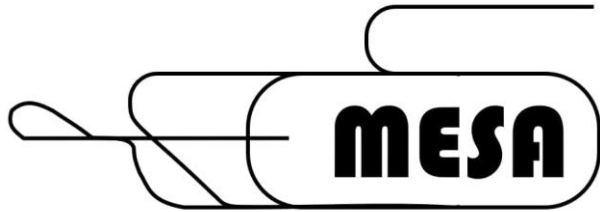


HIGH POLARIZATION PHOTOCATHODES AT MAINZ



Cluster of Excellence
PRISMA++

Precision Physics,
Fundamental Interactions
and Structure of Matter

Kurt Aulenbacher for the MESA Team

Institut für Kernphysik

JGU Mainz

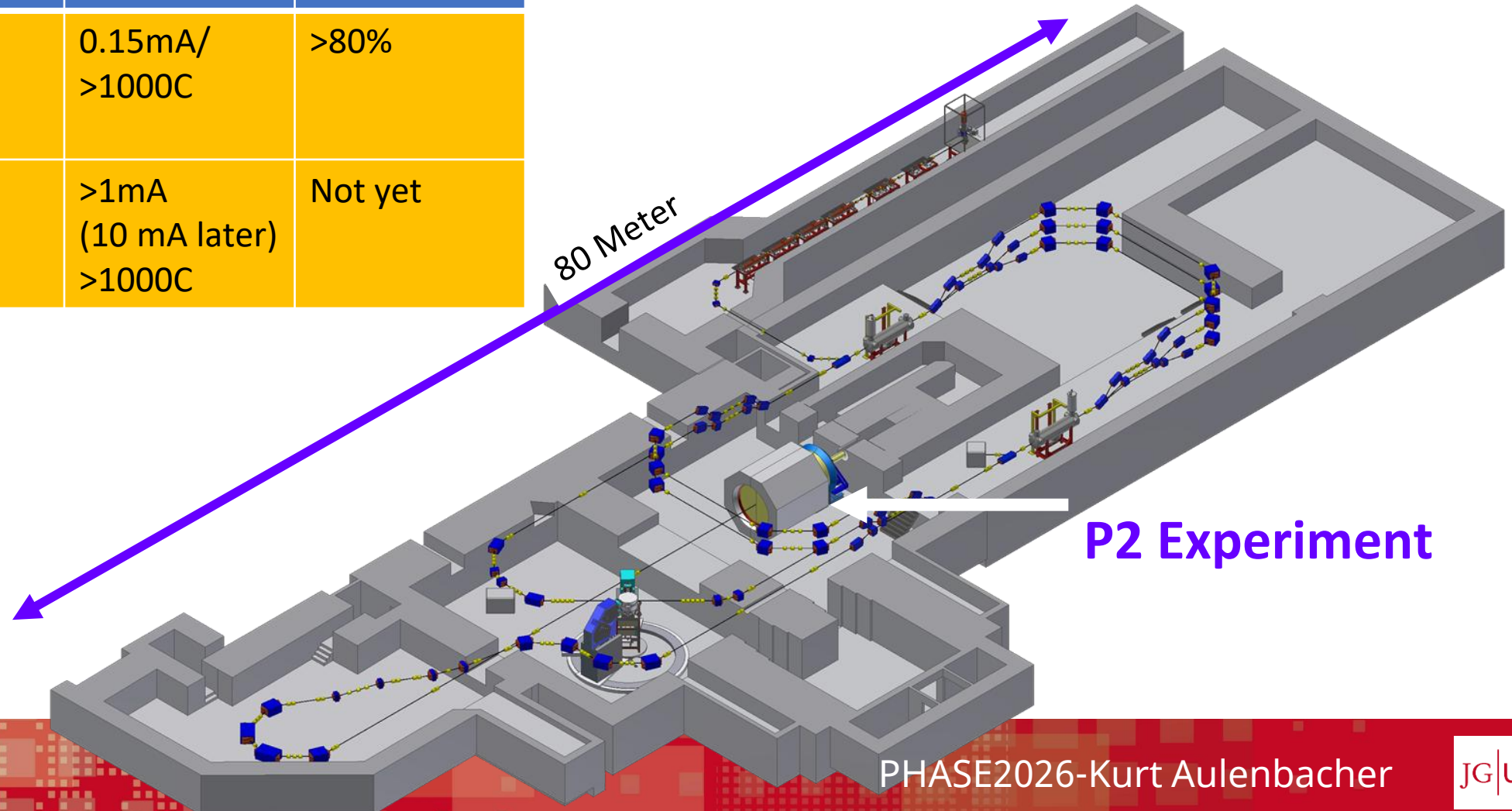
ERL Workshop, Orsay, 22. 09. 2026

OUTLINE

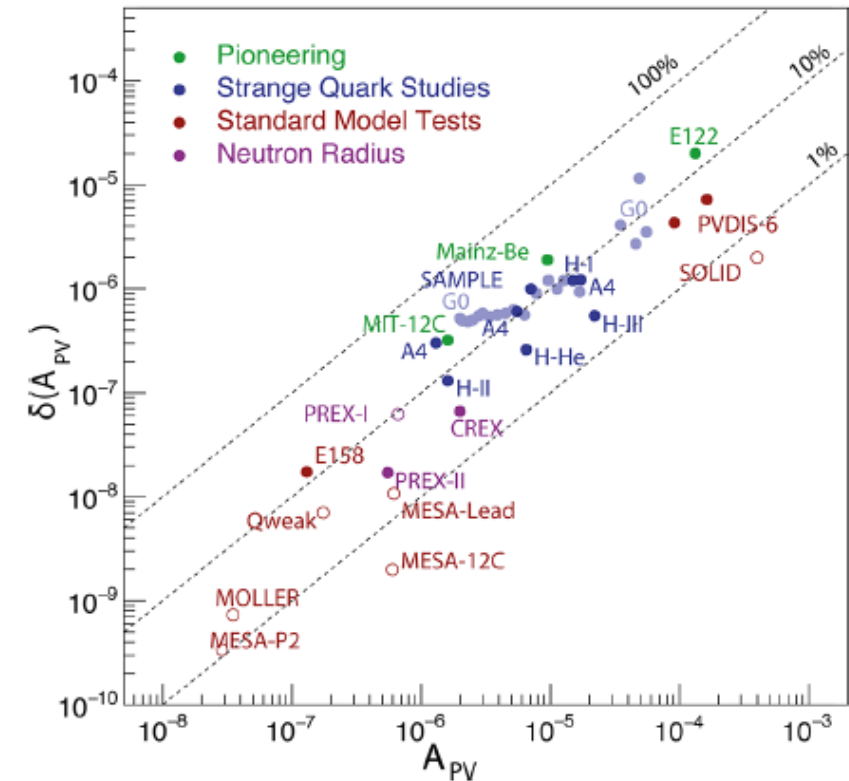
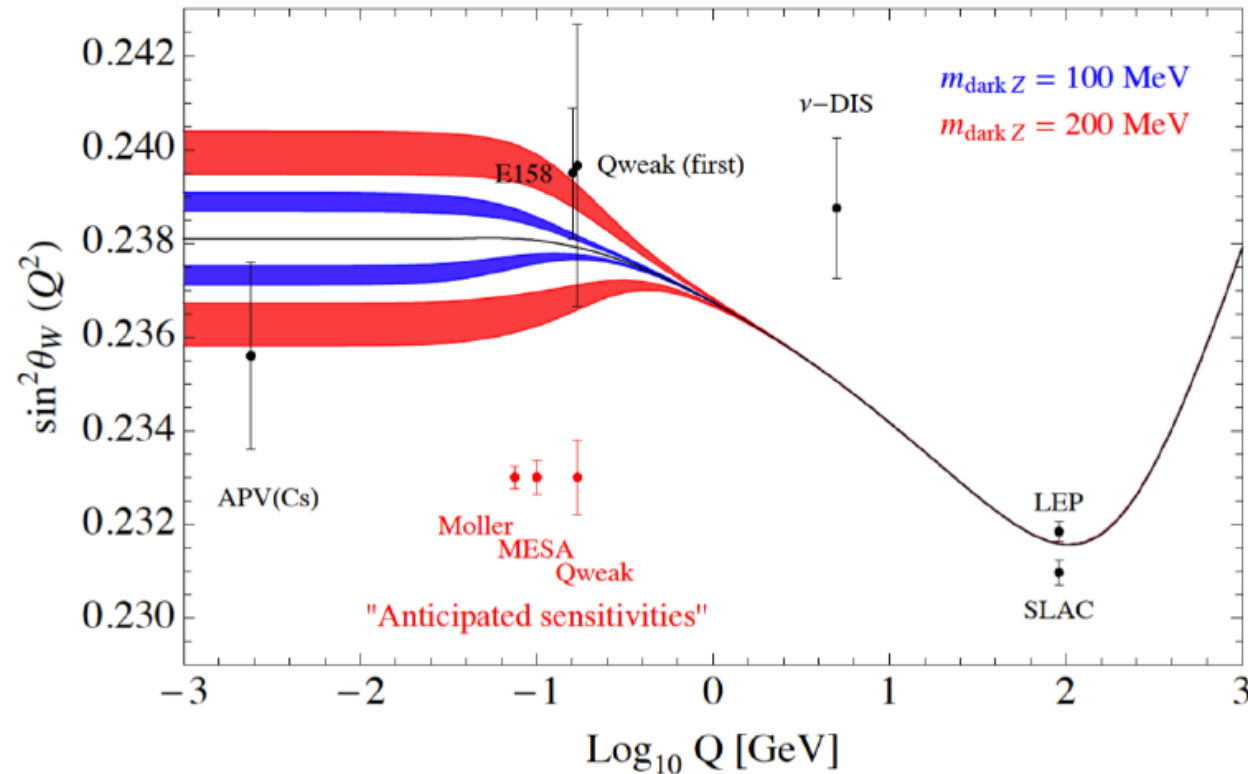
- 1. MESA Photocathode requirements**
- 2. Cathode for ERL-commissioning**
- 3. Surface Photovoltage**
- 4. Cathode supply chain problem**
- 5. Ion backbombardment mitigation**

MAINZ ENERGY-RECOVERING ACCELERATOR (MESA)

Op-mode	Target	Av. Beam current/Charge lifetime	Polarisation requirement
Ext. Beam (EB) „P2 Experiment“	Solid/Liquid	0.15mA/ >1000C	>80%
Energy recovery(ERL)	Gas-jet	>1mA (10 mA later) >1000C	Not yet



EXPERIMENT P2



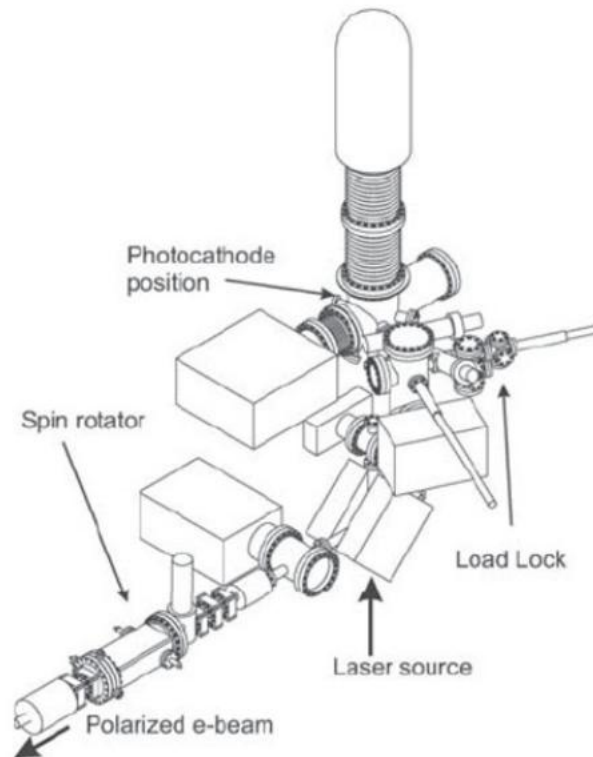
Weak charge of the proton: $1 - 4 \sin^2(\theta_W)$
 A weak charge measurement with accuracy 1.4%
 yields an accuracy $\Delta \sin^2(\theta_W) / \sin^2(\theta_W) = 0.16\% \dots$

The asymmetry is $\propto Q^2$ and $\propto P$

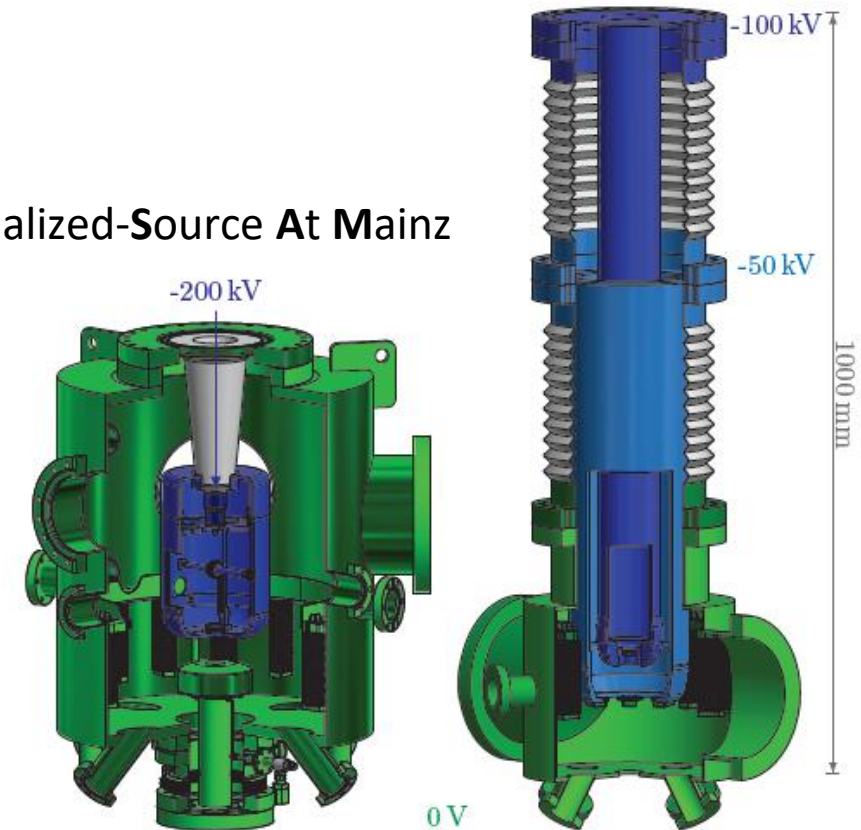
10000 hours of data taking needed when $P > 85\%$ and current 0.15mA

D. Becker et al. Eur. Phys. J. A **54** (2018) 11, 208
 DOI: 10.1140/epja/i2018-12611-6 & 166,

DC-SOURCES AT MAINZ



STEAM=
Small Thermalized-Source At Mainz

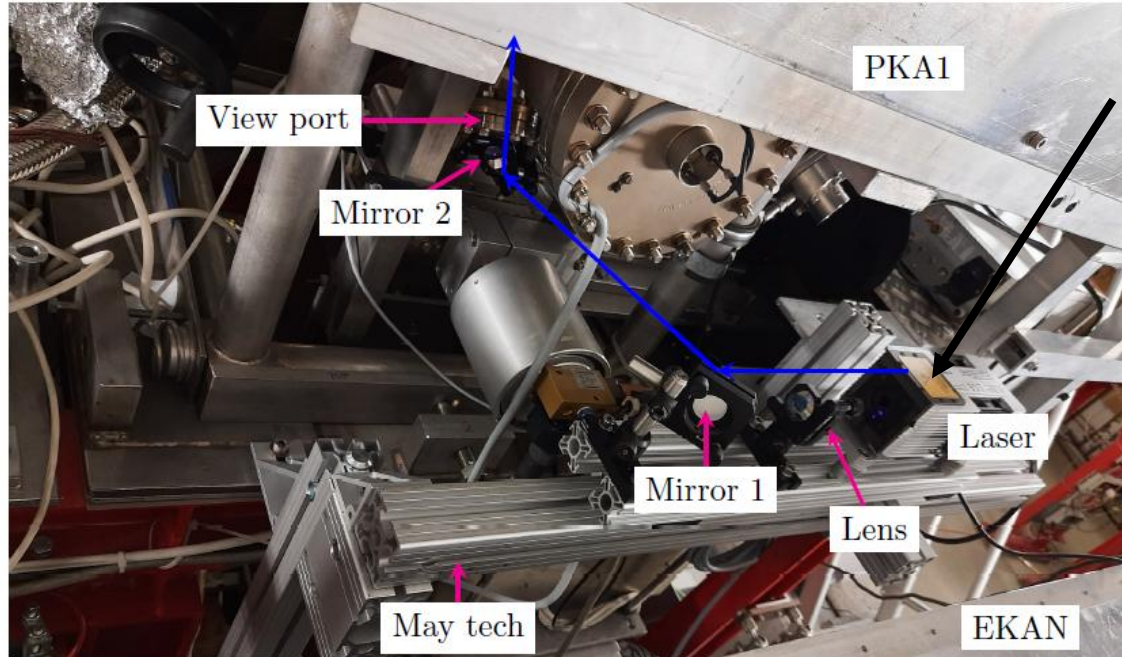


„old MAMI source, PKA1“ ; 2 in operation (3 until 2022)

MESA source „STEAM“ (inverted, no HV-cage)
– in comparison to
MAMI source (shown without HV- cage)

STEAM SYNCHRO-LASER SYSTEMS

TYPE	Wavelen gth	Time structure	Av. power	Remark
Gain Switched Diode „TAIKO“	405nm	Single shot to 100MHz 50ps or DC	0.05 W (0.5nJ /pulse)	Tuning of MESA Unpolarized QE for 10pC: 6%
Er:doped fiber MOPA „MANNY“	778 nm	1300MHz/2 ^N N<10 50-200ps	>3 W >100nJ /pulse	Polarized beam QE for 10pC: 0.2%



TAIKO-Laser at test installation
Size about 10cm
Injected by „side window“

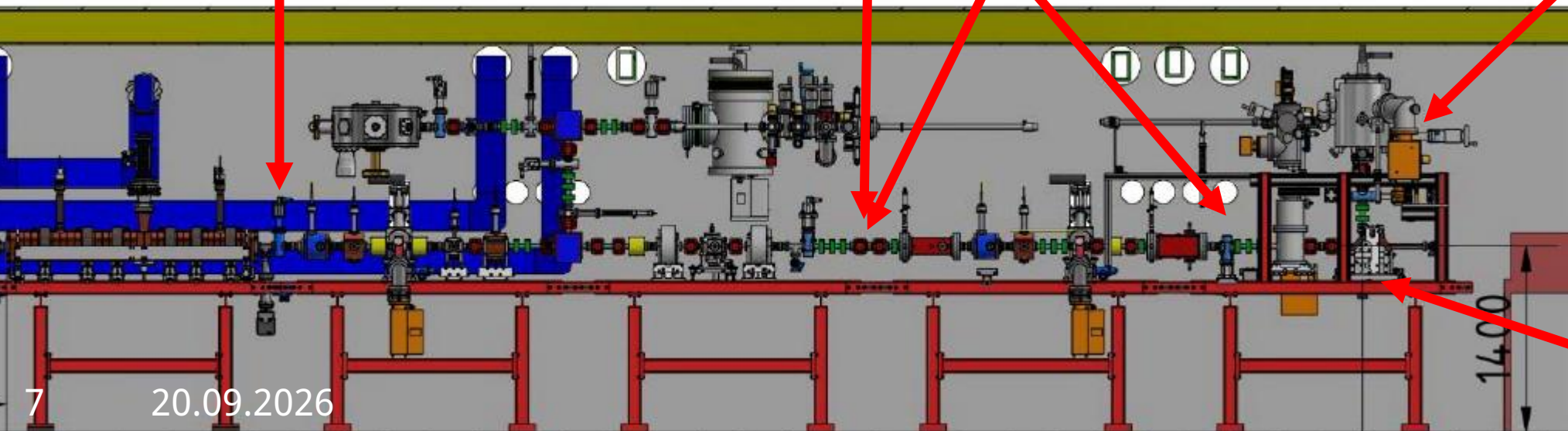


MESA SOURCE IN OPERATION (SO FAR)!

Normalized Emittance measured
(405nm, DC, low current): $0.09 \mu\text{m}$.
3*larger than expected)



Spin rotator and beam diagnostics
for Parity experiment



HIGH BUNCH CHARGE CATHODE FOR MESA?

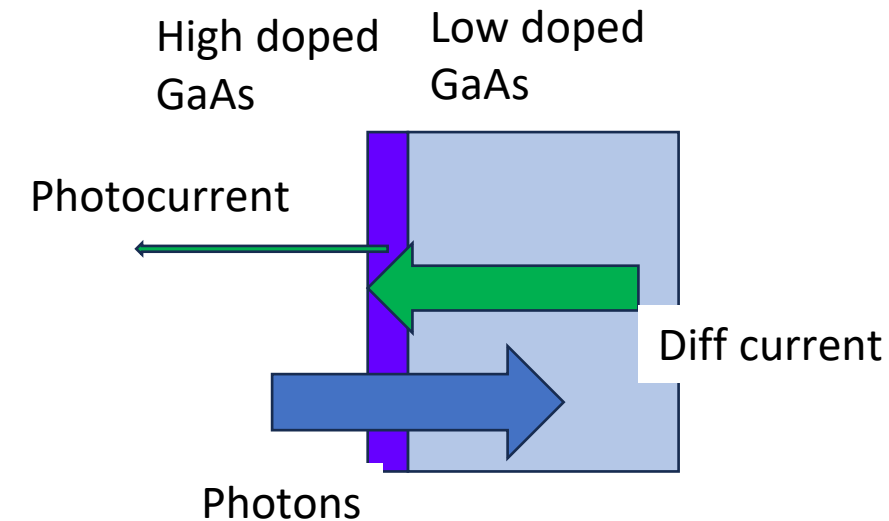
Cooperation with Heinrich Hertz Institut /Fraunhofer Gesellschaft

Goal to reproduce high polarization cathodes

First issue **gradient doping: high QE low SPV, low depolarization**

Test structures delivered by Heinrich Hertz Institut Berlin:

5nm-GaAs:C	$5e19\text{cm}^{-3}$	auf	1 μm -GaAs:C	$5e17\text{cm}^{-3}$
5nm-GaAs:Be	$5e19\text{cm}^{-3}$	auf	1 μm -GaAs:Be	$5e17\text{cm}^{-3}$



Majority of diffusion current ends up in surface zone/band bending region

→ High doping required for fast recombination (nanosecond time scale)

→ High doping for thin band bending region

Dependence on Crystalline Face of the Band Bending in Cs₂O-Activated GaAs[†]

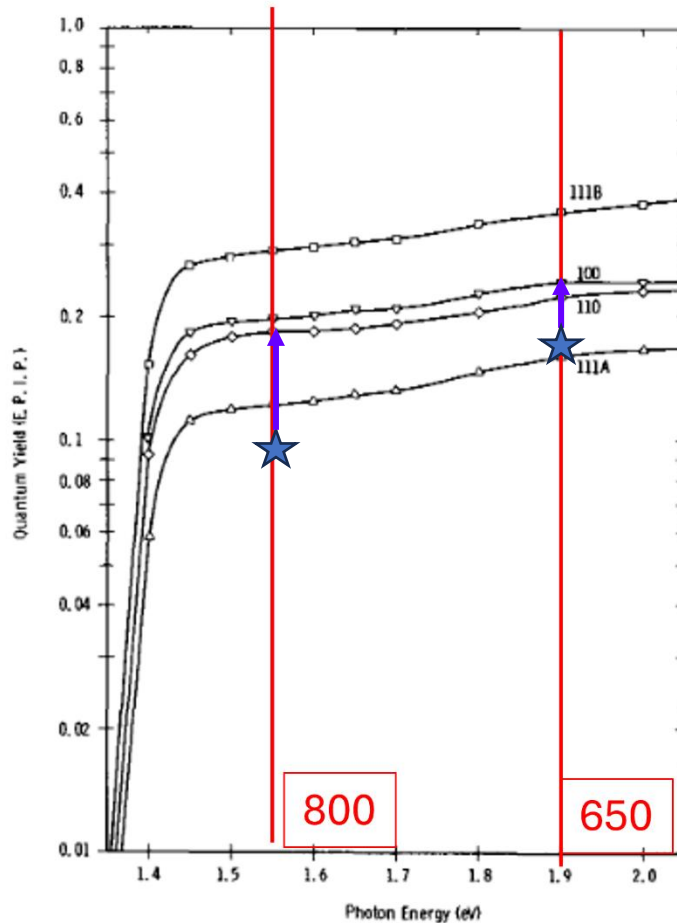
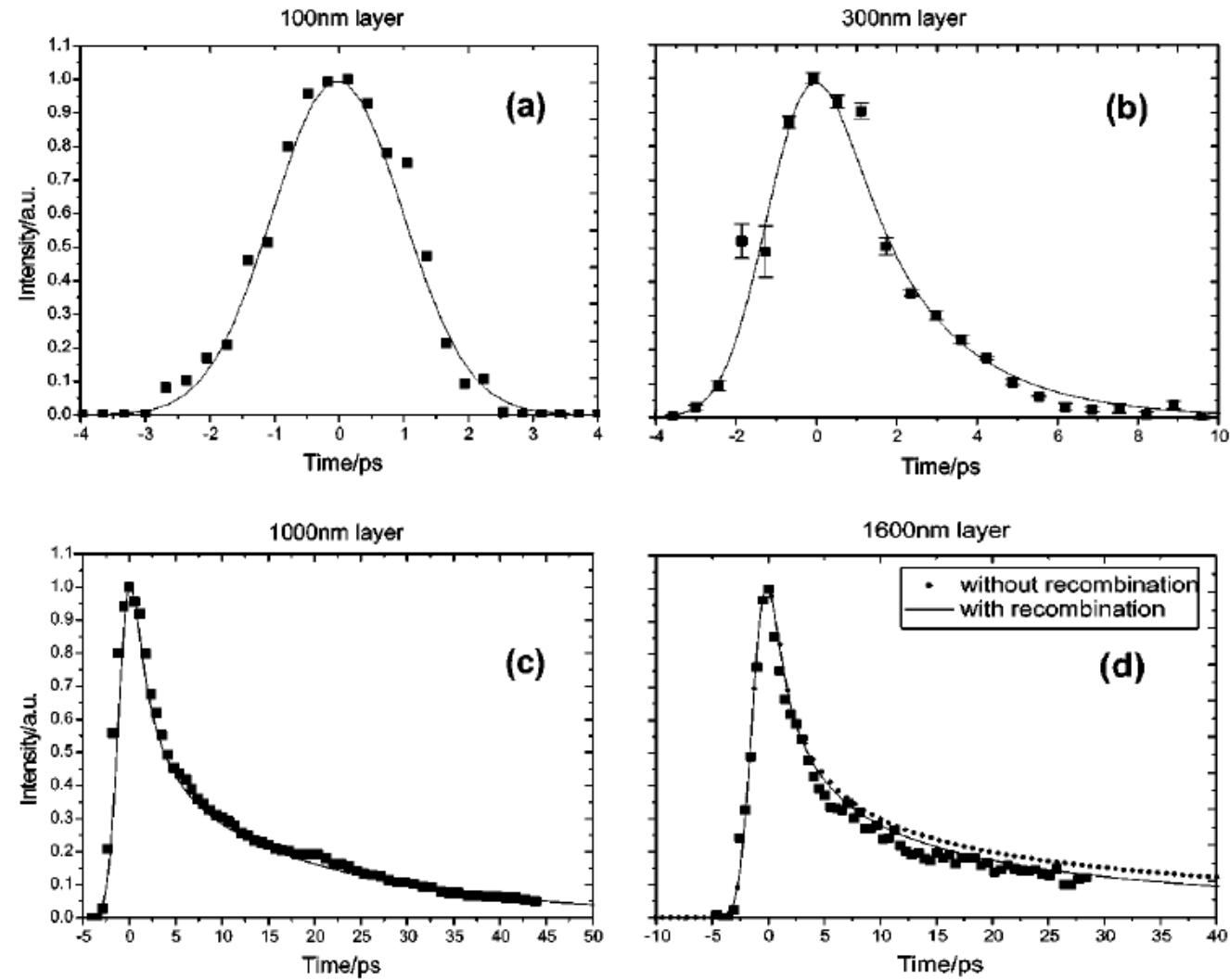


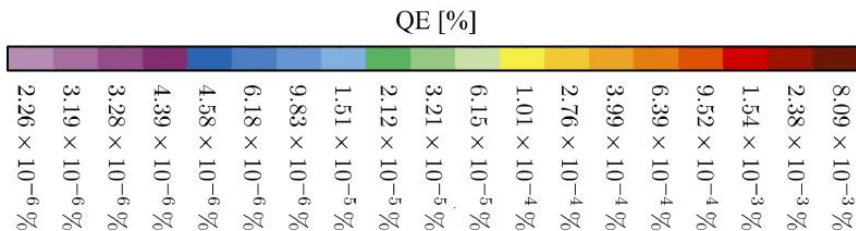
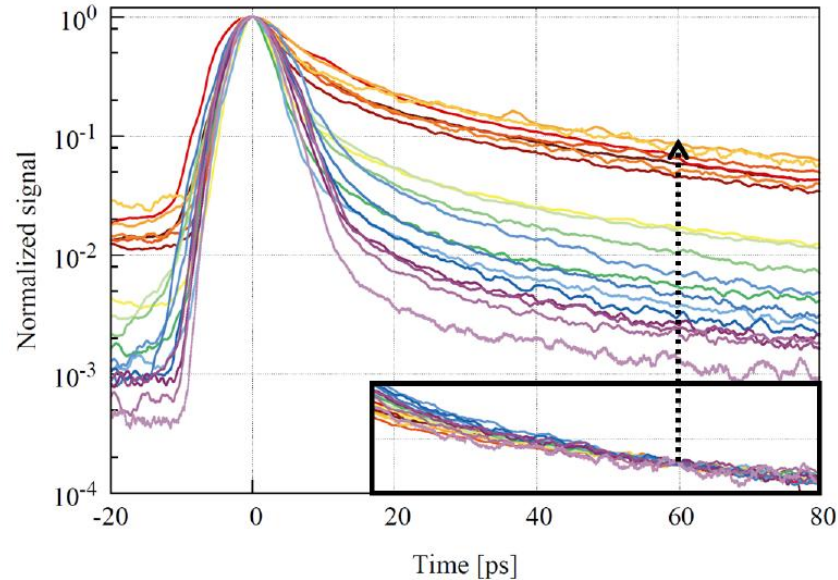
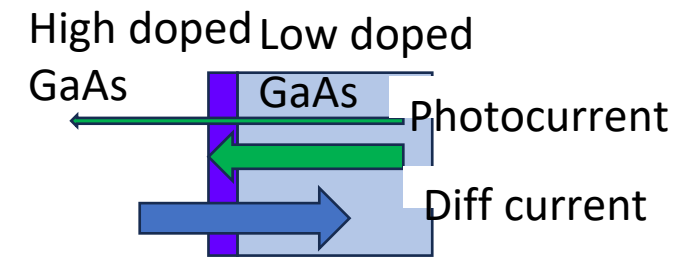
FIG. 5. Photoelectric quantum efficiencies in electrons per incident photon for $5 \times 10^{18}/\text{cm}^3$ Zn-doped liquid epitaxial GaAs samples. The four curves are for {111A}, {110}, {100}, and {111B} surfaces cleaned in the same manner as the *n*-type samples of Figs. 1-4 to avoid faceting, and activated to the peak luminous sensitivity with alternate exposures of cesium and oxygen.

- QE good enough for 10pC bunches (15% at 650nm)
- thin enough for resonable bunch length
- very suitable for optimization of MESA with TAIKO Laser in single bunch mode
- But polarization too low (est. 40-45 %)



1 μ m suitable for 80ps long laser pulses from MESA lasers

SURFACE PHOTO-VOLTAGE?



N. Scahill, PhD thesis Mainz 2022

Experiment: Bulk GaAs, doping $2 \times 10^{19} \text{cm}^{-3}$ $\lambda = 800 \text{nm}$
Produce short pulse with
constant Fluence of $2 \times 10^{-4} \text{pC/mm}^2$ at varying QE

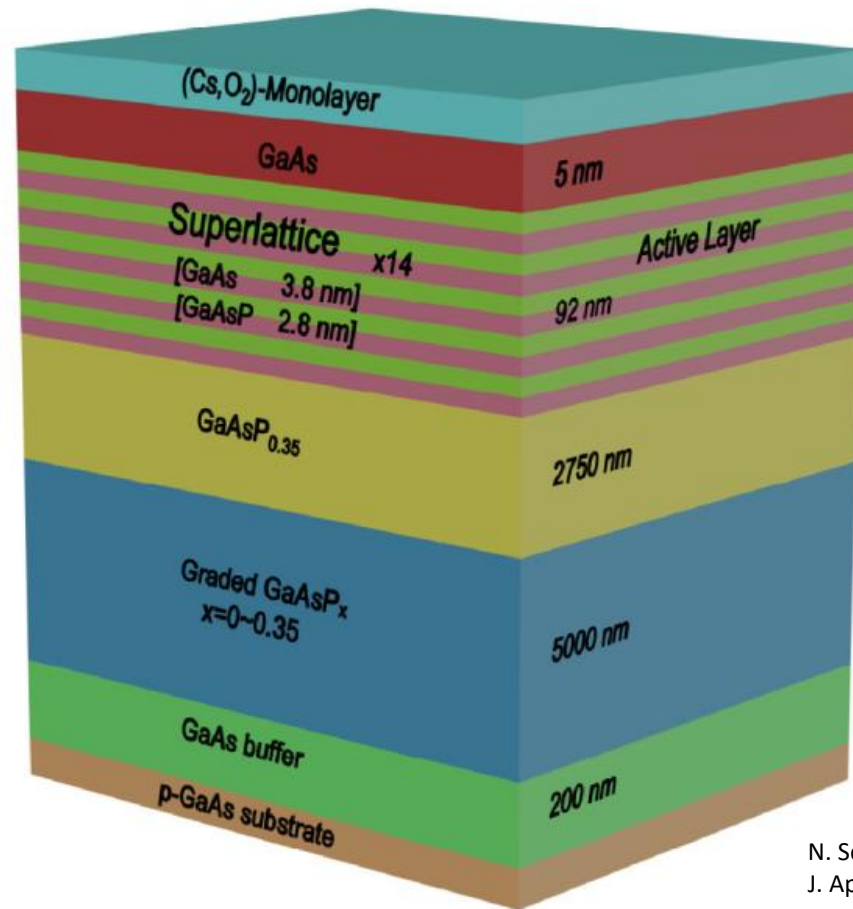
→ Pulse Tail suppression below $\text{QE} = 10^{-4} \%$

→ **QE is reduced after a certain fluence of diffusion current is reached**

Effect is attributed to surface photovoltage, see Mulhollan et al :Physics Letters A, 282(4-5):309–318, 2001.

→ **To produce 0.1pC/mm^2 for MESA polarized beam requirement we need a QE of $> 0.05\%$.**

COMMERCIAL CATHODE AT MAMI



**Manufactured by SVT
company until 2015**

**Last deliveries: too low
polarisation
Surface defects?**

N. Scahill and K.A:
J. Appl. Phys. 132, 185702 (2022); doi: 10.1063/5.0108675

SVT CATHODE IN USE AT MAINZ

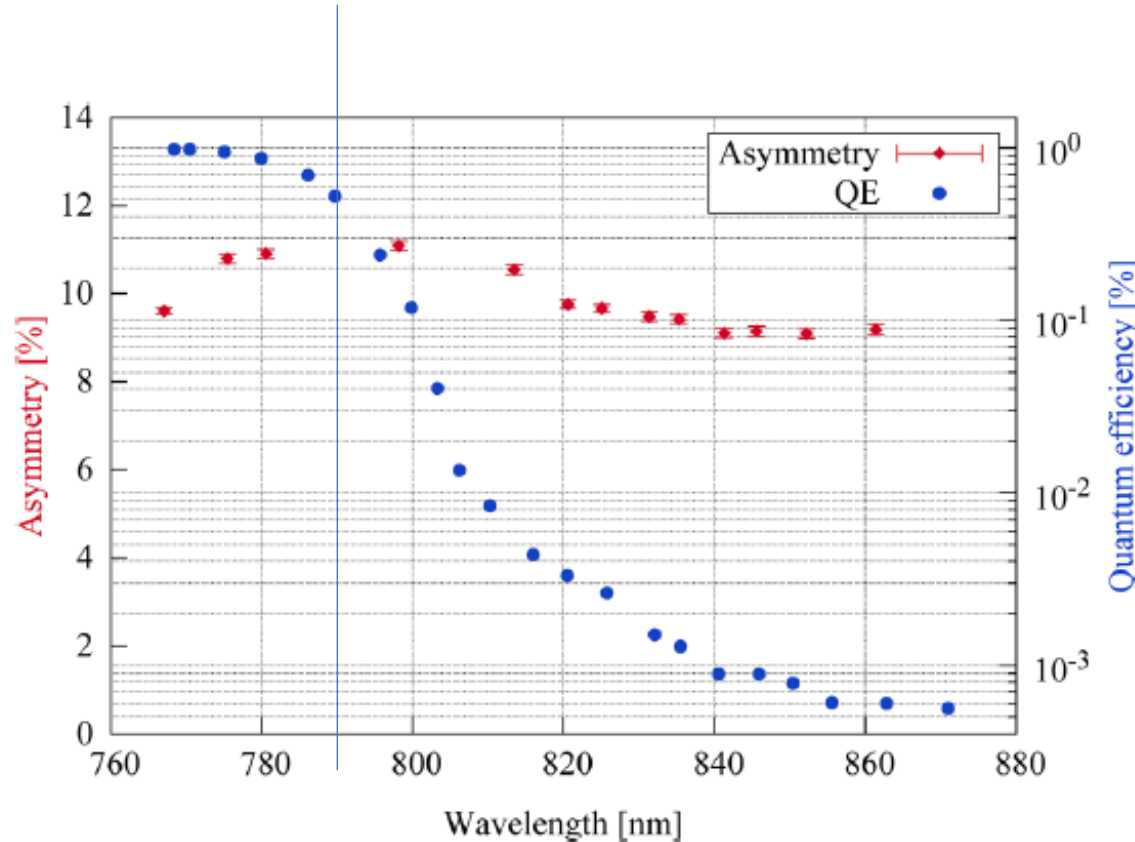


FIG. 4. Mott scattering asymmetry and quantum efficiency as a function of the exciting wavelength for the strained GaAs/GaAsP superlattice.

N. Scahill and K.A:
J. Appl. Phys. 132, 185702 (2022); doi: 10.1063/5.0108675

Mott scattering asymmetry measured at 44 keV

→ Very low analysing power

→ Polarisation 80-90% in maximum

→ QE~0.5%-0.9% at maximum Polarization

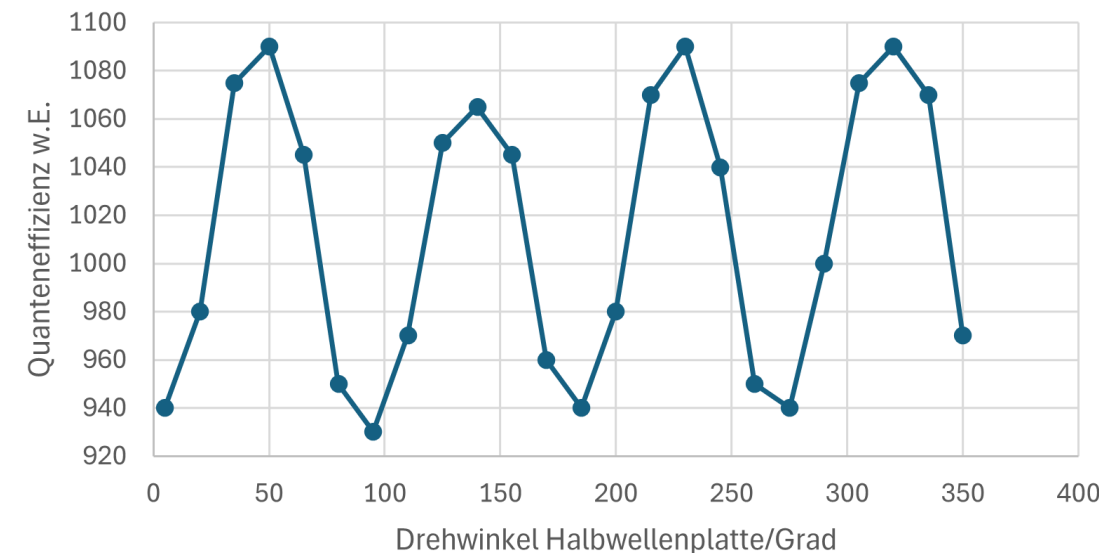
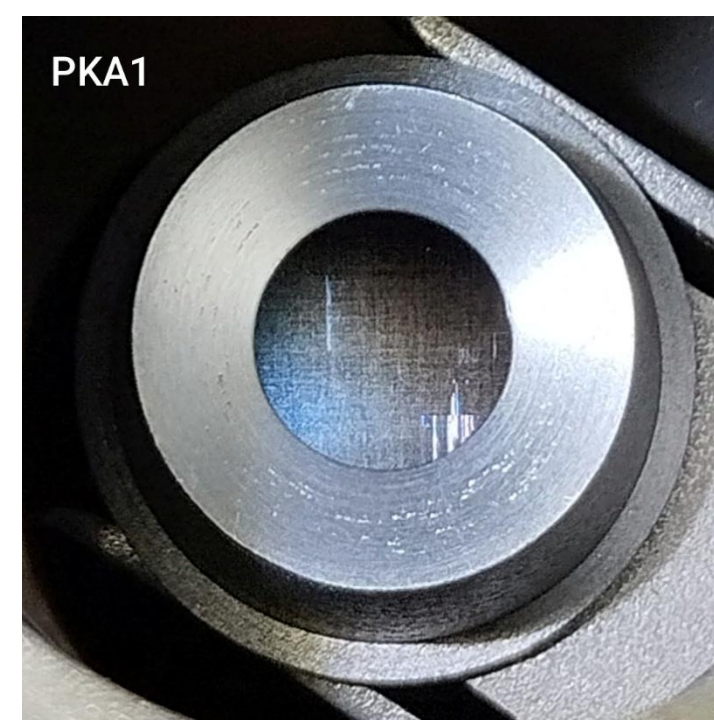
The strained superlattice cathode from SVT can do the job at MESA....

But

It is no longer possible to purchase from company ... Our Stocks are empty

SVT CATHODE ALTERNATIVE

- Chinese Company ACKEN:
- Quarter of a Wafer delivered
- Defects on surface visible
- Polarisation as good as SVT, measured in direct comparison at MAMI
- QE a bit lower
 - activation problem? wavelength?
- High linear analysing power (6%)
 - inhomogeneous strain relaxation?



CHARGE LIFETIME –ION BACKBORDMENT

Best result of MAMI-source PKA1
(2004)

Vacuum lifetime >1000 hours

Charge lifetime 200C (*)

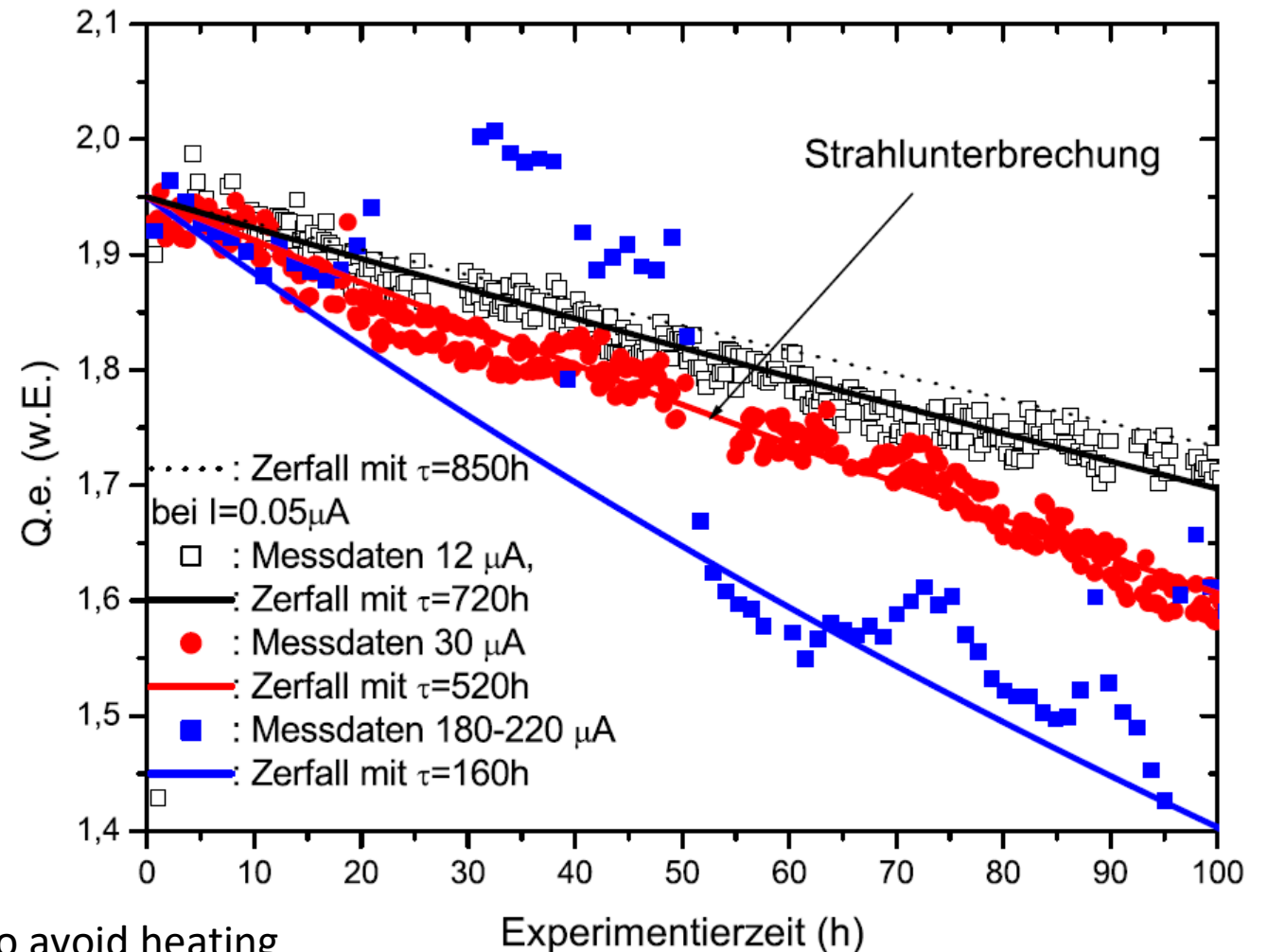
→ Cathode would be reactivated every
2 weeks for P2 (13Coulomb/day)

MESA-source „STEAM“ (**): (2026)

Vacuum $3 \cdot 10^{-10}$ Pa

Vacuum-lifetime >10000 h (405nm)

Charge lifetime: ???



(*): achieved with bulk GaAs (>10mA/Watt) to avoid heating

(**) STEAM= **S**mall **T**hermalized-**S**ource **A**t **M**ainz

HOW TO COPE WITH ION BACKBOMBARDMENT /OUTLOOK:

- + Pressure level in MESA source „STEAM“ probably lower than at MAMI (longer vacuum lifetime observed)
- + shorter acceleration stage in STEAM compared to MAMI/PKA1
- + repeller available in STEAM to suppress ion backstreaming from beamline

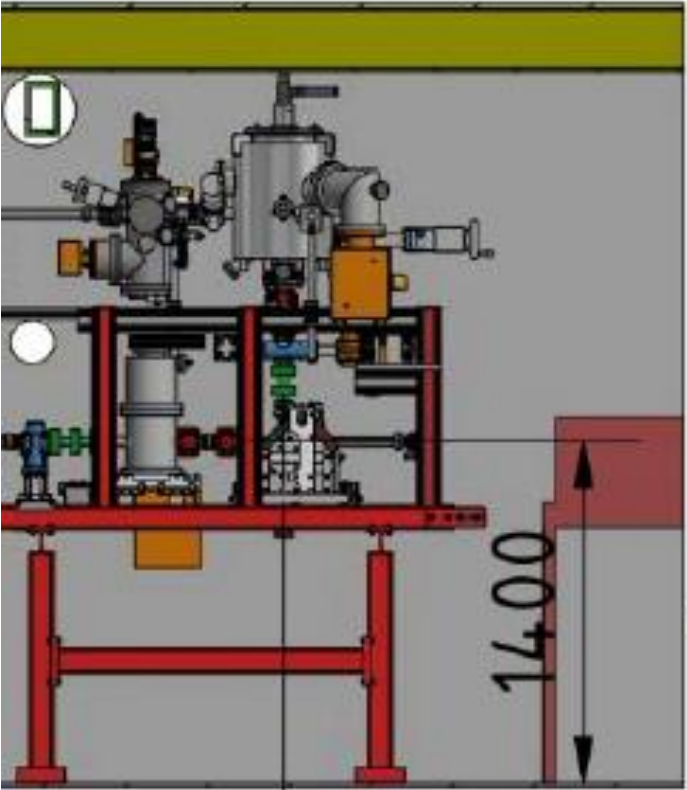
If all this does not help, possibilities nevertheless remain :

- Larger and more excentric laser spot (Fluence lifetime at MAMI $\sim 2500\text{C/mm}^2$)
- BUT: Keep beam losses low!
- Idea: Less sputtering by using heavy Activation/Protection CsBr/CsTe
- Materials with large value of negative affinity: GaN/AlGaN superlattices?

SUMMARY/OUTLOOK

- Challenging cathode requirements from the PV-experiments at MESA/MAINZ, in particular charge lifetime
- Q_{bunch} /Pulse Energy linearity (surface photovoltage) requires relatively high QE at maximum P
- Commercial vendor for GaAs/GaAsP found
- Research activities concerning higher charge lifetime: beam dynamics, activation layers, alternative material with high NEA value.

THANK YOU !



Laser



STEAM

Spin-polarized cathodes are „activated“ on-site and transferred to source in UHV



First beam from Spin-polarized Photosource „STEAM“

Laser	
type	Er-doped fiber
wavelength	780nm
Av. power	Up to 4 Watt
Rep-rate	5-1300 Mhz
Pulse length	50-250ps
photocathode	
type	GaAs/GaAsP SL
wavelength	780nm
Spin-polarization	80-90%
Quantum efficiency	~0.5% (3mA/Watt)
Response time	~1ps
Beam current	150µA
Charge lifetime	>100 Coulomb

MESA PHOTOCATHODE REQUIREMENTS

Source	Operation Voltage	Laser/Time structure	Av. Laserpower/Wavelength/ Pulselenght	Remark
PKA1	100kV	Semiconductor MOPA , 2.449 GHz CW.	0.3W/778nm /80ps	Serves MAMI Accelerator
PKA2 (copy of PKA1)	100kV	Semiconductor DC	0.05 W, 808/786nm	Test source for pol. photocathode developments
PKAT (copy of PKA1)	100kV	Ti:SP, Mode-locked 78 MHz CW	0.5 W 750-850 nm DC or 0.1ps	Time resolved measurements Dismantled in 2022!
STEAM(*)	100-150 (200)kV	Er:Fibre MOPA 1-1300MHz CW	>3 W 778 MHz 50-200 ps	Serves MESA Accelerator Alternative laser: Diode 405nm