# Rencontres QGP France 2018

ALICE

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# Recent Results on Low-Mass Dimuons

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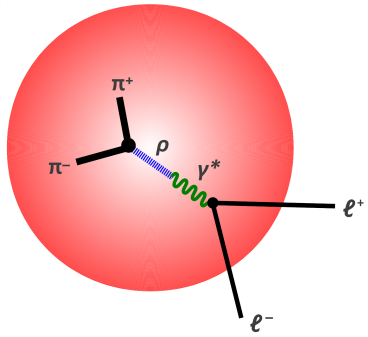
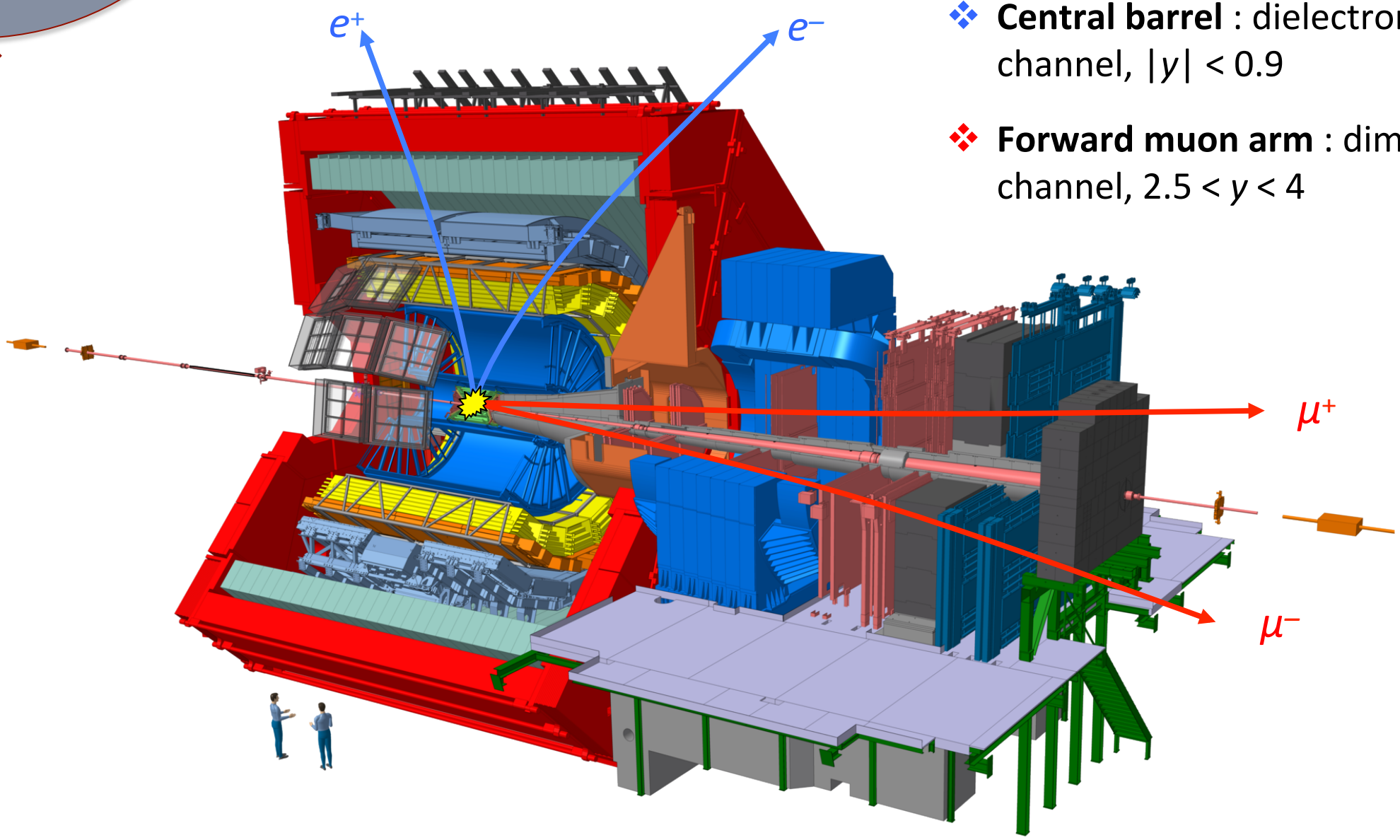
# Low-mass Dimuons: What to Look for

- **Dileptons (= virtual photons) as a golden probe to** study the QCD phase transition and its relations with the chiral symmetry restoration in the deconfined medium
  - Describing medium modifications of the vector mesons spectral functions
  - Measure the dilepton radiation from the partonic phase (QGP) exploiting the double degree of freedom given by the mass and the $p_T$
  - **Not possible with the Run1+Run2 data** (single-muon trigger threshold at 1 GeV/c, small S/B): we shall wait for the MFT and the Run3




- **Dimuons as the decay channel (either 2-body or Dalitz) of light neutral mesons**
  - Unique possibility to identify light-flavored particles at forward rapidity
  - Already possible with the current muon spectrometer and the available data

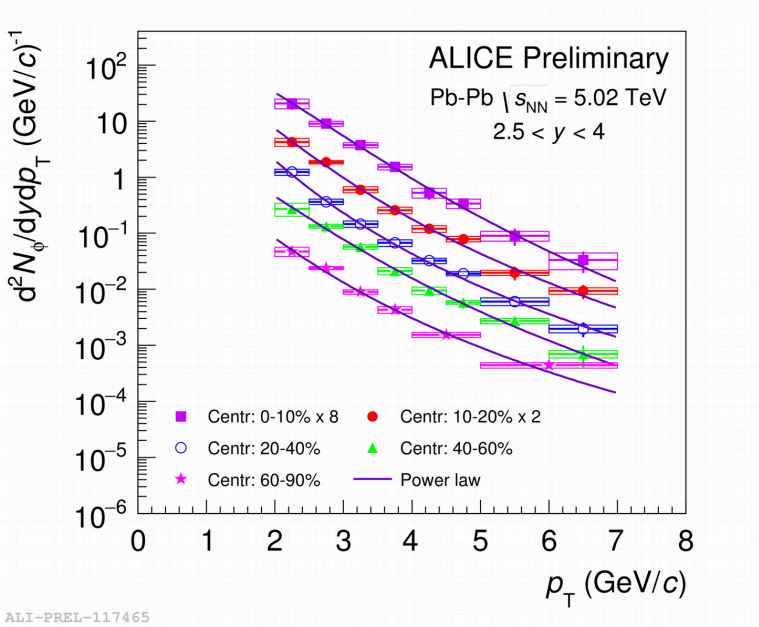
# Measuring Dileptons in ALICE




- **Central barrel** : dielectron channel, $|y| < 0.9$
- **Forward muon arm** : dimuon channel, $2.5 < y < 4$

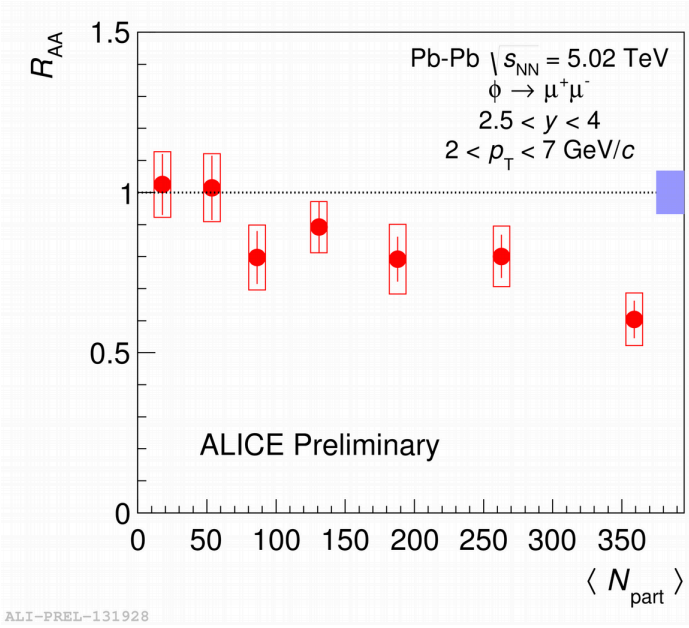
# Pb-Pb Results at 5 TeV: Focus on the ϕ Meson

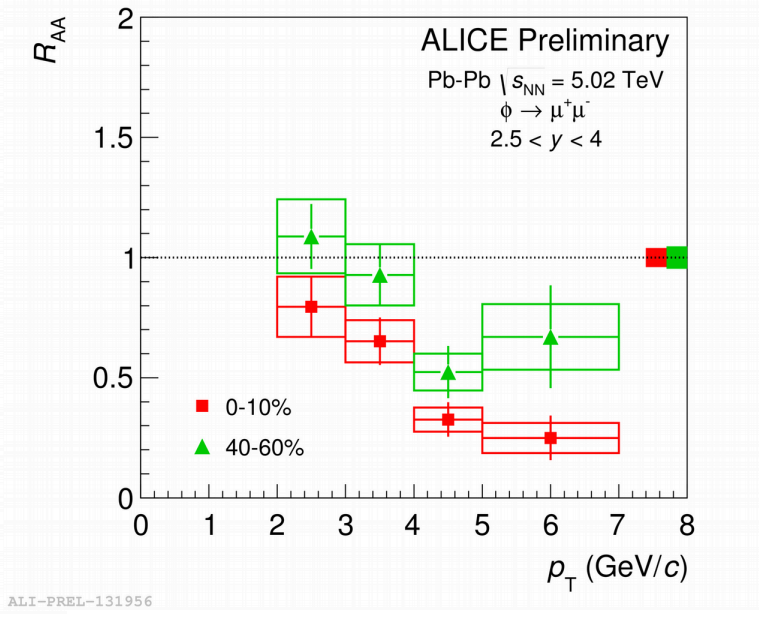
- Pb-Pb at 5.02 TeV: power law function fits well all centralities. Hardening of the $p_T$ spectra towards peripheral collisions




- **$R_{AA}$ vs $N_{part}$:** close to 1 in peripheral collisions. Small decrease from semiperipheral to (semi)central collisions at intermediate $p_T$

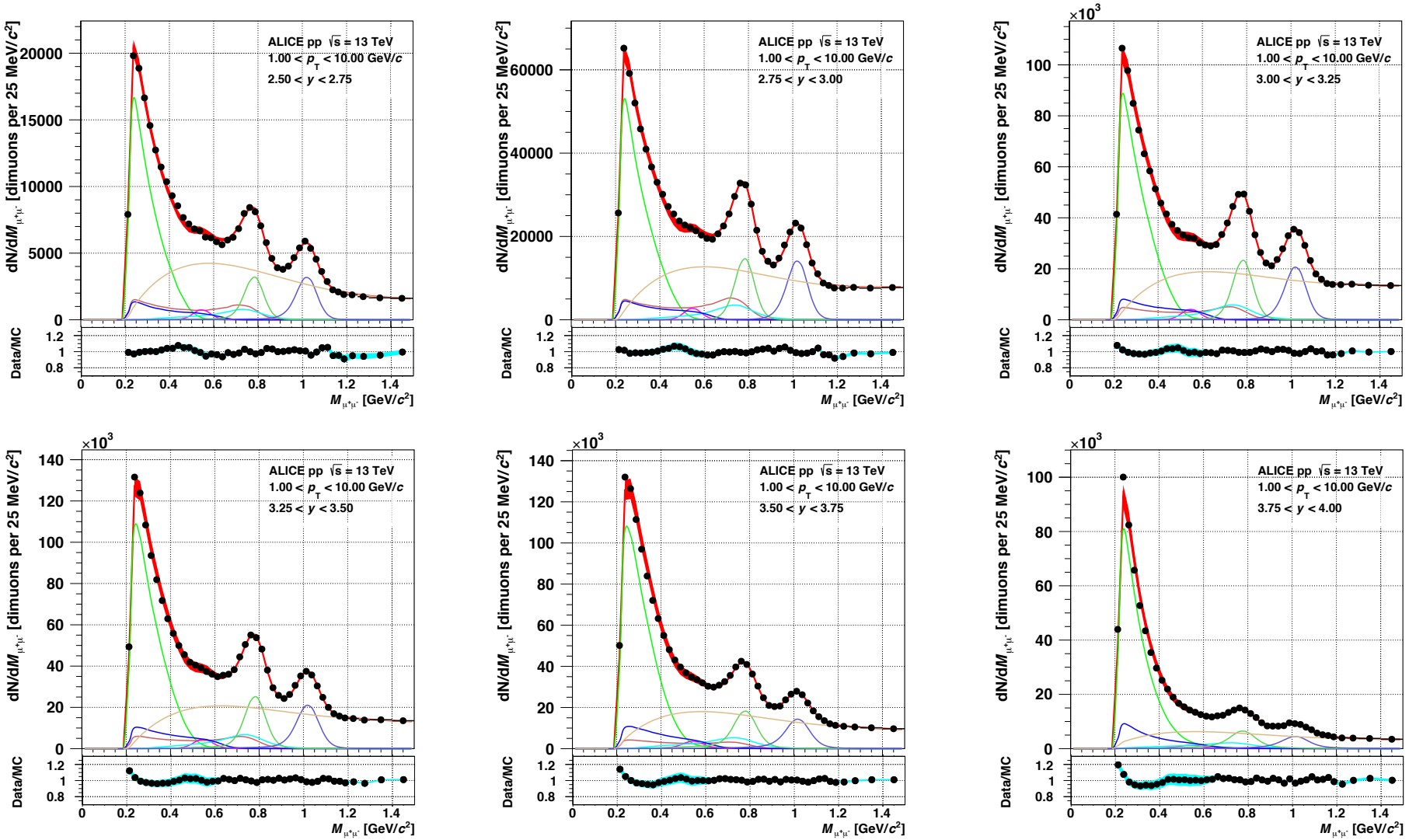
- **$R_{AA}$ vs $p_T$:** clear decrease for $p_T$ > 4 GeV/c in central collisions (onset of the hard-$p_T$ regime). Effect less pronounced for semi-peripheral collisions



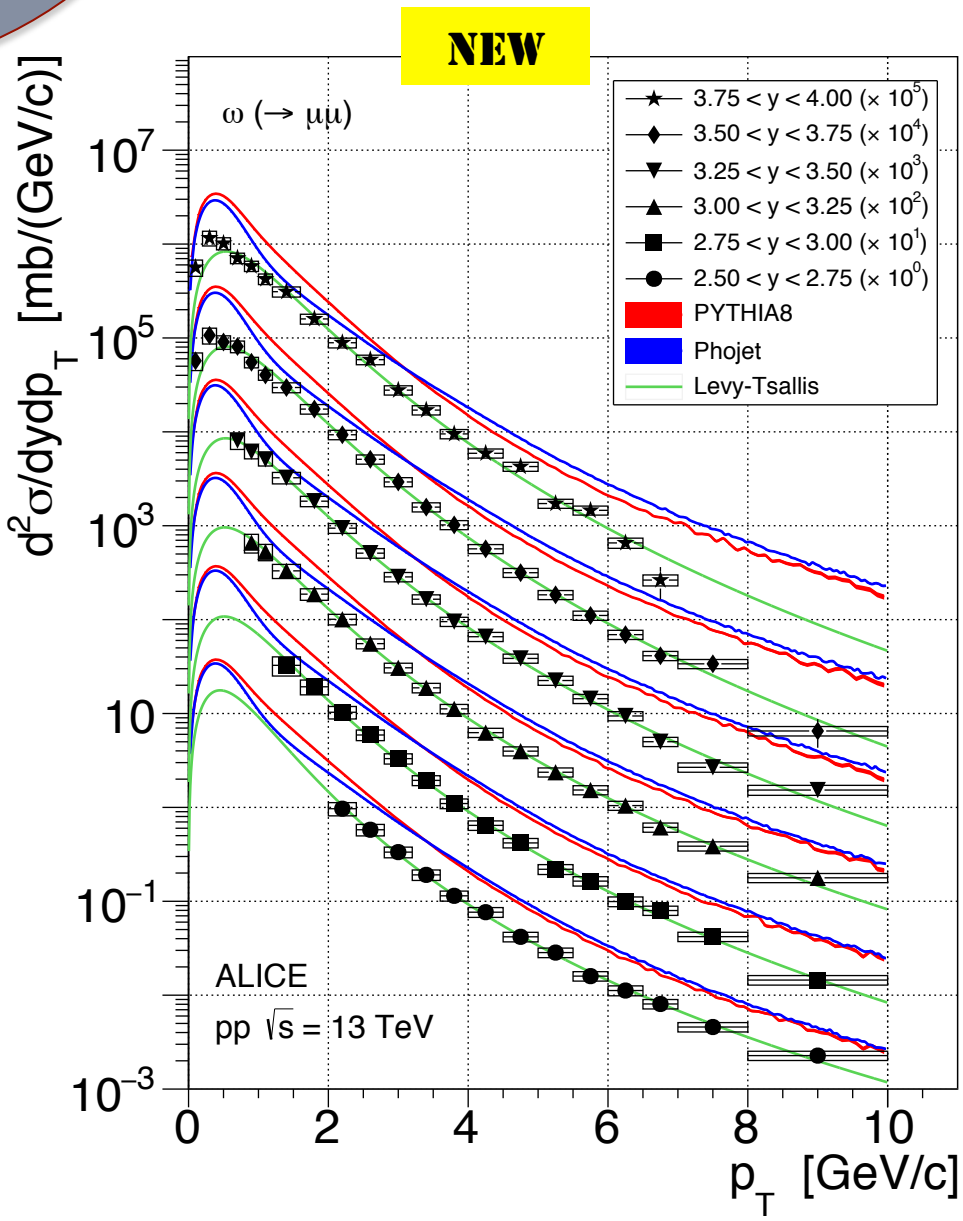



# pp Data at 13 TeV: Double-differential Analysis

- **Large data sample: signal extraction possible vs $p_T$ and rapidity**

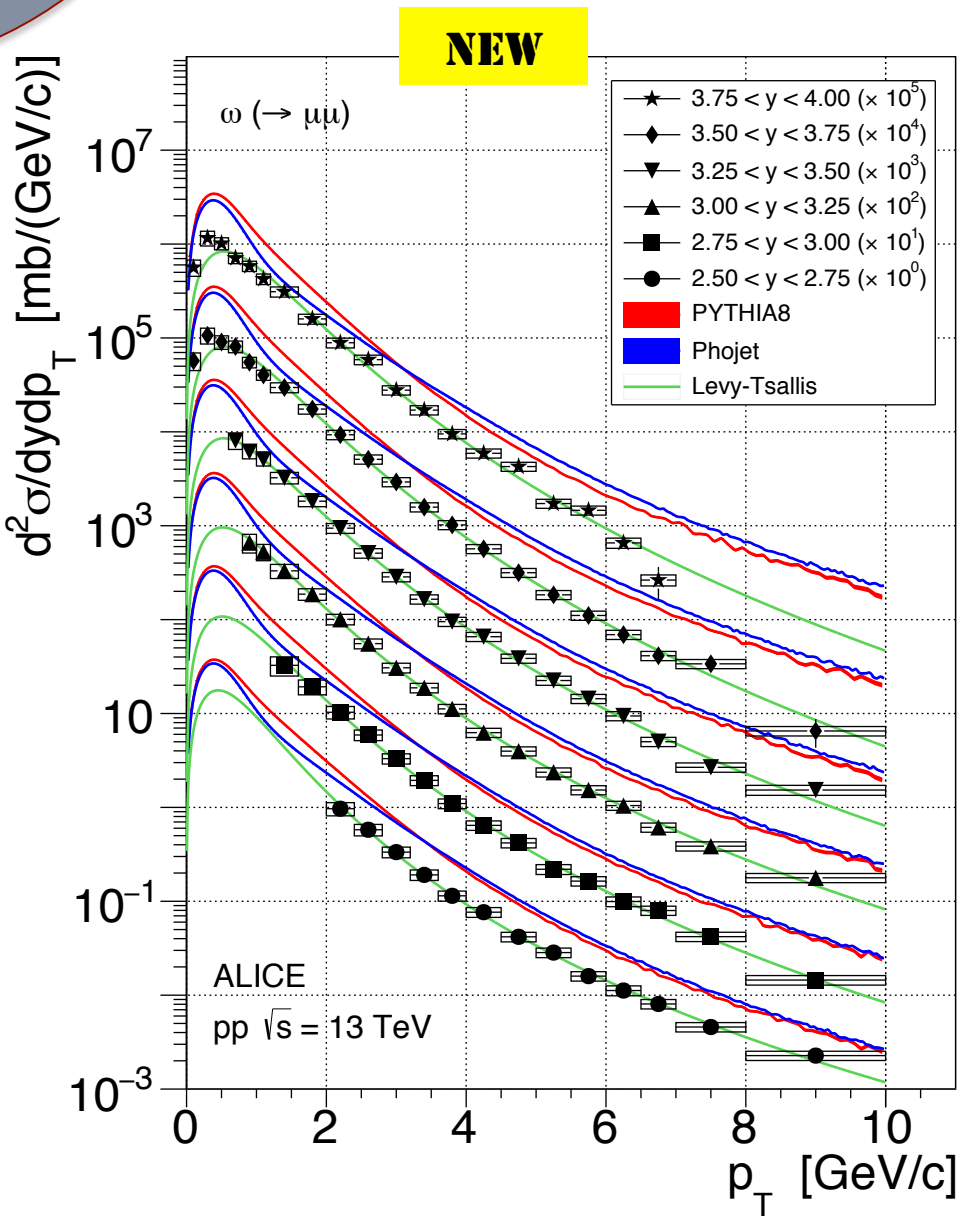


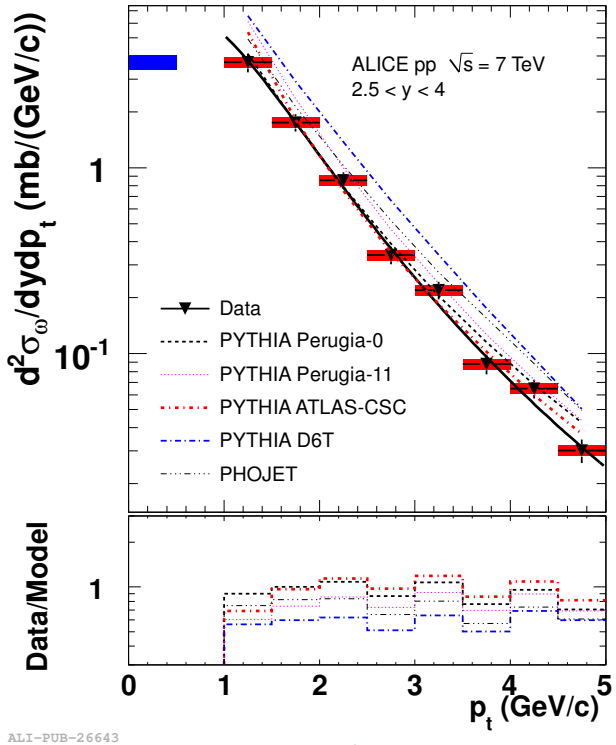
# $p_T$ Spectra: ω Meson




- **Both PYTHIA8-Monash and Phojet overestimate** by an average factor ≈2 the production cross section of the ω meson
- Differences between PYTHIA8 and Phojet are larger at low $p_T$
- Phojet comes closer to data towards $p_T$ ≈ 1-2 GeV/c
- Levy-Tsallis fit works fine above $p_T$ = 0.5 GeV/c

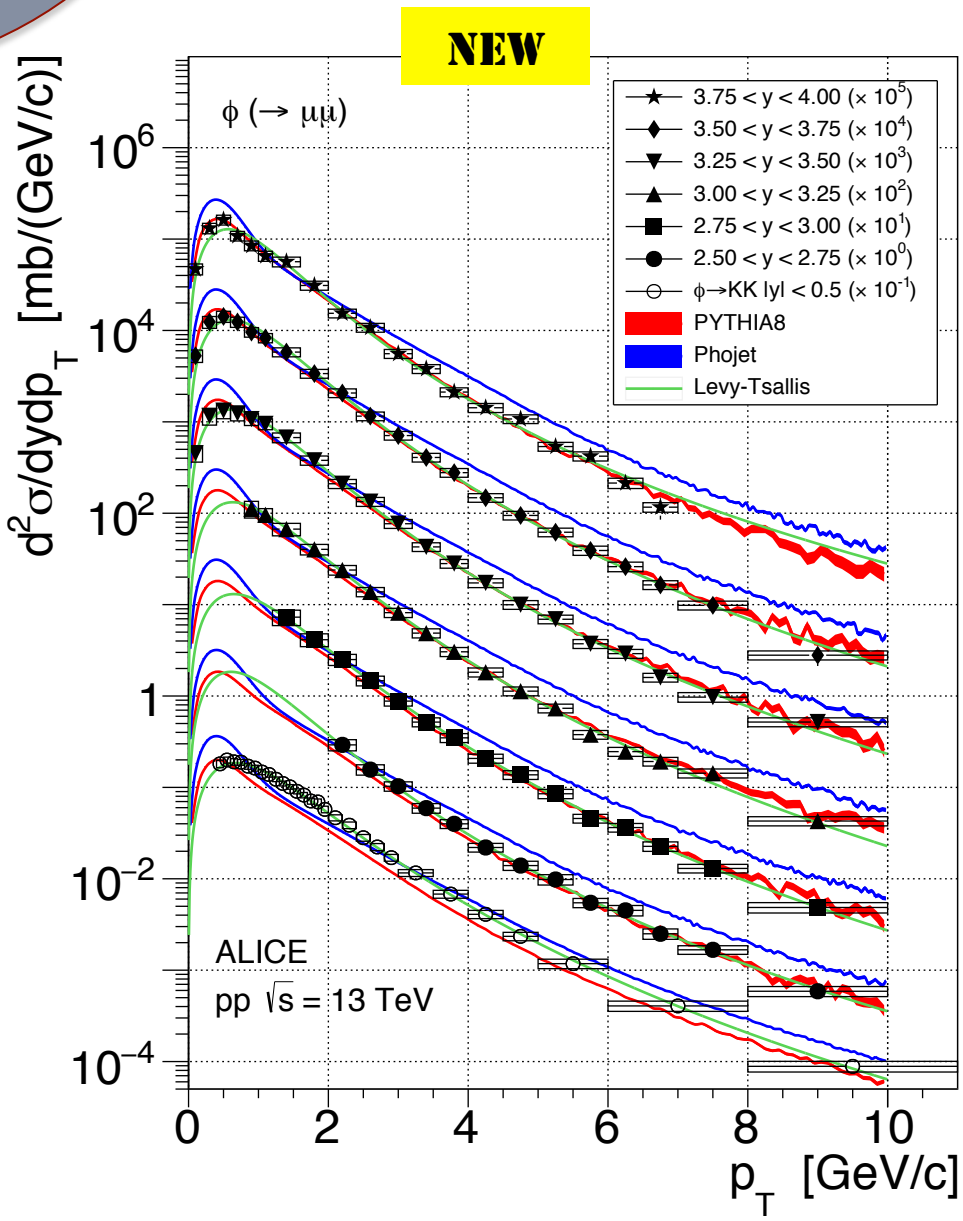
# $p_T$ Spectra: ω Meson




- **Phojet already overestimated pp data at 7 TeV** by a factor between 1.2 and 1.8

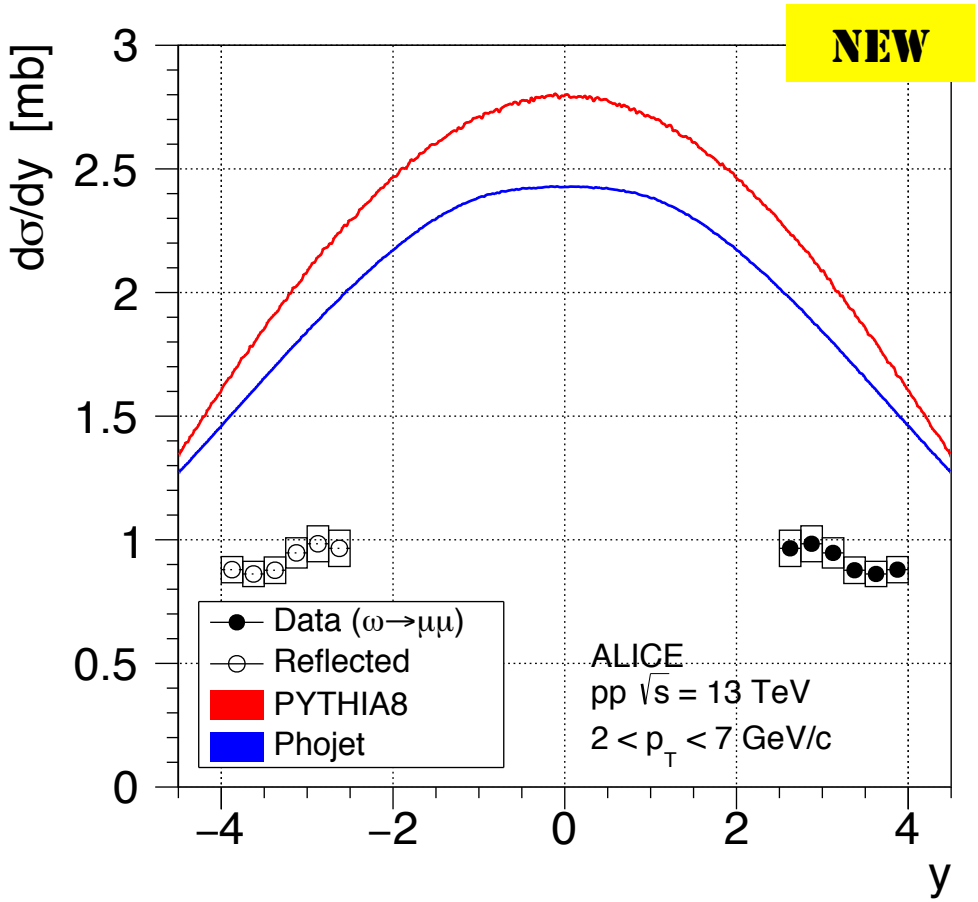
# $p_T$ Spectra: $\phi$ Meson

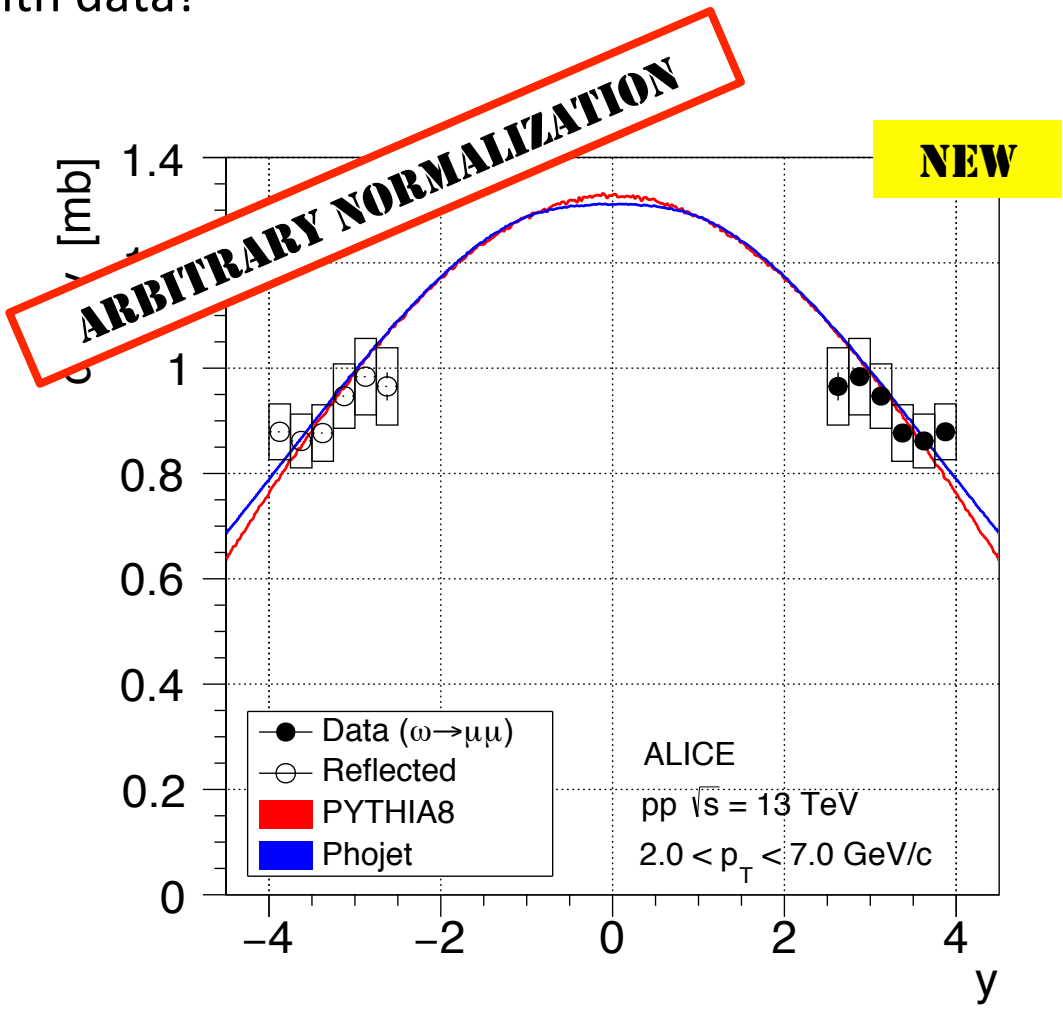



- **PYTHIA8** provides a fair description of the cross section of the $\phi$ meson across the whole measured $p_T$ range
- **Phojet comes close to data only towards $p_T \approx$ 1-2 GeV/c** (it was already the case in pp collisions at 7 TeV)
- Levy-Tsallis fit works fine in the whole $p_T$ range

# Rapidity Dependence – ω Meson

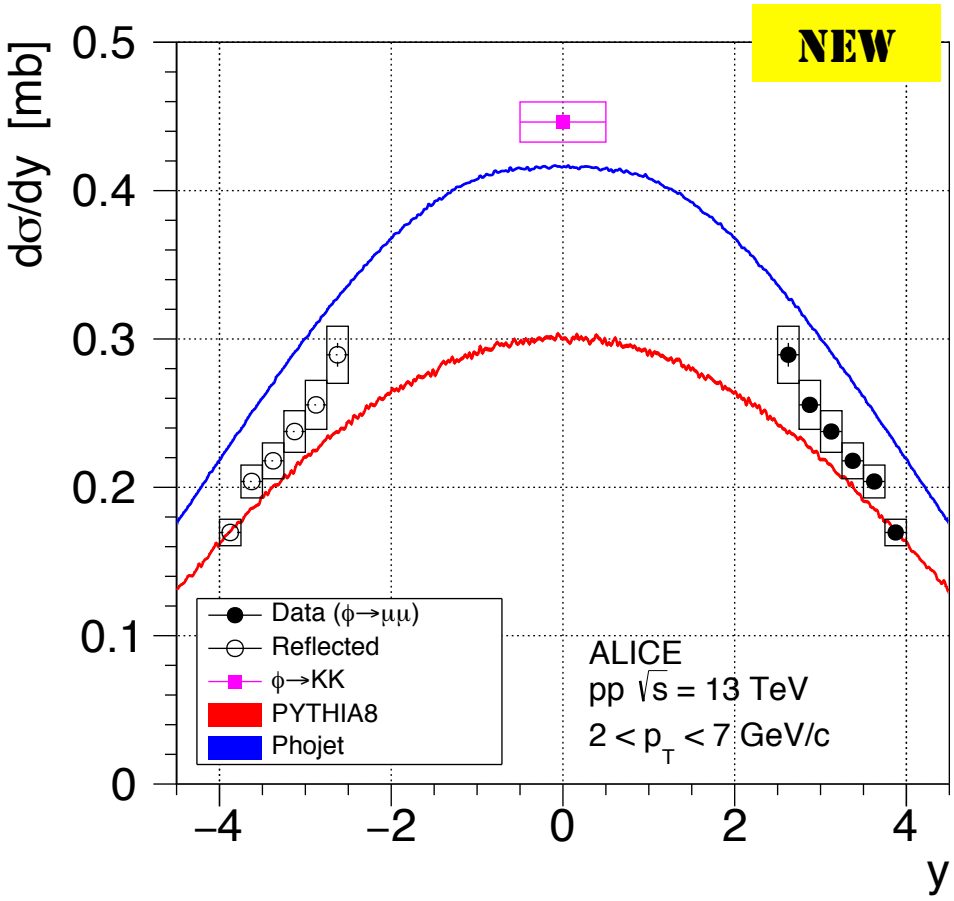
- **Models fail in reproducing the correct normalization...**
- ... but the shape is compatible with data!

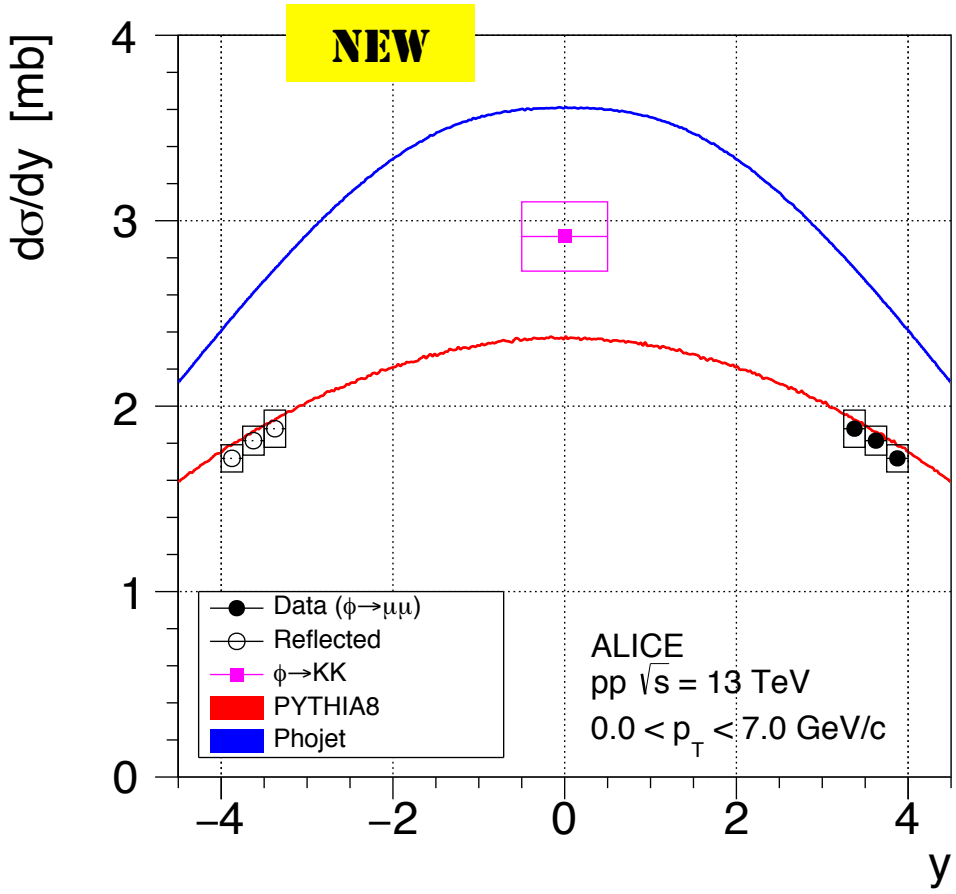


# Rapidity Dependence – ϕ Meson

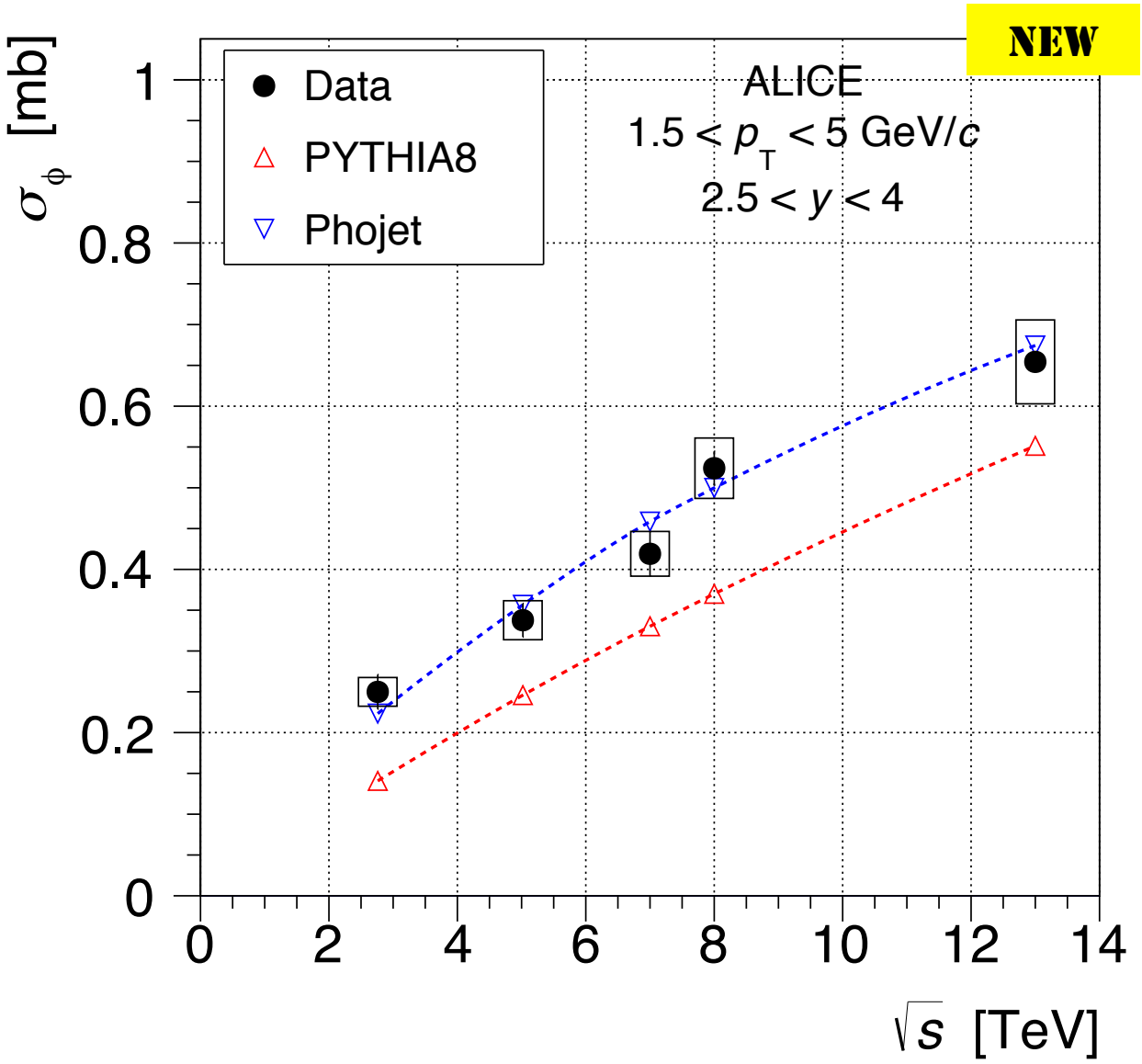
- **The measurement is dominated by the lower limit of the considered $p_T$ range**
- For the ϕ meson, the combined data at forward and mid-rapidity suggest the rapidity distribution to be narrower than the model predictions



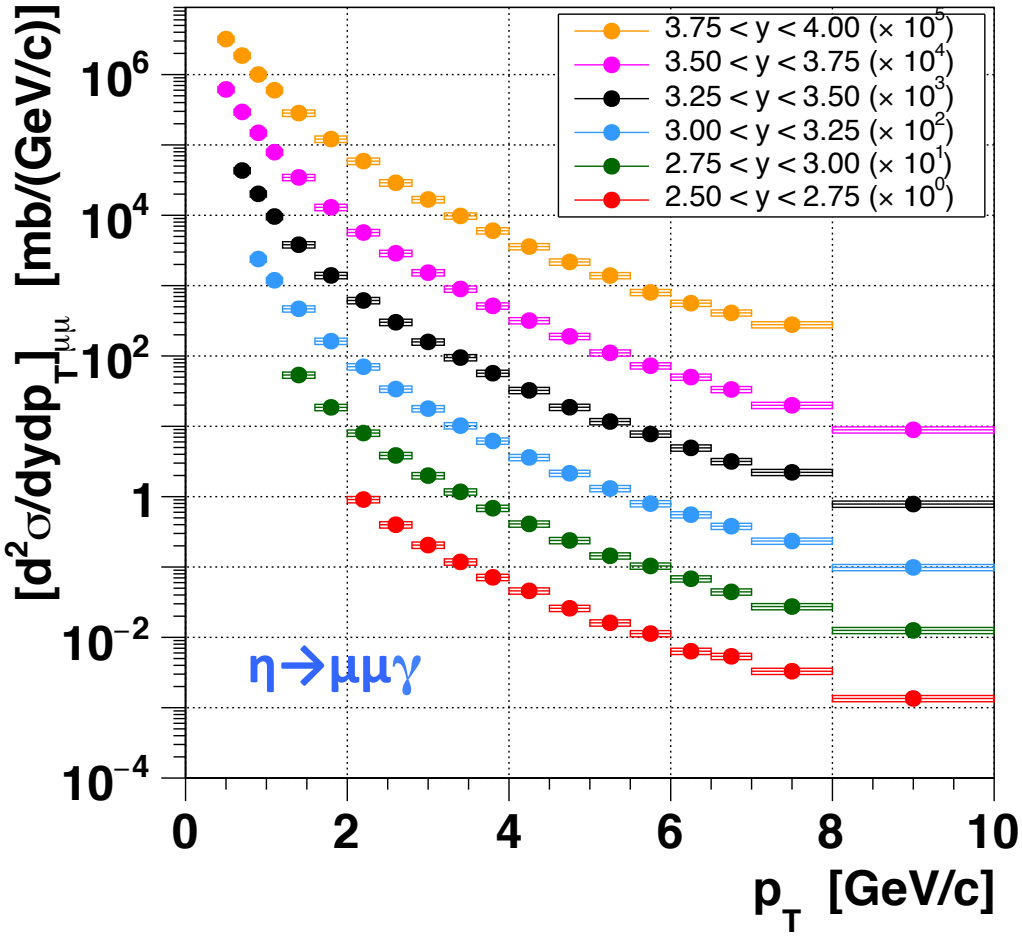
# Energy Dependence – ϕ Meson

- ϕ meson cross section integrated the $p_T$ range common to the available measurements at various energies
- **In the specific phase space considered here,** Phojet described the data fairly well, while PYTHIA8 systematically underestimate the points



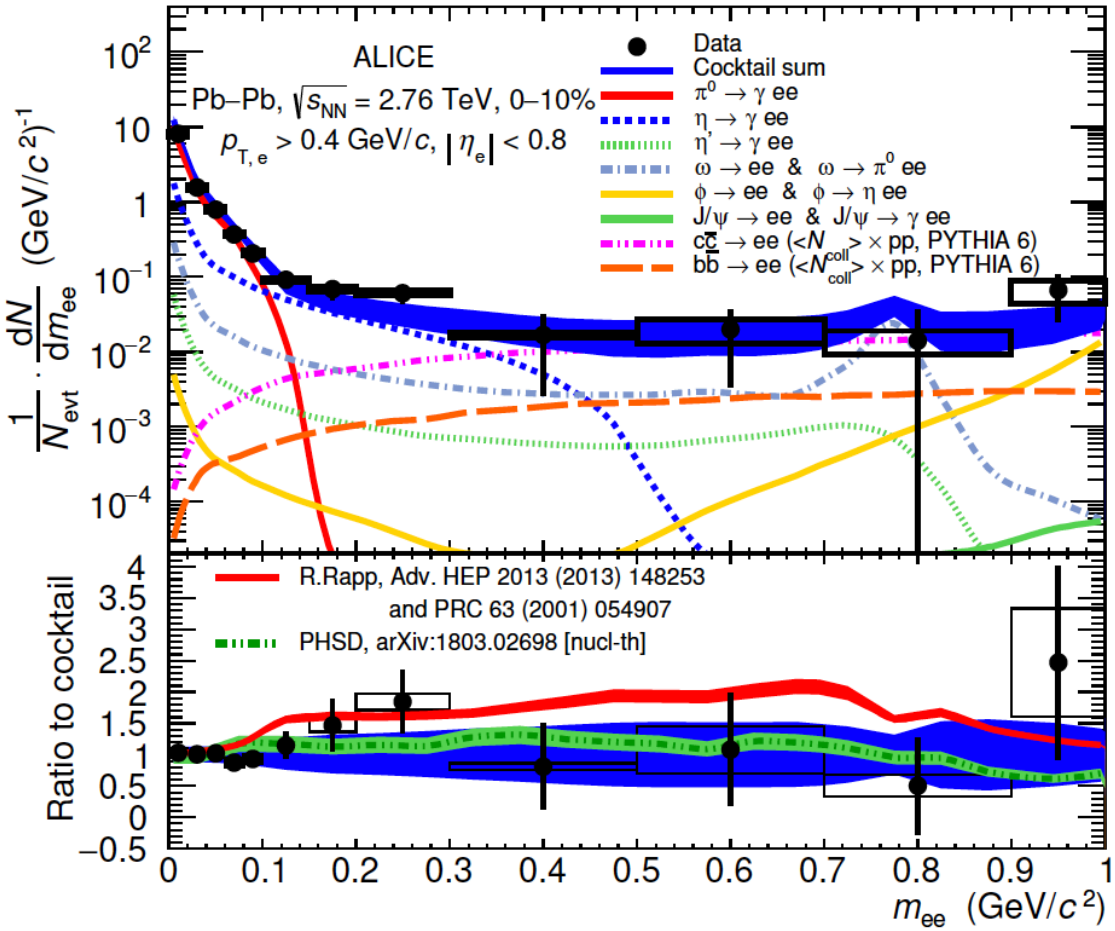
# Outlook

- **pp at 13 TeV: huge potential from the combination of the 2016, 2017 and 2018 data samples**




- **First measurement of the η meson in the Dalitz decay channel** (meson kinematics to be obtained from the dimuon one through either a bin-to-bin correction or a deconvolution)
- Evolution of $p_T$ spectra and rapidity distributions with multiplicity
- **Evolution of ϕ/ω with multiplicity**. (At 5 TeV, the ratio could be studied vs multiplicity from pp to p-Pb to Pb-Pb)

# Dielectrons: Thermal Radiation in Pb-Pb?




Corrected $e^+e^-$ yield in the ALICE acceptance ($p_{T,e}$ > 0.4 GeV/c and $|\eta_e| < 0.8$)

Two models for the thermal radiation:

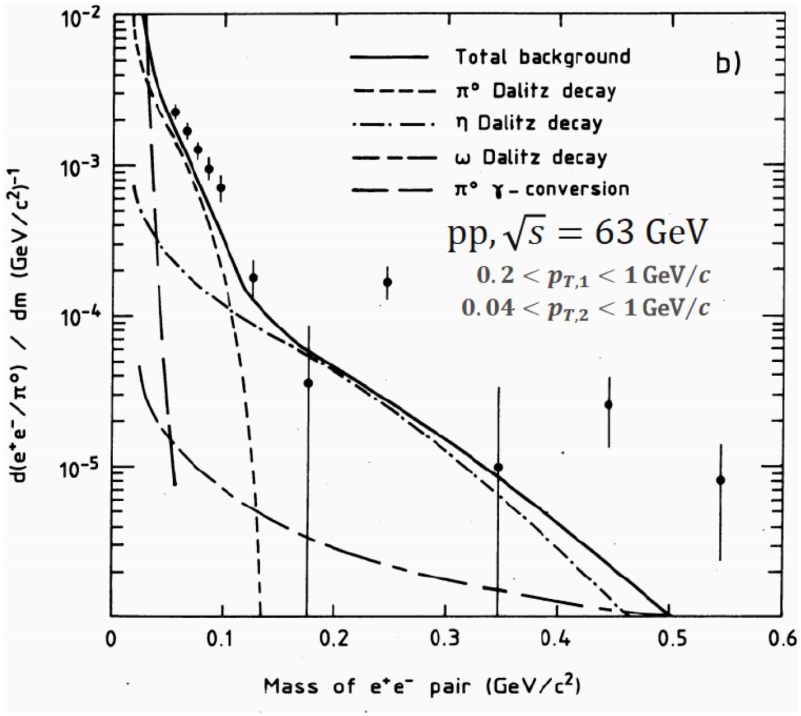
- **R.Rapp:** expanding fireball model with $T_C$ = 170 MeV and hadronic many-body theory
- **PHSD:** Parton-Hadron-String Dynamics transport approach

- **No sensitivity yet for possible thermal radiations from the medium. Run-2 and Run-3 (after upgrades) → more precise measurements**

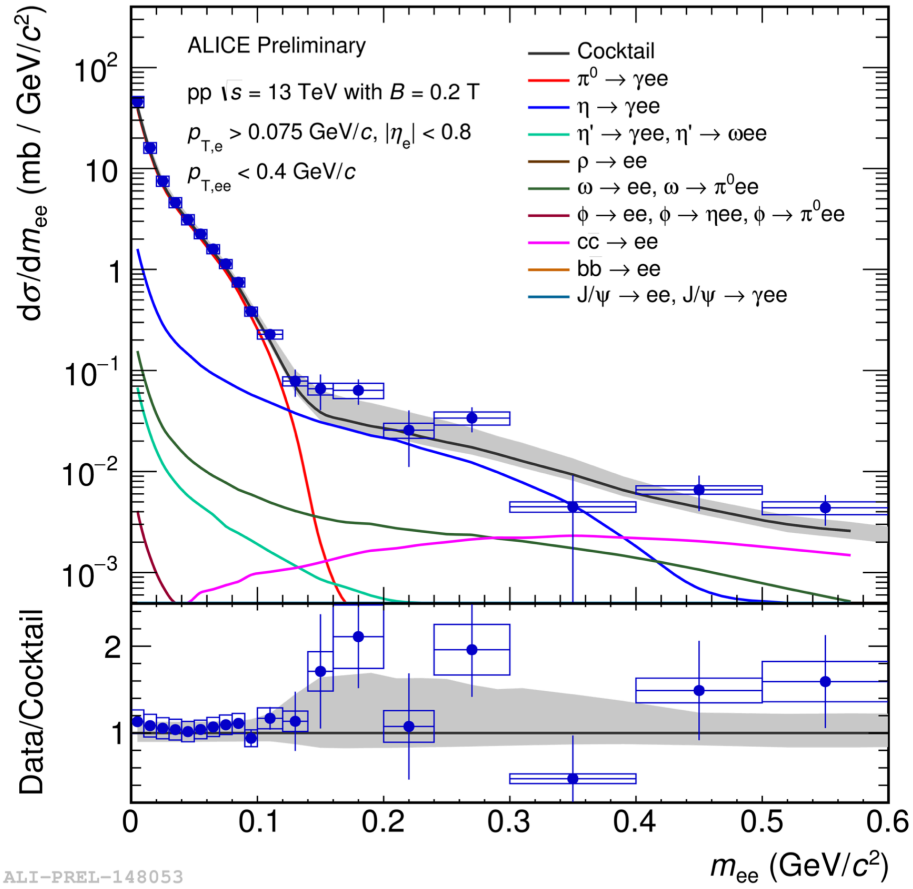
# Dielectrons: Low-Mass Dielectron Excess in pp?

**CERN ISR -- AFS (1987)**

Excess above the cocktail was observed for $0.05 < m_{ee} < 0.6$ GeV/$c^2$




**ALICE (2018)**




- ALICE data in pp at 13 TeV does not rule out an excess. More data at lower magnetic field (being collected) and a better control on the hadronic cocktail are needed.

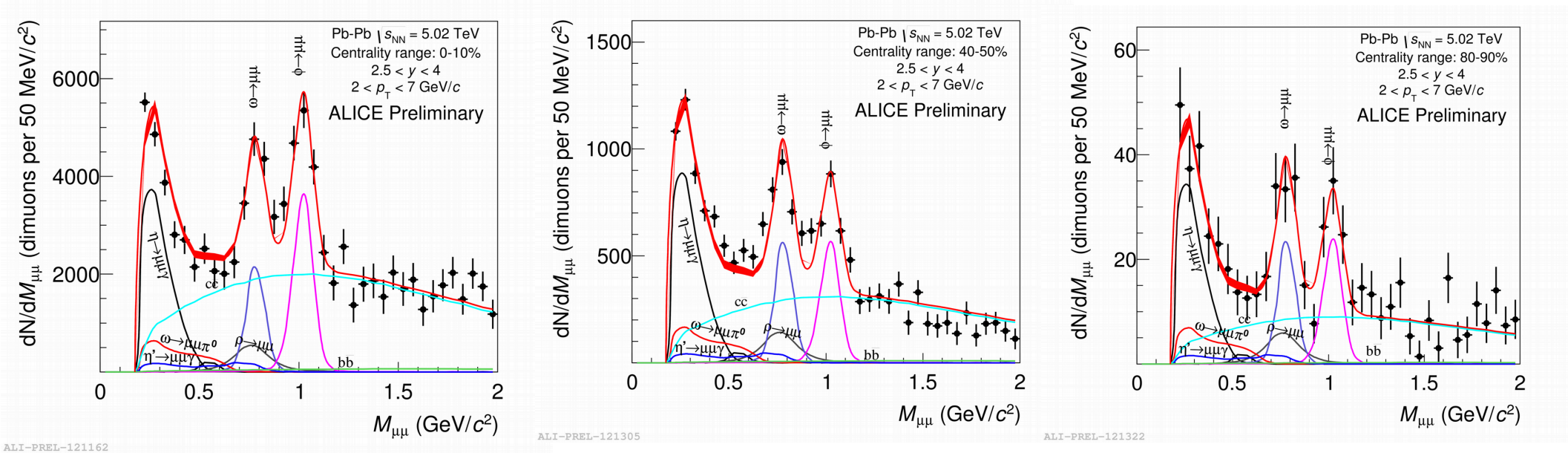
# Backup Slides

# Signal Extraction

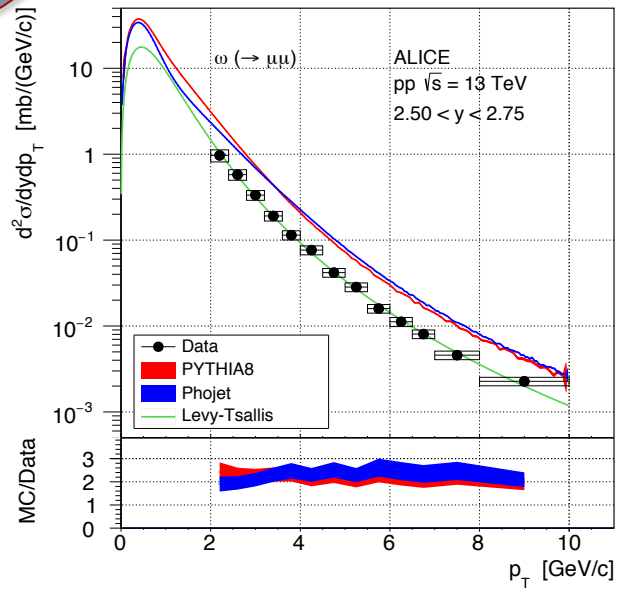
- Mass spectra after background subtraction in several centrality bins for **$2 < p_T < 7$ GeV/c**. Lower $p_T$ limit driven by the single-muon $p_T$ trigger threshold. Larger statistics w.r.t. the 2.76 TeV data

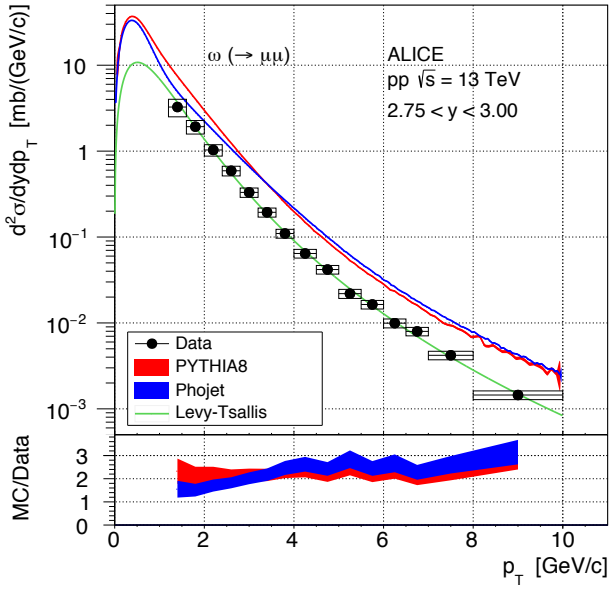
- Ingredients of the fit: hadronic cocktail (dimuon decays of light resonances) and semi-leptonic decays of open heavy flavours

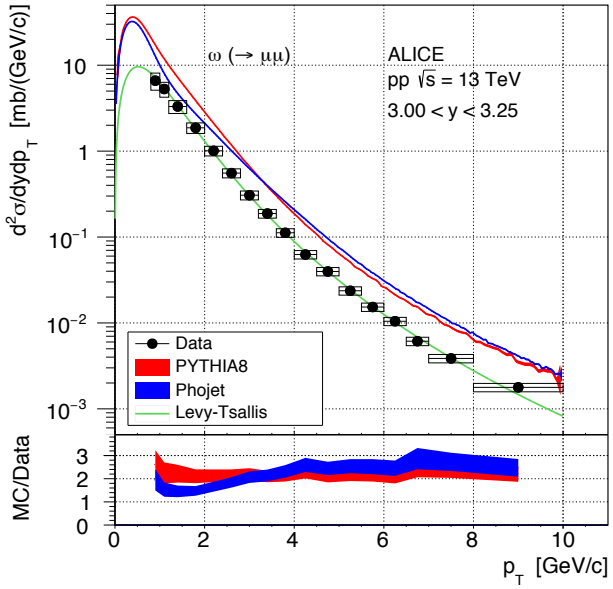
- Free parameters in the fit: η, ω, ϕ and open charm normalizations

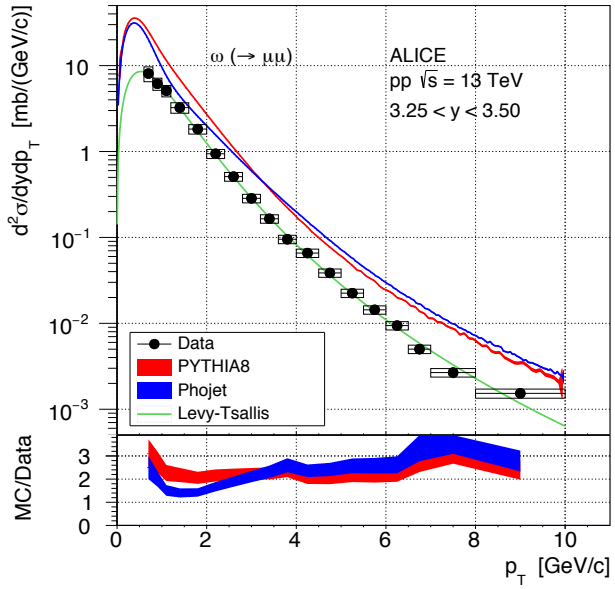


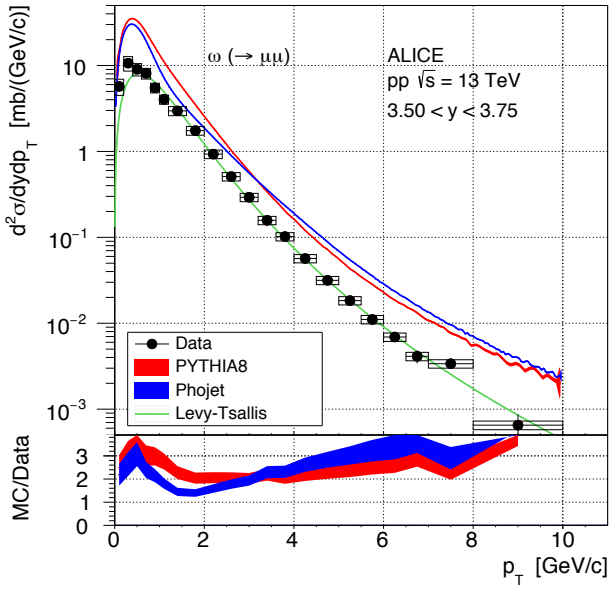
# $p_T$ Spectra in Detail: ω Meson

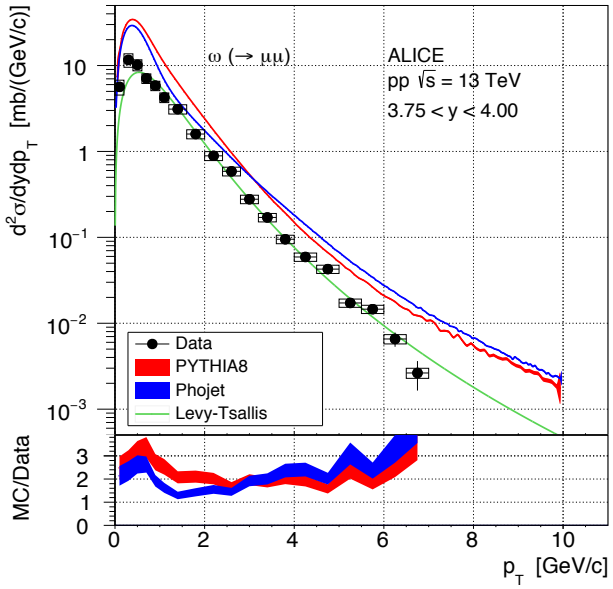


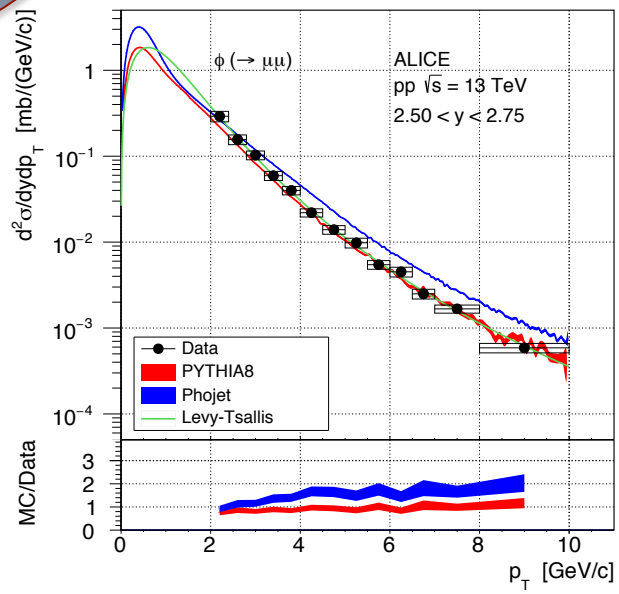



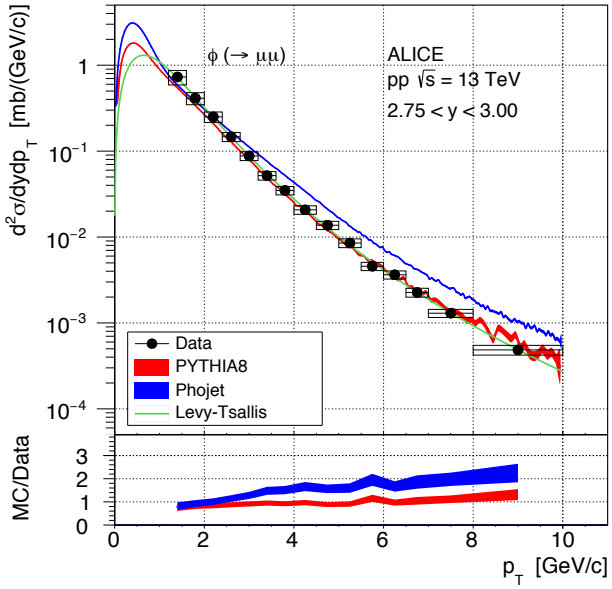



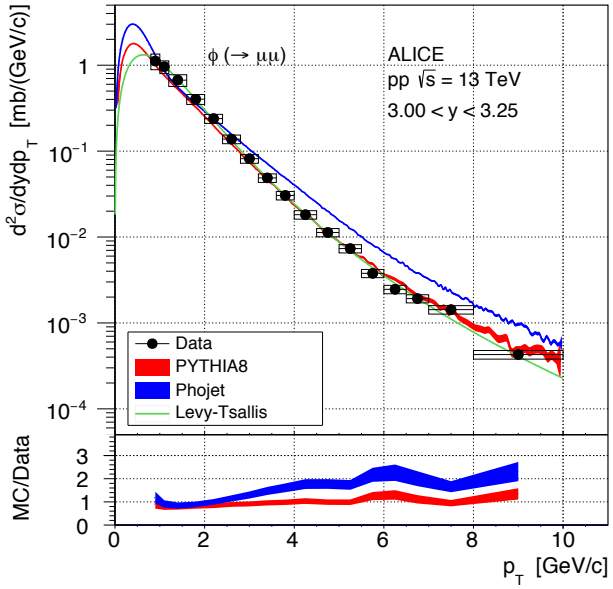



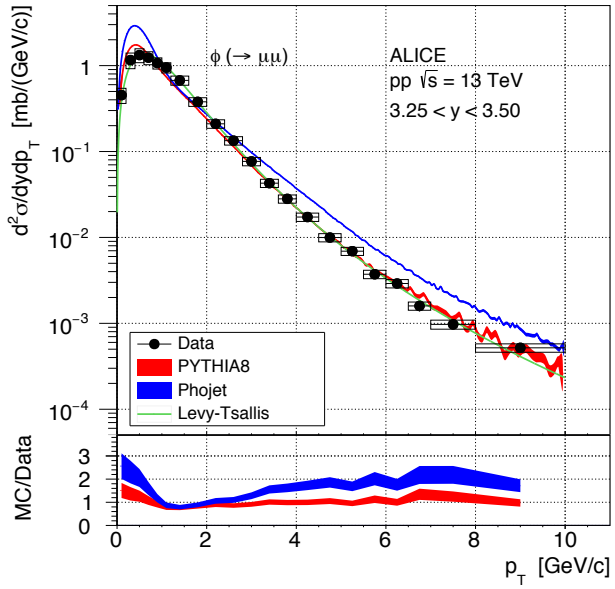



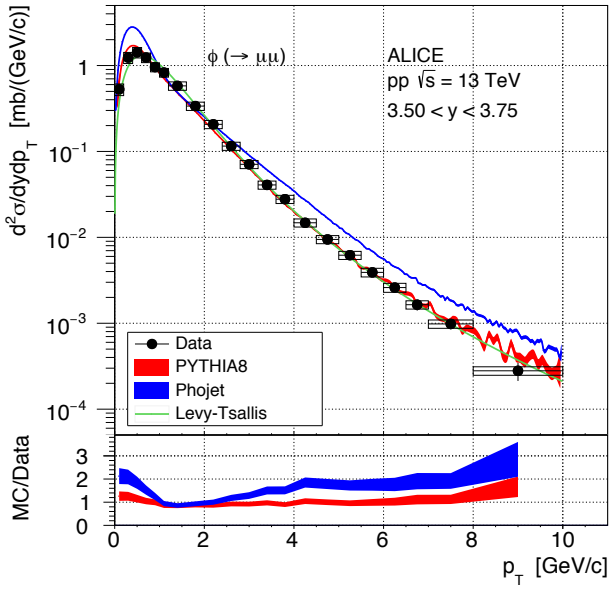
# $p_T$ Spectra in Detail: $\phi$ Meson

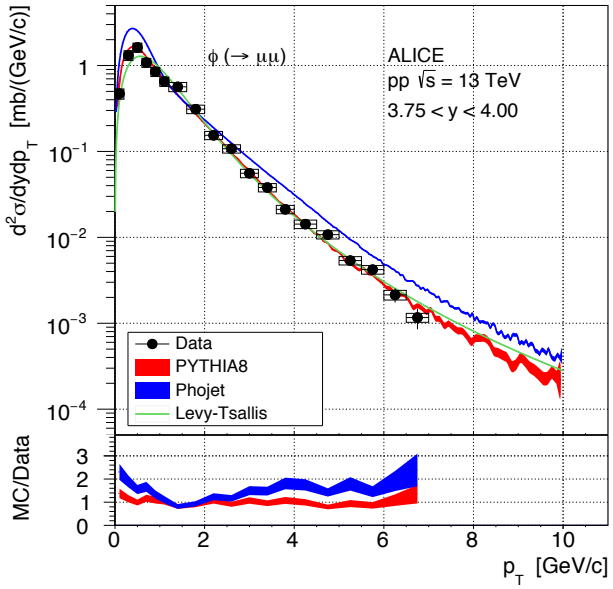


# A Step Back: the Correlated Continuum

- **After the subtraction of the combinatorial background**, we are left with a sample of correlated muon pairs **from Dalitz and 2-body decays of light neutral mesons** (same mother, direct correlation) on top of an underlying continuum

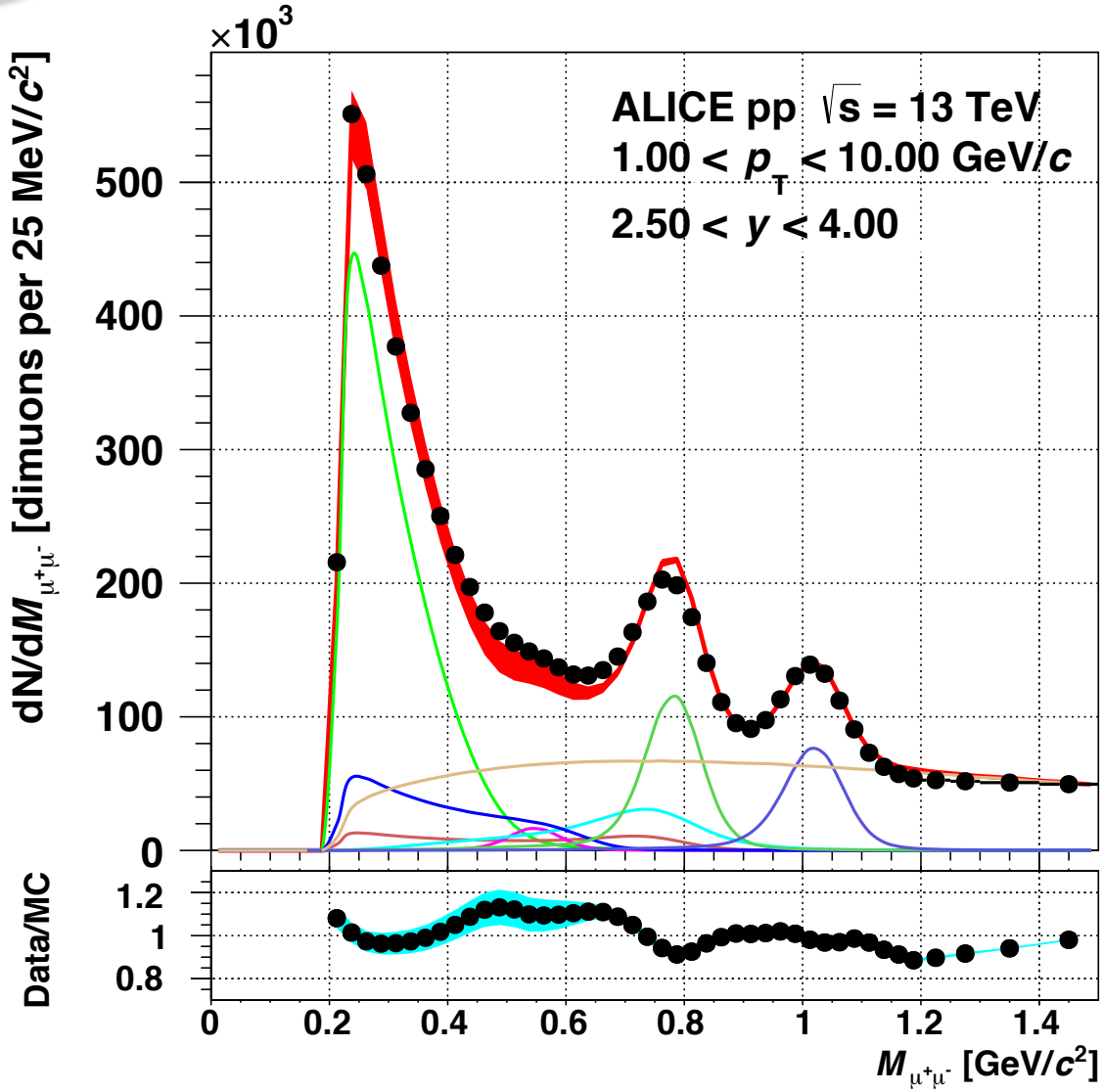
- **What can we say about the underlying continuum?**
  - It is composed of the superposition of correlated muon pairs from open charm and beauty processes, as well as of muon pairs from correlated production of light hadrons
  - Its shape and the normalisation also reflects any possible misestimation of the combinatorial background

- **How can we describe the underlying continuum in the fit of the dimuon mass spectrum?**

# The “Charm+Beauty” Approach

- Following this approach, the correlated continuum is treated as the superposition of the correlated dimuon contributions from the open charm and open beauty processes. **This approach is based on the following assumptions:**
  - No additional, relevant, correlated dimuon component is included in the correlated continuum, beyond the ones from open charm and beauty
  - The shapes of the dimuon invariant mass templates for the open charm and beauty processes are known with negligible uncertainties (with the same precision as the mass templates for the hadronic cocktail processes)
  - The ratio between the open beauty and the open charm dimuon components is known (together with its $p_T$ and y dependence, at the specific energy considered in the analysis), either from measurements or from tuned models like FONLL or PYTHIA

# The "Charm+Beauty" Approach: Rapidity-Integrated

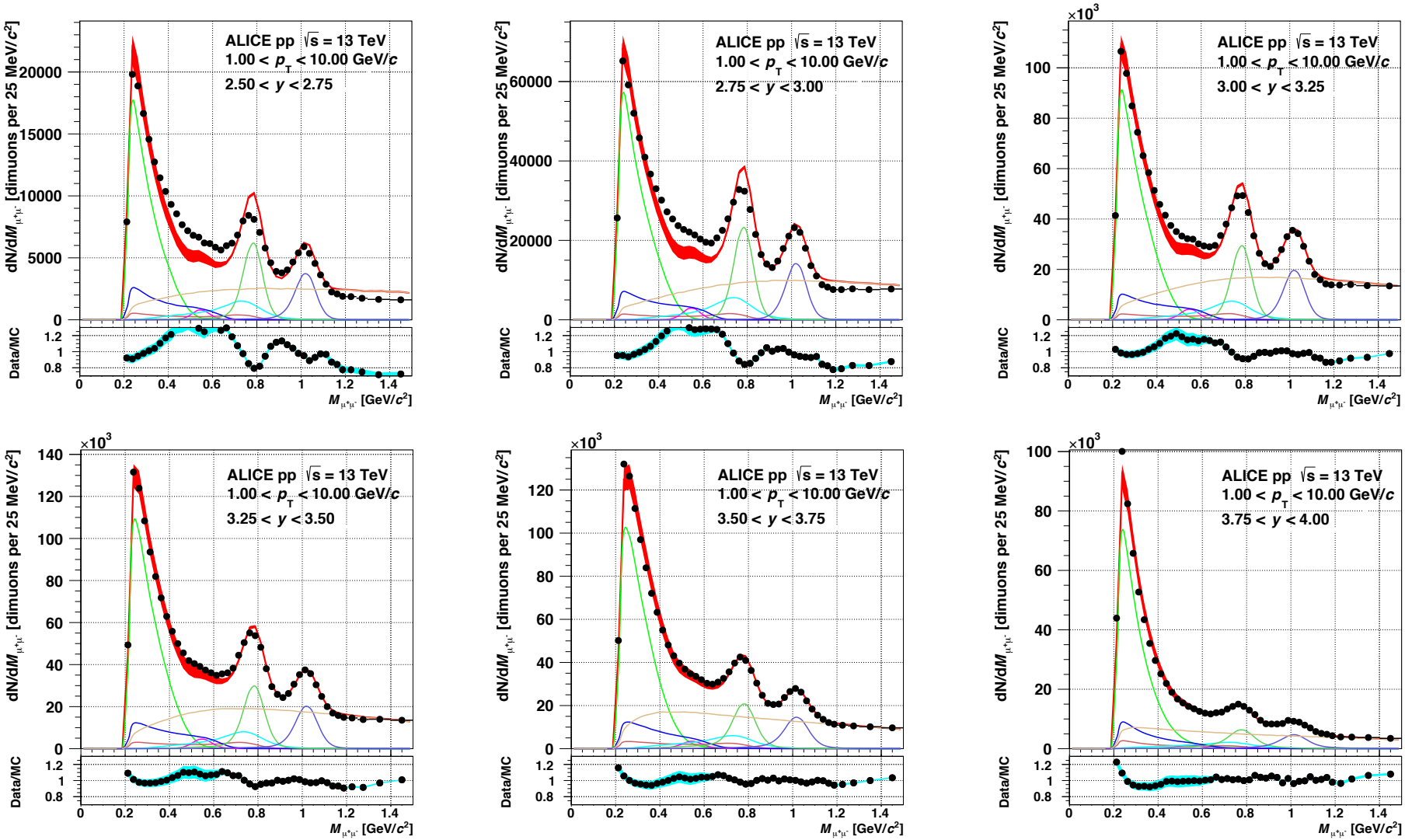



- When integrating over rapidity, the description of the spectrum is fine everywhere except for some tensions between 0.45 – 0.65 GeV/$c^2$

- This tension has been also reported in other low-mass dimuon analyses: **all is fine for the ϕ meson extraction**, but there is a potential bias for the extraction of the ω signal

# The “Charm+Beauty” Approach: vs Rapidity

- **Data/MC tensions show a clear trend vs rapidity**



# The "Charm+Beauty" Approach: vs Rapidity

- **Data/MC tensions increase towards mid-rapidity while basically disappear in the most forward rapidity intervals**

- **These tensions induce a bias on the extraction of the signals of interest for the analysis,** particularly important for the extraction of the ω signal. For this reason, this approach is **not well-fitted for this specific analysis**, aiming to the simultaneous extraction of the η, ω and ϕ, signals as a function of both $p_T$ and rapidity

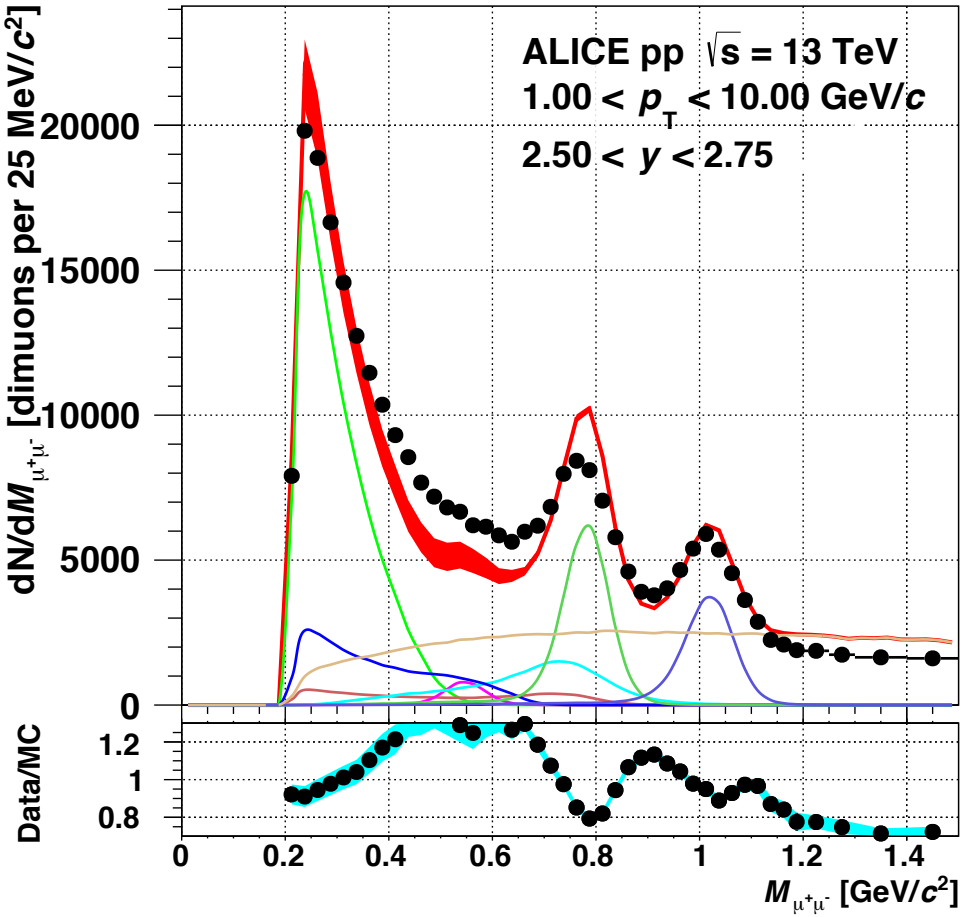
- **Contrary to the double-differential analyses, these tensions are not a main concern for the previous low-mass dimuon analyses in ALICE:**
  - The statistical precision of the available data never allowed for a precise description of the invariant mass spectrum as a function of rapidity
  - The signal extraction was typically limited to the ϕ process only, which is less sensitive to the MC/data tensions, concentrated towards 0.45-0.65 GeV/$c^2$
  - The robustness of the ϕ signal extraction was tested by replacing the "charm+beauty" description by an alternative description in terms of empirical analytical functions

# Which Alternative Approach?

- **The MC/data tensions appearing in the "charm+beauty" approach impose a revision of this simple assumption on the composition of the correlated continuum:**
  - Adding a continuum component from the correlated production of light hadrons? Ongoing work (see https://indico.cern.ch/event/685344/)
  - Evaluating the real fraction of correlated dimuons in the muon pairs originating from the open charm and open beauty process?
- **Alternative approaches for the description of the continuum:**
  - **Free combination of continuum templates** (for instance, charm and beauty)
  - **Empirical functions**
  - **Regularization of the cocktail-subtracted continuum.** NA60-inspired approach with some variations…details in https://indico.cern.ch/event/685344/

# Step1: Fit with Hadronic Cocktail + Charm + Beauty

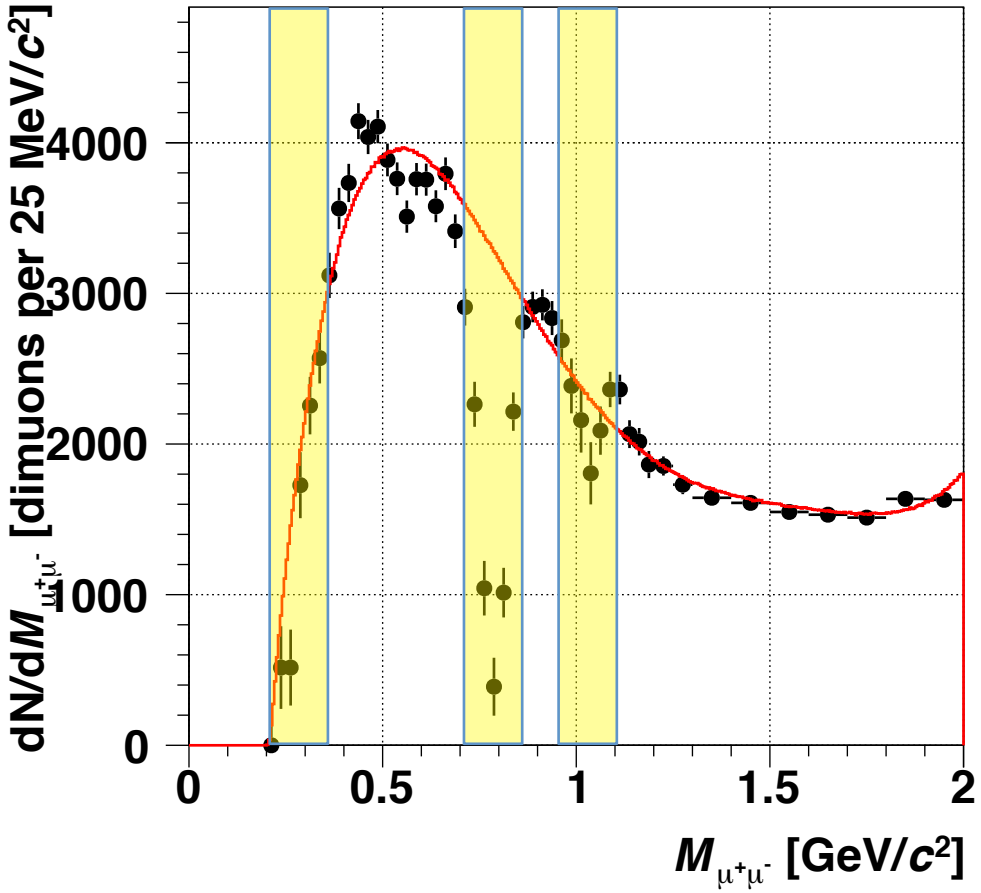
- **The procedure is shown for the ($p_T$-integrated) most problematic rapidity bin**




- **All parameters linking the minor processes of the cocktail to the major ones are fixed in this first fit** (relative BR of 2-body and Dalitz decays of η and ω mesons, η'/ϕ, ρ/ω and bb/cc ratios)

# Step2: Subtracting the Hadronic Cocktail and Fitting

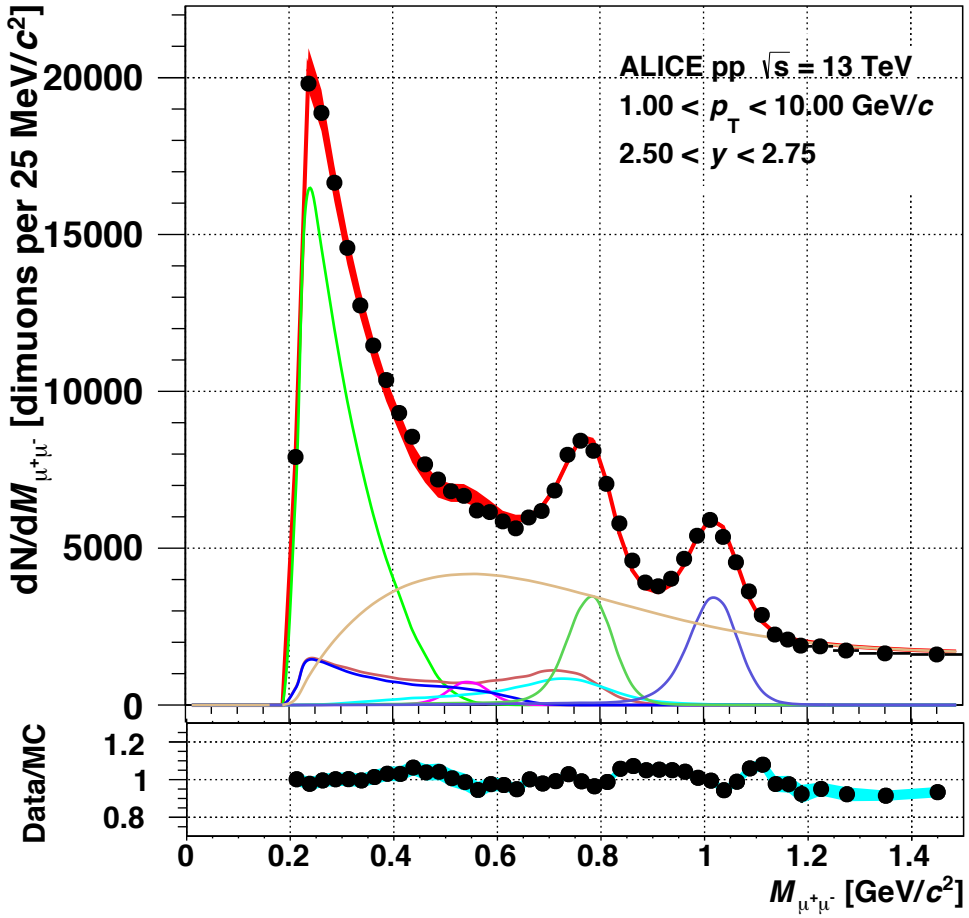
- **The procedure is shown for the ($p_T$-integrated) most problematic rapidity bin**




- **The hadronic cocktail is subtracted** using the normalizations established by the 1st fit on the data
- **The isolated continuum is fitted with a 5th order polynomial** excluding the regions corresponding to the main processes of the cocktail: 2-body decays of ω and ϕ, and Dalitz decay of η
- The isolated continuum is constrained by hand to go to zero at the threshold, to avoid the fit to diverge

# Step3: Fit with Hadronic Cocktail + Continuum

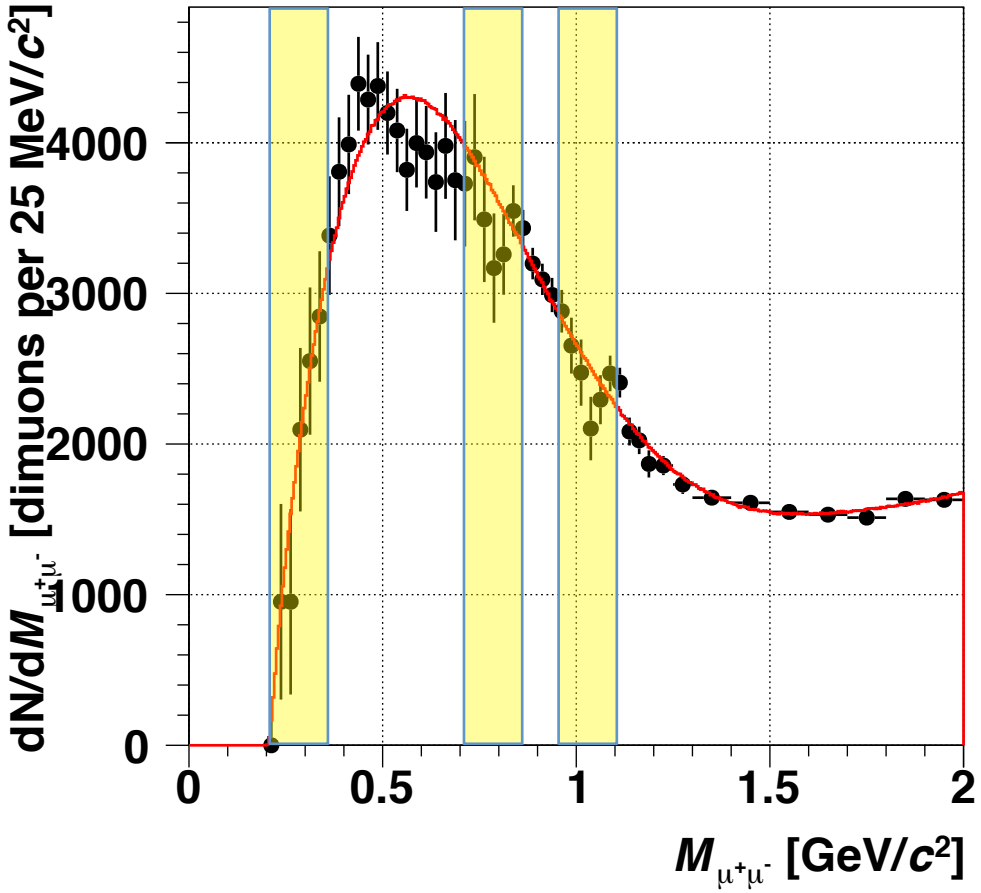
- **The procedure is shown for the ($p_T$-integrated) most problematic rapidity bin**




- The parameterized continuum obtained in Step2 is used to replace charm + beauty
- All parameters linking the minor processes of the cocktail to the major ones are fixed in this second fit, **apart from the η'/ϕ ratio (the less constrained one from data or models)**
- **The data description is already far** better than the one with the continuum described by charm + beauty

# Step4: Subtracting the Hadronic Cocktail and Fitting

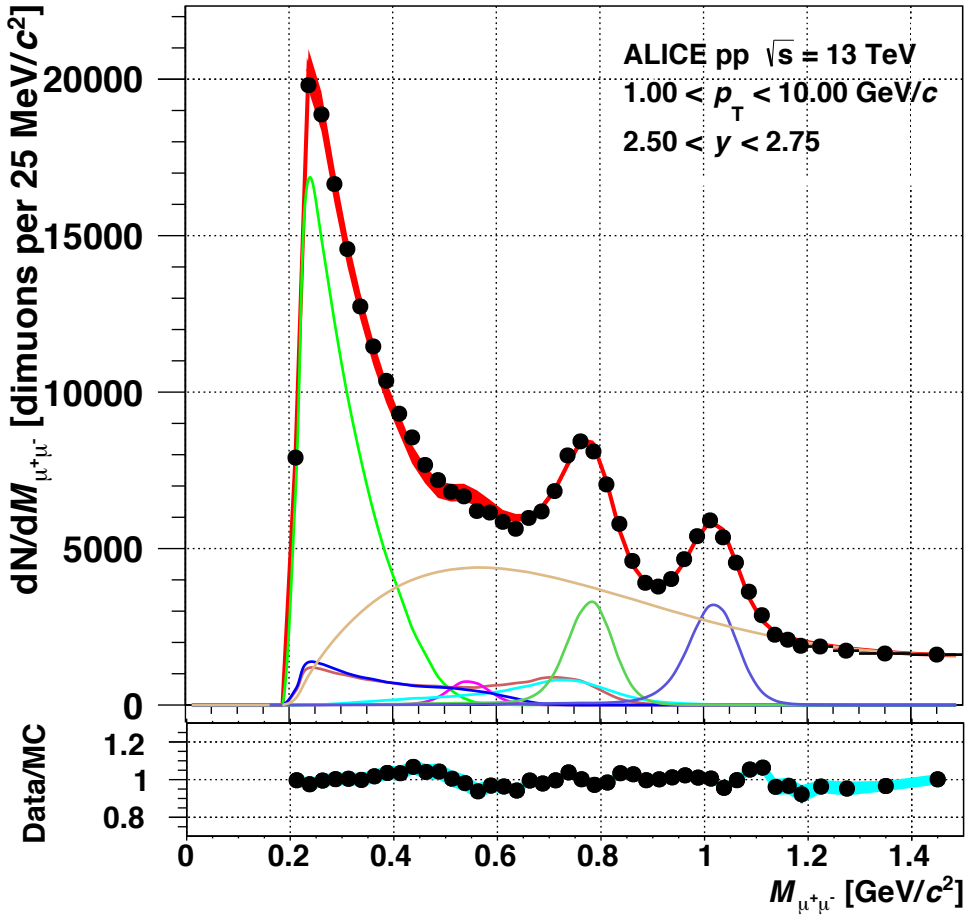
- **The procedure is shown for the ($p_T$-integrated) most problematic rapidity bin**




- **Same procedure as in Step2, but using the results of the 2nd fit on the data**
- The structure of the isolated continuum is smoother than in Step2, but some residual structures could survive in the mass regions of the 2-body decays of ω and ϕ

# Step5: Fit with Hadronic Cocktail + Continuum

- **The procedure is shown for the ($p_T$-integrated) most problematic rapidity bin**




- **Same as Step3**
- **The Data/MC ratio further improves:** flatter than in Step3

# The η'/ϕ Ratio

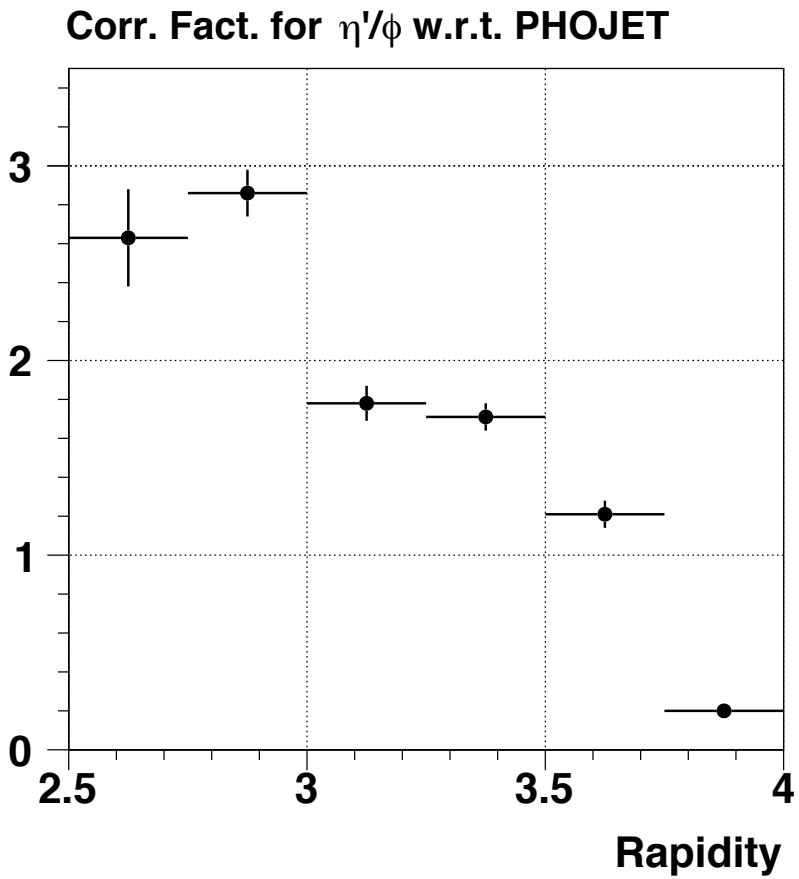
- **The normalization of the η' contribution** is an effective handle to improve the description of the data with the hadronic cocktail

- In the "standard" hadronic cocktail fits, **the η' is fixed to the ϕ meson one through the η'/ϕ ratio** taken from models (e.g. PHOJET)

- Leaving the **η' normalization free is only possible in large statistical samples:**
  - Not possible in each of the $p_T$-y interval considered in the analysis of the 13 TeV data
  - Possible on the $p_T$-integrated or y-integrated data samples
  - The rapidity dependence seems to be more relevant (due to the rapidity dependence of the data/MC tensions in the hadronic cocktail fits)

# The η'/ϕ Ratio

- The η'/ϕ ratio chosen by the data differs from the PHOJET prediction by a correction factor which is 1.65 ± 0.03 in $1 < p_T < 10$ GeV/c and $2.5 < y < 4$




- The rapidity dependence of this correction factor is studied considering the $p_T$-integrated samples
- These values are imposed in the fits over the data in the double-differential analysis **(it is the only difference w.r.t. the procedure described in the previous slides)**
- **When fixed, the** η'/ϕ will be varied by a reasonably large factor (at least 20%), in order to study the associated systematics