Search for polarization effects in the antiproton production process

→ CERN Experiment P349

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- Introduction
- Motivation
- How to get polarized $\bar{p}$
    - $\bar{\Lambda}$-decay
    - Spin-filter method
    - Polarization in $\bar{p}$ production
- Measurement of polarization
    - CNI region
- Experimental setup
- Possible results

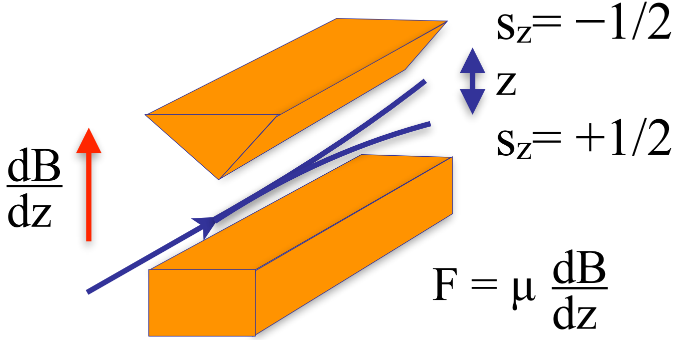
Introduction

hadrons and leptons like proton, antiproton, electron, positron, …

fermions: spin S = 1/2
spin : intrinsic angular momentum ,
⇒ ~~rotation of the particle~~ , quantum behavior without classical analog !

quantized, spin component along quantization axis z : $s_z = +1/2$ or $s_z = -1/2$
magnetic moment $\mu = -\, e/2m\ g\ S$,

Stern-Gerlach



unpolarized beam: ensemble of particles with equal number of $s_z = +1/2$ and $s_z = -1/2$

polarized beam: ensemble of particles with excess of one spin component

$$\text{Polarization } P = \frac{N_{s=+1/2} - N_{s=-1/2}}{N_{s=+1/2} + N_{s=-1/2}}$$

P = 80% : N_+ =90%, N_-=10%
P = 20% : N_+ =60%, N_-=40%

Why polarization?

Generell: strong forces are spin-dependent!

With polarization another degree of freedom under control
⇒ more detailed analysis

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
polarized $\bar{p}$

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 ↑↑

How to get Polarized Antiproton Beams

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,
- 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)

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

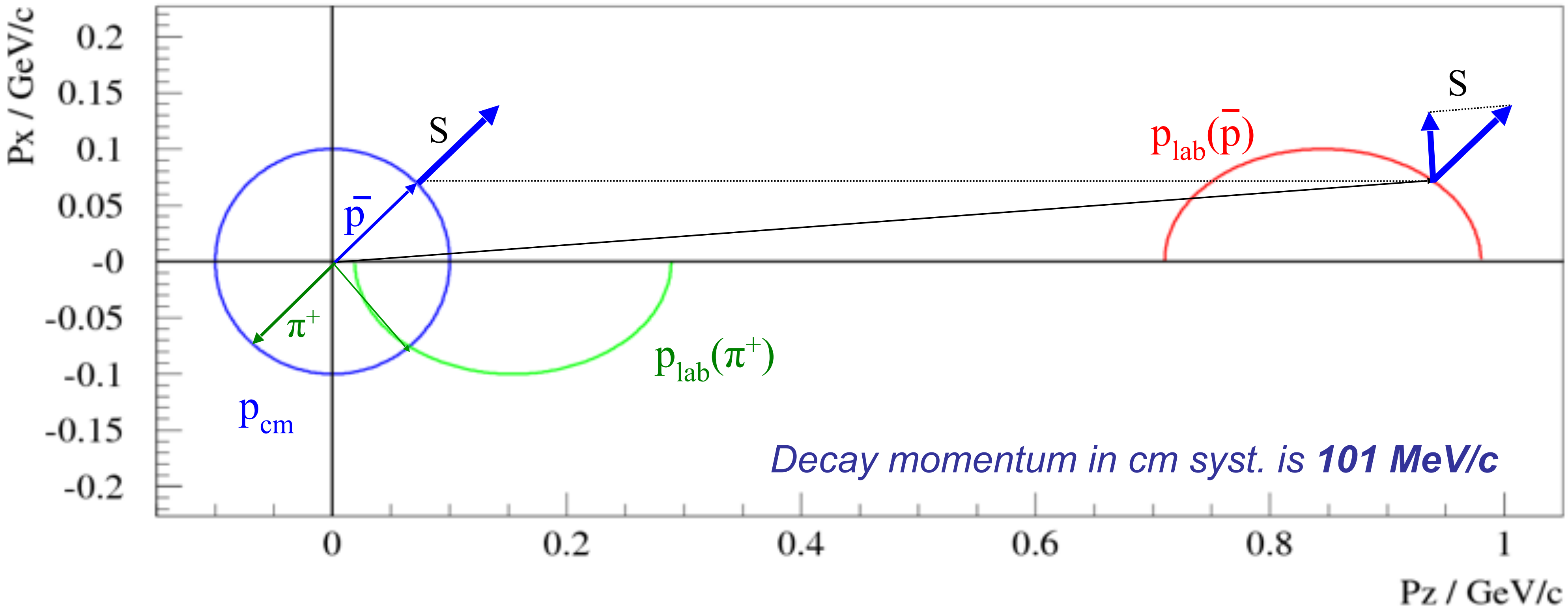
$\bar{p}$ **: helicity h = - 0.64.**

⟹ **limited to dedicated experiments**

Methods to Produce Polarized Antiprotons

Antihyperon decay

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



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

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

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

$\overline{\Lambda}$ production with primary proton beam. At the end an average of **10^4 polarized $\overline{p}$ s^{-1}**

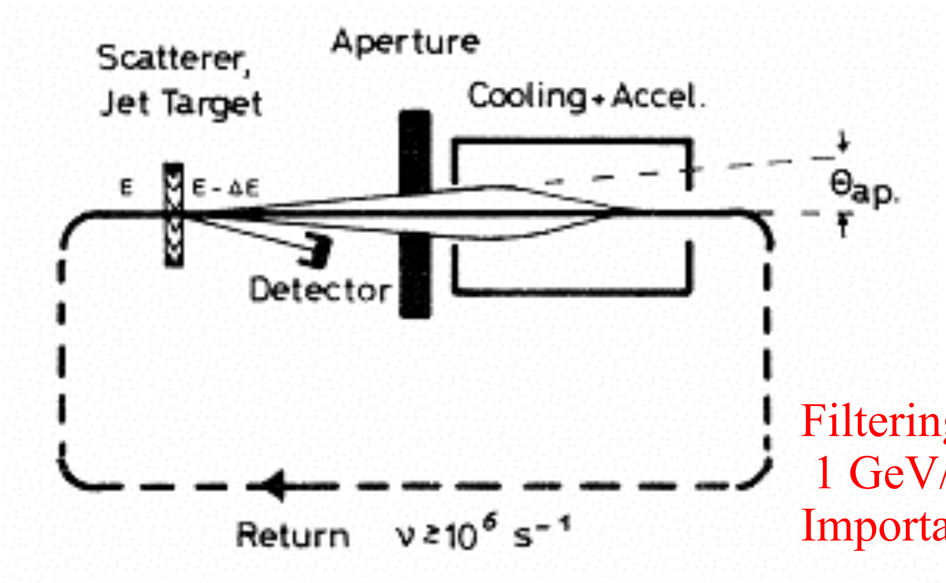
A. Bravar et al. Phys. Rev. Lett. **77**, 2626 (1996)

Methods to Produce Polarized Antiprotons

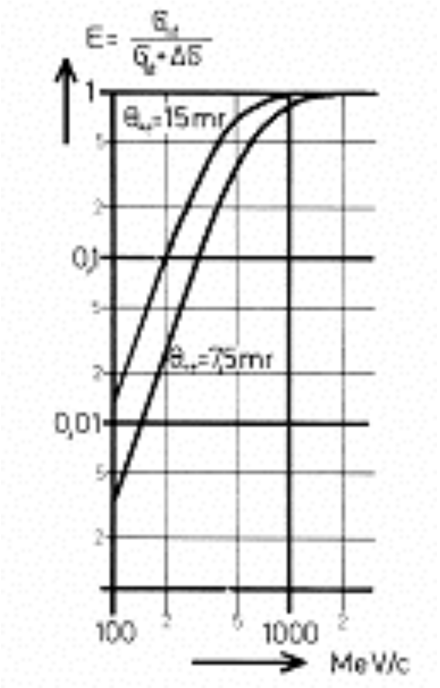
Spin filter method

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.



Filtering below
1 GeV/c →
Important $\Delta\sigma_{Cb}$



$$\Delta\sigma_{Cb} = \int_{\theta_{ap}}^{180^\circ} \frac{d\sigma_{Cb}}{d\Omega}\, d\Omega \approx 261\ \text{mb} \left(\frac{Z_{beam} Z_{target}}{p^* \beta^* \Theta^*}\right)^2$$

$$\sigma = \sigma_H + \Delta\sigma_{Cb}$$

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

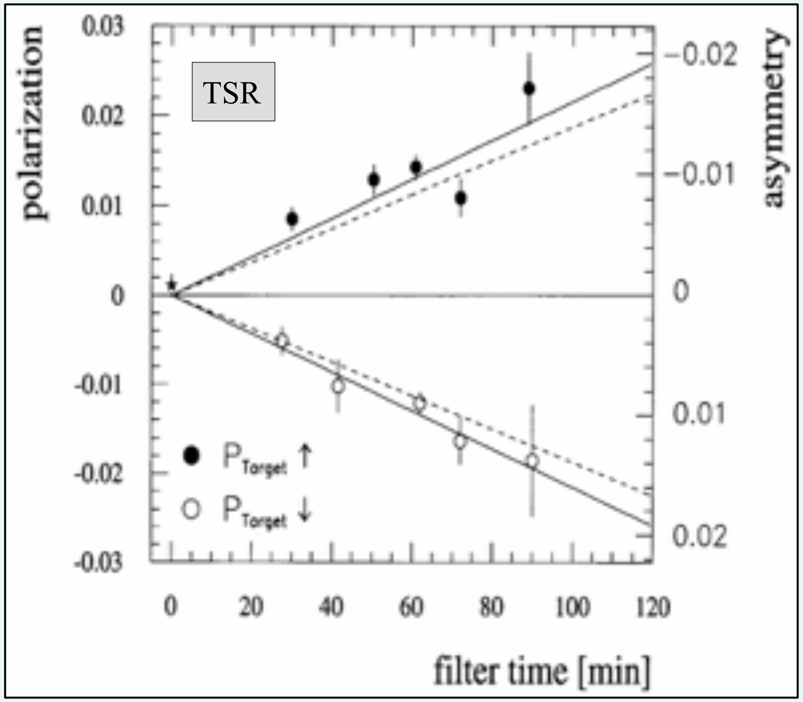
How to get Polarized Antiproton Beams

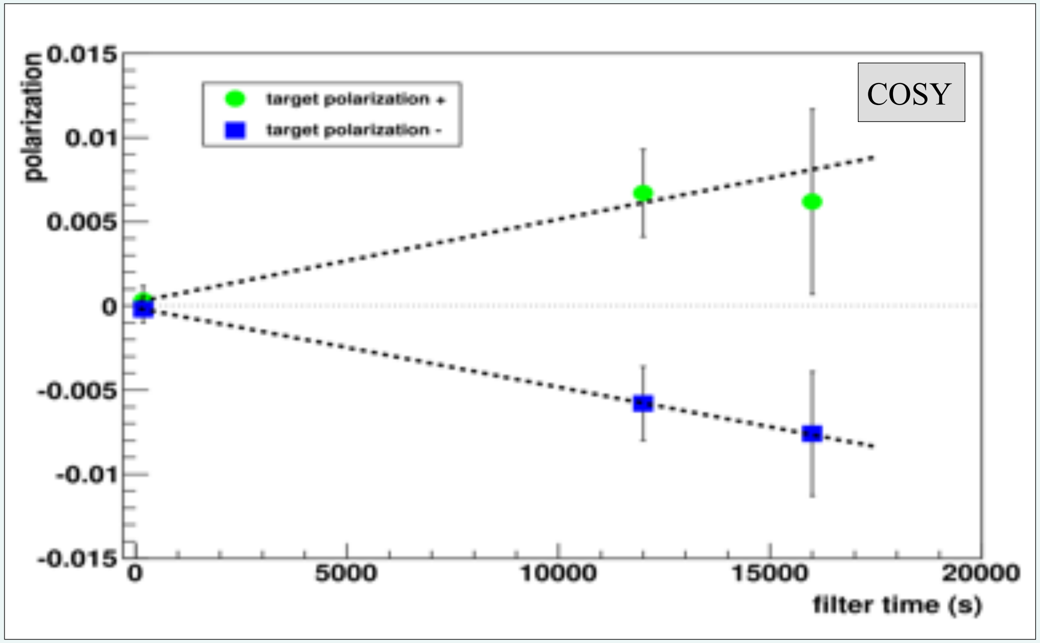
Spin filtering

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)

⇒ reasonable to investigate other possibilities

How to get Polarized Antiproton Beams

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,
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- polarization of trapped antiprotons,
- antihydrogen atoms,
- polarization of produced antiprotons

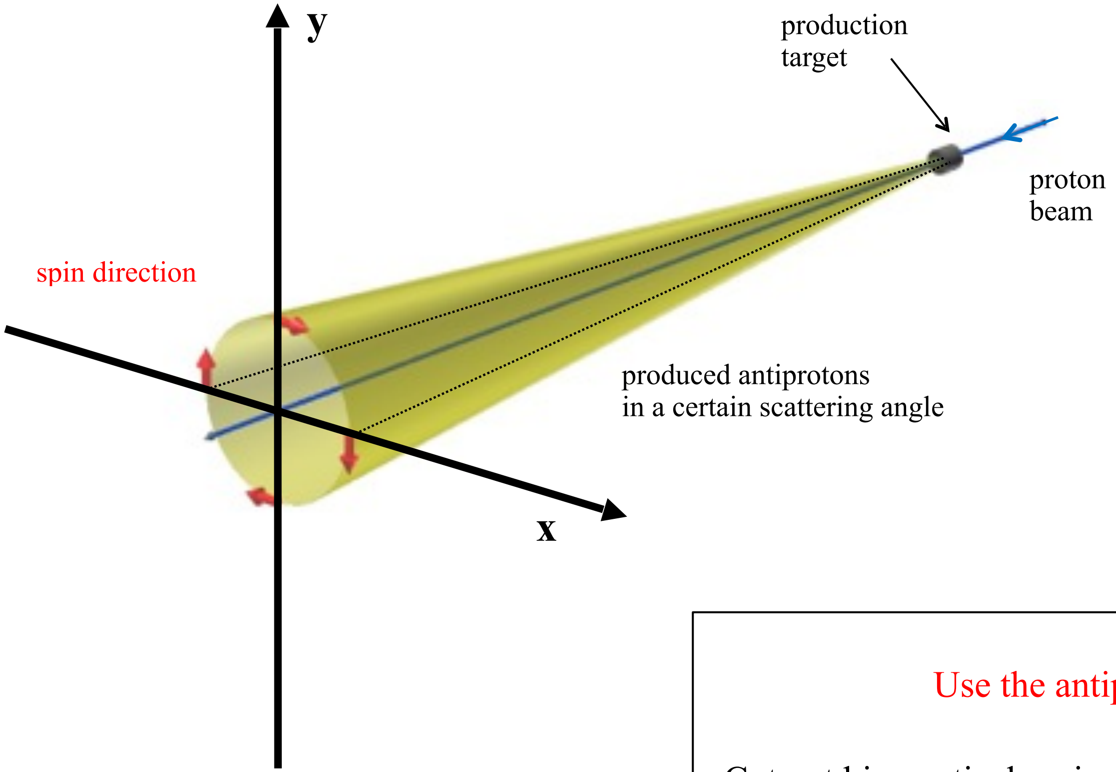
most simple idea:
production of polarized antiprotons

why is polarization expected ?

why not ! (production of hyperons show polarization, e.g. $P(\Lambda) < 20\%$)

would be a simple and „cheap“ solution for a polarized $\bar{p}$ beam
⇒ experimental study of possible polarization effects in $\bar{p}$ production

Polarized production

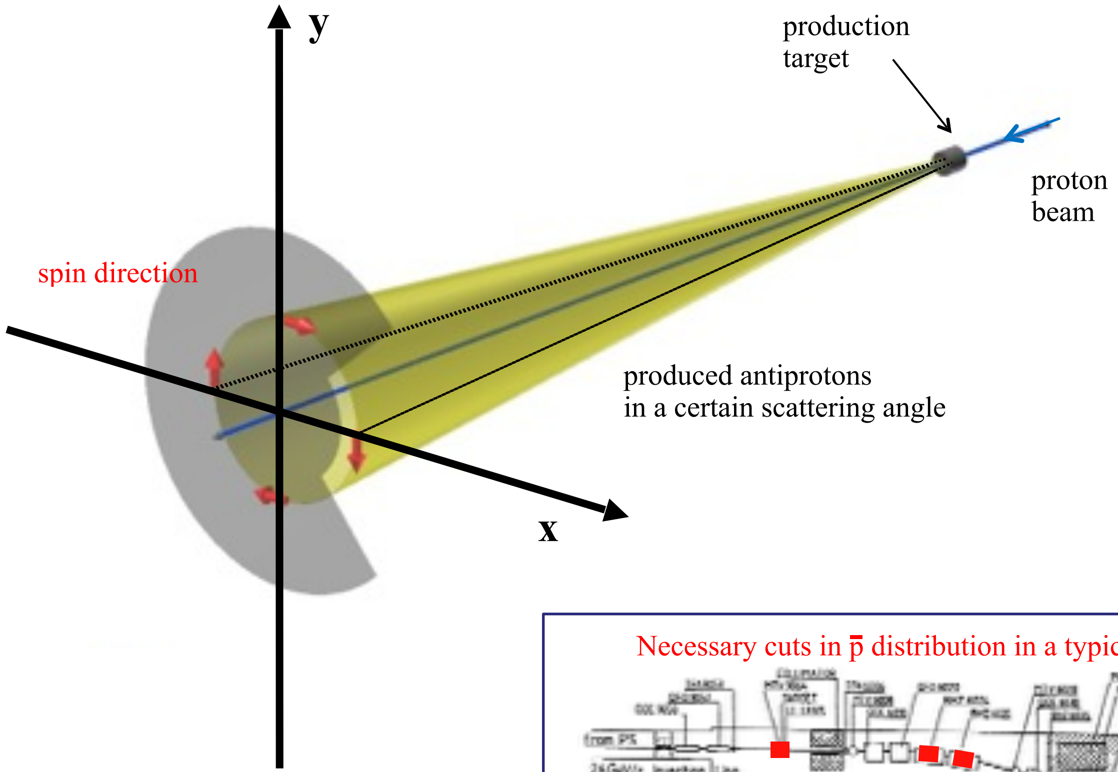


Use the antiproton factory (nearly) as usual.

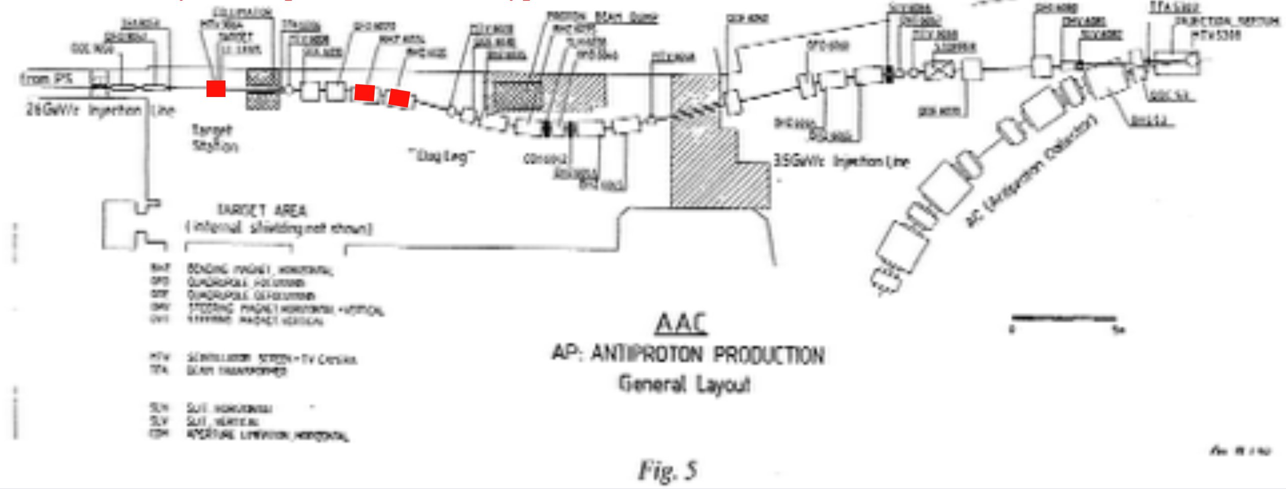
Cut out kinematical regions in the antiproton production spectrum which would dilute vector polarisation

- Avoid pure s wave antiprotons
- Cut one side in the horizontal angular distribution
- Cut up and down angles
- In addition avoid depolarisation in the cooler synchrotron

Polarized production



Necessary cuts in $\bar{p}$ distribution in a typical beam line



$\bar{p}$ production and transport to AD

Measurement of Polarization Effects

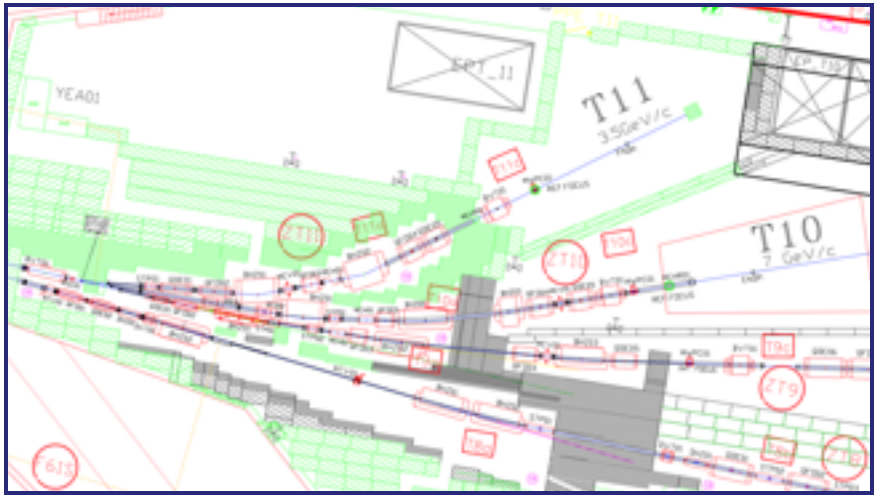
- Production of $\bar{p}$ under useful conditions

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

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

⇒ **T11:**

$\bar{p}$ 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

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

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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)

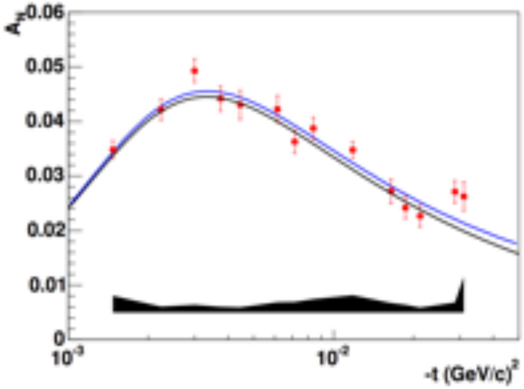
$A_y^{had}(t) \approx \sqrt{t/s}$ (negligible for $t/s \rightarrow 0$)

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

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

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

(μ : magnetic moment)



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

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

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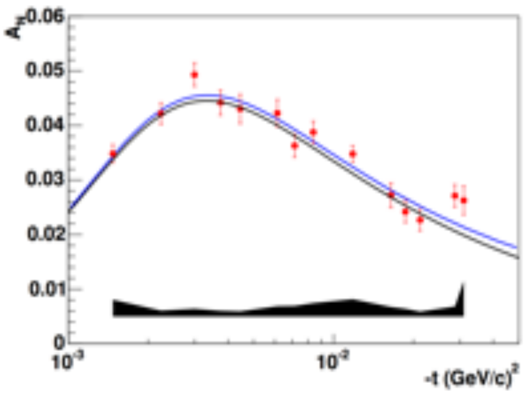

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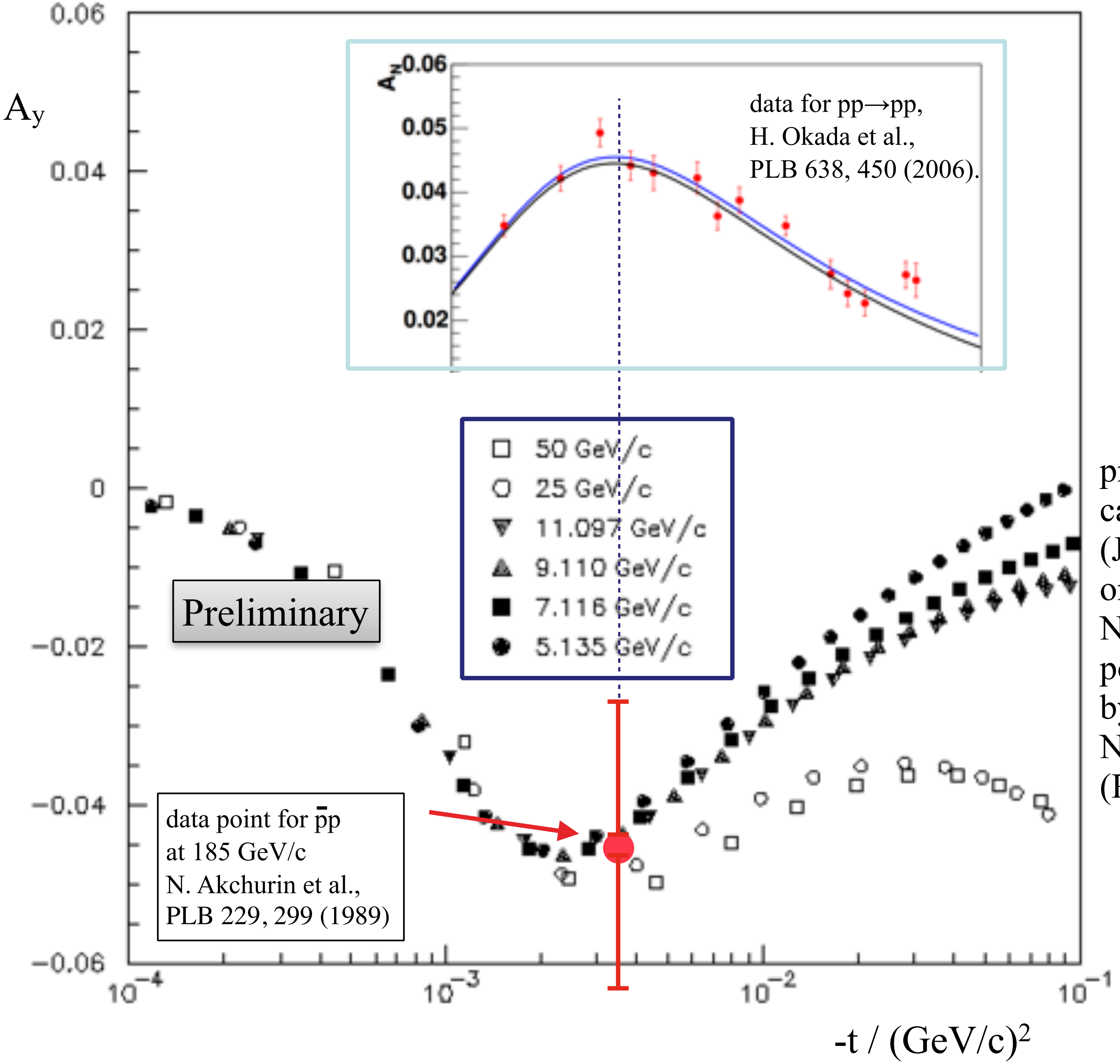
H. Okada et al.,
PLB 638, 450 (2006).

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

valid for $\bar{p}$p at 3.5 GeV/c momentum ?
t_p = ? , A_y = ?

A_y in the CNI Area



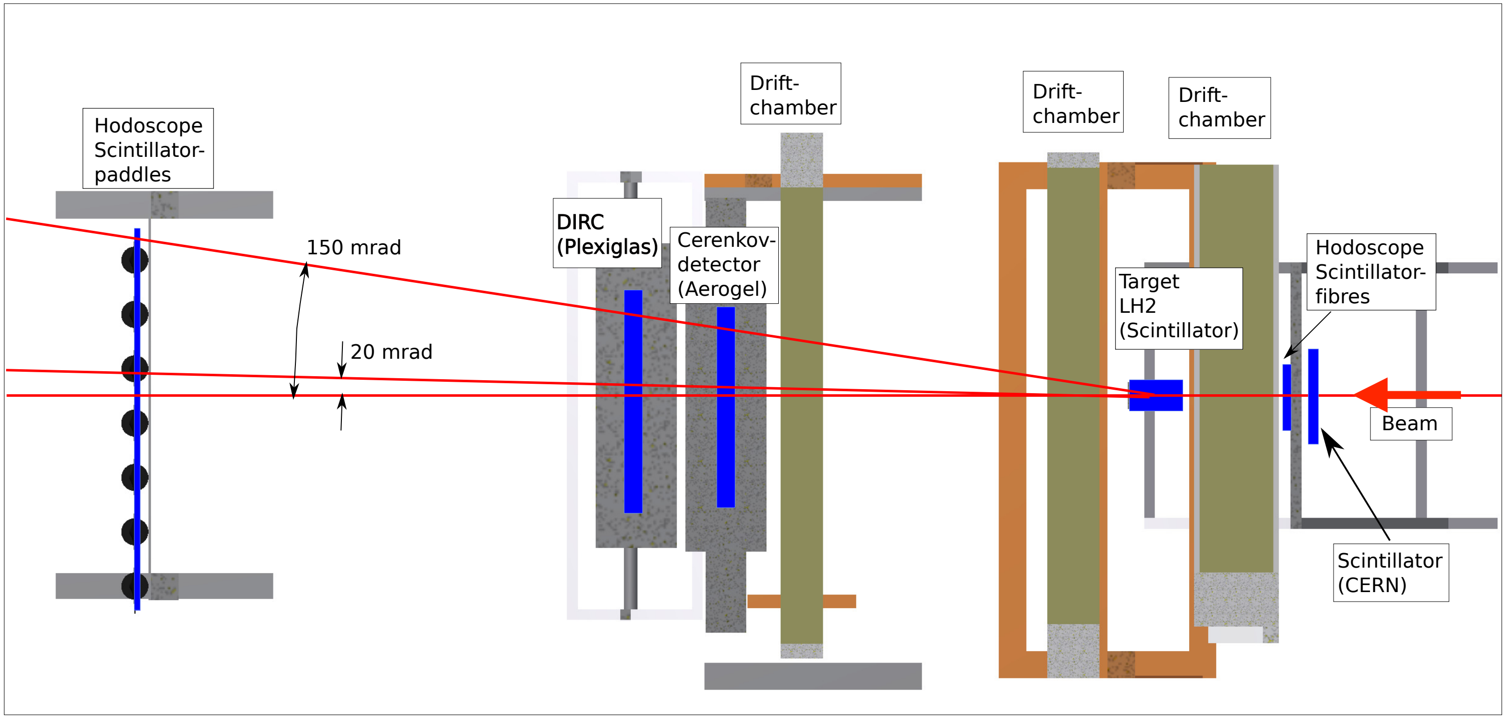
data for pp→pp,
H. Okada et al.,
PLB 638, 450 (2006).

Preliminary

data point for $\bar{p}p$
at 185 GeV/c
N. Akchurin et al.,
PLB 229, 299 (1989)

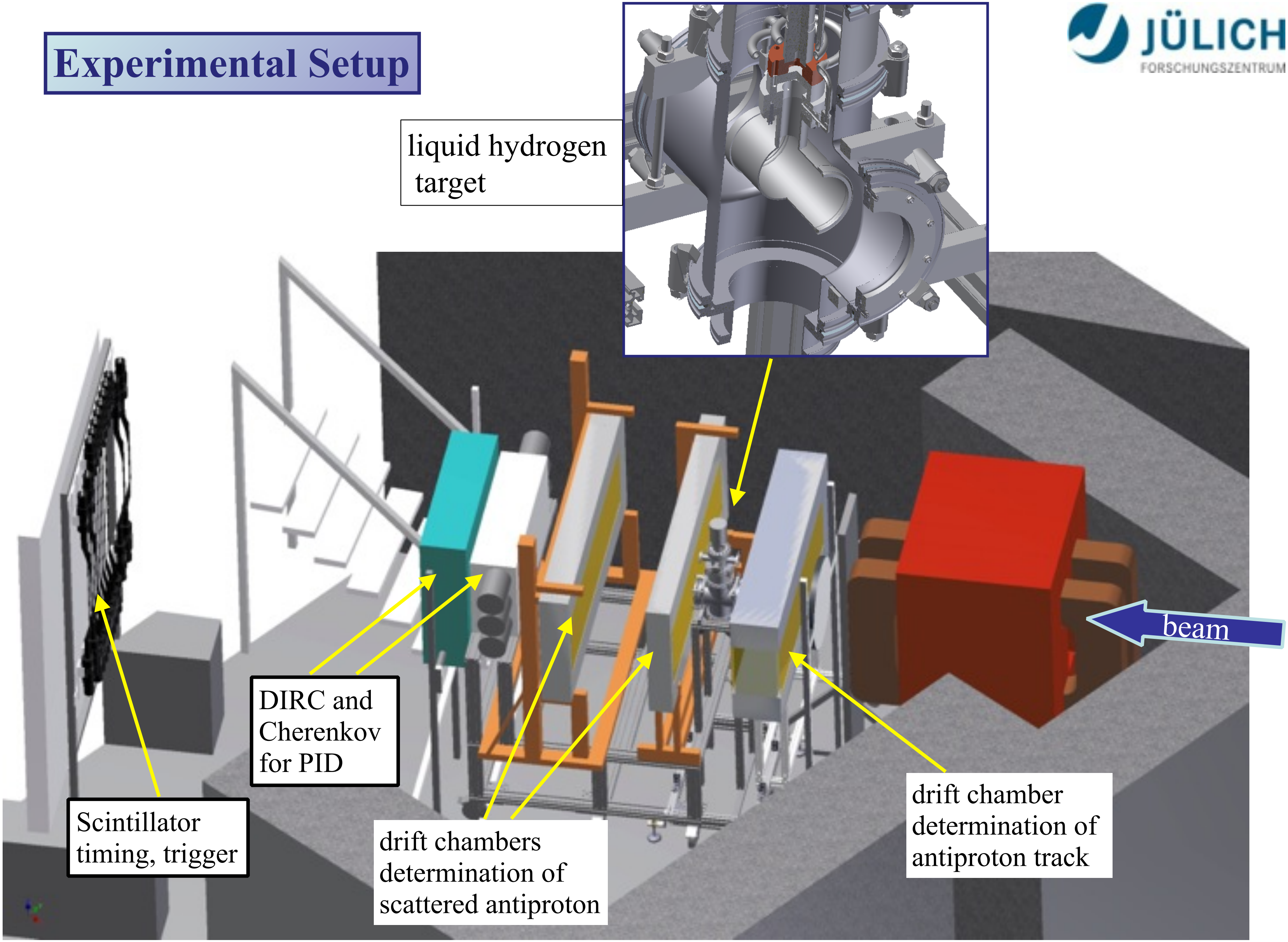
preliminary
calculations for $\bar{p}p \rightarrow \bar{p}p$
(J. Haidenbauer, priv. comm.)
one-boson-exchange
NN potential,
potential parameters determined
by fit to experimental
NbarN data,
(Phys.Rev.D89,114003 (2014))

Experimental Setup



- track reconstruction of primary particle
- elastic scattering in lH_2 - target (scintillator target)
- track reconstruction of scattered particle
- particle ID determination by Cherenkov (online) and DIRC (offline)
- generation of φ-distribution

Experimental Setup



liquid hydrogen target

DIRC and Cherenkov for PID

Scintillator timing, trigger

drift chambers determination of scattered antiproton

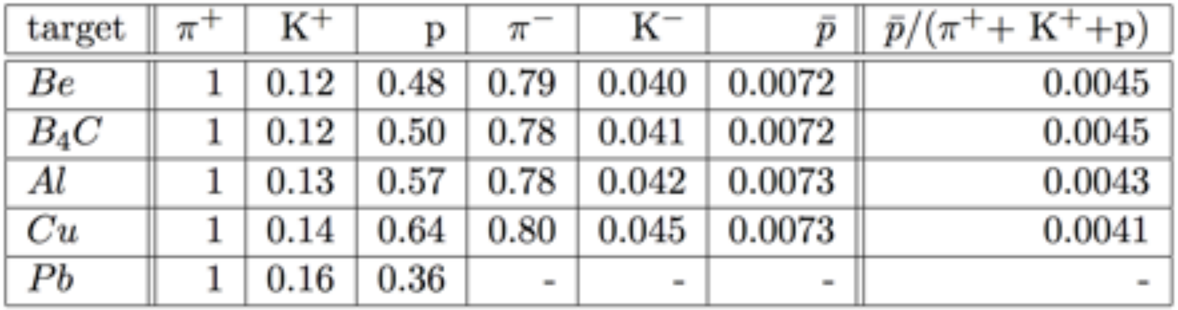
drift chamber determination of antiproton track

beam

Beam Time Estimate

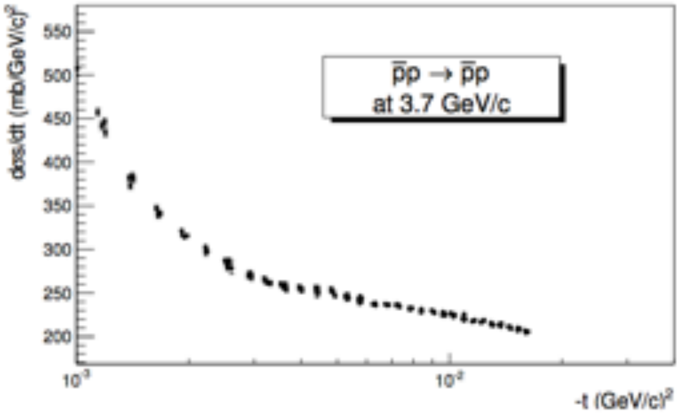
Expected particle ratios

(measured at 127 mrad, 4 GeV/c, T. Eichten et al., 24 GeV/c, Nucl. Phys. B 44, 333-343 (1972)



target	π^+	K^+	p	π^-	K^-	$\bar{p}$	$\bar{p}/(\pi^+ + K^+ + p)$
Be	1	0.12	0.48	0.79	0.040	0.0072	0.0045
B_4C	1	0.12	0.50	0.78	0.041	0.0072	0.0045
Al	1	0.13	0.57	0.78	0.042	0.0073	0.0043
Cu	1	0.14	0.64	0.80	0.045	0.0073	0.0041
Pb	1	0.16	0.36	-	-	-	-

At T11: $1 \cdot 10^6$ particles/spill with setting for positively charged particles (incident proton beam flux between $2 \cdot 10^{11}$ and $3 \cdot 10^{11}$)



from ratios in table: **≈ 4000 $\bar{p}$/spill**,
total flux of negatively charged particles ≈ $5 \cdot 10^5$/spill, i.e. $1 \cdot 10^6$/s

σ (t-range:—0.002 to -0.007) ≈ 1.35 mb
target: 10 cm lH_2 or 10 cm CH

⇒ 3 useful events / spill

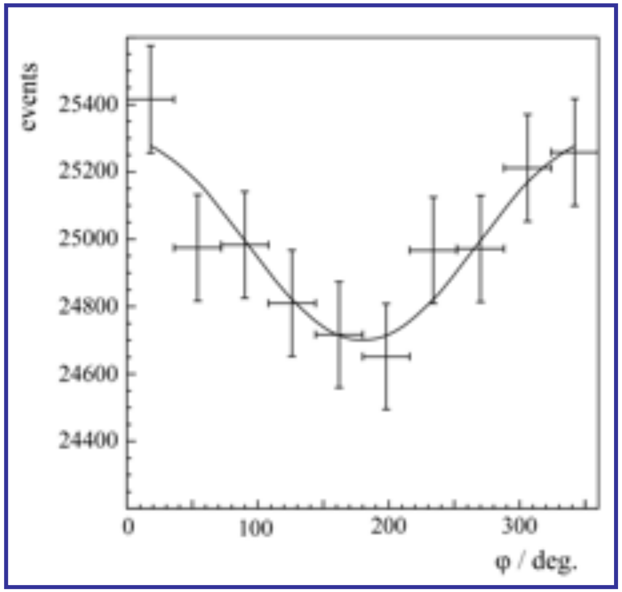
2 spills every 30 s, mean spill rate: 4000 spills/day, 84000 spills in 21 days

3 weeks beam time : $2.5 \cdot 10^5$ expected scattering events

⇒ measurement of 20% polarization possible, statistical precision 25%

Possible Result

MC data sample
for 2.5 10^5 events
including
20% polarization
and 4.5% asymmetry



or
if P = 0

⇒ **no effect**

experiment end of 2014

Polarization of produced antiprotons would drastically simplify the preparation of a polarized antiproton beam!

Apart from polarized antiproton beam:
⇒ better understanding of $\bar{p}p$ interaction

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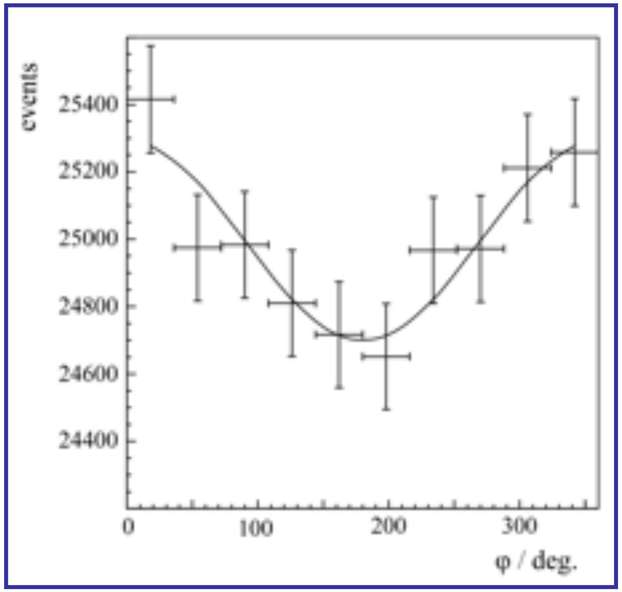

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Thank you for your attention