5th International Solar Neutrino Conference
June 11 - 14, 2018
TU Dresden

Gas-jet targets for nuclear astrophysics

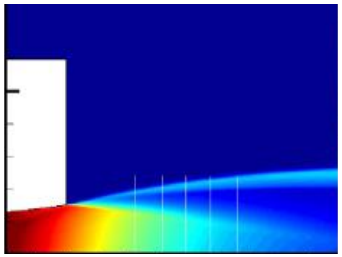
Konrad Schmidt[1,2]

[1] *National Superconducting Cyclotron Laboratory, East Lansing, MI, USA*
[2] *Joint Institute for Nuclear Astrophysics – Center for the Evolution of the Elements, East Lansing, MI, USA*

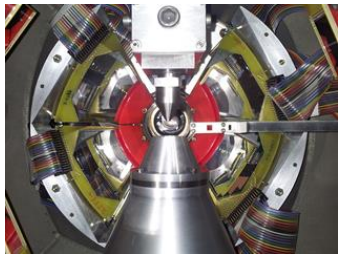
JINA-CEE
NSF Physics Frontiers Center

Outline

Motivation for gas-jet targets



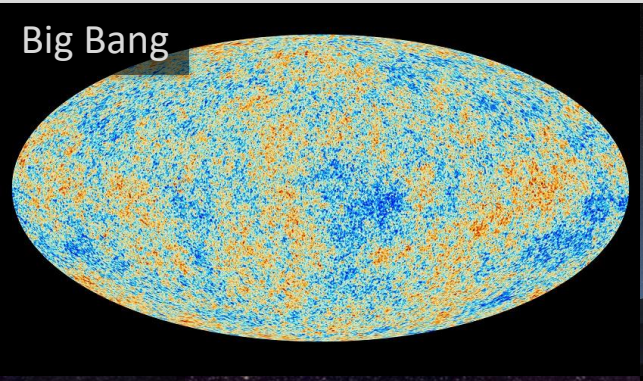
Review of supersonic gas-jet targets in nuclear physics

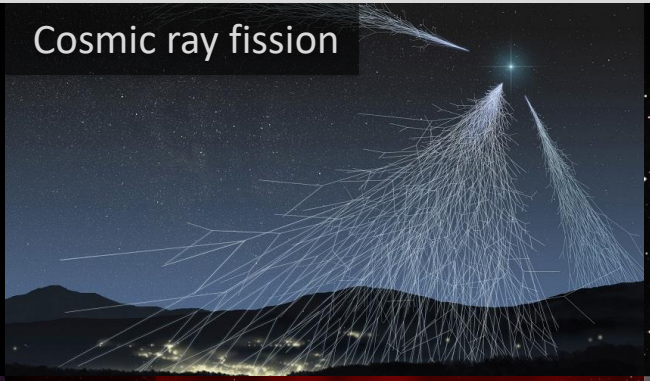


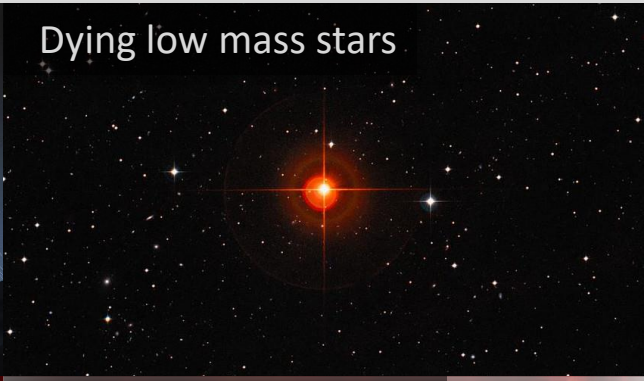
The JENSA gas-jet target

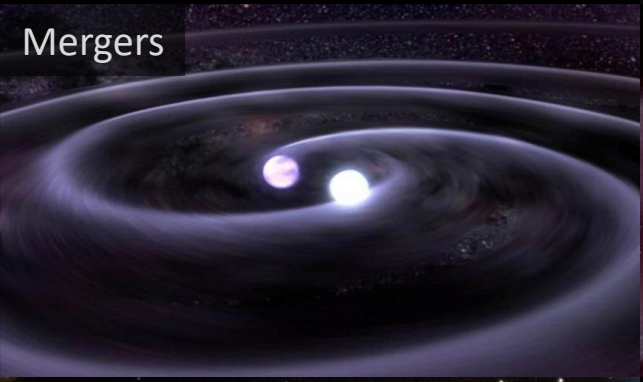
Perspective of future gas targets

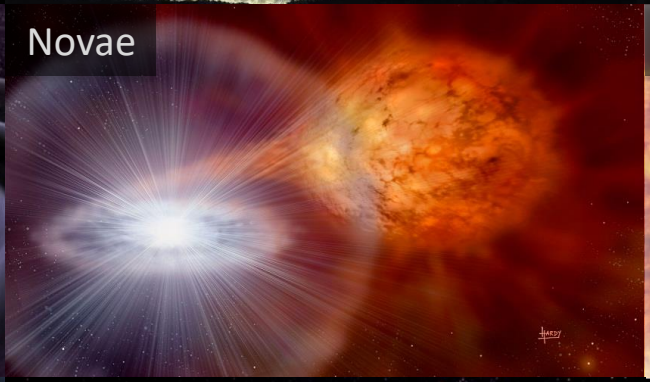
Nucleosynthesis – Why a gas jet target?

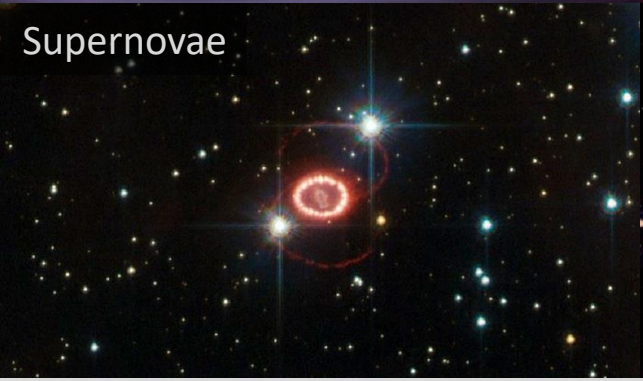


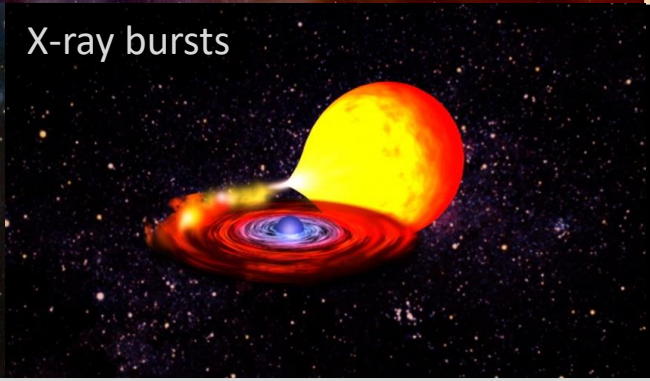












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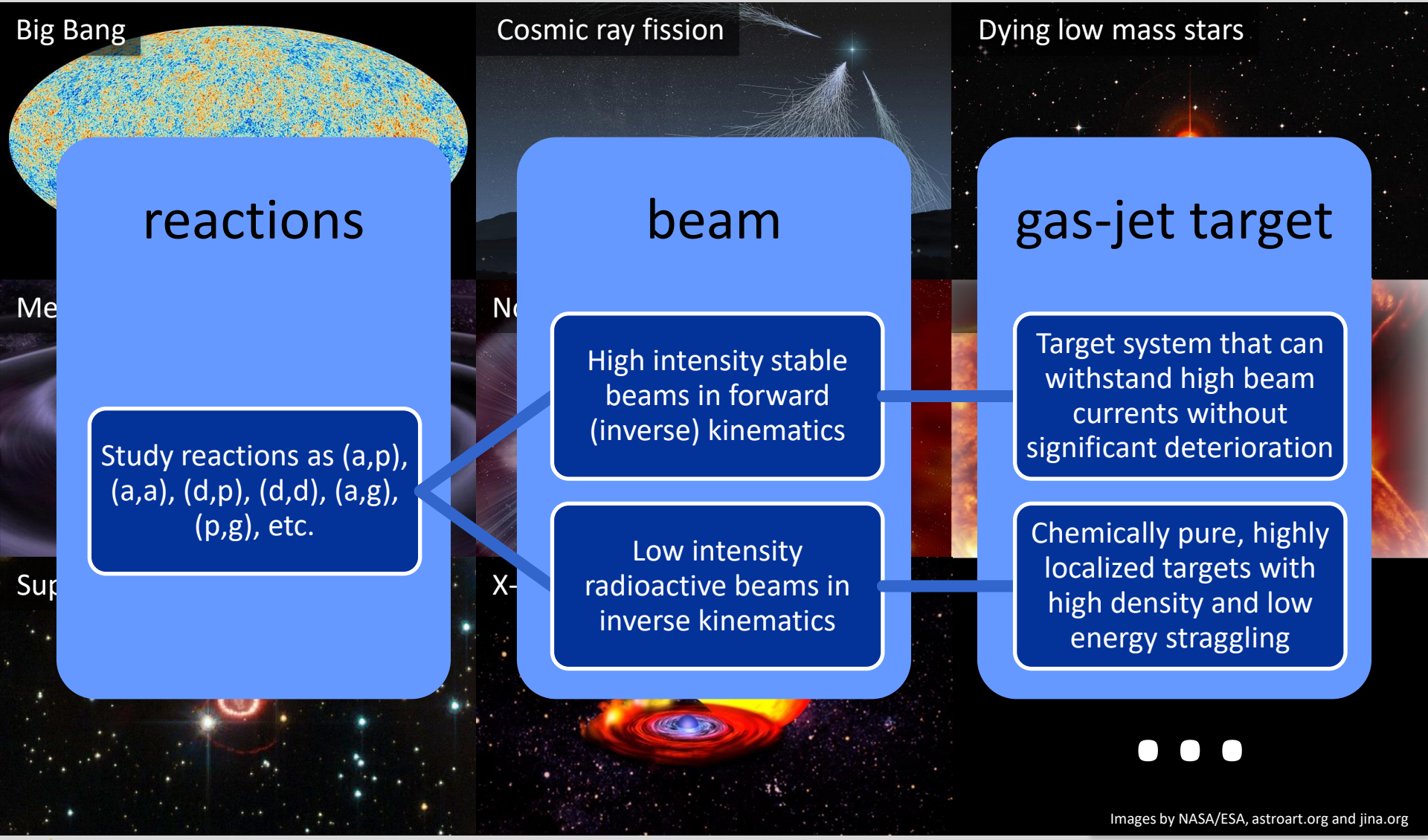
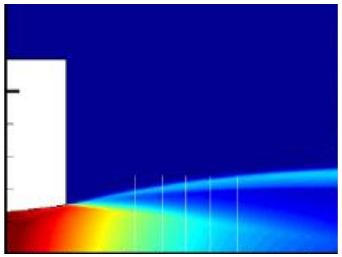
Images by NASA/ESA, astroart.org and jina.org

Nucleosynthesis – Why a gas jet target?

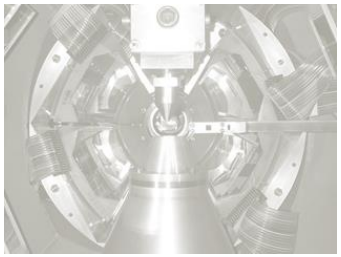


Outline

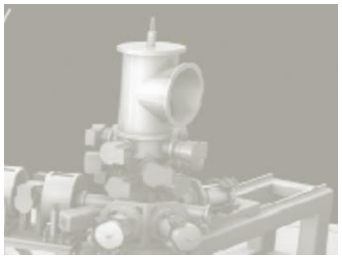
Motivation for gas jet targets



Review of supersonic gas-jet targets in nuclear physics

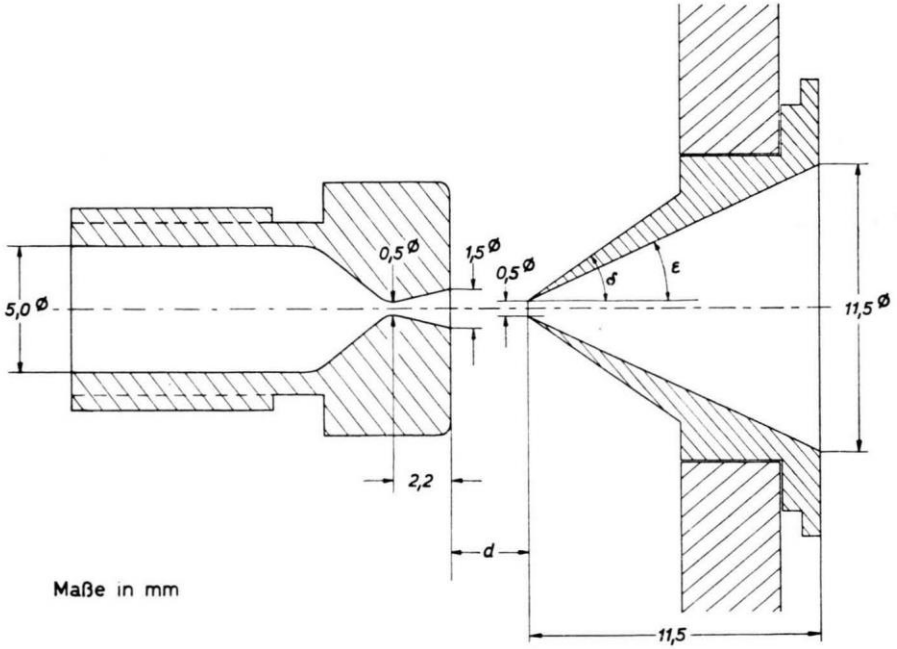


The JENSA gas-jet target

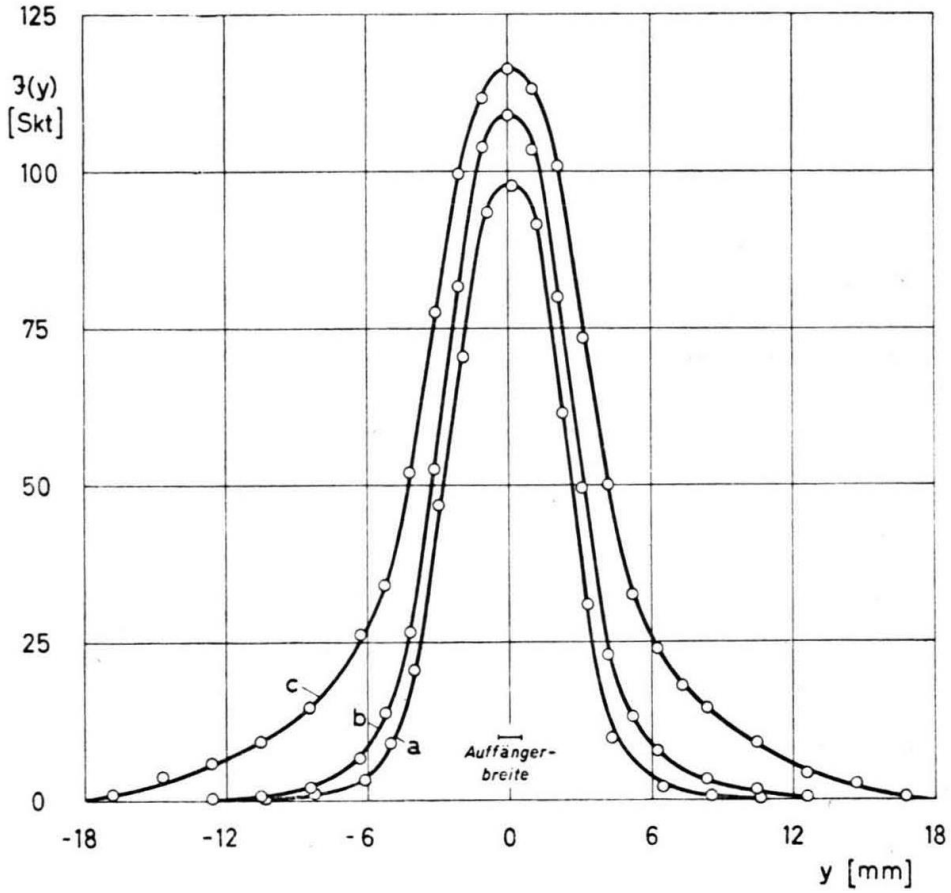


Perspective of future gas targets

First gas-jet target for nuclear physics

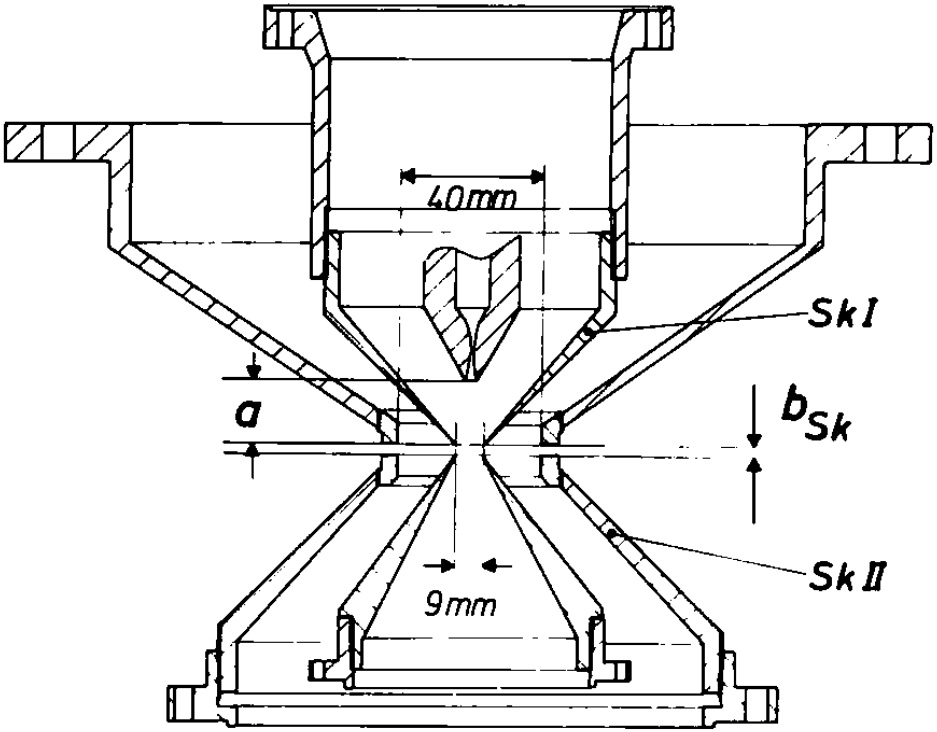


Location and Year	Marburg (Germany) 1954
Target gas	Hydrogen
Particle flux	0.36×10^{18} mol./(cm^2s)
Geometrical width	6 mm
Method	Pressure measurements



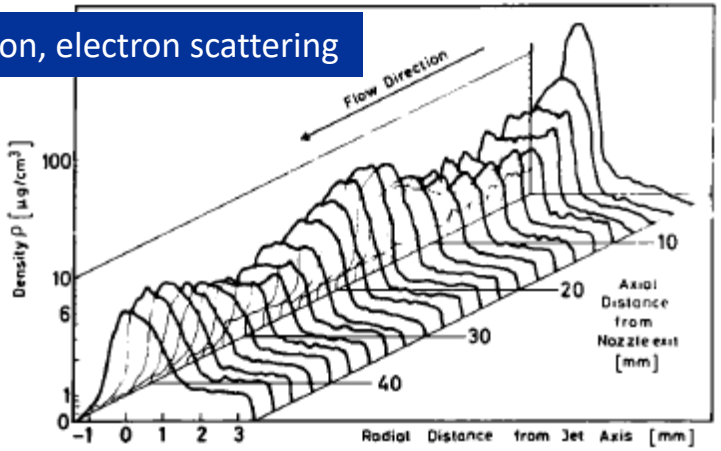
E.W. Becker and K. Bier, Z. Naturforsch. A **9**, 975 (1954)

Argon and nitrogen gas-jet targets

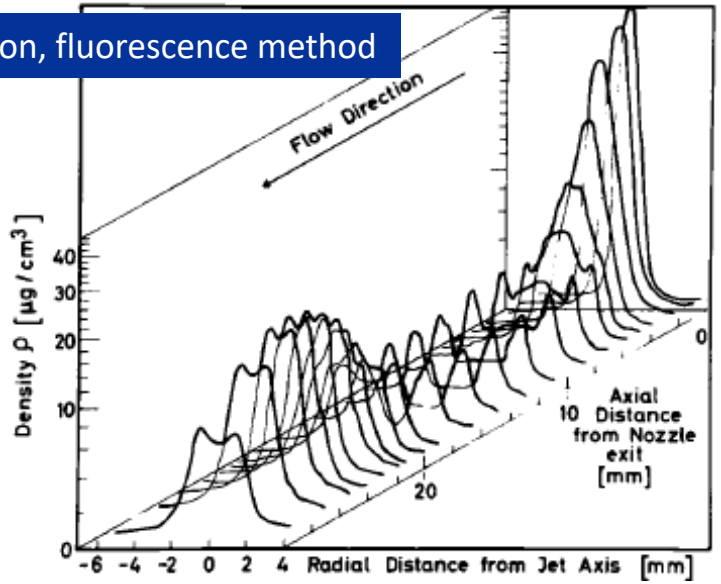


Location and Year	Frankfurt (Germany) 1979
Target gas	Argon and Nitrogen
Particle density	7.3×10^{18} atoms/cm^2
Geometrical width	3 mm
Method	electron attenuation, fluorescence, and scattering

Argon, electron scattering

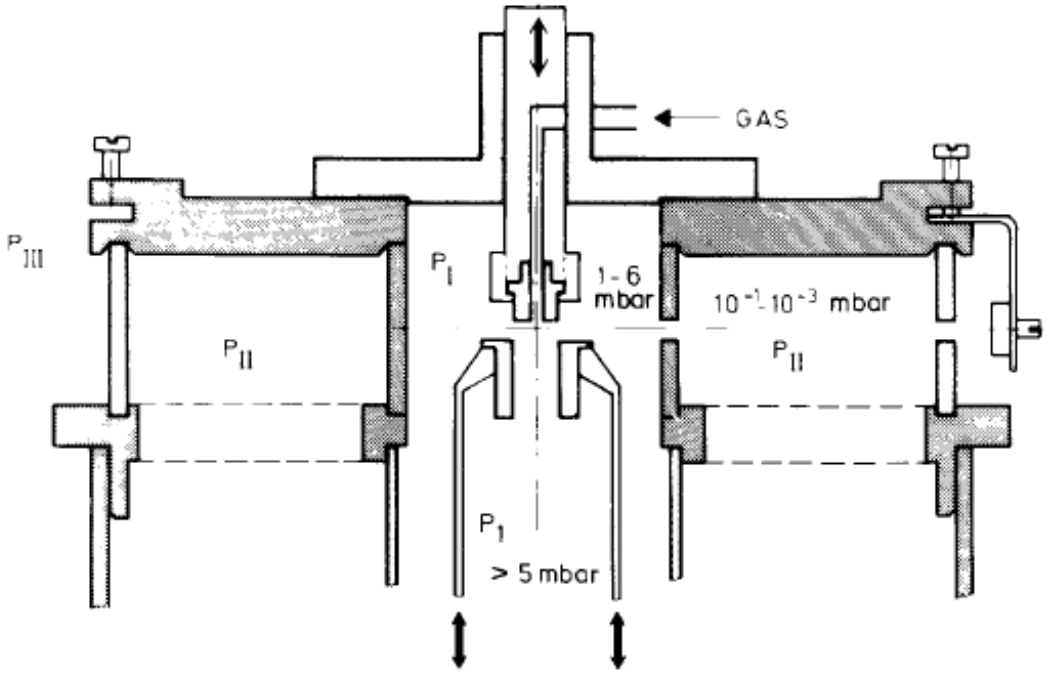


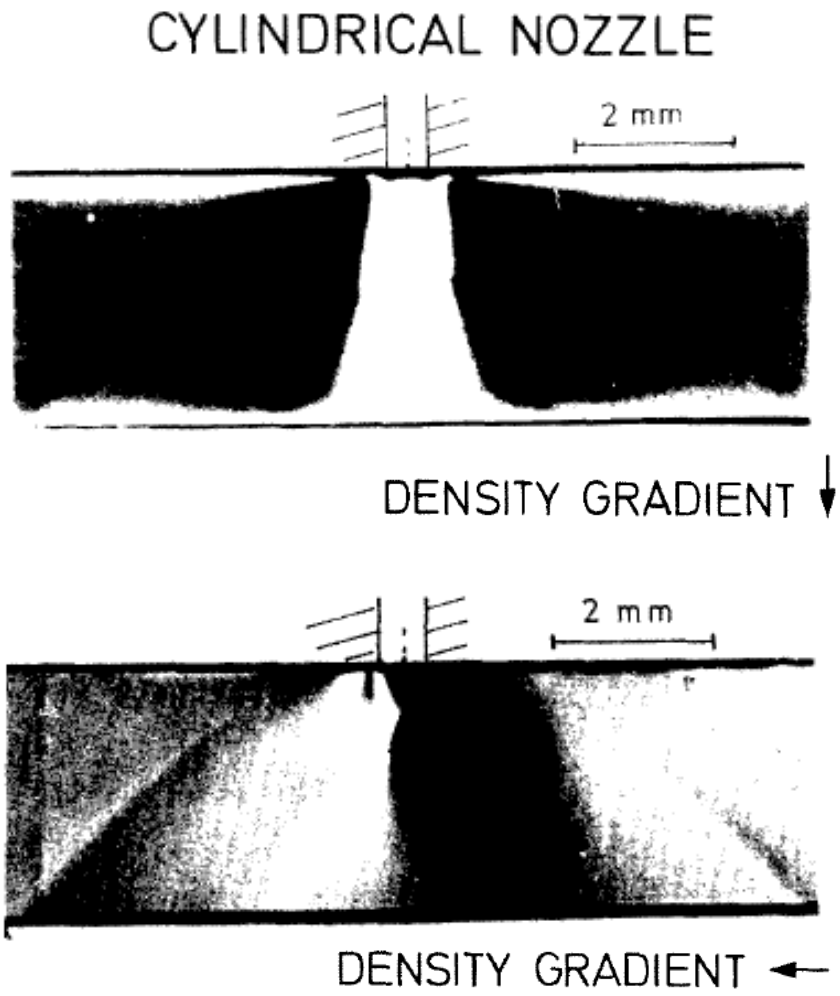
Argon, fluorescence method



W. Tietsch *et al.*, Nucl. Instrum. Meth. **158**, 41 (1979)

High density but low uniformity





Location and Year	Erlangen (Germany) 1979
Target gas	Argon, Nitrogen, Hydrogen
Particle density	47.0×10^{18} atoms/cm^2 for N
Geometrical width	1 - 10 mm
Method	α particle transmission and Schlieren photography

Recircu-lating

G. Bittner *et al.*, Nucl. Instrum. Meth. **161**, 1 (1979)

Experiments with the Erlangen gas-jet

p-p scattering

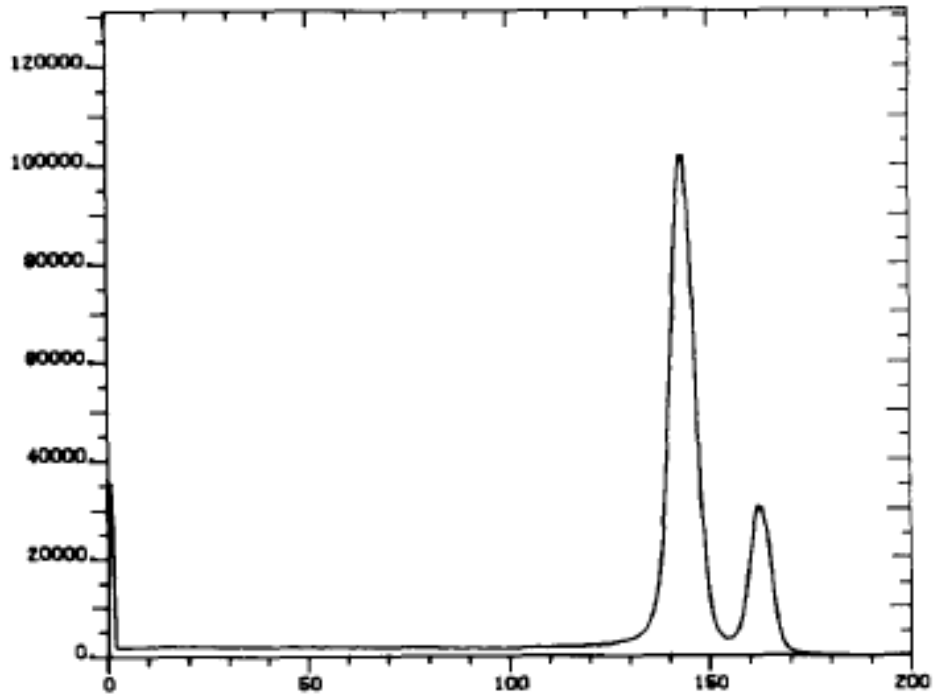


Fig. 13. Spectrum of the p–p reaction at $\theta_{lab} = 7.5°$, the high energy peak corresponds to scattering on gas contaminations.

$^{14}N(d,p)^{15}N$

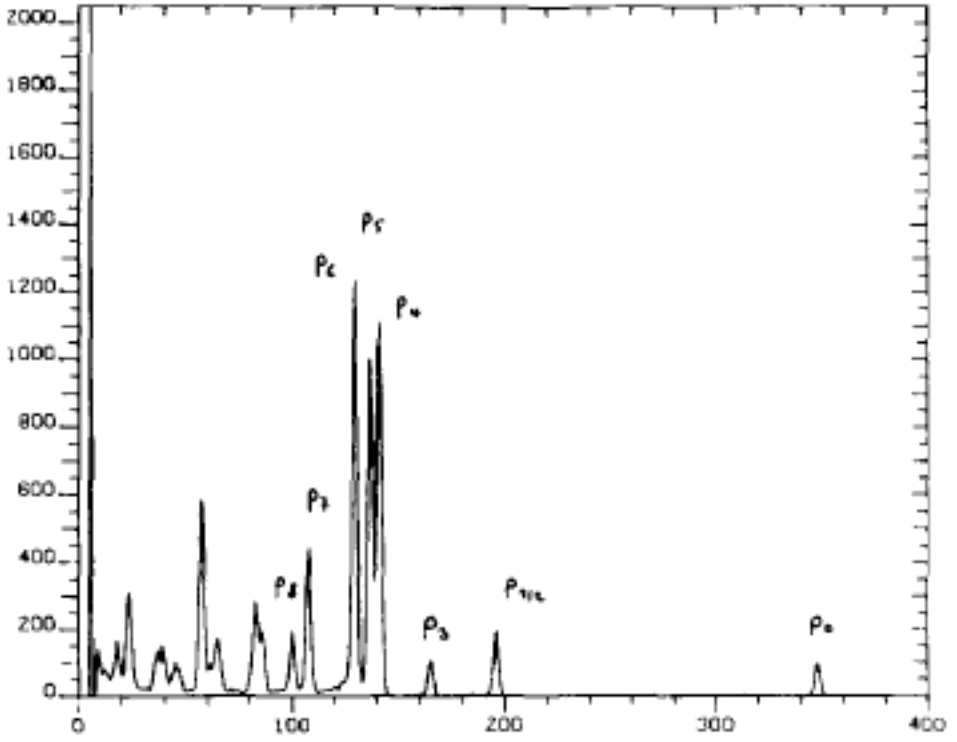
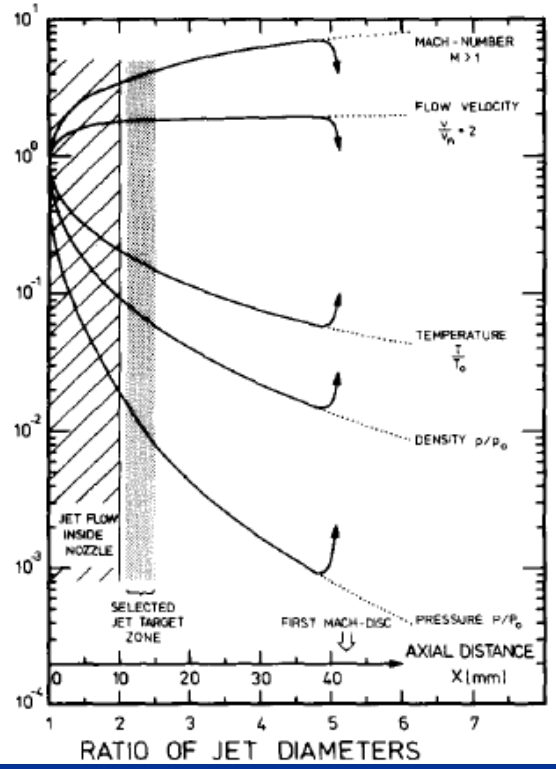


Fig. 14. Spectrum of the reaction $^{14}N(d, p)^{15}N$ at $\theta_{lab} = 20°$.

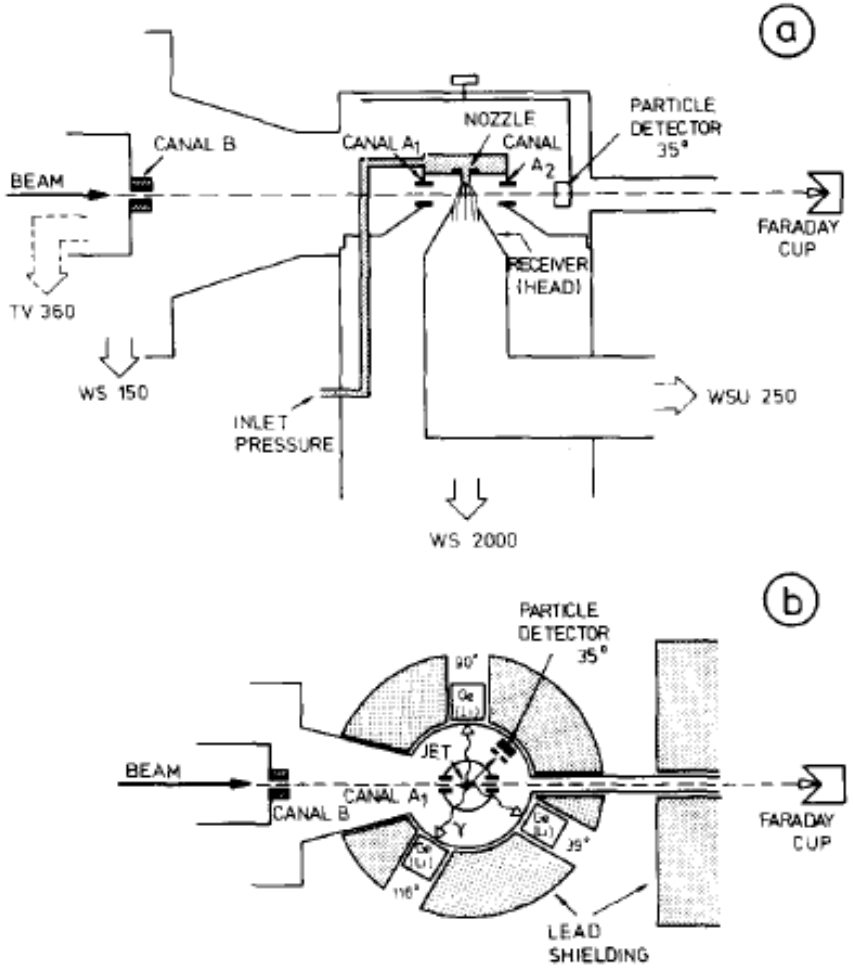
G. Bittner *et al.*, Nucl. Instrum. Meth. **161**, 1 (1979)

The first helium-jet target



Location and Year	Münster (Germany) 1982
Target gas	D_2, ^3He, ^4He, N_2, O_2, Ne, Ar
Particle density	0.34×10^{17} atoms/cm^2 for ^4He
Geometrical width	2.5 mm
Method	p elastic scattering and narrow resonance excitation functions

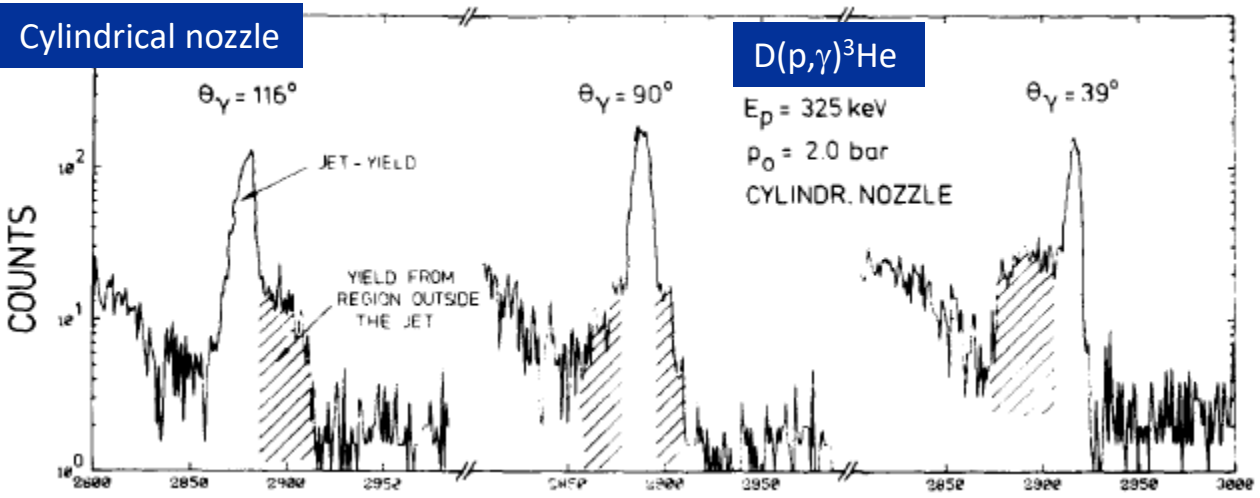
Recirculating



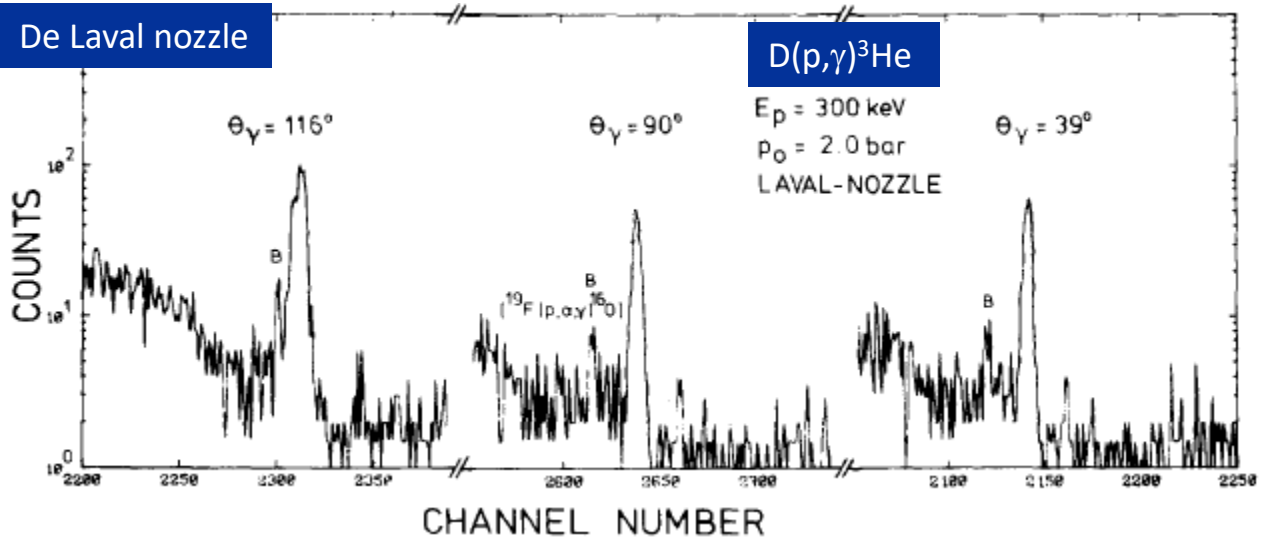
H.W. Becker *et al.*, Nucl. Instrum. Meth. **198**, 277 (1982)

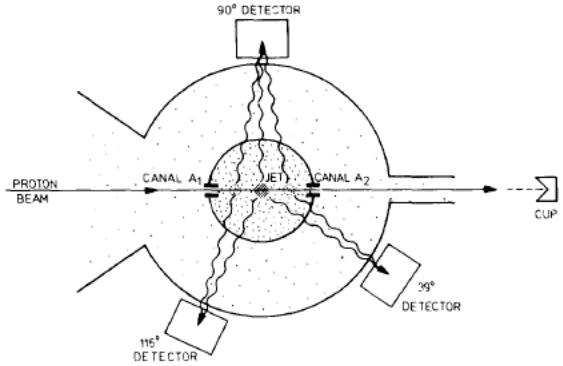
γ-ray spectra with the Münster gas jet

Cylindrical nozzle

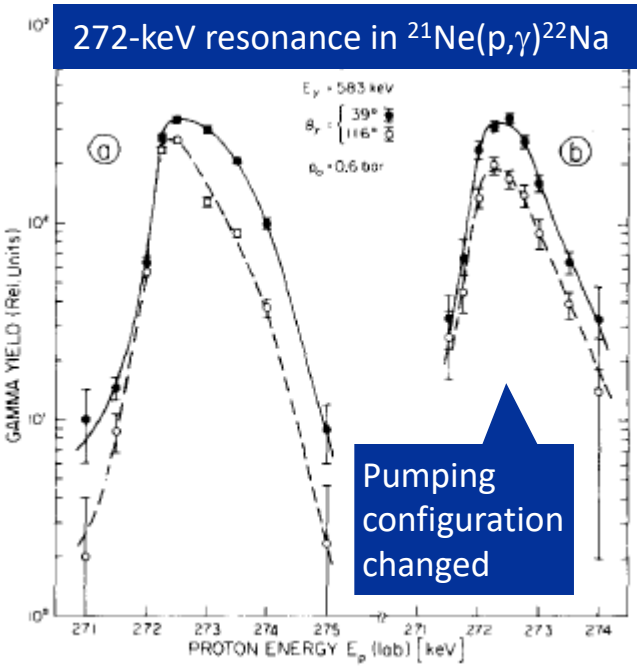


De Laval nozzle





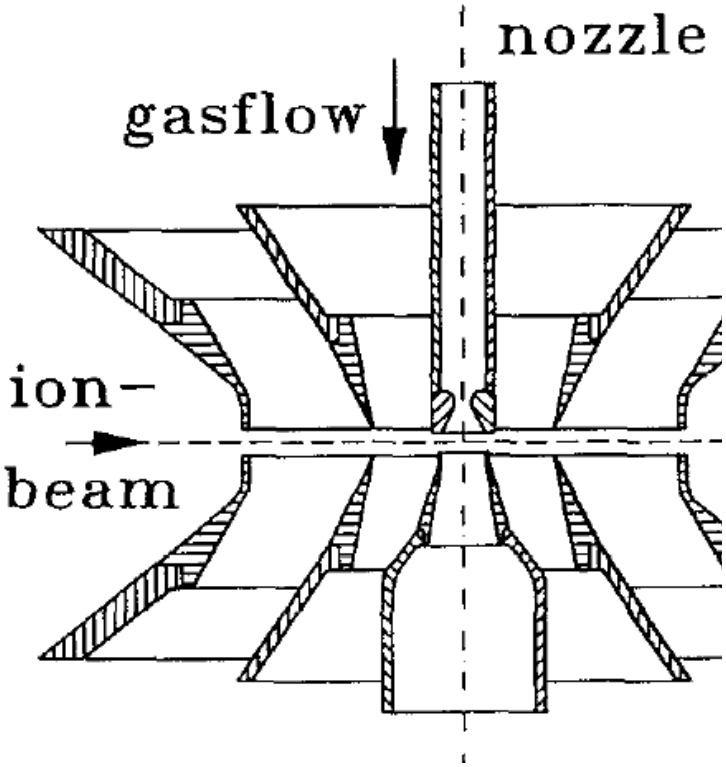
272-keV resonance in $^{21}Ne(p,\gamma)^{22}Na$



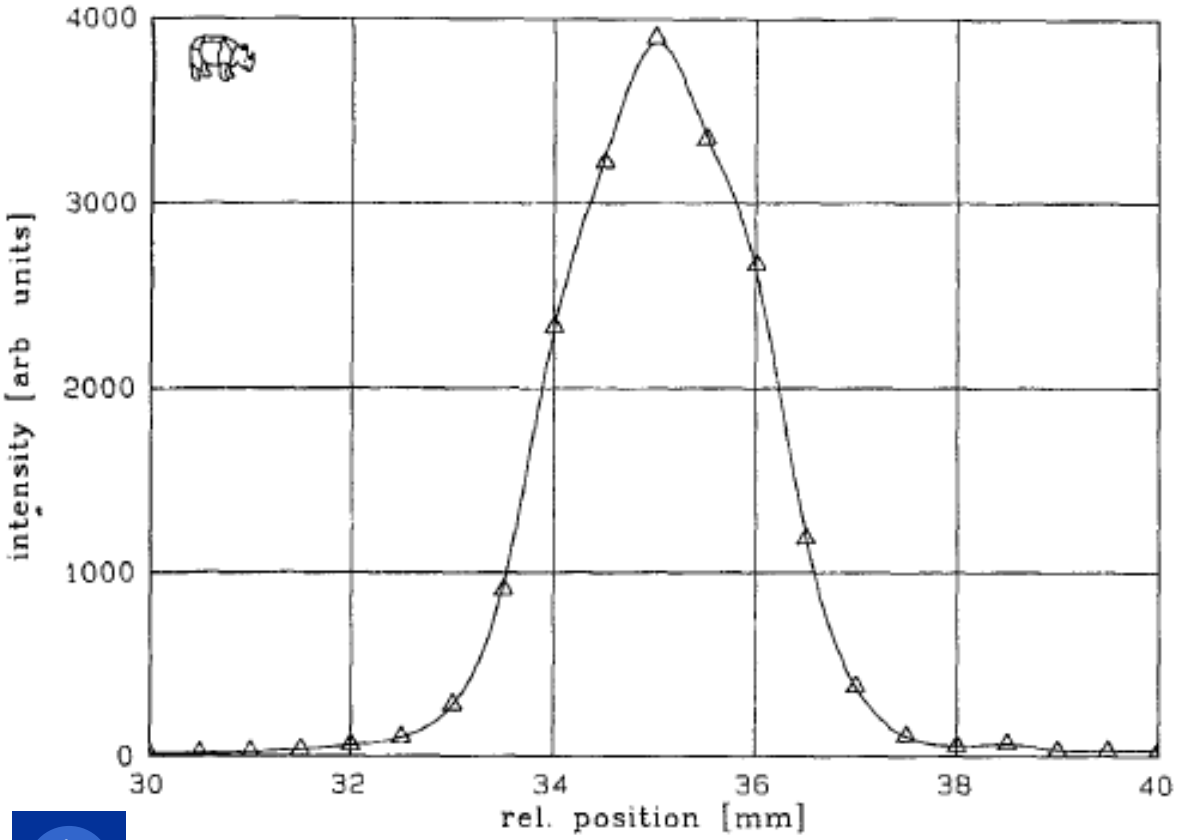
Pumping configuration changed

H.W. Becker *et al.*, Nucl. Instrum. Meth. **198**, 277 (1982)

Gas target facility RHINOCEROS



Jet configuration can be switched to extended gas target with static pressures



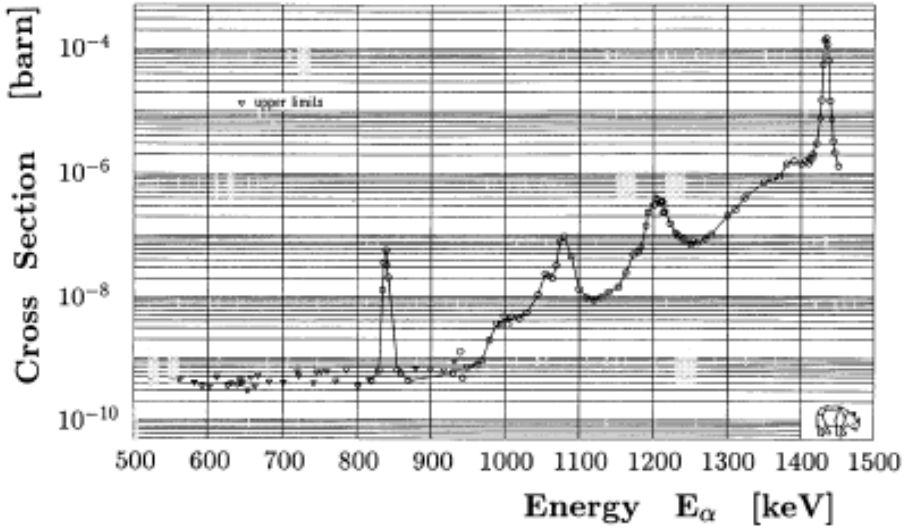
Location and Year	Stuttgart (Germany) 1991
Target gas	D_2, ^3He, ^4He, N_2, O_2, Ne, Ar
Particle density	0.078×10^{18} atoms/cm^2 for ^4He
Geometrical width	2.6 mm
Method	Estimated based on density calculation

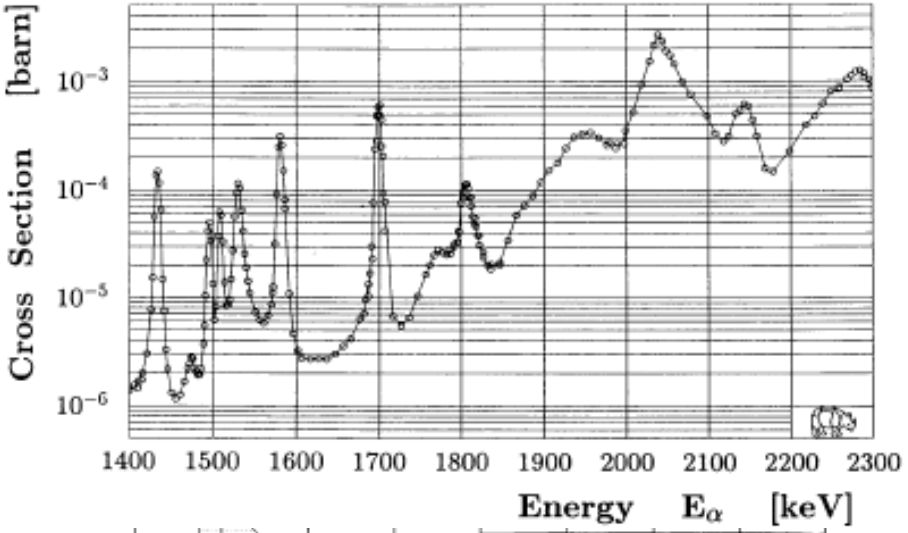
Recircu-lating

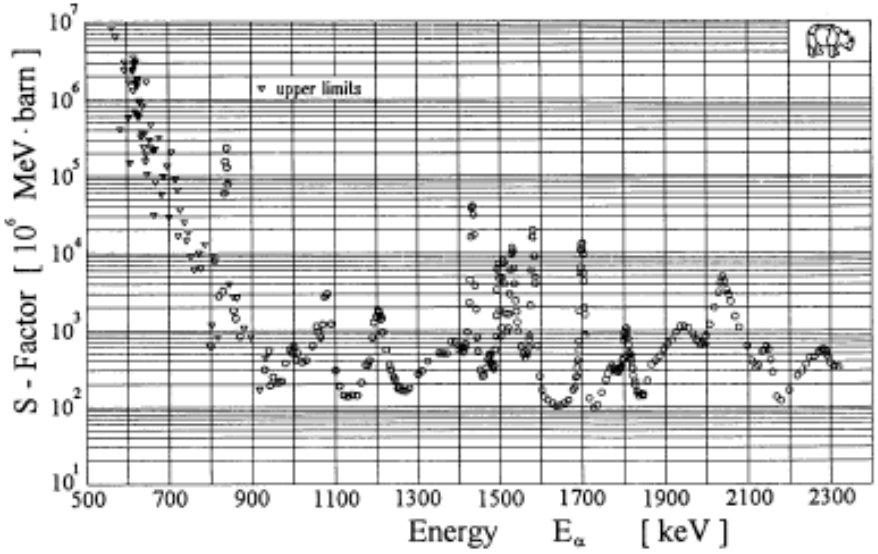
T. Griegel *et al.*, J. Appl. Phys. **69**, 19 (1991)

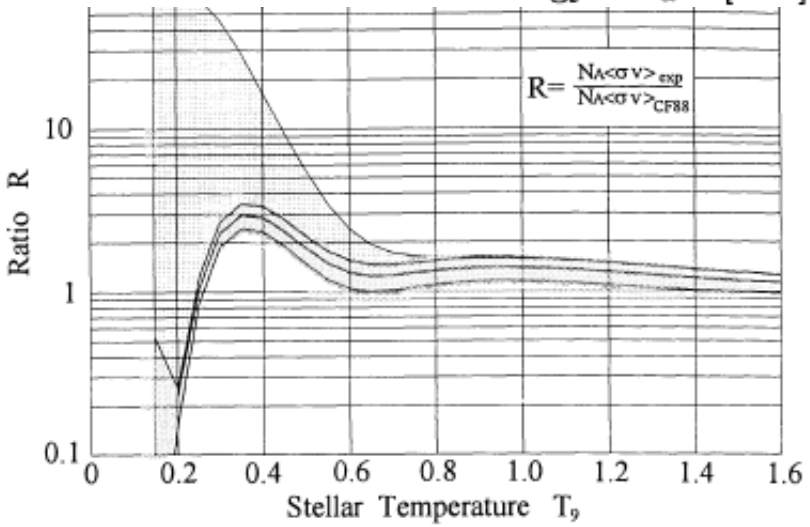
$^{22}Ne(\alpha,n)^{25}Mg$ study with RHINOCEROS

Neutron source for the s-process





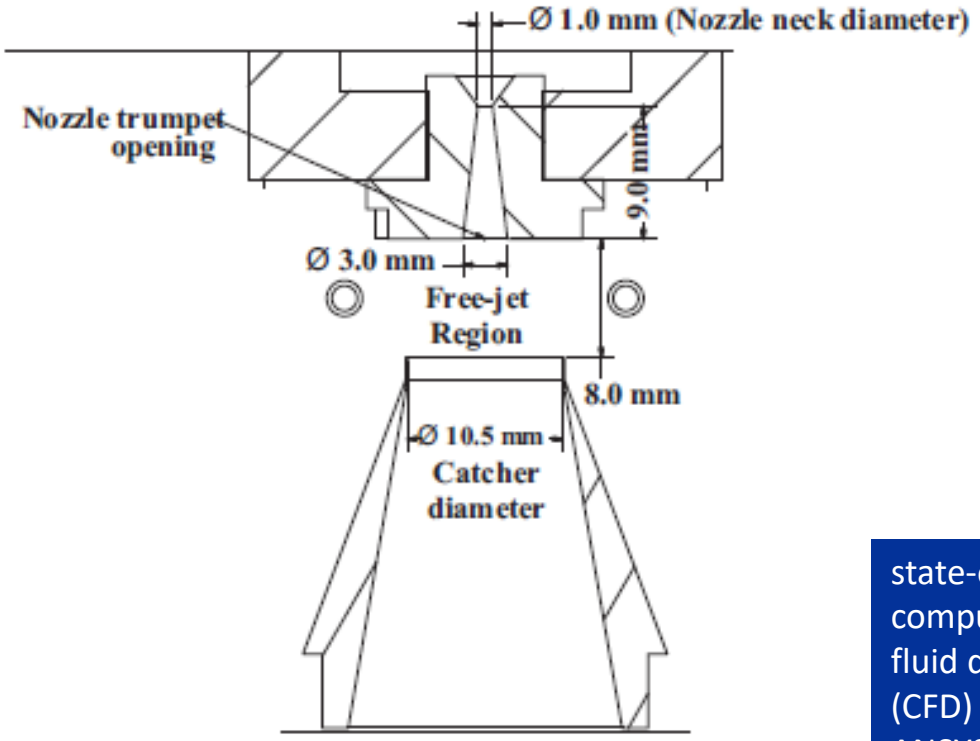


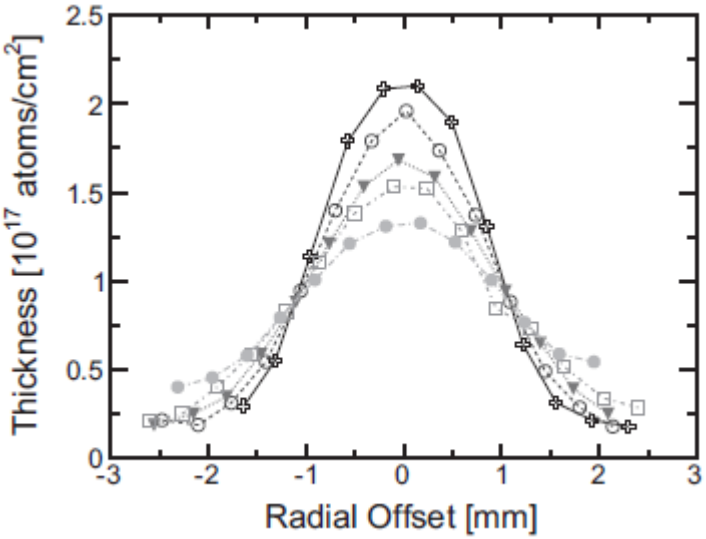


H. W. Drotleff *et al.*, Astrophys. J. **414**, 735 (1993)

CFD calculations for HIPPO

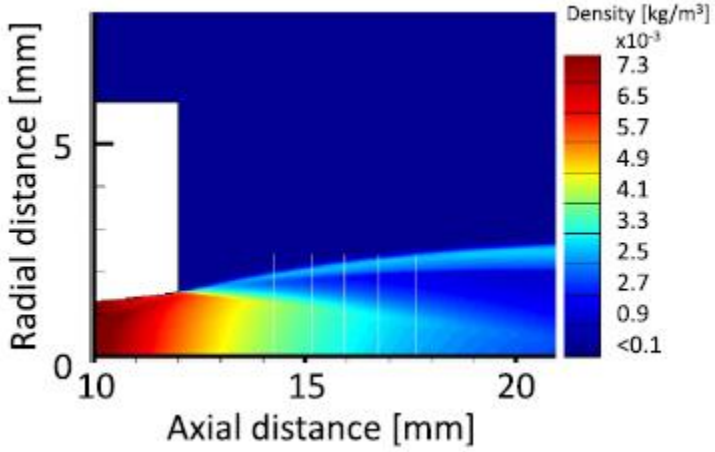
High **P**ressure **Po**int like gas target





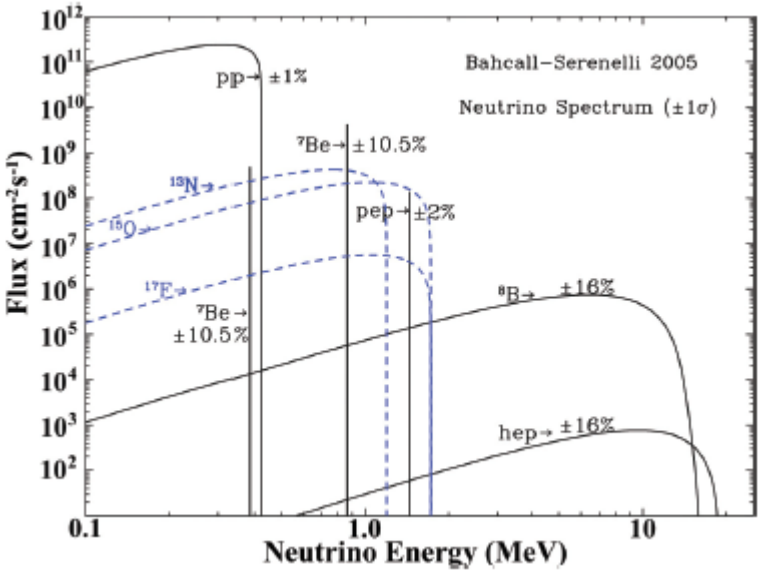
Location and Year	Notre Dame (USA) 2012
Target gas	Helium, Nitrogen
Particle density	0.259×10^{18} atoms/cm^2 for ^{4}He
Geometrical width	2.2 mm
Method	α scattering and α energy loss

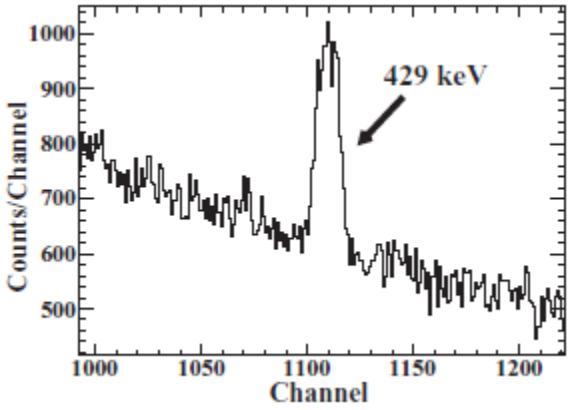
state-of-the-art computational fluid dynamics (CFD) software ANSYS Fluent

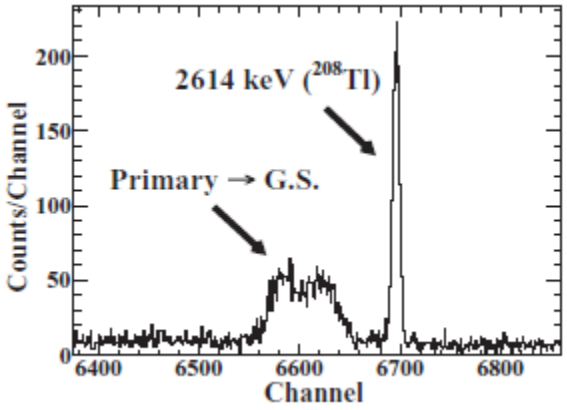


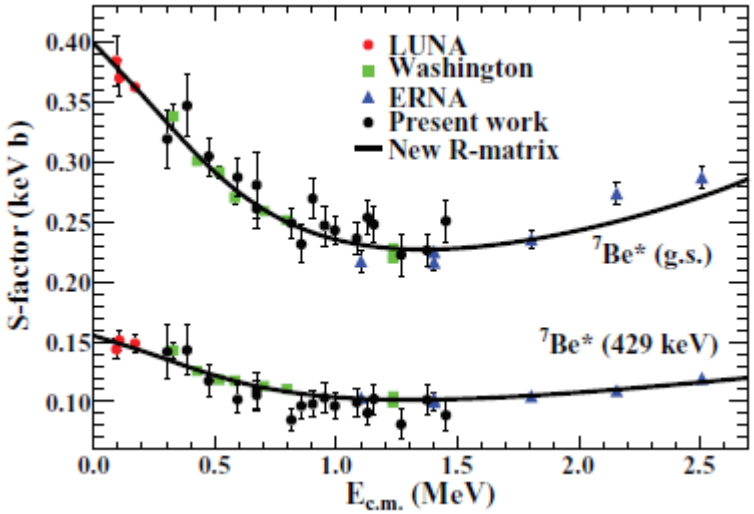
A. Kontos *et al.*, Nucl. Instrum. Meth. Phys. Res. A **664**, 272 (2012)
Z. Meisel *et al.*, Nucl. Instrum. Meth. Phys. Res. A **828**, 8 (2016)

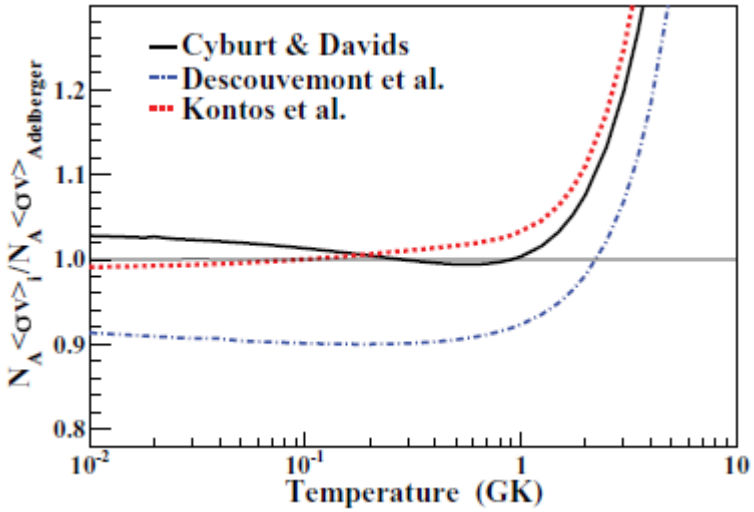
$^3He(\alpha,\gamma)^7Be$ study with HIPPO







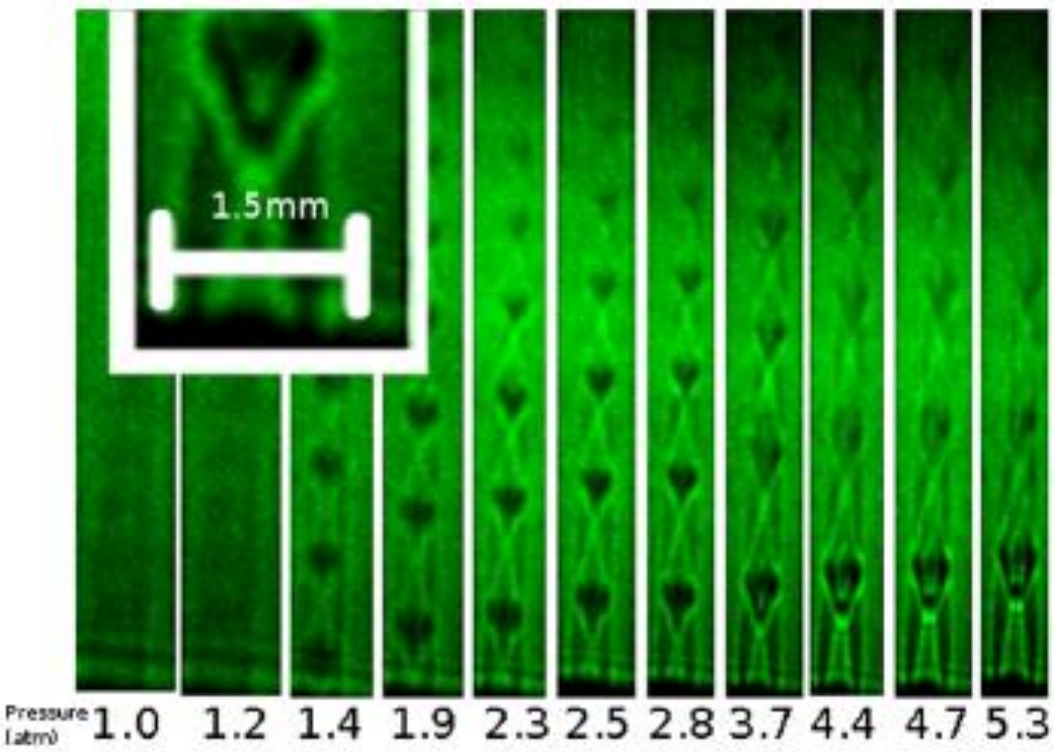


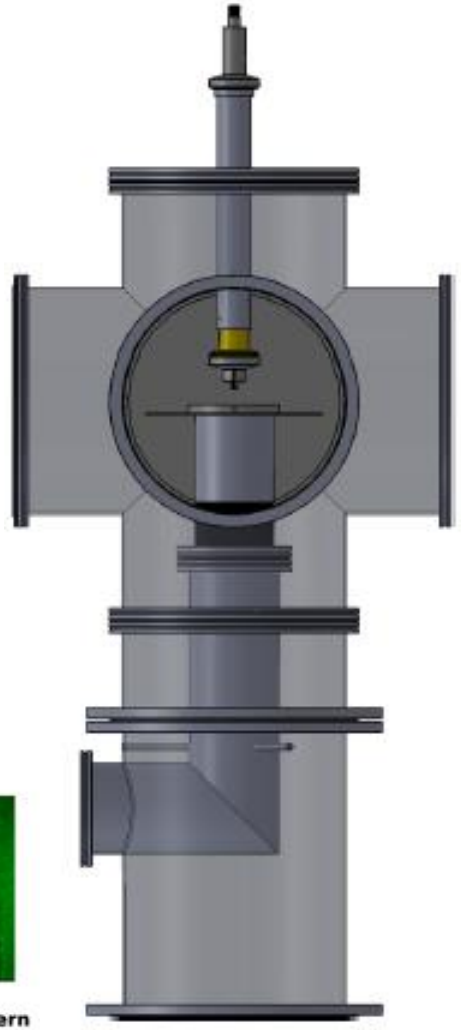


A. Kontos *et al.*, Phys. Rev. C **87**, 065804 (2013)

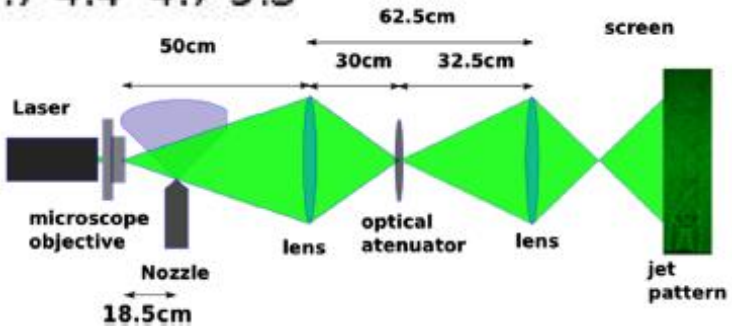
Schlieren images of SUGAR

Supersonic **GA**s jet ta**R**get



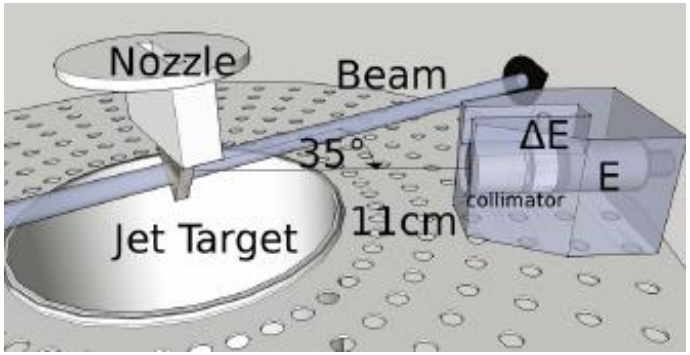


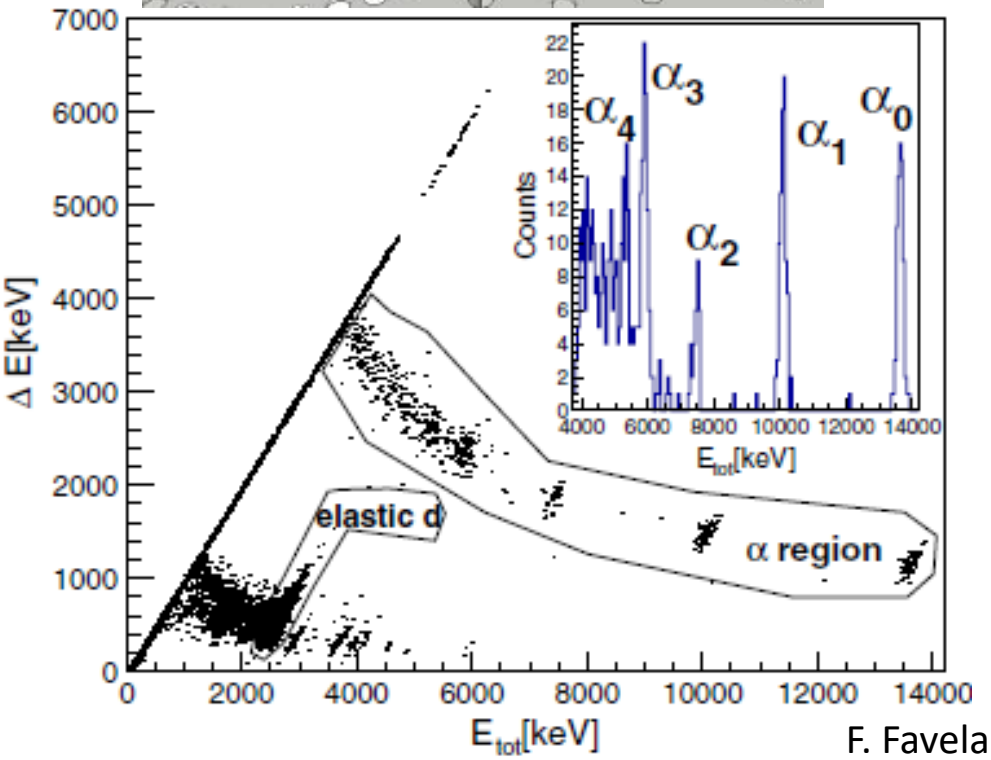
Location and Year	Mexico City (Mexico) 2015
Target gas	Argon, Nitrogen, and Air
Particle density	1.8×10^{18} atoms/cm^2 for ^{4}He
Geometrical width	1.5 mm
Method	Elastic backscattering spectrometry

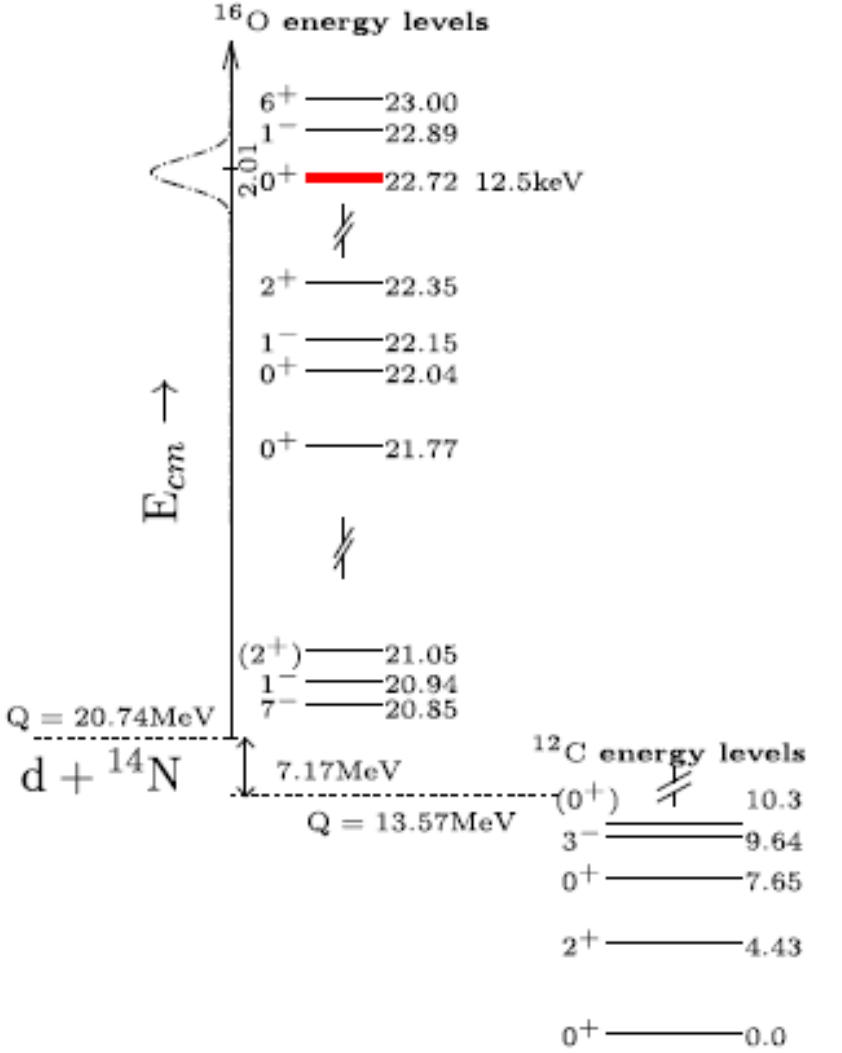


F. Favela *et al.*, Phys. Rev. ST Accel. Beams **18**, 123502 (2015)

$^{14}N(d,\alpha)^{16}O$ study with the SUGAR air jet



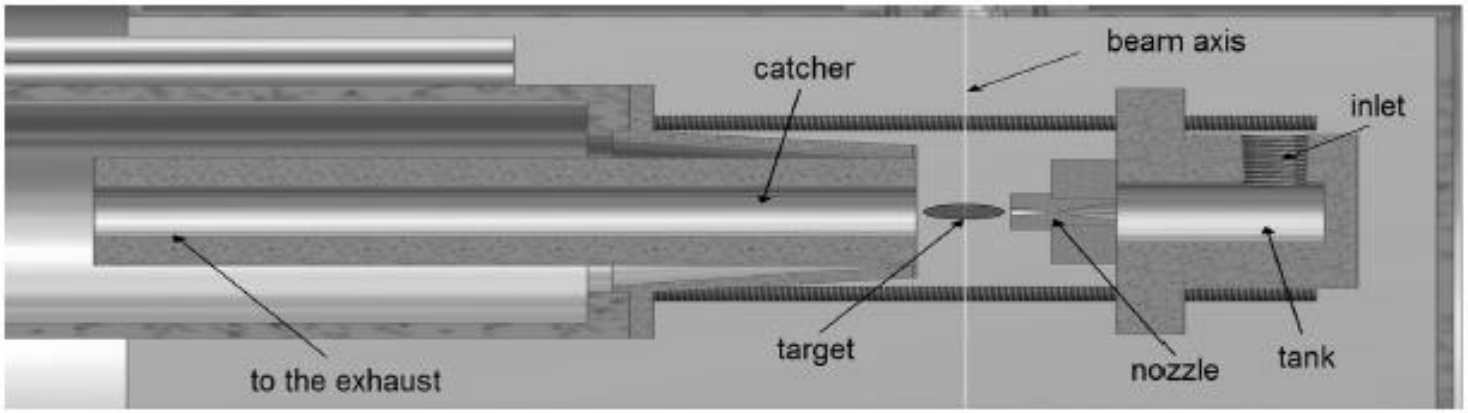




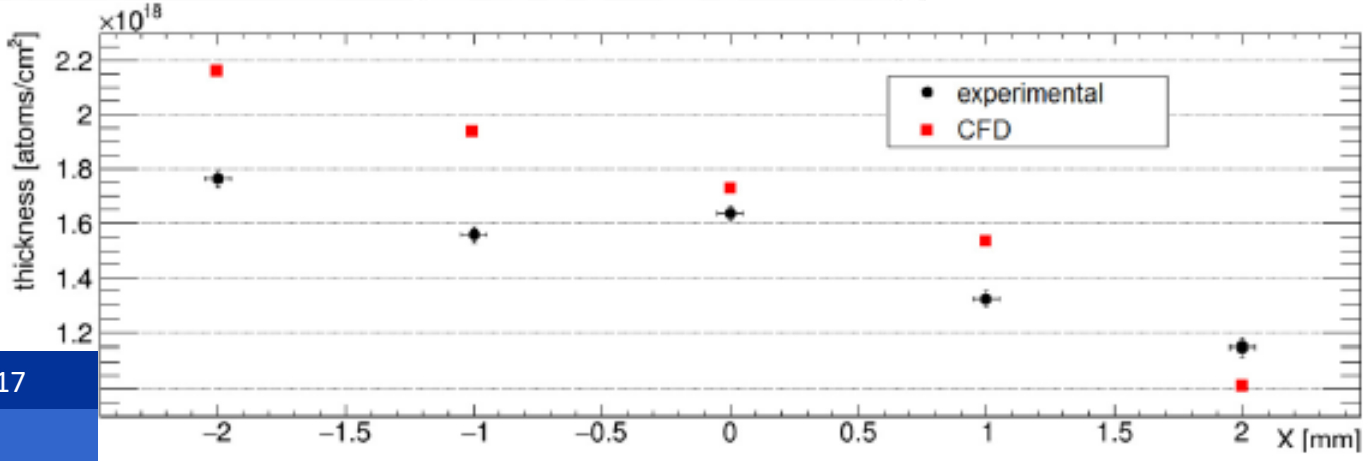
F. Favela *et al.*, Phys. Rev. ST Accel. Beams **18**, 123502 (2015)

Gas jet for the recoil separator ERNA

European **R**ecoil mass separator for **N**uclear **A**strophysics



See talk by Raffaele Buompane about $^{7}Be(p,\gamma)^{8}B$



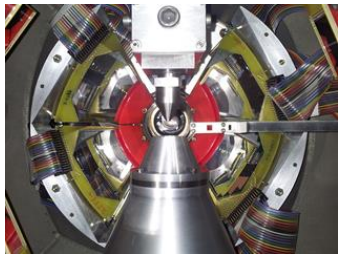
Location and Year	Caserta (Italy) 2017
Target gas	Helium
Particle density	1.97×10^{18} atoms/cm^2
Geometrical width	Not reported
Method	Energy loss of ^{12}C beam

D. Rapagnani et al., Nucl. Instrum. Meth. Phys. Res. B **407**, 217 (2017)

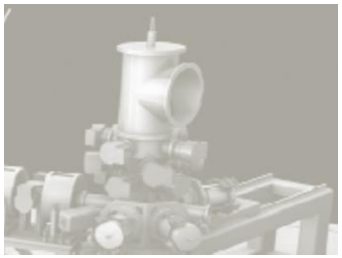
Outline

Motivation for gas-jet targets

Review of supersonic gas-jet targets in nuclear physics

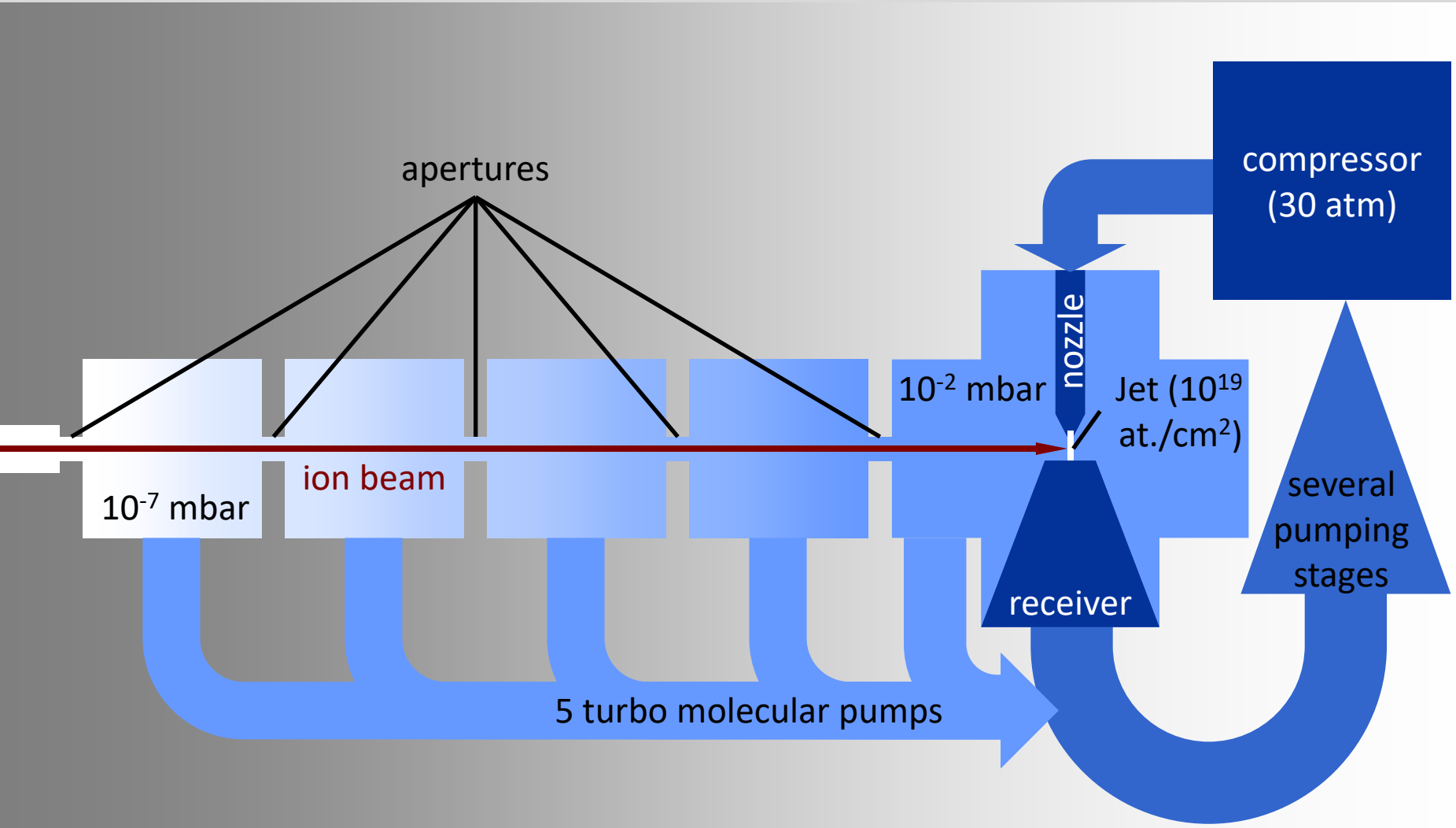


The JENSA gas-jet target



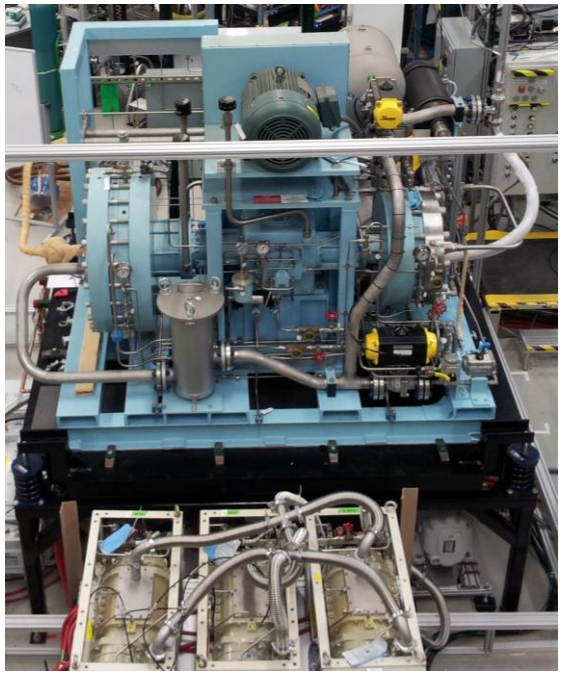
Perspective of future gas targets

Recirculating gas system

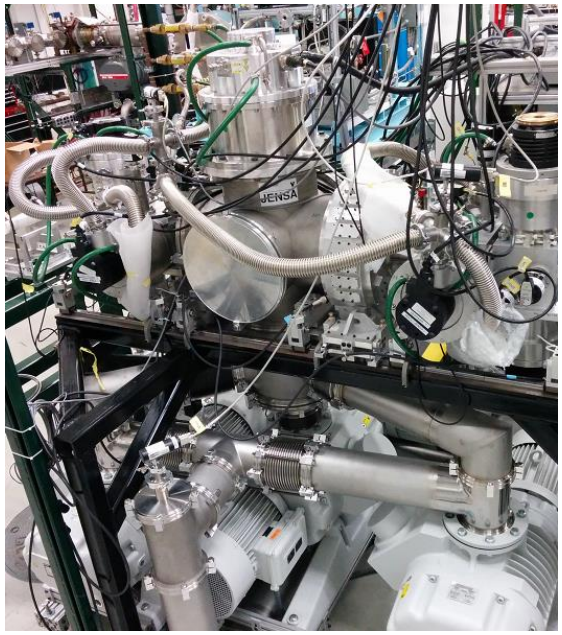


The JENSA gas jet target at NSCL

Jet **E**xperiments in **N**uclear **S**tructure and **A**strophysics



Diaphragm compressor

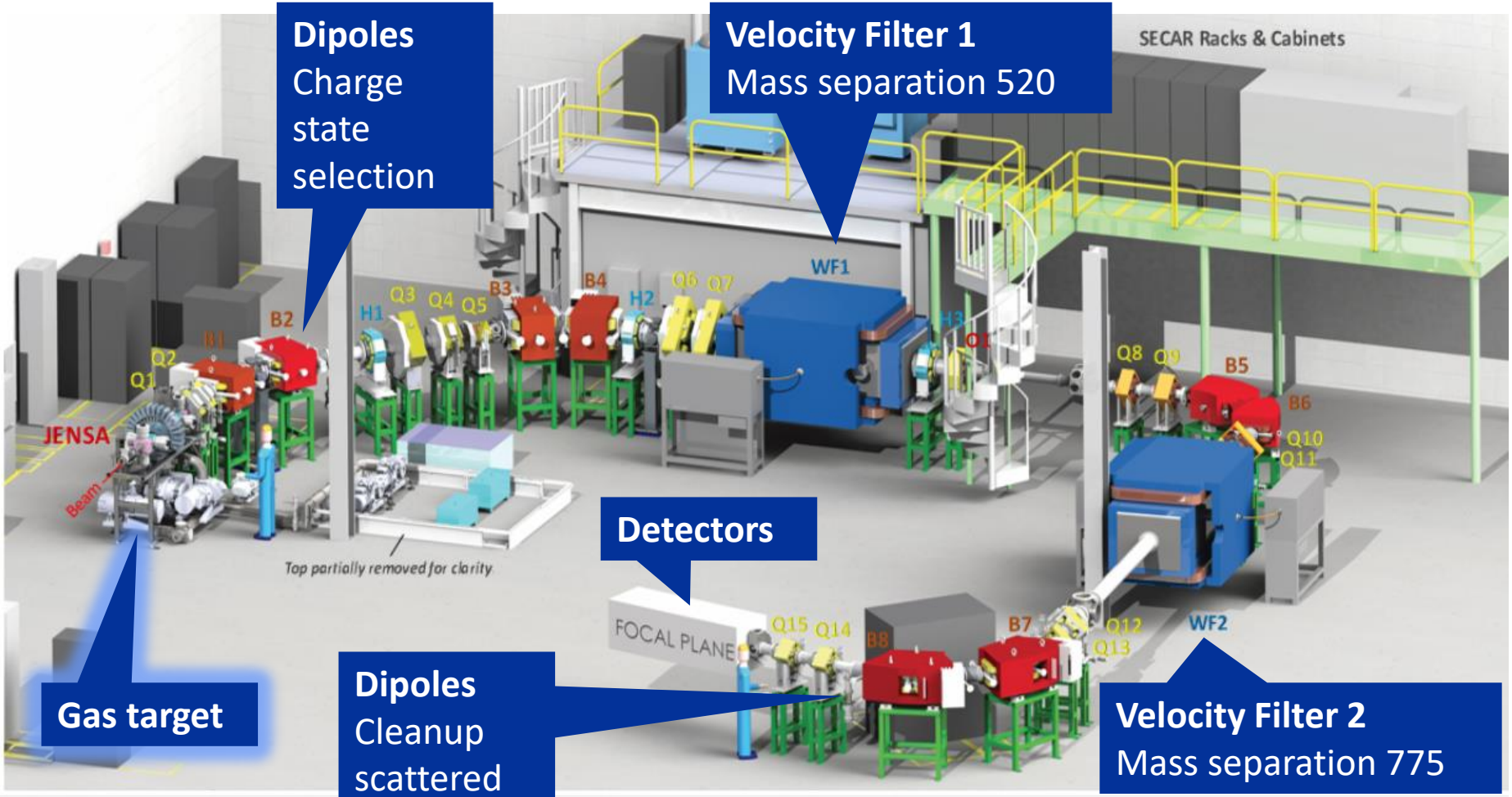


Target chamber and pumps

Nozzle, receiver and Si detectors

JENSA as the main target for SECAR

Recoil **Se**parator for **Ca**pture **R**eactions

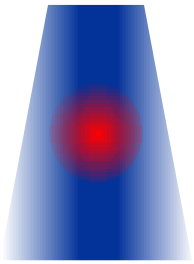


fribastro.org/SECAR/

Attention should be paid to …

1. Distribution of the jet density

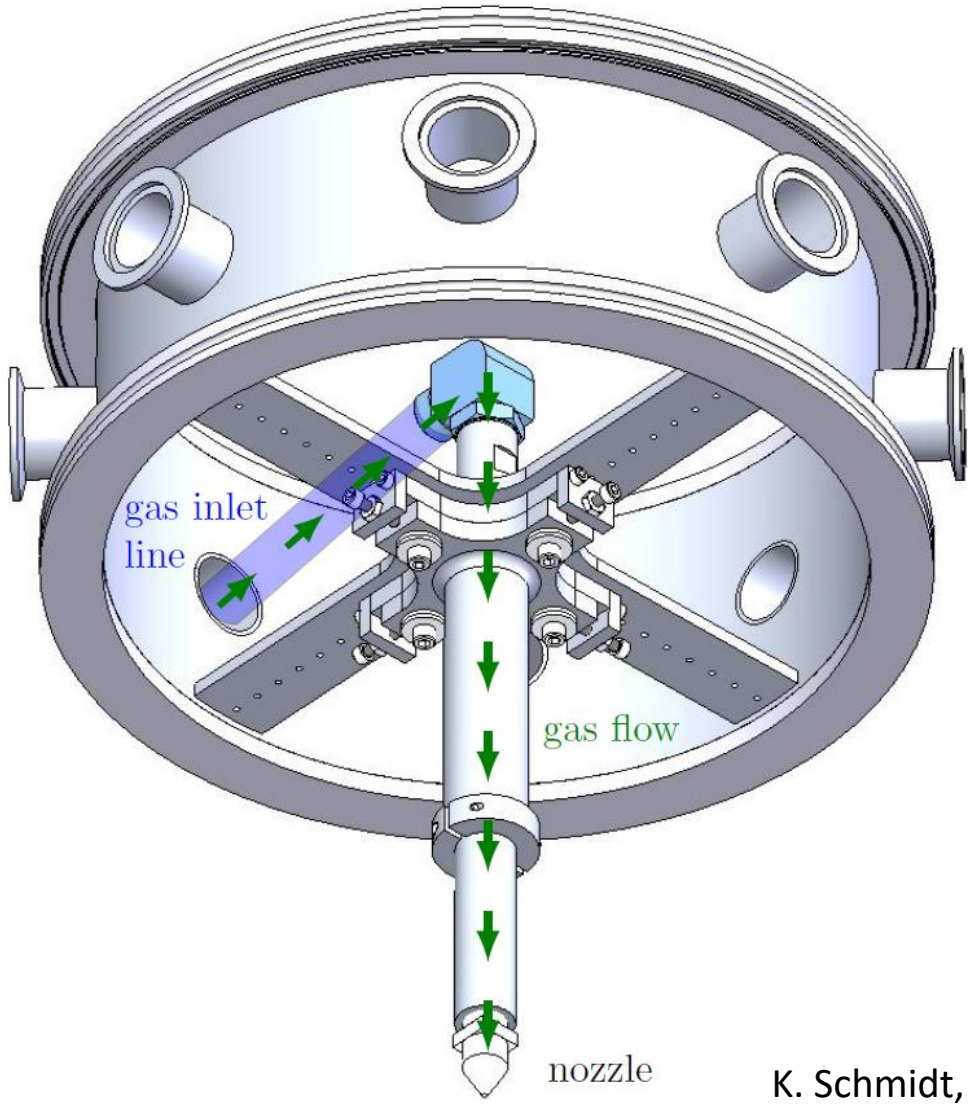
2. Overlap between ion beam and jet

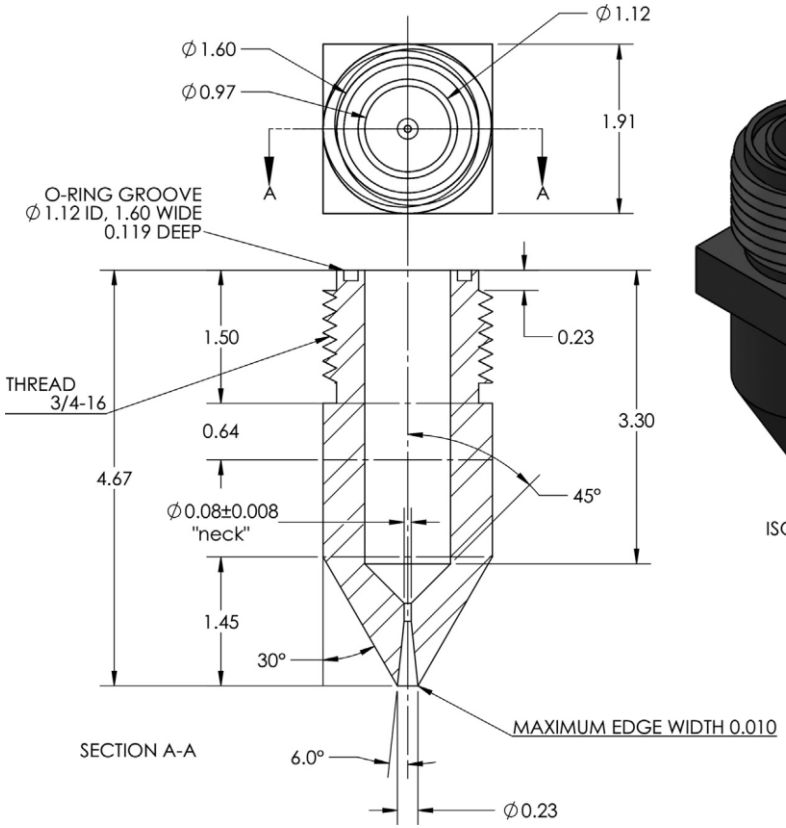


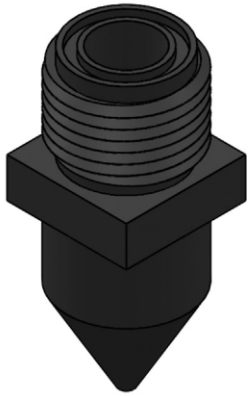
of S_{34} (35–41) is displayed in Table 2. The value quoted for (35) is the published value. There are indications (C. Rolfs, private communication) that this value includes some measurements with a gas-jet target that used an incorrect value for the target thickness. This apparently increases the extracted value of S_{34} to 0.40 keV-barns.

B.W. Filippone, Ann. Rev. Part. Sci. **36**, 717 (1986)

Precise alignment of the nozzle



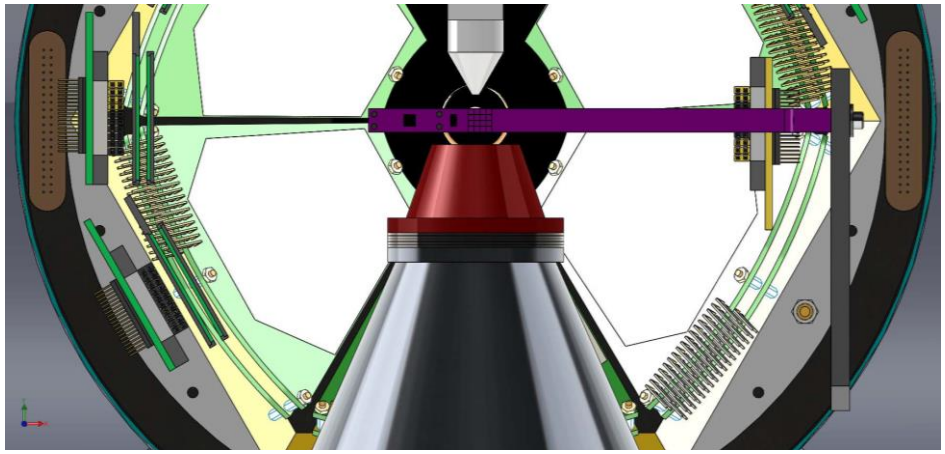


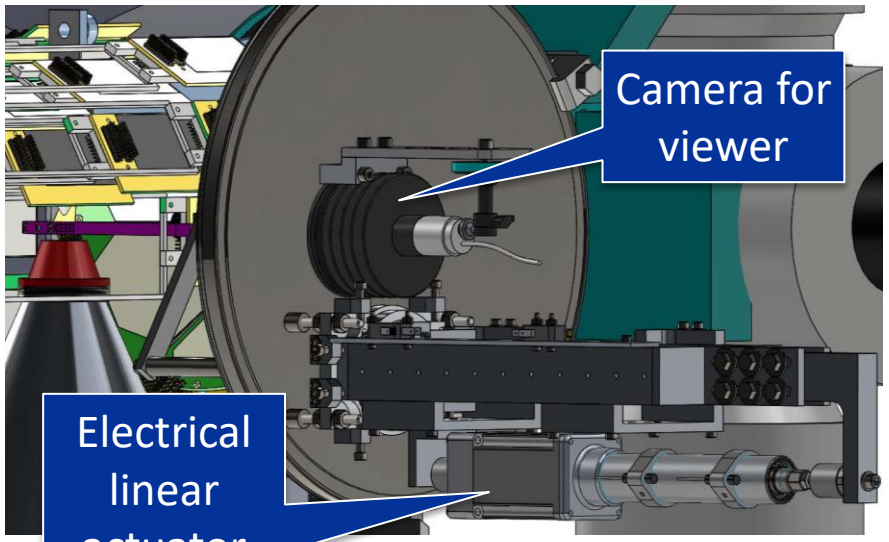


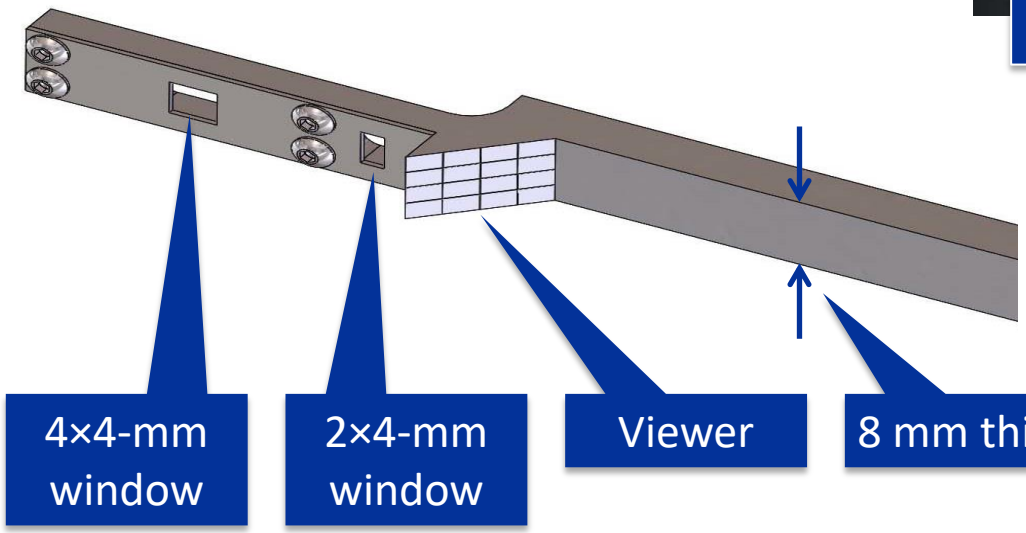
Inner diameter minimum: 0.8 mm

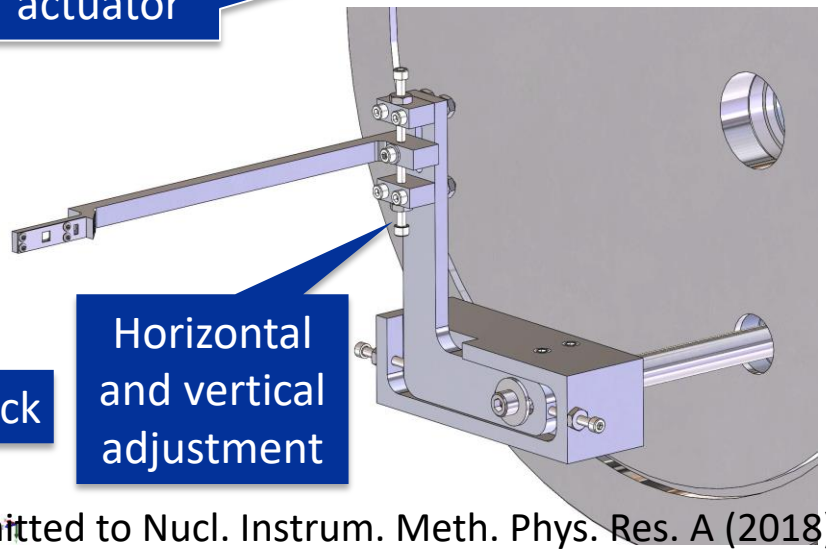
K. Schmidt, submitted to Nucl. Instrum. Meth. Phys. Res. A (2018)

Beam viewer for transmission check



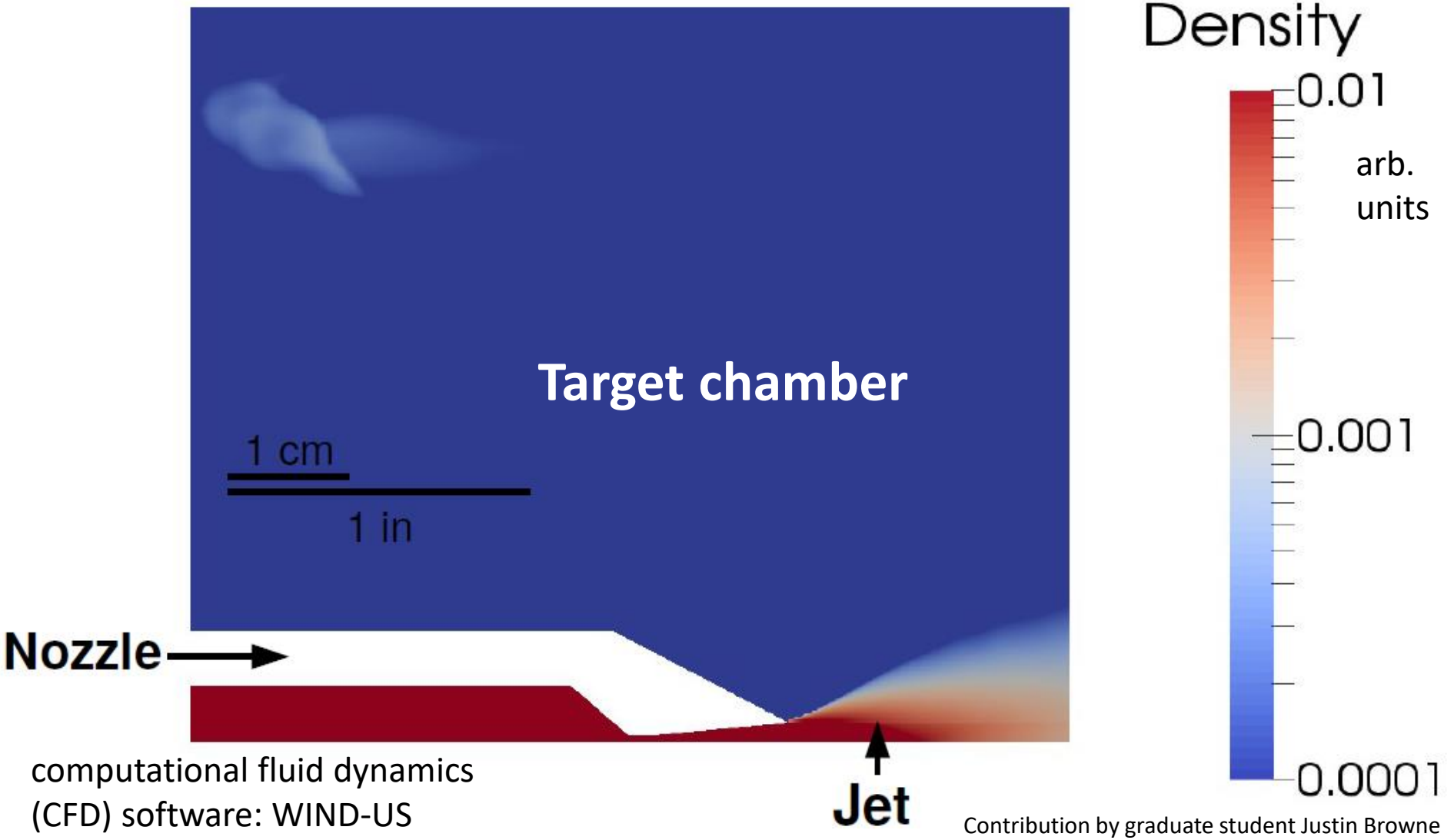






K. Schmidt, submitted to Nucl. Instrum. Meth. Phys. Res. A (2018)

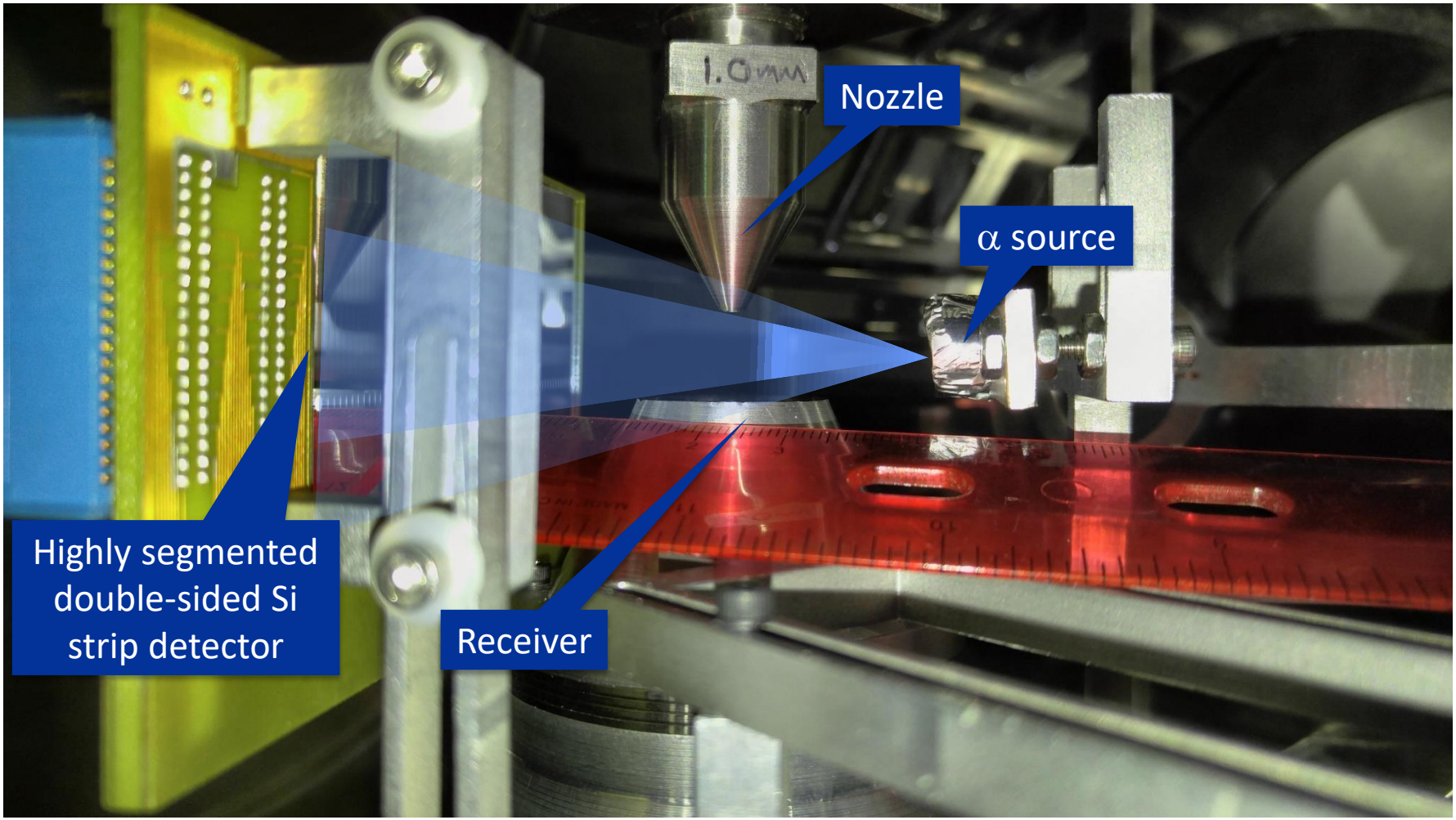
CFD simulation of the jet



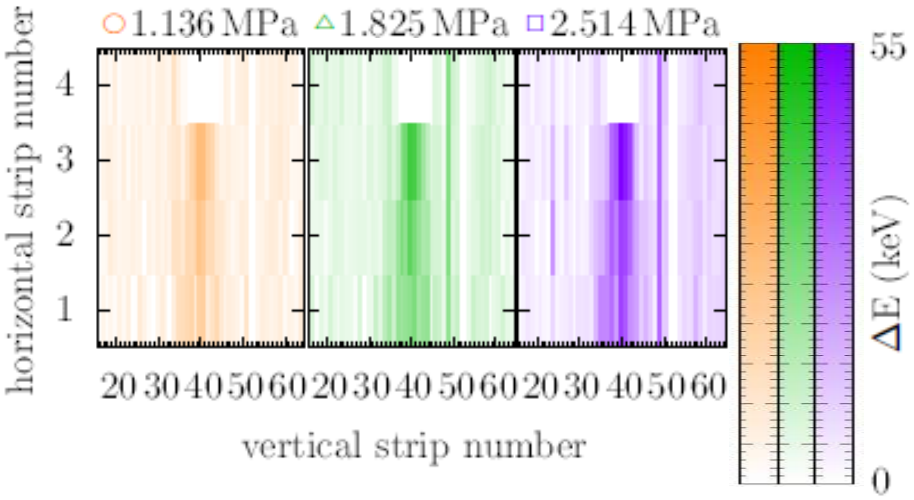
computational fluid dynamics (CFD) software: WIND-US

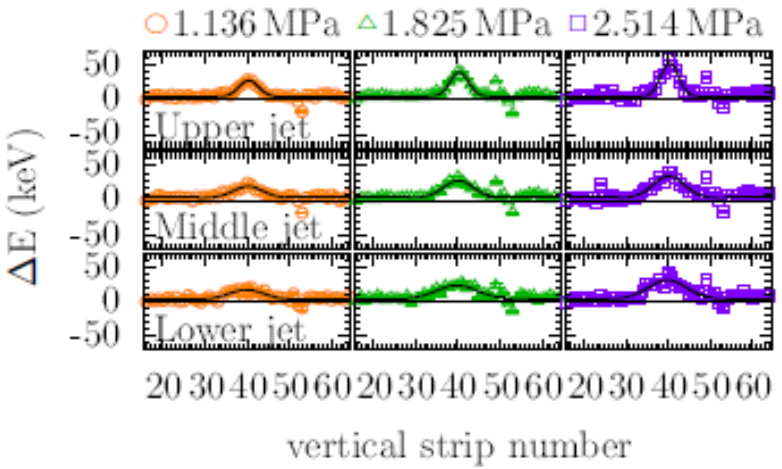
Contribution by graduate student Justin Browne

Setup for jet thickness study



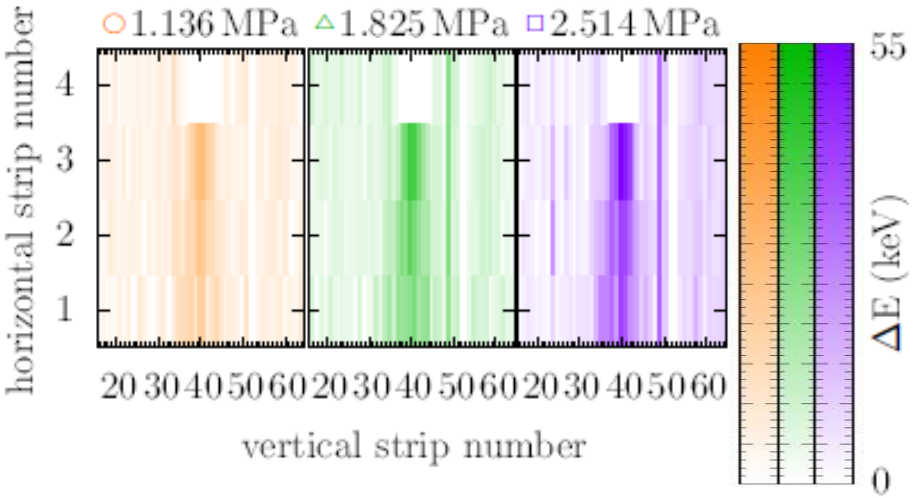
Energy loss, density and width profiles

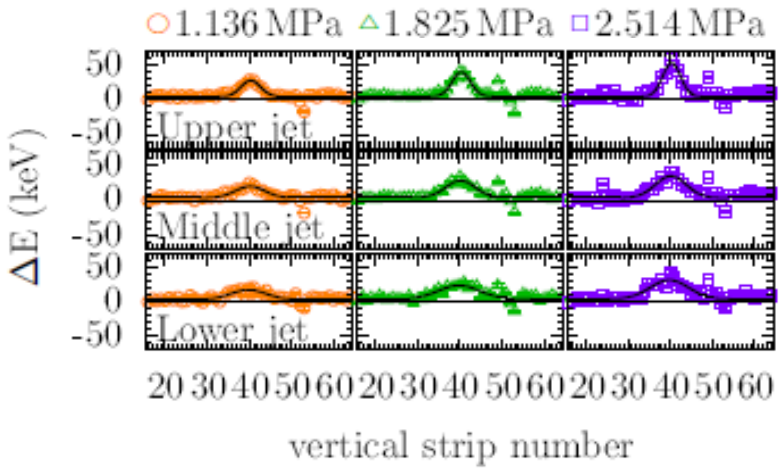


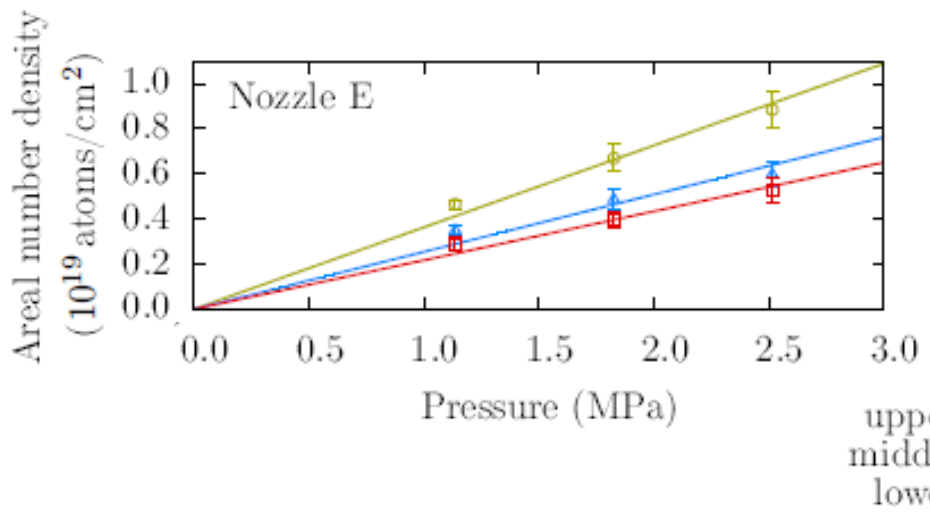


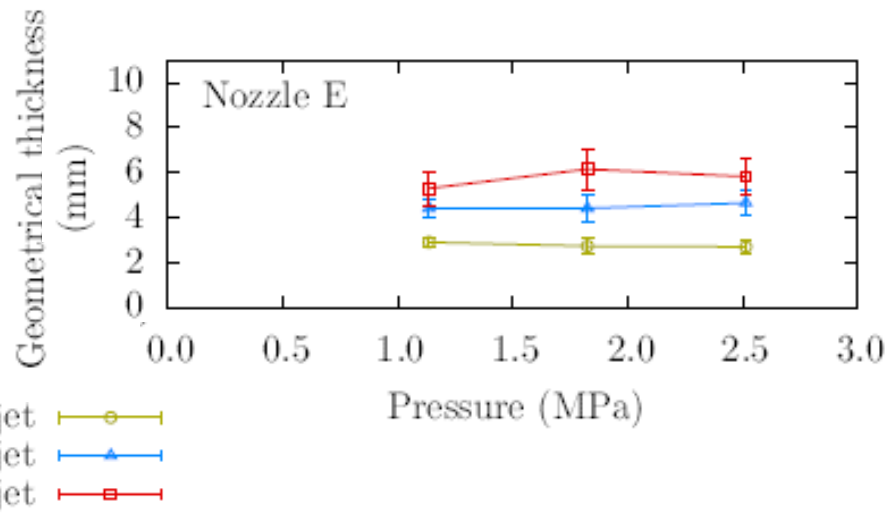
K. Schmidt, submitted to Nucl. Instrum. Meth. Phys. Res. A (2018)

Energy loss, density and width profiles





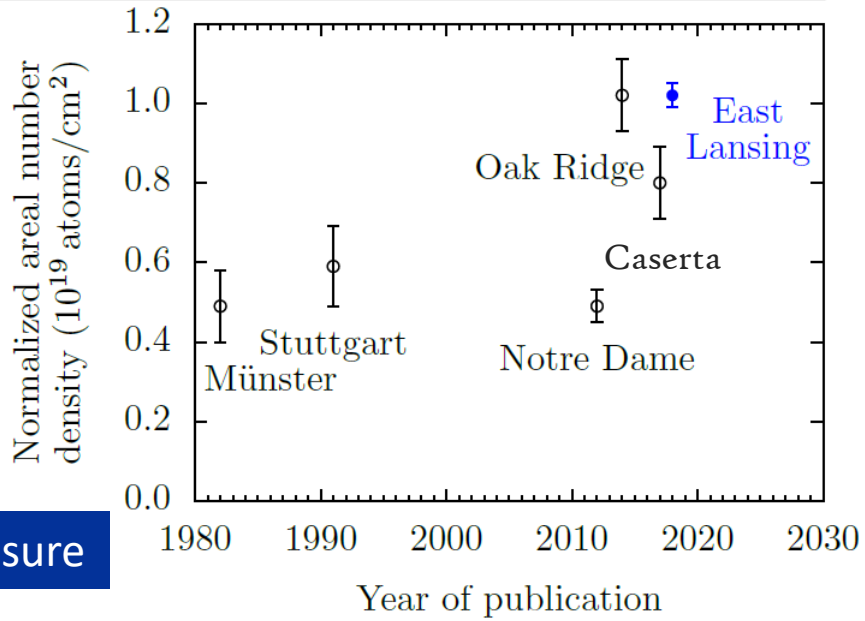




K. Schmidt, submitted to Nucl. Instrum. Meth. Phys. Res. A (2018)

Comparison of different He jets

Location	Year	Input pressure (kPa)	^{4}He jet density (10^{18} at./cm^2)	^{4}He jet FWHM (mm)	Distance from nozzle (mm)	Reference
Münster	1982	200	0.34 ± 0.06	2.5 ± 0.2	1 to 5	[23]
Stuttgart	1991	38	0.078 ± 0.013	2.6 ± 0.2	~ 1.5	[24]
Notre Dame	2012	150	0.259 ± 0.021	2.2 ± 0.2	~ 4	[27]
Oak Ridge	2014	2859	10.2 ± 0.9	5.1 ± 0.3	~ 1	[17]
Caserta	2017	700	1.97 ± 0.21	not reported	~ 5.5	[32]
East Lansing	2018	2515	9.0 ± 0.3	2.03 ± 0.09	$\lesssim 4$	this work

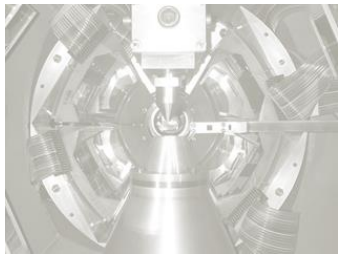


Normalized to 2.859 MPa input pressure

Outline

Motivation for gas-jet targets

Review of supersonic gas-jet targets in nuclear physics



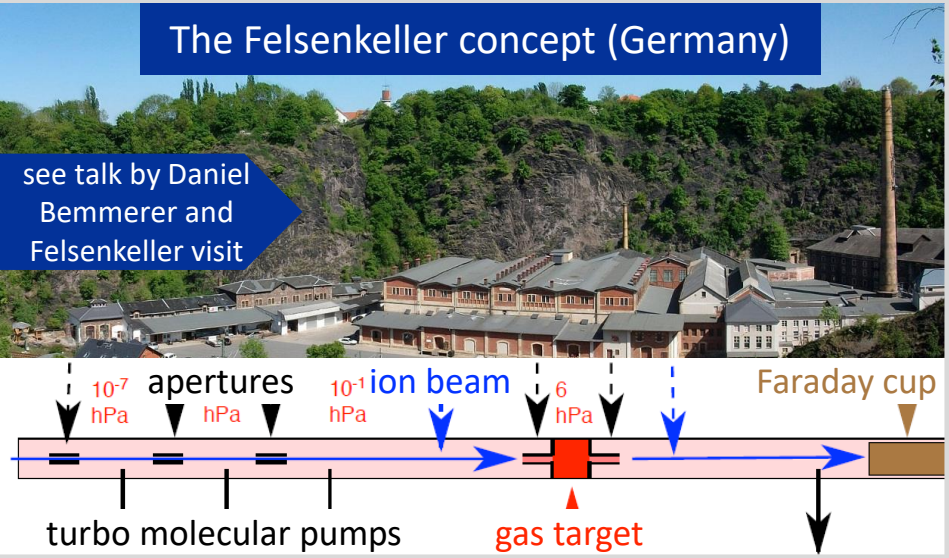
The JENSA gas-jet target

Perspective of future gas targets

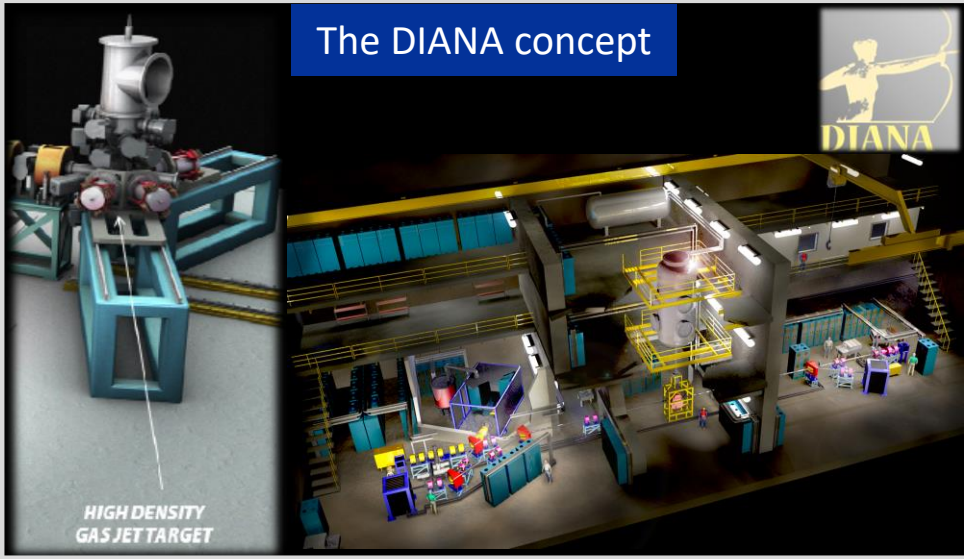
Perspectives of gas targets underground

The Felsenkeller concept (Germany)

see talk by Daniel Bemmerer and Felsenkeller visit

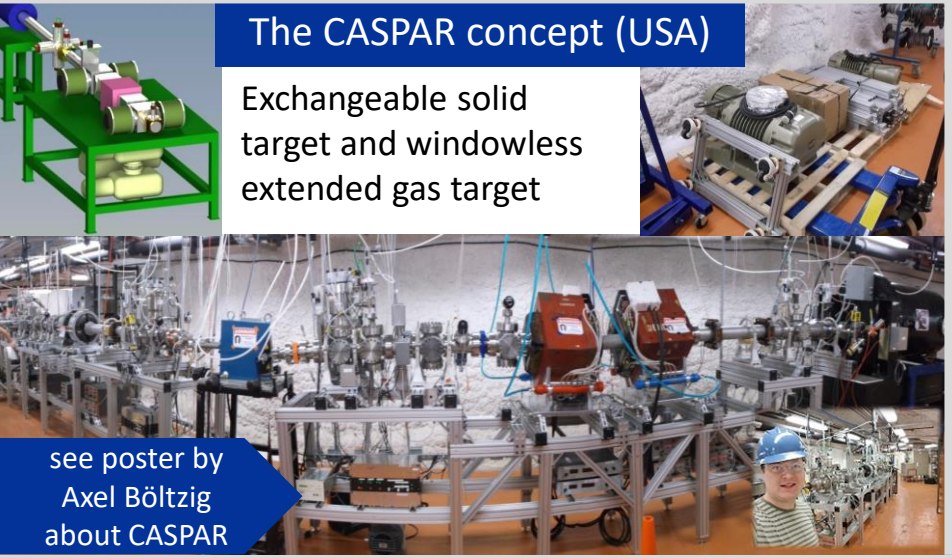


The DIANA concept



The CASPAR concept (USA)

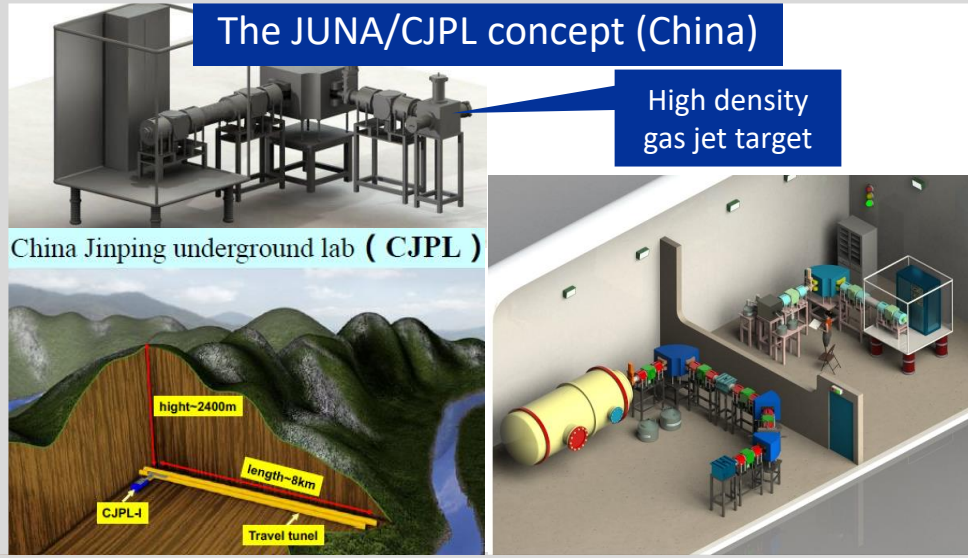
Exchangeable solid target and windowless extended gas target



see poster by Axel Böltzig about CASPAR

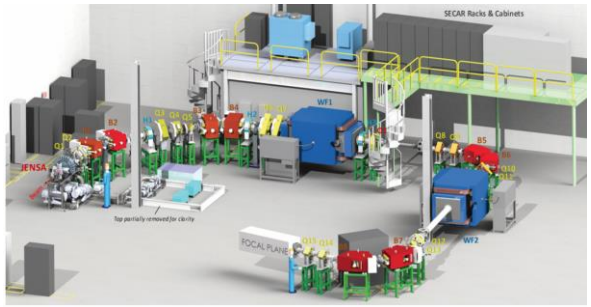
The JUNA/CJPL concept (China)

High density gas jet target



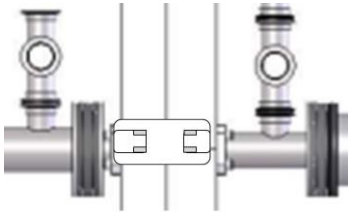
Further perspectives of gas targets

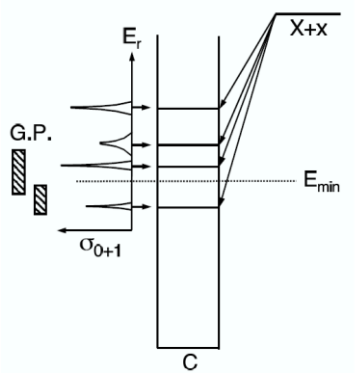
- Planned gas-jet target for DRAGON at TRIUMF (Vancouver, Canada)
- Planned gas-jet target for SPES-INFN (Legnaro, Italy)
- Planned extended gas chamber at JENSA for SECAR (East Lansing, USA)
- …



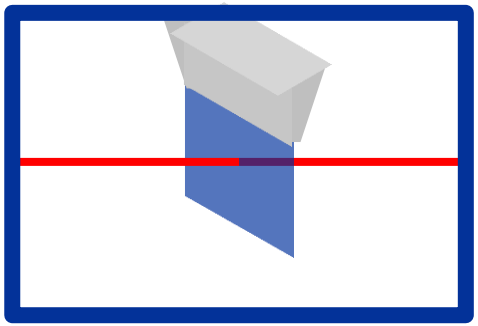
Ideas for the future

- Narrow resonance studies at astrophysical energies need thin gas targets
- Concept for a more homogeneous gas jet target (curtain gas jet)
- Next-generation gas cells
- …





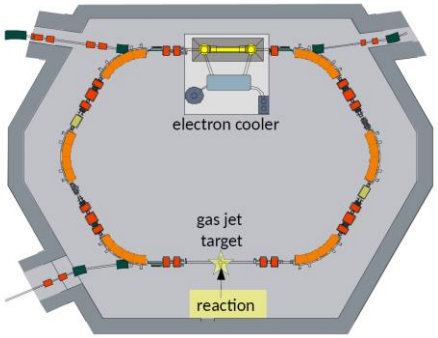
From: C. Iliadis, Nuclear Physics of Stars (Wiley-VCH, Weinheim, 2007).



See e.g. Putignano *et al.*, Proceedings of the 14th Beam Instrumentation Workshop, TUPSM045 (2010)

Further application possibilities:

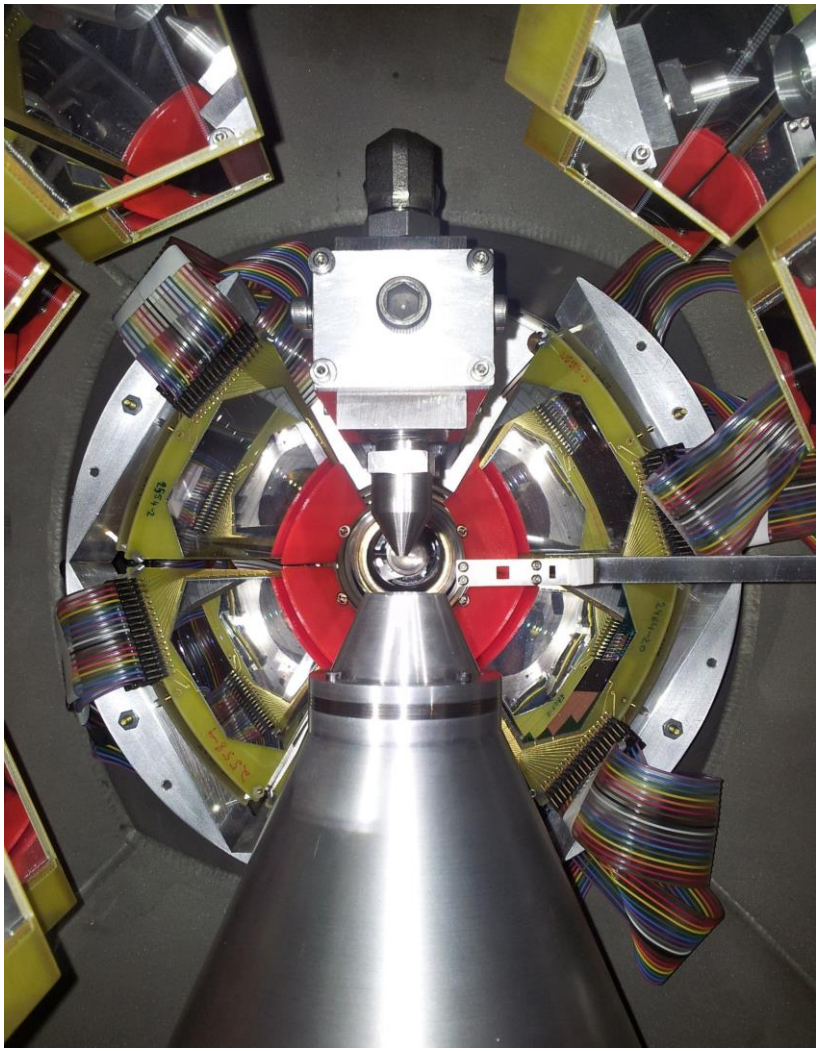
- Gas targets at storage rings – energy loss has to be compensated
- …

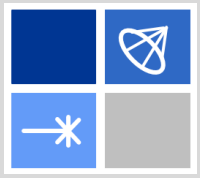


From: Z. Slavkovská, NARRS Workshop 2018

Summary

- Nuclear astrophysics experiments will benefit from next generation gas-target setups
- Low cross-section measurements need pure targets with high densities
- The development of supersonic gas-jet targets culminated in JENSA (10^{19} atoms/cm^2) and is further ongoing
- Future gas targets are planned and in development





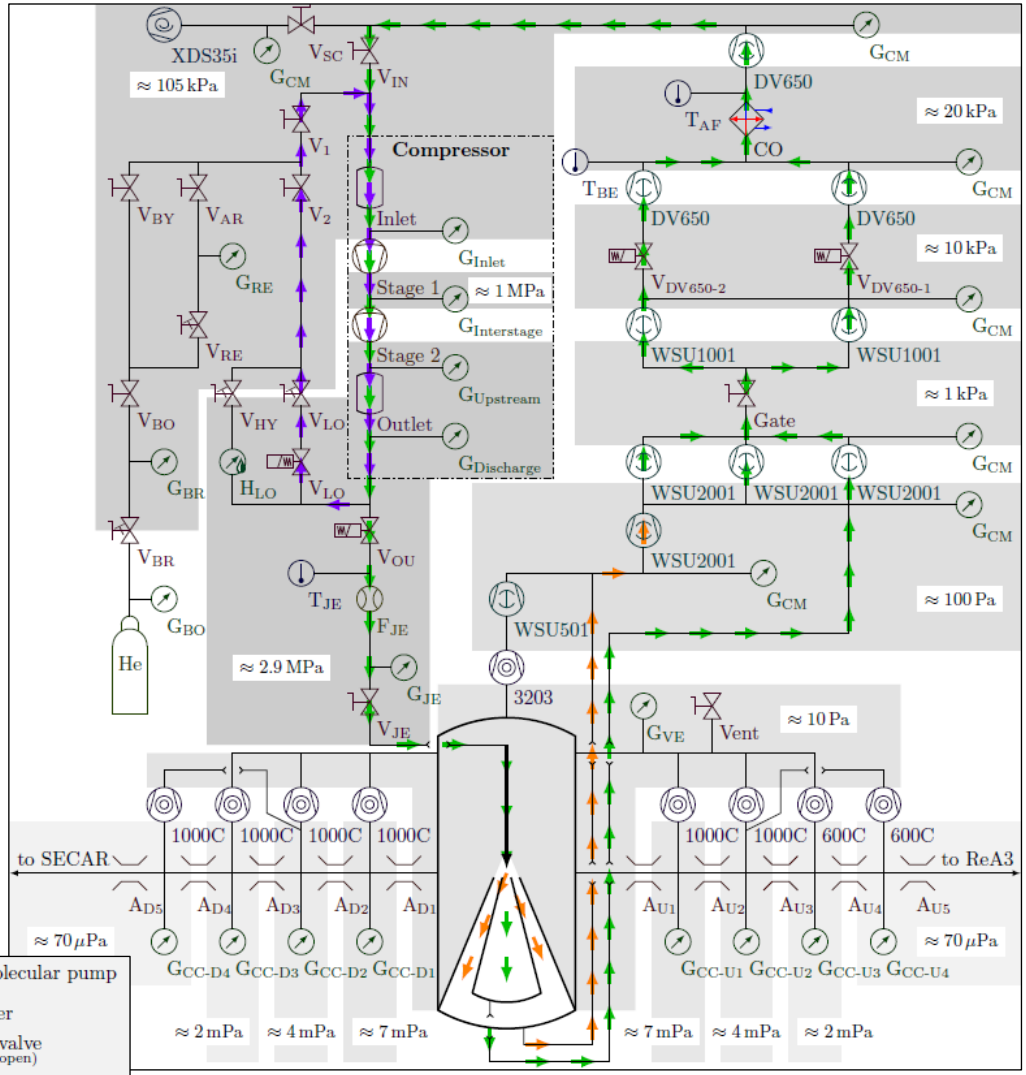
Backup slides

Schematic of the JENSA system

Major gas flow

Needle valve controls the amount of gas directly lead back to the compressor

<10% of the gas is caught by the outer receiver

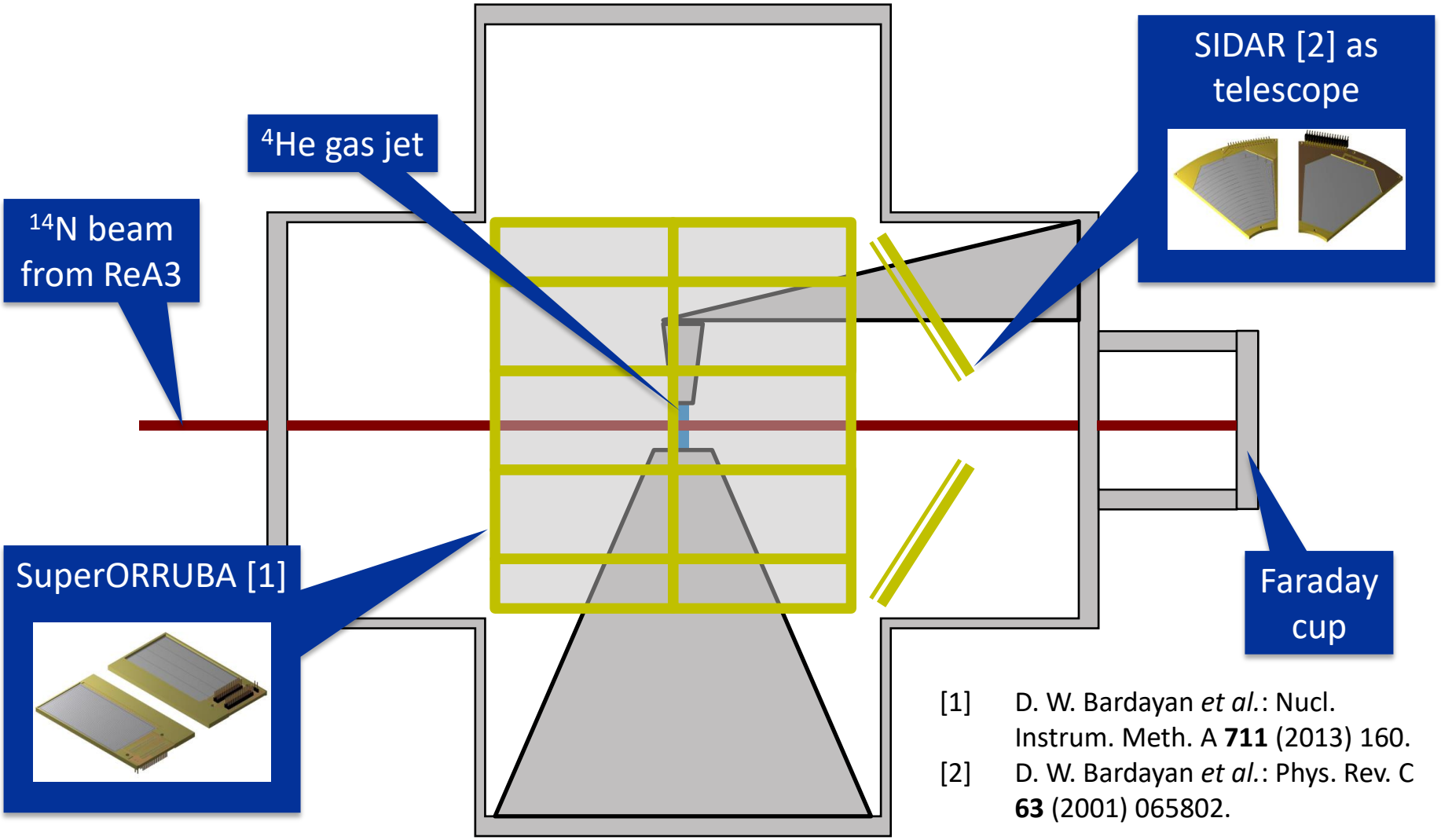


scroll pump · roots blower · diaphragm compressor · turbo molecular pump
pressure gauge · hygrometer · thermometer · flow meter
manual valve · metering valve · solenoid valve (normally closed) · solenoid valve (normally open)
vessel · water cooler · high-pressure He cylinder · nozzle and receiver

Commissioning experiment at NSCL

$^{4}He(^{14}N,p)^{17}O$

Setup for $^{4}He(^{14}N,p)^{17}O$ study

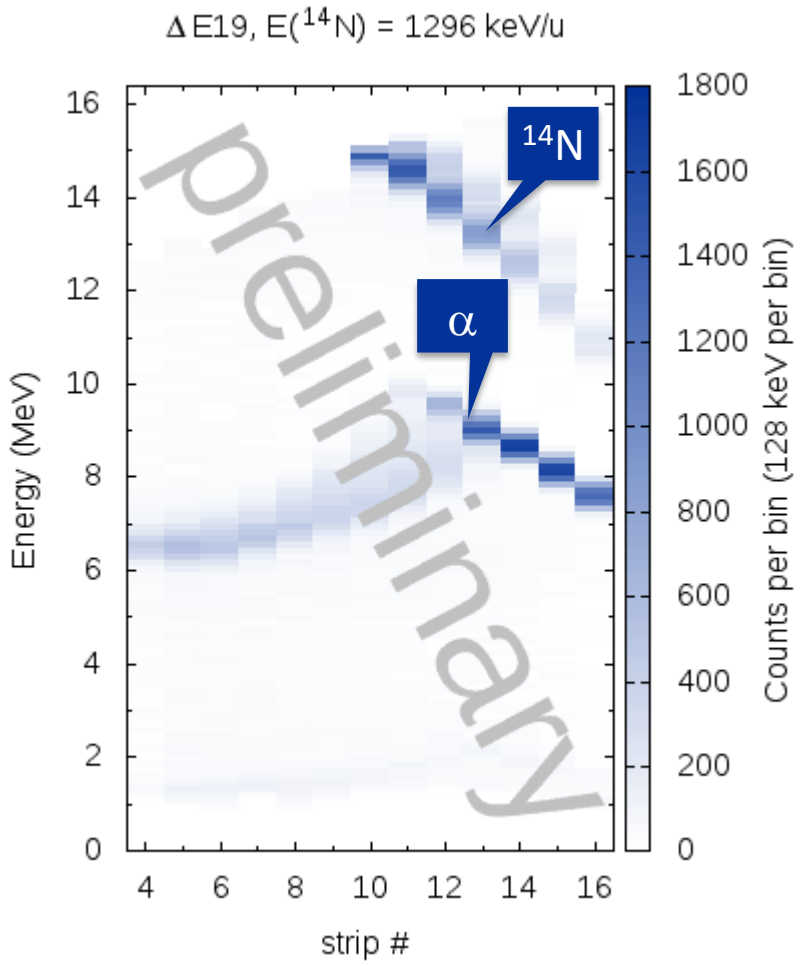


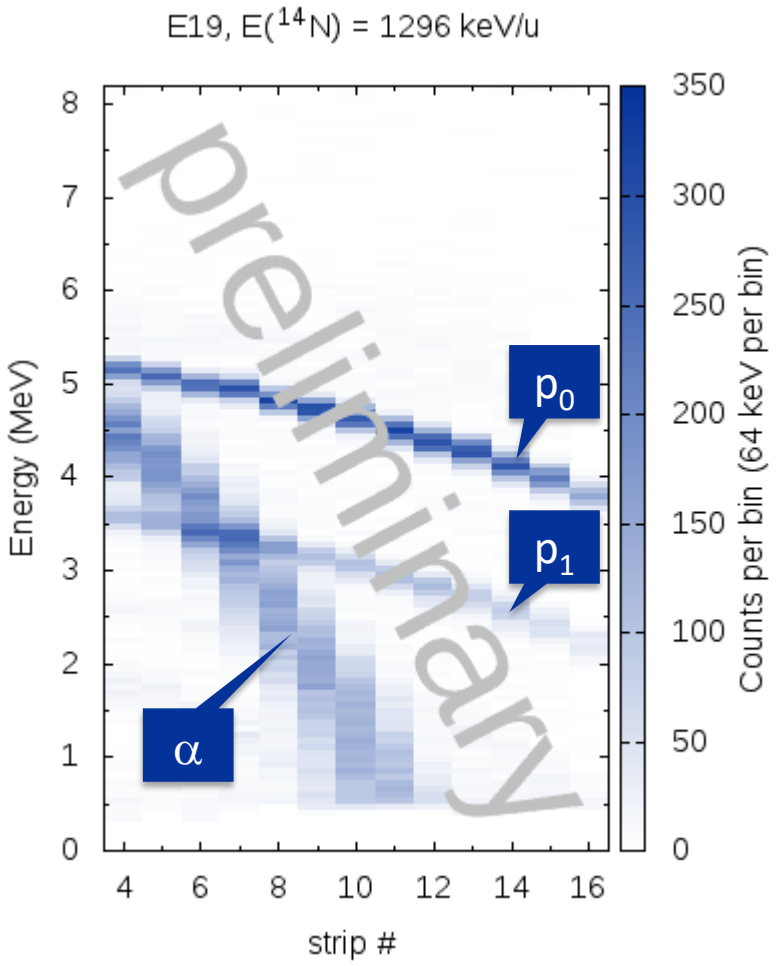
[1] D. W. Bardayan *et al.*: Nucl. Instrum. Meth. A **711** (2013) 160.

[2] D. W. Bardayan *et al.*: Phys. Rev. C **63** (2001) 065802.

$^{4}He(^{14}N,p)^{17}O$ – preliminary results

Segmented Si detector telescope

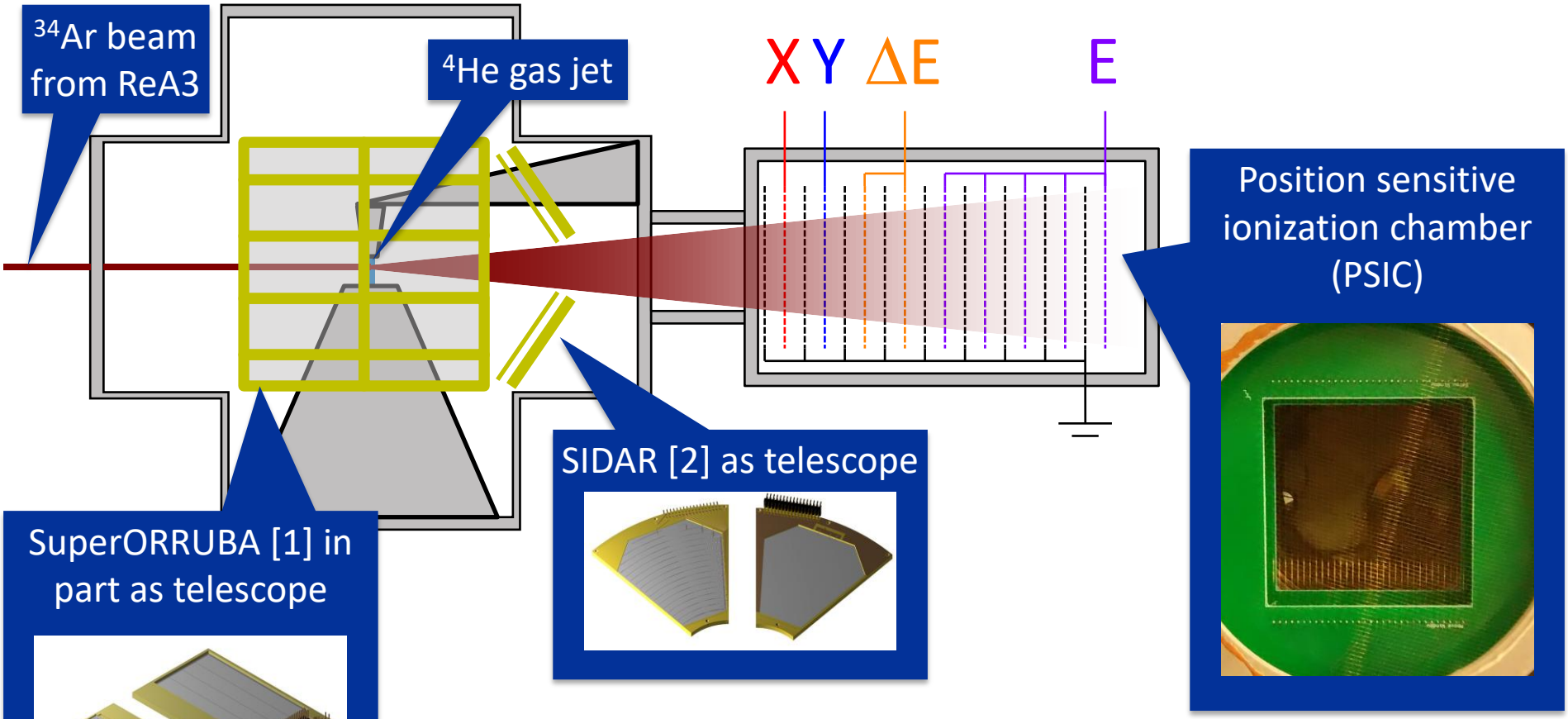




First radioactive beam experiment

$^{4}He(^{34}Ar,p)^{37}K$

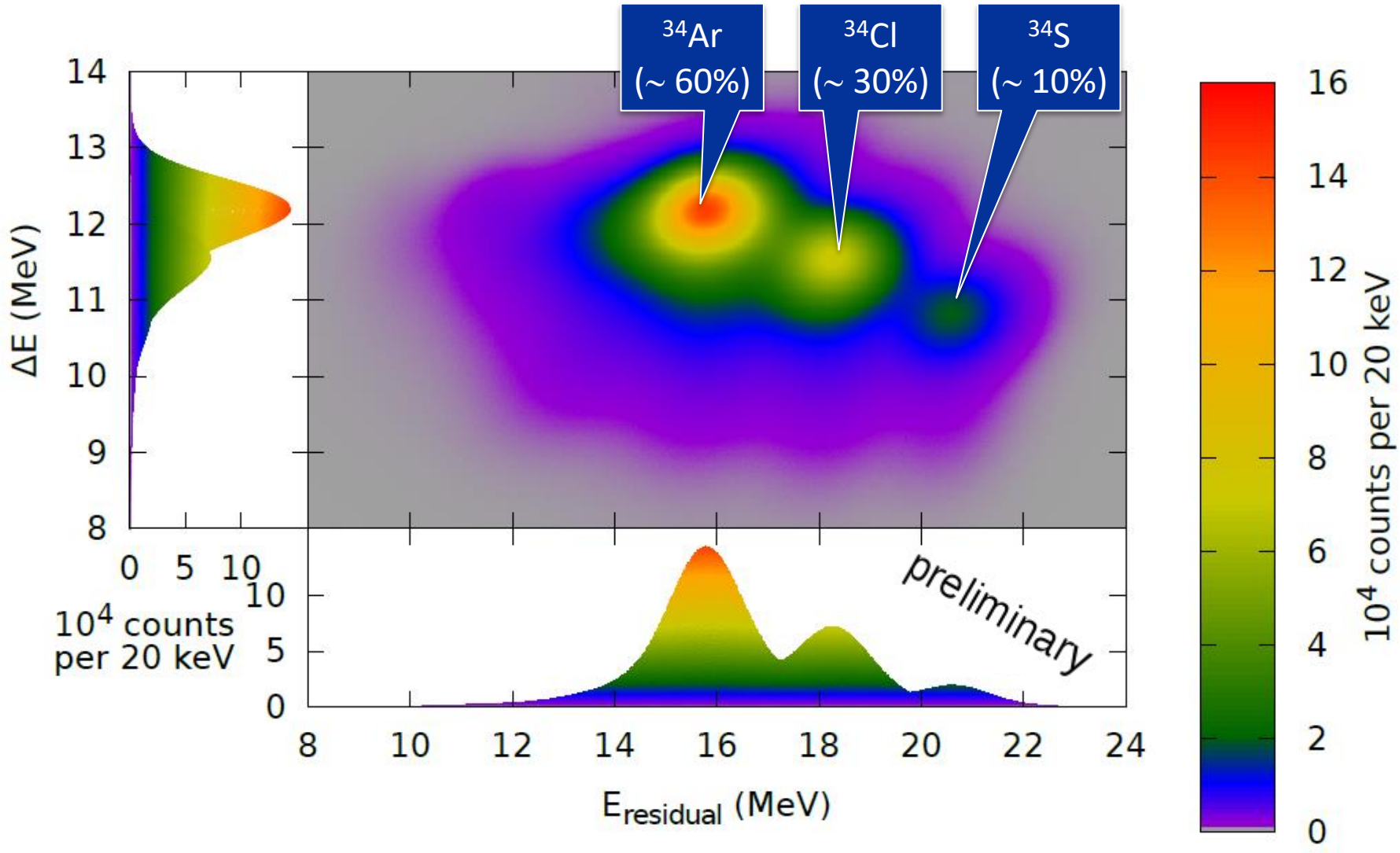
Setup for $^{4}He(^{34}Ar,p)^{37}K$ study



[1] D. W. Bardayan *et al.*: Nucl. Instrum. Meth. A **711**, 160 (2013).

[2] D. W. Bardayan *et al.*: Phys. Rev. C **63**, 065802 (2001).

~3000 pps at 1.625 MeV/u for 108 hours



Proton signals in Si detectors