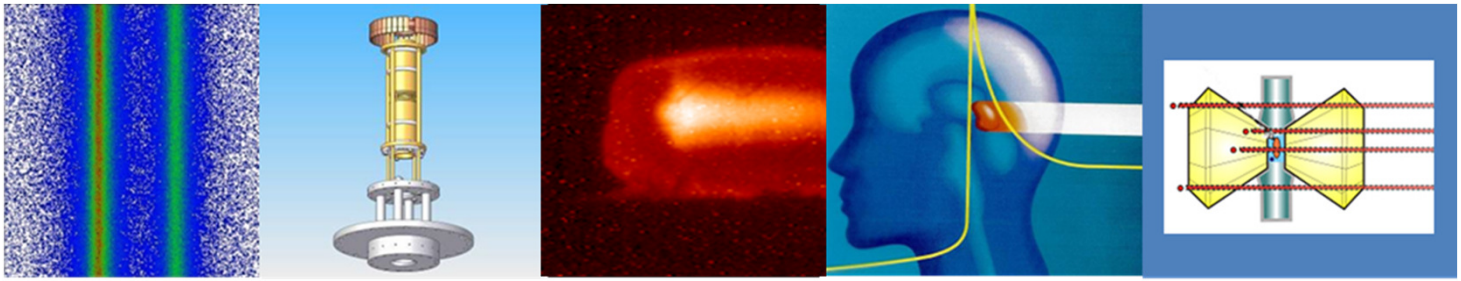


APPA@FAIR

Instrumentation and Basic Requirements

Thomas Stöhlker
GSI, Helmholtz Institute Jena,& Friedrich Schiller University, Jena

Atomic Physics, Plasma Physics, and Applied Sciences

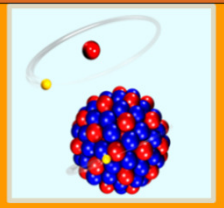
Introduction & The FAIR Facilities of APPA

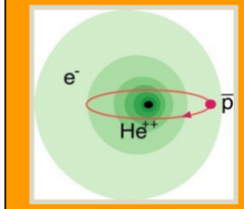
- Modularized Start Version
- The APPA Cave (MSV)
- The Storage Ring Facilities (MSV)

Instrumentation, Detectors and Beam Parameters (MSV)

Midterm Research Program at GSI (2015 and beyond)

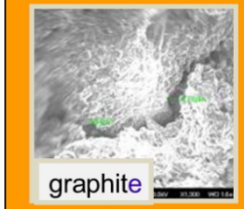
Conclusion


SPARC



FLAIR

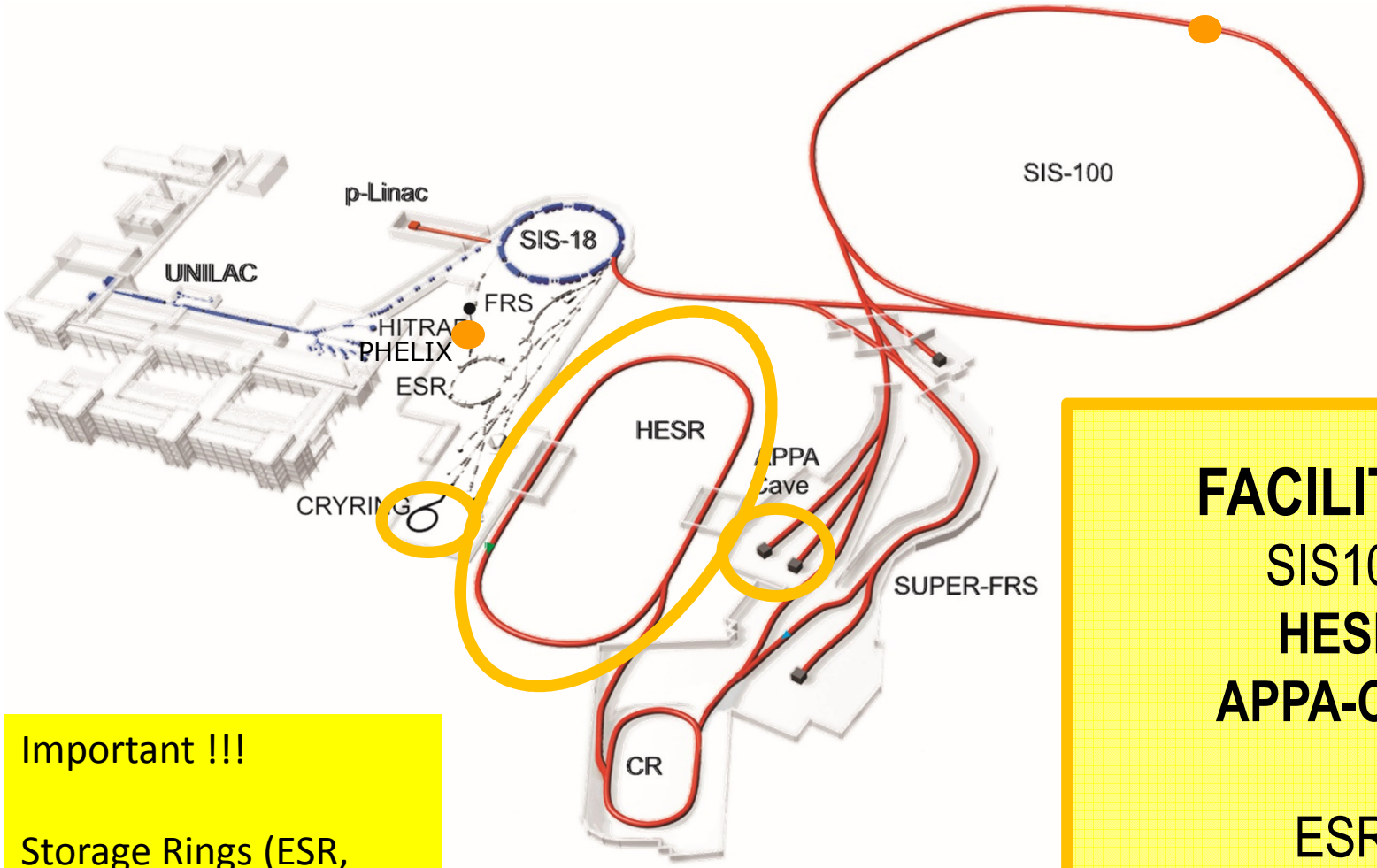

HEGgeHOB/WDM



MAT/BIOMAT


BIO/BIOMAT

FAIR-MSV: APPA Facilities



Important !!!

Storage Rings (ESR, CRYRING) and HITRAP are part of the MSV

FACILITIES

SIS100

HESR

APPA-Cave

ESR

CRYRING

HITRAP

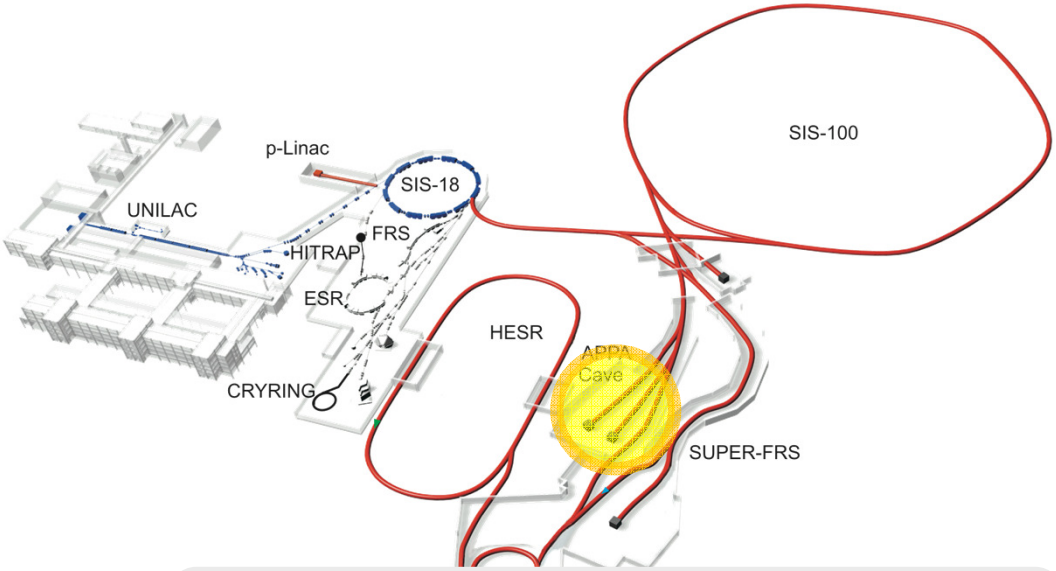
Experiments from all APPA collaborations are located in the APPA cave

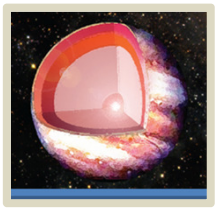
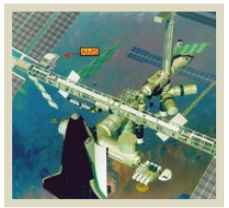
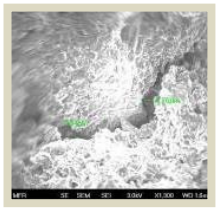
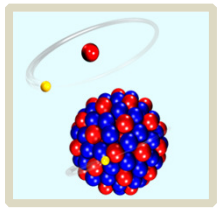
Plasma Physics
Proton Radiography
Warm Dense Matter

Biophysics
Effects of Cosmic Radiation

Materials Science
Radiation Effects at Extreme T,p
Radiation Hardness, Phase Transitions

Atomic Physics
Interaction of Highly-Charged Ions with Crystals



Beam parameters

Plasma Physics:
Heavy ions, e.g. U^{28+}: up to 2 GeV/u, $5 \cdot 10^{11}$ ions
Protons: 5 - 10 GeV, $2 \cdot 10^{13}$ protons

Atomic Physics
few-electron heavy ions:
up to 10 GeV/u, I < 10^8 pps

BioMat
p to U: up to 10 GeV/u
up to 10^8 ions / $5 \cdot 10^{10}$ protons

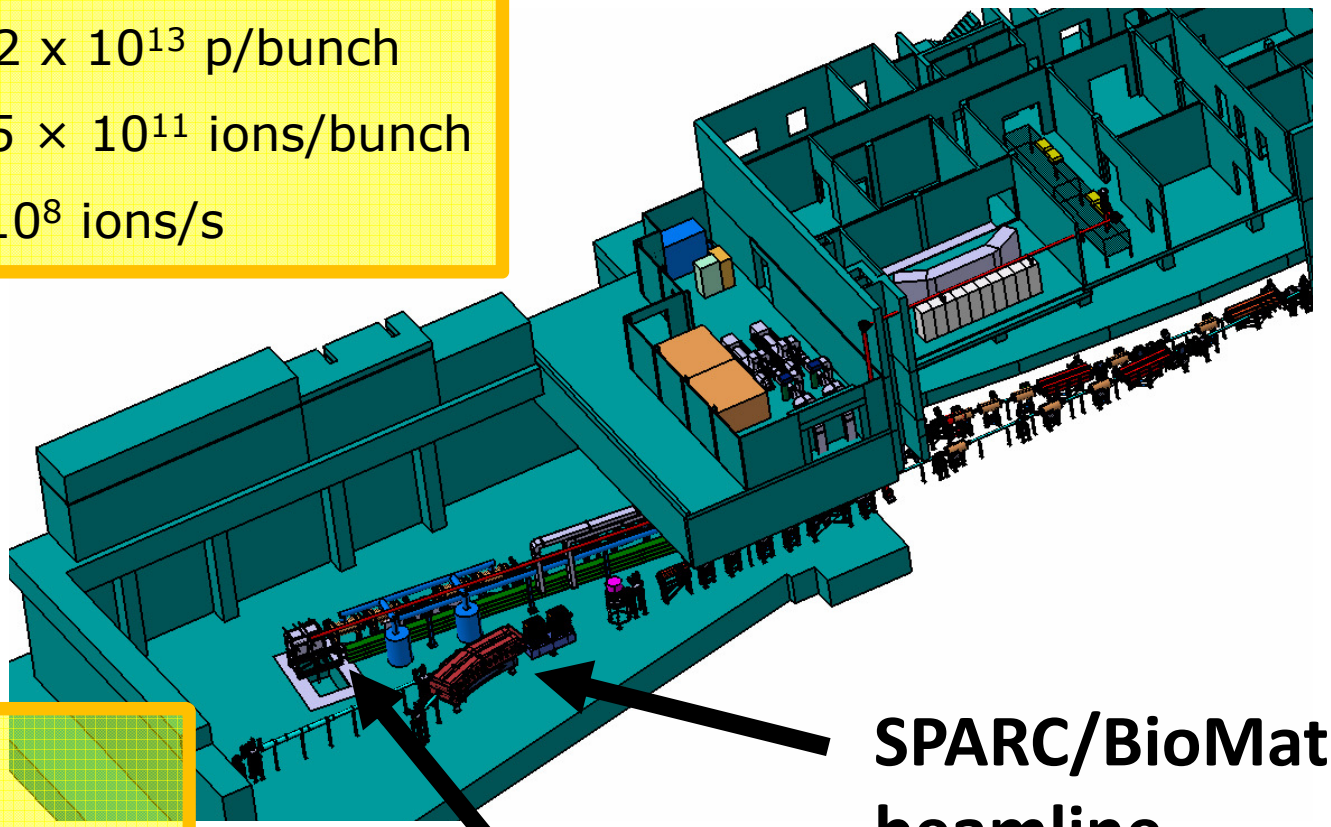
4

FAIR-MSV: APPA Cave

protons (10 GeV): 2 x 10^{13} p/bunch

U^{28+} (2 GeV/u): 5 × 10^{11} ions/bunch

U^{92+} (10 GeV/u): 10^{8} ions/s



- **user facility**
- **several target stations**
- **flexible detector settings**
- **flexible beam shaping**
- **external drivers**

SPARC/BioMat beamline

HEDgeHOB/WDM beamline

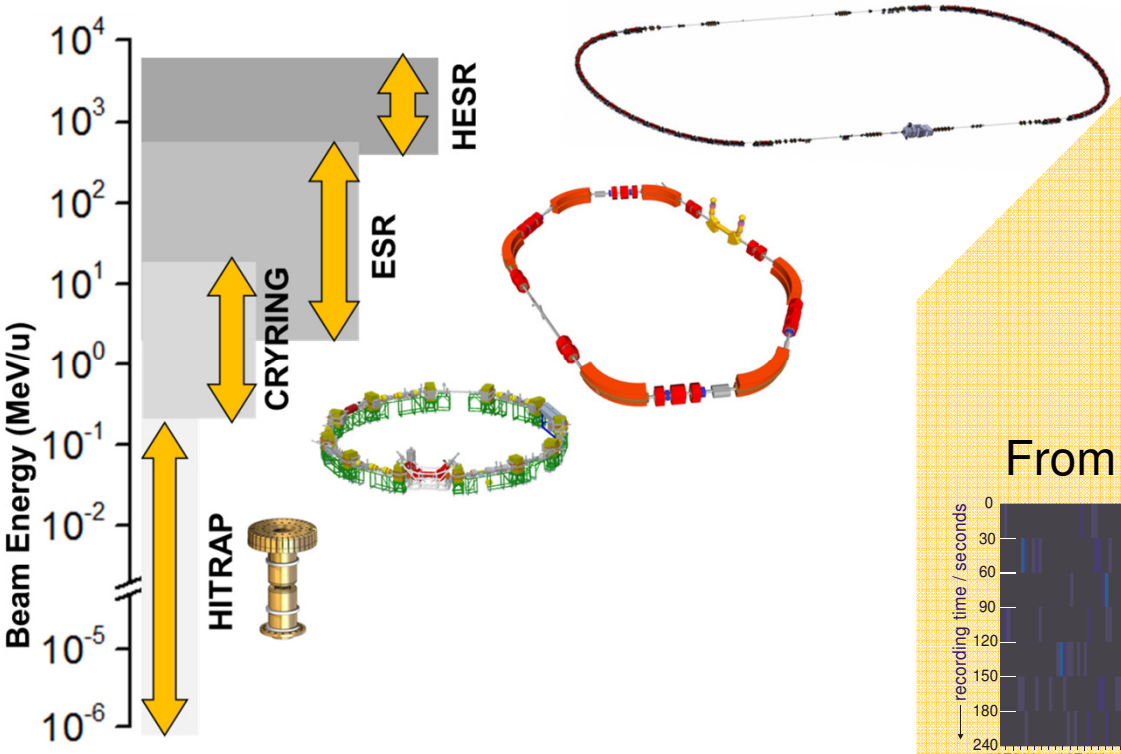
Ion Beam Facilities / Trapping & Storage

Worldwide Unique

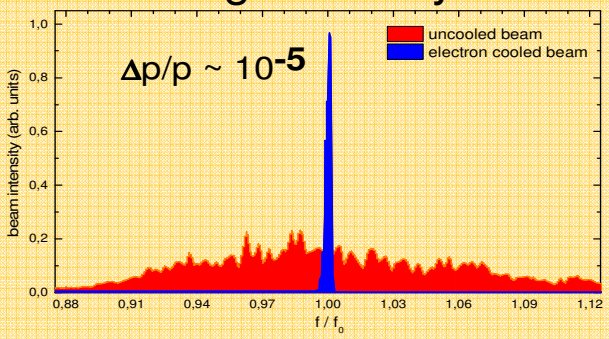
Stored and Cooled

Highly-Charged Ions (e.g. U^{92+}) and Exotic Nuclei

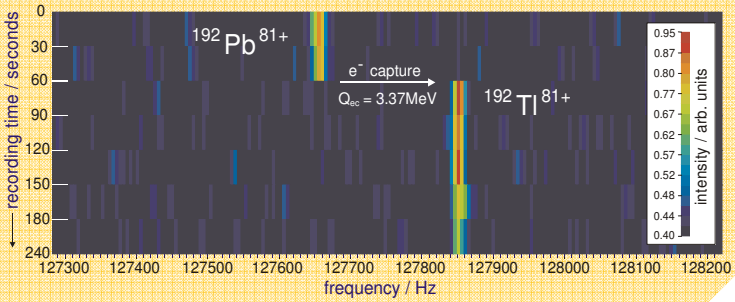
From Rest to Relativistic Energies (up to 4.9 GeV/u)



Cooling: The Key for Precision



From Single Ions to Highest Intensities

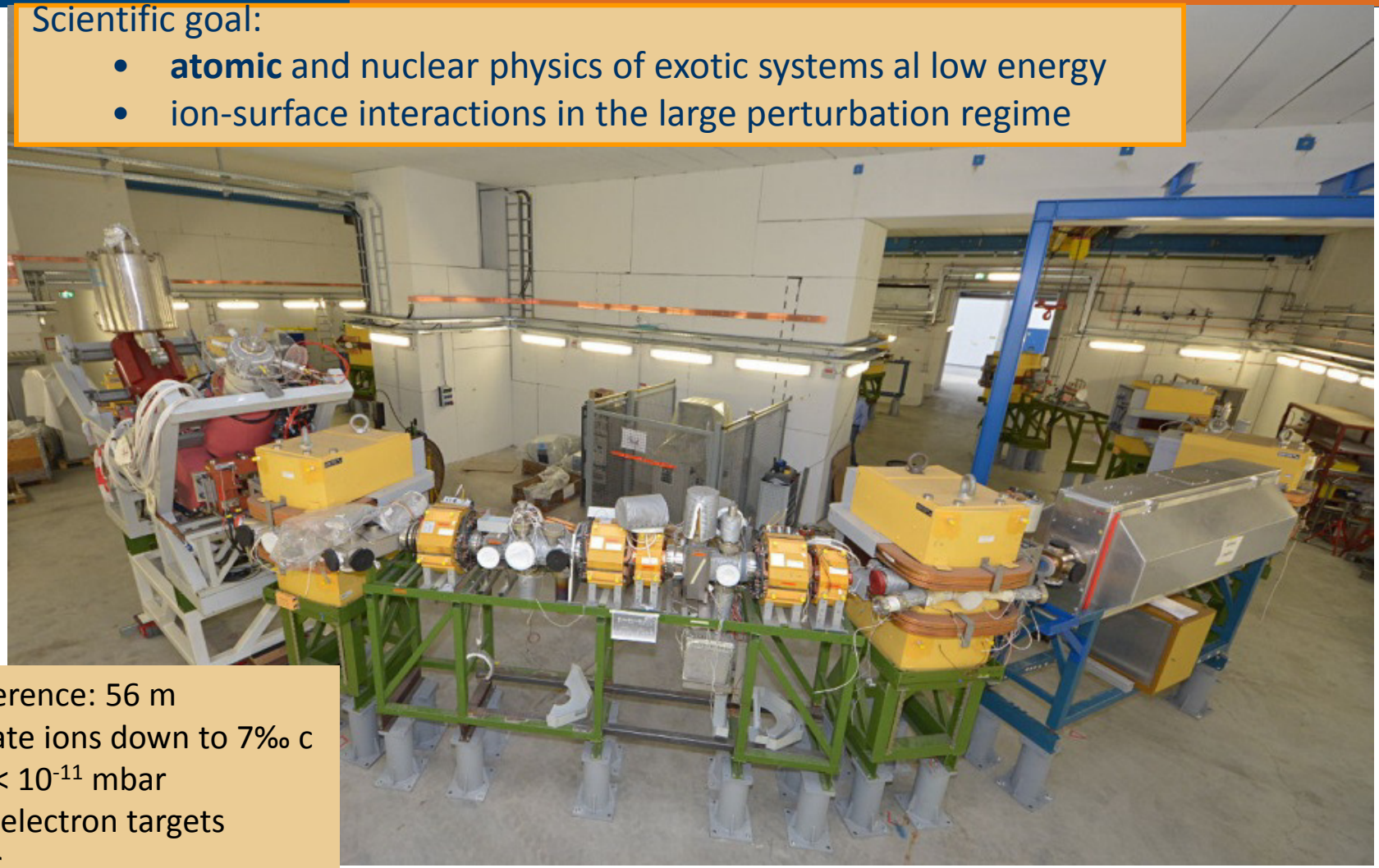


CRYRING at ESR: Status June 2015

Swedish in-kind contribution

Scientific goal:

- **atomic** and nuclear physics of exotic systems al low energy
- ion-surface interactions in the large perturbation regime



- circumference: 56 m
- decelerate ions down to 7‰ c
- UHV: p < 10^{-11} mbar
- gas and electron targets
- e-cooler
- several experiment stations

❖ **first beam in ring expected in 2015/2016**

Atomic Physics, Plasma Physics, and Applied Sciences

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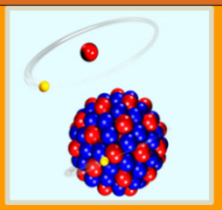
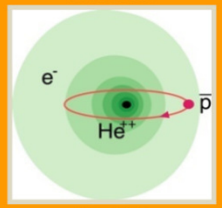
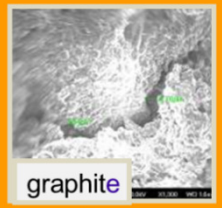

SPARC



FLAIR


HEGgeHOB/WDM



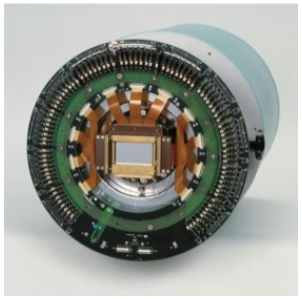
MAT/BIOMAT

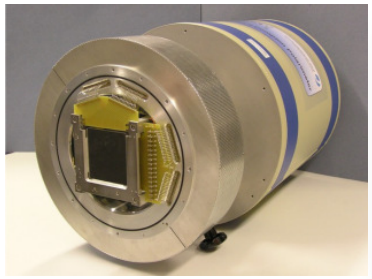

BIO/BIOMAT

Sophisticated & Versatile Instrumentation

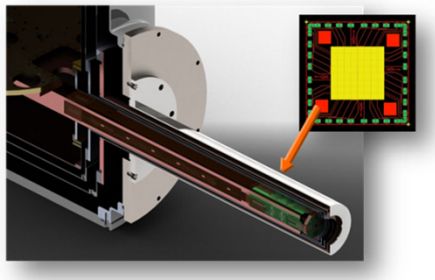
Observables: Photons, electrons, positrons, ions

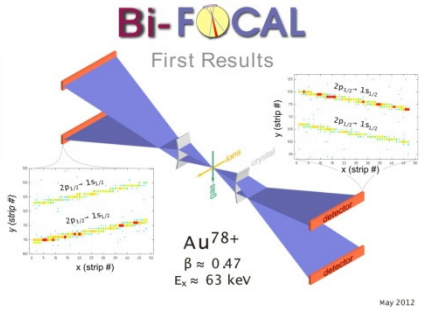
Targets



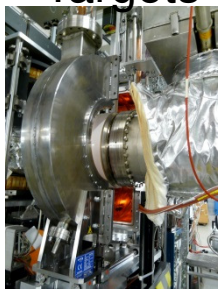


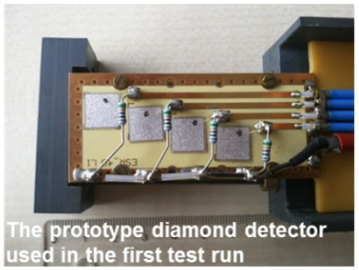
Position-sensitive solid-state detectors



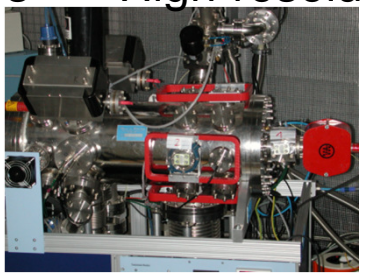


High-resolution spectrometers

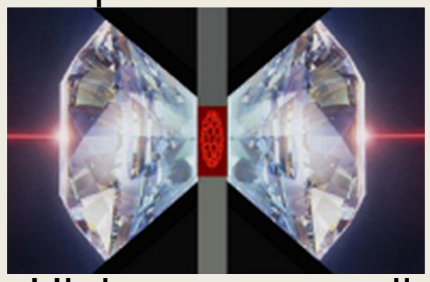




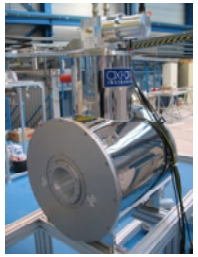
Particle detectors

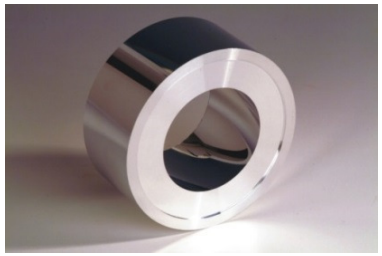


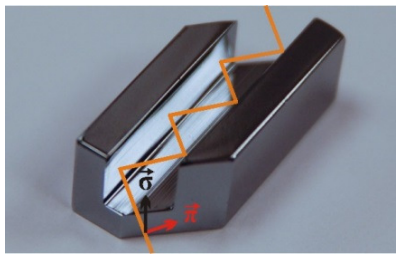
Particle spectrometers



High pressure cell

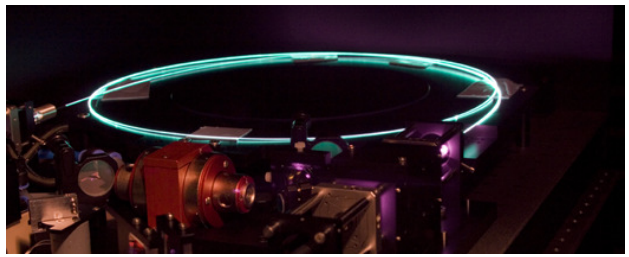






Traps

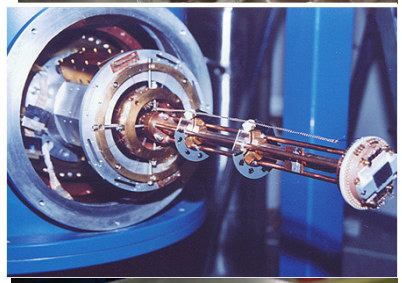
X-ray optics, channel-cut crystals

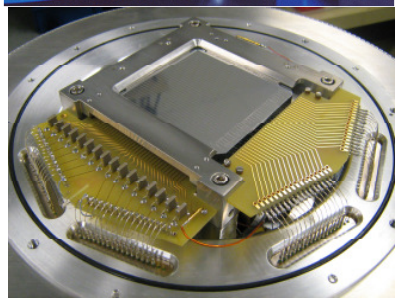


Laser systems

Status Detector Development and Construction

- Development of instrumentation is progressing well
- Several novel detector systems are currently getting commissioned
- Important in-kind contributions from partner institutions have been already received

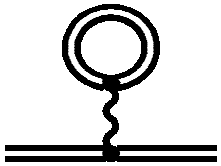




❖ several APPA setups are ready to be installed and can be used in APPA cave and at HESR

Atomic & Fundamental Physics

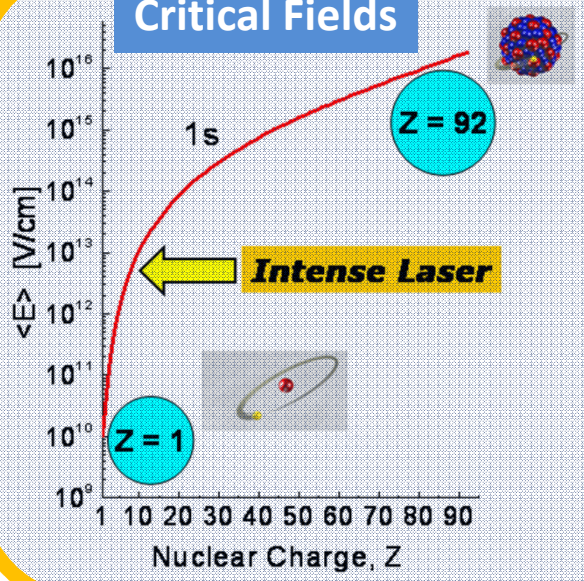
Interplay between Relativity, Correlation, and QED in the Non-Perturbative Regime

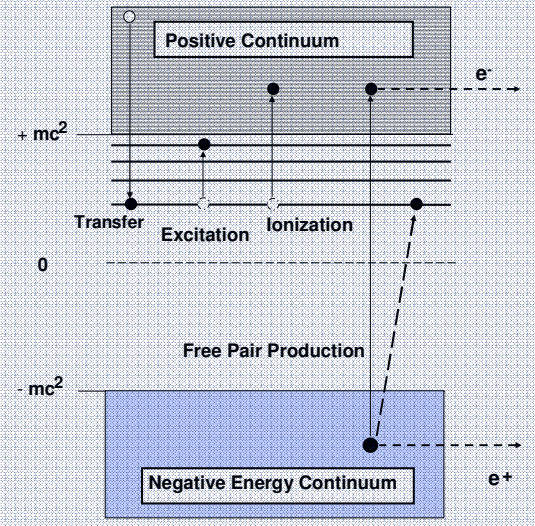


$$\alpha Z \approx 1$$

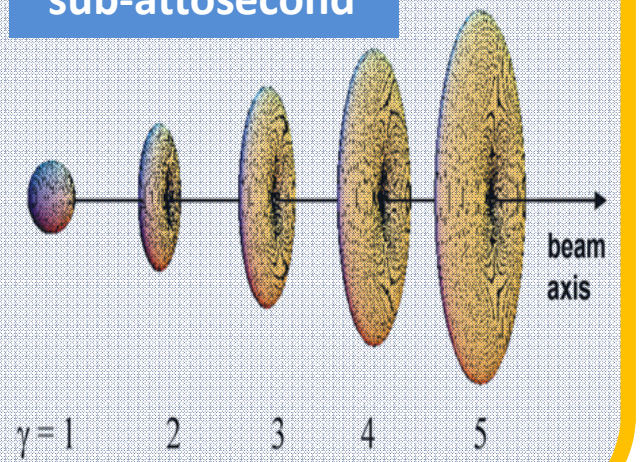
- Radiative corrections in the non-perturbative regime
- Correlated multi-body dynamics for atoms and ions
- Precision determination of fundamental constants
- Influence of atomic structure on nuclear decay properties

Critical Fields



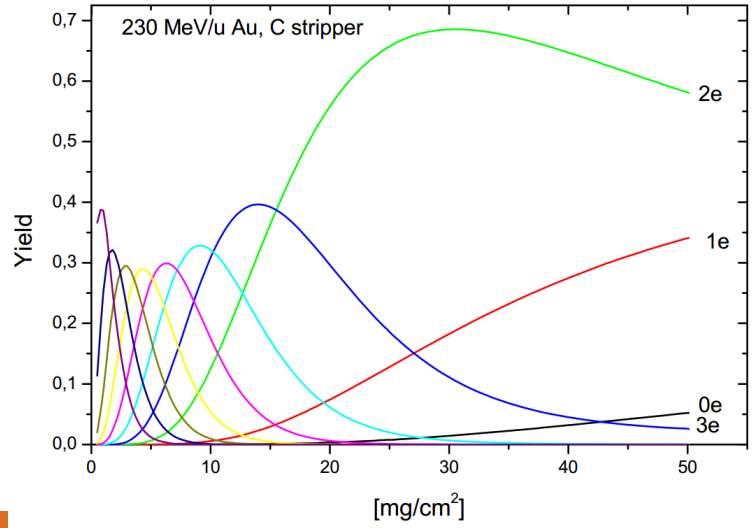


Ultrashort Pulses "sub-attosecond"



SPARC: Design of Stripper Foils / Charge State Tayloring

- Facilities: ESR, CRYRING, Cave A, HESR, APPA Cave
- Projectiles: all elements up to uranium
- Up to the highest possible beam energy (e.g. 10 GeV/u for U92+ at APPA Cave)
- Charge states: main focus is on bare, H-like, He-like, Li-like, Be-like
- Prefered energy for stripping (bare ions): up to 1 GeV/u
- Prefered energy for stripping (few-electron projectiles): between 200 and 400 MeV/u
  - Non-equilibrium thicknesses for stripper targets
  - Broad range of different stripper targets (from C to Nb with different thickenesses)
  - Target station



Novel Instrumentation for Atomic Physics: Towards FAIR

Instrument/ detector	Status	remarks
New internal target (micro-cluster target)	Prototype system in operation at the ESR	TDR for SPARC experiments at HESR has been accepted
Micro-calorimeter detectors	Two systems currently in development at Giessen and Heidelberg	Test experiment at the ESR in 2014
New target chamber (impact parameter)	Work in progress	A first prototype setup installed at the ESR
Diamond detectors	Work in progress	Prototypes applied in experiments
Transverse electron target	Work in progress at U. Frankfurt and Giessen	Dedicated to low beam energies
Electron spectrometer	In progress	TDR has been submitted
X-ray polarimeter	Two prototype systems available	Already applied and tested in experiments at ESR and PETRAIII
Resonant Schottky cavity	Prototype system in operation at the ESR	Already applied and tested in experiments

Novel Instrumentation for Atomic Physics: Towards FAIR

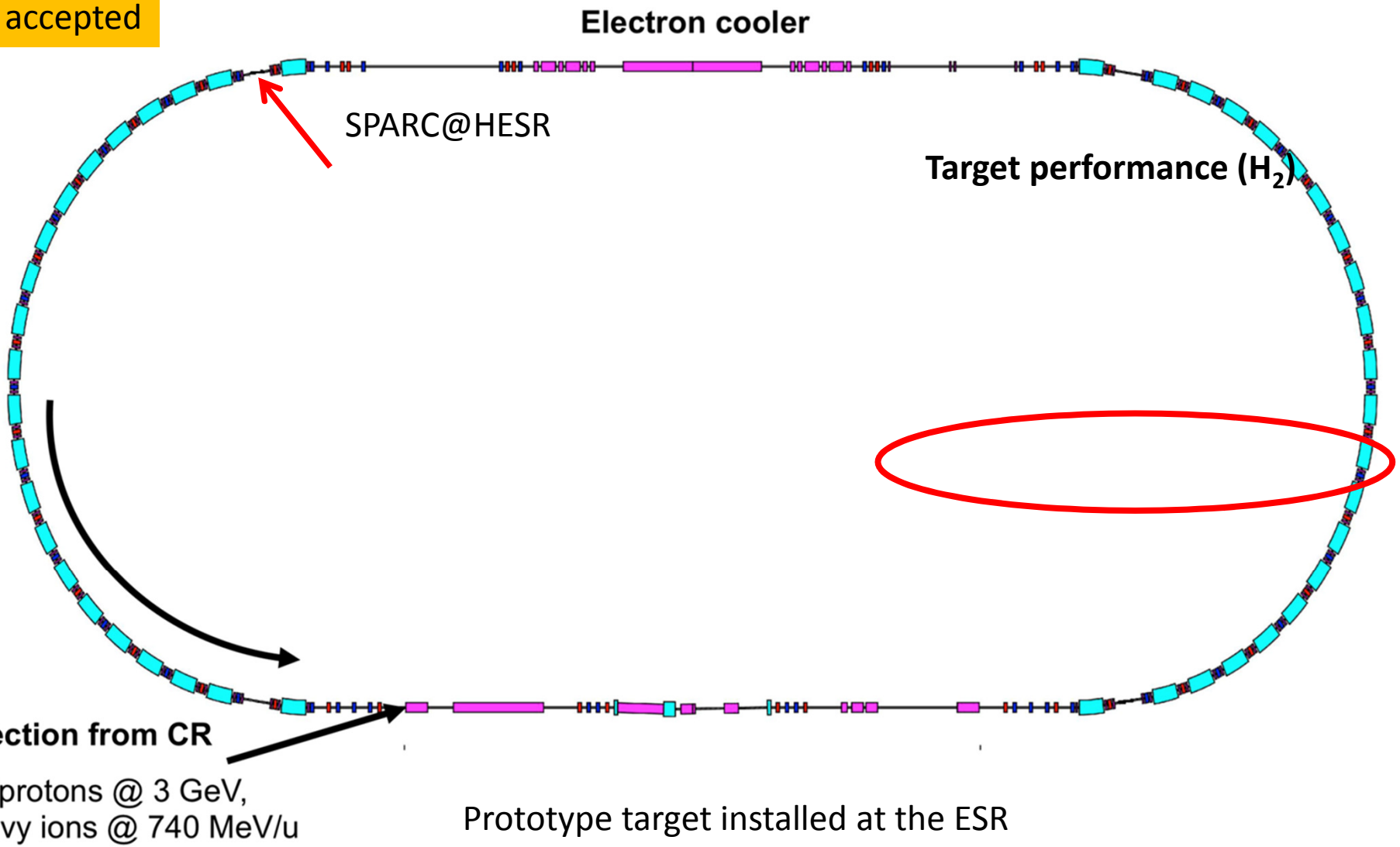
Instrument/detector	status	remarks
Novel laser setup for laser cooling	Prototype system in operation at the ESR	Applied in experiment for C3+
Improved detection system for fluorescence radiation at ESR	In operation at the ESR	Applied in HFS experiments
FOCAL spectrometer	Prototype system in operation at the ESR	Applied in experiment for Au78+

and many more: e.g. x-ray optics, traps, fluorescence spectrometer for target diagnotics etc.

In 2015: University groups received substanital funding by BMBF Verbundforschung

Target@HESR

TDR accepted

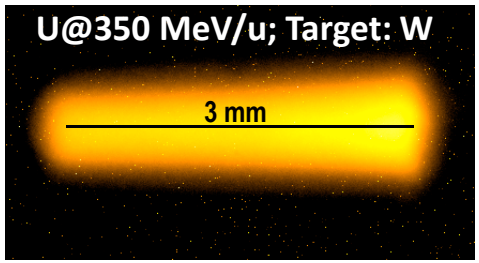


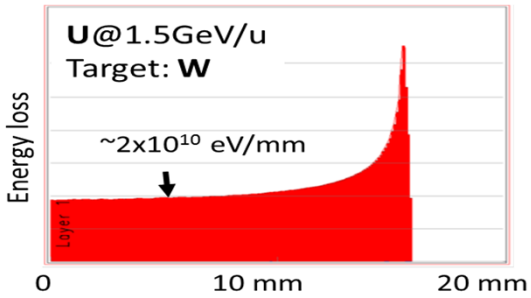
Prototype target installed at the ESR

R. Grisenti et al.

Plasma Physics at FAIR

Interaction of ions and photons with plasmas
Equation of state, phase transitions, transport phenomena
Matter under high pressure
Coupling of intense light with matter





Warm Dense Matter

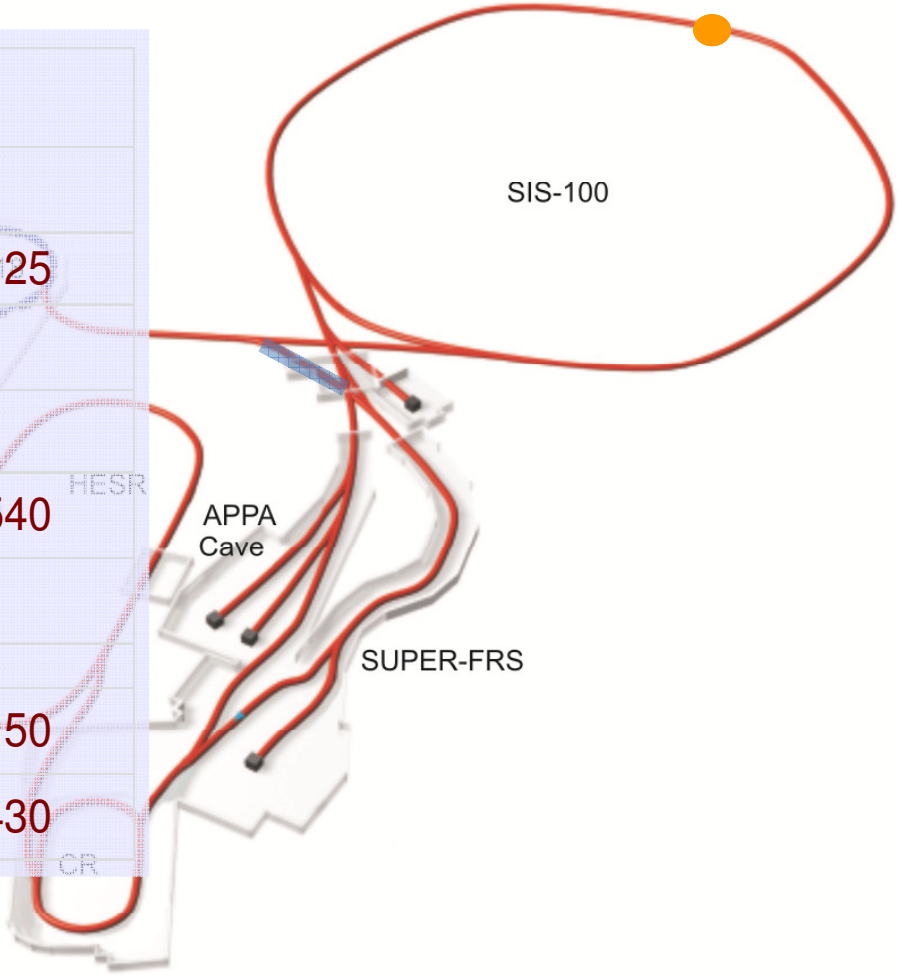
- T ≈ 0.2 – 10 eV
- ρ ≈ solid density
- P ≈ kbar, Mbar

- large volume of sample (mm^3)
- fairly uniform physical conditions
- high entropy @ high densities
- high rep. rate and reproducibility
- any target material

- **FAIR will produce the largest volume of uniform WDM world wide.**
- **Compared to GSI, FAIR will provide a specific intensity and energy deposition increase by a factor of 100.**

Plasma Physics at FAIR

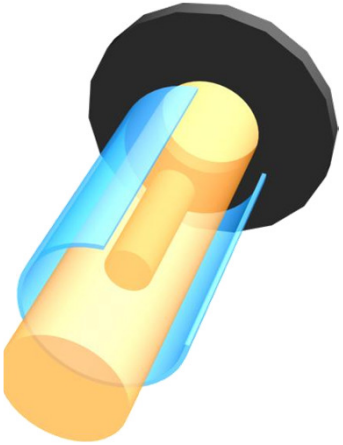
Uranium beam	GSI	FAIR	
E_o	400 MeV/u	0.4 – 2.7 GeV/u	
N	$4 \cdot 10^9$	$5 \cdot 10^{11}$	x 125
E_{beam}	0.06 kJ	19 kJ	
τ	130 ns	70 ns	
P_{beam}	0.5 GW	270 GW	x 540
S_f	~1 mm	~1 mm	
	Lead target		
E_s	1 kJ/g	150 kJ/g	x 150
P_s	5 GW/g	2 TW/g	x 430



Interesting experiments are foreseen even with beam intensities much lower (10^{10}-10^{11}) than the FAIR design value

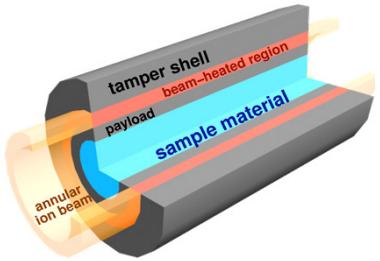
Plasma Physics at FAIR

Target: lead cylinder, l = 2 mm, r = 300 µm



Intensity U^{28+}, τ = 50 ns	Focus (FWHM, mm)	E (kJ/g)	P (kbar)	T(K)
10^{10}	1	1.4	180	9450
10^{11}	1	14	830	56000
10^{11}	4	0.9	103	6250

Target: frozen Hydrogen, l = 5 mm, r = 400 µm

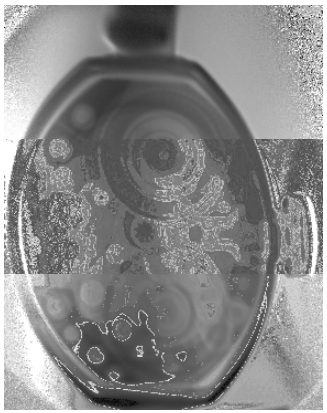


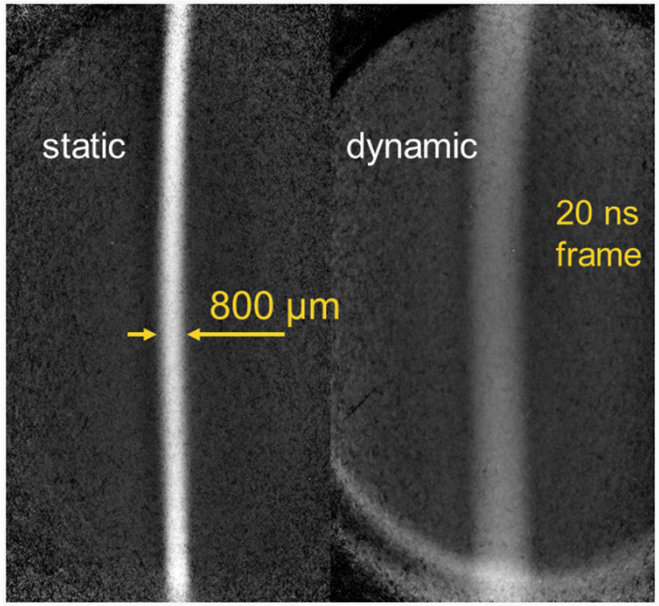
5 x 10^{11}	1	19	3000	3000

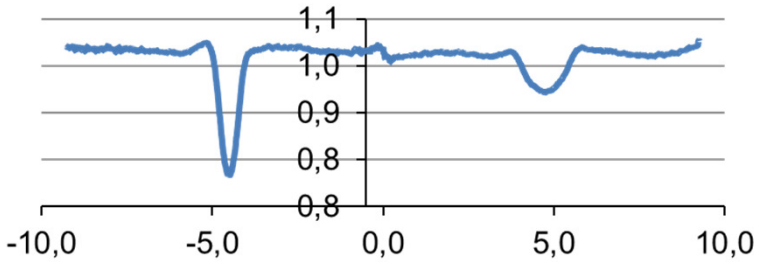
PRIOR Prototype: Dynamic Experiments, July 2014

Goal: to measure density distribution of expanding hot Ta for EoS studies

- Underwater electrical wire explosions (0.8 mm Ta wire in 2 cm of water).
- 35 kV, 40 MA/cm^2, 5 GW deposited
- WDM states in Ta: 10 kJ/g specific energy, ~2 eV temperature, ~km/s expansion velocity.
- Several dynamic experiments were performed to build a time history of the wire expansion.







Proton radiographs

Developed in collaboration with LANL, ITEP, GSI, and TU Darmstadt

PRIOR provides the highest resolution proton micrograph worldwide .

Atomic Physics, Plasma Physics, and Applied Sciences

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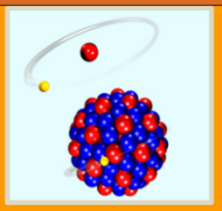
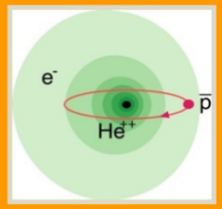
Midterm Research Program at GSI (2015 and beyond)

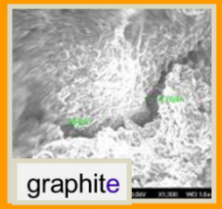
Conclusion


SPARC



FLAIR


HEGgeHOB/WDM



MAT/BIOMAT


BIO/BIOMAT

Midterm research strategy for GSI

- beam time at GSI and external institutes
  - keeping scientific visibility (publications, conferences)
  - education of young scientists
  - maintaining technical expertise
  - cement ties within collaborations
  - testing detectors, concepts

- essential needs
  - not excessive but SECURE funding
  - operation of accelerators (SIS18 and UNILAC)
  - technical infrastructure: IT, laboratories, support people
  - participation in national and international activities (e.g. ATHENA, LHC upgrade, High Data Federation etc.)
  - support of fund raising activities
  - reactivation of existing programs for young scientists

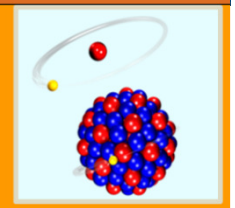
Mid-term research opportunities at GSI
(complemented by external activities)

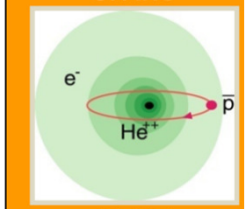
APPA		
ESR-HITRAP-CRYRING	SPARC	Atomic physics, strong field QED, atomic collisions, border to nuclear physics
M Branch, Z0 / Cave A	BIOMAT	Biophysics, heavy ion therapy, Material Science
HHT/PRIOR	WDM/HEDgeHOB	Plasma physics, proton radiography
PHELIX	WDM/HEDgeHOB	Plasma physics, proton acceleration
CBM		
HADES	CBM/HADES	Di-lepton production in pion-induced reactions
ALICE/LHC	ALICE	Run 2: QGP at highest energy, x3-10 statistics. Upgrades for Run 3: Pb-Pb at 50 kHz
NUSTAR		
FRS	NUSTAR	Separator-/spectrometer expt.'s with exotic nuclei
FRS-ESR	NUSTAR	Nuclear physics with exotic beams in a storage ring
HISPEC/DESPEC	NUSTAR	In-beam and stopped-beam spectroscopy experiments
R3B@SIS18	NUSTAR	Reactions with relativistic radioactive beams
SHIP, TASCA	NUSTAR	Physics and chemistry of SHE
PANDA		
External Institutes	PANDA	Search for exotic states at BESIII/Beijing/IHEP (since 2006) and JLAB/Newport (starting 2015)

Mid-term research opportunities at GSI (complemented by external activities)

- **Focused, continuous research** at the current GSI facilities is of utmost importance for the success of the FAIR project. => **GSI/FAIR needs to have an active research program for the time until FAIR is online**
  (as requested by the scientific council, Heuer commission, and “Aufsichtsrat”)
  - **beam times are an important commitment of GSI/FAIR to the national and international scientific communities**
  - **beam time planning at GSI/FAIR must be reliable !**

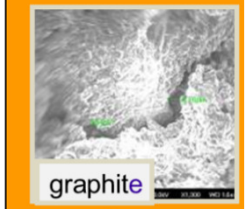
=> beam times must be part of the overall project planning !


SPARC

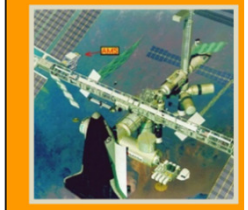


FLAIR


HEGgeHOB/WDM



MAT/BIOMAT


BIO/BIOMAT

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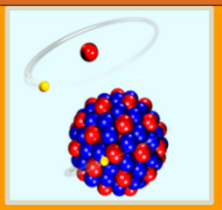
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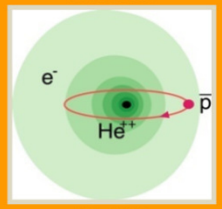

FLAIR


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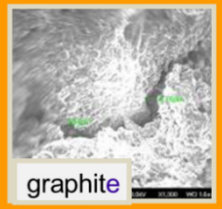

MAT/BIOMAT


BIO/BIOMAT

Conclusion

- For the **next decade and beyond** FAIR offers novel, worldwide unique research opportunities and challenges with large discovery potential for the interdisciplinary research fields of APPA.

- APPA will contribute significantly to the **very first experiments** at FAIR (CRYRING, APPA cave, HESR).

- **Rapid technological advances** in fields like laser, optics, x-ray detectors, and biomedical application implies **a permanent scrutiny** and update of the experimental methods and setups proposed by APPA. => **R&D is still needed**.

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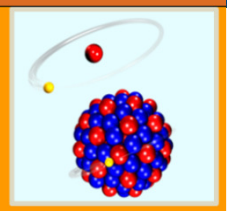
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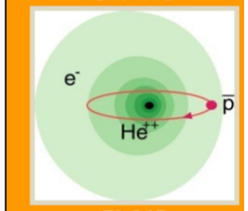

FLAIR


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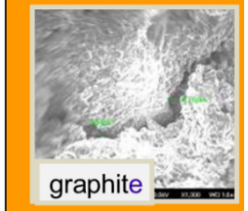


MAT/BIOMAT


BIO/BIOMAT

Thank you for your attention !

Exchange of information between experiments and accelerator groups on a regular basis needed !!!

Day-1: Attosecond Science / Laser Spectroscopy

Using novel XUV laser systems, e.g. Li-like ions up to uranium are accessible !

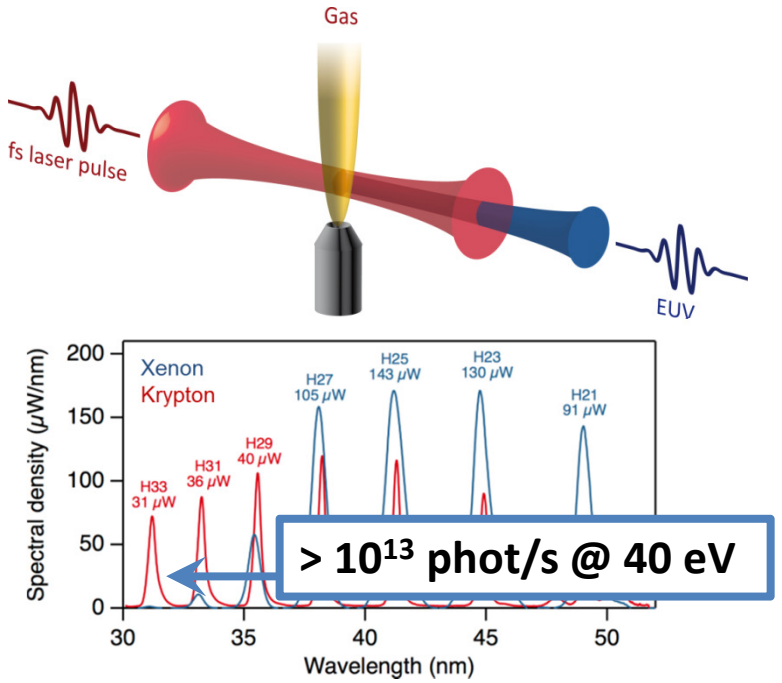
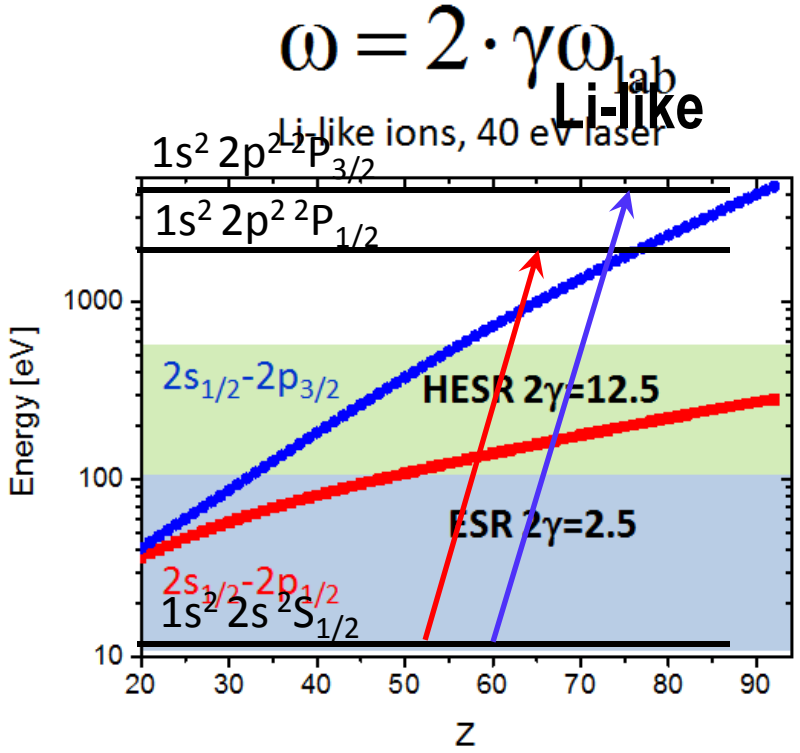


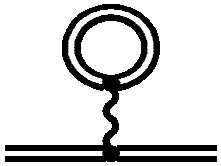
table-top source of high photon flux fs and attosecond pulses



S. Hädrich et al., Nat. Photonics **8**, 779 (2014).

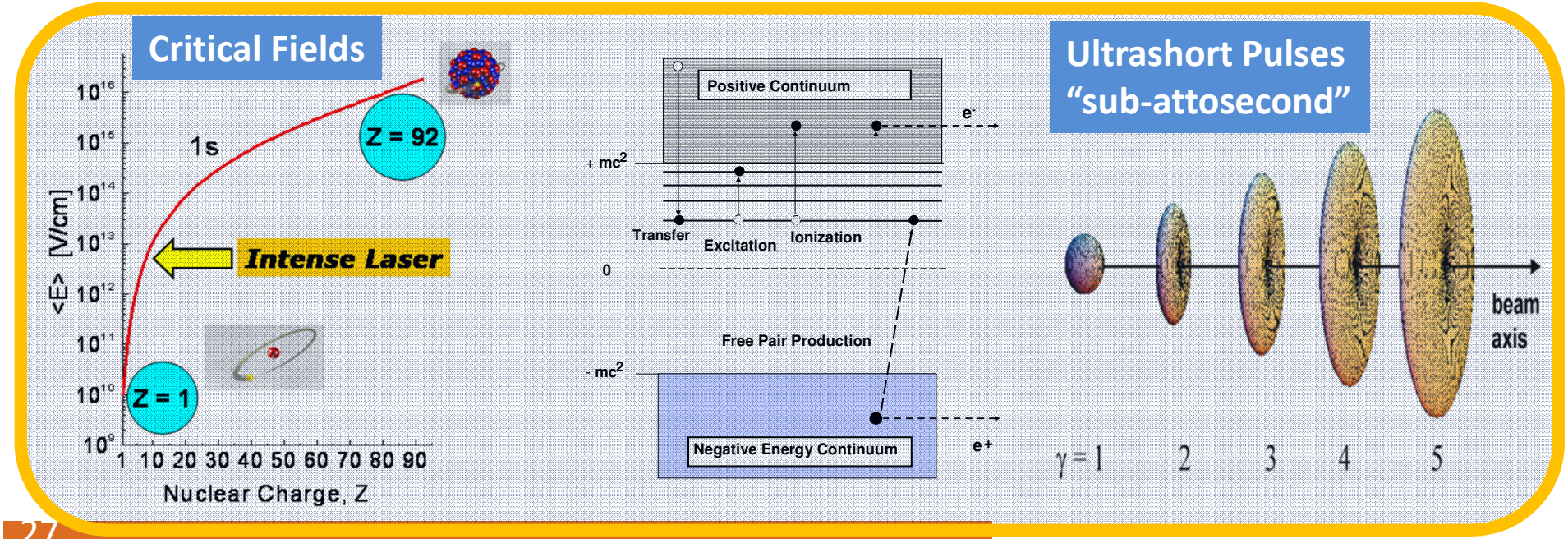
Atomic & Fundamental Physics

Interplay between Relativity, Correlation, and QED in the Non-Perturbative Regime



$$\alpha Z \approx 1$$

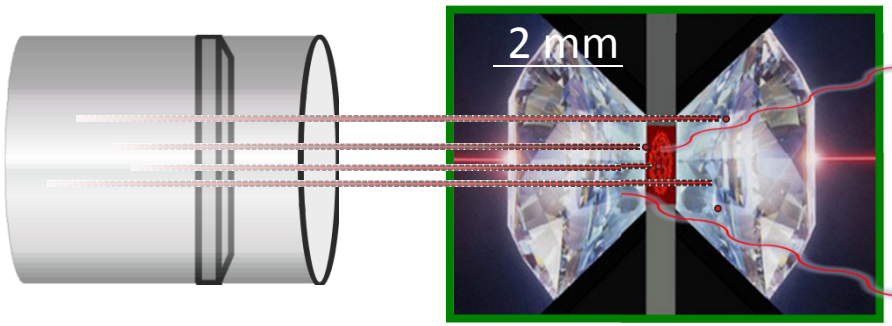
- Radiative corrections in the non-perturbative regime
- Correlated multi-body dynamics for atoms and ions
- Precision determination of fundamental constants
- Influence of atomic structure on nuclear decay properties



MAT: Experiments at APPA Cave

Materials under extreme conditions

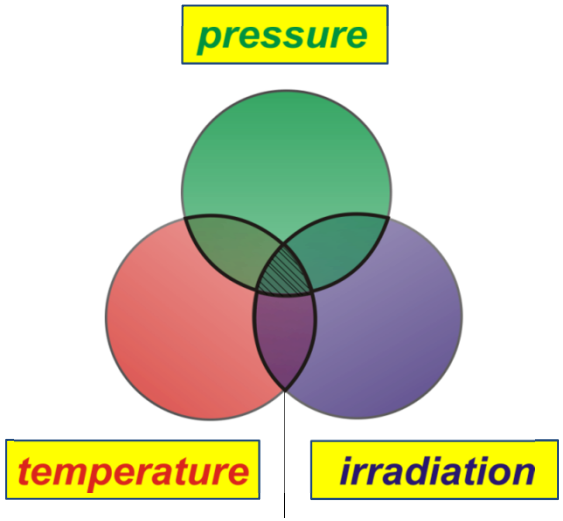
high energy
Au, Pb, U ions



Raman signal

x-ray diffraction

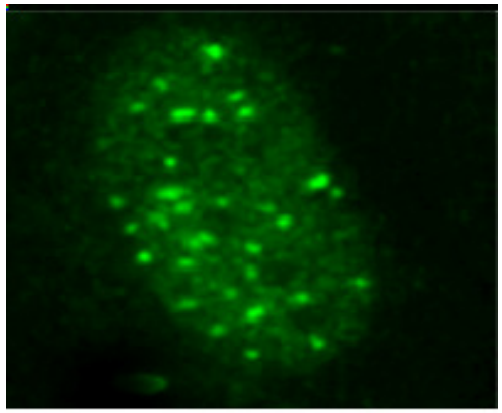
diamond anvil cell
10-1000 kbar



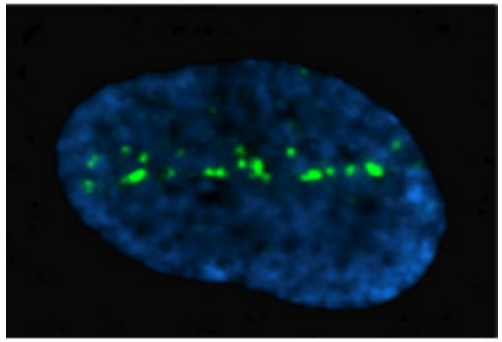
Extreme Environments

- synthesis and stabilization of new materials
- nanoscale manipulation of materials properties
- recover exotic high-pressure phases
- simulate radioactivity effects within Earth's interior

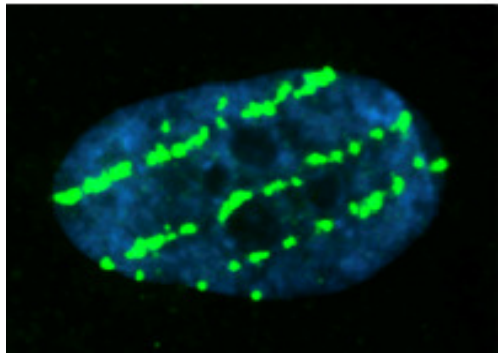
Heavy Ion Tracks Visualized in Human Cells



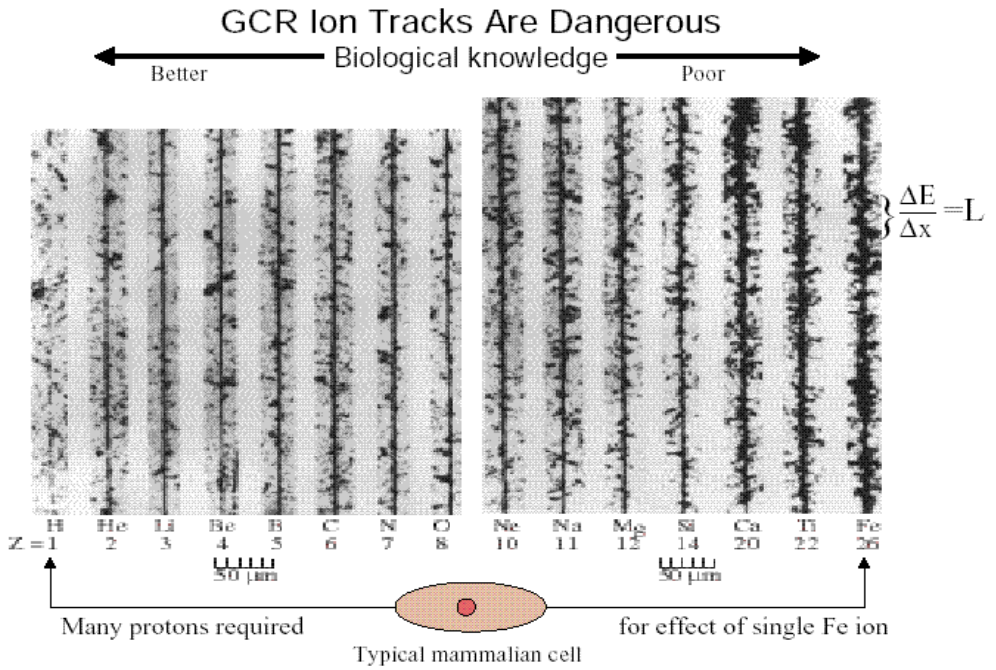
γ-rays

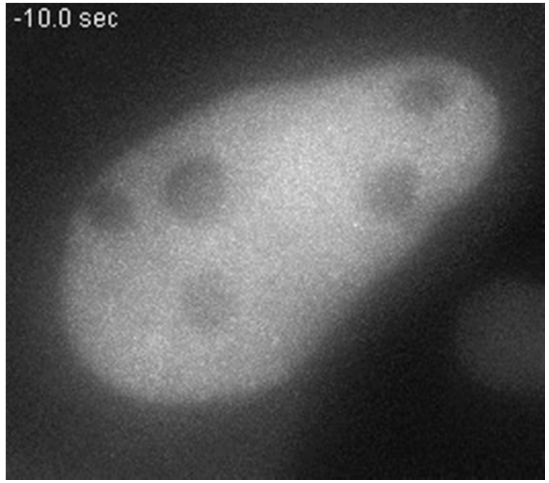


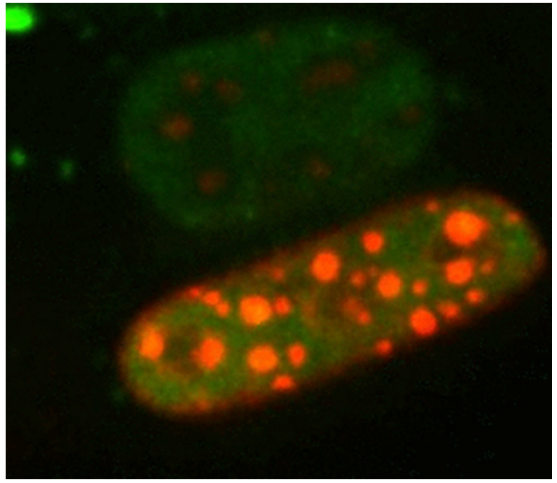
silicon



iron

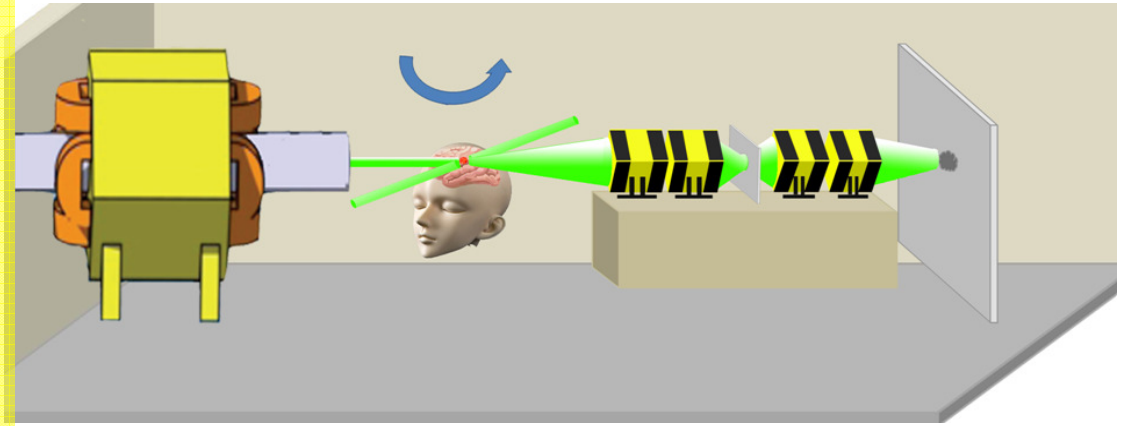


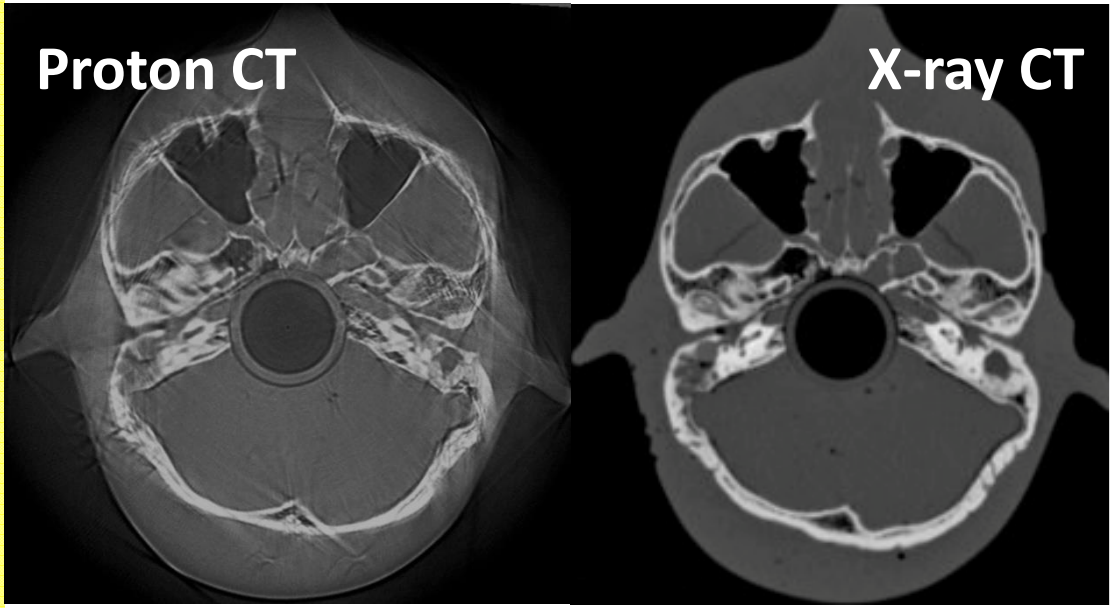




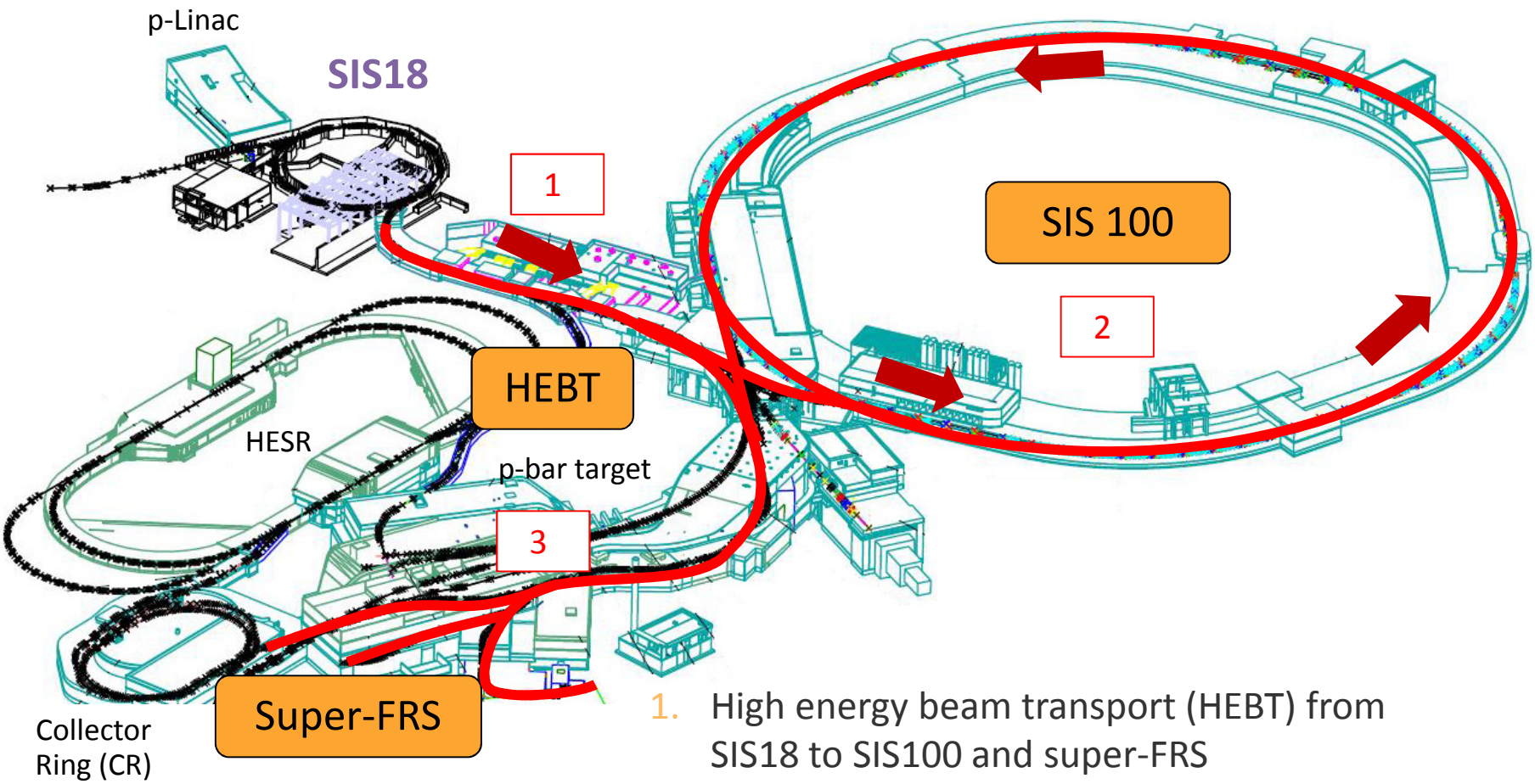
Particle Therapy at FAIR

- **New project (PaNTERA)** within APPA to exploit the PRIOR setup for therapy
- **Relativistic protons** (4.5 GeV) for image-guided, high-resolution, realtime, stereotactic radiosurgery (proton theranostics), (PRIOR setup)
- **CT of phantoms and animals** at LANL (800 MeV protons)
- **Further plans for tests of ^{11}C** and antiprotons in therapy





Scope - Staged realization along the beam towards MSV



1. High energy beam transport (HEBT) from SIS18 to SIS100 and super-FRS
2. SC synchrotron SIS100
3. HEBT100 from SIS100 to Super-FRS and the Super-FRS with three branches

APPA @ FAIR: Conclusion

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- APPA will contribute significantly to the **very first experiments** at FAIR (CRYRING, APPA cave, HESR).

- **Rapid technological advances** in fields like laser, optics, x-ray detectors, and biomedical application implies **a permanent scrutiny** and update of the experimental methods and setups proposed by APPA. => **R&D is still needed**.

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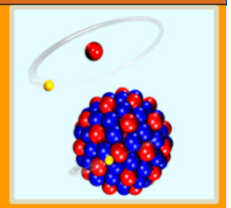
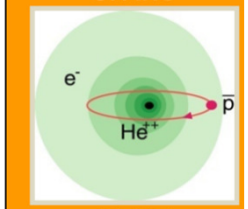
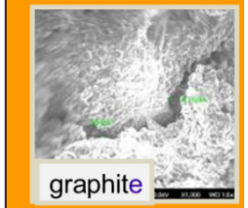

SPARC



FLAIR


HEGgeHOB/WDM

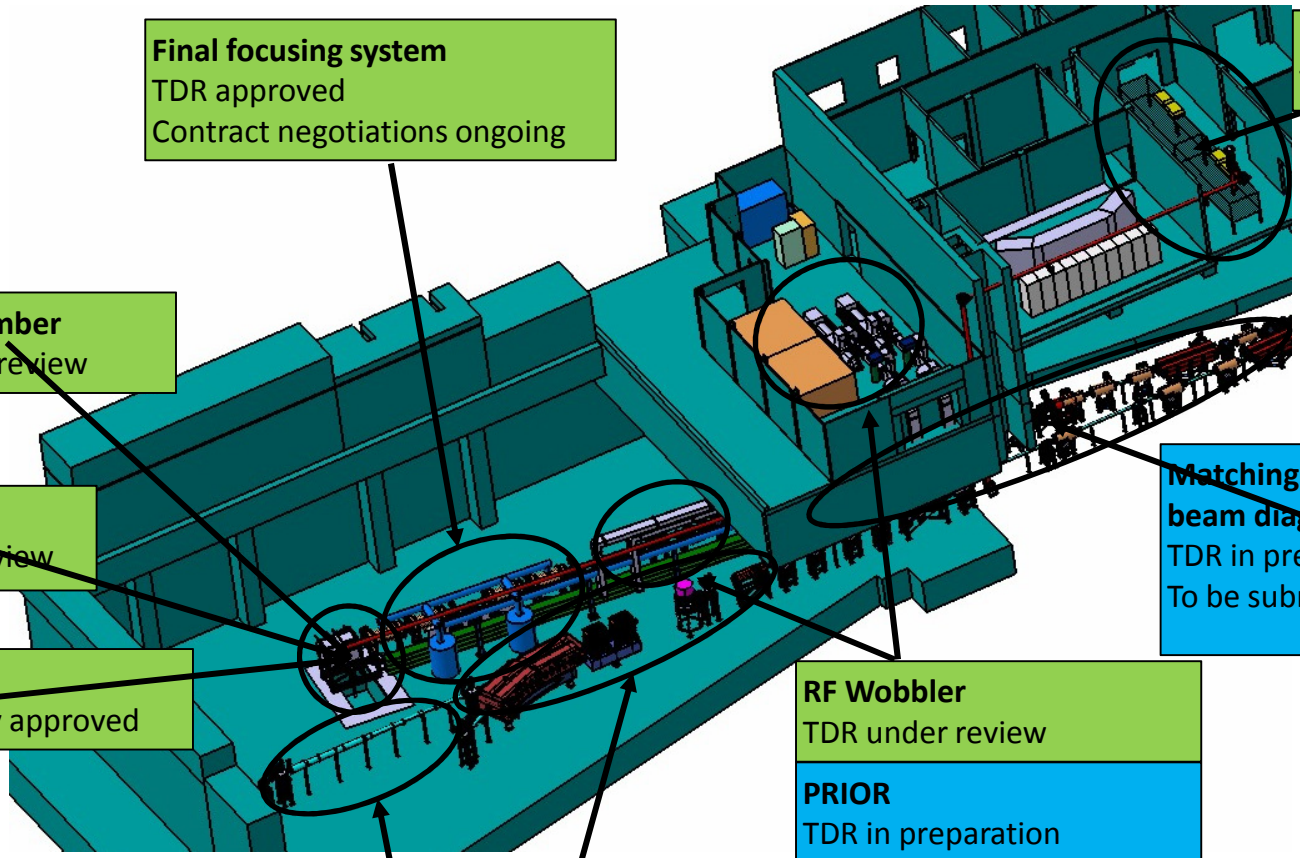


MAT/BIOMAT


BIO/BIOMAT

Thank you for your attention !

Most TDRs for first-day experiments in the APPA cave have been submitted for evaluation



Final focusing system
TDR approved
Contract negotiations ongoing

Diagnostic laser
TDR under review

Target chamber
TDR under review

Detectors
TDR under review

Data acquisition
TDR conditionally approved

Matching section inc. vacuum & beam diagnostics
TDR in preparation
To be submitted in Q4/2015

RF Wobbler
TDR under review

PRIOR
TDR in preparation
To be submitted in 2016

BIOMAT & SPARC beamlines
TDR to be submitted in 2016