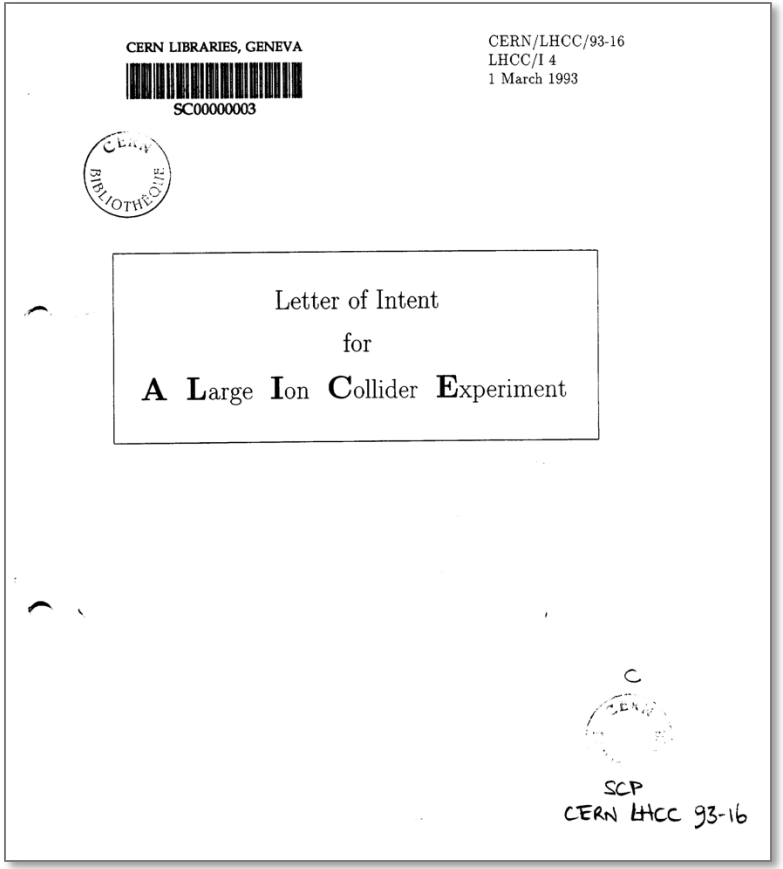
Future measurements in ALICE

Heavy Ion Meeting 2024-11

Busan – November 22, 2024

Saehanseul Oh (Sejong University, LBL)

“Future”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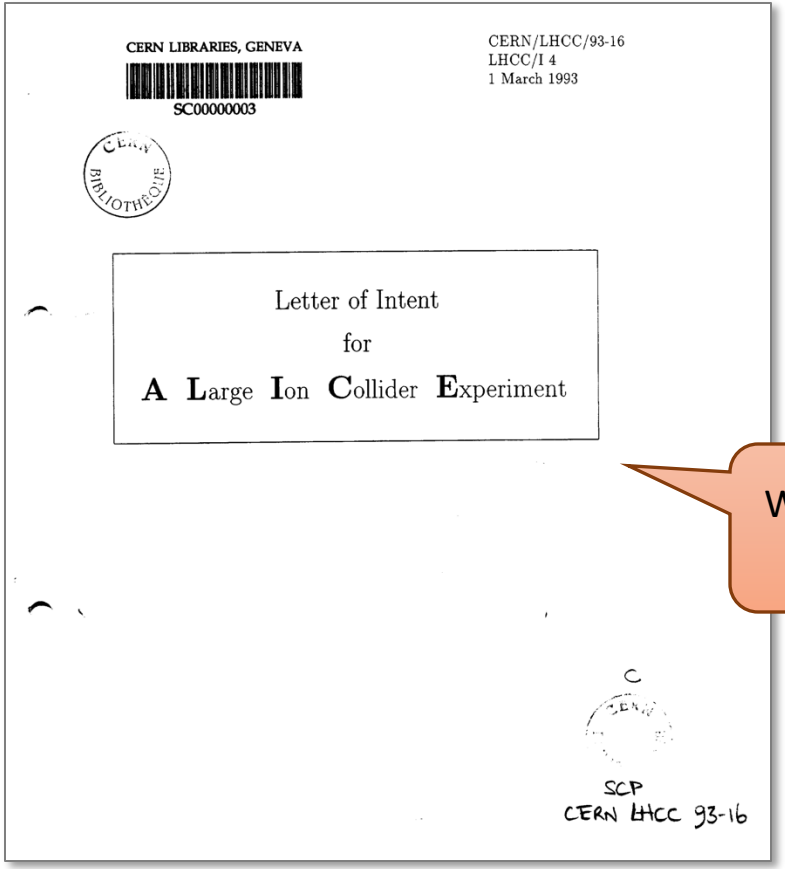
CERN/LHCC/93-16
LHCC/I 4
1 March 1993

Letter of Intent
for
A Large Ion Collider Experiment

SCP
CERN LHCC 93-16

- Letter of Intent for ALICE in 1993
  - https://cds.cern.ch/record/290825

“Future”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What kind physics were considered when the ALICE experiment was initially proposed?

“Future”

1.1 Signals and Observables

In order to establish and analyse the existence of QCD bulk matter and the QGP, a number of observables have to be studied in a systematic and comprehensive way [13]. Some observables are needed to characterize the global features of the state created during the collision in order to constrain theoretical models (e.g. relevant degrees of freedom, size, lifetime, density, dynamical evolution). These observables yield information about the initial conditions and space–time evolution, necessary in order to interpret a specific signal as a QGP signature, or as an indication of new physics. Our strategy is to study a number of these *specific signals* in the same experiment together with *global information* about the events. The signals accessible to our detector are described in detail in the following sections. They are listed below according to the aspect of the collision on which they have a bearing (see [1, 2, 11, 14] for original references):

- INITIAL CONDITIONS: *global event features* measure the number of colliding nucleons and give information on the energy density obtained.
- QUARK-GLUON PLASMA: *prompt photons* can reveal the characteristic thermal radiation from the plasma; the cross-section of *high-p_t hadrons* is sensitive to the energy loss of the partons in the plasma; *J/Ψ production* probes deconfinement.
- PHASE TRANSITION: *Strangeness production* is sensitive to the large s quark density expected from (partial) chiral symmetry restoration in the plasma; *multiplicity fluctuations* are a signature for the critical phenomena at the onset of a phase transition; *particle interferometry* measures the expansion time in the mixed phase, which is expected to be long in the case of a first-order phase transition.
- HADRONIC MATTER: *Particle ratios, transverse-momentum distributions* and *resonance line-shape parameters* are all sensitive to the dynamical evolution of the hadronic phase; *interferometry* allows the measurement of the freeze-out radius of the hadronic fireball.

"Future"

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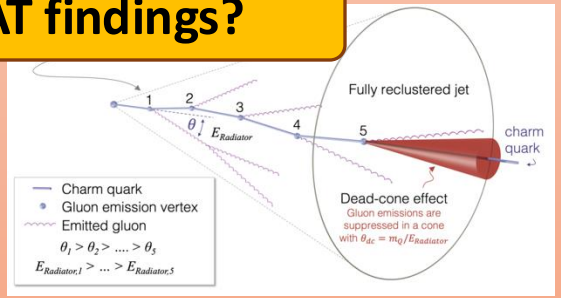
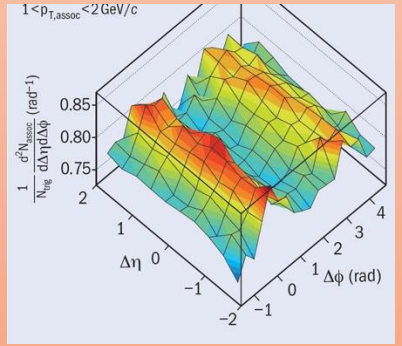
“Future”

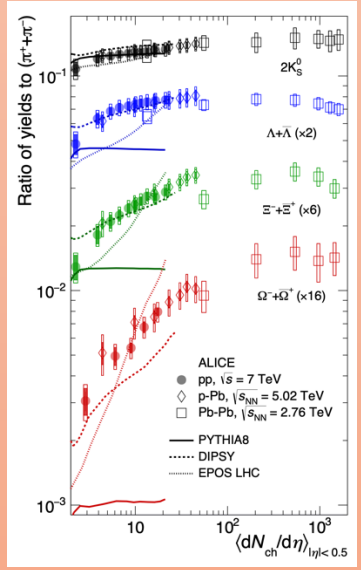
Where are these GREAT findings?



Dead cone effects?



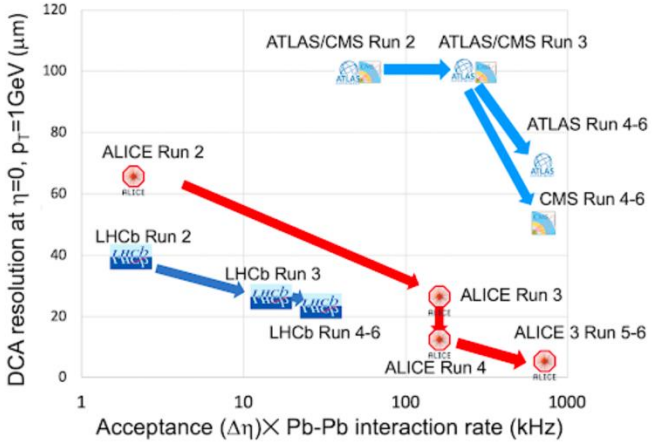
Small system collectivity?



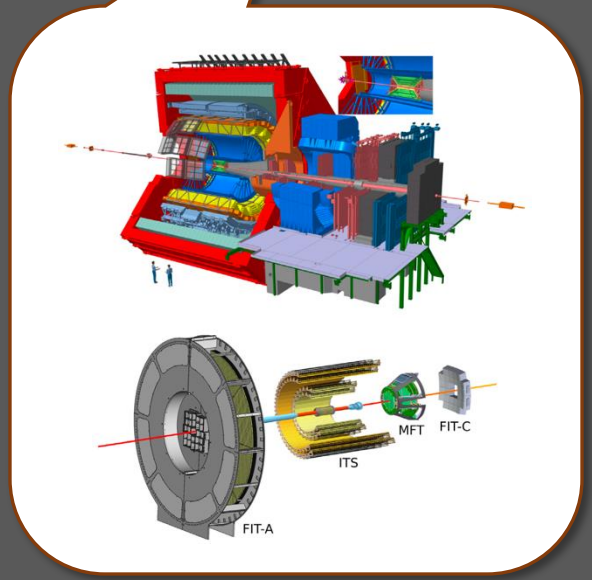
Strangeness enhancement throughout collision systems?

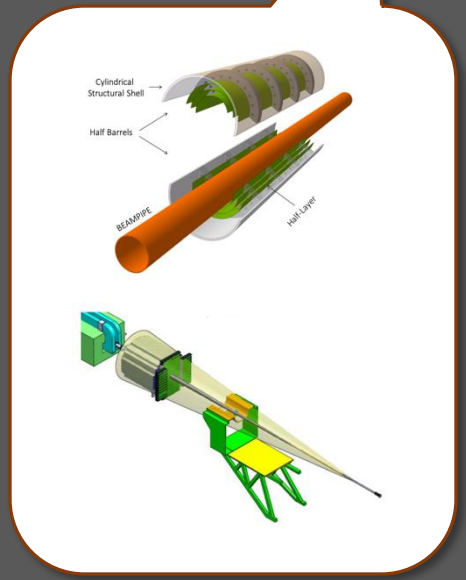
“Future”

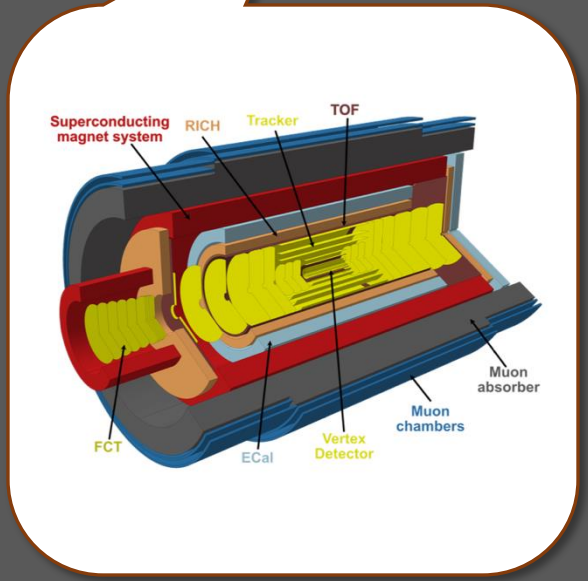
- There exist upgrade plans, and corresponding physics observables to be explored
- But the “future” is not limited to these plans



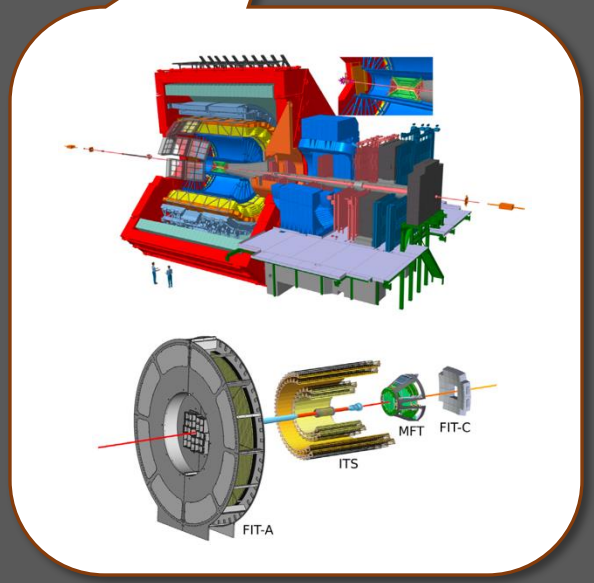
Current and future of the ALICE experiment





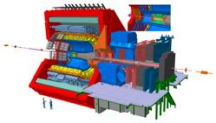


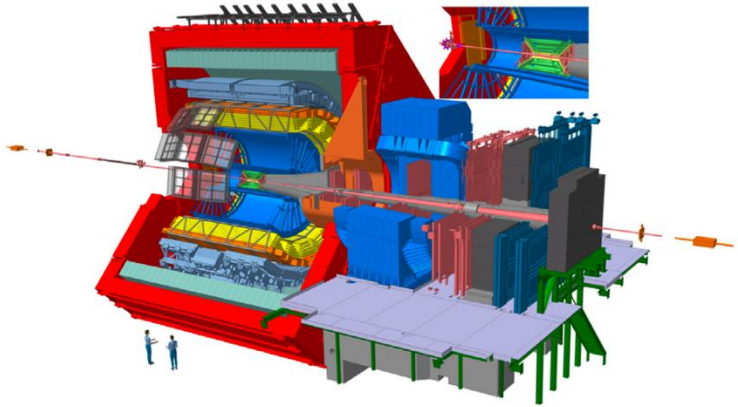
ALICE 2

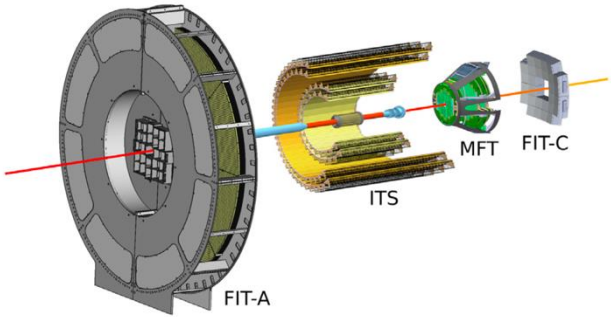


- Fast Integration Trigger
- Inner Tracking System (ITS 2)
- Forward Muon Tracker

ALICE 2 (2022–2026)

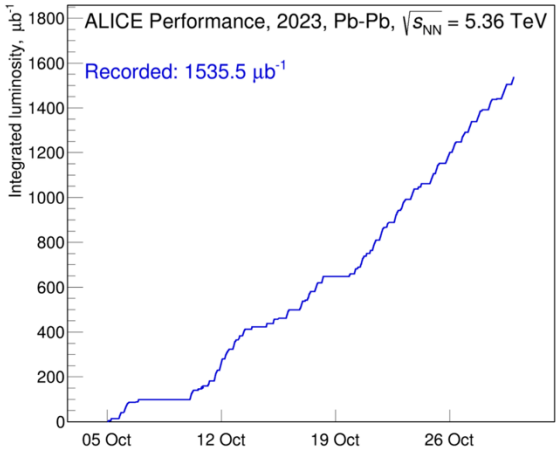






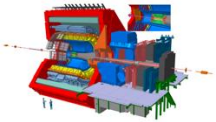
- Upgrade during Long Shutdown 2
  - New Inner Tracking System (ITS 2) based on the MAPS (CMOS Monolithic Active Pixel Sensor) technology
  - Fast Interaction Trigger
  - Forward Muon Tracker
- Main improvements
  - Large minimum-bias data sample (MB Pb-Pb interaction rate is now 50 kHz, 50 times larger than before)
  - Improved tracking efficiency and resolution at low p_T
  - Improved particle identification

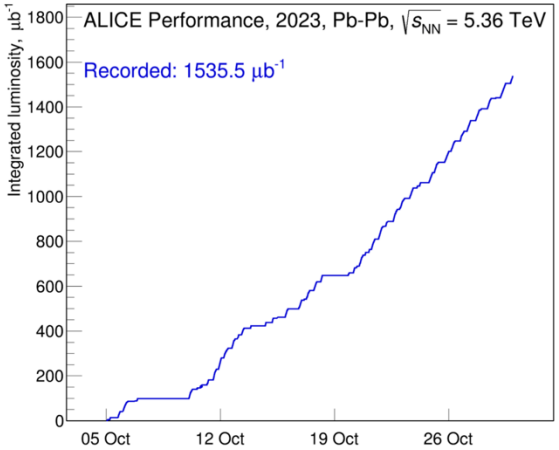
ALICE 2 (2022–2026)



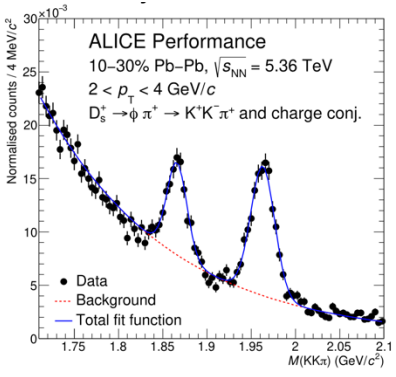
- Pb-Pb data collection
  - Large Pb-Pb data collected in 2023 – First results shown at conferences this year)
  - Pb-Pb data collection on-going in 2024

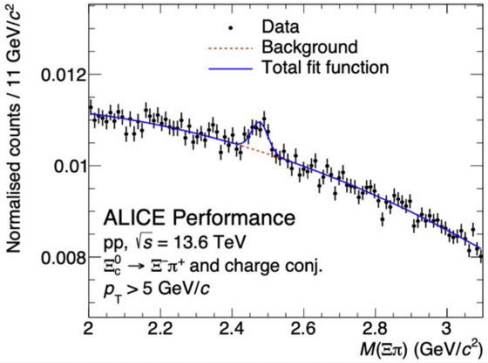
ALICE 2 (2022–2026)

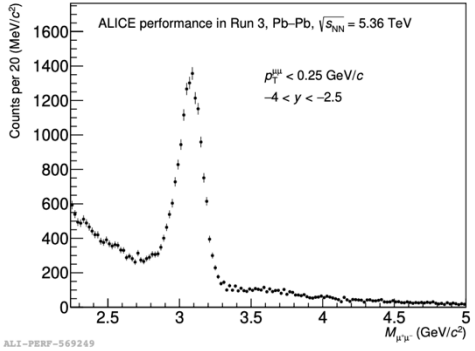




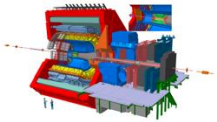
- Pb-Pb data collection
  - Large Pb-Pb data collected in 2023 – First results shown at conferences this year)
  - Pb-Pb data collection on-going in 2024
- Performance plots with improved resolution and larger data samples







ALICE 2 (2022–2026) – Physics program



- Heavy-flavor production
  - Thermalization of heavy quarks in the medium

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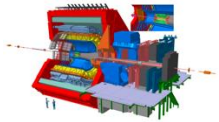

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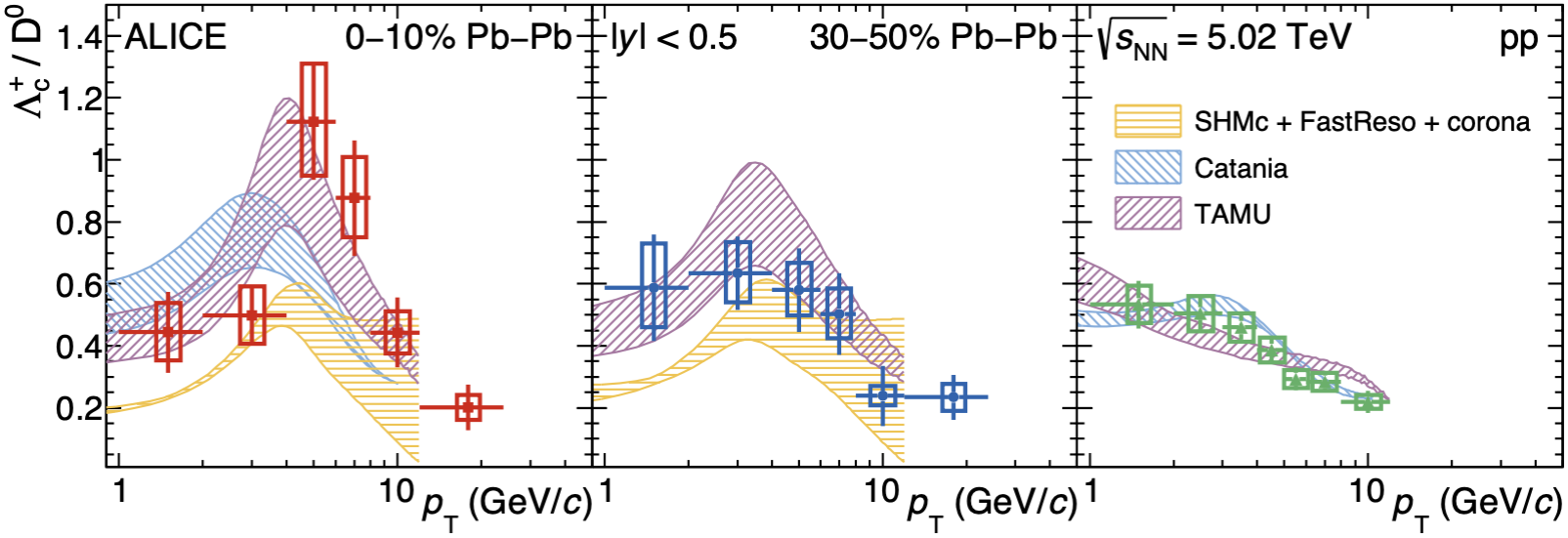
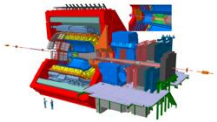
    - ✓ Baryon-to-meson ratio for c and b



arXiv:2112.08156

Agrees with the model calculations with coalescence and fragmentation processes

ALICE 2 (2022–2026) – Physics program



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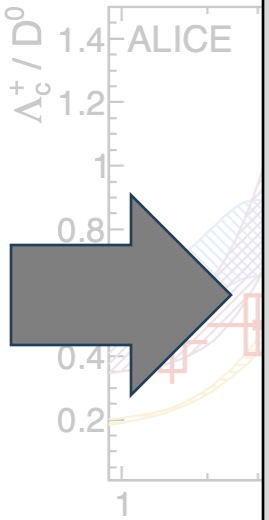
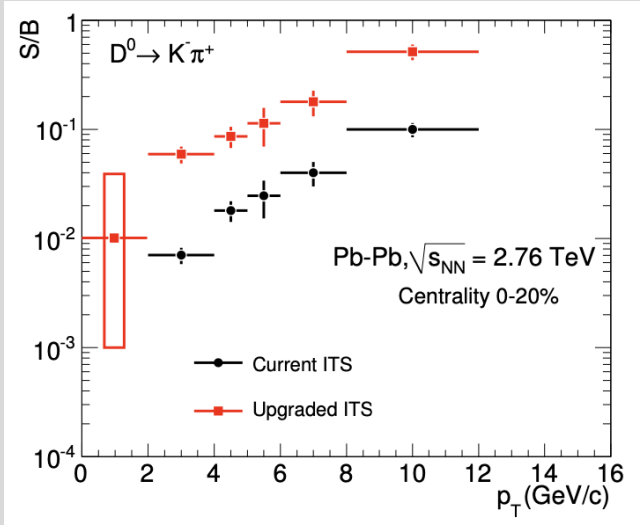
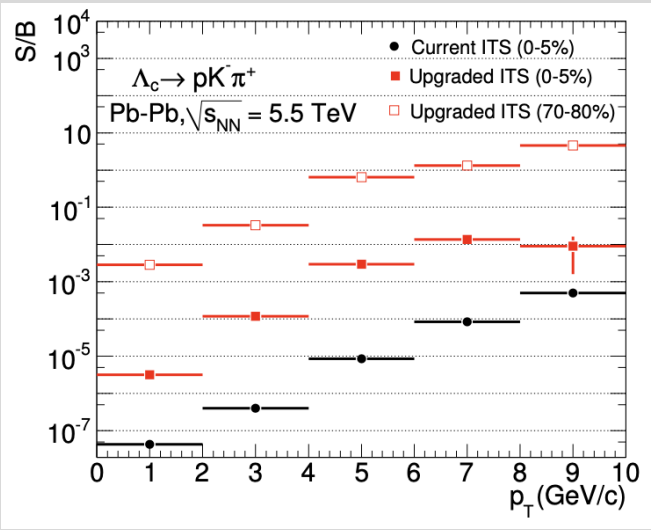


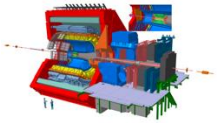




Improved S/B ratio with the ITS2 – Better secondary vertex findings

arXiv:2112.081

ALICE 2 (2022–2026) – Physics program



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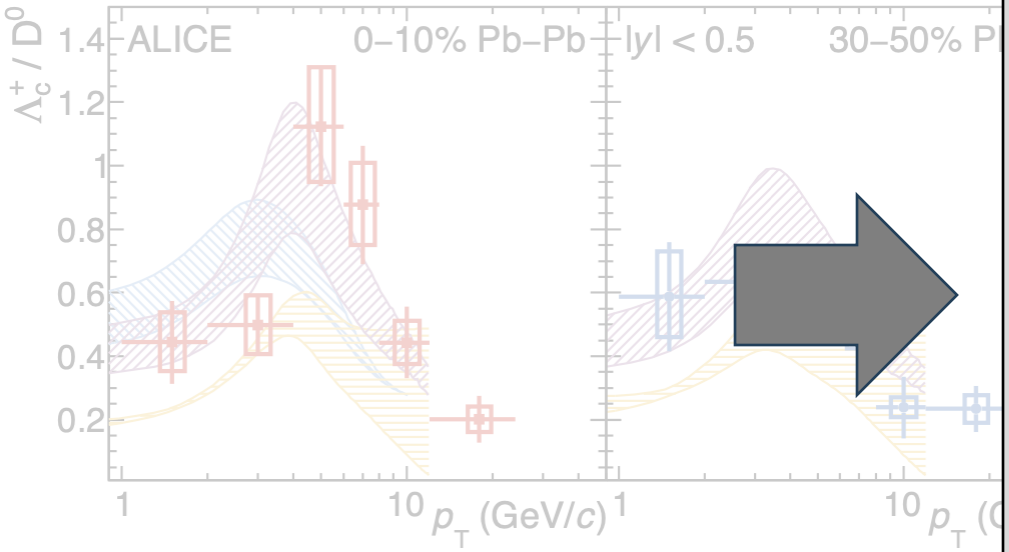

arXiv:2112.08156

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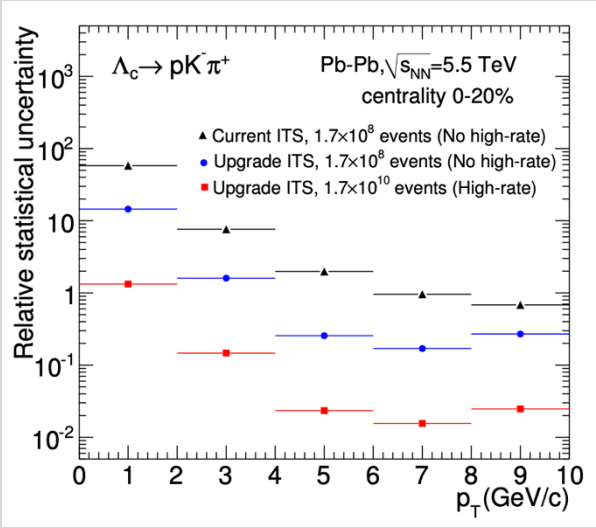
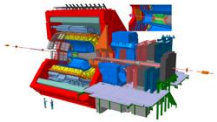
ALICE 2



Relative statistical uncertainties

ALICE 2 (2022–2026) – Physics program



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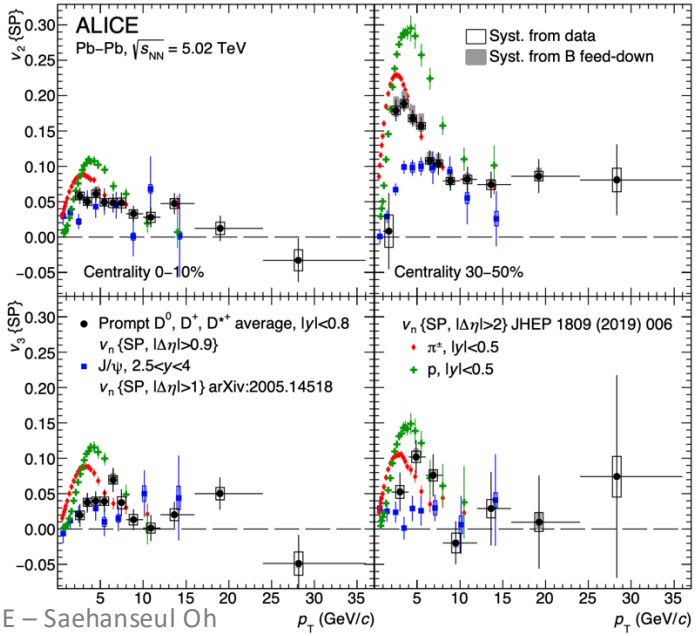
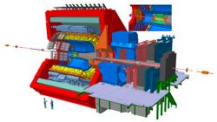


arXiv:2005.1131

Compatible v_n for D mesons – Charm quark hadronization by coalesence

ALICE 2 (2022–2026) – Physics program



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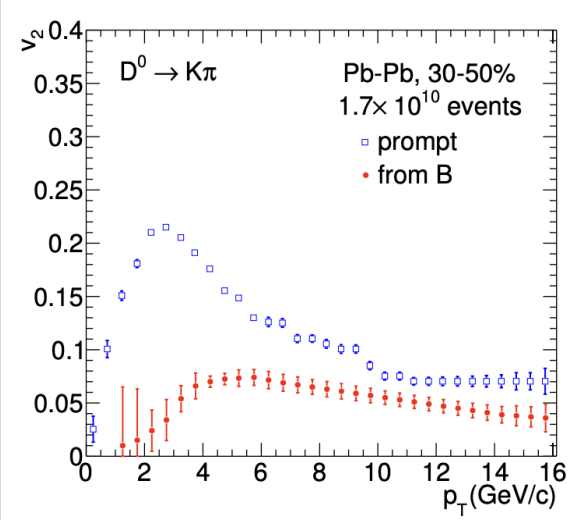
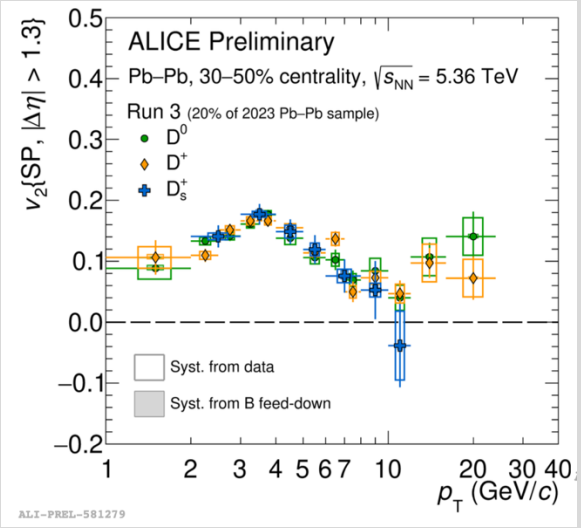
ALICE 2



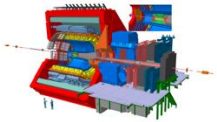
Estimated statistical uncertainties



New preliminary results for v_2 of D mesons

arXiv:2005.1

ALICE 2 (2022–2026) – Physics program



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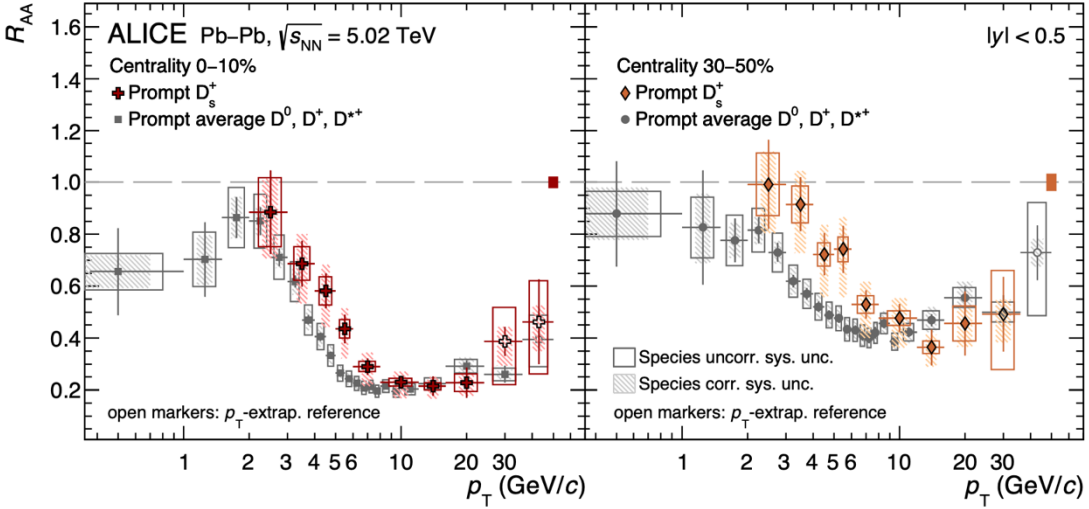
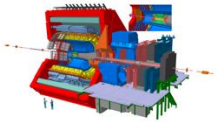
  - In-medium energy loss depending on parton mass and color charge
    - ✓ Nuclear modification factor for D and B mesons



arXiv:2110.10006

Significant suppression – Agreeing with the model with the charm-quark transport in a hydrodynamically expanding QGP and the charm-quark hadronization via coalescence

ALICE 2 (2022–2026) – Physics program



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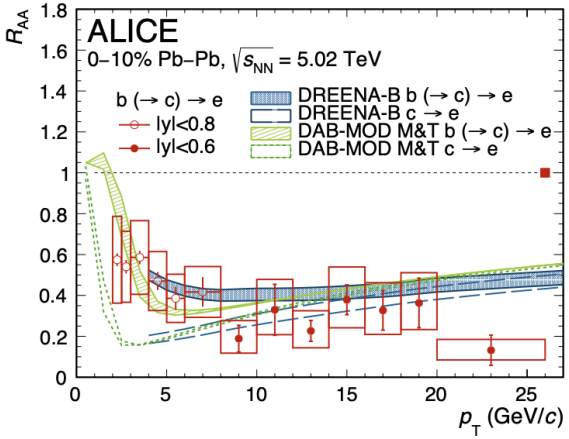
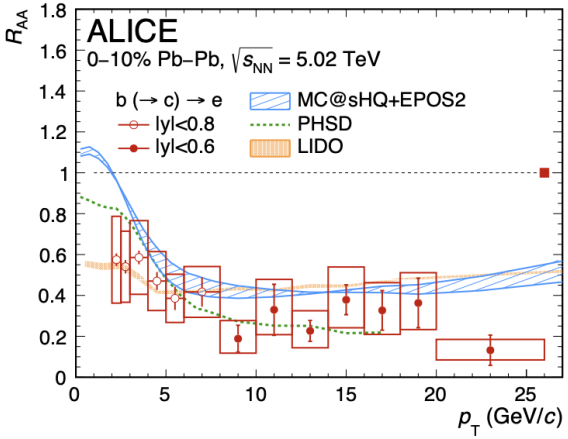
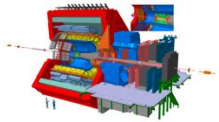




arXiv:2211.13985

Electron from b-hadrons

ALICE 2 (2022–2026) – Physics program



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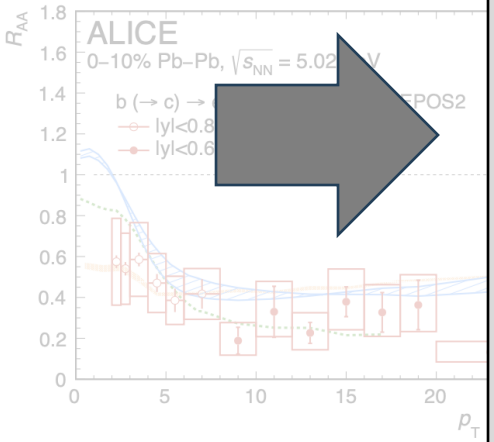
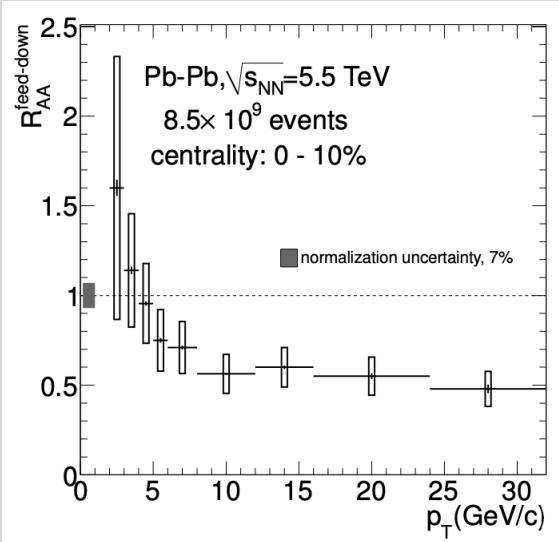
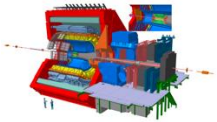


ALICE 2



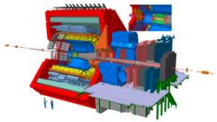
D^0 from b-hadron decay

ALICE 2 (2022–2026) – Physics program



- Quarkonia
  - Suppression and regeneration of quarkonium – Sensitive to the medium properties and there exist various models

ALICE 2 (2022–2026) – Physics program



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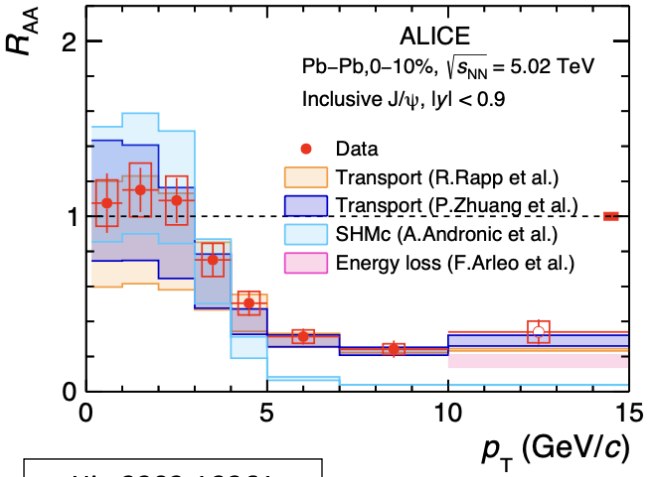
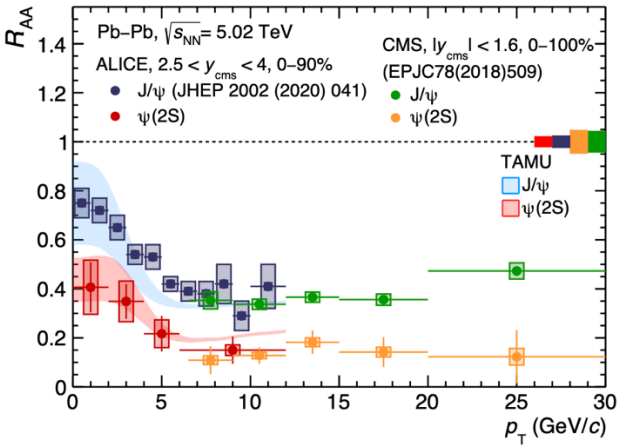


arXiv:2303.13361



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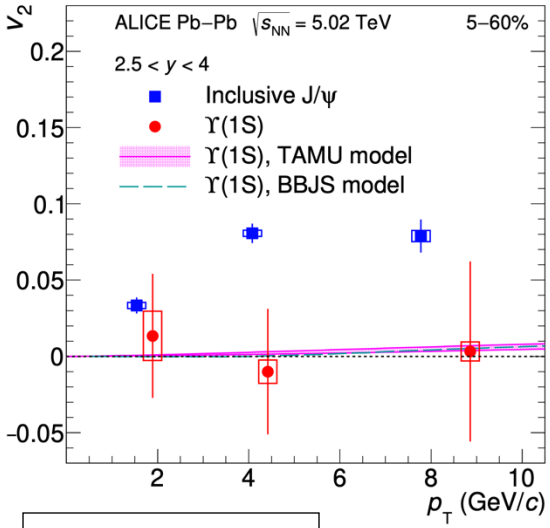
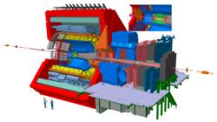


arXiv:1907.03169

Good agreement with models with charm quark recombination

ALICE 2 (2022–2026) – Physics program



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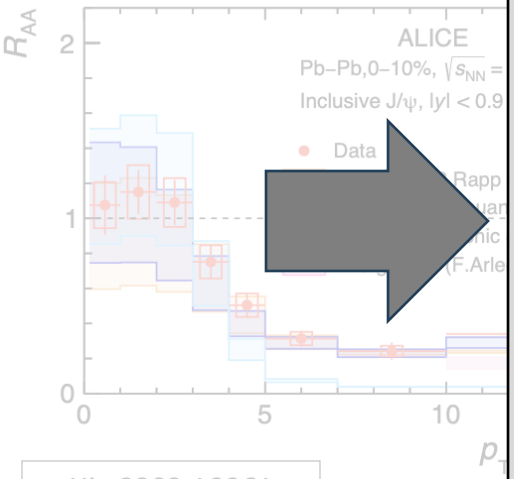
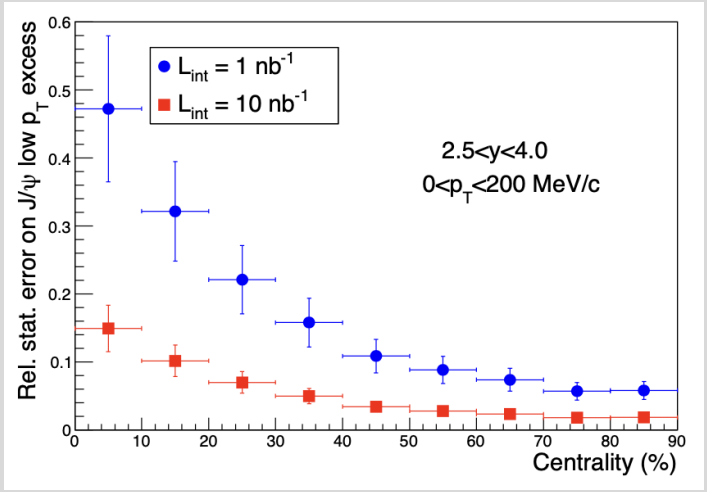
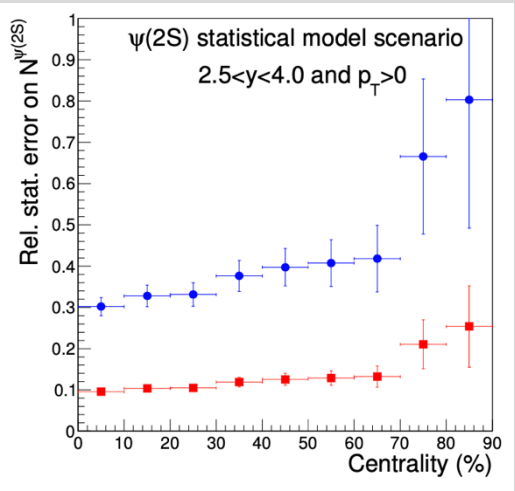


arXiv:2303.13361

ALICE 2

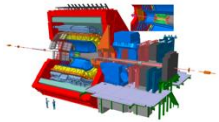




Relative statistical errors on J/ψ and ψ(2S)

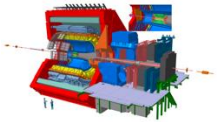
Good agreement with models with charm quark recombination

ALICE 2 (2022–2026) – Physics program



- Low-mass dileptons
  - Electromagnetic radiation provides information about the entire system evolution since the detected particles (photon, dilepton pair) do not interact strongly with the medium
  - Spontaneous chiral symmetry breaking, system temperature, space-time evolution of the system

ALICE 2 (2022–2026) – Physics program



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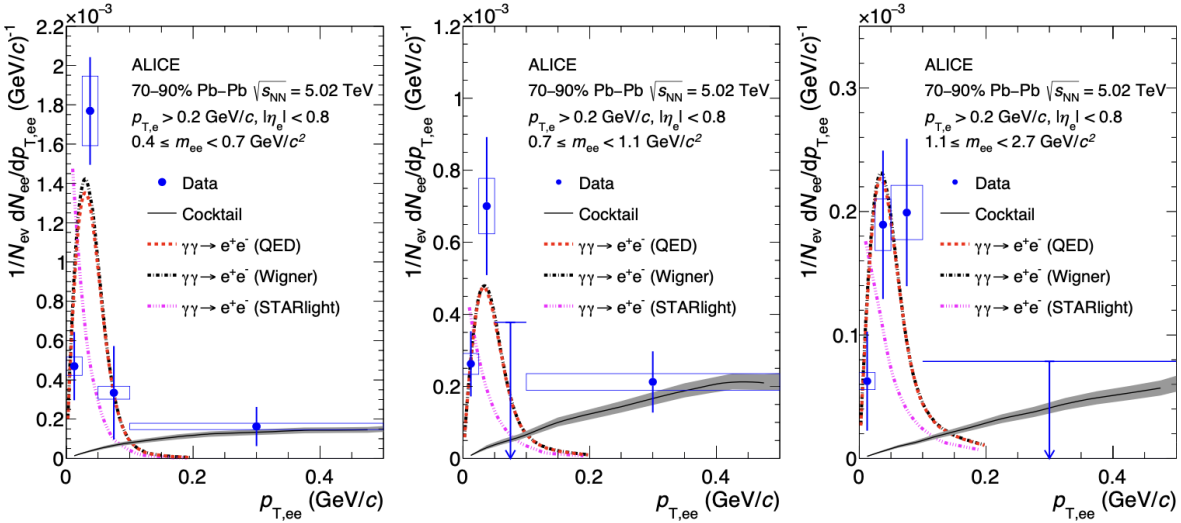
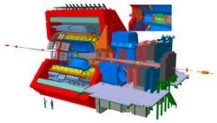


arXiv:2204.11732

Di-eletron yields for different invariant mass range

ALICE 2 (2022–2026) – Physics program



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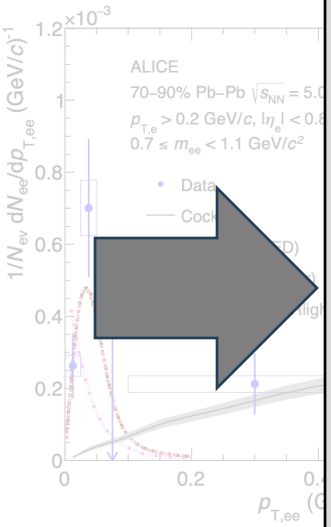
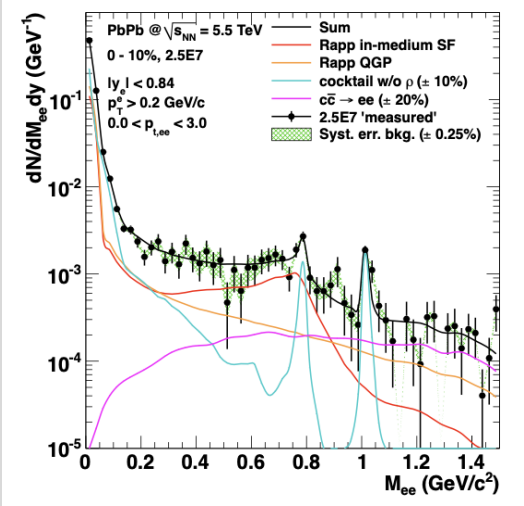


arXiv:2204.11732

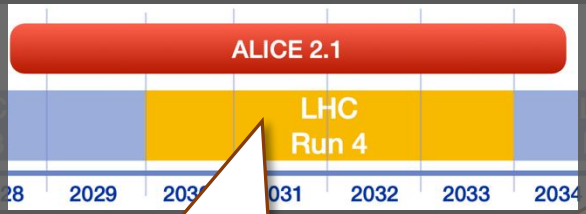
Di-e

ALICE 2

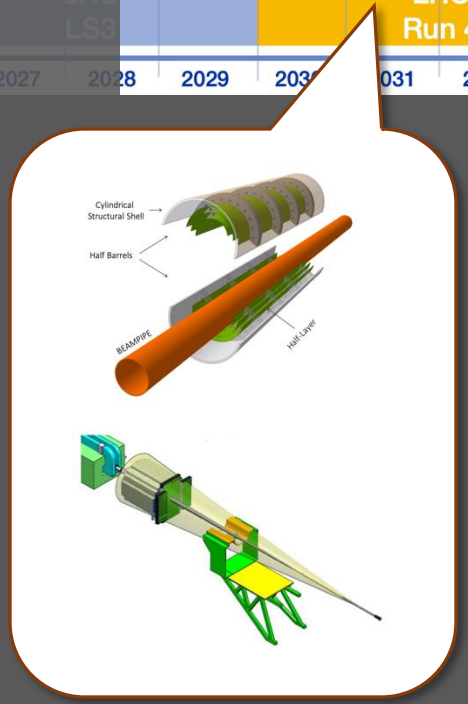


Expected invariant mass spectrum

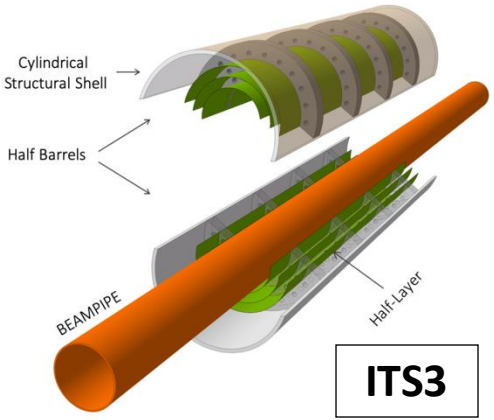
ALICE 2.1



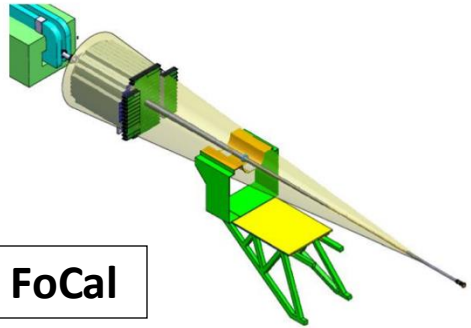
- Inner Tracking System (ITS3)
- Forward Muon Calorimeter (FoCal)



ALICE 2.1 (2030–2033)



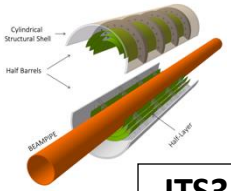
ITS3



FoCal

- Upgrade during Long Shutdown 3 (2026-2029)
  - Replacing the inner 3 layers of ITS2 with truly cylindrical layers (ITS3)
  - Forward Muon Calorimeter (FoCal)
- Main improvements
  - Reduction of the material budget at the midrapidity
  - Significantly improved tracking precision and efficiency at low p_T
  - Improved measurements at the forward rapidity η ~ [3.2, 5.8]

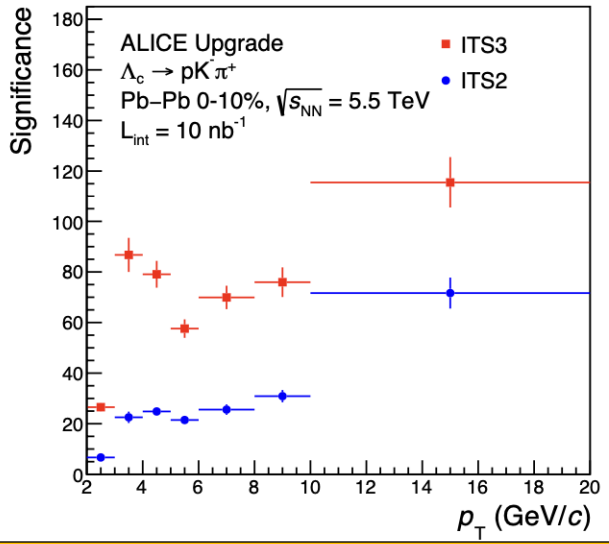
ALICE 2.1 (2030–2033) – Physics program

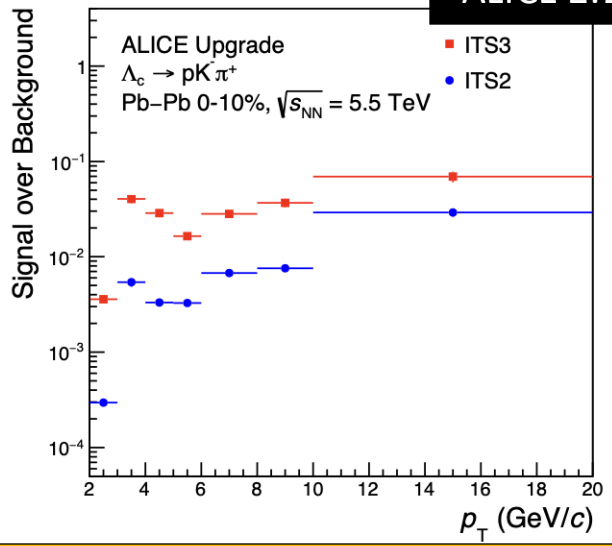


ITS3

- Heavy-flavor production (ITS3)
  - Thermalization of heavy quarks in the medium

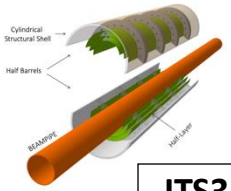
ALICE 2.1





Precise measurement of Λ_c production → Crucial for the total cc-bar cross section → Input for the charmonium re-generation in the QGP

ALICE 2.1 (2030–2033) – Physics program



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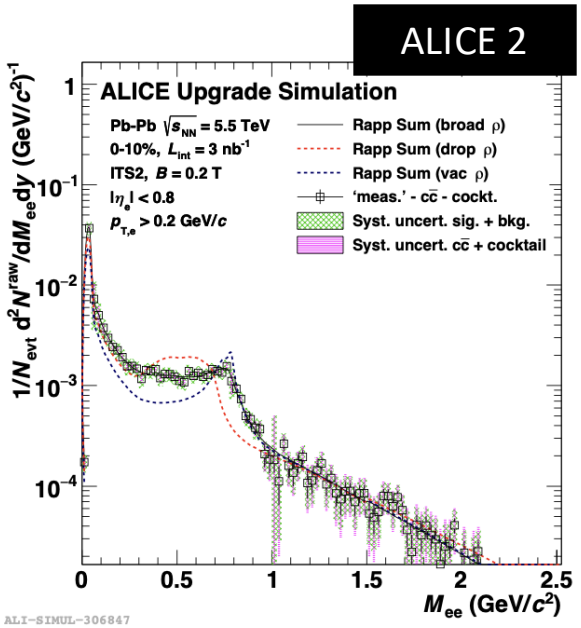
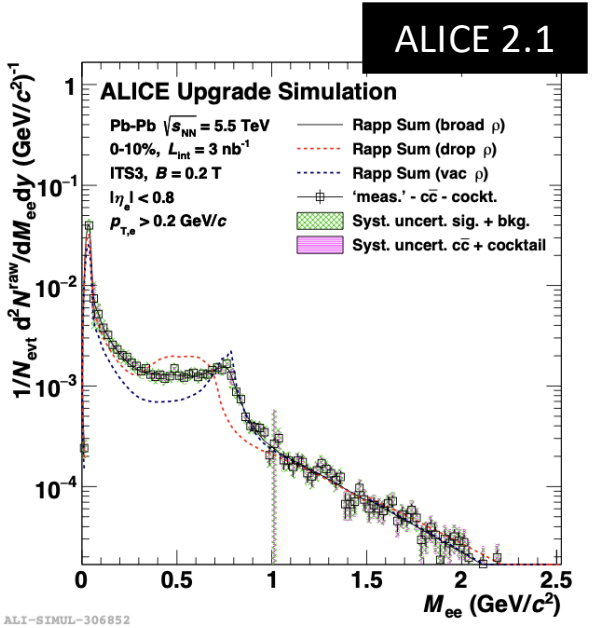
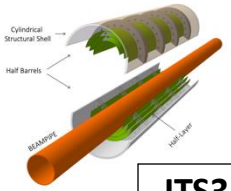




ALICE 2.1 (2030–2033) – Physics program



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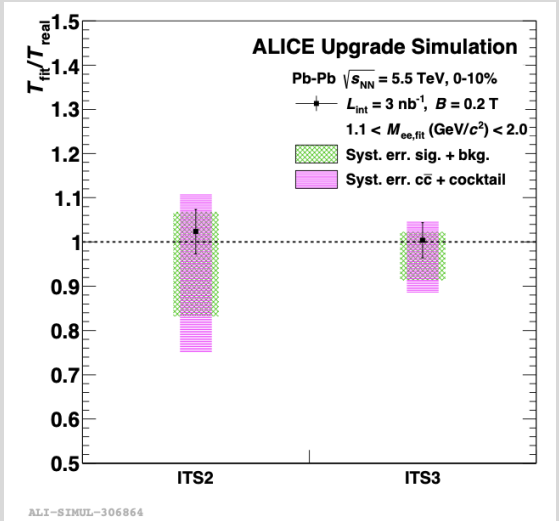
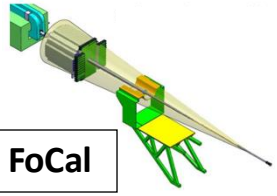
ALICE 2 | ALICE 2.1

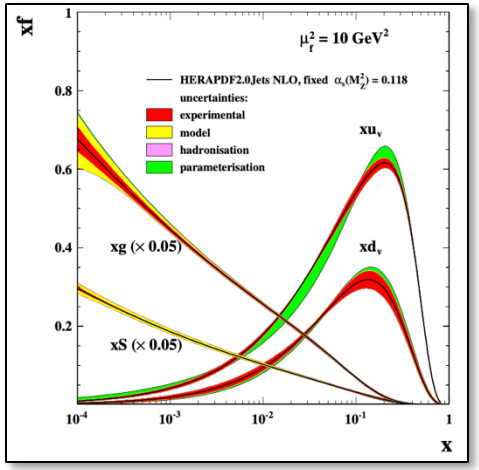


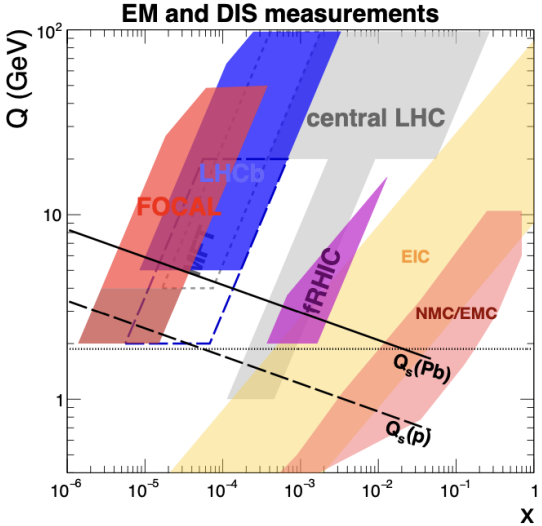
Expected relative uncertainty of the extraction of the T parameter

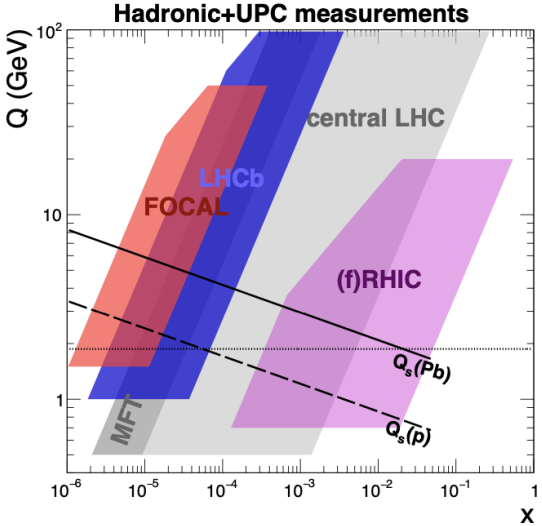
ALICE 2.1 (2030–2033) – Physics program



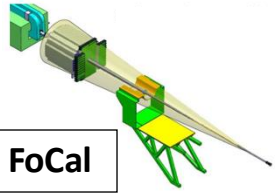
- Forward Calorimeter
  - Highly-granular Si-W electromagnetic calorimeter + metal-scintillator hadronic calorimeter
  - Pseudorapidity interval $3.2 < \eta < 5.8$
  - Enables to access $x \sim 10^{-6}$ region – To study gluon saturation / shadowing



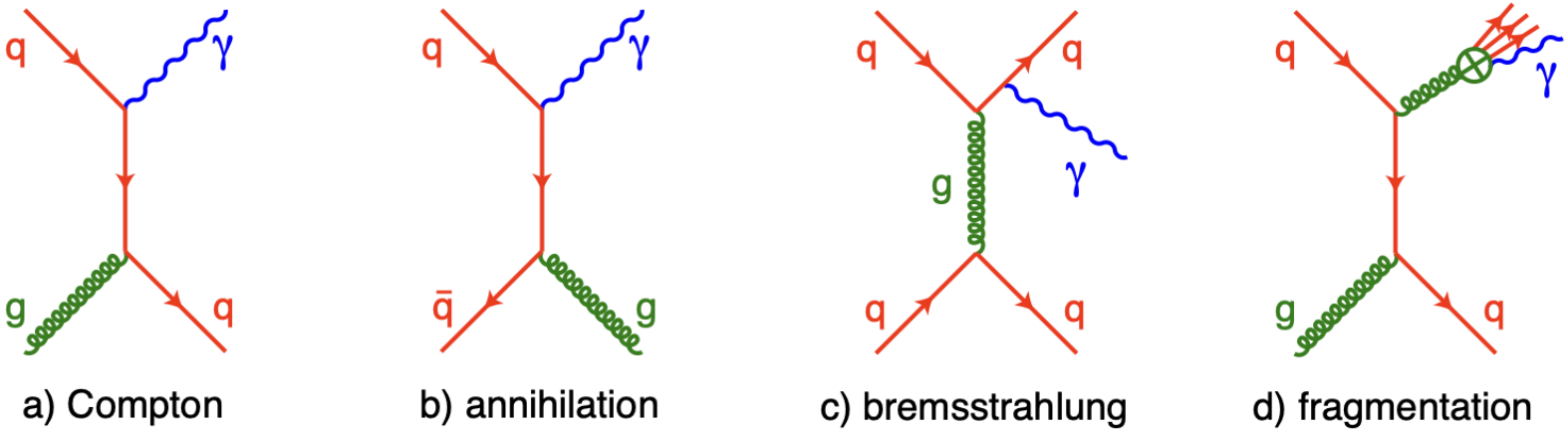




ALICE 2.1 (2030–2033) – Physics program

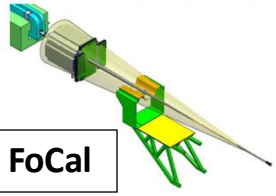


- Forward Calorimeter
  - Gluon density in protons and lead nuclei and its nuclear modification



Feynman diagram for direct photon production

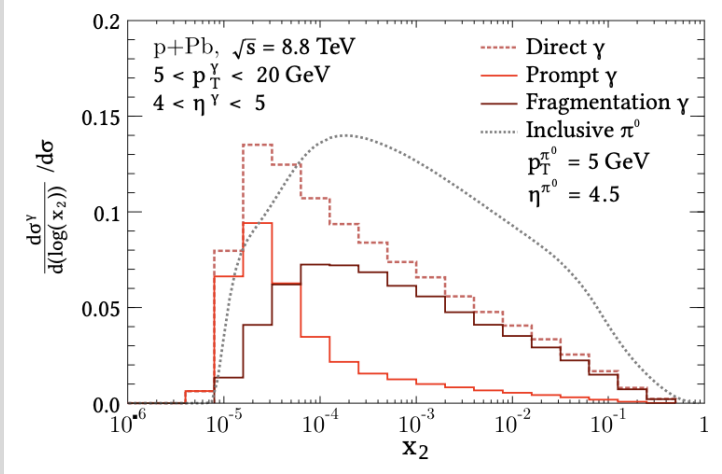
ALICE 2.1 (2030–2033) – Physics program

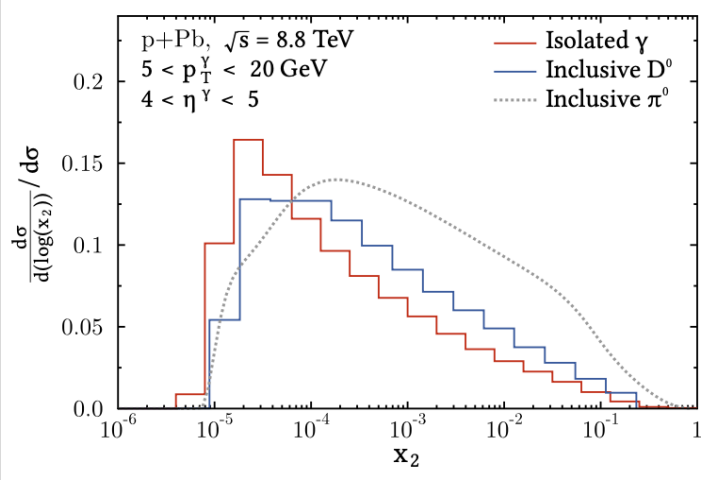


➢ Forward Calorimeter

- Gluon density in protons and lead nuclei and its nuclear modification

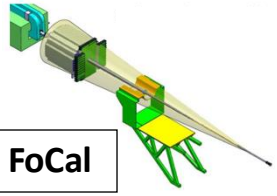
ALICE 2.1





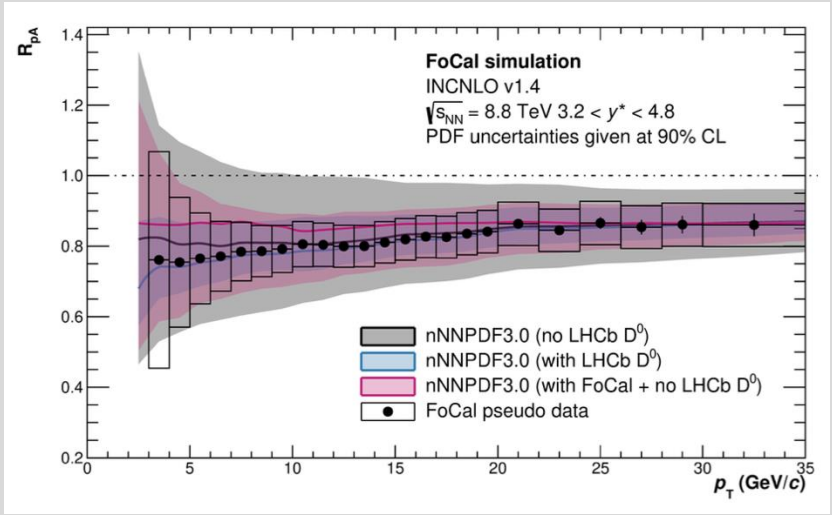
Theory predictions for gluon x distributions probed with direct photon and D meson

ALICE 2.1 (2030–2033) – Physics program



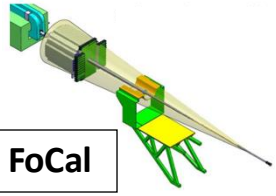
- Forward Calorimeter
  - Gluon density in protons and lead nuclei and its nuclear modification
  - Physical origin of shadowing (saturation) effects

ALICE 2.1



Expected R_{pPb} distribution for inclusive direct photon compared to QCD calculations

ALICE 2.1 (2030–2033) – Physics program



- Forward Calorimeter
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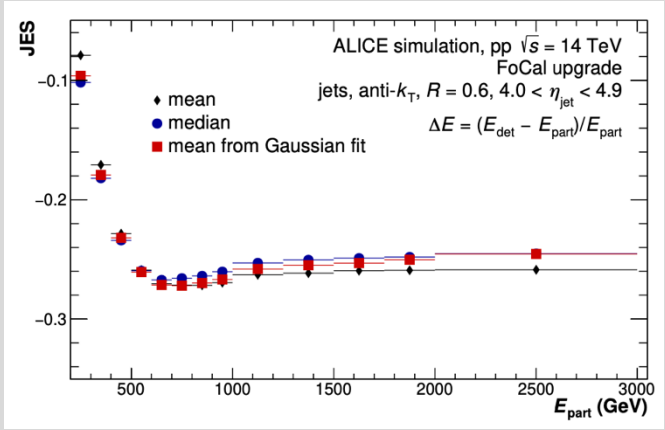
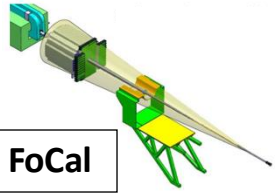
  - Physical origin of shadowing (saturation) effects
  - Jet quenching at forward rapidity – Saturation effects at small x

ALICE 2.1

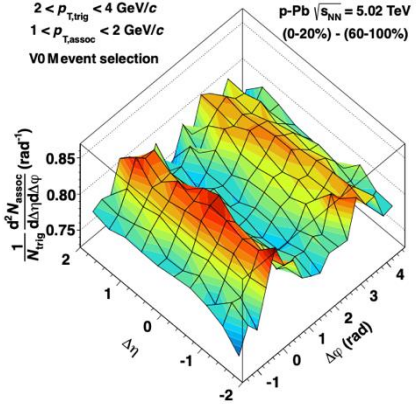


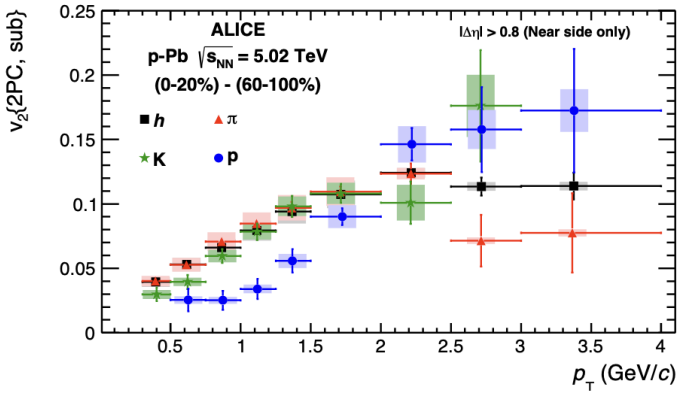
Jet energy scale for R = 0.6 jets in pp collisions

ALICE 2.1 (2030–2033) – Physics program



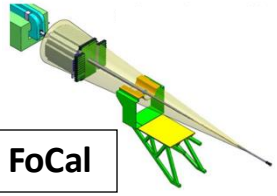
- Forward Calorimeter
  - Gluon density in protons and lead nuclei and its nuclear modification
  - Physical origin of shadowing (saturation) effects
  - Jet quenching at forward rapidity – Saturation effects at small x
  - Long-range flow-like correlations in in pp and p-Pb





- Photon-hadron correlations with Δη ~ [5, 9] is achievable

ALICE 2.1 (2030–2033) – Physics program



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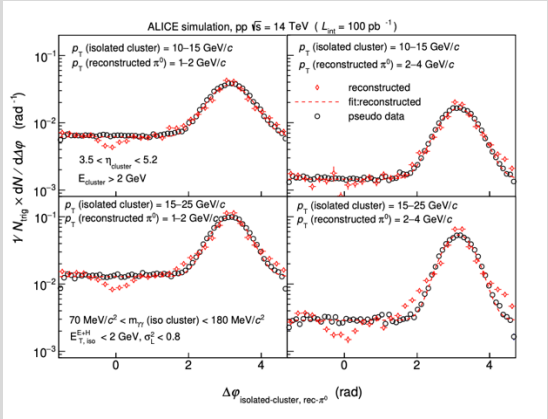
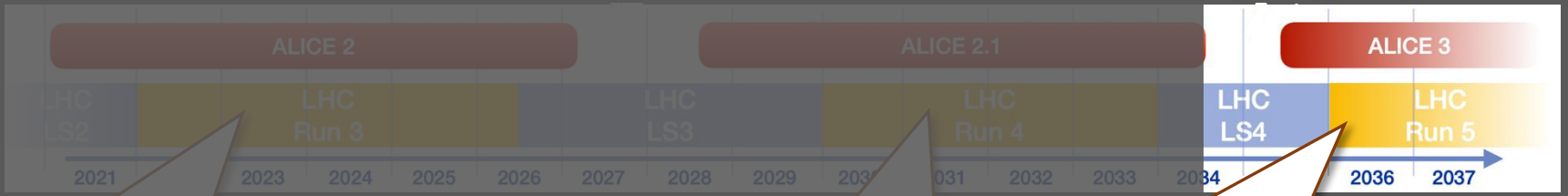
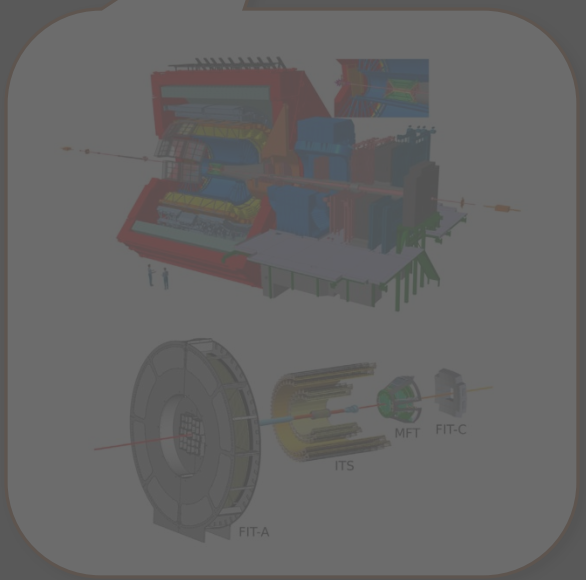


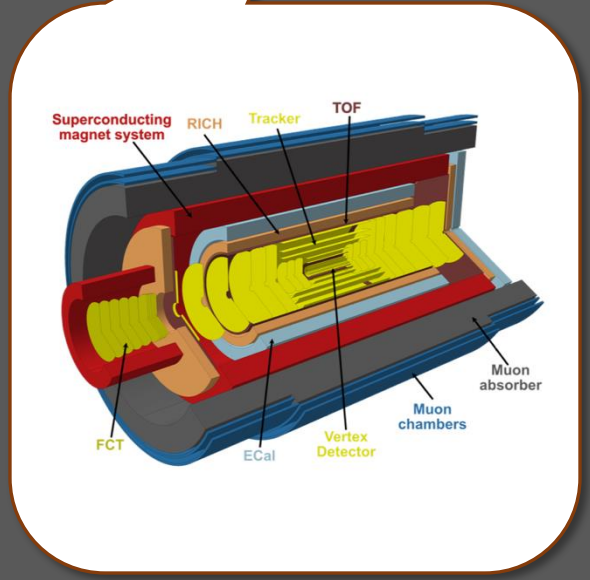
Isolated cluster-π_0 correlation in pp collisions at the FoCal range

ALICE 3

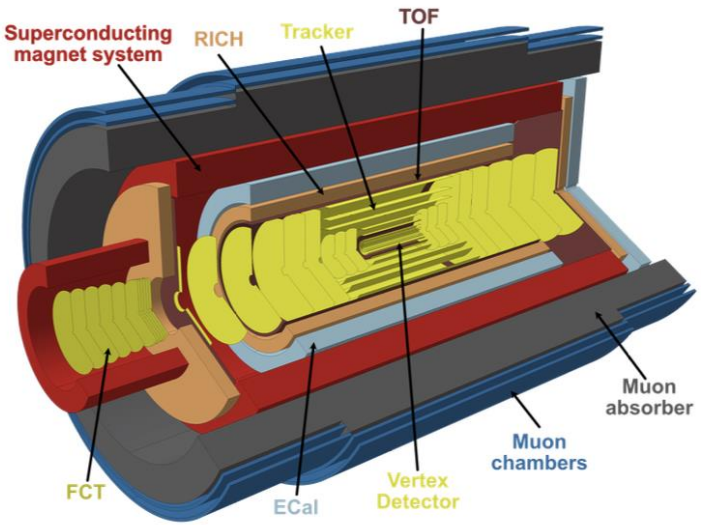




- ALICE 3

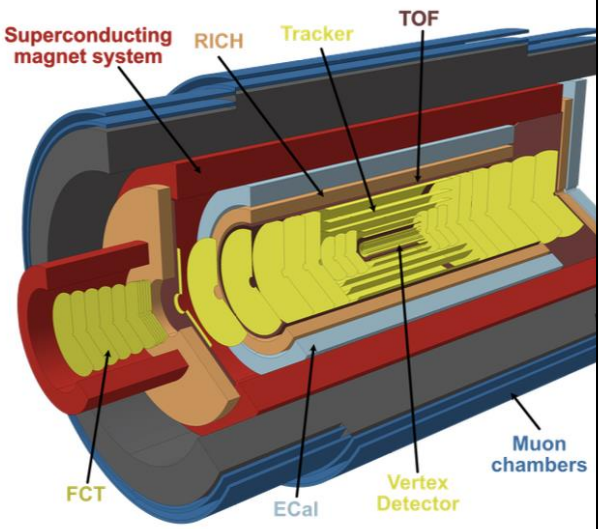


ALICE 3 (2036–)



- Upgrade during Long Shutdown 4
  - Compact all-silicon tracker with high-resolution vertex detector
  - Particle identification detectors
- Main improvements
  - Improved pointing resolution / tracking
  - Particle identification over large acceptance
  - Fast rea-out and online processing

ALICE 3 (2036–)



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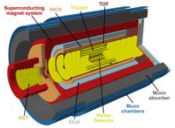
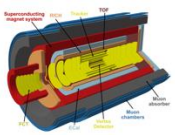
ALICE 3 Letter of Intent, arXiv:2211.02491

ALICE 3 (2036–) – Physics program



- Low-mass dileptons
  - Temperature of the medium before hadronization extractable from the dilepton mass distribution
    - ✓ Photons and dileptons do not suffer from strong final-state interactions
    - ✓ Temperature extraction with photon – Blue shift (rapid bulk expansion changes the energy spectrum of the photon)
    - ✓ Dilepton mass – a frame independent variable

ALICE 3 (2036–) – Physics program



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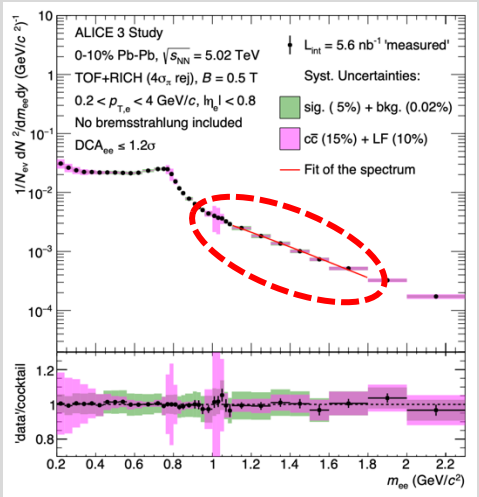
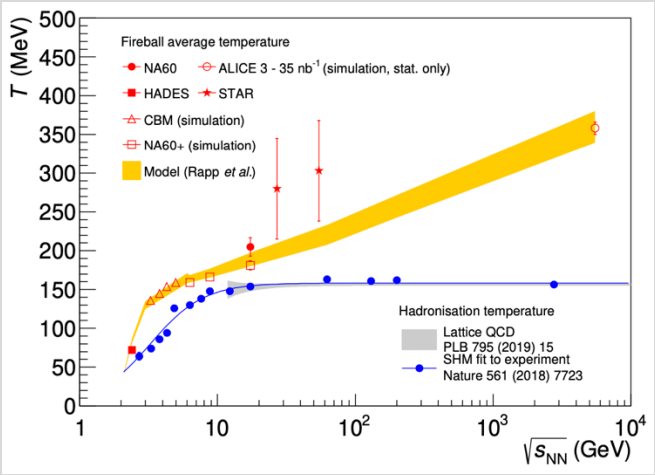
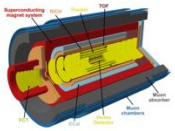
ALICE 3





ALICE 3 (2036–) – Physics program



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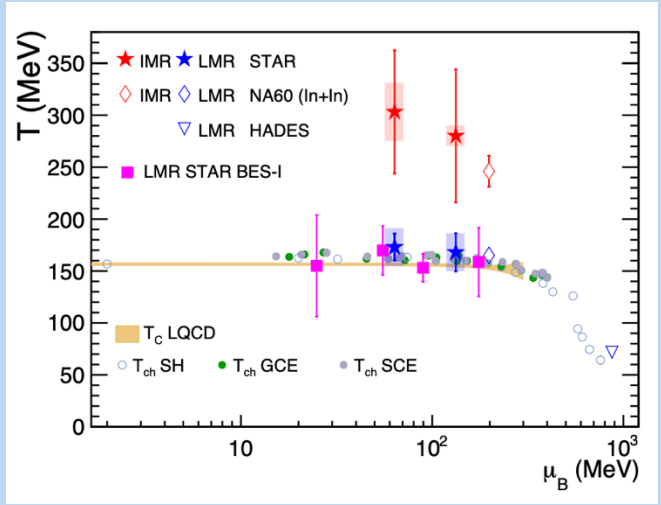
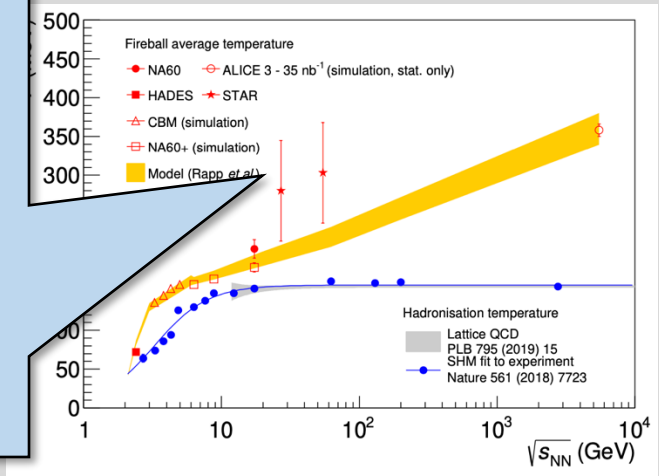
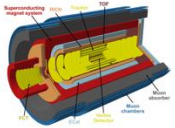


STAR, arXiv:2402.01998, submitted to Nature

ALICE 3

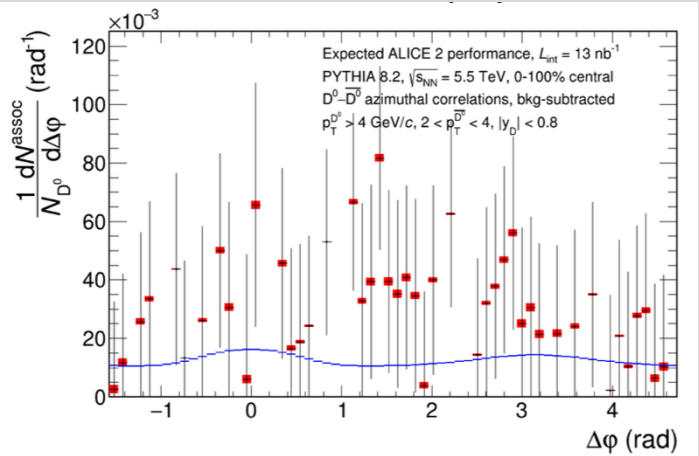


ALICE 3 (2036–) – Physics program



- Heavy-flavor production
  - Thermalization of heavy quarks in the medium
    - ✓ $D\bar{D}$ azimuthal correlations – Angular decorrelation directly probes the QGP scattering

ALICE 2 + ALICE 2.1



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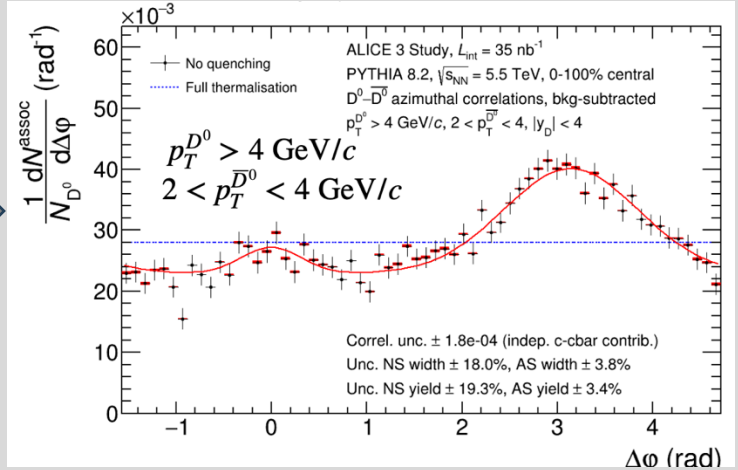
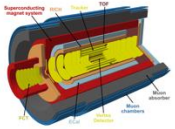
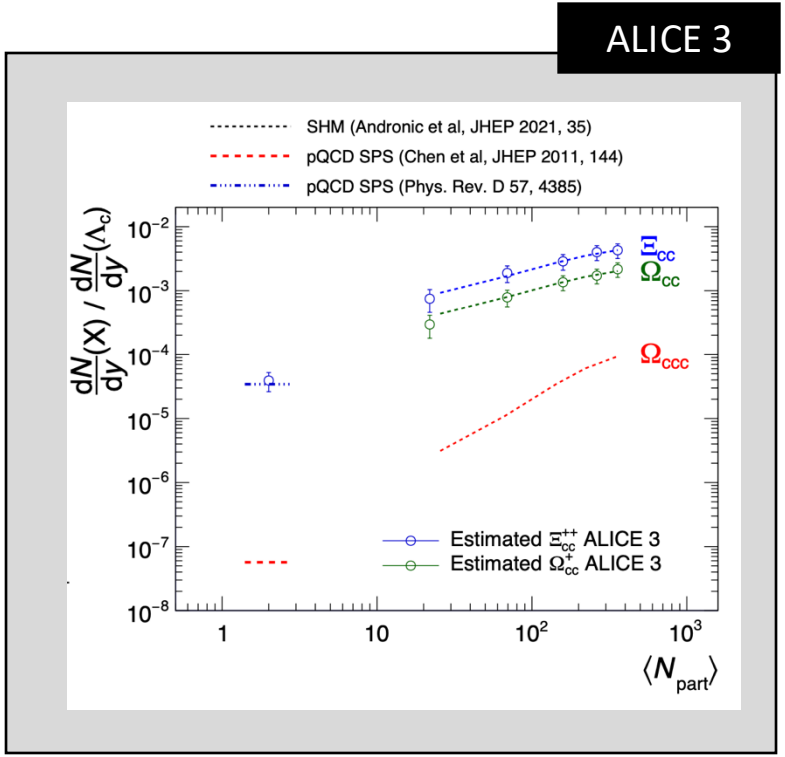


ALICE 3 (2036–) – Physics program

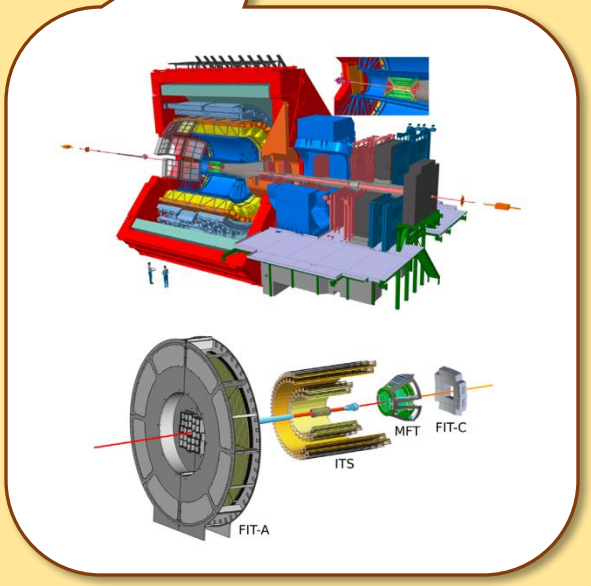


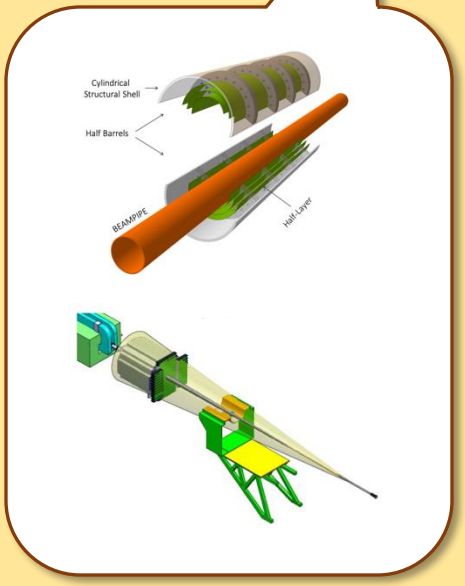
- Heavy-flavor production
  - Multi-charm baryon – Unique probe hadron formation
    - ✓ Statistical hadronization model predicts large enhancement in Pb-Pb collisions

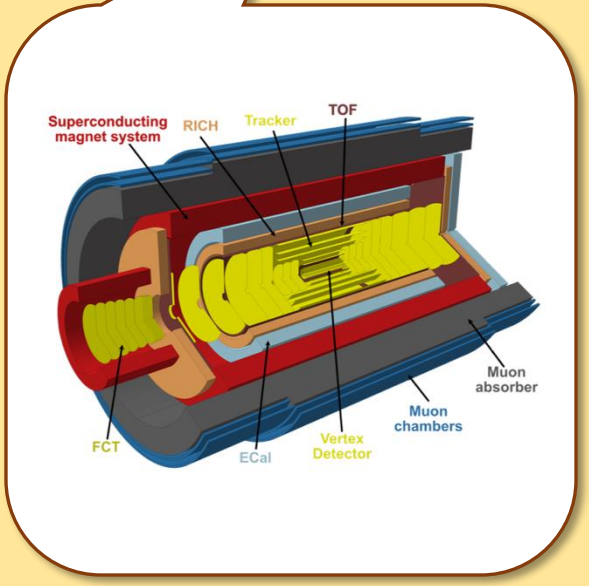


Summary

ALICE 2
ALICE 2.1
ALICE 3
LHC LS2
LHC Run 3
LHC LS3
LHC Run 4
LHC LS4
LHC Run 5
2021
2023
2024
2025
2026
2027
2028
2029
2031
2032
2033
2034
2036
2037

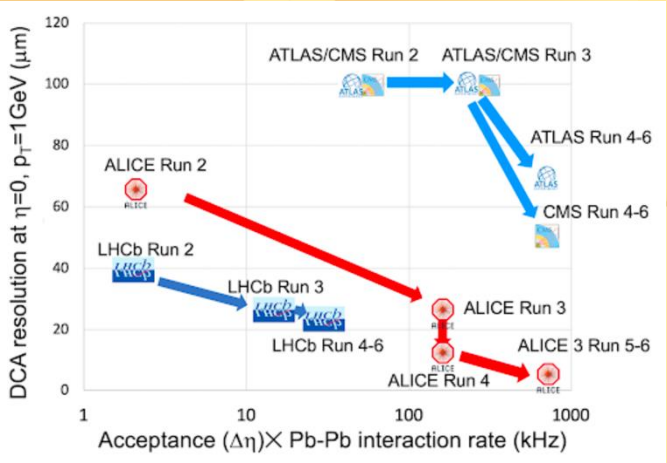

MFT
FIT-C
ITS
FIT-A


Cylindrical Structural Shell
Half Barrels
BEAMPIPE
Half-Layer


Superconducting magnet system
RICH
Tracker
TOF
Muon absorber
Muon chambers
FCT
ECal
Vertex Detector

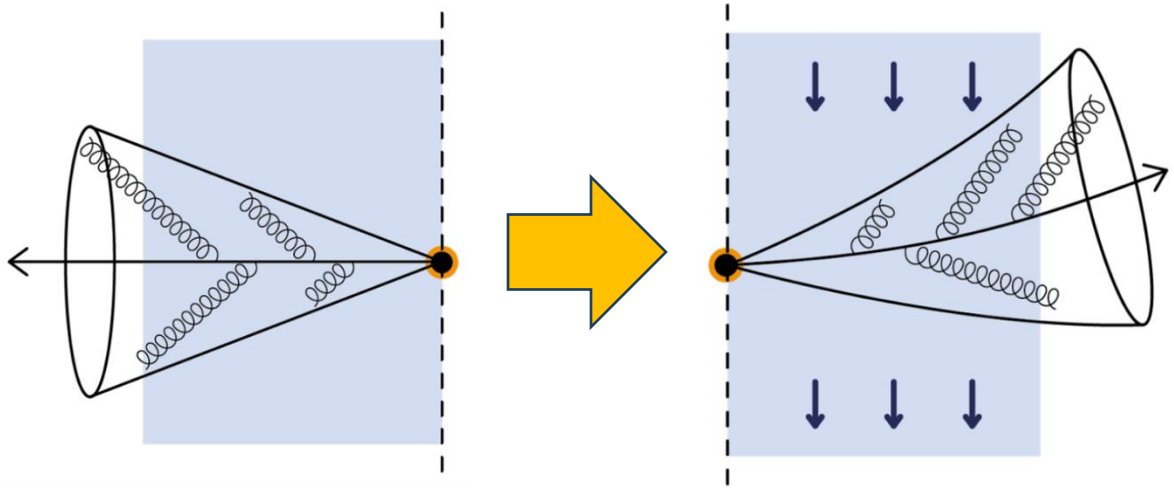
Summary

- New results from ALICE are on the way for the next a few decades
  - Increased statistics, enhanced precision at low p_T sectors, improved pointing resolution
  - Heavy-flavor and dilepton measurements are the driving motivations for the upgrade
  - On-going journey to understand the Quark Gluon Plasma



Jet meausrements

- Recent proposals from theory
  - A flowing QGP requires that jet quenching calculations go beyond static brick setup (HP 2024 – Talks from D. Pablos, J. Silva, X. Mayo, J. Bahder, T. Luo, R. Fries)



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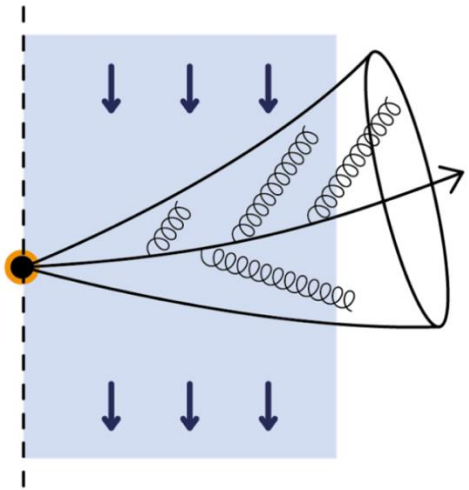

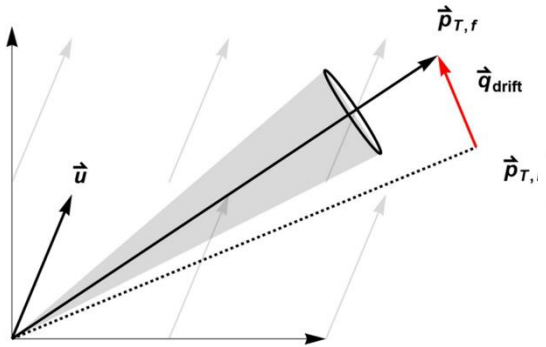

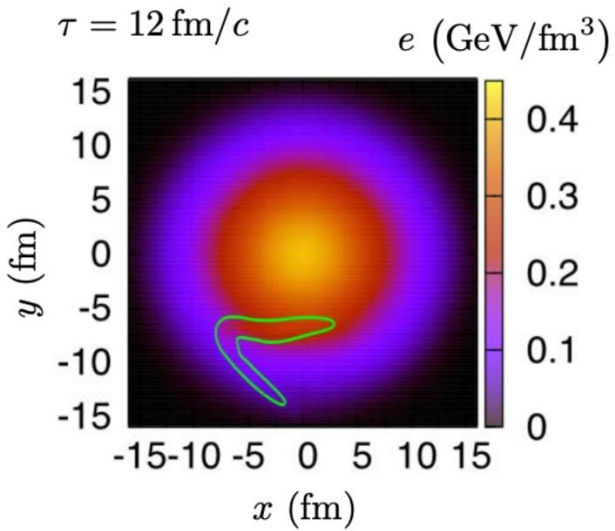

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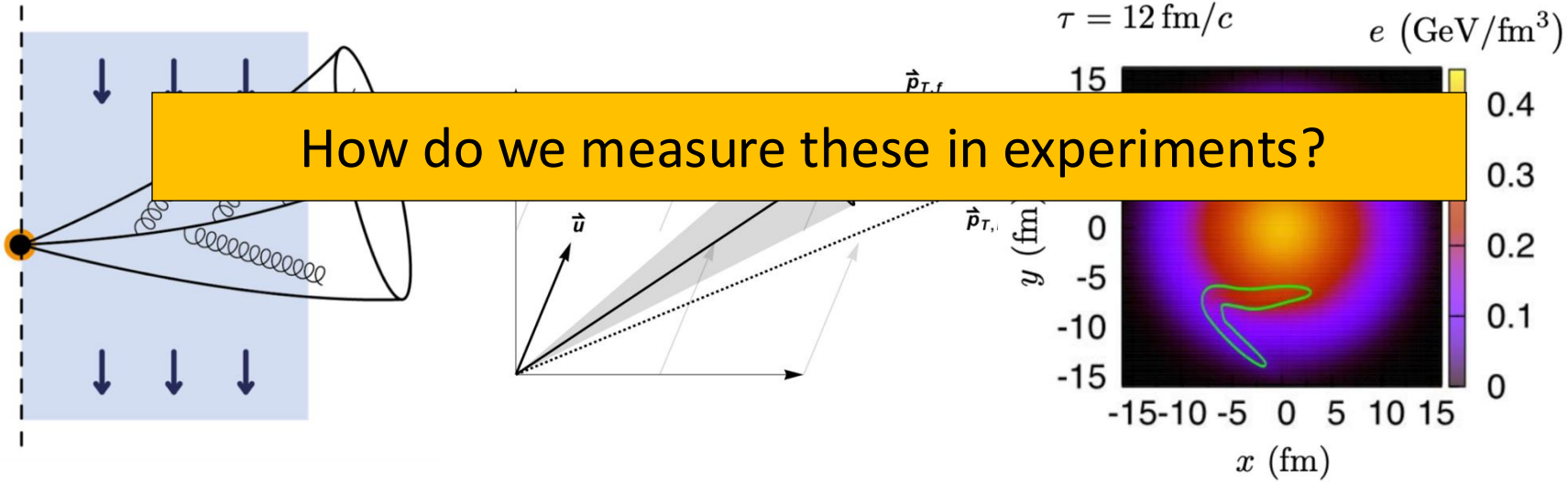

How do we measure these in experiments?

감사합니다.