Silicon detectors for the EXL project

Mirko von Schmid for the EXL-E105 collaboration

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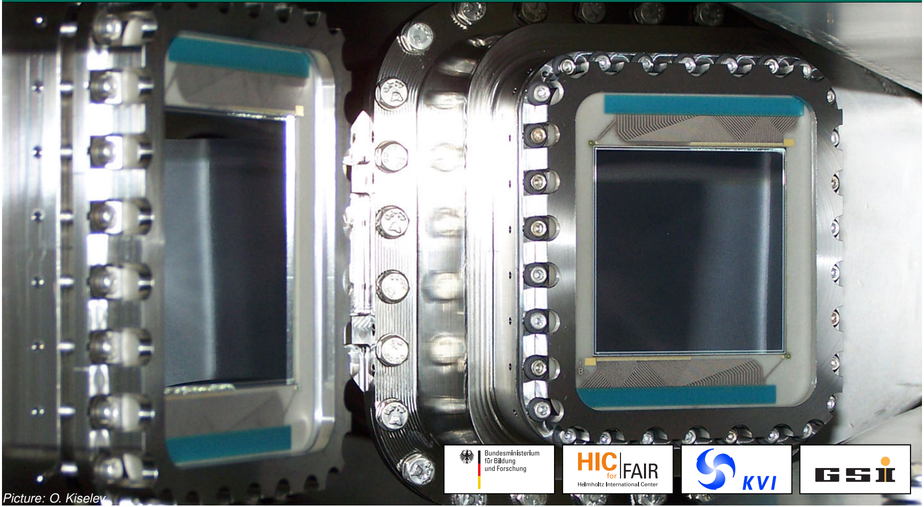
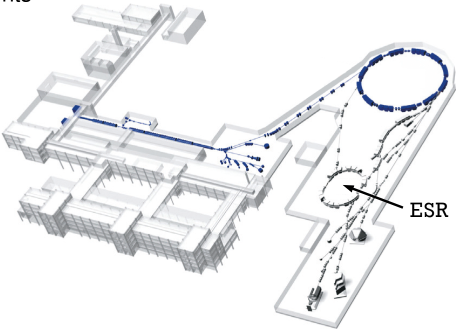


Picture: O. Kiselev

Bundesministerium für Bildung und Forschung
HIC for FAIR Helmholtz International Center
KVI
GSI

The EXL project

- "**EX**otic nuclei studied in **L**ight-ion induced reactions at storage rings"
- **Direct reactions** of exotic beams in **inverse kinematics** on an internal gas-jet target
  - Measurements at very **low momentum transfer**
  - Kinematically complete measurements
  - **High luminosities** due to beam recirculation in storage ring
- First EXL experiment with radio-active beam at the ESR, GSI:
  - ^{20}Ne, ^{58}Ni and $\mathbf{^{56}Ni}$ beams
  - ^{4}He and $\mathbf{H_2}$ gas-jet targets
  - ^{56}Ni(p,p) **luminosity**: $2 \cdot 10^{\mathbf{26}}\ \frac{\text{particles}}{\text{s cm}^2}$



Picture: GSI

Elastic proton scattering in inverse kinematics

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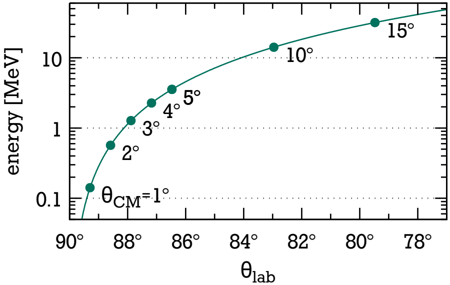
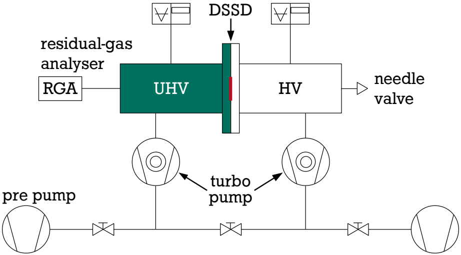
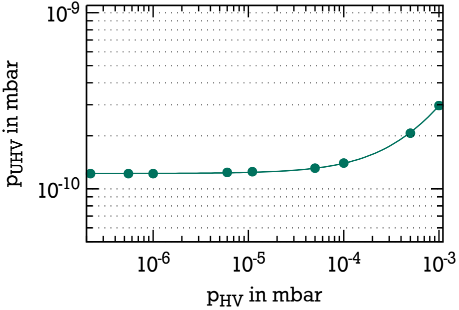
- Kinematics of ^{56}Ni(p,p) at 400 MeV/u:



- Low momentum transfer results in low recoil energies towards $\theta_{\text{lab}} = 90^\circ$.
- **Thin**, **windowless targets** and detectors with **low energy threshold** mandatory.
- Storage ring demands **UHV compatibility**.

Vacuum concept

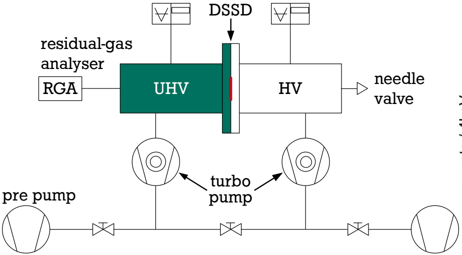


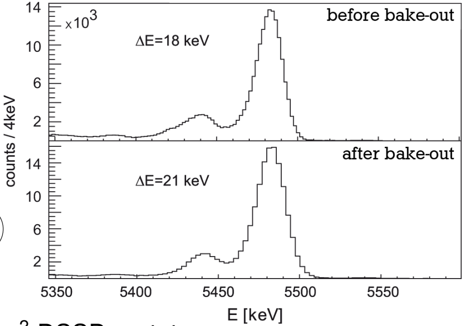


- First successful tests using $(2 \times 2)\,\mathrm{cm}^2$ DSSD prototype
- Artificial leak on HV side (needle valve)
- Vacuum separation by 6 orders of magnitude difference achieved

B. Streicher et al., Nucl. Instr. and Meth. A 654, 604 (2011)

Vacuum concept





- First successful tests using $(2 \times 2)\,\mathrm{cm}^2$ DSSD prototype
- Artificial leak on HV side (needle valve)
- Vacuum separation by 6 orders of magnitude difference achieved
- DSSD survives bake-out without loosing performance

B. Streicher et al., Nucl. Instr. and Meth. A 654, 604 (2011)

Experimental setup at the ESR

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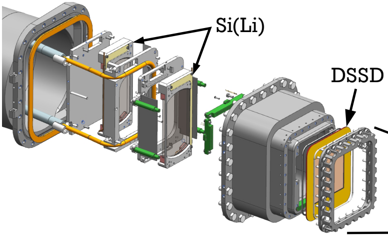
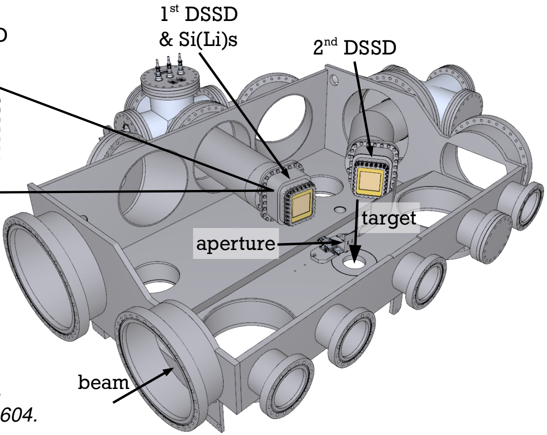
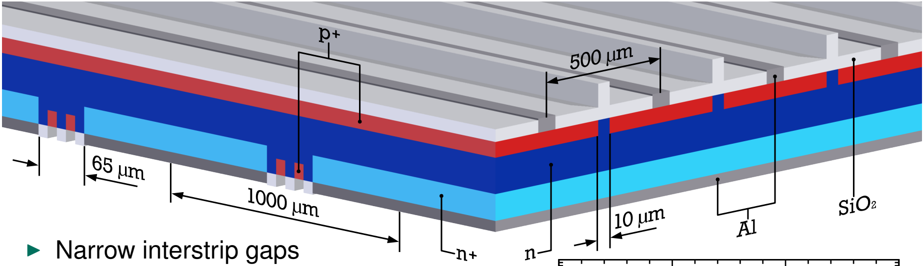




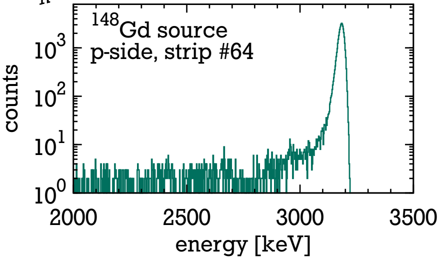
- **DSSD**: 128 $\times$ 64 strips, (6 $\times$ 6) cm^2, 285 μm thick
- **Si(Li)**: 8 pads, (8 $\times$ 4) cm^2, 6.5 mm thick
- **active vacuum barrier**
  See publication of B. Streicher et al., Nucl. Instr. and Meth. A 654 (2011) 604.
- **aperture** to improve angular resolution

figures: M. Lindemulder

DSSDs for EXL by PTI, St. Petersburg – “Compensated“ window design



- Narrow interstrip gaps
- Thin dead layers:
  - p^+-implant on p-side: 500 Å
  - Al metallization: 600 Å
  - thin SiO_2 layer: 500 Å
- Compensation of different energy losses for low-energy particles
- Energy resolution ≈ 25 keV (FWHM)



DSSDs for EXL –
UHV compatible PCB and readout

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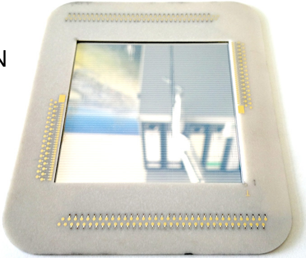
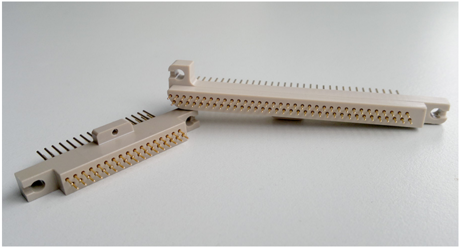
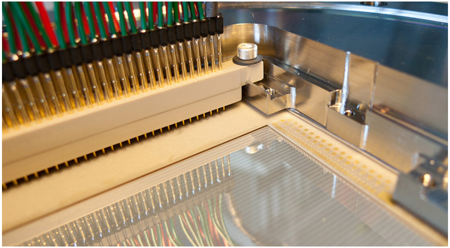
- DSSD on AlN PCB
  - Similar thermal expansion coefficients of Si and AlN
  - “Clean“ UHV side with sealed feedthroughs; no soldering, no connectors etc.
  - Readout of all 192 strips from the back side
- Reversible contacting via spring pins in custom made connector made of PEEK
  - Heat resistant till 160°C at least







Elastic proton scattering
^{56}Ni(p,p) at 390 MeV/u

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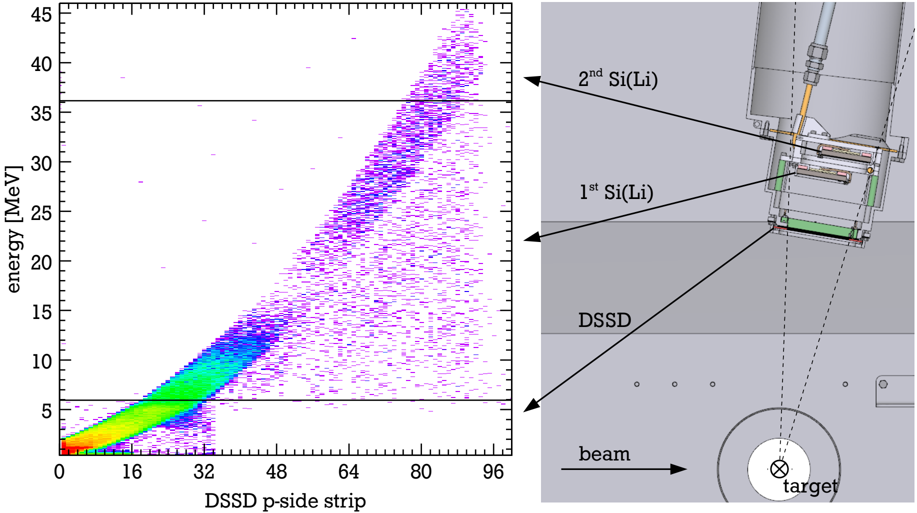
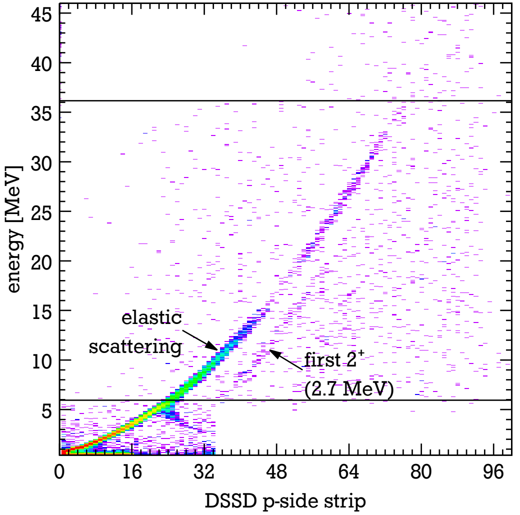
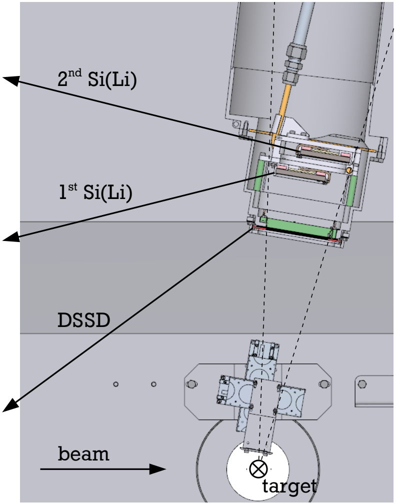


Elastic proton scattering
^{56}Ni(p,p) at 390 MeV/u with 1 mm aperture





Beam-related deterioration of the DSSD

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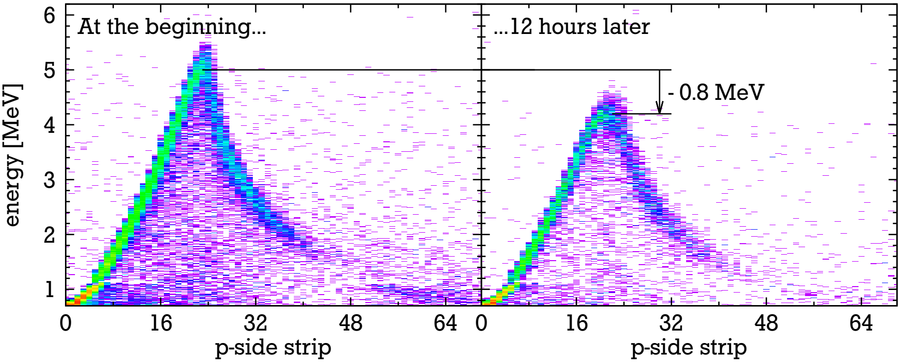
- Beam intensity of stable ^{58}Ni beam $\approx$ 25 times higher.
- Observed deterioration of detector performance over time:
  - Leakage current increasing
  - Lowered punch-through energy $\rightarrow$ decreased depletion depth



Beam-related deterioration of the DSSD – Evolution over time

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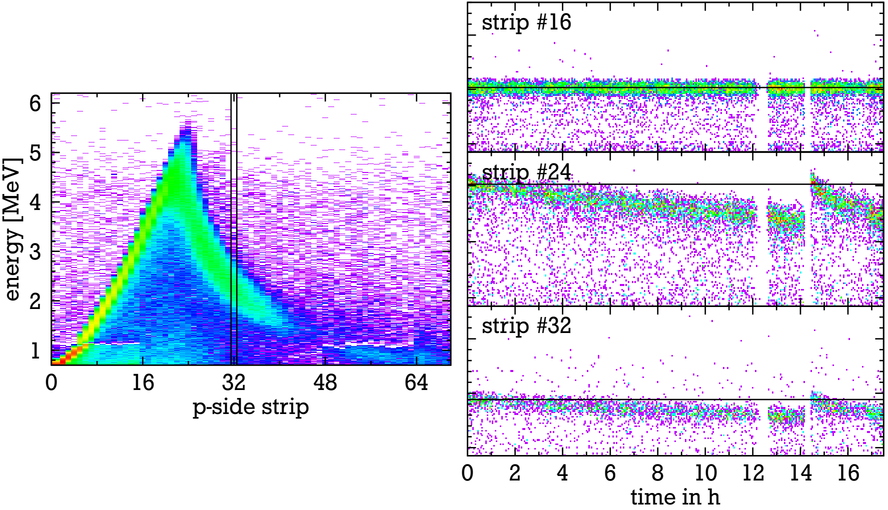
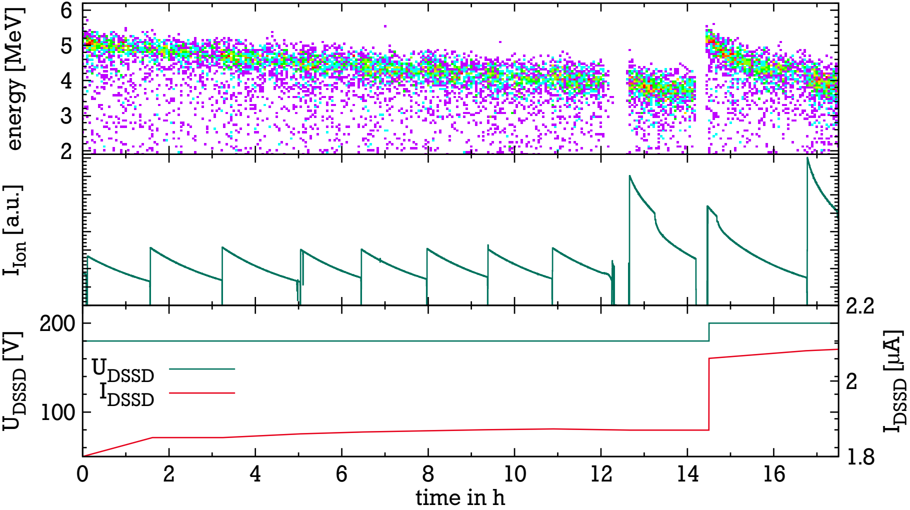


Beam-related deterioration of the DSSD – Evolution over time



Origin of the deterioration?

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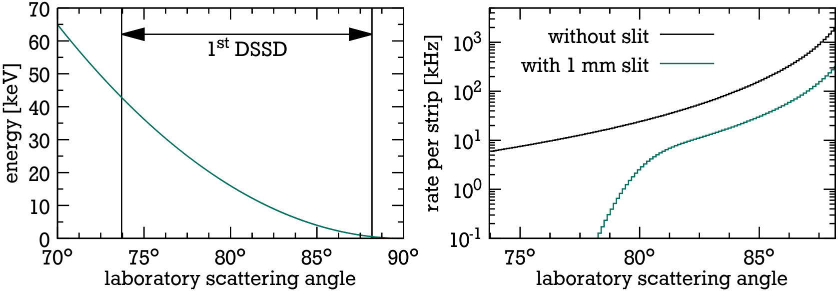
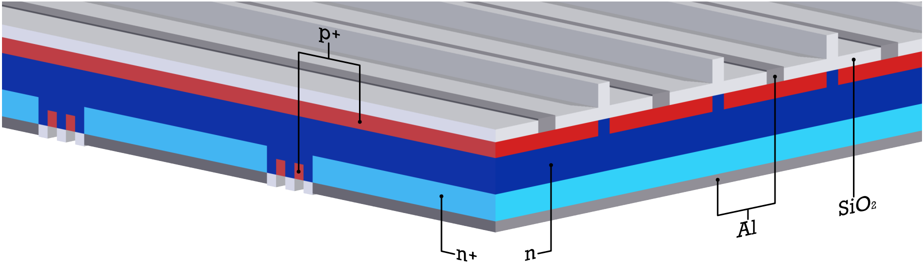
- No high fluxes of high energy particles expected $\rightarrow$ no damage of the bulk
- **Surface effect** $\rightarrow$ elastically scattered electrons (δ-rays) from the target?
- Kinematics for ^{58}Ni(e,e) at 400 MeV/u
  - **Energies below trigger thresholds**
- Rate estimates for luminosity of $10^{28}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
  - **Total rate on DSSD: 21 MHz** (5 MHz with slit aperture)



Origin of the deterioration?



- Delta electrons create electron-hole pairs in SiO_2 layer
- Hole mobility in SiO_2 is orders of magnitude lower than electron mobility
- Build-up of positive charge in SiO_2
  - Counters negative bias voltage
  - Decreases depletion depth

Conclusion

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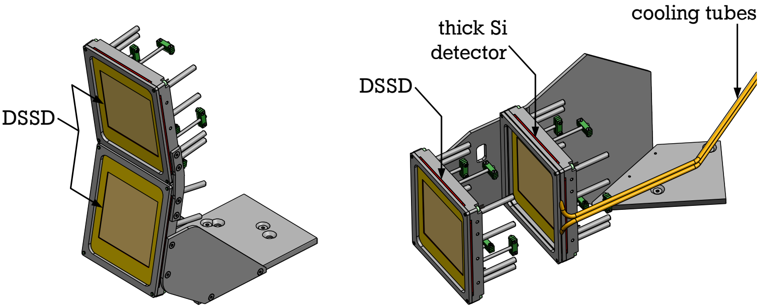
- First successful nuclear reaction experiment with stored exotic beams ever!
- Addressed and solved many challenging difficulties
  - Operation of DSSDs in UHV
  - Principle of vacuum separation proven to work
- Observed beam-related deterioration of the DSSD
  - Deterioration of depletion depth
  - Radiation not visible in DSSD spectrum
  - Dependent on (integral) luminosity
  - Possible explanation: Low energy electrons charging the DSSD's oxide layer
  - Needs further investigation

Outlook

- Upgraded detector setup covering a substantially larger solid angle is planed.
  - Detectors placed directly in the UHV.



- Future experiments envisaged at GSI and at FAIR using CRYRING, ESR and HESR.

Technical drawings: M. Lindemulder, KVI-CART

Thank you for your attention

S. Bagchi[1], S. Bönig[2], M. Csatlós[3], I. Dillmann[4], C. Dimopoulou[4], P. Egelhof[4], V. Eremin[5], T. Furuno[6], H. Geissel[4], R. Gernhäuser[7], M. N. Harakeh[1], A.-L. Hartig[2], S. Ilieva[2], N. Kalantar-Nayestanaki[1], O. Kiselev[4], H. Kollmus[4], C. Kozhuharov[4], A. Krasznahorkay[3], T. Kröll[2], M. Kuilman[1], S. Litvinov[4], Yu. A. Litvinov[4], M. Mahjour-Shafiei[1,8], M. Mutterer[4], D. Nagae[9], M.A. Najafi[1], C. Nociforo[4], F. Nolden[4], U. Popp[4], C. Rigollet[1], S. Roy[1], C. Scheidenberger[4], M. von Schmid[2], M. Steck[4], B. Streicher[2,4], L. Stuhl[3], M. Takechi[4], M. Thürauf[2], T. Uesaka[10], H. Weick[4], J. S. Winfield[4], D. Winters[4], P. J. Woods[11], T. Yamaguchi[12], K. Yue[2,4,13], J.C. Zamora[2], J. Zenihiro[10]

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