Beam-Induced Depolarization: HERA vs. LHC*

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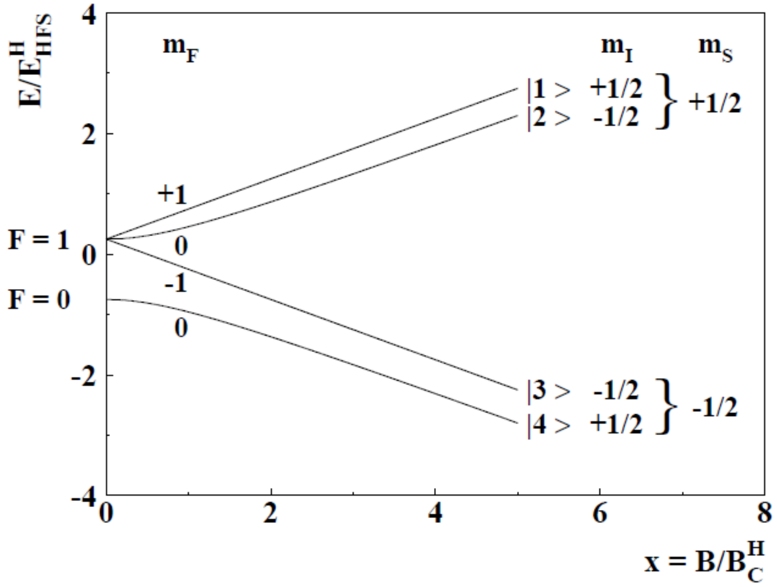


*) See PBC Notes 2018 001

https://cds.cern.ch/record/2632904?ln=de

Beam-induced depolarization (BID)

- After its 1st observation at VEPP-3, this effect has been studied at HERMES, see first measurement with B_{long} publ. in PRL **82** (1999) 1164, and analyzed together with B_{transv} in Diss. Ph. Tait, Erlangen (2006): http://www.hermes.desy.de/notes/pub/06LIB/pntait.06-060.thesis.ps.gz .

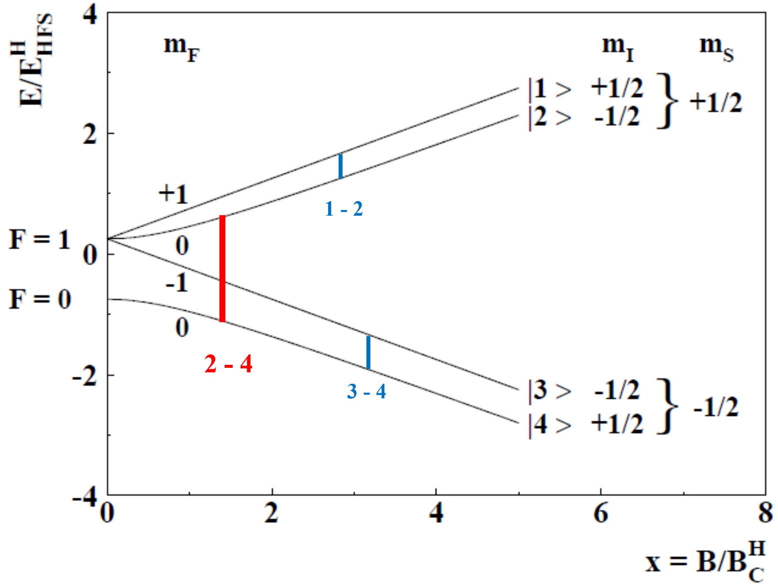
- BID is based on resonant transitions caused by the beam field acting on the polarized H-atoms in an external guide field $B_0 \approx 300$ mT. There are different classes of transitions, depending on the relative orientation of the guide field $\mathbf{B_0}$ and $\mathbf{B_1}$, the rapidly varying beam field component.

  π resonances for $\mathbf{B_1 \perp B_0}$ $\Delta F = 0, \pm 1$ $\Delta_{mF} = \pm 1$,

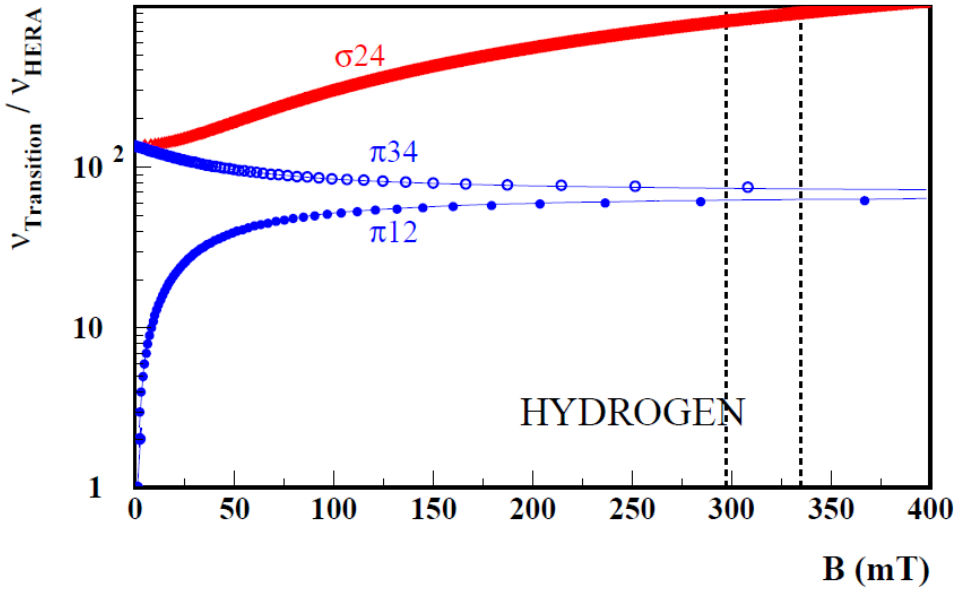
  and

  σ resonances for $\mathbf{B_1 = B_0}$ $\Delta F = \pm 1$ $\Delta_{mF} = 0$.

- Some of these resonances change nuclear polarization. For longitudinal guide field, only the π resonances are present. For <u>transverse field</u>, like at LHCspin, both types of resonances are present. The σ resonances, interchanging states 2 and 4, are densely spaced, i.e. its prevention requires a very high



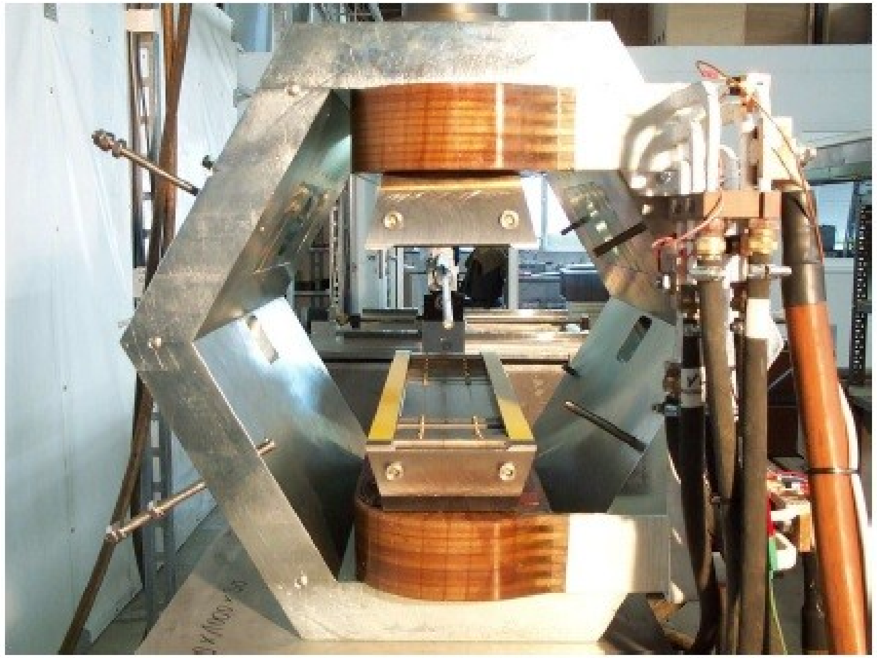
Hydrogen hfs diagram
$B_{crit} = 50.7$ mT

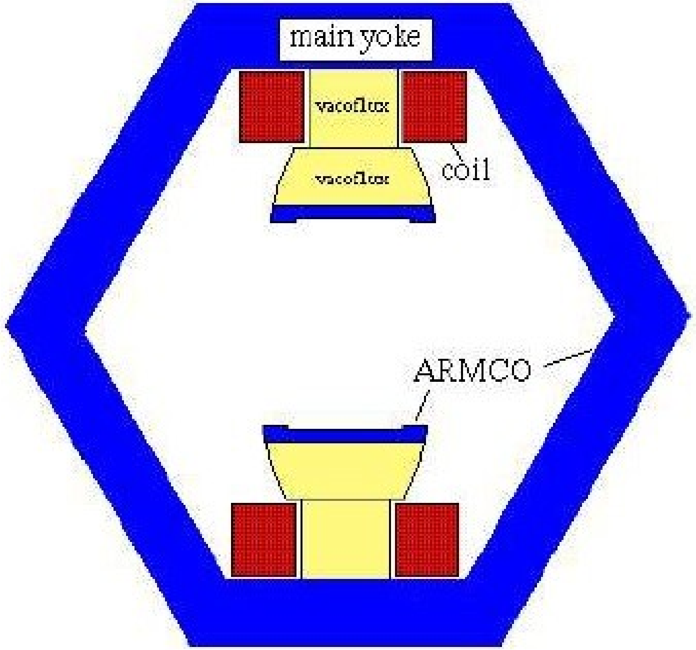


Transverse guide field magnet (HERMES)

In order to resolve the σ_{24} resonances, a field homogeneity in the order of their spacing is required (0.37 mT in the high-field limit).

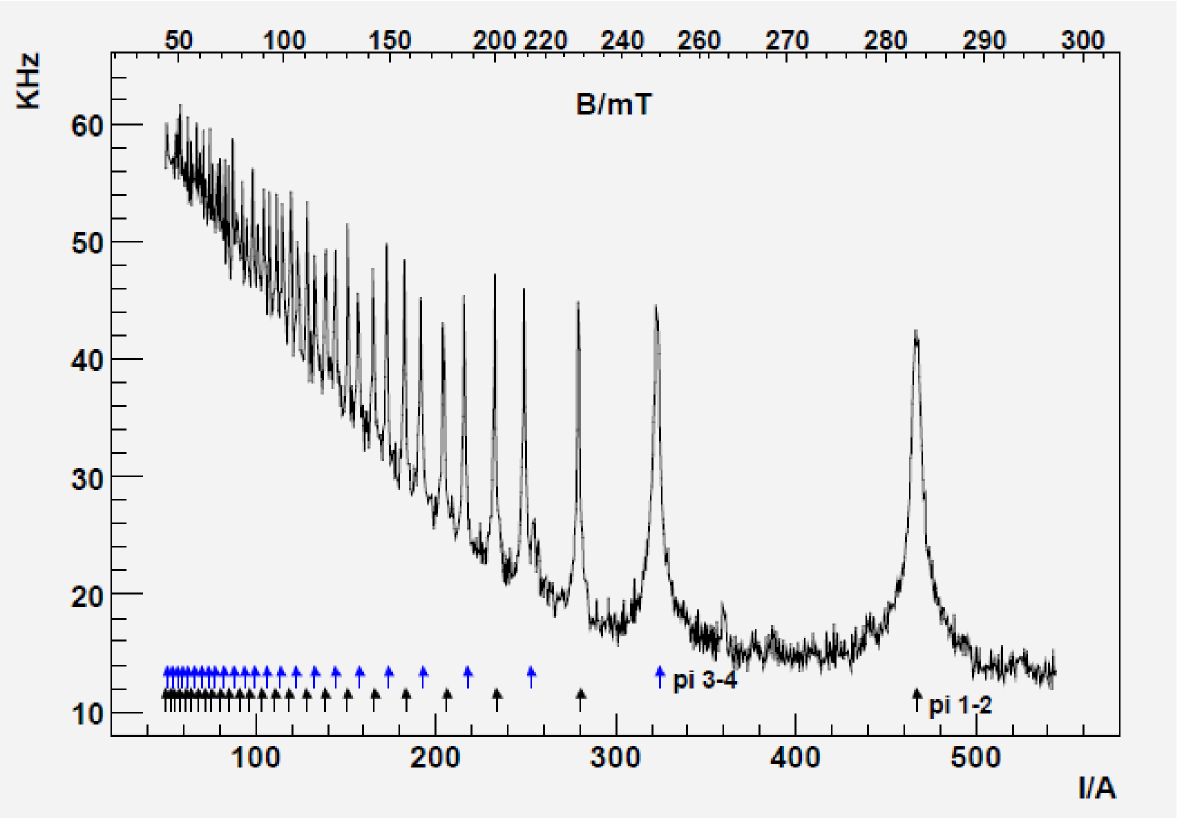
A special magnet with large gap height and high field quality had been built. With the help of shims and correction coils a high homogeneity could be achieved.





Observation of the π resonances

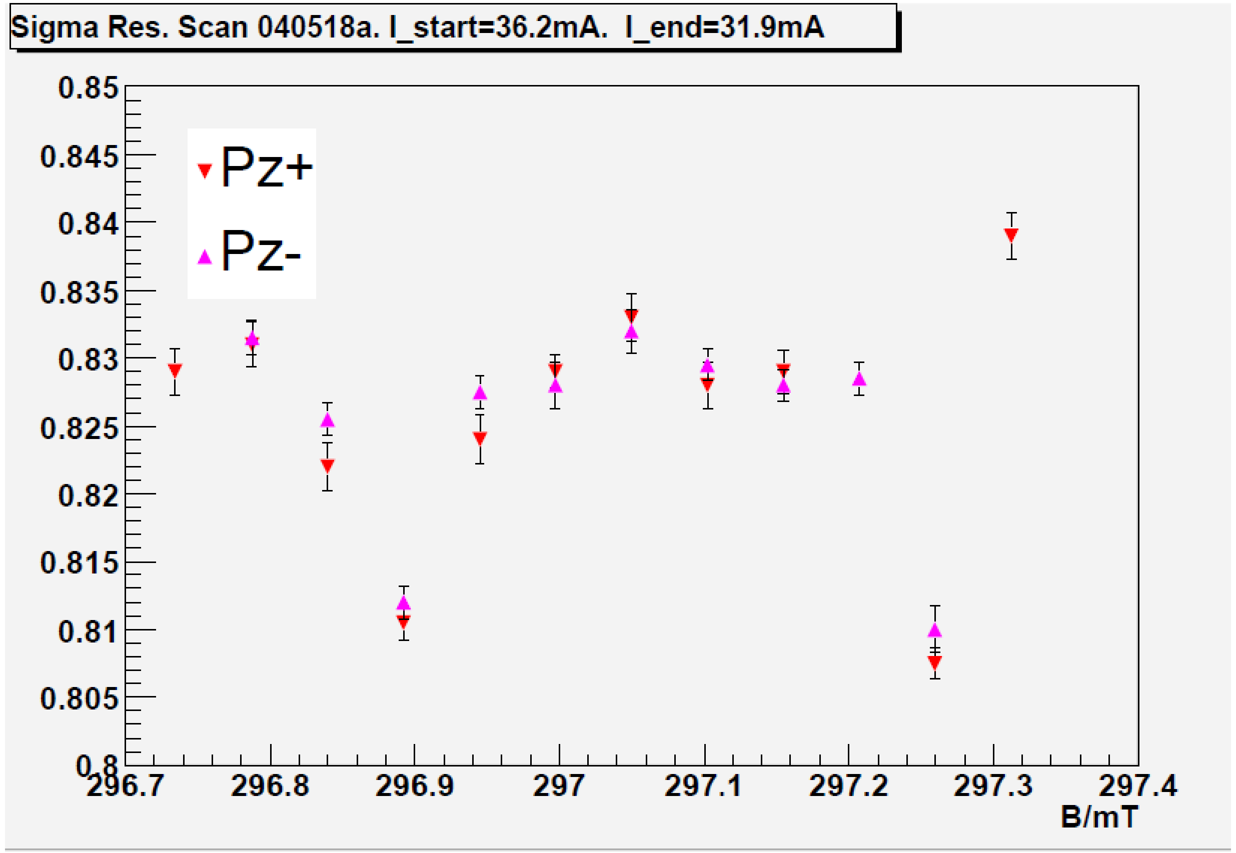
- A practical method to detect the π resonances was the wide range Flip-in method: States |1> and |4> are injected by the ABS, and states |2> and |3> are mea-sured by the BRP. With e beam, the population of the cell gas is changed and detected by the BRP.
- As an example, the BRP rate is shown as function of the current I in the transverse magnet. The π reso-nances 3-4 and 1-2 are clearly visible. At high field the spacing is wide, and individual resonances can be easily selected.
- This is different for the σ_{24} resonances with narrow spacing. In order to suppress them, the B-field must be set to the minimum in-between.



HERMES transverse Running (2002-2005)

During transverse running (2002 – 2005), careful studies to optimize the target polarization have been performed - see a final result of Diss. Ph. Tait on the σ_{24} resonance taken by the target polarimeter (BRP) where the nuclear polarization $P_{z\pm}$ is shown as function of B_0.

Two polarization minima caused by the σ_{24} resonances are clearly visible at a distance in field of about 0.36 mT as expected, demonstrating the high field quality of this rather open magnet.



The Polarization P in between the sigma resonances is 2% higher, only.

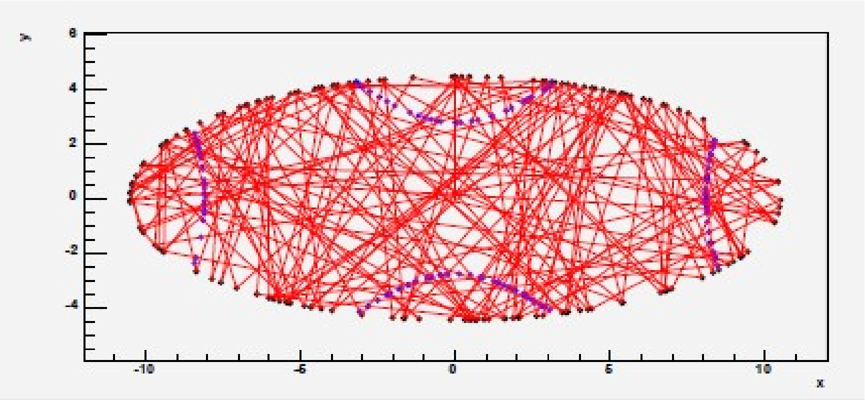
Comparison of BID for HERA and LHC

Key parameters of both machines:

Machine	N_{Bunch}	f_{Bunch} MHz	I_{beam} A	σ_z cm	σ_t ps	$\alpha = 1/\sigma_t^2$ ps^2	1/e width of Fourier spectrum	I_0 Peak current (A)
HERA-e	210	10.41	0.04	0.93	31	$5.203\ 10^{-4}$	5.1 GHz	57.3
LHC	2600	40.08	1.0	7.55	253	$7.81\ 10^{-6}$	0.63 GHz	41.2

Assumptions:

1. The trajectories of the MolFlow simulation are equivalent (see Tait Fig. 4.7 on the right: trajectories are shown in red, blue dots at cell wall are wall bounces, blue dots within the cell: crossings of a resonance).
2. Inhomogeneity equivalent, i.e. the shape of the resonant surfaces are similar (see Tait Fig. 4.6) → duration of resonance crossings have the same statistical distribution.
3. Beam size very small compared to cell radius
4. **The main differences come from the bunch frequency, and the longitudinal width in z or in t ($\sigma_{z/t}$) (see Table).**



Comparison of BID for HERA and LHC

Spin-flip Probability for crossing a $\sigma_{2\text{-}4}$ resonance, with θ = mixing angle, τ = crossing time and n index of passage (Tait Equ. 4.11):

$$\boxed{P_n^\sigma = \sin^2(2\theta)\left(\frac{\mu_B}{2\hbar}\right)^2 B_{\|}^2 \tau^2}$$

$B_{\|}$ is the RF field parallel to B_0 , the guide field. $B_0 = x \cdot B_c$, the critical field of the H-atom. Strong field: $x >> 1$.

$\tan 2\theta \approx 1/x$, i.e. θ small in strong field, and spin-flip probability low.

With our assumptions, we estimate the relative strength of BID by the ratio of the square of $B_{\|}$ for both beams. For the k-th harmonic of the Fourier spectrum (Tait 2.59) we obtain at the $\sigma_{2\text{-}4}$ transition frequency of 8.54 GHz with the parameters of the table

- LHC: $F_{213} = 2 \cdot 1.0\ \text{A} \cdot 1.53\ 10^{-20}$
- HERA: $F_{820} = 2 \cdot 0.04\ \text{A} \cdot 7.53\ 10^{-2}$

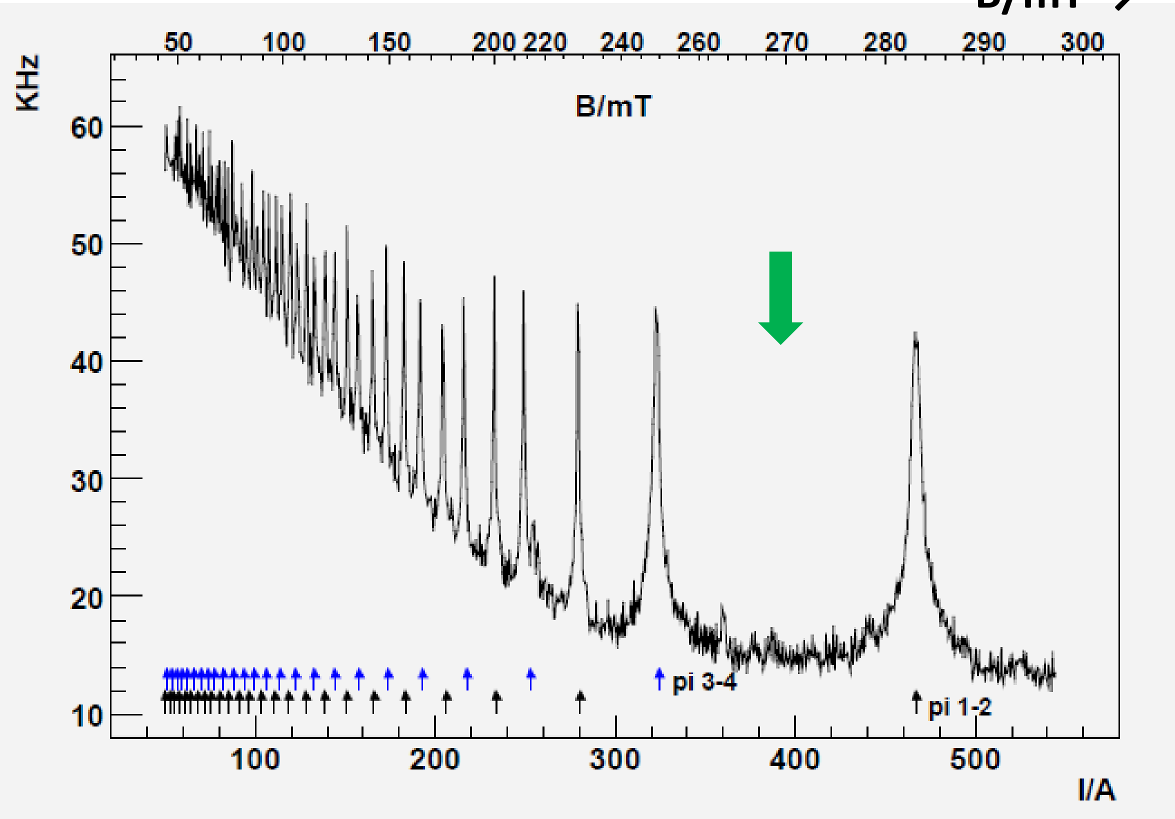
We conclude that resonant depolarization at the LHC via the $\sigma_{2\text{-}4}$ transition is negligible compared to HERA (where it was small, already!), despite the 25 times higher beam current!

Conclusions

In summary, the main differences between HERA-e and LHC are:

- **Bunch frequency f_B:** 10.41 MHz vs. 40.08 MHz. This results for the LHC in a 4x larger spacing of the 'resonant B-values', i.e. it reduces requirements on field quality.
- **Width of the Fourier spectrum:** 5.1 GHz vs. 0.63 GHz. This leads to a rapid fall-off of the relevant Fourier amplitudes of the $\sigma_{2\text{-}4}$ resonance (8.54 GHz) at the LHC.
- **We conclude that depolarization of the H target at the LHC via the $\sigma_{2\text{-}4}$ resonances is neglible. In strong field $B_0 \approx 6\cdot B_c$ the π-transitions are about 30 mT apart.**

B/mT →



Thank you !

Back-up slides

Estimate of the areal density of the PGT

Assumed:

- I_H (100 % HERMES ABS flow) = $6.5 \cdot 10^{16}$/s, may be limited by LHC vacuum constraints or space limitations for the PGT;
- Cell **20** cm long, 1.0 cm i.d., at 100K, with standard feed tube 10 cm long, 1.0 cm i.d.

The **resulting** 100% **density of the polarized gas target is**
$\boldsymbol{\theta = 0.64 \cdot 10^{14}/cm^2}$, about 50% lower than HERMES.

For the future HL-LHC-25ns, the Luminosity achievable with the PGT would be up to $4.4 \cdot 10^{32}/\ cm^2\ s$. To which extent such densities can be realized and exploited in a real experiment, depends on many factors and has to be investigated in more detail.

Coating of the cell surface?

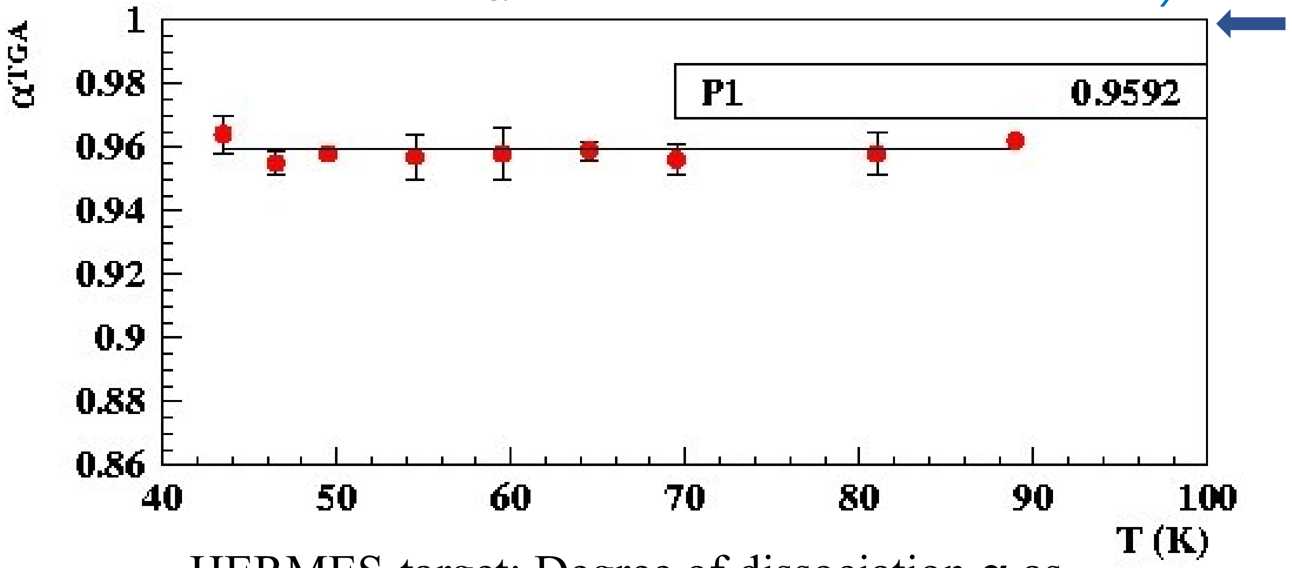
Cell surface with a-C coating: may need a thin water/ice layer to suppress recombination (and thus depolarization)

see HERMES measurement with water on Drifilm, indicating close-to-zero recombination!

A water layer can be produced in dynamical equilibrium by injecting a low water fraction together with the polarized H atoms, set by the O_2 admixture in the dissociator gas H_2.

A lower T_{cell} has two effects: (i) target density increases, and (ii) the ice layer can be produced at a lower O_2 admixture in the dissociator.

note: α = **1** indicates *no molecules detected by TGA*!



HERMES-target: Degree of dissociation **α** as function of the cell temperature **T**. The cell was in use for an extended period (not a new cell).

The SEY of this surface is not known to us and needs to be studied.