Overview of direct photon and neutral mesons measurements with ALICE at the LHC

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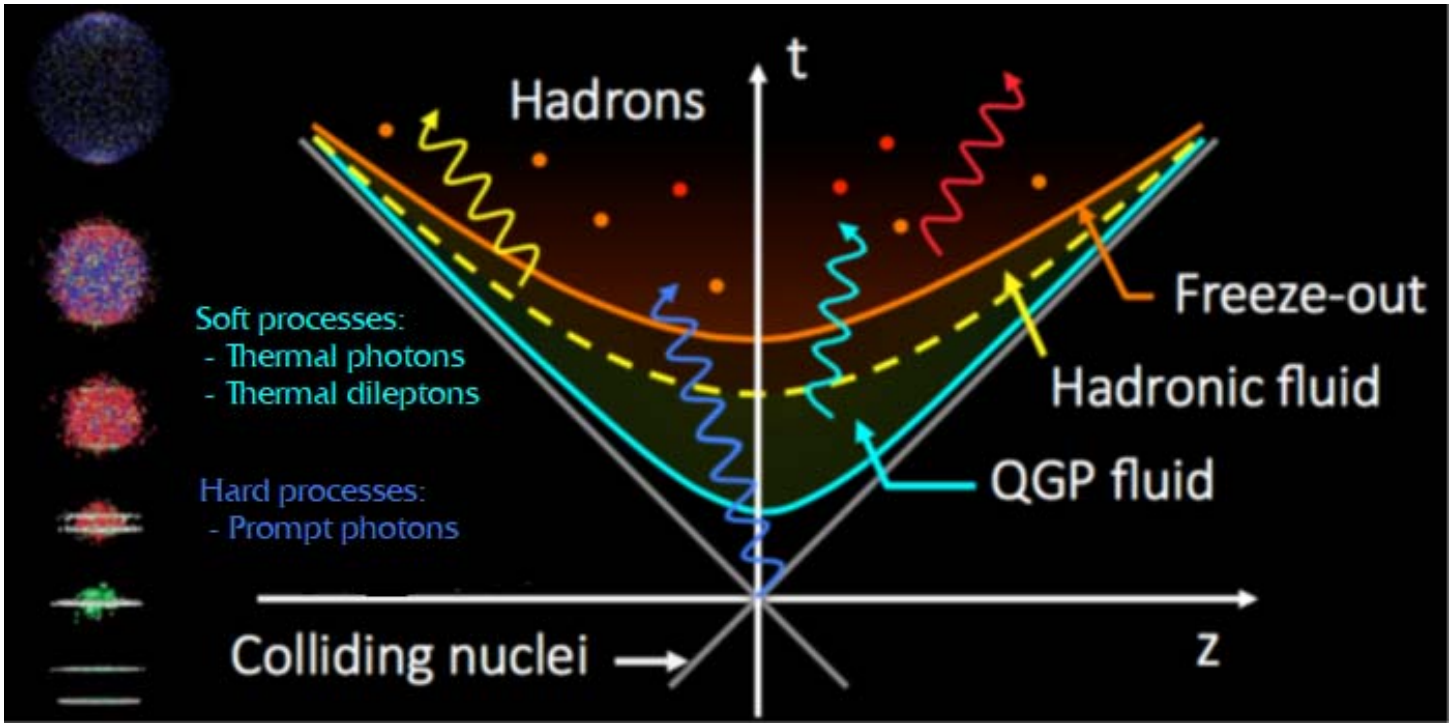
QGP studied through e-m probes (heavy-ion collisions)

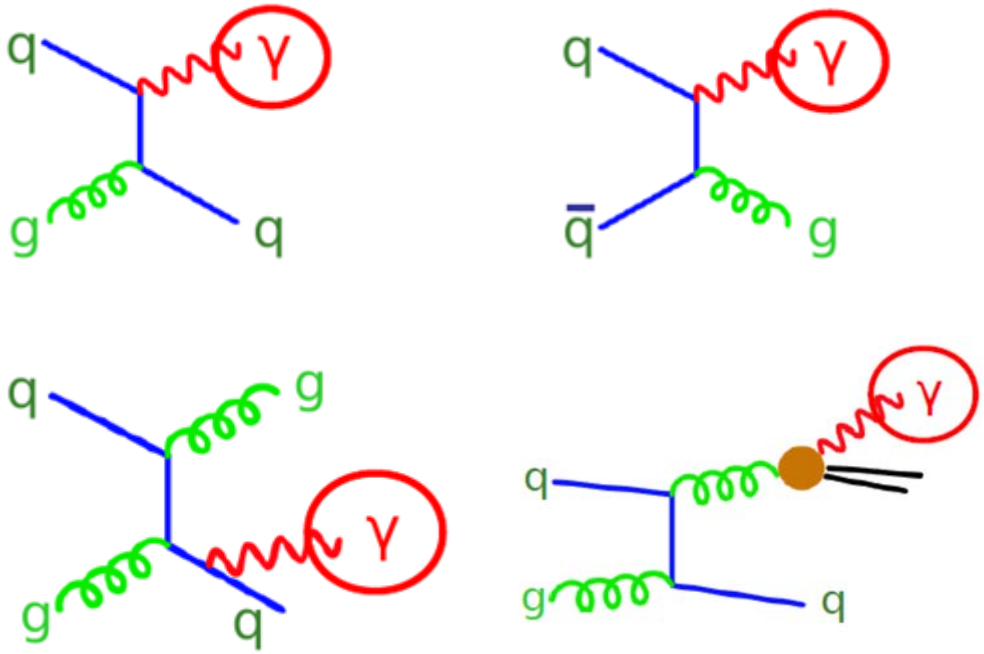
- Study parton energy loss and collective effects in hot medium via π^0 and η spectra modification relative to pp collisions (R_{AA})
- Study thermal and bulk properties of medium with direct photon spectrum measurements. High p_{T} – test of initial conditions and N_{coll} scaling.
- Study collective flow formation and evolution through $v_n^{\gamma,\mathrm{dir}}$
- Measurements of fully reconstructed jets provide possibility to further explore parton energy loss



Study of direct photons and neutral mesons in pp and p-Pb

- High precision and wide p_{T} neutral meson spectra in pp collisions provide test of pQCD predictions, and constraints of parton distribution functions (PDFs) and fragmentation functions (FFs)
- Direct photon spectra in pp collisions also test QCD
- Provides baseline for AA collisions

- p-Pb collisions: study of modifications due to cold nuclear effects (modification of nucleon structure functions in nuclei, isospin effects, test scaling of production with N_{coll})

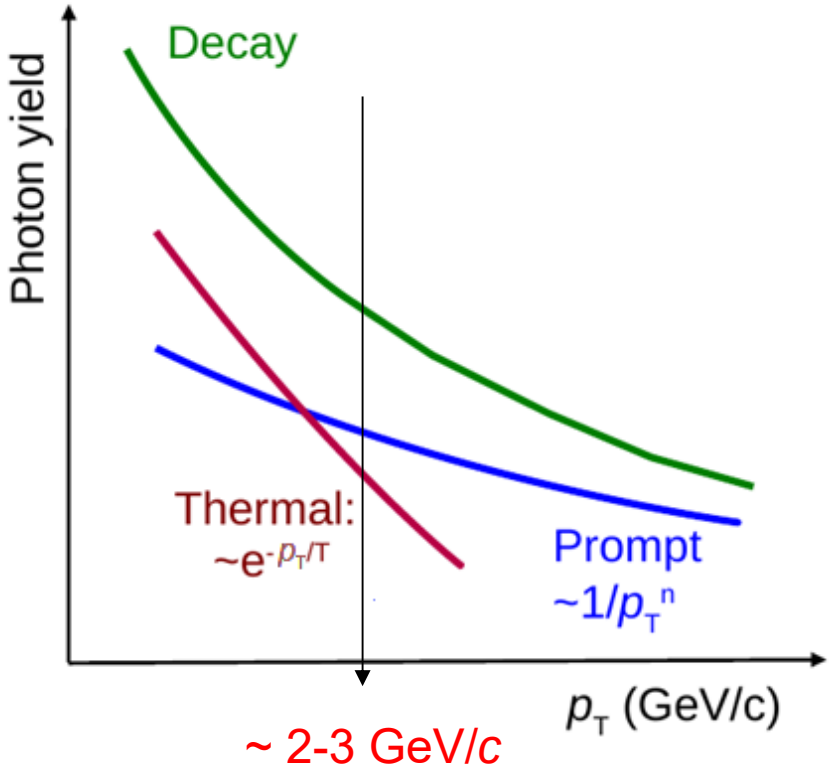


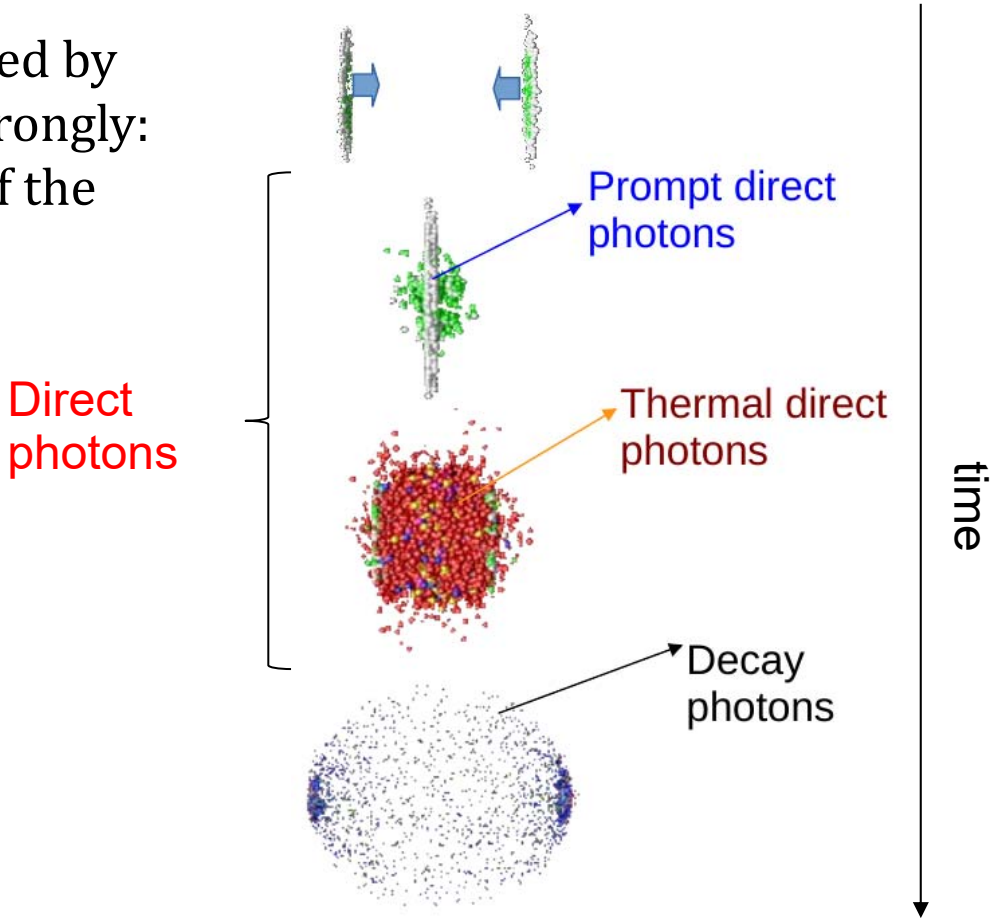
$$\frac{d\sigma^{\gamma,\mathrm{dir}}}{dp_{\mathrm{T}}d\eta} = F_{i/h} \otimes \sigma_{ij} \otimes D_{\gamma/k}$$

$F_{i/h}$– nucleon structure function
σ_{ij} – cross-section of the elementary process
$D_{\gamma/k}$ – fragmentation function

Direct photons – a probe to study QGP

- Photons in heavy-ion collisions are produced by different mechanisms and don't interact strongly: carry out information about the dynamic of the collision.





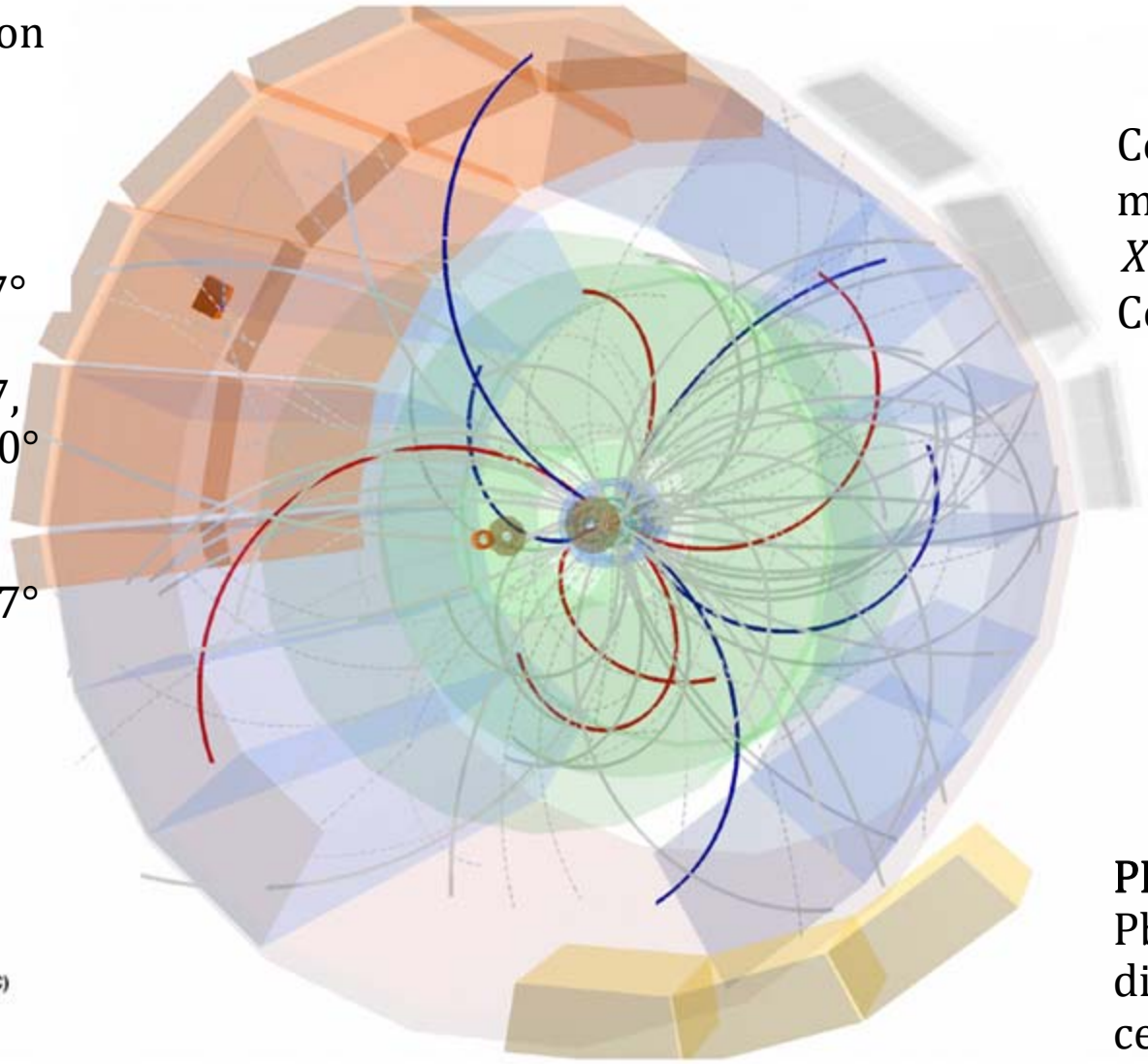
- High p_T: test of initial conditions:
  - N_{coll} scaling
  - PDF modification
- Low p_T: test of hot matter evolution:
  - spectrum
  - collective flow

Photon detection in ALICE

EMCal calorimeter
Pb/scintillator
Sampling calorimeter
distance to interaction point (IP): 4.28 m
cell size 6×6 cm^2

$EMCal$:
$|\eta| < 0.7$,
$80° < \varphi < 187°$
$DCal$:
$0.22 < |\eta| < 0.7$,
$260° < \varphi < 320°$
$DCal$:
$|\eta| < 0.7$,
$320° < \varphi < 327°$

ALICE is an experiment at the LHC designed to study the quark-gluon plasma (QGP)



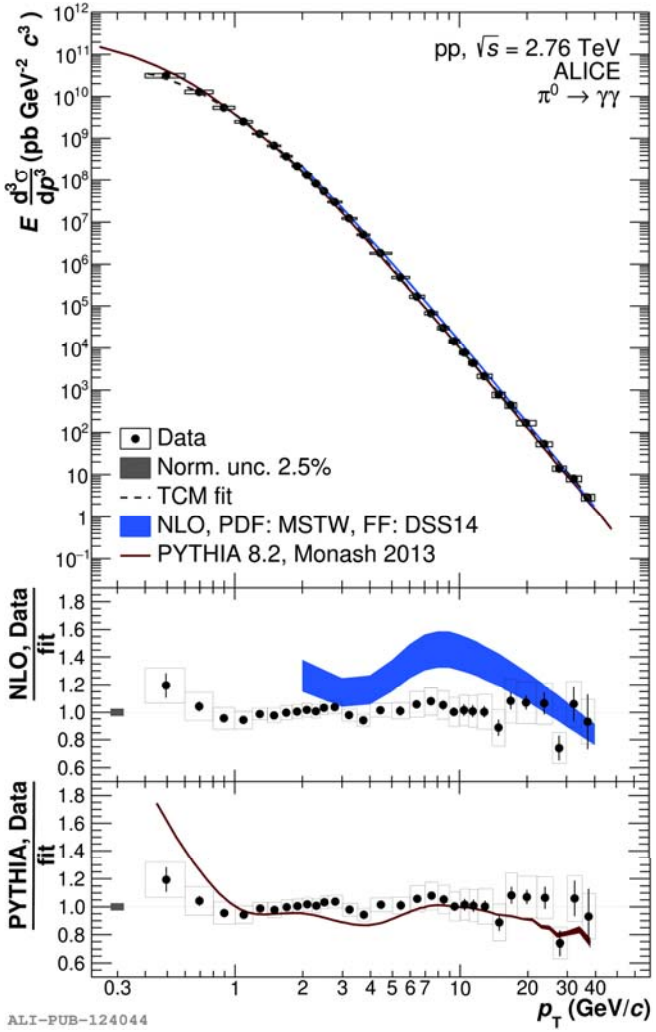
Photon conversion method (PCM)
ITS and TPC
$|\eta| < 0.9$,
$0° < \varphi < 360°$
Conversion in detector material
$X/X_0 = (11.4 \pm 0.5)\%$
Conv. probability ~ 8%

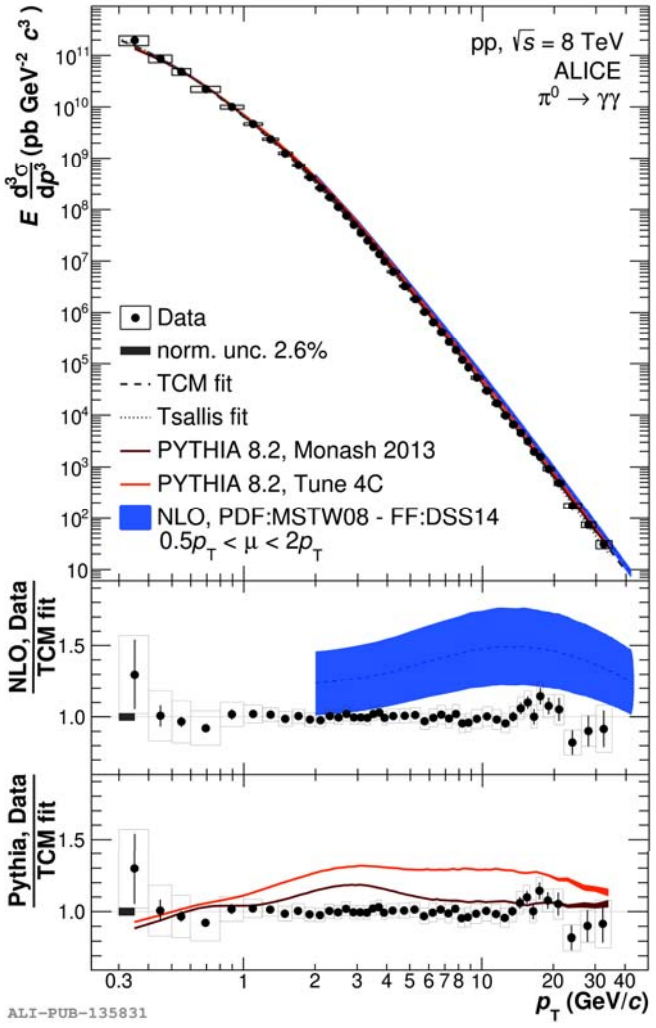
PHOS calorimeter
$PbWO_4$ crystals
distance to IP: 4.6 m
cell size 2.2×2.2 cm^2
$|\eta| < 0.12$,
$260° < \varphi < 320°$

- Complementary techniques: result in excellent precision and p_T range!

π^0 meson measurements in pp

- Neutral meson measurements over wide p_T range provide data for FF and PDF global fits, and are also needed for γ^{dir} measurements.
- Wide range of measurements (shown only $\sqrt{s}$ =2.76 and 8 TeV, but also $\sqrt{s}$ = 0.9, 5.02, 7 TeV published earlier [*]).
- PYTHIA 8.2 with Monash 2013 tune reproduce data well, but for larger $\sqrt{s}$ the difference increases. NLO pQCD calculations generally overestimates data.



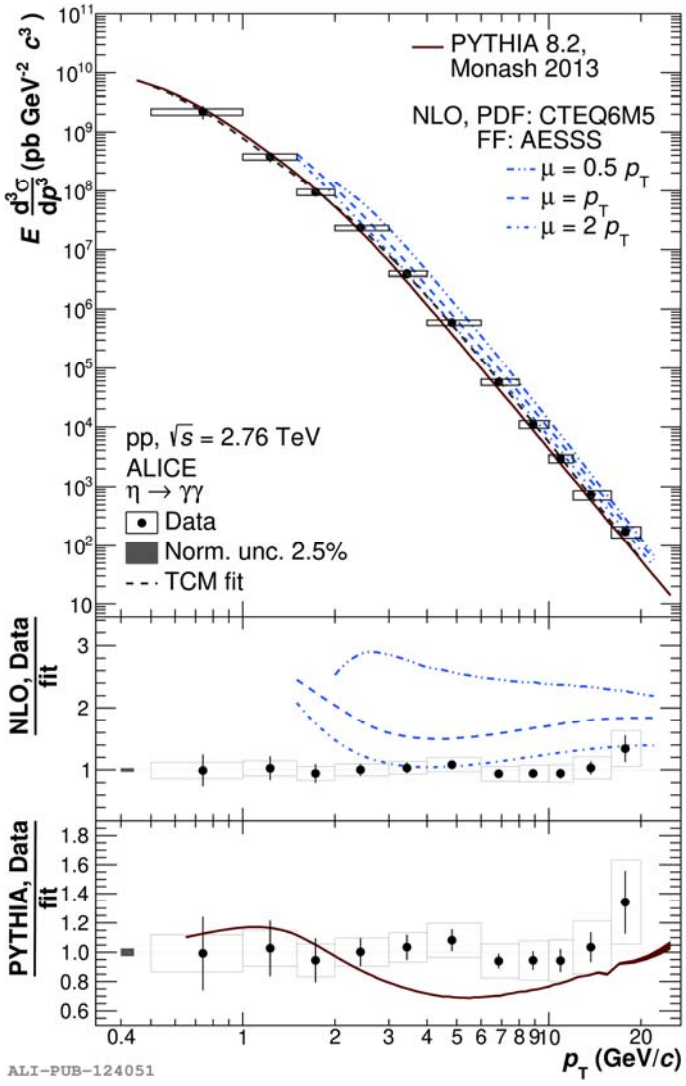


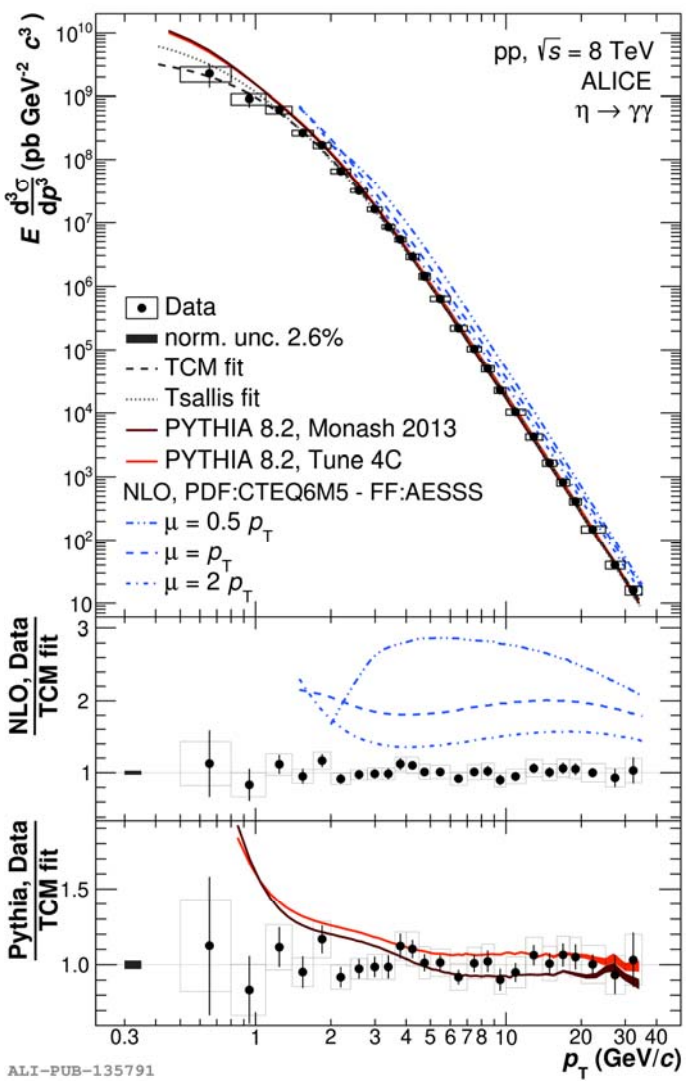
* PLB 717 (2012) 162-172
Eur. Phys. J. C 74 (2014) 3108

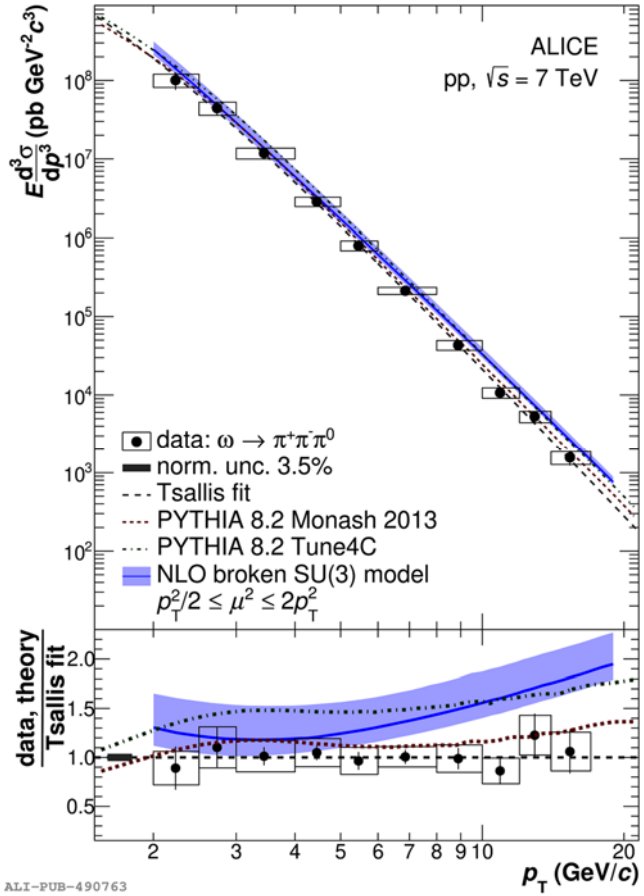
Eur. Phys. J. C 78 (2018) 263
Eur. Phys. J. C 77 (2017) 339

η and ω meson measurements in pp

- η and ω spectra are well reproduced by PYTHIA 8.2.
- NLO pQCD calculations overestimate data.
- Need to update FF for η meson.



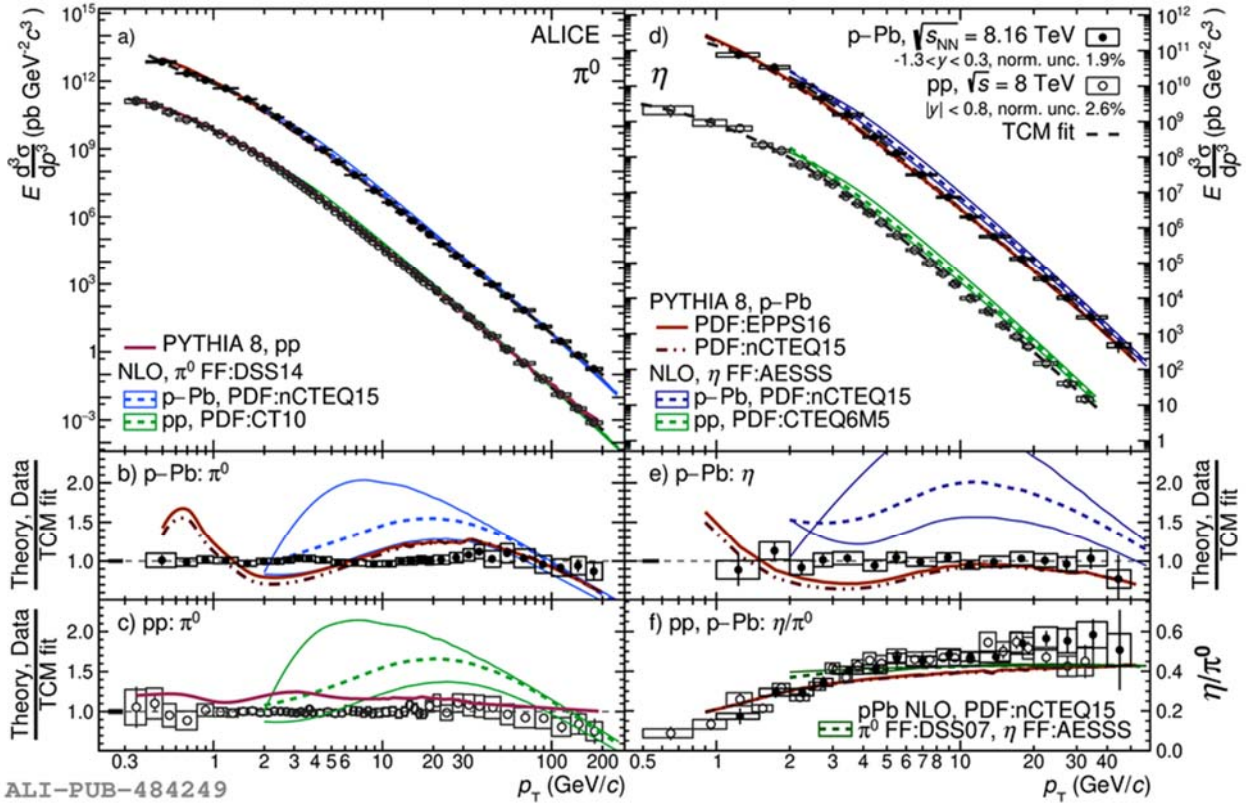


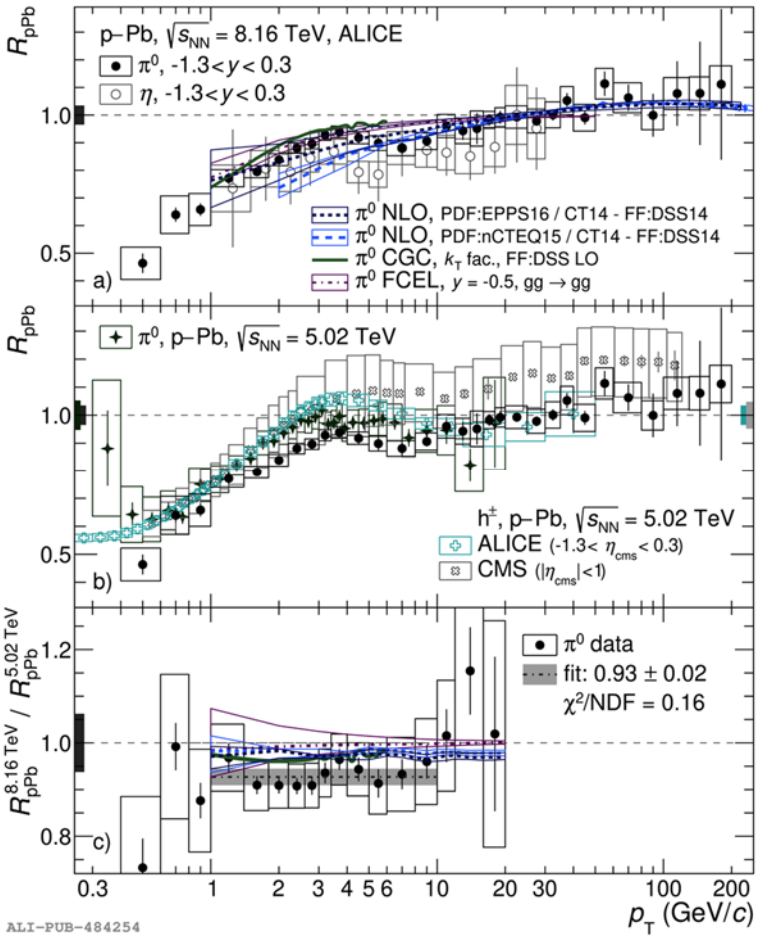


Eur. Phys. J. C 78 (2018) 263
Eur. Phys. J. C 77 (2017) 339
Eur. Phys. J. C 80 (2020) 1130

Neutral meson measurements in p-Pb

- New method of π^0 reconstruction in EMCal (merged clusters) allows to extend p_T range up to 200 GeV/c.
- NLO pQCD calculations overestimate data. PYTHIA 8 generally reproduces π^0 and η spectra, but has problems describing the shape (low p_T, high p_T region). η/π^0 ratio is reproduced well.
- R_{pPb} is consistent with unity above 10 GeV/c and shows suppression below. This is consistent with theory predictions

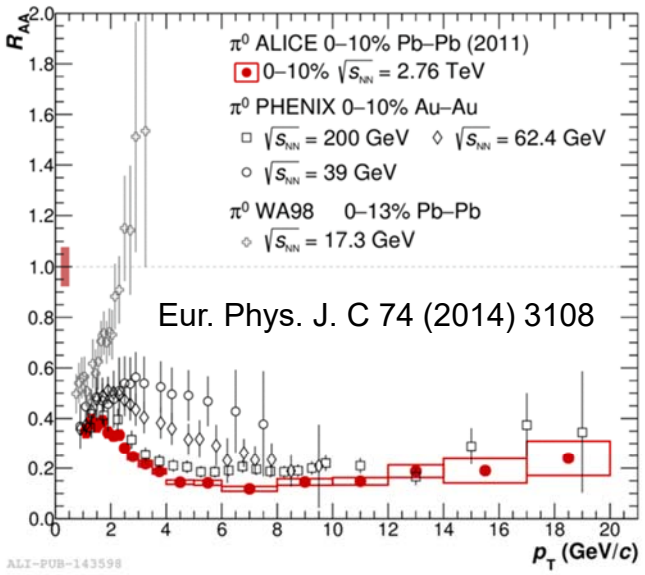


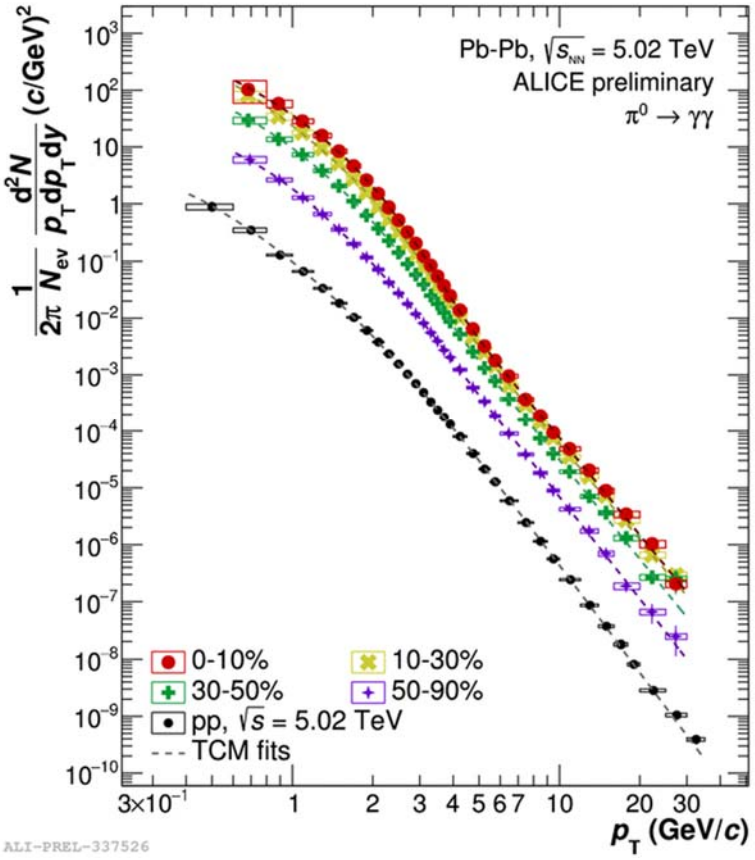


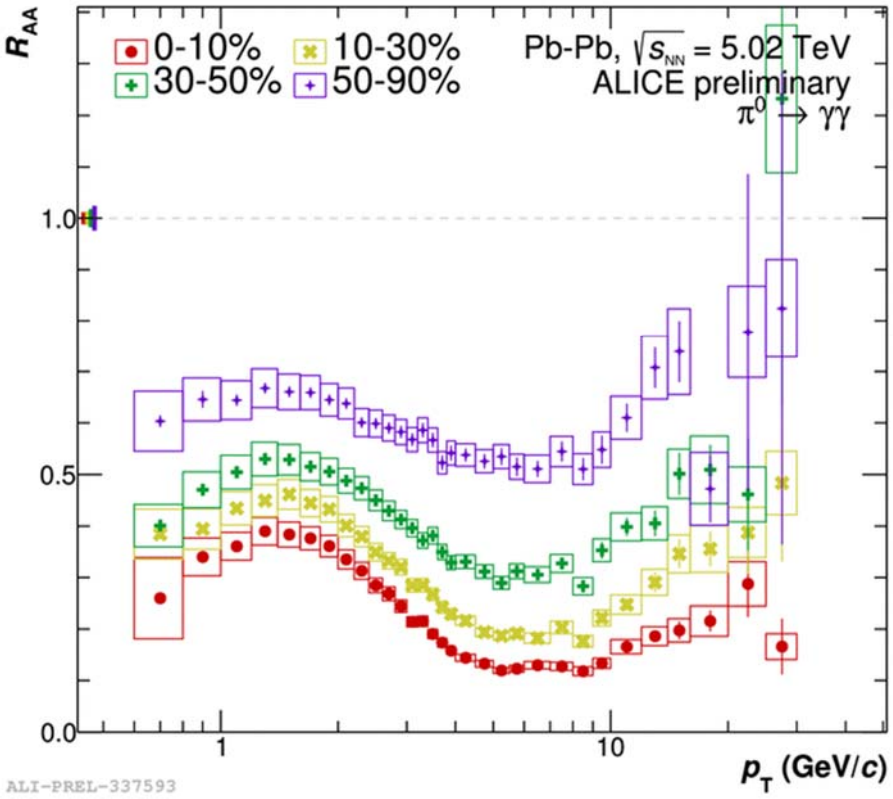
arxiv:2104.03116

Neutral meson measurements in Pb-Pb

- Study parton energy loss in hot medium via π^0 and η spectra modification relative to pp collisions (R_{AA})
- New results on π^0 R_{AA} from Run 2 Pb-Pb collisions at 5.02 TeV:
  - ✓ Similar magnitude of suppression as at 2.76 TeV
  - ✓ p_{T} range 0.6 to 30 GeV/c (Pb-Pb).





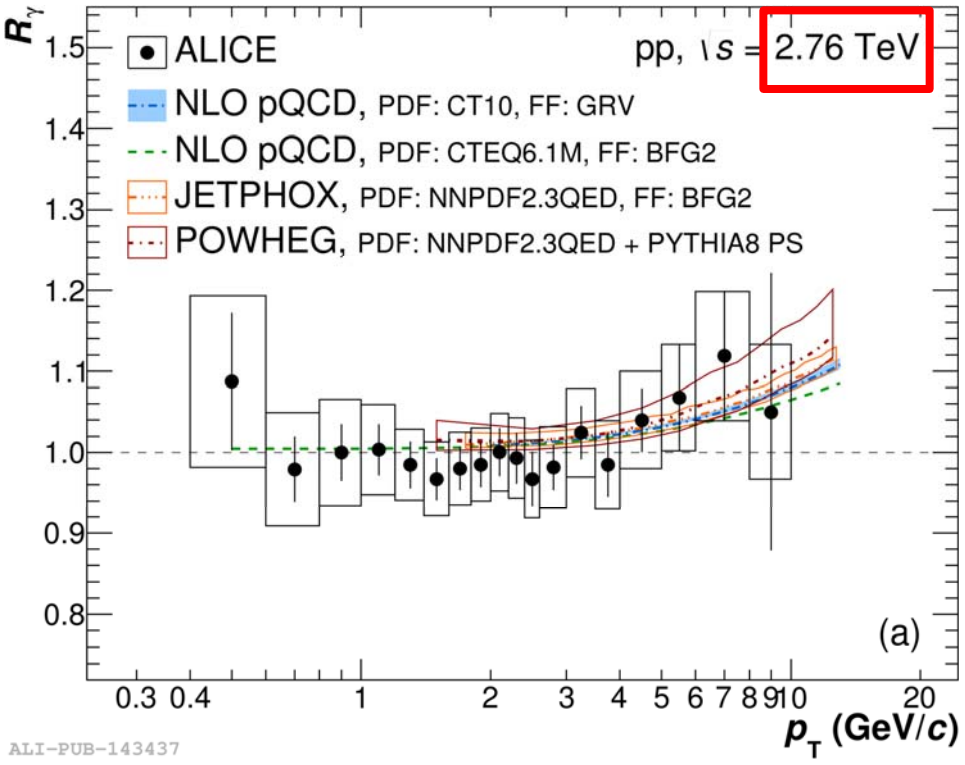


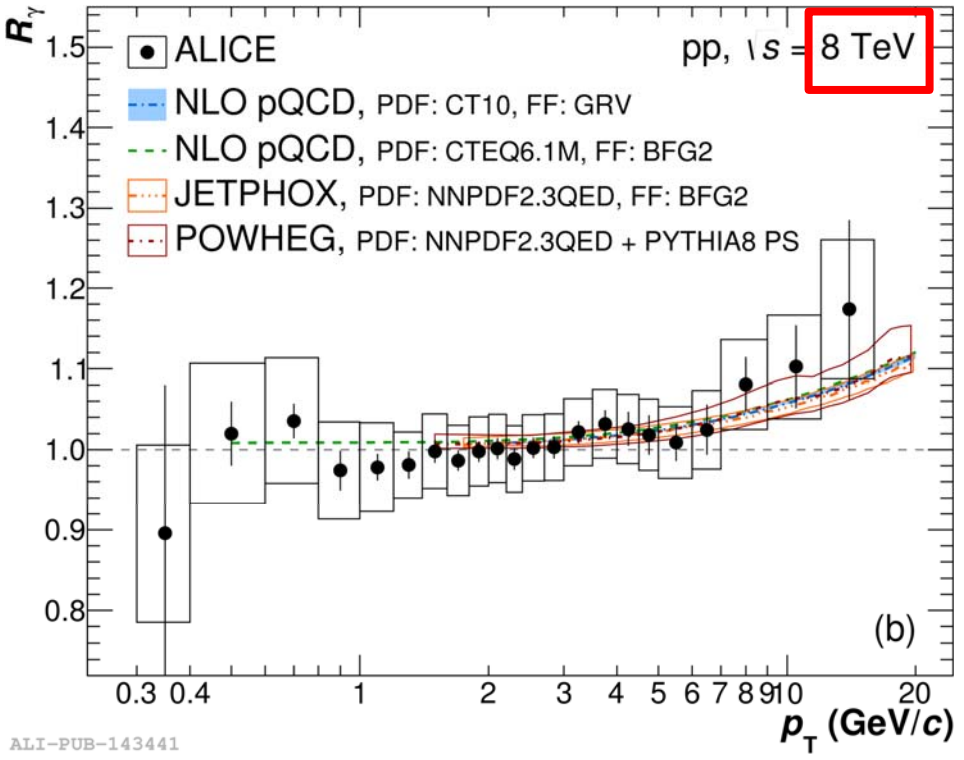
Direct photons in pp collisions

$$R_\gamma = \gamma_{\text{inc}} / \gamma_{\text{decay}} \approx \gamma_{\text{inc}}/\pi^0 \,/\, \gamma_{\text{decay}}/\pi^0{}_{\text{param}}$$

$$\gamma_{\text{dir}} = \gamma_{\text{inc}} - \gamma_{\text{decay}} = (1 - \frac{1}{R_\gamma})\gamma_{\text{inc}}$$

- High p_{T} (>4 GeV/c) – in agreement with pQCD
- Low p_{T} ($<$2-3 GeV/c) – no thermal radiation excess visible within uncertainties





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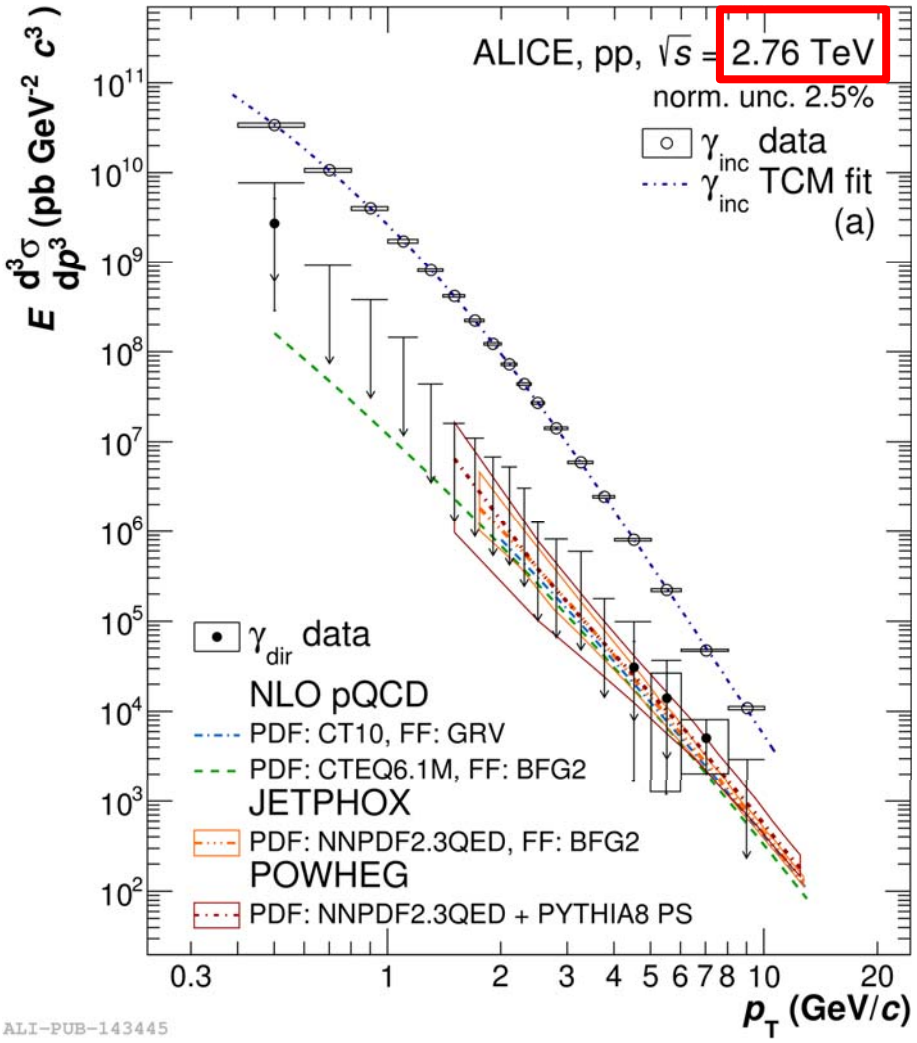
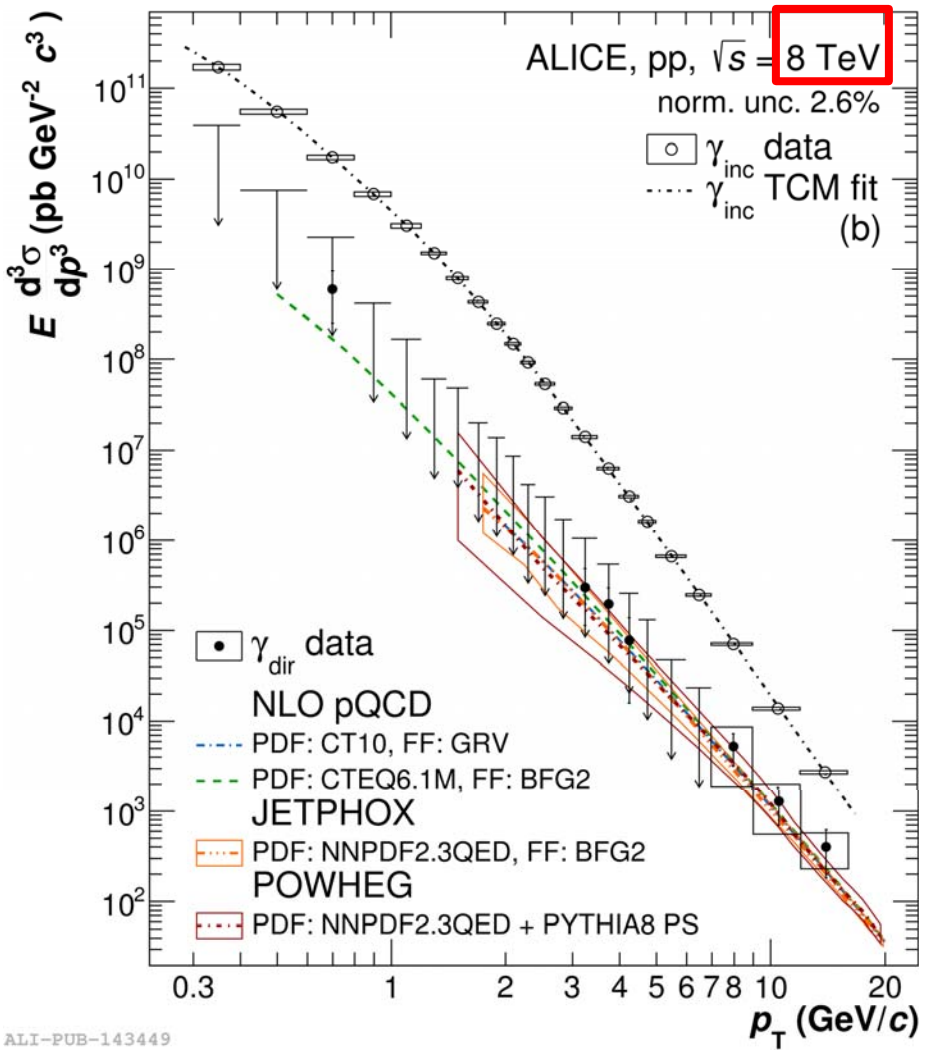
Direct photons in pp collisions

- NLO pQCD calculations are able to reproduce measurements





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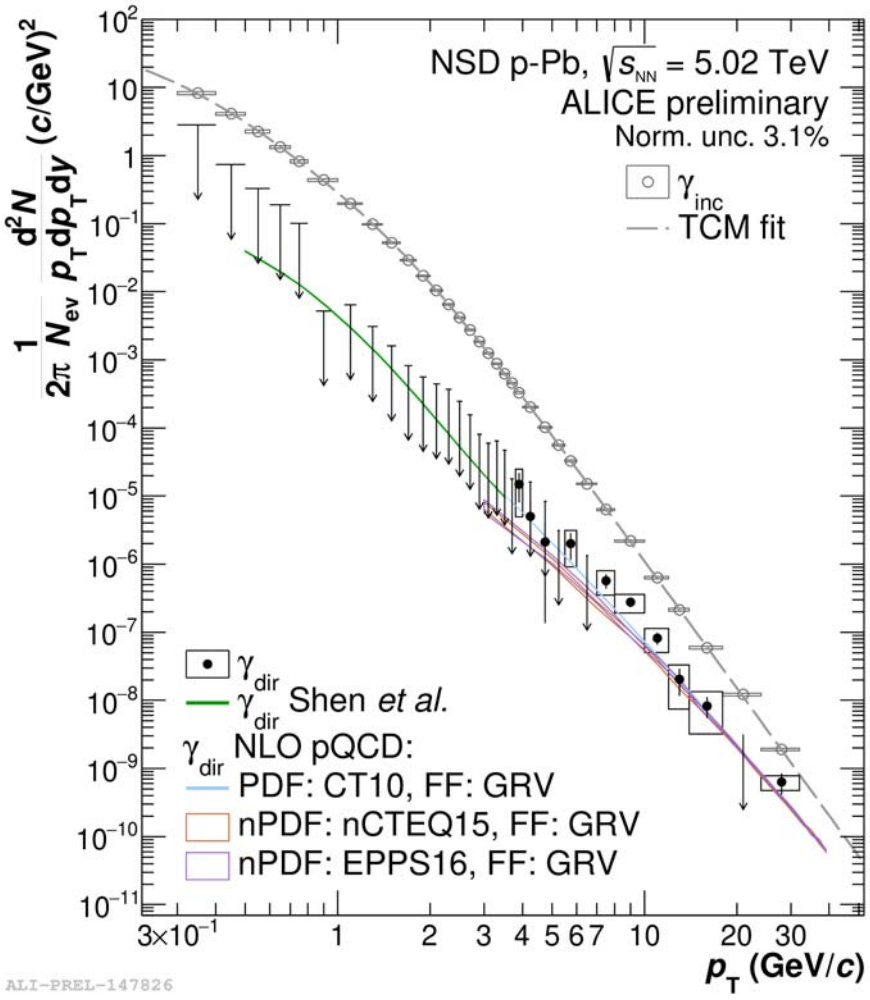
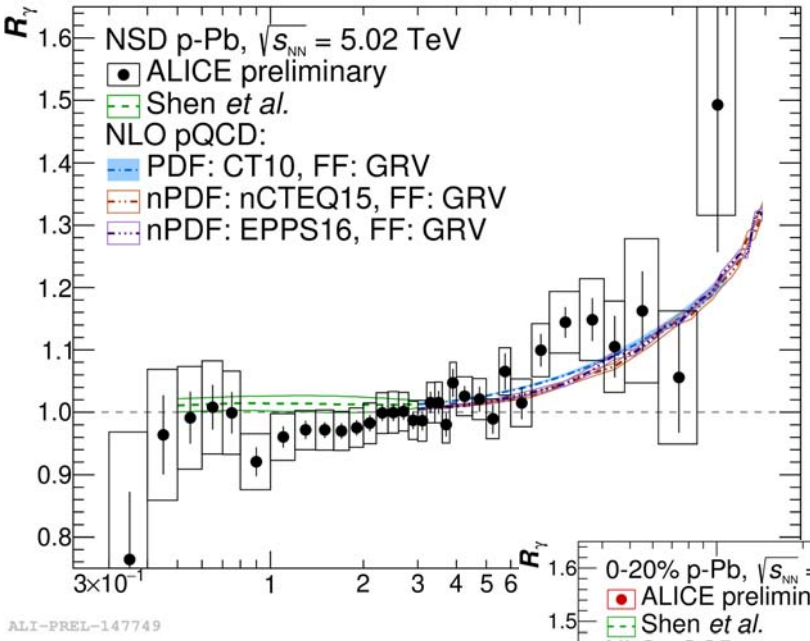
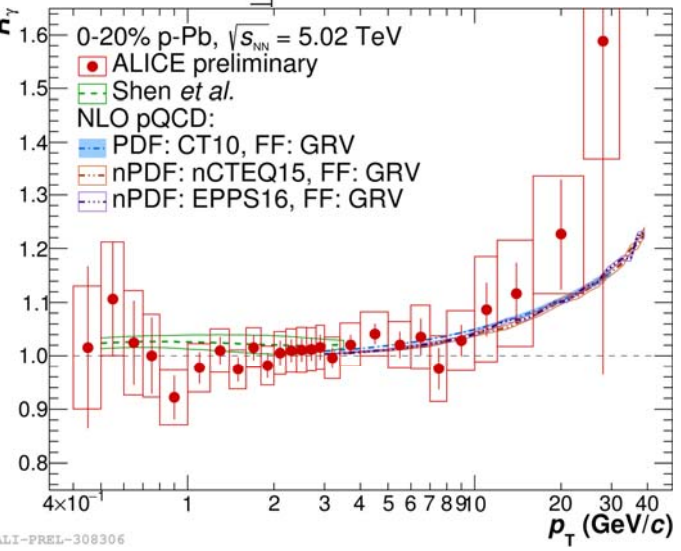
Direct photons in p-Pb collisions

- Direct photon spectrum was calculated in wide p_{T} range up to 30 GeV/c, several NLO pQCD calculations are able to reproduce results
- No thermal radiation fraction is visible at low p_{T} within uncertainties, even in most central 0-20% centrality



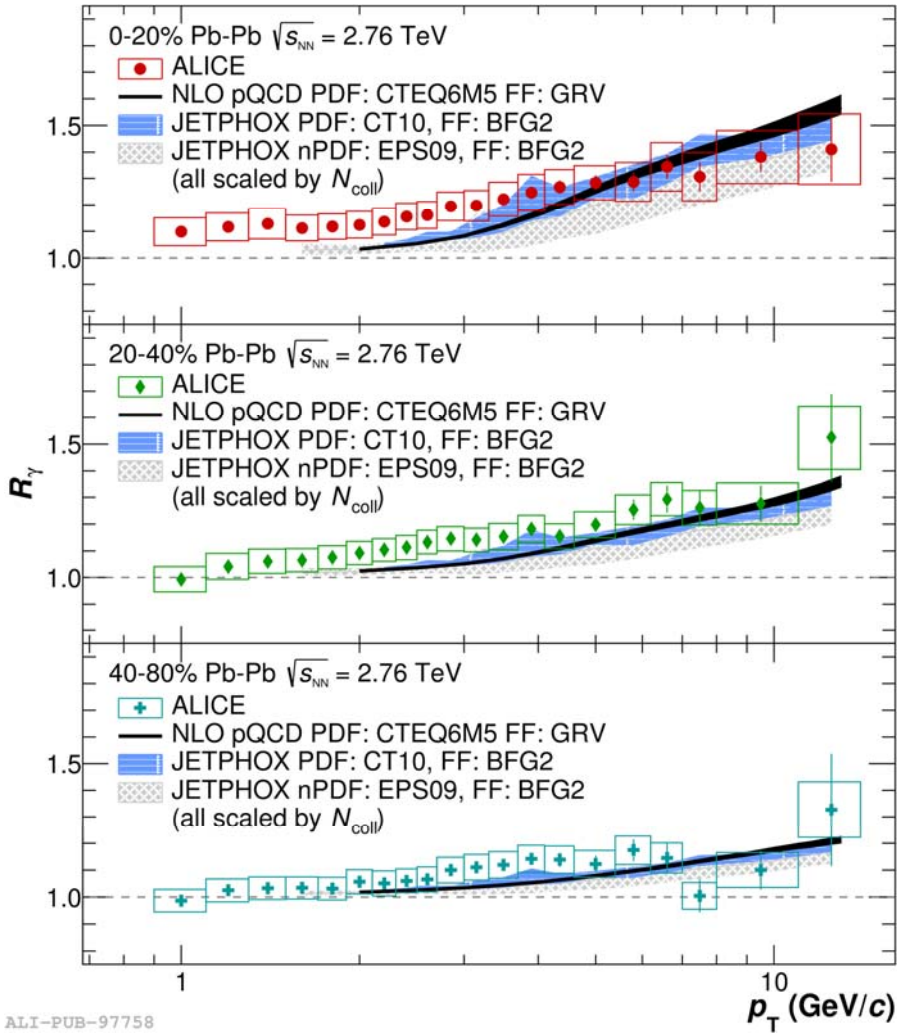


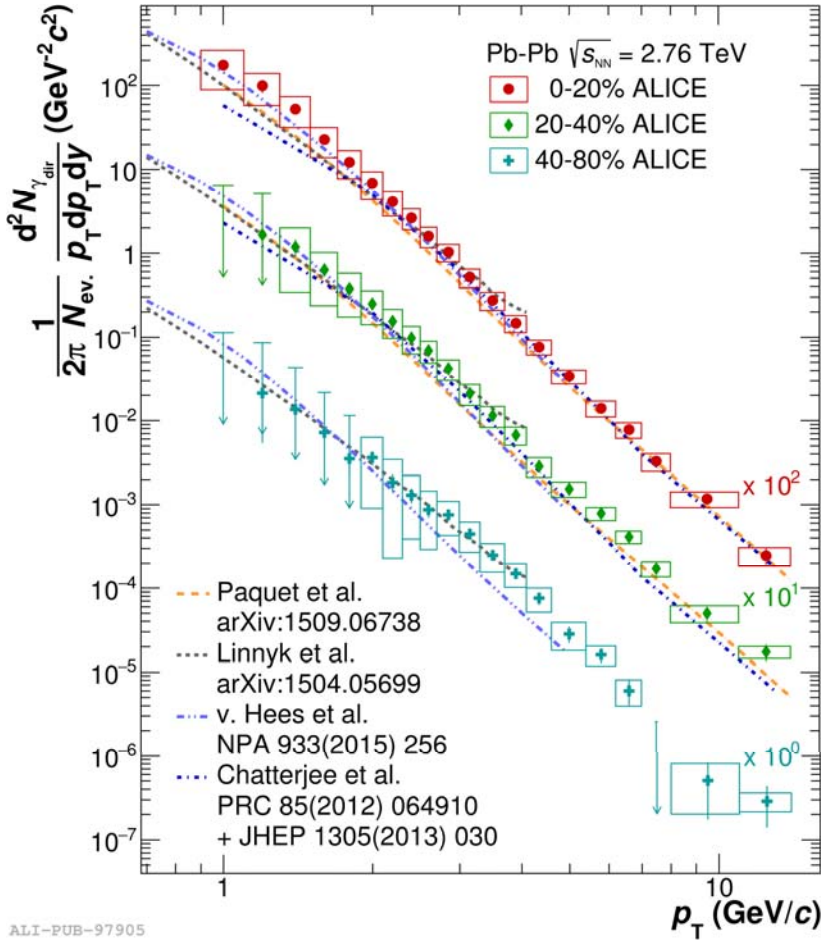


Direct photons in Pb-Pb collisions

- ✓ At low p_{T} (<2-3 GeV/c)
  ~ 8%-15% excess in 0-20% ;
  ~ 8%-9% in 20-40%
- ✓ At high p_{T} (above ~5 GeV/c) in agreement with NLO pQCD and JETPHOX

Comparison with hydro models: Underpredicted, but within uncertainties

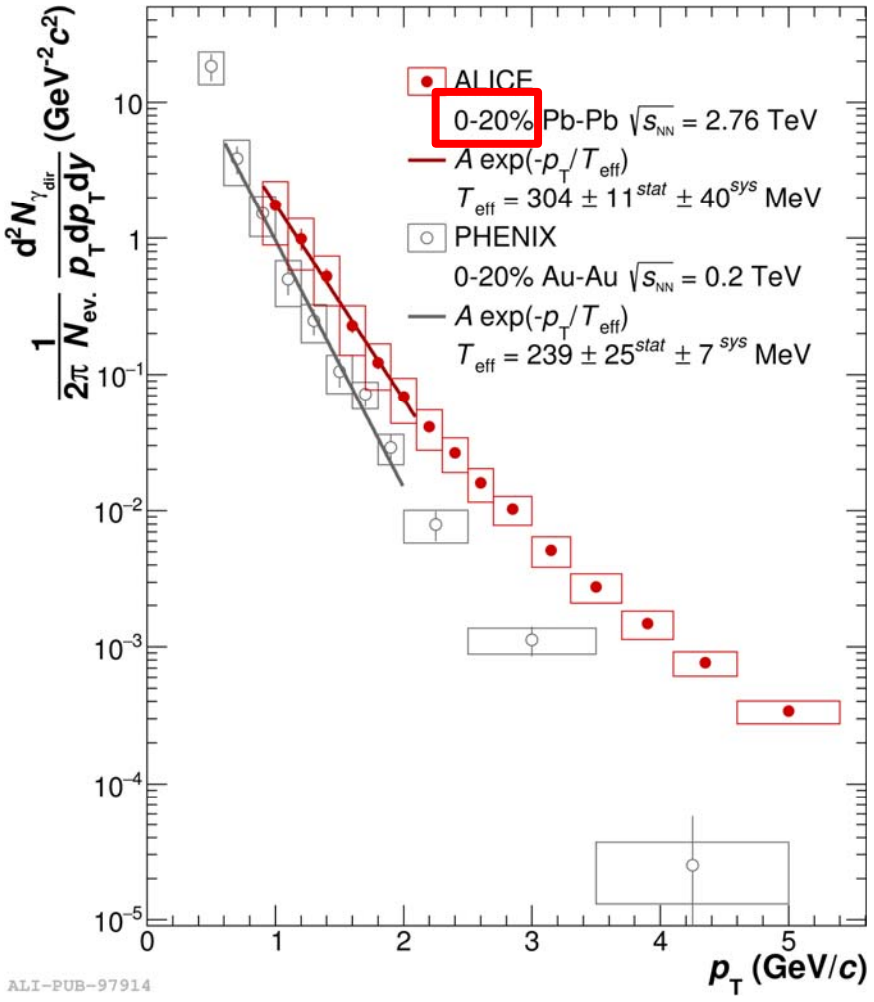


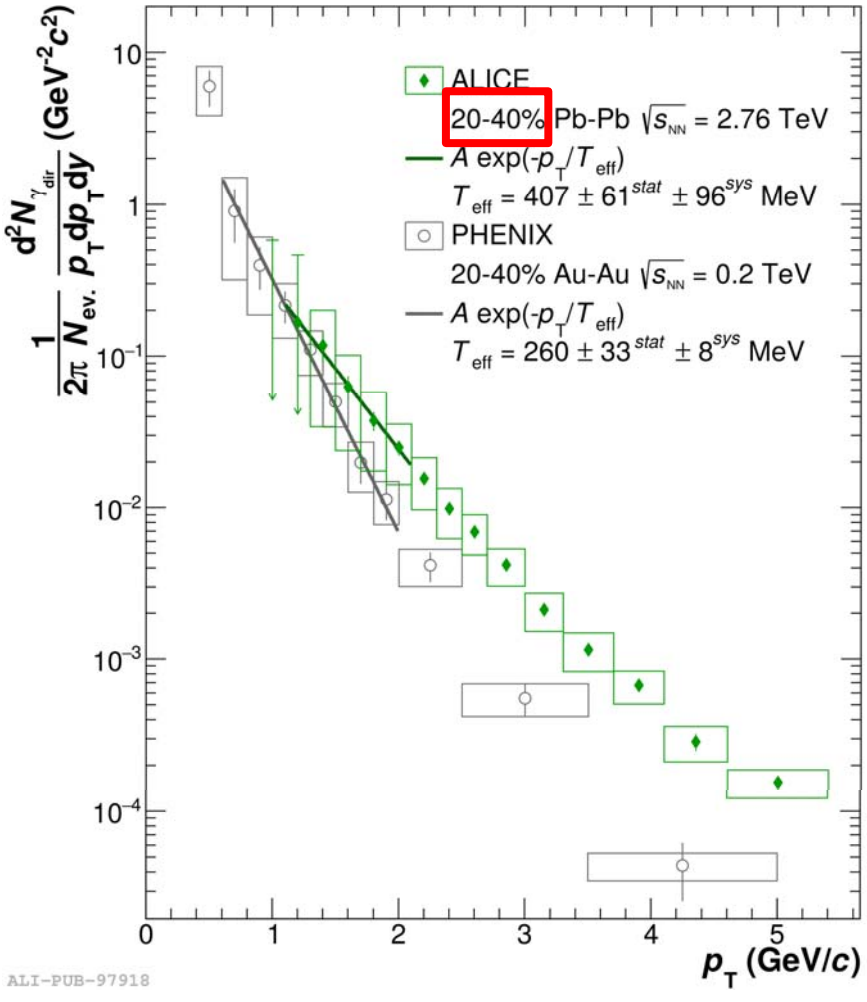


Phys. Lett. B 754 (2016) 235

Direct photons in Pb-Pb collisions

- Effective temperature can be extracted from the low-p_T part of the spectrum
- Both absolute yield of direct photons and effective slope increase with increasing the collision energy





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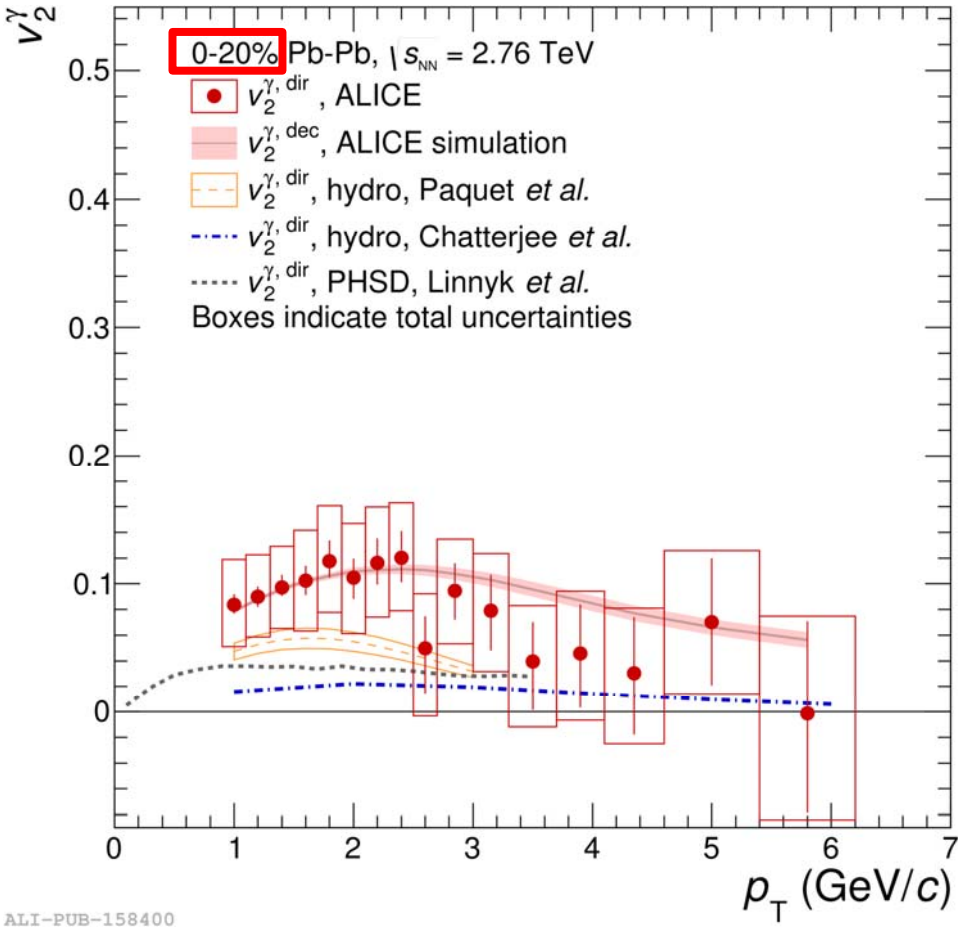
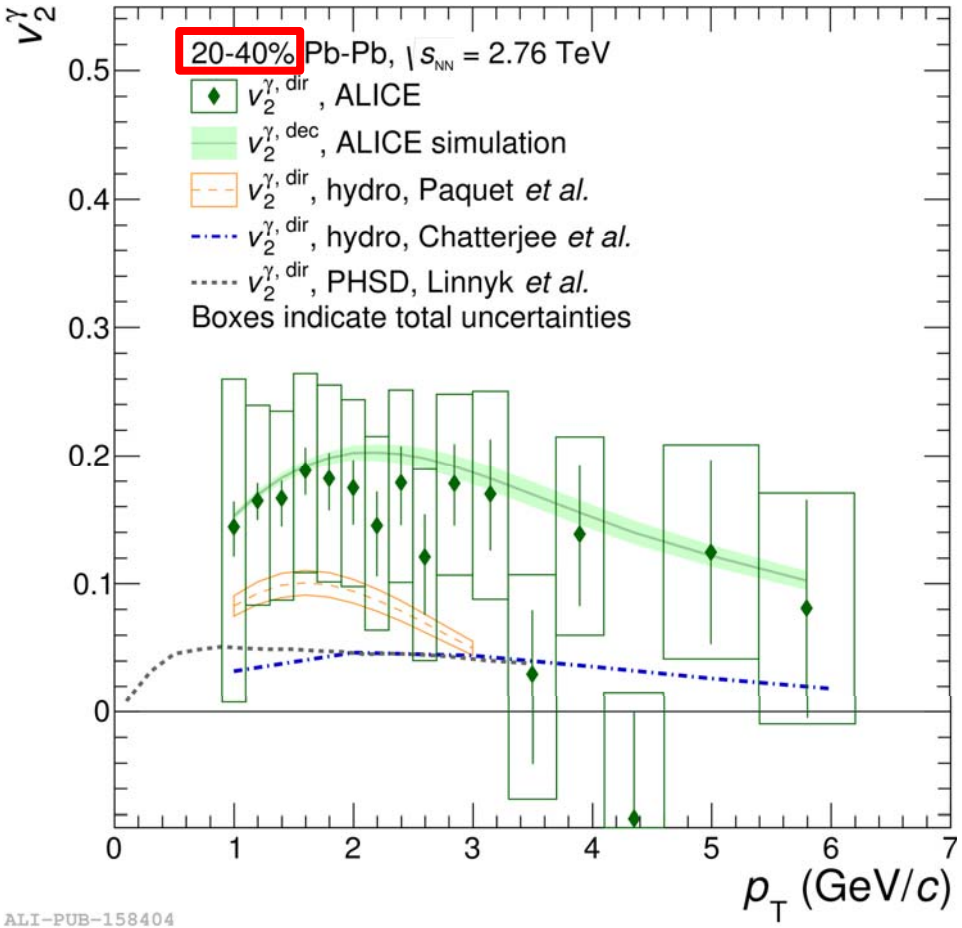
Direct photon flow in Pb-Pb collisions

$$v_2^{\gamma,\mathrm{dir}} = \frac{R_\gamma\, v_2^{\gamma,\mathrm{inc}} - v_2^{\gamma,dec}}{R_\gamma - 1}$$

- Large v_2 for $p_\mathrm{T} < 3$ GeV/c, comparable to hadron flow (for 20-40% - too large uncertainties for conclusions)
- Hydro models underpredict direct photon flow → models need further development, hint for late direct photons production, and early flow formation





Phys. Lett. B 789 (2019) 308-322

Conclusions

- Neutral meson spectra in pp, p-Pb and Pb-Pb collisions measured to large p_{T} constrain models
- Direct photons confirm creation of hot matter in Pb-Pb collisions with significant collective expansion

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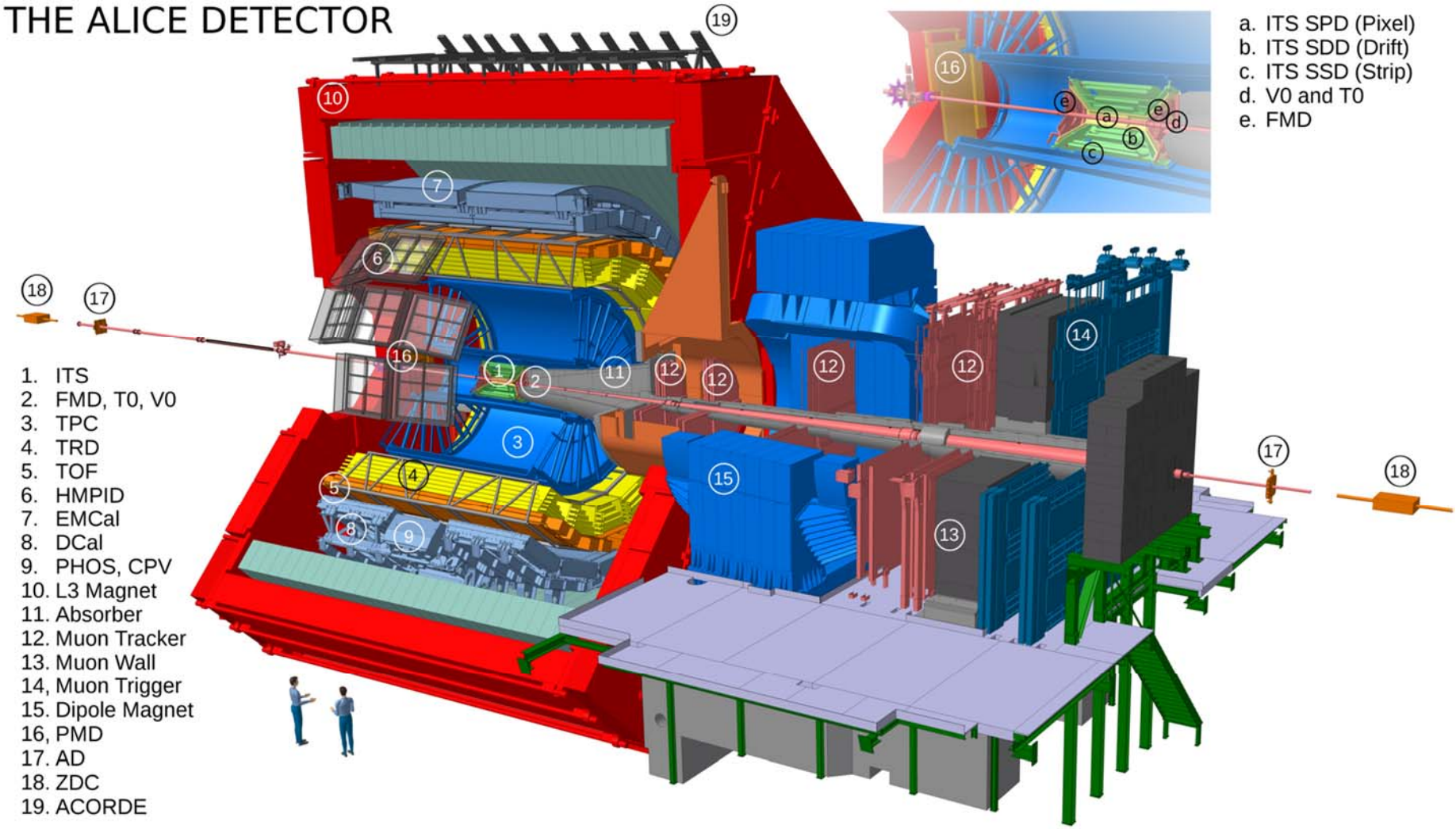
Backup slides

The ALICE experiment at the LHC

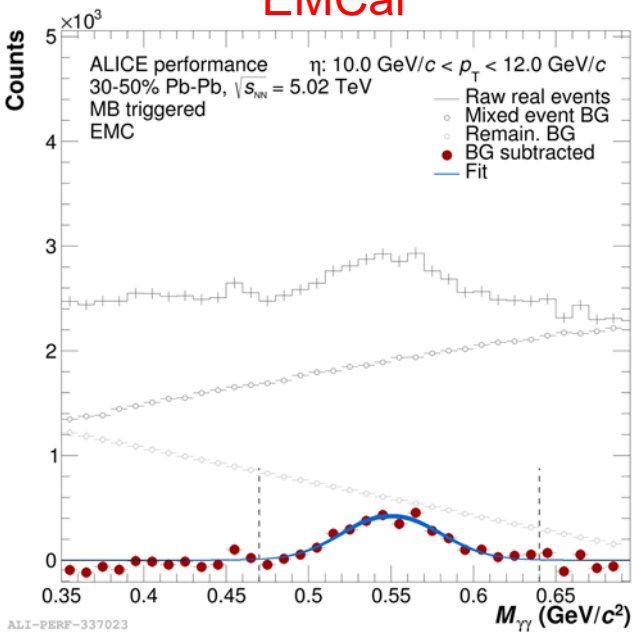


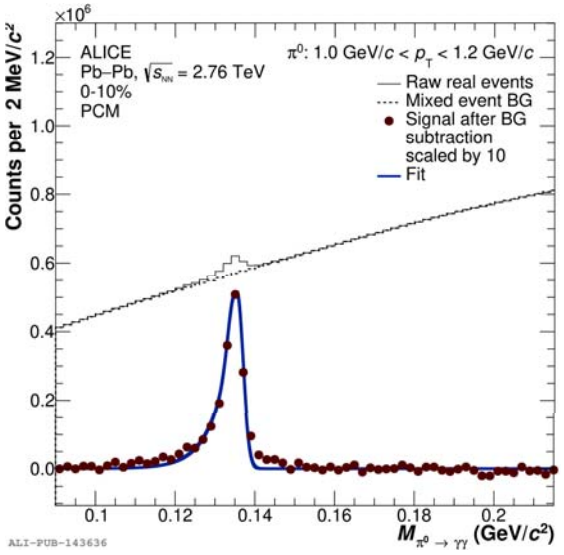
- ALICE is designed to study the quark-gluon plasma (QGP)
- Good tracking and PID capabilities are supplemented with electromagnetic-probe measurements with the help of EMCal and PHOS
- Two long data taking periods: 2010-2013 (Run 1) and 2015-2018 (Run 2). Comprehensive studies on hot QCD matter in pp, pA and AA collisions at LHC energies

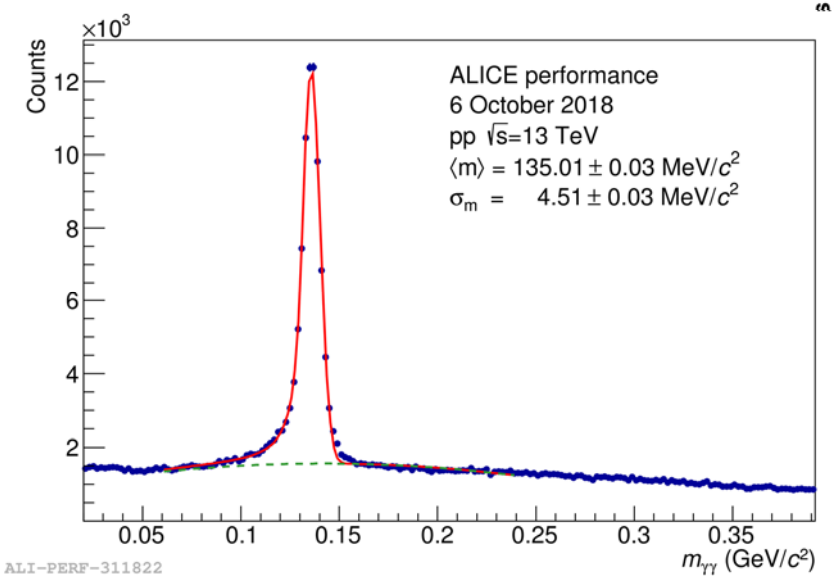
Physics performance: neutral meson measurements

- PHOS, EMCAL, PCM are able to reconstruct neutral mesons in low and high multiplicity environments down to low p_T
- Excellent precision and p_T range thanks to combination of all methods

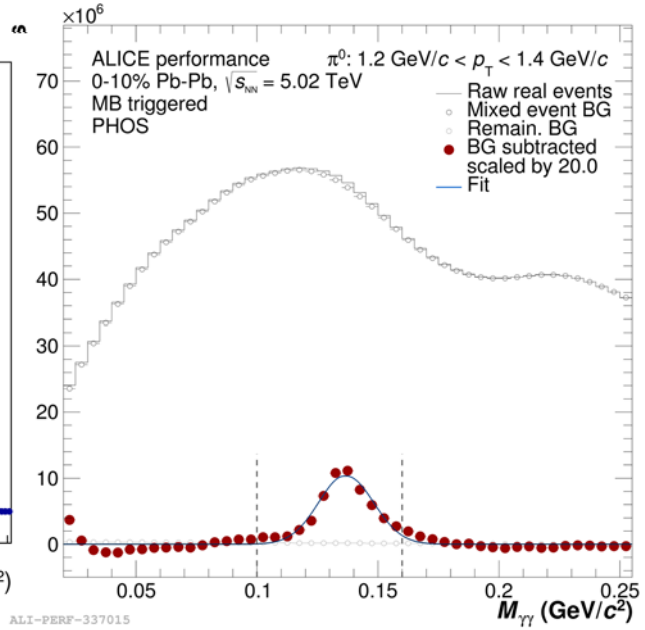
EMCal







PCM

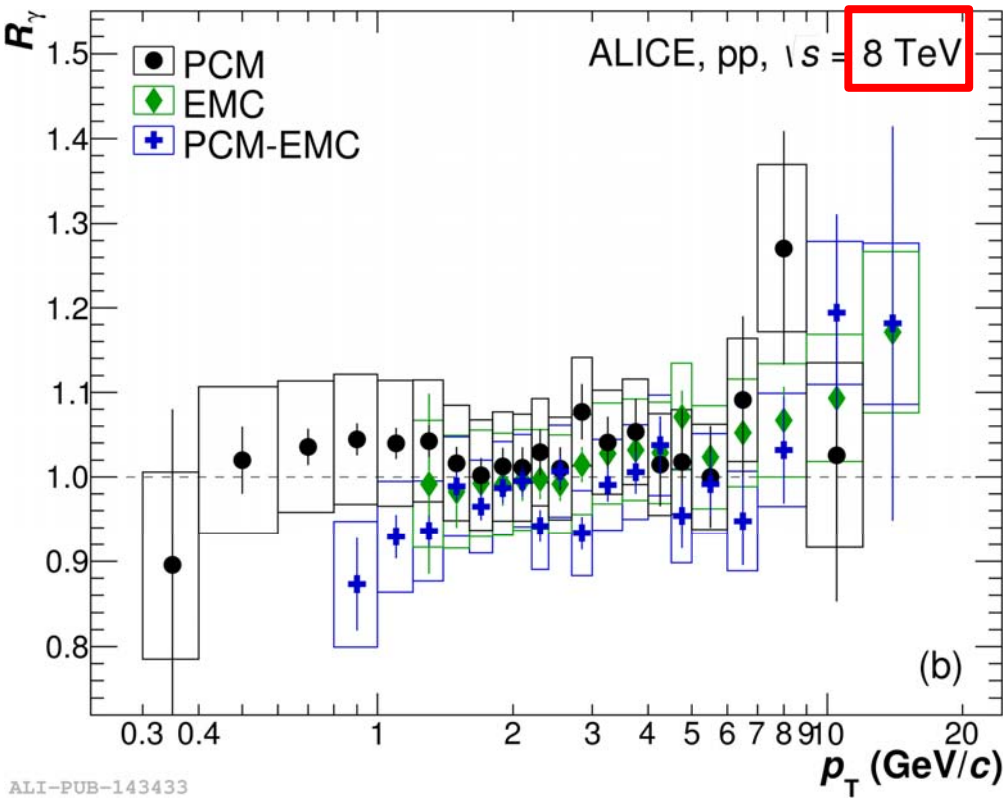


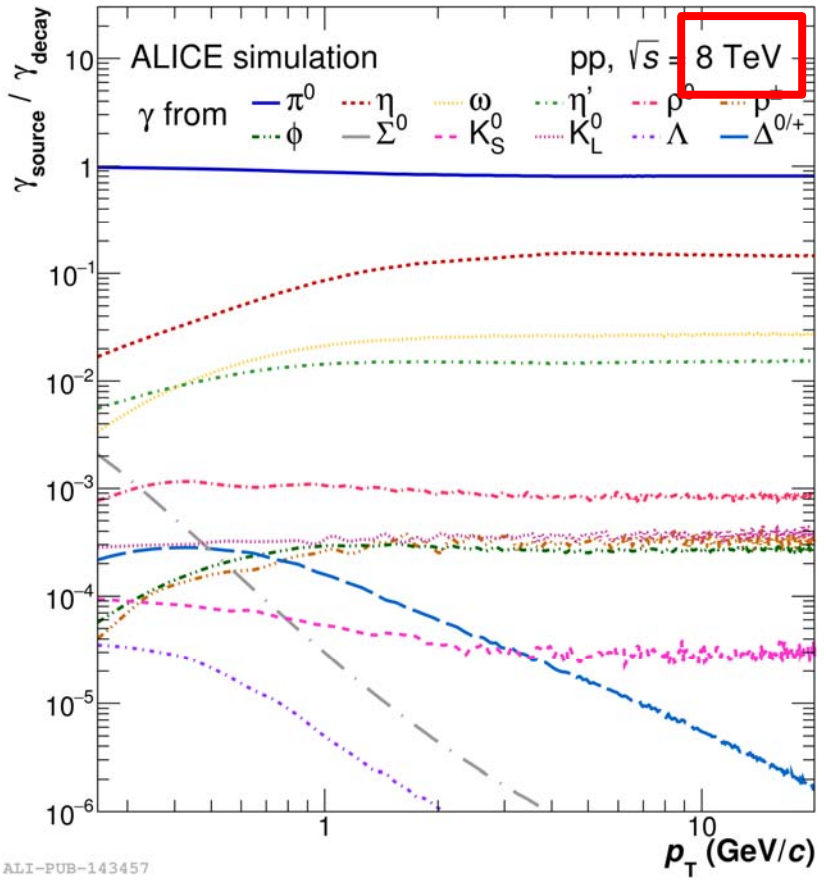
PHOS

Direct photons in pp collisions

- Proton-proton collisions at $\sqrt{s} = 2.76$ and 8 TeV are analyzed
- PCM, EMCal and PCM-EMC methods are used

Systematic uncertainties of individual meas. are dominated by p_T-independent ones: material budget unc. of 4.5% PCM, 2.8% EMC





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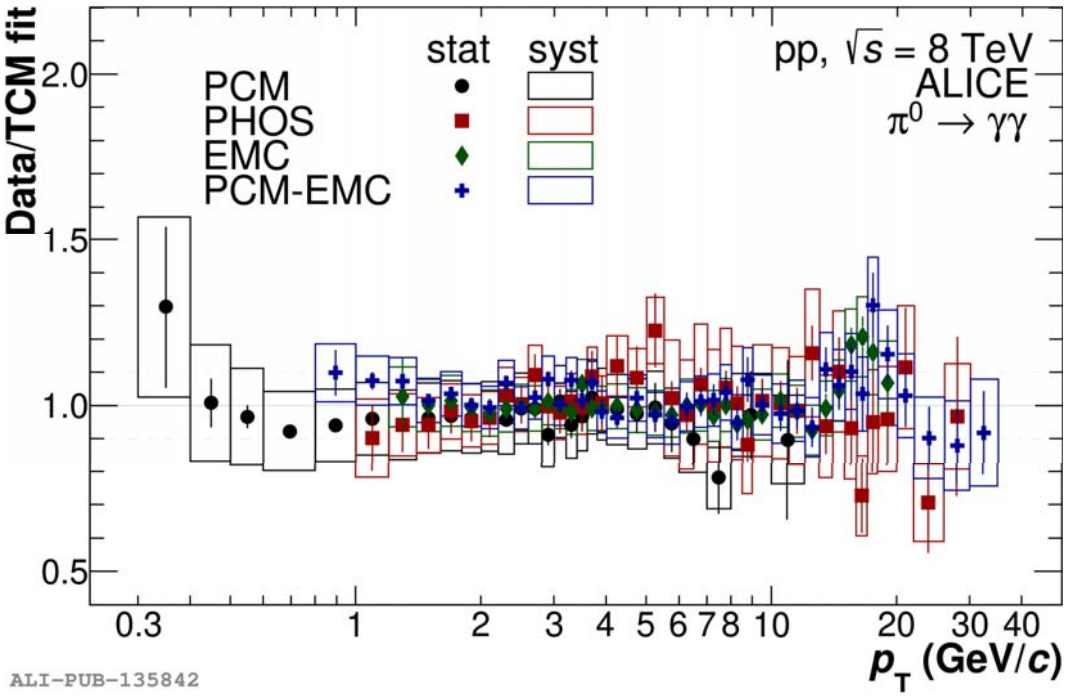
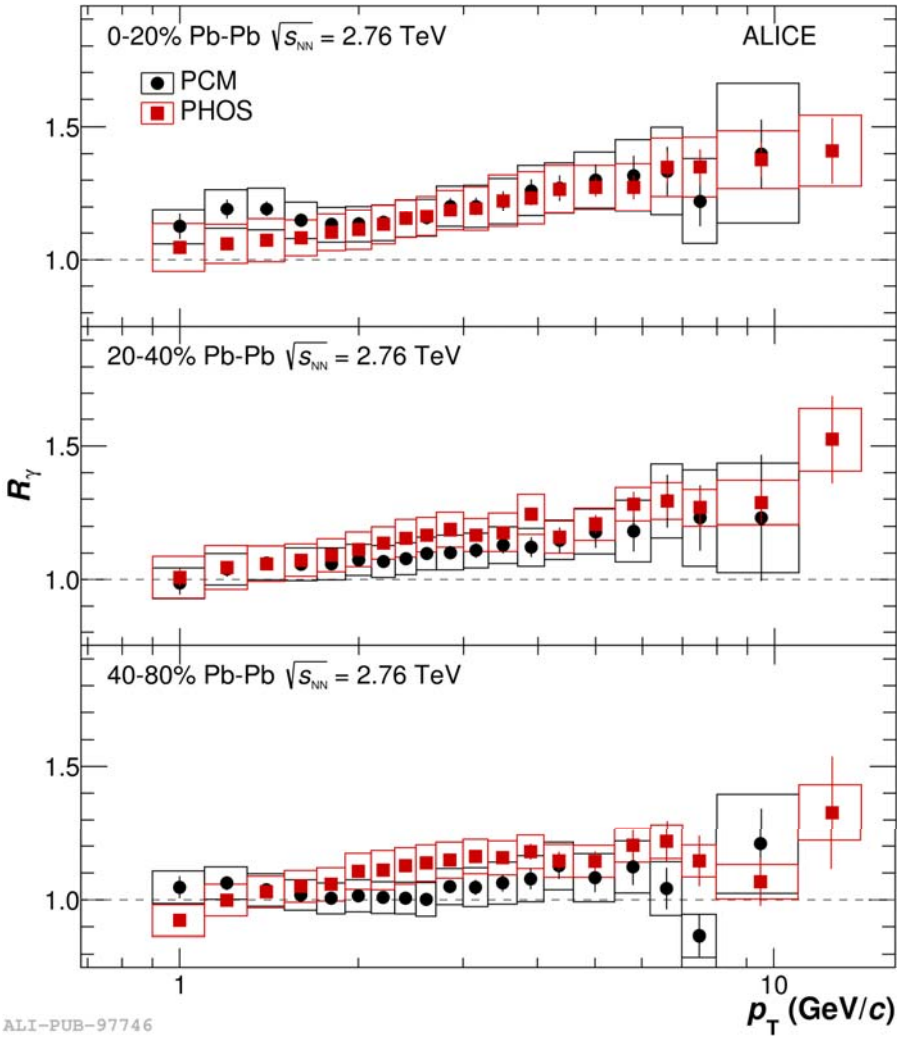
Comparison of methods

- Different measurements produce consistent results

Neutral mesons

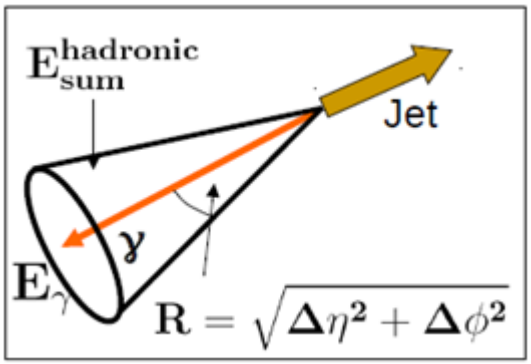


Direct photons in Pb-Pb

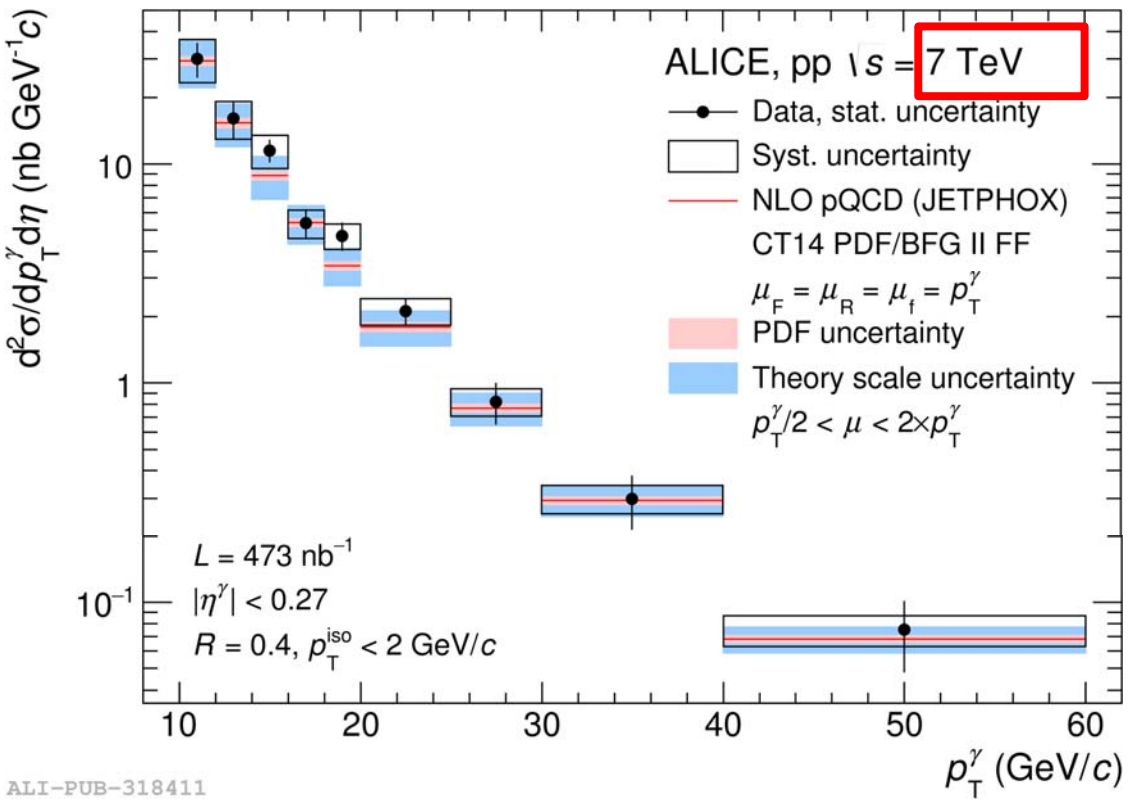


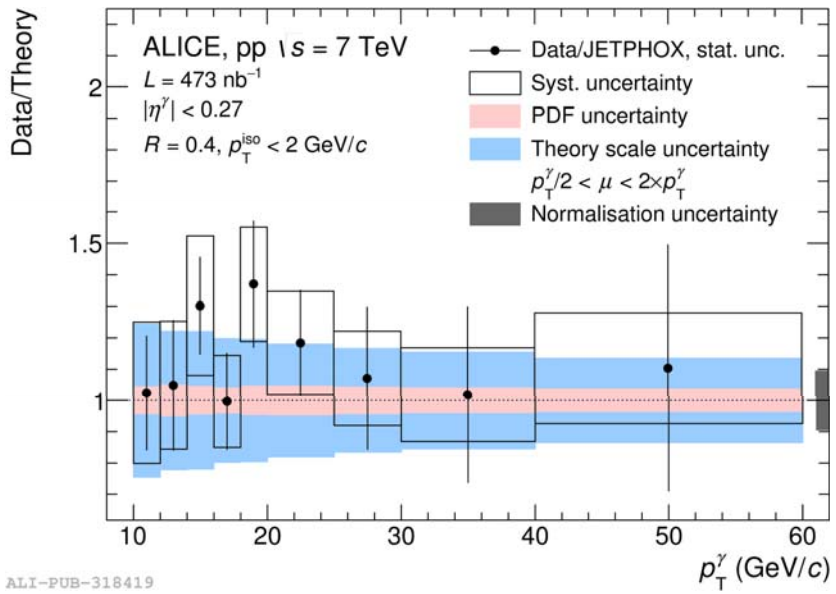
Isolated photons in pp collisions

- Access to direct prompt photons through isolation techniques
- Lower p_{T} (10 GeV/c) reach compared to other LHC experiments
- The measurements are consistent with NLO pQCD predictions



$$p_{\mathrm{T}}^{\mathrm{iso}} = \sum p_{\mathrm{T}}^{\mathrm{cluster}} + \sum p_{\mathrm{T}}^{\mathrm{track}} < 2\ \mathrm{GeV}/c$$



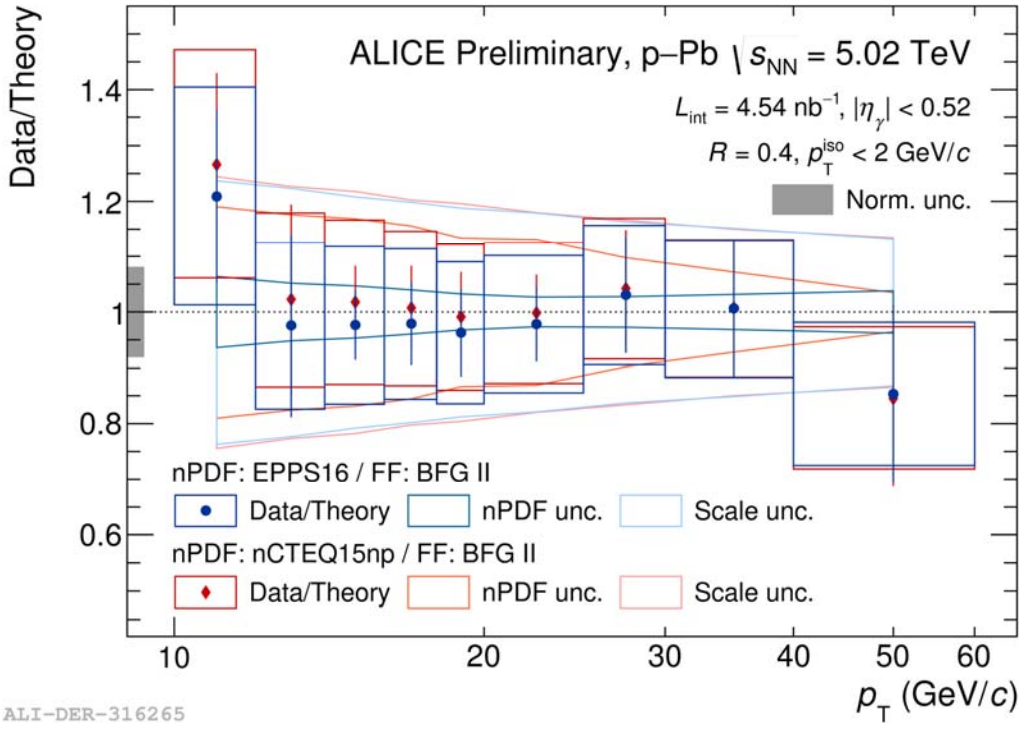


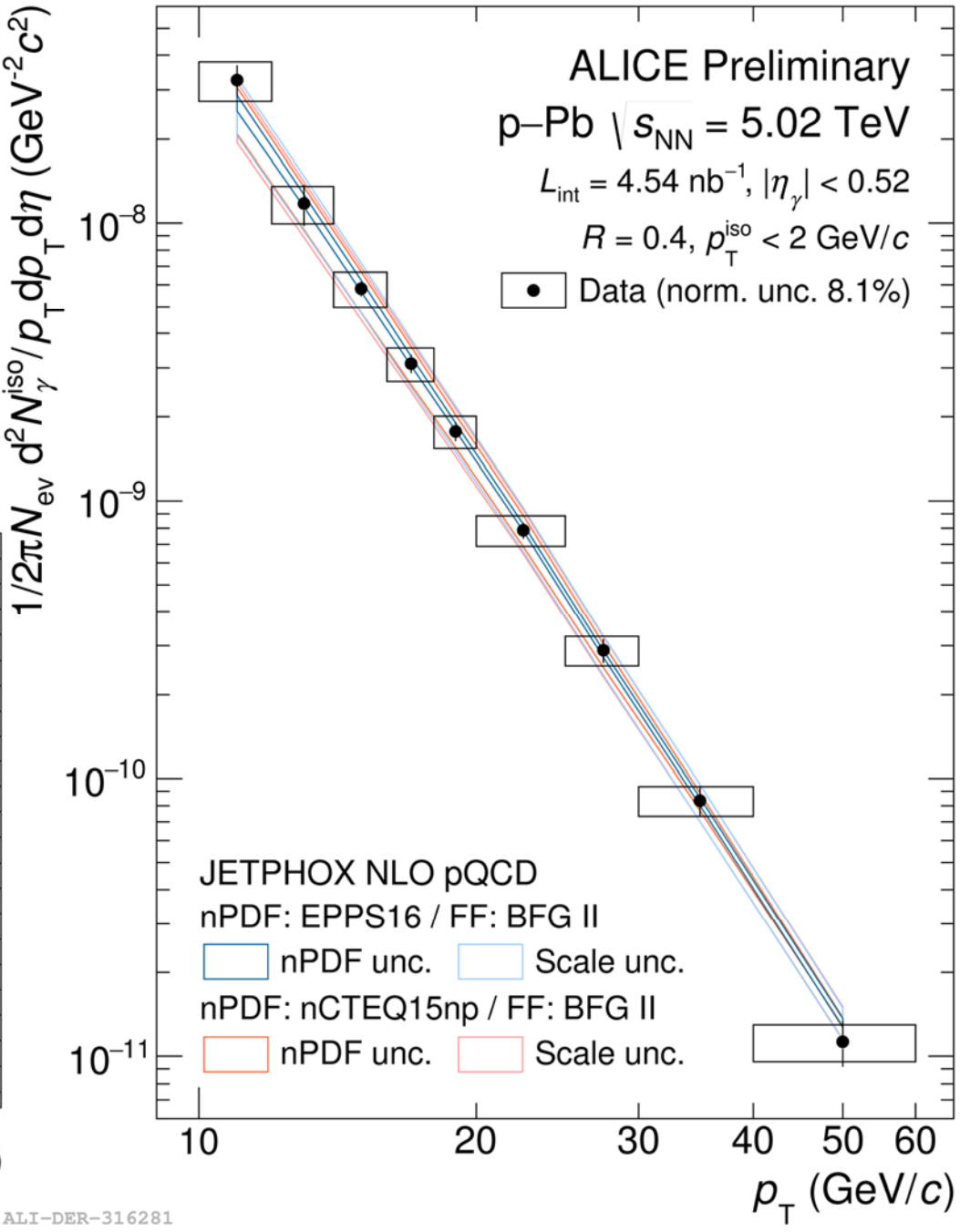
Eur. Phys. J. C (2019) 79: 896

Isolated photons in p-Pb collisions

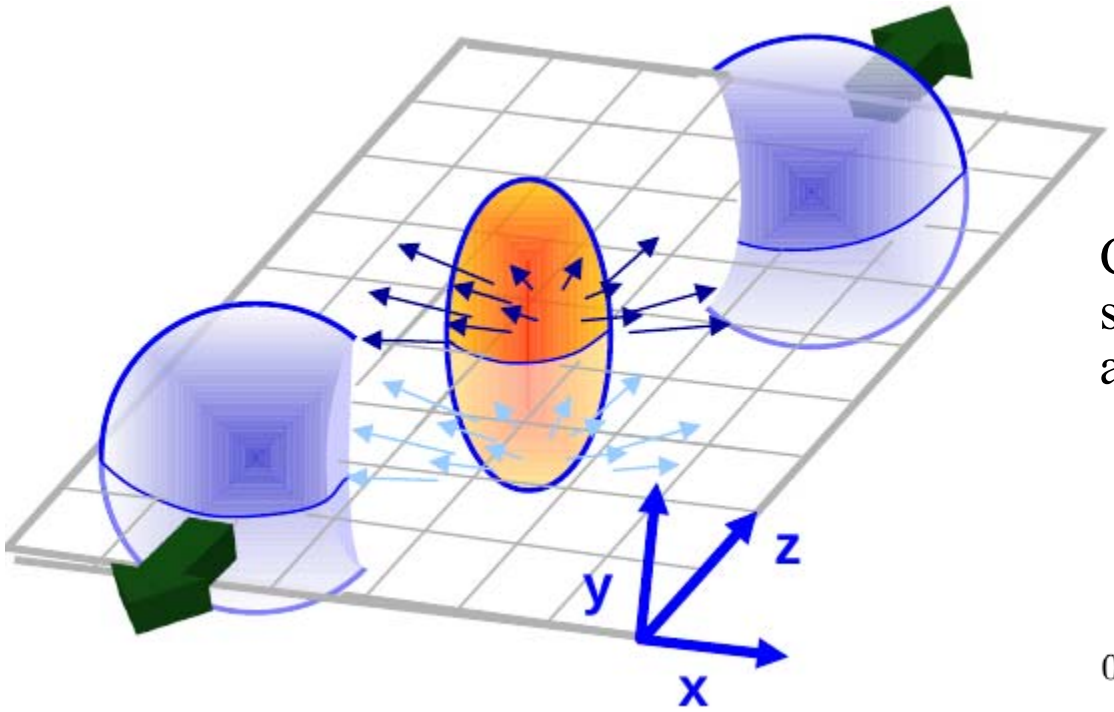
- Isolated photons production was also measured in p-Pb at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV
- The spectrum is also consistent with NLO pQCD predictions

$$p_{\mathrm{T}}^{\mathrm{iso}} - \mathrm{UE} < 2\ \mathrm{GeV}/c$$



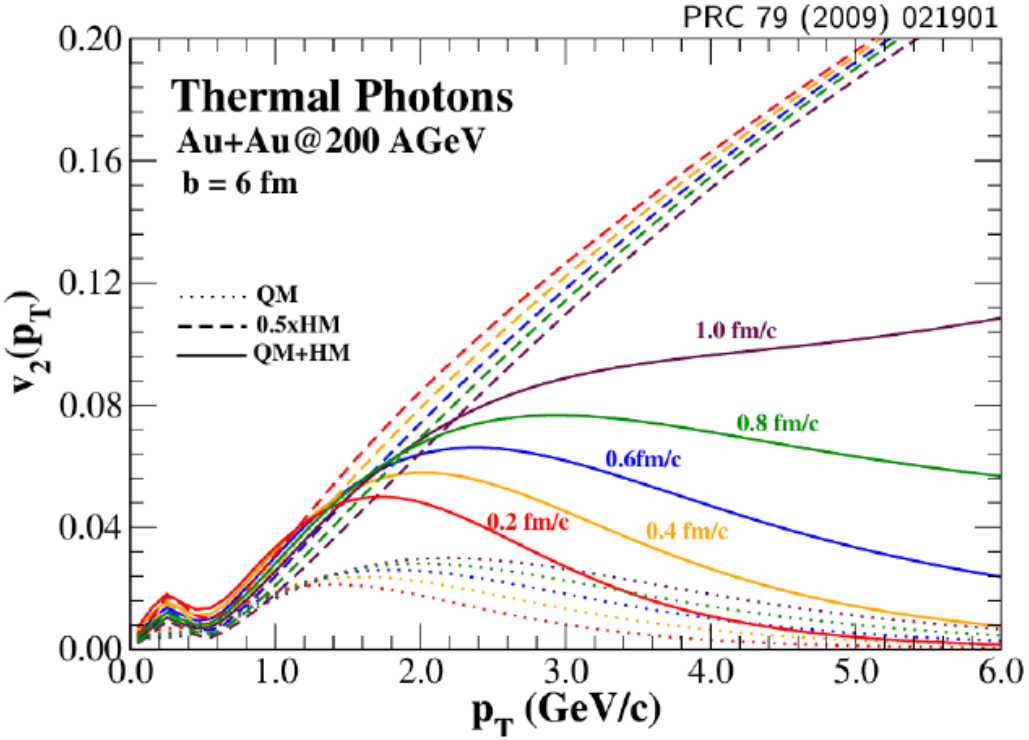


Direct photon flow – an unsolved puzzle?



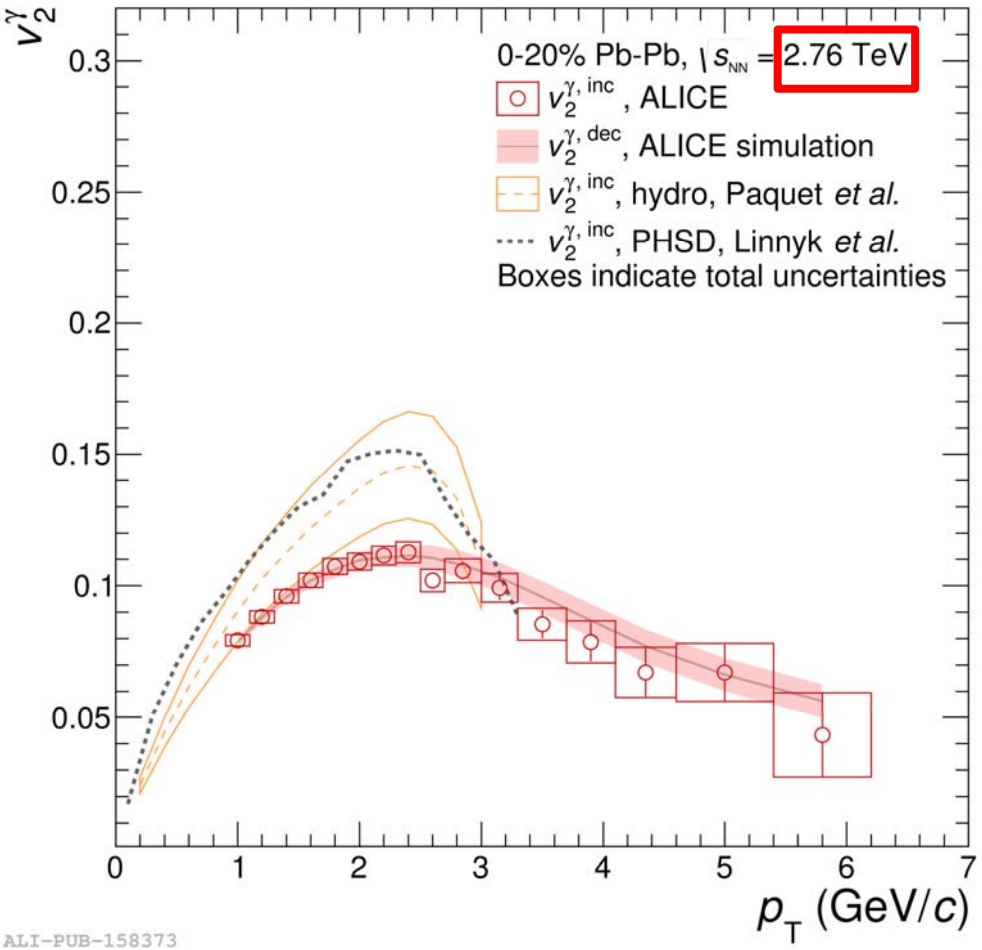
Collective expansion transforms initial spatial asymmetry of fireball to asymmetry in momentum space

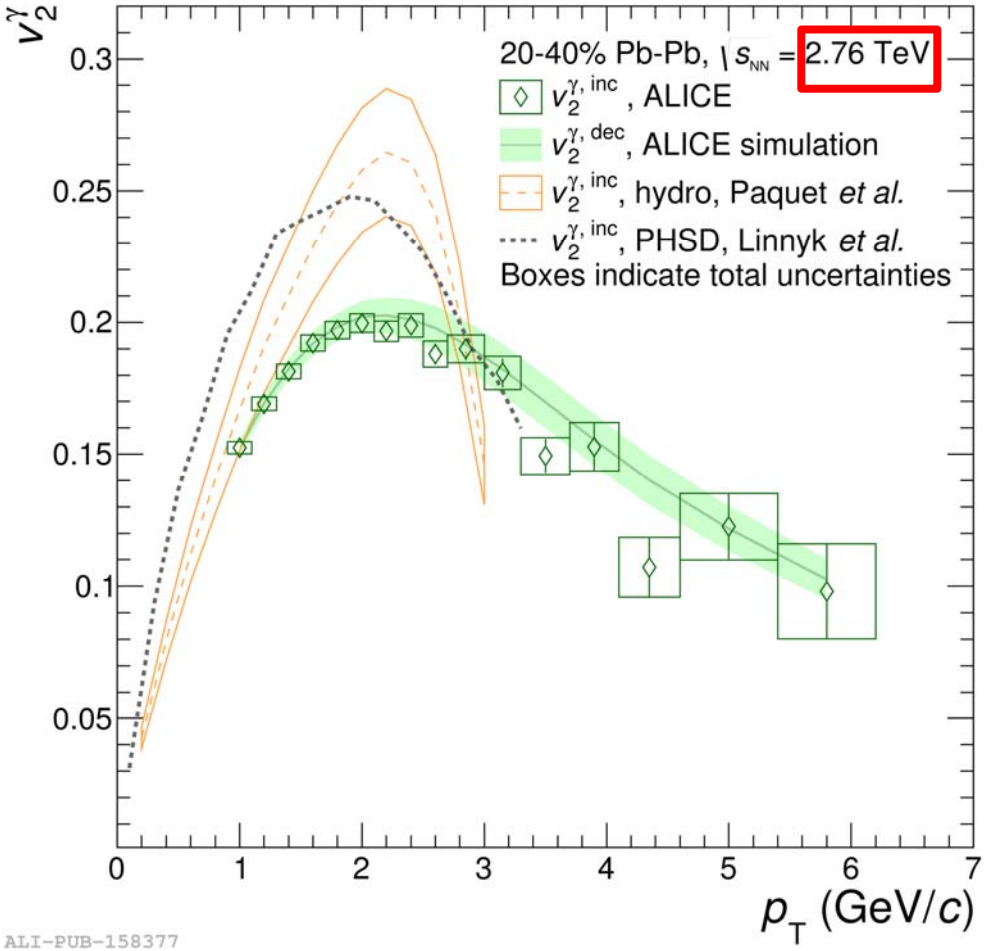
Thermal photons, emitted early from hotter fireball carry smaller collective flow than those, emitted at later stages
=> one can test development of collective flow with direct photons



Direct photon flow in Pb-Pb collisions

- Measurements are done with PCM and PHOS
- Inclusive gamma v_2:
  - ${v_2}^{\gamma\,\mathrm{inc}} = {v_2}^{\gamma\,\mathrm{dec}} \Rightarrow$ Either no contribution of γ_{dir} or ${v_2}^{\gamma\,\mathrm{dir}} = {v_2}^{\gamma\,\mathrm{dec}}$
  - Theory predicts $\sim 30 - 40\%$ higher flow





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