Electron beam polarimetry at ERL's

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P2 collaboration
at IKP Mainz
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Introductionary remarks-1

Spin polarized beams give acces to mainly two fundamental questions
-Spin structure of strongly interacting particles
-Parity violating processes

Observables : Scattering **A**symmetries $$A_{\exp} = P_{beam} S$$

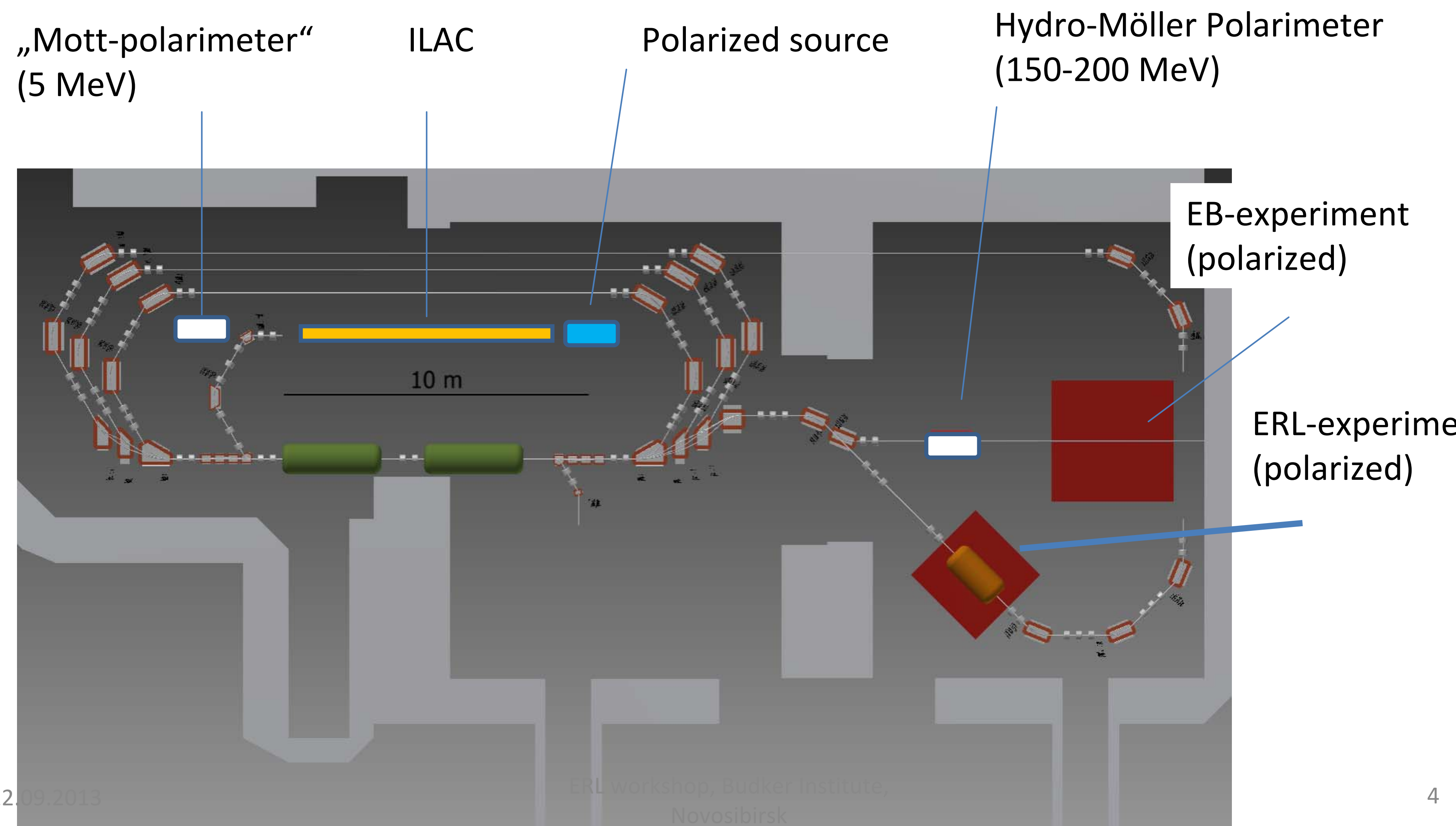
1.) The interesting quantity is **S**
(the „analyzing power“ of the scattering process)
2.) Beams are always partially polarized an error of the polarization measurement may limit the accuracy for **S**!
3.) A „polarimeter“ uses a process for which S is well known and measures $A_{exp}/S=P_{beam}$

Introductionary remarks-2

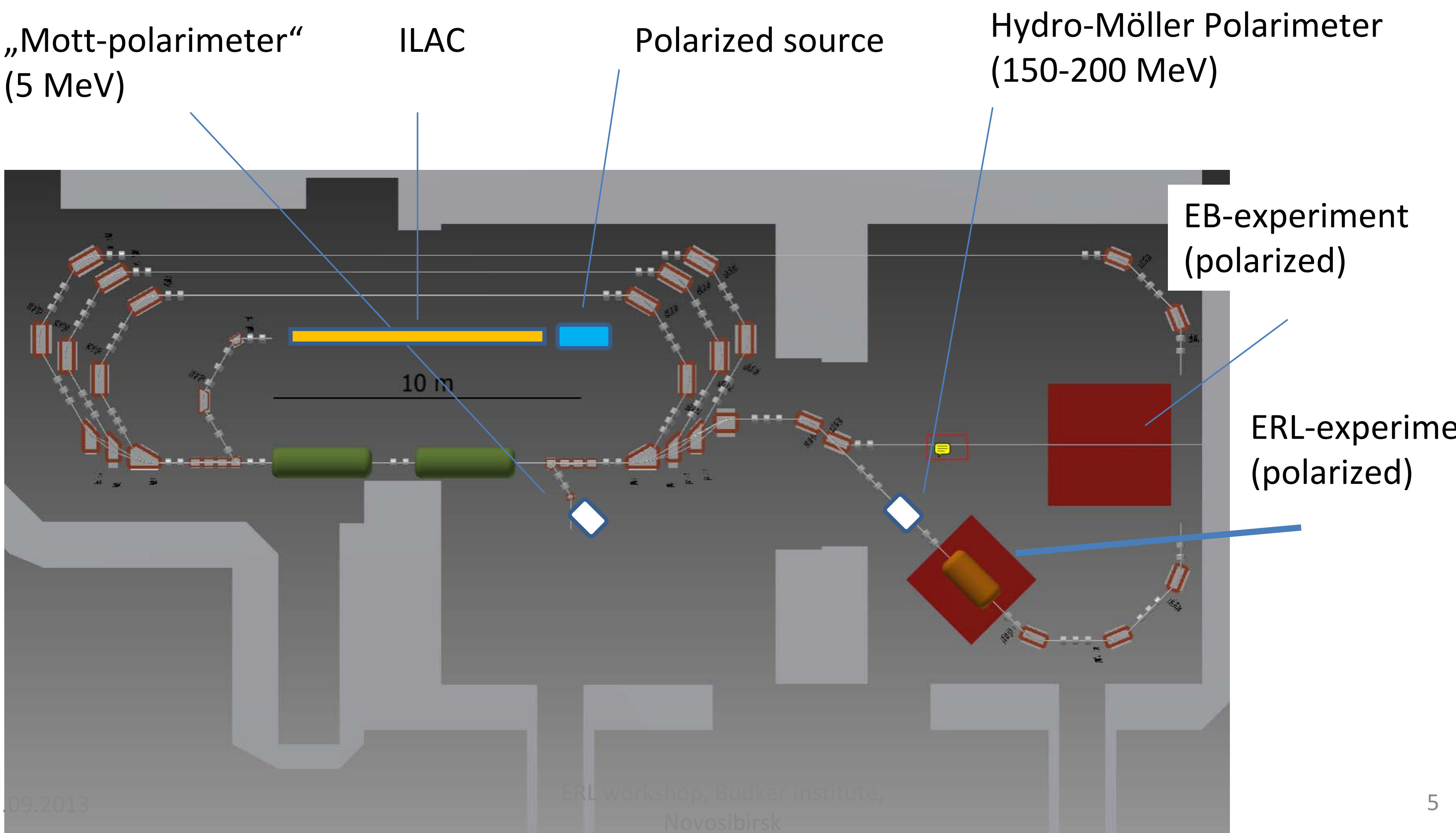
- Spin-Polarized beams at ERL: LHeC. eRHIC, MESA....
- 'Polarimetry' must be minimal invasive if installed upstream of the experiment
- Consequence: Online Operation!
- Polarimetry may also be done in invasive fashion in the beam dump
- Contrary to synchrotrons, depolarization (and self-polarization) should be strongly suppressed

Example: Polarimeter-chain for MESA

MESA: so far, Polarimetry is foreseen only in EB mode!



Scenario: Polarimetry in ERL-mode



Existing Electron-Polarimeter chain at MAMI

Polarimeter	$\Delta P/P$ present (Potential)	Main uncertainty	Measurement Time @1% stat	Operating current	Energy range [MeV]
Mott	0.05 (0.01)	Background	3s-1h	**5nA - 100µA**	1-4
Möller	0.02 (0.01)	Target pol.	30min	**50nA**	300-1500
Laser-Compton	0.02 (0.01)	Calibration, Target pol.	12 h	**20µA**	850-1500

Laser Compton Backscattering E(gamma) ~$4\gamma^2$

Amax~E(gamma)

Laser Compton does not work efficiently below 1GEV!

(in principle the higher E the better)

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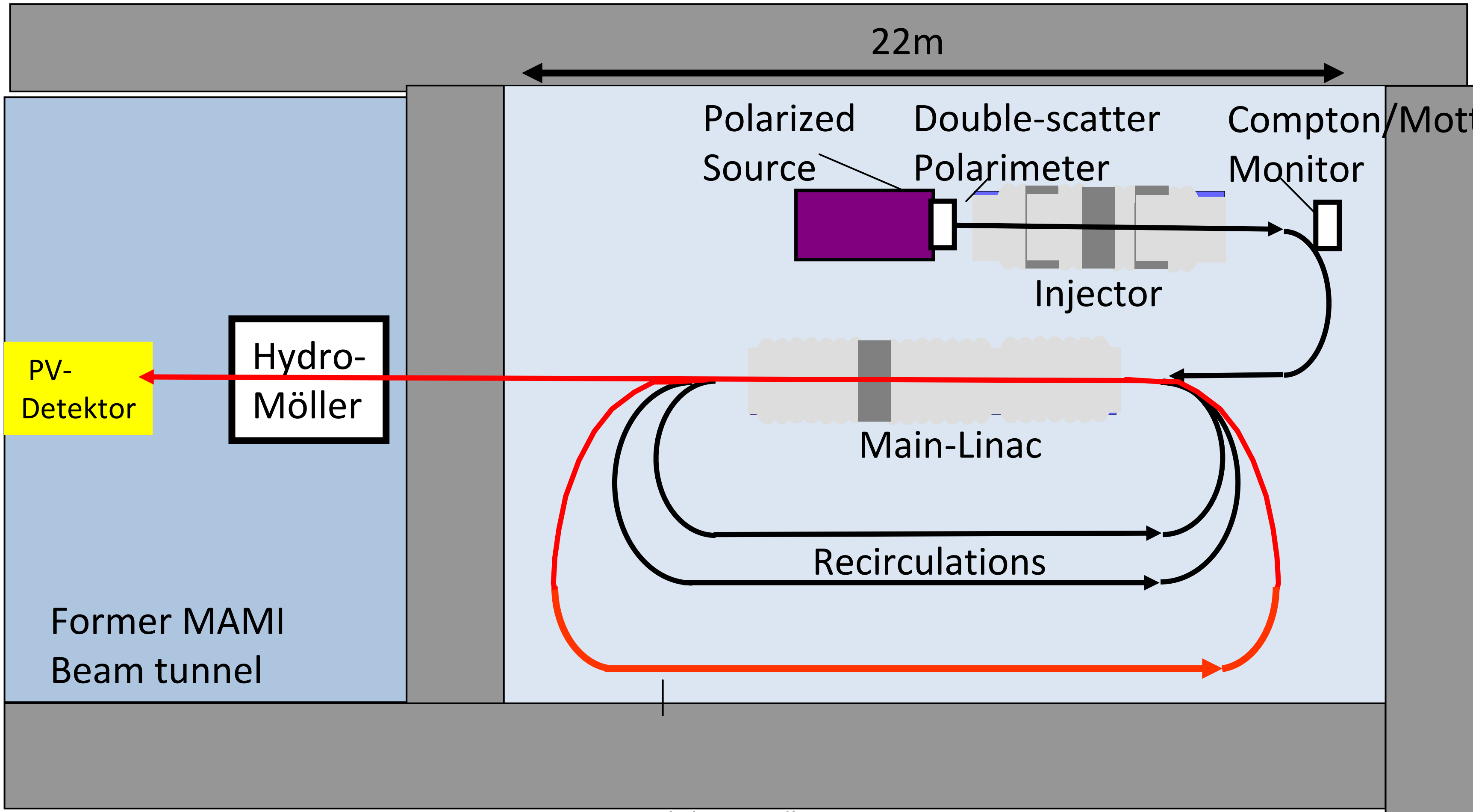
Details : see talk by Valeri Tioukine!

A new concept is needed for demanding Experiments planned at MESA!

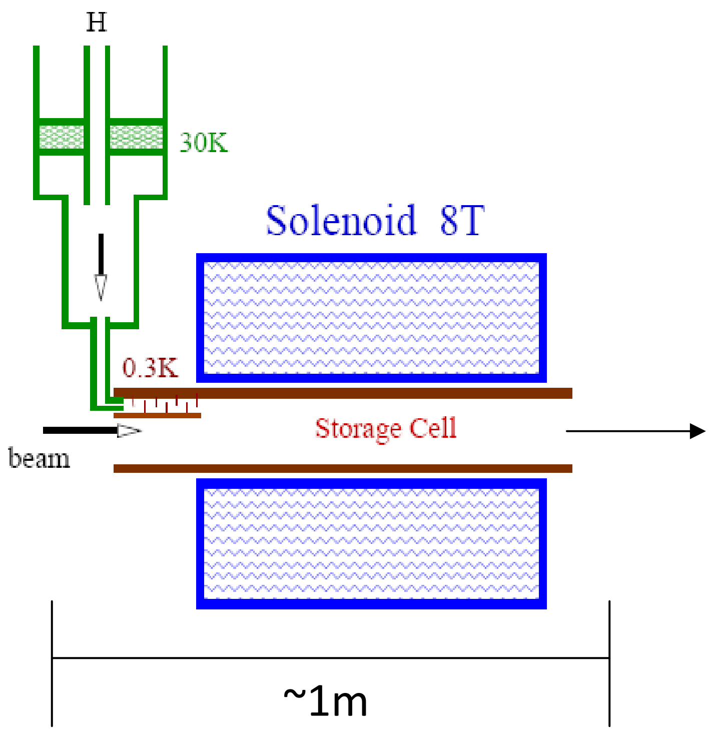
A new Polarimeter-chain for MESA

"Unimpeachable" polarization measurement: two independent polarimeters with $\Delta P/P$ <0.5% each. : "Double-Scatter-Polarimeter" +"Hydro Möller,"
Cross checks and intensity-linking by multi MeV Mott



Hydro-Möller

Chudakov&Luppov, Proceedings IEEE Trans. Nucl. Sc. **51**, 1533 (2004)



+ measurement is non-invasive and
+ provides sufficient statisttical accuracy at the beam current level of the PV experiment

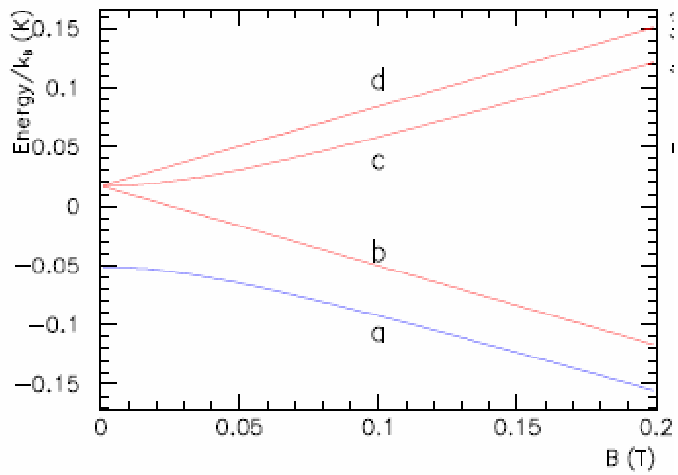
„Prototype“ of atomic trap was donated by UVA/Don Crabb
→Template for cryostate development
→Solenoid may be usable

Polarized Atomic Hydrogen Target

H_1: $\vec{\mu} \approx \vec{\mu_e}$;
H_2: opposite electron spins

Magnetic field B splits H_1 ground state

Low energy	High energy
$\|b\rangle = \|\downarrow\Downarrow\rangle$	$\|d\rangle = \|\uparrow\Uparrow\rangle$
$\|a\rangle = \|\downarrow\Uparrow\rangle \cdot \cos\theta - \|\uparrow\Downarrow\rangle \cdot \sin\theta$	$\|c\rangle = \|\uparrow\Downarrow\rangle \cdot \cos\theta + \|\downarrow\Uparrow\rangle \cdot \sin\theta$



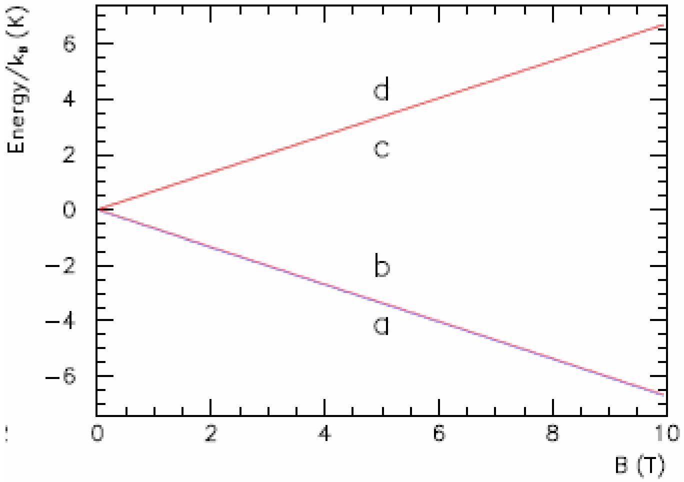
H_1 in B = 8T at T = 300 mK at thermodynamical equilibrium:

$$n_+/n_- = exp(-2\mu B/kT) \approx 3 \cdot 10^{-16}$$

Mixing angle $\tan 2\theta \approx 0.05/B(T)$

At B =8T $\sin\theta \approx 0.3\%$

Mixture ~53% of $|a>$ and ~47% of $|b>$:
$\mathcal{P}_e \sim 1 - \delta, \quad \delta \sim 10^{-5}$,
$\mathcal{P}_p \sim -0.06$ (recombination $\Rightarrow$ ~80%)

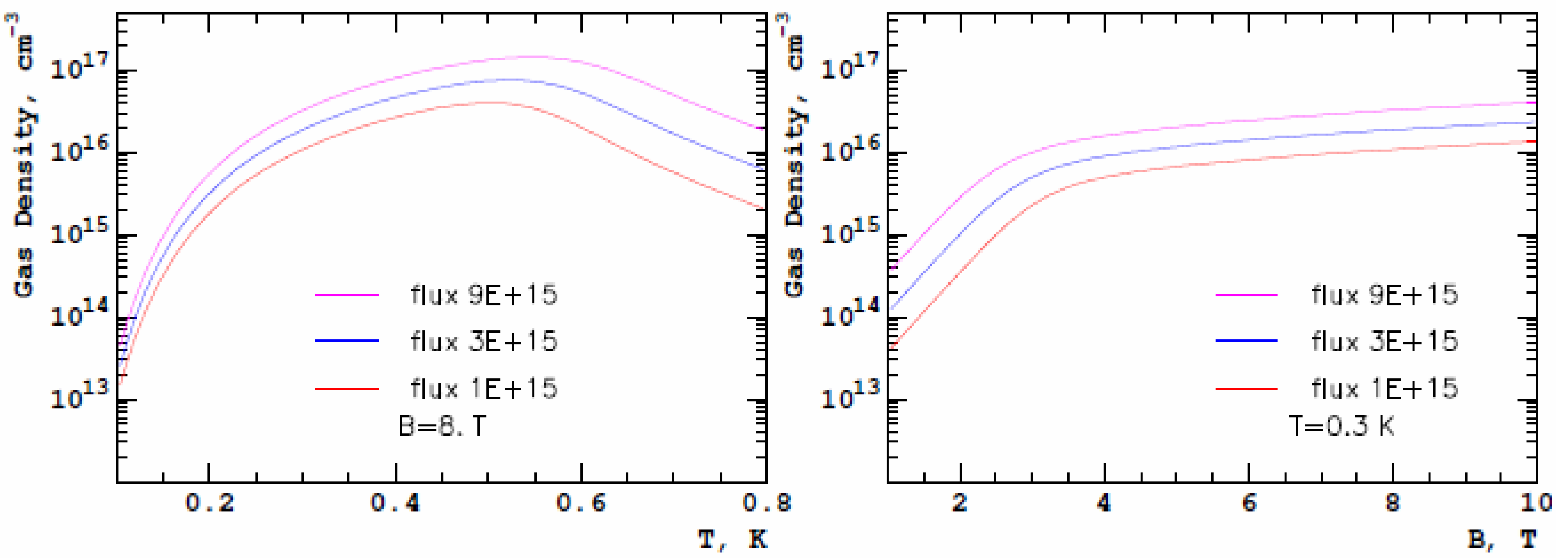


Polarized Atomic Hydrogen Target

Gas Lifetime in the Cell

Loss of hydrogen atoms from the cell due to:

- Thermal escape through the magnetic field gradient → dominates at T > 0.55 K
- Recombination in the gas volume → negligible up to densities of ~ 10^{17} cm^{-3}
- Recombination in the cell surface → constant feeding the cell with atomic hydrogen



Polarized Atomic Hydrogen Target

THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

SFB 1044

PRISMA

Contamination and Depolarization of the Target Gas

No Beam

- Hydrogen molecules $\sim 10^{-5}$
- High energy atomic states $|c\rangle$ and $|d\rangle$ $< 10^{-5}$
- Excited atomic states $< 10^{-5}$
- Helium and residual gas $<0.1\%$ ⟹ empty target measurement with the beam

Beam Impact

- Depolarization by beam generated RF field $< 2 \cdot 10^{-4}$
- Gas heating by beam ionization losses $< 10^{-10}$
- Depolarized ions and electrons contamination $< 10^{-5}$
- Contamination by excited atoms $< 10^{-5}$

Expected depolarization $< 2 \cdot 10^{-4}$

Dilution Refrigerator and Magnet

The very low T = 300 mK of the atomic trap can be reach using a Dilution Refrigerator

Dilution refrigerator and magnet shipped from UVA to Mainz

Conclusion

- The Hydro-Möller follows a ‚paradigma‘:

  „accurate determination of effective analyzing power is achieved by factorization of theoretical and several experimental effects and accurate determination of all of them“ ....the same holds for ....

- Laser-Compton scattering, but there much simpler

$$A_{\exp} = P_{beam} \underbrace{Corr S^{y}{}_{0}}_{S_{eff}} \quad \Rightarrow \text{No } \mathrm{P_T} \text{ !} \qquad \text{(but no change of Paradigma)}$$

A very old idea

In **double** elastic scattering S_{eff} can be **measured**! (…another paradigma…)

After scattering of unpolarized beam :

$$P_{sc} = S_{eff}$$

(Equality of polarizing and Analyzing Power :)

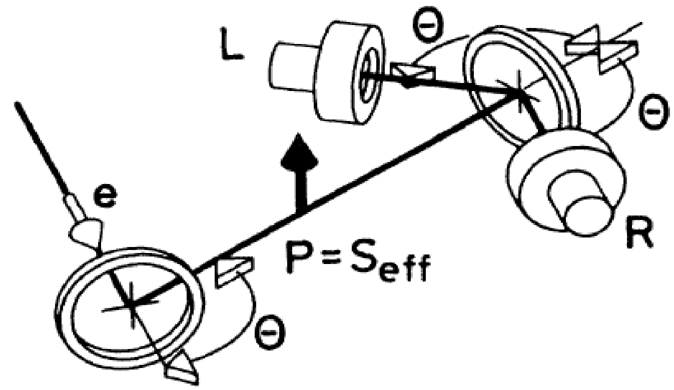
After second "identical" scattering process

$$A_{exp} = S^2_{eff}$$

with great effort to elliminate

apparative asymmetries and to provide 'identical' scattering)

the claimed accuracy in S_{eff} is $< 0.3\%$!



A. Gellrich and J.Kessler
PRA 43 204 (1991)

- The apparatus of Gellrich & Kessler is in our possesion
- Goal:-1 Reproduction of Kesslers claims using test source
- Electronics has been upgraded , measurements will start in 2013 (PhD thesis M. Molitor)
- Then installation at MESA

More remarks

- DSP works at ~100keV; ideal for ,1mA-MESA-stage-1
- Targets **not** extremely thin (~100nm)
- Elimination of apparatus asymmetry depends critically on geometrical arrangement of normalization counters
- Apparatus calibrates S_{eff}, but does not allow to measure S_0
- Claim: Inelastic contributions do not jeopardize the accuracy!
- potential issues

  → how to use with polarized beam?

  → What if the two targets are NOT identical?

Hopster&Abraham (1989):

No problem, If a switchable polarized beam is available **(|P+|=|P-|),** the first target may then be treated as an **auxiliary target** which may be exploited for **systematic cross checks**

HopsterAbraham/Kessler Method

1.) measurement : Pol beam on second target

$$A_1 = S_{eff} P_0$$

2.) with 'auxiliary target': $S_T; +P_0$

$$A_2 = P_T S_{eff} = \frac{S_T + \alpha P_0}{1 + S_T P_0} S_{eff}$$

α = Depolarization factor for first Target

3.with 'auxiliary target': $S_T; -P_0$

$$A_3 = P_T S_{eff} = \frac{S_T - \alpha P_0}{1 - S_T P_0} S_{eff}$$

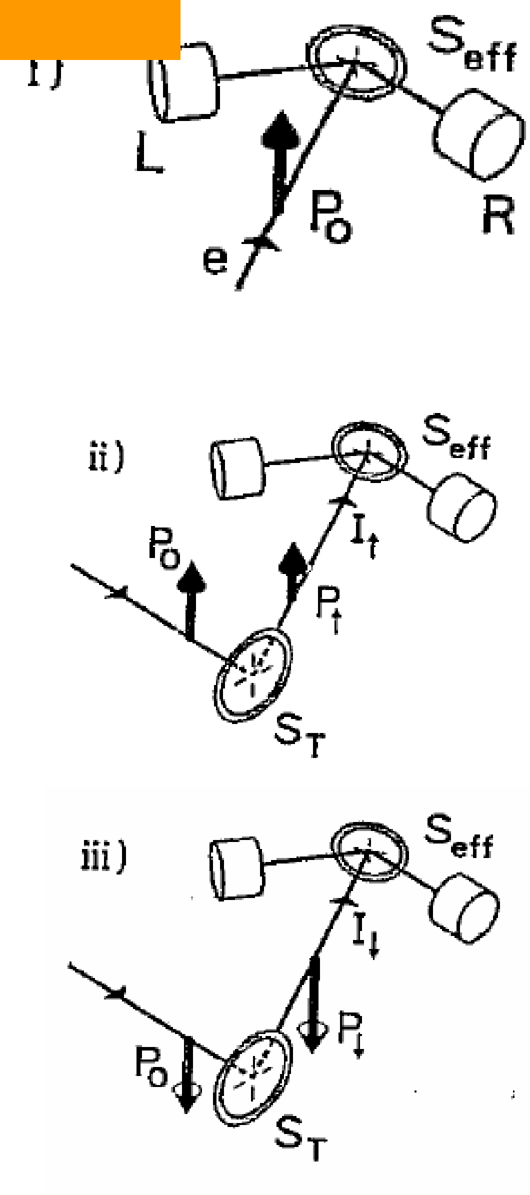
4. unpolarized beam on aux. target

$$A_4 = S_T S_{eff}$$

5. Scattering asymmetry from auxiliary target

$$A_5 = P_0 S_T$$

5 equations with four unknowns→
consistency check for apparative asymmetries!
→ Results achieved by Kessler were consistent <0.3%



S. Mayer et al
Rev. Sci. Instrum. 64 952 (1993)

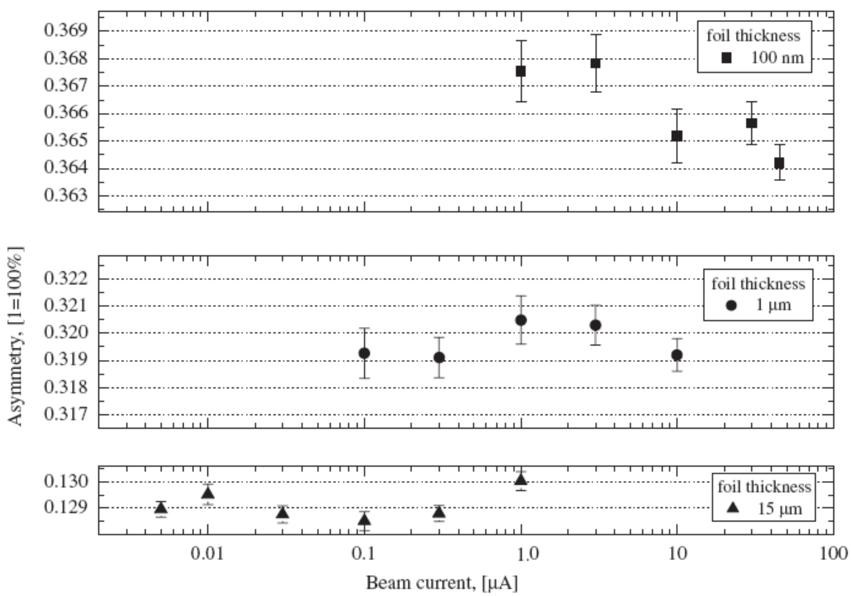
More remarks

- Auxiliary target method was limited by statistical efficiency (today about 5 times better!)
- DSP invasive, but fast.
- Probably not feasible to operate DSP at > 100μA current level, requires ‚linking Polarimeter‘
- Linking with high precision polarimeters to be installed at 5MeV (Mott/Compton-combination
- Mott/Compton combination invasive but extremely fast (O(seconds) <1% stat. accuracy), also control of spin angle

Multi MeV Mott capabilities

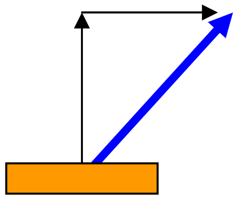
Dynamic Range:

V. Tioukine et al. Rev. Sc. Instrum. **82** 033303 (2011)

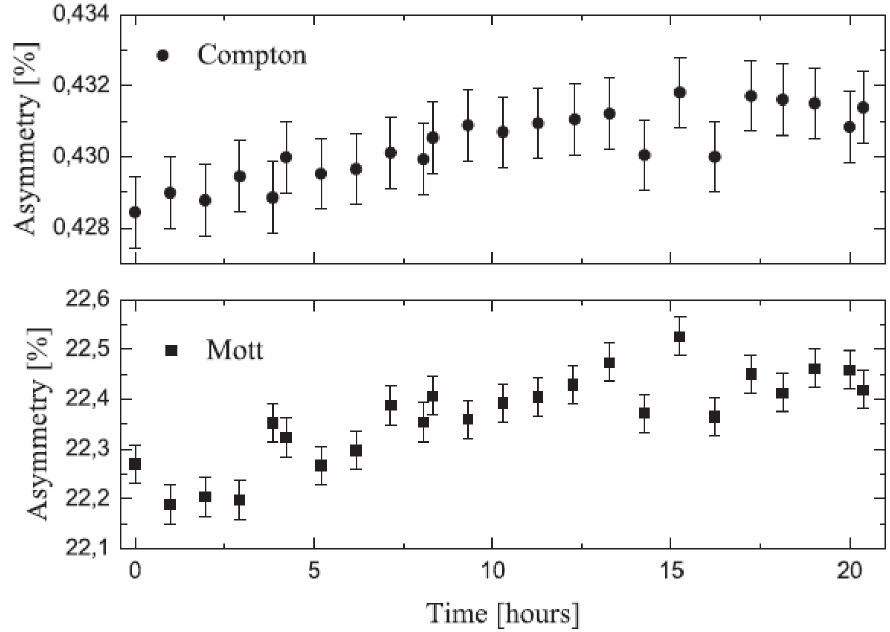


Demonstration of constant polarization over large interval in intensities

Stability:



R. Barday et al. 2011 J. Phys. Conf. Ser. **298** 012022



Polarization Drift consistently observed in transverse AND longitudinal observable at the <0.5% level

Conclusion:

- low and a high energy polarimeter cross-check:
  negl. depolarization due to low energy gain of MESA
- Monitoring, stability and cross calibration can be supported by extremely precise Mott/Compton combination.
- Hydro Möller + DSP may obtain $\Delta P/P < 0.5$ % each,