SEARCH FOR POLARIZATION EFFECTS IN THE ANTIPROTON PRODUCTION PROCESS

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- Motivation
- Polarization Measurement
- Detection system
- Beam time request

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Motivation

Preparation of a polarized antiproton beam

spin degree of freedom → more detailed analyses possible

How to get polarized antiprotons:

many ideas →

mostly
very low intensity
or polarization
is expected

or
calculations impossible
and feasibility studies
require large effort.

- hyperon decay,
- spin filtering,
- spin flip processes,
- stochastic techniques,
- dynamic nuclear polarization,
- spontaneous synchrotron radiation,
- induced synchrotron radiation,
- interaction with polarized photons,
- Stern-Gerlach effect,
- channeling,
- polarization of trapped antiprotons,
- anti-hydrogen atoms,
- polarization of produced antiproton

see e.g:
A.D. Krisch, A.M.T. Lin,
and O. Chamberlain (edts),
AIP Conf. Proc. 145 (1986)

E. Steffens,
AIP Conf.Proc 1008, 1-5 (2008)
AIP Conf.Proc.1149, 80-89 (2009)

H. O. Meyer,
AIP Conf.Proc.1008, 124-131 (2008)

How to get polarized antiprotons:

used method:
hyperon decay: $\bar{\Lambda} \rightarrow \bar{p} + \pi^+$ **(63,9 %)**

Decay ⇒ $\bar{p}$ with helicity h = - 0.64. Lorentz boost creates transverse vector polarization.

First and so far only experiment with **polarized 200 GeV $\bar{p}$** at Fermilab. I~ **10^4 polarized $\bar{p}$ s^{-1}**

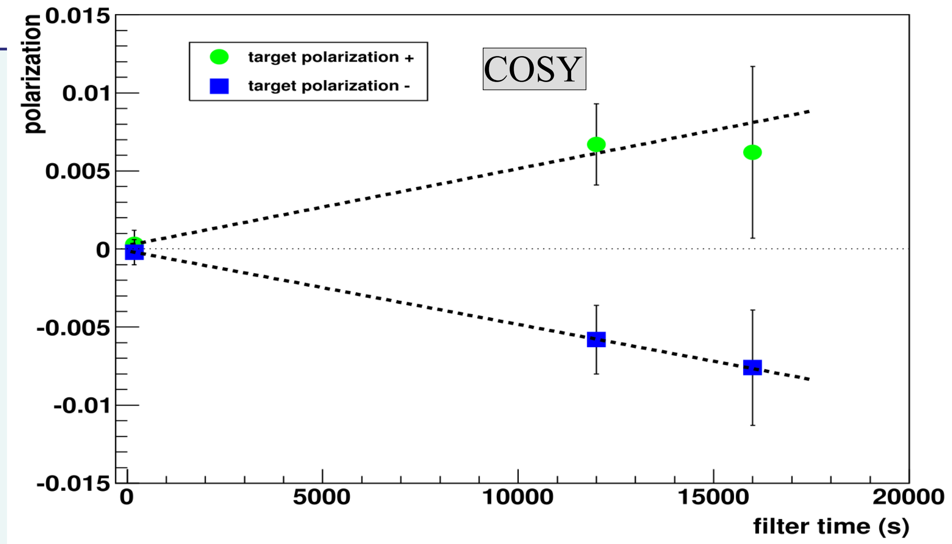
A. Bravar et al. Phys. Rev. Lett. **77**, 2626 (1996)

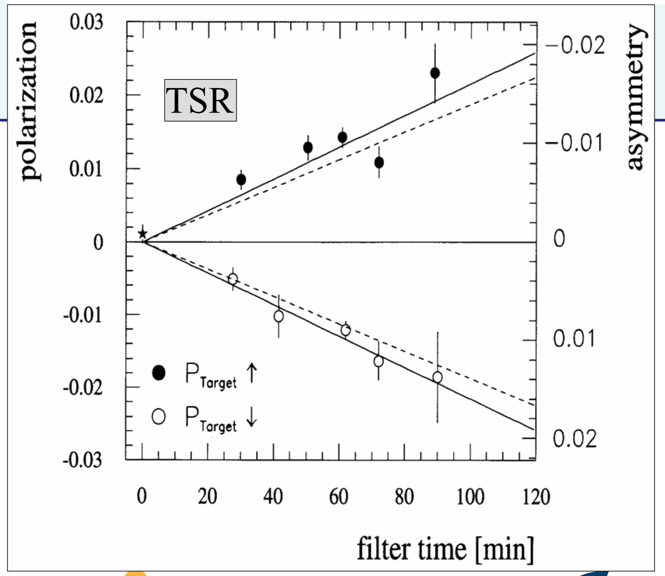
⇒ **limited to dedicated experiments**

proposed method for FAIR:
spin filtering → PAX (PAX collaboration, arXiv 0904.2325 [nucl-ex] (2009)
(suggested for protons at ISR: P.L.Csonka, Nucl. Instr. Meth. **63** (1968) 247).

works in principle,
protons at TSR (F. Rathmann et al., PRL 71, 1379 (1993))
and COSY (W. Augustyniak et al., PLB 718 64-69 (2012))

but enormous effort:
separate filter storage ring (Sibirian snakes),
filter time T ≃ 2τ (beam life time)



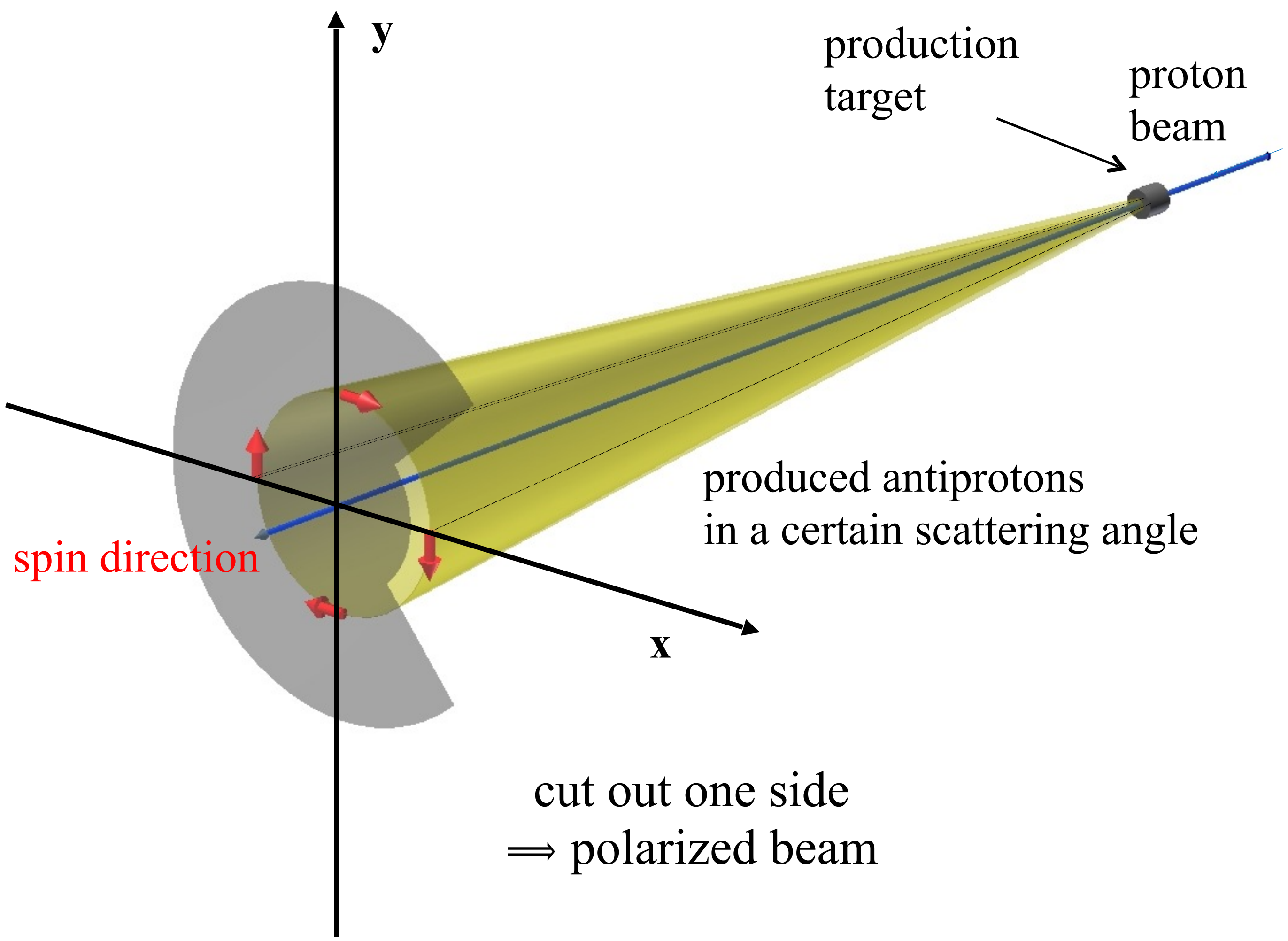


⇒ reasonable to investigate other possibilities

check if antiprotons are produced polarized

How to get polarized antiprotons:

if antiproton production is polarized
→ preparation of a polarized beam very simple



antiproton production:

$$p + p \rightarrow p\,p\,(p\,\bar{p})$$

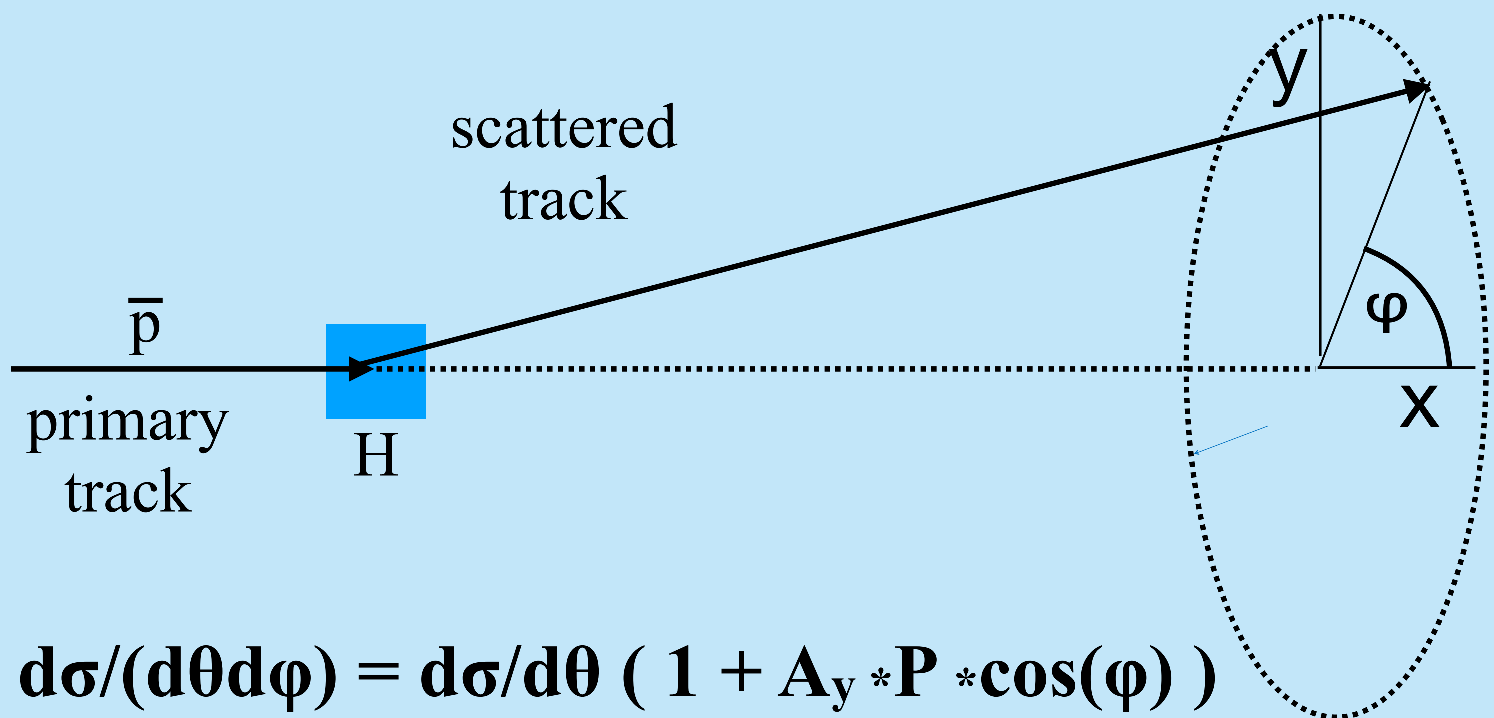
p-wave production
→ spin-orbit interaction
may result in polarization

first view: no asymmetry

but may be due to
certain configuration
in the production process
some polarization is created

in view of the simplification
for a polarized beam preparation
it is worth to investigate a
possible polarized production

Polarization Measurement



$$d\sigma/(d\theta d\varphi) = d\sigma/d\theta\ (\ 1 + A_y * P * \cos(\varphi)\ )$$

Polarization P

Analyzing power Ay

<u>experiment:</u> measurement of the asymmetry of elastic $\bar{p}$ - p scattering at known analyzing power → CNI region : Ay = 4.5 %

A_y in the CNI Area

helicity frame:

$$\phi_1(s,t) = \langle +\tfrac{1}{2} +\tfrac{1}{2} \,|\, \phi \,|\, +\tfrac{1}{2} +\tfrac{1}{2} \rangle,$$

$$\phi_2(s,t) = \langle +\tfrac{1}{2} +\tfrac{1}{2} \,|\, \phi \,|\, \tfrac{1}{2} -\tfrac{1}{2} \rangle,$$

$$\phi_3(s,t) = \langle +\tfrac{1}{2} -\tfrac{1}{2} \,|\, \phi \,|\, +\tfrac{1}{2} -\tfrac{1}{2} \rangle,$$

$$\phi_4(s,t) = \langle +\tfrac{1}{2} -\tfrac{1}{2} \,|\, \phi \,|\, -\tfrac{1}{2} +\tfrac{1}{2} \rangle,$$

$$\phi_5(s,t) = \langle +\tfrac{1}{2} +\tfrac{1}{2} \,|\, \phi \,|\, +\tfrac{1}{2} -\tfrac{1}{2} \rangle.$$

$$\frac{d\sigma}{dt} \sim |\phi_1|^2 + |\phi_2|^2 + |\phi_3|^2 + |\phi_4|^2 + 4\,|$$

$$Ay\,\frac{d\sigma}{dt} = -\,\mathrm{Im}\,[\,(\phi_1 + \phi_2 + \phi_3 - \phi_4)\,\phi_5^*\,]$$

$$\phi_i = \phi_i^{had} + \phi_i^{em}:$$

$$Ay\,\frac{d\sigma}{dt} = \left(Ay\,\frac{d\sigma}{dt}\right)^{had} + \left(Ay\,\frac{d\sigma}{dt}\right)^{em} + \left(Ay\,\frac{d\sigma}{dt}\right)^{int}$$

interference of nuclear non-spin-flip and em spin-flip (due to magnetic moment)

for small t and high energy:
(N. Akchurin et al., Pys. Rev. D 48, 3026 (1993), and ref. cited.)

$A_y^{em}(t) = 0$ (single photon exchange assumed)

$A_y^{had}(t) \approx \sqrt{t/s}$ (negligible for $t/s \to 0$)

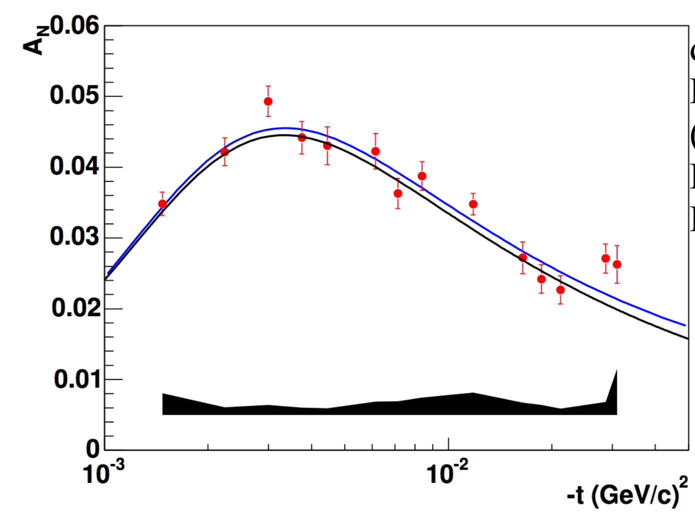
$$A_y^{int}(t) = A_y^{int}(t_p)\,\frac{4\,(t/t_p)^{3/2}}{3\,(t/t_p)^2 + 1}$$

$$t_p = \sqrt{3}\,(8\pi\alpha/\sigma_{tot}) \approx -0.003$$

$$A_y^{int}(t_p) \approx \frac{\sqrt{3}}{4}\,(\mu-1)\,\frac{\sqrt{t_p}}{m} \approx 0.046$$

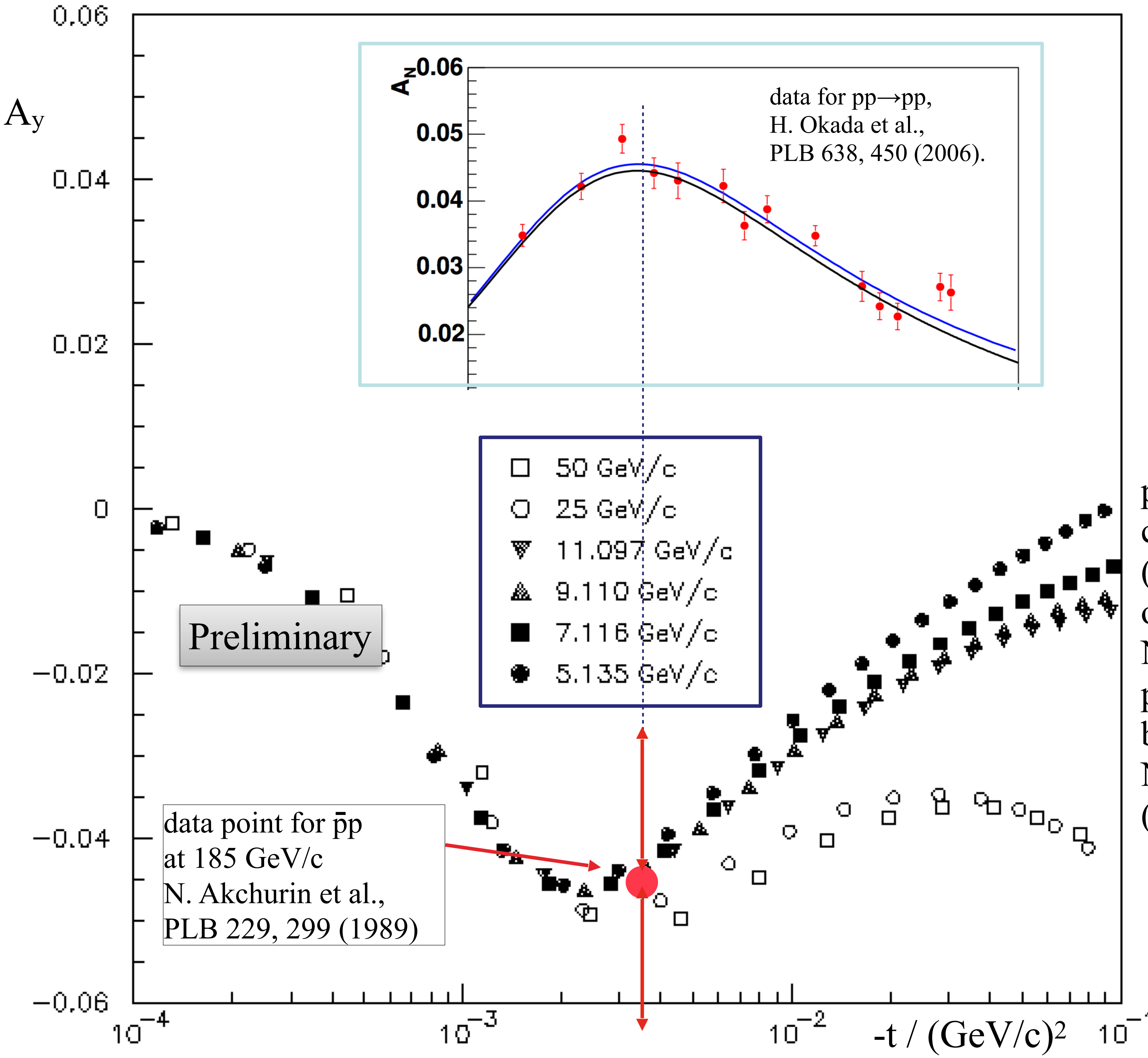
(μ : magnetic moment)

$\Rightarrow$ $A_y \approx 4.6\,\%$, at $t \approx -0.003$
for pp and $p\bar{p}$ (G-parity)



data for pp→pp,
P_p=100 GeV/c,
($\sqrt{s}$ = 13.7 GeV)
H. Okada et al.,
PLB 638, 450 (2006).

A_y in the CNI Area



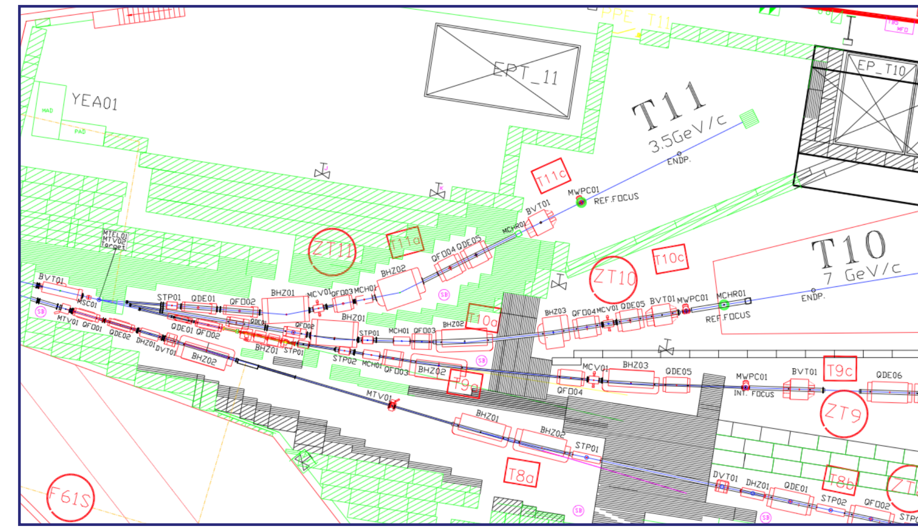
preliminary
calculations for $\bar{p}p \to \bar{p}p$
(J. Haidenbauer, priv. comm.)
one-boson-exchange
NN potential,
potential parameters determined
by fit to experimental
NbarN data,
(Phys.Rev.D89,114003 (2014)

Polarization Measurement

- Production of $\bar{p}$ under useful conditions

$\bar{p}$ momentum ≈ 3.5 GeV/c
($\bar{p}$ production at AD and future FAIR facility)

no s-wave production ($\theta_{lab} > 56$ mrad)



⟹ **<u>T11:</u>**

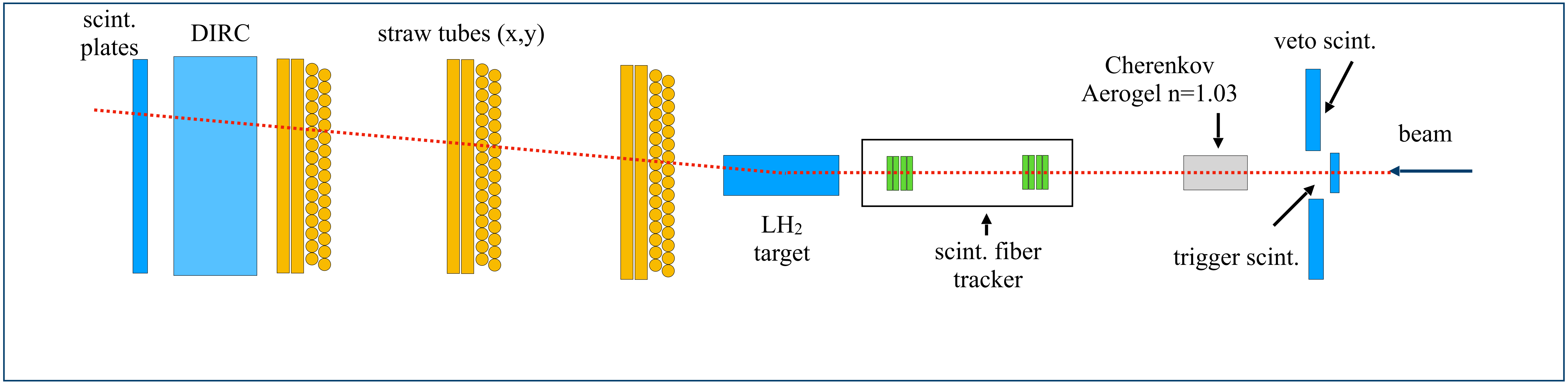
$\bar{p}$ momentum ≦ 3.5 GeV/c (≦ ± 5%)
production angle = 150 mrad (± 3 mrad h, ±10 mrad v)

- Measure transverse polarization

φ - distribution of the scattering of produced $\bar{p}$
in an analyzer target

$d\sigma/(d\theta d\varphi) = d\sigma/d\theta \, (1 + A_y * P * \cos(\varphi))$
with the known A_y of max. 4.5%

Detection System



Plastic scintillators: trigger

Aerogel Cherenkov counter (n=1.03): veto signal for pion

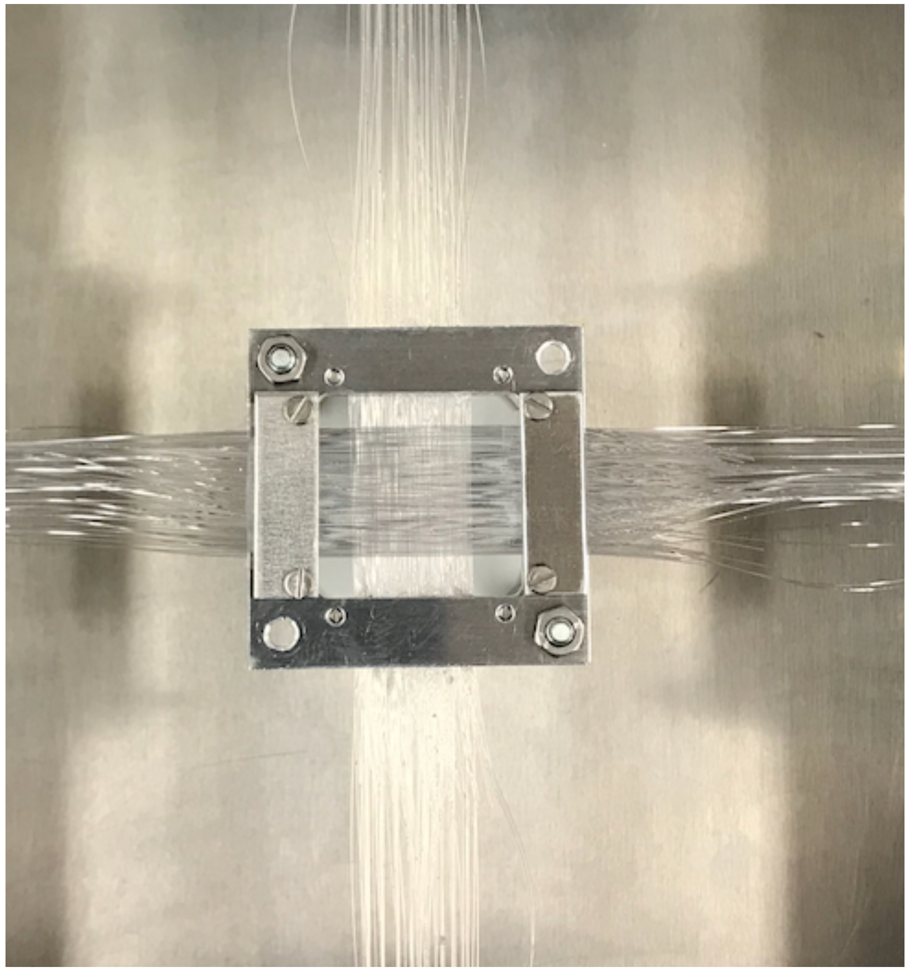
Scintillating fiber tracker: primary track determination

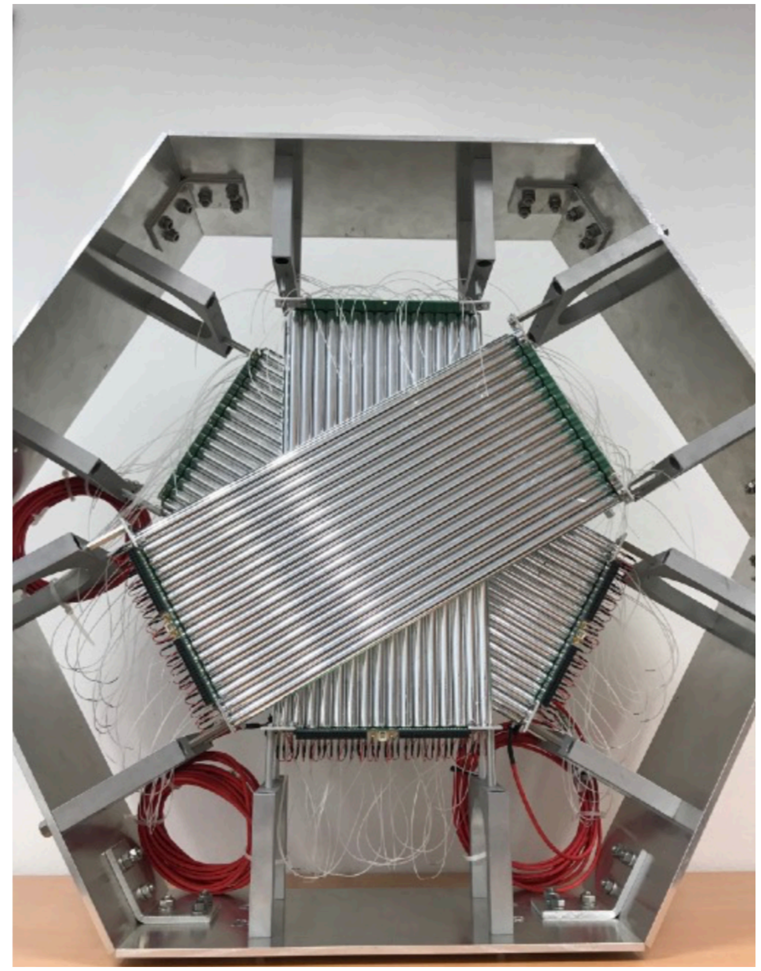
Liquid hydrogen target : antihydrogen scattering

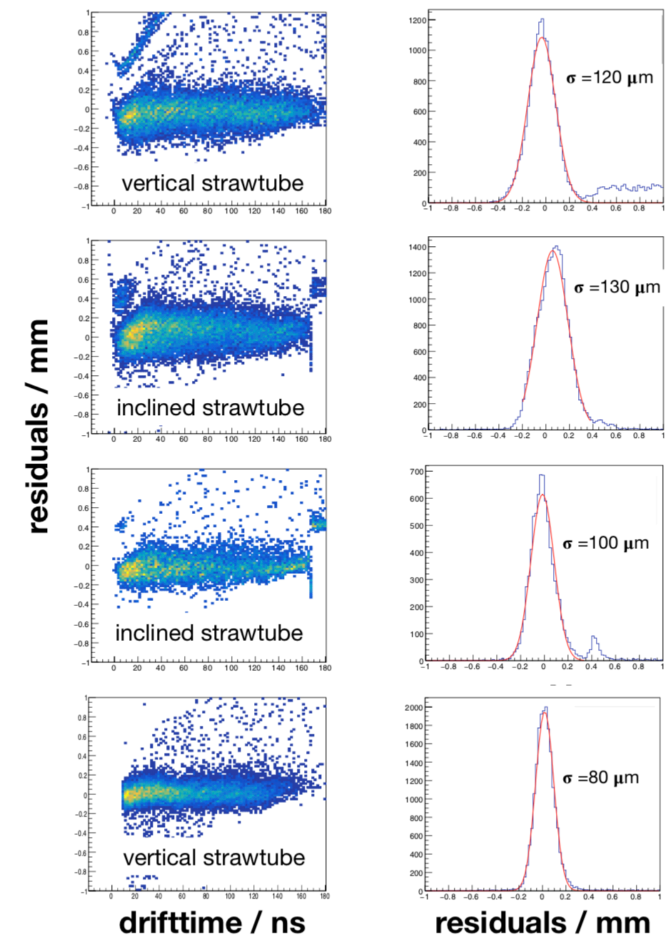
Straw tubes : scattered track reconstruction

DIRC with plexiglas radiator: antiproton identification

Detection System - particle track determination



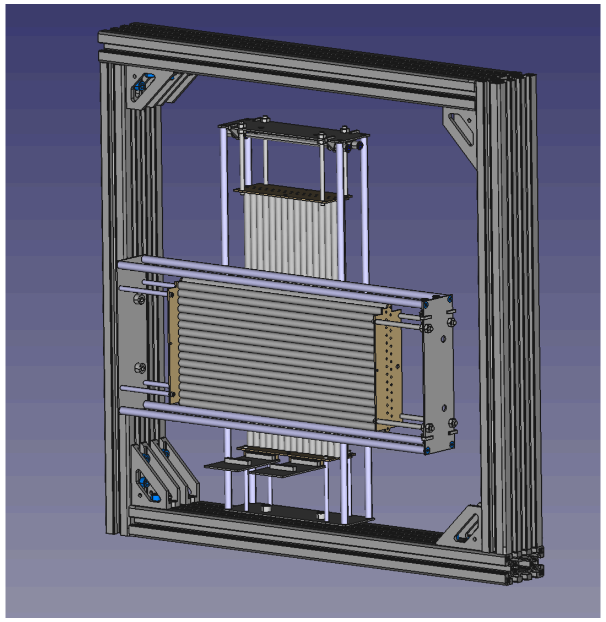




scintillating fibers
0.5 mm thick fibers
overlapping double layers
horizontal and vertical
2 stations separated by 0.4 m

straw tubes
overlapping double layers

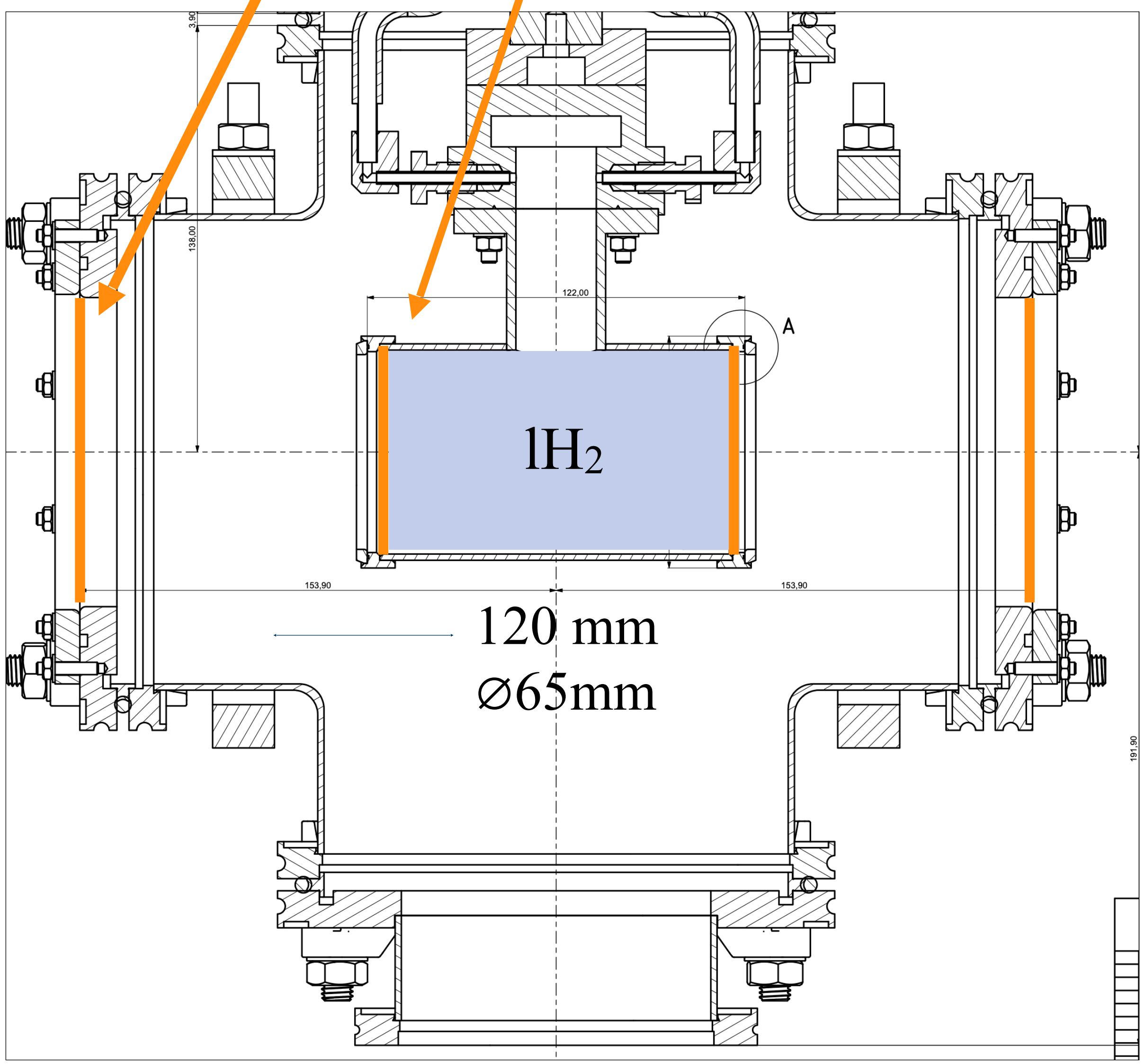
to be changed →
to x,y directions
with 3 stations



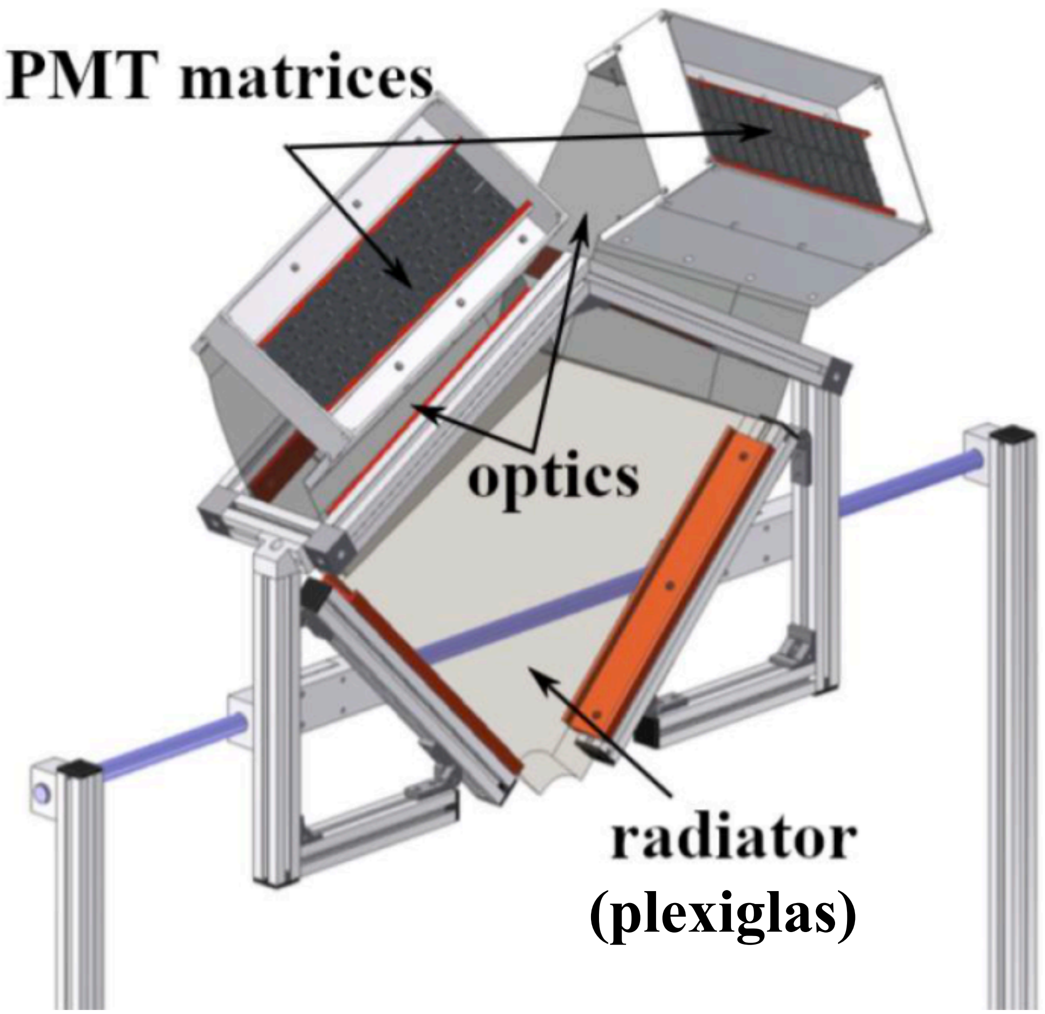
Detection System - Target

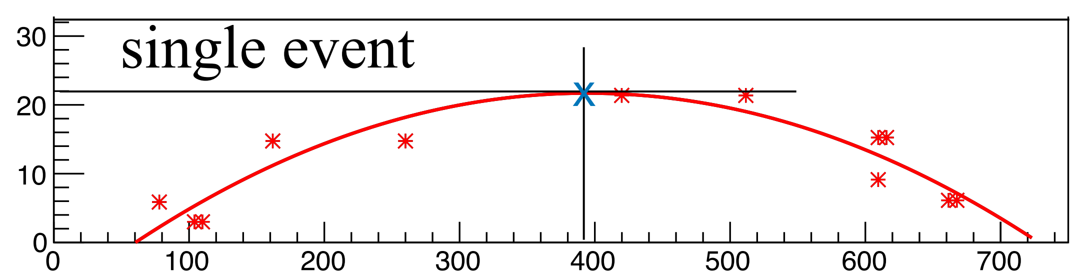
LH_2 target   Volume : ~ 400 cm^3

Kaptonfoil (75 μm)   Kaptonfoil (50 μm)

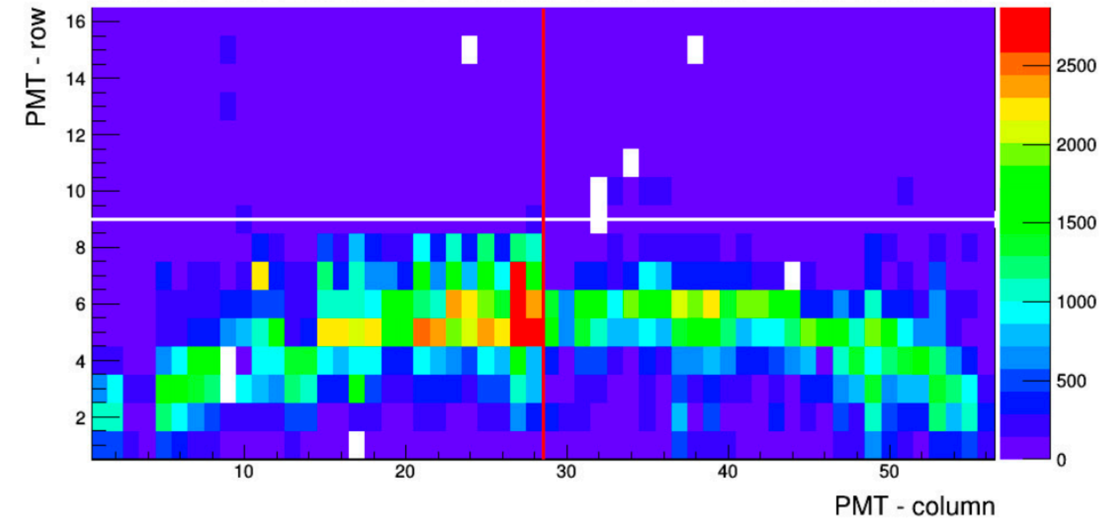


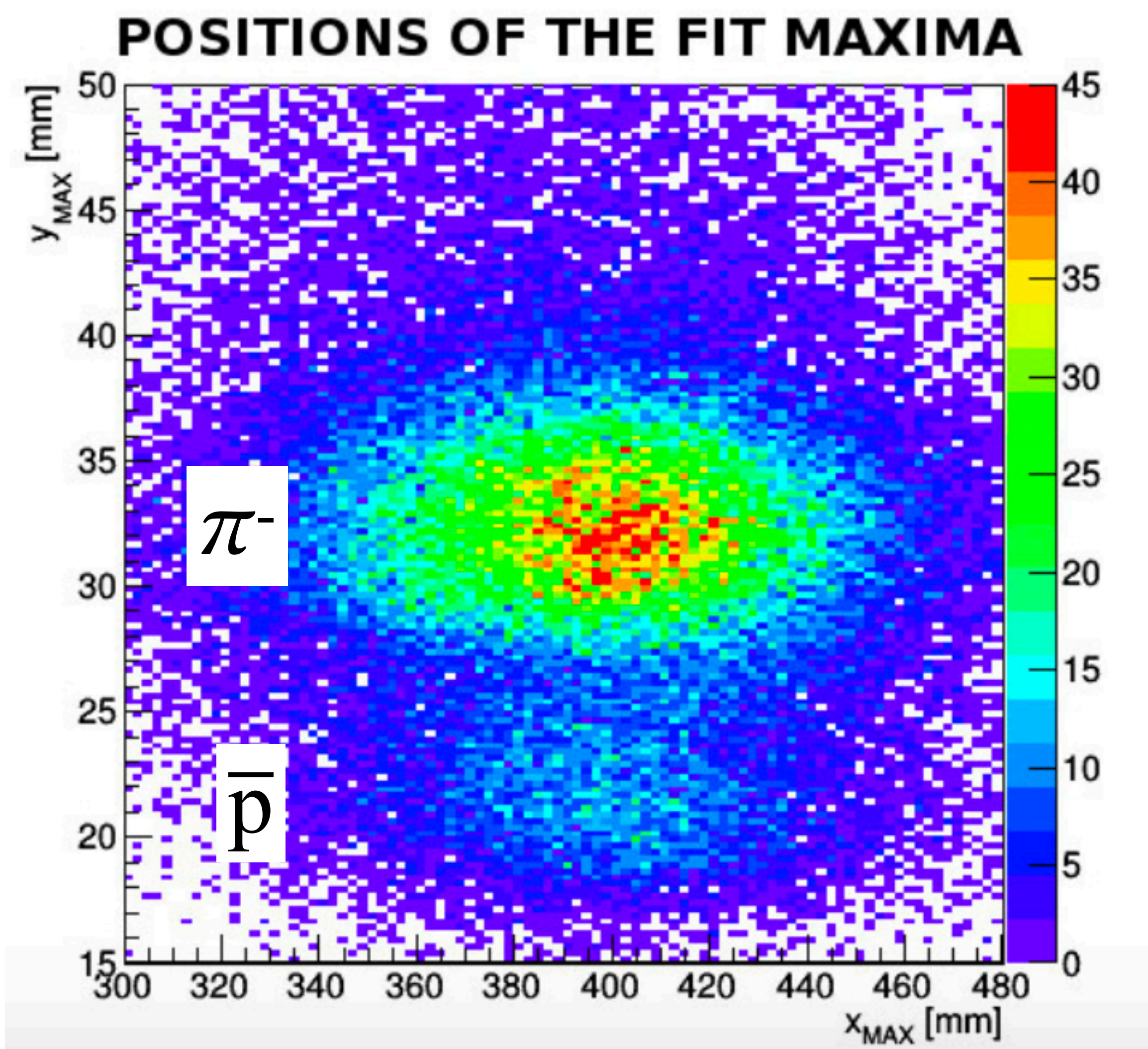
Detection System - DIRC





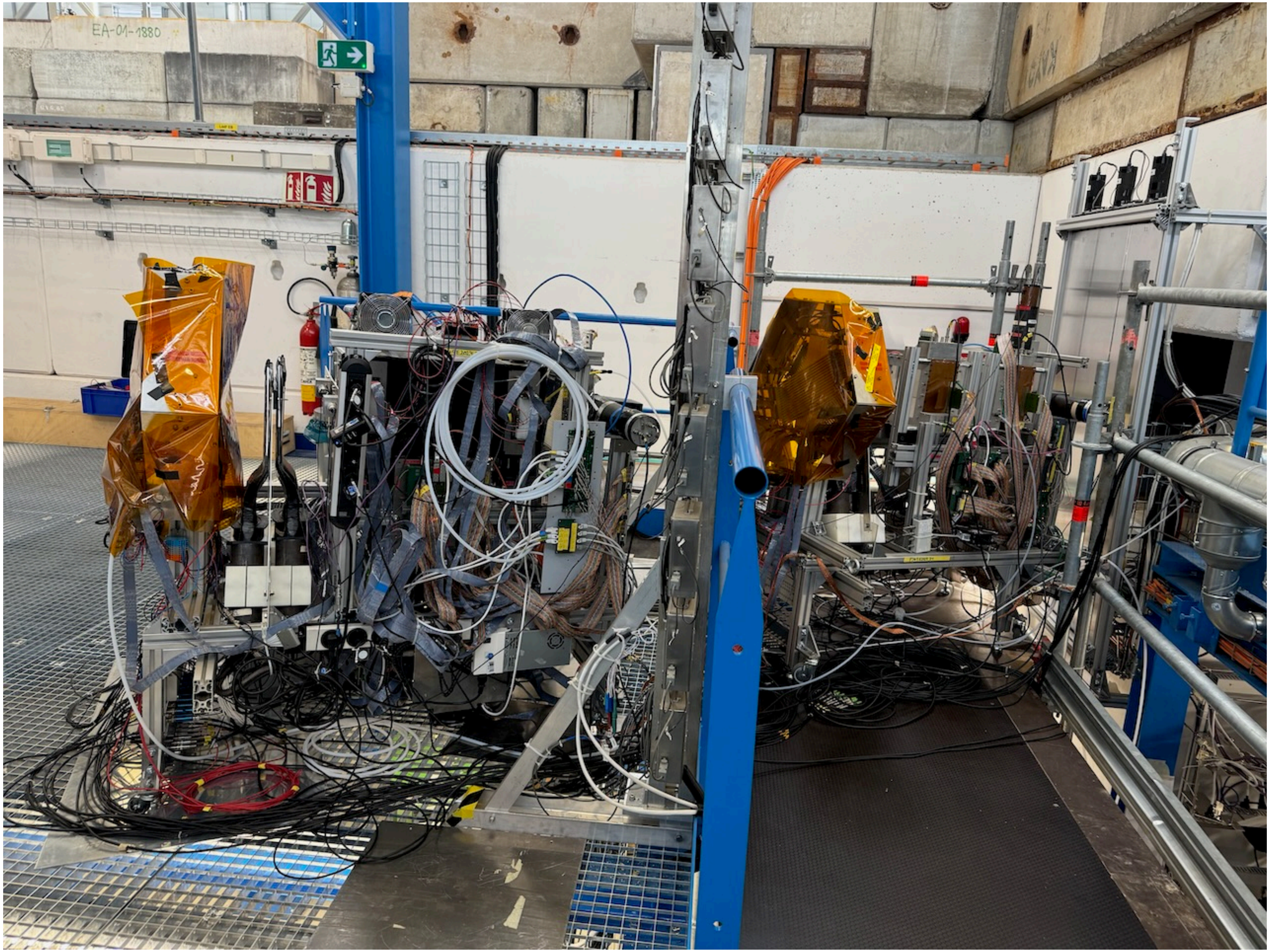
photon hit distribution for an event sample





T11 area (CLOUD experiment)

Test measurements - 08/2024



Detection System

Improvements compared to previous measurements

previous measurement:
large drift chambers
for beam and scattered particles
→ very low efficiency
for the reconstruction of
particle tracks at the
level of a few %

→

new detection system
beam particle:
scintillating fibers
- reduction of the hit rate for a single fiber
- (beam size <10mm: hit rate <1/10 beam rate)
- fast signals, width of few ns

scattered particles:
straw tubes
- separate straws (10mm Ø)
- → beam is separated from scattered particles

Beam Time Request

from previous measurements:

10^6 particles/spill , spill width: 400 ms
→ 8000 antiprotons/spill

online π^- -reduction by Cherenkov-veto: > 1/100

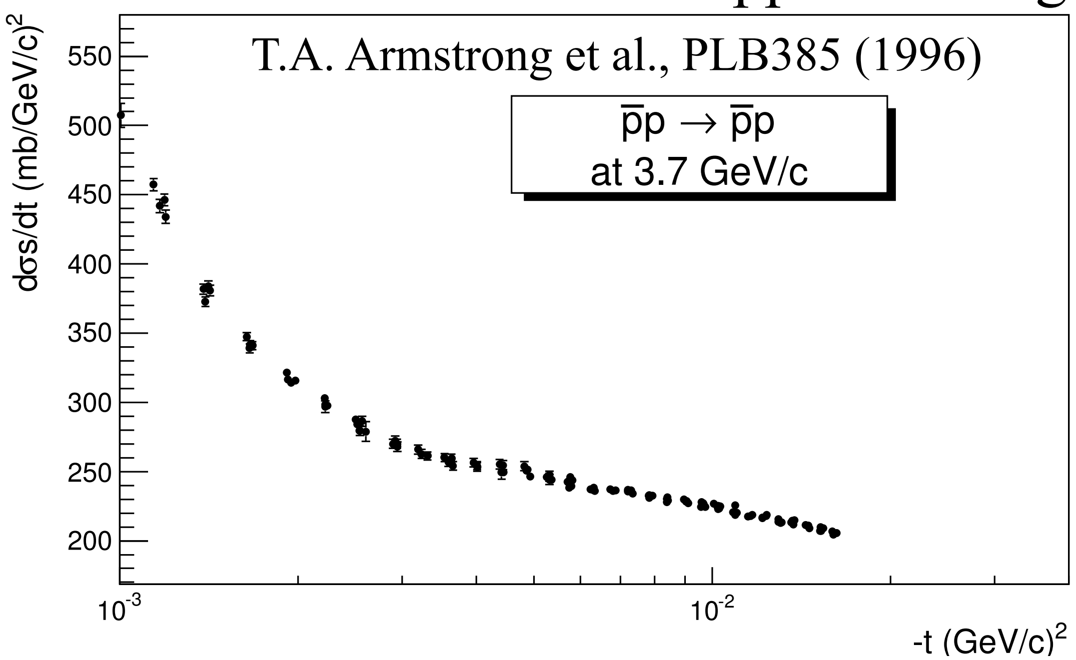
straw tube detection efficiency close to 100%

from cross section and simulation:

about 7 scattering events in a useful t-range

target	$\bar{p}/(\pi^- + K^- + \bar{p})$
Be	0.0086
C	0.0087
Al	0.0088
Cu	0.0086
Pb	-

cross section for elastic p̄p-scattering



beam time request:

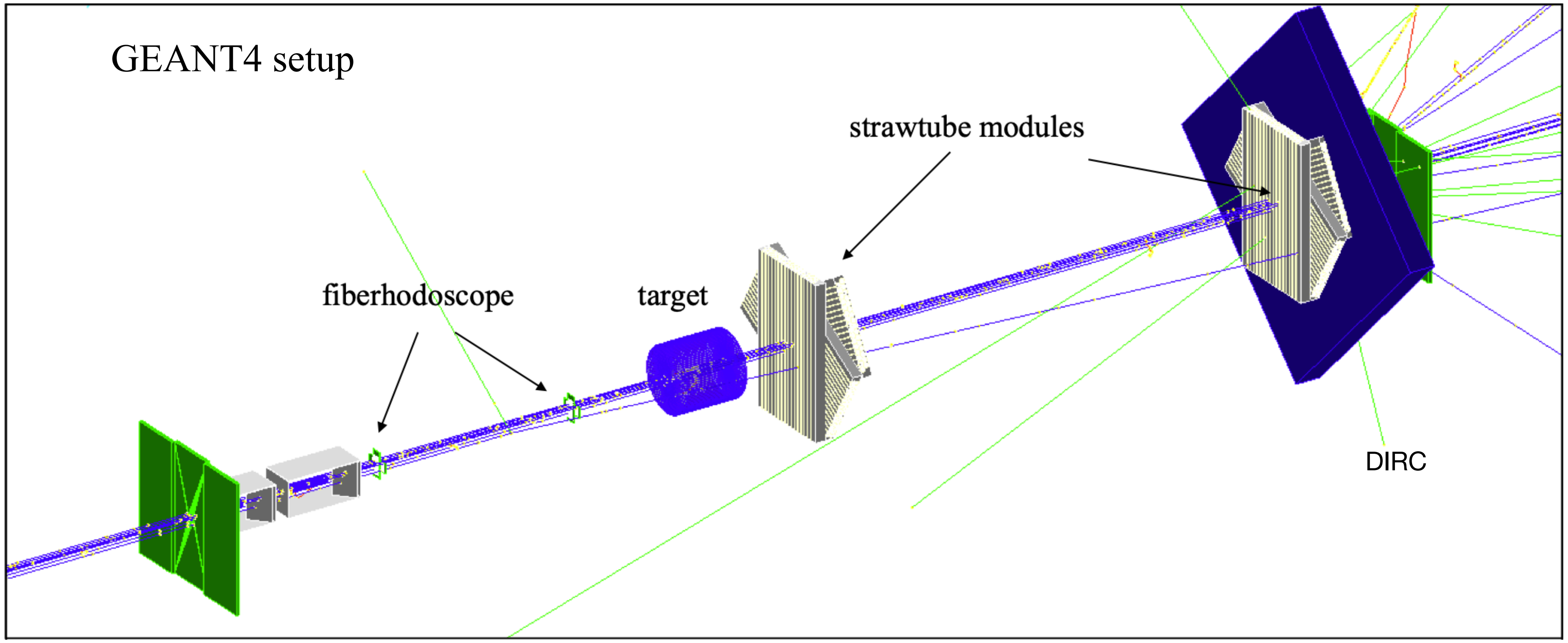
in view of statistics: as long as possible

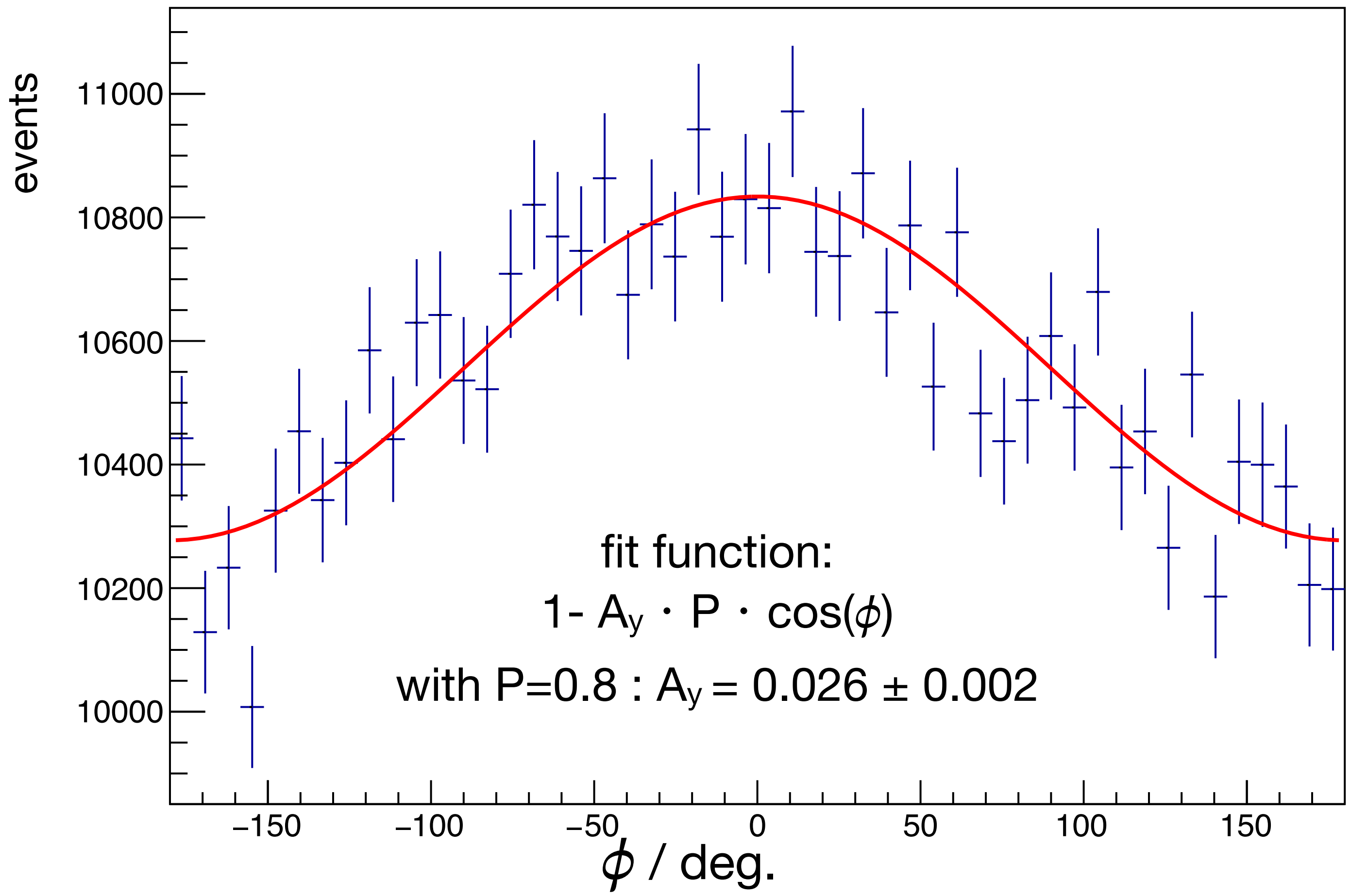
reasonable beam time: **8 weeks**

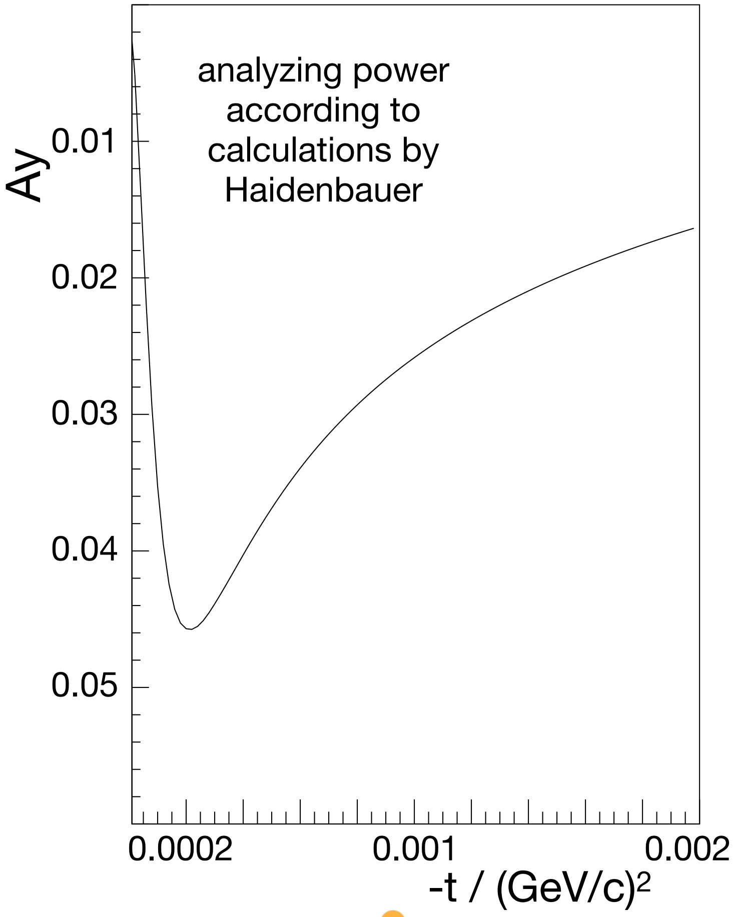
→ $1.6 \cdot 10^6$ scattering events for polarization analysis

Beam Time Request

Simulation of the expected result :
Generation of
elastic scattering events
resulting from 3.5 GeV/c $\bar{p}$
in the lH2-target





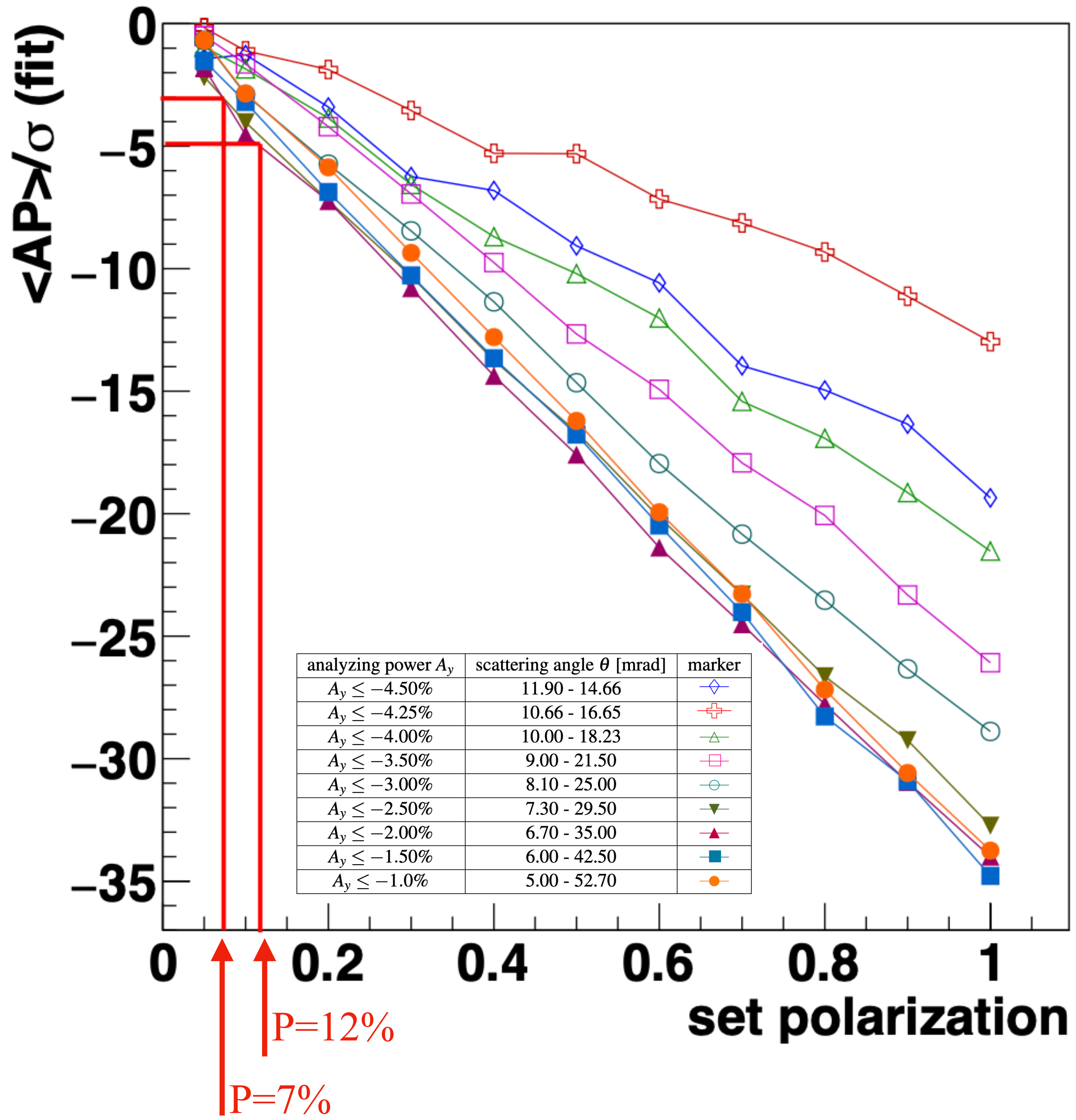


Beam Time Request

achievable precision
as a function of the
assumed polarization

e.g.
assuming
a polarization of 12 %
→ precision 5 σ

assume P=7%
→ precision 3 σ



Beam Time Request

Resources:

Collaboration: detection- and daq-system

CERN: beam time at T11
- mount a scaffold for the detector installation
- removal of CLOUD scintillator wall
- safety aspects under discussion

only user at T11: CLOUD
available time period for data taking with removed Scintillator wall:
July/August 2025 agreed with CLOUD collaboration

(common production target: T10 and T11
→ secondary beam for T11 „always“ produced)

Request: 8 weeks (July 7th - August 29th 2025) (1 day continuous beam)
CLOUD requirement