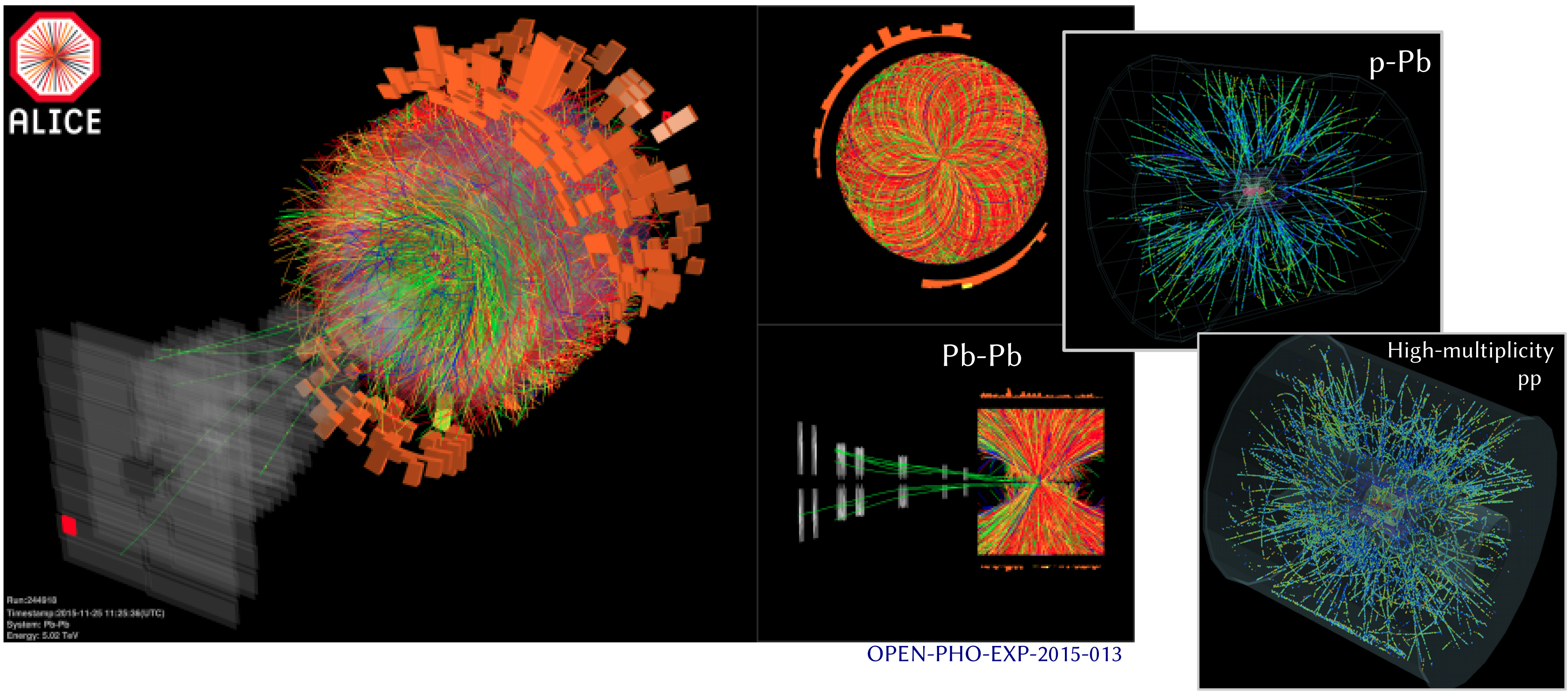
Antonin MAIRE – IPHC Strasbourg
Thursday, Feb. 8th 2018 – **Conseil Scientifique In2p3 2018**

"ALICE et la physique des ions lourds"

A-A, p-A and pp



OPEN-PHO-EXP-2015-013

Outline

Part A - Introduction : QCD+QGP experimentation

Part B - Runs 1+2 status and outcome

Part C - Runs 3+4 preparation and physics perspectives

Part A – QCD+QGP experimentation

I.0 – Intro : QCD fundamental questions

- How does the complexity emerge from the dynamics of the strong interaction ? (*phase diagram of nuclear matter*)

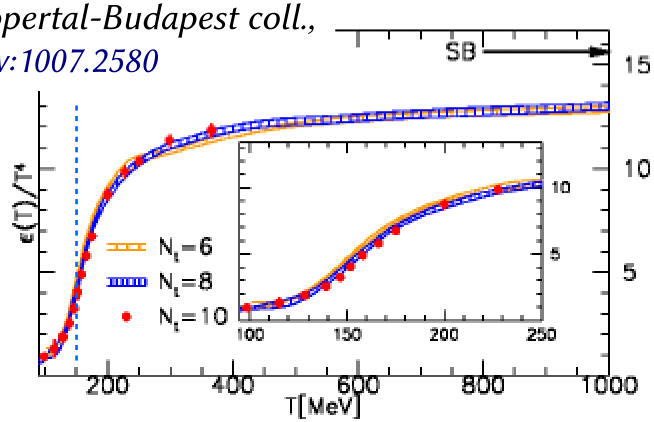
- Can one probe the fundamental symmetries of the QCD Lagrangian and study the QCD vacuum ?

Symmetry Z3
deconfinement

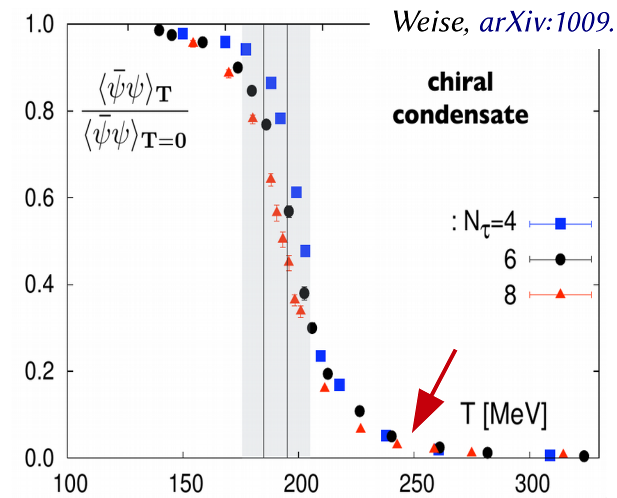
+

Chiral symmetry
dynamic mass of the quarks

Wuppertal-Budapest coll., arXiv:1007.2580



Weise, arXiv:1009.6201

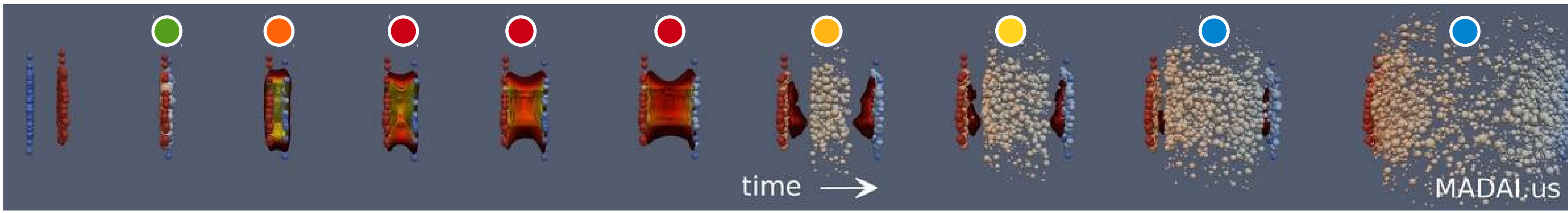


2 symmetries broken under normal conditions,
but 2 symmetries whose *restoration* = accessible in the lab ⟶ uniqueness in HEP !

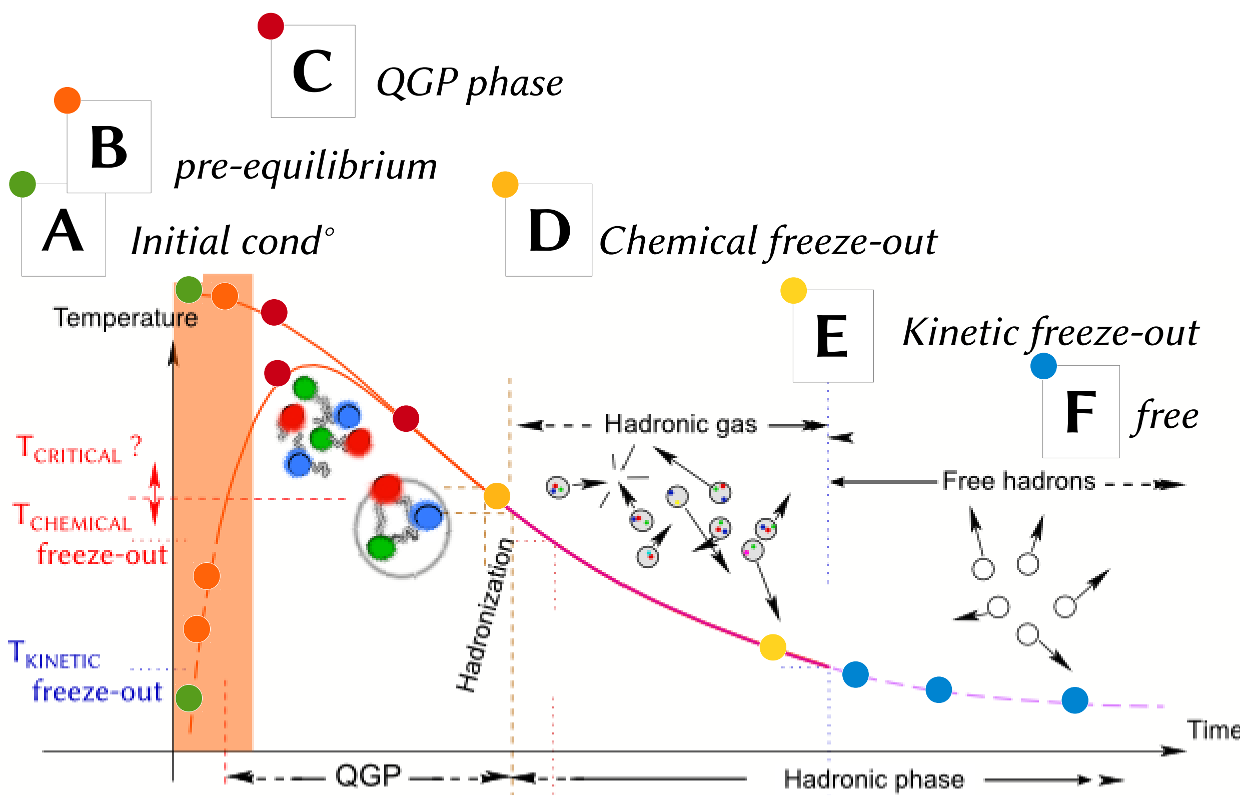
I.1 – Experimental intro : Bjorken scenario

DOI : 10.1103/PhysRevD.27.140

Deconfinement + thermodynamics at ~equilibrium



Courtesy of MADAI.us



⟶ Remark :

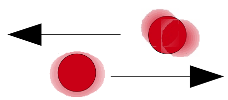
No such thing as a QGP-live vision !
but always, an observation based on remnants from the past ...

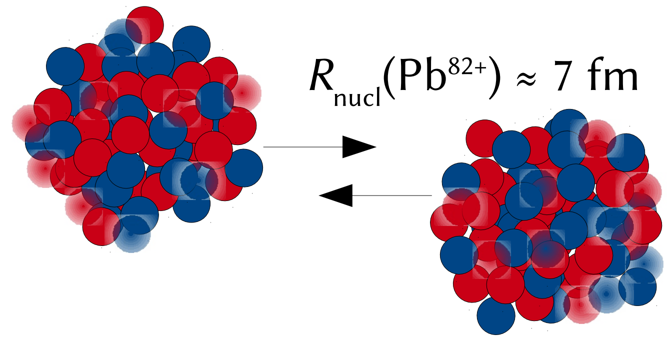
(NB : physics ~ 10^{-23} s / electronic readout > 10^{-12} s)

I.2 – Exp^{al} intro : pp, pA, AA... different physics ?

$R_{nucl}(H^{+}) \approx 1$ fm

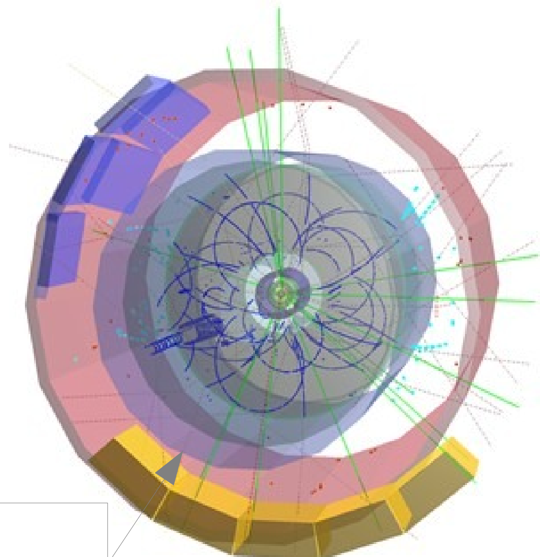
p+p($^{1}_{1}H$)



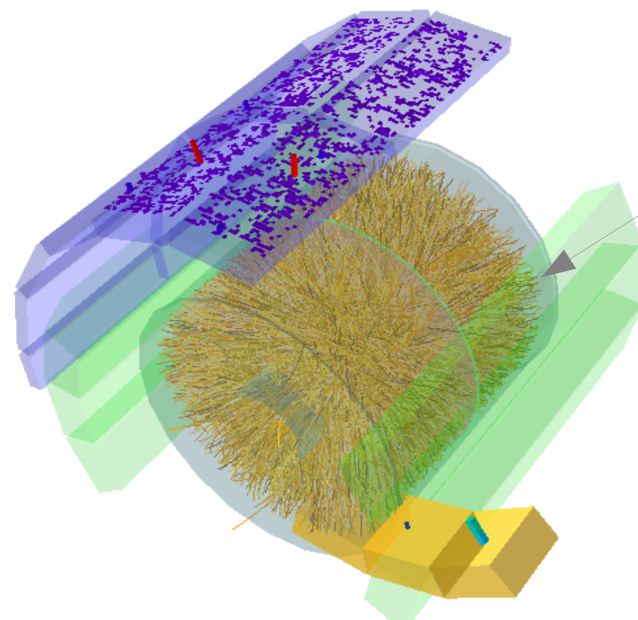


$R_{nucl}(Pb^{82+}) \approx 7$ fm

Pb+Pb($^{208}_{82}Pb$)



p-p,
$\sqrt{s}$ = 2.76 TeV

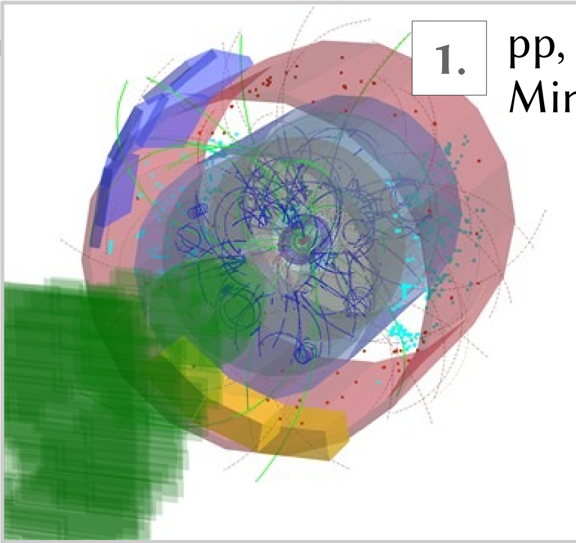


Pb-Pb,
$\sqrt{s_{NN}}$ = 2.76 TeV

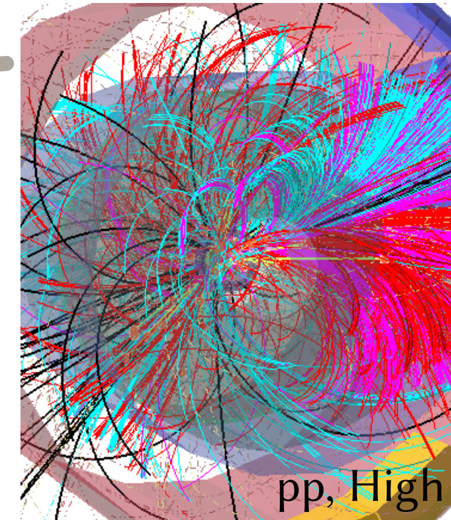
At the same $\sqrt{s_{NN}}$, the *plain* question is :

(p+p) x $N \neq 1$ x (Pb+Pb) ?

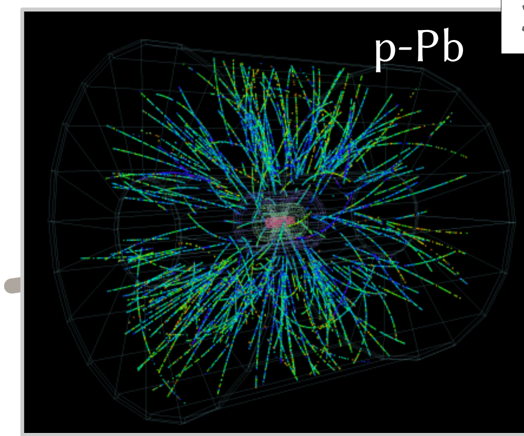
I.3 – Exp^{al} intro : continuum of physics ?



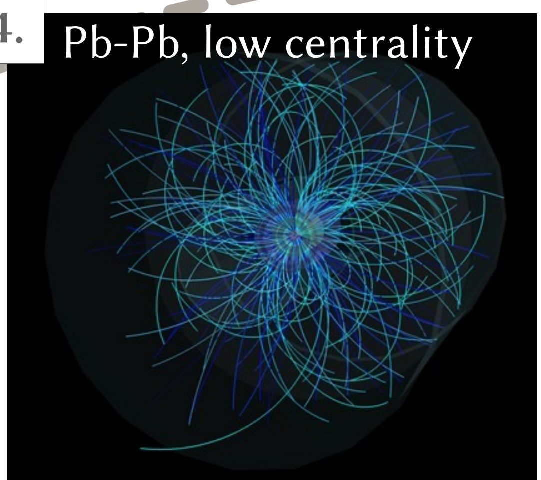
1. pp, Min. Bias



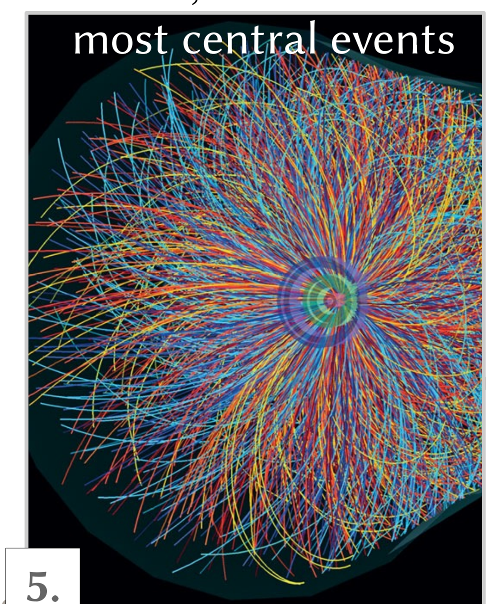
2. pp, High Multiplicity



3. p-Pb



4. Pb-Pb, low centrality

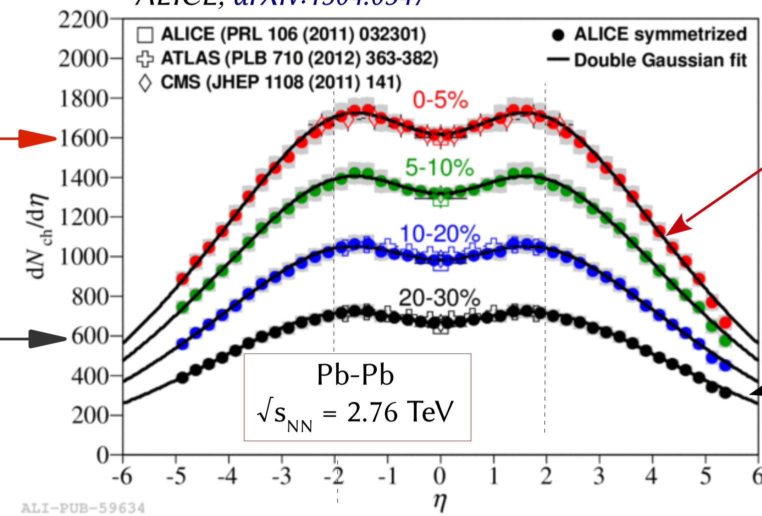


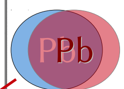
5. Pb-Pb, most central events

CDS/record-1305398

I.4 – Exp^{al} intro : $dN_{ch}/d\eta = f(\eta_{LAB})$

ALICE, arXiv:1304.0347





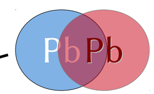
$dN_{ch}/d\eta \approx$ **1600**

in 0-5%

→ *i.e.* $N_{ch,TOT}$ *(0-5%) =* $\int dN_{ch}(0\text{-}5\%)/d\eta$

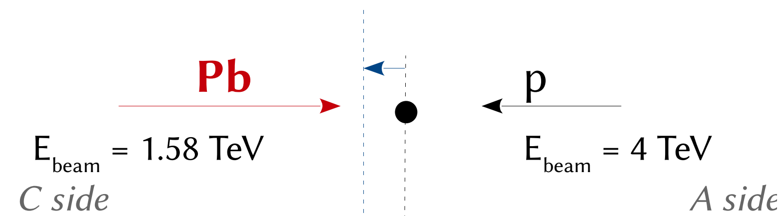
= 17 170 ± 770 ch. particles

(ALICE, arXiv:1509.07299)

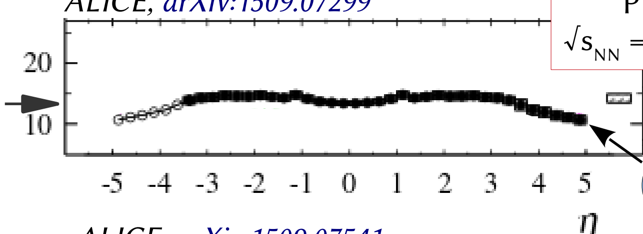


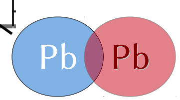
$dN_{ch}/d\eta \approx$ **600**

in 20-30%



ALICE, arXiv:1509.07299

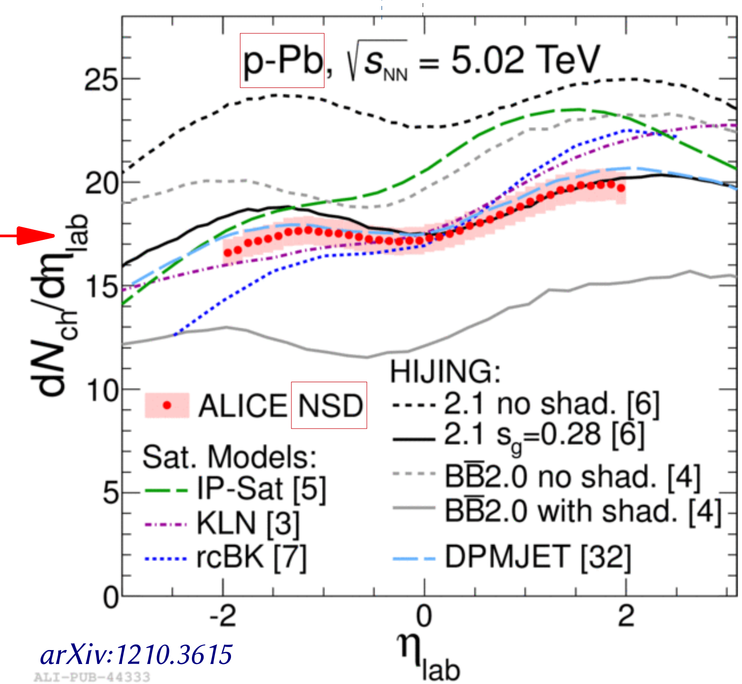




$dN_{ch}/d\eta \approx$ **13**

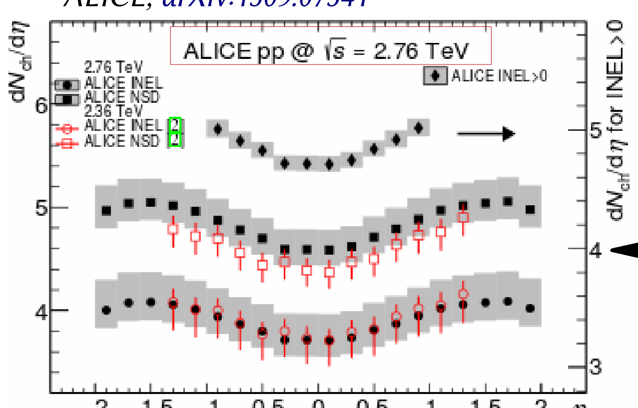
in 80-90%

$dN_{ch}/d\eta_{lab} \approx$ **17**



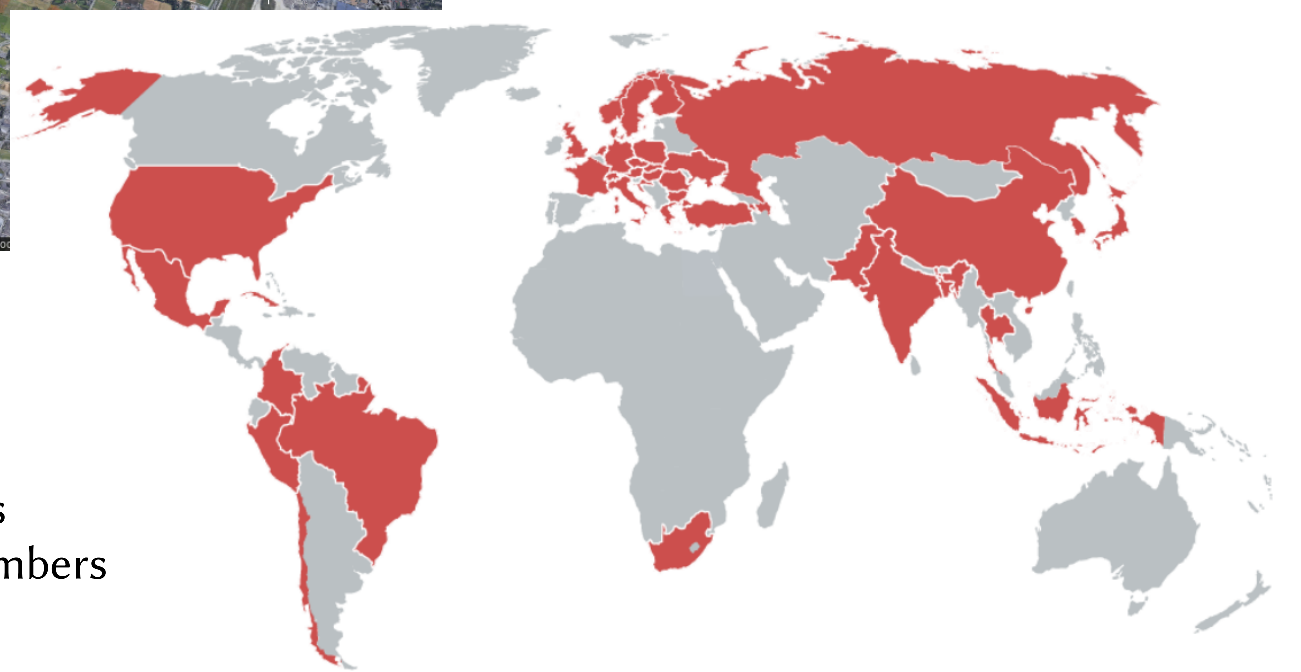
arXiv:1210.3615

ALICE, arXiv:1509.07541



$dN_{ch}/d\eta \approx$ **4-5**

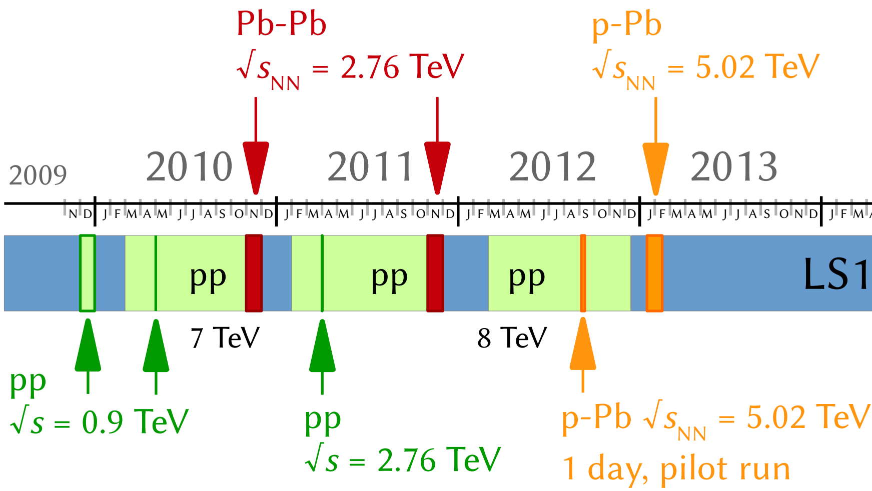
II.1 – ALICE : the experiment and the collaboration



41 countries
178 institutes
≈1.5 x10^{3} members

(1992-2017)

II.2 – ALICE : ALICE campaigns in LHC runs 1+2



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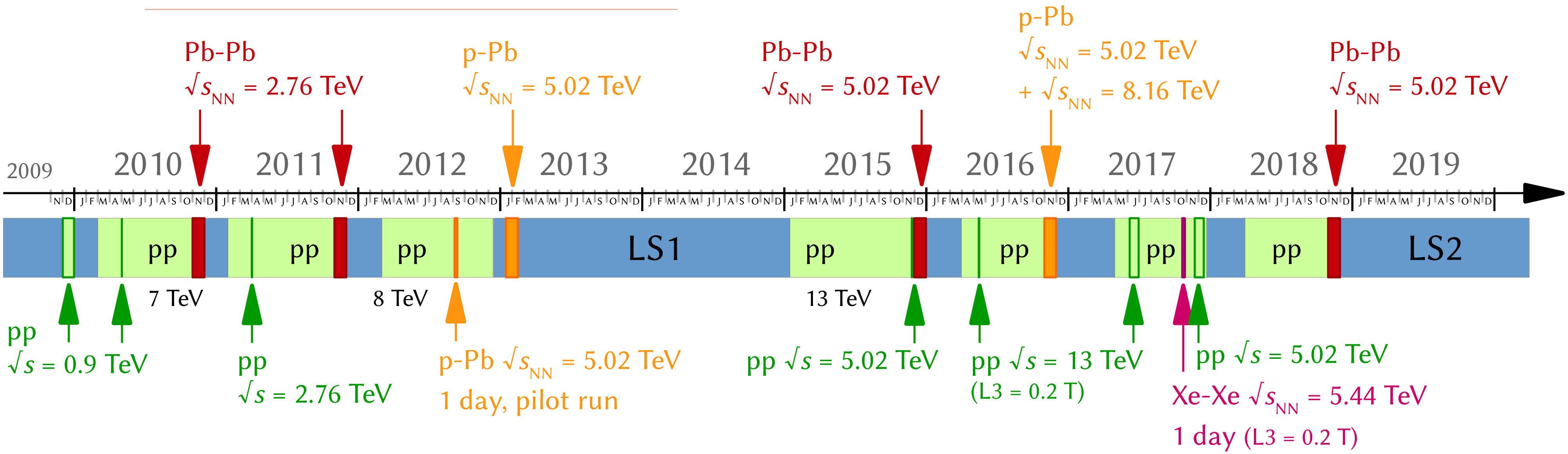

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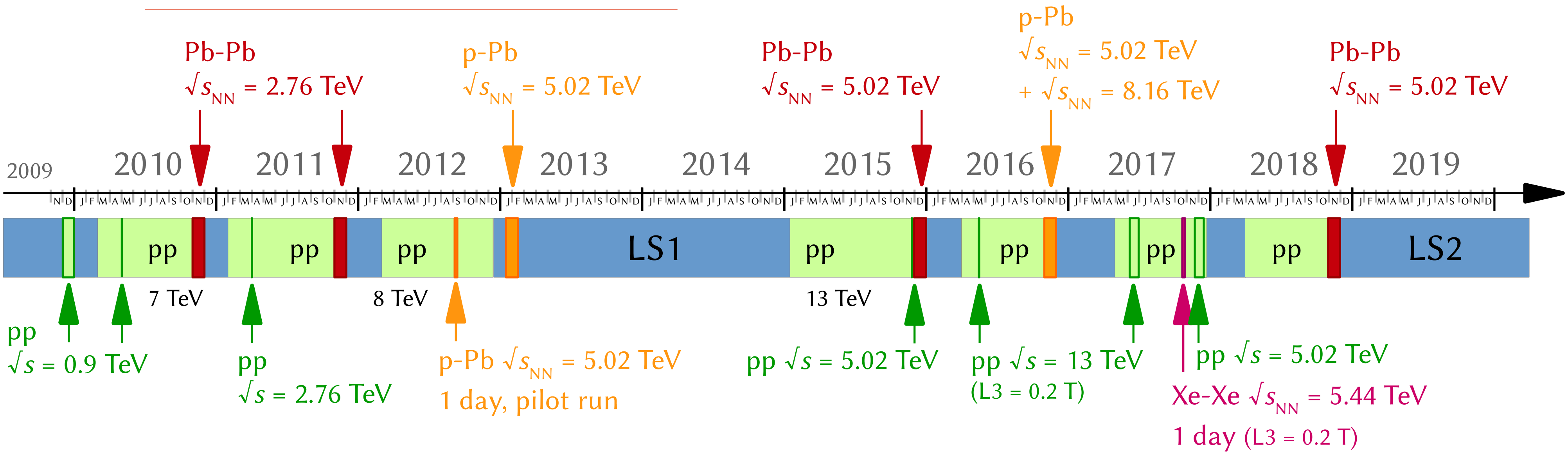

ALICE objectives for Runs 1+2 :

- 1 nb^{-1} in Pb-Pb + "track-equivalent" $\mathscr{L}_{int}$ in pp
- pp campaigns at reference $\sqrt{s}$
- p-Pb campaigns

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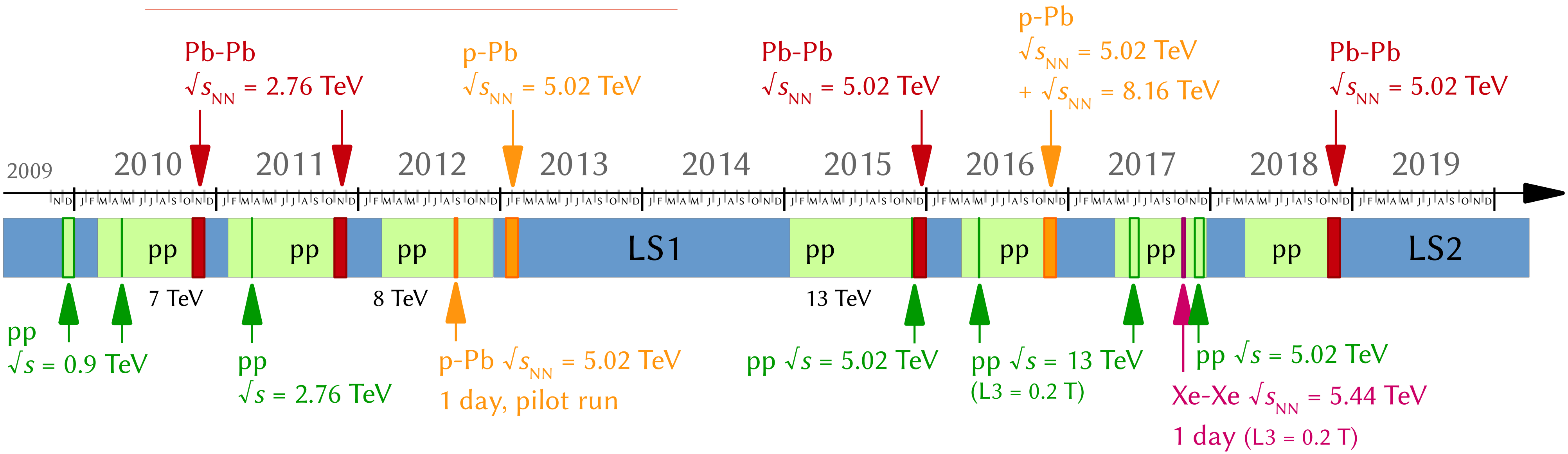

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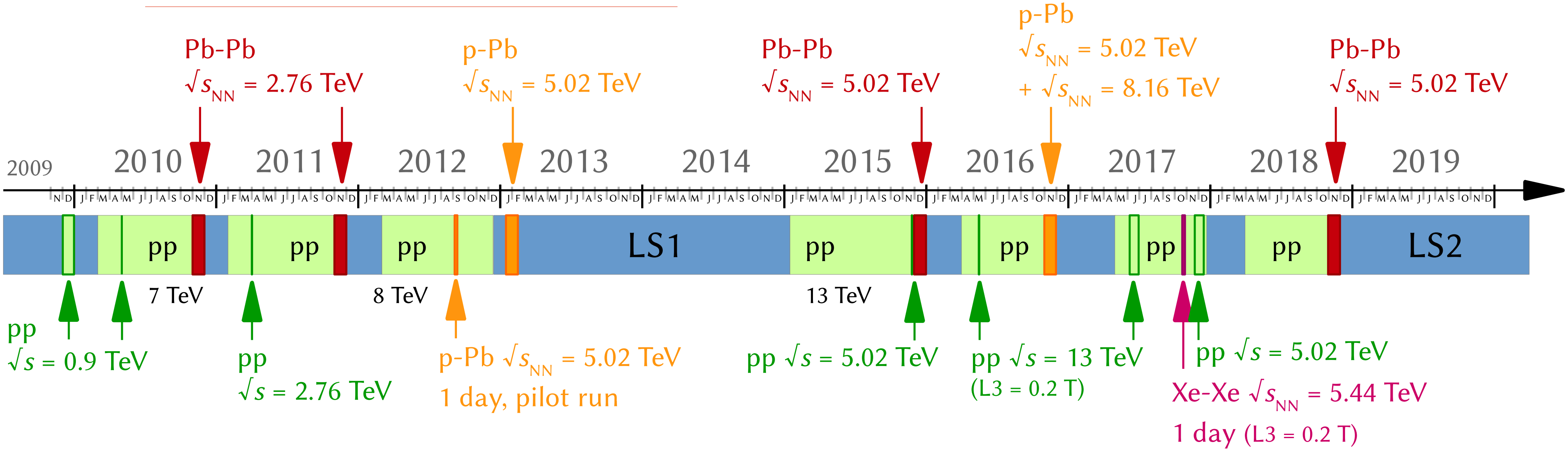
Remark (~for pp) : delivered Vs. inspected Vs. recorded luminosity

e.g. LHC-delivered $\mathscr{L}_{int}$ pp for 2017 (*acc-stats.cern.ch/LHC*) :

CMS, ATLAS ≈ 50 770 pb^{-1} Vs. LHCb ≈ 1870 pb^{-1} Vs. ALICE ≈17.7 pb^{-1}

II.2 – ALICE : ALICE campaigns in LHC runs 1+2



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⟶ ALICE = physics at the event level ≠ physics for particles ~independently of the event

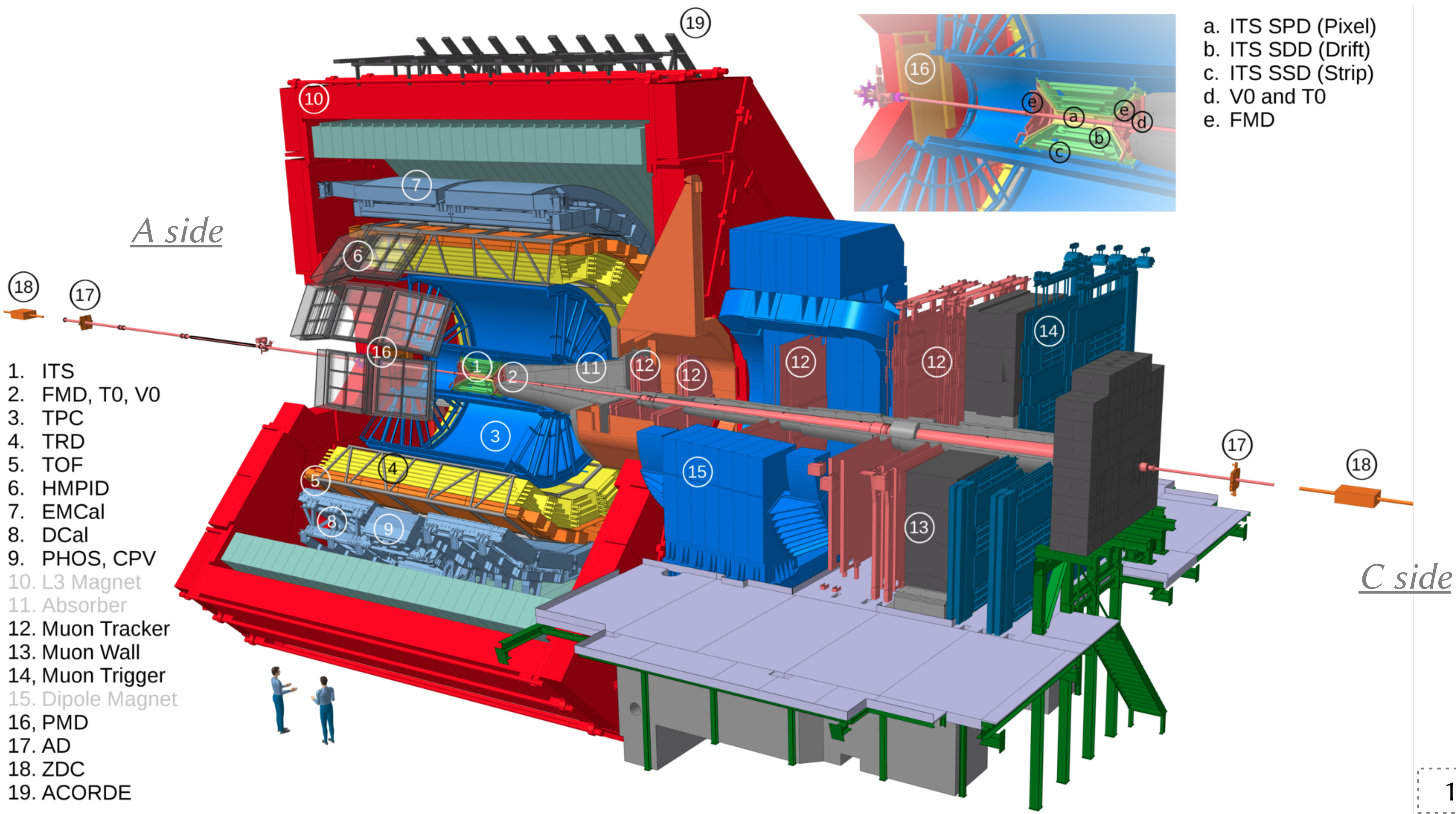
⟶ specific data taking strategy (campaign planning + $\mathscr{L}_{instantaneous}$ leveled at ≈ 2.6 10^{30} $cm^{-2}s^{-1}$) ...

ex : pp pile-up (2015-2018) $\mu_{ALICE} \leq 0.02$ // μ_{CMS} $\mathcal{O}$(40-60)

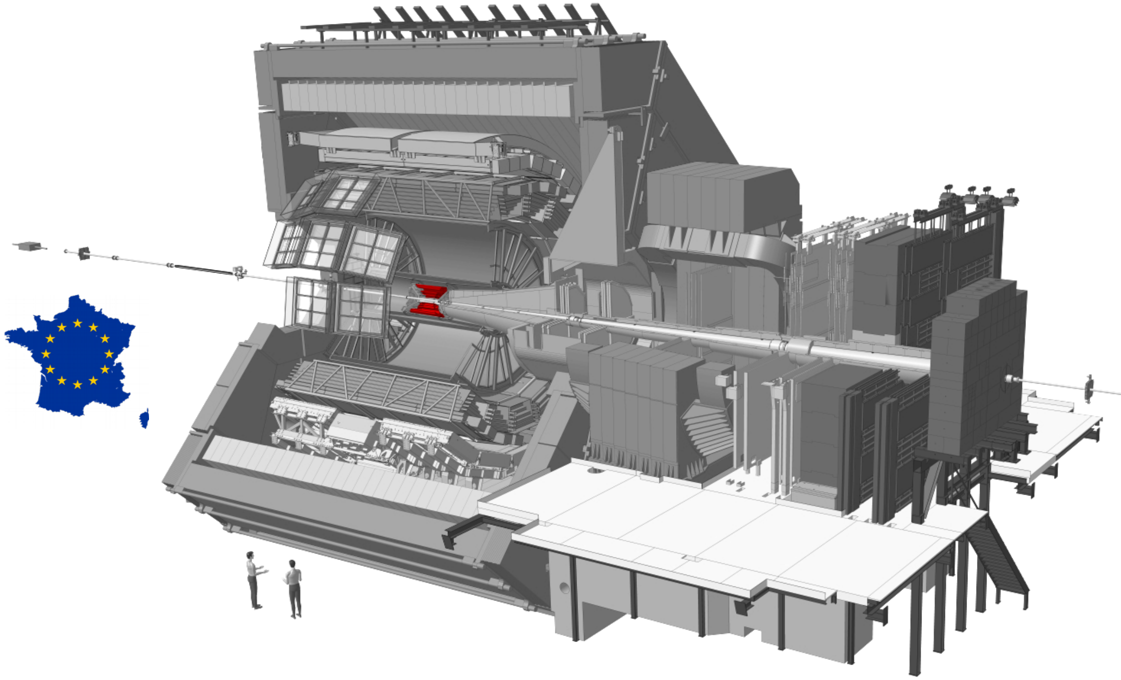
II.3 – ALICE : detector layout

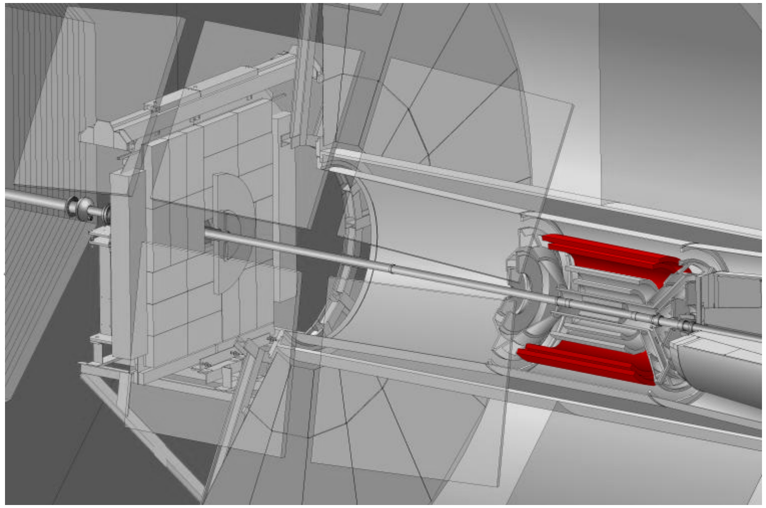
ALICE in run 2 = 20 active sub-detectors of various kinds

⟶ 2 parts : i) forward y + ii) y~0



II.4 – ALICE : ITS





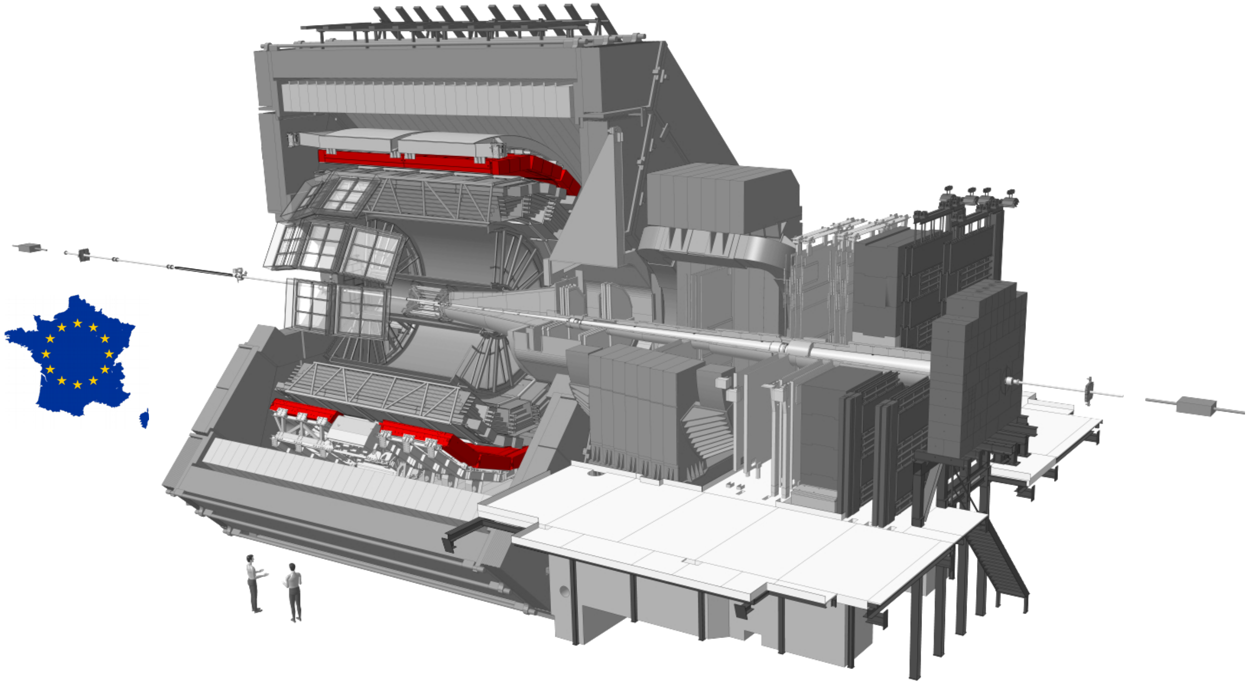
- **Inner Tracking System = ITS**

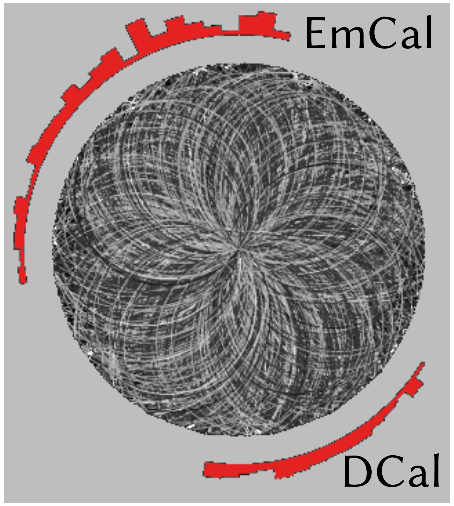
$|\eta_{ITS}|$ < 0.9 at least / $p_T^{threshold}$ ~ 50 MeV/c

2 layers = silicon pixels, SPD (hybrid pixels : 50 x 425 μm²)
2 layers = silicon drift, SDD
2 layers = silicon strips, SSD ←

→ **trigger** (SPD)
→ **vertexing, tracking** (SPD, SDD, SSD)
→ **PID (d*E*/d*x*)** (SDD, SSD)

II.5 – ALICE : EmCal+DCal





- **EmCal+DCal**

≈20 x/X_0 (Pb layers + scintillator layers)

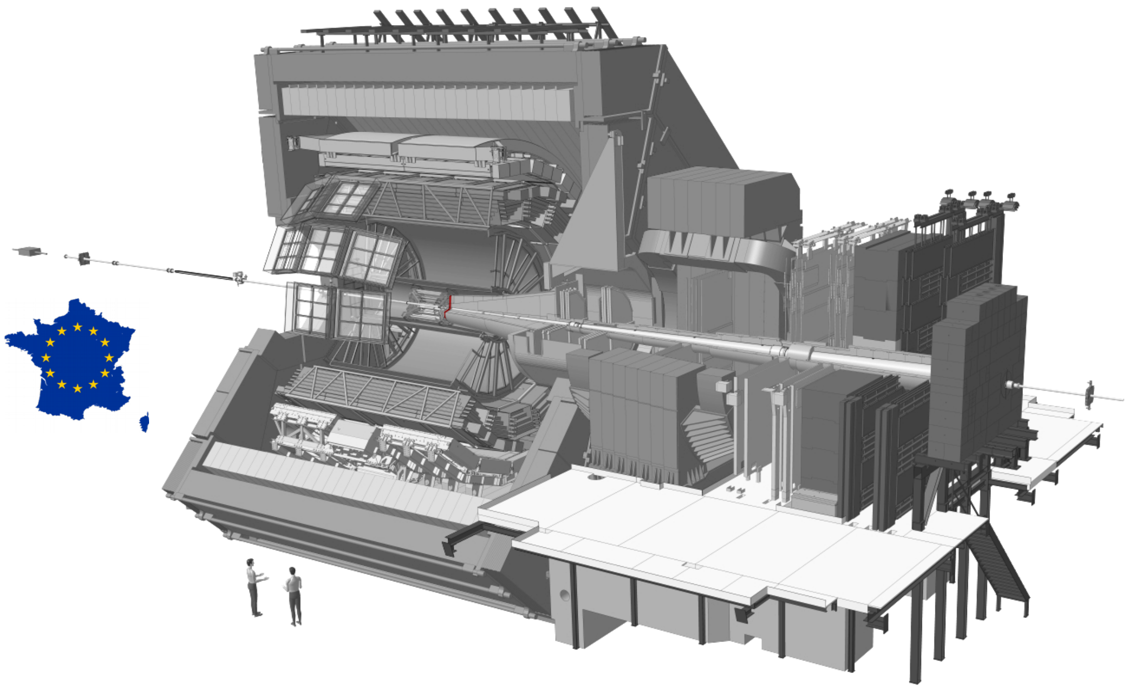
E or $p_T^{threshold} \approx 2$ GeV(/c)

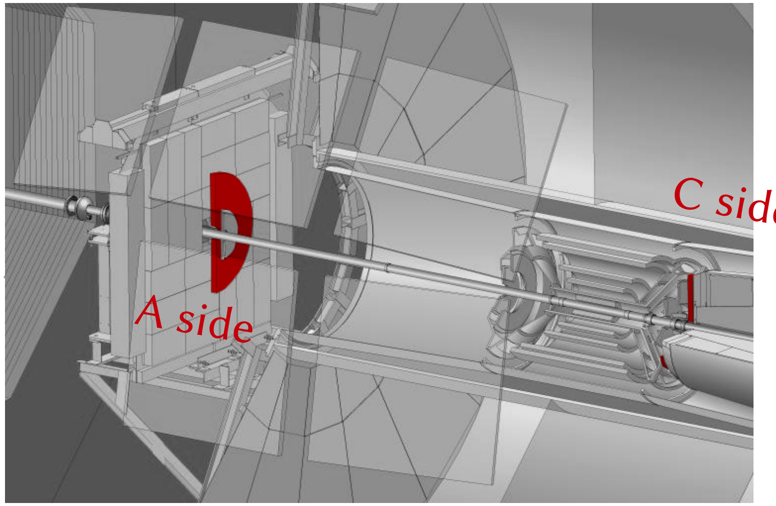
- EmCal : $\Delta\varphi = 107°$ + $|\eta_{EmCal}| < 0.7$
- DCal : $\Delta\varphi = 67°$ + $0.22 < |\eta_{EmCal}| < 0.7$

→ **trigger**

→ **$e^{\pm}$ + direct γ, $\pi^0 \to \gamma\gamma$, $\eta \to \gamma\gamma$, ...**

II.6 – ALICE : VZERO



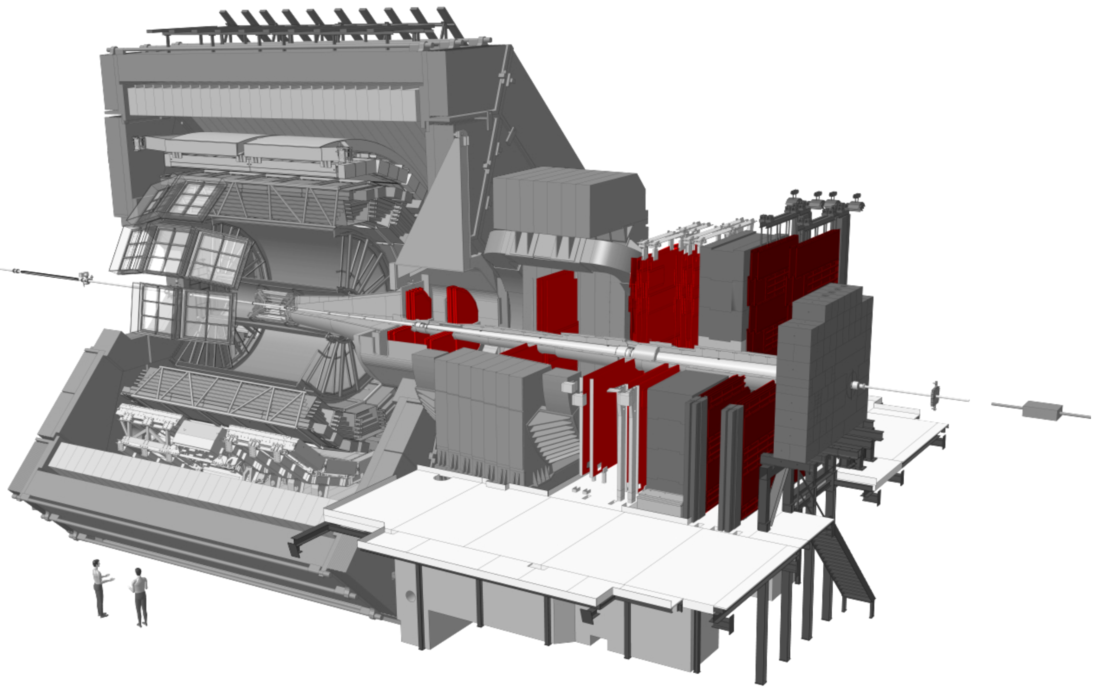


- **VZERO or V0**

V0A = $2.8 < \eta < 5.1$
V0C = $-3.7 < \eta < -1.7$
forward arrays of scintillators

→ **event activity :** Online trigger (Min Bias + Pb-Pb centrality + high-mult. pp)
Offline use = (Pb-Pb, p-Pb, pp)
→ **event selection :** physics vs beam-gas identification
→ **event charac. :** event plane + ref. flow vector (Pb-Pb)

II.7 – ALICE : μ spectrometer



- **μ arm : μ tracking + μ trigger**

$-4 < \eta_{\mu} < -2.5$
dedicated dipole magnet (rigidity = 3 T.m)

μ tracking : 5 stations of MWPC, beyond absorber
μ trigger : 2 stations of RPC, beyond iron wall

→ **μμ (low-mass vector mesons, quarkonia cc, bb, Z)**
→ **single μ (open heavy flavours, $W^{\pm}$)**

III.1 – ALICE features : low p_T

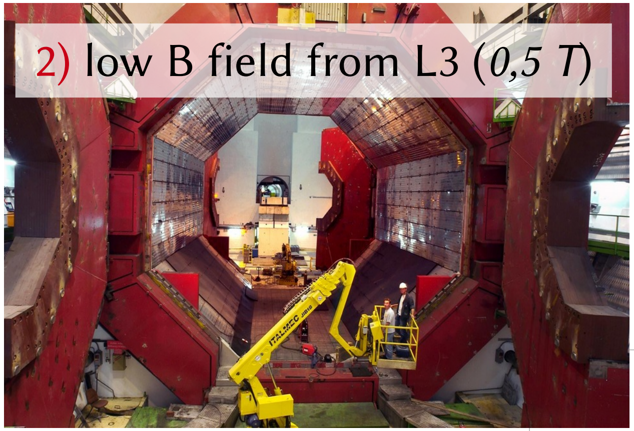
A) Focus on low p_T (≤ 2-3 GeV/c) and intermediate p_T (2-3 ≤ p_T ≤ 8-10 GeV/c)

NB : X% of the particle production sit below p_T ≤ 0.5 GeV/c, ≤ 2 GeV/c, ...

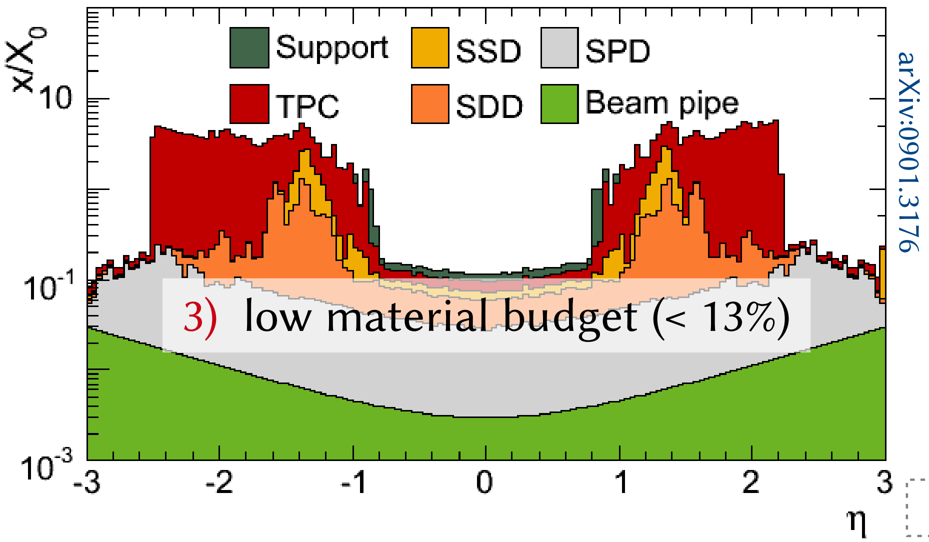
To keep i) large Acceptance x Efficiency, Axε
ii) detection threshold at very low p_T
iii) excellent p_T resolution (ex: ≤1-2% for $p_T \in$ [0.1-10] GeV/c)

- Need 1) ⟶ low event pile-up (in bunch + out-of-bunch) // readout speed // $\mathscr{L}_{inst}$
  - Need 2) ⟶ moderate B field

- Need 3) ⟶ lowest possible material budget x/X_0



To be compared with CMS and ATLAS corresponding figures at y~0

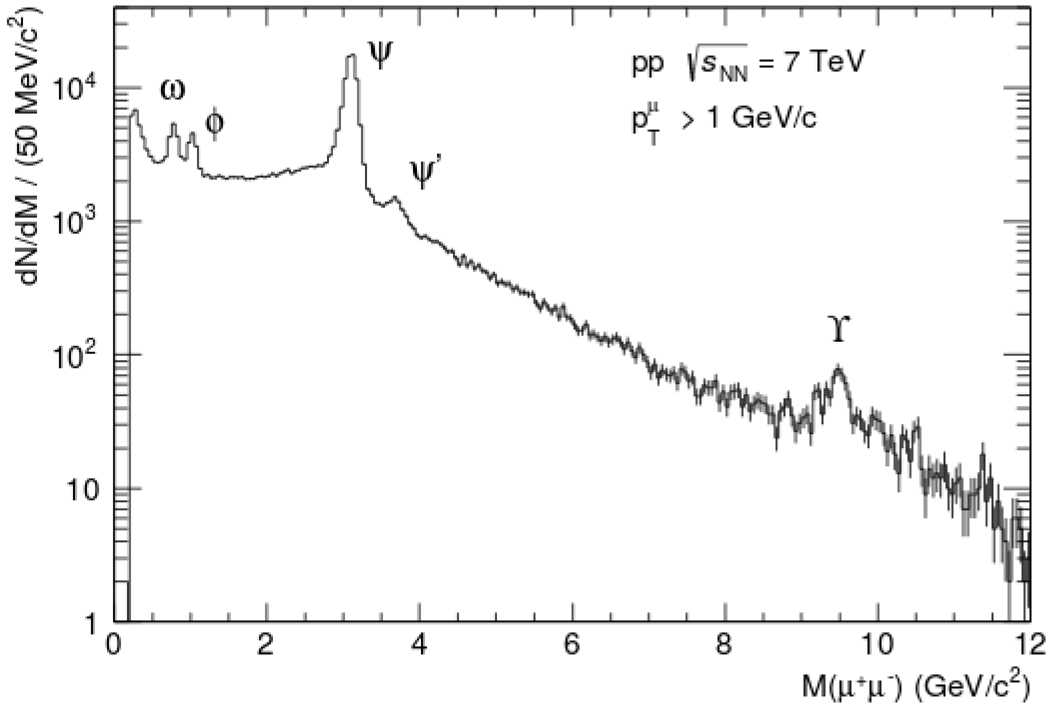


For further details, see ALICE Performance, arXiv:1402.4476

III.2 – ALICE features : passive PID at forward y

B) very good detector-PID capabilities over wide range of p_T

y forward : $\mu^{\mp}\mu^{\pm}$

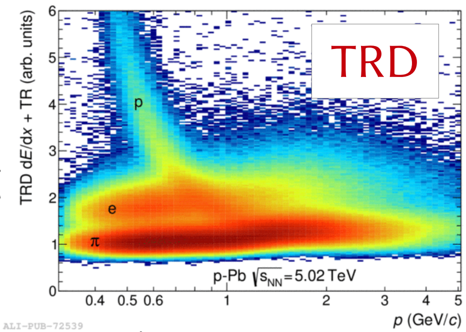


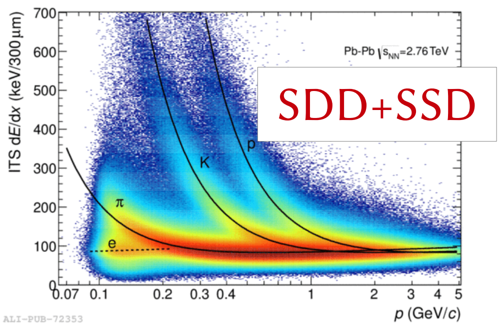
ALICE Perf., arXiv:1402.4476

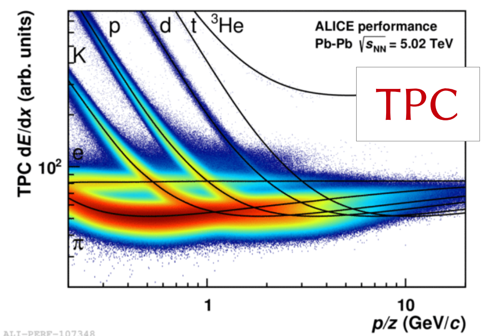
III.2 – ALICE features : PID at y ≈ 0

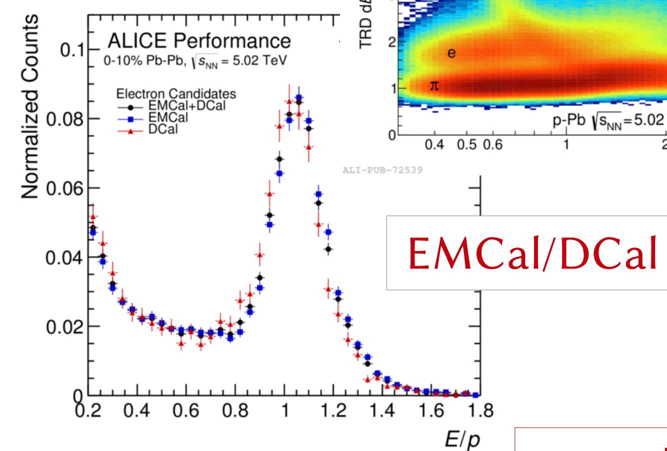
B) very good detector-PID capabilities over wide range of p_T

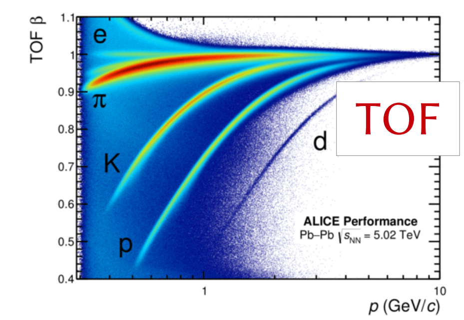
γ, $e^\pm$, $\pi^\pm$, $K^\pm$, p + ^{2}H, ^{3}H, ^{3}He, ^{4}He ...
with help of :

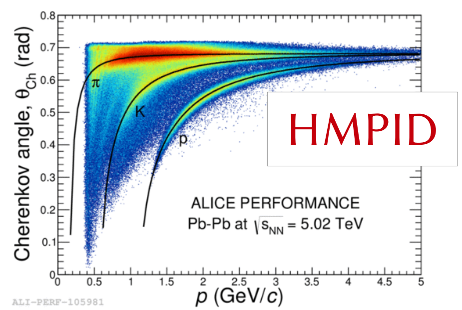




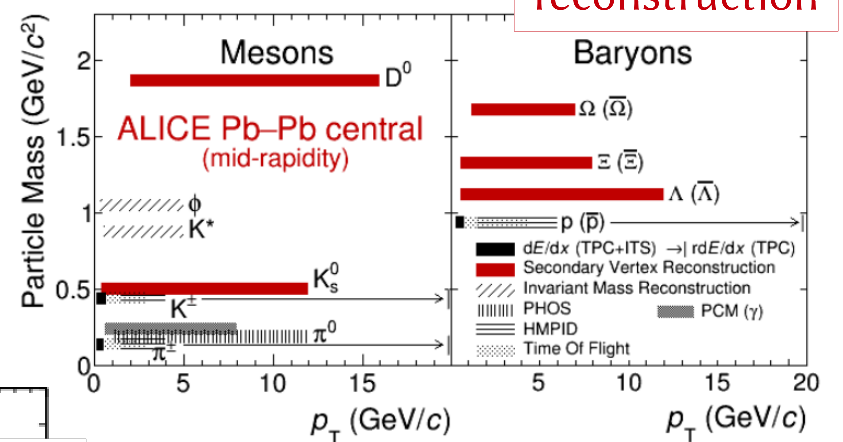


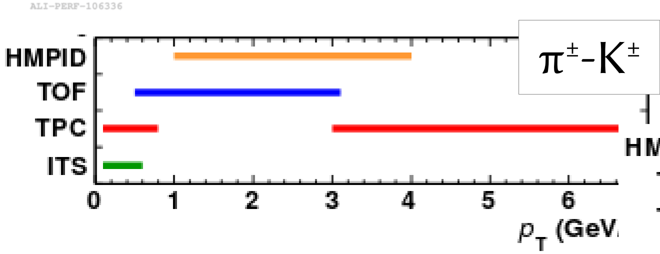


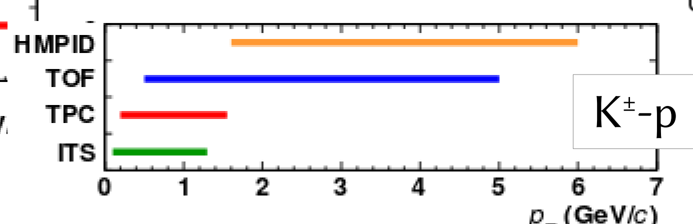




+ topological reconstruction







ALICE Perf., arXiv:1402.4476

III.3 – ALICE features : systematism

Comprehensive and *systematic* measurements in pp, p-Pb and Pb-Pb

$\longrightarrow$ ALICE role for QGP+QCD at LHC

(heavy-)flavour physics :

u,d,s,c,b (t) <=>

π^+ π^0 K^+ K^0_S … p Λ Ξ^- Ω^- …

$\eta(547)$ $\omega(782)$ $K^0(892)$ $\phi(1020)$ $\Sigma^\pm(1385)$ $\Lambda(1520)$ $\Xi^0(1530)$

d t ^3He ^4He $^3_\Lambda H$ …

D^0 D^+ D^{*+} D_S … J/ψ χ_{Ci} $\psi(2S)$ … Λ_C^+ Ξ_C

heavy-flavour ($\mu^\pm$, $e^\pm$)

… ϒ(1S,2S,3S)

γ $W^\pm$ Z + anti-particles.

III.3 – ALICE features : systematism

Comprehensive and *systematic* measurements in pp, p-Pb and Pb-Pb

→ ALICE role for QGP+QCD at LHC

(heavy-)flavour physics :

u,d,s,c,b (t) <=> π^+ π^0 K^+ K^0_S … p Λ Ξ^- Ω^- …

$\eta(547)$ $\omega(782)$ $K^0(892)$ $\phi(1020)$ $\Sigma^{\pm}(1385)$ $\Lambda(1520)$ $\Xi^0(1530)$

d t ^{3}He ^{4}He $^3_\Lambda$H …

D^0 D^+ D^{*+} D_S … J/ψ χ_{Ci} $\psi(2S)$ … Λ_C^+ Ξ_C

heavy-flavour ($\mu^{\pm}$, $e^{\pm}$)

… Y(1S,2S,3S)

γ $W^{\pm}$ Z + anti-particles.

→ ALICE publications

≥ 200 submitted/published papers (in date : 2 Feb. 2018)

Among which :

- 2 Nature Phys., 29 PRL, 29 JHEP, 55 Phys. Lett. B, 31 EPJC, 20 PRC, …
- 6 (*500+ citations*) / 11 (*250+*) / 45 (*100+*) / 45 (*50+*) / …

Average citations ≈ 102.5/article (in date : 7 Feb. 2018)

→ *INSPIRE:find cn ALICE and ac 100+*

III.4 – ALICE features : computing

ALICE (in 2018)

- 64 sites (Tier-0, Tier-1, Tier-2)
  - for tape storage (T0+T2 ≈ 90 PB)
  - for disk storage (T0+T1+T2 ≈ 90 PB)
  - for CPU (≈3x 350.10^3 HEP-Spec06)

Use cases (CPU+Storage) :

≈10% {
1/ Offline detector calibration
2/ Event reconstruction :
- real data :
$\mathcal{O}$(1-2 min) /Pb-Pb 0-5% event
$\mathcal{O}$(1-2 s) /pp Min Bias
}

≈70% {
- MC (gen+transport Geant3,4) :
$\mathcal{O}$(10 min) /Pb-Pb 0-5% event
$\mathcal{O}$(10 s) / pp Min Bias
}

≈20% { 3/ Analysis LEGO train on data & MC }

ALICE-France :

Tier-1 : CC-in2p3
+ Tier-2 : 5 sites (IPHC, GRIF, LPC, LPSC, Subatech)

⟶ Pledge : $\mathcal{O}$(10%) of the whole ALICE Grid

III.5 – ALICE features : Human Ressources

In Run 2 :

ALICE Collaboration : $\mathcal{O}(1100)$ authors (Feb. 2018)
628 total M&O-A (Sept. 2017)

©LaChaineMeteo

ALICE France

- 25 CNRS (+7 CEA)
- 11 University staff,
- 13 PhD Students

+ 22.97 FTE IR+Technicians In2p3 (info basis $\not\approx$ NSIP 2017...)

⟶ <u>Construction/operation</u> :

- V0 (among which project leader)
- μTrk+μTrg (among which project leader)
- ITS-Si Strips SSD
- Em/DCal
- Data Preparation Group DPG (calibration, Quality Assu.)
- Computing

⟶ <u>Scientific management in runs 1+2</u> :

- Deputy spokespersons
- Editorial Board members
- Conference Committee members
- Management Board

⟶ <u>Phys Coordination</u> :

- Physics Working Group convenors
- Physics Analysis Group convenors
- Analysis/Internal Review Committees

Part B – run 1+2 outcome

IV.1 – Runs 1+2 : defining usual observables

1. - p_T spectra : $$\frac{1}{N_{evt}} \frac{d^2 N}{dp_T\, dy} = f(p_T)$$

2. - Yields : $$1/N_{evt}\; dN/dy$$

measured in pp, pA, AA

3. - $R_{AA}(p_T)$ = $$\frac{(1/N_{evt}^{AA})\;\; d^2 N^{AA}/dp_T\, dy}{\langle N_{coll}\rangle\;(1/N_{evt}^{pp})\;\; d^2 N^{pp}/dp_T\, dy}$$

"1 x (Pb–Pb) ≠ n x (pp) ?" ...

Notes :

→ $R_{AA} = 1$, if no visible change in AA ...
e.g. direct photons, $W^{\pm}$, Z^0

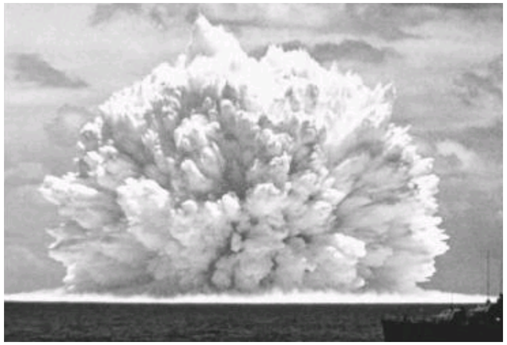
→ $R_{AA} > 1$, if enhancement in the AA system
e.g. strange baryons Λ, Ξ, Ω at low momenta (p_T < 3 GeV/*c*)

→ $R_{AA} < 1$, if suppression in the AA system
e.g. $h^{\pm}$, π, K, p, Λ, D, J/ψ at mid/high p_T (p_T > 3-5 GeV/*c*)

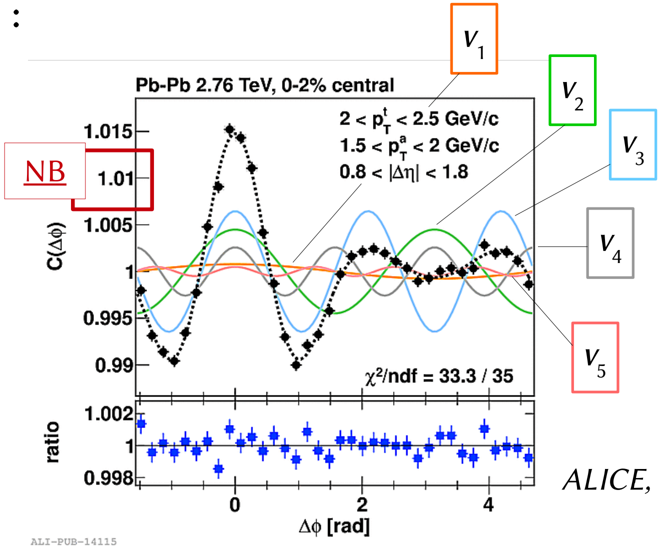
IV.2 – Runs 1+2 : defining usual observables

The 2+2 interleaved families of essential QGP observables :

I. relativistic hydrodynamics of the fireball



($p_T \leq$ 2-3 GeV/c)



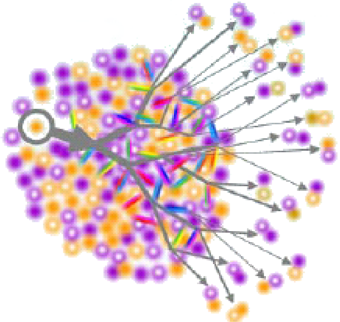
ALICE, arXiv:1109.2501

explosive emission, isotropic in azimuth (radial flow)

+ azimuthal modulations (anisotropic flow, v_n = f[m^0, p_T, centrality])

II. in-medium energy losses :

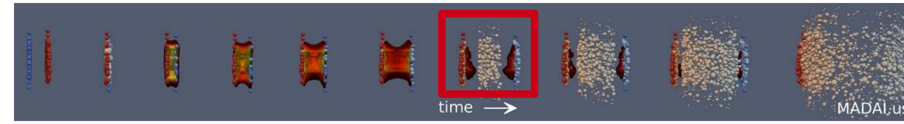
jet quenching, attenuation of high-p_T particles ($p_T \geq$ 6-8 GeV/c)



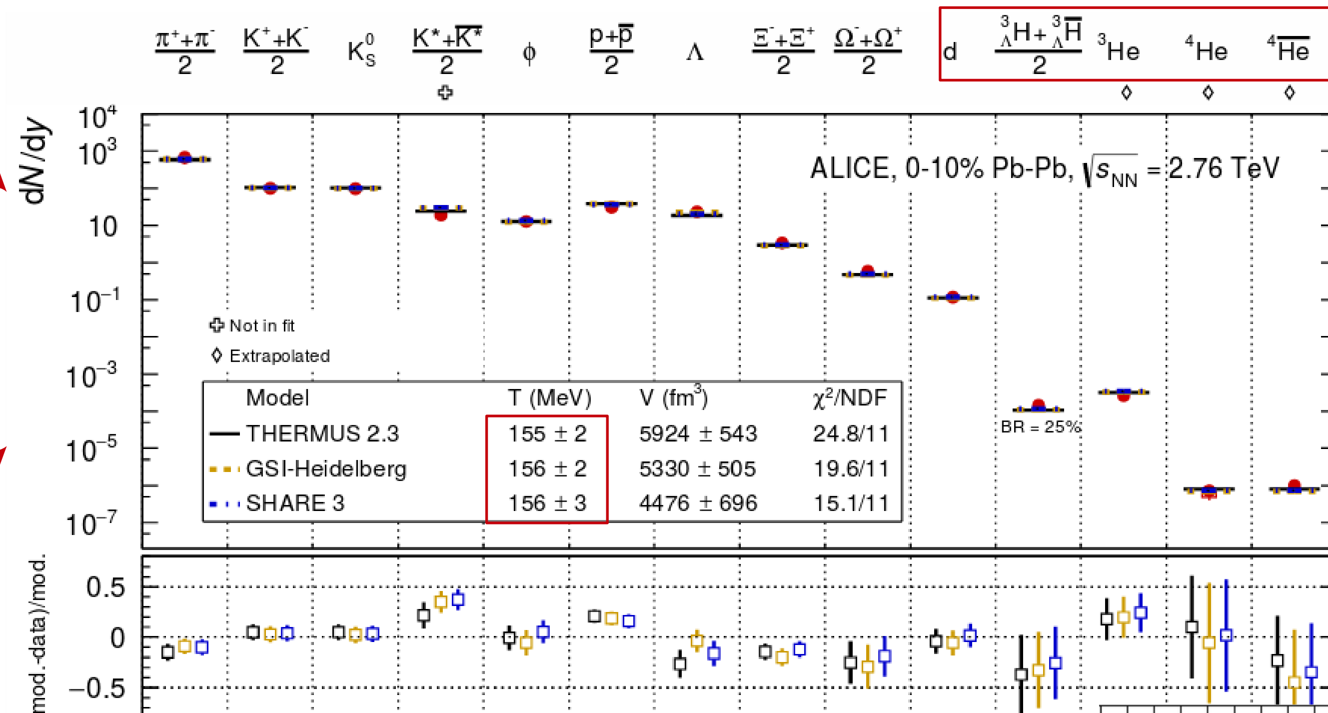
A. via light flavour (u,d,s)

B. via heavy flavours (c,b) : open or hidden

→ *In the following : sample of major ALICE(-France) results …*



V.1 – Runs 1+2 : *u,d,s*



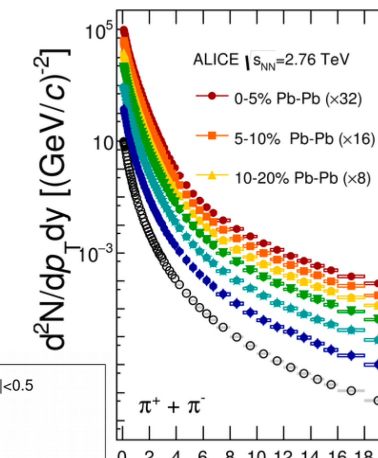
ALICE, arXiv:1710.07531

p_T-integrated yields

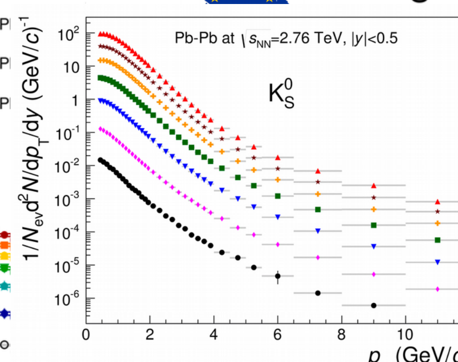
$\int_{p_T} d^2N/dp_Tdy = dN/dy$

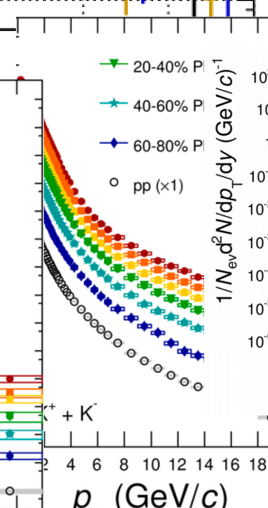
$\longrightarrow$ 14 differential measurements

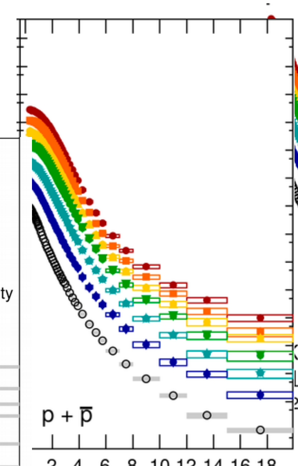
+ comparison to
Statistical **H**adronisation **M**odel
= thermo-statistical model



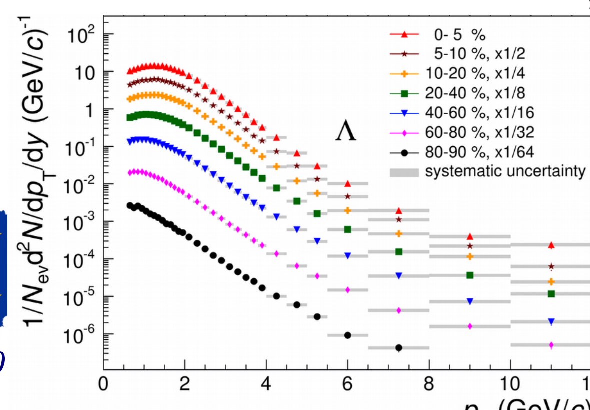
ALICE arXiv:1506.07287





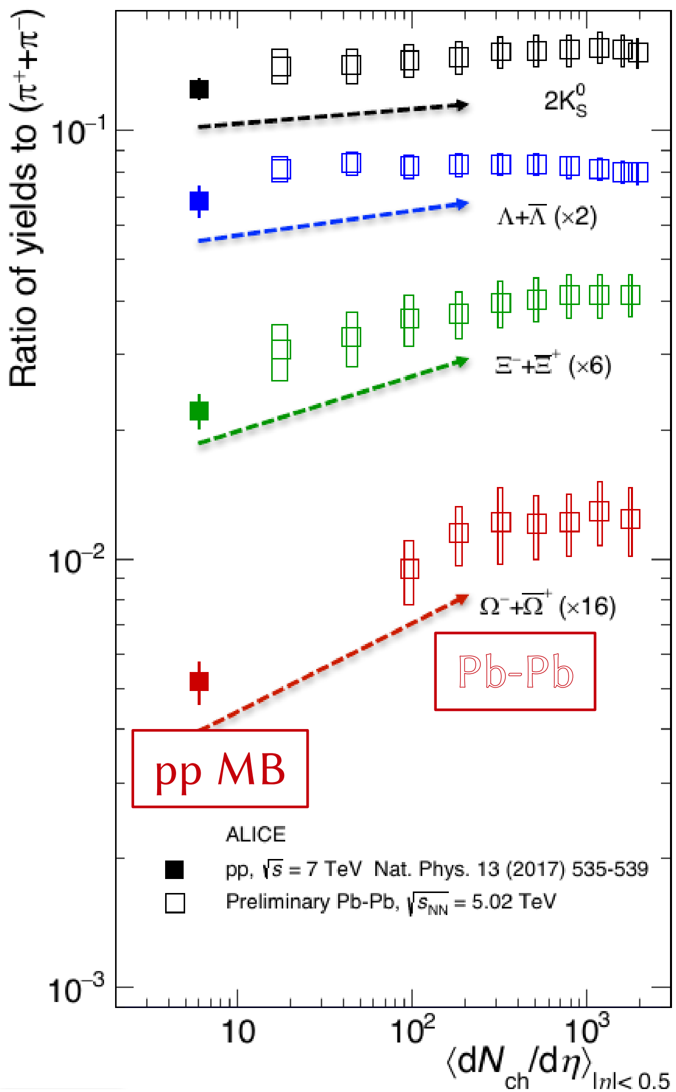


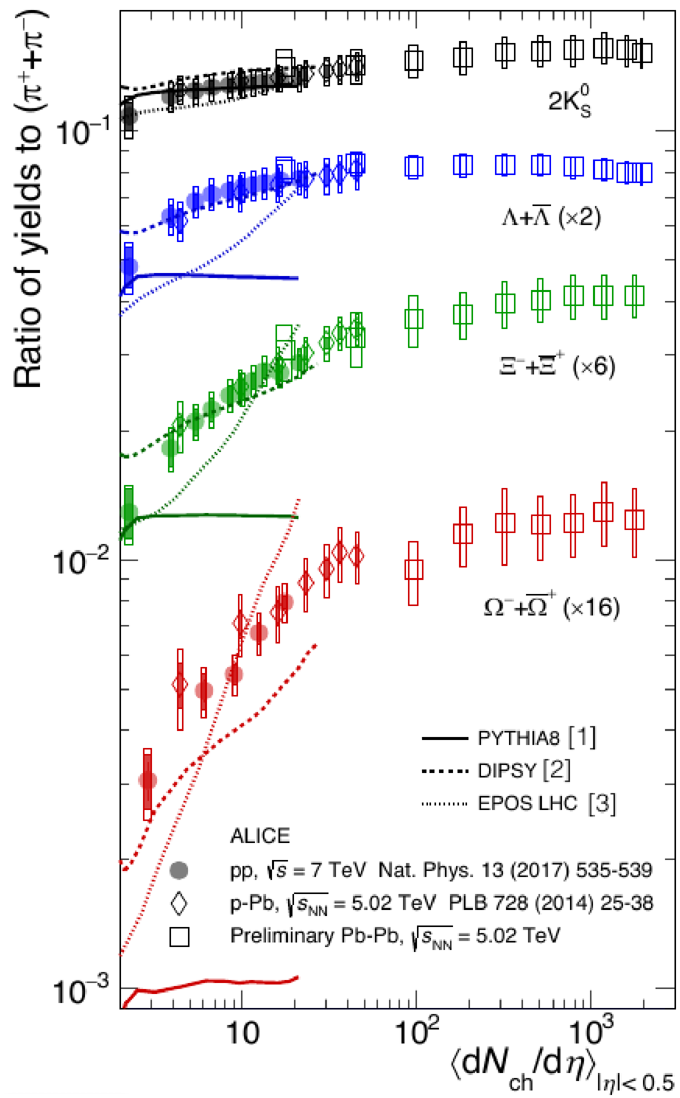
…



ALICE, arXiv:1307.5530

V.2 – Runs 1+2 : *s*, strangeness enhancement, pp to AA





1/ Strangeness enhancement ↗ with strangeness content

2/ Consistent pattern
between
Pb-Pb
p-Pb
pp (!)
for a given multiplicity

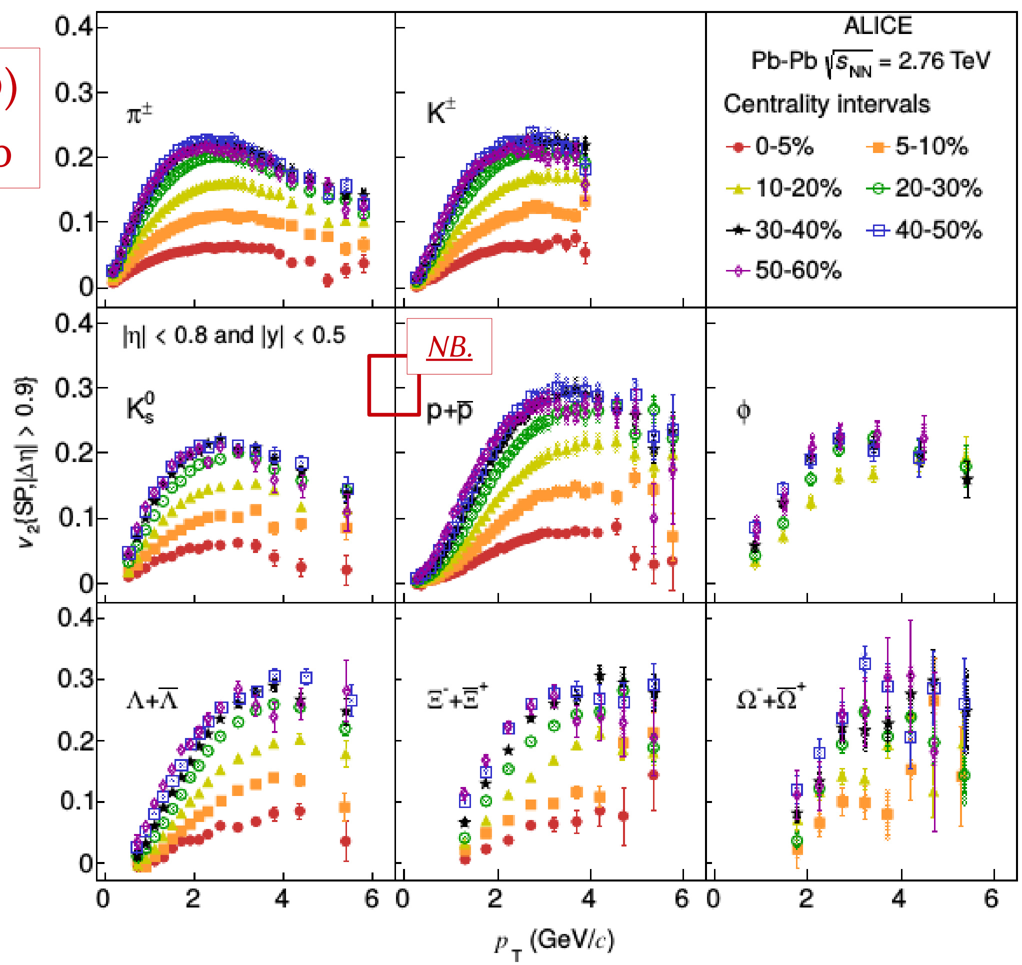
3/ Comparison with models :
Models missing (largely) the data

ALICE, arXiv:1606.07424 (Nature Phys.)

V.3 – Runs 1+2 : hydrodynamics, v_n(PID)

ALICE, arXiv:1405.4632

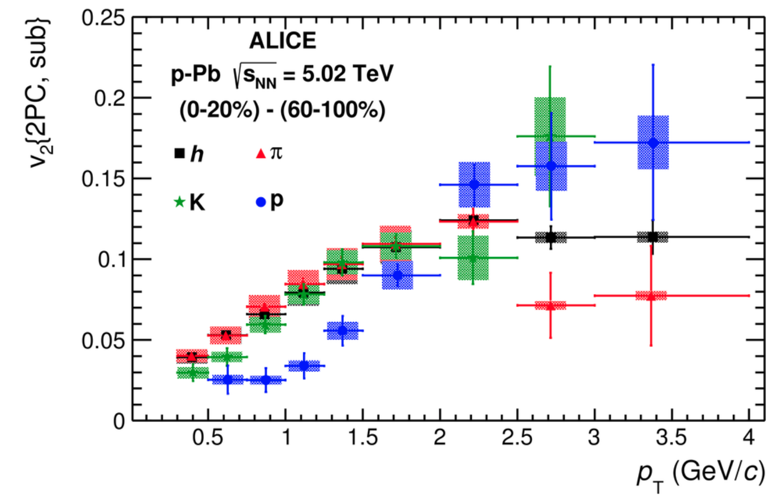
1. v_2(PID) Pb-Pb



NB.

3. v_2(PID) p-Pb

ALICE, arXiv:1307.3237

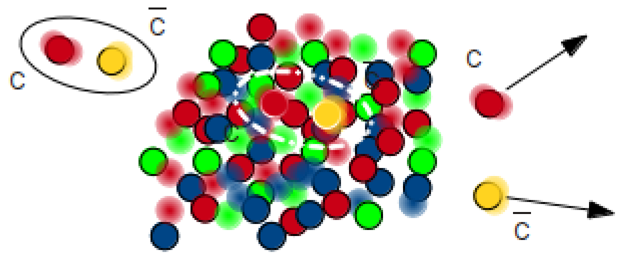


"mass ordering" of v_2 with m_0 in Pb-Pb but also in p-Pb...

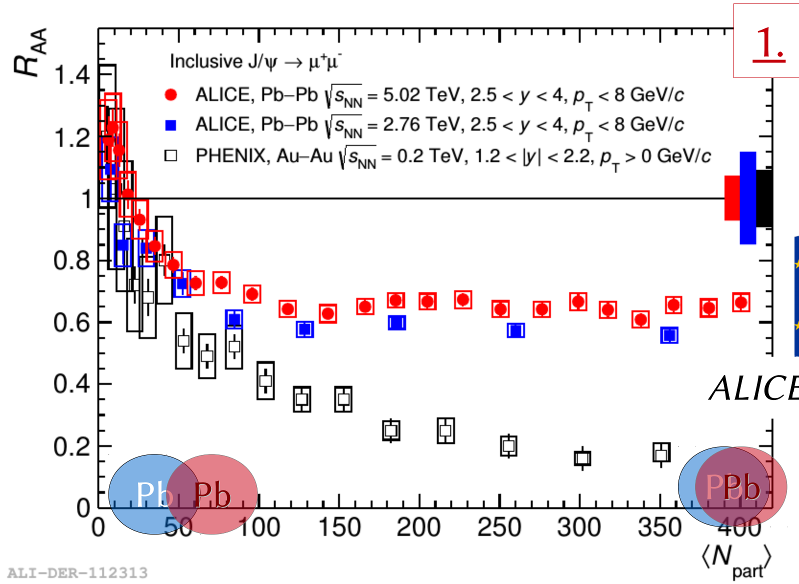
2. v_n(PID) Pb-Pb

→ v_2, v_3, v_4, v_5 = f(p_T, centrality) for π, K, p
ALICE, arXiv:1606.06057

V.4 – Runs 1+2 : *c*, hidden with *inclusive* J/ψ, ψ(2S)



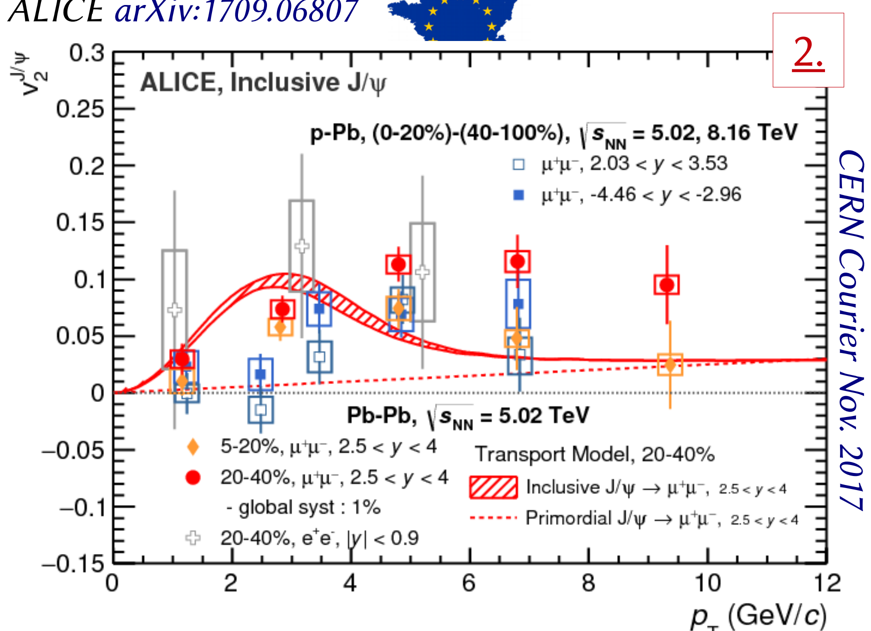
J/ψ(1S) ($c\bar{c}$, m_{PDG} = 3.096 GeV/c^2)
ψ(2S) ($c\bar{c}$, m_{PDG} = 3.686 GeV/c^2)



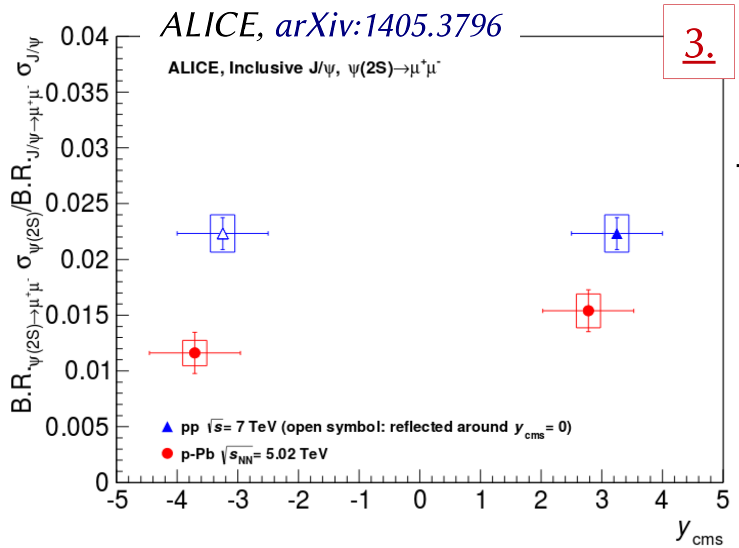
Suppression
Vs.
Recombination

ALICE, arXiv:1311.0214 + Prelim

ALICE arXiv:1709.05260
+ ALICE arXiv:1709.06807



ALICE, arXiv:1405.3796



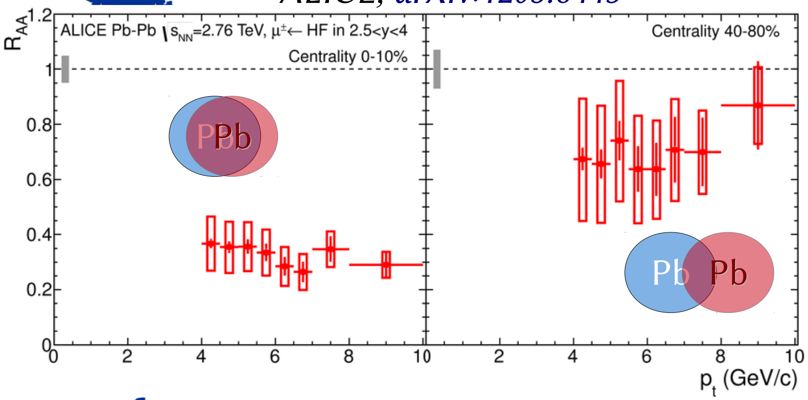
ψ(2S) / J/ψ

p-Pb Vs. pp

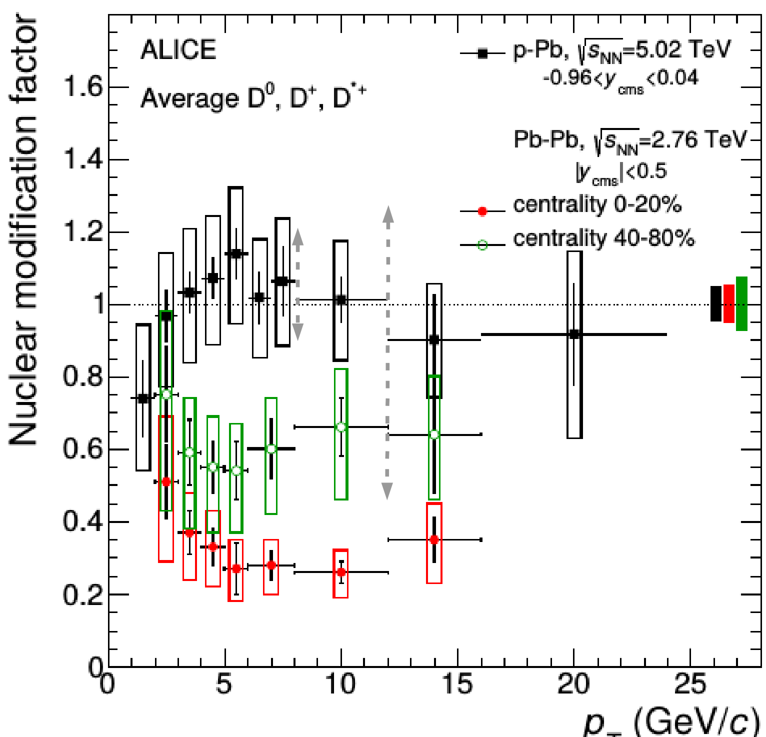
i) v_2(J/ψ) ≠ 0 but also *ii*) v_2(J/ψ) ≠ 0

V.5 – Runs 1+2 : c $(+b)$, open with *prompt* D^0, D^+, D^{*+}, D_S, …

ALICE, arXiv:1205.6443

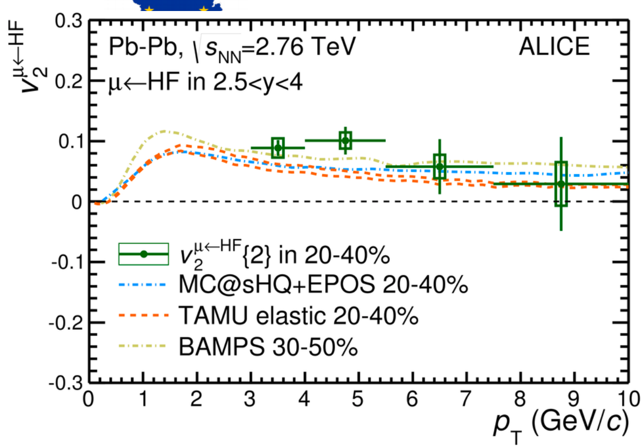


ALICE, arXiv:1405.3452



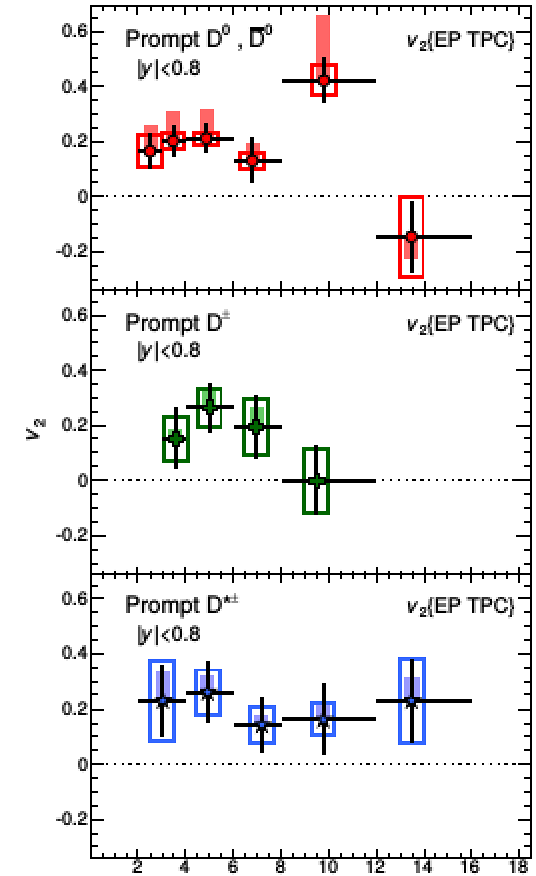
1. Heavy-Flavour μ
R_{AA} + v_2

ALICE, arXiv:1507.03134



2. $R_{pPb}(D) \approx 1$,
while $R_{PbPb}(D) \ll 1$

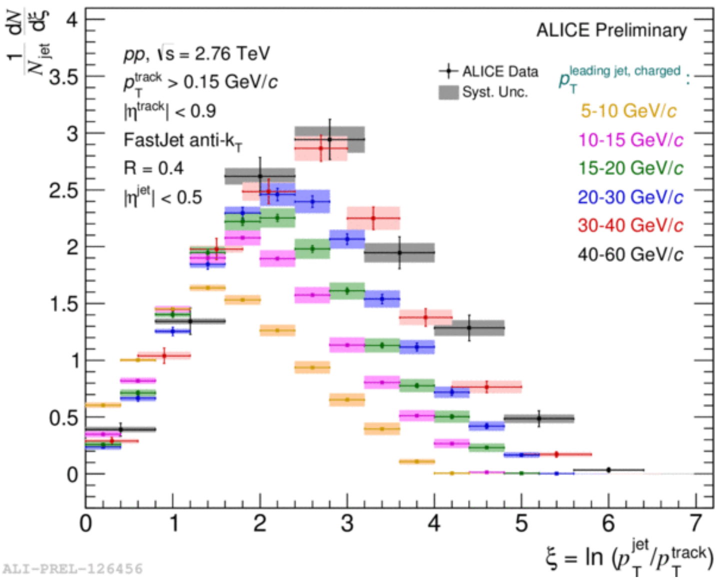
ALICE, arXiv:1405.2001



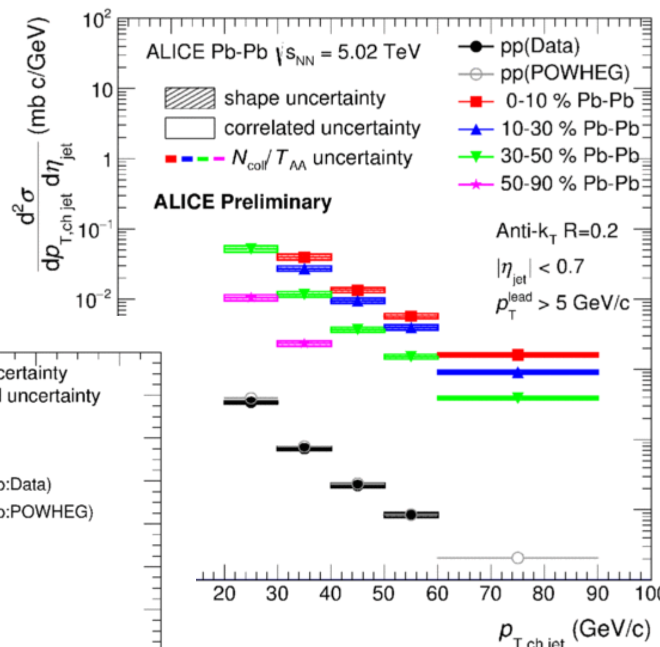
3. $v_2(D) \neq 0$
charm, sensitive
to hydrodynamics !

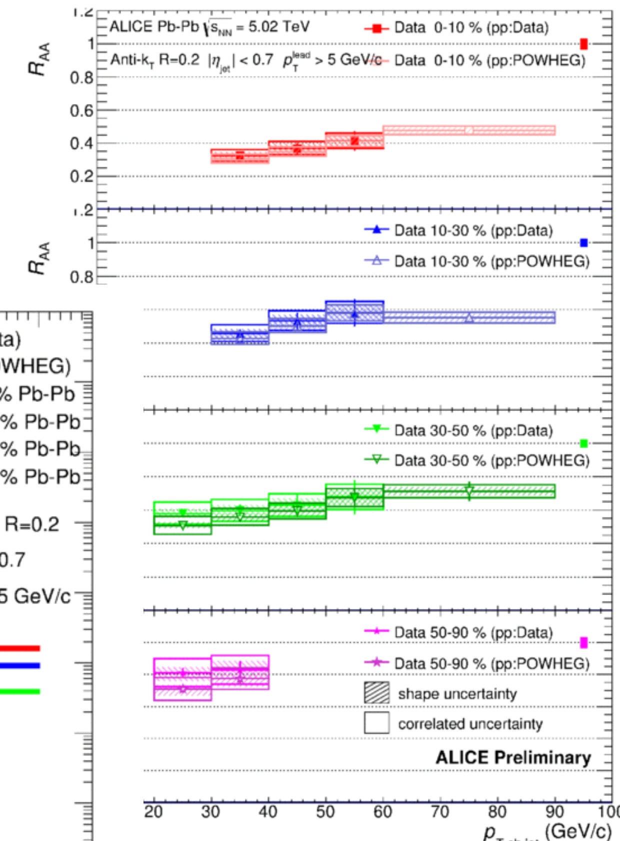
V.6 – Runs 1+2 : high-p_T and jets …

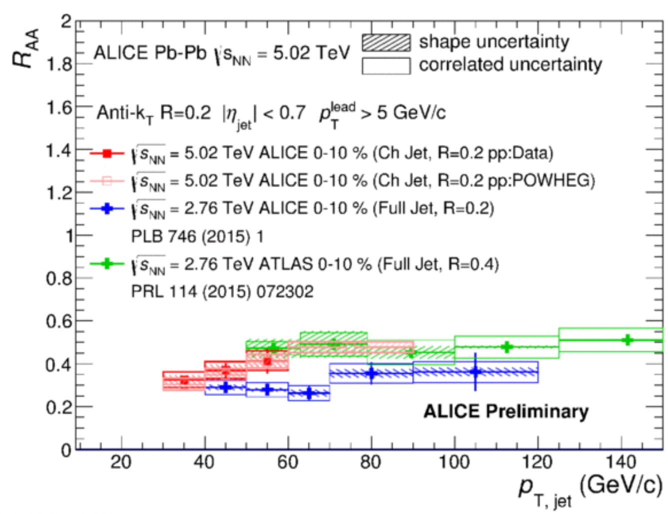
1/ ALICE's say wrt CMS,ATLAS : "lowest high-p_T", i.e. jet ∈ [~10-~100 GeV] + its soft components



EPS-HEP 2017





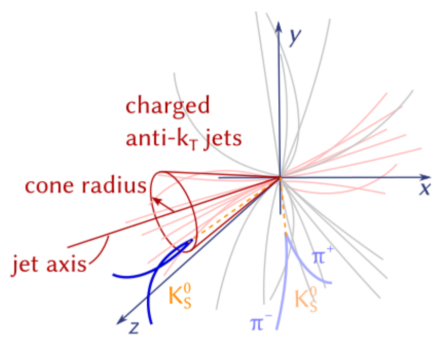


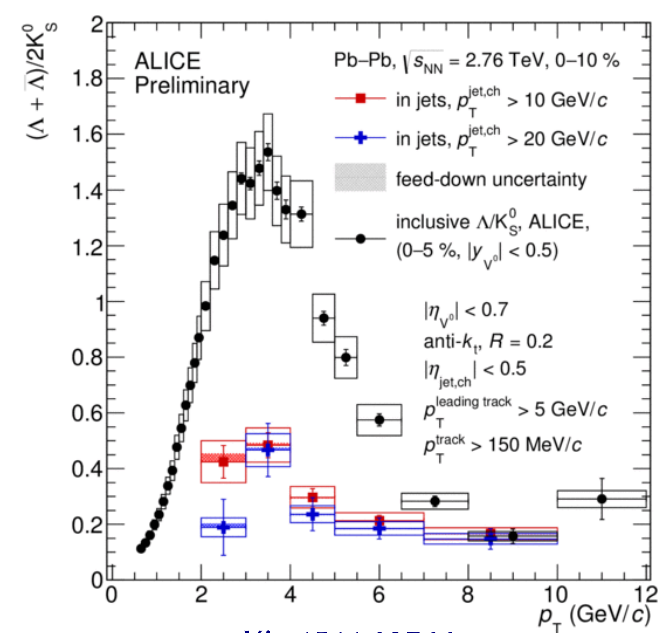
FJKPPL 2017,
Young investigator award

V.6 – Runs 1+2 : high-p_T and jets …

2/ ALICE's say wrt CMS,ATLAS : intra-jet PID, PID+jet

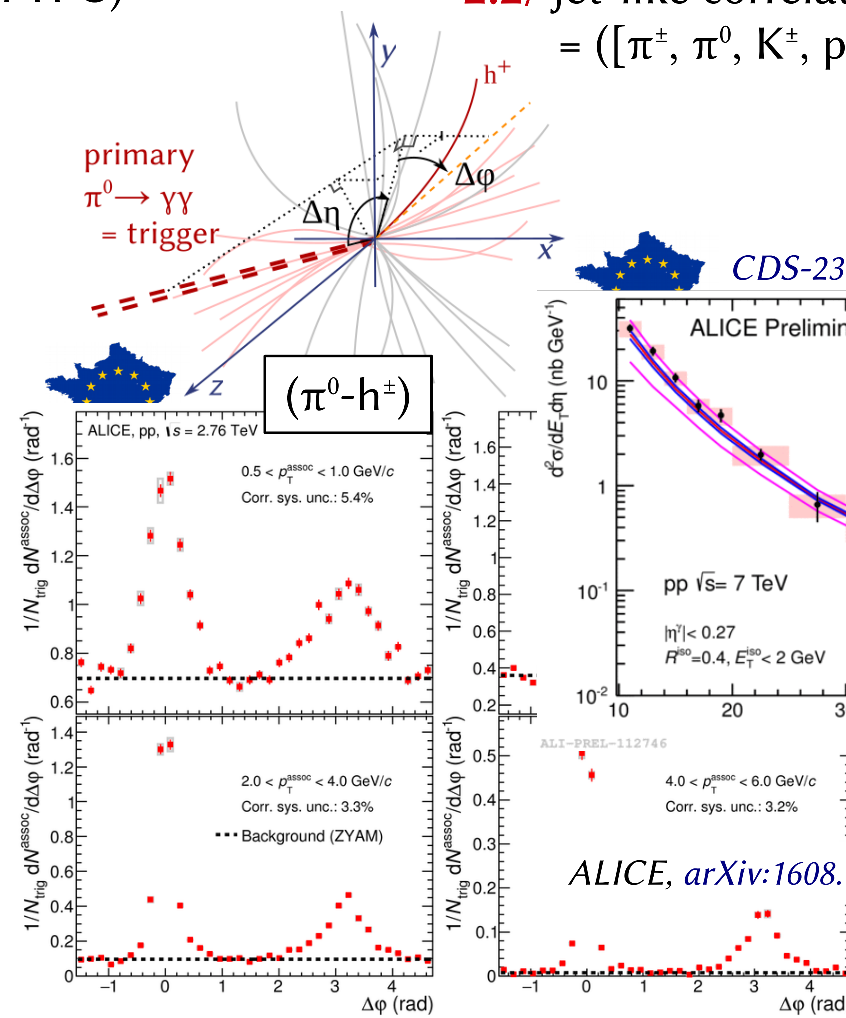
2.1/ Jet hadro-chemistry π, K, p (e.g. with TPC)
but also K^0s, Λ, … D, …





arXiv:1511.02766

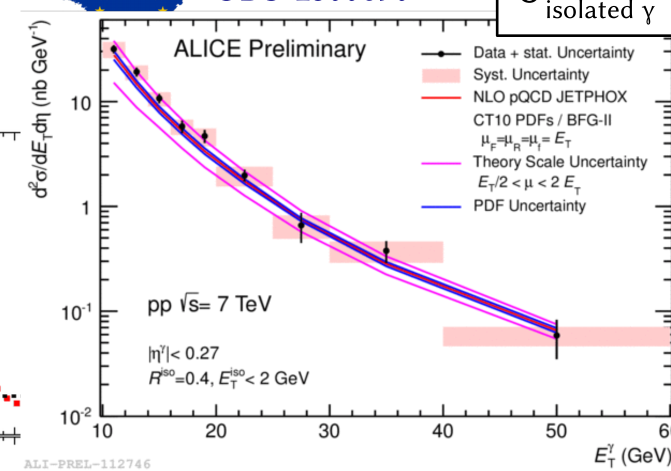
2.2/ jet-like correlations (PID-h$^\pm$)
= ([$\pi^\pm$, π^0, $K^\pm$, p, … γ …]-h$^\pm$)



ALICE, arXiv:1608.07201

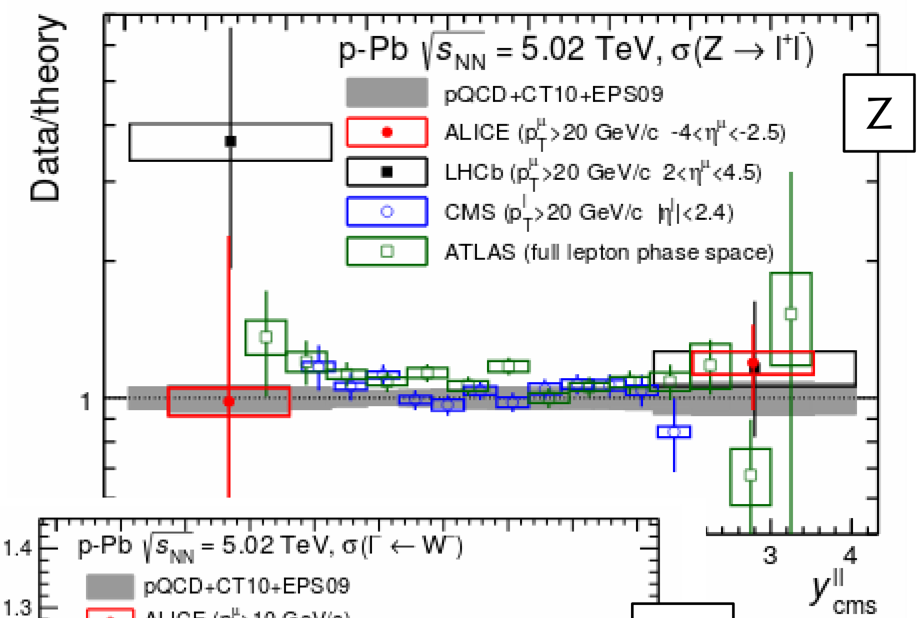
CDS-2300690

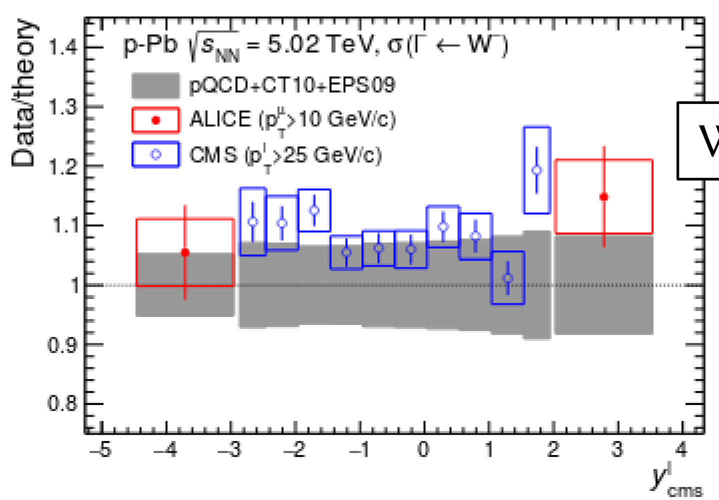
σ isolated γ



V.7 – Runs 1+2 : constraining nPDF (initial state)

1. W±, Z

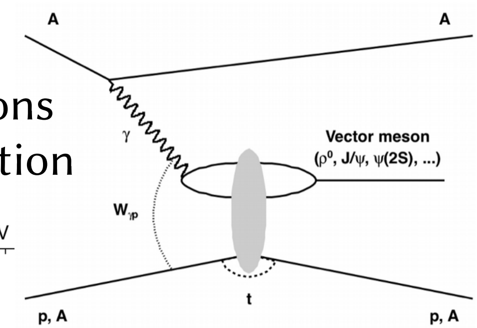


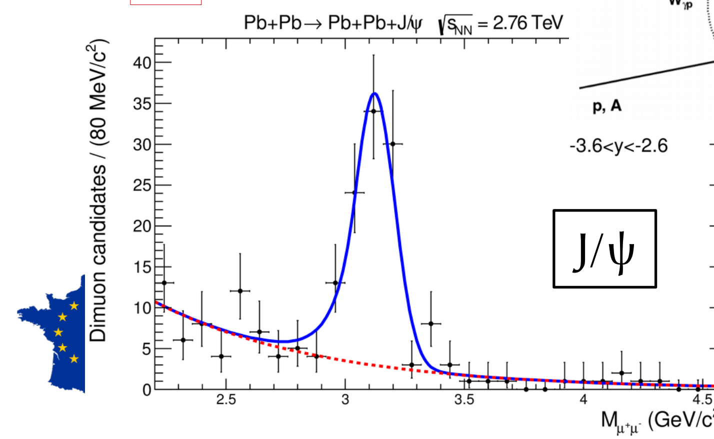


ALICE, arXiv:1611.03002

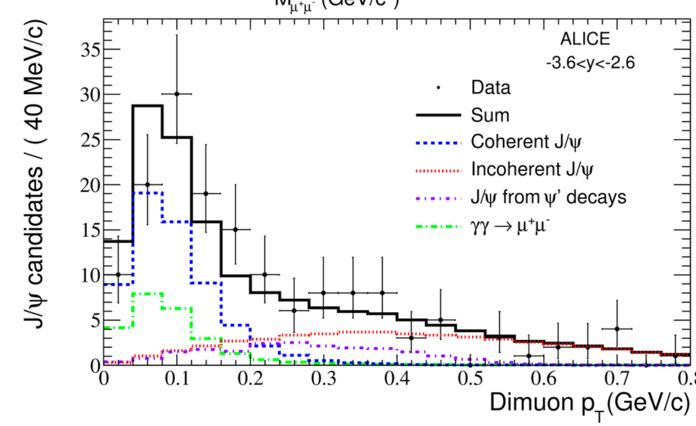
Ultra-peripheric AA collisions

2. → photo-production





ALICE arXiv:1209.3715



+ ψ(2S)

ALICE, arXiv:1508.05076

V.8 – Runs 1+2 : bottom line

→ *early 2018, where are we ?*

Runs 1+2 not yet finished (*pp+Pb-Pb 2018 still to come*), but the situation is rather clear

1/ **Hydrodynamics** = already into a precision era !
(tremendous improvements over the last years, both in theory and experiments)
But, no worry, still some way ahead...

2/ **in-medium energy loss** = not yet there but...
LHC = the place to be for hard probes !

i) drop of $\sigma_{\text{inclusive jet}} \approx 1/p_T^8$ at RHIC Vs. $1/p_T^4$ at LHC...
= nature makes it easier for high $\sqrt{s}$

ii) detectors suited for that (see at least ATLAS, CMS)

3/ the real new thing : AA-like signs at high $\sqrt{s}$ in **small systems** like pp, p-Pb

V.9 – Runs 1+2 : some open questions left

Initial state
- What is the fundamental nature of the initial state ?
  Can <u>hard probes</u> reveal it ?

Equilibration
- Which mecanisms <u>drive</u> a (quantal QCD system) into a (high-T ~equilibrated medium) ?
- such an equilibration, possible in <u>small systems</u> ?
- <u>or</u> are there elementary QCD mechanisms that mimic the observed collective behaviour ?

Chiral symmetry
- Can we prove <u>directly</u> that chiral symmetry is (partially) restored ?

In-medium dynamics
- What does the <u>apparent</u> collective behaviour of c+b tell us ?
- What is the fundamental nature of <u>degrees of freedom</u>
  relevant for QCD at finite T (partons, quasi-particles, ...) ?

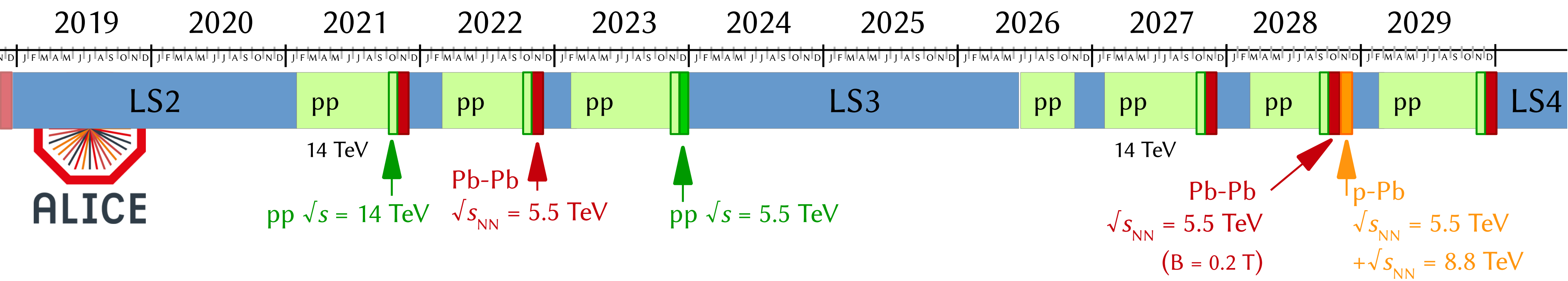
Hadronisation
- Which processes do create hadrons, <u>flavour by flavour</u> ?

Ultimately, which precision do we <u>need to reach</u> in our measurements ?
For comparison/test of QGP fundamental properties calculable from first principles
(*Equation of state, viscostiy, transport coefficient, ...*)

⟶ Runs 3+4 !

Part C – run 3+4 preparation and perspectives

VI.1 – Beyond LS2 : ALICE campaigns in LHC run 3+4



<u>Runs 1+2</u>

= 1 nb^{-1} MB Pb-Pb delivered
⟶ 0.1 nb^{-1} recorded

<u>Runs 3+4</u>

= 10 nb^{-1} MB Pb-Pb delivered
⟶ 10 nb^{-1} recorded

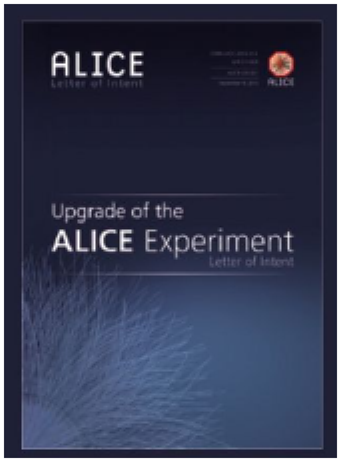
Consequence : **50 kHz in Pb-Pb** // ~200 kHz in pp, p-Pb

⟶ preserve ALICE features (PID, material budget, μ arm, ...)
+ improve tracking precision (ITS, MFT)
+ improve data rate (pile-up challenge)

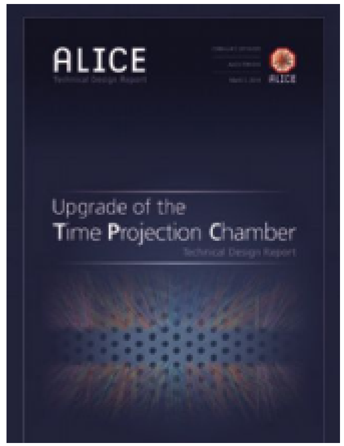
⟶ **specific data taking strategy** :

- "<u>triggerless</u>" readout (small S/S+B ⟶ ~no online trigger)
- *Readout+recorded : <u>50 kHz</u>* Min Bias Pb-Pb
  + a *<u>few 100 kHz</u>* pp, p-Pb collisions
  Runs 3+4 = 100x Run 2
- no more 8-month/year of pp data taking...
  ALICE pp campaign = <u>$\mathcal{O}$(weeks)</u>
  (*main limit : computing capacity*)

VI.2 – Beyond LS2 : TDRs for run 3+4 detectors

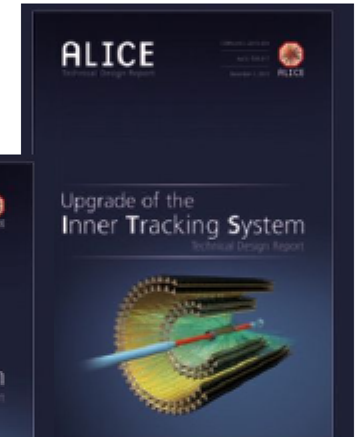


CERN-LHCC-2012-012

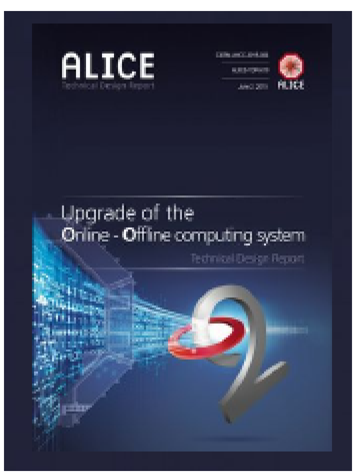


CERN-LHCC-2013-020

CERN-LHCC-2012-005



CERN-LHCC-2013-024



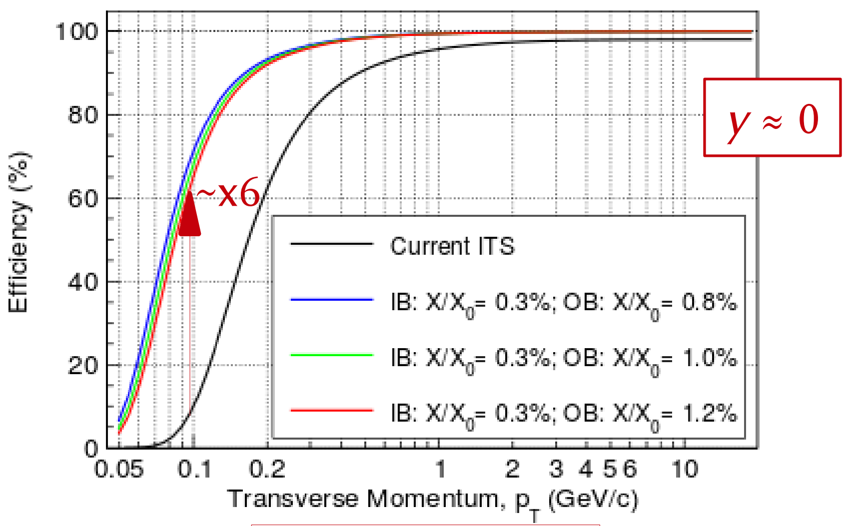
CERN-LHCC-2015-006

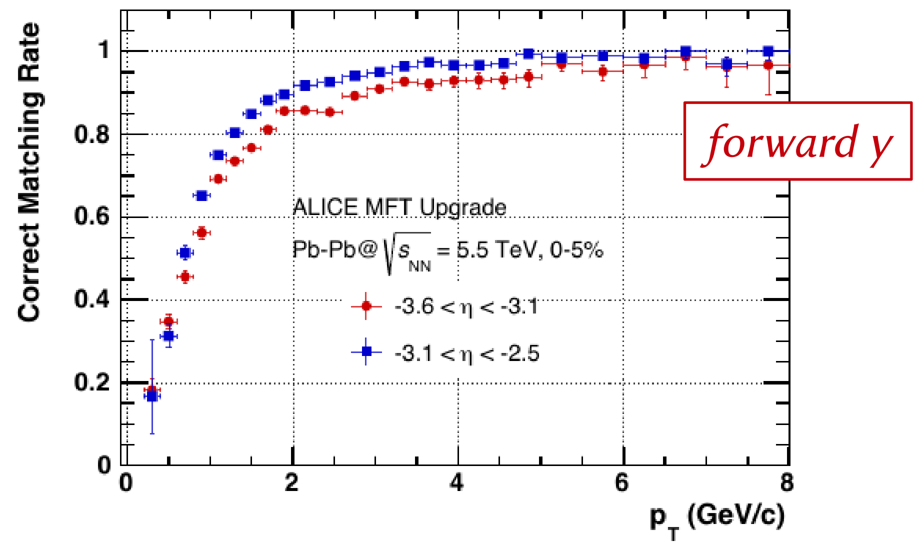
CERN-LHCC-2013-019

CERN-LHCC-2013-014

CERN-LHCC-2015-001

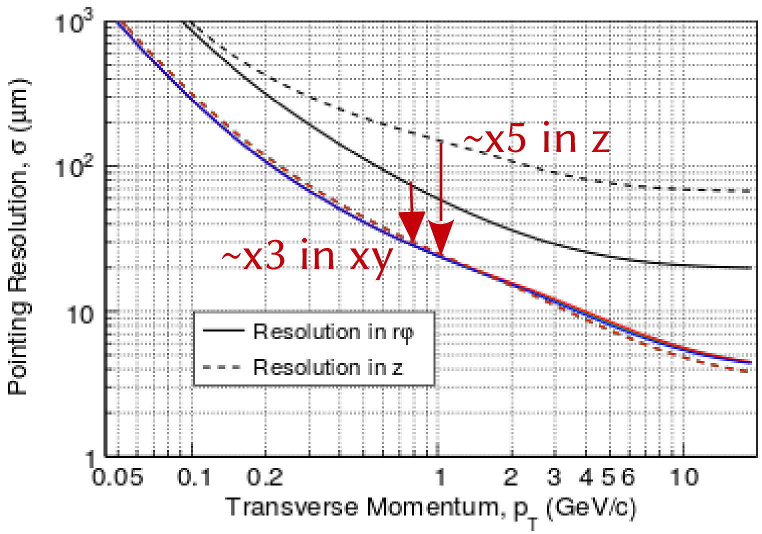
VI.3 – Beyond LS2 : tracking perf. $y \approx 0$ + forward y





ITS stand-alone

μ tracks : MFT+ μ spectrometer



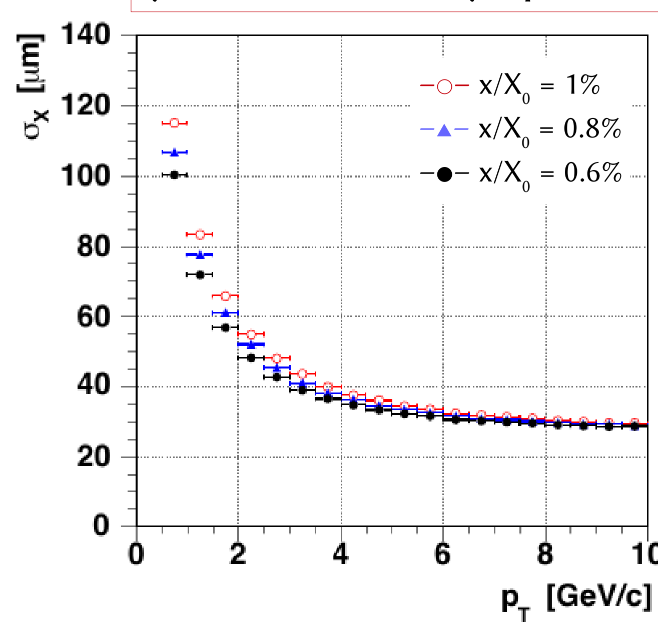
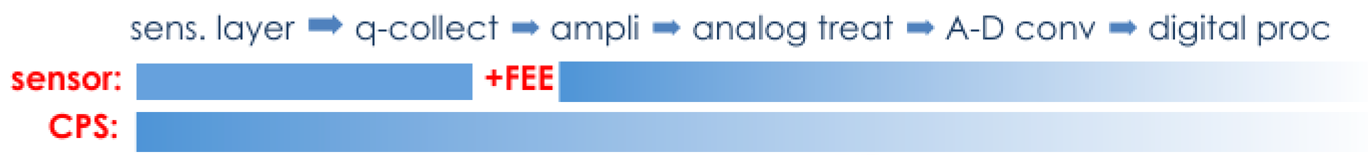


Fig 6.15 + 6.16
TDR MFT
- CERN-LHCC-2015-001

Fig 7.12
TDR ITS Upgrade - CERN-LHCC-2013-024

VII.1 – Upgrade : ITS+MFT chip, ALPIDE

Hybrid pixel sensor ⟶
CMOS pixel sensor ⟶



Here, **ALPIDE** : 0.18-μm CMOS technology by TowerJazz

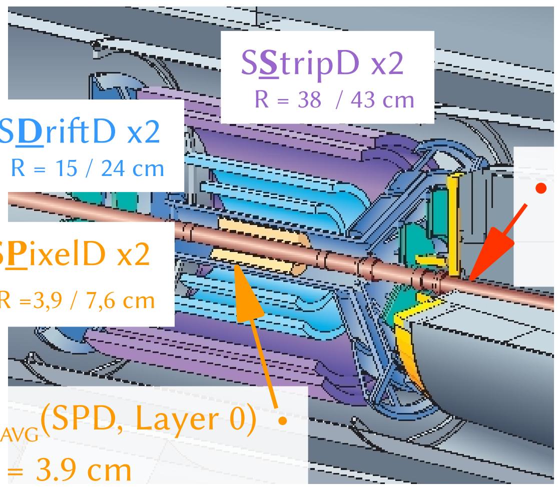
• chip	1.5×3 cm²	
• pixel size	29 x 27 μm²	current SPD hybrid pixels : 50 x 425 μm²
• silicon thickness	50 μm / 100 μm	
• spatial resol°/layer	~5 μm	
• power density	< 50 mW/cm²	
• event-time resol°	~2-5 μs	asynchronous sparsified readout…
• detection efficiency	>99%	⟶ tracking will rely on (space+time stamp) info
• fake-hit rate	<< 10^{-6} /event/pixel	
• NIEL radiation tolrce	>1.7 10^{13} 1MeV n_{eq}/cm²	
• TID radiation tolerance	>2.7 Mrad	

NB : no more d*E*/d*x* information,
unlike current SDD, SSD…

CMOS R&D (IPHC, CEA)

VII.2 – Upgrade : ITS characteristics

ITS Runs 1+2

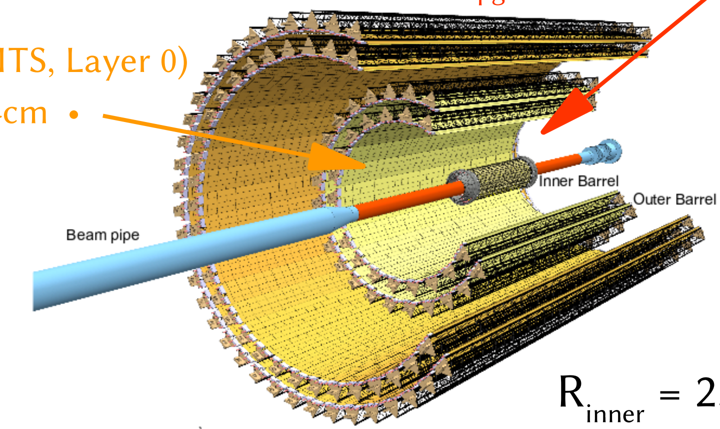


• Beam pipe : $R_{current}$ = 2.9 cm

ITS upgrade Runs 3+4

Beam pipe : $R_{upgrade}$ 1.72 cm •

R_{AVG}(uITS, Layer 0) = 2.4cm •



R_{inner} = 2.4 / 3.2 / 4.0

R_{outer} = 19.6 / 24.5 / 34.4 / 39.3

3 technologies : pixels, drifts, strips
6 layers

- x/X_0 (per layer) ≥ 1.1%

⟶ x/X_0 (ITS) ~ 7.4%

Single technology : CMOS (ALPIDE)
7 layers

- IB, Layer 0,1,2 : x/X_0(per layer) ~0.3%
- OB, Layer 3,4,5,6 : x/X_0(per layer) ~0.8%

⟶ x/X_0 (ITS) ~ 6.9%

VII.3 – Upgrade : ITS+MFT

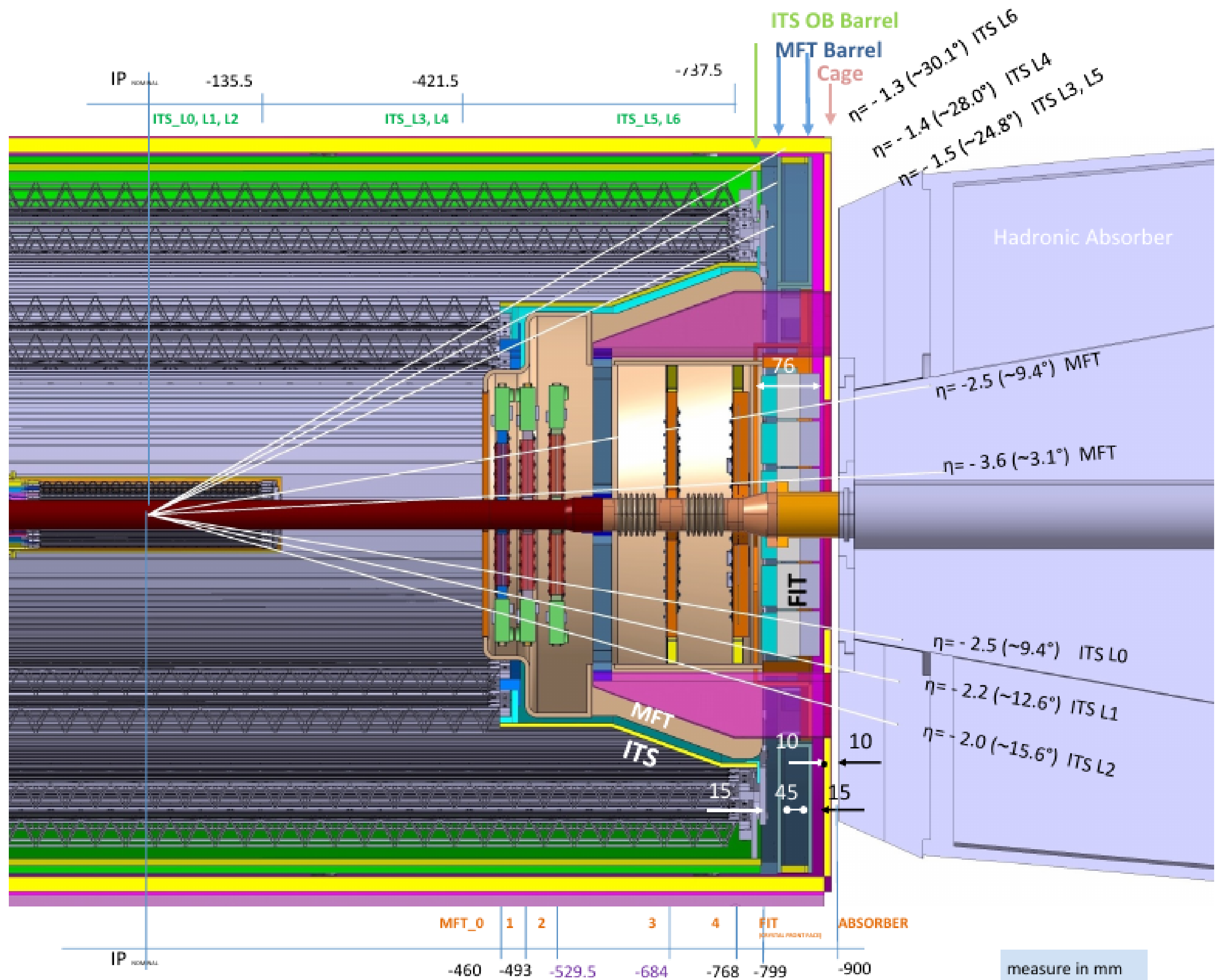
ITS+MFT commonalities

- both equipped with ALPIDE chips
- mechanical structure
  and services bound together
- Removal possibility
  during annual shut down

A first difference

- ITS = 9.4 m²
  = industrial production
  (73% of active surface
  for the last 2 layers)

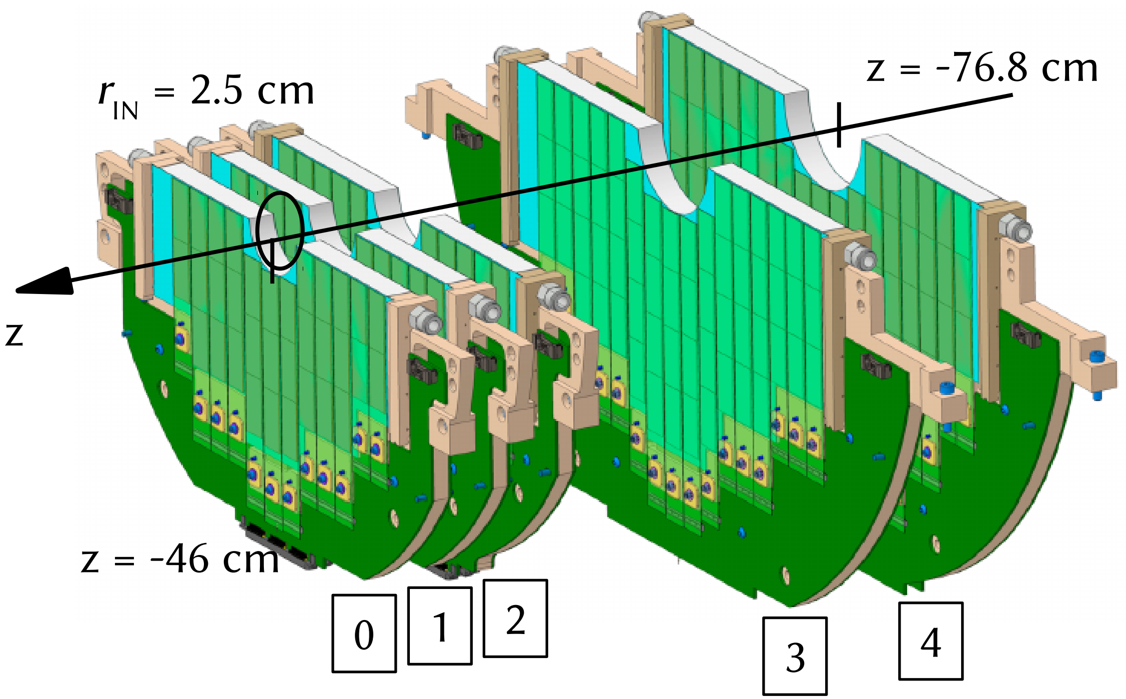
- MFT = 0.4 m²
  = 5% of ITS surface
  but further complexity in layout of ladders



VII.4 – Upgrade : MFT

MFT = vertexing ahead of μ spectrometer
$-3.6 < \eta < -2.5$

(NB : in front of absorber,
no sensitive magnetic field)



Components :
- 5 disks split into 2 halves
- each disk = 2 sides of detection

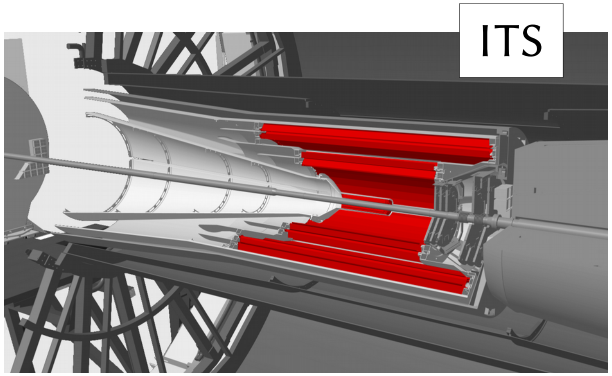
280 ladders out of 920 silicon sensors (2 to 5 chips/ladder)
0.6 % x/X^0 per disk

NB : MFT doses $\mathcal{O}$(700 krad) over 10 years of operation,
~same ballpark as ITS inner layer

VII.5 – Upgrade : ALICE-France commitments

+ Read-out : firmware of Common Readout Unit CRU (LPSC)

VII.5 – Upgrade : ALICE-France commitments



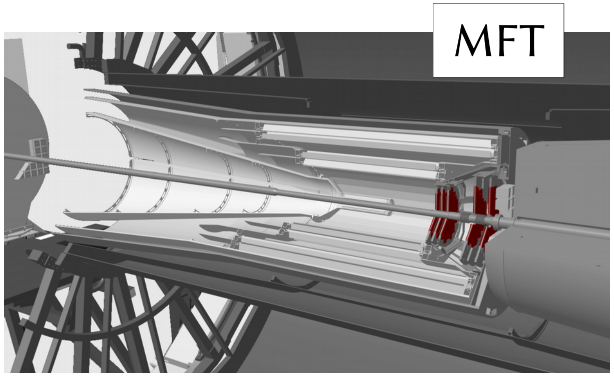
Total cost :
12.8 MCHF

In2p3 :
800 k€

LPSC :
- assembly tool

IPHC :
- module assembly
~400 modules /~2500
(*2x7 chips glued, bonded on flexible circuit*)
- Coordination WG
tracking/simul°/phys perf.

VII.5 – Upgrade : ALICE-France commitments



Total cost :
3.35 MCHF

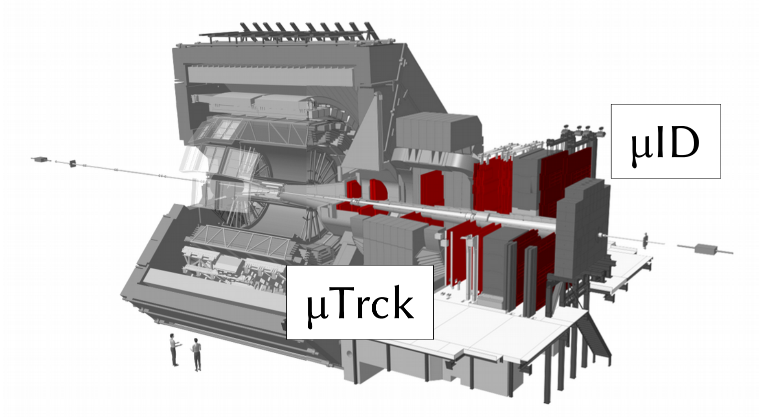
In2p3 :
1.37 M€

- Project leader
- Full detector construction

→ 8 out of 9 WG led
by In2p3/CEA staff

- Coordination WG
tracking/simul°/phys perf.

VII.5 – Upgrade : ALICE-France commitments



Total cost :
1.596 MCHF µTrk
677 kCHF µID

In2p3 :
646 k€ µTrk
430 k€ µID

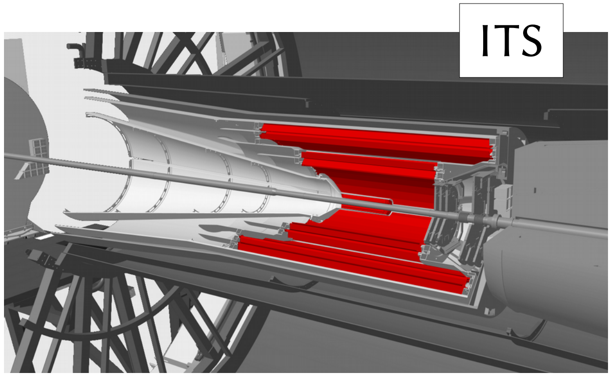
µID LPC + Subatech
- Front-End (FEERIC)
- the whole Read-out electronics

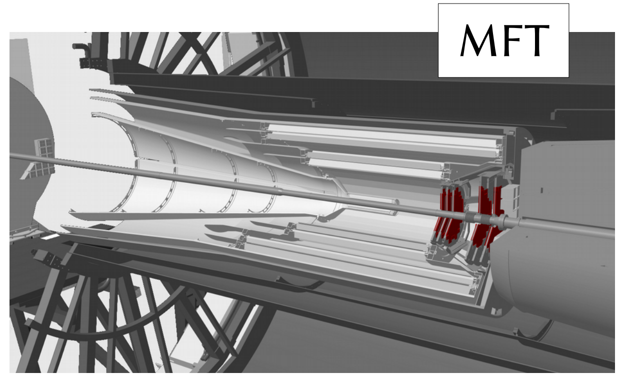
= 250 cards

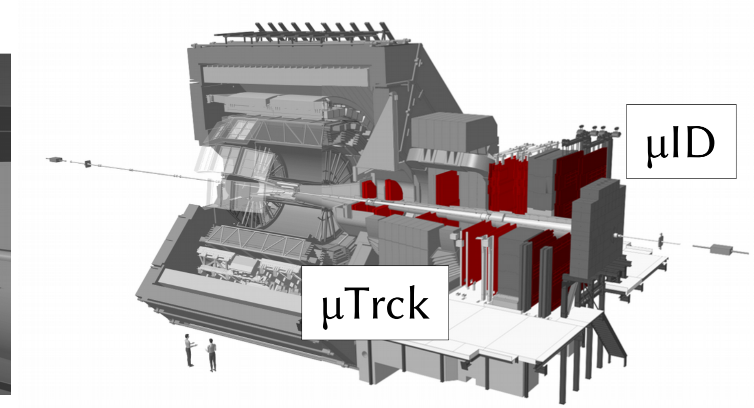
µTrk IPNO (+ CEA)
- the whole Read-out electronics

= 20 000 cards DualSampa

VII.5 – Upgrade : ALICE-France commitments







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= 250 cards

µTrk IPNO (+ CEA)
• the whole Read-out electronics
= 20 000 cards DualSampa

+ Read-out : firmware of Common Readout Unit CRU (LPSC)

VIII.1 – Run-3+4 physics : (fwd y) physics-case summary

	Observable	MUON only p_T^{min} (GeV/c)	MUON only uncertainty	MUON + MFT p_T^{min} (GeV/c)	MUON + MFT uncertainty
Prompt/non-prompt J/ψ ψ(2S)	Inclusive J/ψ R_{AA}	0	5 % at 1 GeV/c	0	5 % at 1 GeV/c
	ψ' R_{AA}	0	30 % at 1 GeV/c	0	10 % at 1 GeV/c
	Prompt J/ψ R_{AA}		not accessible	0	10 % at 1 GeV/c
	J/ψ from b-hadrons		not accessible	0	10 % at 1 GeV/c
Heavy-Flavour μ	Open charm in single μ			1	7 % at 1 GeV/c
	Open beauty in single μ			2	10 % at 2 GeV/c
	Open HF in single μ no c/b separation	4	30 % at 4 GeV/c		
Low-mass μμ	Low mass spectral func. and QGP radiation		not accessible	1–2	20 % at 1 GeV/c

Tab 1

LoI MFT
- CERN-LHCC-2013-014

VIII.2 – Run-3+4 physics : (fwd y) physics-case examples

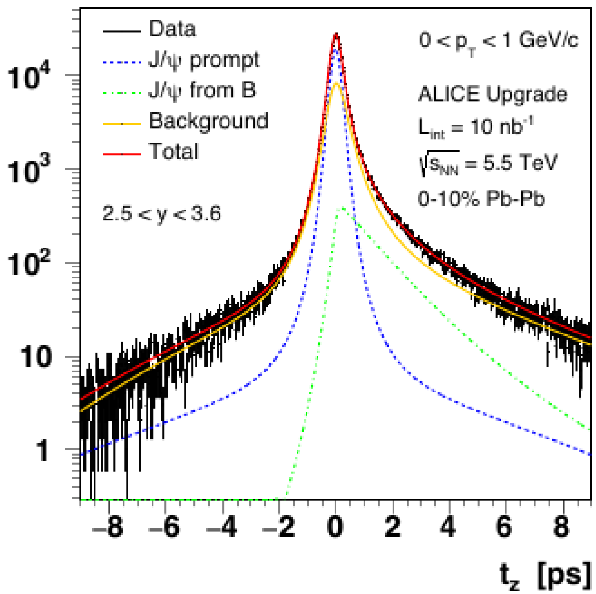
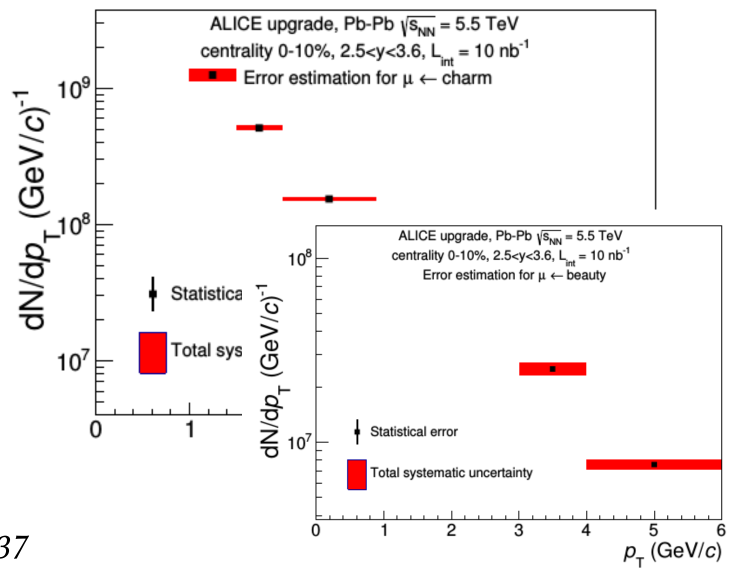
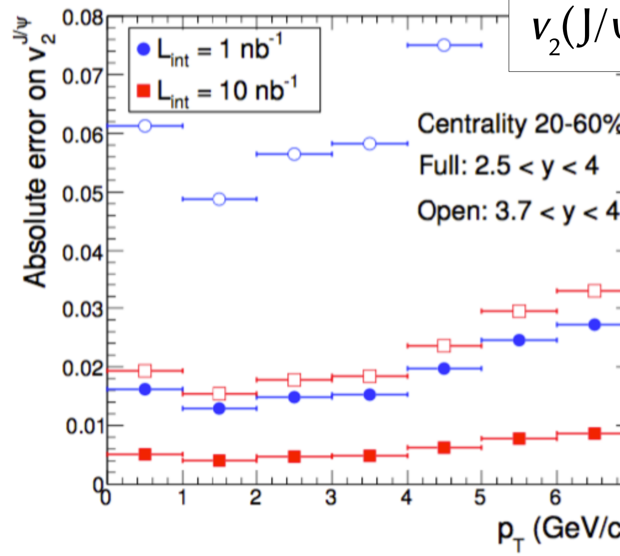


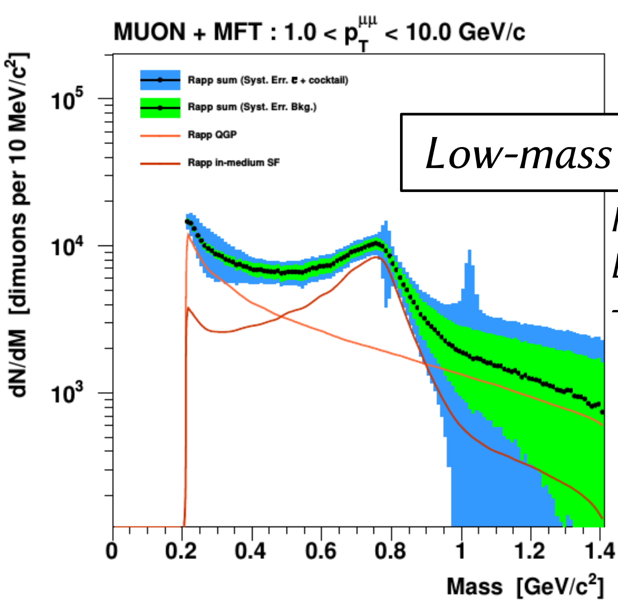
Fig 6.21 + 6.19
TDR MFT
- CERN-LHCC-2015-001

prompt
vs non-prompt
J/ψ and HFμ



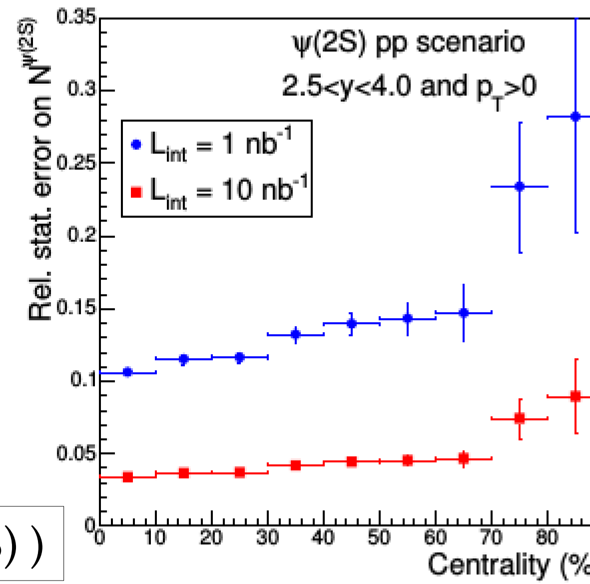


$v_2(J/\psi)$



Low-mass μμ

Fig 2.37
LoI MFT
- CERN-LHCC-2013-014

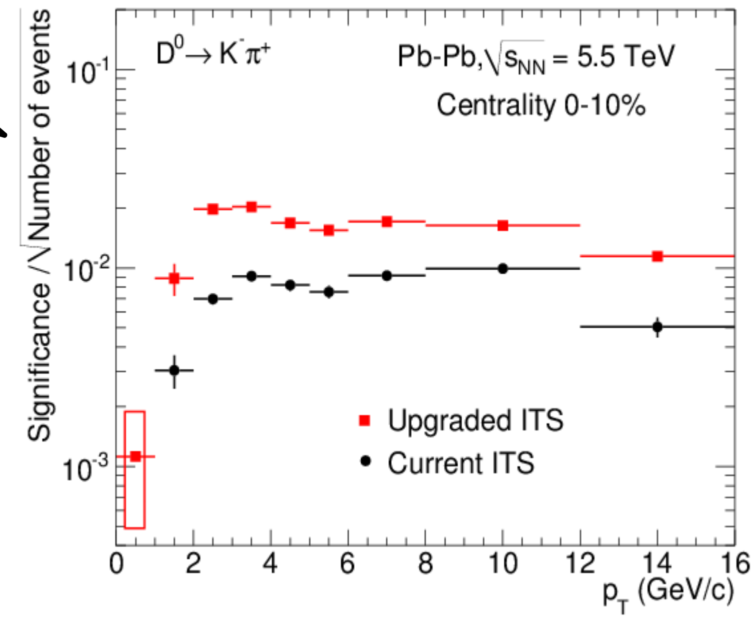


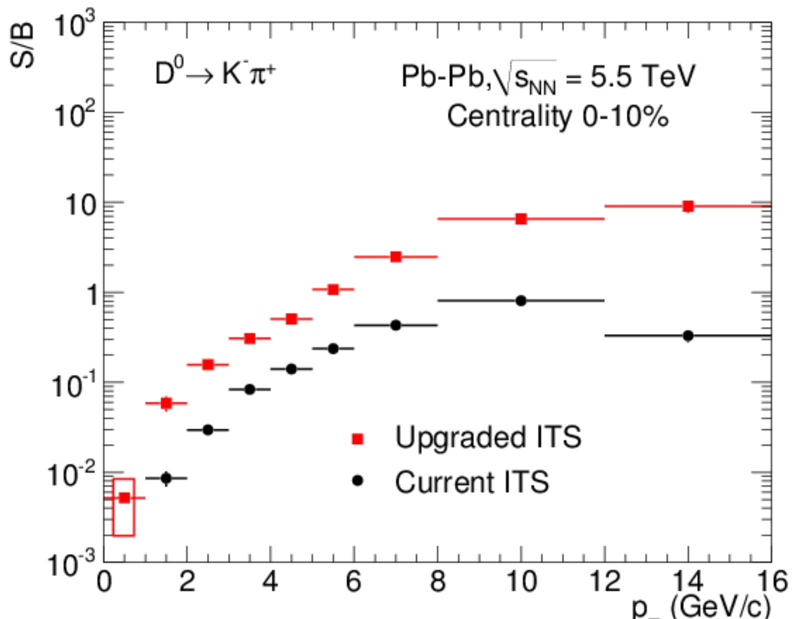
Raw signal(ψ(2S))

VIII.3 – Run-3+4 physics : (y ≈ 0) example, D in Pb-Pb

TDR ITS Upgrade
- CERN-LHCC-2013-024
Fig 8.2

i.e. Significance for $\mathcal{L}_{int}$=10 nb^{-1} = 8.10^9 evts :
~50 for p_T<1 GeV/c, ~10^3 at high p_T ...
(~100 for D^{*+}, ~50 for D_s^+)

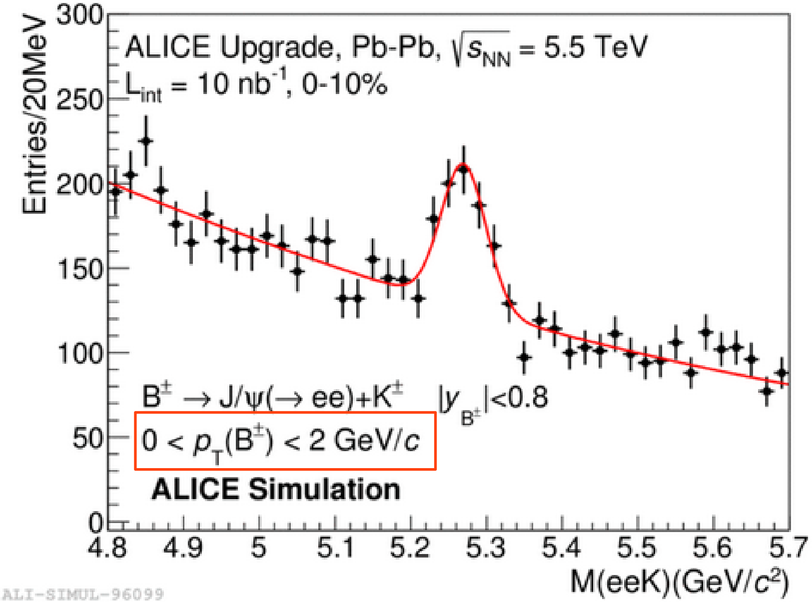


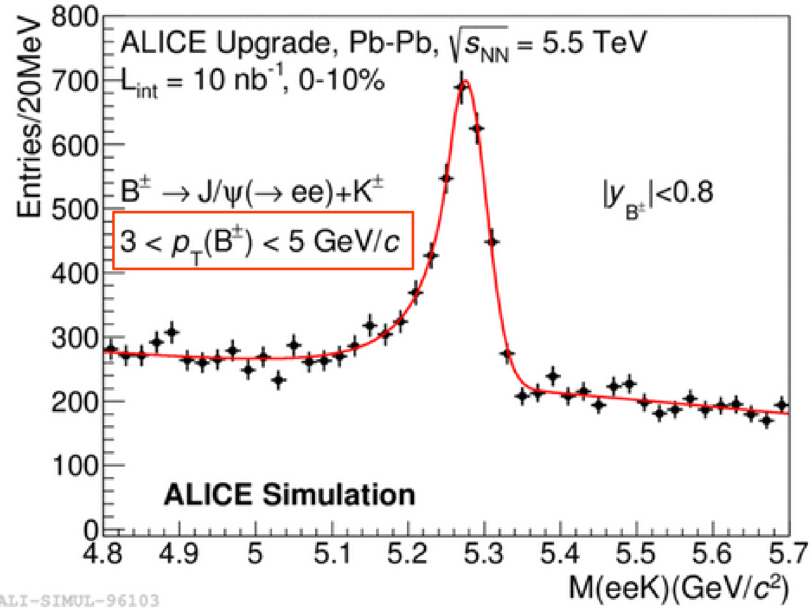


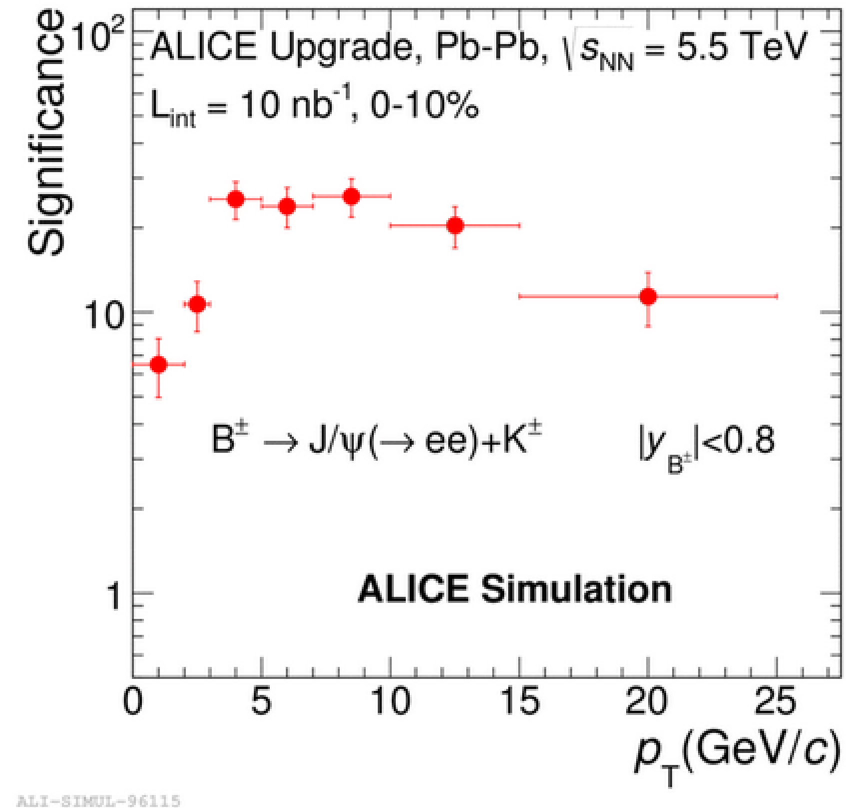
Rejection of combinatorial background :
≈ 5-10x (≈ 2x for D_s^+)

__NB :__ better control on systematics
- *ease signal extraction (S/B, p_T resolution.)*
- *bigger data sample to play with*
- *feed-down correction more straightforward*

VIII.4 – Run-3+4 physics : (y ≈ 0) example, B^+ in Pb-Pb







Hypotheses :

- ITSu+TPC tracking
- TPC PID for $e^\pm$ / TPC+TOF for K^+

NB : Stat uncert. ⟺ 8x10^9 events, 10 nb^{-1}

VIII.5 – Run-3+4 physics : (y ≈ 0) physics-case summary table

Observable	Current, $0.1\,nb^{-1}$ p_T^{min} (GeV/c)	Current, $0.1\,nb^{-1}$ statistical uncertainty	Upgrade, $10\,nb^{-1}$ p_T^{min} (GeV/c)	Upgrade, $10\,nb^{-1}$ statistical uncertainty
Heavy Flavour				
D meson R_{AA}	1	10 %	0	0.3 %
D_s meson R_{AA}	4	15 %	< 2	3 %
D meson from B R_{AA}	3	30 %	2	1 %
J/ψ from B R_{AA}	1.5	15 % (p_T-int.)	1	5 %
B^+ yield	not accessible		2	10 %
Λ_c R_{AA}	not accessible		2	15 %
Λ_c/D^0 ratio	not accessible		2	15 %
Λ_b yield	not accessible		7	20 %
D meson v_2 ($v_2 = 0.2$)	1	10 %	0	0.2 %
D_s meson v_2 ($v_2 = 0.2$)	not accessible		< 2	8 %
D from B v_2 ($v_2 = 0.05$)	not accessible		2	8 %
J/ψ from B v_2 ($v_2 = 0.05$)	not accessible		1	60 %
Λ_c v_2 ($v_2 = 0.15$)	not accessible		3	20 %
Dielectrons				
Temperature (intermediate mass)	not accessible			10 %
Elliptic flow ($v_2 = 0.1$) [4]	not accessible			10 %
Low-mass spectral function [4]	not accessible		0.3	20 %
Hypernuclei				
${}^3_\Lambda H$ yield	2	18 %	2	1.7 %

Run I+II
≈ 1 nb^{-1} MB Pb-Pb delivered
⟶ 0.1 nb^{-1} recorded

Run III
≈ 10 nb^{-1} MB Pb-Pb delivered
⟶ 10 nb^{-1} recorded

TDR ITS Upgrade - CERN-LHCC-2013-024

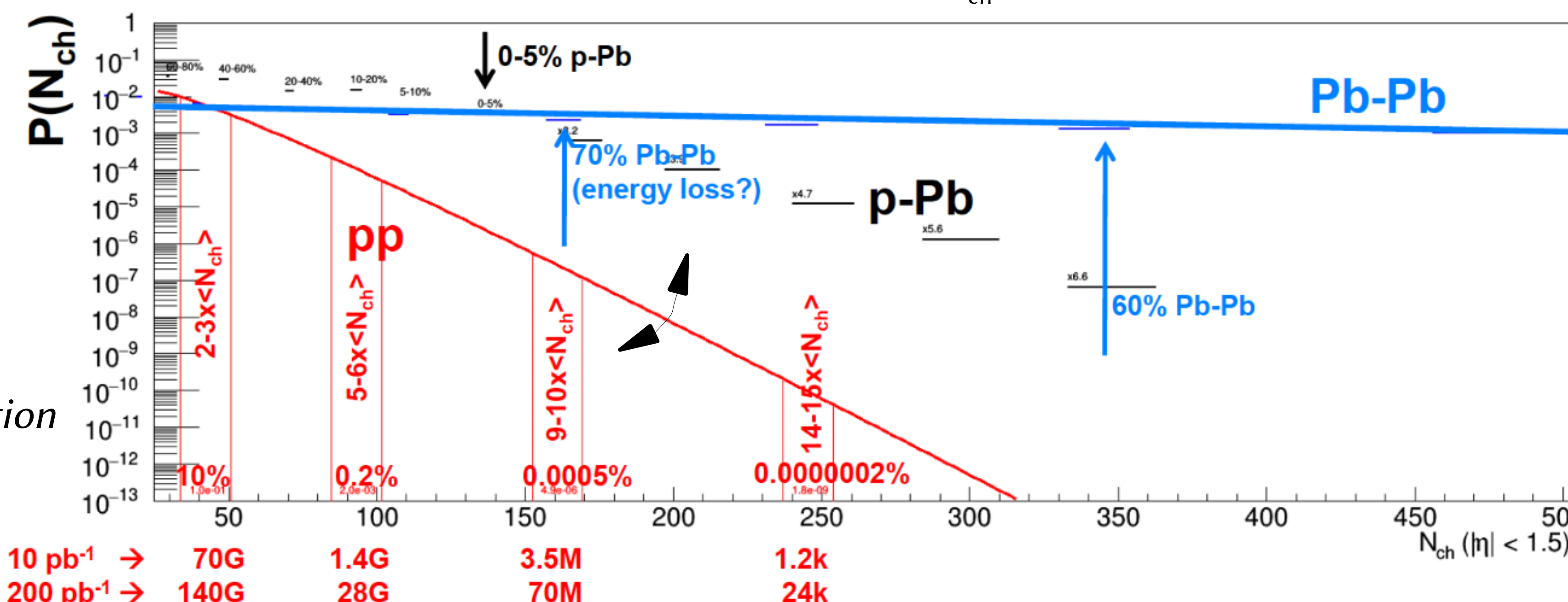
Tab 8.6

VIII.6 – Run-3+4 physics : high-multiplicity pp

HL-LHC Wkshop

pp, p-Pb, Pb-Pb at a same N_{ch}

Beware : Possible caveats in pp extrapolation



pp 5.5 TeV

Multiplicity dependence extension

- further for Ξ, Ω ?
- further for J/ψ ?
- further for D mesons ?
- + a 1st time for light nuclei produced d,t, ^3He, $^{\Lambda}_{3}H$

Wrap-up (1) : Heavy-Ion standard model

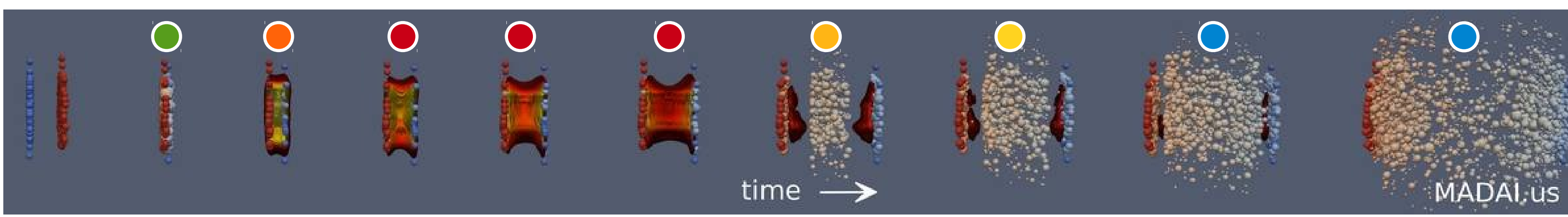
- « QCD at finite temperature » :
  ⟶ Extension of Standard Model

i) How does a *N-body dynamics emerge from elementary QCD interaction*
ii) How it further evolves...

- Ongoing effort pursued over the next decade :
  ⟶ detailed++ understanding of QCD dynamics, from AA to pp
  ⟶ Systematic characterisation, towards textbook measurements (“*precision era” for Runs 3+4*)

Chemical freeze-out

Deconfined phase | Hadron gas | Kinetic freeze-out | Free particles



0. Initial partonic State (CGC ?)

1. Partonic equlibration (glasma phase)

2. Relativistic slightly-viscous hydrodynamic evolution

3. Hadronisation (LQCD)

4. Hadronic transport

= bulk dynamics + hard probe response
= *space-time, flavour, momentum dependences...*

Wrap-up (2) : particles of interest through LHC runs

(heavy-)flavour physics : *u,d,s,c,b (t) behaviour wrt collectivity*

Means : a full span of multi-differential analyses, in small (pp, p-Pb) and large (Pb-Pb) systems
$d^2N(\mathrm{PID})/dp_T dy$ = f(event activity) + v_n(PID) + azimuthal correlations + …

ALICE reach in Runs 1+2

π^+ π^0 K^+ K^0_S … p Λ Ξ^- Ω^- …
$\eta(547)$ $\omega(782)$ $K^0(892)$ $\phi(1020)$ $\Sigma^{\pm}(1385)$ $\Lambda(1520)$ $\Xi^0(1530)$
d t ^{3}He ^{4}He $^3_\Lambda$H …
(D^0 D^+ D^{*+} D_S)… J/ψ χ_{Ci} $\psi(2S)$ … Λ_C^+ Ξ_C
heavy-flavour ($\mu^{\pm}$, $e^{\pm}$)
B^0 $B^{\pm}$ B^0_S … $\Upsilon(1S,2S,3S)$
γ $W^{\pm}$ Z

ALICE reach in Runs 3+4

π^+ π^0 K^+ K^0_S … p Λ Ξ^- Ω^- …
$\eta(547)$ $\omega(782)$ $K^0(892)$ $\phi(1020)$ $\Sigma^{\pm}(1385)$ $\Lambda(1520)$ $\Xi^0(1530)$
d t ^{3}He ^{4}He $^3_\Lambda$H …
(D^0 D^+ D^{*+} D_S) … J/ψ χ_{Ci} $\psi(2S)$ … Λ_C^+ Ξ_C
heavy-flavour ($\mu^{\pm}$, $e^{\pm}$)
B^0 $B^{\pm}$ B^0_S … $\Upsilon(1S,2S,3S)$
γ $W^{\pm}$ Z

Colour conventions :

- ■ : investigations for large parts already explored or in full swing
- ■ : tackled but further precision needed/expected
- ■ : missing (limited by statistics or detector capabilities)

Underlined : with French contributions

Wrap-up (3) : ALICE(-France) take in that matter

ALICE in the characterisation of "QCD at finite temperature" :

1/ low + intermediate p_T focus

2/ PID

3/ systematism of the measurements,
complete panel of measurements, accessible and competitive

∀ y ? ⟶ ALICE : mid ($|y| < 0.9$-1.2) and (μ) forward (-4//-3.6< y < -2.5)

∀ p_T ? ⟶ ALICE : $p_T \geq 0$ GeV/c

∀ system ? ⟶ ALICE : pp, p-Pb, ..., Pb-Pb

∀ event activity ? ⟶ ALICE : pp, p-Pb, ... / Pb-Pb : 100-90% ⟶ 0.5-0% centrality

ALICE-France in that enterprise :

1/ past and future hardware/software <u>commitments</u> and responsabilities
e.g. (ITS, MFT, μ arm, EmCal/DCal) construction, read-out, operation, calibration, tracking ...

2/ physics <u>analyses</u> on various + complementary fronts
to elaborate a same and consistent global understanding