PhD day - Strong interaction

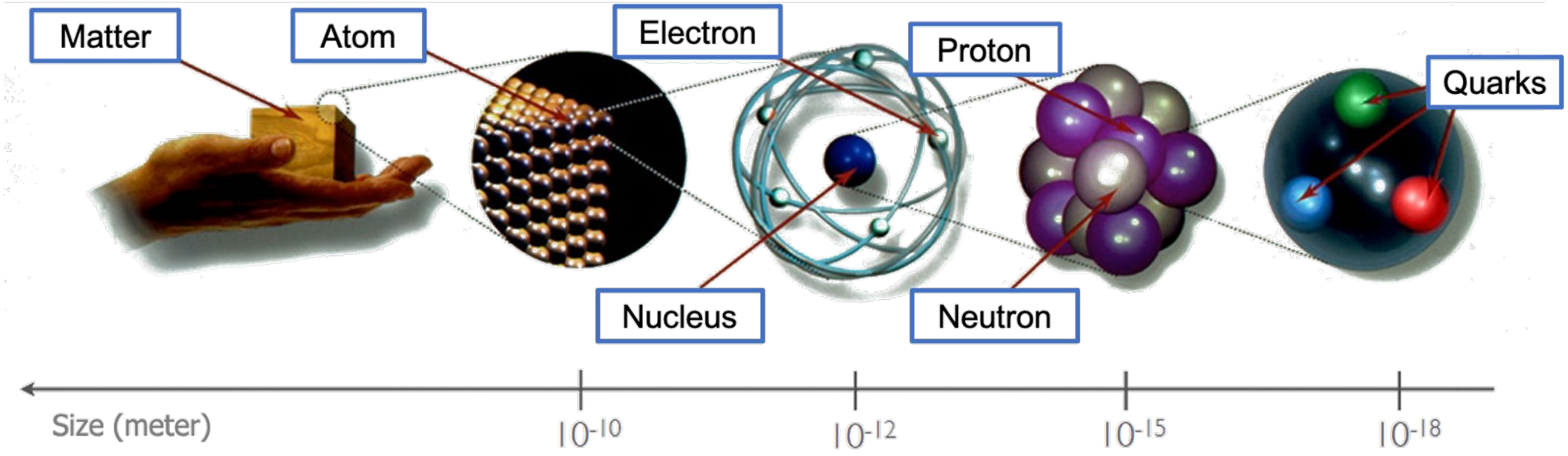
PhD students from DPhN and GANIL

Nuclear physics: what is it?

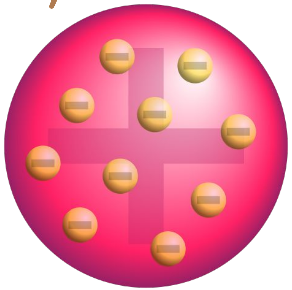
Everyday matter is made up of atoms. Atoms themselves are a bound state of a positively charged nucleus and negatively charged electrons orbiting around it.

On an even smaller scale, the nucleus is composed of protons and neutrons. Probing further, we see that the fundamental bricks of matter are quarks, bound together by gluons.

Nuclear physics is the general study of the atomic nuclei. It helps understand fundamental properties of matter and the physical forces at play



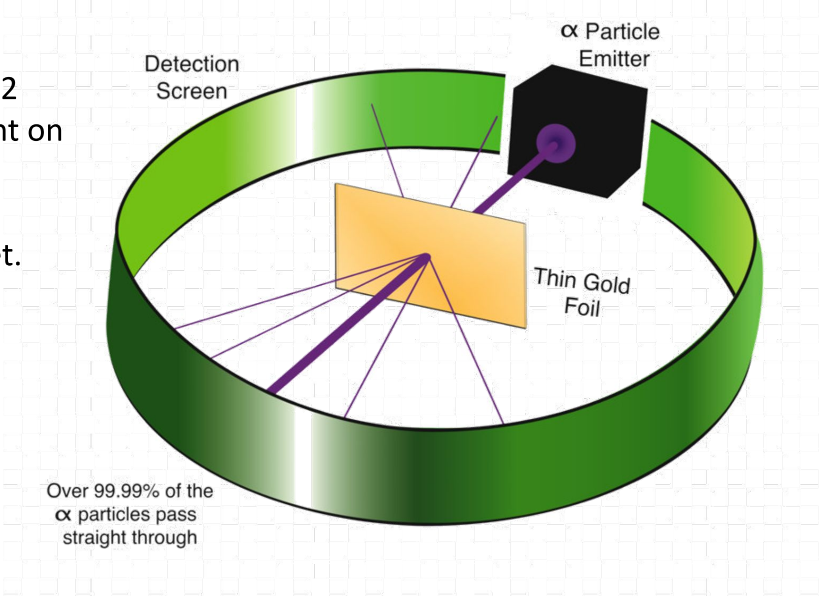
Structure of matter
An old experiment with Rutherford (1910)



Thomson and his atomic model of “plum pudding” (1904) : the atom = electrons drowned in a “soup” of positive charges

Rutherford experiment:

- Alpha particles (nuclei made of 2 protons and 2 neutrons) are sent on a gold sheet
- A detector records the particles shocks after traversing the sheet.



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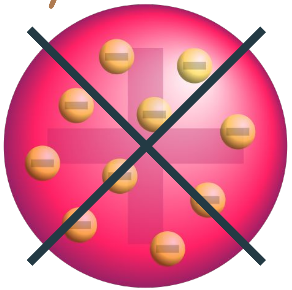
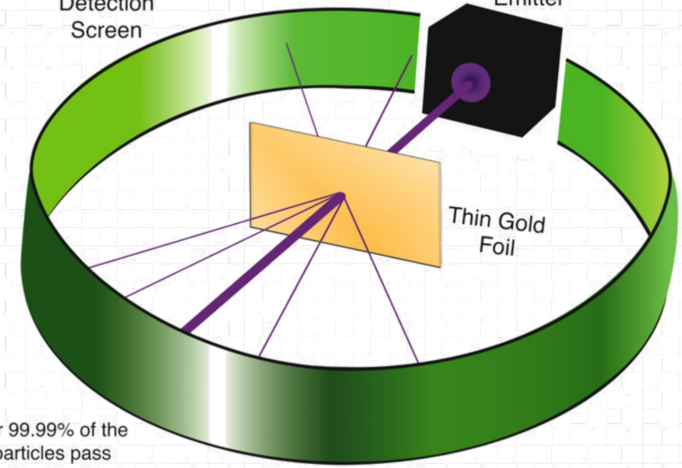
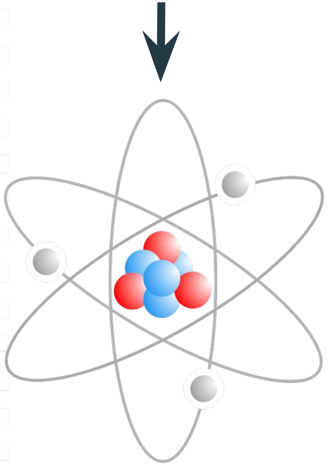


Rutherford experiment:

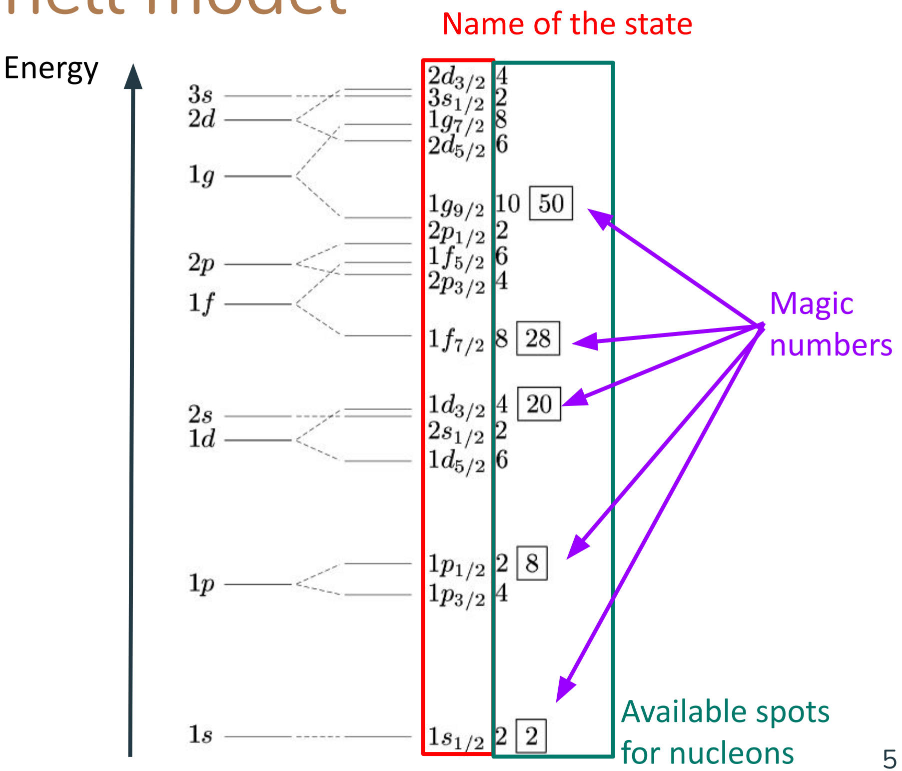
- Most particles are NOT deviated nor absorbed. However, some of them are deviated and others are rejected backwards.
- Conclusion: Rutherford thought of a atom mostly filled with vacuum, and with a positively charged nucleus (massive part of the atom) and electrons orbiting around it like planets around a star: this is the atom planetary model





Structure of matter
The modern view : the shell model

- Atom = nucleus with protons and neutrons + electrons around it organized in orbits
- Protons and neutrons in nucleus : also organized in quantized energy levels
- This structure exhibits interesting properties and needs to be probed for a wide variety of isotopes
- Some configurations are more stabilizing than others : magic numbers



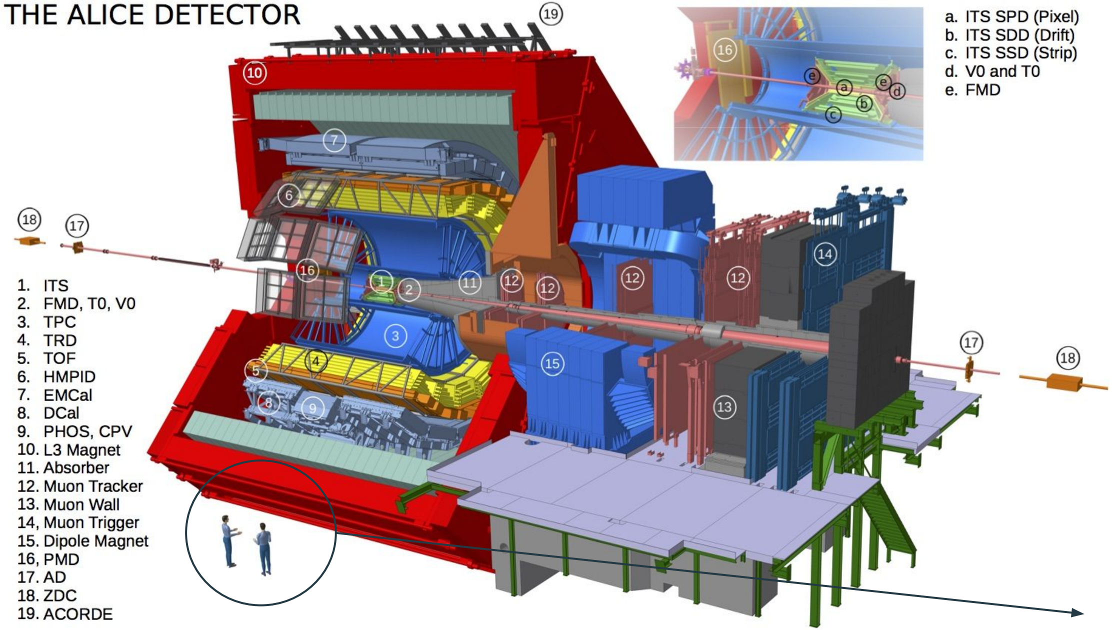
Modern experimental set ups

- After Rutherford, the need of energy to probe the properties of the atomic nucleus has been increasing, and few particles accelerators were built.
- Nowadays, the infrastructure has reached such scale that it needs from hundreds to thousands of people to be operated
- Apart from the infrastructure needed to do the experiment, the increasing amount of data produced ask for many people to work on it

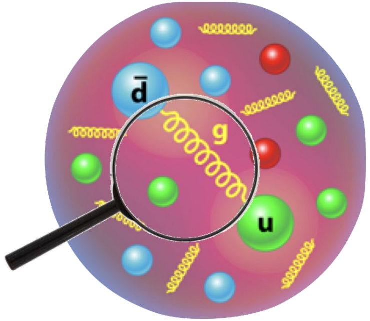
Picture of the SAMURAI dipole at RIKEN aside of multiple detectors

Picture of the current construction site of the GSI/FAIR facility

Today’s accelerators for hadronic physics



- In order to access the information on hadronic interactions within nuclei, they are accelerated up to 99.9999% of the speed of light to be collisioned
- The fragments remaining from the collision give information on the structure of the matter at very small scales, inside nucleons ($< 10^{-15}$m)



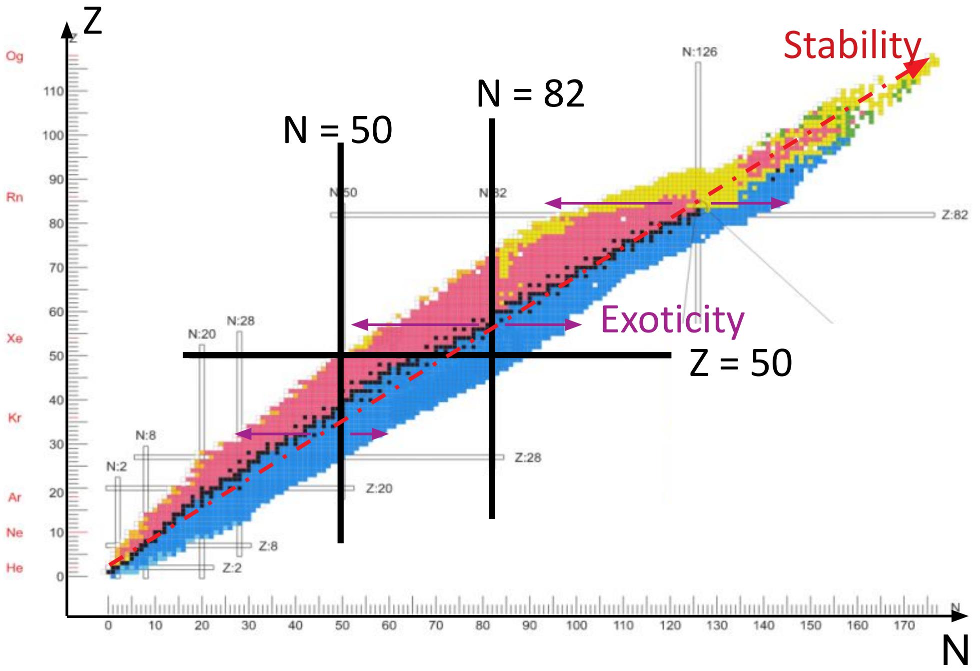
much bigger experiments with time!

Spectroscopy of exotic nuclei

Paul André

Exotic nuclei

Nucleus = N neutrons +Z protons with a certain energy organized in shells



Exotic nuclei

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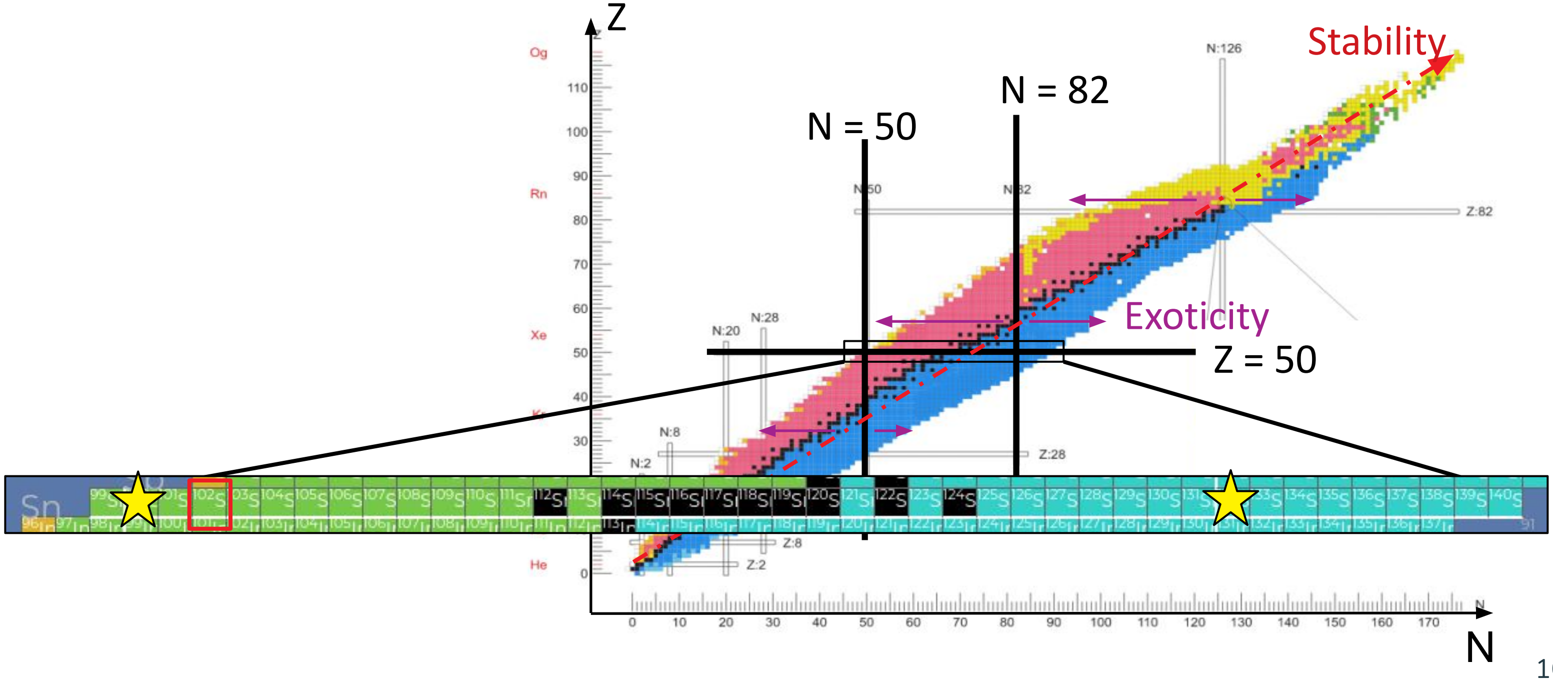

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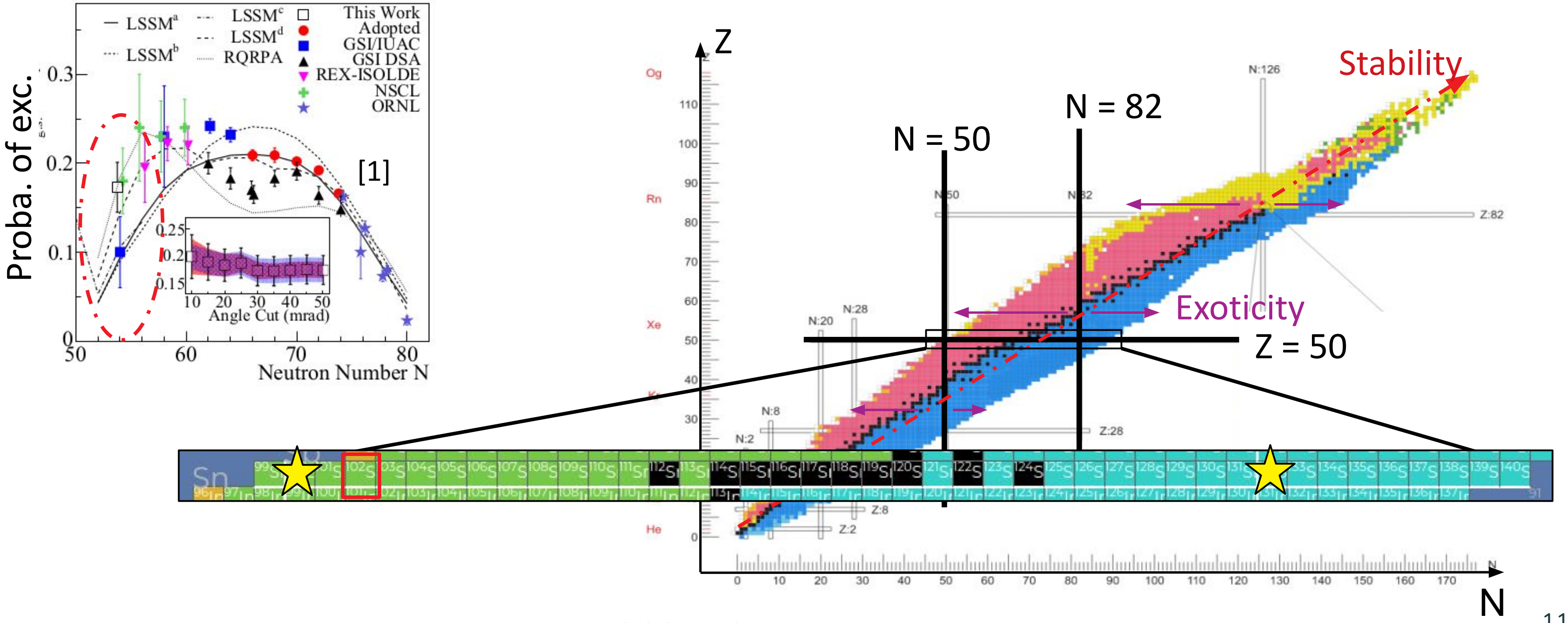
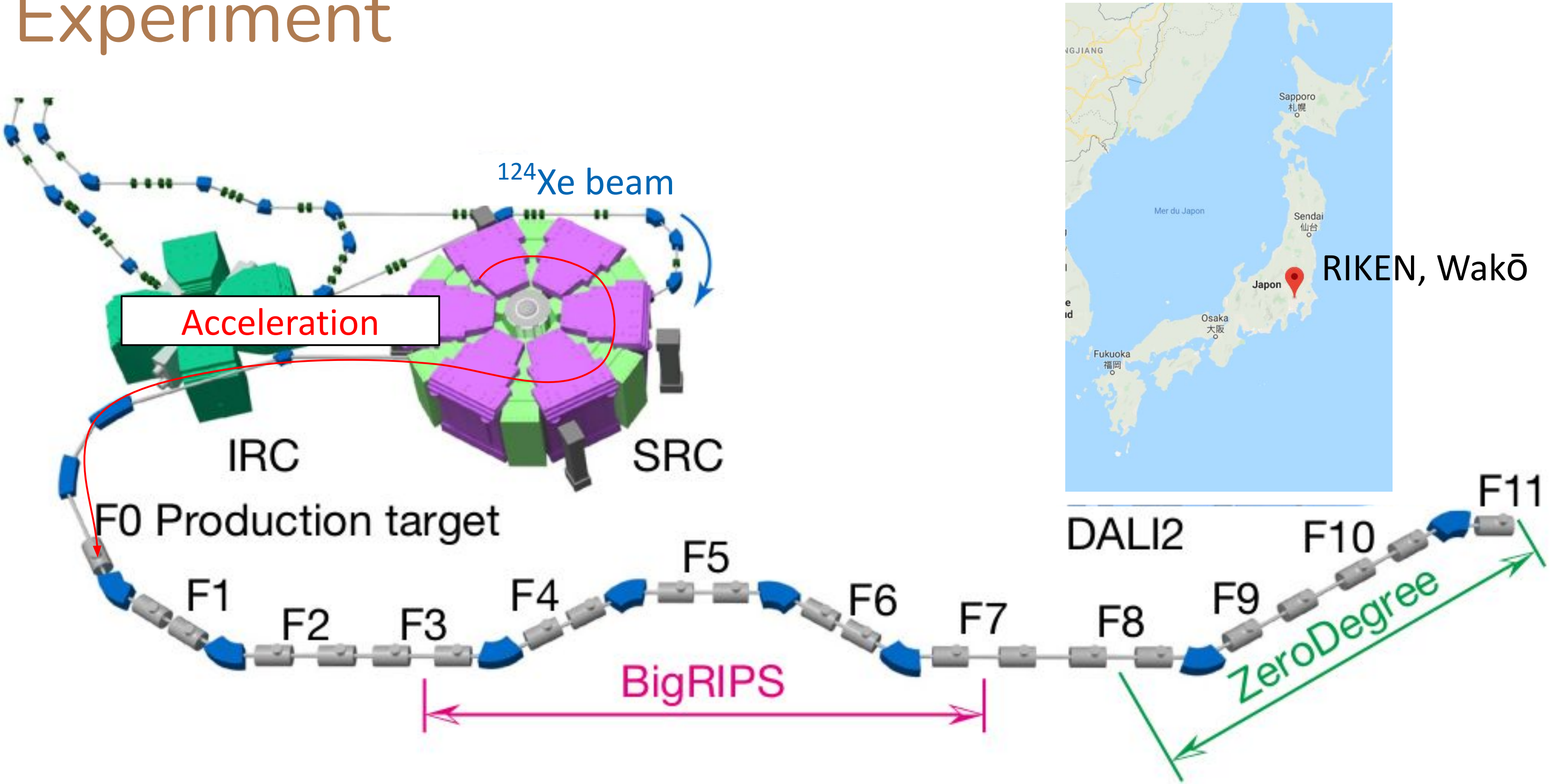


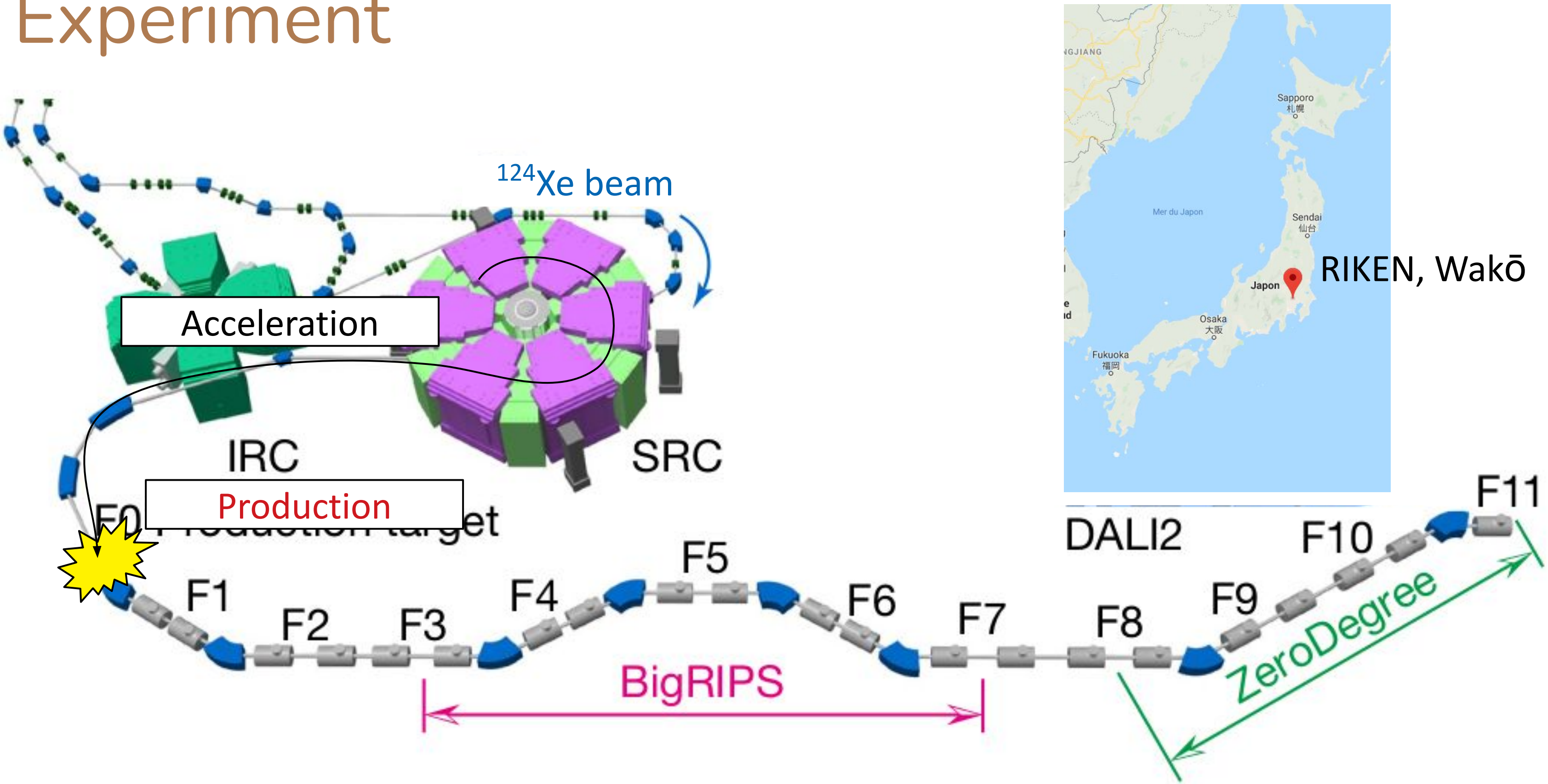
[1] Doornenbal *et al.*, Phys. Rev. C **90**, 061302(R) (2014)

Experiment



RIKEN, Wakō

Experiment



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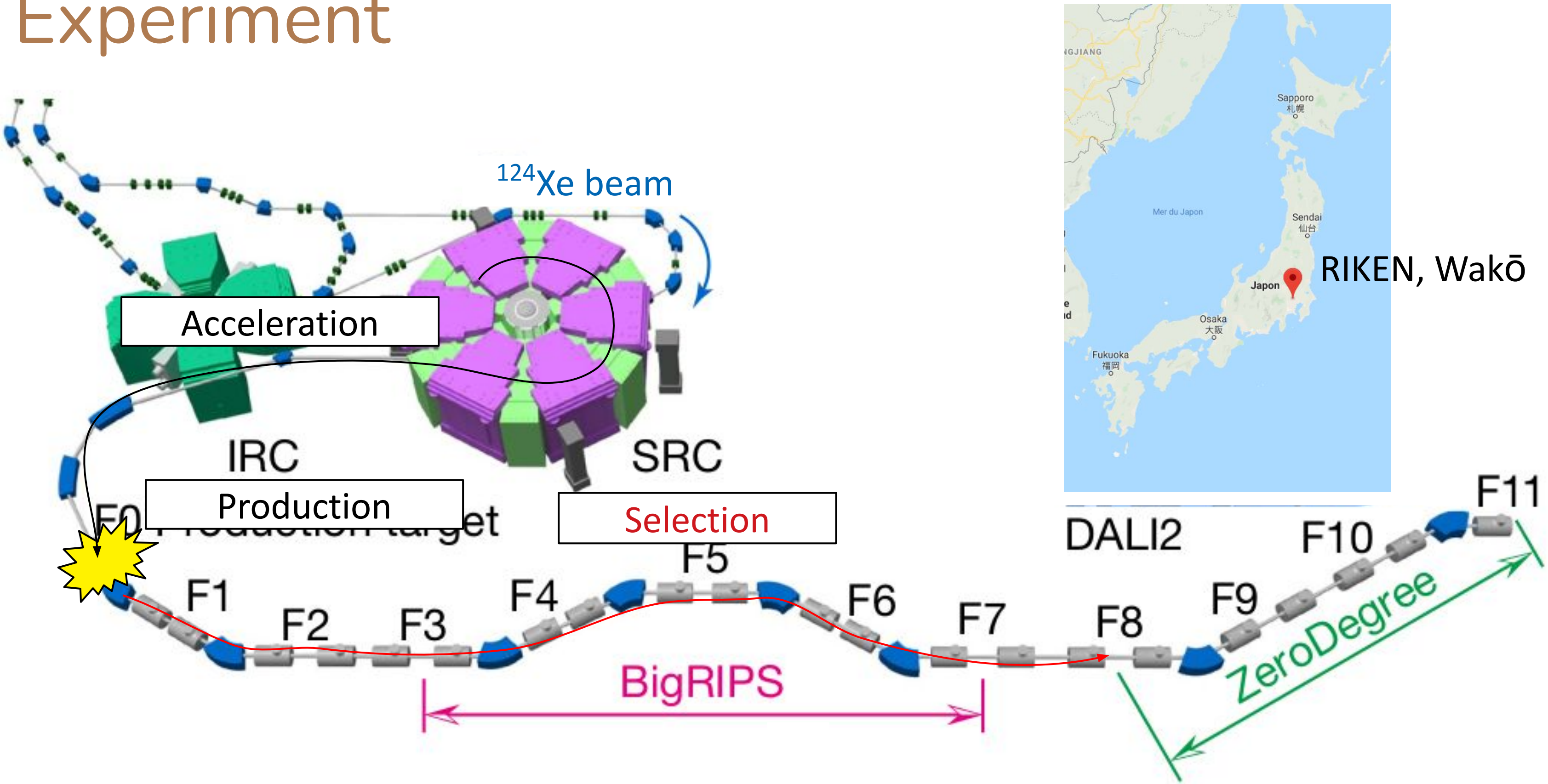
^{124}Xe beam
Acceleration
IRC
SRC
Production
F0
Selection
F1
F2
F3
F4
F5
F6
F7
F8
F9
F10
F11
DALI2
BigRIPS
ZeroDegree
Sapporo
札幌
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仙台
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Fukuoka
福岡
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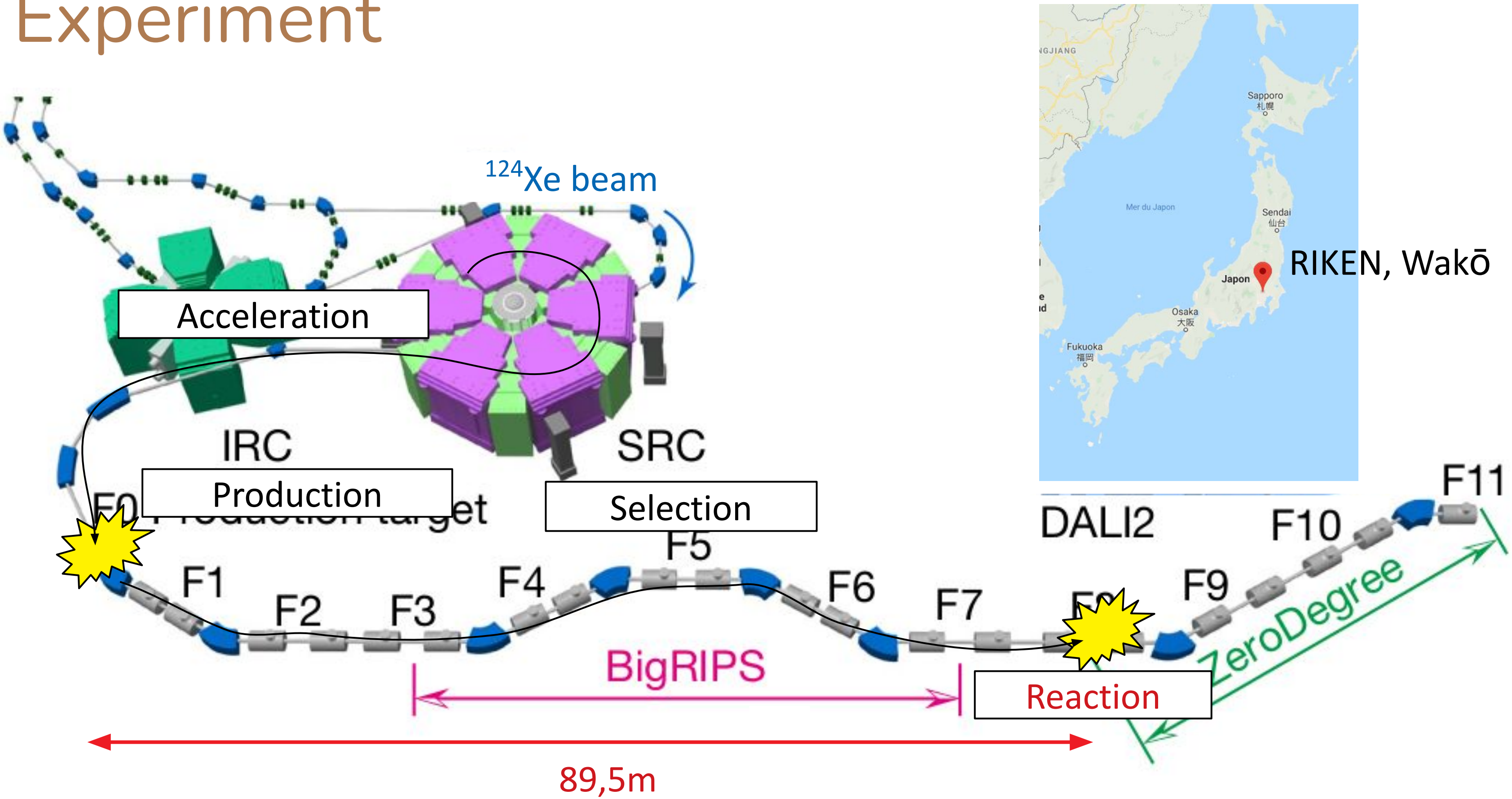

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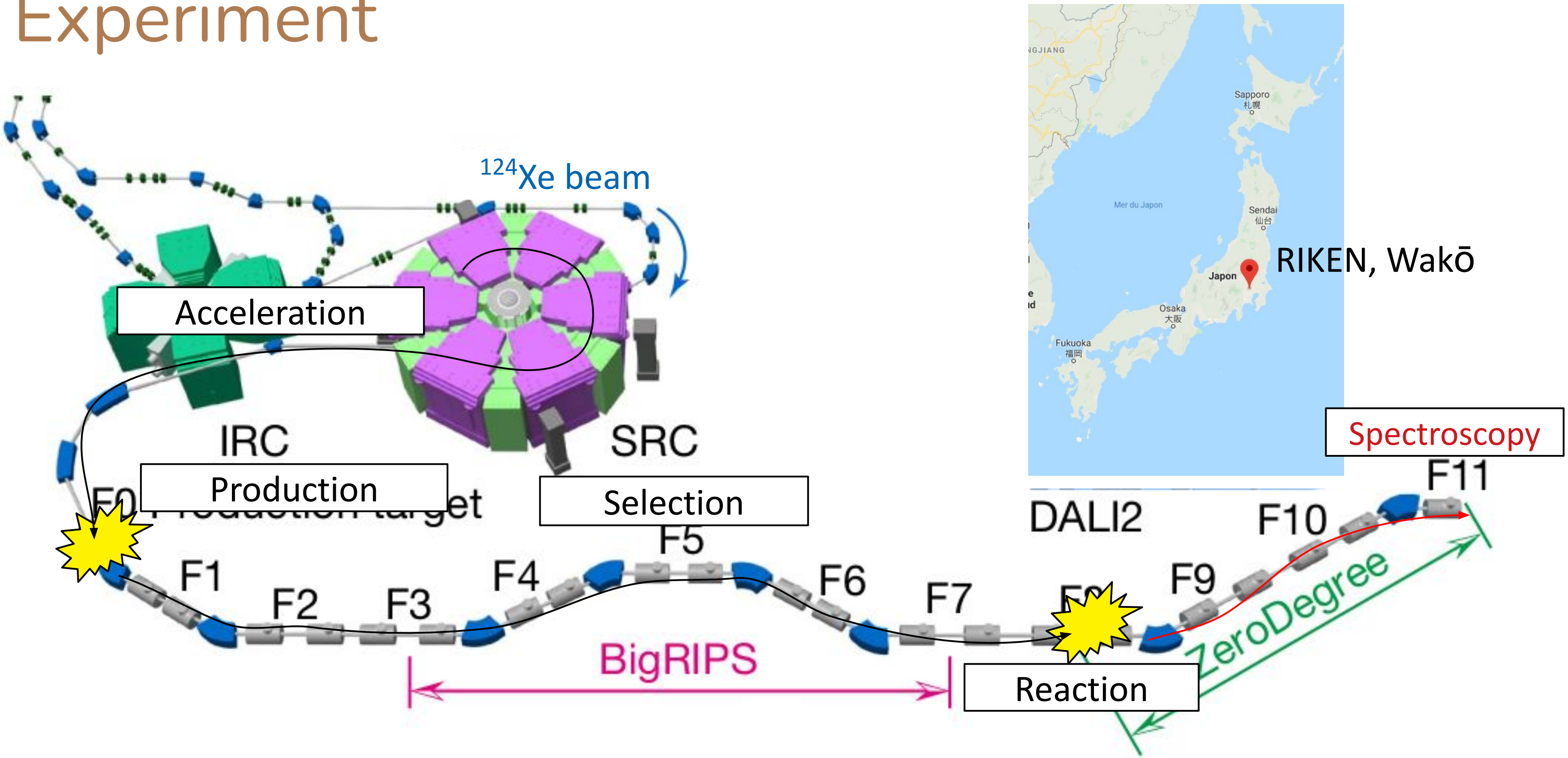

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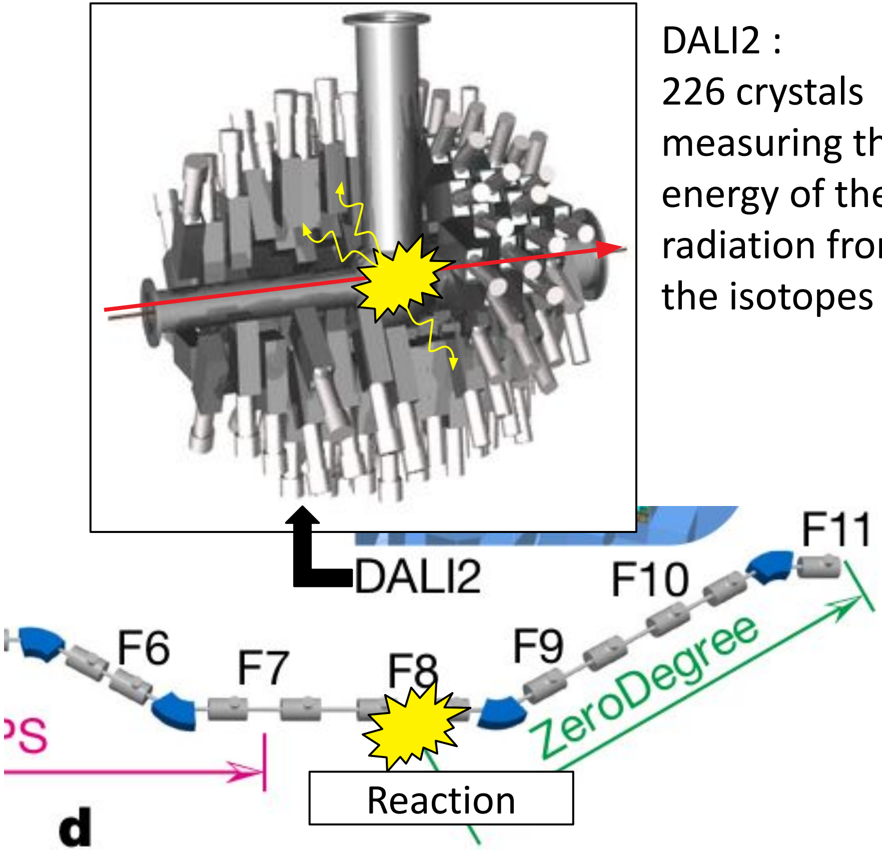
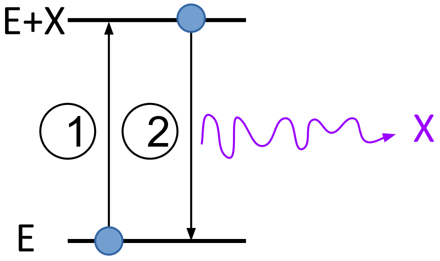
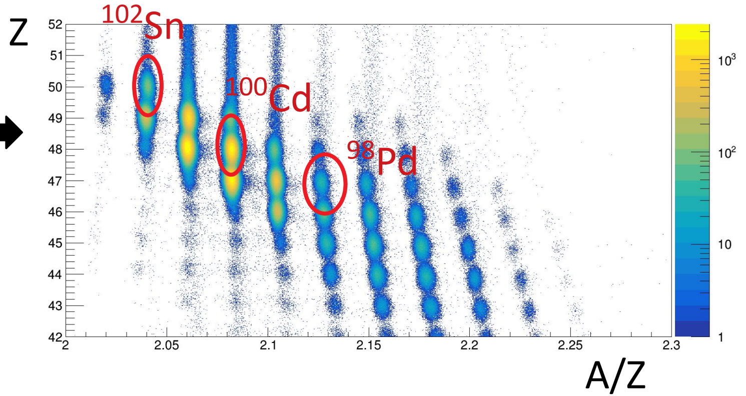
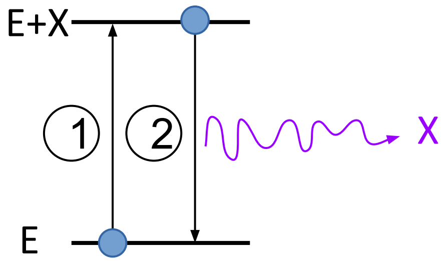


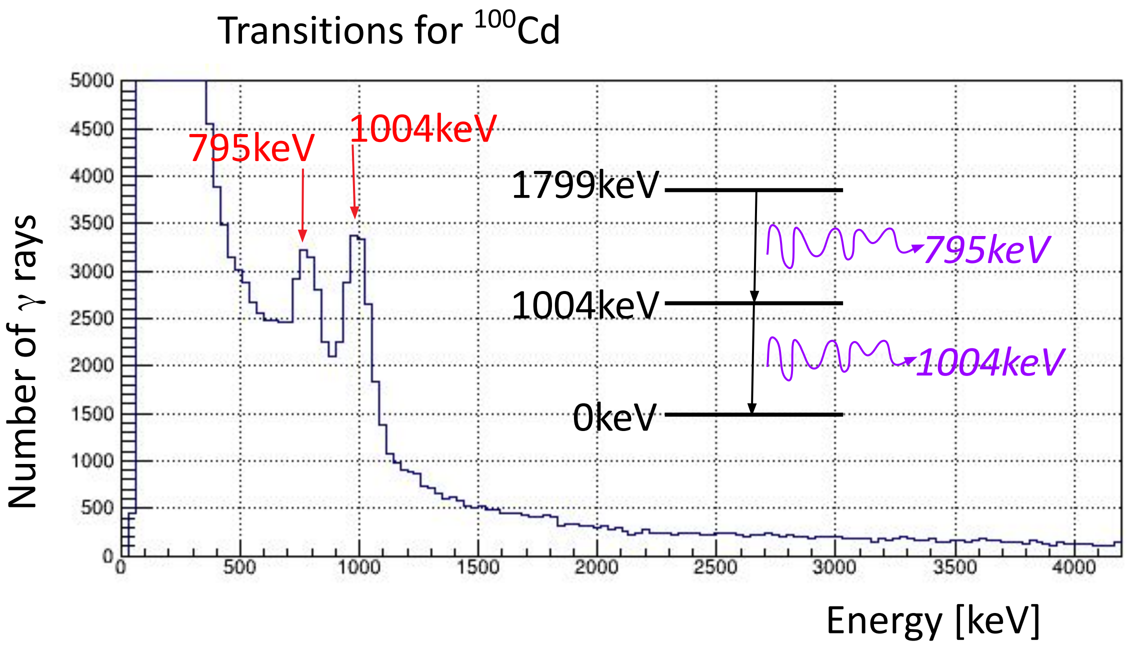
DALI2 :
226 crystals measuring the energy of the radiation from the isotopes





Results





Transition energies + Counting γ rays

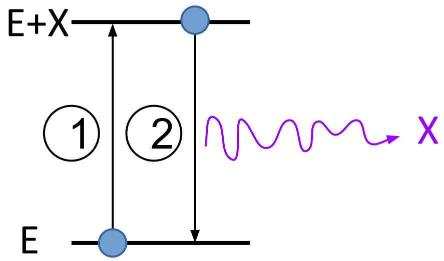
↓

Probability of populating excited states

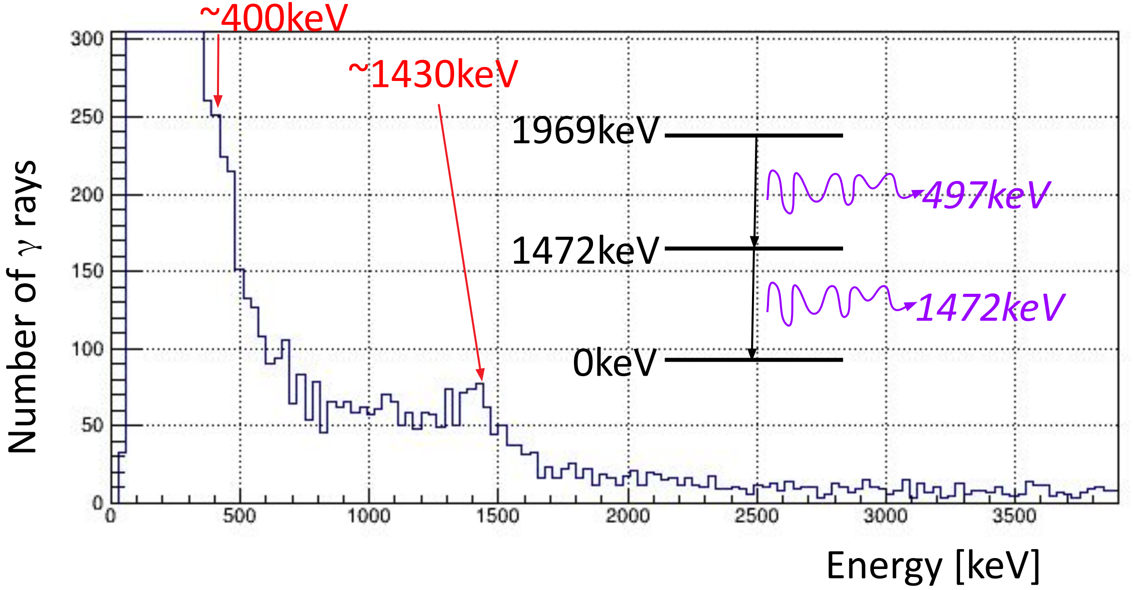
↓

Interaction between nucleons and nuclear structure

Results



Transitions for ^{102}Sn



Transition energies + Counting γ rays

↓

Probability of populating excited states

↓

Interaction between nucleons and nuclear structure

Nuclear equation of state

Julien Lemarié

Constraining the nuclear equation of state

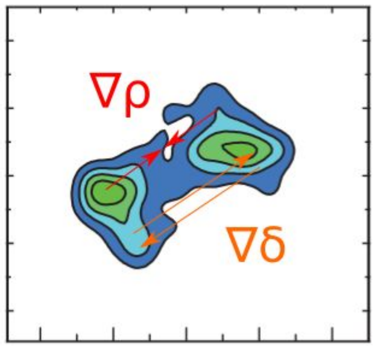
Equation of state -> Connect macroscopic observables as pressure and density
-> Predict liquid-gas phase transition

<u>Application to nuclear physics :</u>

- Nucleus is a few body system
  - Definition of an ideal infinite system -> nuclear matter
- To describe :
  - Behaviour of astrophysical objects (neutron star, supernovae)
  - Global properties of nuclei

How to constrain it?

Nuclear collisions -> Gradient of density $\nabla\rho$ and isospin (assimilated as N/Z) $\nabla\delta$
Experiment at GANIL :
58,64Ni + 58,64Ni@32,52 MeV/A
<u>Purpose :</u>
- Probe the equilibration of neutron and proton during the interaction
<u>To answer the question :</u>
Does the strong interaction favoritize exchange of proton or neutron ?



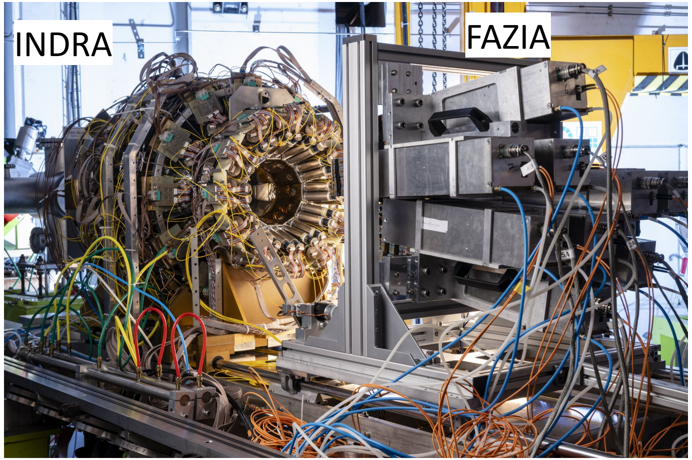
Experimental setup

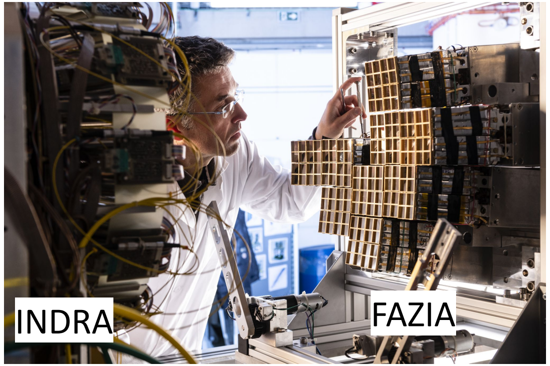
INDRA :

- 4π detector
- Measure charge Z of most nucleus detected

FAZIA :

- Forward array of 192 telescope
- Can measure mass for nuclei of charge until Z=24-25





Goal :

- Detect and identify as many nuclei as possible
- Measure the mass of the projectile like fragment (PLF)

-> more than 1000 independent channels

Methods

Timeline of a nuclear reaction :

Collision of 2 nuclei -> Quasi-Projectile in excited state (QP) -> De-excitation by emission of light particle -> Detection

To determine density and isospin gradient :

-> Need to reconstruct QP

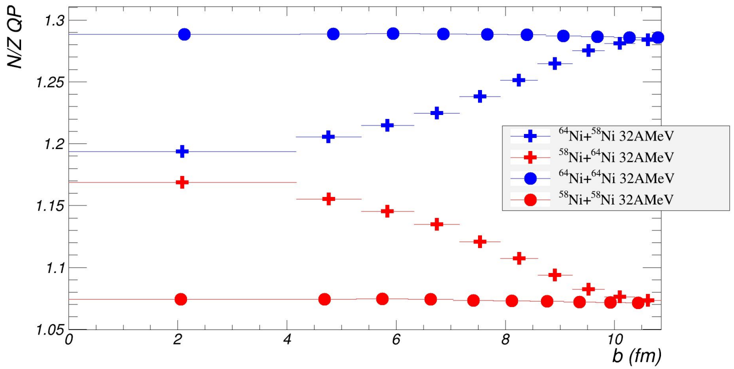
- Use event with enough charge of initial nuclei collected
- Estimate neutron emission with simulations
- Assemble every particle coming from the QP

-> Huge work of event sorting

Calibration just finished, analysis still ongoing

But simulation predict an isospin diffusion (modification of N/Z of the QP)

Simulations of the experiment



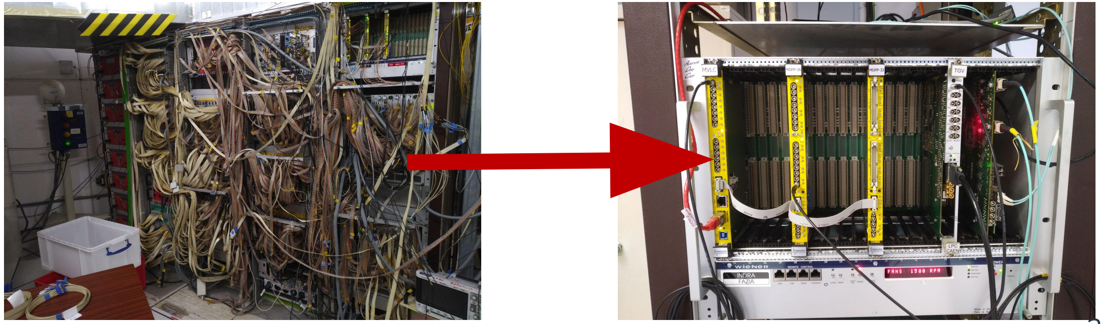
Conclusion

Nuclear equation of state -> Constrain theoretical models

Analysis still ongoing :

- Reconstruct the QP
- Compare with theoretical models (Anti-symmetrised Molecular Dynamics)

- Renew of INDRA electronics



Study of the Quark-Gluon Plasma

Elliptic flow of the J/ψ in proton-proton collisions

Sébastien Perrin

Formation and study of the QGP

Study of Quark-Gluon Plasma (QGP)

- Deconfined state of matter
- Freely-roaming color charges

Formation through Heavy-ion collisions

Pb-Pb ⇒ Formation of QGP

Pb-p, p-p ⇒ Reference (Assume no QGP formation)

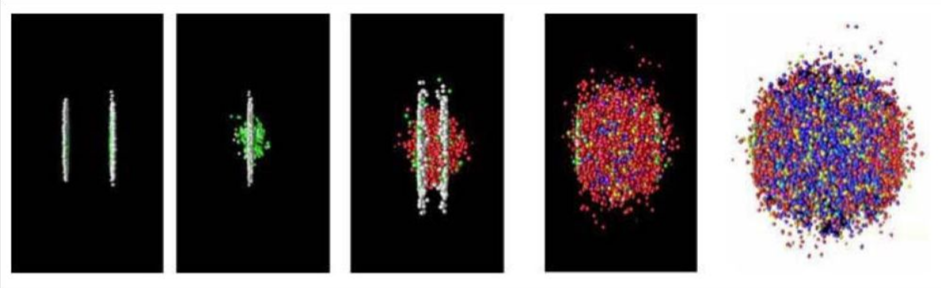
What to look at ?

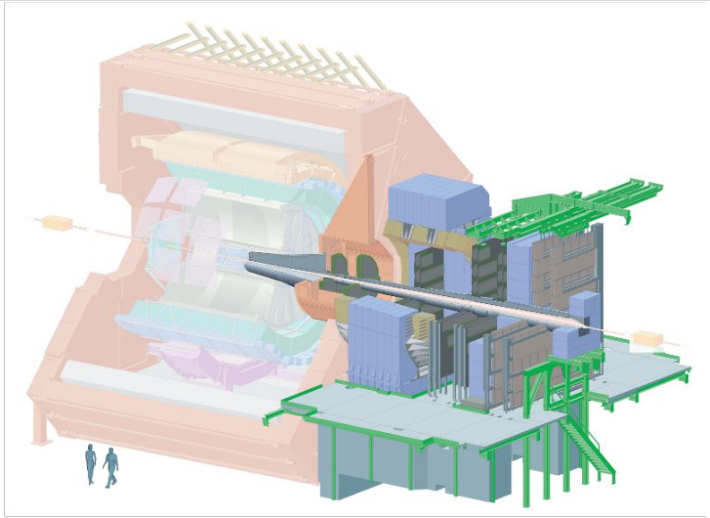
Focus on quarkonium ($Q\bar{Q}$) e.g. J/ψ ($c\bar{c}$)

Formed before the QGP

Influenced by color charges

Insight on QGP properties (e.g. Temperature)

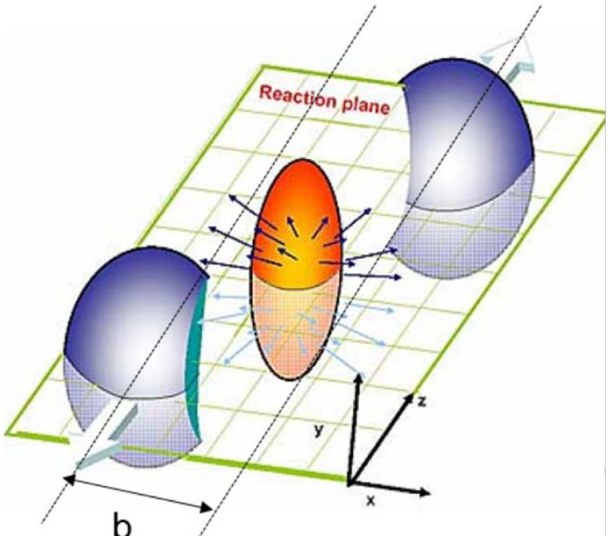




What is flow ?

In Heavy-ion collisions, **anisotropic collision** region

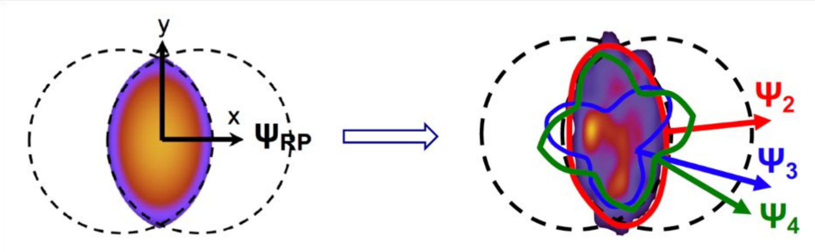
- **Anisotropies in momentum** distribution
- **Long-range correlations** of produced particles



Taken from Universe, 2017

[arXiv:nucl-ex/9805001]

Azimuthal correlations of particles quantified by Fourier coefficients in ϕ angle distribution of particles



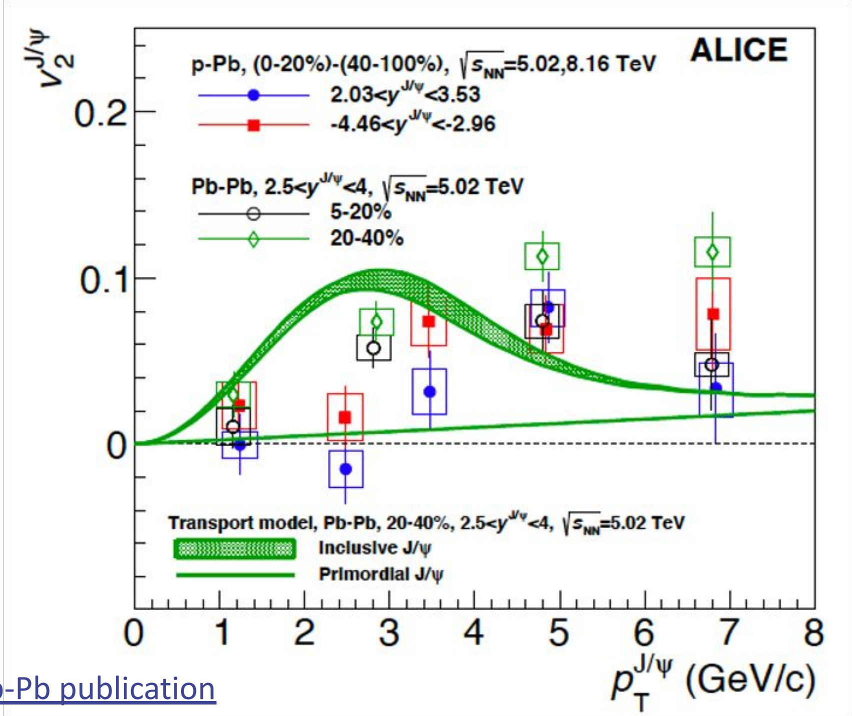
$v2$ (elliptic) : initial geometry of the collision
$v3$ (triangular) : fluctuations

Flow shows collective behaviours : QGP signature

Constrains theoretical models (flow acquired through QGP evolution, recombination of lighter flowing quarks, etc.)

Does the J/ψ flow in pp ?

Non-zero $v2$ measured in PbPb and in pPb collisions



Objective: Find if there is indeed a significant non-zero $v2$ for the J/ψ in pp, the smallest system

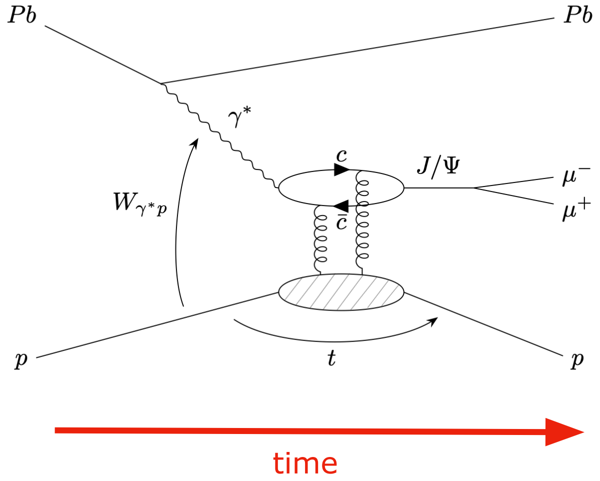
ALICE, p-Pb publication [arXiv:1709.06807]

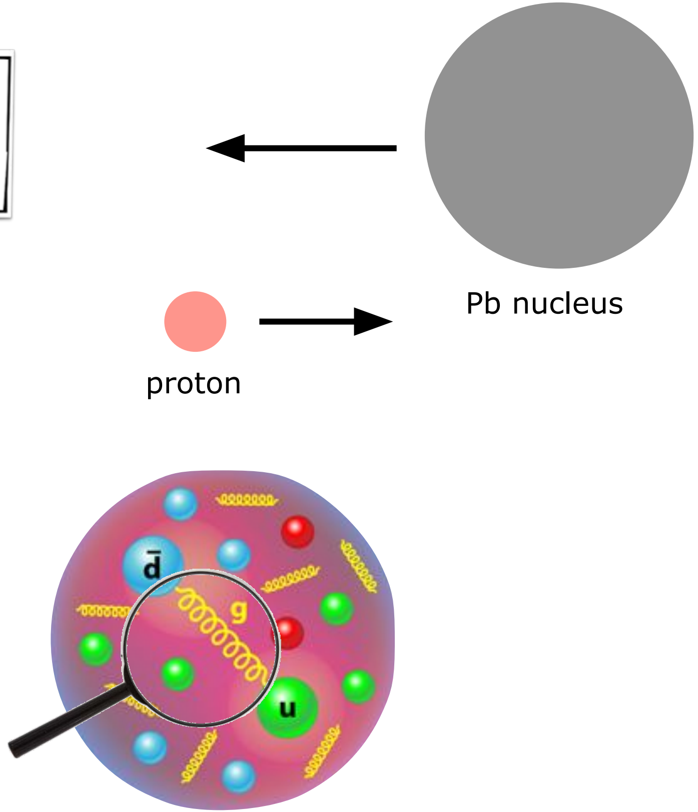
Probing the internal structure of the proton and development of detectors

(Aude Glaenzer)

ALICE = A Large Ion Collider Experiment

Analysis goal: understand the behavior of gluons at small scale, in "ultra-peripheral collisions" of protons and Pb nuclei.





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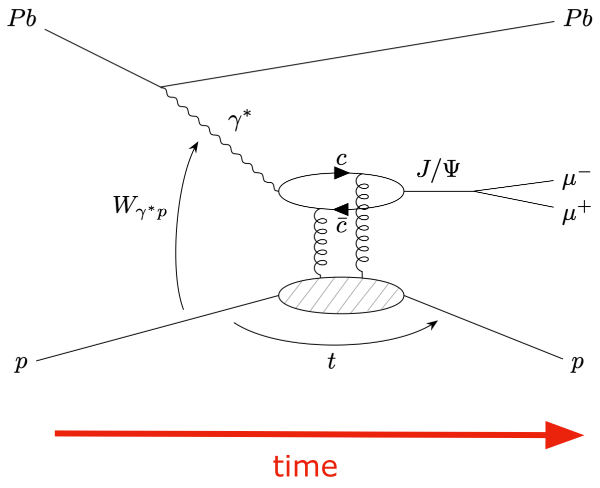
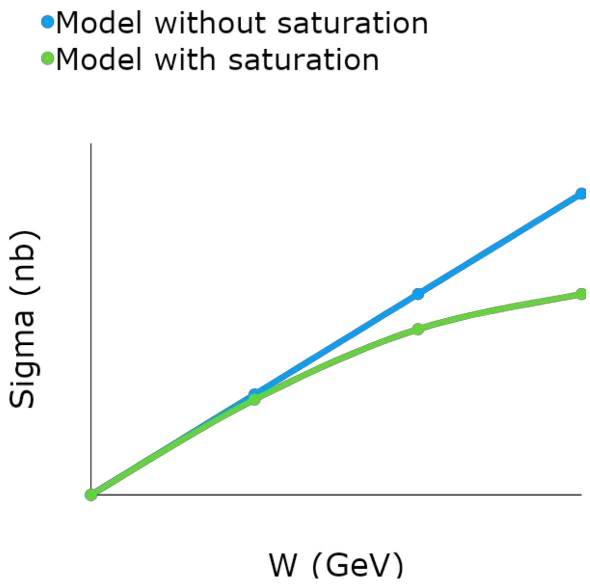
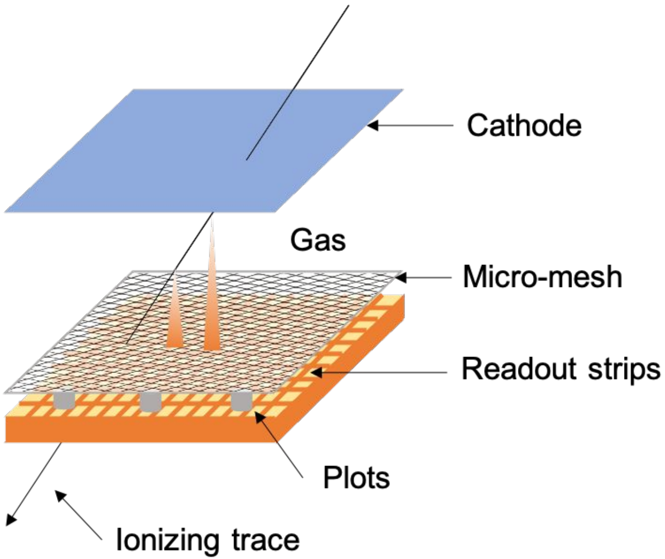


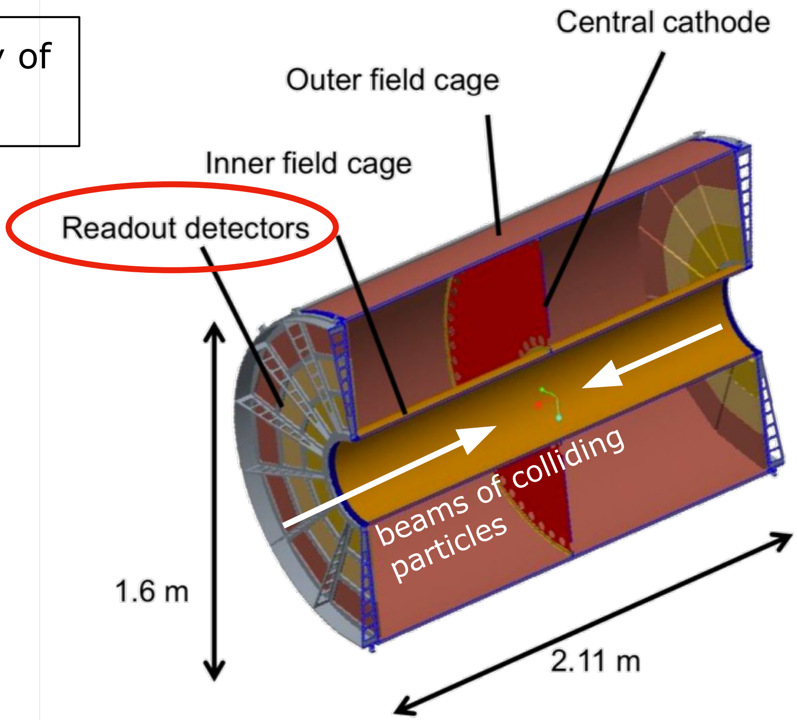


By counting the number of events, one can get the probability for this J/ψ production (or equivalently cross section) to take place

R&D with gaseous detectors

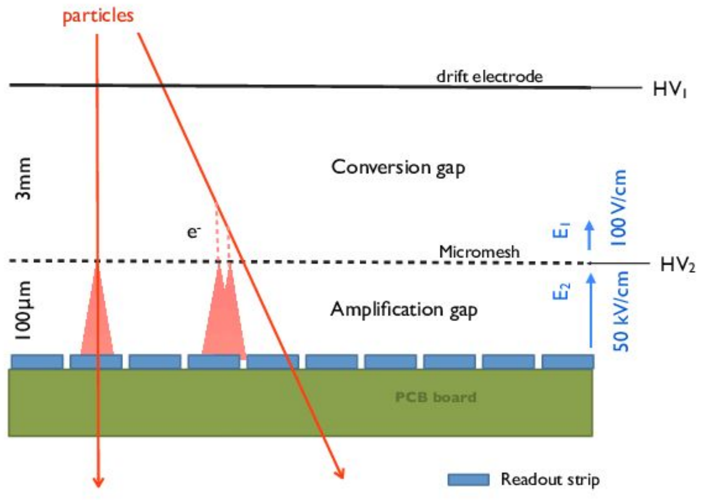
Ultimate goal: reconstruct precisely of the trajectory of a charged particle in the readout detectors



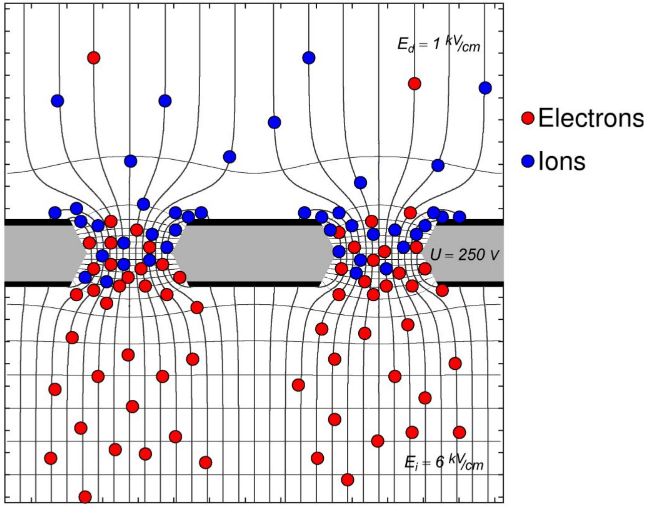


Gaseous detectors

- MicroMEGAS : Micro-MEsh GASeous structure



- GEM: Gas Electron Multiplier



✗ Ion BackFlow (IBF) = proportion of ions resulting from the avalanche that end up in the drift space
→ Might induce distortions of the electric field in the drift region → can deviate particle trajectories