A Large Ion Collider Experiment

ALICE prospects for LHC Run 3 and beyond

Luciano Musa (CERN)

RHIC – BES online seminar

2021 September 14

ALICE

Outline

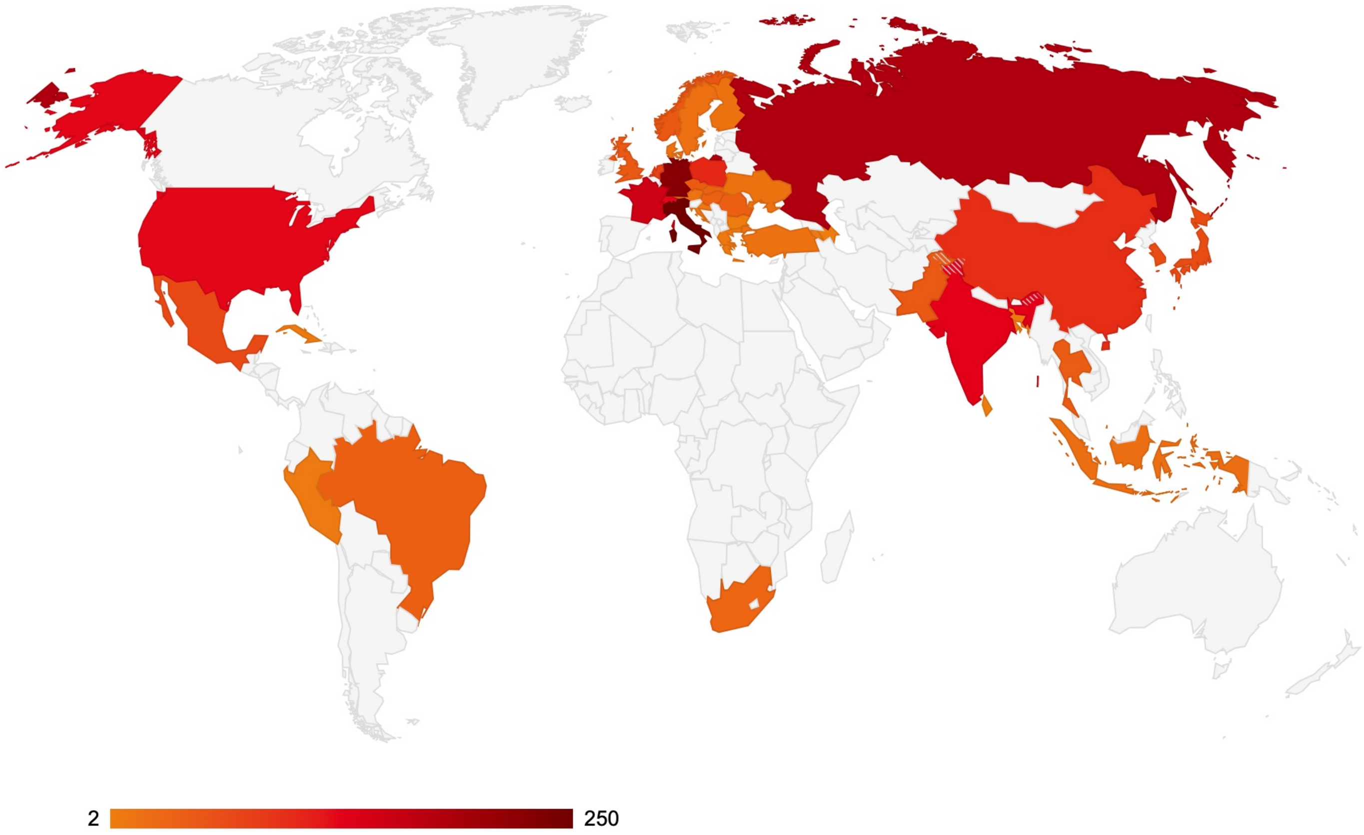
① Introduction

② ALICE Upgrade

③ Physics prospects for Run 3 and Run 4 (few selected topics)

④ Future perspectives

The ALICE Collaboration



42 Countries, 173 Institutes

1946 Members

about **1000 signing authors**

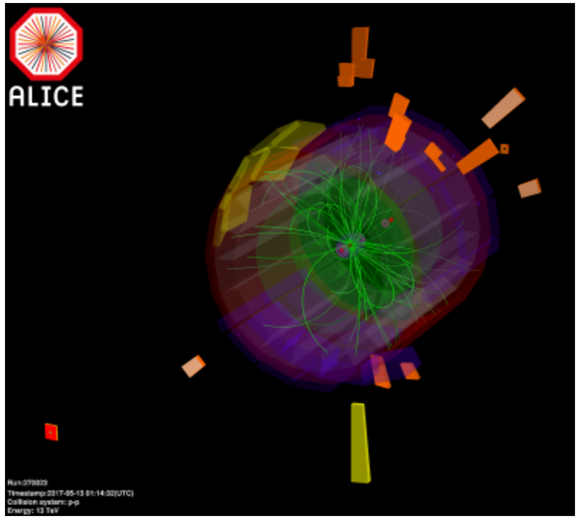
Main stages

- 1992: Expression of interest
- 1997: ALICE approval
- 2000 – 2007: construction
- 2002 – early 2008: Installation
- 2009 – 2018: physics campaign

Heavy Ion Collisions at the LHC

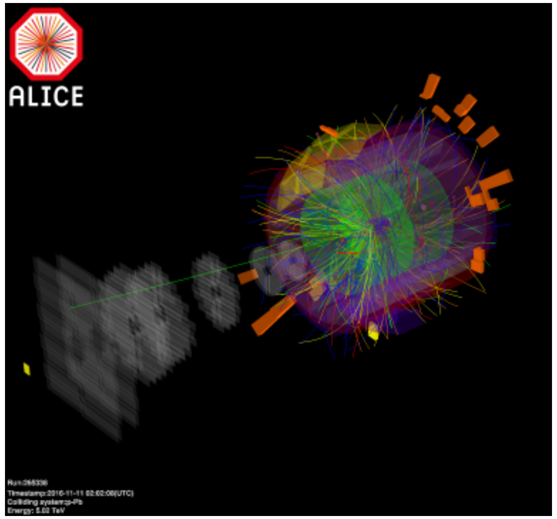
- The LHC collides most of the time protons on protons
- Approximately one month of running time is dedicated to heavy-ions each year (primarily Pb ions)

pp



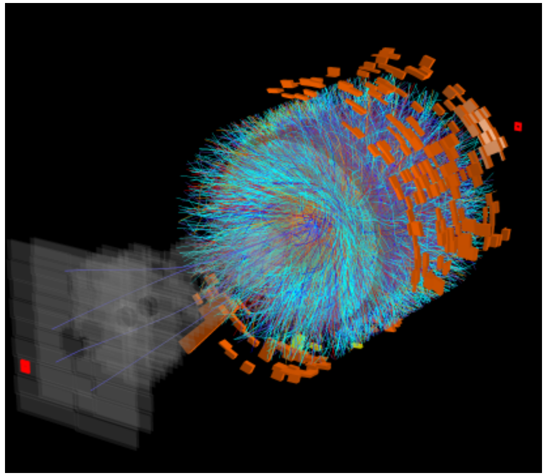
$^{(*)}\sqrt{s_{NN}} = 0.9, 2.76, 5.02, 7, 8, 13\ TeV$

p-Pb



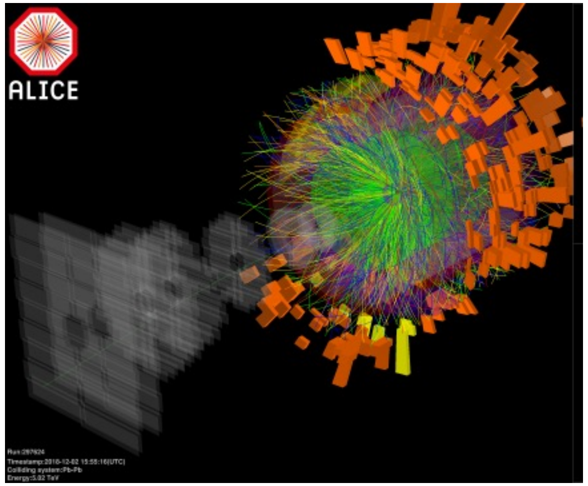
$^{(*)}\sqrt{s_{NN}} = 5.02, 8.16\ TeV$

Xe-Xe



$^{(*)}\sqrt{s_{NN}} = 5.44\ TeV$

Pb-Pb

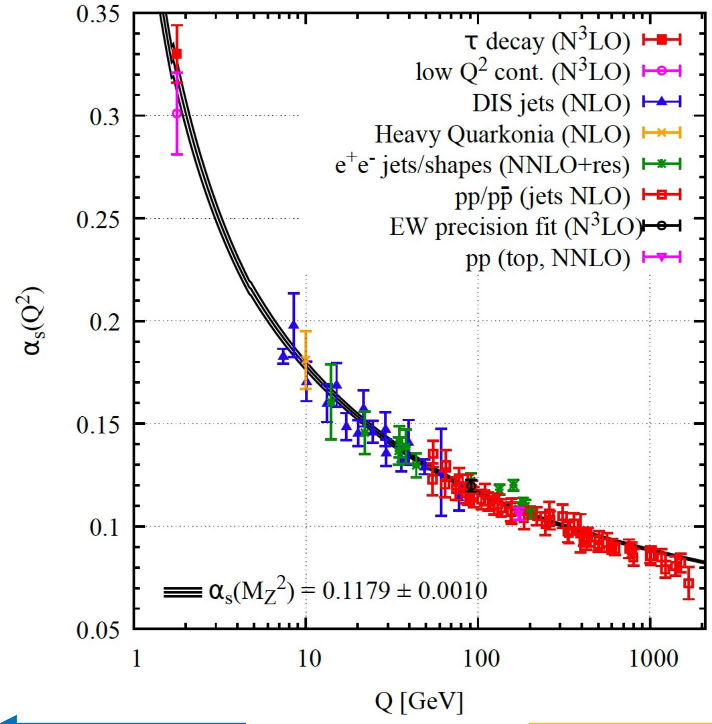


$^{(*)}\sqrt{s_{NN}} = 2.76, 5.02\ TeV$

(*) collisions energy in Run 1 and 2

QGP: asymptotic state of QCD

Quark Gluon Plasma (QGP): at extreme temperatures and densities quarks and gluons behave quasi-free and are not localized to individual hadrons anymore



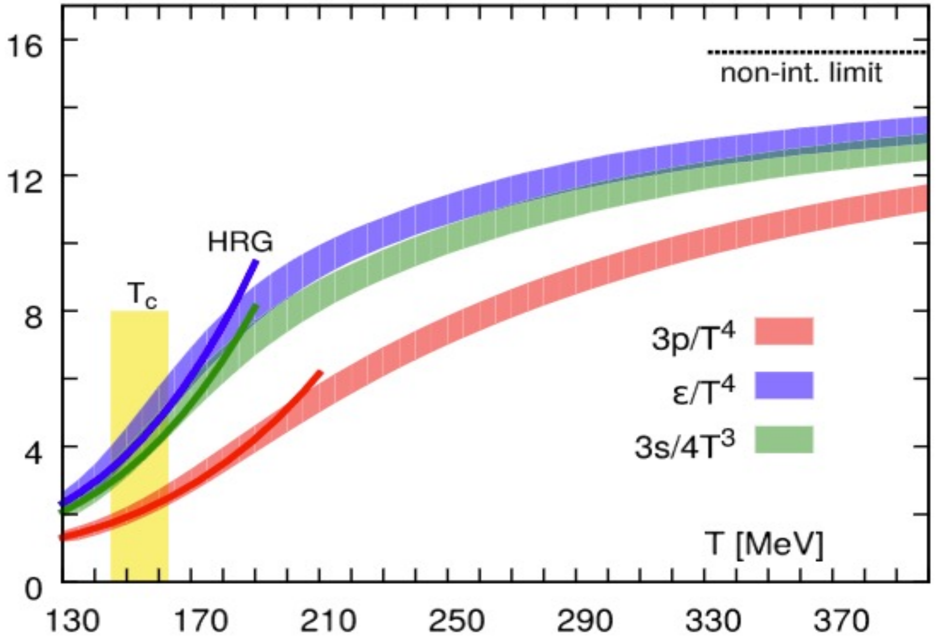
Confinement

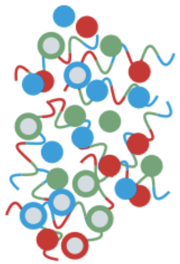
Asymptotic freedom

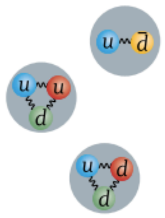
NB: free regime is reached only asymptotically!

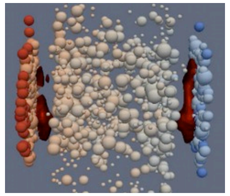
Where is the phase transition?
→ Lattice QCD

[PRD 90 094503 (2014)]

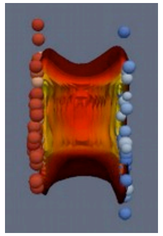








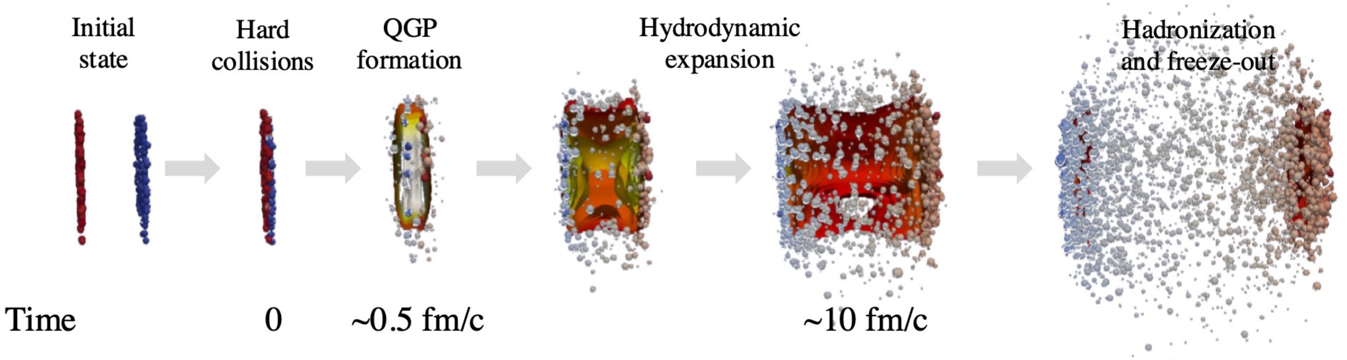
Hadron gas ← $\sim 10^{12}\,K$ → Quark Gluon Plasma



ALICE and the Little Bang

Explore the deconfined phase of QCD matter

LHC Pb-Pb ➪ **large energy density** (initial $\varepsilon > 15$ GeV/fm^3)
& **large volume** (~5000 fm^3)



Visualization by J.E. Bernhard, arXiv:1804.06469

Study the time evolution of the collision

- Initial stage
- Macroscopic properties
- Colour deconfinement
- Parton interactions
- Expansion dynamics
- Hadronic phase

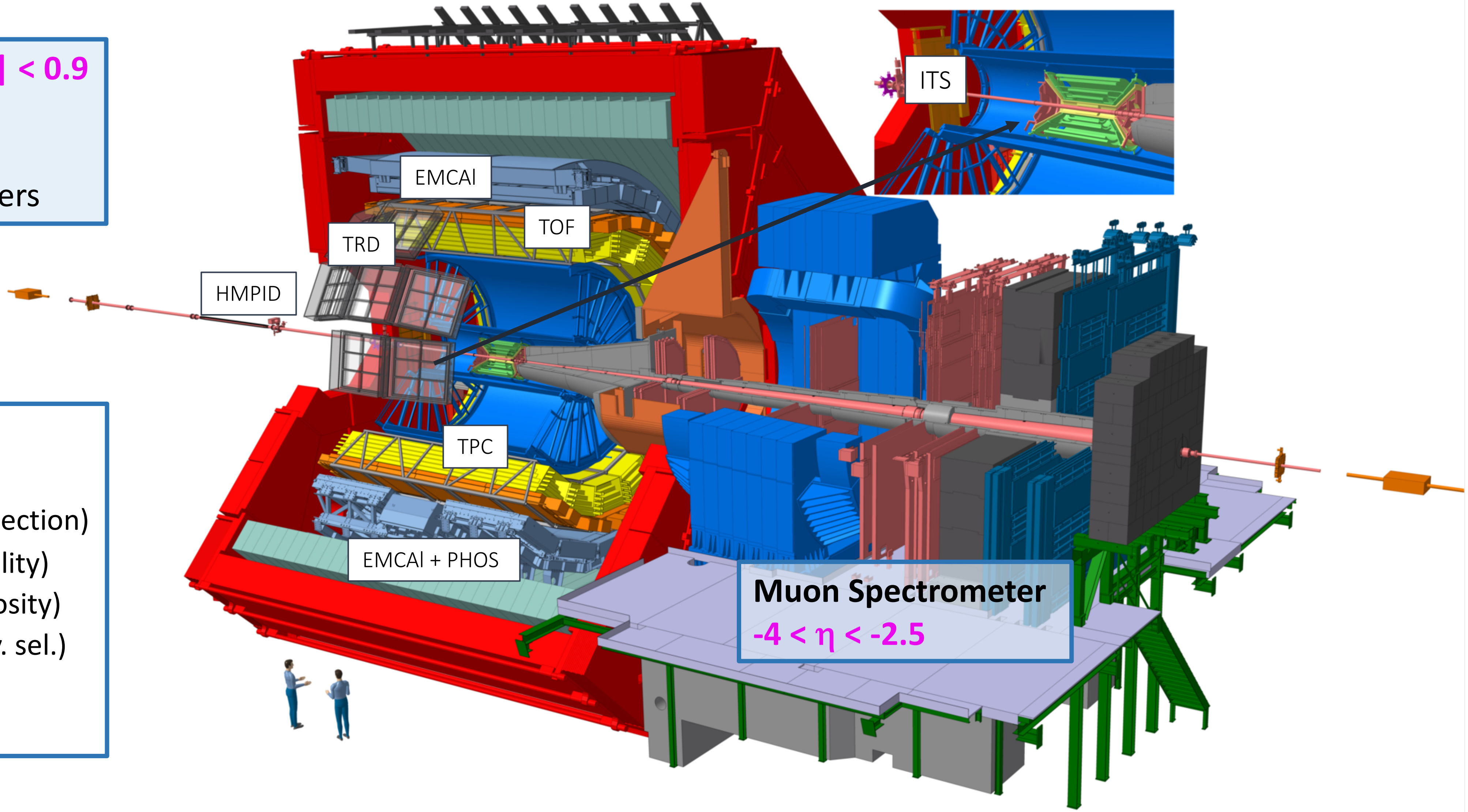
- Light flavour (including light-nuclei) production
- Heavy flavour production
- Quarkonia
- Photons, low-mass dileptons
- Jets
- Ultra Peripheral Collisions

The ALICE detector (version 1: Run 1 + Run 2)

Central Barrel $|\eta| < 0.9$
- Tracking
- PID
- EM-Calorimeters

ACORDE (cosmics)

Forward detectors:
- AD (diffraction selection)
- V0 (trigger, centrality)
- V0 (timing, luminosity)
- ZDC (centrality, ev. sel.)
- FMD (N_{ch})
- PMD ($N\gamma$, Nch)



Muon Spectrometer
$-4 < \eta < -2.5$

ALICE

ALICE data taking and publications

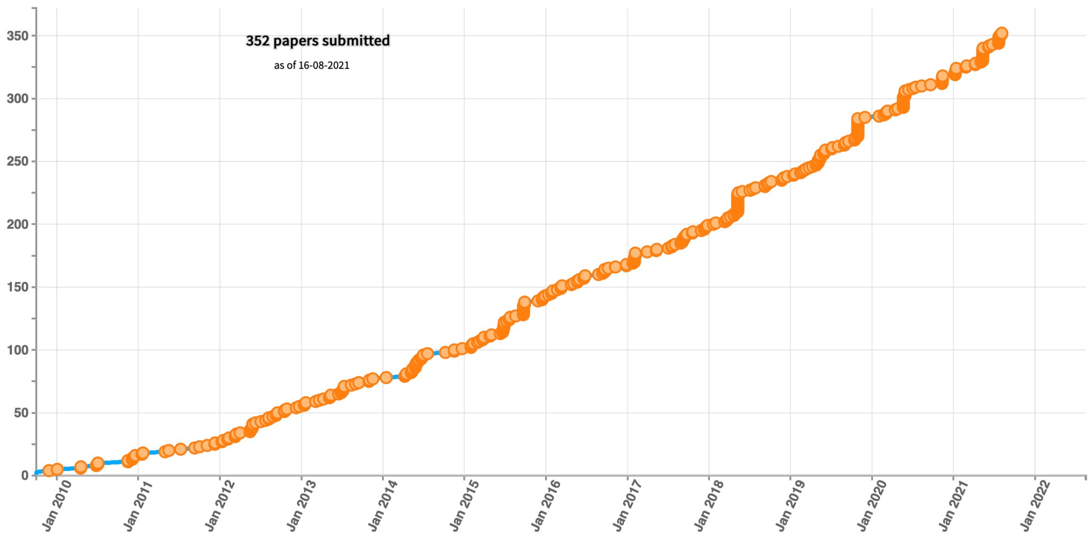
Run 1 (2009 – 2013) LS1 **Run 2** (2015 – 2018) **LS2** **Run 3** (2022 – 2024) LS3 **Run 4** (2027 – 2029)

ALICE I ALICE 2

System	Year(s)	$\sqrt{s_{NN}}$ (TeV)	L_{int}
Pb-Pb	2010, 2011 2015, 2018	2.76 5.02	~75 μb^{-1} ~800 μb^{-1}
Xe-Xe	2017	5.44	~0.3 μb^{-1}
p-Pb	2013 2016	5.02 5.02, 8.16	~15 nb^{-1} ~3 nb^{-1}, ~25 nb^{-1}
pp	2009-2013	0.9, 2.76, 7, 8	~200 mb^{-1}, ~100 nb^{-1} ~1.5 pb^{-1}, ~2.5 pb^{-1}
	2015, 2017	5.02	~1.3 pb^{-1}
	2015-2018	13	~36 pb^{-1}

Run 1 Run 2

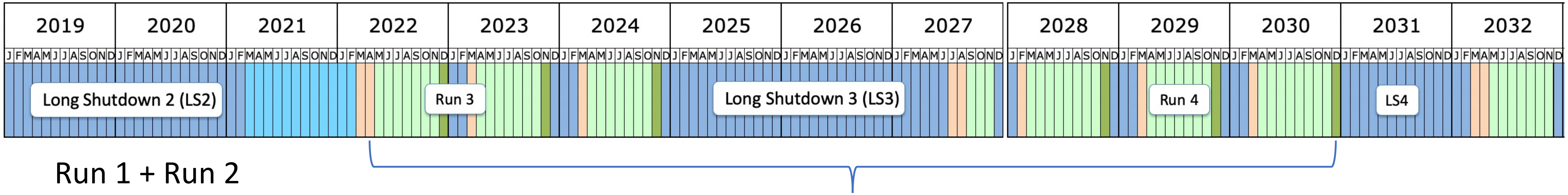
352 ALICE papers on arXiv so far



http://alice-publications.web.cern.ch/submitted

ALICE plans for Run 3 and 4

Long-term LHC schedule



Run 1 + Run 2

$\mathcal{L}_{int}(Pb-Pb) \approx 1nb^{-1}$

$\mathcal{L}_{int}(Pb-Pb) \approx 13\,nb^{-1}$

Run 3 luminosity targets

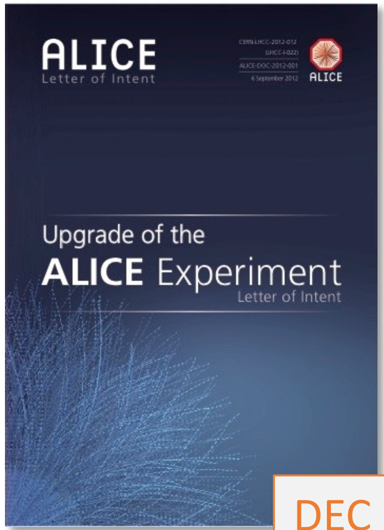
Pb-Pb (**13 nb^{-1}**): x 10 increase wrt Run 1 + Run2 (max interaction rate 50 kHz)

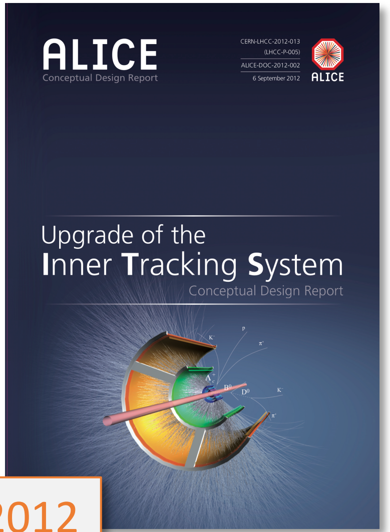
⇨ ALICE continous detector readout (no trigger) and recording

⇨ **x 50 increase in statistics** for most observables (minimum-bias rate limited to 1 kHz in Runs 1 and 2)

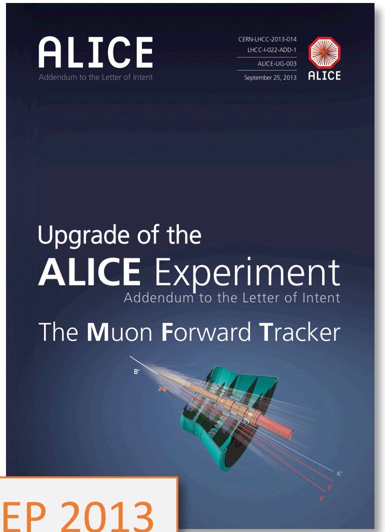
not only Pb-Pb, but also pp (**200/pb**), p-Pb (**~0.6/pb**) and O-O (**~1/nb**)

ALICE Detector Version 2.0 (Upgrades for Run 3 and 4)





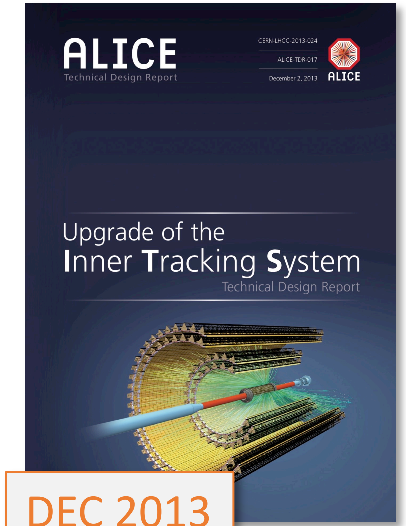
DEC 2012



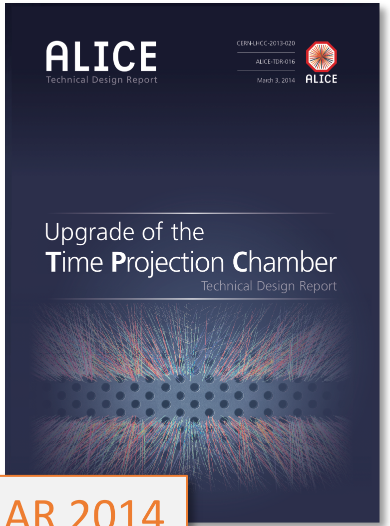
SEP 2013

- From LoI to last TDR: 2013 – 2015 ✓
- Construction: 2016 – 2019 ✓
- Installation: 2020 – 2021 ✓
- Global commissioning: ongoing

NOV 2013

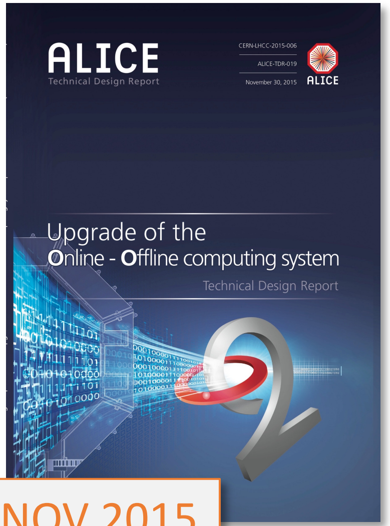


DEC 2013



MAR 2014

MAY 2015



NOV 2015

ALICE Detector Version 2.0 (Upgrades for Runs 3 and 4)

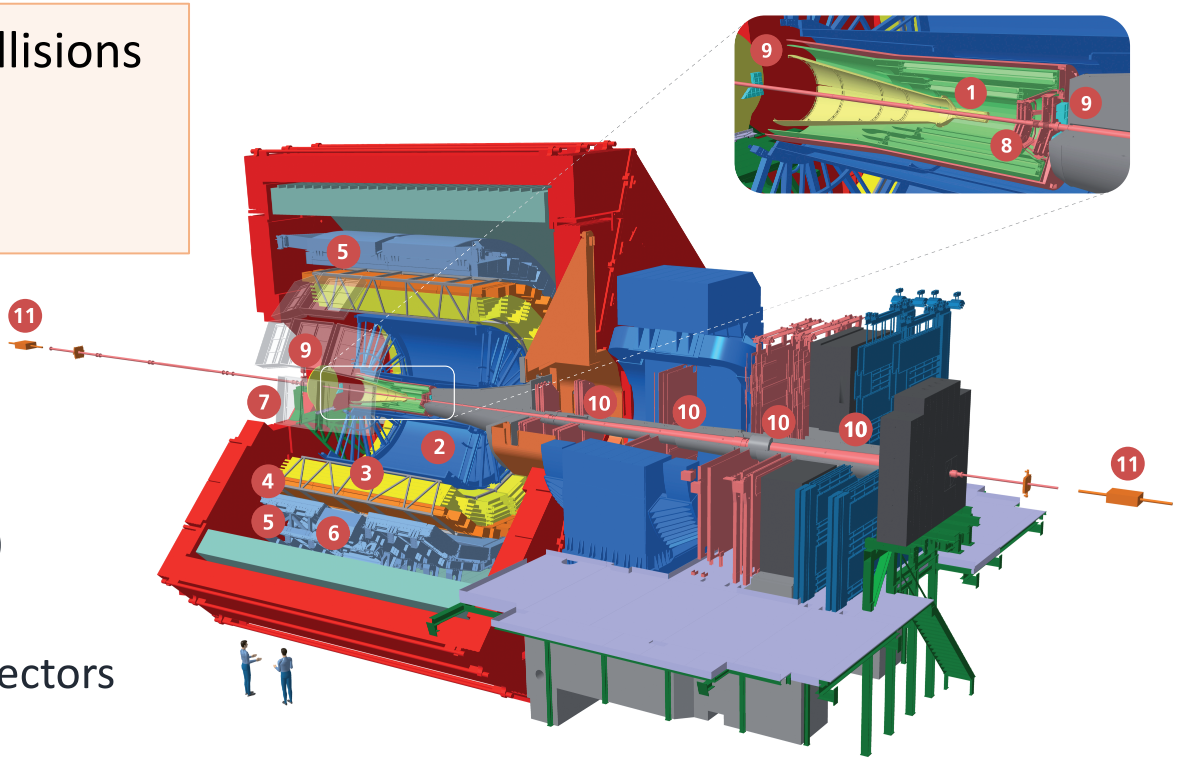
Runs 1 and 2: 1 nb^{-1} of Pb-Pb collisions

Interaction rate ~8 kHz

readout rate ≈ 1 kHz

LS2 upgrade

- New TPC R/O planes
- New silicon tracker (ITS & MFT)
- New Fast Interaction Trigger (FIT)
- New Online/Offline system (**O2**)
- Upgrade readout of all other detectors



1. **ITS** | Inner Tracking System
2. **TPC** | Time Projection Chamber
3. **TRD** | Transition Radiation Detector
4. **TOF** | Time Of Flight
5. **EMCal** | Electromagnetic Calorimeter
6. **PHOS / CPV** | Photon Spectrometer
7. **HMPID** | High Momentum Particle Identification Detector
8. **MFT** | Muon Forward Tracker
9. **FIT** | Fast Interaction Trigger
10. **Muon Spectrometer**
11. **ZDC** | Zero Degree Calorimeter

> Improve tracking resolution at low p_T

x50 statistics increase for most observables

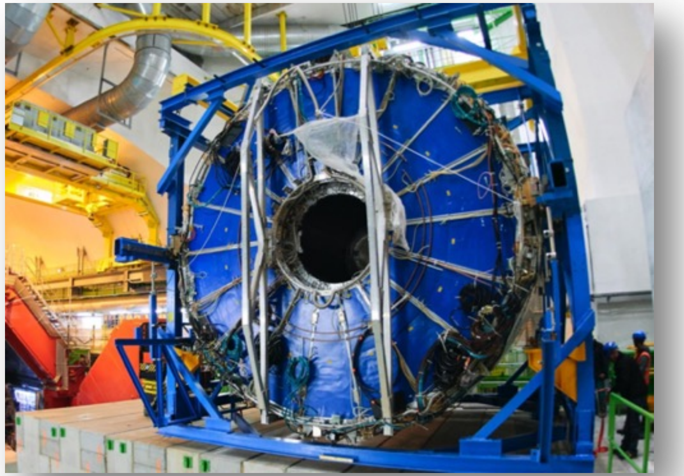
Run 3+Run 4: **13 nb^{-1} of Pb-Pb collisions**

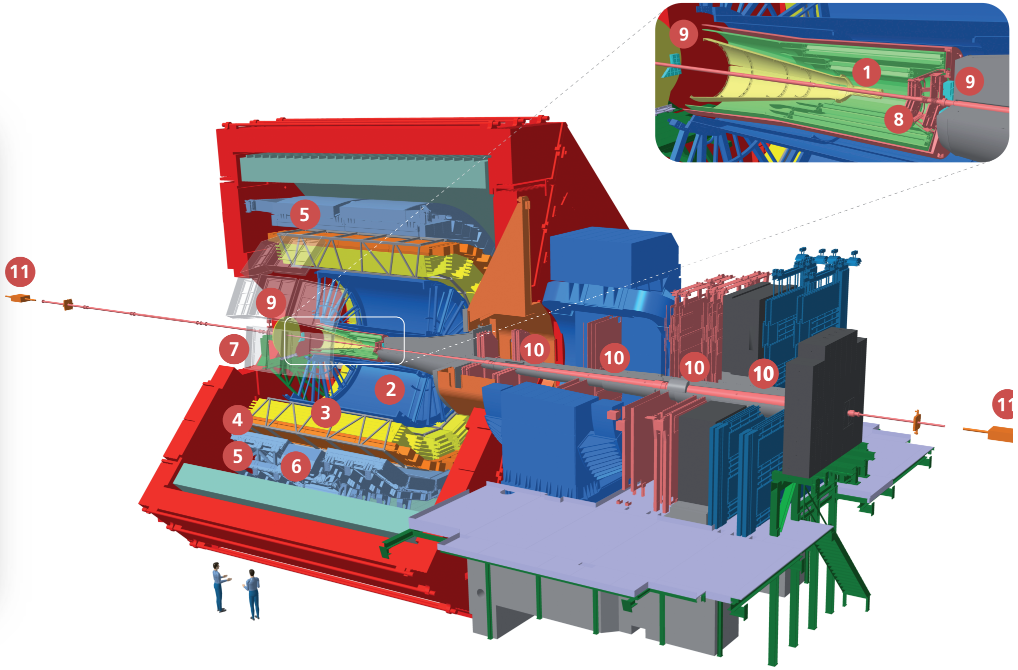
readout rate ≈ 50 kHz (Pb-Pb), ≈ 1 MHz (pp)

online reconstruction : all events to storage!

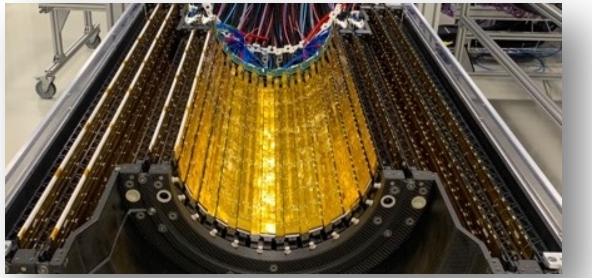
ALICE Detector Version 2.0 (Upgrades for Run 3+)

GEM-based TPC readout

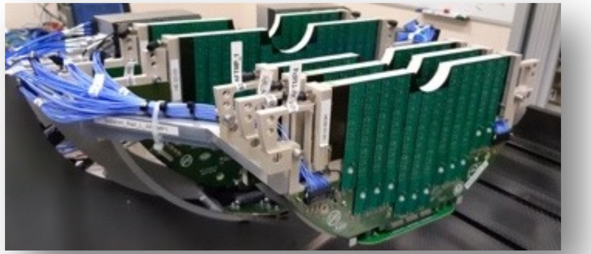




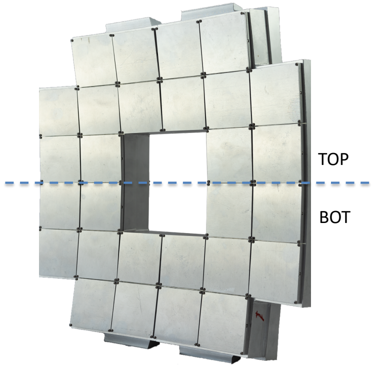
Monolithic-pixel - ITS2



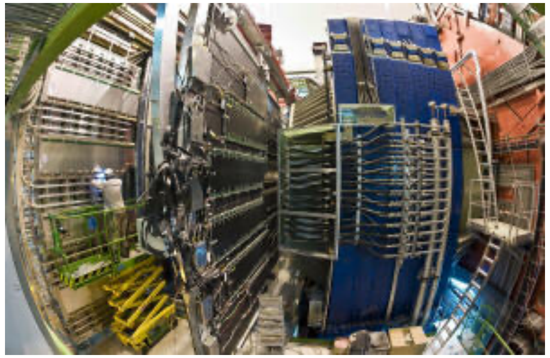
Pixel Muon Forward Tracker (MFT)



Fast Interaction Trigger FIT

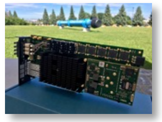


Muon Spectrometer



New Central Trigger Processor (CTP)

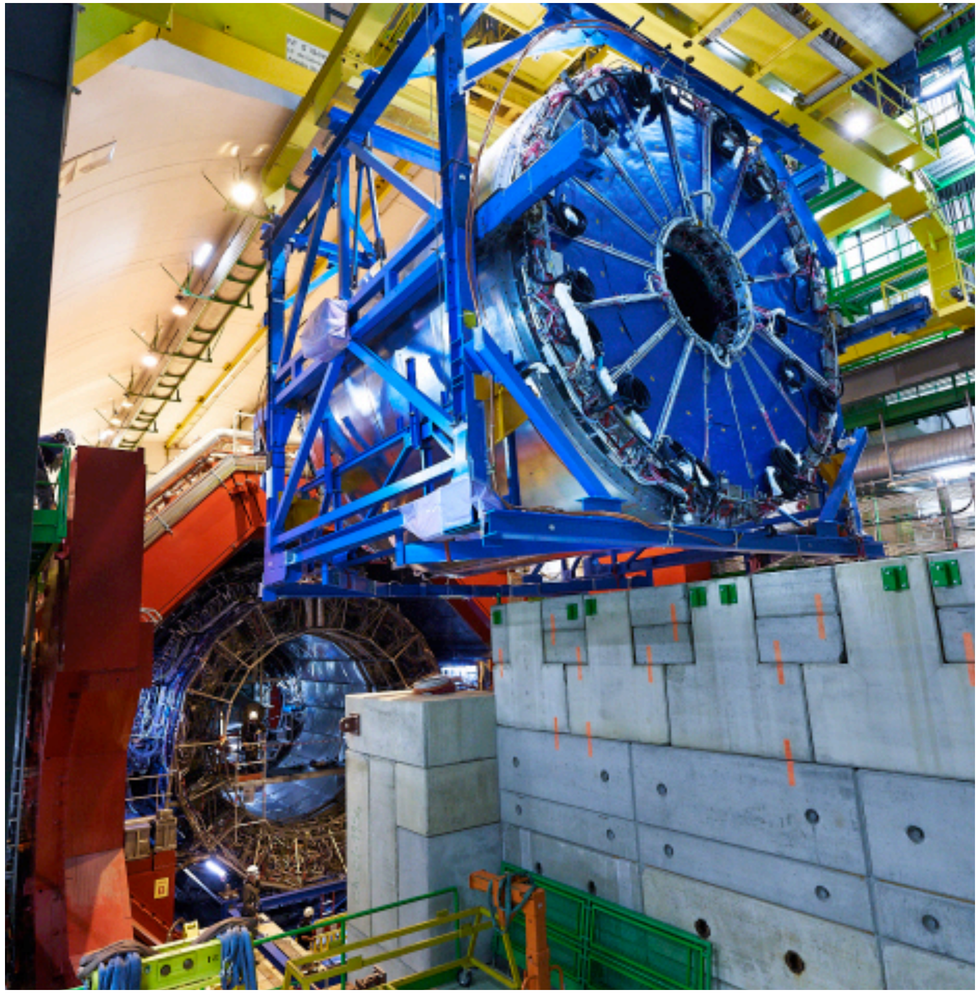
Upgrade of R/O for EMCal, PHOS, TRD, HMPID, ZDC



New Online/Offline (O2)

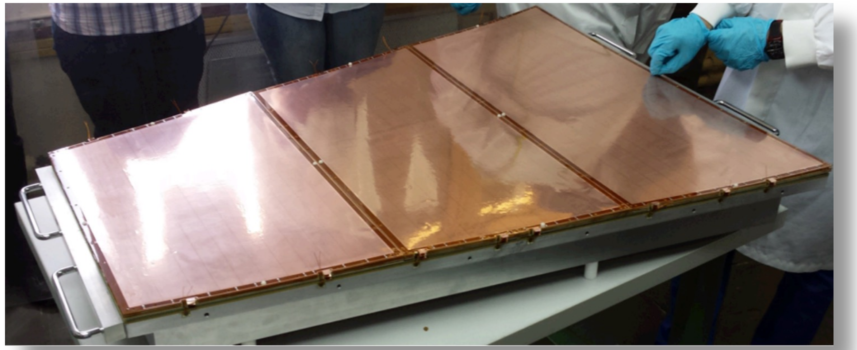
TPC Upgrade for continuous readout

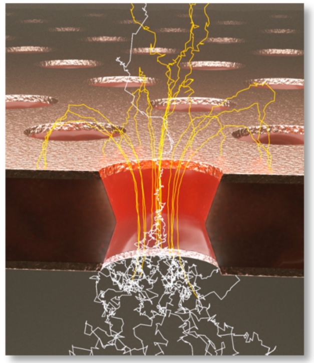
Goal: TPC continuous readout (➪ no gating grid)



Solution: Replace MWPC with 4-GEMs

100 m^2 single-mask foils GEM production



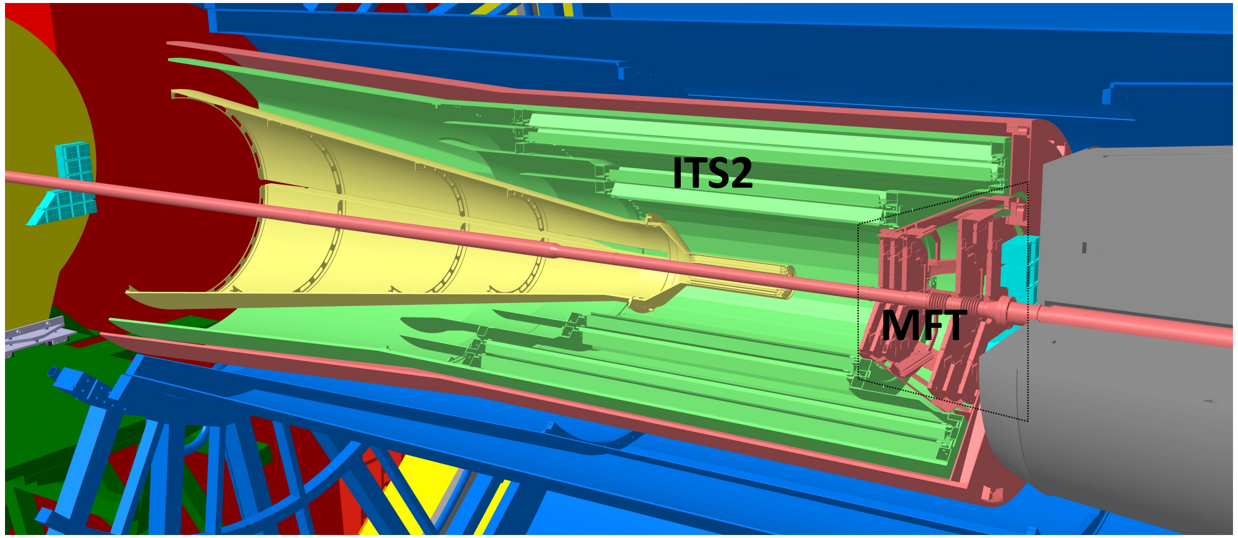


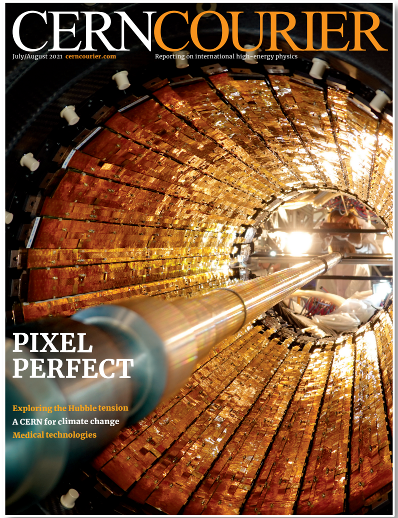
Read Out Chamber

➪ GEM provides ion backflow suppression to **< 1%**

➪ 524 000 pads readout continuously ➪ **3.4 TByte/sec**

New Inner Tracking System and Muon Froward Tracker





Based on MAPS technology (ALPIDE)

- **10 m²** active silicon area
- **12.5 G-pixels**
- **50 μm** thin sensor
- Spatial resolution **~5µm**
- Max particle rate ~ **100 MHz /cm²**

Inner Tracking System upgrade (ITS2)

- Closer to the IP: first layer at ≈22 mm
- Smaller pixels: 28 x 29 μm^2
- Lower material budget: 0.35% X_0

⇨ improved pointing resolution (**x 3**)

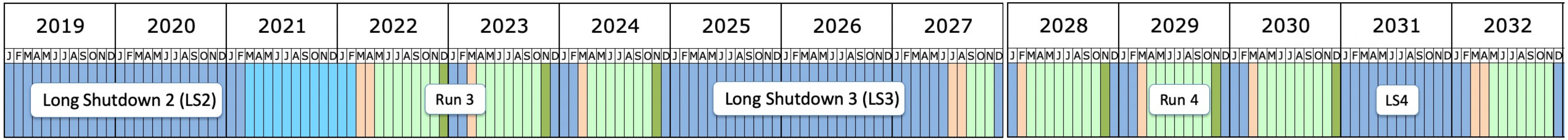
⇨ Improved tracking efficieny at low p_T

New Muon Forward Tracker (MFT)

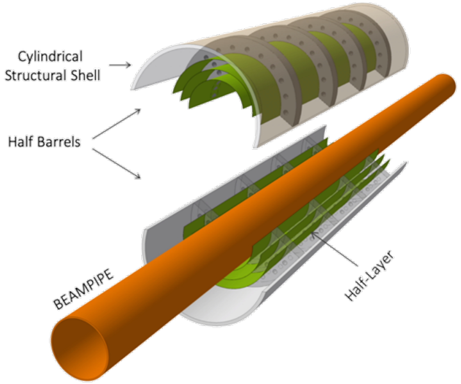
- New forward vertex detector upstream muon absorber

⇨ improved muon pointing resolution

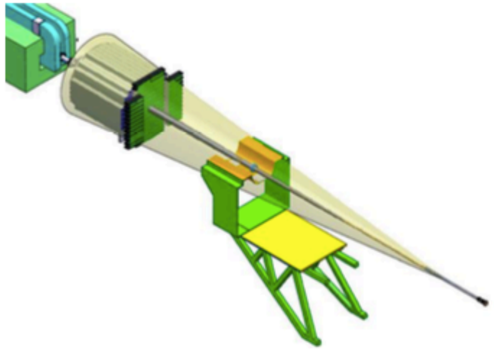
Perspectives: upgrades for Run 4



ITS3



FoCal



ITS3: ultra-thin, truly cylindrical layers
improvement in the measurement of low p_T charm and beauty hadrons and low-mass dielectrons

LoI: CERN-LHCC-2019-018

FoCal: forward EM calo with Si readout
for isolated γ measurement in $3.4 < \eta < 5.8$ in p-Pb

LoI ALICE-PUBLIC-2019-005

ALICE

ALICE in Runs 3-4: Main Physics Goals

QGP radiation

➪ Thermal di-leptons, photons

Heavy-quarks interaction in the QGP

➪ Thermalization and diffusion coefficient of heavy quarks (R_{AA}, collective flow, baryon-to-meson ratio)

Quarkonium melting and regeneration in the QGP

➪ Charmonia down to zero p_T

Emergence of QCD collectivity from pp to AA

➪ Origin of collectivity, search for QGP signals (E-loss, radiation)

Nuclear and hadronic physics

➪ High-precision measurements of light, hyper-nuclei, and hadron-hadron strong interaction

Vertexing

Low p_T

Hadron/e/μ ID

High rate

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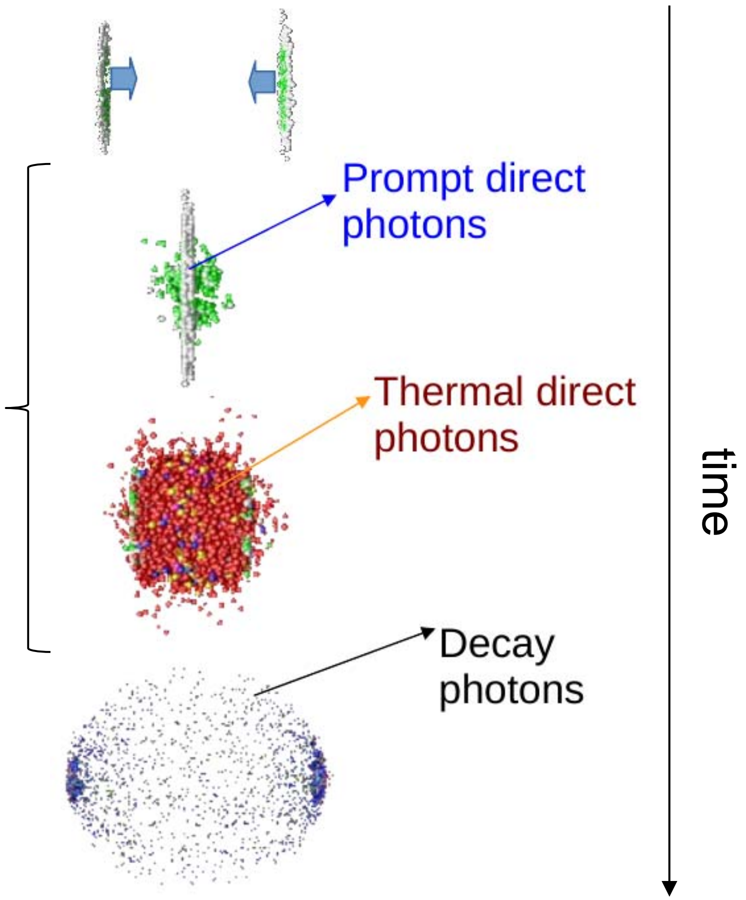
Thermal radiation – direct photons

Direct photons carry information on the medium’s temeprature space-time evolution



direct photons

Prompt photons ($p_T > 5$ GeV/c)
- described by NLO pQCD
- Test initial conditions: N_{coll} scaling, PDF modification

Thermal photons ($p_T < 3$ GeV/c)
- Influenced by flow evolution
- Spectrum, collective flow (comparison to hydrodynamic models)

Decay photons
- Large background from neutral meson decays (π^0, η, ω, …)

Jet-medium interaction
- Scattering of hard partons with thermalized partons

γ detection in ALICE
- Photon conversion in detector material $X/X_0 = (11.4 \pm 0.5)\%$
- Calorimetry : PHOS and EMCal

Thermal radiation – direct photons

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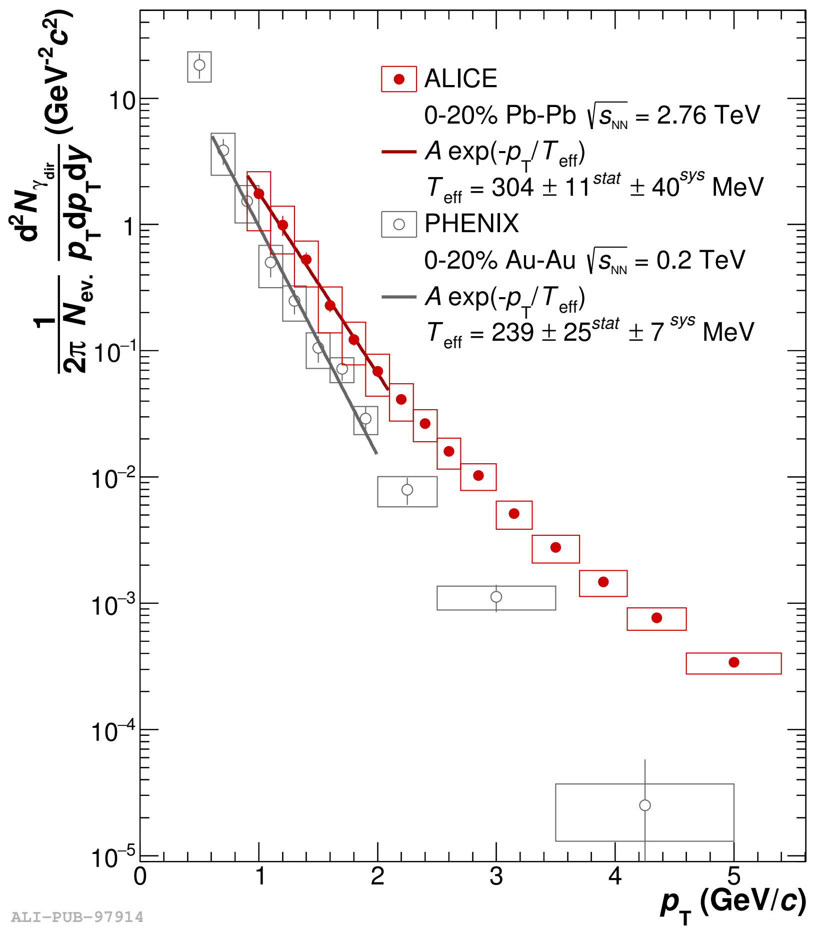
PLB 754 (2016) 235



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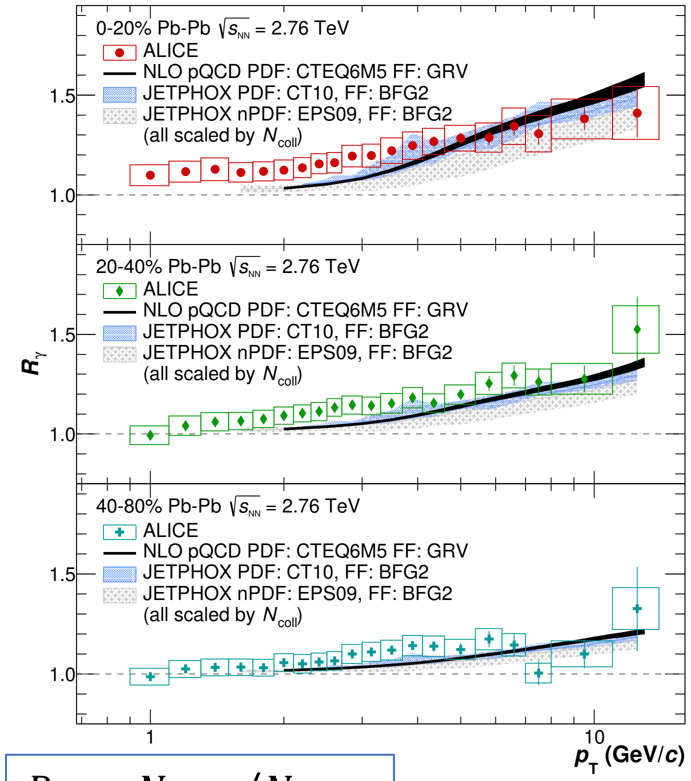
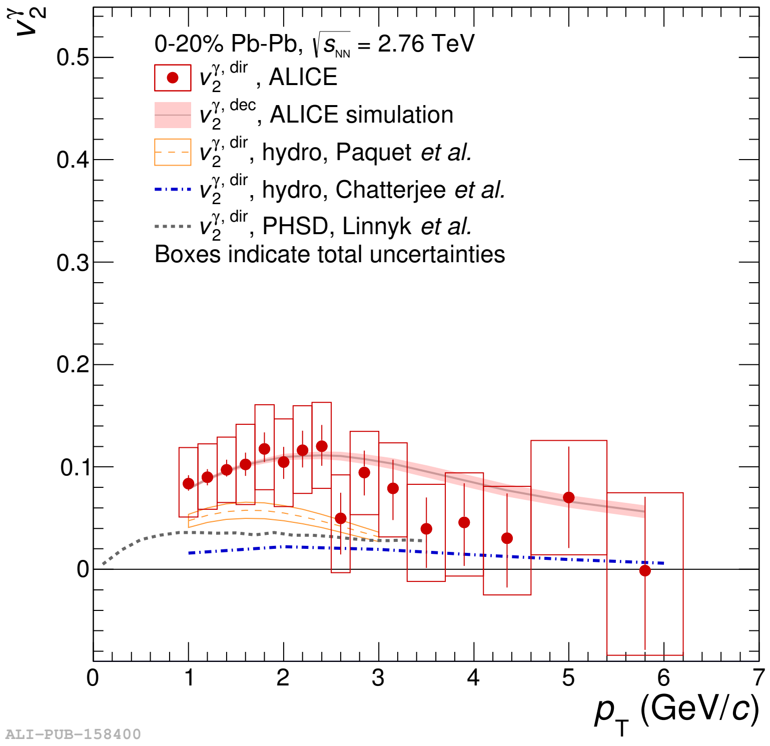
Direct photons in Run 1

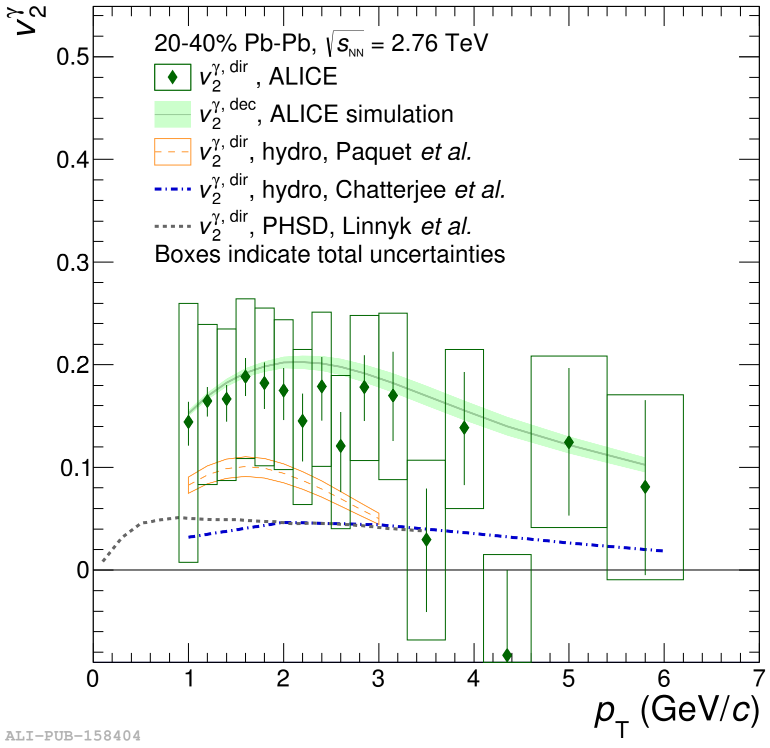
PLB 754 (2016) 235



$$R_\gamma = N_{\gamma,inc}/N_{\gamma,dec}$$



PLB 789 (2019) 308-322



Consistent with thermal radiation

T_{slope} = 304 ± 40 MeV

LHC results consistent with RHIC, but **uncertainties are very large**

Run 3 data should clarify if also at the LHC there is a “photon puzzle”

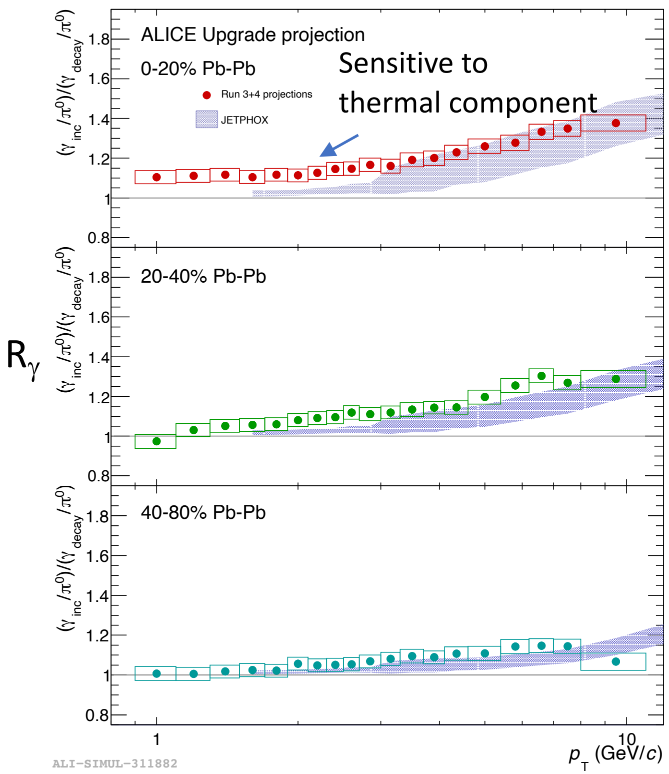
Direct photons – projections for Run 3

Main objective for Run 3: reduction of systematic uncertainties

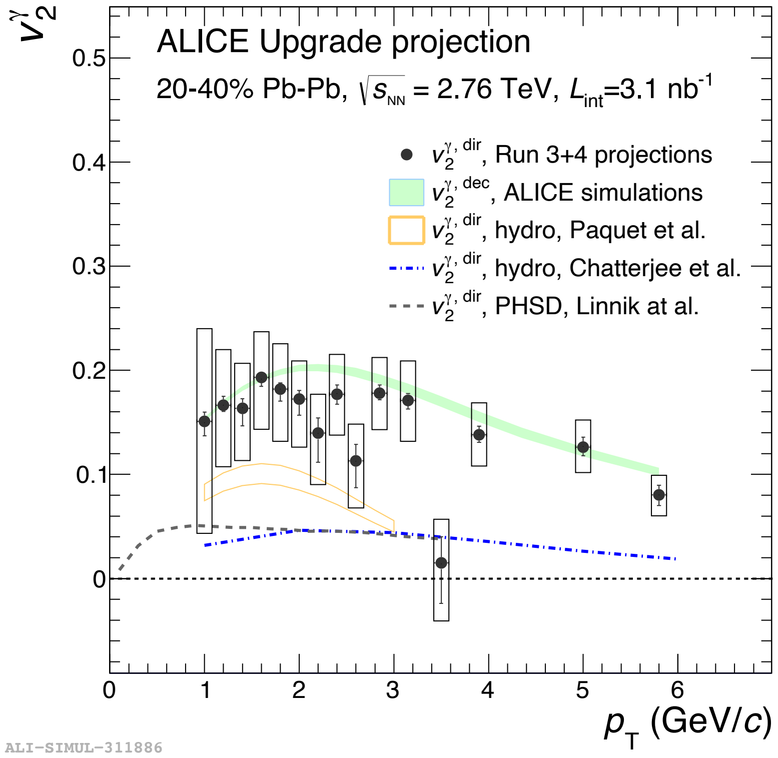
- x 100 statistics
- better calibration of the detector material thickness

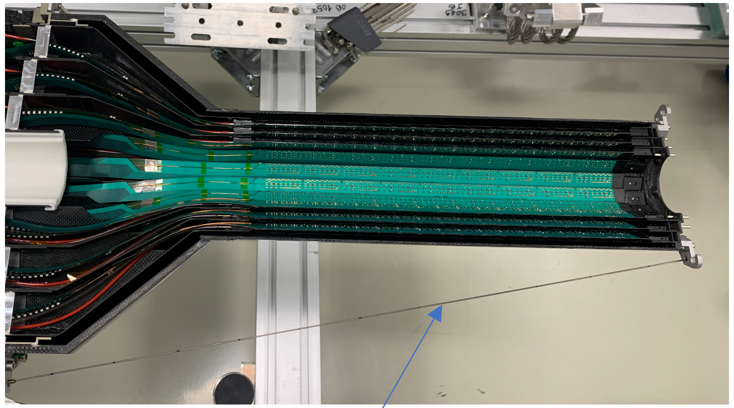
- stat. error: ÷ 10
- **syst. error: ÷ ~2**

Run 3+4



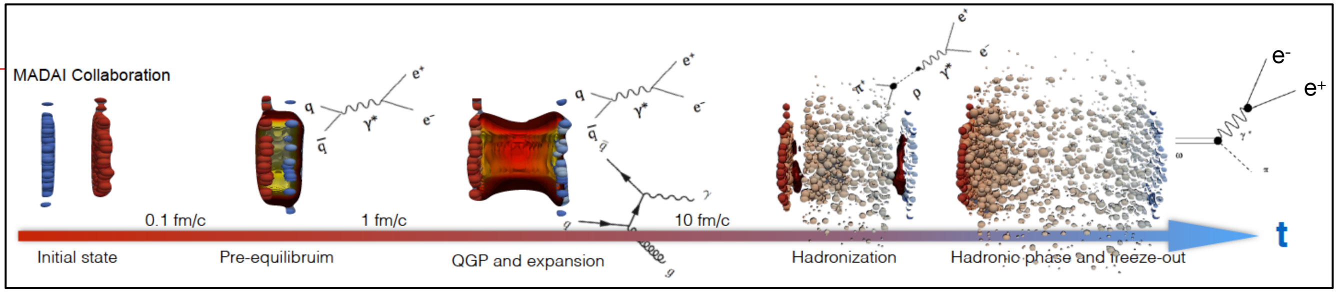
Run 3+4





tungsten wire to calibrate detector material thickness

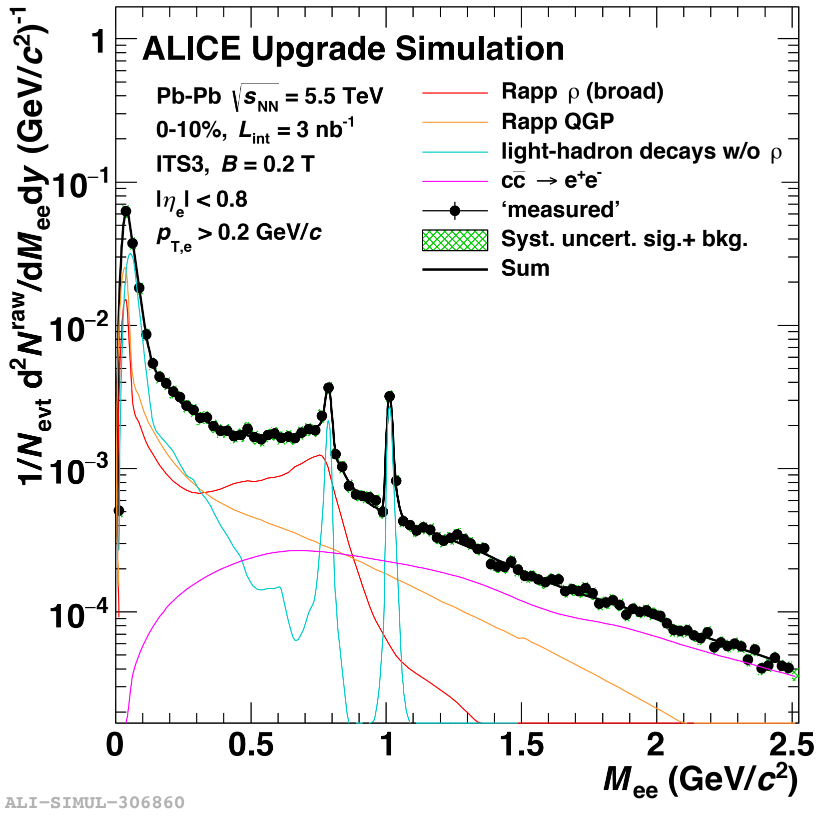
Thermal radiation: dileptons

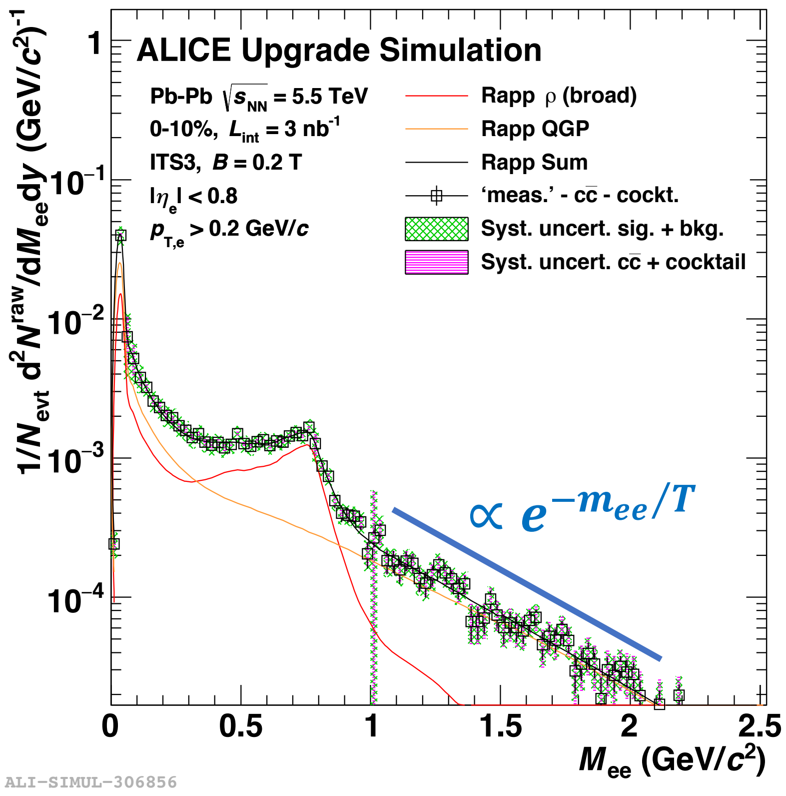


Precise measurement of low-mass dielectron continuum

M_{ee} slope → QGP temperature

Expected performance in RUN4

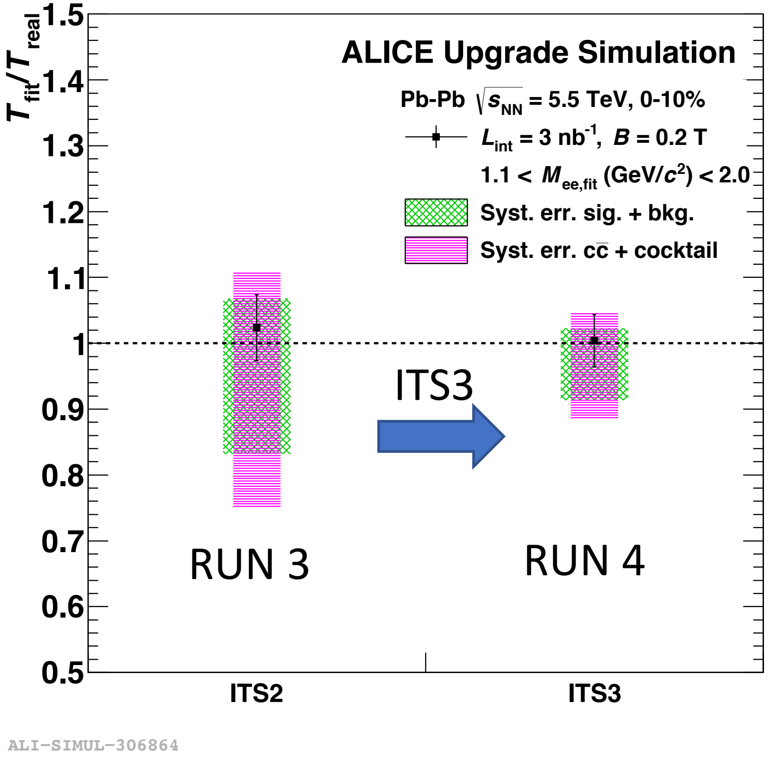


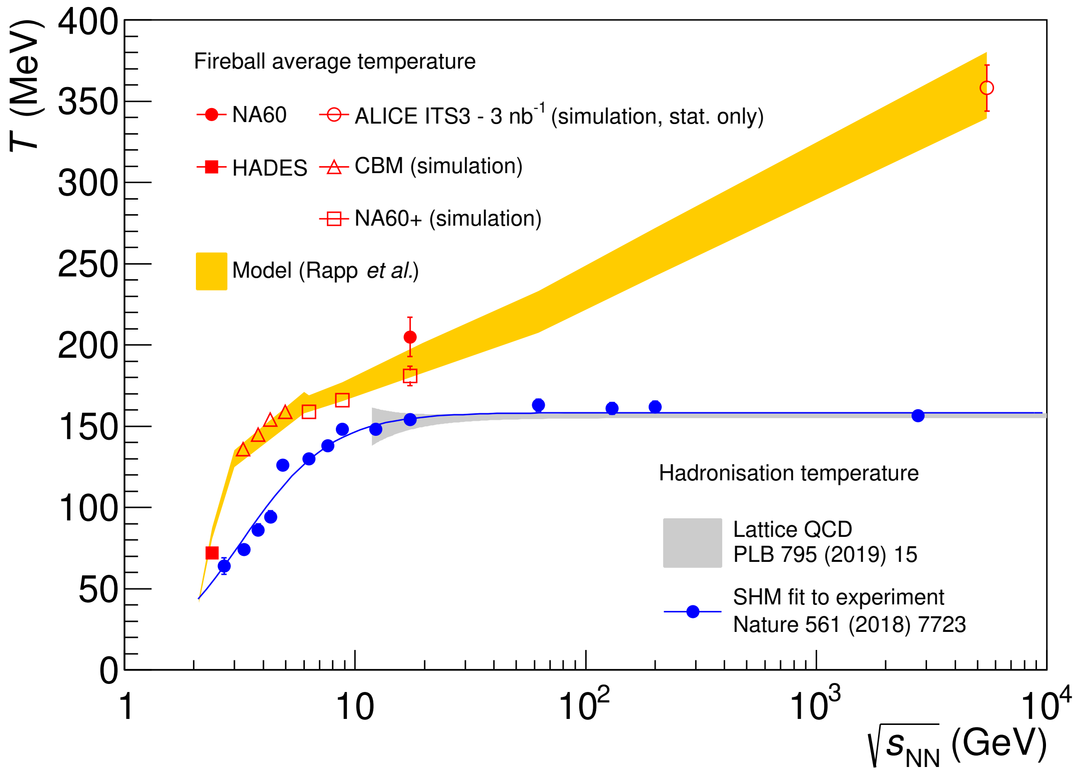


Thermal radiation: dileptons

Improvements with ITS3

- **better charm rejection** (vertexing)
- **reduced** contribution from **conversion** (low material budget)





ALICE in Runs 3-4: Main Physics Goals

QGP radiation
⇨ Thermal di-leptons, photons

Heavy-quarks interaction in the QGP
⇨ Thermalization and diffusion coefficient of heavy quarks (R_{AA}, collective flow, baryon-to-meson ratio)

Quarkonium melting and regeneration in the QGP
⇨ Charmonia down to zero p_T

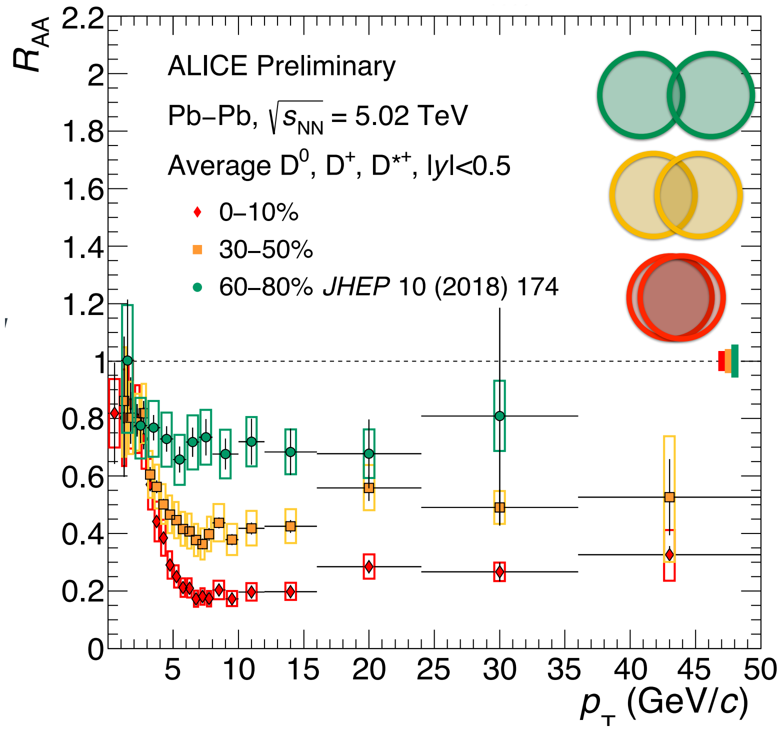
Emergence of QCD collectivity from pp to AA
⇨ Origin of collectivity, search for QGP signals (E-loss, radiation)

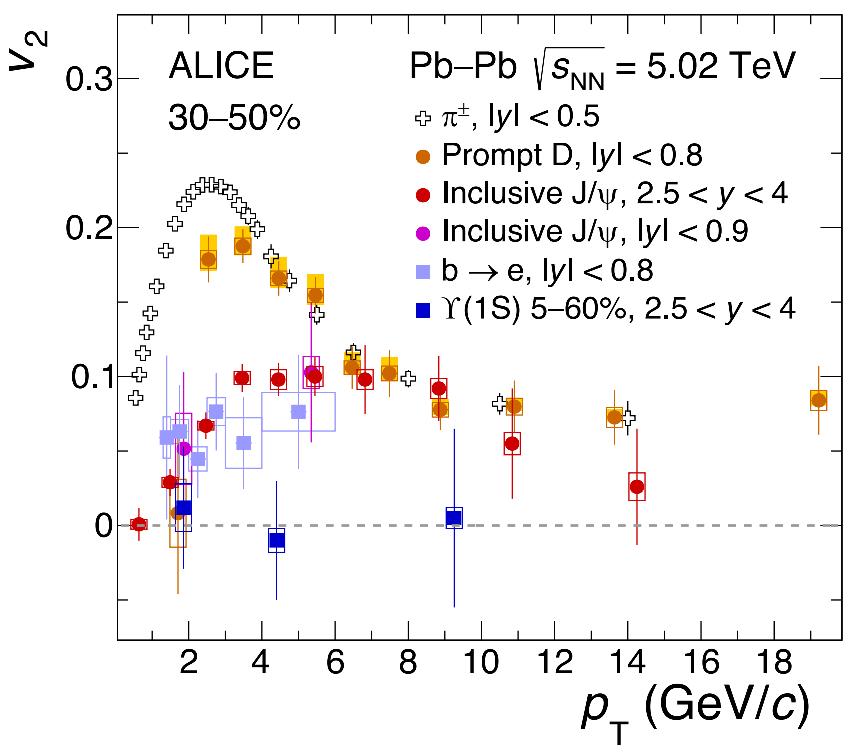
Nuclear and hadronic physics
⇨ High-precision measurements of light, hyper-nuclei, and hadron-hadron strong interaction

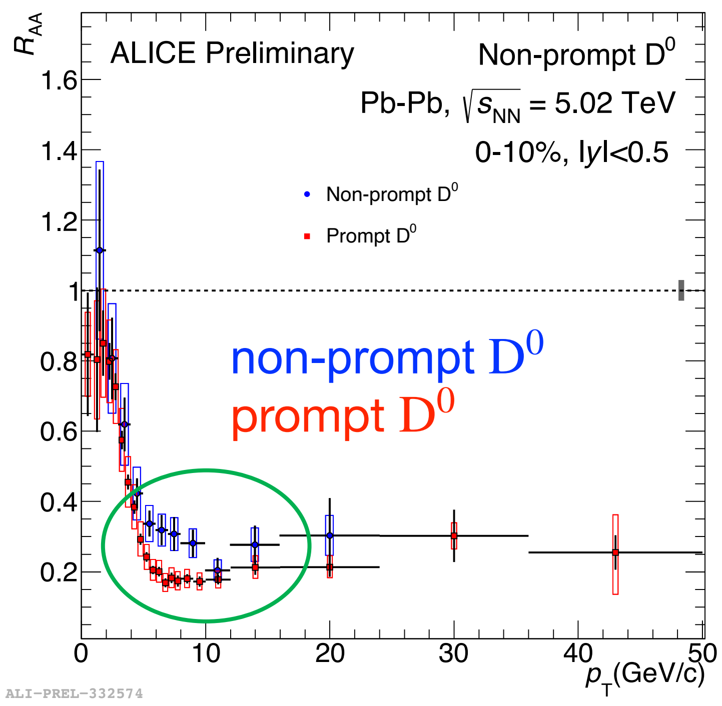
Heavy-quark interaction wiht the QGP

charm and **beauty** quarks interact strongly with the QGP

at low p_T may thermalize and participate in the collective expansion



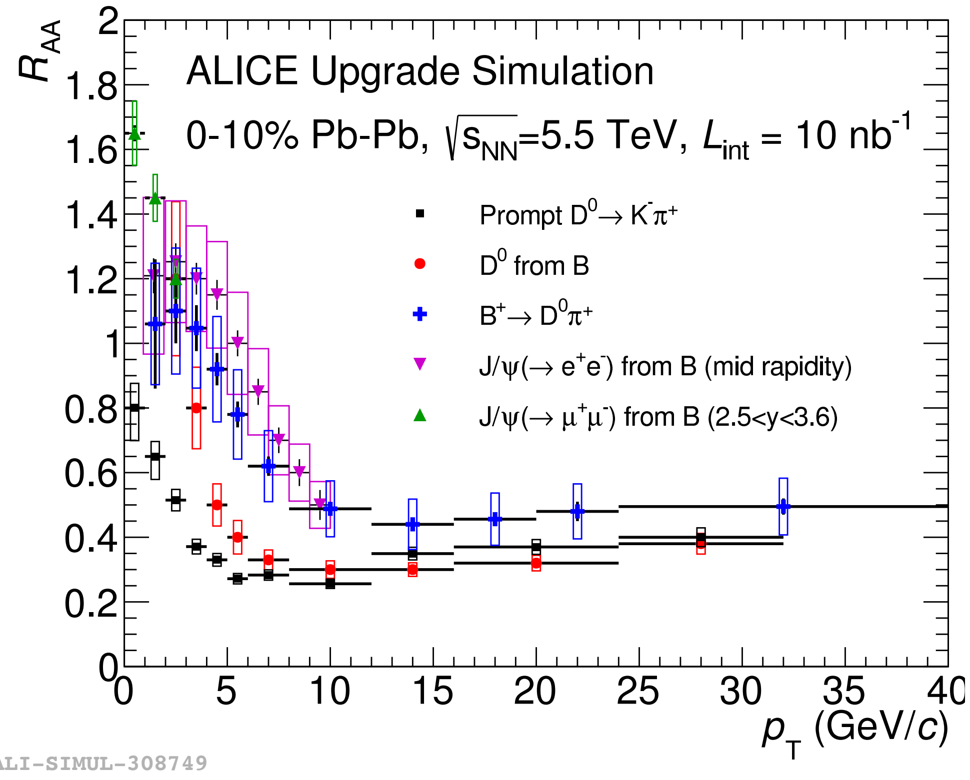




High-precision data needed to get more insight on the microscopic mechanisms of heavy-flavour interaction and diffusion in the QGP

Heavy-flavour: nuclear modification factor and collective flow

Determining the transport coefficients of the QGP

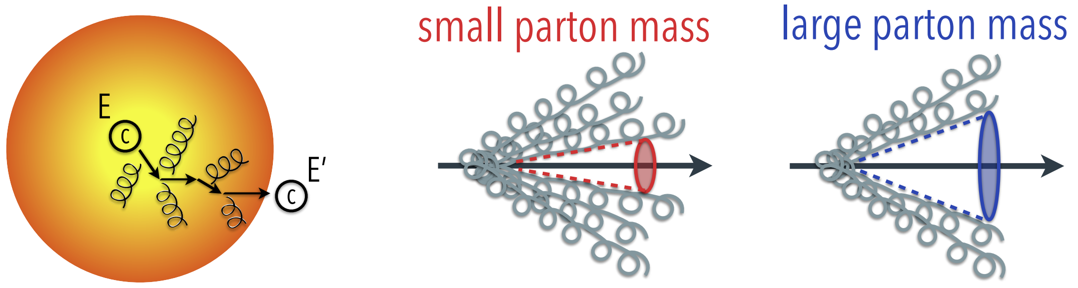


charm hadrons and beauty hadrons can be clearly separated in a wide kinematic range

Precise measurements of R_{AA} provide insights on momentum dependence of heavy quark energy loss

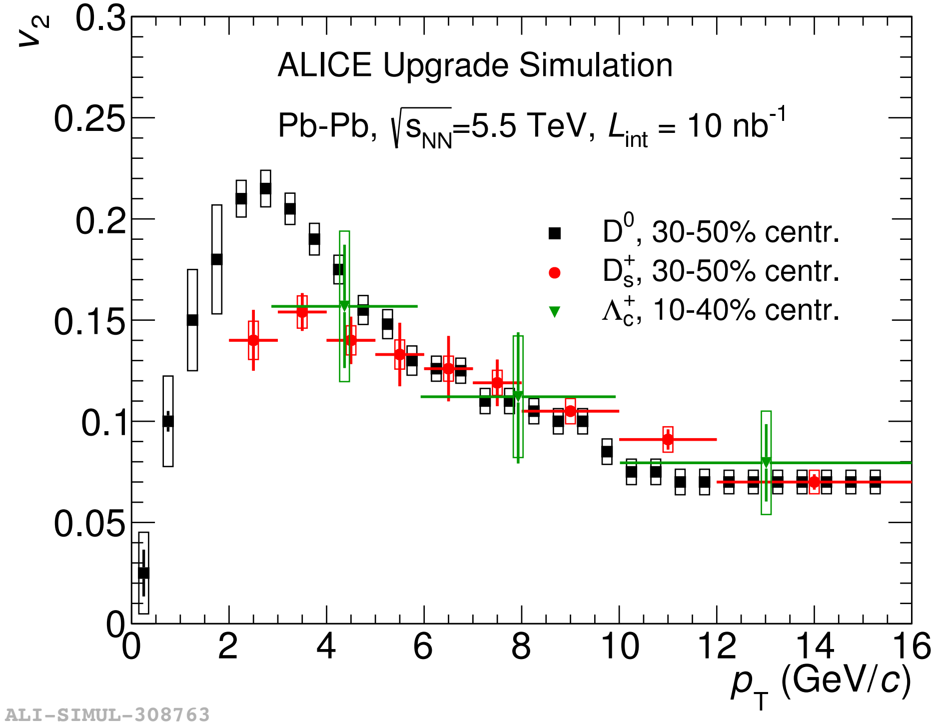
- low p_T: sensitive to **elastic energy loss** and **recombination** with light quarks
- high p_T: sensitive to **radiative energy loss**

⇨ mass and flavour dependence of energy loss



Heavy-flavour: collective flow

Thermalization, coalescence hadronization, energy loss



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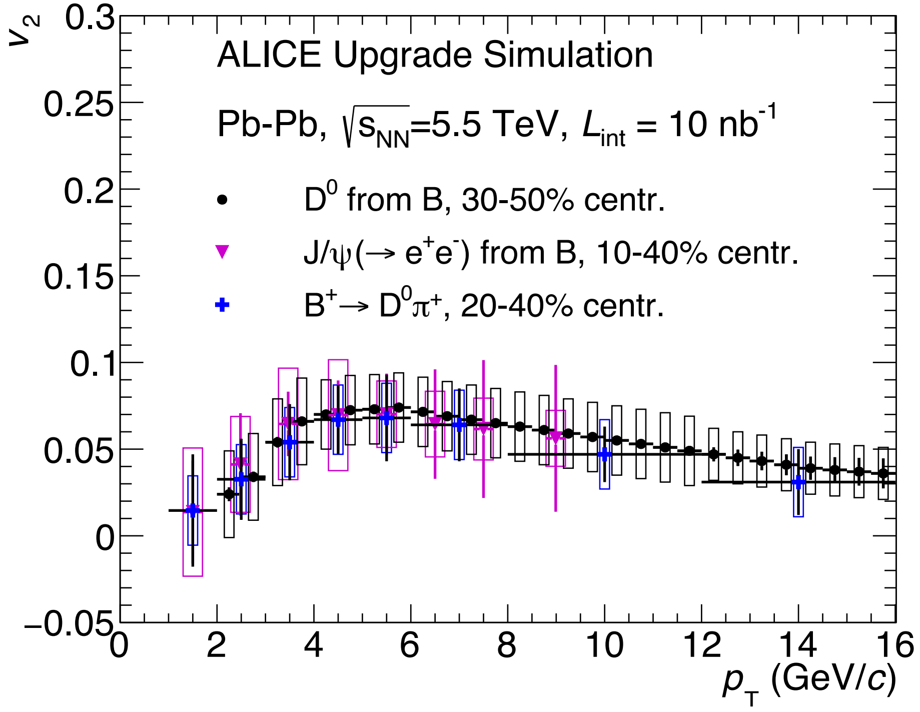
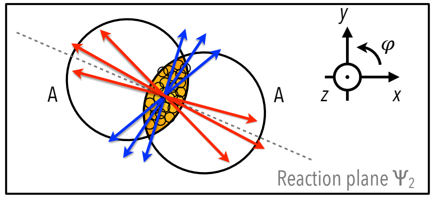




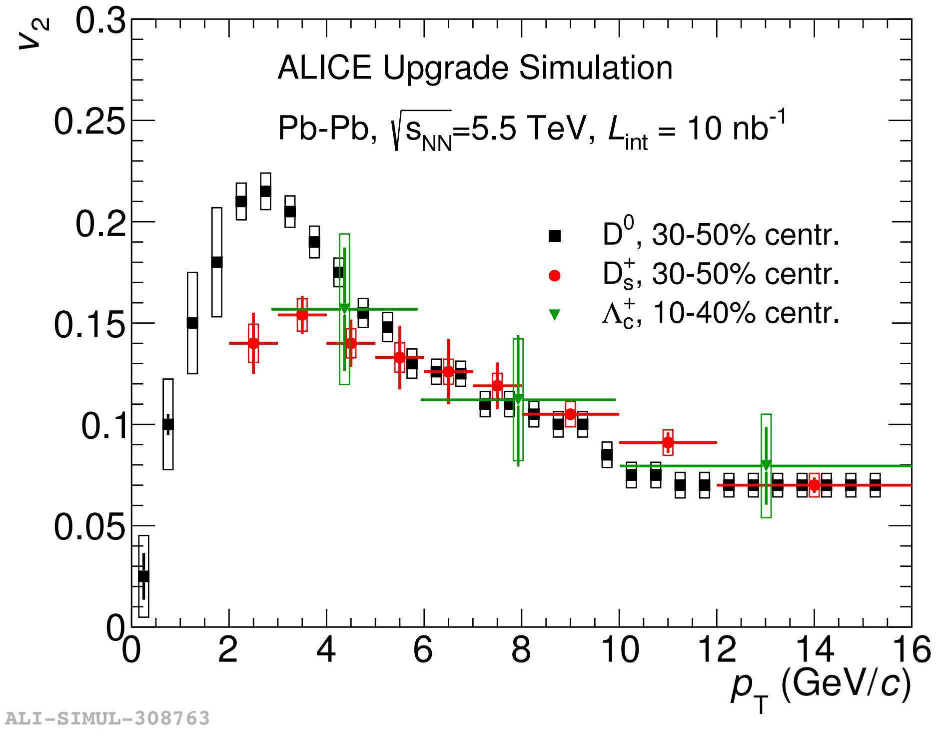
$$v_2 = \langle \cos[2(\varphi - \Psi_2)] \rangle$$

Precise measurements of **flow v2** (and R_{AA}) ⇨ insights on interaction of HQ with medium

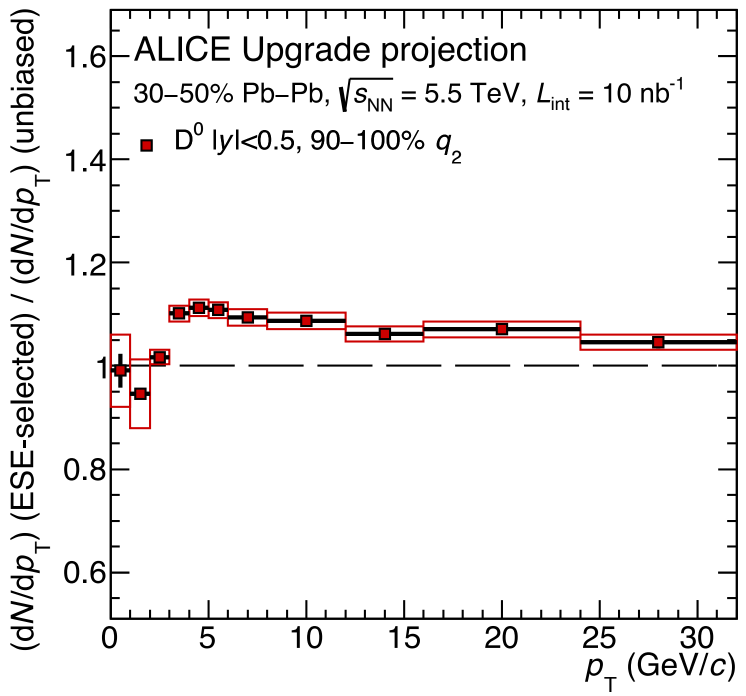
- low p_T: HQ expected to take positive v2 from interaction with LQ and coalescence at hadronization
- high p_T: sensitive to the path-length dependence of energy loss

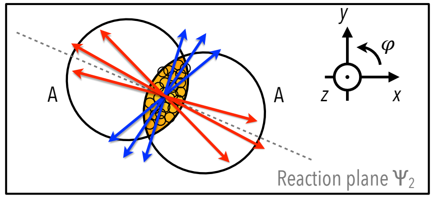
Heavy-flavour: collective flow

Thermalization, coalescence hadronization, energy loss



V$_2$ with Event Shape Engineering





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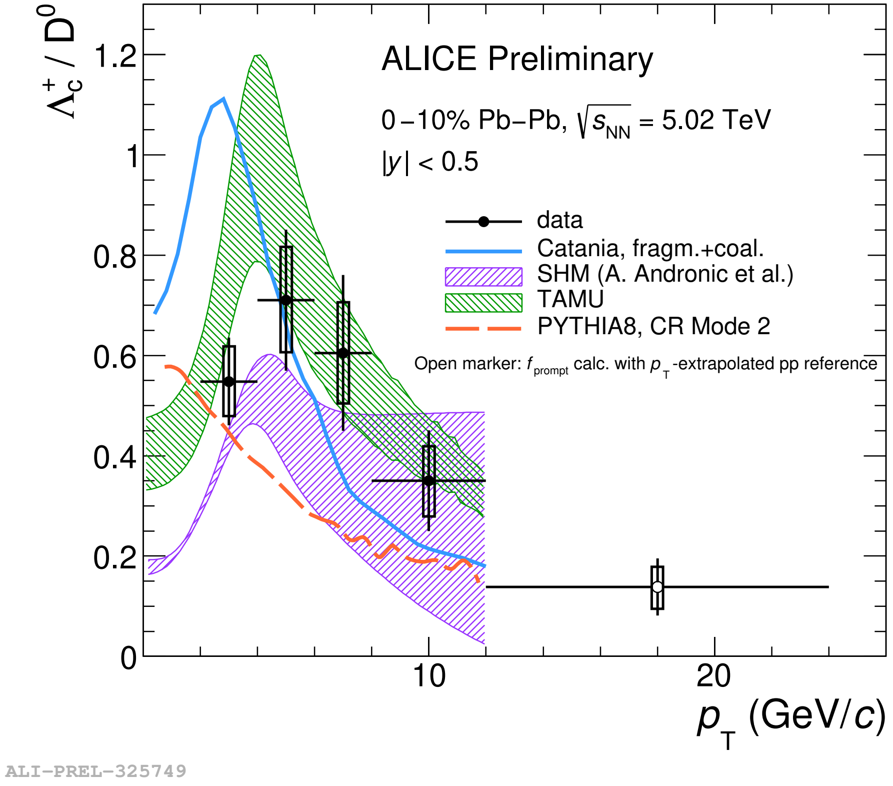
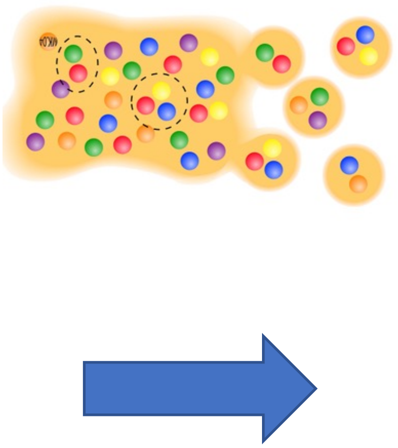
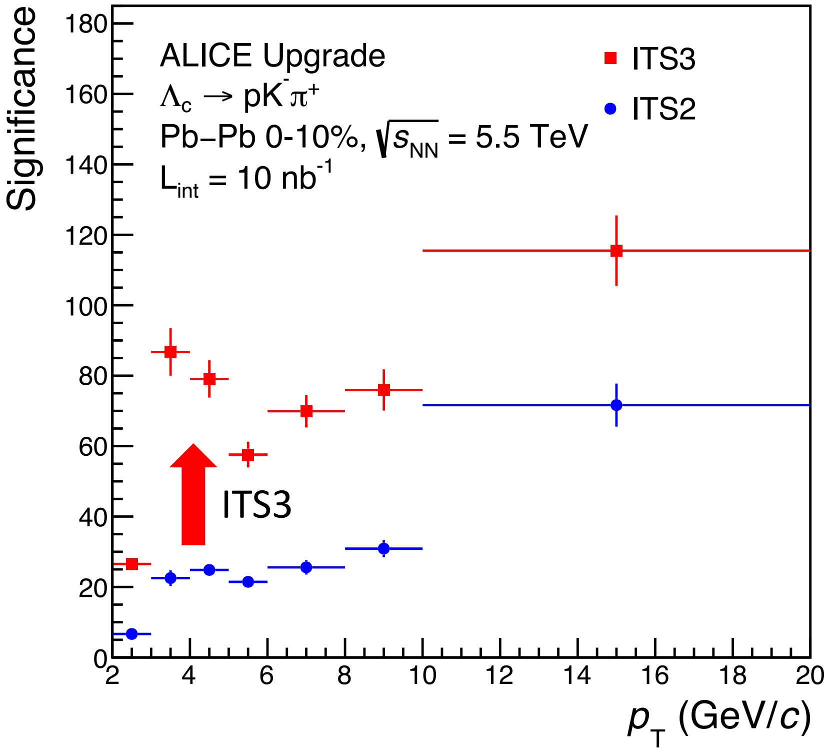
Heavy-quark hadronization in the QGP

Λ_c^+ /D⁰ - first look in Run 2





Λ_c^0 in Run 3 and 4



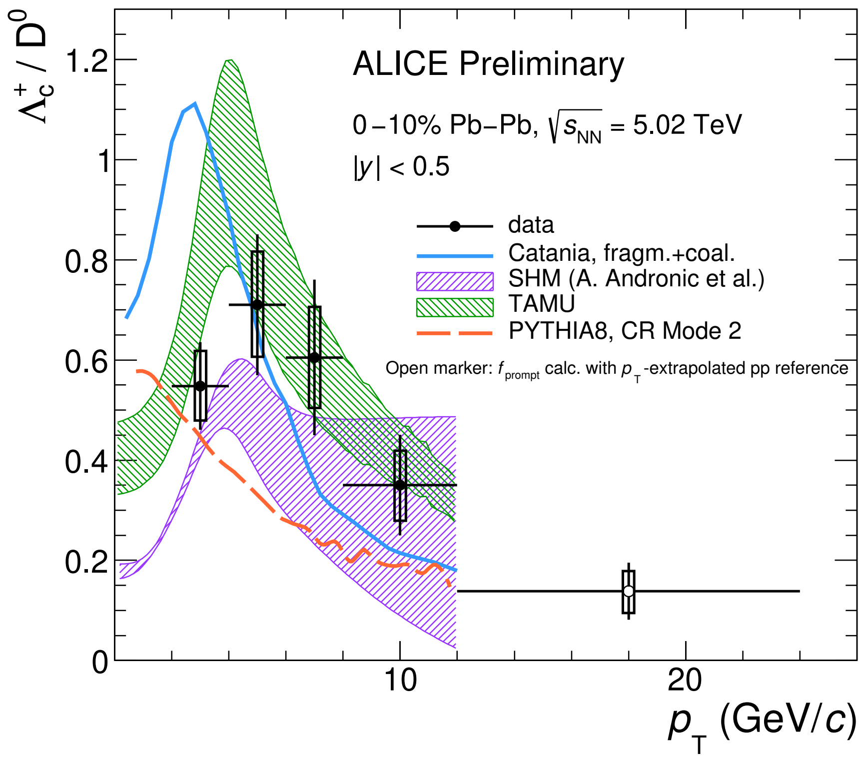
Λ_c/D⁰ for p_T > 4GeV/c described by model with charm hadronization via fragmentation + coalescence

Improved tracking precision of new ITS (and ITS 3 in Run 4) will enable precise measurements for charm baryons …

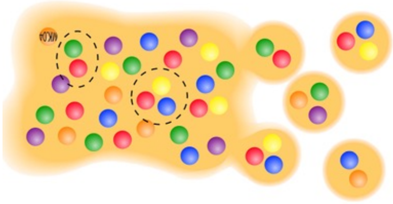
ALICE

Heavy-quark hadronization in the QGP

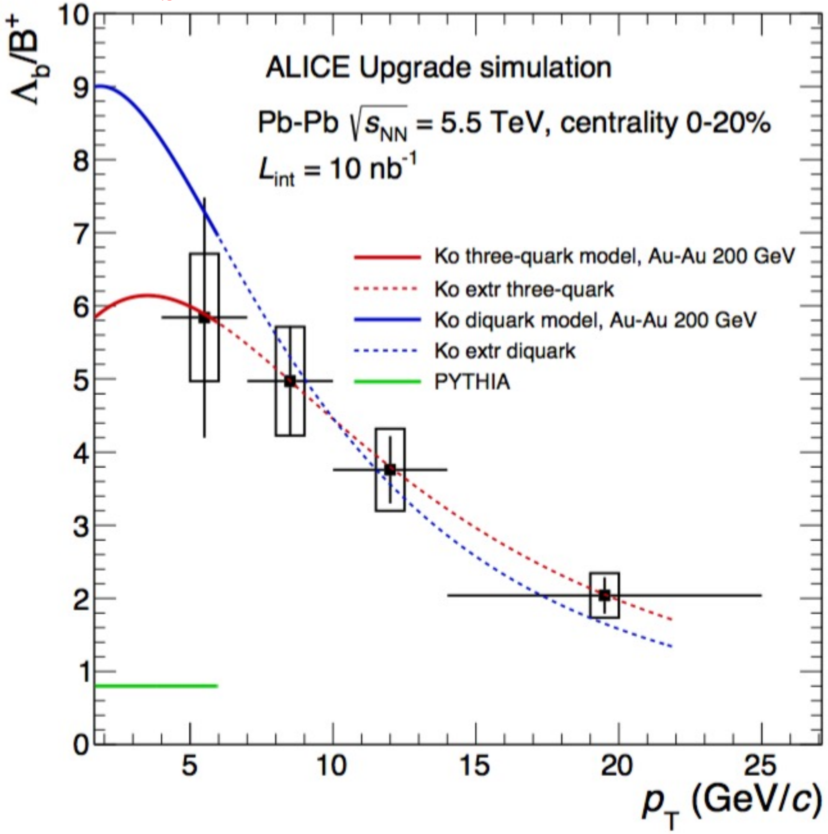
Λ_c^+ /D⁰ - first look in Run 2



ALI-PREL-325749



Λ_b^0/B⁺ in Run 3 and 4



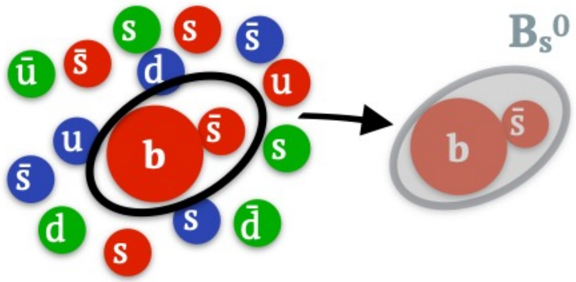
Λ_c/D^0 for p_T > 4GeV/c described by model with charm hadronization via fragmentation + coalescence

Improved tracking precision of new ITS (and ITS 3 in Run 4) will enable precise measurements for charm baryons and **access to beauty baryons**

Strange heavy-flavour hadrons

B_s^0 meson

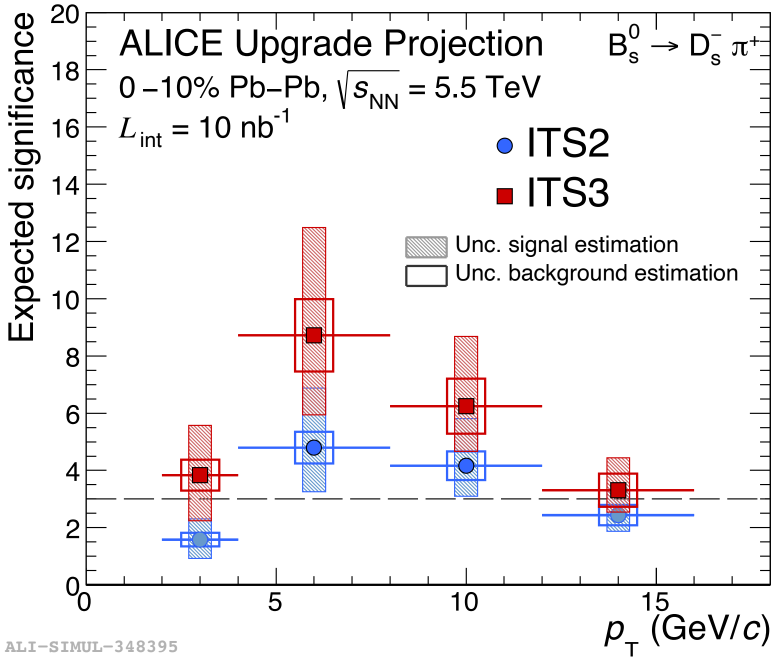
$$B_s^0 \to D_s^- \pi^+ \to \phi \pi^- \pi^+ \to K^+ K^- \pi^- \pi^+$$

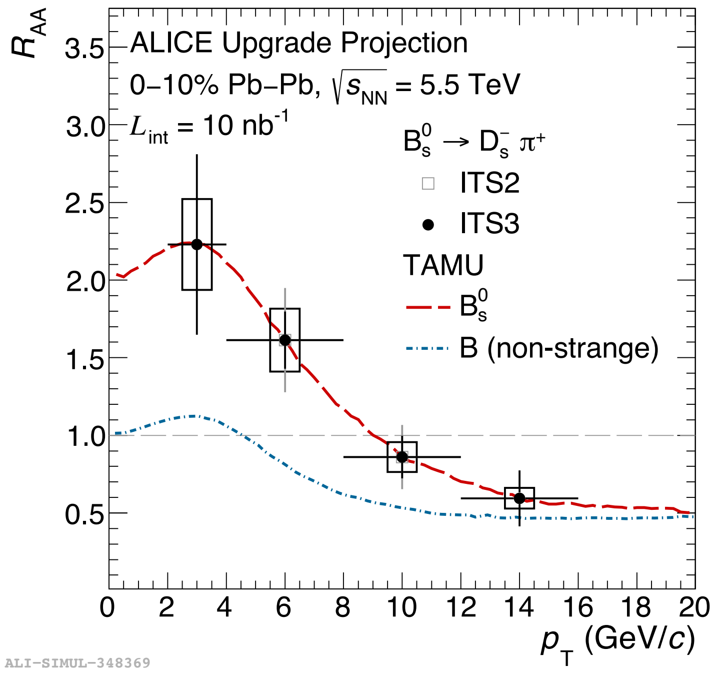


Study beauty-quark hadronization mechanism

B_s^0 production expected to be enhanced

Hadronization of beauty quarks via recombination + enhanced strange-quark production in the QGP





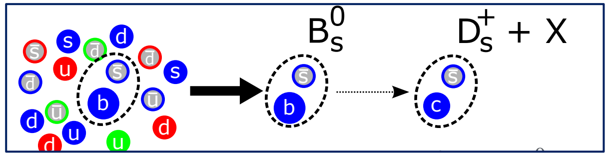
Strange heavy-flavour hadrons

Non-prompt D_s^+

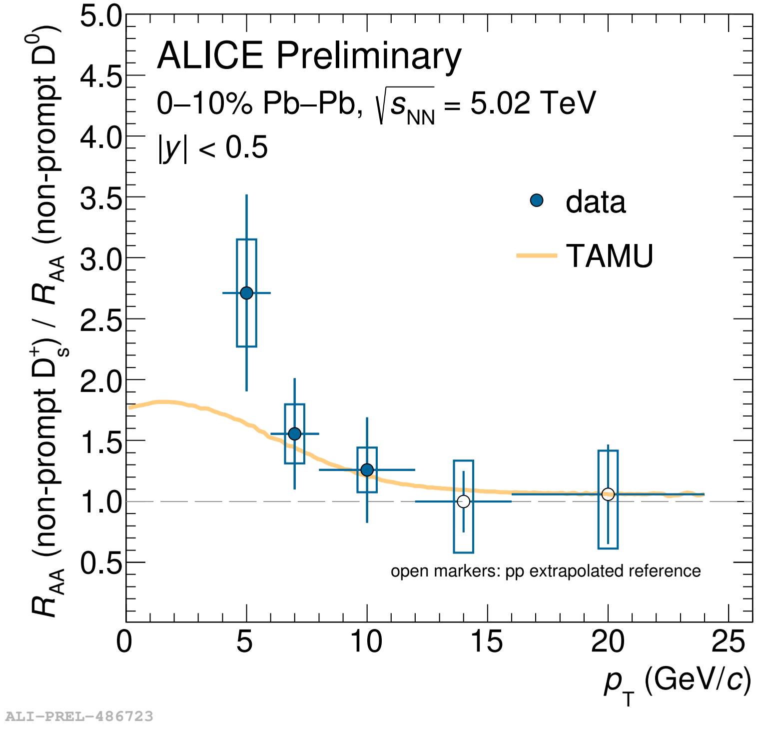
$D_s^+ \rightarrow \phi\pi^+ \rightarrow K^+K^-\pi^+$

Non-prompt $\boldsymbol{D_s^+}$ from B decays (50% from B^0_s)

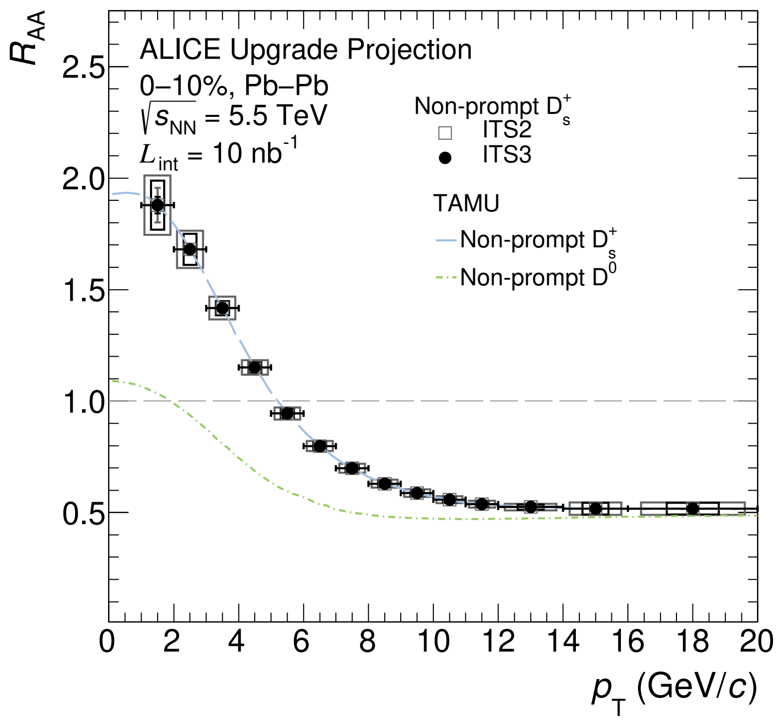
Larger statistical precision than exclusive $\boldsymbol{B_s^0}$



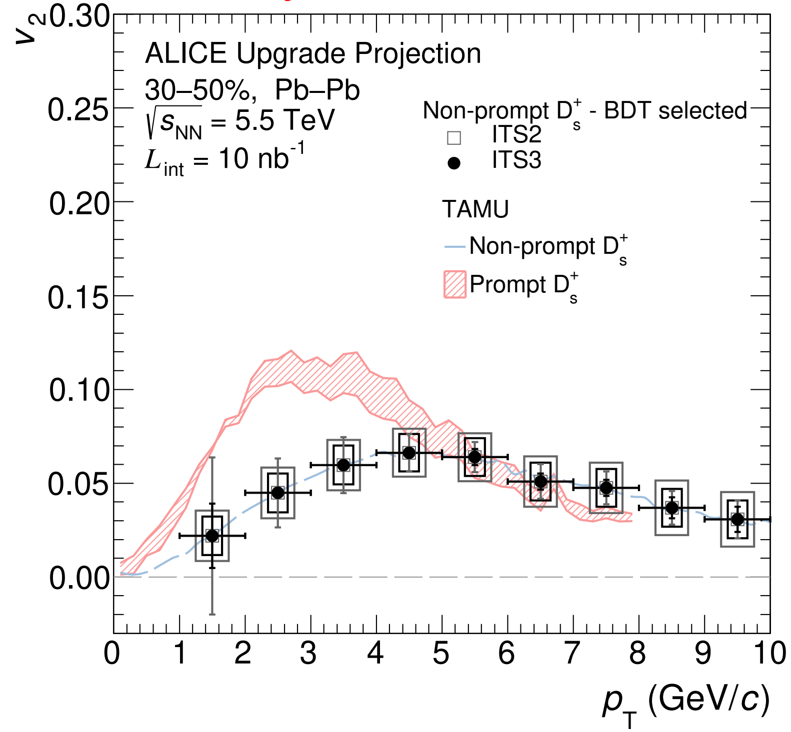
first look in Run 2



Projections for Run 3 and 4



Projections for Run 3 and 4

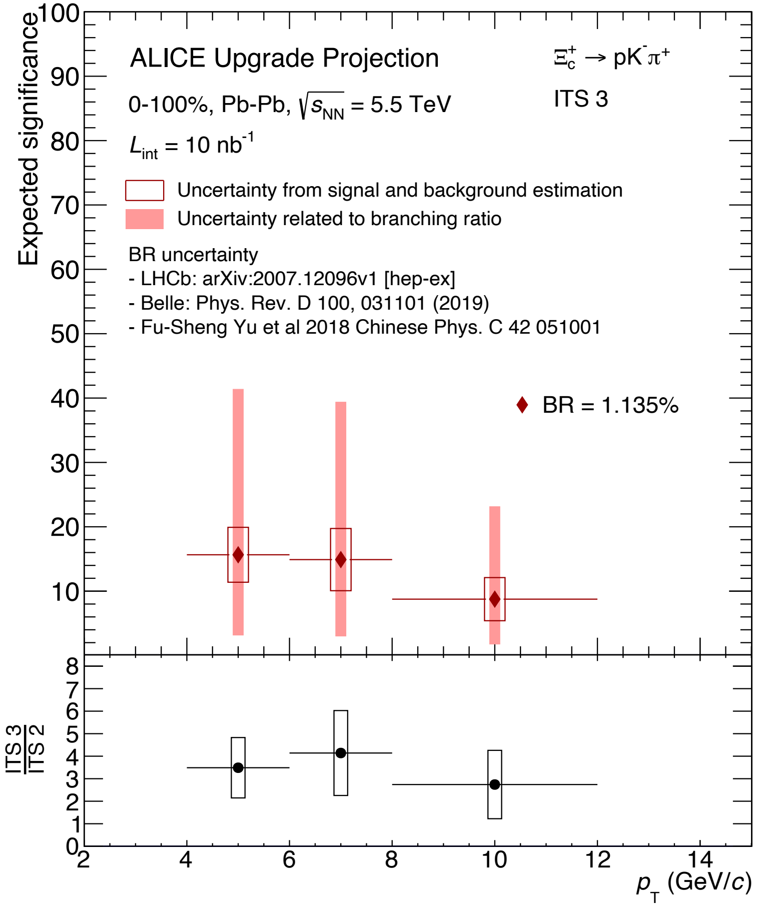


sensitive to beauty-quark hadronization and strangeness enhancement

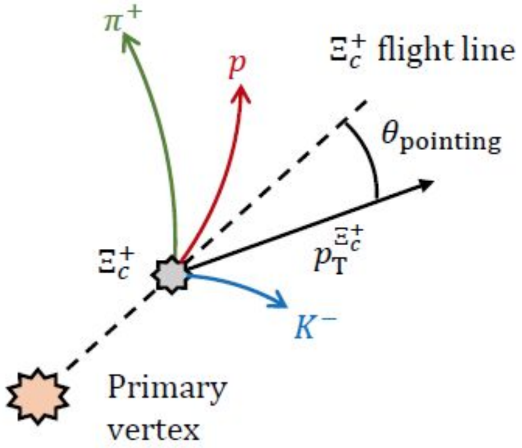
sensitivity to discriminate azimuthal anisotopy for prompt and non-prompt $\boldsymbol{D_s^+}$ (charm vs. beauty)

Strange heavy-flavour baryons

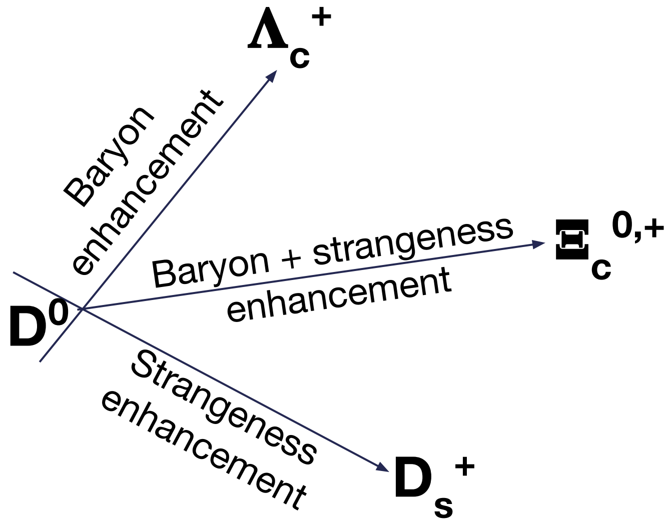
$\Xi_c^{0,+}$ natural candidate to see the combined effect of charm baryon enhancment and the further enhancement in a stangeness-rich QGP



Also first brick for future studies of Ξ_{cc}



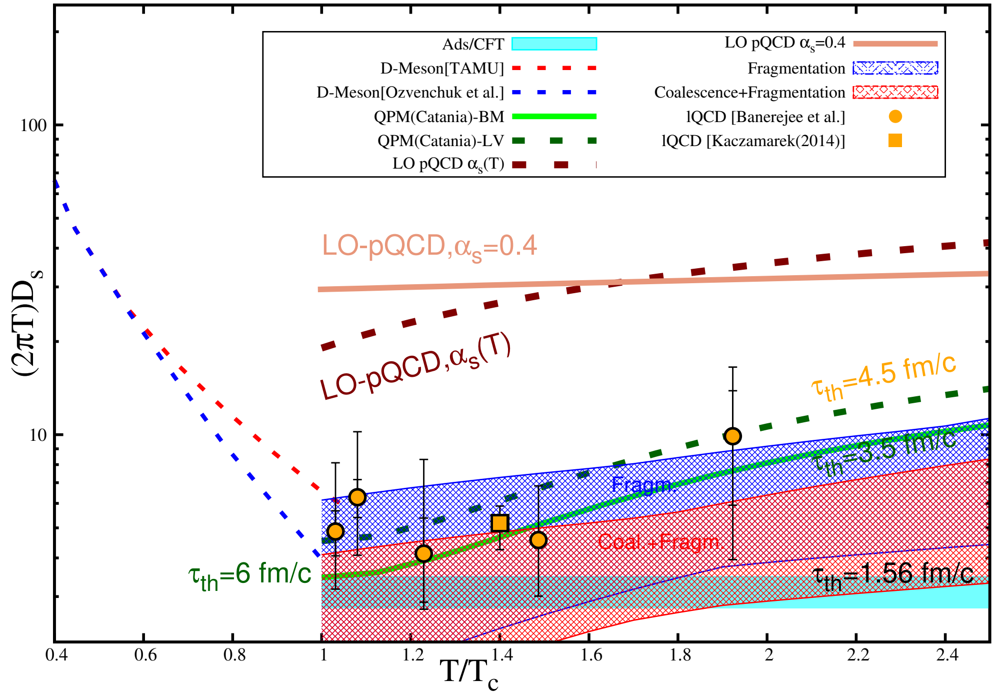
$c\tau \sim 135 \mu m$



Determining transport coefficients

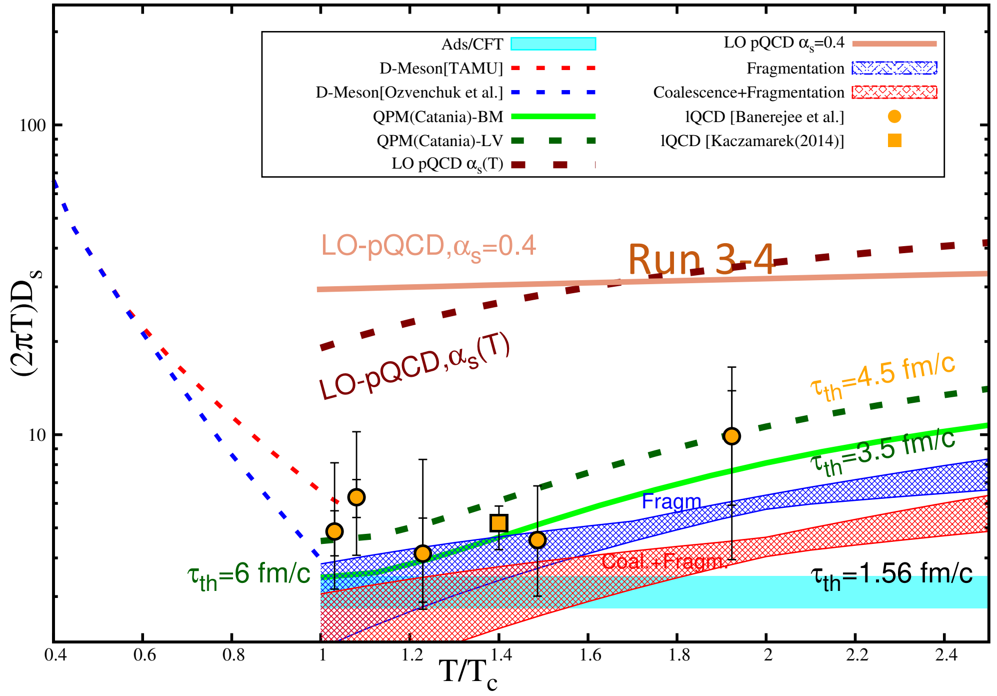
Measuring R_{AA} and v_2 to determine transport coefficients

Current state



Using Run 3-4 data

arXiv:1812.06772, section 5.4.3



Pinning down hadronization mechanisms is also crucial to measure QGP diffusion coefficient

ALICE in Runs 3-4: Main Physics Goals

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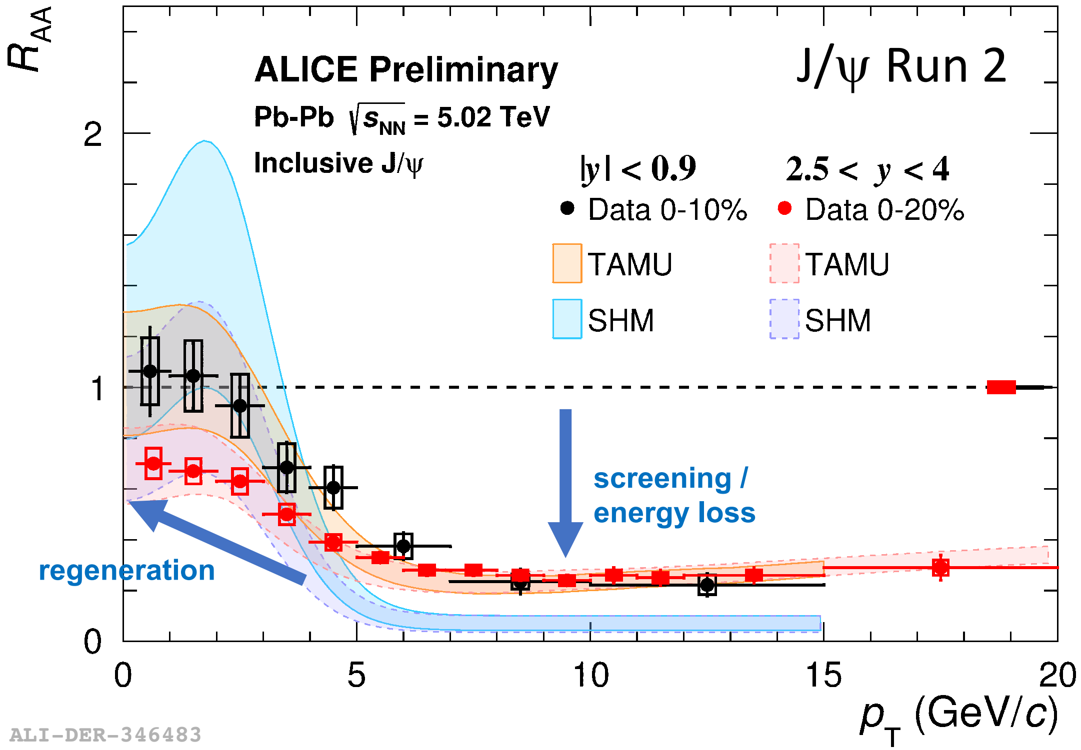
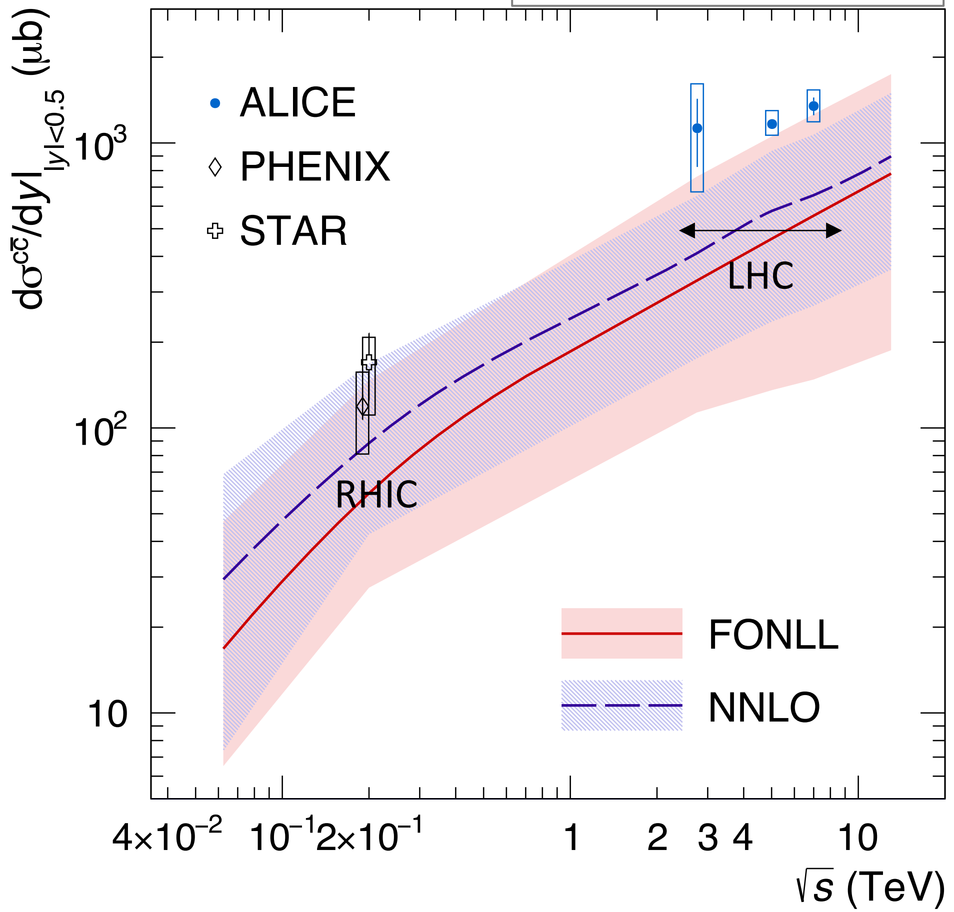
Quarkonium interaction with the hot medium

J/ψ dissociation and (re)generation at the LHC



charm cross-section

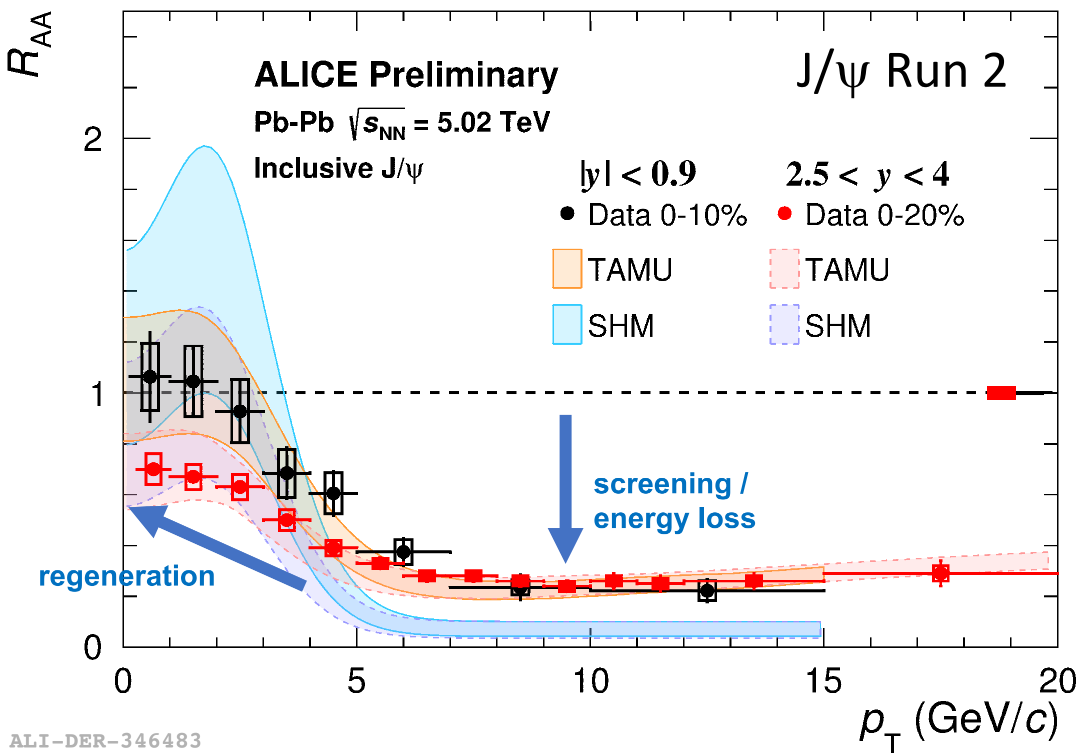


J/ψ suppression reduced at low p_T

⇨ $c\bar{c}$ regeneration balancing the screening in the QGP

Quarkonium interaction with the hot medium

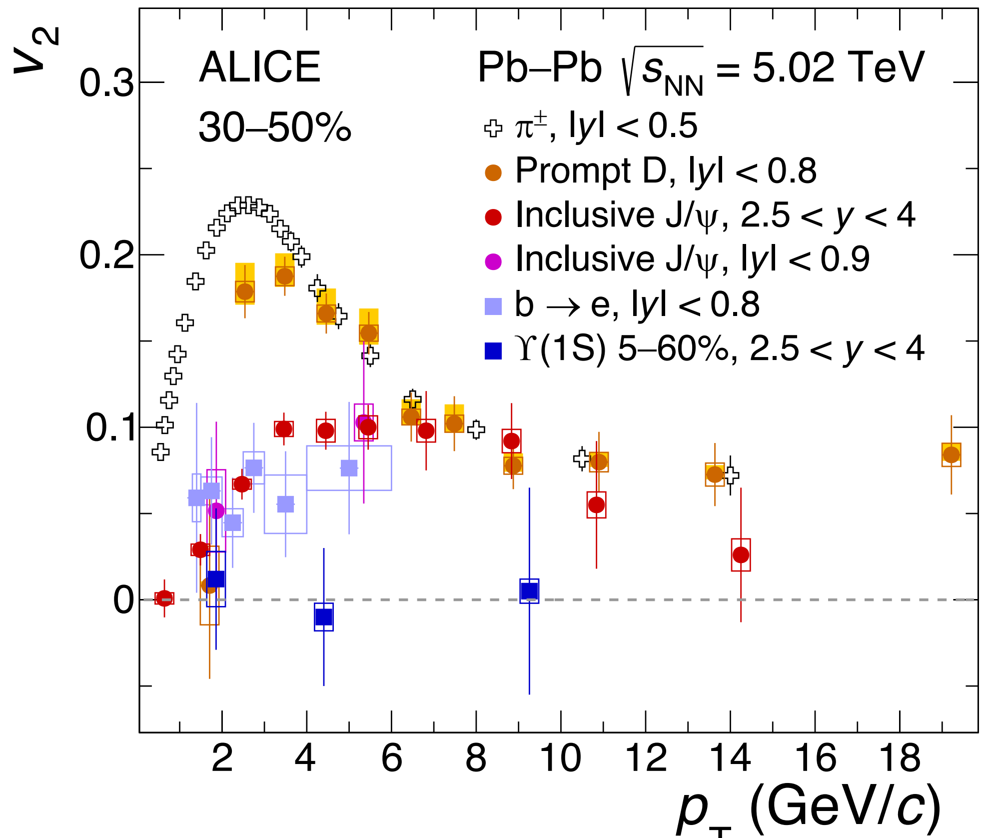
J/ψ dissociation and (re)generation at the LHC



J/ψ suppression reduced at low p_T

⇨ cc regeneration balancing the screening in the QGP

Significant elliptic flow of heavy-flavour

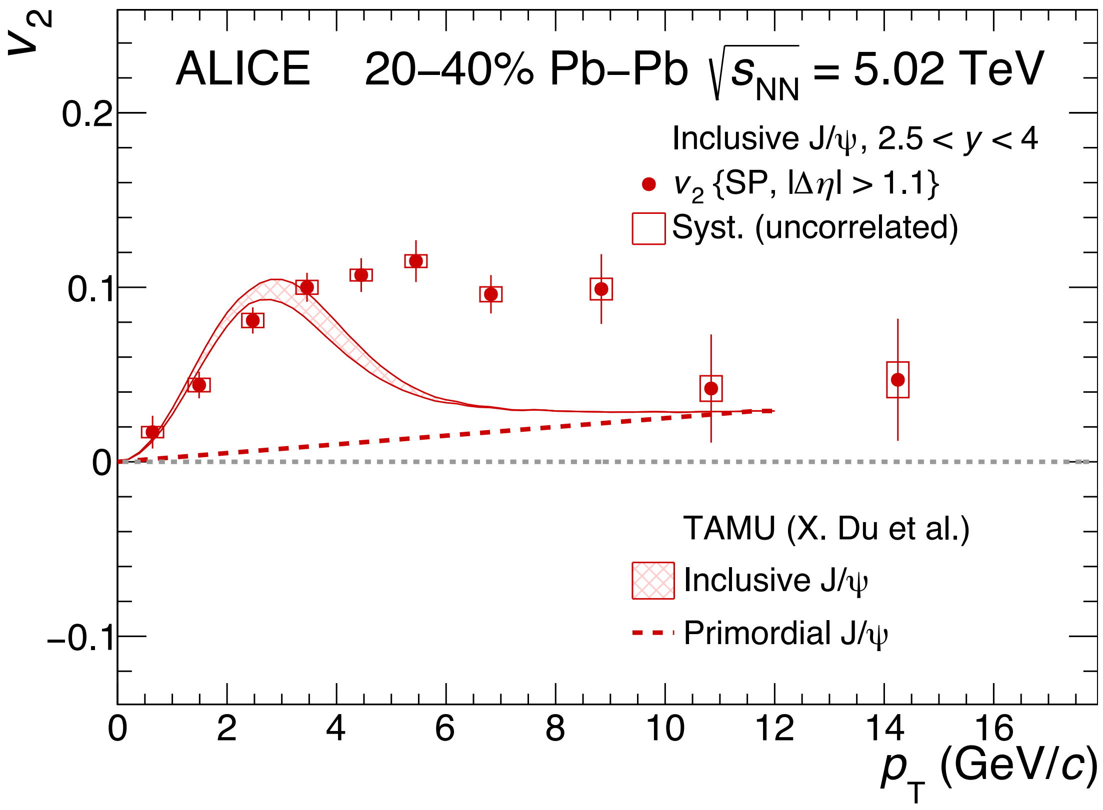


π: JHEP 1809(2018)006 D: arXiv: 2005.11131 J/ψ: arXiv:2005.14518

b → e: arXiv: 2005.11130 Υ(1S): PRL 123(2019)192301

Quarkonium interaction with the hot medium

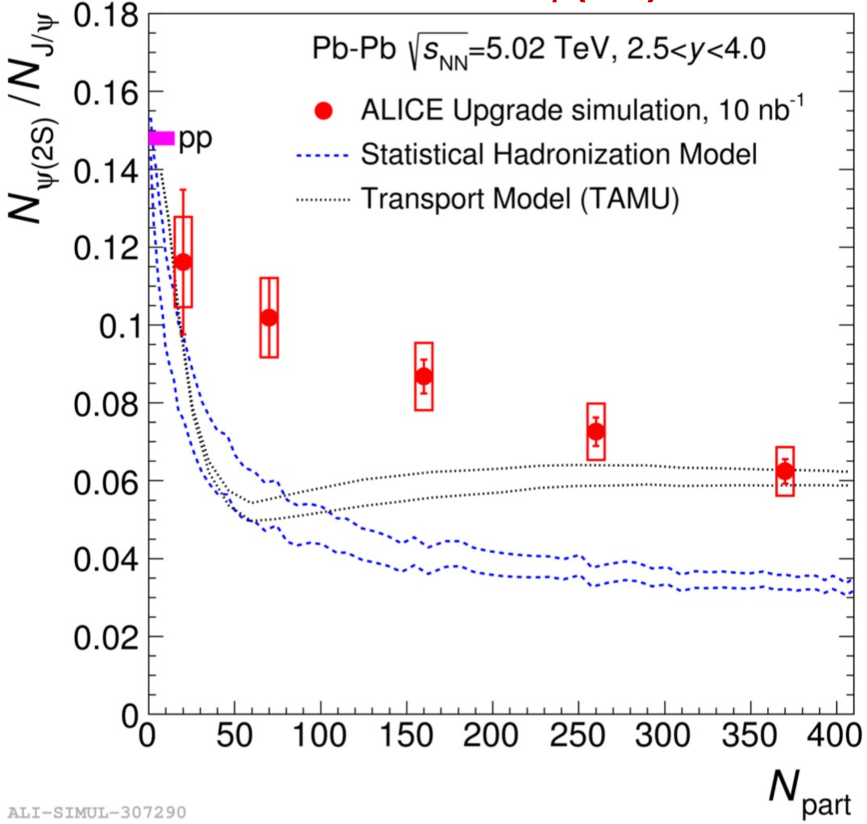
J/ψ elliptic flow



Transport model underestimate data for $p_T > 5$ Gev/c

➪ Important to separate prompt and non-prompt J/ψ and consider path-dependent energy loss

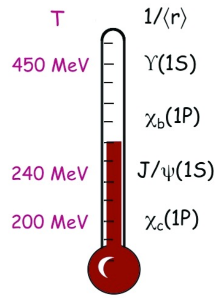
ψ(2S) Run 3-4



ψ(2S) / J/ψ sensitive to binding mechanism of deconfined c quarks

➪ Small model uncertainties

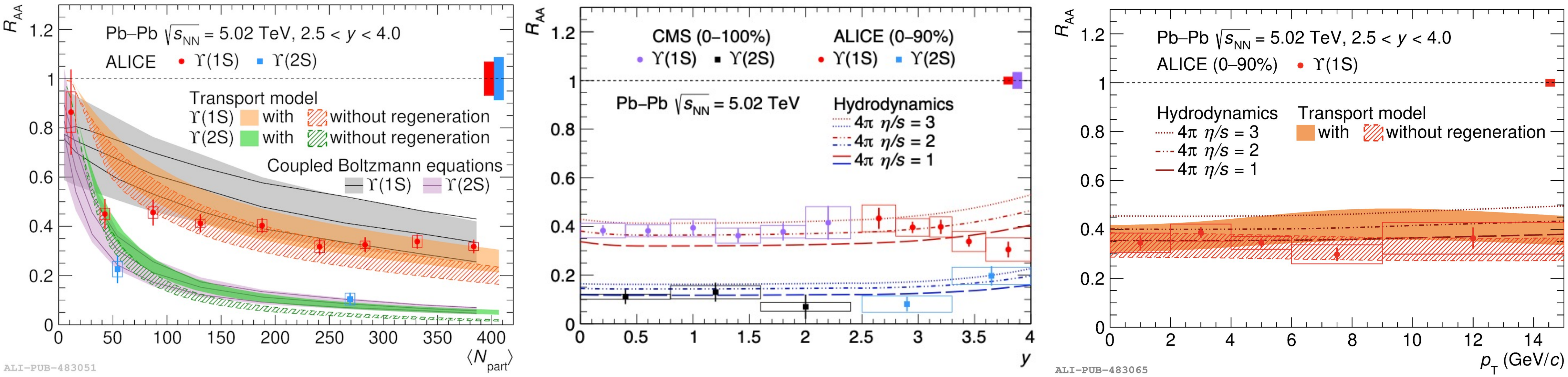
Suppression of bottomonium



Varying the binding energy: ***ψ(2S) < Y(2S) < J/ψ < Y(1S)***

0.05 0.55 0.65 1.1 GeV

arXiv:2011.05758

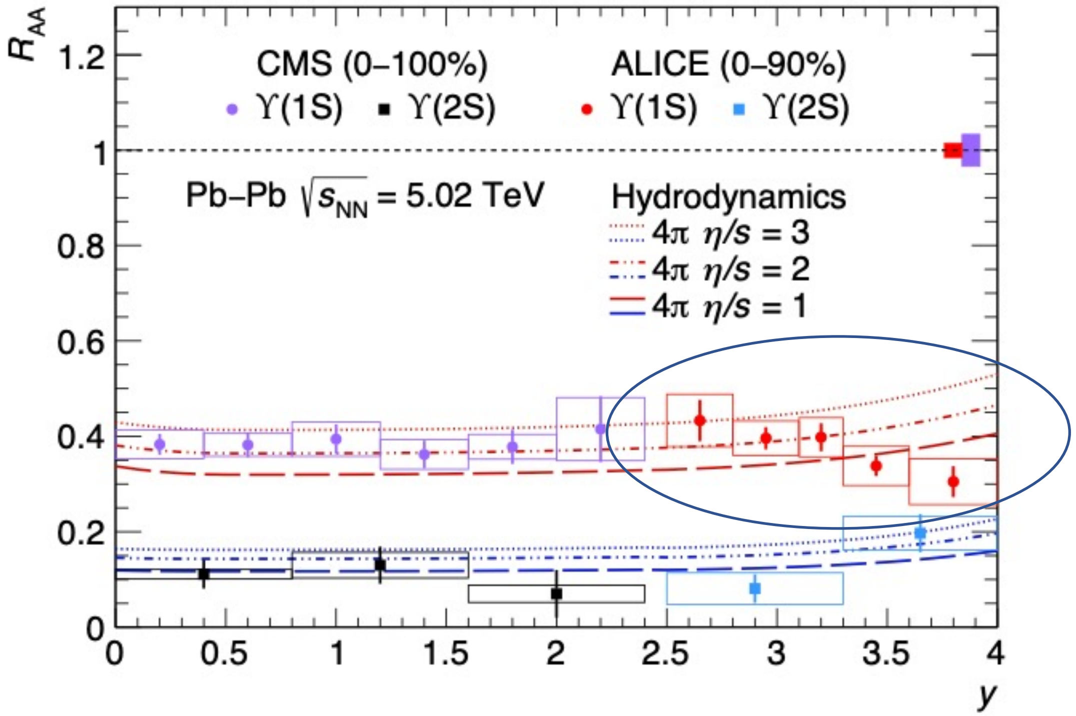


- Centrality dependence consistent with progressive suppression in a hotter and longer-lived medium
- Υ(2S) suppression stronger wrt Υ(1S) consistent with lower binding energy
- Recombination effects small

Suppression of bottomonium

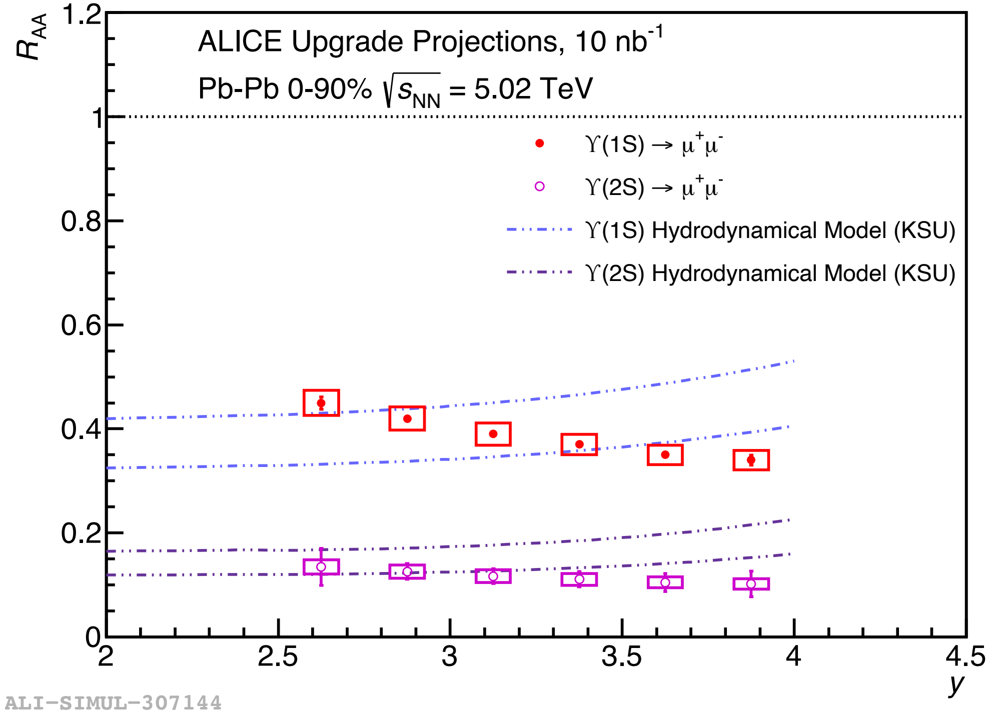
R_{AA} of Υ(1S) and Υ(2s)

Run 2



Hint of a decrease of the RAA at large rapidity not described by models

Run 3 and 4

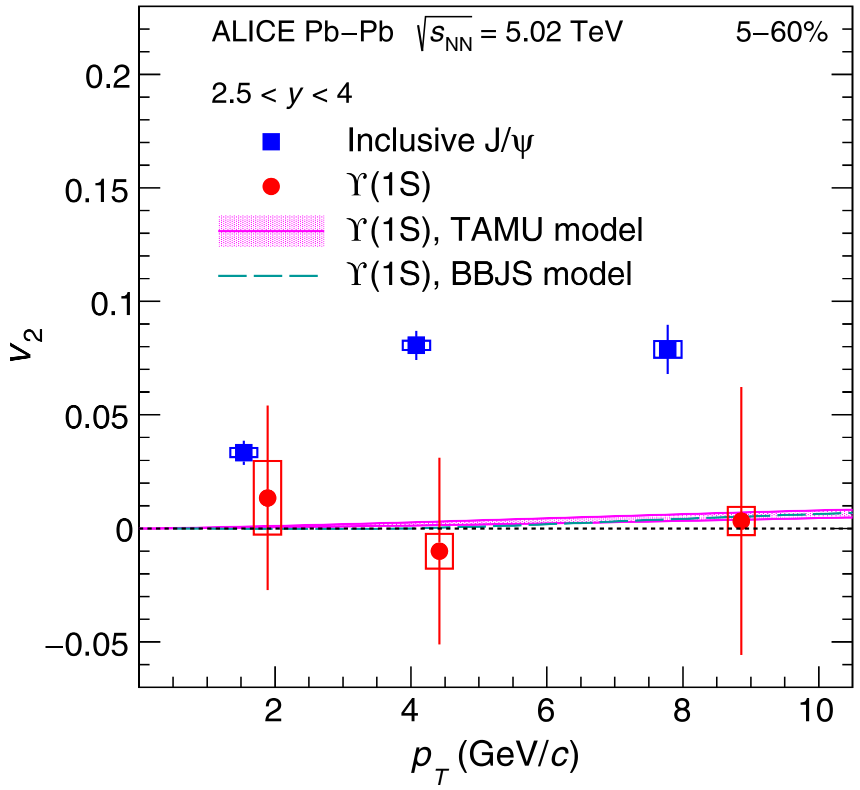


Better test of rapidity dependence predicted by hydrodynamic model

Quarkonium interaction with the medium

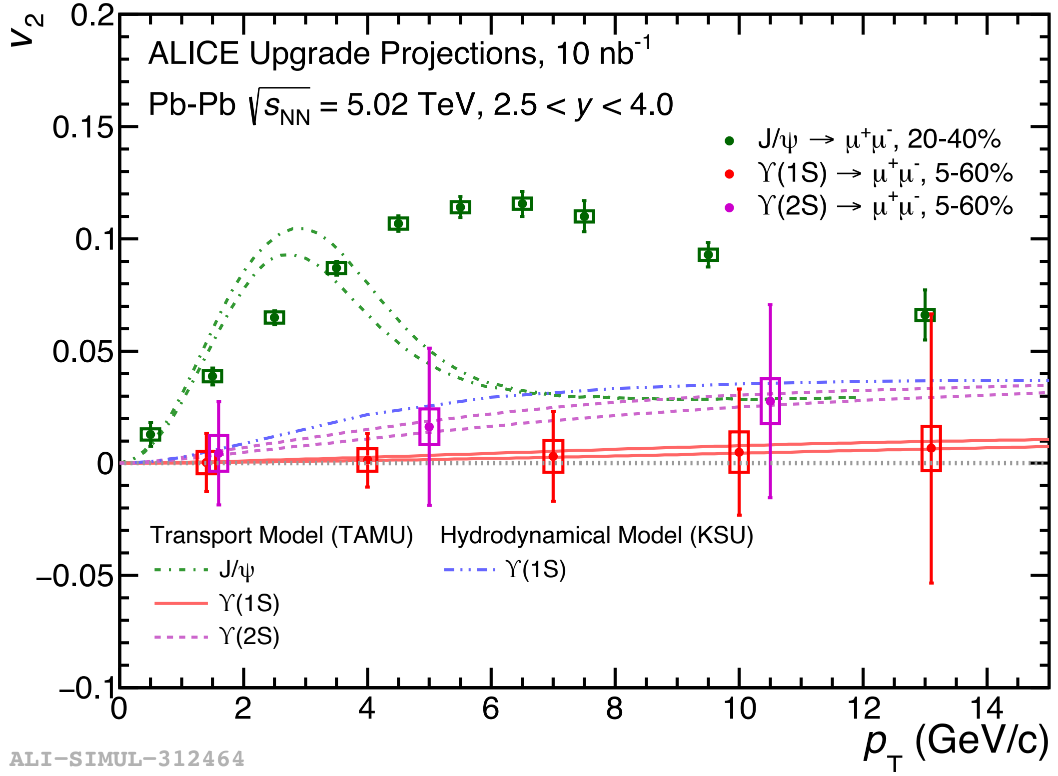
Elliptic flow of ϒ(1S)

A first look in Run 2



Uncertainties too large to unravel a small v_2

Projections for Run 3 and 4



Experimental precision may not be enough

ALICE in Run 3-4: main physics goals

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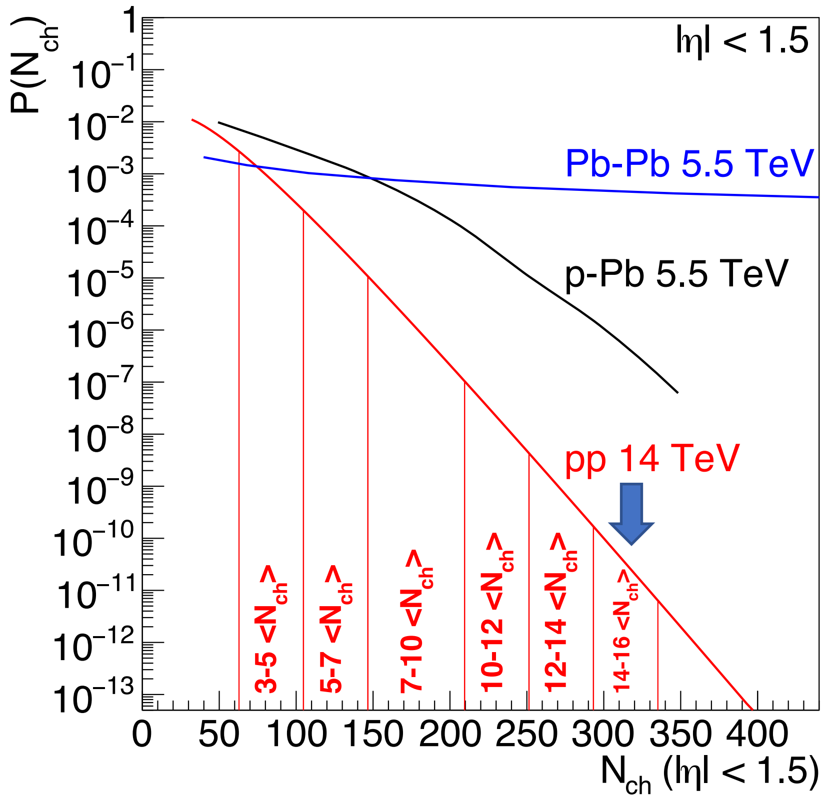
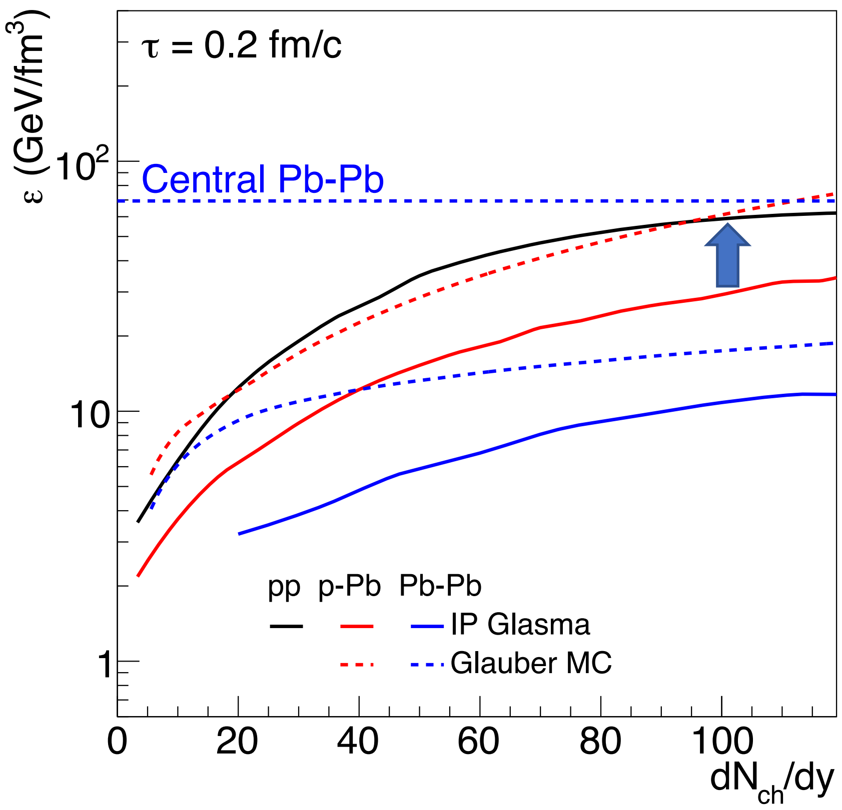
High-rate pp programme: high-multiplicity

ALICE-PUBLIC-2020-005

Is QGP formed in pp or p-Pb collisions?

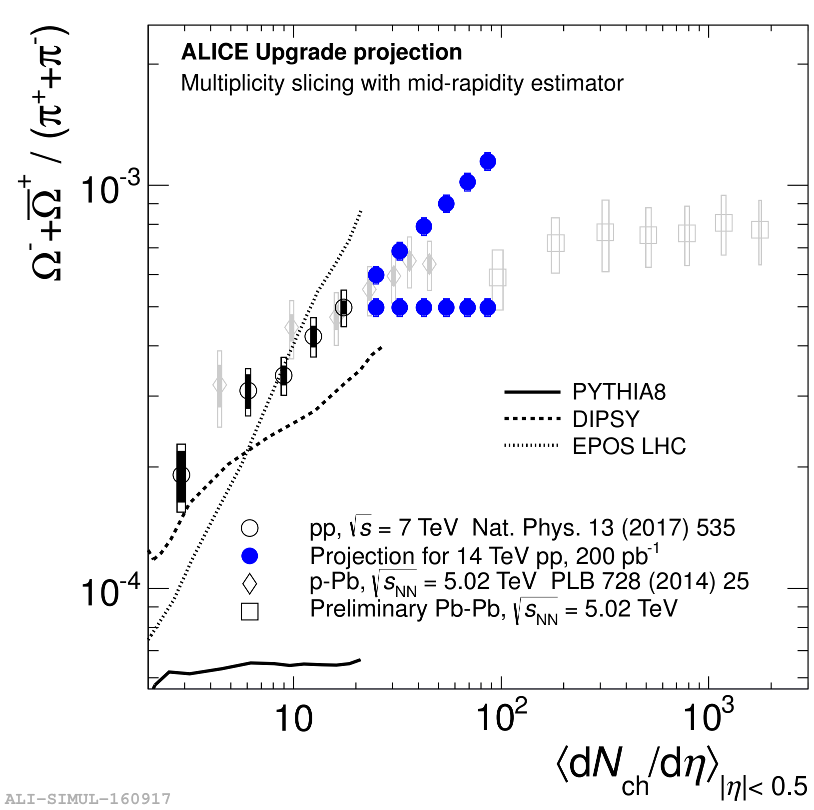


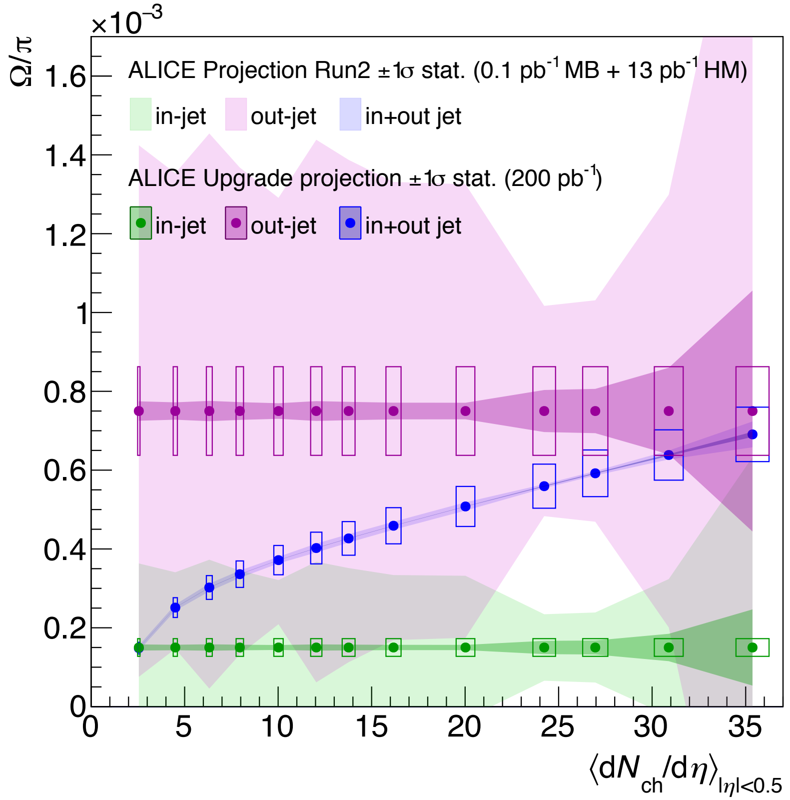


pp data sample of 200 pb^{-1}: access to multiplicities ~15x the average, similar to Pb-Pb 65% centrality, and estimated energy density similar to central Pb-Pb

High-rate pp programme: strangeness

ALICE-PUBLIC-2020-005

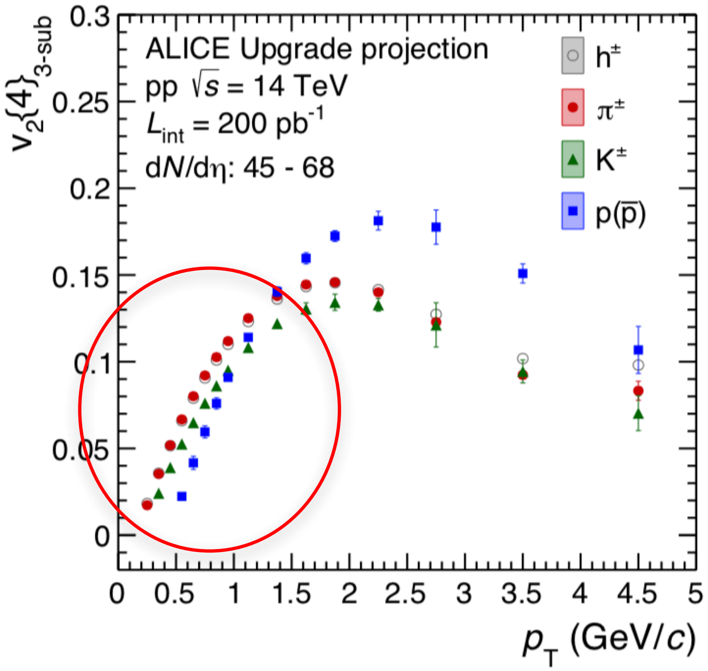




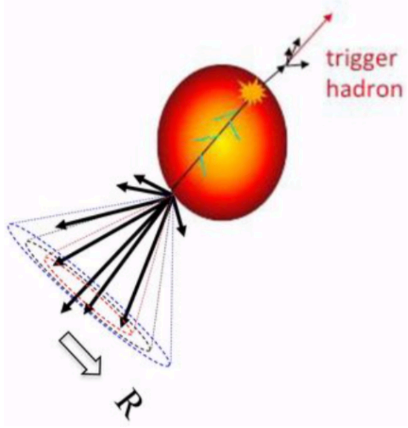
- Multistrange baryon (/pion) increase within pp: a major finding and surprise
- Need much higher reach/statistics to understand the underlying physics
  - Extend Ω/p measurment in pp well within Pb-Pb multiplicity range
  - Multi-differential measurement of Ω/p in jets and “underlaying event”

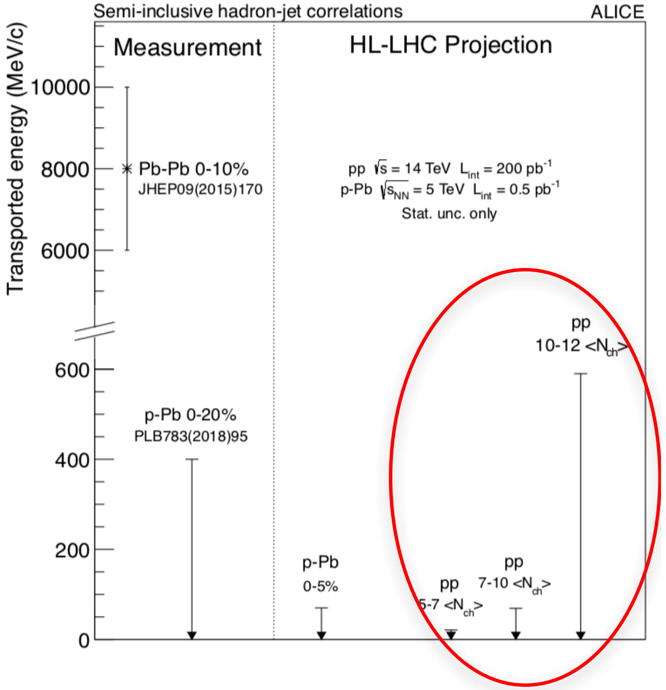
Why flow? No energy loss?

ALICE-PUBLIC-2020-005



h-jet recoil analysis
➪ limit on jet energy shift ΔE





- Is pp flow driven by hydrodynamic expansion?
- Use 4-particle cumulants to measure flow (v_2) of identified hadrons in pp at multiplicities for which mass ordering is seen in Pb-Pb

- If a QGP is formed, would we see energy loss? Energy loss not observed to date in pp and p-Pb!
- Strong extension of current limits with future high multiplicity samples
- pp and p-Pb complementary: independently vary energy density and system size

ALICE in Run 3-4: main physics goals

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Nuclear and hadronic physics

➪ High-precision measurements of light, hyper-nuclei, and hadron-hadron strong interaction

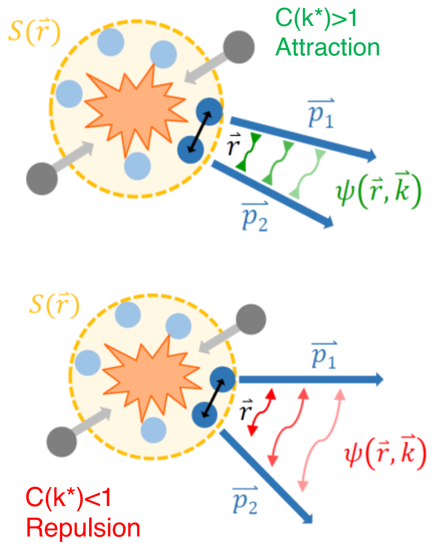
Strong interaction between hadrons

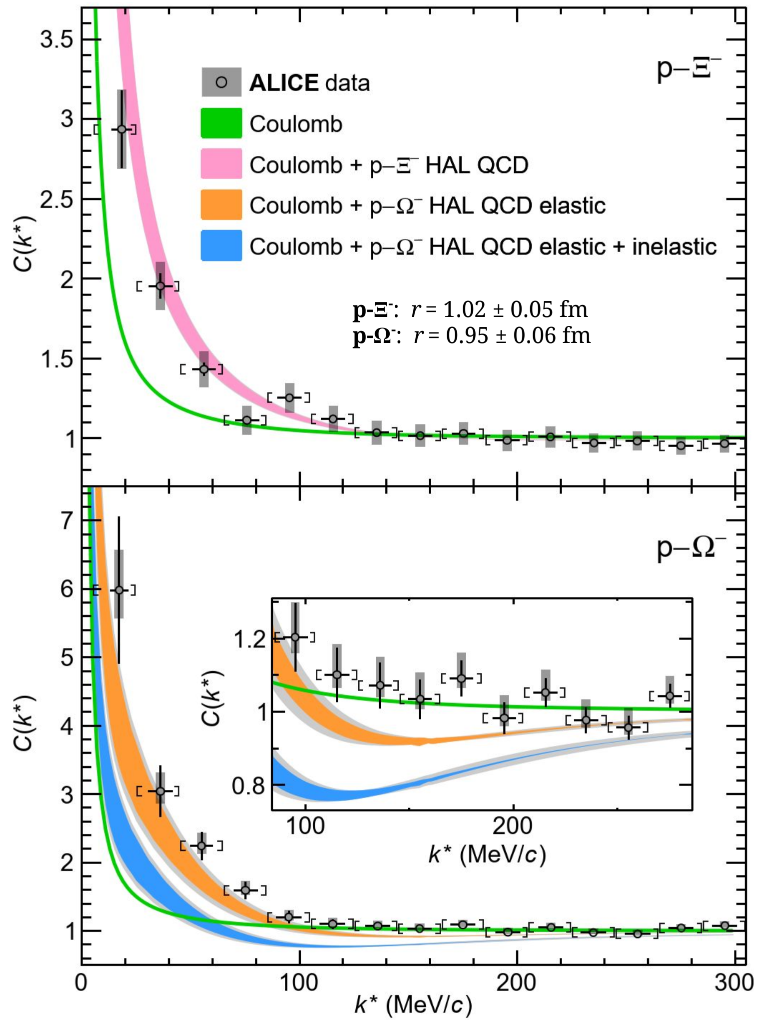
ALICE measurements on topic

Phys. Rev. C 99 (2019) 024001	p-p, p-Λ, Λ–Λ (pp)
Phys. Lett. B 797 (2019) 134822	Λ–Λ (p-Pb)
Phys. Rev. Lett. 123 (2019) 112002	**p-Ξ⁻ (p-Pb)**
Phys. Rev. Lett. 124 (2020) 092301	p-K (pp)
Phys. Letters B 805 (2020) 135419	p-Σ (pp)
Phys. Lett. B 811 (2020) 135849	source size in pp
Nature 588 (2020) 232-238	**p-Ω⁻ (pp)**
arXiv:2104.04427	NΛ – NΣ (pp)
arXiv: 2105.05578	p-ϕ (pp)
arXiv:2105.05683	K-p (Pb-Pb)
arXiv:2105.05190	p-/p, p-/Λ, Λ–/Λ (pp)

"Unveiling the strong interaction among stable and unstable"

Nature 588 (2020) 232-238





Strong interaction among any pair of hadrons from momentum correlations at femtometer distances

- First assessment for p-Ξ⁻ and p-Ω⁻
- Accessible even for Ω-Ω in Run 3

Strong interaction between hadrons

ALICE measurements on topic

Phys. Rev. C 99 (2019) 024001	p-p, p-Λ, Λ–Λ (pp)
Phys. Lett. B 797 (2019) 134822	Λ–Λ (p-Pb)
Phys. Rev. Lett. 123 (2019) 112002	p-Ξ⁻ (p-Pb)
Phys. Rev. Lett. 124 (2020) 092301	p-K (pp)
Phys. Letters B 805 (2020) 135419	p-Σ (pp)
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Nature 588 (2020) 232-238	p-Ω (pp)
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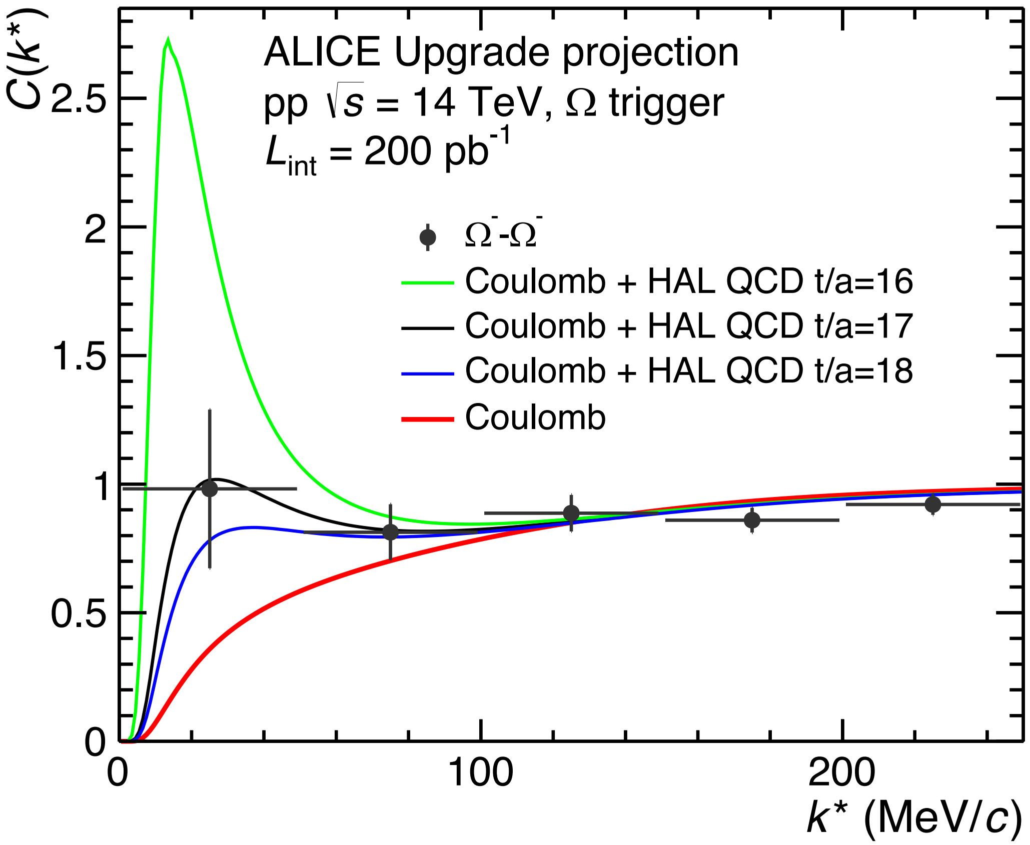
ALICE-PUBLIC-2020-005



Strong interaction among any pair of hadrons from momentum correlations at femtometer distances

- First assessment for p-Ξ⁻ and p-Ω⁻
- **Accessible even for Ω⁻–Ω⁻ in Run 3**

ALICE

ALICE in Run 3-4: main physics goals

QGP radiation

➪ Thermal di-leptons, photons

Heavy-quarks interaction in the QGP

➪ Thermalization and diffusion coefficient of heavy quarks (R_{AA}, collective flow, baryon-to-meson ratio)

Quarkonium melting and regeneration in the QGP

➪ Charmonia down to zero p_T

Emergence of QCD collectivity from pp to AA

➪ Origin of collectivity, search for QGP signals (E-loss, radiation)

Nuclear and hadronic physics

➪ High-precision measurements of light, hyper-nuclei, and hadron-hadron strong interaction

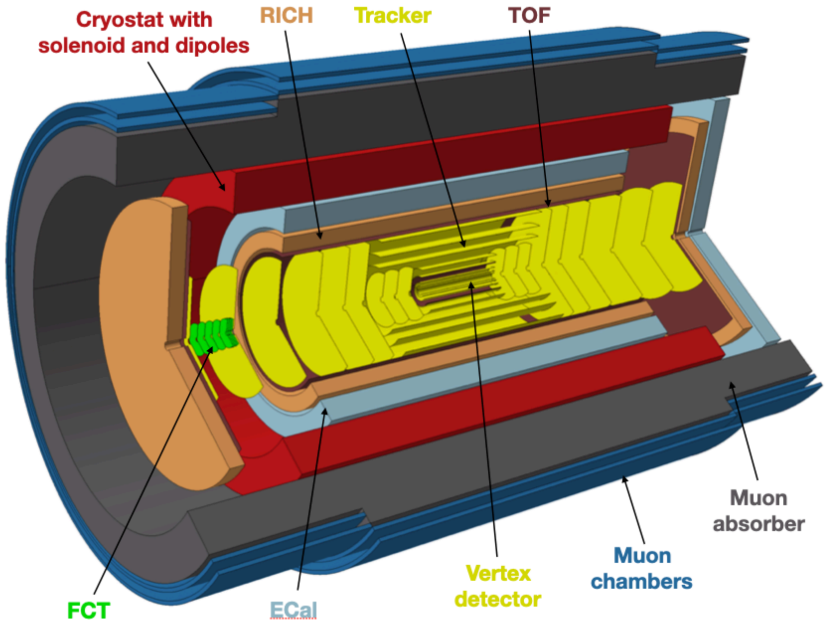
and much more

➪ e.g. fluctuation of conserved charges, vorticity and polarization, CME, jet internal structure, UPC, nPDF, …

ALICE 3: a new dedicated heavy-ion detector for Run 5+ (> 2030)

Novel measurements of electromagnetic and hadronic probes of the QGP at very low momenta

⇨ mechanism of hadron formation in the QGP, QGP transport properties, QGP electrical conductivity, QGP radiation and access to the pre-hydrodynamization phase, Chiral Symmetry restoration, …

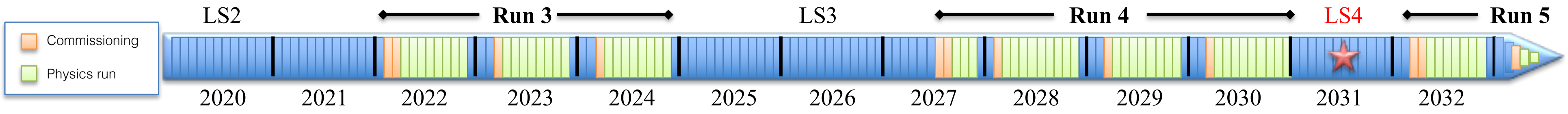


Expression of Interest arXiv:1902.01211

Also submitted as input to the European Strategy for Particle Physics Update (Granada, May 2019)

Timeline

- Conceptual studies ongoing 2019-2021
- Public workshop in October 2021
- Submit a LoI to the LHCC by 2021
- Construction and installation by LS4



Conclusions

A wealth of results based on full Run 2 samples offered

- detailed insights into **QGP properties**
- advances in **high-density QCD**

Run 3 and 4

- Tenfold increase of statistics and strong enhancement of vertexing and tracking at low p_T

⇨ more precision on QGP global properties

⇨ gain better insight into the QGP microscopic properties and dynamics

⇨ gain insight into HI-like phenomena observed in small systems?

Plans for next generation dedicated HI detecor for Run 5 and beyond (ALICE v. 3.0)