Advanced Studies Institute

SYMMETRIES AND SPIN

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Secondary Polarized Beams at LHEP facilities

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Polarized beams acceleration at Nuclotron

- ## Nuclotron - M

  - Modernization of the power supplies and the Nuclotron stored energy damp system
    => reliable operation up to **Emax = 6 GeV/nucleon**;
  - Beam dynamics study and **minimization of the particle losses** at all the stages of accelerator cycle;
  - Upgrade of the accelerator ring vacuum system;
  - Beam extraction system and beam transfer lines upgrade ;
  - **High intensity polarized ion source;**
  - etc.

- ## Source

The existing source of polarized deuterons, POLARIS, can not be effectively used at Nuclotron.

A new ABS of polarized deuterons and protons based on the CIPIOS and INR source units solutions are being designed. The main goal of the project is providing physical experiments with accelerated polarized beams at intensity level 10^{10} part./cycle or above.

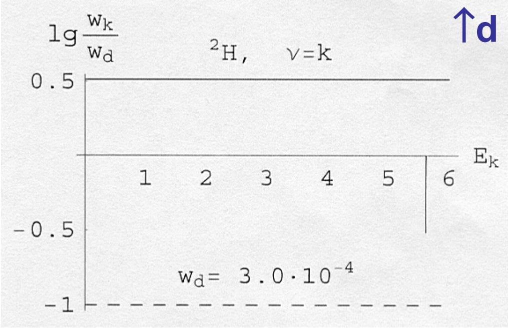
Main parameters of the sources:

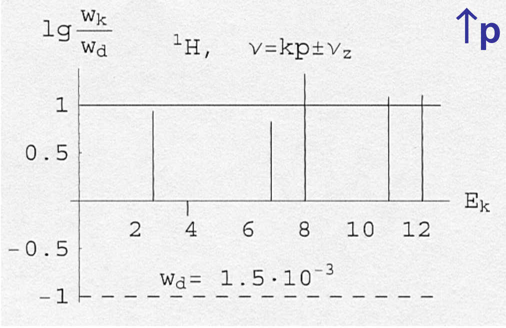
- **$I \cong 10mA$ => $5 \cdot 10^{11}$ $\uparrow D^+$ / $\uparrow H+$ per $\tau = 8\mu s$,**
- **$P \cong 90\%$ of maximal possible vector (±1) and tenzor (+1, -2) polarization.**

Ref.: V.V. Fimushkin, A.S. Belov, et al., EPJ, in print

Beam depolarization

The problem of beam depolarization at acceleration in Nuclotron have been studied theoretically (S. Vocal, A.D. Kovalenko, A.M. Kondratenko et al., arXiv:0802.4153v1 [hep-ex] and ref. therein)





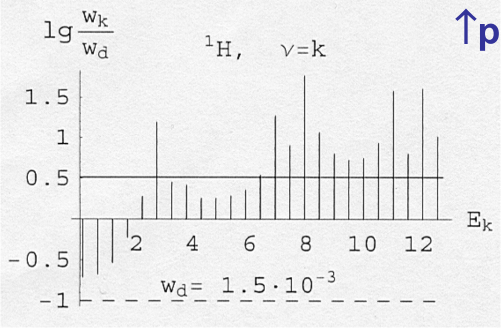


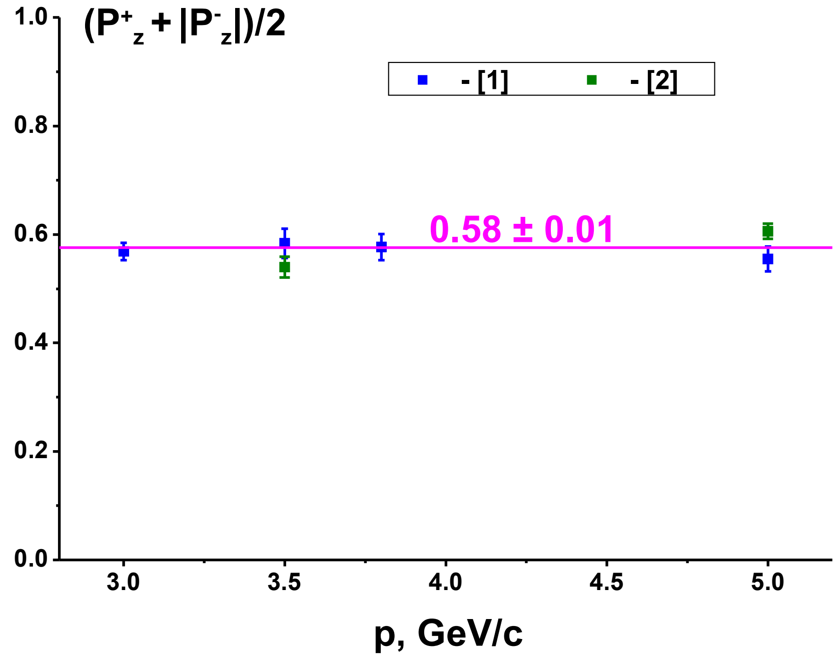
Fig.: The most strong spin resonances in the Nuclotron ring for deuterons and protons.

No depolarization resonances are foreseen for deuterons at the most part of the Nuclotron energy range.

Test run on acceleration and slow extraction of polarized deuterons from the POLARIS source have provided an experimental evidence of the conclusion.

3. Yu.S. Anisimov et al., Part. And Nucl. Lett. 1[118], 2004

5. L.S. Azhgirey et al., Part. And Nucl 2[125], 2005



<u>Depolarization resonances are predicted for protons.</u>

Deuteron breakup as a source of secondary beams (1)

d↑ + A → n↑ + X
d↑ + A → p↑ + X
d + A → n + X

- Cross sections:

$$\sigma = 170 - 210\, mb\; (Be,\, C)\,, \quad \sigma(E) \simeq const$$

- Angular spread and yield at 0° (lab. frame):

$$\sigma_{\theta_x} \simeq 2k_1^{rms}/p_d\;, \qquad Y \propto p_d^2$$

- Relative momentum spread (lab. frame):

$$\delta_p \simeq \frac{2k_1^{rms}}{\beta_d m_d} \rightarrow const$$

k_1 – nucleon internal momentum projection on an axis
p_d, b_d, m_d – deuteron momentum, velocity (lab. frame) and mass

Deuteron breakup as a source of secondary beams (2)

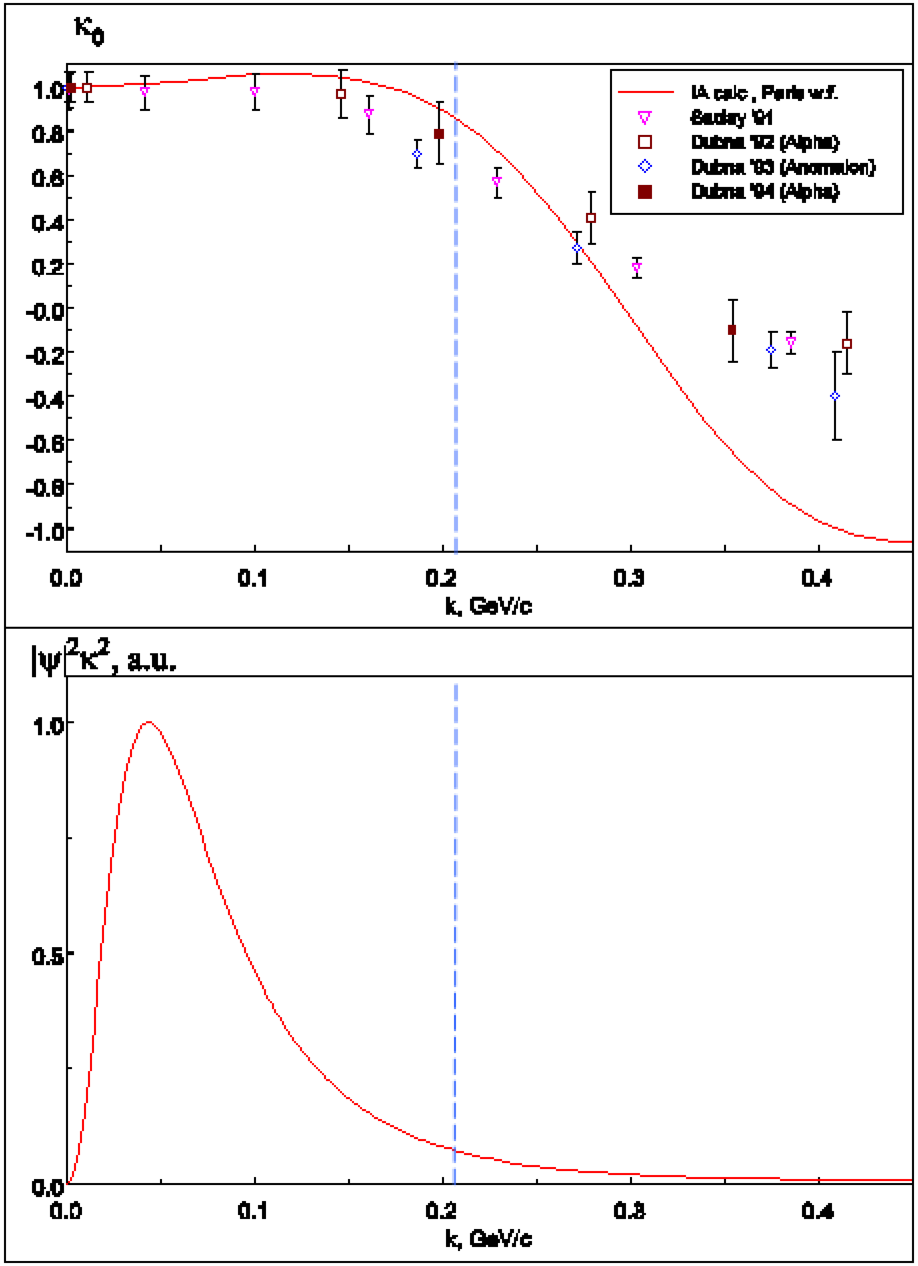
Polarization transfer in reactions

$$d\uparrow + A \to p\uparrow + X \quad \text{at } 0^\circ$$

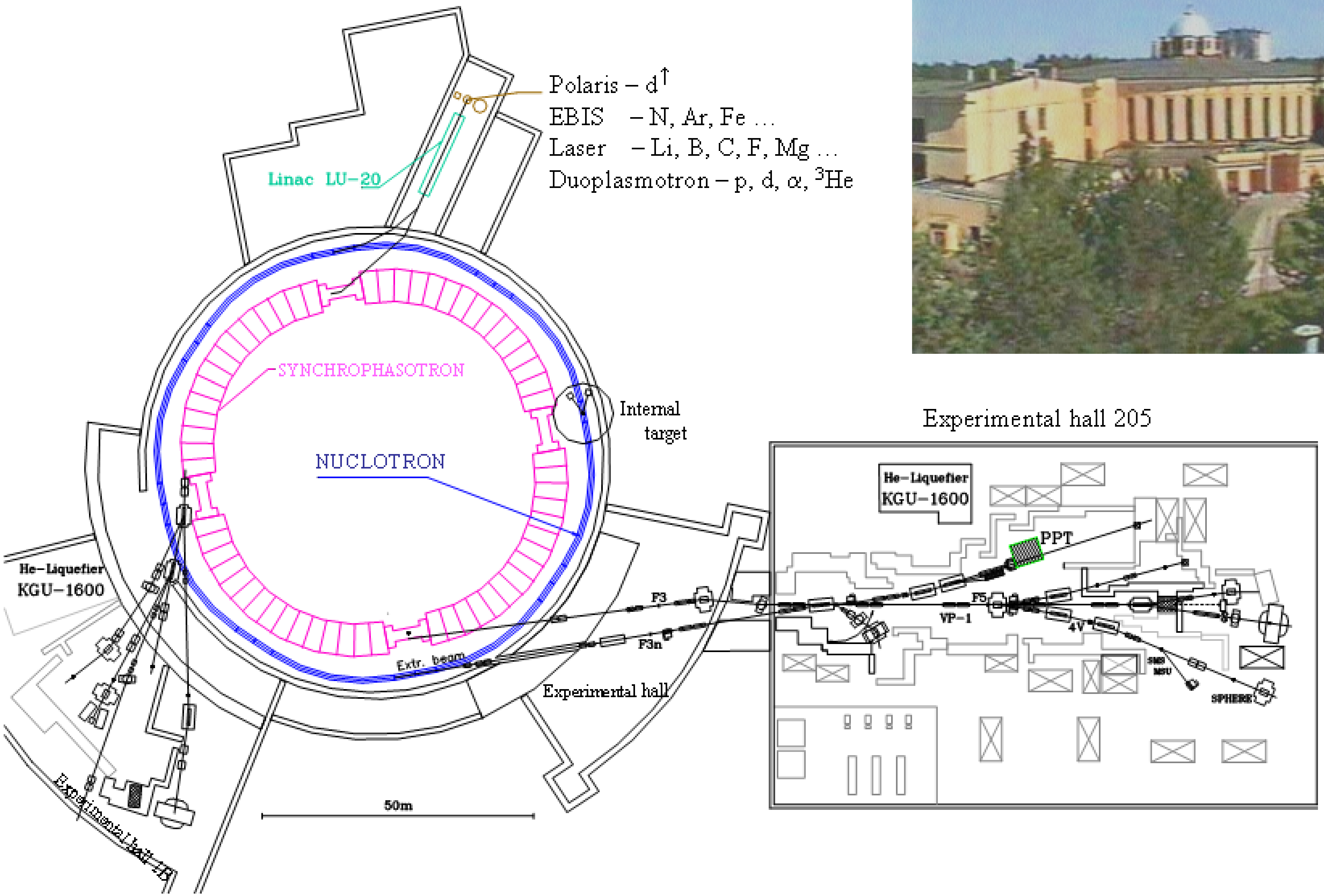
$$\kappa_0 = \frac{P^{(p)}}{P_z^{(d)}}$$

$P^{(p)}$ - polarization of secondary protons
$P^{(d)}_z$ – vector polarization of deuterons (at $P^{(d)}_{zz} = 0$)

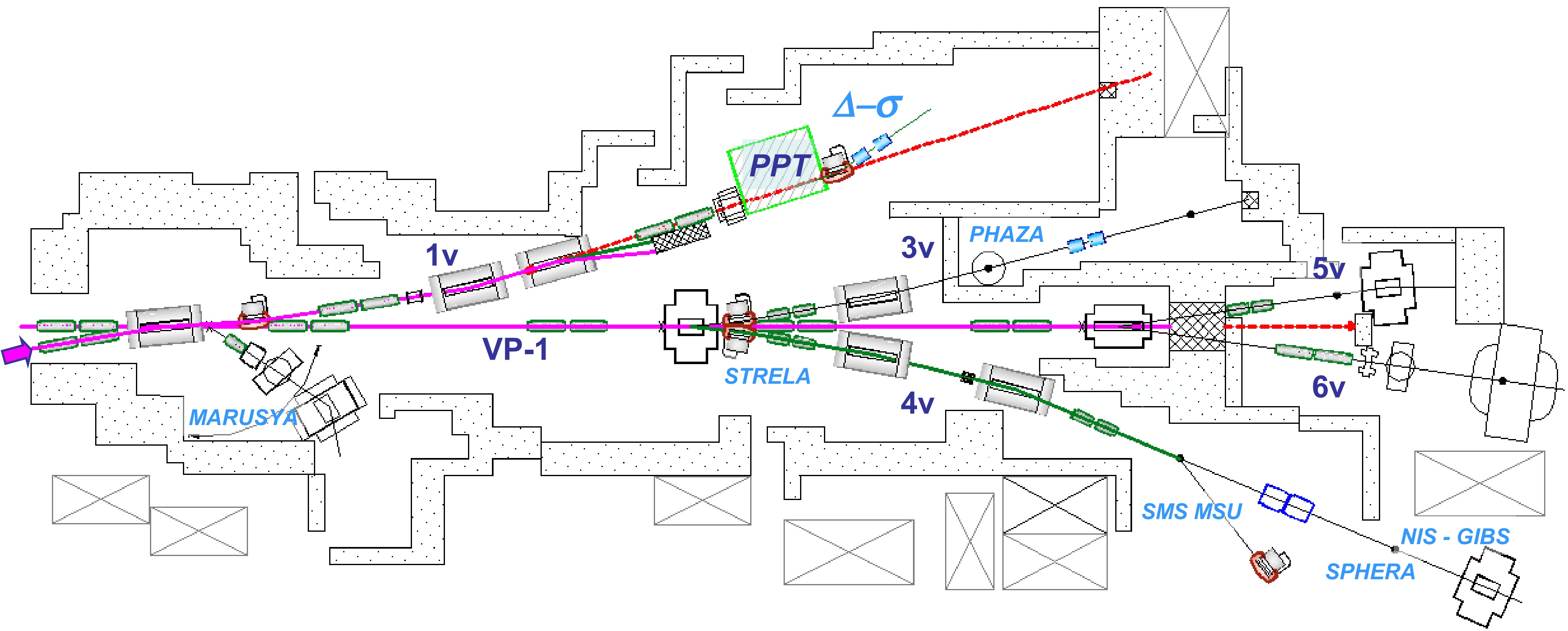
E. Cheung et al., Phys. Lett. B **284**, p.210
T. Dzikowski et al., in: Dubna Deuteron-91, JINR **E2-92-25**, p.181
A.A. Nomofilov et al., Phys. Lett. B **325**, p.327
B. Kuehn et al., Phys. Lett. B **334**, p.298



Spectators of the deuteron breakup practically entirely inherit the polarization of primary vector polarized deuterons.


Polaris – d↑
EBIS – N, Ar, Fe …
Laser – Li, B, C, F, Mg …
Duoplasmotron – p, d, α, ³He
Linac LU-20
SYNCHROPHASOTRON
NUCLOTRON
Internal target
He-Liquefier KGU-1600
Experimental hall 205
PPT
F3
F3n
F5
VP-1
4V
SPHERE
Extr. beam
Experimental hall
Experimental hall 1B
50m

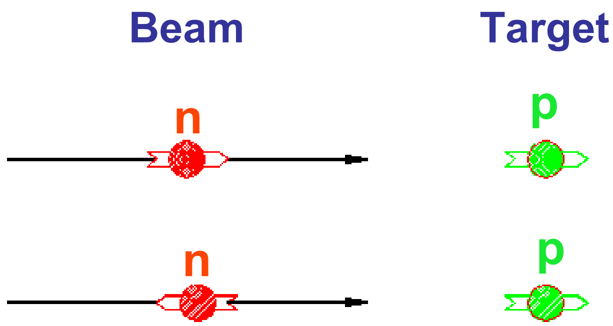
Beam lines and setups layout in an extracted beam experimental area



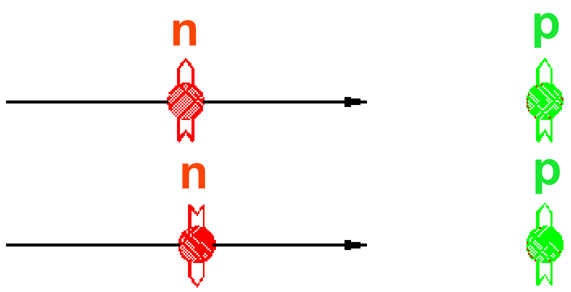
➡	Slowly extracted beams input	– – – –	Neutron beam lines	***PPT***	– Polarized Proton Target
———	Primary polarized deuteron traces at secondary polarized beams forming	———	Sec. polarized protons	*Δ–σ, NIS …*	– setups

- Measurement of the np total cross section differences $\Delta\sigma_L(np)$ and $\Delta\sigma_T(np)$ at the energy range of LHEP accelerator facilities

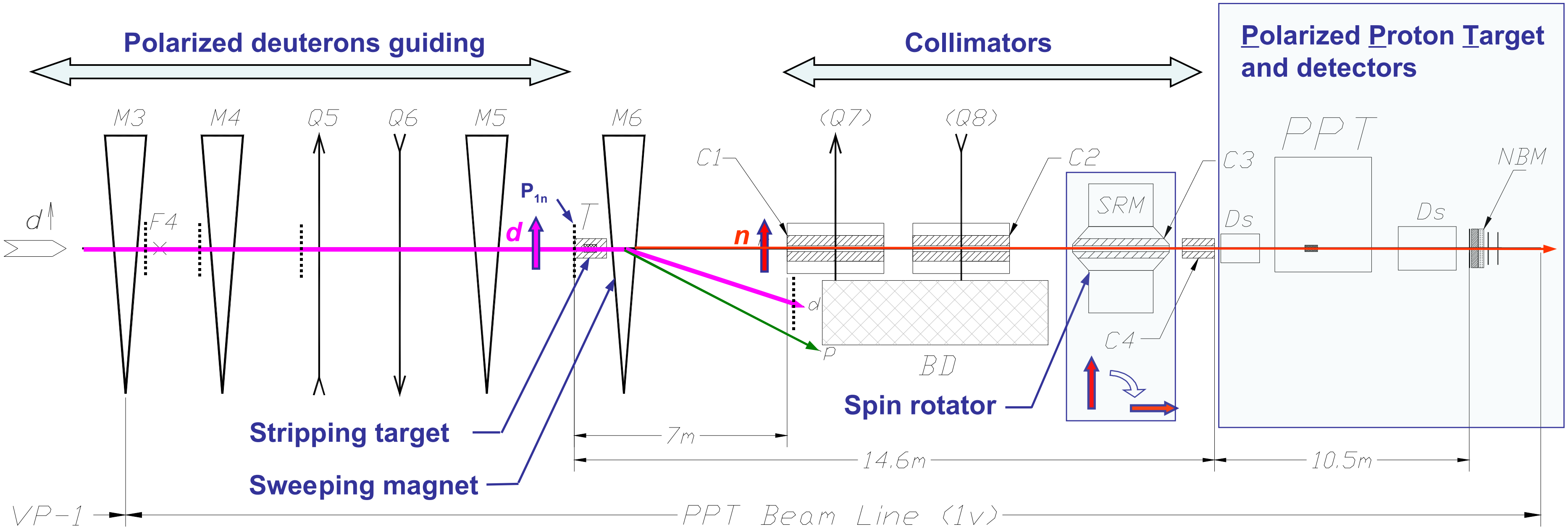
$\Delta\sigma_L$ —



$\Delta\sigma_T$ —



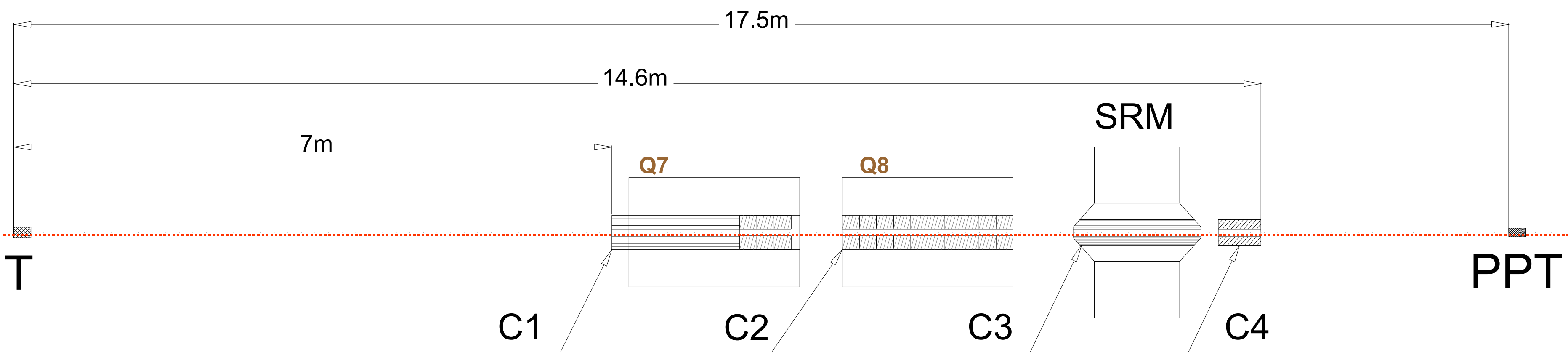
Neutron beam line to the PPT



M – dipole magnets, Q – quadrupoles, BD – beam dump,

P – deuteron beam profilemeters, NBM – neutron beam monitor

PPT neutron beam forming conditions



- **Target:**
  Be, d=20 cm; relative neutron yield $I_n/I_d \cong 0.15$

- **Spin rotating magnet:**
  $B{\cdot}L_{max} = 2.7$ T·m

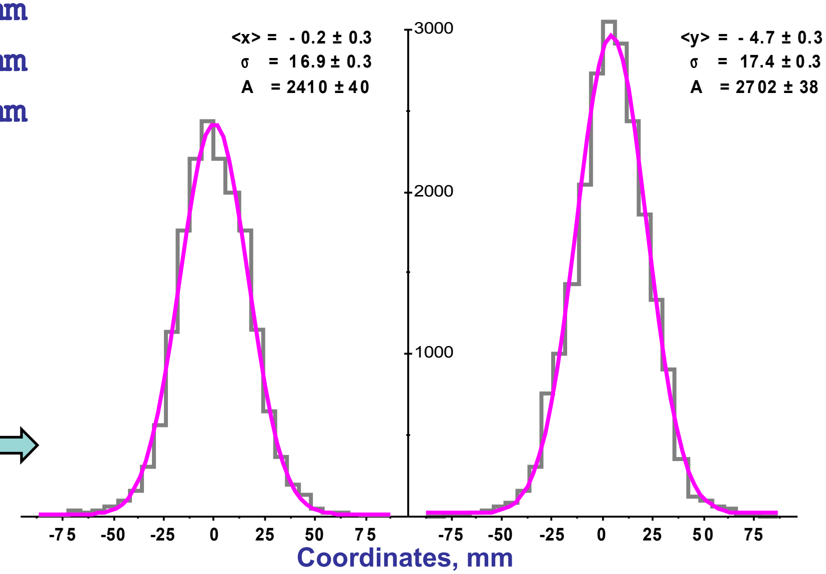
- **Sectioned collimator:**
  - C_1: Fe, L = 1.5m, D = 40mm
  - C_2: Fe, L = 2.5m, D = 30mm
  - C_3: Cu, L = 1.5m, D = 28mm
  - C_4: Cu, L = 0.5m, D = 28mm

  $\Delta\Omega \cong 2.9\ \mu sr$

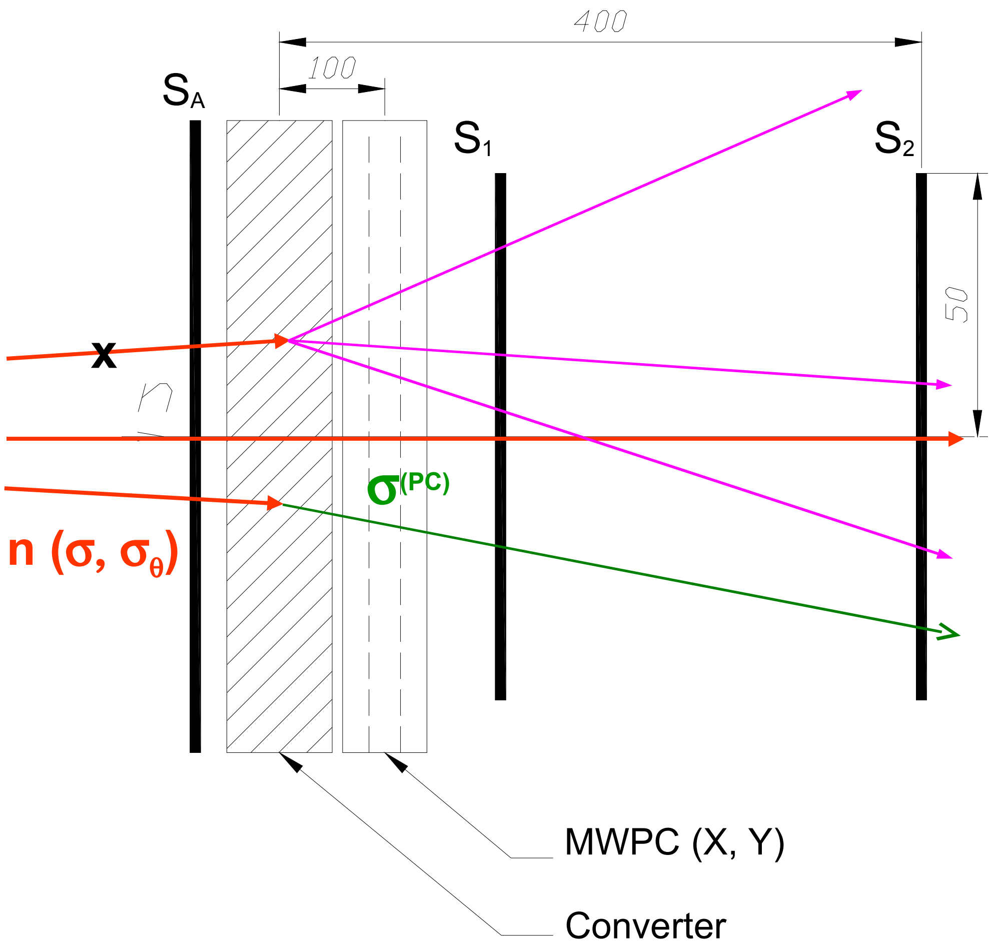
- **Incident polarized deuterons beam:**

  $I_d = 1 - 4 \cdot 10^9$ ppc,
  (Spill $\cong$ 0.5 s, Repetition = 10 s)

Fig.: Example of primary polarized deuterons beam profiles at the neutron-producing target at p_d = 5.0 GeV/c



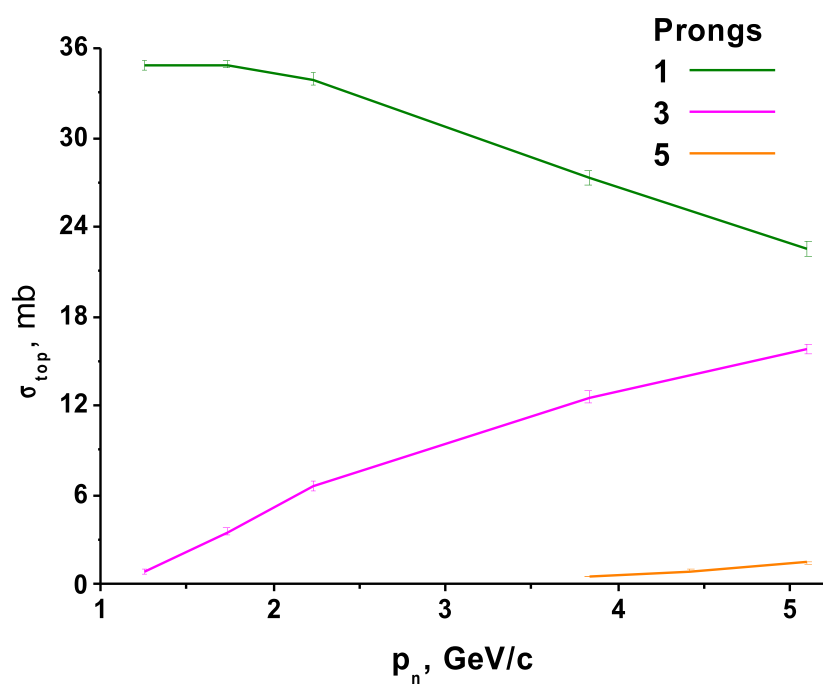
Neutron beam monitoring



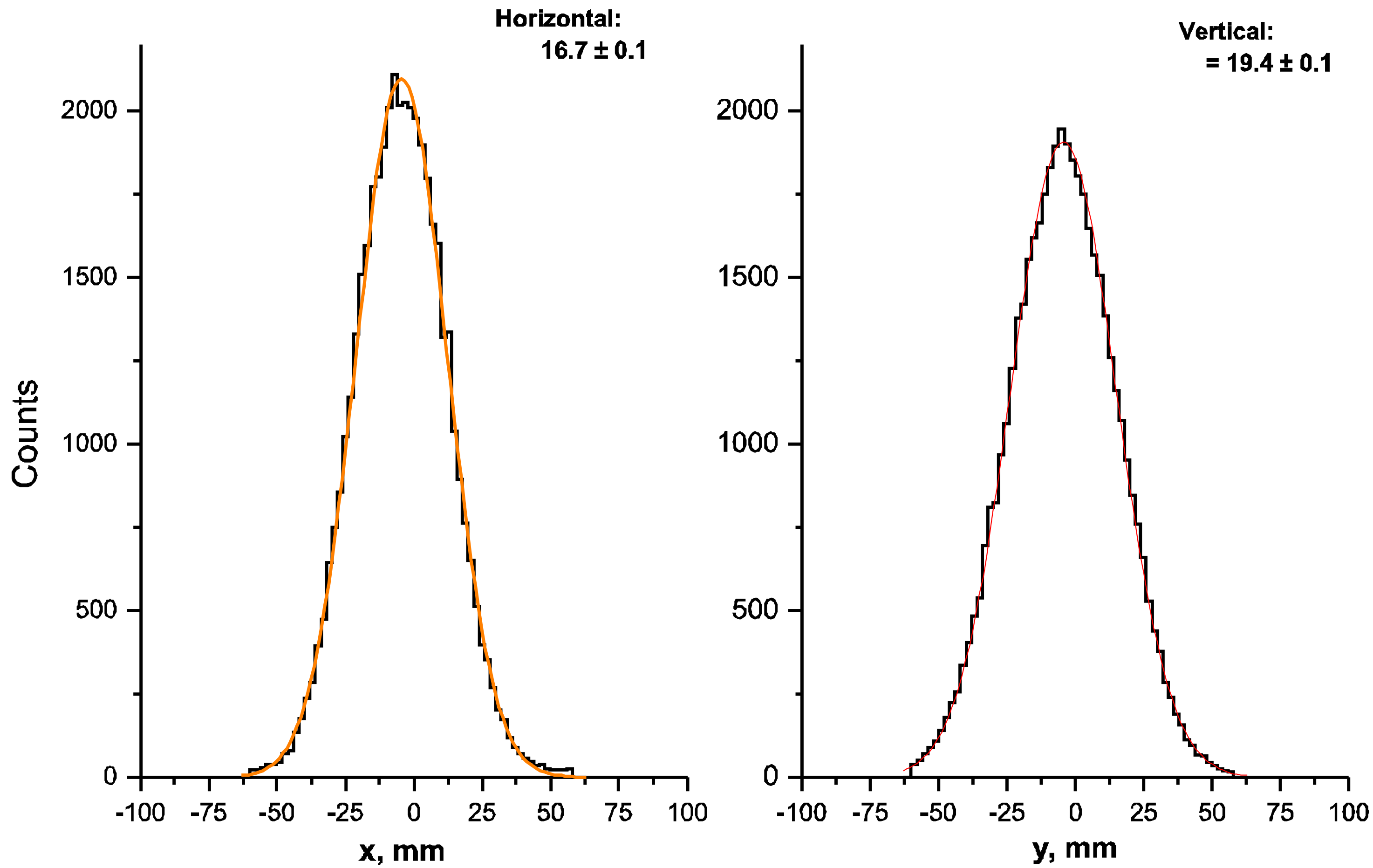
- Converter - polyeth., d=16 cm
- $\overline{S_A} \cdot S_1 \cdot S_2$ - MWPC trig.
- $\sigma^2_{MWPC} = \sigma^2 + \sigma^2_{add.}, \quad \sigma_{add.} \leq 5-6$ mm

Cross sections of np-interactions

Besliu C., et al., Yad.Fiz.43:888-892,1986

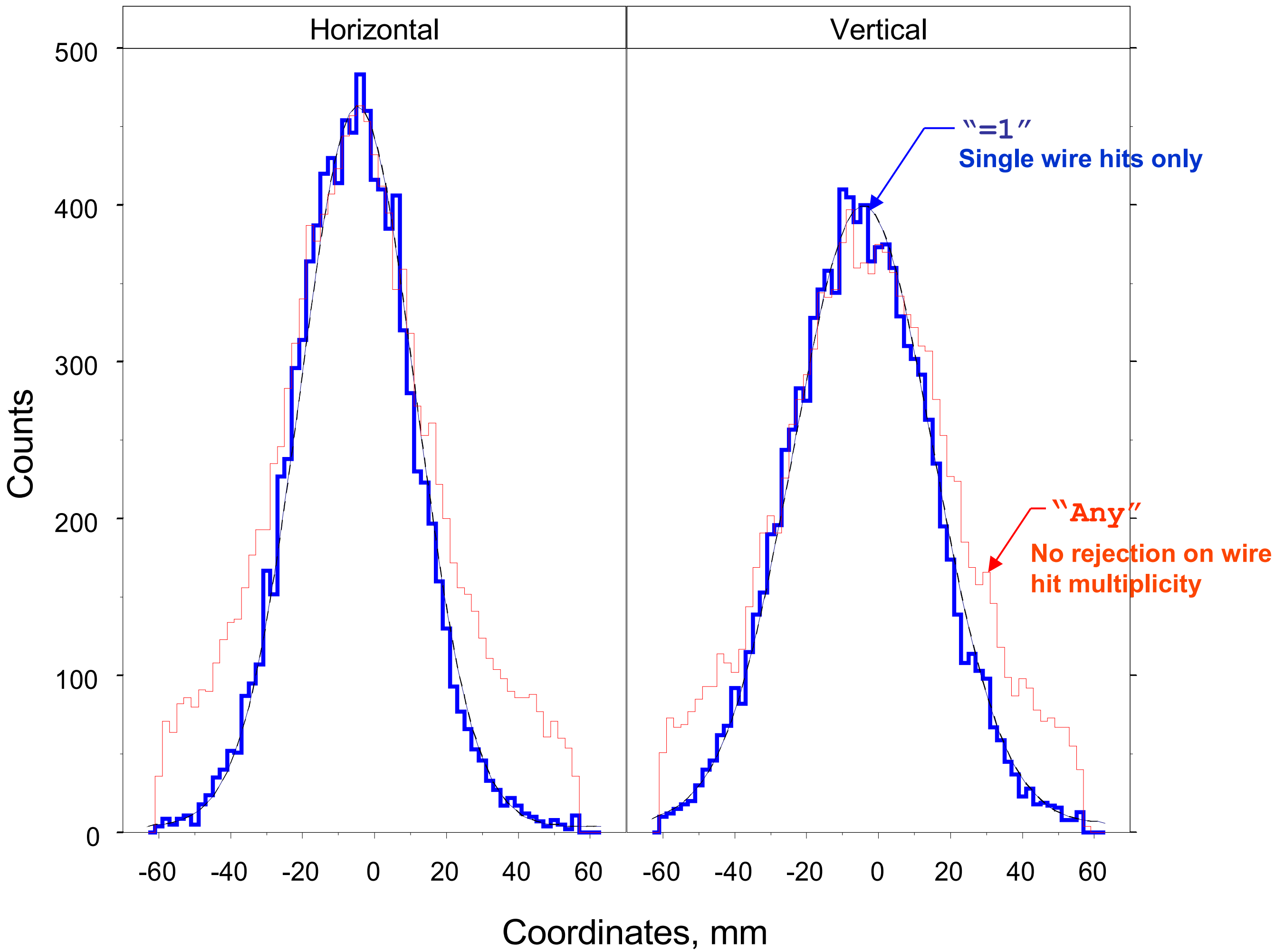


Neutron beam profiles behind the PPT



- **neutron momentum - p_n = 3 GeV/c,**
- **distance from collimator exit - d = 10.5 m**

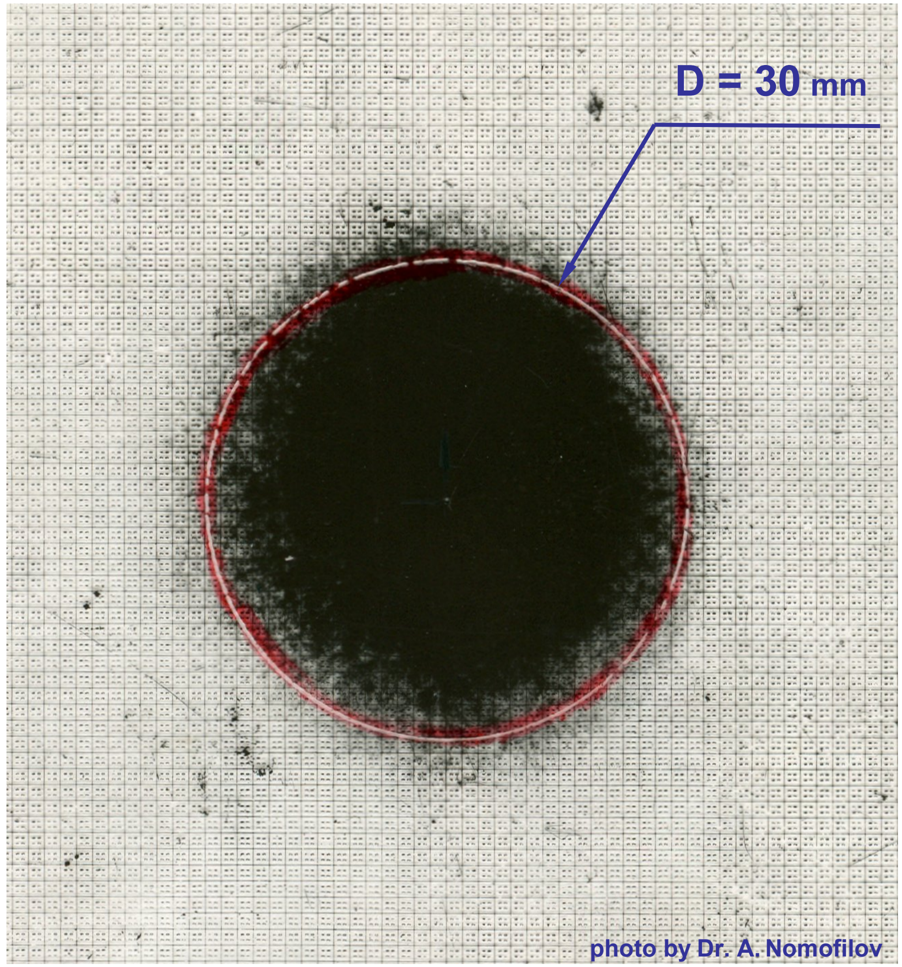
Neutron beam profiles monitoring:
applying event rejection on multiplicity



- neutron momentum - p_n = 3 GeV/c,
- distance from collimator exit - d = 10.5 m

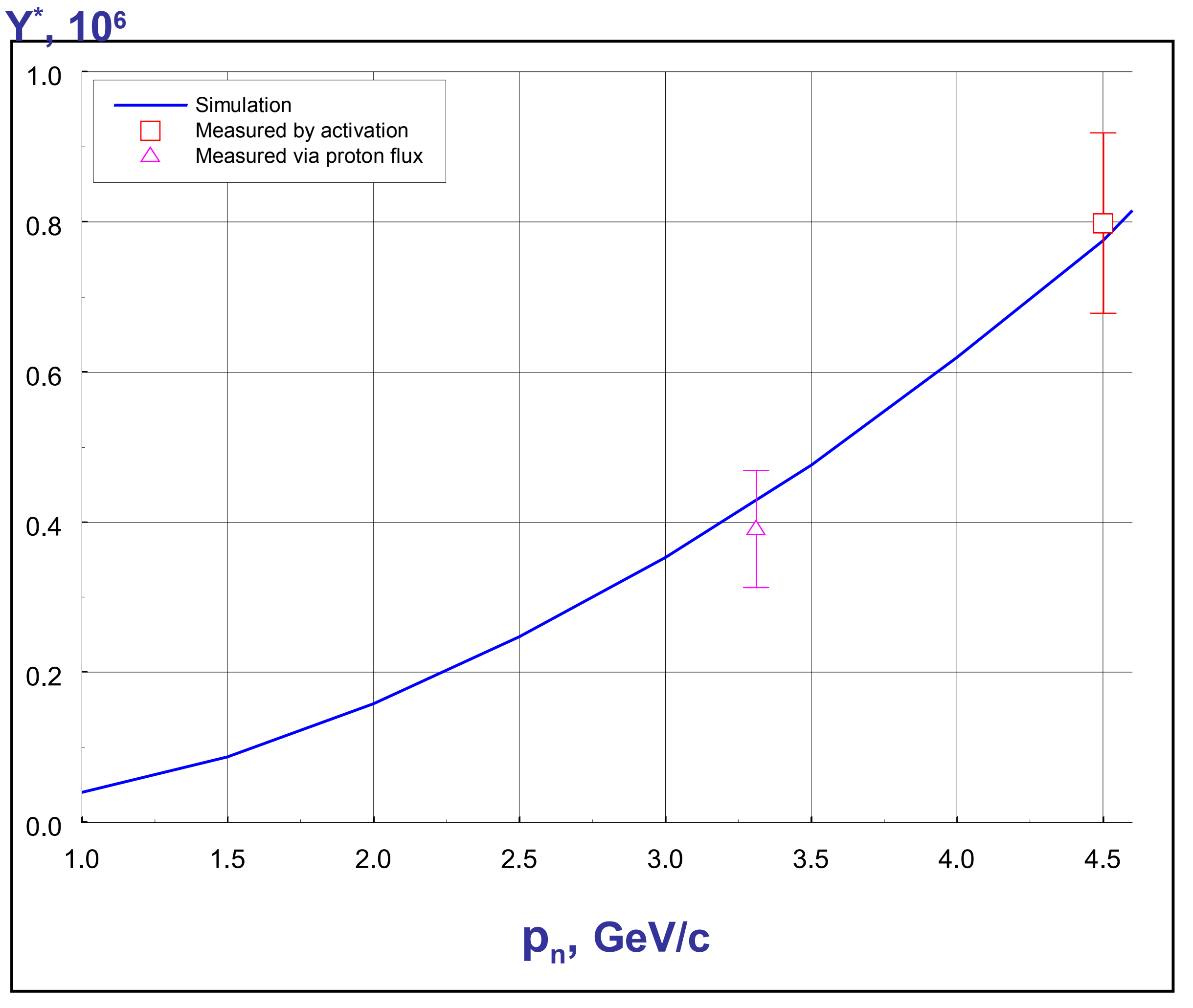
Immediate image of a neutron beam spot

at PPT position, P = 4.5 GeV/c



- black points are stars in an emulsion from neutron interactions
- red circle marks the PPT working boudary

Polarized neutrons yield at the PPT line



* - yield per 10^9 incident deuterons

Polarized neutron beam at PPT

Table: Polarized neutron beams parameters

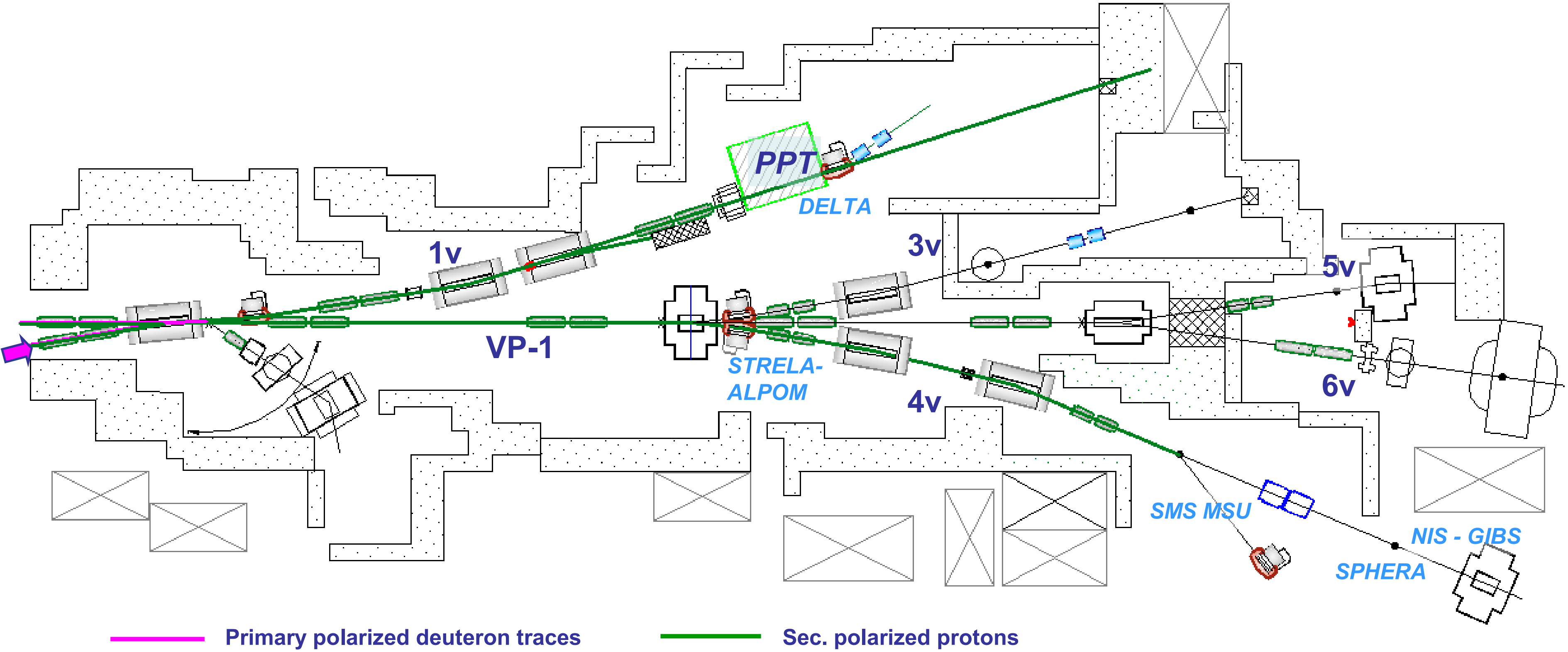
Parameter	Units	I	II
Momentum range	GeV/c	≅ 1 – 4.5	≅ 1 – 6.5 (6.8)
Intensity at p_{max}	ppc	$2 - 4 \cdot 10^6$	$2 - 4 \cdot 10^7$
Polarization		≅ 0.55	≅ 0.90 (?)
Momentum spread (FWHM)	%	≅ 5	≅ 5
Angular spread (σ)	mr	1 – 1.5	1
Full beam size at PPT	mm	≤ 30	≤ 30

I - Synchrophasotron + Polaris

II- Nuclotron-M + HIPDS

$$(P^2 I)_{II} / (P^2 I)_{I} \cong 25$$

Secondary polarized proton beams forming

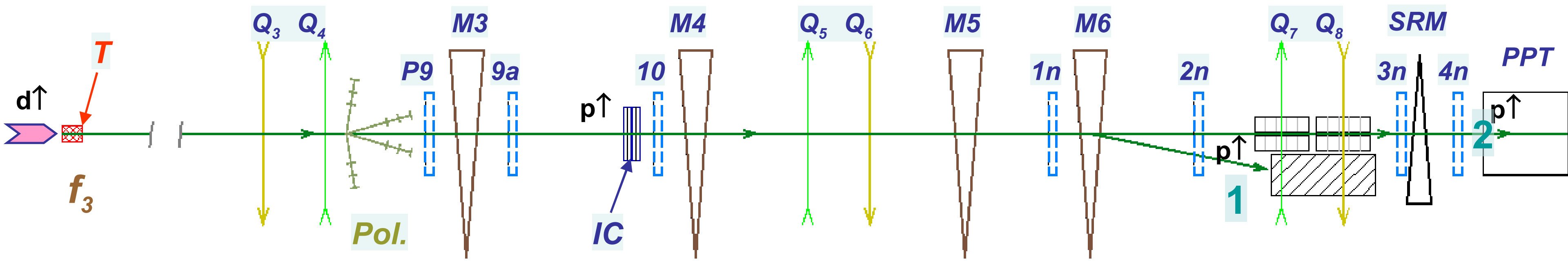


- Measuring proton-nucleus analyzing power $\uparrow p + C$, $\uparrow p + CH_2$ (SMS MSU, SPHERE), $\uparrow p + CH2$ (ALPOM) - carried out experiments.
- Search for the spin-dependent phenomena of π^0- and η-meson production in $\uparrow p + \uparrow p$, $\uparrow n + \uparrow p$ collisions (using polarized nucleon beams at PPT) – DELTA experiment, ready to take data setup.
- Measurement of the energy dependence of the spin correlation parameter A_{00nn} in quasi-elastic $\uparrow p \uparrow p$ scattering at angles close to $\theta_{cm} = 90°$ - pp SINGLET experiment, proposal.

References and discussions on the problems are in the review: F. Lehar, Part. & Nucl. 36, (2005)

Test forming of polarized protons to the PPT (1)

Ref.: P.A. Rukoyatkin, Czech. J. Phys. 52, C695



T – target (Be), *Pol.* – relative polarimeter, *Pi* – profilemeters, *IC* – ionization chamber

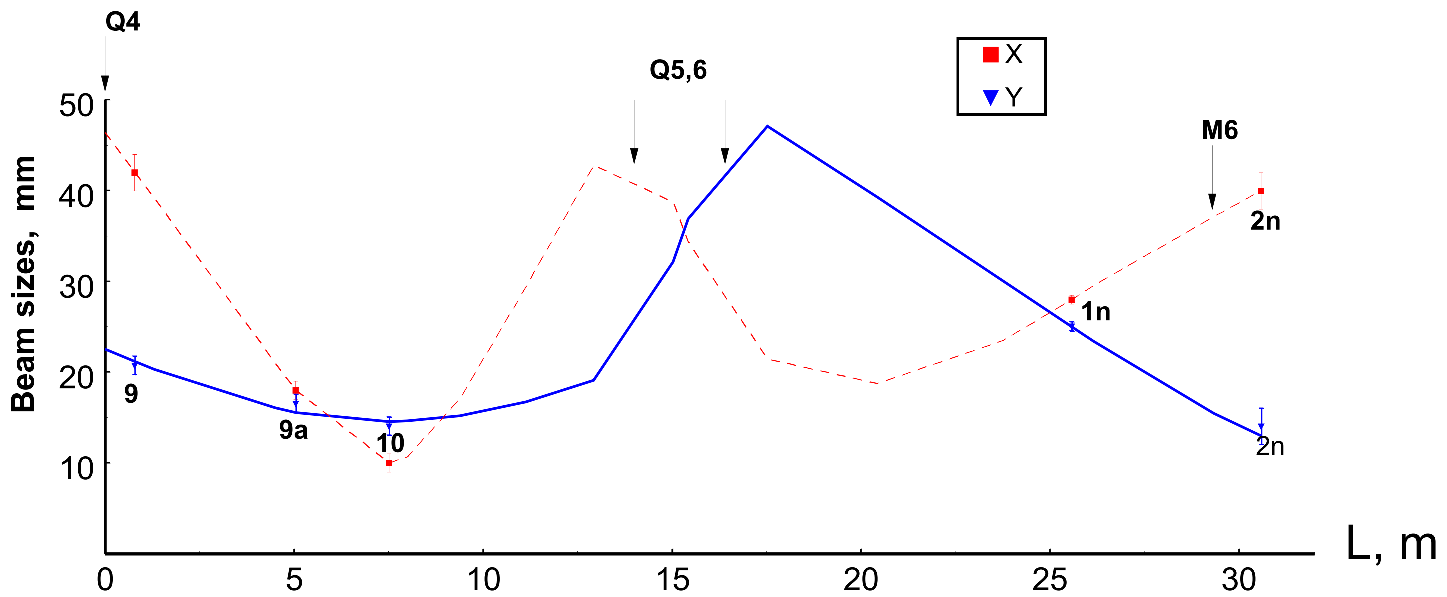
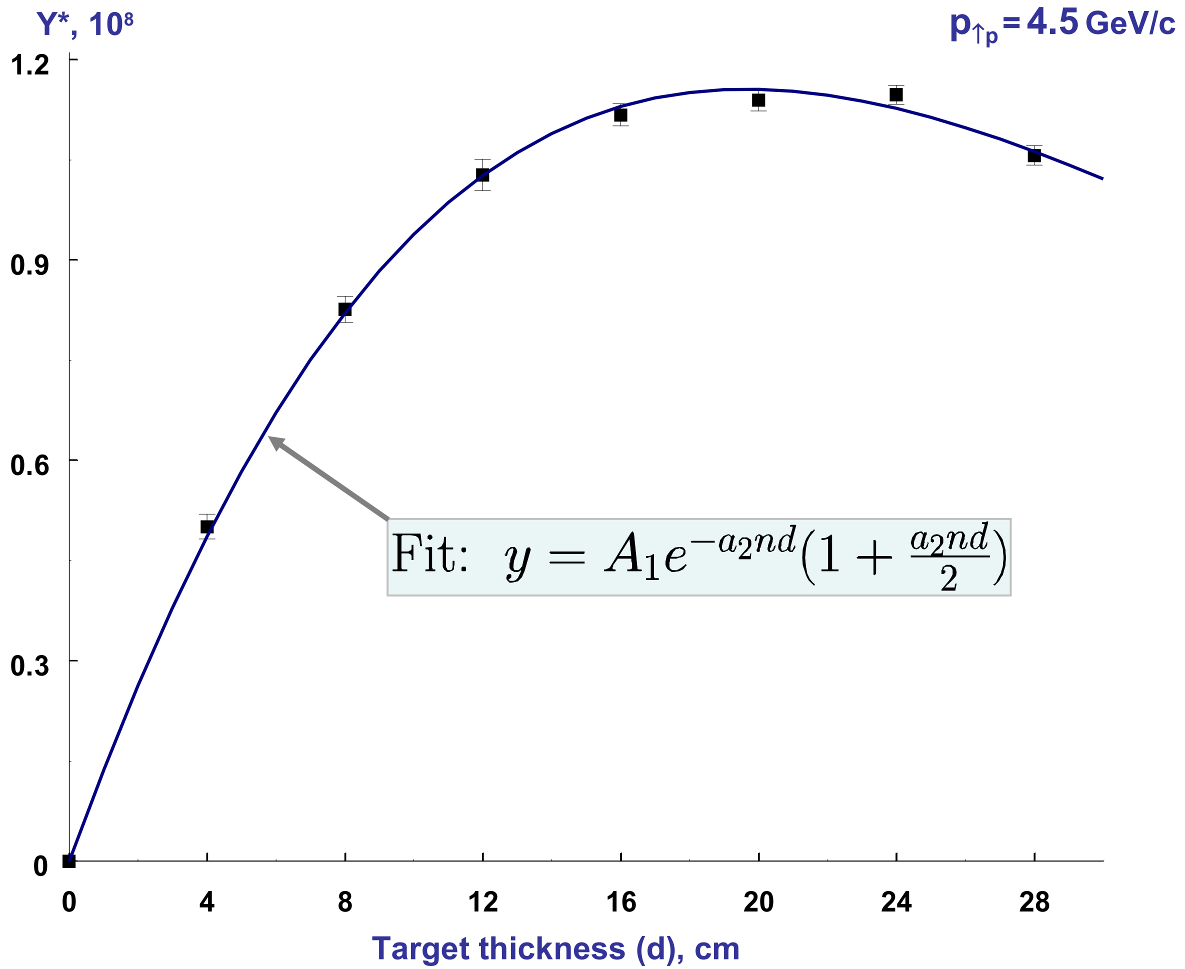


Fig.: Reconstructed envelopes of secondary polarized proton beam at $p_{\uparrow p}$ = 4.5 Gev/c.

Proton beam polarization $P_z^{-/+} \cong -0.39/0.48$ (in accordance to an operation state of Polaris at the run)

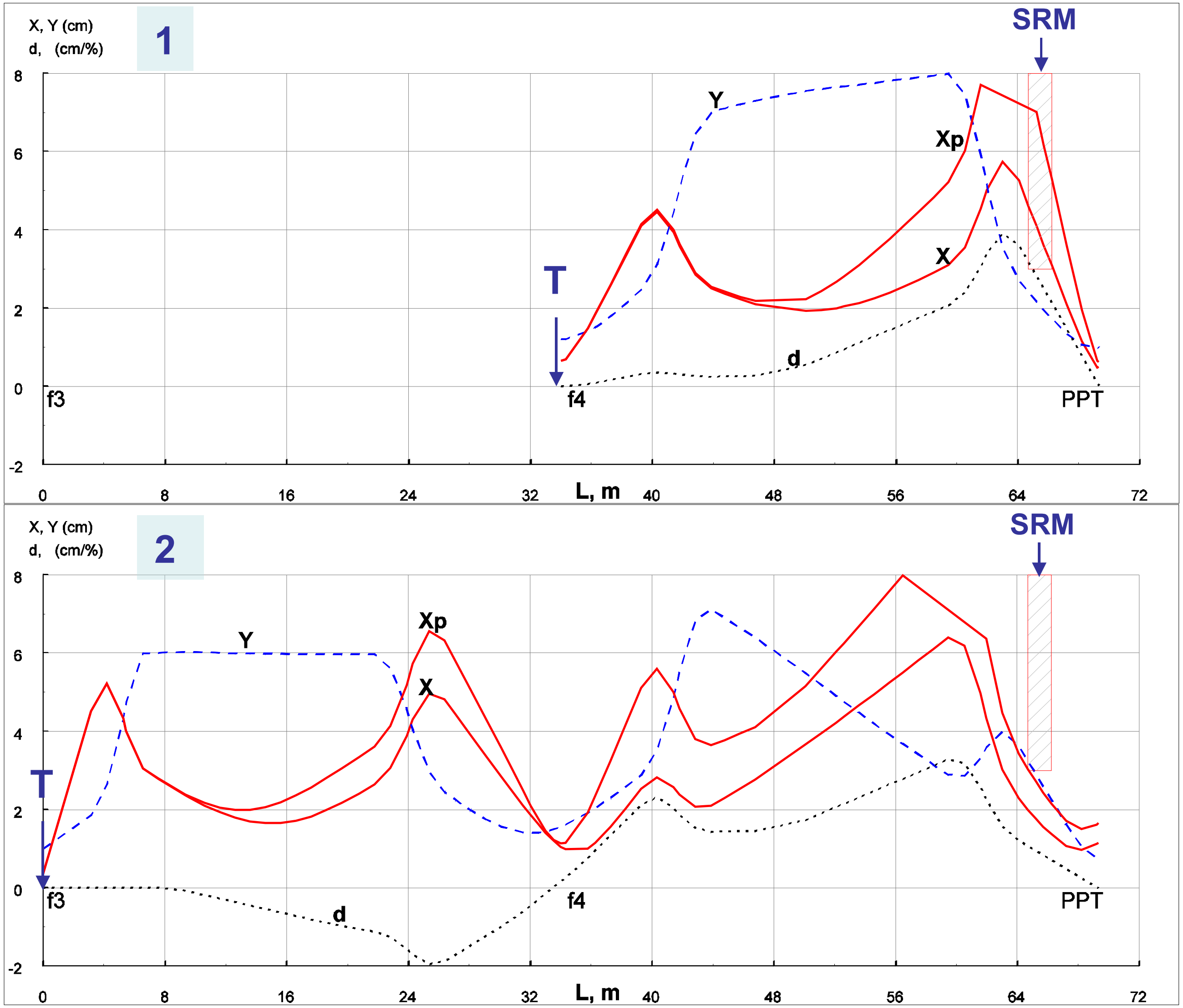
Polarized protons yield from beryllium target



Y* is yield per $3 \cdot 10^9$ incident polarized deuterons.

Fitted parameter $a_2 \cong 605$ mb what agrees with known data $\sigma_{in}(dBe) + \sigma_{tot}(dp) = 635 \pm 40$ mb

Magnetic optics solutions to form polarized protons beams in the PPT line



X,Y – horizontal and vertical beam envelopes

D – linear dispersion

Xp – horizontal envelope at 2% momentum spread

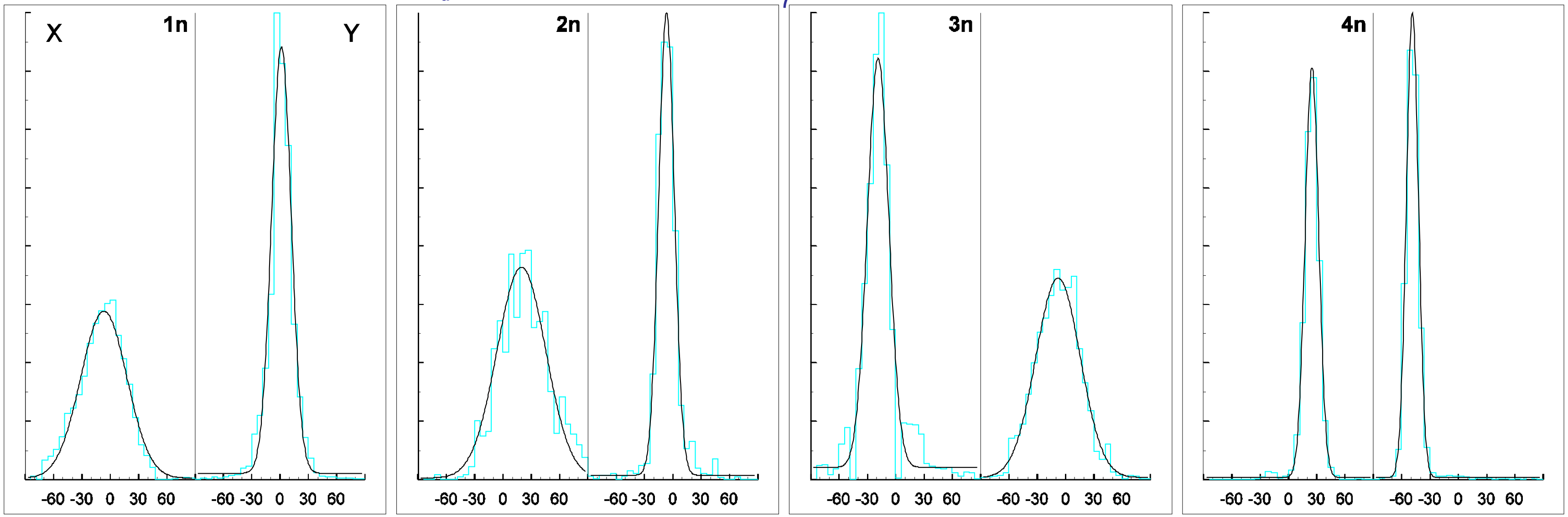
N.B. The spin rotating magnet pole tips create a significant constrain of the horizontal aperture.

1 - scheme with a target position at f4 **2 – one for target position at f3**

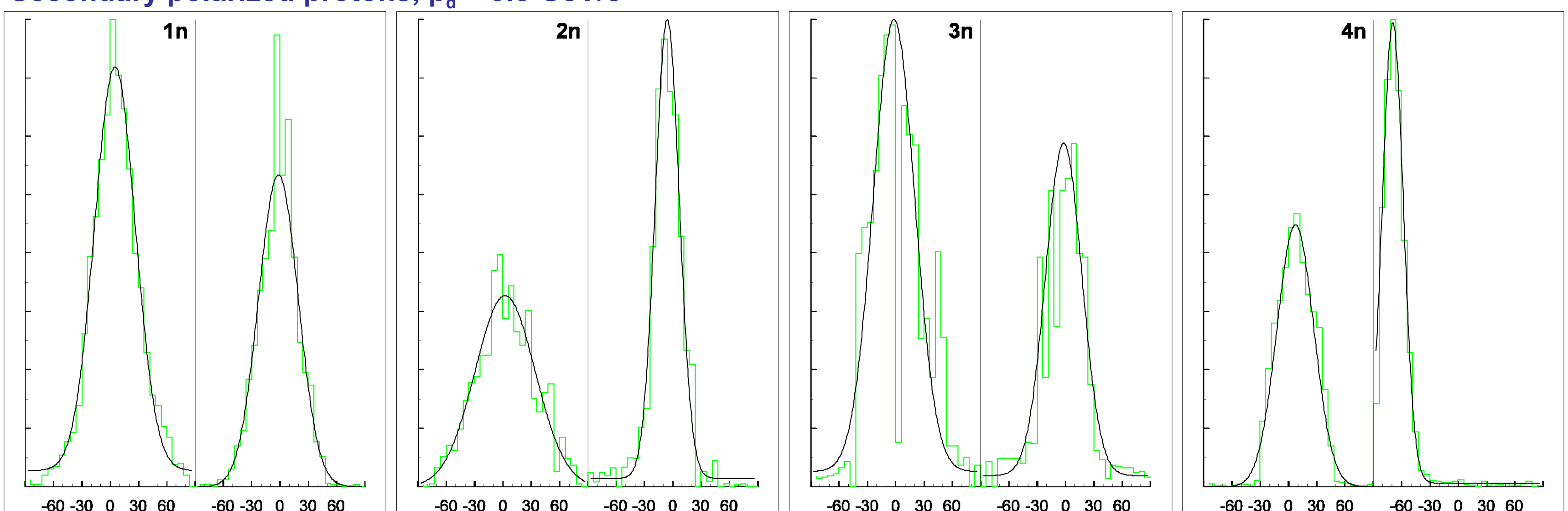
Test guiding of polarized protons to the PPT (2)

Beam profiles before (3n) and after (4n) SRM

Primary polarized deuterons, p_d = 7.6 GeV/c



Secondary polarized protons, p_d = 3.8 GeV/c



Simulated parameters of polarized proton beams at the PPT

for different forming schemes

№	Scheme, initial conditions	Synch. + Polaris $\varepsilon = 50\pi$ mm·mr I_d = 3.10[9], p_d = 9 GeV/c	Nuclotron-M + HIPDS $\varepsilon = 5\pi$ mm·mr I_d = 10[10], pd = 9 GeV/c
1	Target position: **f4** Q_5 - Q_8 lenses polarities: FDDF Primary beam X,Y : S: - 6.5 · 12, N: – 1.0 · 2.0	Y_p[1] = **3.2** ·10^7 h_p[2] = 0.4 % σ_x[3] = 4.5 mm σ_y = 5.1 mm σ_p = 0.9 %	Y_p = **1.3** ·10^8 h_p = 0.0 % σ_x = 4.1 mm σ_y = 2.5 mm σ_p = 0.6 %
2	Target position **f3** Q_5 - Q_8 lenses polarities : FDFD Primary beam X,Y: S: - 3.5 · 10, N: – 1.0 · 2.5	Y_p = **1.1** ·10^8 h_p = 4.2 % σ_x = 6.5 mm σ_y = 5.2 mm σ_p = 1.6 %	Y_p = **4.0** ·10^8 h_p = 0.4 % σ_x = 4.2 mm σ_y = 3.7 mm σ_p = 1.3 %

Sizes, mm

[1] Y_p - proton yield estimation from 20 cm beryllium target

[2] h_p - beam halo (particles, not incoming into the PPT working volume)

[3] $\sigma_{x,y}$, σ_p - r.m.s. beam sizes and momentum spread

Conclusion

Secondary polarized beams based on the deuteron breakup reactions

$$\uparrow d + A \longrightarrow \uparrow n + \ldots$$

$$\uparrow d + A \longrightarrow \uparrow p + \ldots$$

are still being the significant opportunities for spin physics experiments at energies up to 6 GeV/n at the LHEP accelerator facility

End