OVERVIEW MAMI AND MESA

Kurt Aulenbacher,
Institut für Kernphysik,
Johannes Gutenberg-Universität Mainz

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

Schloß Waldhausen, June 29th, 2017

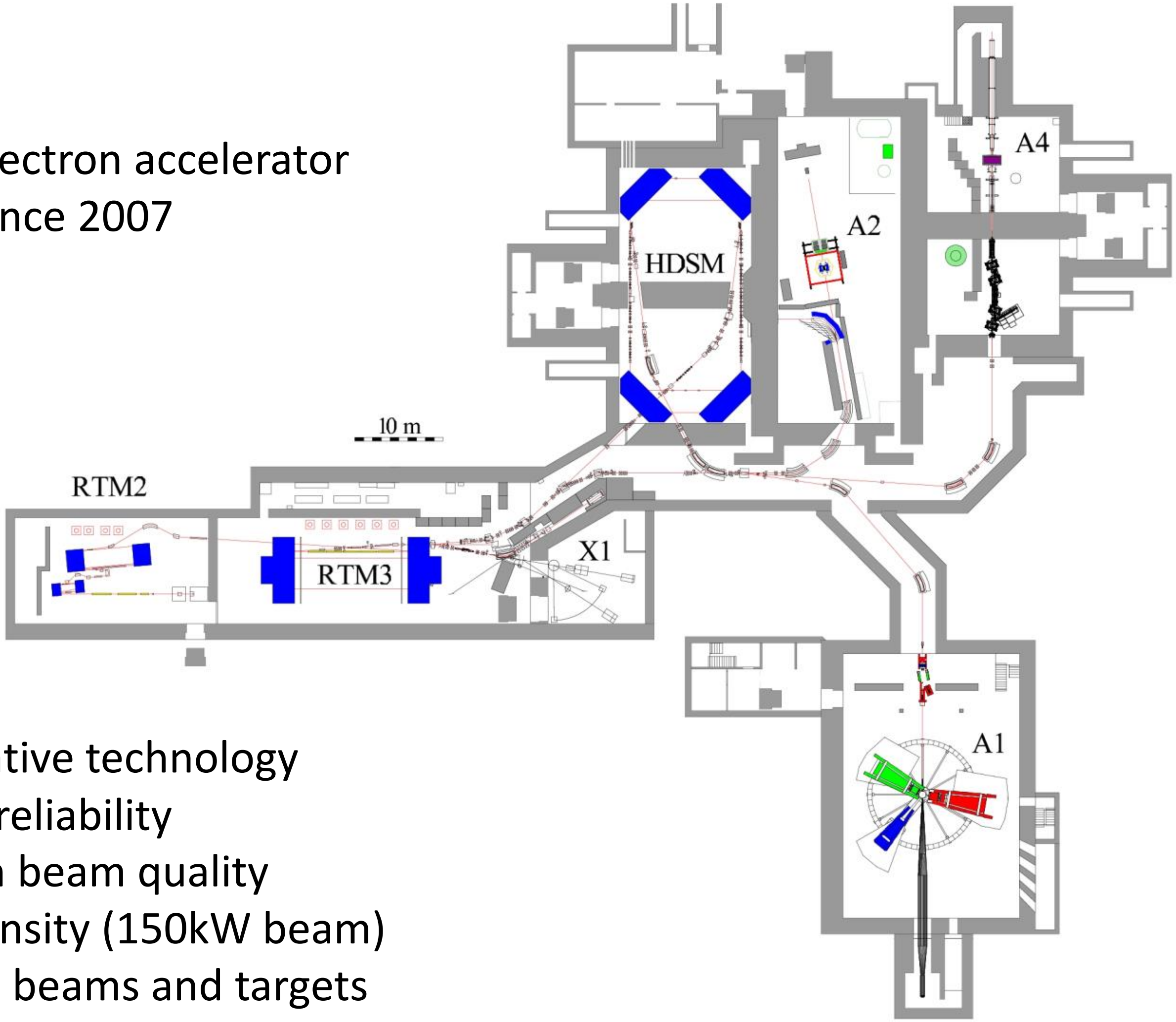
Work supported by DFG through excellence cluster PRISMA

OUTLINE

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

MAMI-C Accelerator

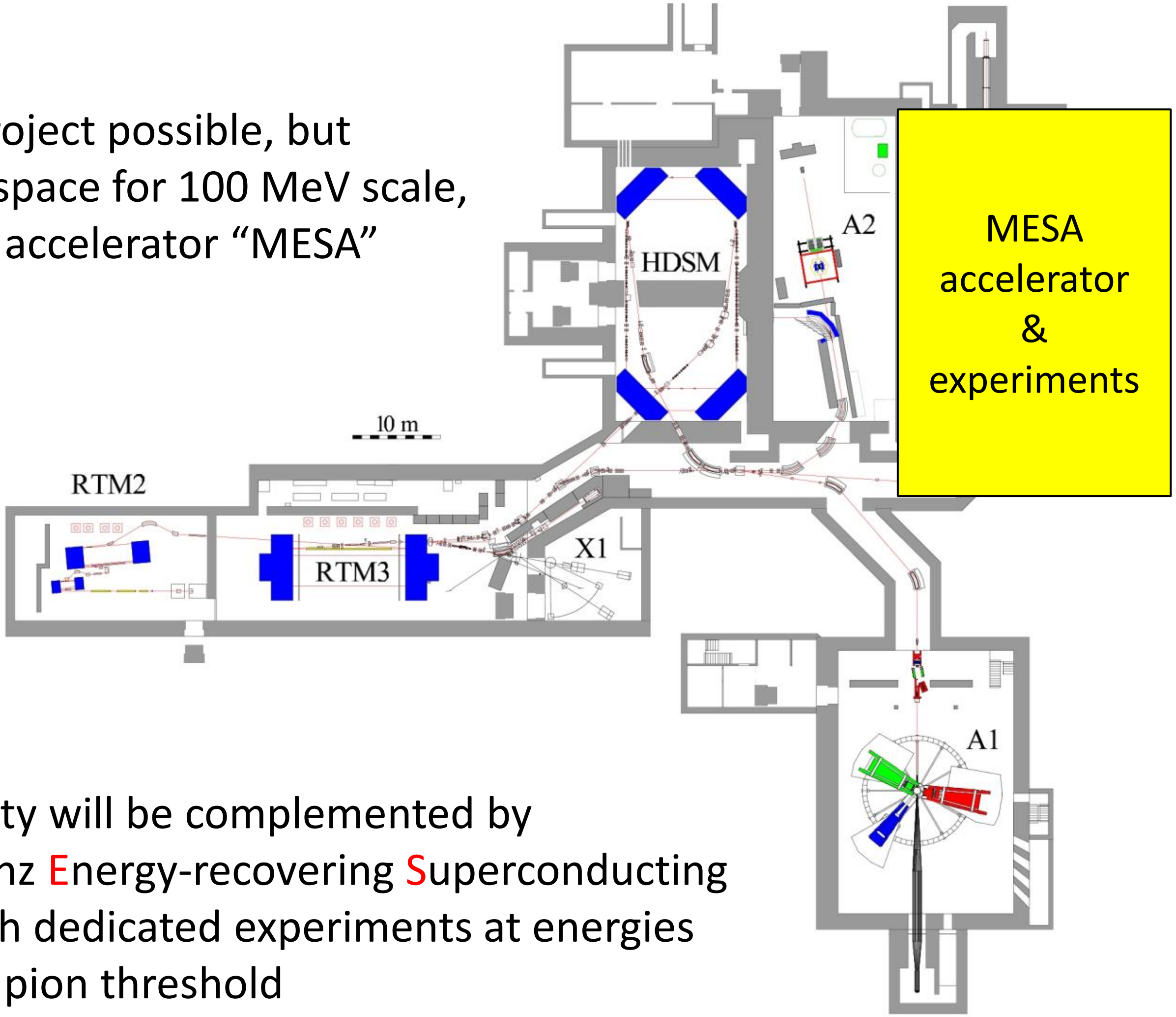
- 1.6 GeV c.w. electron accelerator in operation since 2007



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

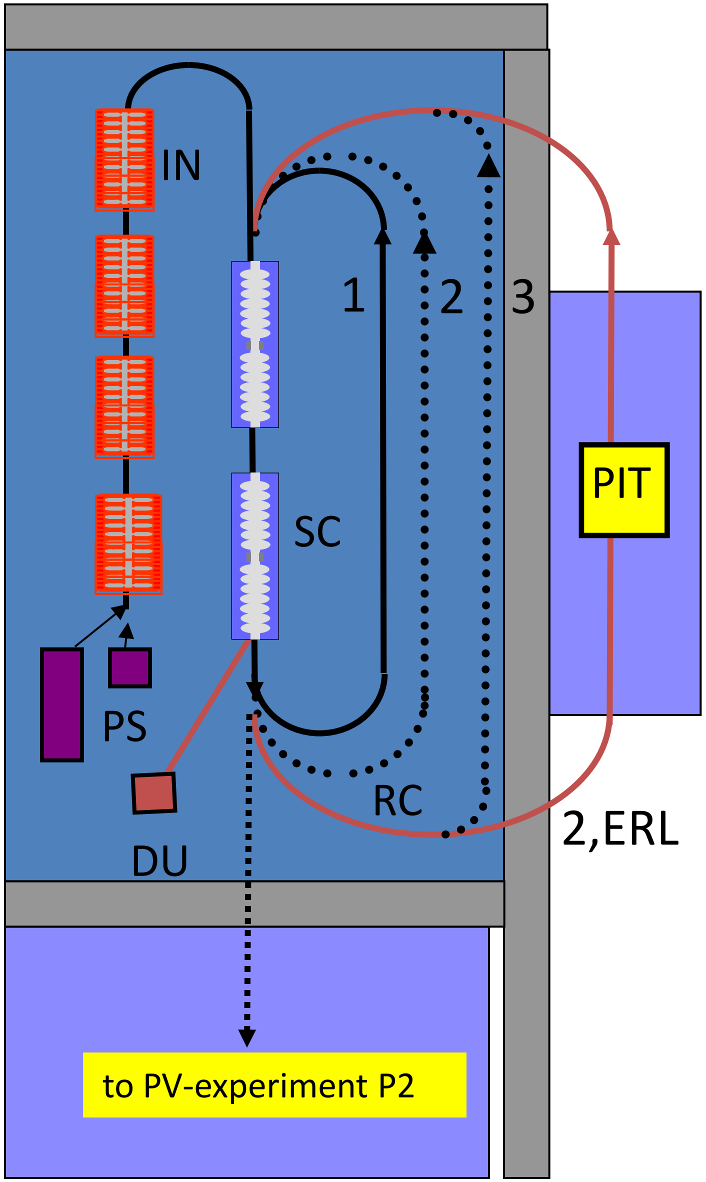
NEW Project - MESA

- no MAMI D project possible, but use available space for 100 MeV scale, high intensity accelerator "MESA"



The MAMI facility will be complemented by MESA , the Mainz Energy-recovering Superconducting Accelerator, with dedicated experiments at energies below or at the pion threshold

MESA concept as proposed in 2009



MESA main objectives

1. Precision measurement of the weak mixing angle (P2-experiment)
2. Accelerator physics: Multi-turn, superconducting ERL
3. New experimental technique for nuclear and particle physics: The PIT - high luminosity/low background at low energies

MESA BEAM PARAMETERS :

CW beam

EB-mode: 150 µA, ~~200~~ 155 MeV spin polarized beam (liquid Hydrogen target L~10^{39})

ER-mode: 1 mA (10 mA), 105 MeV unpolarized beam (Pseudo-Internal Hydrogen Gas target, PIT L~10^{35})

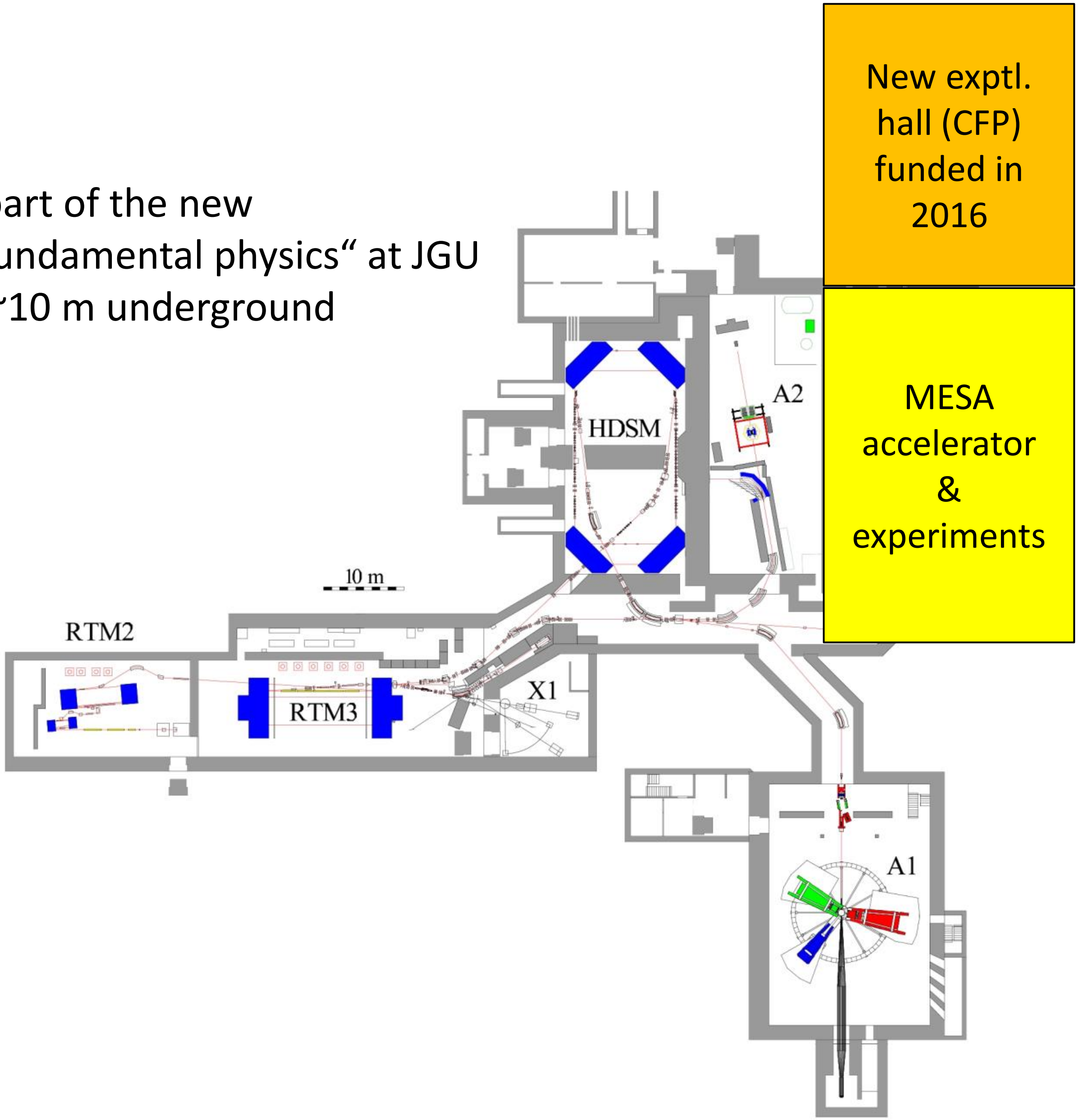
MESA ORGANISATION/ FUNDING

- In 2012 application for excellence cluster „PRISMA“ successful
- MESA is the largest of the „structural initiatives“ within PRISMA
- ~ 15 Scientists, Post docs and PhD students presently work to realize the accelerator, many more for experiments
- In 2015 a „Forschungsbau“ application by PRISMA for a building extension for MESA was successful
- → increased experimental capabilites as an answer to increased demand!
- Downside: MESA commisionig only possible after civil construction work!
- MESA „facility“ is supposed to start operation in 2020

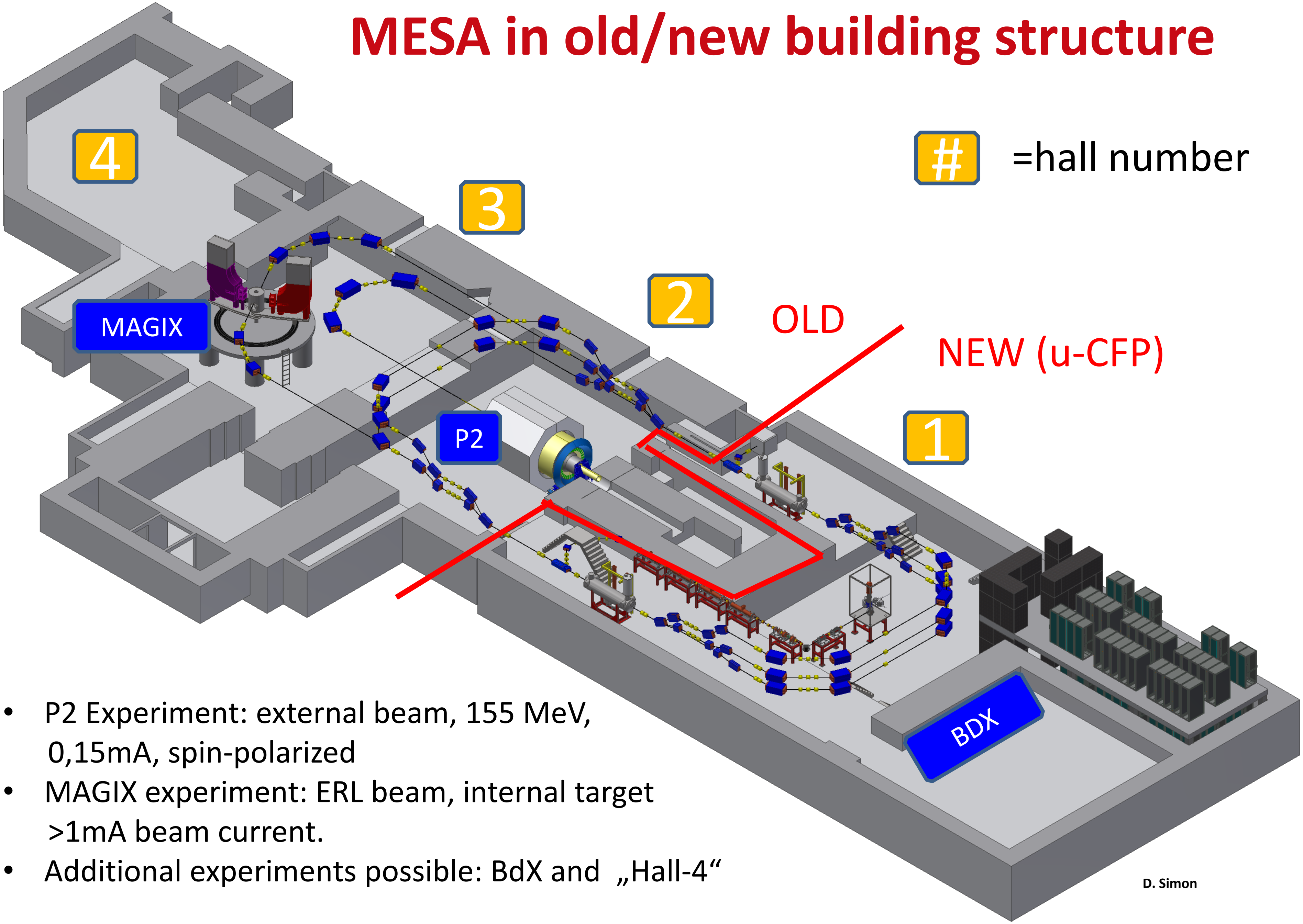
MESA Layout-accelerator and experiments

MESA EXTENSION BUILDING

- Building is part of the new „Center of fundamental physics“ at JGU
- floor level ~10 m underground

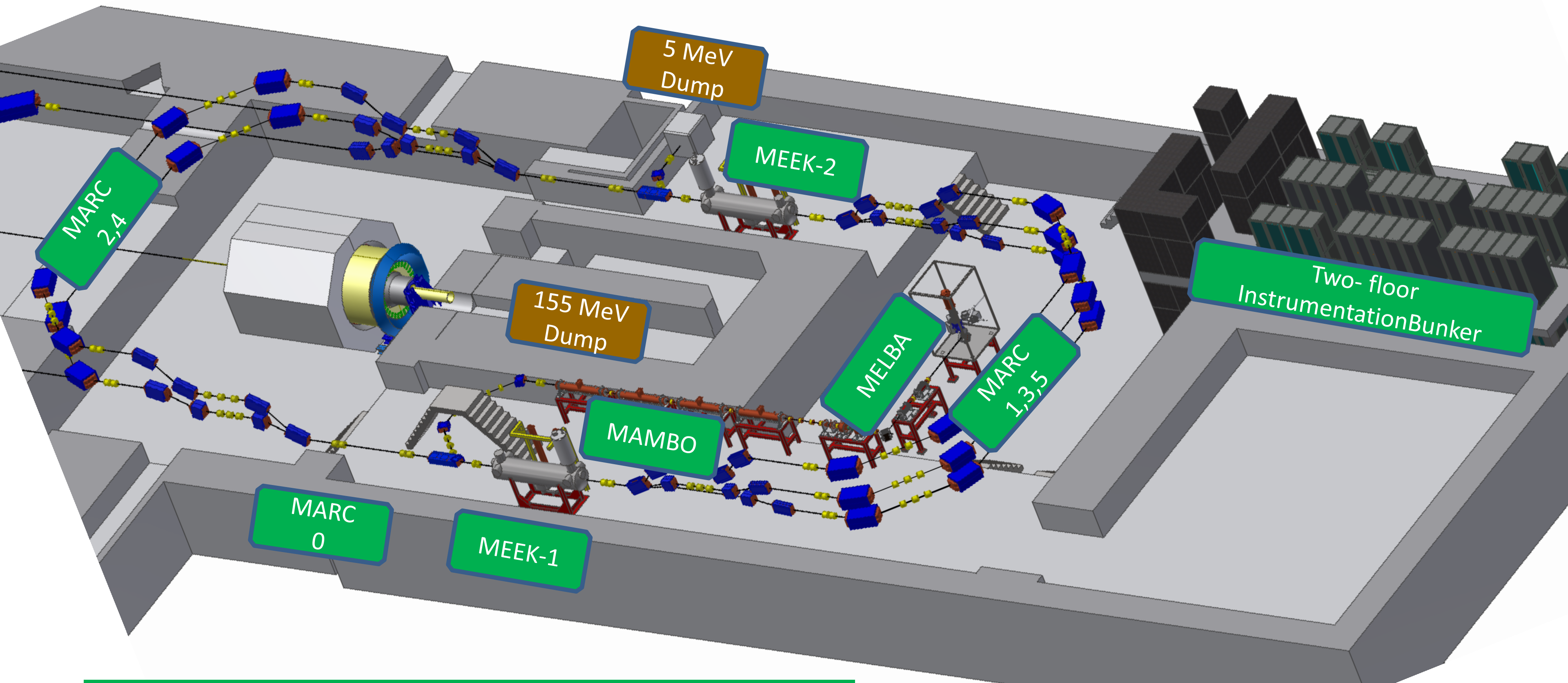


MESA in old/new building structure



- P2 Experiment: external beam, 155 MeV, 0,15mA, spin-polarized
- MAGIX experiment: ERL beam, internal target >1mA beam current.
- Additional experiments possible: BdX and „Hall-4“

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

MESA main component: SRF Cryomodule

Key parameters

- Accelerating Field strength 12,5 MV/m c.w.
- Quality factor Q_0>1,5*10^{10} @ 12,5MV/m c,w.
- four cavities with 1m length each → 50MeV enrgy gain per turn

Most challanging issues

- Fast tuning (microphonics)
- Higher order mode damping → figh Beam instabilites & improved thermal handling

MESA Cryomodules

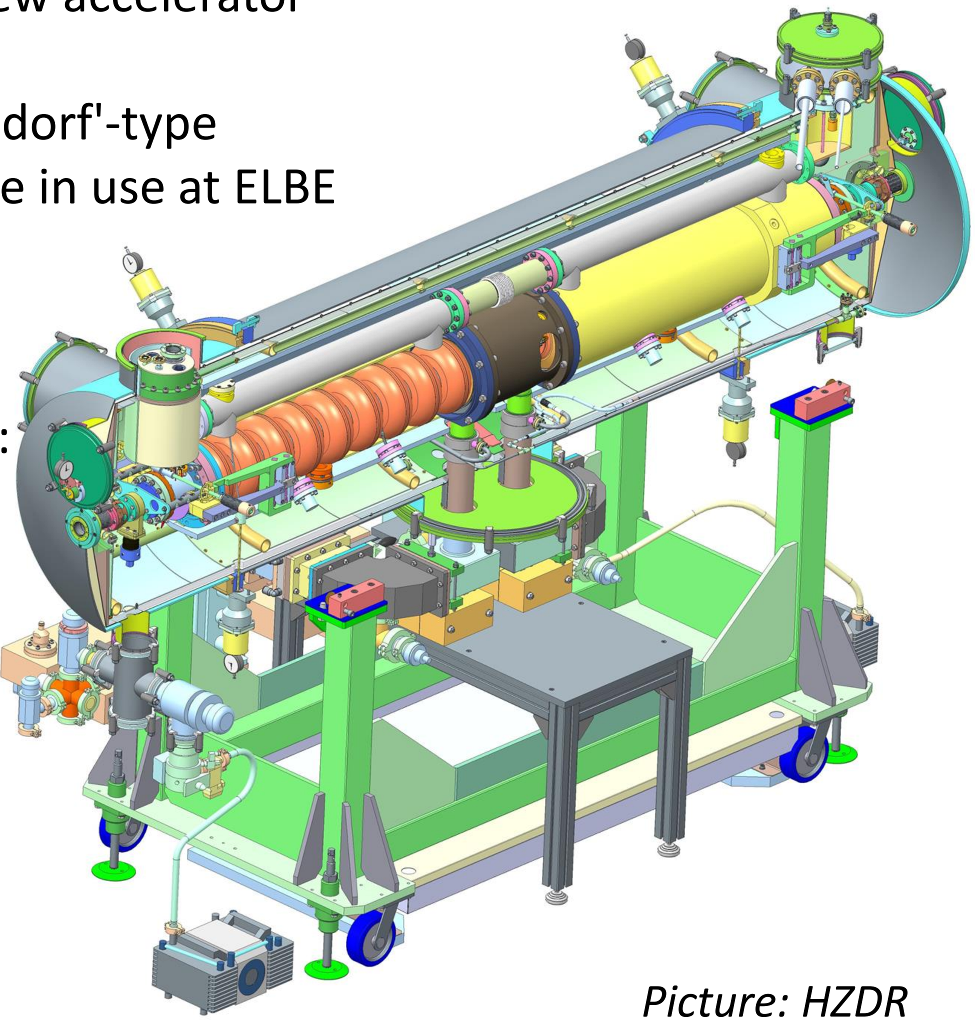
Cryomodules are the backbone of the new accelerator

We ordered Cryomodules of the 'Rossendorf'-type (2 x 9-cell TESLA/XFEL cavities), which are in use at ELBE will be used for MESA

→ we applied some adaptations in order to allow 1 mA ERL operation:

- added tuners with piezo elements (XFEL/Saclay-type)
- used sapphire windows at HOM feedthroughs + many smaller improvements

→ beam current of 10 mA will not be achievable with that type of cryomodule (possible PRISMA 2 project)



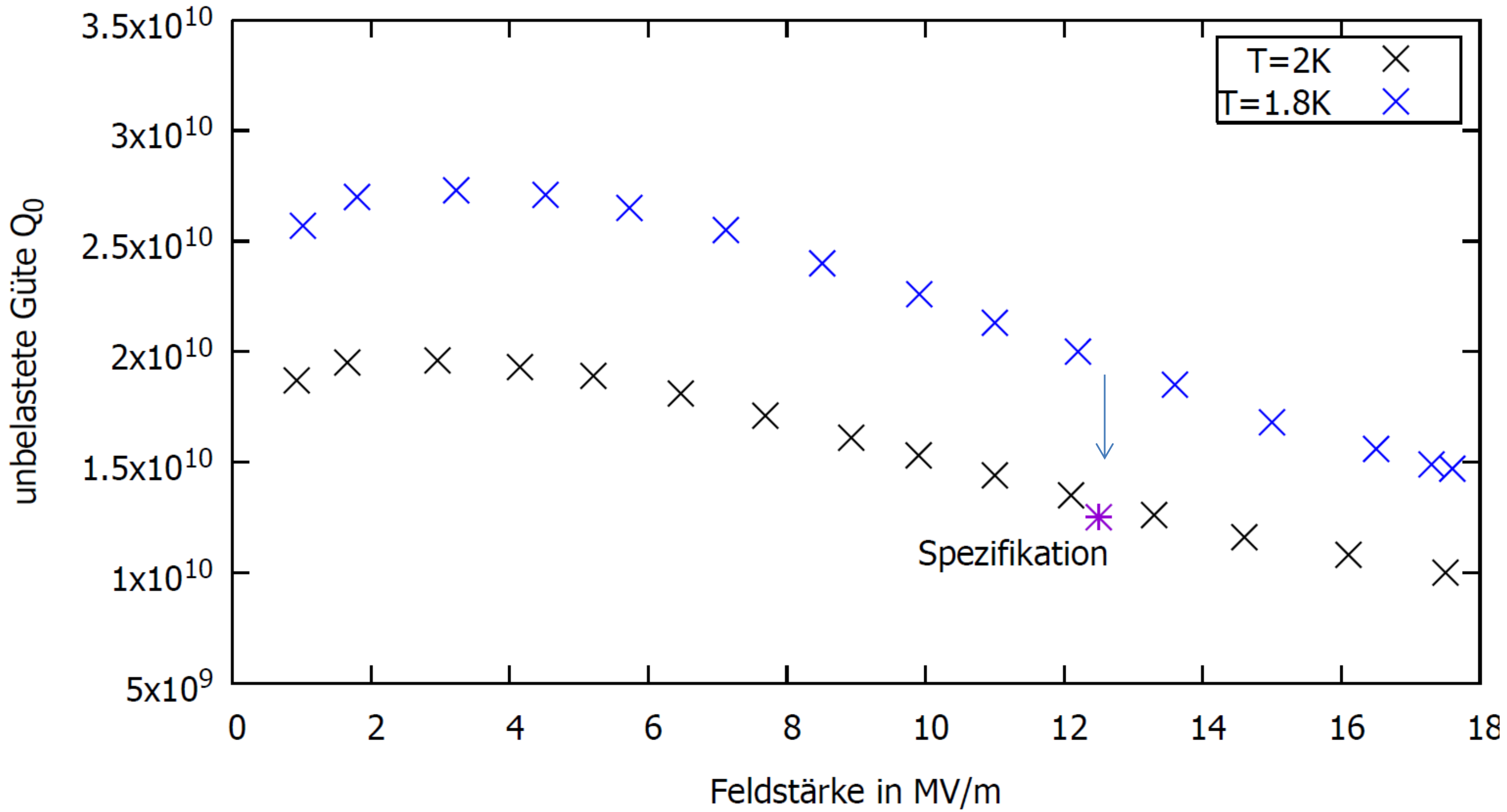
Picture: HZDR

Cryomodule Project Status

- Cavities & power antennae fabricated and tested!
- Assembly of cryostats currently under way
- Delivery of module+2K system expected October this year.
- Perfomance test possible at HIM in Mainz end 2017/beginning 2018

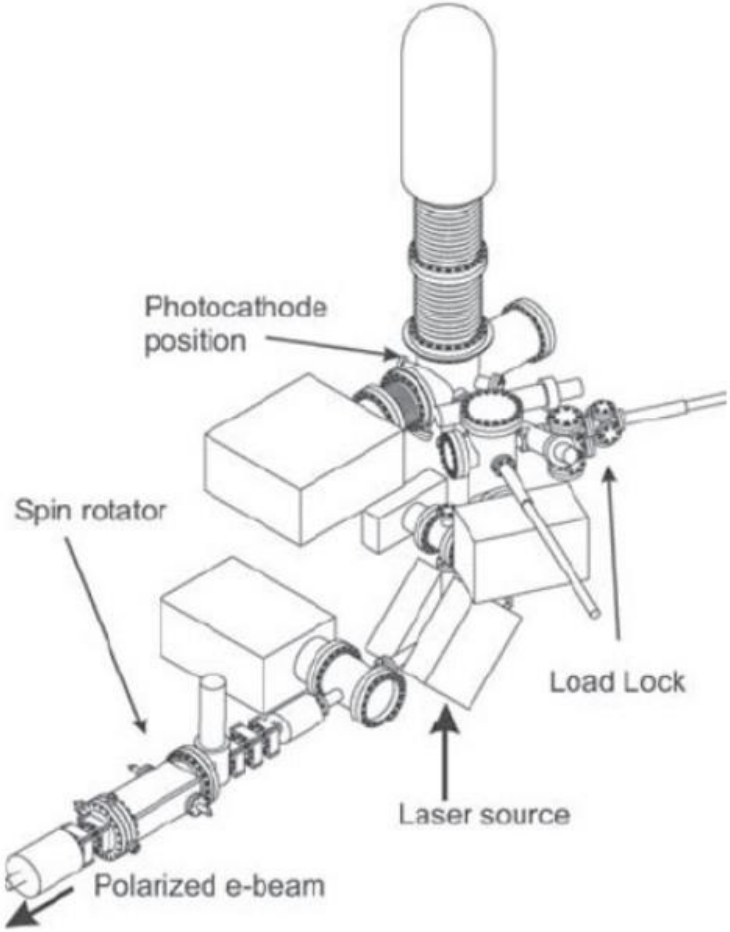
Performance of the „worst of four“

Even **the worst** of the four cavities tested was
*1,7 over specs in Q0 and 1,4*over specs in maximum gradient
BUT: typical reduction of 30% in Q_0 observed after assembly in cryostat (EXFEL-averaqge)

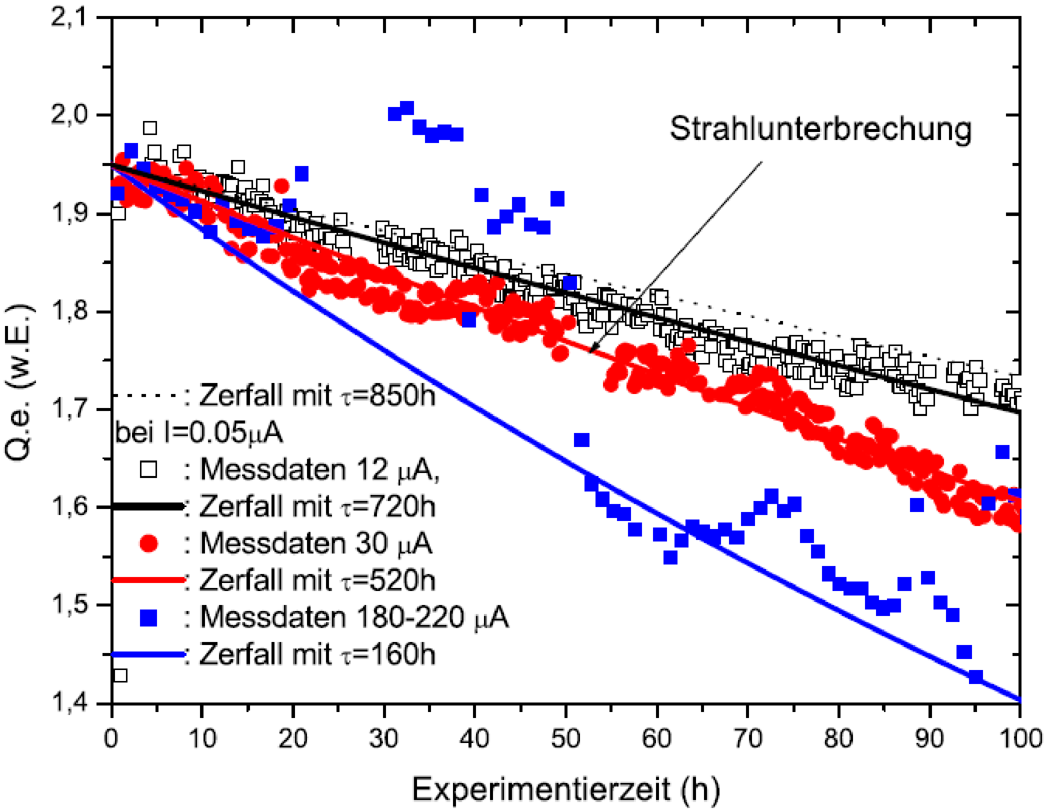


High current polarised beam for MESA : From EB to ERL mode

Some old (2005) results from **M**AMI **O**perational **P**olarized **S**ource (MOPS)



Polarisation: From EB to ERL mode



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 .

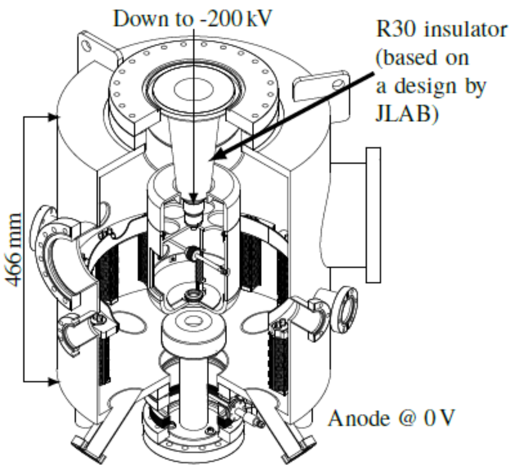
Note: P2 experiment operates at 150μA (**Cathode heating problem must be solved!)**

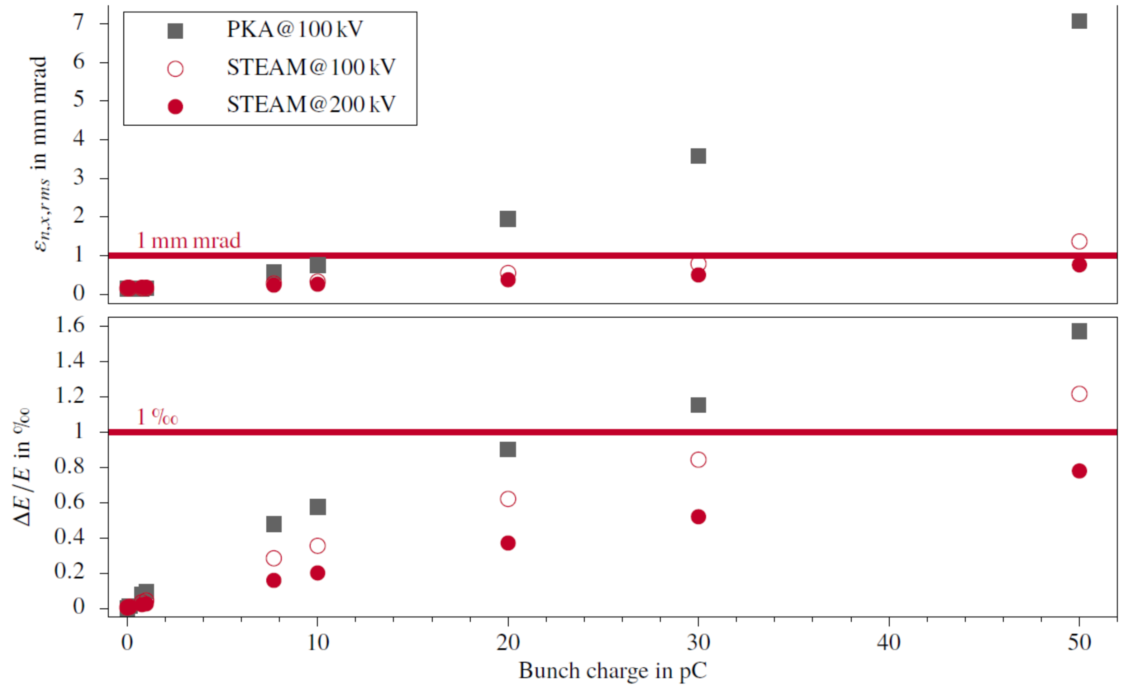
→P2 needs 13C/day

→ ~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! (STEAM project)

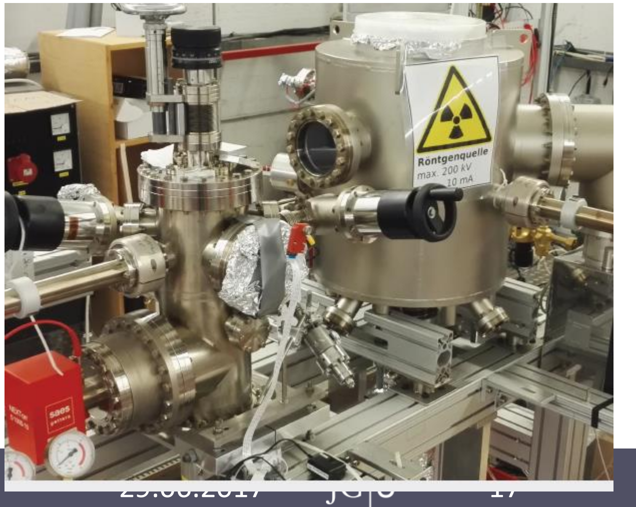
Polarisation: From EB to ERL mode





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
- First beam expected this summer
- Will be used instead of MOPS,
- if succesful STEAM will become MIST (MESA Inverted Source in Thermalized Mode)



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
- MESA cryomodule on good track, delivery and tests this year!
- Purchasing residual „standard" MESA compoennts in 2018/19
- Acclerator set-up is staring in 2020

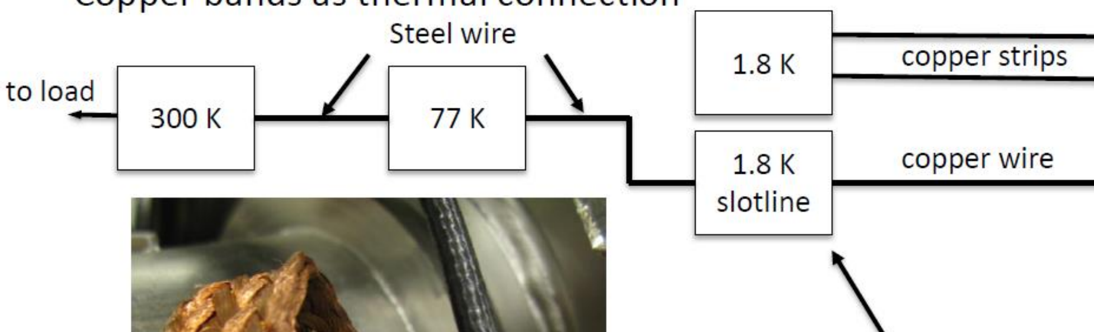
Thank you for your attention!

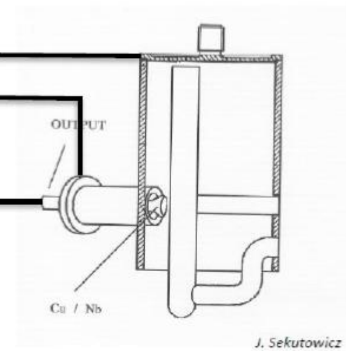
Supplementary transparencies

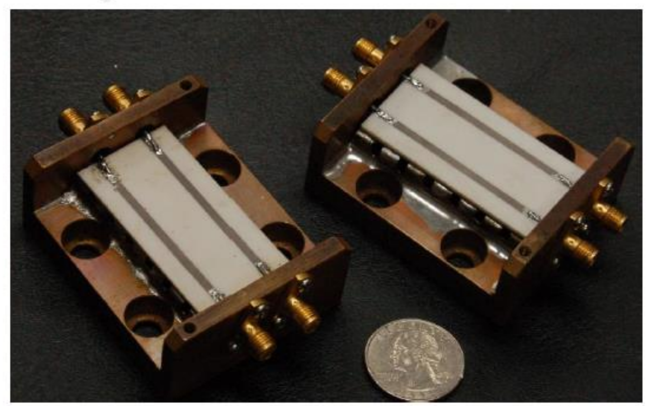
Further Developments by JGU

Possible solution:

- Slotline on cold mass to optimize cooling
- Steel wire between slotline and 300 K (bad thermal connection)
- Copper bands as thermal connection







J. Sekutowicz

MAGIX-impact on beam?

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

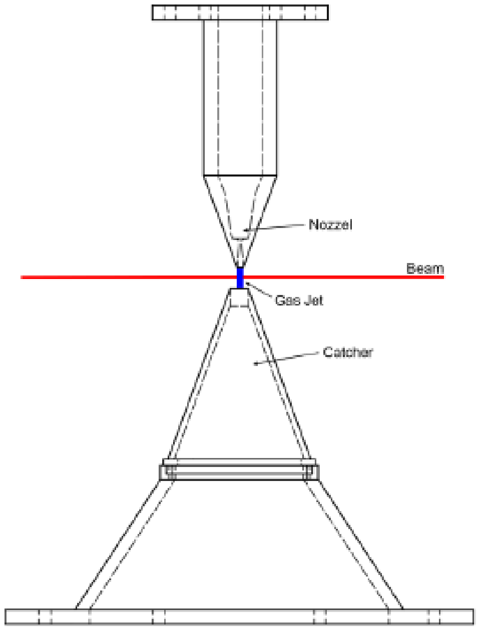
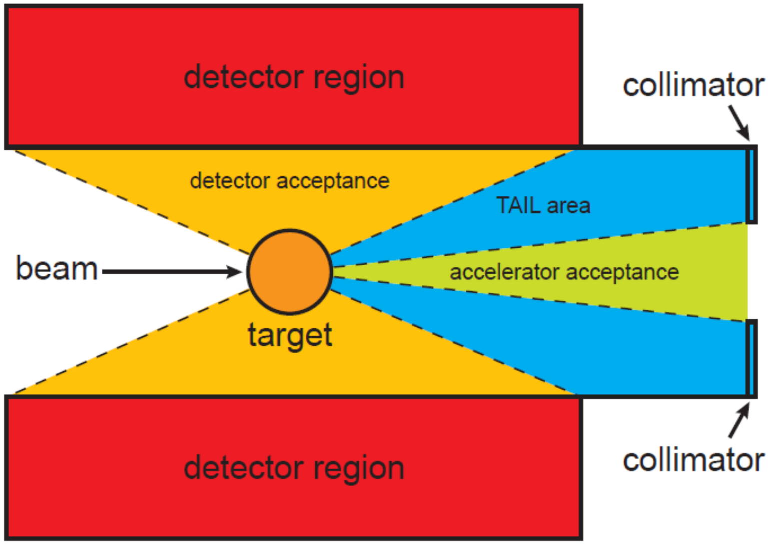


Figure 1: Schematic drawing of the MAGIX gas target.

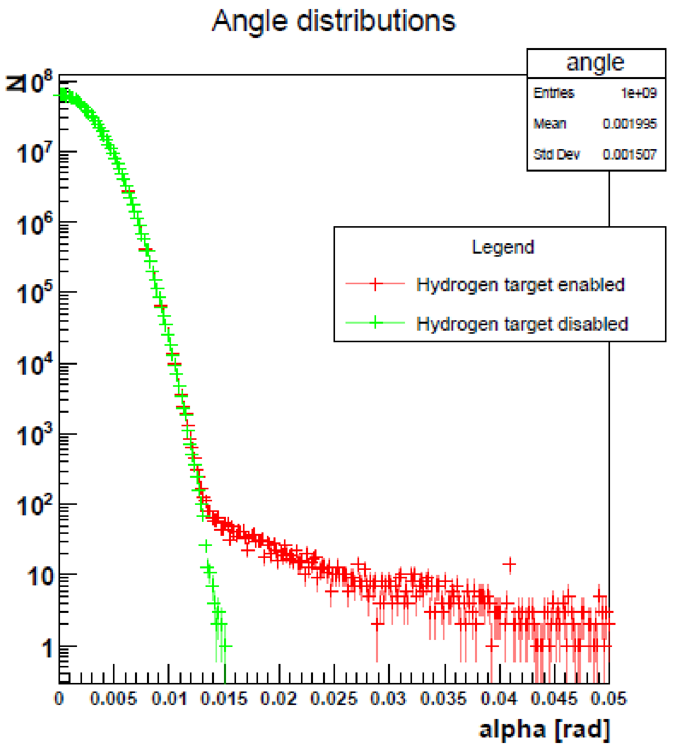


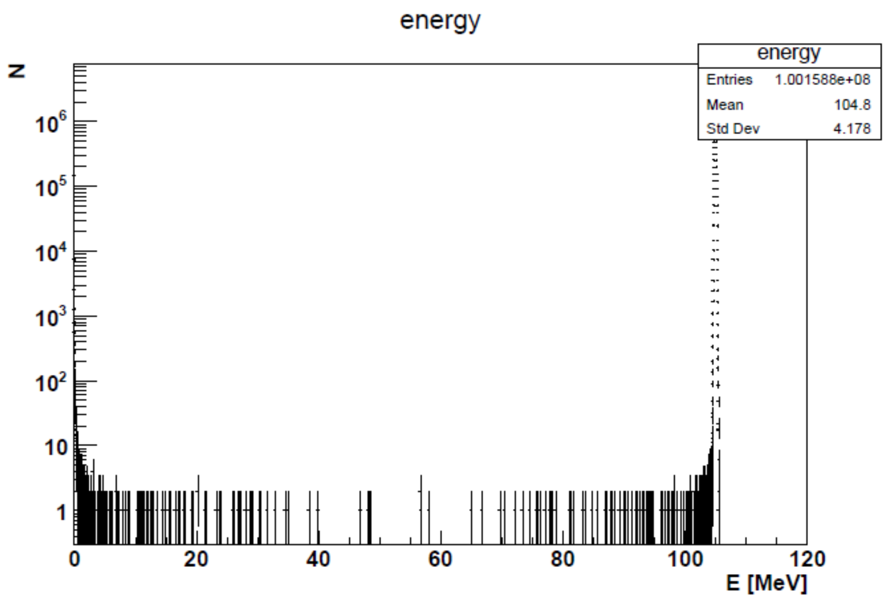
Target areal density 10^{19} nuclei cm^{-2} H_2
→ $6*10^{34}$ $cm^{-2}s^{-1}$ luminosity at 1mA

Schematic Illustration of the TAIL-problem

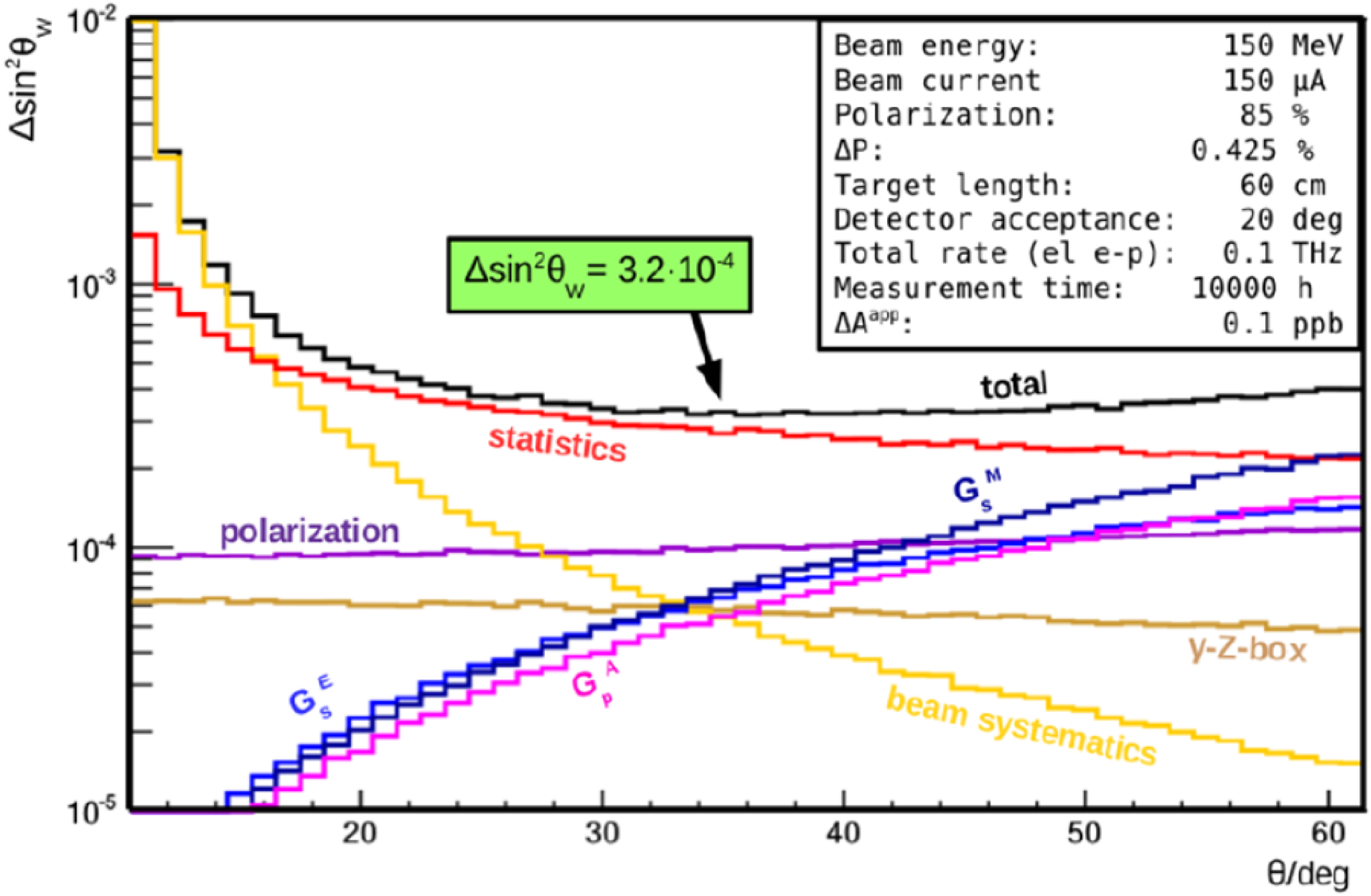
MAGIX-impact on beam?

Geant-4 simulation reveal expected particle distributions





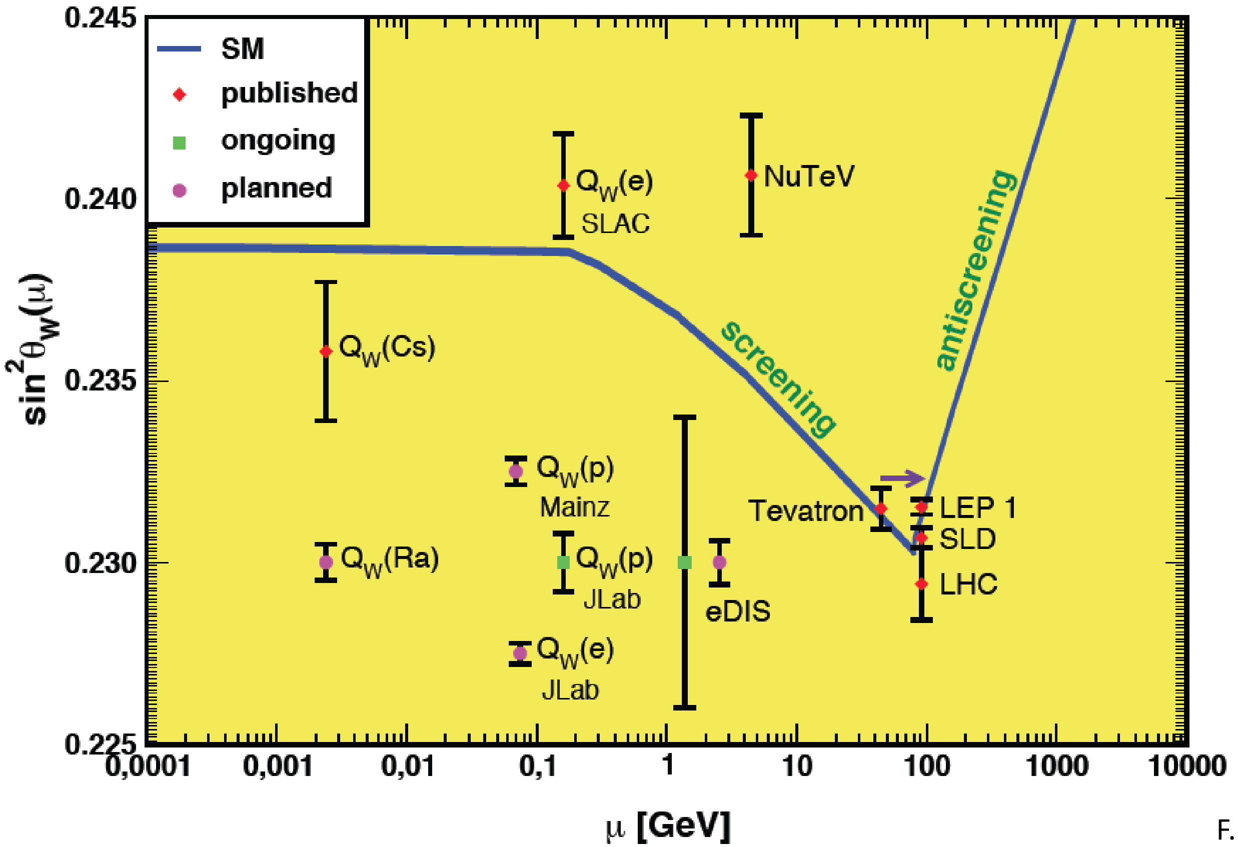
The P2 experiment at MESA



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

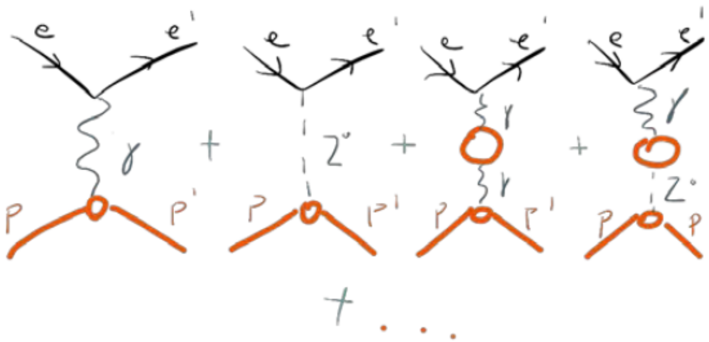


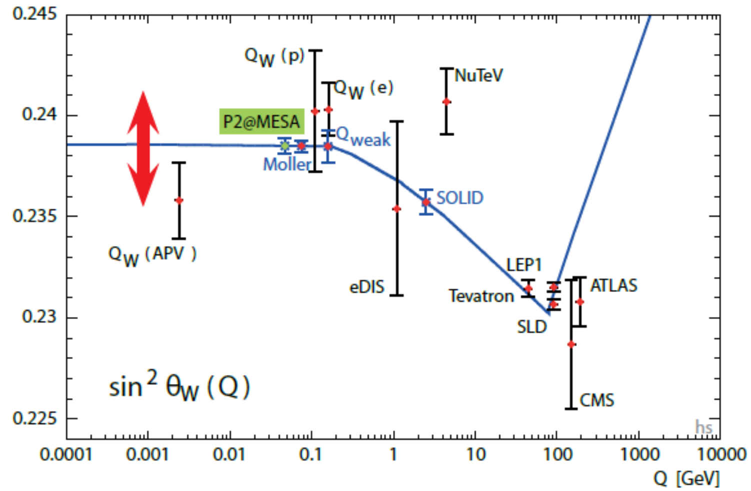
F. Maas PAVI2014 conf.

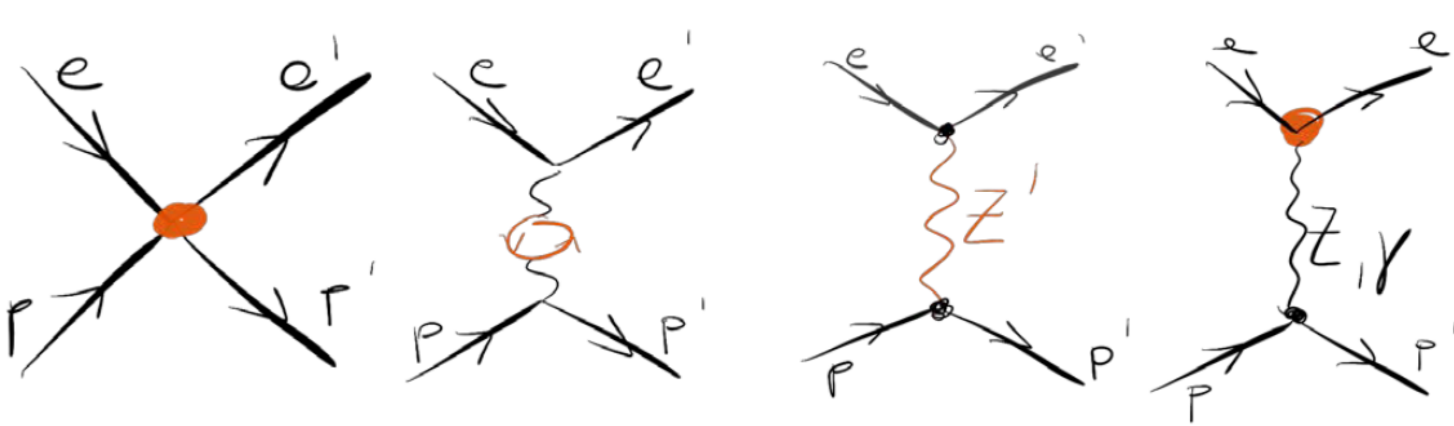
„Running“ of mixing angle: predicted by standard model, and confirmed by several Experiments.

The P2 experiment at MESA

New Physics in the running

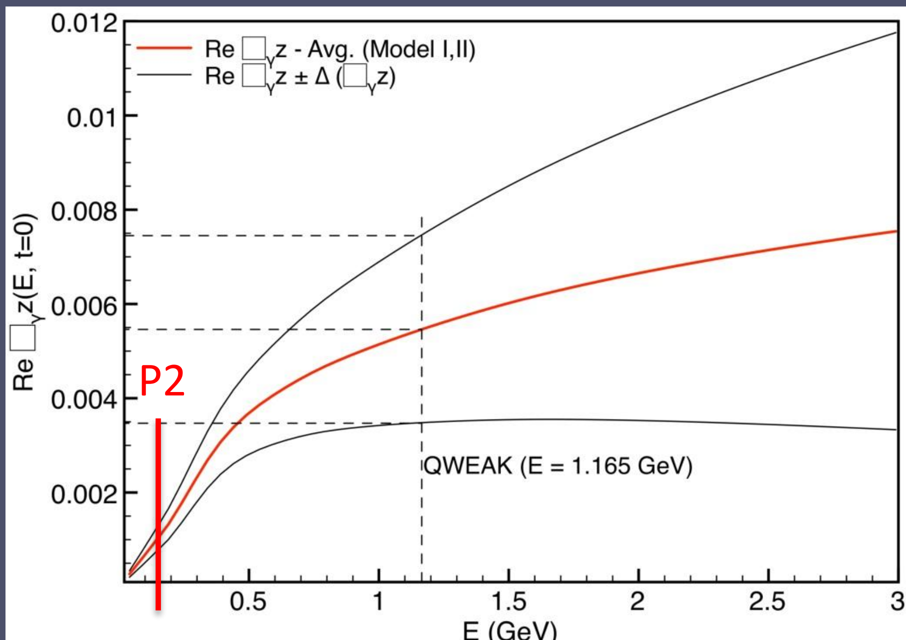






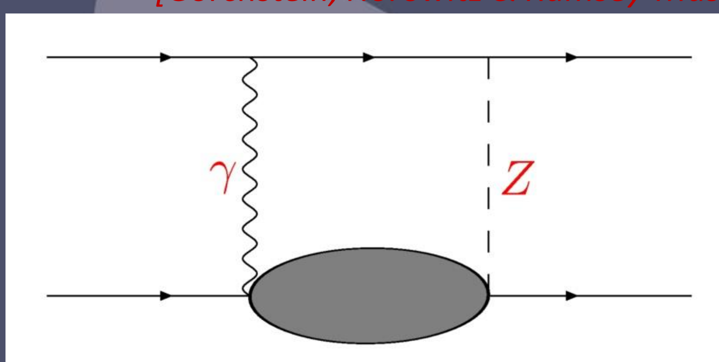
N. Berger

- 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, $\boxdot_{\gamma Z}$

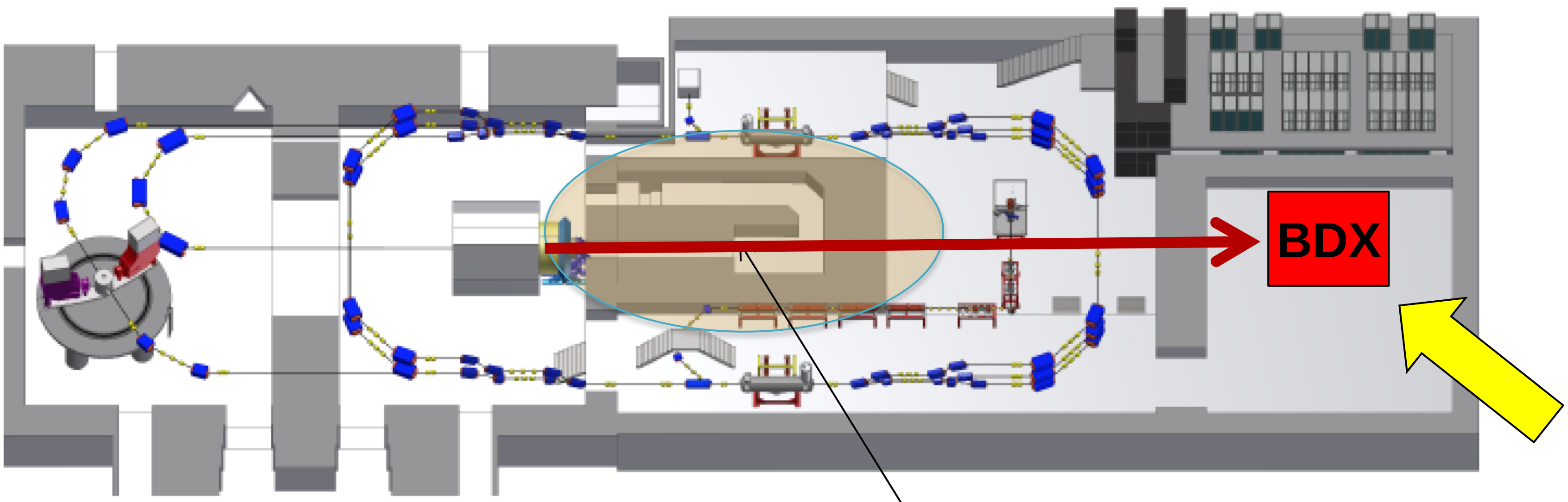
Sensitive to hadronic effects

The P2 Experiment at MESA

-

Beam Dump Experiment (BDX) @ MESA

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



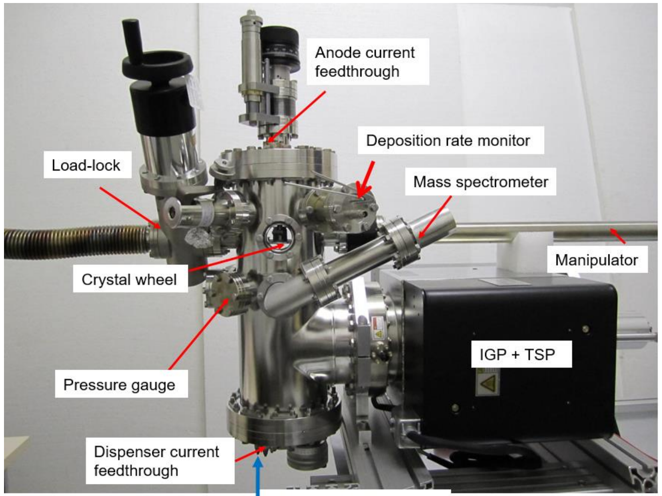
This existing beam dump is going to be the P2 beam dump

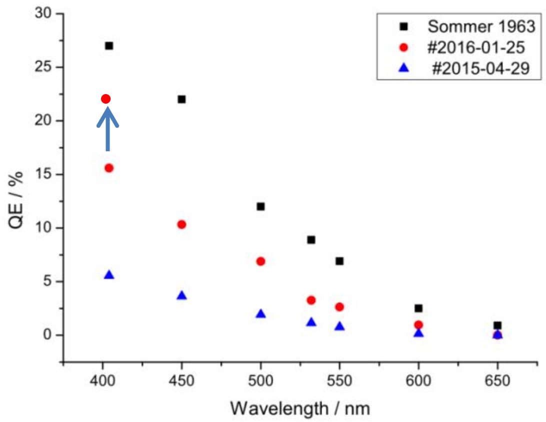
10,000 hours @ 150 µA

→ 10^{23} electrons on target (EOT)

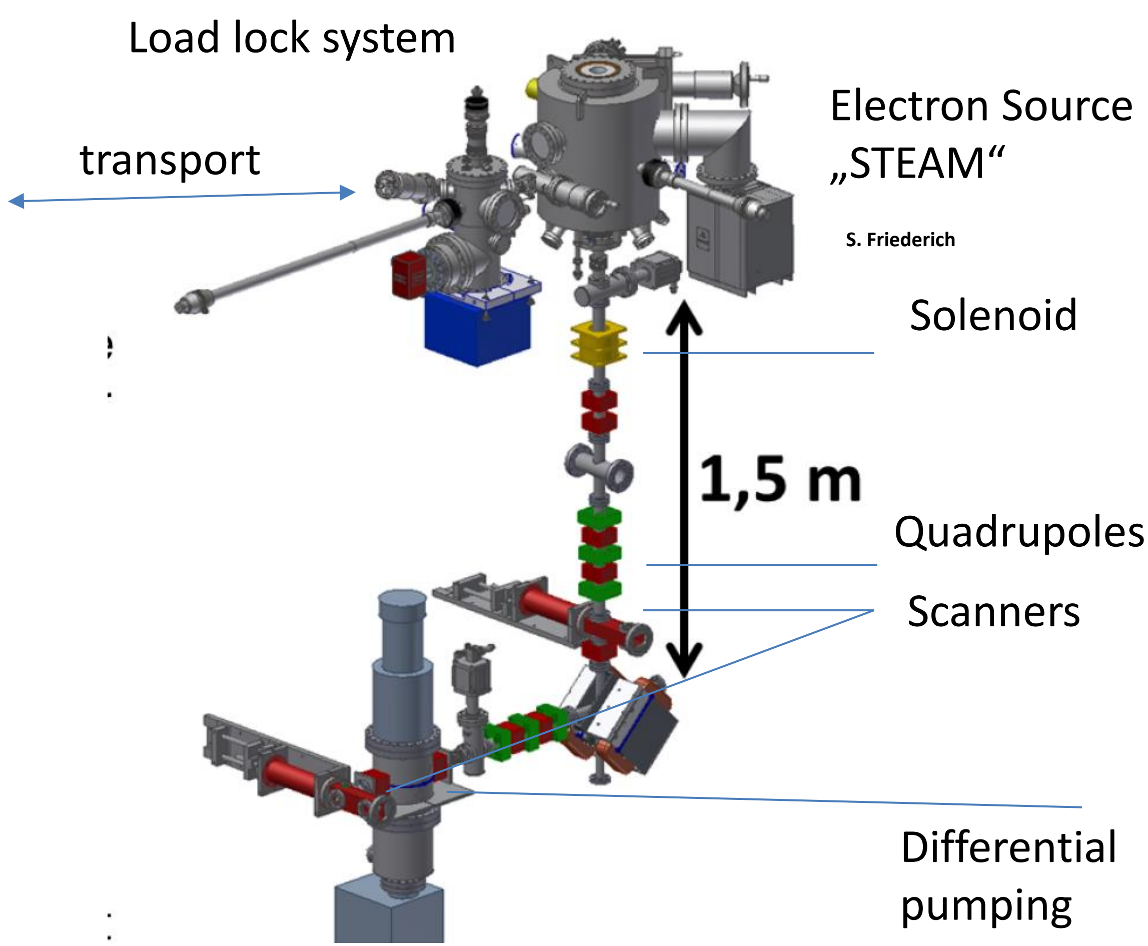
Assembly of source STEAM & first part of beamline "MELBA" has started

Photocathode „factory"





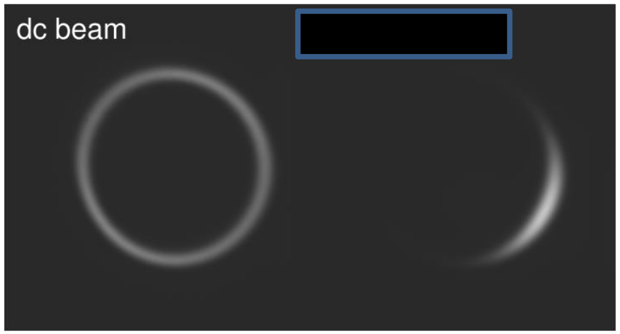
V. Bechthold



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

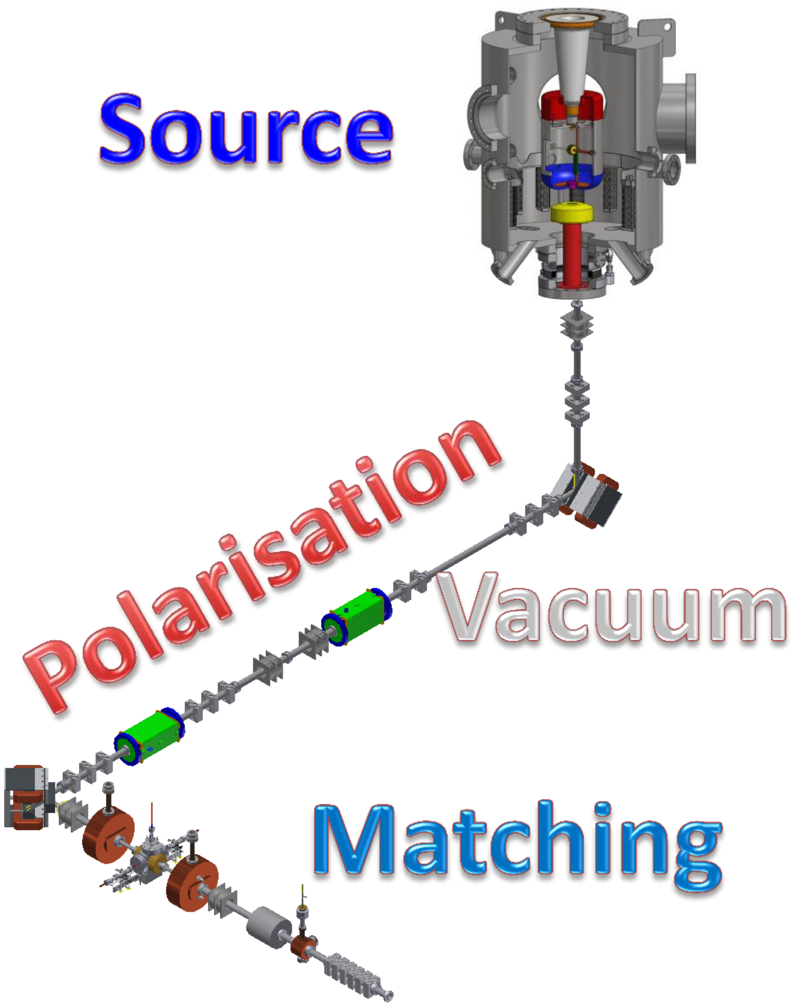
Assembly of MELBA (MEsa Low Energy Beam Apparatus) in 2016

Blue ray disc laser and longitudinal diagnostics already tested….



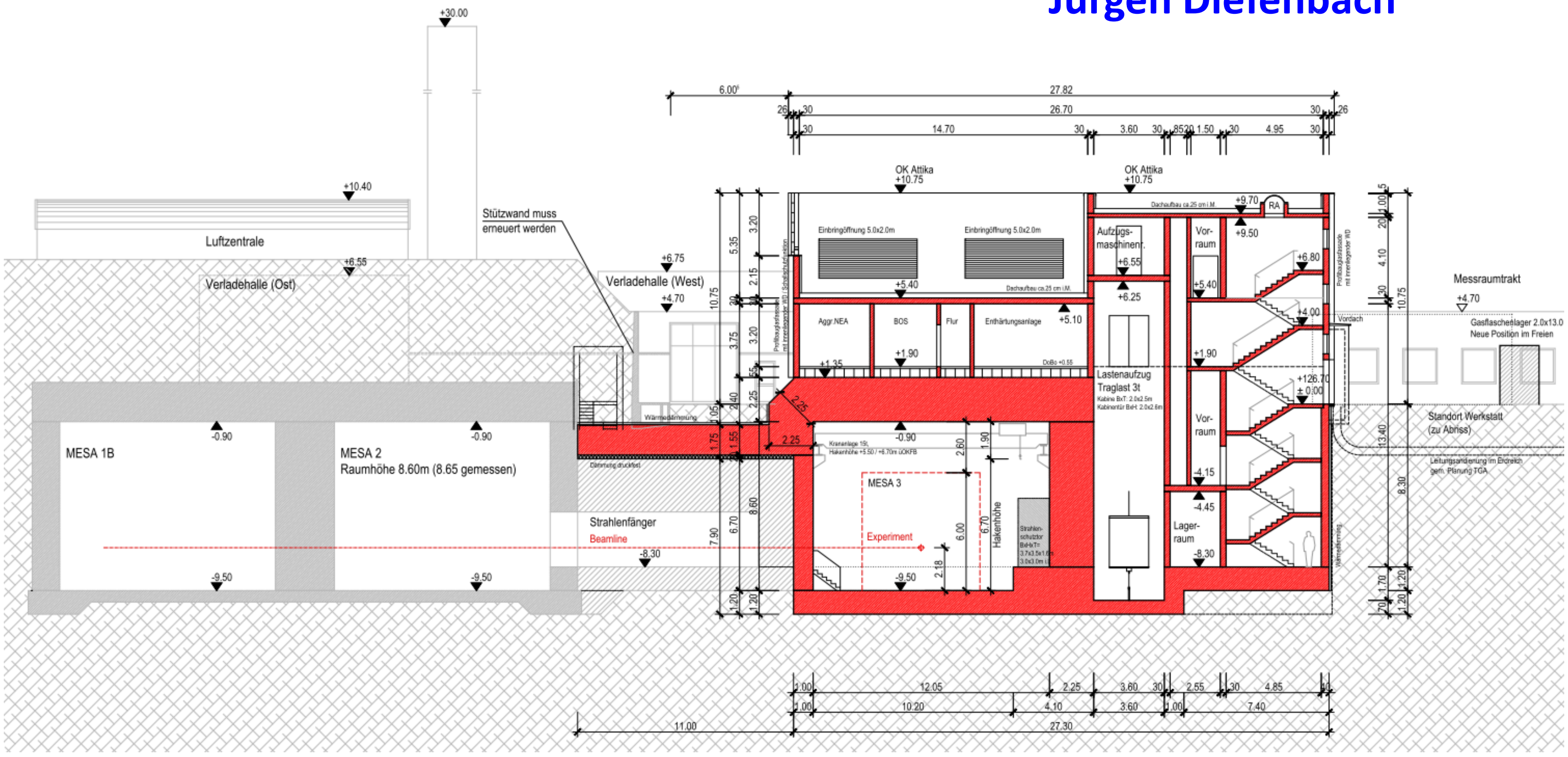
I. Alexander

Longitudinal diagnostics at Bunch charges corresponding to > 1mA average current



"Centrum für Fundamentale Physik", CFP
New underground building-some details

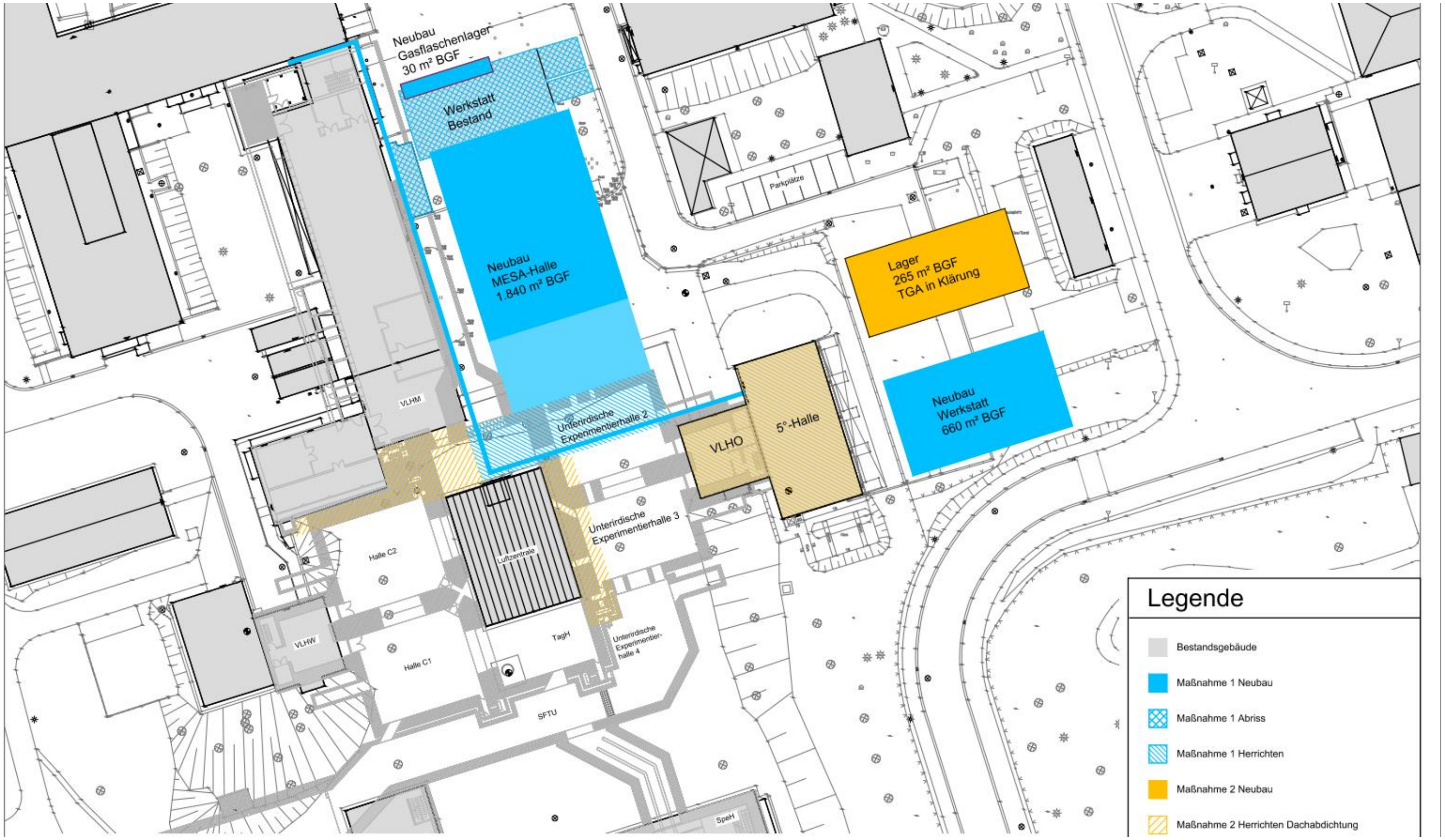
Radiation protection: see talk by **Jürgen Diefenbach**



Note: Experiment and Accelerator power and cooling will be installed in the Technical rooms of new building ! → excellent infrastructure conditions ! (if compared to initial suggestion…)

PLAN "B" – Kryogenics & R.f.

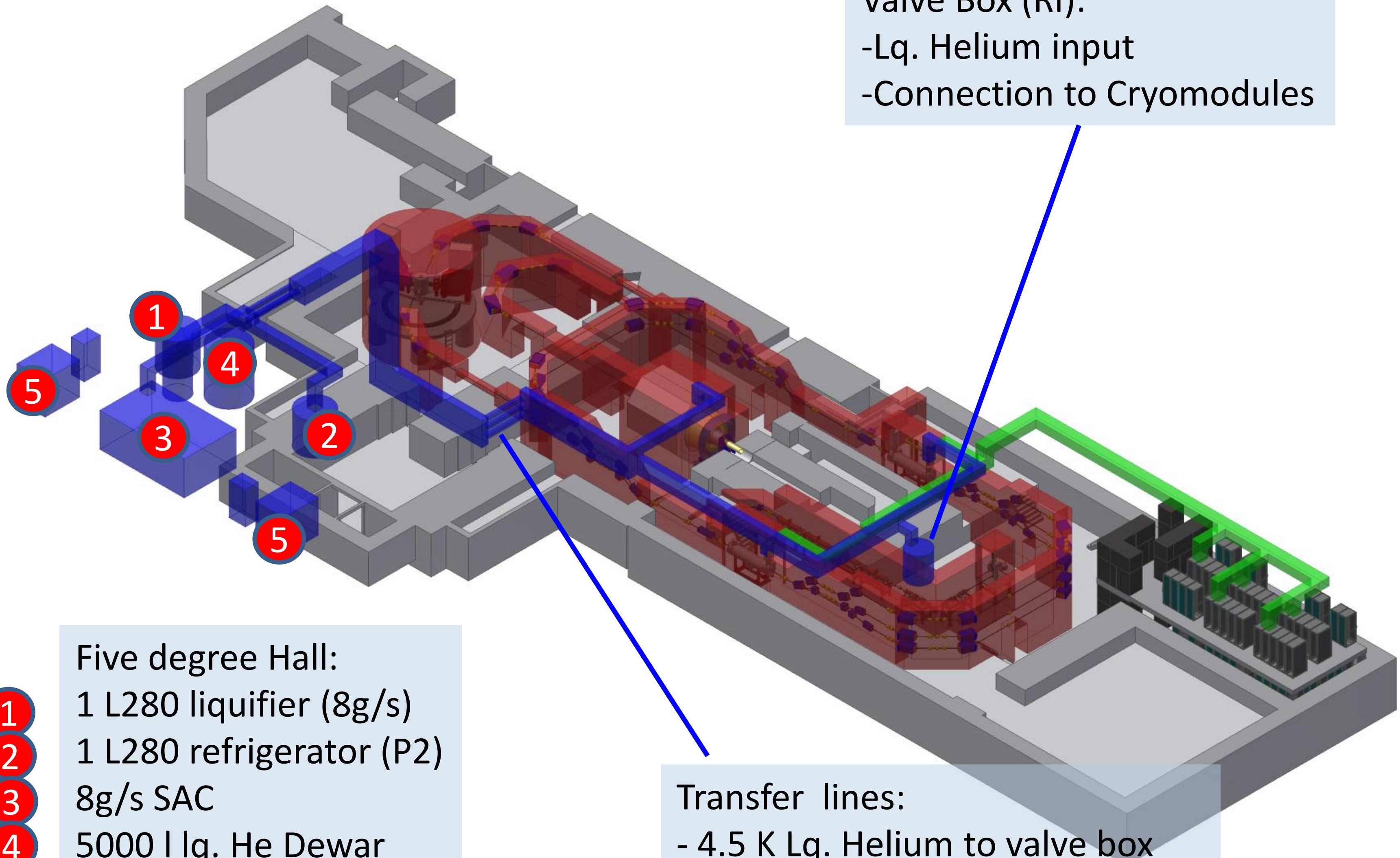
See talk by **D. Simon**



Five degree Hall becomes „Cryogenic center“

PLAN "B" – Kryogenics & R.f.

See talk by **D. Simon**



Valve Box (RI):
-Lq. Helium input
-Connection to Cryomodules

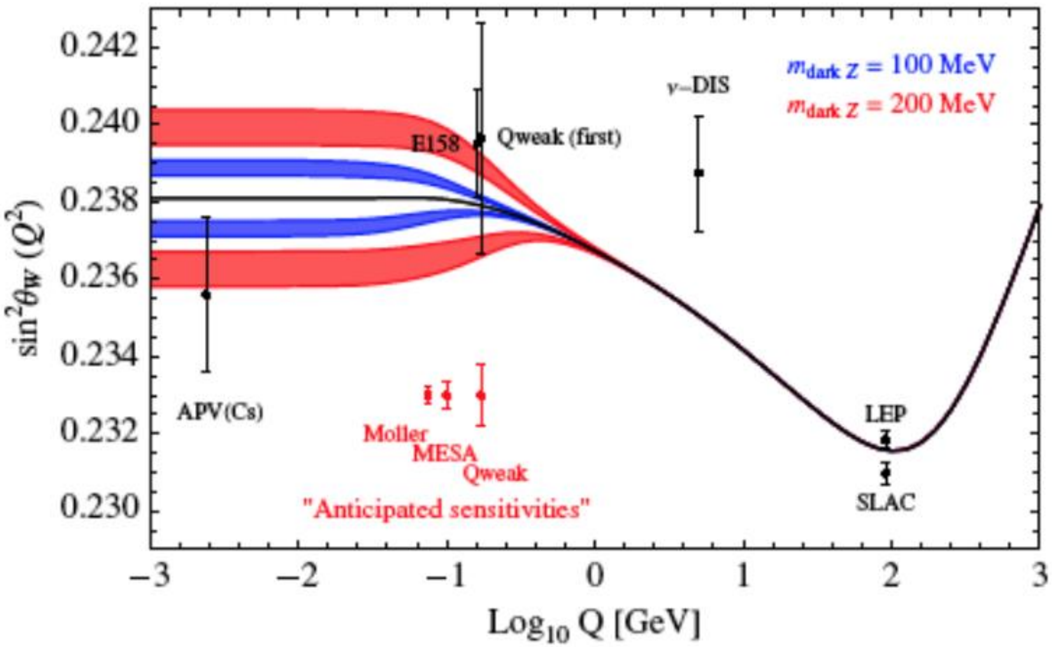
Five degree Hall:

1. 1 L280 liquifier (8g/s)
2. 1 L280 refrigerator (P2)
3. 8g/s SAC
4. 5000 l lq. He Dewar
5. 2*250 kW Kompressor

Transfer lines:
- 4.5 K Lq. Helium to valve box
- 16mbar gas from box

~15 K gas to/from P2 refrigerator

The P2 experiment at MESA



Influence of „dark Z boson" which also contributes to muon anomalous magnetic moment..

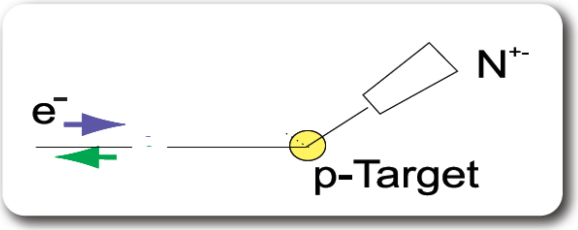
F. Maas, PAVI2014 conf.

„Elastic electron scattering on proton measures $1\text{-}4\sin^2\Theta_W$ → small asymmetry , high sensitivity

- Supressing hadronic contributions favours low momentum transfer and low beam energy

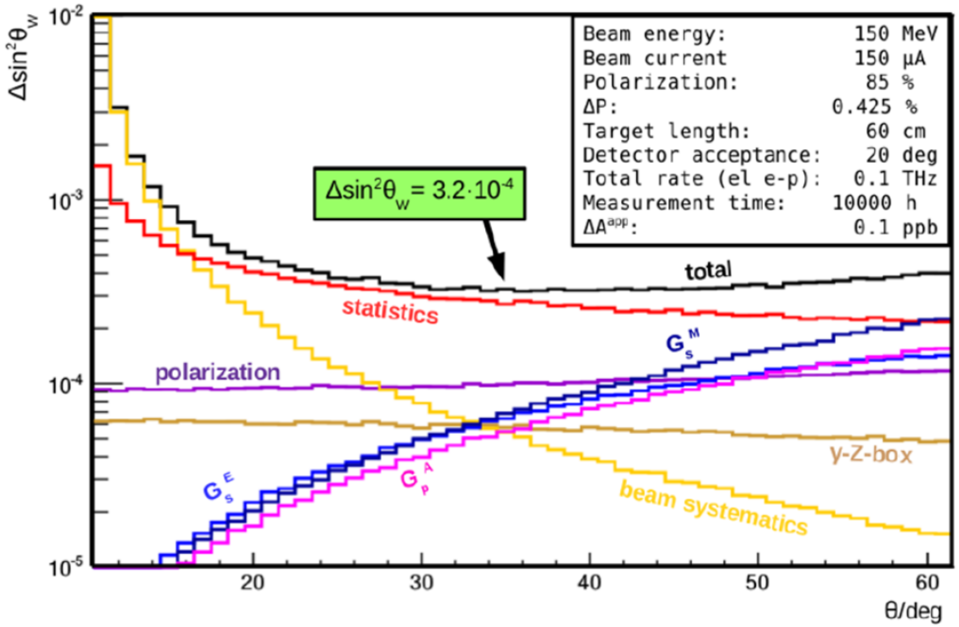
The P2 Experiment at MESA

-basic demands



$$A_{\exp} = PA_{Phys} = \frac{N\uparrow - N\downarrow}{N\uparrow + N\downarrow}$$

$$A_{Phys} \propto \frac{Q^2}{M_Z^2}(1 - 4\sin^2(\Theta_W))$$



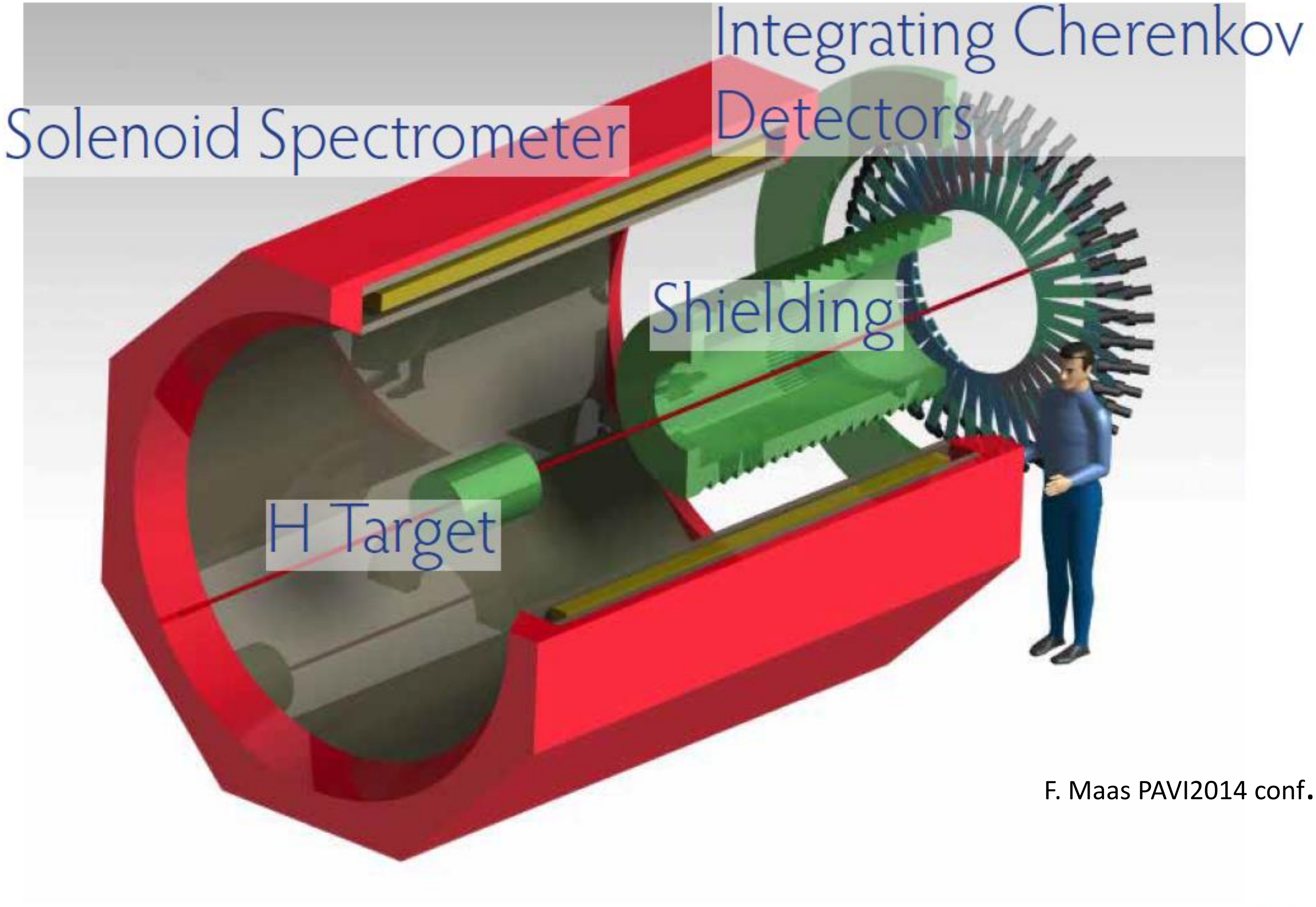
→ small asymmetry =P*35ppb, to be measured with 500ppt accuracy,

→ but high sensitivity towards $\sin^2\theta_W$

- 150 µA Beamcurrent, 60cm lq. H2, Beampol: 85%.,10000 h Data-taking
- High accuracy polarization measurement (ΔP/P=0.5% !!)
- Extremely high demands on control of HC-fluctuations!
- Count rate several hundred Gigahertz → Integrating detector + spectrometer

F. Maas PAVI2014 conf.

The P2 Experiment at MESA
- detector

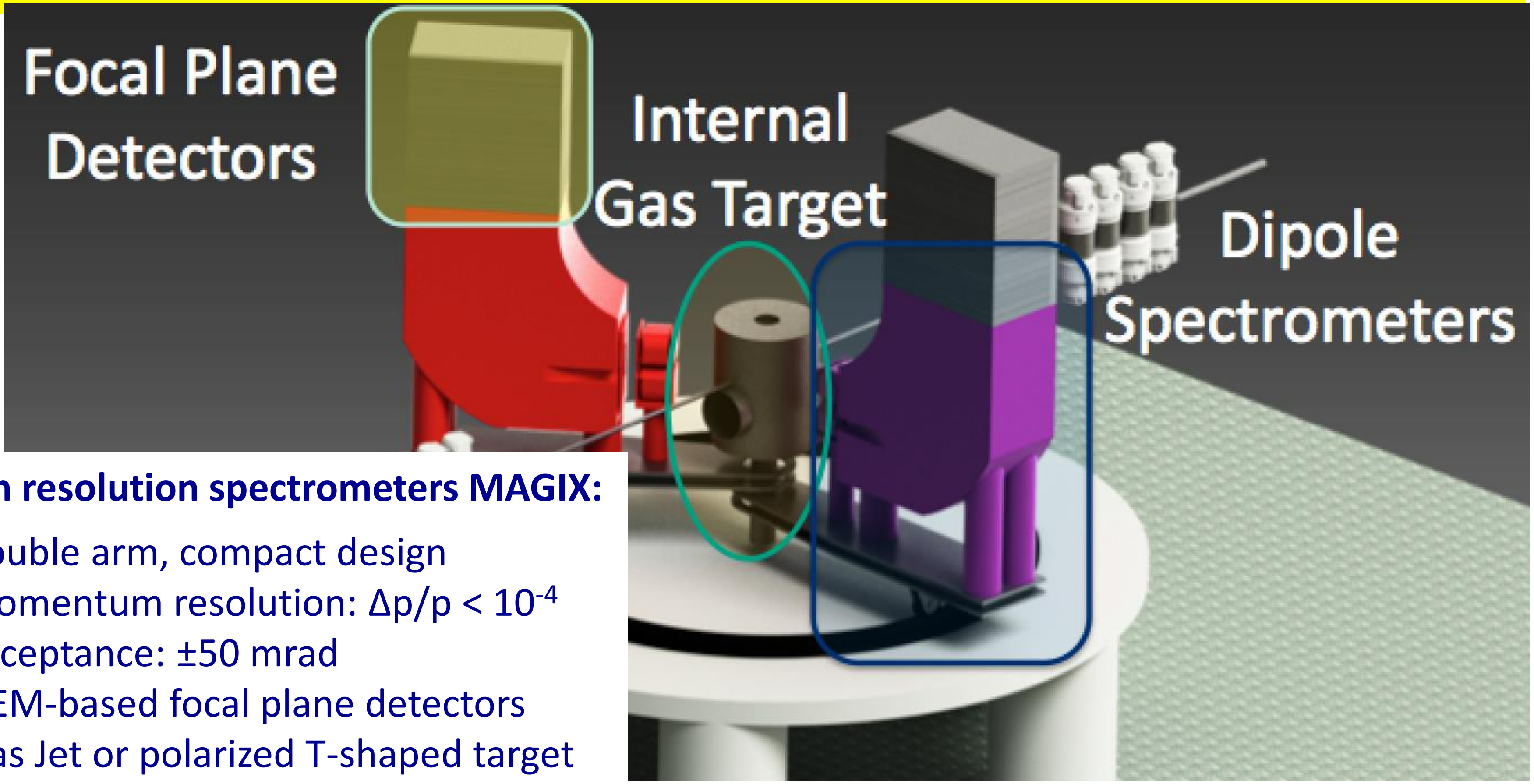


F. Maas PAVI2014 conf.

MAGIX-basic features

Operation of a high-intensity (polarized) ERL beam
in conjunction with light internal target

→ **a novel technique in nuclear and particle physics**
→ **measurement of low momenta tracks with high accuracy**
→ **competitive luminosities**
→ **Small device if compared to GeV scale spectrometer set ups!**



High resolution spectrometers MAGIX:

- double arm, compact design
- momentum resolution: $\Delta p/p < 10^{-4}$
- acceptance: ±50 mrad
- GEM-based focal plane detectors
- Gas Jet or polarized T-shaped target

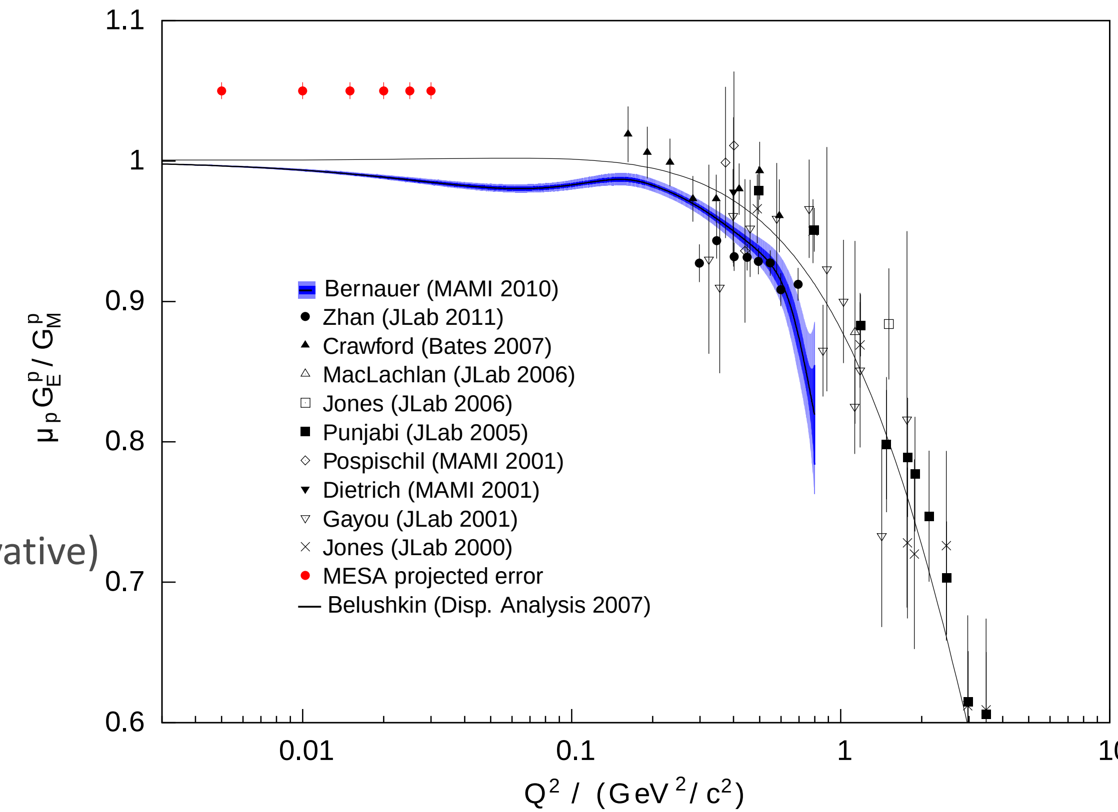
MAGIX polarized portfolio-I / Form factors

Revived interest in form factors due to „proton radius puzzle“

MAGIX allows to address much smaller momentum transfer due to very low energy, momentum transfer and minimized material budget…

H⁻ ion by
The New York Times

Example Electric/Magnetic Form Factor Ratio from double polarized Beam-Target asymmetry

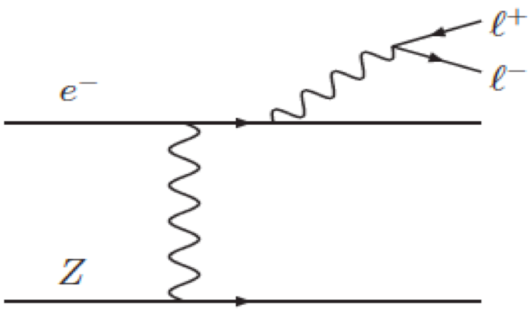


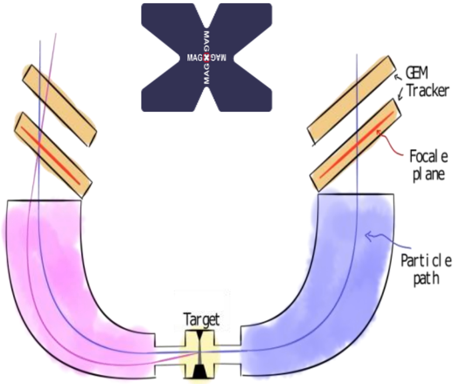
Simulation:

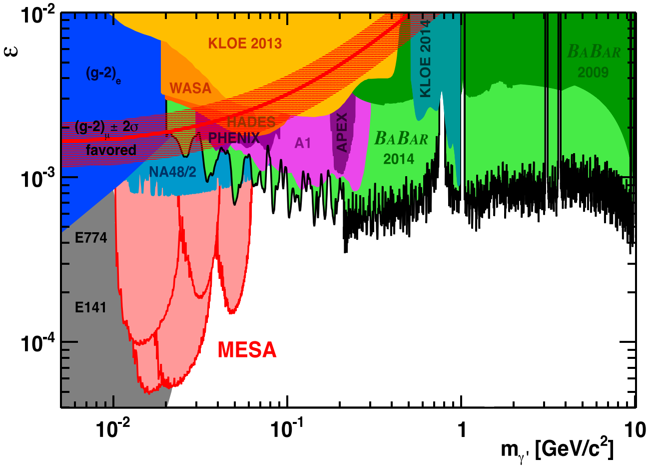
- Polarized target, 3 x 10^{15} / cm^2 (very conservative)
- 80% polarisation
- 1mA beam current, 105 MeV

MAGIX portfolio-II / dark photon searches

- Pseudo internal target experiment: Initially foreseen for dark photon search



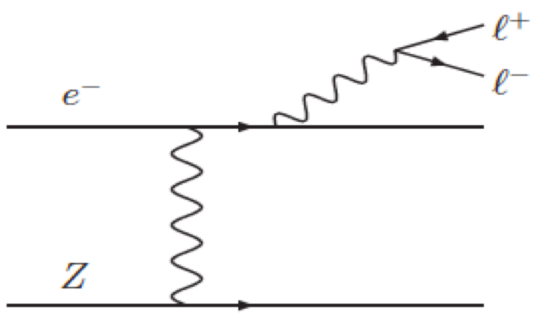


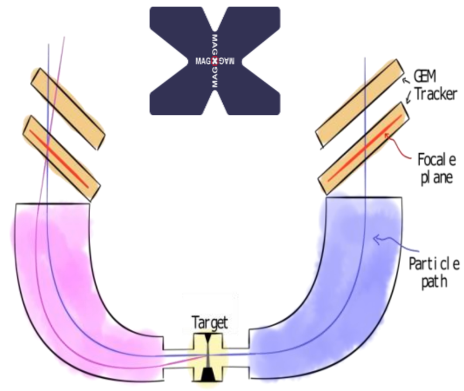


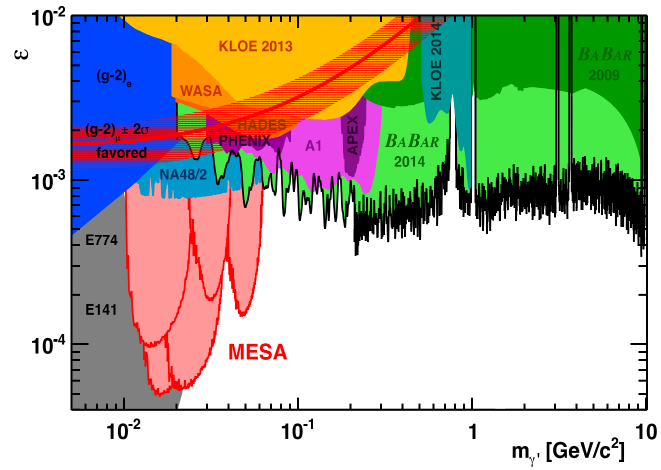
Expected coverage…

MAGIX portfolio-II / dark photon searches

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

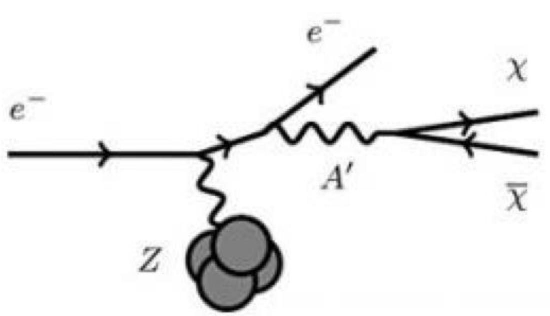






Expected coverage…

- 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!