Physics perspectives for CRYRING@ESR

Michael Lestinsky (GSI-AP)
Stored Beams Seminar, 2014-03-06

Outline

- Project status
- Performance
- Experimental instrumentation
- Research programme
- Summary

Why CRYRING@ESR?

FAIR related R&D:

- Tests of novel detectors and beam diagnostics systems
- Tests of FAIR accelerator control system
- Tests of FAIR safety and radiation protection access systems
- Stand alone operation allows tests in a running environment
- Training of personnel on new controls

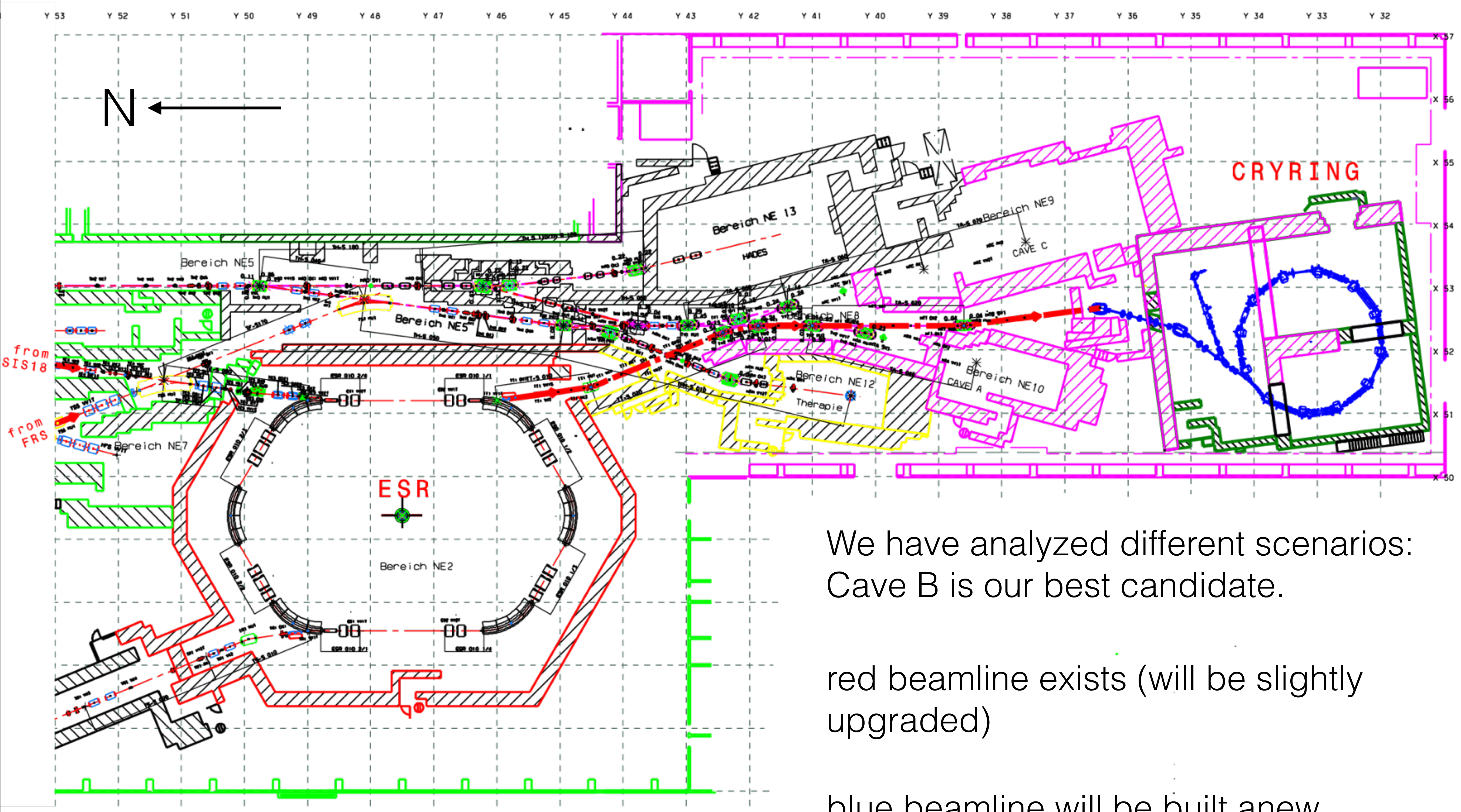
Scientific opportunities:

- Slow, highly charged ions, every ion species available at GSI, exotic nuclei, (in the future pbars?): SPARC, EXL, (in the future FLAIR)
- Exotic shortlived ions: Fast ramping (~1s)
- Atomic, nuclear, biophysics, materials research
- Photonic, electronic and atomic collisions, extraction towards downstream experiments
- Physics programs can continue even during major shutdowns of GSI for FAIR upgrades.

CRYRING History

1985	CRYRING funded by K. and A. Wallenberg foundation
1991	First beam (deuterons) at MSL
1992-2010	CRYRING produces ~400 papers, 43 dissertations, 39 licentiate theses
2006	FAIR Technical report on APPA, SPARC, and FLAIR: CRYRING proposed as LSR
2009	Modularized Start Version (MSV) of FAIR: ~~NESR, FLAIR...~~
Nov. 2011	Proposal for an early installation of CRYRING@ESR to GSI Science Council
Jun. 2012	"CRYRING@ESR: A study group report" submitted, accepted by all committees
Okt. 2012 - Mar 2013	Shipping of CRYRING from Stockholm to Darmstadt

GSI ring topology with CRYRING@ESR

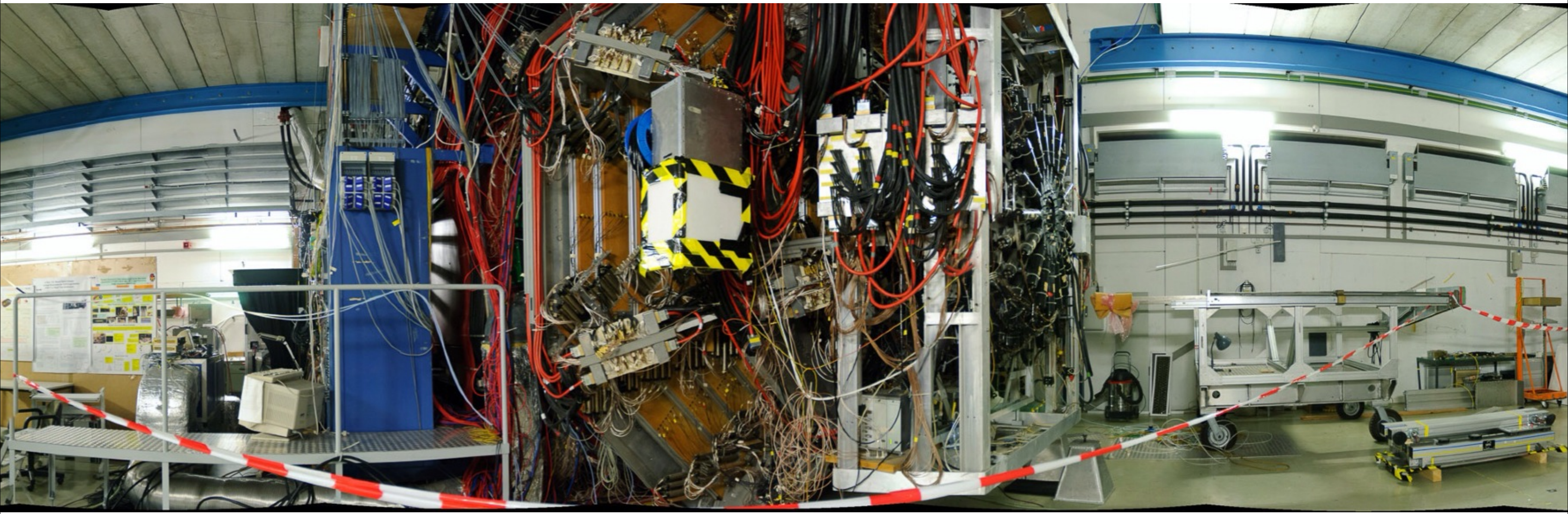


We have analyzed different scenarios:
Cave B is our best candidate.

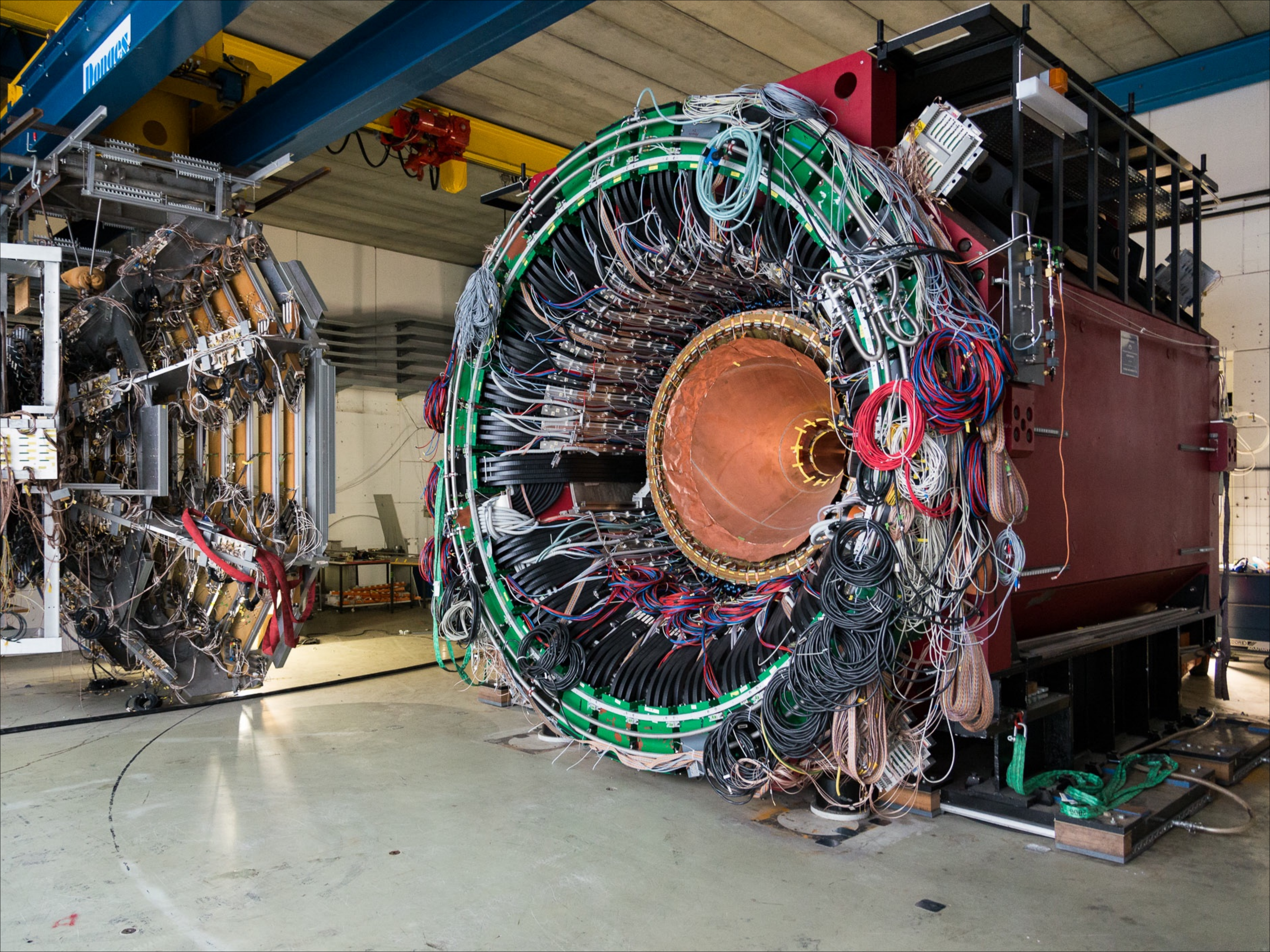
red beamline exists (will be slightly upgraded)

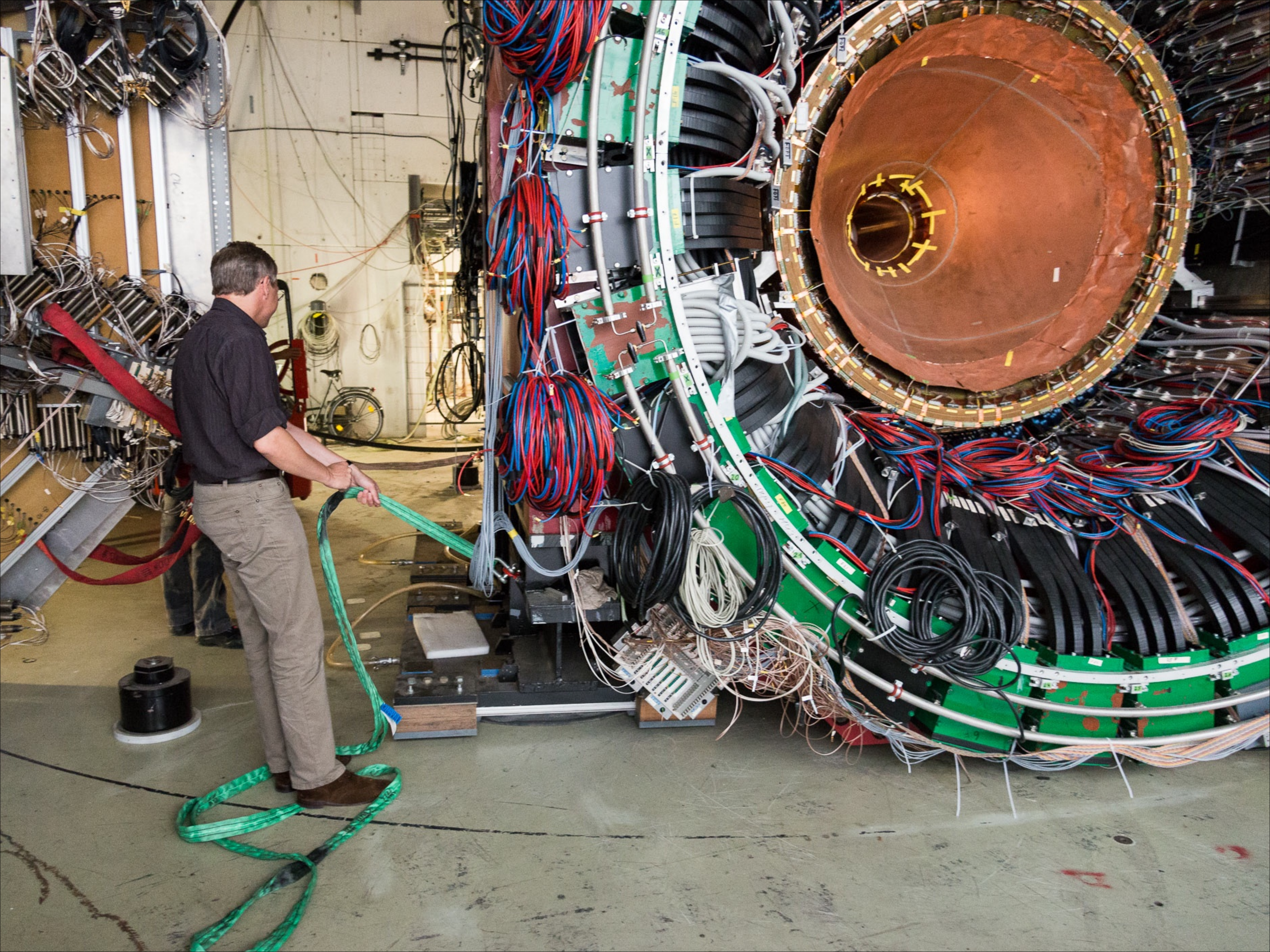
blue beamline will be built anew

Unfortunately, CRYRING also marked the end for FOPI.




Donges
Linde


Donges



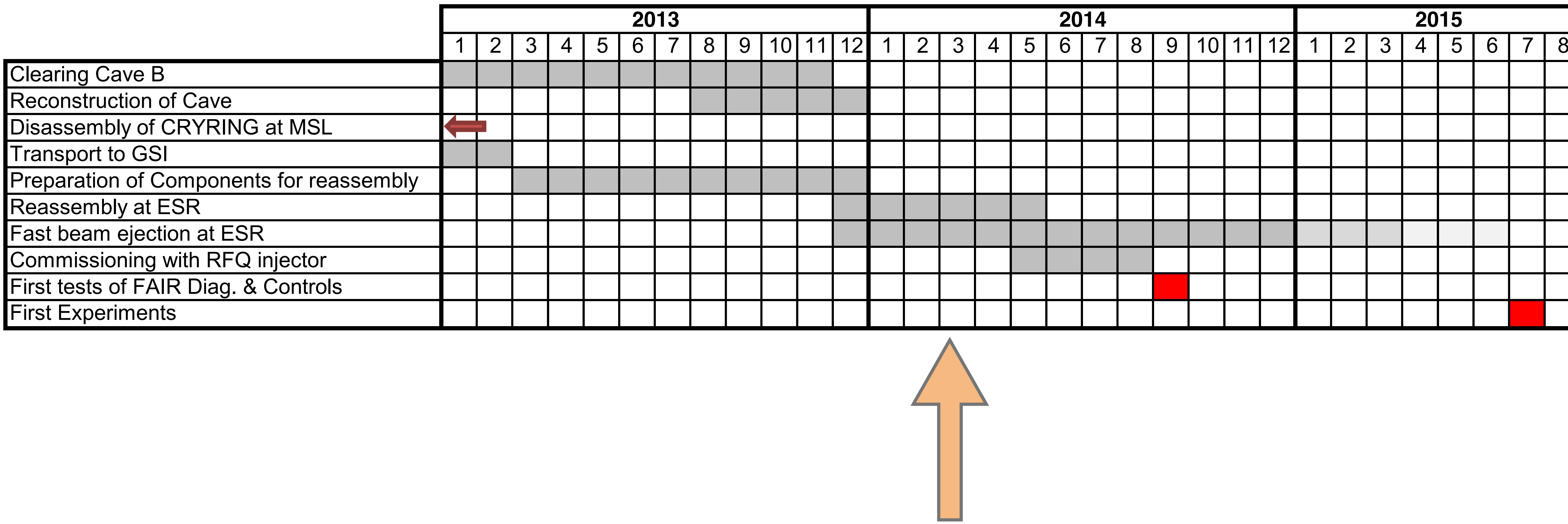

Donges
Linde
GSI
20
Linde


Linde
suffel
GSI
20
Linde


DMS


Rheiner Stahlbau GmbH
Fabr.-Nr.: 890094/1
Traglast: 5t
Baujahr: 1989

Timeline



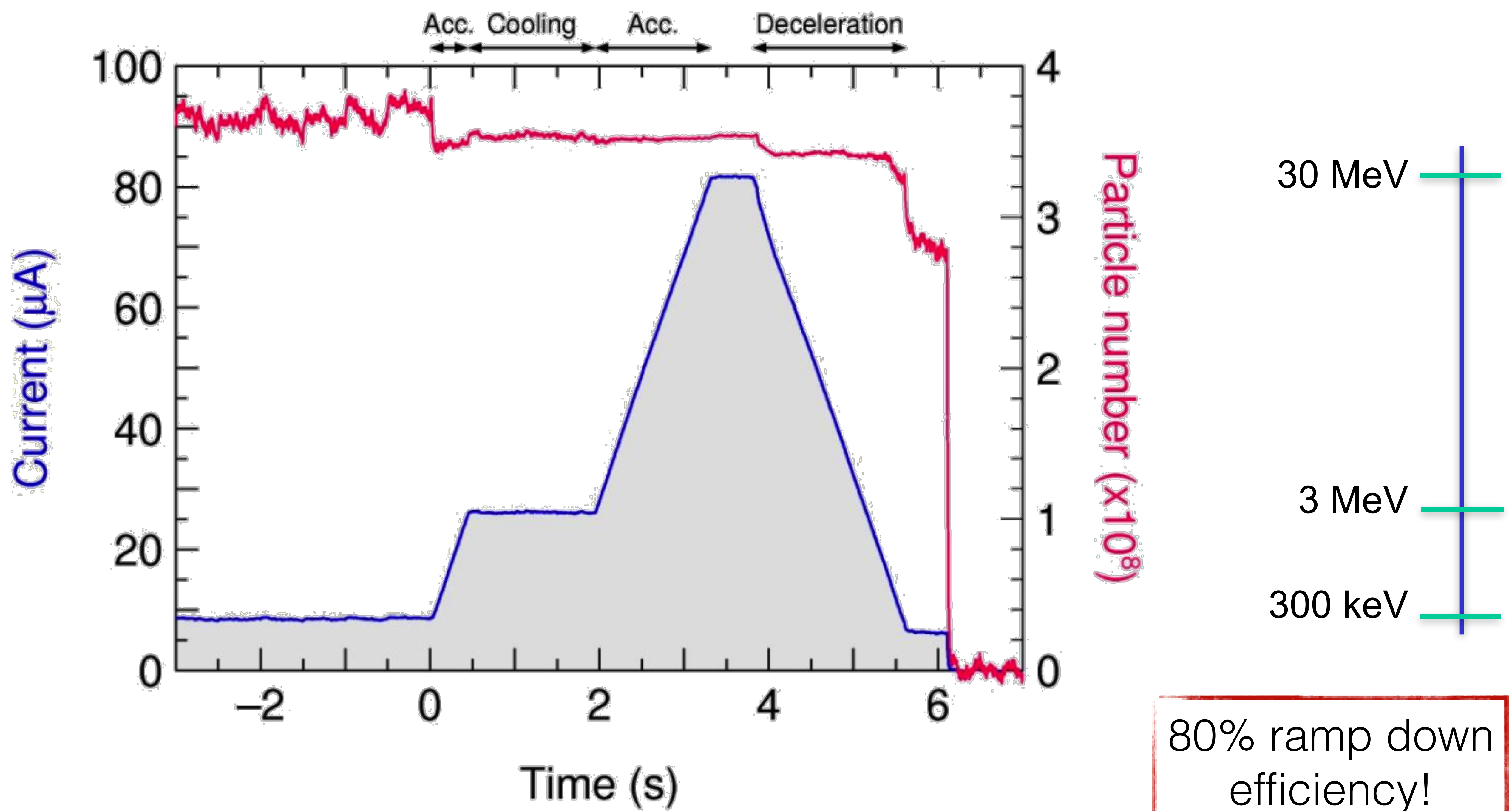
2013
2014
2015
1 2 3 4 5 6 7 8 9 10 11 12
1 2 3 4 5 6 7 8 9 10 11 12
1 2 3 4 5 6 7 8
Clearing Cave B
Reconstruction of Cave
Disassembly of CRYRING at MSL
Transport to GSI
Preparation of Components for reassembly
Reassembly at ESR
Fast beam ejection at ESR
Commissioning with RFQ injector
First tests of FAIR Diag. & Controls
First Experiments

Performance

Circumference	51.63 m => 54.17 m (ESR/2)
Rigidity at injection for ions (p, pbar)	1.44 Tm (0.8 Tm)
Highest possible injection energy for p, pbar	30 MeV
- for	24.7 MeV/u
- for	14.8 MeV/u (13.9 MeV/u)
Lowest Rigidity	0.054 Tm
Lowest Energy	Charge exchange limited
Magnet ramping (de- and acceleration)	1 T/s (4 T/s, 7 T/s)
Vacuum pressure (N	10
Beam injection	Multiturn and fast
Beam extraction	slow and fast
Ion source for stand alone operation	Yes (300 keV/u, q/A > ¼)

Dual Injection System

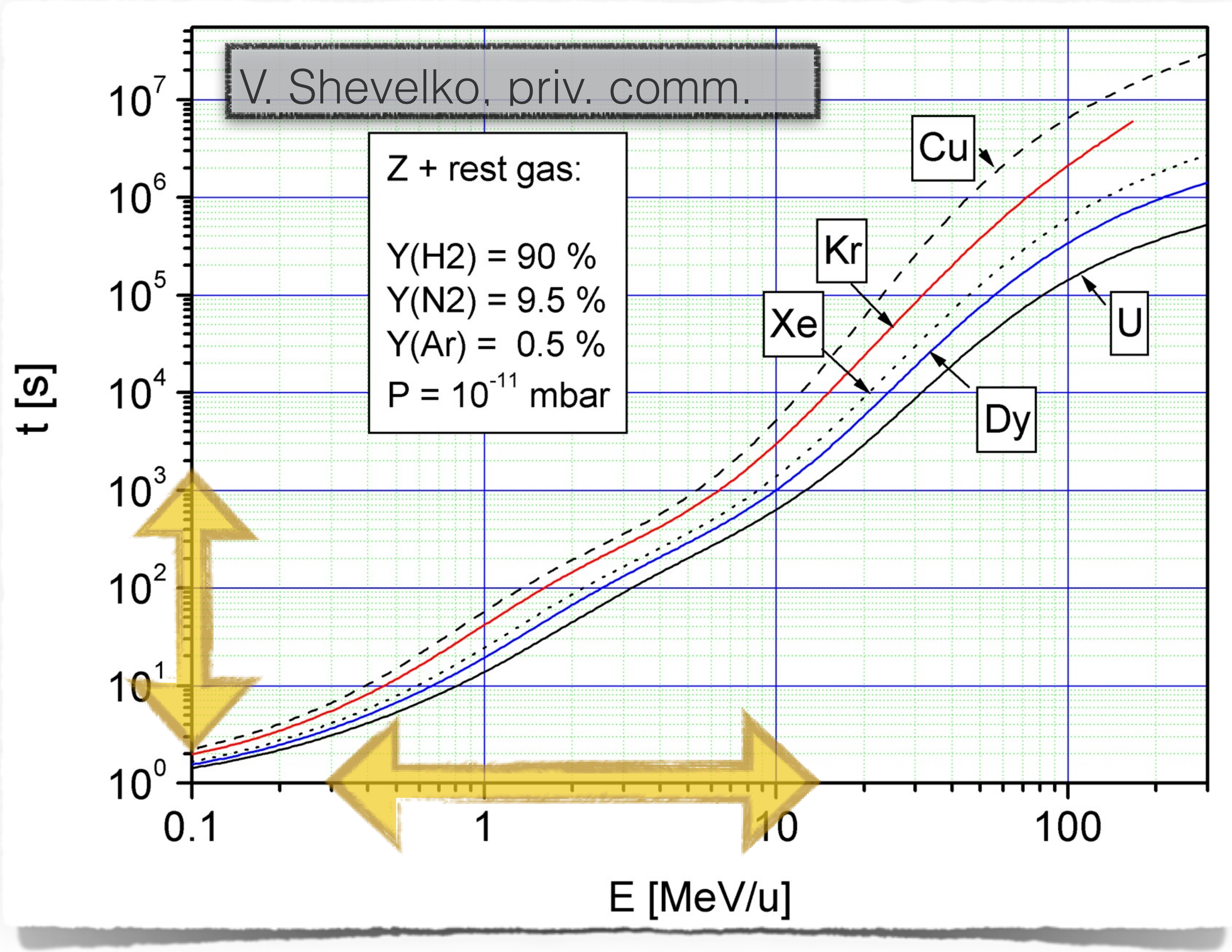
Acceleration and deceleration performance



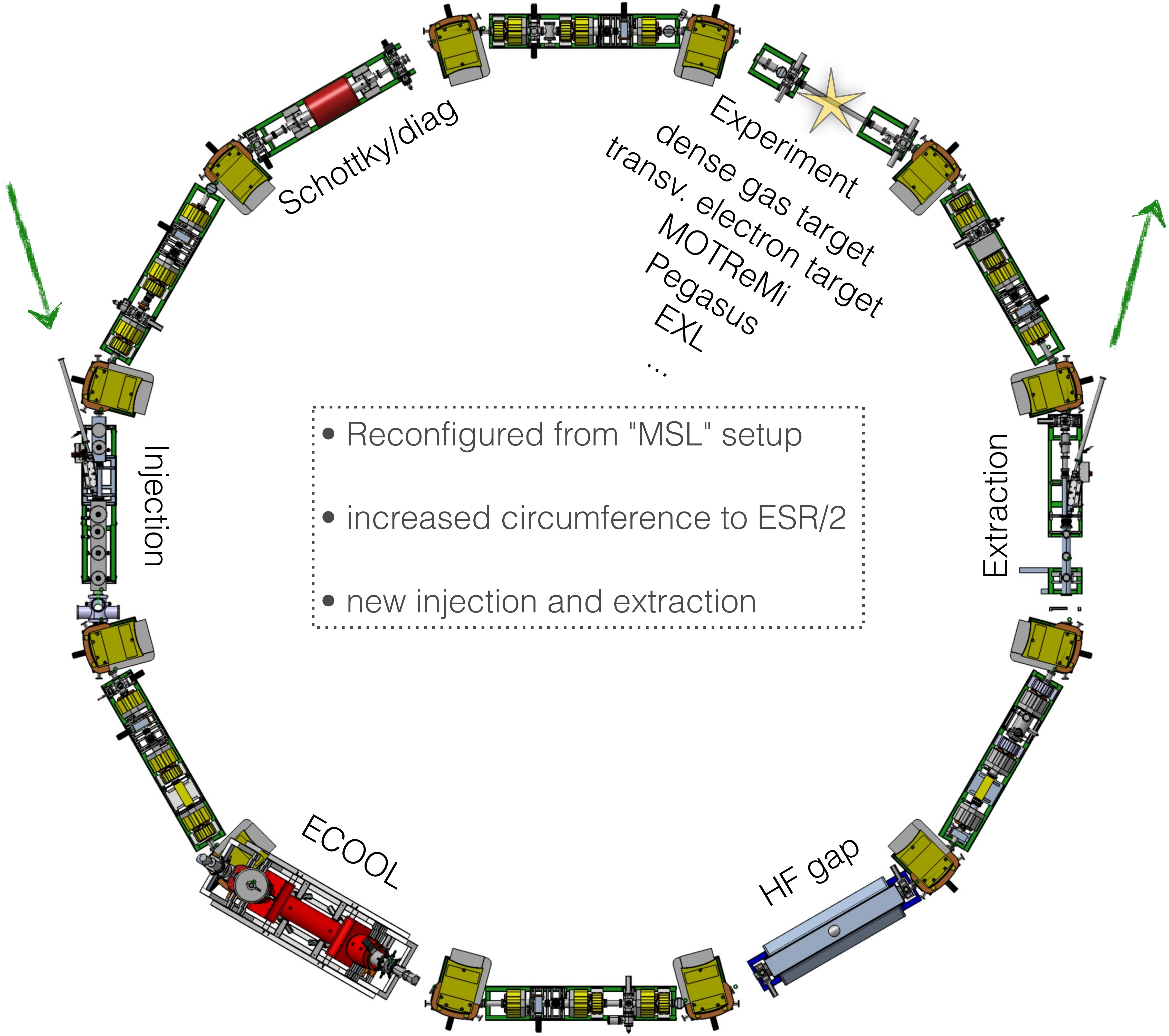
80% ramp down efficiency!

Danared, et al., LSR-TDR, 2011

Lifetimes of bare ions

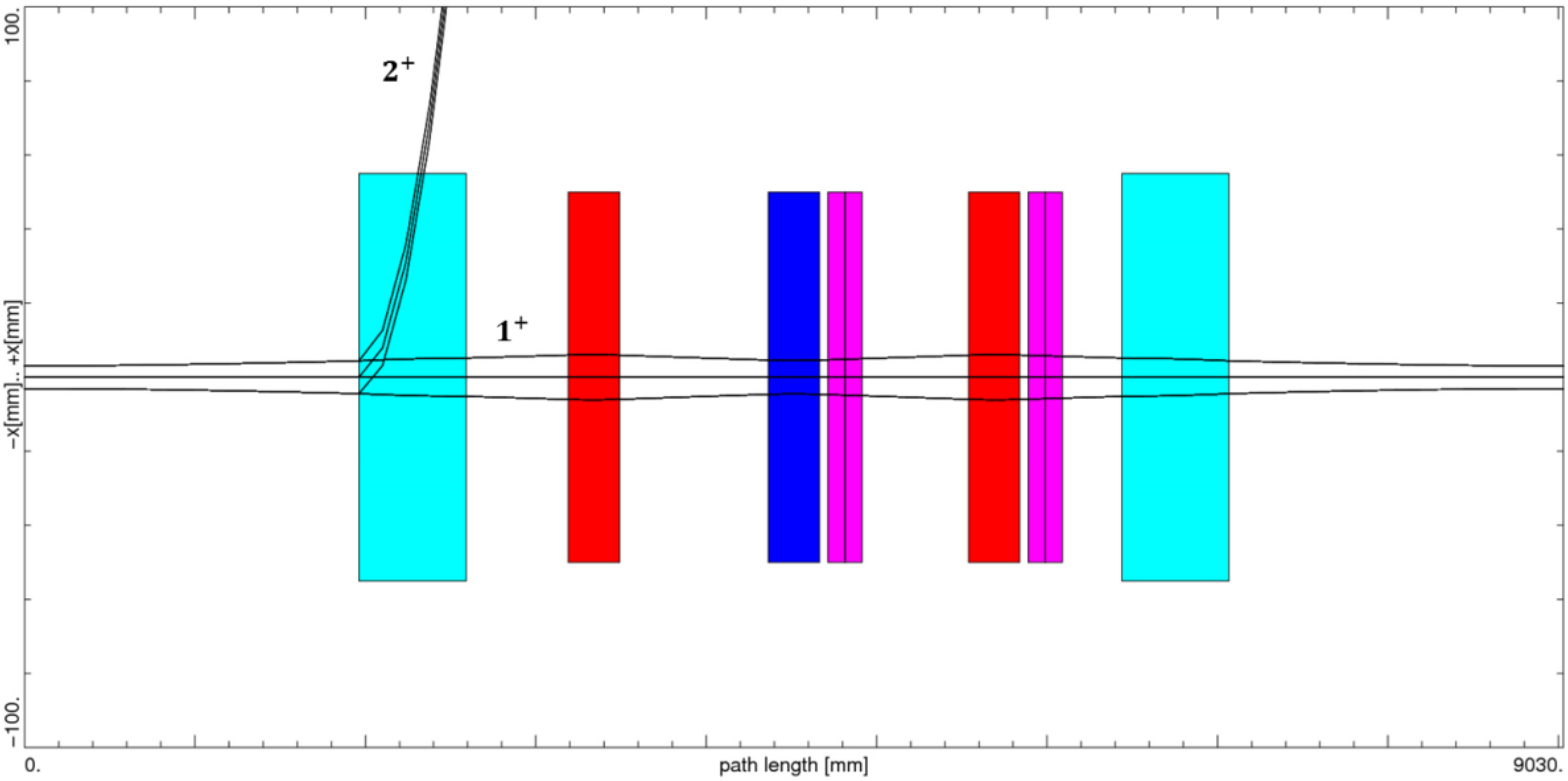


ion beam lifetimes due to rest gas collisions of 3 s to 15 min expected.



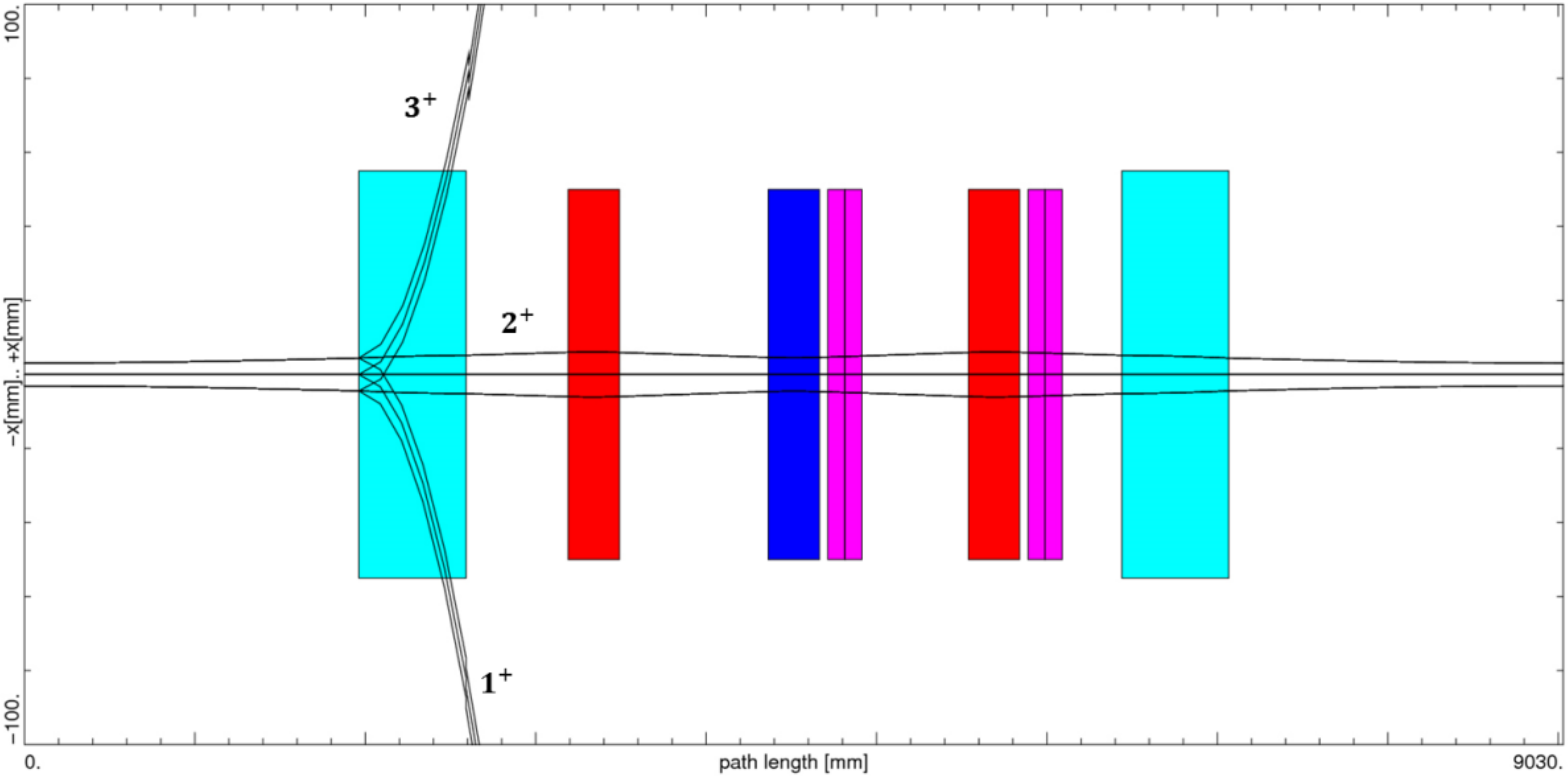
- Reconfigured from "MSL" setup
- increased circumference to ESR/2
- new injection and extraction

Detector positions



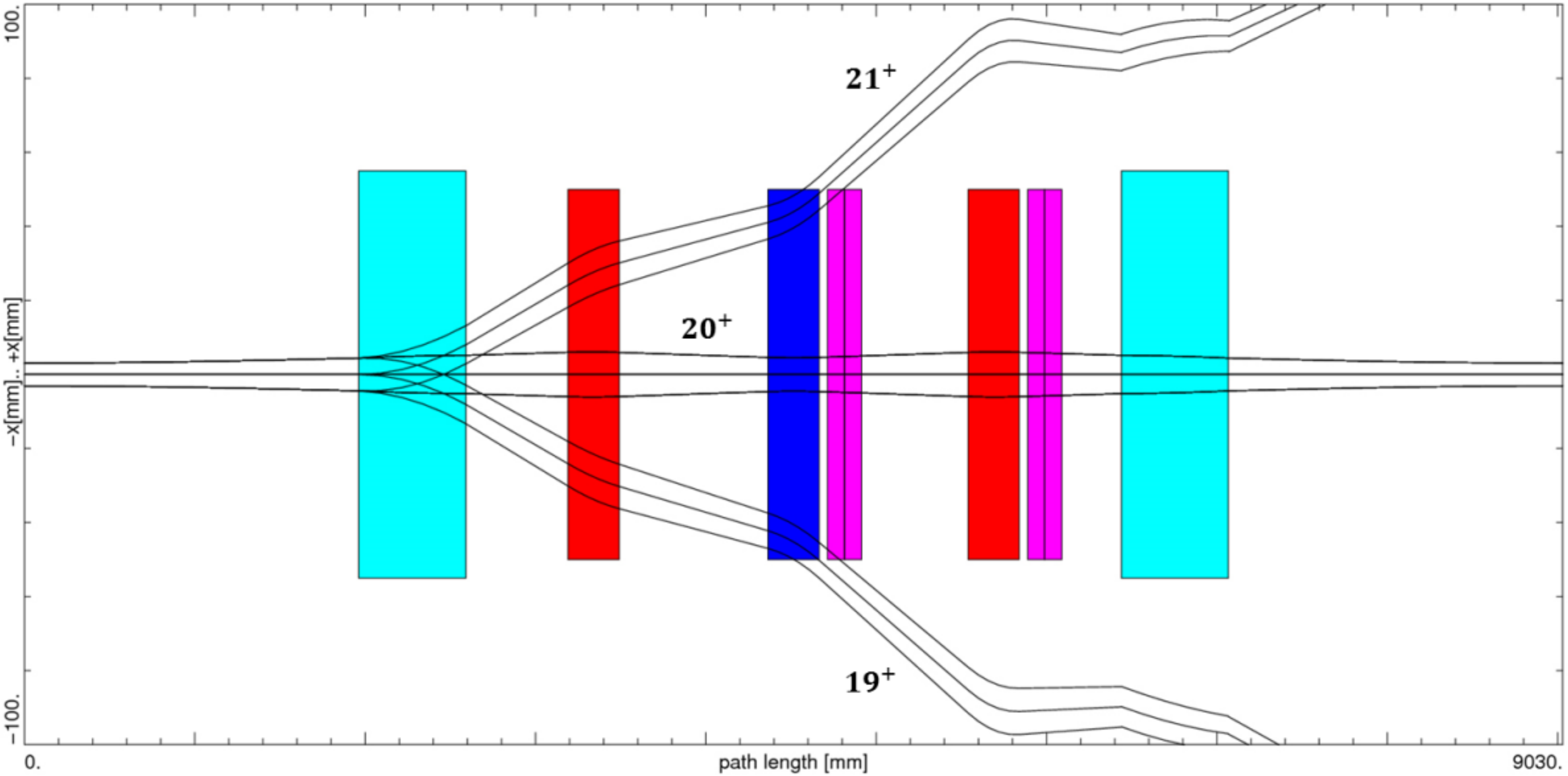
O. Gorda, priv. comm.

Detector positions



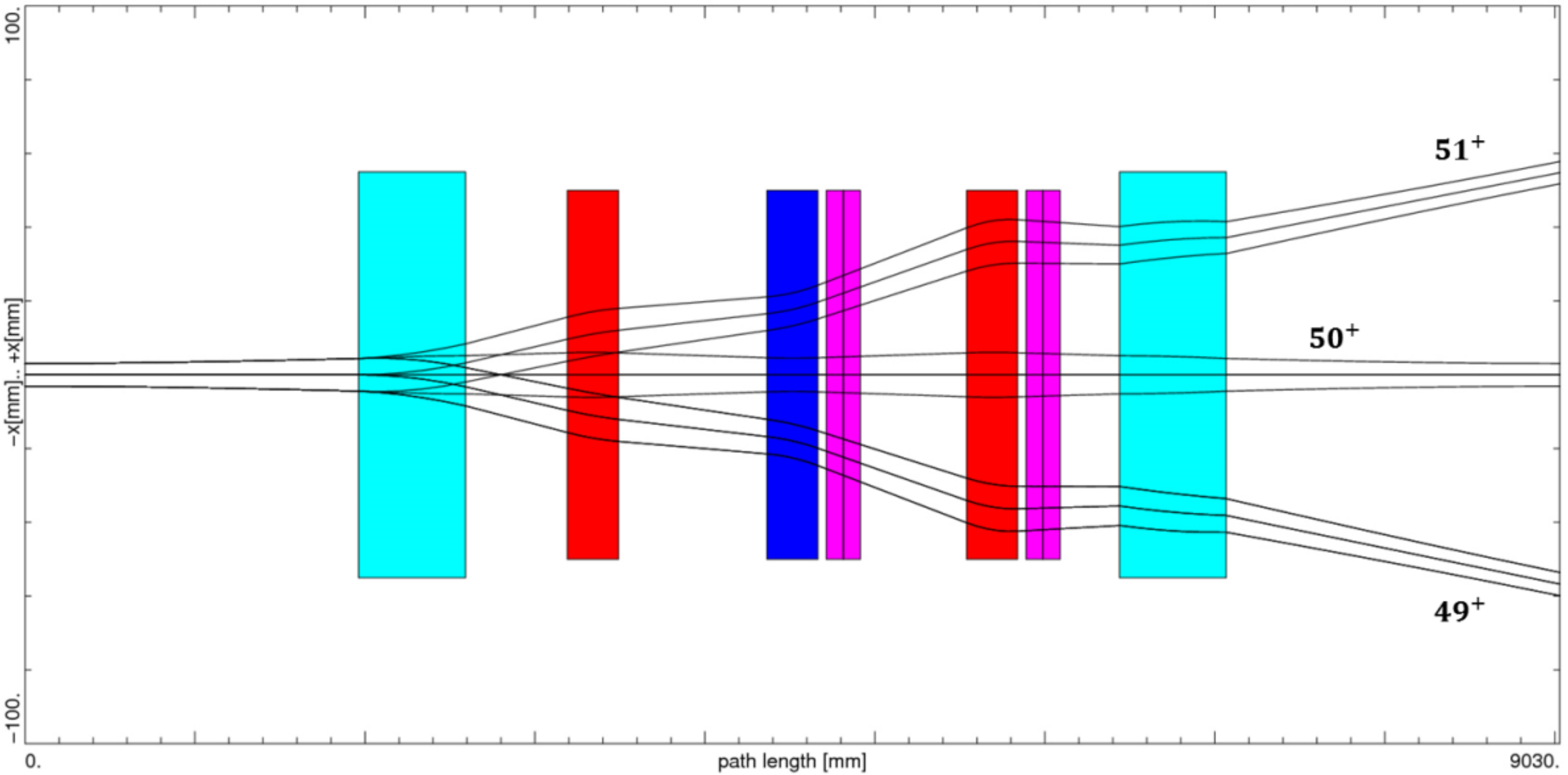
O. Gorda, priv. comm.

Detector positions



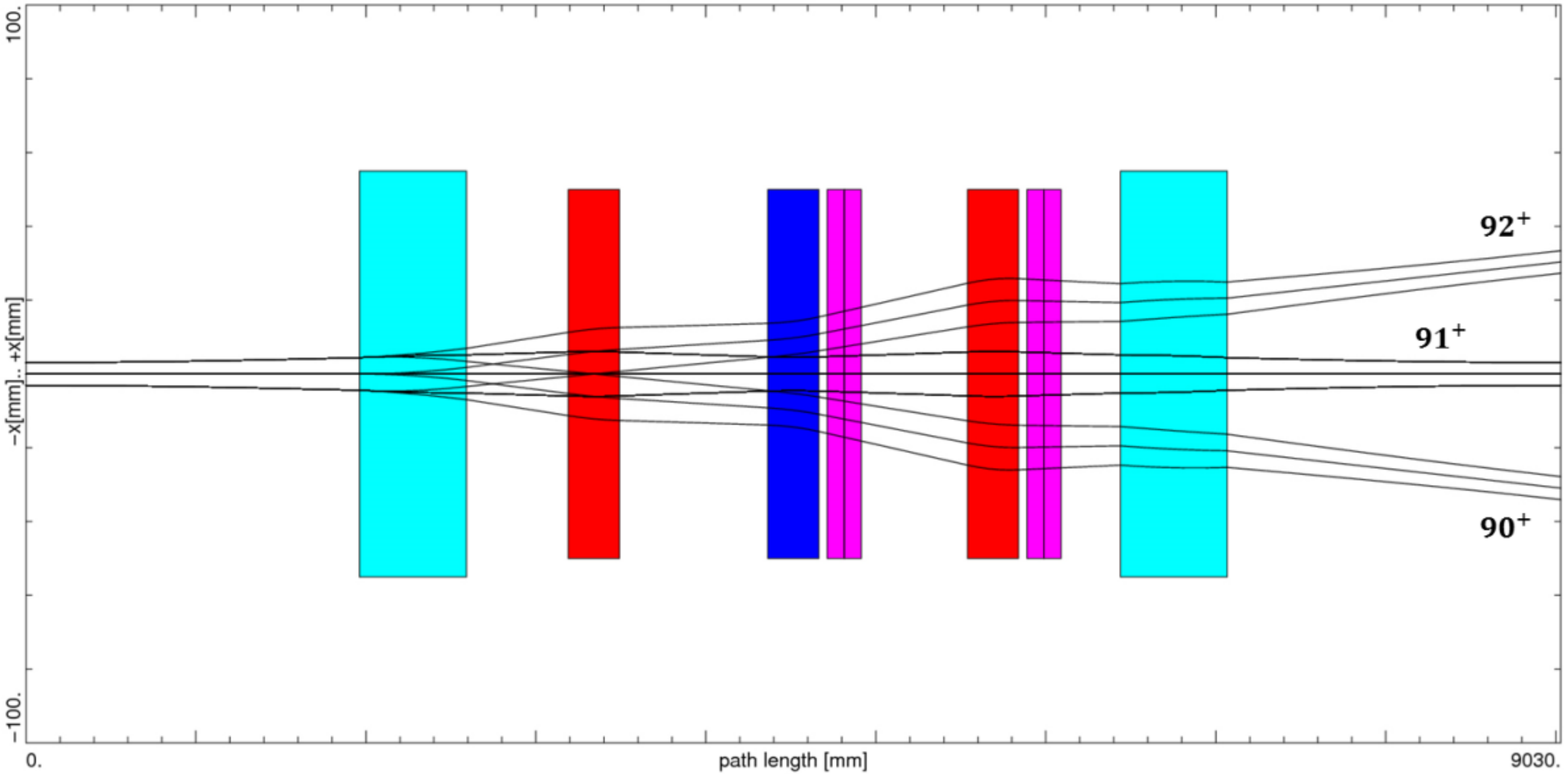
O. Gorda, priv. comm.

Detector positions



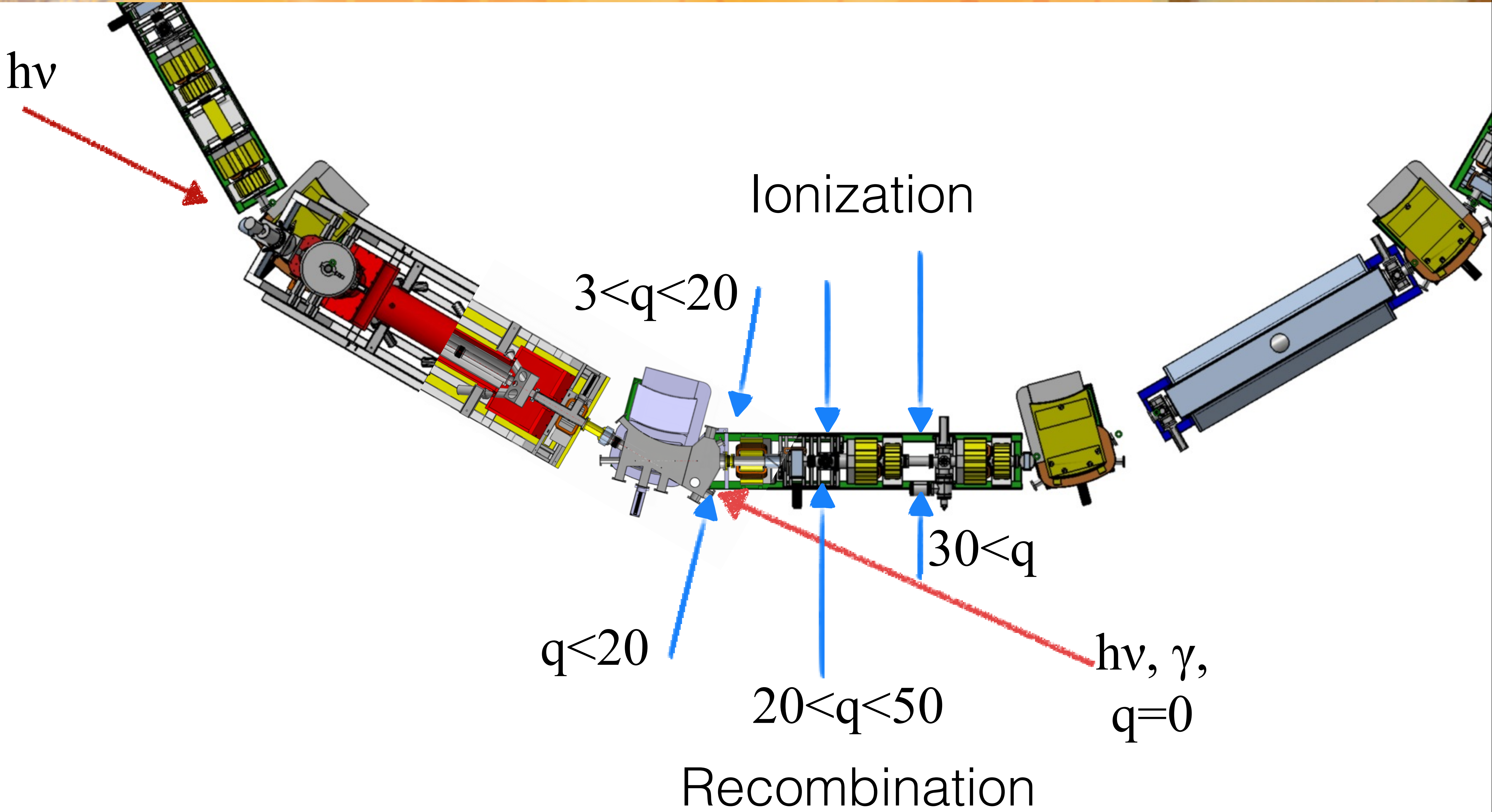
O. Gorda, priv. comm.

Detector positions

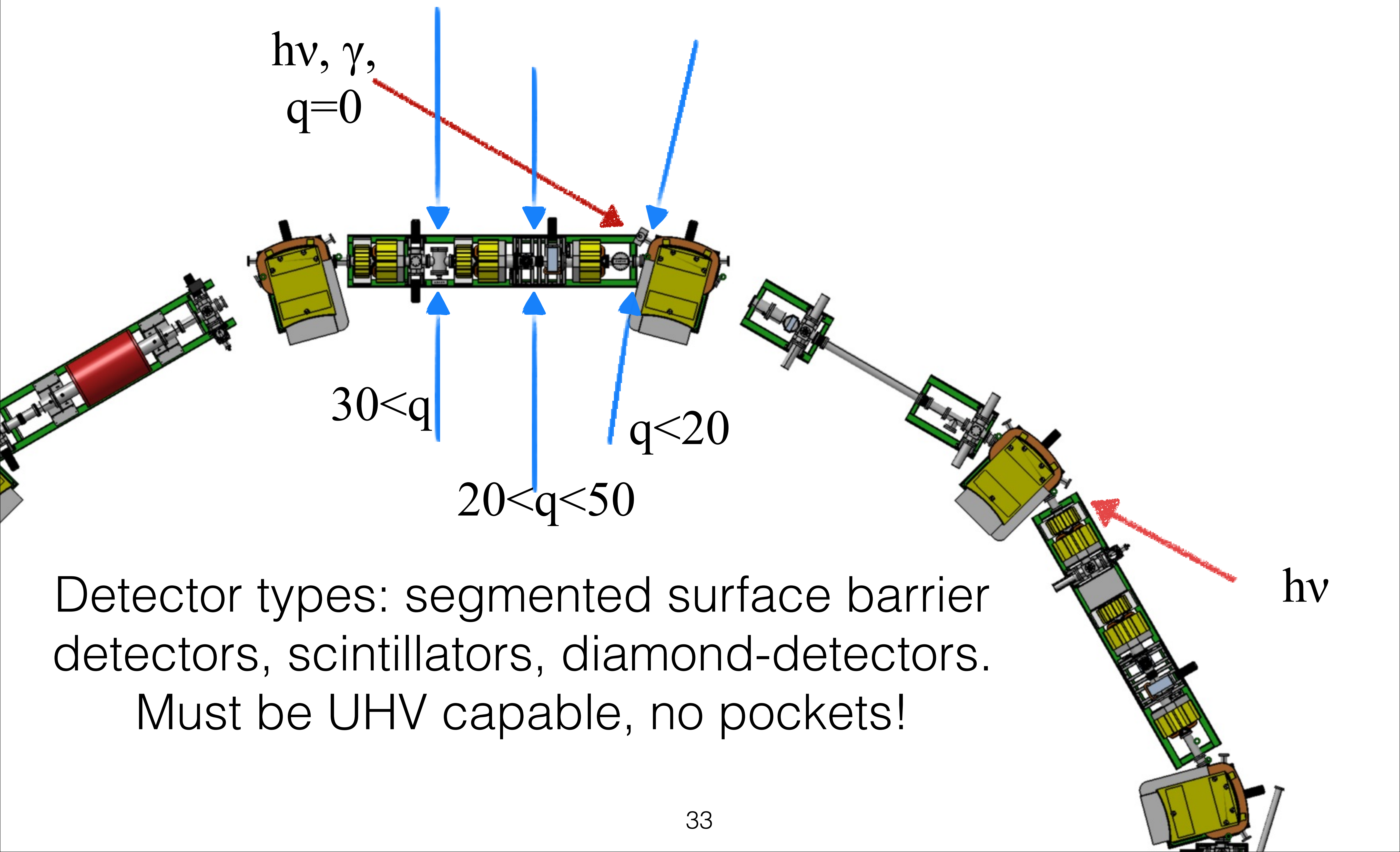


O. Gorda, priv. comm.

Detector positions

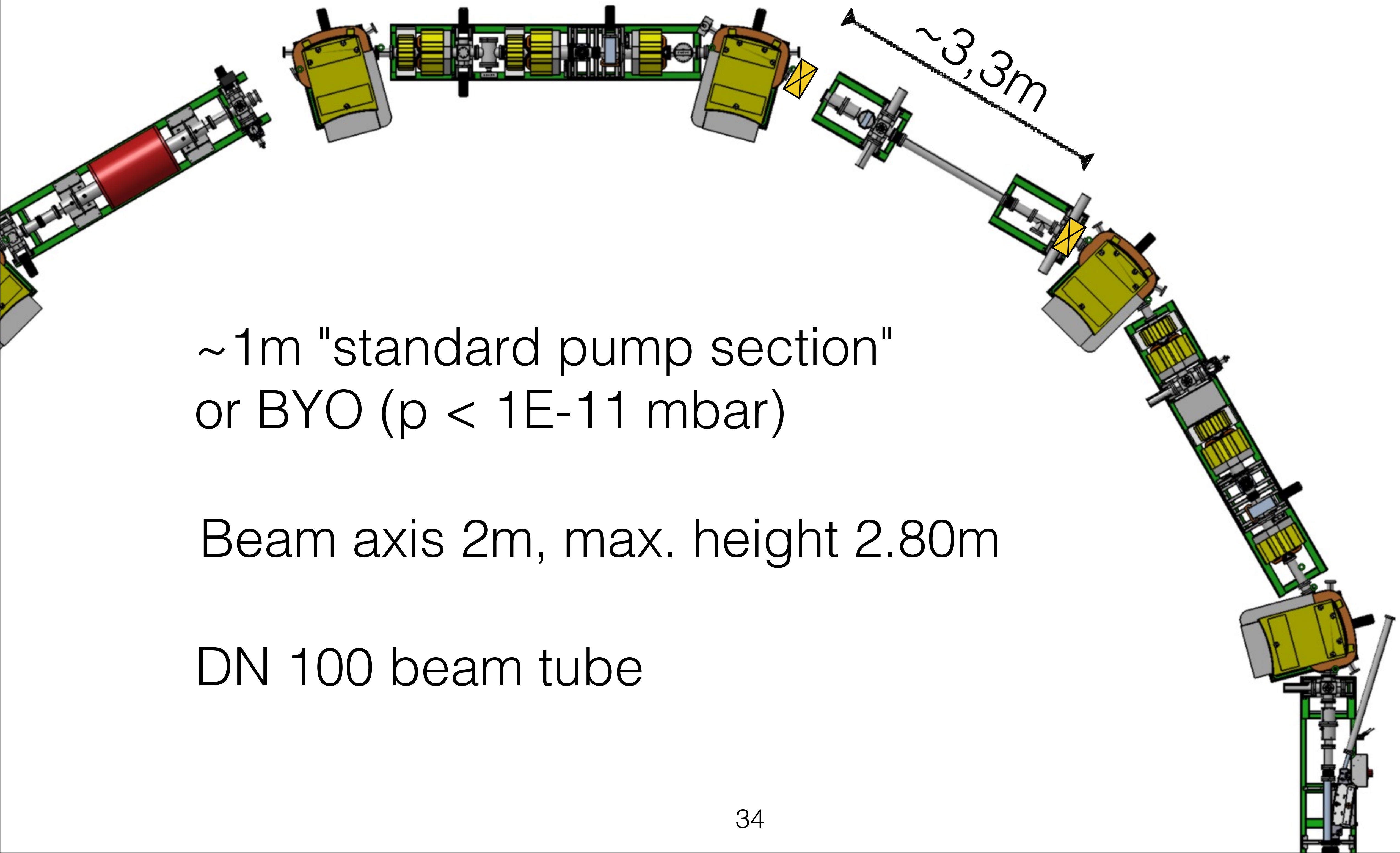


Detector positions



Detector types: segmented surface barrier detectors, scintillators, diamond-detectors. Must be UHV capable, no pockets!

Experiment section



~1m "standard pump section"
or BYO (p < 1E-11 mbar)

Beam axis 2m, max. height 2.80m

DN 100 beam tube

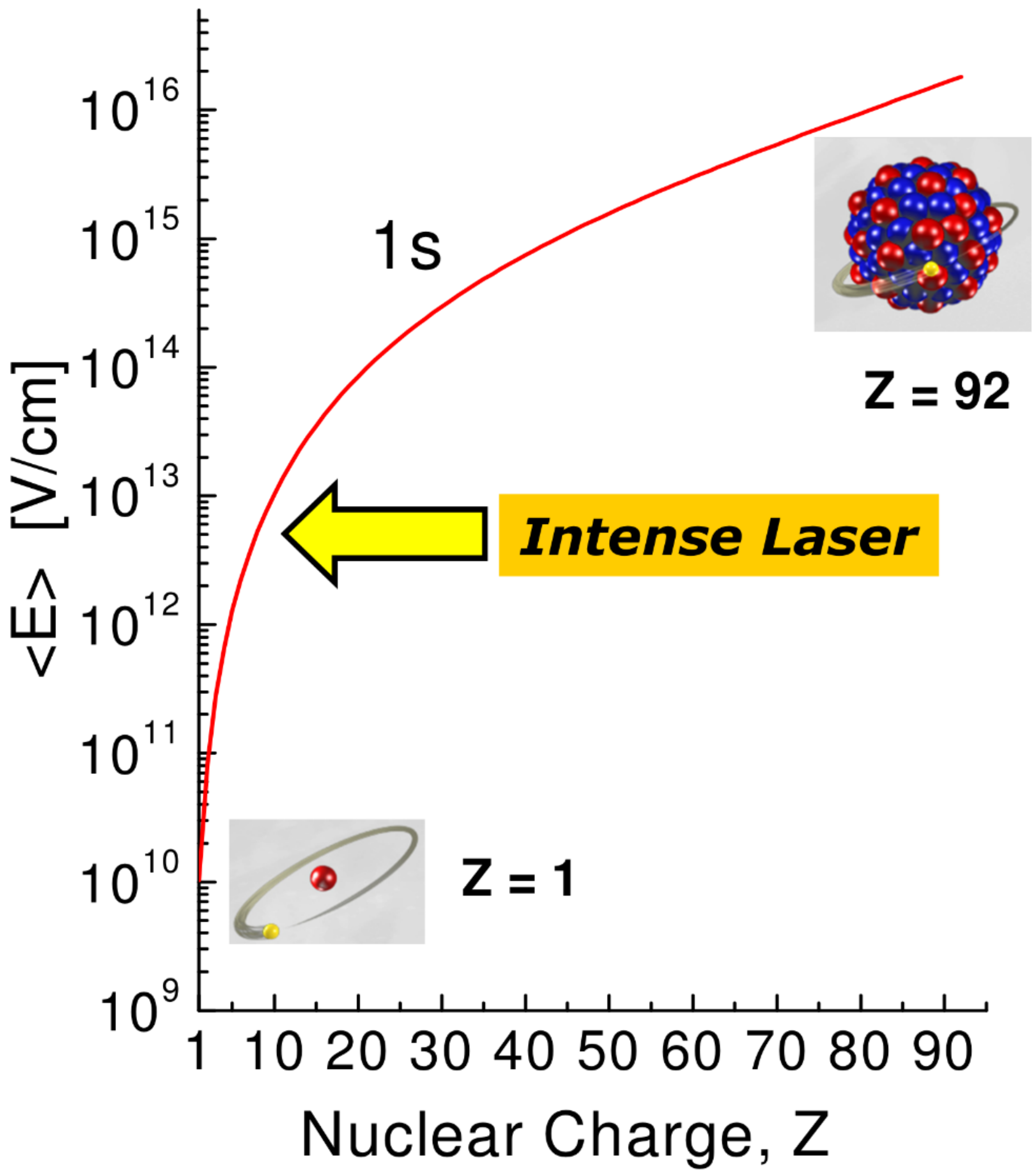
Overview of Physics book submissions

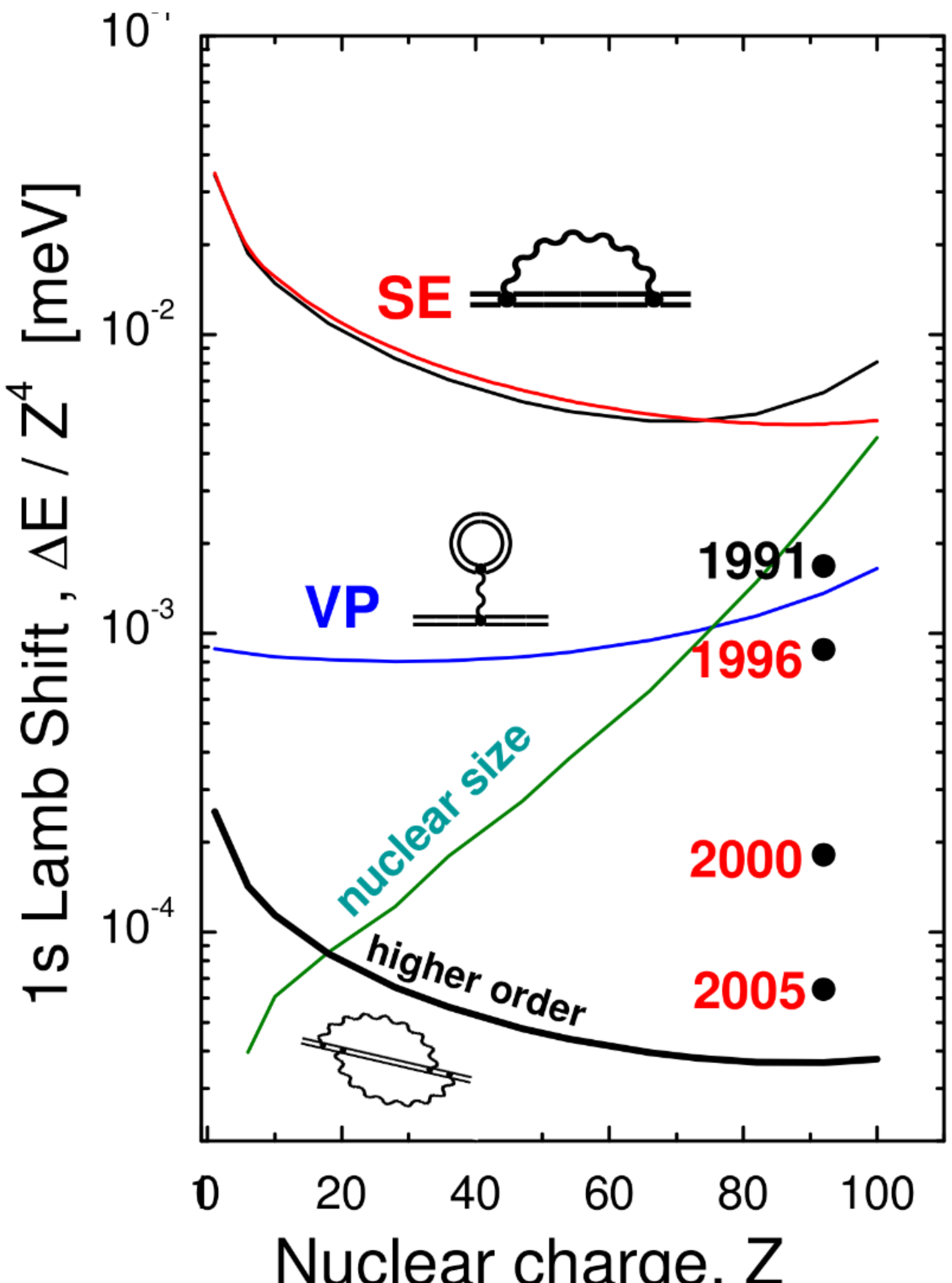
- Collision spectroscopy with electrons, atoms, and molecules
- Precision tests of modern theory in strong fields
- Atomic processes, reaction dynamics, and lifetimes
- Laser-Plasma interactions
- Nuclear Physics at low-energies
  - Exotic nuclear decay modes
  - Transfer reactions at Coulomb barrier
  - Astrophysical capture reactions

So far: 63 Contributors, 24 Institutions, 11 Countries

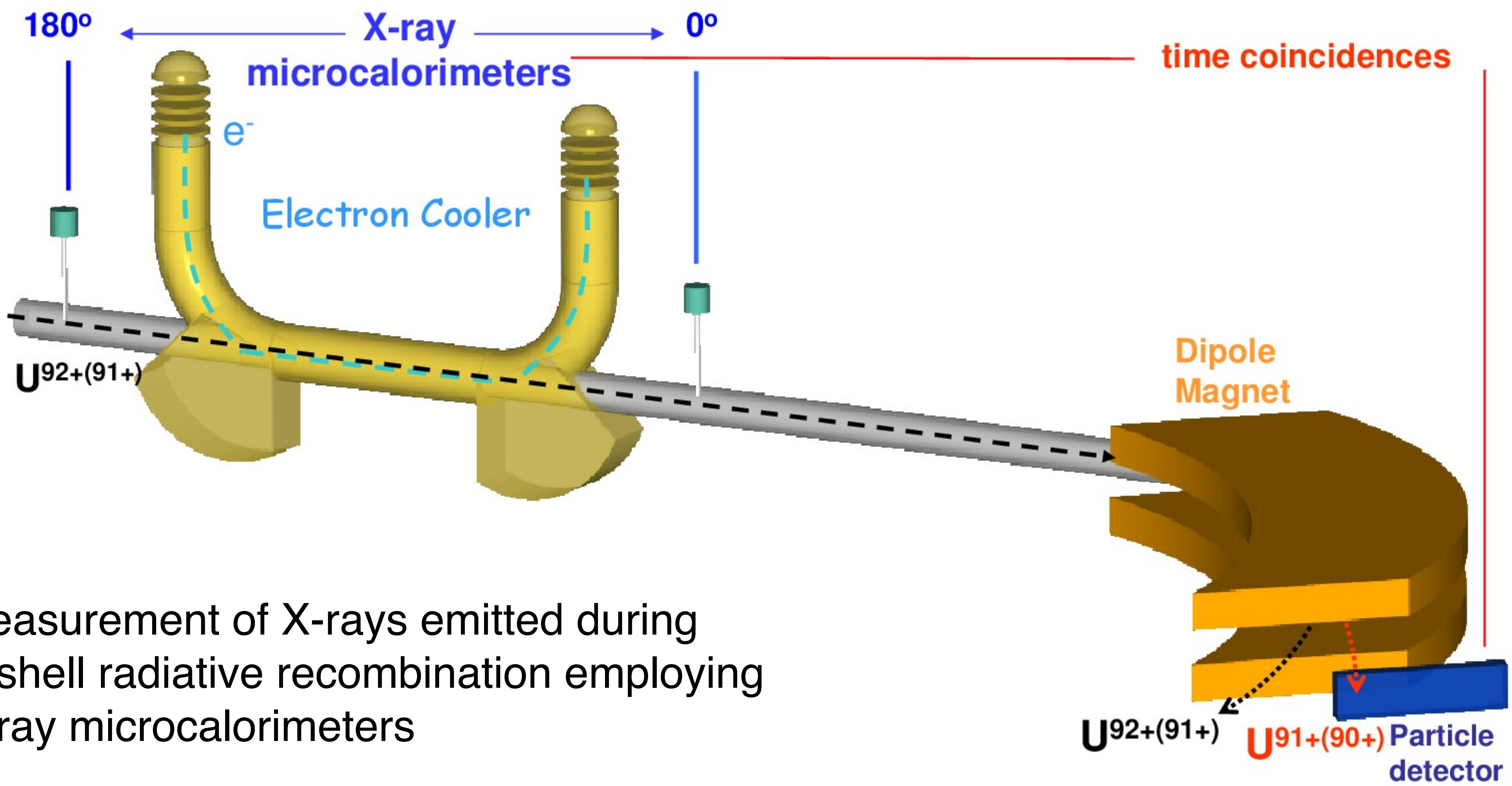
GSI

Atomic Physics with HCI





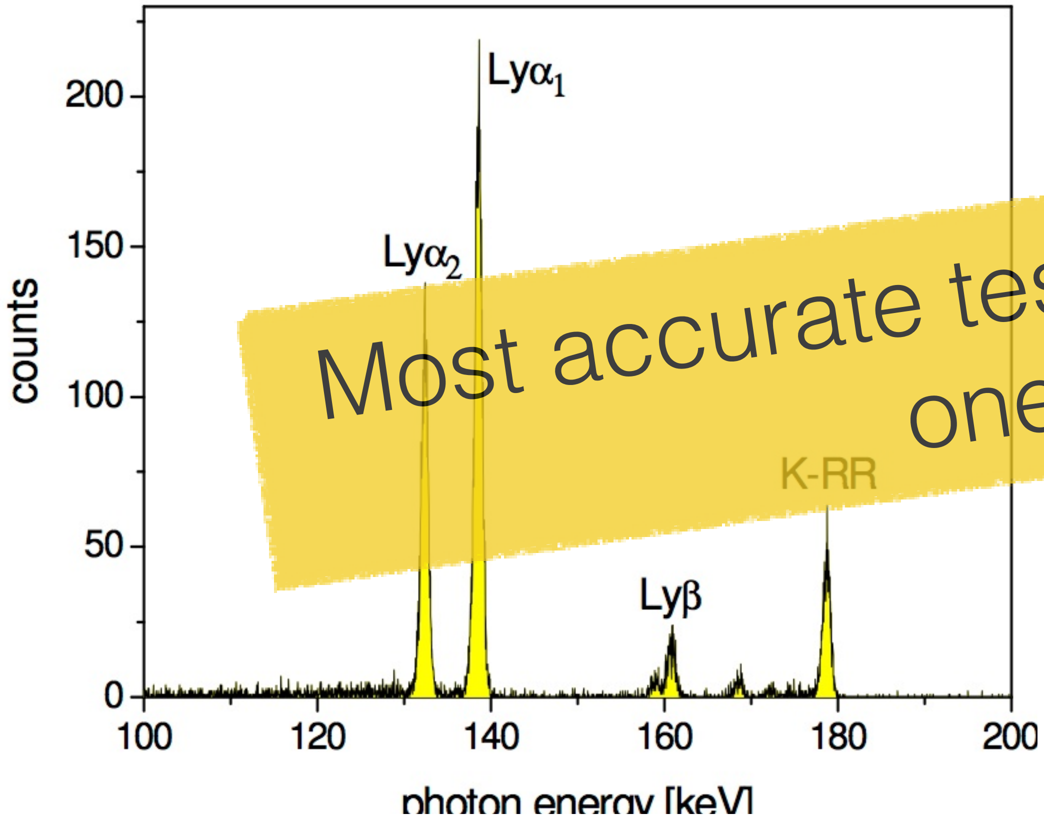
Strong Field QED in Helium-like Ions

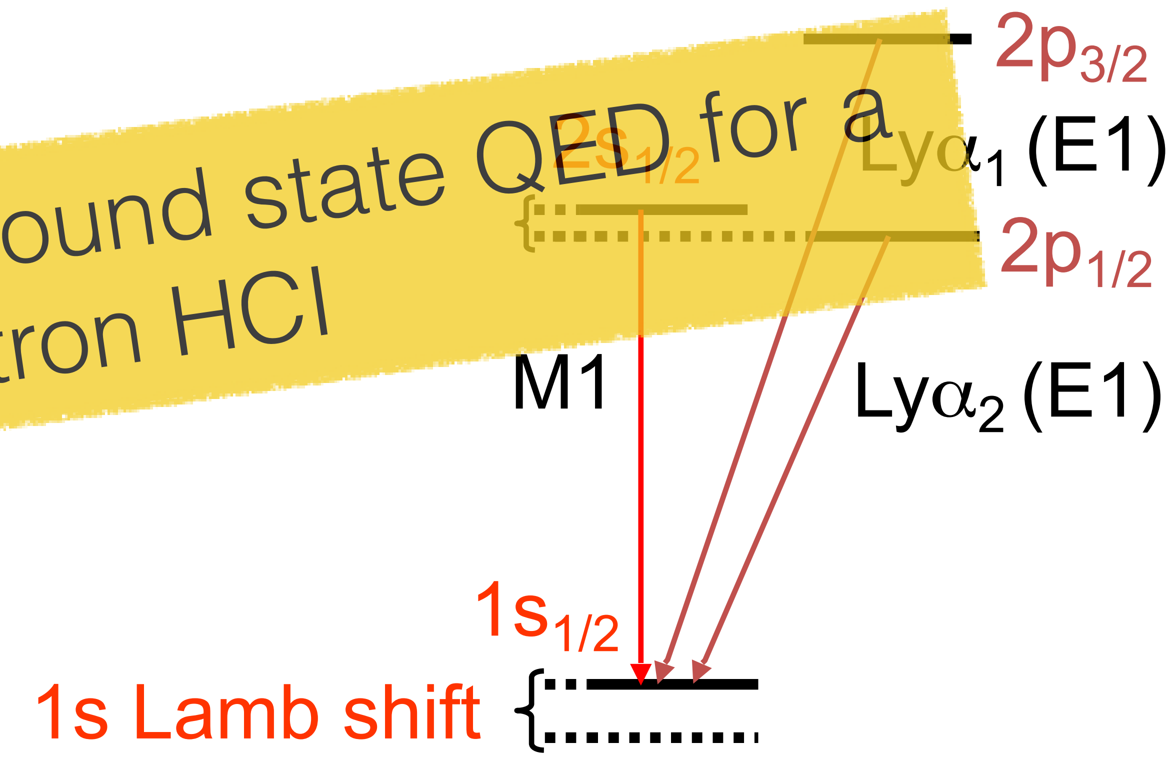


Measurement of X-rays emitted during K-shell radiative recombination employing X-ray microcalorimeters

Accurate measurements of binding energies of K-electron in H- and He-like ions (<1 eV) → highest sensitivity to high-order QED corrections

1s Lambshift in H-like Uranium





Most accurate test of bound state QED for a one-electron HCI

1s-Lamb Shift:

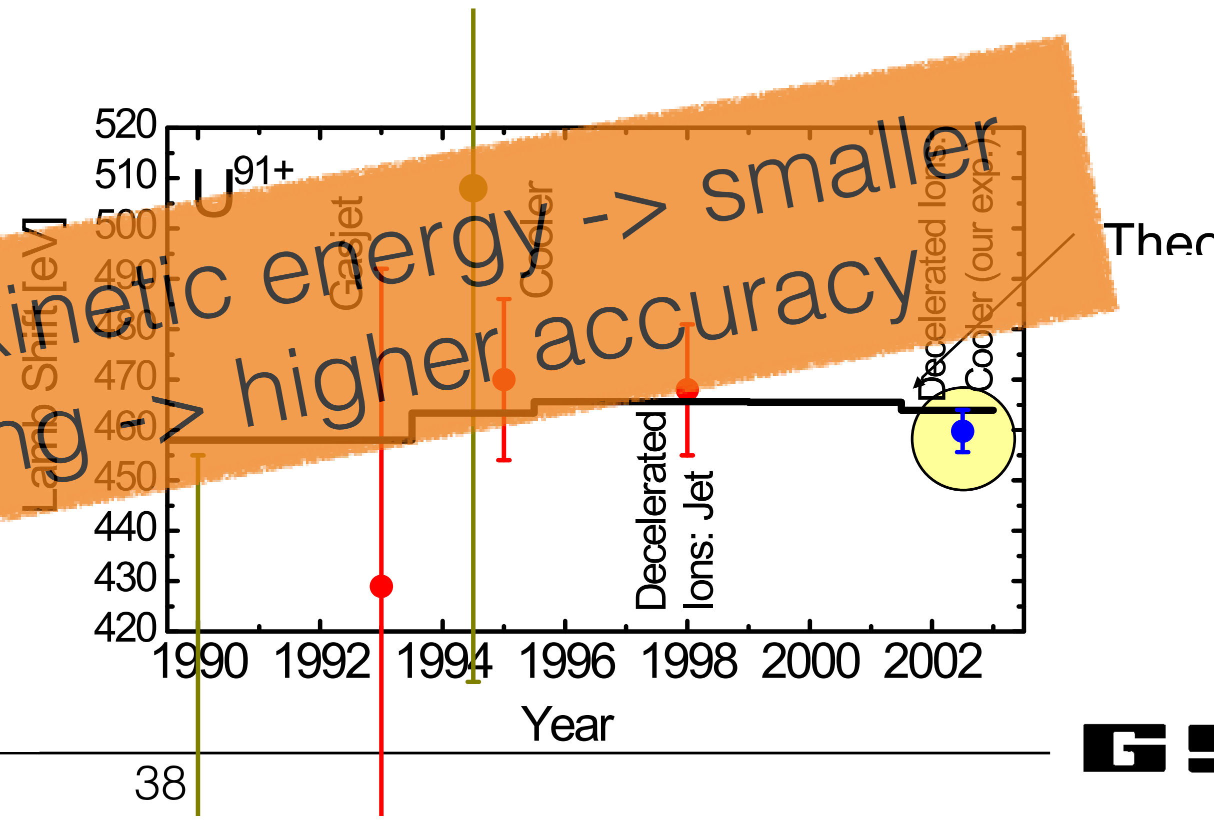
Experiment: 459.8 eV ± 4.6 eV

Theory: 463.95 eV

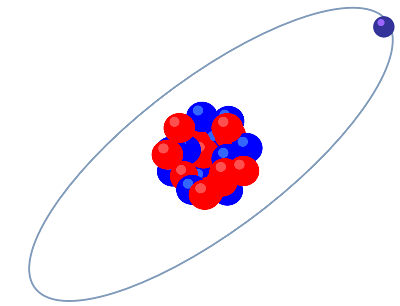
At CRYRING: lower kinetic energy -> smaller doppler broadening -> higher accuracy

A. Gumberidze
PRL 94, 223001
(2005)

Research Highlights
Nature **435**, 858-859
(16 June 2005)



Towards Supercritical Fields



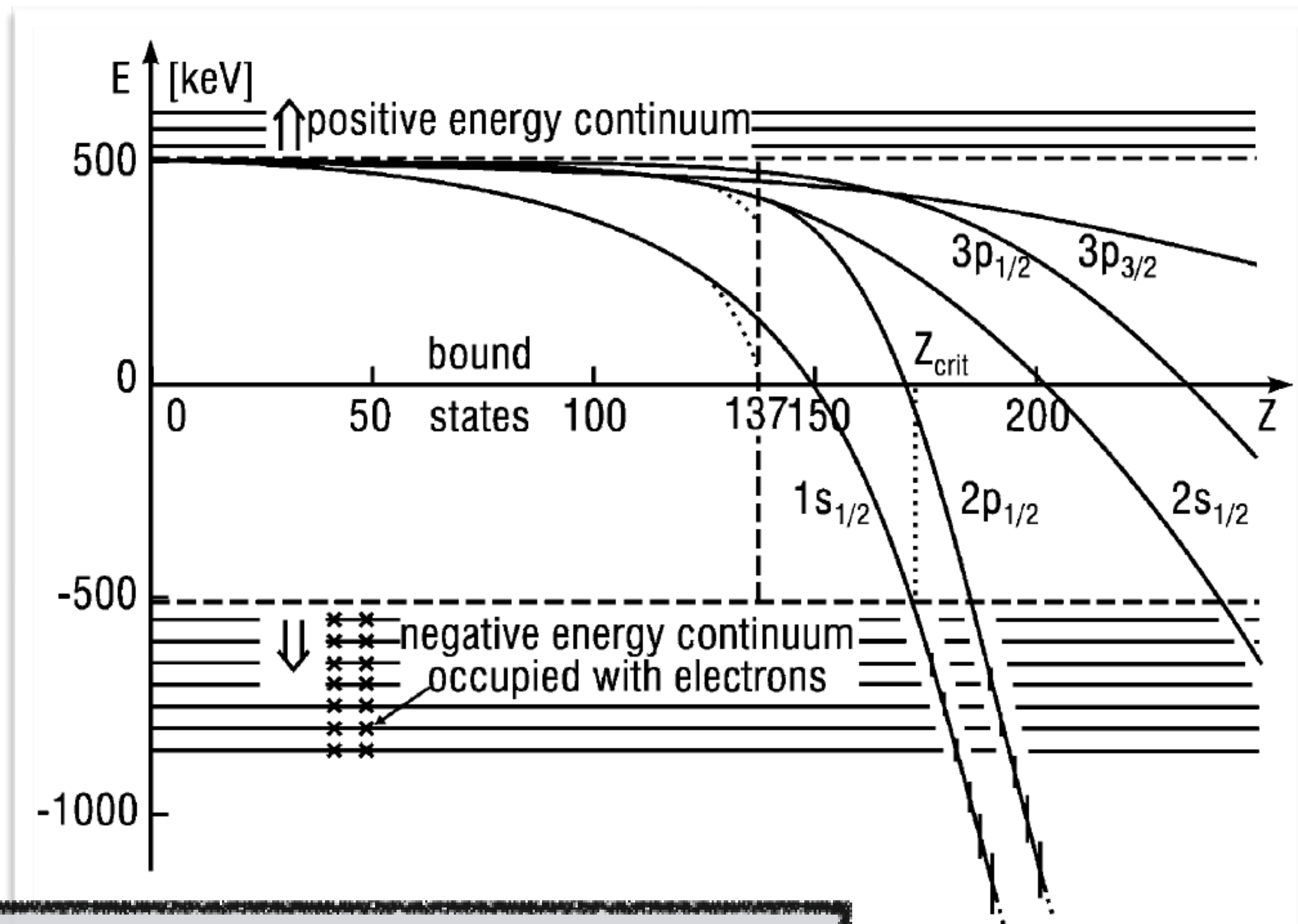
- Dirac energy of a single hydrogen-like electron:

$$E_{1s} = mc^2\sqrt{1-(Z\alpha)^2}$$

- What happens if we increase the nuclear charge Z?

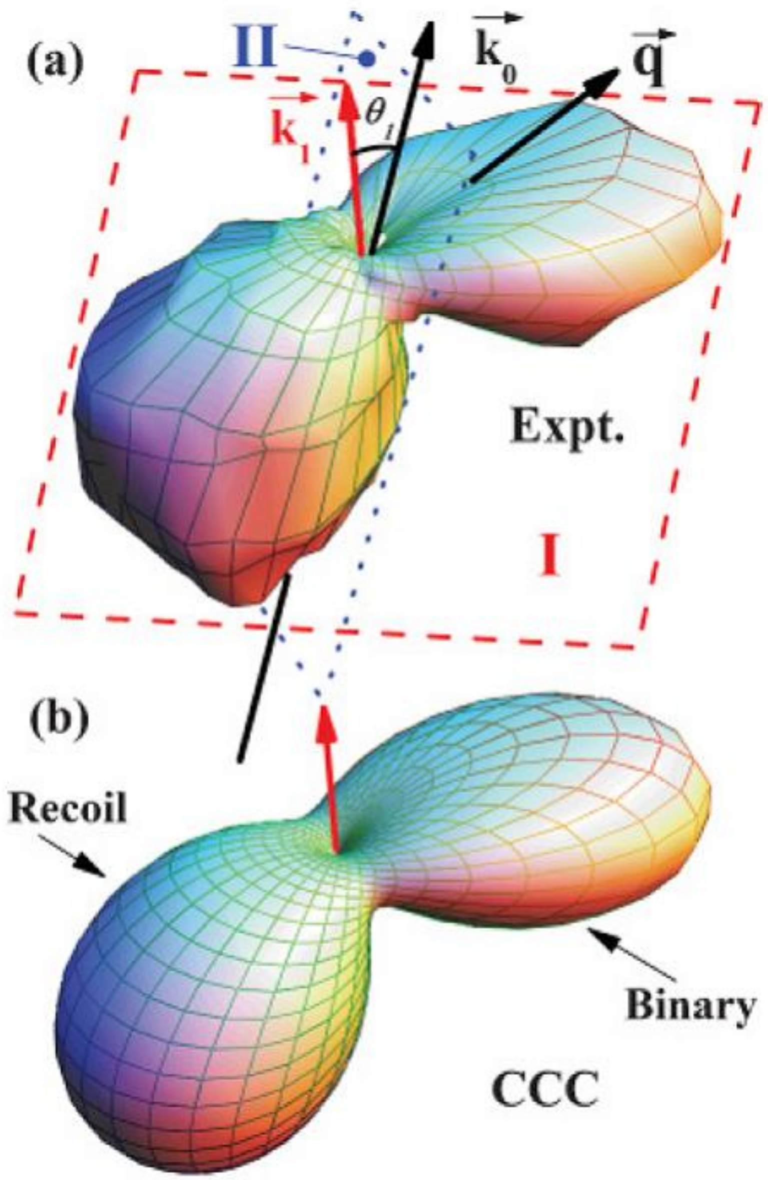
- If nuclear charge of the ion is greater than Z_{crit} the ionic levels can “dive” into Dirac’s negative continuum.

- Physical vacuum becomes unstable: creation of pairs may take place!



With CRYRING: slow collisions, K-shell vacancies, symmetric systems

Electron Spectroscopy



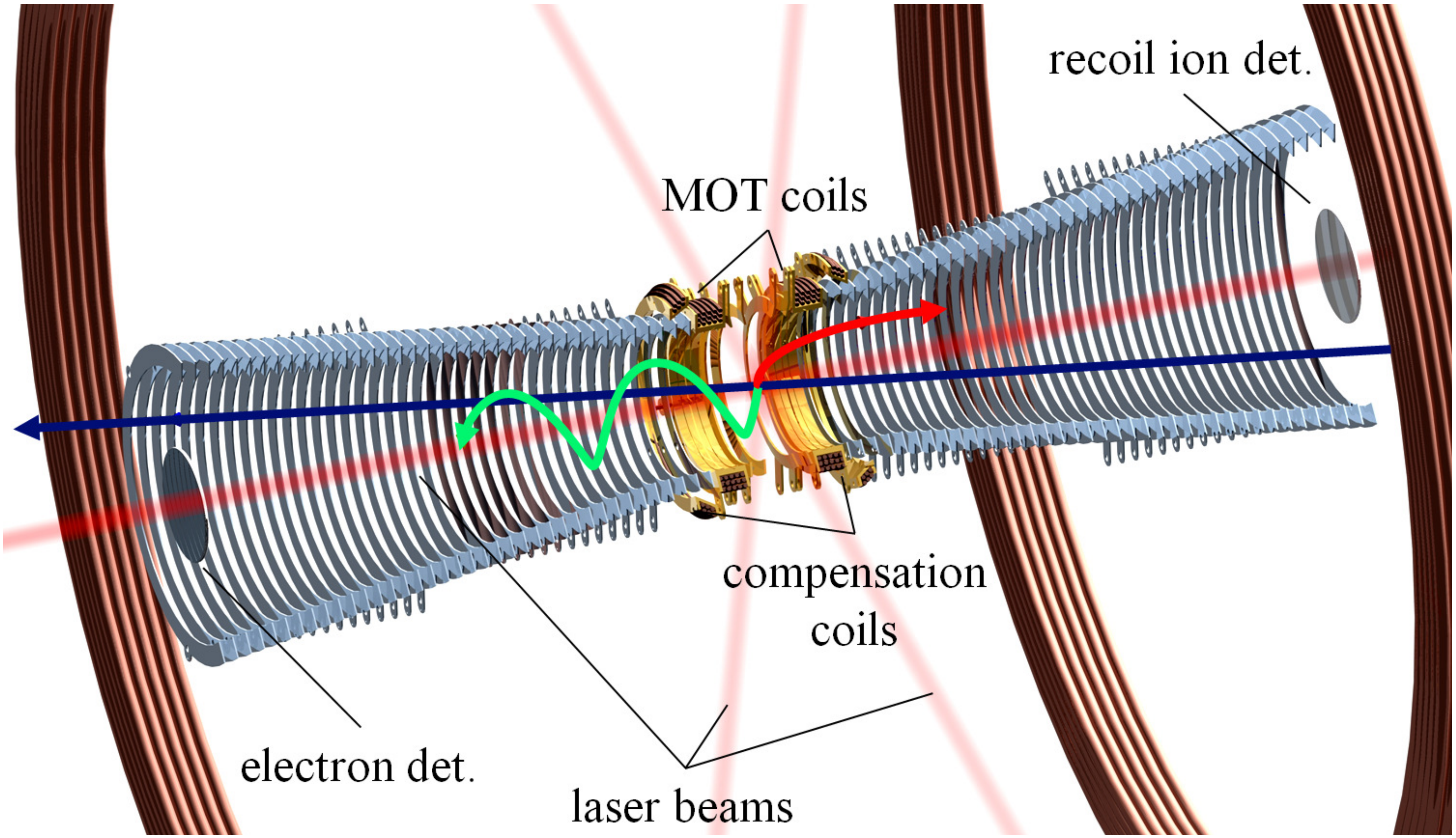
- Ion-Atom collisions in a gas target
- With CRYRING: Slow ions: non-adiabatic collision regime
- Detection of electron and recoiled atoms

Processes:

- Inelastic electron scattering in inverse kinematics
- Radiative electron capture to the continuum (RECC)
- High-energy end of electron-nucleus bremsstrahlung
- Atomic fragmentation

MOTReMi

A novel momentum imaging spectrometer: MOT Reaction Microscope

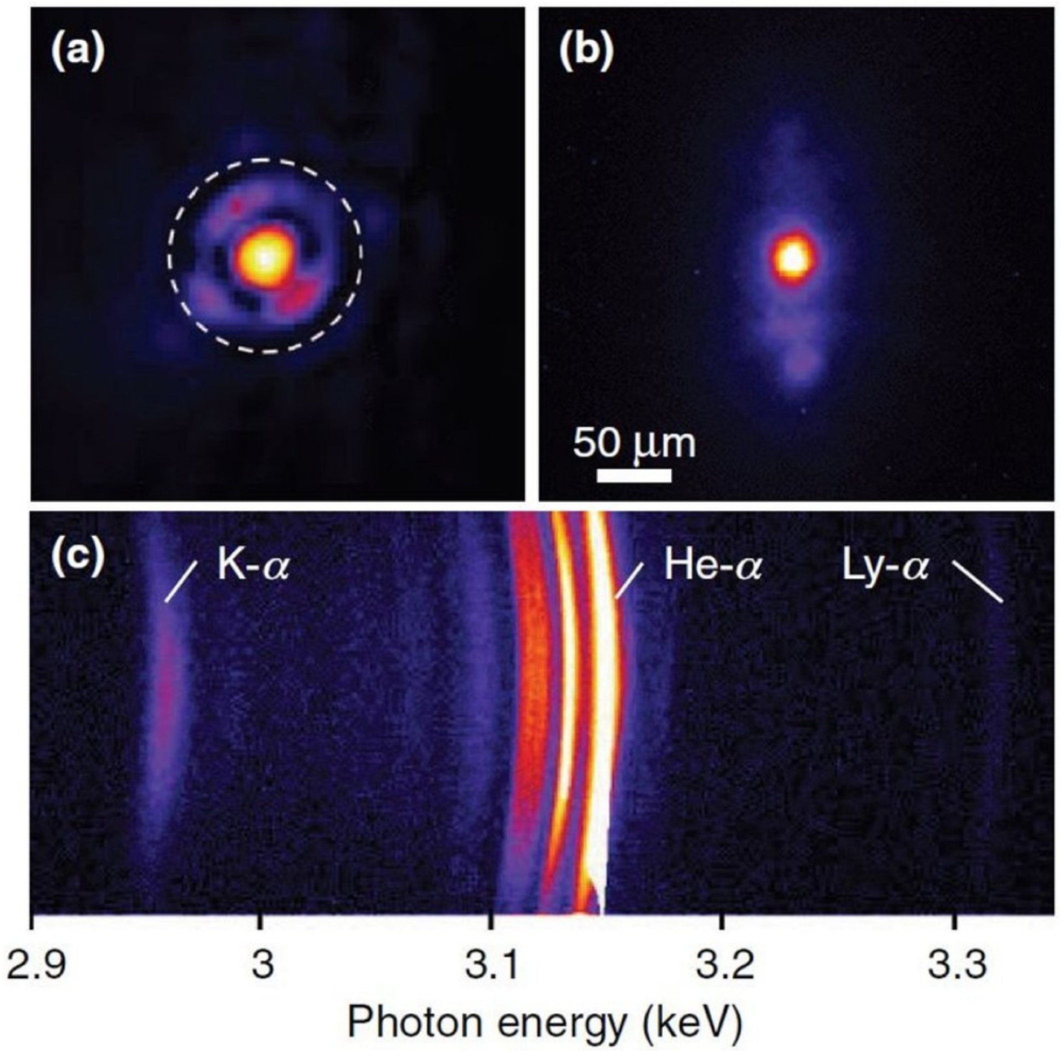


- Structure of HCI
- Dynamics of scattering and fragmentation processes

D. Fischer, et al.

Laserplasma-HCI Interactions

Probing WDM: Laser-heated microdoplets with HCI



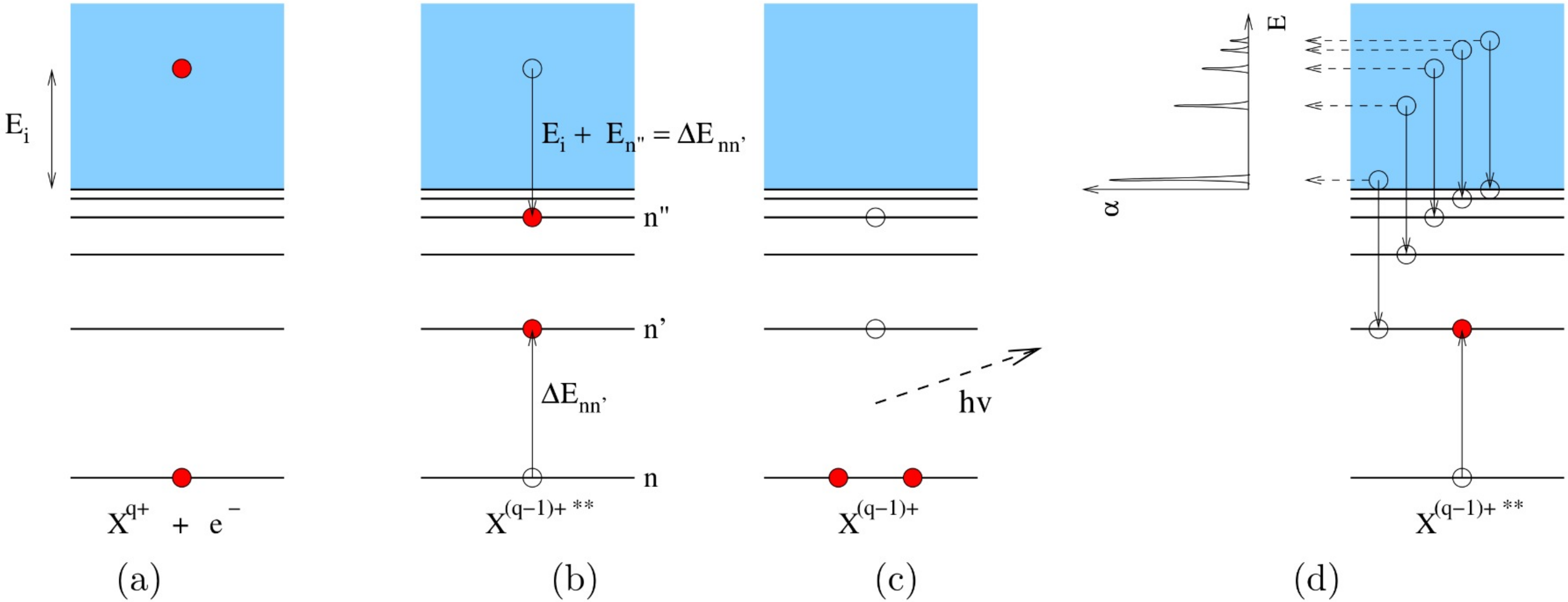
e.g. charge exchange and X-rays of projectile HCI yields information on collective effects in WDM:

- lowering of ionization potential
- energy structure and band structure

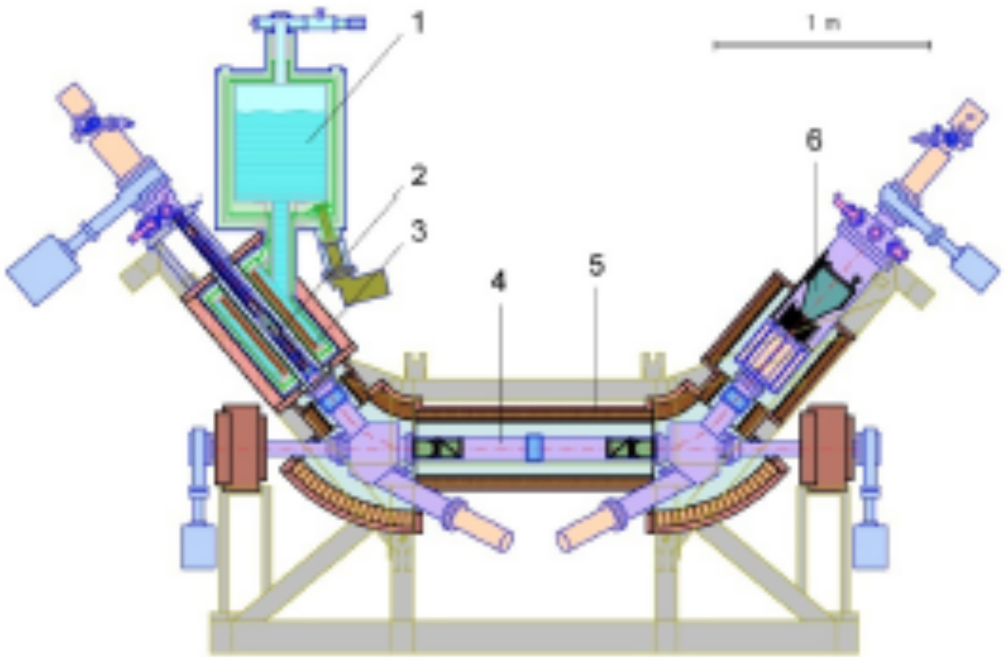
Figure 2.16. (a) Focal laser intensity distribution. The dashed circle indicates the 21 μm diameter argon droplet.
(b) Time-integrated XUV image of the droplet's thermal emission. The laser pulse comes from the left.
(c) X-ray emission spectrum showing the strong argon K-α and He-α transition lines. The K-shell transitions in intermediate charge state argon ions are visible as satellites between the K-α and Heα line

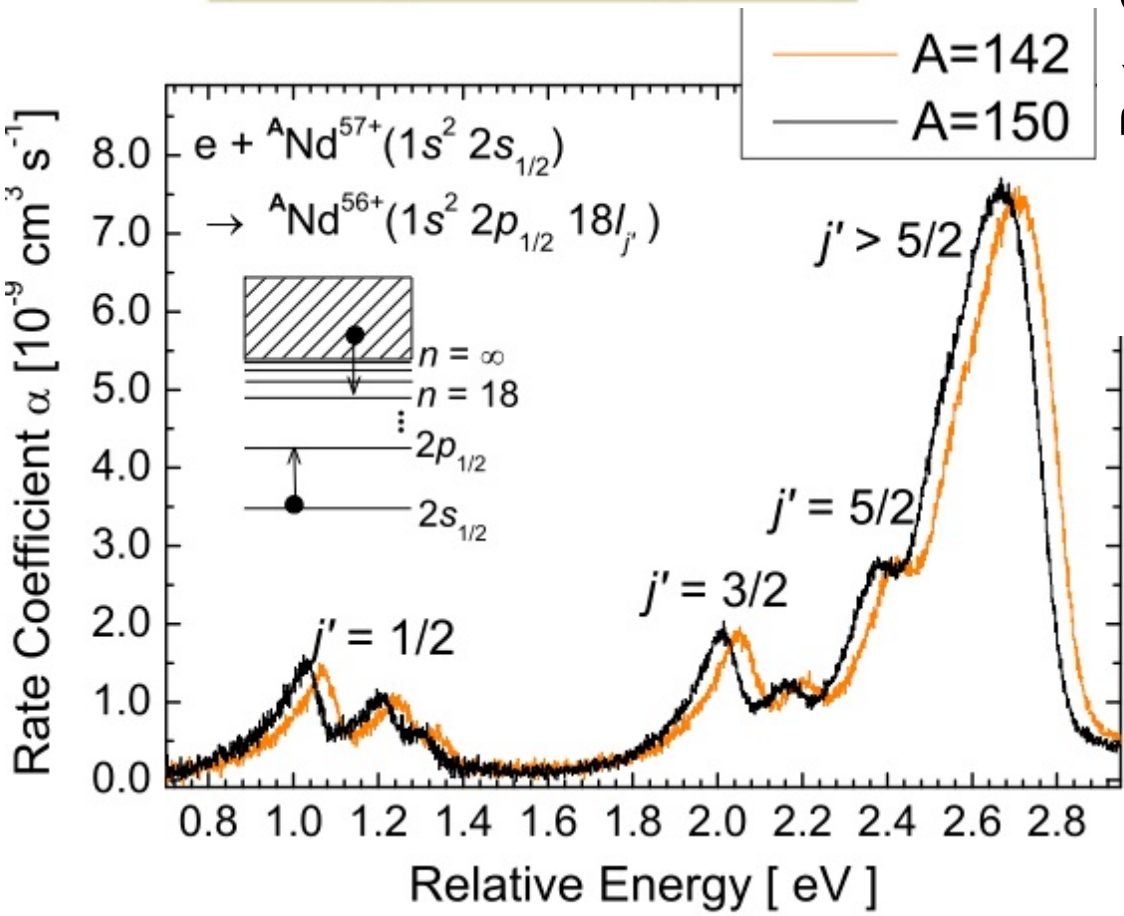
Costa Fraga, et al., 2012

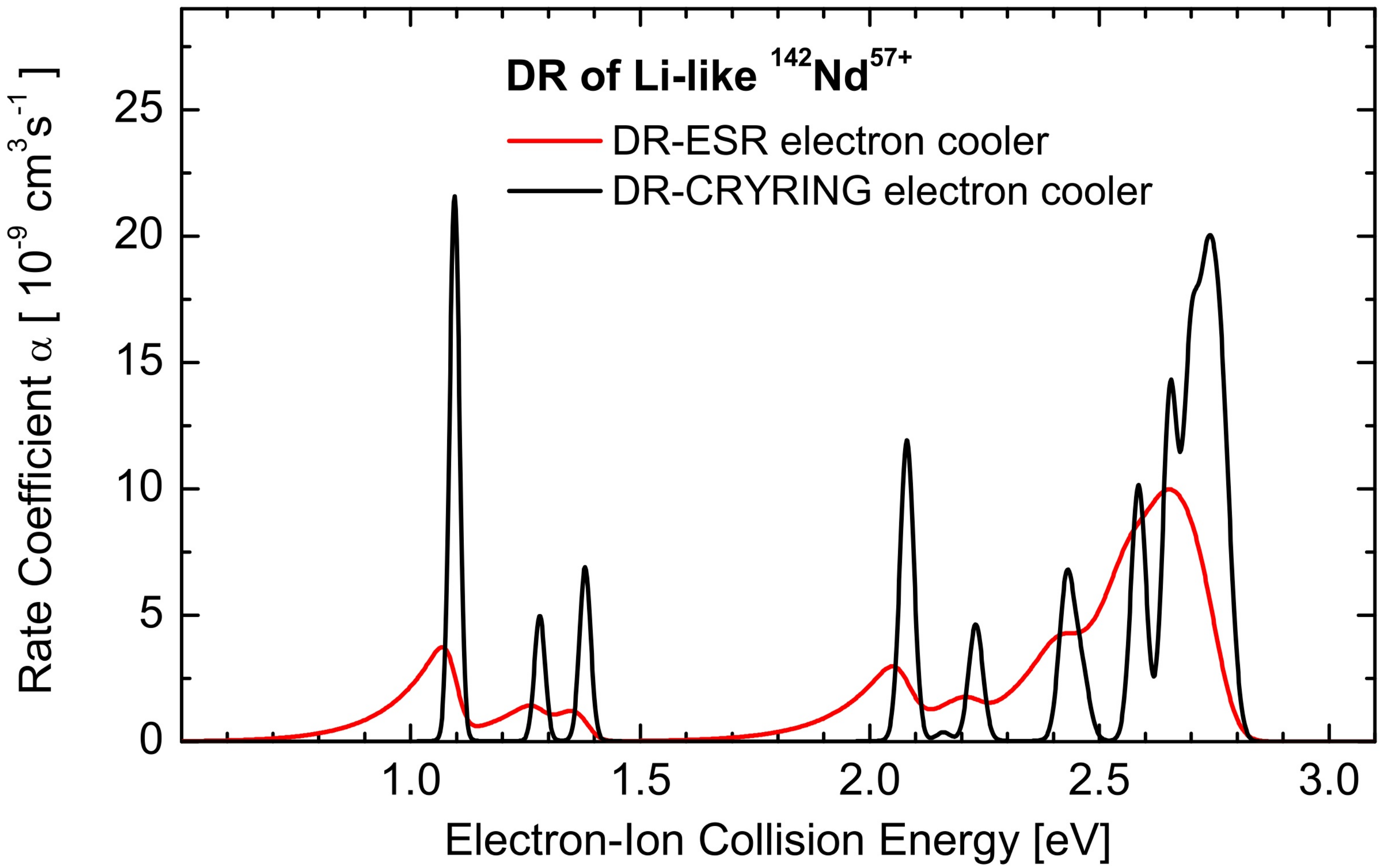
Dielectronic recombination



Electron Collisions

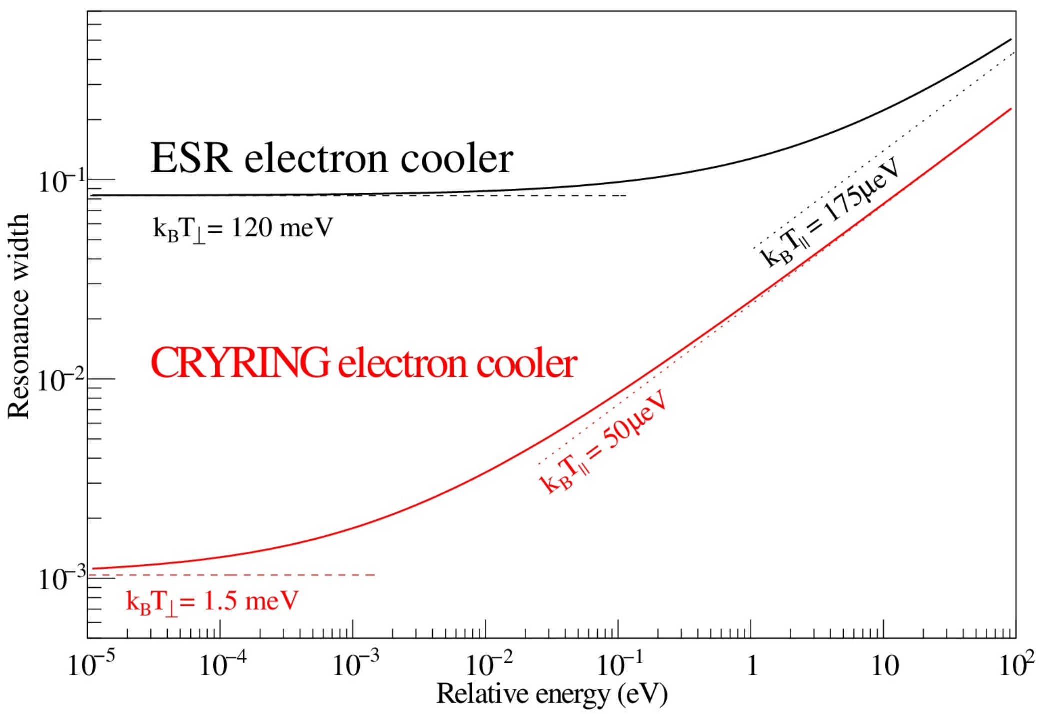




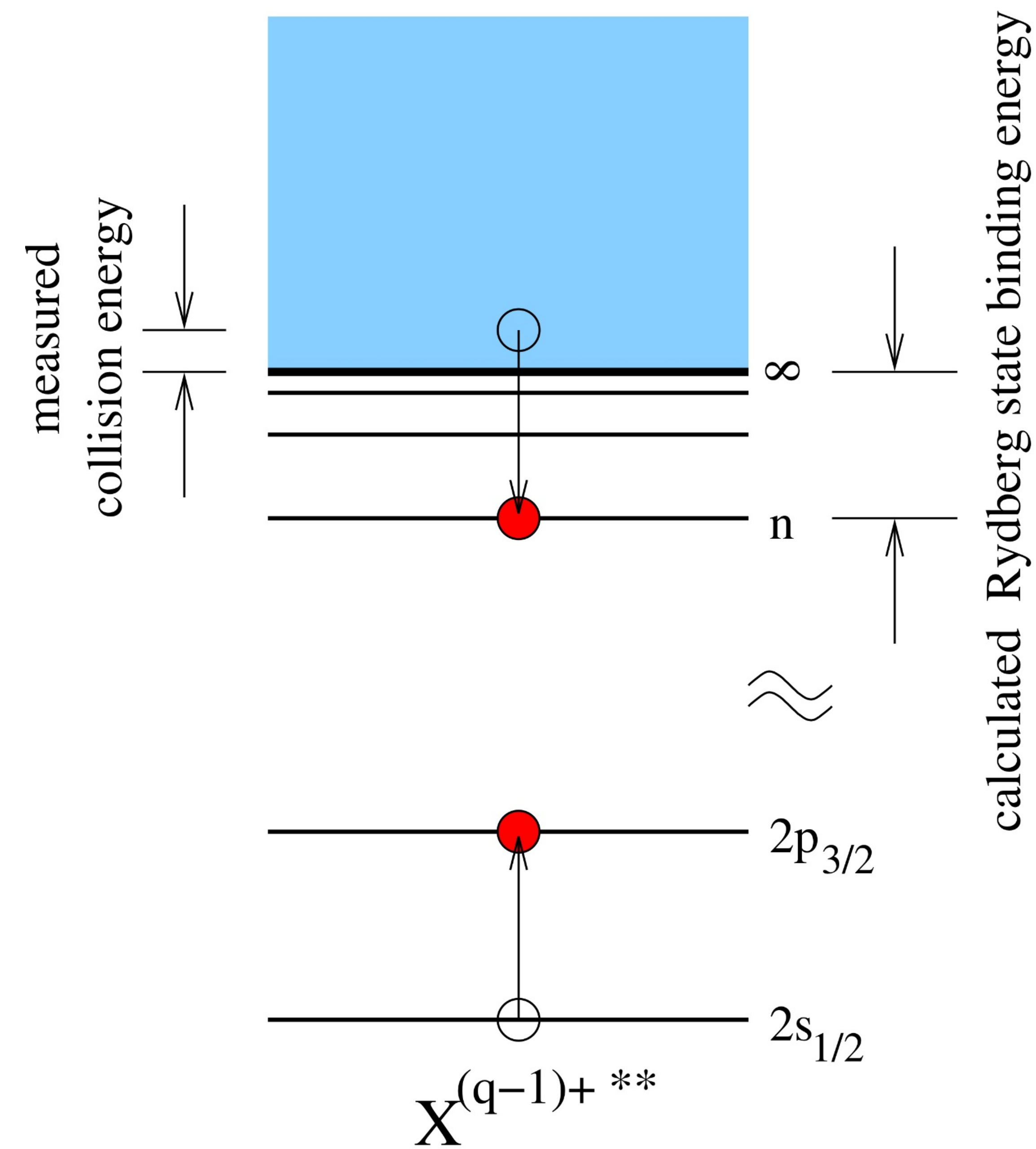


C. Brandau, et al.,
PRL 100, 073201
(2008)

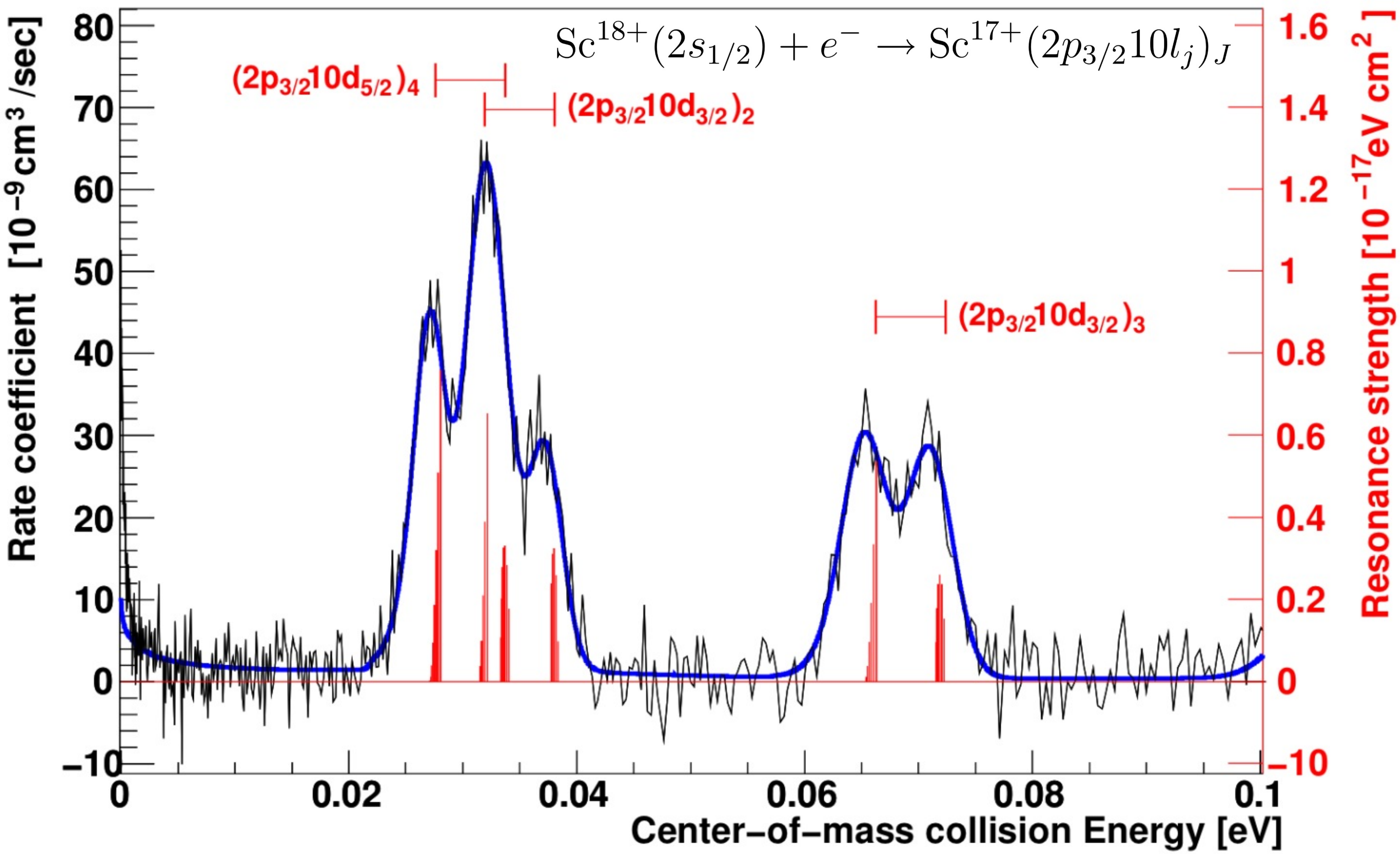
"Near-0" DR



Resolution and precision is highest at "near-zero" relative energies



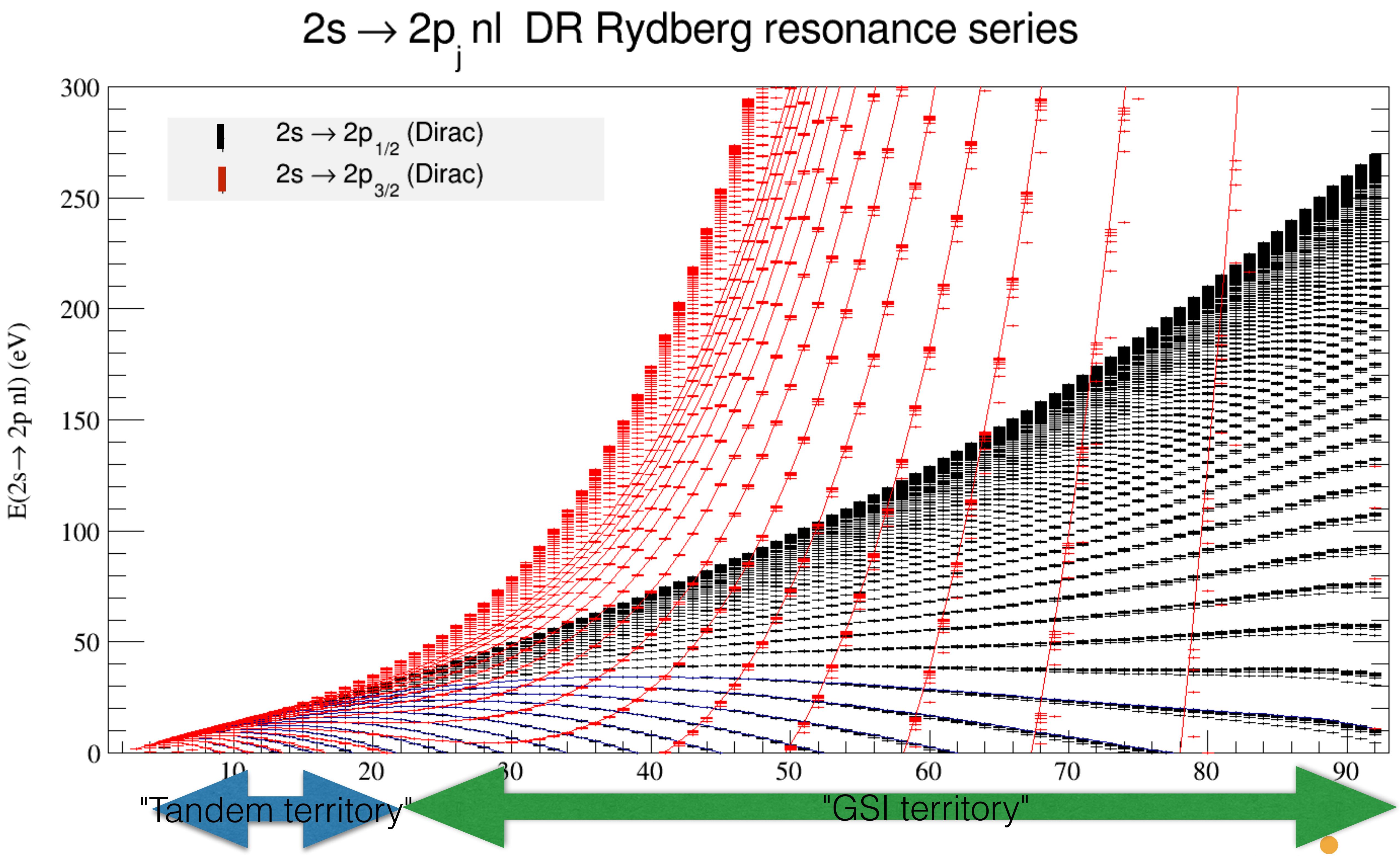
Precision DR



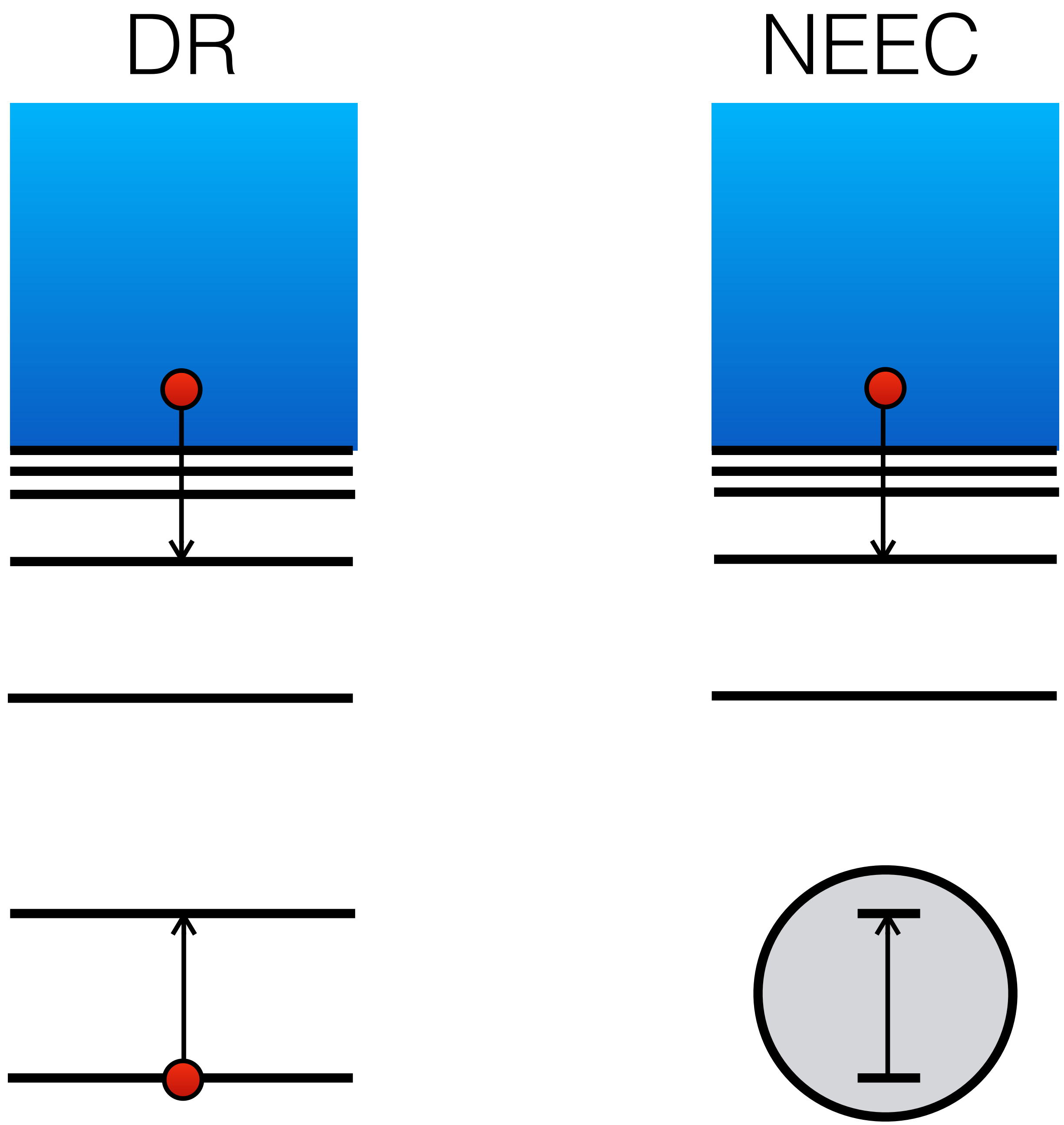
$$E^{\text{expt}}(2s_{1/2} - 2p_{3/2}) = 44.30942(12)(14)$$

Lestinsky, et al., PRL **100**, 033001, (2008)

DR Candidates: Li-like Ions:



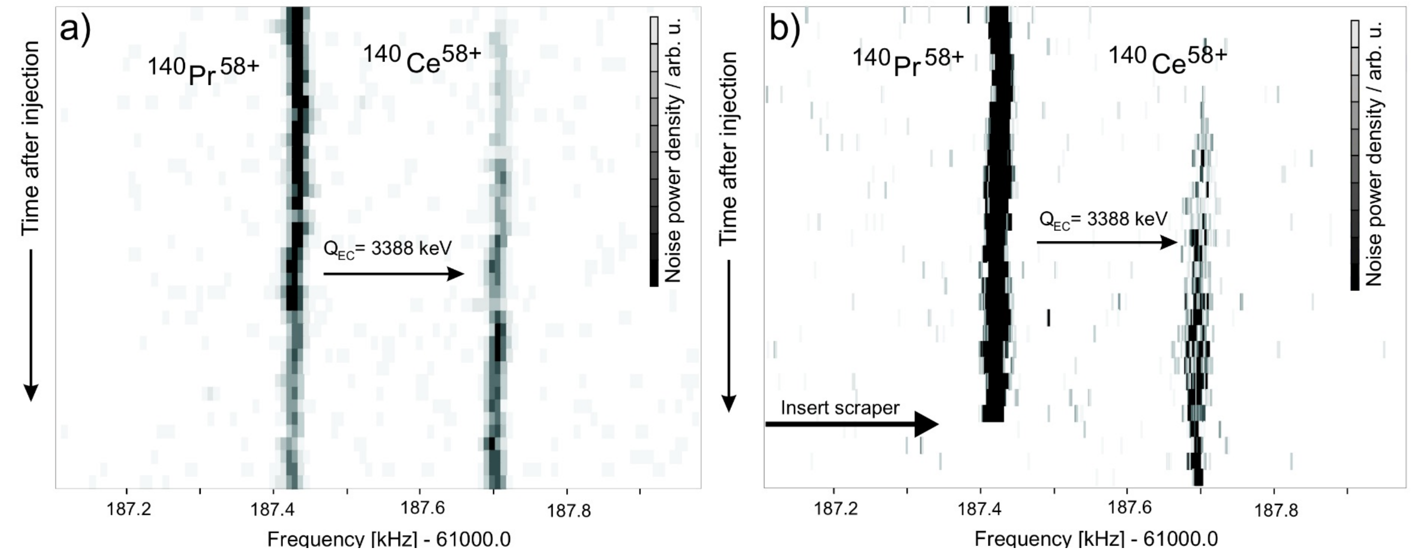
The search for NEEC



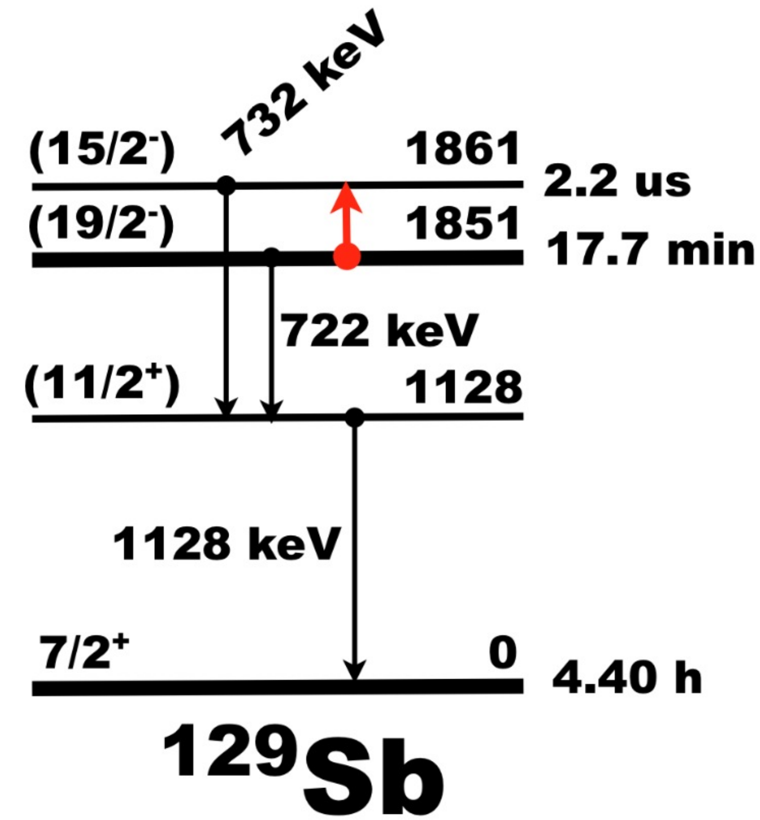
- Fundamentally, this process should exist
- But: Theoretical cross sections small
- Traditional "DR"-Setups in unpromising conditions

The search for NEEC: experimental proposal

- Production of bare $^{129g,m}Sb$ in FRS
- Purification in ESR using scrapers
- Decelerate almost to rest in CRYRING
- At very low energy, implant on solid target
- Bulk provides large electron density -> electron capture -> NEEC
- Observe 732 keV X-rays as "smoking gun"



10 keV NEEC {



Nuclear astrophysics

Nucleosynthesis of proton-rich nuclei beyond iron
Only few experimental data for relevant energy range (Gamow window) in *p*-process

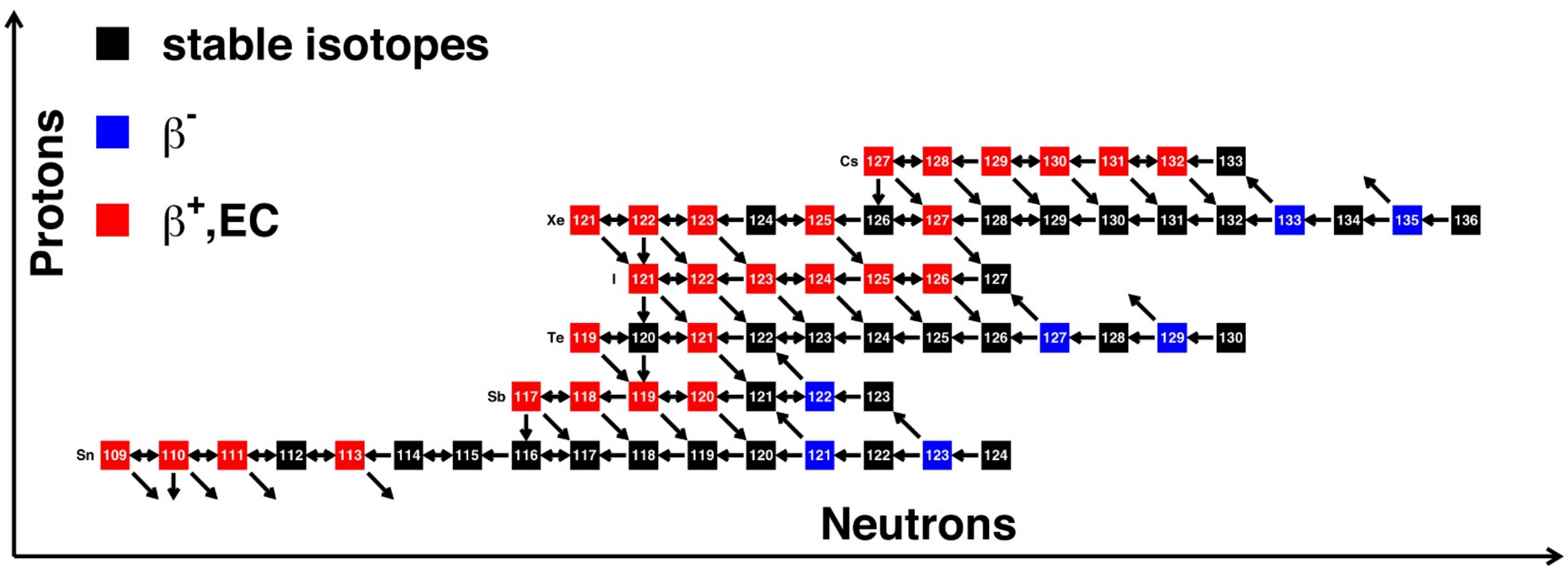


Figure 4.1. Reaction network during the *p*-process nucleosynthesis between Sn and Cs for $T_9 = 2.4$. The *p*-process network is dominated by (γ,n) reactions. Other reactions are shown, if they are dominating. See (Arnould and Goriely, 2003) for more details.

Nuclear astrophysics

Nova (p, γ) reactions

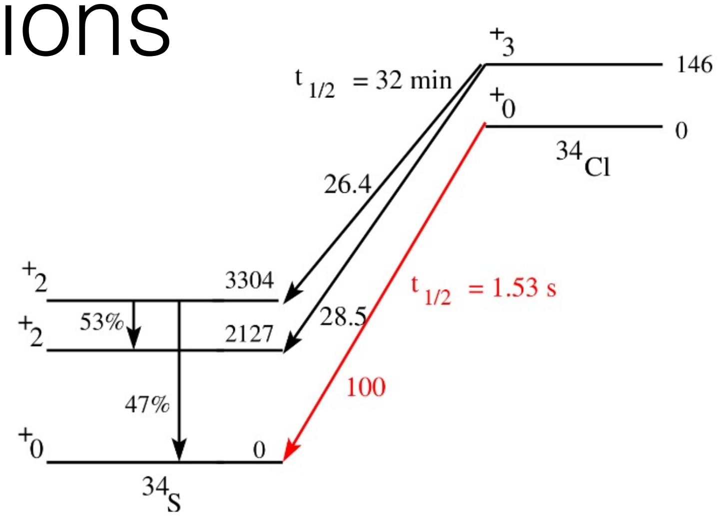


Figure 4.2. β-decay scheme for ^{34}Cl (Firestone, 1996). The ^{34m}Cl isomeric state at 146 keV decays into excited states of ^{34}S producing three γ-rays of astronomical interest. β-decay branchings are given as percentages.

^{34}Cl is a stellar thermometer

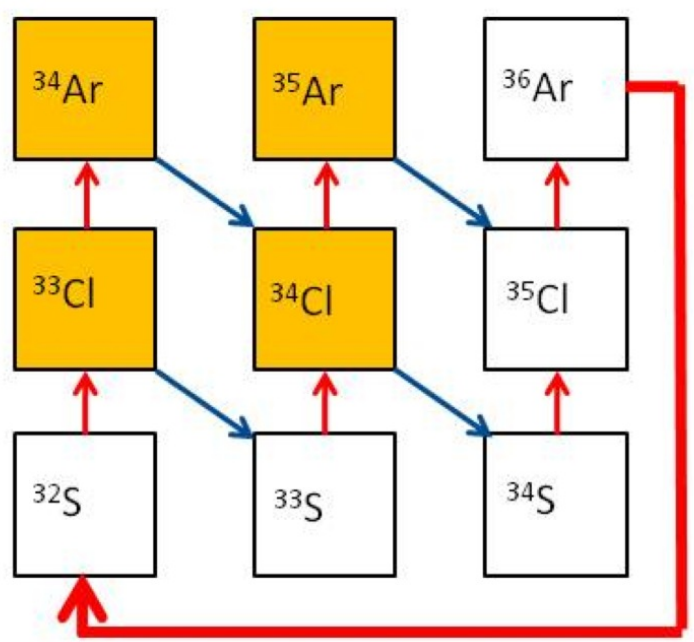


Figure 4.3. The S-Cl burning cycle. β-decays are depicted with blue arrows and (p, γ) reactions are depicted with vertical red arrows. The cyclic nature is depicted by the thick outer red arrow for the (p, α) reaction on ^{35}Cl. ^{34}Cl is the relevant γ-ray emitters.

... and beyond?

- Biology and Biophysics
  - Interactions with slow, extracted HCI (e.g. single cell - single ion?)
  - Biomolecules in ion collisions: Fragmentation pattern and emission characteristics of building blocks of DNA...
- Materials science
- HCI-Surface interactions

Project Status Summary

CRYRING is in Darmstadt.

New Cave B is almost ready for installation. Now: waiting for electricity / light.

Set up will shortly begin, expected commissioning in 2014, baking and beam operation / experiments in 2015.

Still, substantial efforts by GSI and experienced MSL staff required to get back into operation (repairs, modernization, documentation)

Experimental instrumentation needs to be spec'd out (and financed!)

Research Summary

We can do lots of science with CRYRING@ESR:

- Atomic structure and atomic processes
- Nuclear structure, astrophysically relevant rates, (p,γ), (α,γ), nuclear collisions at the Coulomb barrier
- Intersections of atomic and nuclear physics (nuclear magnetic moments, isotope shifts and charge radii, NEEC...)
- Biology, biophysics?
- HCI and surfaces/bulk material?

} already with present GSI accelerators

- pbar, exotic beams, FLAIR

} with FAIR

Acknowledgements

Project team: F. Herfurth, ML, A. Bräuning-Demian, R. Bär, H. Danared, C. Dimopoulou, O. Dolinskyy, W. Enders, M. Engström, S. Fedotova, B. Franzke, M. Frey, O. Gorda, L. Heyl, P. Hülsmann, A. Källberg, Th. Köhler, S. Litvinov, Y. Litvinov, J. Mohr, I. Pschorn, A. Reiter, G. Riefert, J. Roßbach, A. Simonsson, T. Sieber, J. Sjöholm, M. Steck, Th. Stöhlker, G. Vorobjev, N. Winckler, ...

GSI, Stockholm University, KVI Groningen, HI Jena, Krakow University

Fopi: M. Kis, Y. Leifels, ...

?

Th u!

Backup slides