STATUS OF THE MESA PROJECT

- EXPLORING NEW TECHNIQUES FOR ACCELERATOR BASED RESEARCH

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

PRISMA

Work supported by DFG through excellence cluster PRISMA

SPIN 2016,
September 29th, 2016

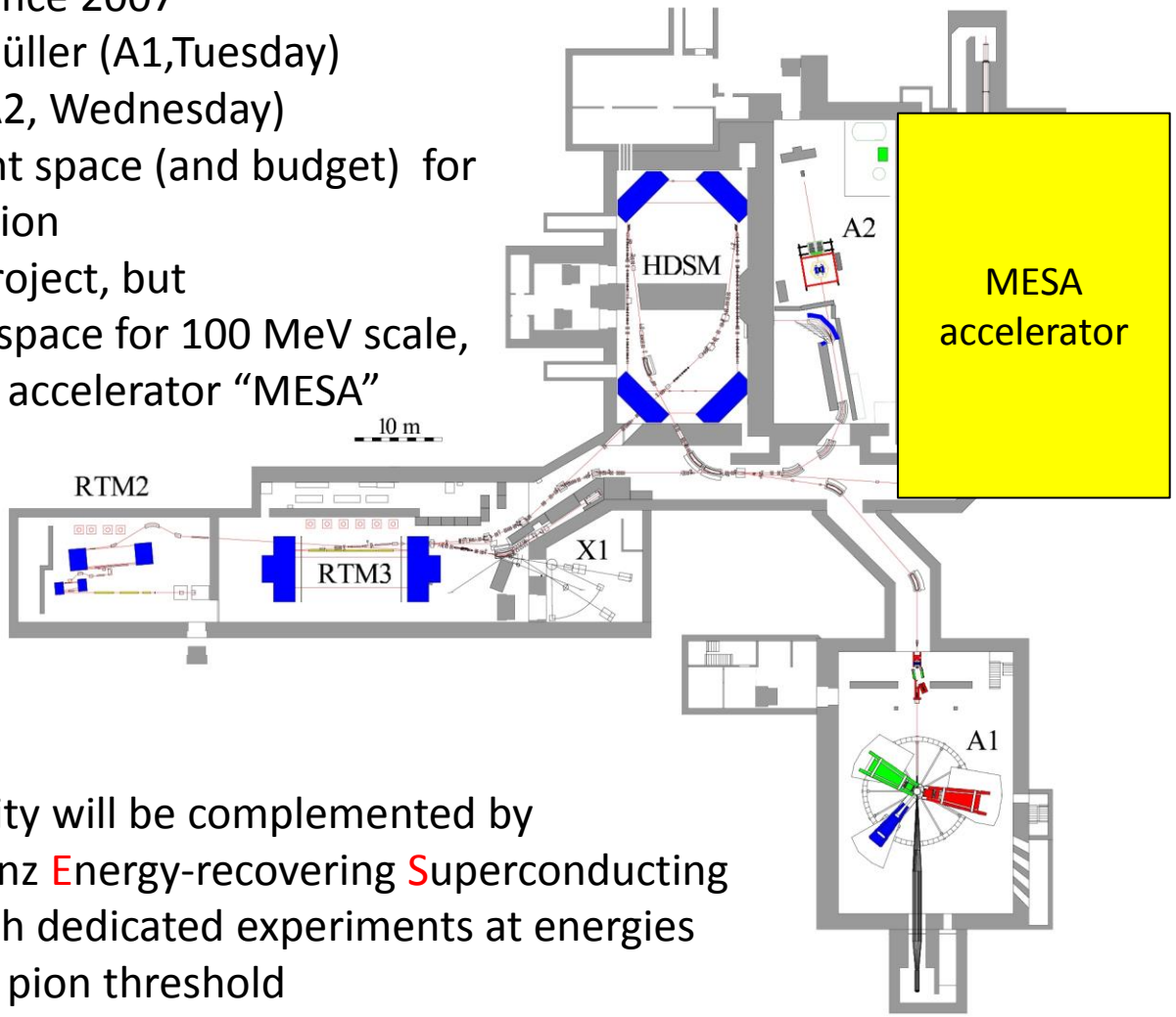
OUTLINE

- The MESA Concept
- Accelerator Layout
- Exp-1: „P2“
  - a conventional polarised beam experiment pushed to the limit
- Exp-2: „MAGIX“
  - opportunities of a new experimental regime at low energies

The MESA Concept:
What is an ERL and what is it good for?

Expanding the MAMI facility by “MESA”

- 1.6 GeV c.w. electron accelerator “MAMI-C” in operation since 2007
- talks by U. Müller (A1,Tuesday) A. Thomas (A2, Wednesday)
- BUT:Insufficient space (and budget) for further extension
- no MAMI D project, 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

The ERL primer

Linacs have many advantages but they are very expensive
Main cost driver for high intensity is RF-power.

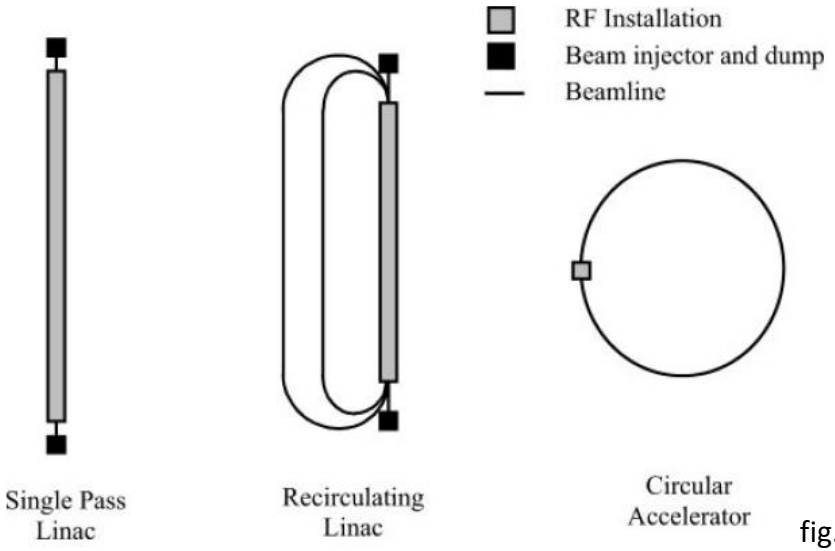


Figure 1 Main accelerator types.

fig. taken from
L. Merminga et al.:
Annu. Rev. Nucl. Part. Sci. 2003. **53**:387–429

- **Recirculating linacs** reduce investment and running costs, but do not really „solve“ the issue
- **Storage rings** are extremely effective, but are limited in luminosity, in particular at low energies

The idea of an **E**nergy **R**ecovery **L**inac is to recover the kinetic energy in the same RF-resonator that has accelerated the particle. (Tigner, 1965).

Tigners idea

Tigner, M. *Nuovo Cim.* 37:1228 (1965)

LETTERE ALLA REDAZIONE

(La responsabilità scientifica degli scritti inseriti in questa rubrica è completamente lasciata dalla Direzione del periodico ai singoli autori)

A Possible Apparatus for Electron Clashing-Beam Experiments (*).

M. TIGNER

Laboratory of Nuclear Studies, Cornell University - Ithaca, N. Y.

(ricevuto il 2 Febbraio 1965)

tions. A schematic drawing of this arrangement is given in Fig. 3. In this configuration the beam is turned back upon itself and re-enters the accelerator where it gives back its energy to the

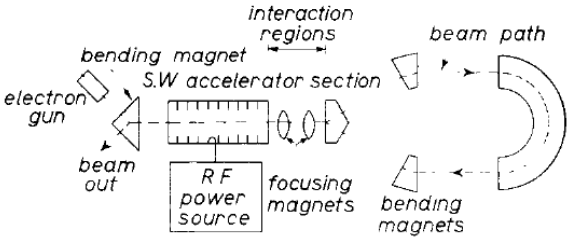
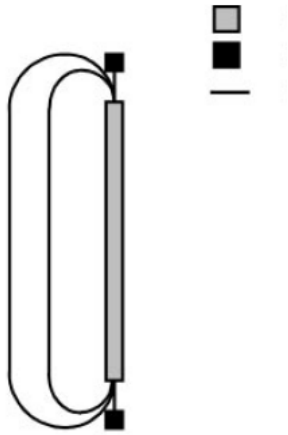


Fig. 3.

accelerating field provided that the path length through the magnet system has been correctly chosen. As shown the magnet system would work only for



Recirculating Linac

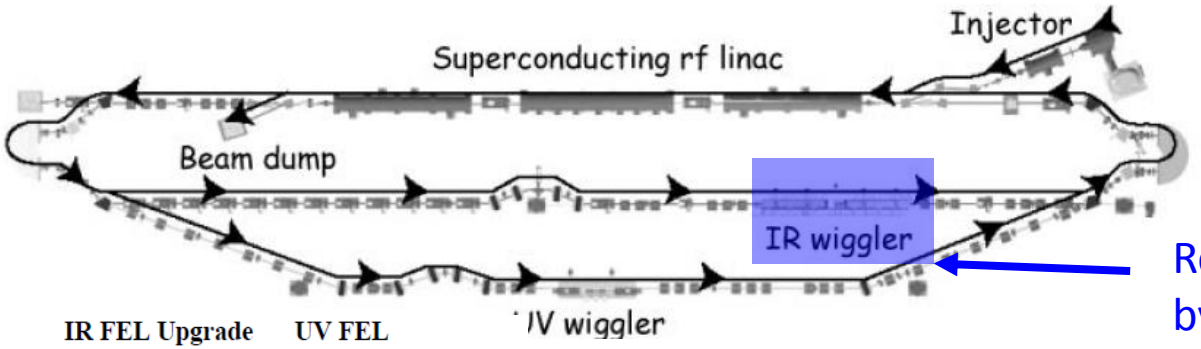
Main accelerator types.

Decelleration demonstrated in the 1970‘s in “Reflexotron” Linacs

→ Parasitic Bunch collisions can be avoided by using the recirculating linac arrangement

→ Idea was not pursued seriously until the 1990’s…

c.w. Laser from an accelerator (JLAB 2001)



Replace wiggler by „Pseudo“ internal target

Parameter	IR FEL Upgrade	UV FEL
Beam energy at wiggler	80–210 MeV	200 MeV
Average beam current	10 mA	5 mA
Bunch charge	135 pC	135 pC
Bunch repetition rate	74.85 MHz	74.85 MHz
Normalized emittance (rms)	13 mm-mrad	5–10 mm-mrad
Bunch length at wiggler (rms)	200 fs	200 fs
Peak current	270 A	270 A
FEL extraction efficiency	1%	0.25%
$\delta p/p$ before wiggler (rms)	0.5%	0.125%
$\delta p/p$ after wiggler (full)	10%	5%
CW FEL power	>10 kW	>1 kW

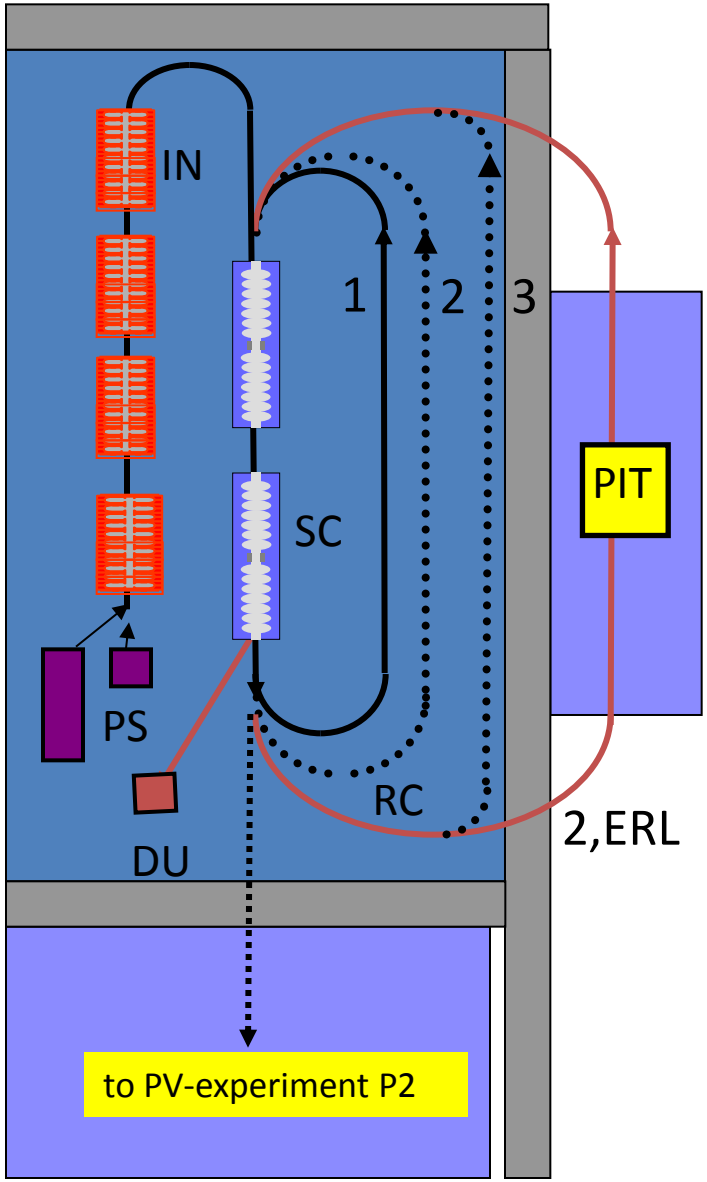
L Merminga et al. Ann. Rev. Part. Sci 53 387 (2003)

JLAB ERL Laser output: 10kW
Beam Power in Wiggler: ~1MW
R.F power needed: ~100kW

The energy taken away by scattered particles in one passage of the target can be much smaller than the one extracted in the FEL
→ Experiments with „Pseudo“ internal targets could be attractive.
(Proposed for dark matter search by Heinemayer et al. (2007): arXiv:0705.4056v2)

MESA Layout

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 (as of today):

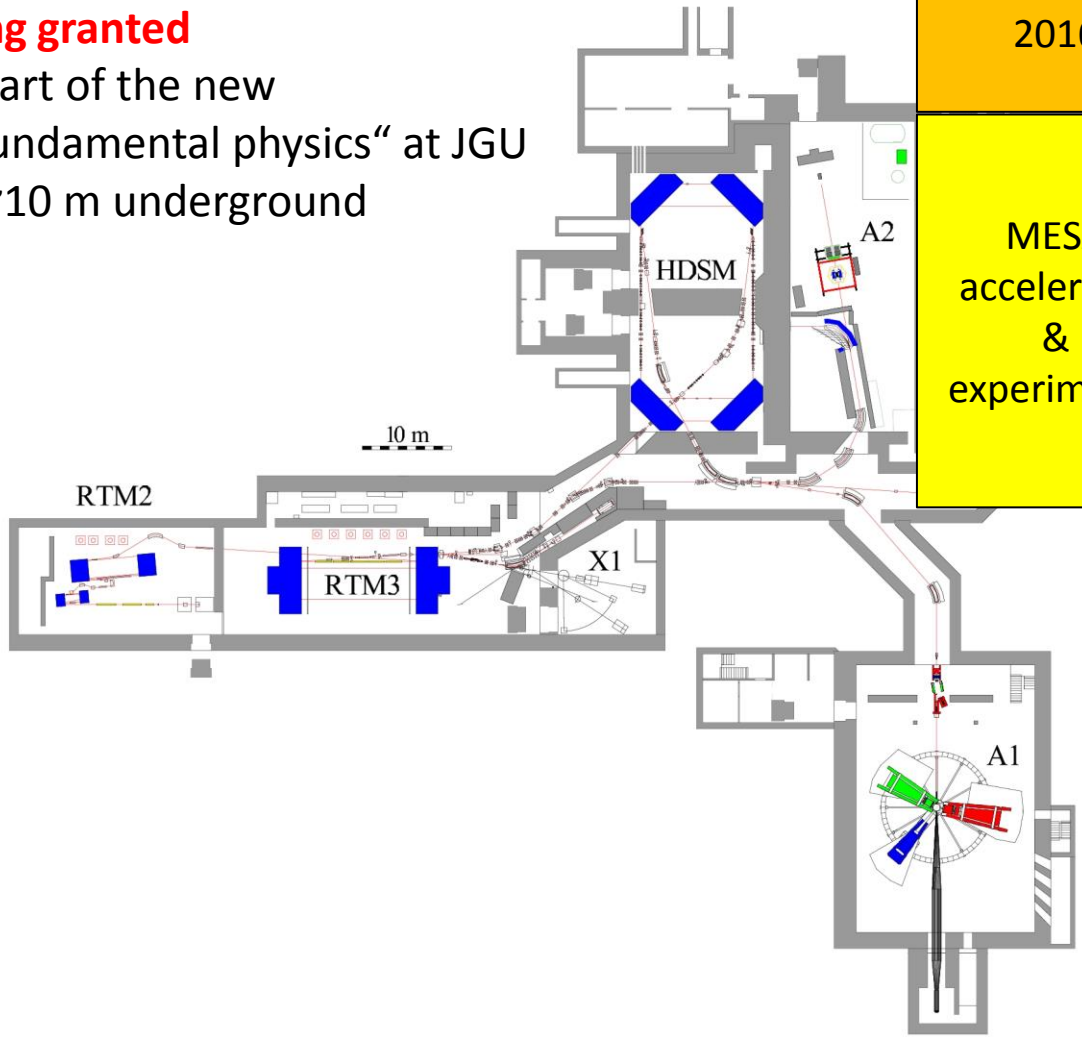
CW beam

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

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

MESA EXTENSION BUILDING

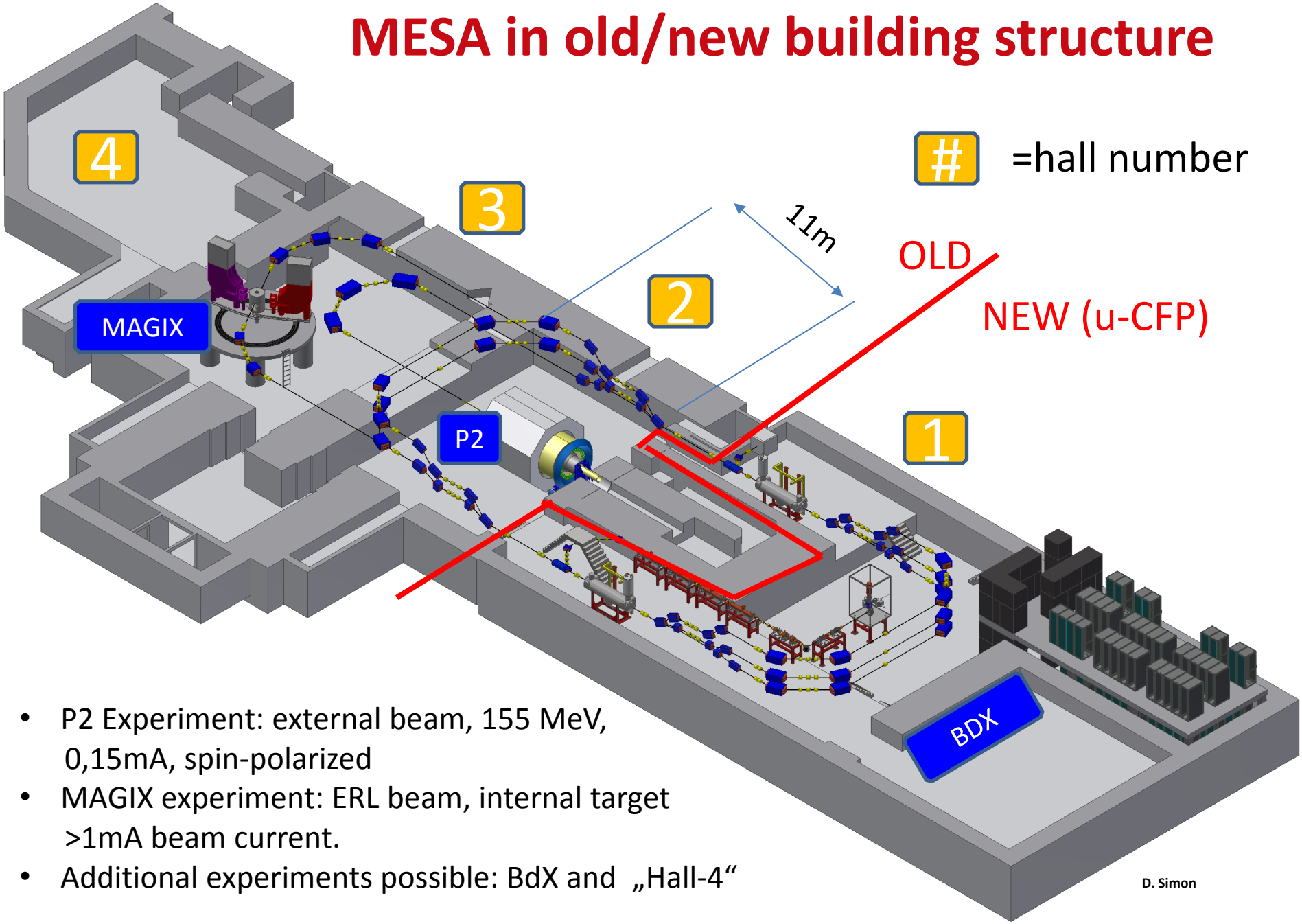
- -Ideas for several additional experiments with MESA ...
- ...Endorsed by funding authorites:
  new building granted
- Building is part of the new
  „Center of fundamental physics“ at JGU
- floor level ~10 m underground



New exptl. hall (CFP) funded in 2016

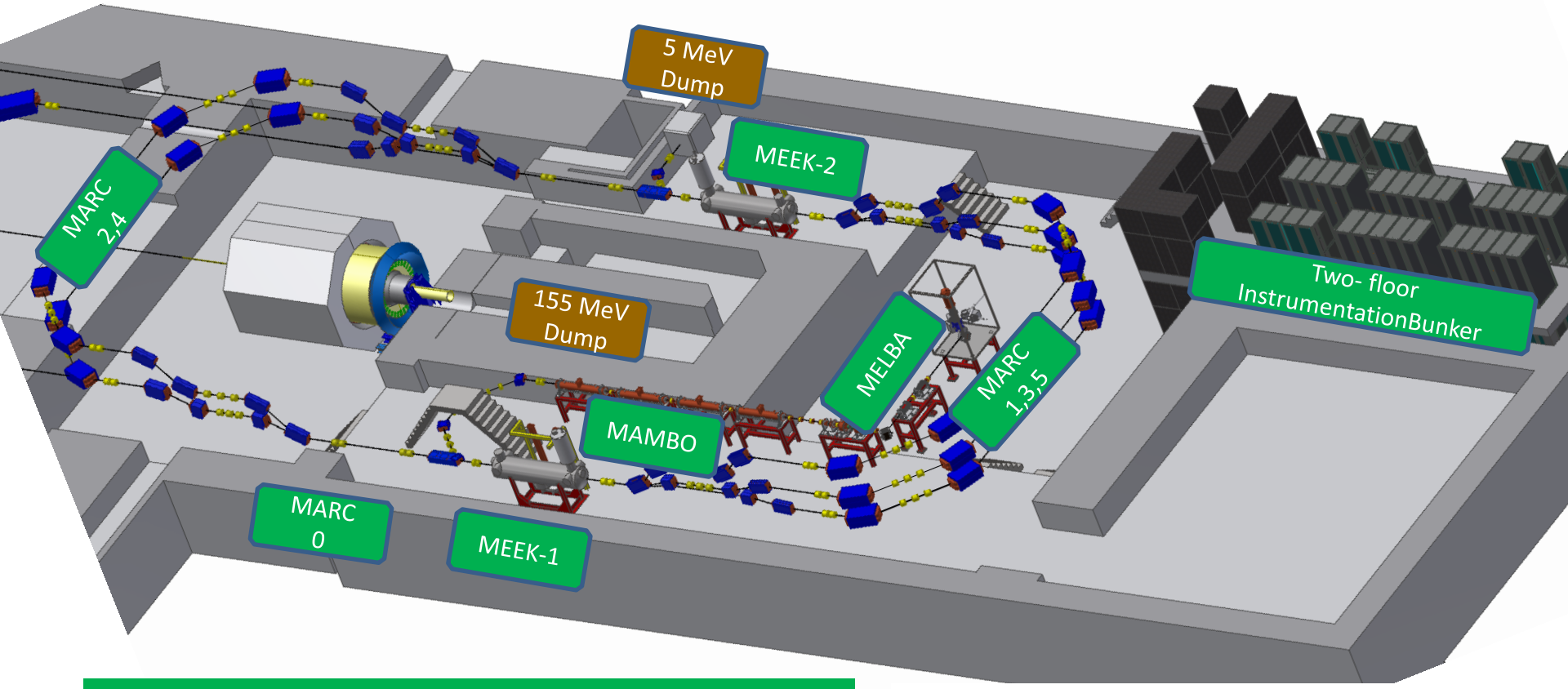
MESA accelerator & experiments

MESA in old/new building structure



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

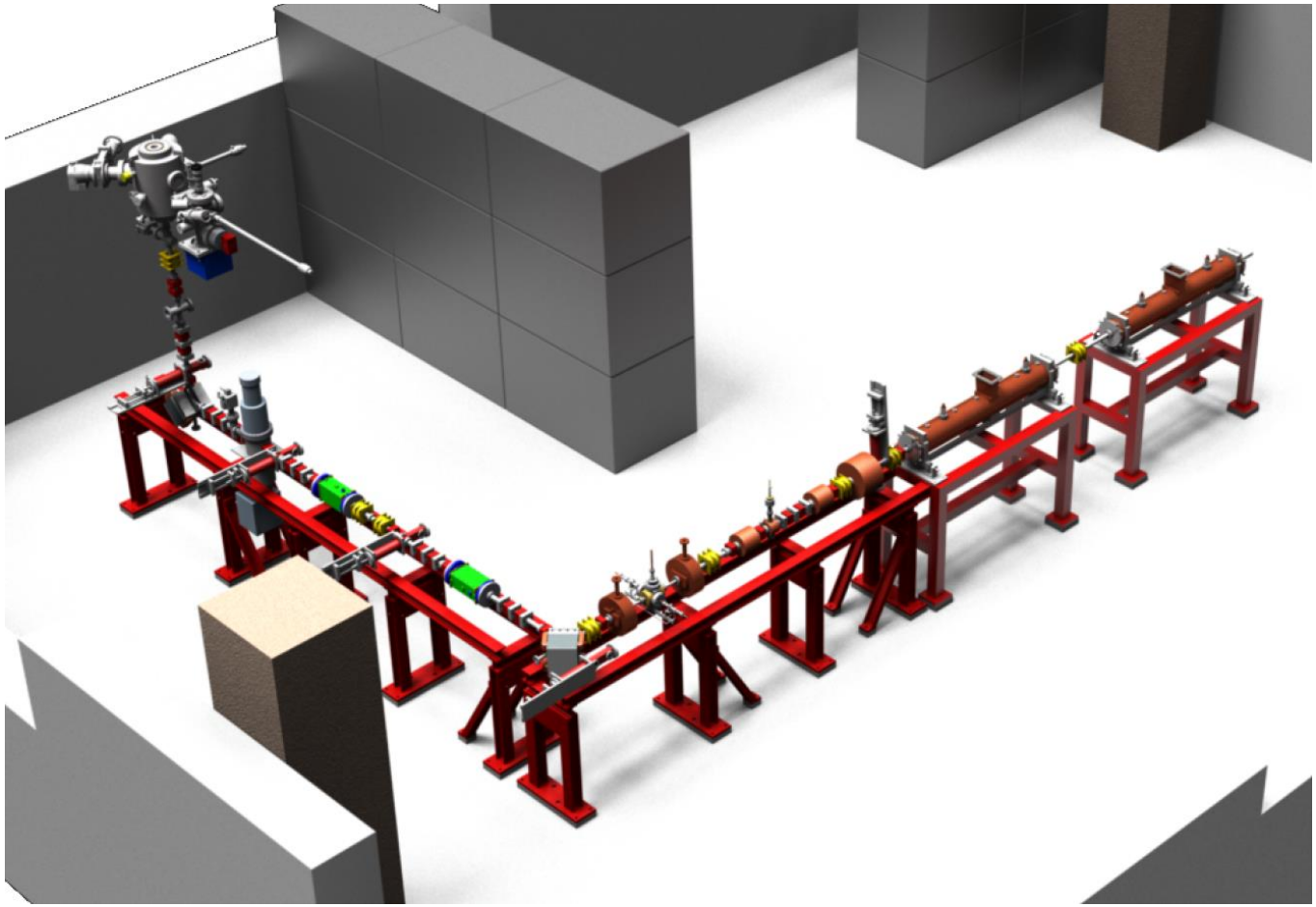
Accelerator components



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

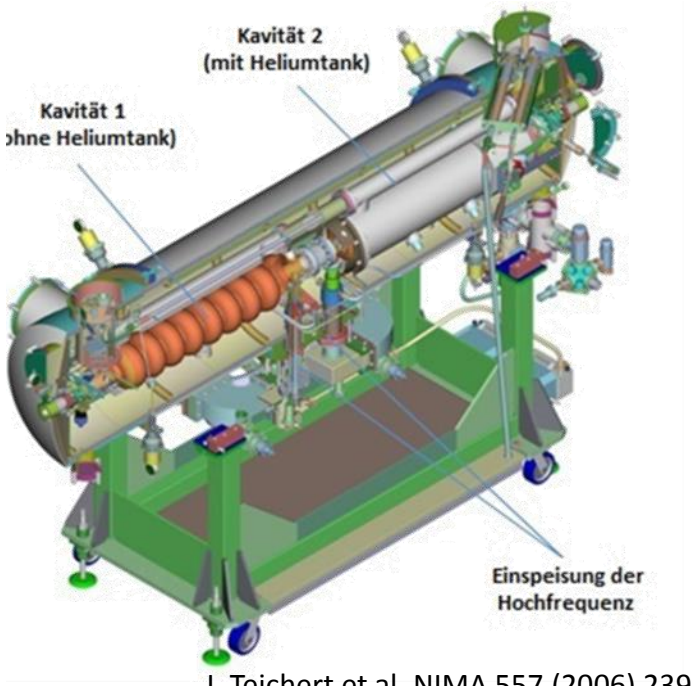
MELBA& MAMBO will be tested until end 2018 in available buiding
MEEK‘s will be tested in new testing hall
MARC‘s cannot be installed before 2020

Beam test of MELBA and “50%” MAMBO planed until end 2018

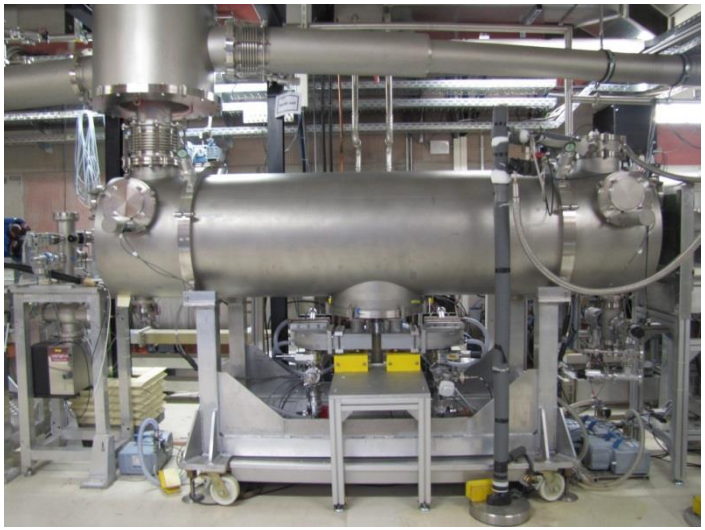


- First two sections of MAMBO will be installed. →2.5 MeV „full relativistic“ beam
- 1300 MHz Rf power generated by **solid state amplifiers** with up to 80kW c.w.
- Beam current >1mA can be tested

MEEK (Mesa Elbe Enhanced Kryomodules)



J. Teichert et al. NIMA 557 (2006) 239

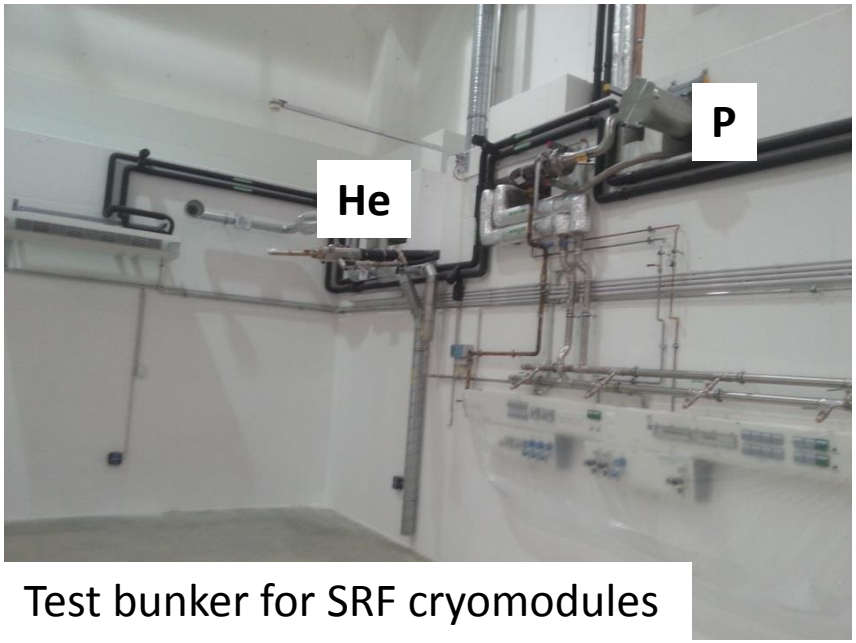


Installation at ELBE

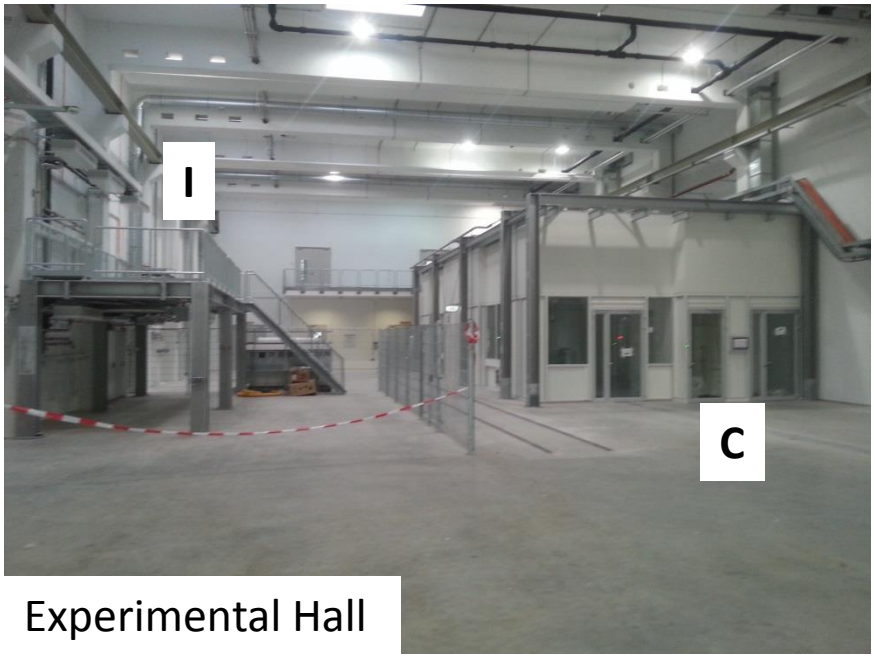
- Design Gradient 13MV/m at Q_0 =1.5*$10^{10.}$
- 2 Cryomodules with four cavities will yield 50MeV energy gain/turn
- „Enhancements“: -faster tuner and improved HOM capabilities for higher current
- Under fabrication at RI Instruments Bergisch Gladbach
- Delivery date for the two modules and April/June 2017
- Performance tests at new „HIM experimental hall“

MEEK Cryomodules
-preparing for the test phase

„Helmholtz Institut Mainz“ (HIM) is eady for operation !



Test bunker for SRF cryomodules

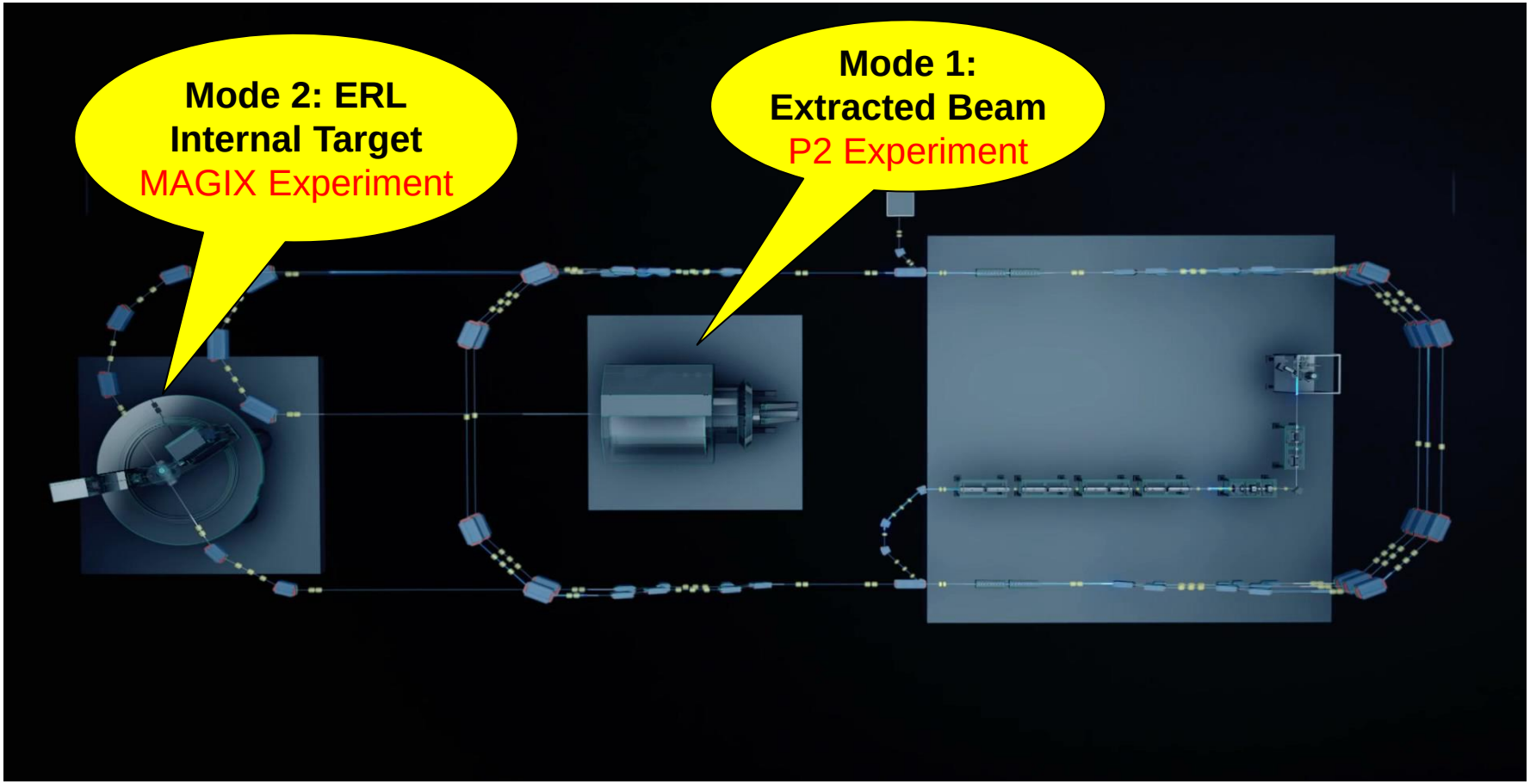


Experimental Hall

01 June 2016

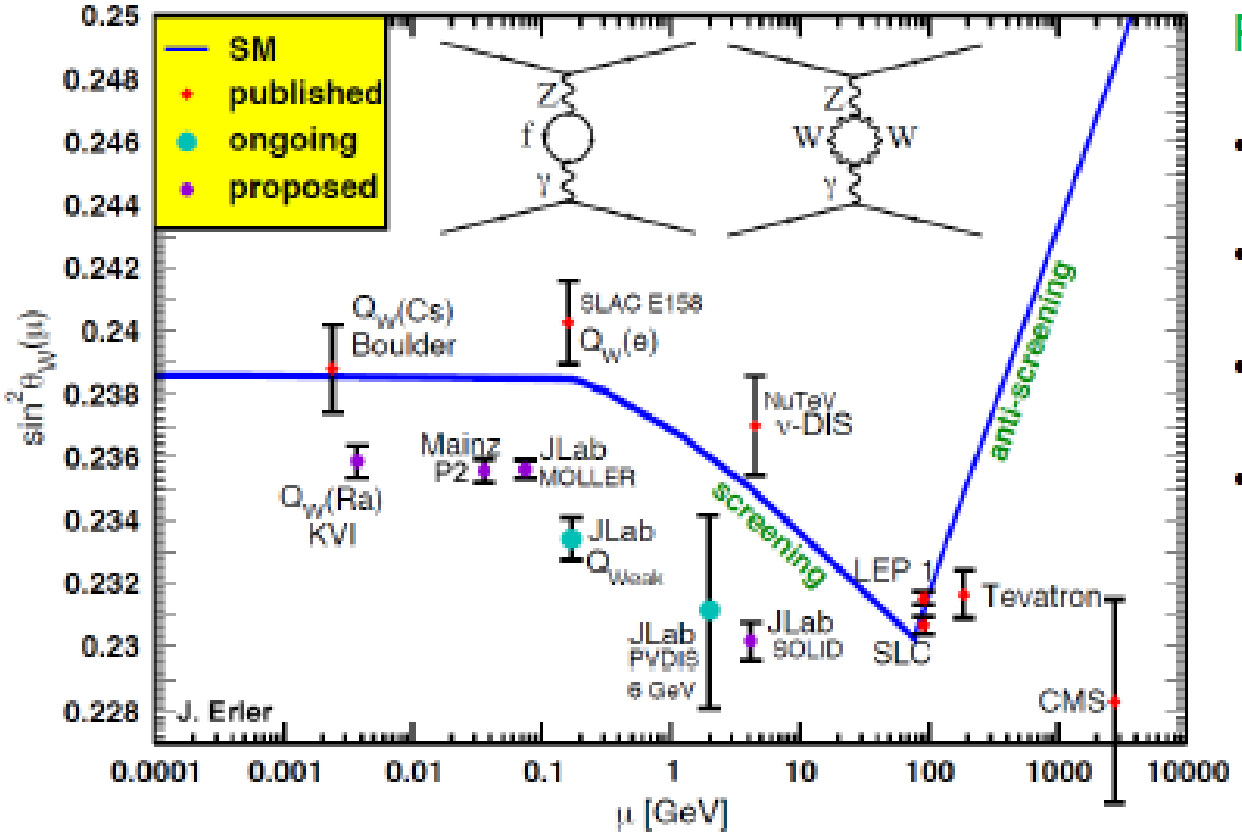
He: Lq. Helium supply line from liquifier in nuclear physics institute: >50l/hour through 220 m long pipe demonstrated. **P:** 4g/s pump stage at 16mbar is presently being ordered.
I: Instrumenttion platform, **C**: Clean room for cryomodule maintenance

Experiments at MESA



http://www.prisma.uni-mainz.de/1795.php#imagefilm

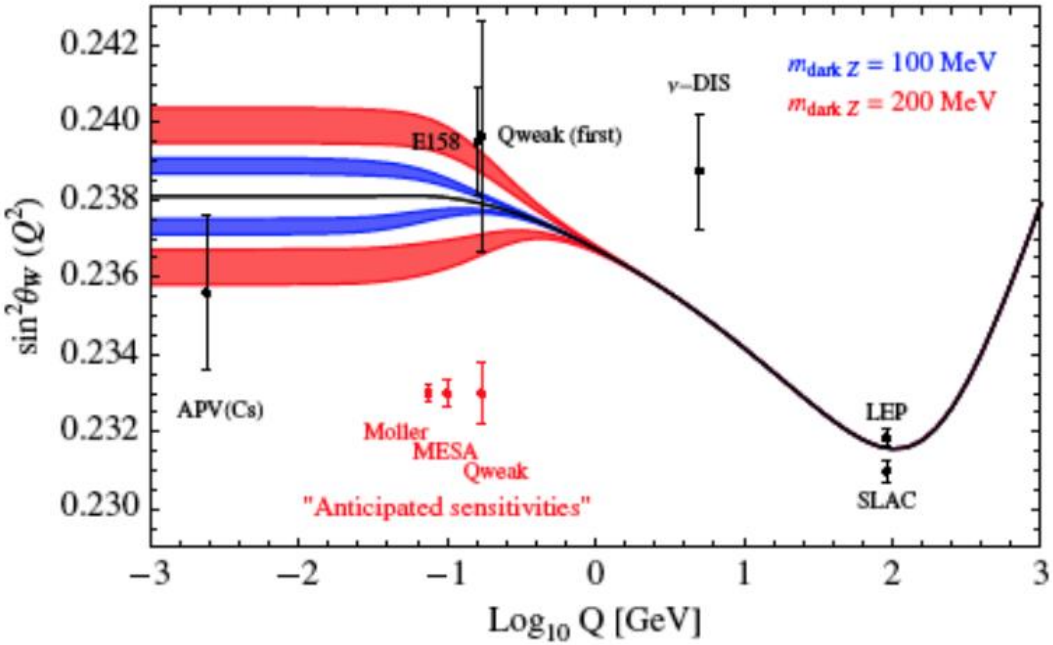
Electroweak mixing angle past, present and future



PDG 2014:

- Q_W(Cs): Atomic parity violation
- SLAC E158: Møller scattering
- NuTeV: Neutrino scattering
- Z-Pole Measurements
  - LEP
  - SLC
  - Tevatron
  - LHC

The P2 experiment at MESA



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

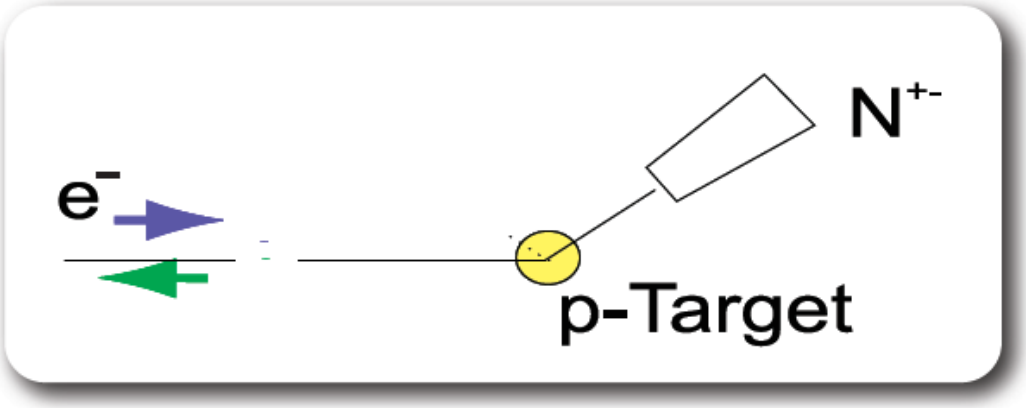
F. Maas, PAVI2014 conf.

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

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

The P2 Experiment at MESA

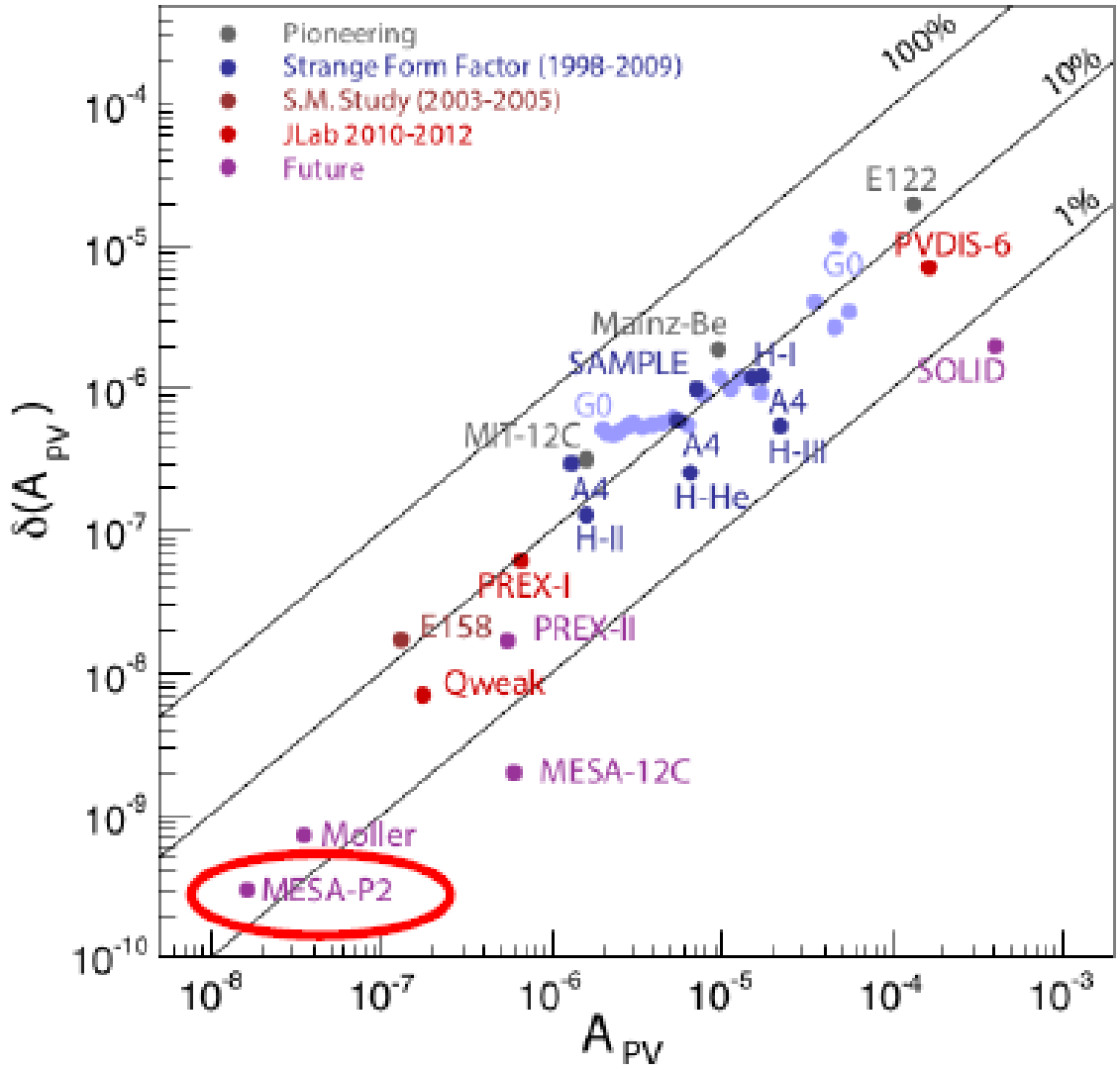
-basic demands



150 µA Beamcurrent , 60cm lq. H2, Beampol: 85%.
10000 h Data-taking (~13-15000 h Runtime)
High accuracy polarization measurement ($\Delta P/P=0.5\%$)
Extremely high demands on control of HC-fluctuations!

→ ~4000h/Year Runtime
→ Accelerator must be optimized for reliability& stability
→ Count rate several hundred Gigahertz→ Integrating detector + spectrometer

The P2 experiment at MESA

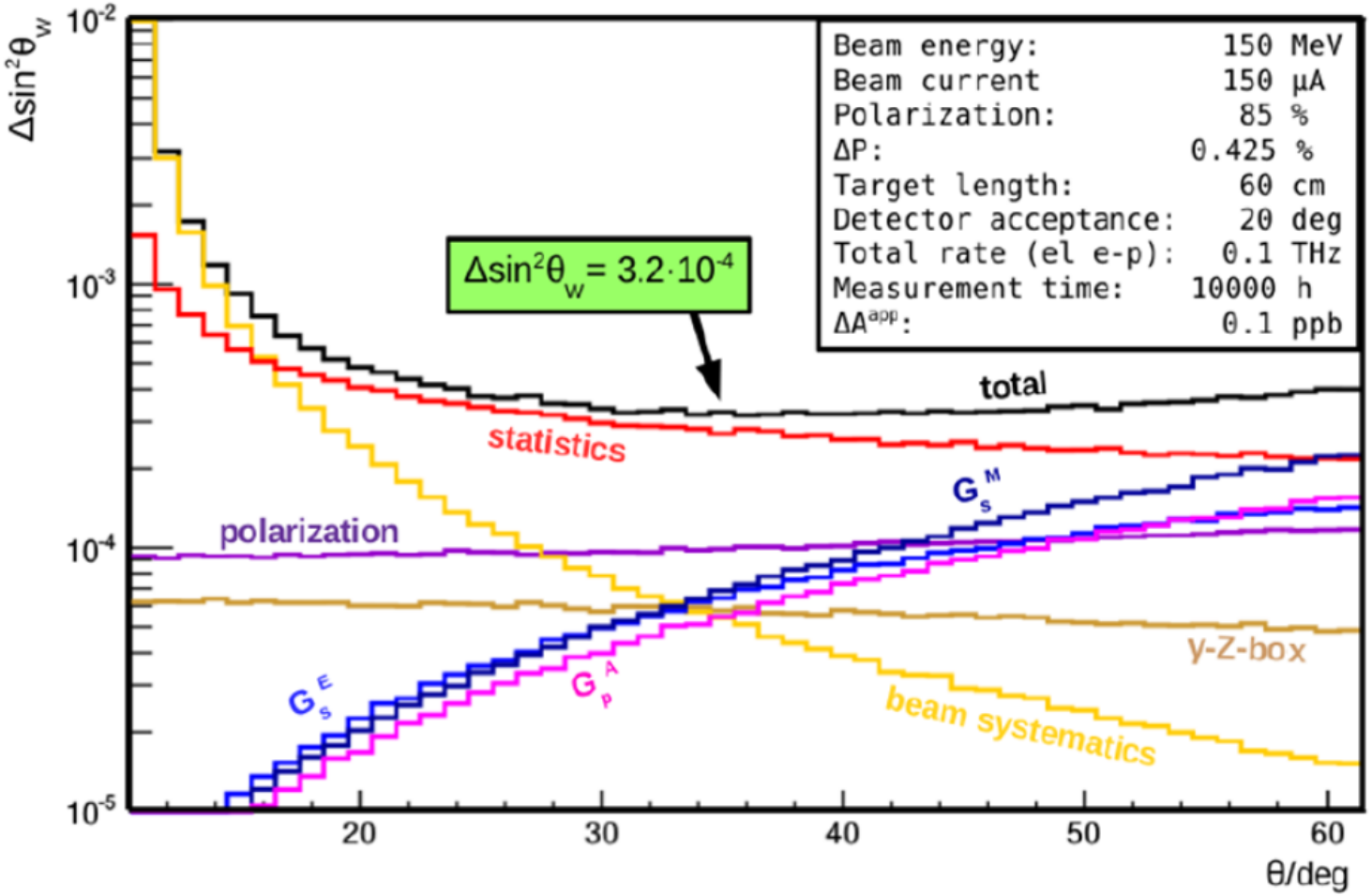


P2 experiment

A = -28.35 ppb

ΔA = 0.44 ppb

The P2 experiment at MESA



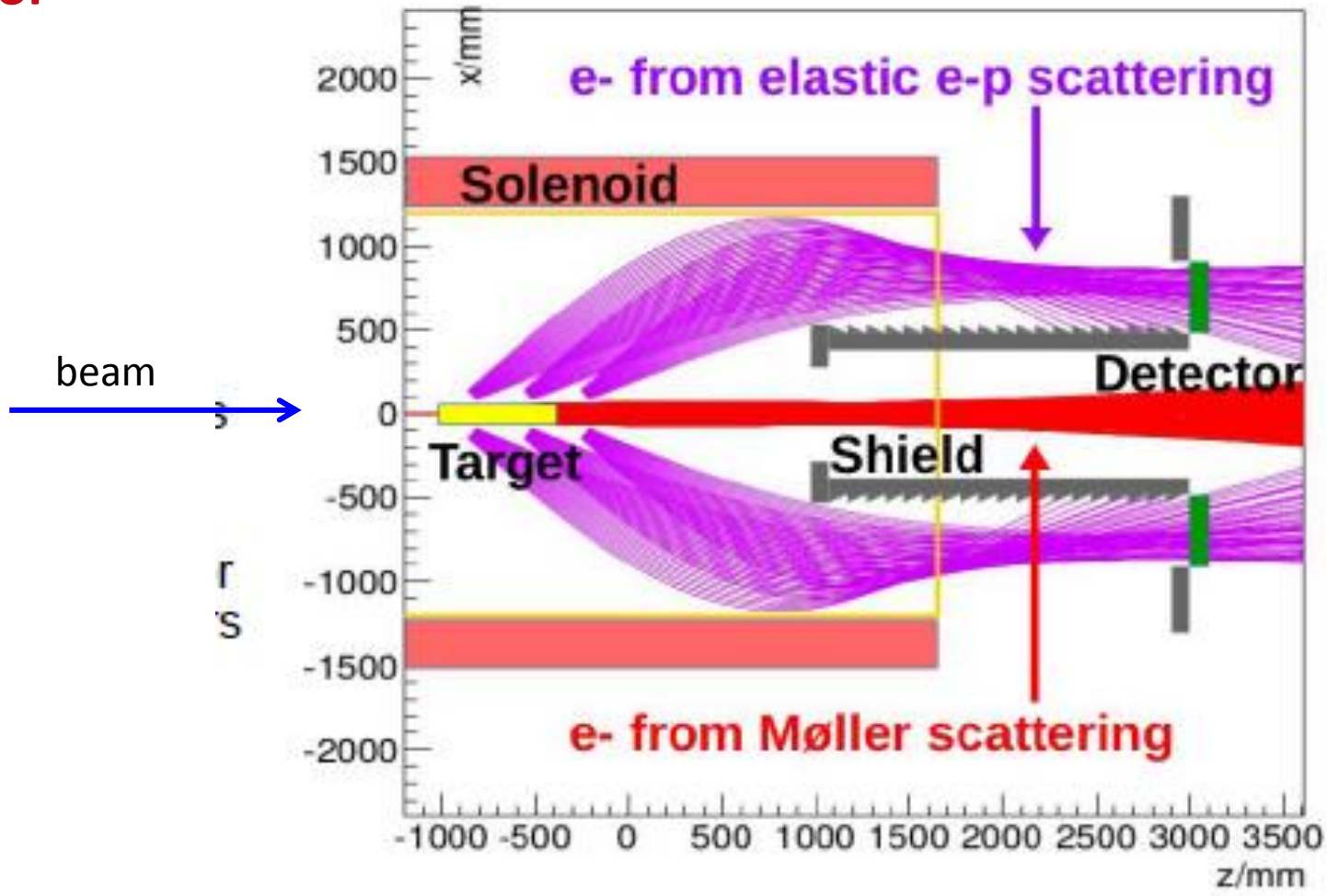
The SM-model value for Asymmetry*Beampol is 28 ppb to be measured with an accuracy of 0.44 ppb….

F. Maas PAVI2014 conf.

Details in Talk by S. Baunack (Tuesday)

The P2 Experiment at MESA

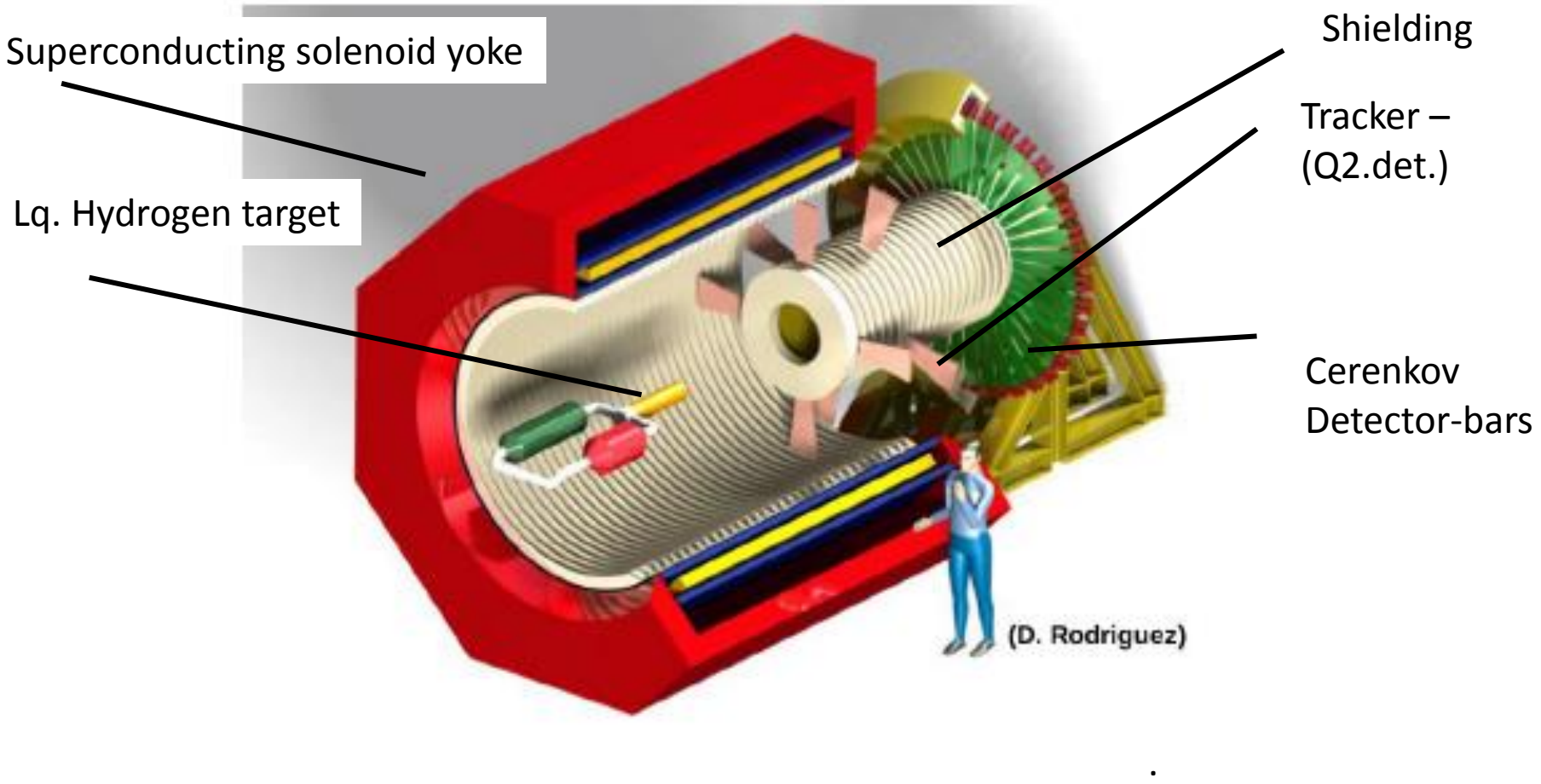
- detector



Further PV experiments using this detector under discussion:
MESA -12C, Neutron skins,

The P2 Experiment at MESA

- detector



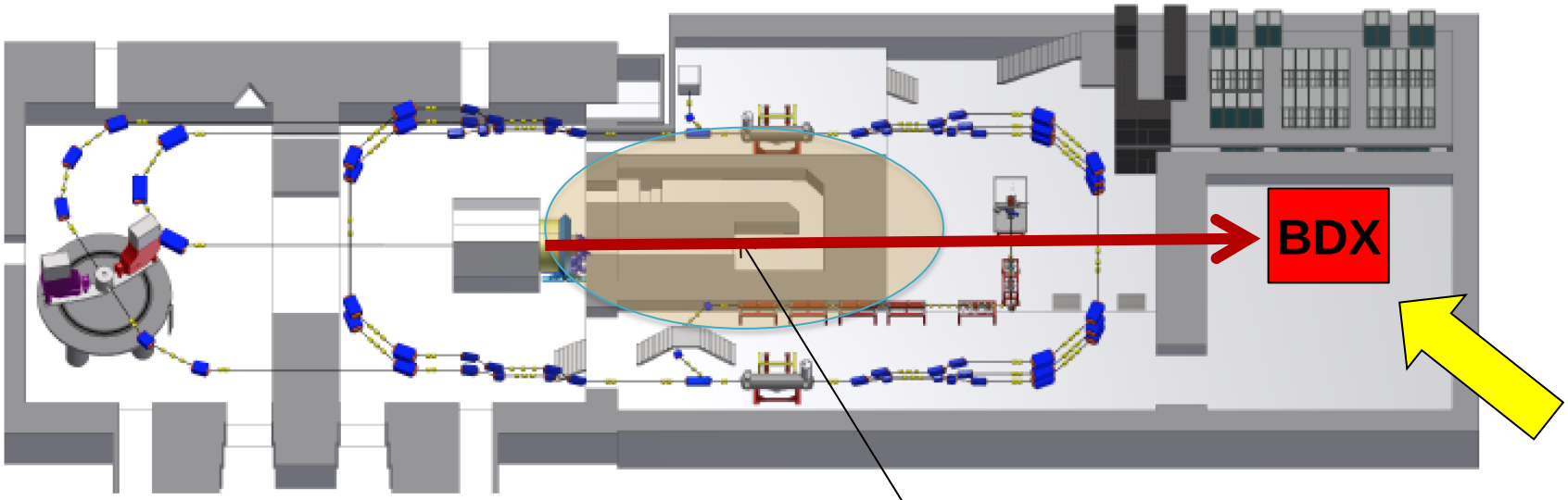
Further PV experiments using this detector under discussion:
MESA -12C, Neutron skins,

The P2 Experiment at MESA

-parallel („for free“) experiment !

Beam Dump Experiment (BDX) @ MESA

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

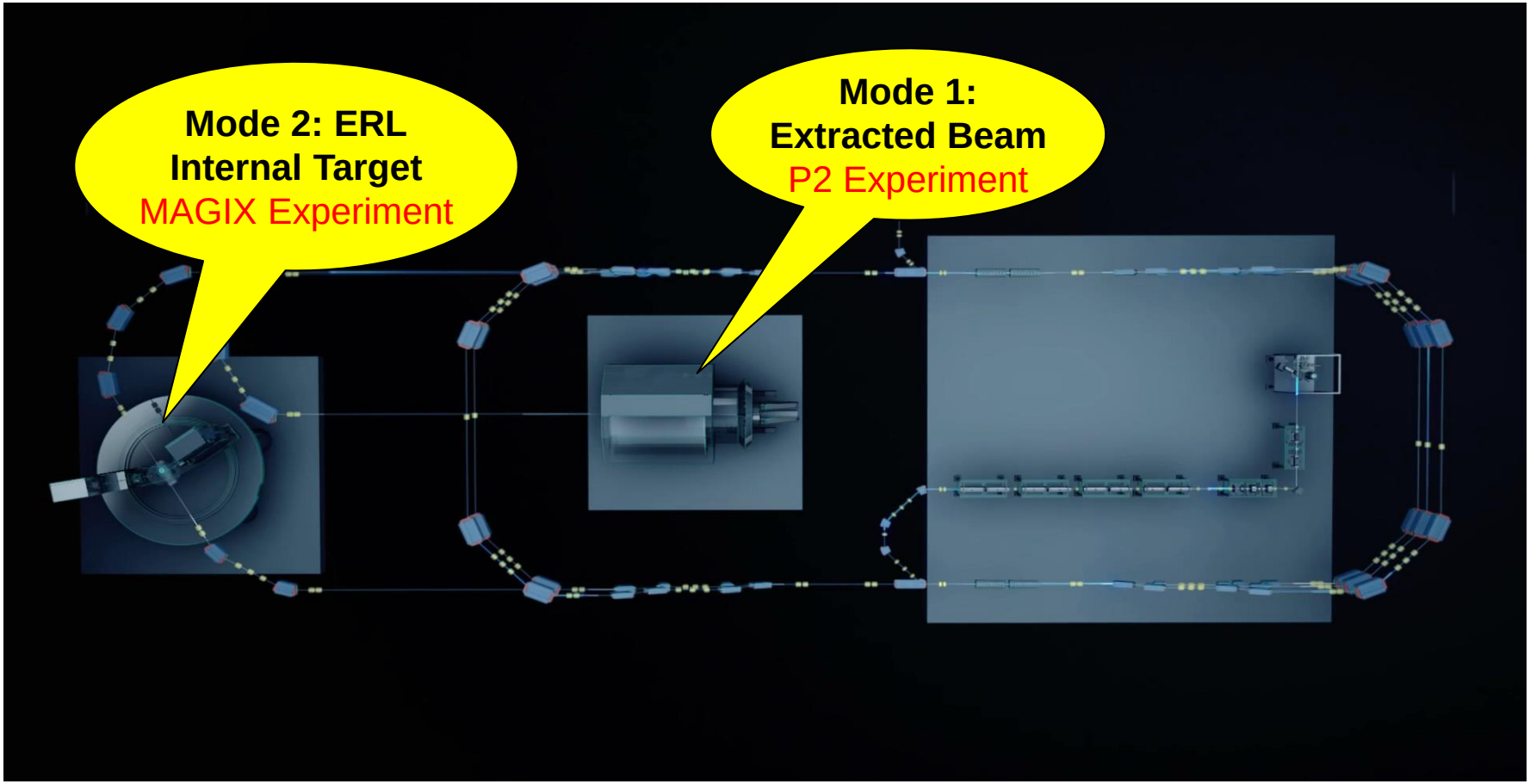


This existing beam dump is going to be the P2 beam dump

10,000 hours @ 150 µA

→ 10^{23} electrons on target (EOT)

The MAinz Gas Internal EXperiment (MAGIX) at MESA

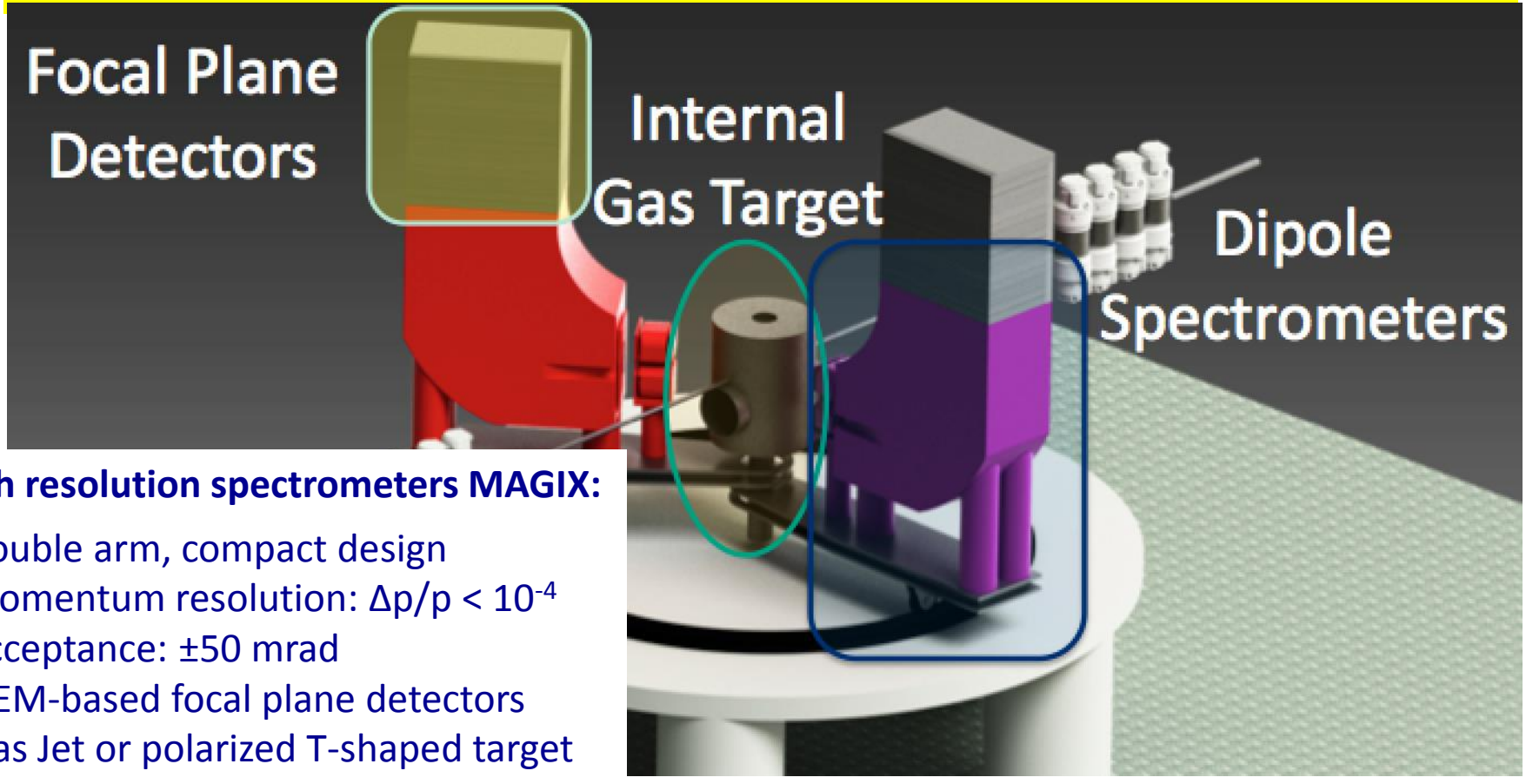


- 1mA Beam current in ERL mode
- → high luminosity in spite of thin (in particular polarized) target.

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!**

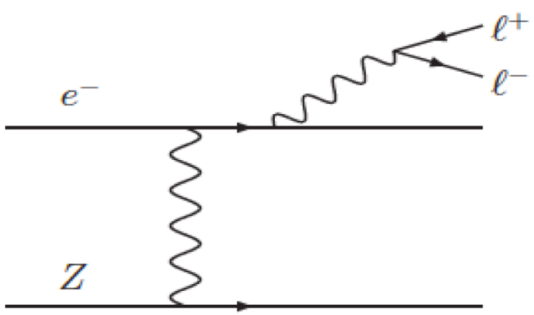


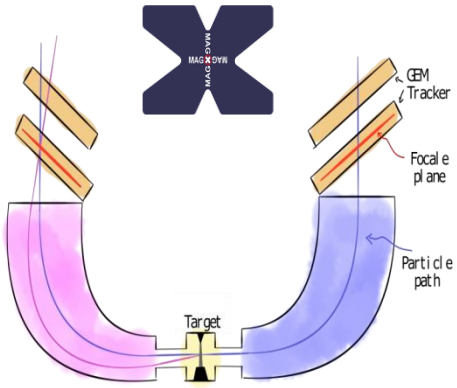
High resolution spectrometers MAGIX:

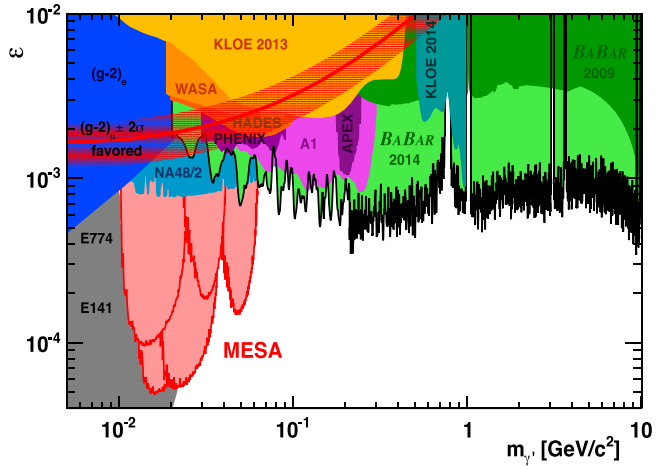
- double arm, compact design
- momentum resolution: $\Delta p/p < 10^{-4}$
- acceptance: ±50 mrad
- GEM-based focal plane detectors
- Gas Jet or polarized T-shaped target

MAGIX portfolio-I / dark photon searches

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



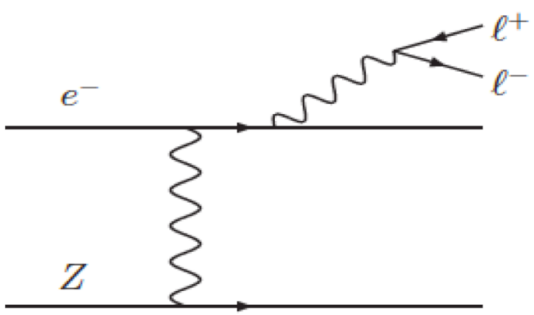


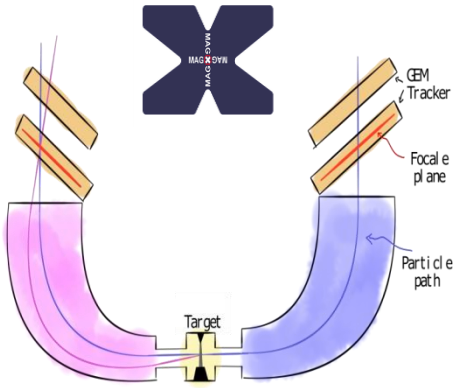


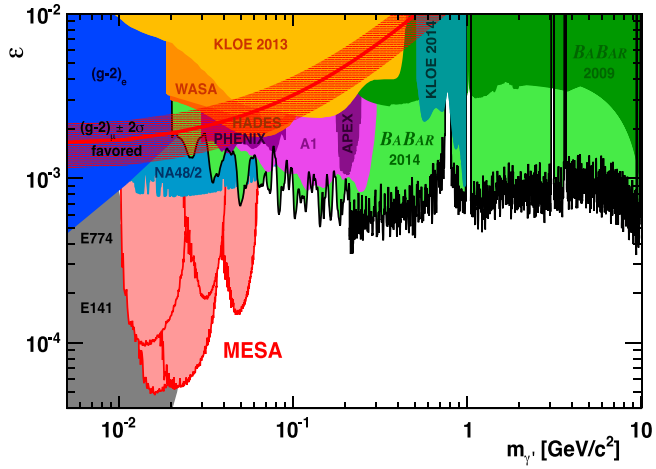
Expected coverage…

MAGIX portfolio-I / dark photon searches

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

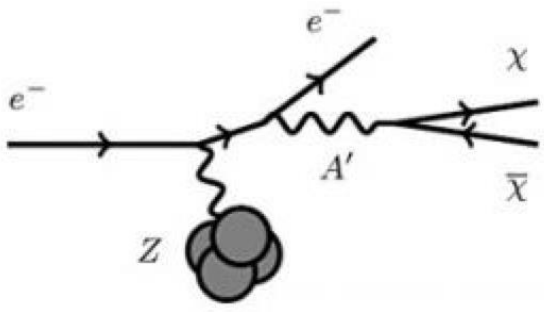






Expected coverage…

- 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…

MAGIX portfolio-II / Form factors

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

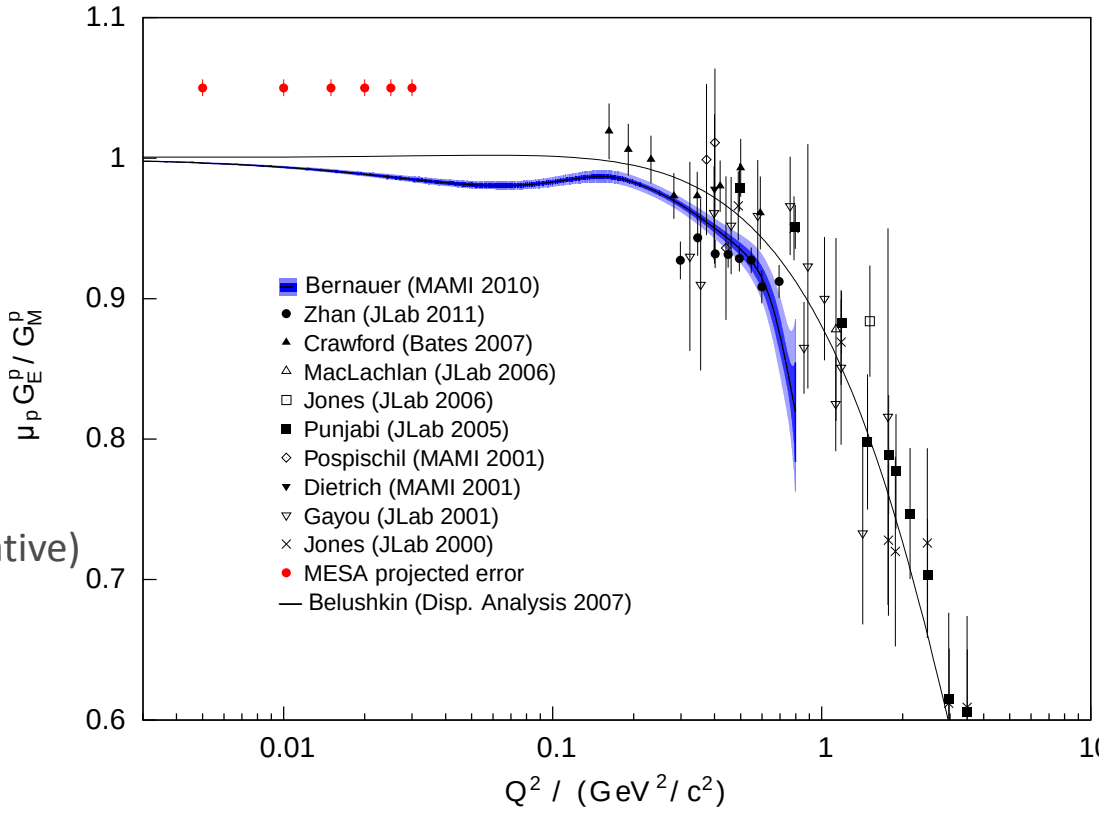
MAGIX allows to address much smaller momentum transfer due to very low energy, momentum transfer and minimzed material budget…

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



Options for MAGIX portfolio III-V ?

….Nuclear astrophysics (S factors)

…. Nuclear physics (three body forces)

……. Nucleon polarizabilities

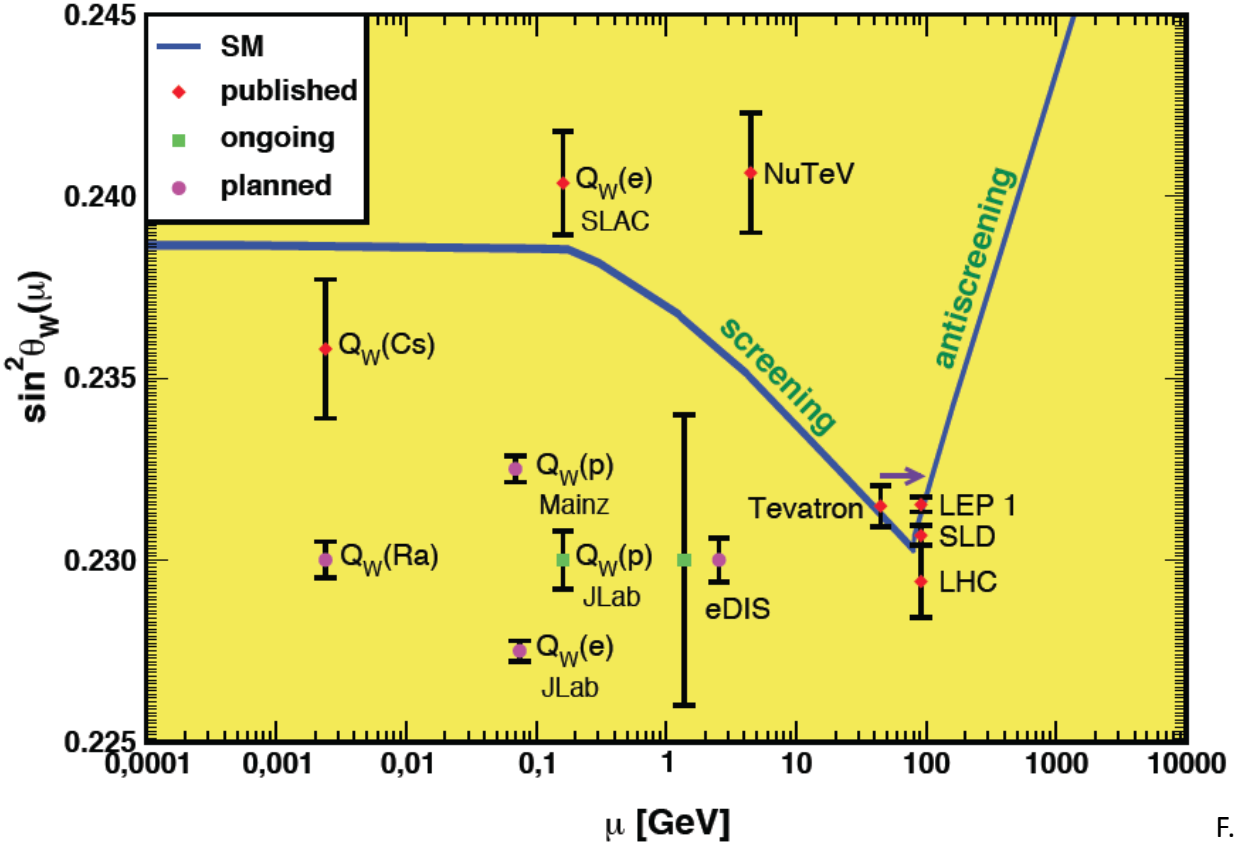
….exploration of possibilities are ongoing!

Conclusion

- MESA is adressing fundamental physics questions by using modern accelerator physics techniques, in particular energy recovery
- Parity violating experiments with external polarized beams – P2 experiment for precision measurement of Electro-Weak mixing angle
- MAGIX experiment employing new ERL concept with very wide physics portfolio -dark matter searches, formfactors, nuclear astrophysics, and more…

Thank you for your attention!

The P2 experiment at MESA



F. Maas PAVI2014 conf.

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

MESA ORGANISATION/ FUNDING

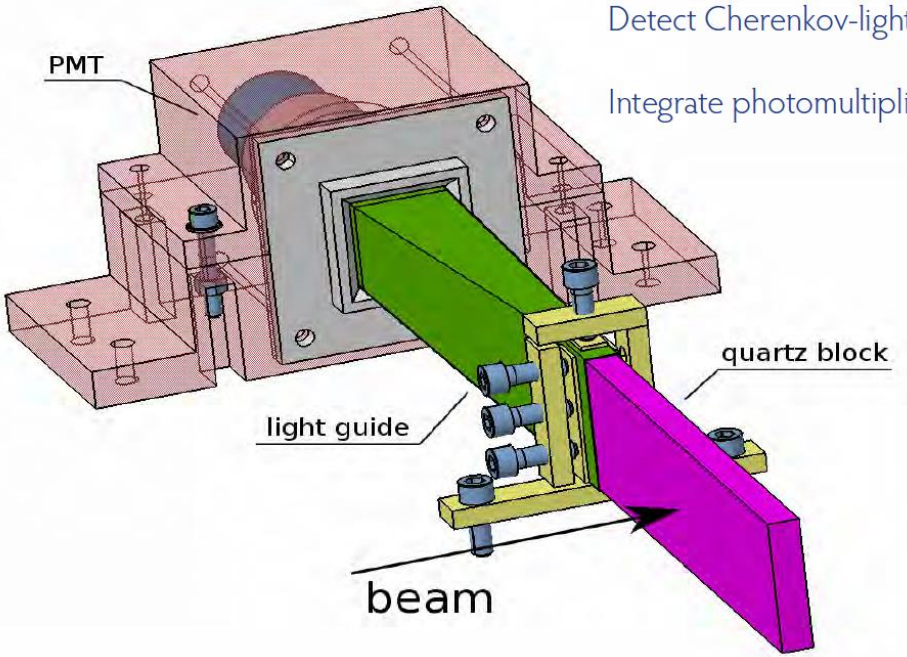
Cluster of Excellence Precision Physics, Fundamental Interactions and Structure of Matter
PRISMA

- 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!
- MESA „facility“ is supposed to start operation in 2020

Supplementary transparencies

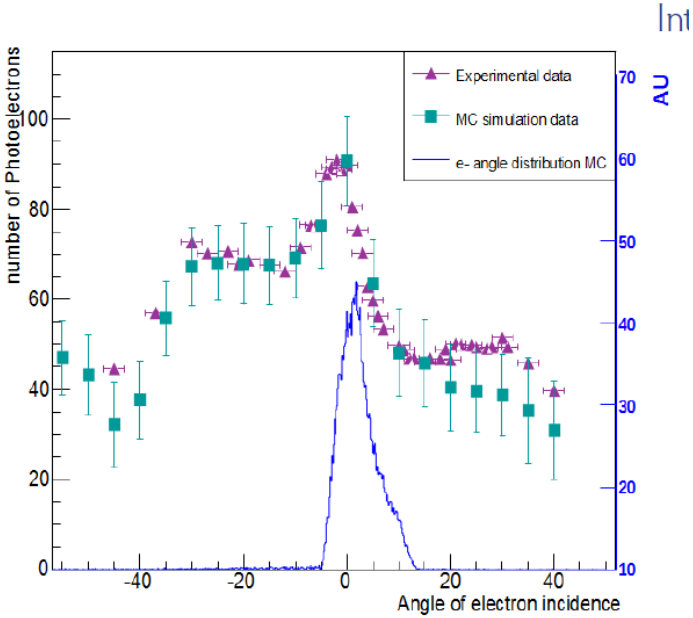
The P2 Experiment at MESA

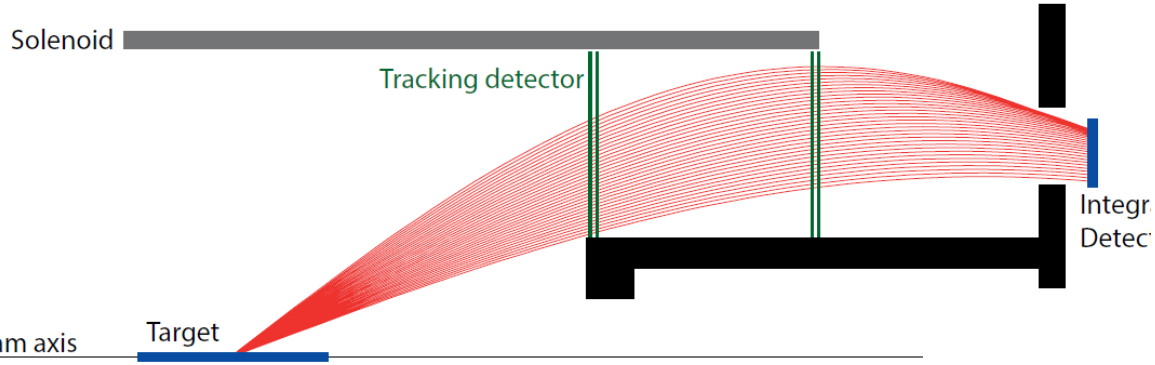
- detector components/tests at MAMI



Detect Cherenkov-light created by electrons

Integrate photomultiplier current

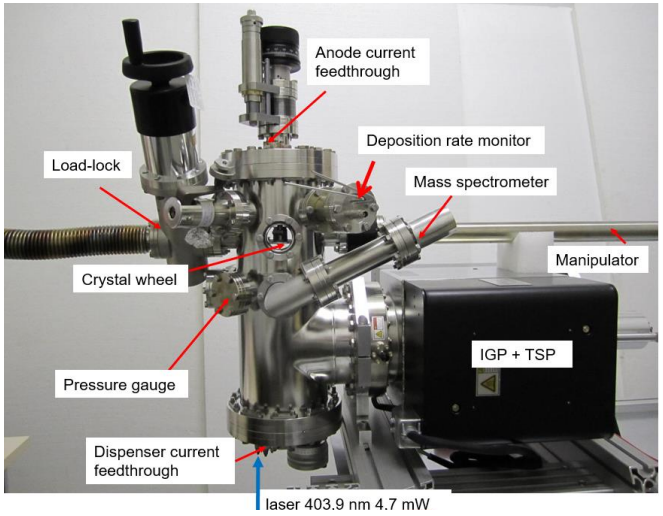


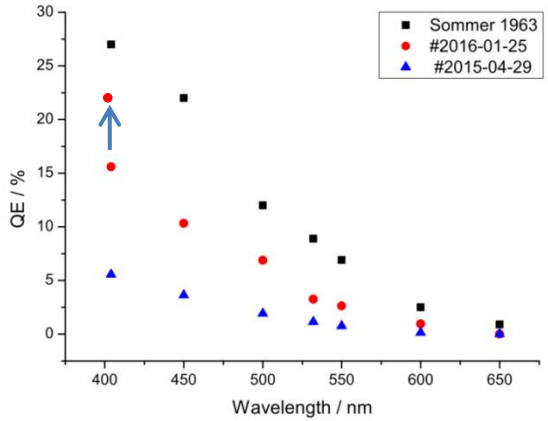


N. Berger

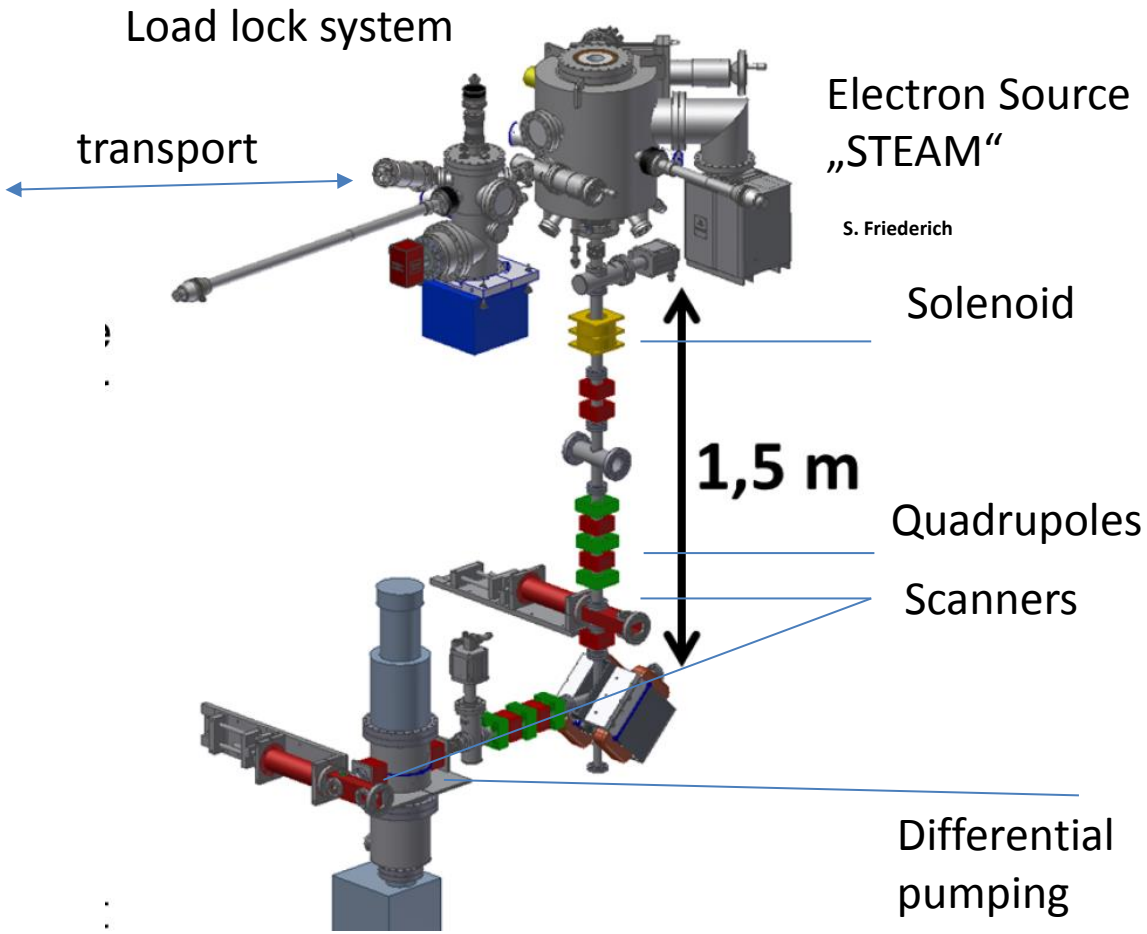
Assembly of source STEAM & first part of beamline "MELBA" has started

Photocathode „factory"





V. Bechthold



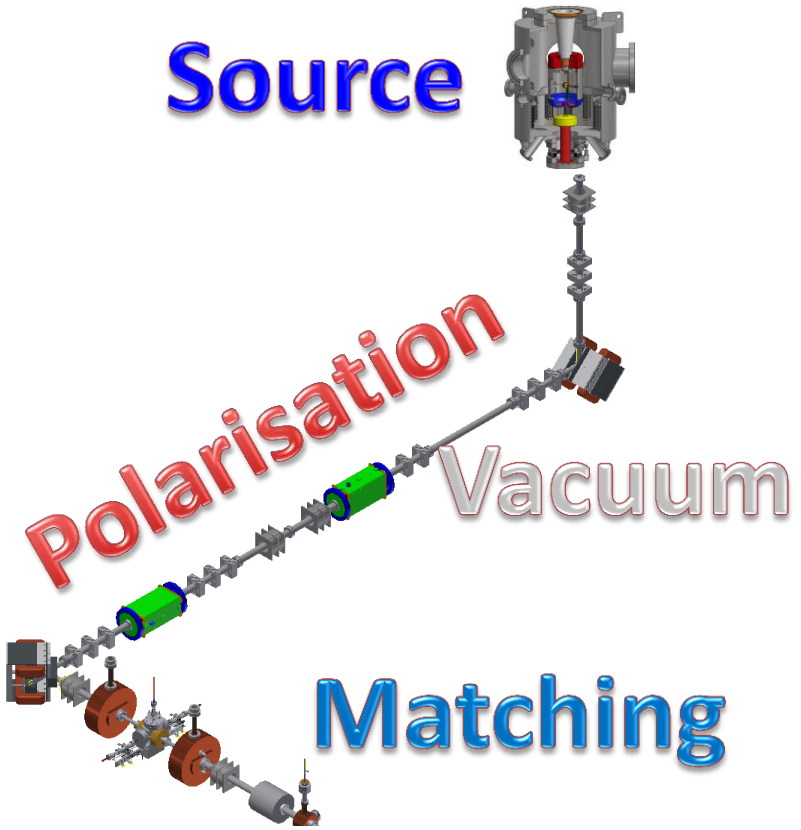
- **Robust Photocathodes with QE=22% (60mA/Watt) at 400 nm: available! → 1mA can be generated with laser from a blue ray disc player**

Full Assembly of MELBA planed until early 2017

„Start to end“ Simulation predicts for 100keV beam:

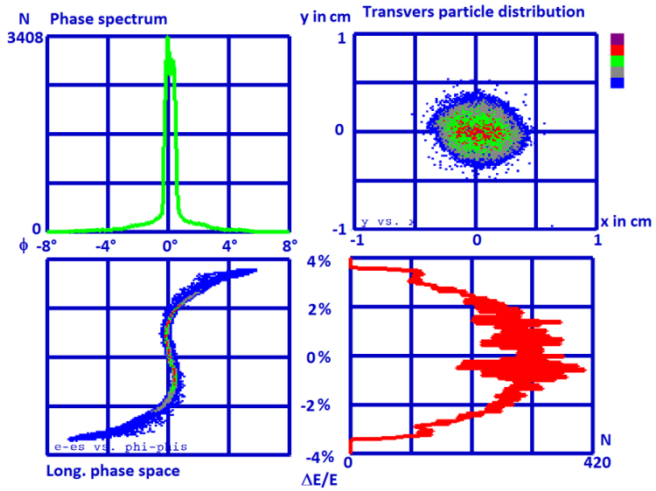
-Compatibility with spin rotation

- Sufficient beam quality for injection into MAMBO with 1pC bunches (=1,3mA)



C. Matrejcek

At the end of MELBA:

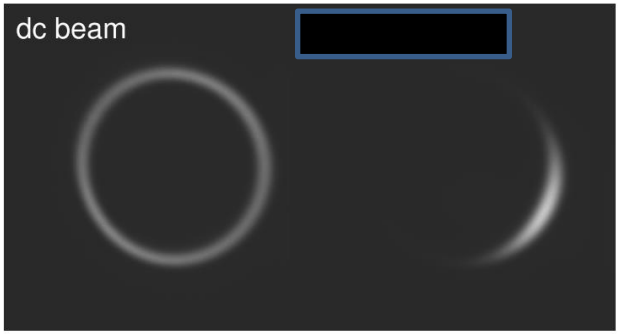


$\frac{\Delta E}{E}_{RMS}$ in %	$\Delta\phi_{RMS}$ in °	$\epsilon_{z,RMS}$ in °keV
1.7	1.3	1.576

α_x	β_x in m	$\epsilon_{x,RMS,n}$ in µm	α_x	β_x in m	$\epsilon_{y,RMS,n}$ in µm
16.5	4.6	0.419	12.2	3.7	0.386

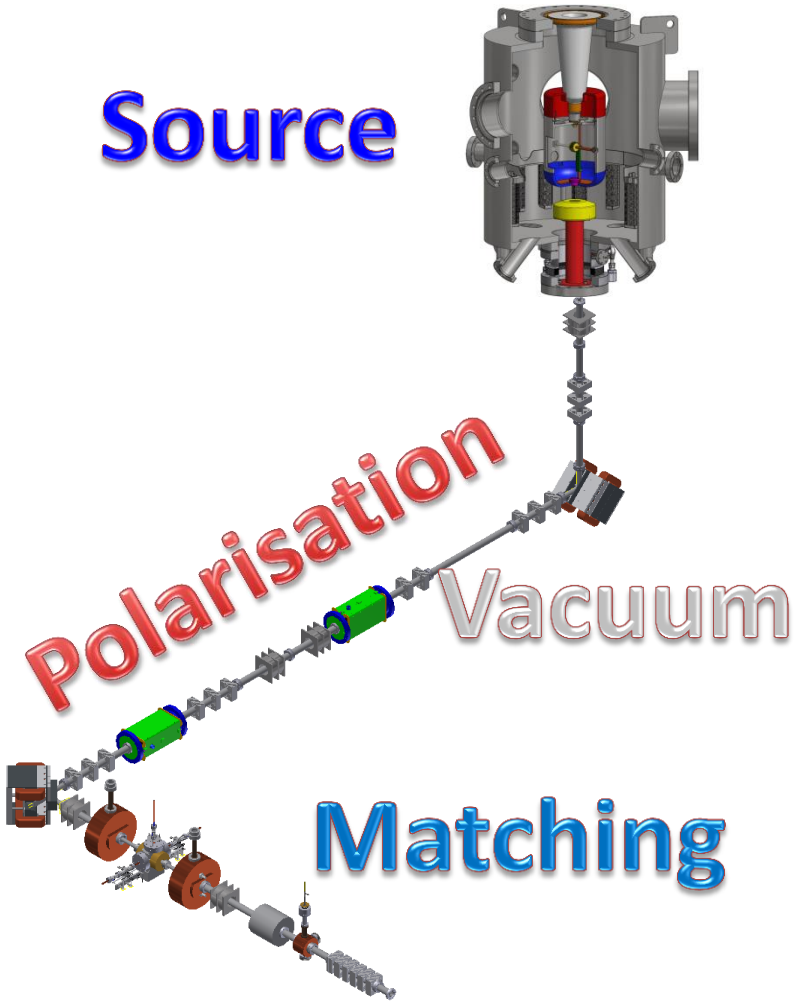
Assembly of MELBA (MEsa Low Energy Beam Apparatus) in 2016

Blue ray disc laser and longitudinal diagnostics already tested….



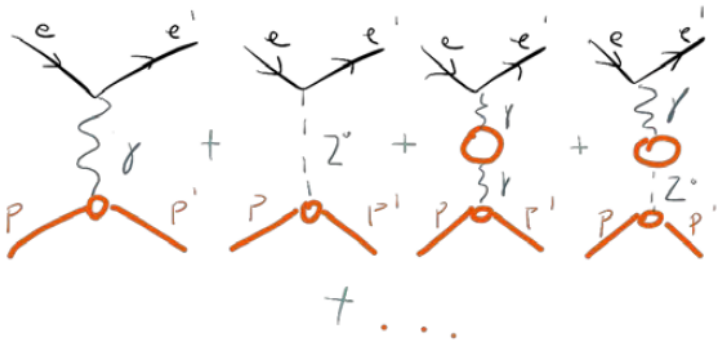
I. Alexander

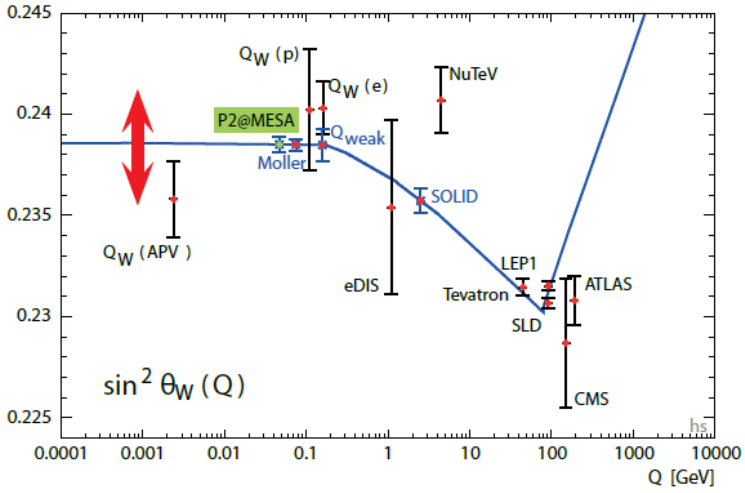
Longitudinal diagnostics at Bunch charges corresponding to > 1mA average current

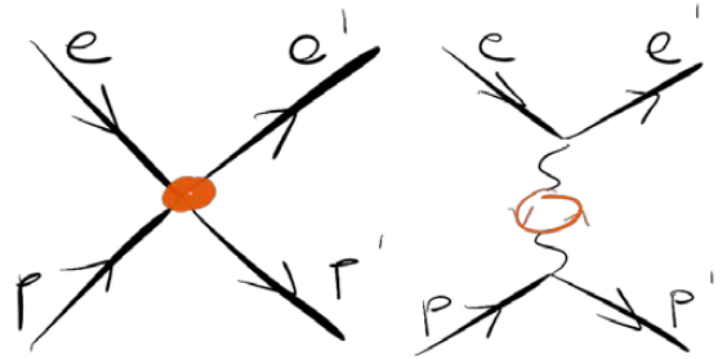


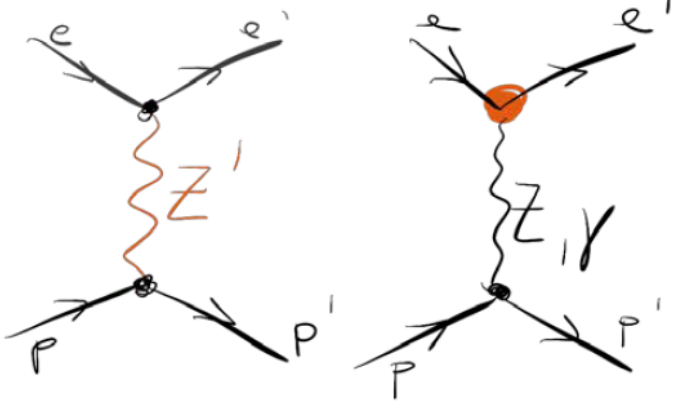
The P2 experiment at MESA

New Physics in the running



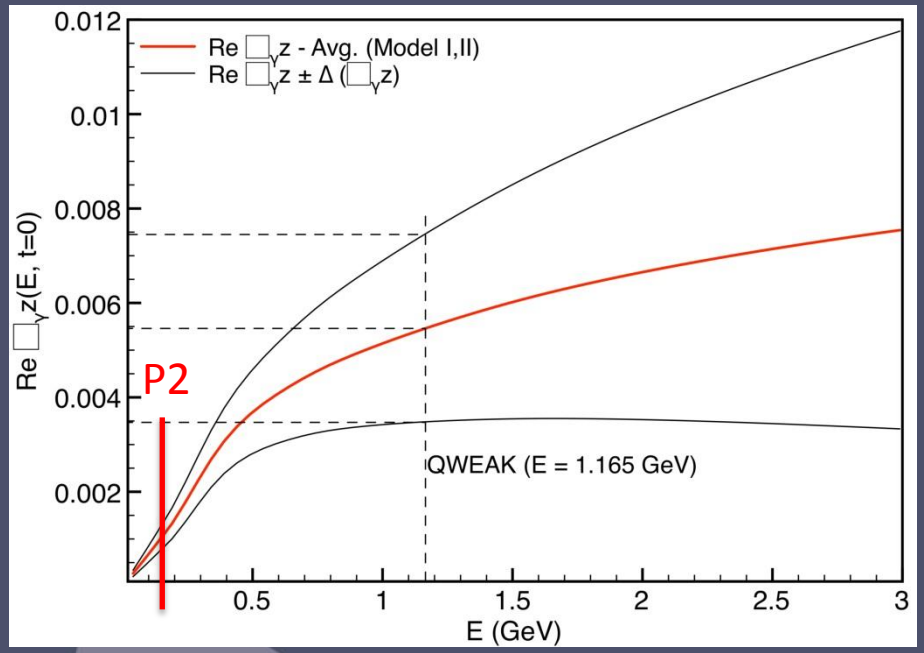






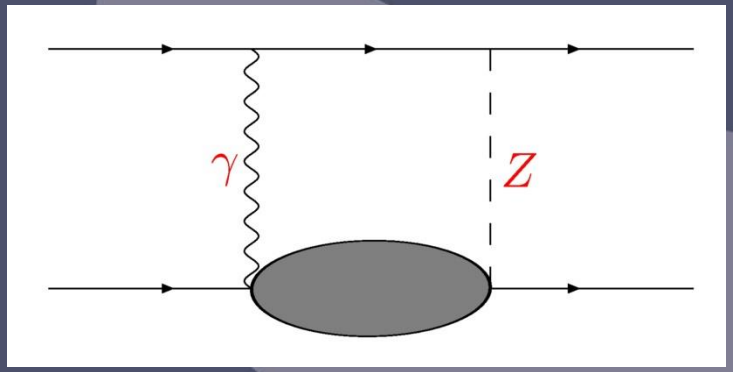
N. Berger

- γZ box graph contributions obtained by modelling hadronic effects:



[Gorchstein, Horowitz & Ramsey-Musolf 2011]

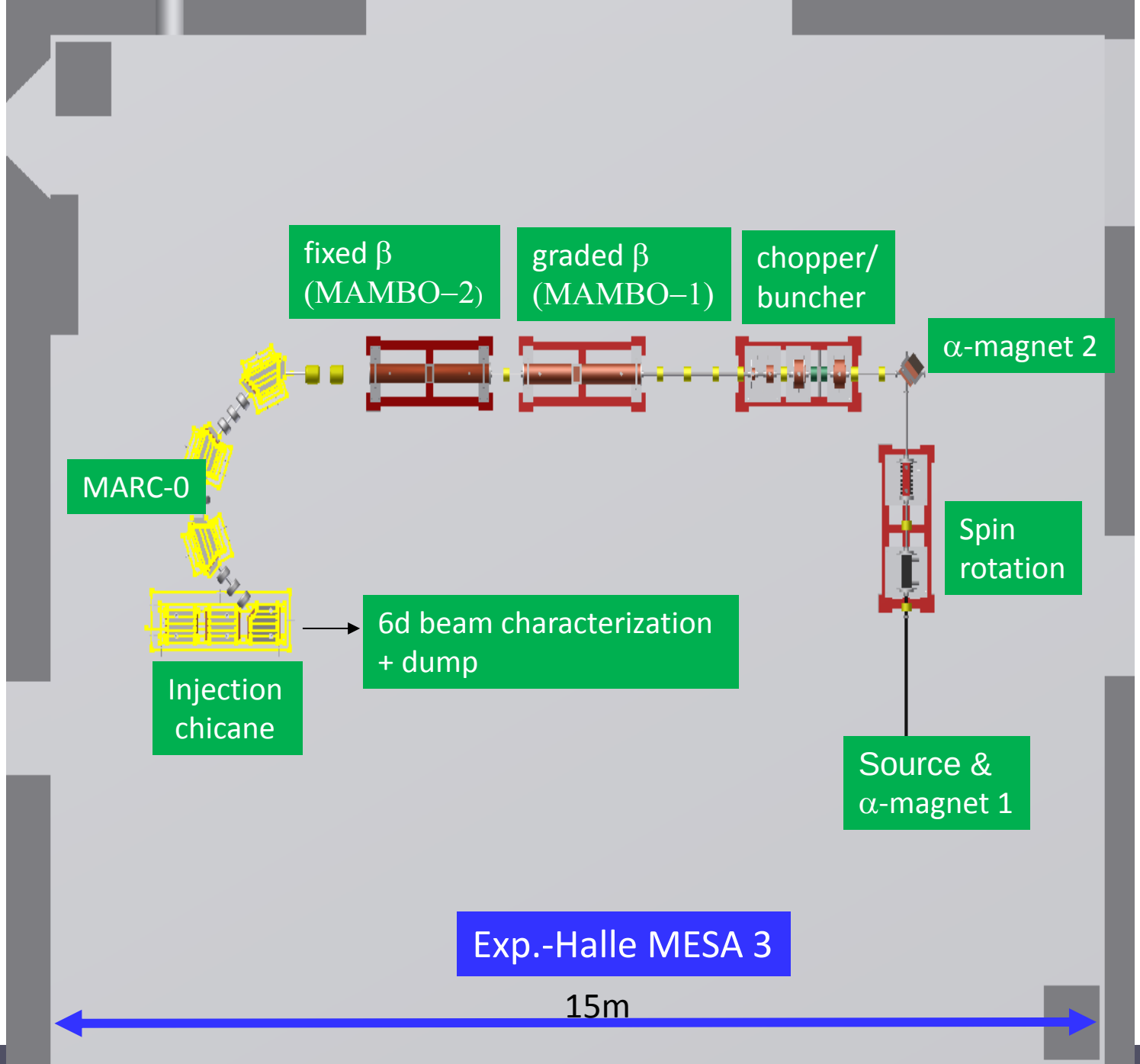
- Hadronic uncertainties suppressed at lower energies
- Low beam energy experiment: **P2 @ MESA**

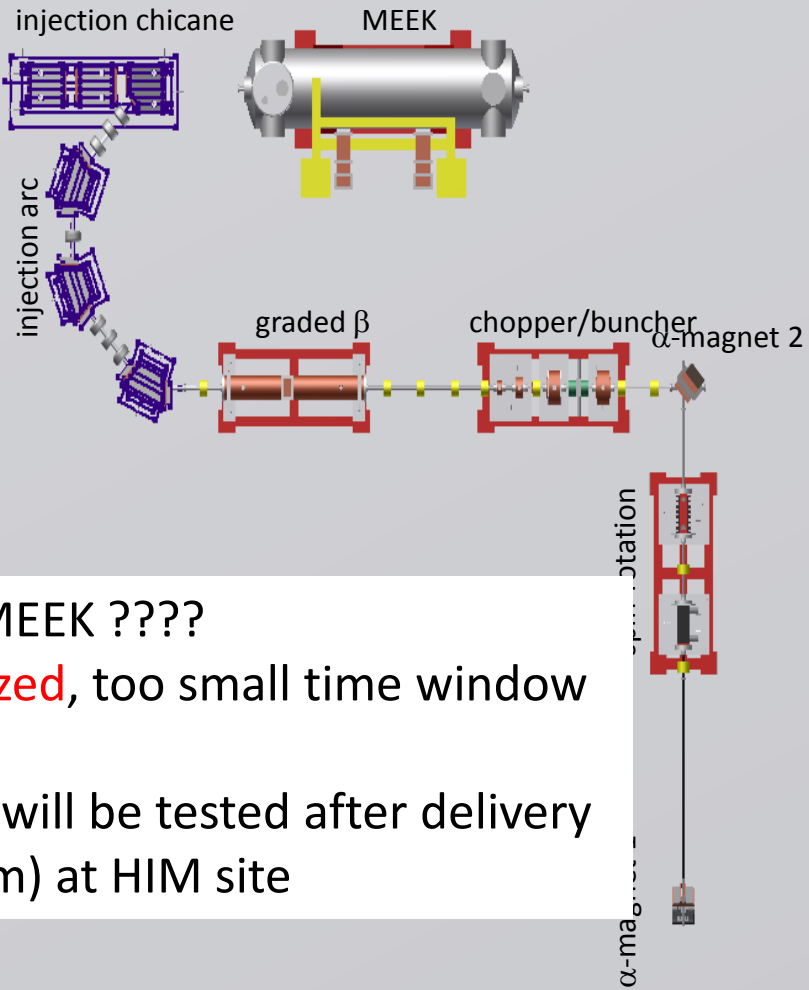


Dominant theoretical uncertainty:

γZ box graphs, $\boxdot_{\gamma Z}$

Sensitive to hadronic effects


fixed β
(MAMBO–2)
graded β
(MAMBO–1)
chopper/
buncher
α-magnet 2
MARC-0
Spin
rotation
6d beam characterization
+ dump
Injection
chicane
Source &
α-magnet 1
Exp.-Halle MESA 3
15m



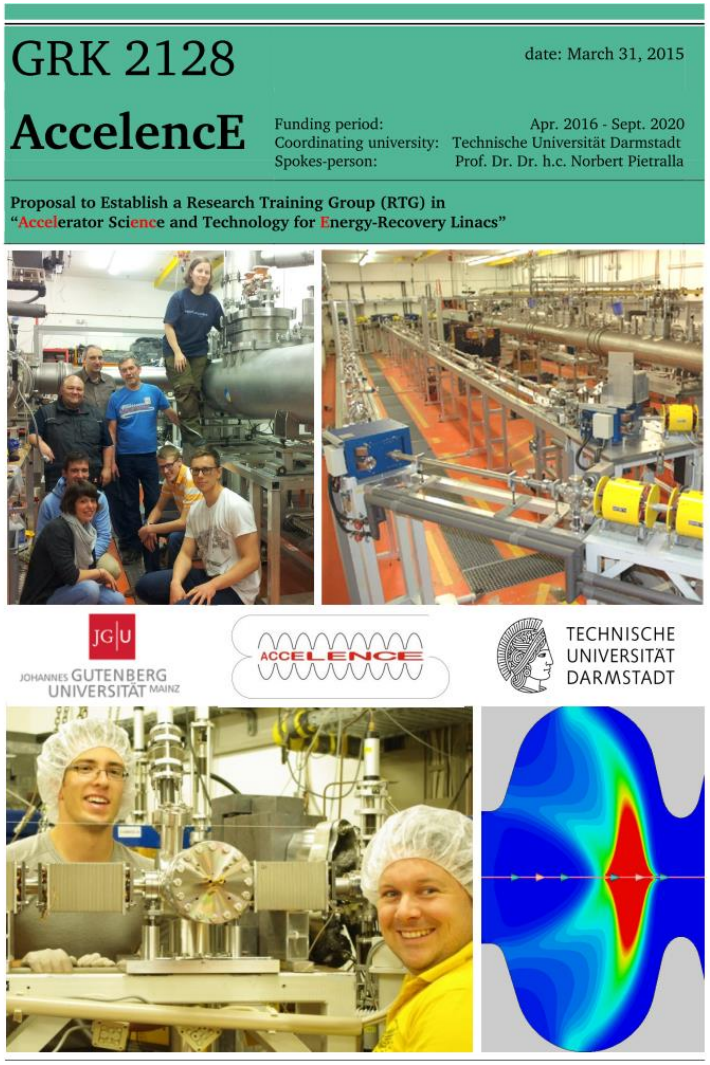
Task 3: add MEEK ????

→ Not favorized, too small time window

Kryomodules will be tested after delivery (without beam) at HIM site

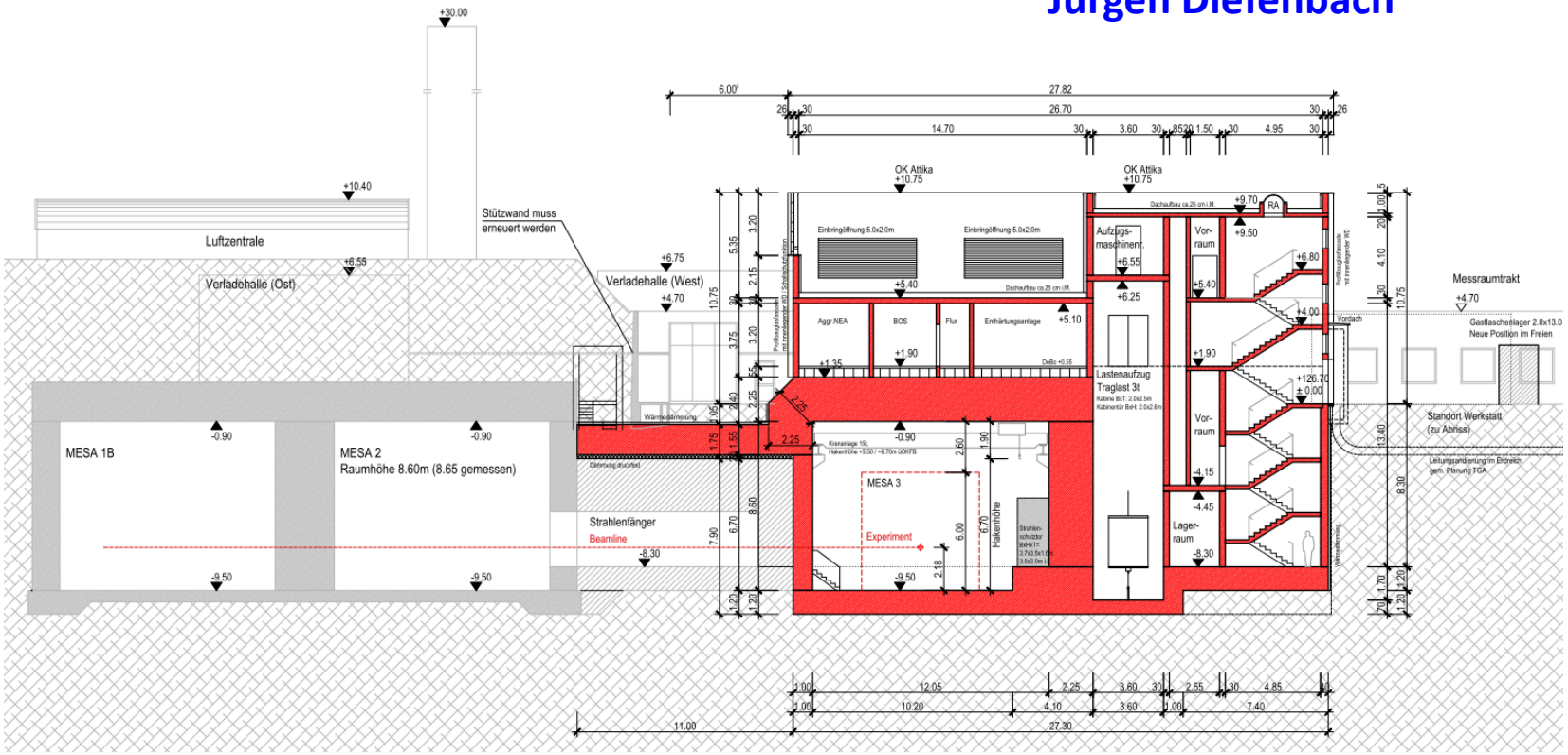
GRK-2128 “Accelence”

- Common application by TUD and JGU for graduate school.
- Accelerator science and technology for enrgy recovery linacs
- Application succesful in 10/2015
- First funding period (4,5 years) starts in 4/2016, 4PhD positions for JGU.



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

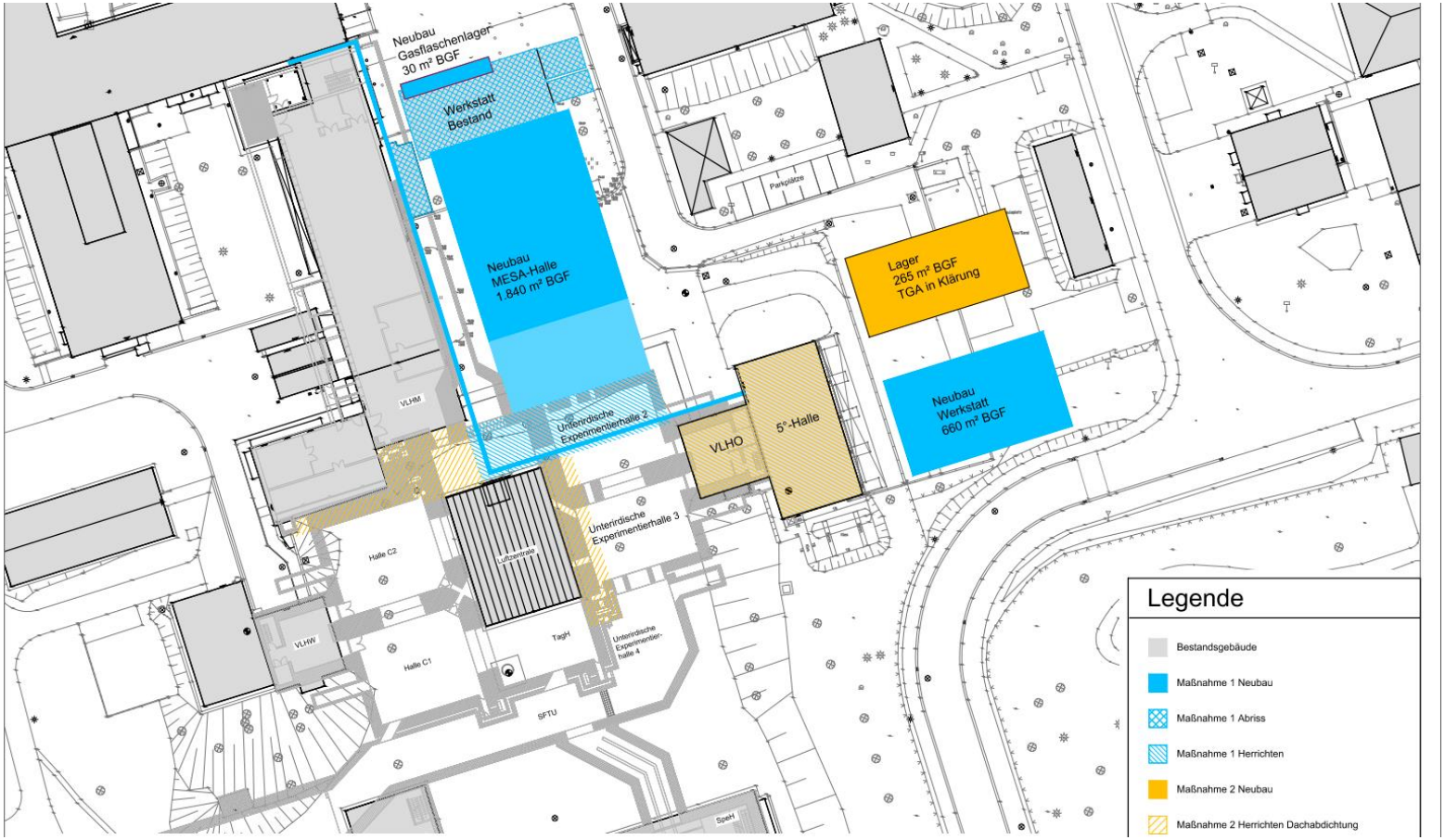
Radiation protection: see talk by
Jürgen Diefenbach



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.

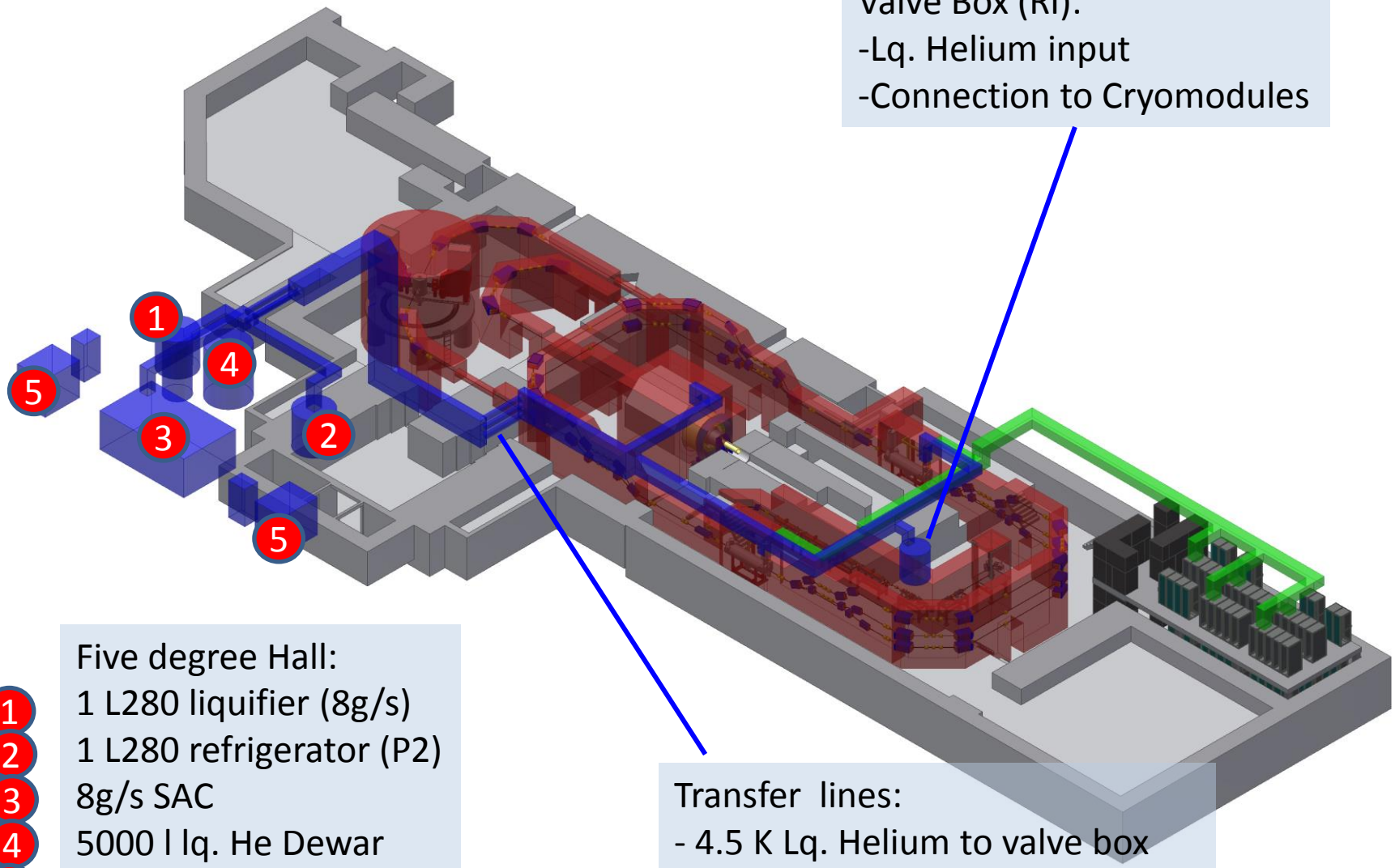
See talk by **D. Simon**



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