A Large Ion Collider Experiment

MUON PHYSICS AT FORWARD RAPIDITY WITH THE ALICE UPGRADE

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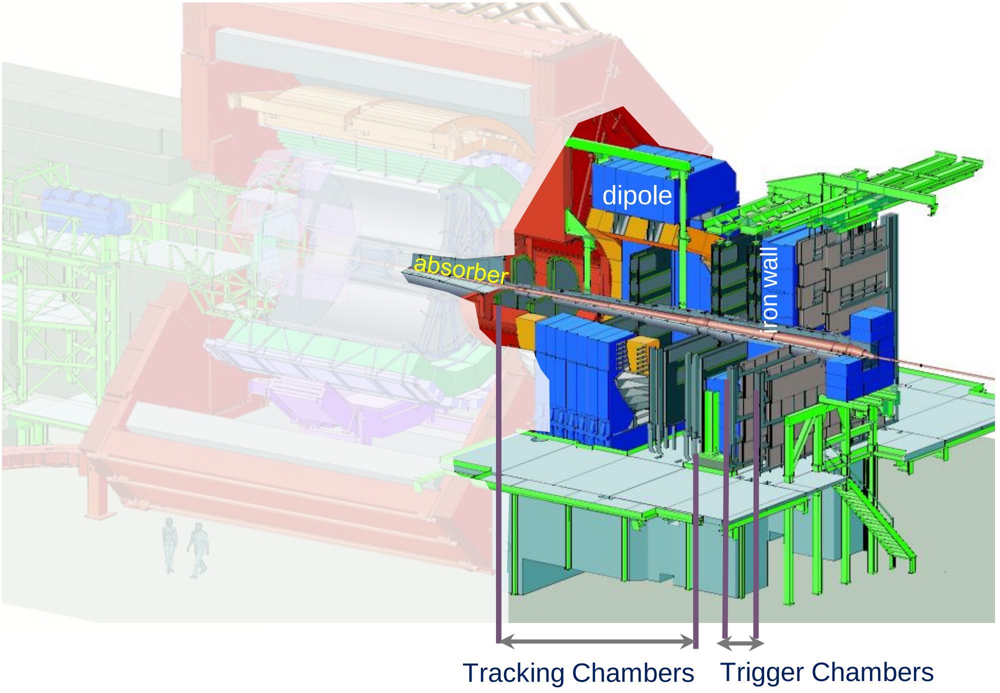
On behalf of the ALICE Collaboration

ALICE Muon Spectrometer



- Detect muons in the polar angular range 2 – 9°, i.e. $2.5 < \eta < 4$ and in the full azimuthal range
- Tracking chambers based on Cathode Pad Chambers grouped in 10 planes with 1.1 million readout channels; spatial resolution ~100 μm
- Trigger chambers based on Resistive Plate Chambers grouped in 4 planes with 21k readout channels; provides single and dimuon triggers with configurable p_T thresholds.

ALICE muon physics − current topics and upgrade motivations

Current topics: Low-mass dimuons, quarkonium states, heavy-flavor single muons, single muons and dimuons from W/Z bosons. Wealth of results published - 38 Muon Pub. / 193 ALICE Pub. ~20% (as of February 2018).

Upgrade motivations:

- **Reduce background from non-prompt sources**
  - Presently, there are large statistical uncertainties due to the large dimuon background from combinatorial π/K, charm and beauty semi leptonic decays . In particular, ψ(2S) measurements are limited by a poor significance of the ψ(2S) signal, namely in Pb-Pb collisions. Drell-Yan production is not accessible

- **Determine the muon production vertex**
  - No charm/beauty separation in single muons possible currently
  - No separation of prompt/non-prompt J/ψ in the present scenario: we miss an important source of information for the study of beauty

- **Improve mass resolution for light neutral resonances**
  - Limited resolution on the dimuon opening angle in the current scenario
- **Faster read-out to cope with the interaction rates expected after LS2**
  - Integrated luminosity during 1 month of Pb-Pb is limited to 1 nb^{-1} due to the present read-out electronics

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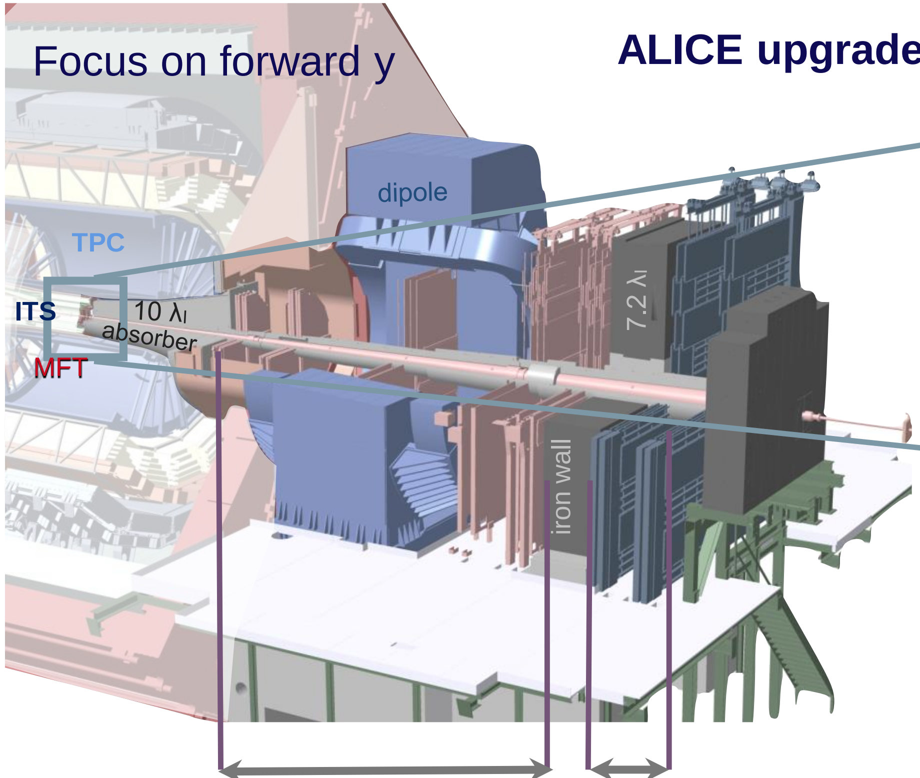
Muon Forward Tracker

Readout upgrade

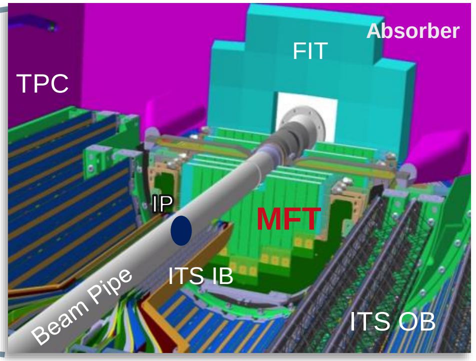
ALICE

ALICE upgrades

Focus on forward y



Upgrade FEE and Readout



New Muon Forward Tracker (MFT)

Target:

- Record **10 nb^{-1}** of Pb-Pb data.
- Read out all Pb-Pb interactions at a maximum rate of **50 kHz** (L = 6×10^{27} cm^{-1} s^{-1})
- Improve **vertexing** and **tracking** capabilities

Strategy:

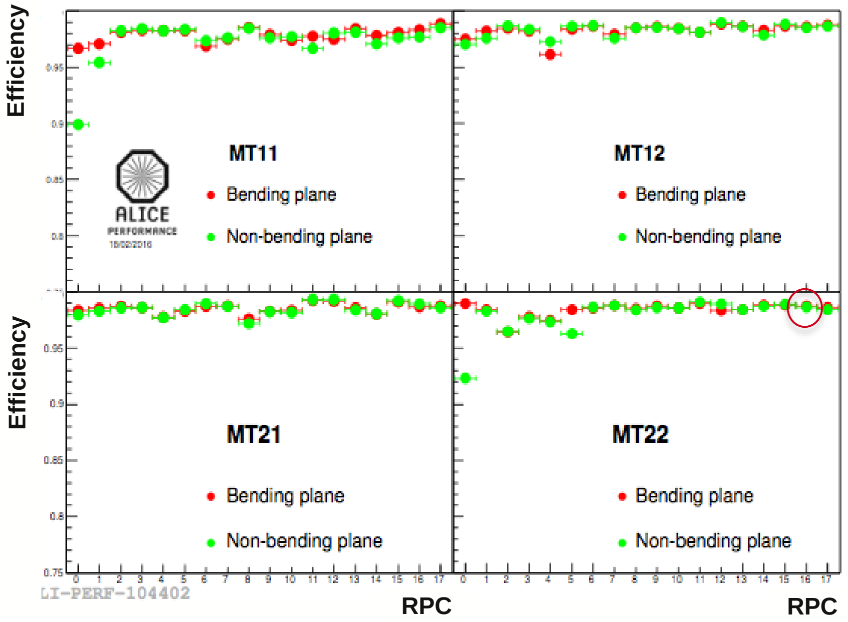
- **Readout upgrade – Muon Tracking and Trigger chambers**
- New Pixel Tracker at forward rapidity**: Muon Forward Tracker (MFT)**
- New Pixel tracker at central rapidity: **Inner Tracking System** (ITS) replacing the current ITS
- **Time Projection Chamber** (TPC) upgrade
- New Trigger detectors – **Fast Integration Trigger** (FIT)
- Upgrade offline and online systems (**O^2 framework**)
- Narrower **beam pipe**

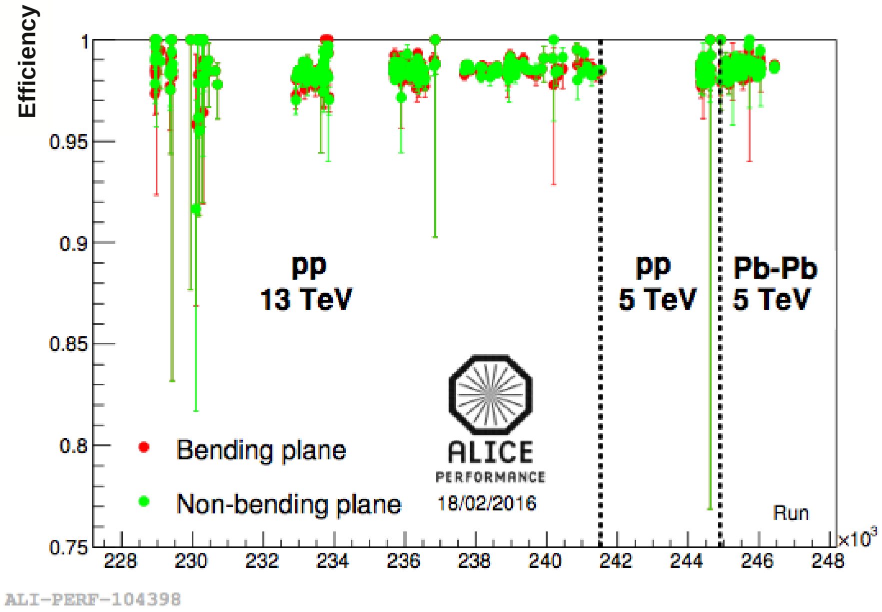
P. Gasik, May 15

Muon-arm upgrade − MID stations

- Increase the rate capability by more than ~1 order of magnitude w.r.t. original design
- Cope with RPC operation in low-gain avalanche mode (required to slow down RPC aging by a factor 3-5 during the high lumi. heavy-ion LHC era)
- New FE chip FEERIC (AMS 0.35 µm)

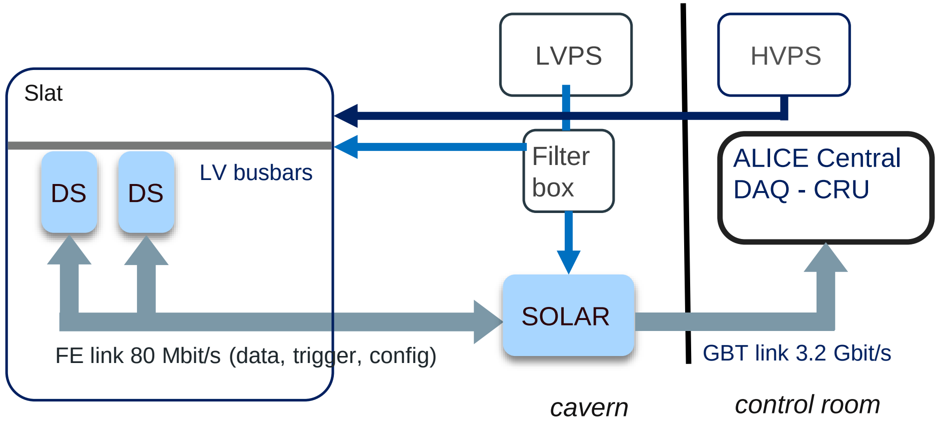
2384 FEERIC cards (+ spares)





- One RPC in ALICE cavern equipped with FEERIC cards (39) - similar efficiency and stability observed w.r.t. the other RPCs

Muon arm upgrade – Tracking stations

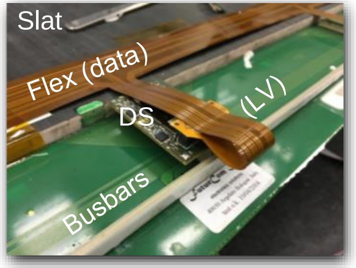


SOLAR (700)

Flex connector / Detector connector

DS top / DS bottom

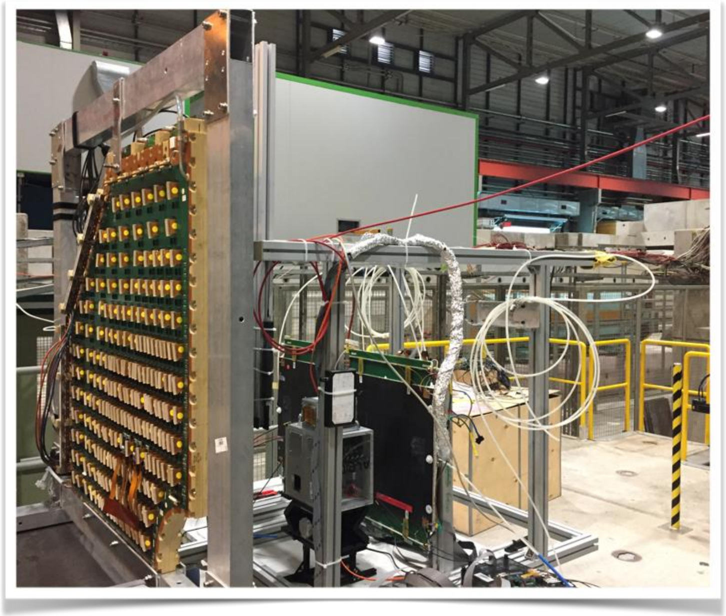
16500 + 2500 (spares)



FE link (flex for the slats) ~3000

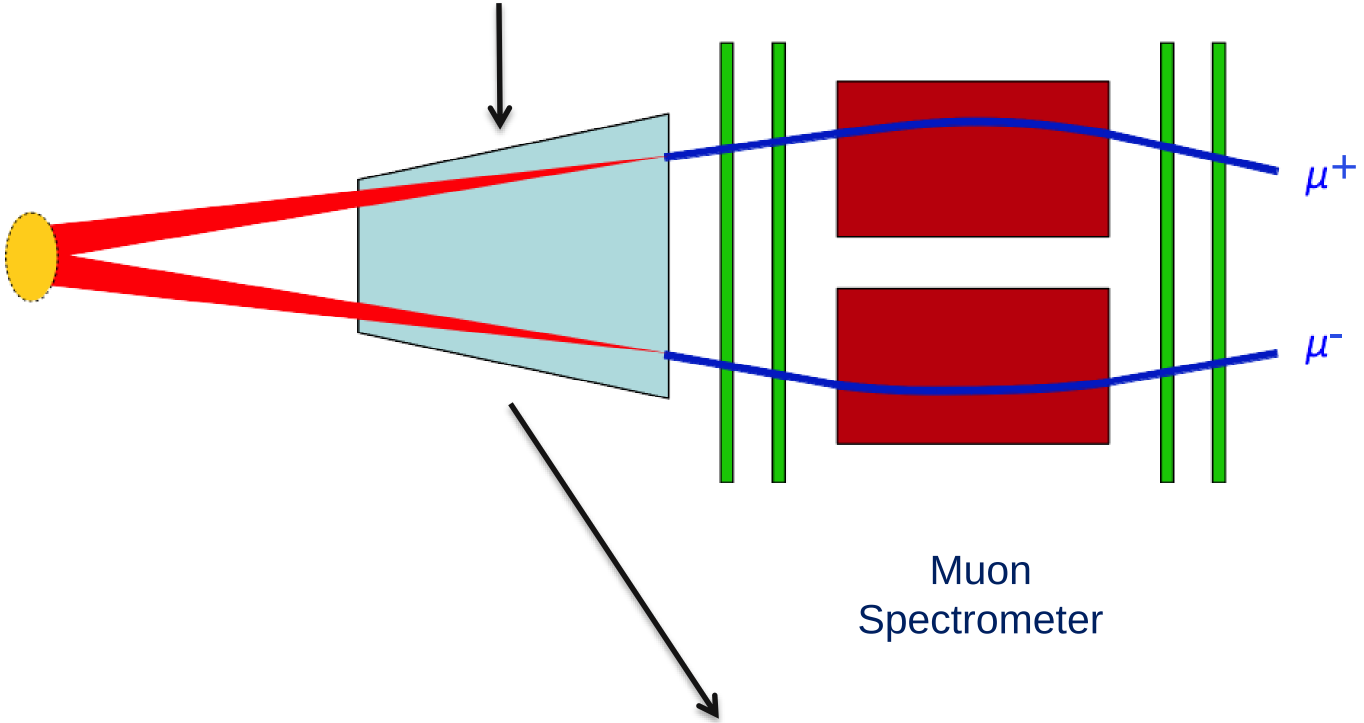
- FE chip (TMC 130 nm) in common with TPC – SAMPA
- FE board hosting two SAMPA chips – Dual Sampa
- FE link: Flex/rigid PCB + ribbon cables
- Concentrator board with GBT – SOLAR
- Common Readout Unit (CRU)

Full chain successfully tested in test beam in 2017 at CERN
- spare slat/quadrant equipped with Dual-Sampa boards
- reference tracks from Si pixel telescope (7 planes of ALPIDE)



Full chain setup at the CERN SPS in September ‘17

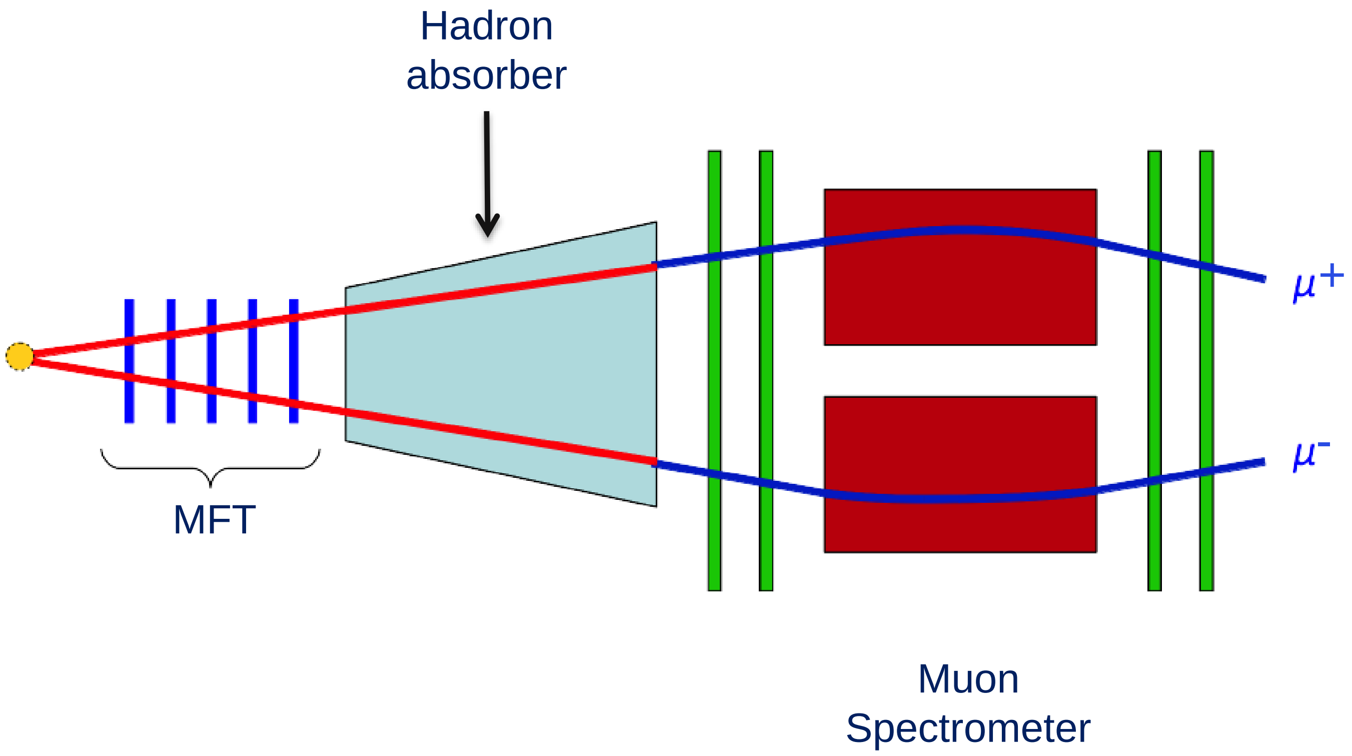
The MFT Concept

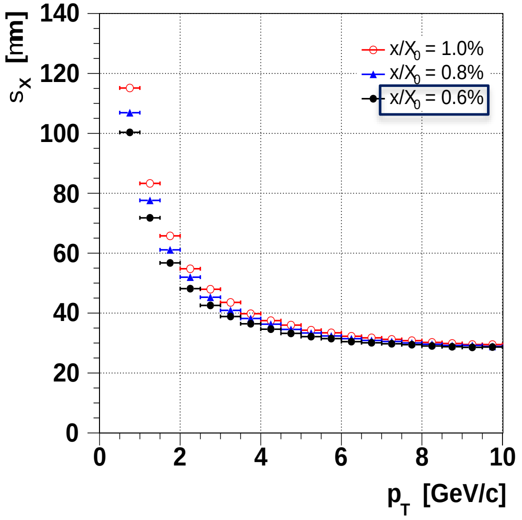


Extrapolating back to the vertex region
degrades the information on the kinematics

The MFT Concept

Muon tracks are extrapolated and **matched to the MFT tracks** before the absorber





CERN-LHC-2015-001

High pointing accuracy gained by the single muon tracks in the transverse direction after matching with the MFT tracks. Pseudo-rapidity window reduces to $2.5 < \eta < 3.6$

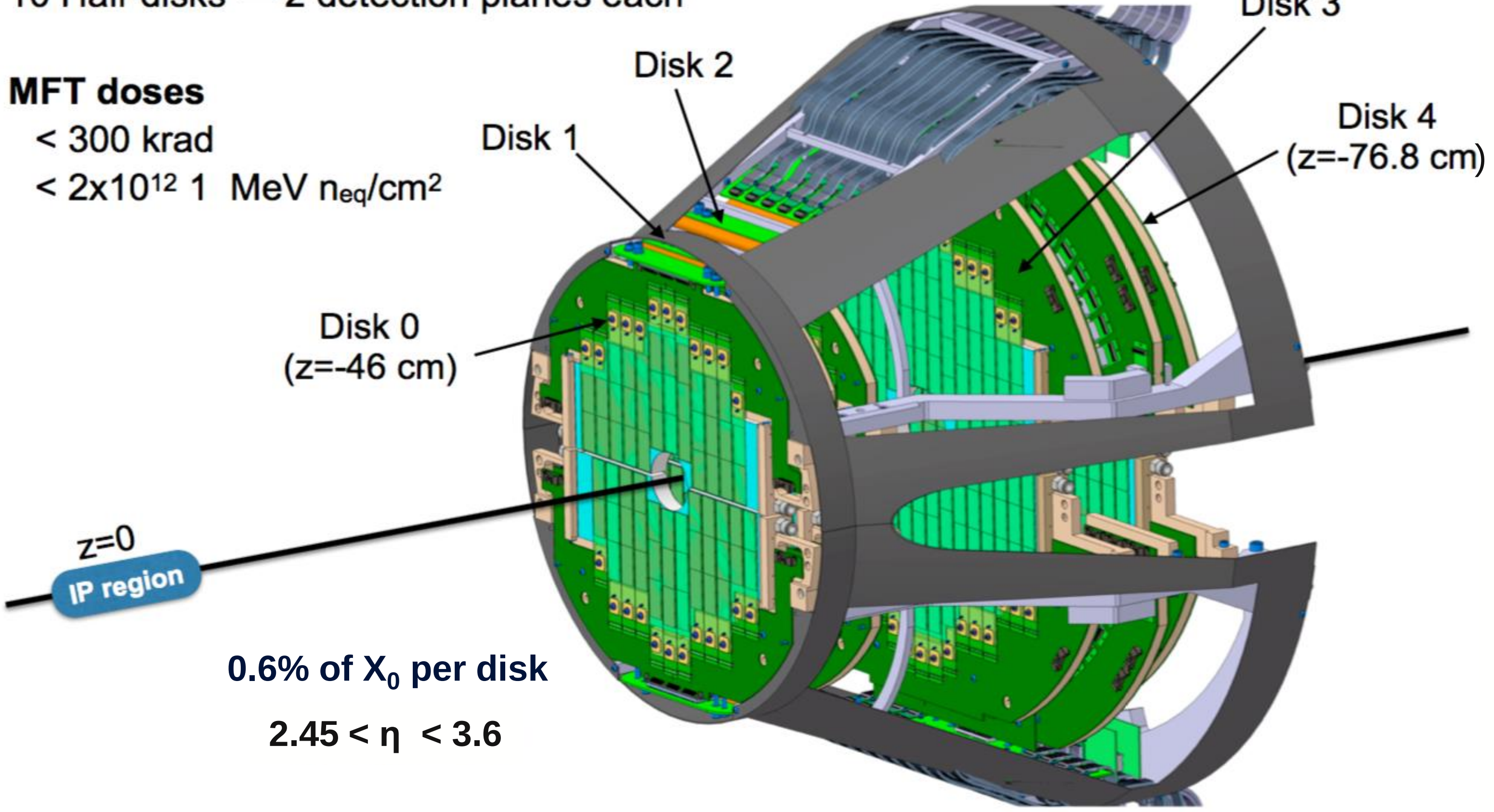
Muon Forward Tracker (MFT)

920 silicon pixel sensors (0.4 m^2) on 280 ladders of 2 to 5 sensors each

10 Half-disks — 2 detection planes each

MFT doses

- < 300 krad
- < 2×10^{12} 1 MeV n_{eq}/cm^2



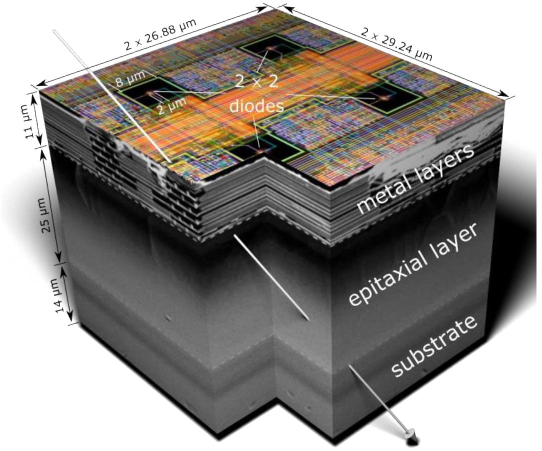
0.6% of X_0 per disk

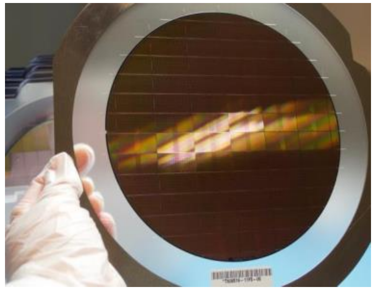
$2.45 < \eta < 3.6$

ALPIDE pixel sensor (ITS Upgrade and MFT)

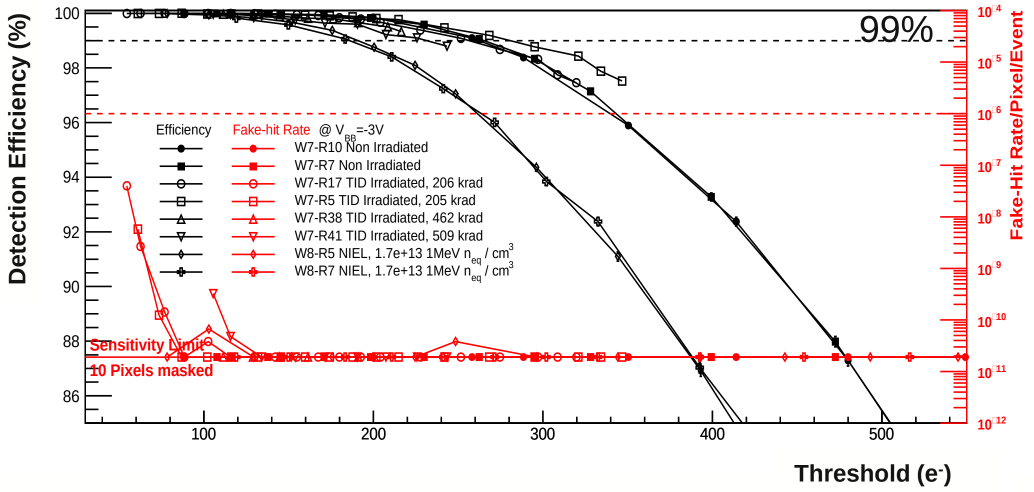
Monolithic Active Pixel Sensors (MAPS), TowerJazz 0.18 μm technology

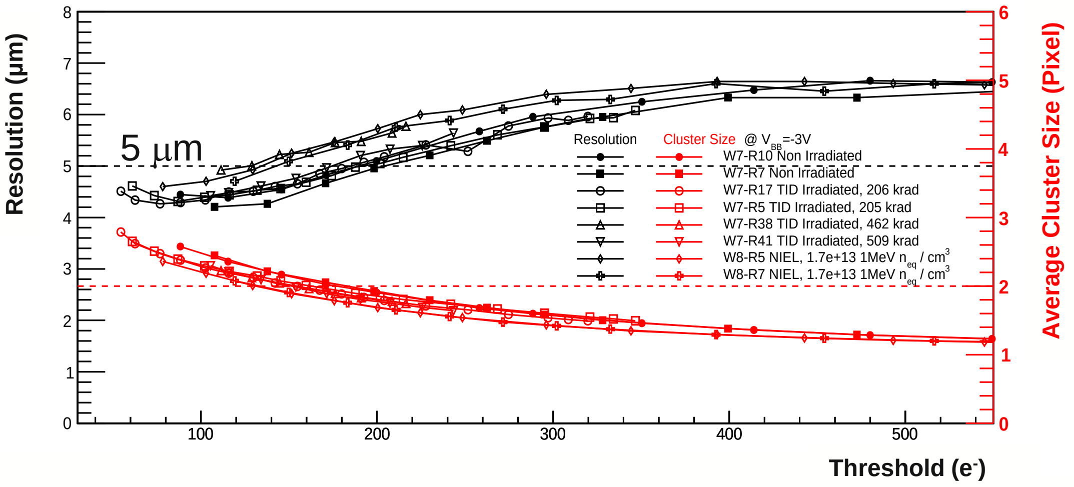
- Sensor size: 15 mm x 30 mm
- Pixel size: 29 μm x 27 μm
- Detection efficiency > 99%
- Event time resolution <4 μs
- Space resolution: 5 μm
- Power consumption: ~40 mW/cm^2
- Radiation dose (Run3+Run4): <300 krad, <2.0x10^{12} 1MeV n_{eq}/cm^2





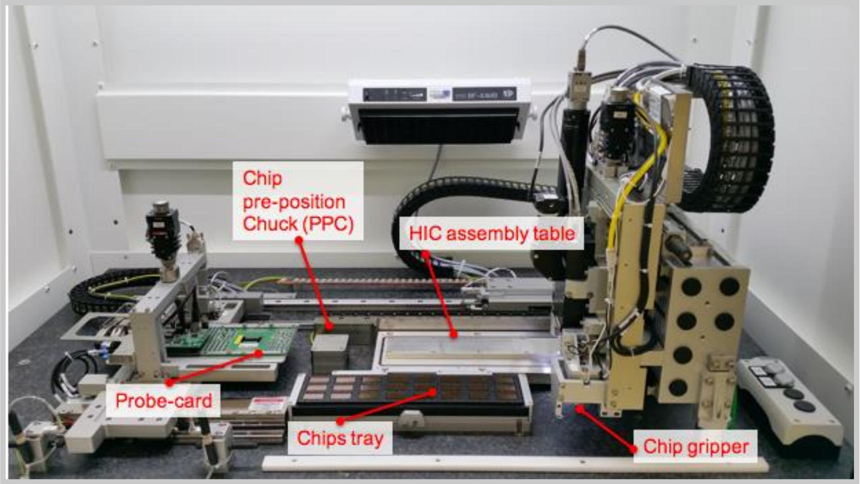
ALPIDE
production finished



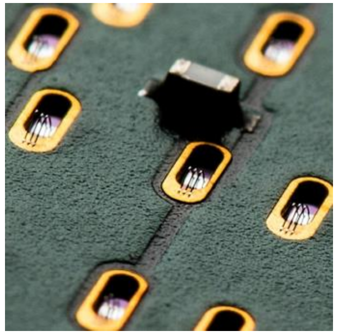


Building the MFT

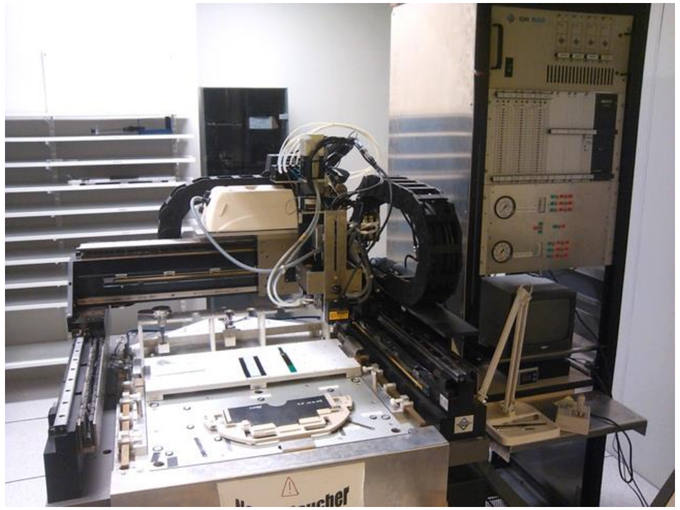
ALICIA7: pick, test and position the chips on the assembly jig



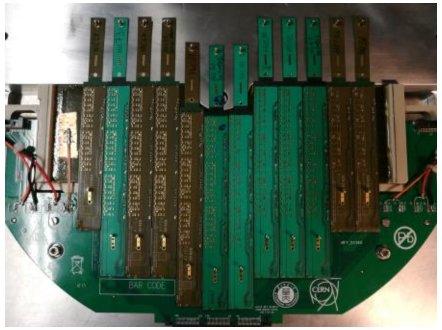
FPC



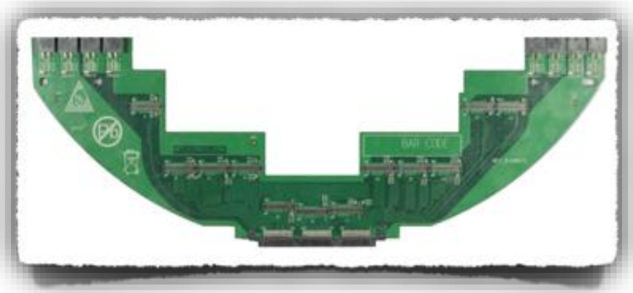
Gantry robot for automatic gluing of the ladder onto the heat-exchanger of a half-disk



MFT cone



MFT disk prototype



Prototype PCB half-disks

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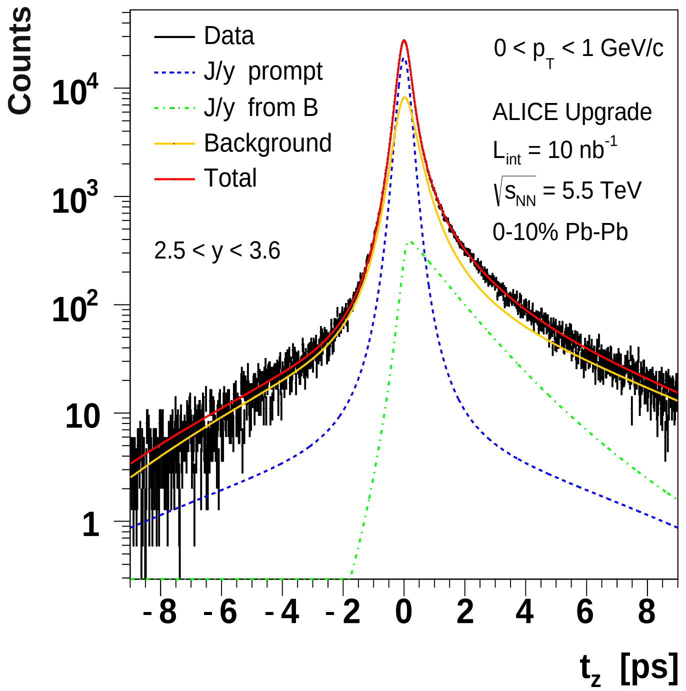
Beauty Measurement with non-prompt J/ψ

The MFT will allow prompt/displaced J/ψ separation down to zero p_T by measuring the pseudo-proper decay time associated to the secondary vertex

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

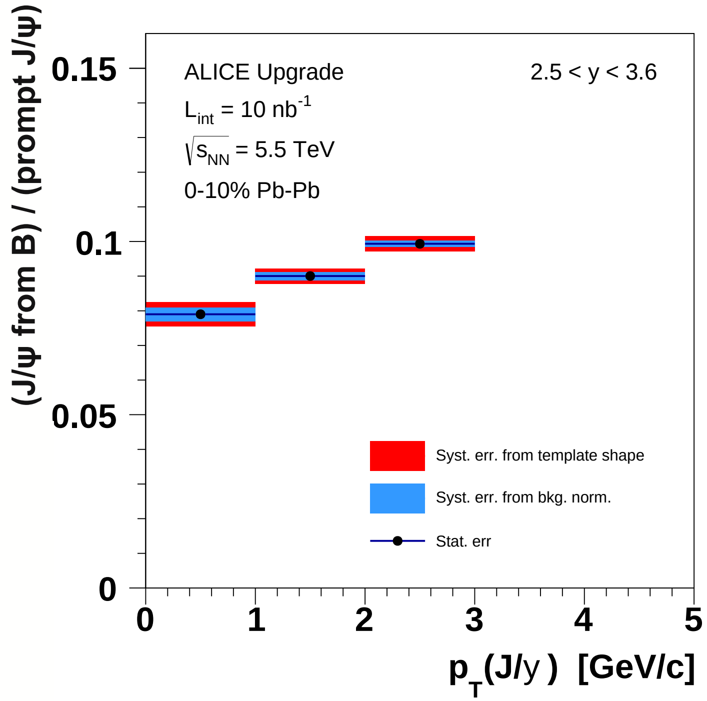


- **Simultaneous fit** of the dimuon invariant mass spectrum and the t_z distribution of the dimuons falling within the chosen J/ψ mass window
- **The fit of the invariant mass spectrum** fixes the normalization of the background and the inclusive J/ψ signal. **The fit of the t_z -distribution** then separates the two J/ψ contributions

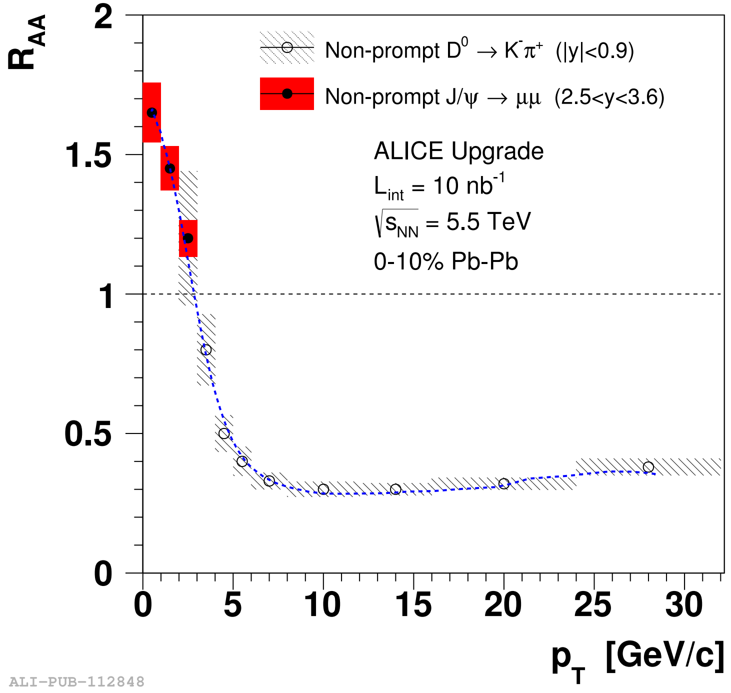
Beauty measurement with non-prompt J/ψ

Displaced/prompt separation possible down to zero p_T of the J/ψ within 5% stat + syst

Beauty R_{AA} measurement possible down to zero p_T of the J/ψ within 7% stat + syst uncertainties in central Pb-Pb



Expected uncertainties on the measurement of the displaced/prompt J/ψ ratio



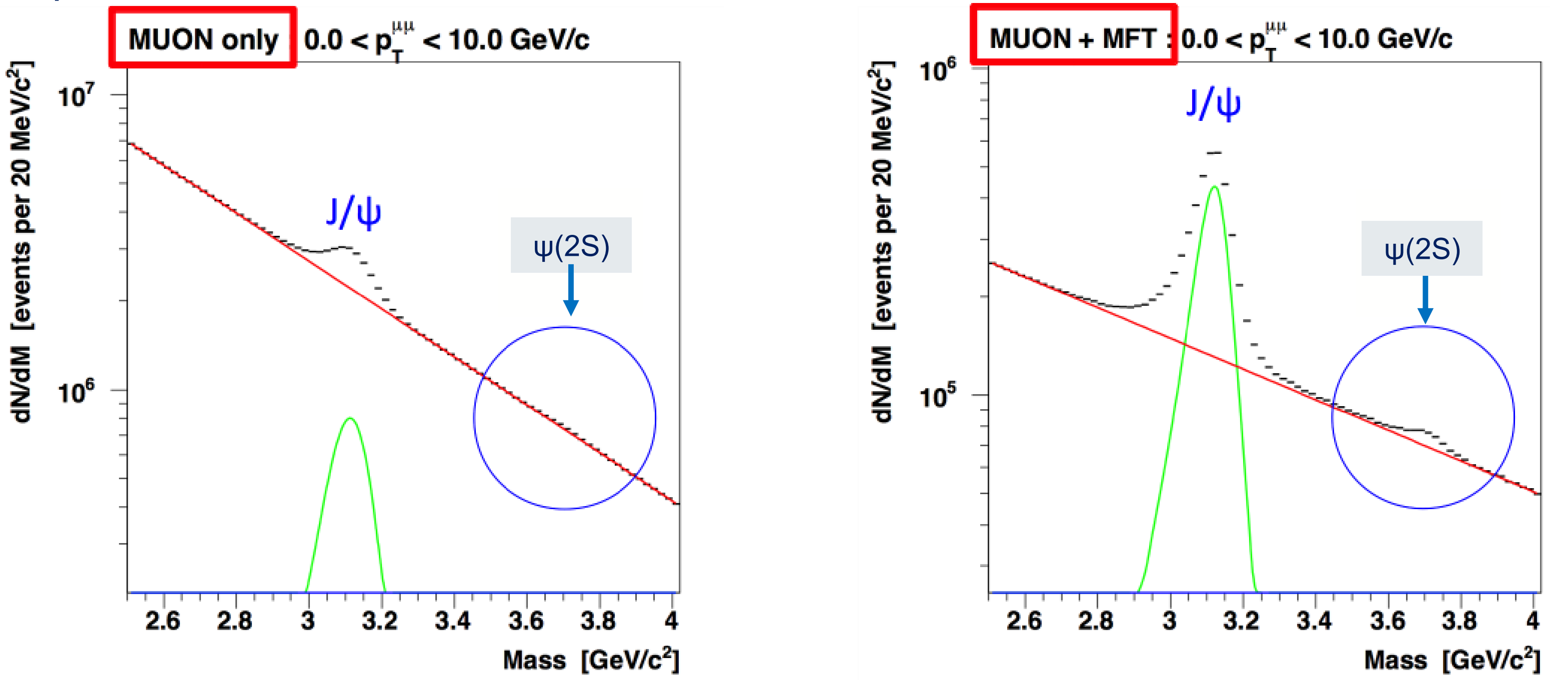
Performance for the measurement of the Beauty R_{AA} at central and forward rapidity

Charmonia

Precision measurement for J/ψ at forward rapidity already in LHC Run 2, but:

- Limited insight into ψ(2S) physics in central Pb-Pb
- Only inclusive measurement available at forward rapidity

MFT will give a robust ψ(2S) measurement by improving the S/B by a factor 5 to 6 w.r.t the current MUON spectrometer

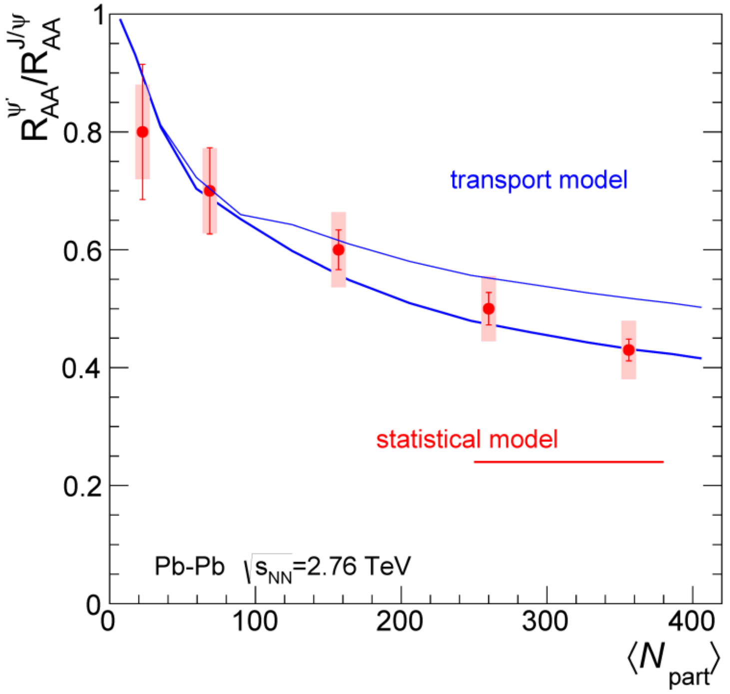


Performance of the dimuon-mass measurement in the charmonium region

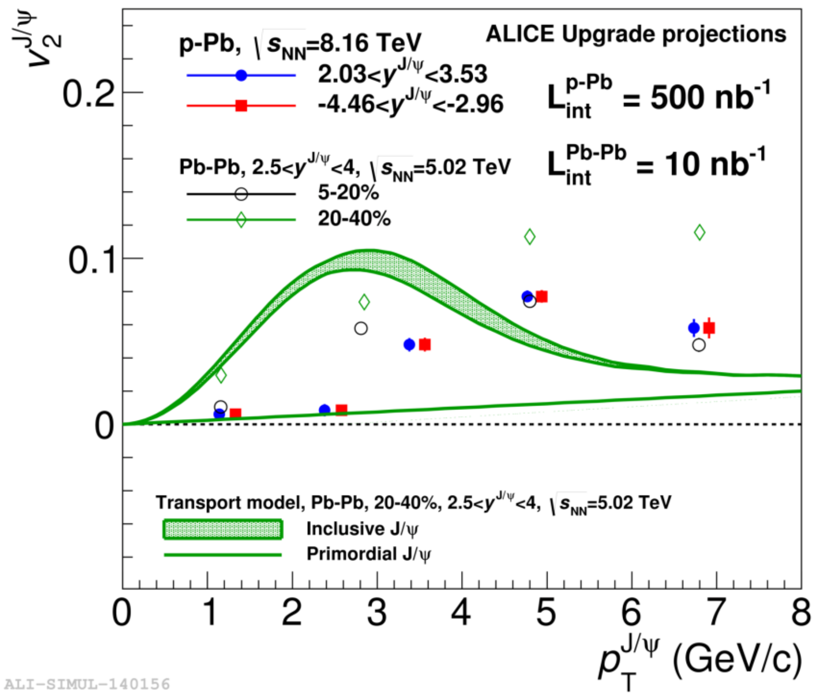
Charmonia

Dissociation/Recombination models for charmonia can be tested by comparing the nuclear modification factors of J/ψ and ψ(2S) down to zero p_T

Precision measurement for J/ψ flow



MUON+MFT performance for the ψ(2S)/(J/ψ) measurement



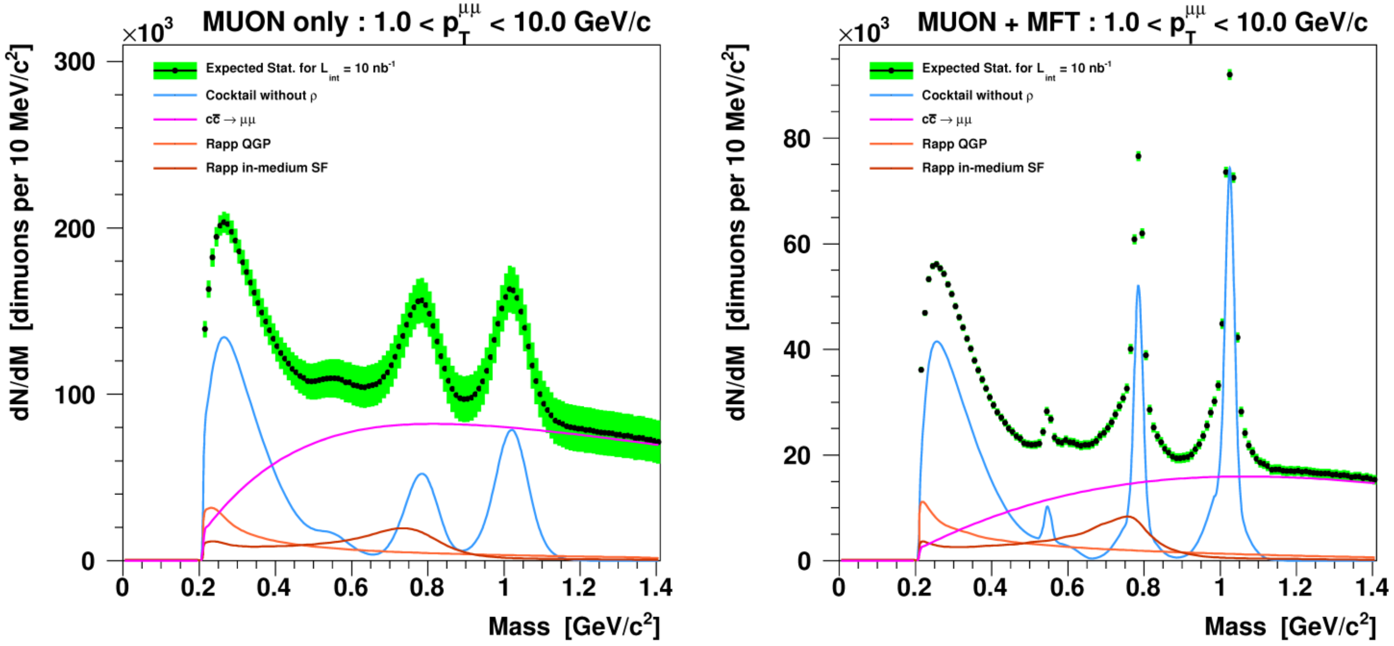
J/ψ v_2 measurement with ALICE upgrade

Low-mass dimuons

Improvement of the mass resolution for light resonances in dimuons

Reduction of combinatorial background

$\sqrt{s_{NN}}$ =5.5 TeV



QGP-related processes will be easier to isolate with the MFT within 20% uncertainty (currently not possible)

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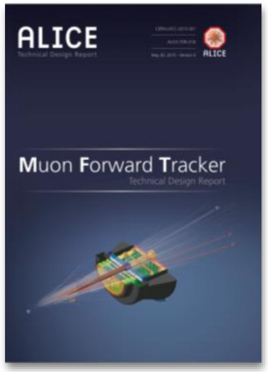
New physics observables with the MFT

Topic	Observables	Muon	Muon+MFT Upgrade
Heavy flavor	R_{AA} (J/ψ from B)	Not accessible	p_T>0 ; 10%
	v_2 (J/ψ from B)	Not accessible	Estimation ongoing
	μ decays from c-hadrons	Not accessible	p_T>1 ; 7%
	μ decays from b-hadrons	Not accessible	p_T>2 ; 10%
Charmonia	R_{AA} (prompt J/ψ)	Not accessible	p_T>0 ; 10%
	v_2 (prompt J/ψ)	Not accessible	Estimation ongoing
	Ψ(2S)	p_T>0 ; 30%	p_T>0 ; 10%
Low mass	Low Mass spectral func. and QGP radiation	Not accessible	p_T>1 ; 20%

Summary and Outlook



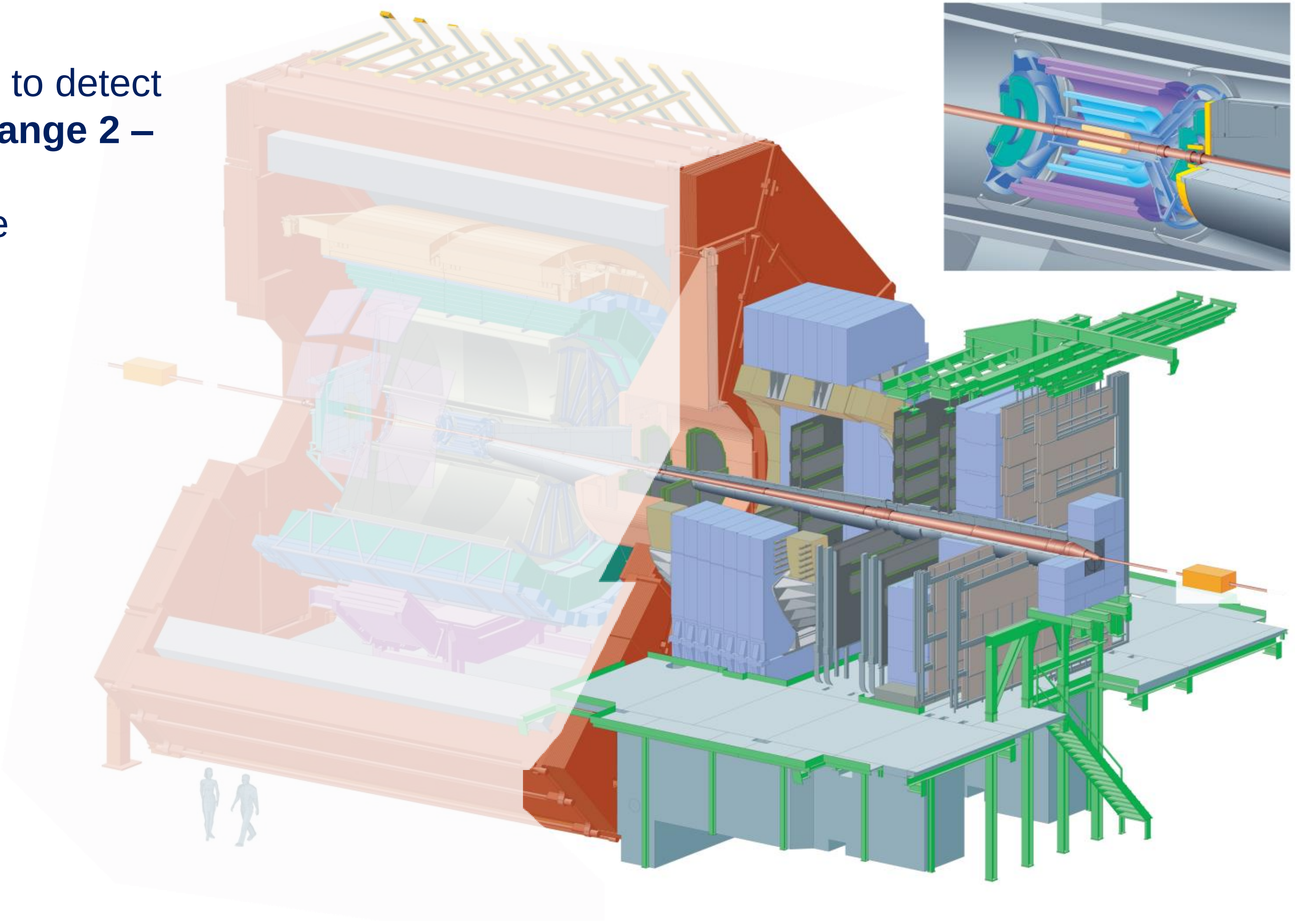
- MFT will enhance the muon physics program in ALICE for Runs 3 and 4
- Muon Tracking and Trigger chambers will be upgraded with new FEE to cope with the higher interaction rates in Runs 3 and 4
- All the ALPIDE chips for MFT have been produced, the production of the 600 MFT ladders has started and the production of MFT disks will start next month
- Pre-production/production ongoing for all other components

Thank You

Spare slides

ALICE Muon Spectrometer

Muon Spectrometer designed to detect muons in the **polar angular range 2 – 9°, i.e. – 4.0 < η < – 2.5**
and in the full azimuthal range



- Hadron Absorber
- Dipole Magnet
- 10 tracking chambers
- Iron wall
- 4 trigger chambers

ALICE muon physics − current topics

ALICE

- **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 $\pi^+\pi^- \longrightarrow \rho \longrightarrow \mu^+\mu^-$

Ref. QM talk/poster

- **Quarkonium states.** Dissociation/recombination in the QGP phase. Test of perturbative QCD hadro-production mechanisms in pp collisions. Quarkonium photo production in UPCs and nuclear collisions.

Ref. QM talk/poster

- **Heavy-flavor single muons.** Energy loss and coupling of charm and beauty quarks with the deconfined medium. Study heavy quark transport in the QGP, hadronization, reference for quarkonia

Ref. QM talk/poster

- **Single muons and dimuons from W/Z bosons.** Golden probes of the nucleus-nucleus and proton-nucleus initial state. Probes of nucleons and nuclei parton structure

Ref. QM talk/poster

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ALICE Upgrade strategy

Motivation

High precision measurements of rare probes at low p_T which cannot be selected with a trigger – require large event samples on tape.

Target

- Pb-Pb recorded luminosity ≥ 10 nb^{-1} plus pp and p-A data

Gain a factor of 100 in statistics for minimum bias trigger and a factor of 10 for muon triggers over the current programme

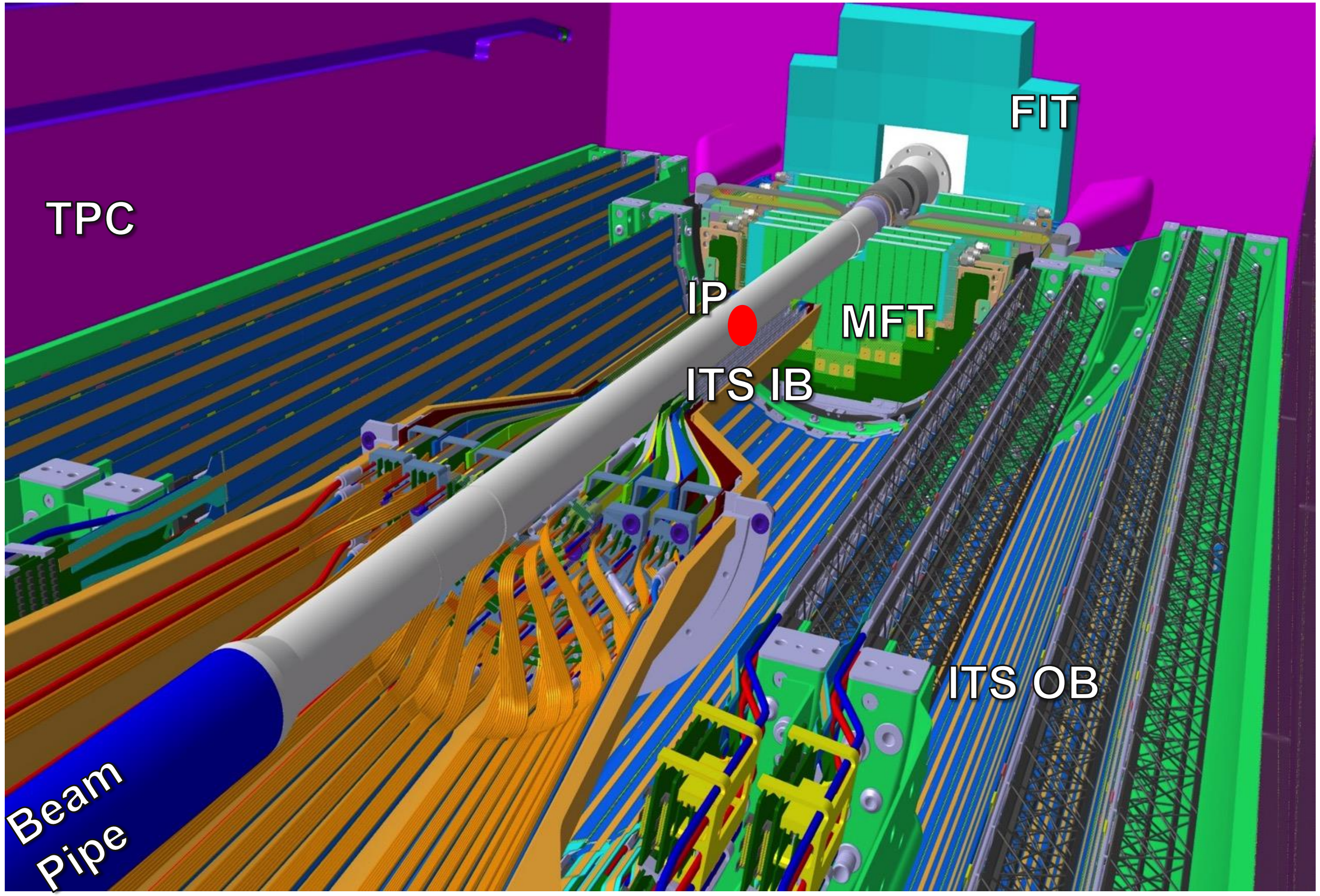
- Improve vertexing, tracking and read-out rate capabilities

Strategy

Upgrade ALICE readout (for several detectors) and online systems

- ➢Read out all Pb-Pb interactions at a maximum rate of 50 kHz ($L = 6\times10^{27}$ cm^{-1} s^{-1}) with a minimum bias trigger
- ➢Perform online data reduction

New silicon trackers: Inner Tracking System (mid-rapidity), Muon Forward Tracker (forward rapidity), along with a new beam pipe with a smaller radius.


FIT
TPC
IP
MFT
ITS IB
ITS OB
Beam
Pipe

MFT design goals

Vertexing for the Muon Spectrometer at forward rapidity

- 5 detection disks, O(5 μm) spatial resolution
- 0.6% of X_0 per disk
- $-3.6 < \eta < -2.45$
- Disk#0 at z = -460 mm, R_{in} = 25 mm (limited by the beam-pipe radius)

Good matching efficiency between MFT and MS

- Disk#4 at z = -768 mm (limited by FIT and the frontal absorber).

Fast electronics read-out

- Pb-Pb interaction rate ~50 kHz, pp interactions ~200 kHz.
- Integration time and dead-time < 20 μs

Charm measurement with single muons

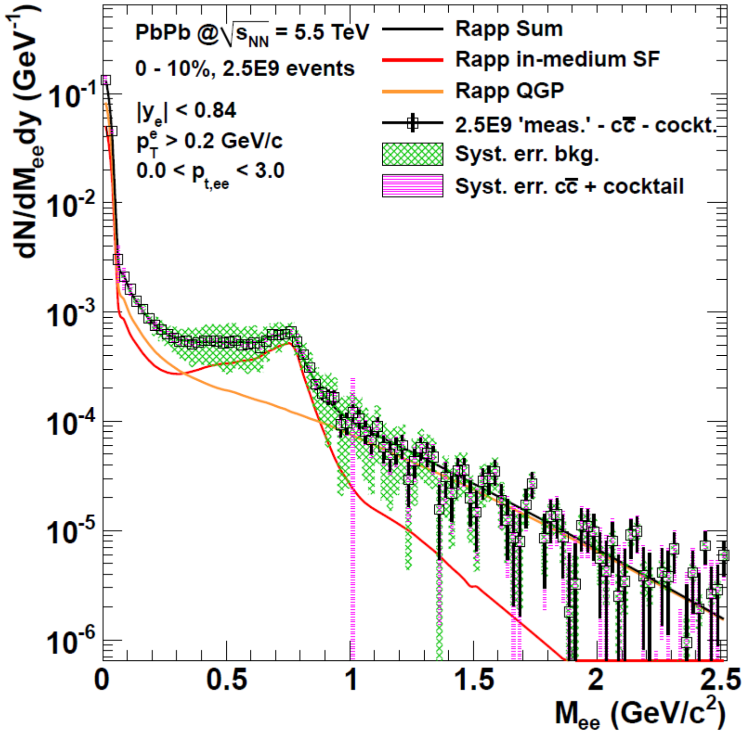
- **Performance studies only available for p_T < 6 GeV/c** because of the limited MC statistics for the background

- **Analysis strategy:** fit of the total transverse offset distribution with the three expected contributions: background, charm and beauty. Templates for each component are extracted from the MC simulations

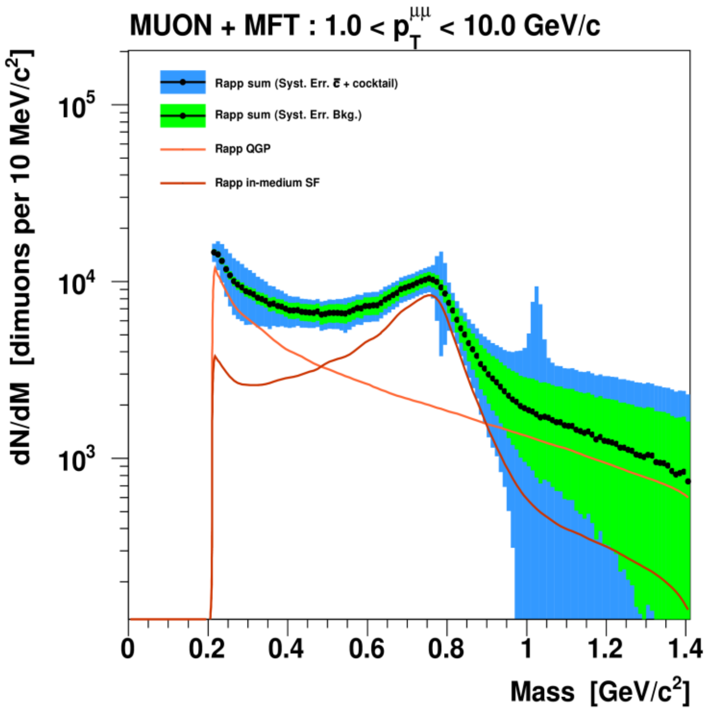
- **Transverse offset:** distance between the primary vertex (measured with the ITS) and the transverse position of the muon tracks extrapolated to the z of the primary vertex

$$\Delta = \sqrt{(x_{\mathrm{V}} - x_{\mathrm{Extrap}})^2 + (y_{\mathrm{V}} - y_{\mathrm{Extrap}})^2}$$

Low mass



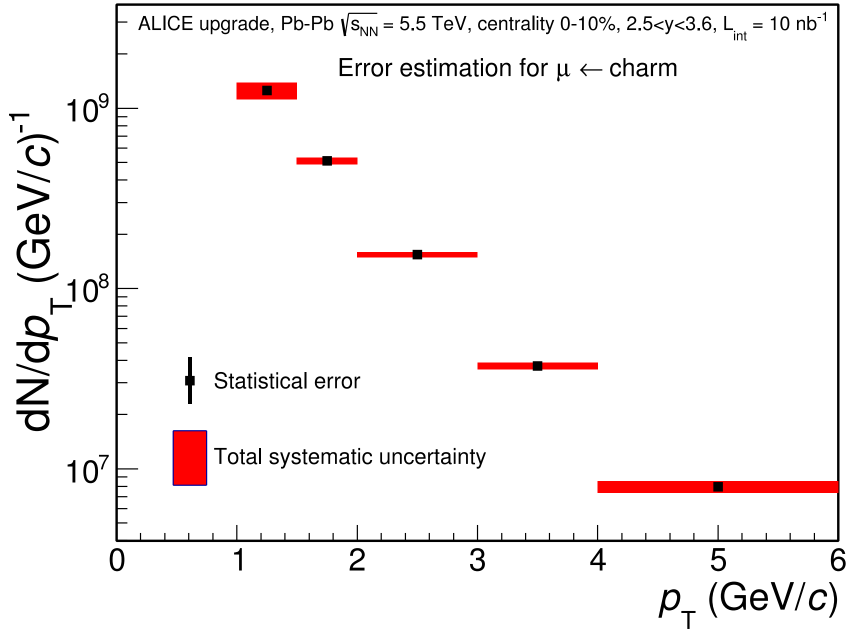
PbPb @ $\sqrt{s_{NN}}$ = 5.5 TeV
0 - 10%, 2.5E9 events
$|y_e| < 0.84$
$p_T^e > 0.2$ GeV/c
$0.0 < p_{t,ee} < 3.0$
Rapp Sum
Rapp in-medium SF
Rapp QGP
2.5E9 'meas.' - $c\bar{c}$ - cockt.
Syst. err. bkg.
Syst. err. $c\bar{c}$ + cocktail
$dN/dM_{ee}dy$ (GeV^{-1})
M_{ee} (GeV/c^2)

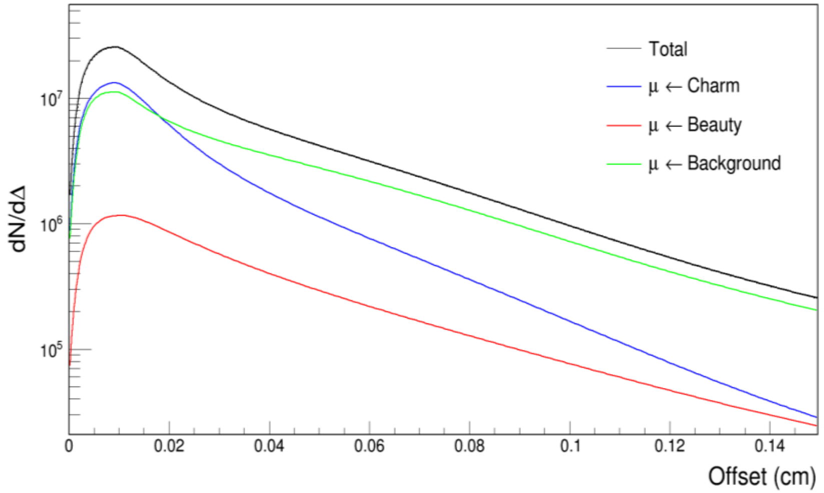


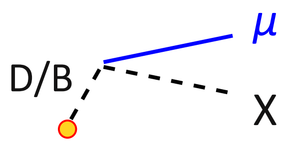
MUON + MFT : $1.0 < p_T^{\mu\mu} < 10.0$ GeV/c
Rapp sum (Syst. Err. $c\bar{c}$ + cocktail)
Rapp sum (Syst. Err. Bkg.)
Rapp QGP
Rapp in-medium SF
dN/dM [dimuons per 10 MeV/c^2]
Mass [GeV/c^2]

Charm measurement with single muons

- ➢ **Charm clearly distinguishable for p_T > 1 GeV/c**
- ➢ At low p_T background mimics beauty template: large uncertainties in beauty extraction

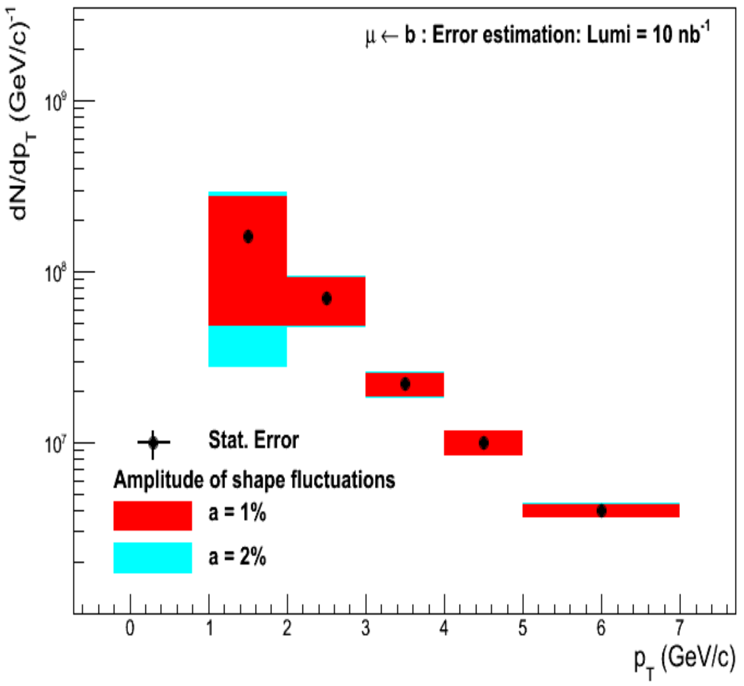






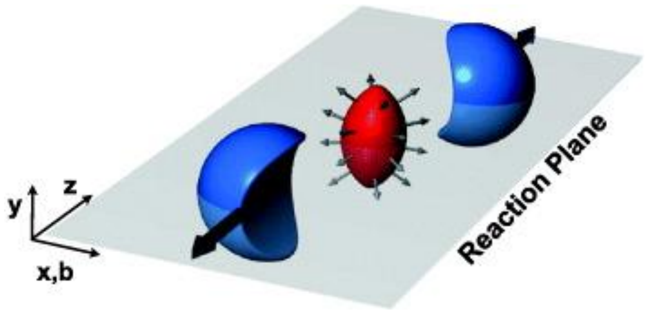
- ➢ **Charm yield** accessible starting from $p_T(\mu)$ = 1 GeV/c (at least)
- ➢ **Important baseline** for charmonium measurements

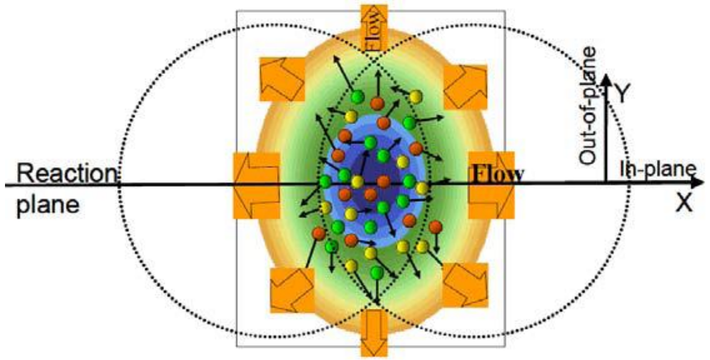
Beauty measurement with single muons

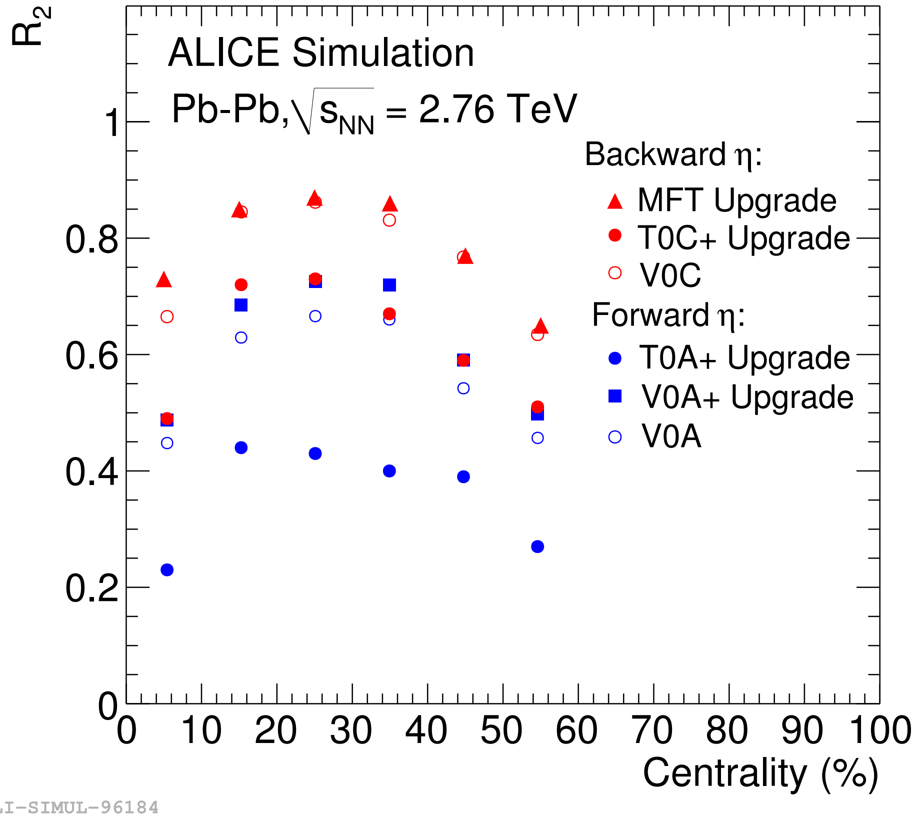


- **Beauty yield** accessible starting from $p_T(\mu)$ = 2 GeV/c

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)