The EXL project

- “EXotic nuclei studied in Light-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 radioactive beam at the ESR, GSI:
  - $^{20}$Ne, $^{58}$Ni and $^{56}$Ni beams
  - $^4$He and $^2$H gas-jet targets
  - $^{56}$Ni($p$,p) **luminosity**: $2 \cdot 10^{26}$ particles s cm$^{-2}$

*Picture: GSI*
Elastic proton scattering in inverse kinematics

- Kinematics of $^{56}\text{Ni}(p,p)$ 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.
First successful tests using \( (2 \times 2) \text{ cm}^2 \) DSSD prototype

Artificial leak on HV side (needle valve)

Vacuum separation by 6 orders of magnitude difference achieved
Vacuum concept

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

B. Streicher et al., Nucl. Instr. and Meth. A 654, 604 (2011)
Experimental setup at the ESR

- **DSSD**: 128 × 64 strips, (6 × 6) cm², 285 µm thick
- **Si(Li)**: 8 pads, (8 × 4) cm², 6.5 mm thick
- **active vacuum barrier**
- **aperture** to improve angular resolution

(figures: M. Lindemulder)
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 $\approx 25$ keV (FWHM)
DSSDs for EXL – UHV compatible PCB and readout

- 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

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

Energy [MeV]

DSSD p-side strip

2nd Si(Li)

1st Si(Li)

DSSD

beam

target

elastic scattering

first 2$^+$ (2.7 MeV)
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
Beam-related deterioration of the DSSD – Evolution over time

- Energy distribution
- Ion current
- DSSD voltage
- DSSD current

Time in hours: 0, 2, 4, 6, 8, 10, 12, 14, 16

Energy levels: 0, 2, 4, 5, 6 MeV

Ion current (a.u.)
DSSD voltage (V)
DSSD current (µA)
Origin of the deterioration?

- No high fluxes of high energy particles expected $\rightarrow$ no damage of the bulk
- **Surface effect** $\rightarrow$ elastically scattered electrons ($\delta$-rays) from the target?
- Kinematics for $^{58}\text{Ni}(e,e)$ at 400 MeV/u
  - Energies below trigger thresholds
- Rate estimates for luminosity of $10^{28} \text{ cm}^{-2} \text{ s}^{-1}$
  - **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

- 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 planned.
  - 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

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