Upgrade and physics perspective of ALICE at the LHC

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for the ALICE Collaboration

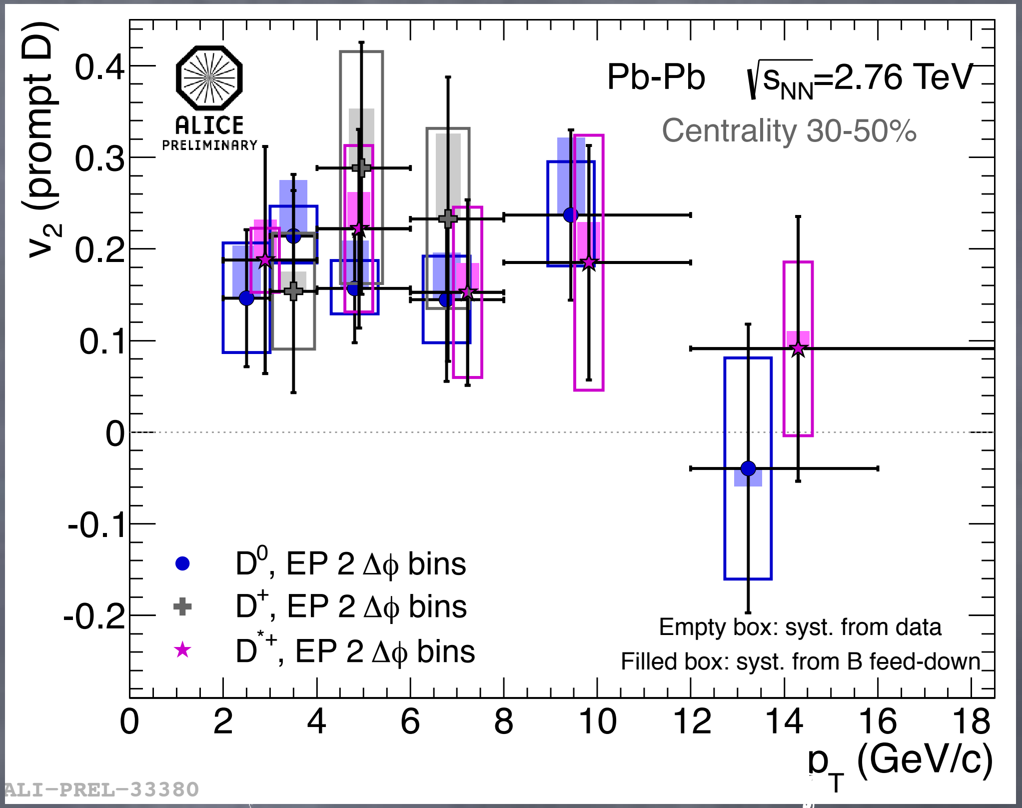
Outline

- ALICE Upgrade strategy for the 2nd LHC Long Shutdown: 2018/2019
  - Physics objectives
  - Selected detector upgrades
  - Physics performance
- Summary

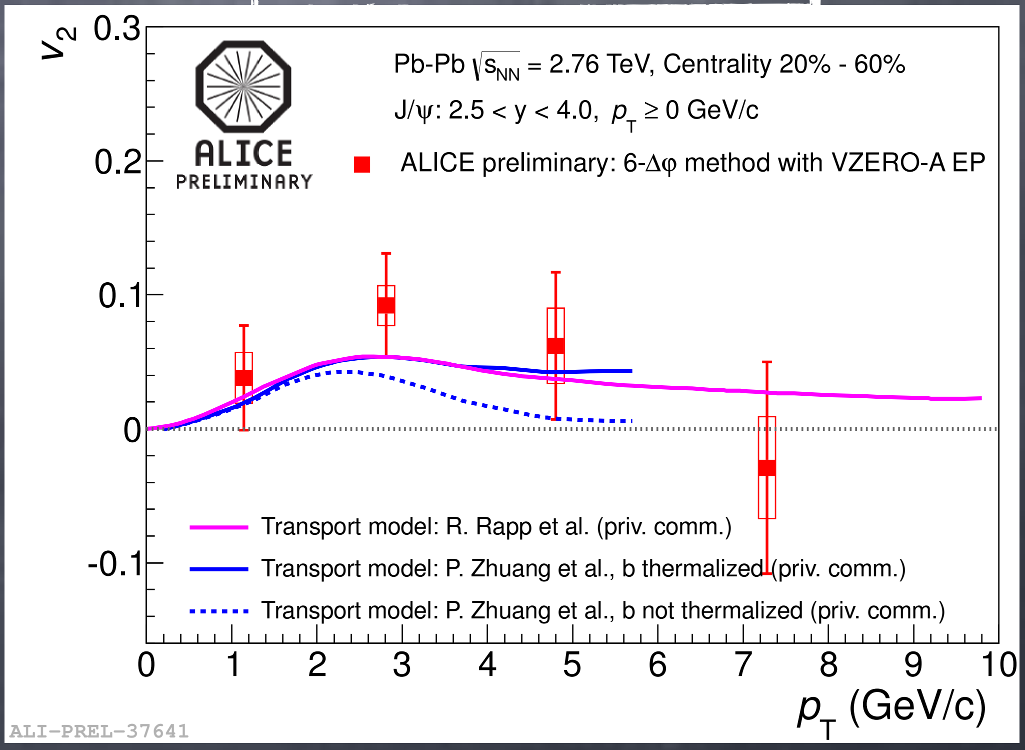
CERN-LHCC-2012-012
CERN-LHCC-2012-013

ALICE Upgrade physics goals I.

- Properties of partons in the Quark-Gluon Plasma (QGP)
- Focus on the heavy flavors: charm and beauty
- Measurement of heavy-flavour transport parameters
- Low momentum quarkonia



Current ALICE data



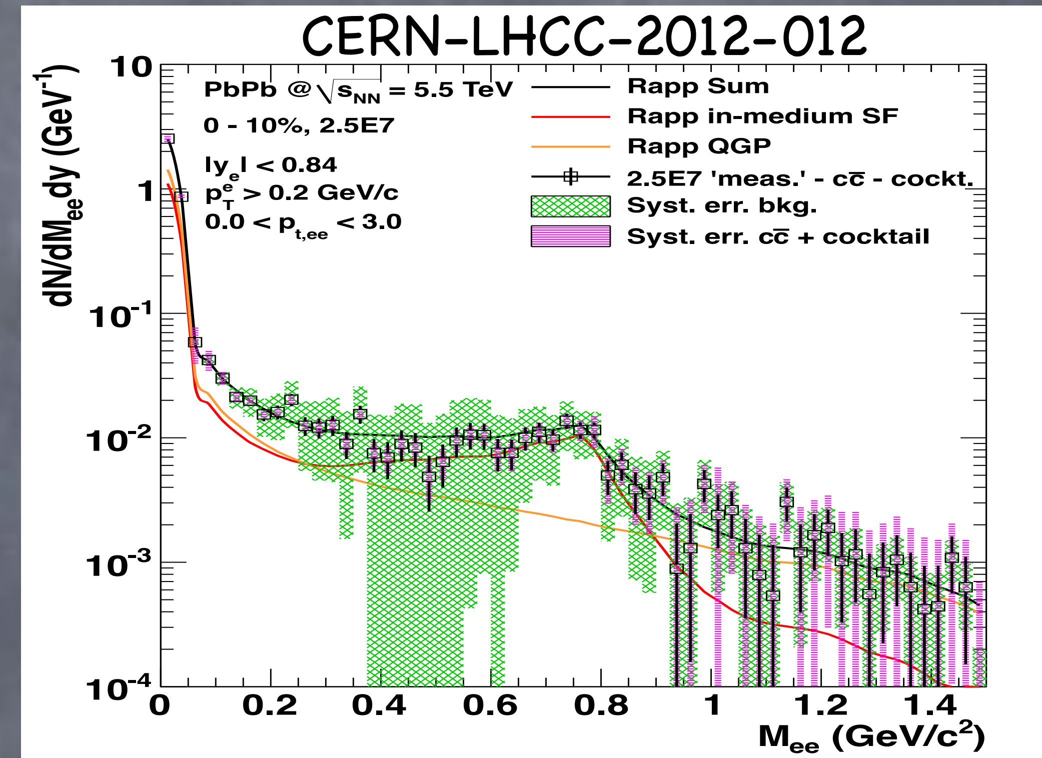
ALICE Upgrade physics goals II.

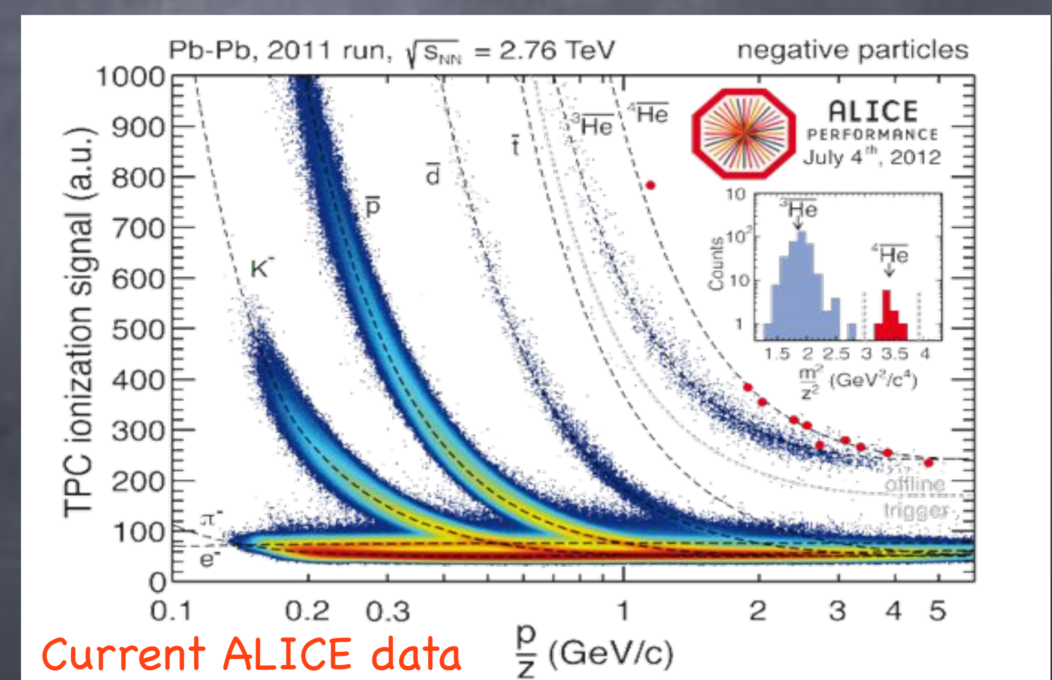
- Measurement of low-mass and low-p_T dileptons
  → Initial temperature, equation of state
  → Chiral symmetry restoration, thermal radiation

- Jet quenching and fragmentation (+ PID)
  → Jet-jet and gamma-jet down to 30 GeV
  → Parton color charge, mass, energy dependence of energy loss

- Exotic nuclear states (eg. anti-^{4}He) and hyper-nuclei (eg. $^5_{\Lambda\Lambda}$H)

- *Under investigation:*
  forward direct photons as signal of gluon saturation





ALICE Upgrade strategy

- Physics signals of interest are rare but not triggerable
  - Low p_T, high combinatorial background
  - Increase rate capabilities for minimum bias heavy-ion collisions
- ALICE runs at high luminosity
  - Record minimum bias Pb-Pb at 50kHz (pipelined)
  - Physics program requires 10 nb^{-1} of integrated luminosity wrt. the currently approved program of 1 nb^{-1}
  - Factor 100 increase in statistics (for untriggered probes)
    - → Requires new ITS (and smaller beam pipe), upgrade of TPC read-out chambers and of readout electronics for other detectors
    - → New O^2 framework (Online-offline) combining new High Level Trigger, Data Acquisition, Trigger system and Offline systems
    - → Better spatial resolution is needed on track reconstruction especially at low p_T improve secondary vertex reconstruction
- Preserve ALICE uniqueness
  - Low p_T measurements and particle identification
- Additional project under internal discussion:

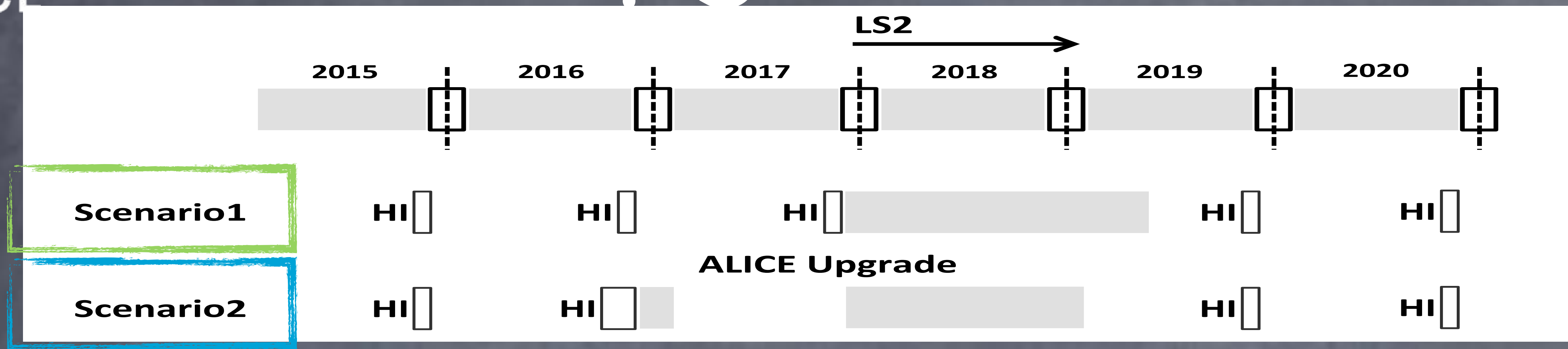
FoCal, a highly granular electromagnetic calorimeter for forward rapidities

Run 1
2010-2013
L^{Int}_{Pb-Pb}= 0.1 nb^{-1}

Run 2
2015-2017
L^{Int}_{Pb-Pb}= 1 nb^{-1}

Beyond LS2
2018-...
L^{Int}_{Pb-Pb}= 10 nb^{-1}

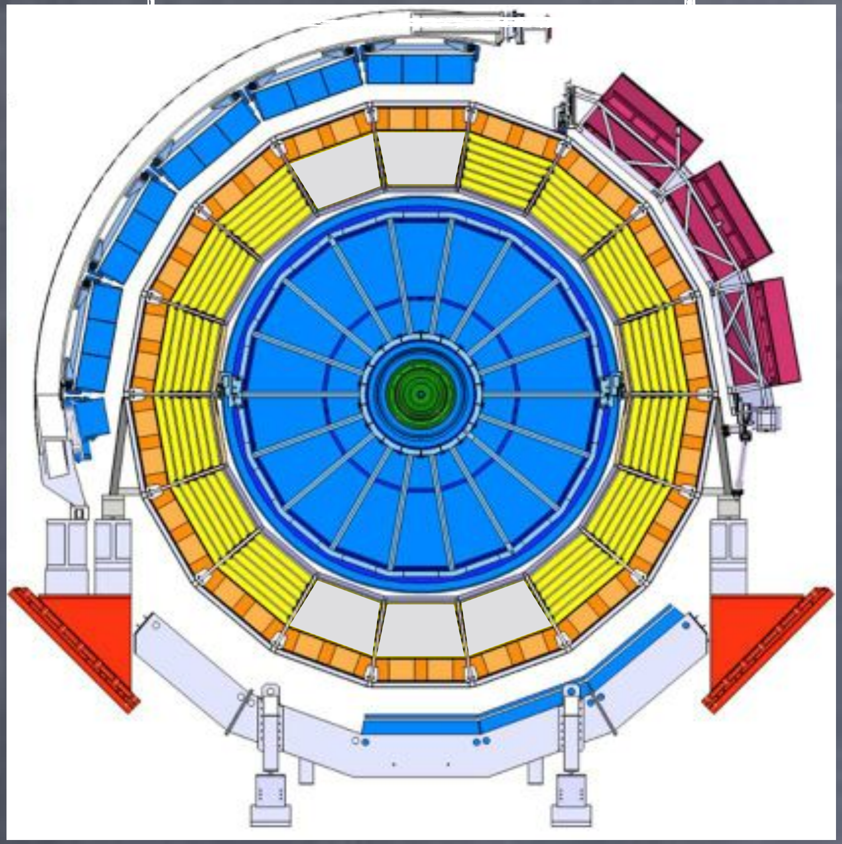
ALICE Upgrade schedule



- The ALICE Upgrade in operation after LHC Long Shutdown 2
- The ALICE program will extend into the HL-LHC era after LS3
- Two installation scenarios depending on the duration of LS2
  - Scenario 1: Complete upgrade in an LS2 of at least 18 months
  - Scenario 2: TPC removed during the "End of Year Technical Stop" 2016/17, no operation in 2017 and upgrade installation in an LS2 of at least 14 months
    - To achieve the 1 nb^{-1} integrated heavy-ion luminosity before LS2, an extended heavy-ion run in 2016 is mandatory

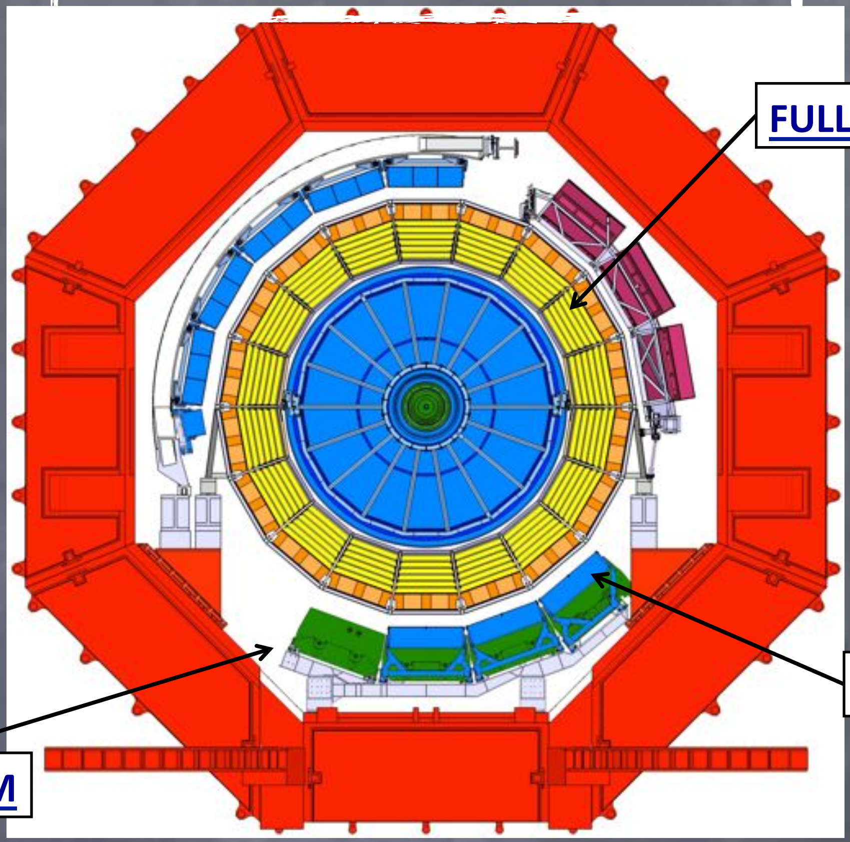
LS1 activities

ALICE 2012



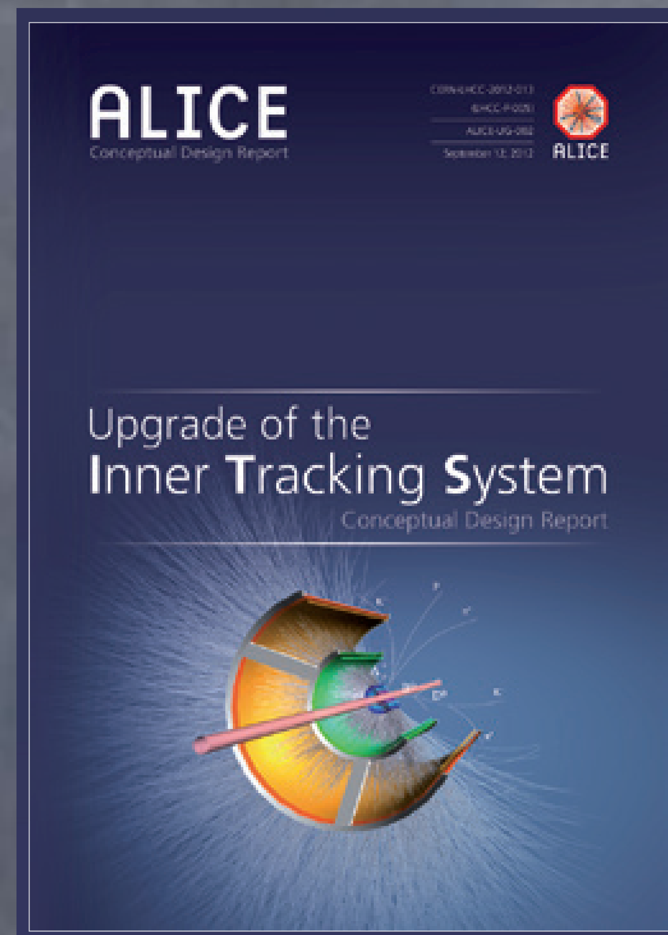
Magnet is not shown!

ALICE after LS1



- Complete …
  …the Transition Radiation Detector (TRD)
  …the Photon Spectrometer (PHOS)
- Install 8 new calorimeter modules (DCAL) opposite to the existing ones (EMCAL)
- Upgrade (consolidation) of DAQ, HLT, Trigger
- TPC: change electronics and gas, factor of 2 faster read-out

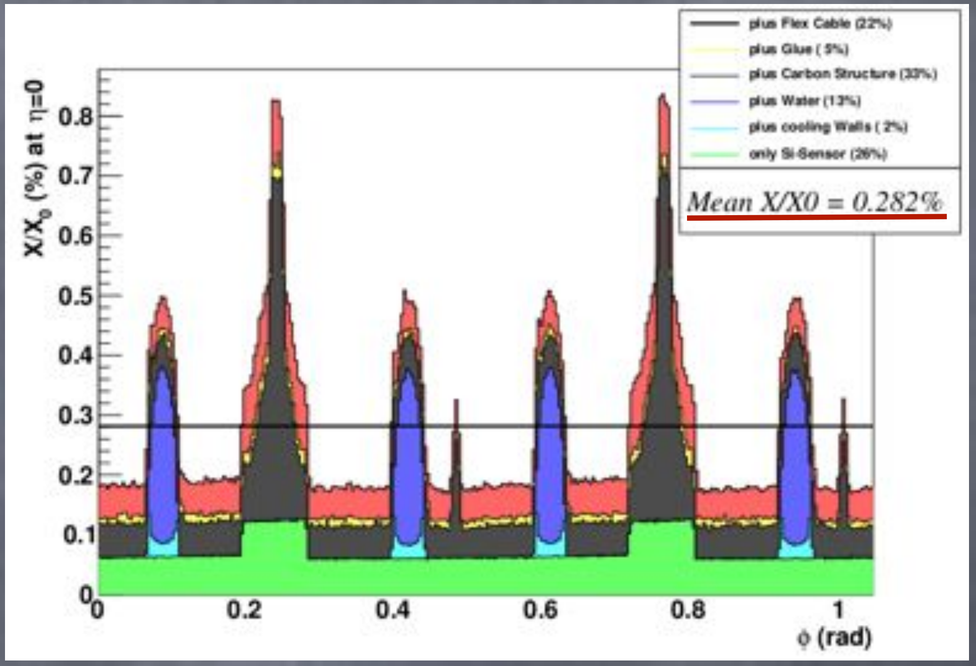
ITS Upgrade project



- Replace the current ITS with a new Inner Tracker
- Project approved by LHCC in Sept. 2012
- Technical design report by the end of 2013

ITS Upgrade design I.

- Improve impact parameter resolution by a factor of ~3



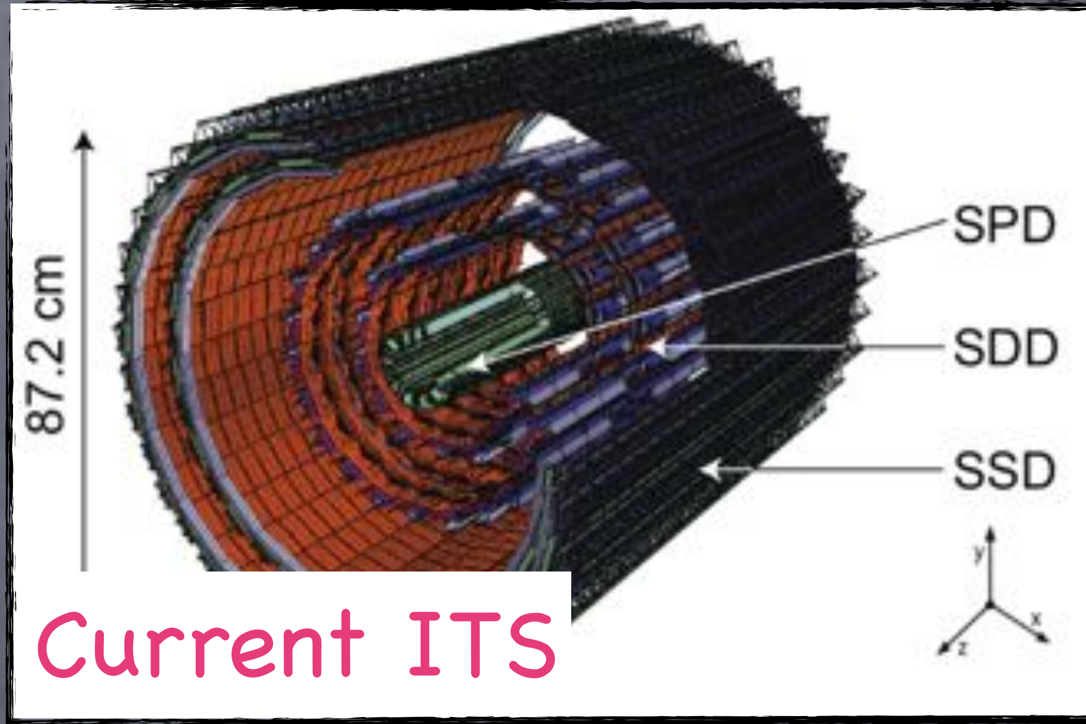
  - First layer closer to IP: 39 mm → 22 mm
  - Reduce material budget: X/X_0 from 1.14 % to 0.3 % (0.8%) for inner (outer) layers

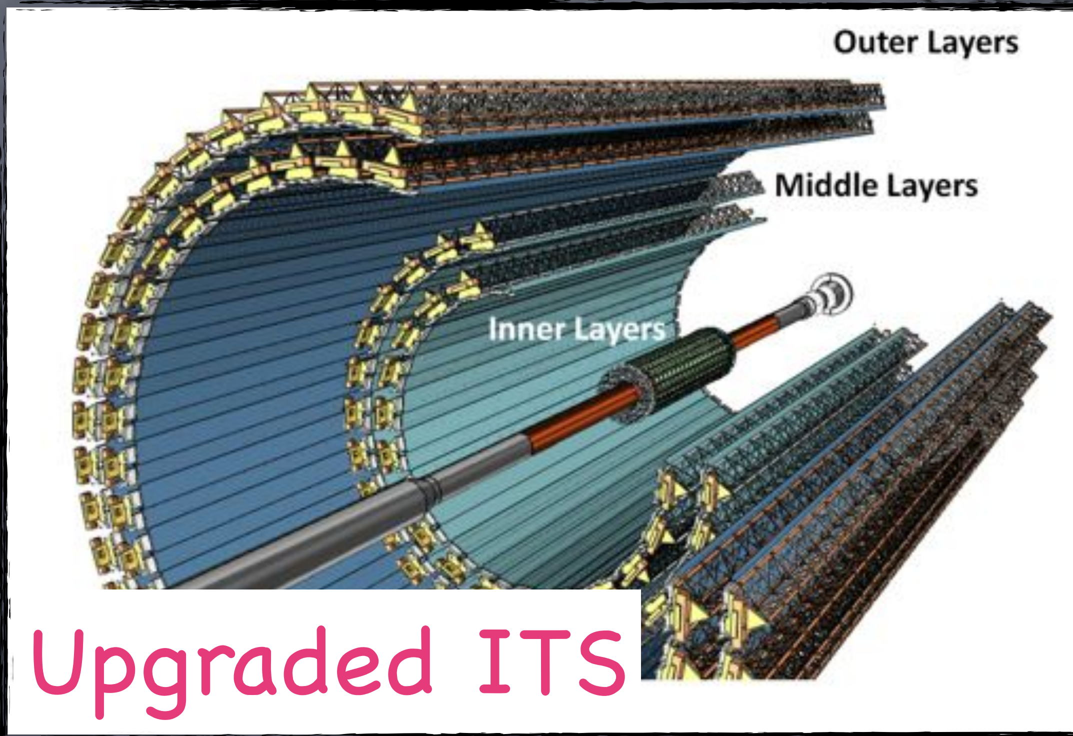
	current ALICE	ALICE upgrade	ATLAS upgrade	CMS upgrade
innermost point (mm)	39.0	22.0	25.7	30.0
x/X_0 (innermost layer)	1.14%	0.3%	1.54%	1.25%
d_0 res. $r\varphi$ (μm) at 1 GeV/c	60	20	65	60
hadron ID p range (GeV/c)	0.1 – 3	0.1 – 3	–	–

  - Reduce pixel size for inner/outer layers from 50x425 um^2 to O (30x30 um^2 / 50x50 um^2)

ITS Upgrade design II.

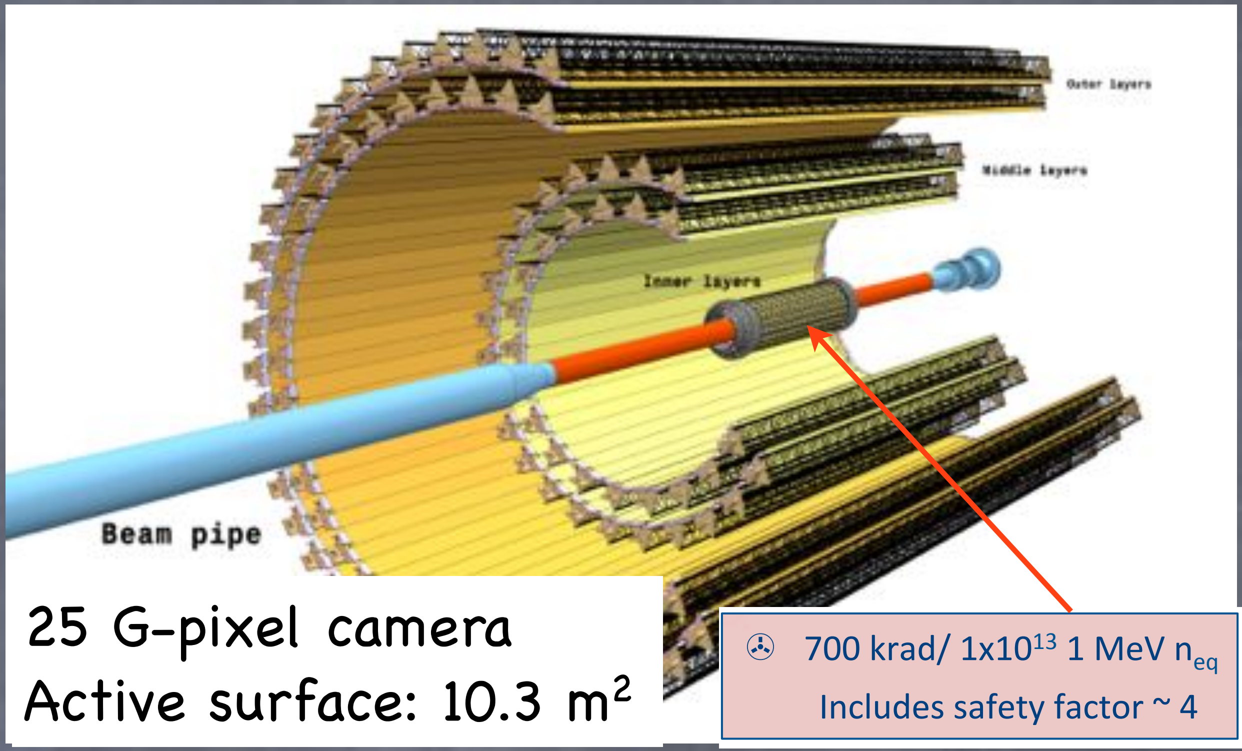
- Improve tracking efficiency and p_T resolution at low p_T
  - Increase granularity 6 → 7 layers
  - Increase radial coverage from 39 - 430 mm to 22 - 430 mm
- Fast readout:
  - readout of Pb-Pb interactions at > 50 kHz and pp interactions up to 1 MHz
- Fast insertion - removal
  - possibility to replace modules during the yearly shutdown

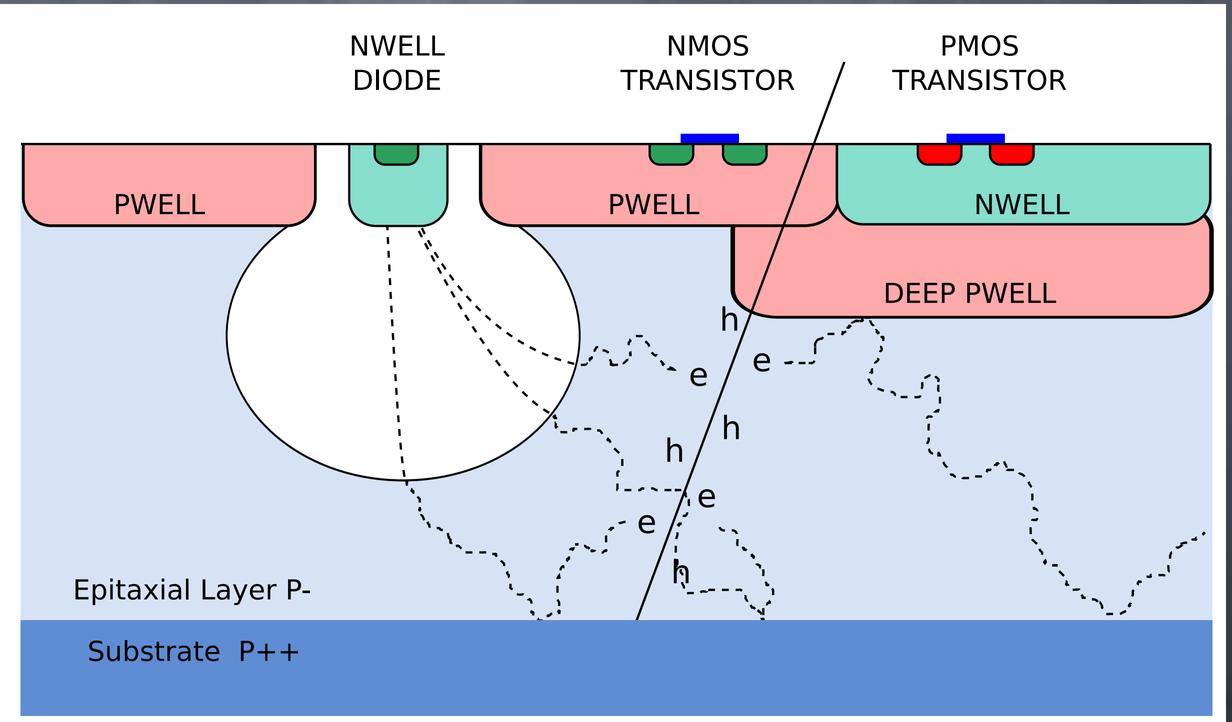




ITS Upgrade technology

- 7 layers of MAPS (Monolithic Active Pixels) → reduced material budget
- Chips using TowerJazz 180 nm technology
  - High resistivity (1-6 kΩcm) epitaxial layer: 18 - 40 μm
  - Total silicon thickness: 50 μm
  - Deep p-well layer to shield PMOS transistors
    → allows in-pixel circuitry:
    eg. in-pixel discriminators

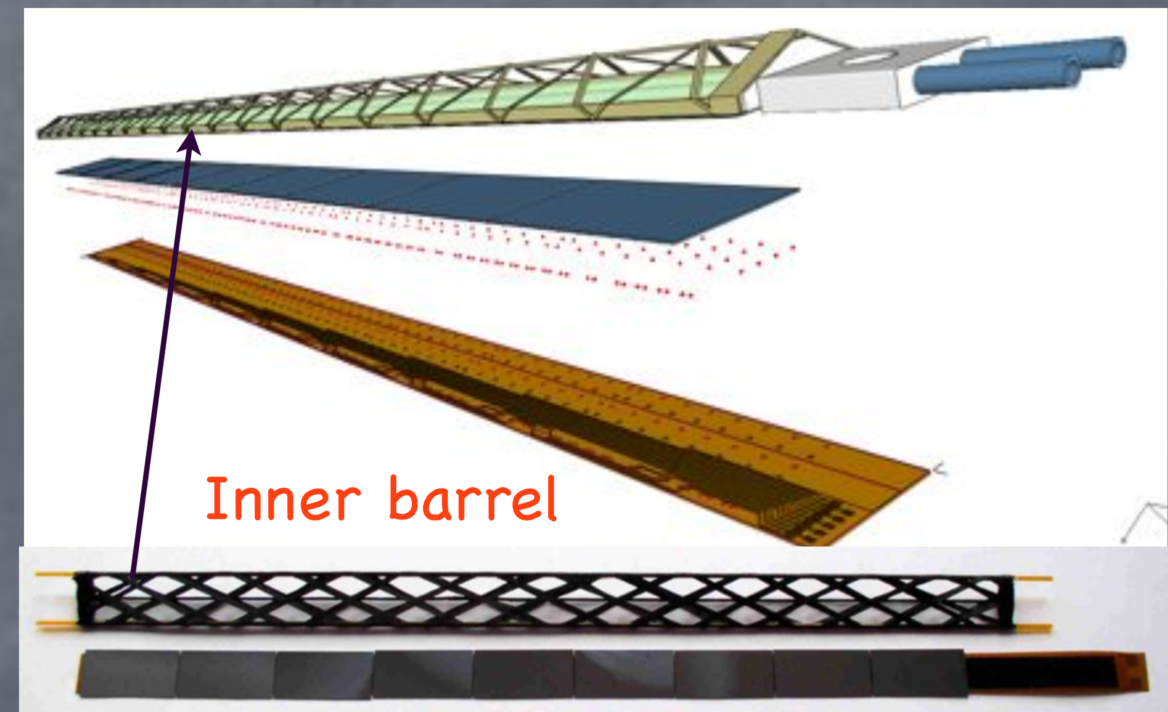


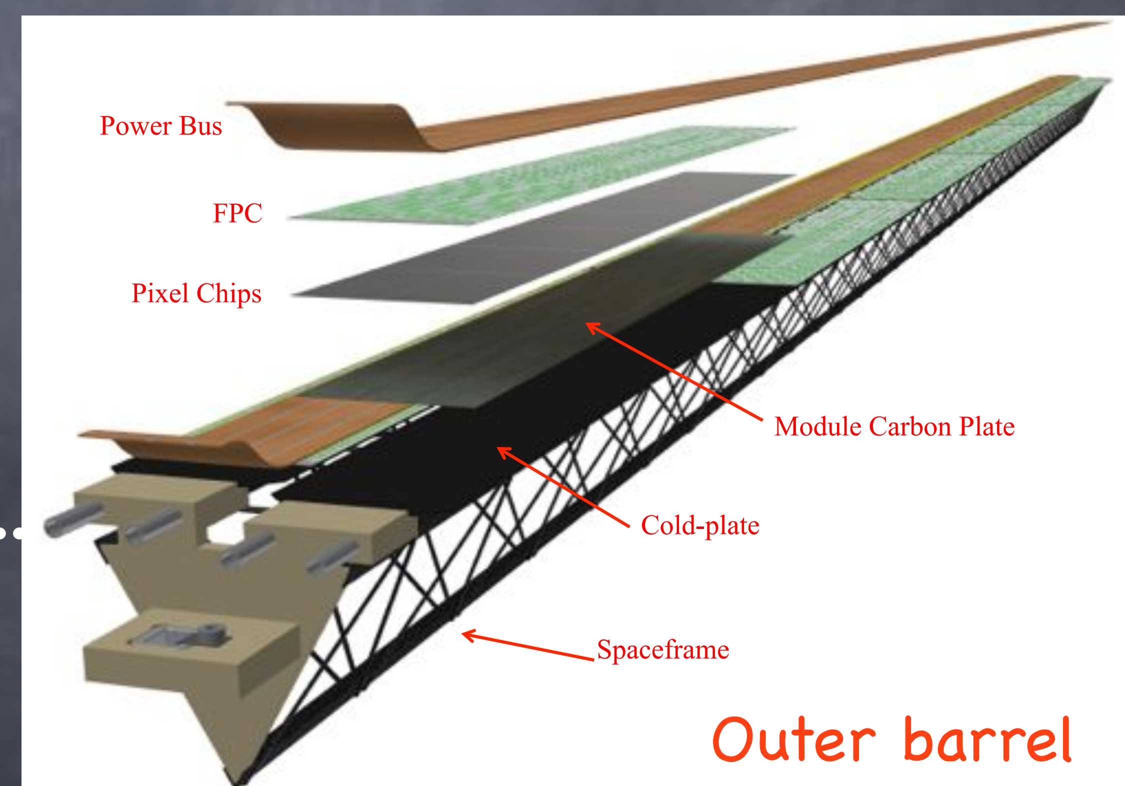


Schematic cross-section of CMOS pixel sensor
(*ALICE ITS Upgrade TDR*)

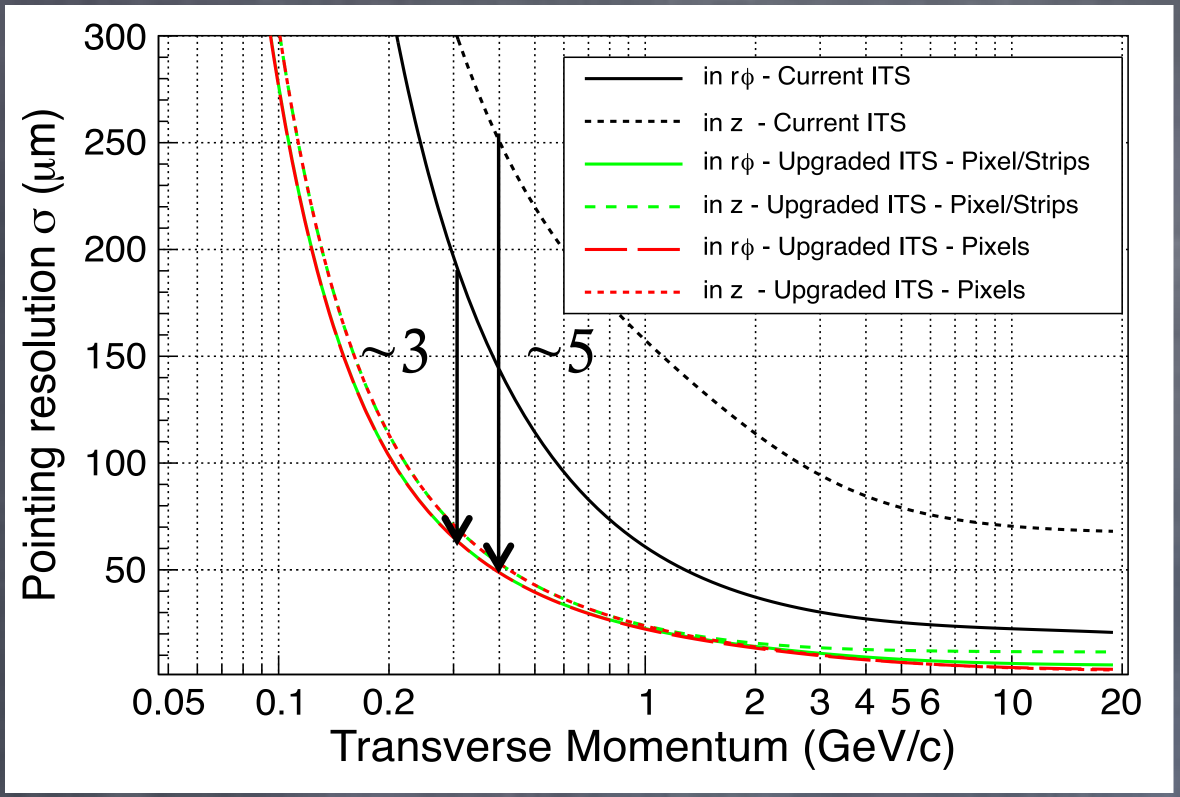
Mechanics and assembly

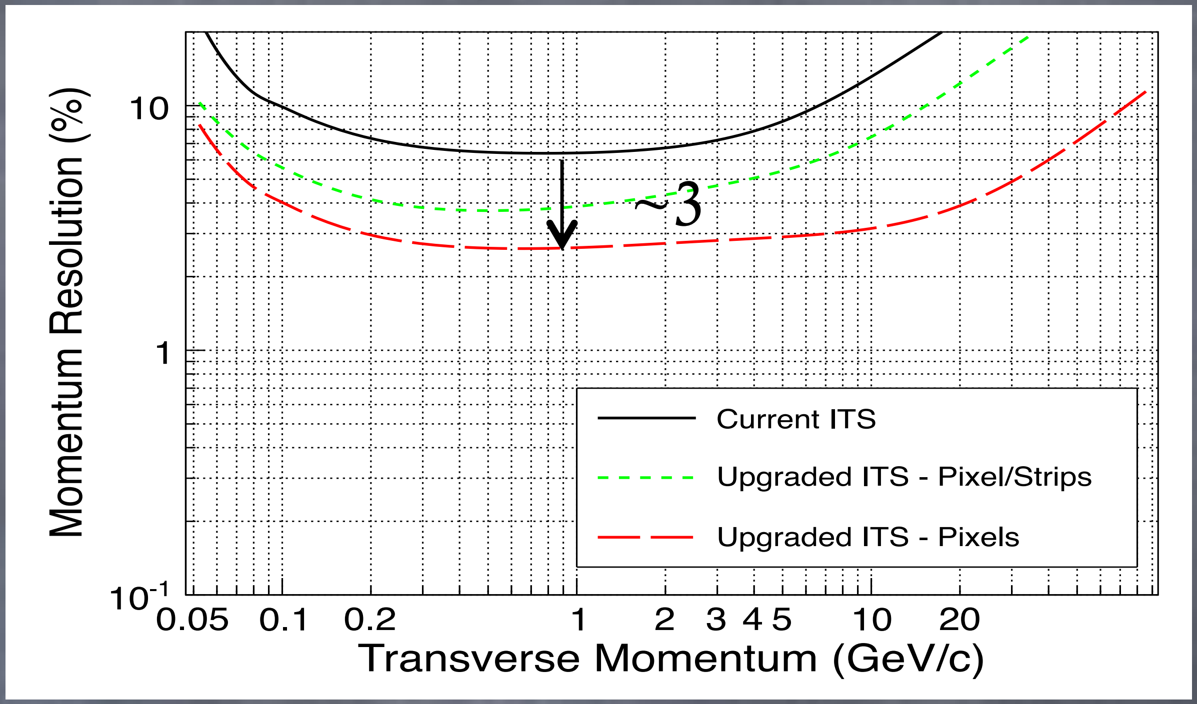
- Dedicated R&D to reduce the material budget to 0.3 % X_0 for the inner barrel
  - Optimized mechanics, cooling, electrical bus, glue, …
  - Extra light mechanical structure: 1.4 - 1.8 g / stave
- Optimize installation, services, …



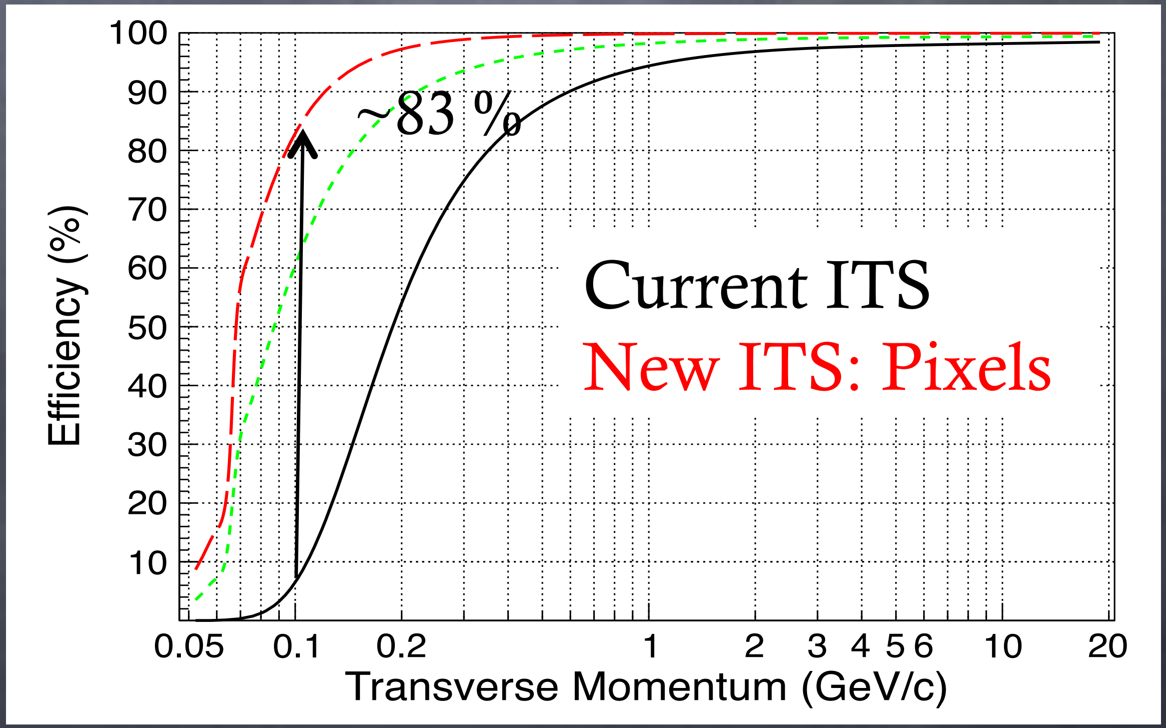


ITS Detector performance





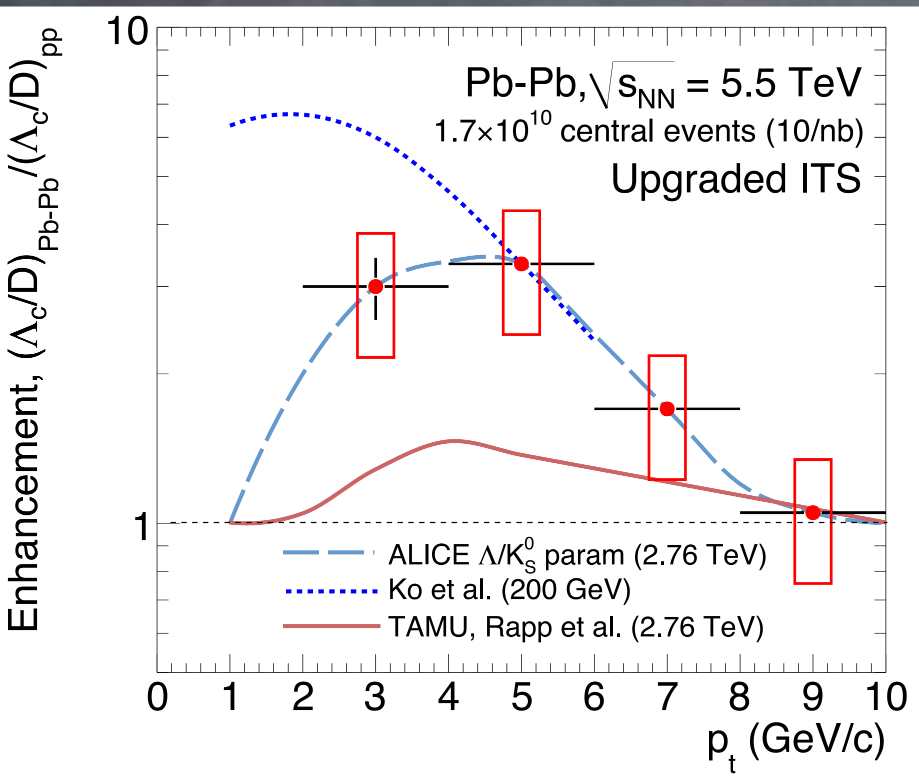
CERN-LHCC-2012-013

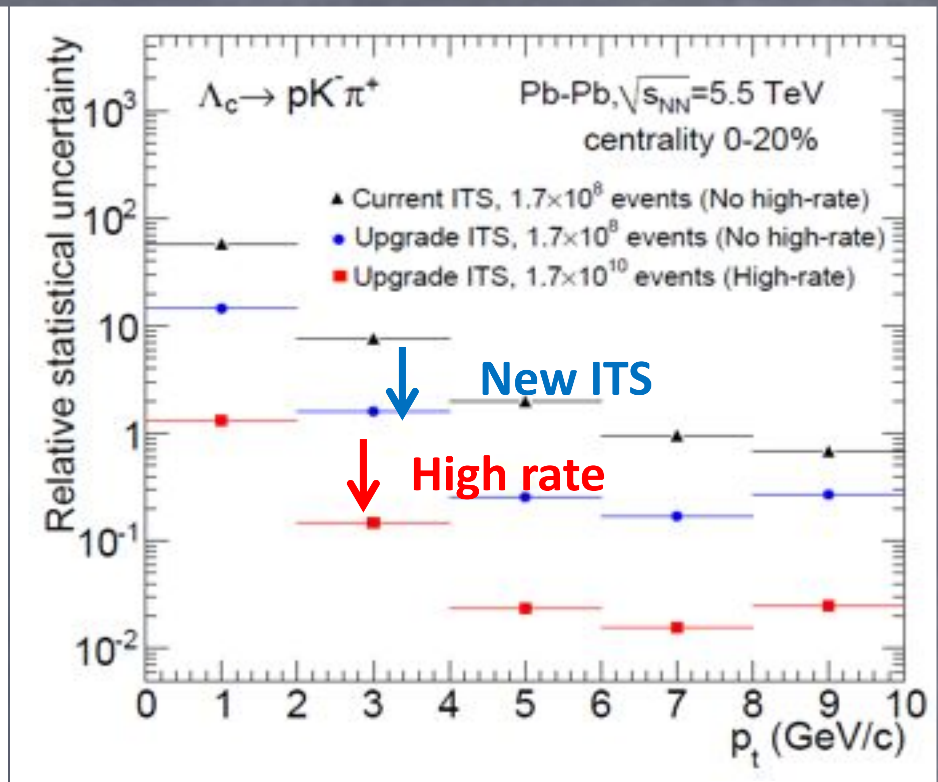


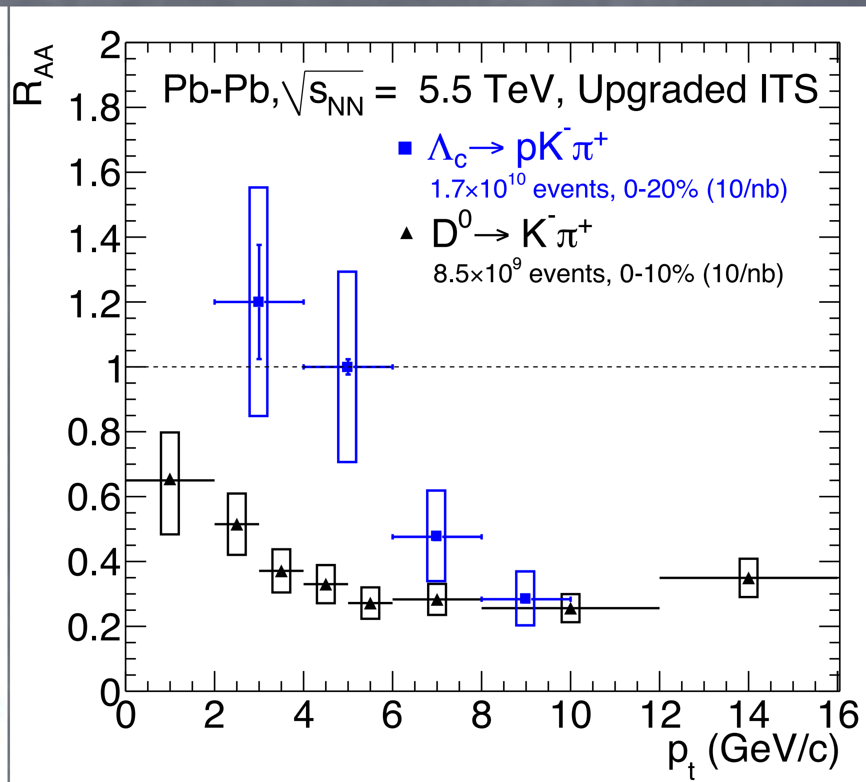
- Standalone track resolution improvement factor ~3 in rϕ and ~5 in z
- Factor ~3 improvement in momentum resolution for standalone tracking
- Standalone tracking efficiency ~83 % at p = 100 MeV/c

ITS Physics performance (sim): hadronization of heavy quarks

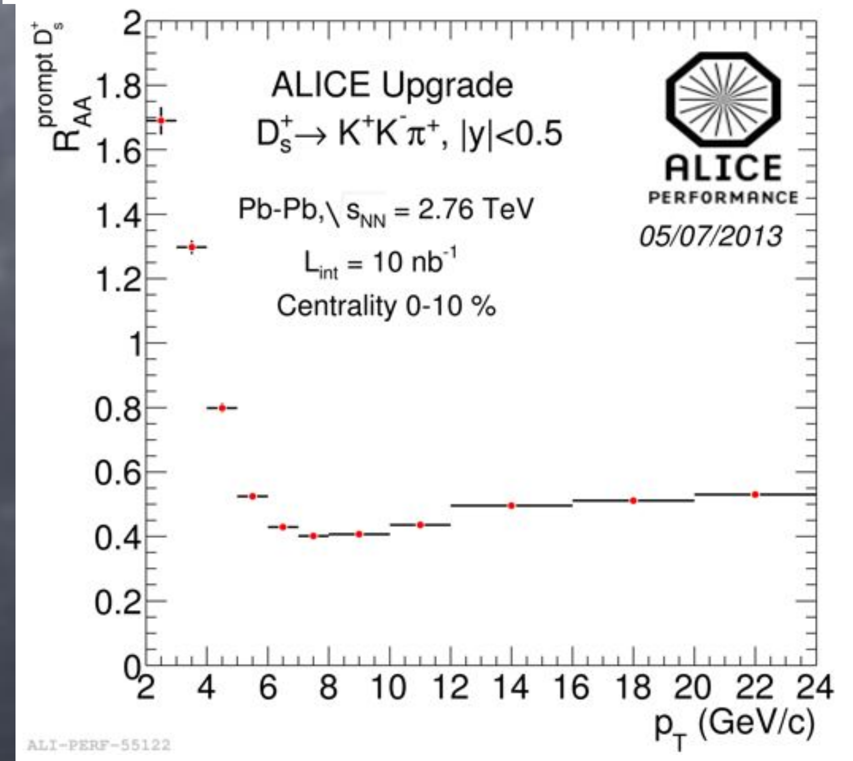
CERN-LHCC-2012-013



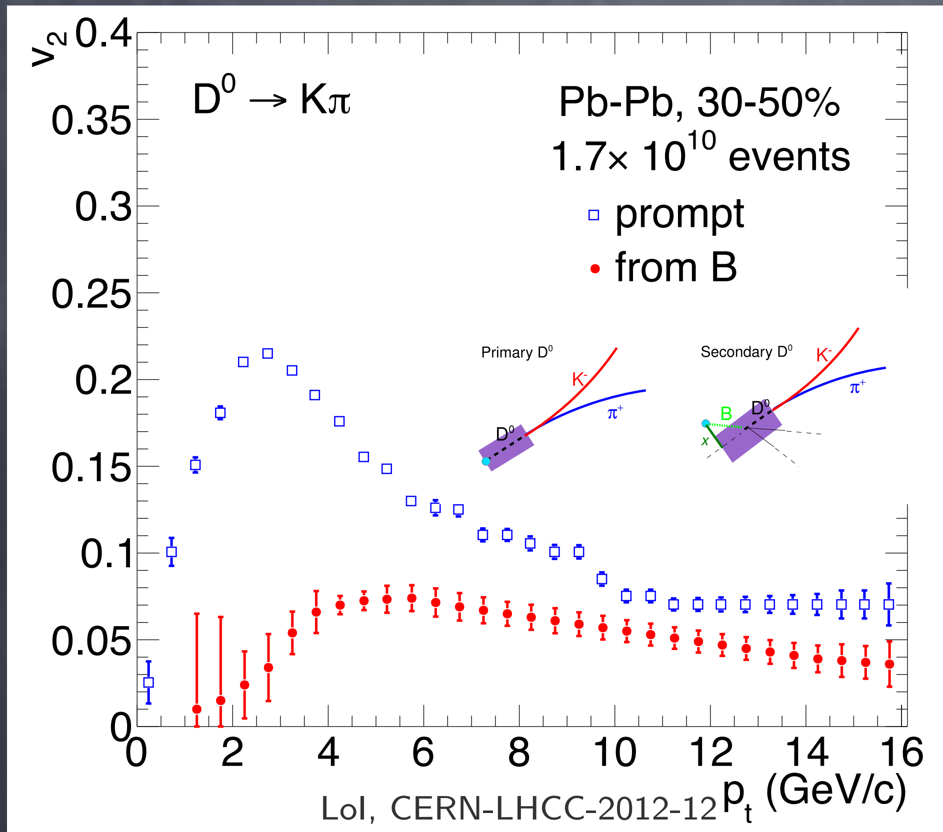


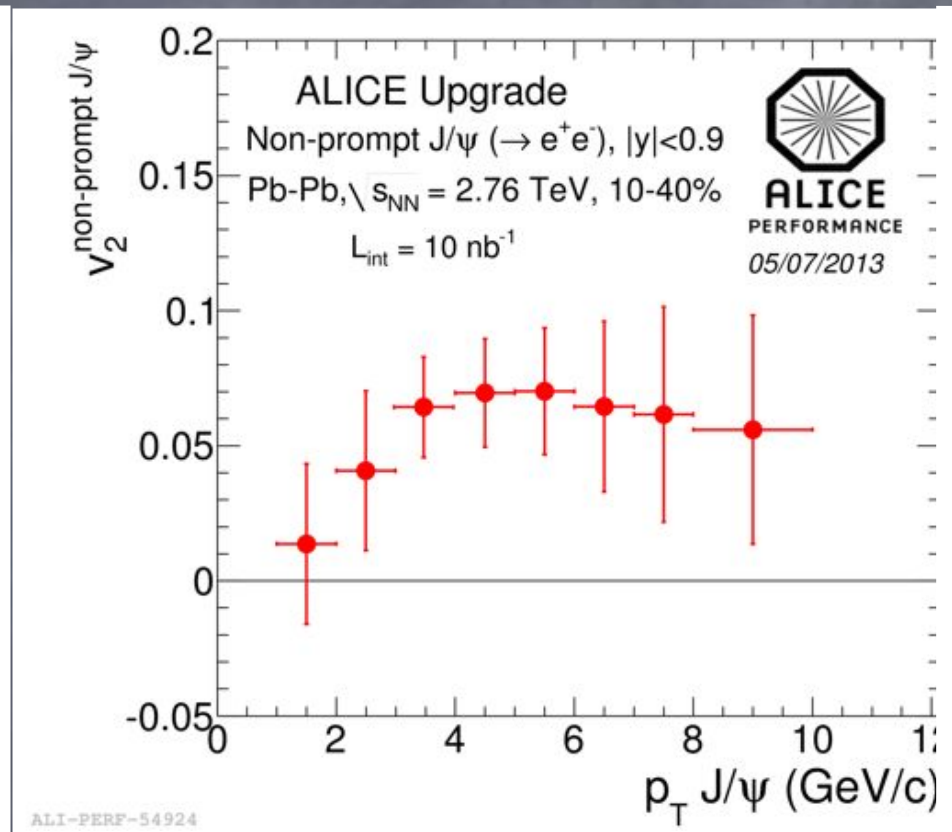


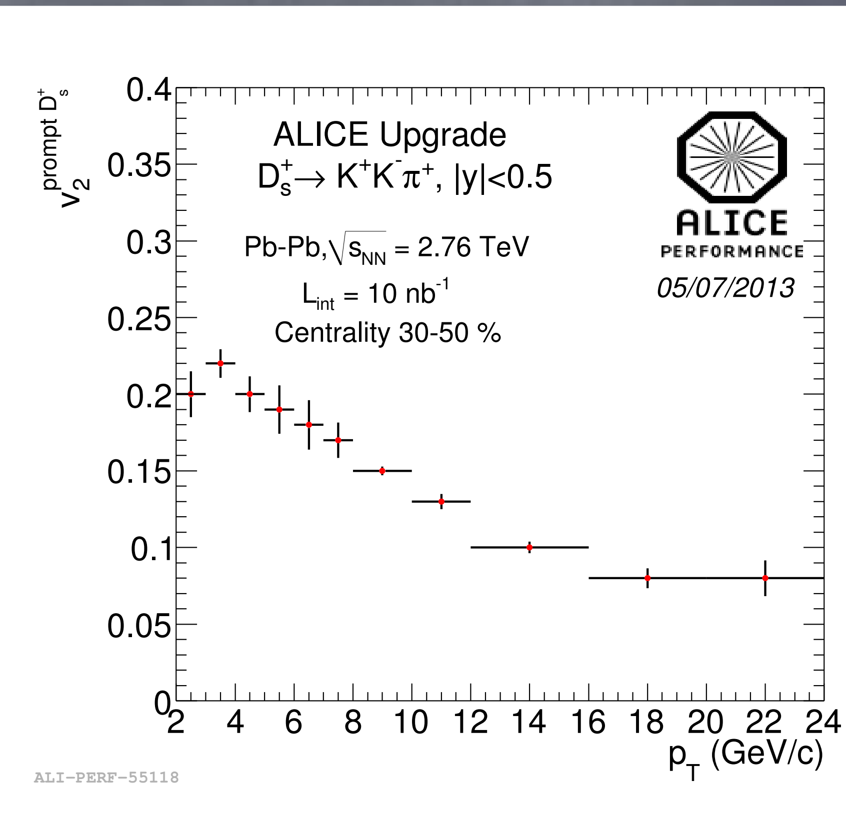
- Heavy quark hadronization via coalescence: Λ_c/D enhancement, larger D_s R_{AA} wrt. D
- Upgraded ITS: low p_T reach, significant reduction of uncertainties
- Detailed performance: TDR, end of 2013



ITS Physics performance (sim): heavy quark collectivity

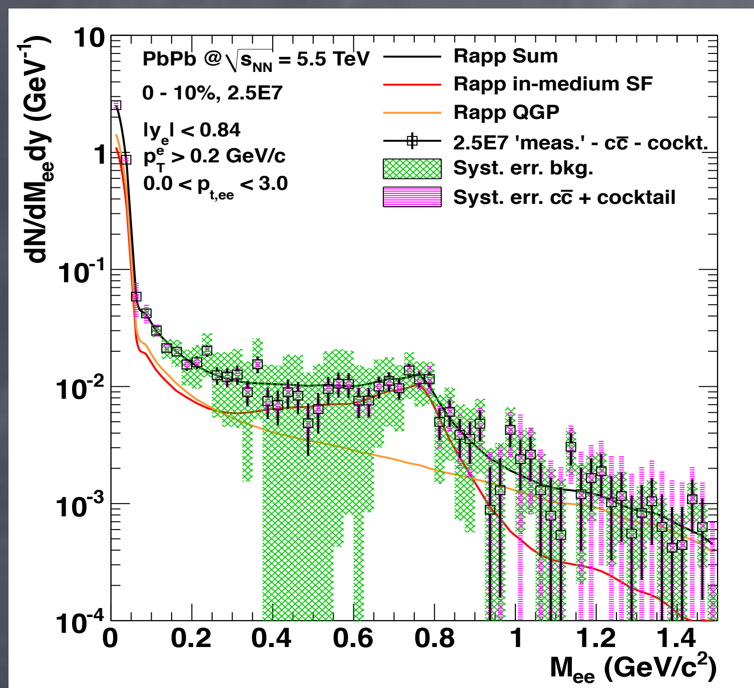


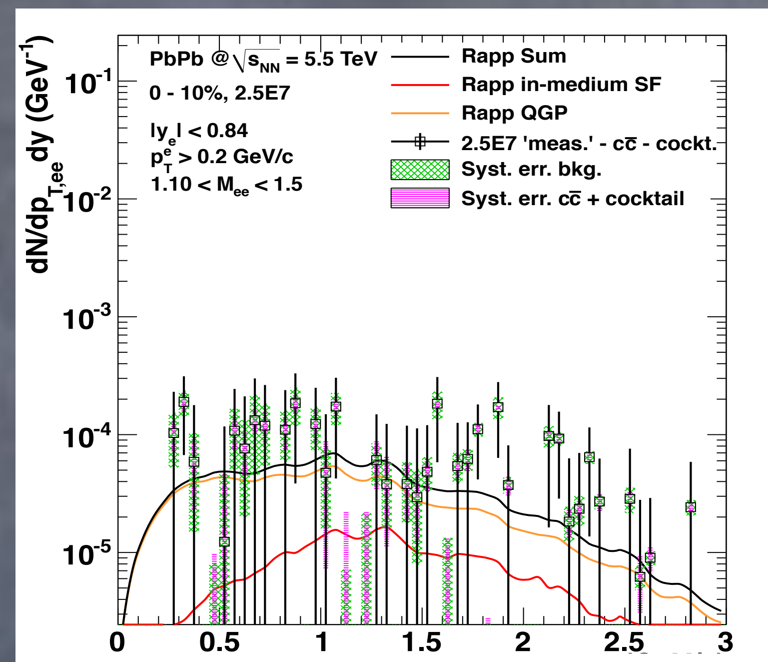




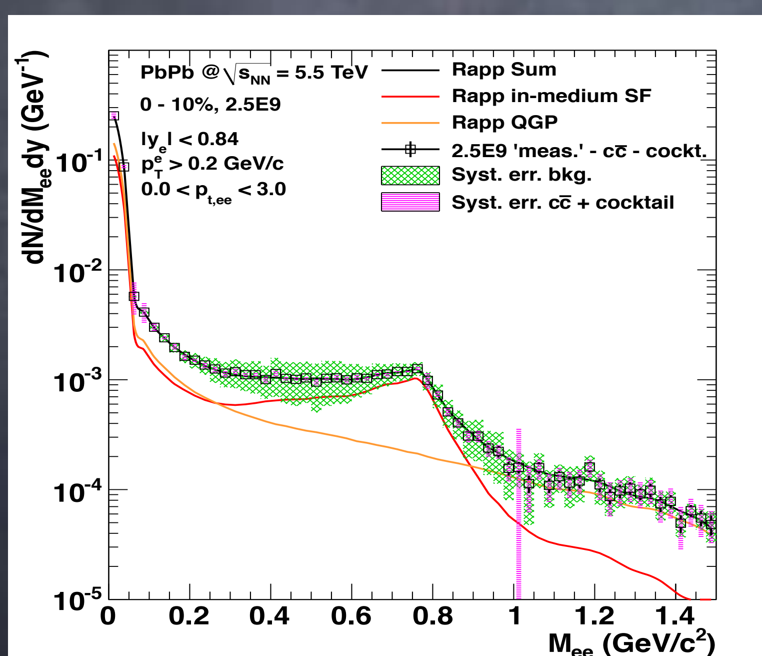
- ITS Upgrade: disentangle charm and beauty collectivity
- Measurement of elliptic flow: prompt and non-prompt D meson, non-prompt J/ψ, D_s
- Detailed performance: TDR, end of 2013

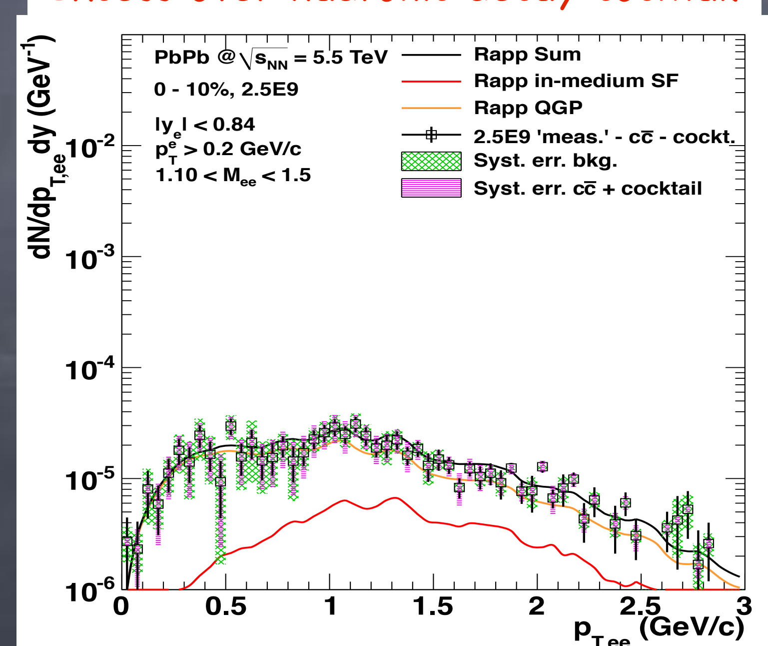
ITS Physics performance (sim): Di-electron spectra





Excess over hadronic decay cocktail





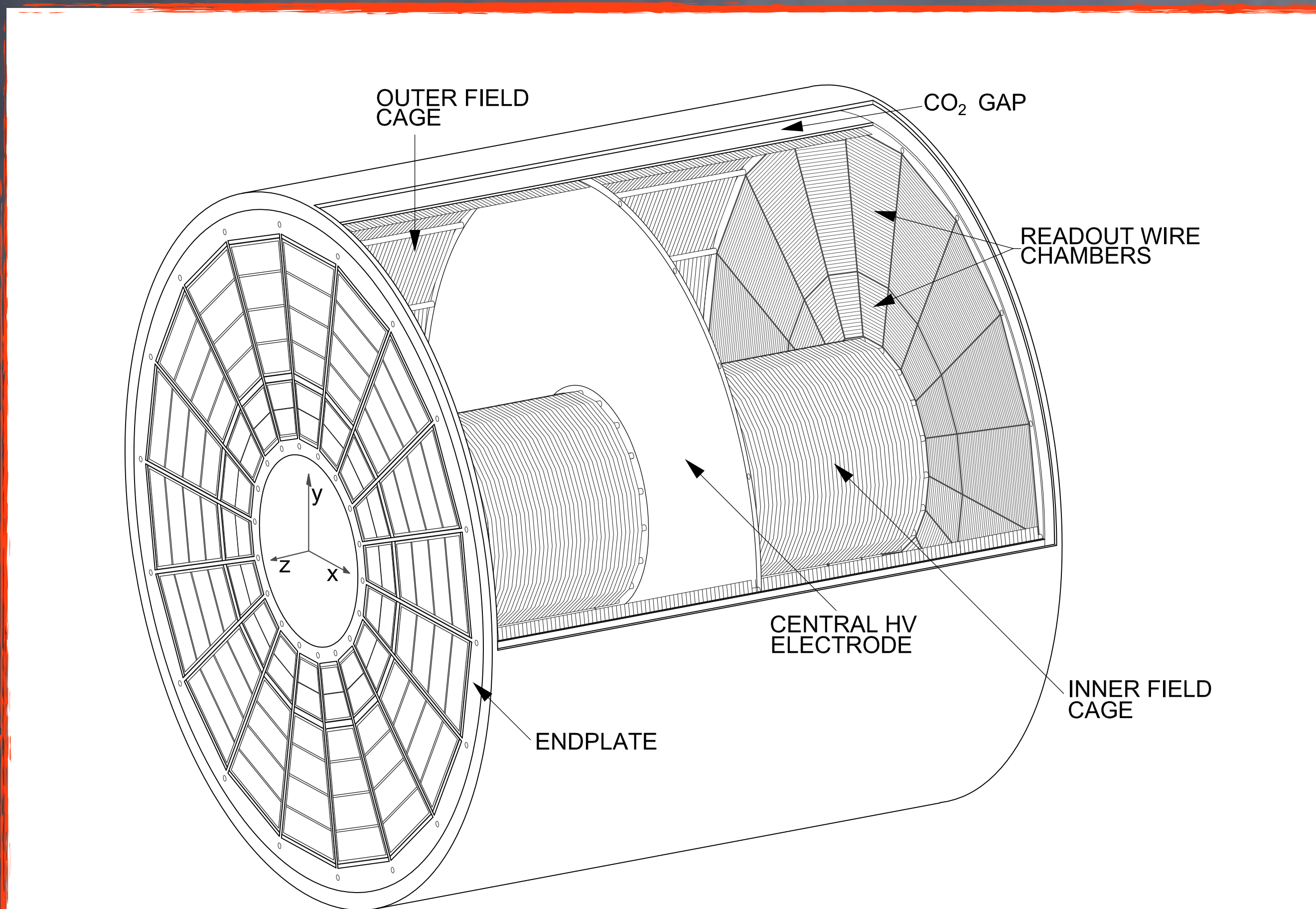
Simulation, current ITS 2.5×10^{7} events

Dedicated run at B = 0.2 T

Simulation, upgraded ITS 2.5×10^{9} events

- Upgraded ITS: vertexing and increased statistics gives access to differential di-electron studies

Time Projection Chamber
Read-out chamber upgrade

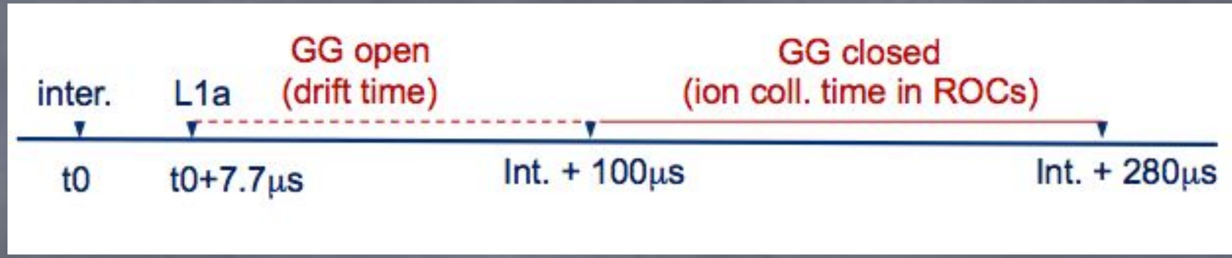


- TPC upgrade (within the ALICE Upgrade) is approved by LHCC in Sept. 2012
- The read-out chambers: MWPCs will be replaced by new GEM based ones

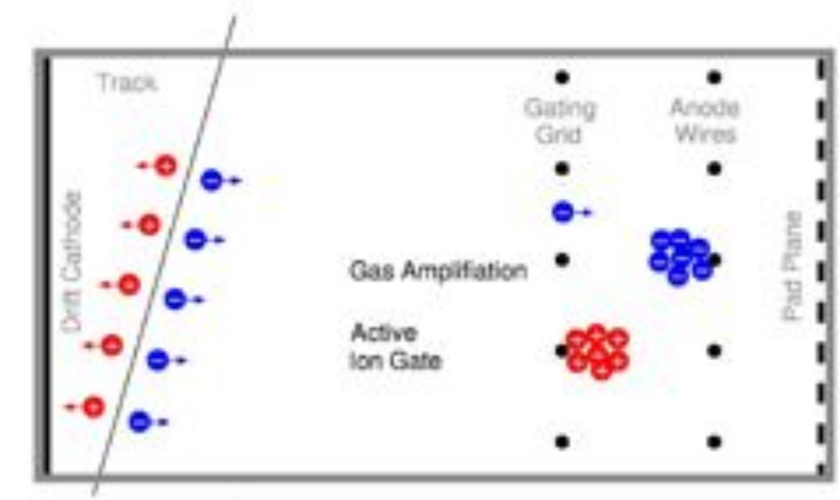
MWPC: Multi Wire Proportional Chamber, GEM: Gas Electron Multiplier

TPC read-out chambers upgrade

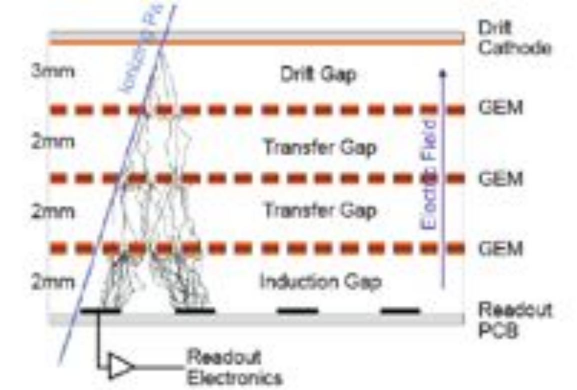
- **Gating grid closed:** prevents electrons to enter the amplification region and ions from preceding events to penetrate into the drift volume



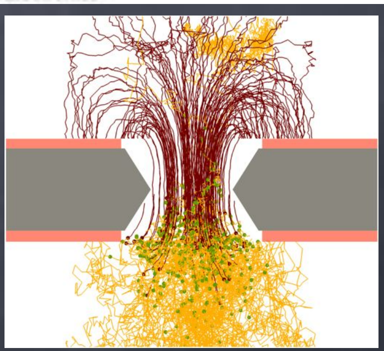
- Effective dead time ~ 280 μs max readout rate ~ 3.5 kHz



- Operating the TPC with gating grid continuously open:
  → Space charge in the drift volume due to back drifting ions
  → Distortion of the electron drift paths
  → Reconstruction of the particle trajectories no longer meaningful



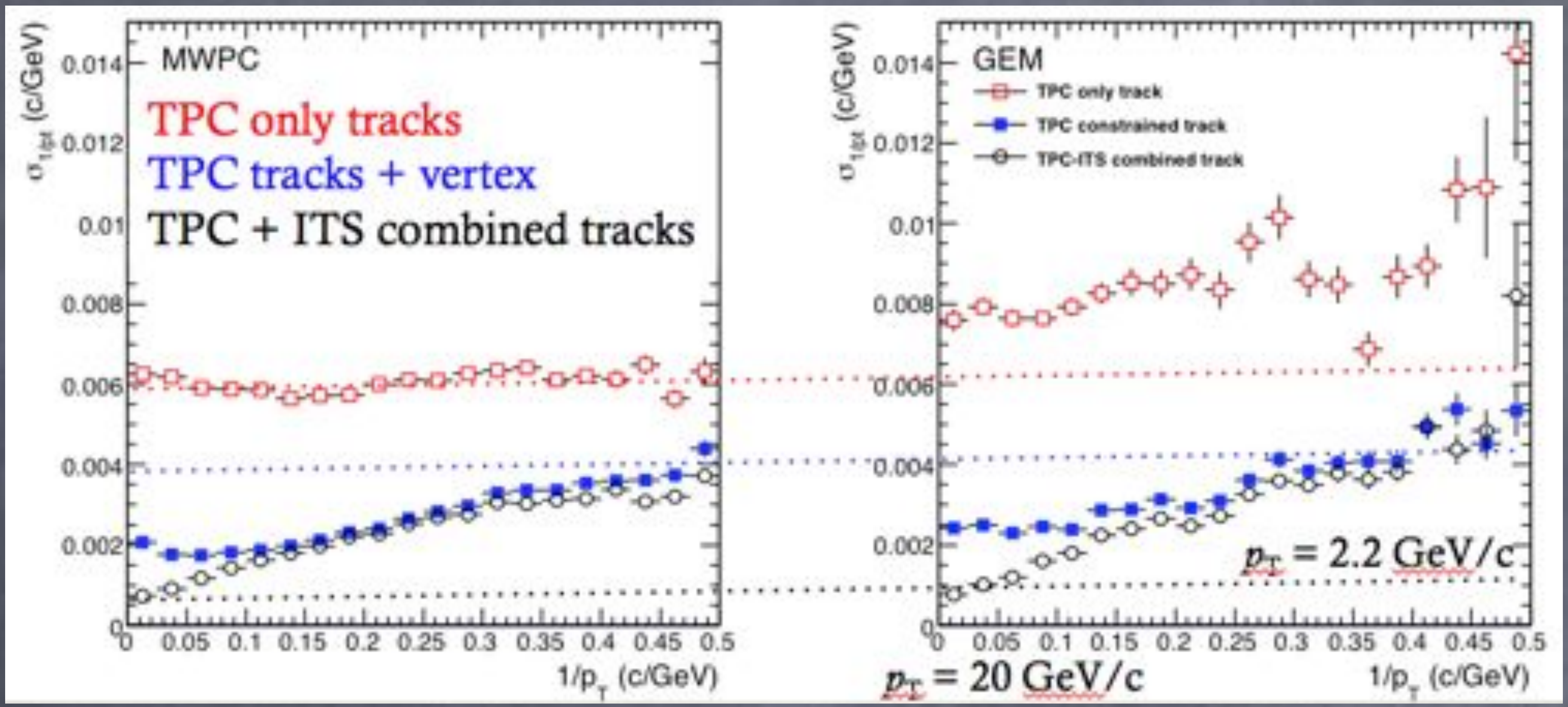
- New read-out planes and front-end electronics for continuous readout, replace MWPC with GEMs: 4 GEM stacks
  Fast electron signal, intrinsic ion blocking (asymmetric field configurations) excellent rate capabilities, faster gas (factor ~ 2-3) replacing Ne-CO_2 with Ne-CF_4



Expected TPC performance

Current: MWPC

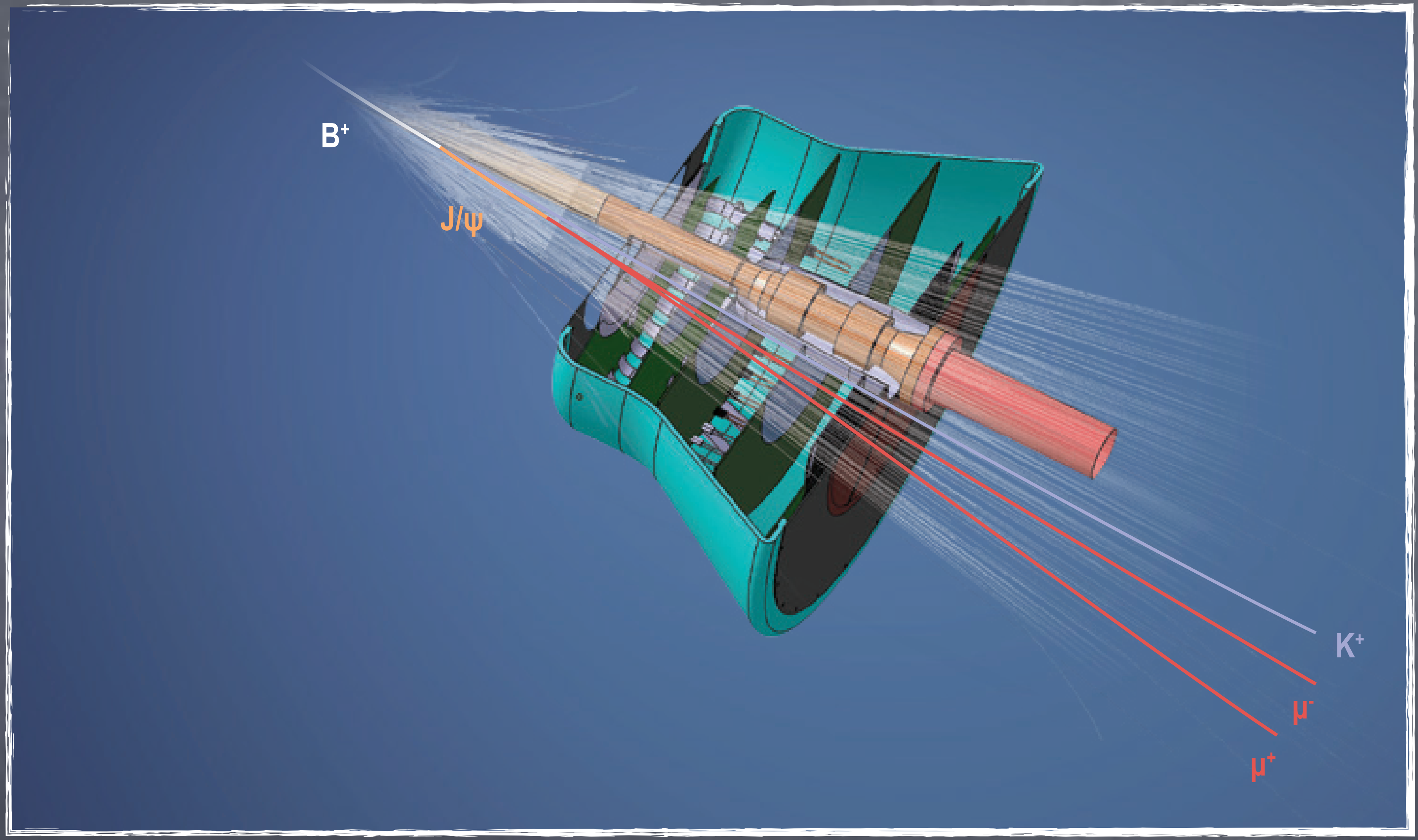
Upgraded: GEM



Upgraded GEM simulation with existing pad planes: not optimized

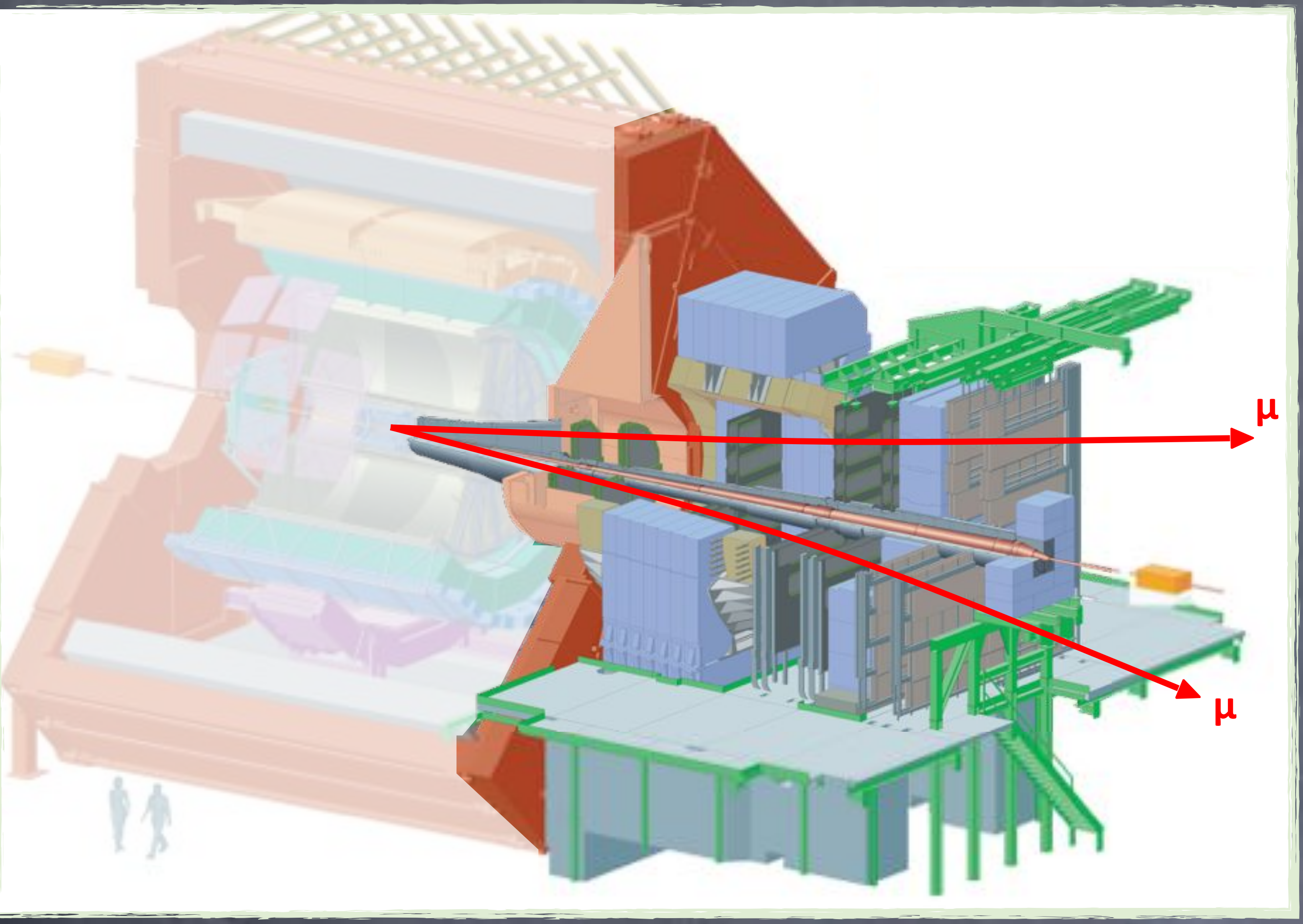
- With existing (not optimized) pad planes standalone resolution slightly worse, but combined tracking not affected
  → Develop new, optimized pad planes to maintain standalone resolution
  → Combined (TPC+ITS) tracking performance is preserved
  → Limited reduction of point spatial resolution
  → No change in momentum resolution

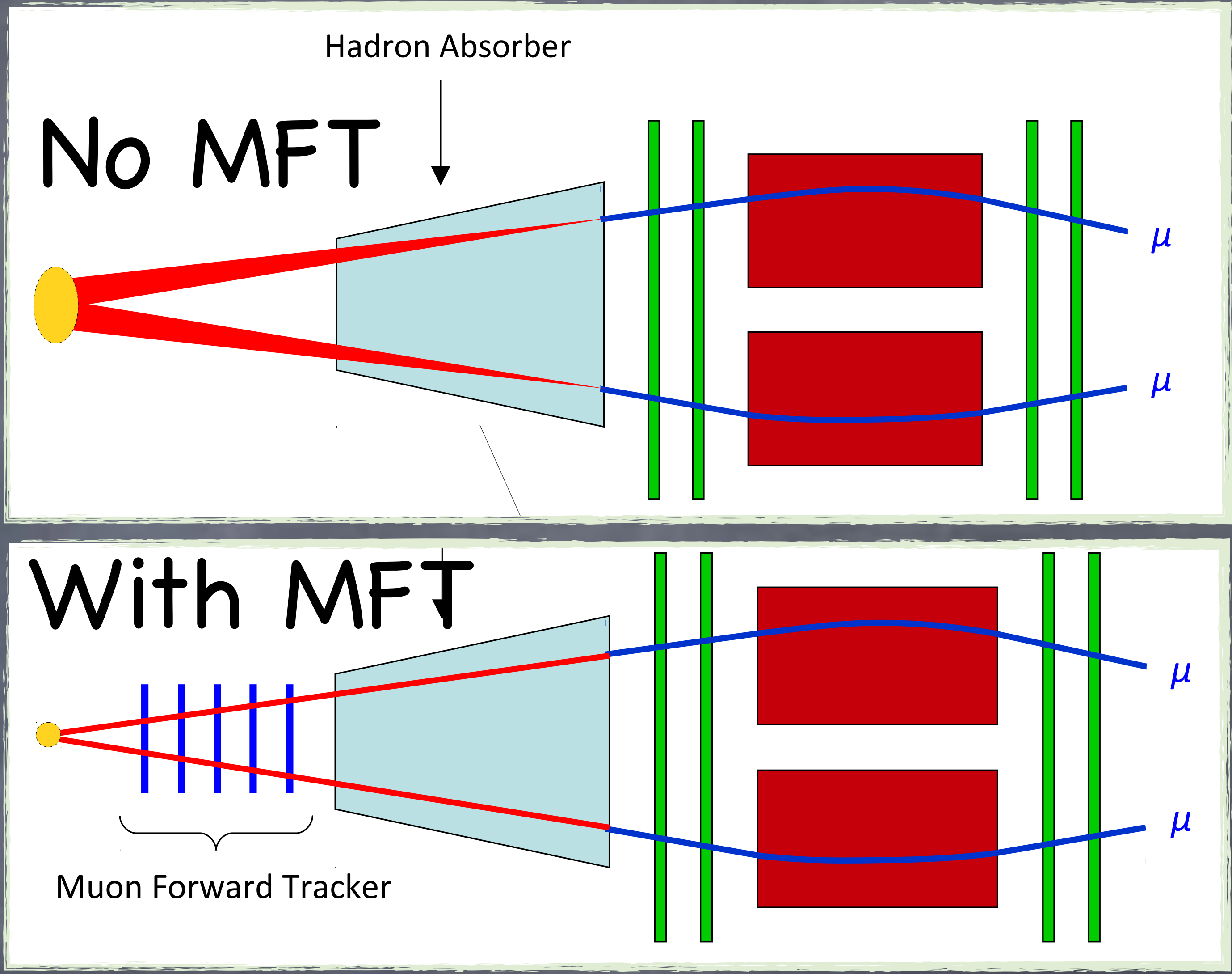
Muon Forward Tracker (MFT)

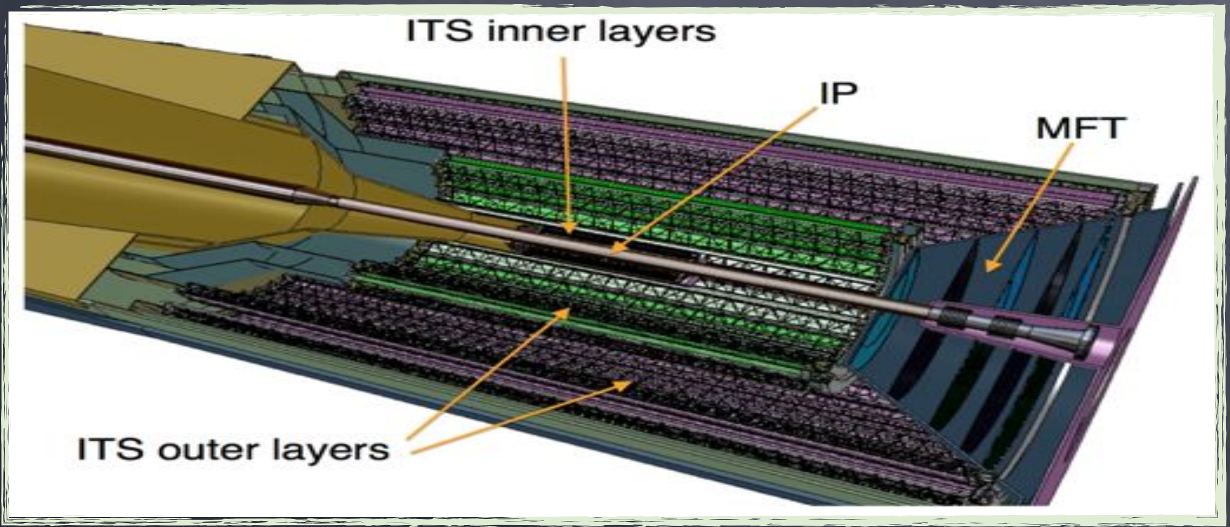


- MFT is approved by ALICE in March 2013
- Submitted for approval to LHCC in Sept. 2013

MFT + Muon Spectrometer



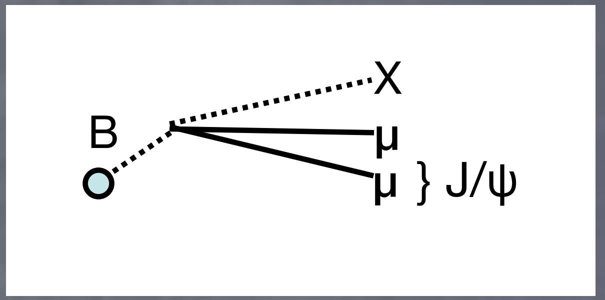




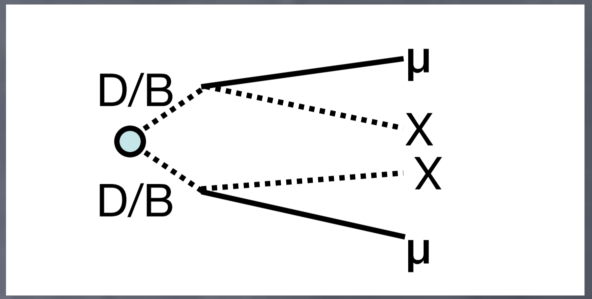
- Silicon pixel tracker (MFT) in front of the absorber (close to IP)
- MFT: 5 additional tracking points for the Muon Spectrometer:
  → enables good secondary vertex resolution

MFT improvements and technology

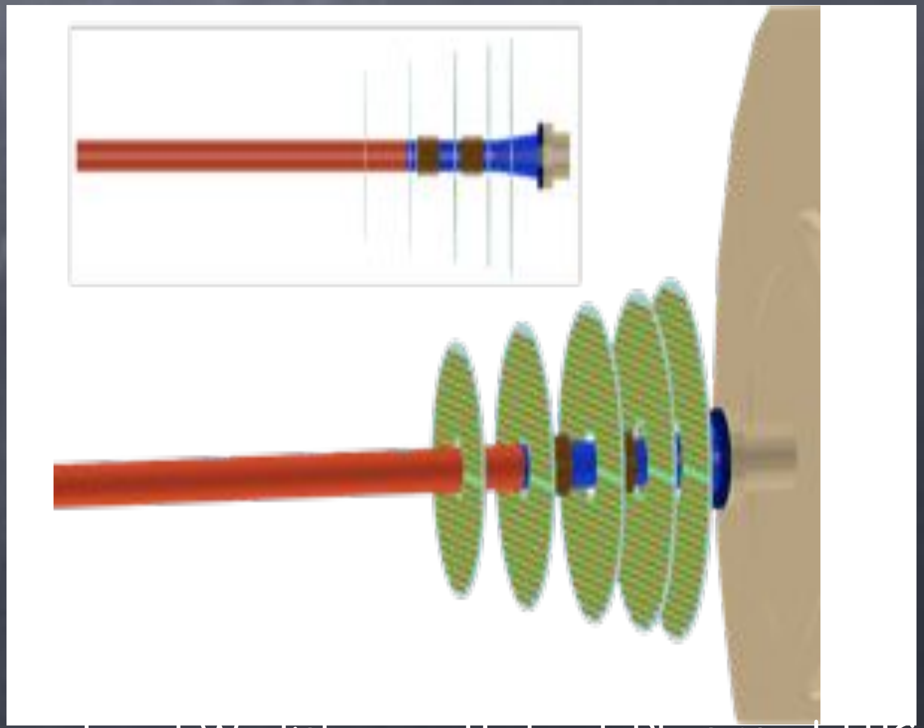
- Measurement of quarkonia & low mass vector mesons
  - → Discrimination between prompt and displaced dimuons (J/ψ from B)
  - → Improvement of the background rejection
  - → Improvement of the invariant mass resolution at low mass



- Separate measurement of open charm and beauty cross-sections
  - → Single muons from displaced vertices of D and B mesons



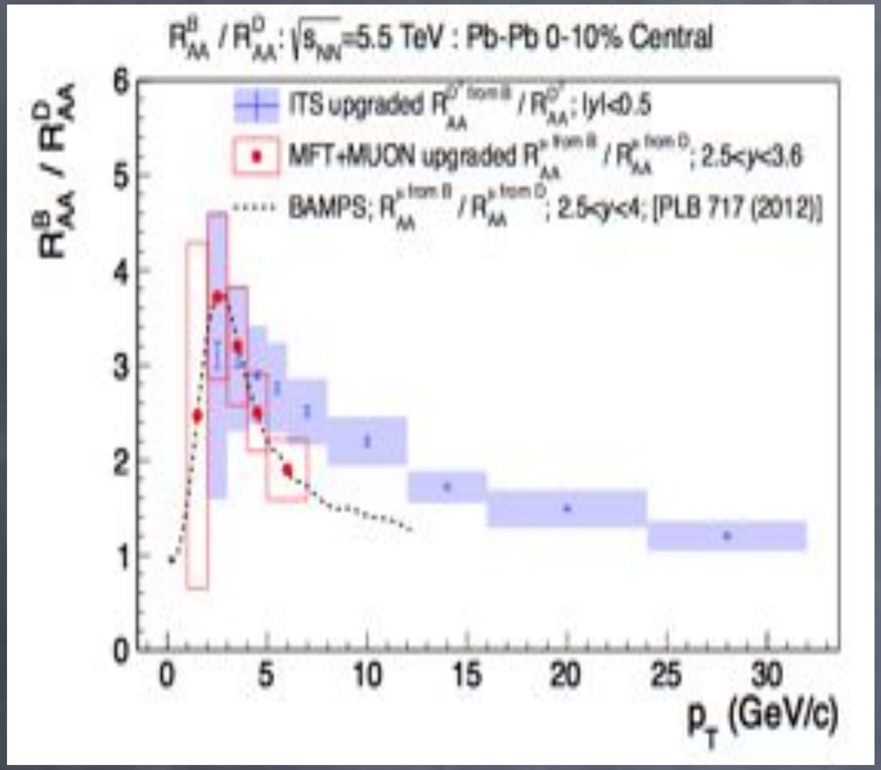
- 5 tracking stations based on monolithic active pixels
  - → Same technology as for the ITS upgrade

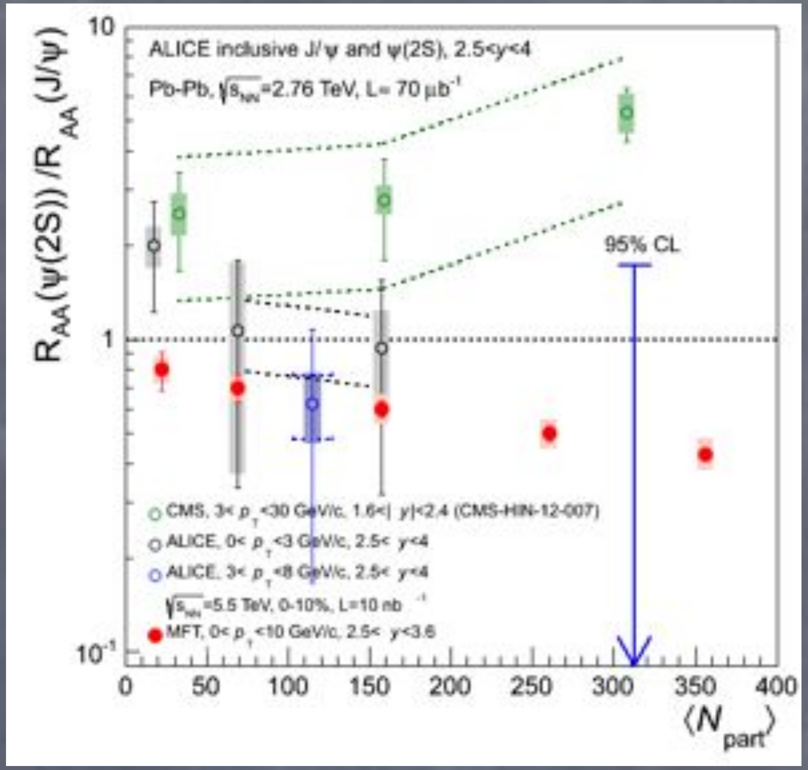


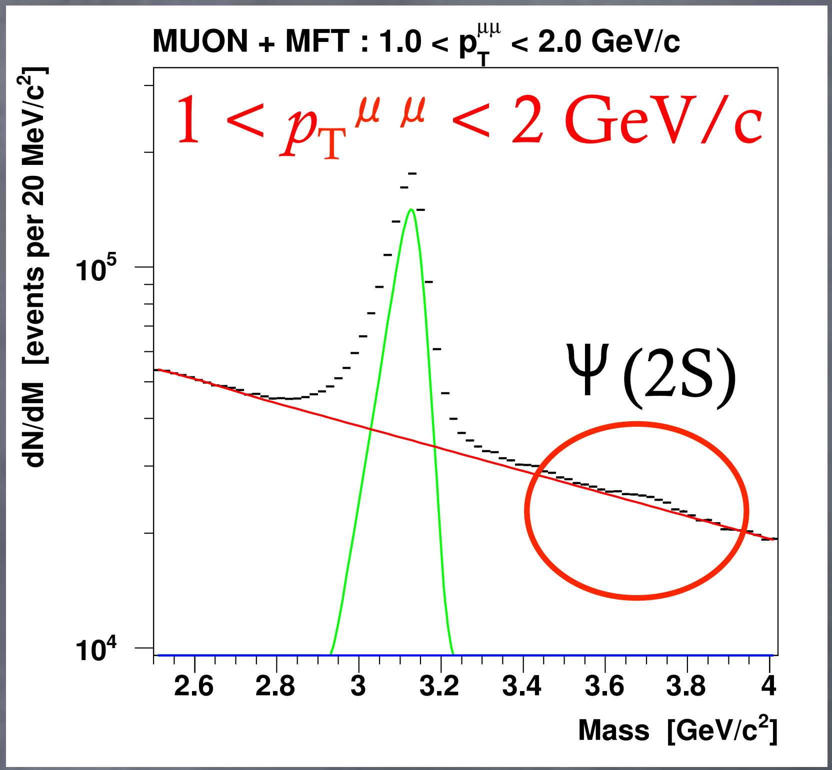
- Distance from IP: $-80 < Z < -50$ cm

- Target material budget: 0.4 % X/X_0 per plane
  - → Pixel pitch ~ 25 μm
  - → Resolution < 5 μm

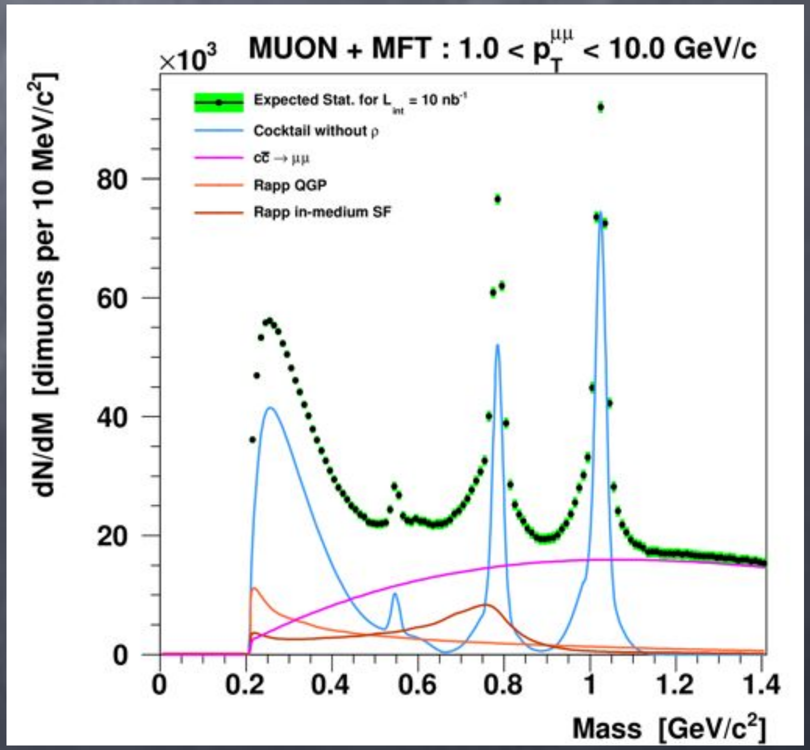
MFT physics performance (sim)







- MUON+MFT and ITS in complementary rapidity range for charm/beauty measurements
- Complementary in rapidity and at low momentum wrt. CMS for J/ψ, ψ(2S)
- ψ(2S) becomes accessible down to very low p_T
- Access to differential dilepton spectra, improved S/B by a factor of 10, mass resolution by a factor of ~ 3 – 5



Upgrade: statistics and uncertainties

Topic	Observable	Approved (1/nb delivered, 0.1/nb m.b.)	Upgrade (10/nb delivered, 10/nb m.b.)
Heavy flavour	D meson R_{AA}	p_T>1, 10%	p_T>0, 0.3%
	D from B R_{AA}	p_T>3, 30%	p_T>2, 1%
	D meson elliptic flow (for v_2=0.2)	p_T>1, 50%	p_T>0, 2.5%
	D from B elliptic flow (for v_2=0.1)	not accessible	p_T>2, 20%
	Charm baryon/meson ratio (Λ_c/D)	not accessible	p_T>2, 15%
	D_s R_{AA}	p_T>4, 15%	p_T>1, 1%
Charmonia	J/ψ R_{AA} (forward y)	p_T>0, 1%	p_T>0, 0.3%
	J/ψ R_{AA} (central y)	p_T>0, 5%	p_T>0, 0.5%
	J/ψ elliptic flow (forward y, for v_2 =0.1)	p_T>0, 15%	p_T>0, 5%
	ψ’	p_T>0, 30%	p_T>0, 10%
Dielectrons	Temperature IMR	not accessible	10% on T
	Elliptic flow IMR (for v_2=0.1)	not accessible	10%
	Low-mass vector spectral function	not accessible	p_T>0.3, 20%
Exotic nuclear states	hyper(anti)nuclei, H-dibaryon	35% ($^4_\Lambda$H)	3.5% ($^4_\Lambda$H)

IMR = Intermediate Momentum Region

Summary

- During the first running period, which will extend until 2017, the ALICE results will provide a description of the global bulk phenomena and a first set of exciting insights into the « small cross section » probes from the heavy flavor sector, the jets and the photons but will leave many important questions unanswered in these domains

- Only the exploitation of the high luminosity in Pb-Pb collisions foreseen after 2018, together with the recent technological advances, will allow one to address new scientific challenges and enable detailed studies of hot QCD matter properties thanks to processes otherwise unreachable

ALICE Upgrade → Busy years ahead!

2012 - 2014 : R&D activities and prototyping
2014 - 2016 : Component fabrication, module construction and characterization
2016 - 2017 : Detector integration and pre-commissioning on surface in laboratory
2017 - 2018 : Installation, commissioning and operation