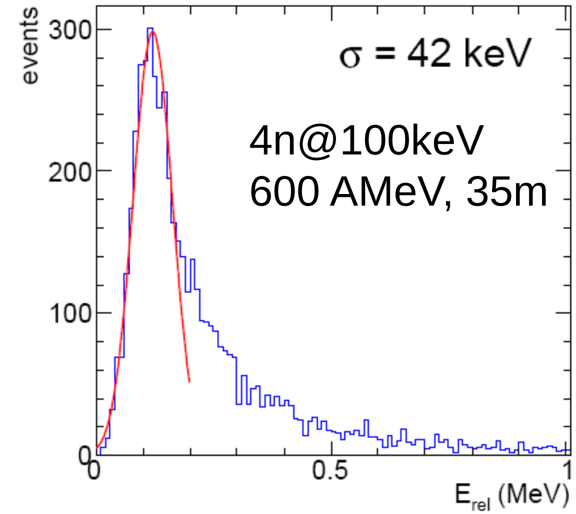
Core +4n (HFB)

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

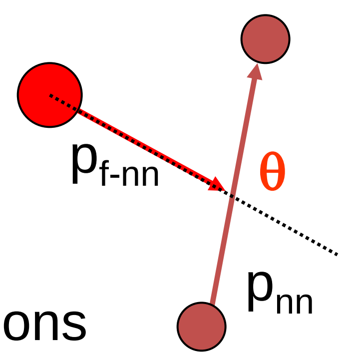


NeuLAND Simul.

- t + 2n + 2n

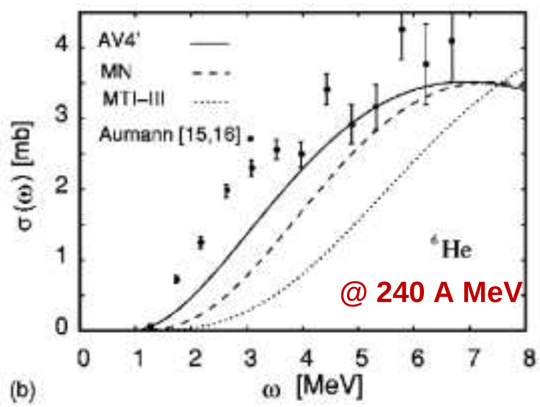
^{11}Li - α → ^{7}H + 2n + 2n
^{8}**He – p** → ^{7}**H + 2n + 2n**

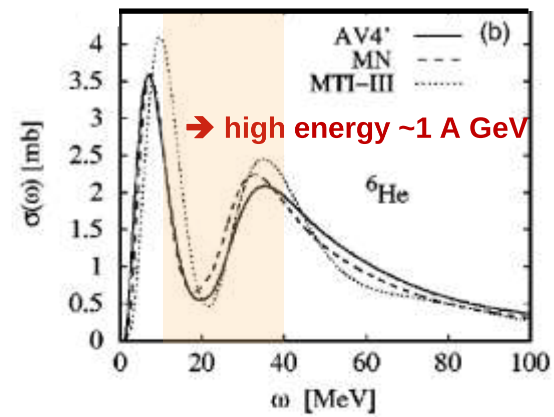
➔ Analysis of three body correlations



Dipole strength Distributions in heavy neutron-rich nuclei

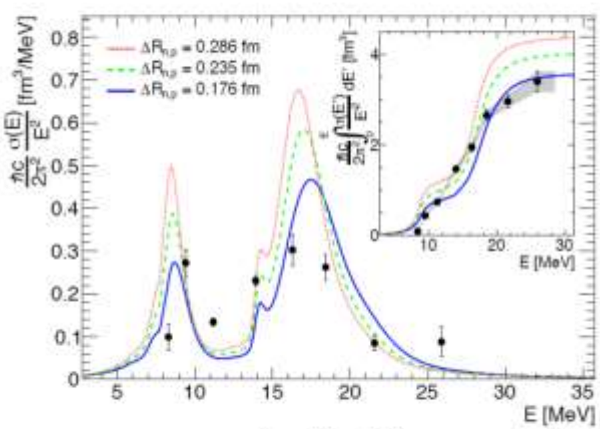
- core vs. neutron skins & halos → density / asymmetry





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

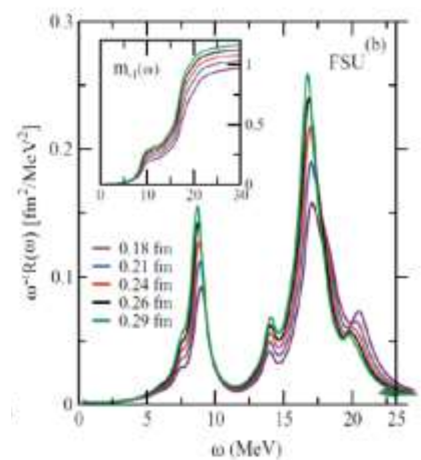
- access to EoS (e.g. neutron star) & low lying E1 strength (r-process)



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

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

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



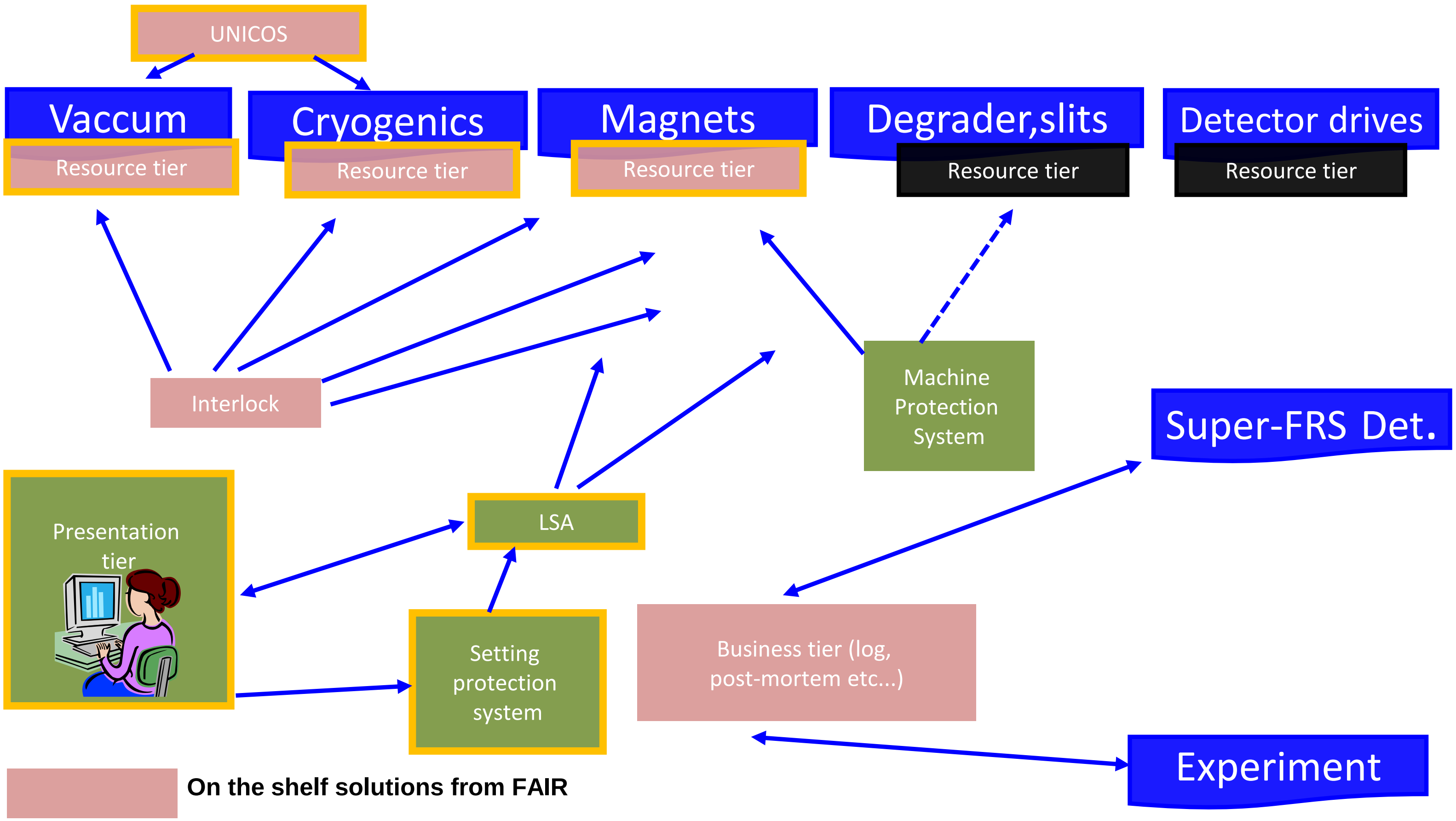
Pb chain & N=126 isotones

~1 A GeV →
bare ions
Fragment identification

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

FAIR controls as seen from Super-FRS

S. Pietri



On the shelf solutions from FAIR

Specific development/implementation for Super-FRS

Concept Will be tested at FRS in 2017/18 (or other NUSTAR exp.)

Some Instances are specific

S. Pietri

- LSA : setting management system, requires physics model of the machine, interface from operator to hardware
(FRS similar to Super-FRS)

- Setting Protection System : intercept dangerous settings before being passed to LSA, requires physic modeling
(FRS similar to Super-FRS)

- UNICOS : industrial solution for FAIR vacuum and cryogenics control ➔ specific adaptation

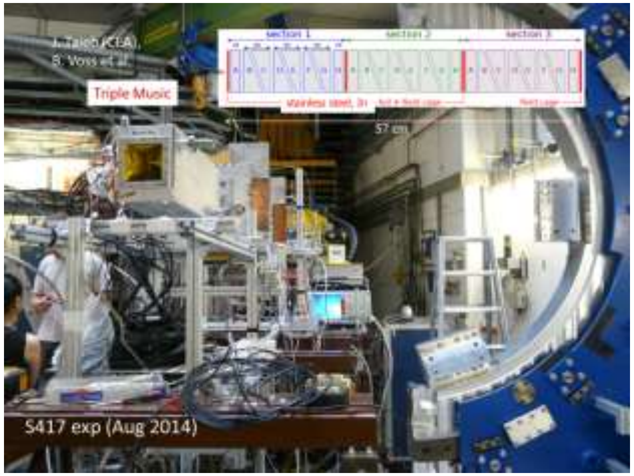
- Interlock : allows or forbids beam in part of the facility depending on hardware status ← conditions, scenarios ➔ model ?

- Machine Protection System : fast beam interruption system to avoid damage on the machine in case of beam loss due to hardware failure ← conditions, scenarios ➔ model ?

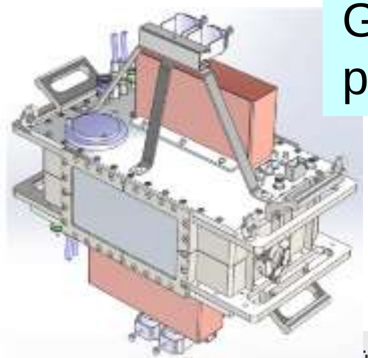
Beam Diagnostics

C. Nociforo, RBEE, RBDL

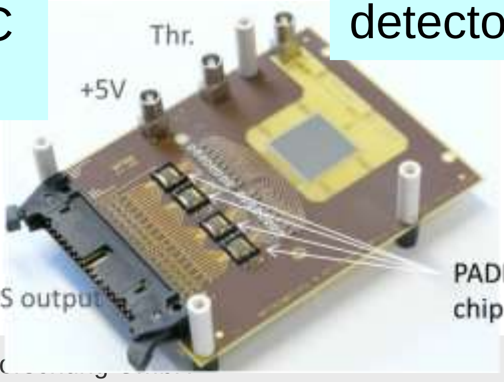
- Full isotope identification (x, y, x', y', DE and TOF)
- Operation modes: fast- and slow-extracted beams
- Special devices (slits, degrader, secondary target, ...)
- Controls → machine safety
- DAQ (in-kind GSI / Sweden)
- Various detector systems
  - ➢ GEM-TPC (Finnish in-kind) Test @ GSI 10/2014
  - ➢ SEM-GRID & ladder system (Finnish in-kind) “
  - ➢ Silicon detectors (EoI Russia) Test @ GSI 08/2014
  - ➢ Diamond detectors (EoI Finland) “
  - ➢ MUSIC detectors (EoI Finland) Test @ GSI 10/2014
- Various test beam-times at FRS/Cave C

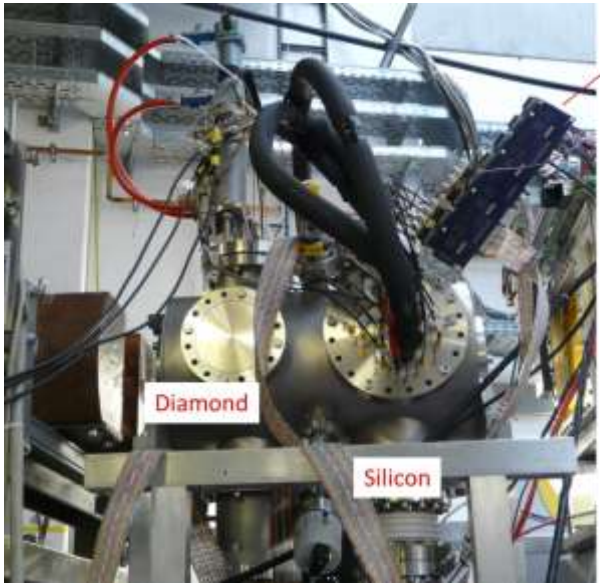


GEM TPC prototype



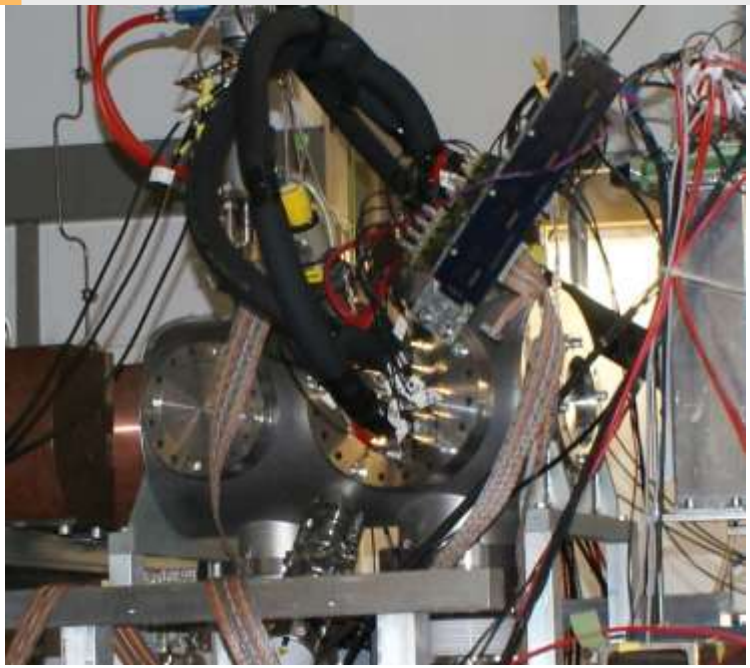
Diamond strip detector

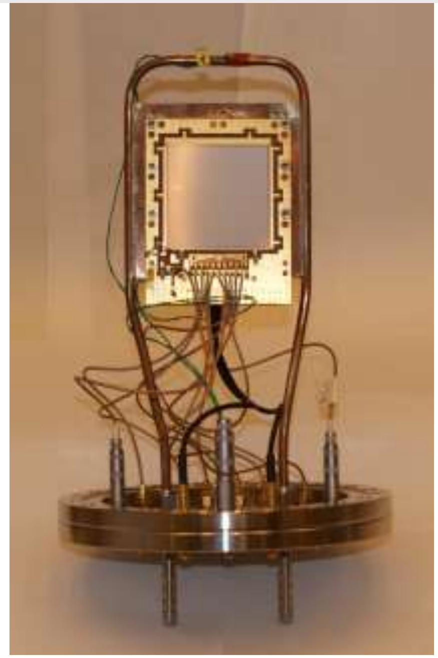


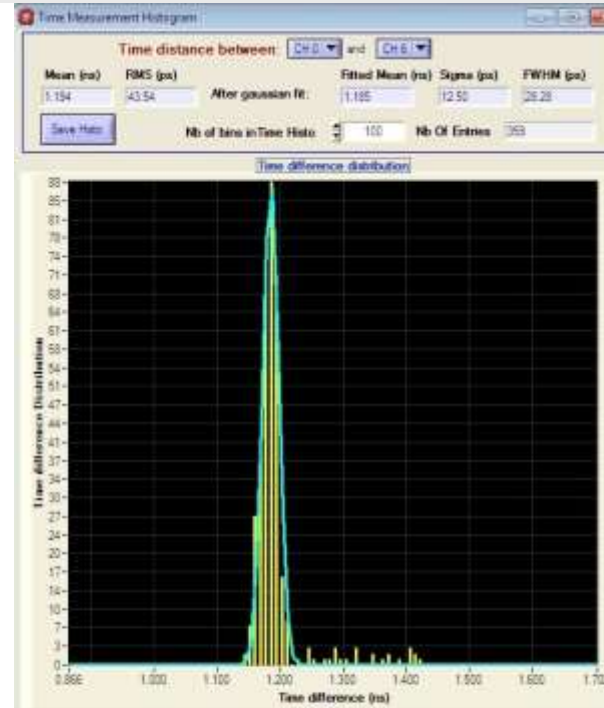


Si detectors for Super-FRS TOF diagnostics

V. Eremin, RBDL







- Two beam tests at GSI in 2012 with ^{238}U@370 MeV/u and ^{197}Au@750 MeV/u
- Beam test in JINR in 2014, Dubna with ^{40}Ar@40 MeV/u
- Beam test at GSI in August 2014 with ^{197}Au@1 GeV/u

- Full-size strip detectors tested
- Low and high intensity irradiation
- Heavy irradiation with a dose equivalent up to 1-2 years of Super-FRS operation
- Functionality is confirmed
- TOF resolution up to 13 ps (σ), required 50 ps

Potential In-Kind contribution of PTI, St. Petersburg, Russia

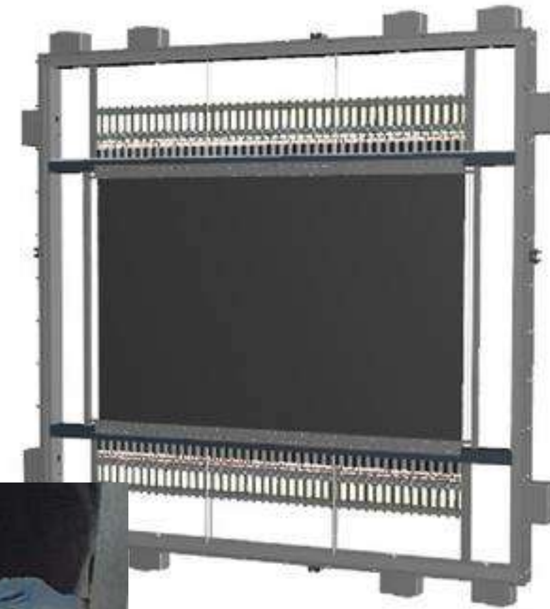
R³B: Time-of-flight detector prototyping

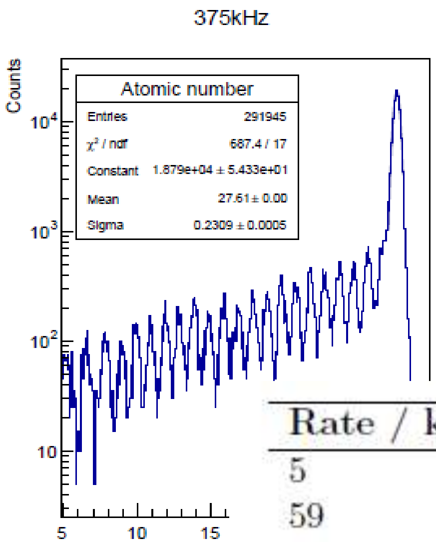
M. Heil, RBEE

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)

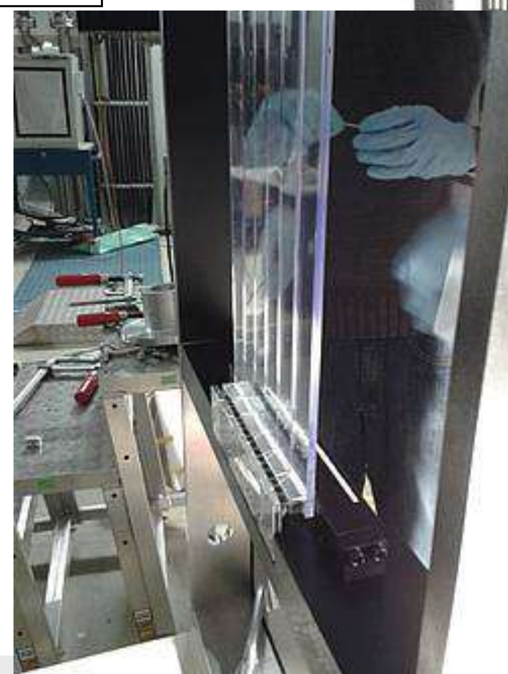
Detector layout





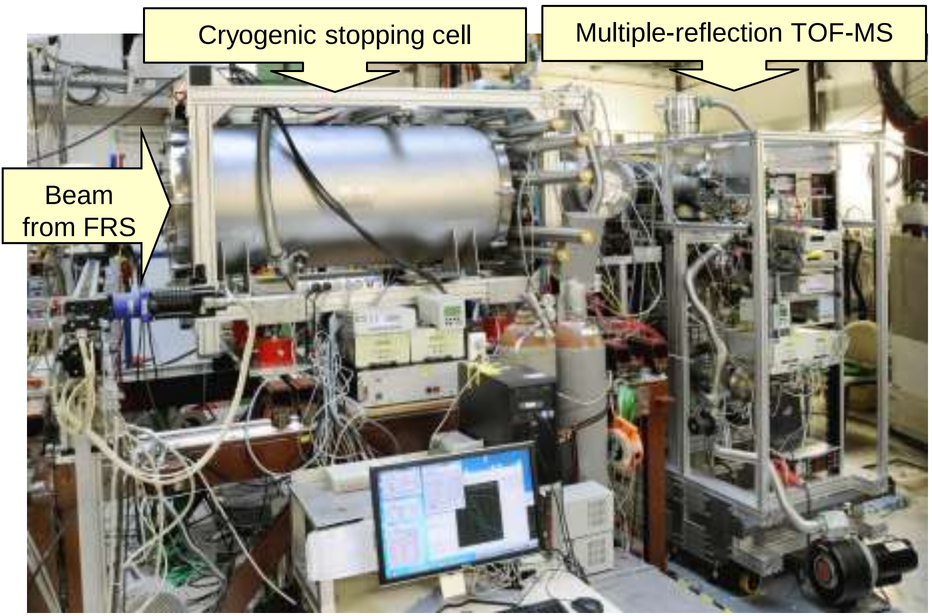
Excellent time and energy resolution at high rates

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

Stopping cell for the LEB of the Super-FRS



Successfull on-line test of the **prototype** of the cryogenic stopping cell at the FRS Ion Catcher 2011/2012

Excellent performance achieved:

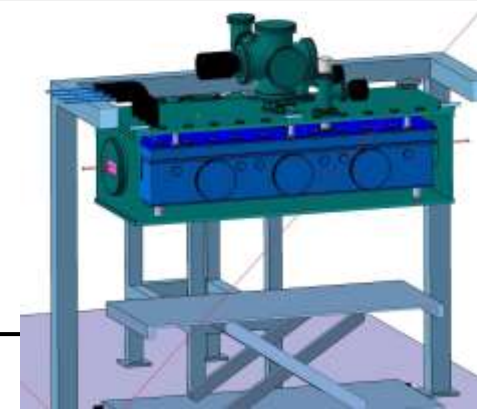
Stopping gas areal density: 5 mg/cm^2
Extraction efficiency: 50%
Extraction times: 25 ms

Test of rate capability
October 2014

Collaboration

- Specifications (PSP 2.4.11.2.x) and contract with Finland in preparation

- TDR (PSP 1.2.1.2) in preparation (to be submitted **2015**)
  Design is based on novel concept with vertical ion extraction:
  - Enables unprecedented rate capability
    and areal density (20 to 40 mg/cm^2)
  - Removes performance bottleneck of present stopping cells



Summary Instrumentation

- Several Components come already online 2015/2016 partly / prototypes / first of series prototypes / fully

➔ Selected Examples

➔ Tests are needed
(@ GSI or other facilities)

- The facilities @SIS are needed as: (2017+)
  - test bench,
  - for commissioning runs,
  - and viable experiments with already existing novel instrumentation.

➔Selected Examples @ Super-FRS

The Project - extended

Super-FRS	RIB production and identification
DESPEC	γ-, β-, α-, p-, n-decay spectroscopy
HISPEC	in-beam □ spectroscopy at low/intermediate energy
ILIMA	masses and lifetimes of nuclei in ground and isomeric states
LASPEC	Laser spectroscopy
MATS	in-trap mass measurements and decay studies
R^{3}B	kinematically complete reactions at high beam energy
ELISE	elastic, inelastic, and quasi-free e–A scattering
EXL	light-ion scattering reactions in inverse kinematics
Super-FRS physics	high-resolution spectrometer experiment
Superheavy elements	synthesis, nuclear structure, atomic physics, chemistry experiments with elements Z ≥ 104

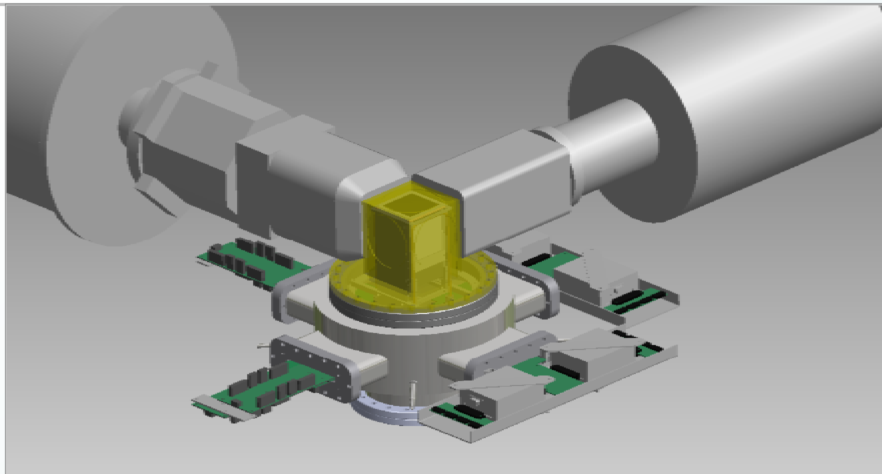
The Approach

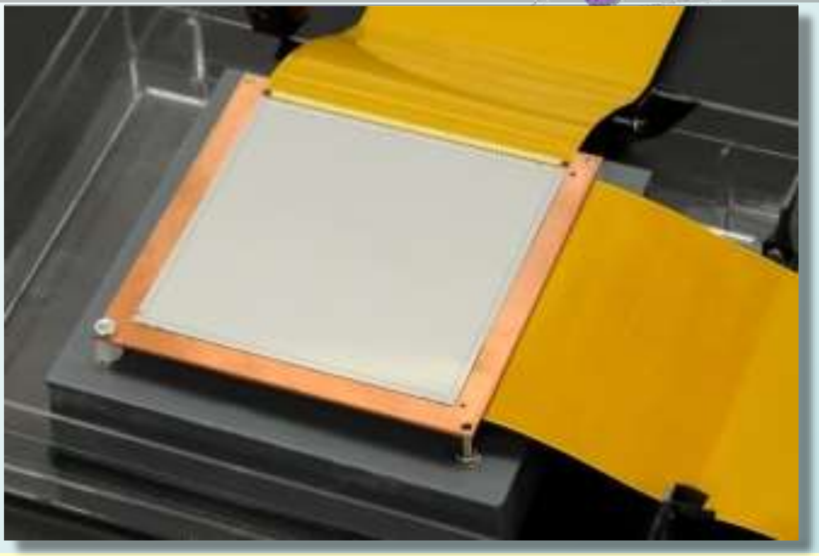
Complementary measurements leading to consistent answers

Mobile Decay Spectroscopy Set-up – MoDSS for SHE research

- Si stop+box (DSSD+SSSD) combined with large volume Ge-detectors

D. Ackermann, RBEE





configuration

- *stop detector: 1 × DSSD (60×60 strips)*
- *box detectors: 4 × SSSD (32 strips)*
- *γ efficiency ≈ 40%*

chamber

- *compact (overall length 35 cm)*
- *Al-cap with thin γ window (1,5 mm)*
- *compatible due to 150 mm standard flange*

DSSD

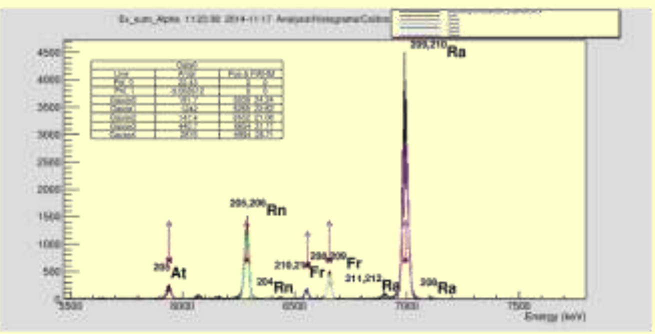
- *integrated cooling (Cu-frame) and connection (flex-PCB)*
- *60×60 strips/mm (pitch 1 mm)*
- *300 µm*

elctronics (partly integrated in the vacuum)

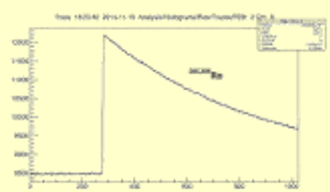
- *analog and digital (FEBEX) options*

first α spectrum (test run at LISE/GANIL)

(ΔE: 20 keV)

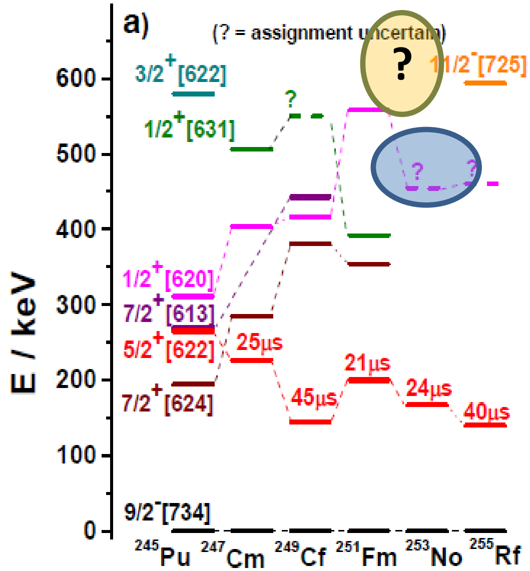


typical α-decay trace (FEBEX)

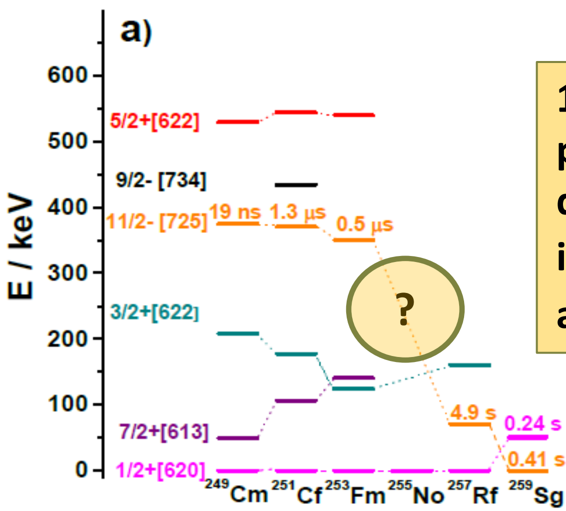


Spectroscopy of SHE @ SHIP – Plans for Near Future

Study of single particle levels in N = 151 and N = 153 isotones relevant for shell gaps and nuclear deformation

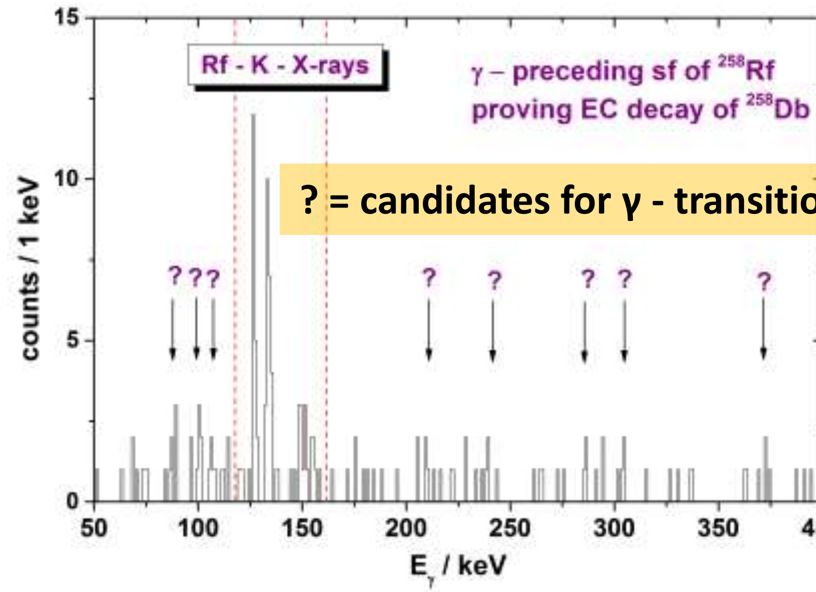


1/2+[620] - determines size of shell gap at
N = 152
to be identified safely in ^{253}No by decay spectroscopy of ^{257}Rf



11/2-[725] – sensitive probe for nuclear deformation - to be identified in ^{253}No and ^{255}No

Study of excited levels in the ee – nucleus ^{258}Rf populated by EC decay of ^{258}Db



? = candidates for γ - transitions

Required

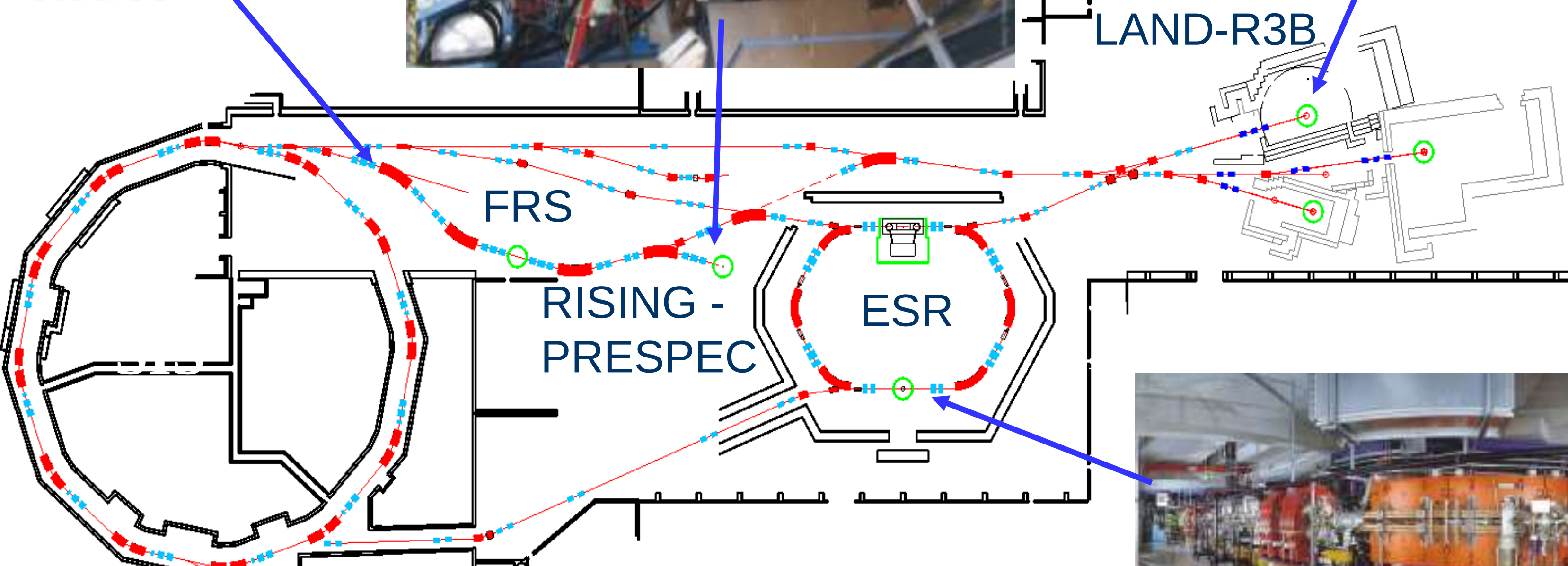
- highly efficient α-, CE-, γ-, SF detection system, digital DAQ – **MoDSS**
- high intense ^{48}Ca-, ^{50}Ti – beams – **UNILAC**
- highly efficient, fast separation, low γ – background - **SHIP**
- moderate beamtimes (2015+)
  5-10 days / experiment

Existing research opportunities at SIS

decay studies,
in-beam spectroscopy

reaction studies

production and separation of exotic nuclei
high resolution spectrometer studies



ground state properties
inverse reactions

The Super-FRS Experiments physics cases

- Rare isotope search experiments (Pietri, Jokinen, Plaß et al.)
- Atomic collision experiments (Purushothaman, Geissel et al.)
- Mesonic atoms and in-medium effects (Itahashi, Weick et al.)
- Exotic hypernuclei and their properties (Saito, Nociforo et al.)
- Exploration of tensor force (Ong,Terashima, Toki, et al.)
- Delta resonances probing nuclear structure (Benlliure, Lenske et al.)
- Nuclear radii and momentum distributions (Kanungo, Prochazka et al.)
- Exotic radioactivity modes (Fomichev, Pfützner, Mukha et al.)
- Low-q experiments with Active Target (Egelhof et al.)
- Low energy reactions (Heinz, Winfield et al.)

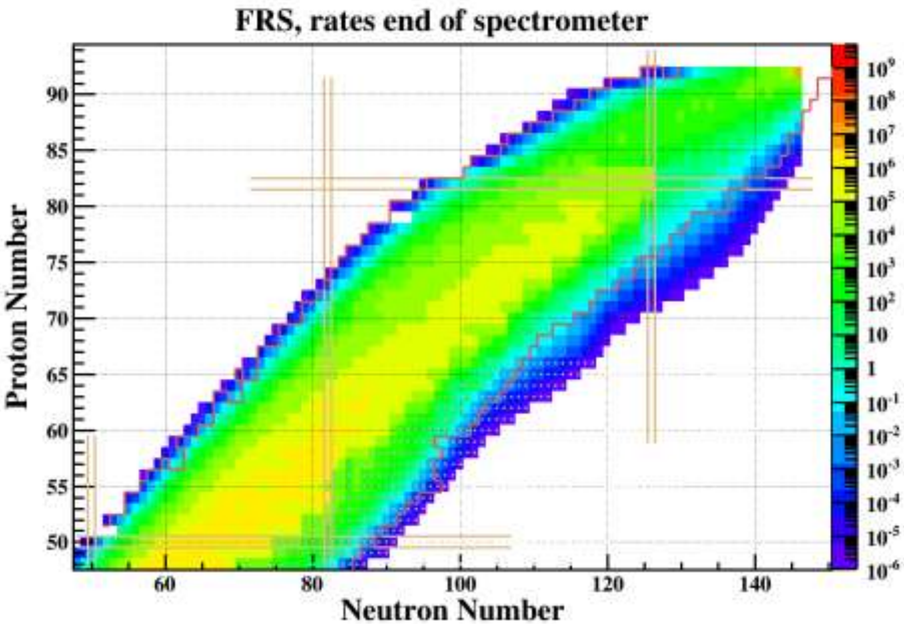
Ideas currently being worked out

New isotopes search experiment

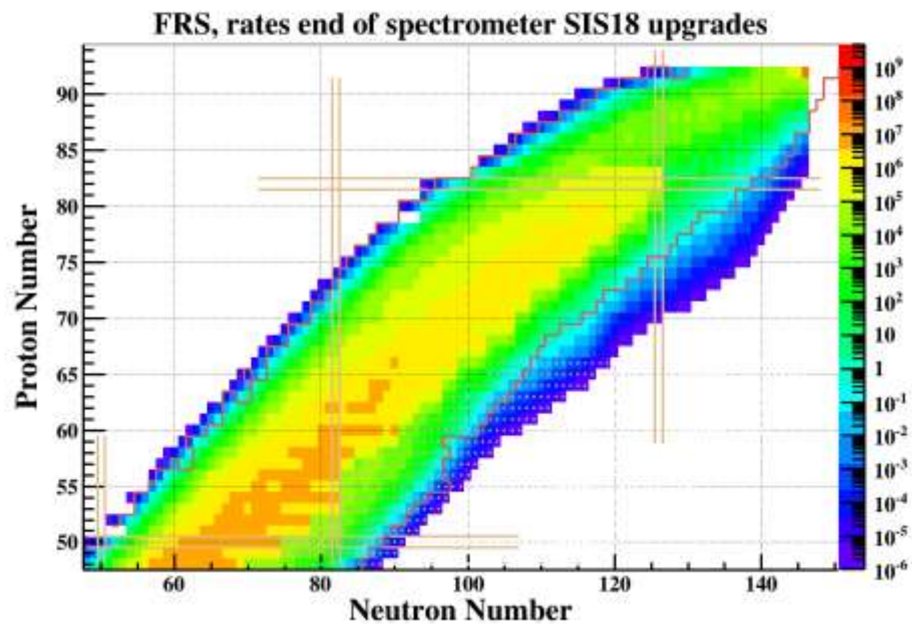
FRS as precursor of the Super-FRS

S. Pietri

2012 best



2018 upgrades



Heavy Z, difficult to reach at RIKEN (charge state identification)
Beam time 2009, despite technical difficulties 60 new isotopes 60<Z<78

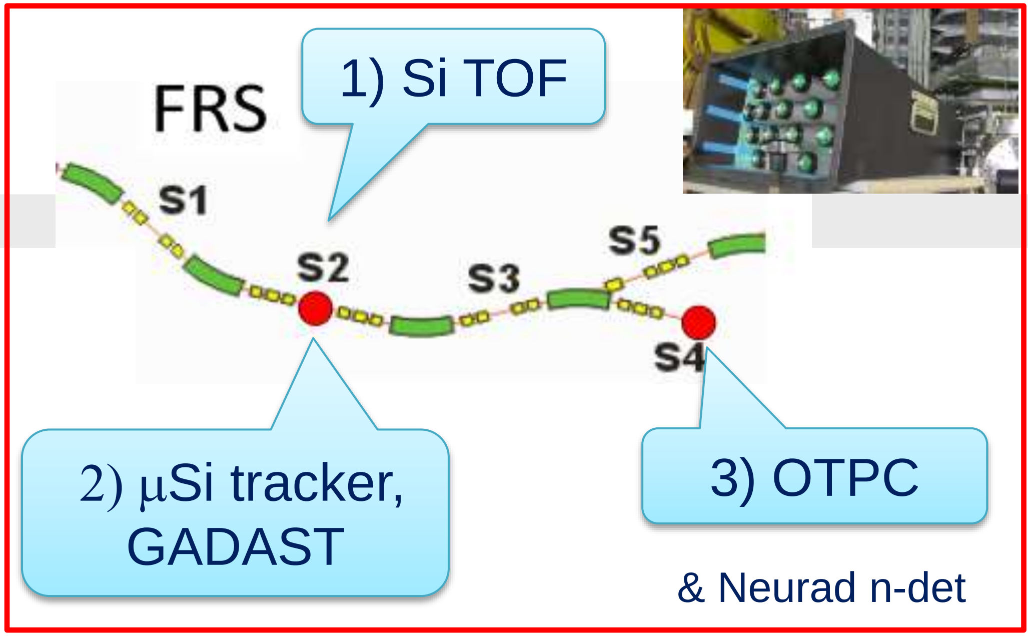
Phys.Lett. B 717, 371 (2012)
J.Kurcewicz et al.

In 2018 could easily get 30 to 40 new isotopes 1 week of beam time
➔ would be a perfect test bench for high rate detector/DAQ development Super-FRS

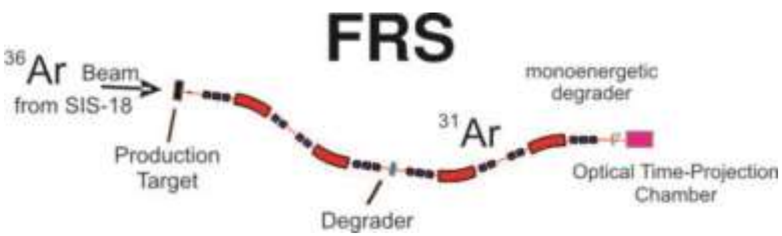
(high rate comes from fission fragments passing in the setting)

Phase0 experiments of EXPERT (EXotic Particle Emission and Radioactivity by Tracking)

I. Mukha



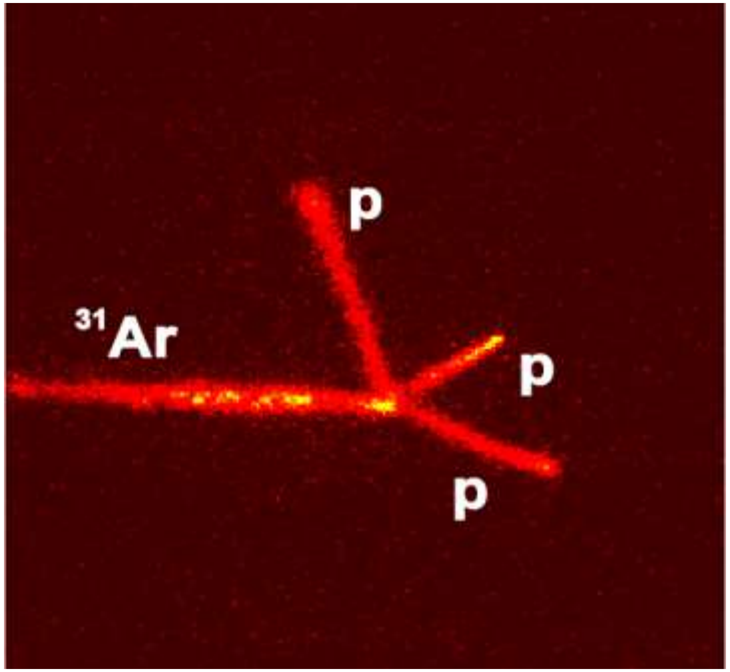
Previous experiment



Two-proton radioactivity of ^{34}Ca, ^{26}S (proposals S271 and S414, respectively)
Four-proton decay of un-observed ^{21}Si (new proposal)

Beta-delayed exotic 3-proton decays, e.g. from ^{27}S (part of the S414 proposal)

Low-energy proton resonances in ^{73}Rb, ^{69}Br (part of the S388 proposal)



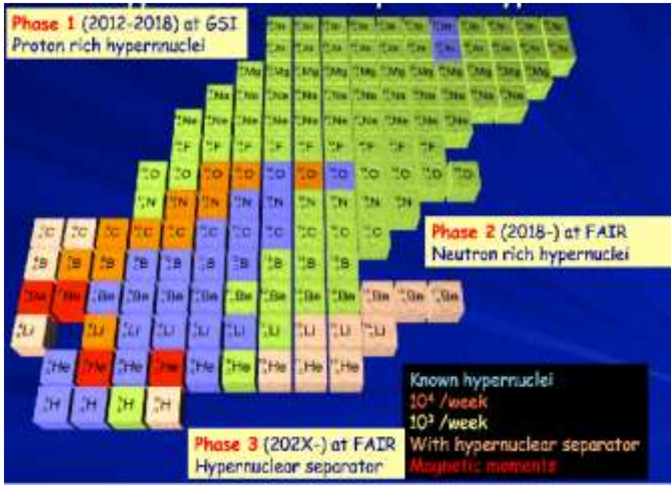
Hypernuclei @ FRS

T. Saito

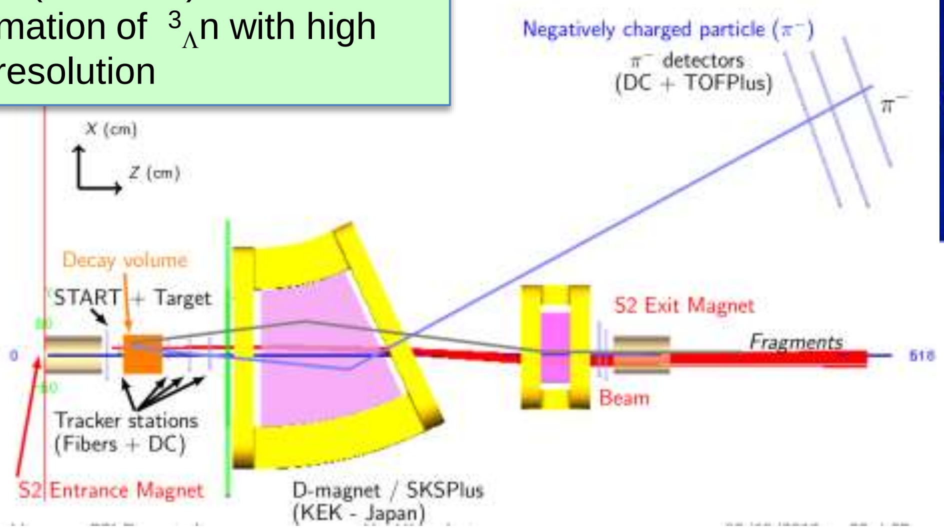
- Hypernuclear spectroscopy with peripheral collisions of heavy ion beams
  - **Possible only at GSI (Ebeam > 1.6 A GeV)**

  c.f. Relativistic heavy ion collisions at RHIC and LHC: only up to 3-body hypernuclei

Observe
- ${}^{4}_{\Lambda}H \rightarrow {}^{4}He + \pi^{-}$ (exclusive)
  Proof of principle
  Lifetime measurement
- ${}^{3}_{\Lambda}n \rightarrow d + \pi^{-}$ (inclusive)
  Confirmation of ${}^{3}_{\Lambda}n$ with high mass resolution



Beams from first half of FRS

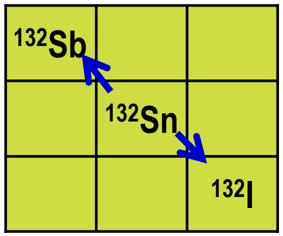


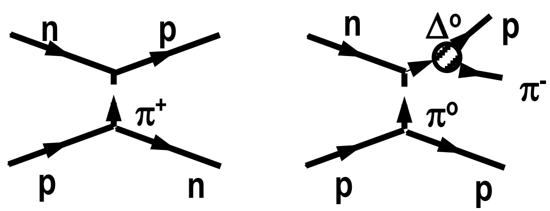
Decay residues to
Second half of FRS
High resolution spectrometer

π^{-} measurements at S2

Nucleon resonances in asymmetric nuclear matter

Isobaric charge exchange reactions.





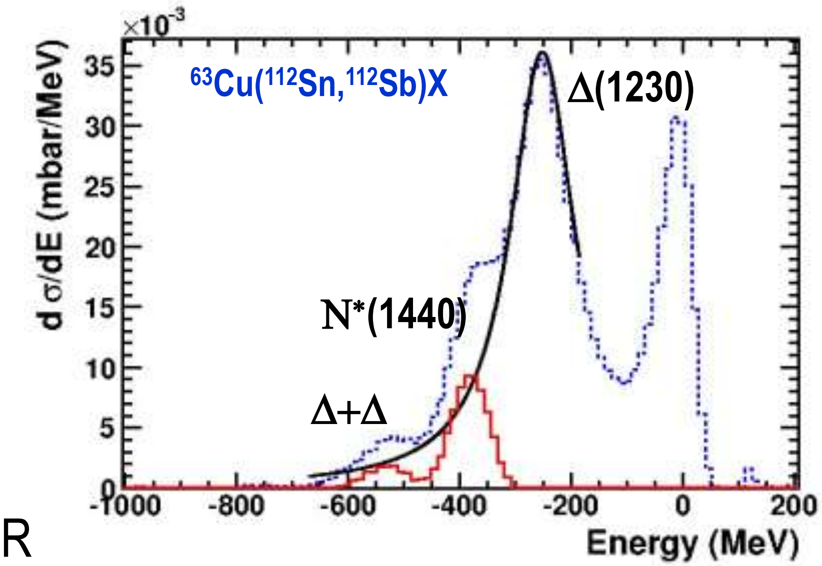
quasi-elastic

inelastic

Relativistic neutron-rich projectiles

High-resolving power spectrometer

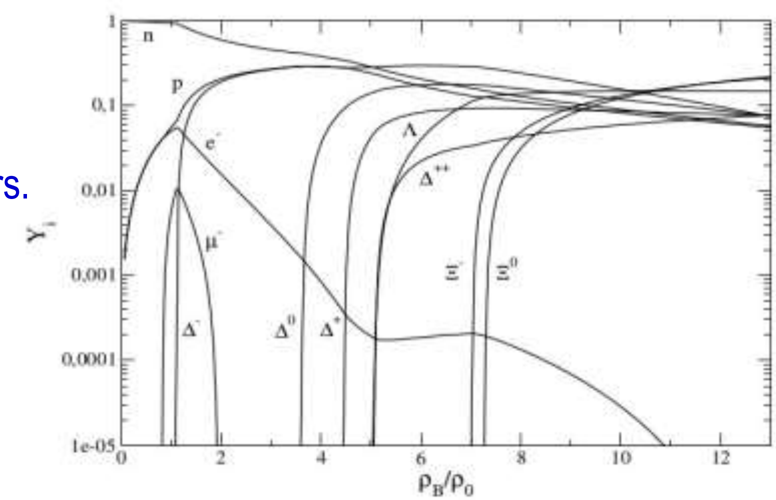
SuperFRS@FAIR



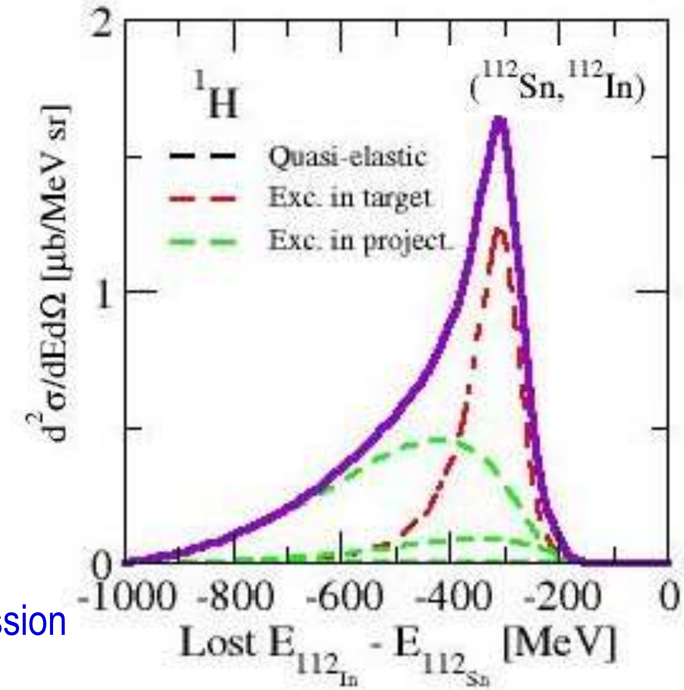
The momentum recoil induced by the pion emission proves the excitation of the resonances

Physics case.

- ✓ In-medium baryon resonances.
- ✓ Role of nucleon excitations in compact and massive neutron stars.
- ✓ Constraining the symmetry energy $\sigma(n,p)/\sigma(pn)$
- ✓ The puzzling nature of the Roper resonance.



Nucleon resonances in asymmetric nuclear matter



First pilot experiment at the FRS (2011).

✓ The in-medium excitation of baryon resonances in isobaric charge-exchange reactions was proved.

✓ These inclusive measurements provide limited information of the properties of the excited resonances.

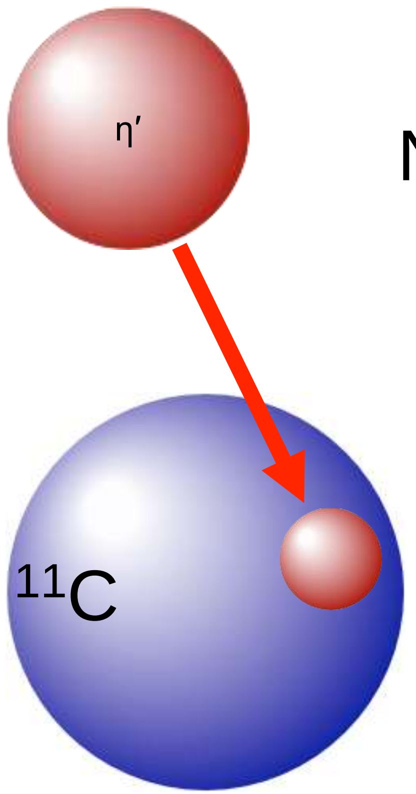
Proposal for a new experiment at the FRS (~2017 ?).

✓ Exclusive measurements measuring in coincidence the pion emission will allow a complete characterization of the baryon resonances.

✓ Such an experiment could be performed with the same experimental setup proposed for the investigation of hyper-nuclei.

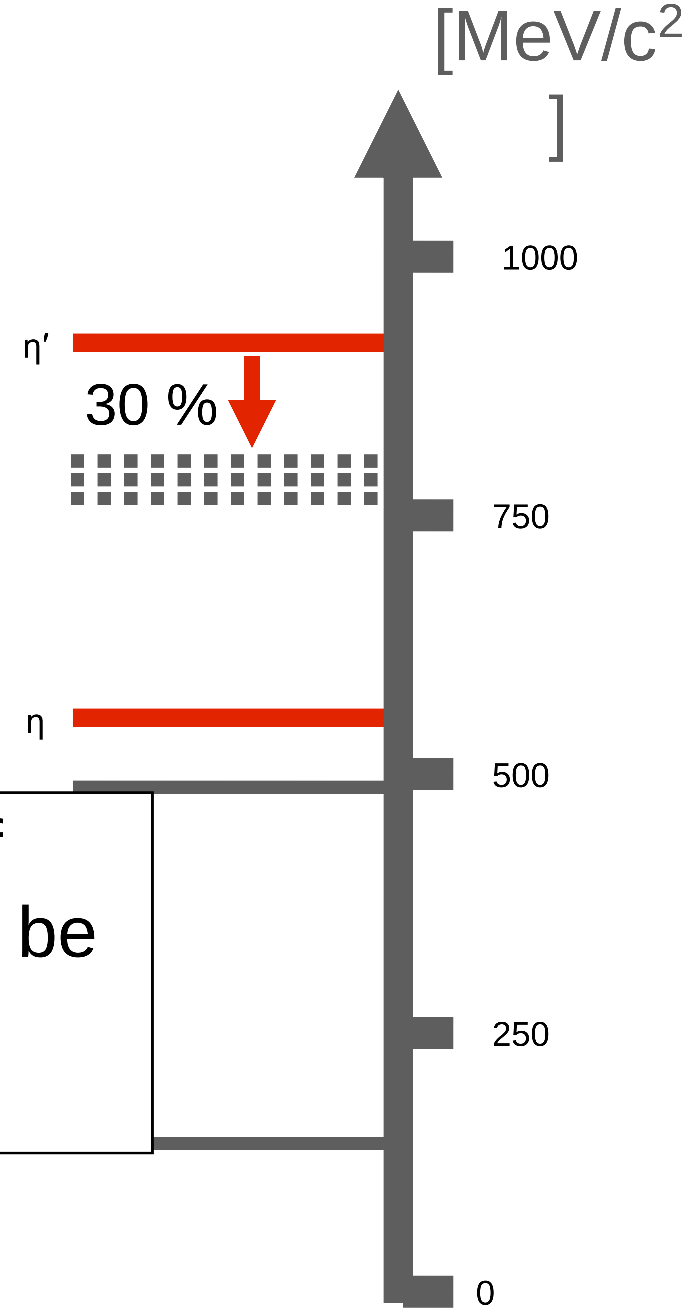
A dedicated experimental program at the SuperFRS.

✓ Final experiments taking advantage of the full capabilities of FAIR and the SuperFRS to investigate the excitation of baryon resonances in very exotic systems η′ mesic nuclei search



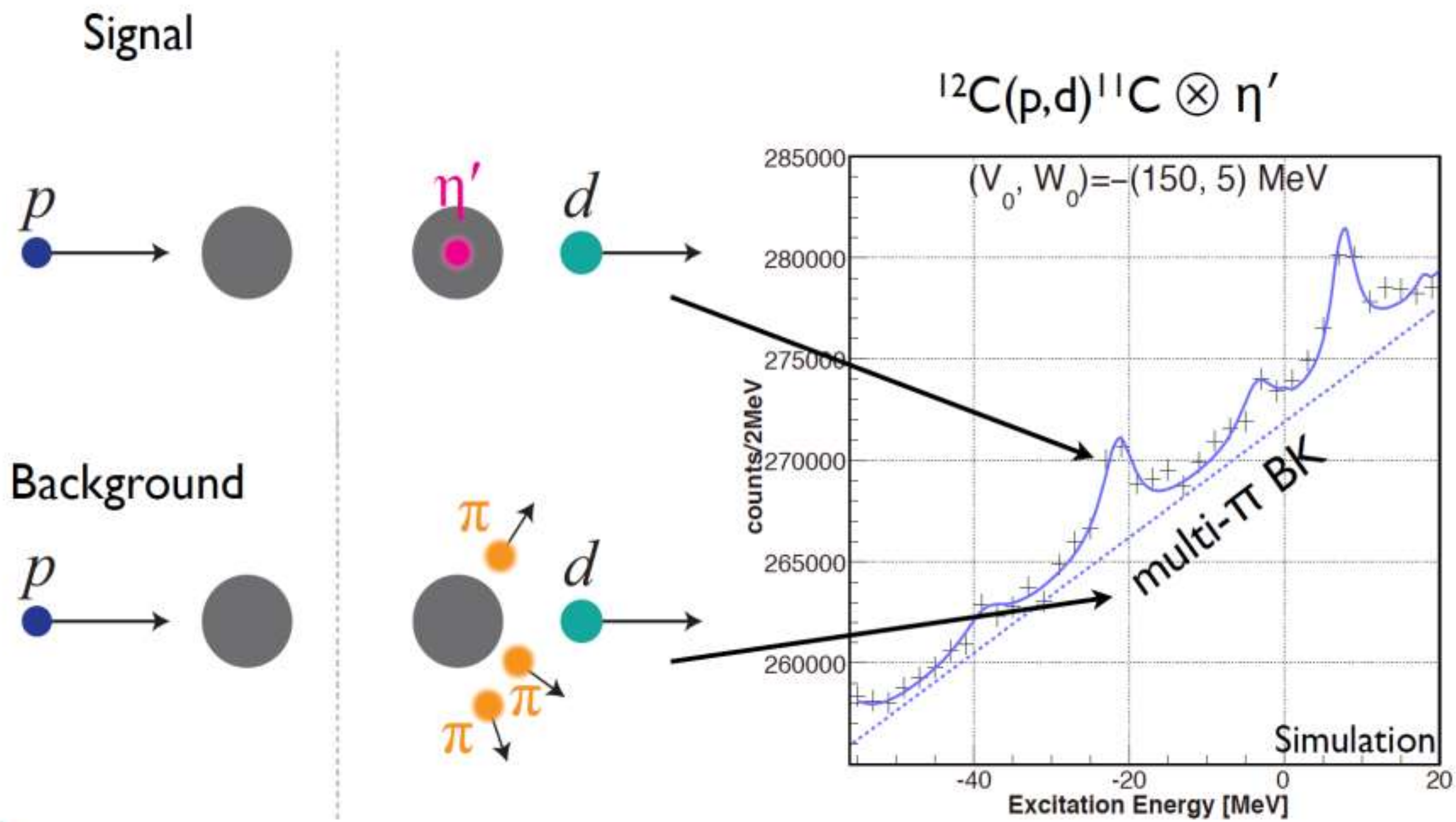
Naive estimation shows 30% reduction of $|m_{\eta'} - m_\eta|$

Q. Mass shift of ~ 150 MeV/c² can be observed in experiment?

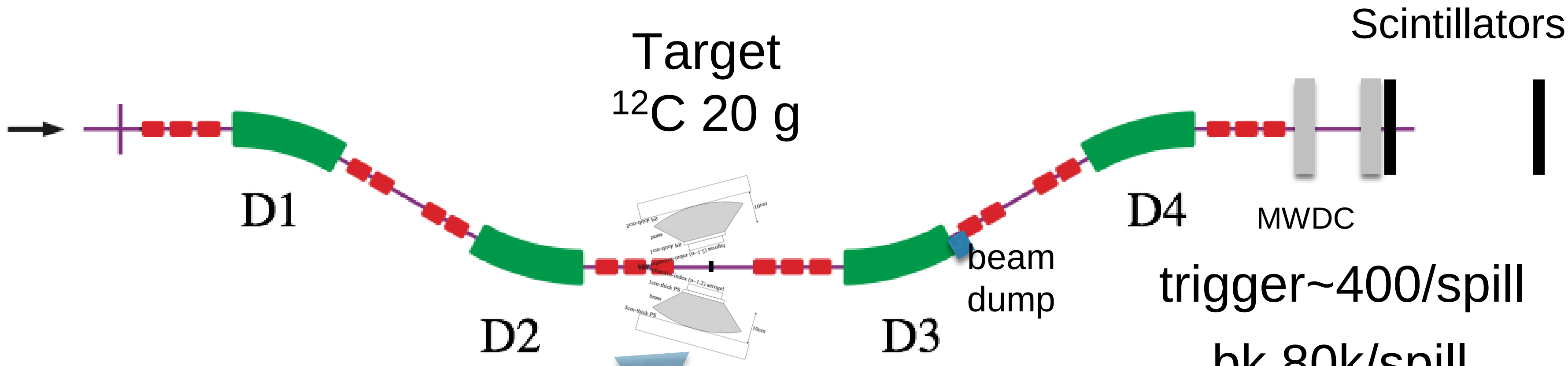


Jido, Nagahiro, Hirenzaki, PRC85(2012)032201(R)

Background in Inclusive Measurement at GSI

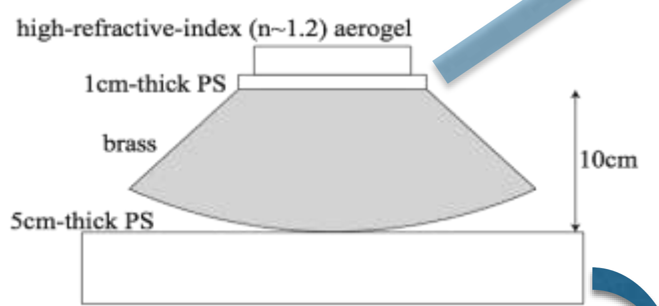


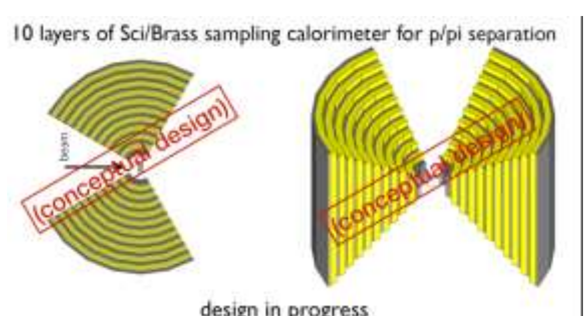
First (pilot) run for exclusive measurement (2017-18)



trigger~400/spill
bk 80k/spill

prototype (p, π) det.

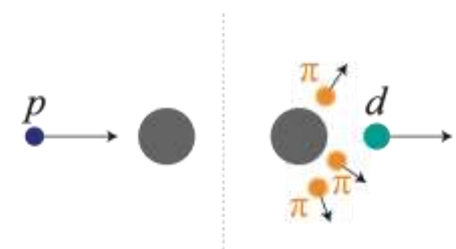


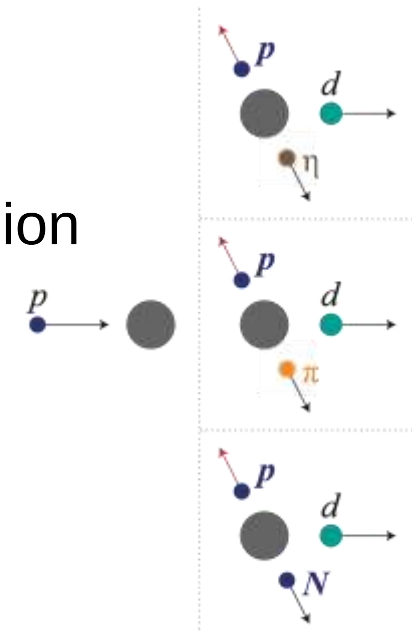


final

Beam T_p = 2.5 GeV
$I_p > 10^8$/spill

Background suppression
by signal tagging

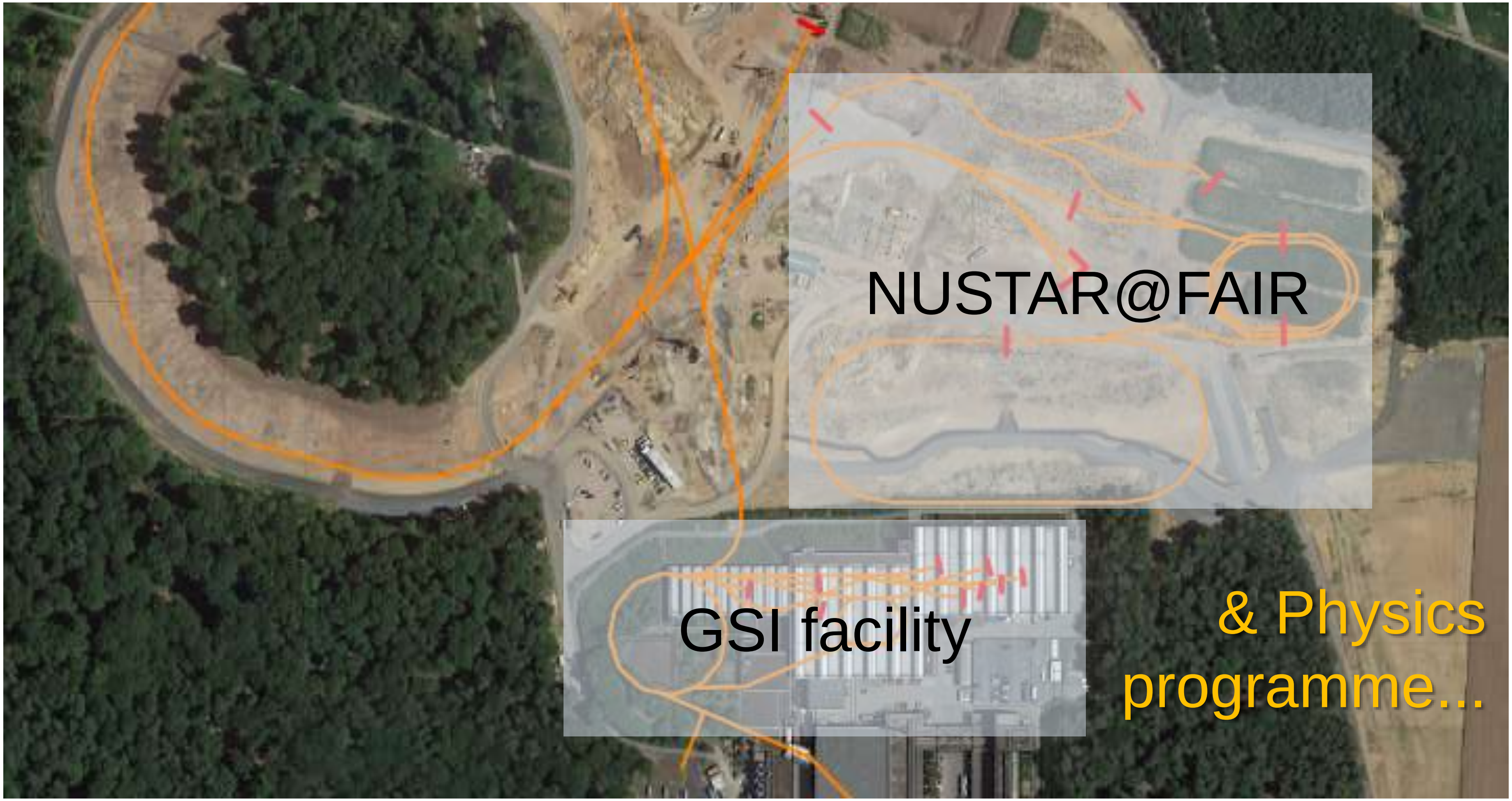




Summary Super-FRS

- Precursor versions of the full setups at Super-FRS can be realized with viable physics programme at the FRS.
- Phase 0 Programme will be discussed in the next Collaboration Meeting (Walldorf April 22nd-24th).
- TDRs will comprise enhancements to the current Super-FRS design for experiments and additional equipment.

Areal view of the combined facility



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