The MAGIX Jet Target

a windowless target for high precision experiments at an energy recovery linac

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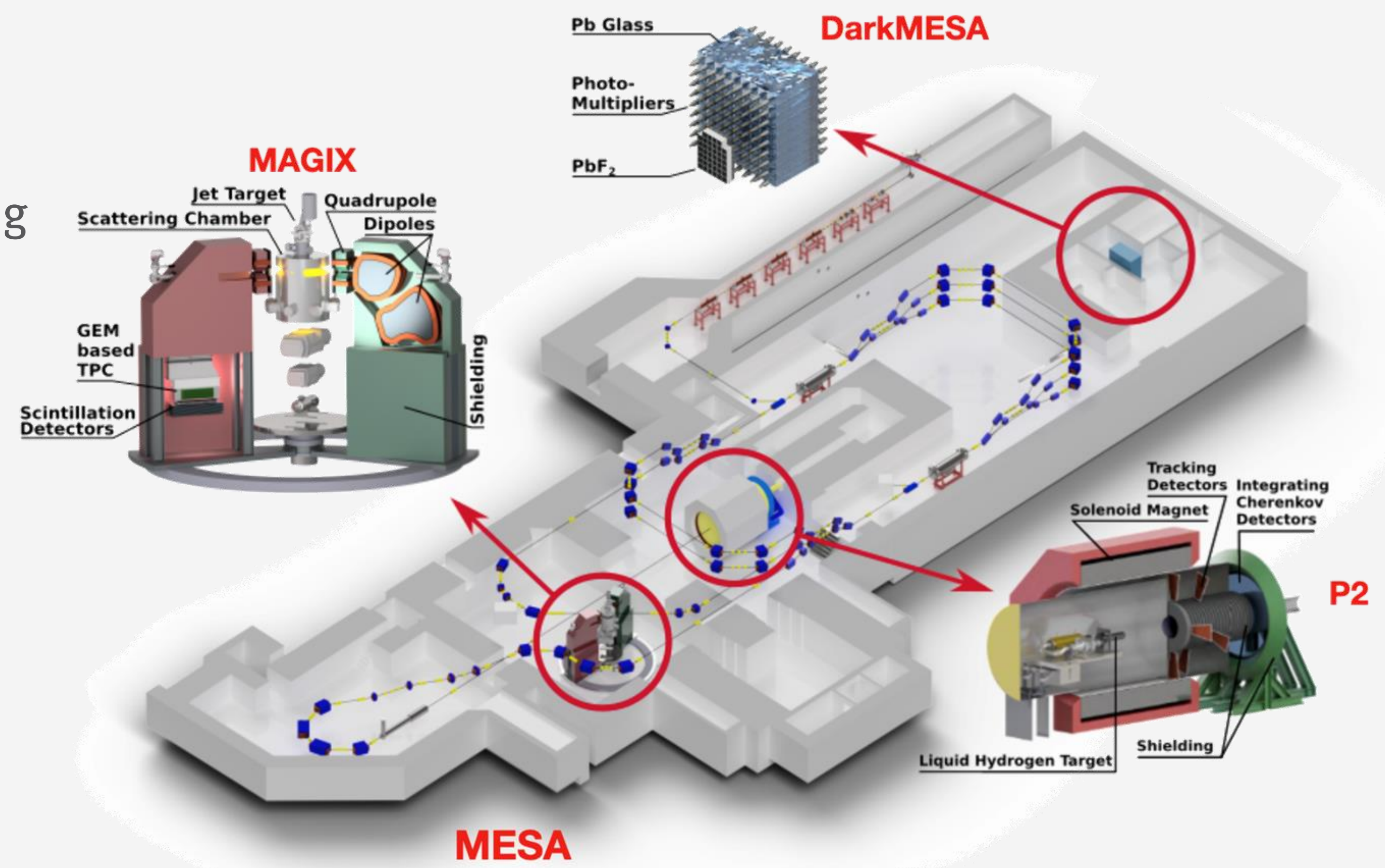
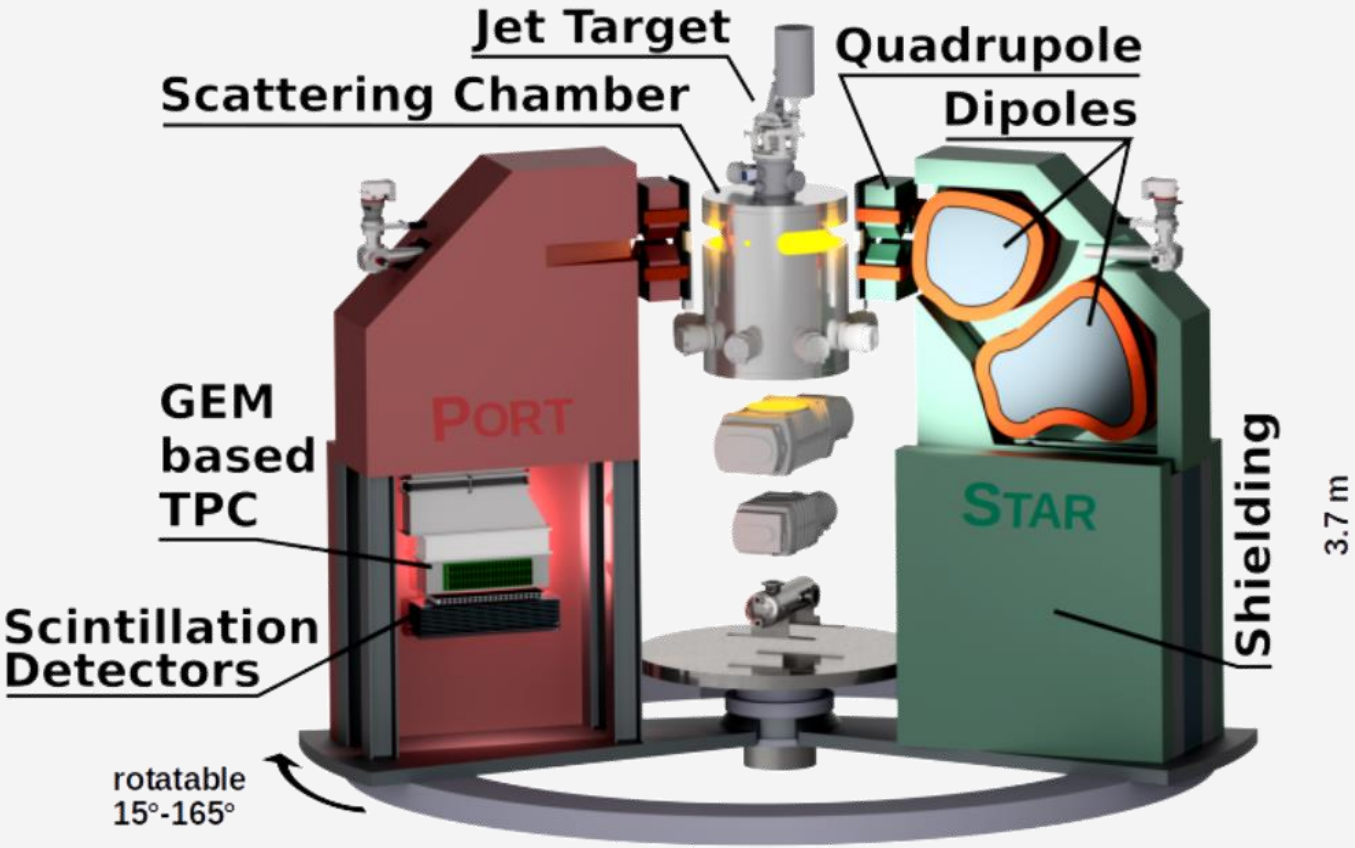
MAGIX@MESA

- Mainz energy-recovering superconducting accelerator (MESA) is under construction
- For MAGIX:
  - Up to 105 MeV electrons
  - Energy recovery in cryomodules (reinjection with 180° phase shift) allows high intensity of 1mA



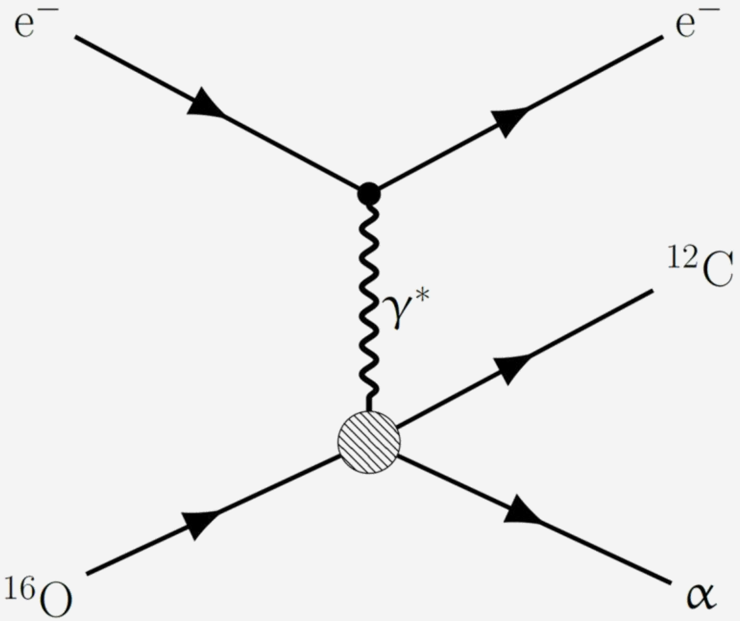
MAGIX@MESA

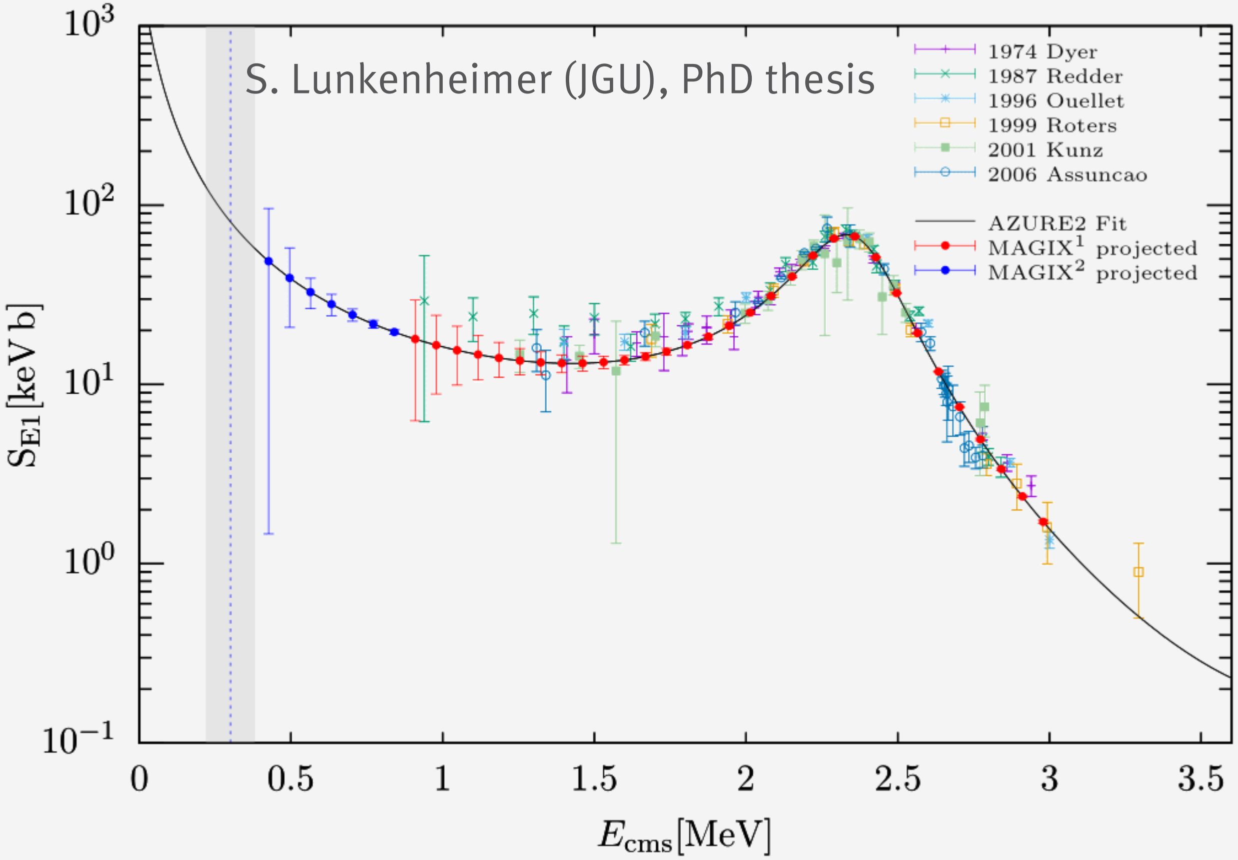
- MAGIX:
  - Interaction of electron beam with windowless jet target
  - 2 magnetic focal-plane spectrometers, rotatable around the interaction point
  - Additional detectors possible like recoil detector, zero-degree detector, …



MAGIX Physics Program

- Nuclear astrophysics: Astrophysical S-factor for $^{12}C(\alpha,\gamma)^{16}O$ in inverse kinematics





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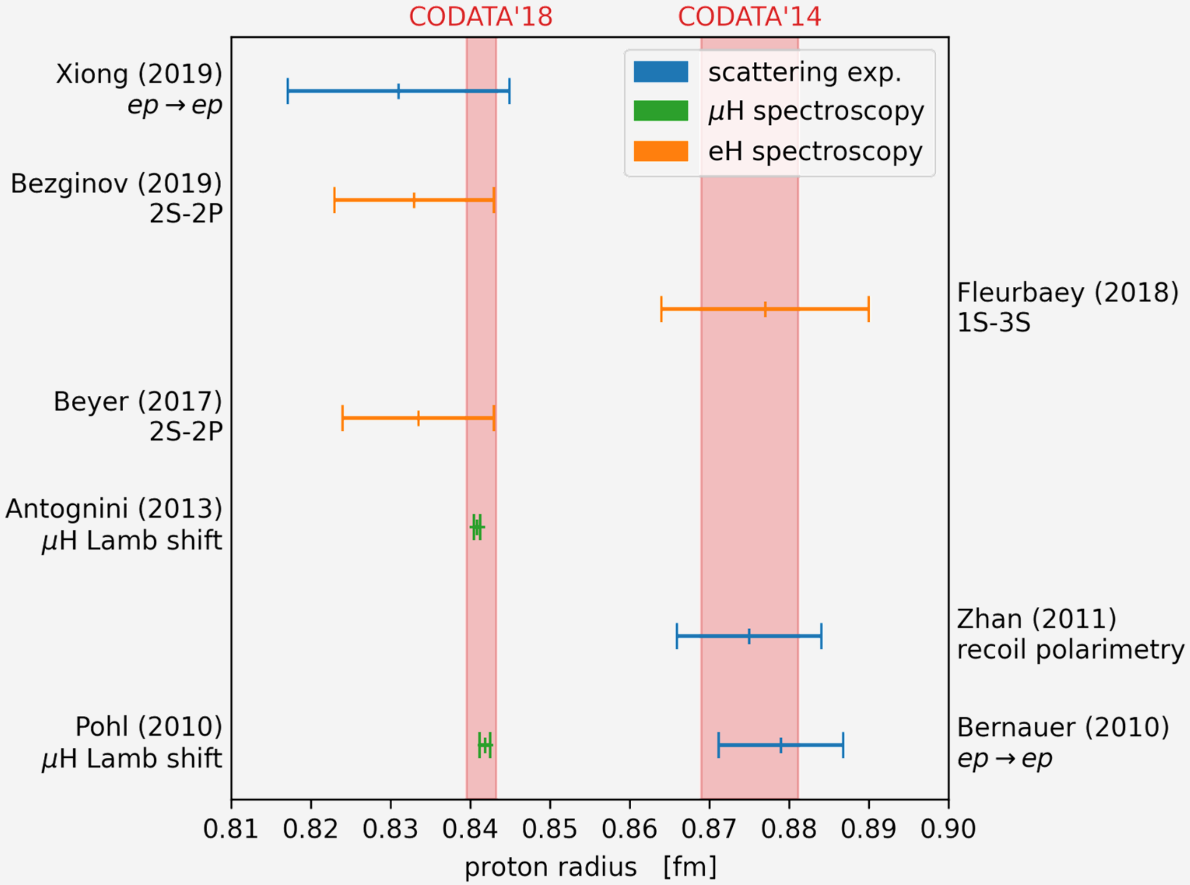
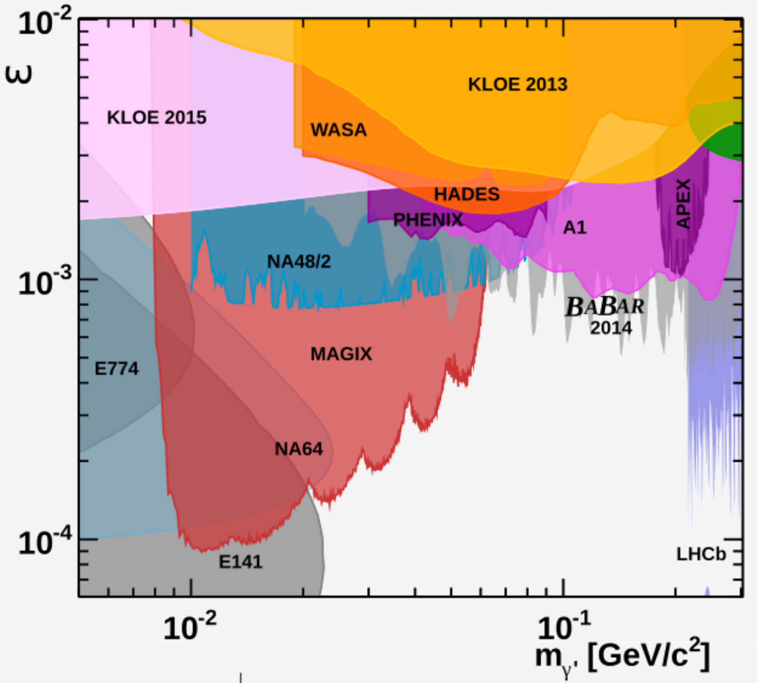
- Nuclear astrophysics: Astrophysical S-factor for $^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$ in inverse kinematics
- Electric and magnetic proton form factor, proton radius puzzle

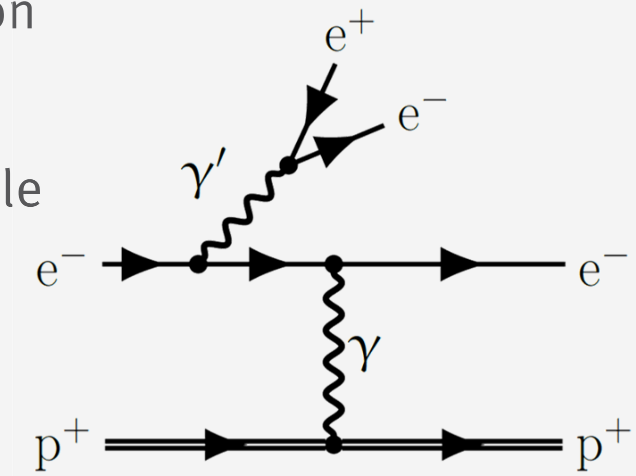


MAGIX Physics Program

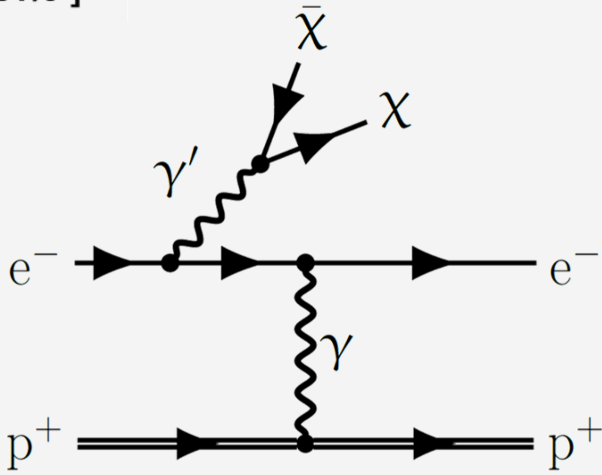
- Nuclear astrophysics: astrophysical S-factor for $^{12}C(\alpha,\gamma)^{16}O$ in inverse kinematics
- Electric and magnetic proton form factor, proton radius puzzle
- Light dark matter search: dark photon via visible and invisible decay



L. Doria et al., PoS(ALPS2019)



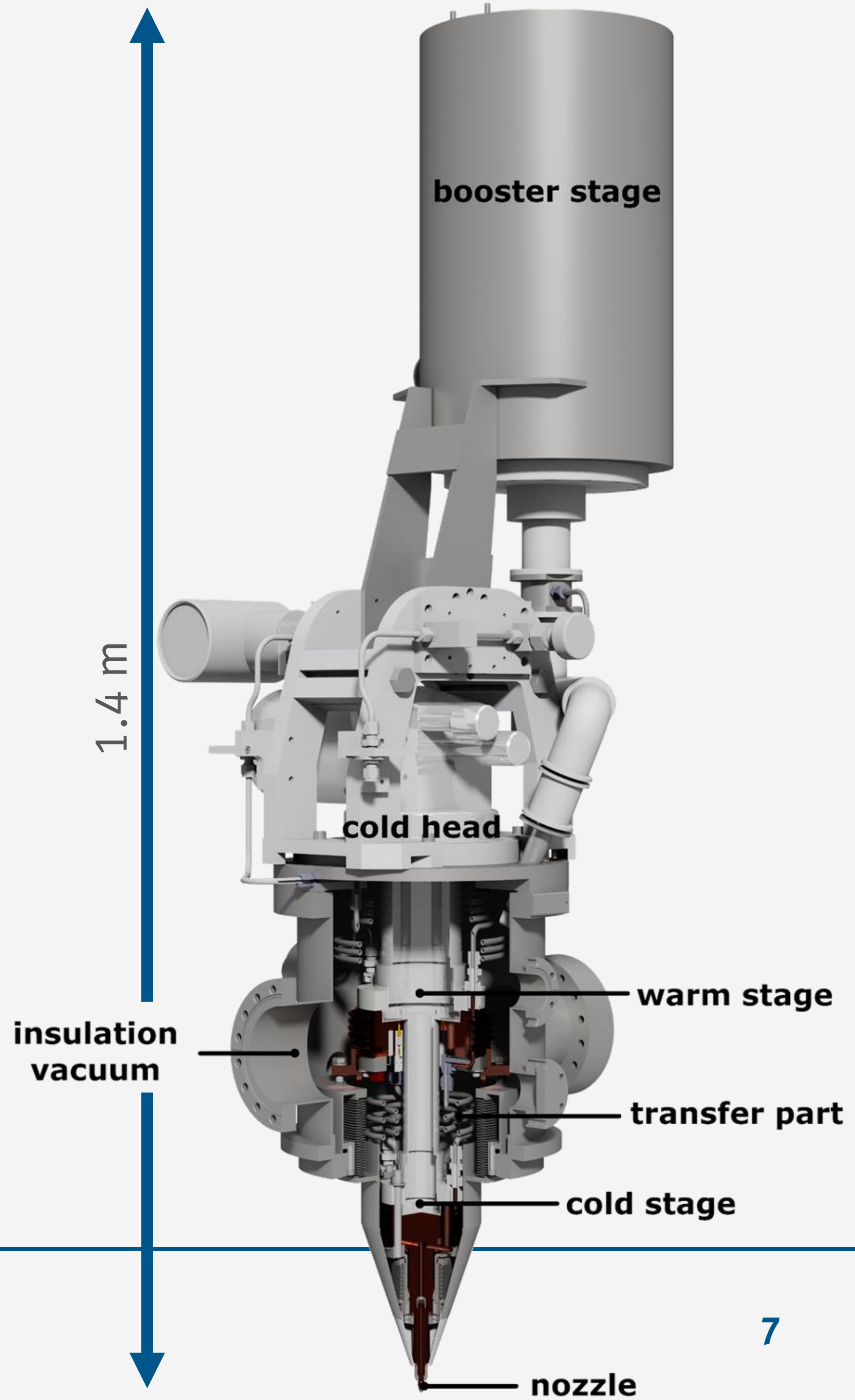
visible decay



invisible decay

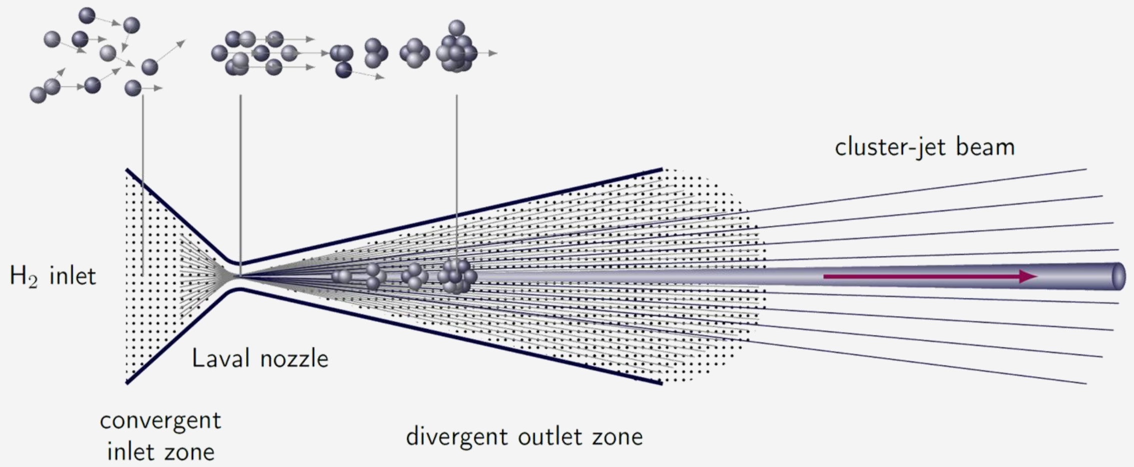
MAGIX Jet Target

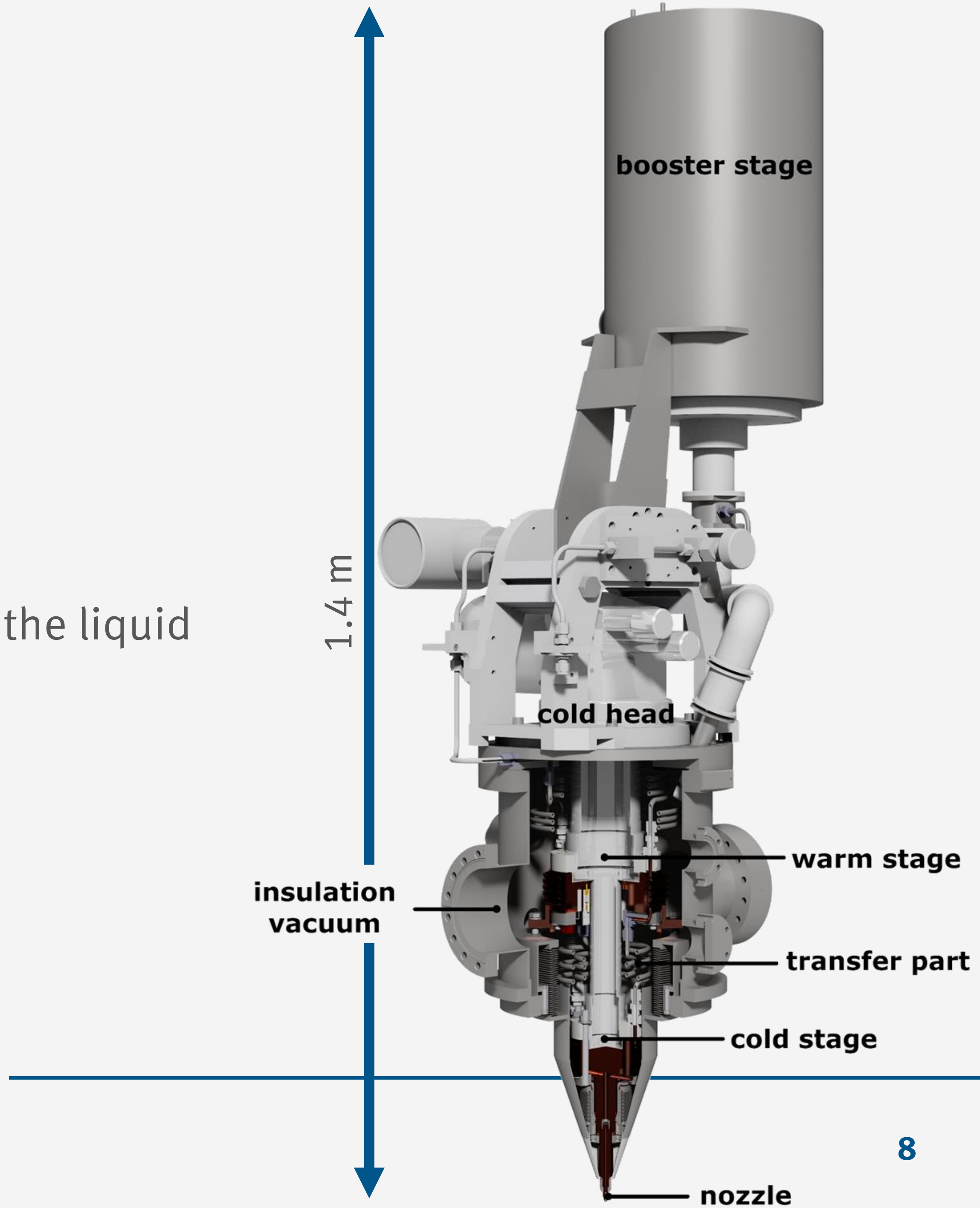
- Main target for MAGIX, built in Münster
- Designed for H_2 gas flows up to 2400 l/h at 40 K
  → Target thickness of more than 10^{18} atoms/cm^2
- Operation with various other fluids like, e.g., He, N_2, O_2, Ar, Xe, …
- Booster stage can be filled with liquid nitrogen for pre-cooling
- Two-stage cold head to reach final temperature
- Separate insulation vacuum chamber around cold head



MAGIX Jet Target

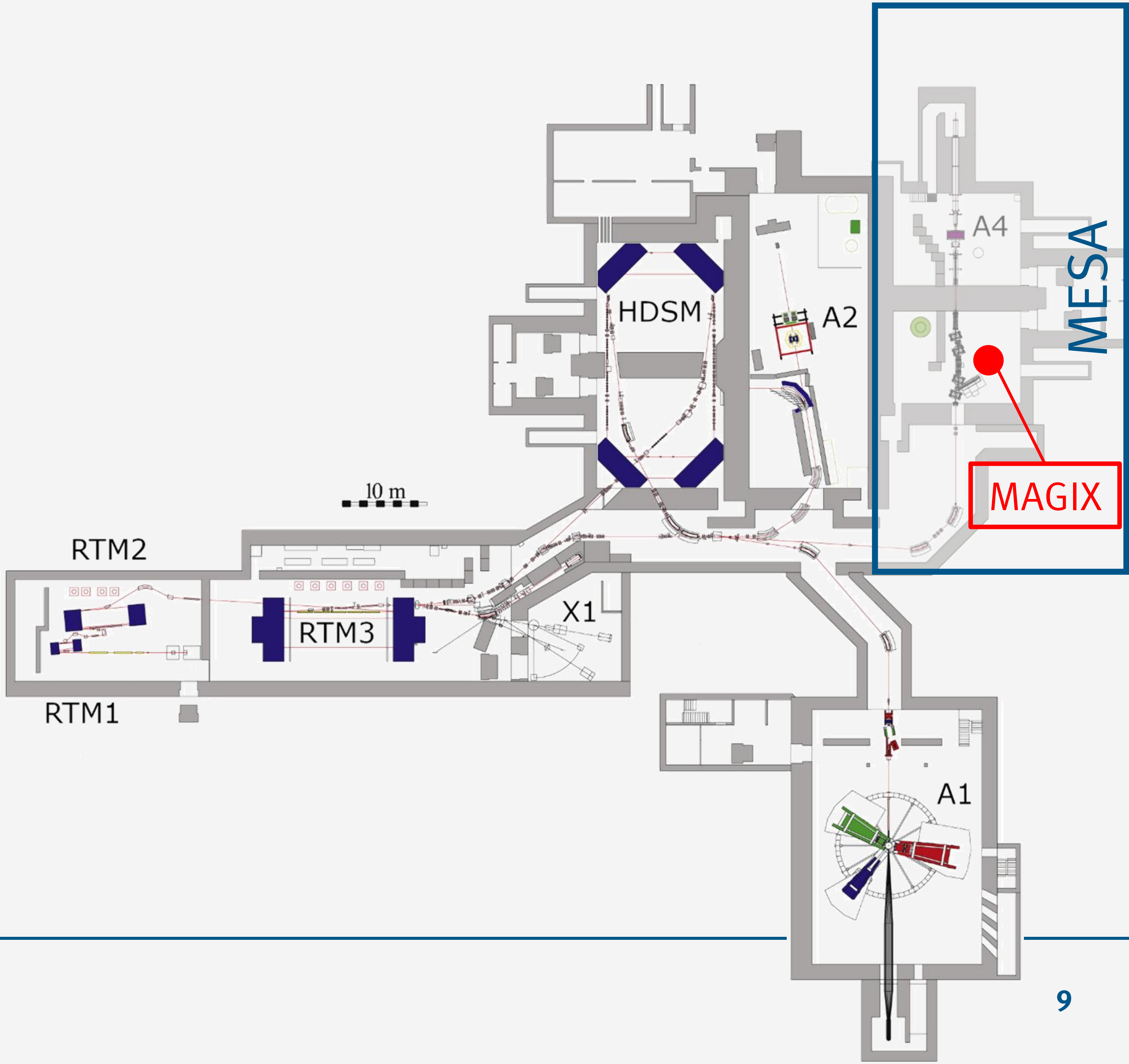
- Gas leaves target through convergent-divergent nozzle
  - Expansion leads to supersonic jet
- Operation close to the vapor pressure curve (or even in the liquid regime) can lead to cluster formation
  → Smaller jet divergence, higher density



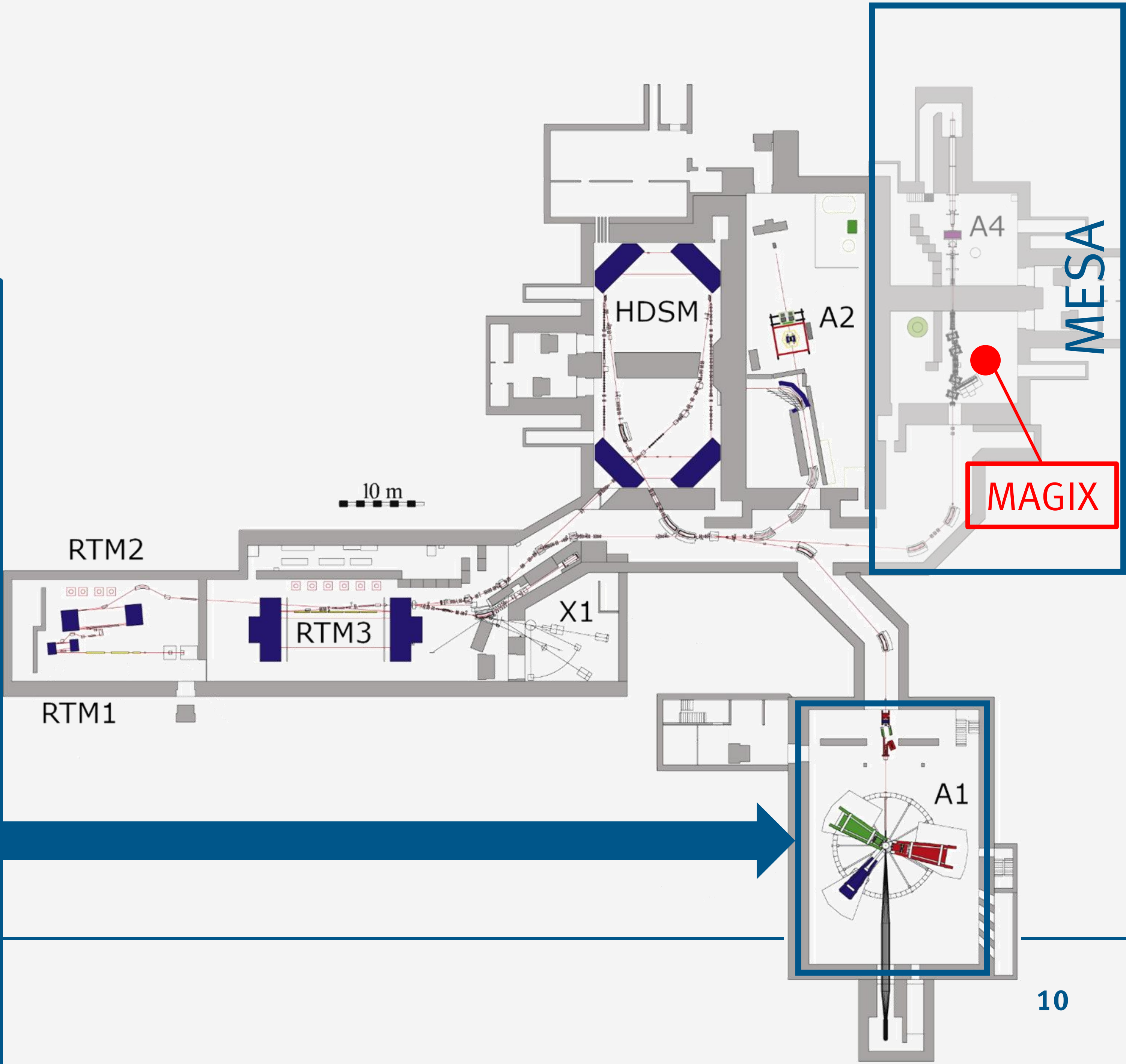


MAGIX@A1

- The existing MAMI facility in Mainz is used for first tests and measurements
- MAMI consists of 4 microtrons and several experiments
- Electron energies up to 1.6 GeV, beam current up to 100 µA
- The A4 hall will be used for MESA



MAGIX@A1



MAGIX@A1

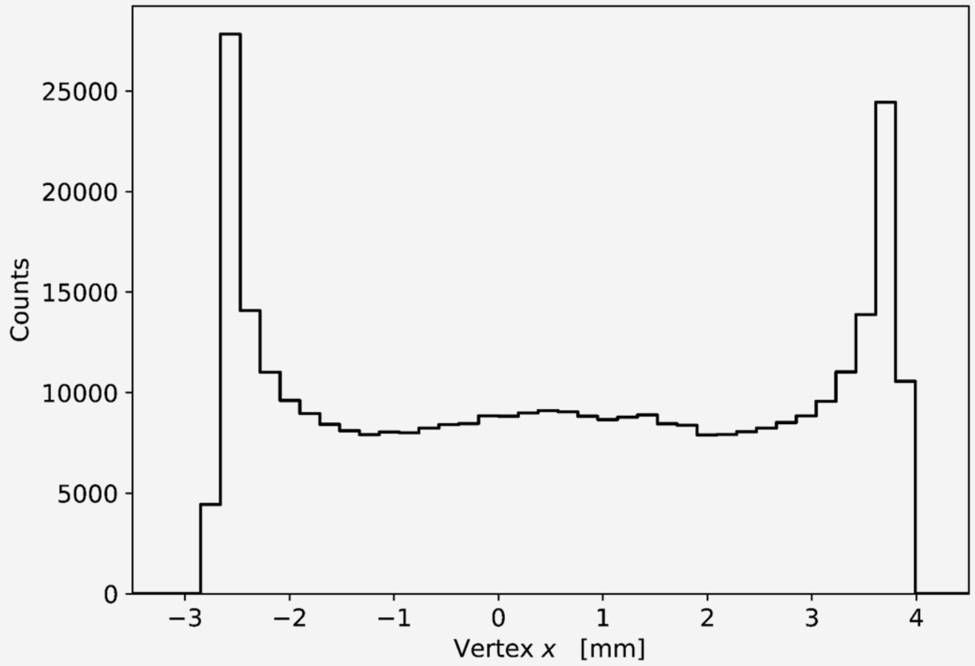
- Three focal plane spectrometers (A, B, C)
- High frequency dipole (wobbler) to deflect electron beam
  - Perfectly suited to scan over target
- Most precise ep-scattering form factor measurements were performed here with liquid H_2 cell target (Bernauer et al.)
- Perfect setup to test MAGIX target and perform first measurements

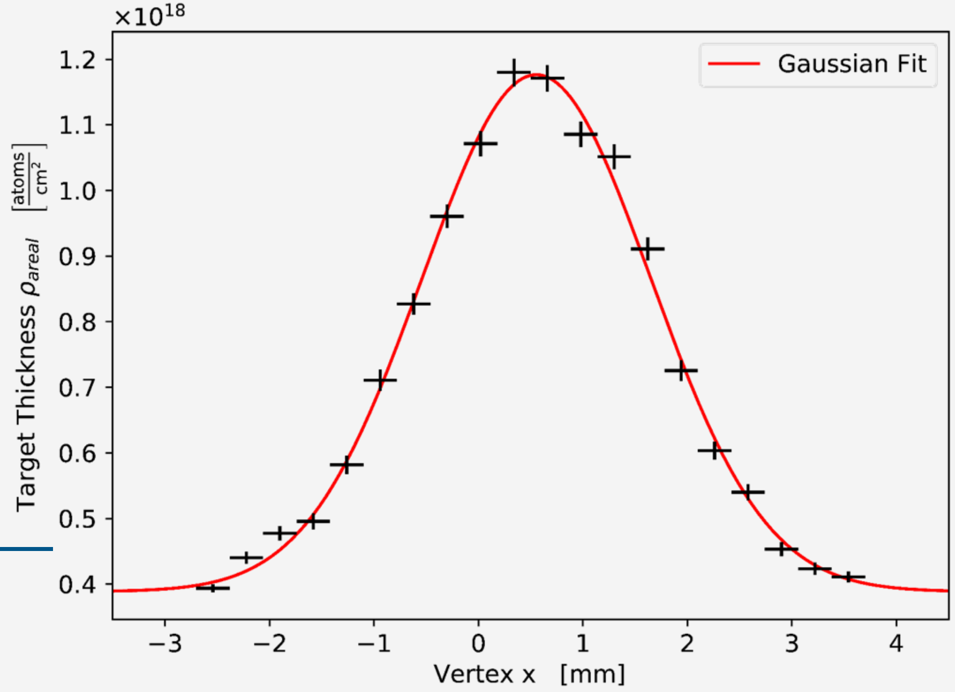
MAGIX@A1

- Interaction about 5 mm behind nozzle
- Gas jet is pumped away through conical catcher
- Already installed at A1@MAMI:
  - For precise alignment, an Al_2O_3 screen is used for beam visualization
  - To reduce a beam halo that scatters at nozzle or catcher a collimator in the beam line is installed

Beam profile scans

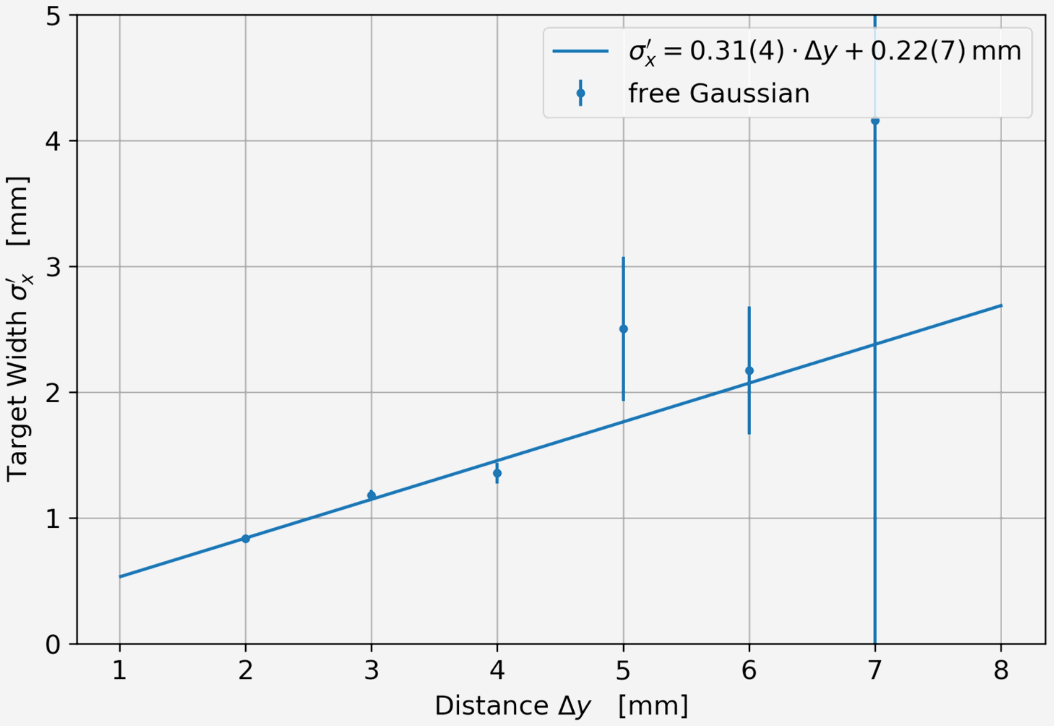
- Wobbler scan, analysis of ep-scattering
- Correction of wobbler distribution (longer time in the edges)
- Background suppression via missing mass
- Vertex-dependent luminosity (thickness) determination with fit to known cross section
- Fit function is convolution of two gaussians (target and known electron beam profile)





Beam profile scans

- Measurement was repeated in different distances
- Jet diverges strongly
  - Half-opening angle of the jet: ~17°
  - Half-opening angle of the nozzle: ~1.4°
- Small jet is preferred for:
  - Higher target thickness
  - Better catcher efficiency

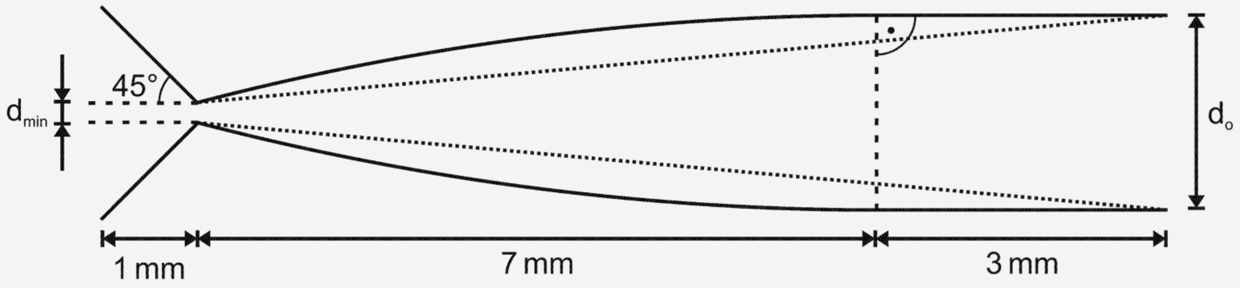


Nozzle Optimization

- Nozzle geometry is crucial for gas expansion and formation of jet
- Gas reaches speed of sound at narrowest point between convergent inlet and divergent outlet
- Expansion in divergent outlet causes:
  - Acceleration to supersonic velocities
  - Rapid decrease in temperature
- Operation close to vapor pressure can lead to cluster formation

Nozzle Optimization – CFD simulation

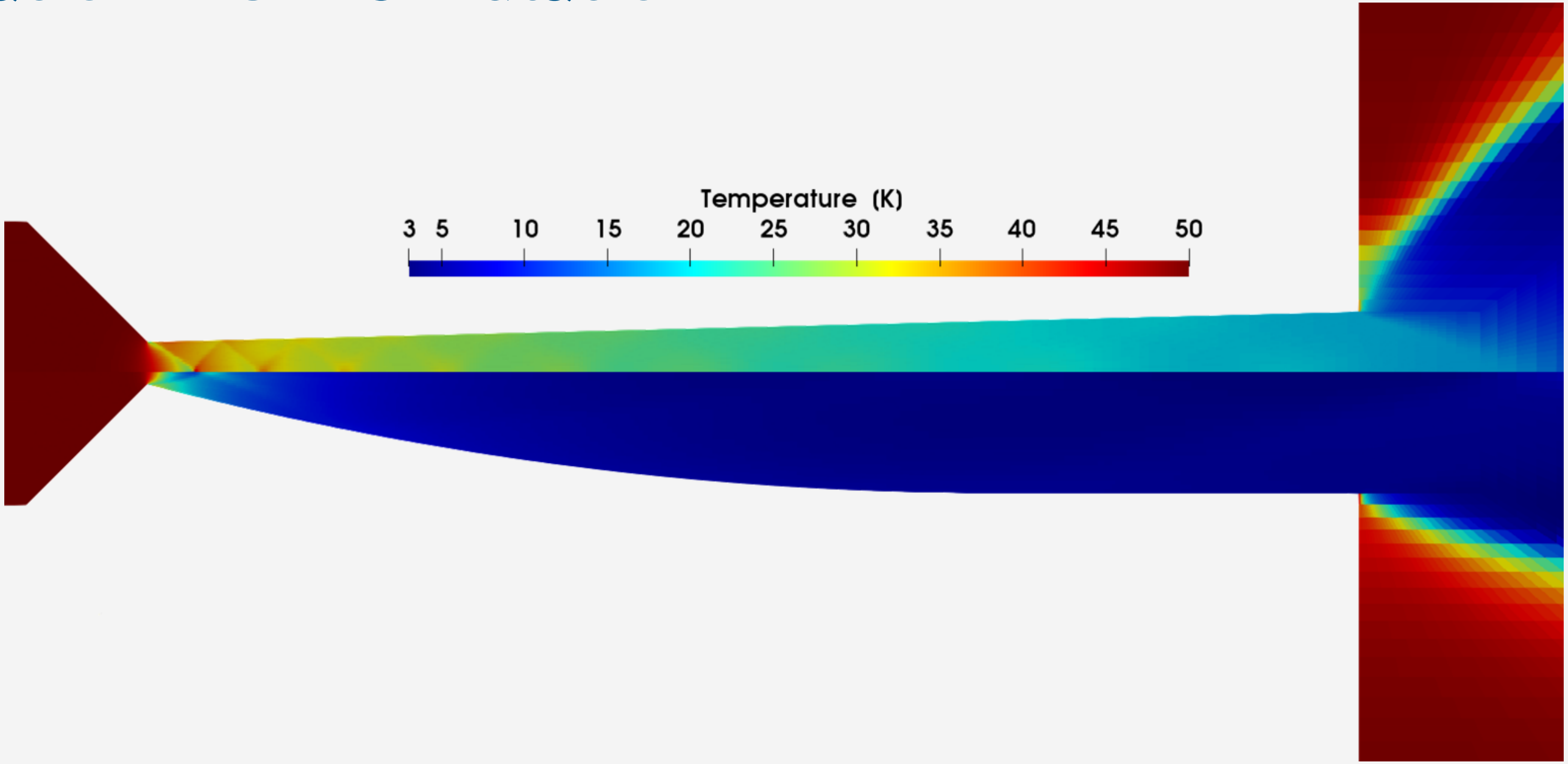
- CFD = computational fluid dynamics → solving Navier-Stokes equations with FVM/FEM
- For cryogenic jet a real gas model is necessary (Peng-Robinson gas)
- Simulations performed with OpenFOAM (solver rhoCentralFoam), open-source software
- Includes temperature dependent thermal conductance, viscosity and heat capacity
- Heat capacity also pressure dependent due to real gas model
- Different nozzle designs (linear and cup shape)
- Different diameters (narrowest and outlet)



Nozzle Optimization – CFD simulation

linear, 500 µm → 1 mm

cup, 200 µm → 2 mm



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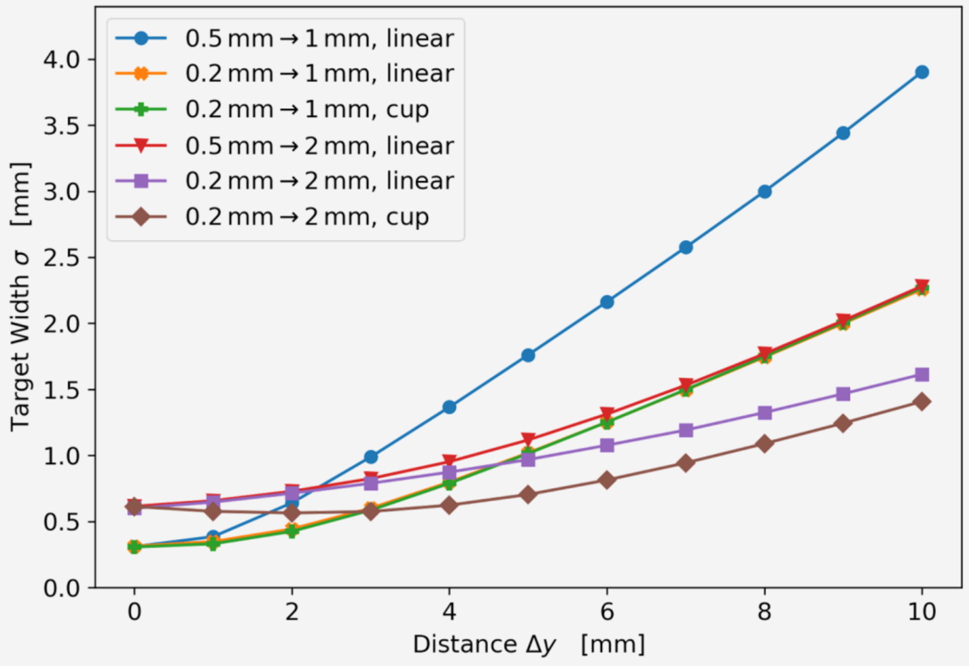
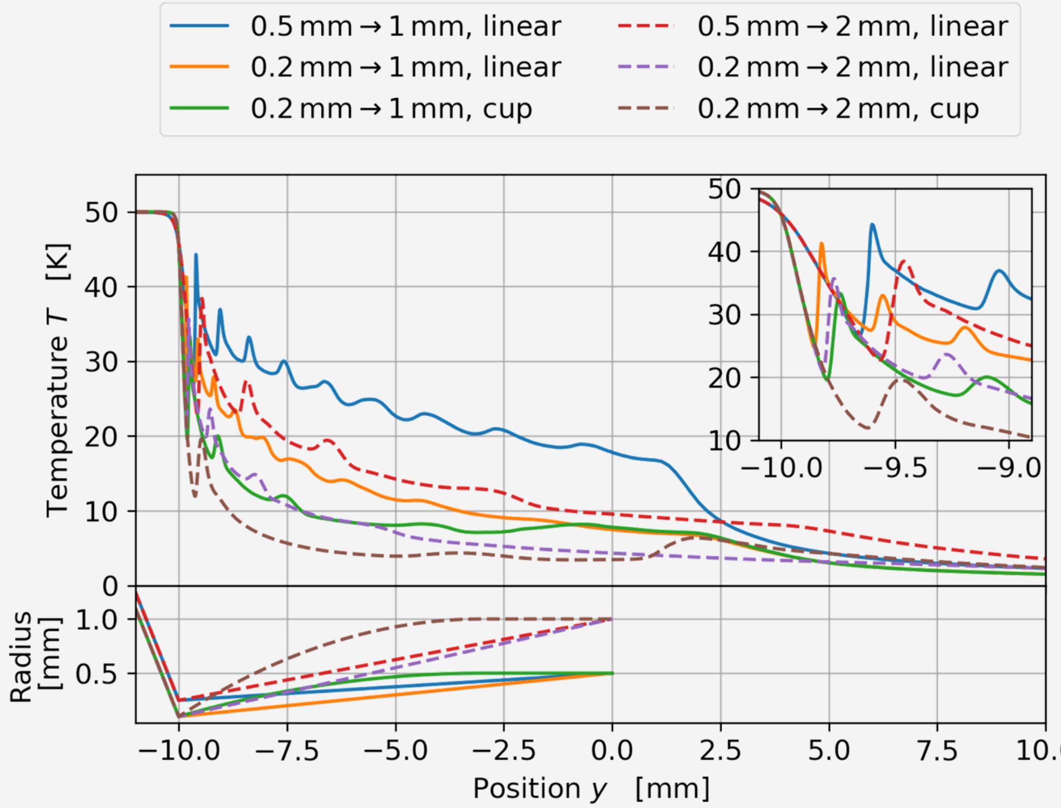
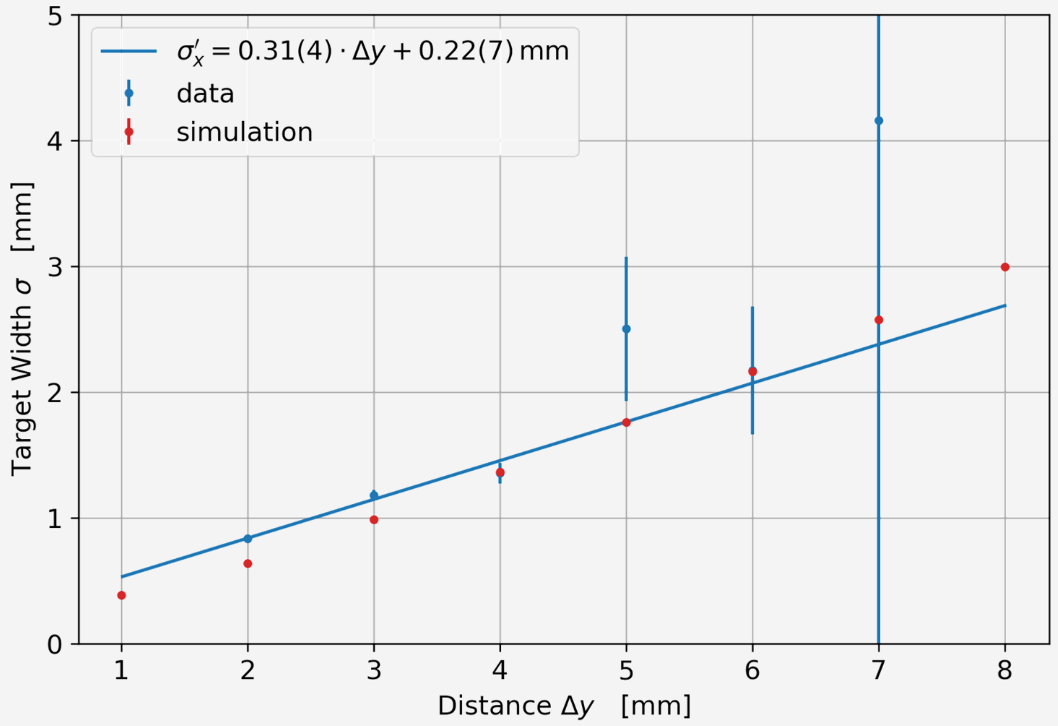




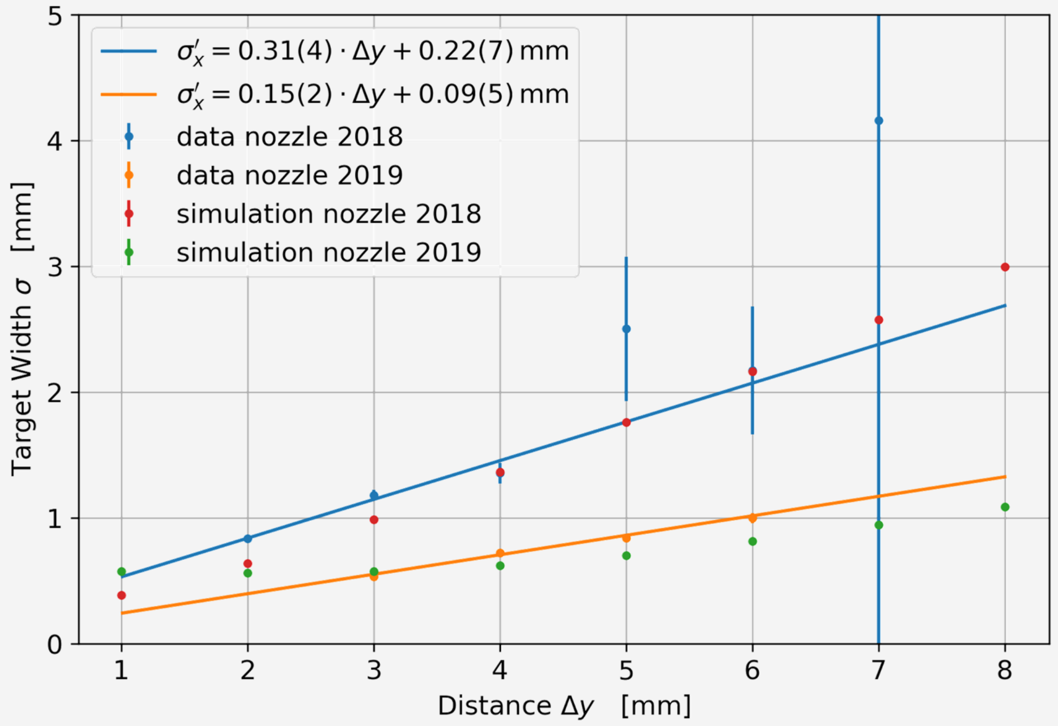
Nozzle Optimization – simulation vs. measurement

- Simulations in agreement with measured target profiles



Nozzle Optimization – simulation vs. measurement

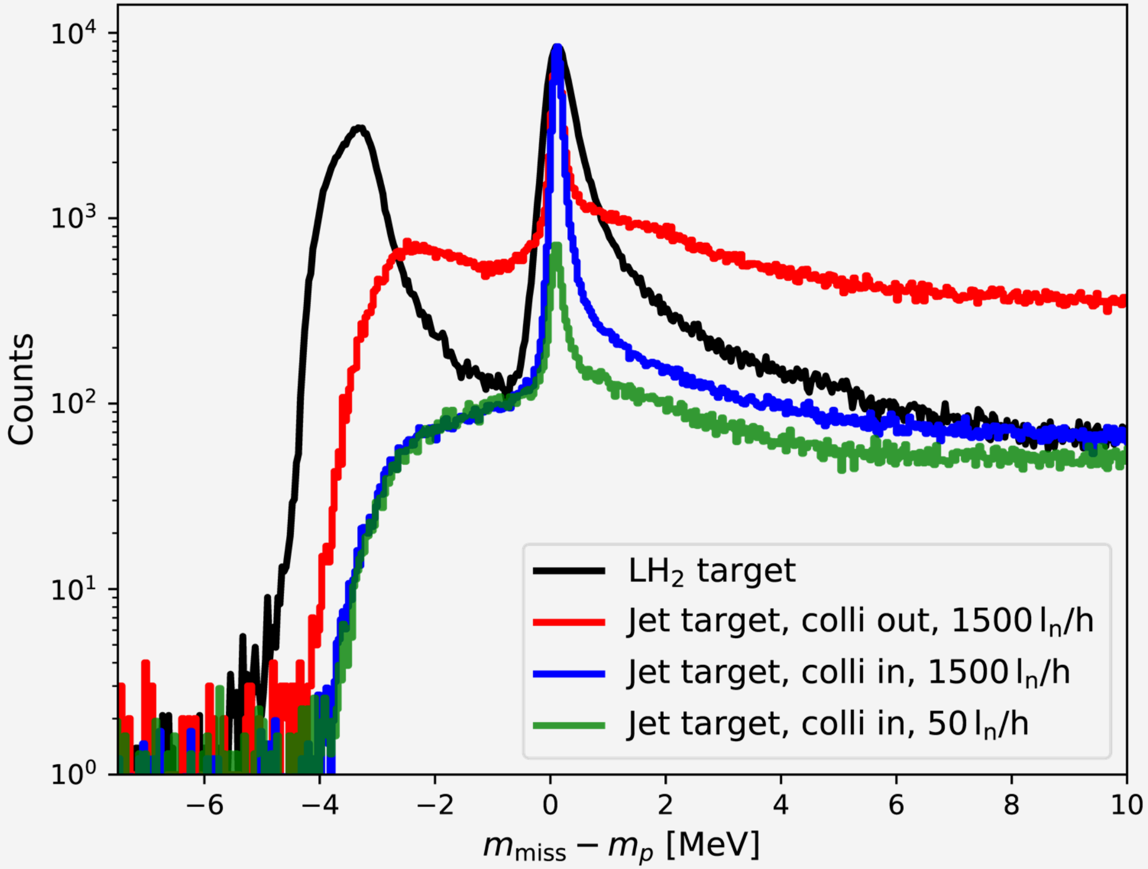
- Simulations in agreement with measured target profiles
- New nozzle was produced in our institute via a galvanization process
- Measurements at MAMI:
  - Divergence reduced by more than a factor of 2
  - Better vacuum conditions (although less pumping speed)



Jet Target vs. Cell Target

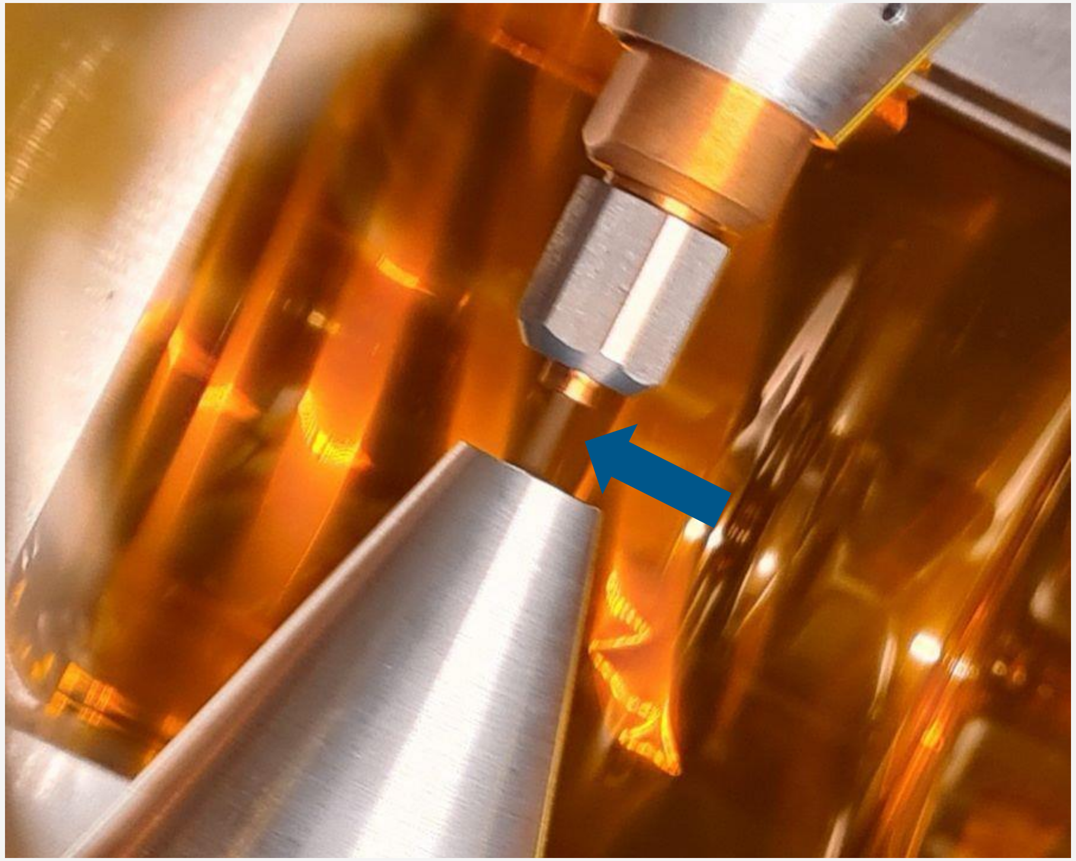
- No background from scattering on cell walls (second peak)
- No multi-scattering at cell walls results in better resolution
- Electron beam halo can scatter at nozzle and catcher due to the small distances → reduced by collimator
  - Strong beam halo due to a broken power supply, much less background in a following beam time

Schlimme et al., Nucl. Instrum. Meth. Phys. Res. A 1013, 165668 (Oct. 2021)



Target Operation with other Gases

- Target operation with various gases planned
- Heavier gases require larger nozzle diameter for same flow or operation in the liquid regime
- First test with Argon (120 µm nozzle)
  - Liquid jet (~5 bar, ~100 K)
  - Nearly no jet divergence visible
- Stable operation over some days
- Nearly background-free data



Summary

- MAGIX jet target fulfills all requirements for an internal target at an energy recovering linac
  - Thickness of more than 10^{18} atoms/cm^2
  - Windowless, no background from target cells, better energy resolution
- Stable operation with various gases proven (hydrogen, argon)
- Optimization of the nozzle design via simulation is confirmed by profile measurements
  - Jet divergence reduced by more than a factor of 2
- Results of first operation are published (S. Schlimme, S. Aulenbacher, P. Brand, M. Littich Y. Wang et al., Nucl. Instrum. Meth. A 1013, 165668 (Oct. 2021))

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Thank you for your attention!