ALICE (DRS):

study of *strongly* interacting matter

7 permanents
+ 1 post-doc
+ 1 PhD

Julien Hamon

Séminaire SHARE

12 January 2017

Outline

(0) Prologue

(i) Introduction to the Physics of ALICE

*How the Quark-Gluon Plasma is **recreated** in the laboratory?*
*How the Quark-Gluon Plasma is **characterised**? A heavy-ion collision history.*

(ii) Activities of the ALICE Strasbourg group

***Physics activities** - Strangeness & Charm*
***Technical activities** - ITS Upgrade, Hardware & Software*

(iii) Summary

Outline

(0) Prologue

(i) Introduction to the Physics of ALICE

*How the Quark-Gluon Plasma is **recreated** in the laboratory?*

*How the Quark-Gluon Plasma is **characterised**? A heavy-ion collision history.*

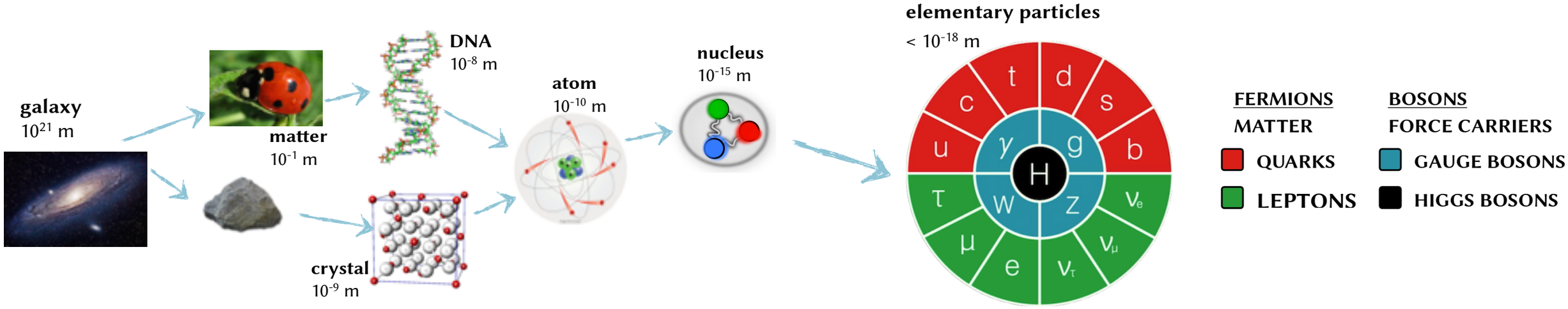
(ii) Activities of the ALICE Strasbourg group

***Physics activities** - Strangeness & Charm*

***Technical activities** - ITS Upgrade, Hardware & Software*

(iii) Summary

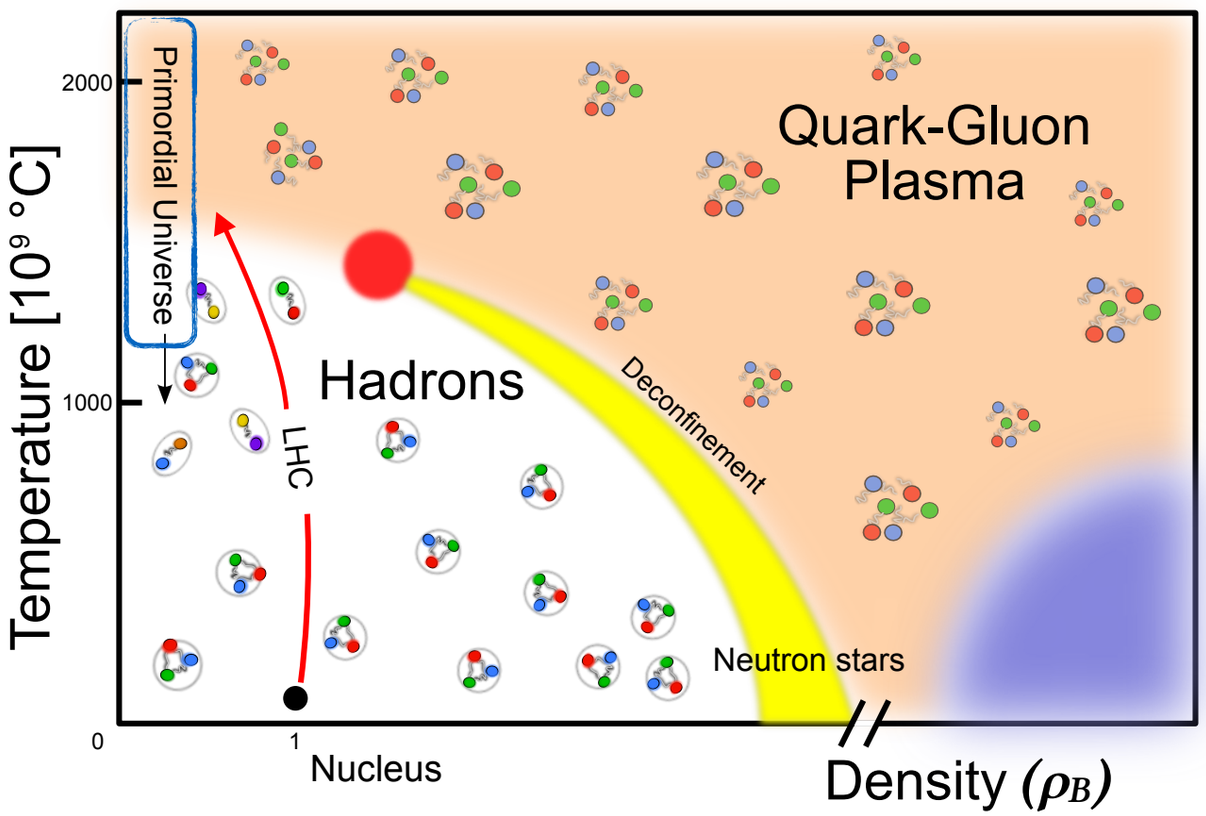
Thermodynamics of (nuclear) matter



Ordinary matter (e.g. neutron, proton) is not elementary but made of **quarks**

Under "normal" conditions of temperature and density, **quarks** are **confined** into **hadrons**

u, d, s, c, b, (t) ⟶ p, n, $\pi^{\pm}$, π^0, $K^{\pm}$, K^0_S, ... , Λ, $\Xi^{\pm}$, $\Omega^{\pm}$, $D^{\pm}$, D^*, D_s, ... >200



Above T_C (≈ 100 000 × T_{Sun}) quarks are **deconfined** and form

a high energy density...

strongly interacting medium...

Quark-Gluon Plasma

- Predicted by Quantum Chromo-Dynamics (~1970)
- Experimentally evidenced ~2000 (SPS, RHIC, LHC)

Outline

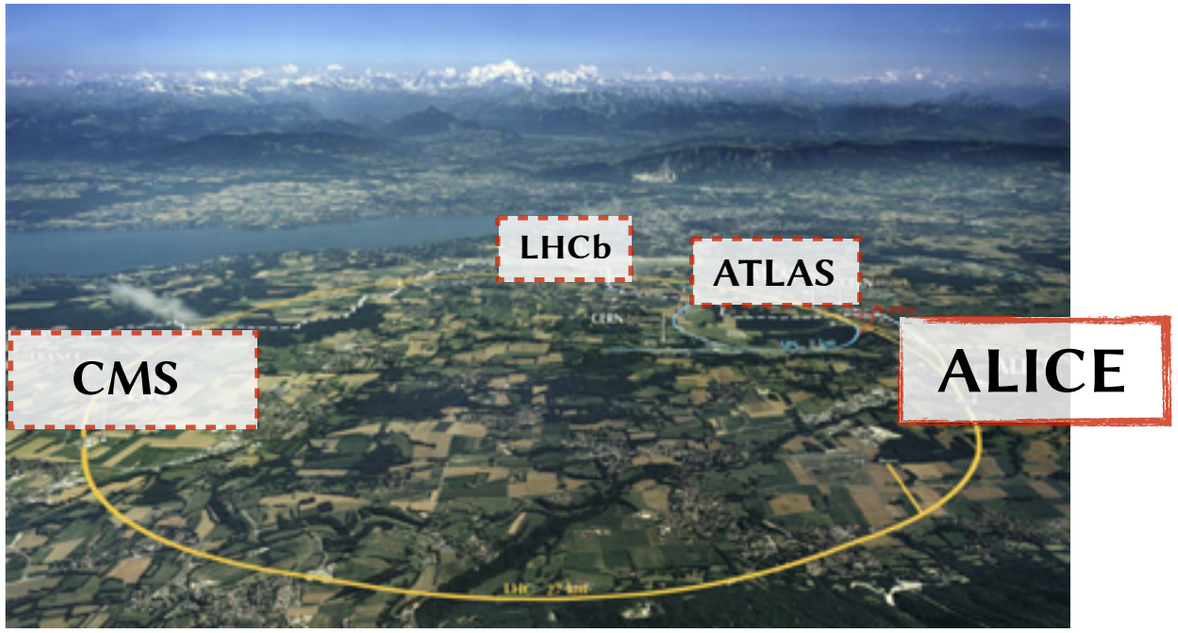
The Large Hadron Collider (CERN)

Accelerator of atomic nuclei (p, Pb)

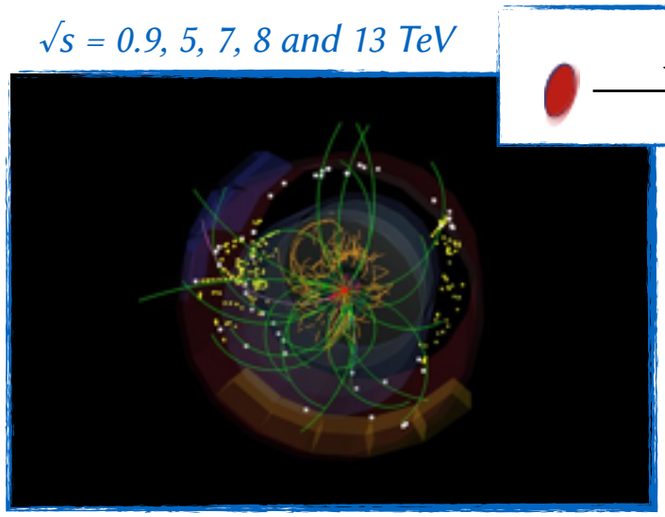
- in operation since 2009
- 26.7 km of circumference

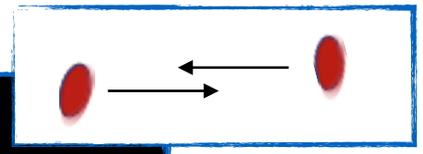
Protons accelerated up to v/c = 0.999999991

!! 11,000 paths around the LHC per second !!



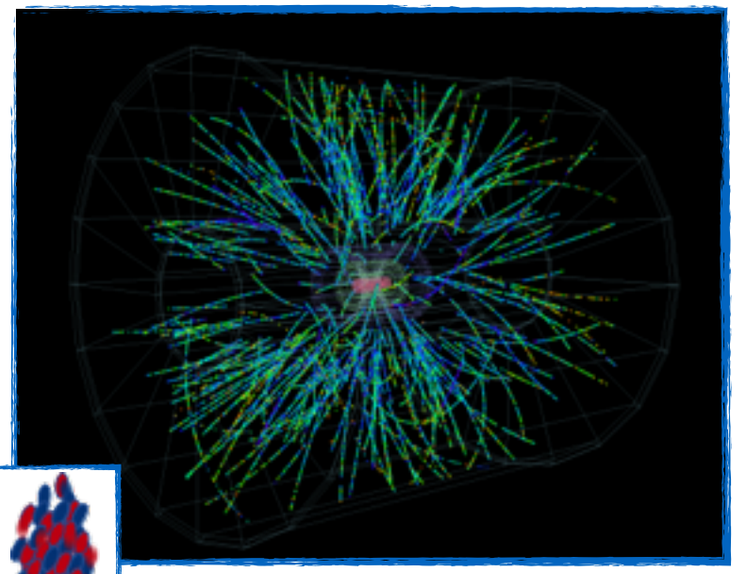
√s = 0.9, 5, 7, 8 and 13 TeV



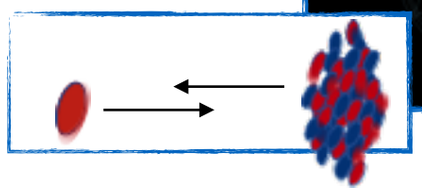


pp

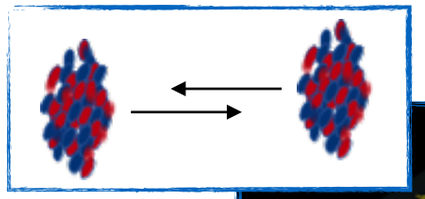
Event displays with ALICE



p-Pb

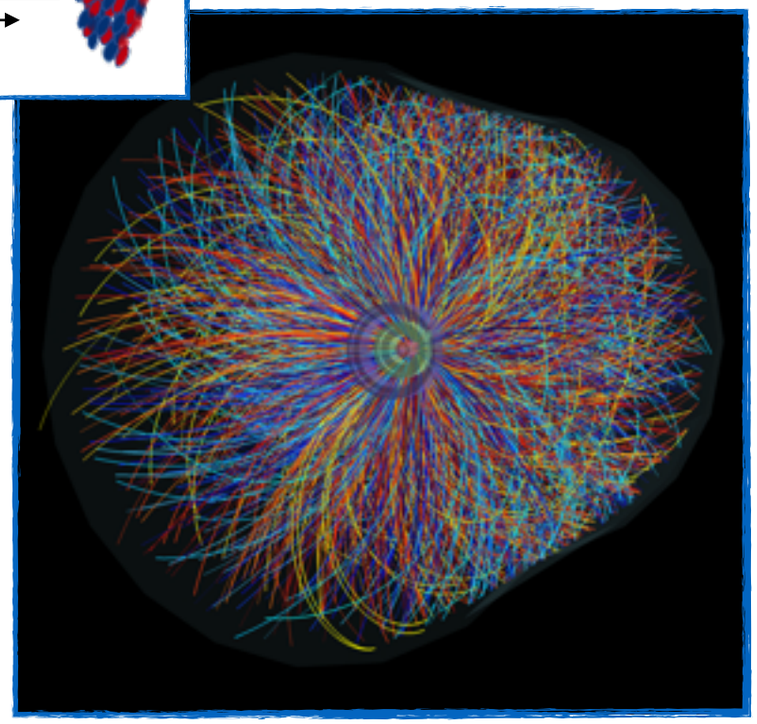


√s_{NN} = 5.02 and 8 TeV



√s_{NN} = 2.76 and 5.02 TeV

Pb-Pb



A Large Ion Collider Experiment (ALICE)

Designed for the study of the Quark-Gluon Plasma (more generally: Quantum Chromo-Dynamics)

- Collaboration of 1550 members, from 151 institutes and in 37 countries
- Detection + Identification of particles
- Low magnetic field (0.5T) + low material budget $\longrightarrow$ study low momentum particles ($\geq$ 100 MeV/c)

16 sub-detectors, whose main components:

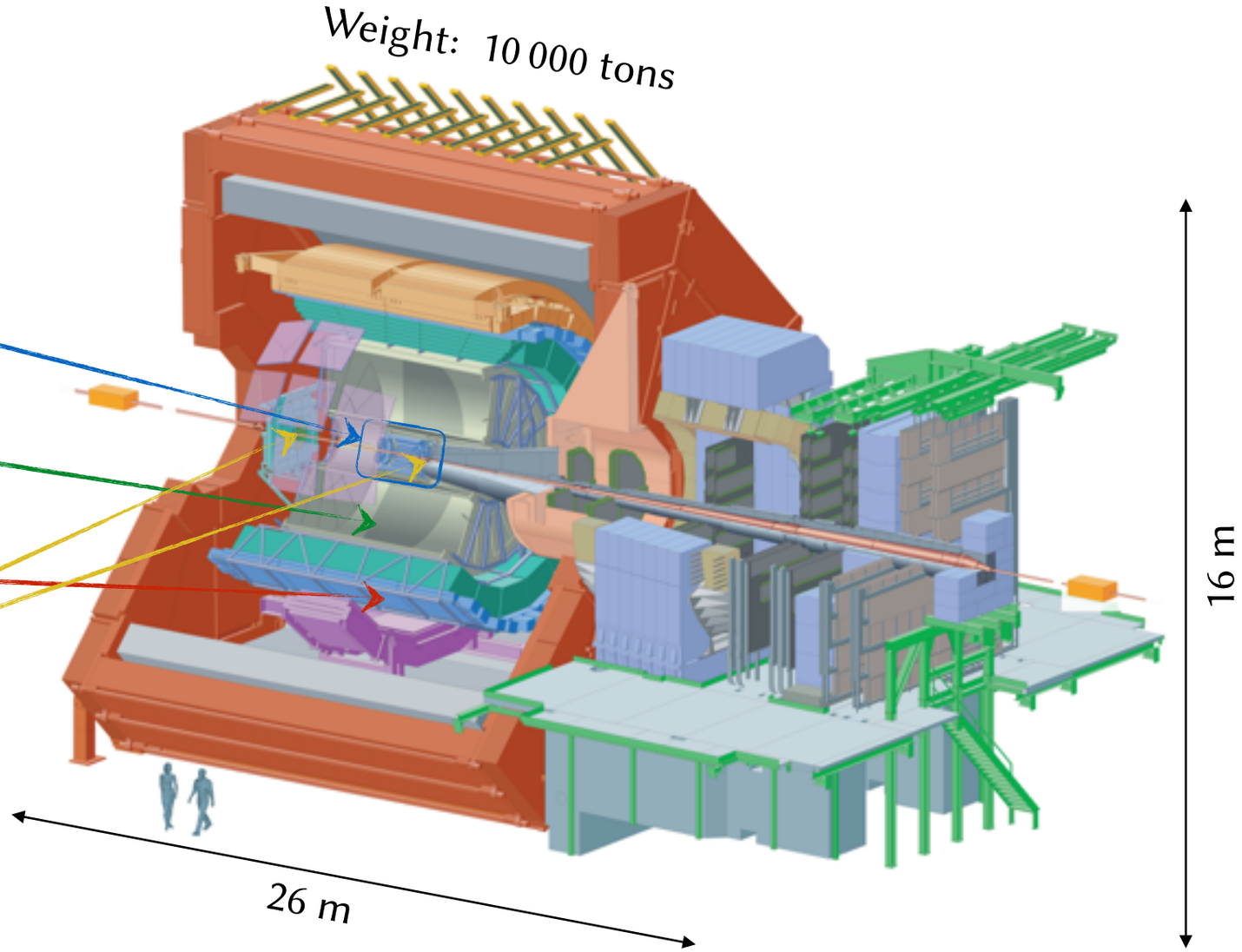
Contribution of IPHC

Inner Tracking System
tracking, vertexing, PID

Time Projection Chamber
tracking, PID

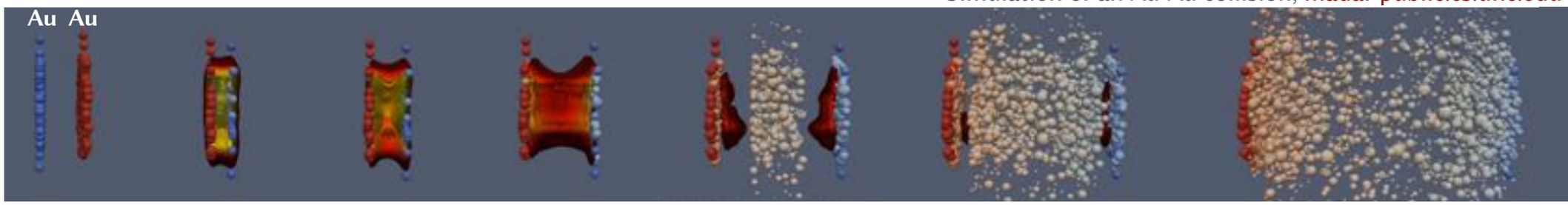
Time Of Flight
tracking, PID

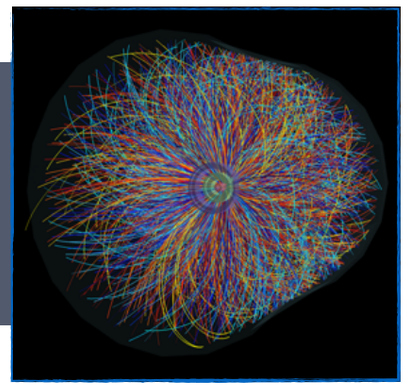
V0
trigger, multiplicity

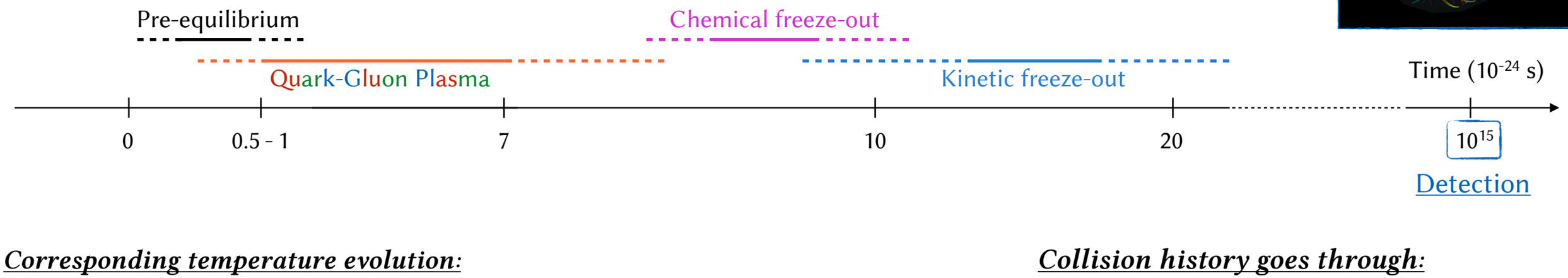


Space-time evolution of a heavy-ion collision

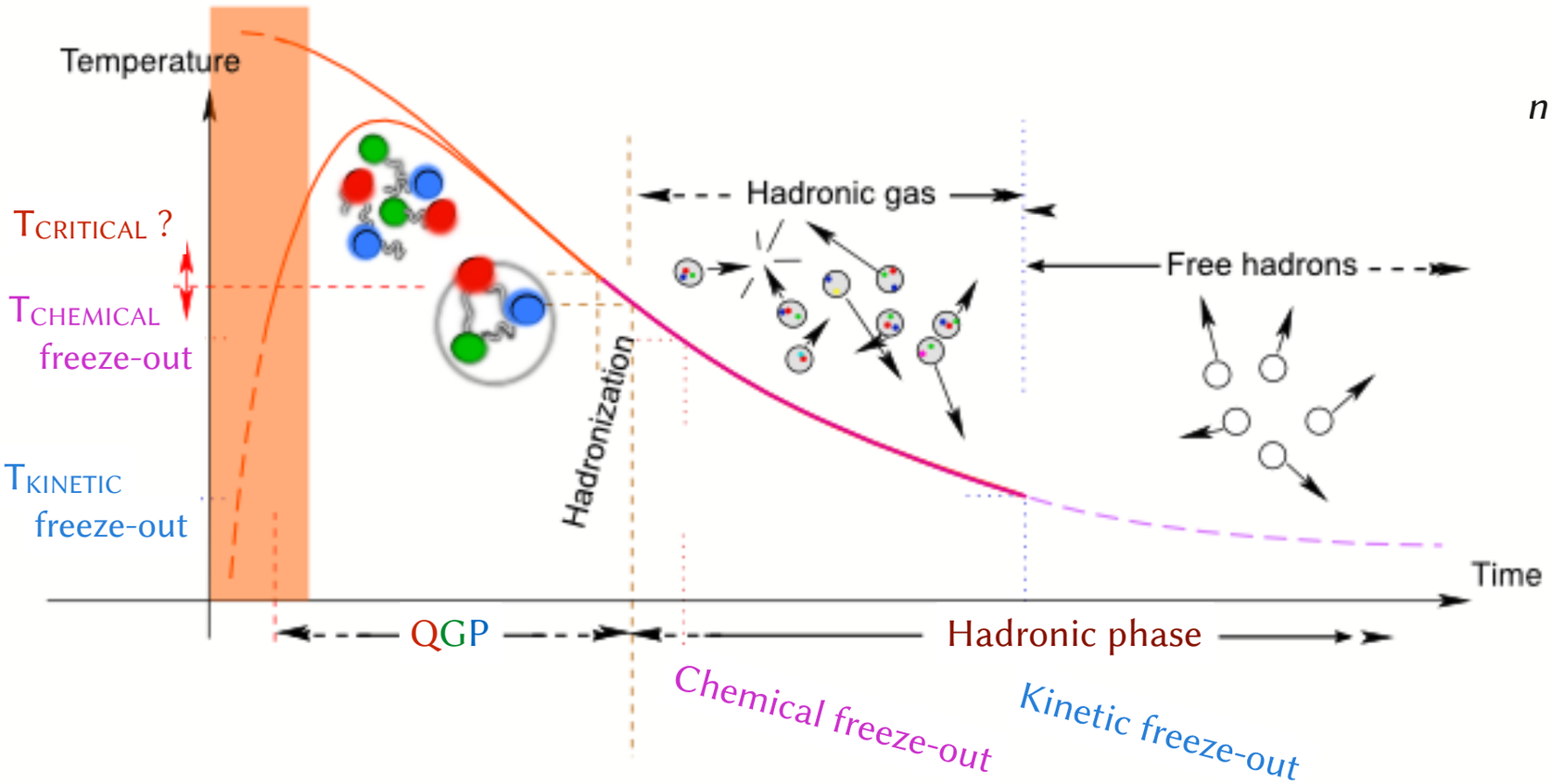
Simulation of an Au-Au collision, madai-public.cs.unc.edu







Corresponding temperature evolution:



Collision history goes through:

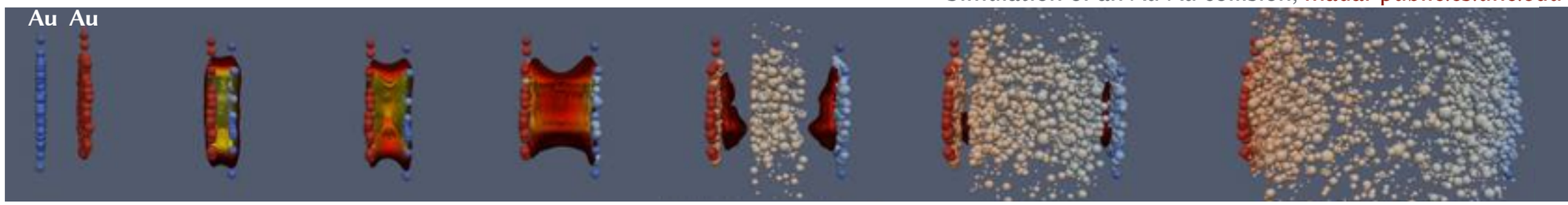
- 1 phase transition met 2 times:

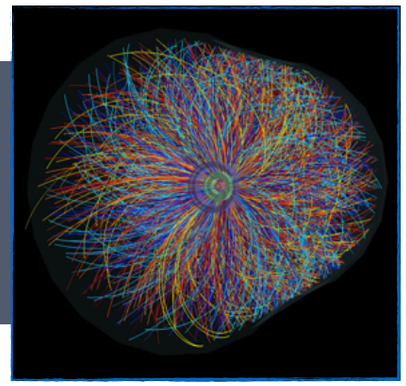
nuclei ⟶ *quark deconfinement* ⟶ *hadron gas*

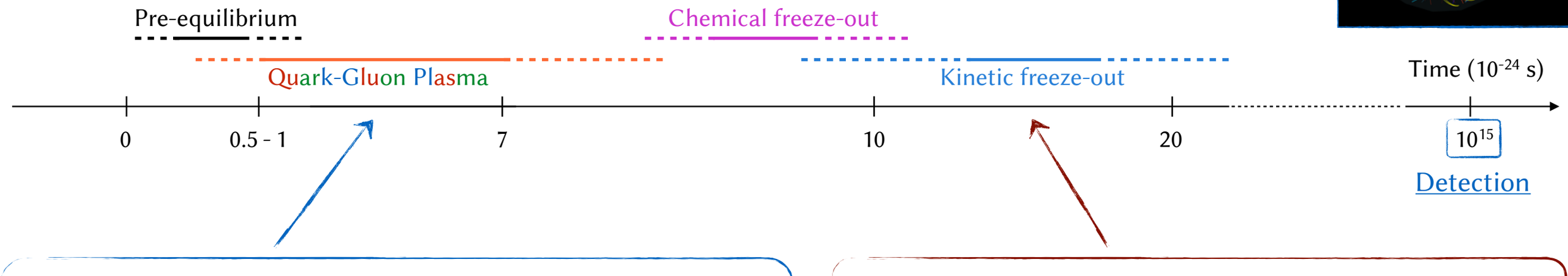
- 2 time- and species-dependent freeze-out

Space-time evolution of a heavy-ion collision

Simulation of an Au-Au collision, madai-public.cs.unc.edu







What we <u>want to</u> access! QGP lifetime 10^{-23} s

QGP characterisation:

- *(i)* thermodynamics (T, V, ε, s, equation of state, ...)
- *(ii)* hydrodynamics properties (viscosity, ...)
- *(iii)* parton dynamics (energy loss, diffusion coef., ...)
- *(iv)* hadronization mechanisms
- *(v)* chiral symmetry restoration

What we <u>do</u> measure! Detection time 10^{-9} s

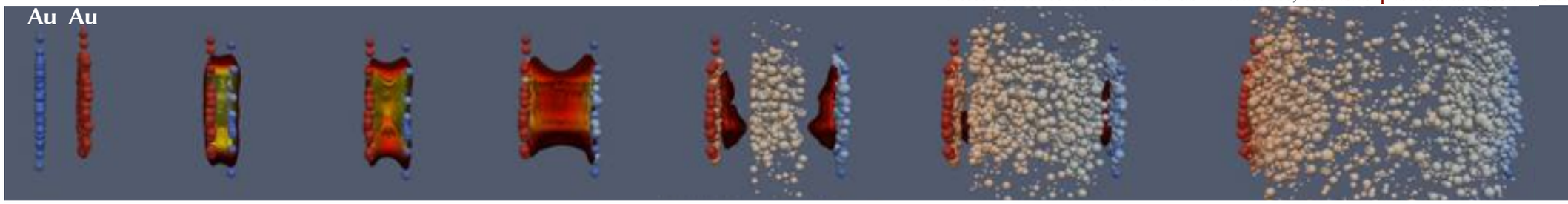
Various hadrons, leptons and photons:

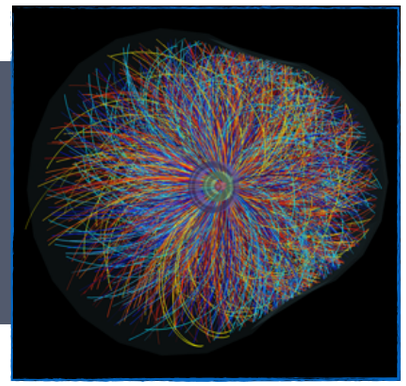
- *(i)* species ($\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$, Λ, $\Xi^{\pm}$, $\Omega^{\pm}$, $D^{\pm}$, J/Ψ, ...)
- *(ii)* kinematic (production vertex, $\vec{p}$, θ, ϕ)

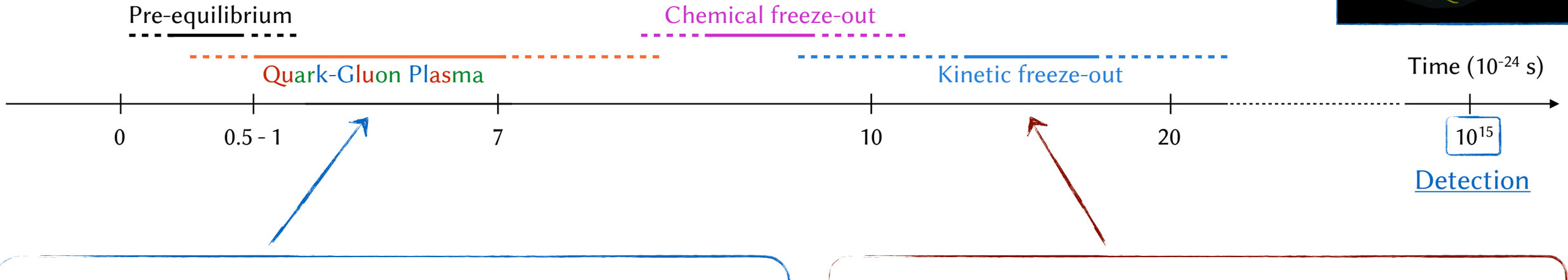
Dynamical evolution of the collision ← *Physicist way* — **Collision _final_ state of hadrons**

Space-time evolution of a heavy-ion collision

Simulation of an Au-Au collision, madai-public.cs.unc.edu

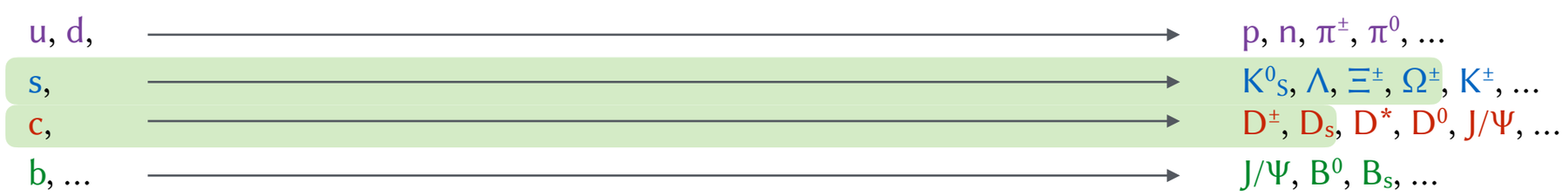






What we want to access! QGP lifetime 10^{-23} s

What we do measure! Detection time 10^{-9} s



Pieces of information can be accessed depending on the studied hadrons (flavour content).

Regarding data analysis:

ALICE Strasbourg focuses on the study of *Strangeness* and *Charm* (with my PhD thesis) degrees of freedom.

Outline

(0) Prologue

(i) Introduction to the Physics of ALICE

*How the Quark-Gluon Plasma is **recreated** in the laboratory?*
*How the Quark-Gluon Plasma is **characterised**? A heavy-ion collision history.*

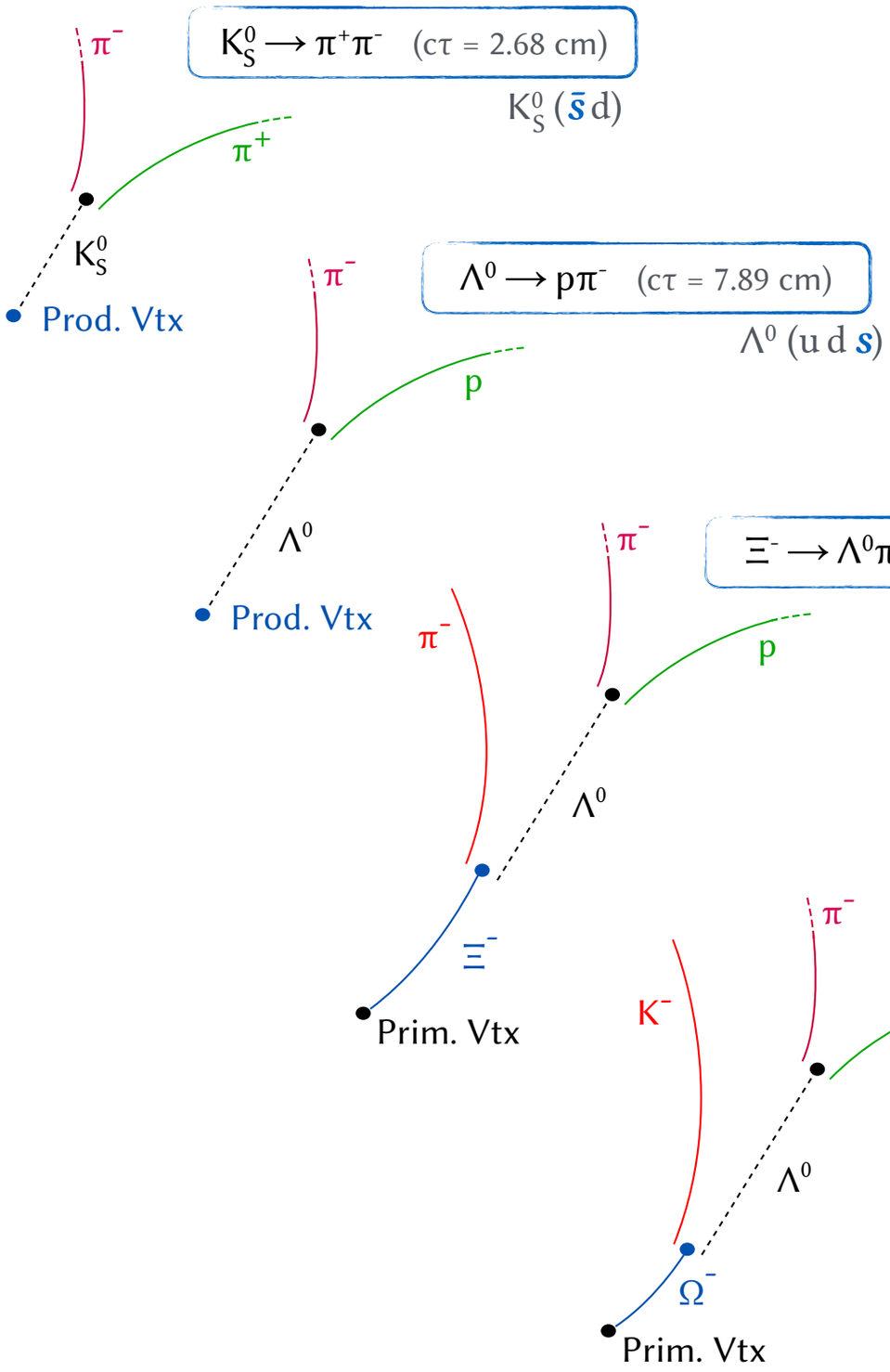
(ii) Activities of the ALICE Strasbourg group

***Physics activities** - Strangeness & Charm*
***Technical activities** - ITS Upgrade, Hardware & Software*

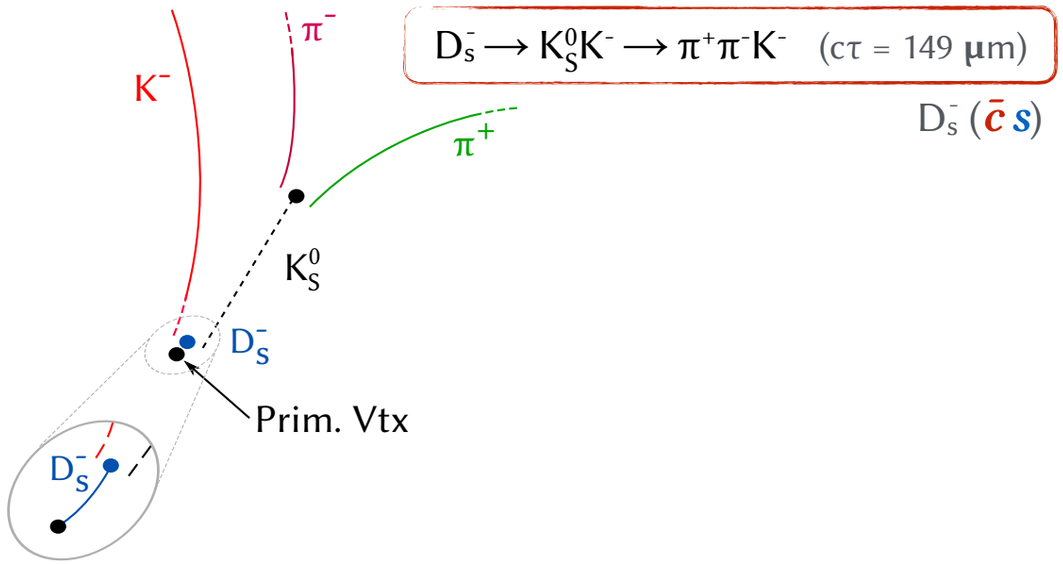
(iii) Summary

Data analysis: from *Strangeness* to *Charm*

Related to Strangeness:



Related to Charm:



- Similar decay topology (V-shaped, cascades)
  !! Much lower decay length for Charm !!
- Invariant mass analyses

  → IPHC historical expertise

Analysis expertise developed at IPHC

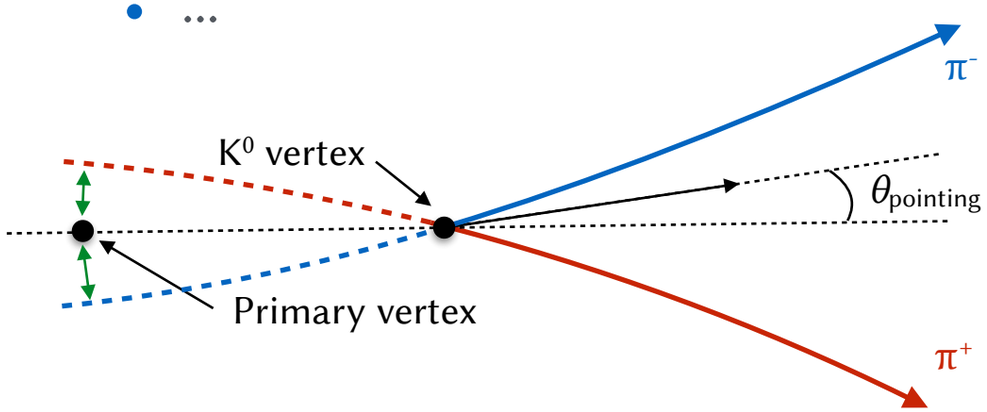
a./ Tracking: from hits registered in the detectors, one has to reconstruct the path of the particle

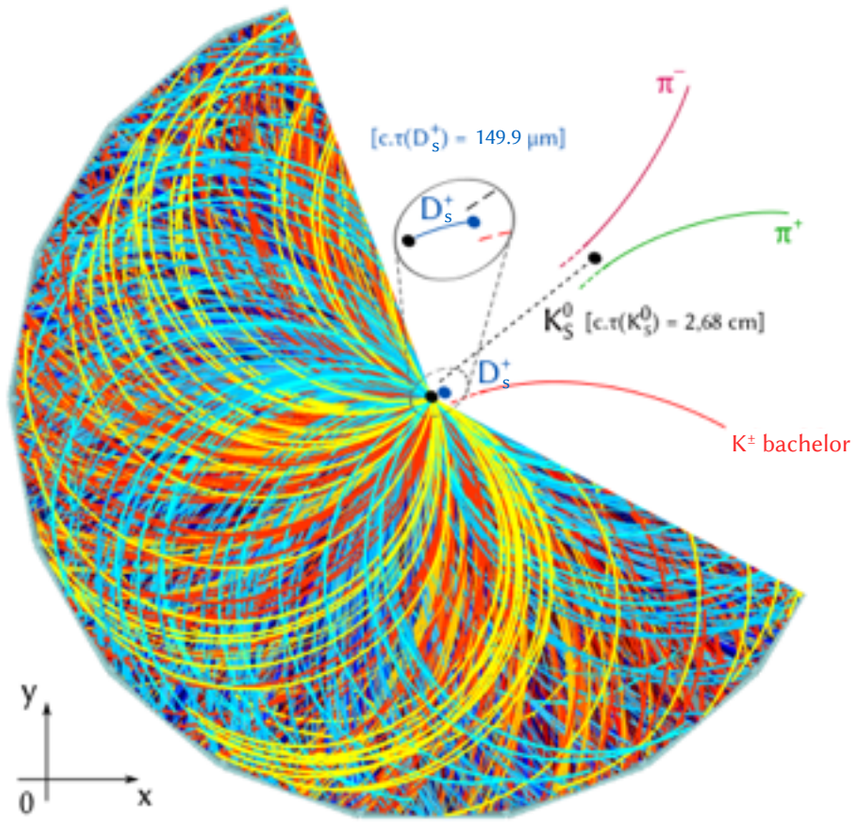
b./ Topological reconstruction (e.g. D_s^-): find 3 tracks spatially compatible that originate from 2 successive decay vertices.

!! Up to ~18000 charged tracks produced per (central) Pb-Pb collisions !!

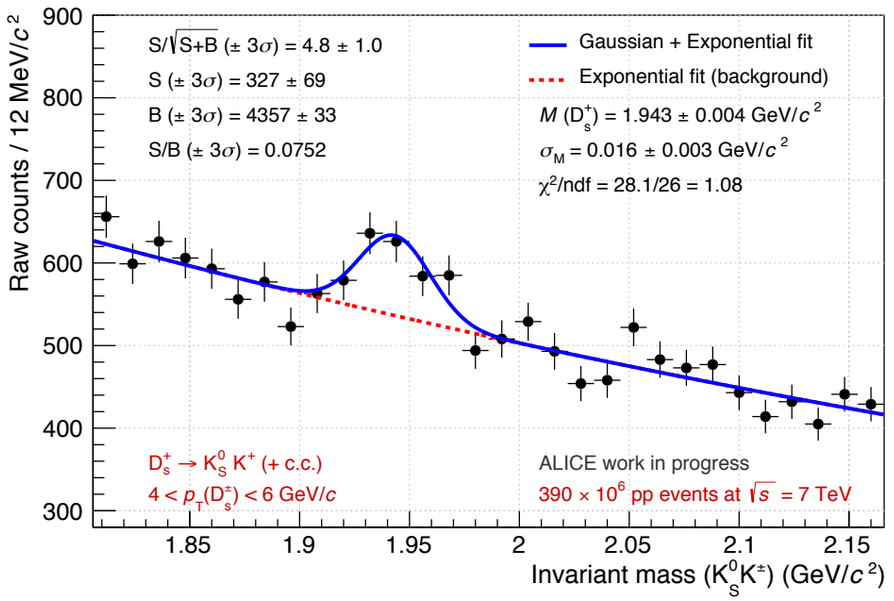
c./ Topological selections: several topological criteria can be applied to reject fortuitous track combinations.

- Distance of closest approach between 2 tracks
- Decay length of the candidate: L_{xy}
- Impact parameter of daughters: d_0
- Pointing angle: $\cos(\theta_{pointing})$
- ...

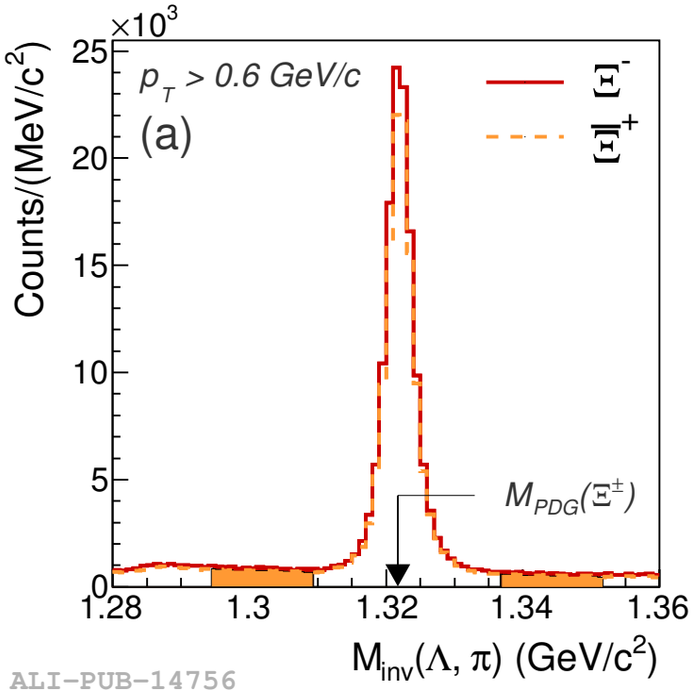




d./ Reconstruct an invariant mass: from the decay products and extract a (sometimes tiny) signal (S) above the background (B)



Strangeness analysis



***IPHC** analyses:*

$K^0_S \longrightarrow \pi^+\pi^-$
$\Lambda^0 \longrightarrow p\pi^-$
$\Xi^- \longrightarrow \Lambda^0\pi^- \longrightarrow p\pi^-\pi^-$
$\Omega^- \longrightarrow \Lambda^0K^- \longrightarrow p\pi^-K^-$

proton-proton @ 900 GeV *(arXiv:1012.3257)*
proton-proton @ 7 TeV *(arXiv:1204.0282)*
Pb-Pb @ 2.76 TeV *(arXiv:1307.5530)*

+ PhD thesis Xitzel Sanchez Castro
+ PhD thesis Vit Kucera

+ Run 2 (waiting for PhD)

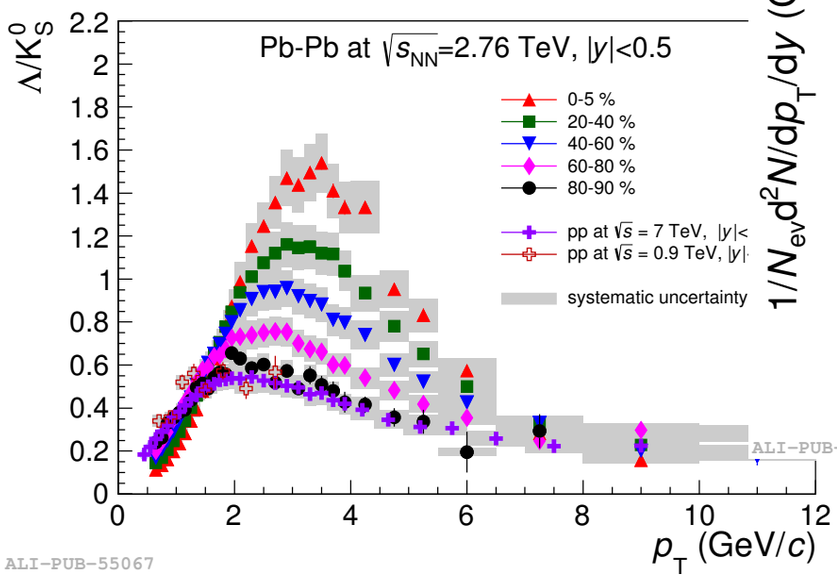
(i) Typical invariant mass distribution:

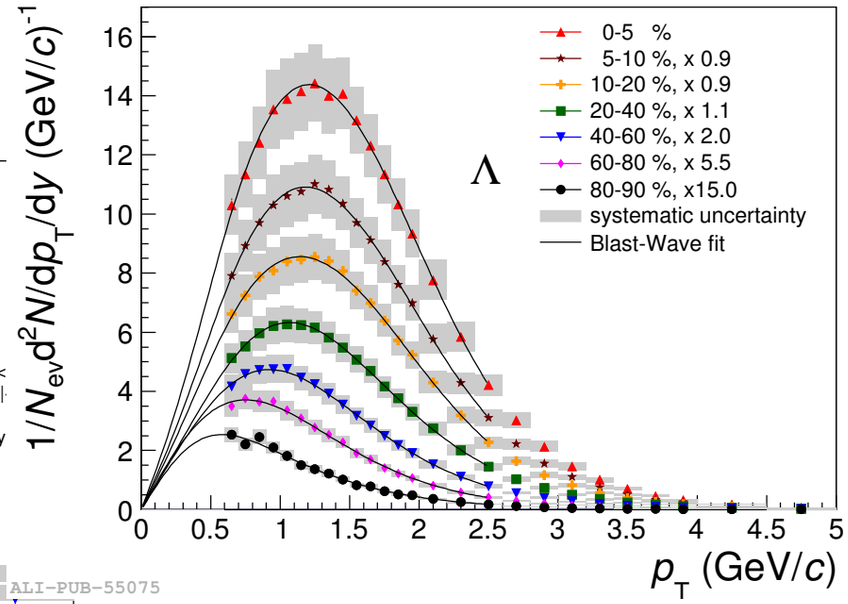
- abundant hadrons
- high significance, high S/B

→ precise measurements, down to low p_T (~ 400 MeV/c)

(ii) Typical observables for extracting physics:

- p_T-spectra
- Λ/K^0 production ratio

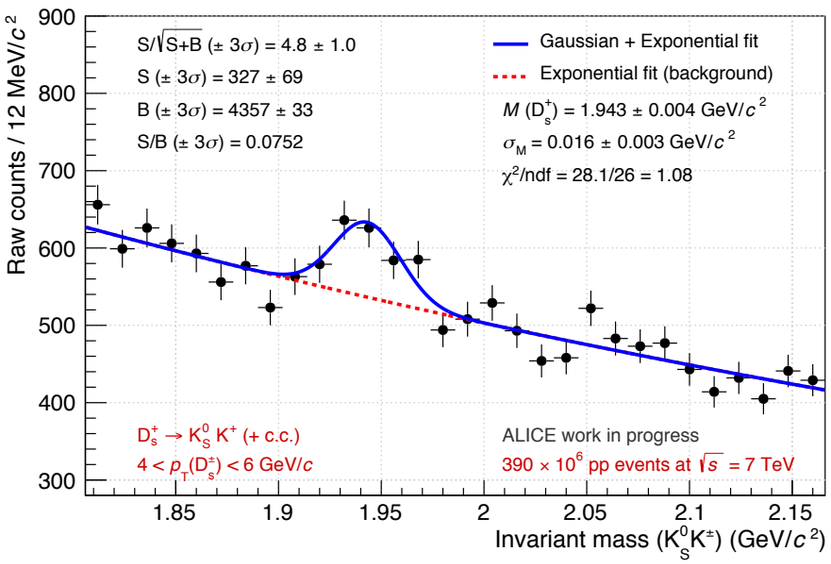




(iii) Extractable information about QGP:

- Hydrodynamical behaviour of the medium (radial and elliptic flow)
- Interplay between medium and jets
- Quark hadronization (fragmentation & recombination)

Charm analysis



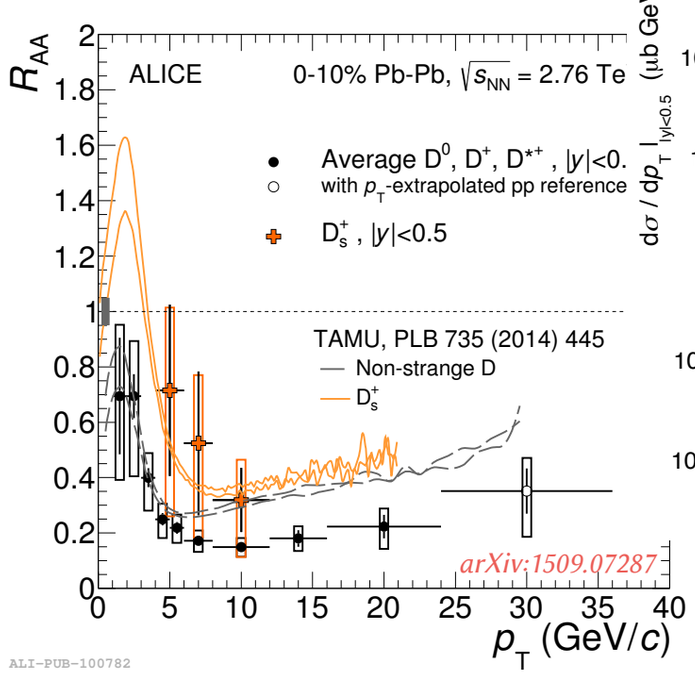
(i) Typical invariant mass distribution:

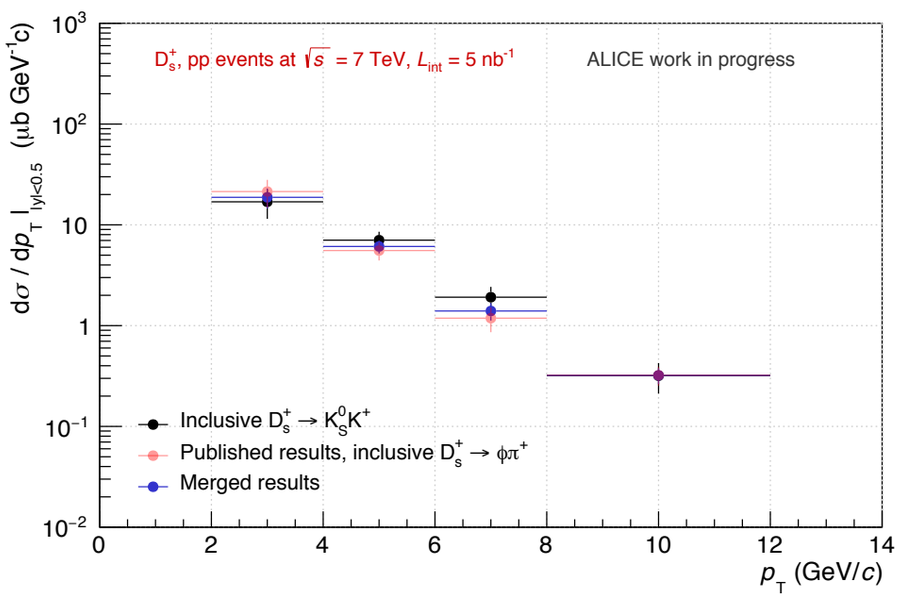
- rare hadrons
- low significance, low S/B

→ first constraints, waiting for more data

(ii) Typical observables for extracting physics:

- differential cross-section
- ratio Pb-Pb/pp





IPHC analyses:

$D_s^- \longrightarrow \phi(1020)\pi^- \longrightarrow K^+K^-\pi^-$
$D_s^- \longrightarrow K_S^0K^- \longrightarrow \pi^+\pi^-K^-$ (*new decay channel*)

proton-proton @ 13 TeV *(PhD ongoing)*
proton-lead @ 5 TeV *(PhD ongoing)*

(iii) Extractable information about QGP:

- Test of perturbative QCD calculations (NLO)
- Interaction between heavy quarks and medium (energy loss)
- Quark hadronization (fragmentation & recombination)

Detector Upgrade: the ITS

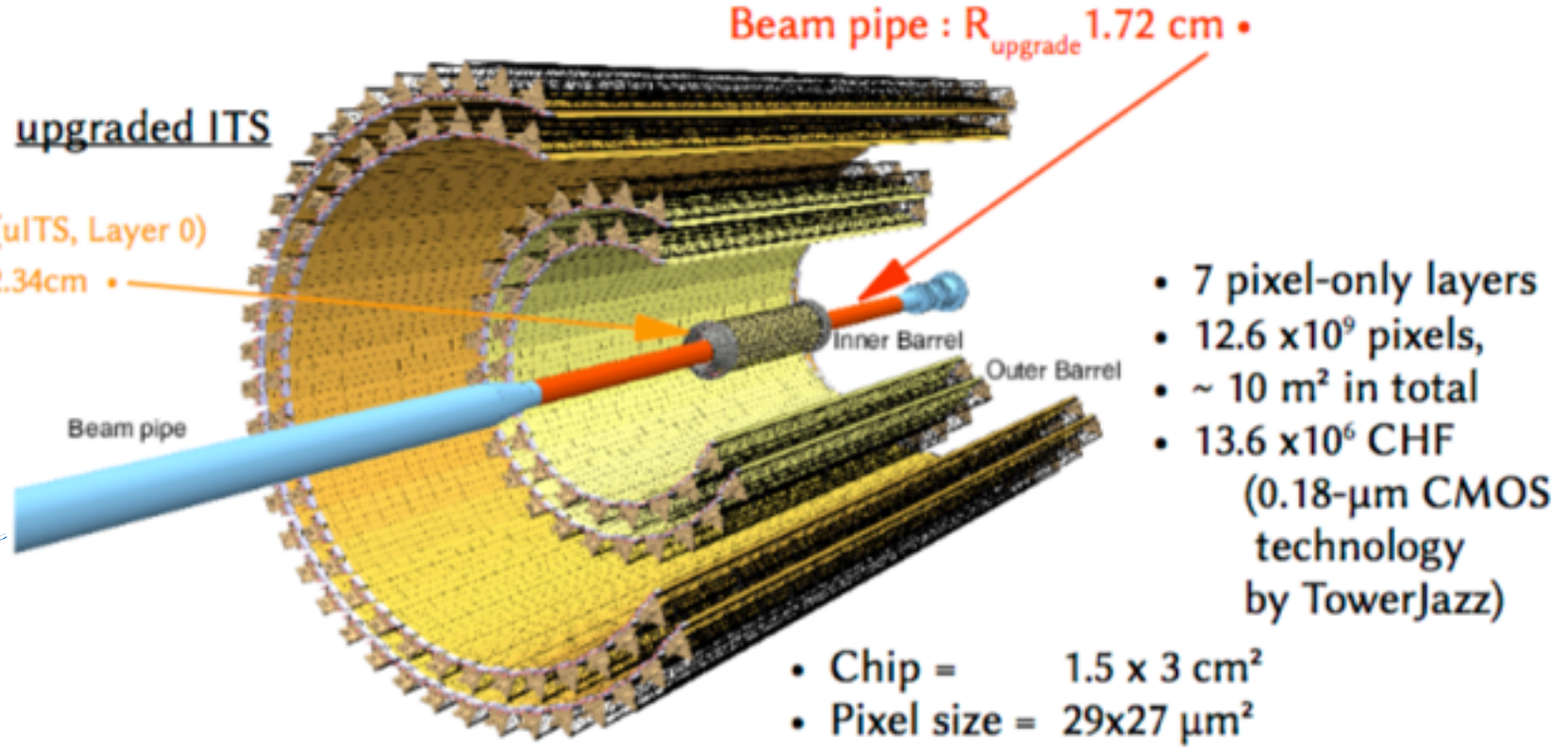
Tracking and analyses based on topological selections will be improved with the **I**nner **T**racking **S**ystem **UPGRADE** (2020)

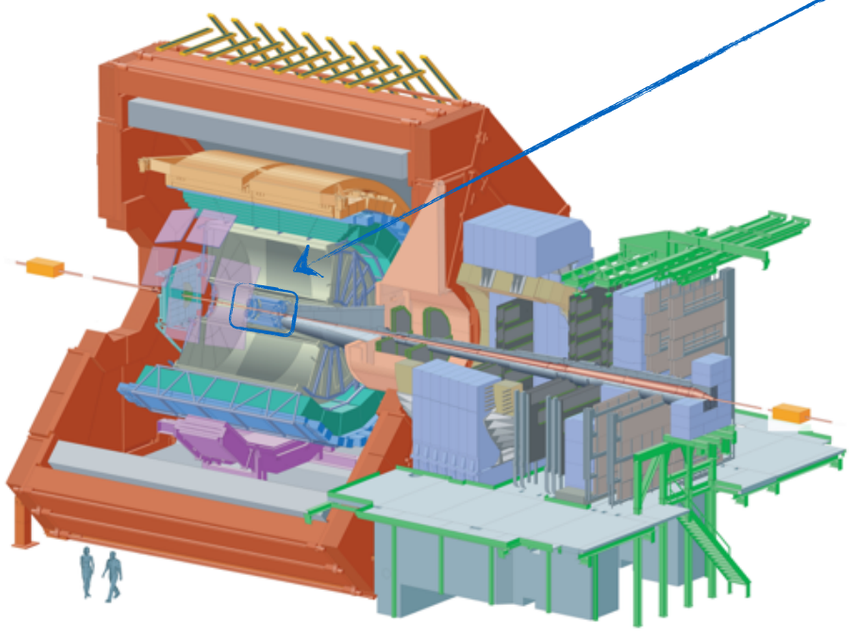
HARDWARE
- Production of 250-400 pixel modules for the outer-barrel layers (ALICE + **µTech**)

SOFTWARE
- Coordination of the new tracking + detector response in simulations

Marc Imhoff,
Franck Agnese,
Christophe Wabnitz,
Olivier Clausse

R&D for CMOS sensors performed by:
- **PIXEL** group of IPHC
- CERN
- other institute





Foreseen physics performances:
- Measurements down to lower momenta and with better precision
  (better granularity + lower material budget closer to the smaller beam pipe)
- Additional hadron species and new observables would be tackled

Detector Upgrade: the ITS

For the module production of the **UPGRADE**, IPHC has acquired:

- 1 wire bonding machine: ***Delvotec G5***
- 1 module assembly machine: ***MAM***

ALICE + **µTech**

!! Module production needs very high precision (~µm) !!

Outline

(0) Prologue

(i) Introduction to the Physics of ALICE

*How the Quark-Gluon Plasma is **recreated** in the laboratory?*
*How the Quark-Gluon Plasma is **characterised**? A heavy-ion collision history.*

(ii) Activities of the ALICE Strasbourg group

***Physics activities** - Strangeness & Charm*
***Technical activities** - ITS Upgrade, Hardware & Software*

(iii) Summary

Summary

The group of IPHC plays a crucial role within ALICE collaboration:

Data analysis

(a) Recognised expertise on ***Strangeness*** analysis (V-shaped and cascades decays)

(b) Leading role in the development of new decay channel reconstruction for ***Charm*** mesons

Upgrade

(c) Pixel module ***productions*** for the ALICE Upgrade (ALICE + **µTech**)

(d) Many responsibilities within the management of the ALICE Collaboration

Simulation of an Au-Au collision, madai-public.cs.unc.edu