FISIC (*) : an experimental program of Atomic Physics

(*) Fast Ion – Slow Ion collisions

- main scientific goals and motivations
- report on the advances …..

FISIC : an experimental program of Atomic Physics
Main goals and motivations

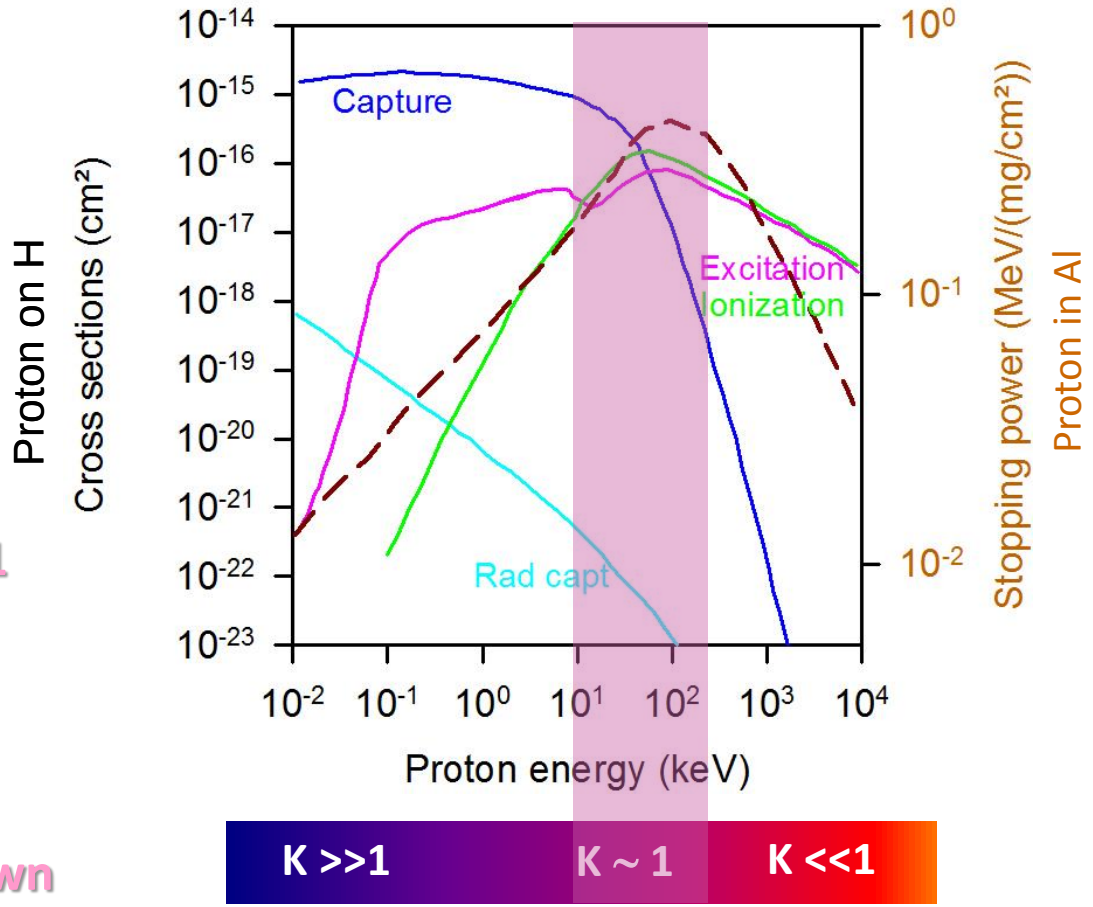
Ion-ion collisions

- **Determination of absolute cross sections of elementary collision processes**
- **with an ultimate control on dressed orbitals of the projectile AND the target ions**
- **Collision regime of interest: K ~ 1**

$$K_p = \frac{v_e}{v_p} \times \frac{Z_t}{Z_p}$$

(for projectile electrons)

There: $\sigma_{capt,\ ion,\ exc}$ are not well known while stopping power is max



non-pertubative……..to……. pertubative regime

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Main goals and motivations

Ion-ion collisions

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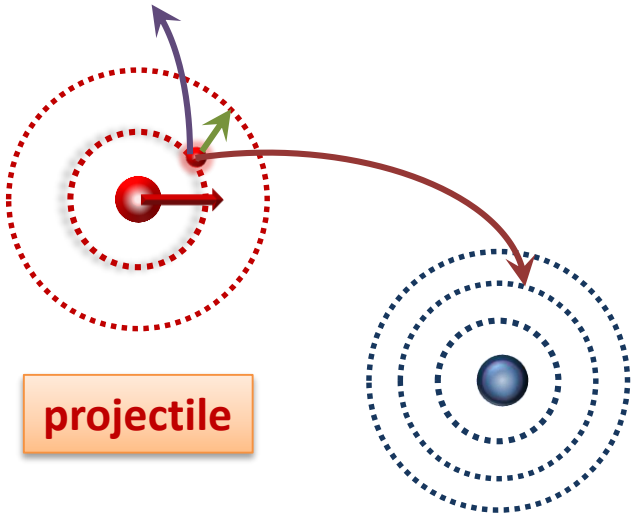
From a pure 3-body system



- **to benchmark the theoretical approaches**

ionization , excitation , capture

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Main goals and motivations

Ion-ion collisions

- **Determination of absolute cross sections of elementary collision processes**
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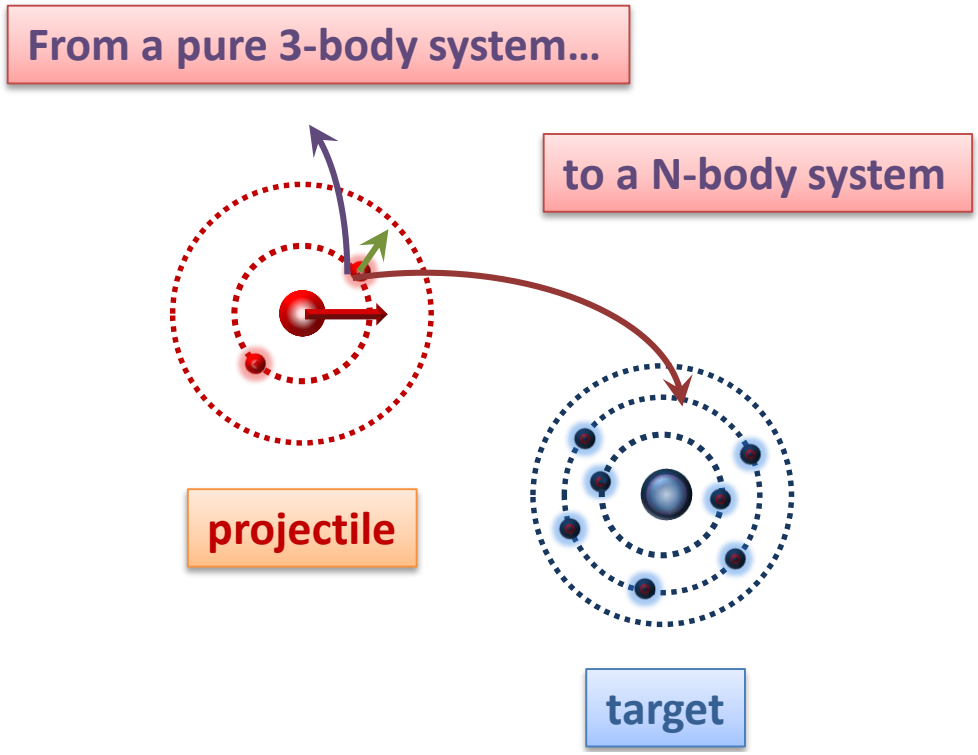
- **Collision regime of interest: K ~ 1**



- **to benchmark the theoretical approaches**
  - effect of electron – electron interactions
  - multiple processes… often neglected !
  - role of Coulomb forces
  - tuning closure of different channels
- **to explore the role of additional electrons – one by one –**

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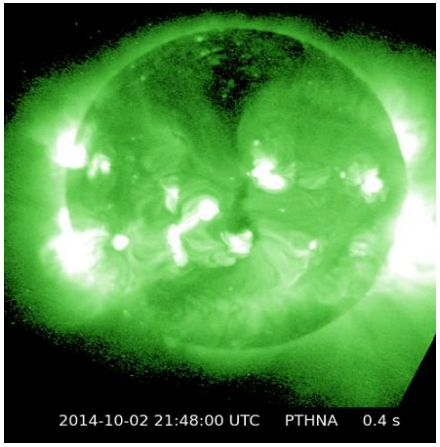
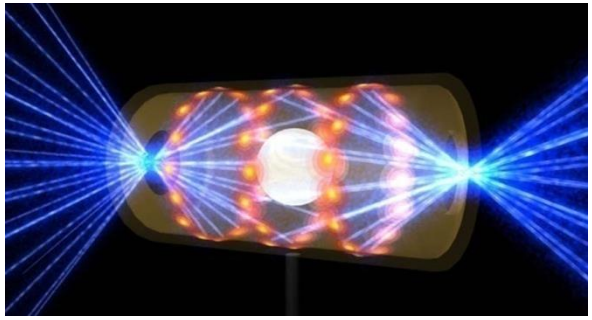
Main goals and motivations

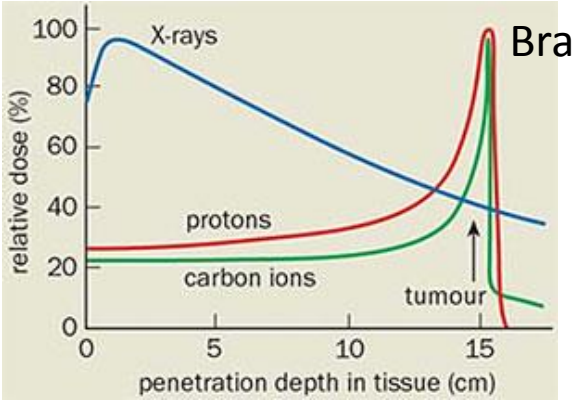
Ion-ion collisions are barely known when ion stopping power is maximum

- in plasmas
  - stellar and interstellar
  - inertial confinement fusion





- in ion-matter interaction
  - material damages



Bragg peak

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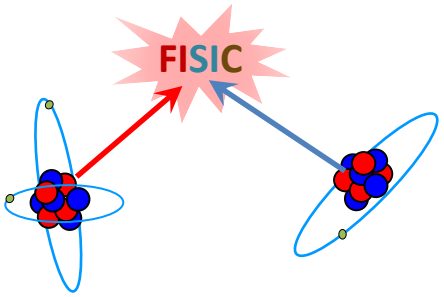
Requirements

a crossed-beam device



High Energy (MeV/u) ion beams (*projectile*)

Low Energy (keV/u) ion beams (*target*)

Beam parameters:

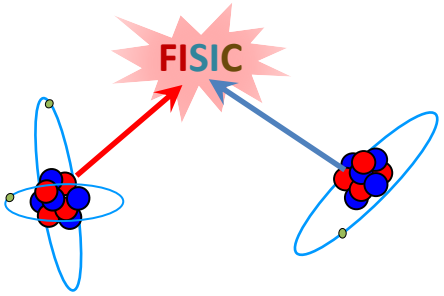
- **Initial energy**
- **Initial charge state Q+ and q+**
- **Beam intensities**

Experimental observables:

- **Final charge states: Q+, (Q±1)+,… q+, (q±1)+,…**
- **Number of ions with a specific charge state**
- **Emission of photons, electrons**

FISIC : an experimental program of Atomic Physics
Requirements

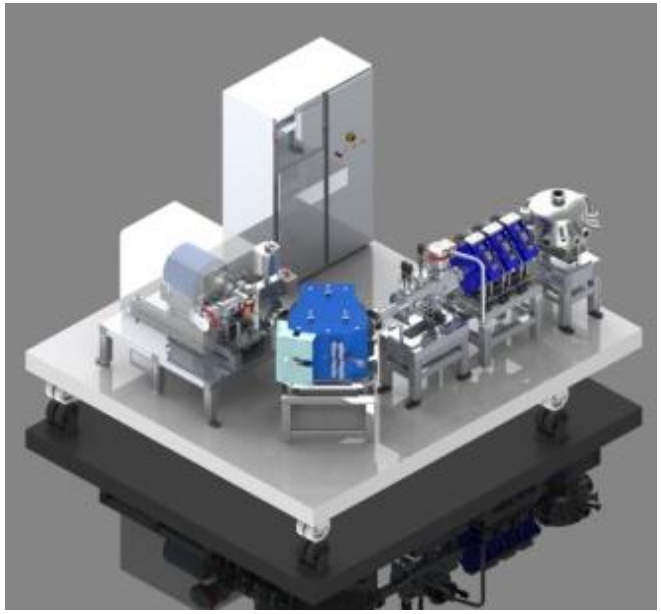
a crossed-beam device



High Energy (MeV/u) ion beams (*projectile*)

Low Energy (keV/u) ion beams (*target*)

❑ **Targets: Low Energy ion beams (keV/u)**



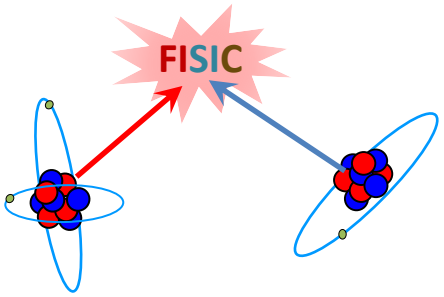
Ion source with its beam line:
stable device, easy to produce ions with $E \leq 20\ q$ kV,
$12 \leq A \leq 40$ and $3 \leq q \leq Z$
with reasonable intensities

Charge state exchange on the residual gas important
⇒ Control of the charge state before the interaction

E. Lamour SPARC collaboration

FISIC : an experimental program of Atomic Physics
Requirements

a crossed-beam device



High Energy (MeV/u) ion beams (*projectile*)

Low Energy (keV/u) ion beams (*target*)

❑ **Targets: Low Energy ion beams (keV/u)**

cross sections to measure from 10^{-20} cm² to 10^{-16} cm² but challenging experiments due to the very dilute target density (max a few 10^{14} cm^3)

❑ **Projectiles: High Energy ion beams (MeV/u)**

Very intense ion beams (10^{12} - 10^{14} pps) for single-pass experiments

Ion storage ring (effective target density increased due to revolution frequency) for multi-pass experiments

good optical quality, perfect selection of the ion charge state

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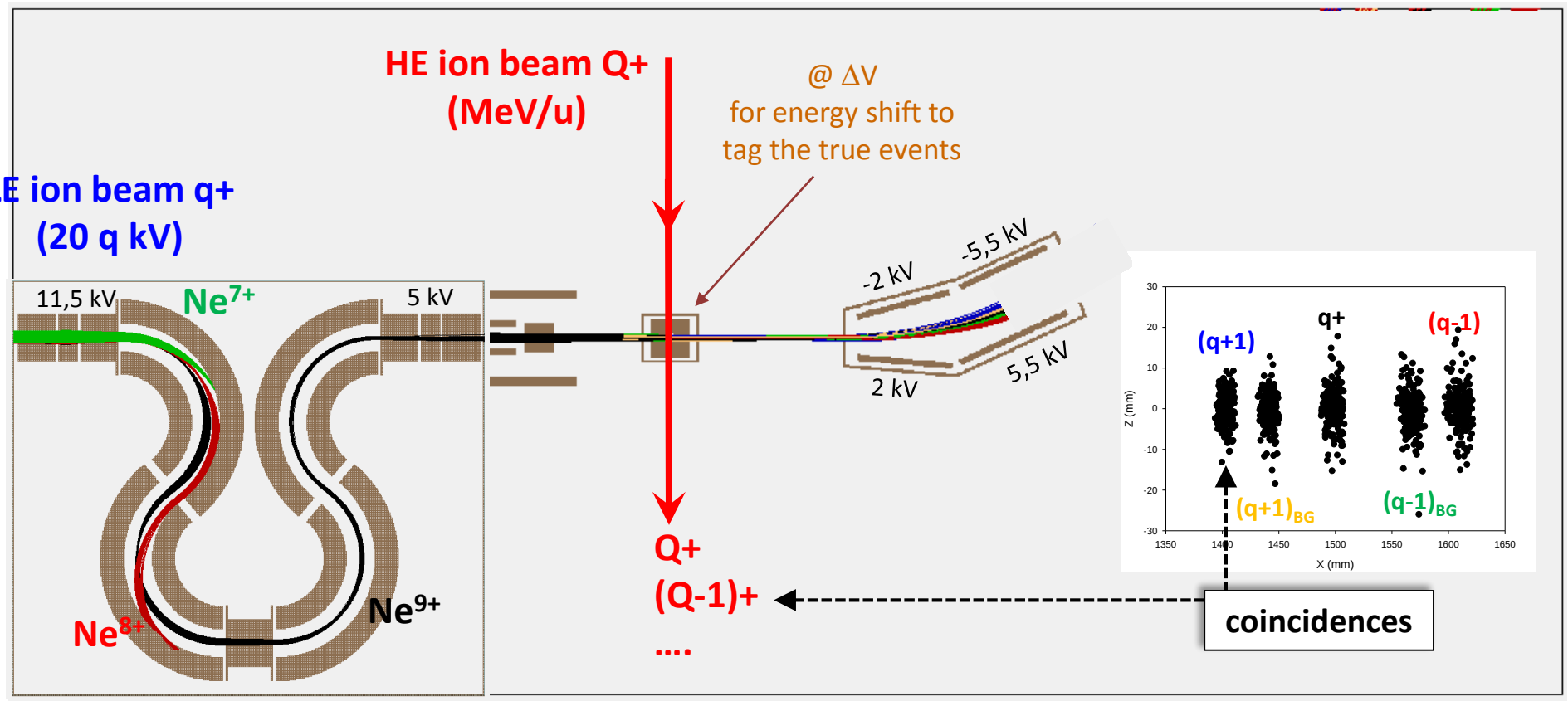
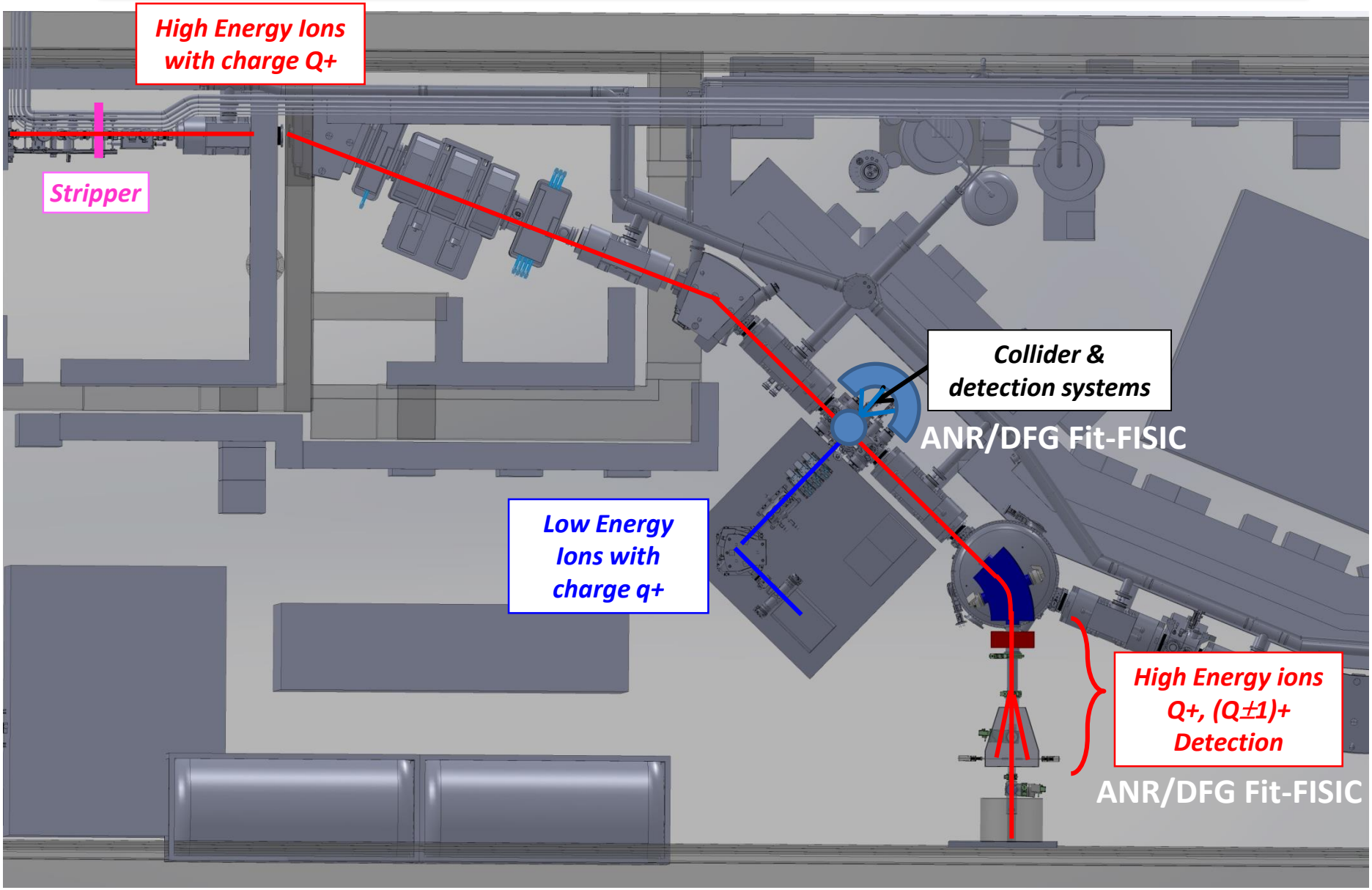
Experimental set-up

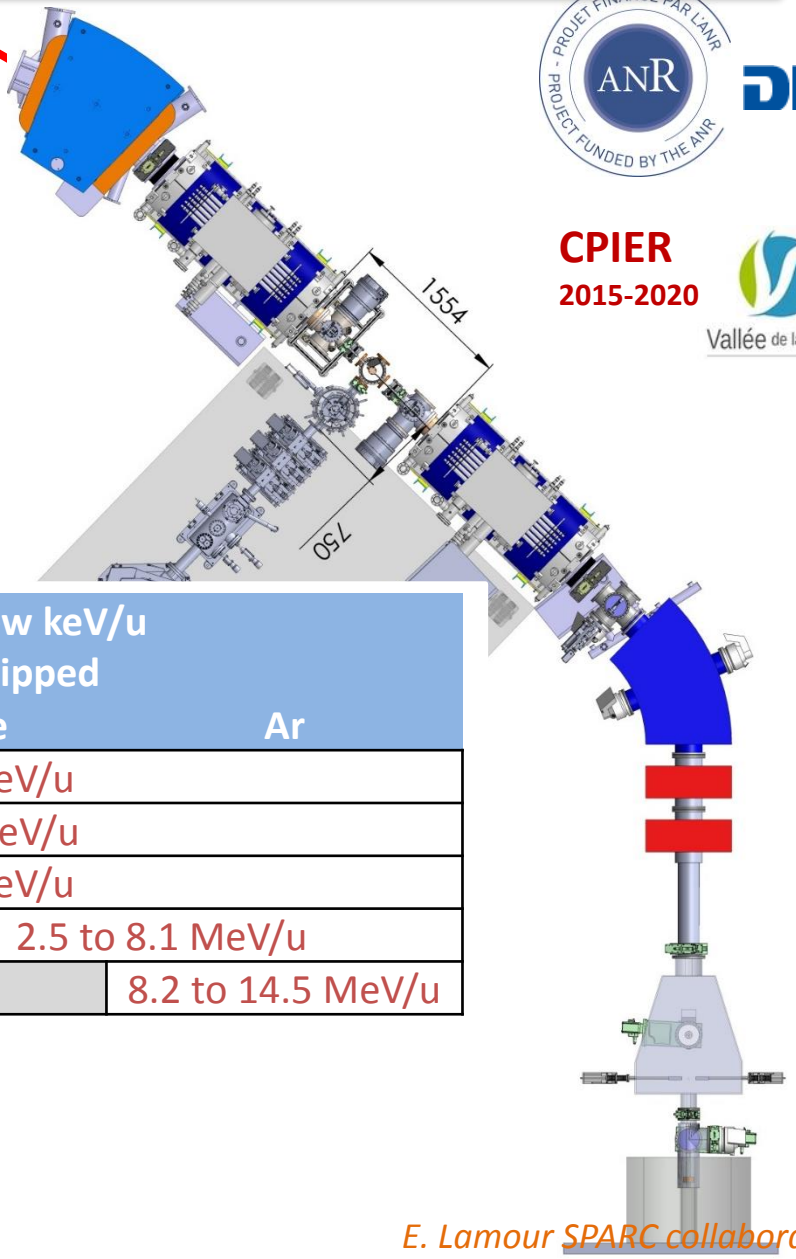


FISIC @SPIRAL2/S3 for single-pass experiments



FISIC @SPIRAL2/S3 : single-pass experiments

HE ion beam
Q+ (MeV/u)



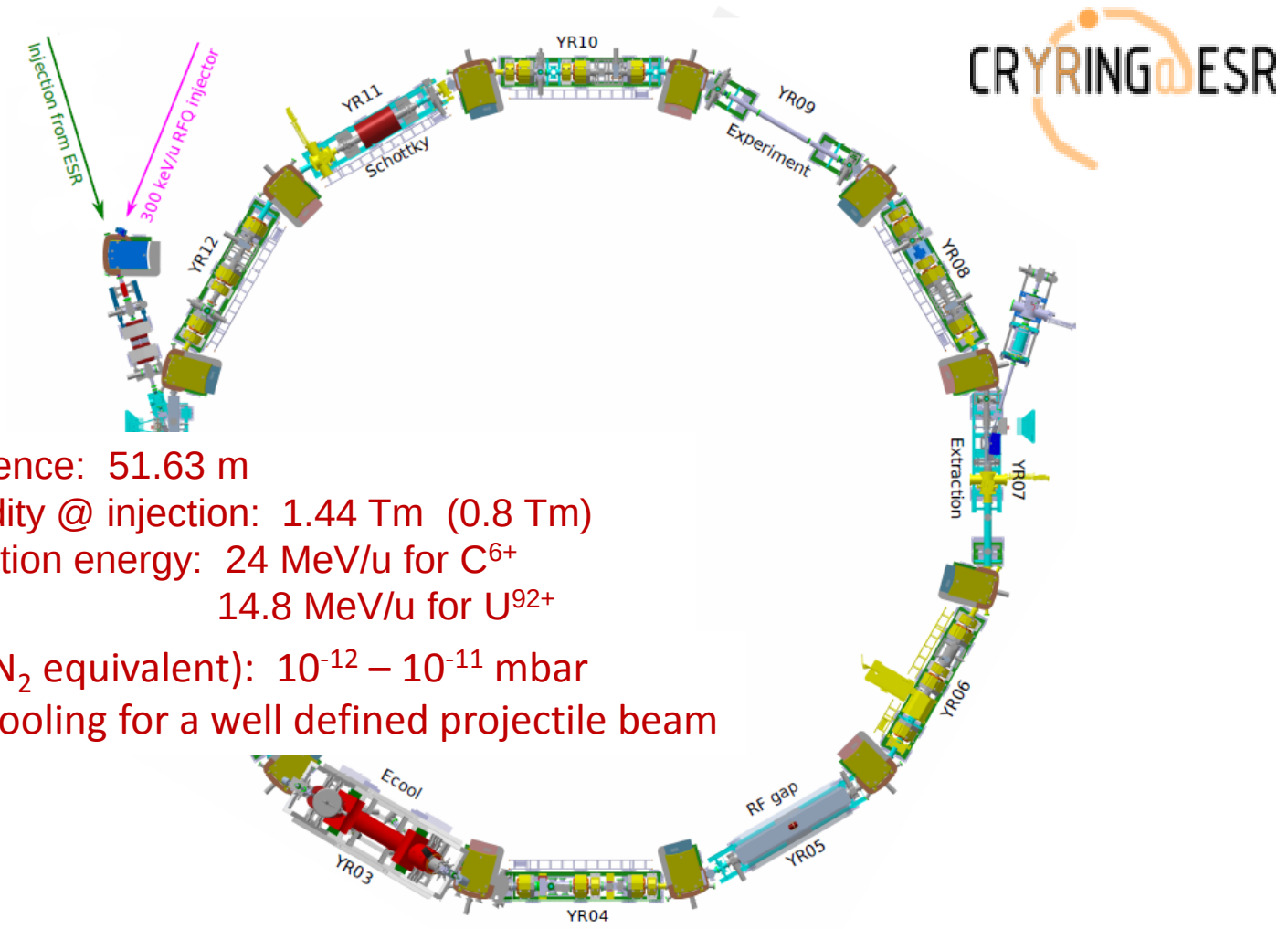
CPIER
2015-2020

Vallée de la Seine

Collision systems available with injector A/q=3

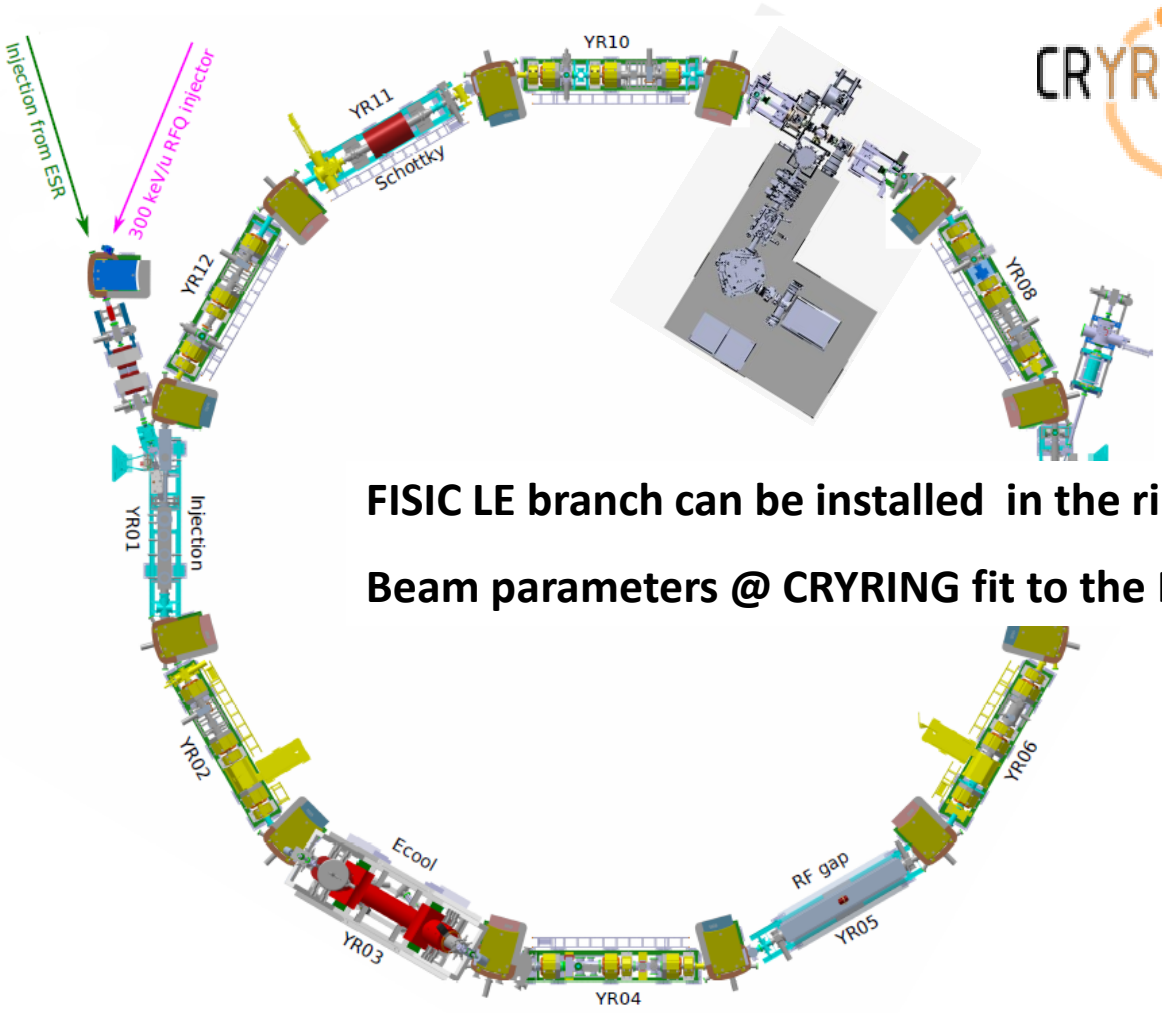
		Slow ions @ a few keV/u 1+ to fully stripped			
		N	O	Ne	Ar
Fast ions	$C^{6+,5+,4+}$	0.9 to 8.1 MeV/u			
	$O^{8+,7+,6+}$	1.2 to 8.1 MeV/u			
	$Ne^{10+,9+,8+}$	1.2 to 8.1 MeV/u			
	$Ar^{18+,17+,16+,15+,14+}$			2.5 to 8.1 MeV/u	
	$Ni^{28+,\ 27+,\ldots\ldots 18+}$				8.2 to 14.5 MeV/u

FISIC @CRYRING : multi-pass experiments



- Circumference: 51.63 m
- Max. Rigidity @ injection: 1.44 Tm (0.8 Tm)
- Max. Injection energy: 24 MeV/u for C^{6+}
  14.8 MeV/u for U^{92+}
- Vacuum (N_2 equivalent): 10^{-12} – 10^{-11} mbar
- Electron cooling for a well defined projectile beam

FISIC @CRYRING : multi-pass experiments



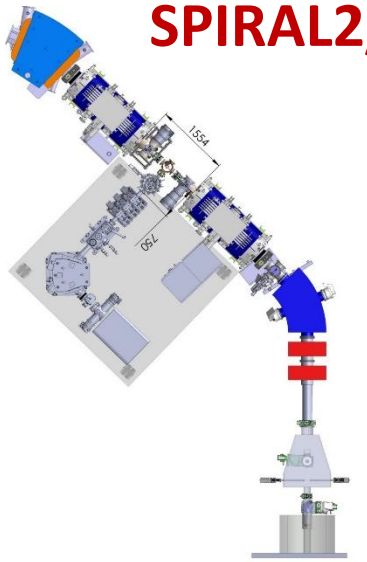
CRYRING@ESR

FISIC LE branch can be installed in the ring

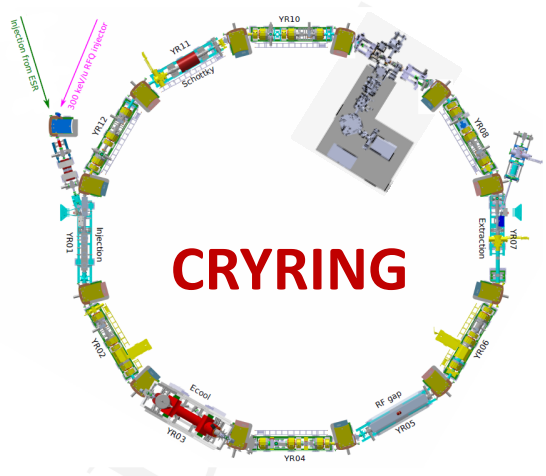
Beam parameters @ CRYRING fit to the FISIC requests

FISIC : an experimental program of Atomic Physics

SPIRAL2/S3



Medium ions: He to Ar
Symmetric collision systems



Heavier ions:… up tu U
Asymmetric collision systems

Fast Ion - Slow Ion Collisions for a wide range of collision systems , i.e. Zp & Zt

Fundamental studies of quantum dynamics of N-body systems in atomic collisions
when ion stopping power is maximum

The FISIC collaboration

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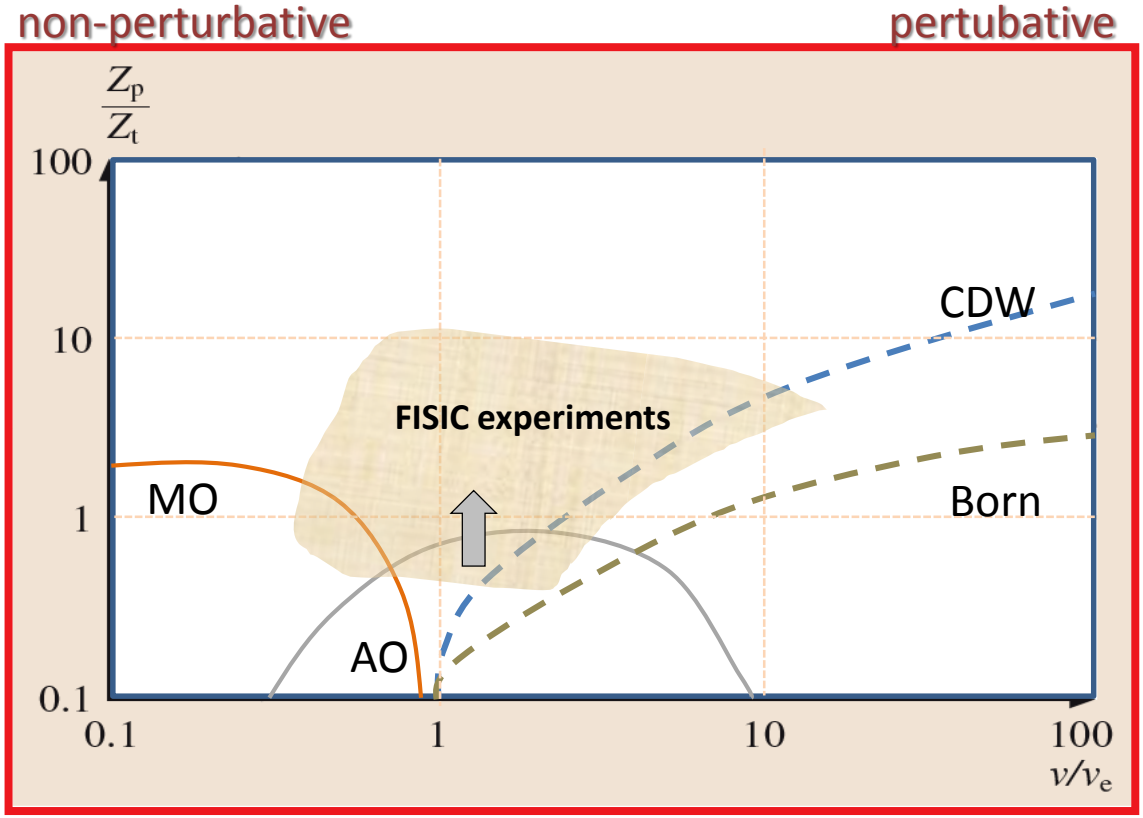
FISIC : Atomic Physics of ion-ion collisions



a breakthrough in atomic collision physics

control of the electronic state on both the target and the projectile