Tests of a polarimeter for laser-driven proton beams at the 45-MeV cyclotron JULIC

JuSPARC (Jülich Short-Pulsed Particle and Radiation Center)

M. Büscher, I. Engin, P. Fedorets, C. Zheng, N. Schnitzler, H. Pfeifer, C. Schneider
R. Engels, O. Felden, C. Kannis, A. Lehrach
H. Glückler, H. Soltner, M. Lennartz, R. Swaczyna, H. Feilbach

29. 09. 2022 I Chuan Zheng

2022 Workshop on Polarized Sources, Targets, and Polarimetry

Mitglied der Helmholtz-Gemeinschaft

JuSPARC

ATHENA
The Helmholtz-Project for Laser-Plasma-Acceleration

GSI

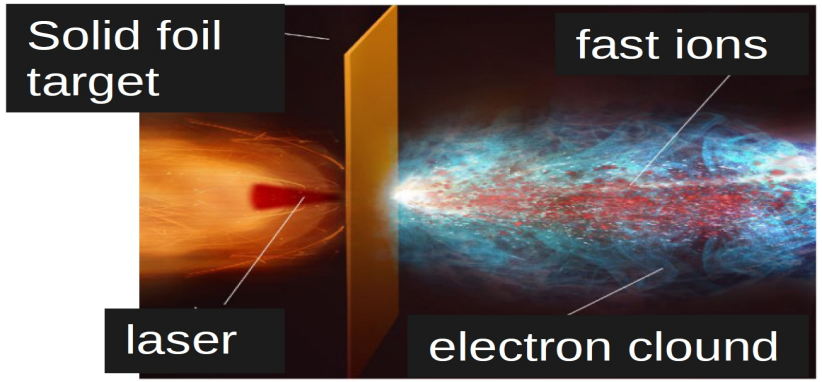
EMMI

JÜLICH
Forschungszentrum

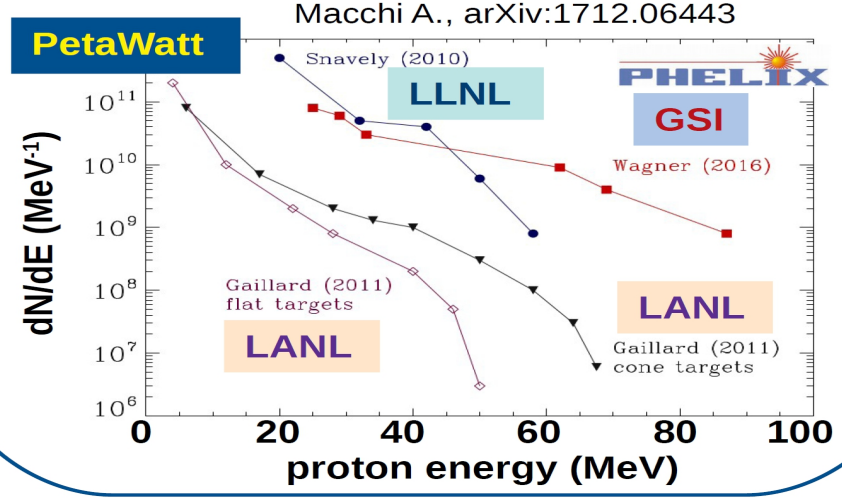
MOTIVATION

laser-driven polarized particle beams

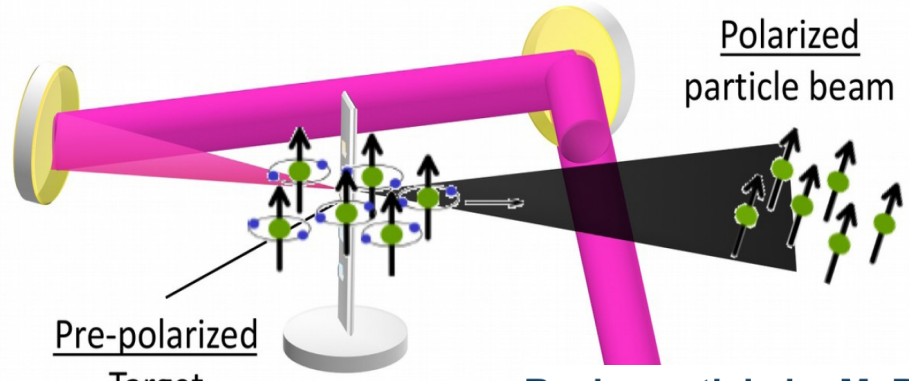
TNSA mechanism



Macchi A., arXiv:1712.06443



Exp. realization of pre-polarized target



JÜLICH Forschungszentrum

Review article by M. Büscher et al.
High Power Laser Sci. & Eng. 8(2020)e36
doi:10.1017/hpl.2020.35

µm-sized plasma

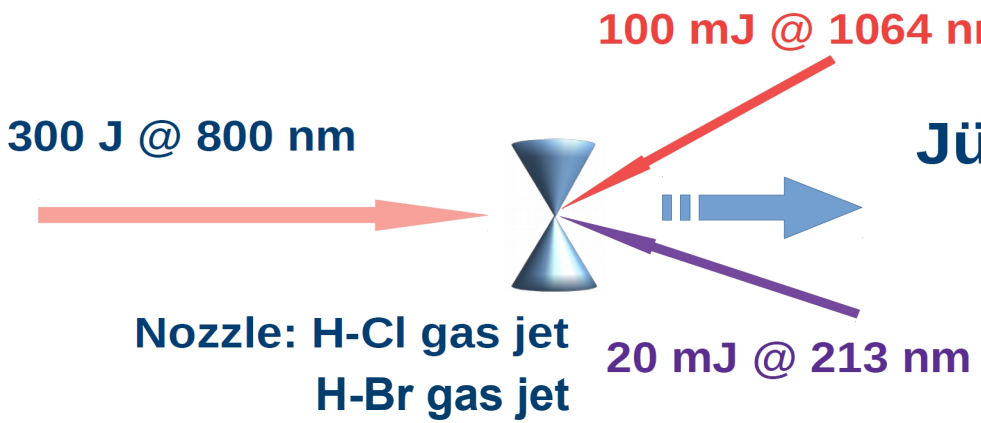
Intense Laser pulse

PHELIX

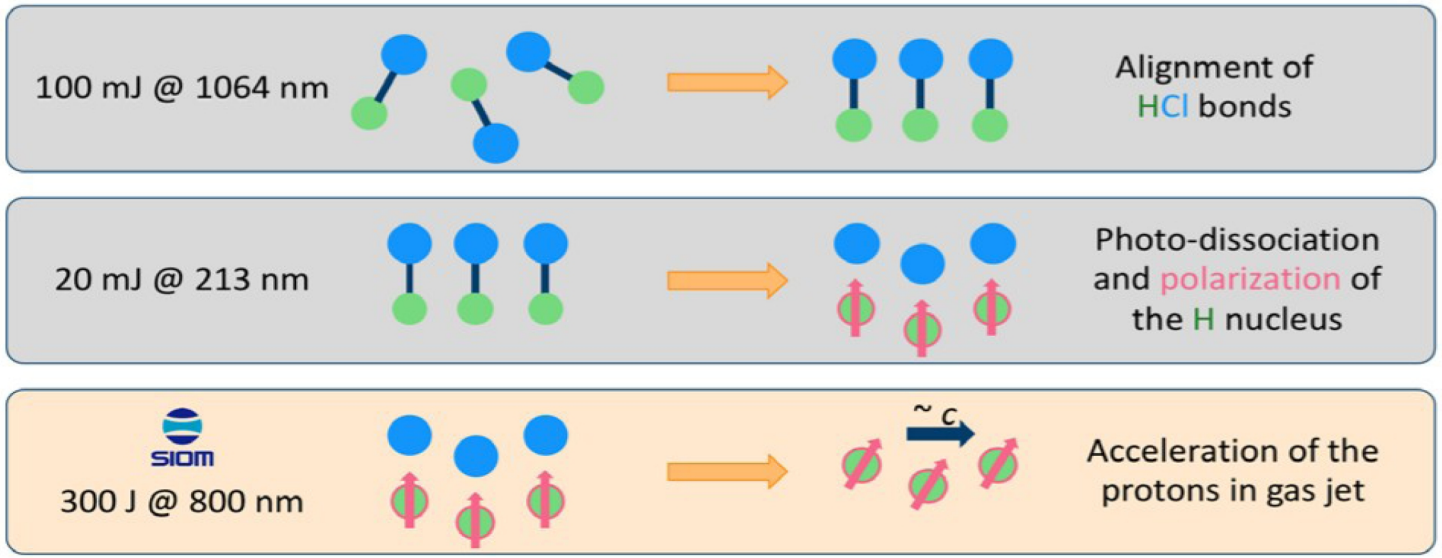
SIOM

MOTIVATION

laser-driven polarized proton beams



Jülich Polarized Hydrogen Target



Hützen et al. High Power Laser Sci. and Eng. **7**(2019)e16

Molecular polarization:
Talk by Chrysovalantis Kannis
this afternoon 14:00

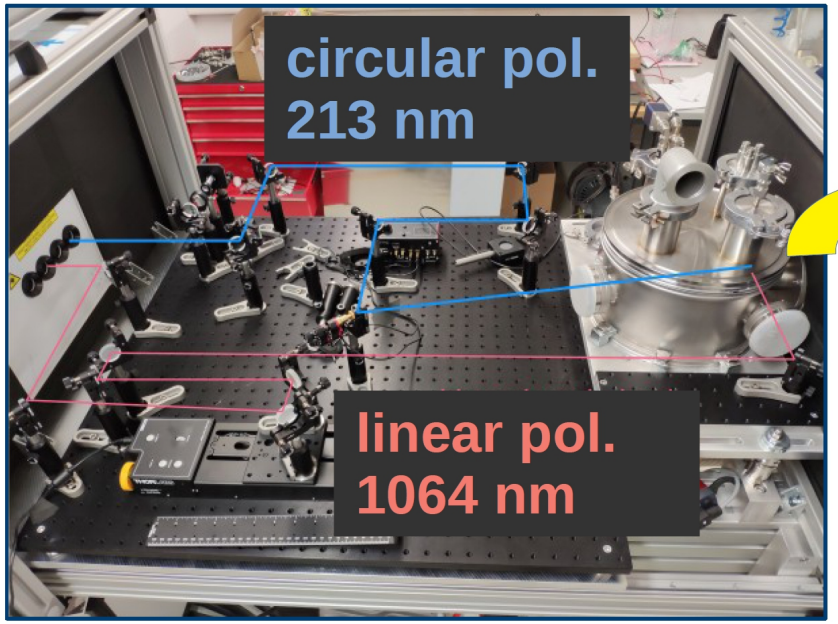
Average pol. of protons can reach

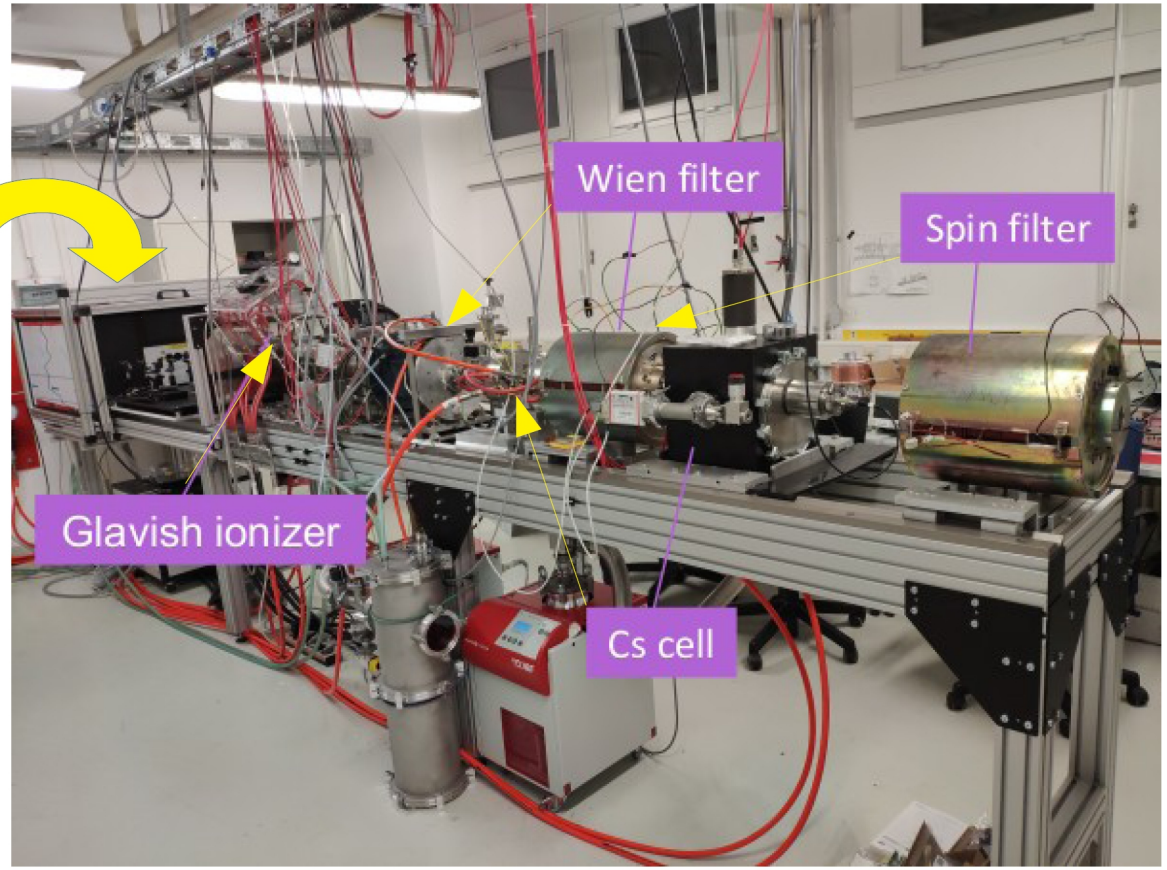
72%. T. P. Rakitzis *et al.* *Science* **300**, 1936 (2003); DOI: 10.1126/science.1084809

Spiliotis et al. *Light: Science & Applications* (2021)10:35 https://doi.org/10.1038/s41377-021-00476-y

MOTIVATION

Polarized hydrogen gas target

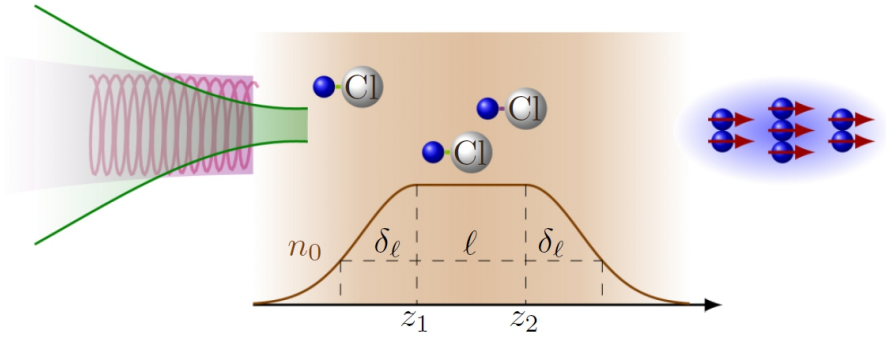




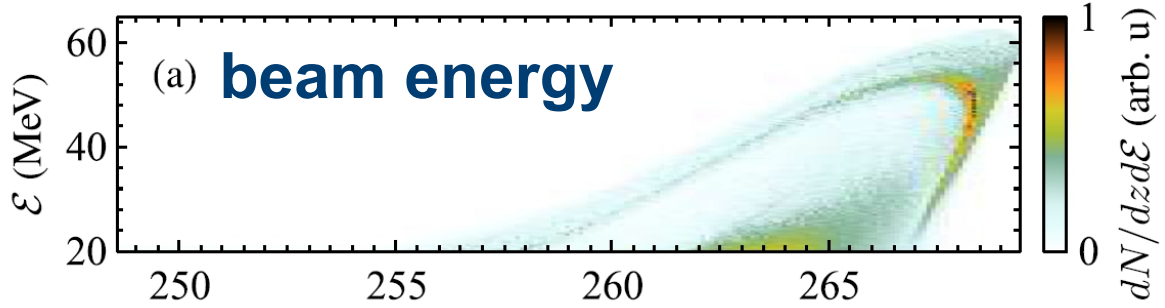
Test with Lamb-Shift Polarimeter @ IKP

POLARIMETRY R&D

Polarimeter for laser-driven proton beams



l = 200λ, δ_l = 5λ, λ ~ 800 nm

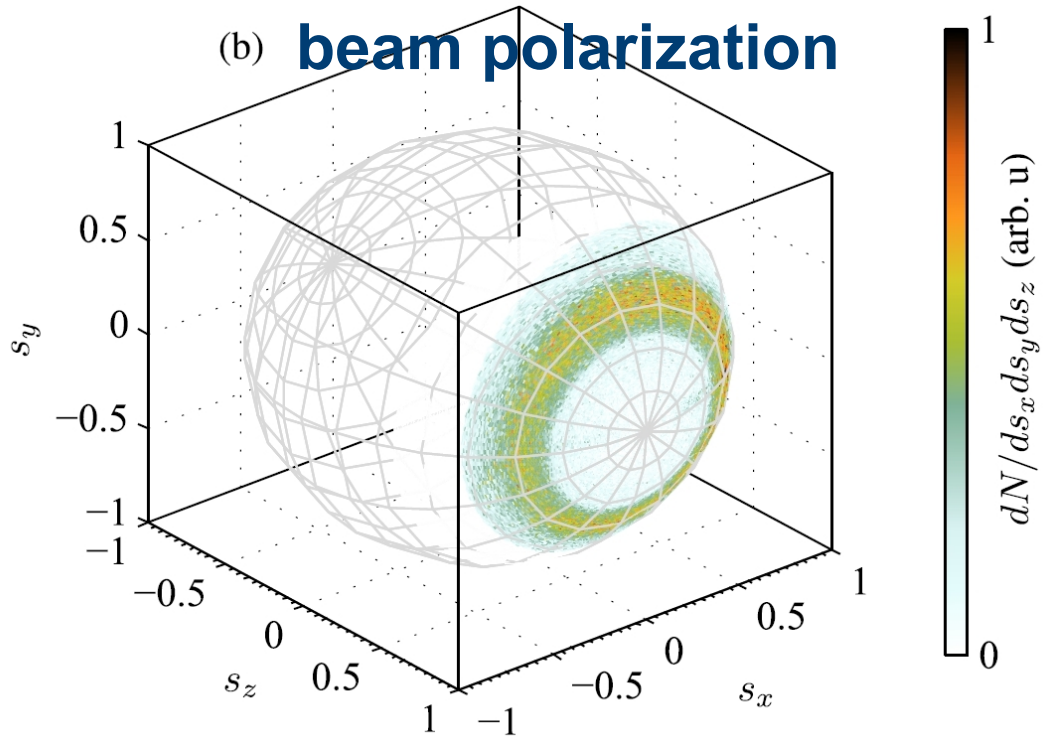


at t = 330λ/c ~ 1x10^{-12} s

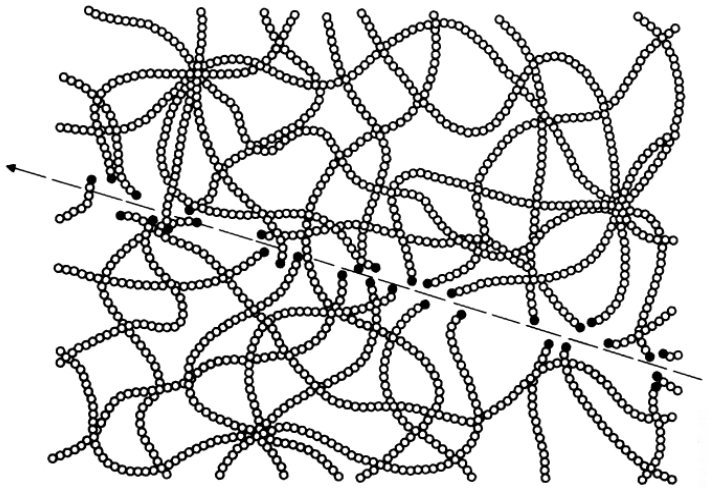
P_L is the laser power, $\mathcal{E}_p$ is the peak proton energy, Q is the total charge, P is the beam polarization. **assuming start from P=100%**

P_L [PW]	$\mathcal{E}_p$ [MeV]	Q [nC]	P [%]
1.34	53	0.26	82
5.37	105	1.3	65
12.1	133	2.4	57
21.5	152	3.1	56

Luling Jin et al. PRE 102 (2020) 011201(R)
J. Thomas et al. Phys. Rev. Accel. Beams 23 (2020) 064401

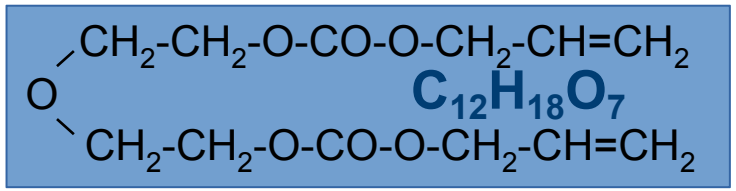


POLARIMETRY R&D Solid-State Nuclear Track Detectors(SSNTDs)

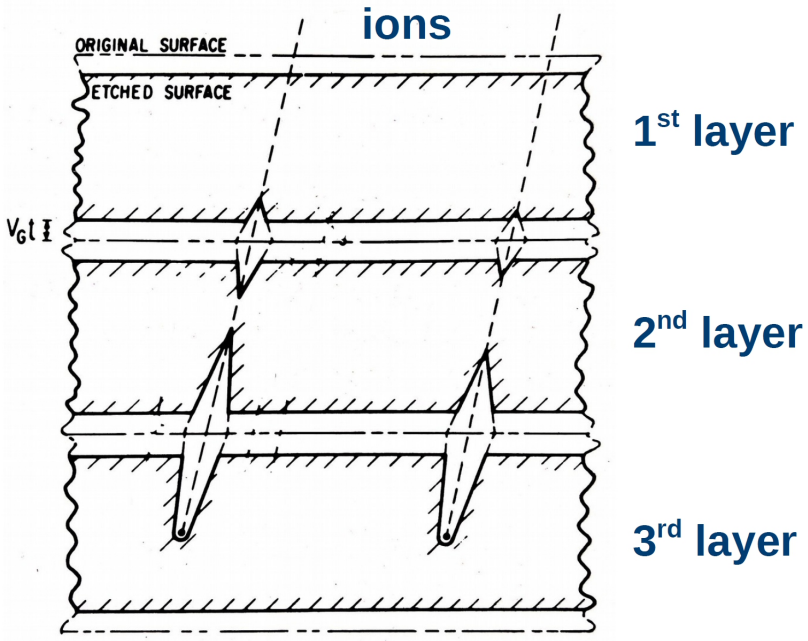


After etching with NaOH

Polyallyldiglycolcarbonat (PADC)



CR-39 track formation threshold ~5 keV/μm (water) or ~10 MeV for protons



proton burst during < 10^{-12} s

a burst of ~10^{10} protons

SSNTDs have no dead time

high detection efficiency

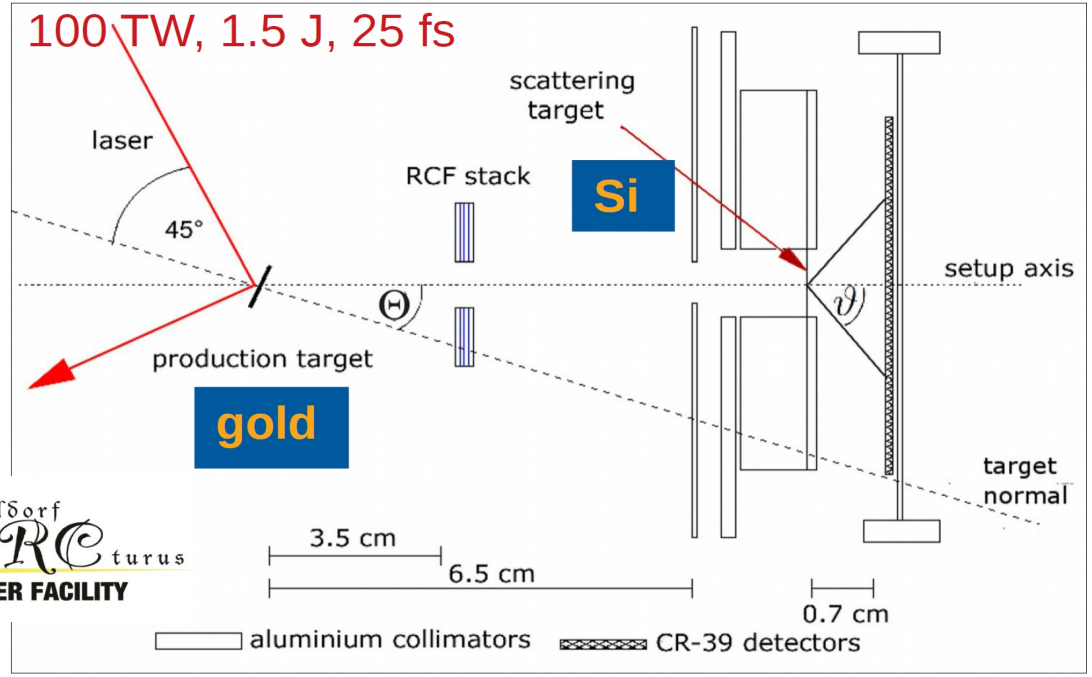
good spatial resolution

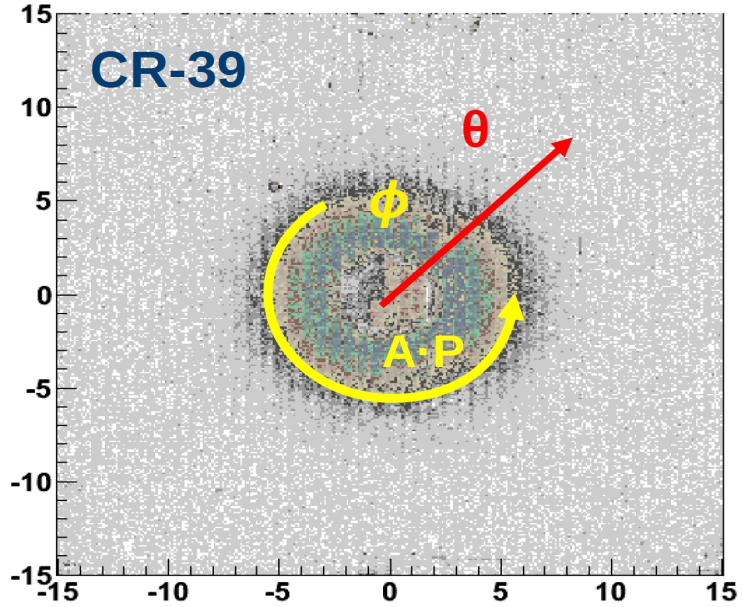
insensitive to X-rays, *γ*-rays

P. B. Price & R. L. Fleischer, Annu. Rev. Nucl. Sci. 21 (1971) 295-334

POLARIMETRY R&D

First polarimeter for laser-driven protons



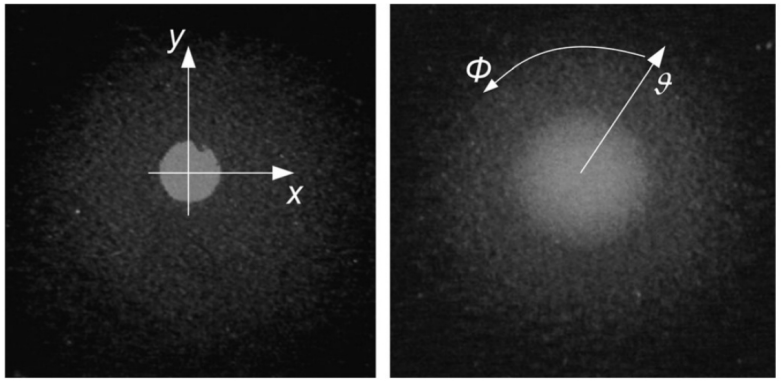


$$\frac{d\sigma}{d\Omega}(\theta,\phi)=\left(\frac{d\sigma}{d\Omega}\right)_0(\theta)[1+A\cdot P\cos\phi]$$

~ 3 MeV protons recorded by CR-39 plate

One shot: 1.3x10^8 protons

P = 0.08 ± 0.03(stat.) ± 0.08(syst.) No polarization!

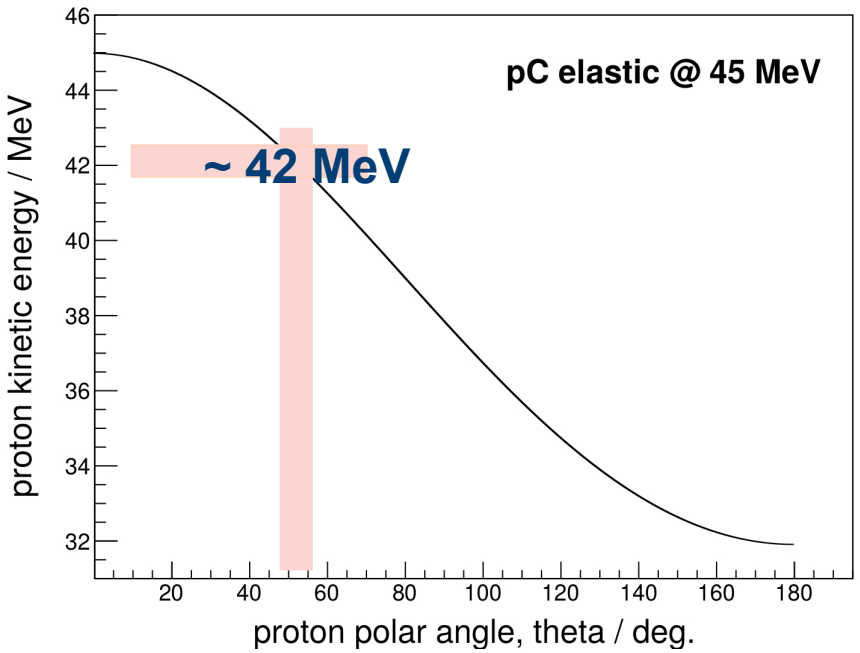


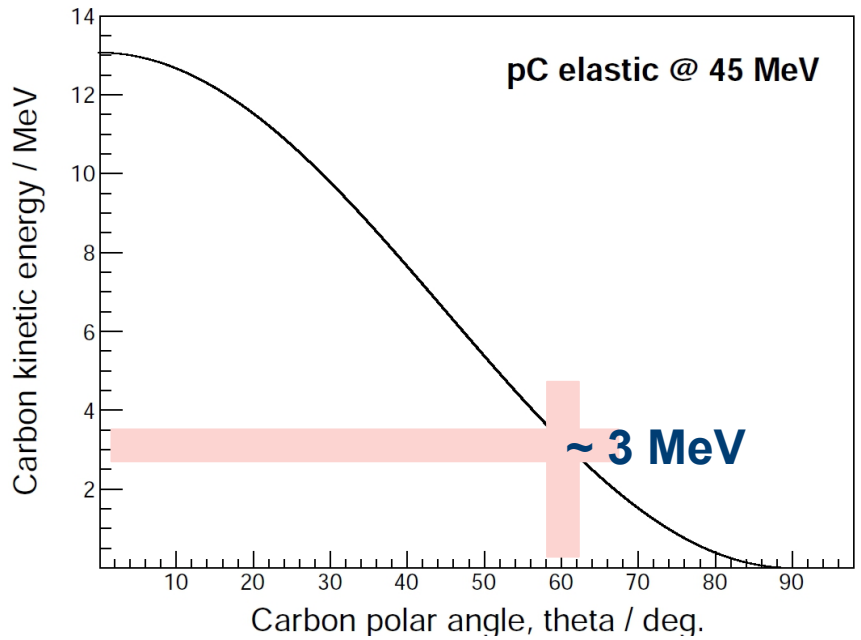
w/o Si with Si

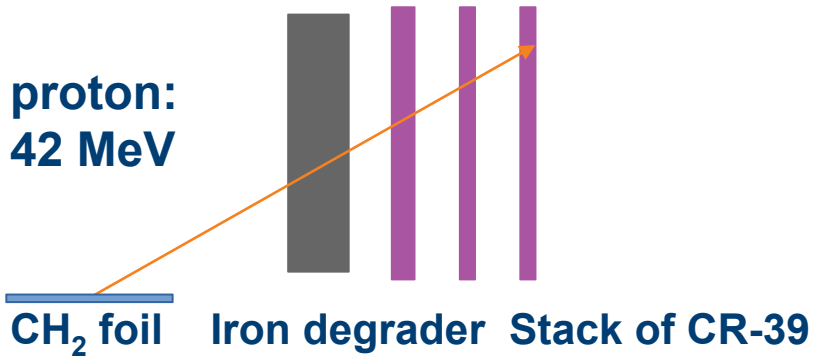
Raab et al. Phys. Plasmas **21**(2014)023104

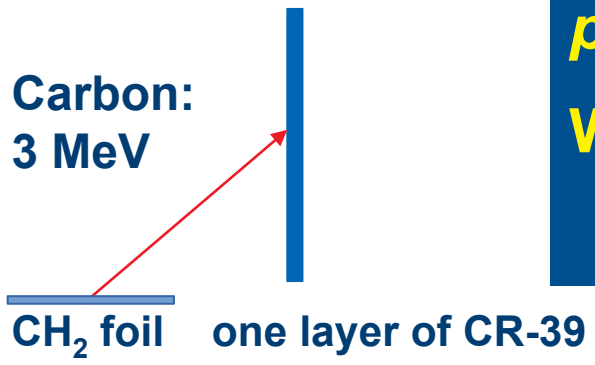
POLARIMETRY R&D

Polarimeter for 45-MeV proton beams









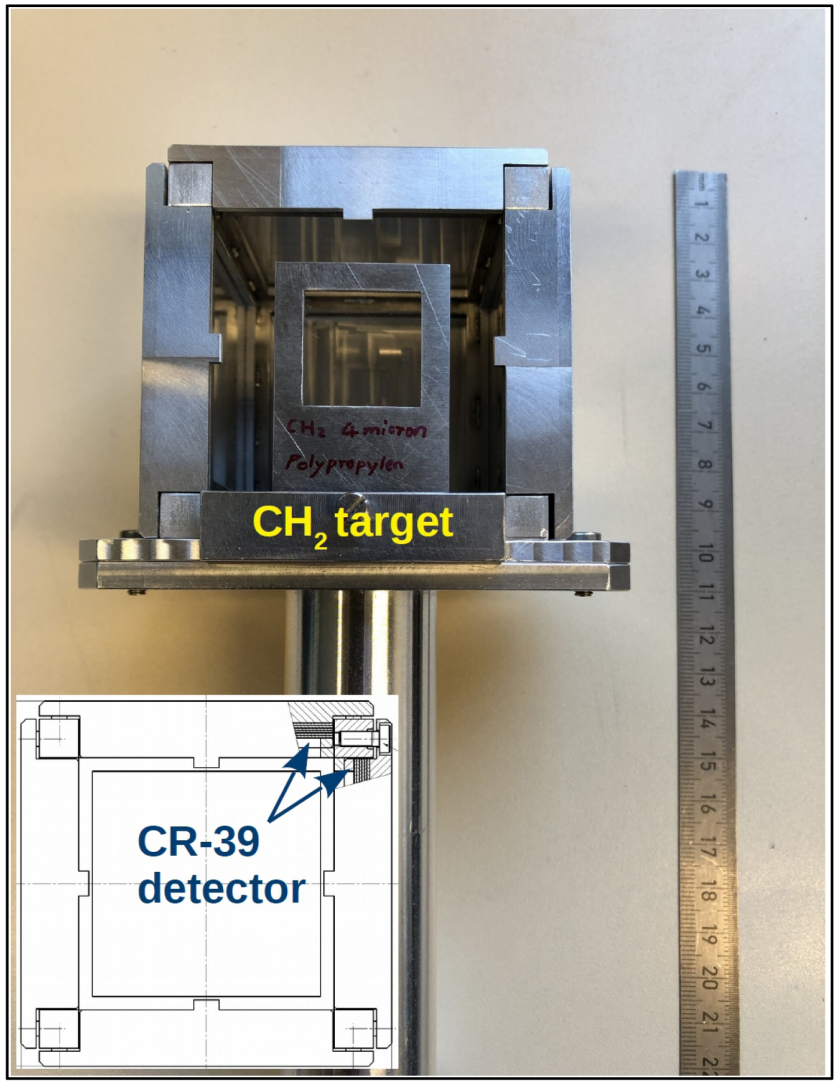
***p*-C: A_N ~ 0.86 (max.)**

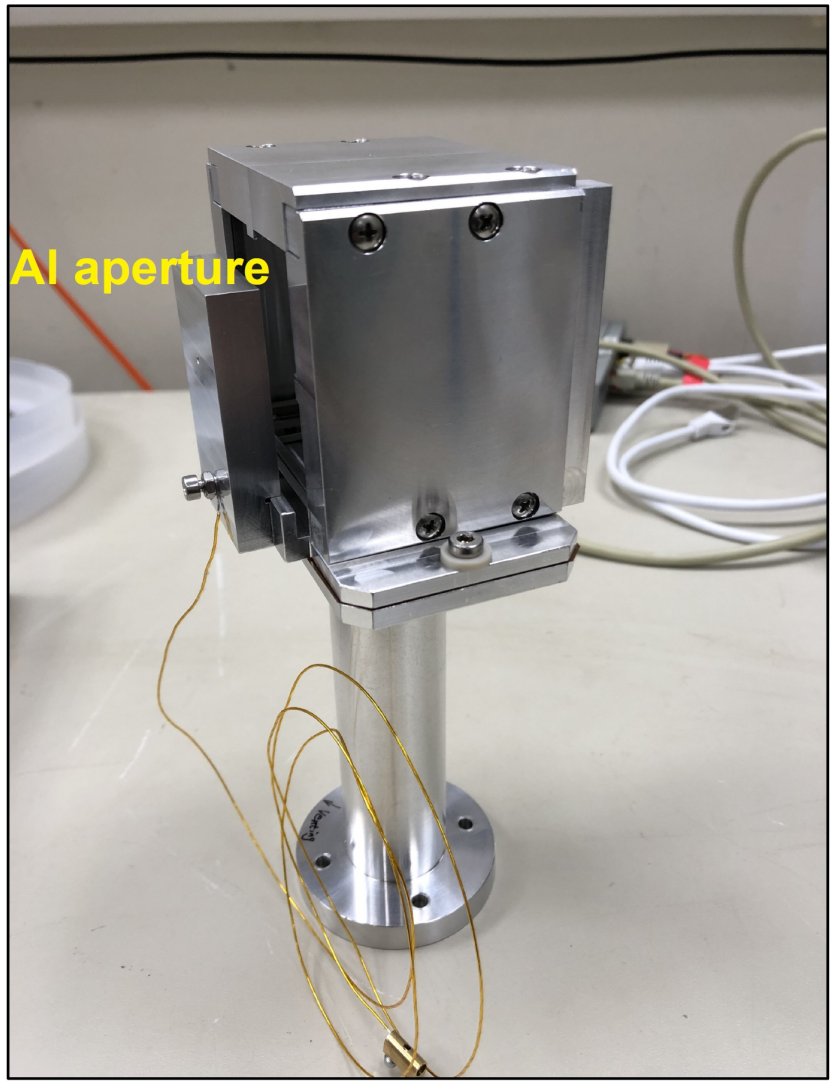
When $\theta_p \approx 52.5^\circ$

$\theta_C \approx 61.8^\circ$

POLARIMETRY R&D

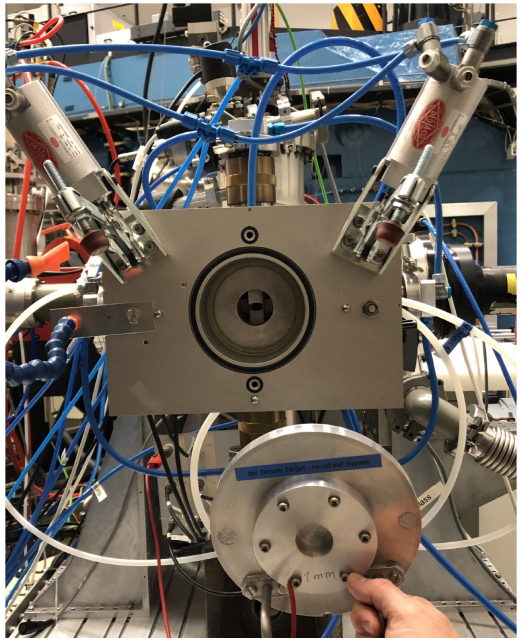
Polarimeter for 45-MeV proton beams





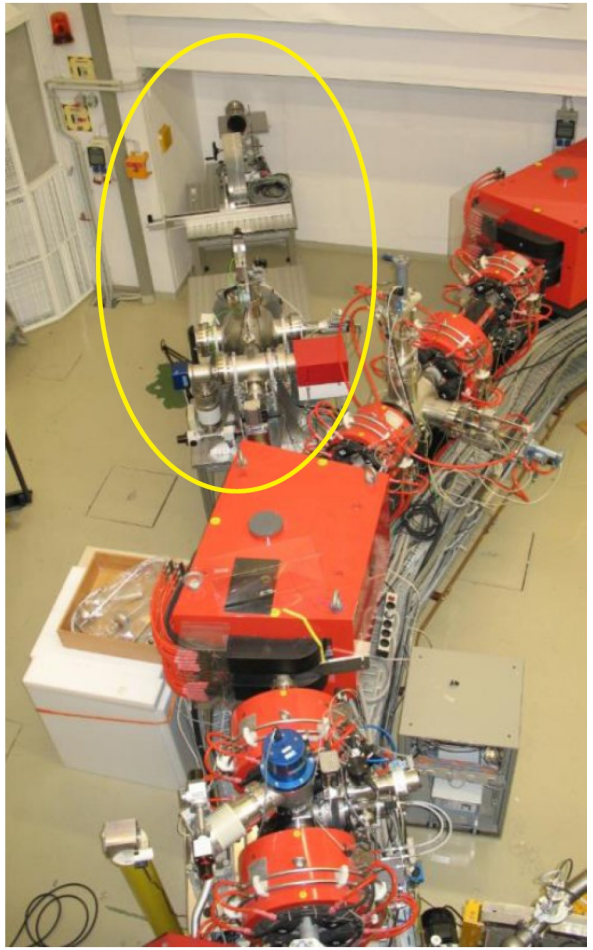
POLARIMETRY R&D

Polarimeter installed at the Irrad station

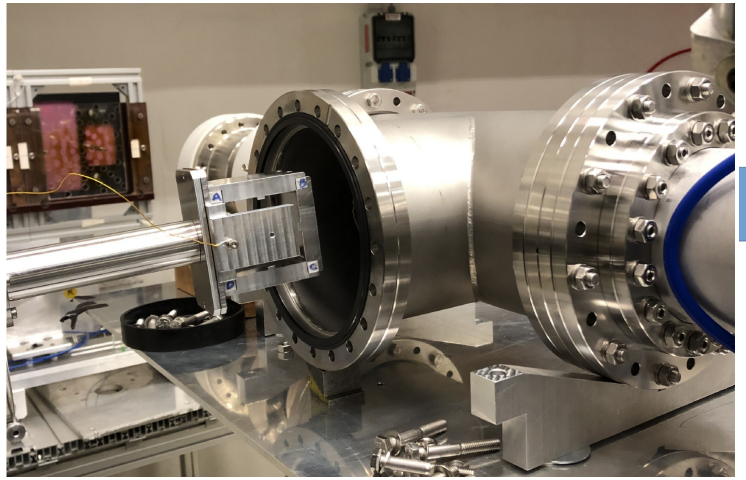


Front view of Irrad station

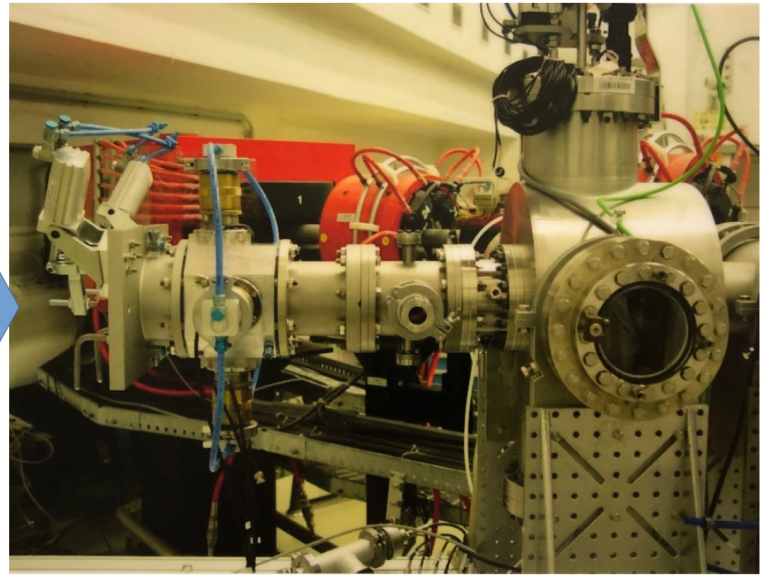
Top view



Polarimeter

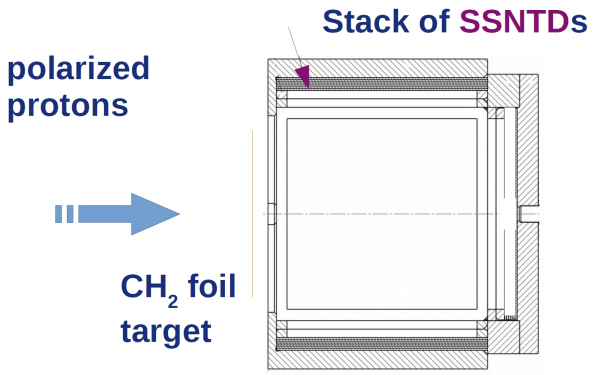


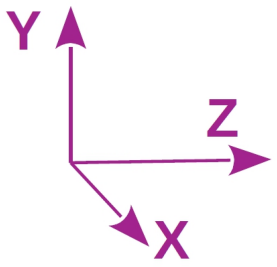
Side view



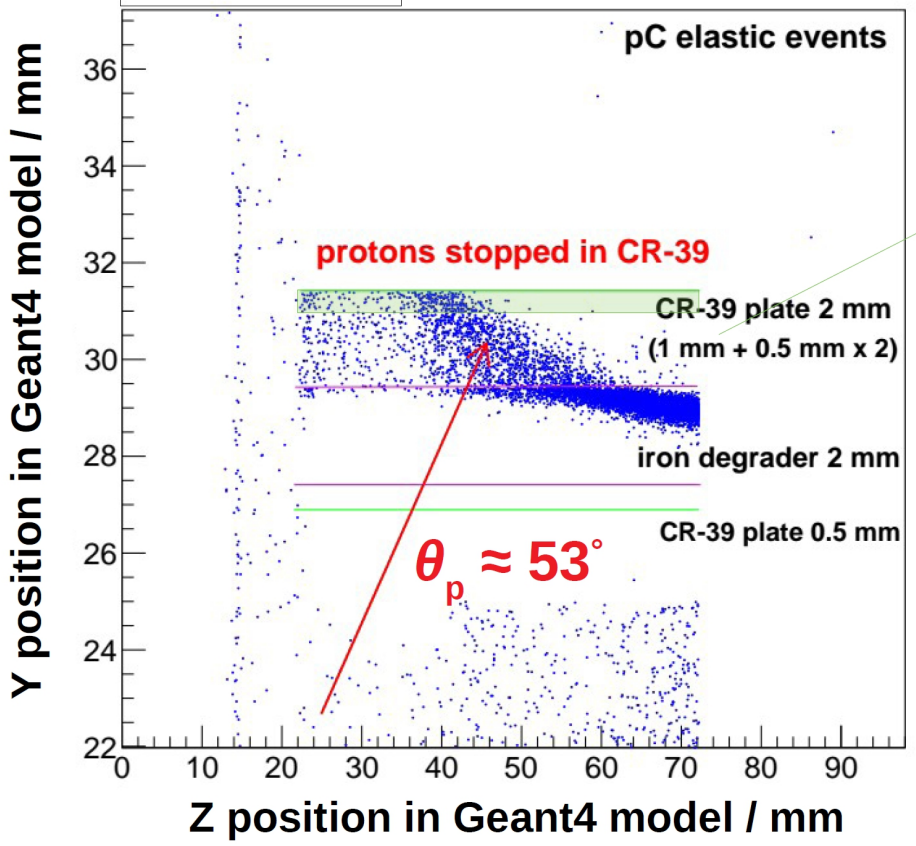
POLARIMETRY R&D

Polarimeter for 45-MeV proton beams

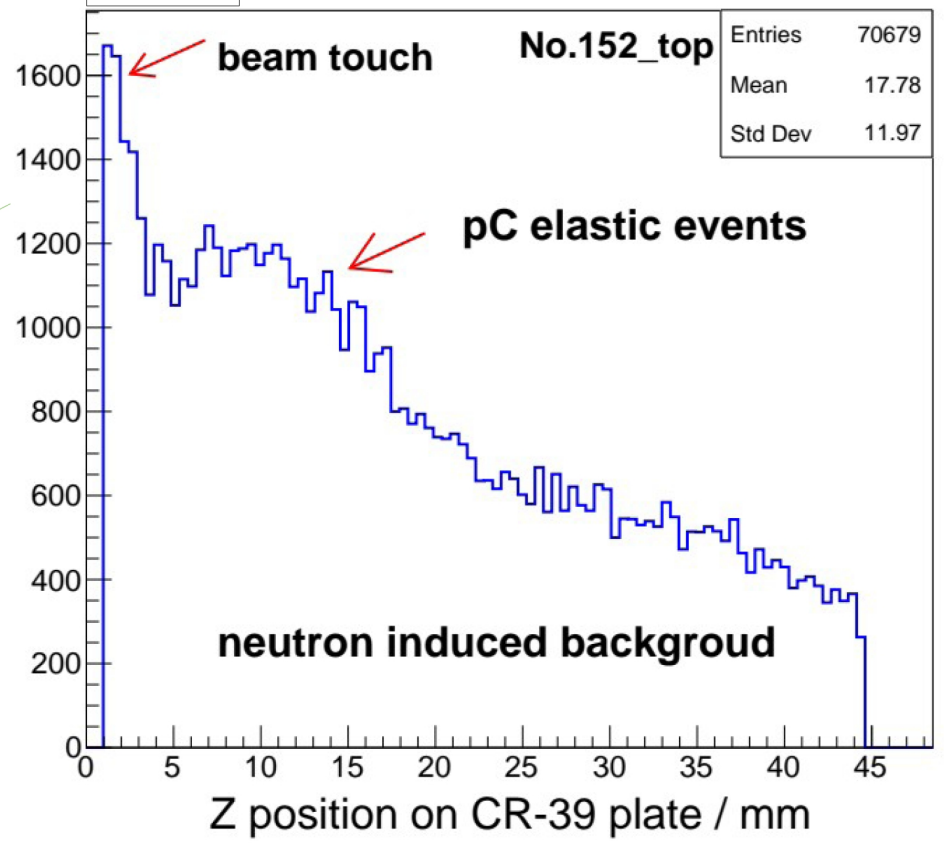




simulation

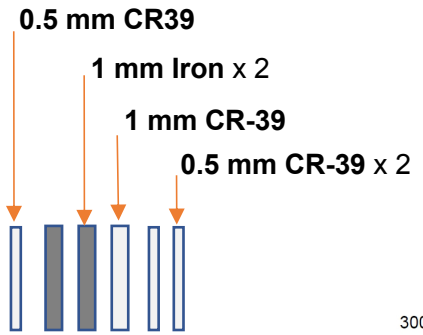


data

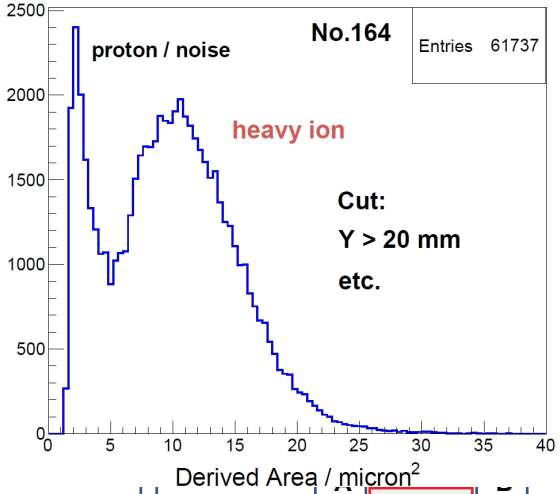


Main background: neutron induced by proton beam on Al aperture

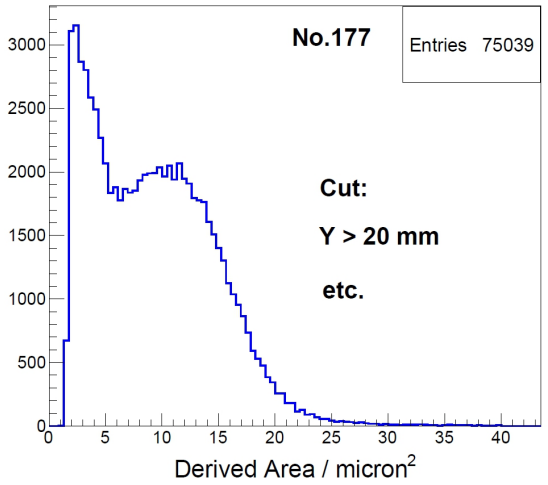
POLARIMETRY R&D Particle identification: proton & carbon ion

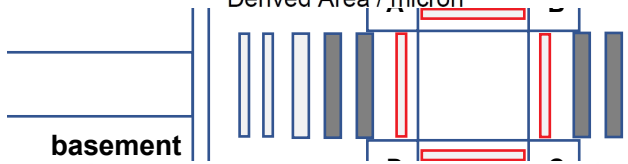


Up

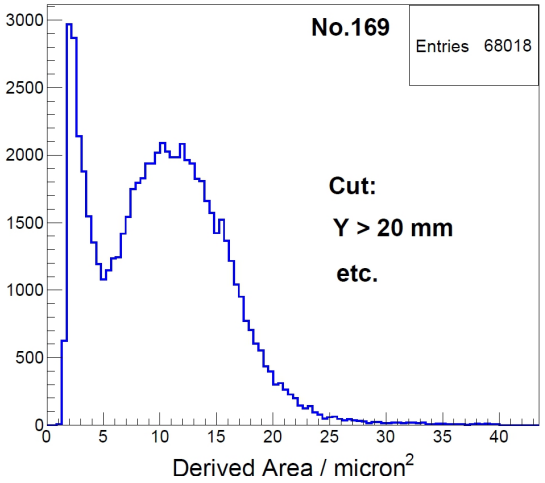


Left

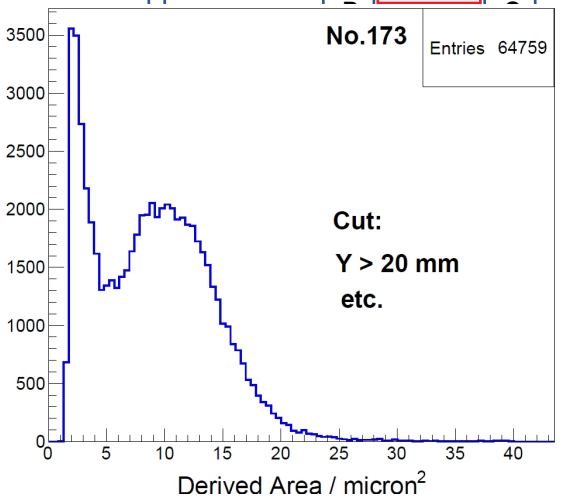




Right

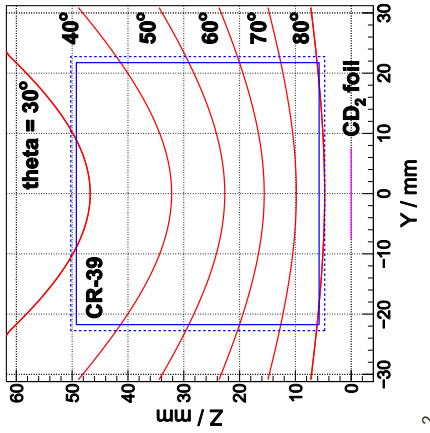


Down



POLARIMETRY R&D

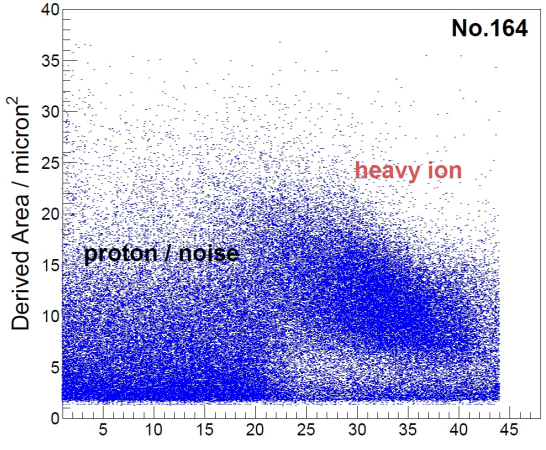
Particle identification: track polar angles



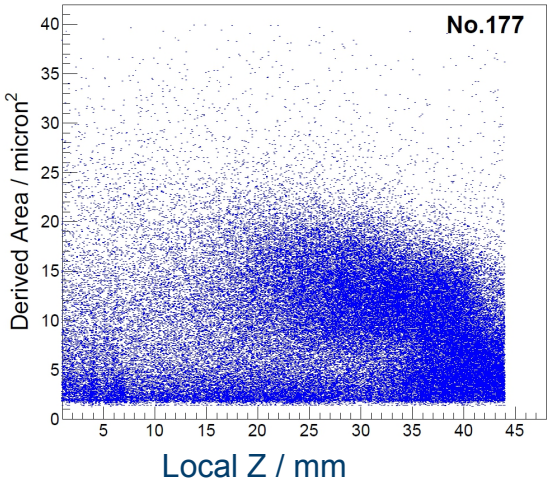
ion track polar angles on CR-39

proton beam

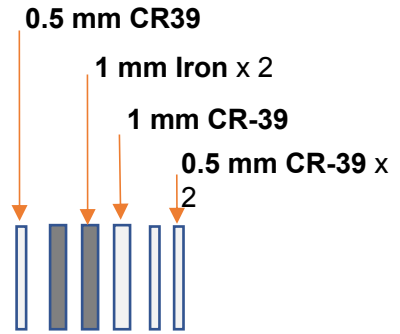
Up

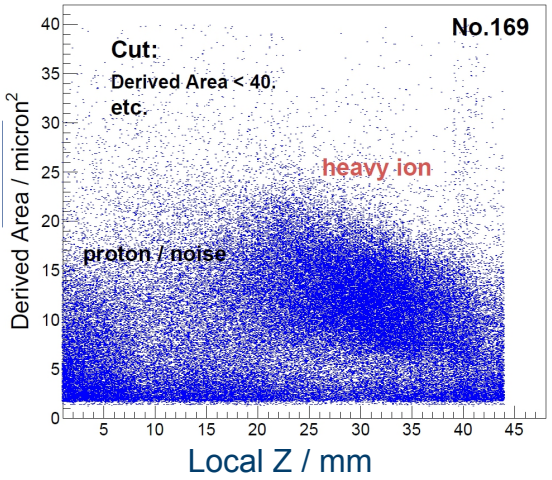


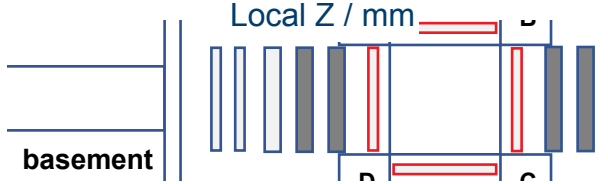
Left



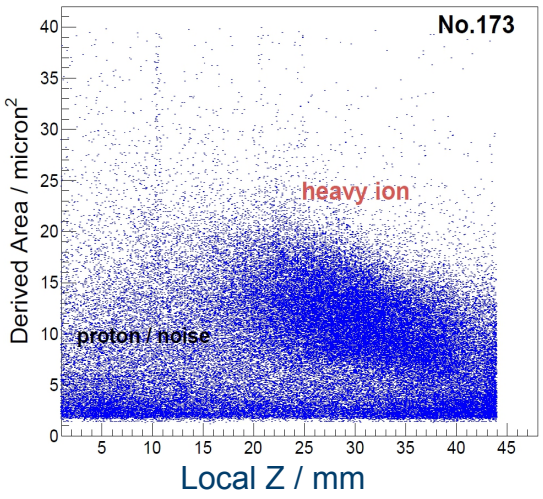
Right





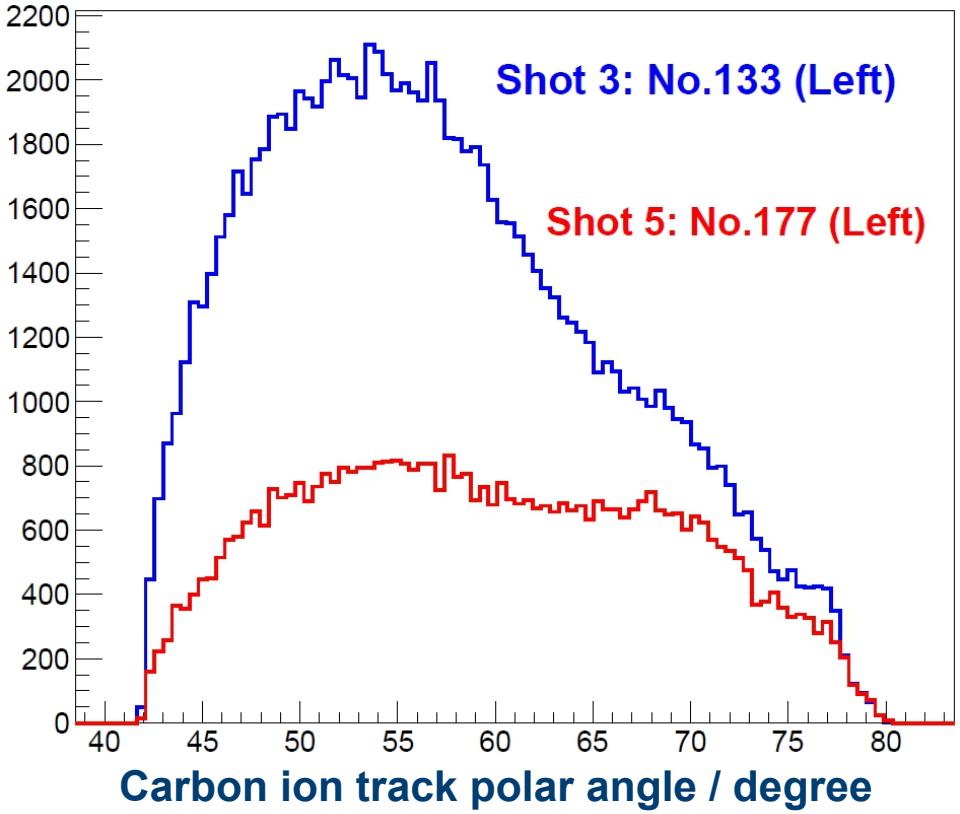


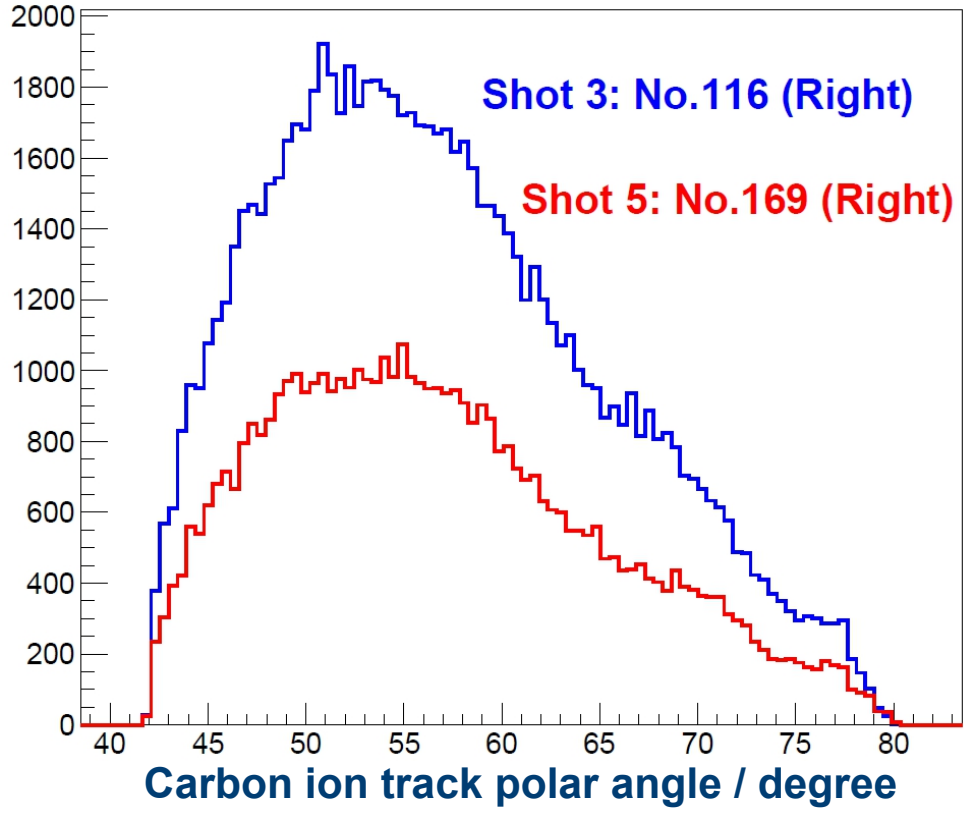
Down



POLARIMETRY R&D Left-right asymmetry: pol. & unpol. runs

Shot No.3 (unpol. beam, 45 MeV, 6 hrs)
Shot No.5 (pol. 60%, 45 MeV, 6 hrs)





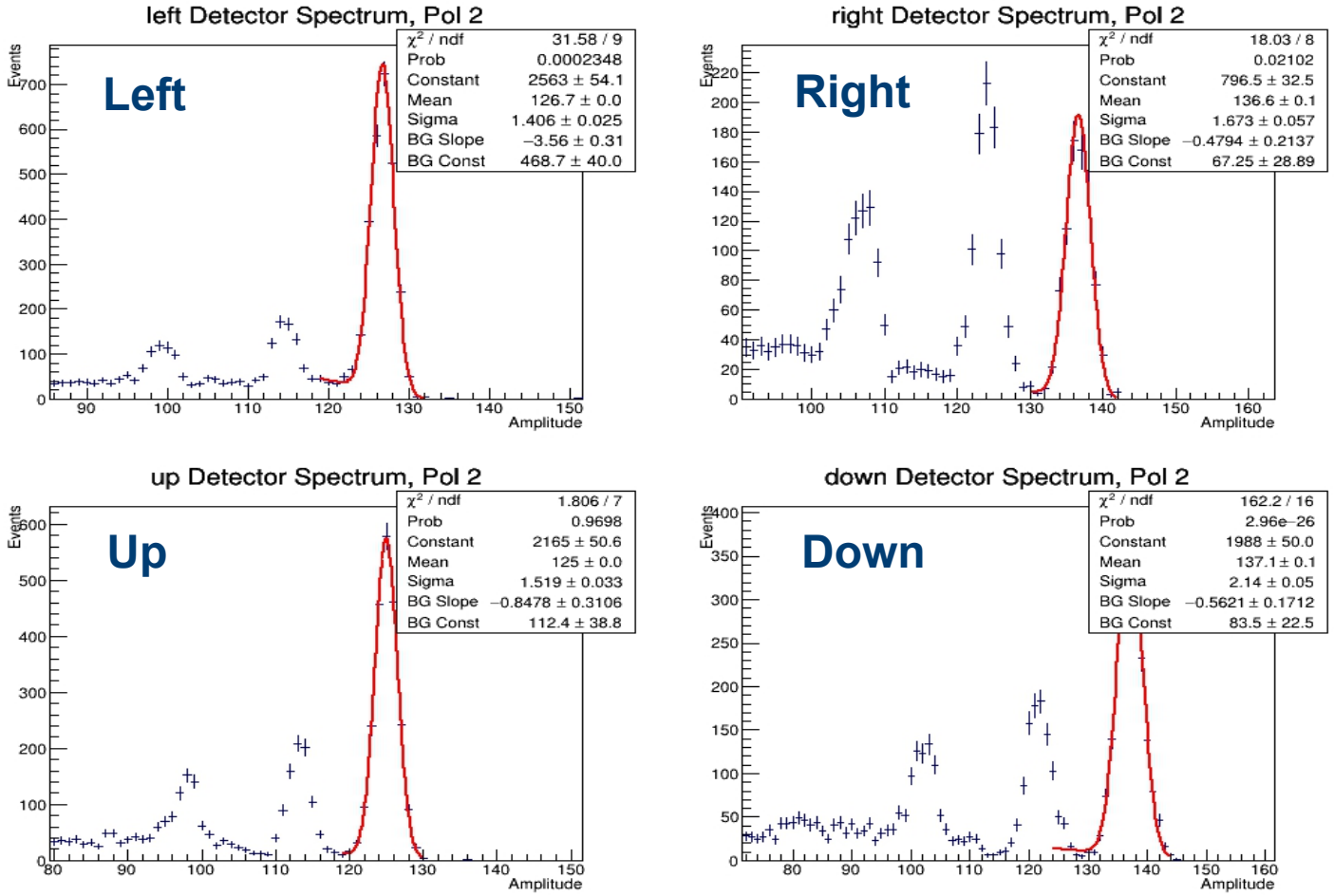
^{12}C: 50 - 55 deg.
=> *p* : 76 - 65 deg.

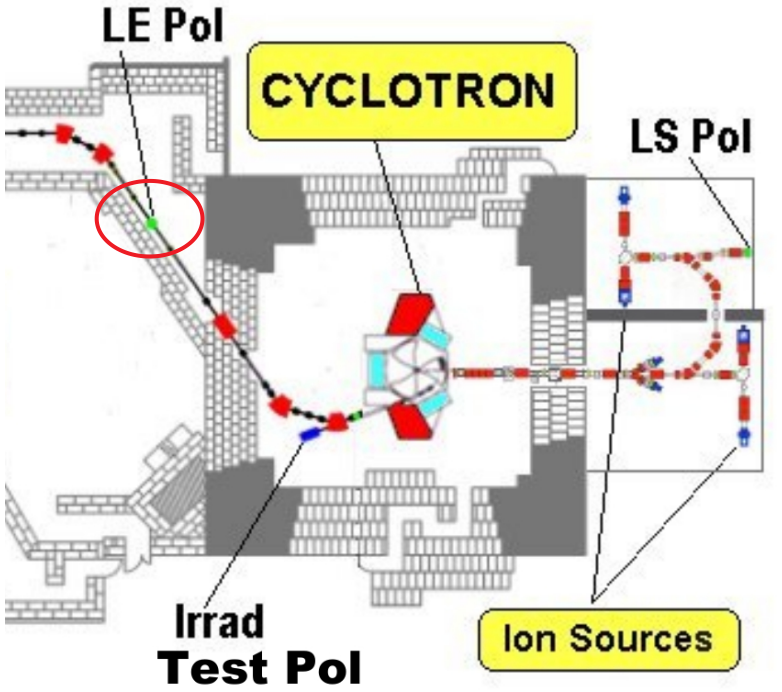
Hor. Asyms.(L-R)
= - 0.17 ± 0.01

Carbon & proton inversed asymm.

POLARIMETRY R&D

Polarimeter LE Pol at JULIC





Polarimetry behind JULIC

O. Felden, Talk at PSTP 2009, September 2009.

Hor. Asymm. (Left - Right) : 0.53 ± 0.02 --> Pol. P_y = (62 ± 2)%

Ver. Asymm. (Up - Down) : 0.04 ± 0.02

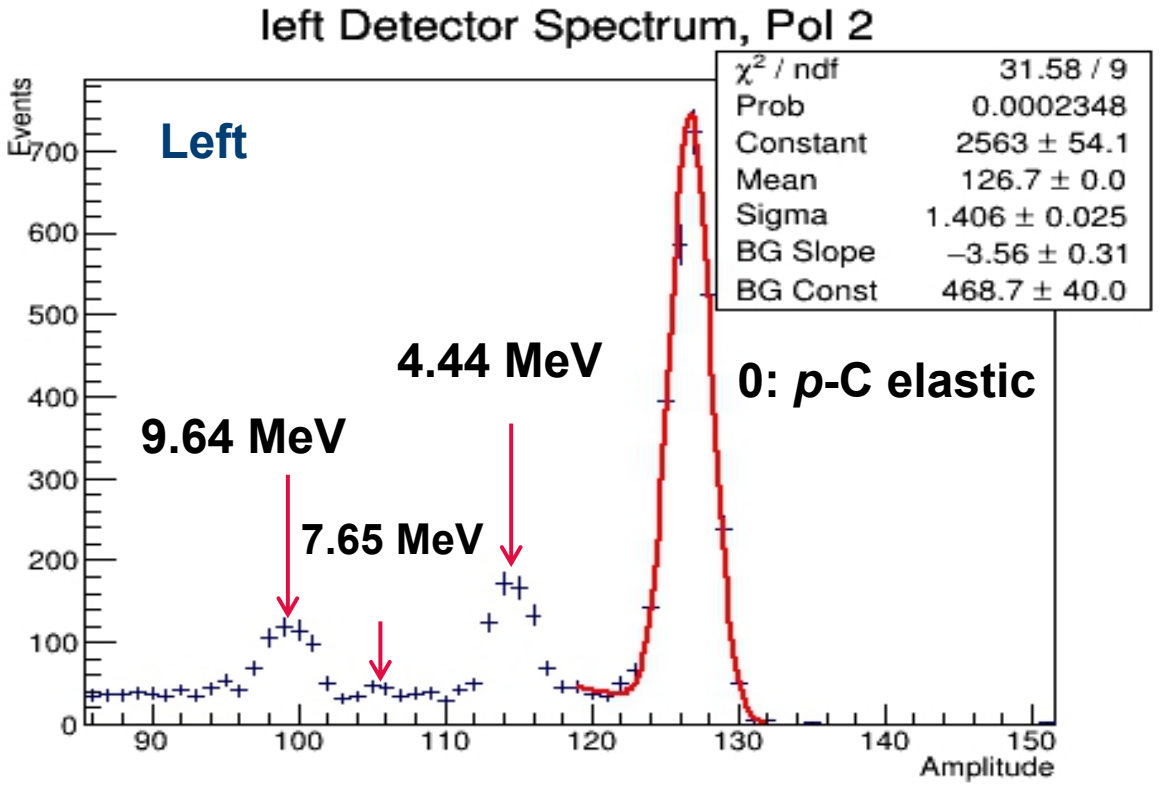
POLARIMETRY R&D

Polarimeter for 45-MeV proton beams

^{12}C Levels

E_{level} (MeV)	J^P	Γ (eV)	Decay
0	0^+	stable	no
4.44	2^+	10.8 x10^{-3}	$^{12}C^* \rightarrow {}^{12}C + \gamma$ (% IT = 100)
7.65	0^+	9.3	$^{12}C^* \rightarrow 3\alpha$ (% α ≈ 100)
9.64	3^-	46 keV	**$^{12}C^* \rightarrow 3\alpha$ (% α ≈ 100)**

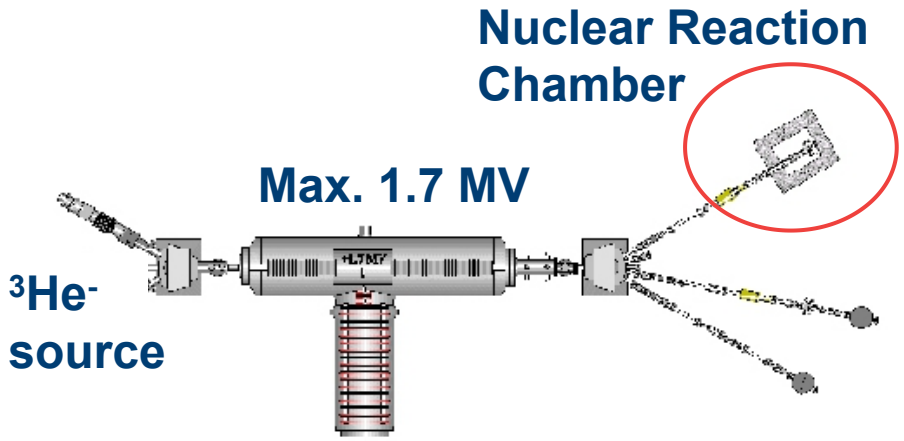
Q(α) = - 7.367 MeV



background from *p*-C inelastic events

POLARIMETRY APPLICATION

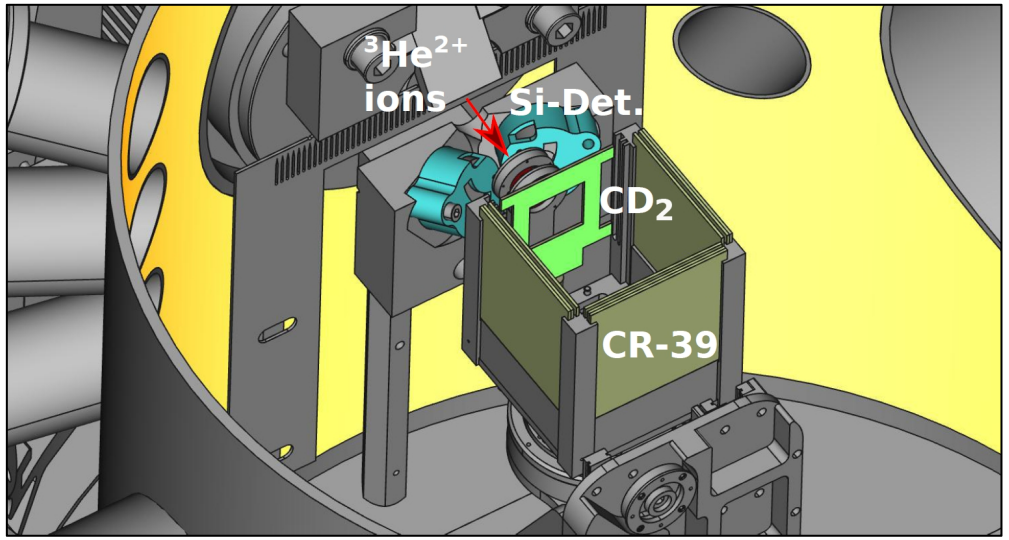
Tandetron Lab@FZJ

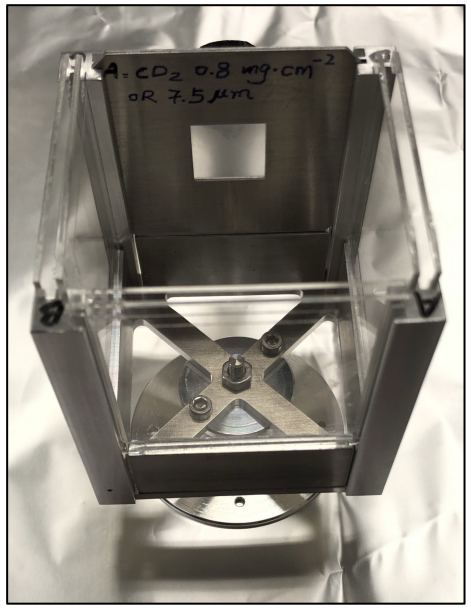


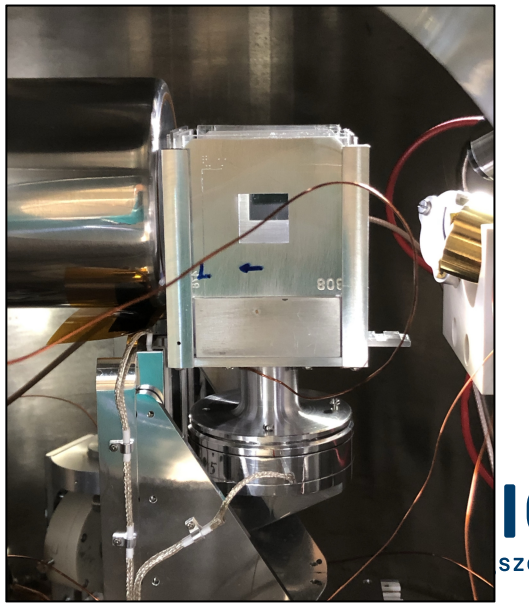
d (^{3}He, p) ^{4}He Q = 18.35 MeV

^{3}He^{2+} ions:	protons:	^{4}He^{2+} ions:
1.45 MeV / 4.5 MeV	12 - 20 MeV	3 - 8 MeV

Polarimeter for ^{3}He ion beams



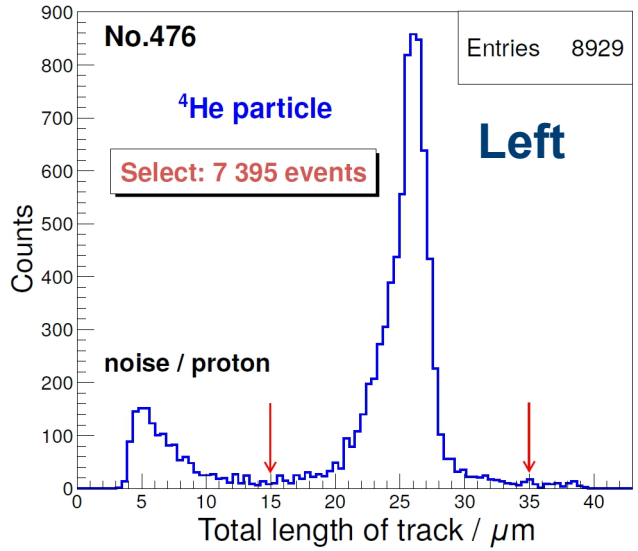


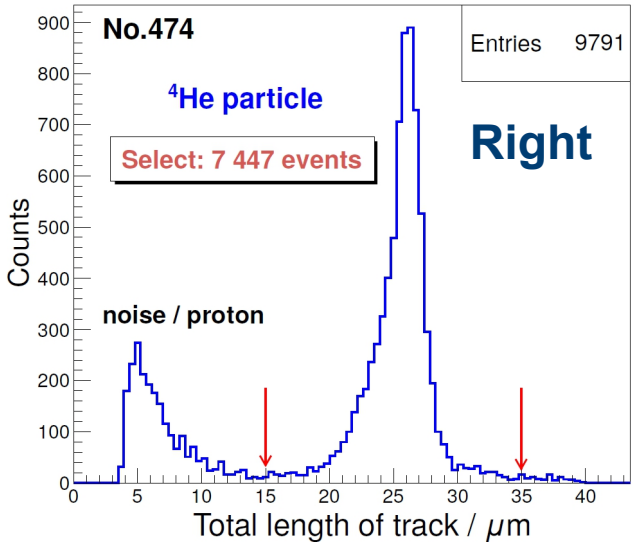


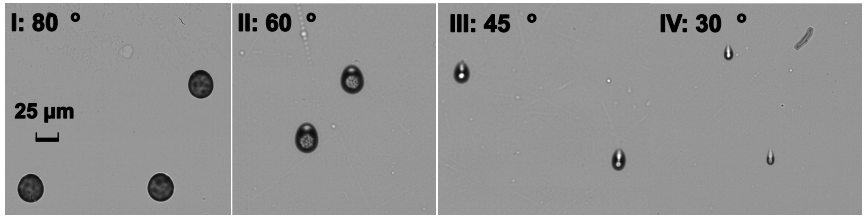
ICH szentrum

POLARIMETRY APPLICATION

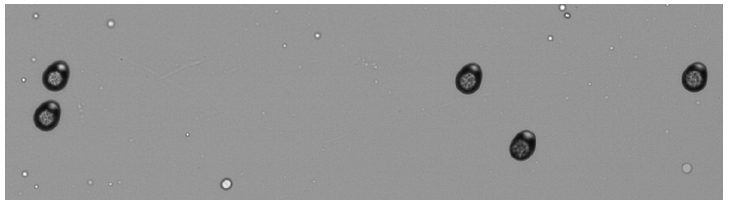
Polarimeter for ^{3}He ion beams

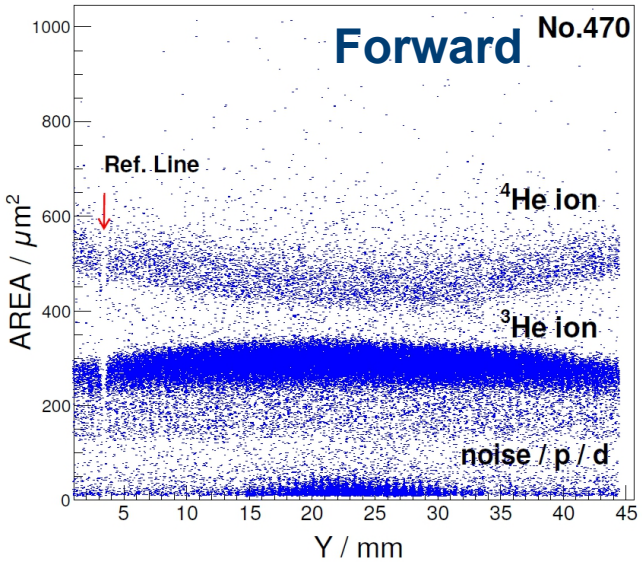


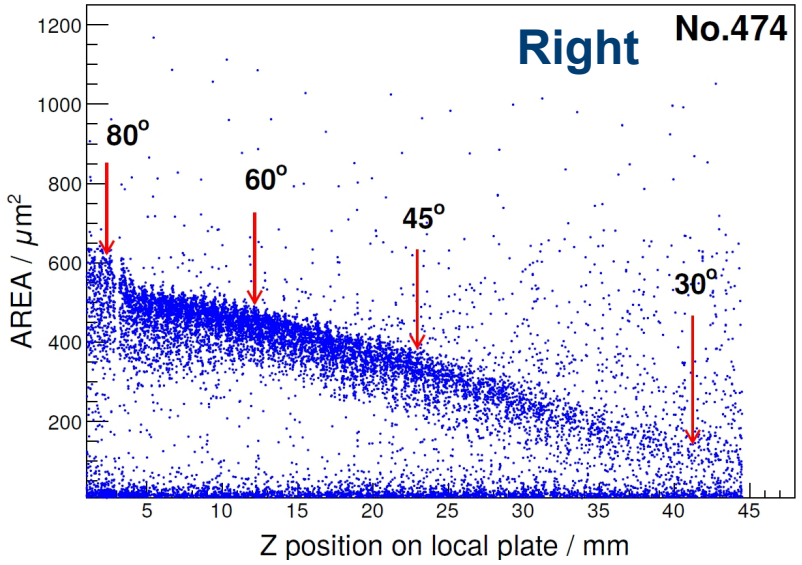




Track profiles & orientations

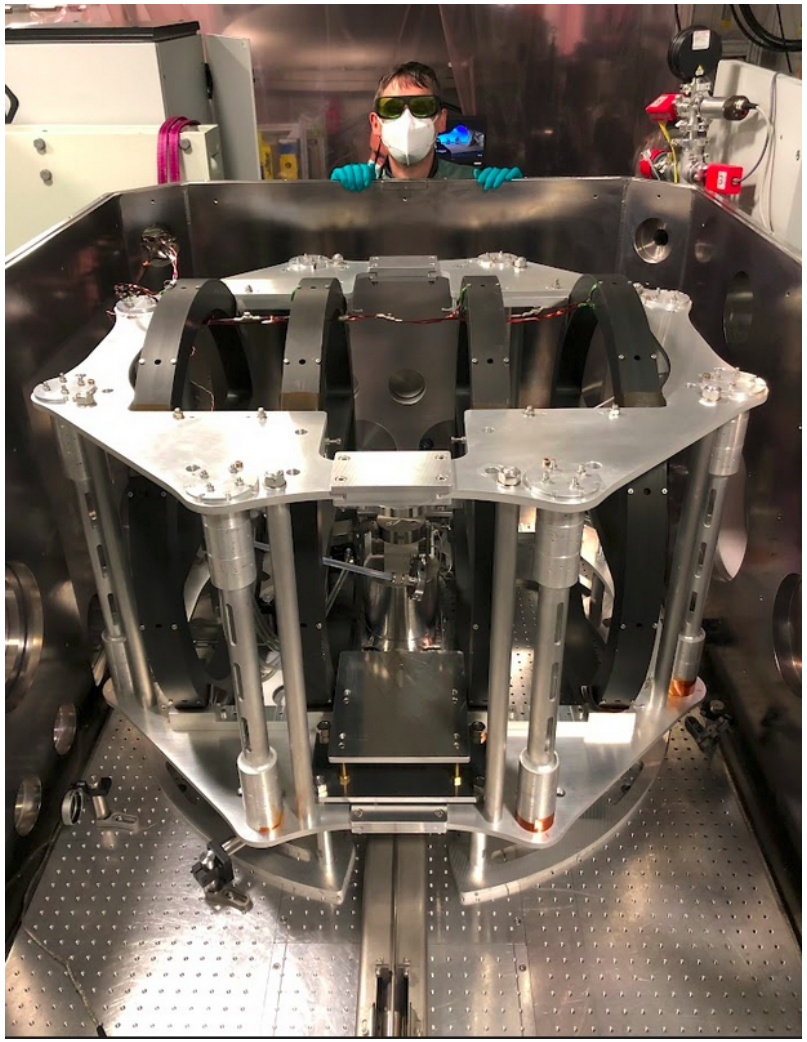


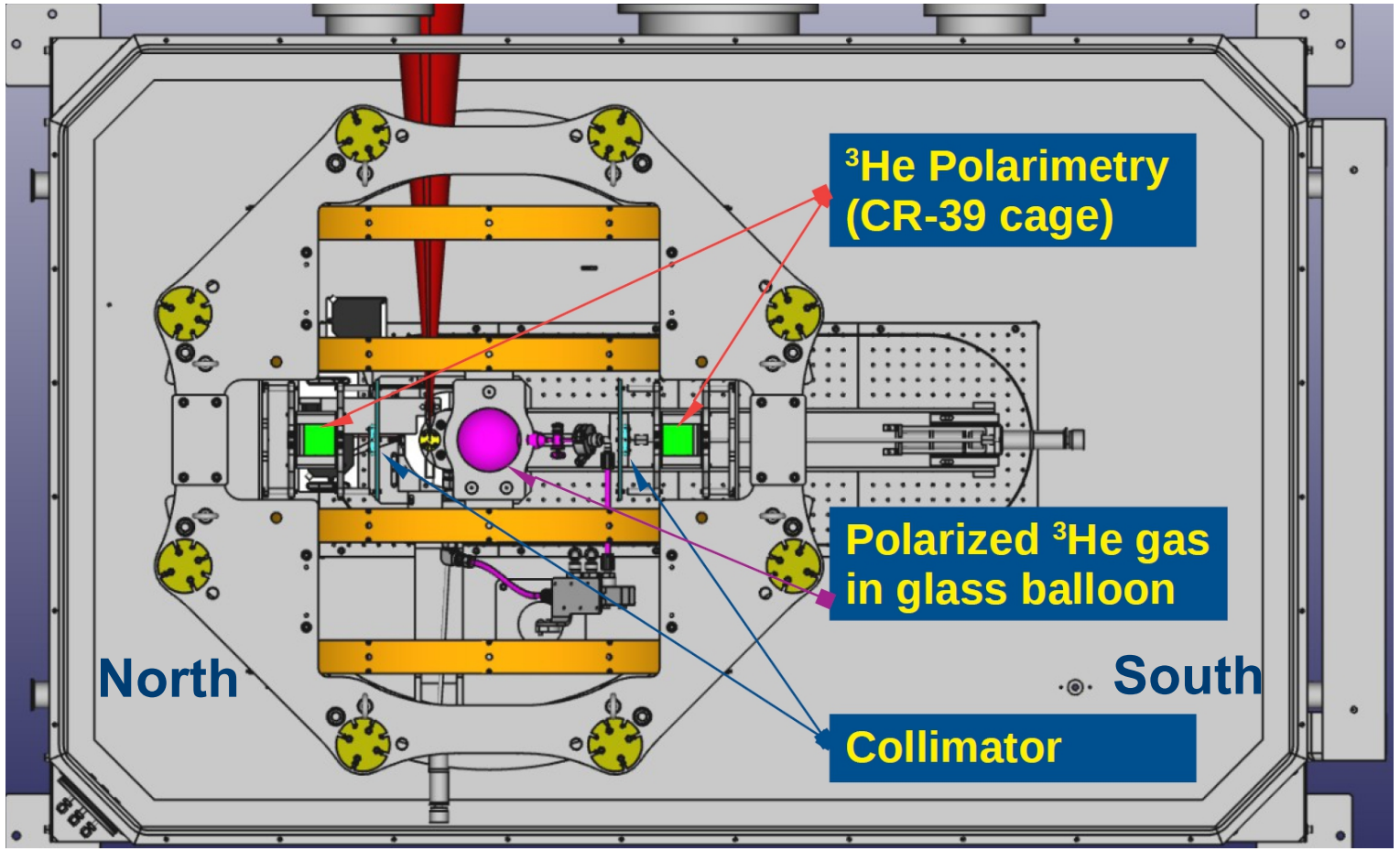




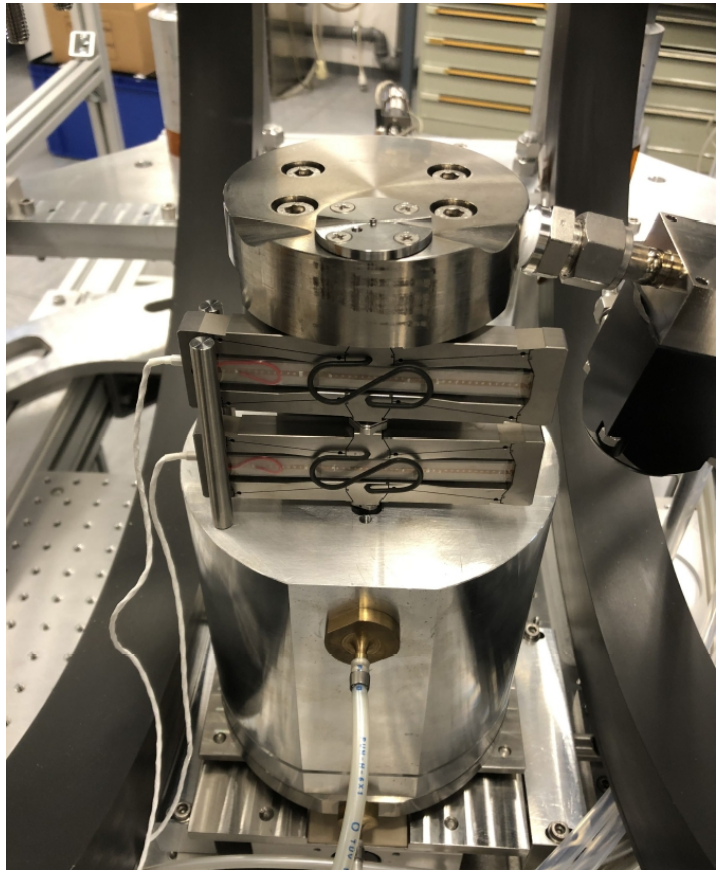
Zheng, C., et al.
Polarimetry for ^{3}He ion beams from laser-plasma interactions (Accepted)
Preprint:
doi:10.20944/preprints202208.0240.v1

POLARIMETRY APPLICATION Laser-driven pol. ^{3}He exp. at PHELIX

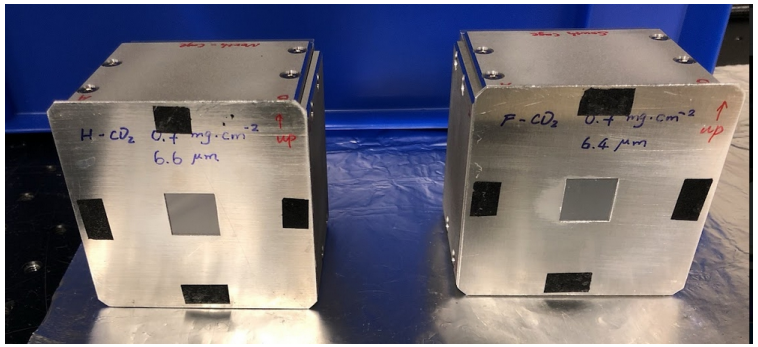


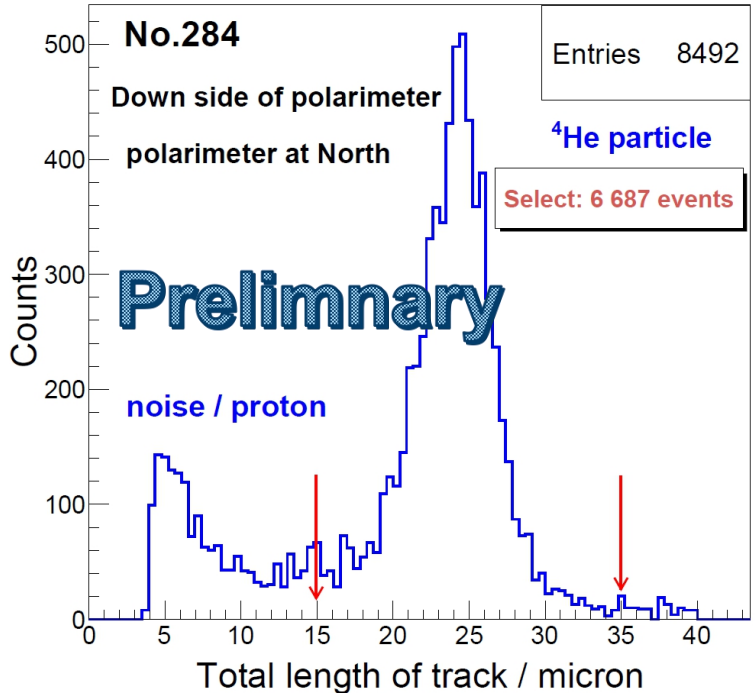


POLARIMETRY APPLICATION Pol. gas target & Polarimeter



Fedorets, P., et al.
A High-Density Polarized ^{3}He Gas-Jet Target for Laser-Plasma Applications
Instruments 6(2022)18





Laser energy : 50 J
Pulse duration : 2 ps
Focal spot size : 15x20 μm^2
Peak intensity : $1x10^{19}$ $W \cdot cm^{-2}$
ASE contrast : 10^{-10}

Data recorded on one side of the polarimeter at north:
6 laser shots / day
at PHELIX

SUMMARY

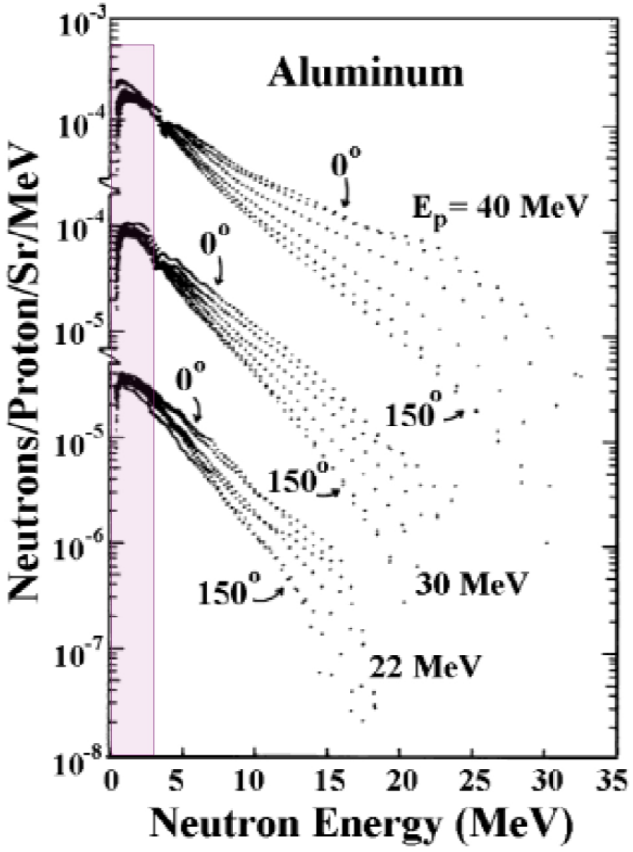
- Polarized particle beams from laser-driven acceleration becom a hot topic in the laser-plasma community.
- New polarimetry is urgently required for laser-plasma exp.
- Our group has developed one kind of polarimeter based on solid-state nuclear track detector(CR-39).
- First use of the polarimeter with a pre-polarized ^{3}He gas jet target at PHELIX has been realized.

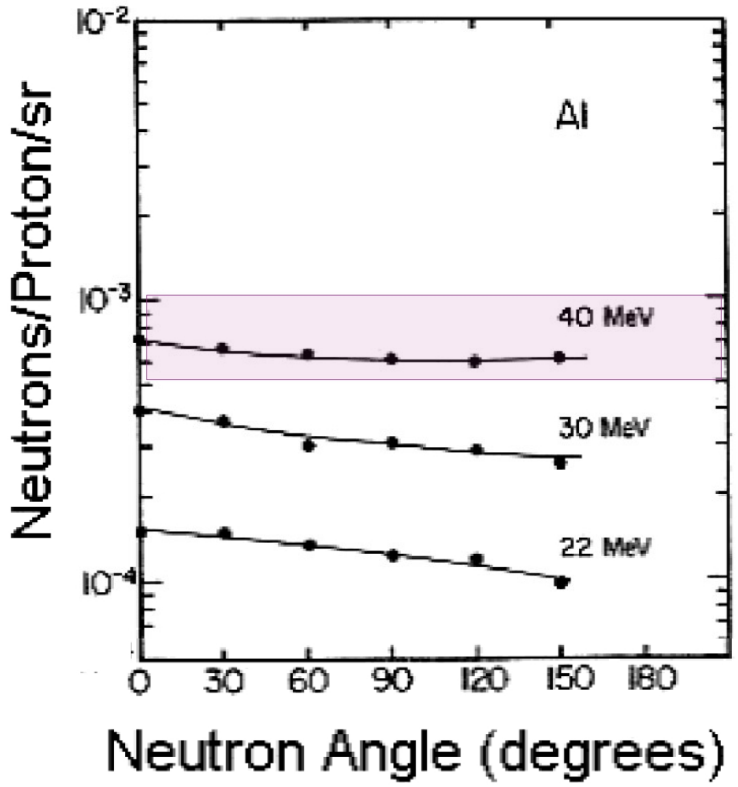
BACKUP

Subline

POLARIMETRY R&D

Production of neutron in Al aperture



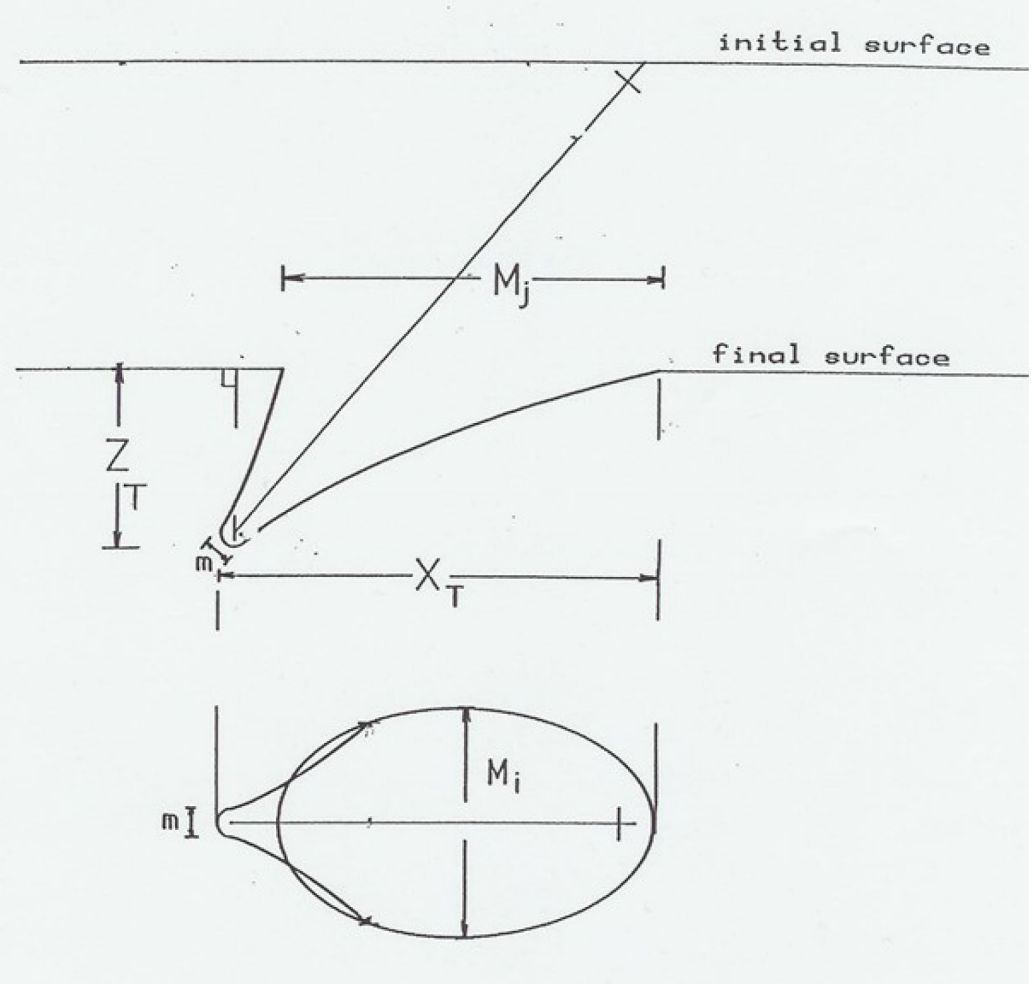


Amos T. M. et al. Nuclear Sci. and Eng. **147**(2004)7

Neutron estimation: ~ 6x10^7 s^{-1}·sr^{-1}, mostly < 5 MeV

POLARIMETRY R&D

Scan image parameters: track profile



Directly measured parameters

M_j : Major axis of opening mouth

M_i : Minor axis of opening mouth

X_T : Total length of track projected in horizontal direction

m : width of track end (or **M2**)

AREA : area within the shape

Estimated parameter

Z_T : Depth of track end projected in perpendicular direction