The Polarimeter chain for the MESA-PV experiment

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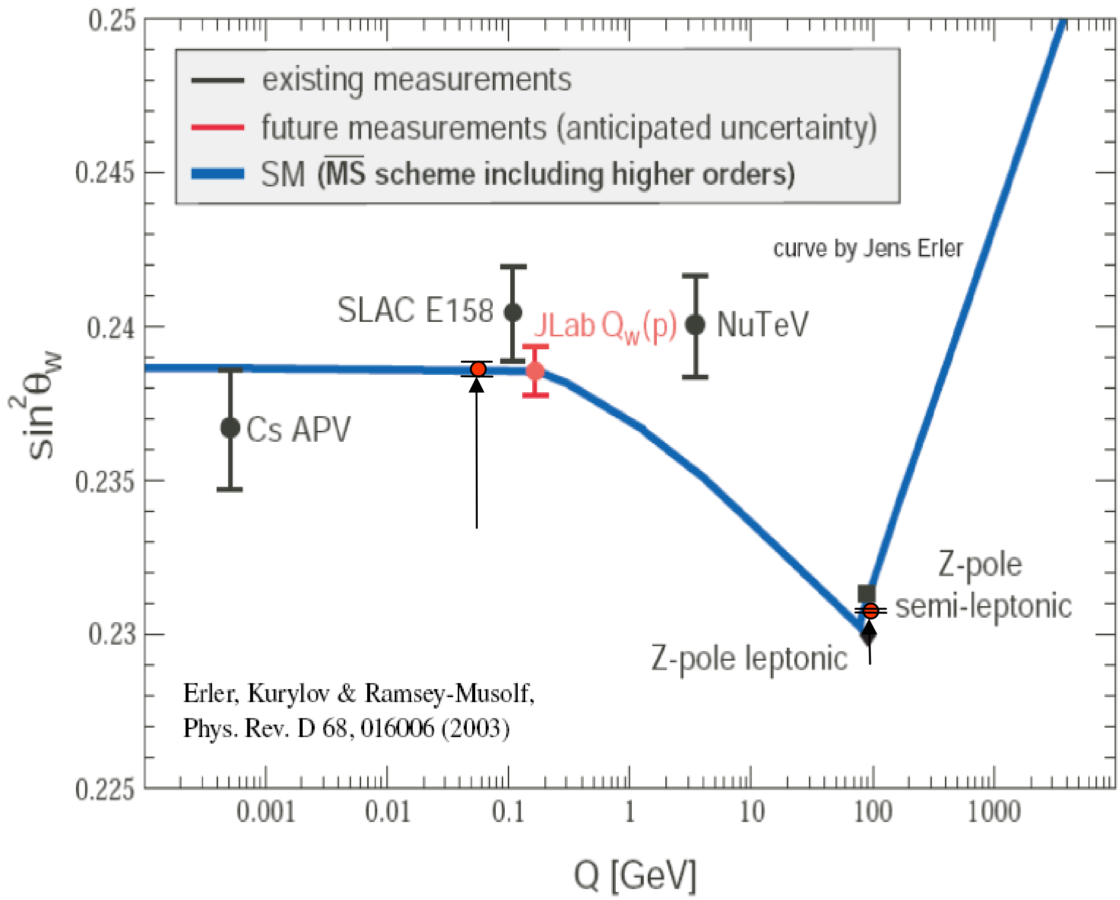
Kurt Aulenbacher for the
B1,B2 and A4 collaborations
at IKP Mainz

Outline

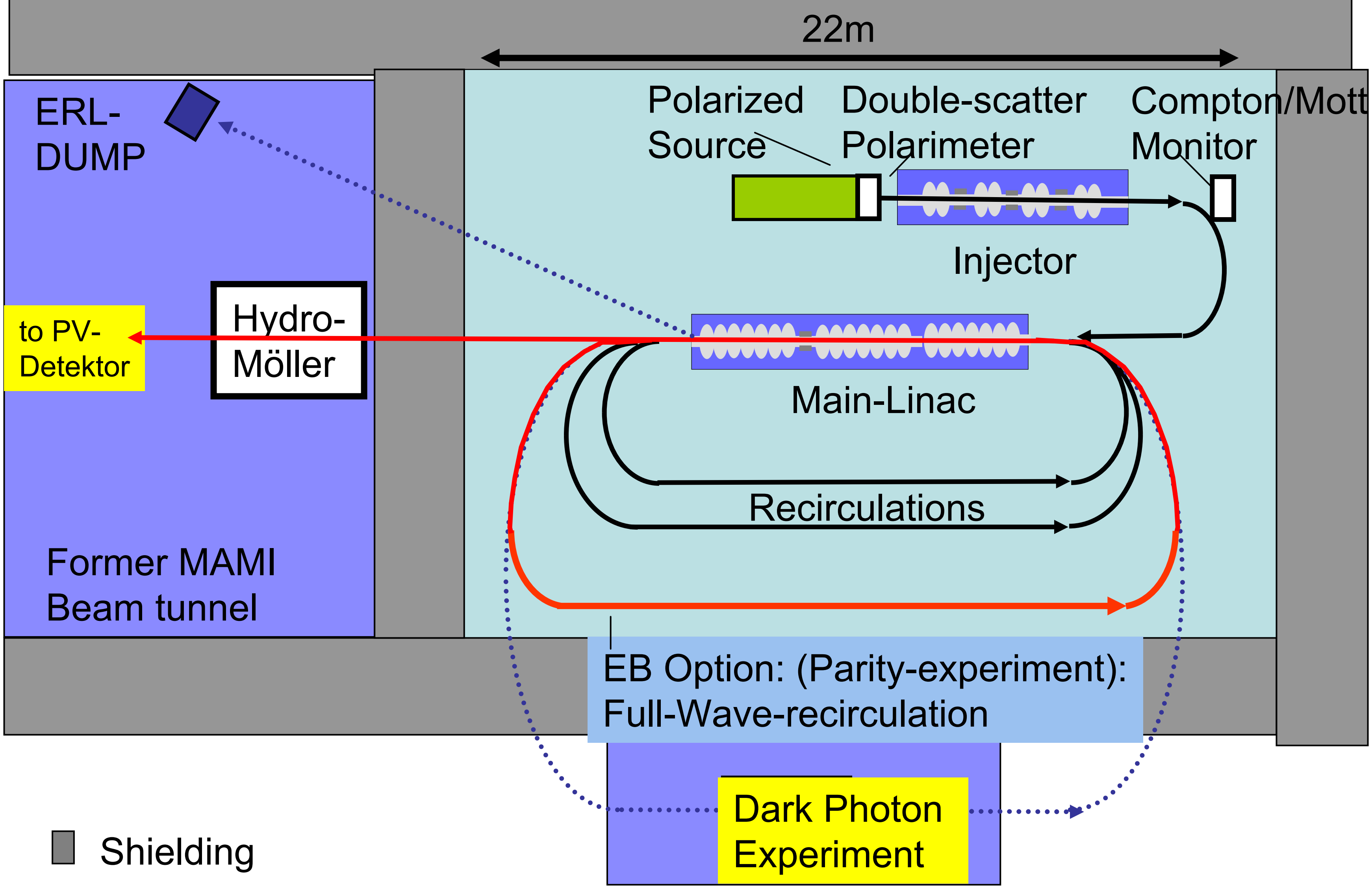
- The MESA-PV experiment at Mainz
- and the eight-fold way to achieve $\Delta P/P$ <0.5%?

Planned $\sin^2(\theta_W)$- Measurement at the MESA facility in Mainz



MESA:
Mainz Energy Recovering
Superconducting Accelerator
MESA-PV:
Operated as "Conventional"
Machine (external polarized beam)
Beam Parameters
E=137 MeV, I=0.15mA, P=0.85
$L \sim 10^{39}$ cm^{-2}s^{-1}

MESA Accuracy goal: $\Delta A_{PV}/A_{PV}=1.6\%$
one (out of many) requirements
→**$\Delta P/P \sim 0.5$ %**

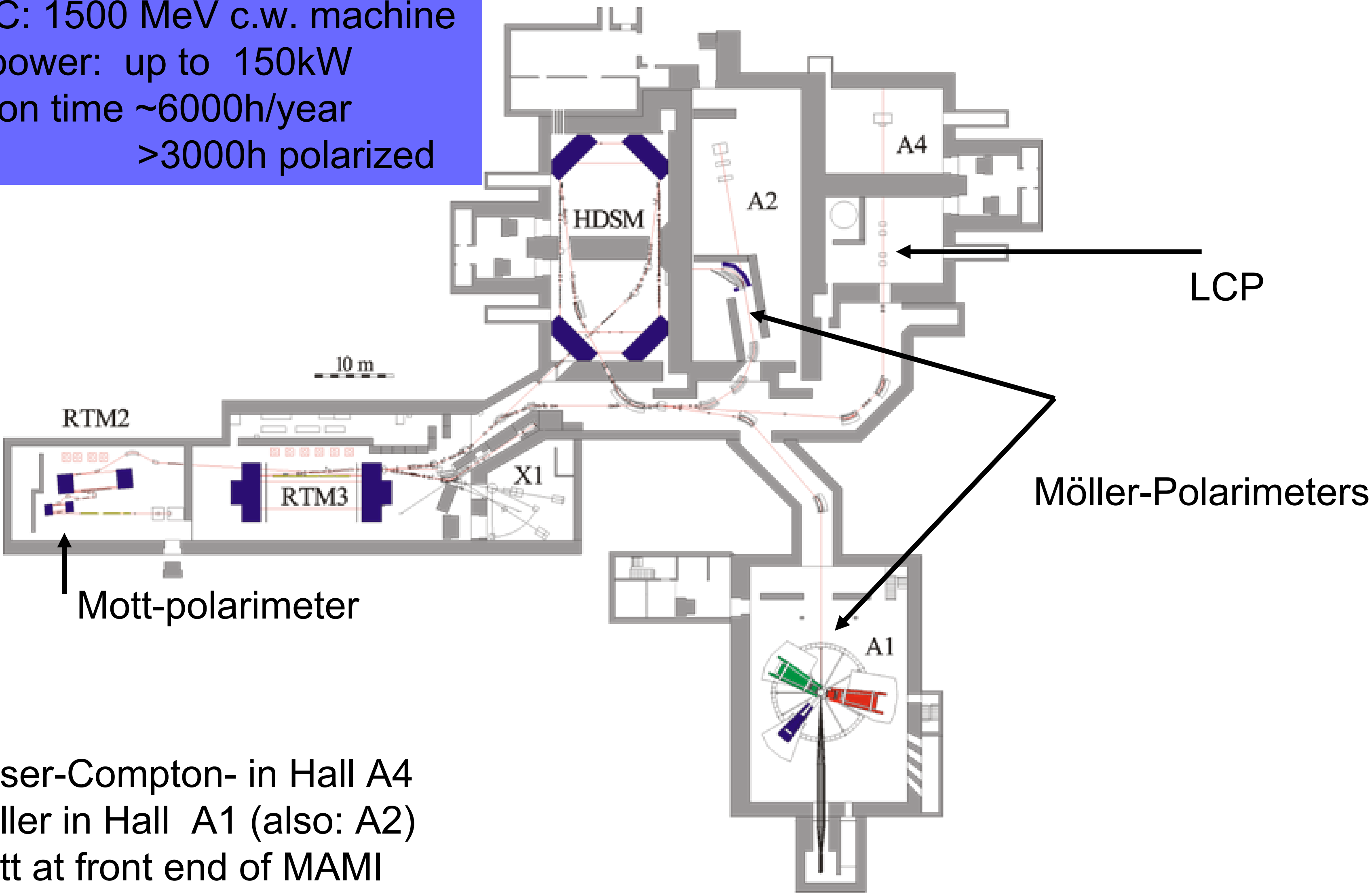


“Unimpeachable” polarization measurement: two independent polarimeters with ΔP/P <0.5% each.

Machine could be in operation in 2017→ start polarimeter tests NOW!

Electron-Polarimeter chain at MAMI

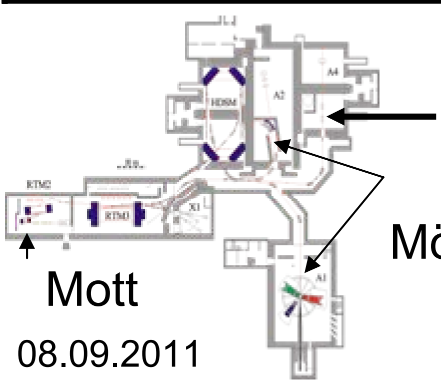
MAMI-C: 1500 MeV c.w. machine
beam power: up to 150kW
operation time ~6000h/year
>3000h polarized



- Laser-Compton- in Hall A4
- Möller in Hall A1 (also: A2)
- Mott at front end of MAMI

Existing Electron-Polarimeter chain at MAMI

Polarimeter	ΔP/P present (Potential)	Main uncertainty	Measurement Time @1% stat	Operating current	Energy range [MeV]
Mott	0.05 (0.01)	Background	3s-1h	**5nA - 40μA**	1-4
Möller	0.02 (0.01)	Target pol.	30min	**50nA**	300-1500
LCP	0.02 (0.01)	Calibration, Target pol.	12 h	**20μA**	850-1500



LCP

Möller-Polarimeters

Mott

Mott is not (yet) competitive in absolute accuracy but provides 'linking' capabilities due to wide dynamic range and good reproducibility

Some remarks

- low energy restriction of Mott scattering

  probably no cause for additional systematics at MESA

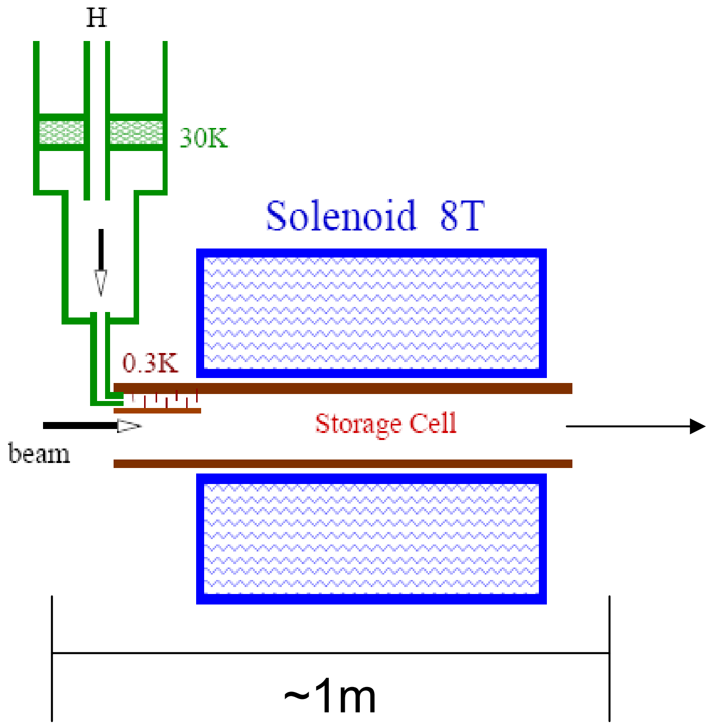
  (→ exact spin tracking possible, no resonances)
- LCP not possible at MESA due to small energy, Hydro-Möller could work
- Different concepts (‚paradigms') of measurements:

  - Hydro Möller ‚double-polarization'

  - Mott ‚double scattering'

Hydro-Möller

Chudakov&Luppov, Proceedings IEEE Trans. Nucl. Sc. **51**, 1533 (2004)
→ see talk by E. Chudakov…



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

Solenoid traps pure H↑ which has a long lifetime due to He-coating of storage cell. All other species are removed quickly from the trap.
→1-ε Polarization can be reasonably well estimated, but measurement difficult.

Some remarks

- Beam/solenoid adjustment critical, due to high field and low energy→ consequences for PV-detector calibration (‚dithering‘), etc
- Scattered electrons may perform several cyclotron oscillations in solenoid field→Detector acceptance determination?
- The Hydro-Möller follows a ‚paradigma‘:
  „accurate determination of effective analyzing power is achieved by factorization of theoretical and experimental effects“

$$A_{\exp} = P_{beam} \underbrace{Corr P_T S_0}_{S_{eff}} \quad \mathrm{Corr = i.e\,dilution\,by\,background}$$

A different aproach

How to avoid the systematic errors caused by individual factors?
Apparent attractiveness of standard (singe-) Mott-scattering:

$$A_{exp} = P_{beam} \underbrace{Corr S^{y}{}_{0}}_{S_{eff}} \quad \Rightarrow \text{No } P_T\text{ !}$$

(but no change of Paradigma)

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 :)

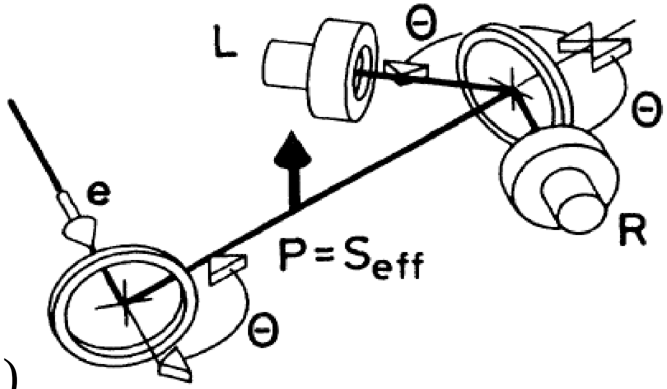
After second "identical" scattering process

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

with great effort to ellíminate

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)

Some remarks

- DSP works at ~100keV; ideal for ‚1mA-MESA-stage-1
- Original Kessler apparatus available
- 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
- 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):
In this case the first target may be treated as an auxiliary
target and the availibility of (switchable) Polarization may be exploited for even better accuracy!

Kessler/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; $-P_0$

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

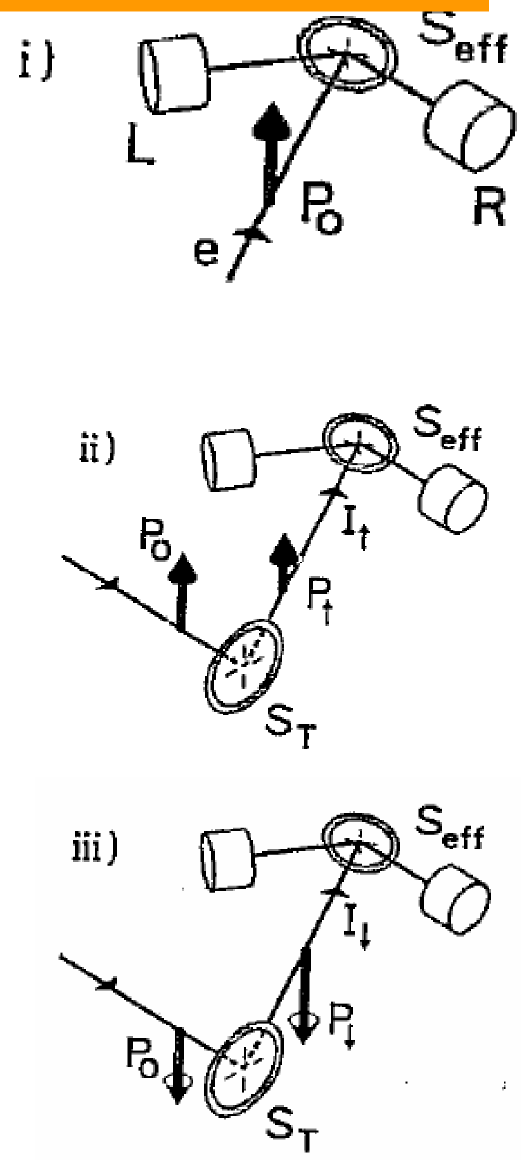
4. unpolarized beam on aux. target

$$A_4 = S_T S_{eff}$$

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%

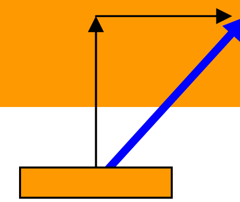


S. Mayer et al
Rev. Sci. Instrum. 64 952 (1993)

Some remarks

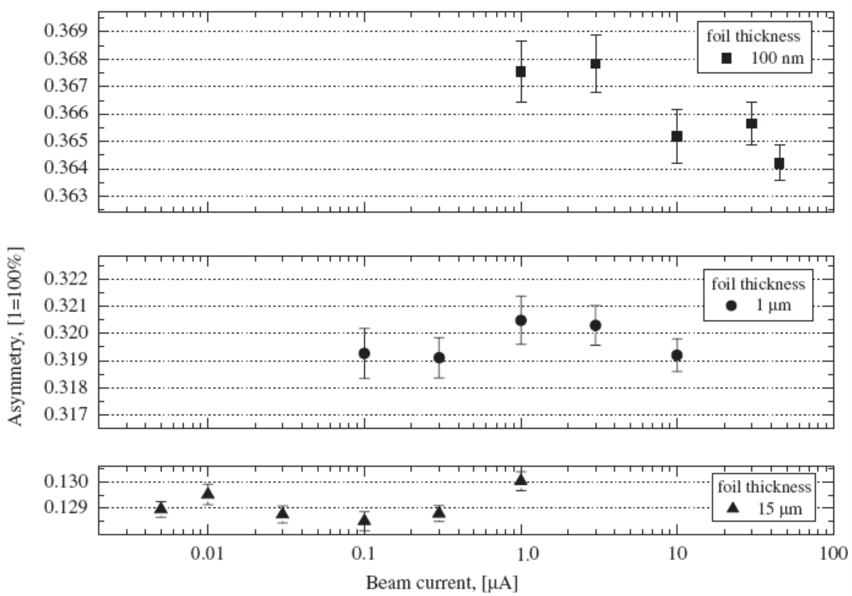
- Auxiliary target method was limited by statistical efficiency (today about 5 times better!)
- DSP invasive, but fast.
- Probably not feasible to operate DSP at > 100μA current level, requires ‚linking Polarimeter‘
- Linking with high precision polarimeters to be installed at 5MeV (Mott/Compton-combination
- Mott/Compton combination invasive but extremely fast (O(seconds) <1% stat. accuracy), also control of spin angle
- In total eight measurements: 5 DSP, 2 linking, 1 Hydro Möller, → ‚the eight-fold way‘

Linking capabilities



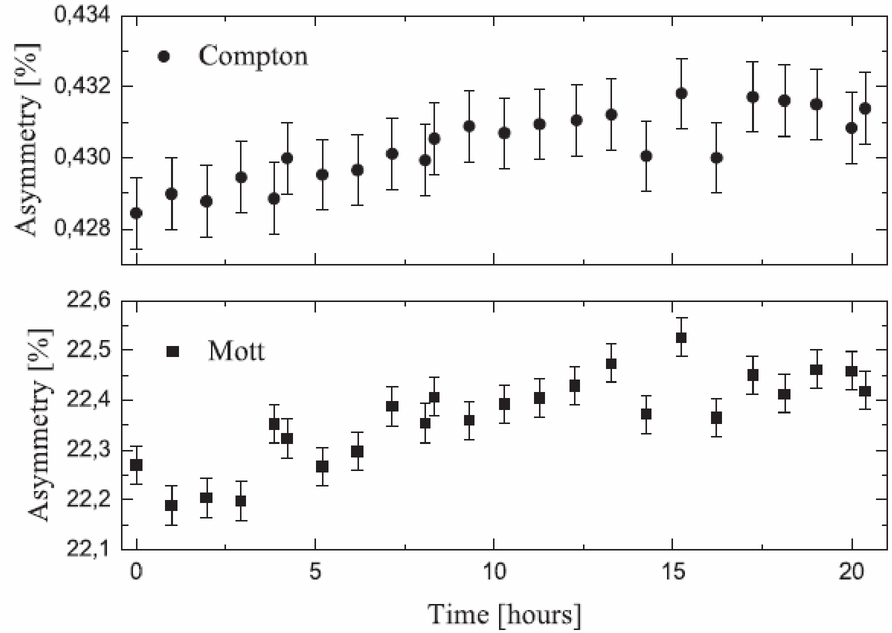
Dynamic Range:

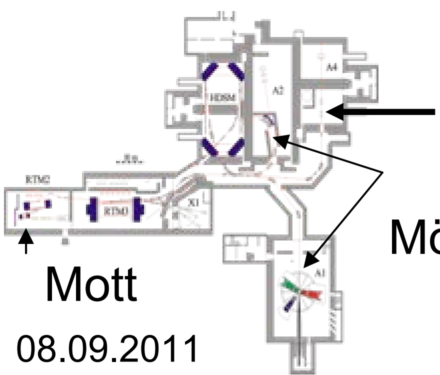
V. Tioukine et al. Rev. Sc. Instrum. **82** 033303 (2011)



Stability:

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



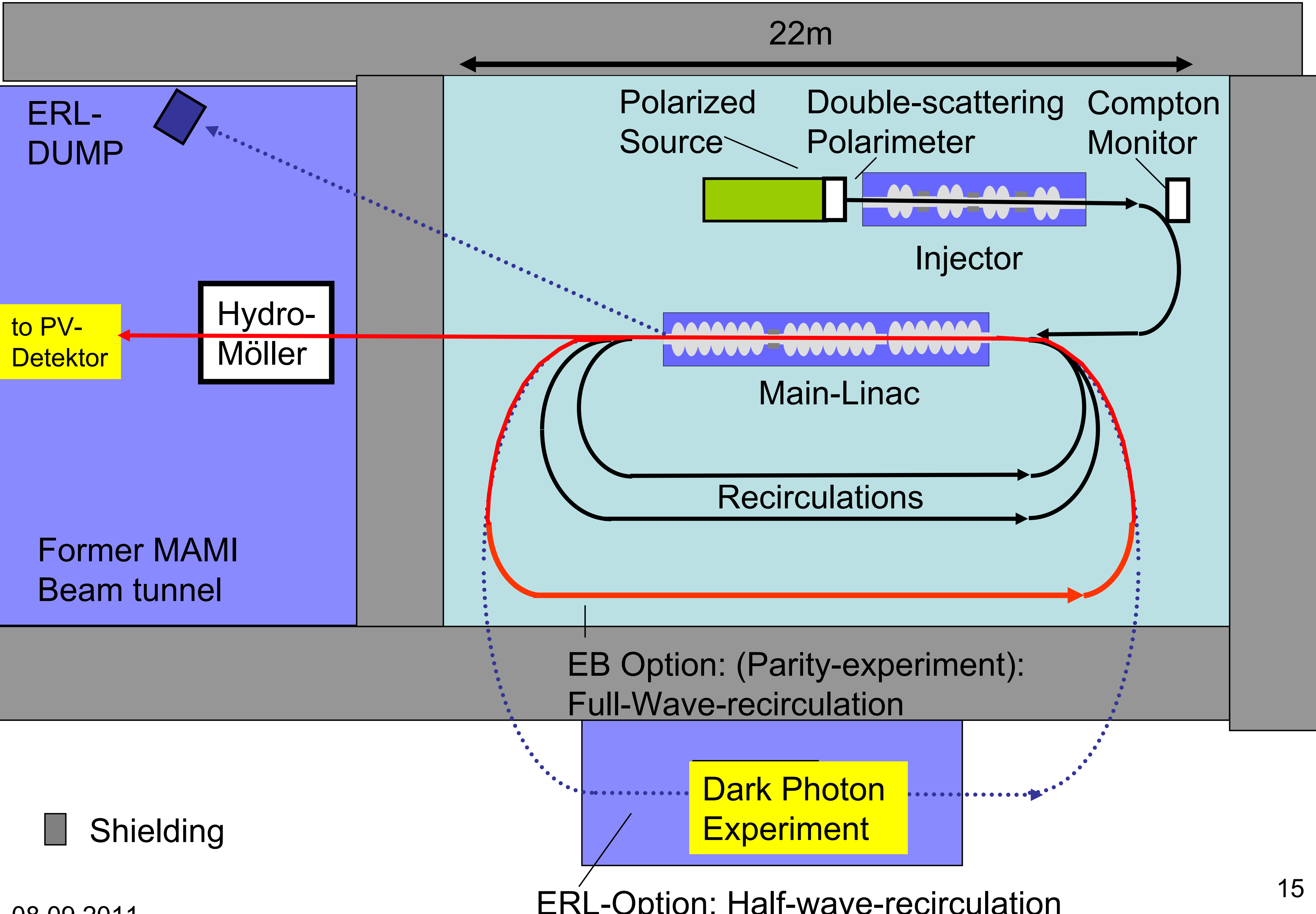


LCP

Möller-Polarimeters

Mott

Polarization Drift consistently observed in transverse AND longitudinal observable at the <0.5% level
(Measurement at 3.5 MeV, 35 μA)
Compton is an analogue, Mott a counting measurement


22m
ERL-
DUMP
Polarized
Source
Double-scattering
Polarimeter
Compton
Monitor
Injector
to PV-
Detektor
Hydro-
Möller
Main-Linac
Recirculations
Former MAMI
Beam tunnel
EB Option: (Parity-experiment):
Full-Wave-recirculation
Dark Photon
Experiment
Shielding
ERL-Option: Half-wave-recirculation

Conclusion:

MESA Spin chain

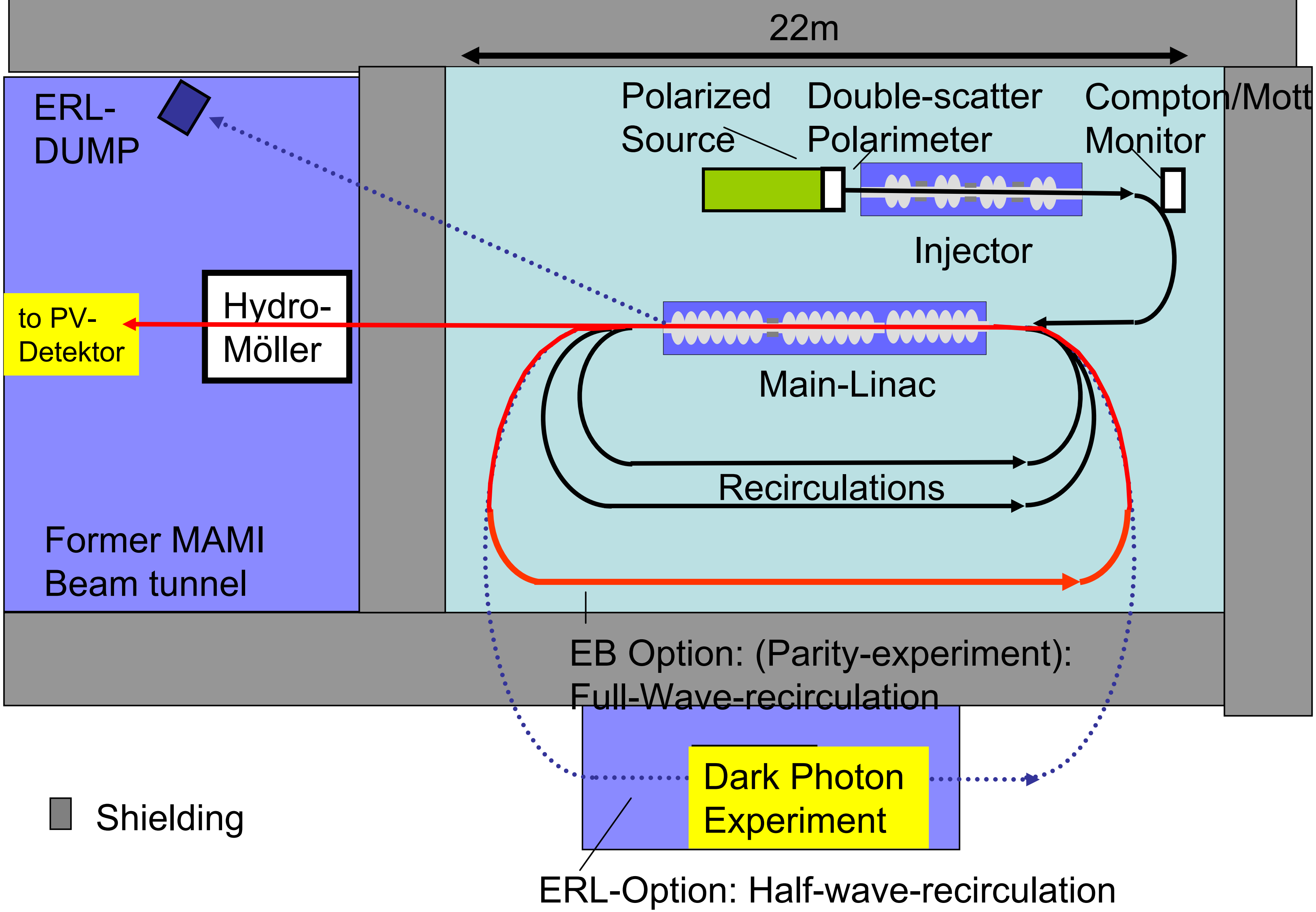
- low and a high energy polarimeter cross-check: negl. depolarization due to low energy gain of MESA
- Monitoring, stability and cross calibration can be supported by extremely precise Mott/Compton combination.
- Hydro Möller + DSP may obtain $\Delta P/P < 0.5$ % each,

Status of MESA

- MESA accelerator & experiments are under design,
- Funding decision within next year.
- MESA-PV data taking possible in 2017/18 (10000h BOT).

Conclusion

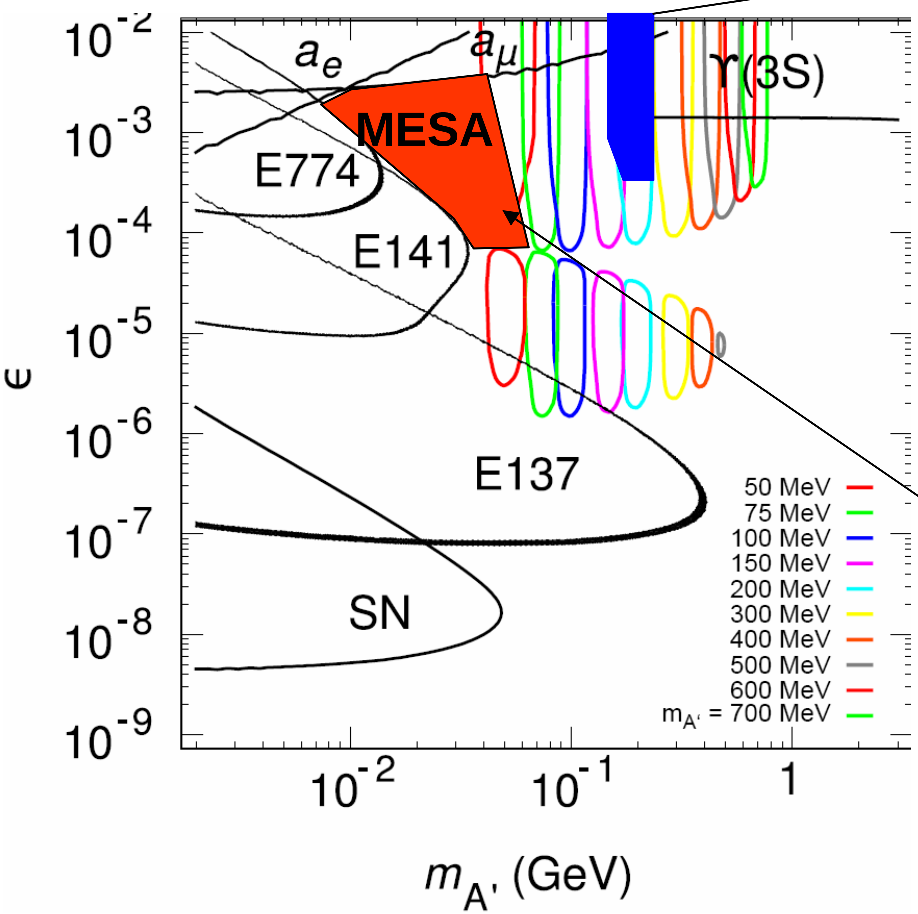
- MESA operates in EB-mode for PV and in ERL-mode for Dark Photon experiment.
- Main cost factor – building - eliminated, other one –SRF- reduced by multi-turn recirculation.
- PV requires extreme beam parameter stability
- …and accurate polarization measurement by a polarimeter chain
- In ERL mode, the new issue is multi-turn recirculation
- no doubt that this project provides room for students and young researches!



"Unimpeachable" polarization measurement: two independent polarimeters with $\Delta P/P$ <0.5% (**NOT: 1%)** each.

MESA-experiments-2- Search for Dark photon at MAMI/MESA

H. Merkel et al. (A1 collab. at MAMI): suggest to measure e+/e- pair invariant mass with double spectrometer set up at MAMI.



Demonstration experiment at MAMI 100μA/855MeV on 0.4% rad. length Tantal (2 weeks runtime) (submitted to PRL)

Limits:
- Low energy regime (background)
- other decay modes of A' ?
- runtime (several years ???)

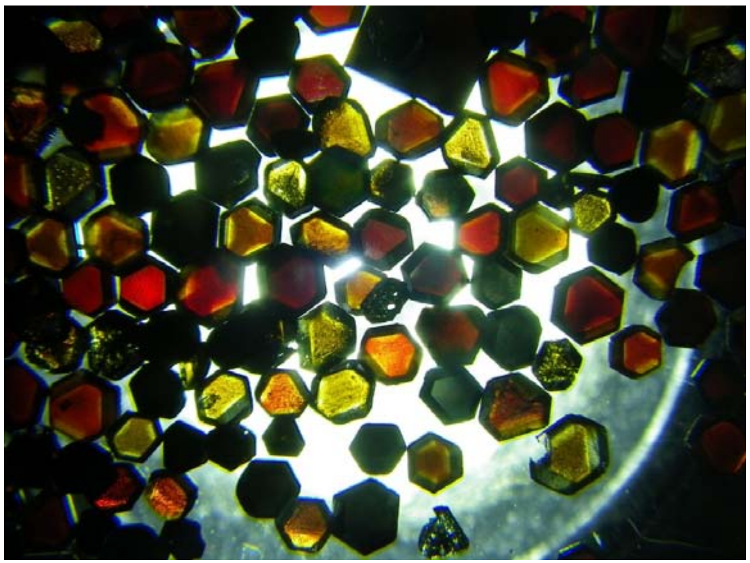
MESA's corner is adjacent to most of the a_μ region (interesting because of 3σ deviation of a_μ from SM)

MESA: Dedicated machine for $m_{A'}$ <100MeV with optimized background

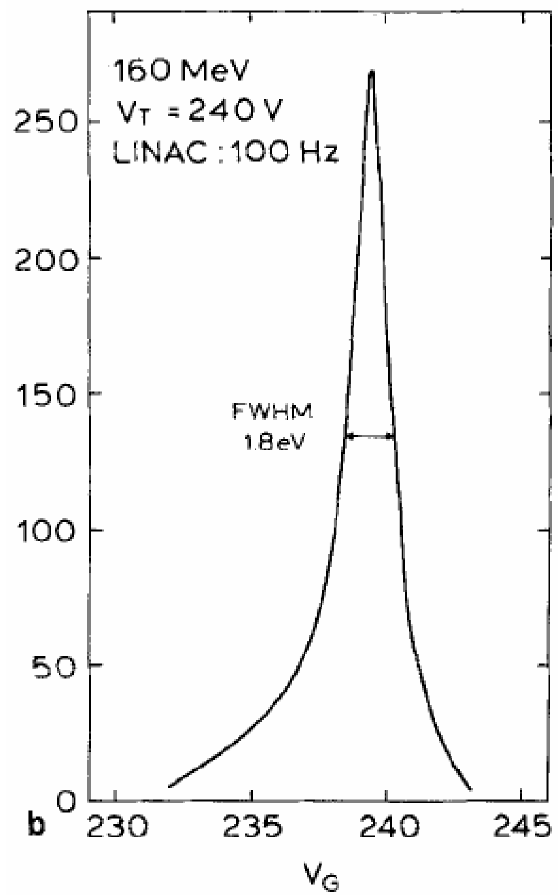
MESA-experiments-3: Applied physics

High beam power electron beam may be used for:

- ERL-mode: Production of nanodiamonds (see talk by F. Jelezko this afternoon)
- EB-mode: High brightness source of cold (polarized) positrons



Color: NV-centers introduced in Diamond.
Irradiated at MAMI for 3 days, 50μA at 14MeV
(J. Tisler et al. ACS NANO 3,7 p.1959 (2009))



G. Werth et al. : Appl. Phys. A 33 59 (1984)

→MESA can produce ~10^9 positrons/s in a beam of <1cm diameter at 120eV
→surface science: magnetic structures
→positronium production

MESA accelerator project rationale and beam parameter goals

- Experiments require a new & innovative accelerator
- ….but energy is low, therefore accelerator ‘affordable’
- MAMI acc. team competence represents basis for development
- Project will be attractive for young students and researchers

Make use of innovations in SRF accelerator science:

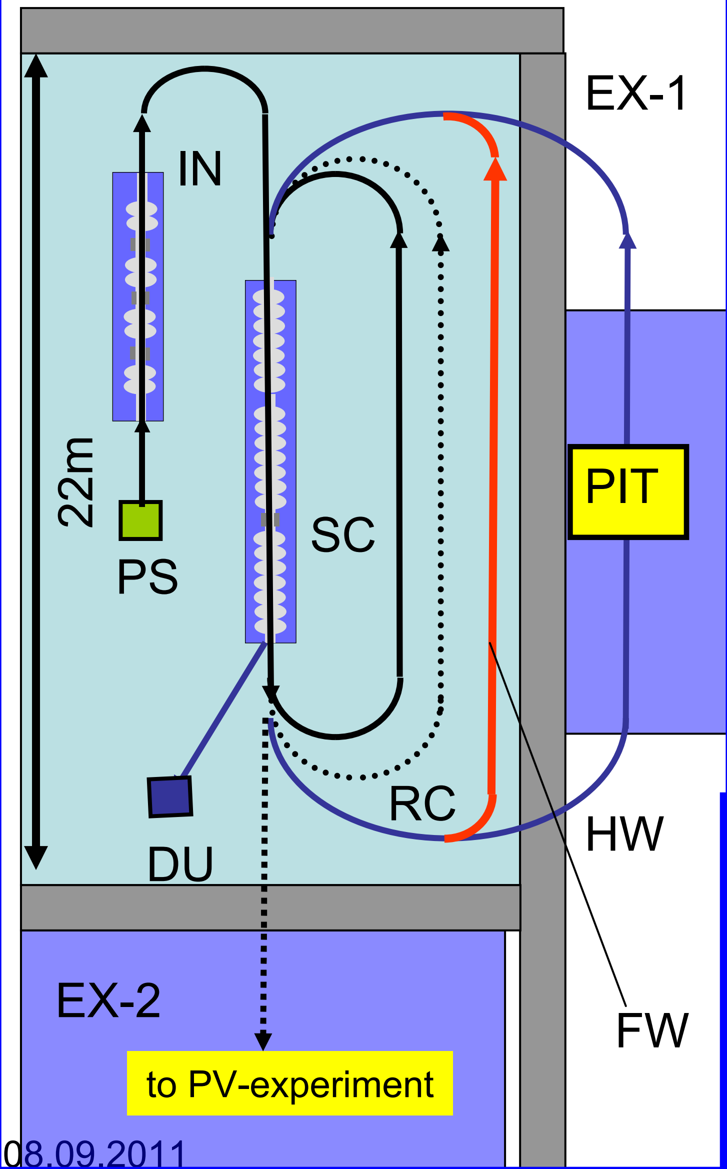
1. Energy recovery linac (ERL)
2. Improvements on high gradient-c.w.-SRF

Beam parameter goals in two **different** modes of operation:

1.) EB-mode External spin-polarized c.w. beam (EB-mode) at 137 MeV (Q^2=0.005GeV/c at 30 degree). L>10^{39} $cm^{-2}s^{-1}$

2.) ERL-mode: 10mA at 100 MeV with L~10^{35} $cm^{-2}s^{-1}$

MESA-LAYOUT



KEY:

PS: Photosource (polarized or unpolarized beam)
IN: 2.5 MeV – injector
SC: 3 Superconducting cavities, @ 13 MV/m. Energy gain 34 MeV per pass.
RC: Beam recirculation 3 times
HW: Third recirculation option 'half wave': Energy Recovery Linac (ERL-) Mode
FW: Third recirculation option: 'full wave' External Beam (EB-) mode
PIT: Pseudo Internal target (ERL mode)
PV: Parity violation experiment (EB-mode)
DU: 2.5 MeV beam dump in ERL-mode
EX: Experimental areas 1 and 2
Existing walls: 2-3m thick shielding

EXPERIMENTAL BEAM PARAMETERS:
1.3 GHz c.w.

EB-mode: 150 µA, 137 MeV polarized beam (liquid Hydrogen target $L{\sim}10^{39}$)

ERL-mode: 10mA, 104 MeV unpolarized beam (Pseudo-Internal Hydrogen Gas target, $L{\sim}10^{35}$)

MESA-beam parameters in comparison

Project/Purpose (status)	Av. Beam current (mA)	# of Recirc.	Norm. emit. (µm)	Bunch charge (pC)
MESA/ particle physics (under design)	10	3	10	7.7
JLAB/ light source (achieved)	10	1	7	7.7
BERLinPro/light source demonstrator (under design, funded)	100	1	1	77
eRHIC/particle physics (under design)	50	6		

- MESA will **not** have to provide extreme bunch parameters
- New issue: **multi-turn recirculation** (two or three times?)→ MESA may be useful as a test-bench for LHeC, eRhic, or others….
- The **challenge** is compliance between ERL and EB operation
  → see talk tomorrow!
  → Discuss now: specific issues for DM and PV

DM: Focusing through the PIT

$$\varepsilon_{\mathrm{Norm}} = 10\mu m \,(\mathrm{or}\ 3.2\ \ \pi\ \mathrm{mm} * \mathrm{mrad} * \mathrm{m_e c})\quad (\mathrm{MESA\ goal})$$

$$\varepsilon_{\mathrm{Geo}} = \frac{\varepsilon_{\mathrm{Norm}}}{\sqrt{\gamma^2 - 1}} \quad \Rightarrow \varepsilon_{\mathrm{Geo}}(100\mathrm{MeV}) \sim 50\mathrm{nm}.$$

Beam diameter as a function of optical function β :

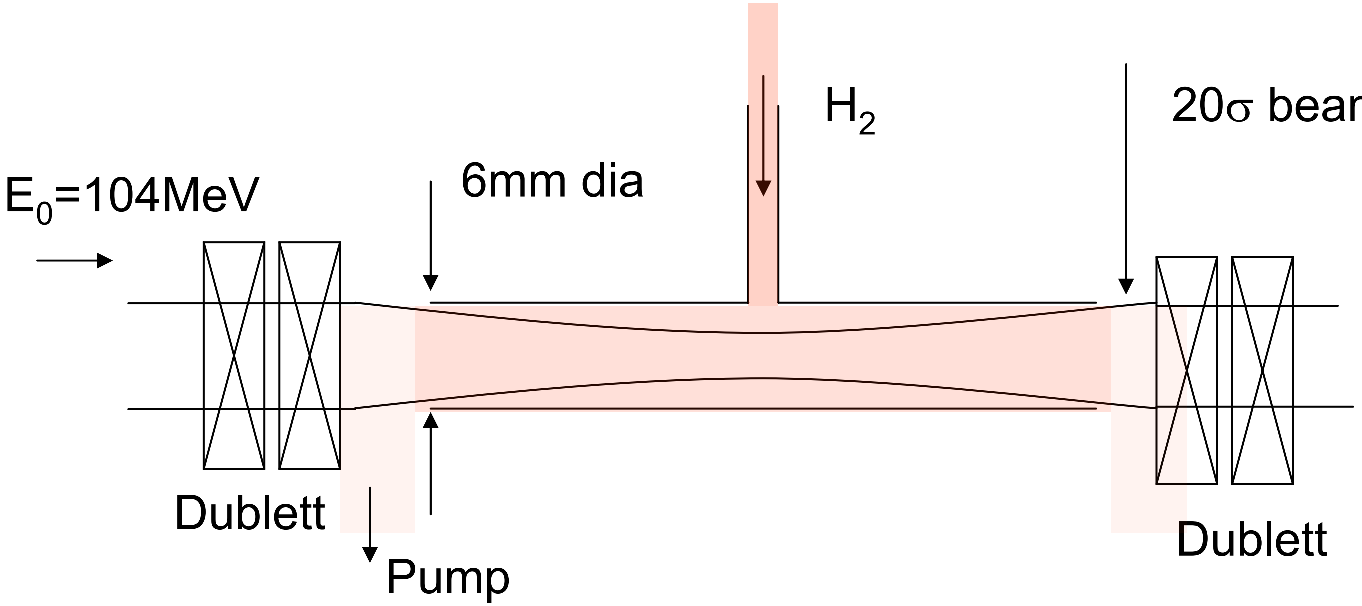
$$\mathrm{r}^2_{\mathrm{beam}}(\mathrm{z}) = \varepsilon_{Geo} * \beta(\mathrm{z})$$

in the field free region around symmetry point $\mathrm{z}^* = 0$

$$\beta(\mathrm{z}) = \beta(z^*) + \frac{\mathrm{z}^2}{\beta(z^*)} = \beta^*(1 + (\mathrm{z}/\beta^*)^2)\ \mathrm{choose}: \beta^* = 1m$$

$\Rightarrow$ Maximum beam diameter ≤ 0.62mm over 2 Meters of length

DM: Focusing through the PIT



Assuming target density N=2*10^{18} atoms/cm^{-2} (3.2 μg/cm^2, 5*10^{-8} X_0)
we have (at I_0=10^{-2} A) luminosity of L= I_0/e*N=1.2*10^{35}cm^{-2}s^{-1}

→(average) ionization Energy loss: ~ 17eV

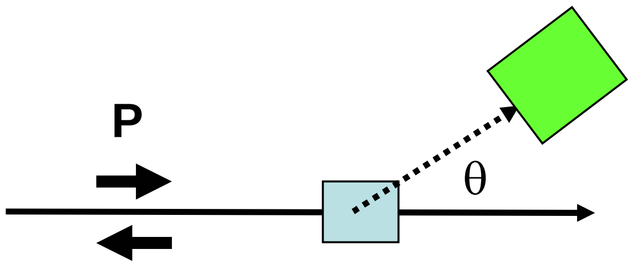
→ could allow to recuperate more energy than in conventional ERL (2.5MeV).

→RMS scattering-angle (multiple Coulomb scattering): 10μrad

→ single pass beam deterioration is acceptable Note: storage ring:
beam emittance lifetime ~ 10milliseconds (stationary vs. variable background…)

→ beam halo & long tails of distribution due to Coulomb scattering have to be studied

PV is a simple experiment



A_{exp}=(N↑-N↓)/ (N↑+N↓)

For elastic scattering on Hydrogen

$$A_{exp} = P\left(\underbrace{(1-4\sin^2(\vartheta_W))Q^2}_{A_{PV}} * \underbrace{Korr + F(G^{E,M}_{P,N}(Q^2), Q^2, E_0\vartheta)}_{\text{minimize syst. errrors by low } Q^2 \text{ and } E_0} \right) + A_{FALSE}$$

$$Korr(\gamma Z) \propto (1 + k(\gamma Z)E_0) \quad ;$$

$$\text{k}(\gamma Z) \text{ is not very well known} \Rightarrow \text{see talks on PV}$$

Penalty for choosing low Q^2: A_{PV} becomes very small (roughly 50 ppb)

→ Even at L>10^{39} the experiment will need about 10000 hours BOT: Experiment cannot be done at MAMI without strong interference with ongoing program.

→ A_{False} must be controlled to <0.4 ppb: Improve established techniques from PVA4 by about an order of magnitude (see accelerator talk tomorrow)

→ $\Delta A_{PV}/A_{PV}$ =1% → ΔP/P < 0.7%, better <0.5%. (MAINZ05-project)

Beam polarimetry is a simple experiment

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{0.proc} \cdot \left(1 + \sum_{i=x,y,z} S_i(\vartheta) \cdot P_i^{Beam} + \sum_{i,j=x,y,z} S_{i,j}(\vartheta) \cdot P_i^{Beam} P_j^T\right)$$

Process examples: Elastic Electron (Mott-)scattering : S_y

Möller - or Compton - Backscattering : S_{zz}

$$A_{Mott} = P_y^{BEAM} \underbrace{S_y(\vartheta, E...)}_{\text{to be determined.}} \;;\; A_{Möller} = P_z^{BEAM} \underbrace{P_z^{Target} S_{zz}(\vartheta, E...)}_{\text{to be determined.}}$$

Ideal polarimeter would have simultaneously:

1.) Online operation at experimental beam conditions,

2.)$\Delta P/P < 0.5\%$,

3.) fast polarization monitoring.

Probably the best approach: The “Hydro-Möller”-Polarimeter

- Online operation possible
- low Levchuk effect (Z=1 vs Z=26 conventional)
- very high $P_T S_{zz}$→ good efficiency in spite of low count rate statistics to 0.5% within about 30min
- $P^{Target}=1-\varepsilon$→ small Target polarization error ($\varepsilon \sim 10^{-5}$)
- Problem: Not realized yet→how does it work?