Light-Ion Induced Direct Reactions with Stored Radioactive Beams – The EXL Project at the Present ESR and at FAIR

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Physics of RARE-RI Ring

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I. Motivation and Research Objectives of EXL*

II. The EXL Detector Setup – Concept and Design Goals

III. R&D on the EXL Recoil Detector

IV. Feasibility Studies and First Experiments at the ESR

V. Conclusions

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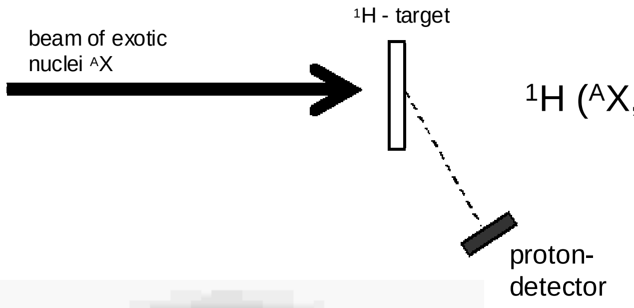
* **EXL**: **EX**otic Nuclei Studed in **L**ight-Ion Induced Reactions at the NESR Storage Ring

I. Motivation and Research Objectives of EXL



^{1}H (^{A}X, ^{1}H) ^{A}X

classical method of nuclear spectroscopy:

⇒ light ion induced direct reactions: (p,p), (p,p'), (d,p), ...
⇒ to investigate exotic nuclei: inverse kinematics

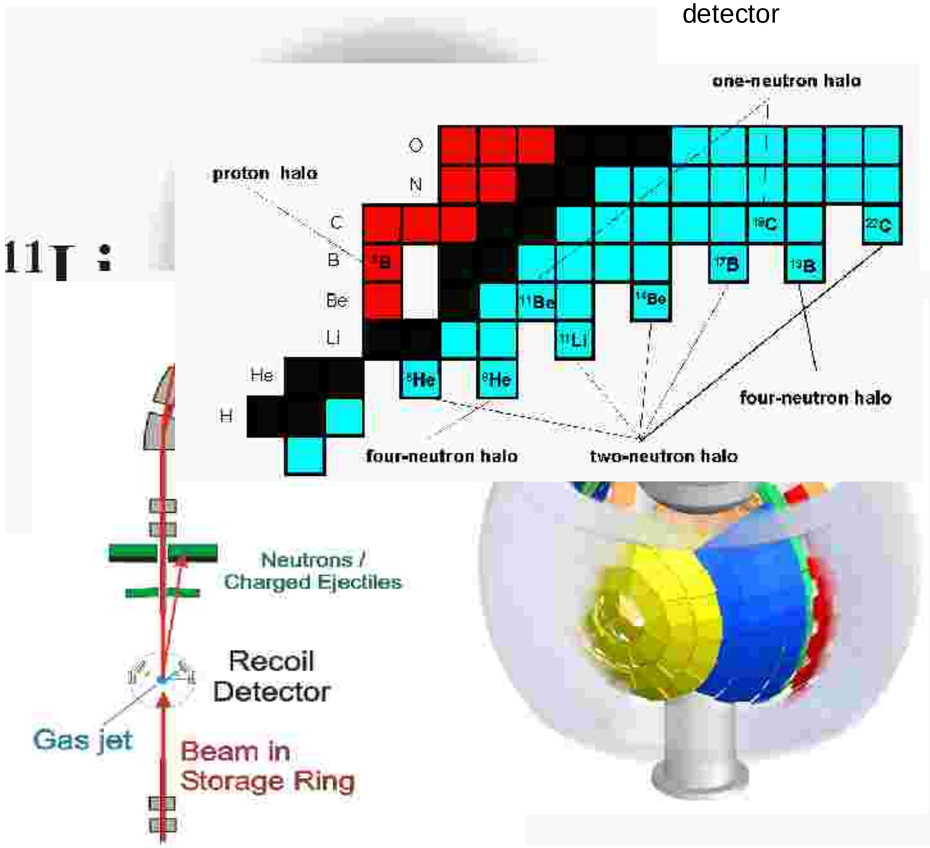
past and present experiments:

⇒ light neutron-rich nuclei: skin, halo structures
⇒ only at external targets

future perspectives at FAIR:

⇒ profit from intensity upgrade (up to 10^4 !!)
⇒ explore new regions of the chart of nuclides and new phenomena
⇒ use new and powerful methods:

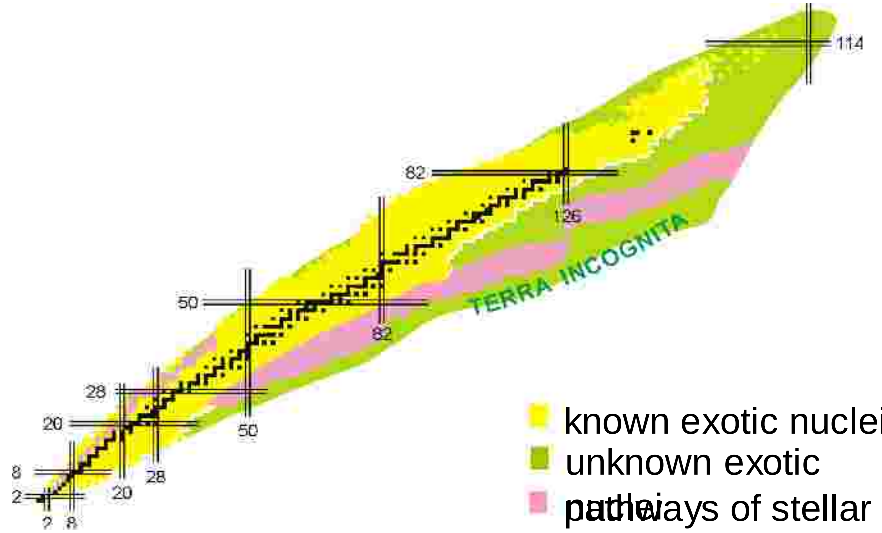
EXL: direct reactions at internal NESR target
⇒ high luminosity even for very low momentum transfer measurements



Perspectives at the GSI Future Facility FAIR

regions of interest:

⇒ towards the driplines for medium heavy and heavy nuclei



- known exotic nuclei
- unknown exotic nuclei
- pathways of stellar nucleosynthesis

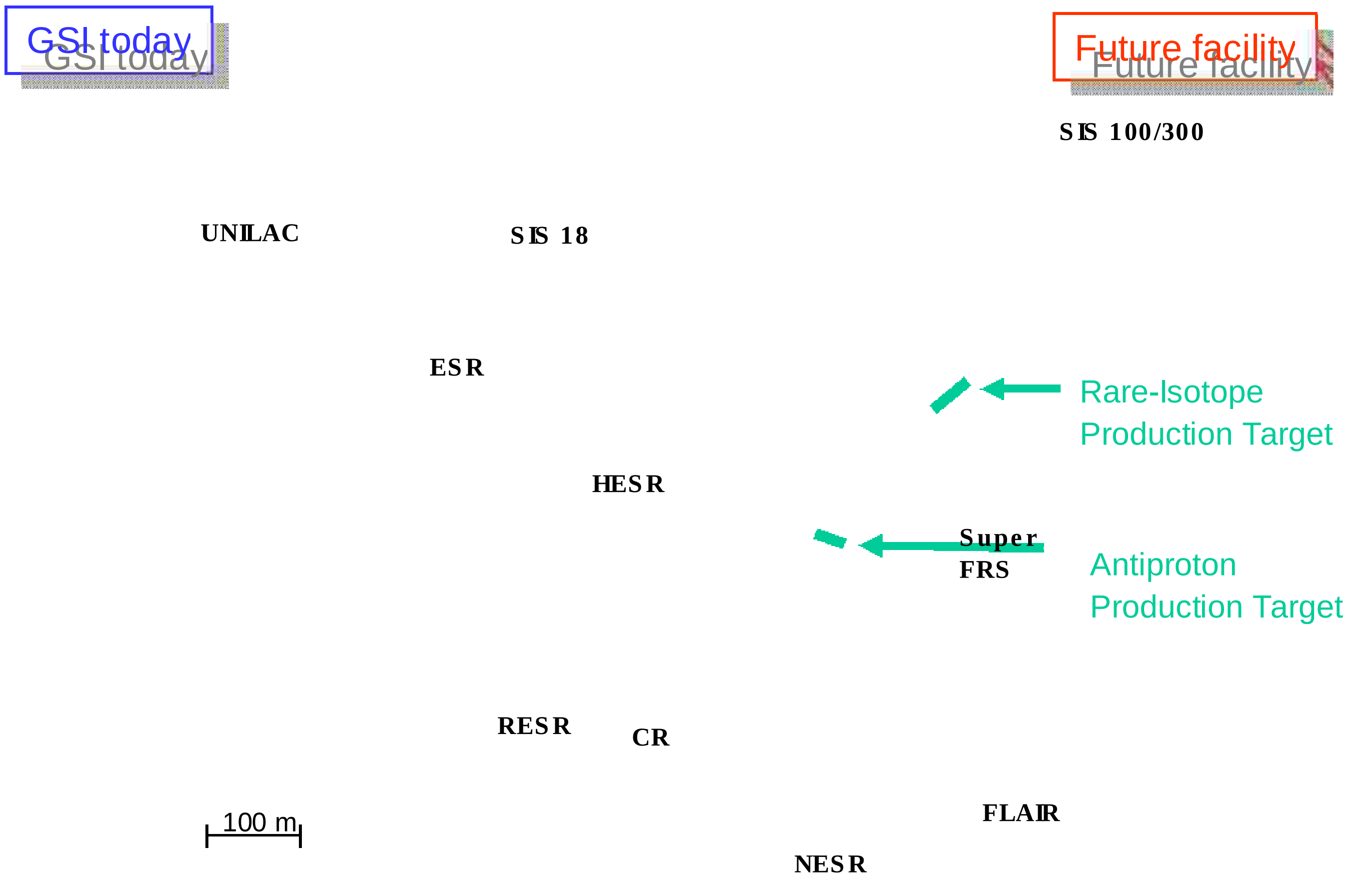
physics interest:

- matter distributions (halo, skin…)
- single-particle structure evolution (new magic numbers, new shell gaps, spetroscopic factors)
- NN correlations, pairing and clusterization phenomena
- new collective modes (different deformations for p and n, giant resonance strength)
- parameters of the nuclear equation of state
- in-medium interactions in asymetric and low-density matter
- astrophysical r and rp processes, understanding of supernovae

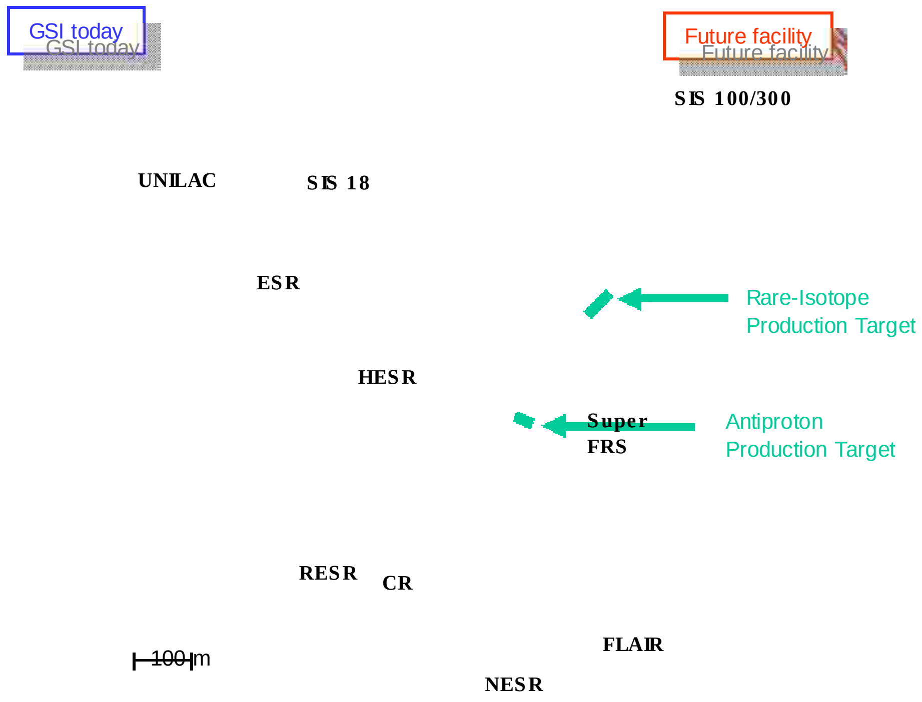
Light-Ion Induced Direct Reactions

- elastic scattering (p,p), (α,α), …
  nuclear matter distribution ρ(r), skins, halo structures
- inelastic scattering (p,p'), (α,α'), …
  deformation parameters, B(E2) values, transition densi ies, giant resonances
- charge exchange reactions (p,n), (^{3}He,t), (d, ^{2}He), …
  Gamow-Teller strength
- transfer reactions (p,d), (p,t), (p, ^{3}He), (d,p), …
  single particle structure, spectroscopic factors
  spectroscopy beyond the driplines
  neutron pair correlations
  neutron (proton) capture cross sections
- knock-out reactions (p,2p), (p,pn), (p,p ^{4}He)…
  ground state configurations, nucleon momentum distribu ions, cluster correlations

FAIR: Facility for Antiproton and Ion Research



FAIR: Facility Characteristics



Primary Beams

- 10^{12}/s; 1.5-2 GeV/u; $^{238}U^{28+}$
- Factor 100-1000 over present in intensity
- $2(4)\times10^{13}$/s 30 GeV protons
- 10^{10}/s $^{238}U^{73+}$ up to 35 GeV/u
- up to 90 GeV protons

Secondary Beams

- Broad range of radioactive beams up to 1.5 - 2 GeV/u; up to factor 10 000 in intensity over present
- Antiprotons 3 - 30 GeV

Storage and Cooler Rings

- Radioactive beams
- e – A collider
- 10^{11} stored and cooled 0.8 - 14.5 GeV antiprotons

Key Technical Features

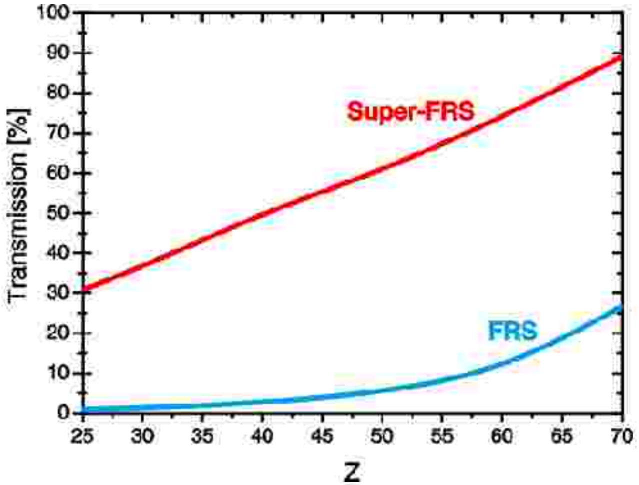
- Cooled beams
- Rapidly cycling superconducting magnets

Nuclear Physics with Radioactive Beams at FAIR: NUSTAR: NUclear STructure, Astrophysics and Reactions

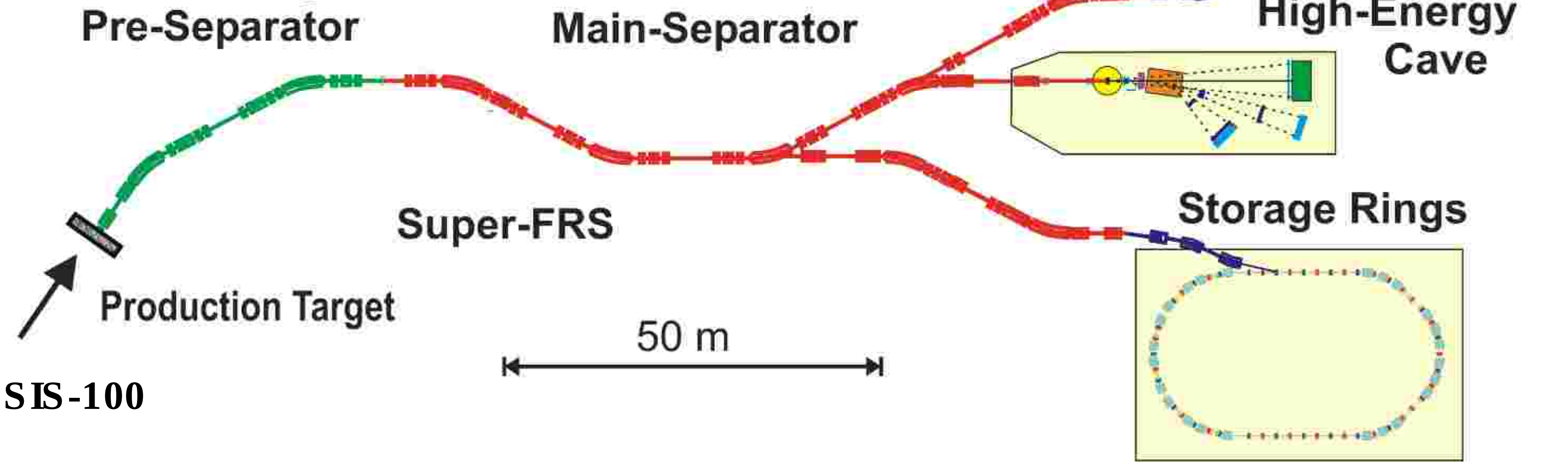
I High intensity primary beams from SIS 100 (e.g. 10^{12} ^{238}U / sec at 1 GeV/u)

II Superconducting large acceptance Fragmentseparator

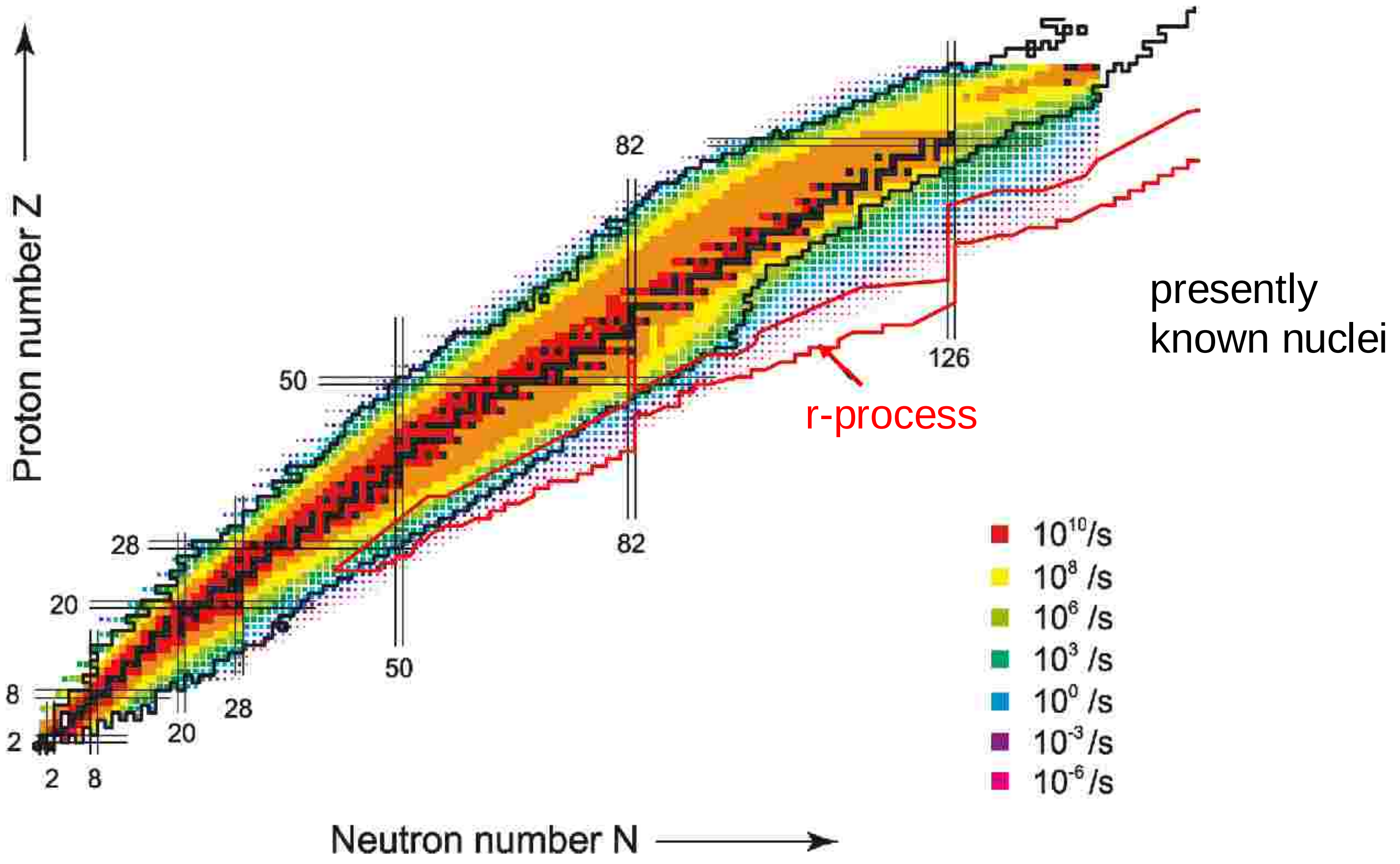
III Three experimental areas



Optimized for efficient transport of fission products



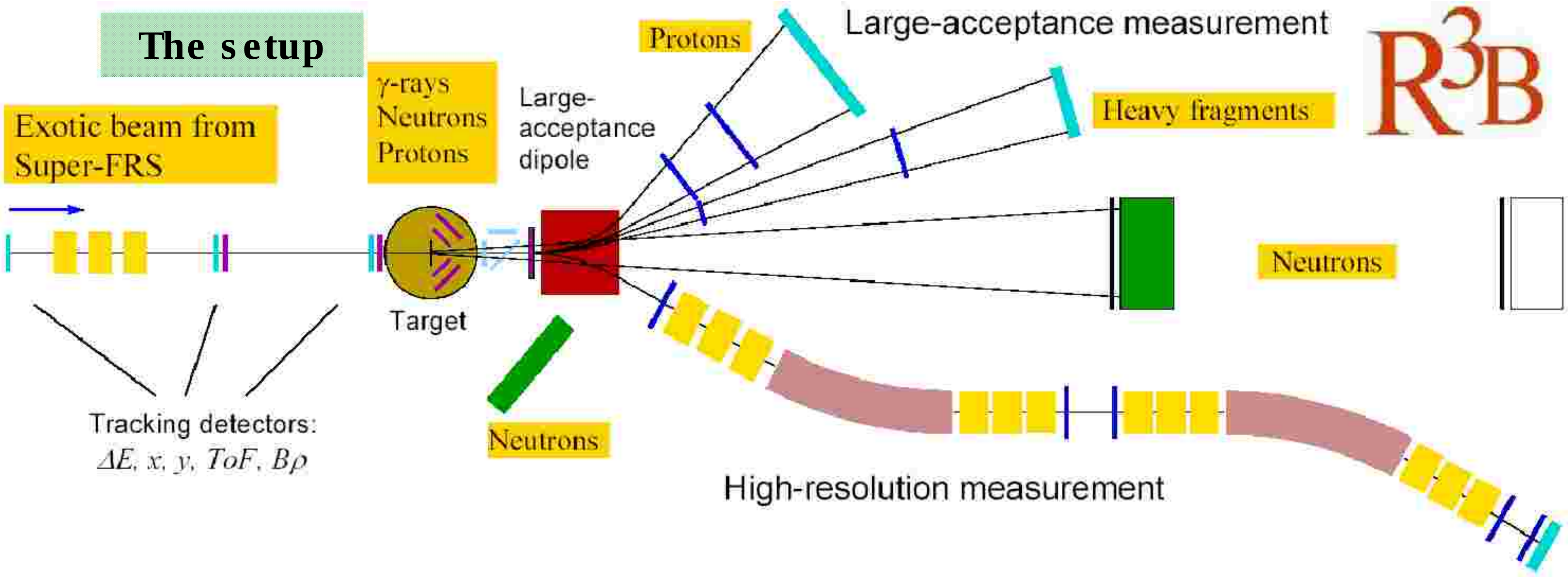
Expected Production Rates



Reactions with Relativistic Radioactive Beams at FAIR

- R^3B: Reactions with Relativistic Radioactive Beams
  $\Rightarrow$ High Energy Branch
- EXL: EXotic Nuclei Studied in Light-Ion Induced Reactions at the NESR Storage Ring
  $\Rightarrow$ Ring Branch
- ELISe: ELectron Ion Scattering in a Storage Ring e-A Collider
  $\Rightarrow$ Ring Branch
- AIC: Antiproton Ion Collider
  $\Rightarrow$ Ring Branch

R3B: Reactions with Relativistic Radioactive Beams



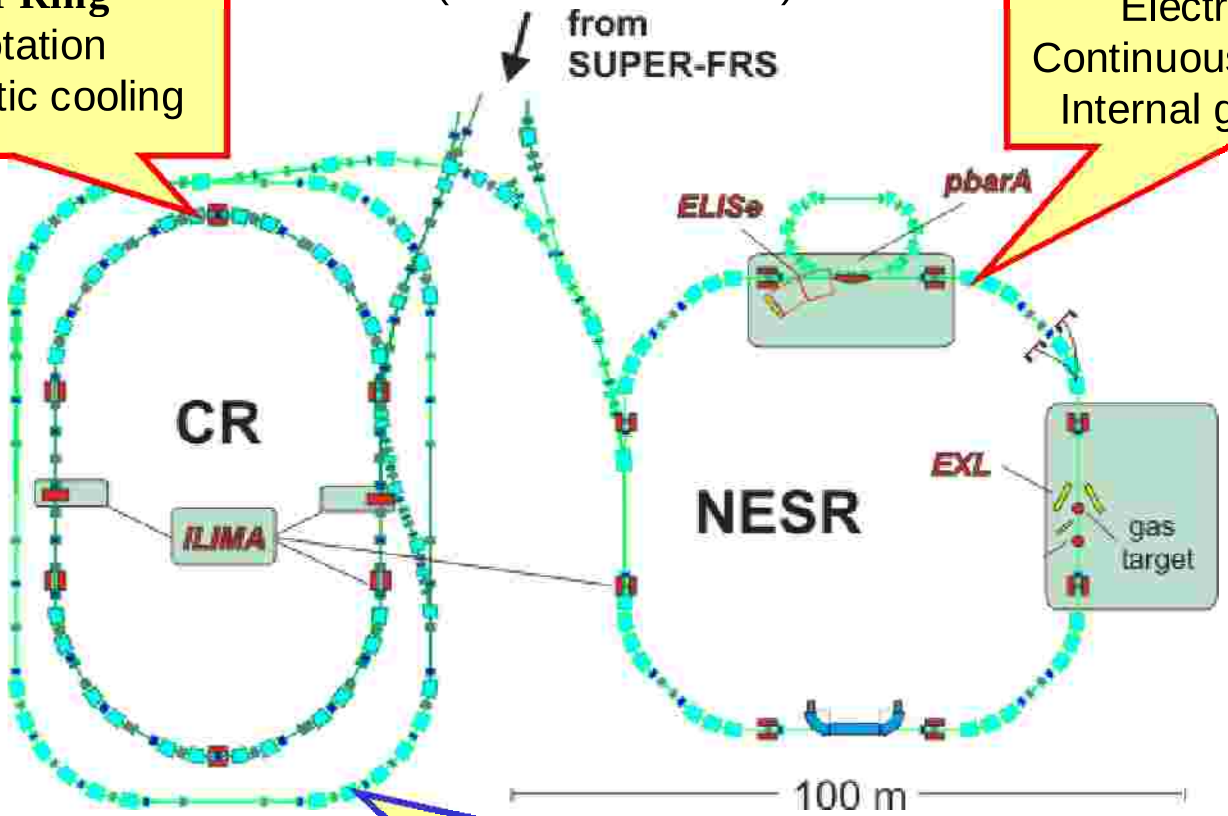
The R³B experiment: a universal setup for kinematical complete measurements

Experiments with Stored Exotic Nuclei

Collector Ring
Bunch rotation
Fast stochastic cooling

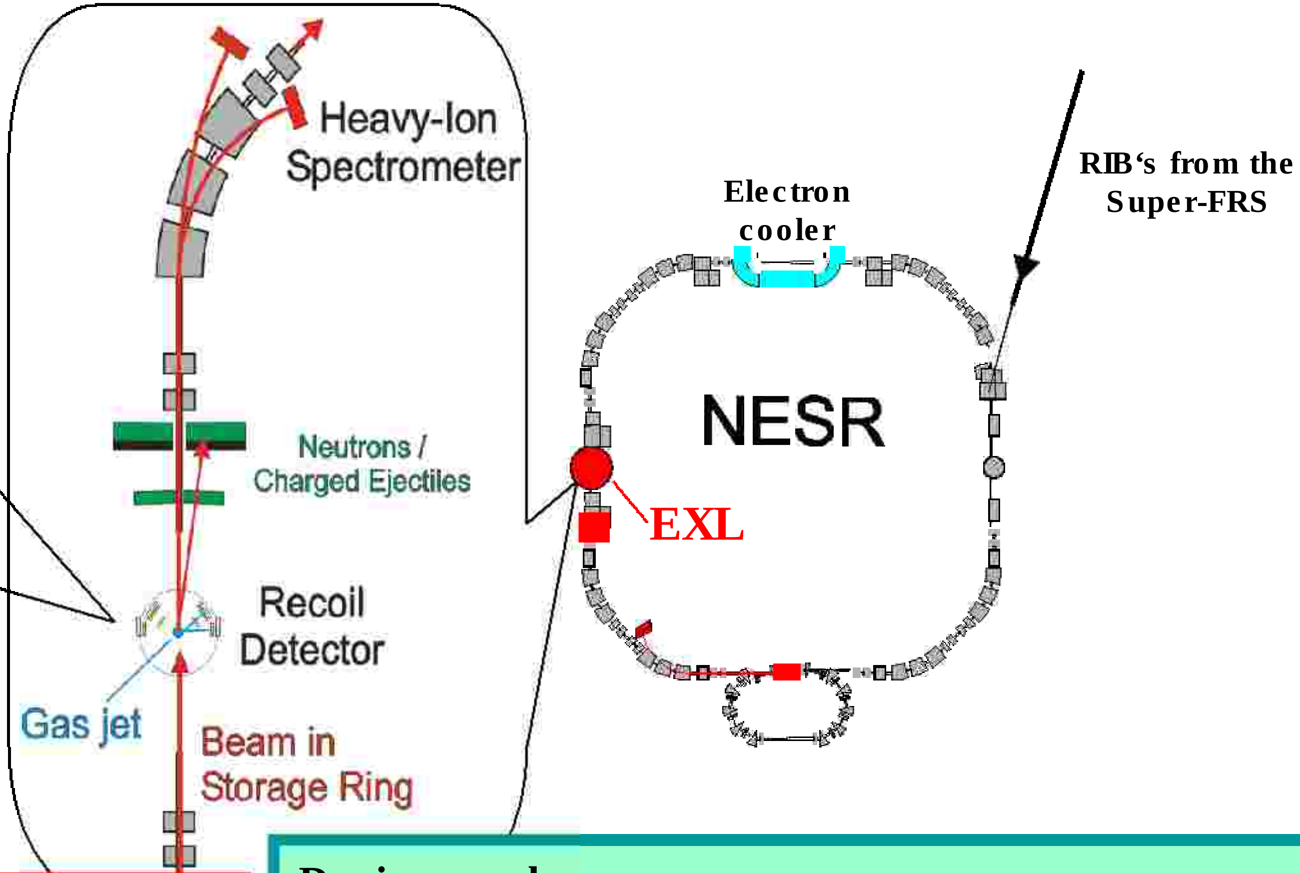
RIB
(740 MeV/nucleon)

NESR
Electron cooling
Continuous accumulation
Internal gas jet targets



RESR
Deceleration (1T/s) to 100 - 400 MeV/nucleon

EXL: EXotic Nuclei Studied in Light-Ion Induced Reactions at the NESR Storage Ring



Detection systems for:

- Target recoils and gammas (p,a,n,?)
- Forward ejectiles (p,n)
- Beam-like heavy ions

Design goals:

- Universality: applicable to a wide class of reactions
- High energy resolution and high angular resolution
- Large solid angle acceptance
- Specially dedicated for low q measurements with high luminosity (> 10^{29} cm^{-2} s^{-1})

Light-Ion Induced Direct Reactions at Low Momentum Transfer

- elastic scattering (p,p), (α,α), …
  nuclear matter distribution ρ (r), skins, halo structures
- inelastic scattering (p,p'), (α,α'), …
  deformation parameters, B(E2) values, transition densi ies, giant resonances
- transfer reactions (p,d), (p,t), (p, ^{3}He), (d,p), …
  single particle structure, spectroscopic factors, spectroscopy beyond the driplines, neutron pair correlations, neutron (proton) capture cross sections
- charge exchange reactions (p,n), (^{3}He,t), (d, ^{2}He), …
  Gamow-Teller strength
- knock-out reactions (p,2p), (p,pn), (p,p ^{4}He)…
  ground state configurations, nucleon momentum distribu ions

for almost all cases:

region of low momentum transfer contains most important information

<u>Speciality of EXL:</u>

measurements at very low momentum transfer

$\Rightarrow$ complementary to R^{3}B !!!

Experiments to be Performed at Very Low Momentum Transfer – Some Selected Examples

- Investigation of Nuclear Matter Distributions:
  - ⇒ halo, skin structure
  - ⇒ probe in-medium interactions at extreme isospin (almost pure neutron matter)
  - ⇒ in combination with electron scattering (ELISe project @ FAIR): separate neutron/proton content of nuclear matter (deduce neutron skins)

method: elastic proton scattering ⇒ at low q: high sensitivity to nuclear periphery

- Investigation of the Giant Monopole Resonance:
  - ⇒ gives access to nuclear compressibility ⇒ key parameters of the EOS
  - ⇒ new collective modes (breathing mode of neutron skin)

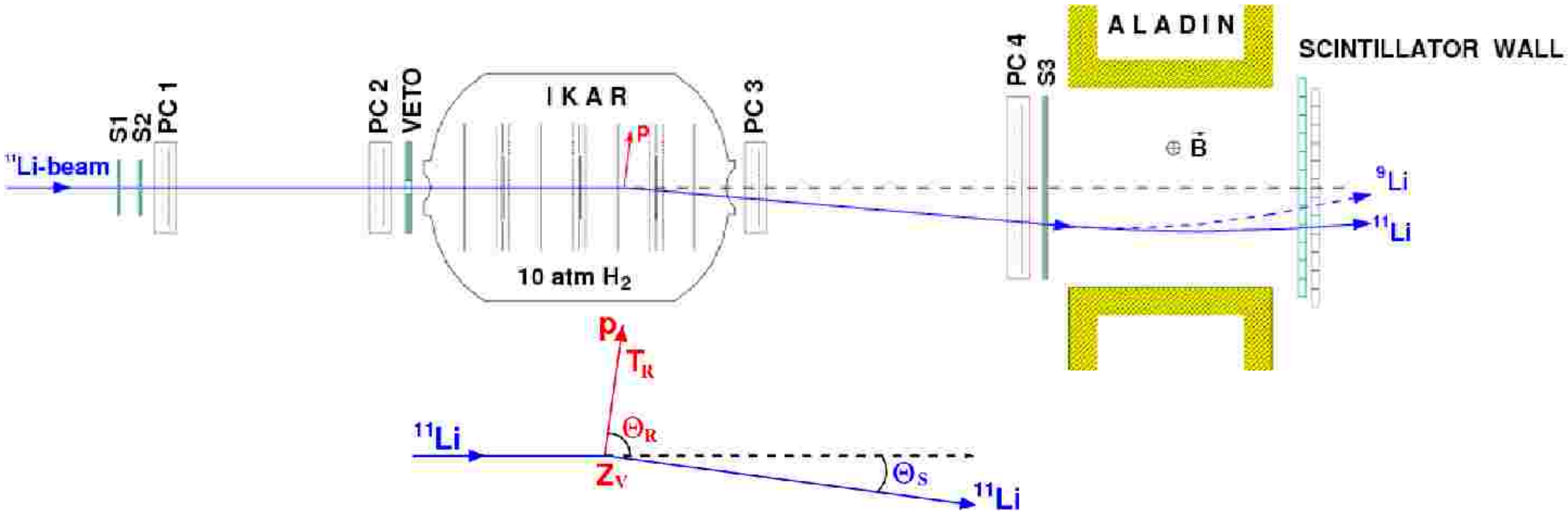
method: inelastic α scattering at low q

- Investigation of Gamow-Teller Transitions:
  - ⇒ weak interaction rates for N = Z waiting point nuclei in the rp-process
  - ⇒ electron capture rates in the presupernova evolution (core collaps)

method: (^{3}He,t), (d,^{2}He) charge exchange reactions at low q

Investigation of Nuclear Matter Density Distributions of Halo Nuclei by Elastic Proton Scattering

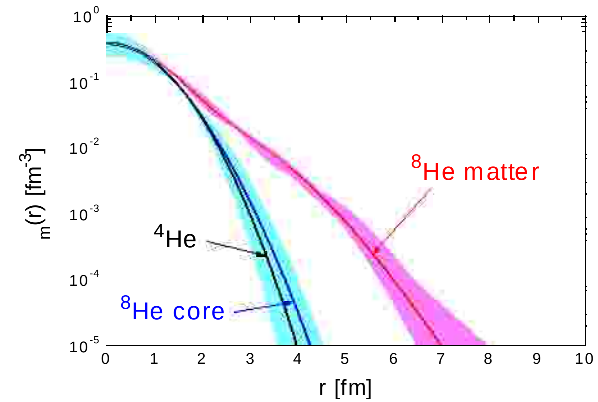
Experimental Setup: Active Target IKAR and Aladin Magnet

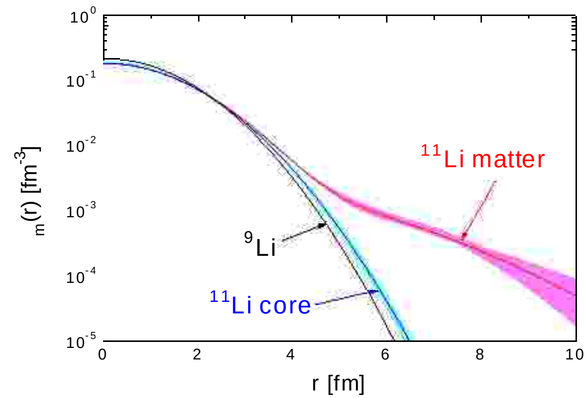


target + recoil detector:	IKAR	} ⇒ $T_{R,}$, θ_R, Z_V
trajectory-reconstruction:	PC 1-4 (Multiwire proportional chambers)	} ⇒ θ_S
beam identification:	S 1-3, Veto (plastic scintillators)	} ⇒ ΔE, TOF, trigger
	ALADIN-magnet + position sensitive scintillator wall	} ⇒ discrimination of projectile breakup

Investigation of Nuclear Matter Density Distributions of Halo Nuclei by Elastic Proton Scattering at Low Momentum Transfer

nuclear matter distributions:





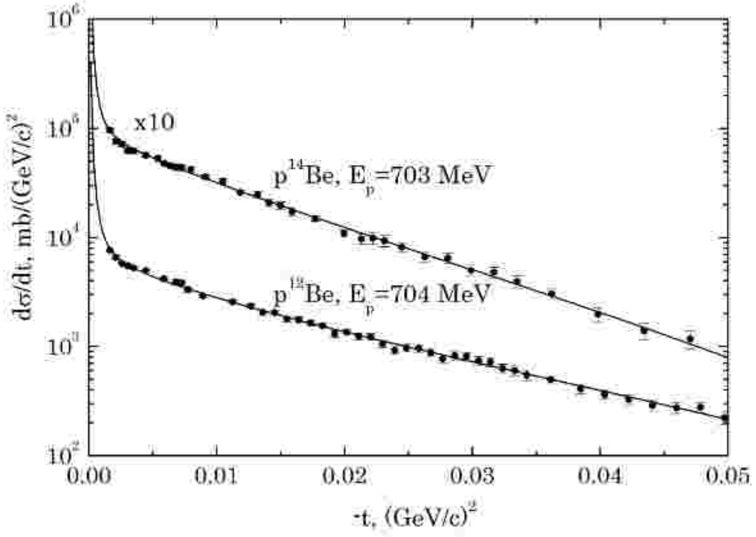
nuclear matter radii:

nucleus	R_{matter}, fm	R_{core}, fm	R_{halo}, fm
^{4}He	1.49 (3)	--	--
^{8}He	2.45 (7)	1.55 (15)	3.08 (10)
^{9}Li	2.43 (7)	--	--
^{11}Li	3.62 (19)	2.55 (12)	6.54 (38)

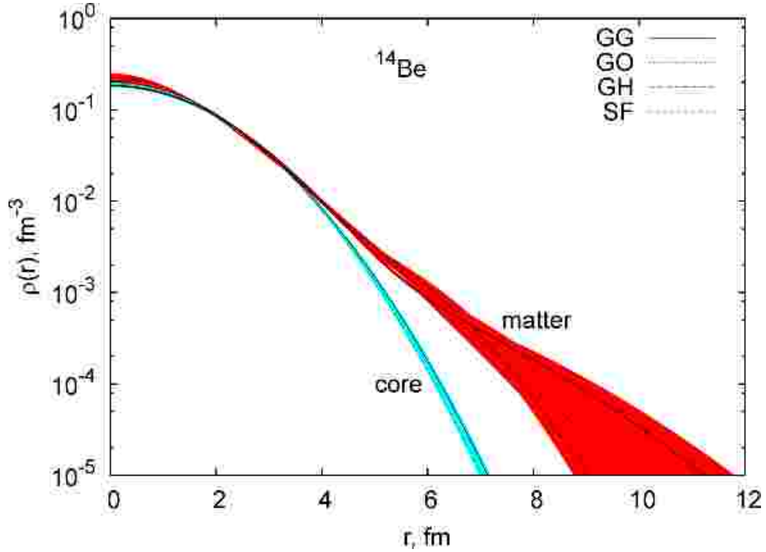
- extended neutron distribution in ^{8}He and ^{11}Li obtained
- size of core, halo and total matter distribution deter ned with high accuracy

Elastic Proton Scattering from ^{14}Be

differential cross section:



deduced nuclear matter distribution:



results for ^{14}Be:

R_{matter} = 3.25 ± 0.04 ± 0.11 fm
R_{core} = 2.65 ± 0.02 ± 0.11 fm

- ^{14}Be exhibits a pronounced core-halo structure
- the picture of a ^{12}Be-core + 2 valence neutron structure is confirmed
- the present data favour a relatively large s-wave component
  (see I. Thompson et. al, Phys. Rev. C53 (1996) 708)

Proposed Experiments at FAIR

l investigation of nuclear matter distributions along isotopic chains towards proton/neutron asymmetric matter

l investigation of the same nuclei by (e,e) (ELISe) and (p,p) (EXL) scattering

ð separate neutron/proton content of nuclear matter

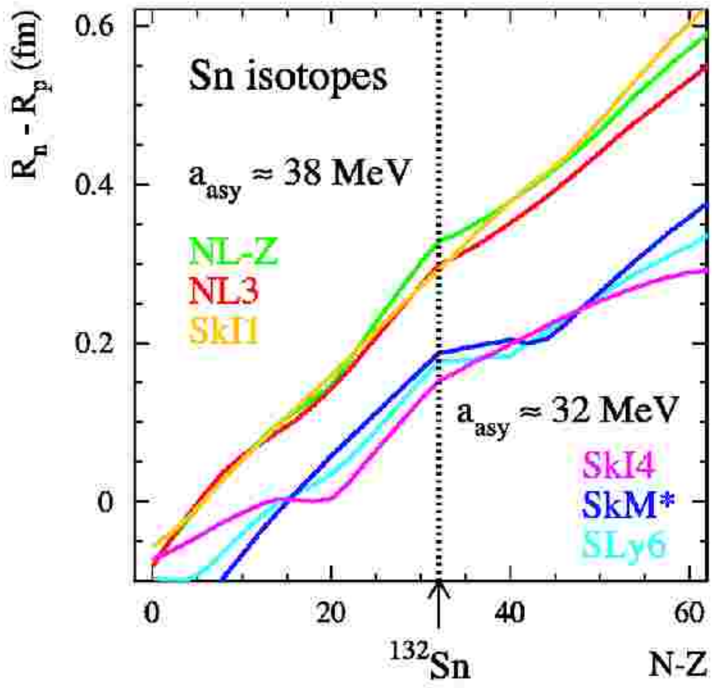
ð unambiguous and “model independent” determination of size and radial shape of neutron skins (halos)

<u>example:</u> Sn isotopes
at the nuclear surface:
almost pure neutron matter

ð probe isospin dependence of effective in-medium interactions

ð sensitivity to the asymmetry energy (volume and surface term!)

theoretical prediction: P.-G. Reinhard



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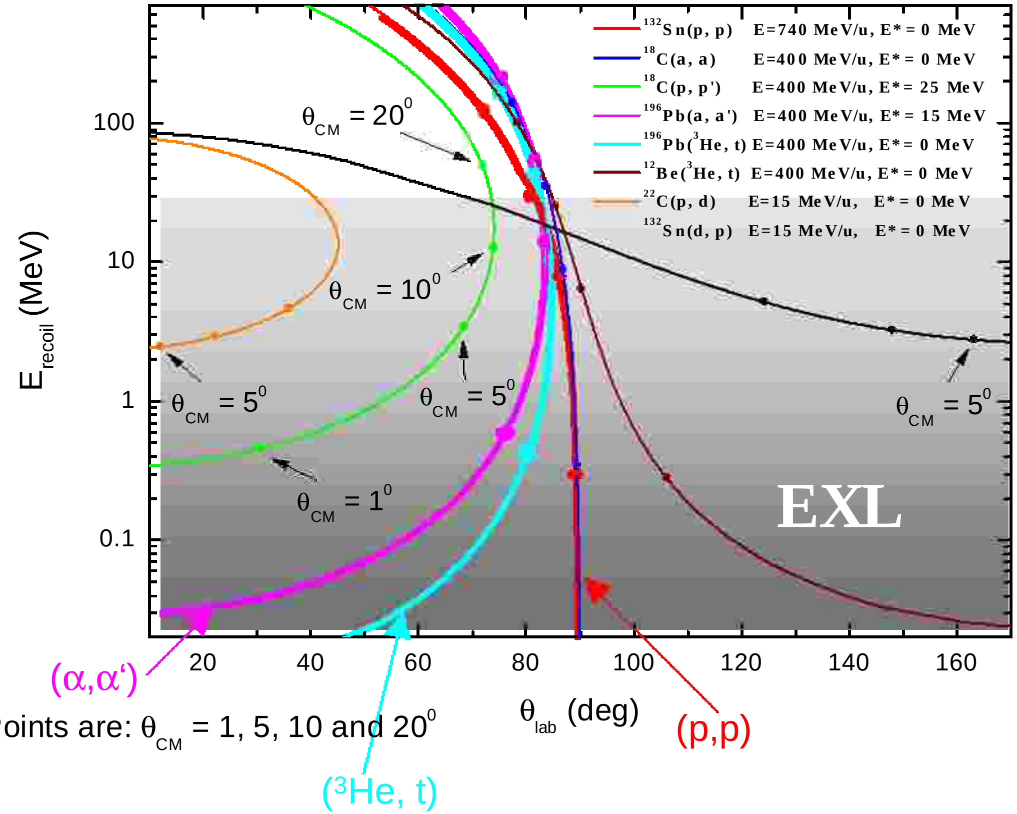
Kinematical Conditions for Light-Ion Induced Direct Reactions in Inverse Kinematics



Points are: θ_{CM} = 1, 5, 10 and 20^0

- required beam energies:
  E ≈ 200 … 740 MeV/u
  (except for transfer reactions)
- required targets: ^{1,2}H, ^{3,4}He
- most important information in region of low momentum transfer
  ⇒ low recoil energies of recoil particles
  ⇒ need thin targets for sufficient angular and energy resolution

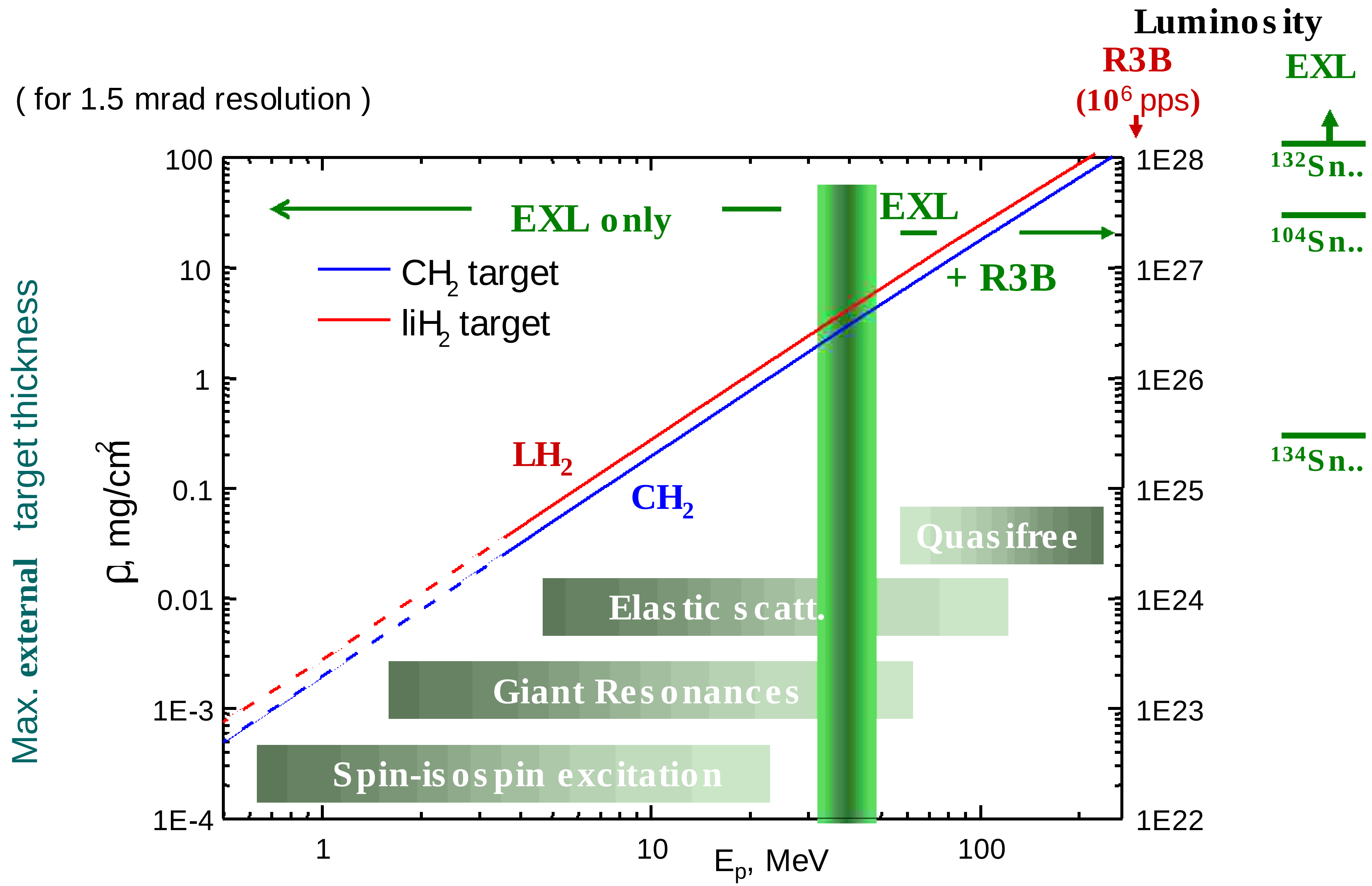
Advantage of Storage Rings for Direct Reactions in Inverse Kinematics

- low threshold and high <u>resolution</u> due to: beam cooling, thin target (10^{14}-10^{15} cm^{-2})
- gain of <u>luminosity</u> due to: continuous beam accumulation and recirculation
- low <u>background</u> due to: pure, windowless $^{1,2}H_2$, $^{3,4}He$, etc. targets
- experiments with <u>isomeric beams</u>

Experiments at very low momentum transfer can only be done at EXL (except with active targets, but with substantial lower luminosity)

Only the world-wide unique combination of Super-FRS and NESR provides high resolution experiments with high luminosity

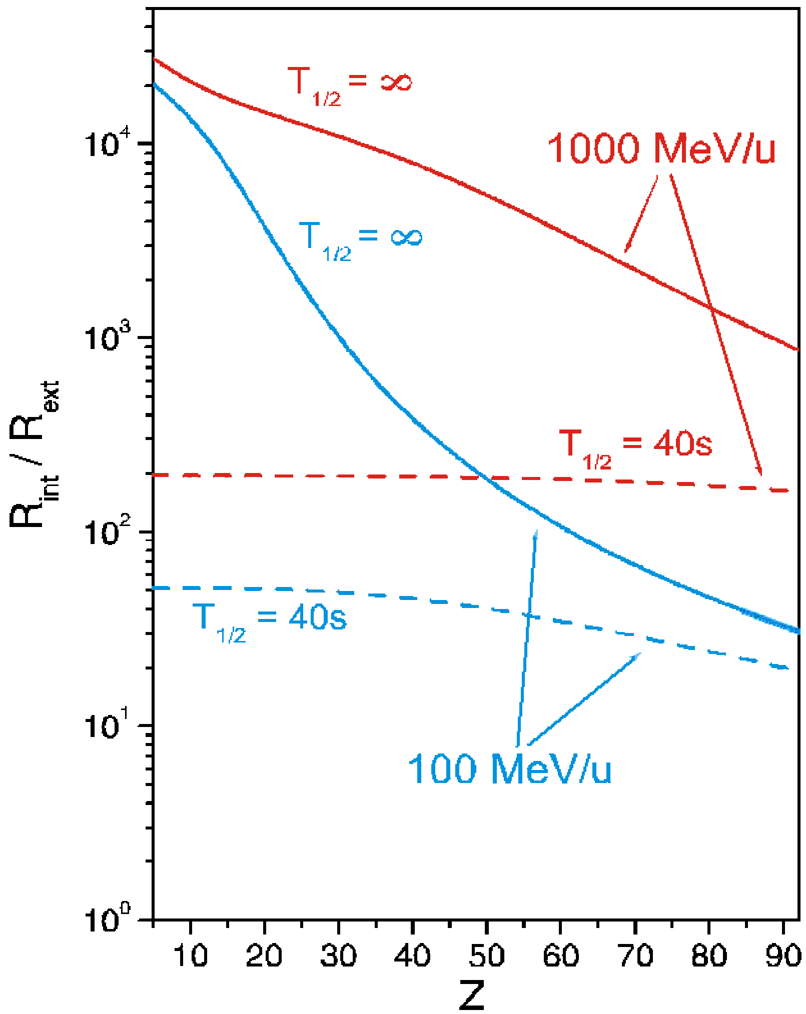
External Target Versus Internal Target



Application of Internal and External Targets – a Comparison

<u>assumptions:</u>
- -- external target: ≤ 1 mg/cm² $(CH_2)_n$
- -- internal target: 10^{14}/cm² hydrogen
  continuous accumulation and stacking
- -- charge exchange cross sections:
  from T. Stöhlker et al.
  (Phys. Rev. A 58 (1998) 2043)

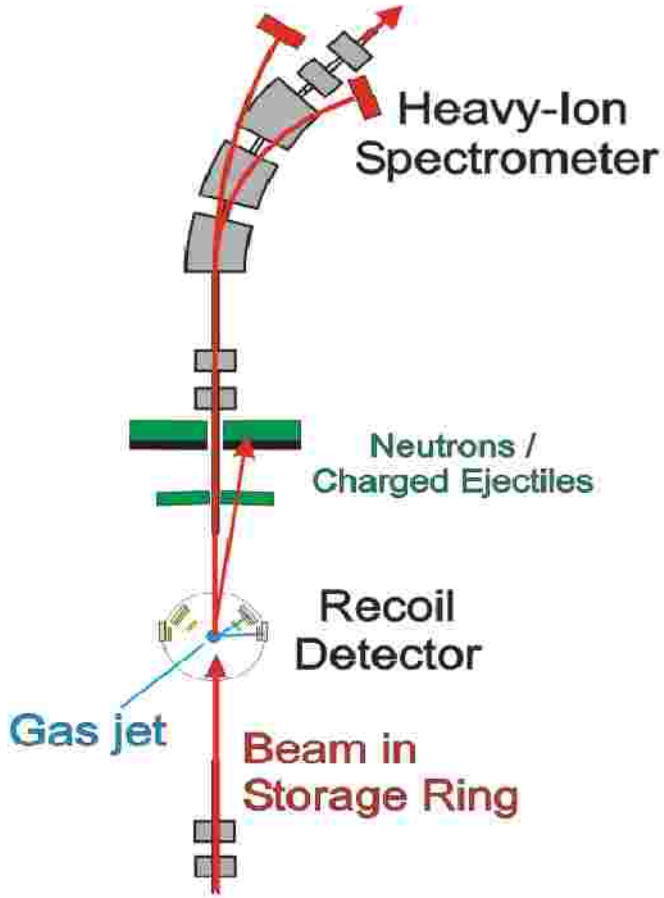
P. Egelhof et al., Phys. Scripta T104 (2003) 151



luminosity gain at internal target depends on:
- Ø energy
- Ø atomic number
- Ø nuclear lifetime

limitations:
- Ø low E and high Z: charge exchange
- Ø high E: nuclear lifetime

II. The EXL Detector Setup - Concept and Design Goals



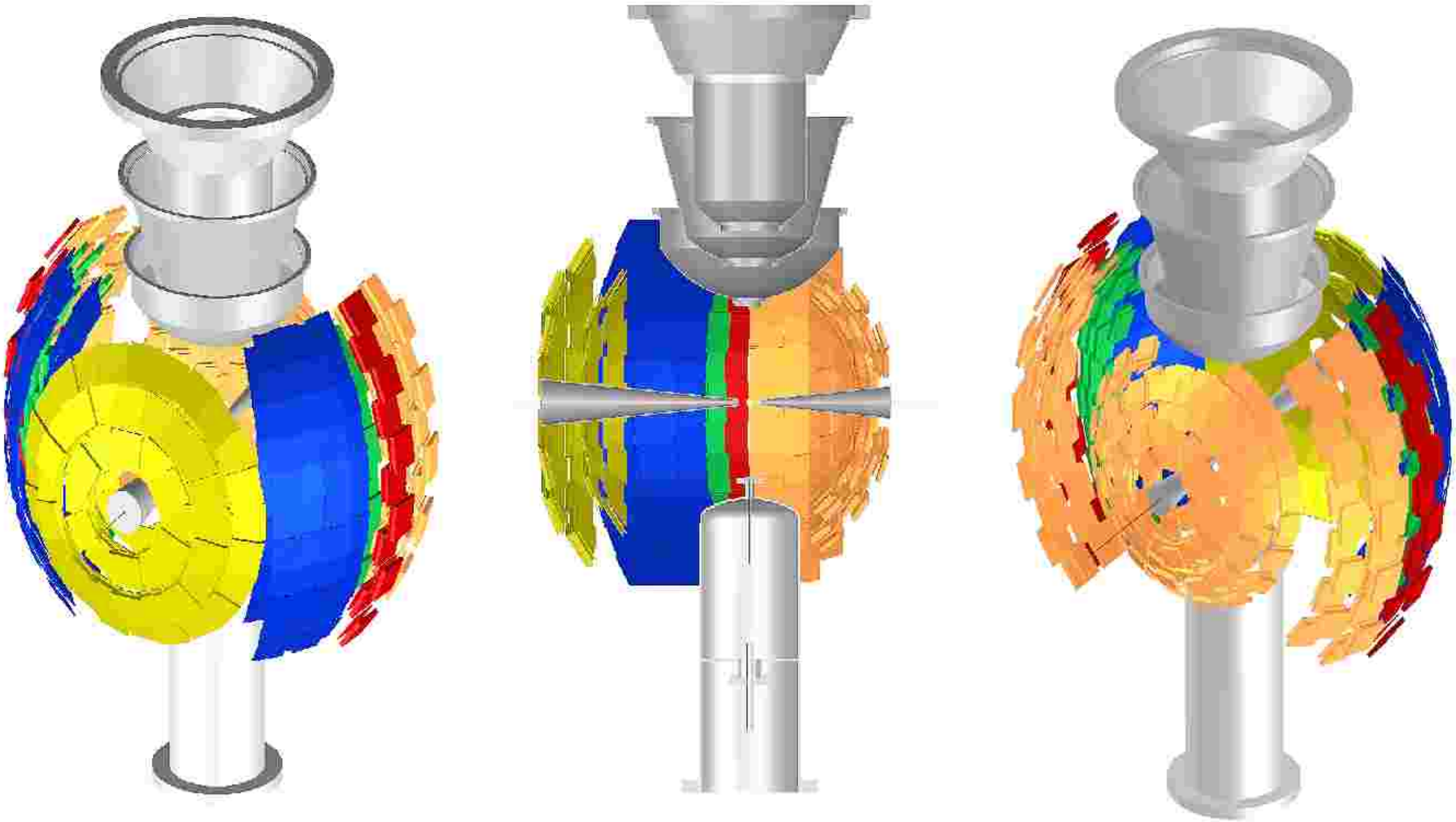
Detection systems for:

- Target recoils and gammas (p,α,n,γ…)
- Forward ejectiles (p,n,γ)
- Beam-like heavy ions

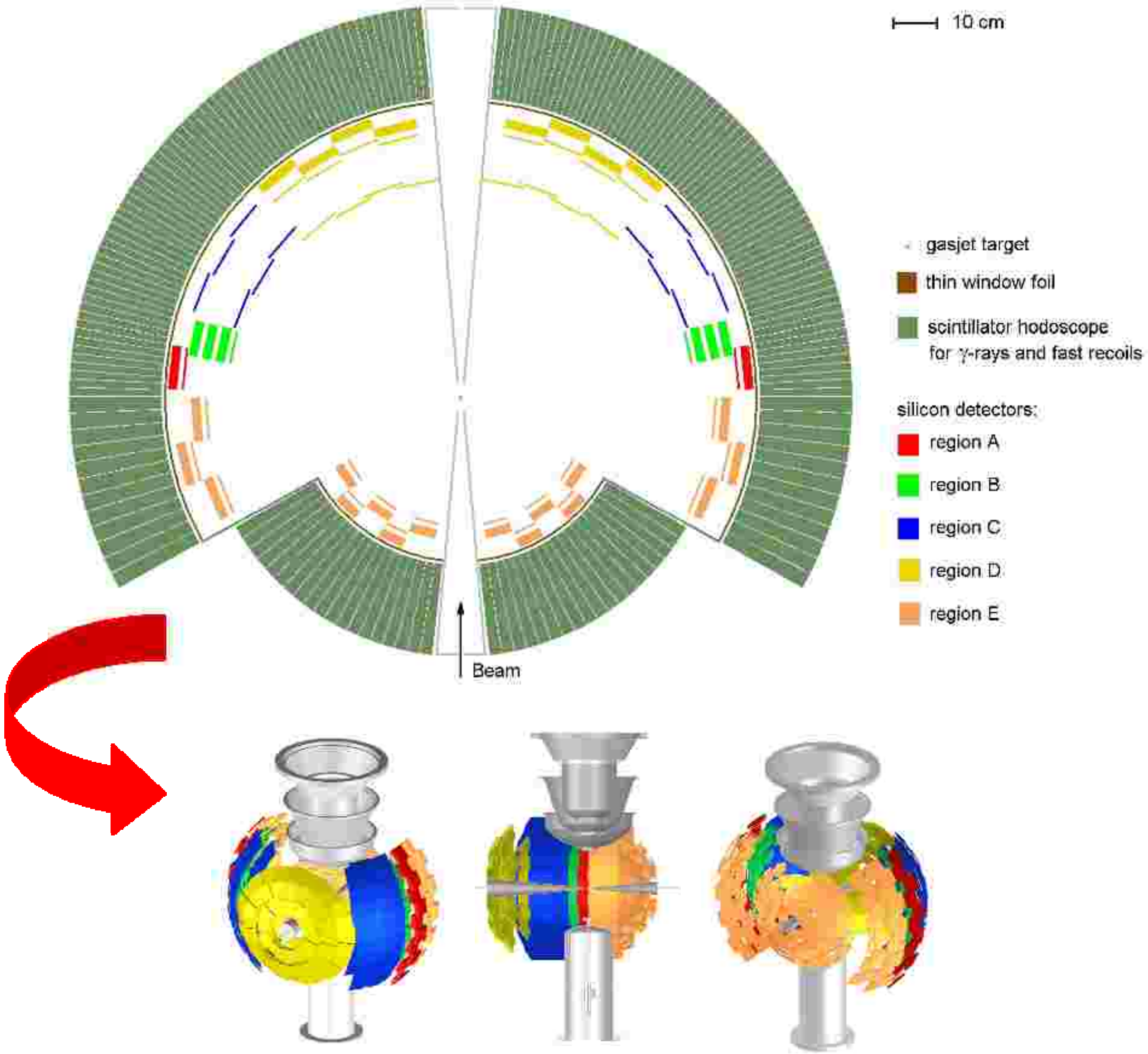
Design goals

- Universality: applicable to a wide class of reactions
- High energy and angular resolution
- Fully exclusive kinematical measurements
- High luminosity (> 10^{28} cm^{-2} s^{-1})
- Large solid angle acceptance
- UHV compatibility (in part)

The EXL Recoil Detector



The EXL Recoil and Gamma Array



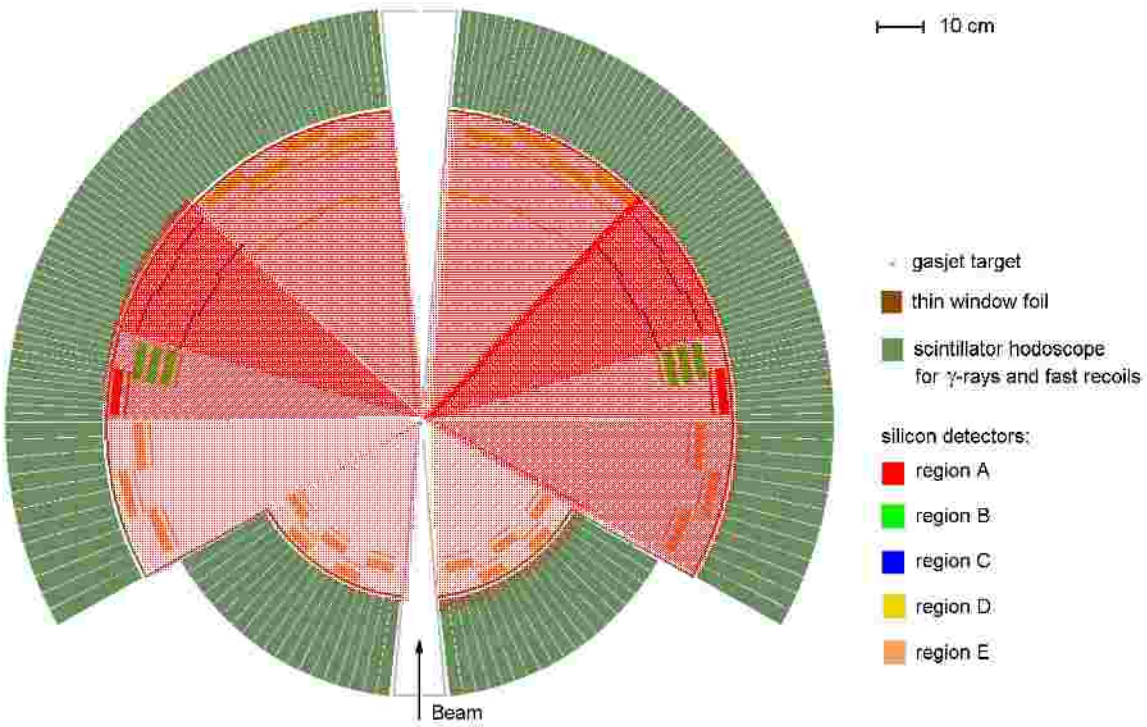
Si DSSD **ð DE, x, y**
300 µm thick, spatial resolution better than 500 µm in x and y,
? E = 30 keV (FWHM)

Thin Si DSSD **ð tracking**
<100 µm thick, spatial resolution better than 100 µm in x and y,
? E = 30 keV (FWHM)

Si(Li) **ð E**
9 mm thick, large area
100 x 100 mm^2,
? E = 50 keV (FWHM)

CsI crystals **ð E, g**
High efficiency, high resolution,
20 cm thick

The EXL Recoil and Gamma Array



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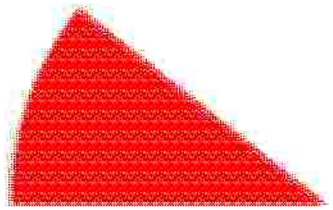


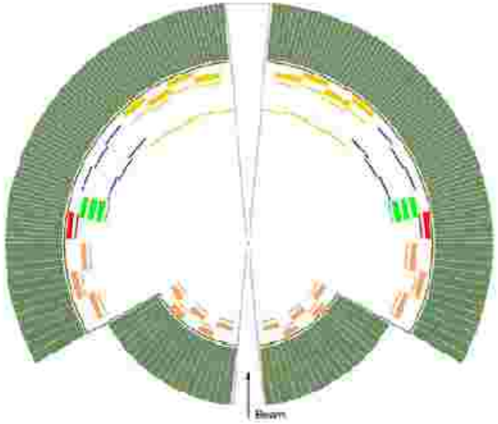
[illegible]

Specifications of the Silicon Detectors for EXL

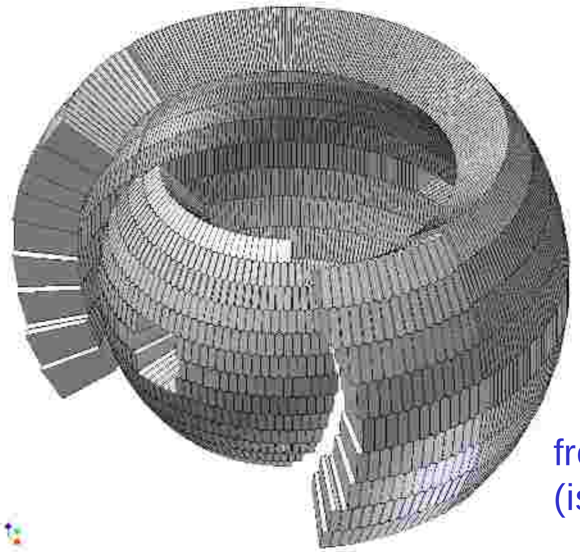
Angular region	T_{lab} [deg]	Detector type	Active area [mm²]	Thickness [mm]	Distance from target [cm]	Pitch [mm]	Number of detectors	Number of channels
A	89 - 80	DSSD Si(Li)	87 x 87 87 x 87	0.3 9	59 60	0.1 -	20 20	34800 180
B	80 - 75	DSSD Si(Li) Si(Li) Si(Li)	50 x 87 50 x 87 50 x 87 50 x 87	0.3 9 9 9	50 52 54 56	0.1 - - -	20 20 20 20	27400 180 180 180
C	75 - 45	DSSD DSSD	87 x 87 87 x 87	0.1 0.3	50 60	0.1 0.1	60 60	104400 34800
D	45 - 10	DSSD DSSD Si(Li)	87 x 87 87 x 87 87 x 87	0.1 0.3 9	49 59 60	0.1 0.1	60 80 80	104400 139200 720
E	170 - 120	DSSD Si(Li)	50 x 50 50 x 50	0.3 5	25 26	0.5 -	60 60	6000 240
E'	120 - 91	DSSD Si(Li)	87 x 87 87 x 87	0.3 5	59 60	0.1 -	60 60	104400 540
Total		DSSD Si(Li)					420 280	555400 2220

Specifications of the Silicon Detectors for EXL

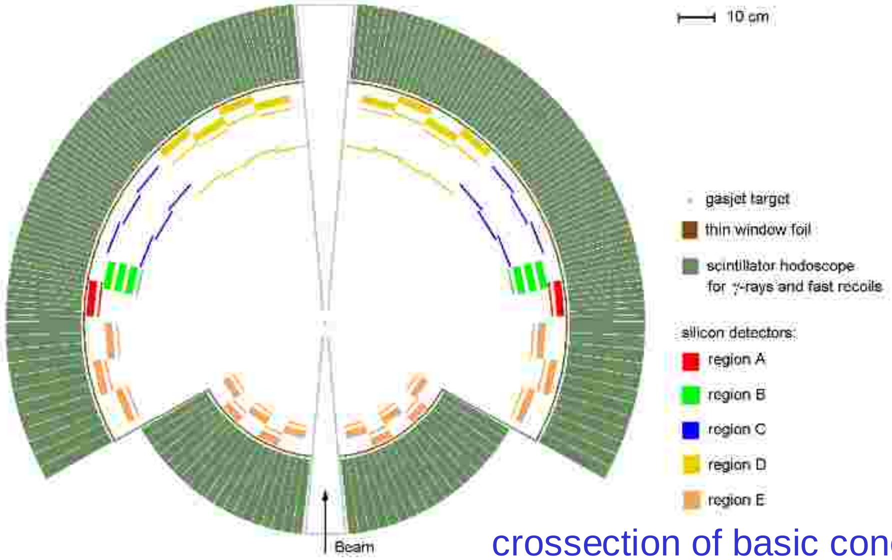
- low threshold = 40 keV
  (⇒ constraints on thickness of entrance windows)
- high energy resolution = 20 keV
- pitch size = 0.5 mm
- active area 65 X 65 mm^2
- large dynamic range: 100 keV to 50 MeV
- readout of energy, time, PSA??
- self triggering
- moderate count rates
- UHV (HV) compatibility (partly)



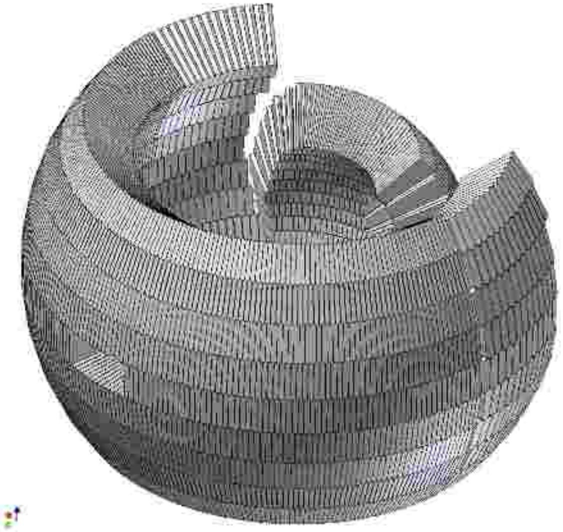
Design Study of the Gamma-Calorimeter



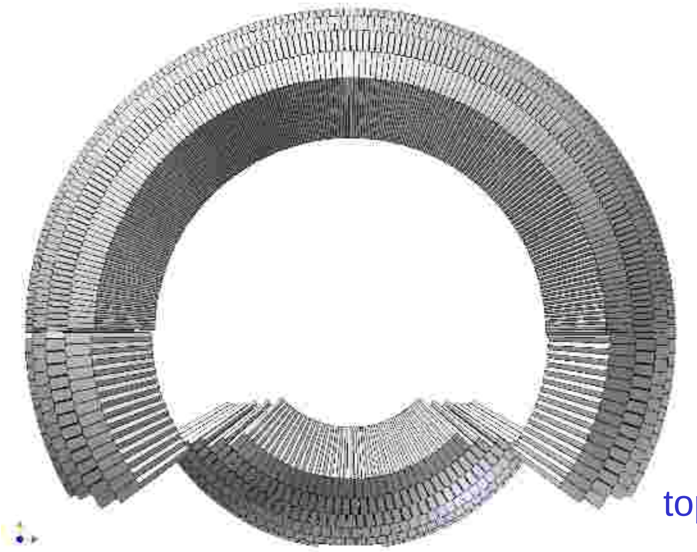
front view
(isometric)



crossection of basic concept



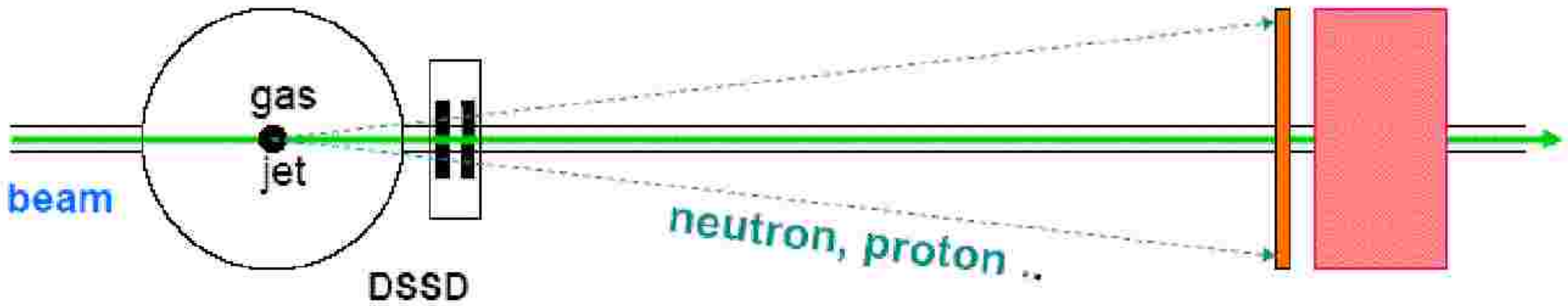
rear view
(isometric)



top view of 3D model

The EXL Forward Ejectile Detector

Kinematically complete measurements:
• detection of forward light particles emitted from the projectile (momenta measured)
• excitation energy of projectile residue, momentum (angular) correlations

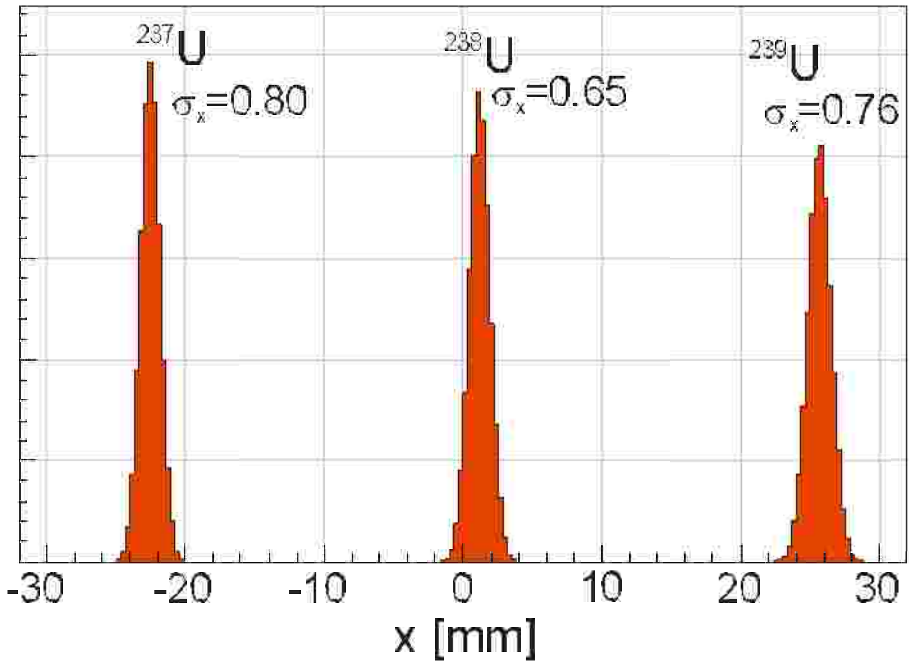


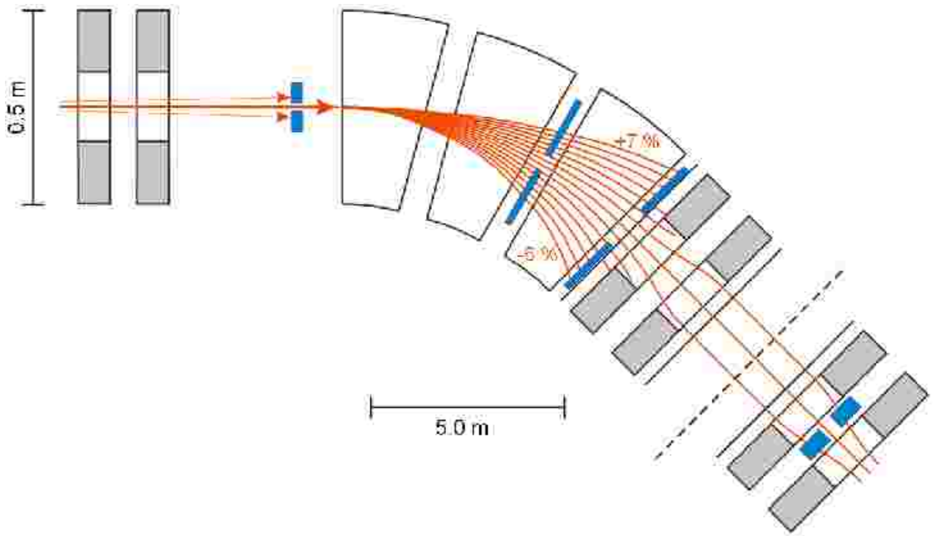
(Phase I)

(Phase II)

• High-resolution TOF and position measurements
• Full solid angle (forward focus)
• Calorimeter: scintillator + iron converter (similar to LAND)

The EXL In-Ring Heavy-Ion Spectrometer





- **Ion-optical mode for NESR as fragment spectrometer**
- **3 heavy-ion detector stations:**

• <u>in front of first dipole magnet for 'reaction tagging‘ (main mode)</u>
• inserted into dipole section for 'tracking' of fragments
• inserted into quadrupole section for 'imaging' properties of magnetic Spectrometer (limited acceptance)

Predicted Luminosities

Target: 10^{14} H atoms cm^{-2}; beam losses included

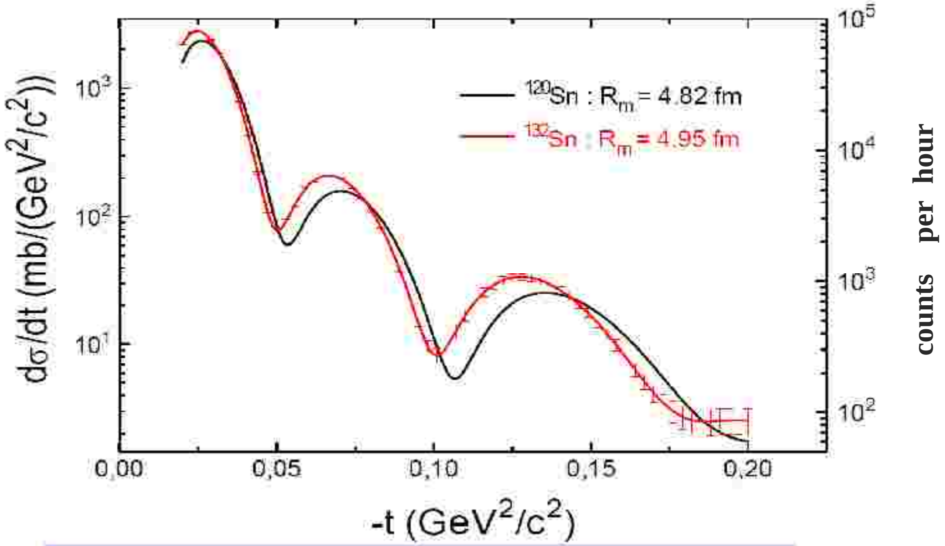
Nucleus	production rate at S-FRS target [1/s]	Lifetime including losses in NESR [s]	740 A.MeV Luminosity [cm^{-2} s^{-1}]	100 A.MeV Luminosity [cm^{-2} s^{-1}]	Luminosity [cm^{-2} s^{-1}] (preliminary)
^{11}Be	2×10^{9}	36	$> 10^{28}$	$> 10^{28}$	
^{46}Ar	6×10^{8}	20	$> 10^{28}$	$> 10^{28}$	8×10^{26}
^{52}Ca	4×10^{5}	12	2×10^{26}	4×10^{25}	9×10^{23}
^{55}Ni	8×10^{7}	0.5	6×10^{26}	5×10^{25}	4×10^{10}
^{56}Ni	1×10^{9}	3800	$> 10^{28}$	$> 10^{28}$	5×10^{26}
^{72}Ni	9×10^{6}	4.1	2×10^{27}	3×10^{26}	2×10^{23}
^{104}Sn	1×10^{6}	51	3×10^{27}	6×10^{26}	3×10^{25}
^{132}Sn	1×10^{8}	93	$> 10^{28}$	$> 10^{28}$	1×10^{27}
^{134}Sn	8×10^{5}	2.7	3×10^{25}	5×10^{24}	4×10^{20}
^{187}Pb	1×10^{7}	34	$> 10^{28}$	3×10^{27}	5×10^{25}

Options to be explored: Deceleration, Multi-charge state operation *(increase luminosity)* ?

Expected Performance

Elastic proton scattering ^{132}Sn (Matter Distribution)

Skin and halos in heavy neutron-rich nuclei

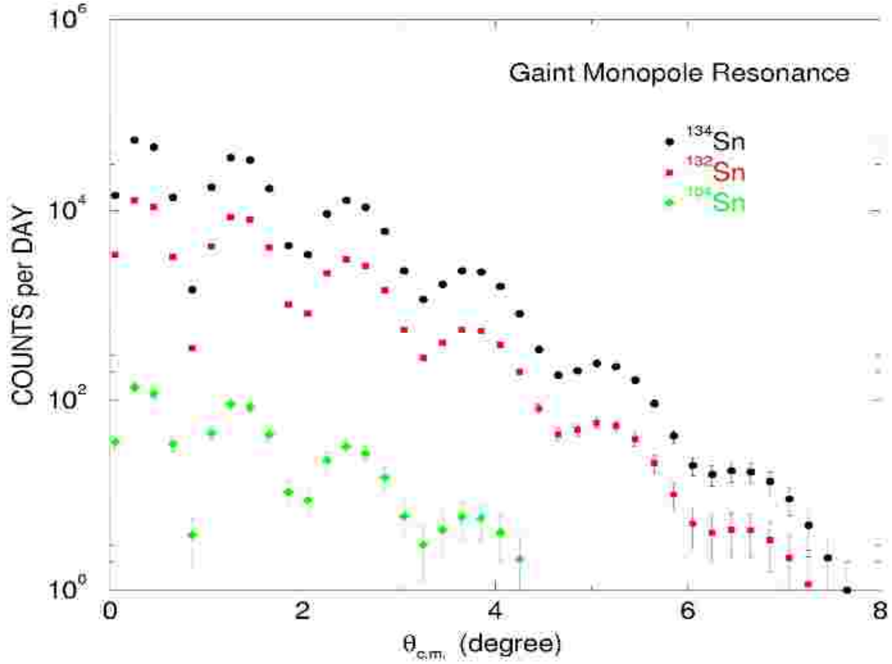


High sensitivity of the method (simulation of experimental conditions as expected at the NESR with a luminosity of 10^{28} cm^{-2} s^{-1})

at present ESR: needs 500 days !!!

Inelastic alpha scattering on Sn isotopes (Giant Monopole Resonance)

Collective modes in asymmetric nuclei, nuclear matter compressibility



at present ESR: needs 10000 days !!!

III. R&D on the EXL Recoil Detector

Aim: determine spectroscopic properties: ? E, ? (dE), efficiency, PSD
resolution of total energy reconstruction
UHV capability

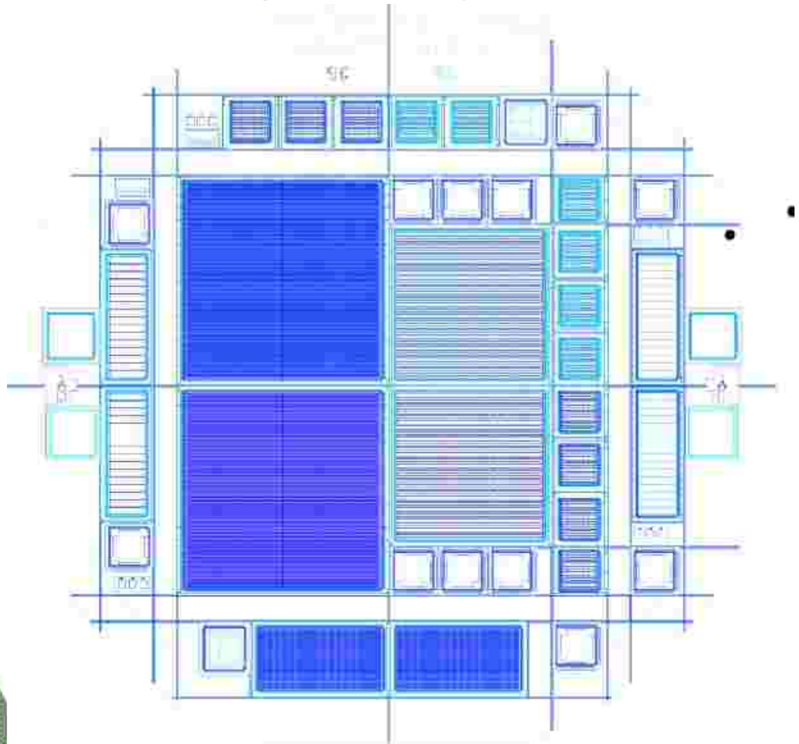
Detectors: 1st series of DSSDs from PTI St. Petersburg
(8 sensors delivered April 2008/ September 2009)
2nd series of DSSD`s with larger size (65 x 65 mm^2)
(5 sensors delivered January 2010)

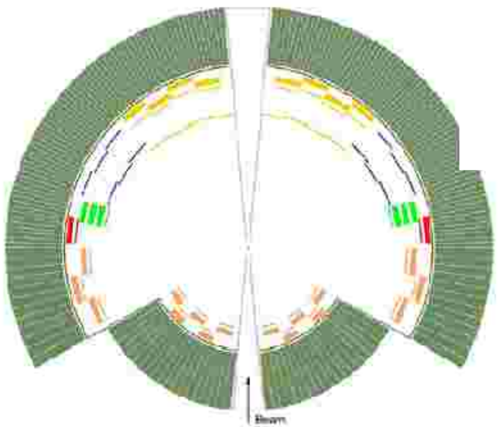
Tests:
2008/2009: GSI: a sources
2008: Edinburgh: a sources
April 2009: KVI Groningen: protons of 50 MeV
July 2009: TU München: a particles E < 30 MeV
September 2009: GSI: protons of 100 and 150 MeV
April 2010: KVI Groningen: protons of 135 MeV
January 2011: TU Tübingen: protons of 1.5 MeV down to 70 keV

Status and Perspectives of R&D

Si - Detectors: DSSD`s

sensors provided by PTI St. Petersburg (V. Eremin et al.)



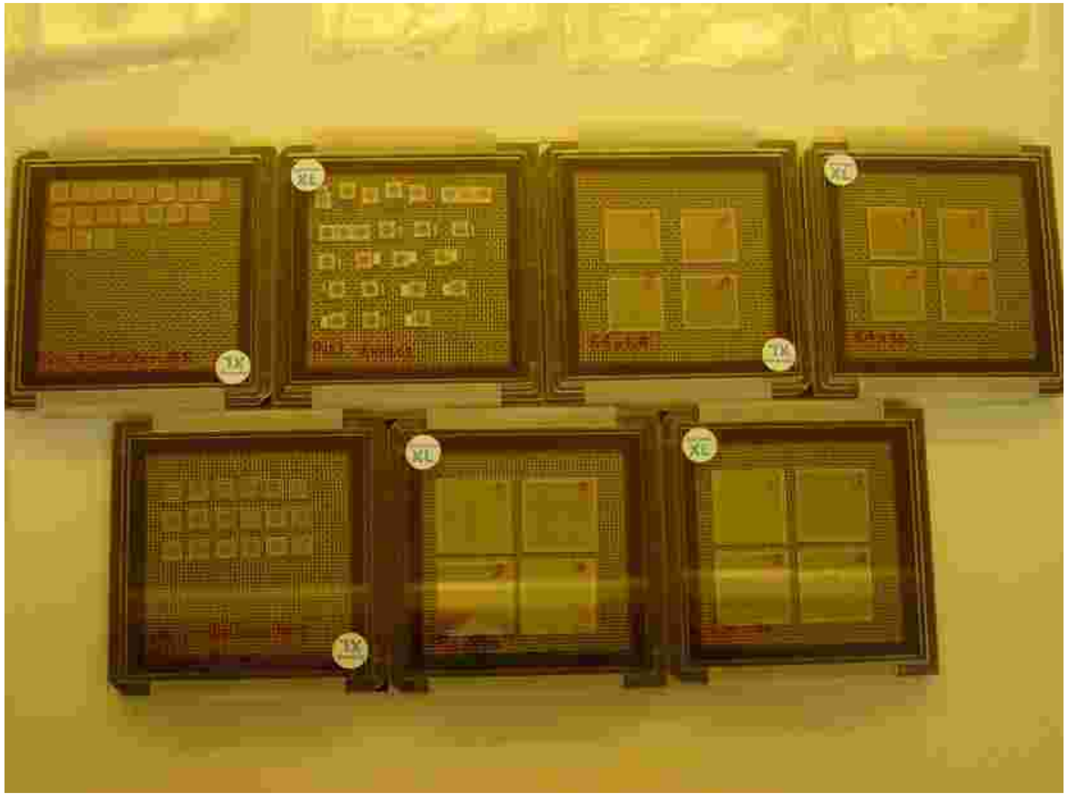


⇒ various test structures for R&D:

a) 21 x 21 mm², strip pitch 300 µm on both sides
b) 27 x 27 mm², strip pitch 100 µm on both sides
c) 27 x 27 mm², strip pitch 100 µm, and 2.5 mm on the other side
d) 21 x 21 mm², strip pitch 300 µm, and 1.25 mm on the other side
e) many smaller-size test structures

DSSD Chips

Production – PTI St. Petersburg (Russia) Si wafer (300nm thick, 4”)

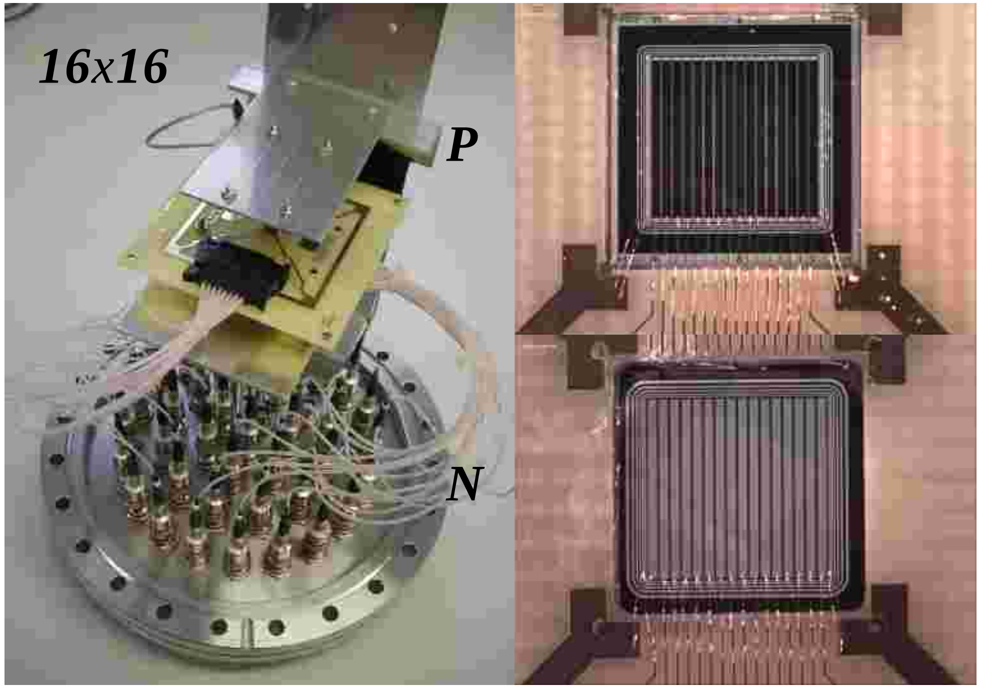


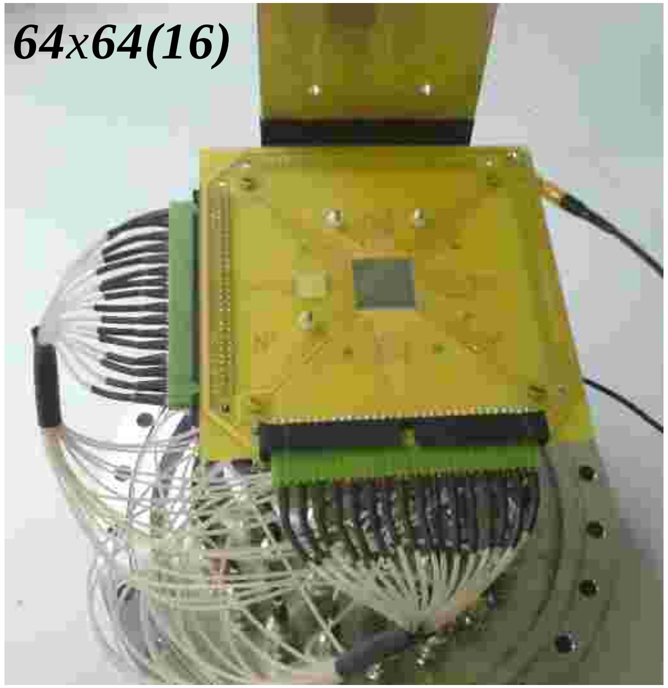
Available DSSDs

pitch	P^+	N^+	No
300µm	16	x 16 (FP):	20
300µm	16	x 16 (P^+):	20
300µm	64	x 16:	4
300µm	64	x 64:	4
100µm	256	x 16:	4
100µm	256	x 256:	4
	PIN:		30

Detector Construction at GSI

- Construction of prototype DSSDs at GSI: **16**x**16** (*4*), **64**x**64** (*4*) + **64**x**16** (*4*)
- Both types use FR-4 PCB with epoxy-glued DSSD chips
- Wedge bonded



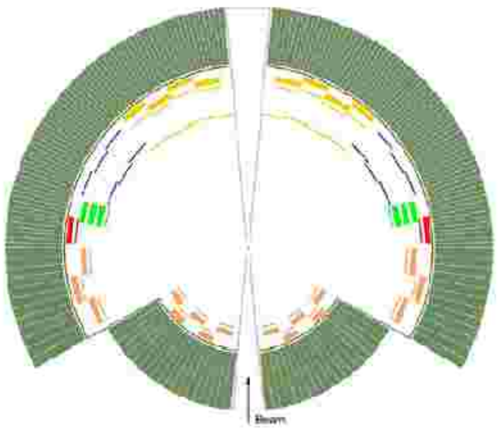


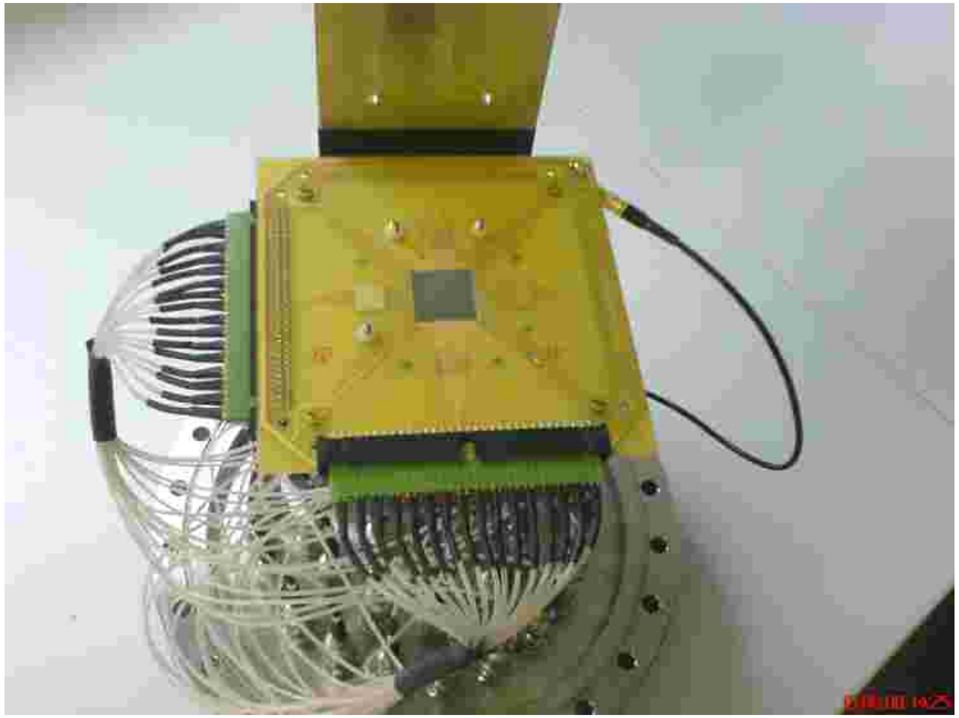
Status and Perspectives of R&D

Si - Detectors: DSSD`s

sensors provided by PTI St. Petersburg (V. Eremin et al.)

setup of working detectors (PCB-board, bonding, readout) at GSI
⇒ 9 detectors: 16X16, 64X16, 64X64 strips, d=300 μm





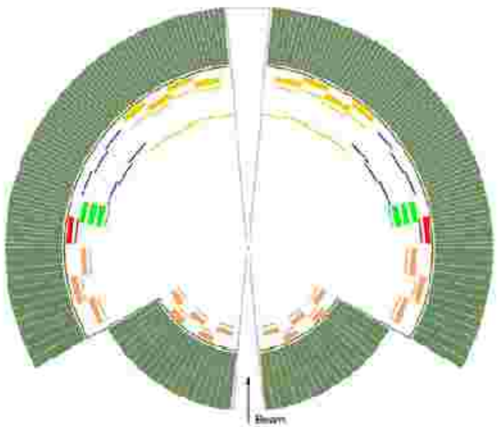
Status and Perspectives of R&D

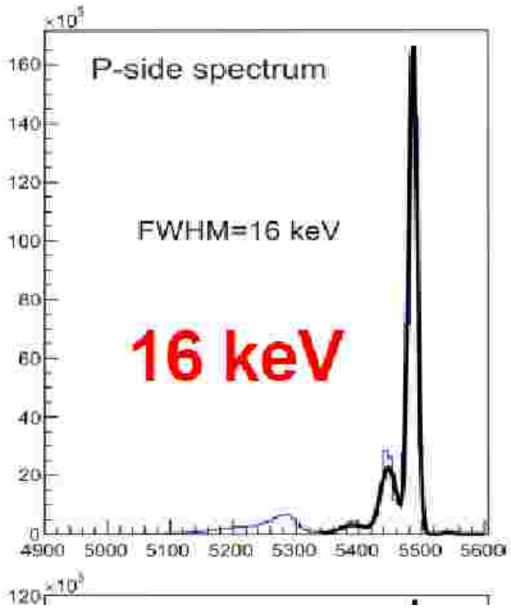
Si - Detectors: DSSD`s

sensors provided by PTI St. Petersburg (V. Eremin et al.)

setup of working detectors (PCB-board, bonding, readout) at GSI
⇒ 9 detectors: 16X16, 64X16, 64X64 strips, d=300 µm

detector tests with a-source performed at GSI and Edinburgh
⇒ up to 128 channels read out, up to 99% working strips, ?E=16keV

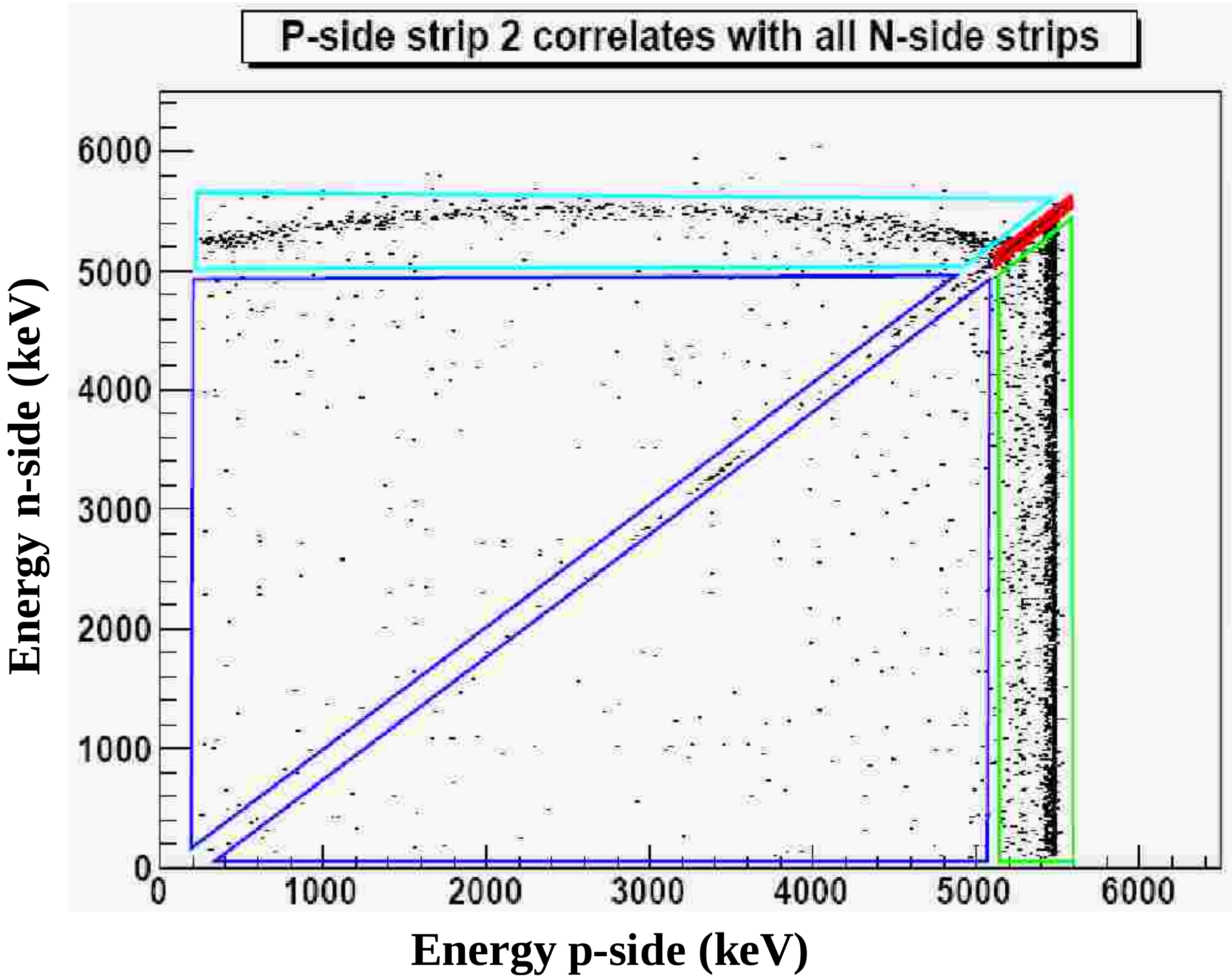




front-rear correlation analysis
⇒ energy resolution and efficiency for p-side and n-side injection

⇒ results to be used as input for design of next generation detectors

Front-Rear Side Correlation Analysis



Event type
P - N

Strip – Strip 76.8 %

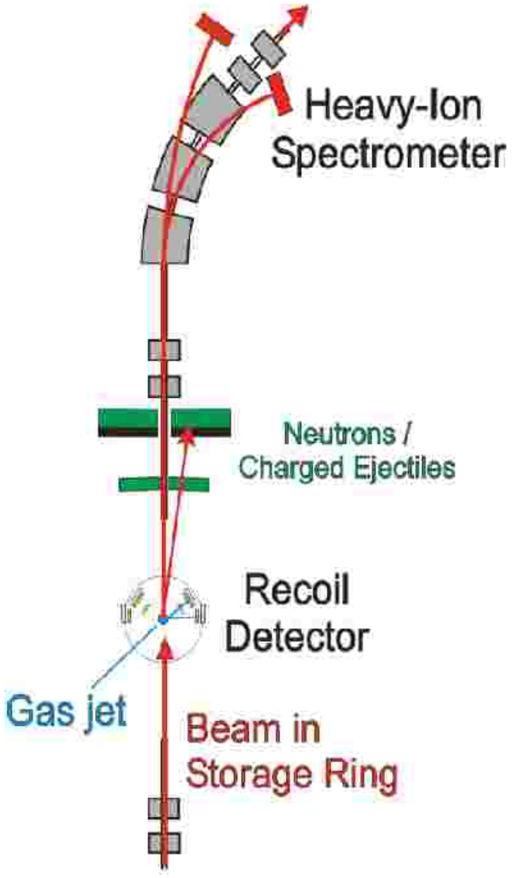
Strip – Interstrip 18,2%

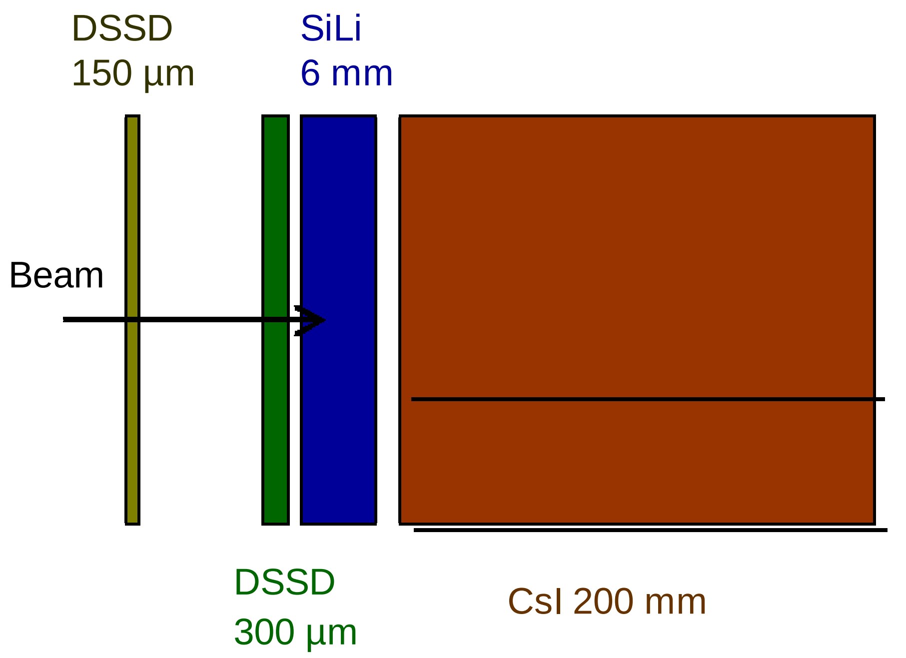
Interstrip – Strip 4,1%

Interstrip – Interstrip 0,9%

Probabilities correspond to pitch structure !

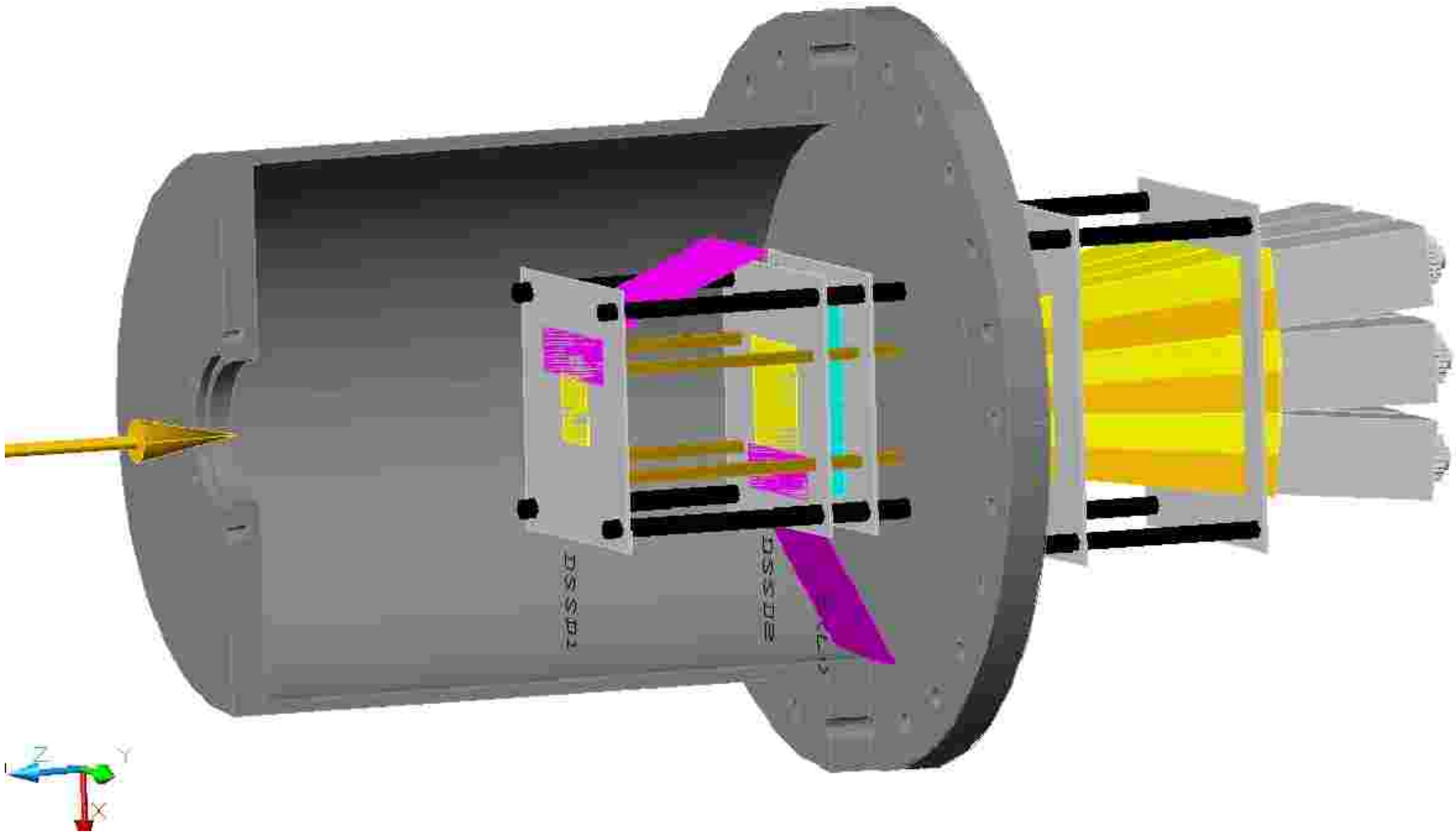
In-Beam Tests with the EXL Demonstrator



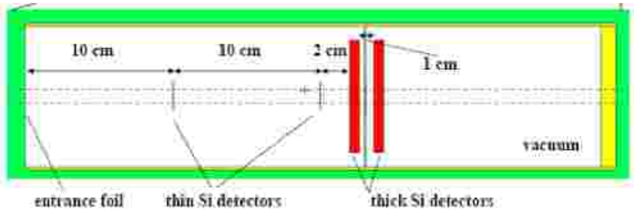


First DSSD – 3 x 3 cm², 64 x 64 strips, pitch 300 µm
Second DSSD – 3 x 3 cm², 64 x 64 strips, pitch 300 µm
SiLi – 9 x 5 cm², 4 x 2 pads
CsI – 3 x 3 crystals with the individual readout

The EXL Demonstrator

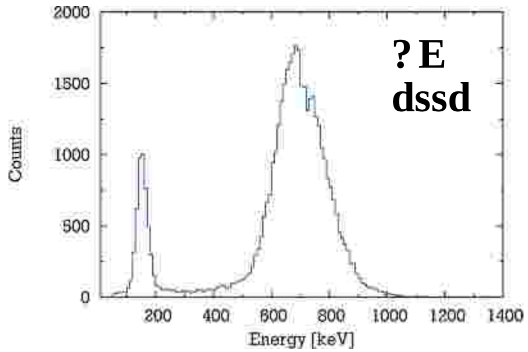


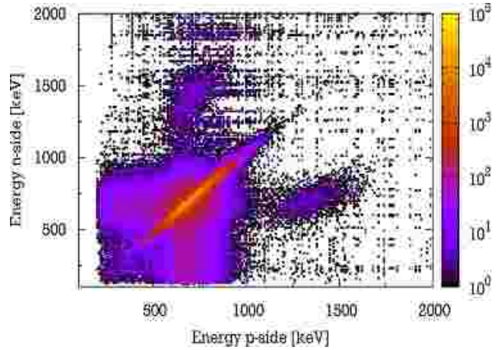
In-Beam Tests at KVI Groningen with 50 MeV Protons

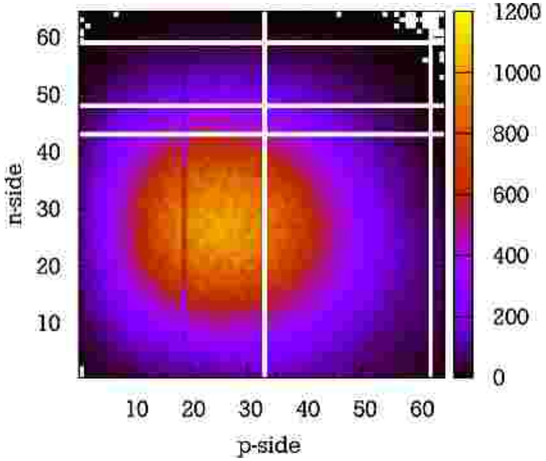


set-up

N/P

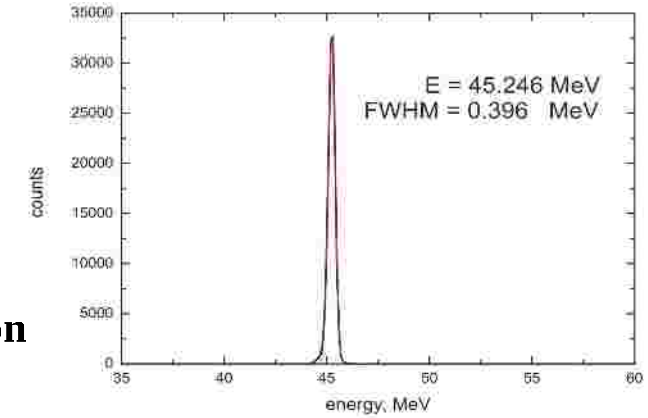






Beam profile

Total energy reconstruction

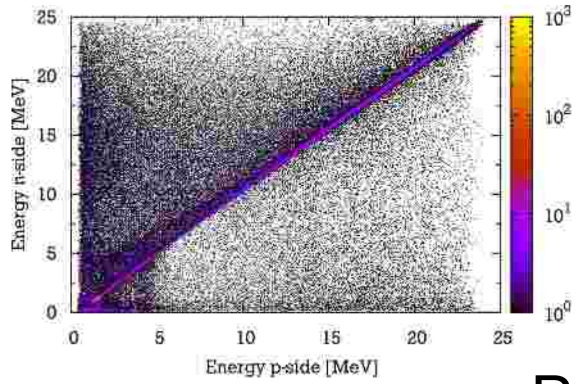


Pulse-Shape Discrimination with DSSD`s

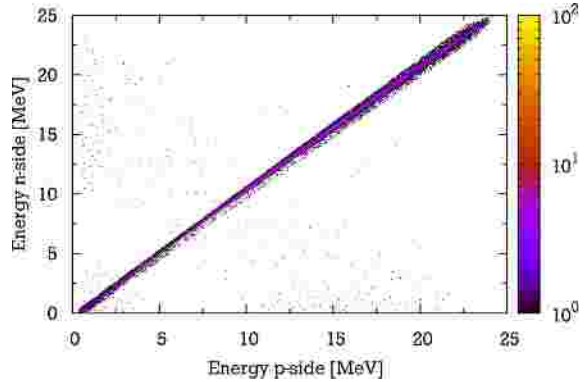
test with p, d, ^{4}He from
^{12}C + ^{12}C @ 70 MeV
TU Munich

M. von Schmid et al.
NIM A629 (2011)197

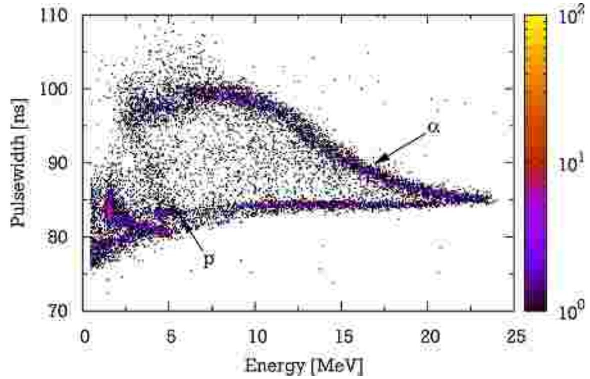
Strip & Interstrip

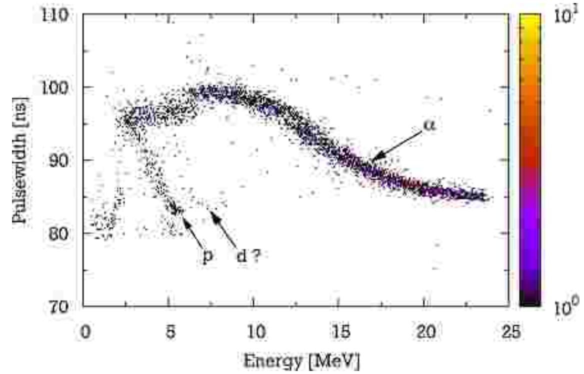


Strip (stopped a ‘s)



P/N





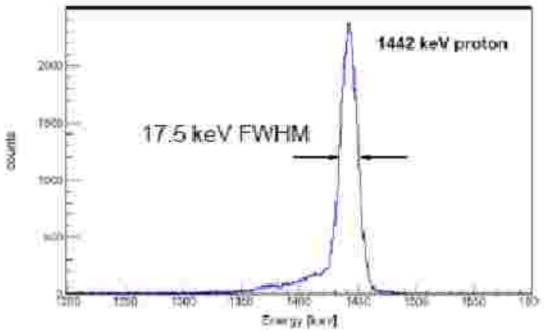
PSD

DSSD strip-strip events show PSD comparable with single PIN diodes

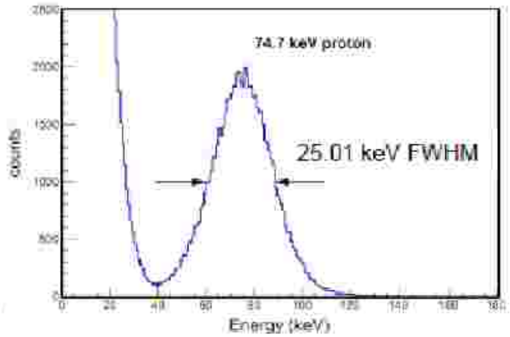
Response to very low energy recoil particles

experiment performed at the 1.5 MV
Van de Graf accelerator at the Univ. Tübingen

- 1503keV protons scattered from C target (37µg/cm²)
- Spectrum shows strip #11 (p side)

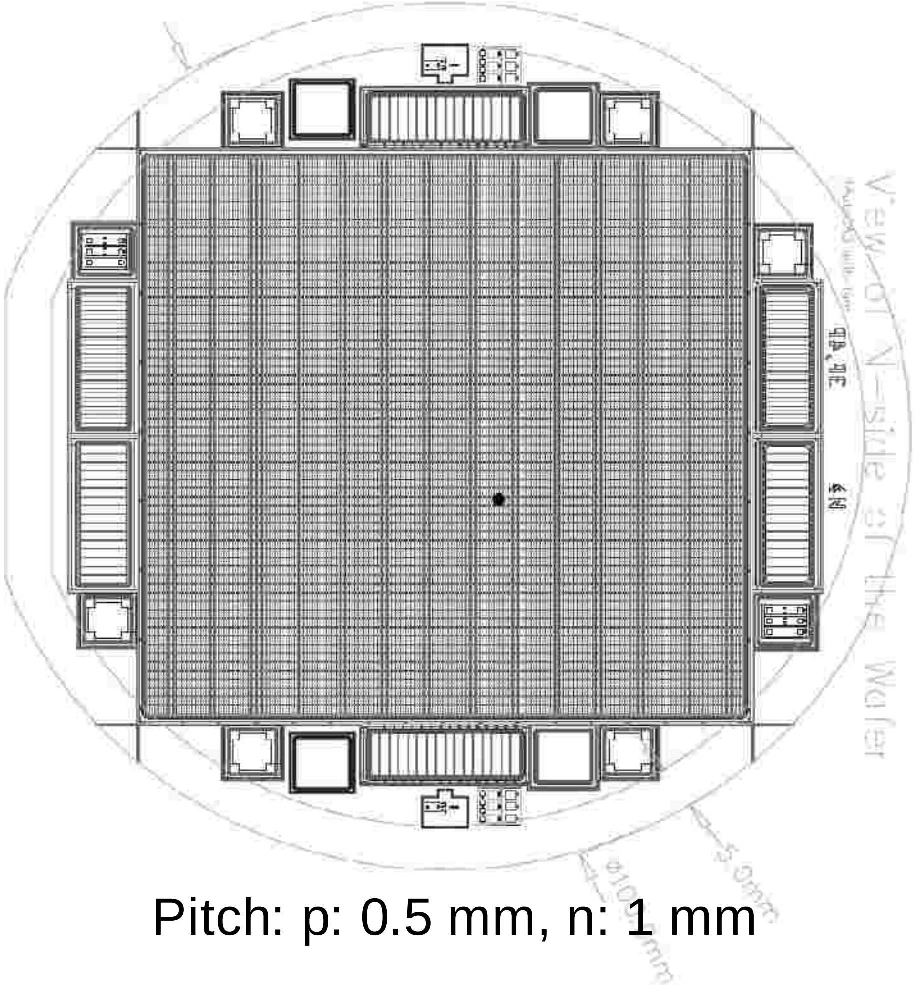


- 818keV H_2 scattered from C target (37µg/cm²), ~3.5µm Mylar degrader in front of DSSD
- Spectrum shows strip #11 (p side)



Pespectives:
2nd Series of DSSD`s from PTI St. Petersburg: 64 X 64 mm^2

65 x 65 mm^2



Pitch: p: 0.5 mm, n: 1 mm

Specification:

<u>Single-crystal silicon</u>: 7 - 20 kOhm× cm
<u>Diode structure:</u> p+ (strips) – i - n+ (strips), orthogonal, n+ - strip insulation, p+ implant
<u>Diode area:</u> 65 x 65 mm^2
<u>Diode topology:</u> Strips on p+ side, 128
Strips on n+ side, 64
<u>Diode thickness:</u> 300 µm
<u>Operational reverse voltage limit:</u> > 100 V

Impact from GSI tests:

<u>Improved p-side layout:</u>

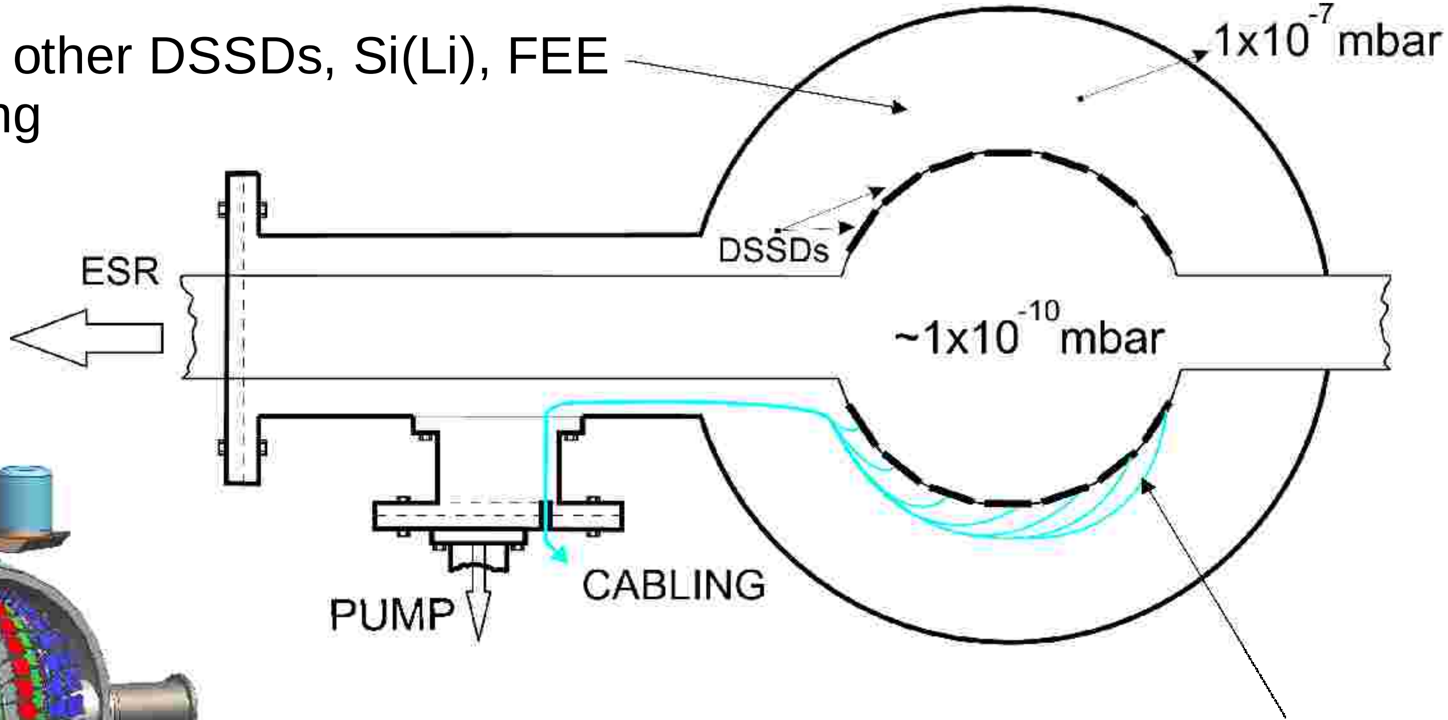
- P-side inplantation depth reduced
- Smaller contact stips at p-side
- Interstrip gap reduced to 10 µm

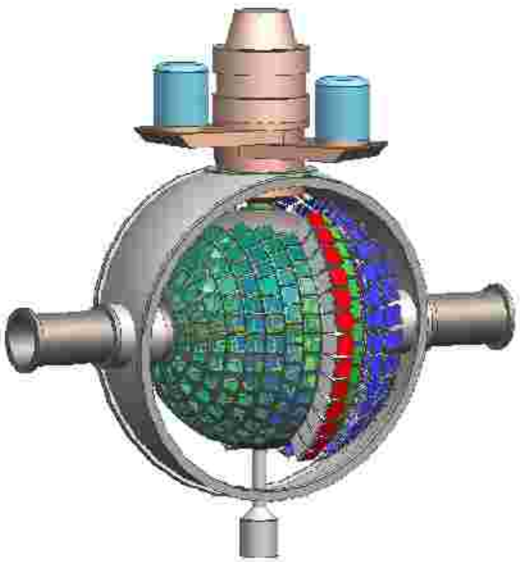
2nd Series of DSSD`s from PTI St. Petersburg: 64 X 64 mm^2

UHV Capability of the EXL Silicon Ball:
Concept: using DSSD`s as high vacuum barrier

- Differential pumping proposed to separate NESR vacuum m EXL instrumentation (cabling, FEE, other detectors)

Space for other DSSDs, Si(Li), FEE and cabling

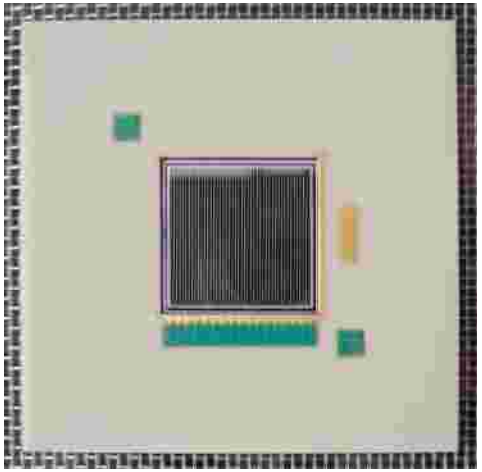




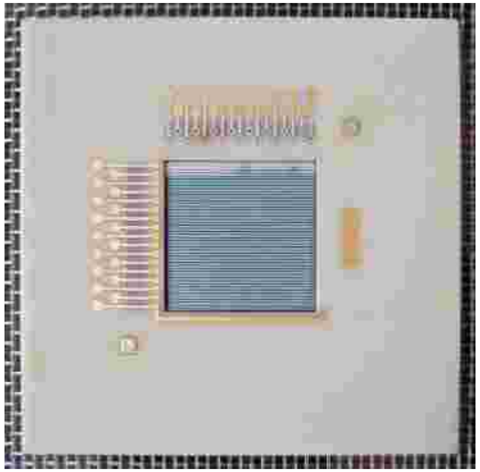
Inner shell of DSSDs on support frame forms (bakeable) vacuum barrier

UHV-Barrier DSSD Prototype Design

P-side: in UHV



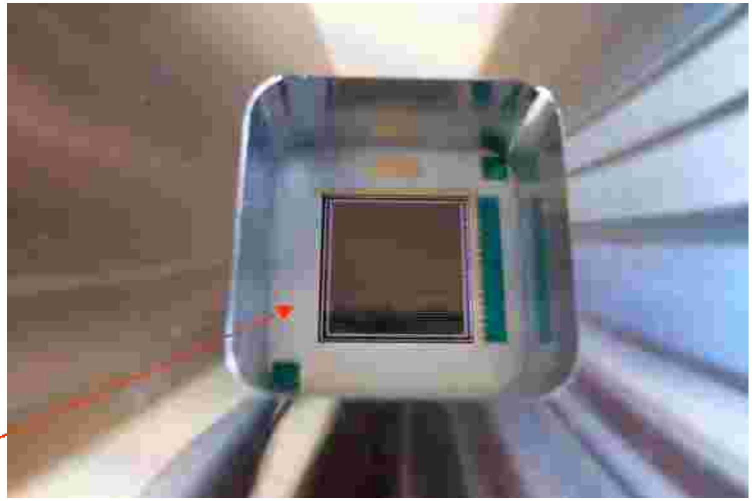
N-side



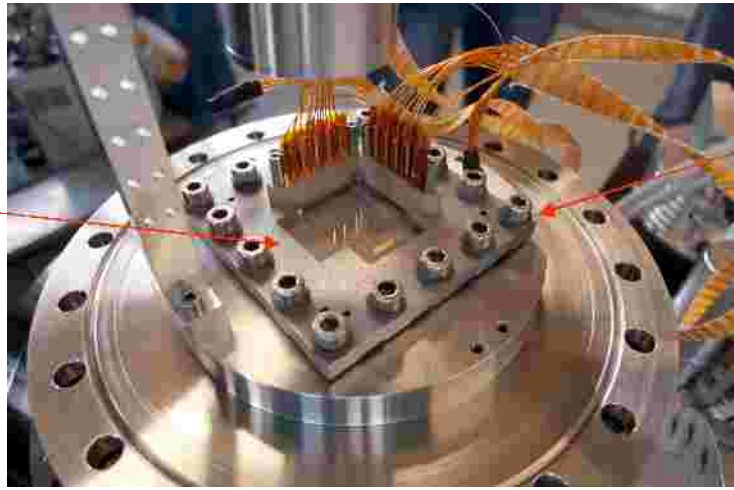
LUST HYBRID-TECHNIK

21 x 21 mm^2 DSSD with 64x64(16) strips mounted into AlN PCB of 60 x 60 mm^2

P-side towards UHV



N-side and spring-pin connectors at auxiliary vacuum



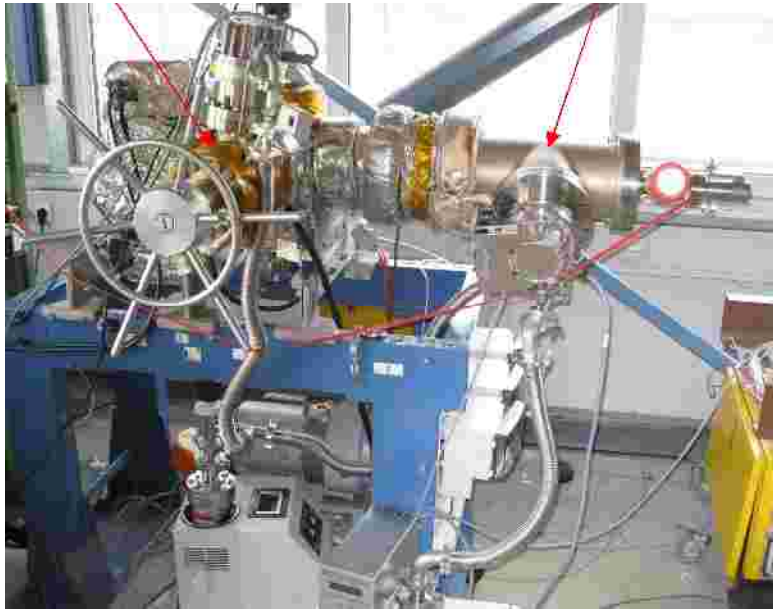
Cup springs

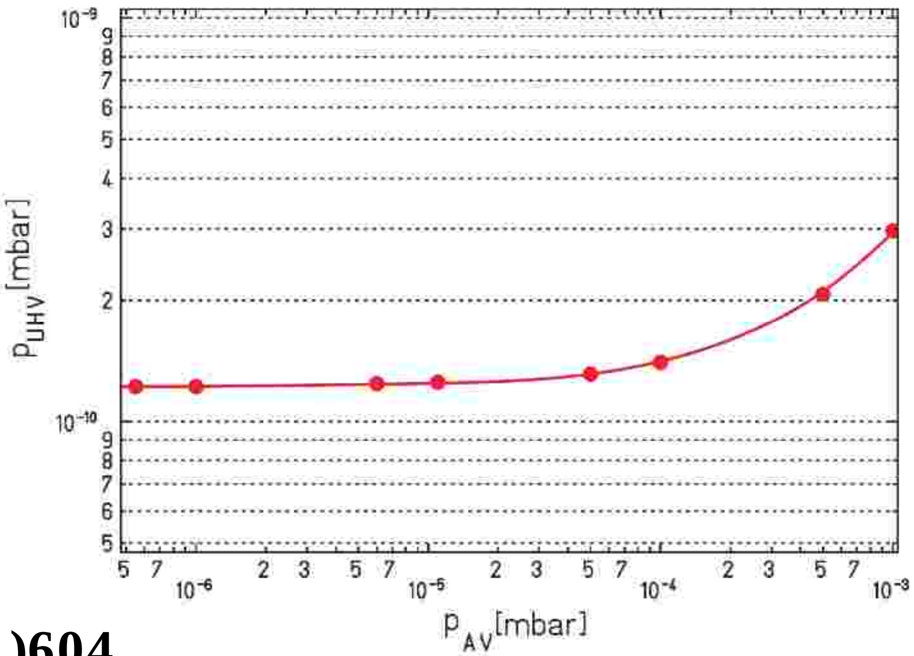
IDI INTERCONNECT DEVICES, INC.

Differential Vacuum Test

- Differential vacuum test using **real DSSD** as a vacuum barrier
  - 6 orders of magnitude difference between low and UH vacuum in wide pressure region
- Vacuum of **$1.2 * 10^{-10}$ mbar** reached – pumping limit of the station

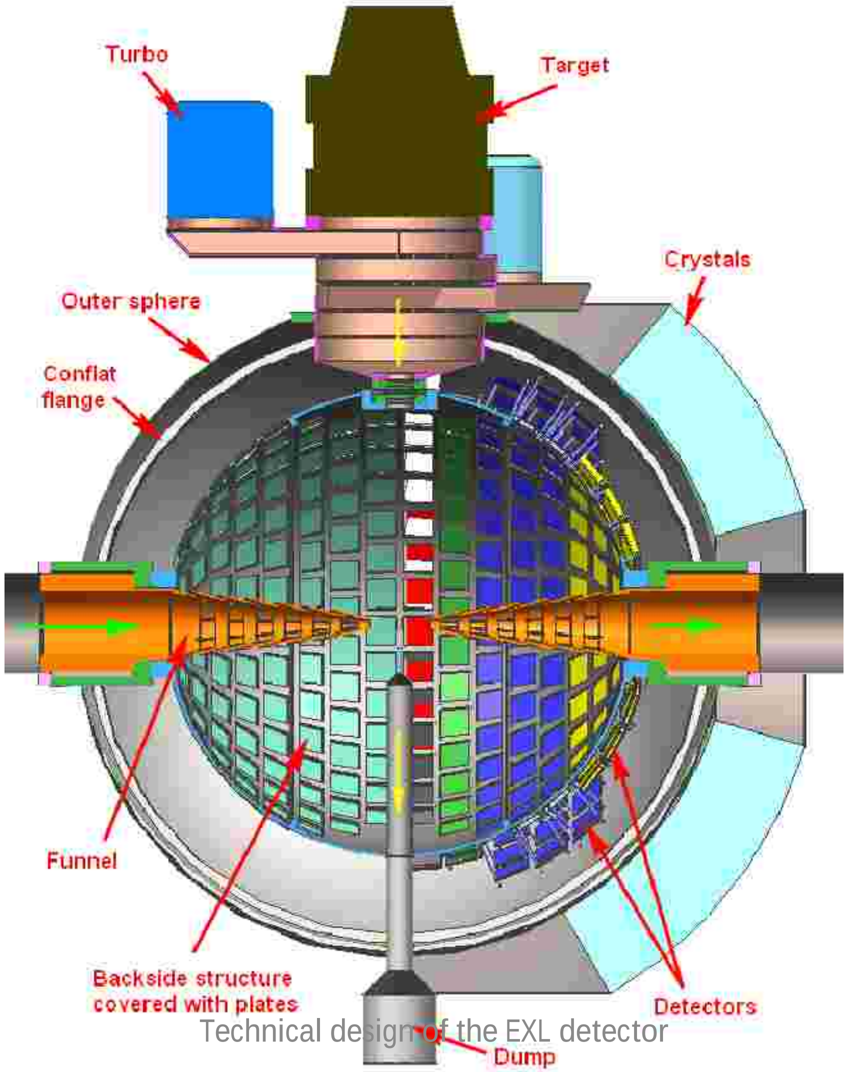
UHV part Low vacuum part Vacuum separation





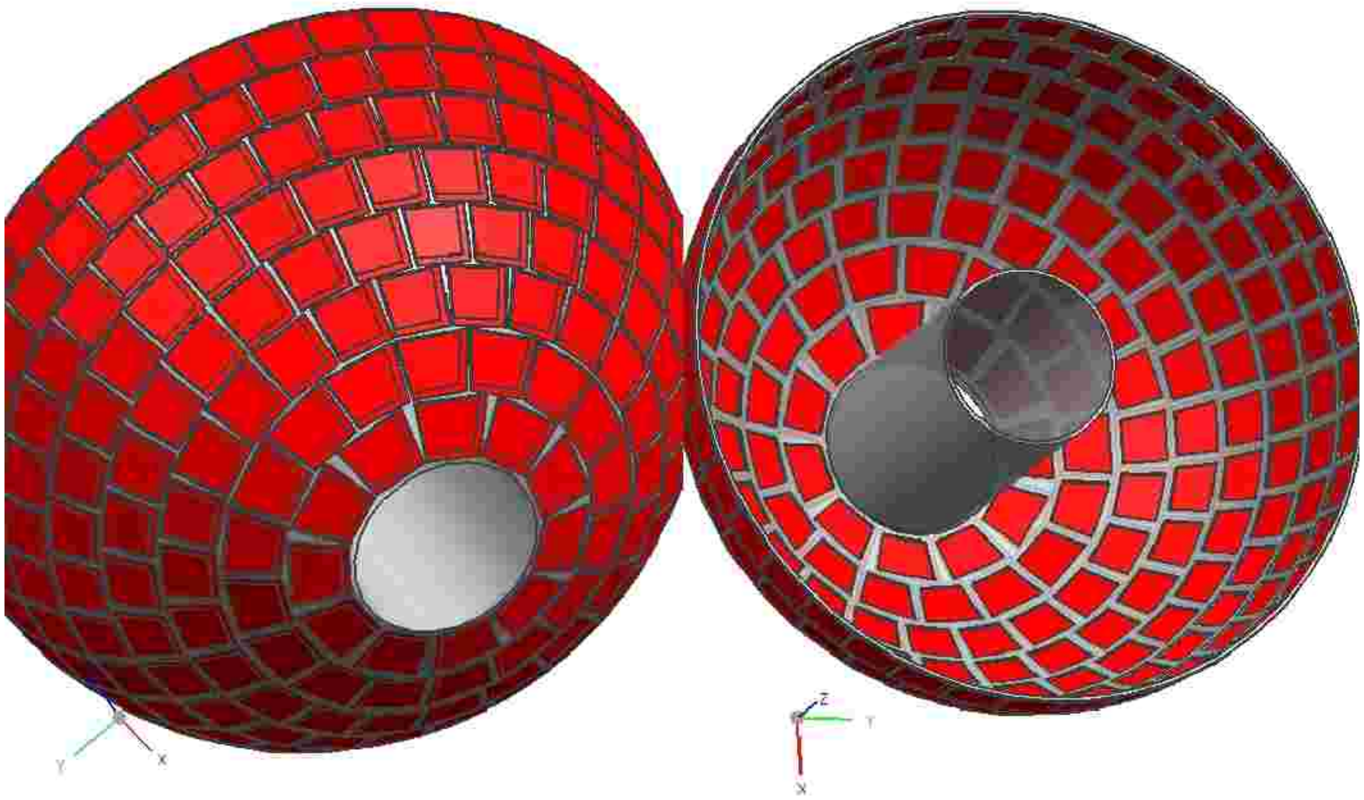
B. Streicher et al., NIM A654 (2011)604

System Integration



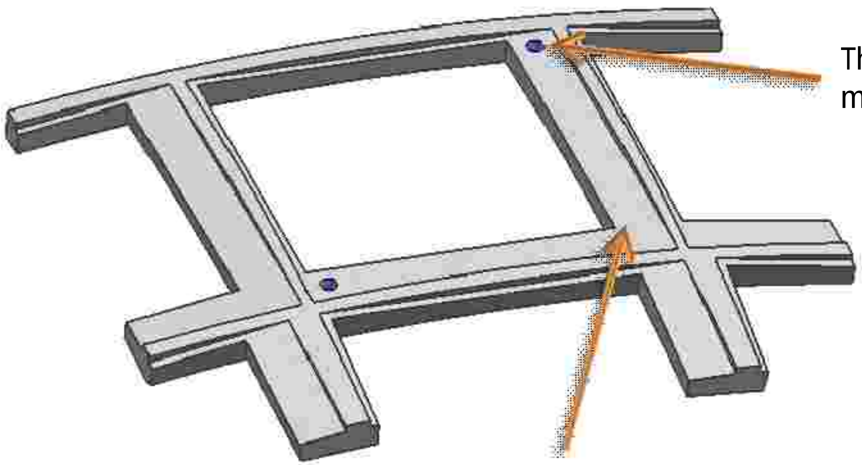
Technical design of the EXL detector

System Integration



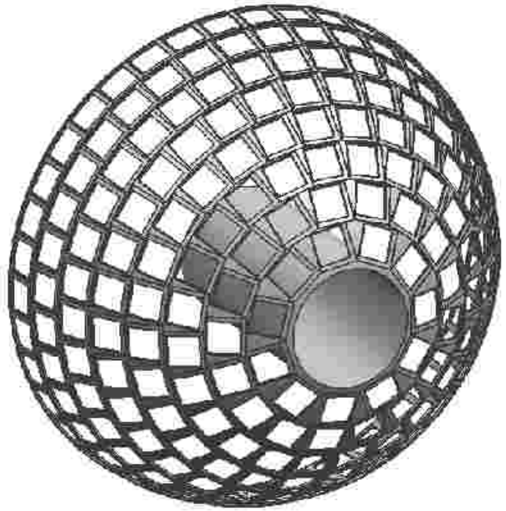
Support Structure

Outside

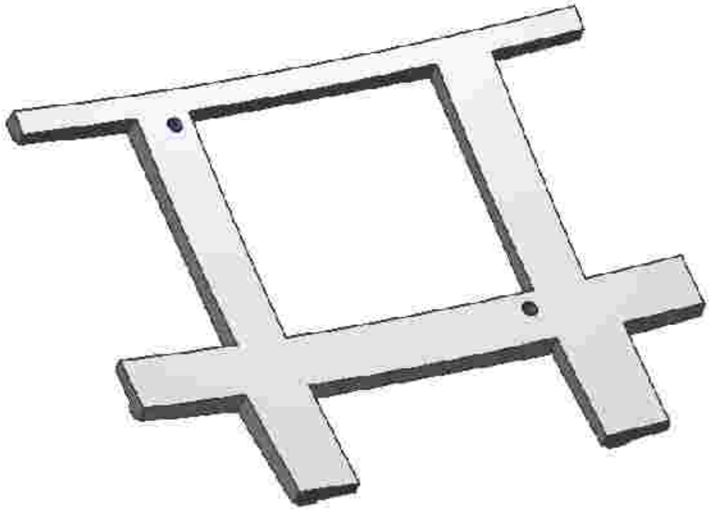


Thread holes for rods to mount detectors

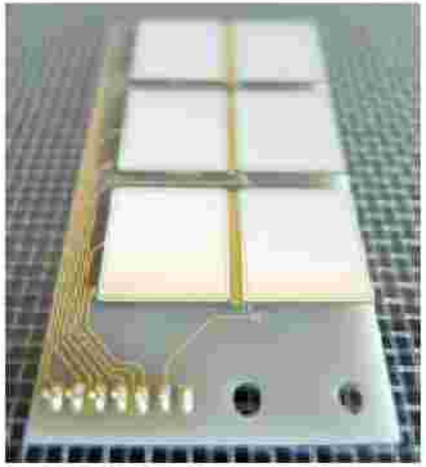
Flat cutouts to support detector and make it vacuum tight

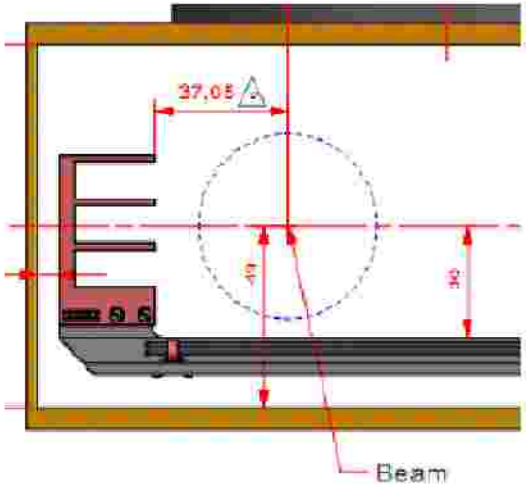


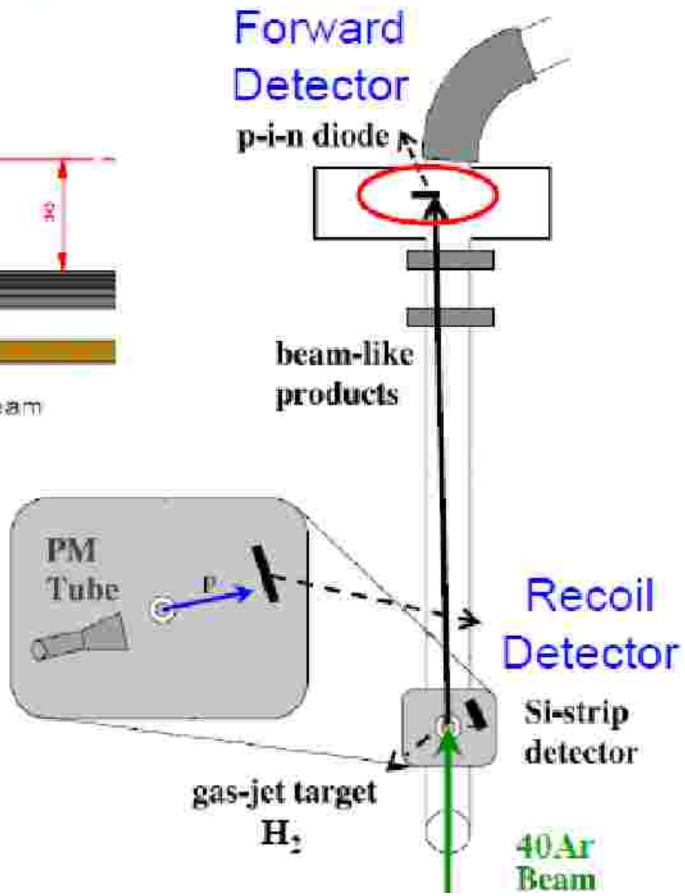
Inside



UHV capable Tagging Detector







- Forward detector before the first dipole, detection of beam like reaction products in coincidence with recoils.
- 6 PIN diodes (1 x 1 cm²) on AlN PCB, directly in the UHV
- Small dead edge, could be very close to the beam
- Baked at 250° C, passed vacuum Test.

IV. Feasibility Studies for EXL and First Experiments at the ESR

experimental conditions:

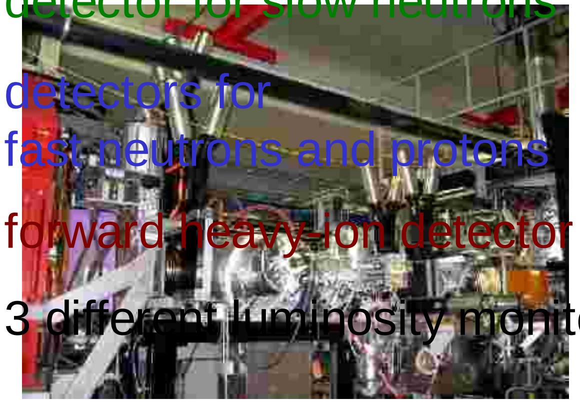
- ^{136}Xe beam, E = 350 MeV/u
- 10^9 circulating ions in ring ⇒ $L \approx 6 \cdot 10^{27}$ cm^{-2} sec^{-1}

experimental setup:

H_2 gas jet target: 6 x 10^{12} cm^{-2}

Si strip recoil detector in UHV

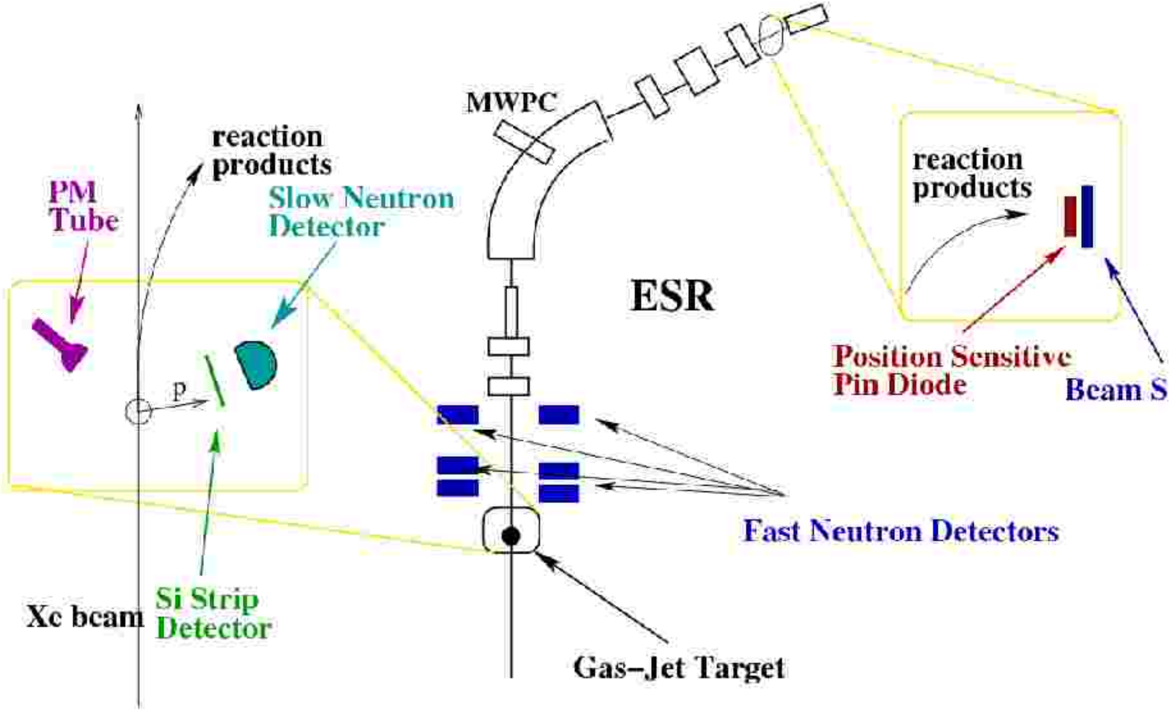
detector for slow neutrons



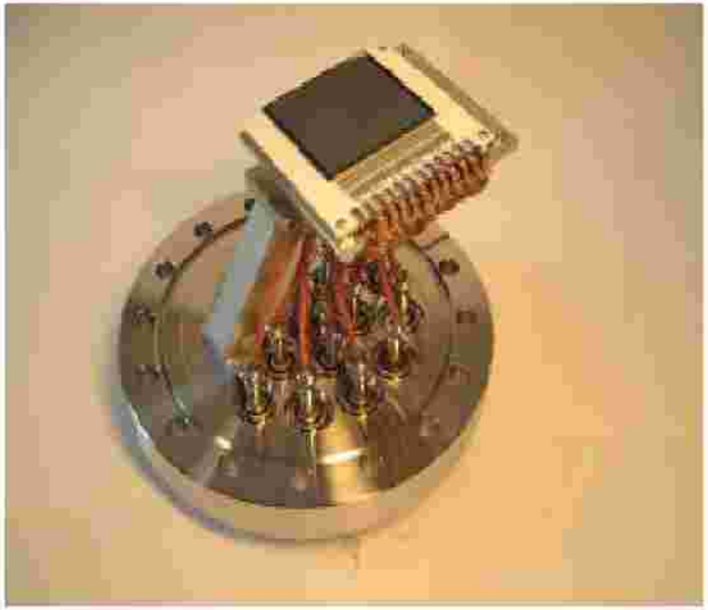
detectors for
fast neutrons and protons

forward heavy-ion detector

3 different luminosity monitors



Si-Strip Detector for Applications under UHV Conditions



- <u>design:</u>

  - active area: 40 x 40 mm^2
  - thickness: 1 mm
  - 40 strips (pitch: 1mm) connected for readout in groups of 8
  - bakeable to 250º Celsius
  - cables: home made

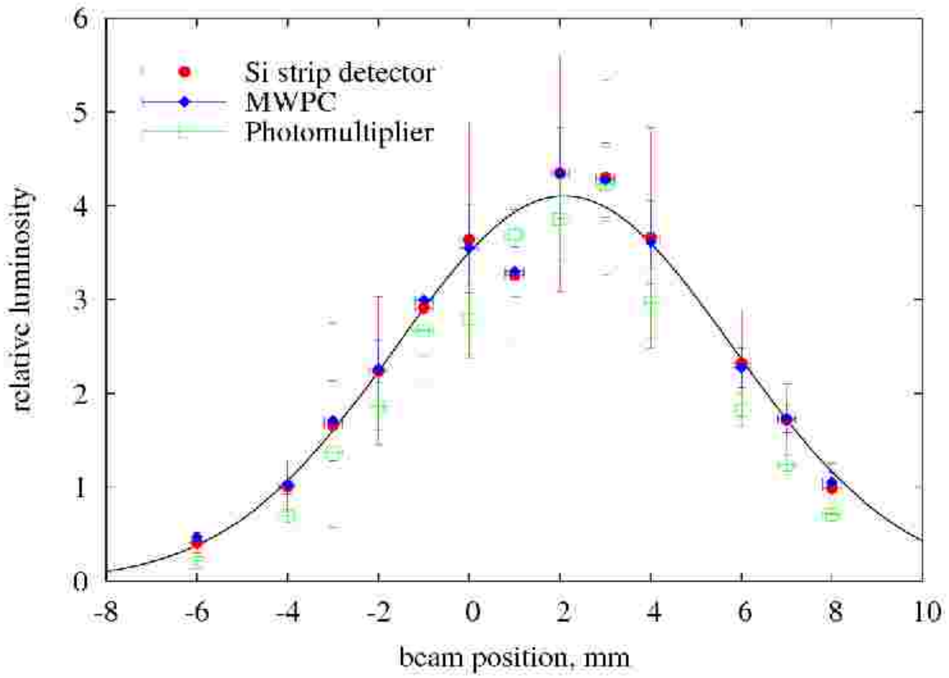
- <u>performance:</u>

  - energy resolution 35 keV FWHM
  - low outgasing rate

Selected Results

performance of luminosity monitors:

Si strip detector:	elastic scattering
MWPC:	atomic charge exchange
Photomultiplier:	light



size of gas jet target:

7.0 ± 0.2 mm

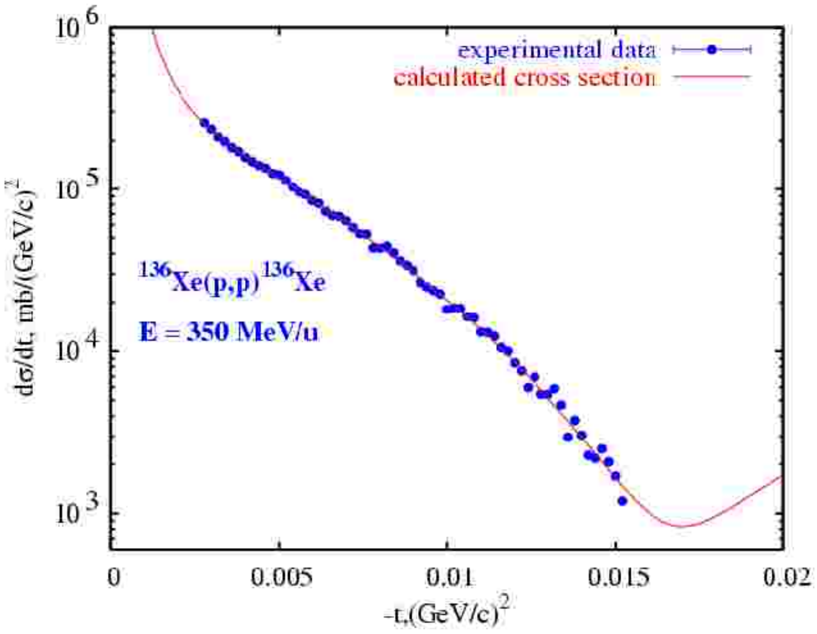
absolute luminosity measured with Si Strip Recoil Detector

deduced luminosity $\Rightarrow L = (6 \pm 2) \bullet 10^{27}\ cm^{-2}\ sec^{-1}$

Selected Results

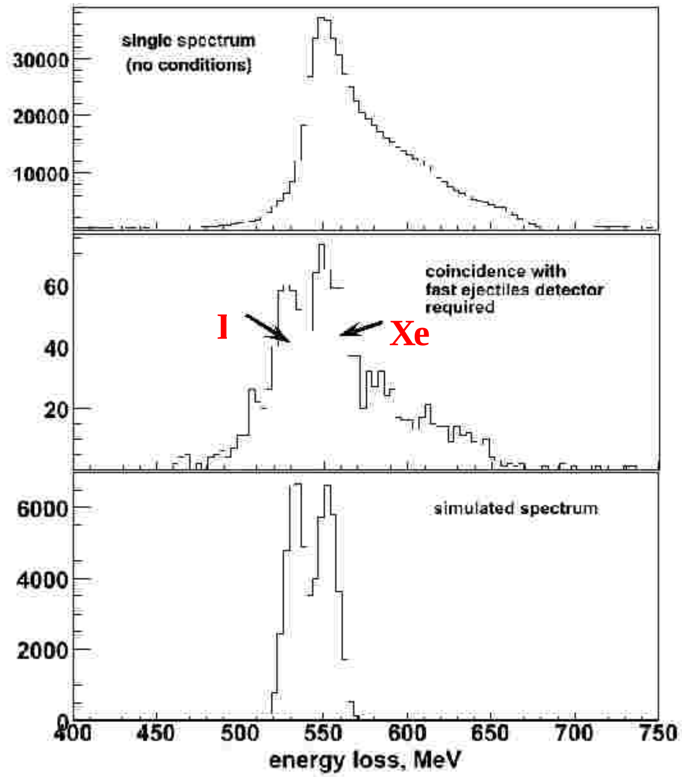
H. Moeini and S. Ilieva et al., NIM A634 (2011)77

Recoil Detector in UHV:
Differential ^{136}Xe(p,p) cross section



data are consistent with
nuclear matter radius: R_m = 4.89 (10) fm
(expected from data on the charge radius)

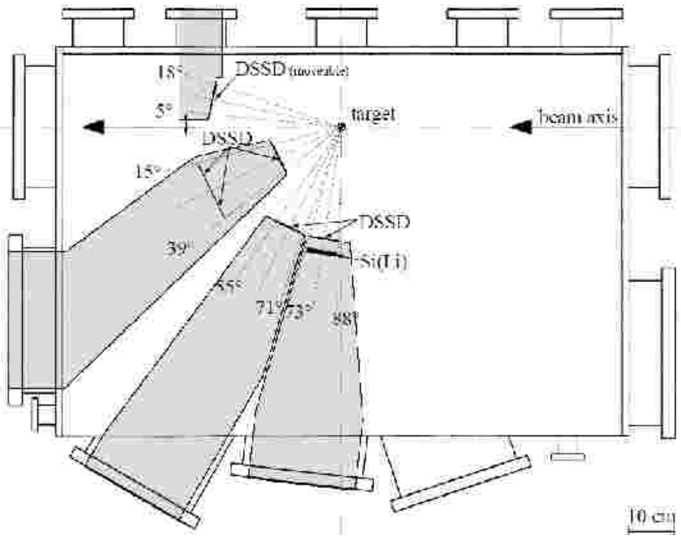
In-Ring Detectors:
Identification of reaction channels



identified reaction channels :
^{136}Xe(p, pn)^{135}Xe
^{136}Xe(p, 2pxn)^{132,133}I

Next Step: Accepted Proposal for Feasibility Studies and First Experiments with RIB`s at the ESR

(p,p), (a,a`), (^{3}He,t) reactions with ^{58}Ni and ^{56}Ni beams



reactions with ^{58}Ni:

proof of principles and feasibility studies:

- background conditions in the environment of an internal target
- low energy threshold
- pulse shape analysis
- target extension and density
- performance of in-ring detection system

reactions with ^{56}Ni:

^{56}Ni: doubly magic, important for nucl. astrophysics:

- (p,p) reactions: nuclear matter distr.
- (a,a`) reactions: giant resonances ISGMR, IVGDR, parameters of the EOS
- (^{3}He,t) reactions: Gamow-Teller matrix elements, important for astrophys.

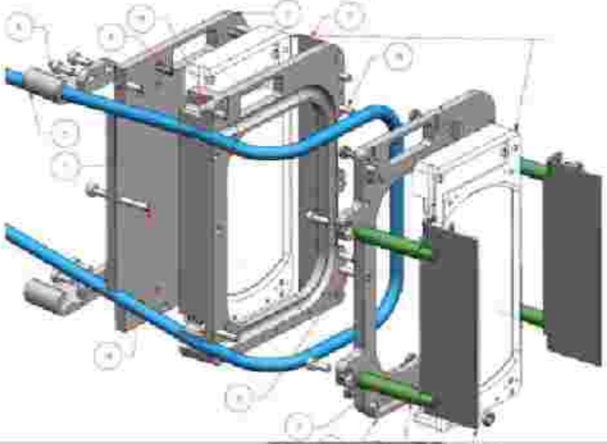
after ESR upgrade:

steps further away from stability

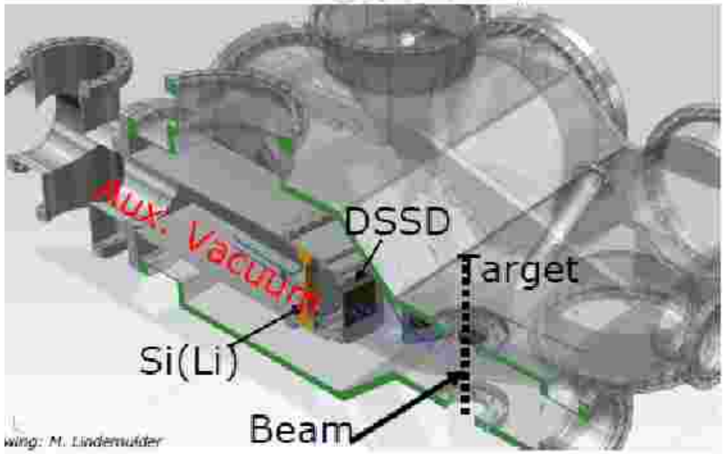
New Detector Chamber at the ESR

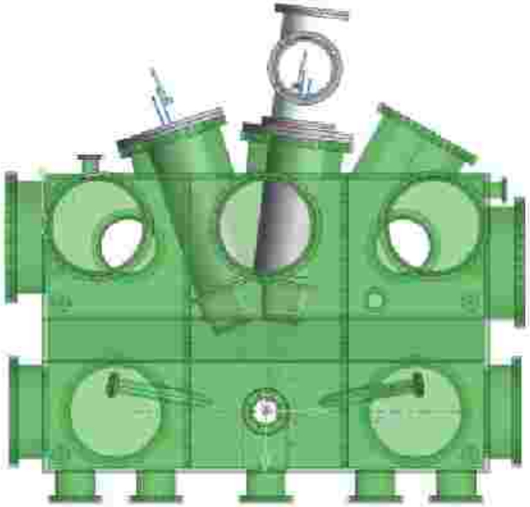
UHV capable Recoil Detectors

Assembly of the EXL's ESR Chamber



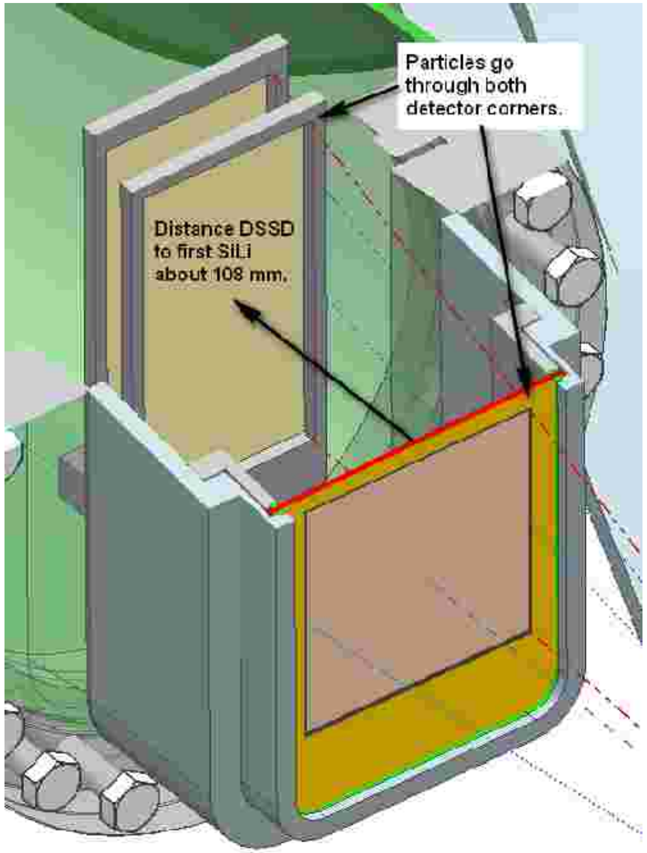
- Thermal tests using the real pocket
  - SiLi cooling vs. pocket baking
- Assembly of a vacuum system
  - Backup system required
- ASIC development + cabling
  - Interconnecting DSSDs with ASIC
  - Proper signal propagation



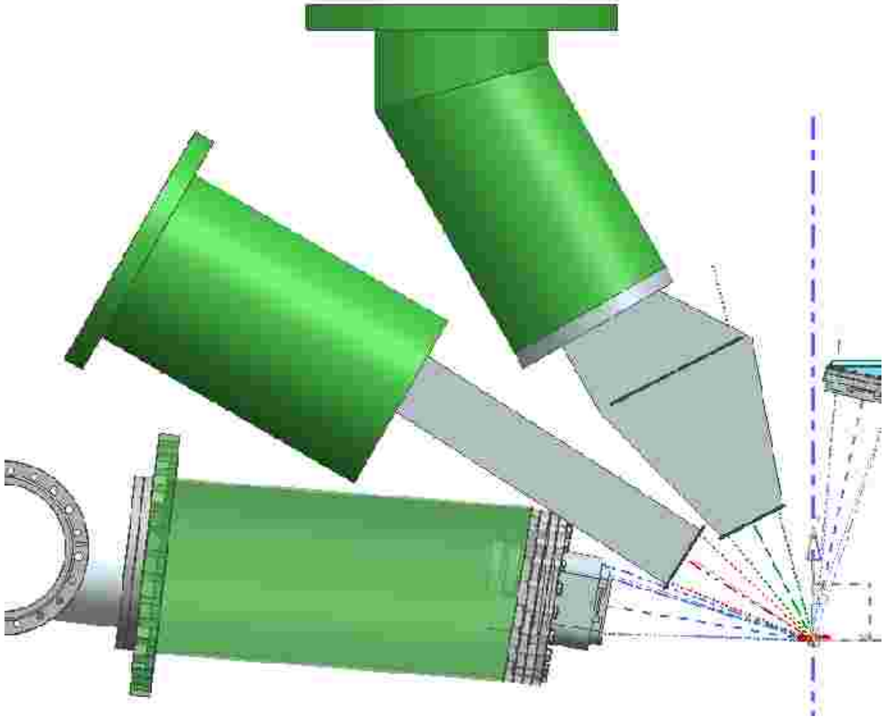


Design Study for First ESR Experiments

M. Lindemulder, KVI



DSSD – SiLi –SiLi telescope



Top view

Work Group on Setup and Test of DSSD Prototypes for EXL

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Feasibility Demonstration at the Present ESR Facility

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N. Kalantar, O. Kiselev, C. Kozhuharov, T. Le Bleis, X.C. Le,
Y. Litvinov, K. Mahata, J. P. Meier, H. Moeini, F. Nolden,
S. Pascalis, U. Popp, D. Rohe, H. Simon, M. Steck, T. Stöhlker,
H. Weick, D. Werthmüller, A. Zalite
and the EXL-collaboration

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Universität Basel, Basel, Switzerland
Johannes Gutenberg Universität Mainz, Mainz, Germany
KVI, University of Groningen, Groningen, The Netherlands
University of Liverpool, Liverpool, United Kingdom

The EXL Collaboration

14 countries, 33 institutes, ~ 135 participants

Univ. São Paulo

TRIUMF Vancouver

IPN Orsay, CEA Saclay

GSI Darmstadt, TU Darmstadt, Univ. Frankfurt, FZ Jülich, Univ. Mainz, Univ. Munich

INR Debrecen

SINP Kolkata

KVI Groningen

INFN/Univ. Milano

Univ. Osaka

JINR Dubna, Univ. St Petersburg, Moscow

CSIC Madrid, Univ. Madrid

Univ. Lund, Mid Sweden Univ., TSL Uppsala

Univ. Basel

Univ. Birmingham, CLRC Daresbury, Univ. Surrey, Univ. York, Univ. Liverpool

The EXL Collaboration

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Uppsala, Sweden, The Svedberg Laboratory - C. Ekström, L. Westerberg
Vancouver, Canada, TRIUMF - R. Kanungo

V. Conclusions

- The Future Facility NUSTAR@FAIR will allow to reach unexplored regions in the chart of nuclei, where new and exciting phenomena are expected.
- The EXL setup is designed as universal detection system providing high resolution and large solid angle coverage for measurements at low momentum transfer.
- The use of stored cooled radioactive beams within the EXL project will have considerable advantage over external target experiments in many cases.
- The realization of the UHV compatible Si ball is most challenging.
- The status of R&D and Feasibility Studies is very prom
  $\Rightarrow$ the major technical problems are solved.
- EXL will allow to use a world wide unique experimental technique.
- A number of important physics questions can be only adressed by EXL.

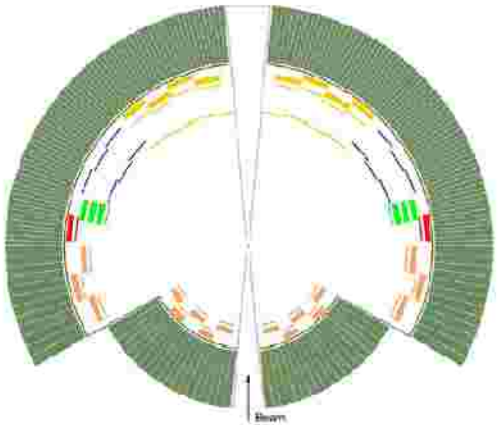
R&D on Internal Target for EXL

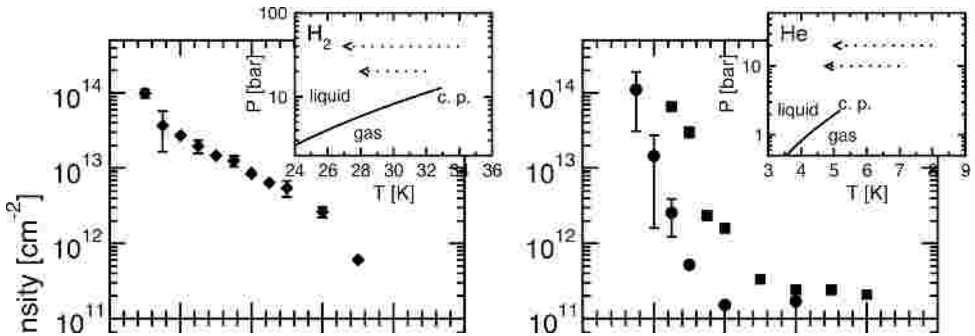
new target option: cryogenic droplet targets
(R.Grisenti et al., Frankfurt)

as compared to conventional gas-jet target: (d = 10^{14} cm^{-2}, s = 5 mm):
$\Rightarrow$ potentially higher density and smaller target extension

first successfull tests at the ESR performed
$\Rightarrow$ results are promising d = 10^{14} cm^{-2} reached for H and He!
but dramatic pressure increase under ion bombardment

$\Rightarrow$ target extension: s ˜ 7 mm, expected for NESR: s ˜ 1 mm



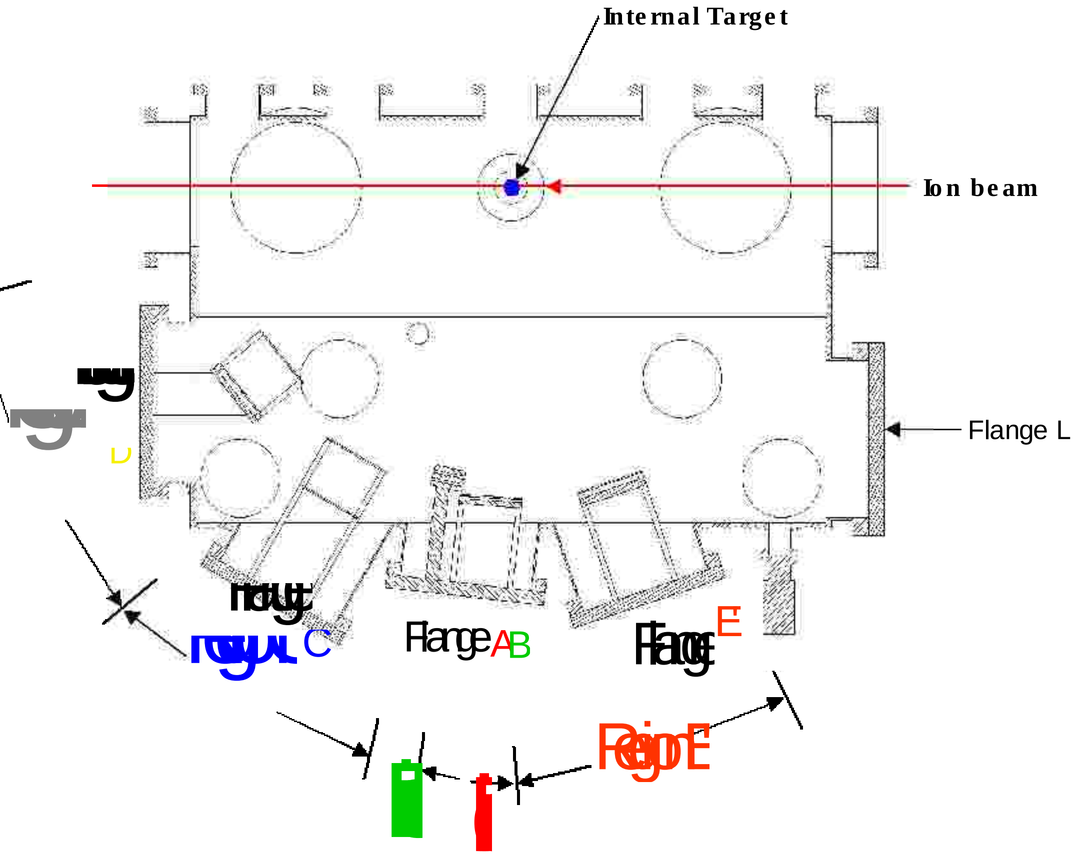


The New Recoil Detector Chamber at the ESR

Region	θ_{Lab} *)	θ Flange axis	Covered θ range	Flange size in mm
A	90° – 80°	83°	95° - 73°	Ø250
B	80° – 75°	83°	95° - 73°	Ø250
C	75° – 45°	60°	71° - 52°	Ø 250
D	45° – 10°	0°	28° - 18°	200x250
E'	120° –91°	109°	98° - 118°	Ø250
L		180°	136,5° – 43,5° **)	200x250

*) according to the angular regions A – E' defined in the Technical Proposal

Interaction Chamber Part (IC)



Detector Chamber Part (DC)

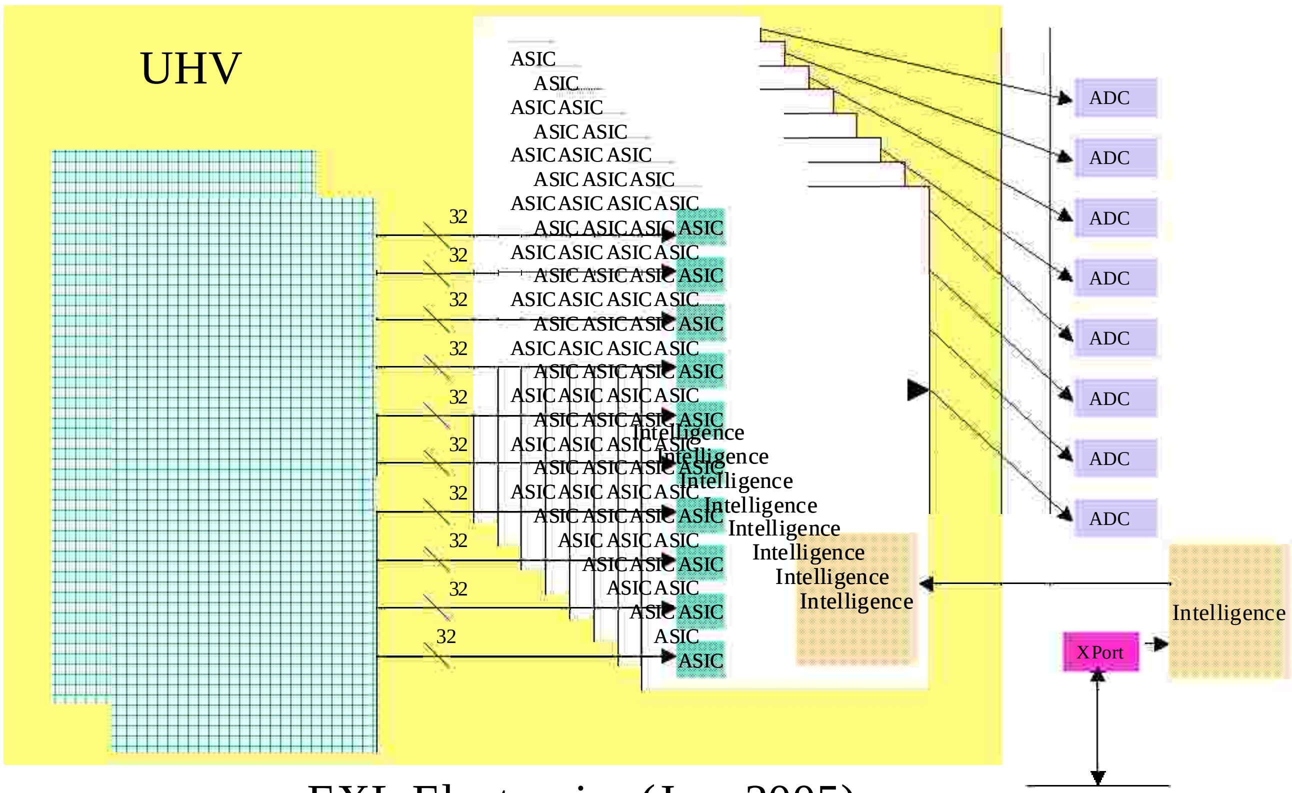
EXL Electronics

Detectors-
560000 channels
DSSD and SiLi

ASIC cards- approx
17500 ASICs on 1750 cards
(32 channels/ASIC)

ADC cards- 1750
ADCs on 219 cards
(320 channels/ADC)

- Large number of channels
- Large dynamic range, low threshold
- UHV – Low power dissipation, baking
- Space constraints

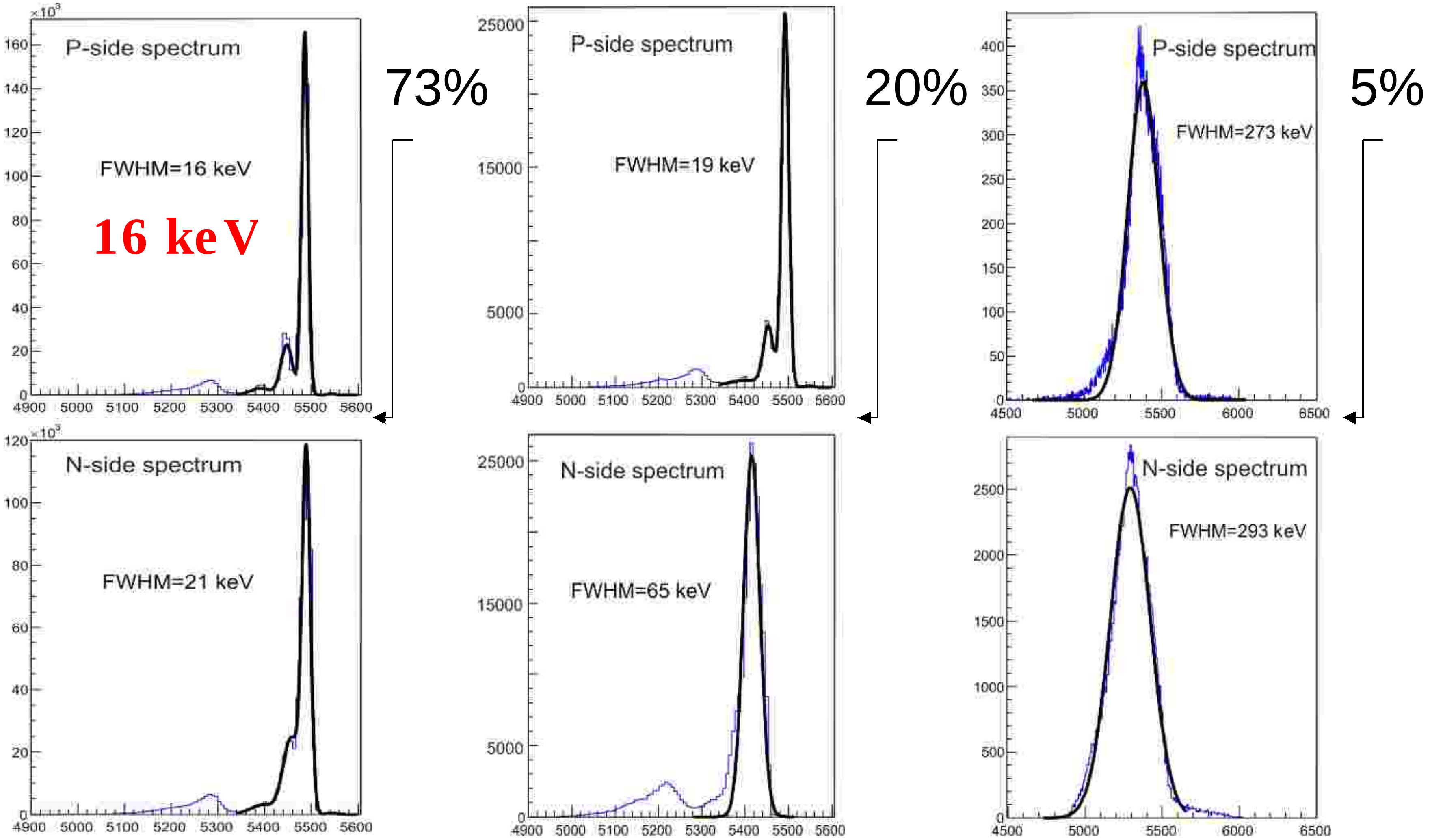


EXL Electronics (Jan 2005)

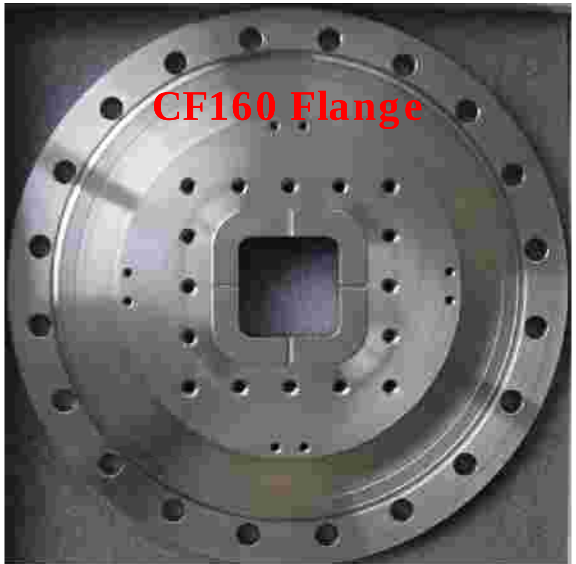
Synergy with NUSTAR.

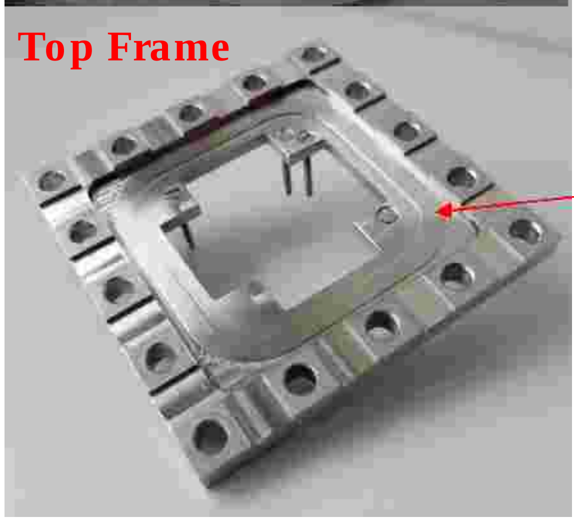
Correlation Analysis Results

Strip[P] - Strip[N] Strip[P] - Interstrip[N] Interstrip[P] - Strip[N]

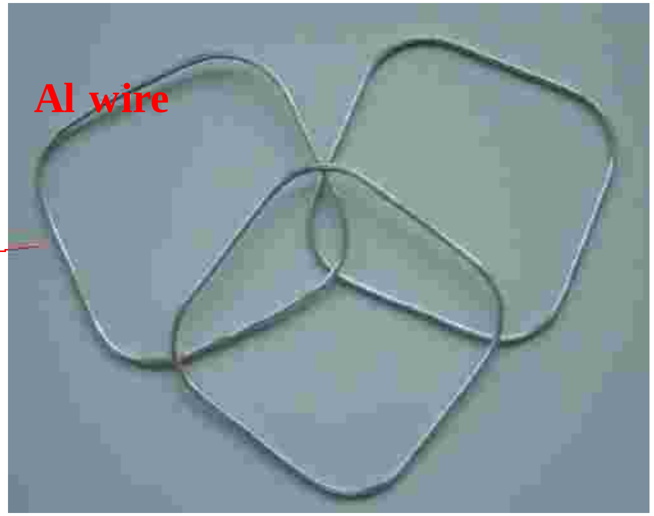


Mechanical Construction





- Base frame machined from CF160 flange
- Top frame from stainless steal has groove that presses on PCB and mounts for connectors
- Aluminium wires as a vacuum seal, used on both sides of the AlN PCB



Luminosity Gain by Use of Internal Targets

R(int) = I_0 X s(nuclear reactions) / s(atomic charge exchange)

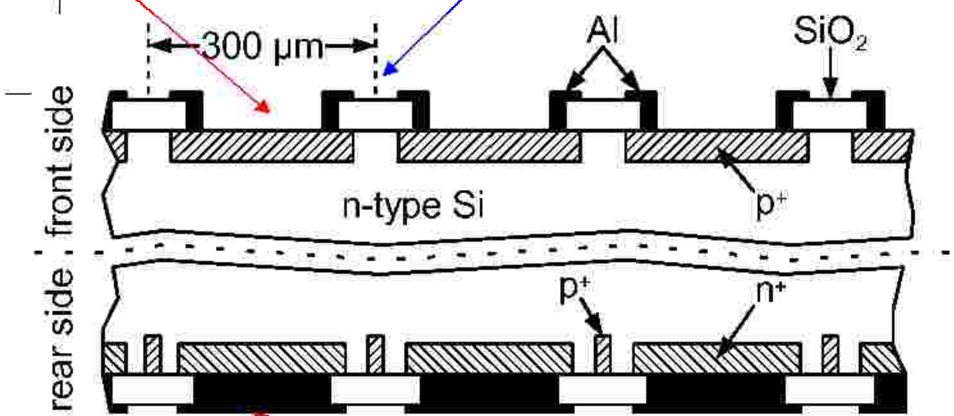
R(ext) = I_0 X s(nuclear reactions) X N(target)

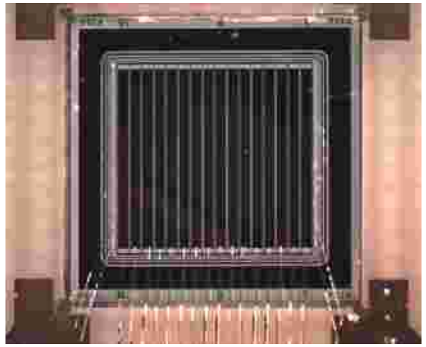
$\Rightarrow$ R(int) / R(ext) = 1/ (s(atomic charge exchange) X N(target))

Basic DSSD Structure (16 x 16 strips, 300 µm pitch)

P-side strips partly metallized,
„Thin window design“

<u>Small interstrip gap of 15µ</u>
(~ 5% of pitch)

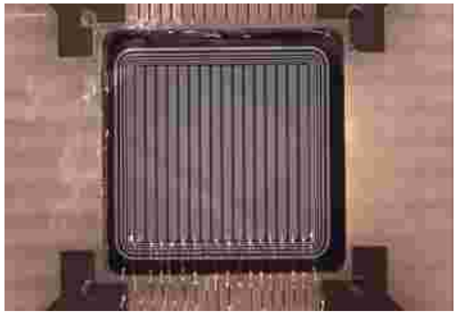




P-side - N-side

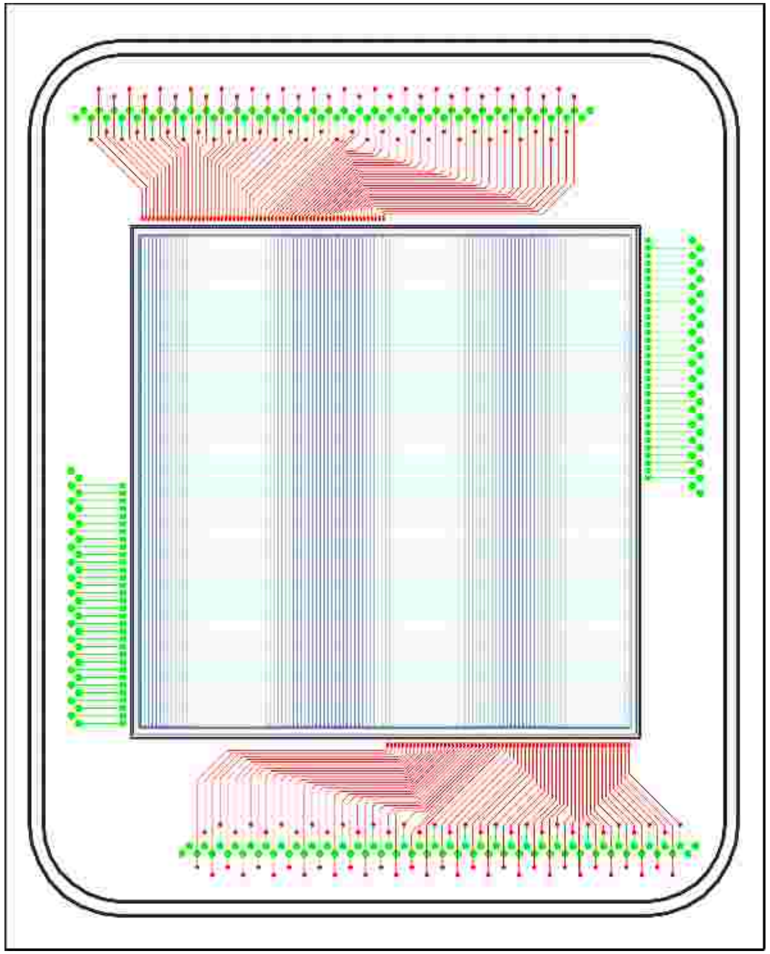
<u>Interstrip gap:</u>
65µ (by p^+ imp.)
(~ 22 % of pitch)

N-side strips
metallized



Also valid for 64x64 and 64x16 DSSDs

PCB Design for 65 x 65 mm² DSSD`s



-- **P-side: 128 strips**

-- **N-side: 64 strips**

AlN PCB lapped and polished:

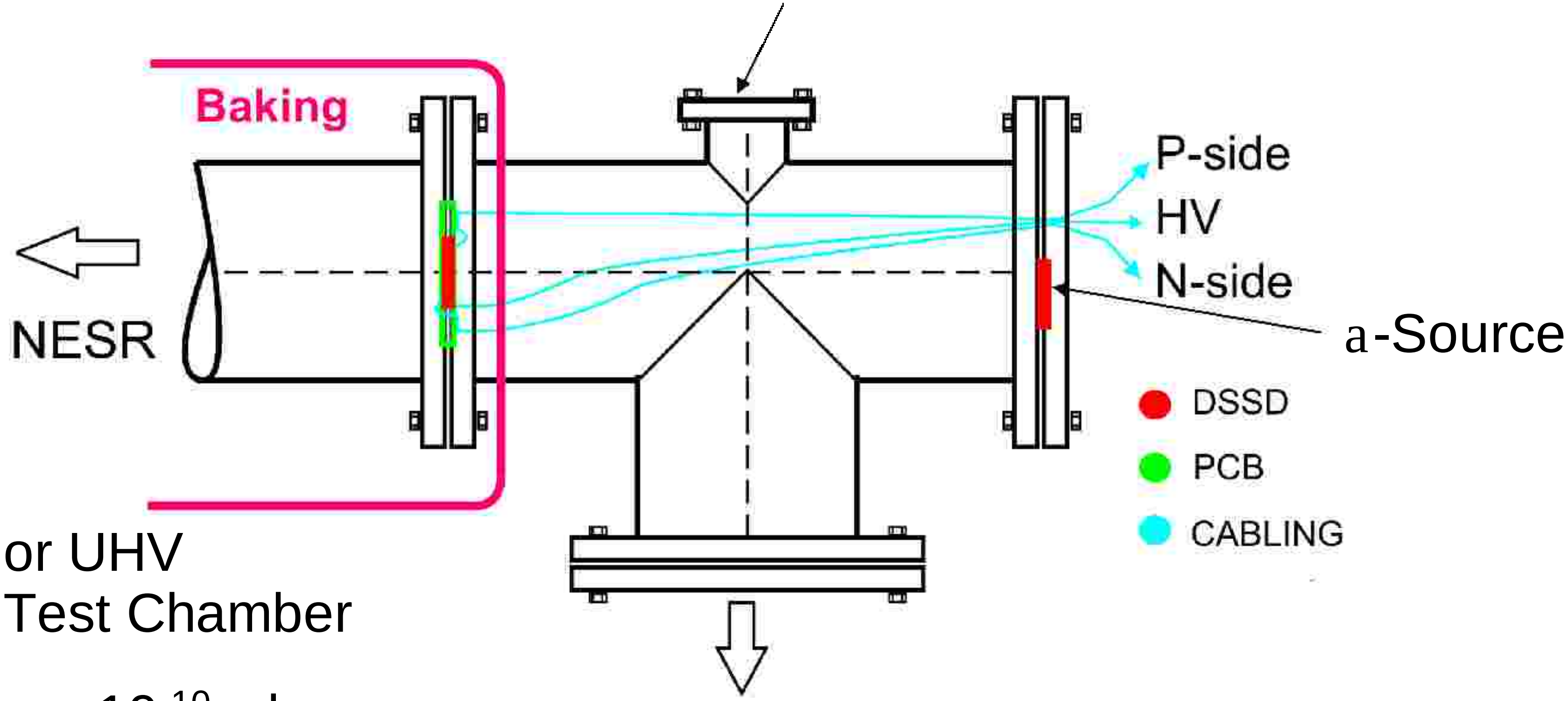
Roughness < 0.5 µm
Parallelity < 50 µm

Production: 2010

LUST
HYBRID-TECHNIK

Vacuum-Barrier Demonstrator

P and T diagnostics

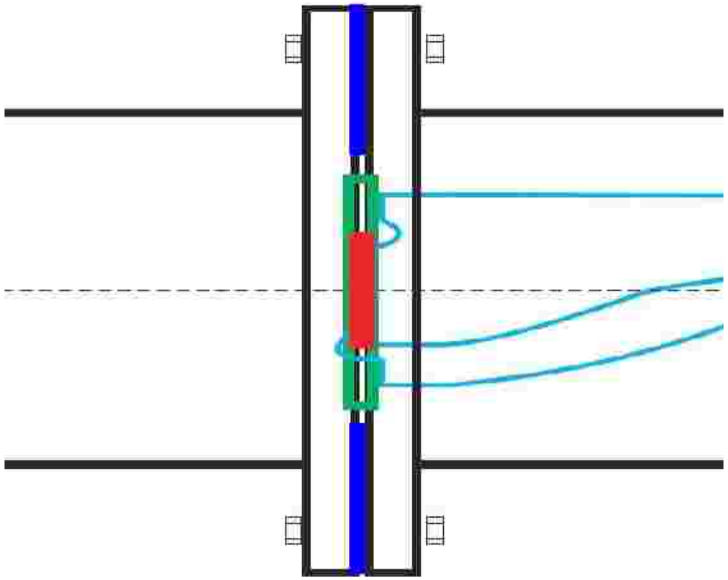


or UHV
Test Chamber

p < 10^{-10} mbar

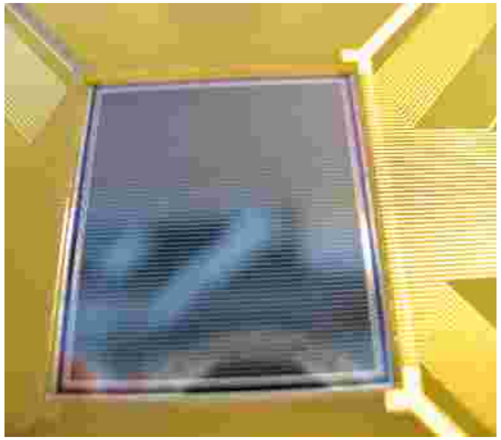
Auxiliary vacuum
p~ 10^{-7} mbar

DSSD as Vacuum Window



? DSSD
? ceramic PCB
? copper gasket

DSSD: 64 x 64 strips,
21 x 21 mm^2, 300µm



mounted on ceramic PCB,
with low-outgasing epoxy.

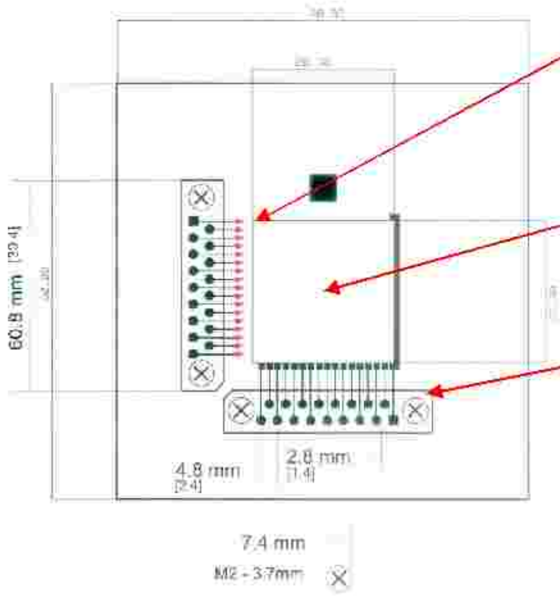
Ceramic PCB Design

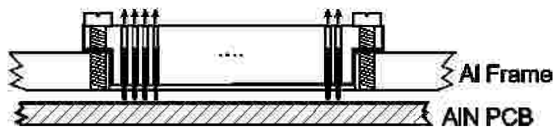
p-side in UHV,
n-side in aux.vacuum

Plate-through contacts

DSSD: 64 x 64 strips, 21 x 21 mm^2, 300µm

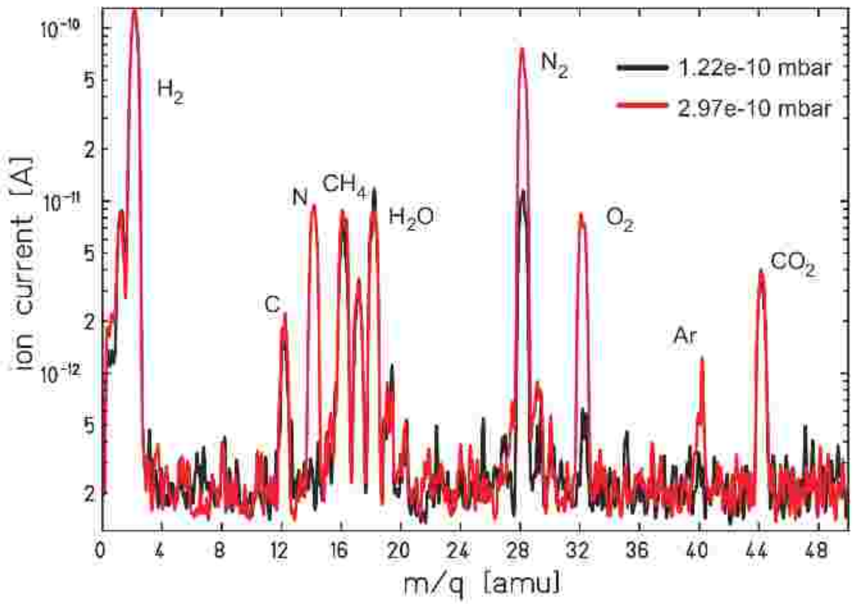
Spring-pin connector



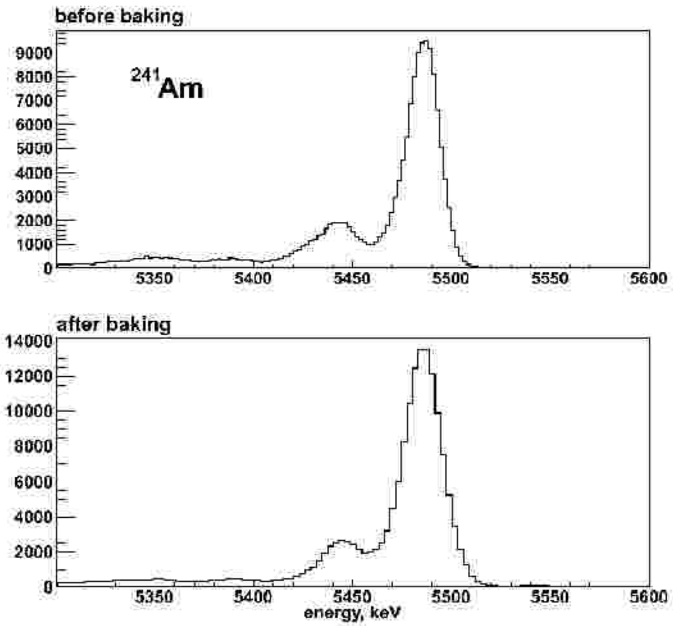


All components bakeable to 200 °C

Differential Vacuum Test



Rest-gas analysis favourable



DSSD as UHV – HV vacuum barrier works fine

Spectral response unchanged after <u>three</u> baking cycles (to 220 º)