# SEARCH FOR POLARIZED ANTIPROTON PRODUCTION

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CERN/PS P349


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# SEARCH FOR POLARIZED ANTIPROTON PRODUCTION

- Motivation
- Methods for polarized $\bar{p}$ beam production
  - Λ-decay
  - Spin-filter method
  - Polarization in $\bar{p}$ production ?
- Measurement of polarization
  - CNI region
- P349 experiment
- Status of the analysis
  - Drift chamber calibration
  - DIRC analysis
- Summary and outlook

# Motivation

## Preparation of a polarized antiproton beam

High Energy: nucleon quark structure :

logitudinal momentum distribution $f_1(x)$
helicity distribution

precise data
DIS $g_1(x)$

transversity distribution $h_1(x)$ ← PAX collaboration, polarized $\overline{p}$

arXiv 0904.2325 [nucl-ex] (2009)

Low Energy: spin degree of freedom → more detailed analyses possible

e.g. : $\overline{p}\,p$ annihilation at rest

high density target
→ stark mixing → S-wave

possible states:
$^1S_0$ singlet ↑↓
$^3S_1$ triplet ↑↑

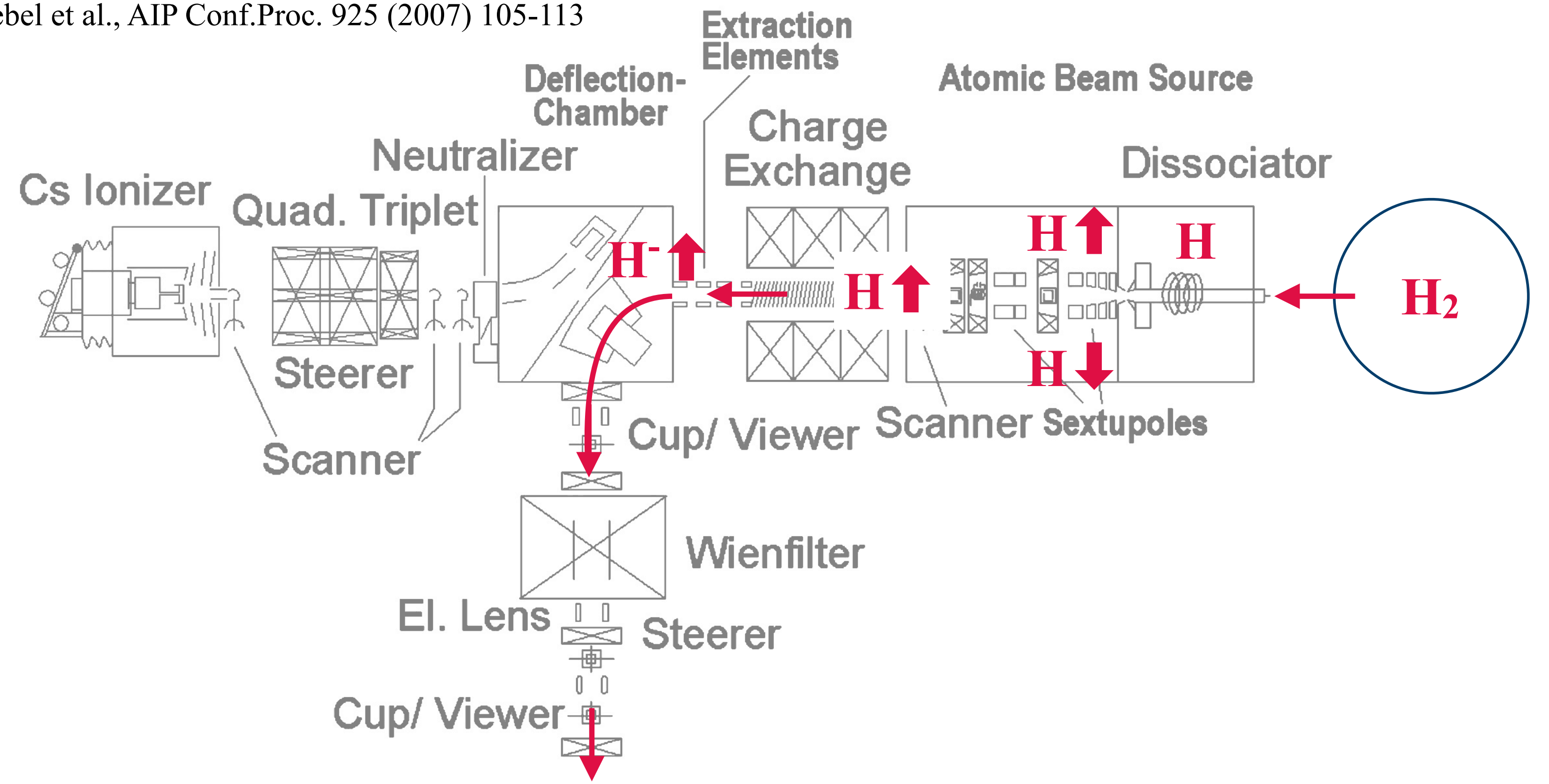
antiprotonic atom spectroscopy

# Methods for Polarized Beam Production

**in case of protons**

e.g. $H^-$ source at COSY

Gebel et al., AIP Conf.Proc. 925 (2007) 105-113




polarized $H^-$ beam



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# Methods for Polarized Beam Production

**in case of protons**

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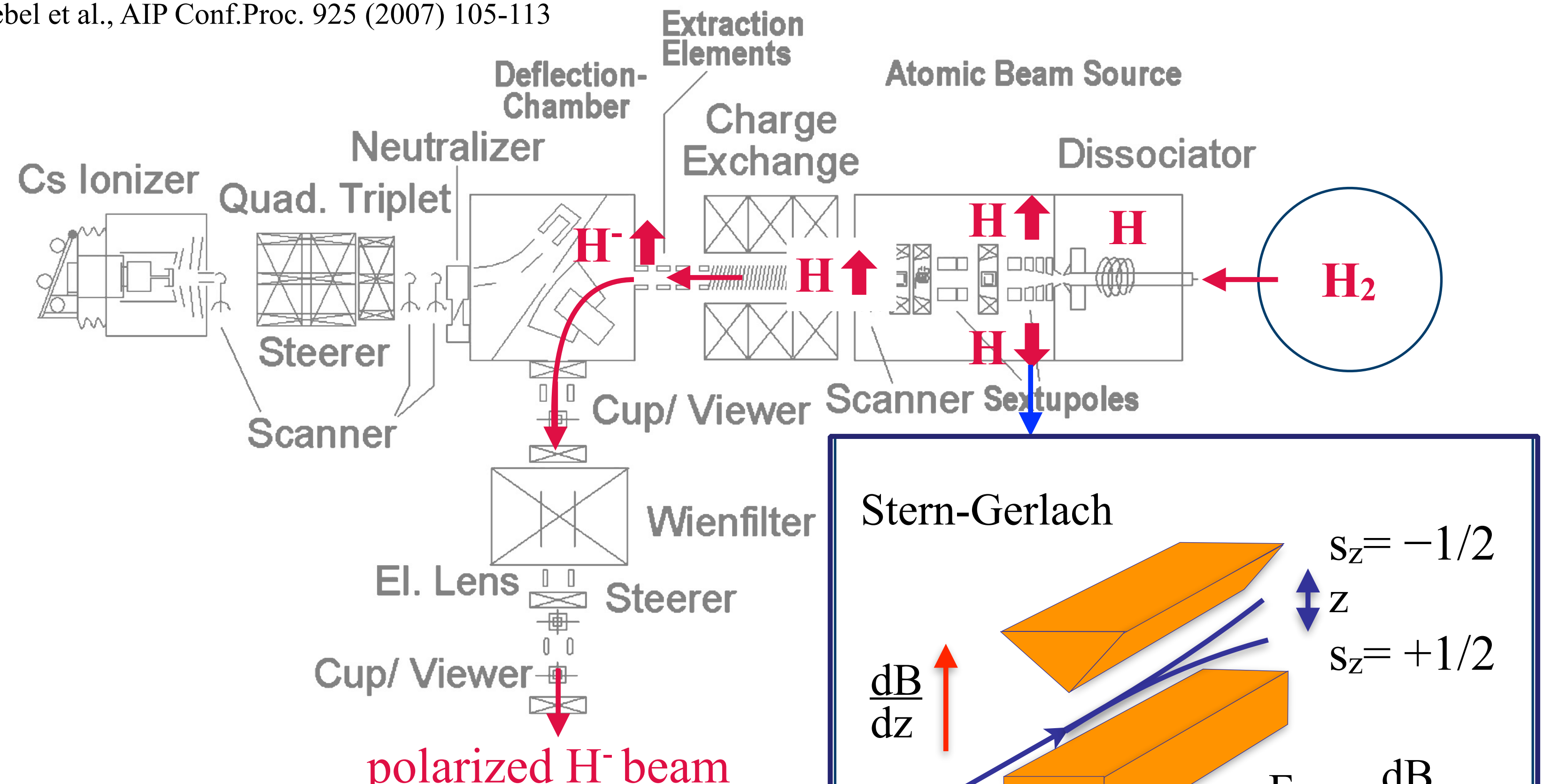


# Methods for Polarized $\overline{p}$ Beam Production

**many ideas →**

mostly
very low intensity
or low polarization
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,
  - antihydrogen atoms,
  - polarization of produced antiprotons

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

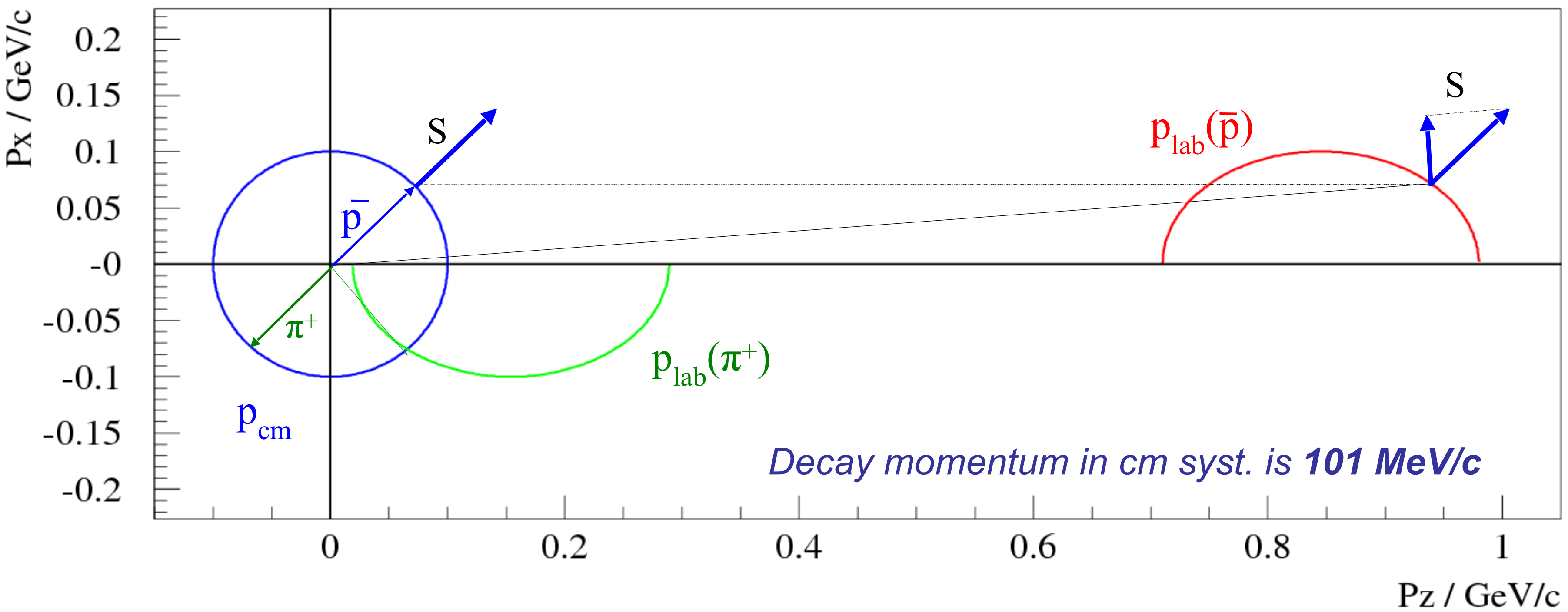
E. Steffens, AIP Conf.Proc 1008, 1-5 (2008), AIP Conf.Proc.1149, 80-89 (2009)

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

# Methods for Polarized $\bar{p}$ Beam Production

Antihyperon decay

$\bar{\Lambda} \rightarrow \bar{p} + \pi^+$ ( 63,9 %)




*Decay momentum in cm syst. is **101 MeV/c***

**Decay makes $\bar{p}$ with helicity h = - 0.64.**

Lorentz boost creates transverse vector polarization.

# Methods for Polarized $\bar{p}$ Beam Production

## Antihyperon decay

First and so far only experiment with **polarized 200 GeV $\bar{p}$** at Fermilab.

$\bar{\Lambda}$ production with primary 800 GeV/c proton beam.

At the end an average of **$10^4$ polarized $\bar{p}$ $s^{-1}$ with 0.45 polarization**

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

being planned:

SPACHARM project at U-70 IHEP (Protvino)

Proton beam: 50 - 60 GeV/c, polarized antiproton beam: 15 - 45 GeV/c

Intensity: $(0.8 - 4.0) \times 10^4$ polarized p/cycle, polarization: 0.45

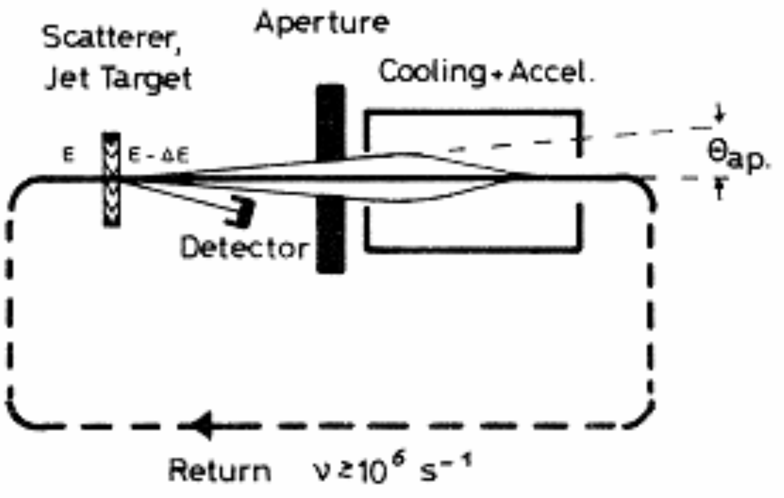
V. A. Okorokov et al., J.Phys.Conf.Ser. 938 (2017) no.1, 012014.
I. I. Azhgirey et al., J. Phys.Conf. Ser. 798 (2017) 012177.

# Methods for Polarized $\bar{p}$ Beam Production

## Spin filter method

Suggested for the ISR at CERN : P.L.Csonka, Nucl. Instr. Meth. **63** (1968) 247

**If singlet and triplet cross sections are different**, then an internal polarized target depletes one of the stored spin components faster than the other. Polarization rises on the expense of intensity.




**Spin filtering for**

**polarized antiprotons works only with cooling**

avoids beam blow up and
losses by multiple scattering

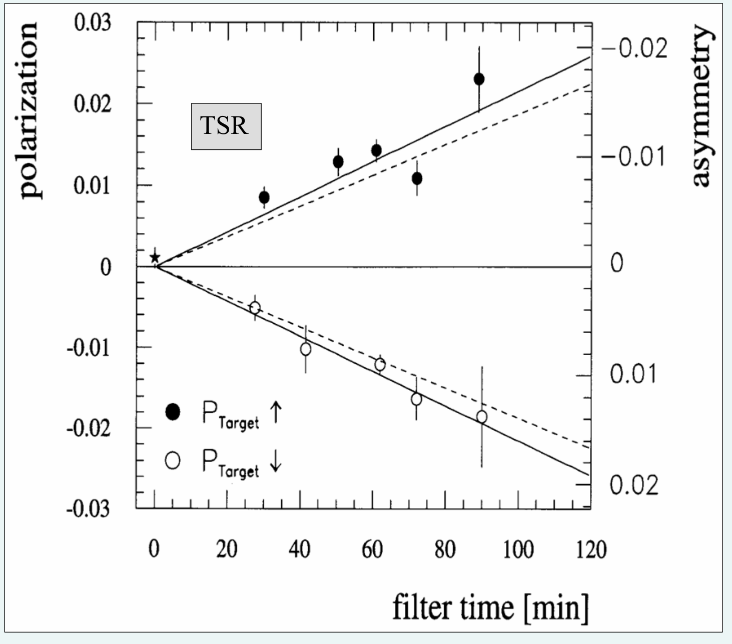
K.Kilian 1980, Pol. Conf. Lausanne,
K.Kilian & D.Moehl 1982, Erice LEAR workshop

# Methods for Polarized $\overline{p}$ Beam Production

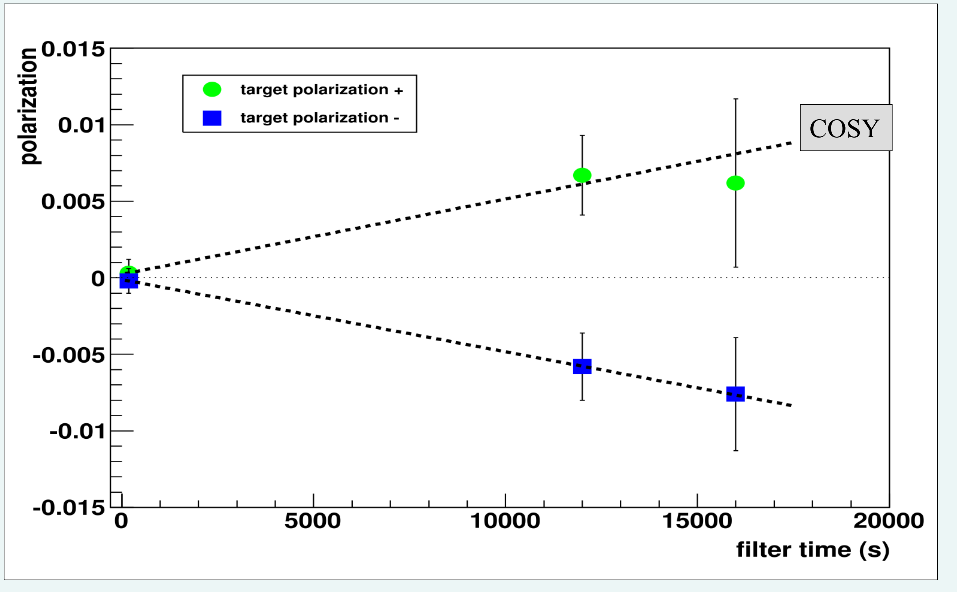
**Spin filtering**

**proposed method for FAIR → PAX**
(PAX collaboration, arXiv 0904.2325 [nucl-ex] (2009)

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))



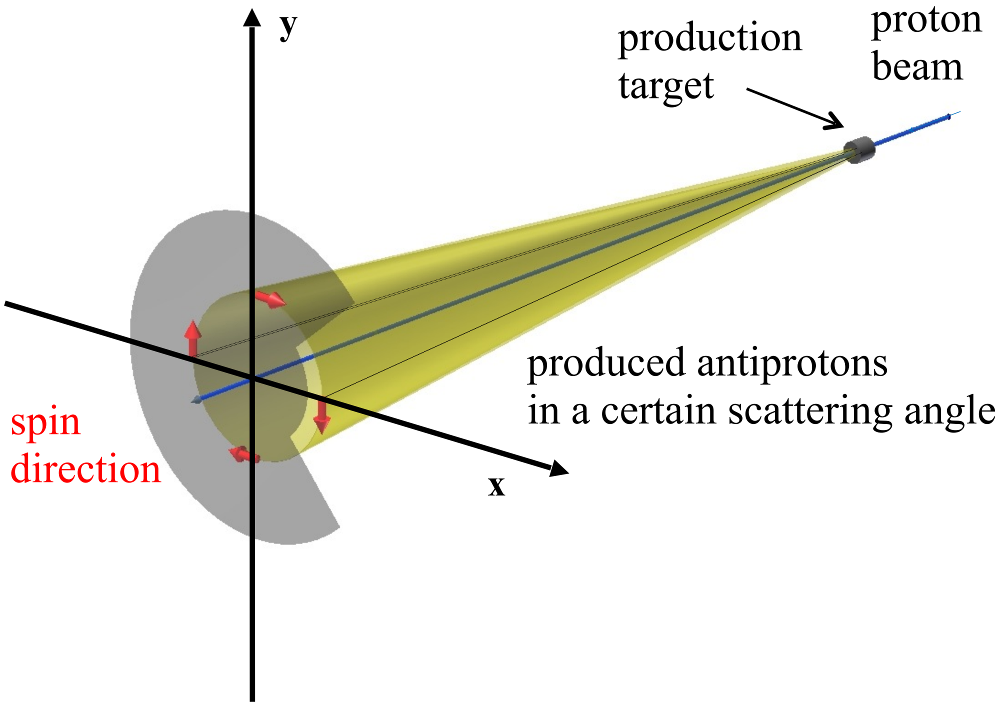

but enormous effort:
separate filter storage ring (Sibirian snakes),
filter time T ≃ 2τ (beam life time)

to be confirmed for antiprotons !

# Methods for Polarized $\overline{p}$ Beam Production

## Polarization in $\overline{p}$ Production ?

simplest method (if production polarized)




first step: check antiproton polarisation

Use the antiproton factory (nearly) as usual.

Cut one side in the horizontal angular distribution

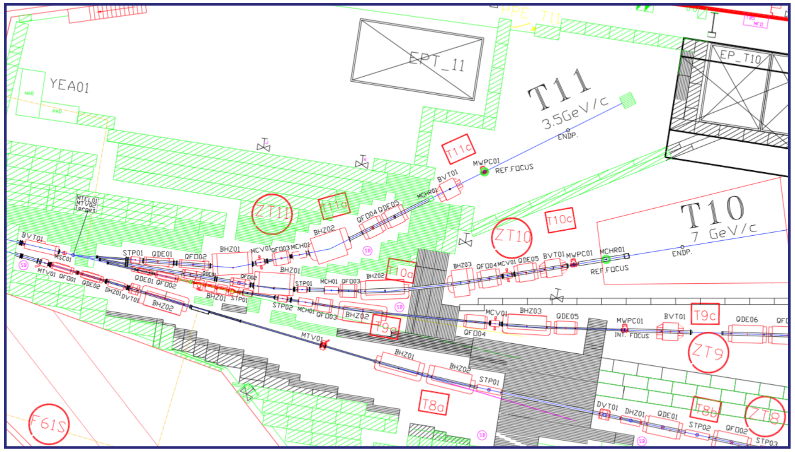
Cut up and down angles

Avoid pure s wave antiprotons

In addition avoid depolarisation in the cooler synchrotron

# Measurement of Polarization

CERN/PS testbeam east area




- 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 mr (±3mrad h, ±10mrad v)

- Measure transverse polarization via elastic $\bar{p}$ p scattering

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

$d\sigma/(d\theta d\varphi) = d\sigma/d\theta \, ( 1 + A_y * P * \cos(\varphi) )$
determination of polarization P requires knowledge of $A_y$
⇒ **CNI region**

# $A_y$ in the CNI Area

helicity frame:

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

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

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

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

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

$$\frac{d\sigma}{dt} \sim |\phi_1|^2 + |\phi_2|^2 + |\phi_3|^2 + |\phi_4|^2 + 4|\phi_5|^2$$

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

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

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

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)

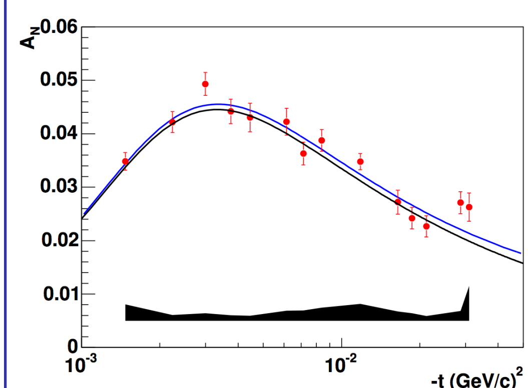
$A_y^{had}(t) \approx \sqrt{t/s}$ (negligible for $t/s \to 0$ )

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

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

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

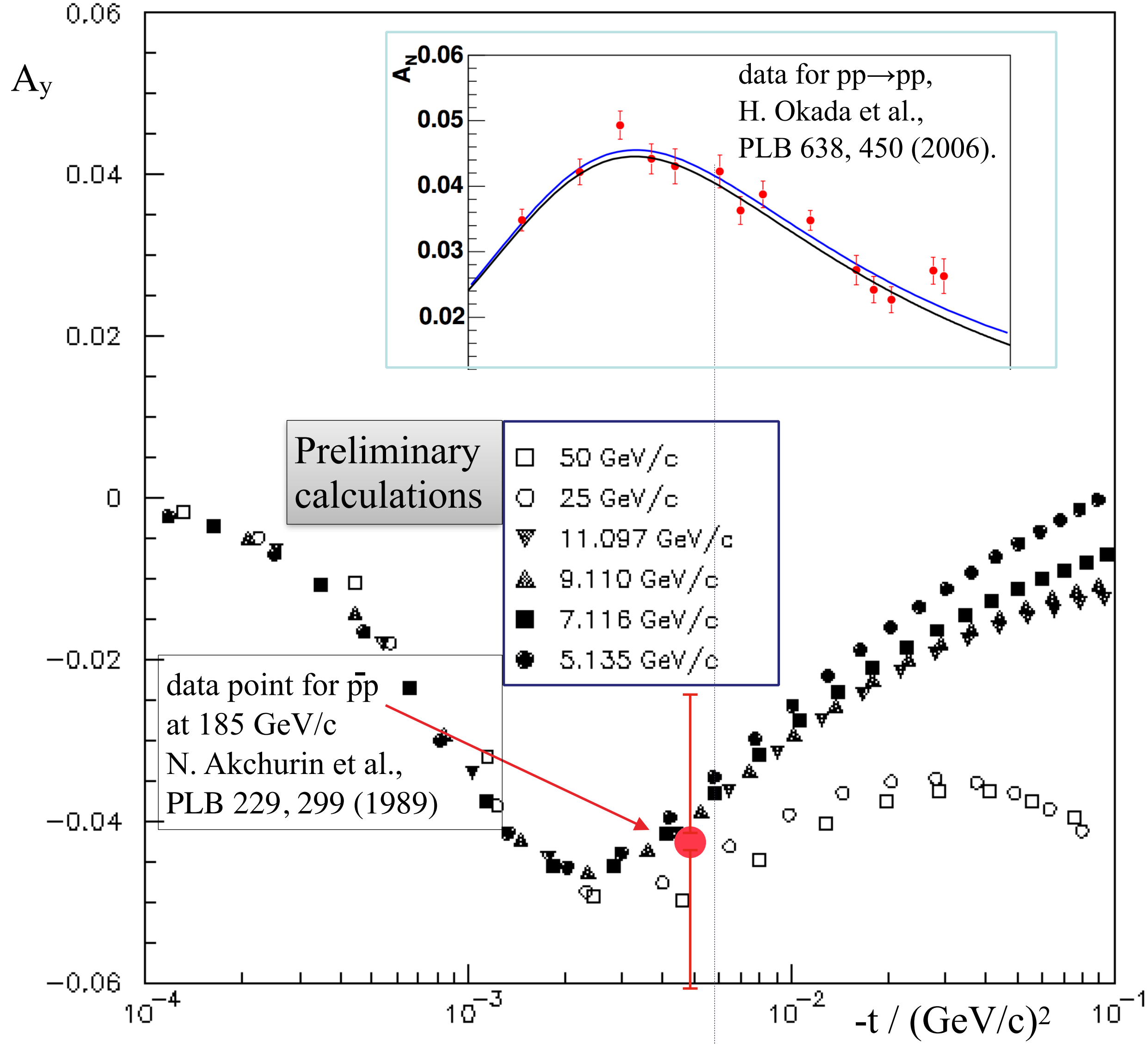
($\mu$ : magnetic moment)




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

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

# $A_y$ in the CNI Area




preliminary
calculations for pp → pp
(J. Haidenbauer, priv. comm.)
one-boson-exchange
NN potential,
potential parameters determined
by fit to experimental
NbarN data,
(Phys.Rev.D89,114003 (2014)



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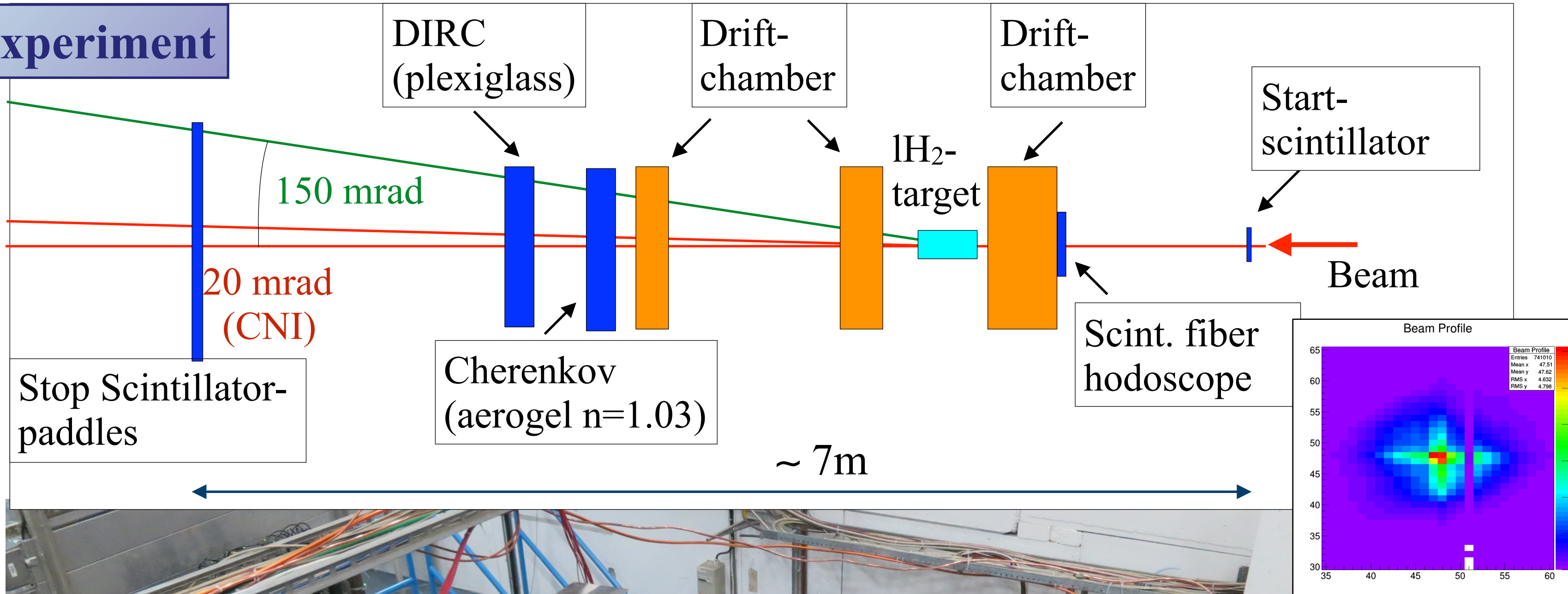
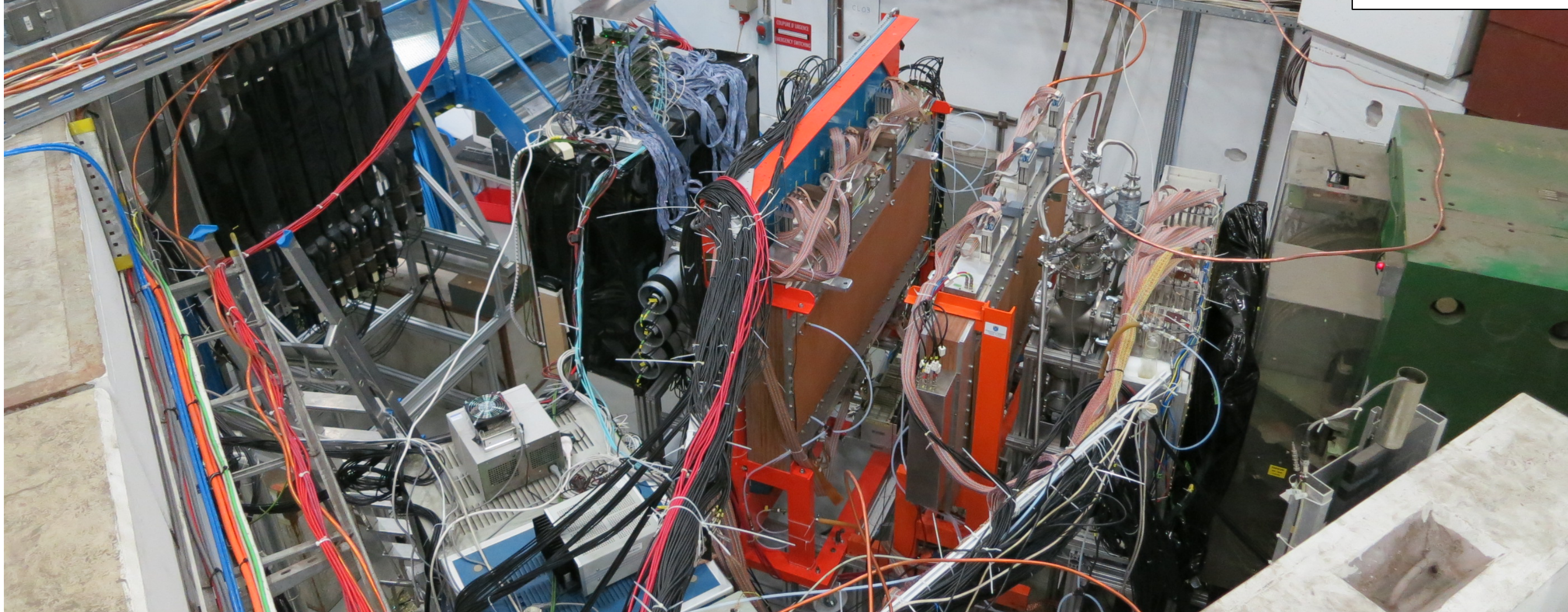
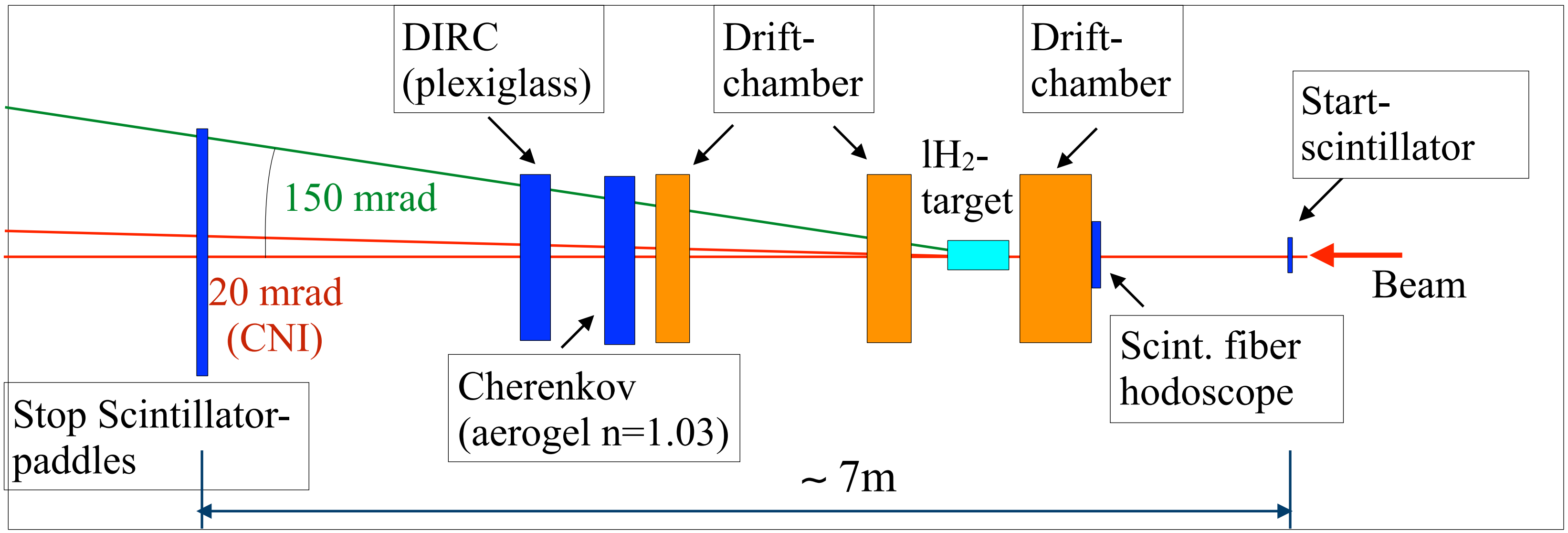
# P349 Experiment

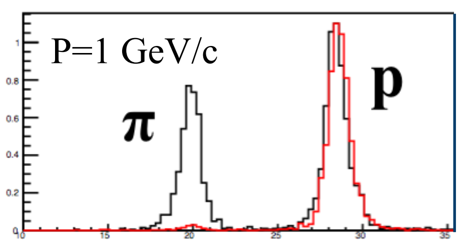


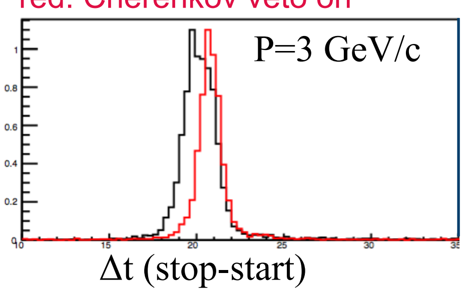
# P349 Experiment

trigger: start ∧ stop ∧ (no Cherenkov-signal)



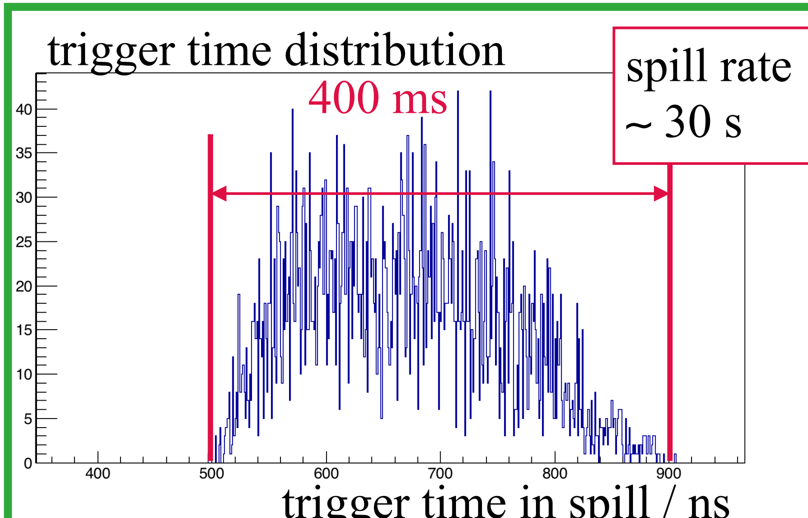




separate datasets:
black: data no Cherenkov veto
red: Cherenkov veto on




check of
Cherenkov veto
with p/$\pi$+

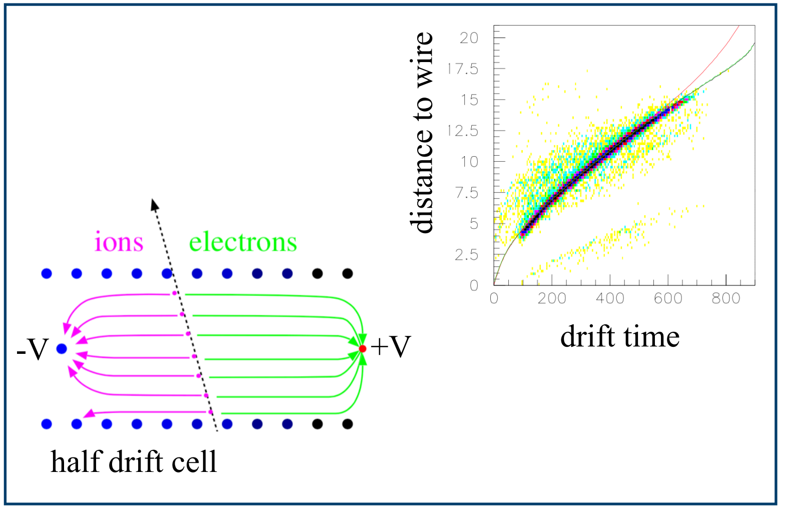
→ suppression
of pions
~ 1/30



# P349 Experiment

Data analysis procedure to determine the polarization

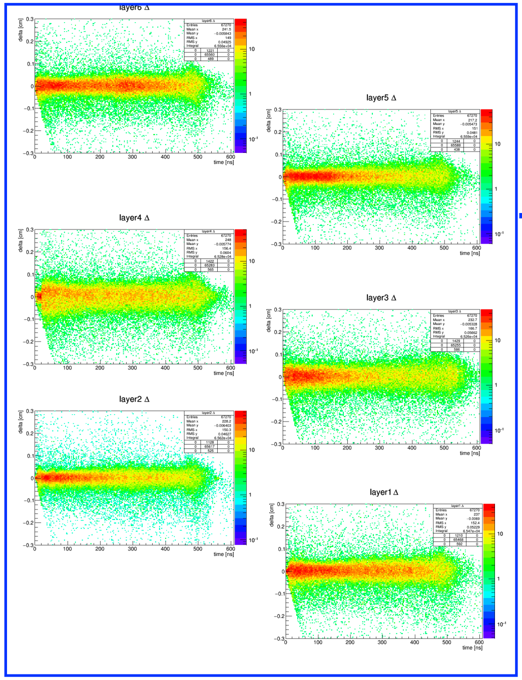
- ✓ track reconstruction of beam particles
- ✓ track reconstruction of scattered particles
    - ✓ drift chamber calibration
    - ✓ detector positioning

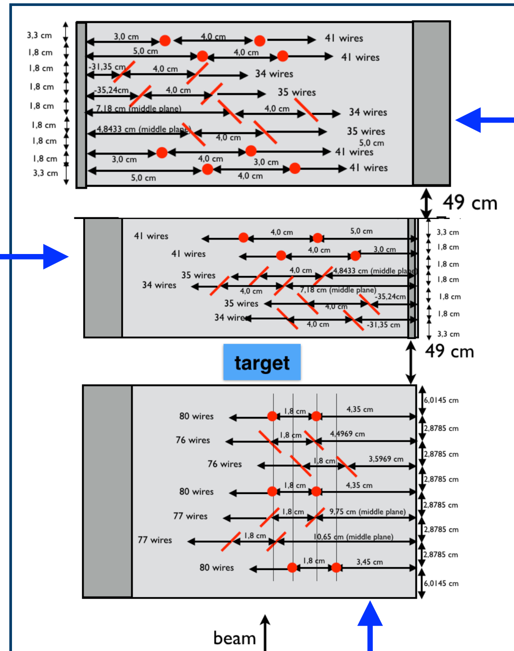


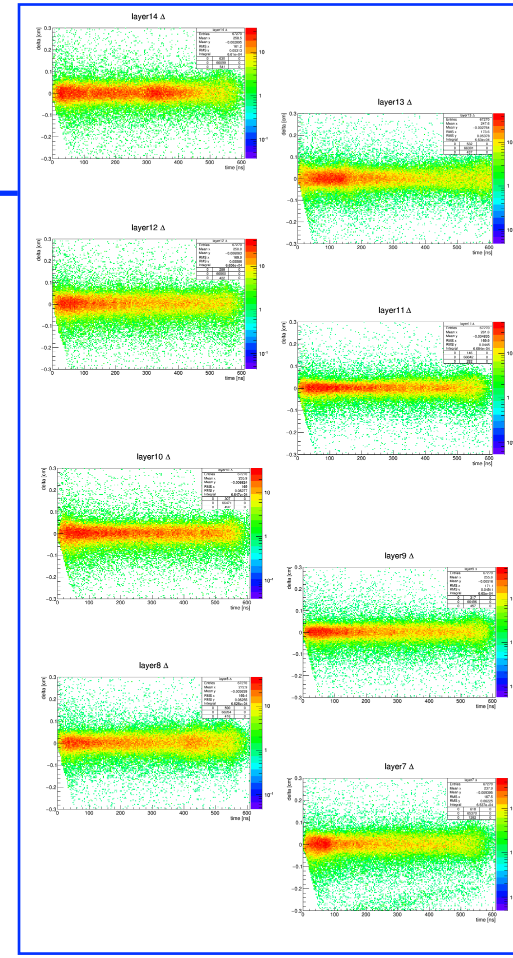

- particle identification
    - DIRC
      position/angle dependent analysis of photon distribution
- extraction of elastic scattering events
- determine polarization from $\varphi$ angular distribution

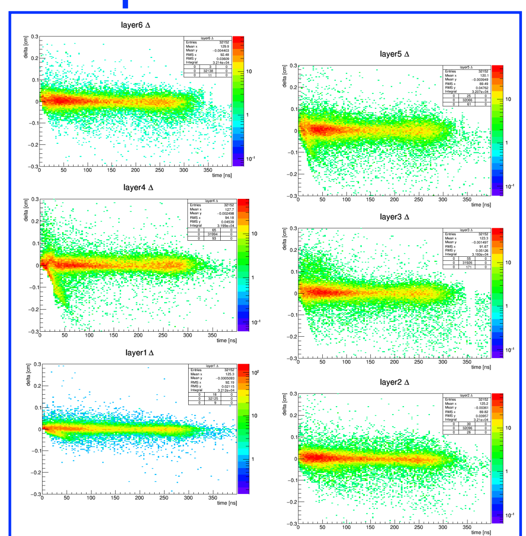
# Status of the Analysis

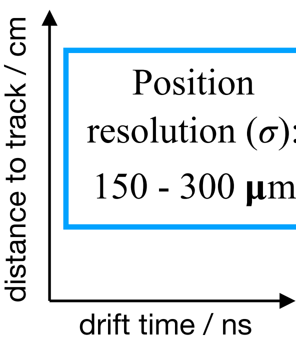
## Drift Chamber Calibration





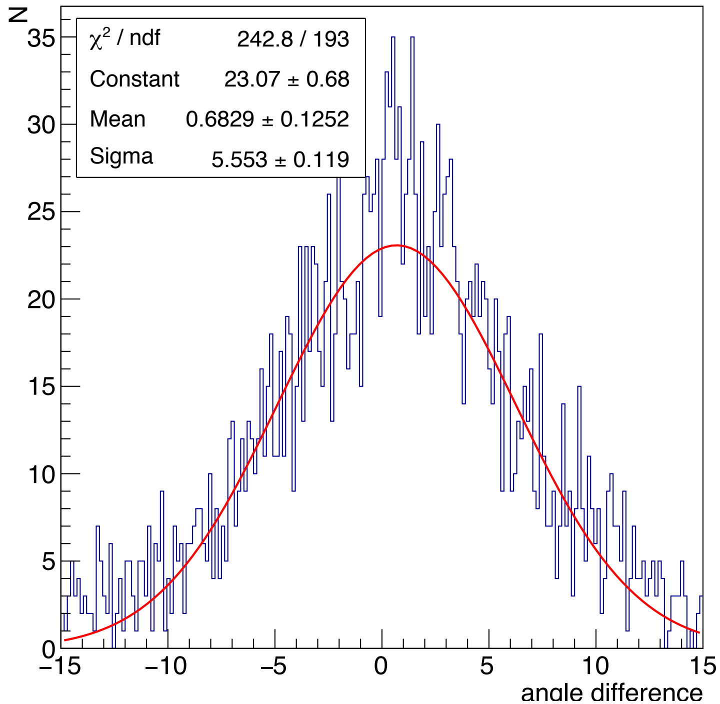





Position resolution ($\sigma$): 150 - 300 µm

⇨ expected track resolution: < 1 mrad

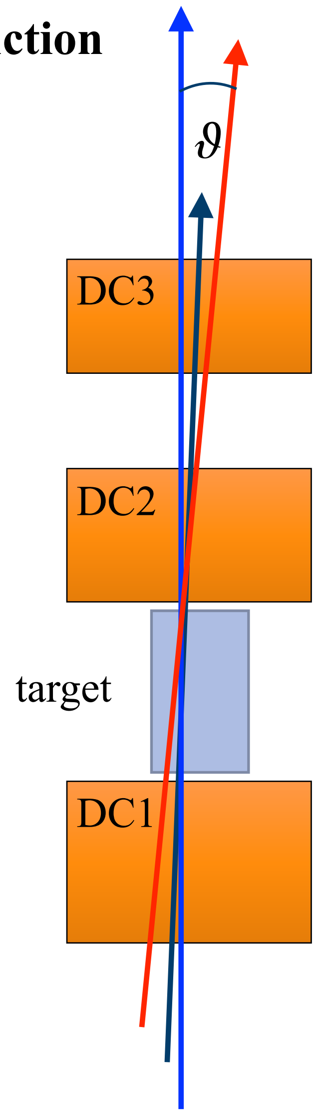
# Track Reconstruction




$\vartheta$(DC1-track - DC2/DC3-track) / mrad

track resolution: ~ 5 mrad

⟹ optimize calibration and DC positioning




1. selection of unscattered particles: track fit including signals of all 3 DC's

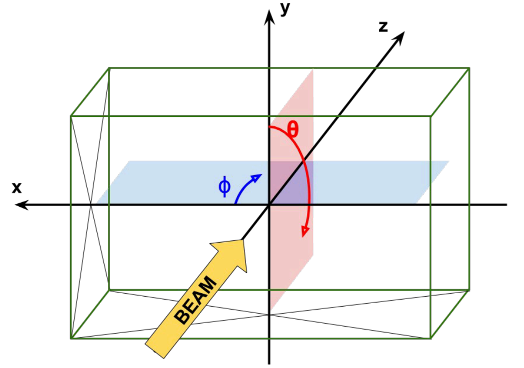
2. reference track: track fit from DC1 signals

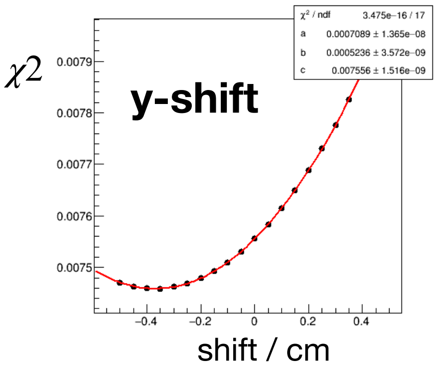
3. determine track resolution: track fit from DC2+DC3 signals

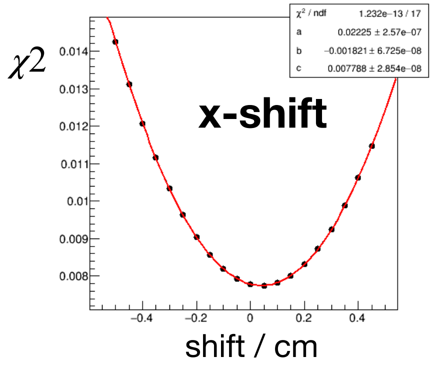
# Status of the Analysis

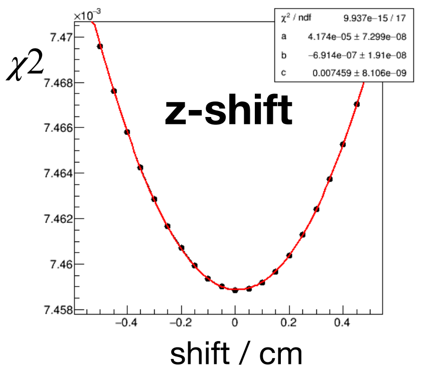
## DC Positioning

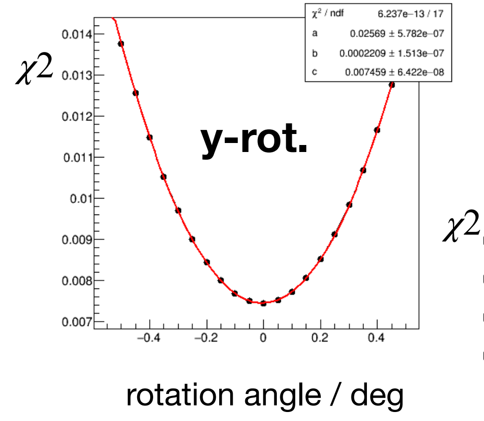
DC3 is shifted/rotated relative to DC2
determine mean $\chi 2$ for track fit
as a function of shift

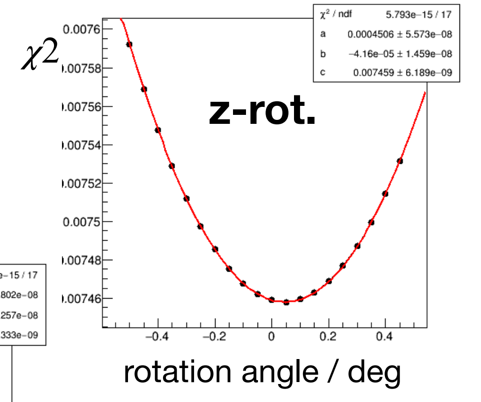


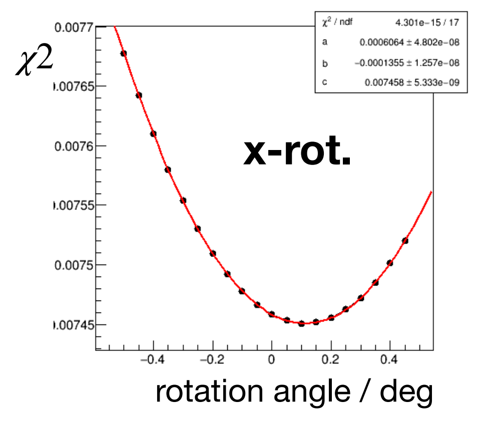



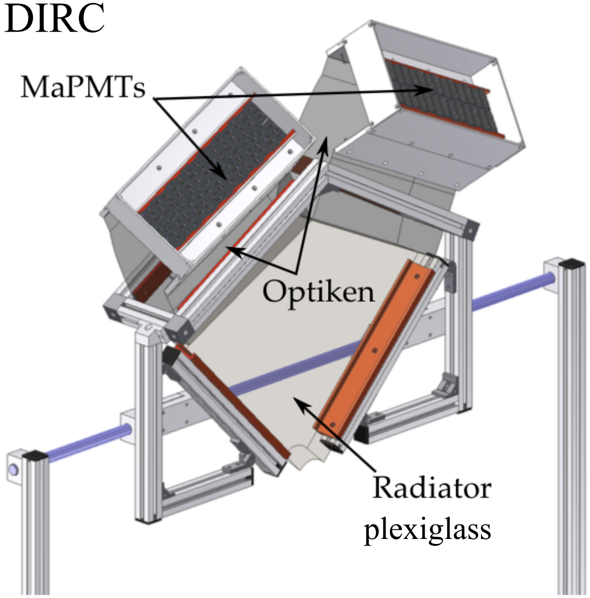



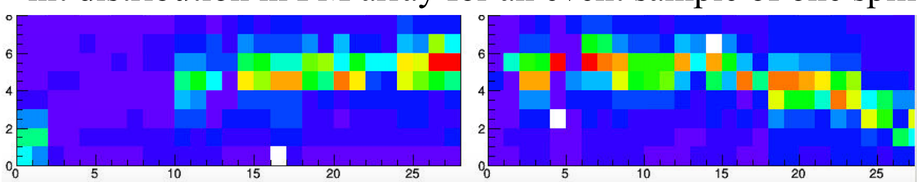

track reconstruction precision
sufficient for positioning

# DIRC Analysis

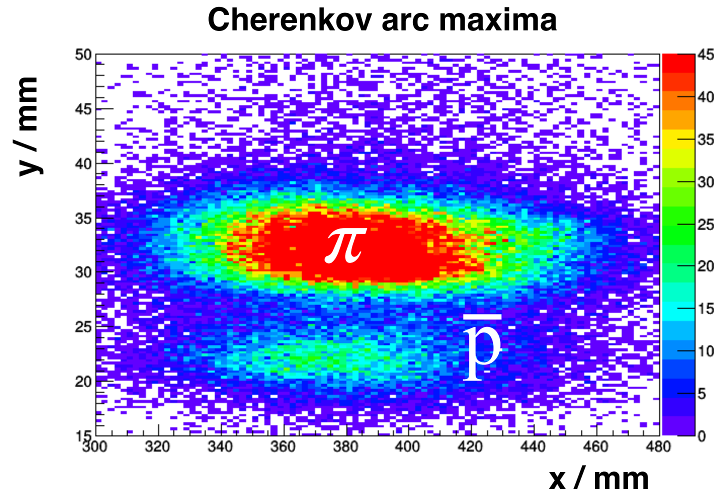
DIRC



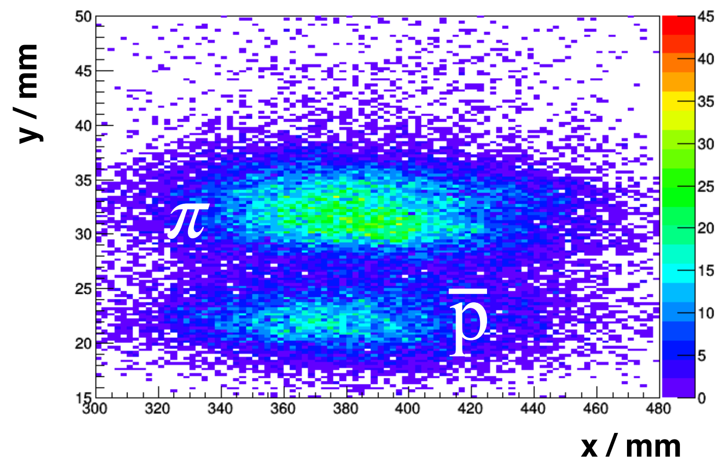

hit distribution in PM array for an event sample of one spill



Particle identification works
requires position and angular dependent
Cherenkov arc reconstruction (MC supported)




with additional offline cut on aerogel signals



# Summary and Outlook

- Data have been taken for the analysis of antiproton polarization
- Track reconstruction and particle identification works
- Data analysis is ongoing : fine tuning of DC calibration and positioning
  detailed DIRC analysis
  extraction of $\overline{p}$ scattering event and polarization determination

- additional measurement in July/August 2018 with improved detector setup