

Proposal (SPSC-P-349):

Search for polarization effects in the antiproton production process

Dieter Grzonka, IKP Forschungszentrum Jülich



D. Grzonka, K. Kilian, J. Ritman, T. Sefzick

Institut für Kernphysik, Forschungszentrum Jülich, 52425 Jülich, Germany

W. Oelert

Johannes Gutenberg-Universität Mainz, 55099 Mainz, Germany

E. Widmann, J. Zmeskal

Stefan-Meyer-Institut für subatomare Physik, Boltzmanngasse 3, 1090 Wien, Austria

P. Moskal, M. Zielinski

Institute of Physics, Jagiellonian University, ul. Reymonta 4, PL-30 -059 Krakow, Poland

M. Wolke

Department of Physics and Astronomy, Uppsala University, Box 516, 751 20 Uppsala, Sweden

P. Nadel-Turonski

Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606

T. Horn,

Physics Department, 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. Ettenauer, CERN, Physics department

W. Eyrich, F. Hauenstein, A. Zink

Physikalisches Institut, Universität Erlangen, Erwin-Rommel-Strasse 1, 91058 Erlangen, Germany

- Motivation
 - Ideas for polarized \bar{p} beams
 - Polarization in \bar{p} production
- Measurement of polarization
 - CNI region
- Experimental setup
- Expected results
 - Beam time request

Motivation

Preparation of a polarized antiproton beam

High Energy:

nucleon

quark structure : longitudinal momentum distribution
helicity distribution

$f_1(x)$

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 %)

Decay $\Rightarrow \bar{p}$ 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. $I \sim 10^4$ polarized \bar{p} s⁻¹

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

→ limited to dedicated experiments

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,
 - anti-hydrogen 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)

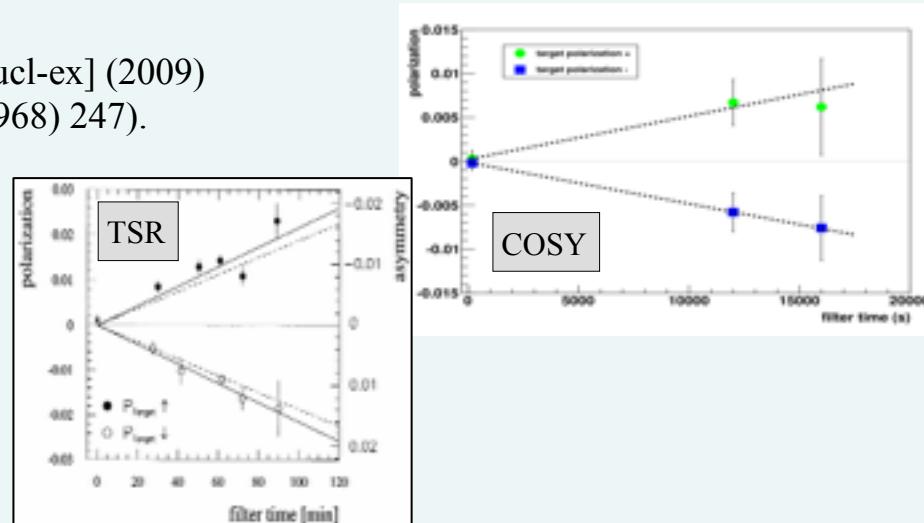
H. O. Meyer,
AIP Conf. Proc. 1008, 124-131 (2008)

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 (Siberian snakes),
filter time $T \approx 2\tau$ (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,
 - 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)

**most simple idea:
production of polarized antiprotons**

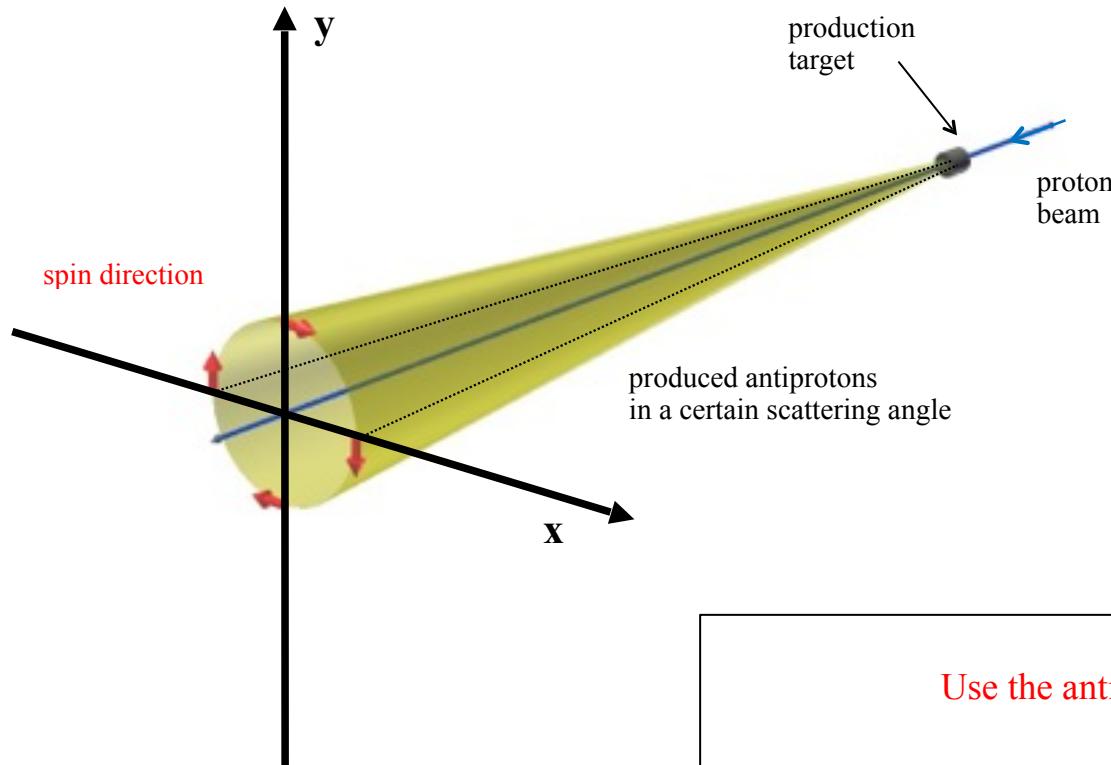
why is polarization expected ?

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

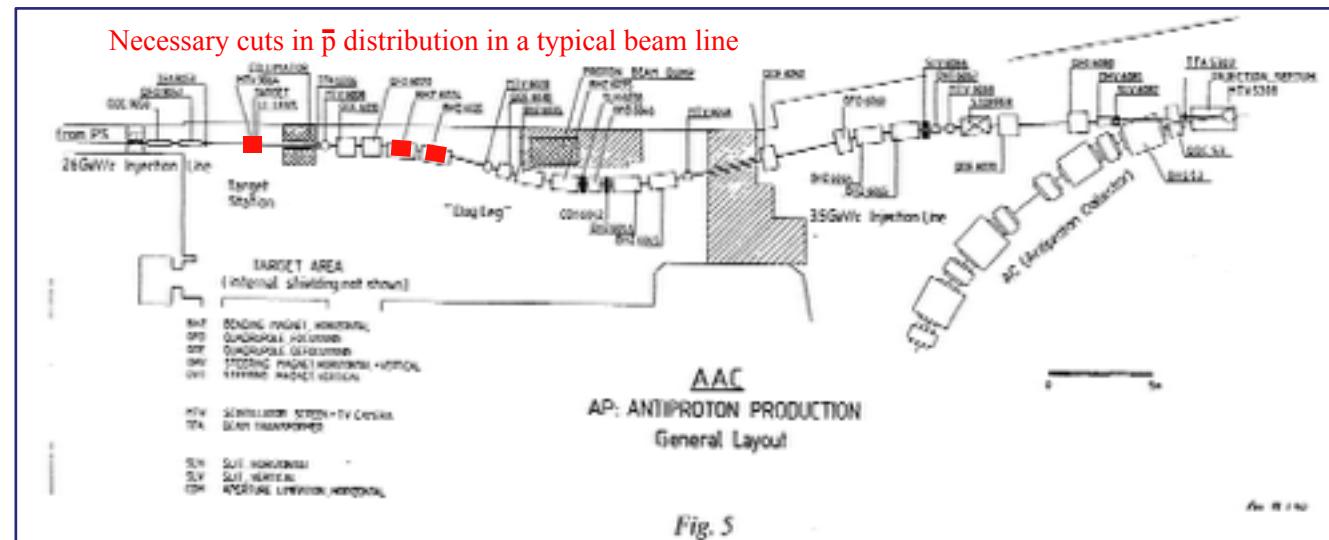
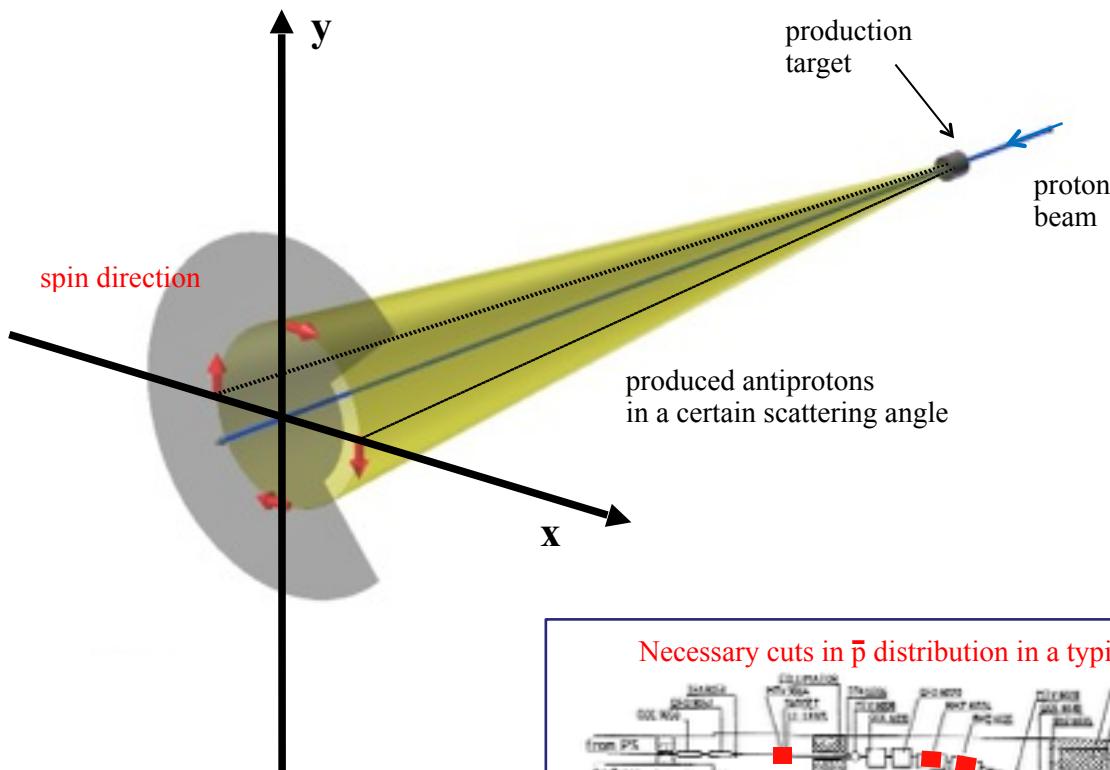


Fig. 5

p⁻ production and transport to AD

Measurement of Polarization Effects

- Production of \bar{p} under useful conditions

\bar{p} momentum $\approx 3.5 \text{ GeV}/c$

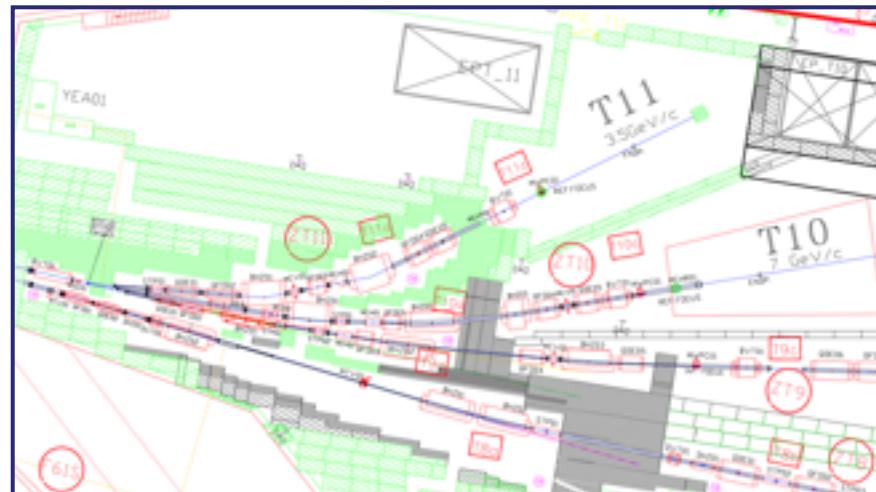
(\bar{p} production at AD and future FAIR facility)

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

→ T11:

\bar{p} momentum $\leq 3.5 \text{ GeV}/c (\leq \pm 5\%)$

production angle = 150 mrad ($\pm 3 \text{ mrad h}, \pm 10 \text{ mrad v}$)



- 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:

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

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

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

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

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

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

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

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

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

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



A_y in the CNI Area

helicity frame:

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

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

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

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

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

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 $\rightarrow 0$)

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

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

$$A_y^{\text{int}}(t_p) \approx \frac{\sqrt{3}}{4} (\mu - 1) \frac{\sqrt{t_p}}{m} \approx 0.046 \quad (\mu : \text{magnetic moment})$$



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

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

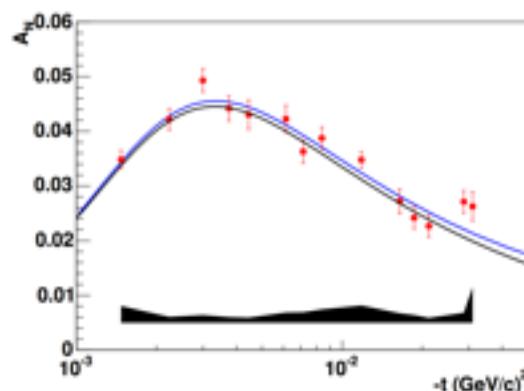
$$Ay \frac{d\sigma}{dt} = -\text{Im} [(\phi_1 + \phi_2 + \phi_3 - \phi_4) \phi_5^*]$$

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

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



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



data for pp \rightarrow 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

helicity frame:

$$\begin{aligned}\phi_1(s,t) &= \langle +\frac{1}{2} + \frac{1}{2}|\phi| + \frac{1}{2} + \frac{1}{2} \rangle, \\ \phi_2(s,t) &= \langle +\frac{1}{2} + \frac{1}{2}|\phi| - \frac{1}{2} - \frac{1}{2} \rangle, \\ \phi_3(s,t) &= \langle +\frac{1}{2} - \frac{1}{2}|\phi| + \frac{1}{2} - \frac{1}{2} \rangle, \\ \phi_4(s,t) &= \langle +\frac{1}{2} - \frac{1}{2}|\phi| - \frac{1}{2} + \frac{1}{2} \rangle, \\ \phi_5(s,t) &= \langle +\frac{1}{2} + \frac{1}{2}|\phi| + \frac{1}{2} - \frac{1}{2} \rangle.\end{aligned}$$

for small t and high energy:

(N. Akchurin et al., Phys. Rev. D 48, 3026 (1993).)

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

A_y^{had}(t) ≈ √(t/s) (negligible for t/s → 0)

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

$$\begin{aligned}t_p &= \sqrt{3} (8\pi a/\sigma_{\text{tot}}) \\ &\approx -0.003\end{aligned}$$

$$A_y^{\text{int}}(t_p) \approx \frac{\sqrt{3}}{4} (\mu - 1) \frac{\sqrt{t_p}}{m} \approx 0.046 \quad (\mu : \text{magnetic moment})$$



⇒ A_y ≈ 4.6 %, at t ≈ -0.003
for pp and p̄p (G-parity)

valid for p̄p at 3.5 GeV/c momentum ?
t_p = ?, A_y = ?

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

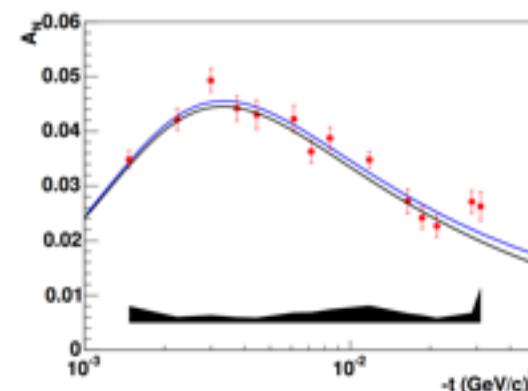
$$Ay \frac{d\sigma}{dt} = -\text{Im} [(\phi_1 + \phi_2 + \phi_3 - \phi_4) \phi_5^*]$$

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

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

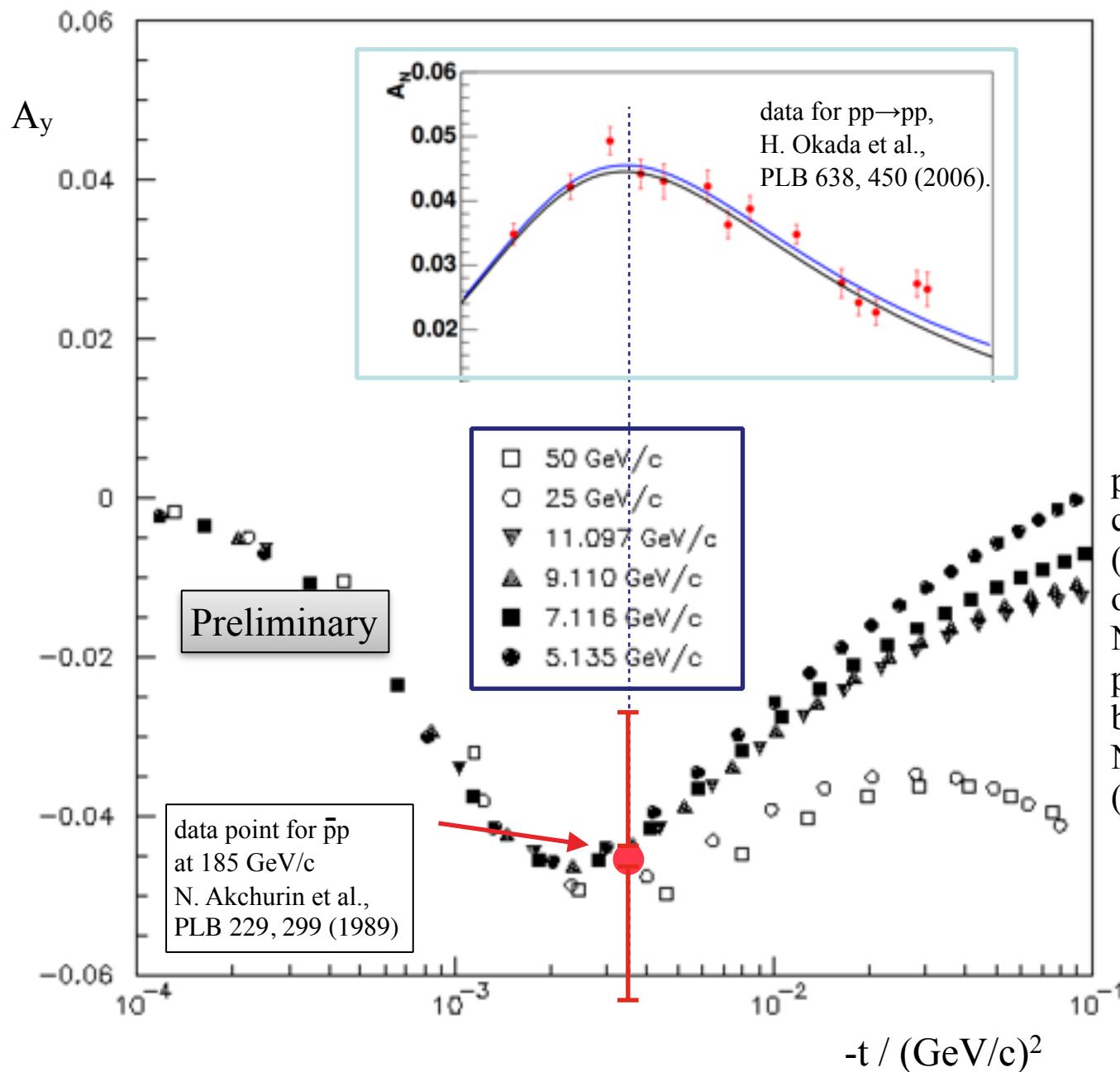


interference of nuclear non-spin-flip and em spin-flip
(due to magnetic moment)

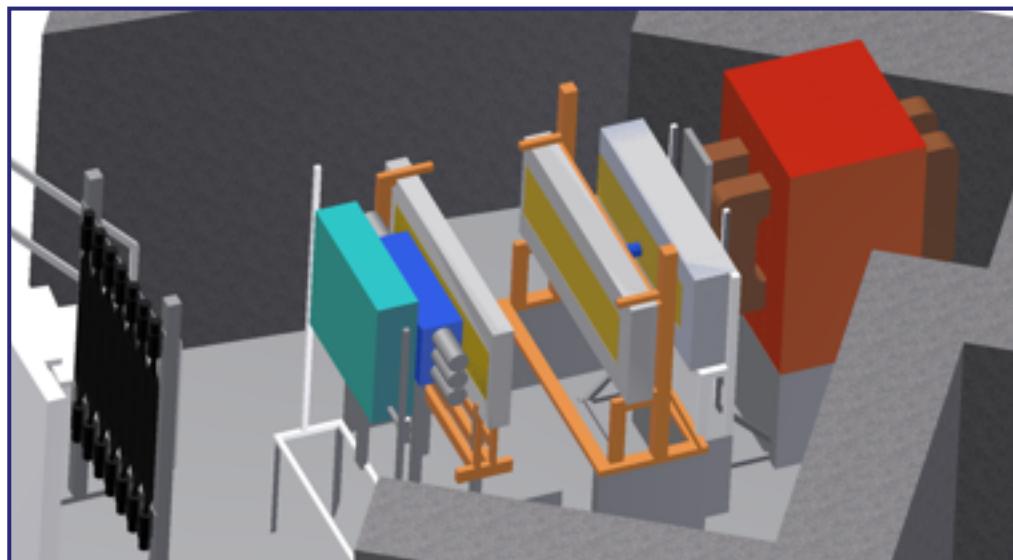
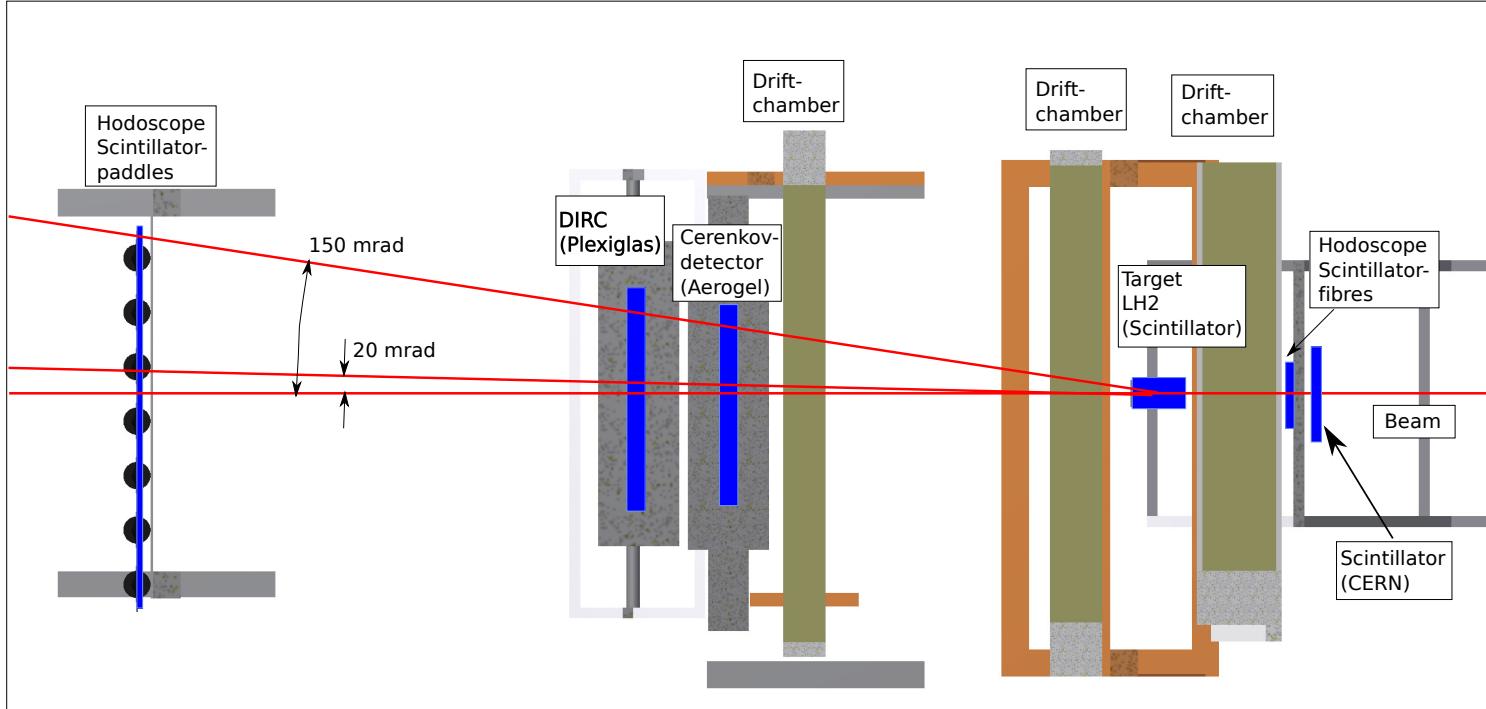


data for pp → pp,
P_p = 100 GeV/c,
(√s = 13.7 GeV)
H. Okada et al.,
PLB 638, 450 (2006).

A_y in the CNI Area



Experimental Setup



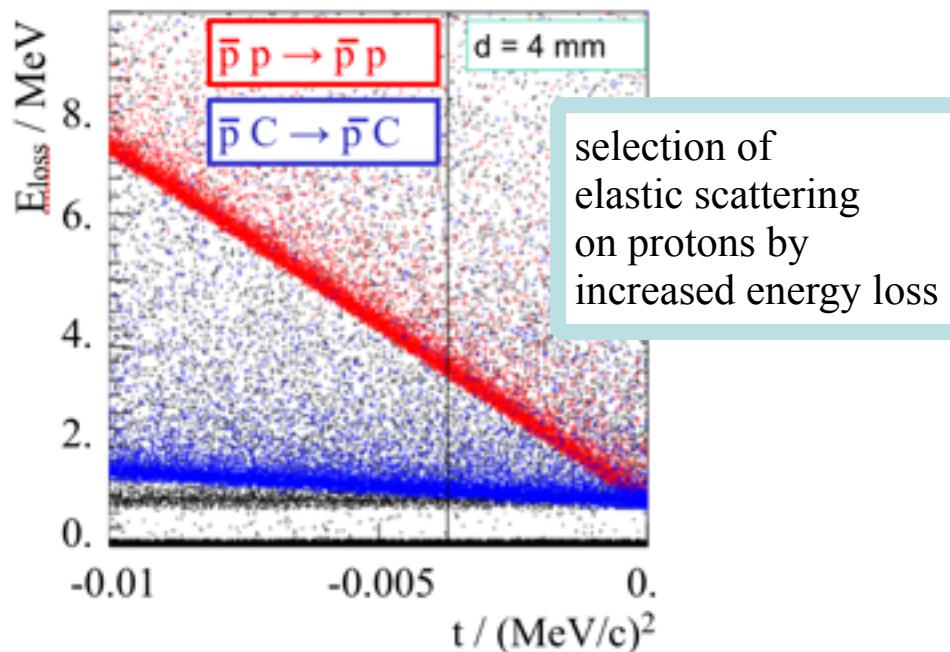
- track reconstruction of primary particle
- elastic scattering in LH₂ - target (scintillator target)
- track reconstruction of scattered particle
- particle ID determination by Cherenkov (online) and DIRC (offline)
- generation of φ -distribution

Experimental Setup

Target

Measurement: IH_2 , no background
 from scattering on nuclei
 useful target length reduced
 to separate reactions in
 window material

Test: scintillator material
 several layers of
 4 mm scintillator moduls
 background studies,



Drift chambers

used at COSY-11 experiments
 track resolution $\leq 1\text{ mrad}$ ($1\text{ GeV}/c$ p)

Cherenkov

aerogel, $n=1.03$
 veto signal for pions
 estimate: proton/pion discrimination
 $> 1/40$, threshold $\geq 1\text{ pe}$

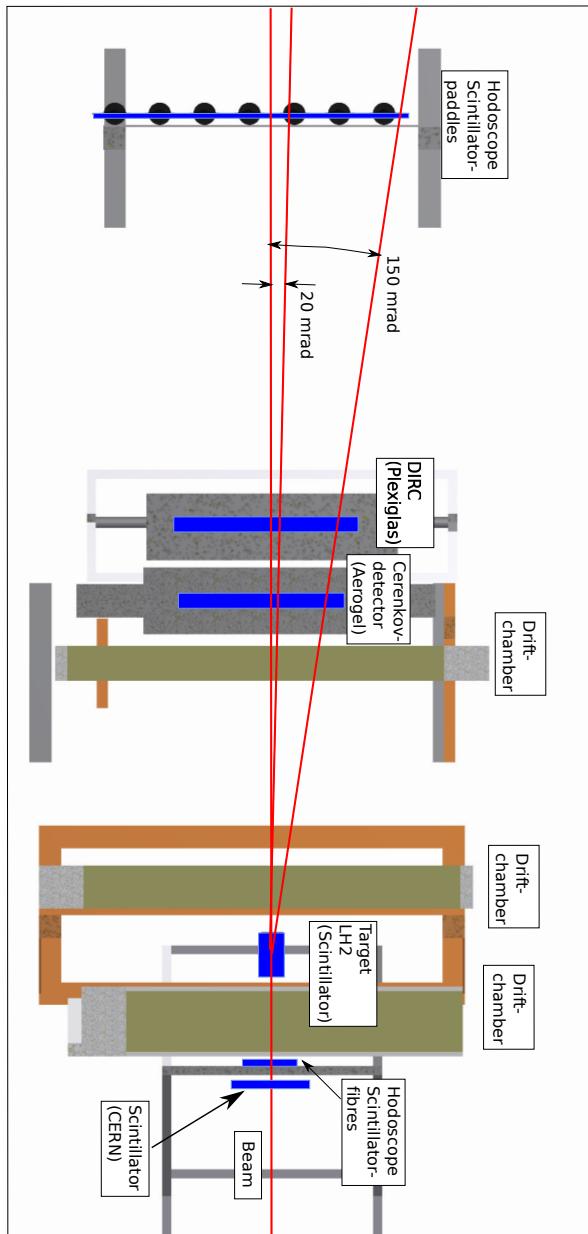
DIRC

Plexiglas,
 proton-pion separation = 7.8σ
 (measured)

DAQ

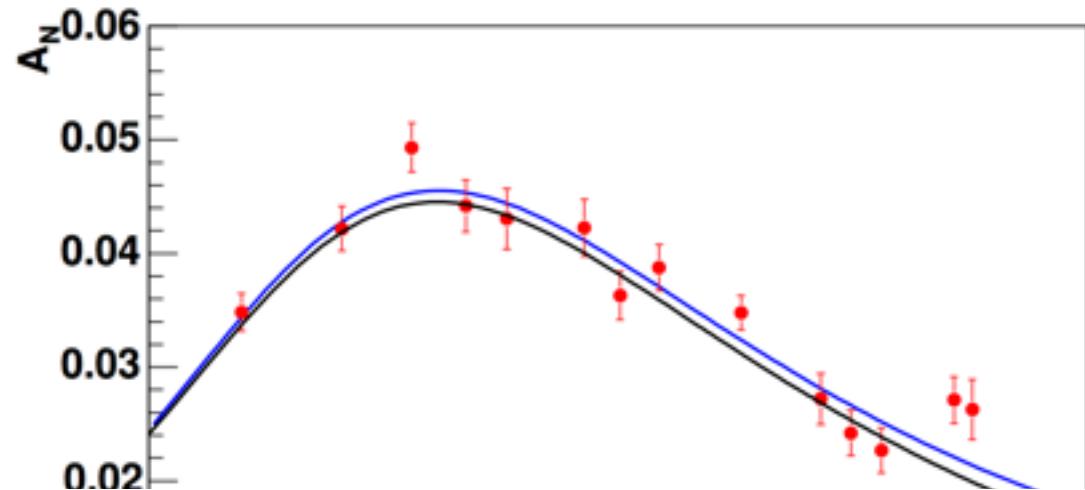
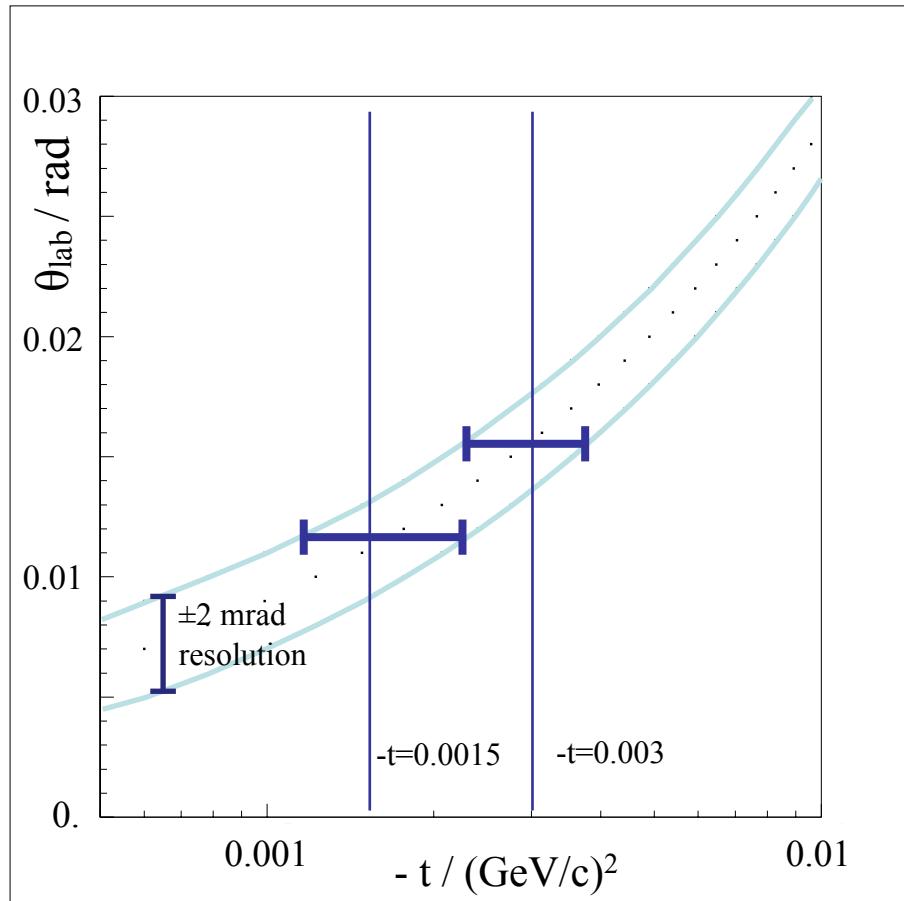
TRB3 boards
 few 10 kHz eventuate

Experimental Setup



<u>component</u>	<u>status</u>	<u>institution</u>
scintillator hodoscope	scintillator modules available, preparation in Jülich	Jülich
DIRC	ready for operation	Erlangen
Cherenkov	shipped from JLAB to Jülich assembling and testing in Jülich	JLAB, Jülich
drift chambers	ready for operation	Jülich, Kracow, Uppsala
target	lH_2 will be prepared scintillator-target in preparation	Vienna Jülich
DAQ	ready for operation	Erlangen, Kracow, Jülich

Precision in t - Measurement

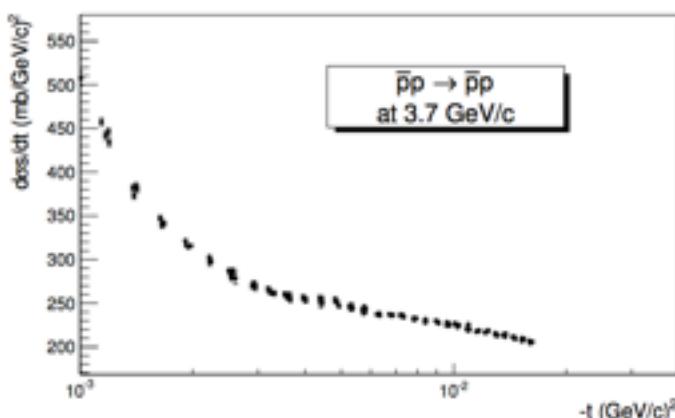


Expected particle ratios

(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: $\approx 4000 \bar{p}/\text{spill}$,
total flux of negatively charged particles $\approx 5 \cdot 10^5/\text{spill}$, i.e. $1 \cdot 10^6/\text{s}$

σ (t-range: -0.002 to -0.007) $\approx 1.35 \text{ mb}$
target: 10 cm LH₂ or 10 cm CH

⇒ 3 useful events / spill

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

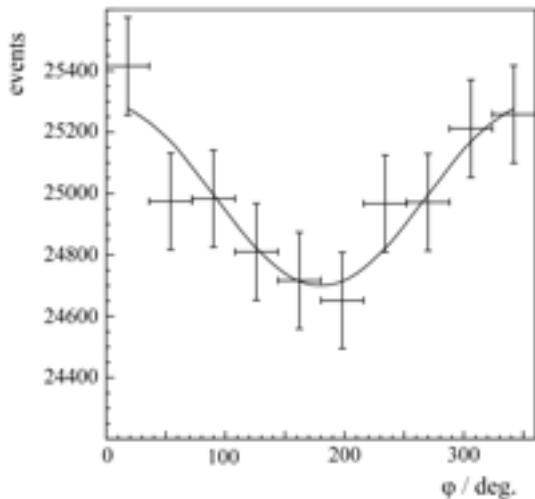
3 weeks beam time : $2.5 \cdot 10^5$ expected scattering events

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

Possible Result

optimistic view:

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



more conservative view:

$A_y < 4.5\%$ and $-t_p < 0.003$,
no asymmetry observed

in any case: further studies needed

experiment can be considered as a first step towards
search for polarization effects in antiproton production

to be done in further studies:

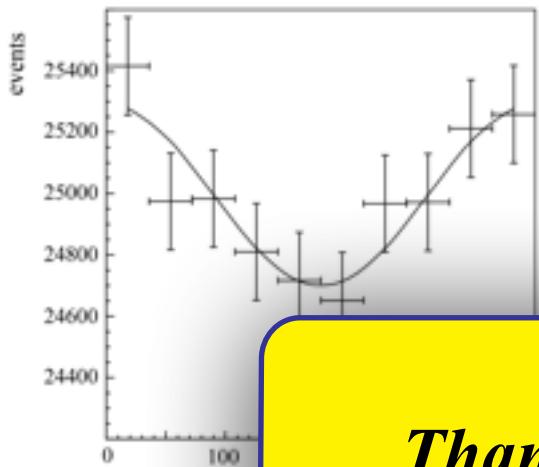
- measurement of A_y with polarized target (frozen spin)
- improvement of detection system
 - reduce straggling (vacuum)
 - optimize detector components

⇒ requires data for background studies and development of improved system
2-3 weeks beam time requested at the T11 test beam
after CLOUD beam time in November/December 2014.

Possible Result

optimistic view:

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



more conservative view:

$Ay < 4.5\%$ and $-t_p < 0.003$,
no asymmetry observed

Thank you for your attention

in any case: further studies needed

experiment can be considered as a first step towards
search for polarization effects in antiproton production

to be done in further studies:

- measurement of Ay with polarized target (frozen spin)
- improvement of detection system
 - reduce straggling (vacuum)
 - optimize detector components

⇒ requires data for background studies and development of improved system
2-3 weeks beam time requested at the T11 test beam
after CLOUD beam time in November/December 2014.

PS user schedule for 2014

schedule issue date: 17-Jun-2014

 Version: 2.0  LHC Exp.  PS/SPS Exp.  INT Exp.  Other Exp.

	Jul					Aug					Sep					Oct					Nov					Dec				
Week	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52				
Machine																														
East Area	T8 - Irrad	EA Setup 5	7h 17h	7h 17h	7h 17h	7h 17h	7h 17h	7h 17h	7h 17h	7h 17h	7h 17h	7h 19h	7h 19h	7h 19h	7h 19h	7h 19h	7h 19h	7h 19h	7h 19h	7h 19h	7h 19h	7h 19h	7h 19h	7h 19h	7h 19h	7h 19h				
	T9	EA Setup 5	TOTEM 4	RE29 (DAMPE) 4	LHCb 13	ATLAS NSW 7	Clic pix 7	CMS ECAL 13	INSULAB 7	BL4S 7	ALICE FOCAL 14	Clic pix 7	Calice (ahcal) 14	FCAL 7	RE29 (DAMPE) 14	RE21 (CBM) 14	Calice (ahcal) 12	LHCb 7												
	T10	EA Setup 3	ALICE ITS 7	ALICE FIT-T0+ 7	ALICE FIT-V0+ 7	CMS RPC 7	ALICE ITS 7	ALICE TOF-MRPC 7	NA58 (RICH) 21	ALICE ITS 7	ALICE PHOS 7	ATLAS NSW 7	ALICE T0+ 7	NA58 (ECAL) 10	ALICE ITS 7	ALICE TOF-MRPC-HMPID 14	ALICE ITS 7	ALICE PHOS 7	ALICE TPC 7	ALICE TOF-MRPC 10										
	T11 Cloud	EA Setup 5													CLOUD 42		CLOUD 14	CLOUD 7												
TT2A		nTOF Setup 5													nTOF 153															

For further information contact the PS/SPS-Coordinator. Email: SpS.Coordinator@cern.ch, Tel: +41 76 487 3845.

 The latest version of the schedule are available here: <http://sps-schedule.web.cern.ch/sps-schedule/>

This schedule is synchronized with injector schedule v1.4

No beam during Technical Stops (TS), limited beam availability during Machine Developments (MD)