THE POLARIZED INJECTION SYSTEM FOR MESA

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PRISMA

Work supported by DFG through excellence cluster PRISMA and by BMBF through Projekt „HOPE-II“

Spin 2018, Ferrara September 10th 2018

Motivation: New Experiments at the Mainz energy-recovering accelerator – “MESA”

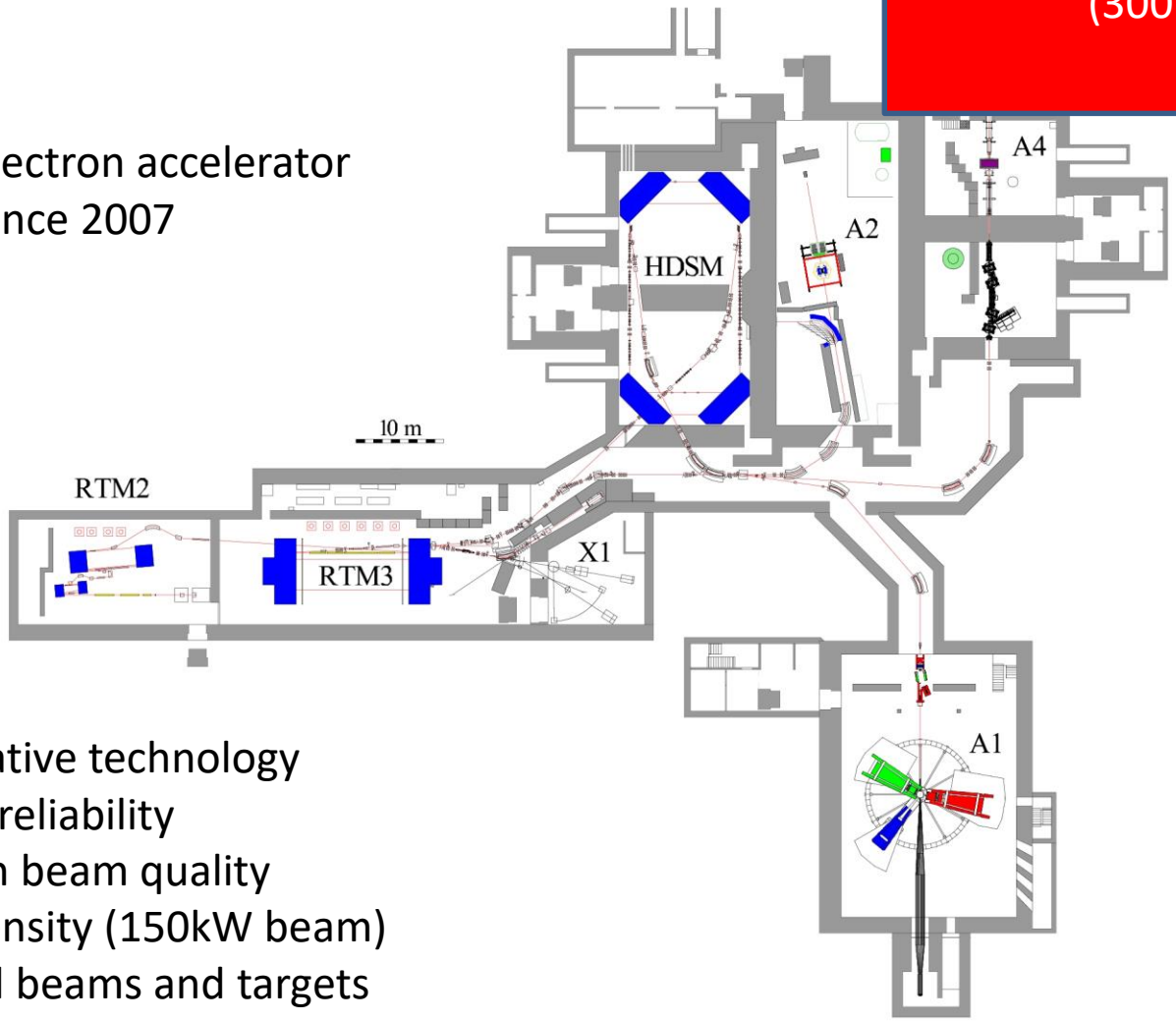
- Exp-1: „P2“
  - a conventional polarized beam experiment pushed to the limit
- Exp-2: „MAGIX“
  - opportunities of a new experimental regime at low energies

Both experiment need high intensity spin-polarized beams with increased demands!

Existing:
The MAMI-C Accelerator

Area for 20GeV
MAMI-D????
(300*300m)

- 1.6 GeV c.w. electron accelerator in operation since 2007



- Conservative technology
  → high reliability
- Very high beam quality
- High intensity (150kW beam)
- Polarized beams and targets

"limits of growth have been reached"

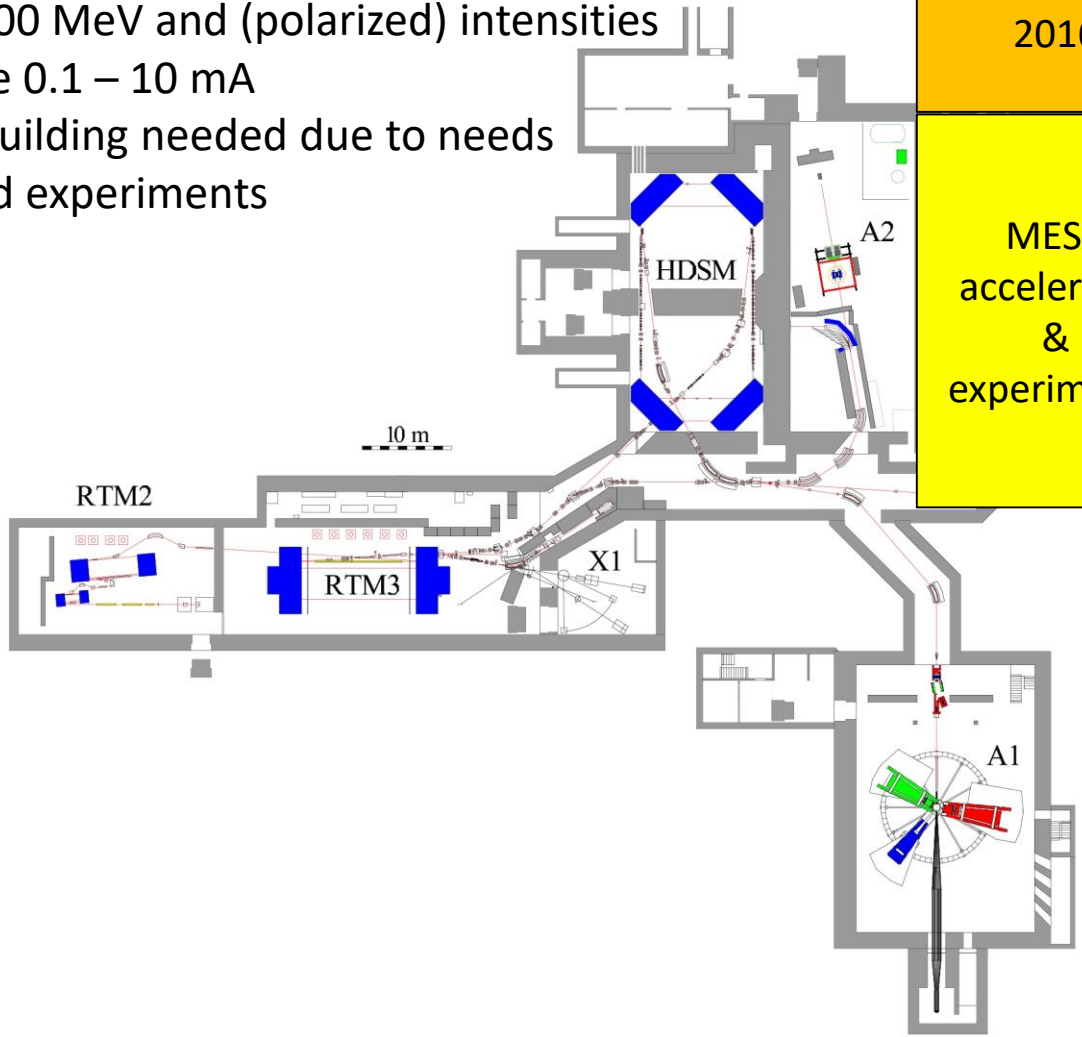
BUILD SMALLER: MESA

(MAINZ ENERGY-RECOVERING SUPERCONDUCTING ACCELERATOR)

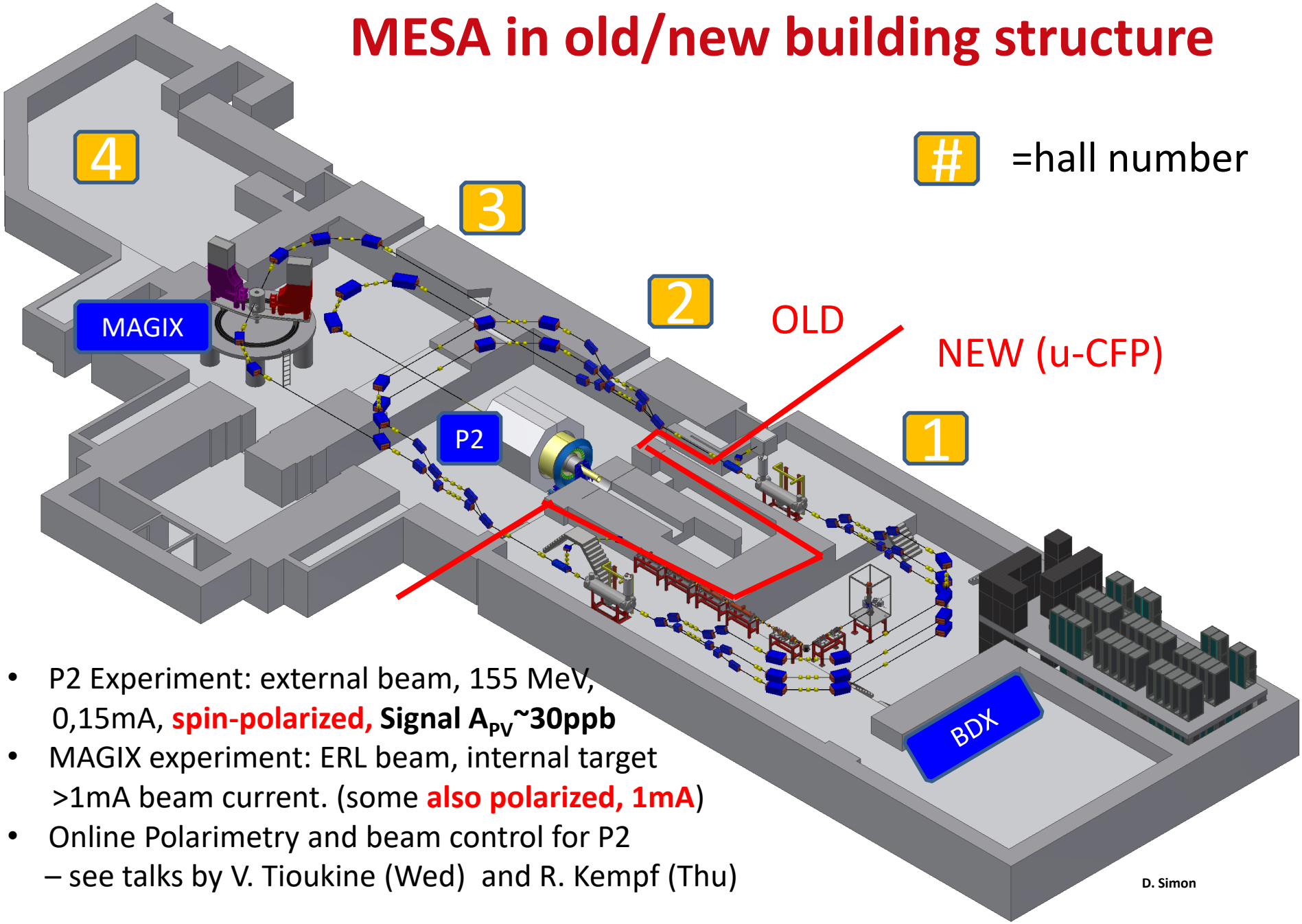
- MESA: E=100 MeV and (polarized) intensities in the range 0.1 – 10 mA
- Extension building needed due to needs of proposed experiments

New exptl. hall (CFP) funded in 2016

MESA accelerator & experiments

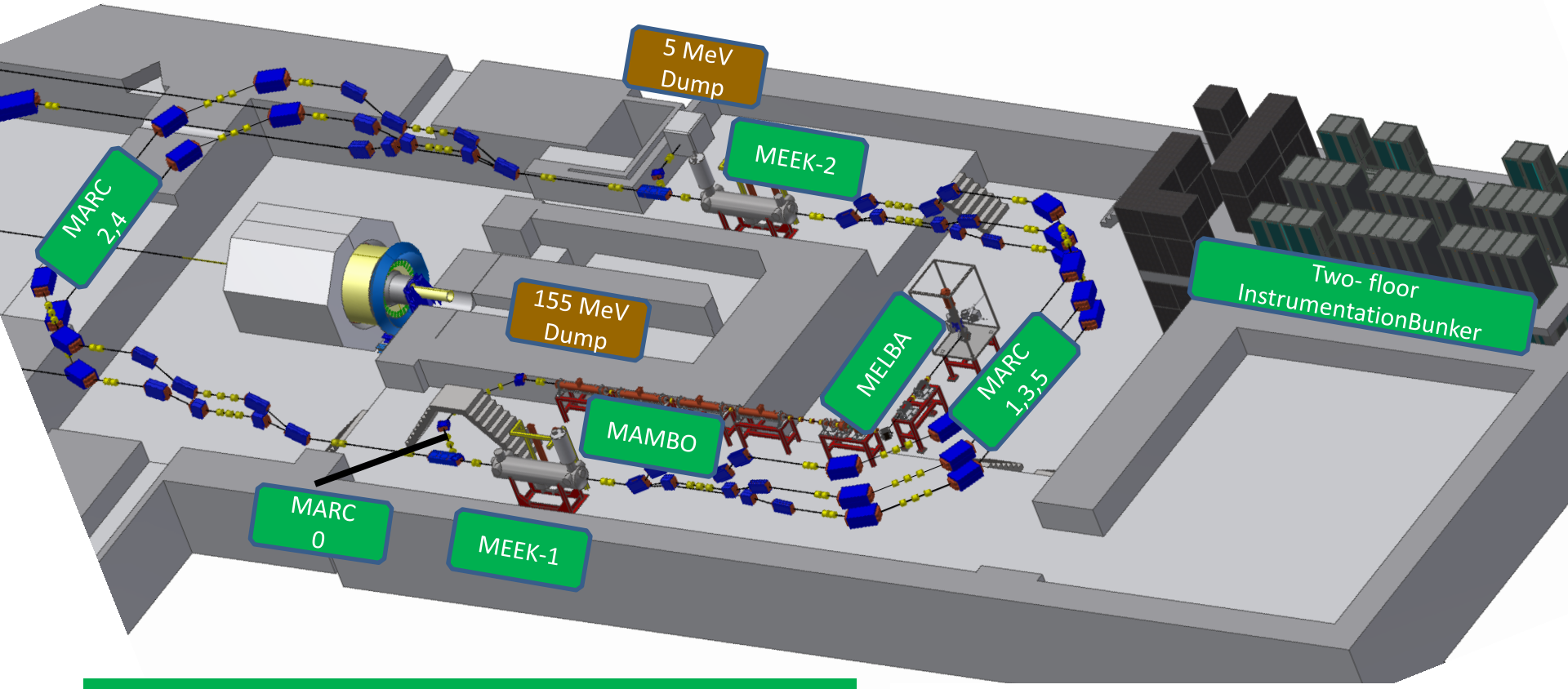


MESA in old/new building structure



- P2 Experiment: external beam, 155 MeV, 0,15mA, **spin-polarized, Signal A_{PV}~30ppb**
- MAGIX experiment: ERL beam, internal target >1mA beam current. (some **also polarized, 1mA**)
- Online Polarimetry and beam control for P2 – see talks by V. Tioukine (Wed) and R. Kempf (Thu)

MESA Accelerator components

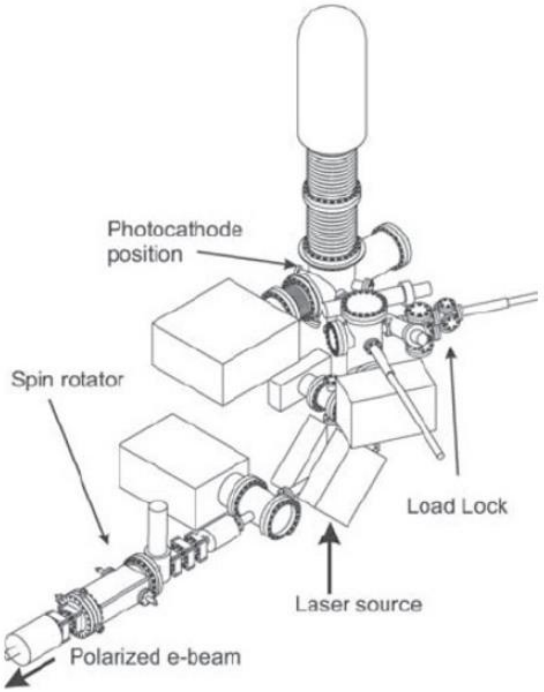


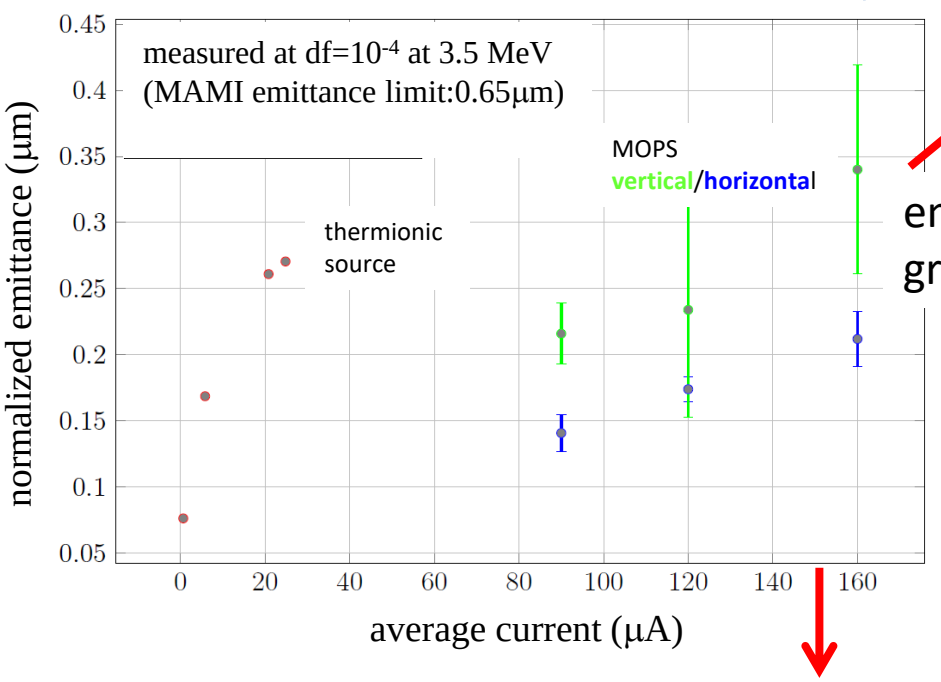
MELBA: MEsa Low –energy Beam Apparatus
MAMBO: MilliAMpere Booster
MEEK: Mesa Elbe-Enhanced-Kryomodule
MARC: MESA (recirculation) ARC

MELBA& MAMBO will be tested until end 2018 in available buiding
MEEK‘s will be tested in new testing hall
MARC‘s cannot be installed before 2020

MAMI Operational Polarized Source (MOPS): A starting point for MESA

- Beam Quality (measured after Injector) is o.k. for P2,
- but emittance increase due to gun and injection system properties
- →Source/injection modifications required for 1mA (or more) at MAGIX





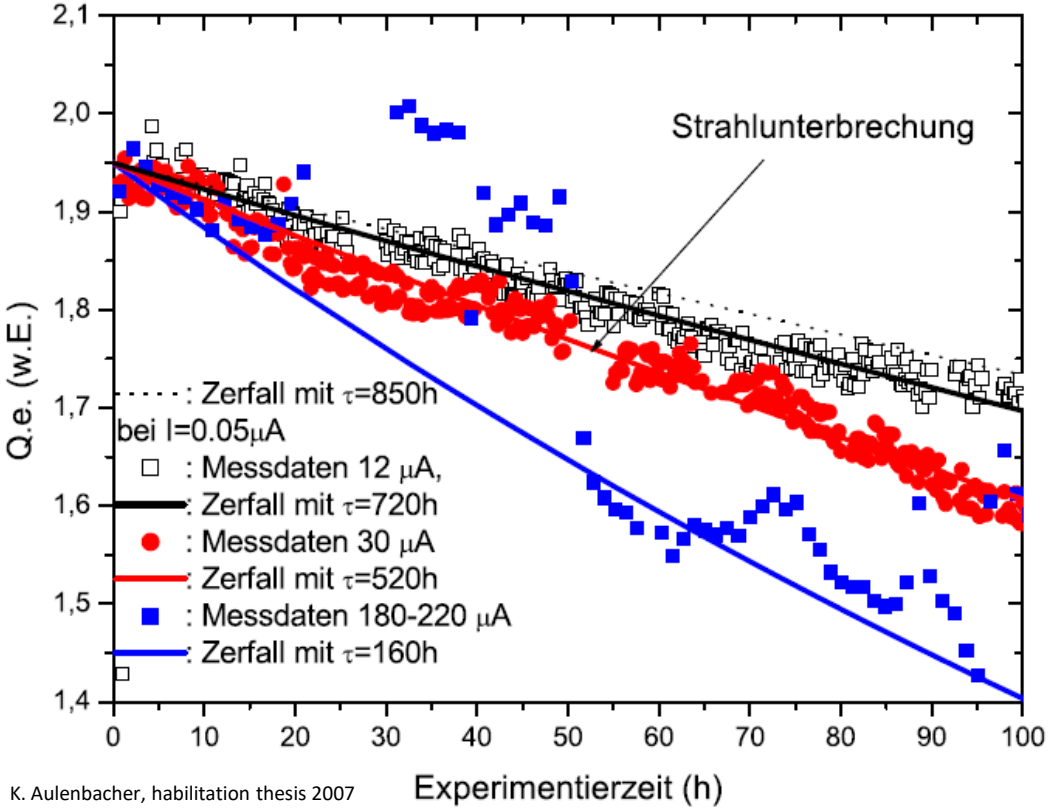
ε_{Limit}=0,65µm

emittance growth

P2 beam current

S. Heidrich, PhD thesis (2018)

MOPS cathode lifetime



K. Aulenbacher, habilitation thesis 2007

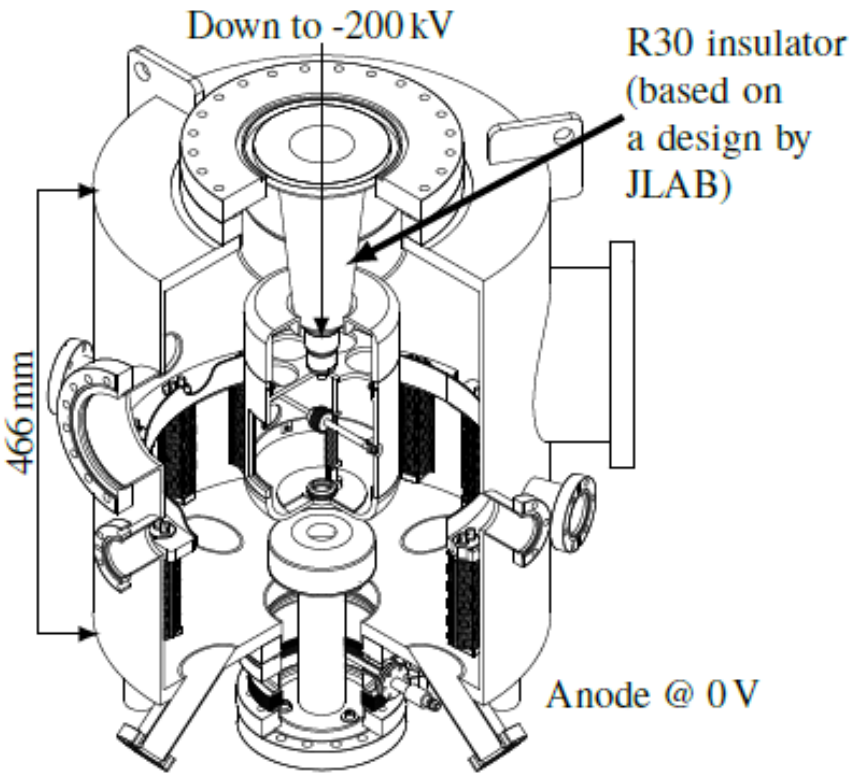
Plot shows results from
- GaAs based superlattices (I≤30μA)
- bulk GaAs (I=200μA result)
- operated at 800nm.
- Spot size on cathode σ~0.1mm

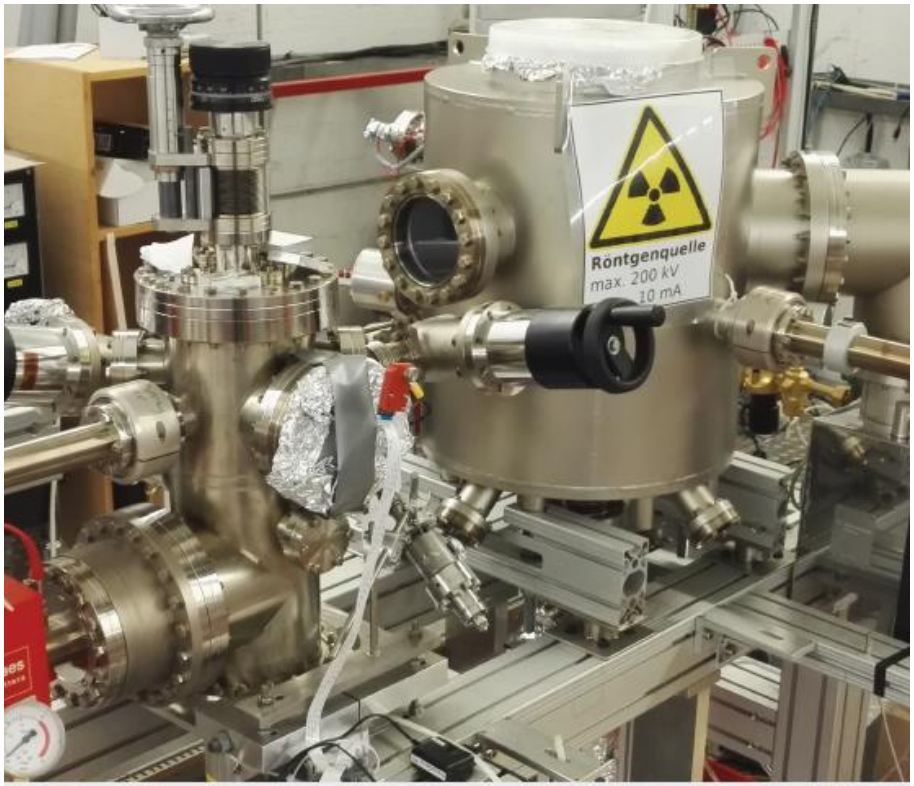
Analysis of results shows:

- Operation with HV on, zero current (i.e. 50nA) τ=850 hours
- Current dependent lifetime term: „Charge lifetime“ is 200 Coulomb .

Note: P2 experiment operates at 150μA (**Cathode heating problem must be solved!)**
→P2 needs 13C/day
→ ~Two weeks continuous operation possible, fits well to planned operation mode of MESA
→ Cathode exchange <3hours→ possible to operate at 1mA polarised average current, but lifetime improvement desirable!

New inverted source „STEAM“

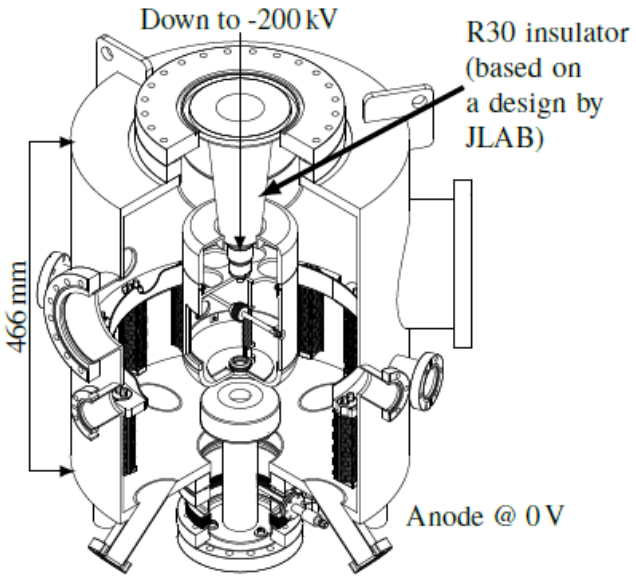




Research project: Small **T**hermalized **E**lectron-source **A**t **M**ainz (STEAM)

- ❖ Inverted source (JLAB inspired)
- ❖ Technical improvements wrt MOPS : less surface area, better bakable, higher pumping speed, magnetic shielding easier

New inverted source „STEAM“

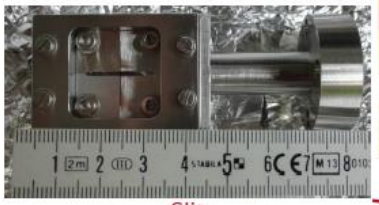


S. Friedrich PhD thesis

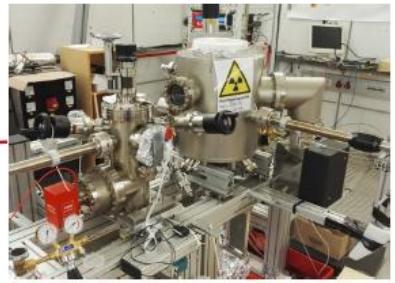
- Higher cathode extraction field at 100kV (MOPS:E=0.9MV/m, STEAM:E=2.5MeV/m)
- At fixed Voltage and emittance, space charge saturation current is ~7 *higher in STEAM

  $I = U^{3/2} \cdot Perv \sim p_o\ U^{\frac{3}{2}} \left(\frac{r_{Cath}}{d}\right)^2 = p_o\ \ U^{\frac{-1}{2}} r_{Cath}^2 (E)^{\ 2}$ → several mA possible
- 200kV operation: (further increase of current by * 2.8 →> 10mA possible
- Pressure $5*10^{-10}$ Pa (Extractor gauge measurement).
- Field emission sets in at 140 kV (no processing so far)
- Tests at 100keV beam energy since 12/2017 with first part of injection system MELBA (**M**ESA **L**ow-energy **B**eam **A**pparatus)

Status of MELBA


Slit


Double solenoid

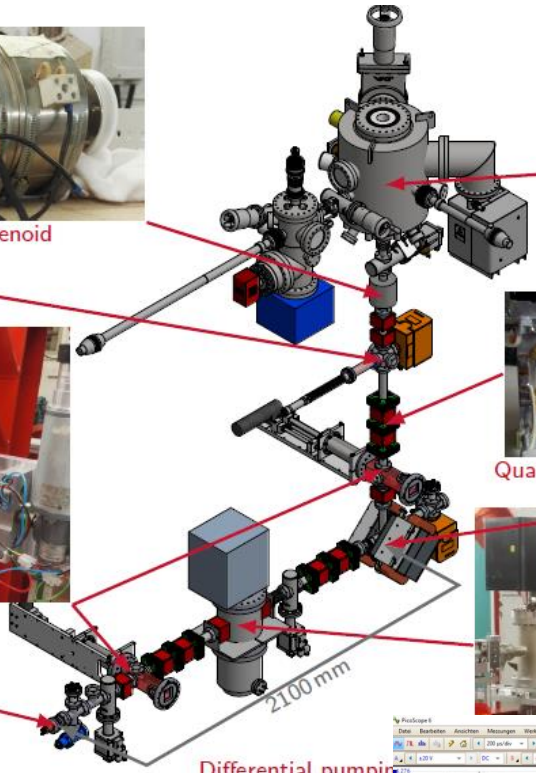

STEAM and preparation chamber


Quadrupol triplets

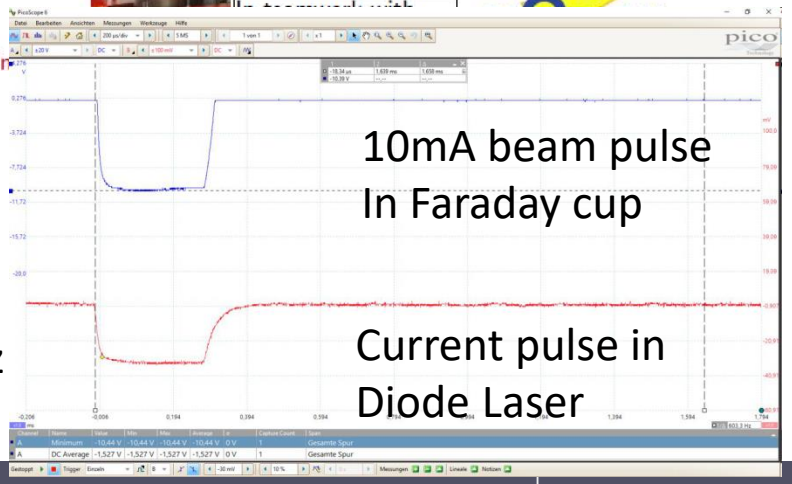

Alpha magnet


Scanner


Beam dump



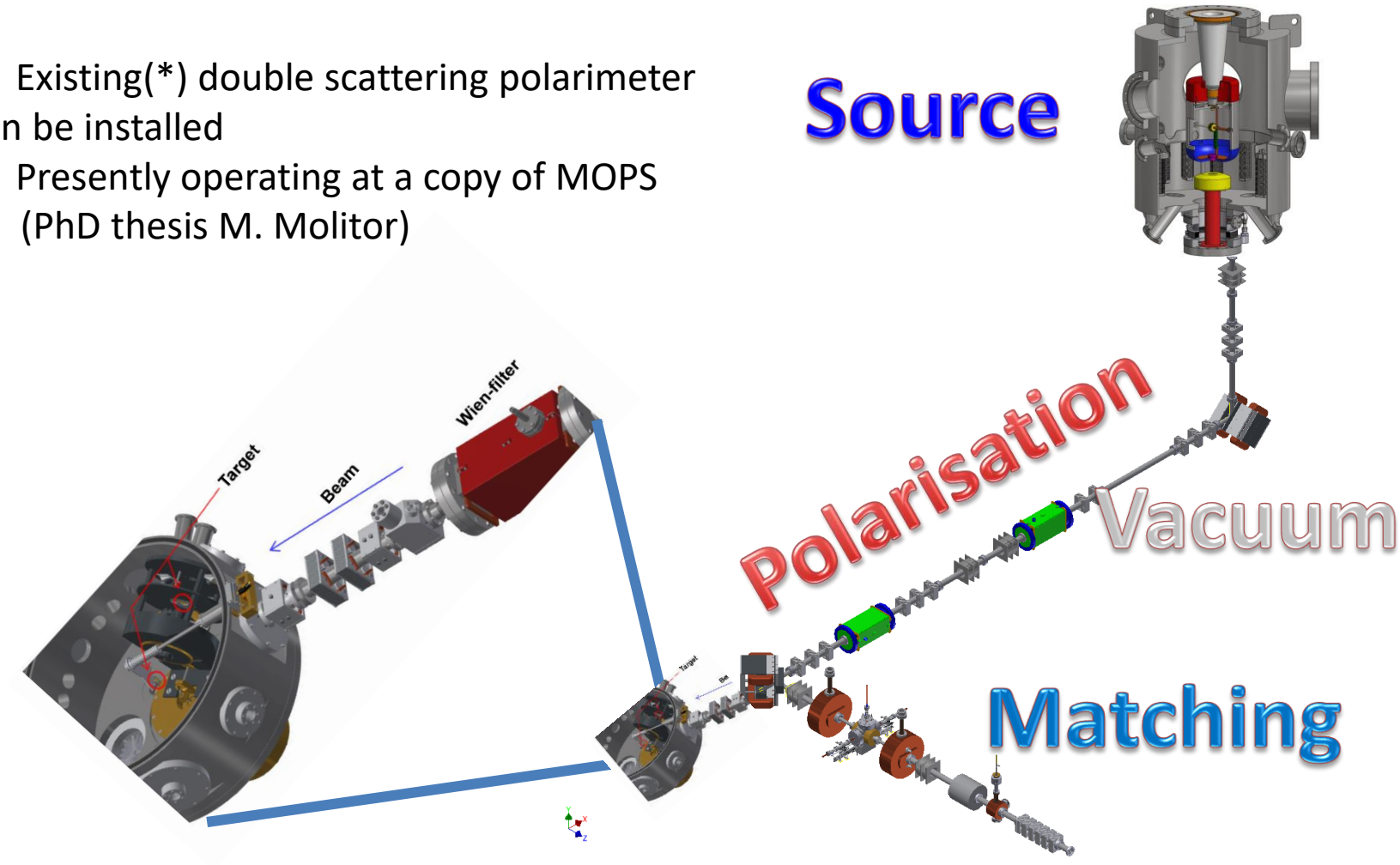
Differential pumpin



S. Friederich, C. Matejcek,P. Heil (3*PhD thesis)
10mA beam demonstrated! (02/09/2018)
Beam diagnostics:
(using modulated 800nm d.c.-Laser, 300µs pulses), 2Hz
→ Emittance investigations with wires & screens

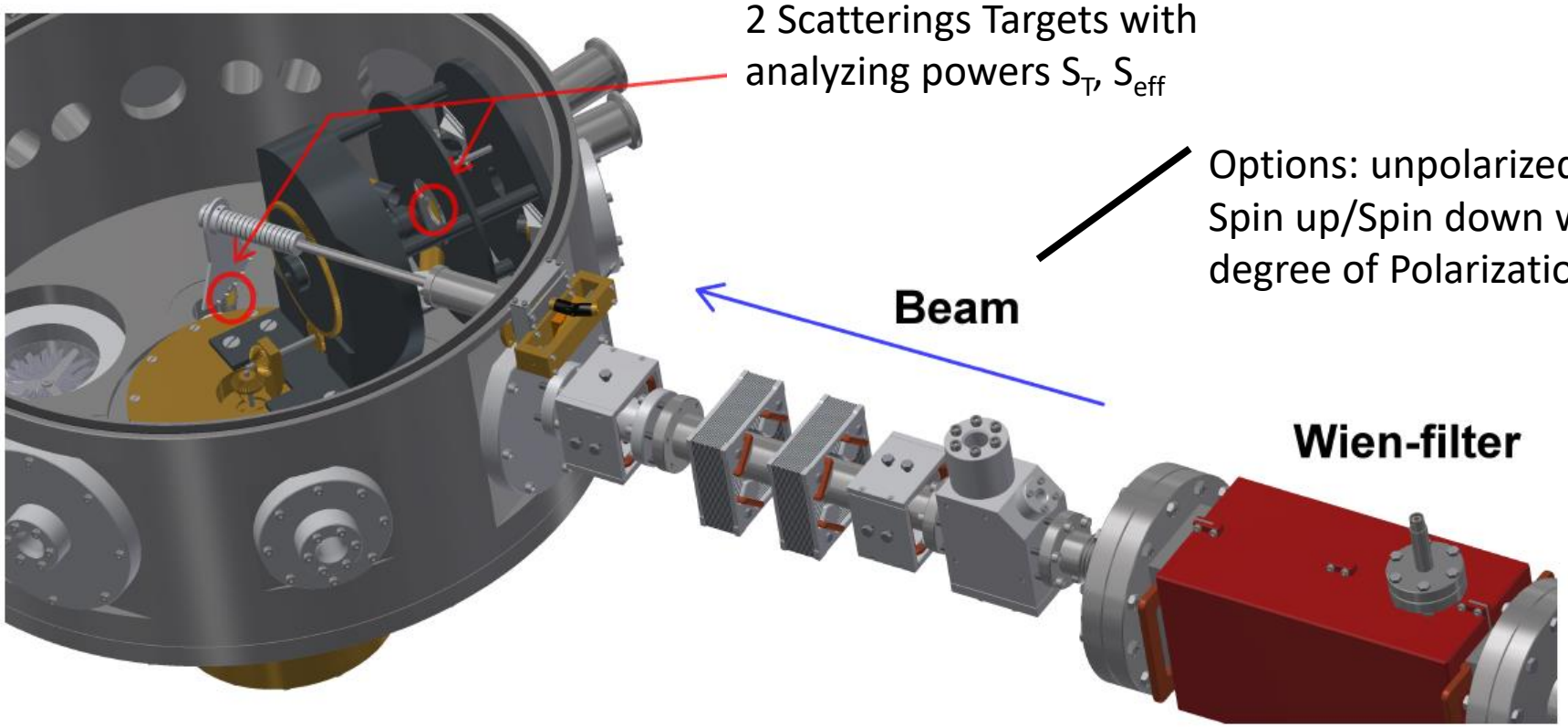
Future Polarisation measurement at MELBA with the double scattering polarimeter (DSP)

- Existing(*) double scattering polarimeter can be installed
- Presently operating at a copy of MOPS (PhD thesis M. Molitor)

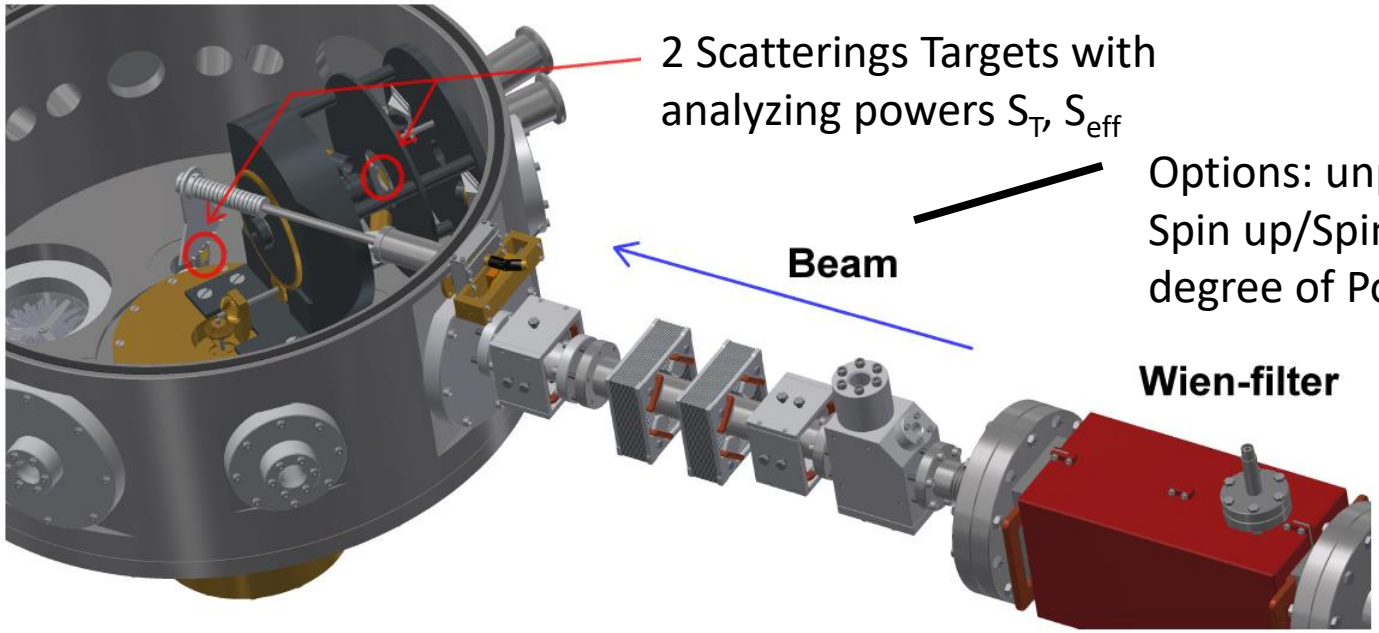


(*) Gift from uNiversity of Münster/Germany

Features of the DSP



Calibration measurements



Single scattering

$$A_2 = P_0 S_{eff}$$

$$A_5 = P_0 S_T$$

Unpolarized double scattering asymmetry

$$A_1 = S_T S_{eff}.$$

Vertical polarization after first scattering with pol beam

$$P_\uparrow = \frac{S_T + \alpha P_0}{1 + P_0 S_T}$$

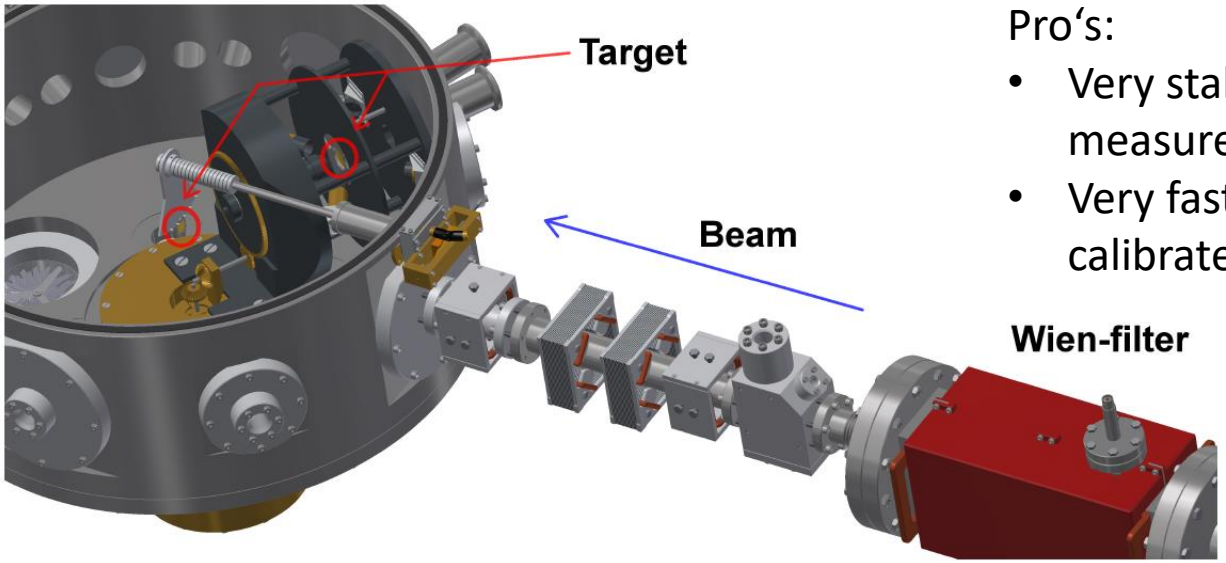
$$P_\downarrow = \frac{S_T - \alpha P_0}{1 - P_0 S_T}.$$

Double scattering Asymmetry with pol. beam

$$A_3 = P_\uparrow S_{eff}$$

$$A_4 = P_\downarrow S_{eff}$$

Results from Calibration measurements



PhD thesis M. Molitor

Pro's:

- Very stable/reproducible measurements
- Very fast measurements (once calibrated)

$$S_{eff,unpol} = 0.300 \pm 0.001$$
$$S_{eff,1} = 0.295 \pm 0.001$$
$$S_{eff,2} = 0.288 \pm 0.002$$

Stat. Errors!

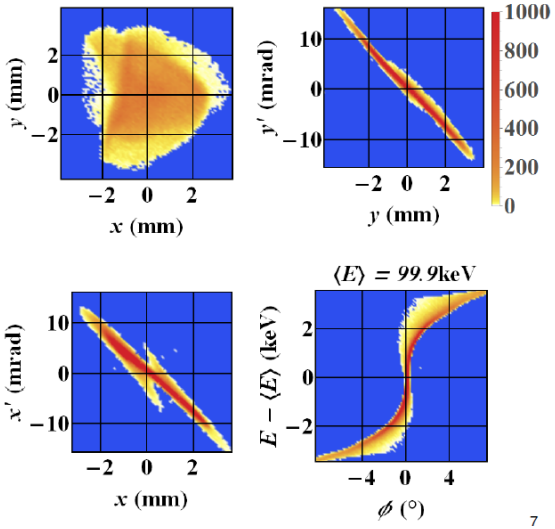
CON'S

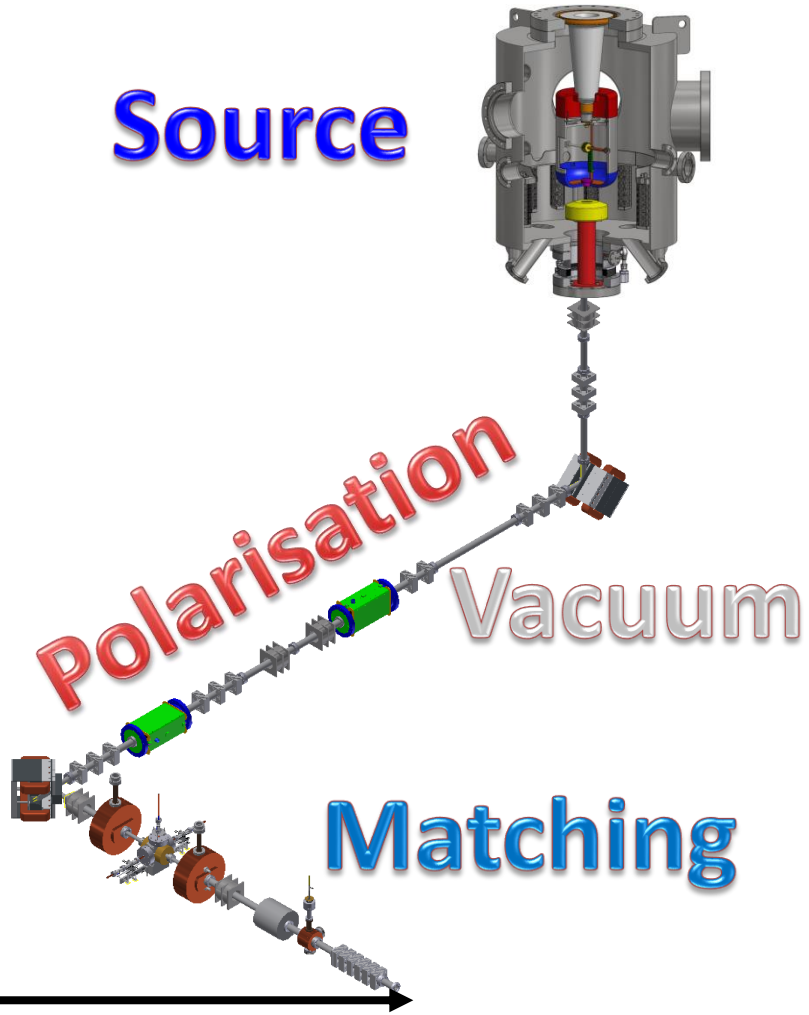
- Different methods do NOT give the same result (by 4%)
- Analyzing power by double scattering not consistent with foil thickness extrapolation method (by ~10%)
- No online capability
- Only low currents

Beam quality at injection -simulation

Simulations
Phase space 1.3 mA

- $x_{rms} = 1.429\,\text{mm}$
- $y_{rms} = 1.442\,\text{mm}$
- $x'_{rms} = 5.887\,\text{mrad}$
- $y'_{rms} = 5.854\,\text{mrad}$
- $\epsilon_{x,rms,n} =$ 0.576 mm mrad (0.114 mm mrad)
- $\epsilon_{y,rms,n} =$ 0.484 mm mrad
- $\Delta\phi_{rms} = 2.044°$
- $\Delta E_{kin,rms} =$ 1.777 keV
- 0 % loss of particle



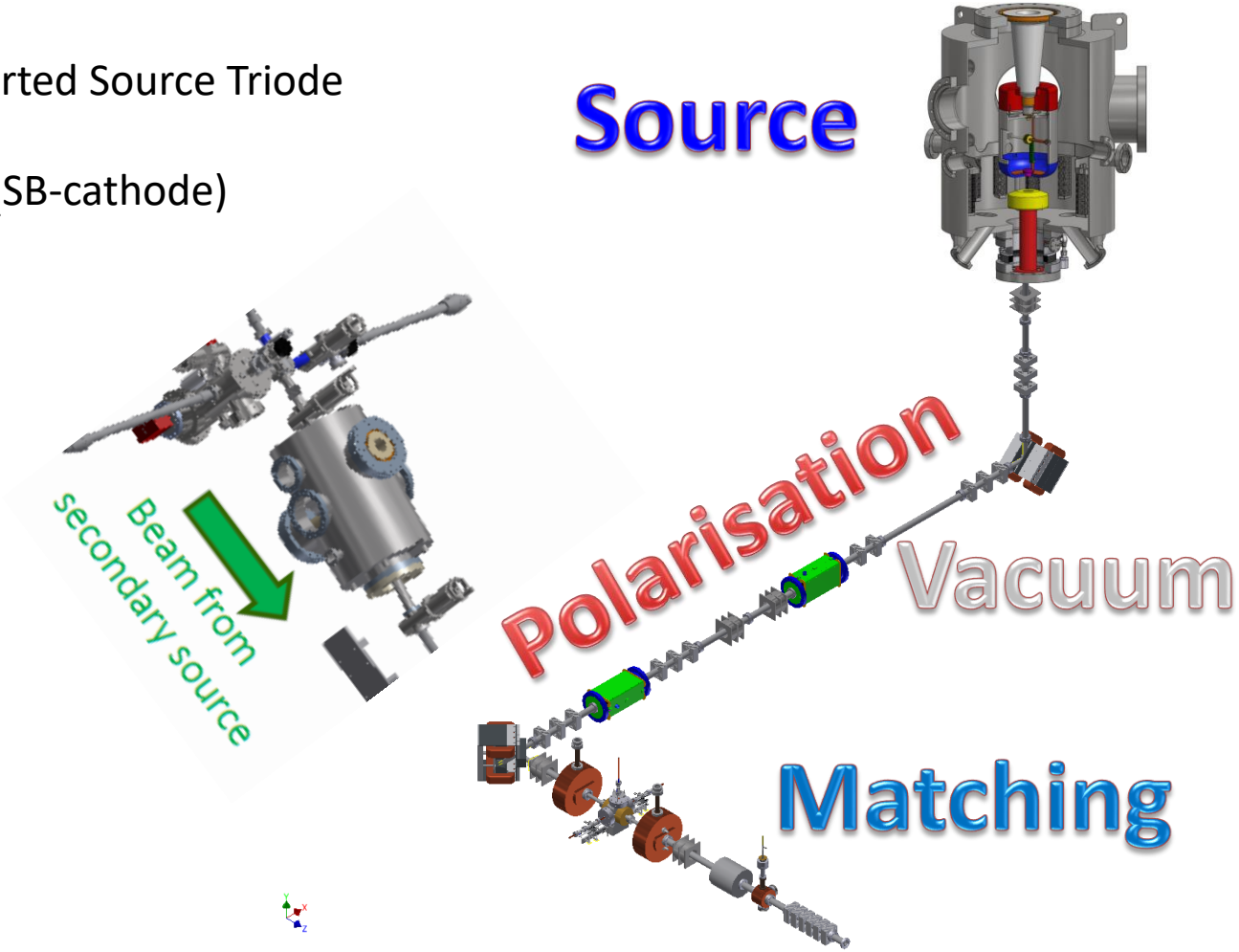


PhD work Chr. Matejcek, P. Heil
→ goal: experimental confirmation

From Steam to MIST
- A source for beams with I >>1mA

Work by M. Dehn & L. Hein

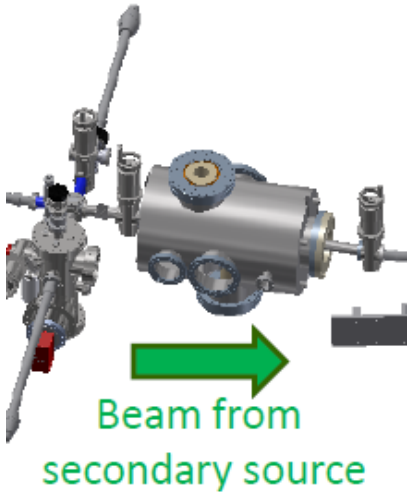
MIST = MESA Inverted Source Triode
200kV, 5 MV/m
(unpolarized, KCs_2Sb-cathode)

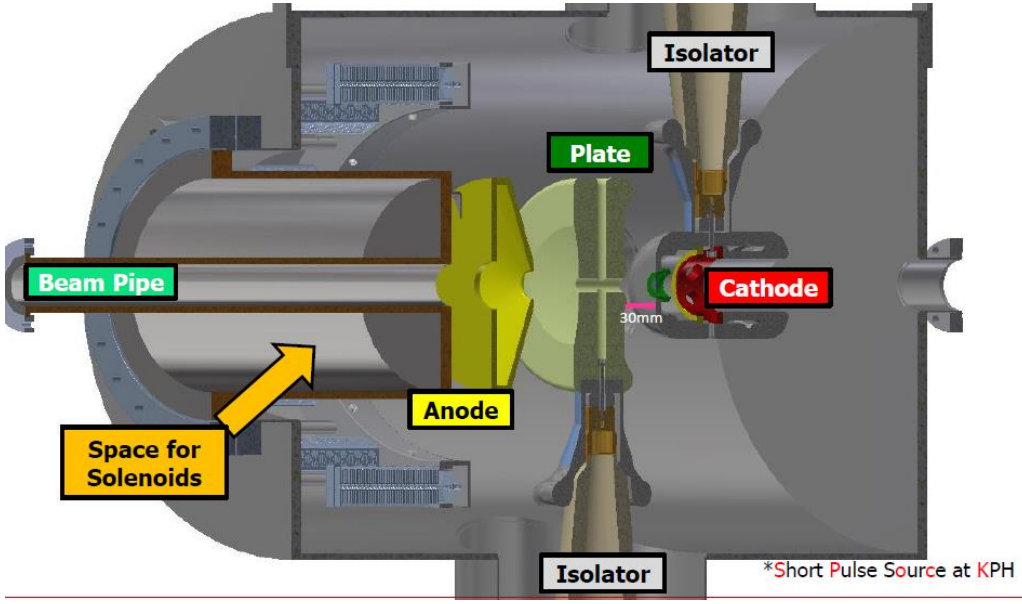


Work by M. Dehn & L. Hein

Why triode?

MIST = MESA Inverted Source Triode
200kV, E=1-5 MV/m
(to begin with, unpolarized, KCs_2SB-cathode)





- The 200kV triode will allow to control the field level at the cathode-electrode in order to avoid field emission
- Up to 150 kV postacceleration (source on hot deck) → 350KV

→ Will allow more than 10mA with good beam quality

- In principle also polarized operation possible (150+200kV postacceleration)

→ Project started, hardware set-up starts 2019

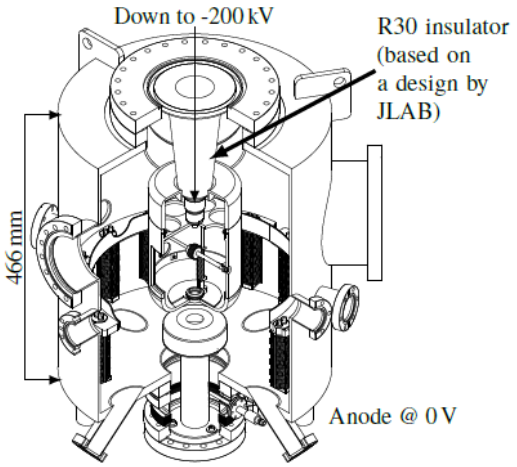
Conclusion/Outlook

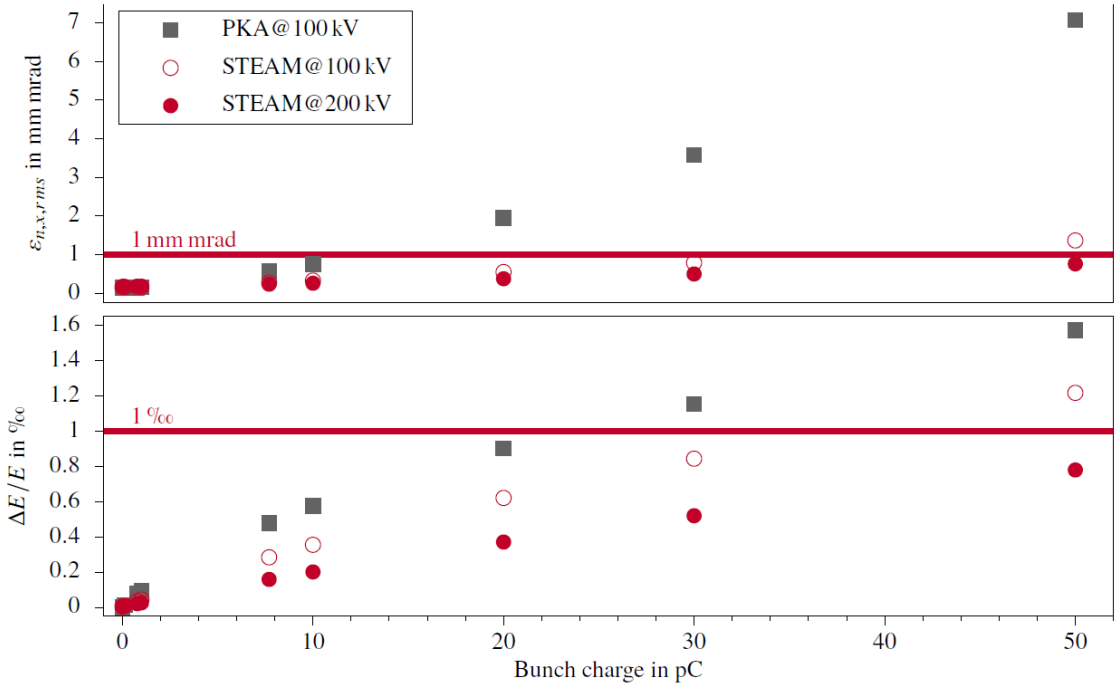
- MESA is adressing fundamental physics questions by using modern accelerator physics techniques, in particular energy recovery
- Good perspective to use ~1mA polarized beams for MAGIX internal target experiment
- Injector system MELBA under test, 10mA beam transport achieved,
- beam quality investigations ongoing
- Double scattering polarimter already useful…
- but systematic effects not yet under control, investigations ongoing
- Short injection for 10 mA beam at MESA foreseen
- new triode source is under design

Thank you for your attention!

Supplementary transparencies

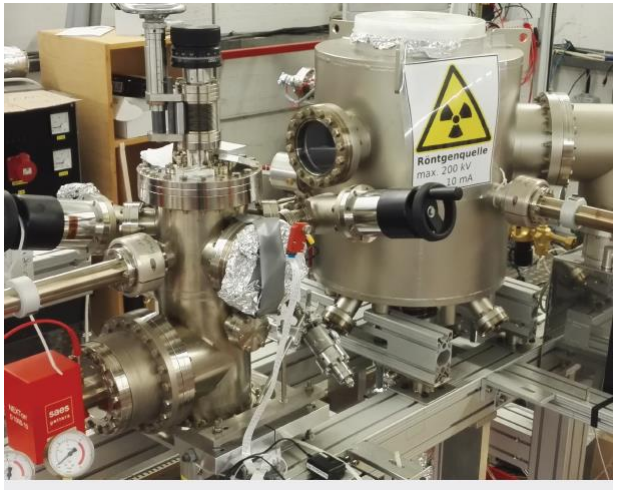
Polarisation: From EB to ERL mode





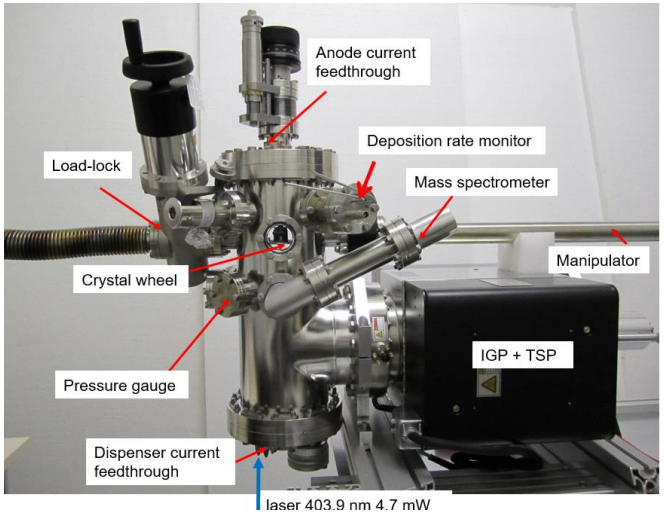
Small **T**hermalized **E**lectron-source **A**t **M**ainz (STEAM)

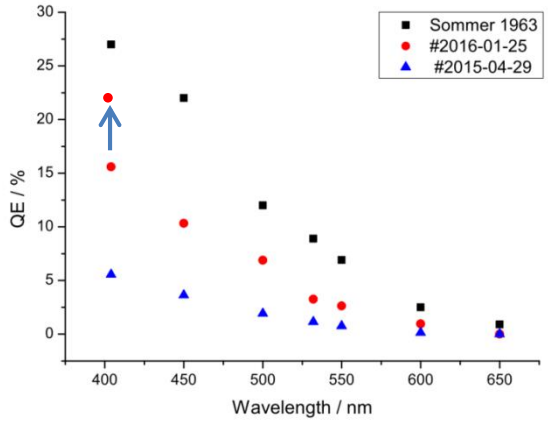
- New approach: inverted source (JLAB)
- Higher cathode extraction field at 100kV
- Potential for 200kV operation
- Can be be used instead of MOPS,
- if succesful STEAM will become MIST (MESA Inverted Source in Thermalized Mode)



Assembly of source STEAM & first part of beamline "MELBA" has started

Photocathode „factory"





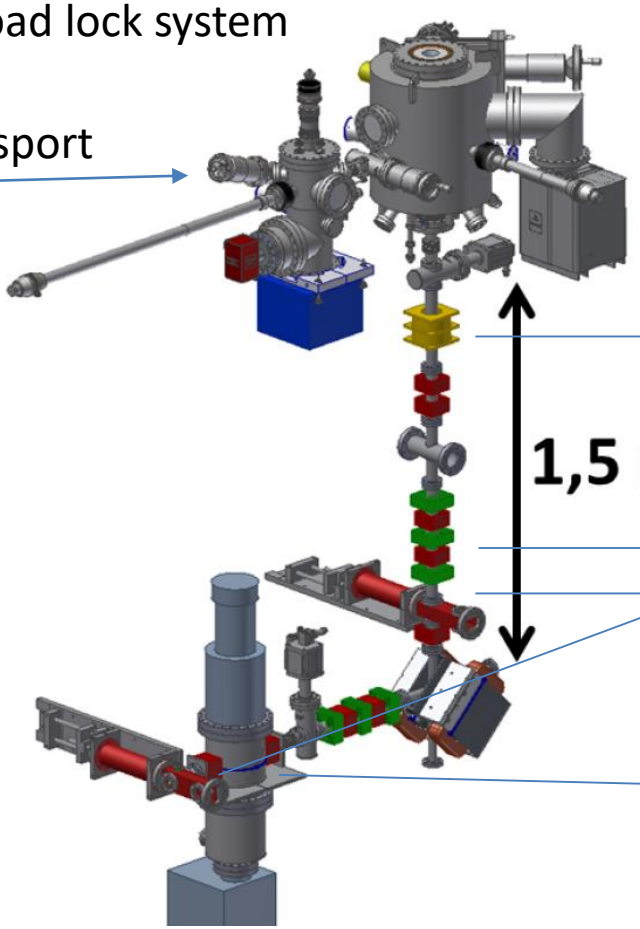
V. Bechthold

Load lock system

transport

Electron Source „STEAM"

S. Friederich



- **Robust Photocathodes with QE=22% (60mA/Watt) at 400 nm: available! → 1mA can be generated with laser from a blue ray disc player**

MAGIX-impact on beam?

TArget **I**nduced ha**L**o (TAIL)
Poster by B. Ledroit

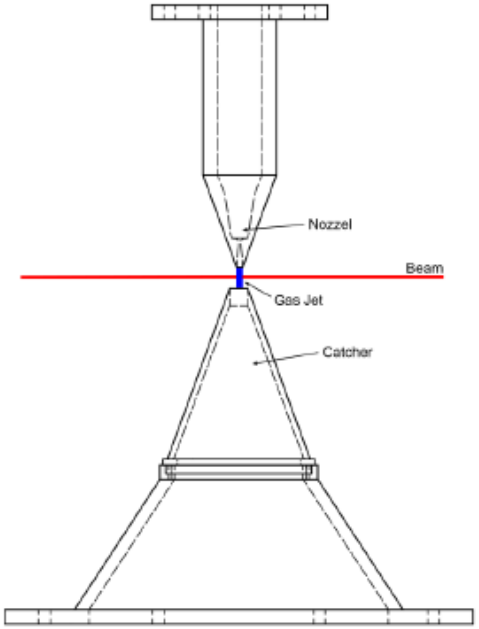
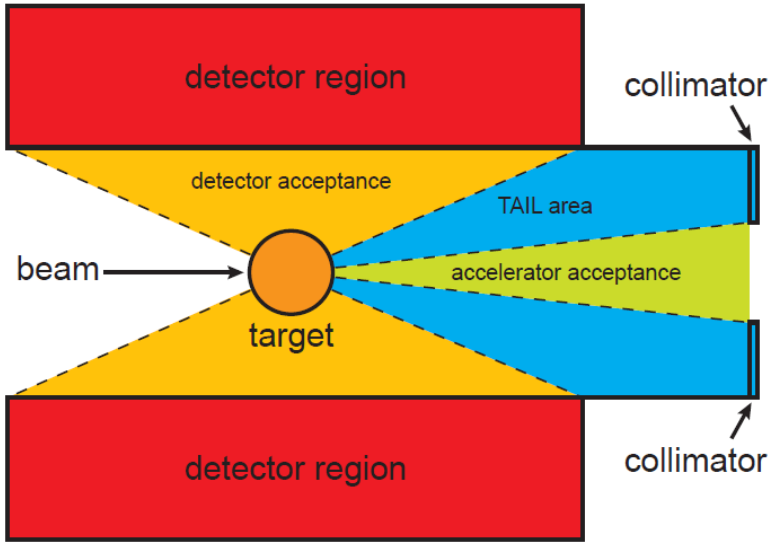


Figure 1: Schematic drawing of the MAGIX gas target.

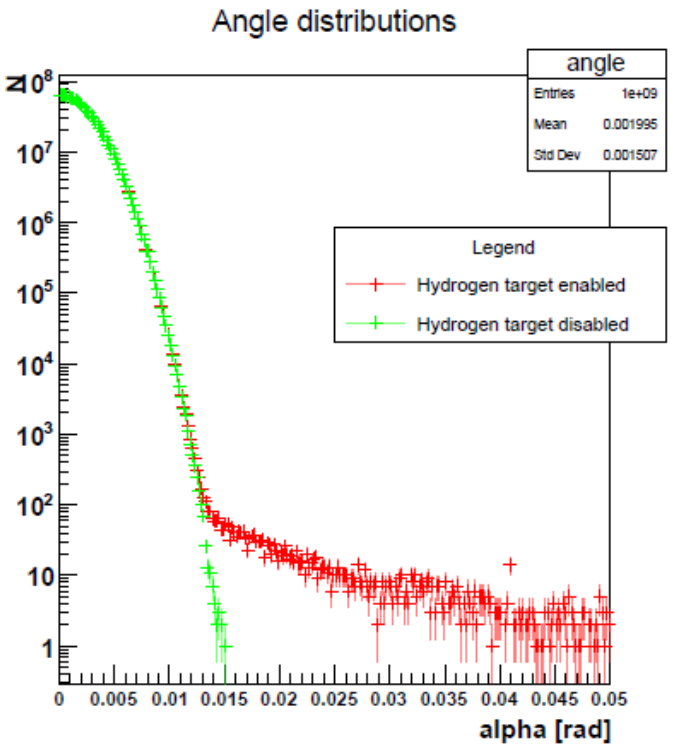


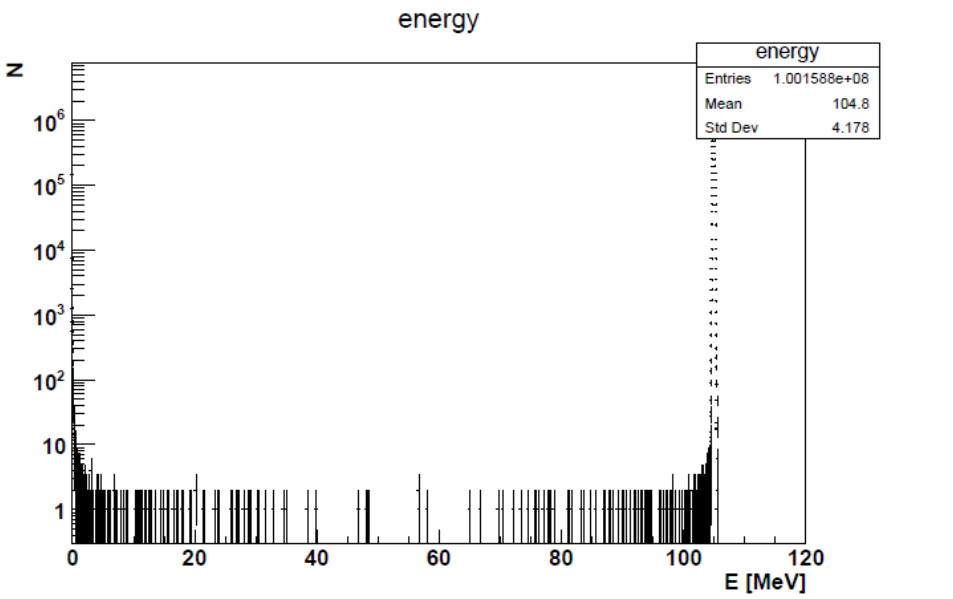
Target areal density 10^{19} nuclei cm^{-2} H_2
→ $6*10^{34}$ $cm^{-2}s^{-1}$ luminosity at 1mA

Schematic Illustration of the TAIL-problem

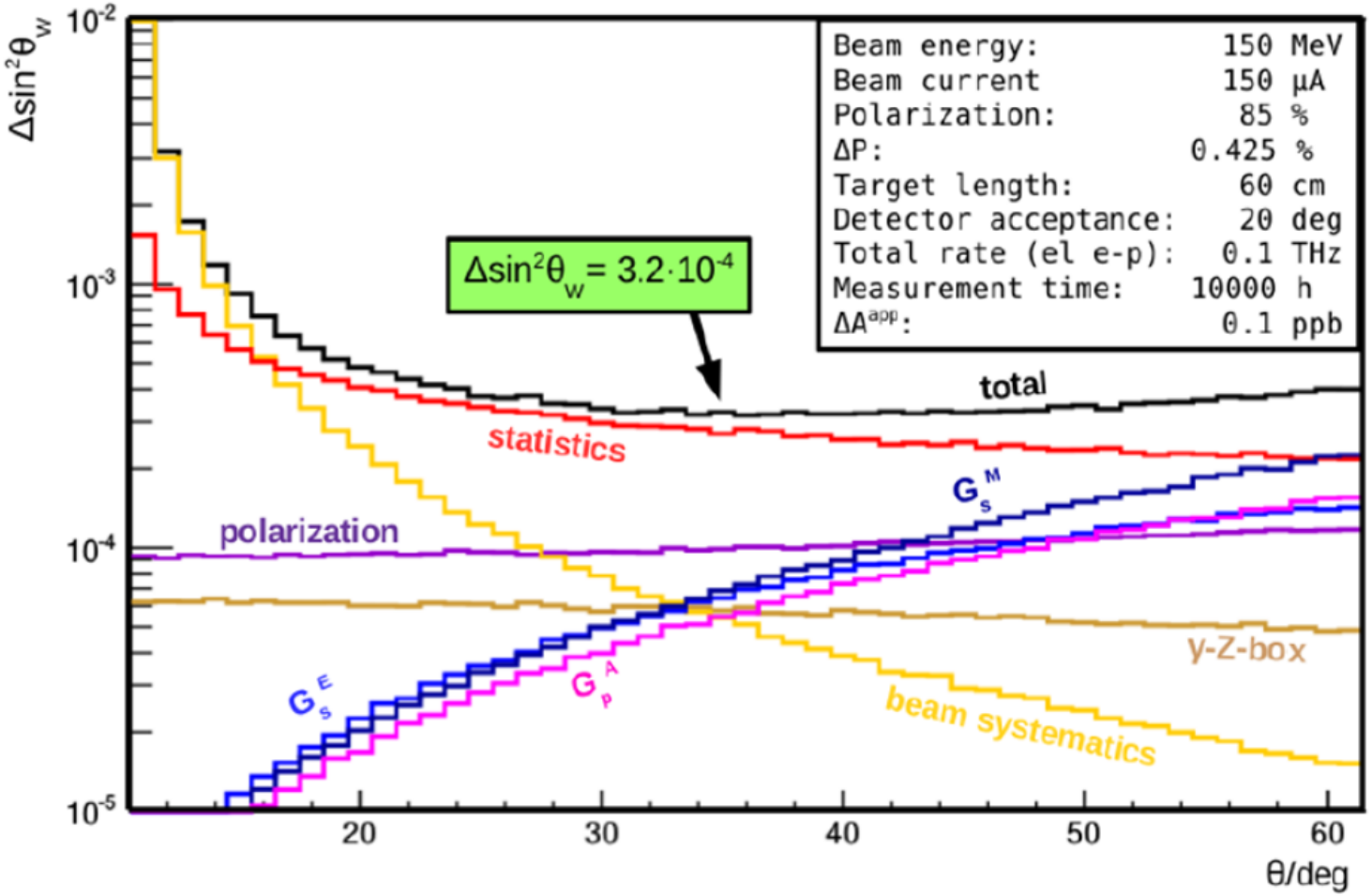
MAGIX-impact on beam?

Geant-4 simulation reveal expected particle distributions





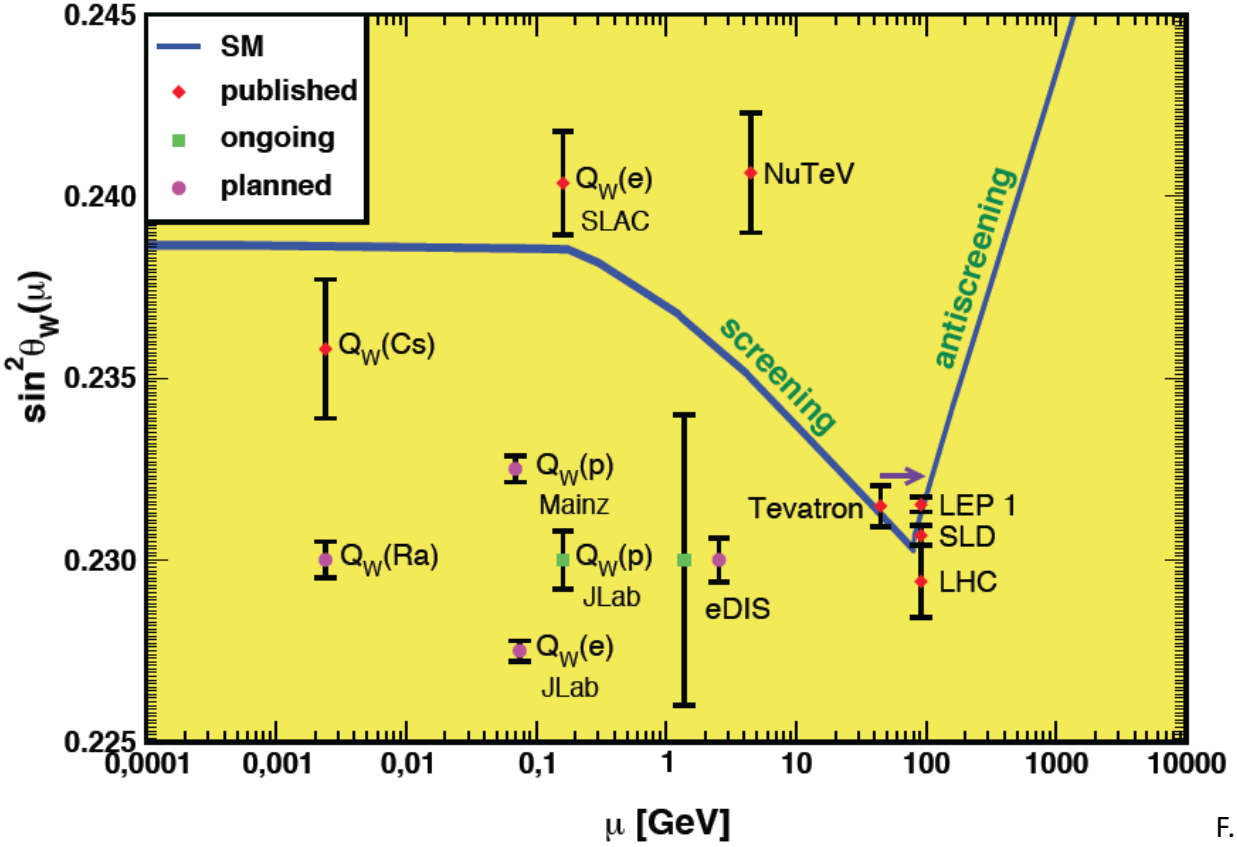
The P2 experiment at MESA



The SM-model value for Asymmetry*Beampol is 28 ppb to be measured with an accuracy of 0.44 ppb….

F. Maas PAVI2014 conf.

The P2 experiment at MESA

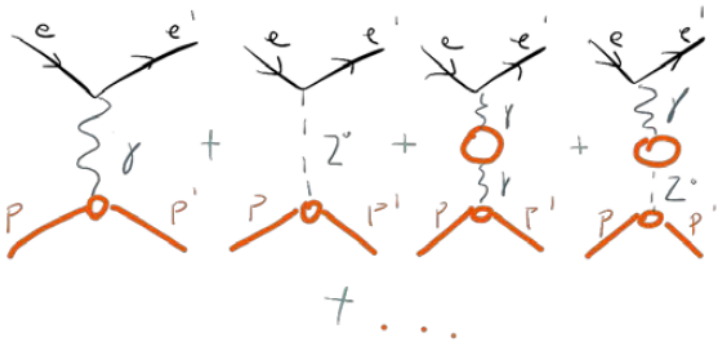


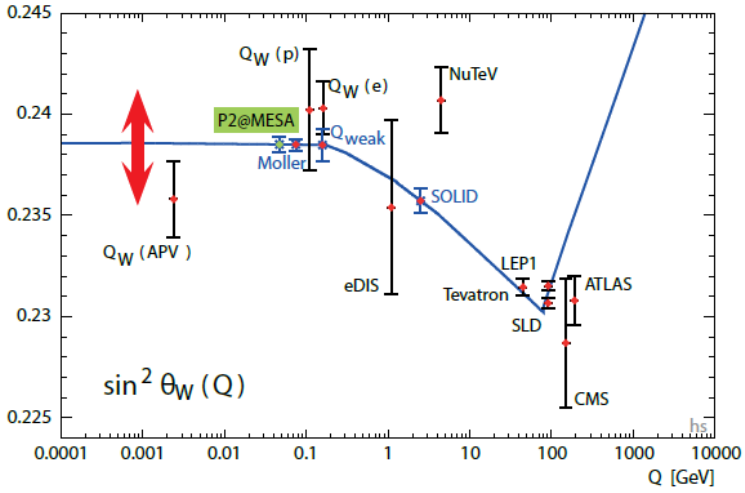
F. Maas PAVI2014 conf.

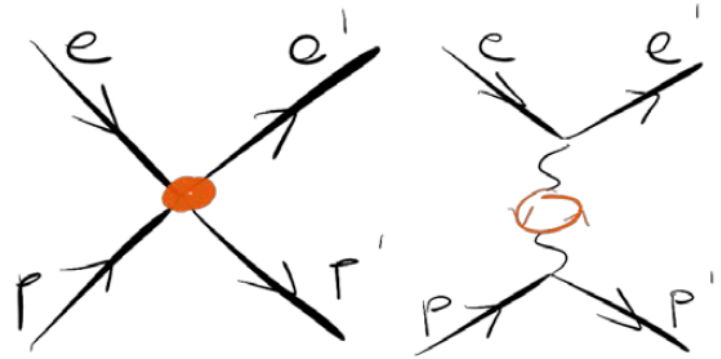
„Running“ of mixing angle: predicted by standard model, and confirmed by several Experiments.

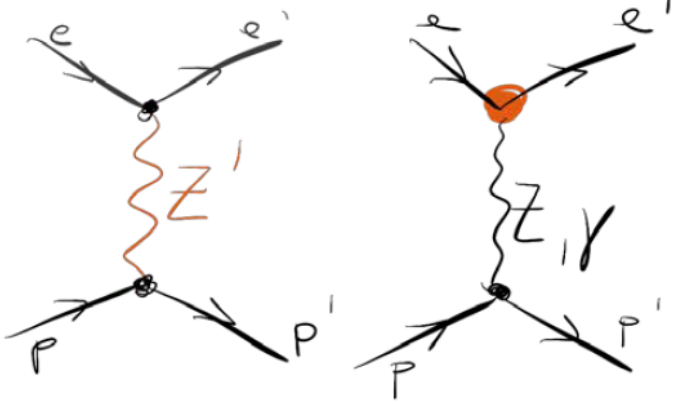
The P2 experiment at MESA

New Physics in the running



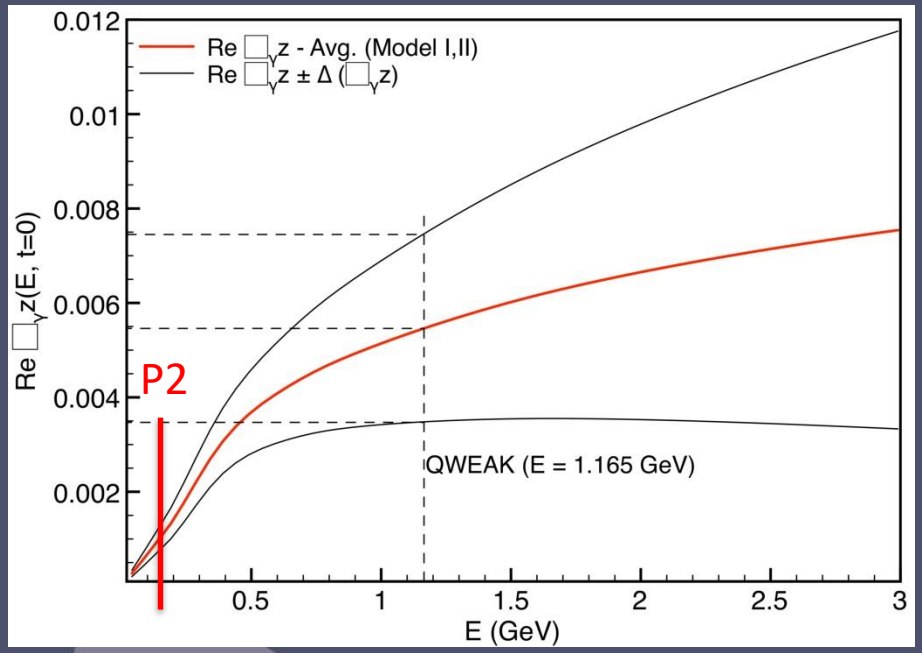






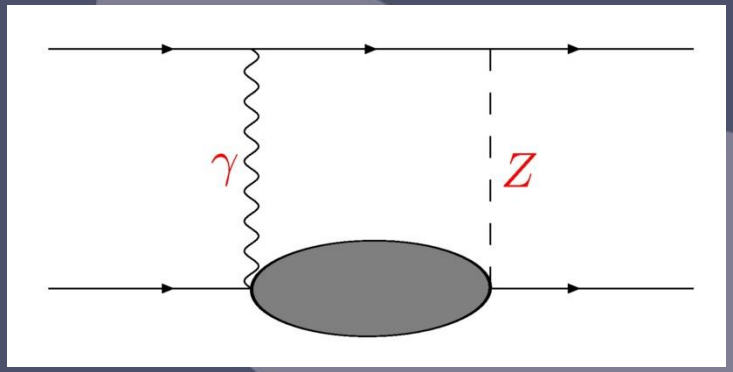
N. Berger

- γZ box graph contributions obtained by modelling hadronic effects:



[Gorchstein, Horowitz & Ramsey-Musolf 2011]

- Hadronic uncertainties suppressed at lower energies
- Low beam energy experiment: **P2 @ MESA**



Dominant theoretical uncertainty:

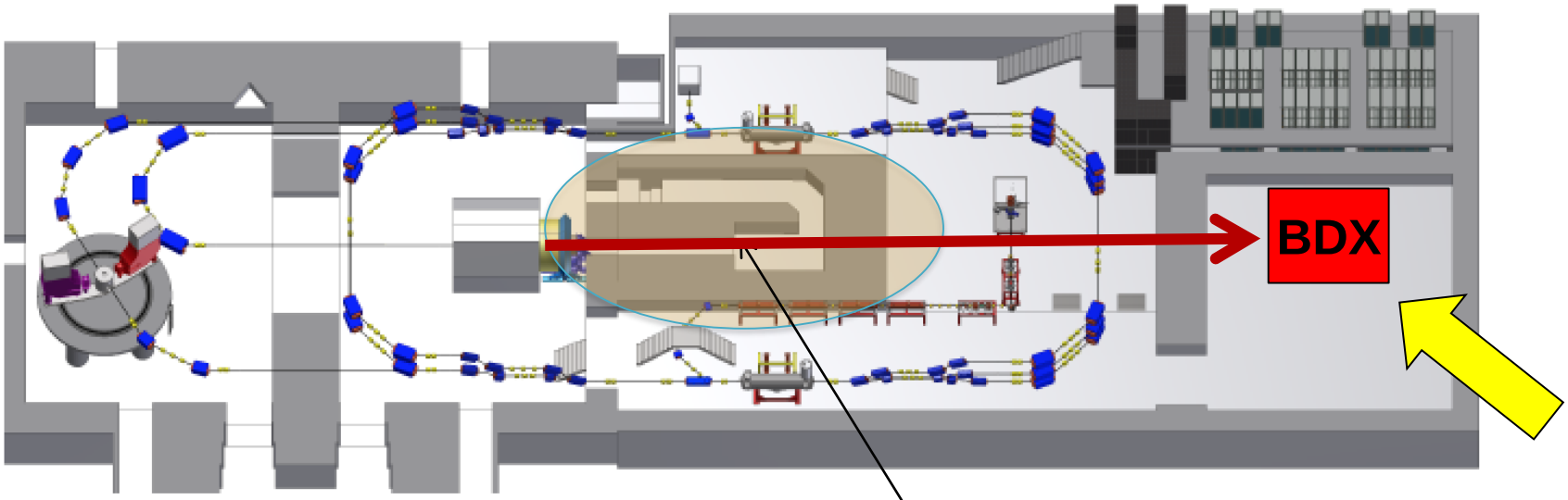
γZ box graphs, $\boxdot_{\gamma Z}$

Sensitive to hadronic effects

The P2 Experiment at MESA

Beam Dump Experiment (BDX) @ MESA

Electron Scattering on Beam Dump → Collimated pair of Dark Matter particles !



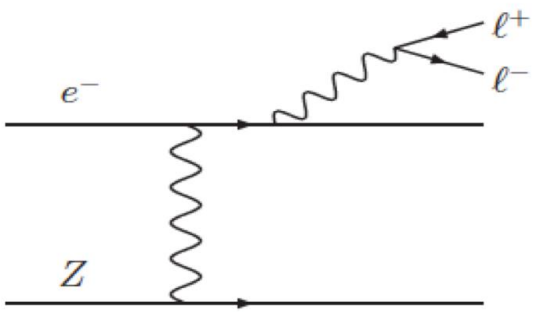
This existing beam dump is going to be the P2 beam dump

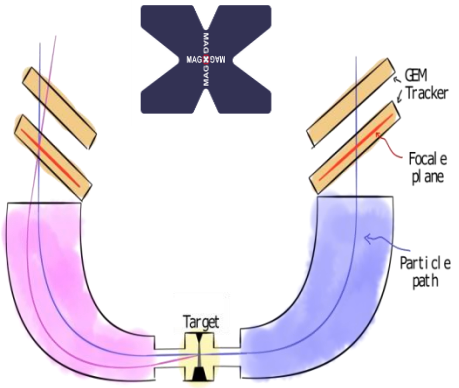
10,000 hours @ 150 µA

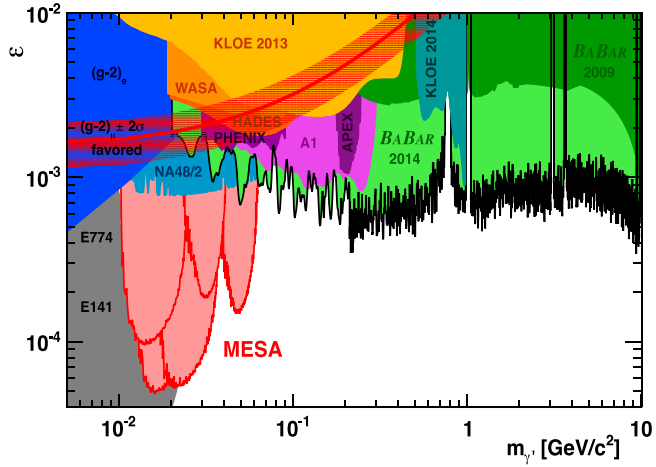
→ 10^{23} electrons on target (EOT)

MAGIX portfolio-II / dark photon searches

- Pseudo internal target experiment: Initially foreseen for dark photon search.
  Dark photon decays into light lepton pair..

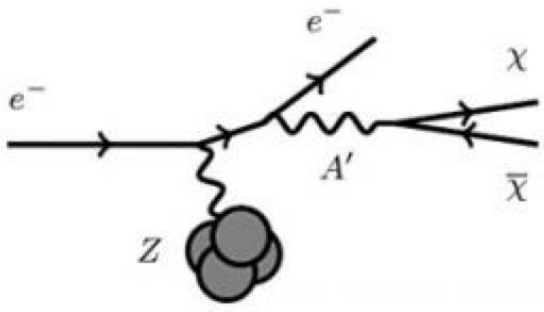






Expected coverage…

- g-2 band could as well be motivated by „invisible“ decay into dark matter…



$$m^2_{\gamma'} = (e + p - e' - p')^2$$

We currently investigate which coverage can be obtained by using very thin HV MAPS detector for proton recoil measurement…

Options for MAGIX portfolio II-V ?

…. Dark photon searches

….Nuclear astrophysics (S factors)

…. Nuclear physics (three body forces)

……. Nucleon polarizabilities

….exploration of possibilities are ongoing!