

The EXL Collaboration



Univ. São Paulo



TRIUMF Vancouver



IMP Lanzhou



VTT Helsinki



IPN Orsay, CEA Saclay



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



INR Debrecen



SINP Kolkata, BARC Mumbai



KVI Groningen



INFN/Univ. Milano



Univ. Teheran



Univ. Osaka



JINR Dubna, PNPI Gatchina, KRI St. Petersburg, Ioffe Inst. St. Petersburg, Kurchatov Inst. Moscow



CSIC Madrid, Univ. Madrid



Univ. Lund, Mid Sweden Univ., Univ. Uppsala, Chalmers Inst. Göteborg



Univ. Basel



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



Tbilisi State University, Ilia Chavchavadze State University, Tbilisi, Georgia

18 countries, 37 institutes, 172 participants



KVI

Status of EXL

The EXL collaboration

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Vancouver, Canada, TRIUMF - R. Kanungo

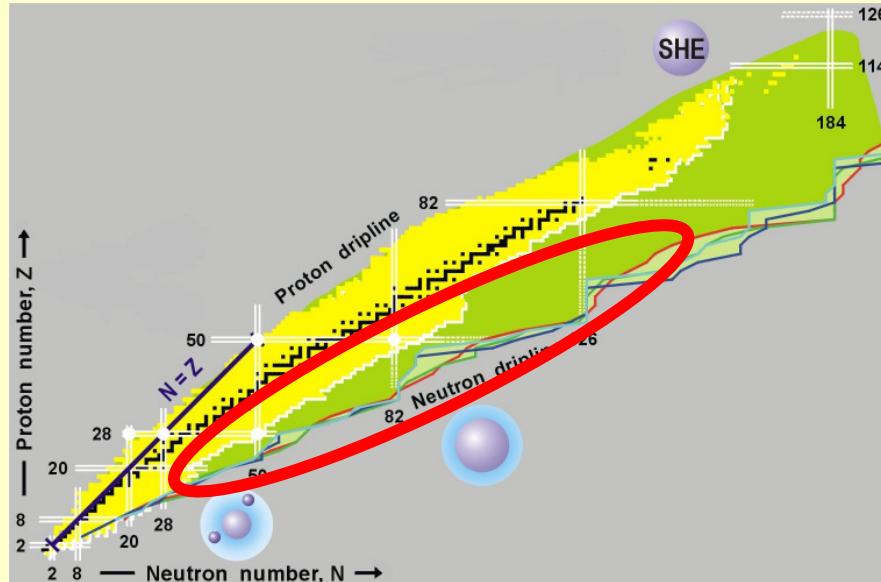
Main Physics Goals

regions of interest:

towards the driplines for medium heavy and heavy nuclei

physics interest:

- matter distributions (halo, skin...)
- single-particle structure evolution (new magic numbers, new shell gaps, spectroscopic 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 asymmetric and low-density matter
- astrophysical r and rp processes, understanding of supernovae



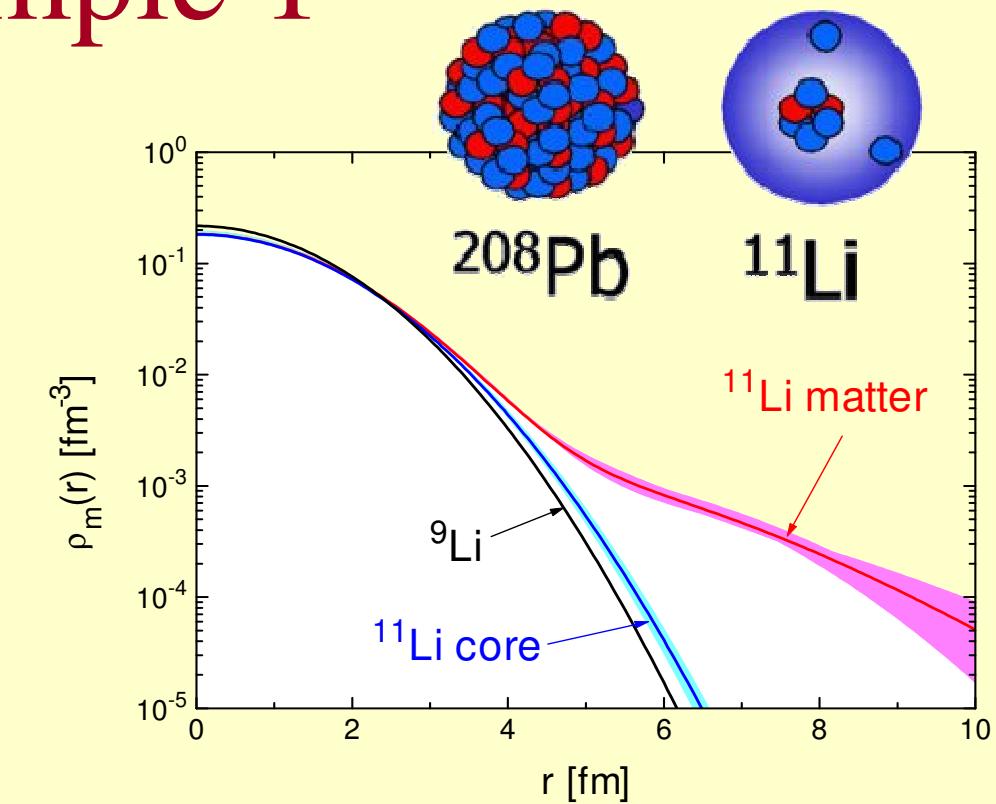
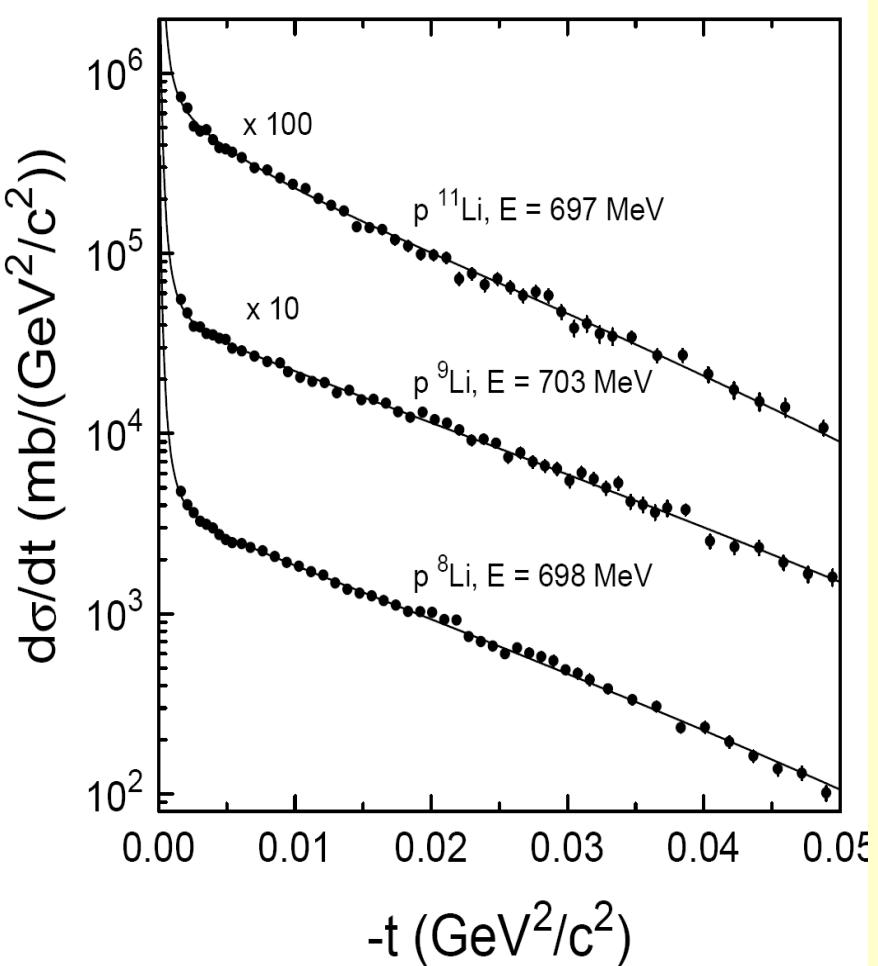
Light-ion induced direct reactions

- Elastic scattering (p,p), (α,α), ...
Nuclear matter distribution $r(r)$, skins, halo structures
- Inelastic scattering (p,p'), (α,α'), ...
Deformation parameters, $B(E2)$ values, transition densities, giant resonances
- Charge exchange reactions (p,n), ($^3\text{He},t$), ($d,^2\text{He}$), ...
Gamow-Teller strength
- Transfer reactions (p,d), (p,t), ($p, ^3\text{He}$), (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), ($p,p^4\text{He}$)...
Ground state configurations, nucleon momentum dist., cluster correlations

Why low momentum transfers hadronic scattering?

- ✓ Investigation of Nuclear Matter Distributions along Isotopic Chains:
 - 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 Giant Monopole Resonance in Doubly Magic Nuclei:
 - 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 pre-supernova evolution (core collapse)
- method: $(^3\text{He}, t)$, $(d, ^2\text{He})$ charge exchange reactions at low q

Example 1

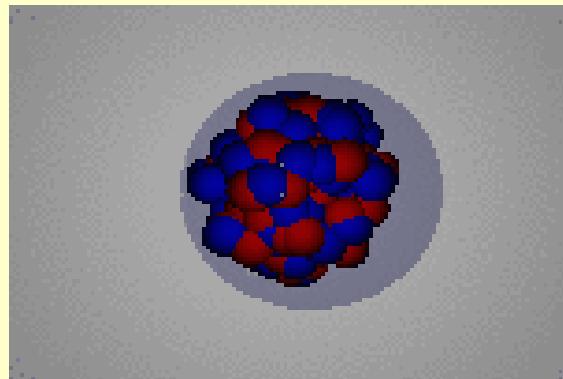


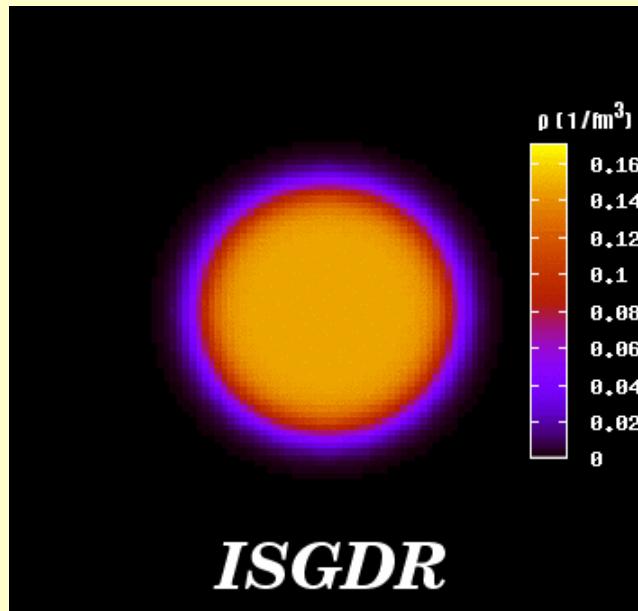
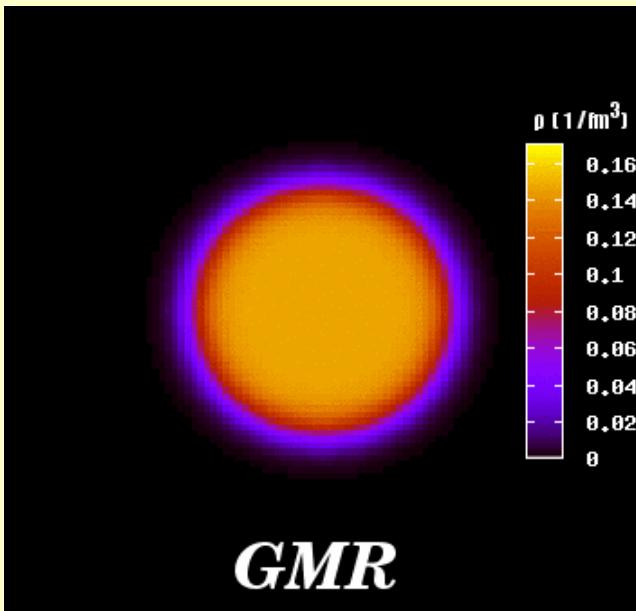
Small-angle proton elastic scattering
nuclear matter distribution

P. Egelhof et al., Eur. Phys. J. A 15, 27 (2002)

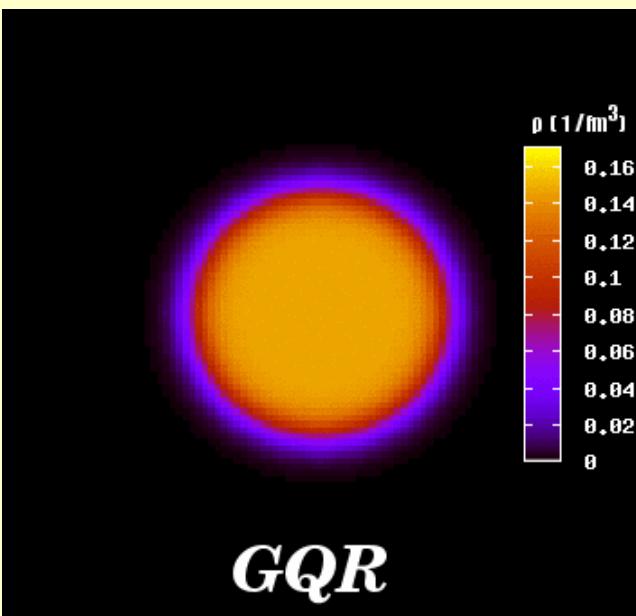
Example 2

- New collective modes (different deformations for p and n, giant resonance strength)

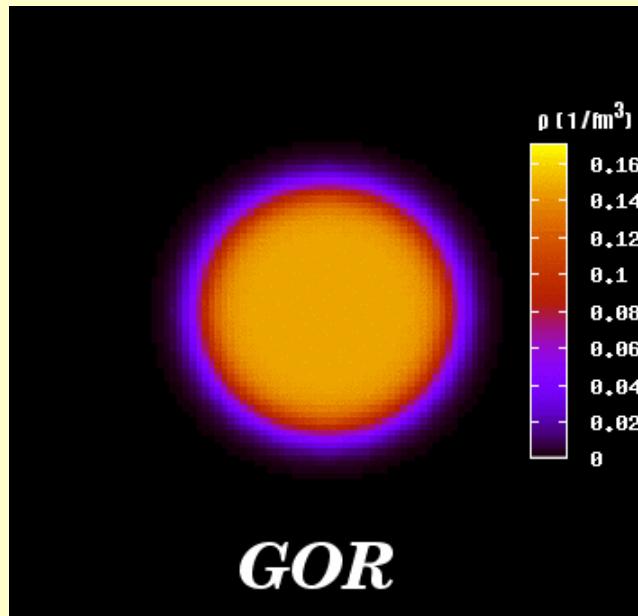




ISGDR



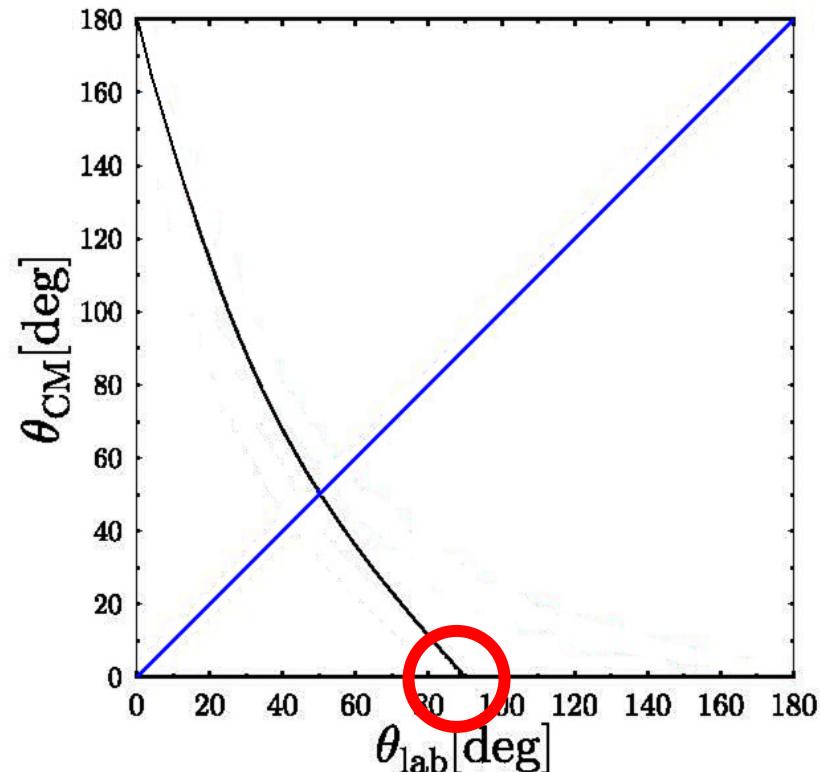
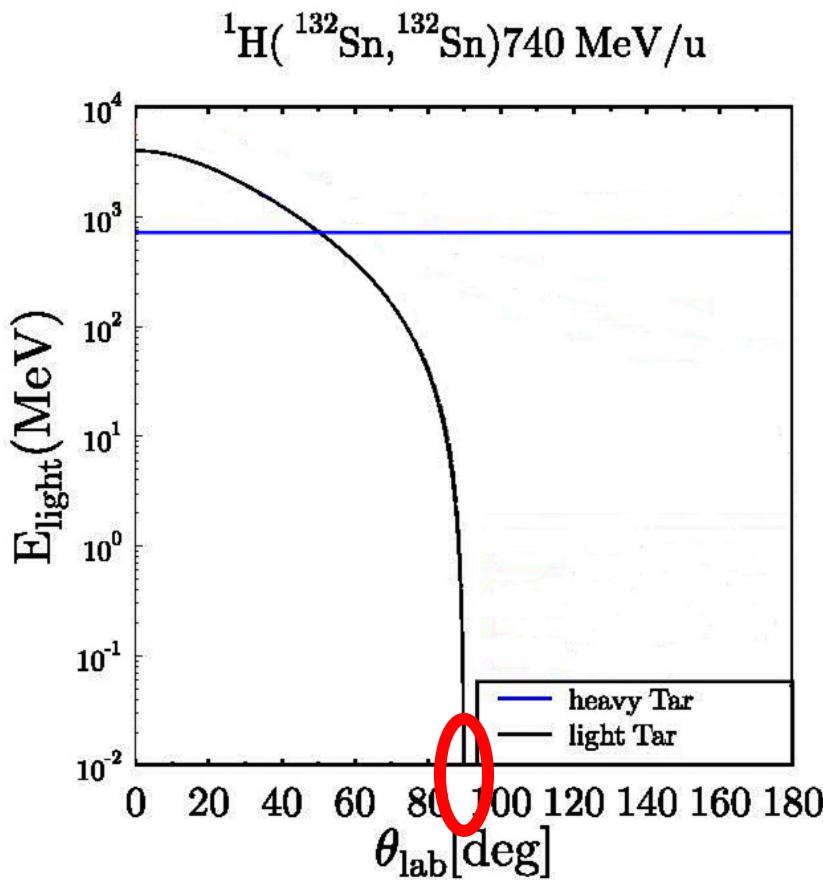
GQR



GOR

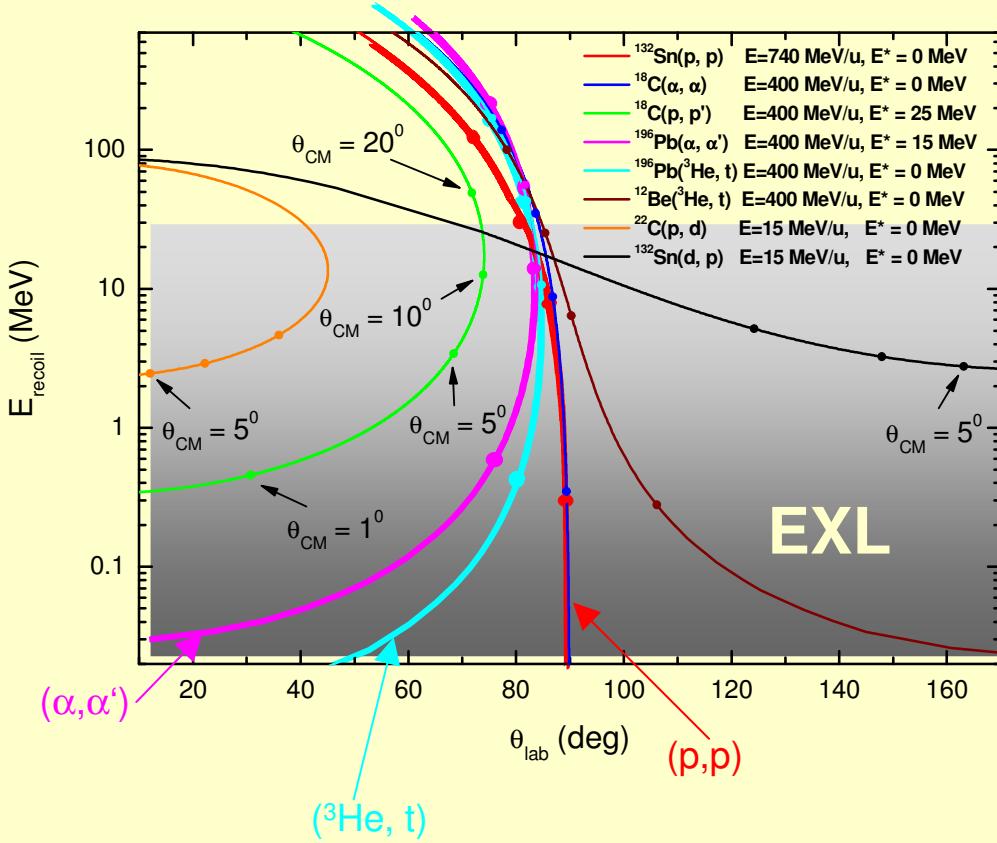
M. Itoh

Kinematics for collision of protons with exotic nuclei (with fixed heavy/light target)



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

The EXL domain @ low-momentum transfer is essential for elastic & inelastic scattering and charge-exchange reactions



❖ Required beam energies

$E \sim 200 - 740$ MeV/nucleon
(except for transfer reactions)

❖ Required targets

Light nuclei (e.g. $^{1,2}\text{H}$, $^{3,4}\text{He}$)

❖ Most important information in the region of low-momentum transfer

detect recoil particles of low energies

need thin targets for sufficient angular and energy resolution

Advantages and disadvantage of inverse kinematics for radioactive isotopes in the ring

Disadvantages:

Hostile environment

Very small recoil energies for low q

Thin targets

Advantages:

Large intensities in the ring

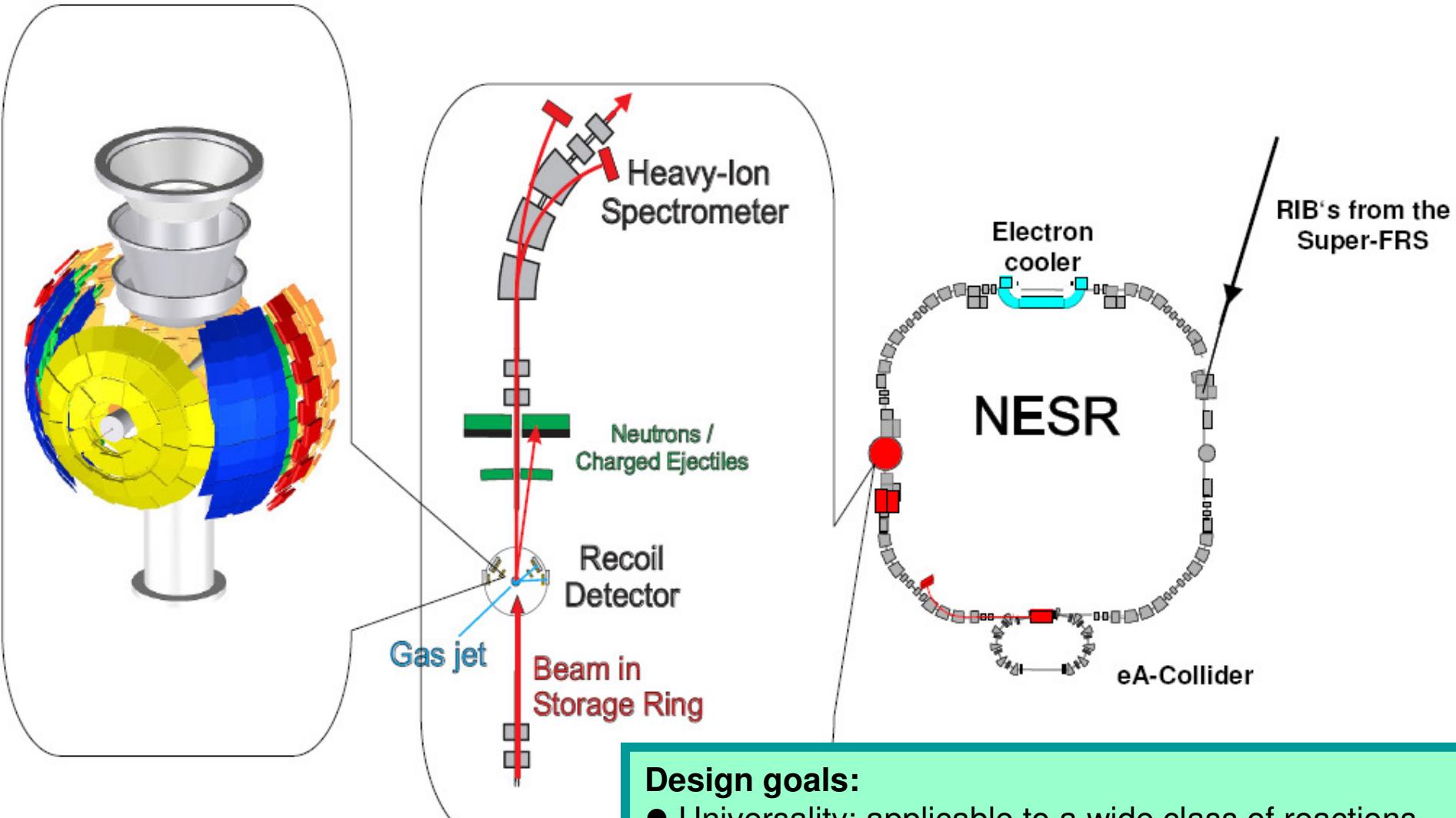
Little energy loss in the target

No target window (no background)

High resolution of the beam (cooling)

Forward focusing for high-energy particles

Details of the EXL setup



Detection systems for:

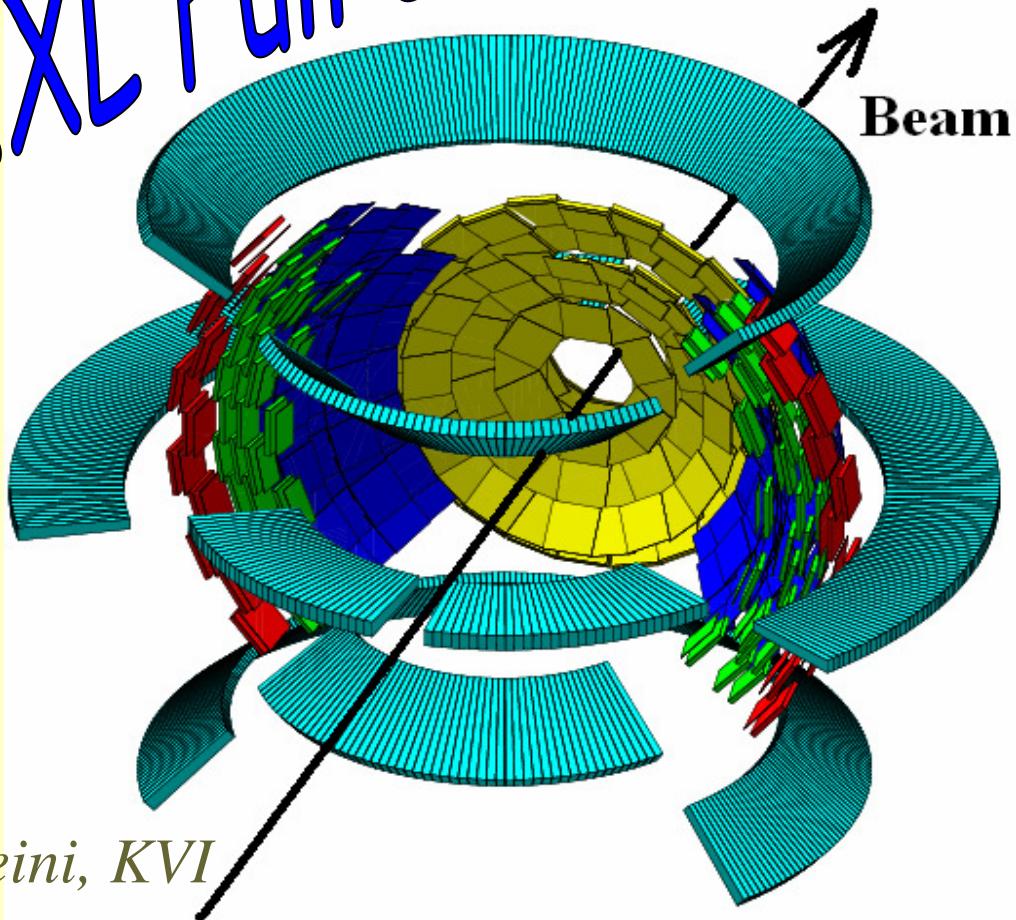
- Target recoils and gammas (p, α, n, γ)
- Forward ejectiles (p, n)
- Beam-like heavy ions

Design goals:

- Universality: applicable to a wide class of reactions
- Good energy and angular resolution
- Large solid angle acceptance
- Specially dedicated for low q measurements with high luminosity ($> 10^{28} \text{ cm}^{-2} \text{ s}^{-1}$)

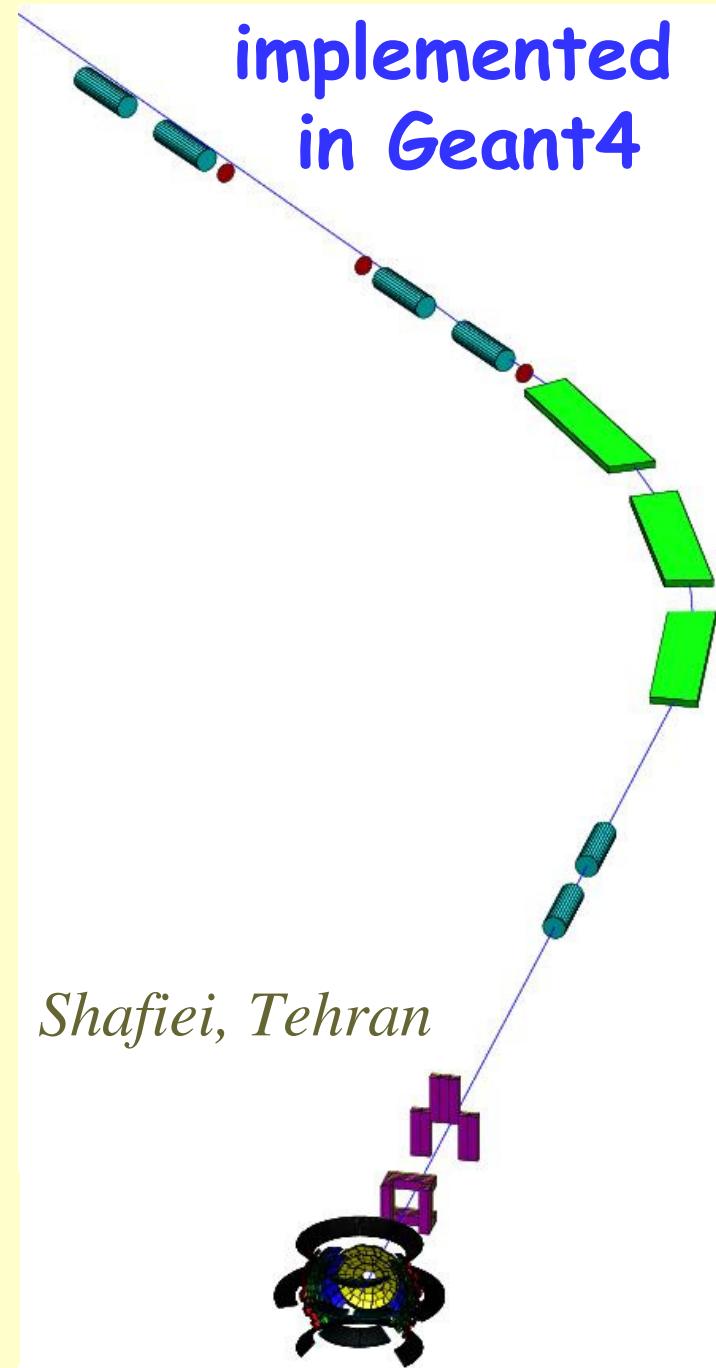
SIMULATIONS

EXL Full Geometry

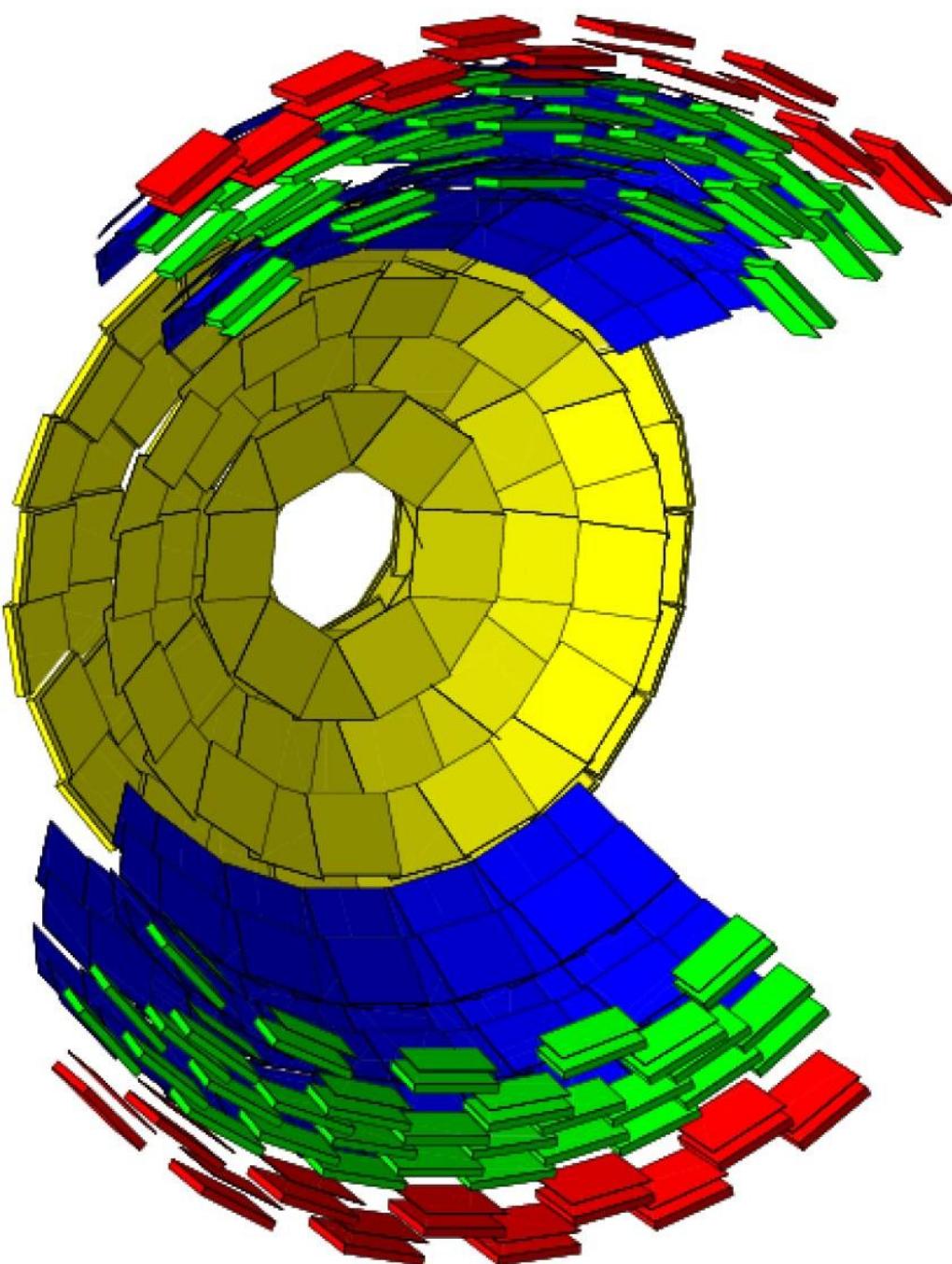


Moeini, KVI

Approximately 560000 channels for
Si-detector setup (~700 elements) and
calorimeter crystals (~2500 crystals)



Shafiei, Tehran



ESPA

Zalite, Milan

- **Si DSSD**

300 μm thick, spatial resolution better than 500 μm in x and y, ΔE 30 keV (FWHM).

- **Thin Si DSSD**

<100 μm thick, spatial resolution better than 100 μm in x and y, ΔE 30 keV (FWHM).

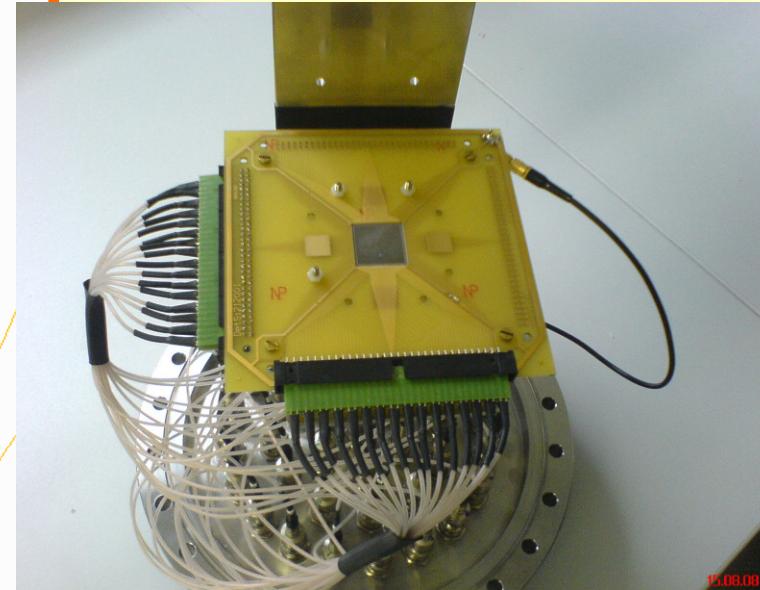
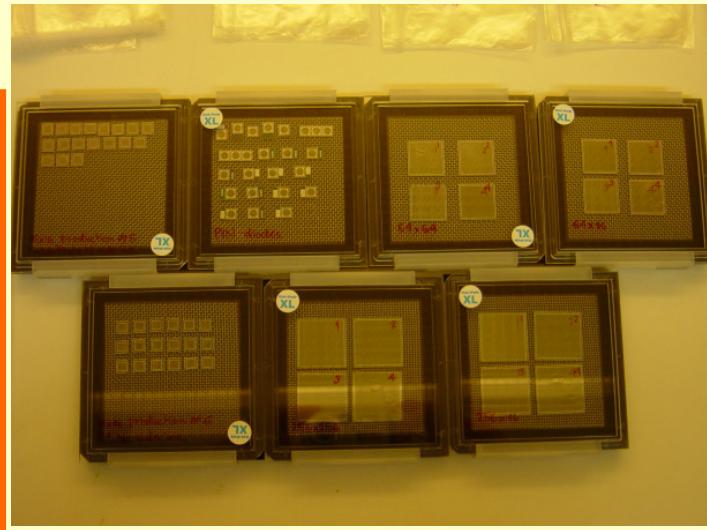
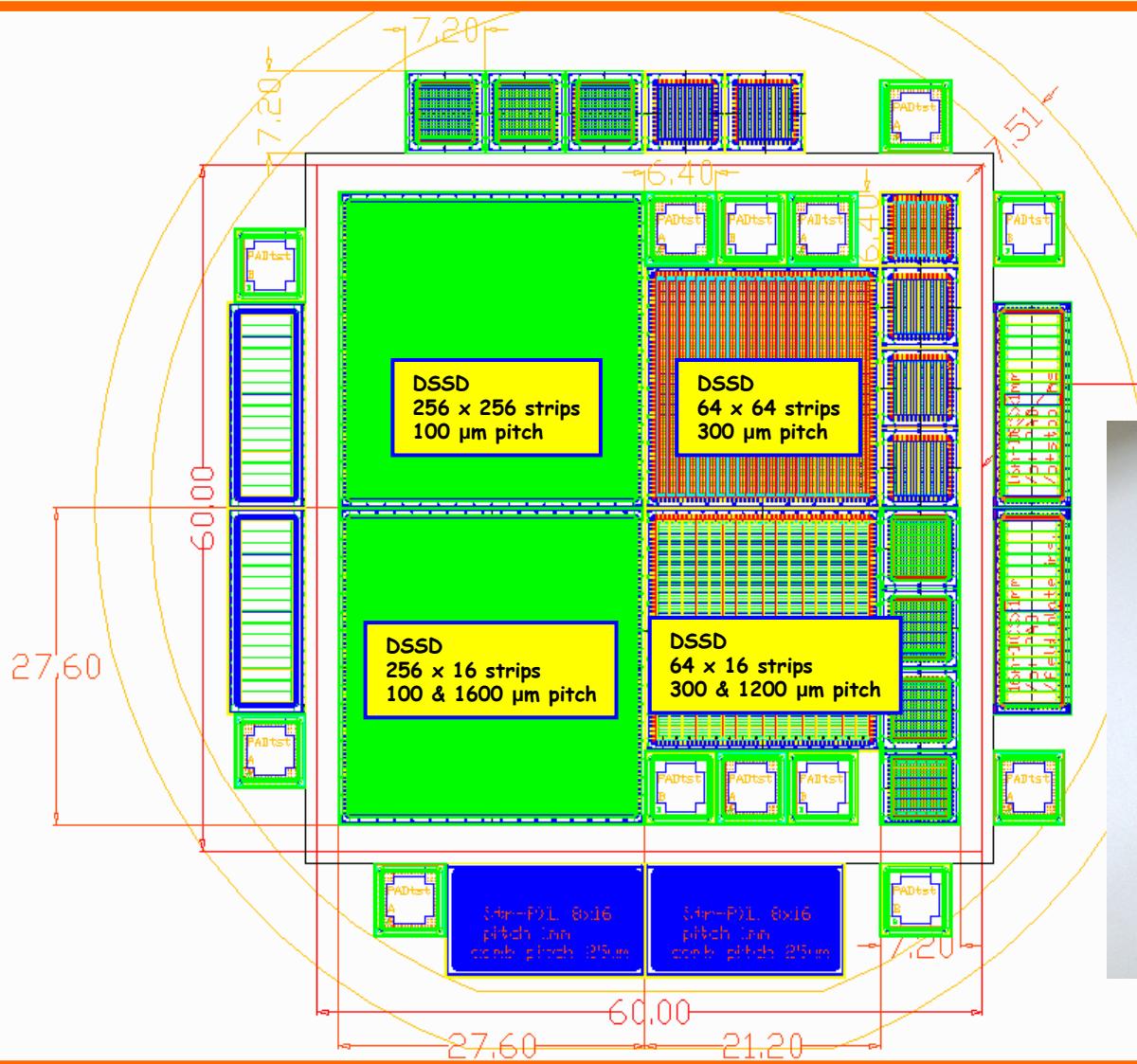
- **Si(Li)**

9 mm thick, large area 100x100 mm^2 , ΔE 50 keV (FWHM).

- **CsI crystals**

High efficiency, high resolution, 20 cm thick.

Wafer layout with DSSDs



Tests at PTI, GSI & Edinburgh

Baby DSSDs evaluation

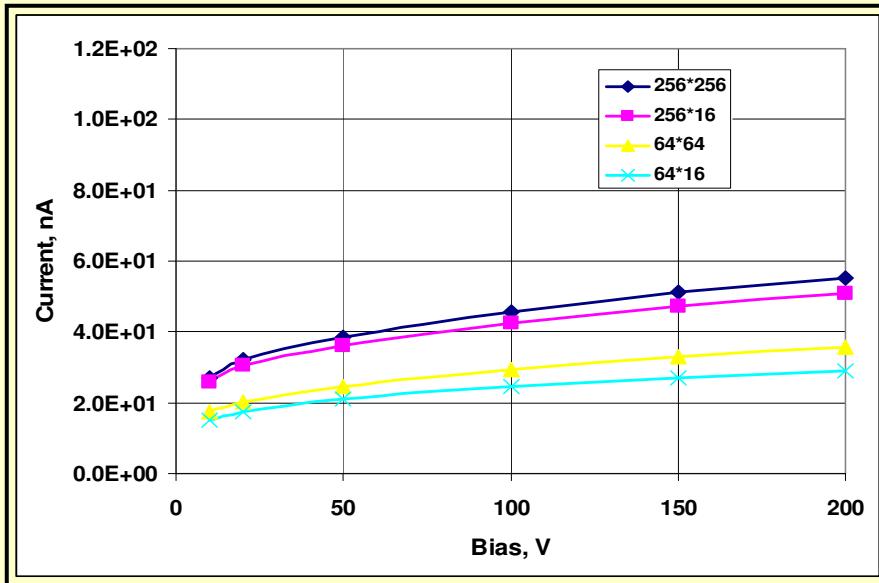
Streicher, Chung et al., GSI

Eremin et al., PTI, St. Petersburg

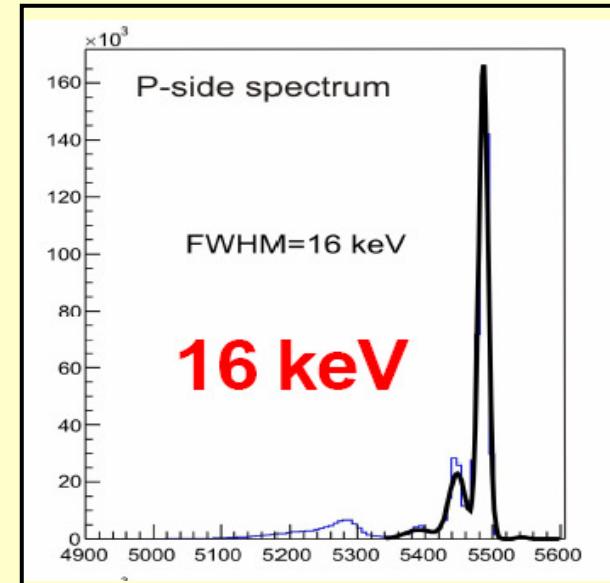
Davinson et al., Edinburgh

Rigollet et al., KVI

Current – voltage characteristics of baby DSSDs
and the related test strip structures



Spectrum of ^{241}Am alphas measured
with DSSD



The leakage current density is **8nA/cm²** at 100V.

The single strip leakage current of **20 pA/strip** is negligible for the detector noise performance.

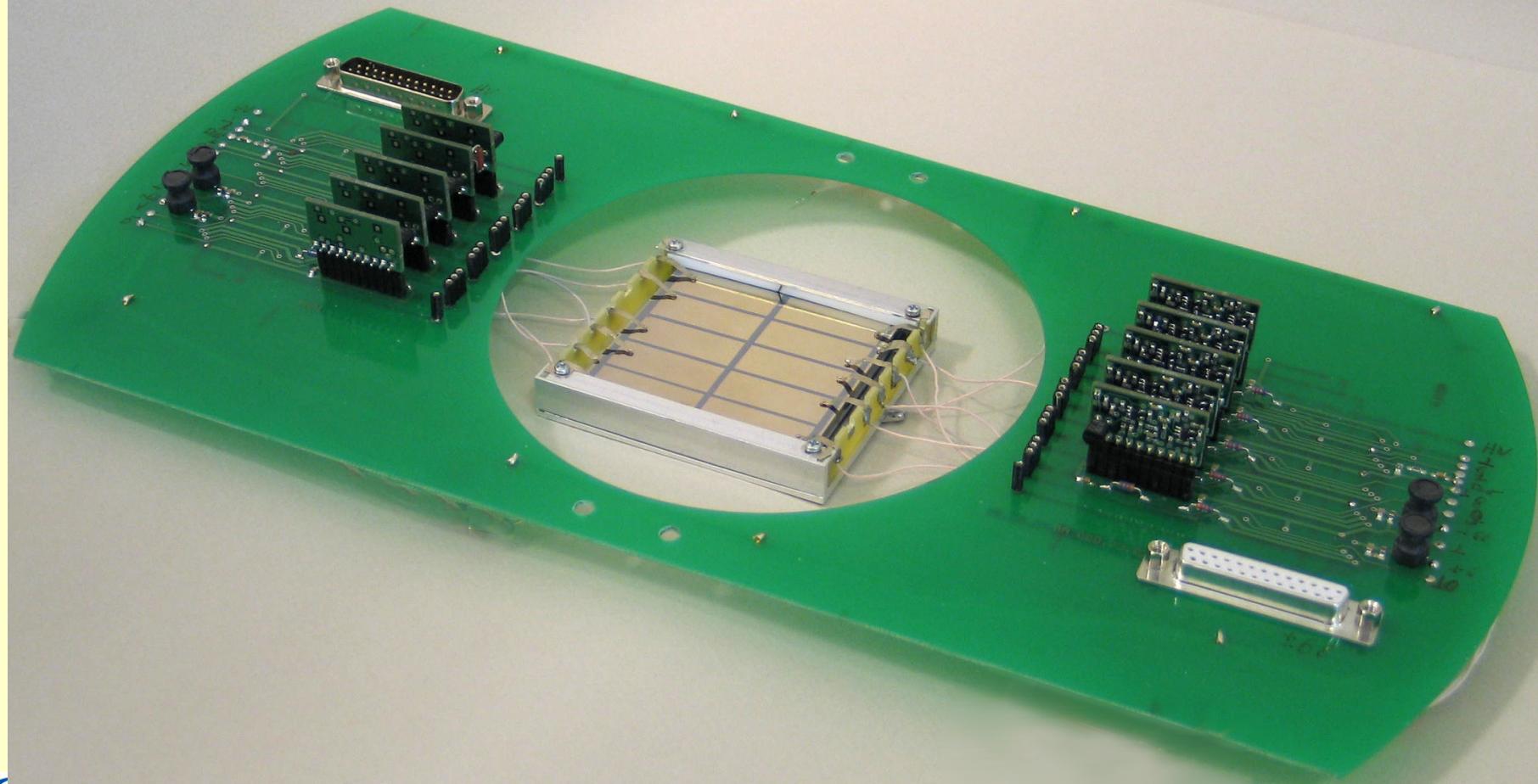
The energy resolution of **16 keV** is defined by the Landau fluctuations in the strip P+ implant.

Final prototype from PTI

- 65x65 cm² Ready by mid 2009 for tests

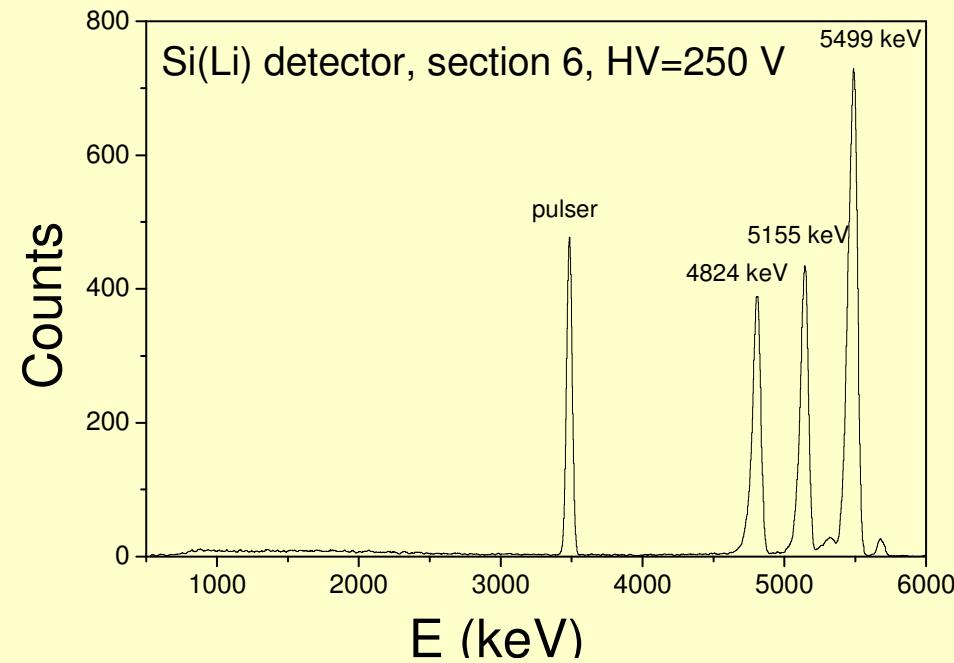
Si(Li)prototype 65x65x6 mm³

Seliverstov et al., PNPI, St. Petersburg

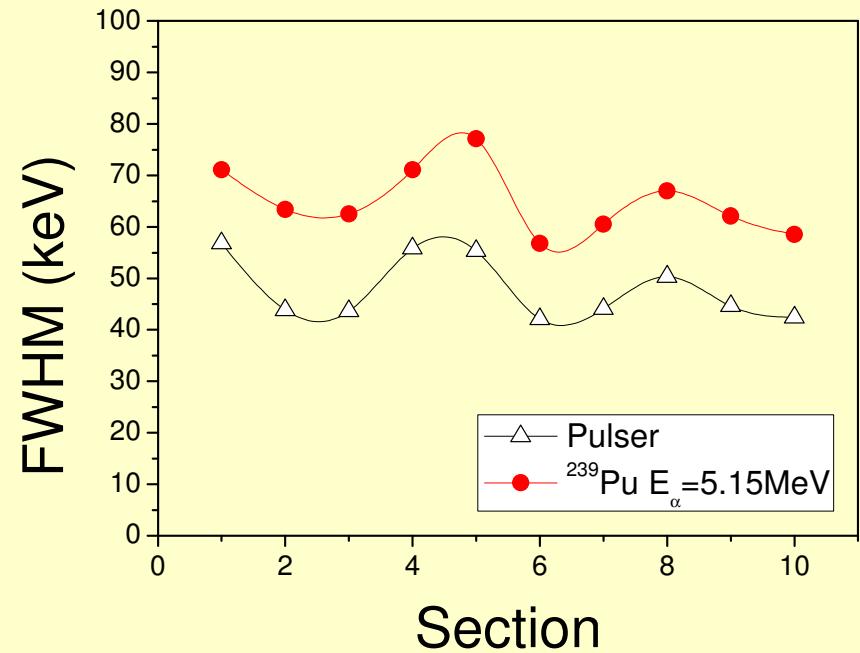


Parameters Si(Li) detector 65x65x6 mm³

PNPI prototype #2



α -spectrum of pixel #6, HV=250V



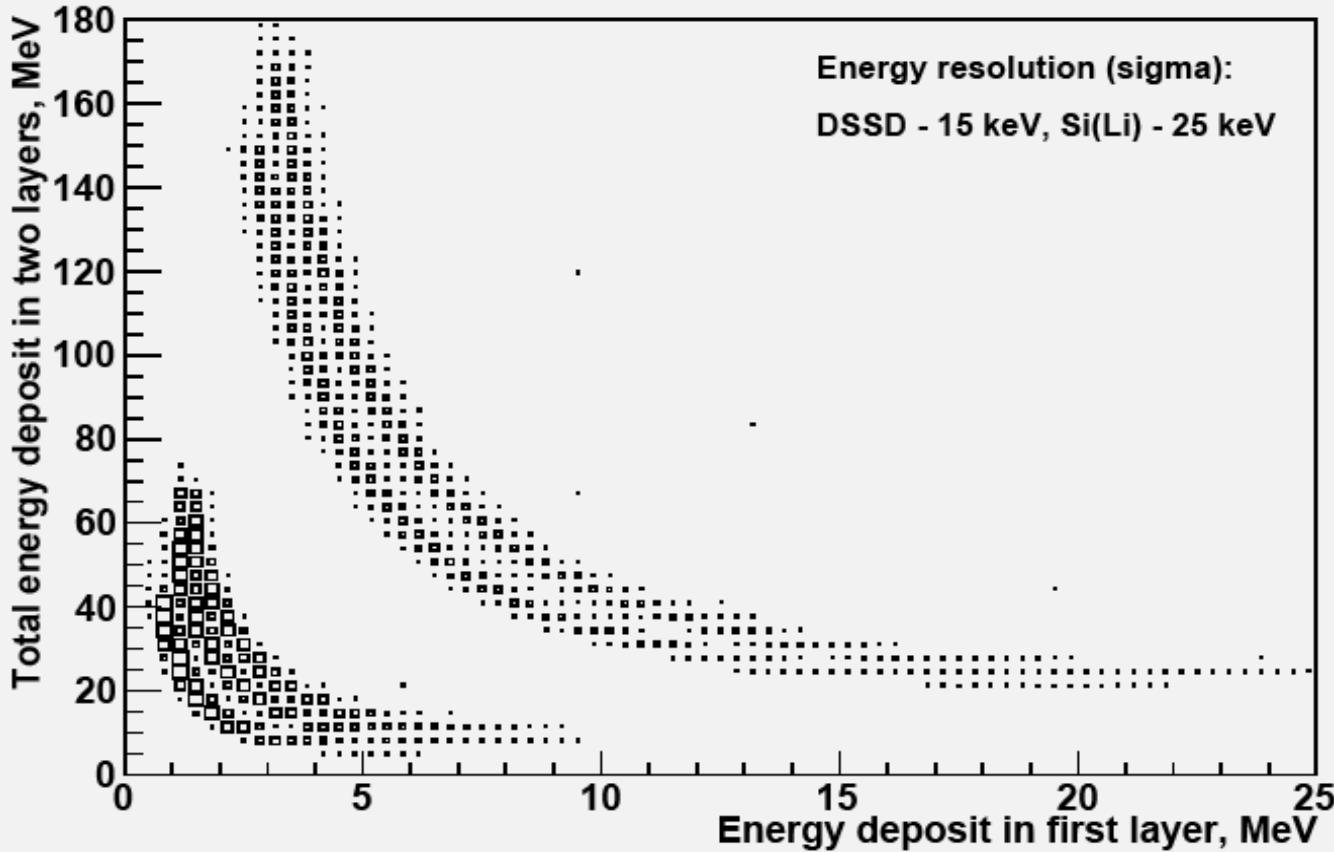
Energy resolution for different pixels

Seliverstov et al., PNPI, St. Petersburg

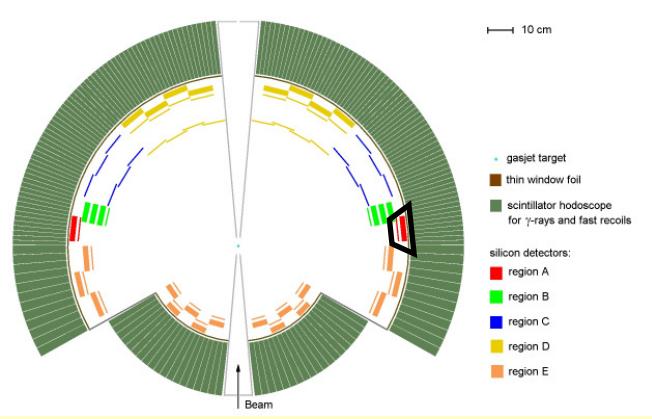
E-dE simulation

Zalite et al., PNPI, St. Petersburg

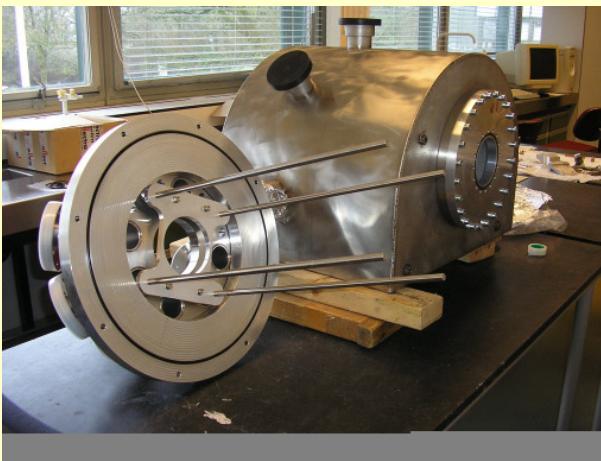
Region B, second layer (9 mm): protons, deuterons, tritons, He3, He4



EXL demonstrator



Rigollet et al., KVI

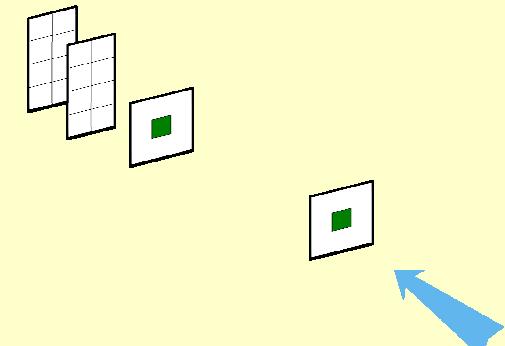


Beam tests at KVI (April 2009):
50 MeV protons from AGOR cyclotron

UHV flange and
Feed-throughs
designed at KVI



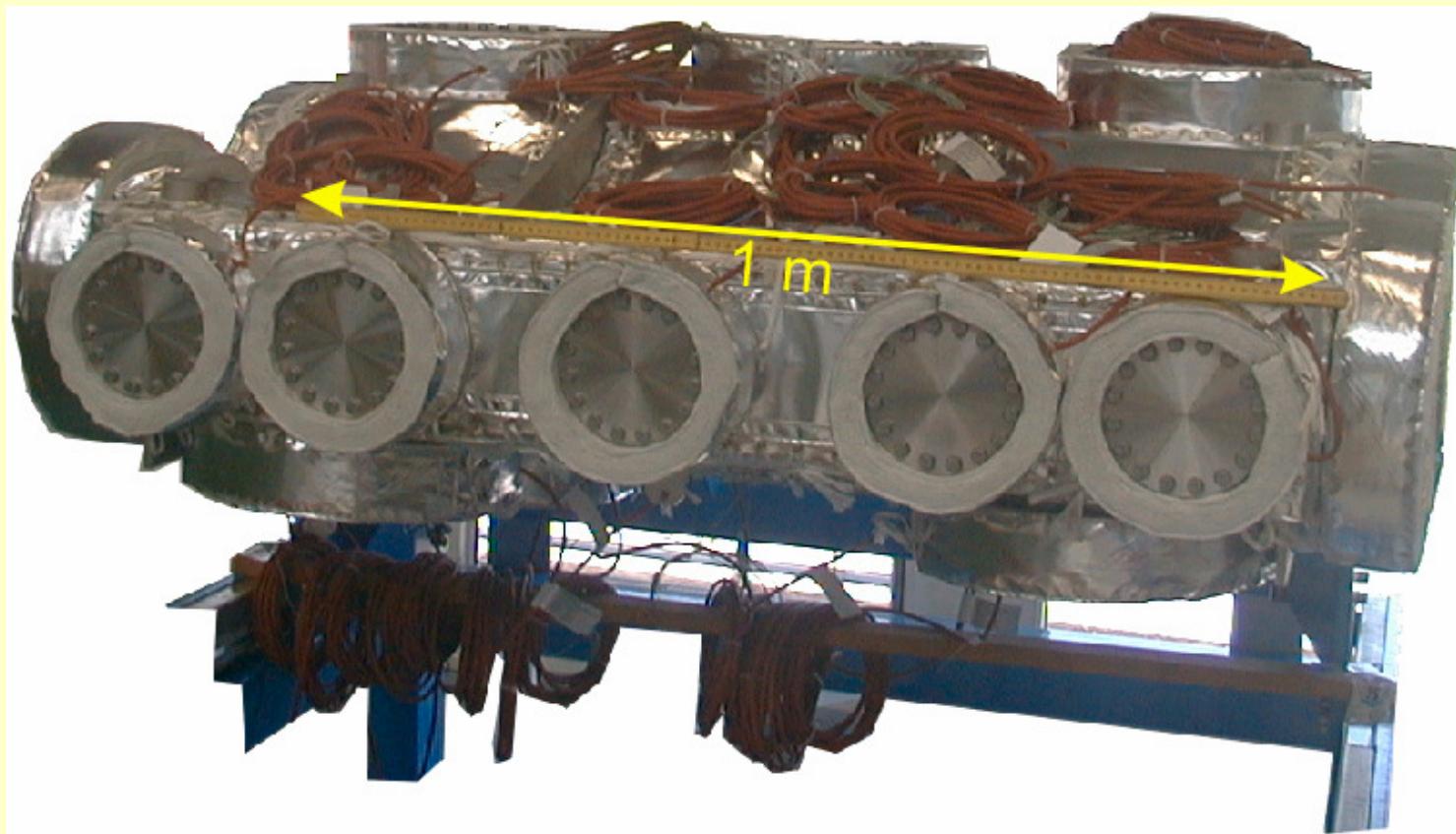
Stacked ΔE DSSDs
built at GSI and
instrumented by
Edinburgh electronics,
backed by thick Si(Li)
E detectors.



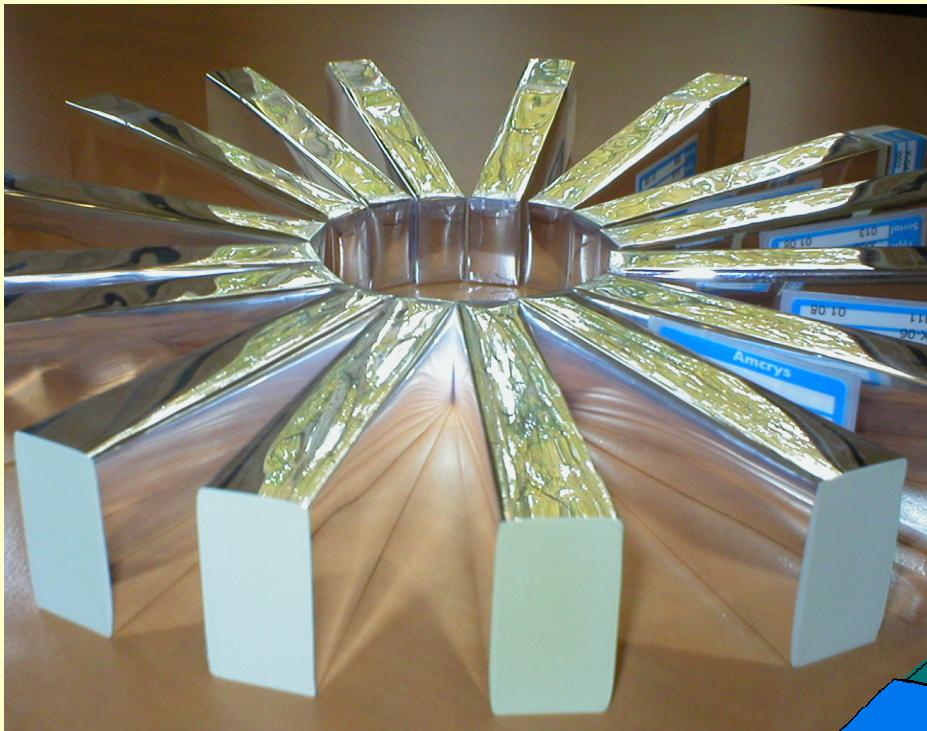
New Detector Chamber at the ESR

Ready to be mounted

Egelhof et al., GSI

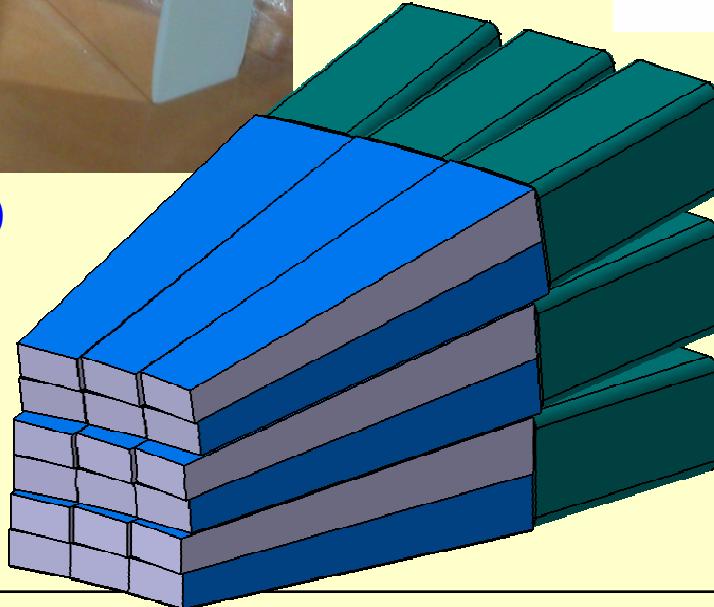


Demonstrator calorimeter R3B-EXL @ Orsay

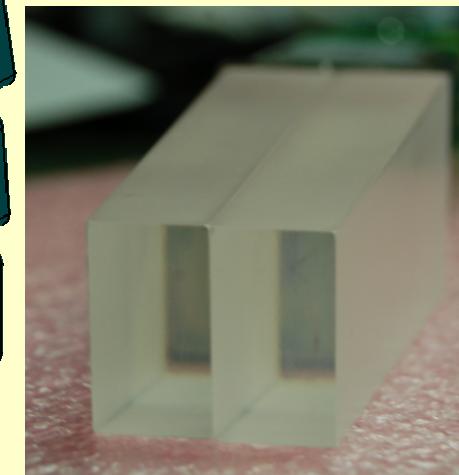
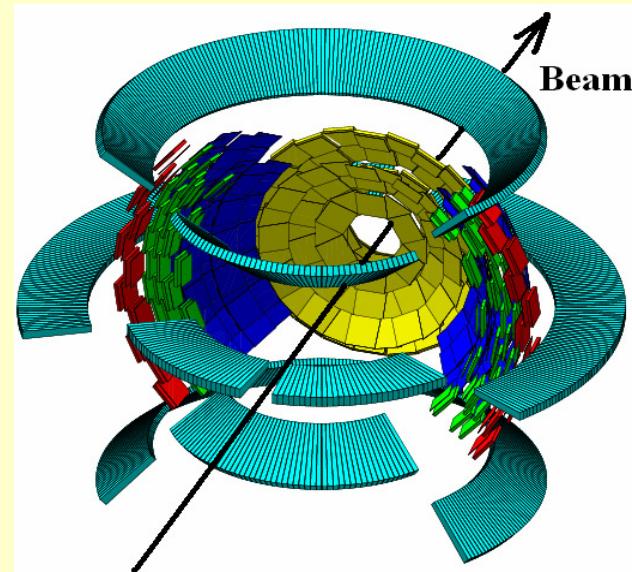


We have received 18 CsI(Tl)
crystals from Amcrys.

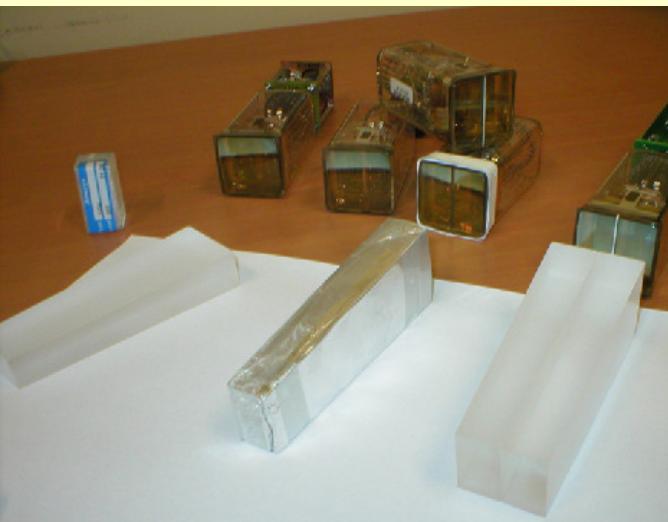
Scarpaci *et al.*, Orsay



Status of EXL



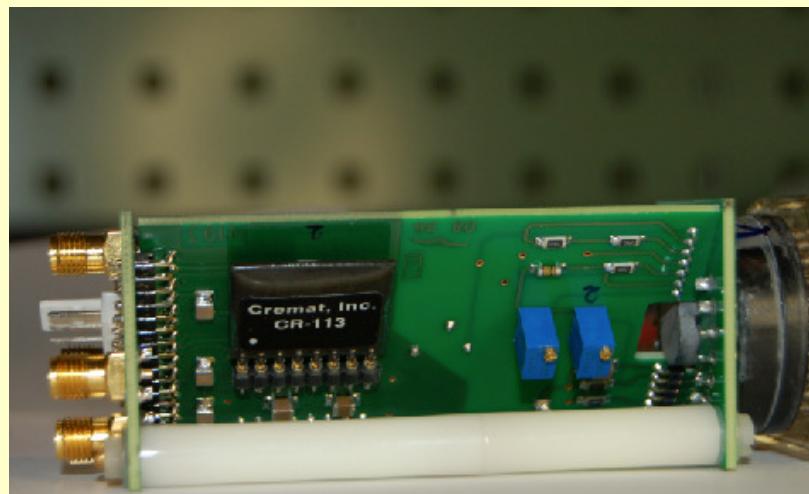
Prototype parts



CsI crystal from Amcrys



Double PMTs from Photonis
CREMAT preamps and bases



Scarpaci et al., Orsay

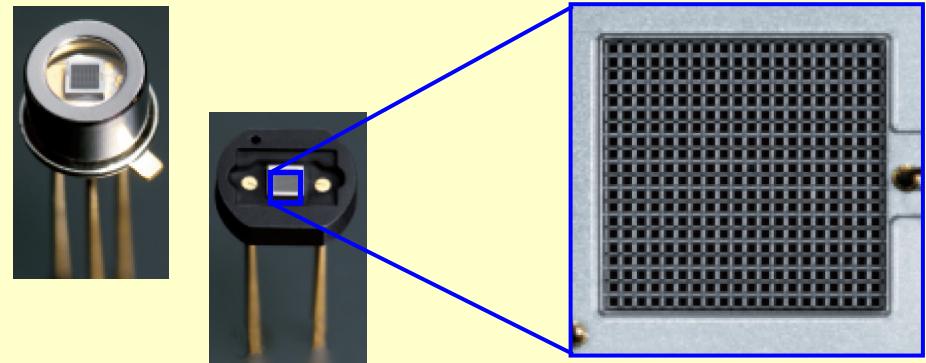
Status of EXL

SiPMT tests @ Madrid

Fraile et al., Madrid

- SiPM (G-APD, MPPC, ...) have many advantages compared to APD and PMT:

- High gain
- Low Voltage
- Fast Timing
- Compact size
- Low cost
- Compatible with magnetic fields



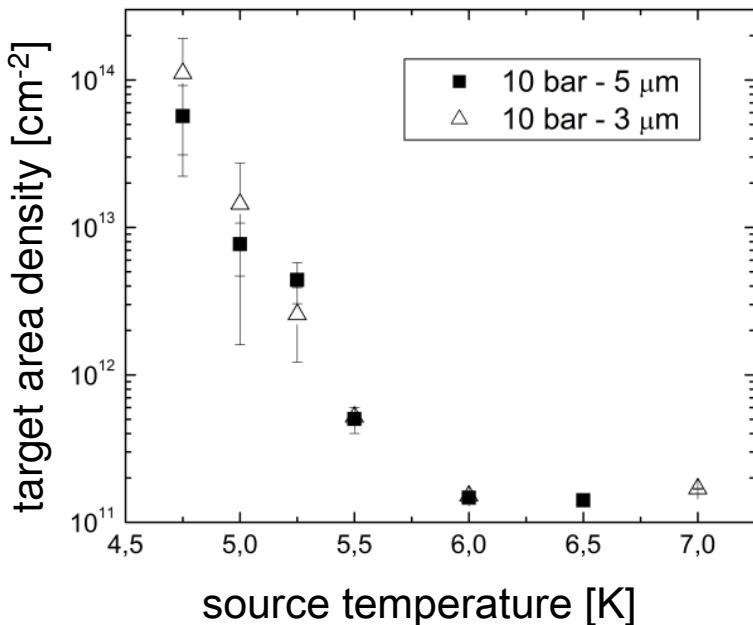
New Low-Z internal target

R. Grisenti et al., Frankfurt

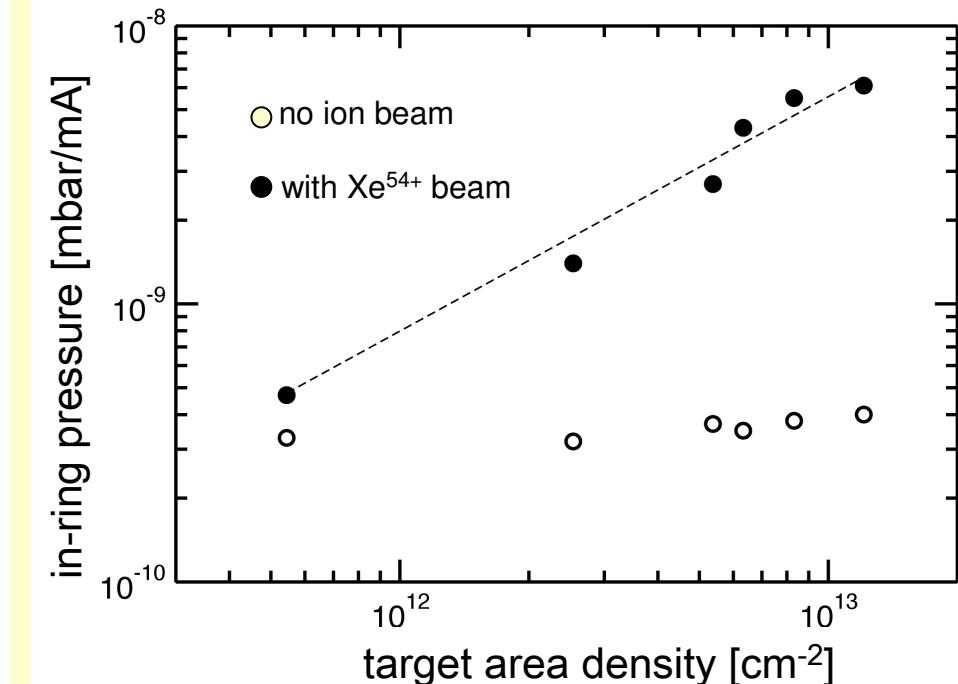
Cryogenically cooled liquid helium microjet



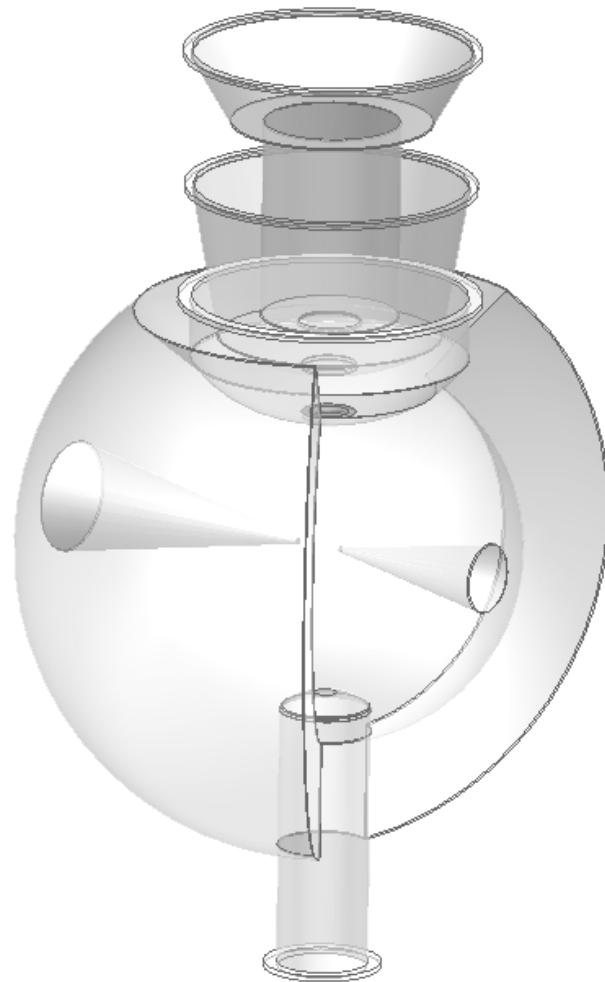
Measured target areal densities at different nozzle diameters and temperatures



Pressure in the scattering chamber as a function of the target areal density

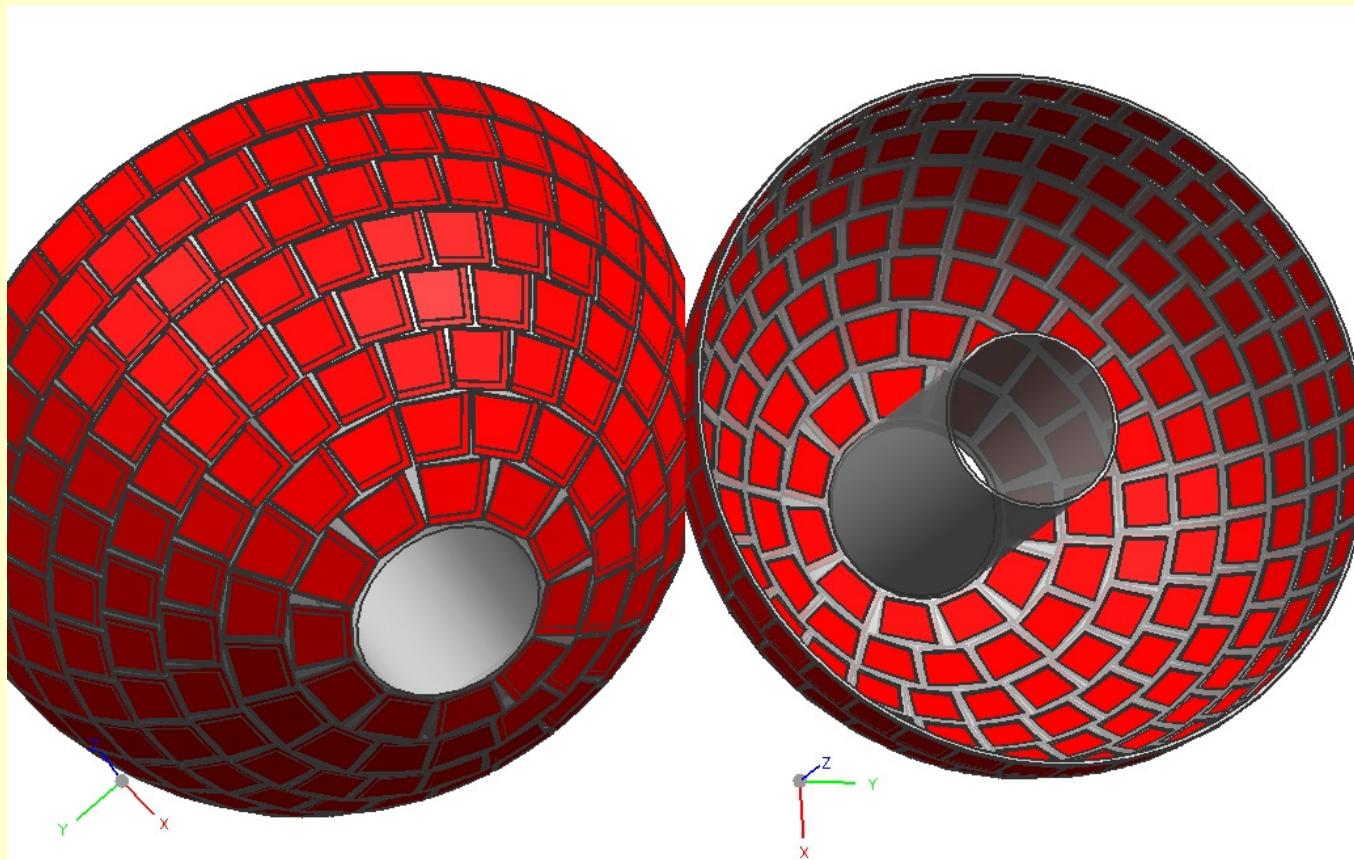


Mechanical Design



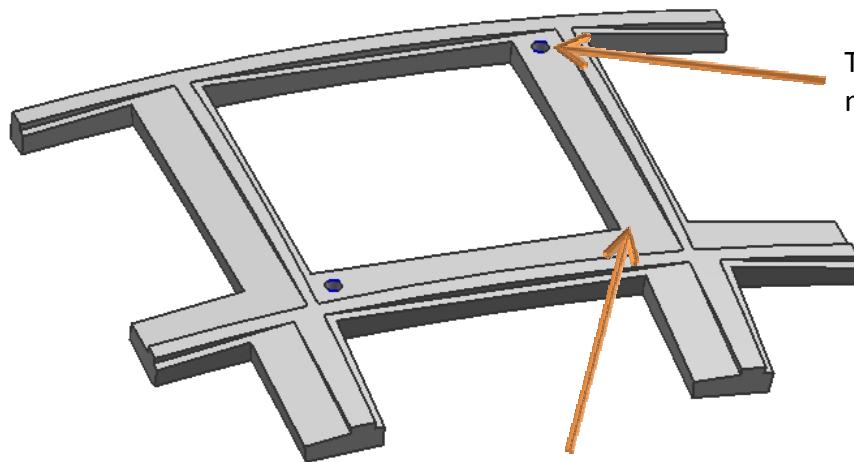
“Honey-comb” structure

Lindemulder et al., KVI



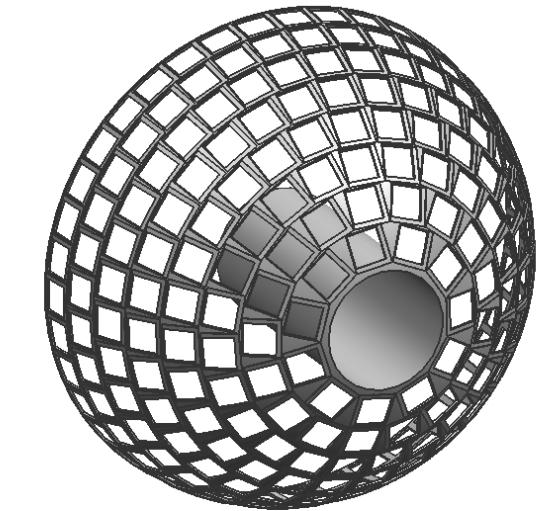
Support structure

Outside

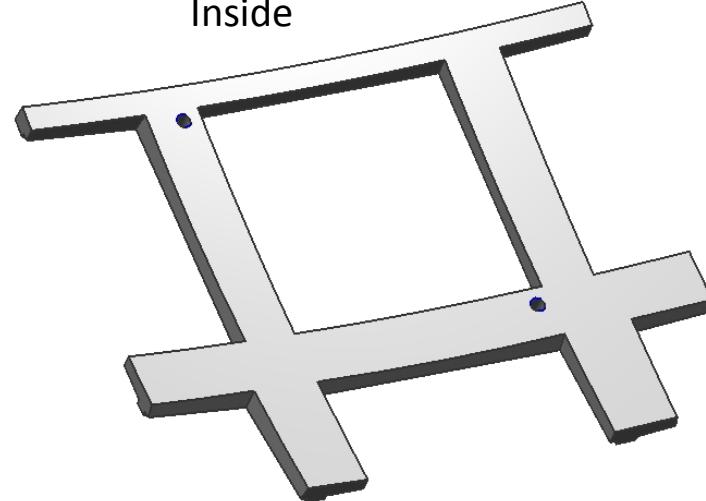


Thread holes for rods to
mount detectors

Flat cutouts to
support detector
and make it
vacuum tight



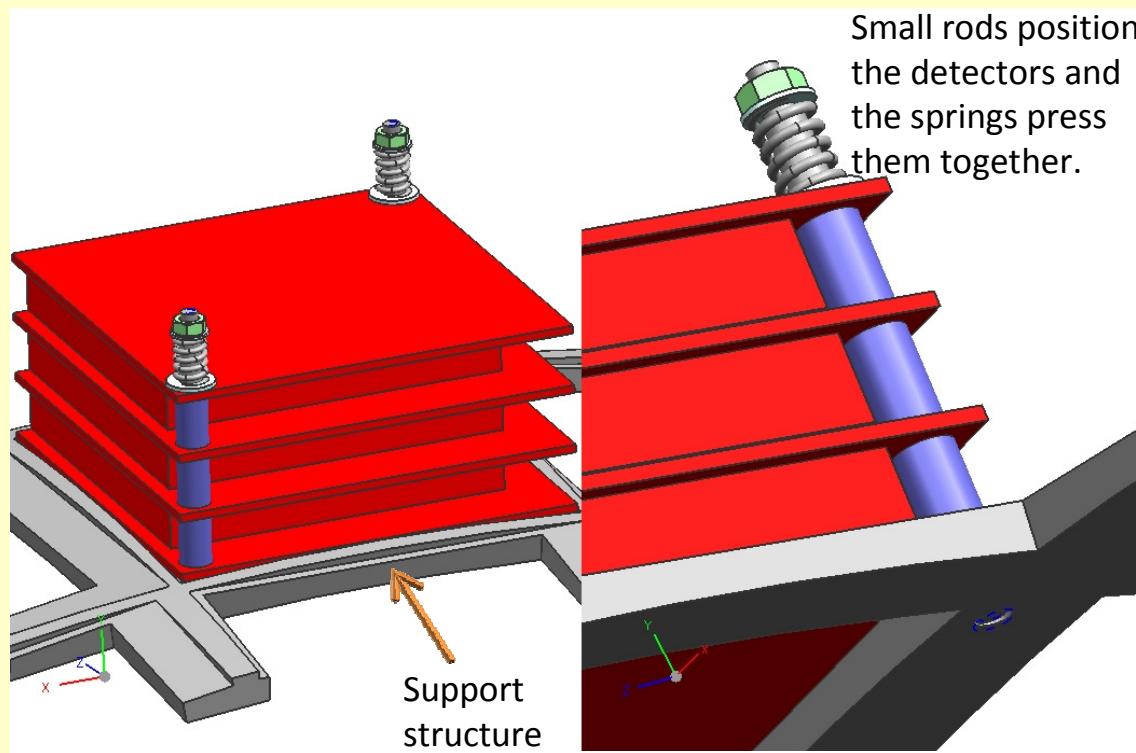
Inside



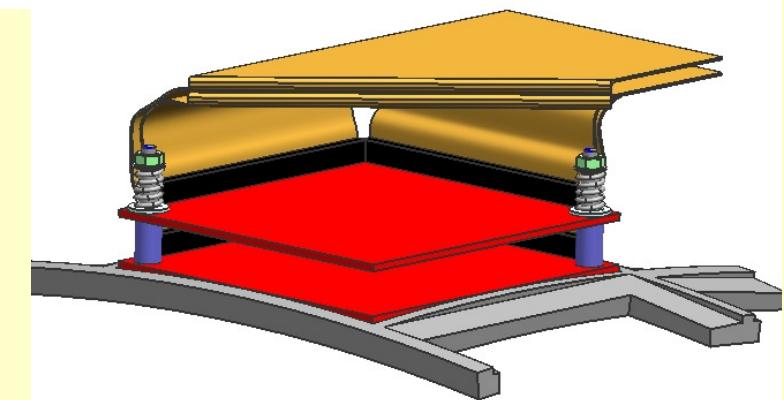
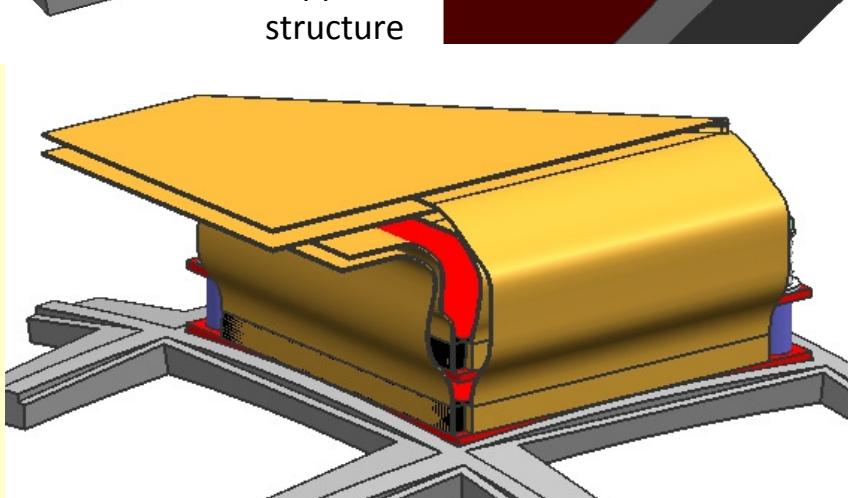
Lindemulder et al., KVI

Status of EXL

Connecting detectors



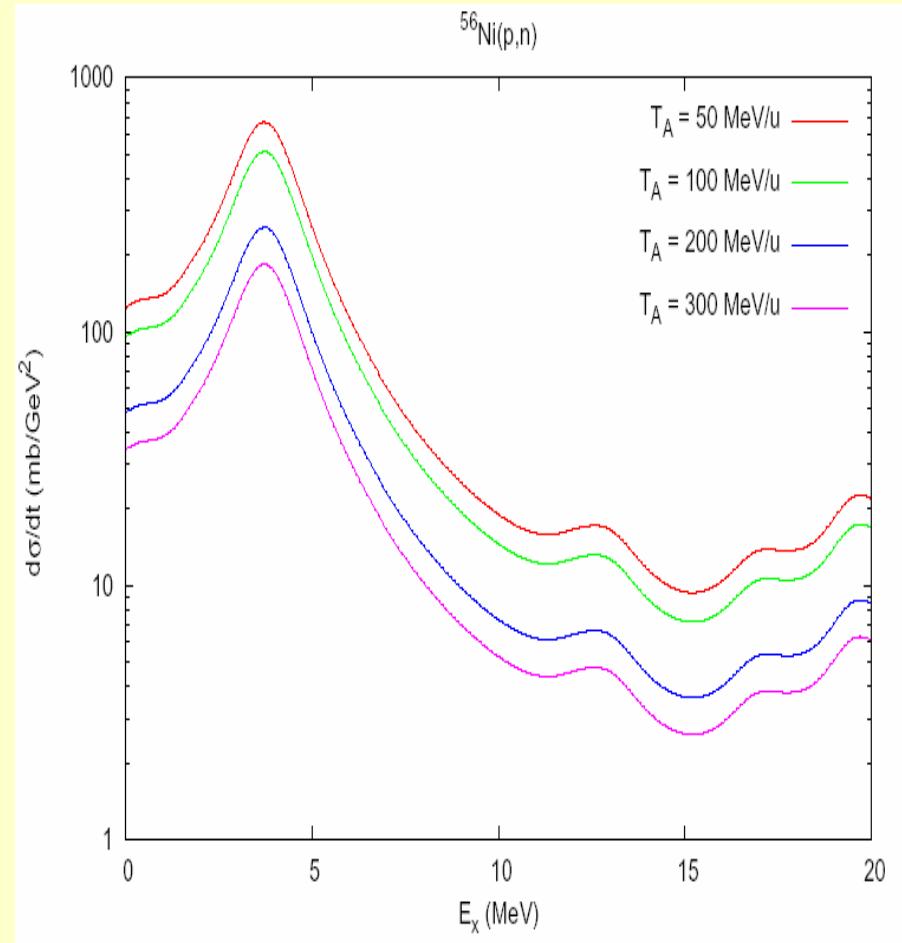
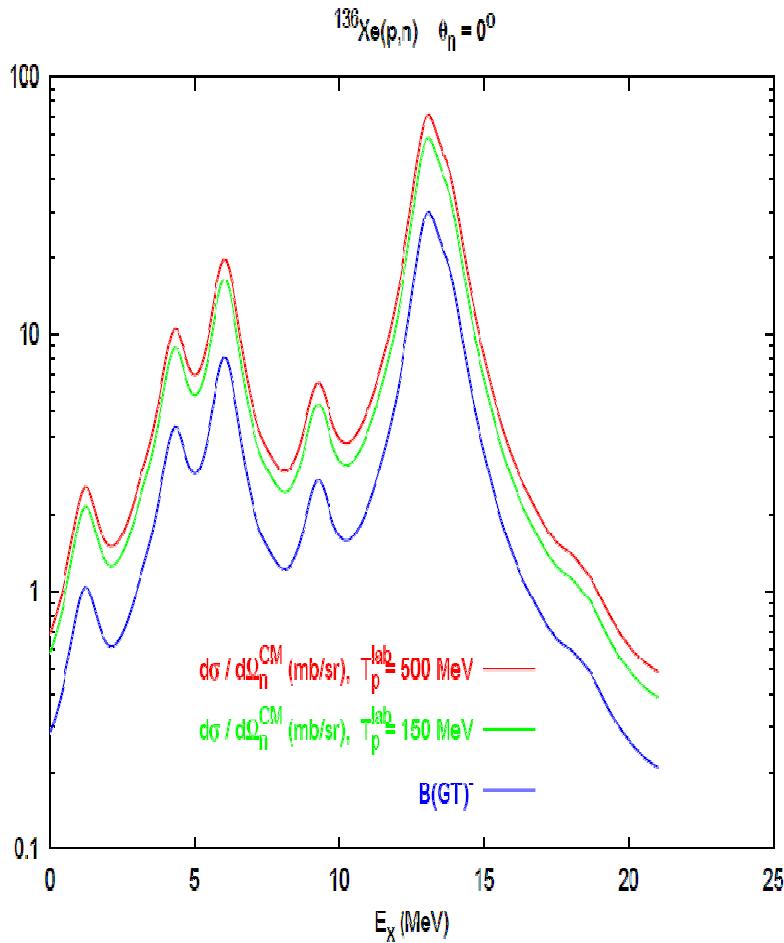
Lindemulder et al., KVI



Status of EXL

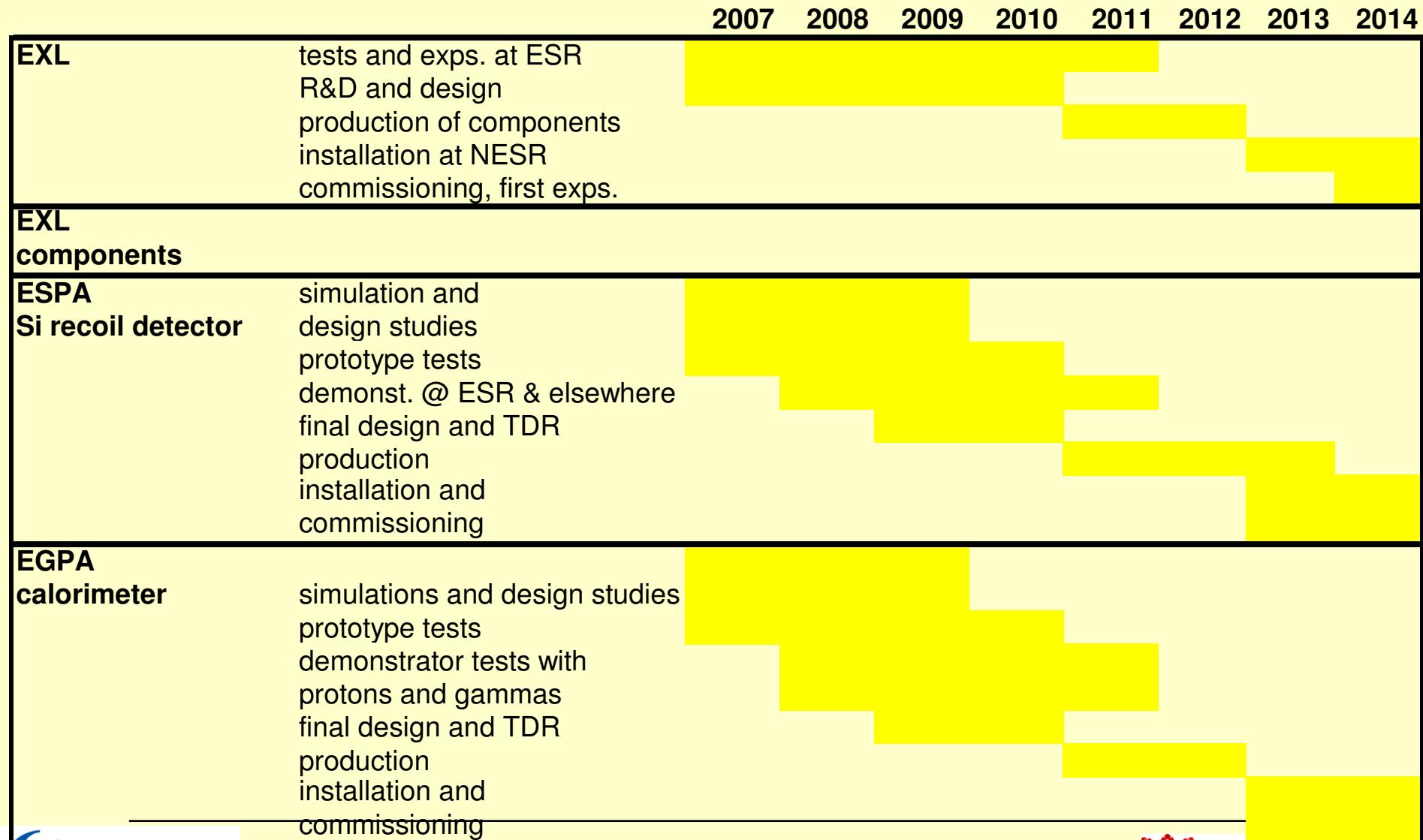
On the theoretical ground

Udias et al., Madrid

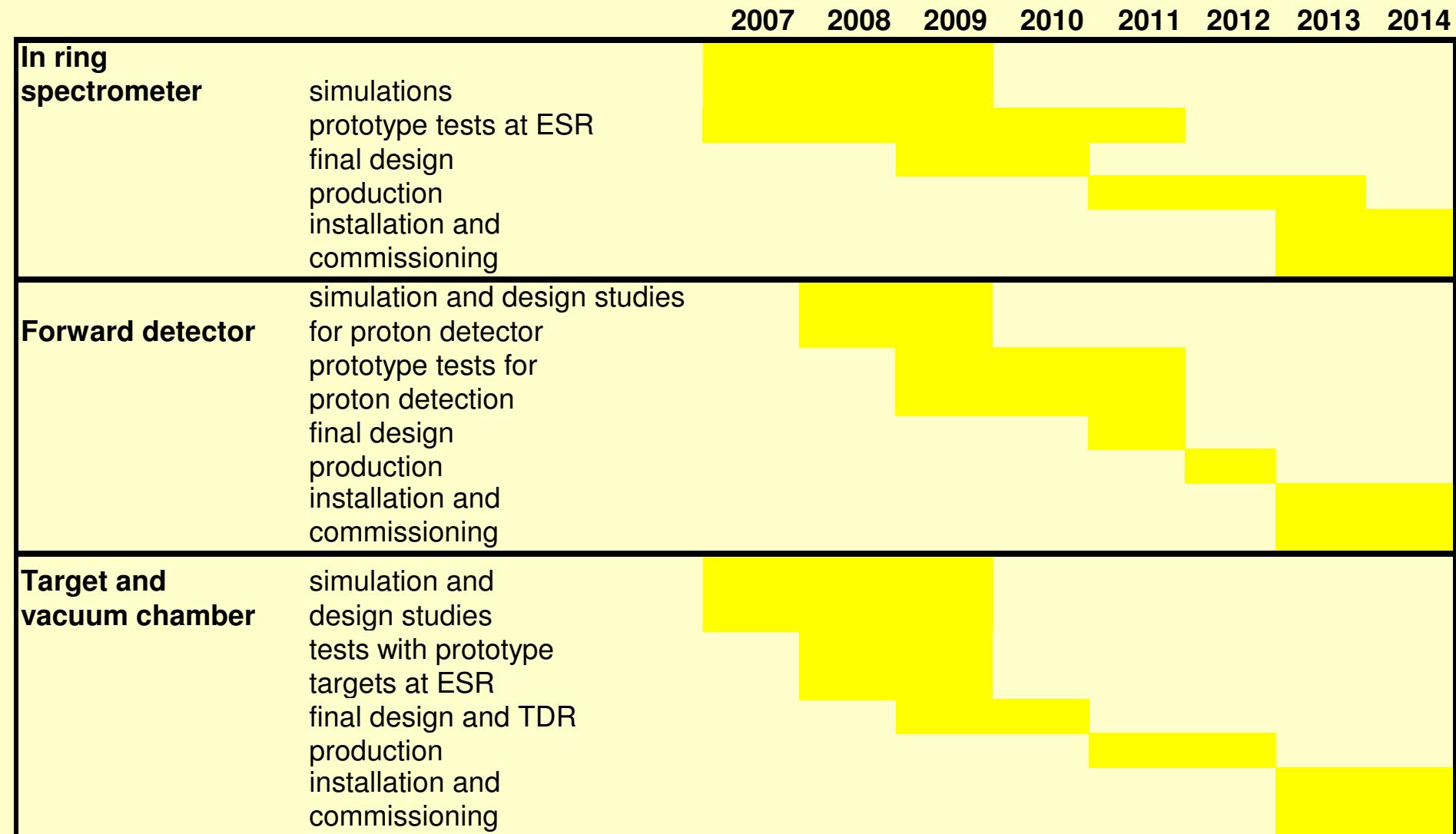


(p,n) cross-sections for ^{136}Xe and ^{56}Ni and other nuclei have been generated.

The EXL Time Schedule



The EXL Time Schedule



Conclusions and outlook

- After showing that the ring experiments in inverse kinematics are possible, intensive R&D has started.
- Simulation machinery ready.
- DSSD and Si(Li) prototypes have been made.
- Calorimeter design with R3B in progress.
- High target densities to be expected soon.
- TDR at the end of 2010.
- Test measurements along the way at various laboratories.

Thank you!

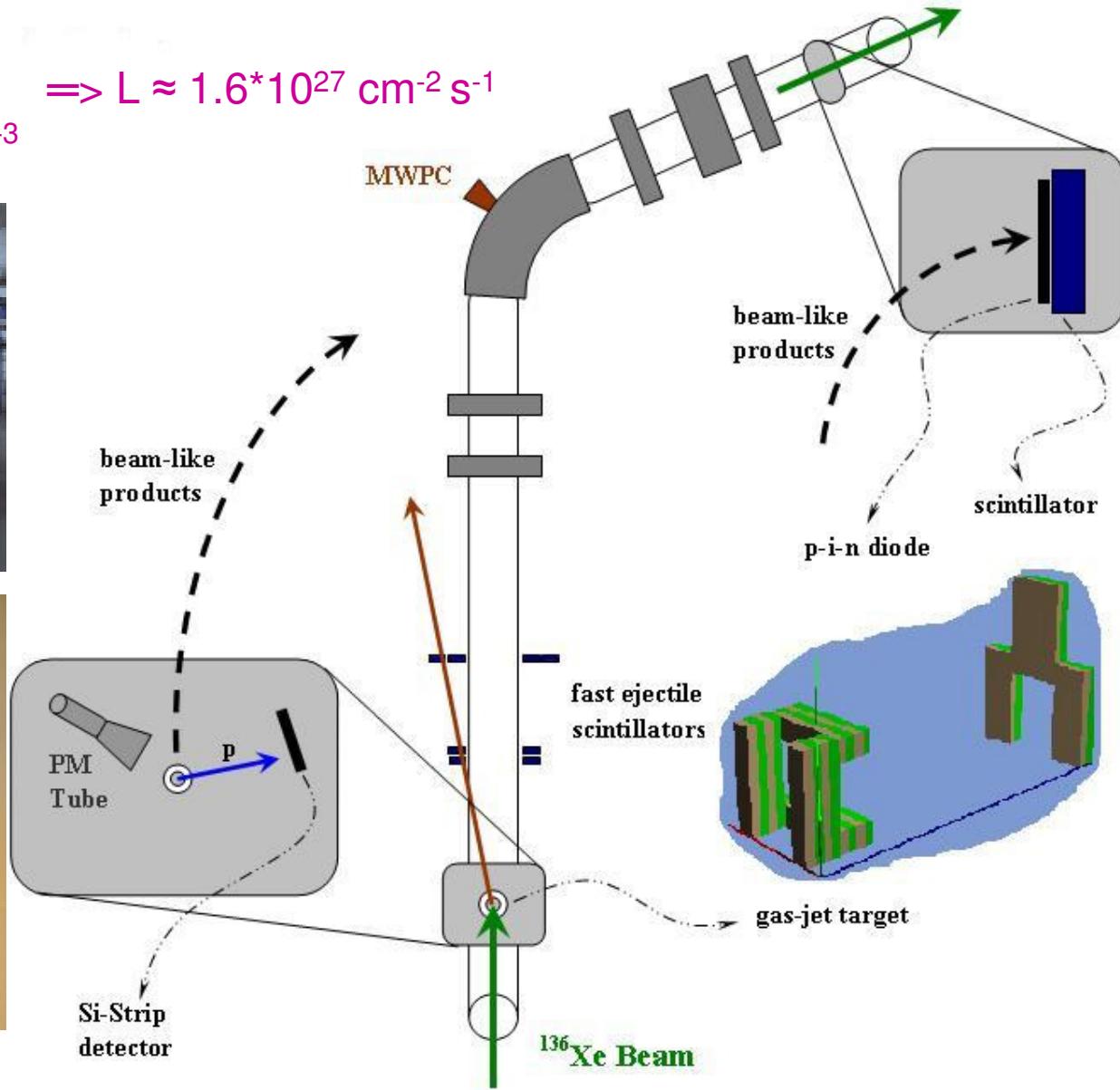
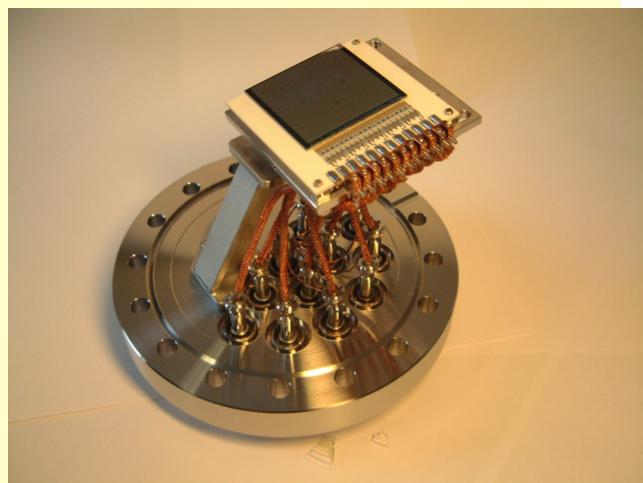
Feasibility study at the existing ESR

^{136}Xe beam, $E = 350 \text{ MeV/u}$

10^9 circulating ions in ring

target density $\approx 2.3 \cdot 10^{12} \text{ cm}^{-3}$

$$\Rightarrow L \approx 1.6 \cdot 10^{27} \text{ cm}^{-2} \text{ s}^{-1}$$



Status of EXL

Luminosity monitors

Si strip detector:

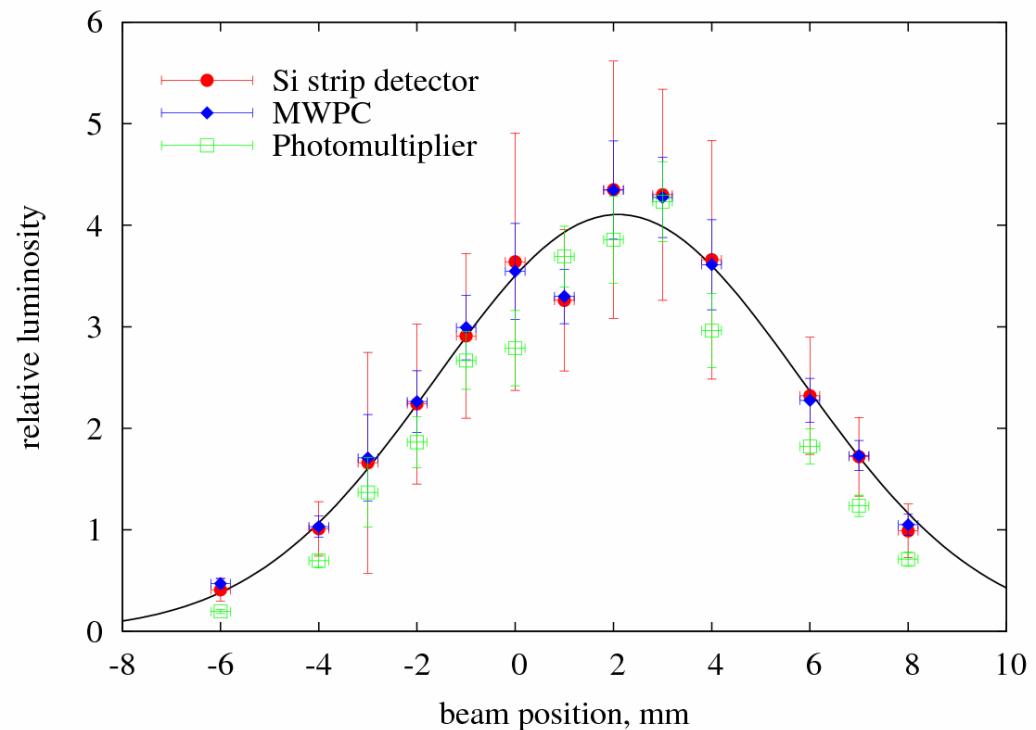
MWPC:

Photomultiplier:

elastic scattering

atomic charge exchange

light



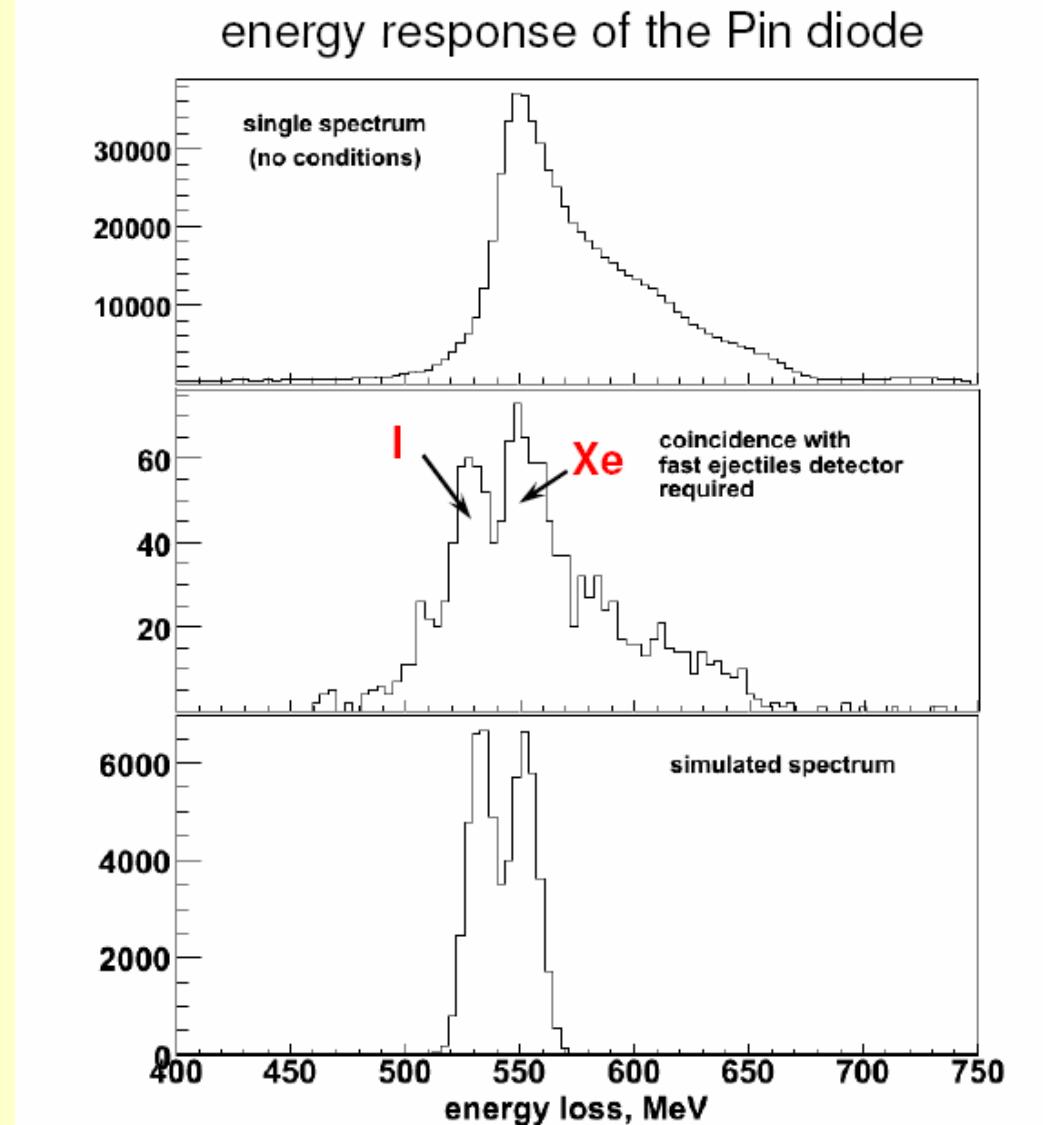
size of gas jet target:
 7.0 ± 0.2 mm

absolute luminosity measured with Si Strip Recoil Detector

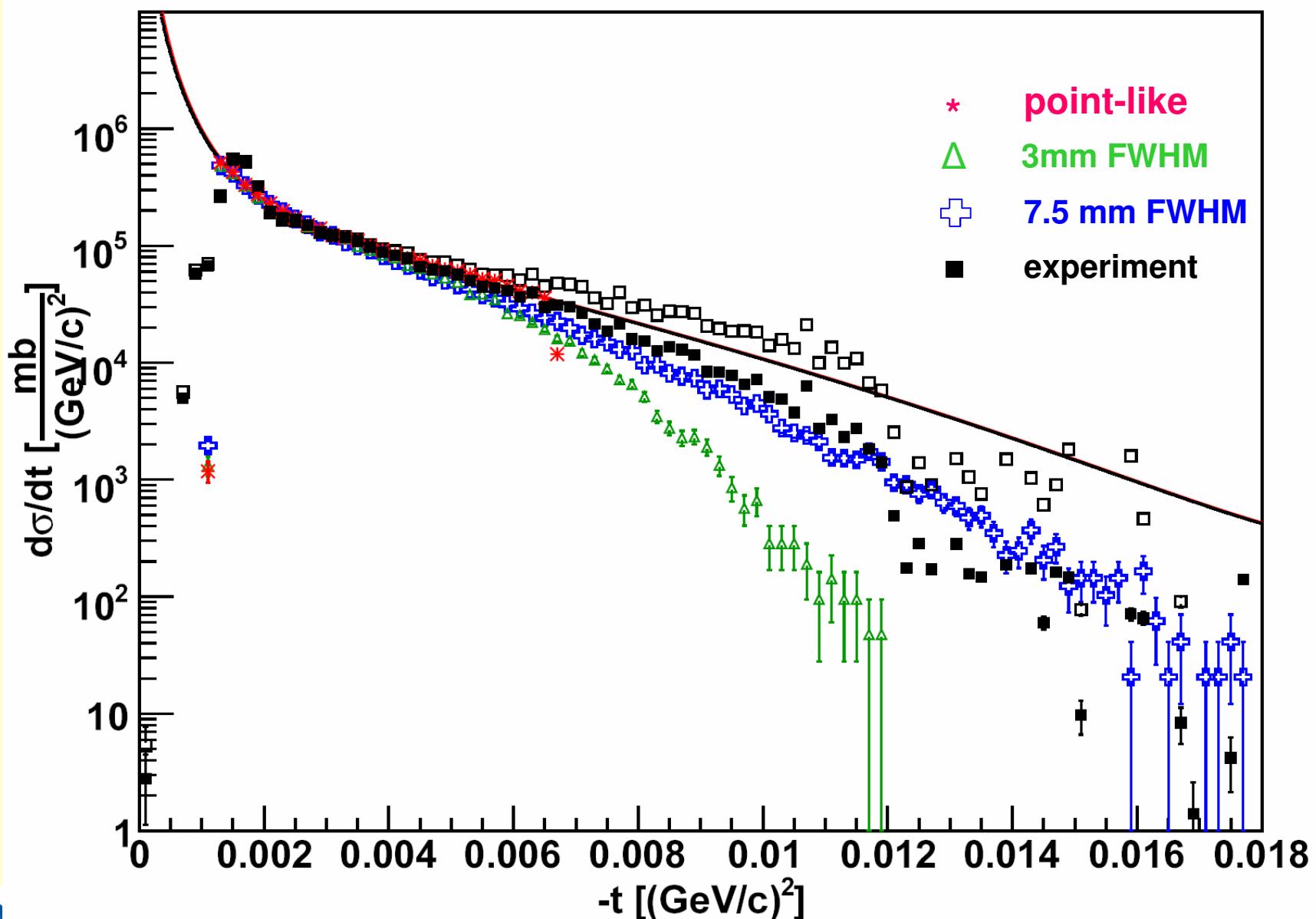
deduced luminosity $L = (6 \pm 2) \cdot 10^{27} \text{ cm}^{-2} \text{ sec}^{-1}$

Selected Result

Identified reaction channels:



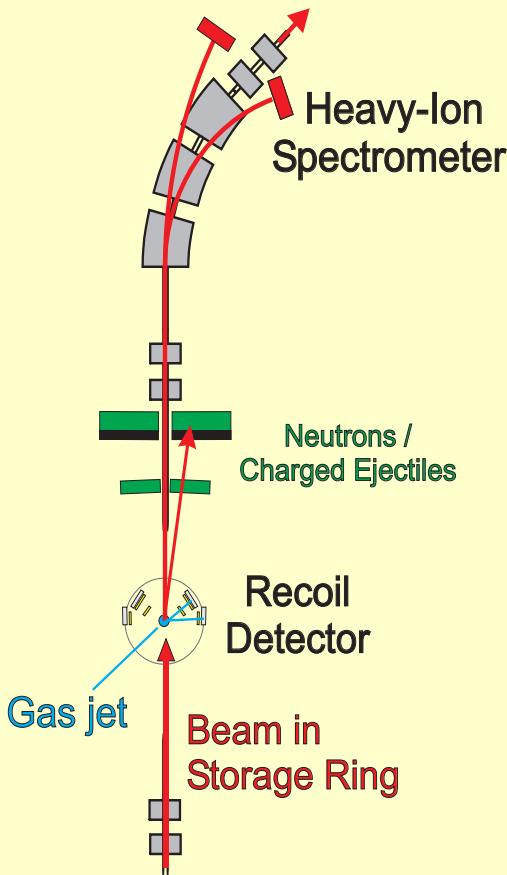
Elastic Scattering Cross Section ($E > 500\text{keV}$)



EXL Management Bord

Spokesperson	N. Kalantar (KVI)
Deputy Spokesperson	P. Egelhof (GSI)
Project Manager	N. Kalantar (KVI)
Technical Director	P. Egelhof (GSI)
Deputy Technical Director	V. Eremin (St. Petersburg)
GSI contact person	H. Weick (GSI)

EXL Working Groups and Responsibilities



Coordinators, other participating institutes

Sub-project	Members
Key-experiments/ Simulations	KVI (N. Kalantar), Milano (G. Colo) , Basel (F. Thielemann), GSI (P. Egelhof), U.C. Madrid (J.M. Udiás), CSIC Madrid (P. Sarriguren), Liverpool (M. Chartier), Guildford (J. Al-Khalili), São Paulo (A. L'pine-Szily), IPN Orsay (E. Khan), Chalmers (T. Nilsson), PNPI (A. Zalite), Tehran (M. Mahjour-Shafiei), Kurchatov (L. Chulkov), TRIUMF (R. Kanungo), Osaka (Y. Fujita)
Internal target/ Vacuum	GSI (T. Stöhlker), TSL (L. Westerberg) , FZ Jülich (F. Rathmann), Frankfurt (R. Grisenti)
Si particle array	GSI (P. Egelhof) , TU Darmstadt (N. Pietralla), Daresbury (R. Lemmon), KVI (C. Rigollet), Chalmers (T. Nilsson), Liverpool (M. Chartier), Guildford (W. Catford), Birmingham (M. Freer), Mainz (B. Steicher), FZ Jülich (T. Kring), Dubna (A. Artukh), TSL (L. Westerberg), TU München (M. Böhmer), Sundsvall (G. Thungström), BARC (A. Shrivastava), St. Petersburg (Y. Murin), St. Petersburg PTI (V. Eremin), PNPI (D. M. Seliverstov), Lanzhou (H. Xu), VTT (S. Eronen)
Gamma-ray and charged-particle calorimeter	IPN Orsay (J.A. Scarpaci) , Lund (B. Jakobsson) Dubna (A. Artukh), GSI (J. Gerl), BARC (A. Shrivastava), U.C. Madrid (J.M. Udiás), TU Darmstadt (N. Pietralla), KI Moscow (L. Chulkov), Lanzhou (H. Xu)
Slow-neutron detector	ATOMKI (A. Krasznahorkay)
Fast-ejectile detector	GSI (K. Boretzky), KVI (C. Rigollet) , Mainz (J.V. Kratz), Frankfurt (J. Stroth), Kolkata (U. Datta Pramanik), PNPI (A. Khanzadeev)
Storage ring/ Heavy- ion spectrometer	GSI (H. Weick), TU München (T. Fästermann) , KVI (N. Kalantar), PNPI (A. Khanzadeev)
FEE and DAQ	Daresbury (I. Lazarus), GSI (H. Simon) , TU München (M. Böhmer), KVI (H. Wörtche), PNPI (V. L. Golovtsov), Lund (B. Jakobsson), Lanzhou (H. Xu)

Investment Costs for the Construction of the EXL Setup

Summary of Investment costs for Phase 1 of the project

EXL Phase 1		Investment costs (k€)	
Internal target/ Vacuum system		710	710
Luminosity monitor		80	80
Target-recoil detector	Si detectors	2,890	9,020
	Electronics/ADC	2,640	
	Electronics development	240	
	CsI detectors	1,800	
	Slow-neutron detector	130	
	Vacuum chamber (incl. feedthroughs)	1,320	
Forward-ejectile detector		200	200
Heavy-ion spectrometer		570	570
DAQ, on/off-line computing		300	300
Mechanics, infrastructure, misc.		400	400
Total		11,280	

Summary of Investment costs for Phase 2 of the project

EXL Phase 2		Investment costs (k€)	
Target-recoil detector	Si detectors	1,580	3,700
	Electronics/ADC	1,320	
	CsI detectors	800	
Forward-ejectile detector		2,500	2,500
Total		6,200	

Cost Matrix: Intended Sharing of Investment Costs

			Target Recoil and Gamma Detector										
	Target/ Vacuum	Lum. Monitor	Si Array	FEE/ ADC	CsI Array	Neutr. Det.	Vacuum Chamber	Forw. Det.	In-ring Spectr.	DAQ	Mechanics Infrastr.		
Country/ Institute													Sum Country
Brazil													0
Univ. Sao Paulo													
Canada													0
TRIUMF Vancouver													
China													??
IMP Lanzhou					??								
Finland													0
VTT Helsinki													
France													600
IPN Orsay					600								
Germany													2790
GSI Darmstadt	710	80	300				400	70	300		200		2060
TU Darmstadt			250		250								
Univ. Frankfurt													
Univ. Giessen													
FZ Jülich													
Univ. Mainz								30					
TU München									100	100			
Hungary													130
ATOMKI Debrecen						130							

Cost Matrix: Intended Sharing of Investment Costs

			Target Recoil and Gamma Detector										
	Target/ Vacuum	Lum. Monitor	Si Array	FEE/ ADC	Csl Array	Neutr. Det.	Vacuum Chamber	Forw. Det.	In-ring Spectr.	DAQ	Mechanics Infrastr.		
Country/ Institute												Sum Country	
India													0
Mumbai													
CKolkata													
Italy													0
Univ. Milan													
Japan													0
Univ. Osaka													
Russia													12150
FLNR/JINR Dubna													
KI Moscow					350								
PNPI Gatchina			1000						2950	160			
KRI St. Petersburg			810										
PTI St. Petersburg			6880										
Spain													20
CSIC Madrid													
Univ. Madrid			20										
Sweden													0
Chalmers													
Univ. Lund													
Mid- Sweden Univ.													
TSL Uppsala													

Cost Matrix: Intended Sharing of Investment Costs

			Target Recoil and Gamma Detector										
	Target/ Vacuum	Lum. Monitor	Si Array	FEE/ ADC	CsI Array	Neutr. Det.	Vacuum Chamber	Forw. Det.	In-ring Spectr.	DAQ	Mechanics Infrastr.		
Country/ Institute												Sum Country	
Switzerland													0
Univ. Basel													
The Netherlands													80
KVI Groningen								30		50			
UK													500 ?
Daresbury Lab.													
Univ. Birmingham													
Univ. Edinburgh													
Univ. Liverpool													
Univ. Surrey													
Sum	710	80	9260	0	1200	130	400	3080	560	150	200		16270

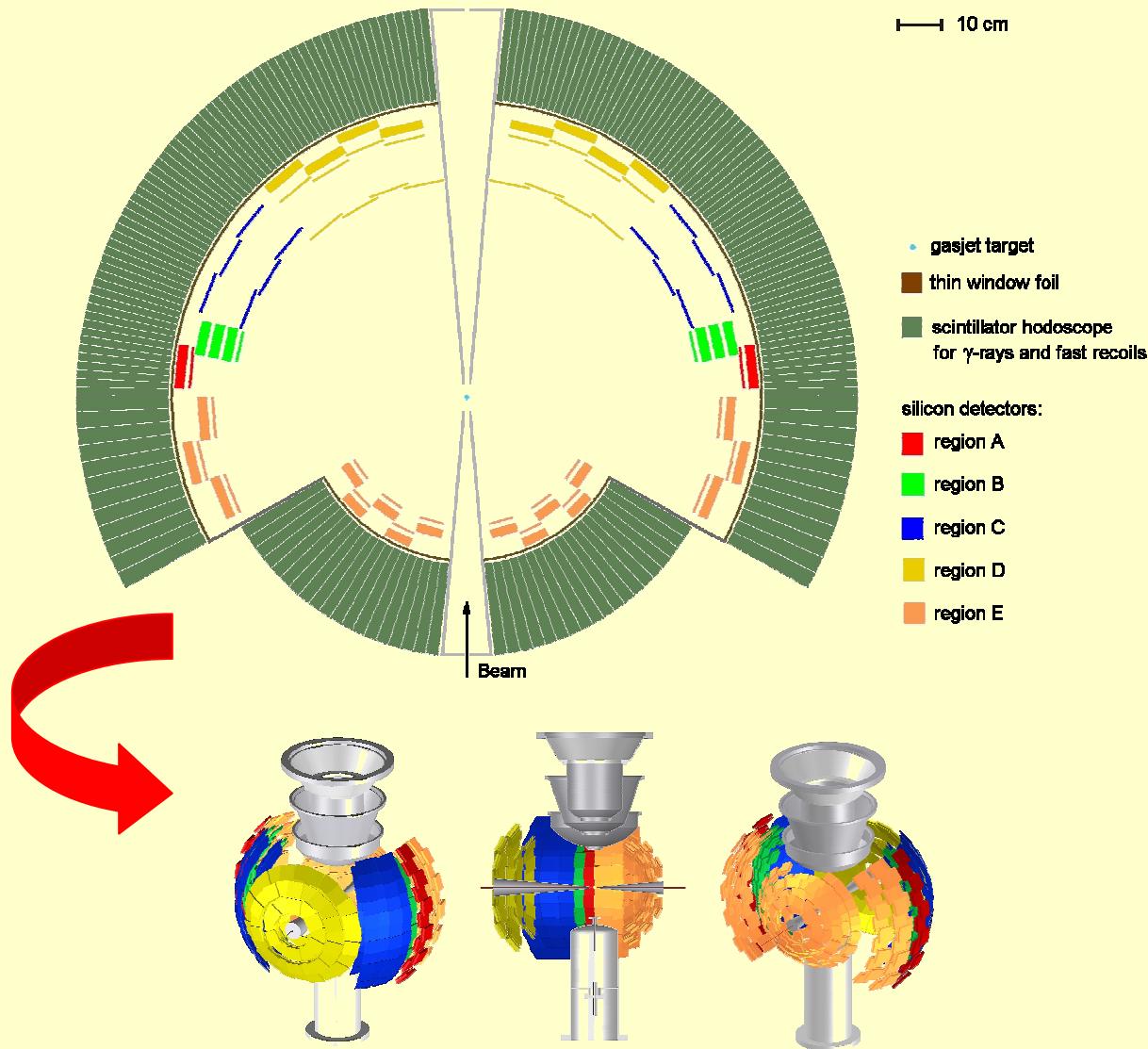
Cost Estimate: phase 1: 11280
 phase 2: 6200
 sum: 17480

German universities application of about 300 kEuro, Dec. 08

Challenges and problems to be solved for EXL

- Recoil Detector:
 - silicon ball (DSSD and Si(Li)):
 - high resolution
 - low threshold
 - large number of detectors and readout channels
 - UHV compatibility?
 - calorimeter (CsI):
 - high resolution and efficiency
 - high granularity
 - geometry
- Vacuum System:
 - satisfy demands of UHV conditions in NESR
 - differential pumping?
 - two chamber solution for silicon ball and calorimeter
- Internal Target:
 - gas jet: density and extension
 - alternative targets (cryogenic droplet target, polarized target etc.)

The EXL Recoil and Gamma Array



10 cm

- gasjet target
- thin window foil
- scintillator hodoscope for γ -rays and fast recoils
- silicon detectors:
 - region A
 - region B
 - region C
 - region D
 - region E

Si DSSD $\Rightarrow \Delta E, x, y$
300 μm thick, spatial resolution better than 500 μm in x and y,
 $\Delta E = 30 \text{ keV (FWHM)}$

Thin Si DSSD \Rightarrow tracking
<100 μm thick, spatial resolution better than 100 μm in x and y,
 $\Delta E = 30 \text{ keV (FWHM)}$

Si(Li) $\Rightarrow E$
9 mm thick, large area
100 x 100 mm^2 ,
 $\Delta E = 50 \text{ keV (FWHM)}$

CsI crystals $\Rightarrow E, \gamma$
High efficiency, high resolution,
20 cm thick

Specifications of the Silicon Detectors for EXL

Angular region	Θ_{lab} [deg]	Detector type	Active area [mm ²]	Thickness [mm]	Distance from target [cm]	Pitch [mm]	Number of detectors	Number of channels
A	89 - 80	DSSD	87 x 87	0.3	59	0.1	20	34800
		Si(Li)	87 x 87	9	60	-	20	180
B	80 - 75	DSSD	50 x 87	0.3	50	0.1	20	27400
		Si(Li)	50 x 87	9	52	-	20	180
		Si(Li)	50 x 87	9	54	-	20	180
		Si(Li)	50 x 87	9	56	-	20	180
C	75 - 45	DSSD	87 x 87	0.1	50	0.1	60	104400
		DSSD	87 x 87	0.3	60	0.1	60	34800
D	45 - 10	DSSD	87 x 87	0.1	49	0.1	60	104400
		DSSD	87 x 87	0.3	59	0.1	80	139200
		Si(Li)	87 x 87	9	60	-	80	720
E	170 - 120	DSSD	50 x 50	0.3	25	0.5	60	6000
		Si(Li)	50 x 50	5	26	-	60	240
E'	120 - 91	DSSD	87 x 87	0.3	59	0.1	60	104400
		Si(Li)	87 x 87	5	60	-	60	540
Total		DSSD Si(Li)					420 280	555400 2220

EXL Technical Board

Sub-Project	Members	Institute
Chair	P. Egelhof	GSI Darmstadt
Deputy	V. Eremin	St. Petersburg
Key-experiments/ Simulations	G. Colo N. Kalantar	Univ. Milano KVI
Internal target/ Vacuum	T. Stöhlker L. Westerberg	GSI Darmstadt Univ. Uppsala
Target-recoil detector	R. Lemmon P. Egelhof	CLRC Daresbury GSI Darmstadt
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Fast-ejectile detector	K. Boretzky C. Rigollet	GSI Darmstadt KVI Groningen
Storage ring/ Heavy-ion spectrometer	H. Weick T. Föstermann	GSI Darmstadt TU München
FEE and DAQ	I. Lazarus H. Simon	CLRC Daresbury GSI Darmstadt
R ³ B representative	R. Lemmon/ O. Tengblad	CLRC Daresbury CSIC Madrid