Low mass dilepton measurements with ALICE at the LHC

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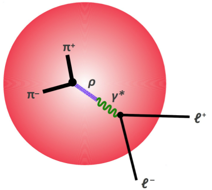
Universiteit Utrecht

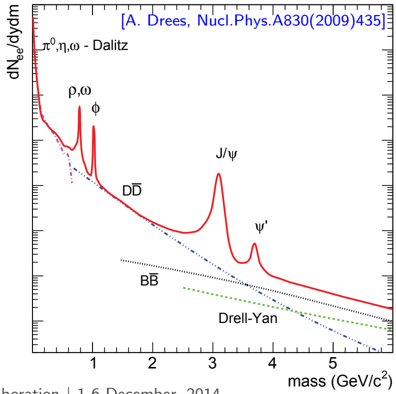
Dileptons in heavy ion collisions

- **Penetrating probe of the strongly interacting hot and dense medium**
  with 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
  - ω, ϕ etc 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 ($D\overline{D}$) semi-leptonic decay
    $\rightarrow$ QGP thermal radiation
  - High mass $M > 3$ GeV/c^2
    $\rightarrow$ heavy flavour ($B\overline{B}$) and quarkonium (J/ψ and ψ')
    $\rightarrow$ Drell-Yan process

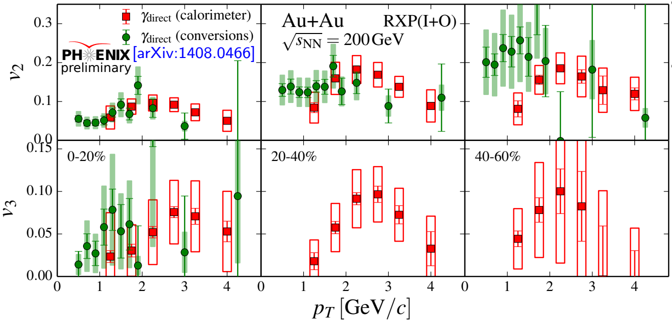
A dielectron continuum sketch



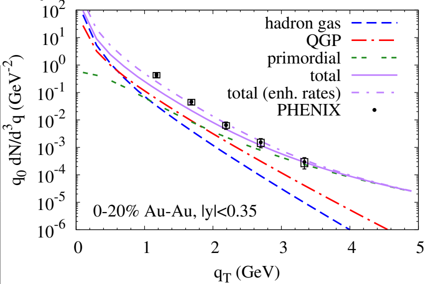
Further on motivations: from RHIC to LHC energy

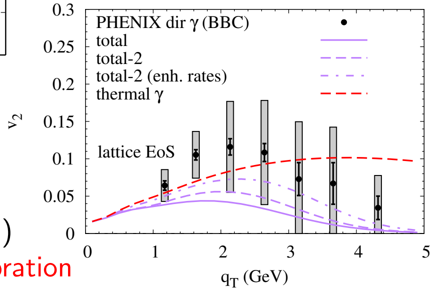
ALICE

- Measurements in Au-Au collisions at 200 GeV at RHIC
  - Large direct photon flow (v_2, v_3) & relative small slope
  - theoretical interpretation → challenging



[R. Rapp, H.van Hees, M. He, arXiv:1408.0612]





- Measurements at the LHC energy
  - virtual photon with internal conversion to l^+l^-
    → different uncertainty vs conversion approach
  - higher photon yield (smaller photon elliptic flow?)
    → crucial for confirmation of early or late equilibration

Thermal photon radiation in heavy ion collisions at the LHC

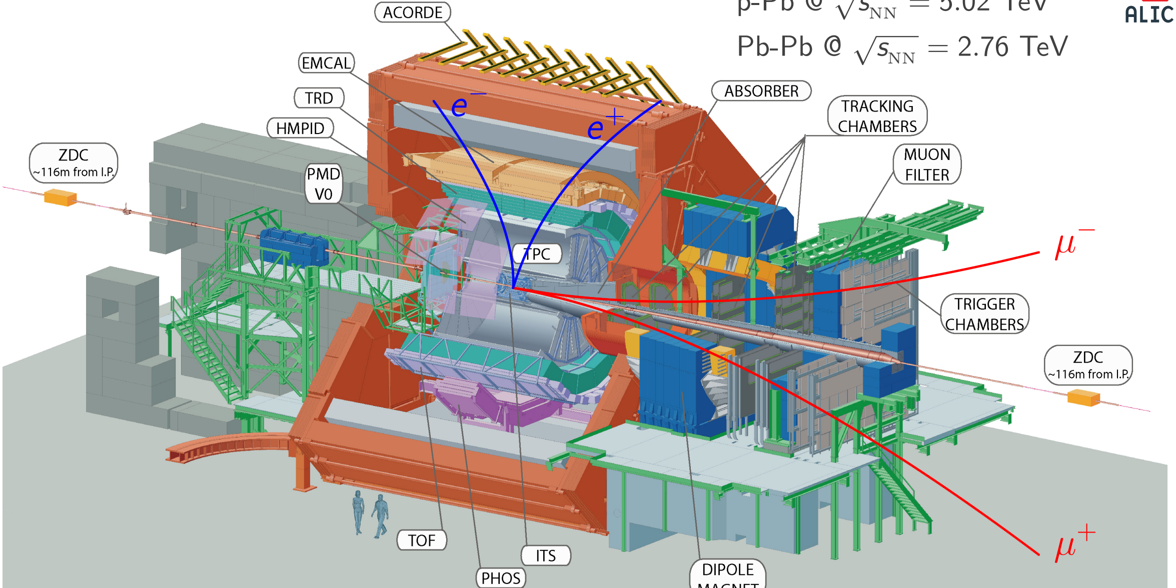
- **Thermal radiation from hadron gas and QGP *vs* c.m.s energy and centrality**
  $\rightarrow$ **accessible with low & intermediate mass dileptons in ALICE**
  - **Spectrum**: $\rightarrow$ temperature T
  - **Flow** (v_2, v_3) $\rightarrow$ formation time τ_0

  $\rightarrow$ **Advantages of ALICE:** low p_{T} lepton tracking and PID (mid-rapidity: e, forward: μ)
  - **mid-rapidity via electrons:** large combinatorics from background electrons
    $\rightarrow$ not possible with any trigger strategy: abundant low momentum electrons
    $\rightarrow$ electron from various sources:
    photon conversions in materials and various hadronic sources
    $\rightarrow$ large uncertainties in charm and beauty cross sections measurement
  - **forward rapidity via dimuons:** large contamination of low momentum muons
    $\rightarrow$ 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**
  $\rightarrow$ **see talk by K. Reygers**

Dileptons with ALICE experiment

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



central barrel: $|\eta| < 0.8$
$e^{\pm}$ with ITS, TPC, TOF (TRD)

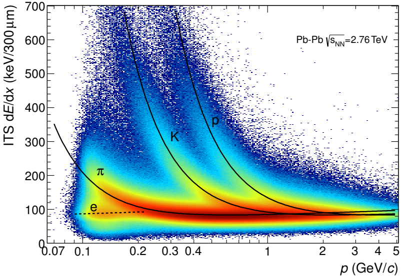
forward: $-4 < \eta < -2.5$
$\mu^{\pm}$ with MTR, MCH

Dielectrons with ALICE central barrel

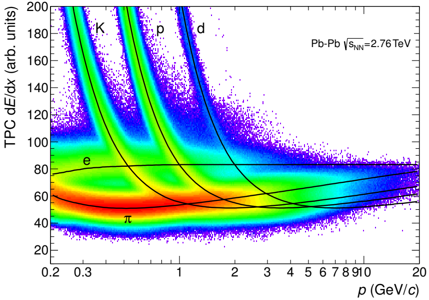
Inner Tracking System, Time Projection Chamber and Time Of Flight

Electron identification with ITS, TPC and TOF

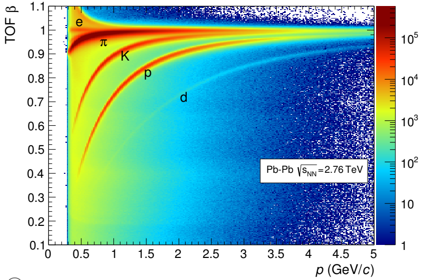
- Inner Tracking System



- 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

ALICE

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

R-factor (acceptance correction factor in 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 $c\bar{c}$, $b\bar{b}$ decays to dielectrons: D, B mesons & quarkonium
  - virtual direct photons, Drell-Yan process

- **Thermal photon extraction:**

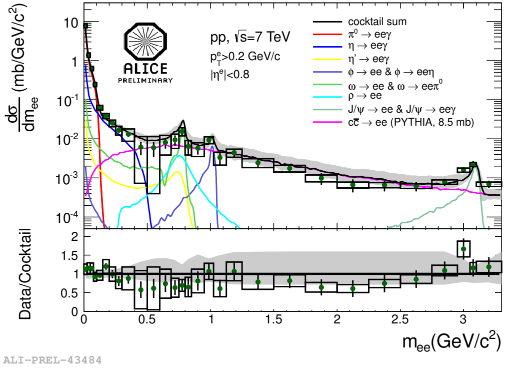
  - efficiency corrected signal distribution, compared with a hadronic cocktail

    $\rightarrow$ need input for cocktail generation: π^0 (η, ϕ, J/ψ etc), $c\bar{c}$, $b\bar{b}$ cross-sections

    $\rightarrow$ looking for excess at low mass region (only done in pp so far)

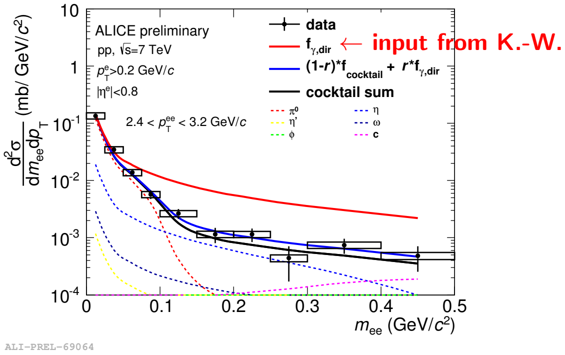
Dielectrons in pp collisions at $\sqrt{s} = 7$ TeV vs hadronic cocktail

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



❑ γ^* production: Kroll-Wada equation

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



❑ 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

❑ Fit function:

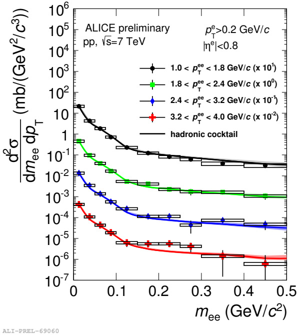
$$f_{total} = (1-r)\cdot f_{\mathrm{cocktail}} + r\cdot f_{\gamma,\mathrm{direct}}$$

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

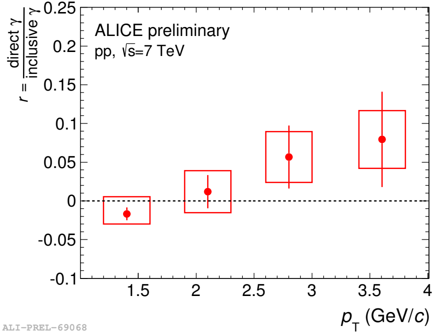
Thermal direct photon in pp collisions at $\sqrt{s} = 7$ TeV

❑ Direct photon extraction

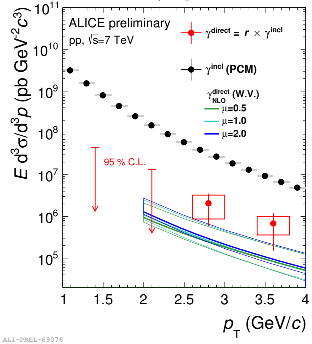
Fits in various p_{T} bins



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



Direct γ spectrum



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

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

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

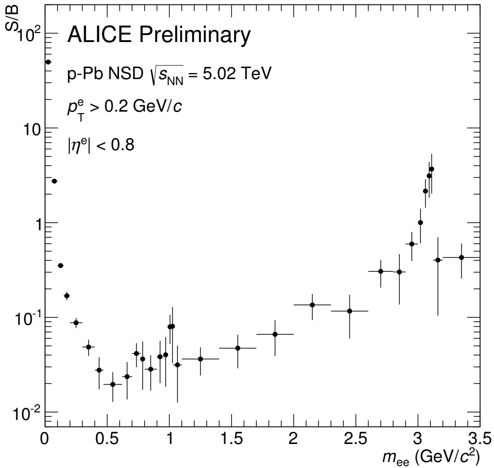
❑ Comparison to pQCD NLO calculations

$\Rightarrow$ consistent within uncertainties

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

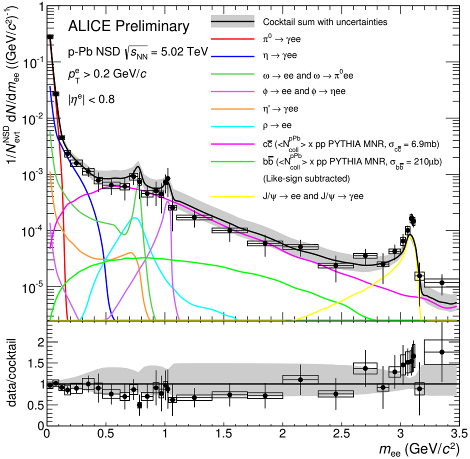
❑ Dielectron invariant mass continuum

signal/background ratio



ALI-PREL-69755

mass continuum vs cocktail



ALI-PREL-69715

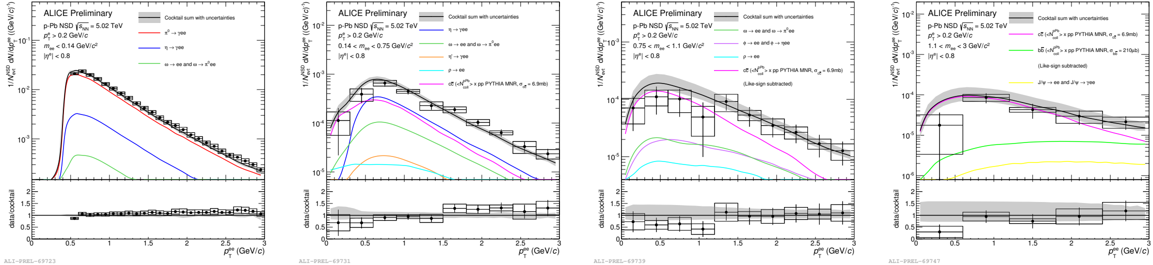
❑ Compared with hadronic cocktails → consistency within the uncertainties

(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: $p_{\mathrm{T}}^{e,min} = 0.2$ 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



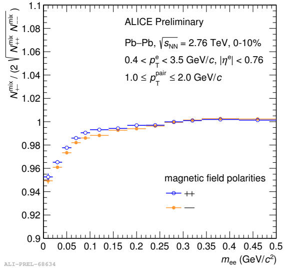
❑ Compared with hadronic cocktails

→ consistency within uncertainties seen in all mass ranges

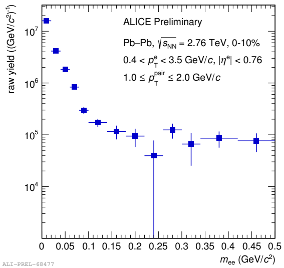
Low mass dielectrons in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

0-10% central collisions: $0.4 < p_T^e < 3.5$ GeV/c & $1.0 < p_T^{ee} < 2.0$ GeV/c

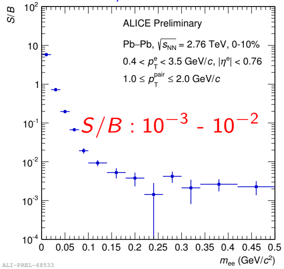
R-factor



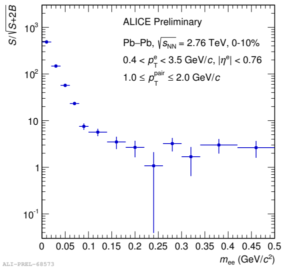
mass continuum



S/B ratio



significance



Limitations in current uncorrected measurements

- Low dielectron pair efficiency: ~ 10-20% level
- Small S/B ratio: ~ 10^{-3} - 10^{-2} and limited significance
- For signal extraction: large uncertainties from hadronic cocktail calculations

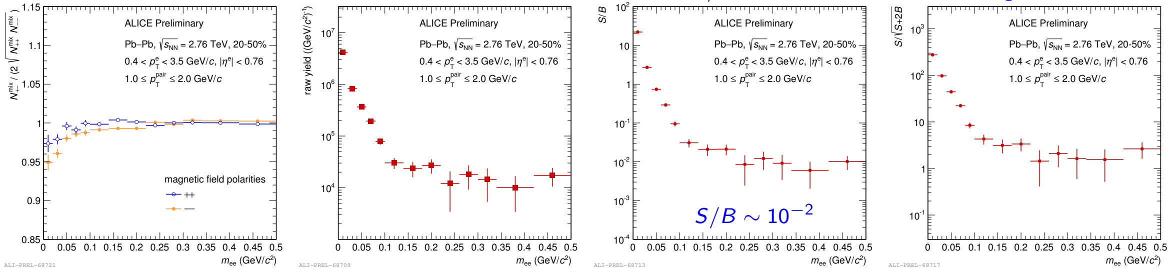
Ideas for improvement

- balance between electron purity in e-ID and detector inefficiency
- reduction of combinatorial background: photon conversion rejection
- interplay between S/B ratio and significance
- precise measurements for input to cocktail calculation: precise description of background

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

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

R-factor | mass continuum | S/B ratio | significance



❑ Limitations in current uncorrected measurements

- ❑ Low dielectron pair efficiency: $\sim$ 10-20% level
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❑ Ideas for improvement

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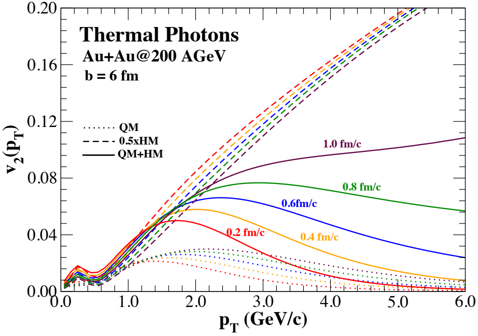
Dielectrons flow in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV

ALICE

- System evolution history: early or late thermalisation?

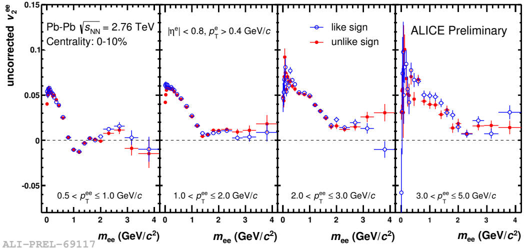
$$E\frac{d^3N}{dp} = \frac{1}{2\pi}\frac{d^2N}{p_{\mathrm{T}}dp_{\mathrm{T}}dy}\left[1 + \sum_{n=1}^{\infty} 2v_n\cos(n\Delta\varphi)\right]$$

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 $\sqrt{s_{\rm NN}} = 2.76$ TeV

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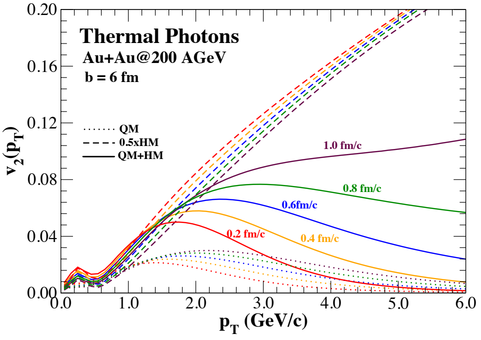

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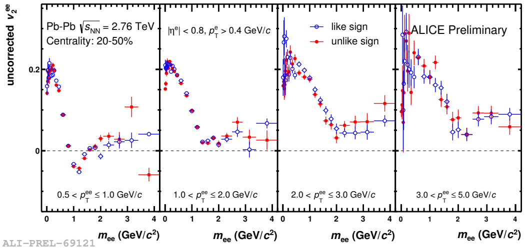
❑ 20-50% semi-central collisions



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

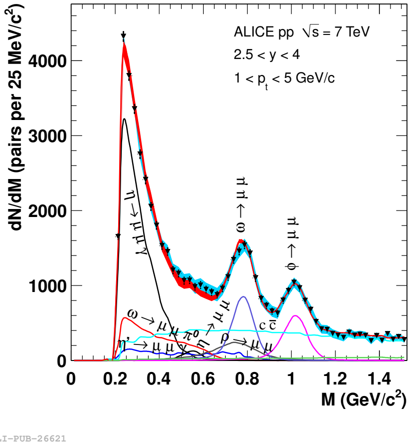
Dimuons with ALICE muon arm

Muon Tracking Chambers and Muon Trigger

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

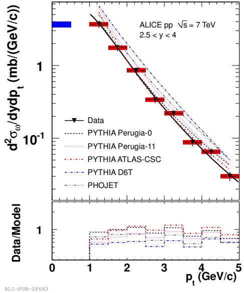
❑ Low mass dimuon spectrum: good agreement between signal and MC sources

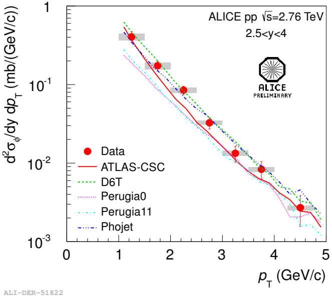
❑ ω and ϕ are accessible in pp at 2.76 and 7 TeV (baseline for p-Pb and Pb-Pb)



[ALICE Collaboration, Phys. Lett. B**710** (2012) 557]

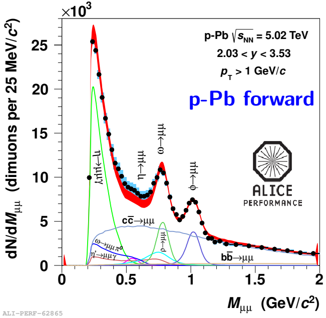
❑ p_{T} differential cross sections of ω and ϕ in pp

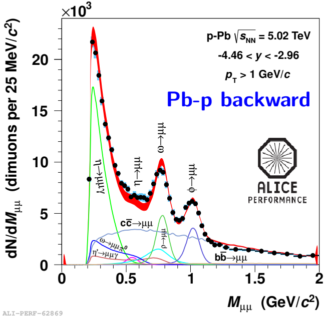




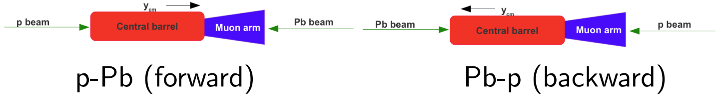
- for ω: data in good agreement with PYTHIA tunes Perugia-0 and ATLAS-CSC;
- for ϕ: PYTHIA tunes Perugia0 and Perugia11 underestimate the data by about a factor of 2; in fair agreement with ATLAS-CSC, D6T tunes; in good agreement with Phojet;

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





- Asymmetric systems: p-Pb and Pb-p collisions

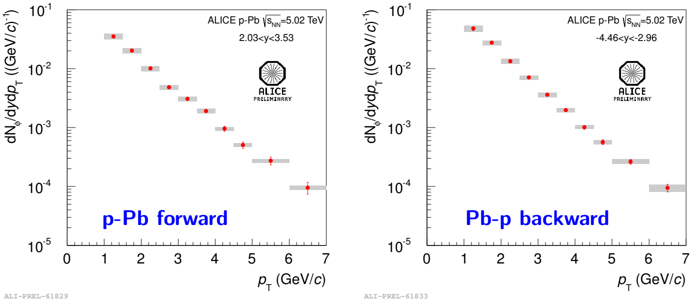


- Hadronic cocktail fits

→ Fair agreement: data vs hadronic cocktail

→ Systematical uncertainties on signal extraction: 7%

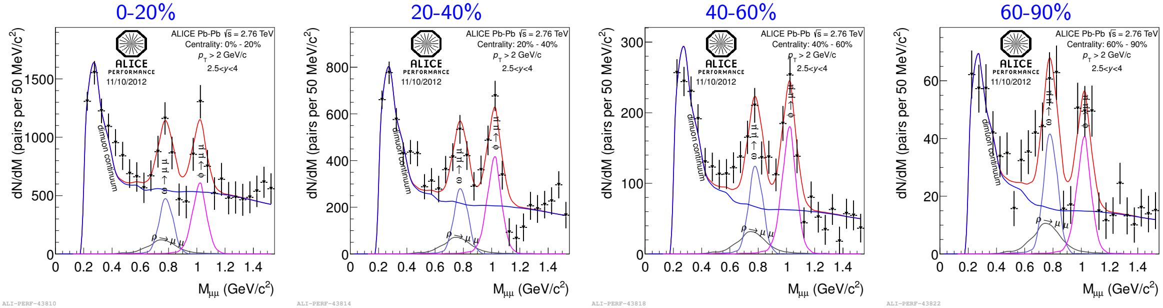
- ϕ production at forward / backward rapidity



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

ALICE

❑ 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 | <u>RUN3 after ALICE major upgrade</u>

With RUN2: higher statistics and better detector performance

ALICE

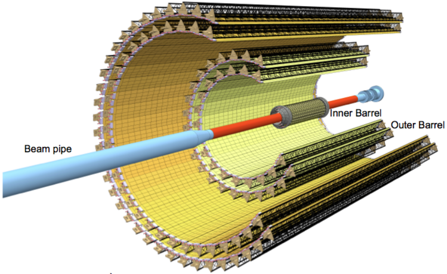
- **Sources of improvements expected**
  - **Higher $\sqrt{s}$ with higher luminosity and data rate**
    - $\rightarrow$ faster TPC: higher data taking rate (upgraded electronics)
  - **Rare trigger under consideration**
    - $\rightarrow$ High multiplicity trigger
    - $\rightarrow$ TRD and EMCAL 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 matching $\rightarrow$ reduces hadron contamination

$\Rightarrow$ measurements of S, S/B and significance with smaller uncertainties expected

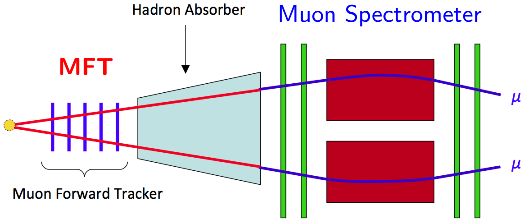
With RUN3 after major upgrades- after 2019

- Precise measurements of low mass lepton pairs emitted from the QGP

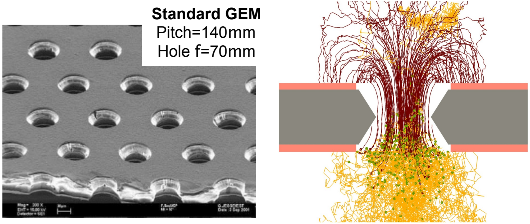
- central barrel: new ITS



- muon arm: MFT + MUON



- central barrel: GEM-TPC



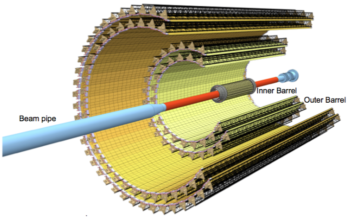
ALICE major upgrade for RUN3

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

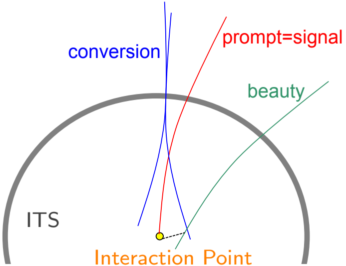
With upgraded ITS

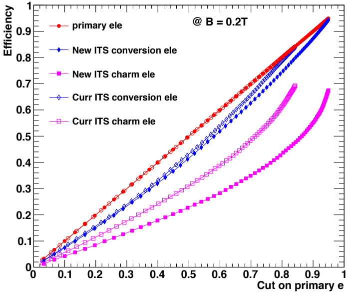
❑ Gains from the upgraded ITS vs current ITS

- ❑ 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}



The new ITS



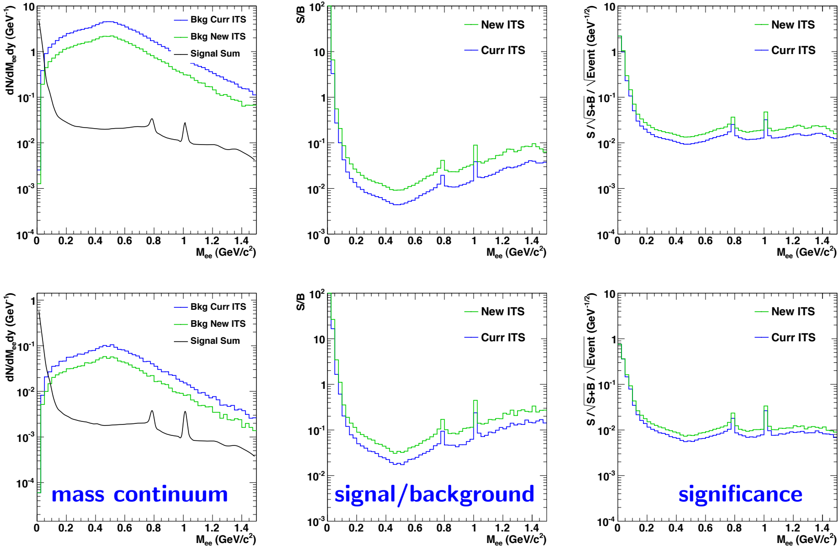


[ITS upgrade Letter of Intent (LoI) and Technical Design Report (TDR) JPG **41** (2014) 087002]

With upgraded ITS: much better S/B and significance

ALICE

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



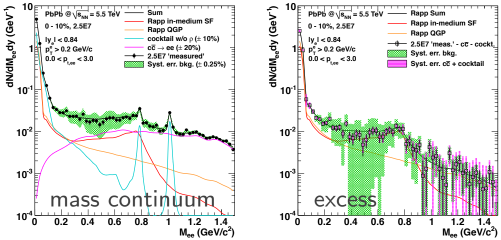
← 0-10%

← 40-60%

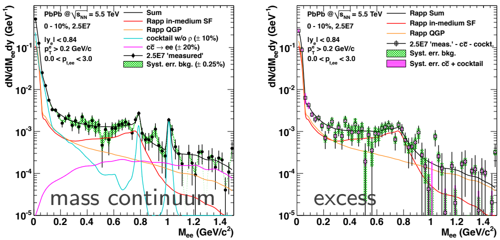
[ALICE upgrade LOI: CERN-LHCC-2012-012]

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

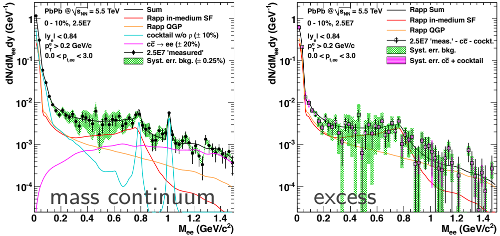
- **Current ITS, current rate**
  loose DCA cut (not possible)



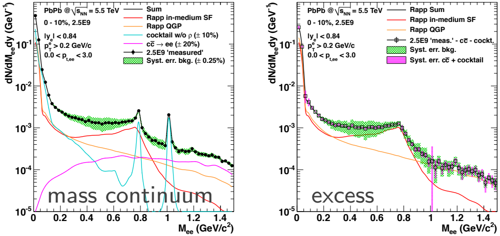
- **New ITS, tight DCA cut**
  current rate (reduced syst., stat. limited)



tight DCA cut (improvement marginal)



new rate (excess accessible!)



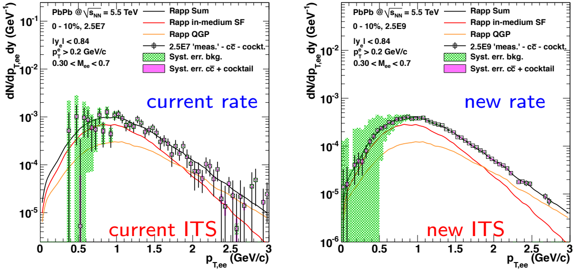
[ALICE upgrade LOI: CERN-LHCC-2012-012]

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

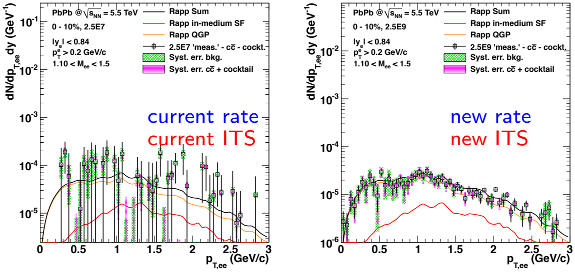
ALICE simulation: p_T spectrum in Pb-Pb at $\sqrt{s_{NN}} = 5.5$ TeV

❑ Dielectron excess with tight DCA cut

❑ $0.3 < M_{ee} < 0.7$ GeV$/c^2$



❑ $1.1 < M_{ee} < 1.5$ GeV$/c^2$



[ALICE upgrade LOI: CERN-LHCC-2012-012]

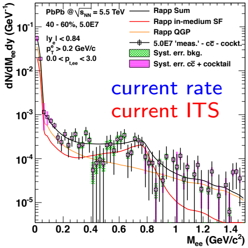
❑ With new ITS and new rate

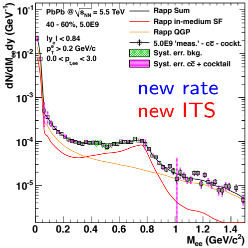
- ❑ much smaller stat. and syst. uncertainties

  → dielectron excess accessible in low and intermediate mass

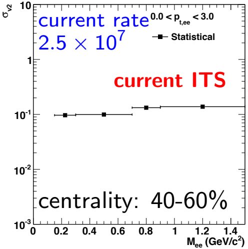
ALICE simulation: T and v_2 extraction in Pb-Pb at 5.5 TeV

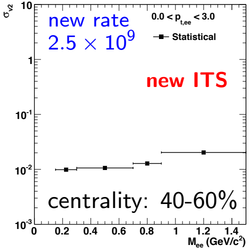
❑ Pb-Pb at $\sqrt{s_{\rm NN}} = 5.5$ TeV: 40-60%





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

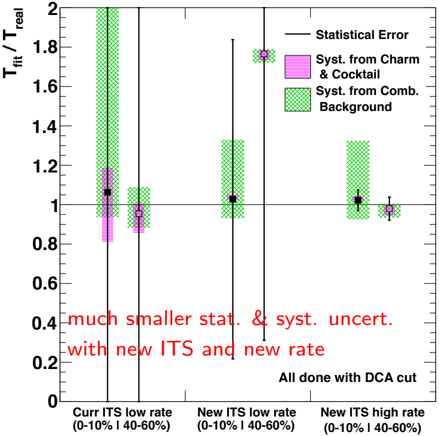




significant improvement with new ITS and new rate

❑ T extraction with fit to mass continuum

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

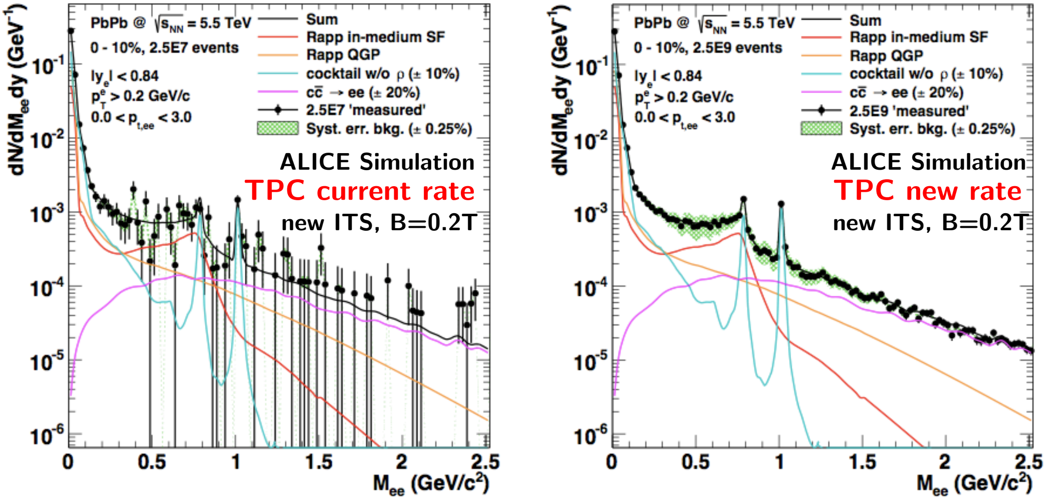


[ALICE upgrade LOI: CERN-LHCC-2012-012]

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

ALICE simulation: with upgraded ITS + TPC

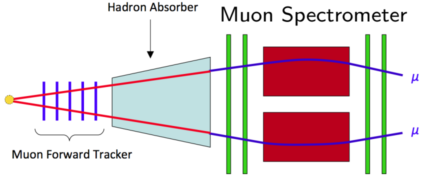
❑ Comparison with current TPC rate vs new TPC rate with new ITS



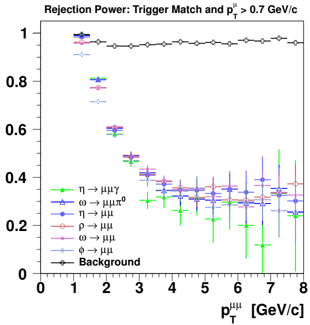
[ALICE upgrade LoI (CERN-LHCC-2012-012)]

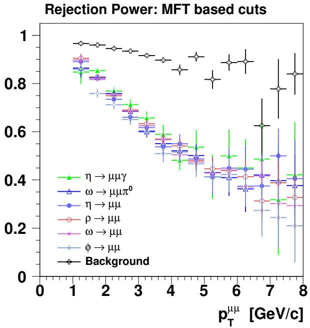
❑ Comparison of Poisson-sampled spectrum to expected hadronic and medium-induced sources

With upgraded muon arm: Muon Forward Tracker (MFT)



[MFT upgrade LoI and TDR]



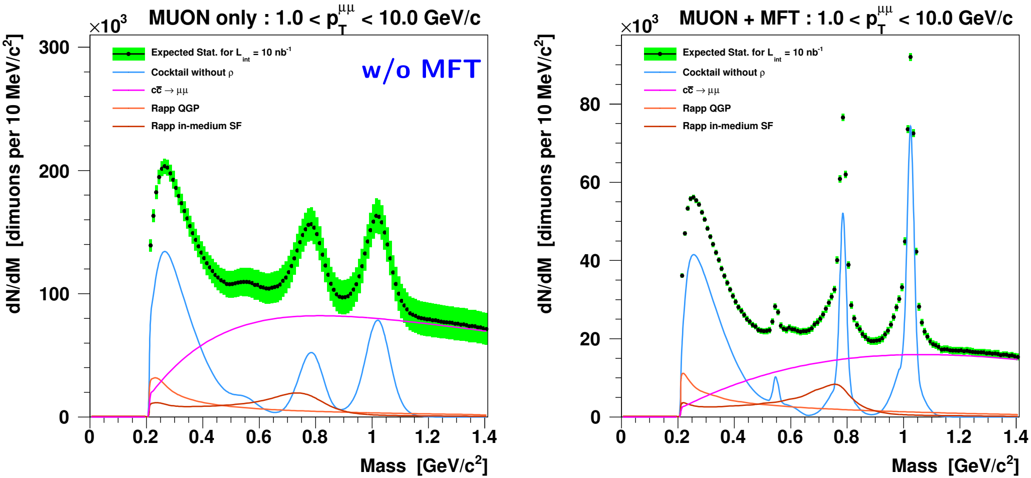


- **With MFT**
  - precisely measure the displacement of muons
    → reduces muons from charm and beauty semi-muonic decays
  - precise measurement of dimuon opening angles
    → precise determination of 2-body decays of light resonances
  - better rejection of background muon contributions to the comb.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

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



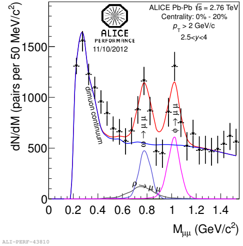
[MFT upgrade LoI]

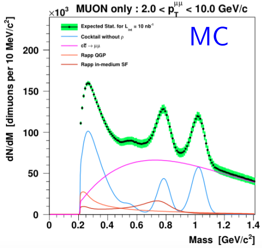
after comb. background subtraction and normalised to $L_{int} = 10\ nb^{-1}$

Low mass dimuons w/o MFT

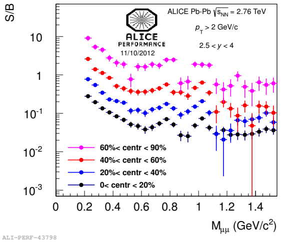
❑ Pb-Pb at 5.5 TeV (MC) vs Pb-Pb at 2.76 TeV (data)

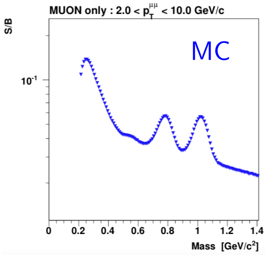
data





data





raw signal signal / background ratio

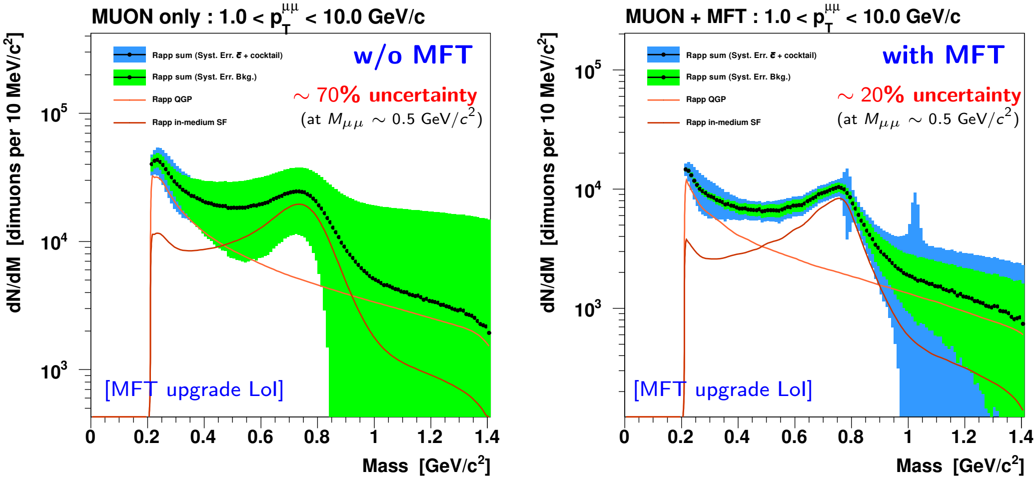
[MFT upgrade LoI]

- ❑ 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**

    $\rightarrow$ large uncertainties does not allow conclusion $\rightarrow$ lack of accuracy
  - **too small S/B in current Pb-Pb data**

    $\rightarrow$ 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**

$\Rightarrow$ large reduction of uncertainties of S and 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

    $\Rightarrow$ accessing the excess with accuracy in measuring:

    p_{T} **spectrum and elliptic flow of thermal photons**

STAY TUNED!

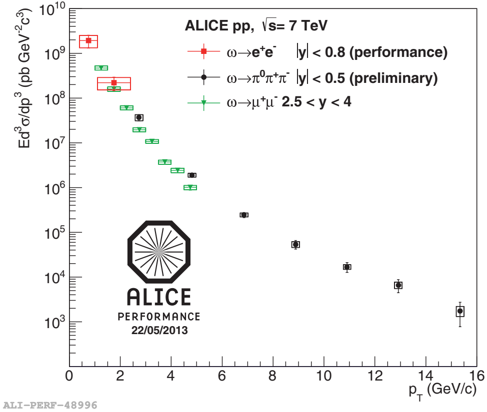
THANK YOU FOR YOUR ATTENTION

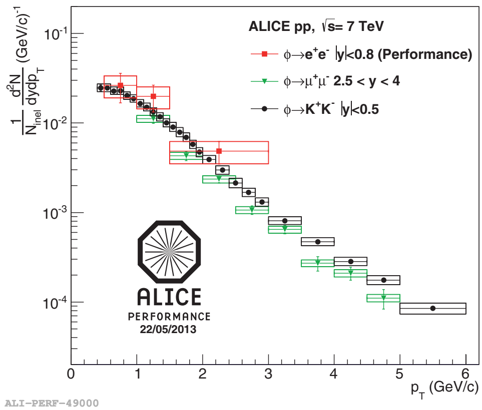
Extra slides

ϕ and ω production in pp collisions at 7 TeV with dielectrons

ALICE

- results of ω and ϕ from e^+e^- channel comparing to other decay modes



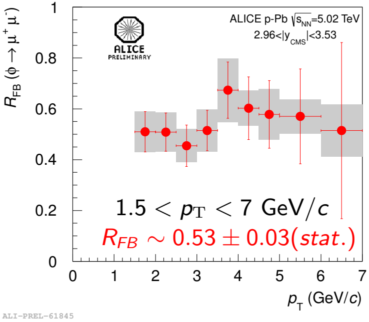


⇒ Consistent within uncertainties

⇒ However, larger statistical and systematical uncertainties from e^+e^- channel

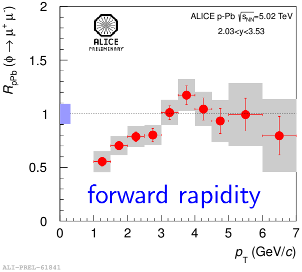
R_{FB} and R_{pPb} with dimuons: p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV

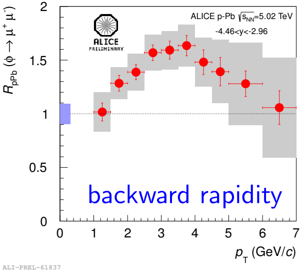
- ❏ $R_{FB} = \dfrac{Y_{forward}}{Y_{backward}}$



R_{FB}: **flat vs p_{T} and $\neq 1$**
$\Rightarrow$ asymmetry in ϕ production in p-A collisions in forward and backward rapidity

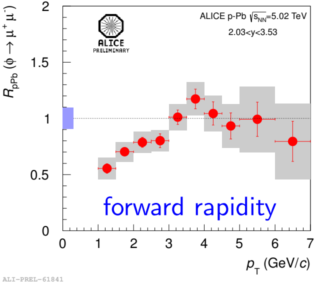
- ❏ **Nuclear modification factor:** $R_{pPb} = \dfrac{Y_{pPb}}{\sigma_{pp}\langle T_{pPb}\rangle}$

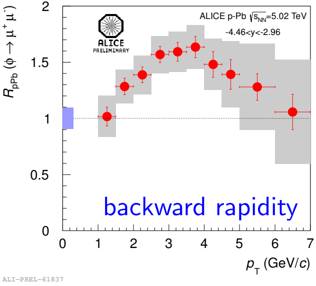




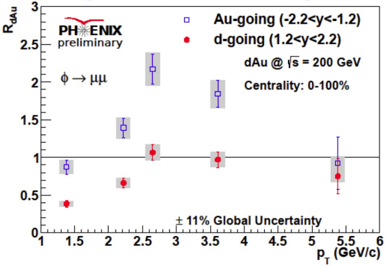
$\rightarrow$ σ_{pp} at 5.02 TeV:
interpolation from pp collisions at 2.76 and 7 TeV
$\rightarrow$ T_{pPb} is nuclear overlap function in p-Pb collisions

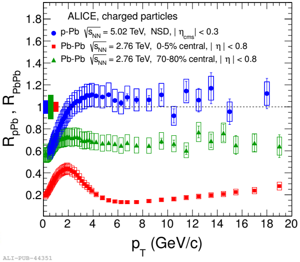
Comparing to RHIC d-Au results and ALICE mid-rapidity results





[PHENIX at QM'14]





bottom left figure:

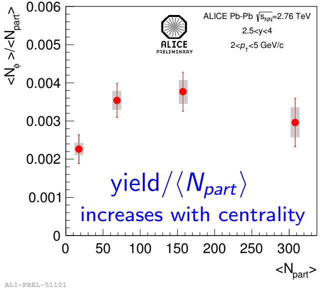
$\Rightarrow$ similar trend as RHIC results in d-Au collisions at 200 GeV

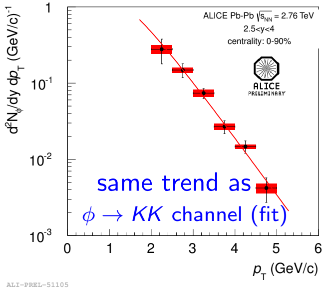
- forward: saturation $p_T > 3$ GeV/c
- backward: $R_{pPb} > 1$: Cronin like peak

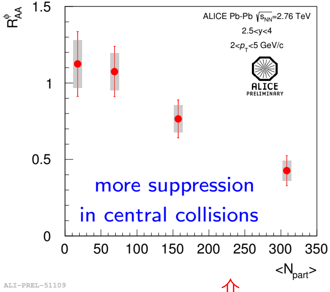
bottom right figure:

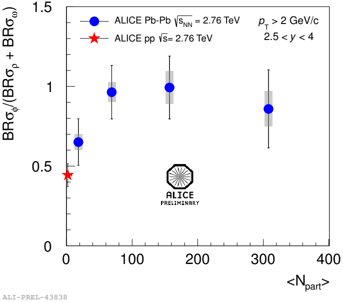
$\Rightarrow$ similar shape as ALICE charged particle R_{pPb} at mid-rapidity

ϕ yield in Pb-Pb collisions









- $BR\sigma_\phi/(BR\sigma_\rho + BR\sigma_\omega)$ saturates in central events
- nuclear modification factor similar trend as in Au-Au and Cu-Cu collisions at 200 GeV at mid-rapidity

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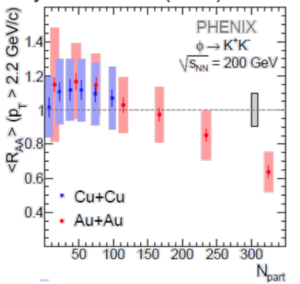
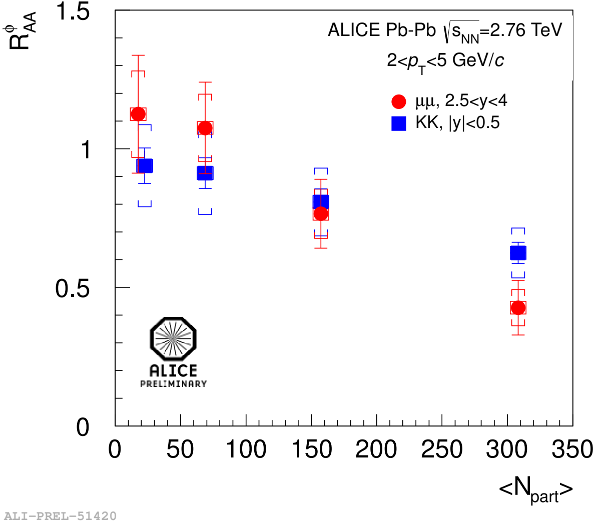


ϕ nuclear modification factor R_{AA}



- **Comparison with result from $\phi \rightarrow KK$ channel**
  - Agreement within uncertainties point by point
  - However with different slope

    $\rightarrow$ possible difference in hydrodynamic push at mid-rapidity and forward rapidity?