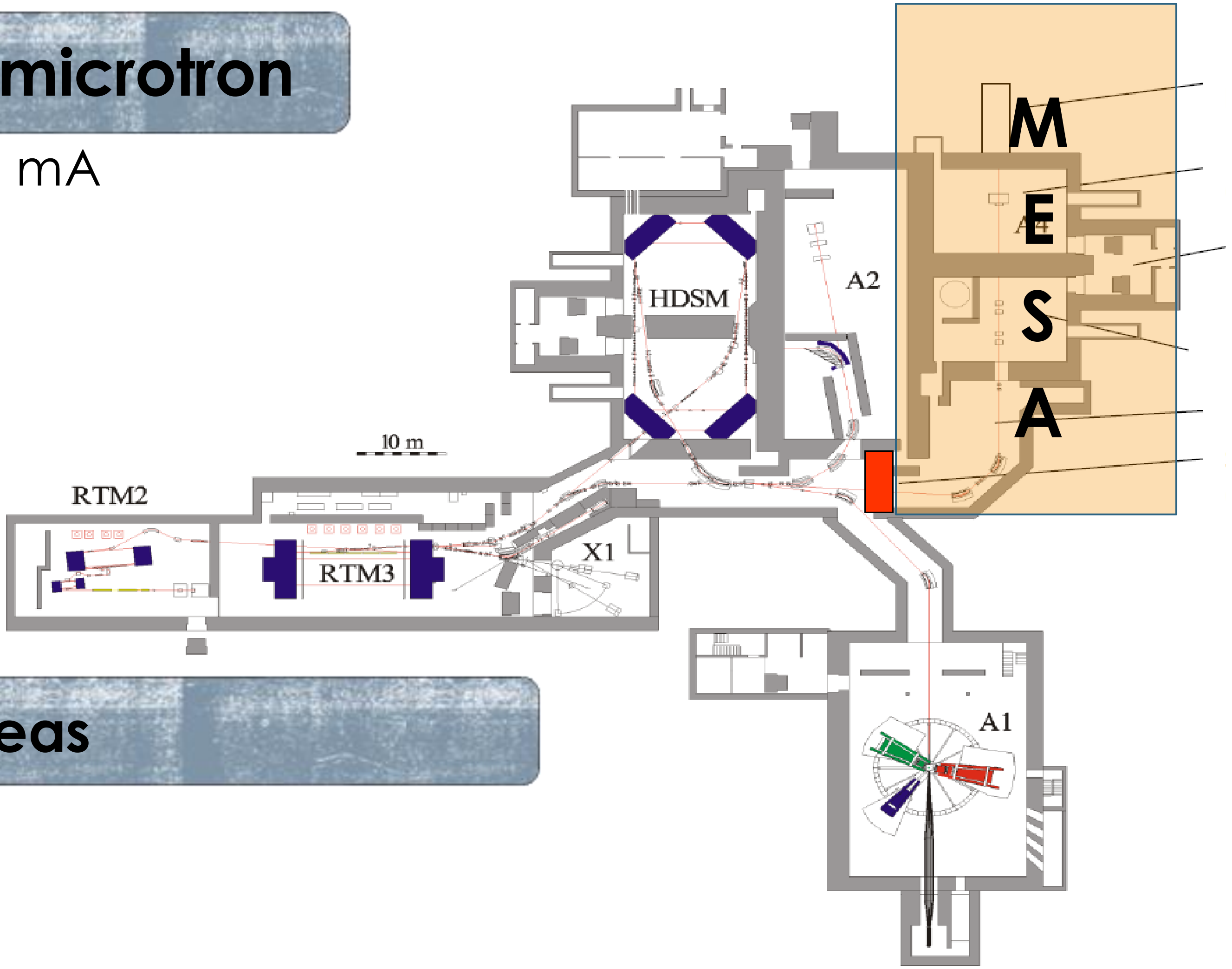
THE MESA PROJECTS

MAG MAG MAG MAG

CURRENT FACILITY: MAMI

MAMI - Multi-stage microtron

- 1.5 GeV electrons @ 0.1 mA
- Active since 1979
- Long list of scientific accomplishments



Four experimental areas

- A1: Electron scattering
- A2: Real photons
- X1: Hard X-Ray sources
- A4: Parity violation (Replaced by MESA)

MAINZ ER SUPERCONDUCTIVE ACCELERATOR

Multi-turn, superconducting ERL

Energy recovery mode

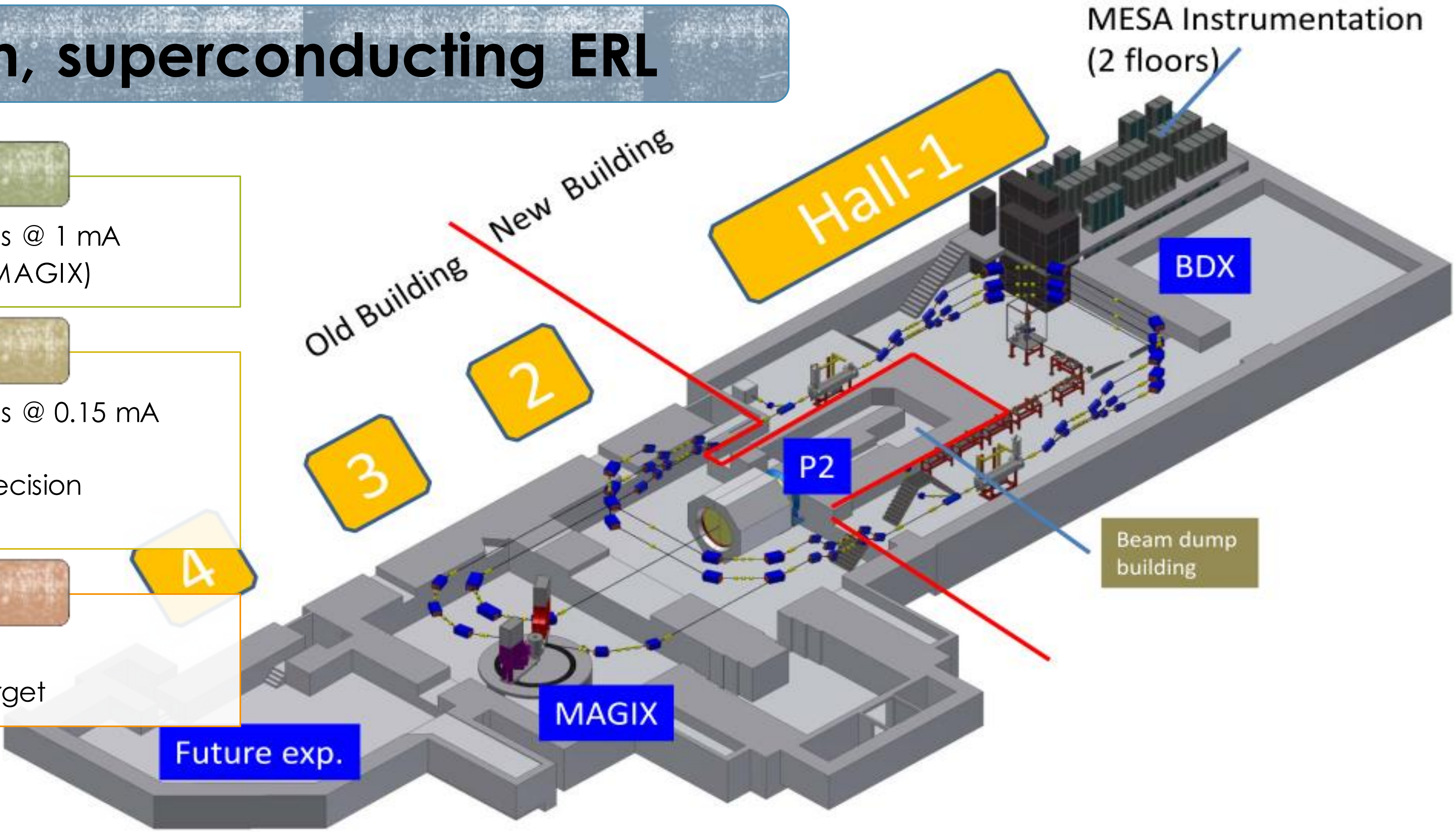
- 105 MeV polarized electrons @ 1 mA
- Internal target scattering (MAGIX)

External beam

- 155 MeV polarized electrons @ 0.15 mA
- Dedicated experiment (P2)
- Electroweak asymmetry precision measurement

Beam dump experiment

- Behind the P2 beam dump
- About 10^{23} electrons on target



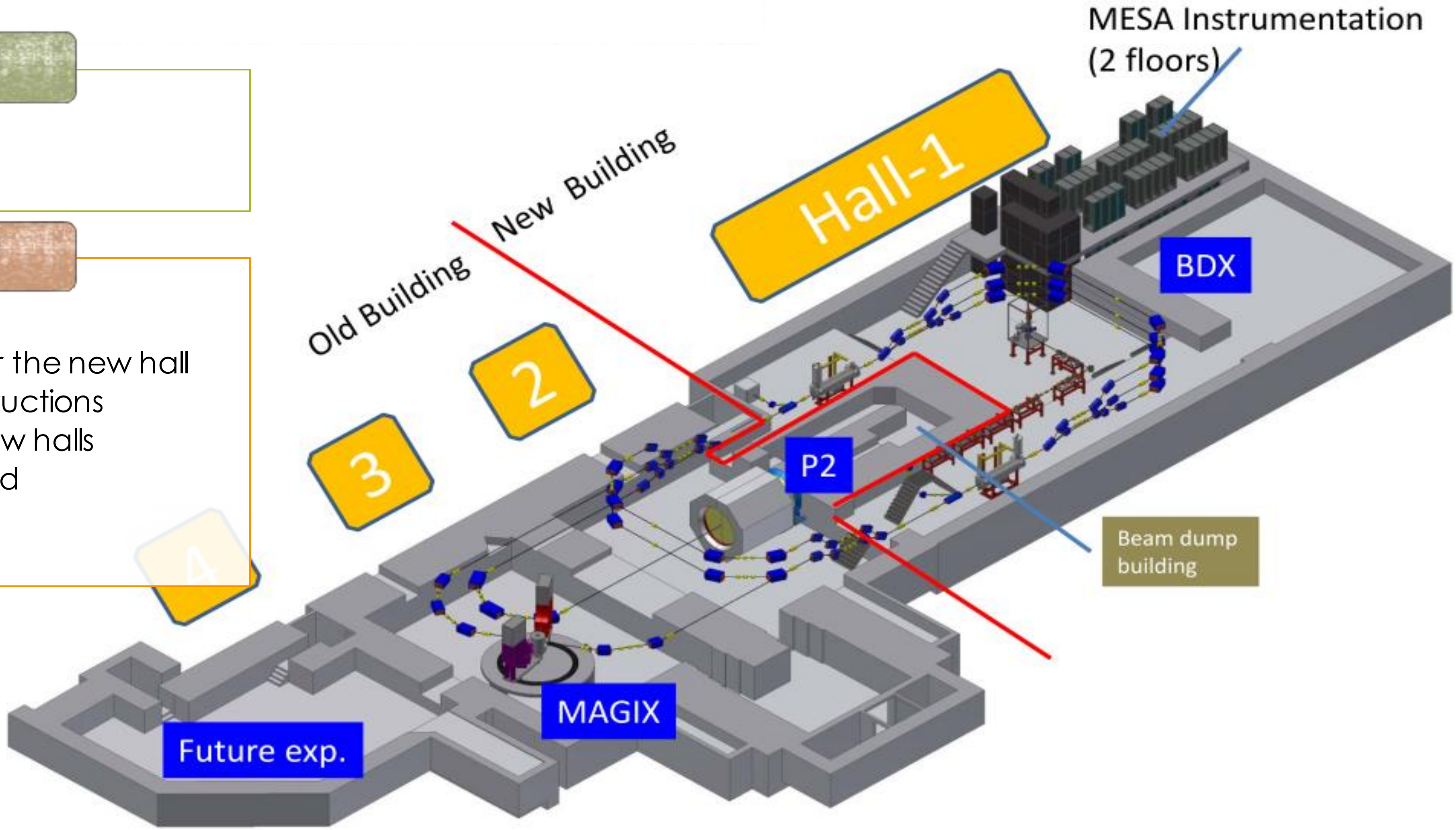
MESA SCHEDULE

Extension hall approved

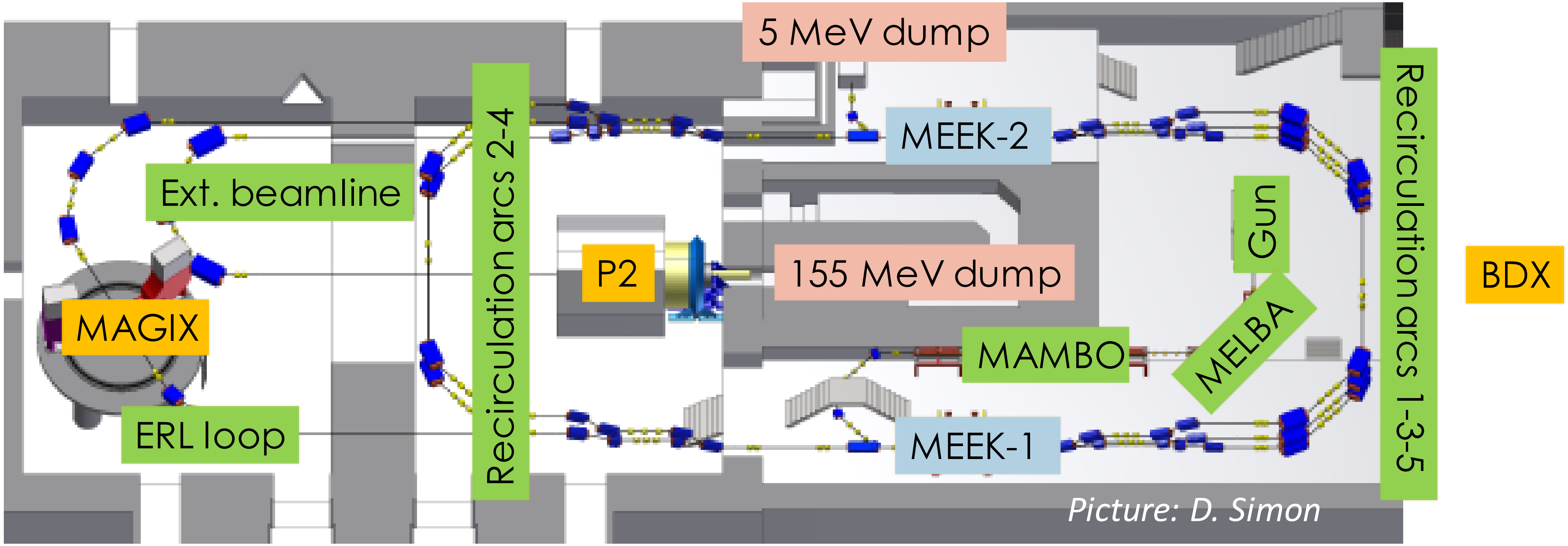
- More space
- Delayed schedule

Construction schedule

- 2017 Ancillary buildings
- 2018 Ground breaking for the new hall
- 2019 Underground constructions
- 2020 Hand over of the new halls
- 2021 MESA installation and commissioning
- 2022 Start of operation



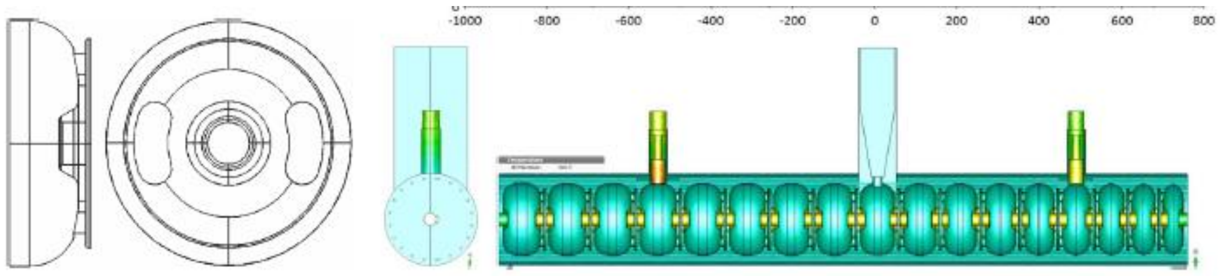
ACCELERATOR LAYOUT



MELBA	MEsa Low-energy Beam Apparatus
MAMBO	MilliAMpere BOoster
MEEK	Mesa Extended Elbe-type Kryomodule

- Room temperature section
- Superconductive section
- Dumps
- Experiments

MAMBO: MILLIAMPERE BOOSTER



Design inspired by the MAMI injector LINAC

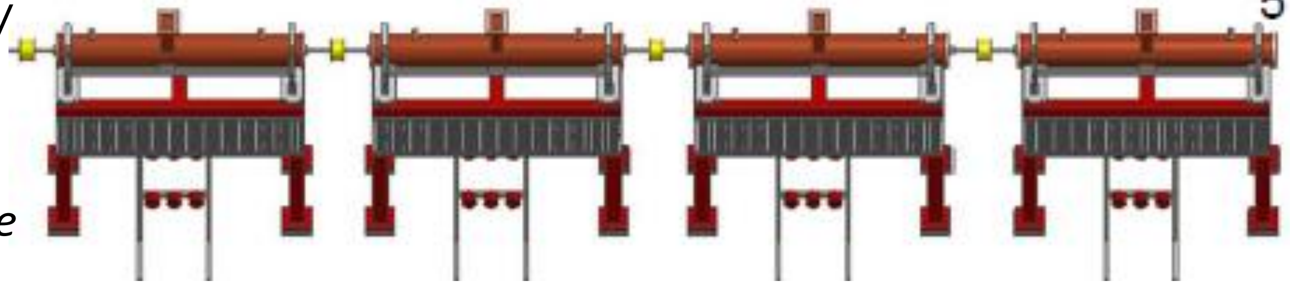
- 4 room temperature RF bi-periodic $\pi/2$ standing wave structures @ 1.3 GHz
- 1 graded-β , 3 const. β sections; Energy gain ΔE=1.25 MeV/section
- RF-Amplifiers: SSA with ~90 kW (graded β) and 3 x ~60 kW (fixed β)

Status

- Design completed
- Test cavity ordered
- 15 kW SSA-prototype ordered
- Complete testing on-site before the new-hall construction

100 keV

5 MeV



Pictures: R. Heine

MESA CRYOMODULES

Rossendorf-type cryomodules

- 2x9-cell TESLA/XFEL cavities

Adaptations for 1 mA operations

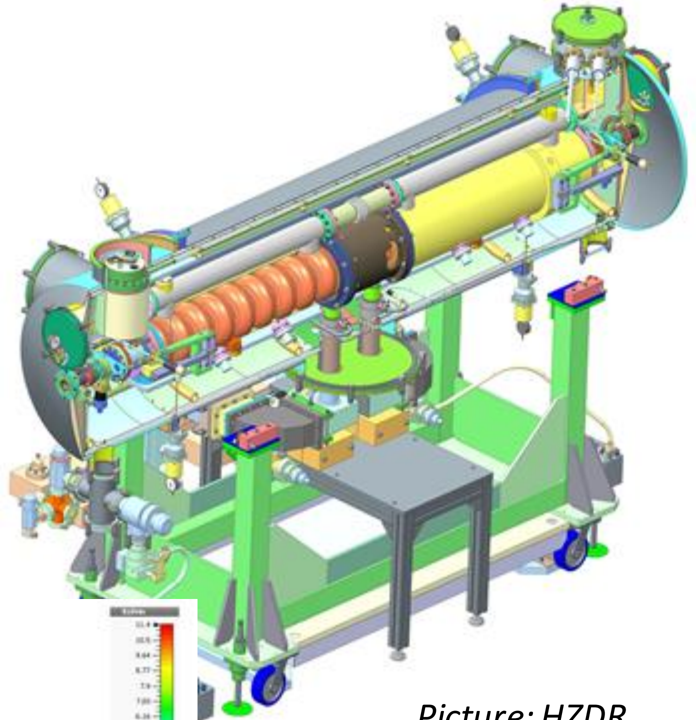
- Added tuners with piezo-elements
- Sapphire windows at HOM feedthroughs
- 10 mA not achievable with this cryomodule

HOM antenna development

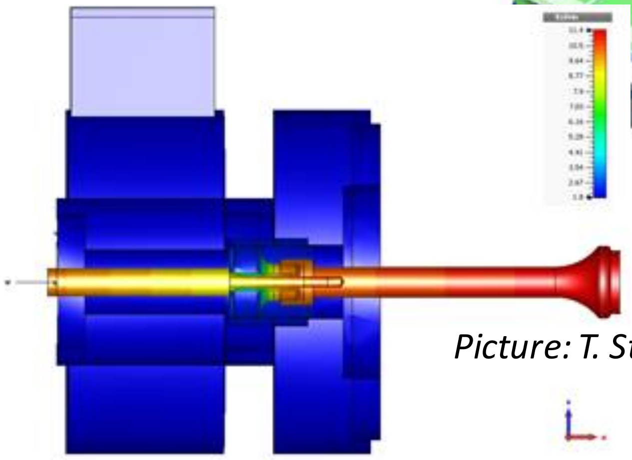
- Thermal calculations for the HOM antenna ongoing
- Efficiency limited by the heat input from the cable
- Prototype for thermal conduction tests

Cryomodule production

- Four cavities and high-power couplers assembled
- Component testing ongoing
- Completion of first cryomodule planned for September-October 2017
- Cryomodule test to start in fall 2017



Picture: HZDR



Picture: T. Stengler

ENERGY SPREAD REDUCTION

Short bunching

- Energy spread is roughly proportional to the bunch length
- Additional errors come from phase and amplitude jitter in the rf

Symmetric non-isochronous acceleration

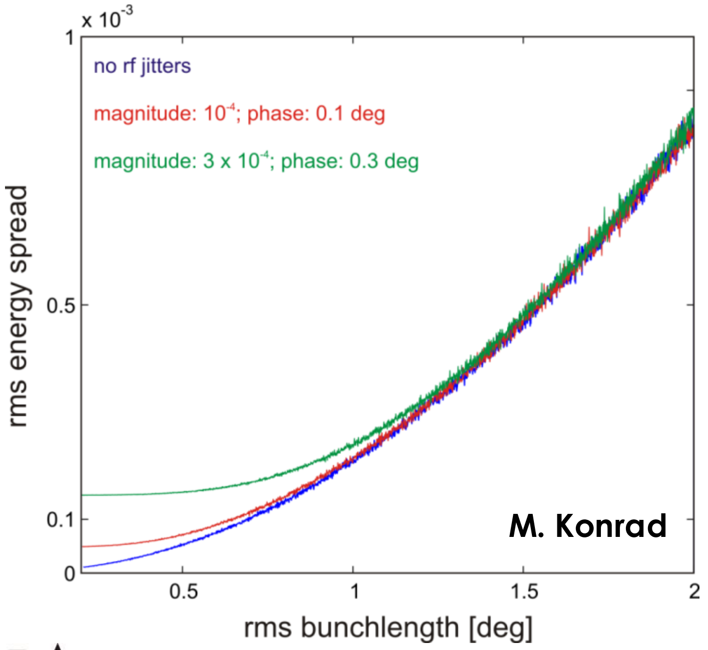
- Energy spread reduction through the off-crest acceleration
- Efficient energy recovery and no disturbance on the accelerating bunches due to the symmetric charge configuration

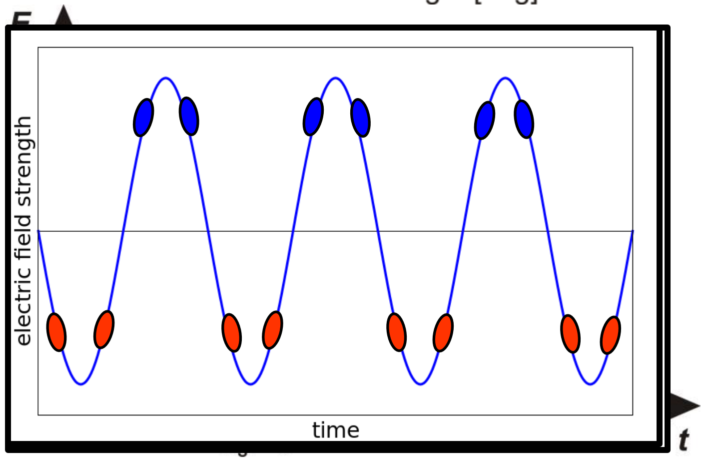
Relative ERL energy spread

- $\frac{\Delta E}{E} = 7.16 \cdot 10^{-4}$ for long bunch isochronous acceleration
- $\frac{\Delta E}{E} = 2.68 \cdot 10^{-4}$ for long bunch symmetric non-isochronous
- Calculations for the short bunch non-isochronous case are ongoing

EB energy spread

- $\frac{\Delta E}{E} = 5.5 \cdot 10^{-5}$ short bunches in non-isochronous mode
- < 10 KeV at 155 MeV nominal energy





P2 EXPERIMENT

A dedicated measurement of the electroweak mixing angle

THE WEAK MIXING ANGLE

Essential SM parameter

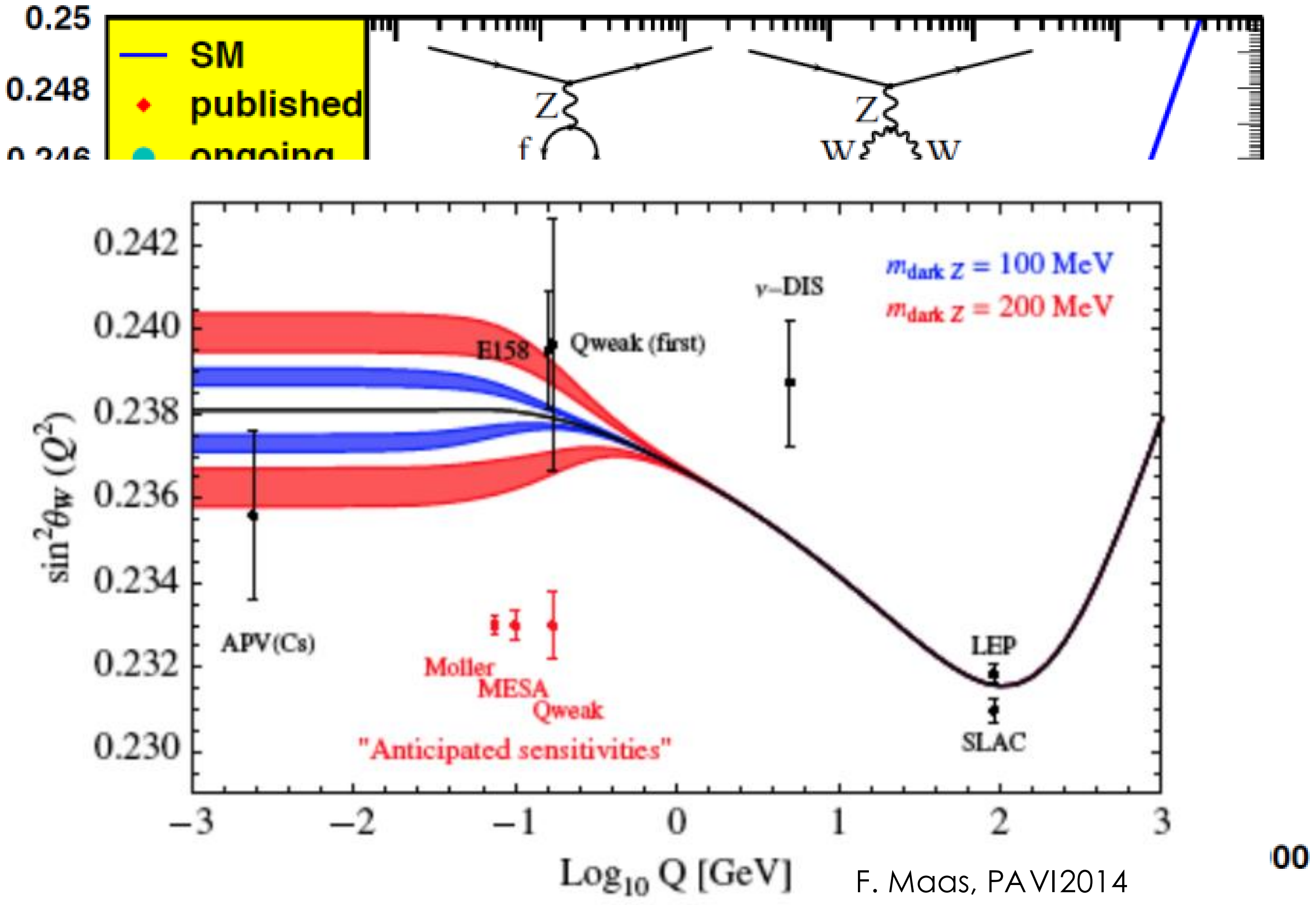
- When including radiative corrections it is scale dependent

Current measurements

- Most precise measurements at the Z-pole
- Many ongoing and proposed experiments at lower energy scales
- JLAB and Mainz on the front line

Low energy measurements

- Discrepancies at low energy can be due to new BSM physics
- E.g. Dark boson hypothesis



F. Maas, PAVI2014

MEASUREMENT OF THE WEAK ANGLE

Proton weak charge

- Direct correlation with the mixing angle
- 1.5% precision in $Q_w(p)$ corresponds to a 0.13% precision in $\sin^2\theta_w$

Weak charge with electron probes

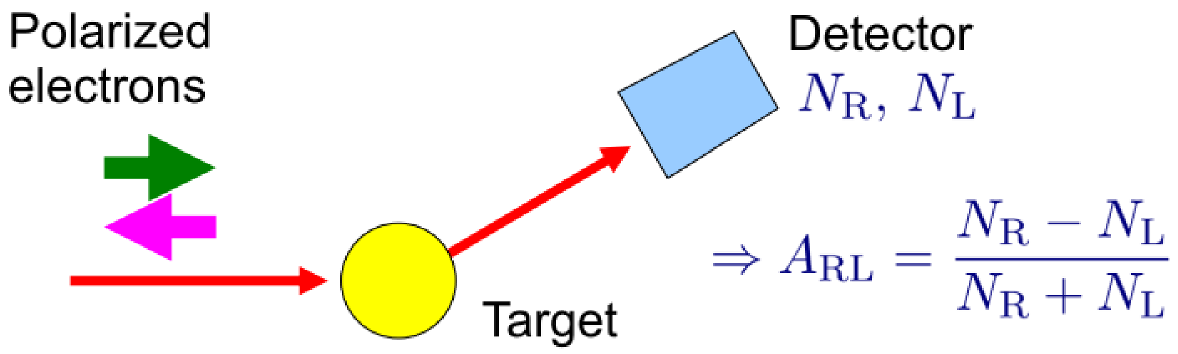
- Use polarized electrons
- Measure the cross-section asymmetry in the elastic electron-proton scattering

The P2 experiment

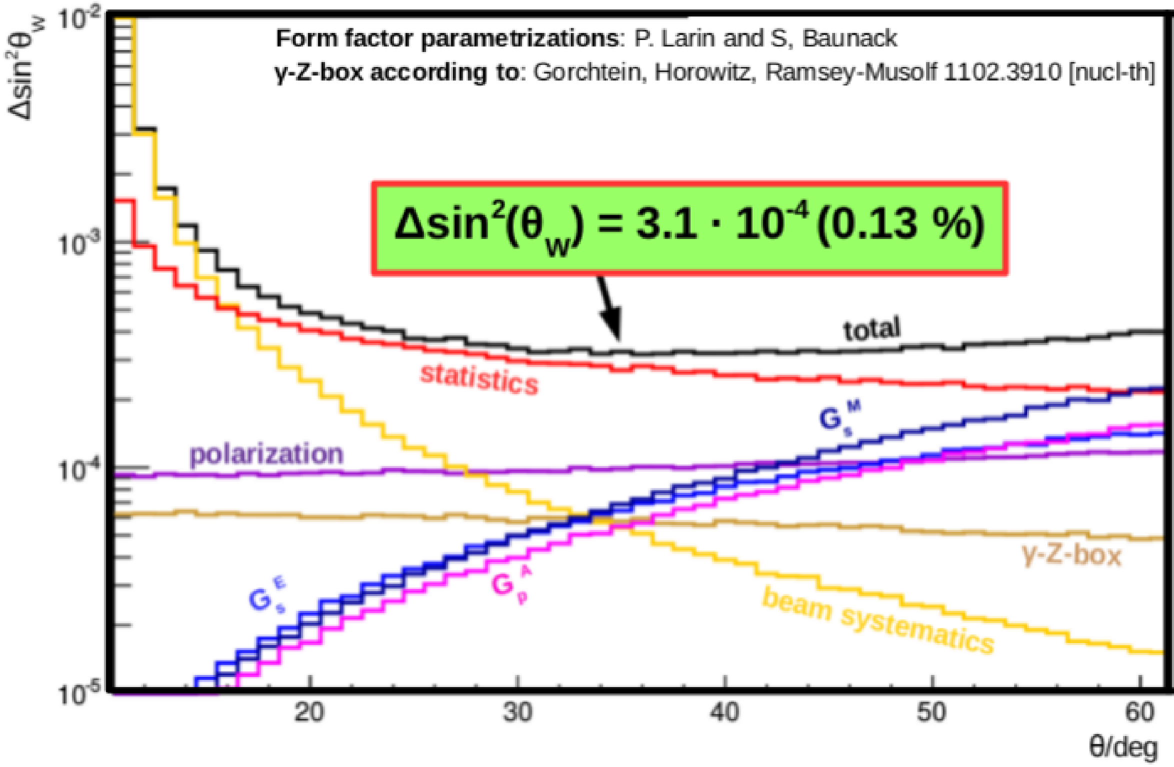
- Fixed target experiment with polarized electron beam
- Fix angle integrating detector synchronized with rapidly switching polarized beam

$$Q_w(p) = 1 - 4\sin^2\theta_w$$

$$A_{LR} = \frac{\sigma(e_\downarrow) - \sigma(e_\uparrow)}{\sigma(e_\downarrow) + \sigma(e_\uparrow)} = -\frac{G_F Q^2}{4\sqrt{2}\,\pi\,\alpha}\left(Q_w(p) - F(Q^2)\right)$$



P2 OPERATIONAL PARAMETERS



Beam energy:	155 MeV
Beam current:	150 μA
Polarization:	(85±0.5)%
Target:	60 cm lH2
Acceptance:	2π·(35°±10°)
Rate:	0.5 THz
Runtime:	10000 h
ΔA^{app}:	0.1 ppb

	Total	Statistics	Polarization	Apparative	FF	$\mathrm{Re}(\square_{\gamma ZA})$
$\Delta\sin^2(\theta_W)$	3.1e-4 (0.13 %)	2.6e-4 (0.11 %)	9.7e-5 (0.04 %)	7.0e-5 (0.03 %)	1.4e-4 (0.04 %)	6e-5 (0.03 %)
ΔA^{exp}/ppb	0.44 (1.5 %)	0.38 (1.34 %)	0.14 (0.49 %)	0.10 (0.35 %)	0.11 (0.38 %)	0.09 (0.32 %)

THE DETECTOR CONCEPT

Liquid hydrogen target

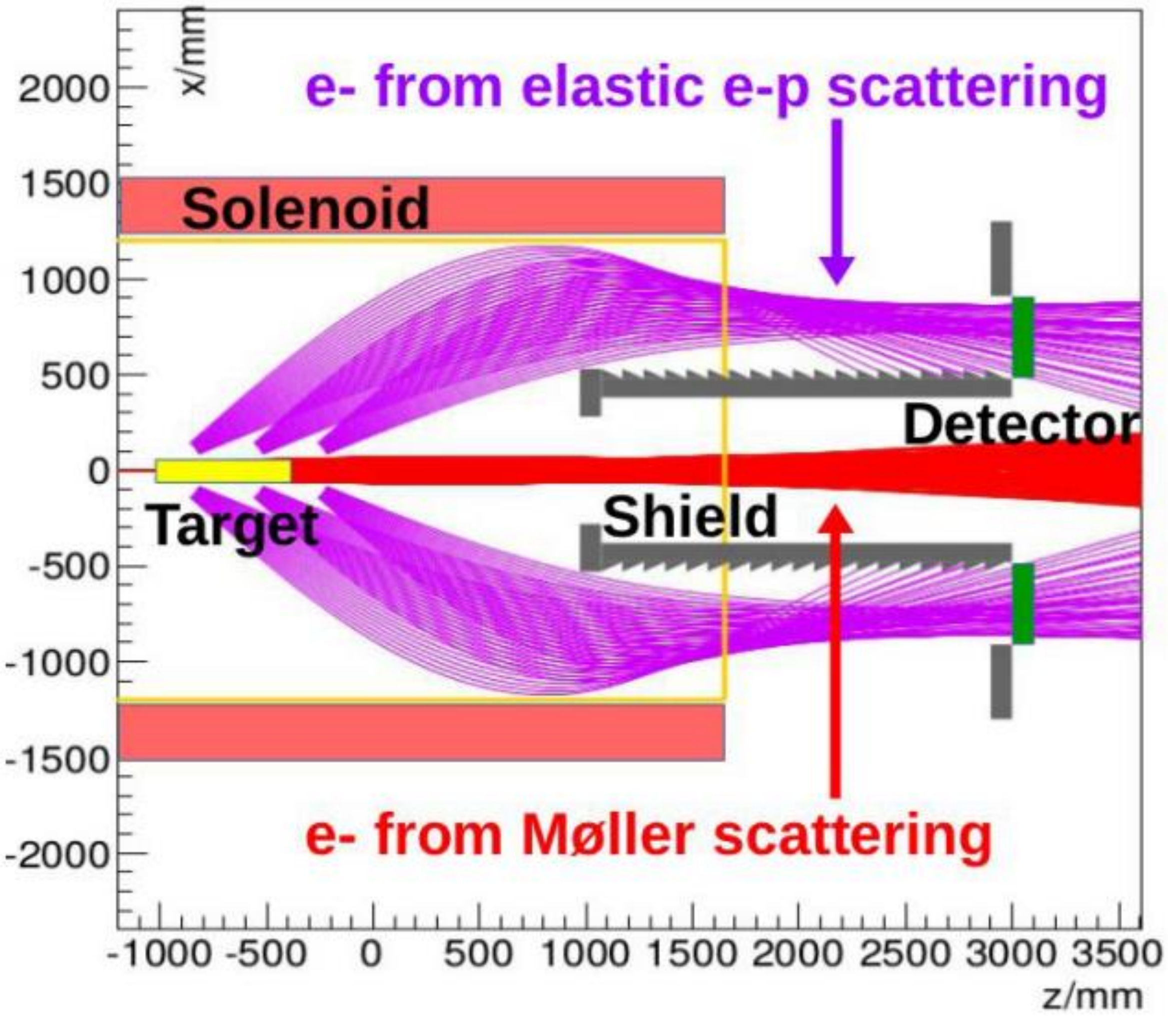
- Design underway

Solenoid magnet

- Focusing the elastic scattered particles on the detector
- Simulated with FEM and GEANT

Integrating detectors

- Thin, fast and granular detectors
- HV monolithic active pixel sensors
- Current generation is MUPIX7 with $9.4\ \mathrm{mm}^2$ active surface
- Tested at MAMI



MAGIX EXPERIMENT

A versatile experiment for precision measurements at low energy

PHYSICS PROGRAM

Hadronic structure

- Proton form factors (electric and magnetic)
- Nuclear polarizabilities
- Light nuclei form factors (Deuteron and helium)

Few-body physics

- Deuteron and ^{3}He breakup
- ^{4}He monopole transition factors
- Test of effective field theories
- Inclusive electron scattering

Precision cross-sections

- ^{16}O(e, e'α)^{12}C S-factor

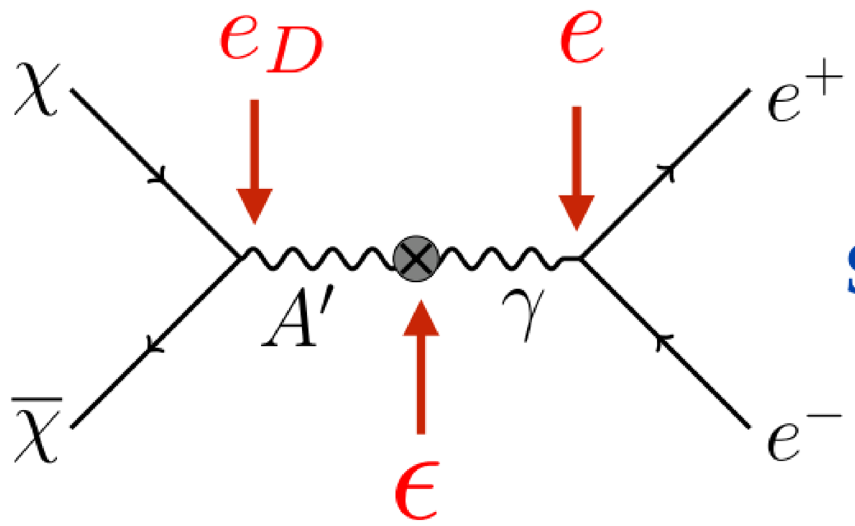
Search for exotica

- Direct dark photon search
- Invisible decaying dark photon search

DARK PHOTON

$$\alpha_D \equiv \frac{e_D^2}{4\pi}$$

DM



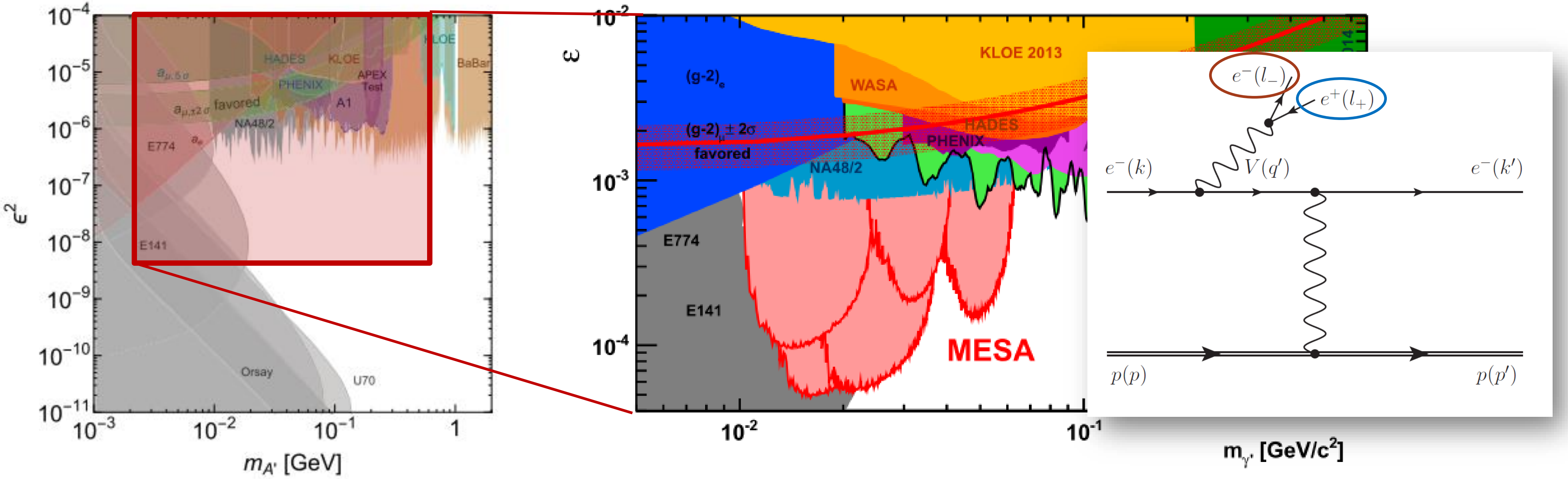
SM

$$\alpha \equiv \frac{e^2}{4\pi}$$

Dark sector mediator

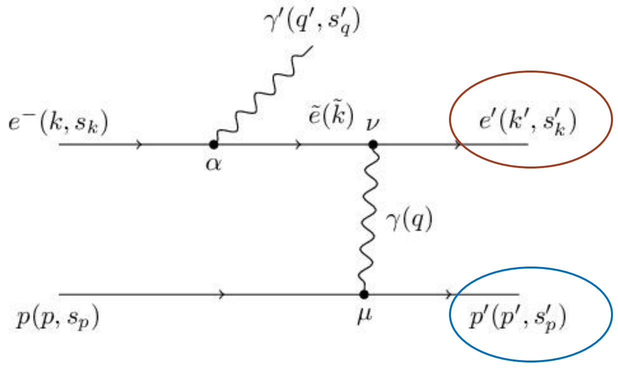
- Massive U(1) boson
- Same quantum numbers of the SM photon
- Can undergo kinetic mixing with the SM photon (parameterized by ϵ)
- Magix can search for invisible or visible decays (possible when there is no DM particle kinematically accessible)

DARK PHOTON VISIBLE DECAYS



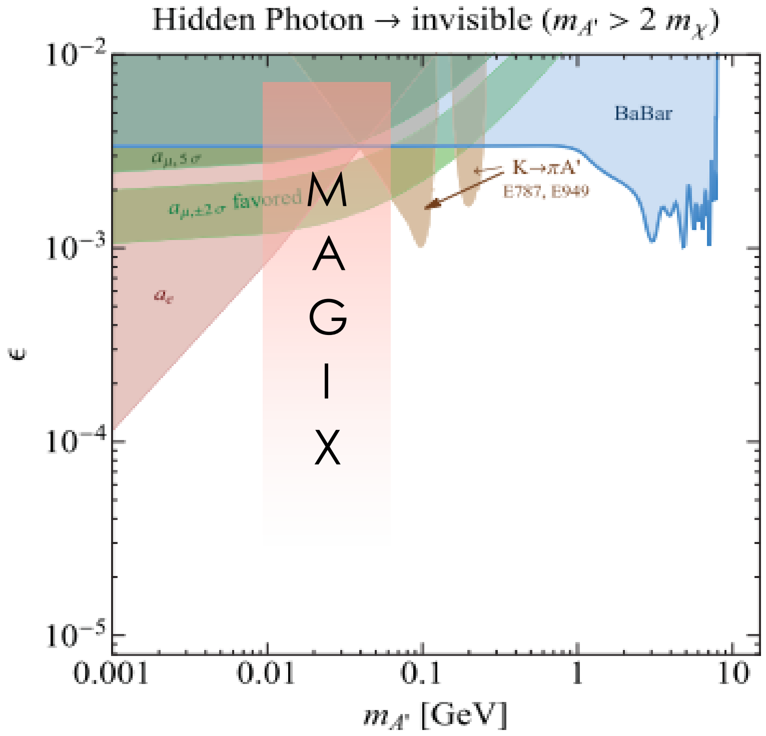
Measure the momenta of e^+ e^- in coincidence	Bump hunting in the invariant mass distribution	Mass sensitivity: 10 – 60 MeV	Coupling down to about $\epsilon > 5 \cdot 10^{-5}$

DARK PHOTON INVISIBLE DECAYS



Mass sensitivity about 10-60 MeV

Coupling sensitivity unknown



Full kinematic reconstruction

- Spectrometer for electron
- Second detector for the proton

Work in progress

- Spectrometer efficiency for proton detection
- Do we need a separate recoil detector?

PROTON RADIUS PUZZLE

Proton charge radius

- The derivative of the form-factor for $Q^2 \rightarrow 0$

Electronic measurements

- Hydrogen hyperfine structure
- Electron scattering
- $r_e = 0.8775(51)$

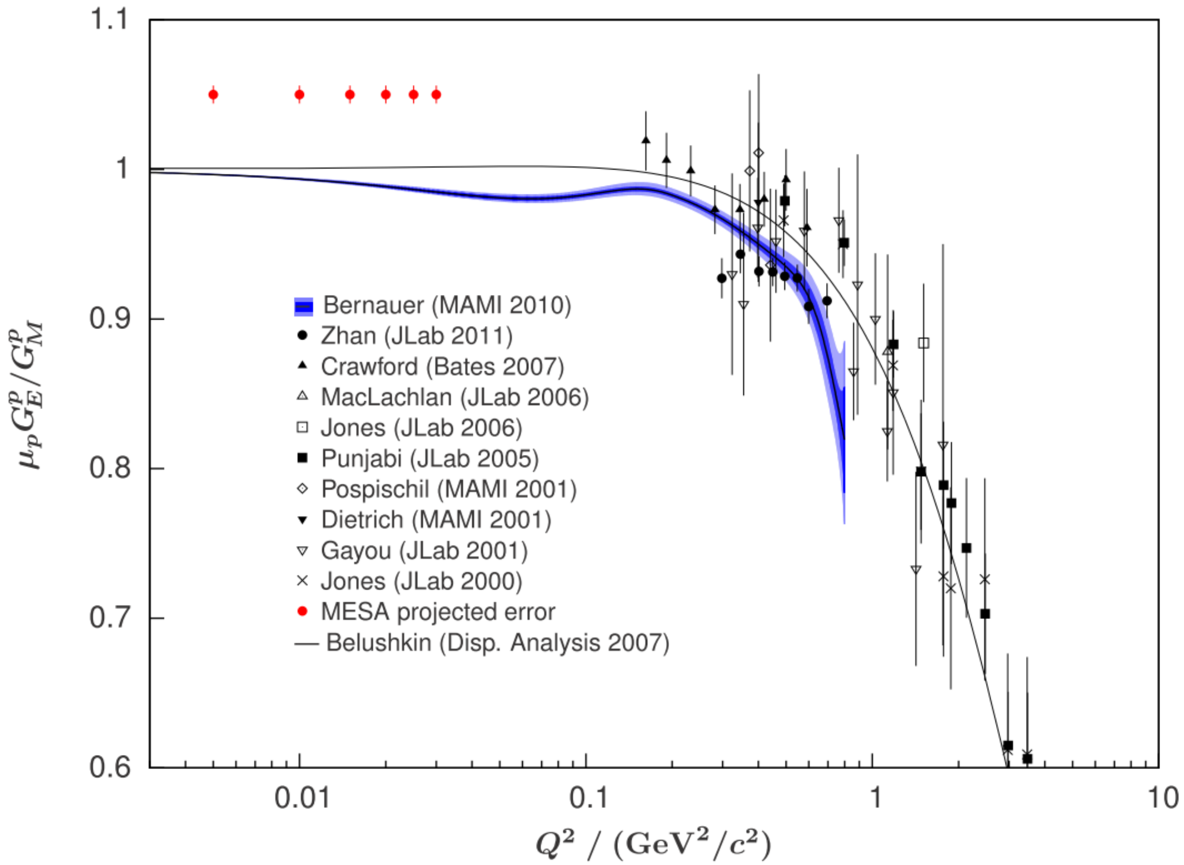
Muonic measurements

- Lamb shift of a muonic hydrogen
- $r_\mu = 0.84087(39)$

Electron scattering Q^2

- Direct measurements with current experiments $Q^2 > 0.3\ \mathrm{GeV}^2$
- Extrapolation to 0 to derive the form factor

Measure the form factors at lower Q^2



7 σ discrepancy

proton radius[fm]

CR

py

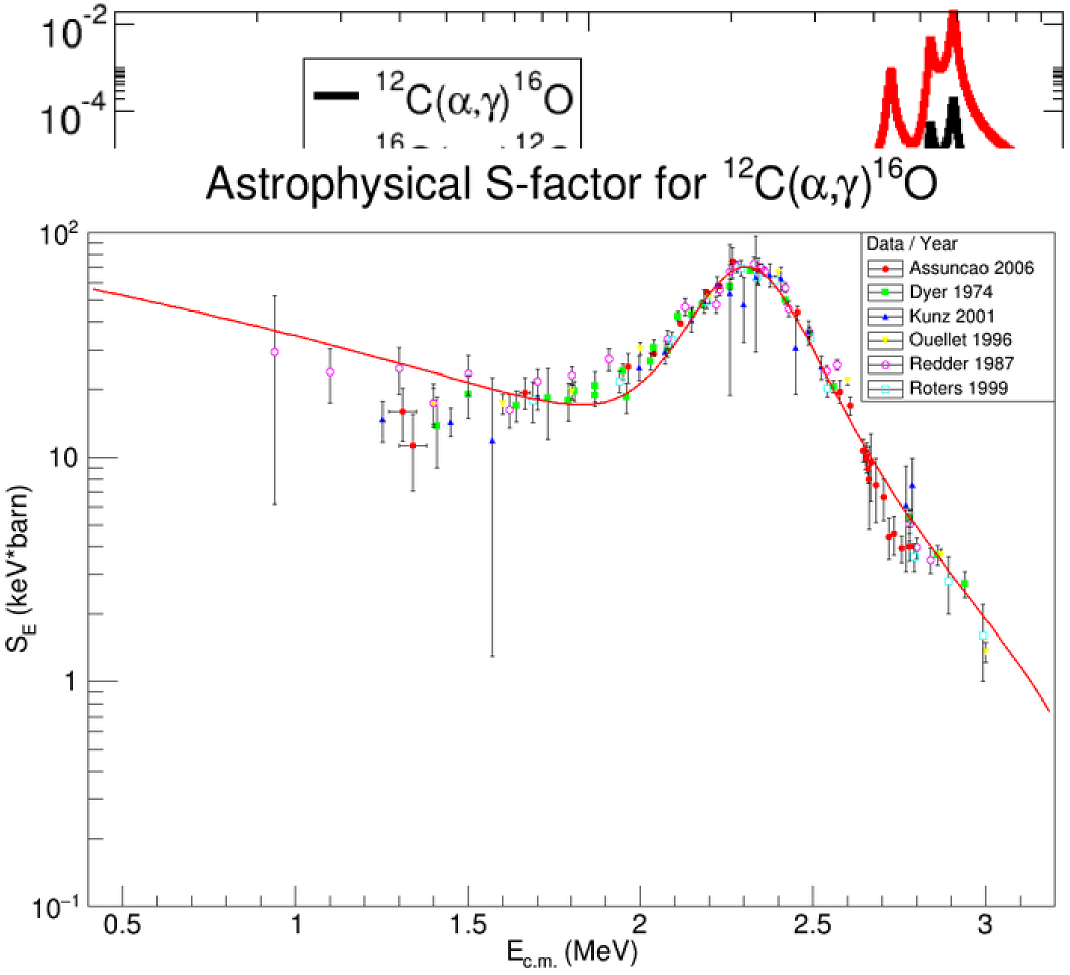
on

Low energy nuclear cross-sections

- Relevant for astrophysical modelling
- $^{12}C(\alpha,\gamma)^{16}O$ important to model late stellar burning
- Thermal energy at burning point (Gamow peak energy) ~300 KeV
- Very low cross-section $\sim 10^{-16}$ barn

Inverse reaction $^{16}O(\gamma,\alpha)^{12}C$

- 2 orders of magnitude cross-section improvement $10^{-16} \rightarrow 10^{-14}$ barn
- Time-reversal correlation with the previous reaction
- Poor data coverage at 1 MeV and below
- MAGIX can measure this cross-section at $E_{cm} < 1$ MeV
- Simulations underway



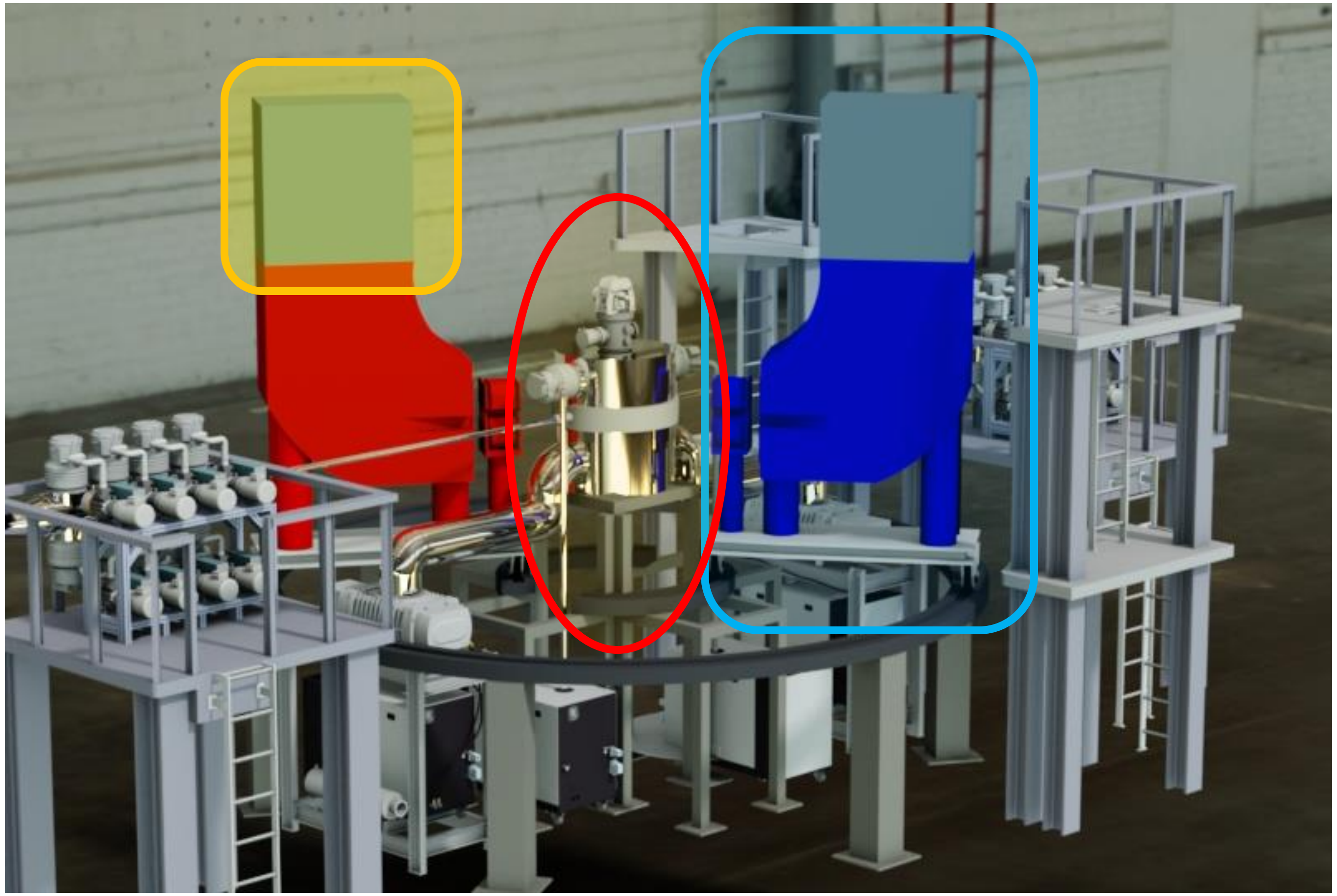
THE MAGIX SETUP

Internal Gas Target

Twin ARm DIpole Spectrometer

Focal Plane Detectors

A high-precision multi-purpose experimental setup



EXPERIMENTAL CHALLENGES

High resolution on low momentum electrons

- 1 < p < 100 MeV
- $\frac{\Delta p}{p} \approx 10^{-4}$
- $\Delta\theta \cong 0.9$ mrad

Recoil particle detection

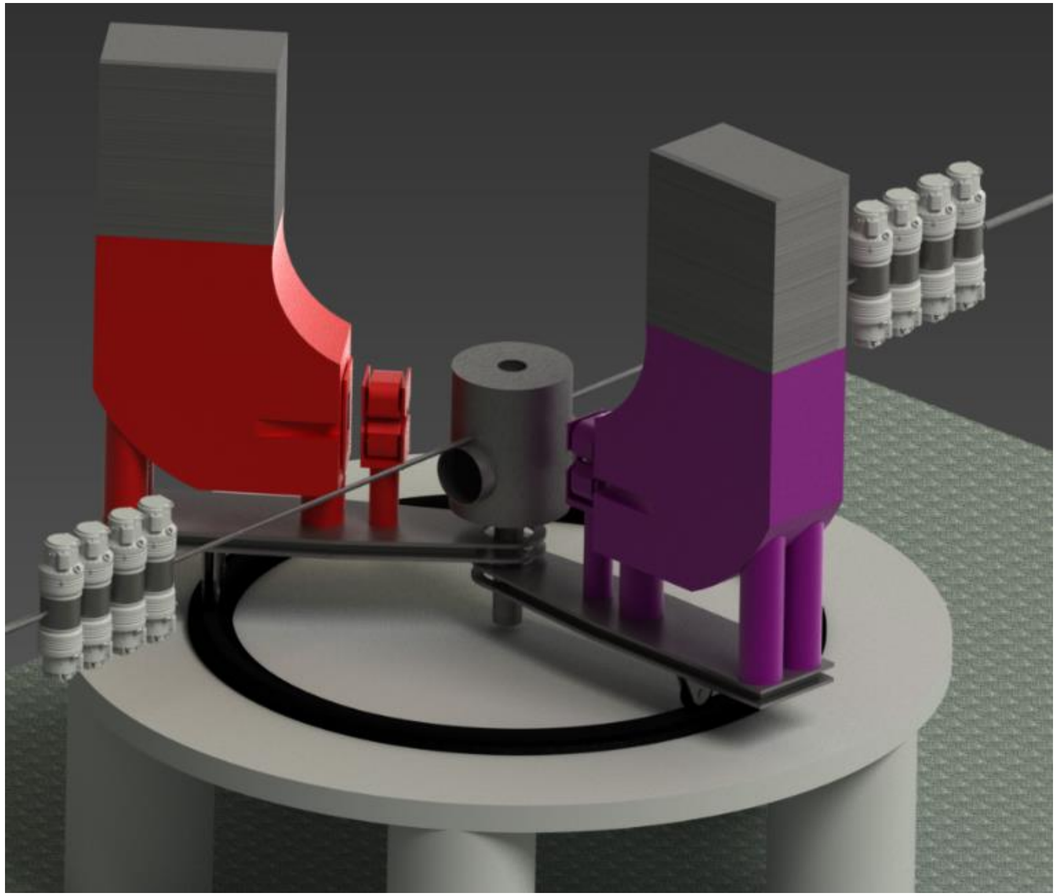
- Detection of recoil protons and alphas necessary for some planned experiments (e.g. DP invisible decays)

Material reduction

- Uncontained gas target
- No window before the magnet
- Thin detector design

High rate capability

- With a CW operation rates up to $O(1\ MHz)$
- Count rates of $O(100\ KHz)$



WINDOWLESS GAS TARGET

Limited material thickness

- Low energy electrons and recoil nuclei to measure
- Beam recapture after the interaction

High luminosity

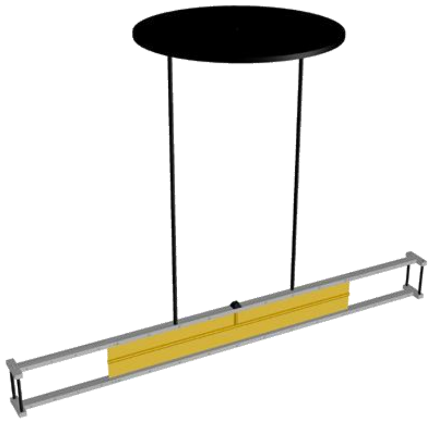
- Target luminosity $10^{35} cm^{-2} s^{-1}$

Gas polarization

- Required for some studies

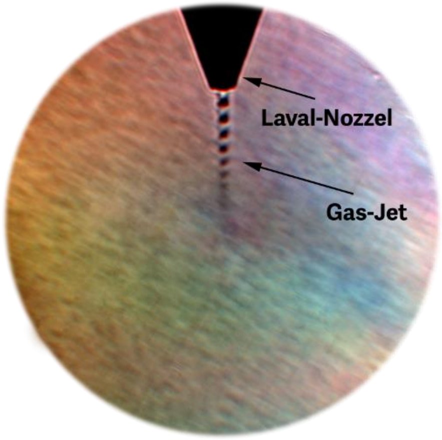
Polarized gas

- Molecular Flow inside a mylar tube



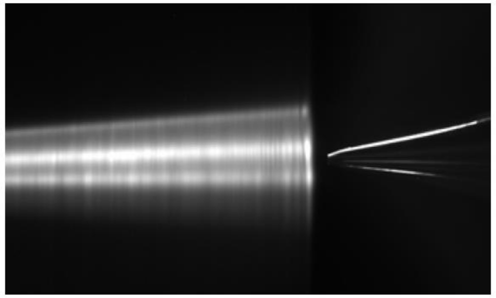
Supersonic jet

- 2 mm wide jet stream in vacuum
- 10^{19} atoms / cm^2



Cluster-Jet

- Molecular clustering @ 40K
- Increase self-conatinment



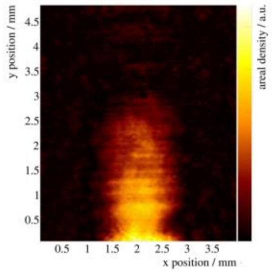
GAS TARGET DEVELOPMENTS

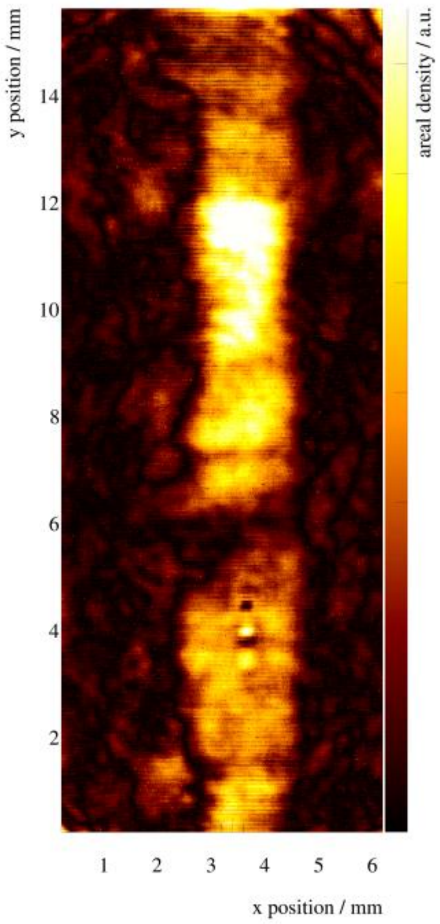
Cluster target prototype

- 40K Hydrogen
- 4 bar injection pressure
- >15 cm long contained beam
- Integrated density to be measured

A1 target test

- Target prototype currently installed on A1@MAMI
- Testing of the gas injection system and the slow control
- New proton radius measurement with ISR and reduced background





SPECTROMETERS

Momentum focusing

- Linear mapping of momenta to one coordinate in a focal plane

Angular focusing

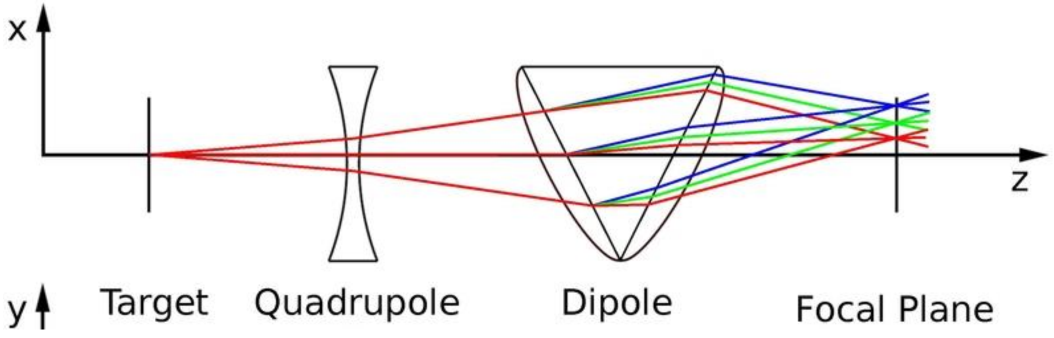
- Mapping of the scattering angles to position and angles at the focal plane.

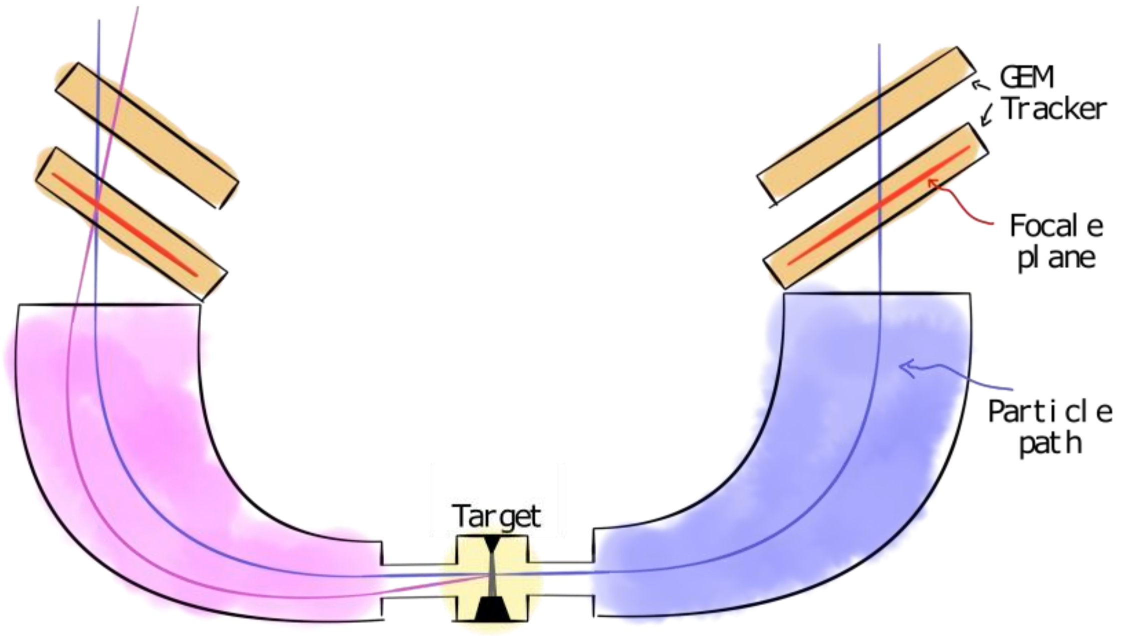
Advantages

- Extremely good momentum and angular resolution
- Depending on the acceptance of the spectrometer and size of the focal plane

Disadvantages

- Limited geometric acceptance
- Compensated by the high luminosity





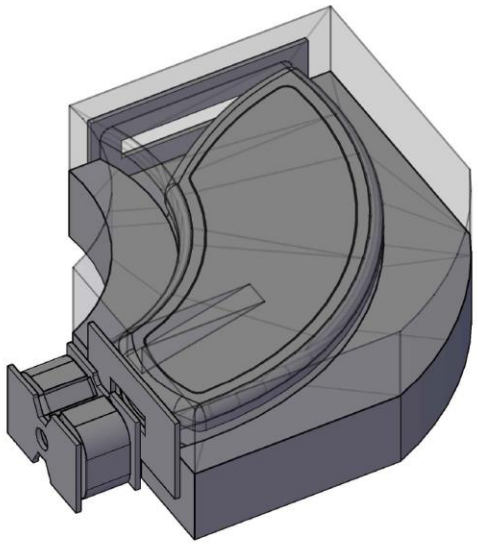
SPECTROMETER DESIGN

Quadrupole + Dipole

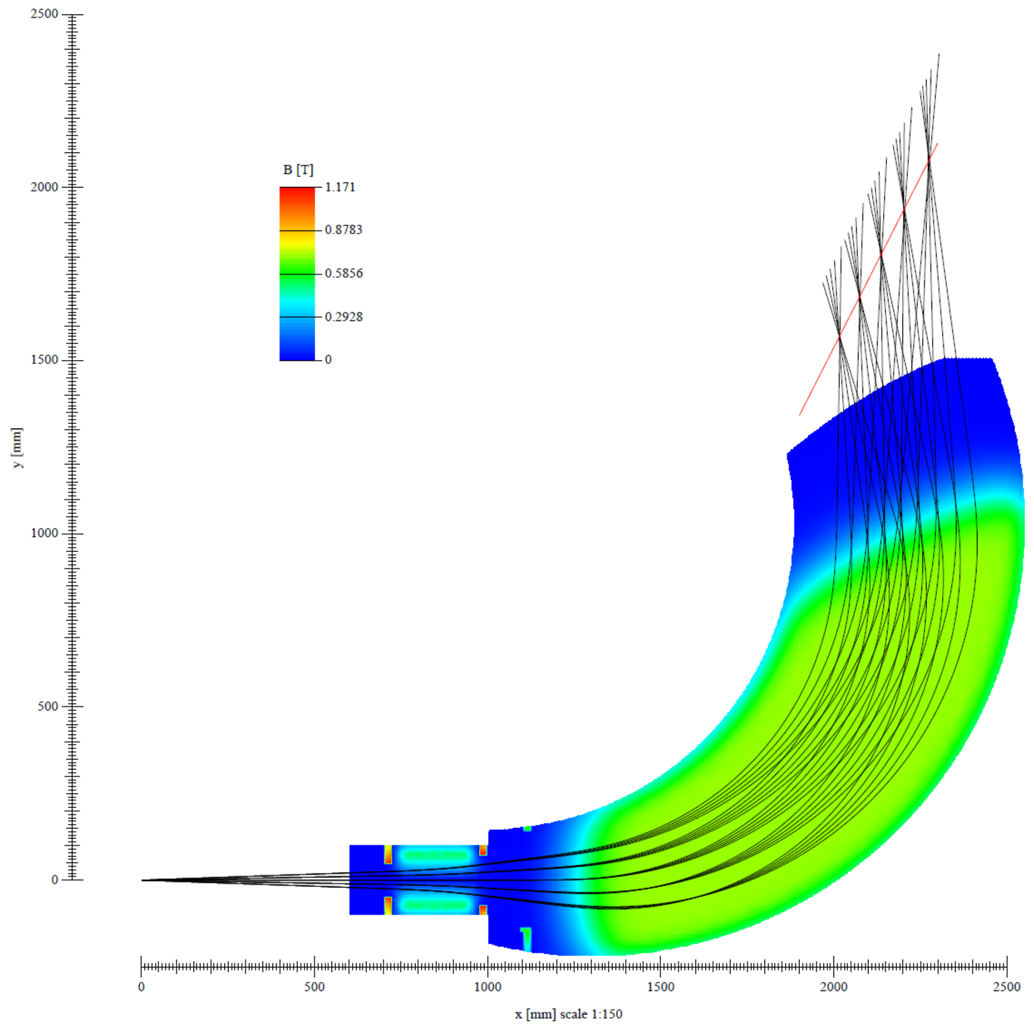
- 200 MeV maximum momentum
- 45 MeV momentum acceptance @ 100 MeV
- 120x30 cm^2 focal plane

Performance simulation

- 10^{-4} relativ e momentum resolution
- 0.9 mrad scattering angle resolution
- Assuming 50 μm resolution at the focal plane



Currently developing a few additional variants



FOCAL PLANE DETECTORS

Gas detectors

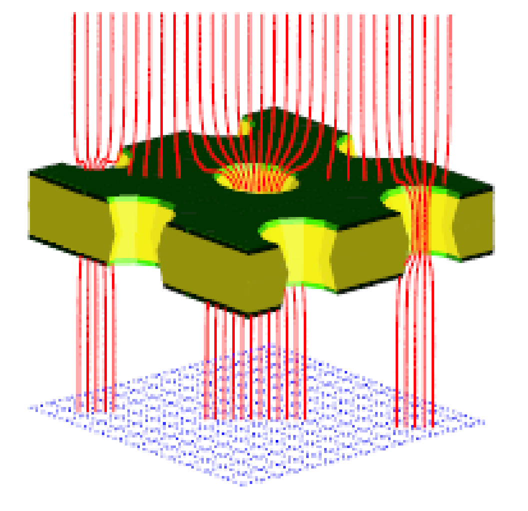
- Low material budget
- Low cost for large area coverage

MPGD

- Modern gas amplification systems
- Resolutions of the order of 50 μm achieved by several detectors

GEM

- High rate capability
- Good stability at high rate
- Adaptable to many exp. needs



2 Layer Hodoscope
• Simple detector to built • Uniform and high position resolution • Moderate material thickness • Only 2 reconstructed points

Short drift TPC
• Challenging at very high rates • Minimal material thickness • Multiple samples and full track reconstruction possible

MATERIAL MINIMIZATION

Challenges

- Multiple scattering of 10 – 100 MeV electrons between layers less than $\Delta\theta \cong 0.9\ \mathrm{mrad}$
- Detection of protons of momentum < 50 MeV in the first tracking layer

Foil readout

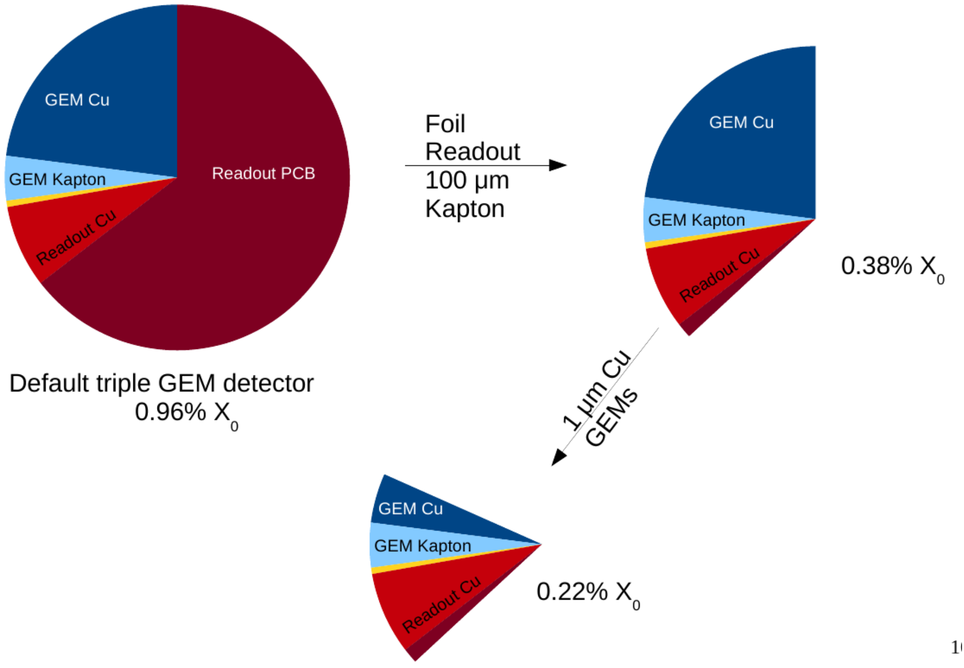
- Kapton foil readout planes in the first hodoscope layer
- Single layer padded strip layout

Thin GEM

- Thin copper coating or chromium coating
- First test-beam with chromium GEM this summer

Inert material reduction

- Vacuum membrane has cathode
- Single gas volume for the two layers



ADDITIONAL DETECTORS

Recoil detectors

- Silicon strips integrated in the scattering chamber
- Detection of recoil protons and alpha at low momenta

Trigger and PID

- Fast scintillators for triggering and timestamping
- Time-of-flight measurement to reduce cosmic backgrounds

0-degree tagger and forward detectors

- Measurement of forward photons
- Integrated in the first bending dipole after the experiment
- Moller luminometer integrated in the scattering chamber

BEAM DUMP EXPERIMENT

DARK MATTER BEAMS

A dark matter beam

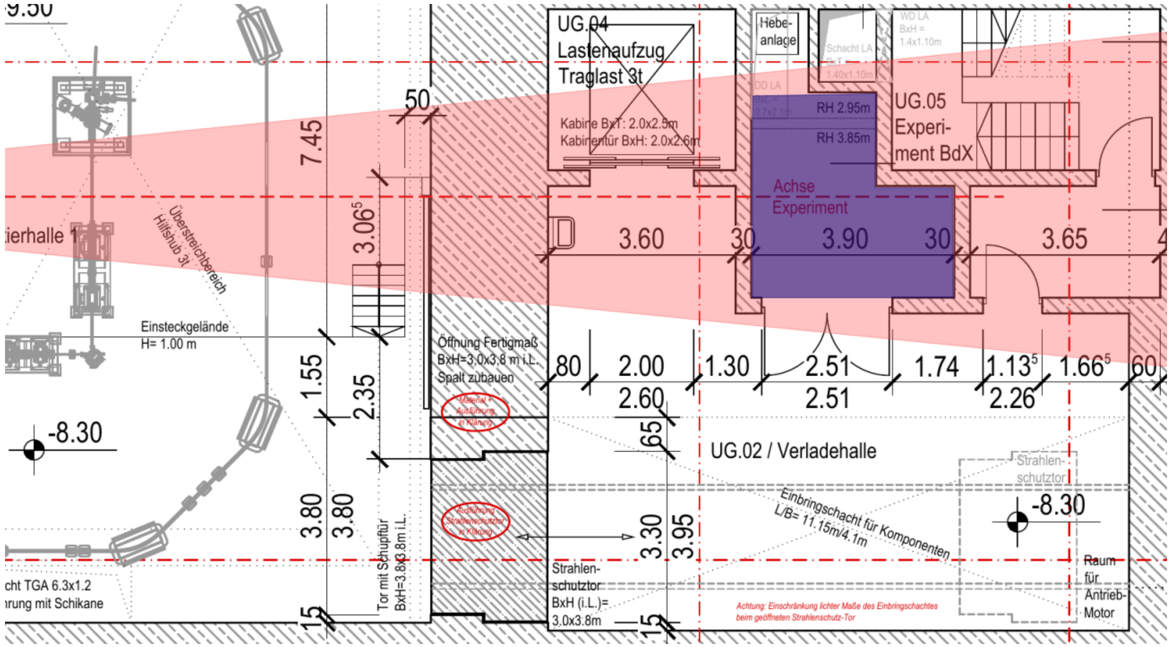
- Dark matter particles may be produced in an electromagnetic shower
- Energy and angular distribution depending on the particle mass and initial beam energy

Dark matter beam at MESA

- Produced by the interaction of the extracted beam with the P2 beam dump
- 10 degrees angular divergence due to kinematics and multiple scattering in the dump
- Shower simulation underway

Detecting a dark matter beam

- If DM particles are produced in an electromagnetic shower they may be detected via the inverse reaction
- Detect the electron recoil in a large volume detector



BDX @ MESA

Dedicated floor space

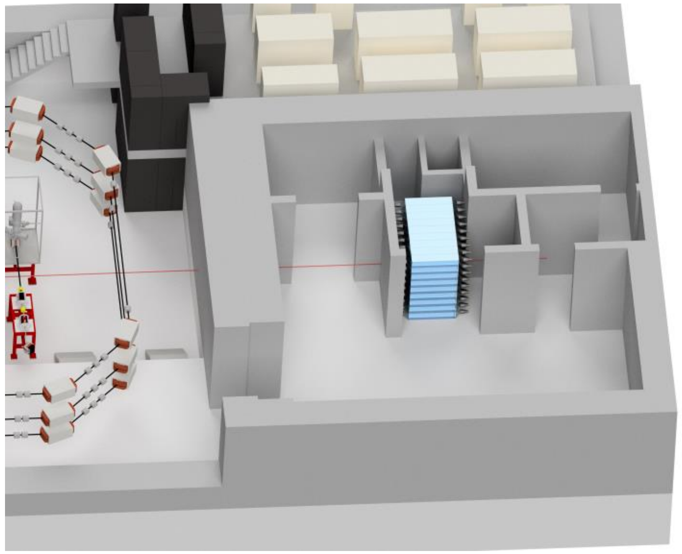
- Allotted space for the experiment in the new hall
- About $12\ \mathrm{m}^2$ floor space available
- Good placement flexibility due to the large cone radius (about 4 m)

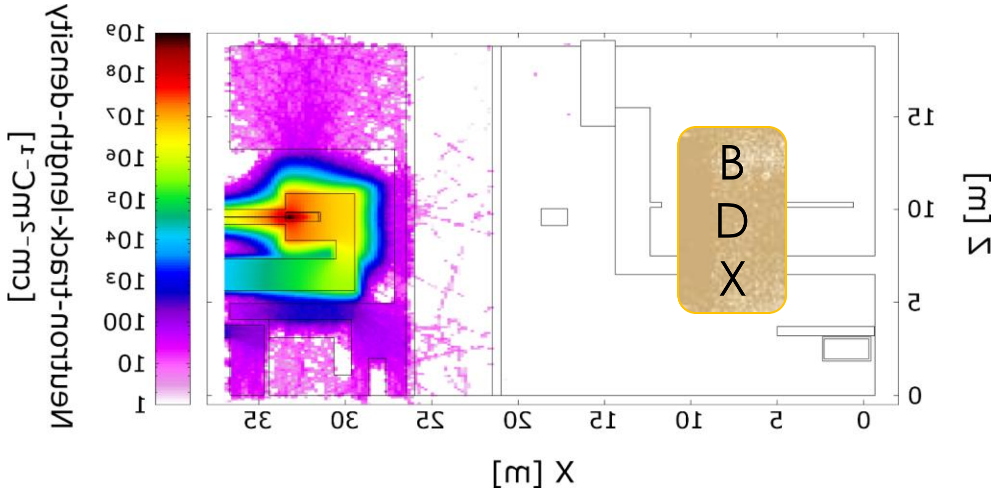
Detector

- 81 scintillating crystals with PMT readout
- Optimized for Cherenkov counting to reduce backgrounds
- Double readout and veto detectors for possible background suppression

Development status

- Shower simulation under development
- Simple detector prototype under study to be tested at MAMI
- FLUKA simulation of Neutron background completed with promising results





CONCLUSIONS

CONCLUSIONS

MESA

- High intensity and high precision machine
- Energy recovery and external beam modes
- Operations expected to start in 2021-2022

P2

- Dedicated experiment for the measurement of the Weinberg angle
- Requires very high polarization and energy control
- Simulations and prototyping under way

Magix

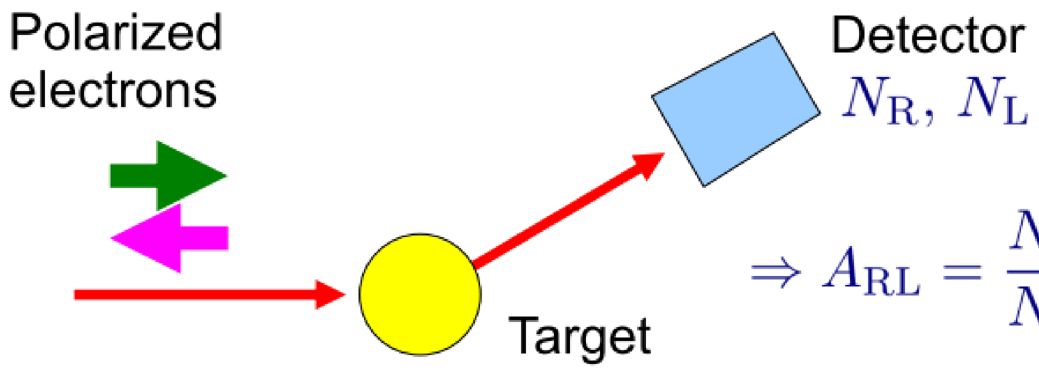
- Versatile experiment for high precision measurements
- Wide and growing physics program
- Physics simulations in advanced state of development
- Detector prototyping and testing under way
- Some components already ordered

Beam dump experiment

- Dedicated space behind the P2 beam dump
- Guaranteed 10^{23} electrons on target from P2 scheduled operations

THANK YOU FOR YOUR ATTENTION

Parity violating electron scattering



$$\Rightarrow A_{RL} = \frac{N_R - N_L}{N_R + N_L}$$

Statistics:

One needs about 10^{18} events

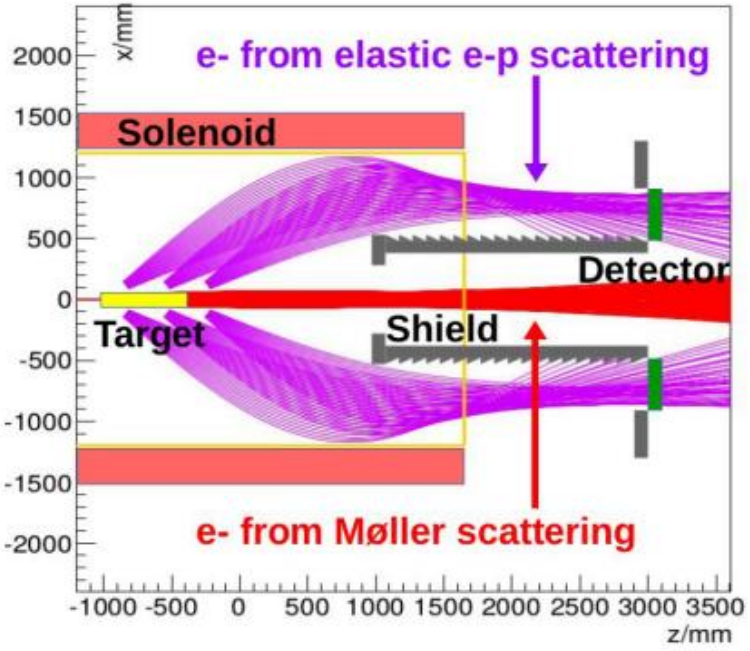
- High Luminosity
- High degree of polarization
- Large acceptance
- Fast detectors

Systematics:

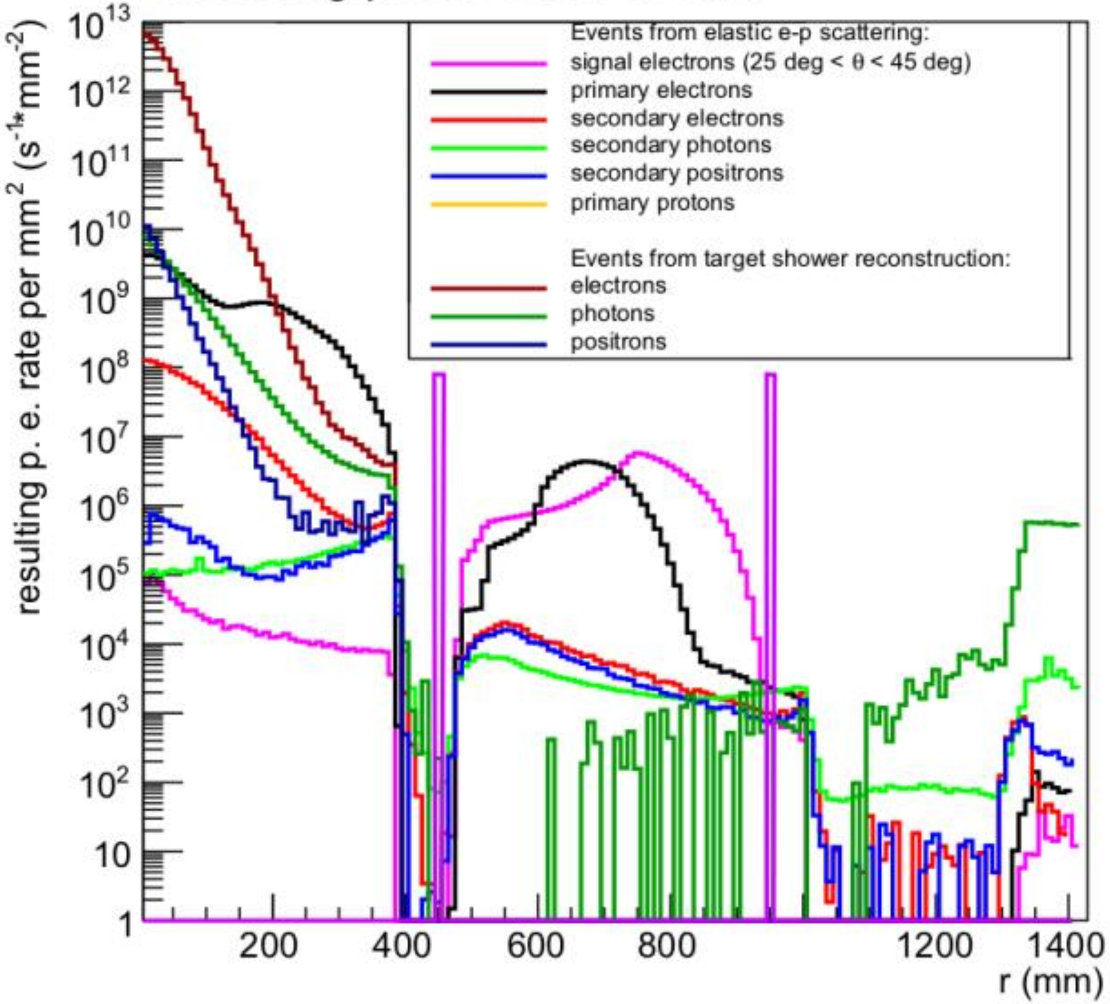
- Separation ot the elastic scattered electrons
- Beam polarization measurement
- Helicity correlated beam fluctuations
  - *Beam intensity*
  - *Beam position*
  - *Beam energy*

Magnet spectrometer - Simulations

Result of the GEANT4-simulations: Photoelectron rates for various processes

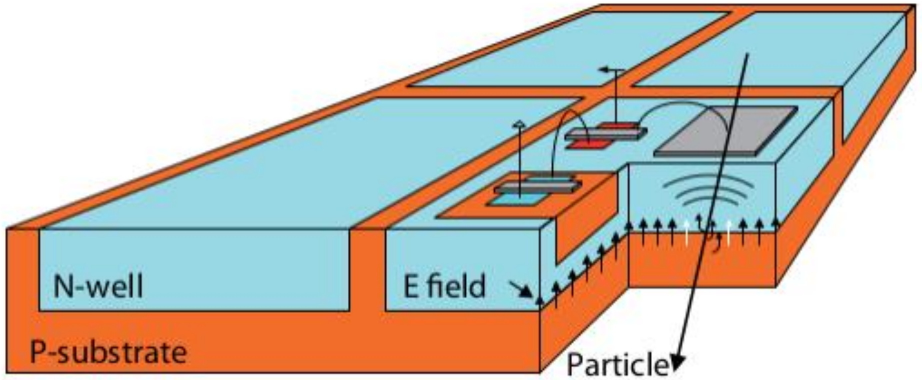


Resulting photo electron rate



September 26-30, 2016 S. Baunack, Spin '16, Urbana-Champaign 26

Tracking detectors: Determination of Q^2

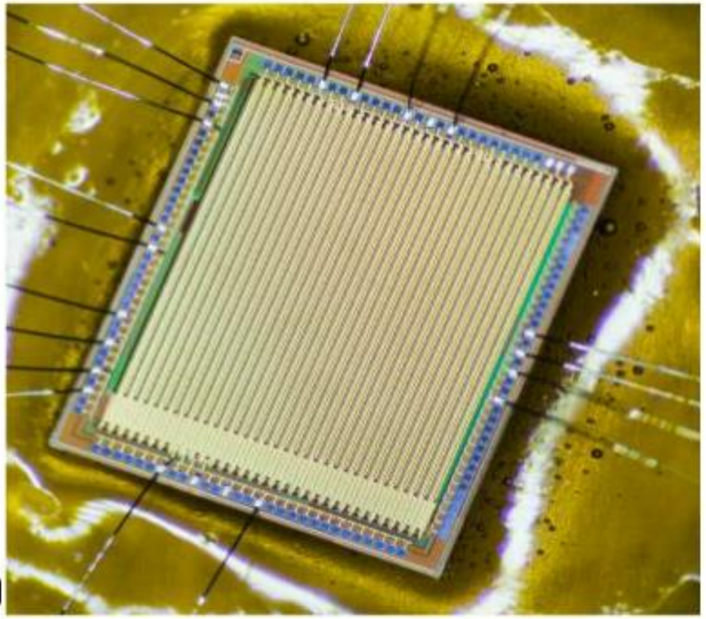


- Fast collection of charge
- Logics directly implemented on the chip:
  Digital Output (Adress of impact position and time stamp)

- Current generation (MUPIX7):
  40 x 32 pixels
  80 x 103 μm pixel size
  9.4 mm² active area

- Position resolution at the order of the pixel size
- Detection efficiency > 99%
- Time resolution <20 ns

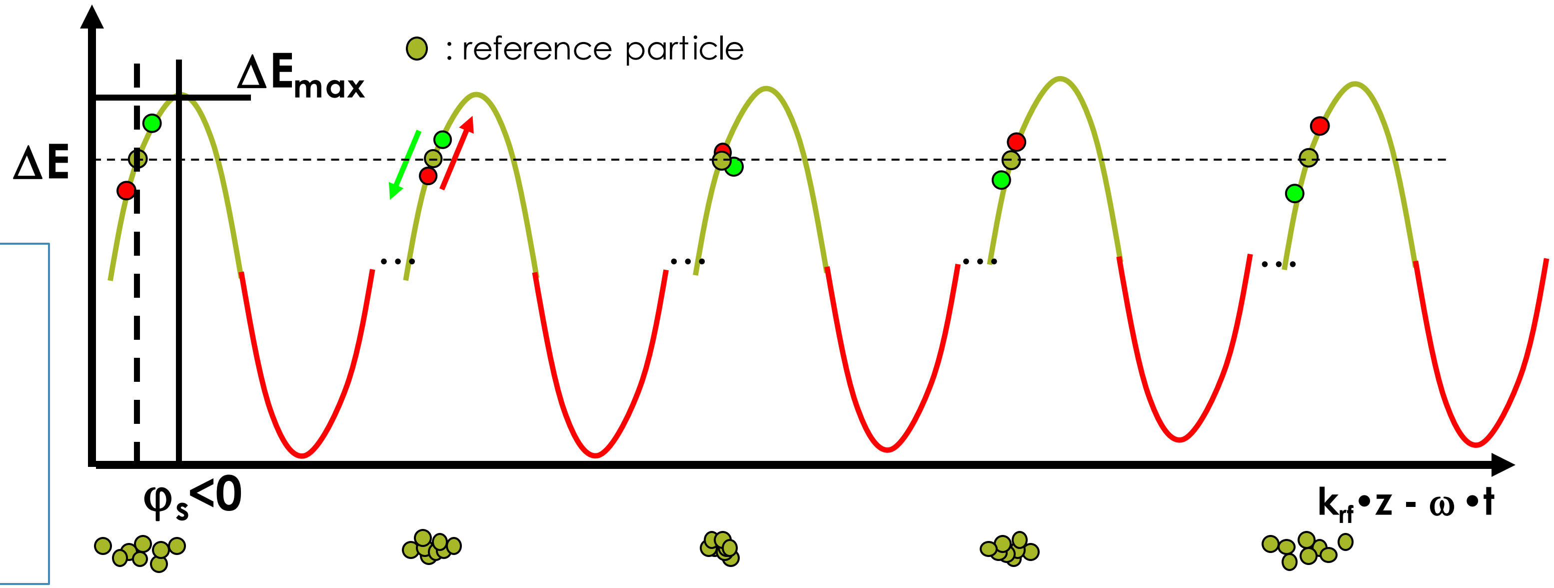
- Beam tests at MAMI (electrons/photons)

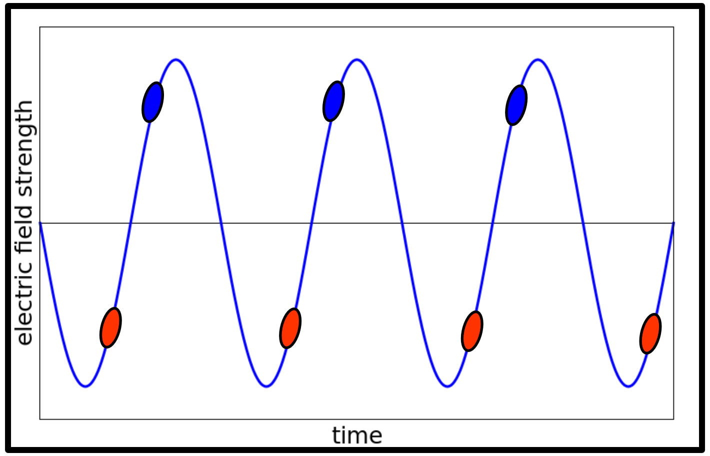


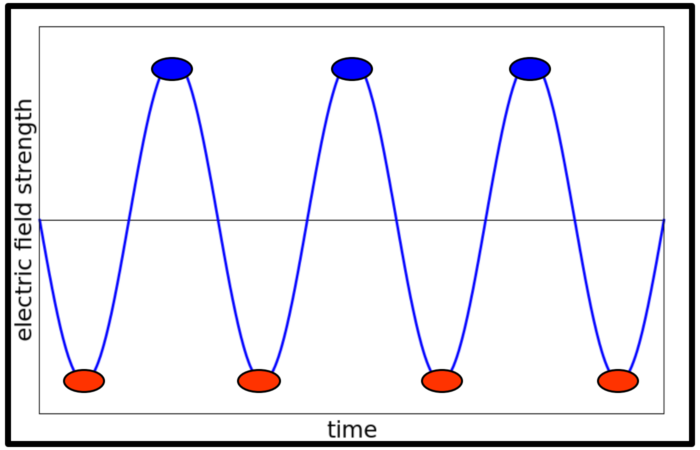
ERL ENERGY STABILIZATION

Energy spread reduction

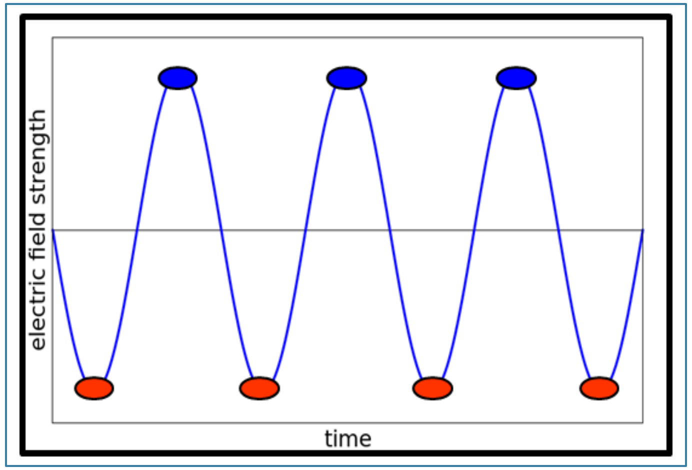
- The typical technique is the off-crest acceleration
- Feedback effect tends to reduce the energy spread in the bunch

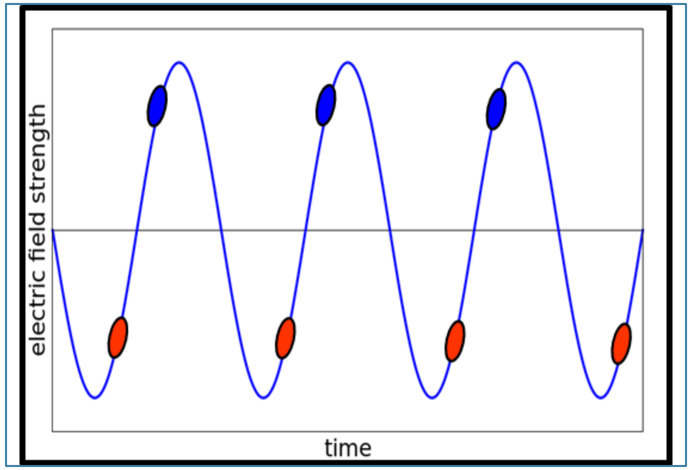


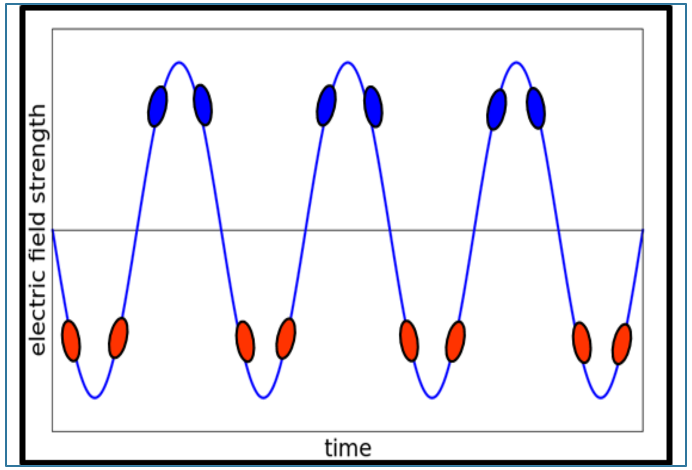




ERL NON-ISOCHRONOUS OPERATION







Isochronous operation

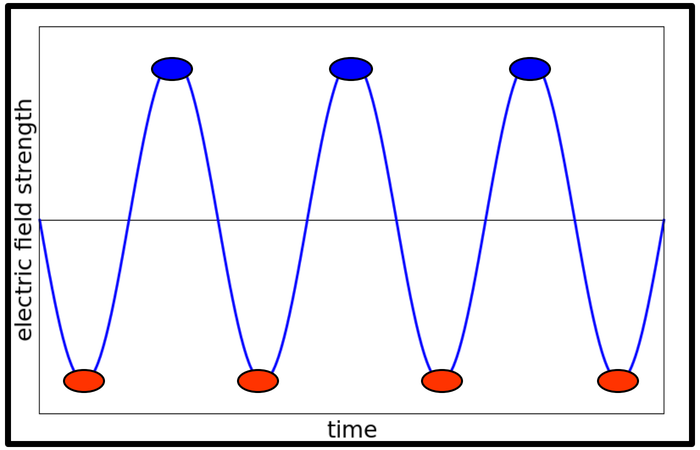
- Bunches in phase with the rf-peak
- High energy recovery efficiency
- High beam energy spread

Asymmetric non-iso

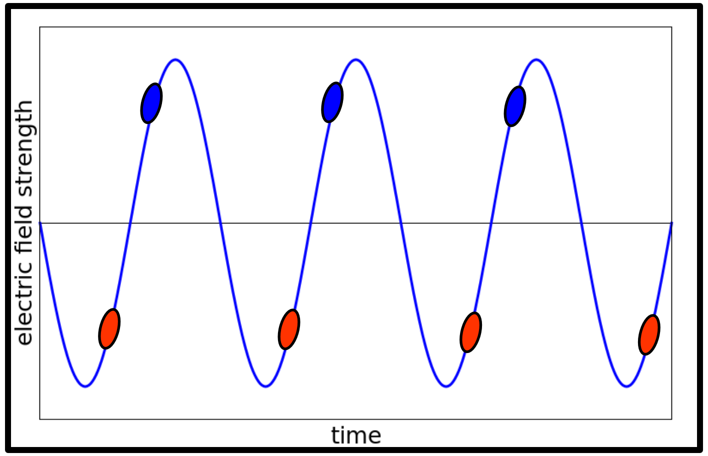
- Bunches not at the rf-peak
- Reduced beam energy spread
- Decelerating bunches at different phase
- Possible influence on accelerating bunches

Symmetric non-iso

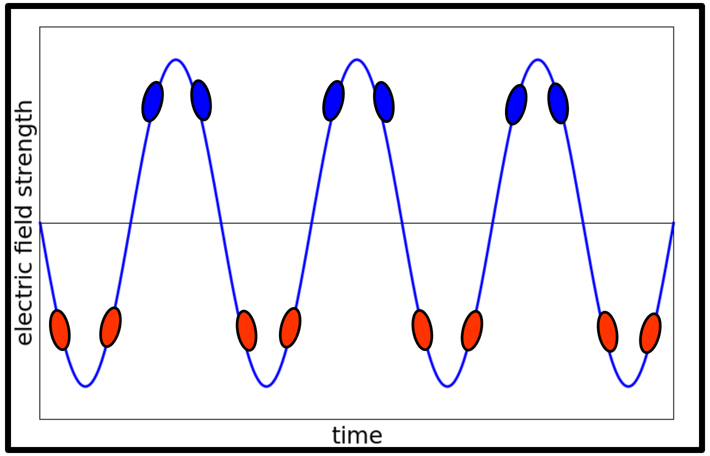
- Possible due to the double sided design of MESA
- First 2 passes on one edge, the other 2 on the opposite
- Improved energy spread with increased efficiency



electric field strength
time

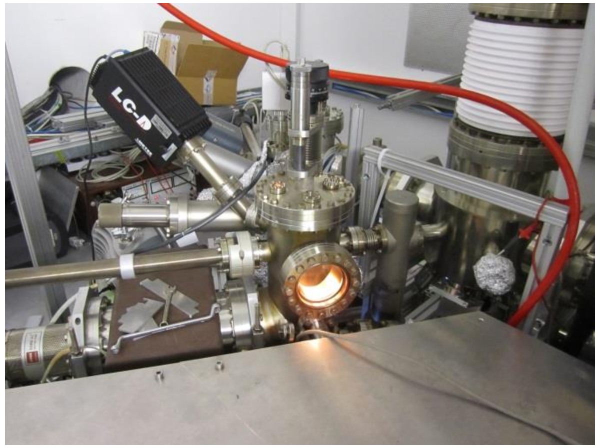


electric field strength
time



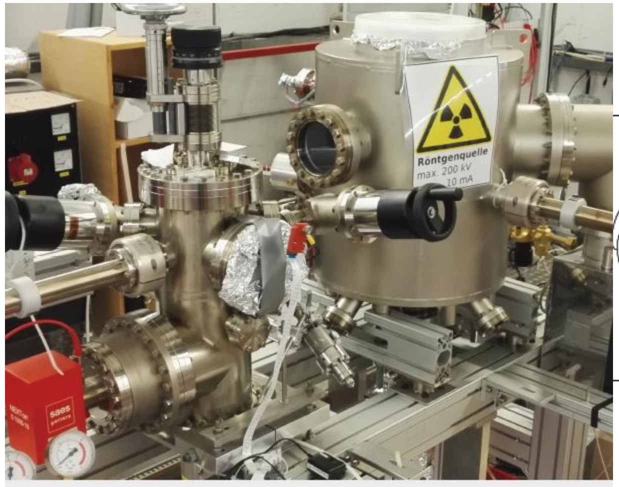
electric field strength
time

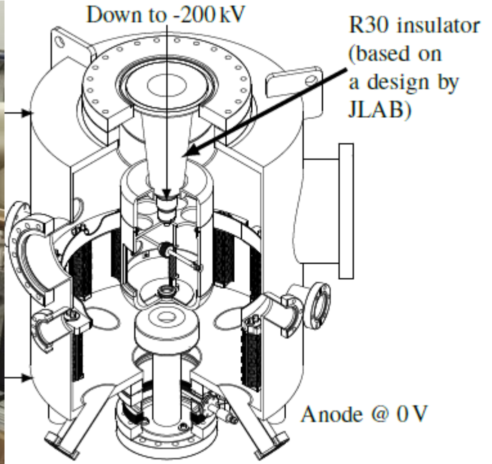
POLARISATION: FROM EB TO ERL MODE



MESA **P**olarized **S**ource (MAPS)

- ❖ Essentially a copy of MOPS
- ❖ But: higher pumping speed
- ❖ Many small details…
- better vacuum lifetime (>*2)
- Charge lifetime 700C@2mA (but at 400nm!)
- Components for **ME**sa **L**ow-energy **B**eam **A**pparatus (MELBA) tested: Beam diagnostics, Wien filter, Polarimeter, deflector cavity





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
- ❖ Main research objective: demonstrate low temperature near bandgap emission at bunch charge >1pC.
- ❖ Poster by Simon Friederich, this conf.
- ❖ First beam expected this summer
- ❖ Will replace MAPS, if succesful (STEAM→MIST)

MESA LATTICE

Recirculation lattice under revision

- Incorporate the latest changes of the layout
- Start-to-end simulation of ERL and extracted beams
- Energy spread minimization through non-isochronous beam dynamics
- Stability and acceptance maximation

Lattice modelled with:

- In-house matrix program
- MAD X
- PARMELA for space charge and pseudo-damping due to the main linac modules
- MATLAB tracking code for non-isochronous working points