Polarization analysis of antiprotons produced in pA collisions

D. GRZONKA, FORSCHUNGSZENTRUM JÜLICH

CERN/PS P349

D. Alfs, D. Grzonka, F. Hauenstein*, K. Kilian, D. Lersch, J. Ritman, T. Sefzick	IKP, Forschungszentrum Jülich, 52425 Jülich, Germany
B. Glowacz, P. Moskal, M. Zielinski	IP, Jagiellonian University, ul. Reymonta 4, PL-30 -059 Krakow, Poland
M. Diermaier, E. Widmann, J. Zmeskal	SMI für subatomare Physik, Boltzmanngasse 3, 1090 Wien, Austria
W. Oelert	Johannes Gutenberg-Universität Mainz, 55099 Mainz, Germany
M. Wolke	Dep. of Physics and Astronomy, Uppsala University, Box 516, 751 20 Uppsala, Sweden
P. Nadel-Turonski	Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606
M. Carmignotto, T. Horn,	PD, The Catholic University of America, 210 Hannan Hall, Washington, DC 20064
H. Mkrtchyan, A. Asaturyan, A. Mkrtchyan, V. Tadevosyan, S. Zhamkochyan	A. I. Alikhanyan Science Laboratory (Yerevan Physics Institute), Yerevan 0036, Armenia
S. Malbrunot-Ettenauer	CERN, Physics department
W. Eyrich, A. Zink	PI, Universität Erlangen, Erwin-Rommel-Strasse 1, 91058 Erlangen, Germany

*Present address: Old Dominion University, Norfolk, Virginia, USA

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Polarization analysis of antiprotons produced in pA collisions

- 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 $\bar{p}$ arXiv 0904.2325 [nucl-ex] (2009)

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

e.g. : $\bar{p}$ 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 $\overline{p}$ 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)

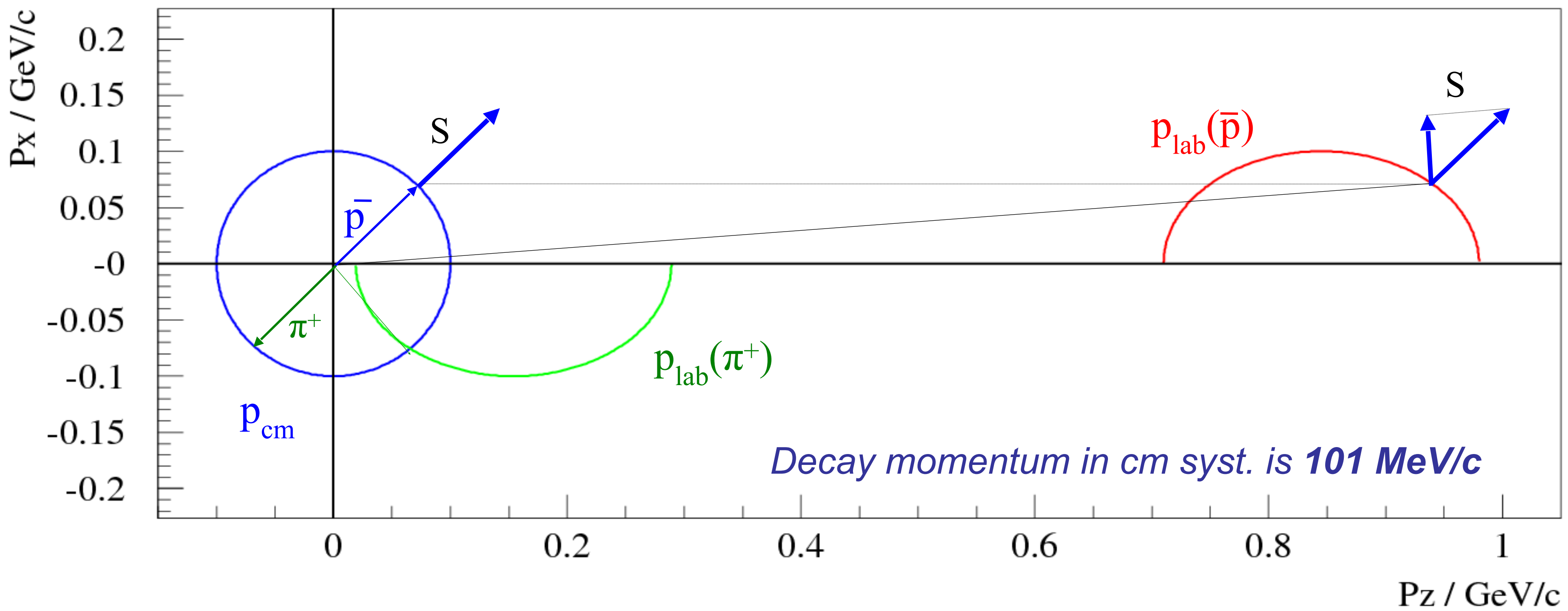
E. Steffens, AIP Conf.Proc 1008, 1-5 (2008), AIP Conf.Proc.1149, 80-89 (2009)

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 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

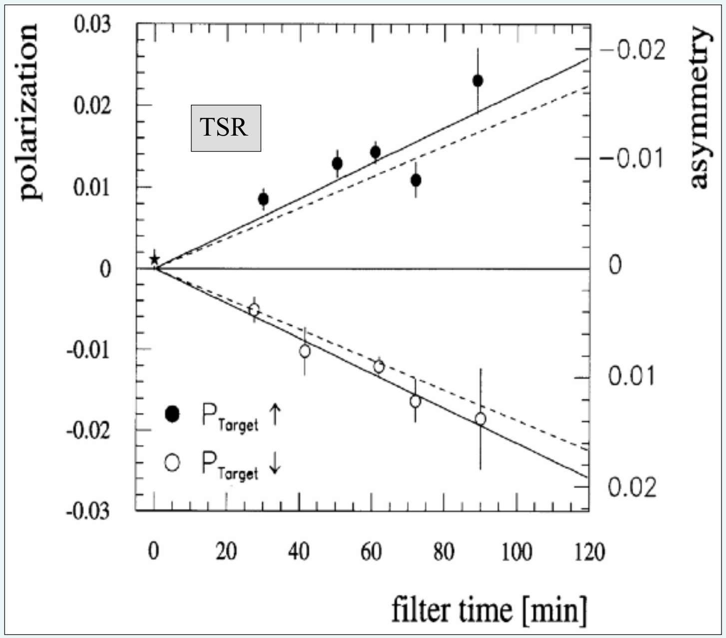
V. A. Okorokov et al., J.Phys.Conf.Ser. 938 (2017) no.1, 012014.
I. I. Azhgirey et al., J. Phys.Conf. Ser. 798 (2017) 012177.

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

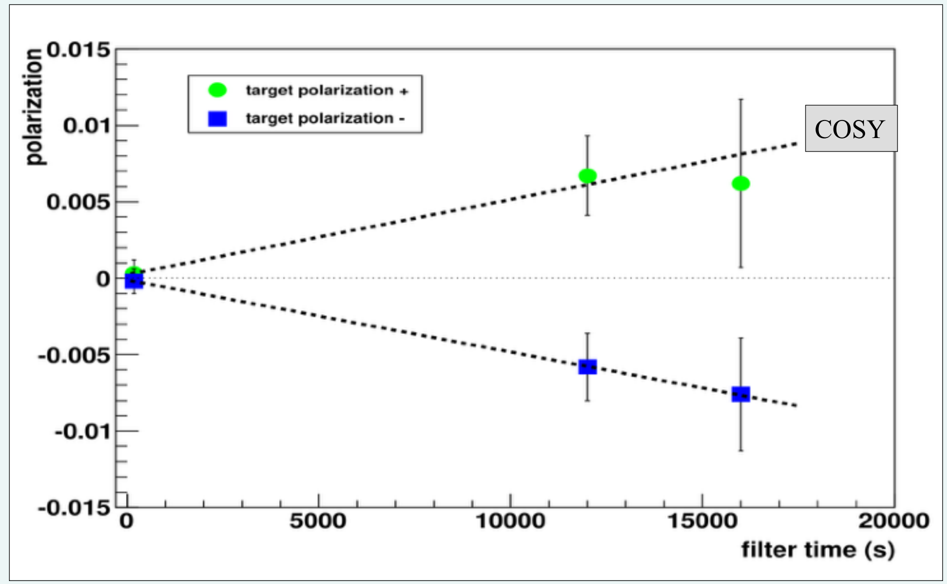
Spin filtering

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))



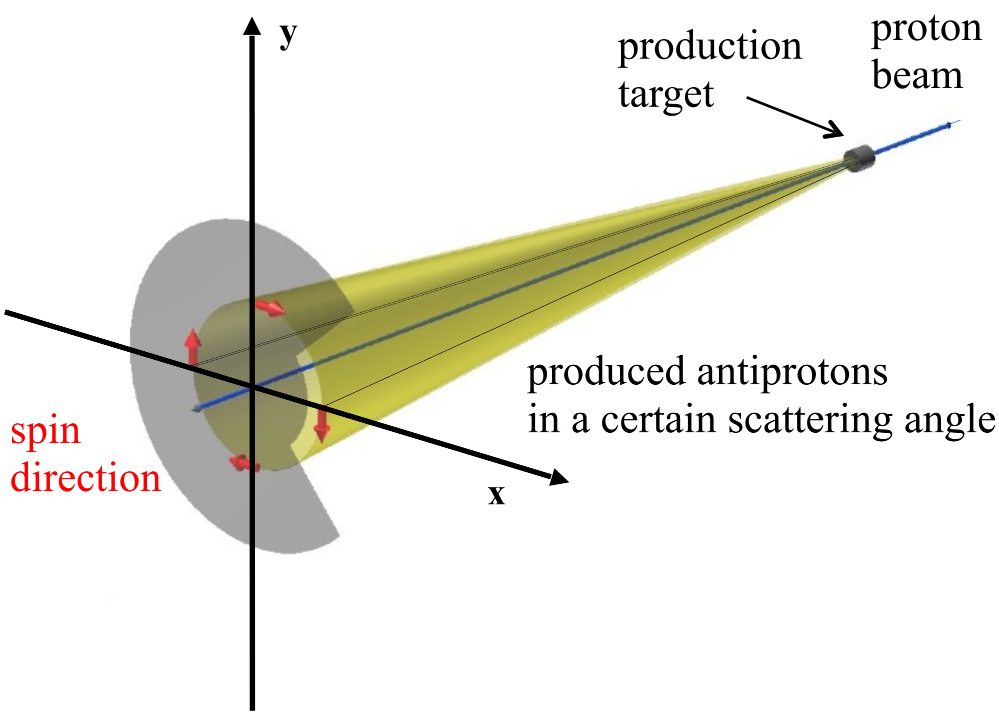
but enormous effort:
separate filter storage ring (Sibirian snakes),
filter time T ≃ 2τ (beam life time)

to be confirmed for antiprotons !

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

Polarization in $\bar{p}$ 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

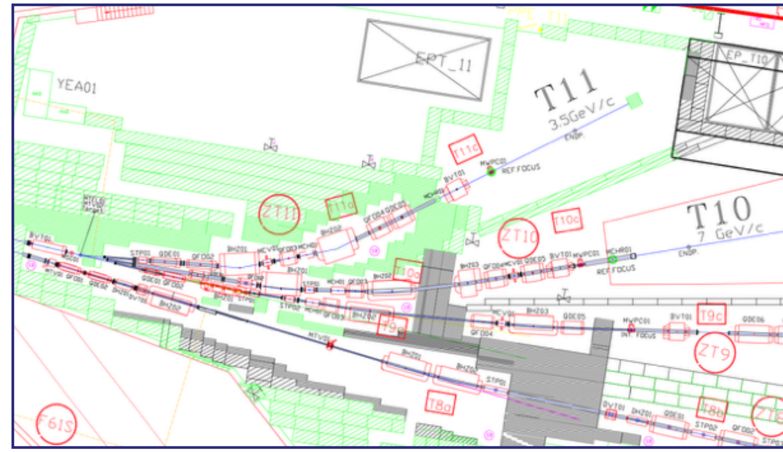
Cut up and down angles

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 (θ_{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 $t/s \to 0$)

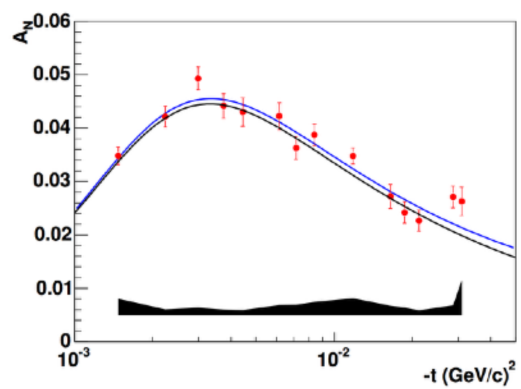
$$A_y^{int}(t) = A_y^{int}(t_p)\,\frac{4\,(t/t_p)^{3/2}}{3\,(t/t_p)^2 + 1}$$

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

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

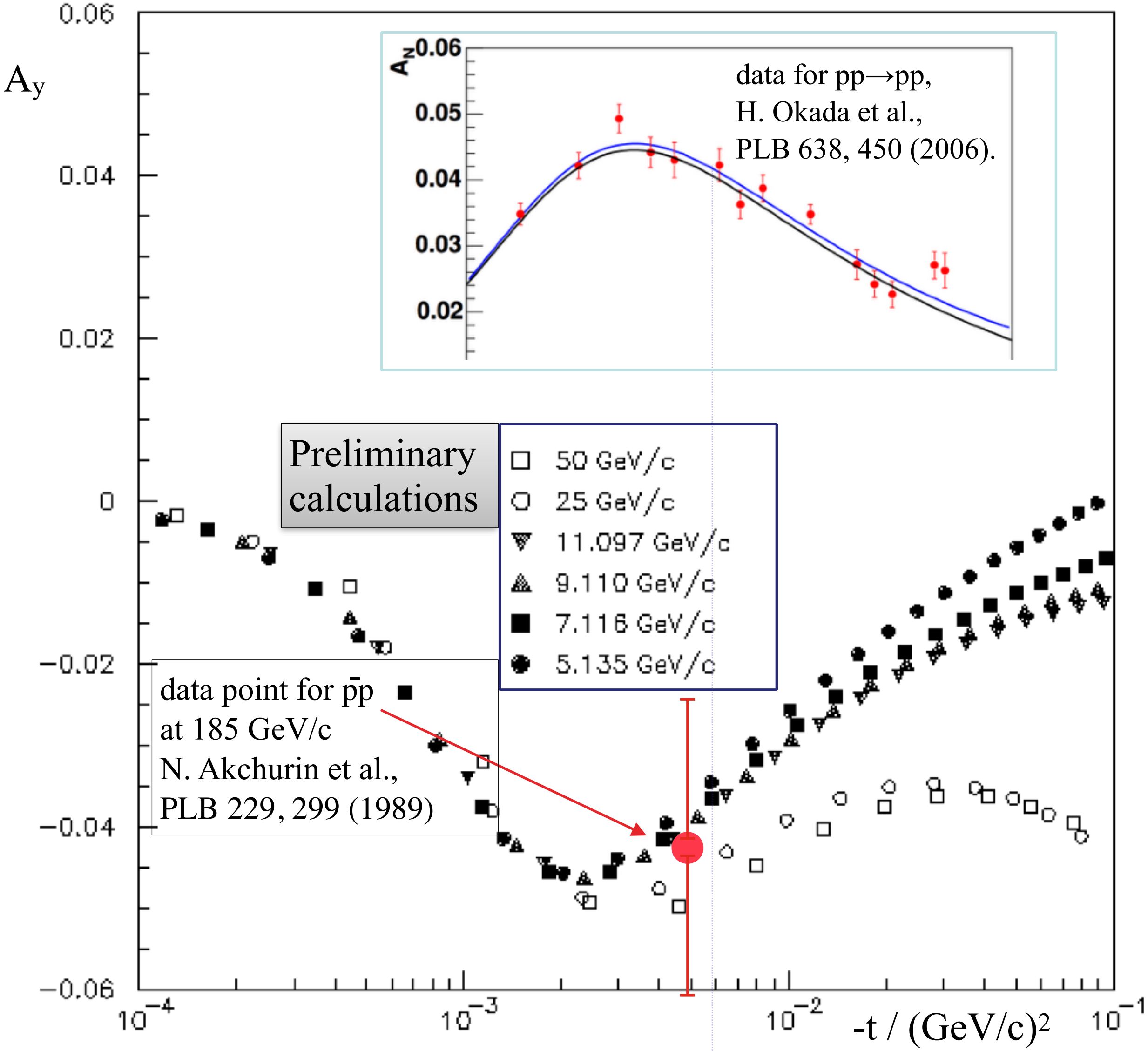
(μ : magnetic moment)

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



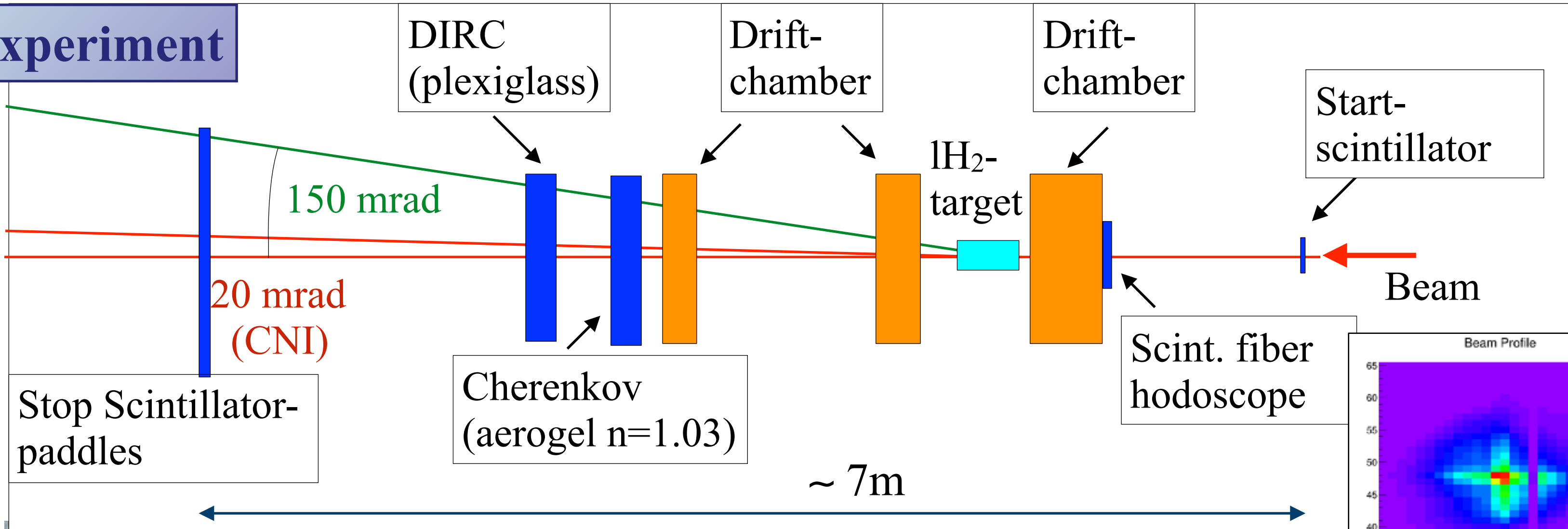
data for pp→pp,
P_p=100 GeV/c,
($\sqrt{s}$ = 13.7 GeV)
H. Okada et al.,
PLB 638,
450 (2006).

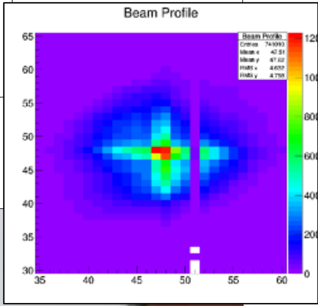
A_y in the CNI Area

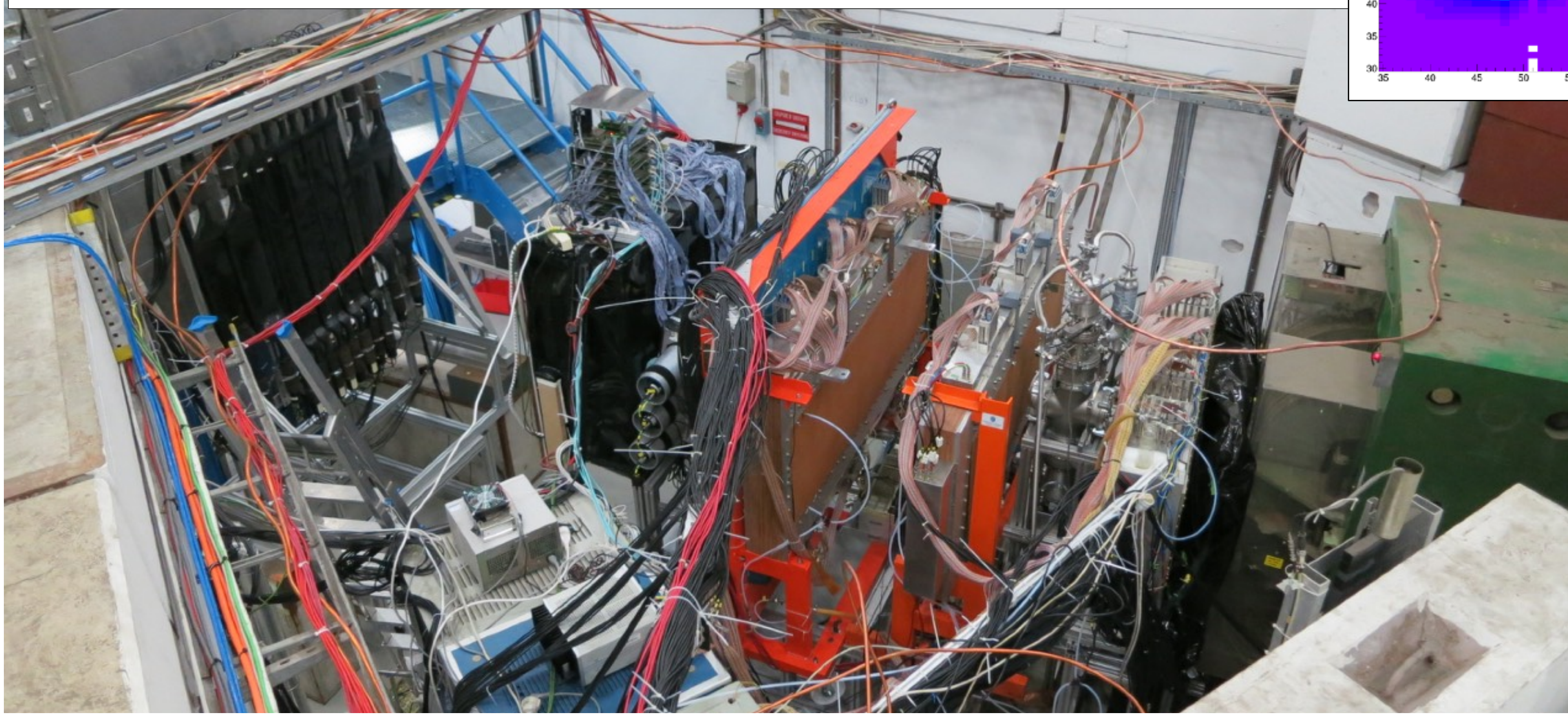


preliminary calculations for pp → pp (J. Haidenbauer, priv. comm.) one-boson-exchange NN potential, potential parameters determined by fit to experimental NbarN data, (Phys.Rev.D89,114003 (2014)

P349 Experiment

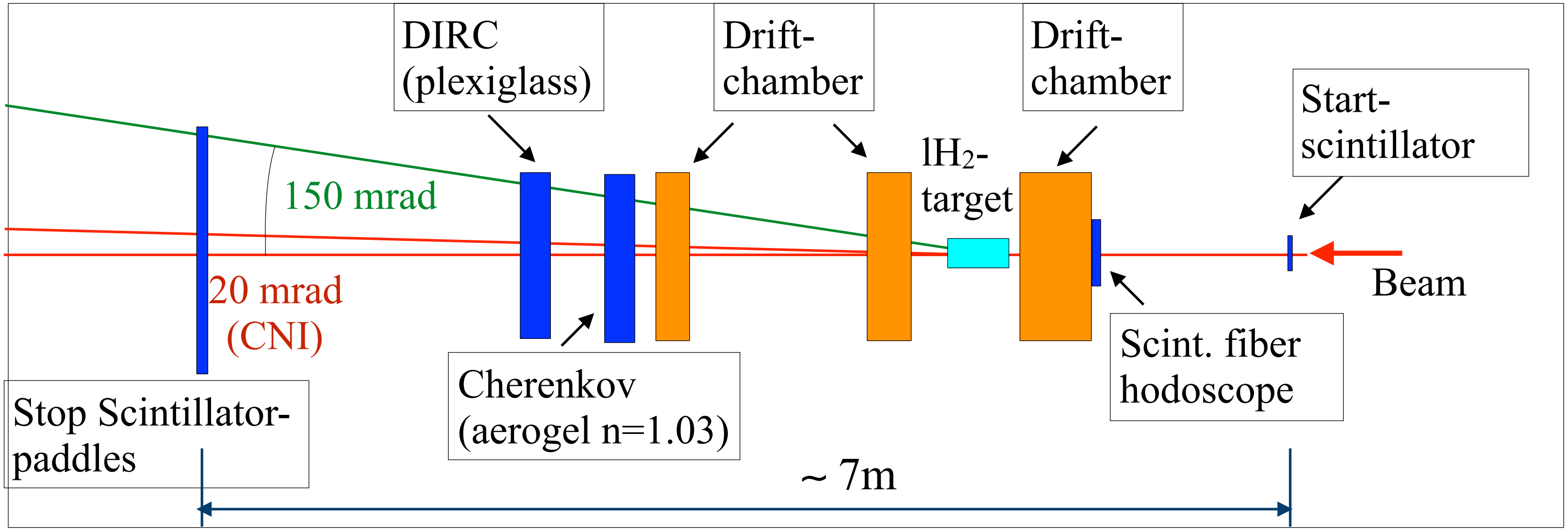


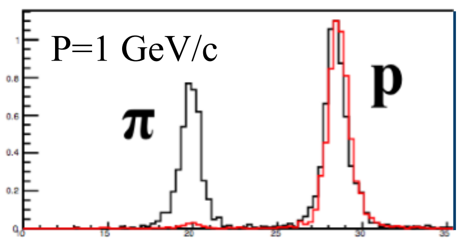




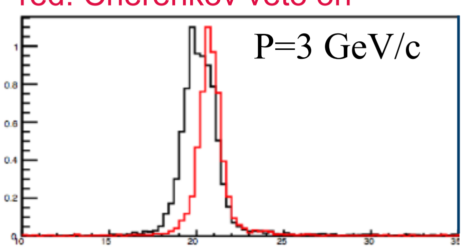
P349 Experiment

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



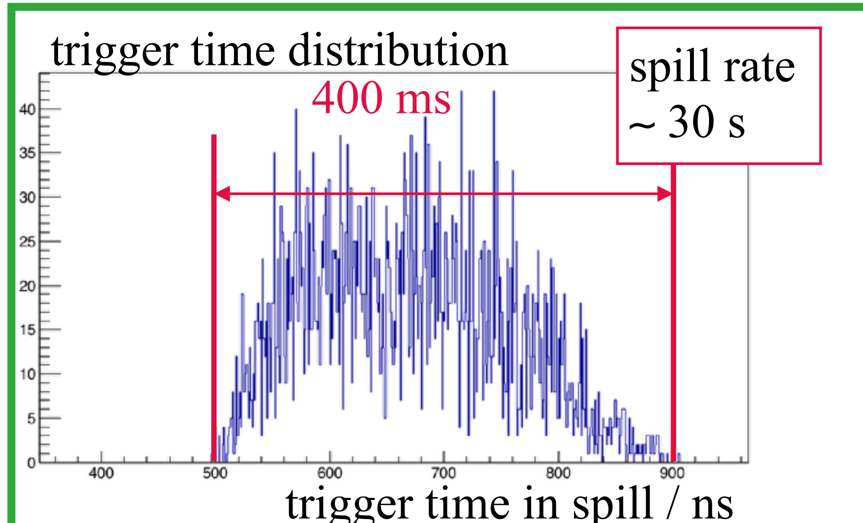


separate datasets:
black: data no Cherenkov veto
red: Cherenkov veto on



check of Cherenkov veto with p/π+

→ suppression of pions ~ 1/30



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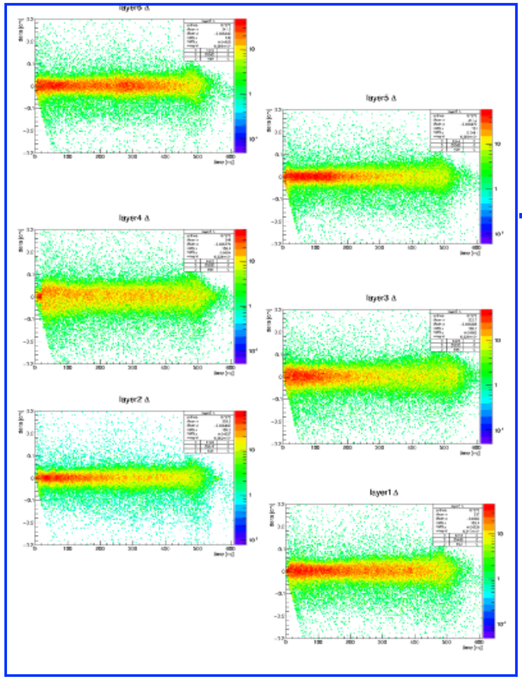
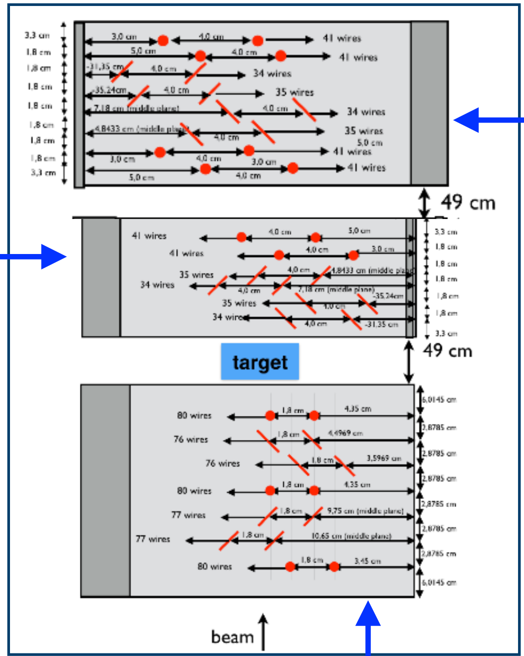
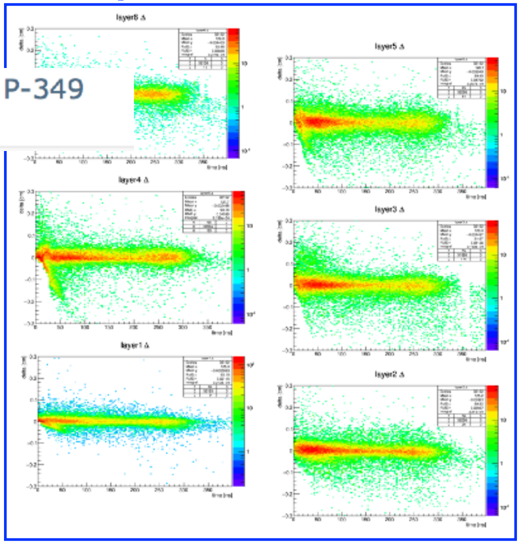
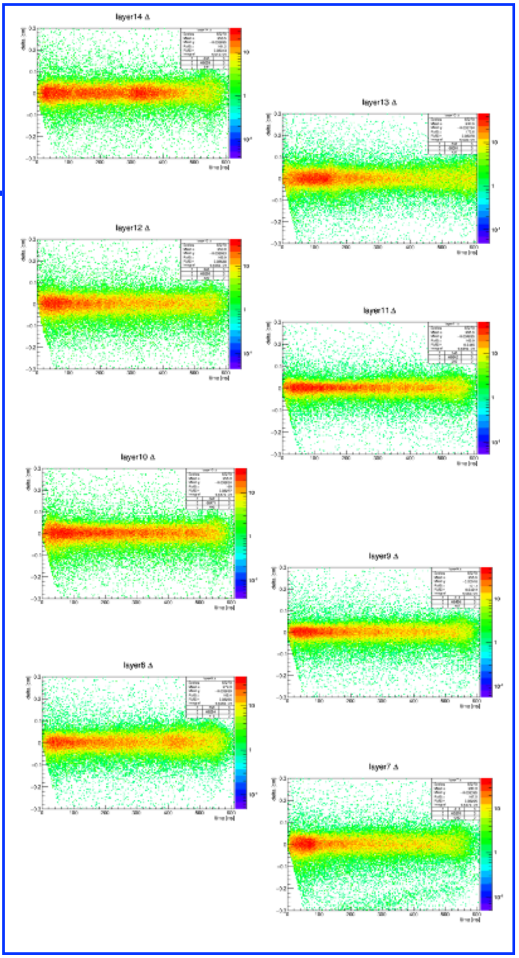
Status of the Analysis

Drift Chamber Calibration

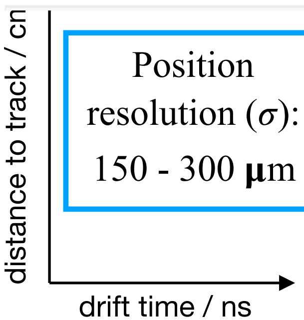








Drift chamber calibration and particle identification in the P-349 experiment



Position resolution (σ): 150 - 300 µm

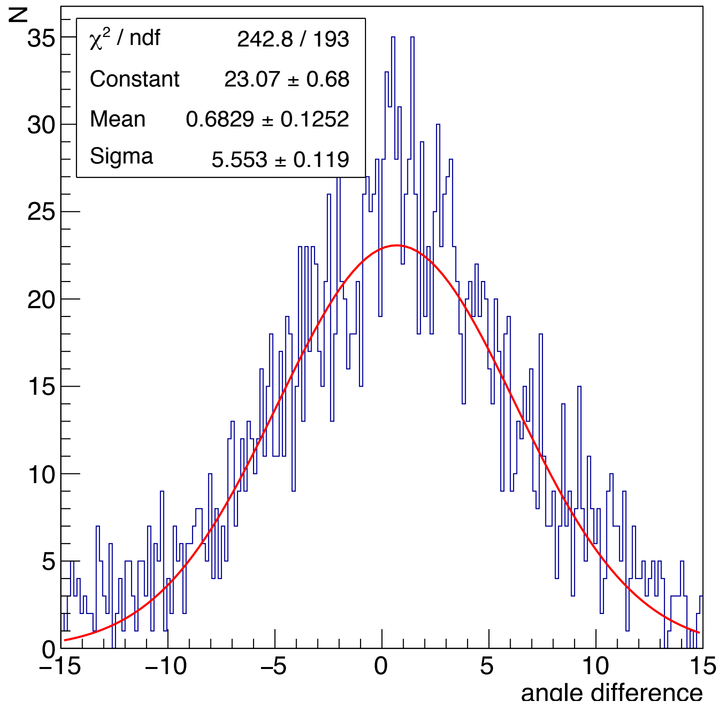
⇨ expected track resolution: < 1 mrad

Poster: Drift chamber calibration and particle identification in the P-349 experiment
Marcin Zieliński

JÜLICH Forschungszentrum

Status of the Analysis

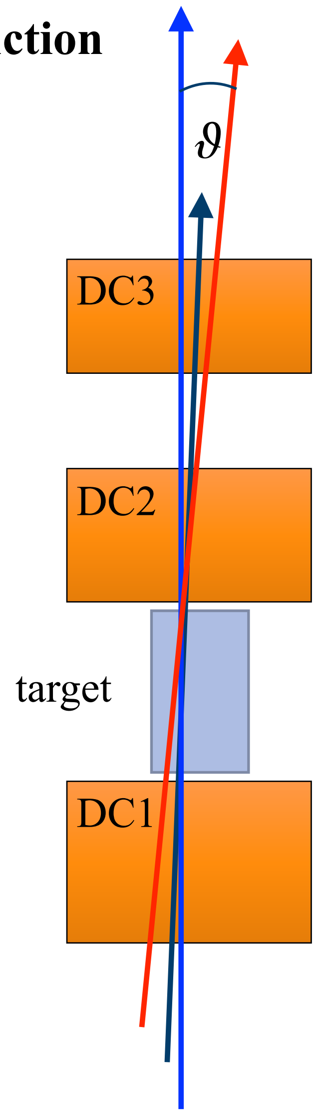
Track Reconstruction



ϑ(DC1-track - DC2/DC3-track) / mrad

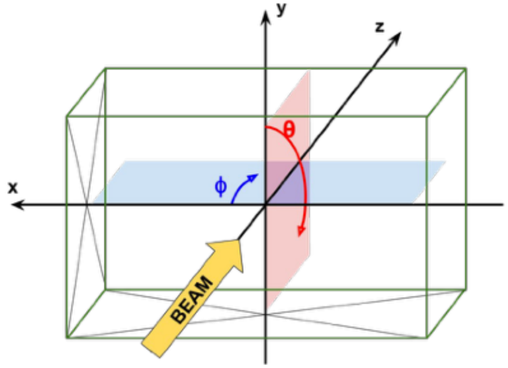
track resolution: ~ 5 mrad

$\Longrightarrow$ optimize calibration and DC positioning

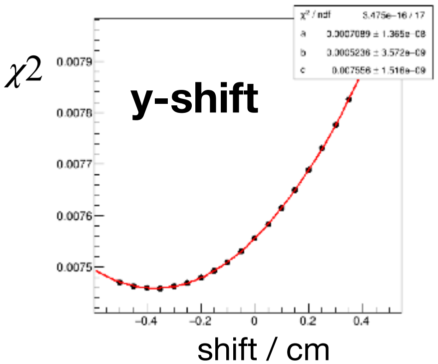


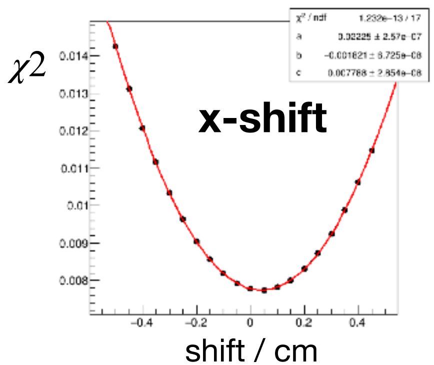
1. selection of unscattered particles:
   track fit including signals of all 3 DC's
2. reference track:
   track fit from DC1 signals
3. determine track resolution:
   track fit from DC2+DC3 signals

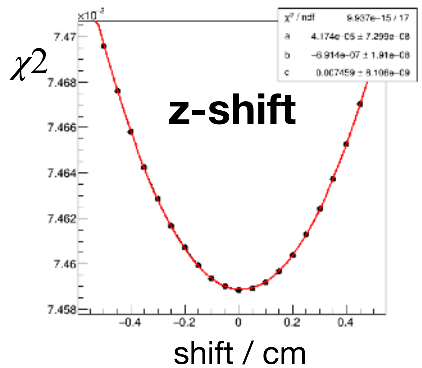
DC Positioning

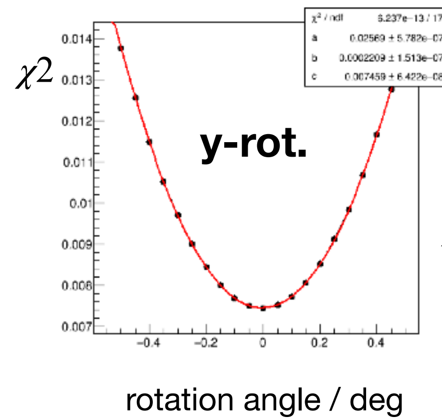


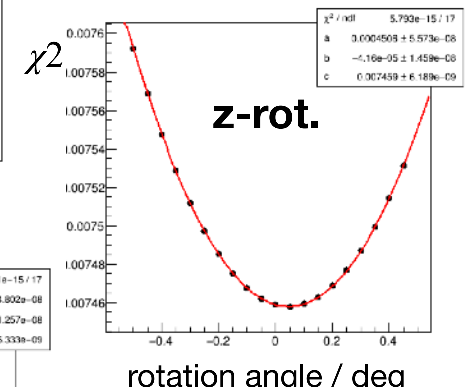
DC3 is shifted/rotated relative to DC2
determine mean $\chi 2$ for track fit
as a function of shift

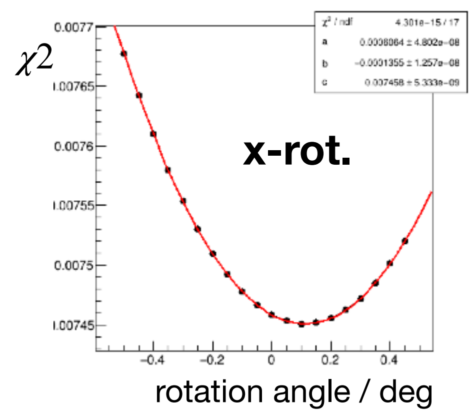










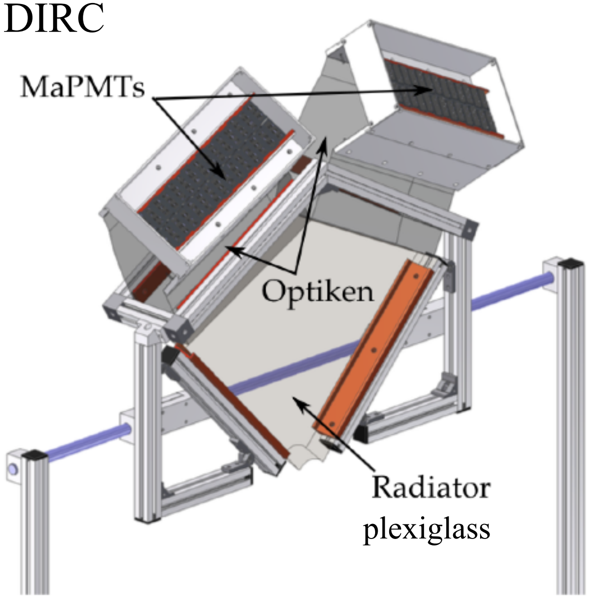


track reconstruction precision sufficient for positioning

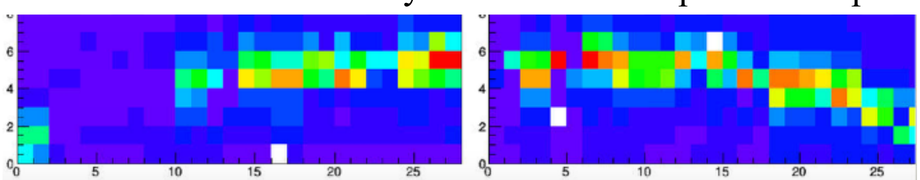
Status of the Analysis

DIRC Analysis

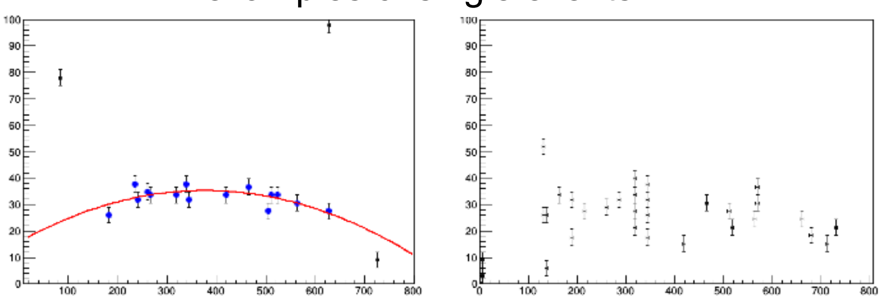
DIRC



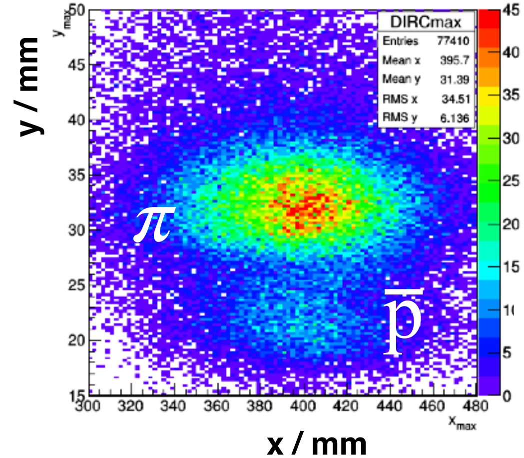
hit distribution in PM array for an event sample of one spill

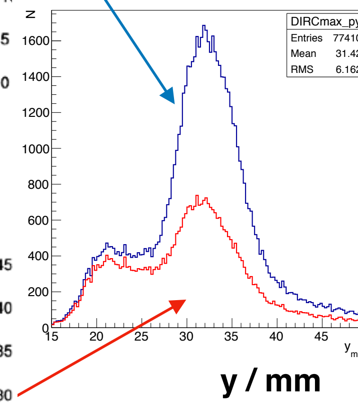


examples of single events

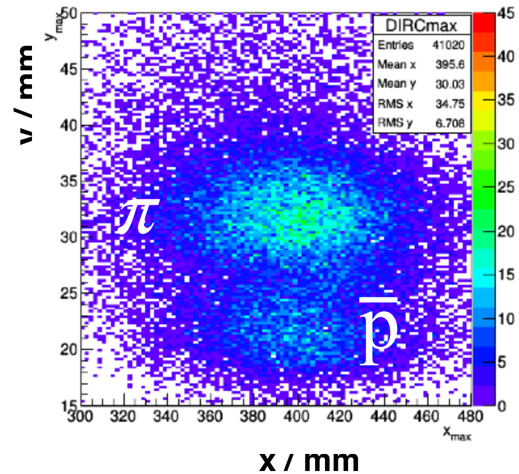


Cherenkov arc maxima



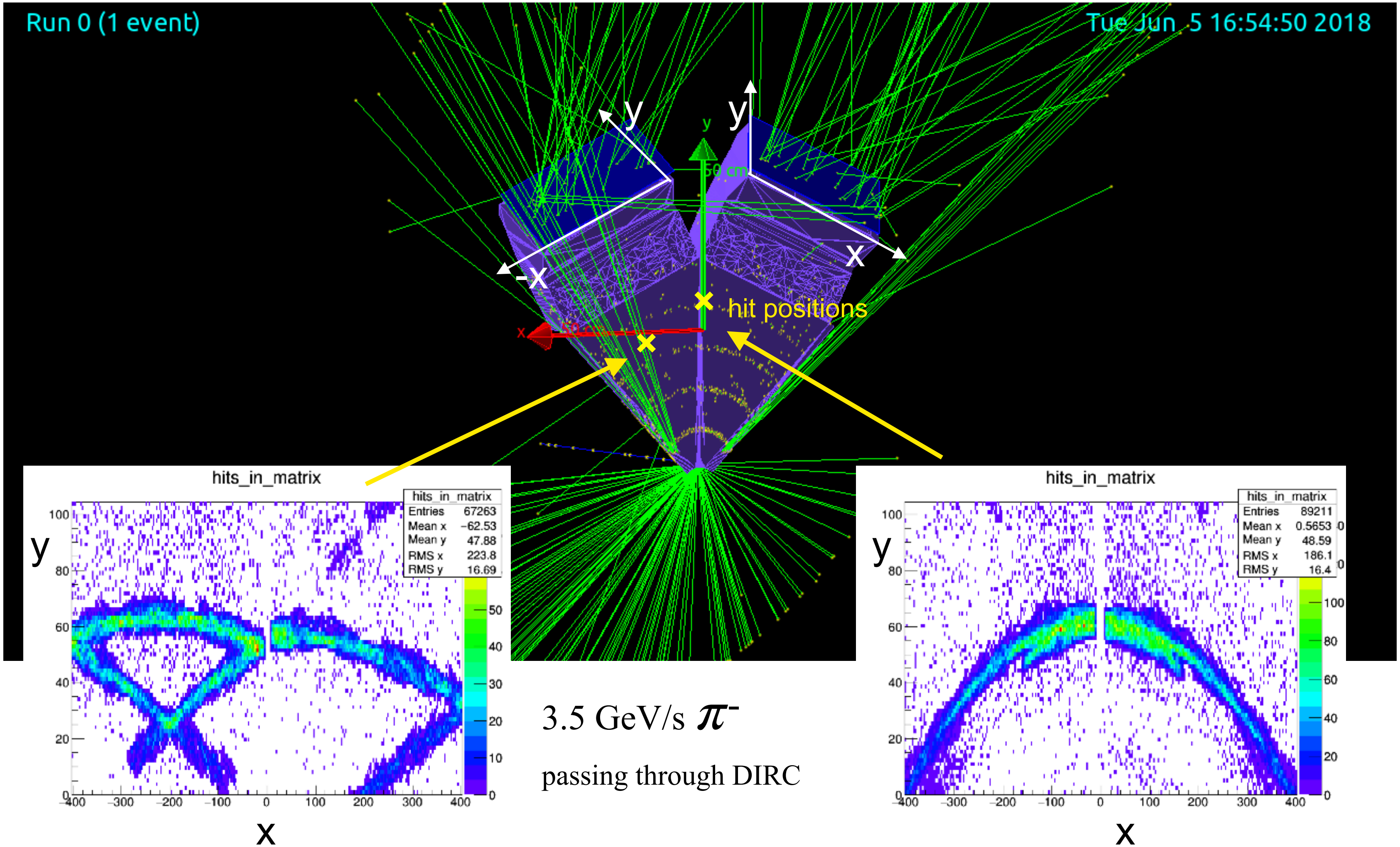


with additional offline cut on aerogel signals



Particle identification works
requires more detailed analysis

Cherenkov photon generation in DIRC with GEANT4



3.5 GeV/s π^-

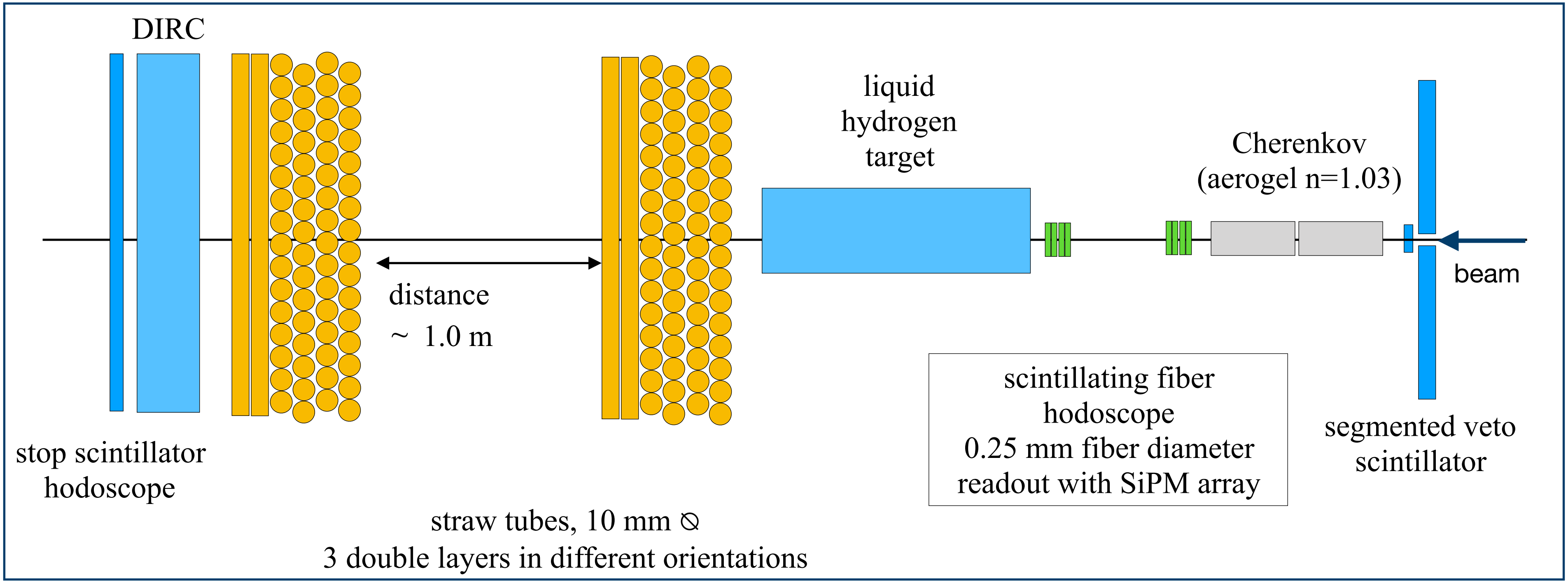
passing through DIRC

$\Longrightarrow$ position and track angle dependent distribution to be considered for particle ID determination

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 $\bar{p}$ scattering event and polarization determination

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



Detection system for the new measurement