Low-mass dielectron measurements in pp, p-Pb and Pb-Pb collisions with ALICE at the LHC

Otón Vázquez Doce (TU-Munich)
on behalf of the ALICE Collaboration.

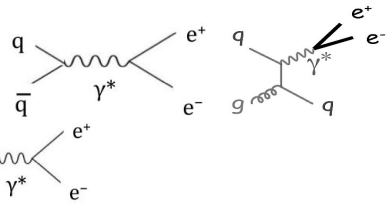
XIIIth Quark Confinement and the Hadron Spectrum, Maynooth, Ireland.
5th August, 2018.

Low mass dielectrons at the LHC

Electromagnetic radiation from the whole evolution of the collision, arriving to the detector practically unaffected

Dielectrons in heavy-ion collisions:

- Thermal radiation:
  - Quark-gluon plasma
  - Hadronic gas



- modification in the $c\bar{c}$, $b\bar{b}$ production
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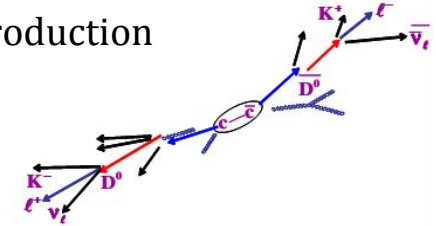
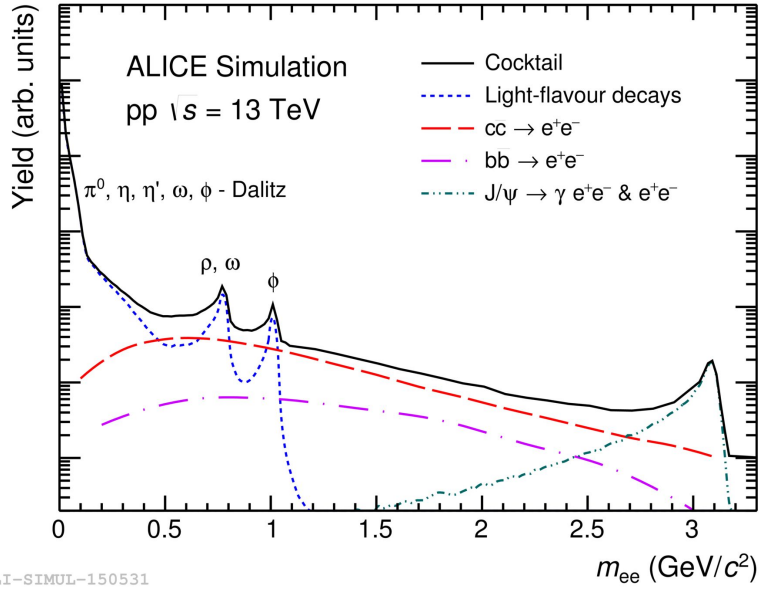


- In-medium modification of vector mesons:
  - ρ mass-shape modification, connected to the predicted chiral symmetry restoration



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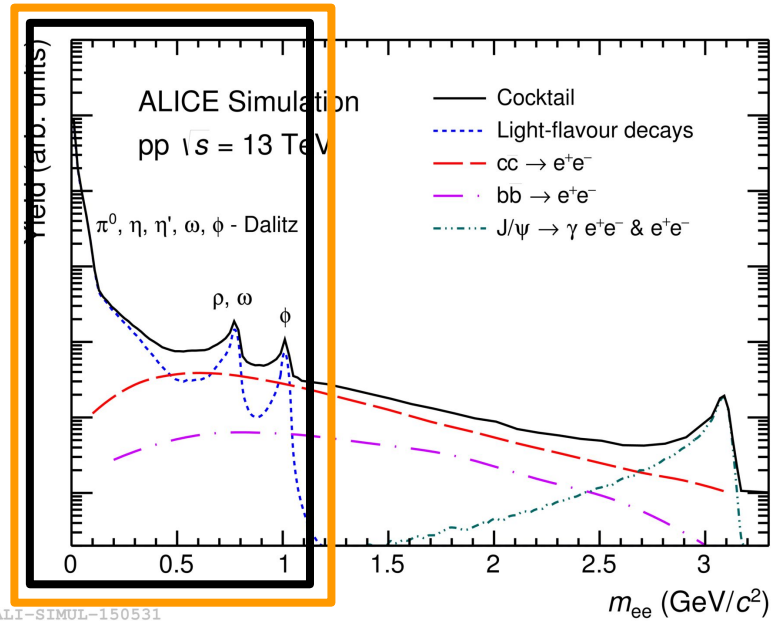

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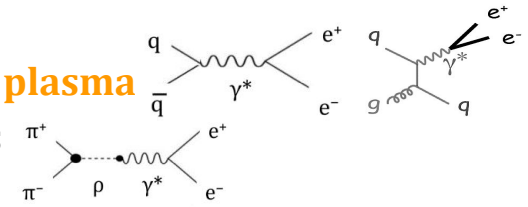

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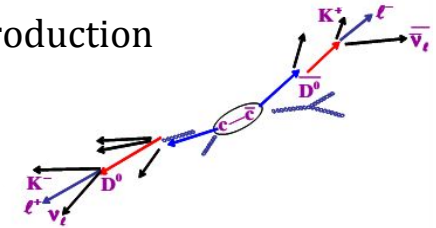

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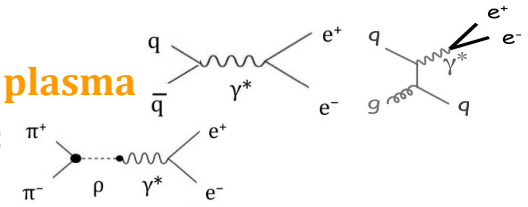

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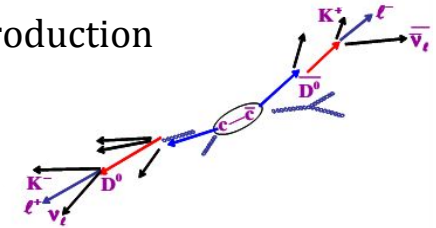

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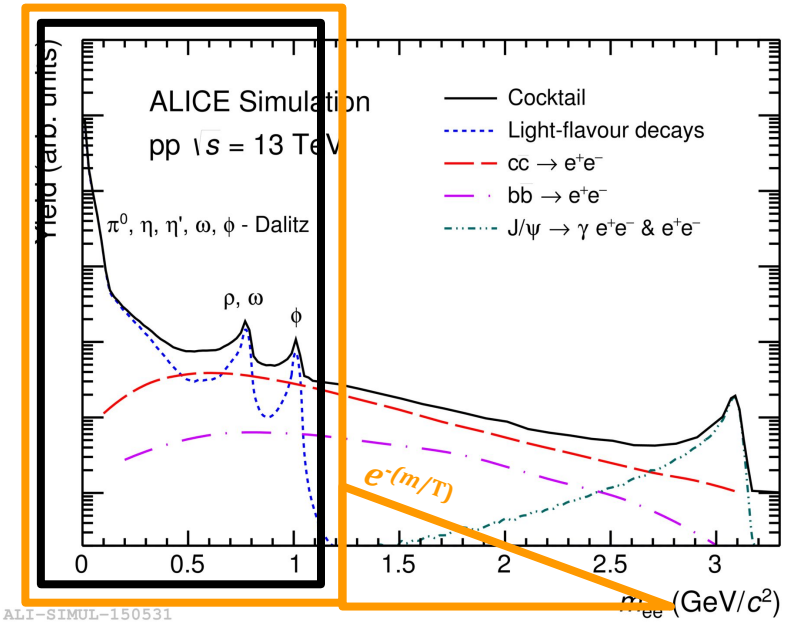

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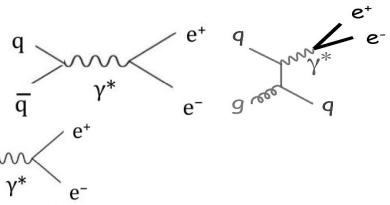

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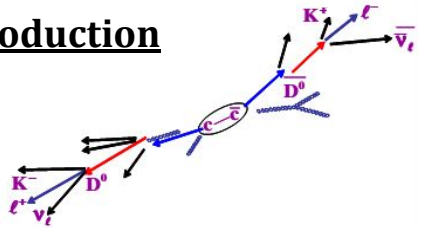

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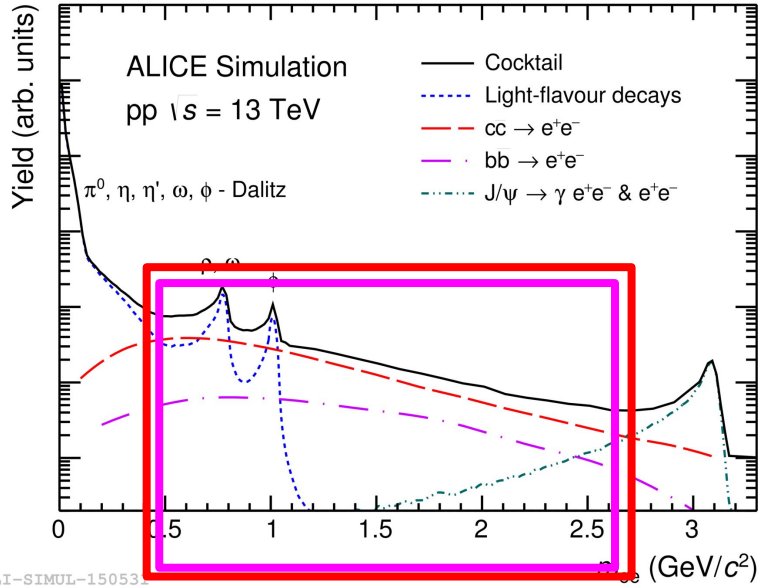

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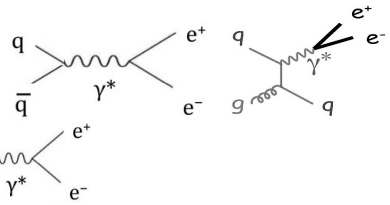

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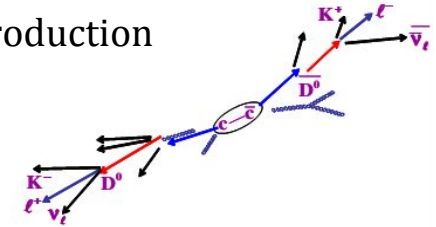

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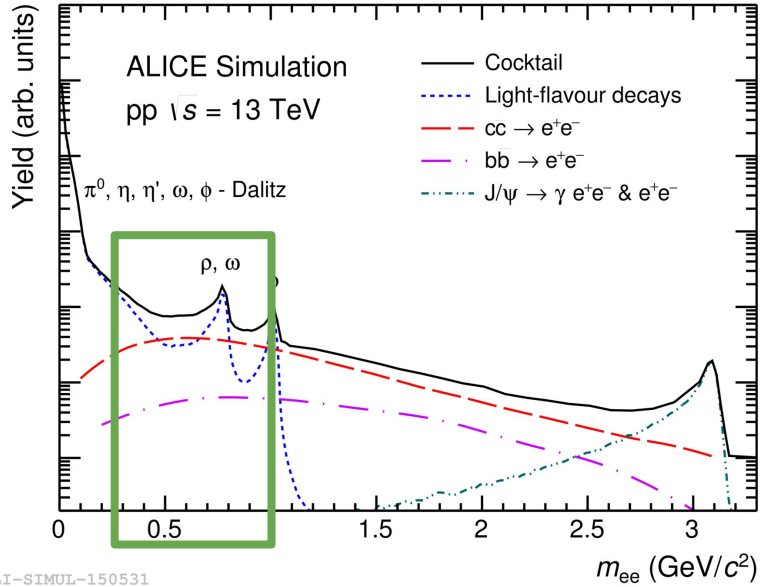

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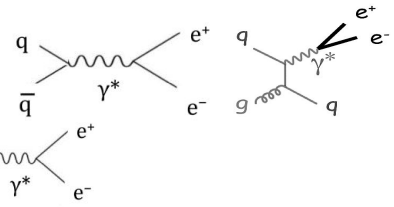

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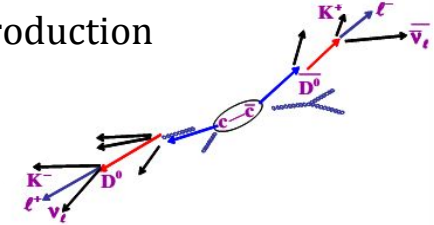

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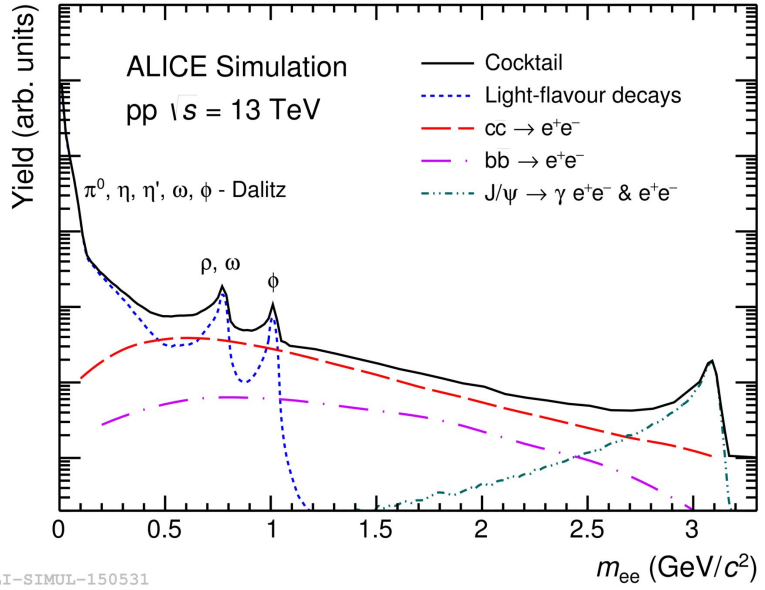
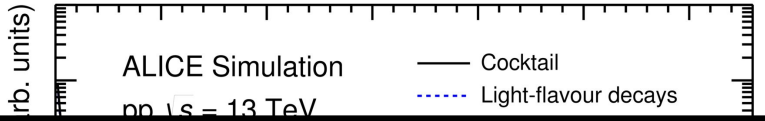


Dielectrons with ALICE:

- from low p_T at midrapidity:
  $|\eta|<0.8$
  $p_{T,e}$<0.2-0.4 GeV/c
- Background removed by subtracting the same-sign dielectron spectrum

Low mass dielectrons at the LHC



Dielectron analyses with ALICE Run-1 and Run-2 data

- **Pb-Pb** collisions $\sqrt{s_{NN}}$ = **2.76 TeV,** 5.02TeV
- p-Pb collisions $\sqrt{s_{NN}}$= 5.02 TeV
- **pp** collisions $\sqrt{s}$ = **7 TeV, 13 TeV**

First dielectron results at theLHC, recently submitted:

arXiv:1807.00923 [nucl-ex]

arXiv:1805.04391 [nucl-ex], arXiv:1805.04407 [nucl-ex]

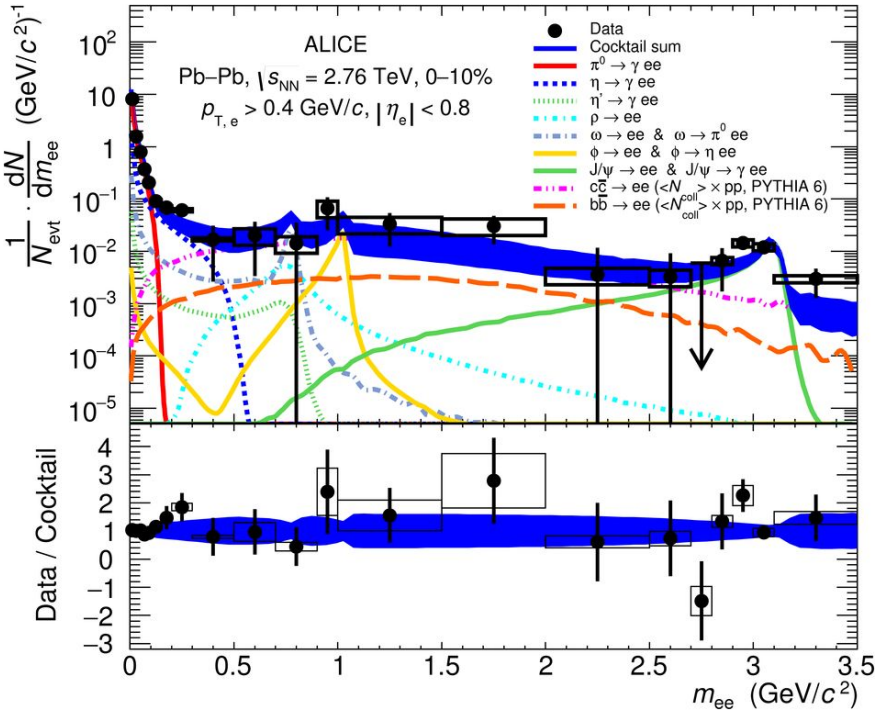
- chiral symmetry restoration effects
- ρ mass shape modification.

same-sign dielectron spectrum

Low mass dielectrons with ALICE: Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV

Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV

NEW: arXiv:1807.00923 [nucl-ex], submitted to PRC



- Most central events: **0-10% centrality class**
- Hadronic cocktail:
  - π^0 and η/π and $K^{\pm}/\pi^{\pm}$ ratios (for η) measured by ALICE, the rest from m_T scaling.
- Heavy flavour:
  - <u>method I</u>:

    PYTHIA normalized without medium effects to pp measurement $\times N_{coll}$

Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV

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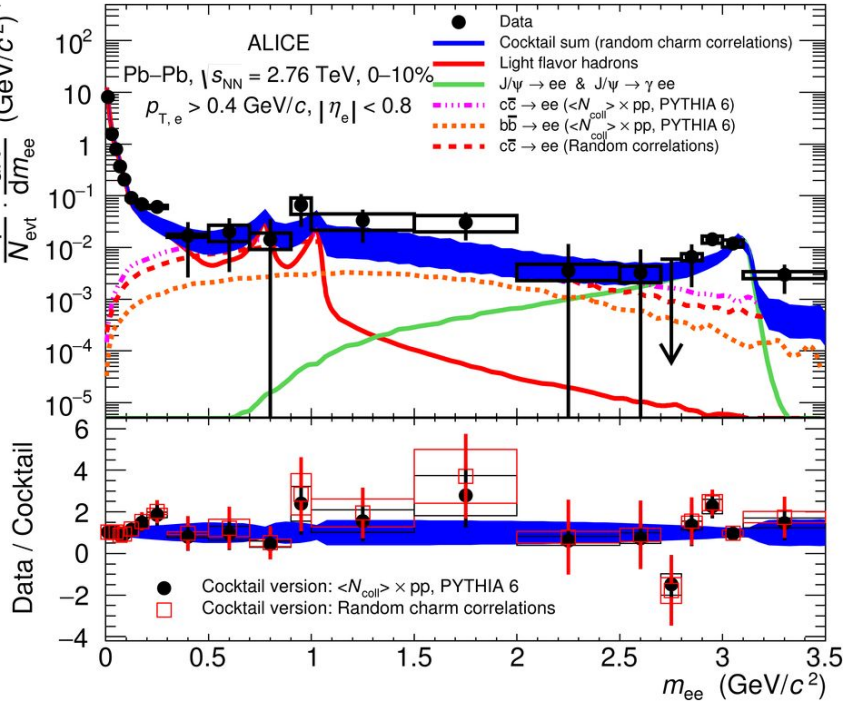

- Heavy flavour:
  - method I:
    PYTHIA normalized without medium effects to pp measurement $\times N_{coll}$
  - method II:
    randomization of dielectron pair
    -> reduce cc̄ yield by a factor 2 (acceptance)

- **Data compatible with cocktail** within uncertainties
  - Is there room for additional contributions?
  - Data/cocktail (excluding ρ) in 0.15-0.7 GeV/c^2:
    R = 1.40 ±0.28(stat.) ±0.08(syst.) ±0.27(cocktail)

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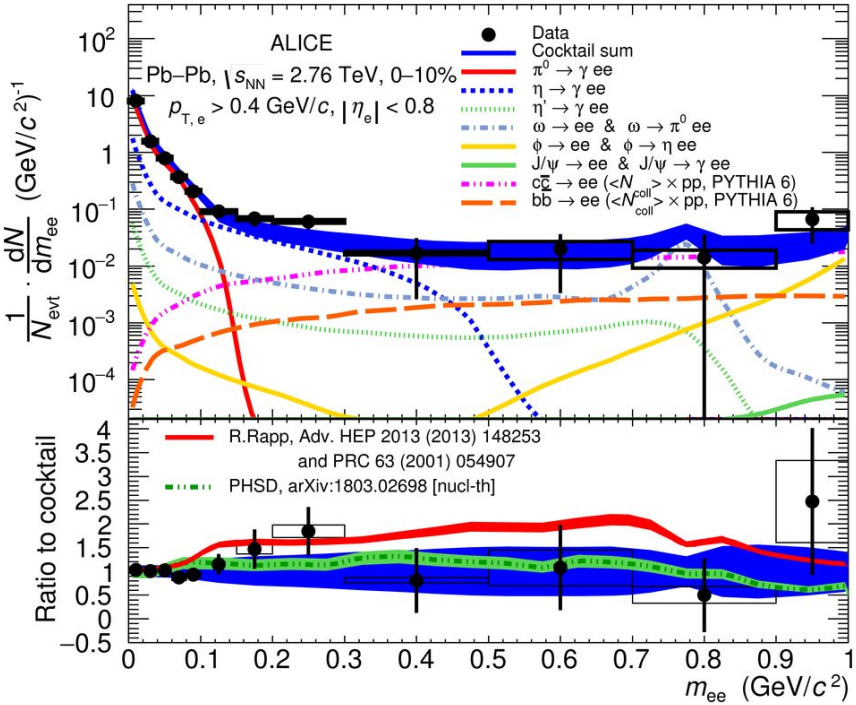

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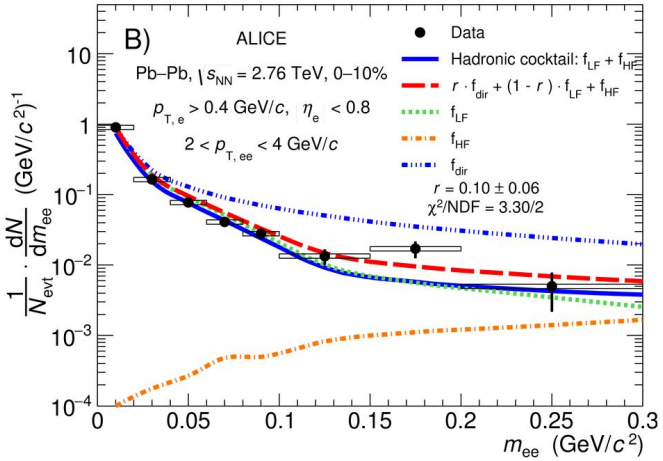
- **Expanding fireball model**
  R. Rapp, Adv. HEP 2013 (2013) 148253, R. Rapp, PRC 63 (2001) 054907.
- **Parton-Hadron-String Dynamics** transport approach
  T. Song et al., Phys. Rev. C 97, 064907.

Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV

NEW: arXiv:1807.00923 [nucl-ex], submitted to PRC

- Look for direct photons at $p_T > 1\text{GeV}/c$: fit **r (virtual direct γ/inclusive)** in the low-mass region 100-300 MeV/c^2

$$f(m_{ee}) = r \cdot f_{dir}(m_{ee}) + (1-r) \cdot f_{LF}(m_{ee}) + f_{HF}(m_{ee})$$



- Small internal conversion probability O(α_{em})
- suppress hadronic background by going to $m_{ee} > m_{\pi 0}$
- Direct virtual γ described by Kroll-Wada (QED), for $p_{T,ee} >> m_{ee} \sim 1/m_{ee}$

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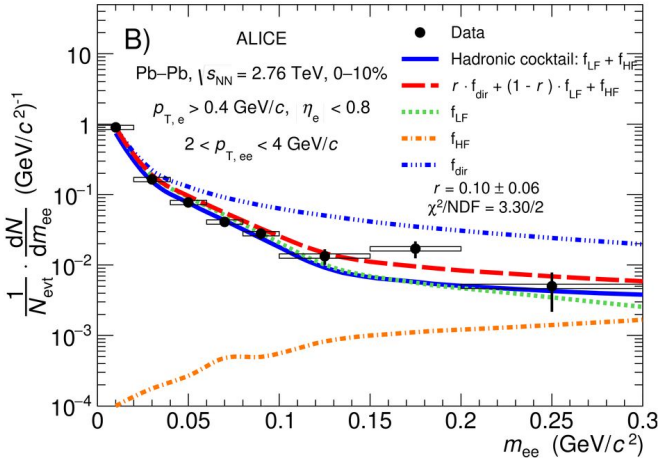

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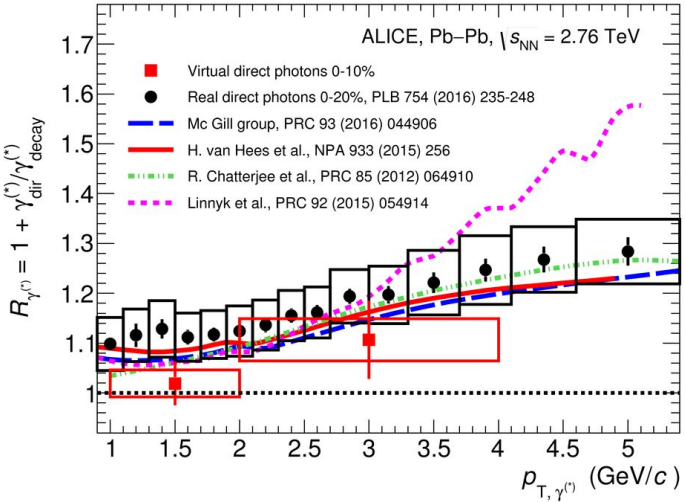
- virtual photon contribution extracted for two different p_T bins



- Compatible with ALICE and RHIC direct γ measurements **R~1.15**

ALICE Collaboration, Phys. Lett. B 754 (2016) 235-248
PHENIX Collaboration, Phys. Rev. Lett. 104 (2010) 132301

pp $\sqrt{s}$ = 7 TeV

arXiv:1805.04391[nucl-ex], submitted to JHEP

pp $\sqrt{s}$ = 13 TeV

arXiv:1805.04407 [nucl-ex], submitted to PLB

Study of dielectrons in pp collisions:

- baseline for HIC collisions measurement
- study of **heavy-flavour production** mechanisms and obtain production cross sections
- **virtual direct photons** to be compared with pQCD
- characteristics of the **high-multiplicity events**.

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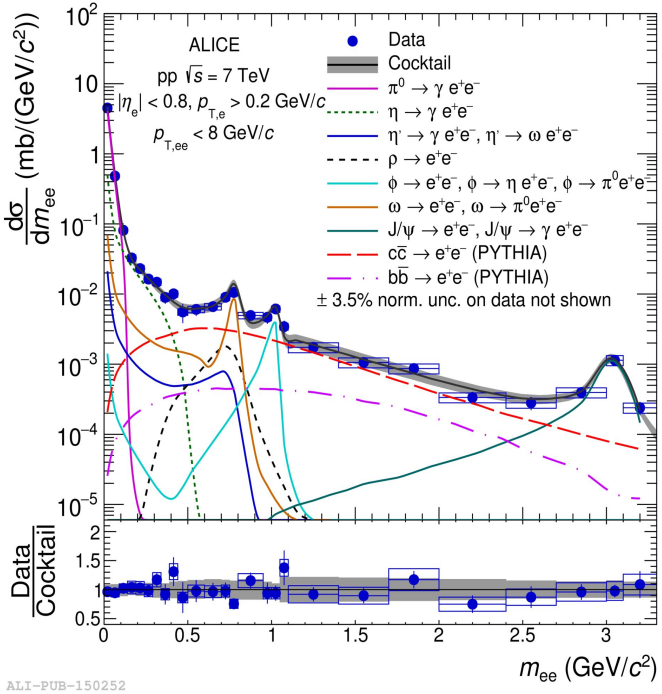

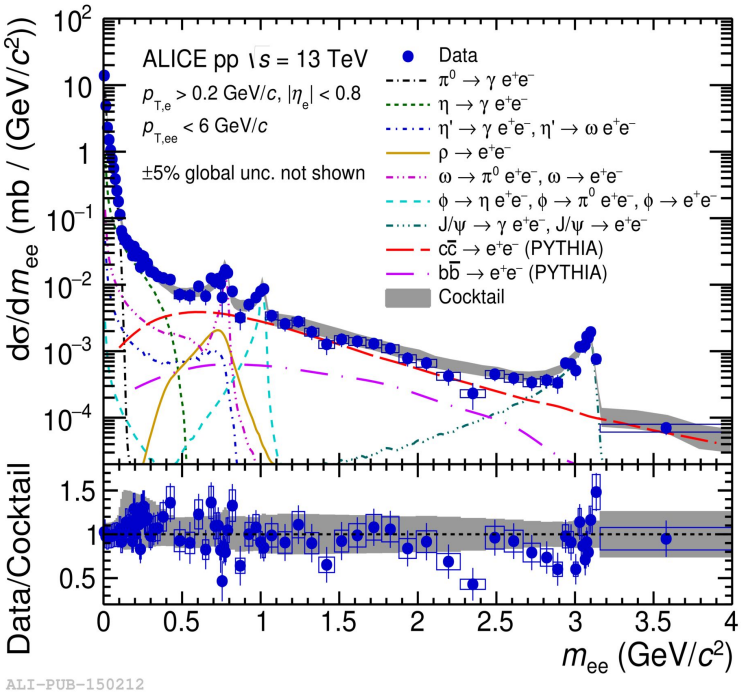

Data described by the cocktail within uncertainties

- measured $\pi^{\pm}$, η, ϕ and J/ψ (7 TeV), $\pi^{\pm}$ (13 TeV), $\omega/\pi^{\pm}$ and $\rho/\pi^{\pm}$ from PYTHIA8 Monash.
- $c\bar{c}$, $b\bar{b}$: PYTHIA6 Perugia2011 (shape) & measured cross sections at pp $\sqrt{s}$ = 7 TeV (D, B mesons)

ALICE Collaboration, Eur. Phys. J. C77 (2017) 550, Eur. Phys. J. C71 (2011) 1645

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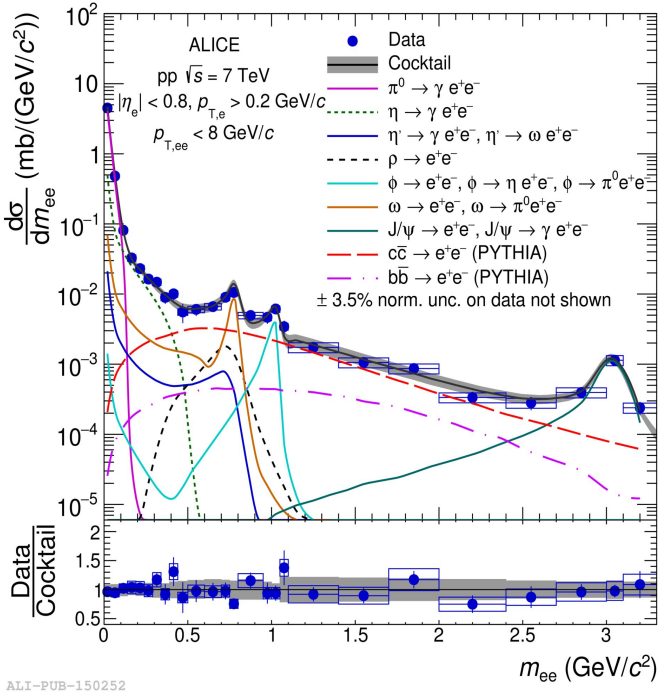

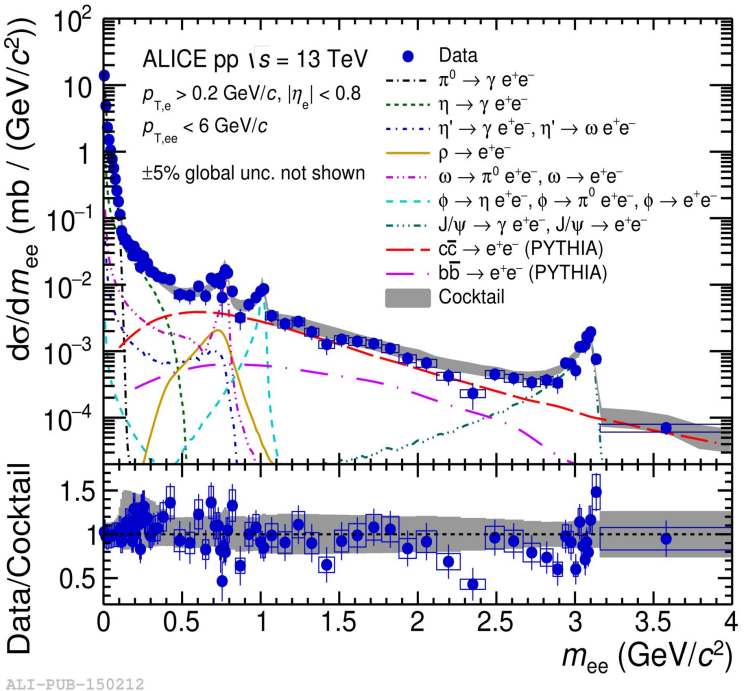

Extraction of **HF cross sections** in a method sensitive to the pair correlation predicted by different generators.

- Fit 2D m_{ee}-$p_{T,ee}$
- For pp $\sqrt{s}$ = 7 TeV additional fit with DCA

pp $\sqrt{s}$ = 7 TeV

arXiv:1805.04391[nucl-ex], submitted to JHEP

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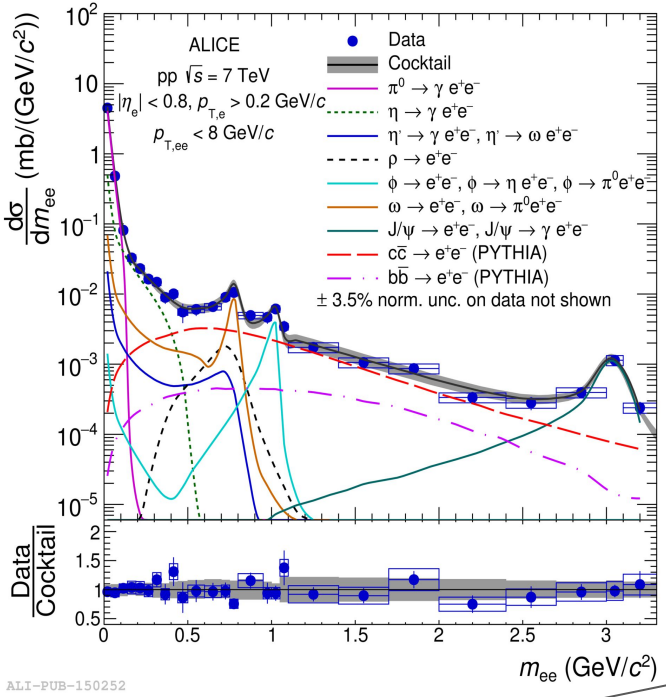

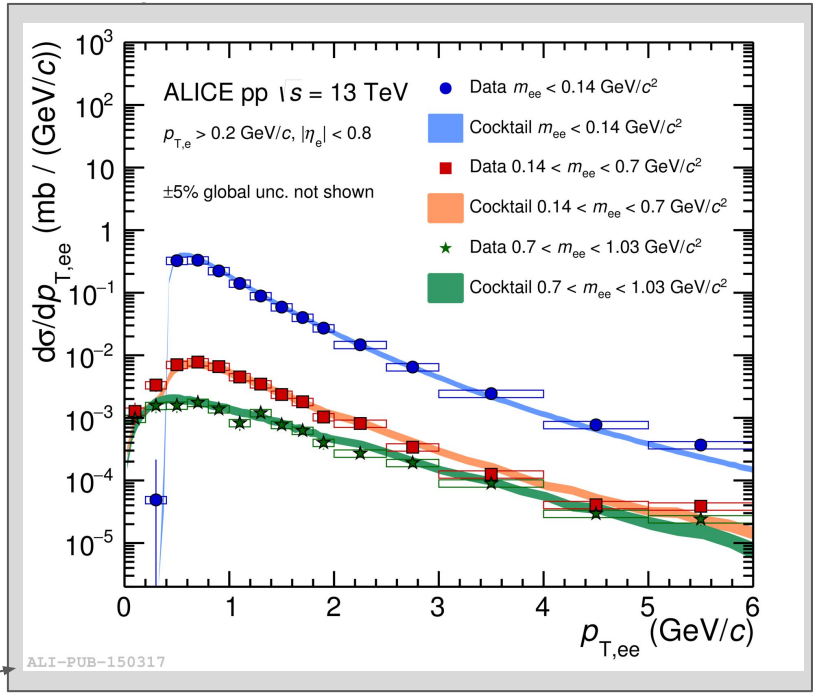

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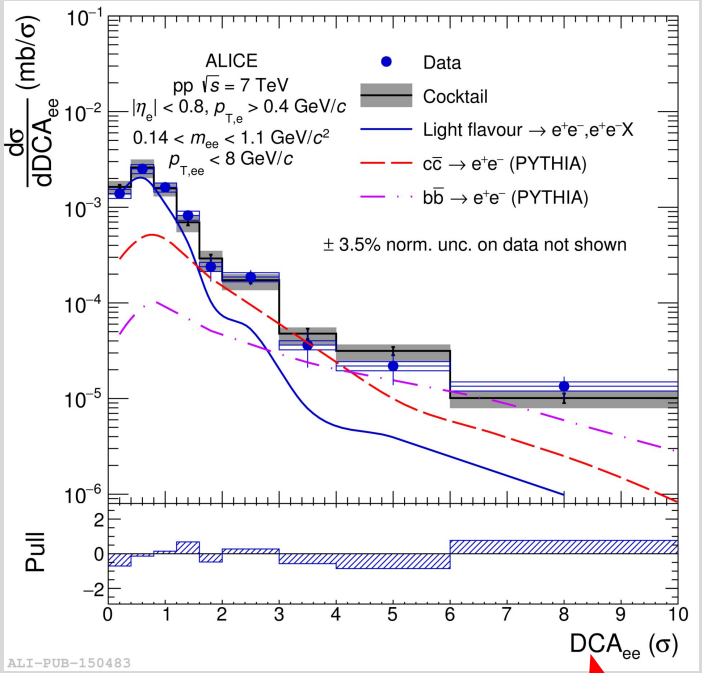
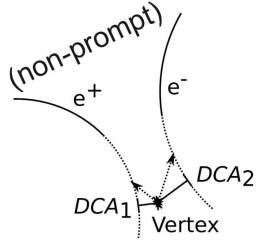


DCA = Distance-Of-Closest-Approach to primary vertex of $e^{\pm}$

$$DCA_{ee} = \sqrt{\frac{(DCA_{xy,1}/\sigma_{xy,1})^2 + (DCA_{xy,2}/\sigma_{xy,2})^2}{2}}$$



- Can **separate prompt** and **non-prompt (HF) sources:** D mesons cτ ~ 150 μm, B mesons cτ ~ 470 μm

- better DCA_{ee} resolution in Run-3:
  →will be able to extract prompt thermal signal above $m_{ee} \sim 1 GeV/c^2$

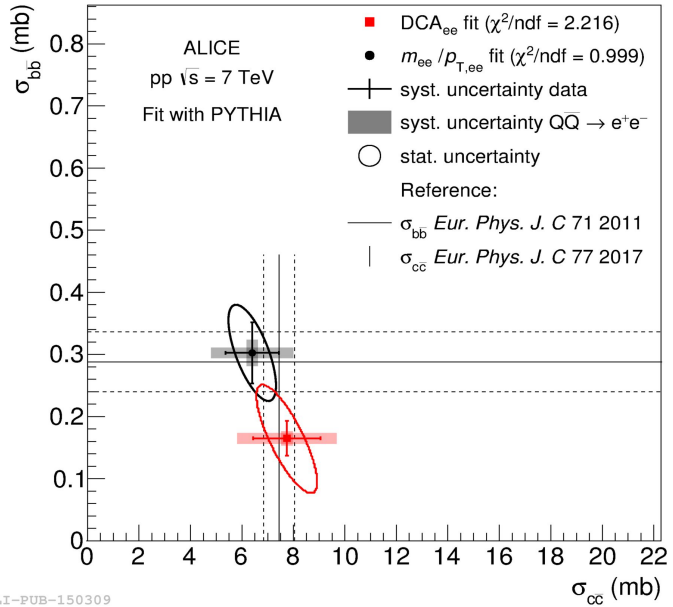
Extraction of **HF cross sections** in a method sensitive to the pair correlation predicted by different generators.

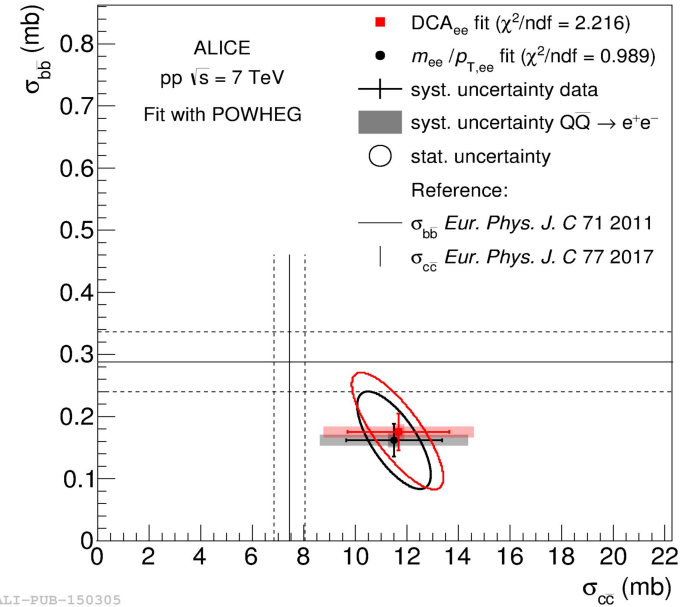
- Fit 2D m_{ee}-$p_{T,ee}$
- For pp $\sqrt{s}$ = 7 TeV additional fit with **DCA**

pp $\sqrt{s}$ = 7 TeV

arXiv:1805.04391[nucl-ex], submitted to JHEP

- **2D m_{ee}-$p_{T,ee}$ and DCA** fits agree, compatible with previous independent measurements of single HF hadrons
- **Model dependence** is large (data and BR uncertainties are fully correlated between generators)
  - PYTHIA: leading order with parton shower
  - POWHEG: NLO, PYTHIA for parton shower



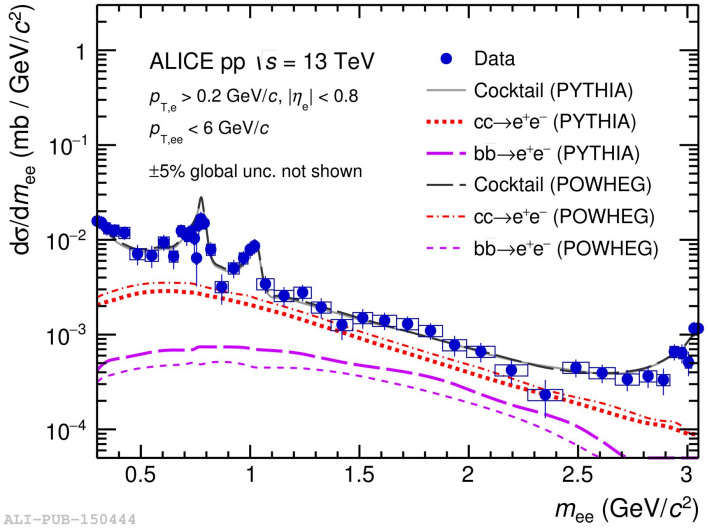


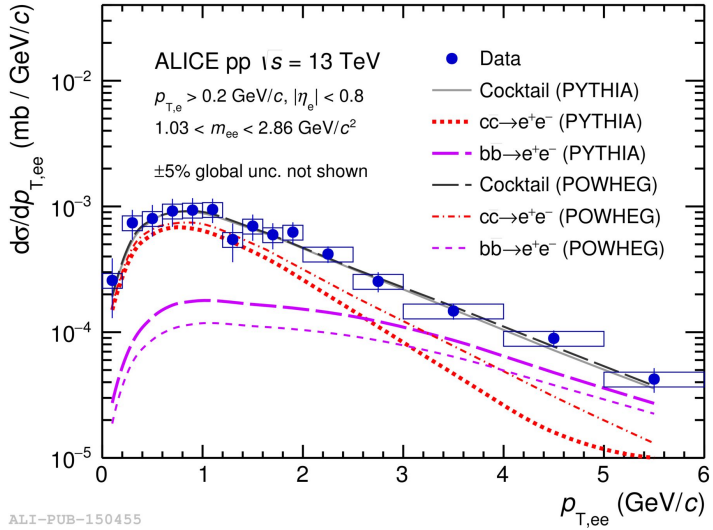
pp $\sqrt{s}$ = 13 TeV

arXiv:1805.04407 [nucl-ex], submitted to PLB

- Similar model dependence is observed as for results in pp at $\sqrt{s}$ = 7 TeV
  (correlated BR uncertanties ~22% not shown)

	PYTHIA	POWHEG
$d\sigma_{c\bar{c}}/dy\|_{y=0}$	$974 \pm 138\,(stat.) \pm 140\,(syst.)$ µb	$1417 \pm 184\,(stat.) \pm 204\,(syst.)$ µb
$d\sigma_{b\bar{b}}/dy\|_{y=0}$	$79 \pm 14\,(stat.) \pm 11\,(syst.)$ µb	$48 \pm 14\,(stat.) \pm 7\,(syst.)$ µb





pp $\sqrt{s}$ = 13 TeV. High multiplicity.

arXiv:1805.04407 [nucl-ex], submitted to PLB

ALICE studies on **pp High-Multiplicity events:** Similar features as in heavy-ion collisions observed:

- Long-range angular correlations
- Enhanced strangeness production

Search for modifications dielectron spectrum

- Possible production/destruction of ρ mesons
- Multiple Parton Interactions
- Possible thermal radiation

pp $\sqrt{s}$ = 13 TeV. High multiplicity.

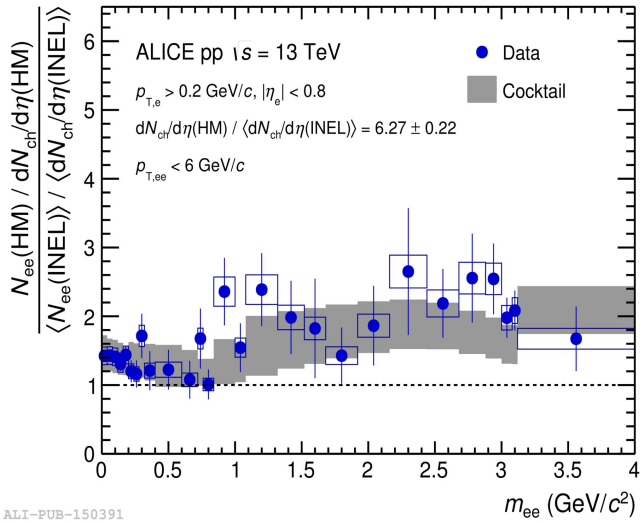
arXiv:1805.04407 [nucl-ex], submitted to PLB

Compare with expectation from known modifications scaled by N_{ch}

$$\frac{N_{ee}(HM)}{\langle N_{ee}(INEL)\rangle} \times \frac{\langle dN_{ch}/d\eta(INEL)\rangle}{dN_{ch}/d\eta(HM)}$$

Cocktail includes:

- Hardening of **charged-hadrons p_T spectrum**
- **D meson** and **J/ψ** more-than-linear **enhancement vs mult.**
- same enhancement for beauty



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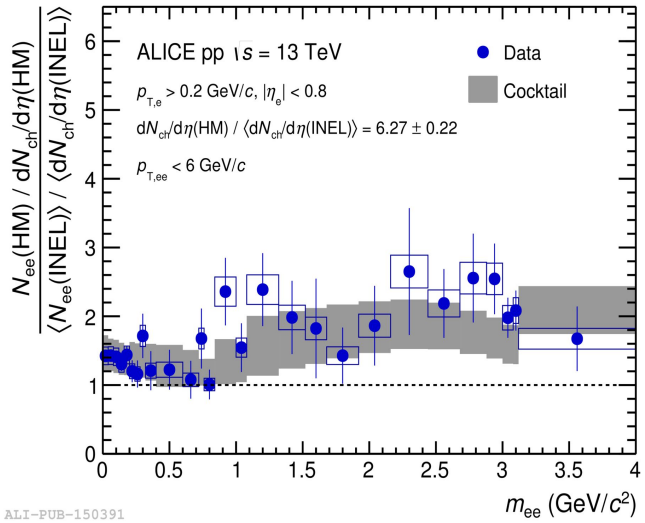
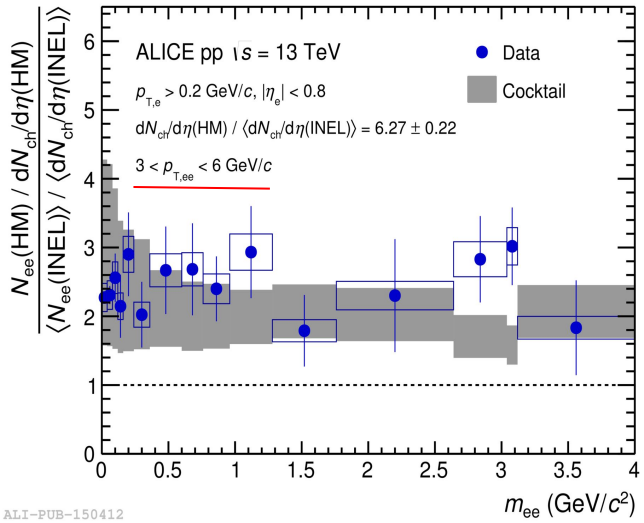




→No additional deviation from already known effects.

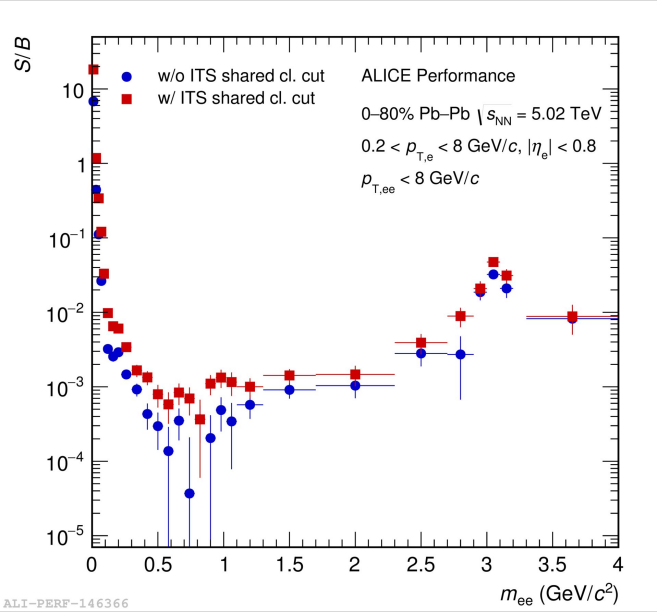
→**p_T dependence well described.**

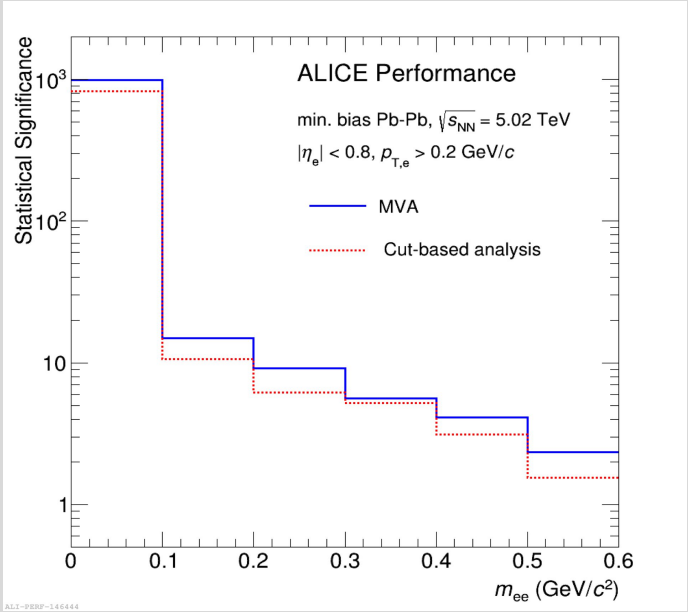
Current analyses

Current analyses

Pb-Pb $\sqrt{s_{NN}}$= 5.02 TeV

- **Acceptance gain**! $p_{T,e} > 0.4$ GeV/c $\rightarrow p_{T,e} > 0.2$ GeV/c
- background rejection improved, 2 methods:
  - based in number of ITS shared clusters
  - **MVA approach `**

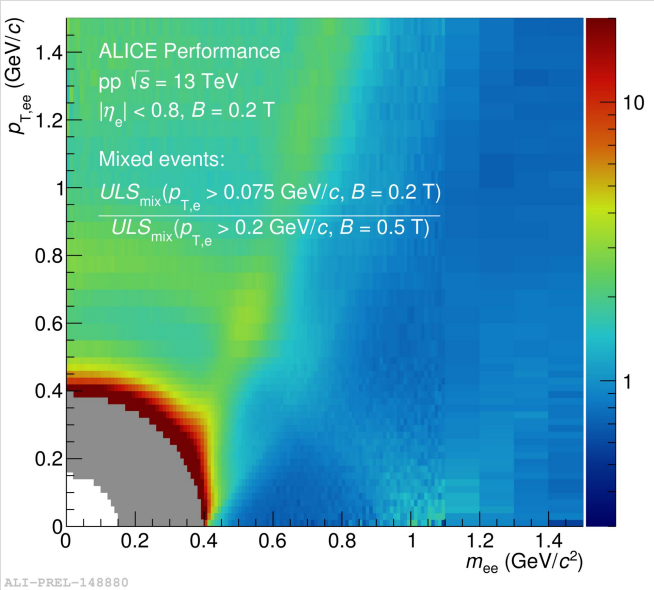


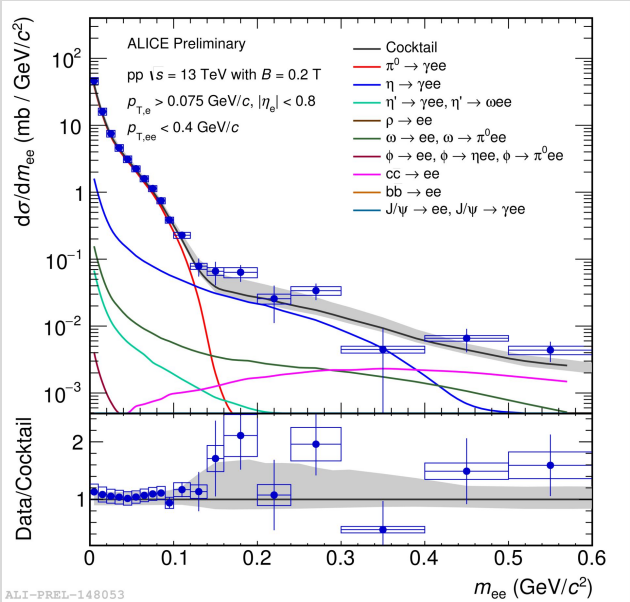


Current analyses

pp $\sqrt{s}$=13 TeV, Low B: from 2016-17 exploratory runs. **Much more available!**

- Access to soft dielectron production: low $p_{T,ee}$ - low m_{ee}
- acceptance from single electron $p_{T,e}$ 0.075 GeV/c





- AFS: Excess of dielectrons at the ISR avobe η region at very low $p_{T,ee}$

Summary and future

pp collisions

- Measurement of **heavy-flavour production cross-sections** and direct photons
  - Dileptons should play an important role in the understanding of low p_T charm production
  - Can separate prompt and non-prompt sources with DCA
- First low-mass dielectron analysis of **high-multiplicity events**

Pb-Pb collisions

- Compatible with hadronic cocktail with room for additional contributions
- ALICE Run3:
  - **detector upgrade** (ITS and TPC): higher rate and background rejection power
  - precise studies on spectral shape of vector mesons and access to T_{init}

In this talk

Collision system	N of events, $\mathcal{L}_{int}$	Trigger
pp at $\sqrt{s}$ = 7 TeV	~ 370 M ($\mathcal{L}_{int}$ ~ 6 nb^{-1})	min. bias
pp at $\sqrt{s}$ = 13 TeV	~ 440 M ($\mathcal{L}_{int}$ ~ 7.8 nb^{-1}) ~ 80 M ($\mathcal{L}_{int}$ ~ 2.7 pb^{-1}) ~ 150 M ($\mathcal{L}_{int}$ ~ 2.7 nb^{-1})	min. bias high mult. (0-0.05% V0M) min. bias (low B-field)
Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV	~ 20 M ($\mathcal{L}_{int}$ ~ 23 μb^{-1})	0-10% centrality

Hadronic cocktail inputs

Pb-Pb 2.76 TeV

Measured π^0 spectrum, η/π and $K^{\pm}/\pi^{\pm}$ ratios for η [1-3]

m_T scaling for other hadrons

pp 7 TeV

measured $\pi^{\pm}$ (for π^0), η, φ and J/ψ [2,4-6]

m_T scaling for η', $\omega/\pi^{\pm}$ and $\rho/\pi^{\pm}$ from PYTHIA 8 Monash 2013 tune (describes well pp data at $\sqrt{s}$ = 2.76 and 7 TeV)

HF: PYTHIA 6 Perugia 2011 tune scaled to measured cross sections [7,8]: σ_{cc} = 7.44 ± 0.60 mb, σ_{bb} = 288 ± 48 μb

pp 13 TeV

π^0 : measured $h^{\pm}$ in pp at $\sqrt{s}$ = 13 TeV and $\pi^{\pm}/h^{\pm}$ at $\sqrt{s}$ = 7 TeV [9,10]

η: measured η/π^0 ratio in pp at $\sqrt{s}$ = 7 TeV

$\omega/\pi^{\pm}$ and $\rho/\pi^{\pm}$ from PYTHIA 8 Monash 2013 tune

η', φ: m_T scaling

J/ψ: PYTHIA 6 scaled to $d\sigma_{J/\psi}/dy|_{y=0}$ extrapolated with FONLL from $\sqrt{s}$ = 7 TeV [11]

cc and bb: PYTHIA 6 Perugia 2011 tune scaled to the extrapolated FONLL cross sections from the $\sqrt{s}$ = 7 TeV measurement:

$d\sigma_{cc}/dy|_{y=0} = 1296\ ^{+172}_{-162}$ μb, $d\sigma/dy|_{y=0} = 68^{+15}_{-16}$ μb

[1] ALICE Collaboration, Eur. Phys. J. C74, 10, 3108 (2014)
[2] ALICE Collaboration, Phys. Lett. B717, 162 (2012)
[3] ALICE Collaboration, Phys. Lett. B736, 196 (2014)
[4] ALICE Collaboration, Eur. Phys. J. C. 72 (2183) 2012
[5] ALICE Collaboration, Phys. Lett. B 704 (442) 2011
[6] ALICE Collaboration, Phys. Lett. B 718 (692) 2012
[7] ALICE Collaboration, Eur. Phys. J. C77 (2017) 550
[8] ALICE Collaboration, Eur. Phys. J. C71 (2011) 1645
[9] ALICE Collaboration: Phys. Lett. B 753 (2016) 319,
[10] ALICE Collaboration: Eur. Phys. J. C 73 (2013) 2662,
[11] ALICE Collaboration: JHEP 11 (2012) 065

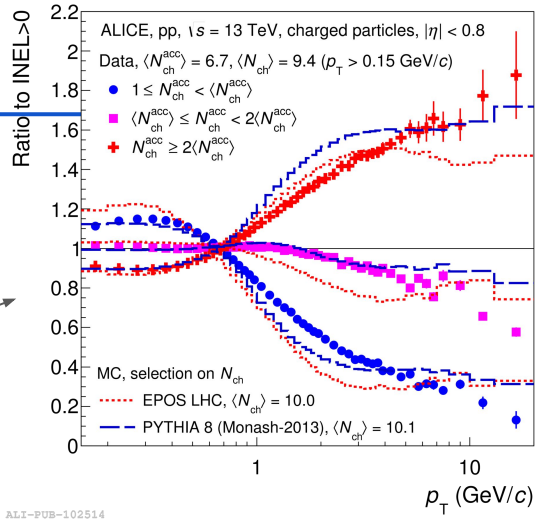
pp $\sqrt{s}$ = 13 TeV. High multiplicity.

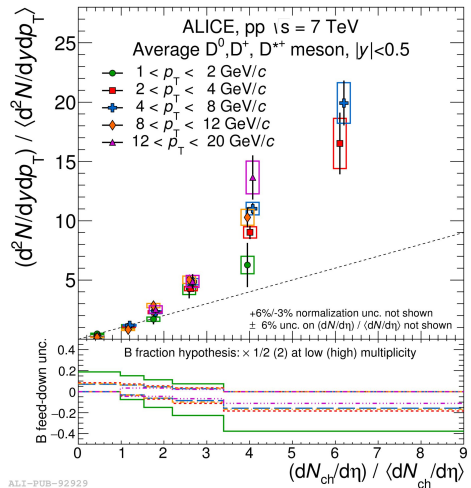
arXiv:1805.04407 [nucl-ex], submitted to PLB

$\mathbf{dN_{ch}/d\eta(HM)\ /\langle dN_{ch}/d\eta(INEL)\rangle = 6.27 \pm 0.22}$ (measured at $\eta \sim 0$)

Input for high-multiplicity cocktail calculations:

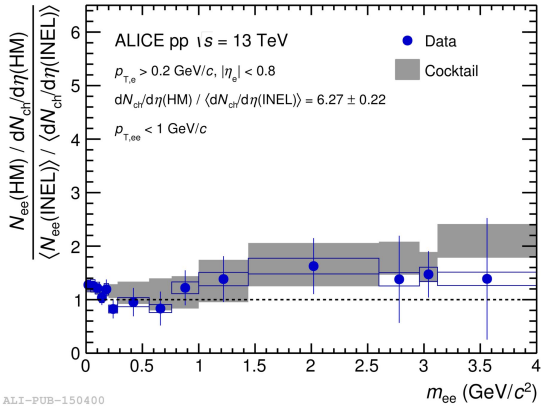
- LF: modification of p_T spectrum of charged particles in events with higher multiplicities [1]
- Assume same scaling with multiplicity for all LF hadrons at the same m_T
- HF: multiplicity dependent production of D meson [2] and inclusive J/ψ [3] in pp at $\sqrt{s}$ = 7 TeV
- Same enhancement for beauty is assumed as for open charm

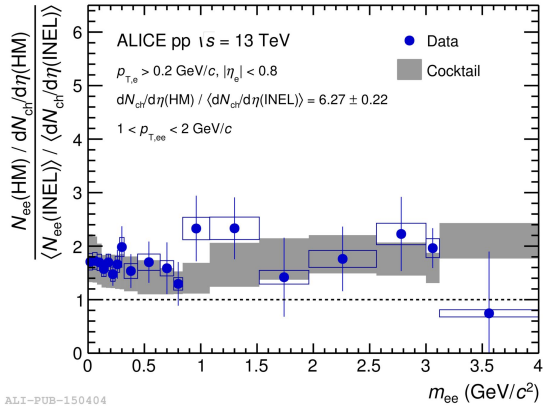


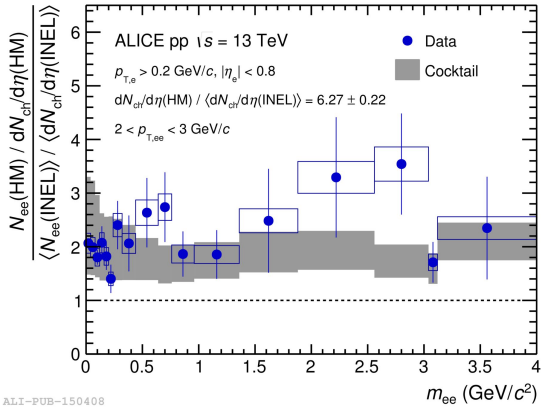


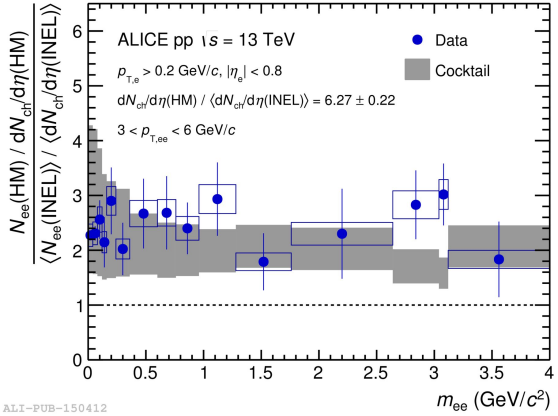
[1] ALICE Collaboration, Phys. Lett. B 753, 319 (2016)
[2] ALICE Collaboration, JHEP 09, 148 (2015)
[3] ALICE Collaboration, Phys. Lett. B 712 (2012) 165

pp $\sqrt{s}$ = 13 TeV. High multiplicity.









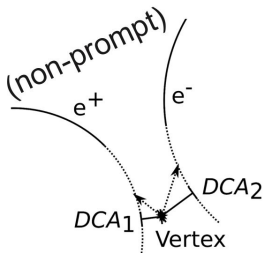
Compare with expectation from known modifications scaled by N_{ch}

$$\frac{N_{ee}(HM)}{\langle N_{ee}(INEL)\rangle} \times \frac{\langle dN_{ch}/d\eta(INEL)\rangle}{dN_{ch}/d\eta(HM)}$$

→No additional deviation from already known effects. p_T dependence well described

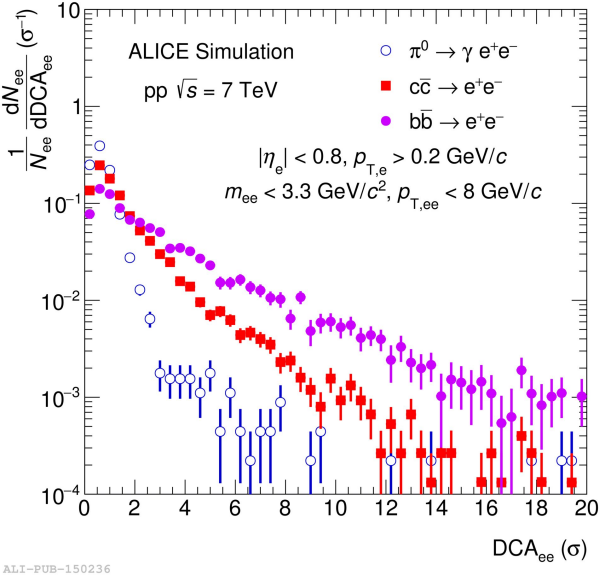
pp $\sqrt{s}$ = 7 TeV. DCA

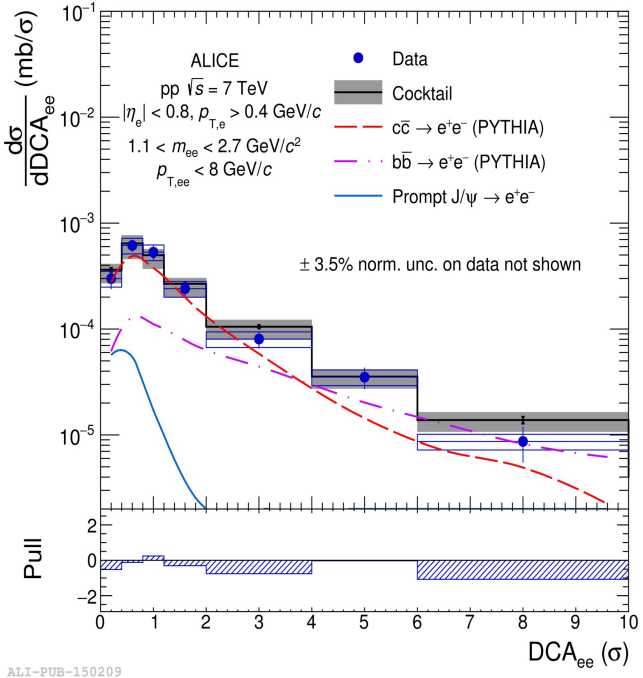
arXiv:1805.04391[nucl-ex], submitted to JHEP

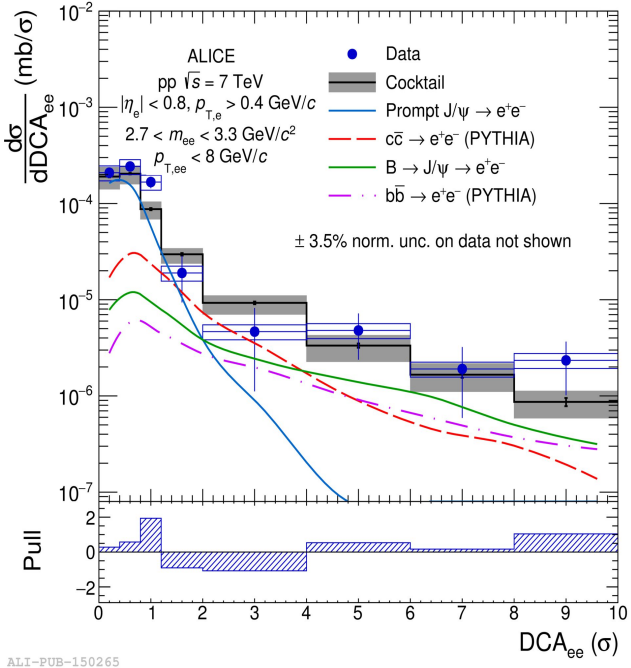


DCA = Distance-Of-Closest-Approach to primary vertex of electrons

- Obtain DCA_{ee} templates from MC, normalise to cocktail and compare with data
- Good description of data in all observed mass regions







pp $\sqrt{s}$ = 7 TeV

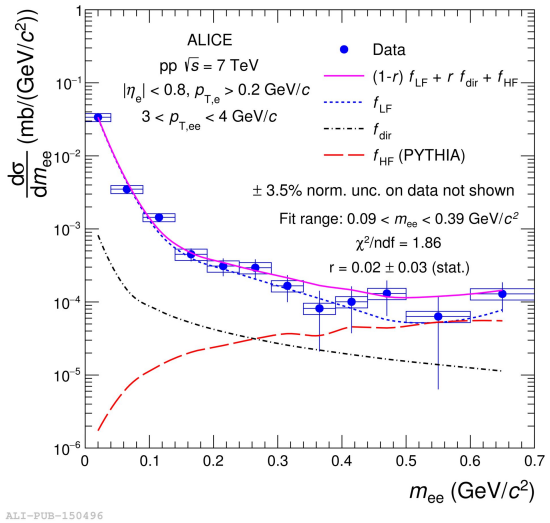
arXiv:1805.04391[nucl-ex], submitted to JHEP

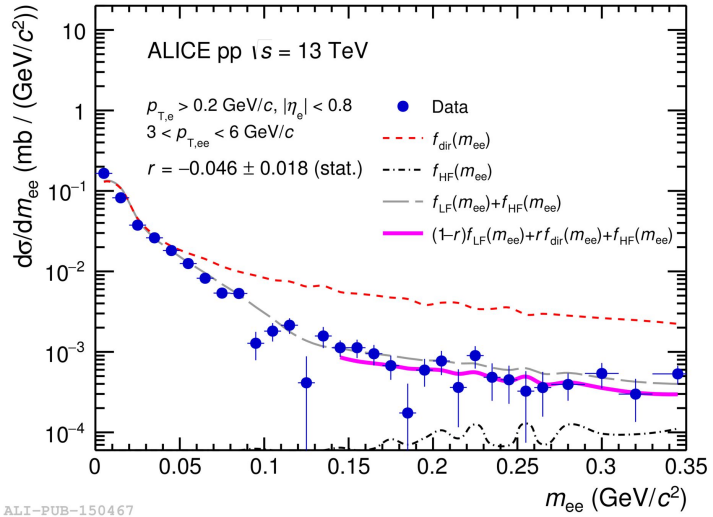
pp $\sqrt{s}$ = 13 TeV

arXiv:1805.04407 [nucl-ex], submitted to PLB

Direct virtual photons at $p_T > 1\text{GeV}/c$: fit **r** (virtual direct γ/inclusive) in the low mass region 100-300 MeV/c^2

- No significant direct photon contribution is observed
- Results in inelastic events are consistent with pQCD NLO calculations
- Upper limits at 90% C.L. are extracted with the Feldman-Cousins method





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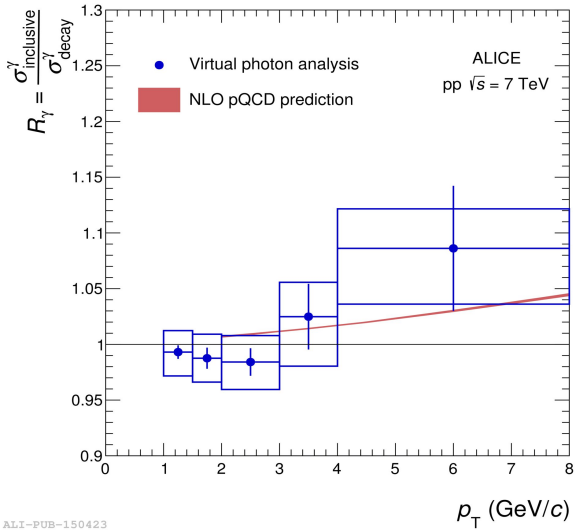
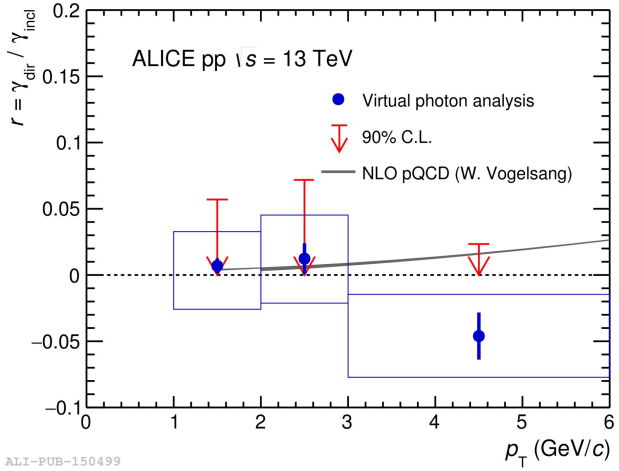
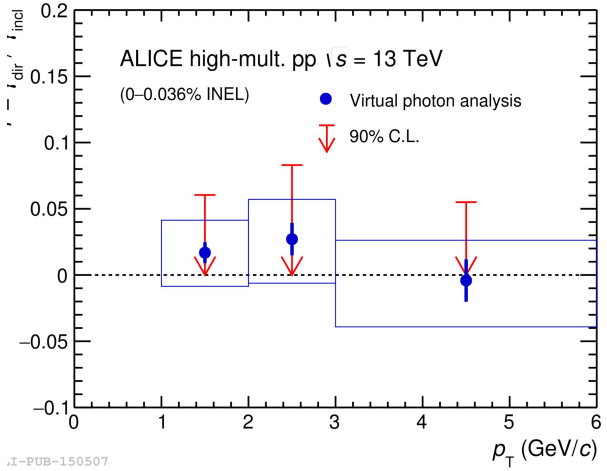






ALICE experiment

ITS (Inner Tracking System)

- Primary vertex position
- Tracking
- PID (via dE/dx)

TPC (Time Projection Chamber)

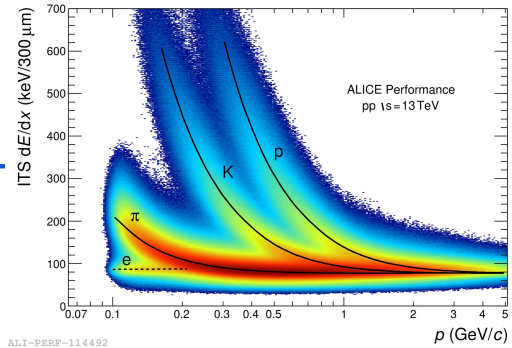
- Tracking
- PID (via dE/dx)

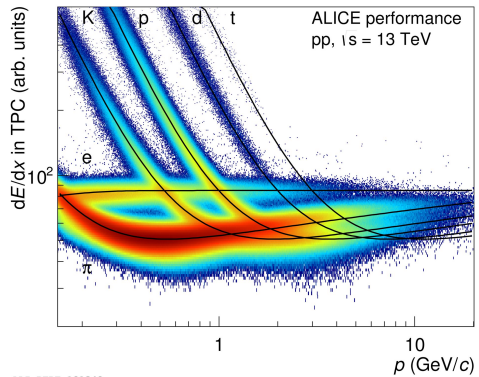
TOF (Time Of Flight)

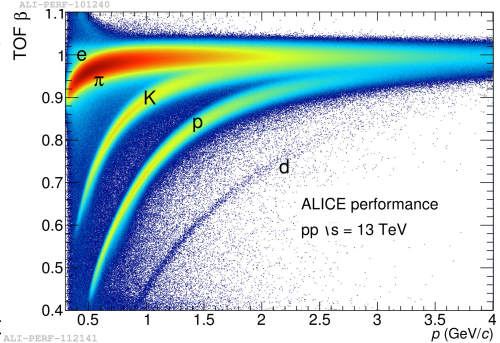
- PID (via TOF measurement)

V0: Used as centrality estimator

T0: Collision time measurement





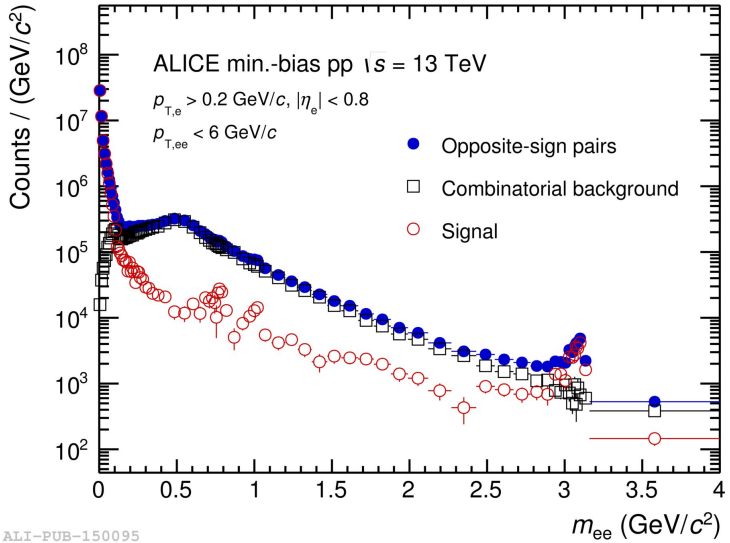


Signal extraction

Raw yield $N^{+-} \rightarrow$ **"ULS" = Signal** + $B_{combinatorial}$

"LS" = $B_{combinatorial}$ = $B_{correlated}$ + $B_{uncorrelate}$

Correlated background: e. g. double Dalitz decay, jets.
Uncorrelated background: random electron combinations

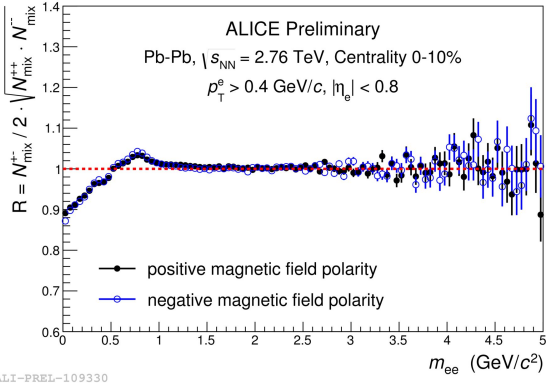


- **Conversion rejection:**
  - Single track cuts (ITS-TPC matching, track χ^2, number of clusters and layers)
  - Pair rejection:
    - Pre-filter for low mass pairs.
    - φ_V: pair orientation w.r.t. the magnetic field

- Efficiency corrections
  - Pair efficiency for correlated pairs
  - Pre-filter efficiency correction

LS = $R \cdot 2\sqrt{N^{++} \cdot N^{--}}$

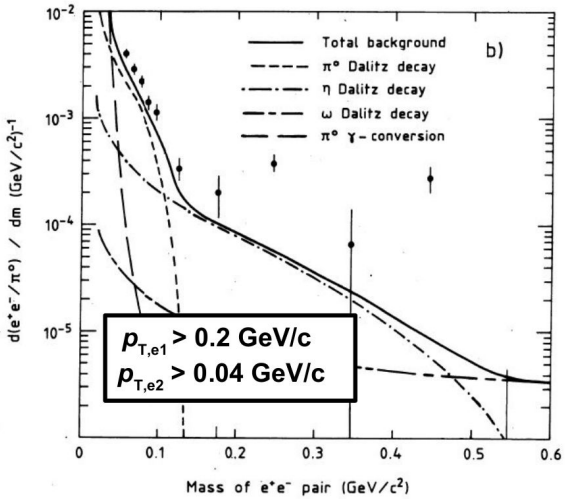
R accounts for the different acceptance for ULS and LS

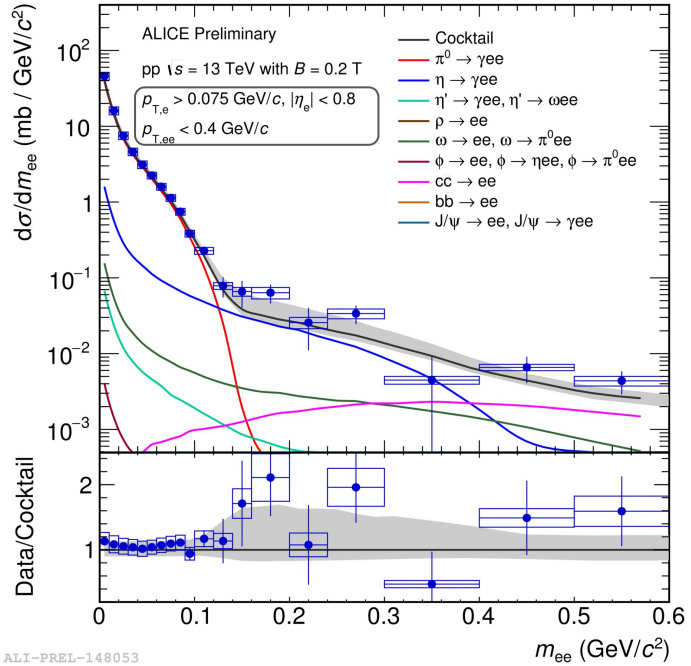


pp $\sqrt{s}$ = 13 TeV, Low B

from 2016-17 exploratory runs. **Much more available!**

- Access to soft dielectron production: low $p_{T,ee}$ - low m_{ee}
- acceptance from single electron $p_{T,e}$ 0.075 GeV/c





Excess of dielectrons observed by the AFS experiment at the ISR (pp $\sqrt{s}$ = 63 GeV) for 0.05 < m_{ee} < 0.6 GeV/c^2 and very low $p_{T,ee}$

Ph. D. thesis of V.Hedberg, Lund University (1987)

pp $\sqrt{s}$ = 13 TeV, Low B

from 2016-17 exploratory runs. **Much more available!**

- Access to soft dielectron production: low $p_{T,ee}$ - low m_{ee}
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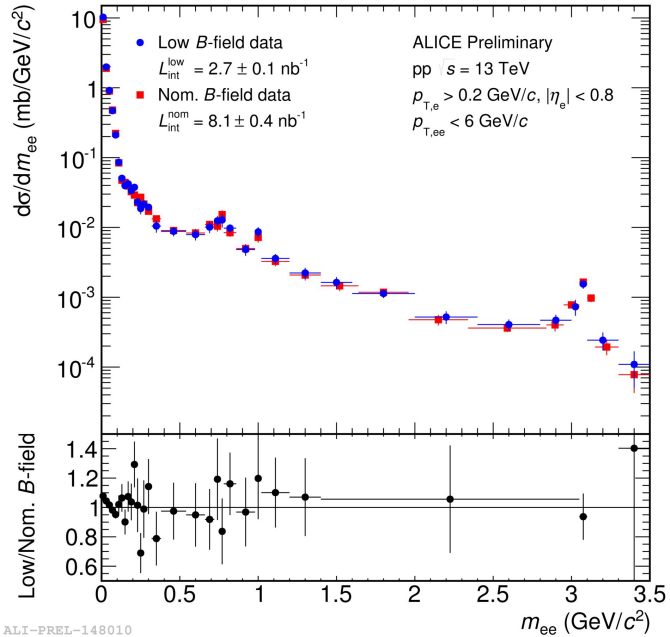
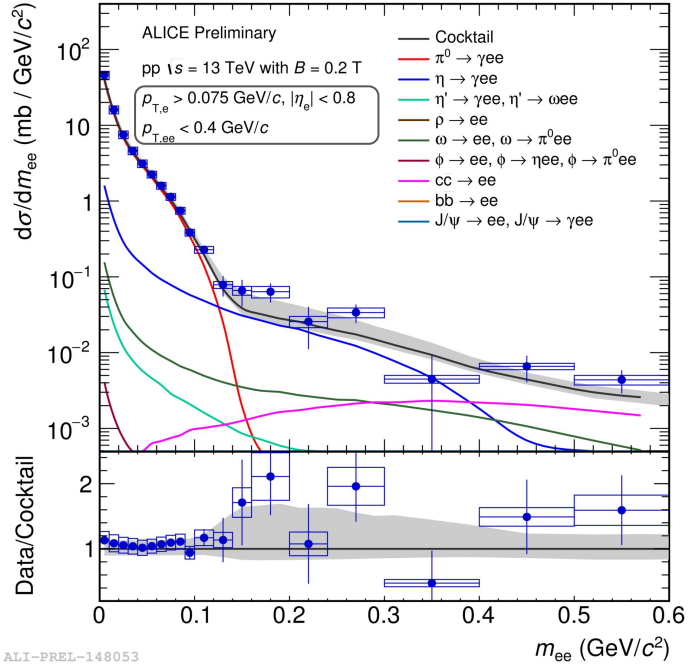
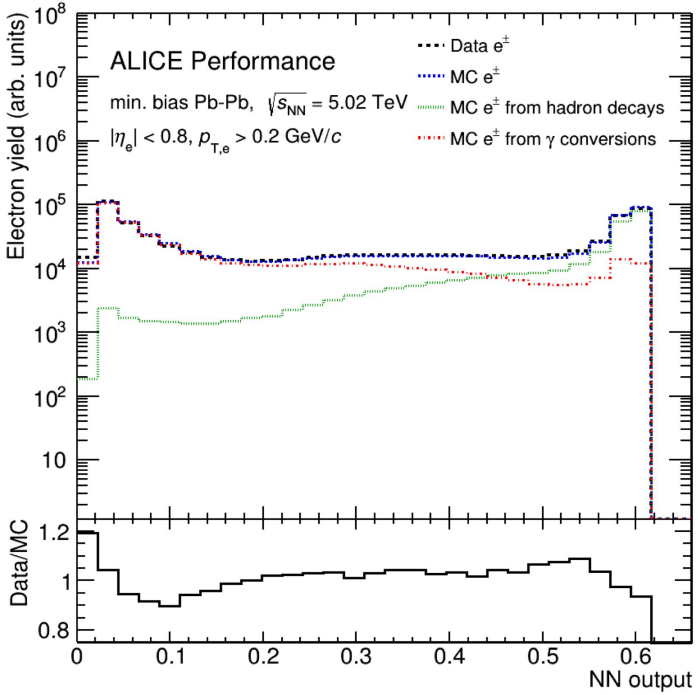
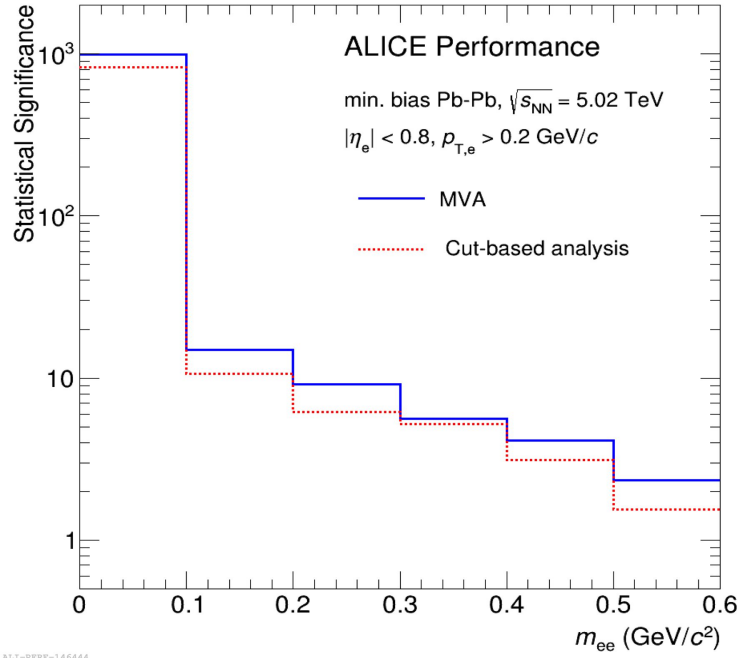




MVA analyses:

Background rejection (Pb-Pb 2.76 TeV)
MVA approach with 19 variables (track + pair)

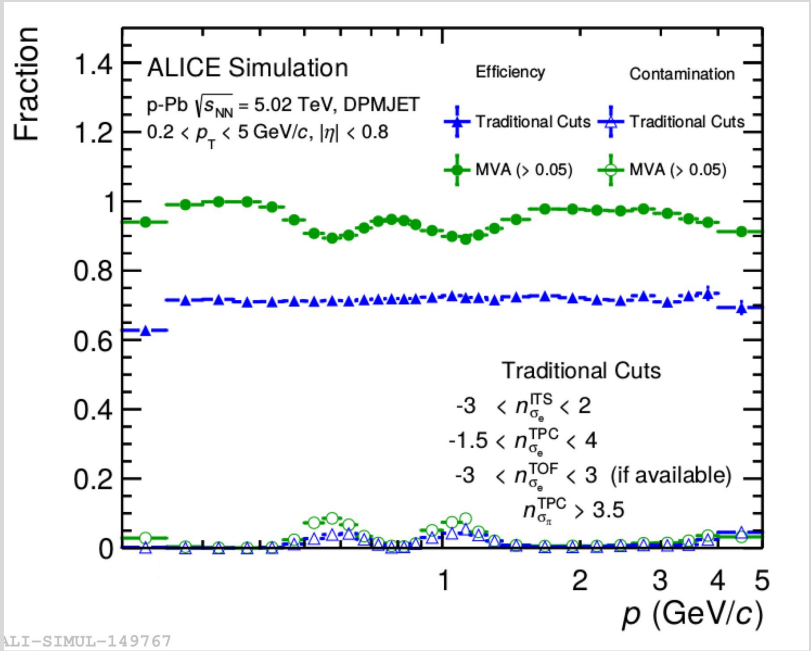


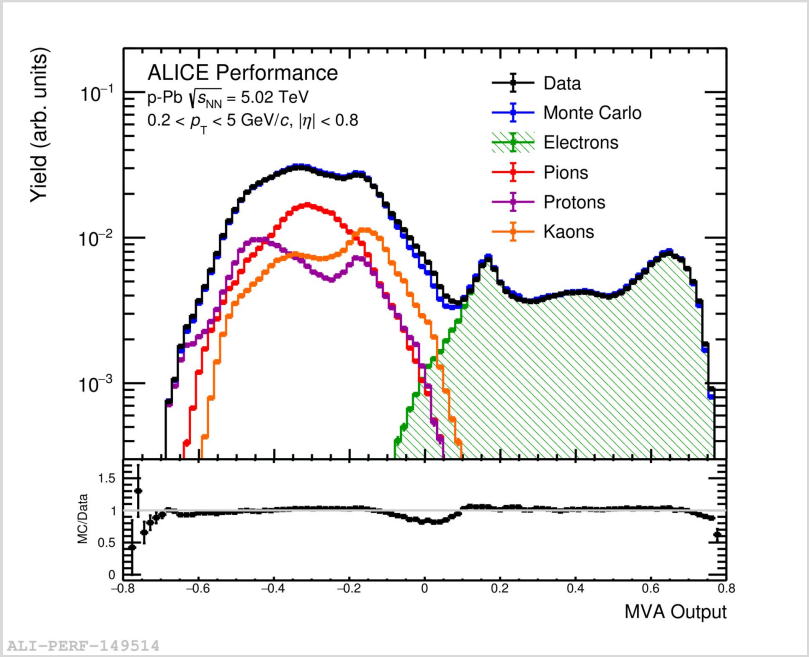


Current analyses

p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV

- **PID** based in **MVA** analysis
- Improvement in selection efficiency w/o increasing contamination





ALICE experiment

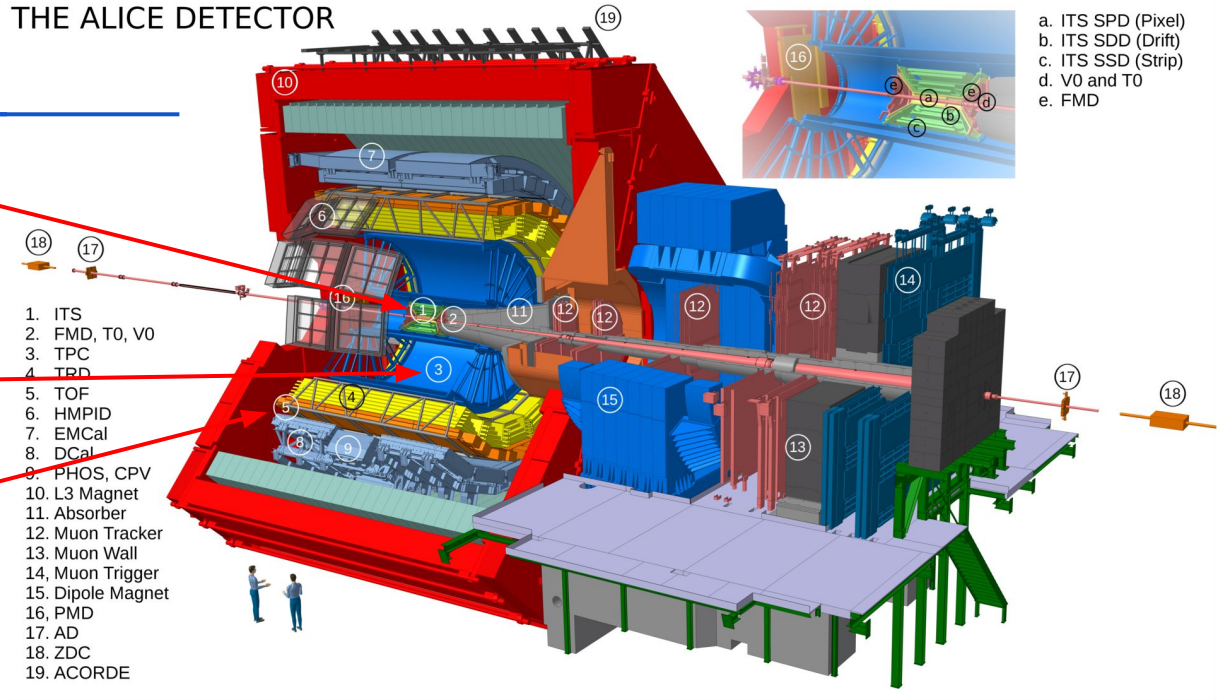
ITS (Inner Tracking System)
- Primary vertex position
- Tracking
- PID (via dE/dx)

TPC (Time Projection Chamber)
- Tracking
- PID (via dE/dx)

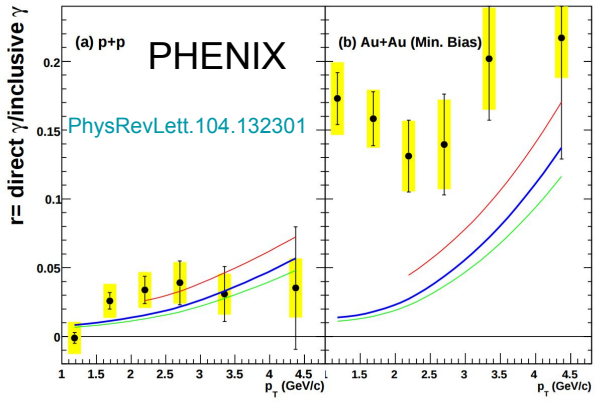
TOF (Time Of Flight)
- PID (via TOF measurement)

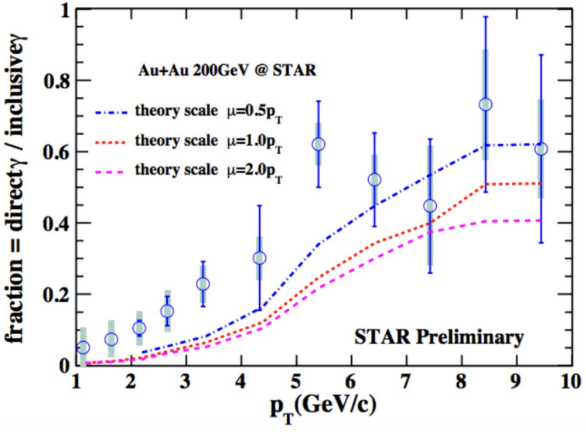
V0: Used as centrality estimator

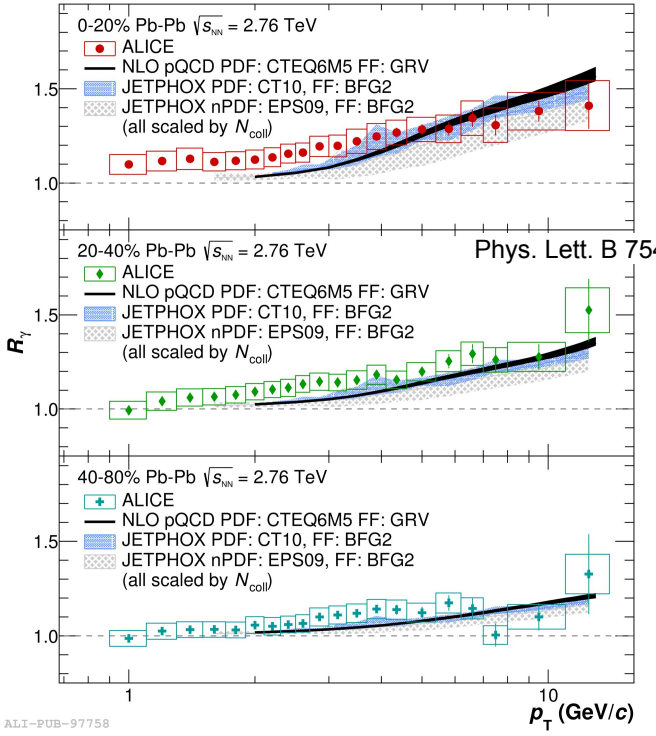
T0: Collision time measurement



Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV: Virtual photons results







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$$r = 1 - \frac{1}{R_\gamma}$$

Combined PCM and PHOS double ratio R γ in the 0–20%, 20–40%, and 40–80% centrality classes compared with pQCD calculations for nucleon-nucleon collisions scaled by the number of binary collisions

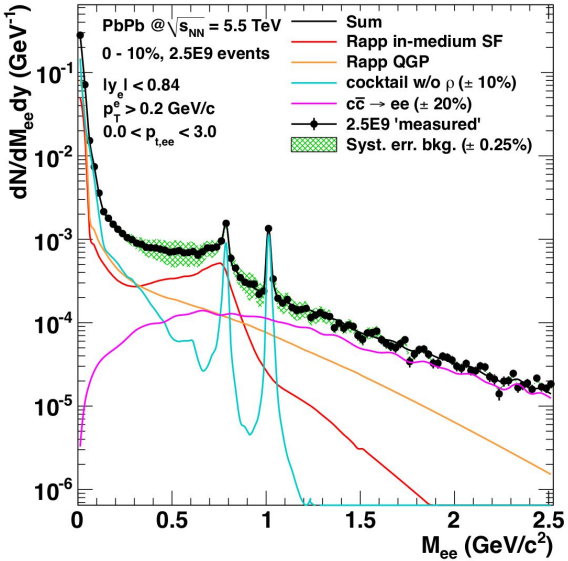
Future: ALICE upgrade

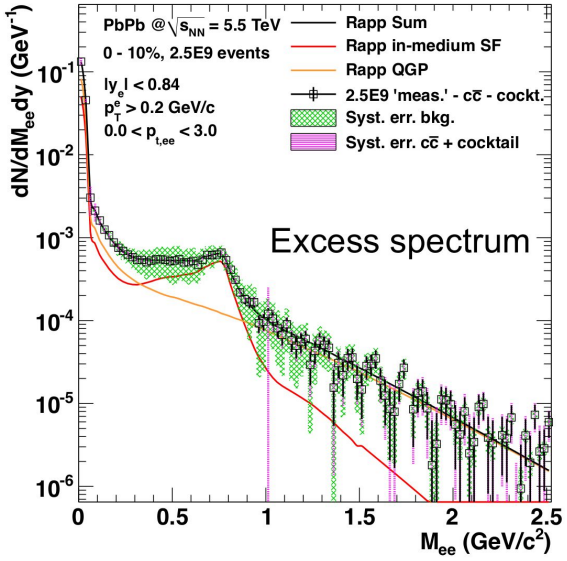
ITS upgrade

- Reduced material budget X/X_0 to 0.3% **(x4)** and improved vertex resolution **(x3).**
- Higher readout rate up to 50 kHz for Pb-Pb **(x50)**

TPC upgrade

- New readout chamber with quadruple GEM foils for continuous readout
- High acquisition rate, up to 50 kHz Pb-Pb **(x100)**





- Increase low m_T acceptance with low B (0.2 T) run
- **DCA cuts reduce cc̄ contribution**
- Exponential fit for m_{ee}>1.1GeV/c^2

$$dN/dm_{ee} \sim e^{-m/T}$$

slope **precision ±10% stat ±10-20% syst**

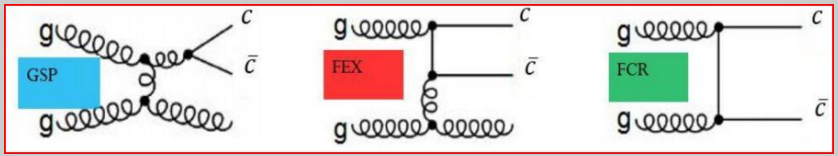
J. Phys. G 41 (2014) 087002

pp $\sqrt{s}$ = 13 TeV

arXiv:1805.04407 [nucl-ex], submitted to PLB

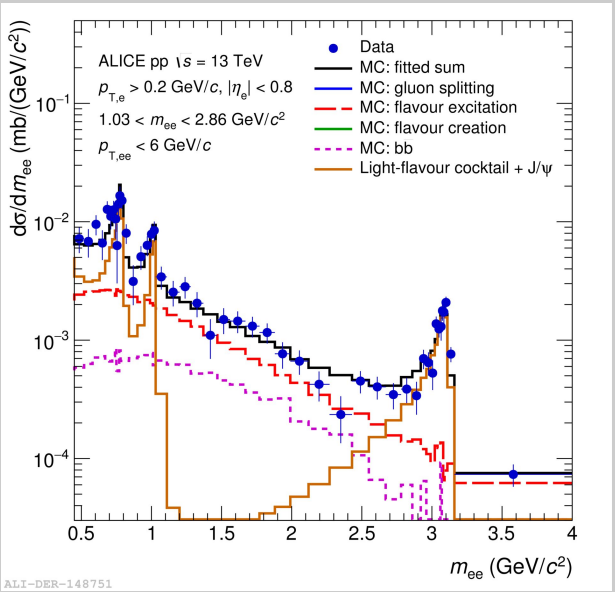
Study different charm production mechanisms with PYTHIA 6

- **Gluon splitting** (55%)
- **Flavour excitation** (20%)
- **Flavour creation** (10%)
- (bbbar 15%)



Fit results:
- GSP: (0.00 ± 0.67)
- **FEX: (0.68 ± 0.06)**
- FCR: (0.00 ± 0.99)
- bbar (0.32 ± 0.06)

→Poor constraint on FCR and GSP contributions: more data needed, or exploit angular correlations



pp $\sqrt{s}$ = 7 TeV. PYTHIA vs POWHEG

arXiv:1805.04391[nucl-ex], submitted to JHEP

$c\bar{c}$	PYTHIA	POWHEG	PYTHIA/POWHEG
4π	1.	1.	
$\|\eta_e\| < 0.8$	0.0754	0.0518	1.46
(uncorrelated e^+e^-)	(0.0428)	(0.0299)	(1.43)
$\|\eta_e\| < 0.8$	0.0148	0.0100	1.48
$1.1 < m_{ee} < 2.7\,\mathrm{GeV}/c^2$			
$\|\eta_e\| < 0.8$ & $p_{T,e} > 0.2\,\mathrm{GeV}/c$	0.0146	0.0098	1.49
$1.1 < m_{ee} < 2.7\,\mathrm{GeV}/c^2$			
$\|\eta_e\| < 0.8$ & $p_{T,e} > 0.4\,\mathrm{GeV}/c$	0.0115	0.0077	1.49
$1.1 < m_{ee} < 2.7\,\mathrm{GeV}/c^2$			

- Different treatments of the production mechanisms c-c pair:
  - c quarks **rapidity distribution** for POWHEG slighly broader than PYTHIA
  - **pseudorapidity correlation** between the quark (and electron) pair also **model dependent** and differs.

(hadronisation & decay kinematics are the same in both generators)