2018 LHC Days in SPLIT

Diocletian's Palace / Palazzo Milesi – Split (Croatia)
17-22 September 2018

Antonio Uras

on behalf of the ALICE, ATLAS, CMS and LHCb Collaborations

IPN Lyon – CNRS/IN2P3

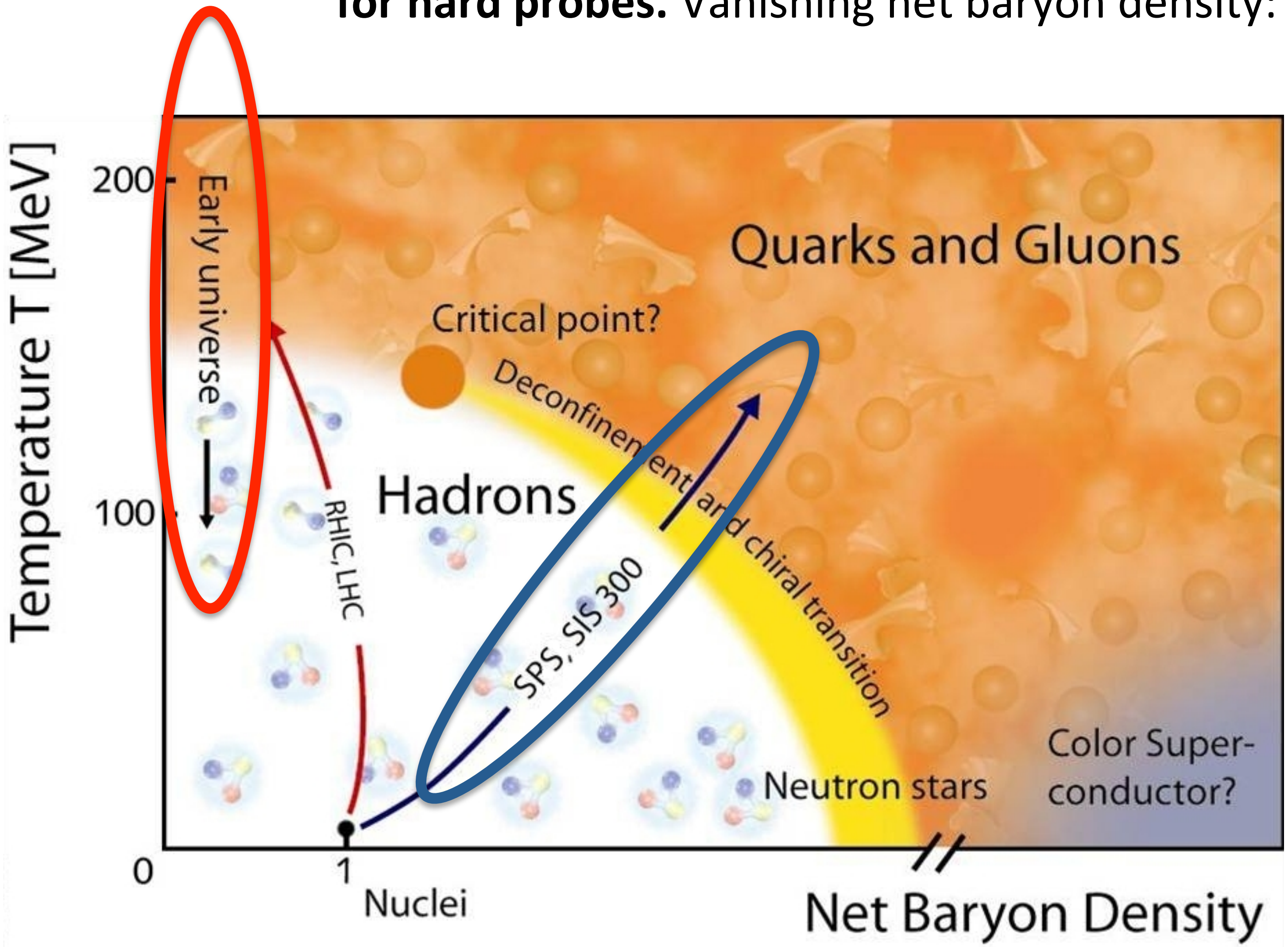
Future heavy-ion programme at the High-Luminosity LHC

Outline

- LHC Luminosity evolution and Heavy-Ion running timeline
- Heavy-Ion physics program at LHC beyond 2020
- Experiment upgrades and strategies
- Selected performance studies

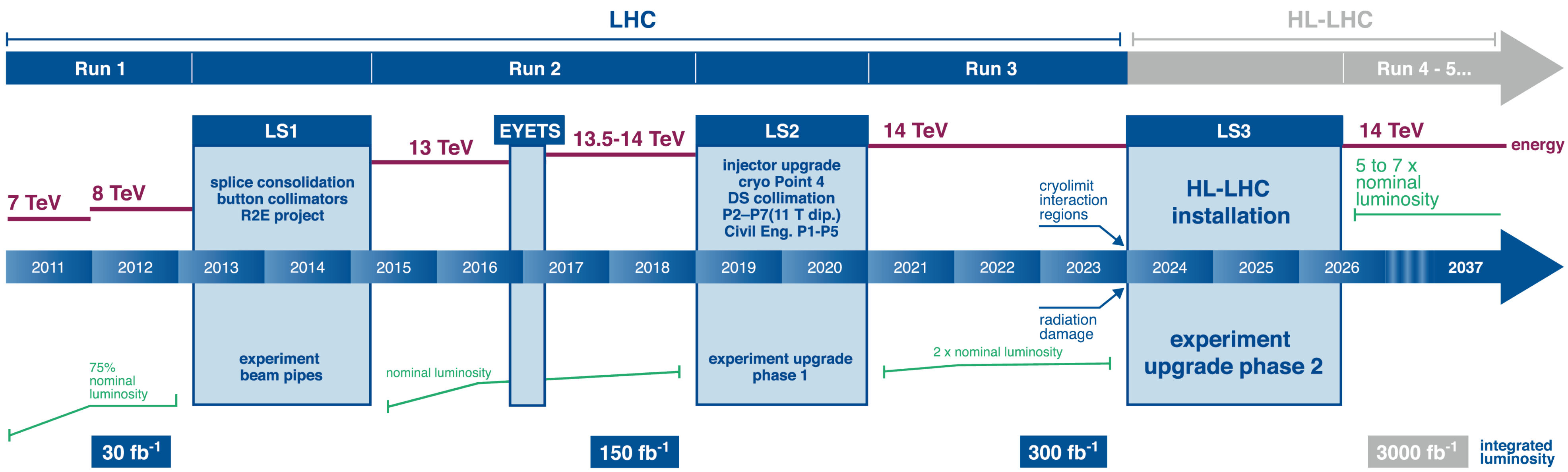
Heavy-Ion Physics at the LHC

❖ **The high-energy frontier: large and long-living QGP, large cross-sections for hard probes.** Vanishing net baryon density: Early Universe conditions



❖ **The low-energy frontier:** focus on bulk observables. Energy scan: search for the critical point and characterization of the phase transition

LHC/HL-LHC Plan [https://hilumilhc.web.cern.ch/about/hl-lhc-project]



Main upgrades relevant for the Heavy-Ion physics (LS2: 2019-2020)

- LHC collimator upgrades: target L ≈ $6{\times}10^{27}$ cm^{-2} s^{-1} for Pb-Pb (i.e. 50 kHz int. rate)
- Major ALICE and LHCb upgrades, important upgrades for ATLAS and CMS
- Focus on rare probes, their coupling with QGP medium and (medium-modified) hadronization

Heavy-Ion Running Conditions at the LHC

Heavy-Ions in LHC Run 2 (2015): [J.M. Jowett, M. Schaumann – IPAC2016, Busan, Korea]

- Pb-Pb collisions at 5.02 TeV per nucleon pair (c.m. energy of the 2013 p-Pb run)
- 18 days of operation for physics, design luminosity surpassed by a factor of 3.6
- Integrated luminosity of up to 0.7 nb^{-1} per experiment
- Specific bunch patterns providing Pb-Pb collisions in LHCb, for the first time

New Heavy-Ion run in Nov. 2018 (same energy as the 2015 run, L_{int} = 1-1.5 nb^{-1} per exp.)

Heavy-Ions in LHC Runs 3+4 (2021 ➔):

- Experiments request for Pb-Pb: $L_{int} > 10\ nb^{-1}$ (ALICE LoI: 10 nb^{-1} with nominal solenoidal field + 3 nb^{-1} with reduced solenoidal field)
  - ×100 larger min. bias sample for ALICE w.r.t. Run 2
  - ×10 larger rare trigger sample for ATLAS/CMS w.r.t. Run 2
- pp reference, p-A. Investigating feasibility for lighter nuclei collisions

Heavy-Ion Physics at the LHC Run3+4 (I)

- **Jets: characterization of the energy-loss mechanism, both as a testing ground for the multi-particle aspects of QCD and as a probe of the medium density**
  - Differential studies of jets, b-jets, di-jets, γ/Z-jet at very high p_T (main focus of ATLAS and CMS)
  - Flavor-dependent in-medium fragmentation functions (main focus of ALICE)

- **Heavy flavors: mass dependence of energy loss, study of in-medium thermalization and hadronization as a probe of the medium transport properties**
  - Low-p_T production and elliptic flow of several HF hadron species, with first measurements of beauty at forward rapidity down to zero p_T (main focus of ALICE)
  - B hadrons and b-jets (main focus of ATLAS and CMS)
  - LHCb: performance under investigation

Heavy-Ion Physics at the LHC Run3+4 (II)

- **Quarkonium: precision study of quarkonium dissociation pattern and regeneration, as probes of deconfinement and of the medium temperature**
  - Low-p_T charmonium production and its elliptic flow (main focus of ALICE)
  - Multi-differential studies of Y states (main focus of ATLAS and CMS)
  - LHCb: performance under investigation

- **Prompt dilepton production: (i) thermal radiation** to map temperature during system evolution; **(ii) modification of ρ meson spectral function** as a probe of the chiral symmetry restoration; **(iii) analysis of the continuum** to study low-mass Drell-Yan production and put limits on low-mass dark γ'/Z' boson production
  - Improved background rejection for prompt dielectrons and dimuons down to low-p_T (ALICE)

ALICE Upgrade Strategy (I)

- **Detector specificities (strengthened with the upgrades):**
  - Hadron and lepton identification
  - Light-weight and precise trackers
  - Low magnetic field

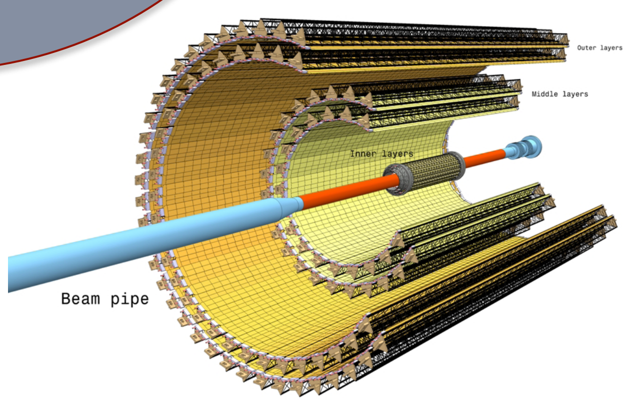
Talk by F. Reidt
Tuesday 9:00

- **Main observables…**
  - Low-p_T Heavy Flavors
  - Low-p_T Charmonium
  - Prompt dileptons down to low-mass and low-p_T

ALICE Upgrade LOI + addendum: CERN-LHCC-2012-012, CERN-LHCC-2013-014
ALICE TPC Upgrade TDR: CERN-LHCC-2013-020
ALICE ITS Upgrade TDR: CERN-LHCC-2013-024
ALICE MFT TDR: CERN-LHCC-2015-001
ALICE Online-Offline Upgrade TDR: CERN-LHCC-2015-006

- **… are based on "untriggerable" signals!**
  - Record all events at up to 50 kHz in Pb-Pb (currently 0.5 kHz): strong data reduction needed (from 1 TB/s to 85 GB/s via online reconstruction)
  - HL-HI-LHC: increase of minimum-bias sample ×50-100 w.r.t. Run 2

ALICE Upgrade Strategy (II)



New Inner Tracking System (ITS)

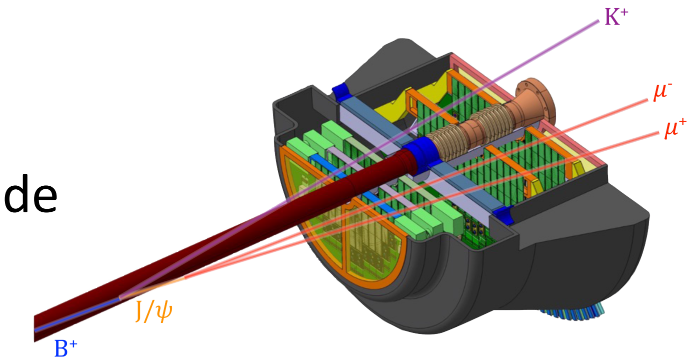
- New pixel technology: improved granularity and resolution, reduced material budget

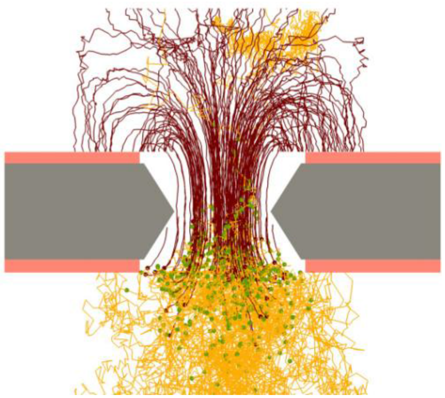
New Forward Muon Tracker (MFT)

- Vertex tracker for the forward muon spectrometer: heavy flavor vertices, prompt/displaced muon discrimination

TPC Upgrade:

- Replacement of the MWPC-based readout by detectors employing GEMs to allow TPC operation in continuous mode





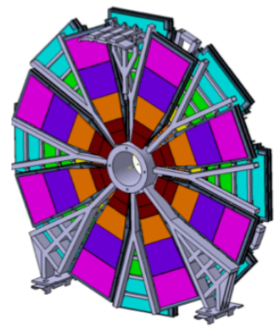
Upgraded read-out for many detectors, new integrated Online-Offline (O^2), new Fast Interaction Trigger detector

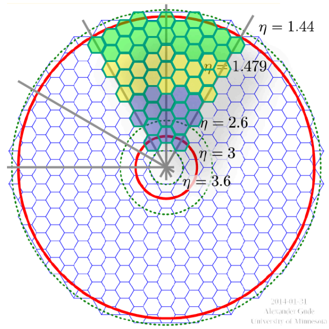
- Upgraded ALICE will record Pb-Pb data at 50 kHz (1 kHz in Run 2)

CMS/ATLAS Upgrades Relevant for Heavy-Ions

- **CMS detector**
  - Lighter silicon tracker with extended coverage out to η = 4
  - GEM muon stations matching the η coverage of the tracker
  - New high granularity calorimeter endcaps that together with the tracker will enable particle-flow reconstruction at large rapidity

- **ATLAS detector**
  - Complete replacement of the internal tracker
  - Level-I track trigger
  - Upgraded calorimeter electronics and muon trigger system





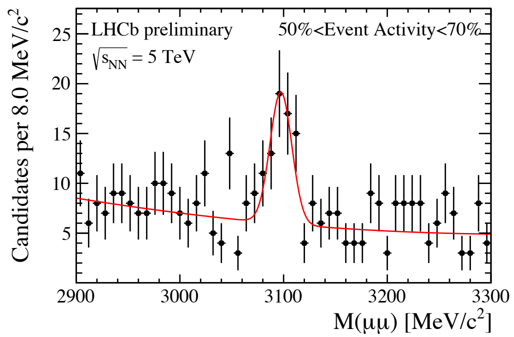
- **Timing detectors in ATLAS and CMS (pile-up rejection)** should allow for π/K/p separation by time-of-flight measurement in the range 0.7 - 2 GeV/*c*

Main focus on triggerable signals (complementary strategy w.r.t. ALICE): muon, jet, displaced track triggers

- Trigger/DAQ approach: strong event recording reduction from 50 to 0.1 kHz
- HL-LHC: increase of sample ×10 w.r.t. Run 2

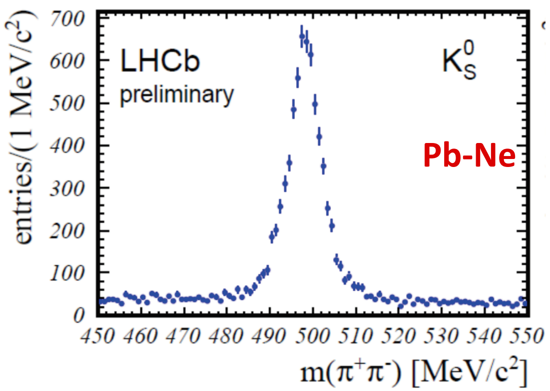
LHCb as a Heavy-Ion Detector

- **Very successful participation in the 2013 p-Pb run. First Pb-Pb run in 2015!**
  - Detector performance and potential in heavy-ion (collider mode) will be clear after the analysis of the 2015 data



- **Exploration of LHCb unique features: forward acceptance, vertexing, PID, calorimetry**
  - Cold nuclear matter effects on prompt/non-prompt quarkonia and open HF down to zero p_T
  - First observation of Z production in p-Pb

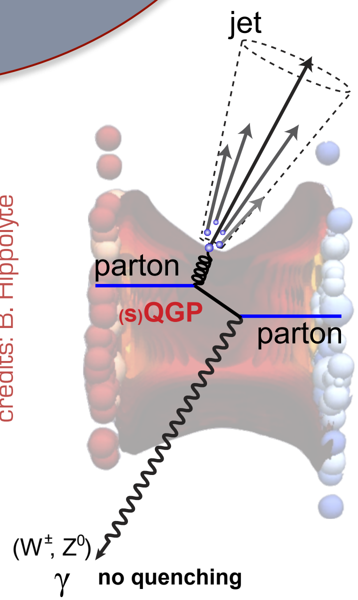
- **SMOG system: LHCb data taking in fixed-target mode (currently unique at the LHC)**
  - Various gases can be injected. $\sqrt{s_{NN}}$ up to ∼100 GeV
  - To be continued after LS2 with possibly more noble gas species



- **Upgrades (LS2) most relevant to Heavy-Ions:**
  - New trackers (pixel, strip, scintillating fiber)
  - Readout upgrade: exploiting full delivered p-Pb luminosity

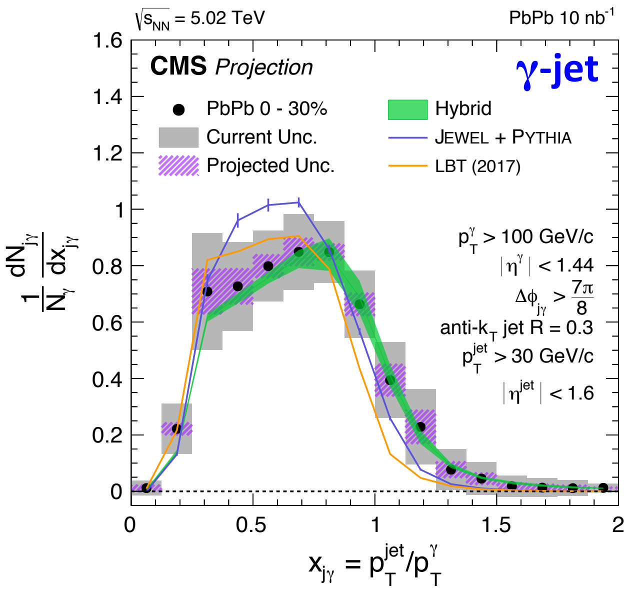
Jet Quenching in ATLAS and CMS

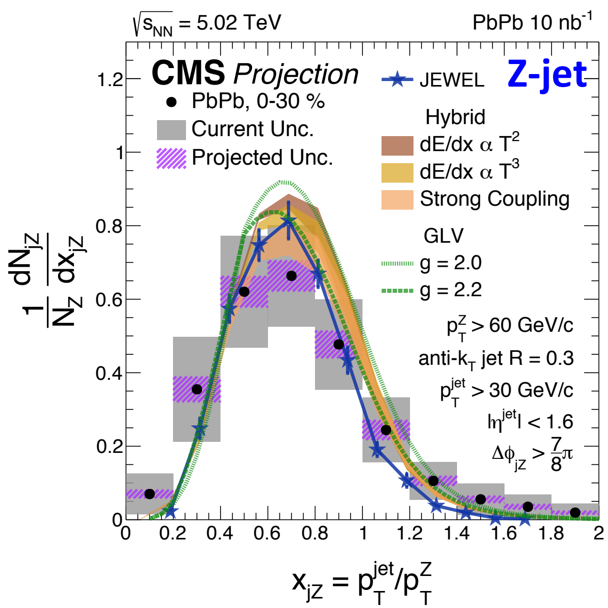
- **High precision γ-jet, Z-jet correlations ($E^{\gamma/Z} = E^{jet}$ before medium effects), di-jets, with dedicated b-jet triggering**
  - 10M di-jets with $p_{T,1} > 120$ GeV/c (CMS, 10 nb^{-1})
  - 140k b-jets with $p_T > 120$ GeV/c (CMS, 10 nb^{-1})
- **Understand medium response and energy radiation details, map path-length dependence (radiative ~L^2, collisional ~L)**

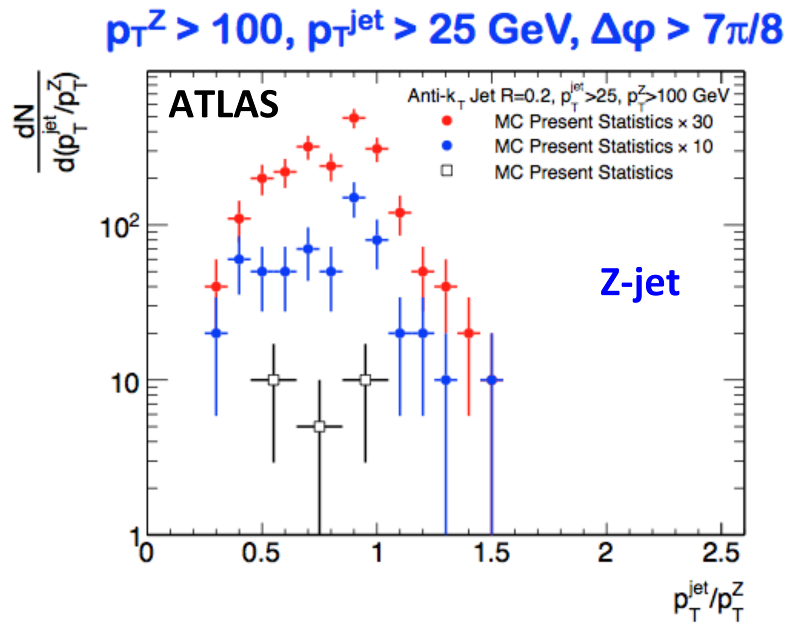


credits: B. Hippolyte

CMS Proj. : CMS-PAS-FTR-17-002







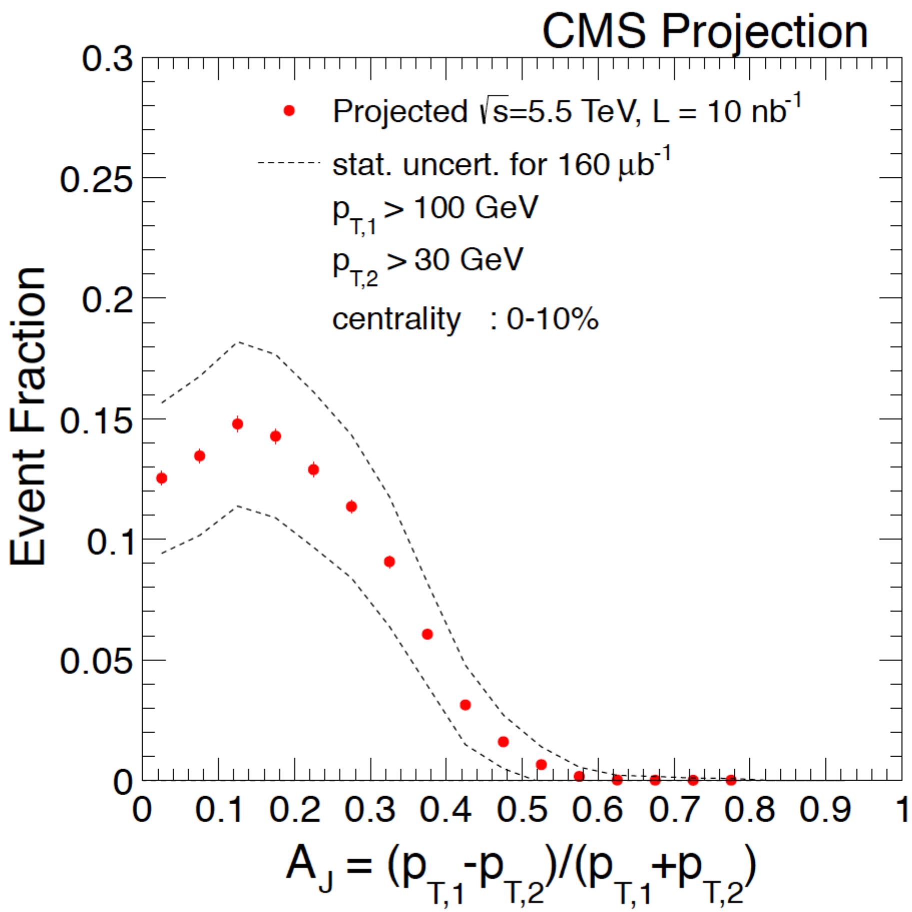
b-jets in ATLAS and CMS

❖ **b-jets profit from efficient tagging algorithm**, thanks to the large decay length of the beauty hadrons

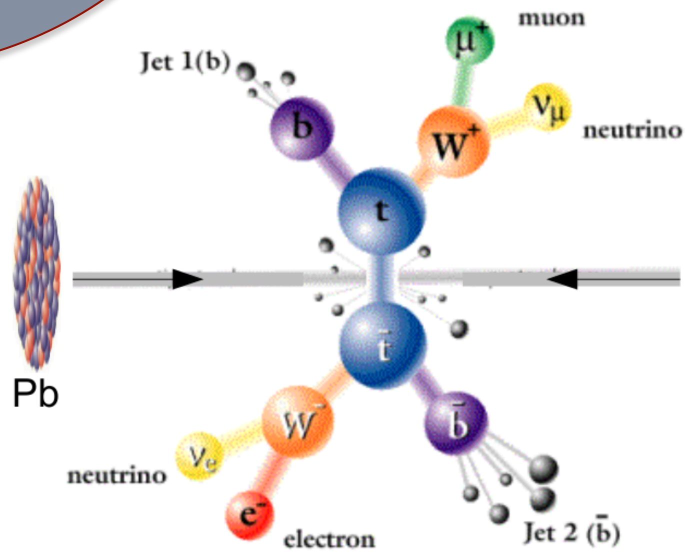
❖ Of the order of 140k b-jets with $p_T > 120$ GeV/c are expected with $10\ nb^{-1}$ of Pb-Pb collisions at 5.5 TeV

❖ Experimental channels with the smallest systematic uncertainties:
- **γ/Z-jet**
- **Double b-jets**

Main observables: energy or p_T imbalance. Predictions from theory?



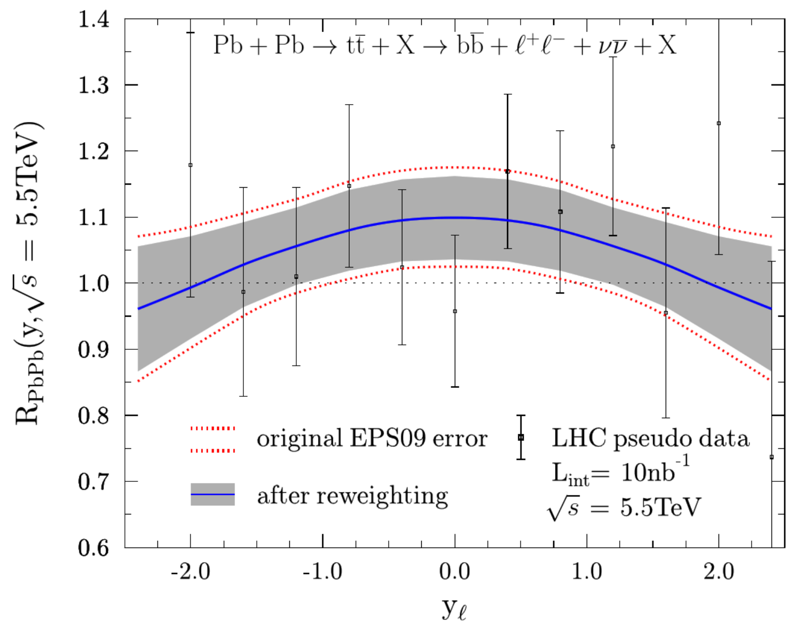
Double t-jets at the LHC?



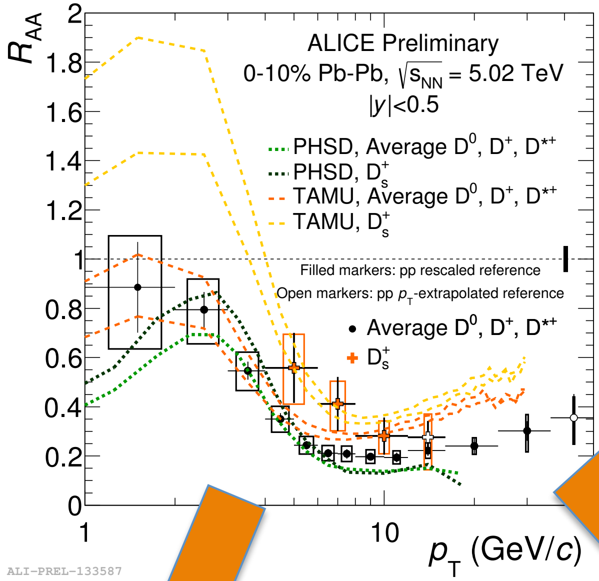
- Production of the top quark was never observed in heavy-ion collisions
- Due to its large mass it decays before hadronizing, almost 100% of the time to W+b
- **Short decay time: decay happens typically before QGP formation…**

https://indico.cern.ch/event/698005/contributions/2906348/attachments/1611768/2559610/dde_ttbar_hl_lhc_ions_march18.pdf

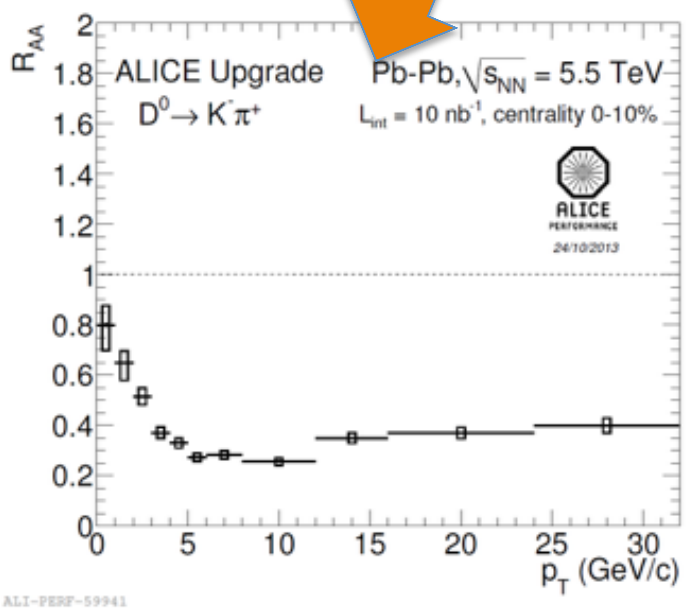
- … however, by selecting **high-momentum t pairs** one can select a sample of tt pairs spending a fraction of their lifetime inside the QGP: energy loss measurement could be afforded
- Nearly 35 000 tt pairs expected for 10 nb^{-1} Pb-Pb collisions at 5.5 TeV, with ≈ 450 reconstructed pairs in the $l^{+}l^{-}$ + bb + MET channel

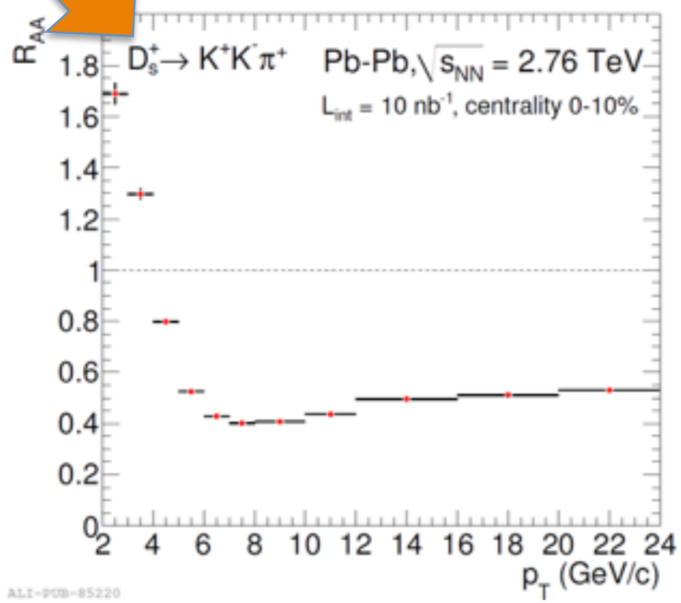


Charmed Mesons in ALICE



- D^0: standard candle for charm measurements. Total uncertainties with the new ITS below 10% down to zero p_T thanks to:
  - Easier signal extraction (background down by a factor 5-10)
  - Precise prompt component isolation



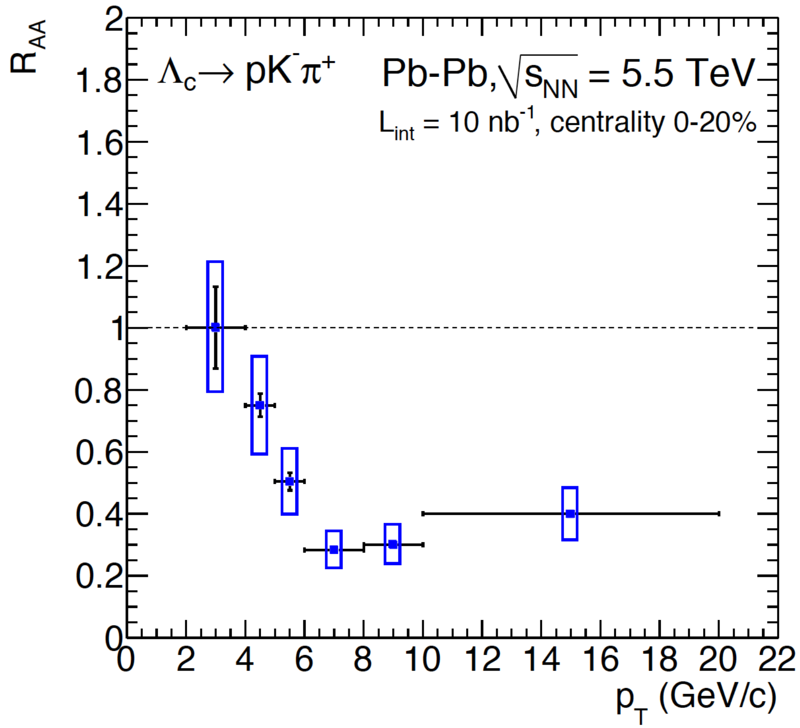


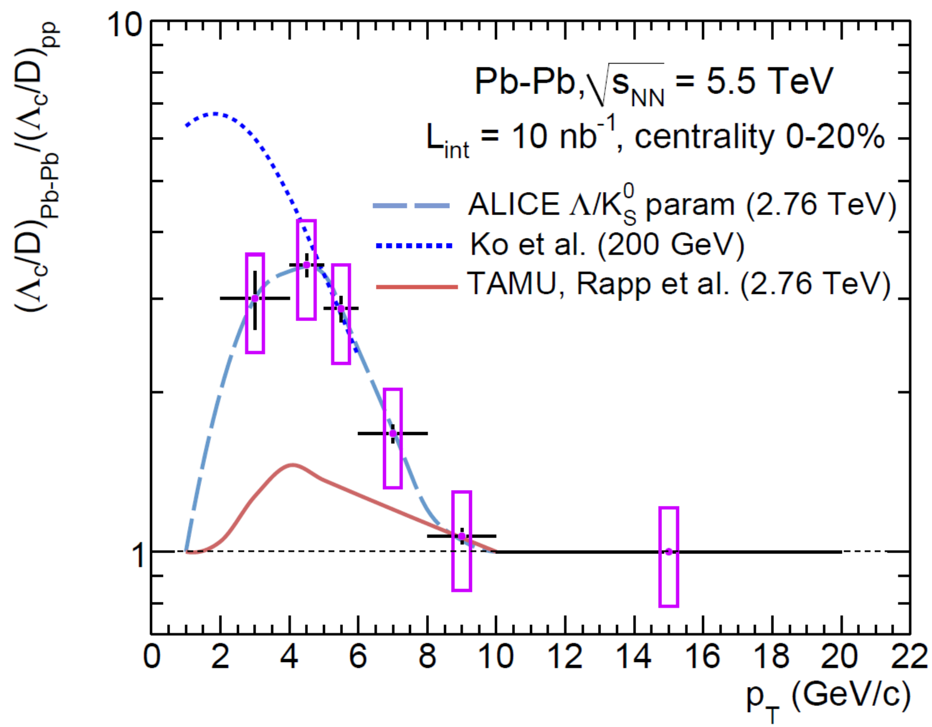
- D_s also accessible down to zero p_T (systematics under evaluation)

Charmed Baryons

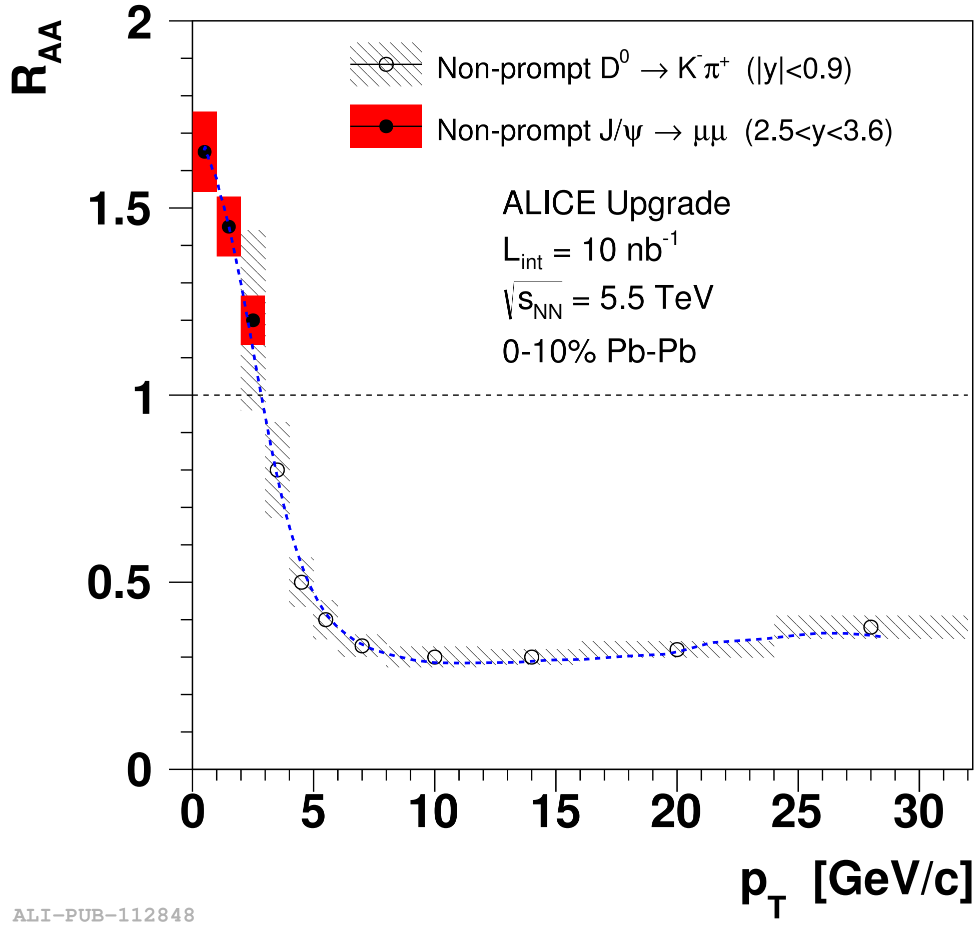
Baryon/meson ratio and baryon R_{AA} in charm sector with the upgraded ITS

- Λ_c measurement needed, but...
- ... $\Lambda_c \rightarrow pK\pi$ not accessible with the current ITS in Pb-Pb
- **Upgrade improvement in resolution** allows for cleaner vertex separation: Λ_c production measurable down to p_T = 2 GeV/c





- **ALICE can combine beauty measurements at mid- and forward-rapidity** to better constrain theoretical models. Golden channels: displaced D^0 at mid-rapidity, displaced J/ψ at forward rapidity

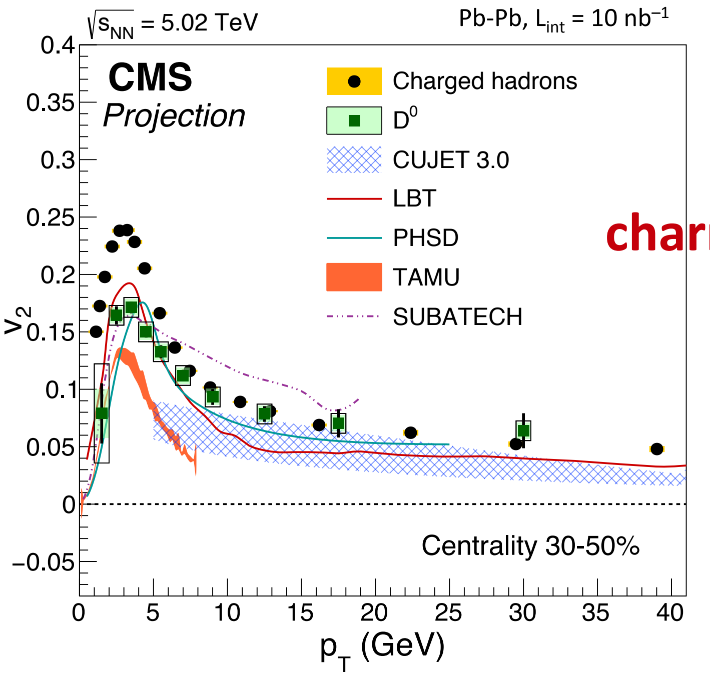


- **Displaced/prompt separation** possible at forward rapidity down to zero p_T(J/ψ) within 5% stat. + syst. uncertainties

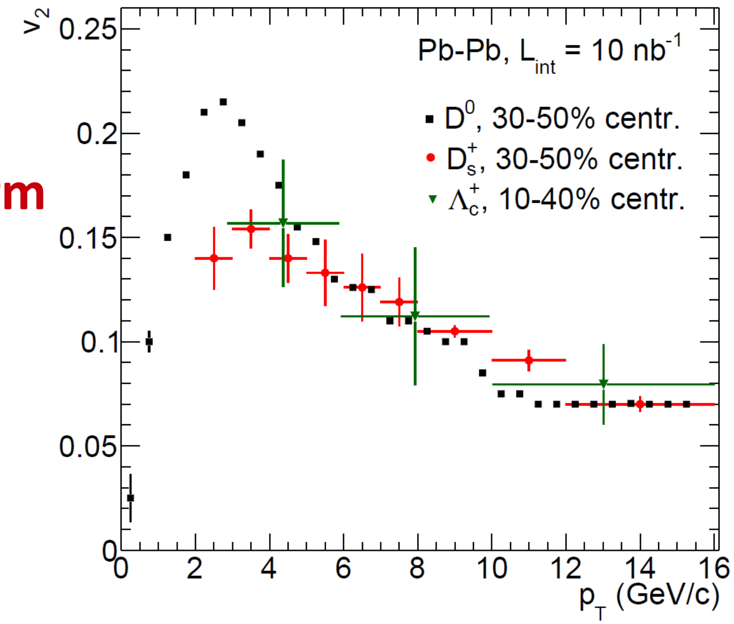
- **Beauty R_{AA} measurement** possible down to zero p_T(J/ψ) within 7% stat. + syst. uncertainties even in central Pb-Pb

Elliptic-flow measurement will be addressed by ALICE both at mid- and forward-rapidity for both charm and beauty sectors. CMS will also perform precise measurements of the charm elliptic flow at mid-rapidity

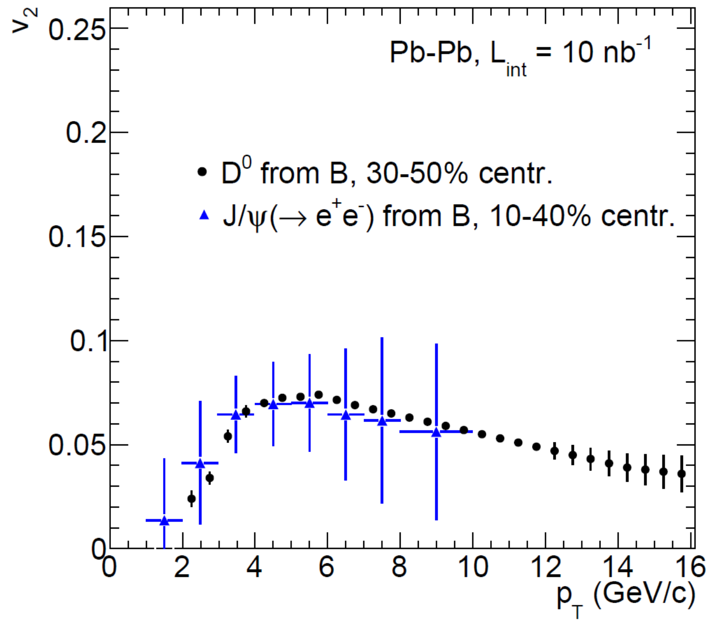
- **Mid-rapidity:** prompt charm mesons/baryons; D mesons and J/ψ from B (figures)
- **Forward:** single muons from D; J/ψ from B + single muons from B (in evaluation)



charm

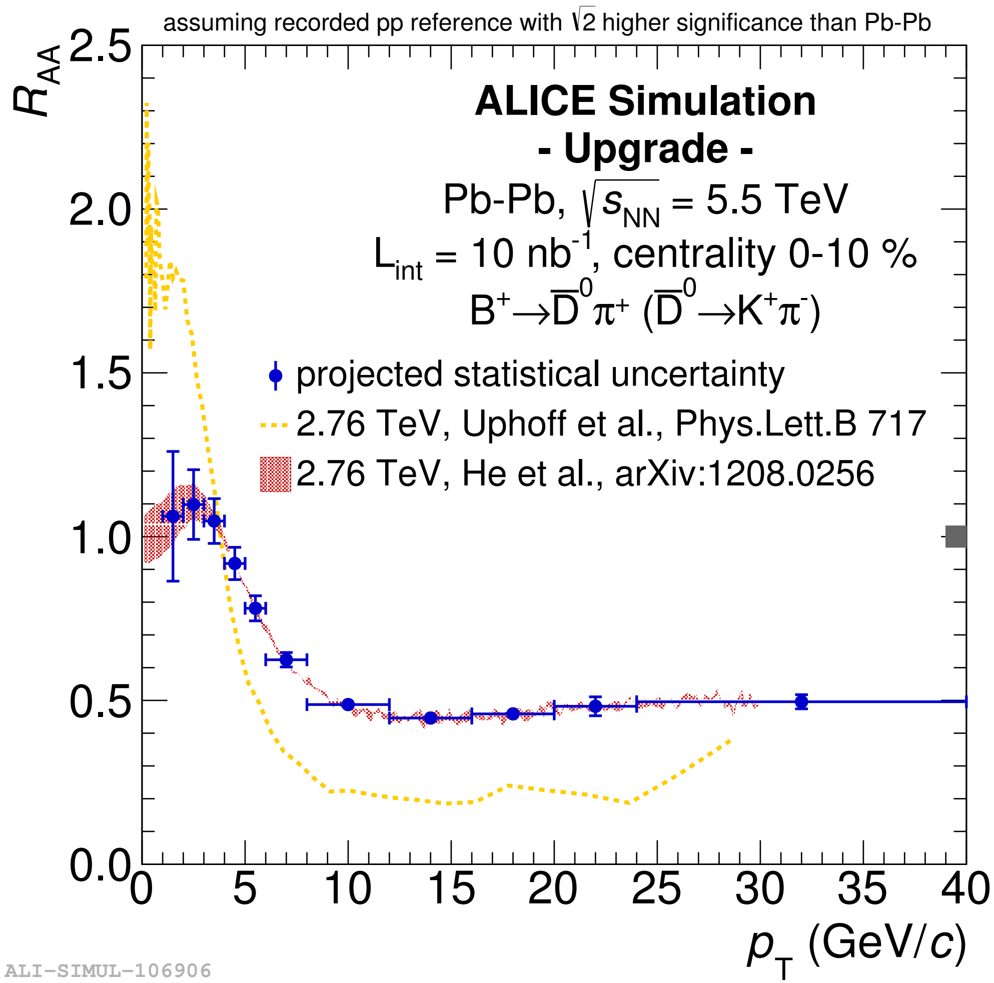


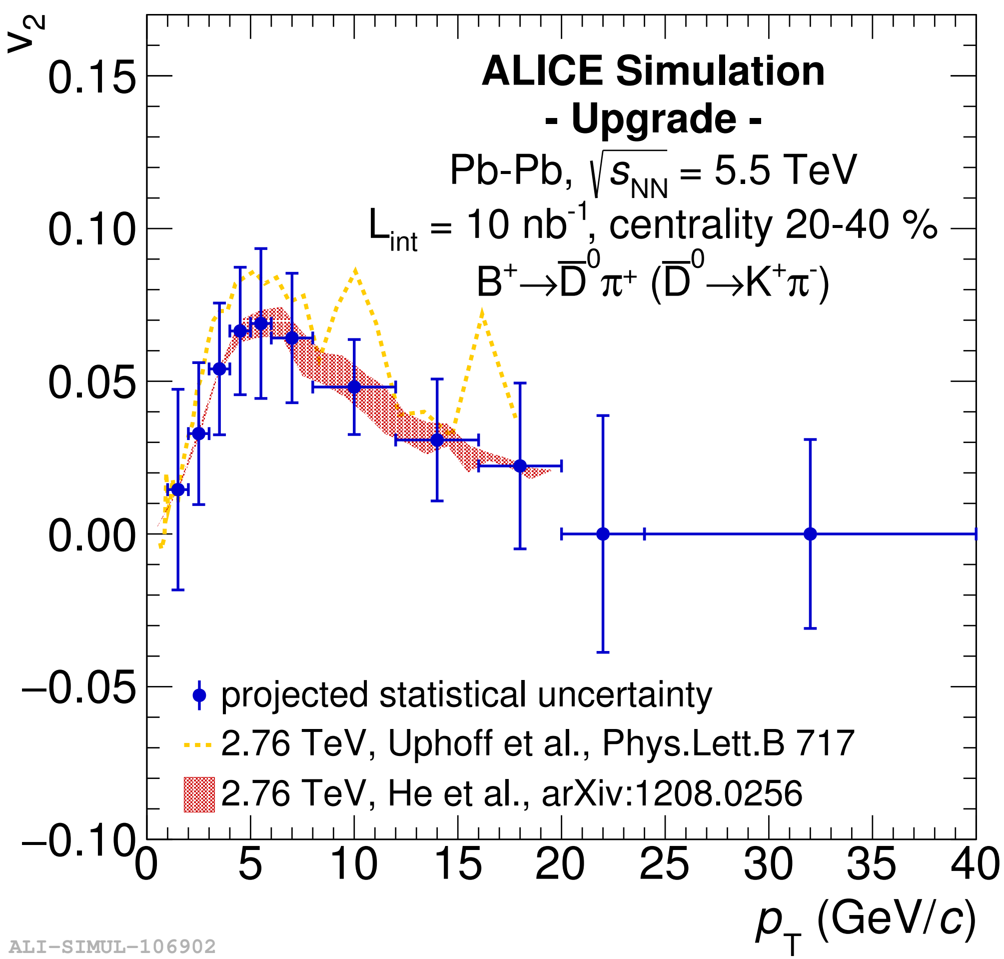
beauty



Full Beauty Hadron Reconstruction

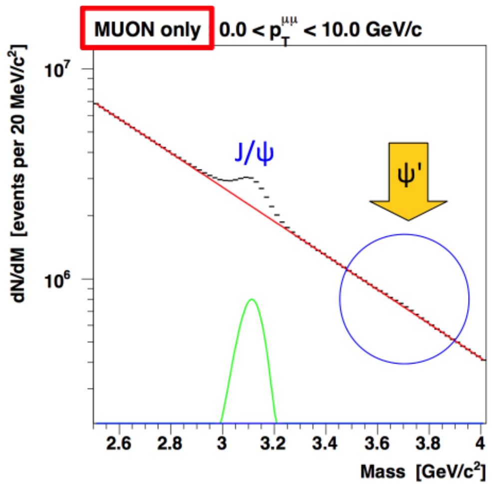
- **R_{AA} and v_2 measurements possible for B^+ reconstructed in the** displaced $D^0\pi^+$ channel down to low p_T (ALICE central barrel)

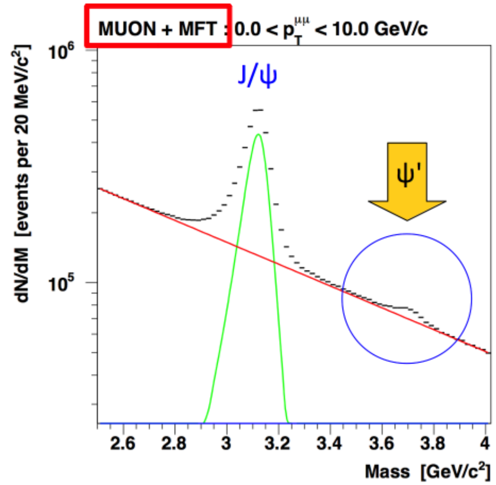


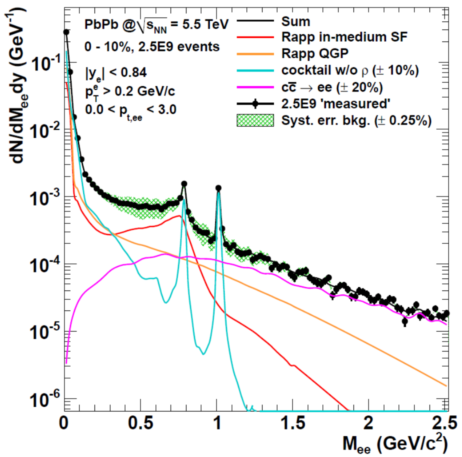


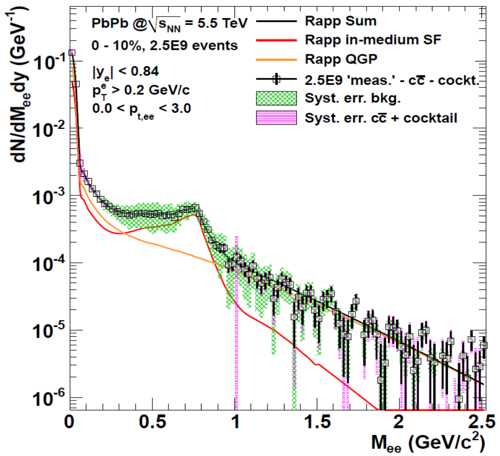
Improved discrimination of prompt/displaced dileptons thanks to the upgraded ITS (central dielectrons) and MFT (forward dimuons)

- **Isolation of forward prompt J/ψ** (not possible without the MFT)
- **S/B improvement for ψ(2S)** in central Pb-Pb (dimuon channel) by a factor 6-7





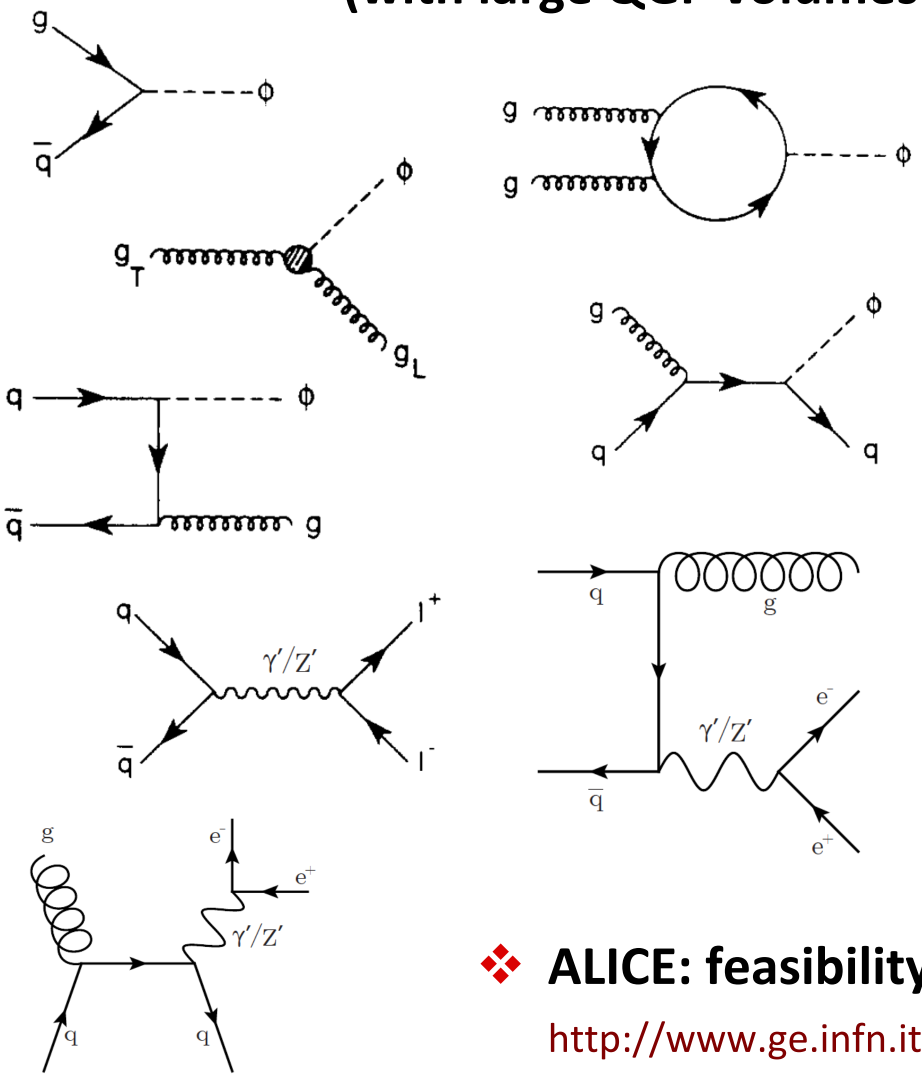




- **Isolation of medium-modified ρ; thermal radiation from QGP**
- **Excellent performance in the dielectron channel** with a dedicated low magnetic field (low-p_T acceptance)

Light BSM Bosons from QGP: a Case for HL-LHC?

Light scalar or vector BSM bosons could be observed in **high-energy (with large QGP volumes produced), high-luminosity nuclear collisions**



J. Ellis & P. Salati, Nuclear Physics B342 (1990)
J. Davis & C. Böhm, arXiv:1306.3653

- **Resonance in the thermal dilepton production from the QGP** for masses up to 3 GeV/c^2: dilepton measurements in ALICE could set limits on quark- and lepton-couplings of light BSM bosons

- **Heavier bosons** would mainly decay into multiparticle states involving cc and ττ pairs, and are **no longer detectable in the ee or μμ channels**

- **ALICE: feasibility studies on dark photons of mass < 100 MeV/c^2**

  http://www.ge.infn.it/~ldma2015/presentations/wednesday-morning/05_gunji.pdf

Summary

- **Heavy-Ion physics in LHC Runs 3+4: fully exploit the potential of the machine as a high-luminosity HI collider**
  - Pb-Pb > 10nb^{-1} : rare triggers ×10 w.r.t. Run 2 (CMS, ATLAS), ×50-100 for minimum bias (ALICE)
  - pp reference at Pb-Pb energy; p-Pb; possibly light ions

- **Rich physics program being prepared by the experiments**
  - Upgraded detectors and DAQ systems to cope with the high interaction rate
  - **ALICE:** focus on untriggerable probes by recording all events after online data volume reduction
  - **CMS/ATLAS:** focus on triggerable probes with L1 and High-Level Triggers to reduce the rate of recorded events
  - **LHCb:** potential for the HL-HI-LHC will be clear once the results of the 2015/18 Pb-Pb runs are available

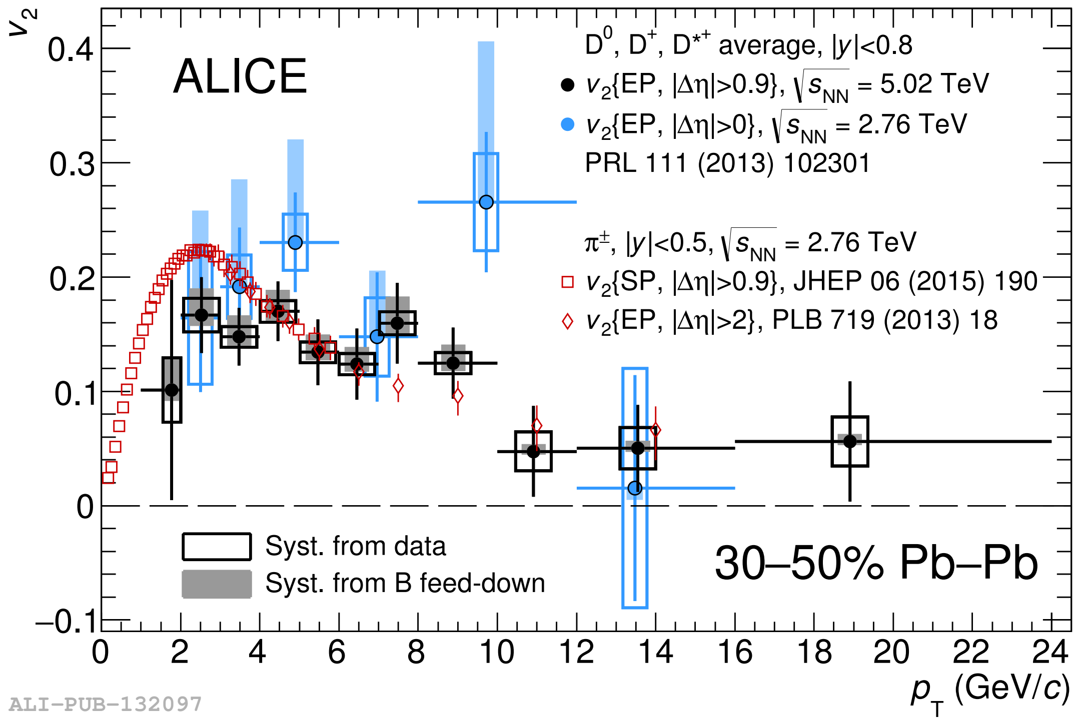
- **Yellow Report under preparation** within the HL-LHC Physics workshop input, for the update of the European Strategy for Particle Physics (2020)

Backup Slides

❖ **Moving from an exploratory phase to a precision-measurement phase**

➡ Quantitative leap in the precision of the experimental observations

- ✓ Heavy quarks take part in collective expansion
- ✓ Still challenging to see expected hierarchy in energy losses
- ✓ Distinguish between b/c energy losses is limited to high p_T
- ✓ No access in Pb-Pb to charm and beauty baryons: baryon/meson ratio for light flavor only
- ✓ Room for more differential measurements on quarkonia



Heavy-Ion Physics: Why at High-Luminosity?

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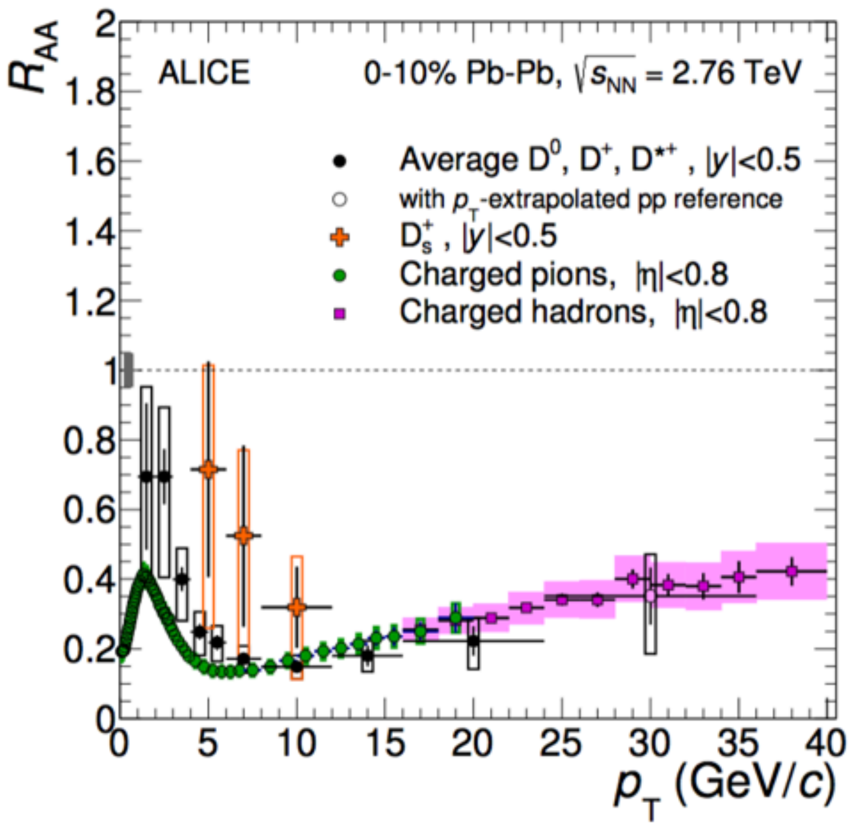

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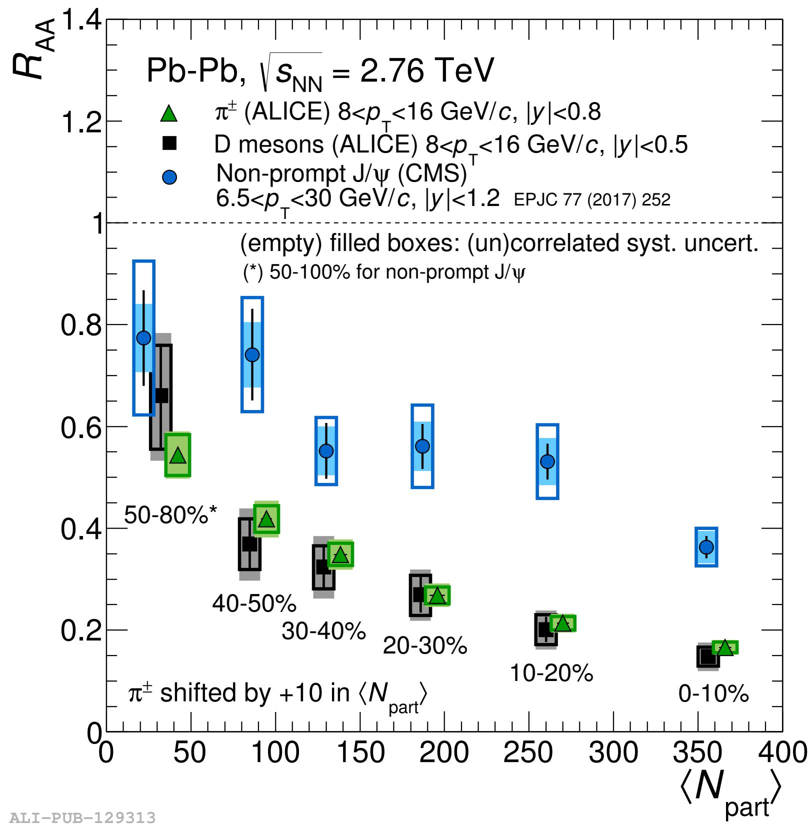

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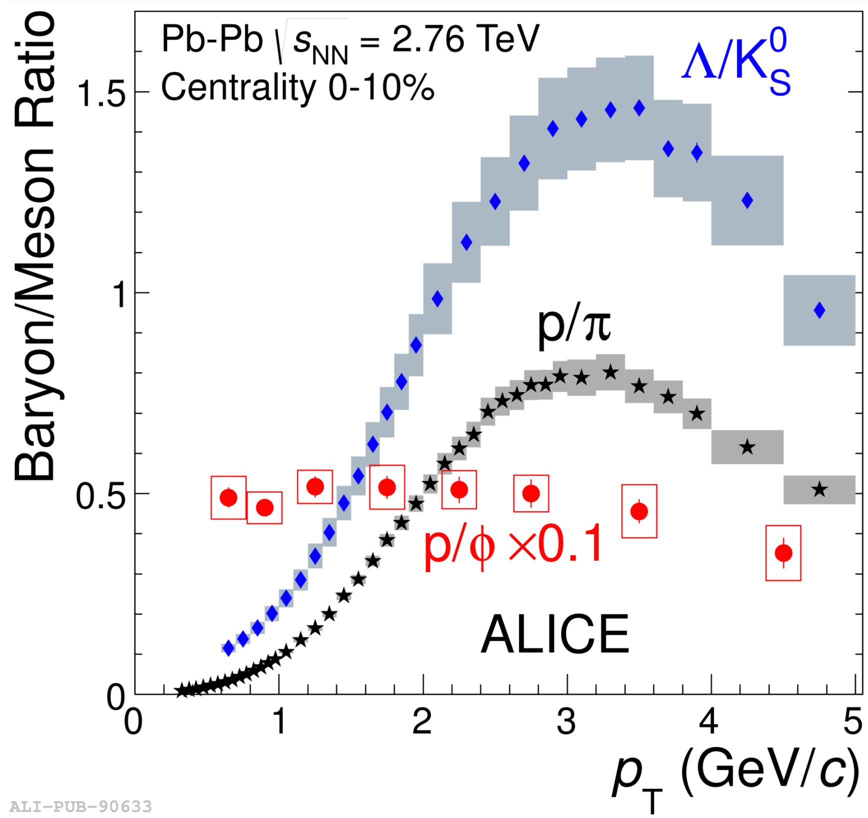

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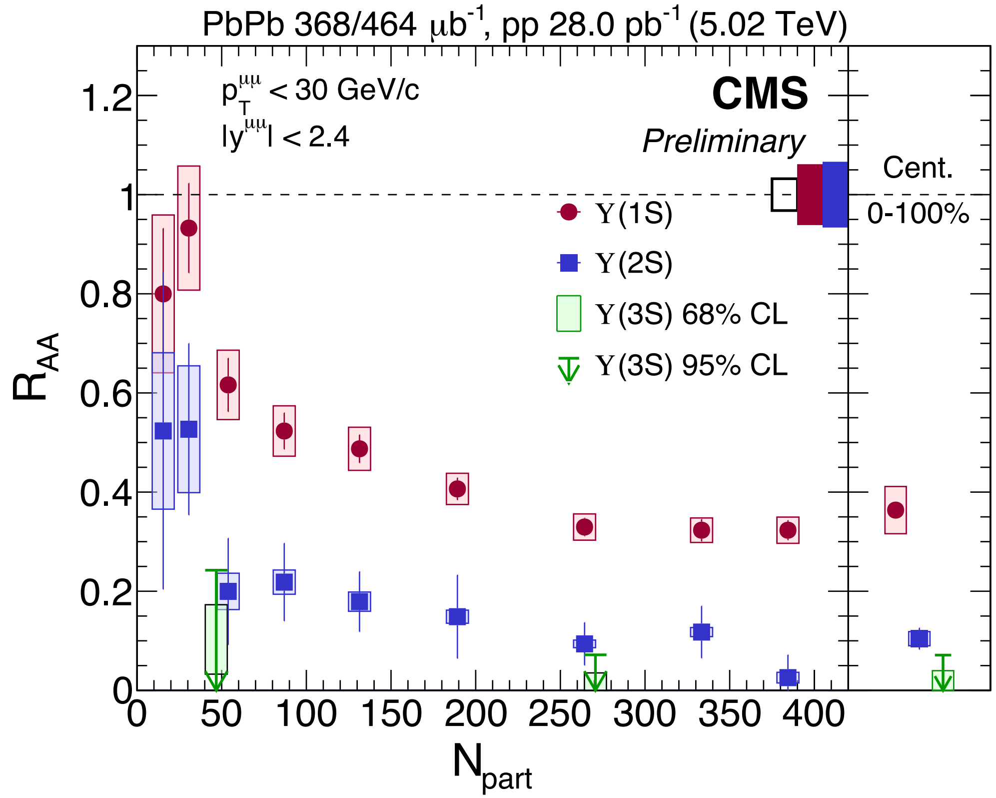


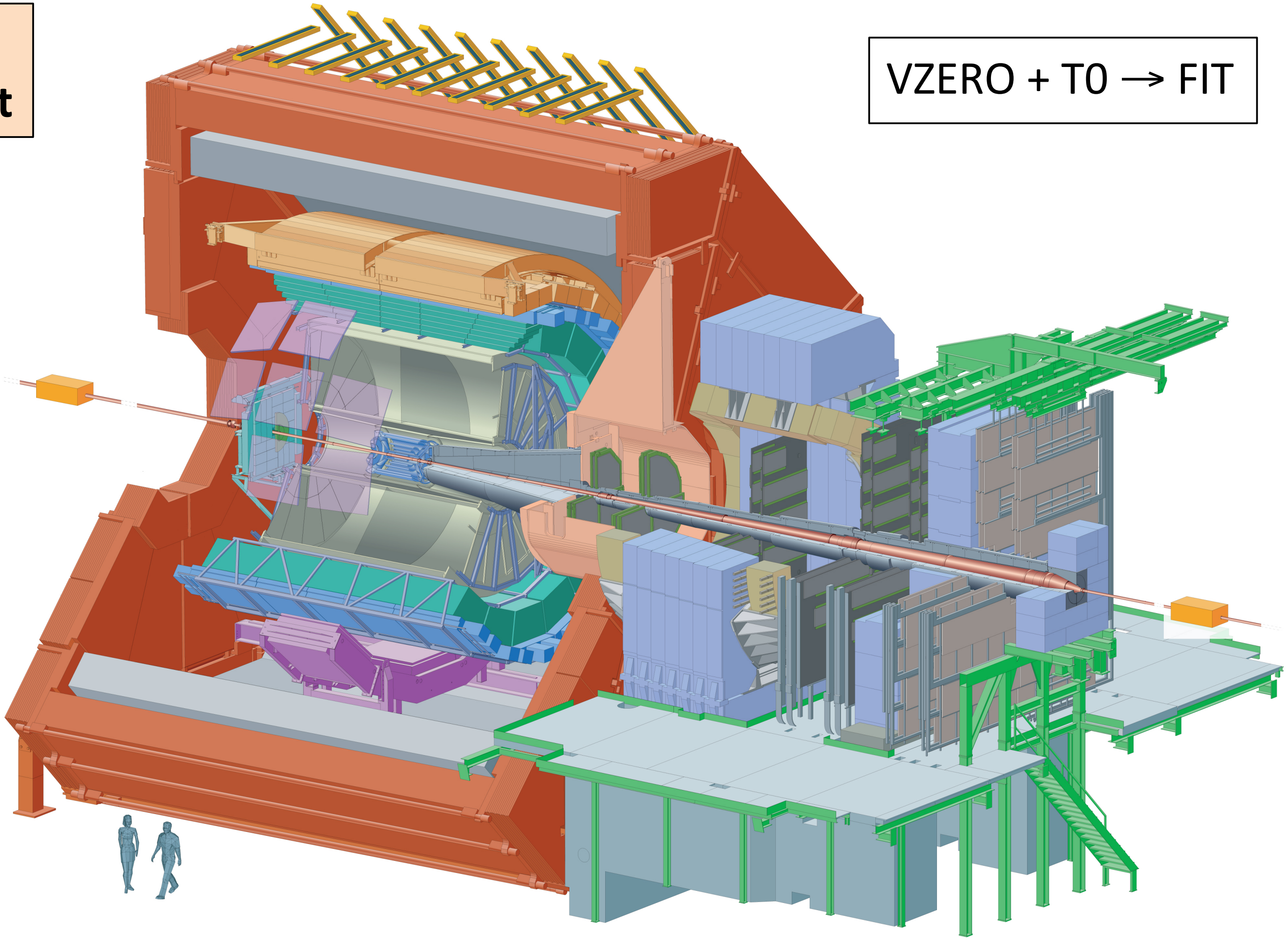
ALICE Upgrade Strategy

Muon Forward Tracker

TPC: new GEM readout chambers, pipelined readout

VZERO + T0 → FIT

TRD, TOF, PHOS, EMCAL, Muon spectrometer: New readout electronics



New beam pipe: smaller diameter

New ITS: high resolution, low material budget

Data Acquisition Strategies in Pb-Pb

Target luminosity in Pb-Pb after 2020 implies huge data volumes per second (in the case of ALICE, up to 1 TB/s). Two approaches are foreseen:

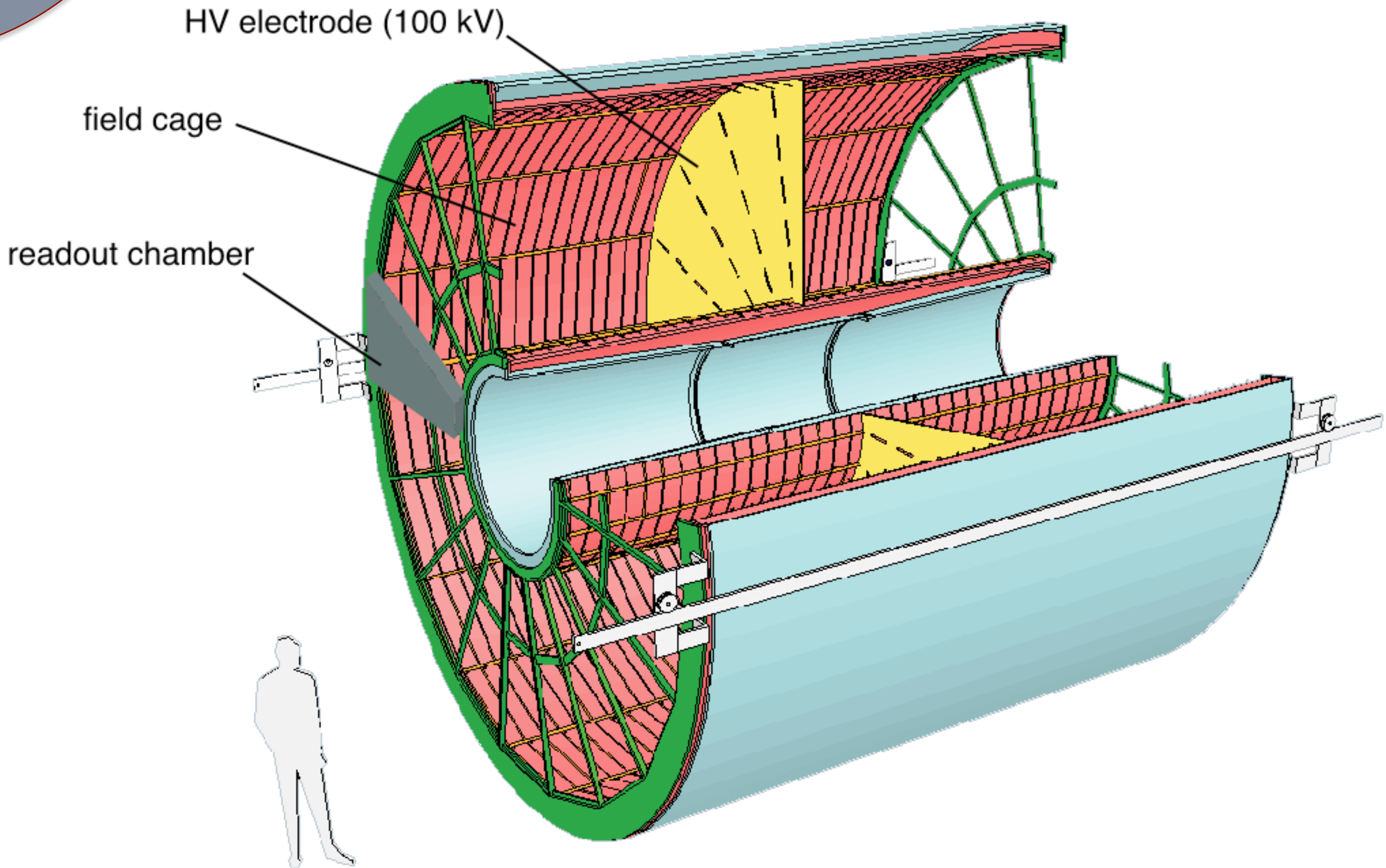
Reduction of the event size: the ALICE way

- Data transfer in continuous mode fashion or by using minimum bias trigger
- Dedicated time markers used to “chop” data in Time Frames to be inspected
- Local compression (e.g. for TPC cluster finding)
- Online calibration & global reconstruction replace original raw data with compressed
- Optimized for untriggerable probes (low-p_T signals and complex topologies)
- Increase of minimum-bias sample ×100 w.r.t. Run 2

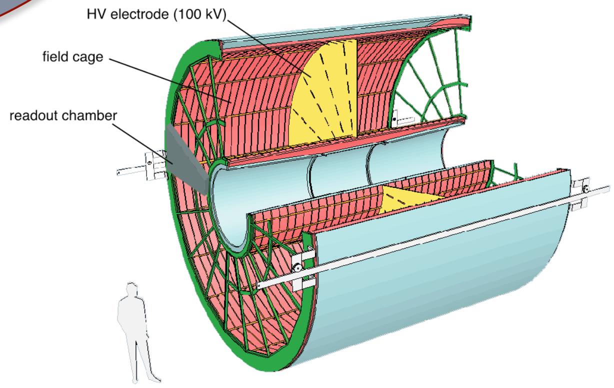
Reduction of the recorded event rate: the ATLAS/CMS way

- Strong reduction of the event recording rate from 50 to 0.1 kHz by combining trigger and DAQ
- Optimized for triggerable signals (muons, jets, displaced track topologies)
- Increase of rare-triggered event sample ×10 w.r.t. Run 2

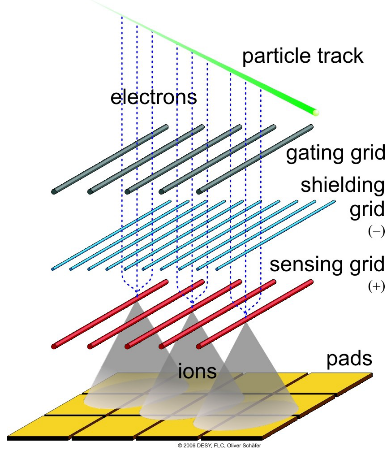
The ALICE Upgraded TPC



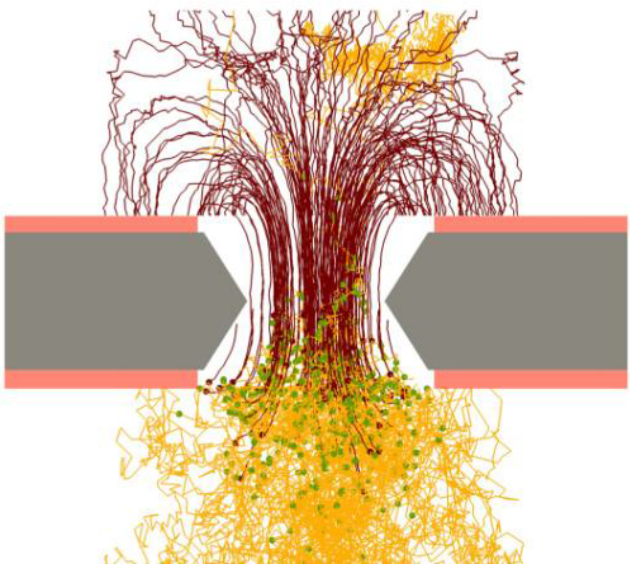
The ALICE Upgraded TPC



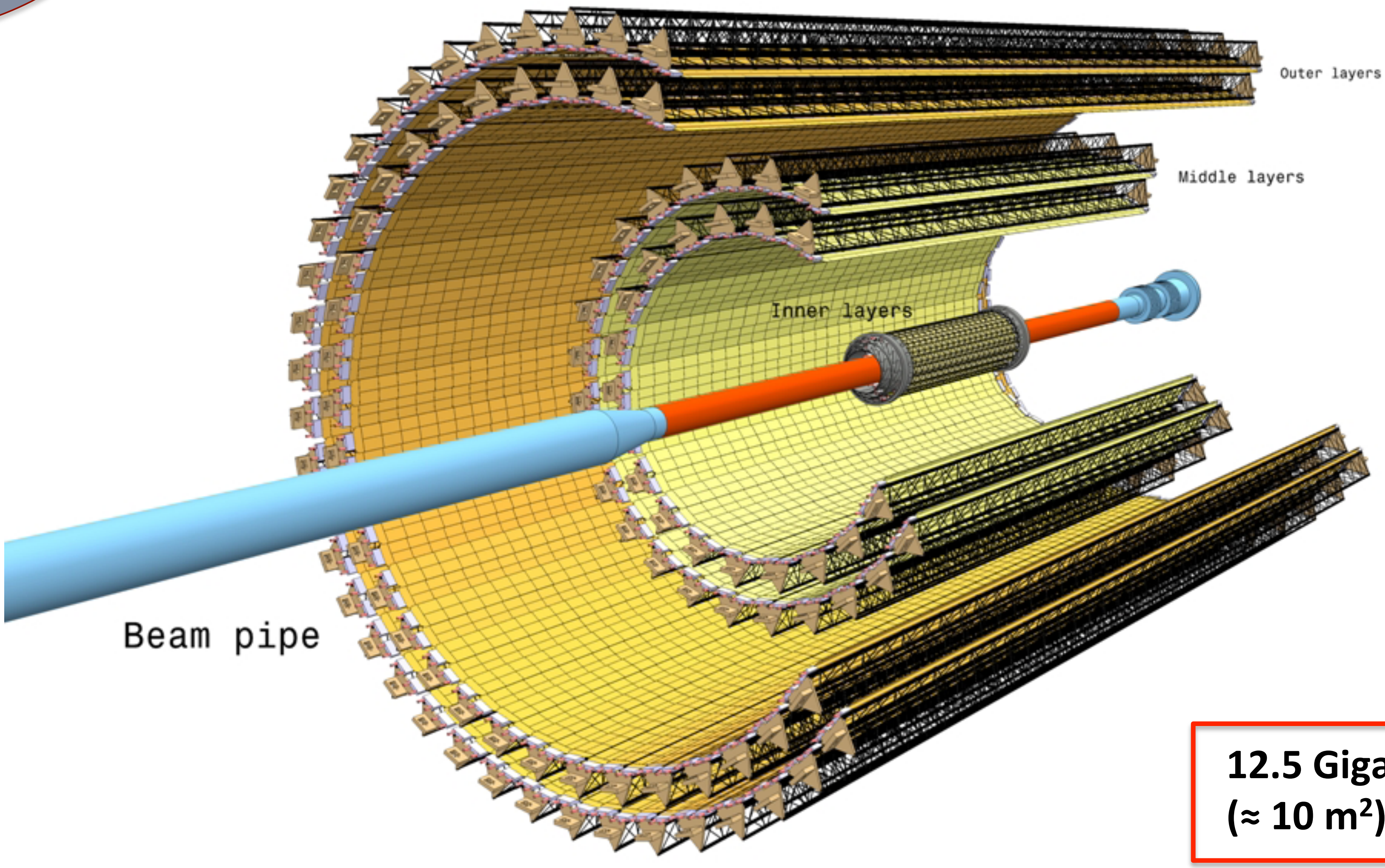
- **At the readout plane**, the signal is amplified and collected on a segmented readout structure
- Traditionally, ions from amplification are collected on a **gating grid which limits rate capability**



- **MWPCs:** ion clearing time (drift from readout to gating grid) introduces dead time. Max. readout rate: 3.5 kHz
- **GEMs:** Intrinsic Ion BackFlow (IBF) suppression ➜ no gating required, continuous readout possible. **However, residual 1% IBF** induces a non-negligible space charge distribution inside the TPC drift volume (7500 piled-up events @ 50 kHz) to be carefully accounted for

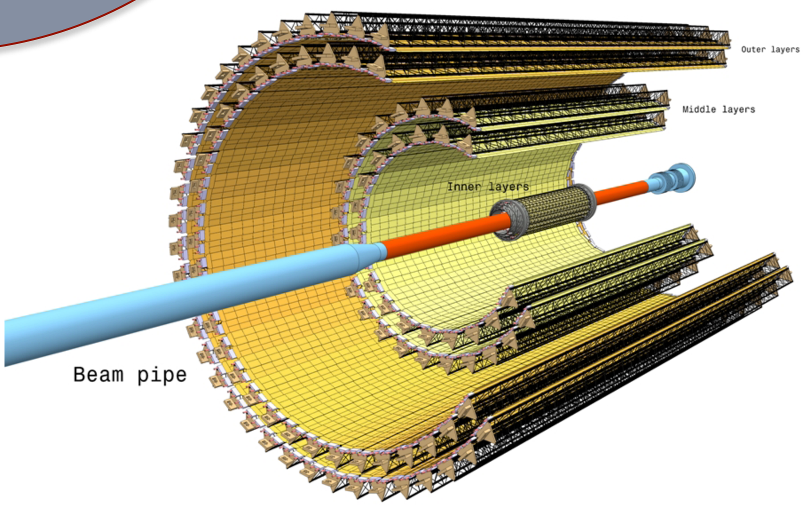


The ALICE Upgraded ITS



12.5 Giga pixel
(≈ 10 m^2)

The ALICE Upgraded ITS



Improve impact parameter resolution by a factor ~3

- Smaller beam pipe (R = 1.9 cm)
- Inner layer as close as possible (R = 2.2 cm)
- Thinner beam pipe (ΔR = 800 μm)
- Less material budget: thin sensors, 7 layers of monolithic pixel detectors (goal: 0.3% X_0 for inner layers, 0.8% X_0 for outer layers)
- Smaller pixel size: ≈ 28×28 μm² for the inner layers

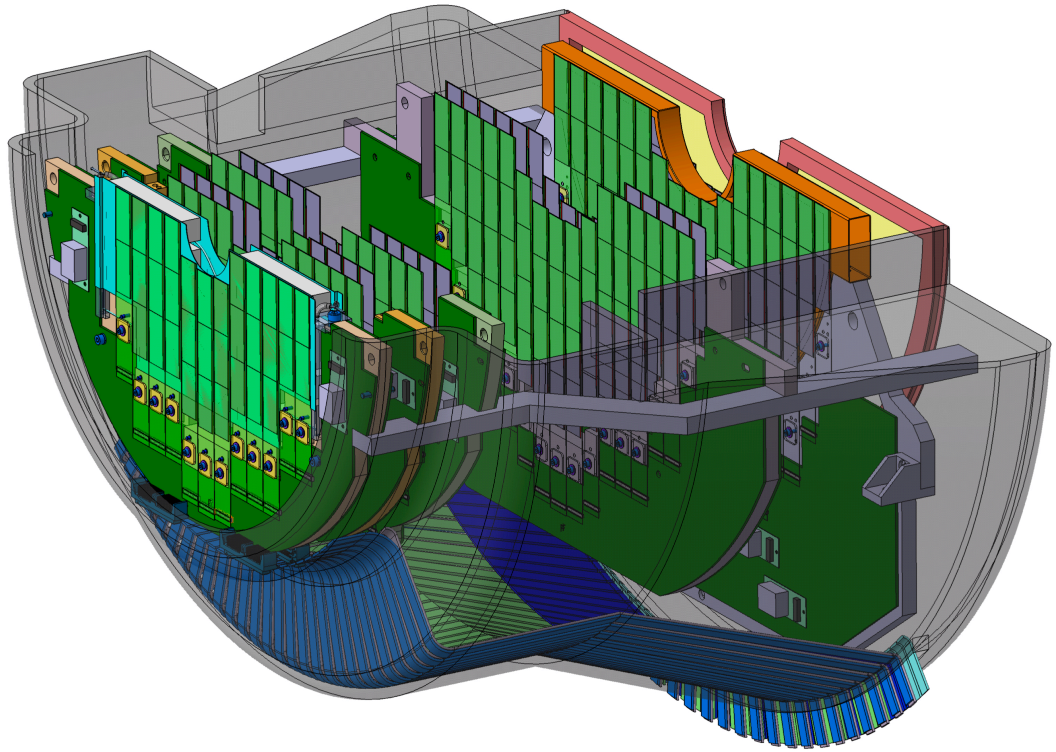
High standalone tracking efficiency and p_T resolution

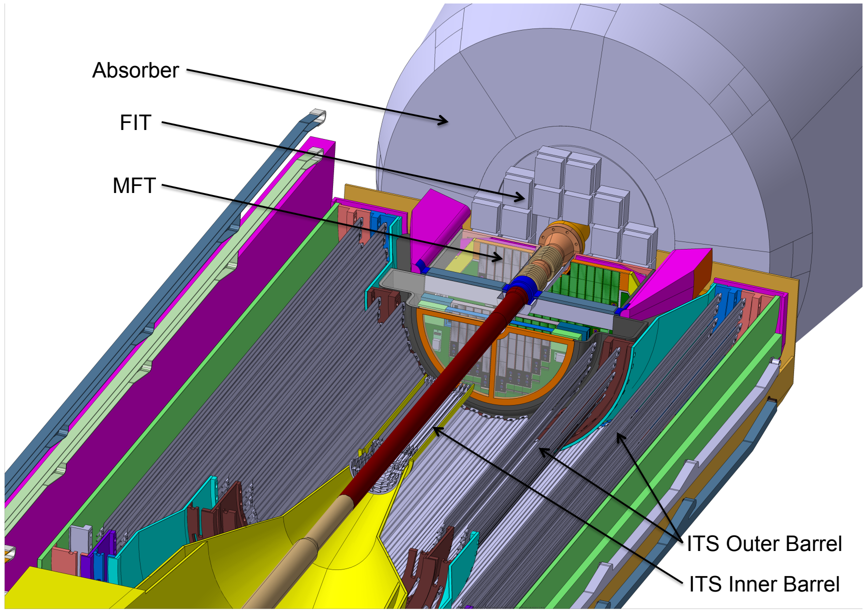
- Increase granularity: 6 layers → 7 layers with spatial resolution σ(rϕ,z) = 4-6 μm
- Fast readout: readout of Pb-Pb interactions at 50 kHz and pp up to 1 MHz

	current ALICE	ALICE upgrade	ATLAS upgrade	CMS upgrade
innermost point (mm)	39.0	22.0	25.7	30.0
x/X_0 (innermost layer)	1.14%	0.3%	1.54%	1.25%
d_0 res. $r\varphi$ (μm) at 1 GeV/c	60	20	65	60
hadron ID p range (GeV/c)	0.1–3	0.1–3	–	–

The ALICE Muon Forward Tracker (MFT)

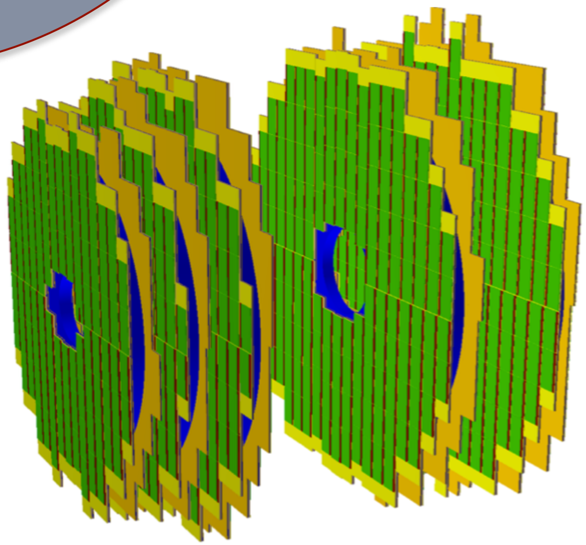
- **MFT: vertex tracker for the Muon Spectrometer**, to be installed between the interaction point and the hadron absorber





- **Precise tracking of muons:** identification of secondary vertices (J/ψ from B), measurement of single muon offset at the primary vertex

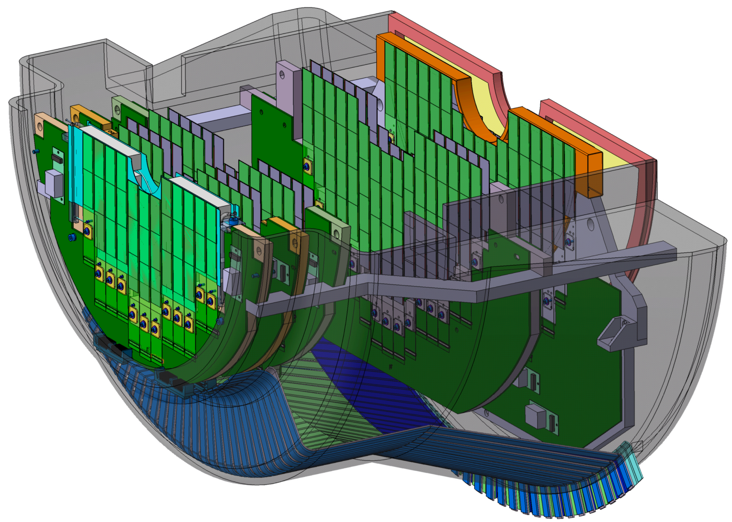
The ALICE Muon Forward Tracker (MFT)



- **896 silicon pixel sensors (0.4 m²)** in 280 ladders of 1 to 5 sensors each
- **10 half-disks, 0.6% x/X_0 and 2 detection planes each**
- **5% of the ITS surface, twice the ITS inner barrel**

- **Nominal acceptance:** $\begin{cases} 2.5 < \eta < 3.6 \\ \text{Full azimuth} \end{cases}$

- **Inner radius limited by the beam pipe**. Combined MFT+MUON acceptance will be 0.4 unity of rapidity smaller than current MUON one



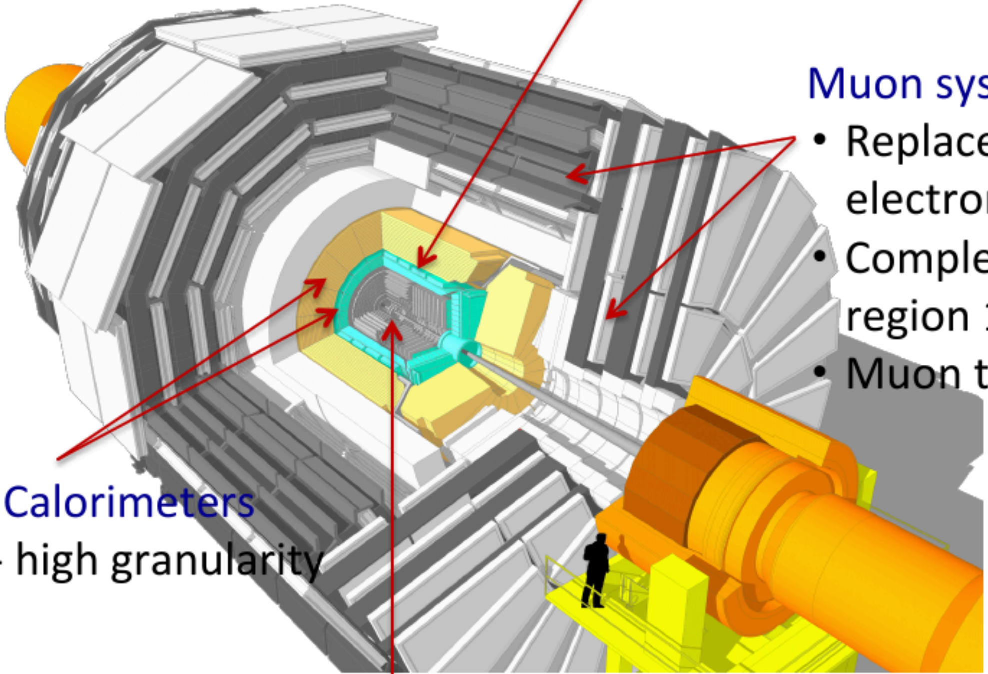
CMS Upgrades Relevant for Heavy-Ions

Trigger/HLT/DAQ
- Track information at L1-Trigger
- L1-Trigger: 12.5 μs latency - output 750 kHz
- HLT output ≃7.5 kHz

Barrel EM calorimeter
- Replace FE/BE electronics
- Lower operating temperature (8◦)

Muon systems
- Replace DT & CSC FE/BE electronics
- Complete RPC coverage in region $1.5 < \eta < 2.4$
- Muon tagging $2.4 < \eta < 3$

Installation during LHC LS3 (2024-26)



Replace Endcap Calorimeters
- Rad. tolerant - high granularity
- 3D capability

Replace Tracker
- Rad. tolerant - high granularity - significantly less material
- 40 MHz selective readout (Pt≥2 GeV) in Outer Tracker for L1-Trigger
- Extend coverage to $\eta = 3.8$

ATLAS Upgrades Relevant for Heavy-Ions

- **ATLAS detector Phase 1 Upgrade (before Run 3)**
  - Level-I trigger based on hardware track reconstruction and fitting: extra resources will be available in L2 trigger for more advanced selection algorithms (b-tagging, lepton identification…)
  - Calorimeter electronics upgrades: improved segmentation
  - New forward muon detectors with better performance at high occupancy

- **ATLAS detector Phase 2 Upgrade (before Run 4)**
  - Complete replacement of the ATLAS inner detector with silicon pixel and strip detector with substantially reduced material budget

- **Main benefits:**
  - Better pattern recognition in Pb-Pb (reduced multiple scattering, rates for photon conversion and electron bremsstrahlung)
  - Improved mass resolution for the Υ states
  - Improved background rejection for γ/Z-jet events

ALICE Muon Physics: Current Items

- **Low-mass dimuons.** Non-perturbative aspects of QCD through Dalitz and 2-body decays of light narrow resonances close to freeze-out. (Hidden) strangeness production. Thermal emission mediated by the broad vector meson ρ in the form $\pi^+\pi^- \longrightarrow \rho \longrightarrow \mu^+\mu^-$

- **Quarkonium states.** Dissociation/recombination in the QGP phase (and in smaller systems?). Thermal charm production at low p_T. Test of perturbative QCD hadro-production mechanisms in pp collisions. Photo-production in ultra-peripheral heavy-ion "collisions"

- **Heavy-flavor single muons.** Energy loss and coupling of charm and beauty quarks with the deconfined medium

- **Single muons and dimuons from W/Z bosons.** Standard candle reference for in-medium effects. Probes of nucleons and nuclei parton structure

ALICE Upgrade Strategy

- **ALICE will run at 50 kHz in Pb-Pb** (i.e. $L = 6\times10^{27}\ \mathrm{cm}^{-1}\ \mathrm{s}^{-1}$) with minimum bias (pipeline) readout (max readout with present ALICE set-up: ≈ 0.5 kHz)
    - Gain a factor of 100 in statistics over current program: **×10** from the integrated luminosity ($1\ \mathrm{nb}^{-1} \rightarrow 10\ \mathrm{nb}^{-1}$) and **×10** from the pipelined readout allowing inspection of all collisions. Inspect $o(10^{10})$ central collisions instead of $o(10^{8})$

- **Improve vertexing and tracking at low p_T:** better spatial resolution is needed on track reconstruction to improve secondary vertex reconstruction

- **This entails a major upgrade of the whole apparatus:**
    - New, smaller radius beam pipe
    - New inner tracking system: upgraded ITS + MFT
    - High-rate upgrade for the readout of the TPC, TRD, TOF, CALs, DAQ/HLT, Muons and Trigger detectors

ALICE Upgrade Strategy

LHC roadmap: ion runs

Run2 : $\mathcal{L}_{integrated}^{Pb-Pb} = 1.0\ nb^{-1}$

Run3: $\mathcal{L}_{integrated}^{Pb-Pb} = 6.0\ nb^{-1}$

Run4 : $\mathcal{L}_{integrated}^{Pb-Pb} = 7.0\ nb^{-1}$

MFT Upgrade Physics Program

As a vertex tracker for the Muon Spectrometer, the MFT will have a major impact on several items of the ALICE muon physics

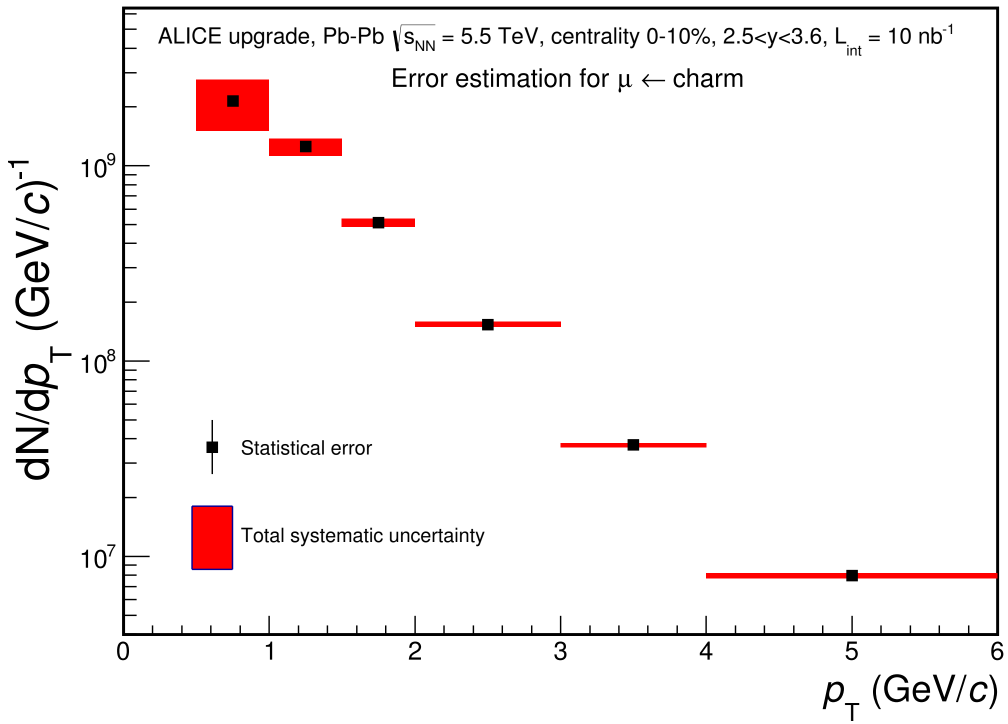
- **Open heavy flavors**
  - Charm measurement down to p_T = 1 GeV/c in the single muon channel
  - Beauty measurement down to p_T = 0 in the non-prompt J/ψ channel
- **Prompt Charmonium production**
  - Prompt/non-prompt J/ψ separation down to p_T = 0
  - ψ(2S) measurement in central Pb-Pb collisions, down to p_T = 0
- **Low-mass dimuons**
  - Improved mass resolution for resonances
  - Sensitivity to prompt continuum

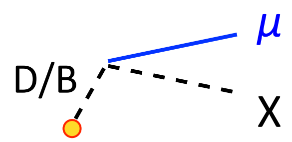
- **And also:**
  - Event plane measurement and azimuthal correlations at forward rapidity
  - Isolation of any prompt signal involving p_T > 1 GeV/c (Drell-Yan, limits on light BSM bosons?)

Muons from Charm with the MFT

- **Analysis based on the transverse offset measurement:** distance between the primary vertex (measured with the ITS) and the transverse position of the muon tracks extrapolated to the z of the primary vertex

- Pointing resolution requested to be better than 100 μm down to $p_T(\mu)$ = 1 GeV/c





- **Charm yield** accessible starting from $p_T(\mu)$ = 1 GeV/c (at least)

- **Important baseline** for charmonium measurements at forward rapidity

Beauty Measurement with non-prompt J/ψ

- **Prompt/displaced J/ψ discriminating variable:** longitudinal projection of the primary-secondary vertex distance considered for the analysis

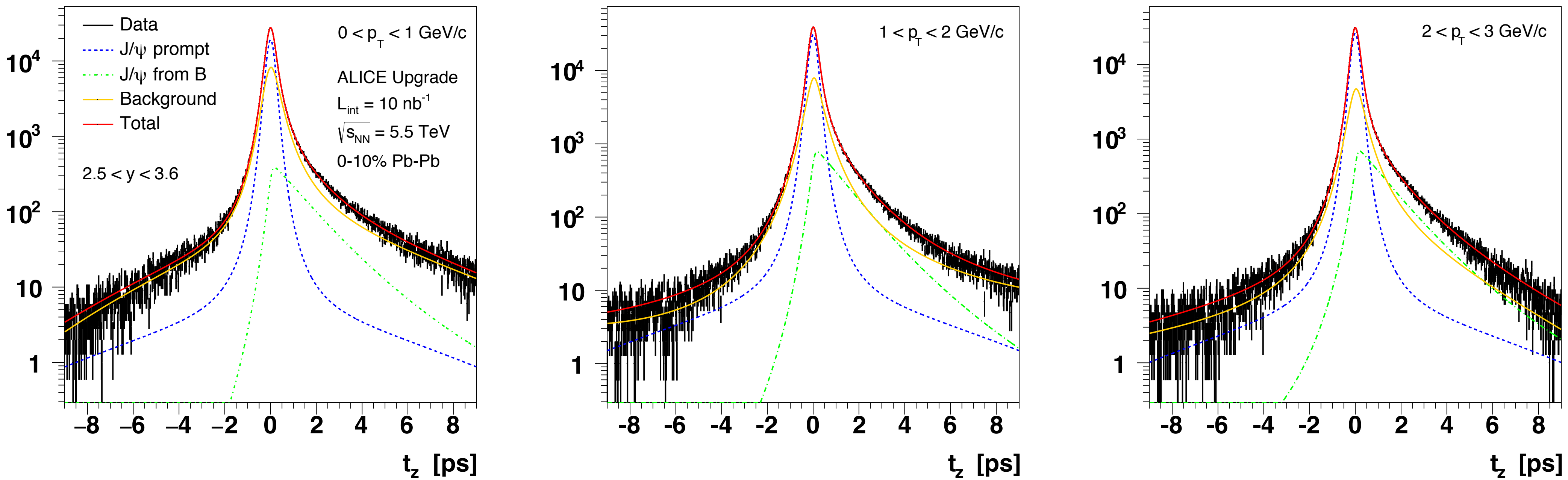
$$t_z = \frac{\left(z_{J/\psi} - z_{\mathrm{vtx}}\right) \cdot M_{J/\psi}}{p_z}$$

- **Analysis Strategy: double (possibly simultaneous) fit** on the dimuon invariant mass spectrum and the t_z distribution of the dimuons falling within the chosen J/ψ mass window
  - **The fit on the invariant mass spectrum** fixes the normalization of the background and the inclusive J/ψ signal. **The fit on the t_z distribution** then separates the two J/ψ contributions

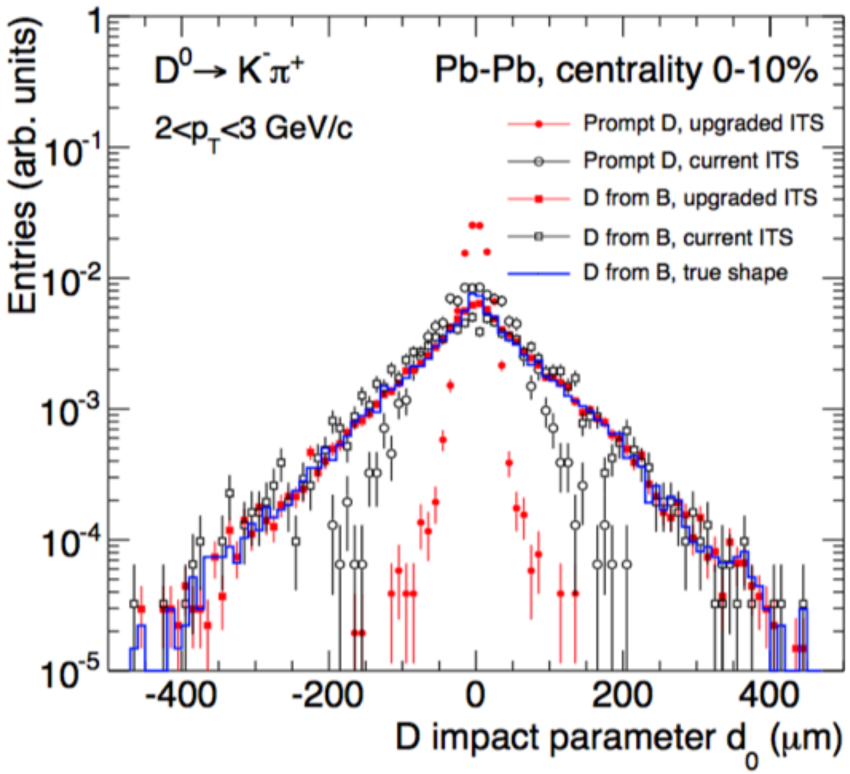
Non-prompt J/ψ: t_z Template Fits

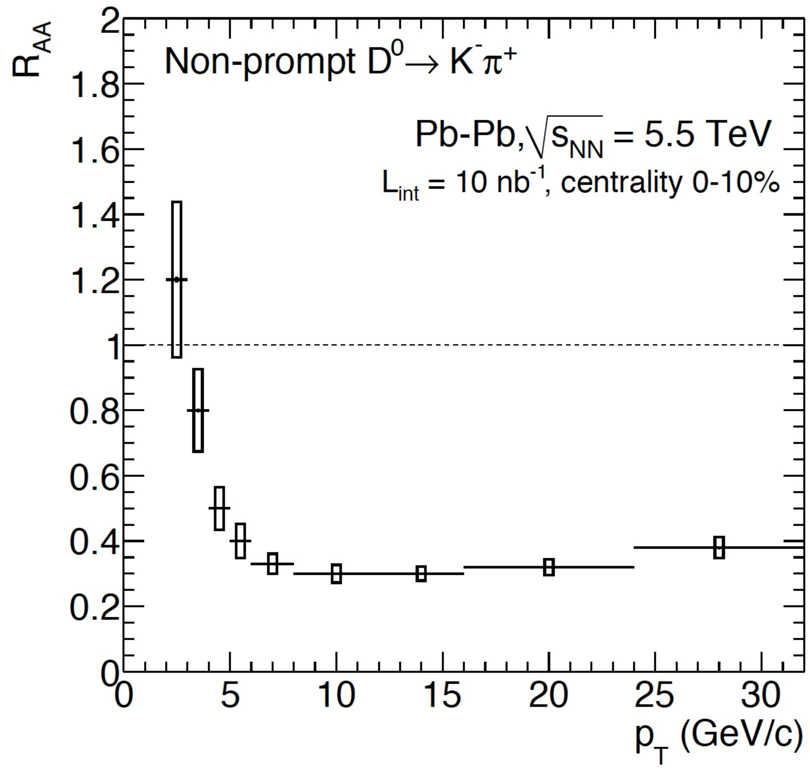
- **Weak p_T dependence of the t_z templates:** prompt/non-prompt J/ψ effective down to zero p_T

- **Background template:** cross-check possible between mixed event technique and data-driven side-band method. Normalization fixed by the fit on the invariant mass spectrum



Beauty Measurements: Non-Prompt D^0 and J/ψ





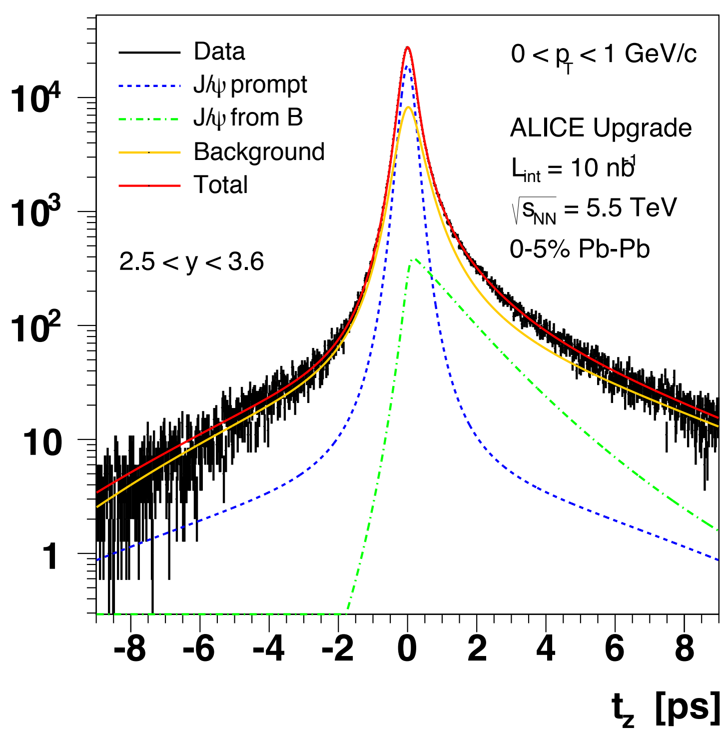
- B.R. (B → D^0 + X) ≈ 60%
- B: cτ ≈ 460-490 μm → we can exploit the impact parameter distributions
- With upgraded ITS resolution on impact parameter improves by a factor 3: better separation of prompt and non-prompt components

- **Non-prompt D^0 (beauty)** production accessible down to p_T = 2 GeV/c

Beauty Measurements: Non-Prompt D^0 and J/ψ

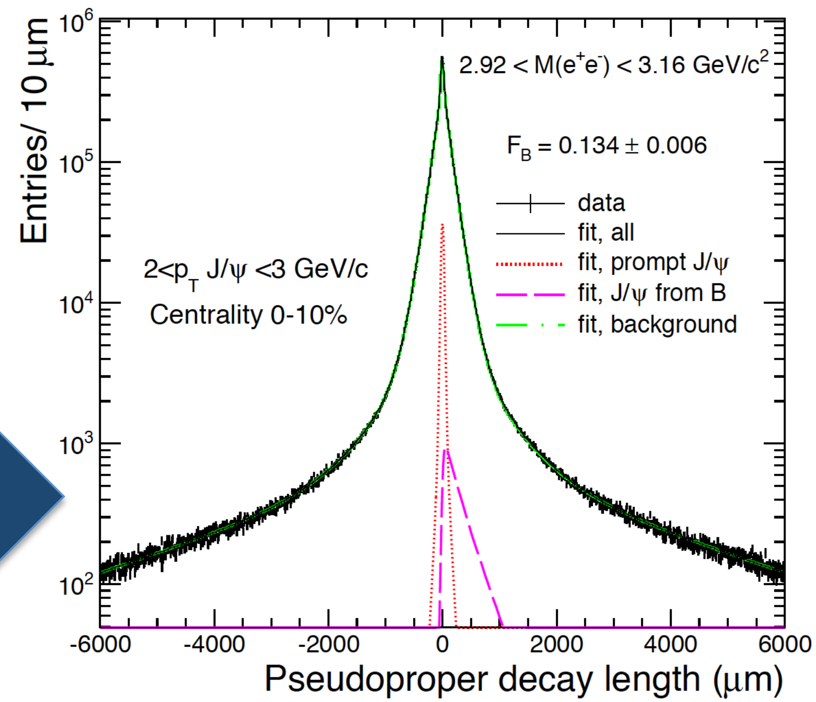
Based on the reconstruction of J/ψ (to dileptons) secondary vertex: transverse (ITS) and longitudinal (MFT) distance to primary vertex

- **Complementary rapidity ranges** from central barrel (dielectron) and muon arm (dimuon) measurements
- **Dimuon signal advantaged** because of the better signal/background ratio



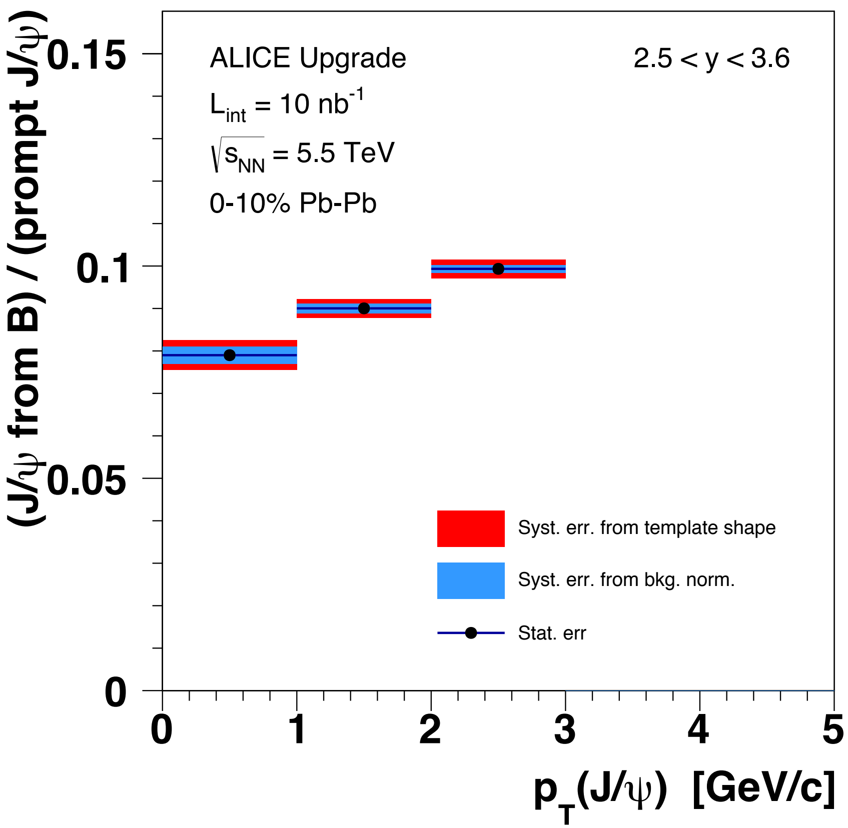
MFT

ITS

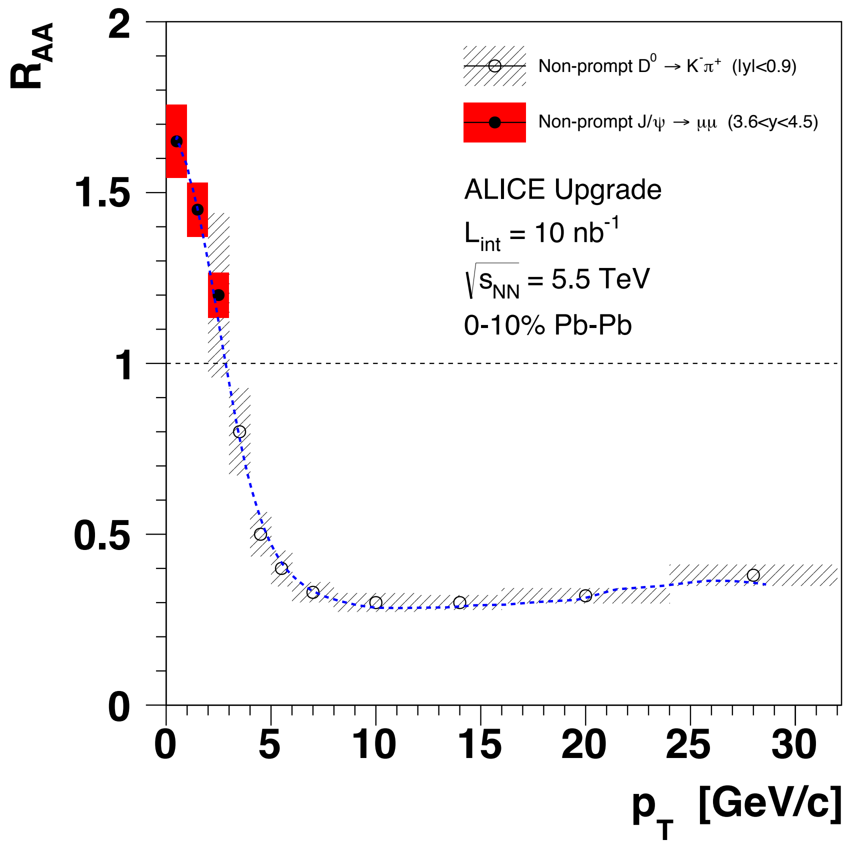


Beauty Measurement with non-prompt J/ψ

- **Displaced/prompt separation** possible down to zero $p_T(J/\psi)$ within 5% stat + syst uncertainties
- **Beauty R_{AA} measurement** possible down to zero $p_T(J/\psi)$ within 7% stat + syst uncertainties even in central Pb-Pb



MFT TDR



Prompt Charmonia: J/ψ and ψ'

- **Precision measurement for J/ψ at forward rapidity already in LHC Run 2, but:**
  - No insight on ψ' physics in central Pb-Pb
  - Only inclusive measurement available at forward rapidity

MFT

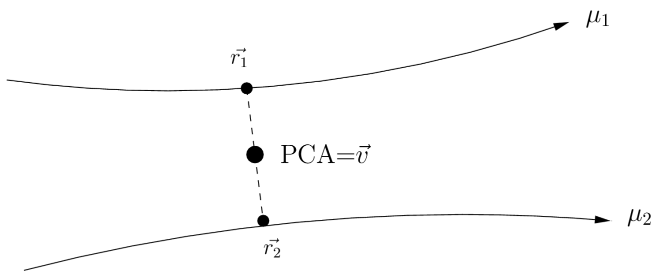
PCA: Point of Closest Approach between two muon tracks

PCA Quality: Estimates the probability that both muons are coming from the PCA

Powerful tool to improve the S/B when the tracks have p_T > 1 GeV/c

$$f_i(\vec{v}) = \exp\left[-0.5(\vec{v}-\vec{r_i})^T V_i^{-1}(\vec{v}-\vec{r_i})\right]$$

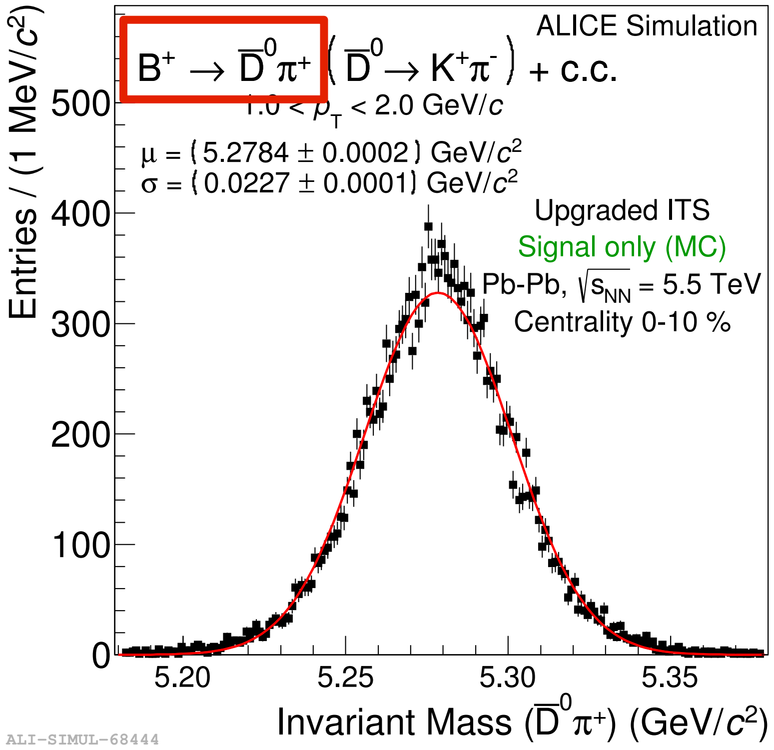
where $\vec{r_i}$ is the point of closest approach of track i to the point $\vec{v}$. V_i is the covariance matrix of the track i at $\vec{r_i}$

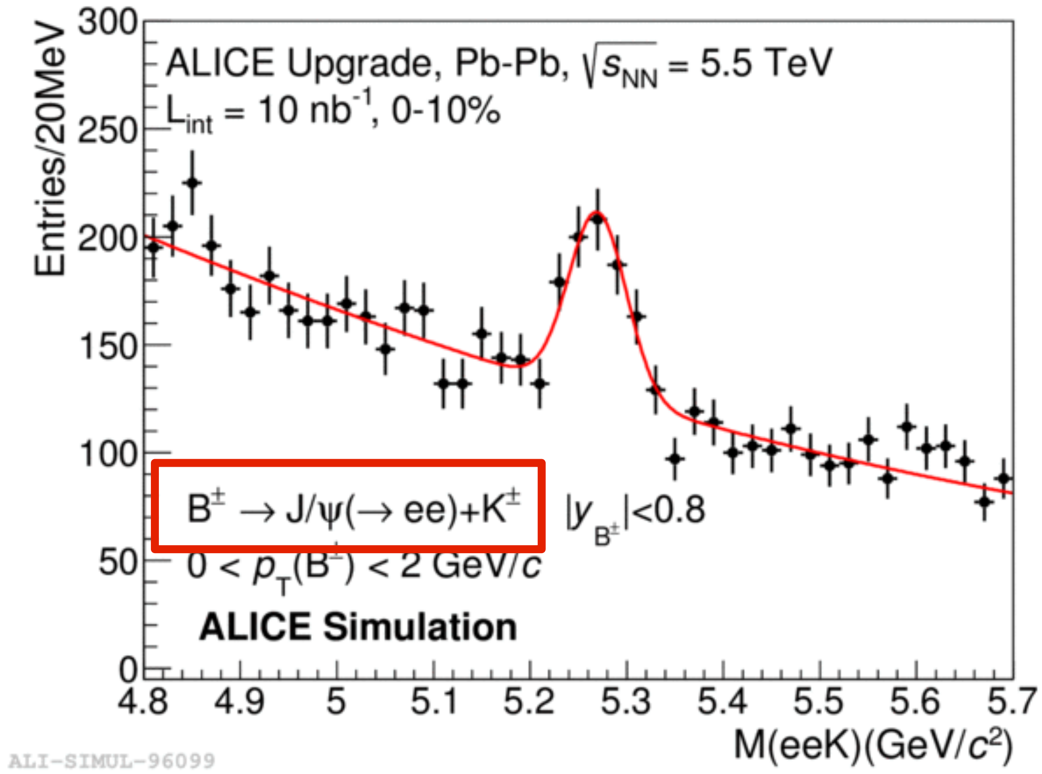


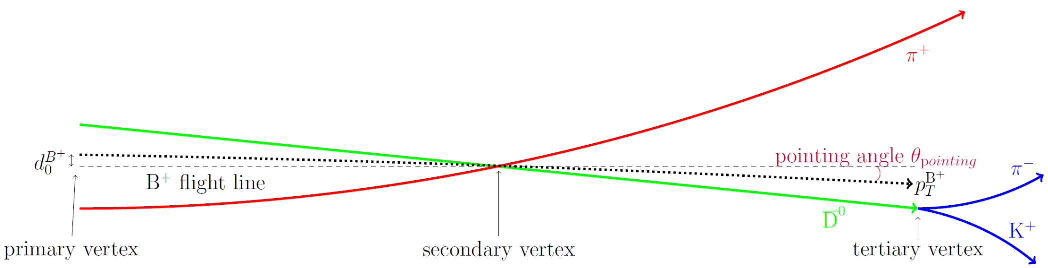
Probability that the two tracks come from the same vertex $\vec{v}$

$$P(\vec{v}) = \frac{2 f_1(\vec{v}) f_2(\vec{v})}{f_1(\vec{v}) + f_2(\vec{v})}$$

Full Beauty Hadron Reconstruction



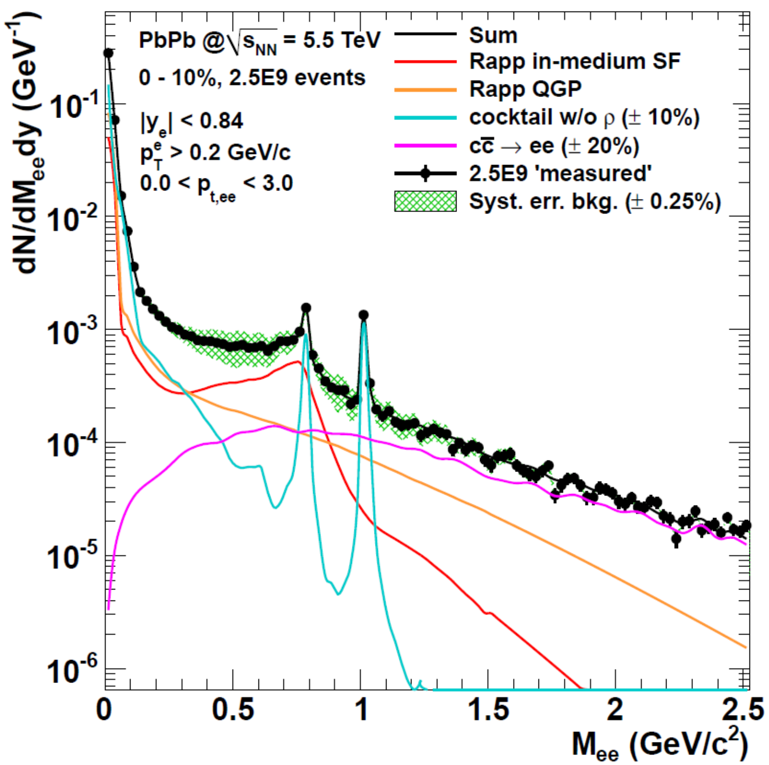


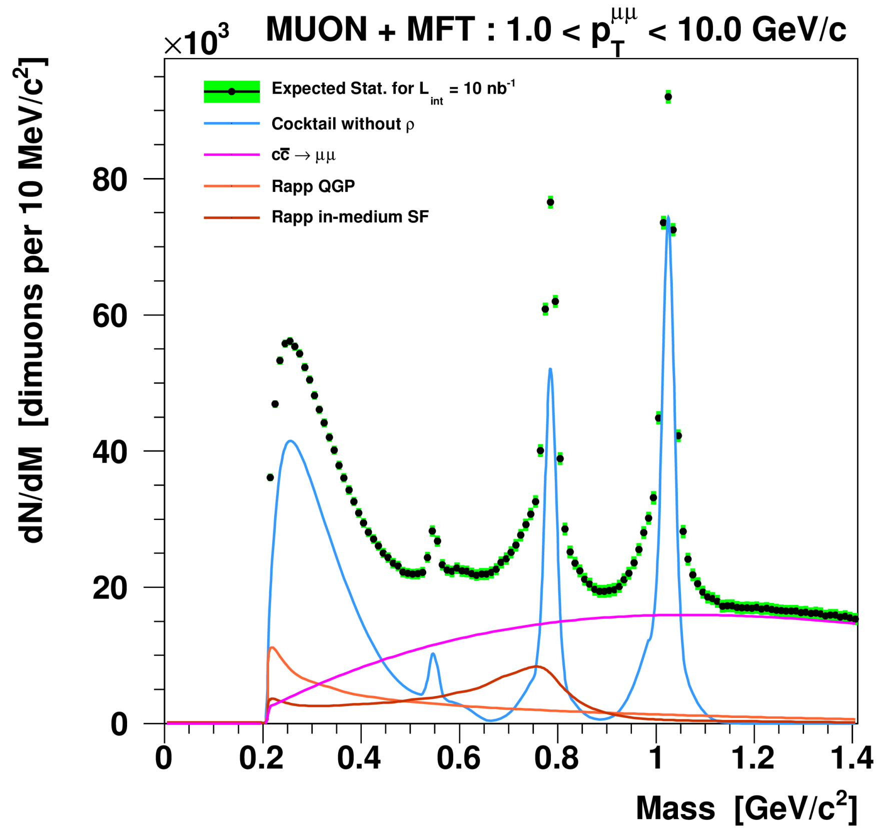


- **Exclusive B$^+$ reconstruction** in the displaced D^0 and J/ψ channels down to low p$_T$ (only possible in the ALICE central barrel)

Low Mass & Continuum Dileptons

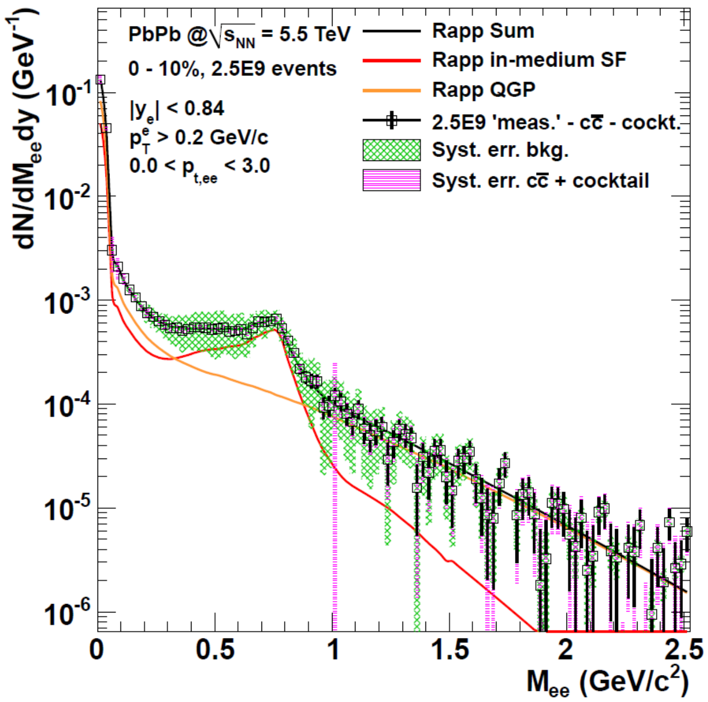
- **Low and intermediate mass dileptons** both in the dielectron (mid rapidity) and dimuon (forward rapidity) channels
- Isolation of prompt sources needs **precise measurement of dilepton offset**
- In addition, **MFT will improve the mass resolution** for light resonances in dimuons

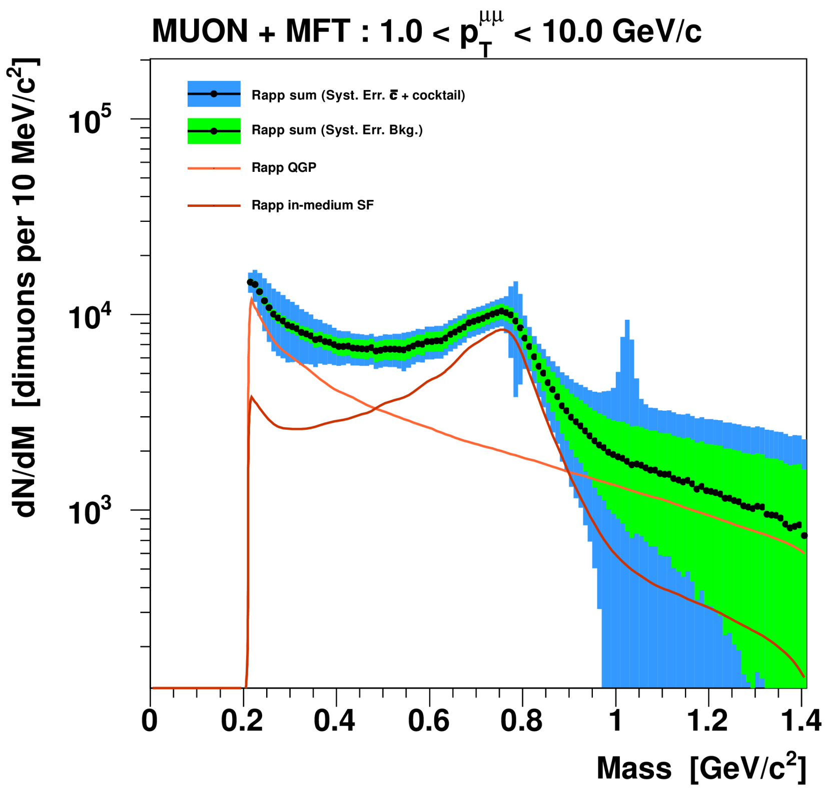




Low Mass & Continuum Dileptons

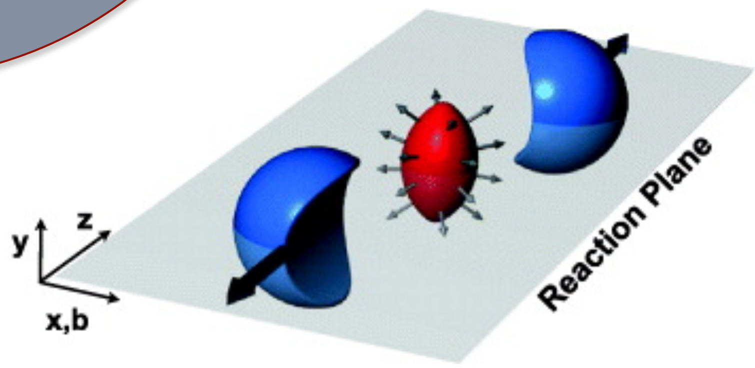
- **Precise measurement of dilepton offset** to remove charm and π/K continuum
- **Dielectron channel advantaged** thanks to the excellent offset resolution of the upgraded ITS, but dedicated low magnetic field needed for low p_T acceptance
- Charm rejection strategy for the MFT must e optimized for the intermediate masses

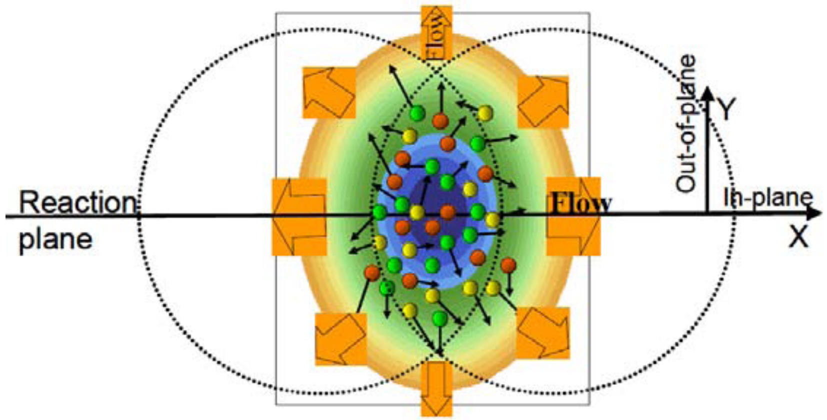


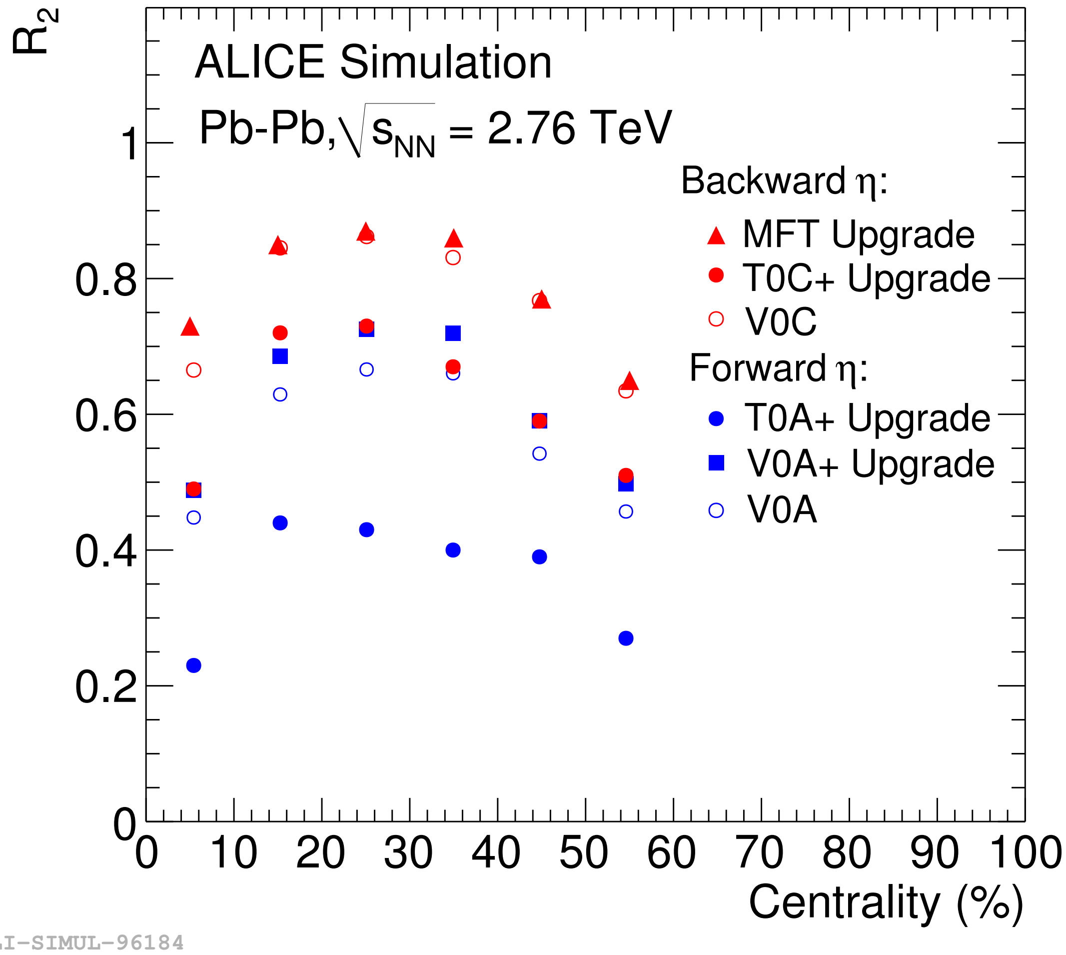


Other Items & Outlook

Reaction Plane Measurement







- **Excellent reaction plane resolution**, thanks to the high-granularity and the possibility to perform a standalone tracking (excluding contaminations from noisy clusters)

Low-Mass Drell-Yan Measurement

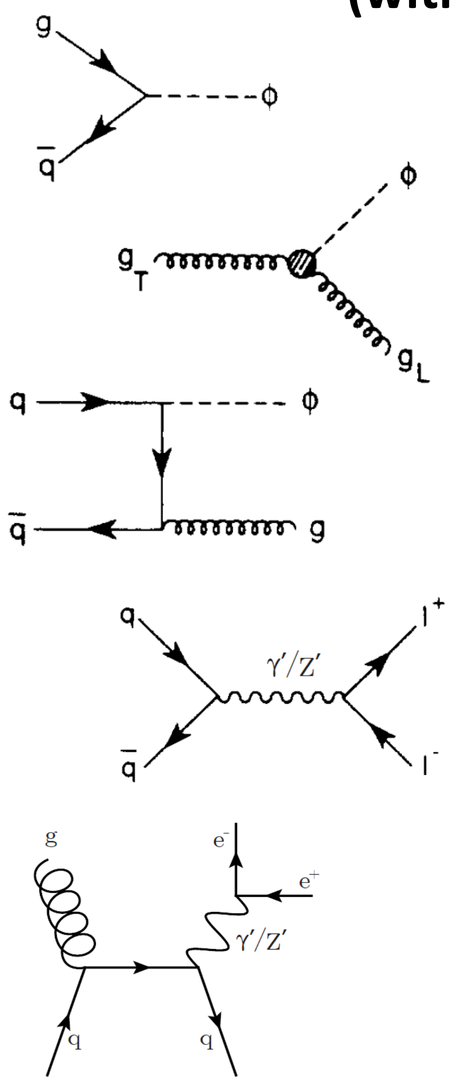
Low-mass (< 10 GeV/c^2) Drell-Yan lepton-pair production at forward rapidity: important source of information on the partonic structure of protons

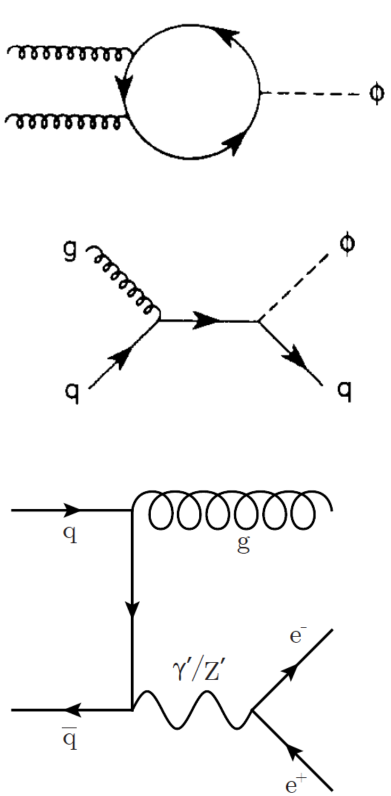
- Constraints on the gluon distribution and its nuclear dependence through the transverse momentum distributions
- Information about the onset of (gluon) saturation at small-x

Drell-Yan: main source of prompt dimuons between J/ψ and ϒ at the LHC

- Easily identifiable with a mass-offset combined fit on MFT-matched dimuons
- Due to the relatively large mass, a strong single-μ p_T cut (p_T > 2 GeV/c) can be imposed to improve the quality of the sample

Light scalar or vector BSM bosons could be observed in **high-energy (with large QGP volumes produced), high-luminosity nuclear collisions**





J. Ellis & P. Salati, Nuclear Physics B342 (1990)
J. Davis & C. Böhm, arXiv:1306.3653

- **Resonance in the thermal dilepton production from the QGP** for masses up to 3 GeV/c^2: dilepton measurements in ALICE could set limits on quark- and lepton-couplings of light BSM bosons

- **Heavier bosons** would mainly decay into multiparticle states involving cc and ττ pairs, and are **no longer detectable in the ee or μμ channels**

- **ALICE: feasibility studies on dark photons of mass < 100 MeV/c^2**

http://www.ge.infn.it/~ldma2015/presentations/wednesday-morning/05_gunji.pdf