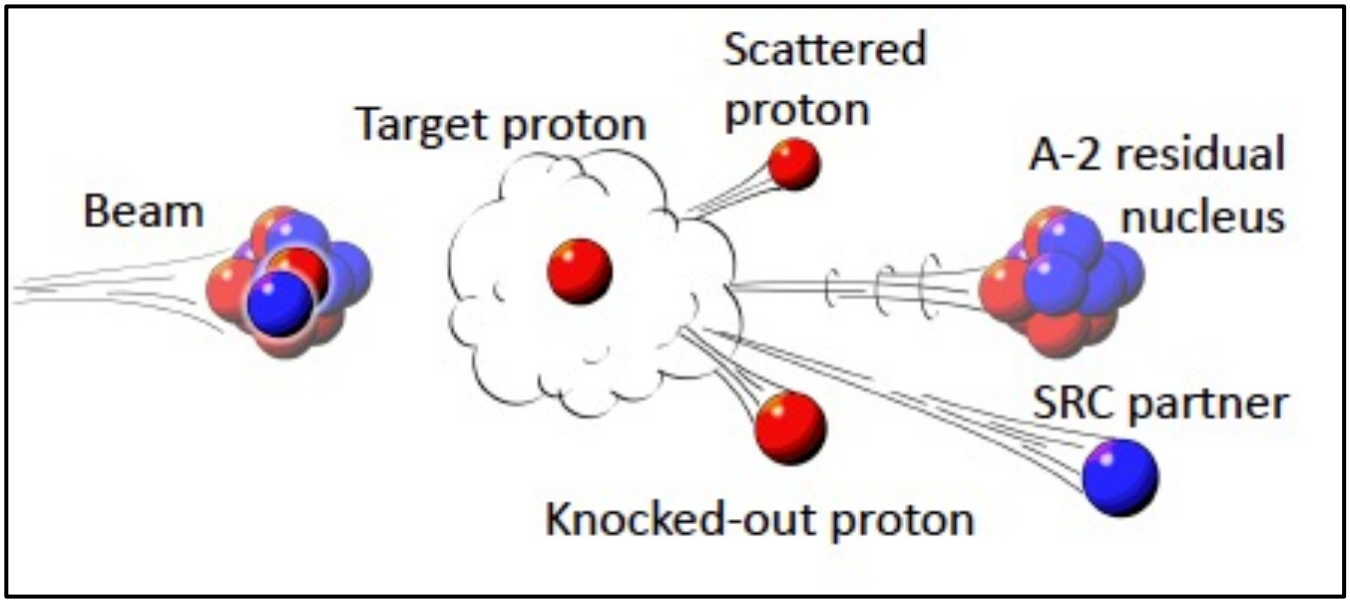
# SRC experiment with unstable beams at GSI-FAIR

A.Corsi, CEA/IRFU/DPhN for S522 collaboration

*SRC-EMC Workshop, CEA Paris-Saclay, Jan. 31st 2023*

# SRC studies in inverse kinematics

- Pilot experiment in Dubna in 2018 with $^{12}C$ beam (+follow up in 2022)
  See talk J.Kahlbow and G.Johansson
  M.Patsyuk, J.Kalhbow et al., Nature Phys. 2021
- Experiment in GSI Darmstadt with $R^3B$ setup in May 2022 with $^{16}C$ and $^{12}C$ beam



# Why unstable beams?

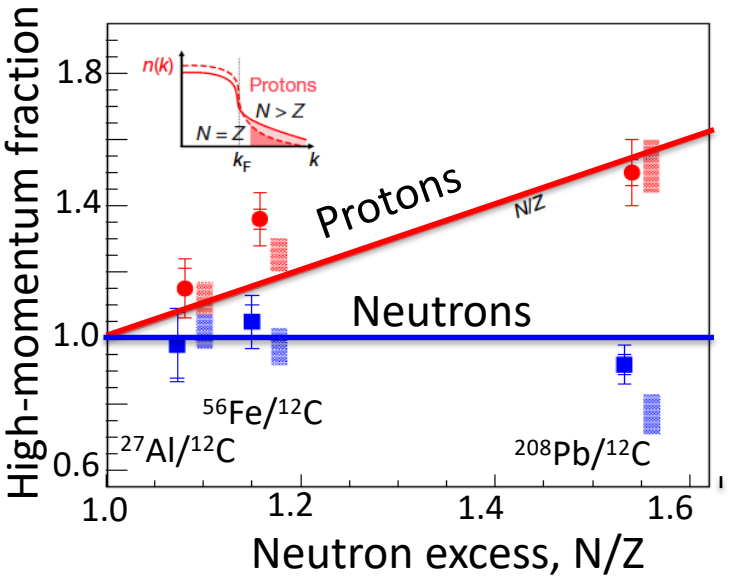
- Dominance of np/pp pairs

⇒ increase of high momentum proton fraction

- Relevant to understand the structure of asymmetric nuclei

BUT:

- Cannot disentangle mass and N/Z dependence with stable nuclei
- Need to use reference nucleus with very different structure ($^{12}$C for $^{208}$Pb)
- Need to use heavy nuclei to have neutron excess, no ab-initio calculations




M.Duer et al., Nature 560, 617 (2018)

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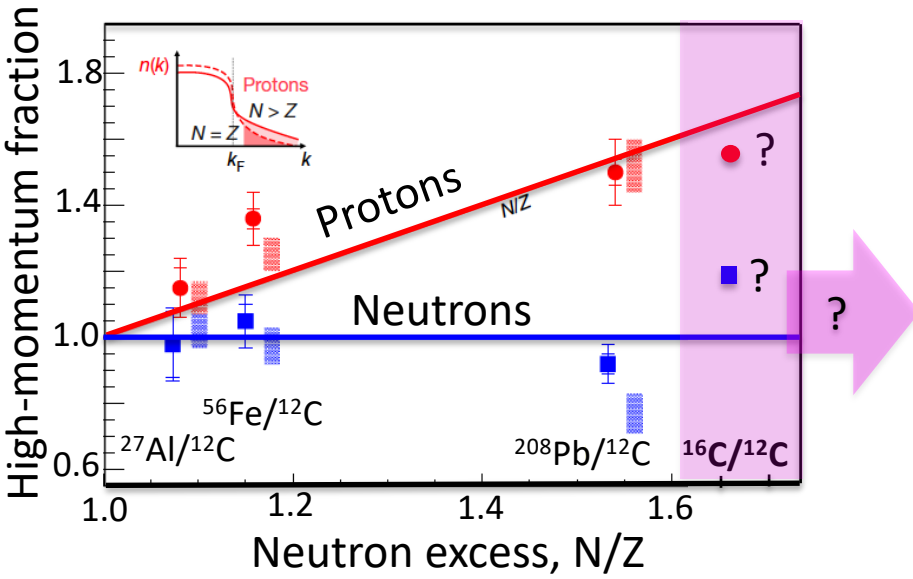
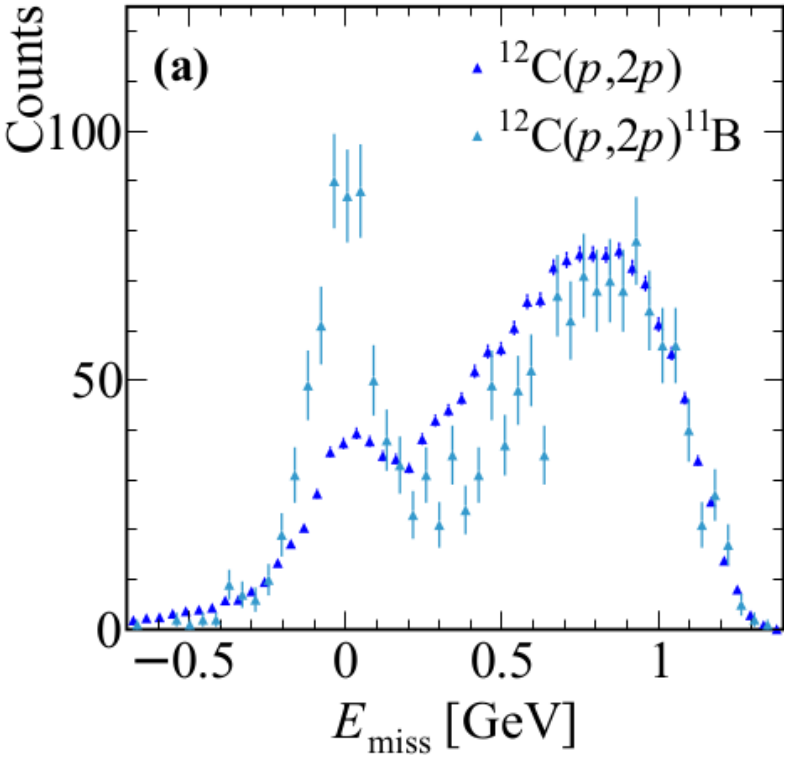
⇒ $^{16}$C/$^{12}$C at GSI with R$^3$B setup




Adapted from Nature 560, 617 (2018)

# Specificities of GSI measurement

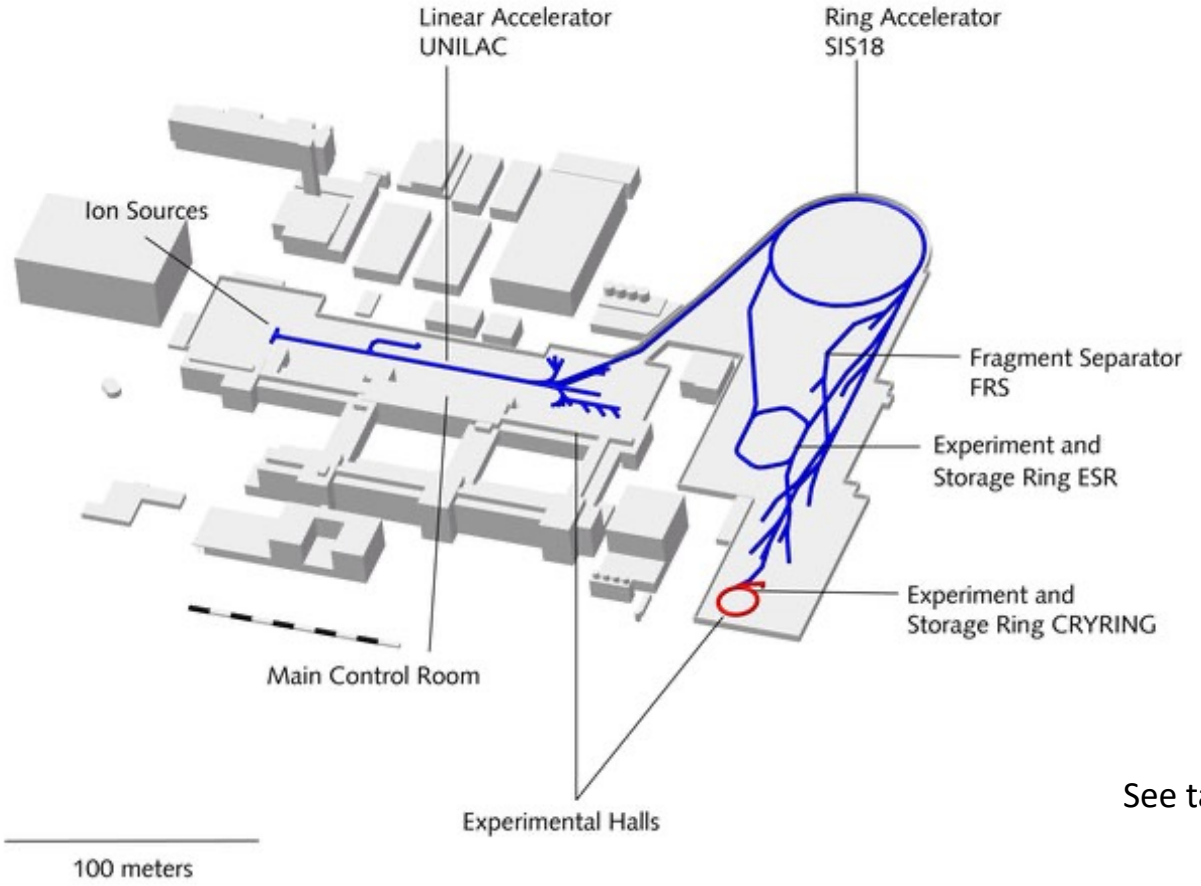
- Capitalize on what has been learned in Dubna (suppression of FSI)
- Beam energy 1.25 GeV/u vs 3.2 GeV/u at Dubna
- Fully exclusive measurement including fragment and SRC partner
- Availability of many reaction channels e.g. fragment decay to alpha
- High resolution of $R^3B$ setup




M.Patsyuk, J.Kahlbow et al., Nature Phys. 2021

# Setup at GSI/R$^3$B

- UNILAC+SIS18: beams from protons to U up to 18 Tm (4.5 GeV for protons, 1 GeV/u for U)
- Production of radioactive isotopes in-flight and separation via the Fragment Separator
- Our experiment: primary beam $^{18}$O @ 1.3 GeV/u, secondary beam $^{16}$C @ 1.25 GeV/u with 95% purity





GSI Darmstadt

See talk T.Aumann about GSI future

# Setup at GSI/R$^3$B



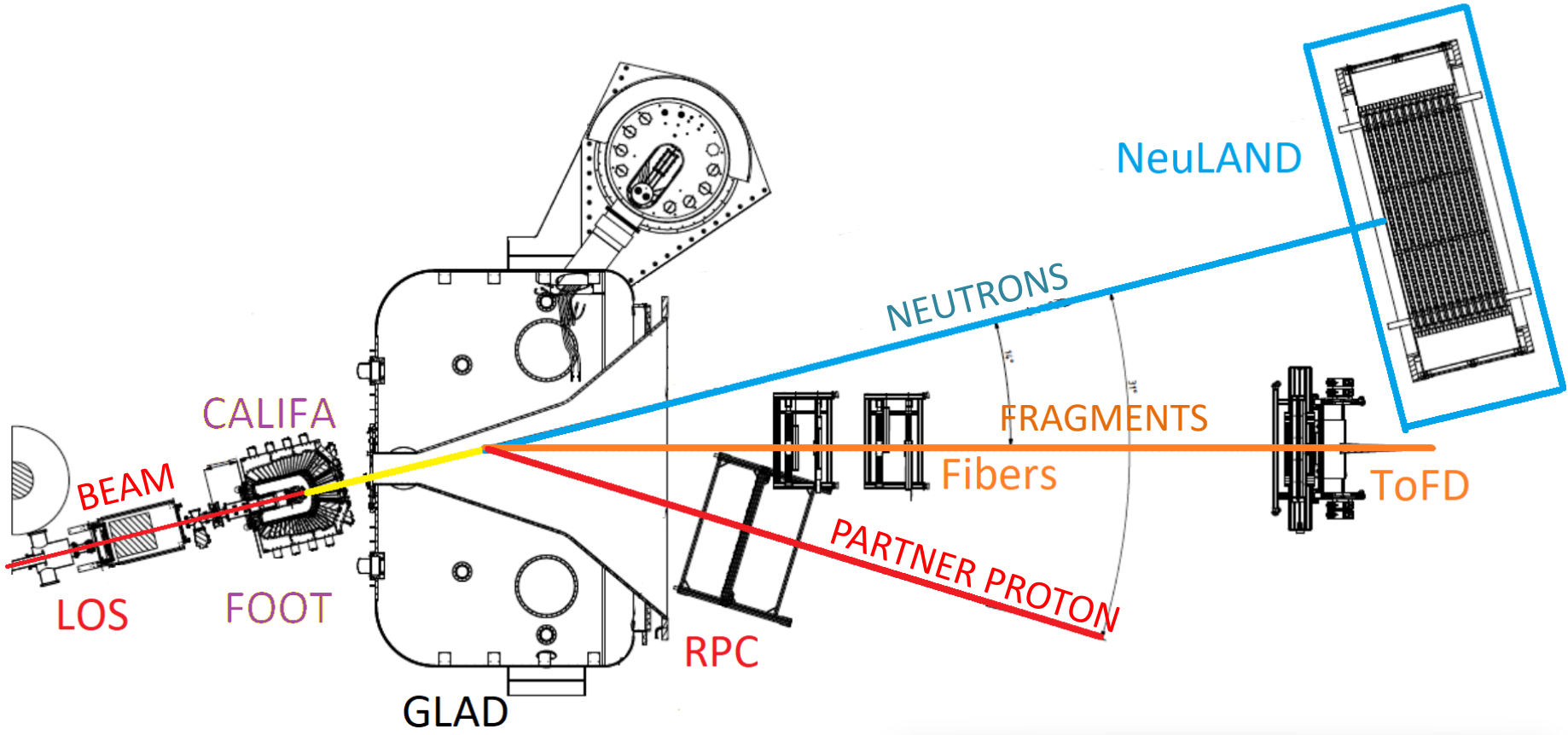
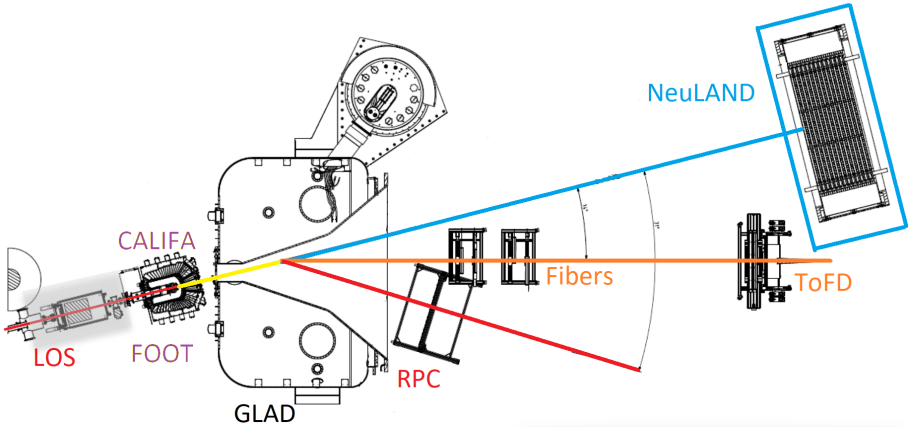
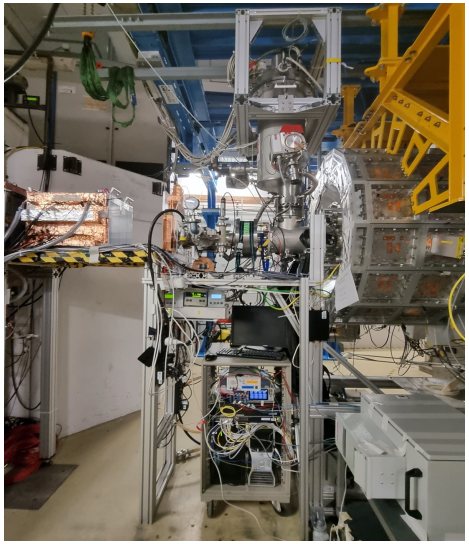


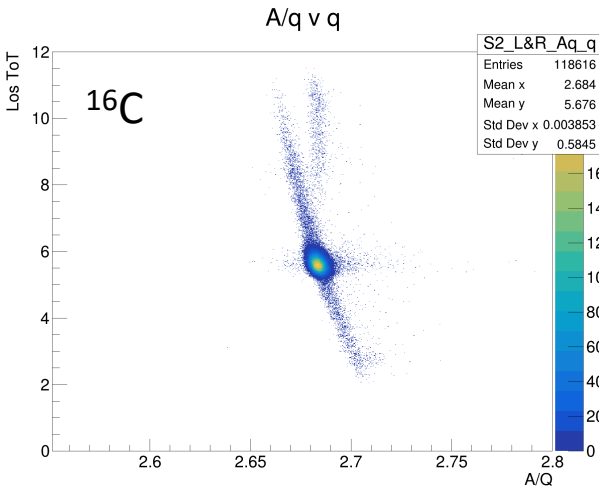

Image courtesy D.Koerper and M.Xarepe

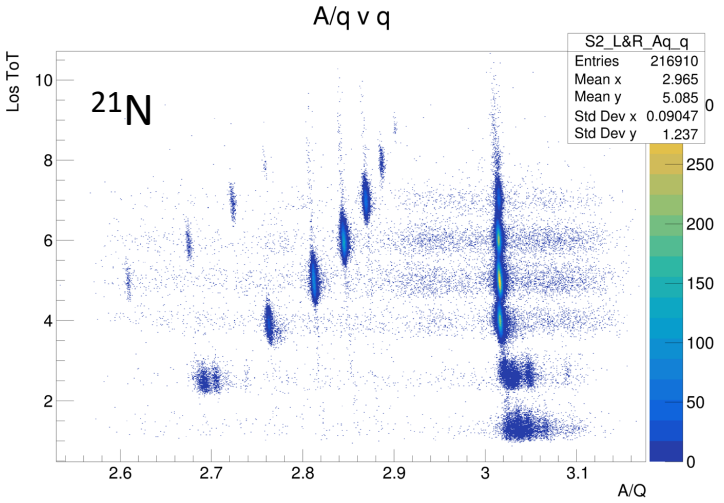
# Setup at GSI/R$^3$B

- Incoming beam tracking & charge with MUSIC+MWPC (CEA DAM)
- Beam timing and charge with LOS scintillator, Tof resolution ~75 ps (with respect to FRS scintillator at S2)
- High rate capability ($10^5$ pps)



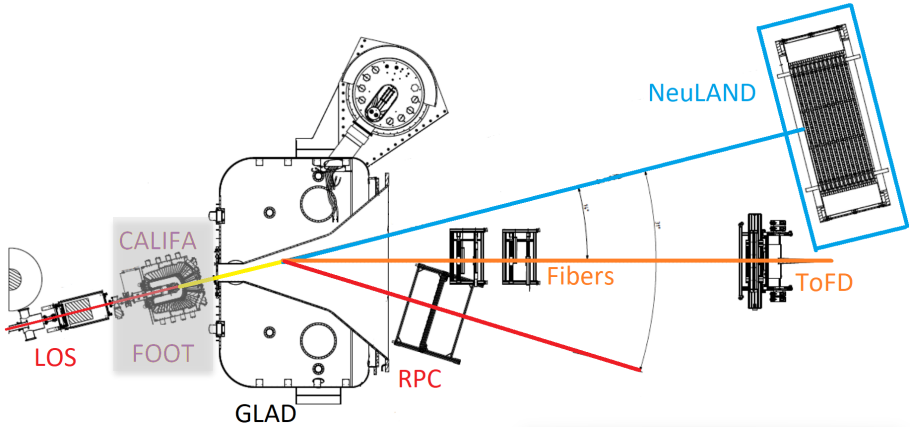


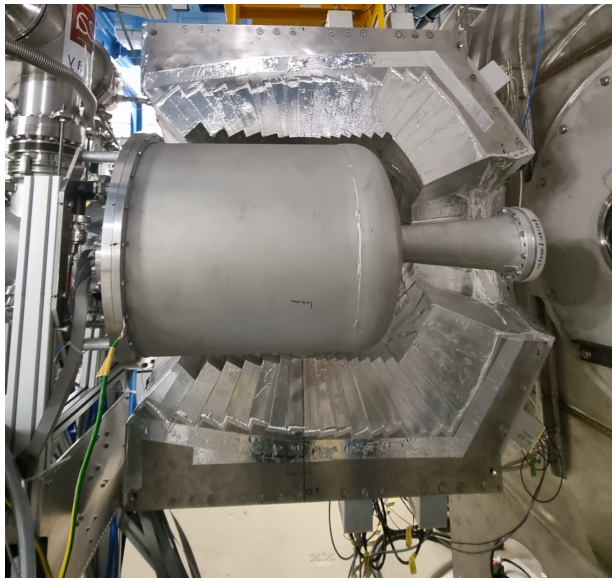



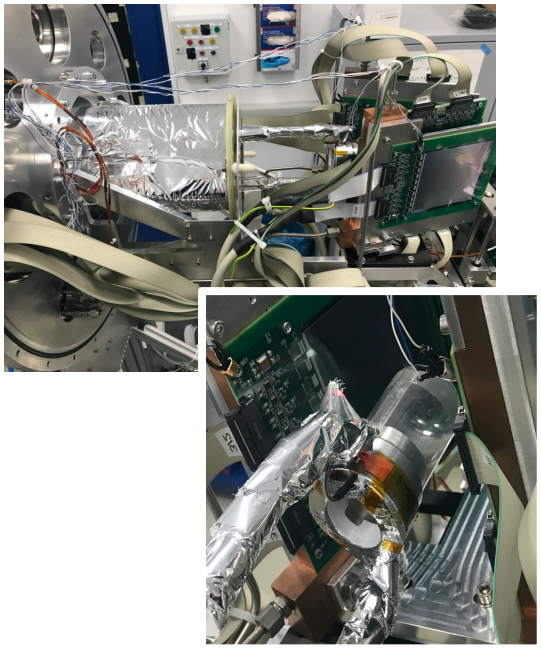

COURTESY N.MAZUMDAR (TUDa)

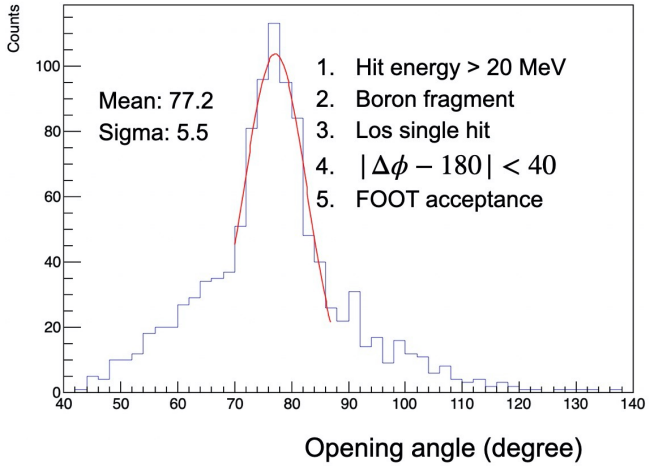
# Setup at GSI/R$^3$B

- Liquid H target available in different sizes, here 5 cm long (CEA Saclay, ANR grant)
- Worked in a closed loop for 23 days
- FOOT SSD tracking array (for protons at large angles and fragments)
- CALIFA calorimeter (CsI) to detect gamma and protons (punch-through at ~320 MeV)





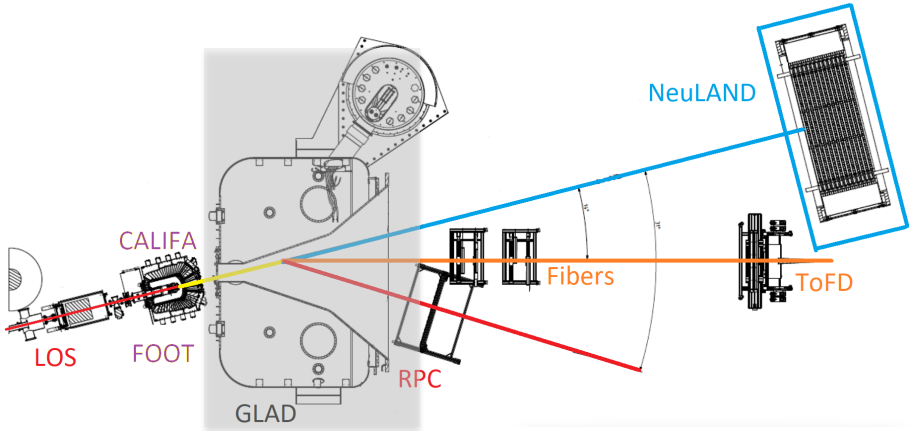


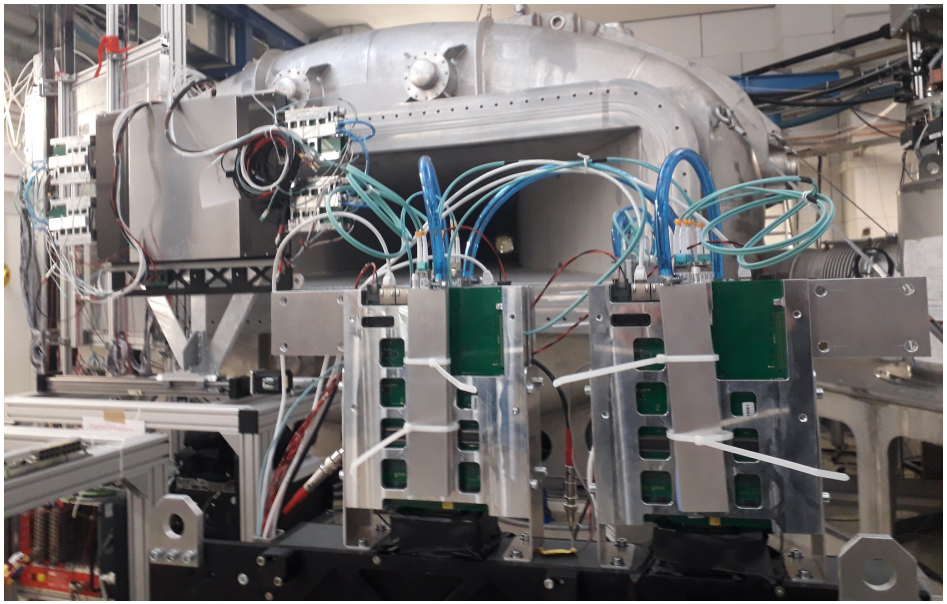

COURTESY W.QI( MIT)

# Setup at GSI/R$^3$B



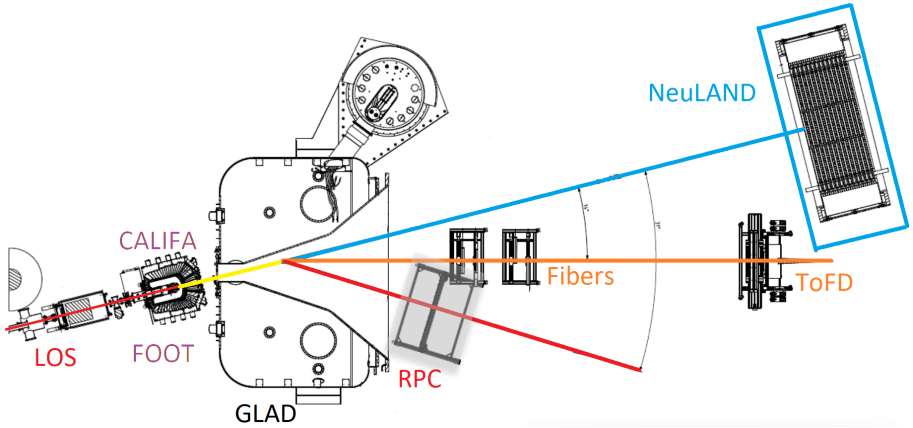
- GLAD large acceptance dipole magnet
- Acceptance 80 mrad
- Maximum bending power 18 Tm
  (1.25 GeV/u for $^{16}$C, 1.9 GeV/u for $^{12}$C)

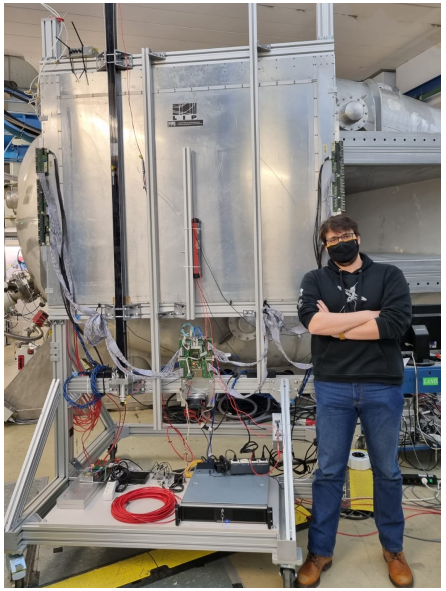


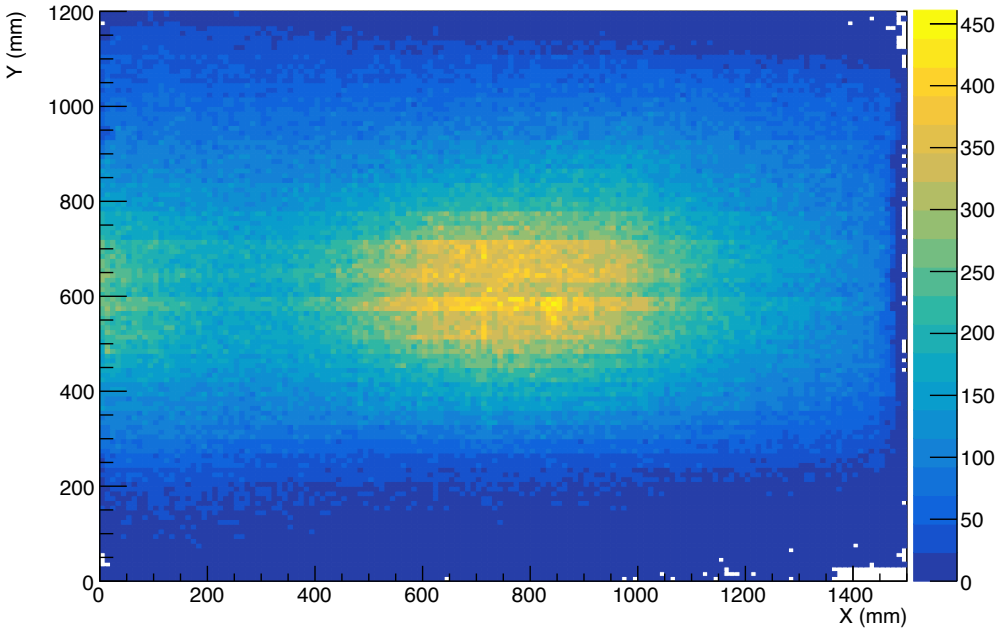



# Setup at GSI/R$^3$B

- Resistive Plate Chamber (RPC) detector (LIP Portugal)
- Main feature: excellent time resolution ~50 ps standalone
- 100 ps Time of Fligth resolution
  => 2% momentum resolution
- Installed at large angles (30°, 40°) to detect the partner proton



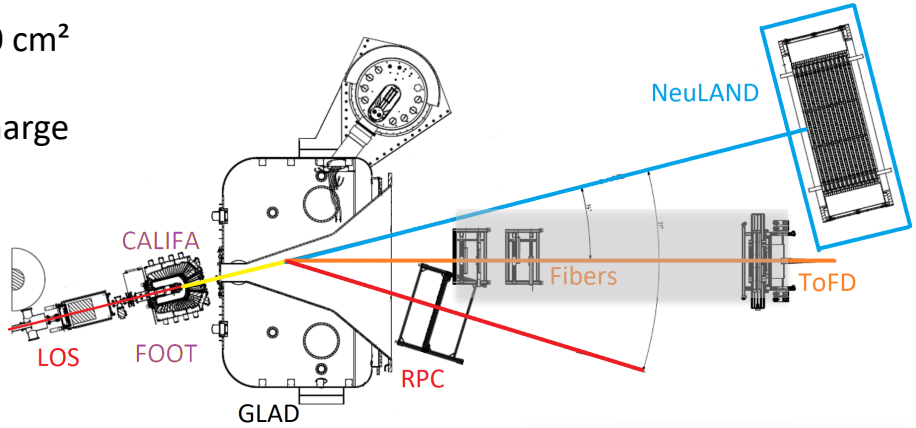



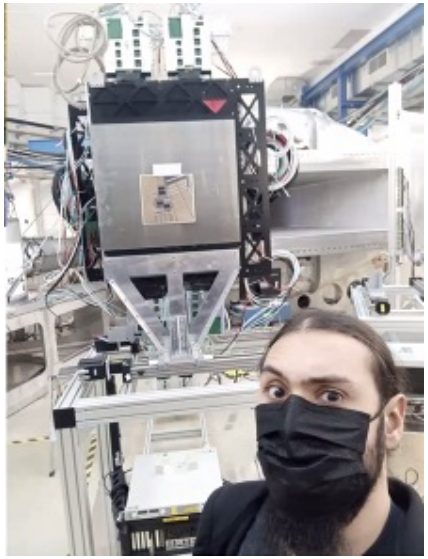


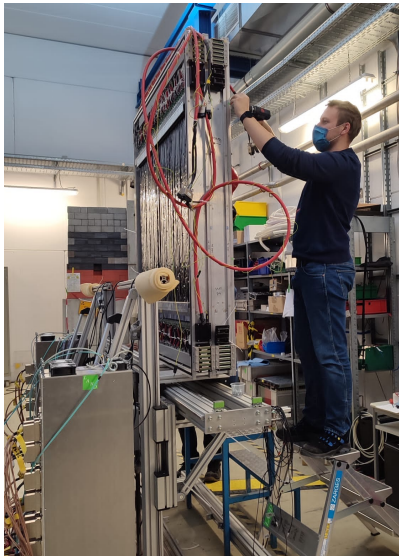

COURTESY M.XAREPE (LIP)

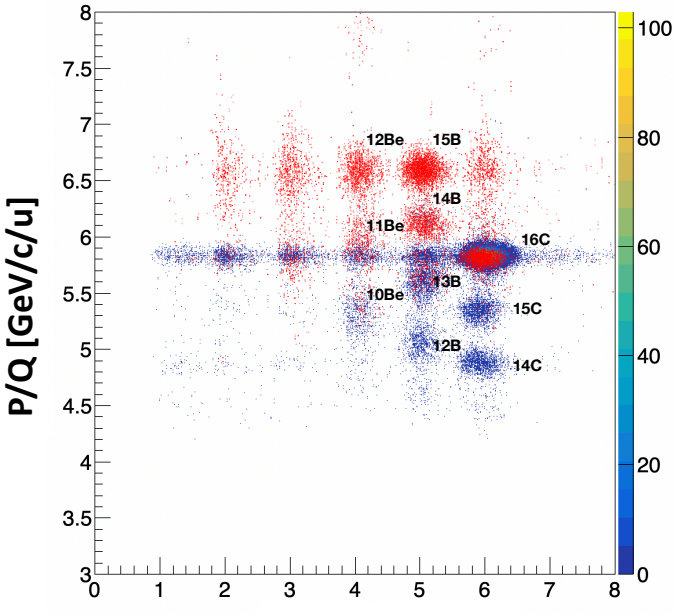
# Setup at GSI/R³B

- 2 sets of fibers detector to track the fragments (xyxx)
- 512 fibers of 1 mm thickness, active area of about 50 x 50 cm²
- Time of Flight detector (TOFD) for fragment timing and charge
- 4 walls of 44 plastic scintillators, 1.2 m wide
- 0.1-0.2% momentum resolution (sigma) expected



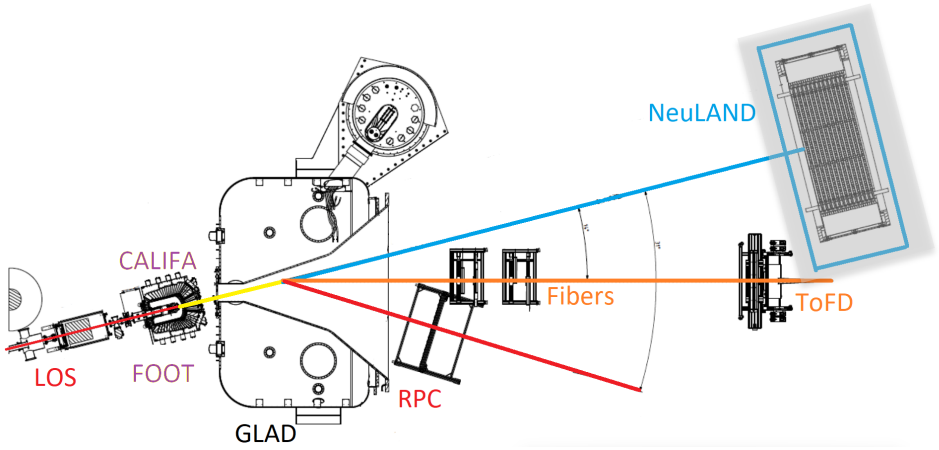


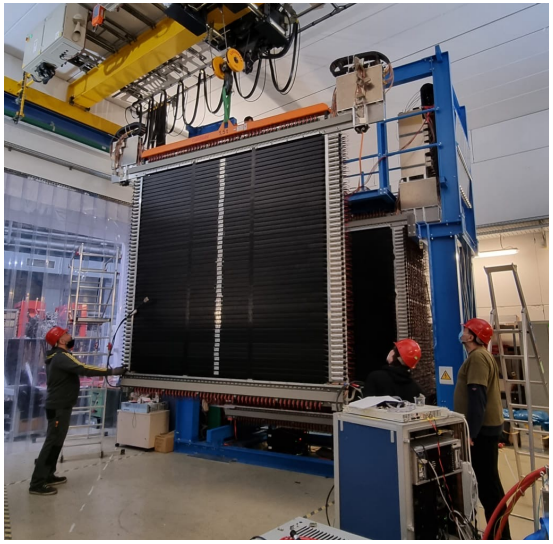


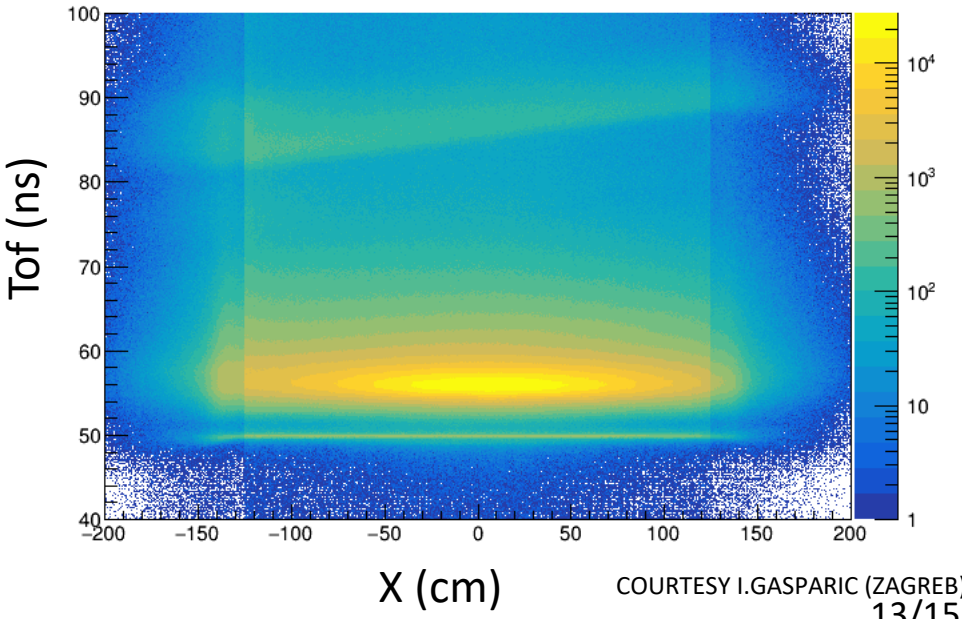

WITH MDF ANALYSIS, COURTESY V.PANIN (GSI)

# Setup at GSI/R$^3$B

- NeuLAND array for multi-neutron detection with high space and time resolution ($\sigma_t$<150 ps)
- Currently: 13 double planes ⇔ 70% efficiency at ~ 1 GeV
- Goal: 30 double planes



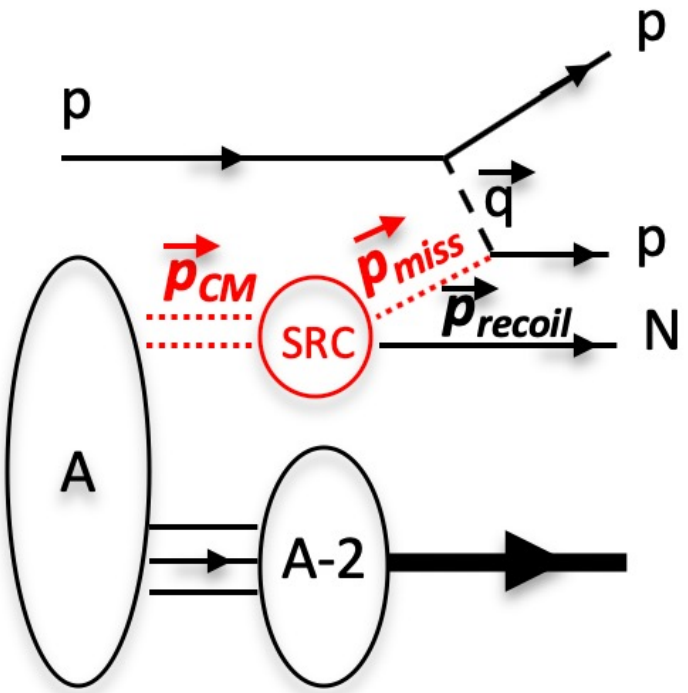






COURTESY I.GASPARIC (ZAGREB)

# Observables

- Inclusive and exclusive (i.e. gated on an excited state) cross sections for (p,2p)
- Final state identified (Z, mass, excitation energy)
- Fragment ID (A-1, A-2, A-3…)
- missing momentum $p_{miss}$ (inclusive and exclusive, i.e. in coincidence with the recoil nucleon)
- Center of mass momentum of the pair $P_{CM}$
- #SRC events vs (p,2p)
- #pn SRC vs. #pp SRC



# Status and perspectives

- Data analysis ongoing
- 4 PhD students (A.Lagni, E.Lorentz, H.Qi, M.Xarepe) working on this experiment, + 3 PhD students on same detectors for another experiment (A.Barrière, N.Mozumdar, M.Feijoo)
- Next steps:
  1. Finalize several calibrations (FOOT, CALIFA, Fibers, TOFD)
  2. Finalize PID and event selection
  3. Calculate momentum of each particles, and reconstruct missing momentum
  4. Apply cut for SRC events and plot relevant observables
  5. Get in contact with theorists

Credits for slides: A.Lagni, A.Revel (CEA Saclay), J.Kahlbow (TAU & MIT), I.Gasparich (Zagreb), N.Mozumdar (TUDa), V.Panin (GSI), H. Qi (MIT), M.Xarepe (LIP)