SPARC at FAIR:

Experimental requests for atomic physics experiments

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for the SPARC Collaboration

OUTLOOK

- What makes the FAIR facility attractive for atomic physics?

- Experimental conditions:
  - locations
  - beam parameters
  - operation modes

- Ion Stripper

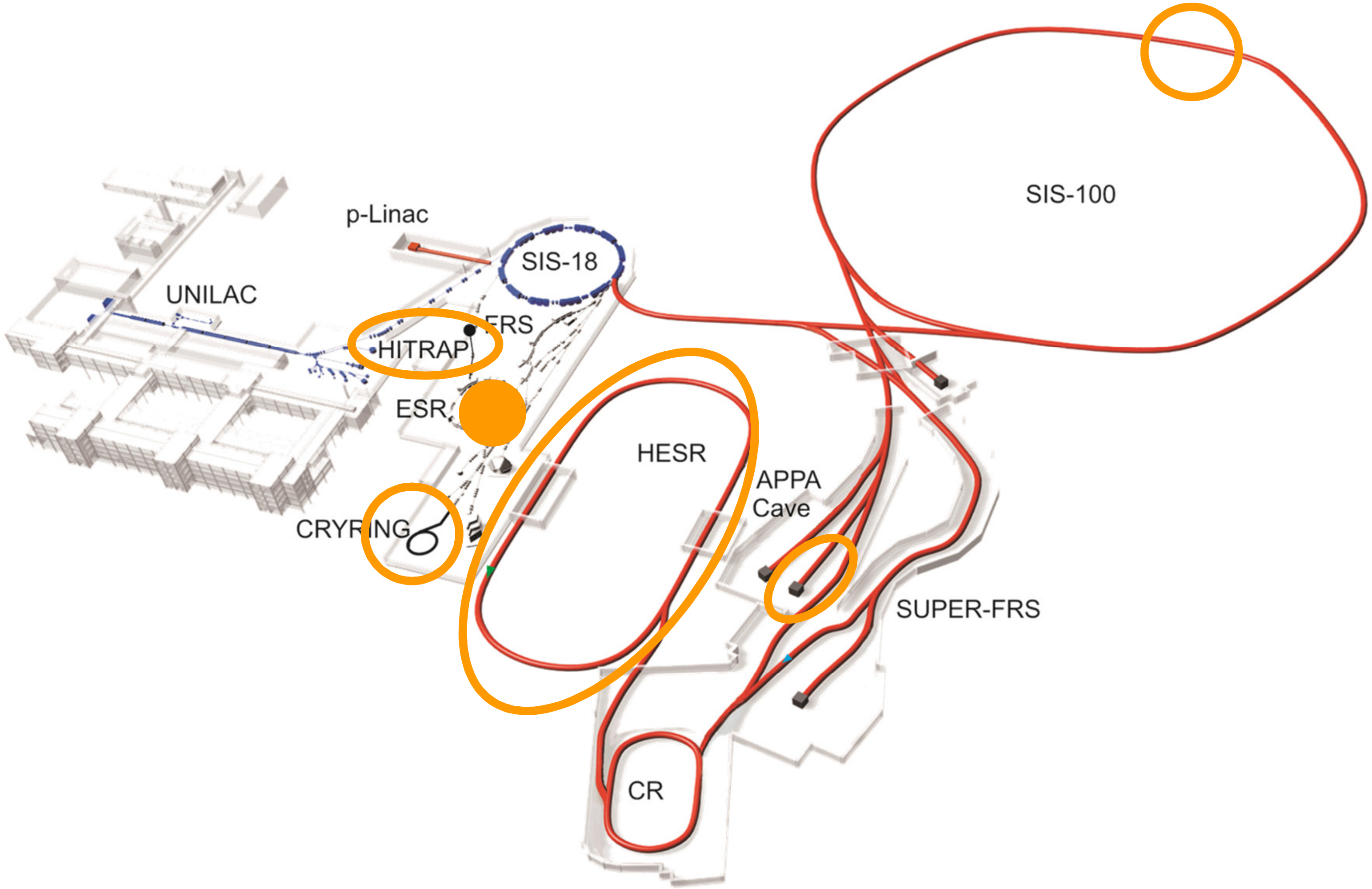
Investigate the limits!

Precision Investigations of ionic and atomic systems in high static and dynamic electromagnetic fields:

- **non-perturbative regime**
- **correlated many-body dynamics**
- **precision determination of fundamental constants**

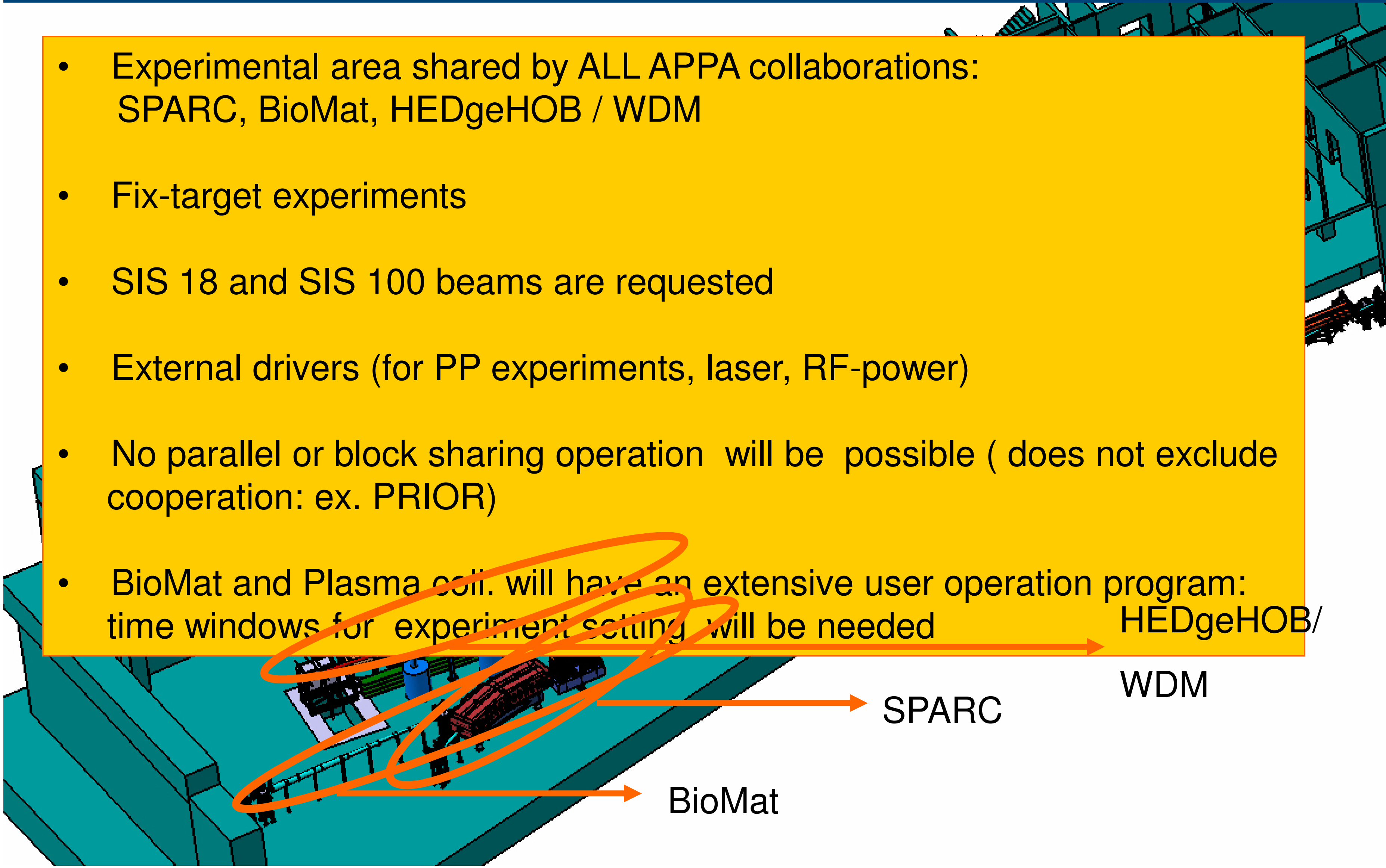
- strong static electromagnetic fields: **Highly Charged Ions**
- fast varying electromagnetic fields: **relativistic energies ($\gamma > 1$)**
- ultra short interaction times: relativistic energies (atto sec)
- strong perturbative potential fields: **low-energy HCI** (~keV/u)
- high luminosity (moderate to low beam intensity and thin targets): **stored beams**
- high resolution measurements: **cooled beams**, trapped ions / exotic systems

Facilities for Atomic Physics at FAIR

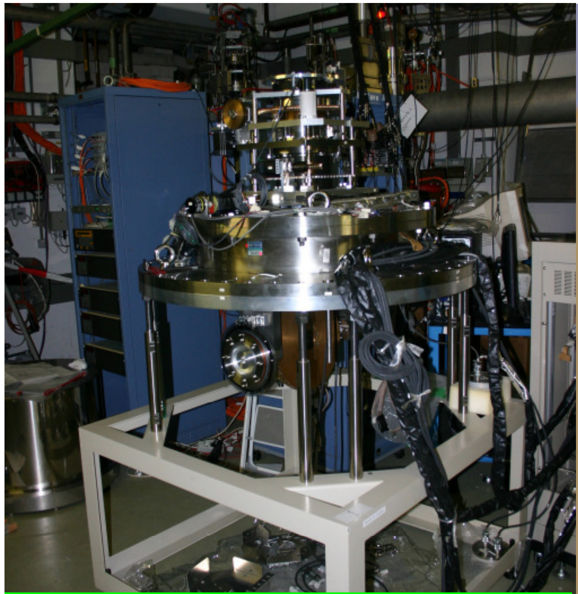


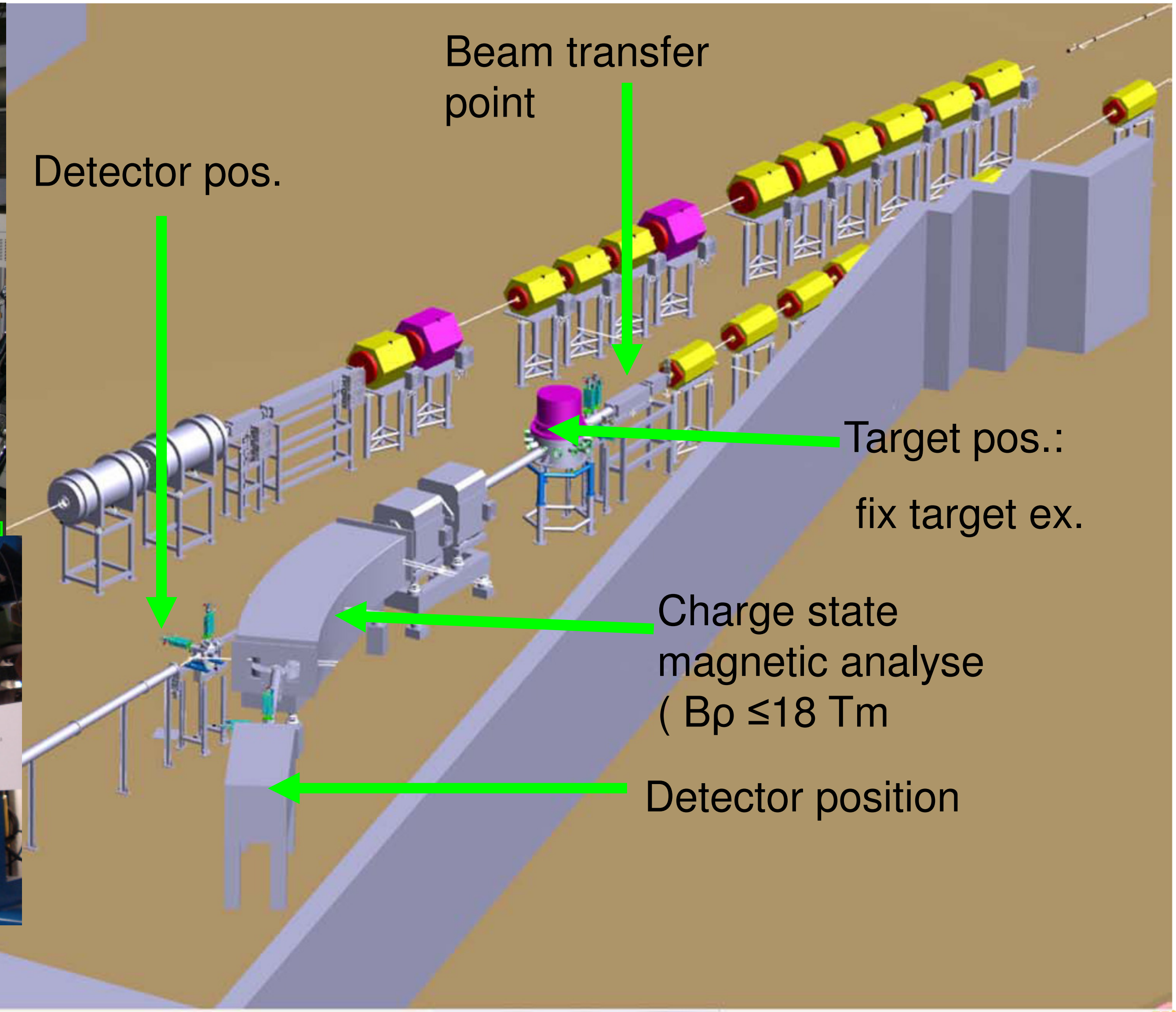
APPA Cave

- Experimental area shared by ALL APPA collaborations: SPARC, BioMat, HEDgeHOB / WDM
- Fix-target experiments
- SIS 18 and SIS 100 beams are requested
- External drivers (for PP experiments, laser, RF-power)
- No parallel or block sharing operation will be possible (does not exclude cooperation: ex. PRIOR)
- BioMat and Plasma coll. will have an extensive user operation program: time windows for experiment setting will be needed



APPA cave: SPARC Beam Line





SPARC at APPA cave

Beam parameters for normal operation

- **Ion species**: stable, mostly heavy ions (Au, Pb, U) in highest charge states; does not exclude the use of lighter ions: Ar, Xe
- **Beam energies**: up to 10 GeV/u for U^{91+}
- **Beam intensity**: 1x 10^8 pps
- **Delivery:** SIS 18 and SIS 100
- **Slow extraction**, flat top, max. pulse length
- **Momentum spread**: ~ $\Delta p/p=10^{-4}$
- **Beam spot**: as small as possible (few mm^2?), no hallow
- **Stable beam** on target

U^{28+} is not an option for SPARC in APPA cave

We trade intensity for beam emitance and stability

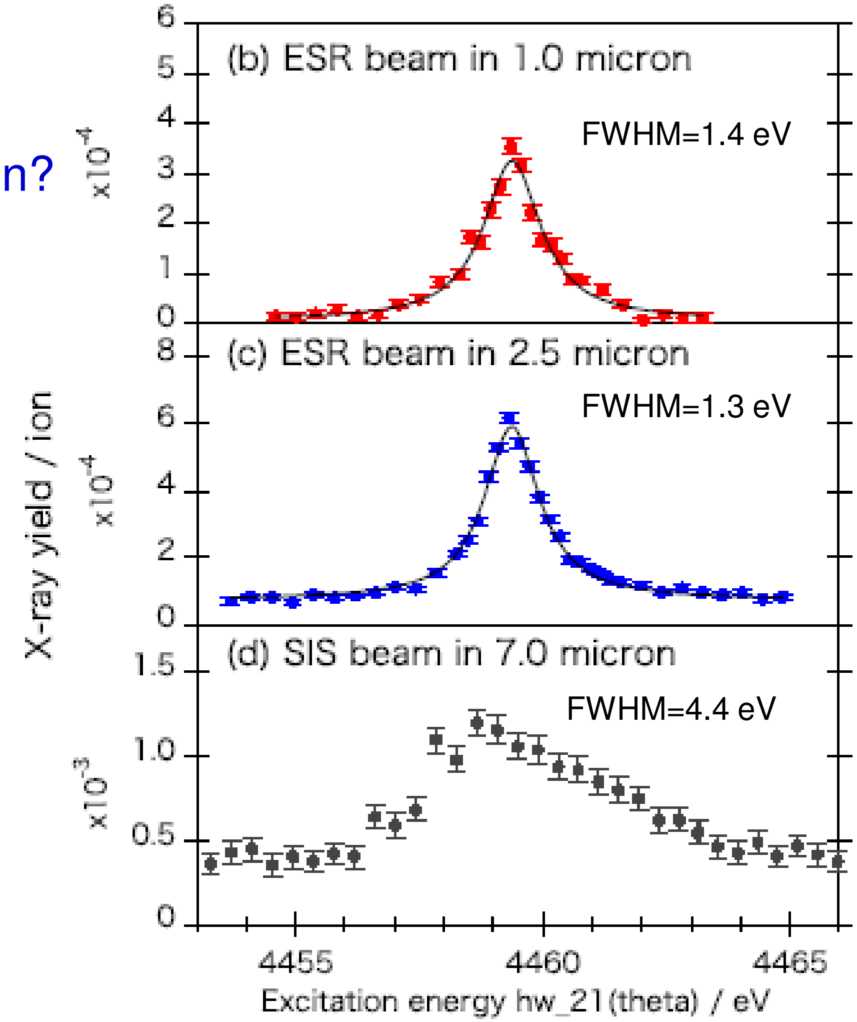
Stripping after SIS 18 is required

SPARC at APPA cave

For channeling experiments:

- small beam spot → local collimation?
- small beam divergence
- lowest possible momentum spread
- (rel.) low beam intensity
- beam energies of few GeV/u

Experiments at cave A are still planed 2016-2020?

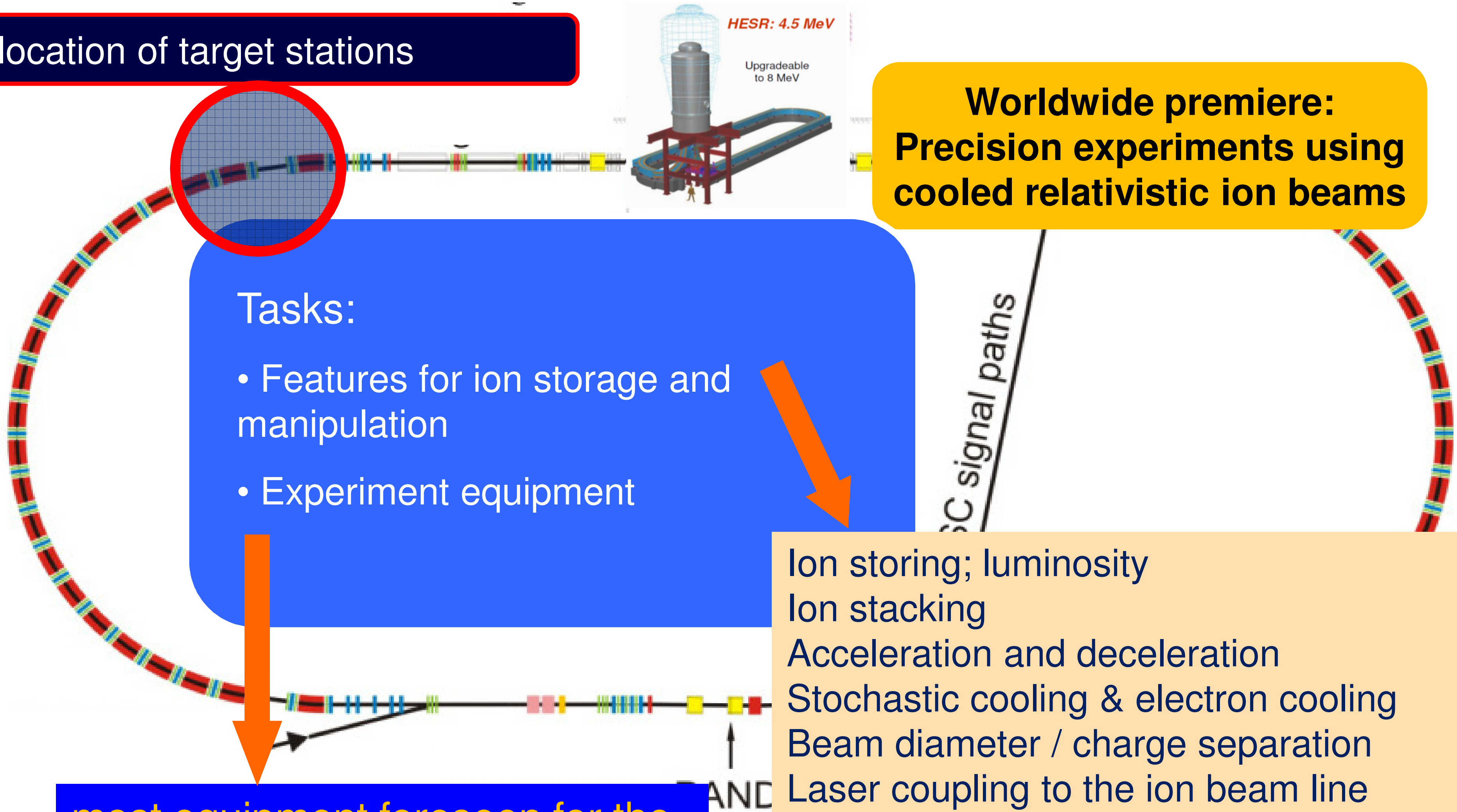


192 MeV/u U^{89+} channeled in Si crystal:

ESR and SIS18 test experiments

SPARC experiments at HESR

location of target stations



Worldwide premiere: Precision experiments using cooled relativistic ion beams

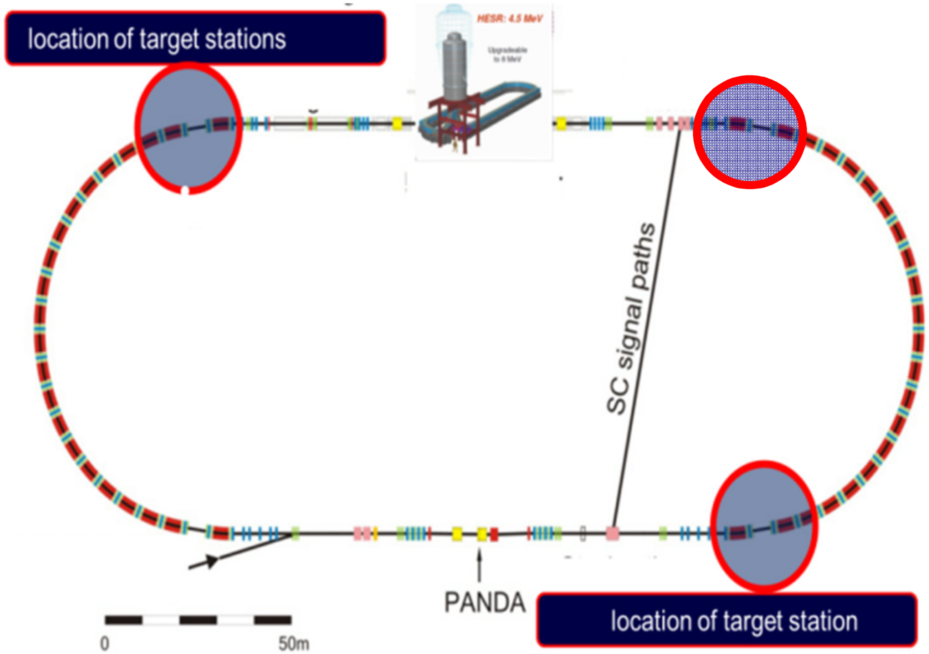
Tasks:

- Features for ion storage and manipulation
- Experiment equipment

Ion storing; luminosity
Ion stacking
Acceleration and deceleration
Stochastic cooling & electron cooling
Beam diameter / charge separation
Laser coupling to the ion beam line

most equipment foreseen for the NESR can be used at the HESR

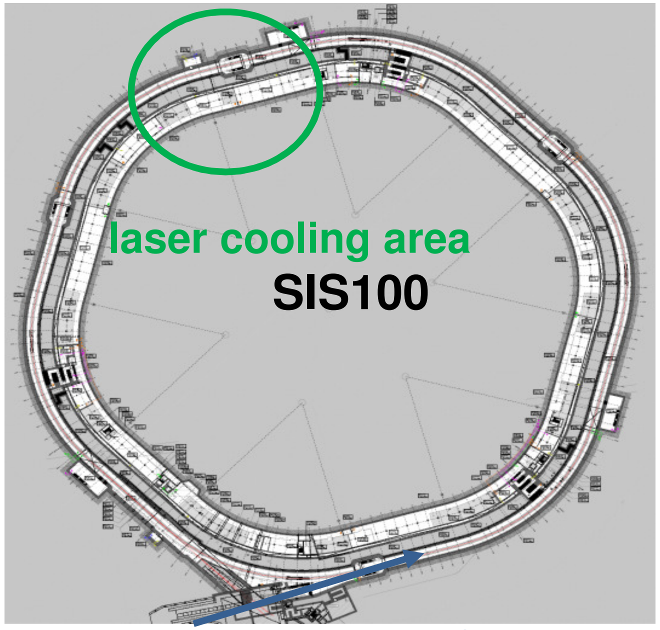
SPARC at HESR



1. High density Gas Target experiments
2. Laser spectroscopy

- **Ion species**: p to U and radioactive beams
- **Delivery**: SIS 18 and SFRS
- **High charge states**: bare to 4 electrons→stripping after SIS18 or at SFRS
- **Ion energy**: 0.2 to 5 GeV/u (acceleration/ deceleration)
- **Beam cooling**: electron (?) and stochastic in HESR
- **Injection from CR**: fast, 12÷13 Tm (740 MeV/u fix energy) cooling???
- **Emittance**: 1 mm mrad from SIS 18

SPARC at SIS100

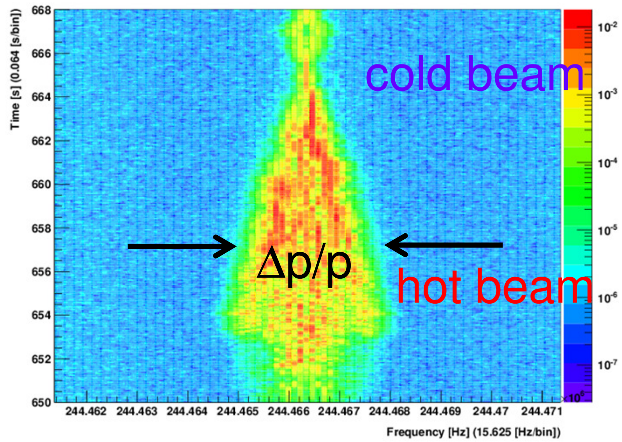


Large Lorenz boost of the relativistic ions

- Laser cooling
- Laser spectroscopy

In-ring experiments

No parallel operation



122 MeV/u C^{3+} ions stored in the ESR laser frequency scanning

Tests at IMP Lanzhou started in 2014

Laser cooling:

- the technique is understood (was already tested on C^{3+} at ESR) but

- the way towards a standard cooling scheme still needs an R&D an program to investigate the possible applications: beam–laser combination

- will not be an universal tool

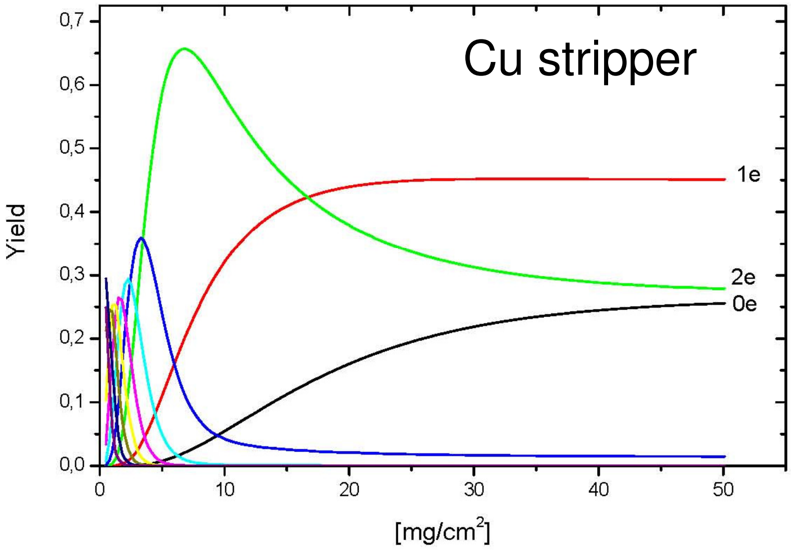
- the choice of the ion species and energy depends on the available laser

HCI production: Charge State Tayloring

Different charge states (bare to Be-like) will be required: a stripper after the SIS 18 is needed

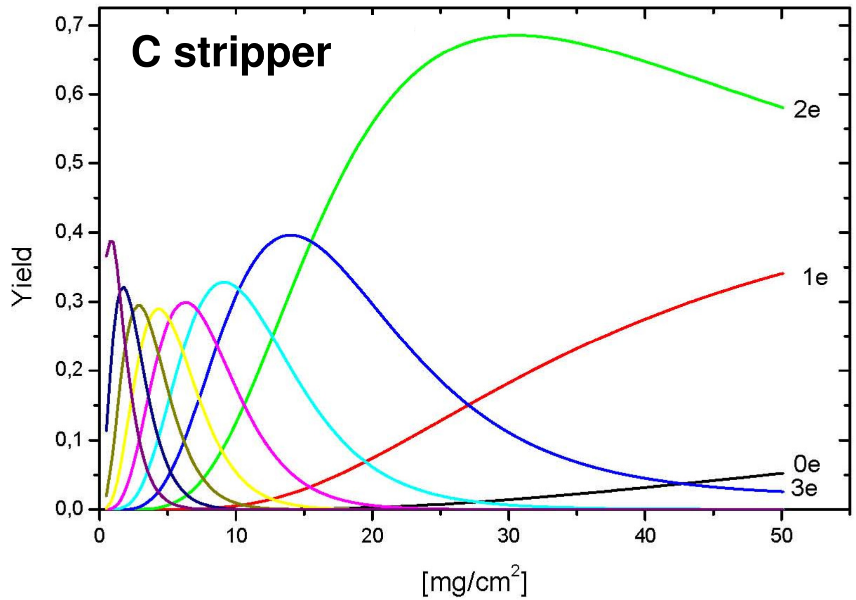
In SIS 18 high charge states should be injected (ex. U^{73+} is needed)

Stripping simulations

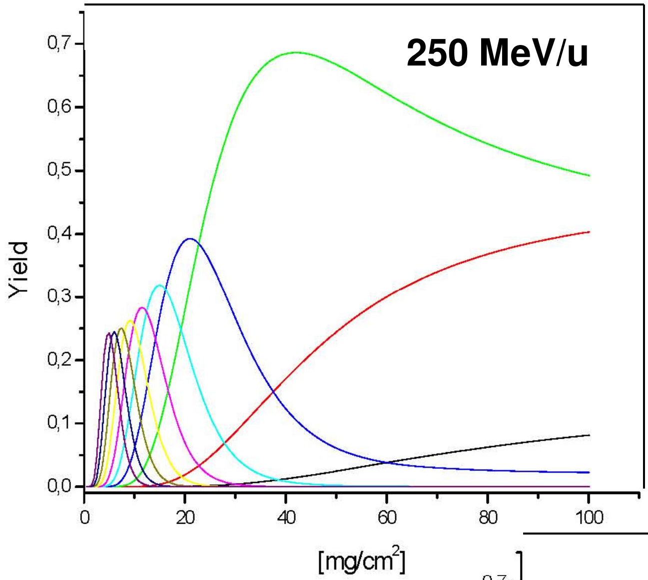


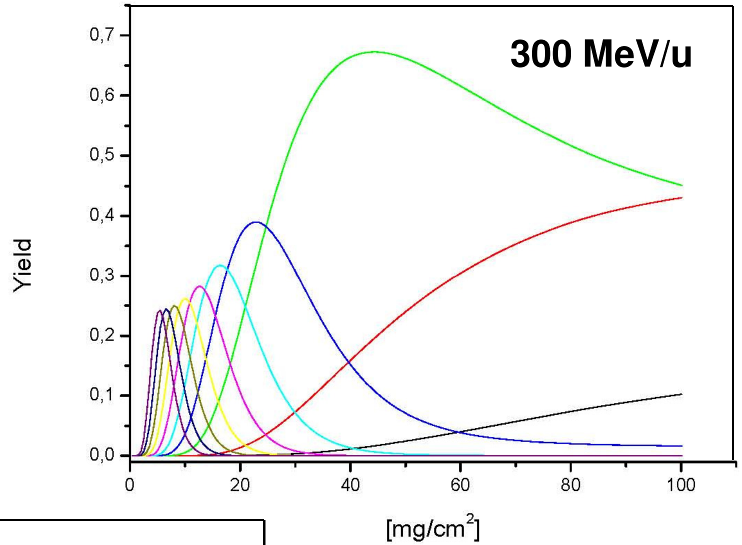
Au, 230 MeV/u

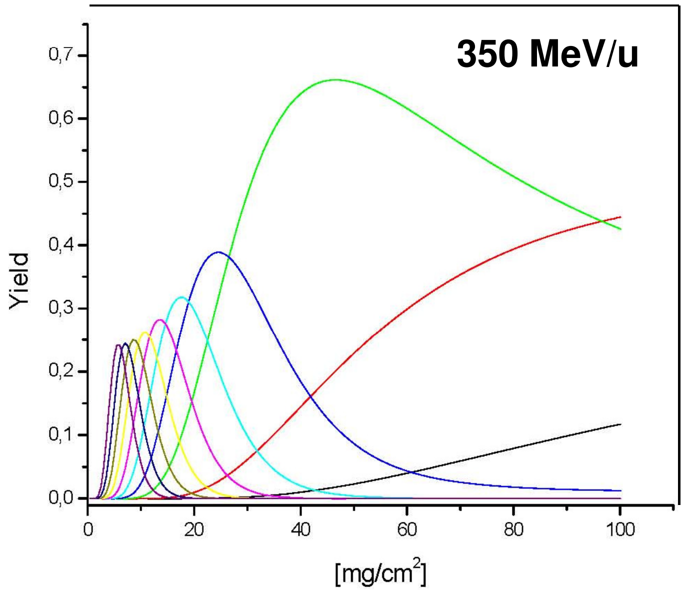
Q_{in}= 59



Stripping simulations







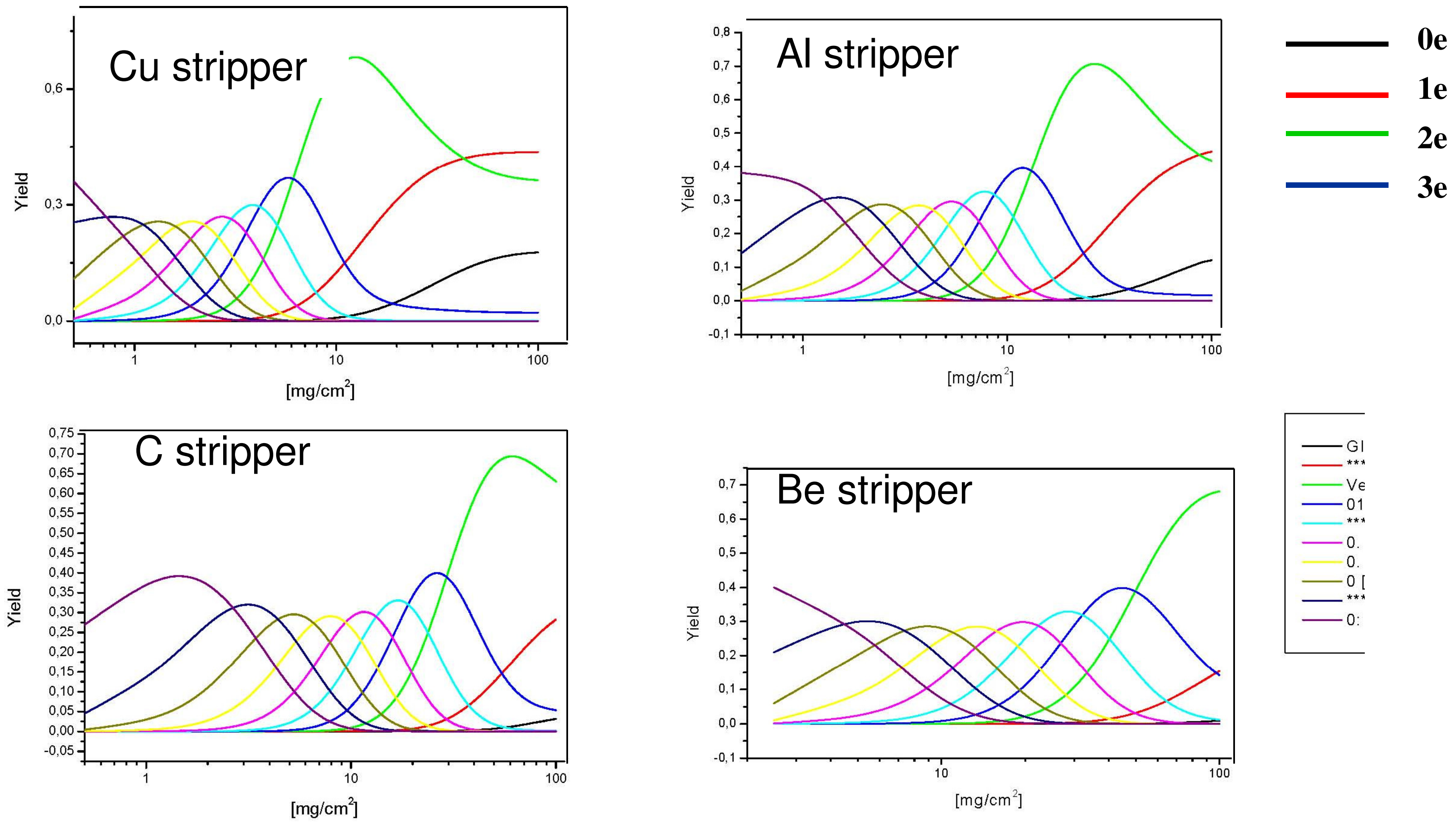
0e
1e
2e
3e

Bi, Q_{in}= 63+

C stripper

Stripping simulations

Uranium, 300 MeV/u, Q_{in}= 73+



SPARC Stripper

Summary:

- Different charge states are required: bare to 3-4 electrons; no equilibrium charge states
- Striping energy rather ‘low’ for SPARC
- Different stripper materials (C to Nd) and thicknesses (hundreds of **μm**) are needed for optimum charge state yield
- Stripper rather thin → mechanical and thermal stability: size, insertion mode, beam intensity

Conclusions:

- SPARC requirements are different from CBM’s
- Not possible to work just with ONLY one stripper foil
- Production of many different charge states with similar intensities: in some cases, important part of the beam must be discarded after the stripper

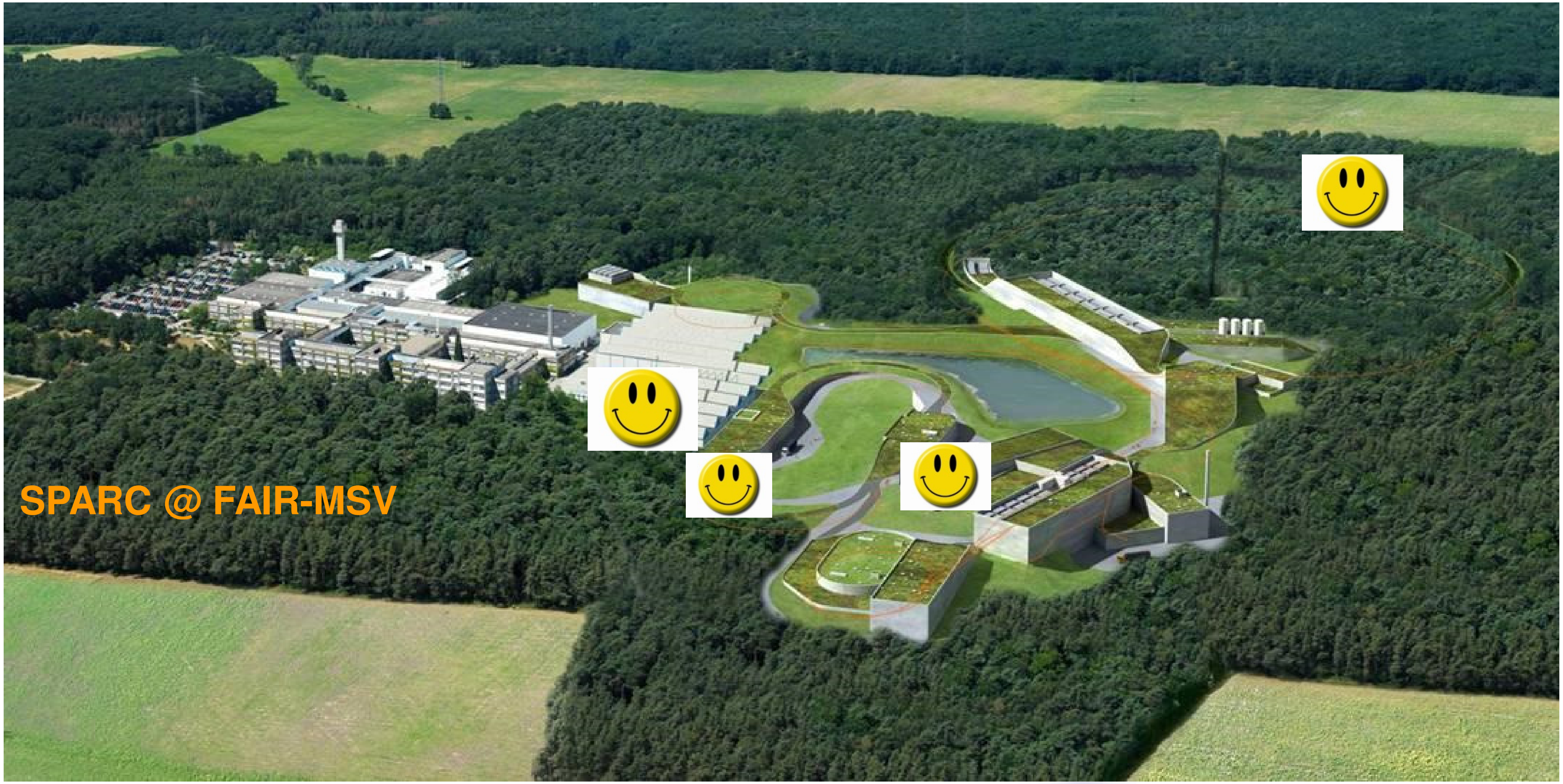
Questions:

1. Location
2. Design
3. Operation: beam energy, parallel operation

Concluding remarks

1. Large variety of Experiments at different locations, no monolithic detector system → all stations should will be used
2. SPARC experiments will require a large variety of beams in terms of energy, charge state and ion species; there is no ‘standard’ beam for atomic physics experiments
3. SPARC requires moderate to high beam intensities
4. Single-pass and in-ring experiments requires slow and fast extracted beams from SIS 18 and/or SIS100
5. A dedicated stripper is needed after the SIS18
6. The parallel operation will be challenging in APPA cave as well as in HESR
7. Uniqueness of the facility: **HCI in storage rings in a broad energy range**

Thank you for your attention!



Rad. Prot: Beam parameters for APPA cave

Errichtungsantrag APPA cave 2011

Target-punkte	Nutzer	Ion	Energie [GeV/u]	Intensität [s^{-1}]	Strahl-dump
XPP2	Plasma-physik	$^{238}U^{28+}$	0,5	1,4E+09	XPP2SD1
XAP1	Atom-physik	$^{238}U^{92+}$	10	1E+08	XBM2SD
XAP1	Atom-physik	$^{238}U^{92+}$	1	1E+08	XAPDSD
XBM1	BIOMAT	p	10	5E+10	XBM2SD
XBM2	BIOMAT	$^{238}U^{28+}$	10	1E+10	XBM2SD

Tabelle 2: Strahlparameter der APPA-Experimente in G050 für Experimente mit Protonen und Uran-Ionen. Die Positionen der verschiedenen Target- und Strahldumppunkte sind in Abb. 2 dargestellt.