

How a bent crystal could polarize the antiprotons

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Outline

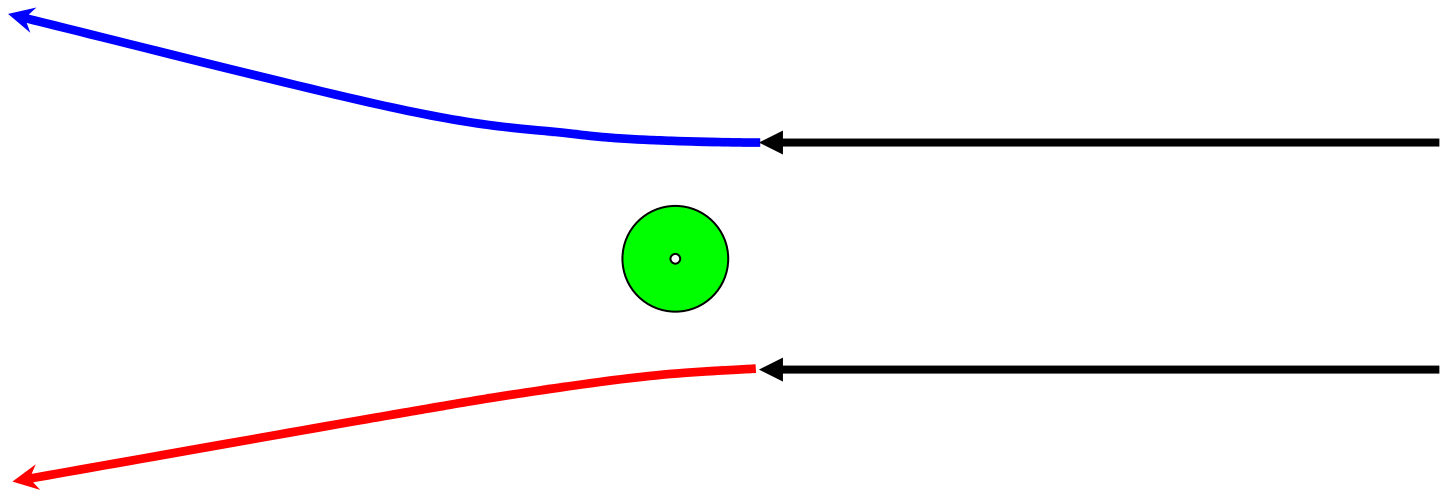
- Basics of the phenomenon.
- Numerical examples.
- Application to antiprotons.
- Estimation of a volume reflection capabilities.
- A bit of physics.
- Conclusions.

Definition

$P \neq 0$

$A \neq 0$

$P = 0$

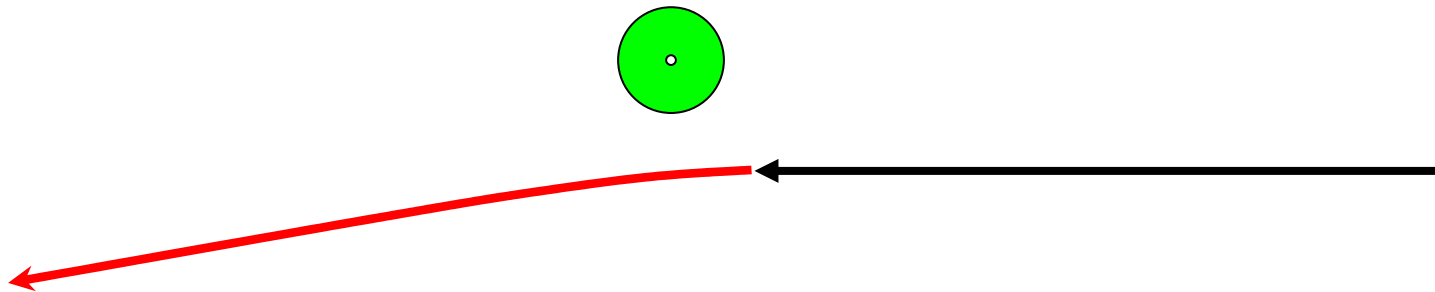


Junior hunter exercise

$P \neq 0$

$A \neq 0$

$P = 0$

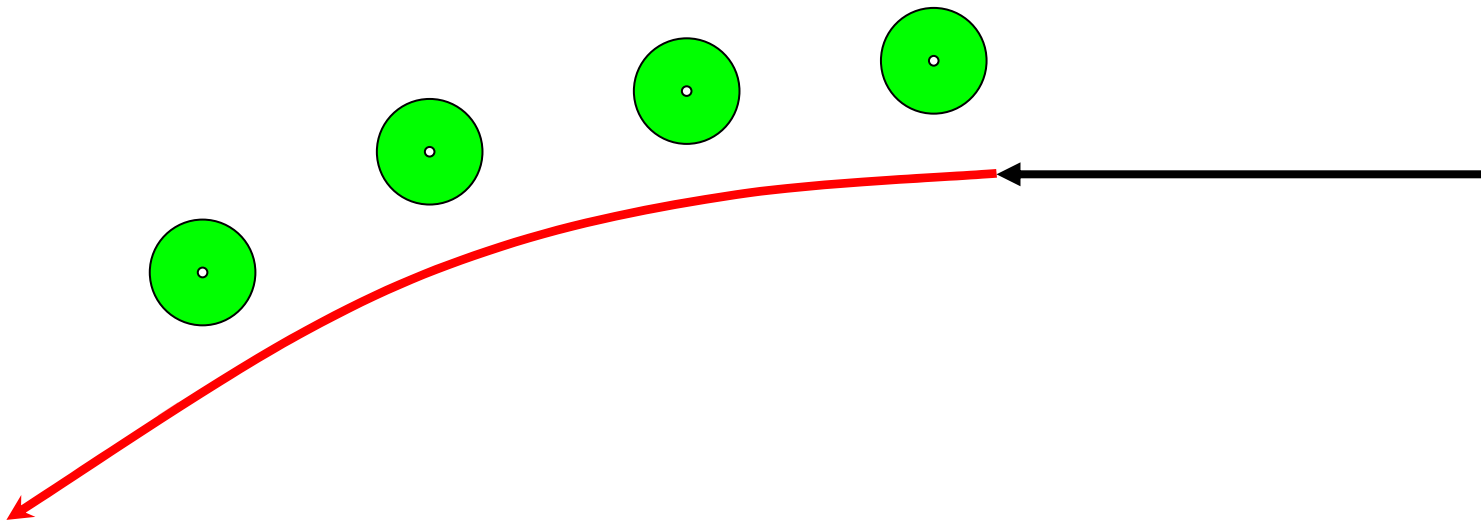


Senior hunter exercise

$P \neq 0$

$A \neq 0$

$P = 0$



Consequences from the definition

A beam,
extracted by means of a bent crystal,
must be polarized
by definition
if an analyzing power is not zero

(and we know for sure that it is not zero).

Polarization calculation

$$P = \frac{(1 + A)^N - (1 - A)^N}{(1 + A)^N + (1 - A)^N}$$

Naïve example: all scatterings occur at the same (critical) angle



Critical channeling angle in *Si*

$$\theta = 5 \mu\text{rad} / p^{1/2} (\text{TeV}/c)^{1/2}$$

$$@ p = 70 \text{ GeV}/c \Rightarrow \theta \approx 20 \mu\text{rad}$$

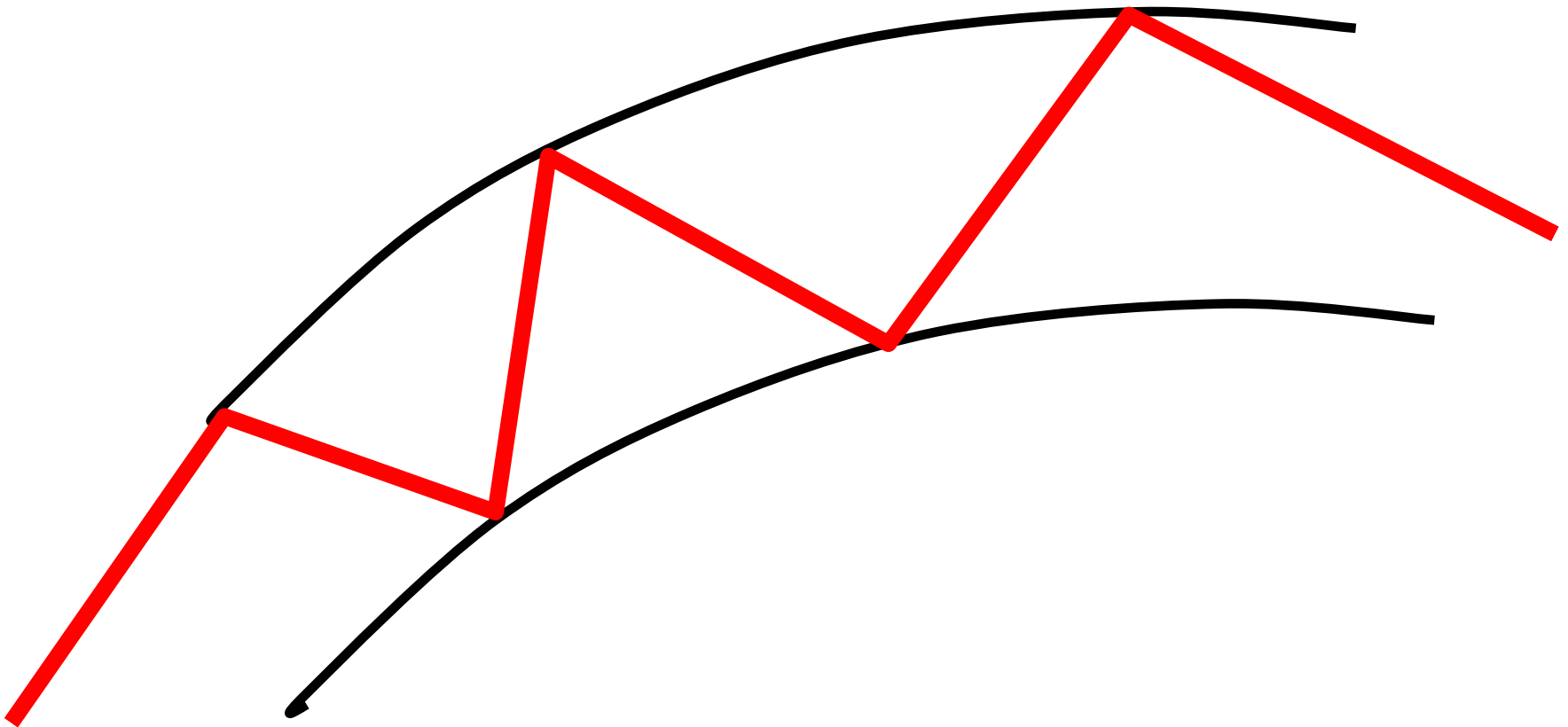
$$@ \theta \approx 20 \mu\text{rad} \Rightarrow |t| = 2 \times 10^{-6} (\text{GeV}/c)^2$$

100 mrad bend gives $N = 5000$

If $A = 10^{-4}$ then we get $P \approx 0.46$

Lemma:

$$\sum \theta_i = \text{Crystal Bent} \pm (\sim \theta_{\text{critical}})$$



Analyzing power at small $|t|$

Excerpt from talk by A. Bravar (BNL) at Spin05

$$A_N = C_1 \phi_{flip}^{em} * \phi_{non-flip}^{had} + C_2 \phi_{flip}^{had} * \phi_{non-flip}^{had}$$

In absence of hadronic
spin – flip contributions

A_N is exactly calculable

(Lapidus & Kopeliovich):

$$A_N = \sqrt{\frac{8\pi Z\alpha}{m_p^2 \sigma_{tot}^{pA}}} \frac{y^{3/2}}{1+y^2} (\mu - 1) \quad y = \frac{\sigma_{tot}^{pA} t}{8\pi Z\alpha}$$

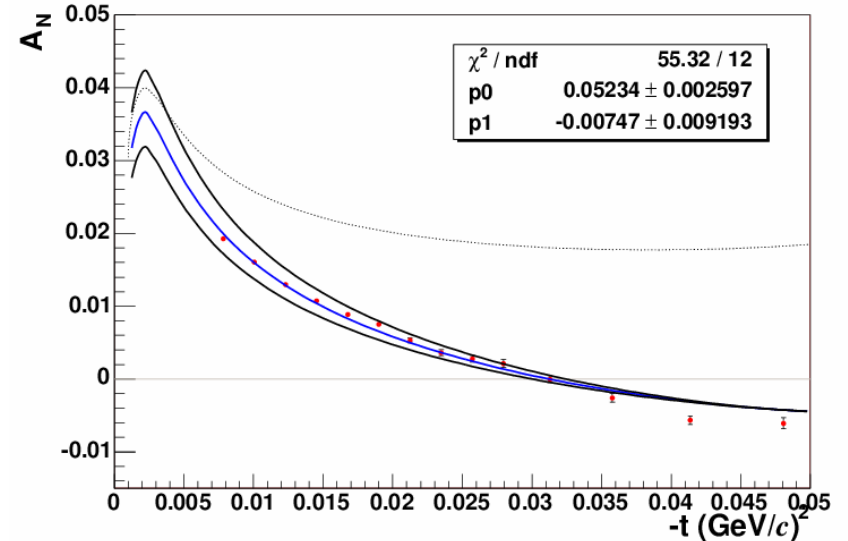
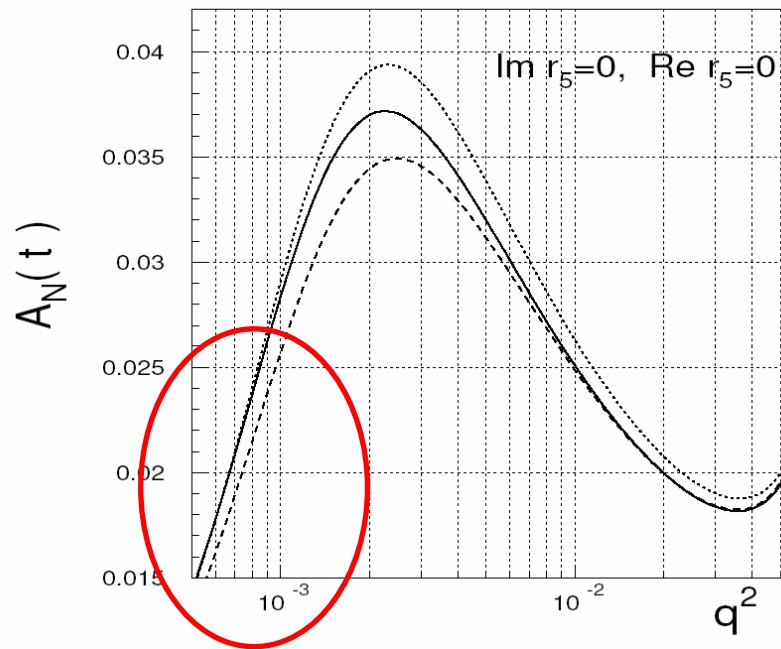
For very small $|t|$ A_N can be approximated by

$$A_N \approx |t|^\alpha f(s)$$

where α – depends on helicity of initial and final state particles,
 $f(s)$ – is a function of the total energy.

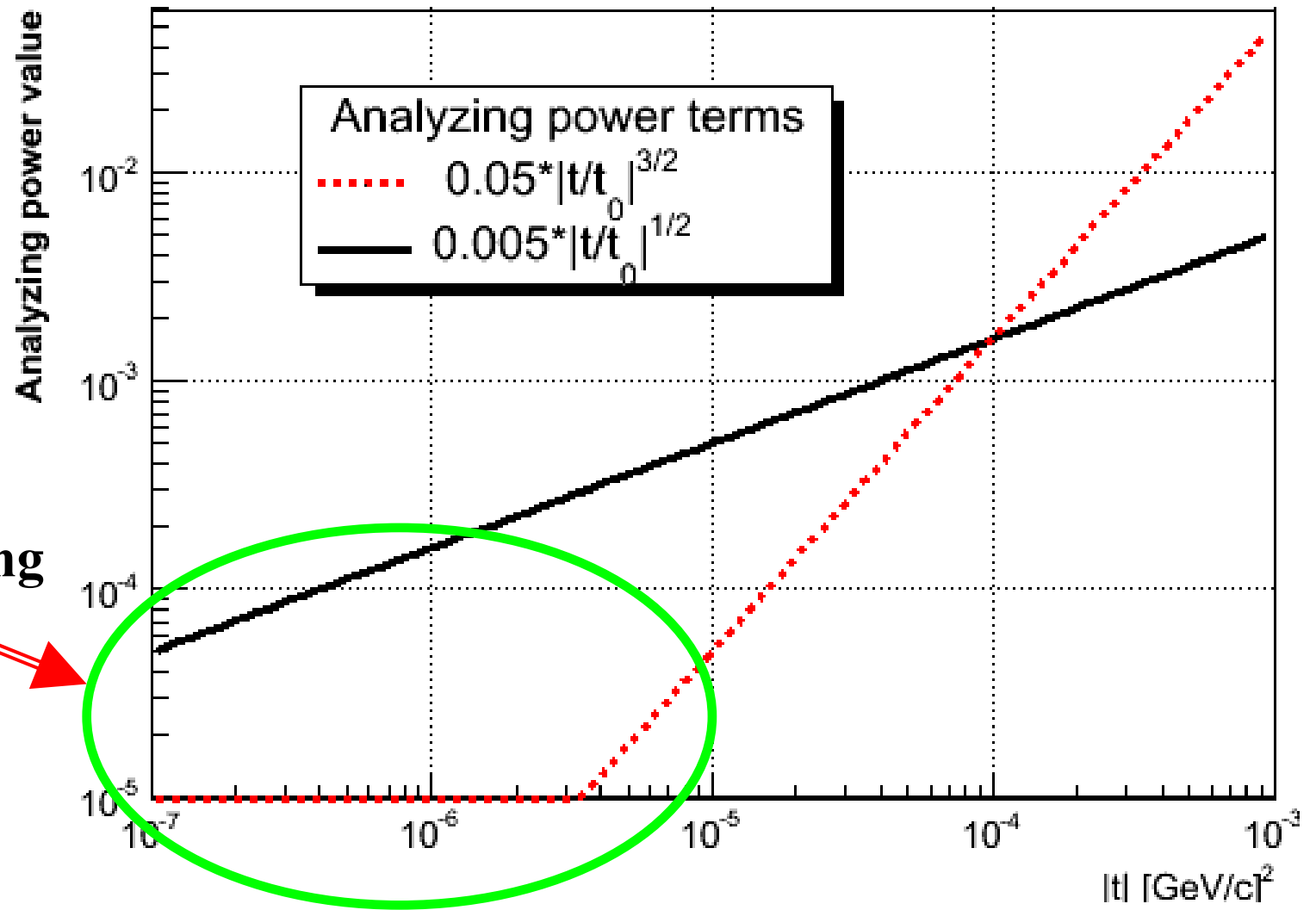
Analyzing power at small $|t|$

B.Z. Kopeliovich and T.L. Trueman, hep-ph/0012091

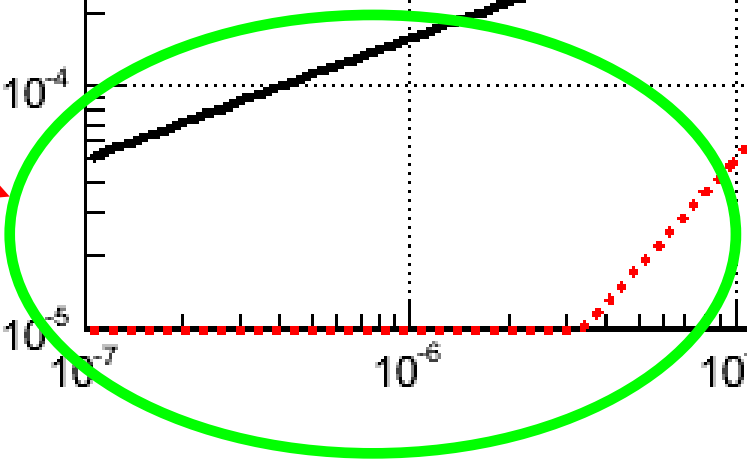


Kopeliovich –
Truemann model
PRD64 (01) 034004
hep-ph/0305085

Analyzing power evolution at small t



Channeling
is here



Assumptions

*To get a numerical estimation let us assume
a linear dependence
of an analyzing power on the scattering angle*

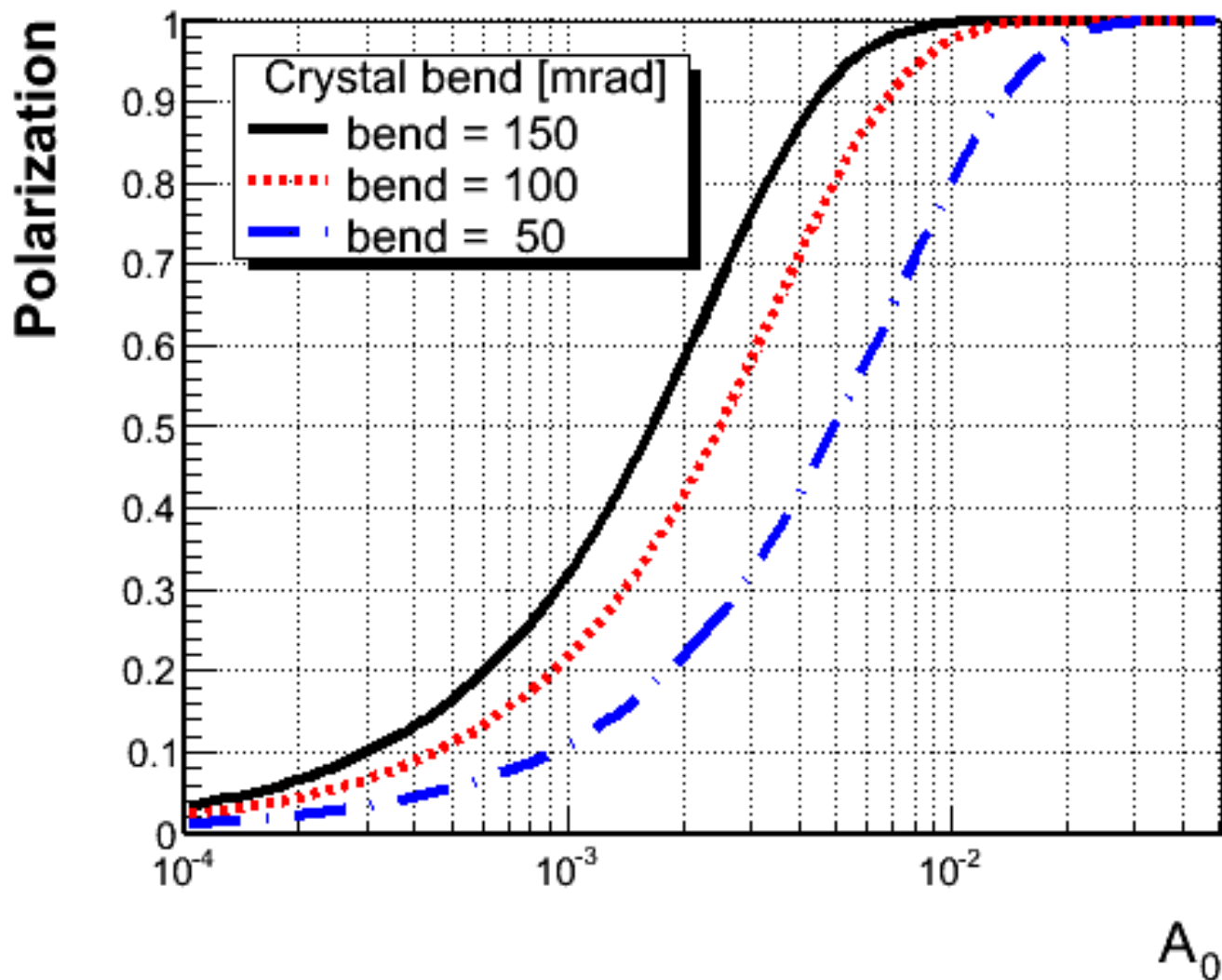
$$A(t) = A_0 \cdot |t/t_0|^{1/2}$$

for very small $|t| < |t_0| = 10^{-3} (GeV/c)^2$

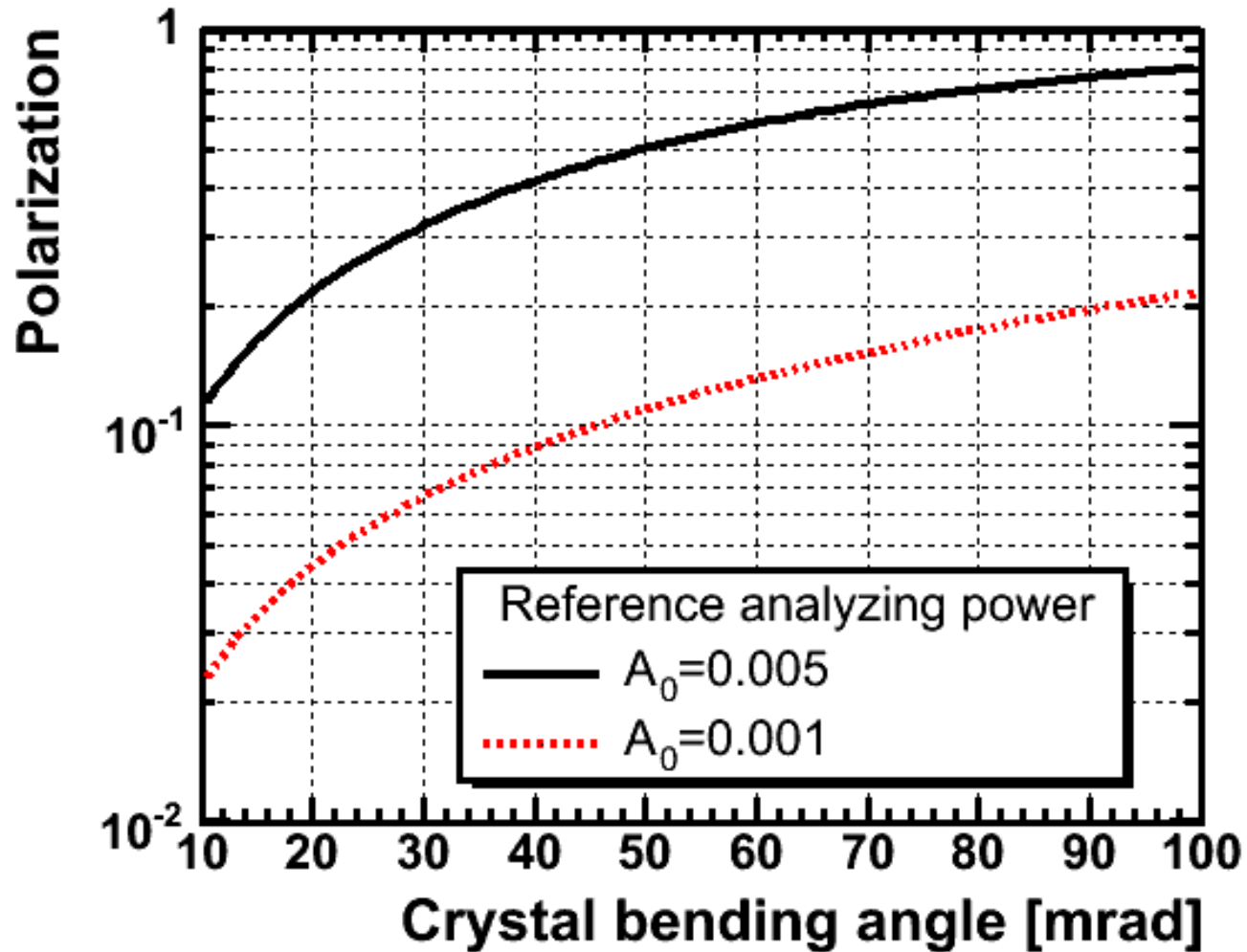
If we consider the channeling as a sequence of scatterings off the crystal lattice then the result does not depend on the beam trajectory inside the crystal.

Polarization depends only on the crystal bent.

Dependence on the A_0



Dependence on the crystal bent



Remark on a general case

- If the analyzing power dependence on the scattering angle is not a linear function then the resulting polarization will depend on a trajectory of the particle inside the crystal.
- Channeling in a crystal occupies the transfer momentum domain at
$$|t| < 10^{-5} (GeV/c)^2$$
- No experimental data on the analyzing power exists today in this domain.

Antiproton in a bent crystal



$$F_{centrifugal} = F_{electrostatic} = \pm Ze^2 \left(\frac{1}{r_1^2} - \frac{1}{r_2^2} \right)$$

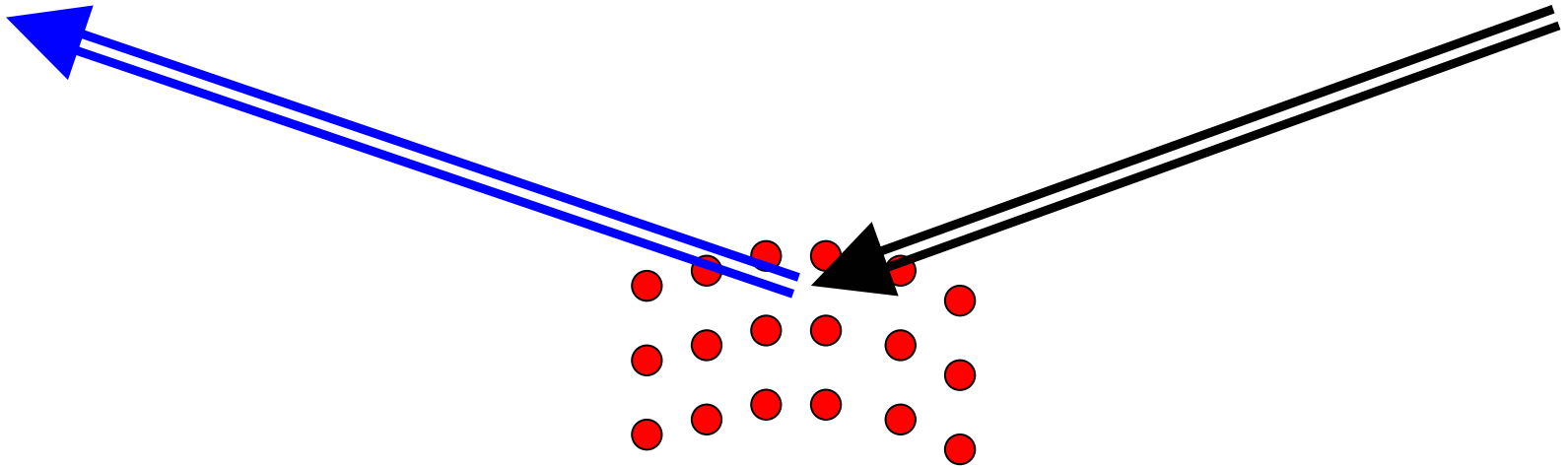
The question about shape of the potential remains open.

Repulsive/Attractive



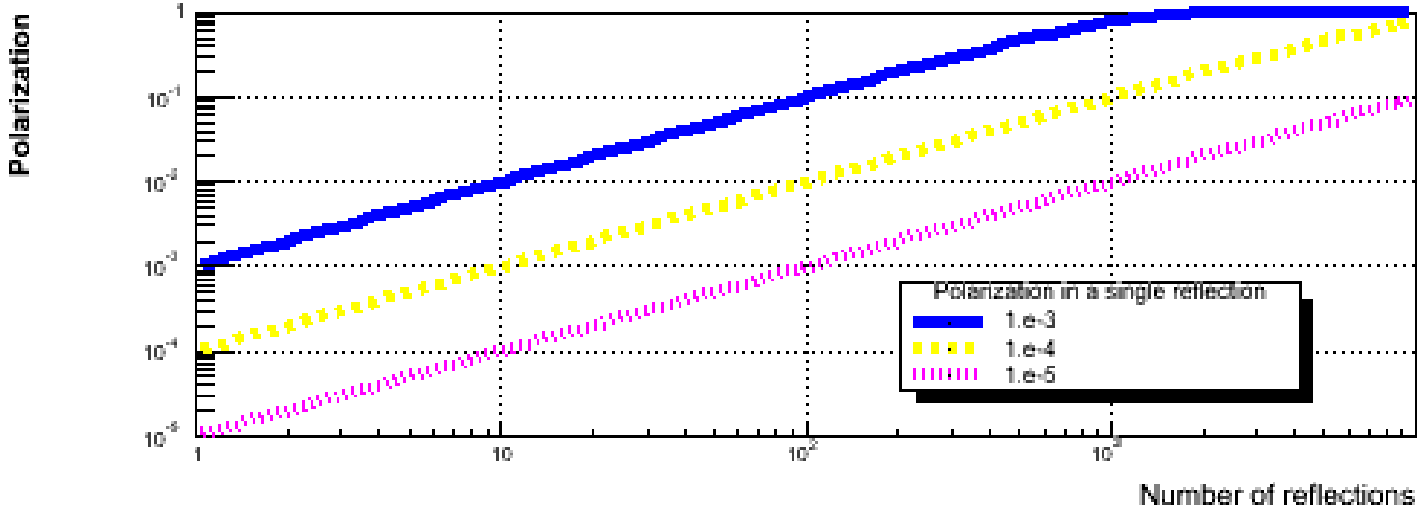
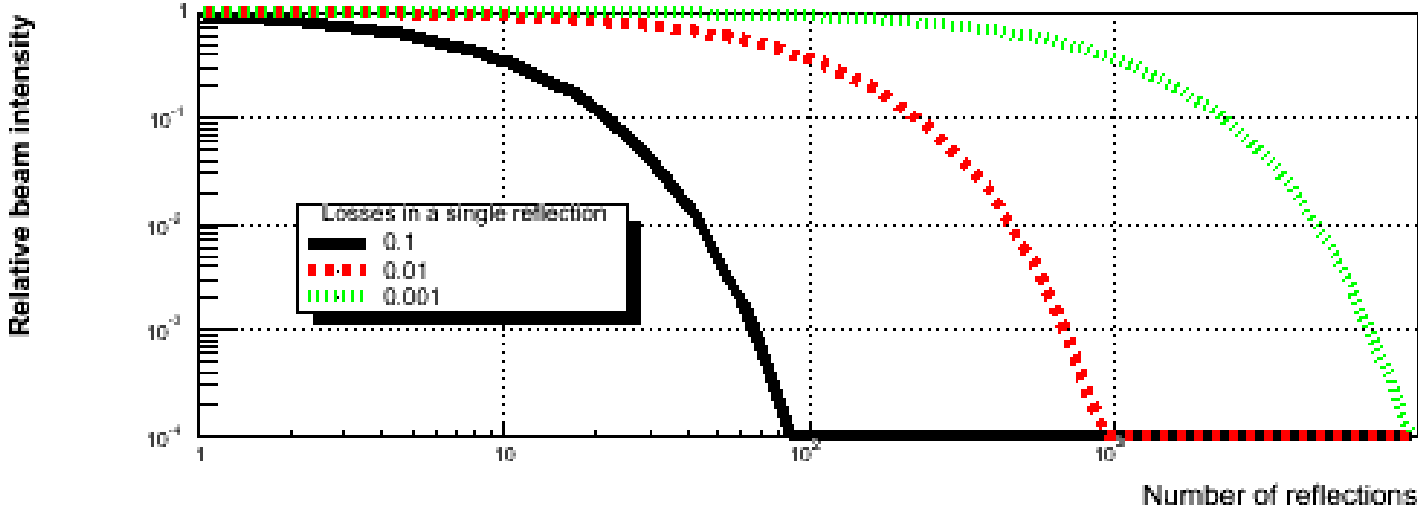
But where are the electrons?

Volume reflection



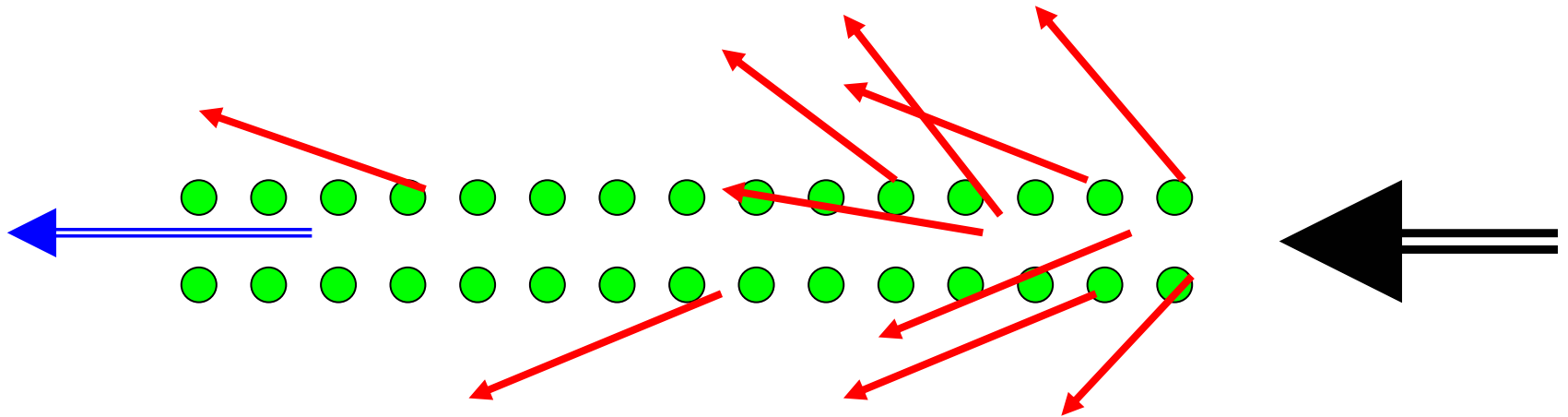
Since it is single scattering it should work with about the same efficiency for protons and for antiprotons due to identity of the equilibrium condition.

Estimation of volume reflection capabilities

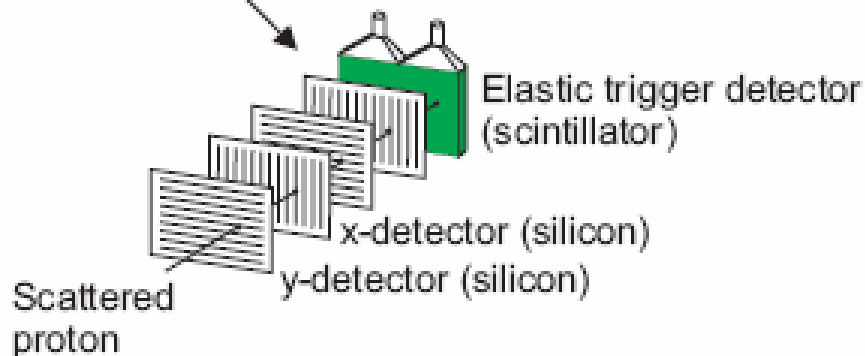
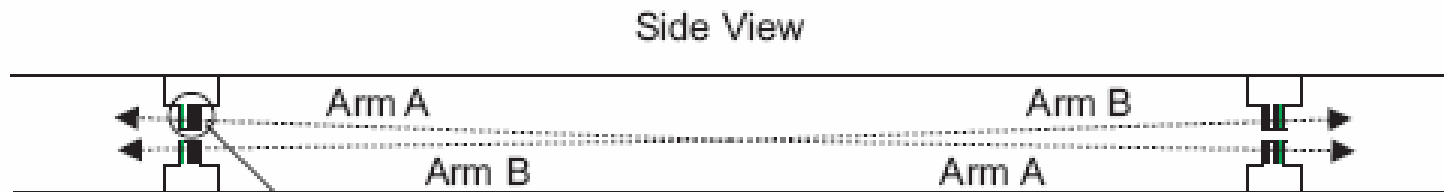
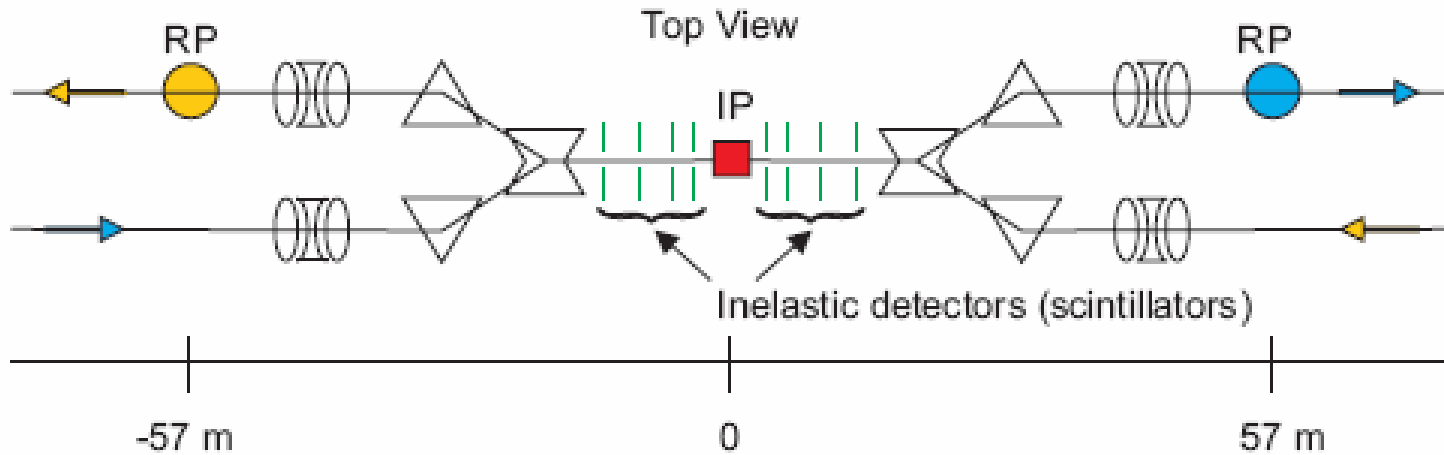


A remark on the efficiency of the volume reflection

One could imagine a mechanism of a beam conditioning in which efficiency improves with the number of reflections.



pp2pp experiment layout



$$|t| \geq 5 \times 10^{-4} (\text{Gev}/c)^2$$

A bit of physics – interpretation of measurement of a beam polarization

- Channeling
 - one needs to know the exact trajectory inside the crystal;
 - and a model of analysing power.
- Volume reflection
 - fixed scattering angle;
 - in a circulating beam it is easier to measure polarization.

Conclusions

- Bent crystal extraction provides a polarization in the resulted beam (*strict*).
- With certain assumptions a beam polarization could be big enough for practical needs.
- It is also possible to get a beam polarization using a multi turn volume reflection off a bent crystal.
- Using the volume reflection techniques one can utilize *a la RICH* polarimeter to make measurements.
- Since there is no experimental data today the measurements of a beam polarization provides a tool for a physics in $|t| < 10^{-5} (GeV/c)^2$ domain which is hardly, if not at all, attainable with the other methods.