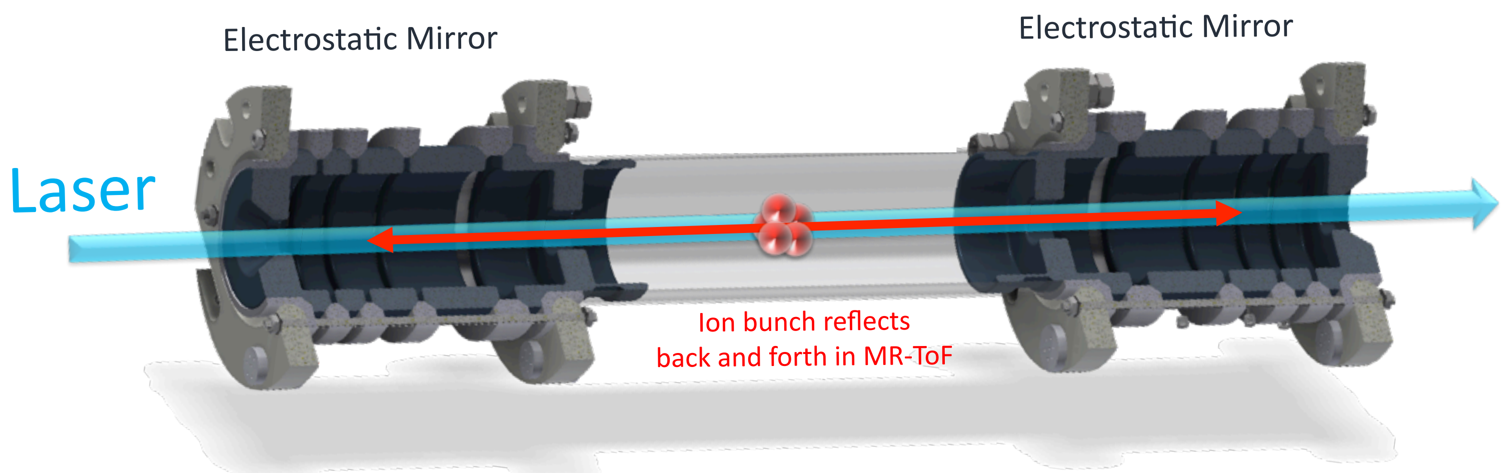
Status and timing of MIRACLS installation at LA2 (and RCX10)

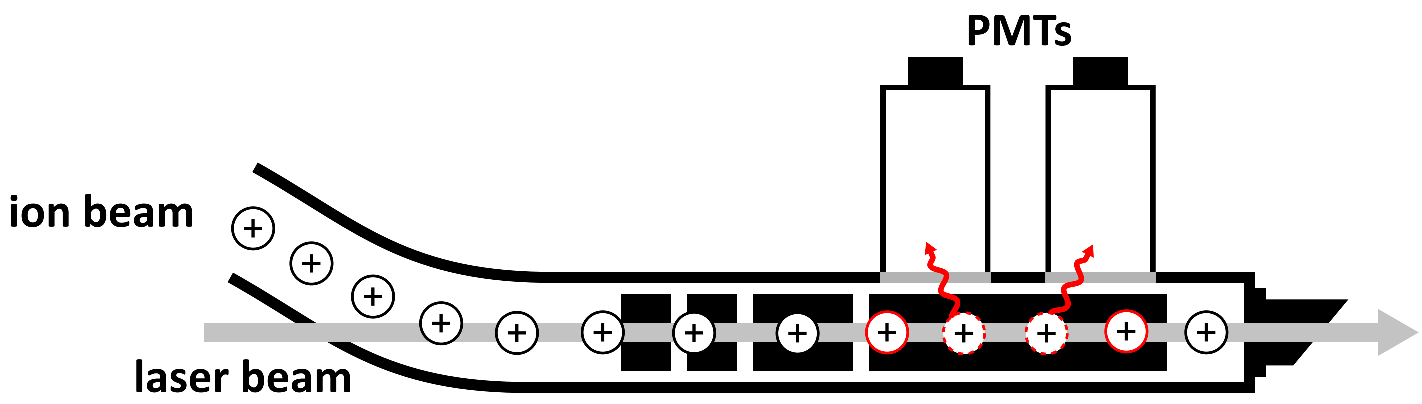


Stephan Malbrunot-Ettenauer
CERN research physicist

Outlook

- Recall: MIRACLS
- Summary of MIRACLS' proof-of-principle experiment
- Planning for a compact MIRACLS at LA2
- Planning for full MIRACLS at RCX10 (=NICOLE site)

Collinear Laser Spectroscopy (CLS)



beams of ≥30 keV
minimises Doppler-broadening
⇒ high resolution

$$\delta\nu \propto \frac{\delta E}{\sqrt{E}}$$

K. Blaum, et al., Phys. Scr. T152, 014017 (2013)
P. Campbell et al., Prog. Part. and Nucl. Phys. 86, 127-180 (2016)
R. Neugart et al., J. Phys. G: Nucl. Part. Phys. 44, 064002 (2017)

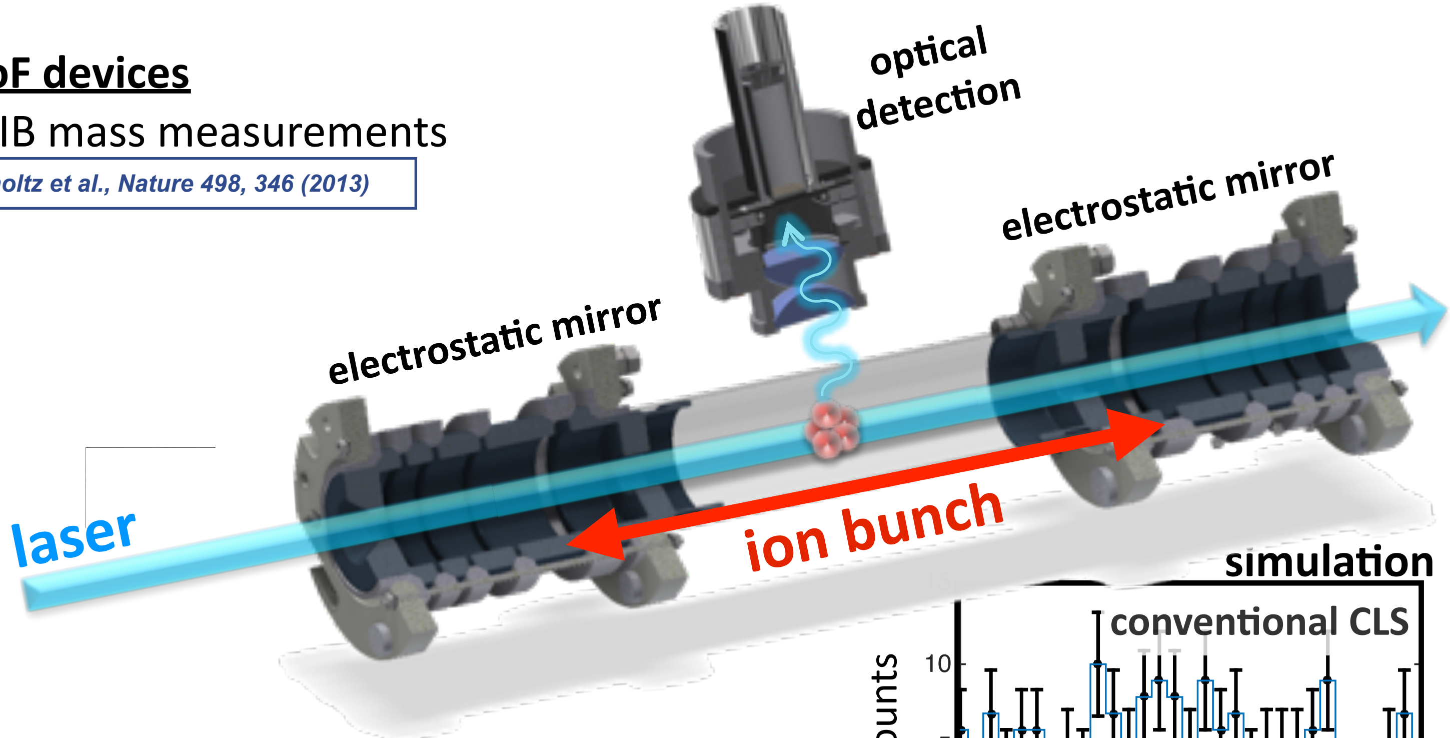
the Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy

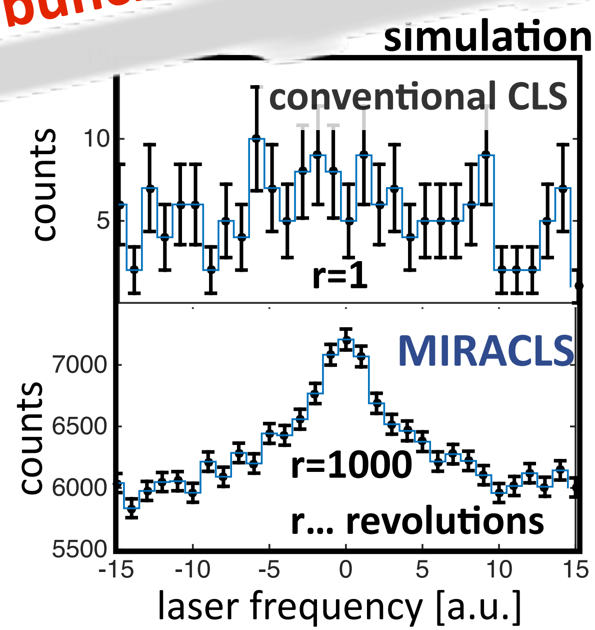
trap ⇒ long observation time ⇒ higher sensitivity ⇒ more exotic nuclides accessible

→ **MR-ToF devices**

first RIB mass measurements

F. Wienholtz et al., Nature 498, 346 (2013)



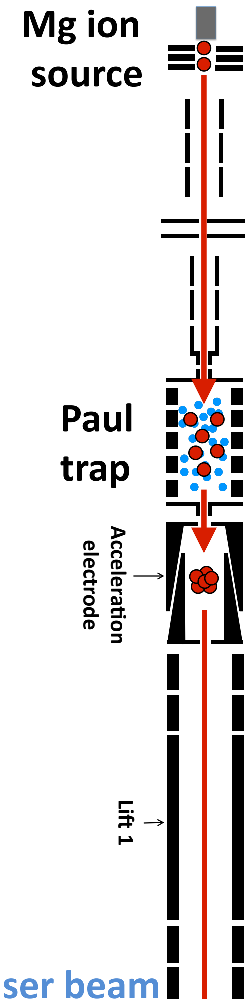


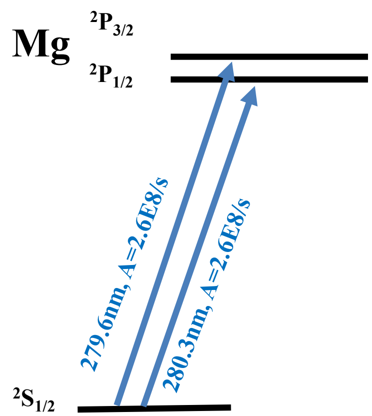
novel approach for collinear laser spectroscopy:

- ion trap ⇒ long observation time
- 30 keV beam ⇒ high resolution

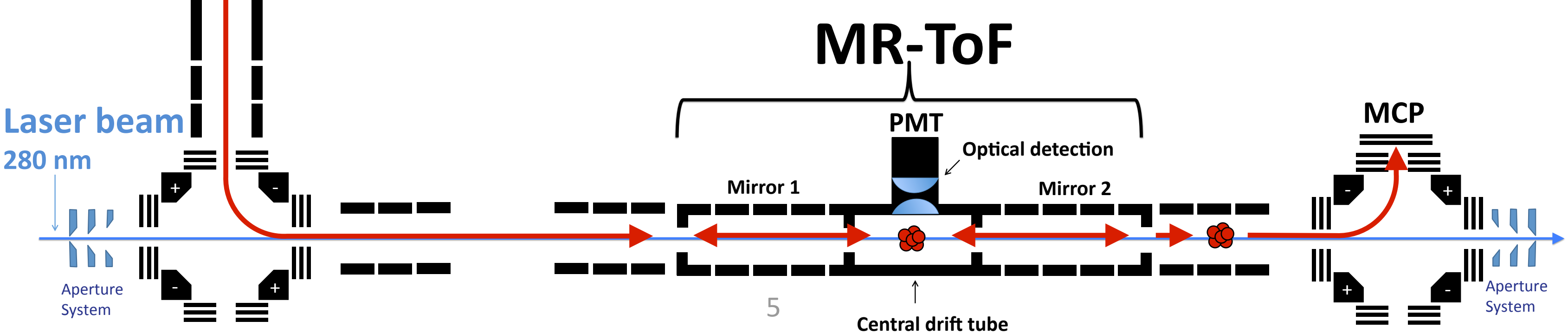
proof-of-principle experiment

- modified existing MR-ToF (low beam energy)
- adapted for purpose of CLS
- demonstrate potential of the technique
- validate simulations for the 30 keV device

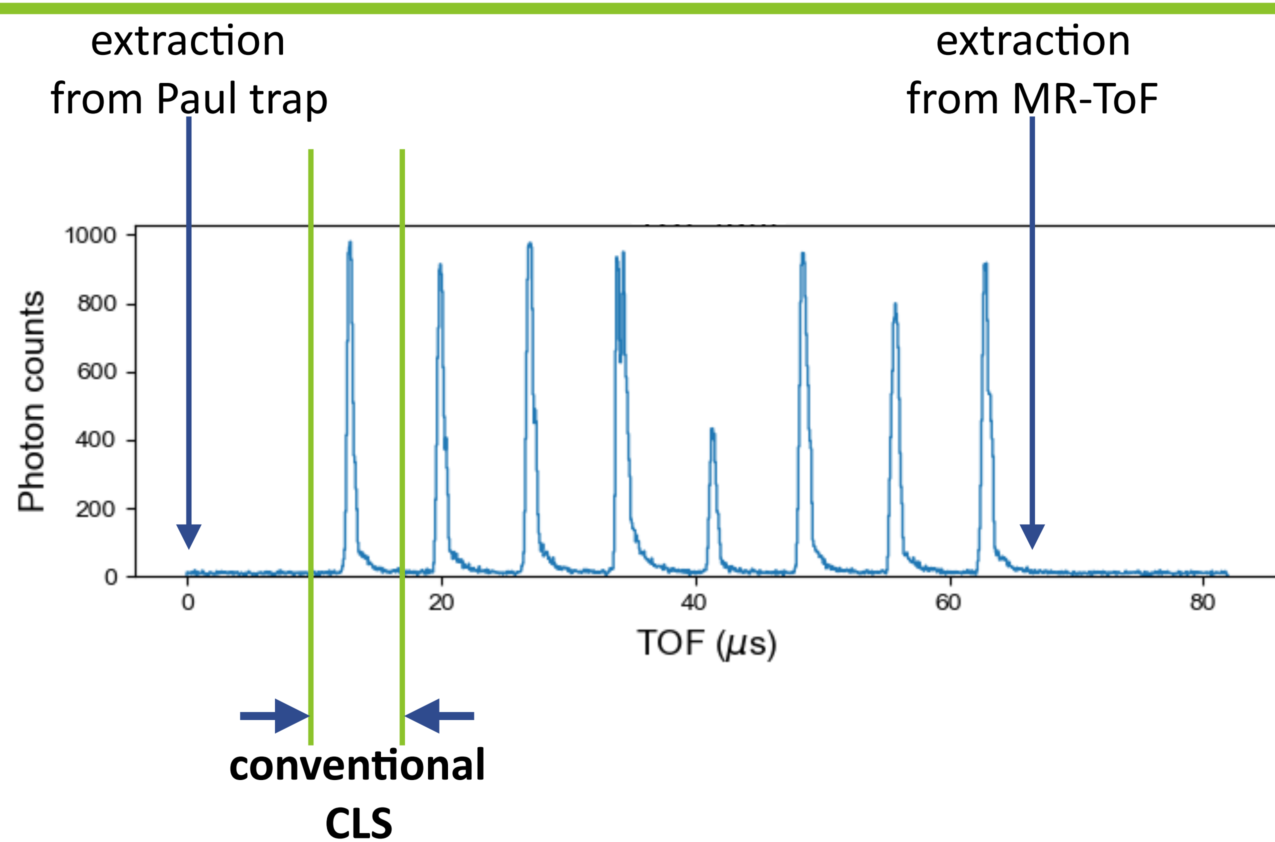




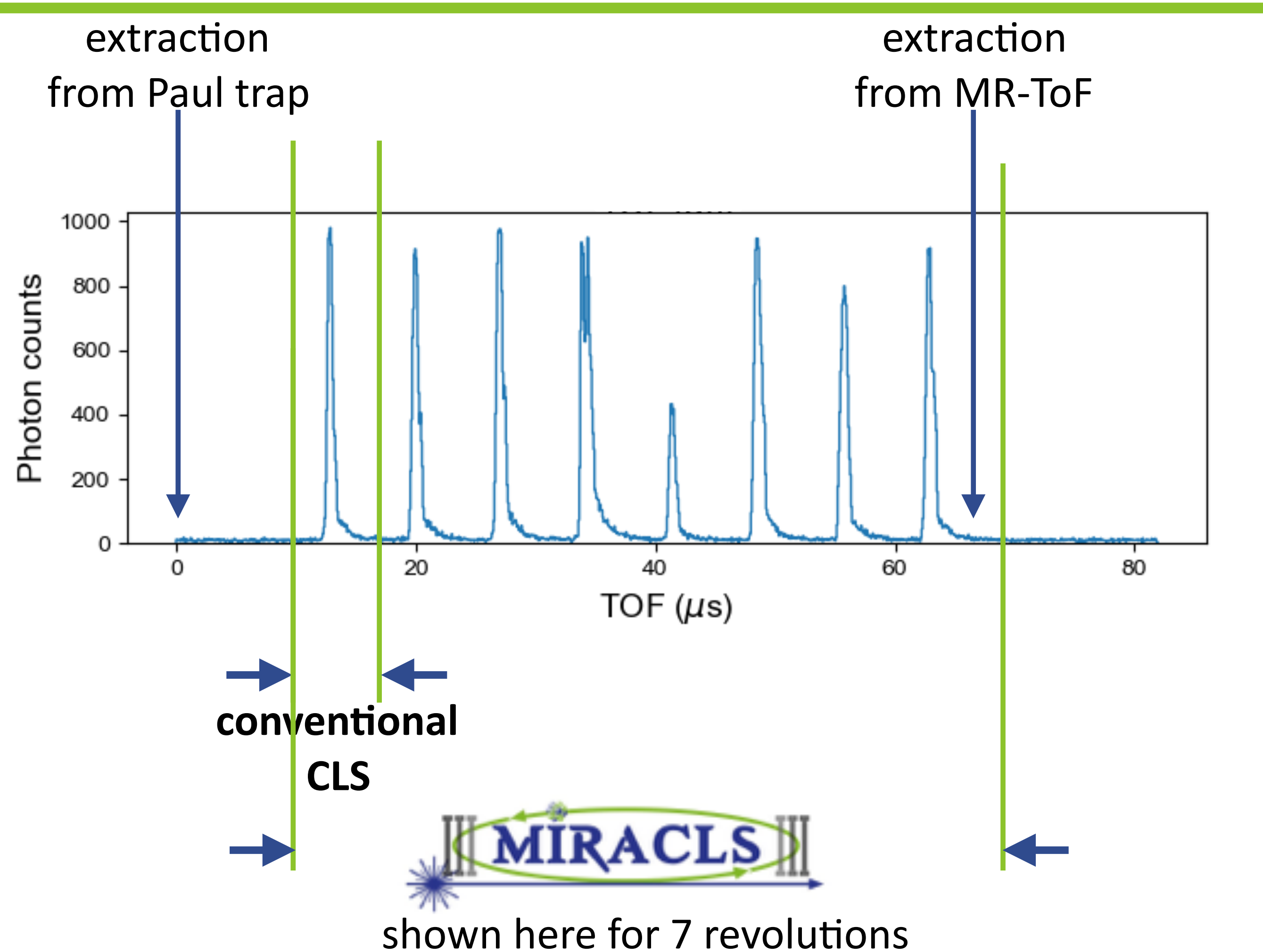
F. Maier et al., Hyperfine Interact. 240, 54 (2019)
S. Lechner et al., Hyperfine Interact 240, 95 (2019)
S. Sels et al., Nucl. Instr. Meth. B 463, 310 (2020)
V. Lagaki et al., Acta Phys. Pol. B 51, 571 (2020)
V. Lagaki et al., in preparation



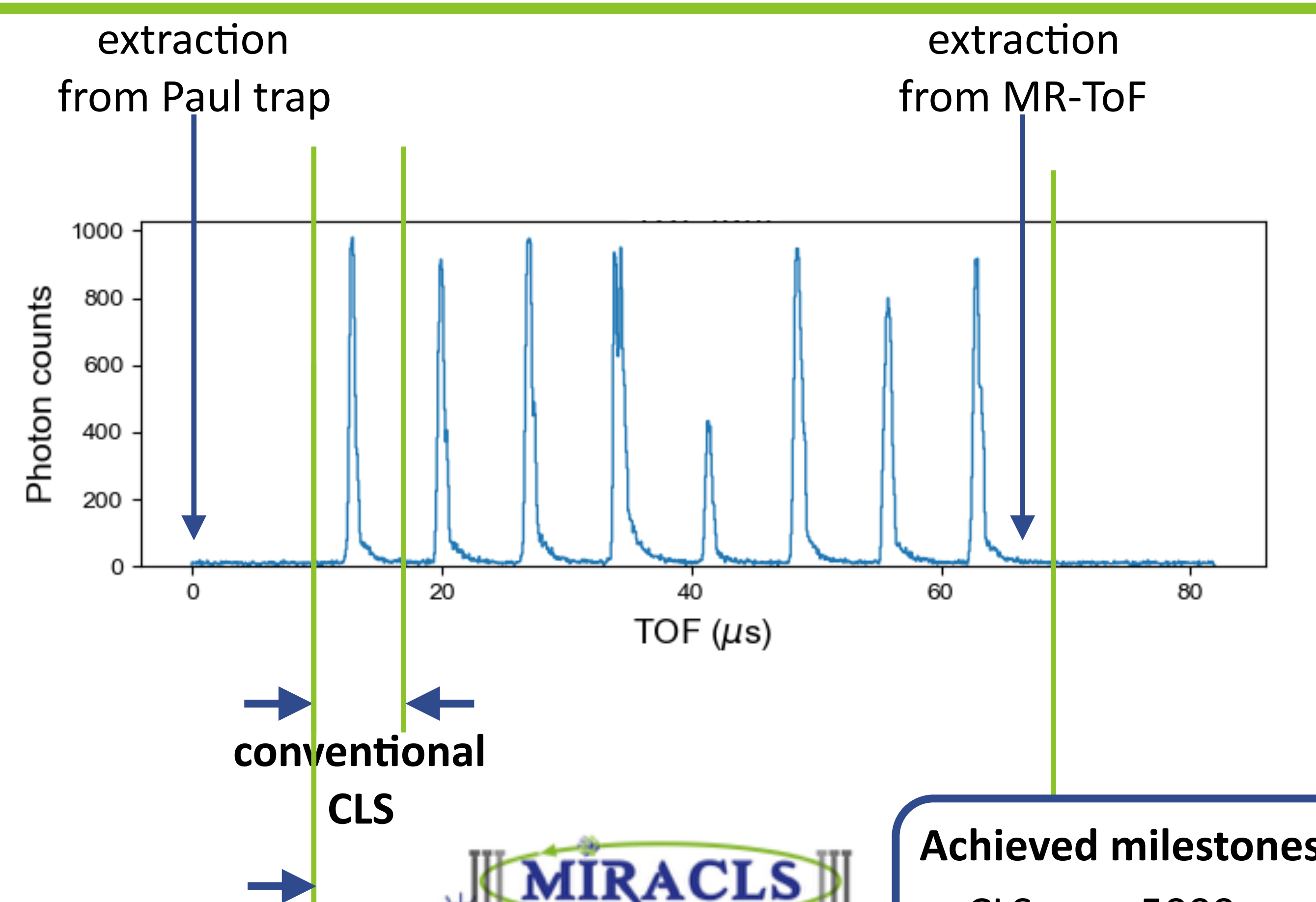
First CLS signals in an MR-ToF



First CLS signals in an MR-ToF



First CLS signals in an MR-ToF

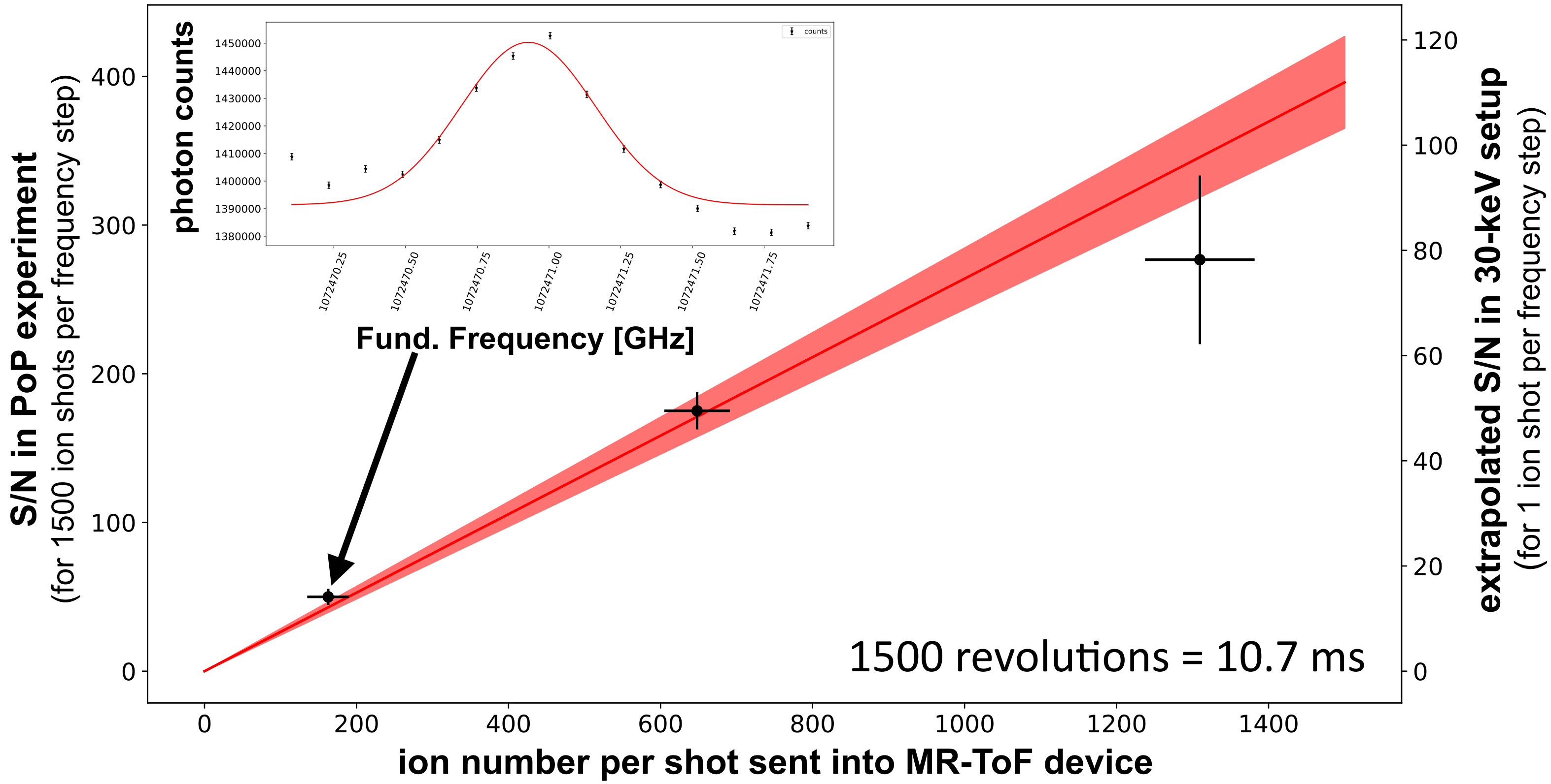


shown here for 7 revoluti

Achieved milestones

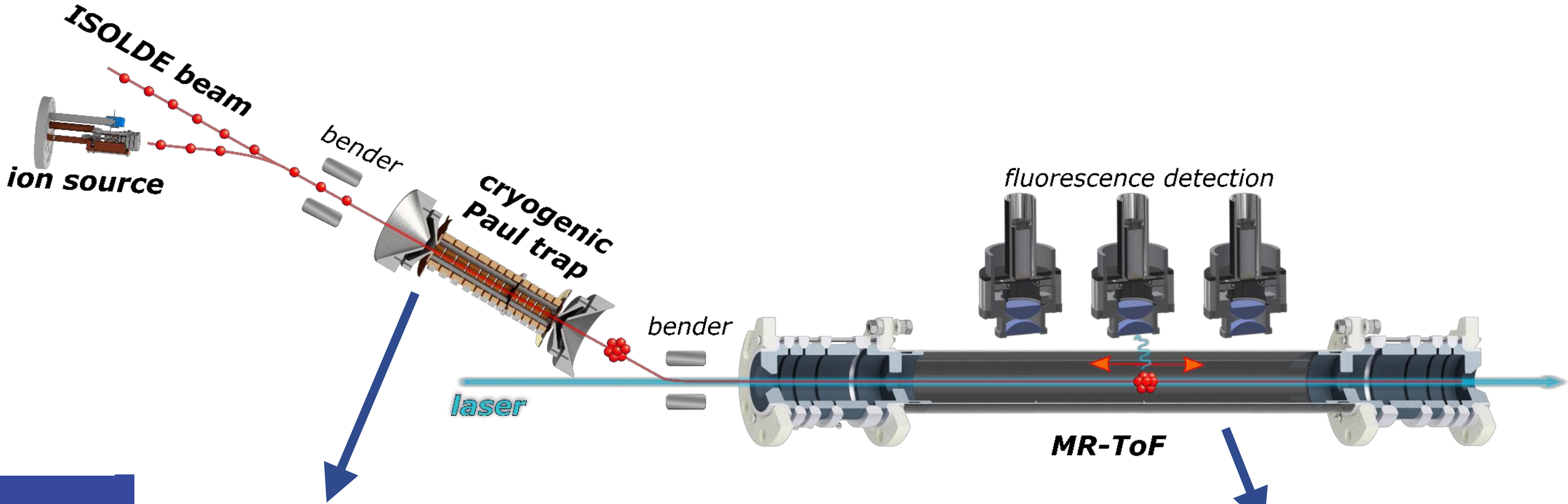
- CLS over 5000 revolutions
- simultaneous anti/collinear laser spectroscopy
- optical re-pumping

MIRACLS sensitivity in $^{24}Mg^+$



online measurements with O(10) ions/sec possible

MIRACLS 30-keV setup



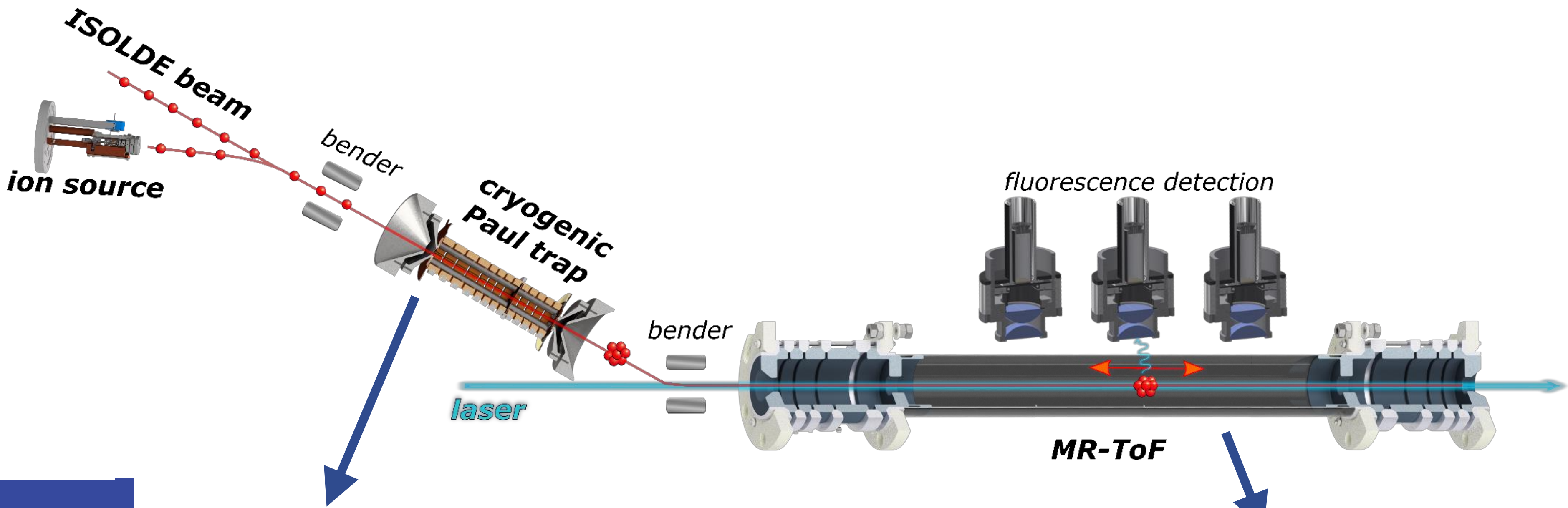
<u>unique linear Paul trap</u>

- beam cooling to cryogenic temperature for optimal (longitudinal) emittance

➡ good time focus and energy spread

<u>30 keV MR-ToF</u>

MIRACLS 30-keV setup



unique linear Paul trap

- beam cooling to cryogenic temperature for optimal (longitudinal) emittance

➡ good time focus and energy spread

30 keV MR-ToF

new opportunities

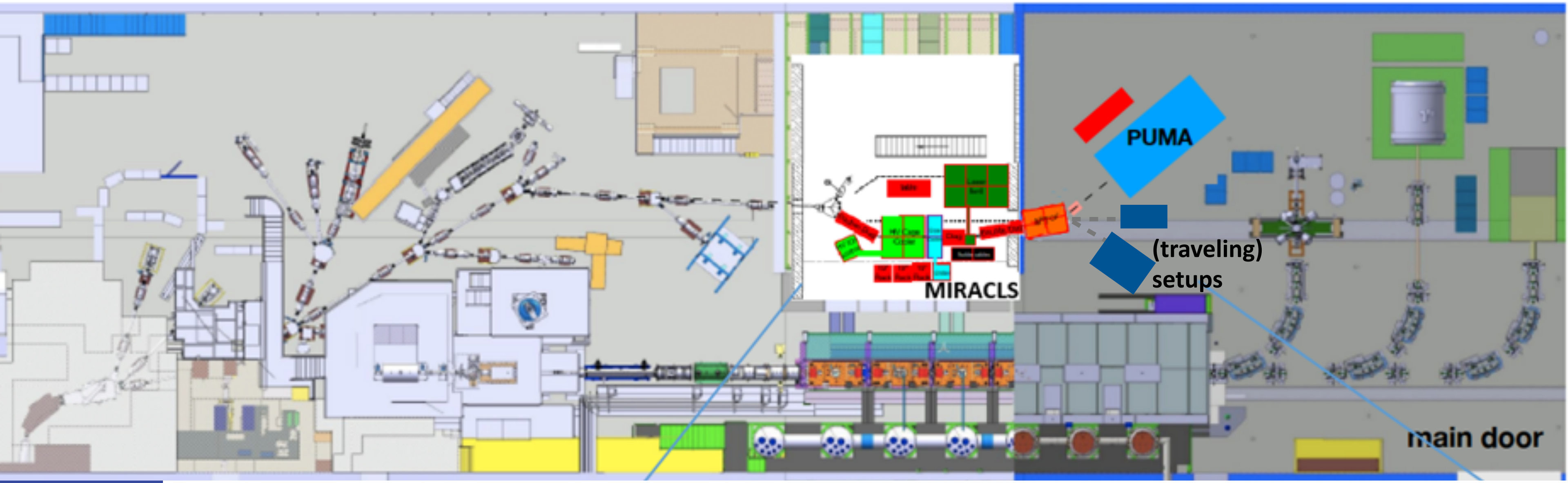
- fast & selective mass separation
  (fundamental physics & applications)
- spectroscopy of negative ions
- excellent emittance (PUMA, emission channeling,…)
- fundamental physics with radioactive molecules (e.g. EDM searches)

Integration plan at ISOLDE

MIRACLS at RCX10

- laser lab?
- ion-beam emittance?
- no crane access
- NICOLE still there

Integration plan at ISOLDE



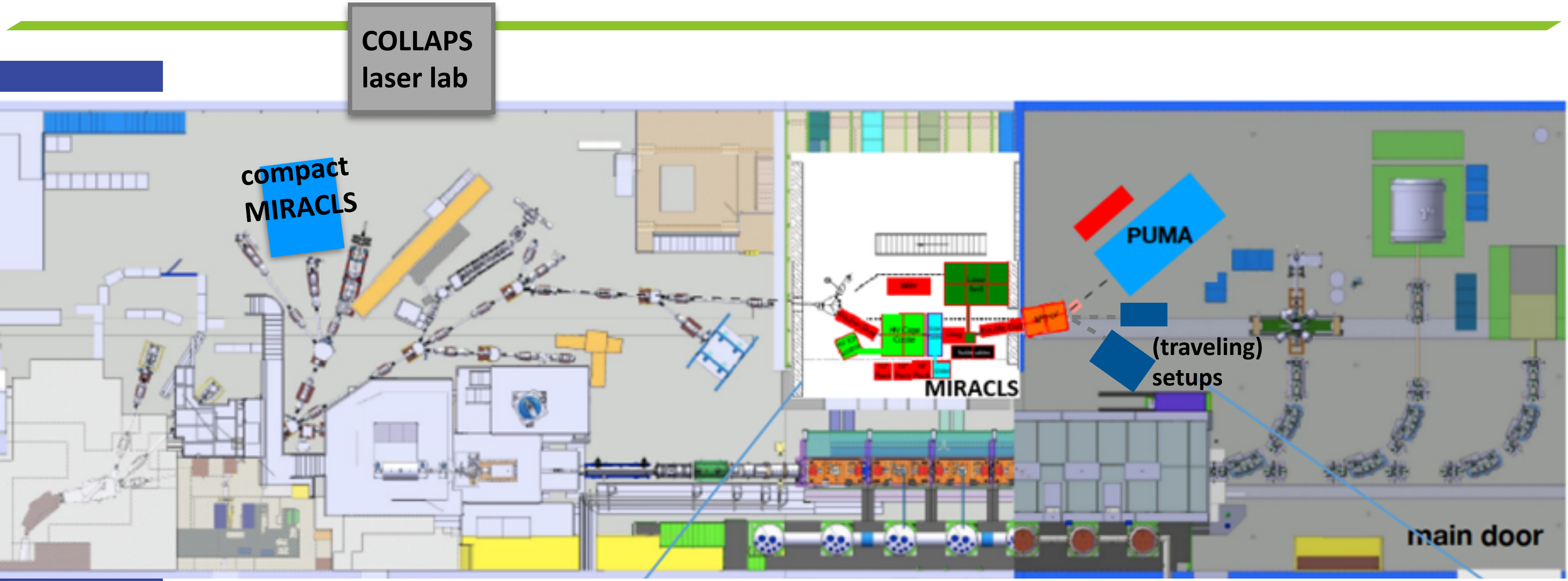
<u>MIRACLS at RCX10</u>

- laser lab?
- ion-beam emittance?
- no crane access
- NICOLE still there
- **<u>COVID lockdown:</u>**

  ➡ lost already 4 months

  ➡ many developments still on hold

Integration plan at ISOLDE



MIRACLS at RCX10

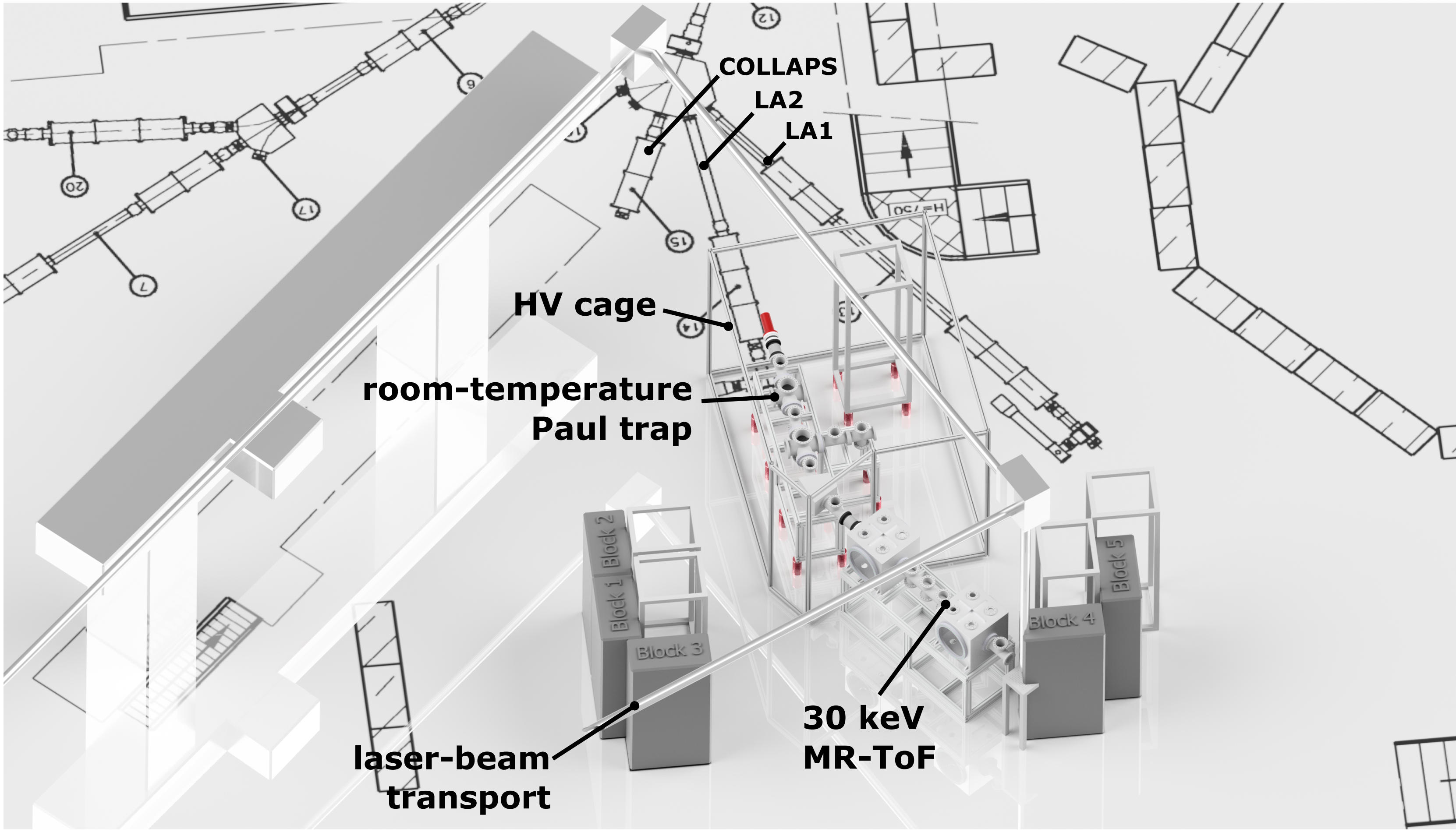
- laser lab?
- ion-beam emittance?
- no crane access
- NICOLE still there
- **COVID lockdown:**
  ➡ lost already 4 months
  ➡ many developments still on hold

S. Malbrunot: ISCC June 2020

Compact MIRACLS at LA2

- COLLAPS laser lab
- measured emittance at LA1 in 2019
- crane access
- currently free location
- **COVID lockdown:**
  ➡ start with room-temperature Paul trap
  ➡ reutilise components of PoP experiment
  ➡ 'best possible' MR-ToF

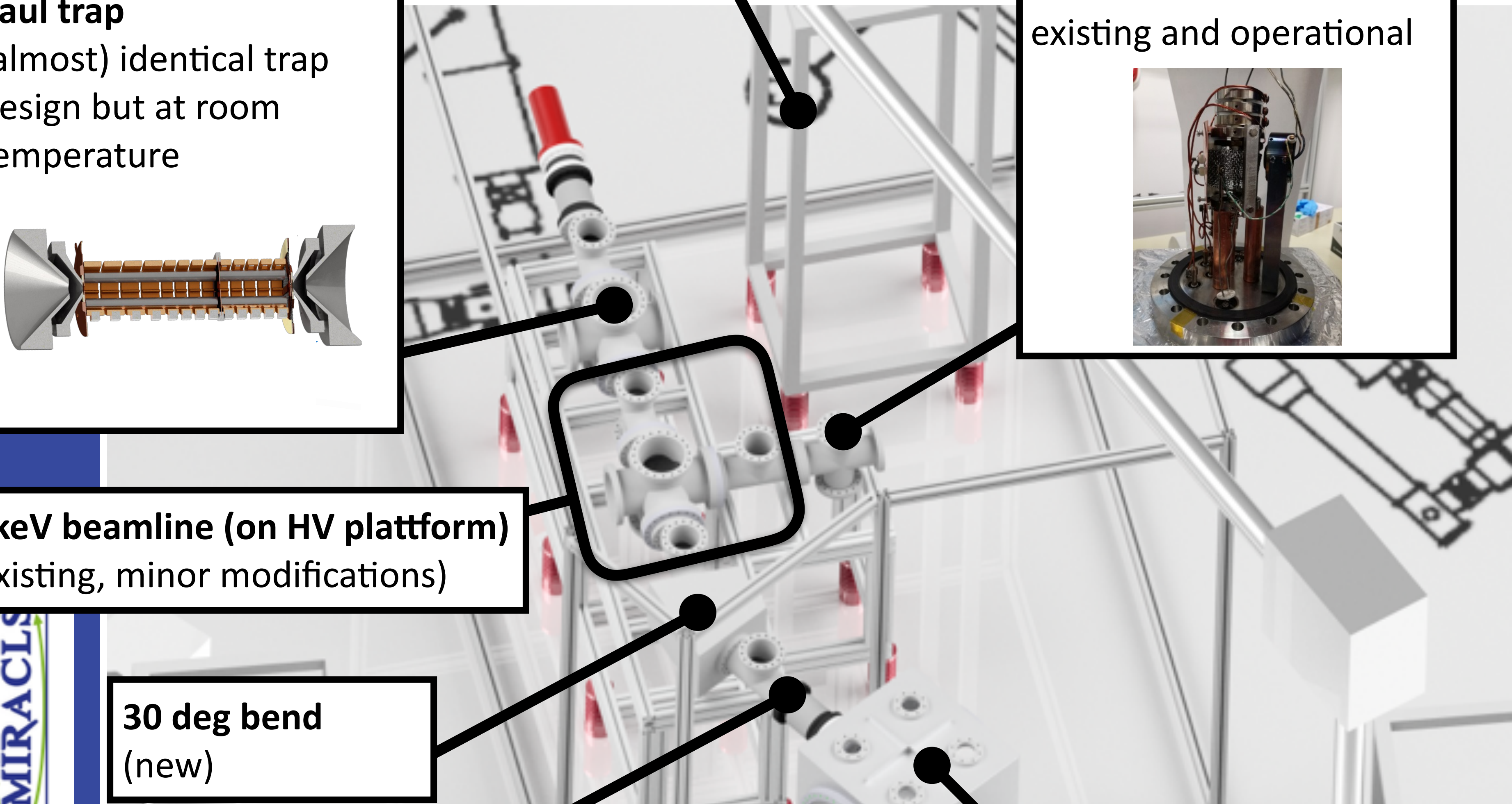
MIRACLS at LA2



discussions about integrations ongoing

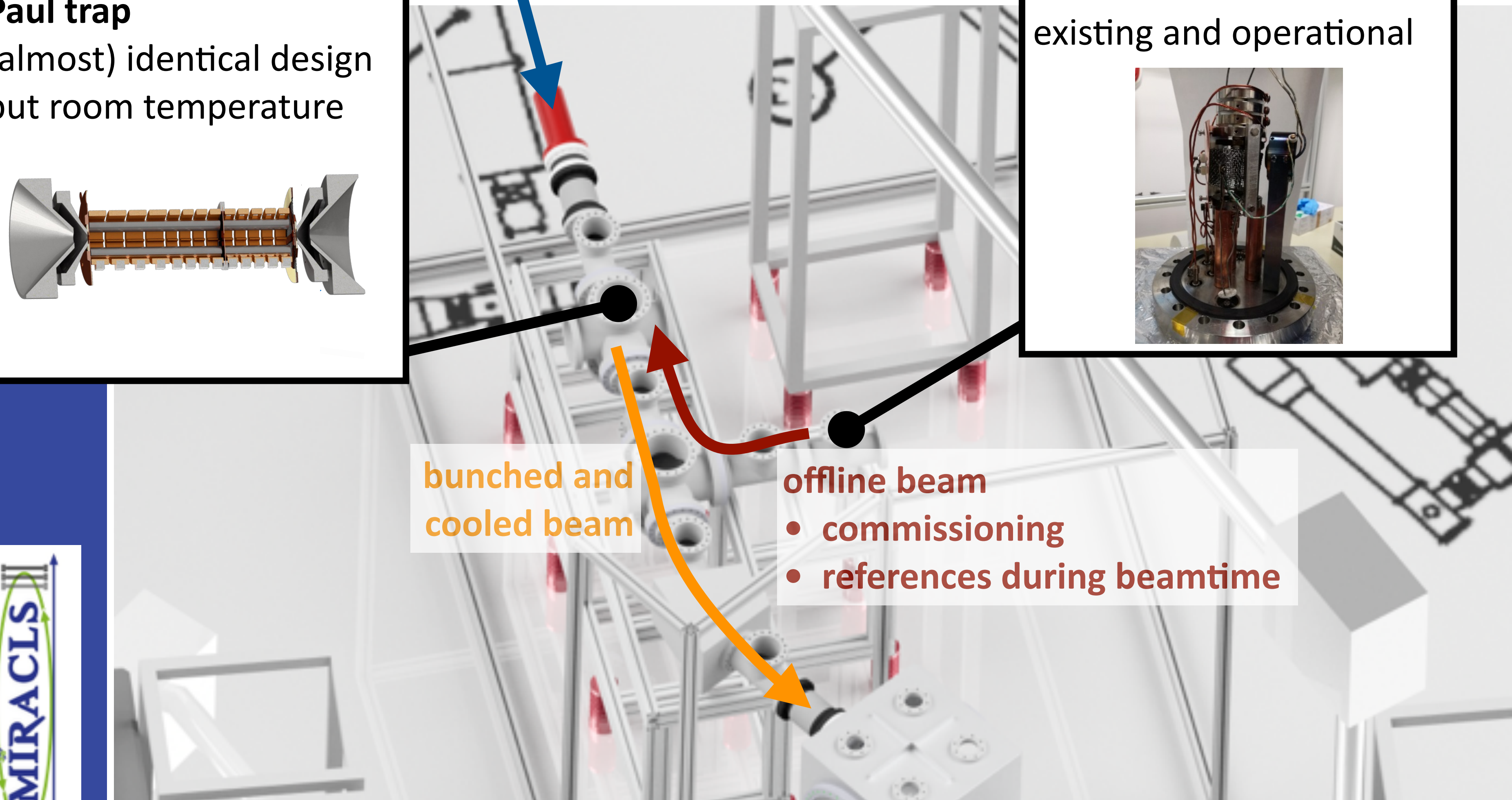
(K. Johnston, E. Siesling, Di Giulio, J. Devine, J. Troska, COLLAPS, etc.)

MIRACLS at LA2



MIRACLS at LA2

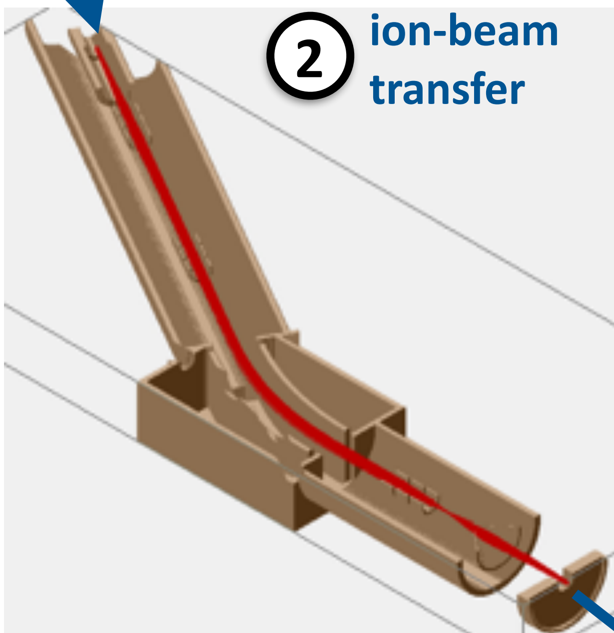
Paul trap
(almost) identical design
but room temperature



offline ion source
existing and operational

Simulations of ion beam optics (Mg)

1 ion cooling in Paul trap



2 ion-beam transfer

3 trapping in MR-ToF

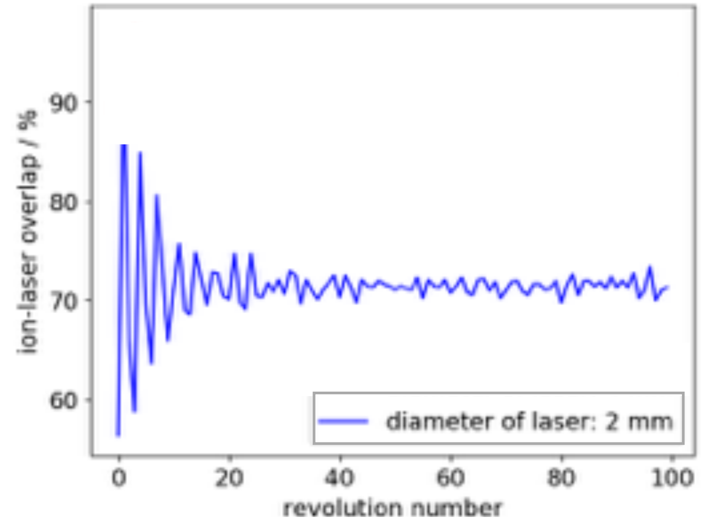
- 3-step simulation approach
- benchmarked for PoP setup in

F. Maier et al., Hyperfine Interact. 240, 54 (2019)

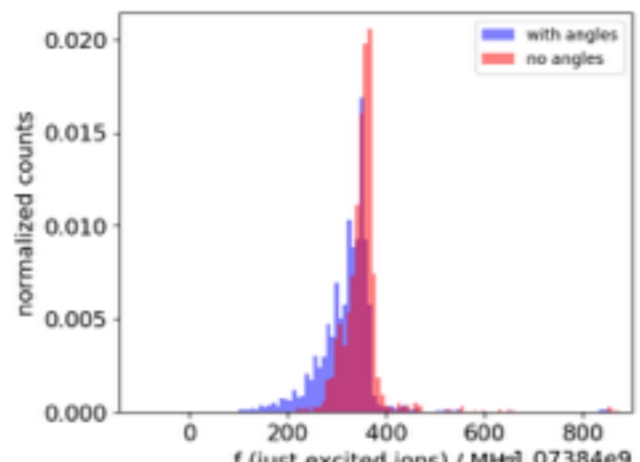
- setup not optimal, but addresses first physics

Results:

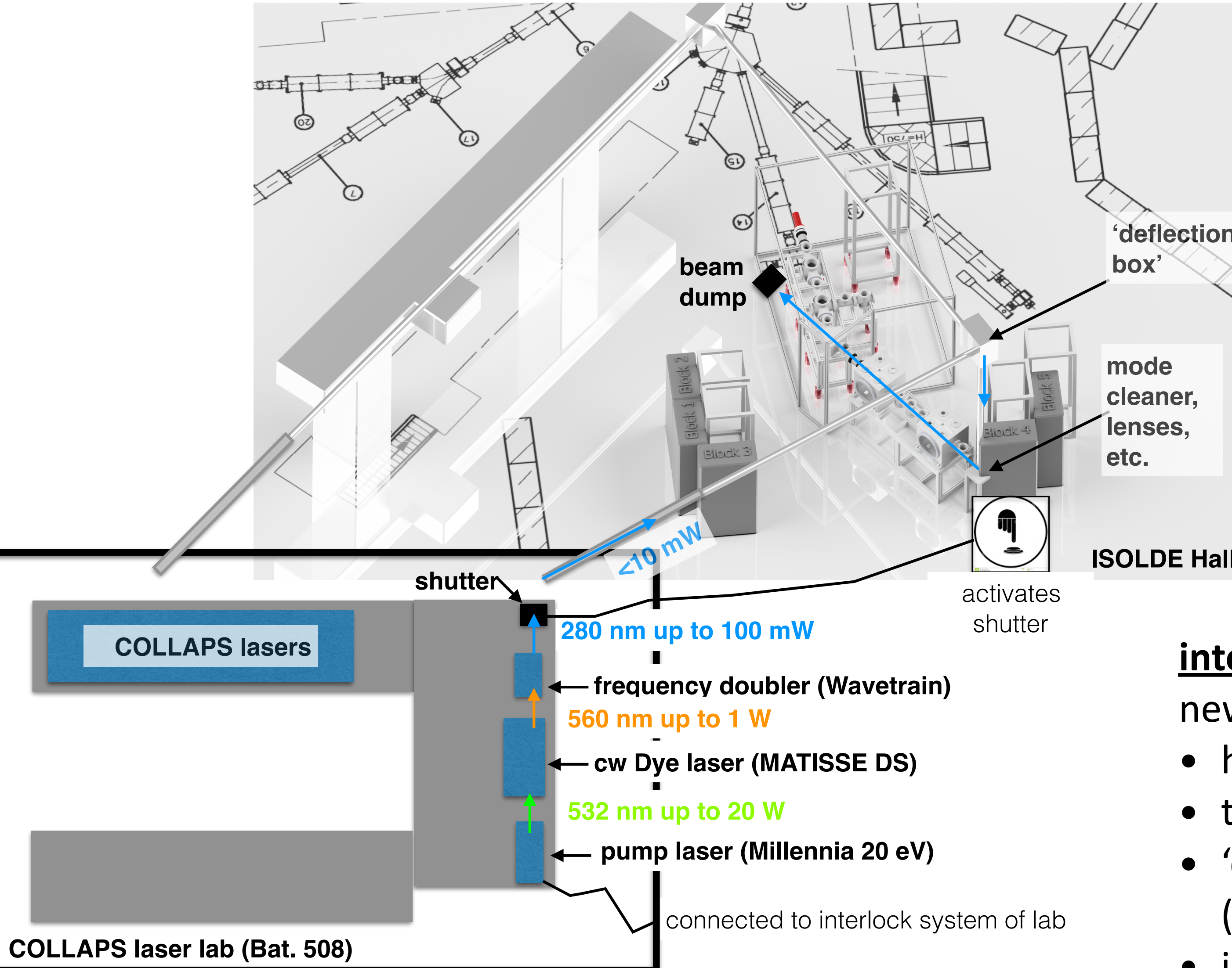
- trapping efficiency >90 %
- laser ion-overlapp



- CLS resonance



Laser Setup



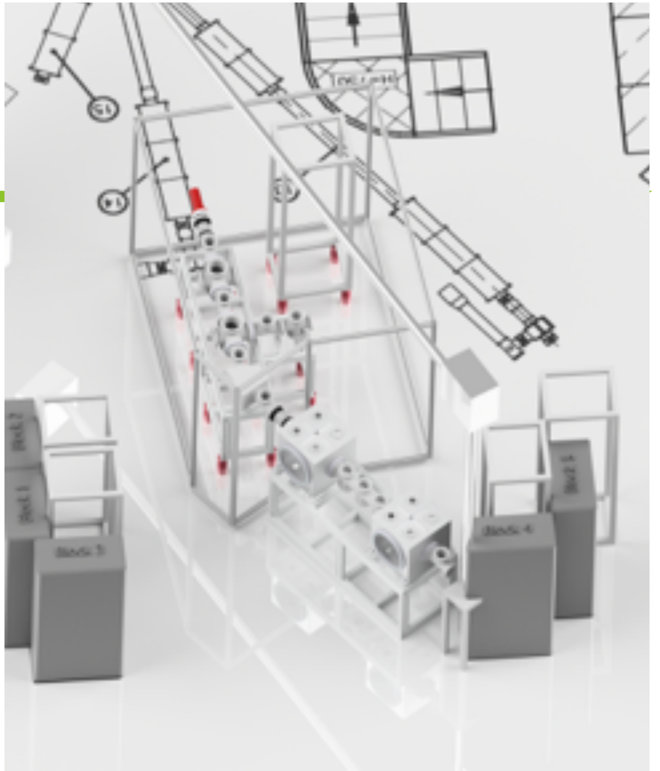
discussions with CERN safety ongoing
(L. Di Giulio, J. Troska, K. Johnston)

integration requirements

new laser-transport tubes

- hole ISOLDE-laser lab
- tube installation
- 'deflection box' with (temporary) access
- interlock system

Required Resources



Infrastructure at LA2

- laser-beam transport (see previous slide)
- removal of block 5
- displacement of block 4 (including distribution of power, pressurised air; radiation detector, etc.)
- removal and relocation of cable trays
- passage through LA1 or LA2?
- electrical power: 80 kW (peak), ideally low noise
- pressurised air, cooling water

Required information

- **access to ISOLDE 3D model**
  - ➡ for minimal interference with COLLAPS and LA1
  - ➡ safety (laser, access, etc.)
- ion-beam optics along ISOLDE beamline
- emittance measurement at LA2 (TRIUMF emittance meter?)

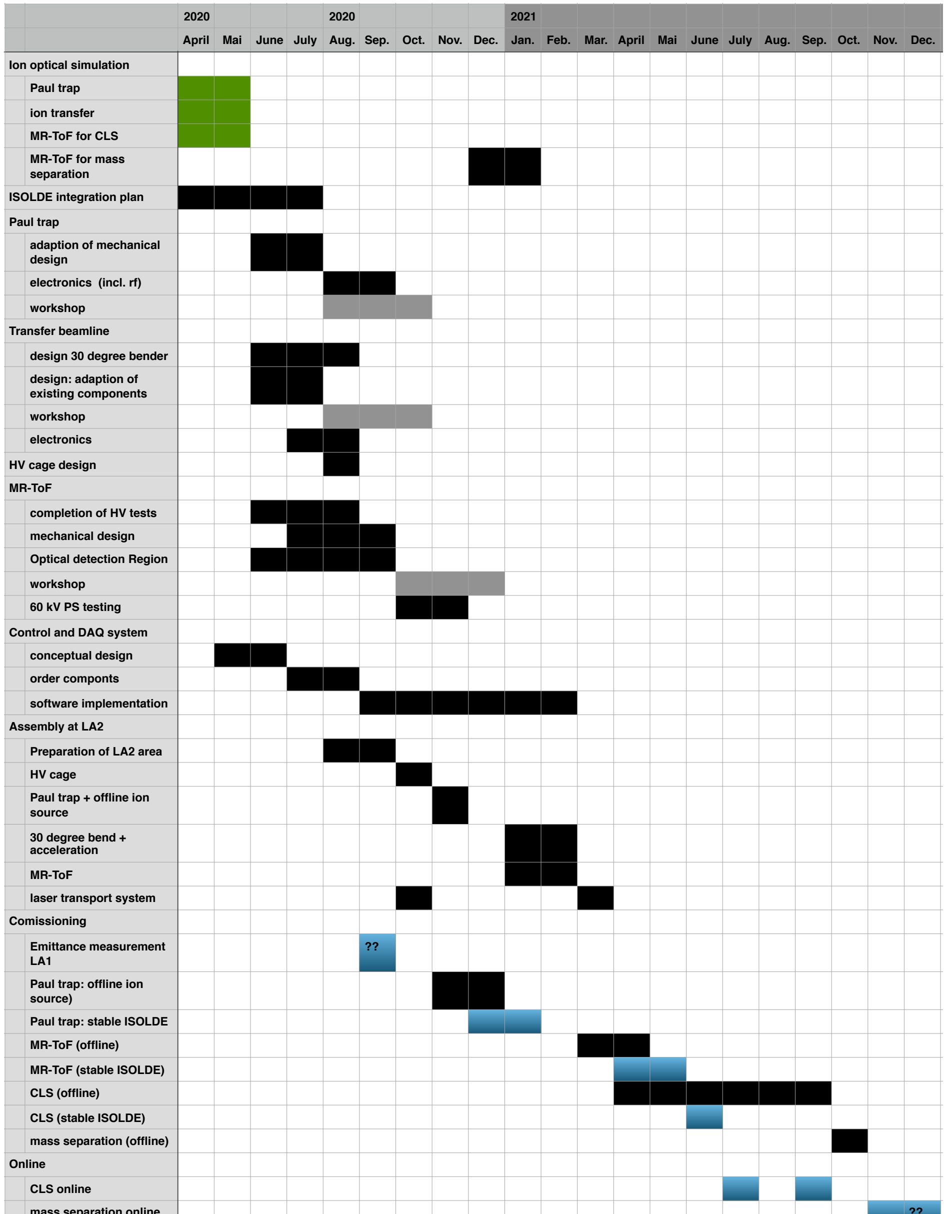
additional lab space:

- air conditioning at all times in COLLAPS laser lab (including early 2021)
- lab space for clean assembly of apparatus
- DAQ room/section (?)

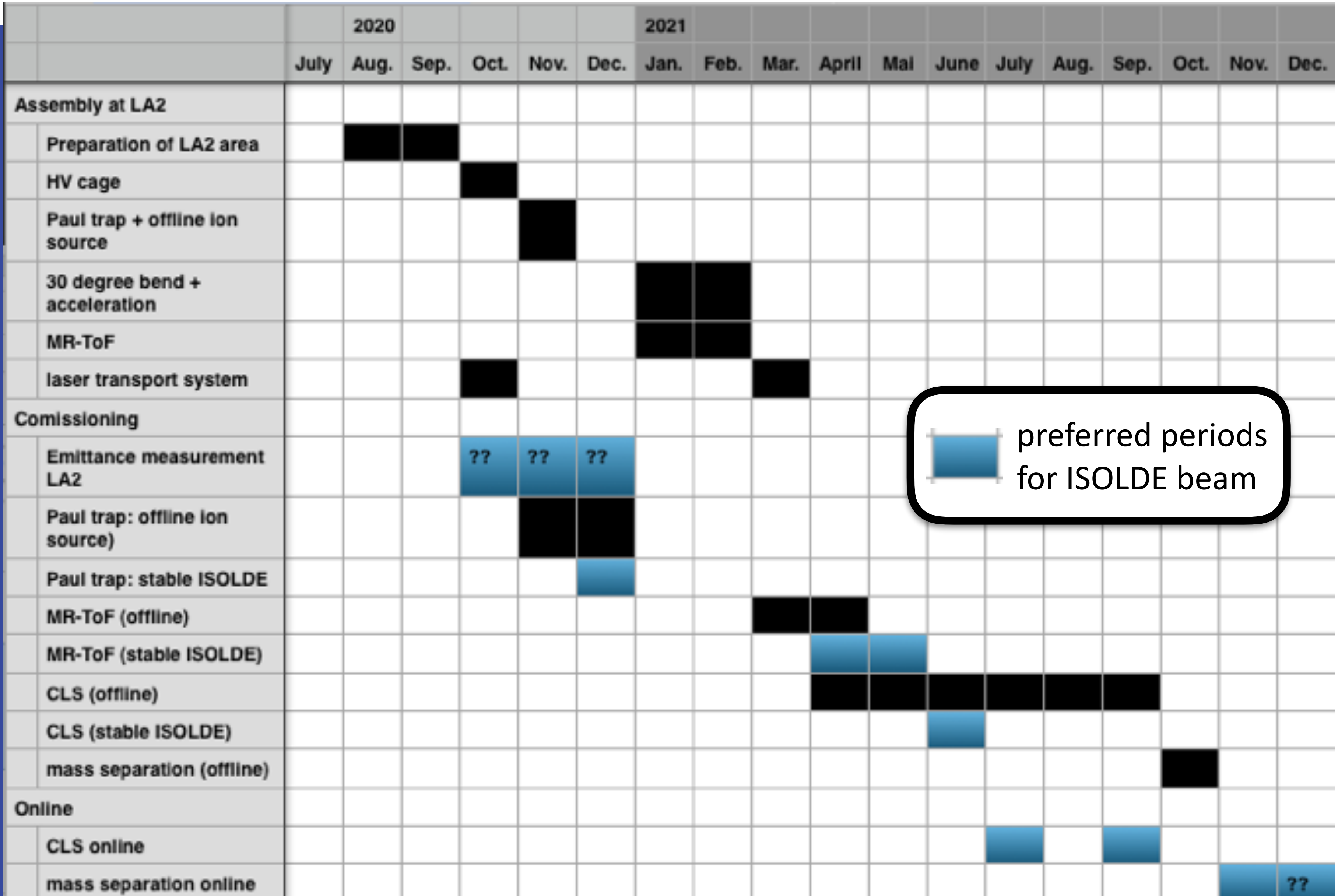
ISOLDE beam requirements

- ISOLDE operation at 50 keV
- if possible, stable ISOLDE beam for emittance measurement (fall 2020)
- stable ISODLE beam (end of 2020 and early 2021) to establish ion-beam transfer
  - ➡ initially e.g. ^{39}K ok, later $^{24-26}Mg$ and something heavier e.g. ^{133}Cs
  - ➡ continuous beam for GPS (2020)
  - ➡ HRS+ISCOOL for bunched ions (2021)
  - ➡ 3x 4 days

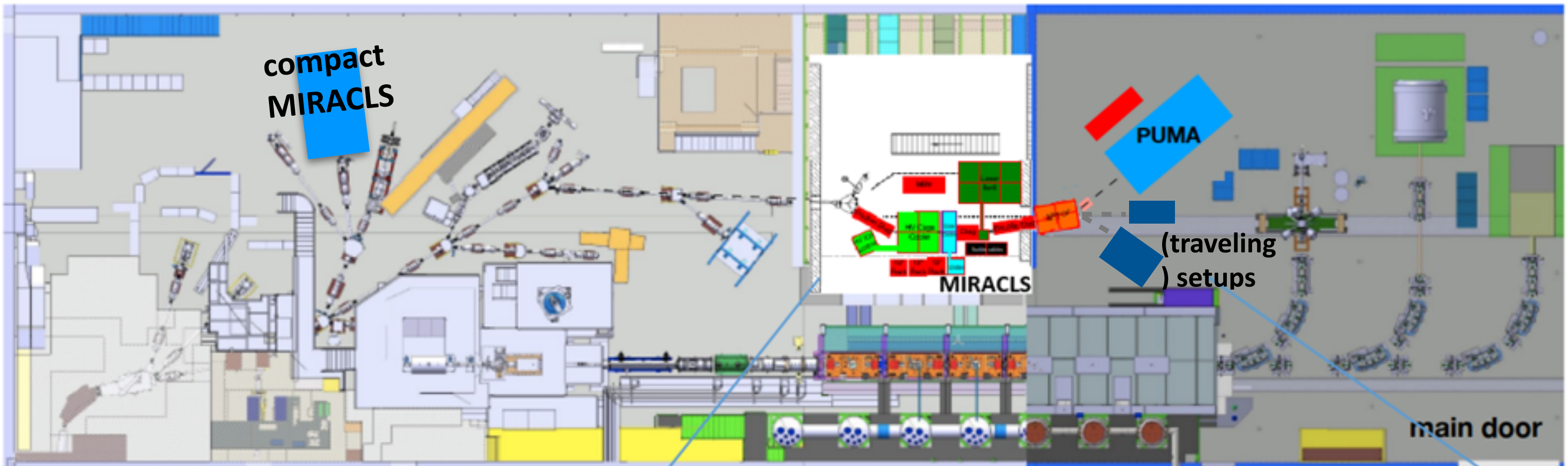
Timeline: compact MIRACLS



Timeline: compact MIRACLS



Full MIRACLS at RCX10



main upgrade: cryogenic Paul trap

- better MIRACLS performance
- essential for MR-ToF mass separation with high ion capacity
- cooling of molecules ↔ *R. F. Garcia Ruiz et al., Nature 581, 396 (2020)*
- high quality RIB to downstream users

proposal for integration

- **2021:** independent commissioning of cryogenic Paul trap at RCX10
- **2022:** experiments with (ionic) radioactive molecules
- **end of 2022:** end of compact MIRACLS and move 30-keV MR-ToF to RX10
- **2023:** beam deliver to PUMA and others

Summary and Conclusions

- Successful proof-of-principle experiment
  - ➡ demonstration of novel technique
  - ➡ benchmark of simulation approach for 30-keV MR-ToF
  - ➡ experimental sensitivity estimate
- compact MIRACLS@LA2
  - ➡ response to COVID-19 lockdown
  - ➡ initial setup with reduced complexity (and capabilities)
  - ➡ addresses ERC science goals within funding period
  - ➡ commissioning of 30-keV MR-ToF device
- MIRACLS@RCX10
  - ➡ MIRACLS in its full potential
    - incl. downstream users and mass separation
  - ➡ initial&independent commissioning of cryogenic Paul trap
    - first physics with radioactive molecules

MIRACLS

collaboration:

CERN, Universität Greifswald – Wissen lockt. Seit 1456, Technische Universität Darmstadt

team members:

P. Fischer, **V. Lagaki, S. Lechner, F. Maier, P. Plattner**,
H. Heylen, M. Rosenbusch, **S. Sels**, F. Wienholtz, **M. Vilen**,
R. Wolf, W. Nörtershäuser, L. Schweikhard,
S. Malbrunot- Ettenauer (Spokesperson)

MIRACLS Alumni:
F. Hummer (2019), **L. M. Bartels** (2018),
F. Maier (2018), **L. Fischer** (2017)
F. Stabel (2017), **S. Sailer** (2017)

CERN based people:
PhD students
MSc students
BSc students
Fellows

funding:

erc European Research Council, ATTRACT, CERN **Medical Applications Funds**

https://miracls.web.cern.ch

ISOLDE