Dilepton and future measurements at ALICE

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Dileptons in heavy ion collisions

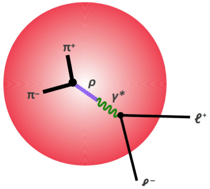
- **Penetrating probe of the strongly interacting hot and dense medium**

  small or negligible final state effects

  - ρ broadening per in-medium modification

    $\rightarrow$ probes chiral aspects of phase transition
  - thermal photon radiation via low and intermediate mass dileptons

    $\rightarrow$ sensitive to the temperature history of the medium
  - ϕ, ω production



- **Dileptons within different mass ranges**
  - Low mass $M < 1.1$ GeV$/c^2$

    $\rightarrow$ conversions, neutral meson (Dalitz) decay

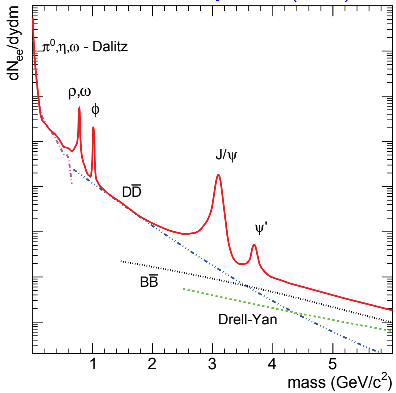
    $\rightarrow$ direct photons
  - Intermediate mass $1.1 < M < 3$ GeV$/c^2$

    $\rightarrow$ heavy flavour ($c\bar{c}$) semi-leptonic decay

    $\rightarrow$ QGP thermal radiation
  - High mass $M > 3$ GeV$/c^2$

    $\rightarrow$ Quarkonium and Drell-Yan process

A.Drees, Nucl.Phys.A830(2009)435



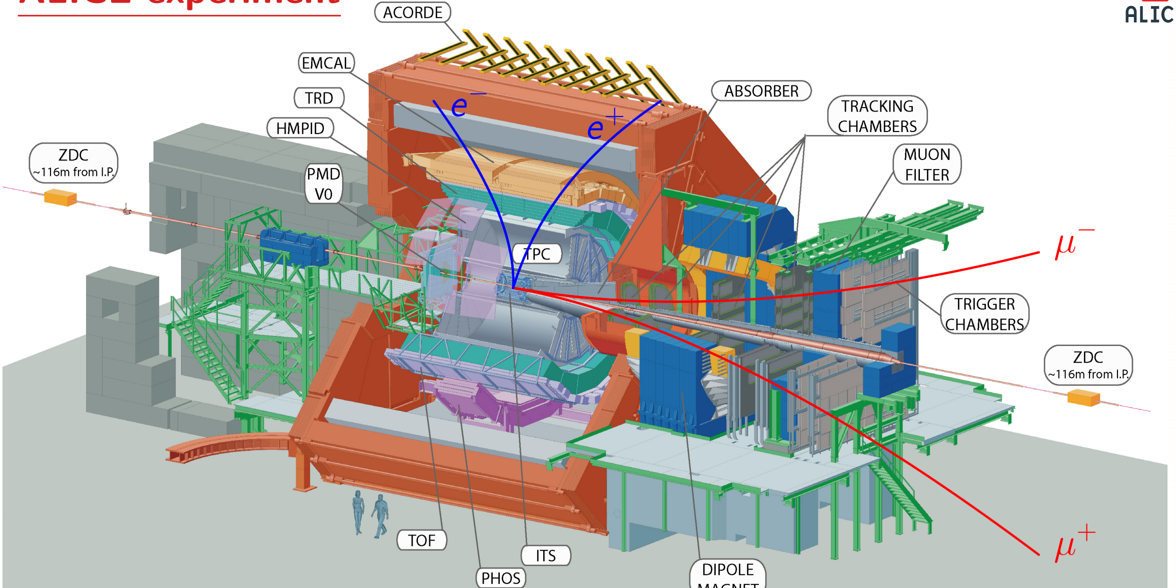
Thermal photon radiation in heavy ion collisions

- **Thermal radiation from hadron gas and QGP *vs* c.m.s energy and centrality**
  → **accessible with low & intermediate mass dileptons in ALICE**
  - **Spectrum**: → temperature T
  - **Flow** (v_2, v_3) → formation time τ_0

  → **Advantages of ALICE:** low p_{T} lepton tracking and PID (mid-rapidity: e, forward: μ)
  → **Current difficulties**: very small S/B ratio
  - **mid-rapidity via electrons:** large combinatorics from background electrons
    → not possible with any trigger strategy: abundant low momentum electrons
    → electron from various sources:
    photon conversions in materials and various hadronic sources
    → large uncertainties in charm and beauty cross sections measurement
  - **forward rapidity via dimuons:** large contamination of low momentum muons
    → with current muon tracking and triggering
    - large combinatorial background in low mass dimuon
    - not accessible with the current muon arm

- **Spectrum and flow via external photon conversions method (PCM) in ALICE**
  → **see talk by F. Bock**

ALICE experiment



central barrel: $|\eta| < 0.8$

$e^{\pm}$ **with ITS, TPC, TOF (TRD)**

forward: $-4 < \eta < -2.5$

$\mu^{\pm}$ **with MTR, MCH**

Dileptons with ALICE

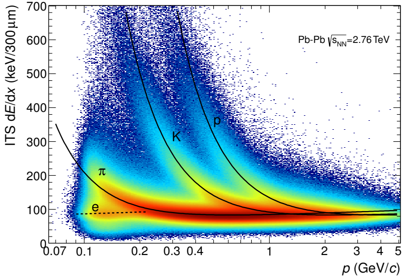
pp @ $\sqrt{s} = 2.76, 7, 8$ **TeV** | **p-Pb @** $\sqrt{s_{\mathrm{NN}}} = 5.02$ **TeV** | **Pb-Pb @** $\sqrt{s_{\mathrm{NN}}} = 2.76$ **TeV**

Dielectrons with ALICE central barrel

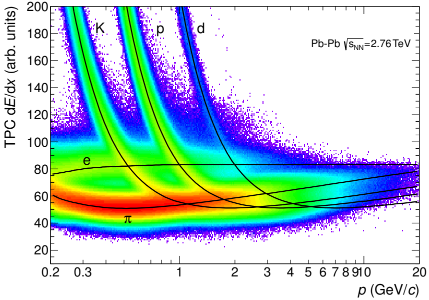
Inner Tracking System, Time Projection Chamber and Time Of Flight

Electron identification with ITS, TPC and TOF

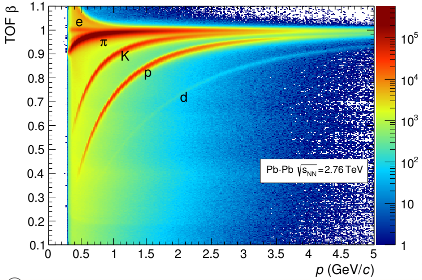
- Inner Tracking System



- Time Projection Chamber



- Time Of Flight



- **Electron selection in pp, p-Pb & Pb-Pb**

Syst.	ITS	TPC	TOF	h-contam.
pp	no	*e* incl.	*h* rej.	$< 1\%$
p-Pb	*e* incl.	*e* incl.	*h* rej.	$< 10\%$
Pb-Pb	*e* incl.	*e* incl.	*h* rej.	$< 10\%$

- TOF is efficient from $p > 0.3$ GeV/c
  $\rightarrow$ using ITS for electron PID complementarily
- ITS, TPC: $p_{\mathrm{T}} > 0.2$ GeV/c; TOF: $p_{\mathrm{T}} > 0.4$ GeV/c

[ALICE Collaboration, arXiv:1402.4476]

ALICE central barrel: dielectron measurement

- **Signal extraction: like sign, unlike sign and event-mixing approach**

R-factor (event mixing)	$N_{+-}^{\mathrm{ME}}/\sqrt{N_{++}^{\mathrm{ME}}N_{--}^{\mathrm{ME}}}$
Background N^{bkg} (like sign and event mixing)	$R \cdot 2\sqrt{N_{++}^{\mathrm{SE}}N_{--}^{\mathrm{SE}}}$
Signal N^{sig} (unlike sign)	$N_{+-}^{\mathrm{SE}} - N^{\mathrm{bkg}}$

- **Background subtracted signal contains all correlated dielectron pairs**

  (to be corrected by detector effects)

  - remaining photon conversions (small after strict track selection)
  - neutral meson (Dalitz) decays $\pi^0, \eta, \eta', \rho, \omega, \phi$
  - correlated back-to-back $c\bar{c}$, $b\bar{b}$ decays to dielectrons: D, B mesons & quarkonium
  - virtual direct photons, Drell-Yan process

- **Thermal photon extraction:**

  - efficiency corrected signal distribution, compared with a hadronic cocktail

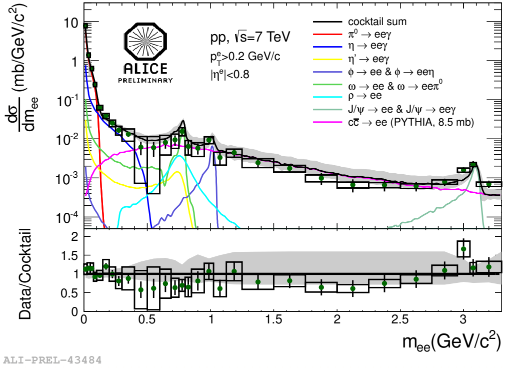
    → input: measured π^0 (η, ϕ, J/ψ) or charged pion spectrum, $c\bar{c}$, $b\bar{b}$ cross-sections

    → looking for excess at low mass region (only in pp so far)

Dielectrons in pp collisions at $\sqrt{s} = 7$ TeV vs hadronic cocktail

ALICE

❑ p_{T} integrated dielectron mass continuum consistent with cocktail estimation



❑ Cocktail calculations

→ using parameterisation of π^0, η, ϕ, J/ψ from ALICE measurements; (η', ω, ρ from m_{T} scaling);

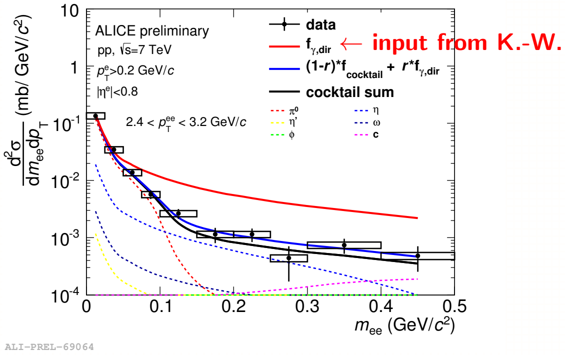
→ $c\bar{c}$ input: cross section = 8.5 mb (PYTHIA)

❑ Large systematic uncertainties

→ from input spectra

❑ γ^* production: Kroll-Wada equation

$$\frac{1}{N_\gamma}\frac{dN_{ee}}{dm_{ee}} = \frac{2\alpha}{3\pi}\sqrt{1-\frac{4m_e^2}{m_{ee}^2}}\left(1+\frac{2m_e^2}{m_{ee}^2}\right)\frac{1}{m_{ee}}$$



❑ Fit function:

$$f_{total} = (1-r)\cdot f_{\mathrm{cocktail}} + r\cdot f_{\gamma,\mathrm{direct}}$$

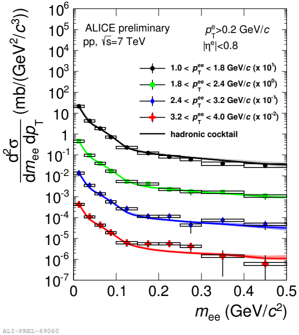
(fit parameter $r \propto$ ratio of direct over inclusive photons)

Thermal direct photon in pp collisions at $\sqrt{s} = 7$ TeV

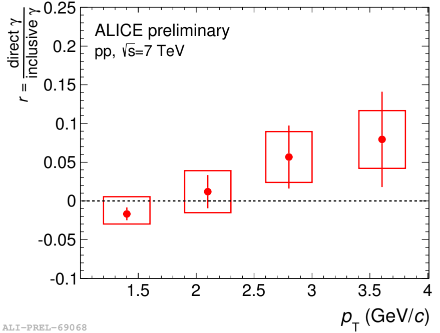
ALICE

❑ Direct photon extraction

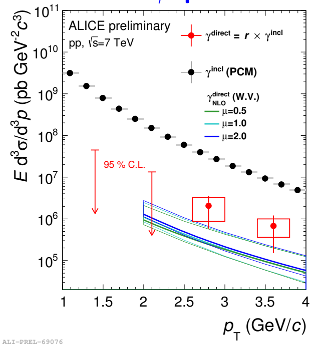
Fits in various $p_{\rm T}$ bins



Fit parameter $r = \gamma_{\rm direct}/\gamma_{\rm inclusive}$



Direct γ spectrum



❑ **Assumption:** $\frac{\gamma_{\rm direct}}{\gamma_{\rm inclusive}} = \frac{\gamma^*_{\rm direct}}{\gamma^*_{\rm inclusive}}$

$\Rightarrow \gamma_{\rm direct} = r \times \gamma_{\rm inclusive}$

($\gamma_{\rm inclusive}$ measured with PCM)

❑ **Comparison to pQCD NLO calculations**

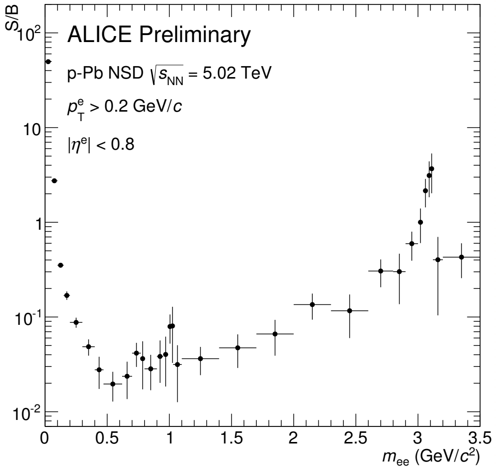
$\Rightarrow$ consistent within uncertainties

Dielectrons in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

ALICE

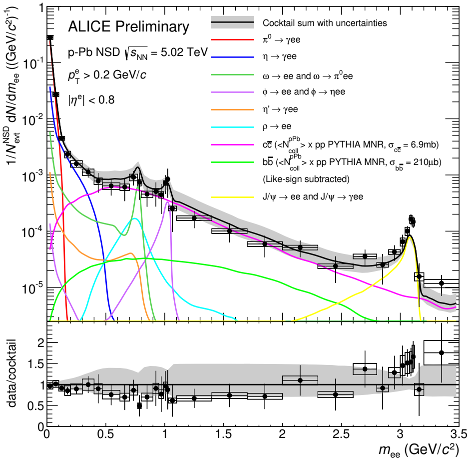
❑ Dielectron invariant mass continuum

signal/background ratio



ALI-PREL-69755

mass continuum vs cocktail



ALI-PREL-69715

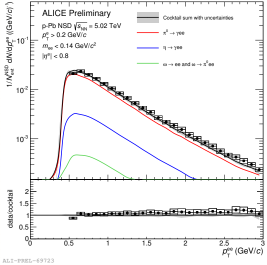
❑ Compared with hadronic cocktails → consistency within the uncertainties[1]

[1] mainly from the input for cocktail estimation

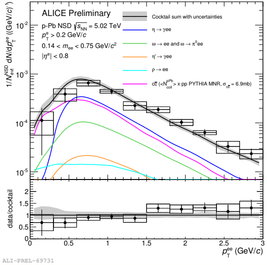
Dielectrons in p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV

- **Transverse momentum spectra within various m_{ee} intervals: $p_{\mathrm{T}}^{min} = 0.2$ GeV/c**

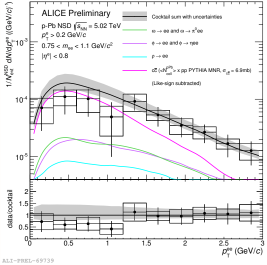
$m_{ee} < 0.14$ GeV/c^2



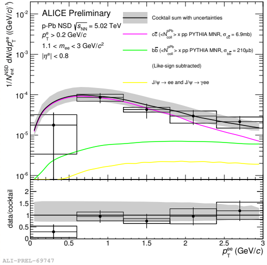
$0.14 < m_{ee} < 0.75$ GeV/c^2



$0.75 < m_{ee} < 1.1$ GeV/c^2



$1.1 < m_{ee} < 3.1$ GeV/c^2



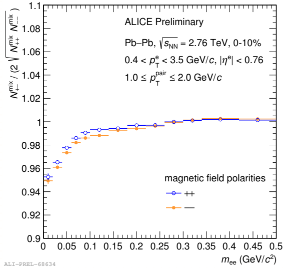
- **Compared with hadronic cocktails → consistency seen in all mass ranges**

With current uncertainty from cocktail estimation: ⇒ **no conclusion can be drawn**

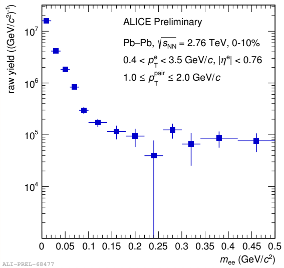
Low mass dielectrons in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV

❑ 0-10% central collisions: $0.4 < p_{\rm T}^{e} < 3.5$ GeV/c & $1.0 < p_{\rm T}^{ee} < 2.0$ GeV/c

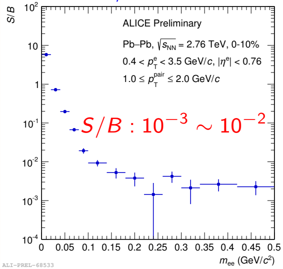
R-factor



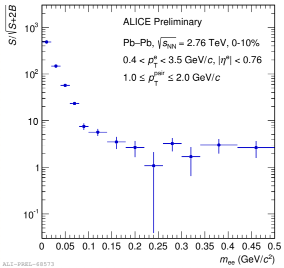
mass continuum



S/B ratio



significance



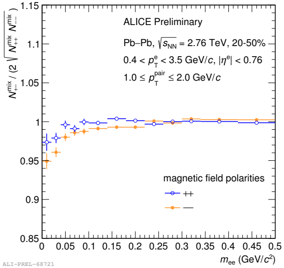
❑ Limitations in current uncorrected measurements

- ❑ **Low dielectron pair efficiency: $\sim$ 10-20% level**
  $\rightarrow$ balance between electron purity in e-ID and detector inefficiency
- ❑ **Small S/B ratio** $10^{-3} \sim 10^{-2}$ $\rightarrow$ reduction of combinatorial background
- ❑ **Limited significance** $\rightarrow$ interplay between S/B ratio and significance
  $\rightarrow$ precise description of background shape (realistic MC helps)
- ❑ **Need precise measurement of input** to hadronic cocktail calculations
  $\rightarrow$ neutral mesons and heavy flavour contributions ($c\bar{c}$ and $b\bar{b}$ cross sections)

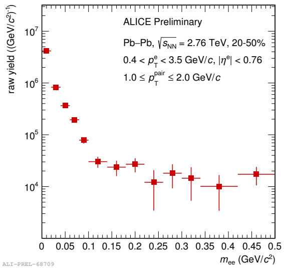
Low mass dielectrons in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV

❑ 20-50% semi-central collisions: $0.4 < p_{\mathrm{T}}^{e} < 3.5$ GeV/c & $1.0 < p_{\mathrm{T}}^{ee} < 2.0$ GeV/c

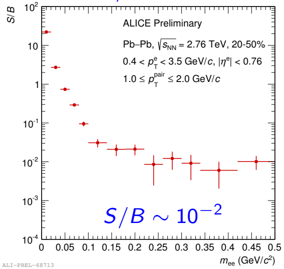
R-factor



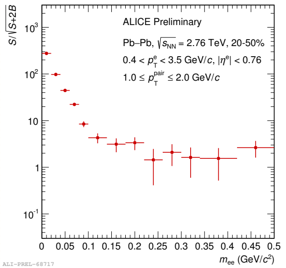
mass continuum



S/B ratio



significance



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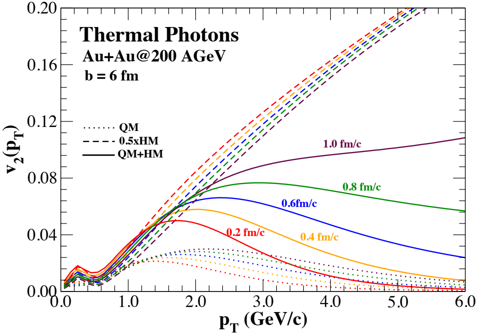
Dielectrons flow in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV

ALICE

System evolution history: early or late thermalisation?

$$E\frac{d^3N}{dp} = \frac{1}{2\pi}\frac{d^2N}{p_{\mathrm{T}}dp_{\mathrm{T}}dy}\left[1+\sum_{n=1}^{\infty}2v_n\cos(n\Delta\varphi)\right]$$

R. Chatterjee et. al., PRL **96**, 202302 (2006)
PRC **79**, 021901 (2009)

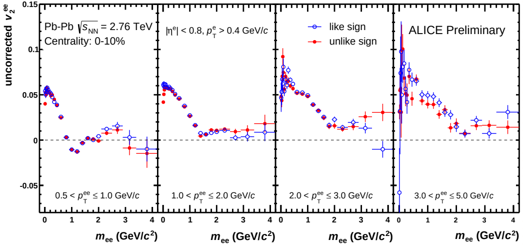


(formation time τ_0 of the QGP)

Status of ALICE measurement

- Possible for dielectron flow study
  - → low momentum electron ID
  - → event plane: VZERO (large η gap)
- Non-trivial with small S/B ratio

0-10% central collisions



Small S/B ratio leads to huge uncertainties in background extracted dielectron v_2

Dielectrons flow in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

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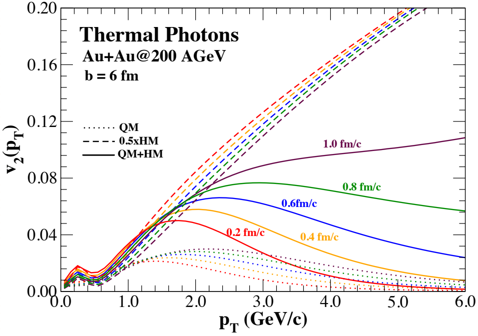

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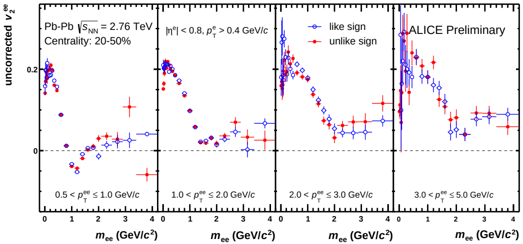
❑ **20-50% semi-central collisions**



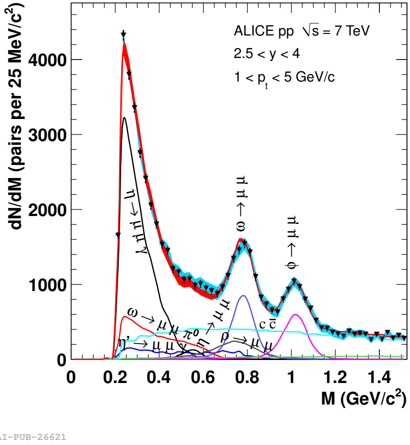
❑ **Small S/B ratio leads to huge uncertainties in background extracted dielectron v_2**

Dimuons with ALICE muon arm

Muon Tracking Chambers and Muon Trigger

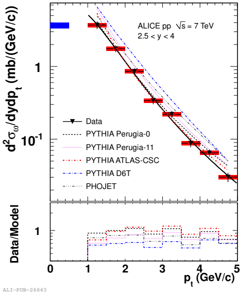
Low mass dimuons in pp collisions at $\sqrt{s} = 7$ TeV

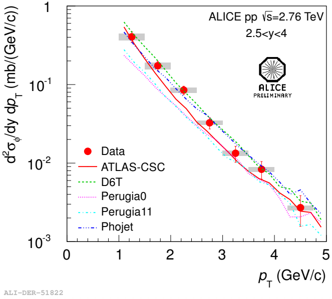
❑ Low Mass Dimuon Spectrum: good agreement between signal and MC sources



[ALICE Collaboration, Phys. Lett. **B710** (2012) 557]

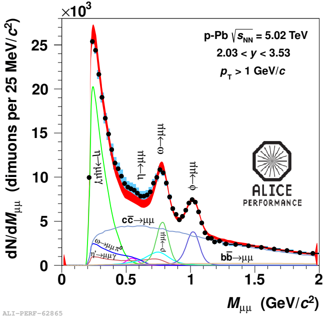
- ❑ p_T differential cross sections of ω and ϕ $\rightarrow$ accessible
- ❑ ϕ meson $\rightarrow$ PYTHIA tunes Perugia0 and Perugia11 underestimate the data by about a factor of 2 both at 2.76 and 7 TeV

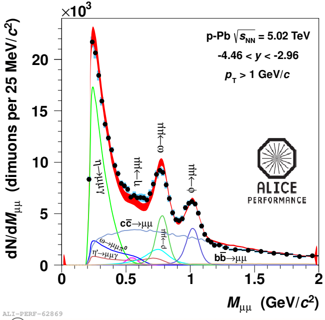




❑ Thermal photon radiation not accessible

Dimuons in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

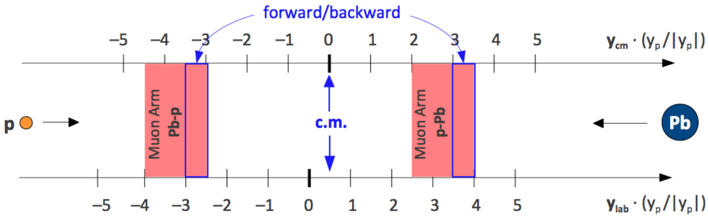




- **Hadronic cocktail fits**
  - Asymmetric systems: p-Pb and Pb-p

    $\rightarrow p_T^{\mu\mu} \geq 1$ GeV/c

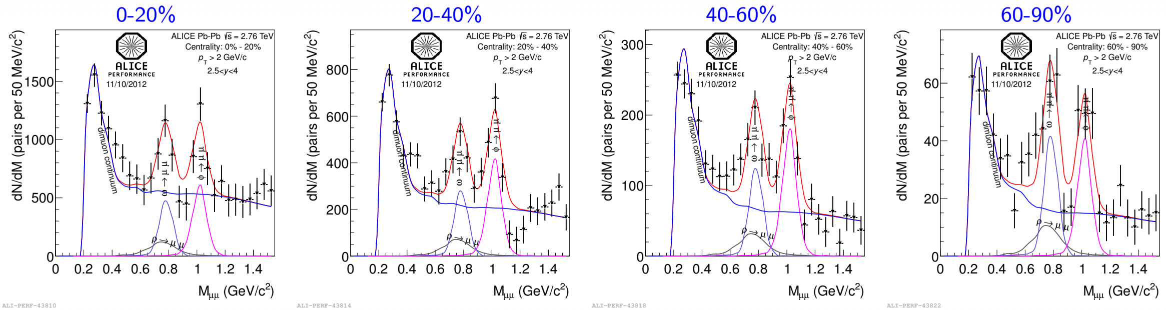
    $\rightarrow$ Fair agreement reached between data and hadronic cocktail + open HF
  - Systematical uncertainties on signal extraction: 7%



- **ω and ϕ production: accessible**
- **Thermal photon radiation: not accessible**

Low mass dimuons in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV

❑ Invariant mass continuum vs hadronic cocktail fits



❑ Extraction of vector mesons possible

- ❑ $p_{\rm T}^{\mu\mu} \geq 2$ GeV/c

❑ Large statistical uncertainties: not allowing precise measurement of the underlying continuum

- ❑ statistical uncertainty $\sim$ 10 - 40%

❑ Thermal photon radiation: not possible

Future measurements with ALICE

RUN2 after ALICE readout upgrade | RUN3 after ALICE major upgrade

With RUN2: higher statistics and better detector performance

ALICE

- **Sources of improvements expected**
  - **Higher $\sqrt{s}$ with higher luminosity and data rate**

    $\rightarrow$ faster TPC: higher data taking rate (upgraded electronics)
  - **Rare trigger under consideration**

    $\rightarrow$ High multiplicity trigger

    $\rightarrow$ TRD and EMCAL trigger
    - constrain better the contribution from heavy flavour electrons
  - **Detector completion**

    $\rightarrow$ SPD (ITS first 2 layers) recovery from failed cooling in RUN1
    - larger acceptance for electron tracking & identification
    - better conversion rejection probability

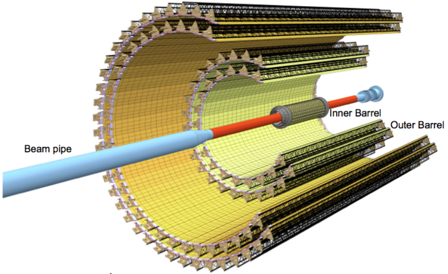
    $\rightarrow$ Completed installation of TRD
    - larger acceptance in electron tracking and identification
    - improves TPC-TOF mis-matching $\rightarrow$ reduces hadron contamination

$\Rightarrow$ **signal, S/B ratio improvements expected**

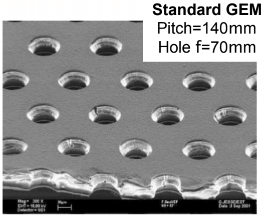
With RUN3 after major upgrades- after 2019

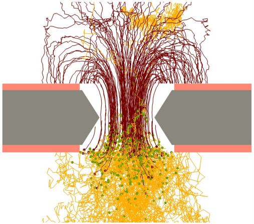
❑ Precision measurements of low mass lepton pairs emitted from the QGP

❑ central barrel: new ITS

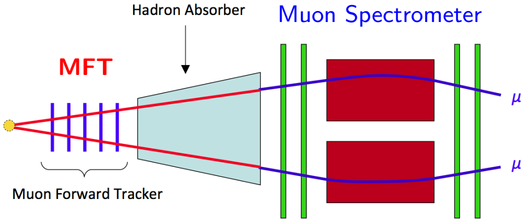


❑ central barrel: GEM-TPC





❑ muon arm: MFT + MUON

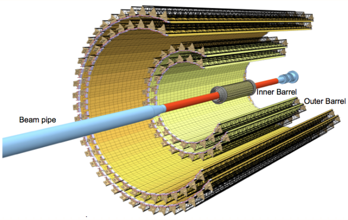


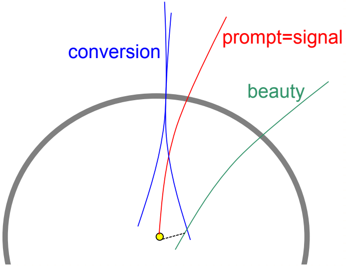
❑ ALICE major upgrade for RUN3

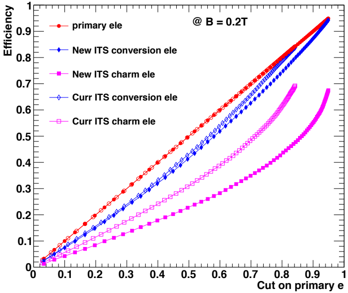
- ❑ ITS: high impact parameter resolution
- ❑ GEM-TPC: better electron tracking and data taking rate
- ❑ MFT: displaced muons, removal of background muons

With upgraded ITS

- Gains from the upgraded ITS vs current ITS
  - tracking based conversion rejection possible → via topology cut
  - better impact parameter (DCA) resolution
    - → separation of heavy flavour electrons and prompt signals
    - → ×2 gain in rejection of electrons from beauty-decay
  - lower material budget → higher tracking efficiency at low p_{T}



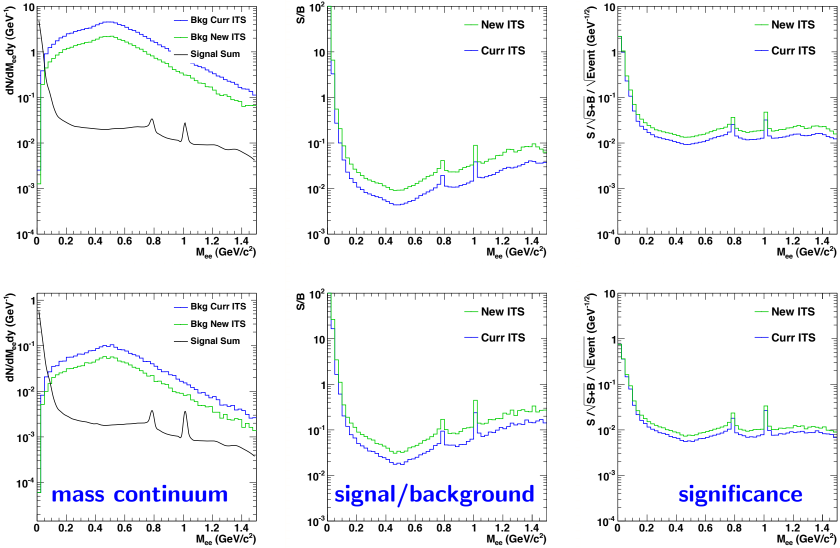




[ITS upgrade Letter of Intent (LoI) and Technical Design Report (TDR) JPG **41** (2014) 087002]

With upgraded ITS: much better S/B and significance

- **Comparison current ITS & new ITS: Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 5.5$ TeV**



← 0-10%

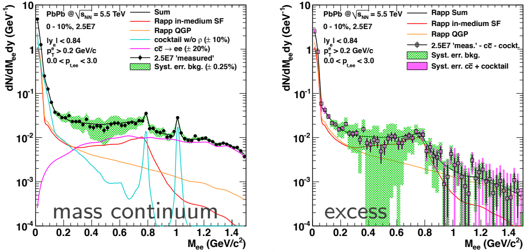
← 40-60%

ALICE simulation Pb-Pb at $\sqrt{s_{NN}} = 5.5$ TeV: comparison

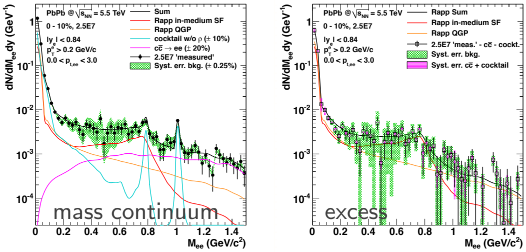
ALICE

❑ Current ITS, current rate

loose DCA cut (not possible)

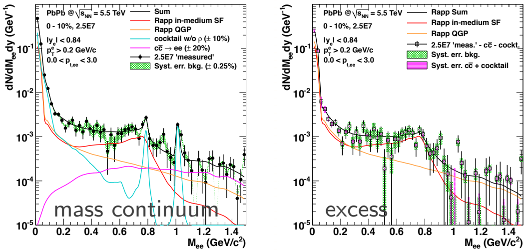


tight DCA cut (improvement marginal)

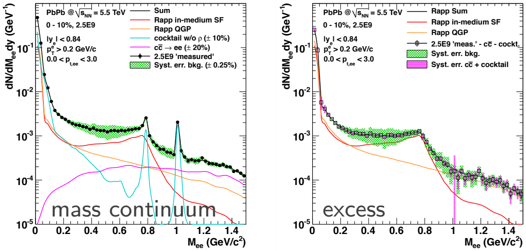


❑ New ITS, tight DCA cut

current rate (reduced syst., stat. limited)



new rate (excess accessible!)

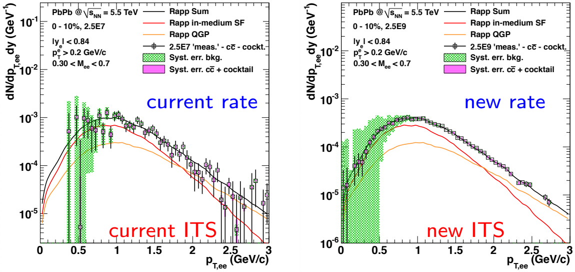


❑ Quantitative access to the excess → with new ITS + high rate + tight DCA cut

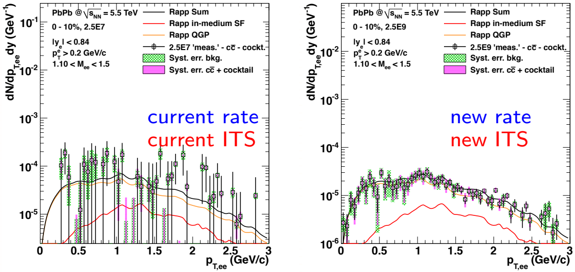
ALICE simulation: p_{T} spectrum in Pb-Pb at $\sqrt{s_{\mathrm{NN}}} = 5.5$ TeV

Dielectron excess with tight DCA cut

$0.3 < M_{ee} < 0.7$ GeV$/c^2$



$1.1 < M_{ee} < 1.5$ GeV$/c^2$

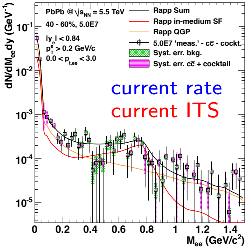


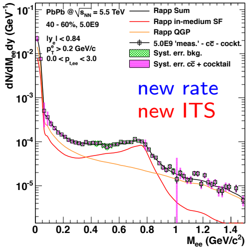
With new ITS and new rate

- much smaller stat. and syst. uncertainties
  $\rightarrow$ dielectron excess accessible in low and intermediate mass

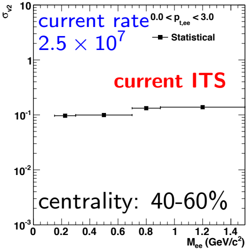
ALICE simulation: T and v_2 extraction in Pb-Pb at 5.5 TeV

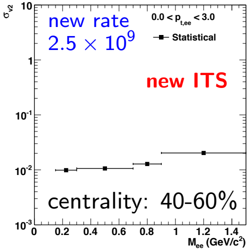
❑ Pb-Pb at $\sqrt{s_{NN}} = 5.5$ TeV: 40-60%





❑ Stat. uncertainties for e^+e^- elliptic flow

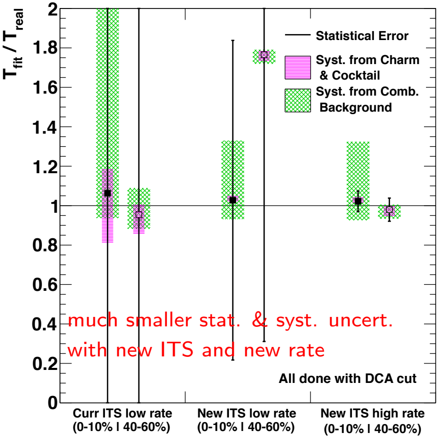




significant improvement with new ITS and new rate

❑ T extraction with fit to mass continuum

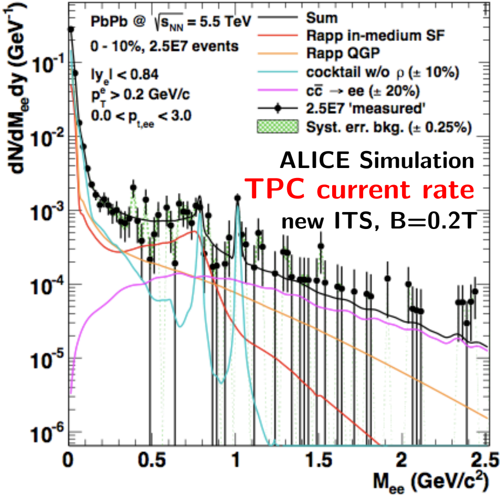
$$\frac{dN_{ee}}{dM_{ee}} \propto e^{-M_{ee}/T_{\mathrm{fit}}}$$

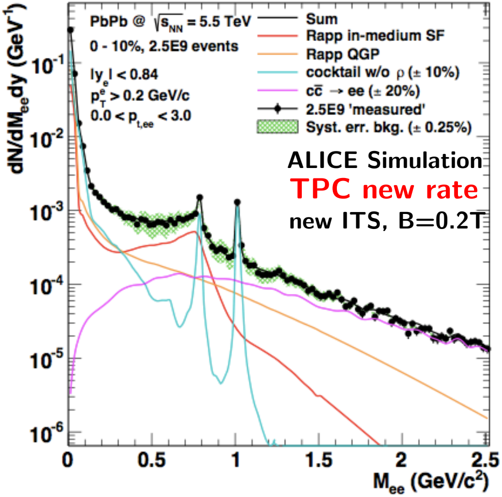


- ❑ current low rate: 2.5×10^7 events
- ❑ new high rate: 2.5×10^9 events

ALICE simulation: with upgraded ITS + TPC

- Comparison with current TPC rate vs new TPC rate with new ITS

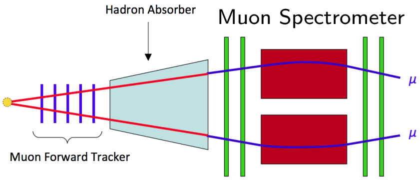




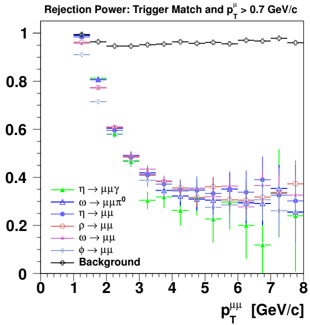
[TPC upgrade LoI and TDR: CERN-LHCC-2013-020]

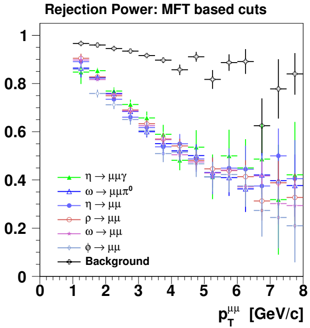
- Comparison of Poisson-sampled spectrum to expected hadronic and medium-induced sources

With upgraded muon arm: Muon Forward Tracker (MFT)



[MFT upgrade LoI and TDR]





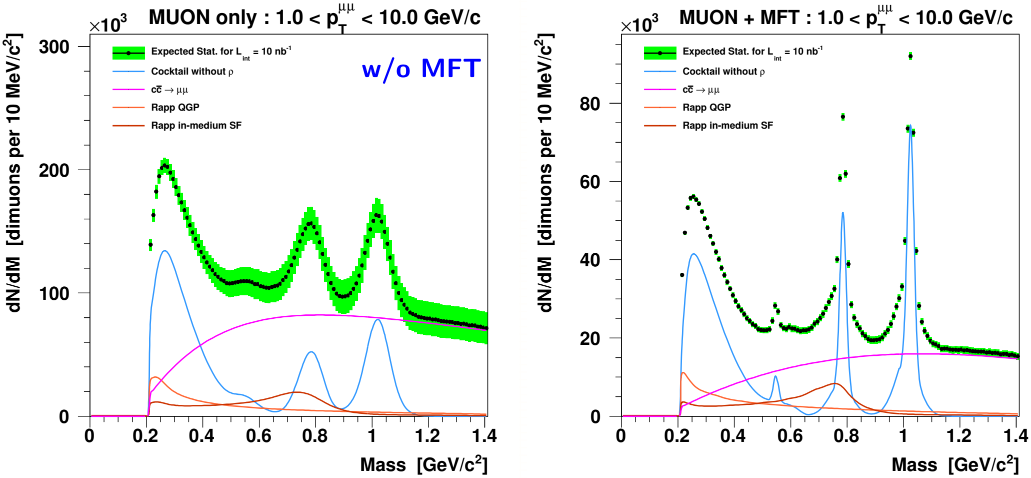
- **With MFT**
  - precisely measure the displacement of muons
    → reduces muons from charm and beauty semi-muonic decays
  - precise measurement of dimuon opening angles
    → precise determination of 2-body decays of light resonances
  - better rejection of background muon contributions to the comb. background
  - better mass resolution: matching between MUON tracks and MFT clusters

⇒ **expect enhancement of S/B ratio without losing significance**

Low mass dimuons w/o and with MFT

ALICE

- expected low mass dimuon spectrum, Pb-Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV

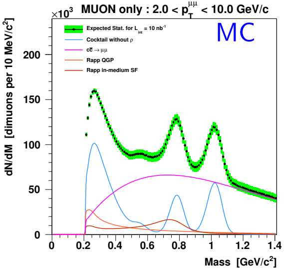


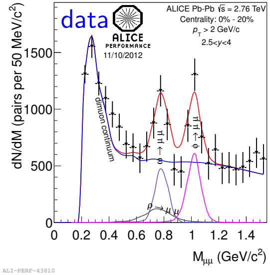
→ after comb. background subtraction and normalised to $L_{int} = 10\ nb^{-1}$

Low mass dimuons w/o MFT

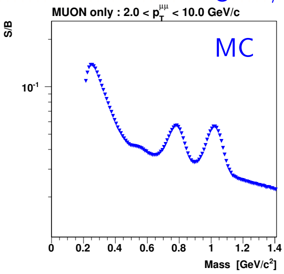
❑ Pb-Pb at 5.5 TeV (MC) vs Pb-Pb at 2.76 TeV (data)

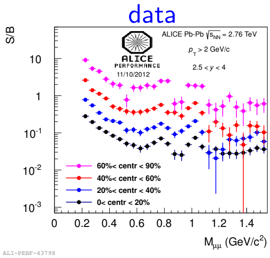
mass spectrum





signal / background



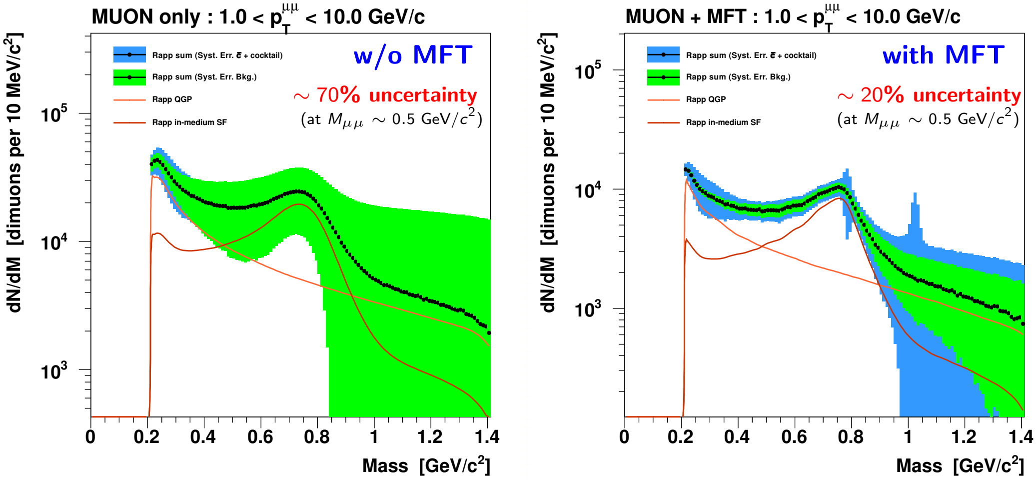


- ❑ same minimum dimuon momentum: $p_T^{\mu\mu} > 2$ GeV/c
- ❑ MC and data: after comb. background subtraction
- ❑ MC: Pb-Pb at 5.5 TeV, normalised to $L_{int} = 10\ nb^{-1}$
- ❑ data: LHC11h Pb-Pb at 2.76 TeV

❑ Much improved stat. + syst. uncertainties and improved S/B ratio

Low mass dimuons w/o and with MFT

❑ Mass continuum excess in 0-10% central Pb-Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV



- ❑ same minimum dimuon momentum: $p_T^{\mu\mu} > 1$ GeV/c
- ❑ after comb. background subtraction, normalised to $L_{int} = 10\ nb^{-1}$
- ❑ after subtraction of hadronic cocktail and heavy flavour ($c\bar{c}$) contribution

Summary

- **ALICE with existing data**
  - **results from pp and p-Pb collisions: in agreement with hadronic cocktail**
    → large uncertainties does not allow conclusion → lack of accuracy
  - **too small S/B in current Pb-Pb data**
    → challenging task for thermal photon extraction (work in progress)
- **ALICE in RUN2**
  - **higher rate possible**: upgrade in TPC electronics
  - **complete geometrical acceptance of TRD and current ITS (repair)**
  - rare trigger implementation (in consideration)
    ⇒ **possible improvement in S/B**
- **ALICE with major upgrades (ITS, TPC and MFT) for RUN3**
  - **thermal photon radiation from QGP with low mass dileptons**
    as major physics goal of the ALICE upgrade program
    ⇒ accessing the excess with accuracy in measuring:
    p_{T} spectrum and elliptic flow of thermal photons

STAY TUNED!

THANKS FOR YOUR ATTENTION