Polarized source applications

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Cluster of Excellence Precision Physics, Fundamental Interactions and Structure of Matter
PRISMA

HOPE II

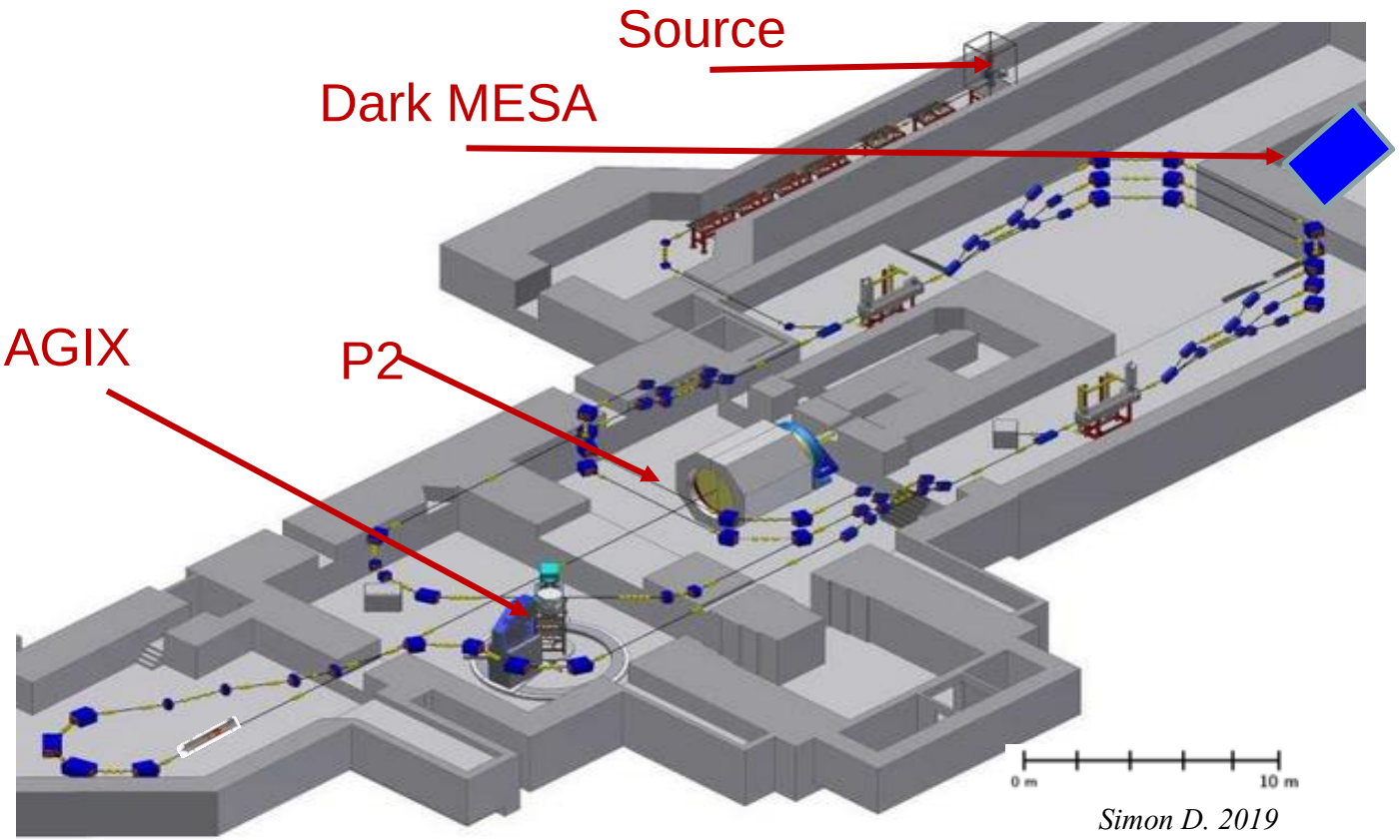
Outline

- Introduction – Applications of polarized beams
- Advantages of “polarized”-Photocathodes
- Limitations and challenges – surface photovoltage, charge lifetime, fluence lifetime
- Summary and outlook

Future (challenging) applications of polarized beams

- Solid state physics with magnetic interaction
  → high brillance beams (microscopy) & high time resolution
  (e.g. Spin polarized ultrafast e-diffraction, “SUED-beams”)
  typical application: E_{source} ~keV-MeV, t_p<<1ps, ε_{norm}<1μm
  QB>pC, f =kHz-MHz
- Particle physics – spin interaction at “fundamental” scales
  → medium (peak) brillance, high average current sources
  e.g. ERL-based double polarized
  e-Ion collider (eRHiC, LHeC) E_{source}~200-500keV,
  cw. operation, current average mA – 50mA

Example: cw-spin-polarized beam: MESA



Simon D. 2019

Experiment	*Mode*	*E (MeV)*	*I (mA)*	*Data taking (h)*	*Polarisation*
P2	EB	155	0.15	15000	0.85, mandatory
MAGIX	ER	105	1-10	?	0.85, if possible

Strained Superlattice-cathode

GaAs/GaAsP"Strained Superlattice" :
(T. Maruyama et al. Appl. Physics. Lett. 85,13 (2004) 2640)
SL causes shift of Band gap energy wrt GaAs and removal of degeneracy
: Gradient doping

$SLAC/SVT - Superlattice$

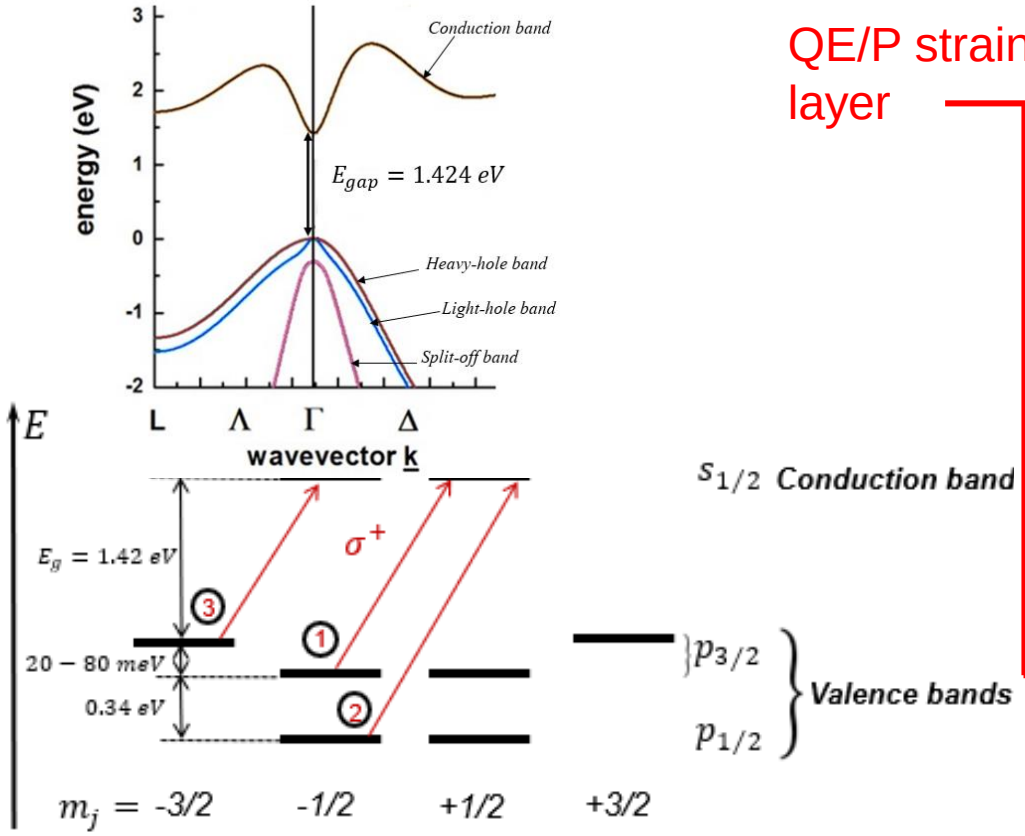
GaAs	5 nm	$p=5 \times 10^{19}$ cm^{-3}
GaAs/GaAsP SL	(3.8/2.8 nm) ×14	$p=5 \times 10^{17}$ cm^{-3}
$GaAsP_{0.35}$	2750 nm	$p=5 \times 10^{18}$ cm^{-3}
Graded $GaAsP_x$ ($x = 0$~0.35)	5000 nm	$p=5 \times 10^{18}$ cm^{-3}
GaAs buffer	200 nm	$p=2 \times 10^{18}$ cm^{-3}
p-GaAs substrate ($p>10^{18}$ cm^{-3})		

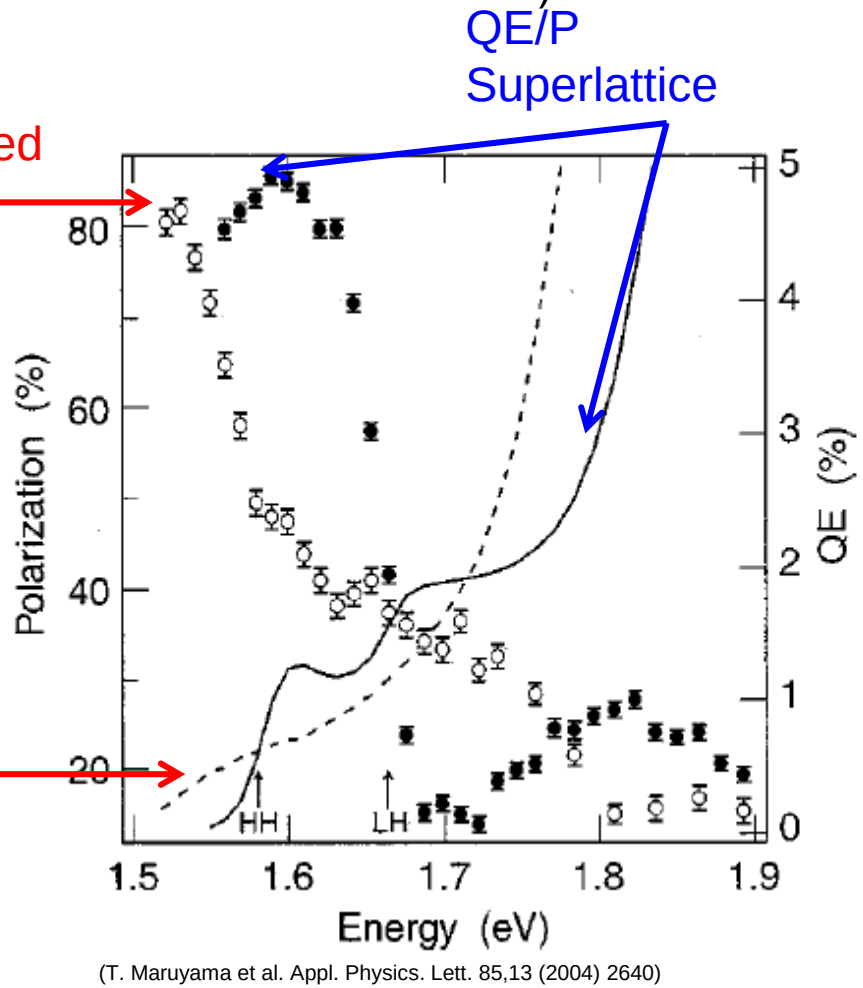
Strained Superlattice-cathode

Strained Superlattice vs "strained layer" :

SL causes shift of Band gap energy wrt GaAs and removal of degeneracy

→ "Band structure engineering" (e.g. frequency double telecom lasers…)

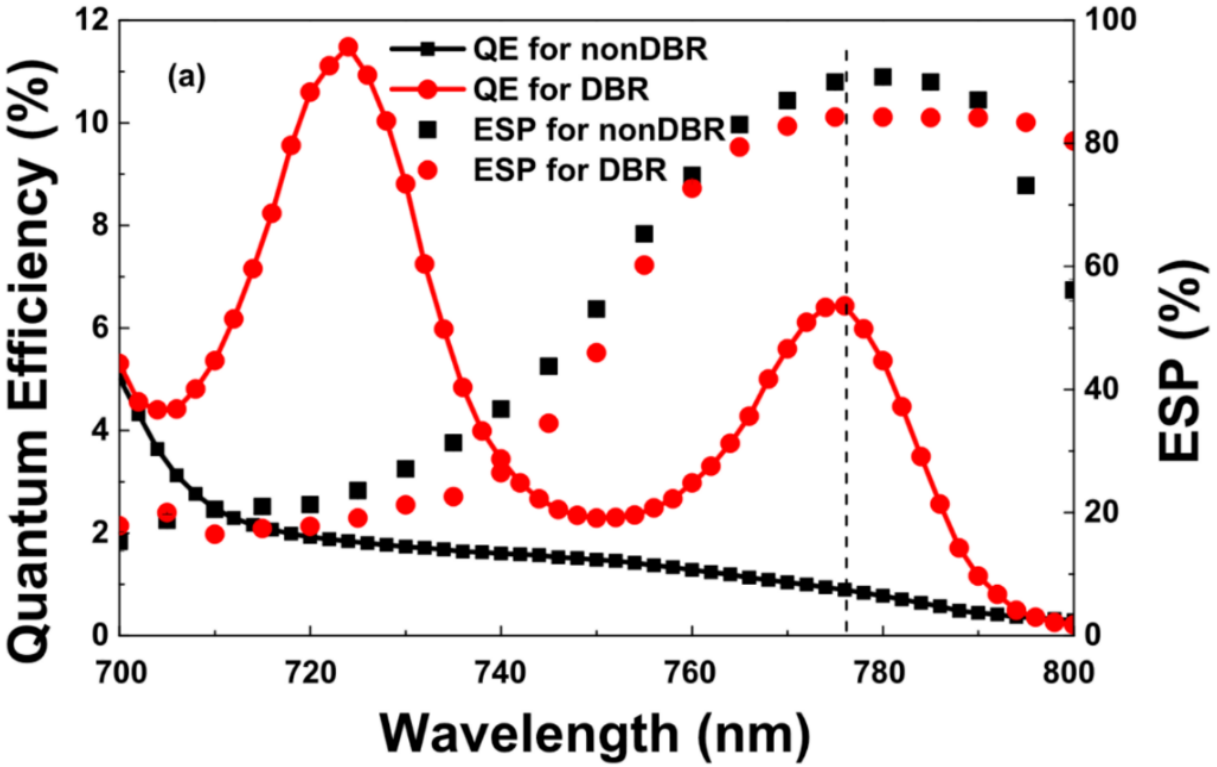




(T. Maruyama et al. Appl. Physics. Lett. 85,13 (2004) 2640)

"Resonant" Strained Superlattice-cathode

JLAB/*SVT – Superlattice*



W. Liu et al. Appl. Physics. Lett. 109,252104 (2016) doi: 10.1063/1.4972180

Absorption enhanced by DBR-Reflector causing active region to be a cavity with enhanced absorption at resonance
→ increased QE. 6% @ 770nm (>30mA/Watt) @ >80% Pol.

Further Advantages of SL

1. Due to low doping in small active region: large mean free path $\lambda \approx d_{active}$
   → fast t<<5ps
2. almost 100% “sink” at surface
   → no tail (see talk by N. Scahill tomorrow)
3. Huge “gradient” doping at surface
   → high current density and/or fluence possible in spite of “photovoltage”
4. (Quite) low transverse energy due to NEA-near band gap operation

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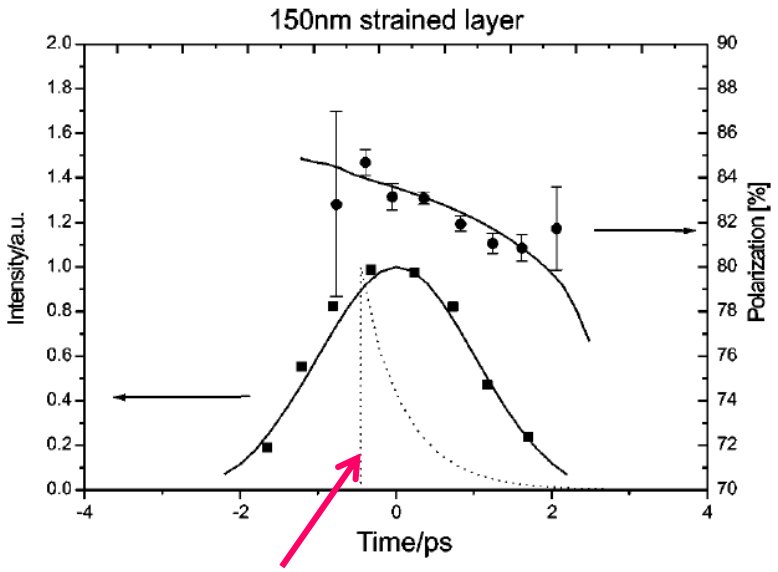
K. Aulenbacher et al. J. Appl. Phys., Vol. 92, No. 12, (2002) 7536



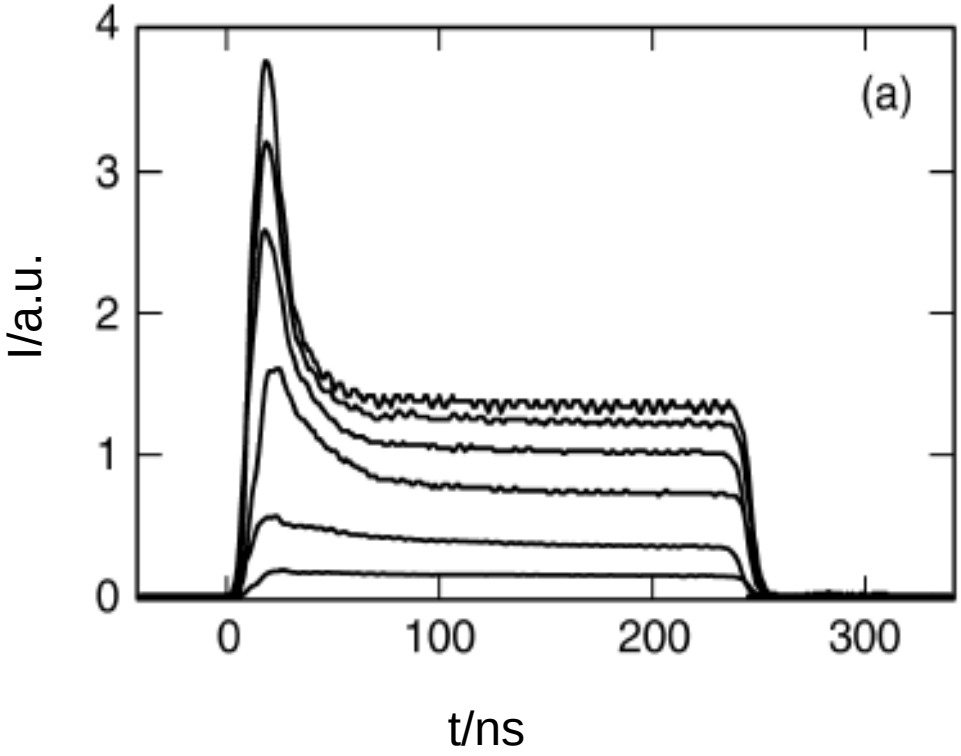
expected response without exp. resolution

Limitations of Spin-polarized Photcathodes

Limitations of Spin-polarized Photcathodes

SLAC pulse-measurements for increasing laser intensity

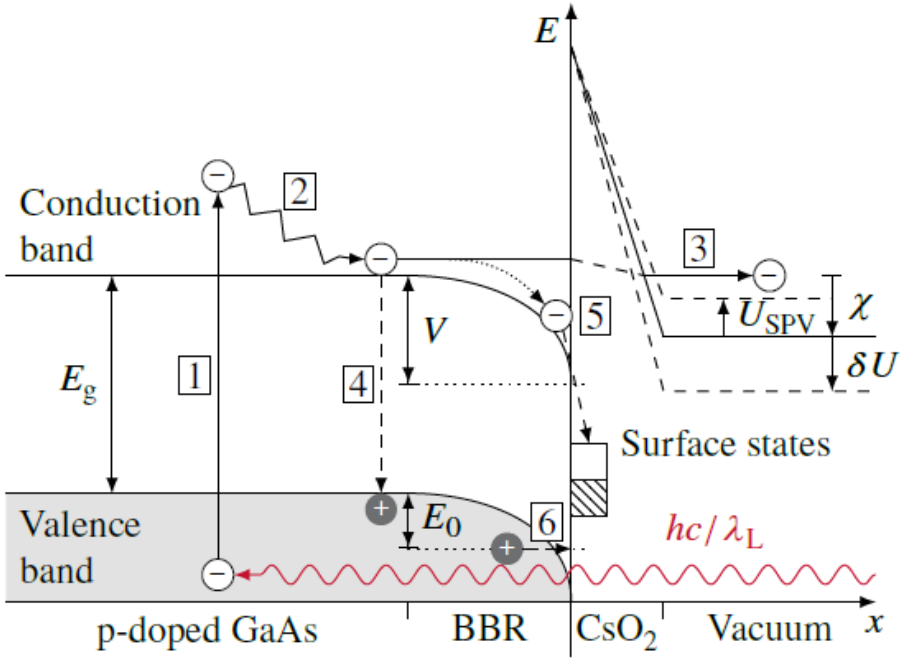
G.A. Mulhollan et al. / Physics Letters A 282 (2001) 309–318



How that?

Limitations of Spin-polarized Photocathodes

Trapped electrons in surface region create “Photovoltage” which reduces NEA
Model: Thermal equilibrium is NEA-state , but current diffusing to surface charges “condenser”, hole current discharges towards equilibrium



Consequence:

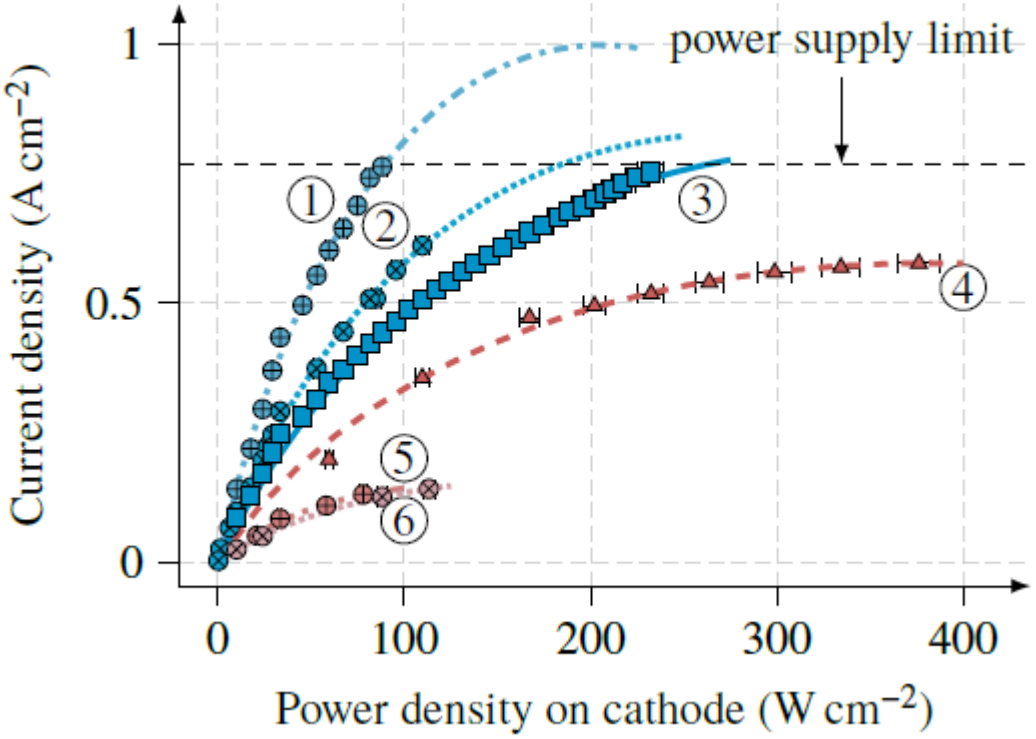
- current density limit in steady state (may be much lower than vacuum space-charge limit)
- typical time constants of τ~ns lead to “charge limit” for bunches <τ
- high fields, high doping level favorable

$$\frac{I_e}{A} = QE_0 \frac{\lambda_L}{hc} \frac{P}{A} \left[1 - \frac{E_0}{\tilde{\chi}} \ln\left(1 + \frac{QE_0}{j_p} \frac{\lambda_L}{hc} \frac{P}{A} \right) \right]$$

Model used by
G.A. Mulhollan et al. / Physics Letters A 282 (2001) 309–318

Limitations of Spin-polarized Photcathodes

S. Friederich et al. IPAC 2019 doi:10.18429/JACoW-IPAC2019-TUPTS011
Fits according to model



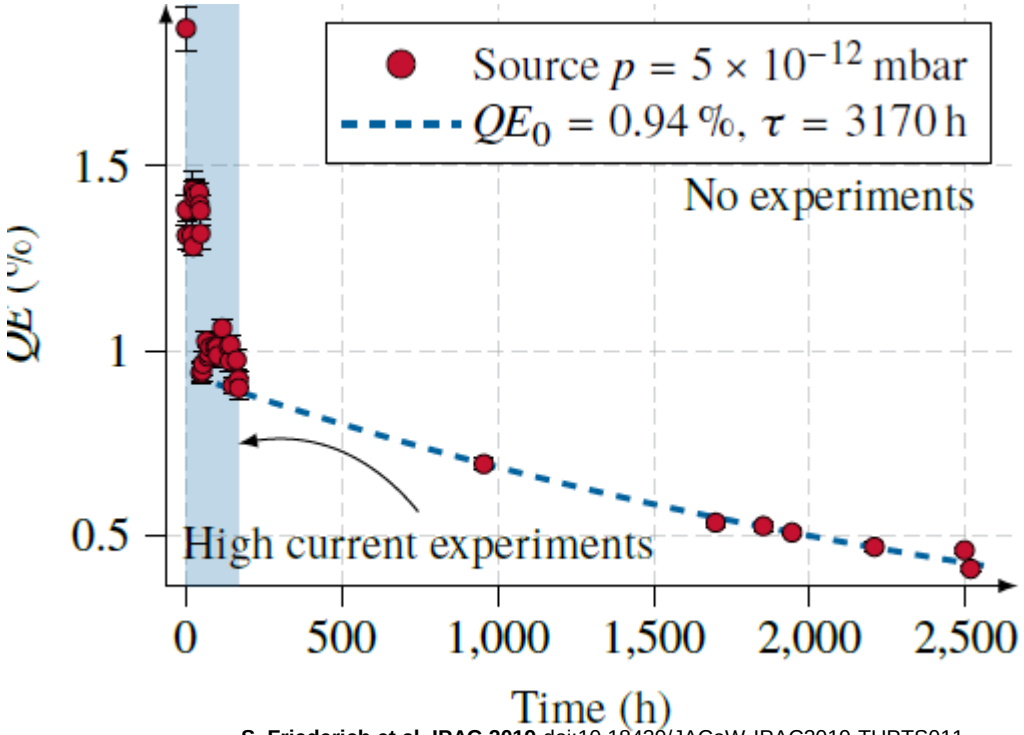
No.	QE_0
①	2.40 %
②	1.55 %
③	1.15 %
④	0.85 %
⑤	0.50 %
⑥	0.39 %

steady state-current measurements with the MESA-source 2.5MV/m, doping level 1-2*10^{19}

For practical purposes it is obviously important **to avoid reduction of q.e.**

Difficulties of Spin-polarized Photcathodes

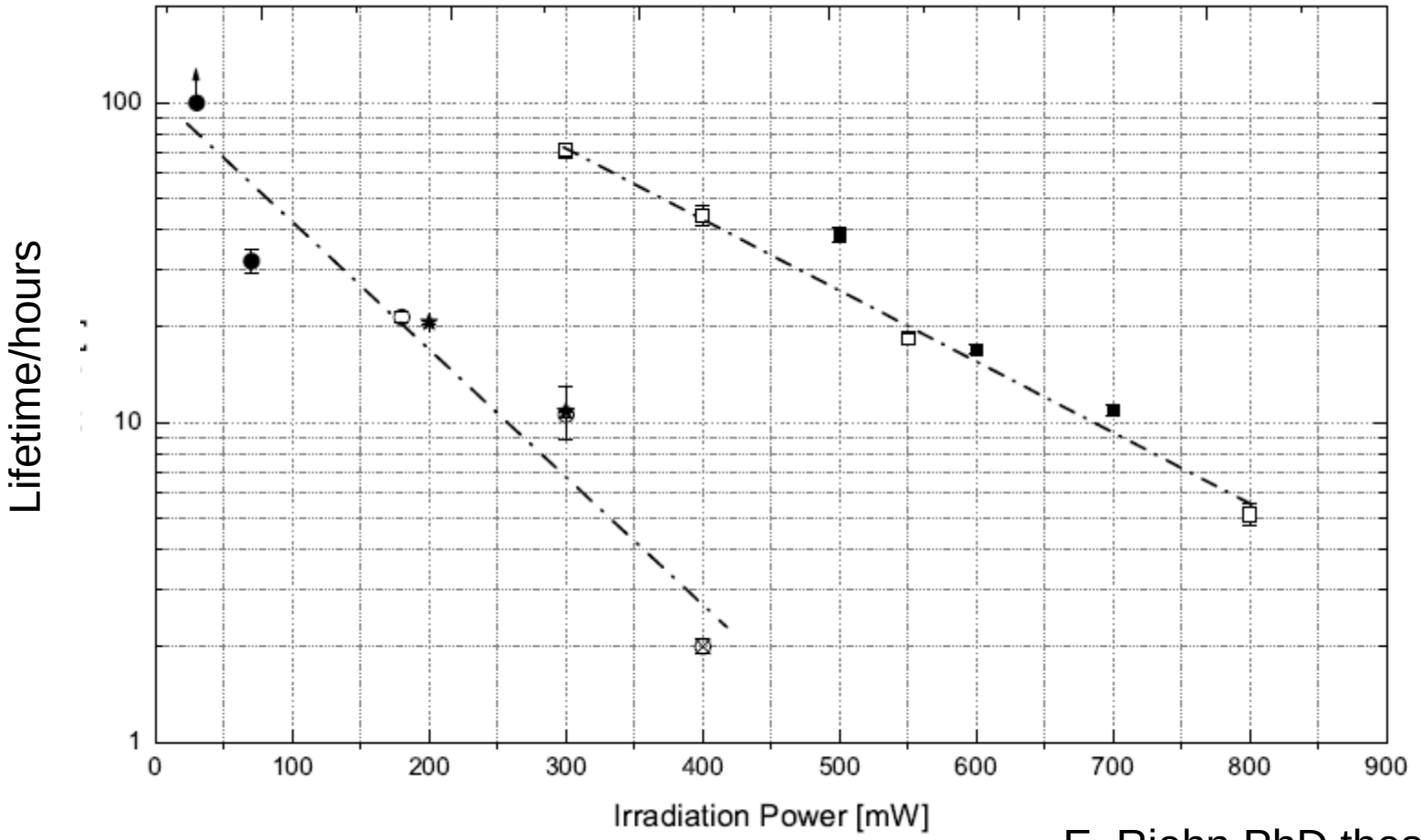
Another illustration from MESA-source operation:



S. Friederich et al. IPAC 2019 doi:10.18429/JACoW-IPAC2019-TUPTS011

Observation : Beam losses are (highly) detrimental.
Field emission counts as beam loss (or worse)
empirical: loss of 100nA reduces lifetime to 100hours
several tricks allow to reduce losses below 10^{-6} in the vicinity of the source
note finite lifetime without operation→ chemical (thermal) decomposition?

Difficulties of Spin-polarized Photcathodes



E. Riehn PhD thesis, Mainz 2011

Good heat conductivity is essential!

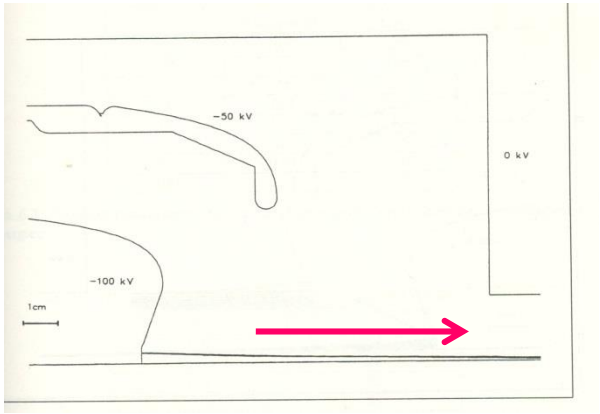
Good example: U. Weigel et. al achieve $\Delta T = 15K/W$

Nuclear Instruments and Methods in Physics Research A 536 (2005) 323–328

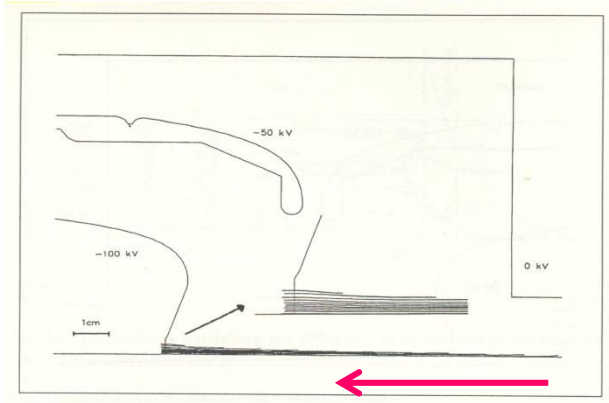
However....

$$\frac{1}{\tau} = \sum_i \frac{1}{\tau_i}$$

Besides the contributions already discussed there is **Ion backbombardment**.

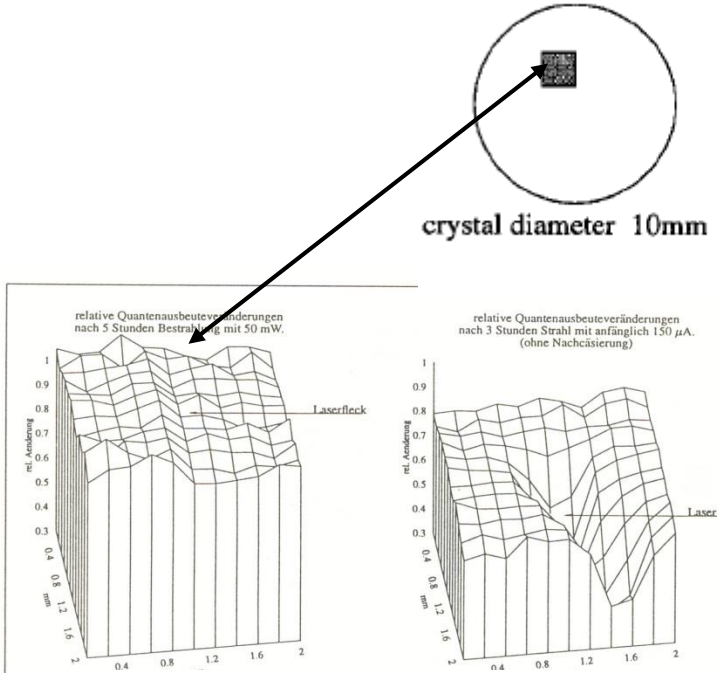


excentrically started Electron-beam



causes back traveling ions

PhD thesis Aulenbacher
Mainz 1994, see also Andresen et al. SLAC pub

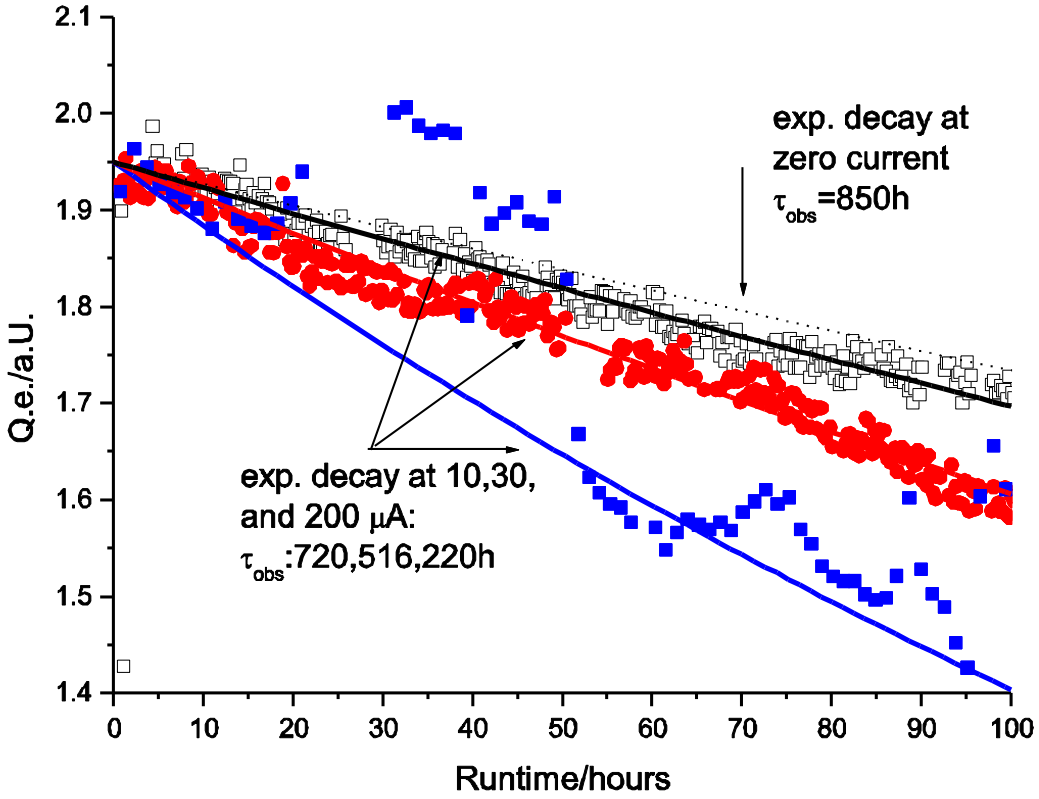


Experimental finding

However....

$$\frac{1}{\tau_{Obs}} = \sum_i \frac{1}{\tau_i}$$

Besides the contributions already discussed there is **Ion backbombardment**. Example from MAMI-beam-times



Charge lifetime:
$C_\tau = I * \tau_{obs} = Q = const!$

Here ~200C !

Fluence lifetime:
$F = C_\tau / A_{beam} \sim 10^5$ C/cm^2

Note: ε_{norm}~100nm in these experiments (150μm Laser spot rms)
→ can Charge lifetime be increased to >>1000C at ε~1μm?

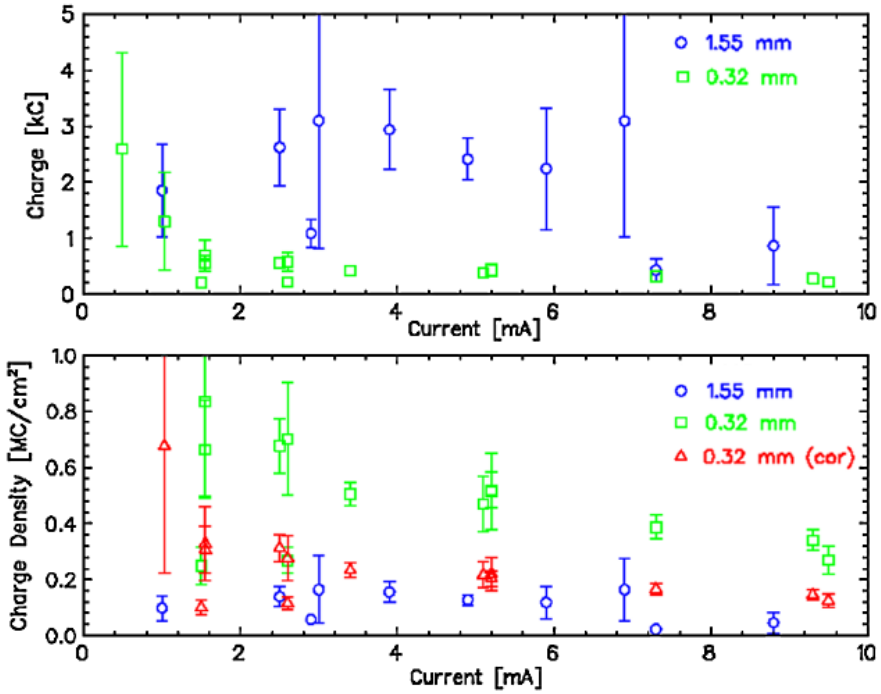
Scaling of Charge lifetime ? ?

Careful experiments have been done at JLAB:
achieved >1000C with green light illumination at about 9mA current
Open question: other contributions become non negligible
(Heating, non-linear transmission loss?)

Note that (non-linear space charge may create halo…)

Charge lifetime

Fluence lifetime



J. Grames et al.
PHYS. REV. ST.-AB 14, 043501 (2011

Conclusion

- GaAs/GaAsP superlattice cathodes offer high polarization (>85%), high QE (>1%) fast response (probably <1ps) and low tail (see N. Scahill's talk tomorrow) as well as low thermal emittance

- they seem well suited to fulfill materials-science applications needs like SUED. However, high voltage limitations have to be taken into account (d.c. fields < 5-10MV/m?)

- The so far achieved charge lifetimes of about 1000 C limit practical current to about 1mA. (Cathode regeneration every 300 hours).

- Projects like ERL based collliders require more R&D to shift the limit: Control of Ion backbombardment, (non-linear) transmission loss and cathode heating are pressing issues.

- SRF gun could improve on most of the problems mentioned

Thank you for your attention!