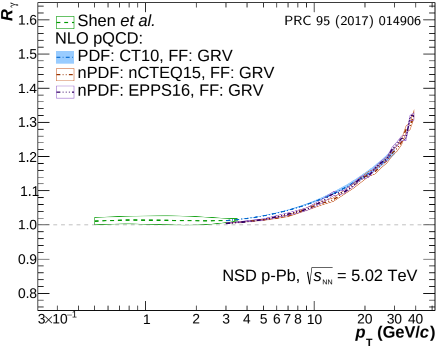
Direct Photon Production at low p_T at the LHC

Friederike Bock for the ALICE Collaboration, CERN

ECT* workshop 2018: Electromagnetic Radiation from Hot and Dense Hadronic Matter, Trento, Italy

Run:295587
Timestamp:2018-11-08 22:47:20(UTC)
System: Pb-Pb
Energy: 5.02 TeV



γ created during entire space time evolution after collision, leave medium unaffected
$\Rightarrow$ ideal probe

pp, p–Pb & Pb–Pb collisions

Prompt Photons

- Calculable within NLO pQCD
- Test of binary scaling in p–Pb & Pb–Pb at high p_T
- Not affected by collective expansion

Additional sources Pb–Pb (p–Pb, pp?) collisions

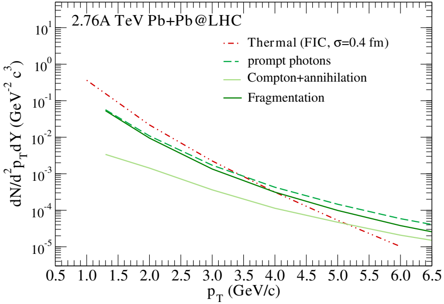
Thermal Photons

- Scattering of thermalized particles
- Exponentially decreasing, dominant at low p_T
- Susceptible to flow evolution

Jet-Medium Interactions

- Scattering of hard partons with thermalized partons
- In-medium (photon) bremsstrahlung emitted by quarks
- Possibly affected by flow evolution

PRC 88 (2013) 034901



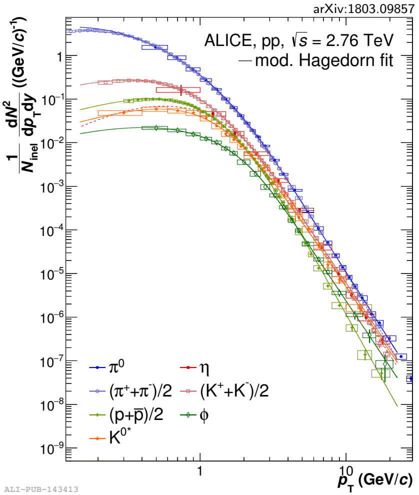
Direct Photon Extraction

Subtraction Method:

$$\gamma_{\text{direct}} = \gamma_{\text{inc}} - \gamma_{\text{decay}} = \left(1 - \frac{\gamma_{\text{decay}}}{\gamma_{\text{inc}}}\right) \cdot \gamma_{\text{inc}}$$

$$= \left(1 - \frac{1}{R_\gamma}\right) \cdot \gamma_{\text{inc}}$$

- Inclusive photons: measure all photons that are produced
- Decay photons: calculated by decay simulation from measured or m_{T} scaled particle spectra



Double Ratio:

$$R_\gamma = \frac{\gamma_{\text{inc}}}{\pi^0} \Big/ \frac{\gamma_{\text{decay}}}{\pi^0_{\text{param}}} \qquad \text{if } > 1 \text{ direct photon signal}$$

Numerator: Measured inclusive γ spectrum per π^0 Denominator: Estimated sum of all decay photons per π^0

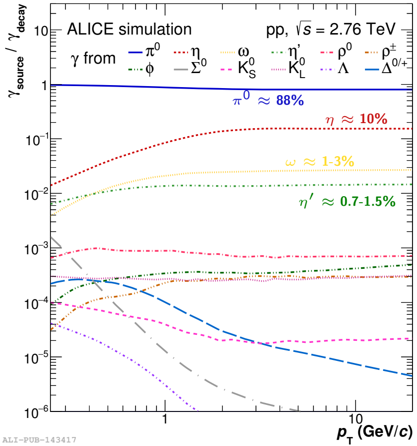
$\rightarrow$ advantage of ratio method: cancellation of some large uncertainties

Subtraction Method:

$$\gamma_{\text{direct}} = \gamma_{\text{inc}} - \gamma_{\text{decay}} = \left(1 - \frac{\gamma_{\text{decay}}}{\gamma_{\text{inc}}}\right) \cdot \gamma_{\text{inc}}$$
$$= \left(1 - \frac{1}{R_\gamma}\right) \cdot \gamma_{\text{inc}}$$

- Inclusive photons: measure all photons that are produced
- Decay photons: calculated by decay simulation from measured or m_T scaled particle spectra

arXiv:1803.09857



Double Ratio:

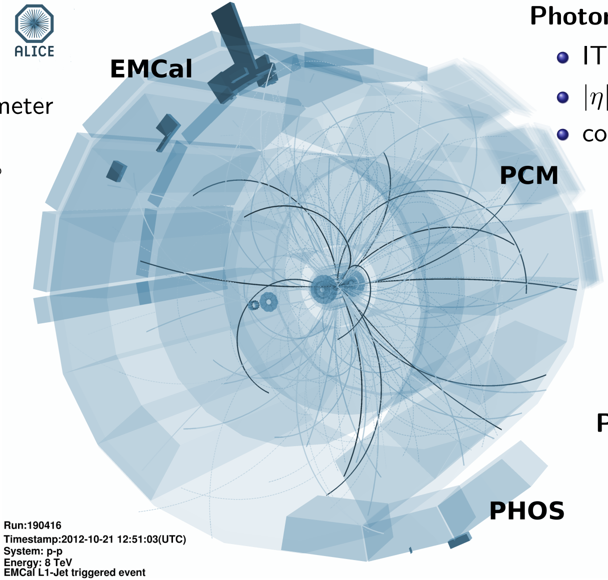
$$R_\gamma = \frac{\gamma_{\text{inc}}}{\pi^0} \Big/ \frac{\gamma_{\text{decay}}}{\pi^0_{\text{param}}} \quad \text{if } > 1 \text{ direct photon signal}$$

Numerator: Measured inclusive γ spectrum per π^0 Denominator: Estimated sum of all decay photons per π^0

$\rightarrow$ advantage of ratio method: cancellation of some large uncertainties

EMCal calorimeter

- Pb/scintillator sampling calorimeter
- $|\eta| < 0.7$, $80^\circ < \varphi < 180^\circ$



Photon Conversion Method (PCM)

- ITS and TPC
- $|\eta| < 0.9$, $0^\circ < \varphi < 360^\circ$
- conversion in detector material
  - $X/X_0 = (11.4 \pm 0.5)\%$
  - conv. probability $\sim 8\%$

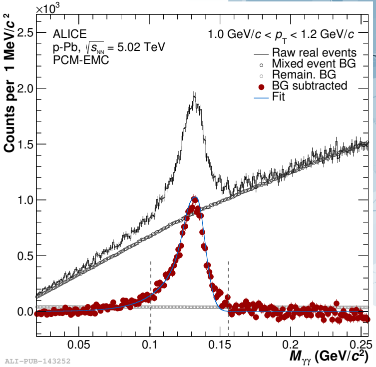
PHOS calorimeter

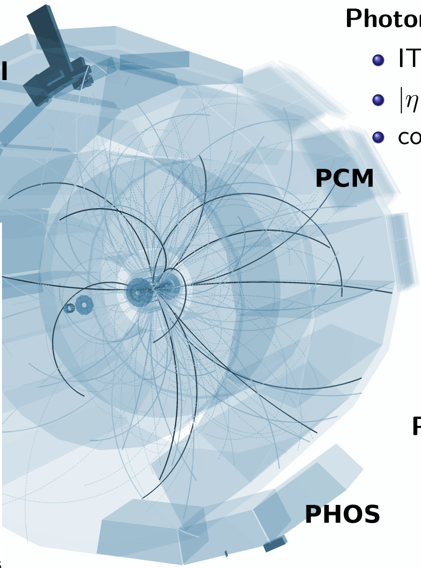
- $PbWO_4$ crystals
- $|\eta| < 0.12$, $260^\circ < \varphi < 320^\circ$ (2009-2013)

EMCal calorimeter

- Pb/scintillator sampling calorimeter
- $|\eta| < 0.7$, $80^\circ < \varphi < 180^\circ$

arXiv:1801.07051





Photon Conversion Method (PCM)

- ITS and TPC
- $|\eta| < 0.9$, $0^\circ < \varphi < 360^\circ$
- conversion in detector material
  - $X/X_0 = (11.4 \pm 0.5)\%$
  - conv. probability $\sim 8\%$

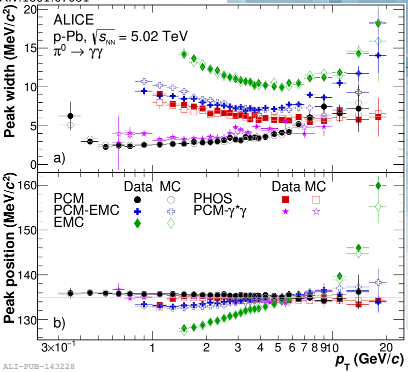
PHOS calorimeter

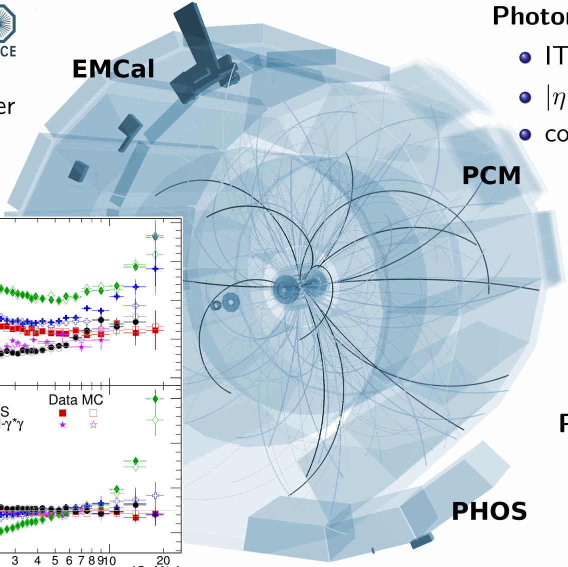
- $PbWO_4$ crystals
- $|\eta| < 0.12$, $260^\circ < \varphi < 320^\circ$ (2009-2013)

EMCal calorimeter

- Pb/scintillator sampling calorimeter
- $|\eta| < 0.7$, $80^\circ < \varphi < 180^\circ$

arXiv:1801.07051





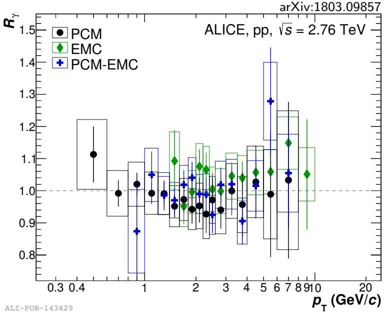
Photon Conversion Method (PCM)

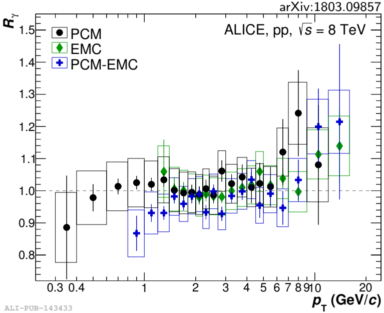
- ITS and TPC
- $|\eta| < 0.9$, $0^\circ < \varphi < 360^\circ$
- conversion in detector material
  - $X/X_0 = (11.4 \pm 0.5)\%$
  - conv. probability $\sim 8\%$

PHOS calorimeter

- $PbWO_4$ crystals
- $|\eta| < 0.12$, $260^\circ < \varphi < 320^\circ$ (2009-2013)

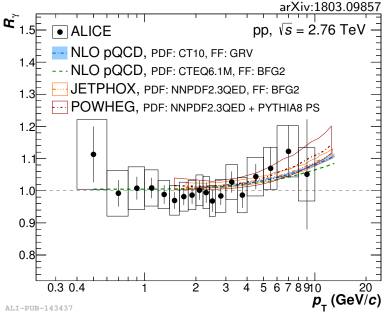
Direct Photons in pp

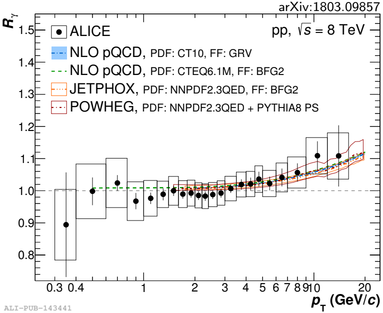


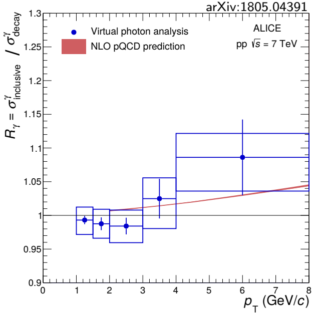


- Systematic uncertainties of individual meas.
  $\rightarrow$ dominated by p_T-independent
  material unc. of 4.5% PCM & 2.8% EMC
- p_T reach
  - $0.4 < p_T < 10$ GeV/c in pp, $\sqrt{s} = 2.76$ TeV
  - $0.3 < p_T < 14$ GeV/c in pp, $\sqrt{s} = 8$ TeV
- Combination of 3 reconstruction techniques via
  BLUE method

Direct Photons in pp







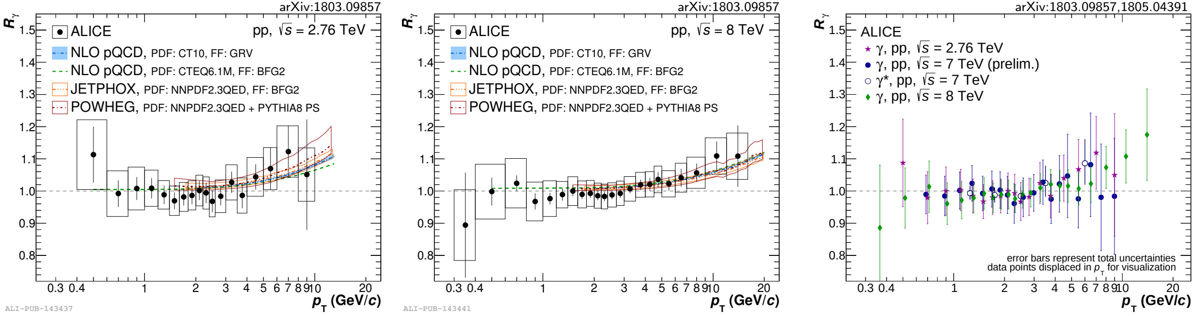
- Systematic uncertainties of individual meas.
  $\rightarrow$ dominated by p_T-independent material unc. of 4.5% PCM & 2.8% EMC
- p_T reach
  - $0.4 < p_T < 10$ GeV/c in pp, $\sqrt{s} = 2.76$ TeV
  - $0.3 < p_T < 14$ GeV/c in pp, $\sqrt{s} = 8$ TeV
- Combination of 3 reconstruction techniques via BLUE method

- Within uncertainties no significant excess at low p_T observed for real or virtual photons

$\rightarrow$ supports interpretation in Pb–Pb as medium effects

- About $1 - 2\sigma$ deviation from unity for $p_T > 7$ GeV/c
- All pp results at LHC with similar uncertainties

Direct Photons in pp



- Systematic uncertainties of individual meas. $\rightarrow$ dominated by p_{T}-independent material unc. of 4.5% PCM & 2.8% EMC
- p_{T} reach
  - $0.4 < p_{\mathrm{T}} < 10$ GeV/c in pp, $\sqrt{s} = 2.76$ TeV
  - $0.3 < p_{\mathrm{T}} < 14$ GeV/c in pp, $\sqrt{s} = 8$ TeV
- Combination of 3 reconstruction techniques via BLUE method

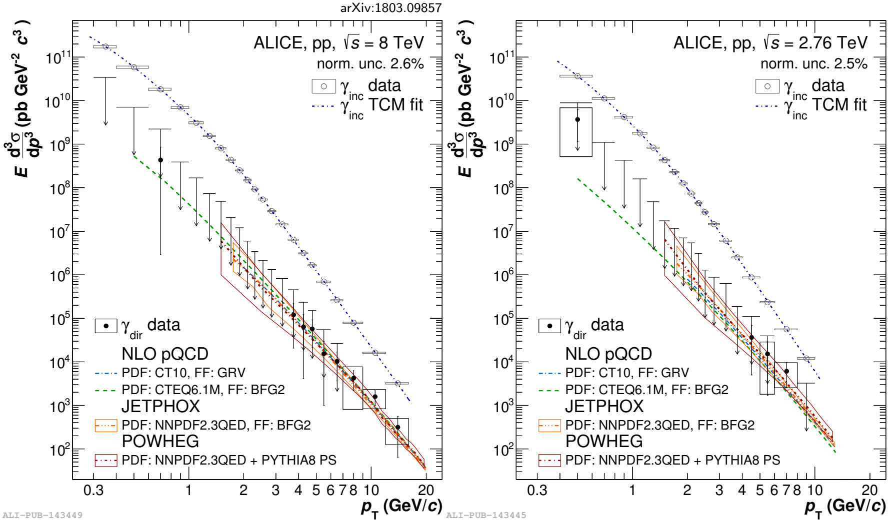
- Within uncertainties no significant excess at low p_{T} observed for real or virtual photons

$\rightarrow$ supports interpretation in Pb–Pb as medium effects

- About $1 - 2\sigma$ deviation from unity for $p_{\mathrm{T}} > 7$ GeV/c
- All pp results at LHC with similar uncertainties

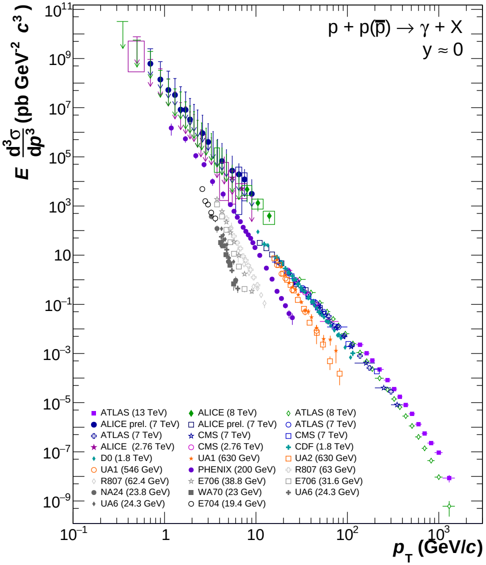
Direct Photons in pp

- Upper limits at 90% C.L. (arrows) determined where R_γ with total uncertainties consistent with unity
- NLO calculations consistent with measurements at all pp energies



Theory calculations from:
W. Vogelsang (CT10,nCTEQ15,EPPS16/GRV), J.F. Paquet (CTEQ6.1M/BFG), JETPHOX, POWHEG

Direct Photons in pp($\bar{\text{p}}$) collisions



Can we learn something more from comparing to other energies?

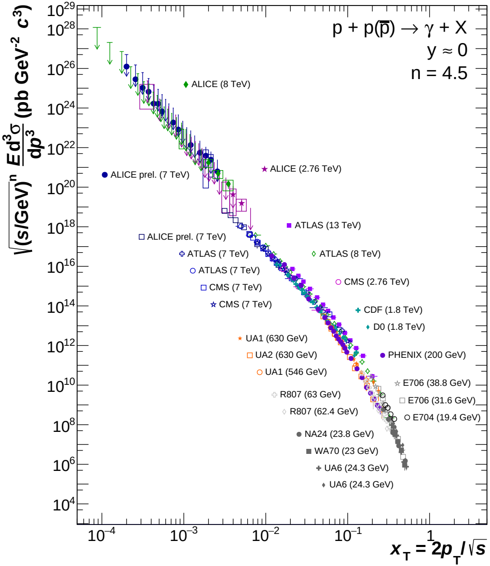
- Large variety of results available from $\sqrt{s} = 19.4$ GeV - 13 TeV for (isolated) direct photons
- Decent agreement at large $\sqrt{s}$ & high p_T between pQCD & data
- All pp data seem to align on a common x_T-curve within $\pm(20-50)\%$, if scaled with $(\sqrt{s})^n$ with **n = 4.5**
- Intriguing number:

→ Pure vector gluon exchange: $n = 4$

→ Scale breaking effects in QCD could increase this number

→ Closer look needed if data could be described even better by slightly different **n** - could help to pin down prompt photon contribution even at low p_T

Direct Photons in pp($\bar{\text{p}}$) collisions



Can we learn something more from comparing to other energies?

- Large variety of results available from $\sqrt{s} = 19.4$ GeV - 13 TeV for (isolated) direct photons
- Decent agreement at large $\sqrt{s}$ & high p_T between pQCD & data
- All pp data seem to align on a common x_T-curve within $\pm(20-50)\%$, if scaled with $(\sqrt{s})^n$ with $\mathbf{n = 4.5}$
- Intriguing number:

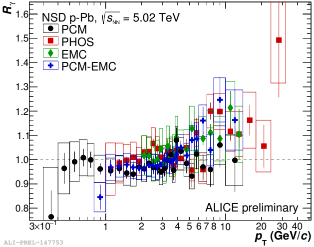
→ Pure vector gluon exchange: $n = 4$

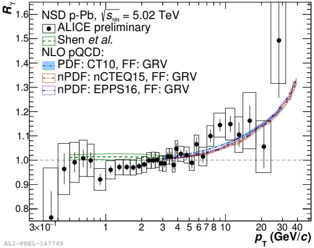
→ Scale breaking effects in QCD could increase this number

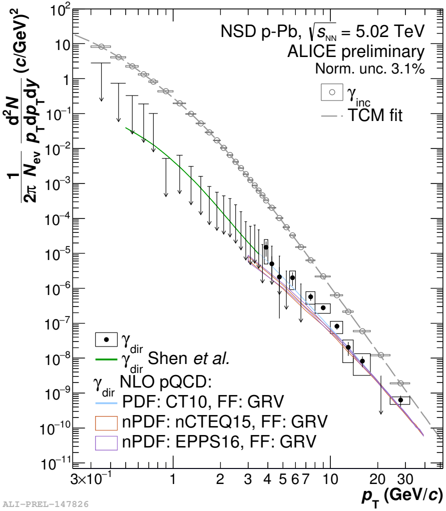
→ Closer look needed if data could be described even better by slightly different **n** - could help to pin down prompt photon contribution even at low p_T

Direct Photons in p–Pb at LHC at low p_T?

- Combination of 4 reconstruction techniques via BLUE method
- Individual sys uncertainties O(5-10%), combined total O(4-5%)
- Upper limits at 90% C.L. (arrows) determined where R_γ with total uncertainties consistent with unity
- **0-20% central collisions don't show a significant excess**
- NLO & thermal (*Shen et al.*) calculations consistent with measurements





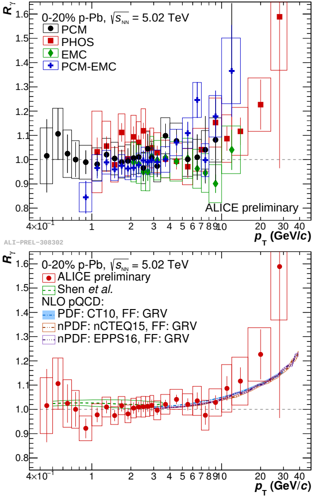


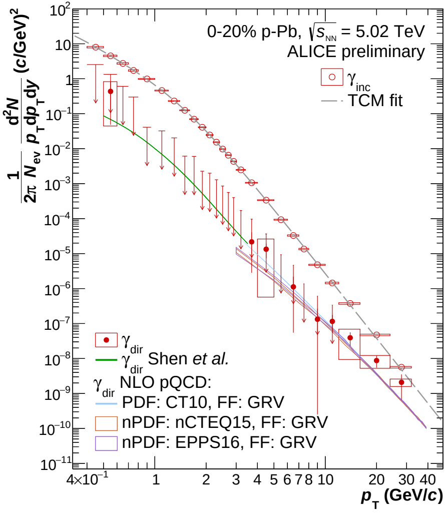
Theory calculations from:
W. Vogelsang (CT10,nCTEQ15,EPPS16/GRV), J.F. Paquet (CTEQ6.1M/BFG), C. Shen

Shen *et al.* arXiv:1609.02590

Direct Photons in p–Pb at LHC at low p_T?

- Combination of 4 reconstruction techniques via BLUE method
- Individual sys uncertainties O(5-10%), combined total O(4-5%)
- Upper limits at 90% C.L. (arrows) determined where R_γ with total uncertainties consistent with unity
- **0-20% central collisions don't show a significant excess**
- NLO & thermal *(Shen et al.)* calculations consistent with measurements



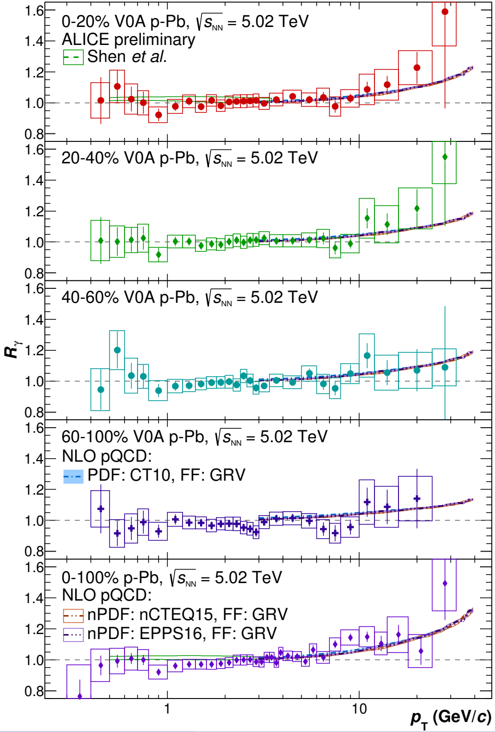


Theory calculations from:
W. Vogelsang (CT10,nCTEQ15,EPPS16/GRV), J.F. Paquet (CTEQ6.1M/BFG), C. Shen

Shen *et al.* arXiv:1609.02590

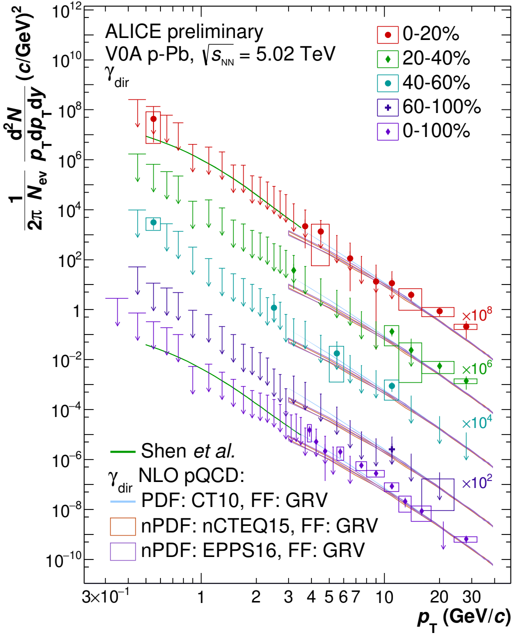
Evolution of Direct Photons in p(d)–A

- No significant photon excess seen at low p_T in any multiplicity slices in p–Pb collisions at the LHC
- N_{coll} scaling works at mid rapidity
- Possibility to use γ_{dir} at high p_T or $Z^0/W^{\pm}$ to calibrate N_{coll} for p(d)-A collisions in different multiplicity slices
  $\rightarrow$ Current ALICE data does not have sufficient statistics at high p_T
- $1/N_{coll}$ scaled spectra align with one another within 1σ for each collision energy
- x_T and $1/N_{coll}$ scaled spectra align within 20-50% on a common curve for data from $\sqrt{s_{NN}} = 0.2 - 8$ TeV



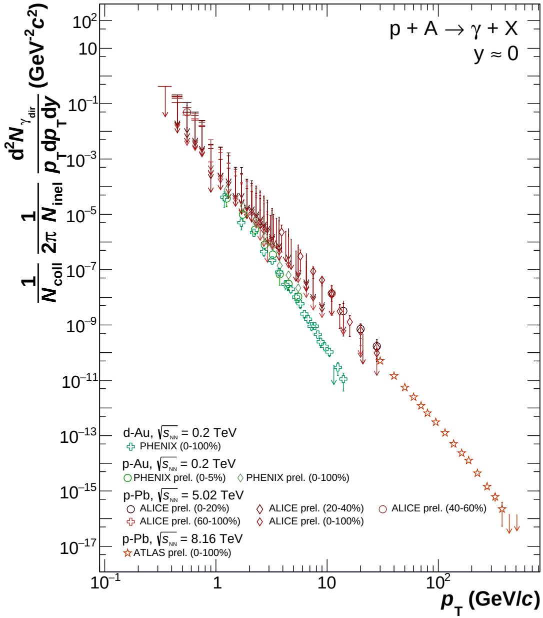
Evolution of Direct Photons in p(d)–A

- No significant photon excess seen at low p_{T} in any multiplicity slices in p–Pb collisions at the LHC
- N_{coll} scaling works at mid rapidity
- Possibility to use γ_{dir} at high p_{T} or $\mathrm{Z}^0/\mathrm{W}^{\pm}$ to calibrate N_{coll} for p(d)-A collisions in different multiplicity slices
  $\rightarrow$ Current ALICE data does not have sufficient statistics at high p_{T}
- $1/N_{\mathrm{coll}}$ scaled spectra align with one another within 1σ for each collision energy
- x_{T} and $1/N_{\mathrm{coll}}$ scaled spectra align within 20-50% on a common curve for data from $\sqrt{s_{\mathrm{NN}}} = 0.2 - 8$ TeV



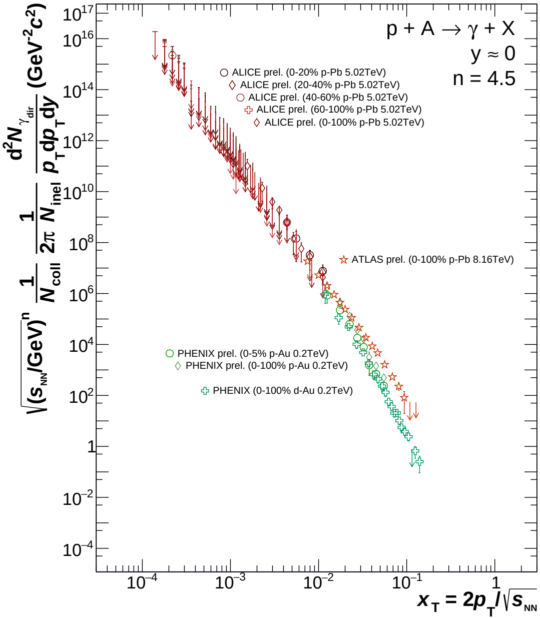
Evolution of Direct Photons in p(d)–A

- No significant photon excess seen at low p_{T} in any multiplicity slices in p–Pb collisions at the LHC
- N_{coll} scaling works at mid rapidity
- Possibility to use γ_{dir} at high p_{T} or $Z^0/W^{\pm}$ to calibrate N_{coll} for p(d)-A collisions in different multiplicity slices
  $\rightarrow$ Current ALICE data does not have sufficient statistics at high p_{T}
- $1/N_{\mathrm{coll}}$ scaled spectra align with one another within 1σ for each collision energy
- x_{T} and $1/N_{\mathrm{coll}}$ scaled spectra align within 20-50% on a common curve for data from $\sqrt{s_{\mathrm{NN}}} = 0.2 - 8$ TeV



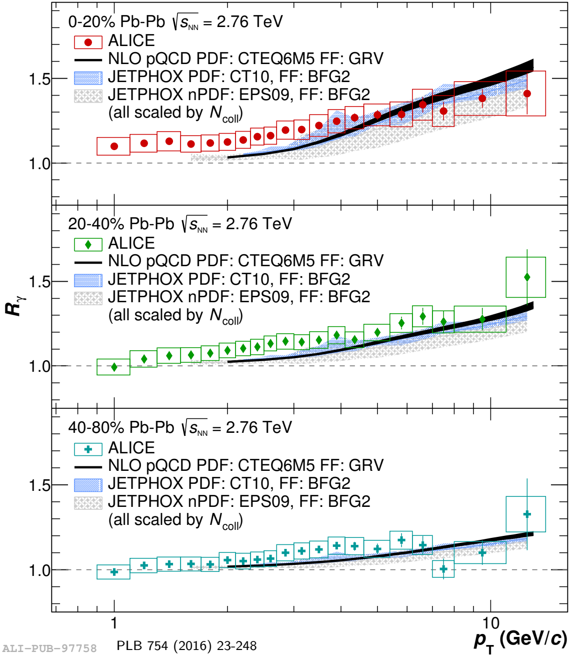
Evolution of Direct Photons in p(d)–A

- No significant photon excess seen at low p_T in any multiplicity slices in p–Pb collisions at the LHC
- N_{coll} scaling works at mid rapidity
- Possibility to use γ_{dir} at high p_T or $Z^0/W^{\pm}$ to calibrate N_{coll} for p(d)-A collisions in different multiplicity slices
  $\rightarrow$ Current ALICE data does not have sufficient statistics at high p_T
- $1/N_{coll}$ scaled spectra align with one another within 1σ for each collision energy
- x_T and $1/N_{coll}$ scaled spectra align within 20-50% on a common curve for data from $\sqrt{s_{NN}} = 0.2 - 8$ TeV



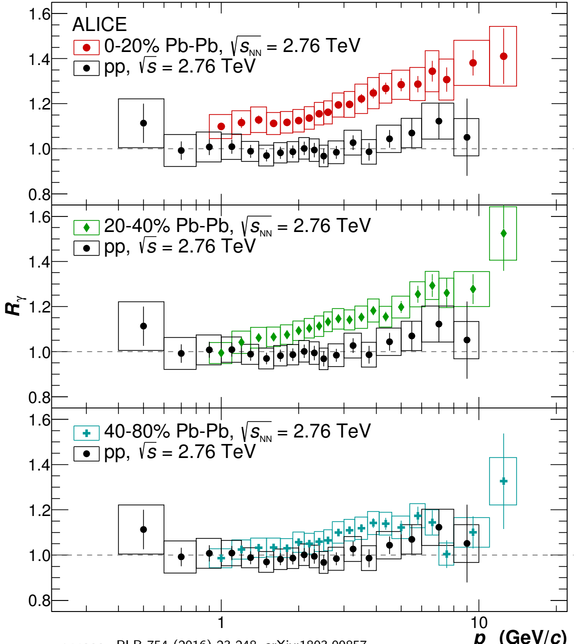
Direct Photons in Pb–Pb

- Direct photon excess measured with combined PCM + PHOS in 3 centrality classes with 2010 Pb–Pb data
- R_γ excess at high p_T for all centralities
- γ^{dec} suppressed by $\approx R_{\mathrm{AA}}^{\pi^0}$ $\rightarrow$ larger excess in central collisions
- Low p_T $\sim$ 15% excess in 0 – 20% and $\sim$ 9% in 20 – 40%
- In agreement with NLO pQCD, JETPHOX above 5 GeV/c
- No low p_T excess seen in pp collisions at same center-of-mass energy
- Scaled pp spectrum & upper limits fully consistent with Pb–Pb results



Direct Photons in Pb–Pb

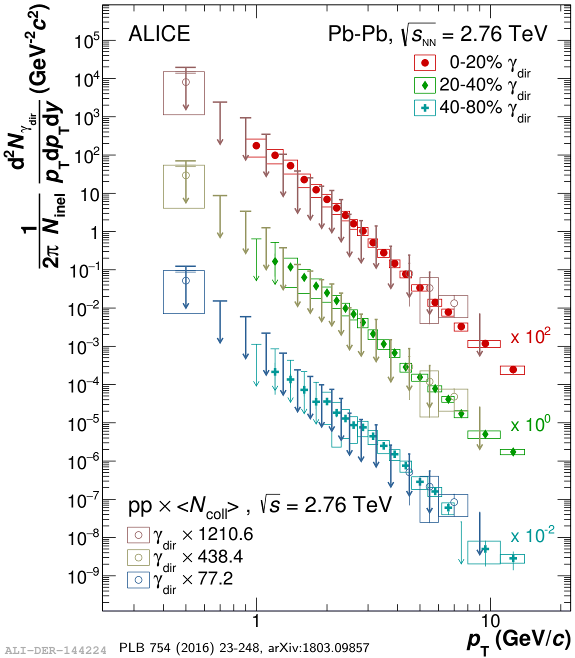
- Direct photon excess measured with combined PCM + PHOS in 3 centrality classes with 2010 Pb–Pb data
- R_γ excess at high p_T for all centralities
- γ^{dec} suppressed by $\approx R_{\mathrm{AA}}^{\pi^0}$
  $\rightarrow$ larger excess in central collisions
- Low p_T $\sim 15\%$ excess in $0-20\%$ and $\sim 9\%$ in $20-40\%$
- In agreement with NLO pQCD, JETPHOX above 5 GeV/c
- No low p_T excess seen in pp collisions at same center-of-mass energy
- Scaled pp spectrum & upper limits fully consistent with Pb–Pb results



ALI-DER-144220 PLB 754 (2016) 23-248, arXiv:1803.09857

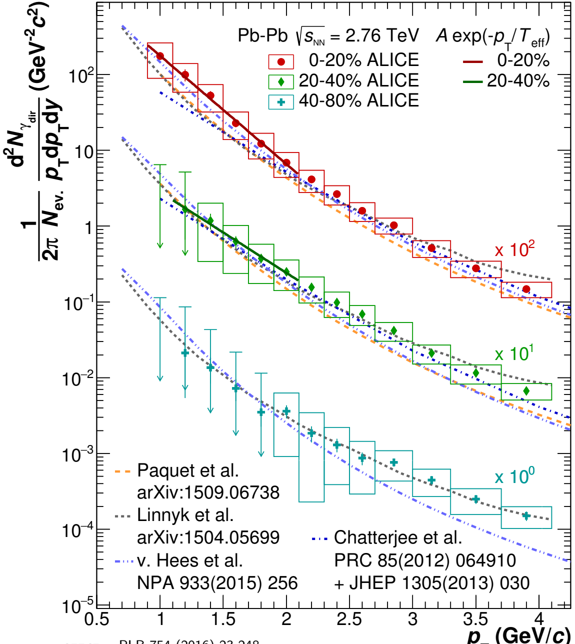
Direct Photons in Pb–Pb

- Direct photon excess measured with combined PCM + PHOS in 3 centrality classes with 2010 Pb–Pb data
- R_γ excess at high p_T for all centralities
- γ^{dec} suppressed by $\approx R^{\pi^0}_{\mathrm{AA}}$
  $\rightarrow$ larger excess in central collisions
- Low p_T $\sim$ 15% excess in 0 – 20% and $\sim$ 9% in 20 – 40%
- In agreement with NLO pQCD, JETPHOX above 5 GeV/c
- No low p_T excess seen in pp collisions at same center-of-mass energy
- Scaled pp spectrum & upper limits fully consistent with Pb–Pb results



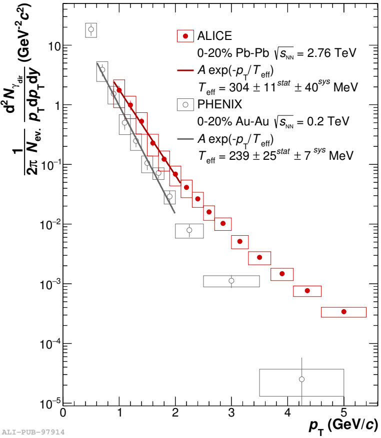
Direct Photons in Pb–Pb - Theory Comparison

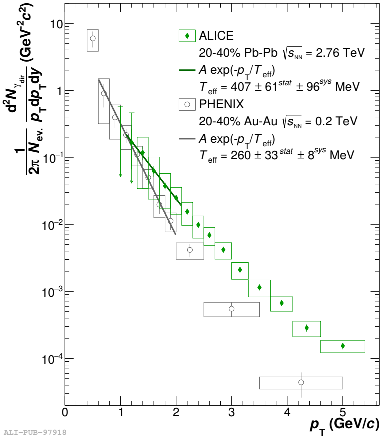
- Theoretical predictions in agreement with the data within $1-2\sigma$ for $p_{\mathrm{T}} < 4$ GeV/c
- Calculations differ by up to 50% using different hydro parameters, transport models & photon production rates in the QGP and hadron gas phase
- For all calculations a significant contribution from the hadron gas phase is necessary to simultaneously describe the $v_2^{\gamma_{\mathrm{dir}}}$ and spectra



PLB 754 (2016) 23-248

Direct Photons in A–A collisions

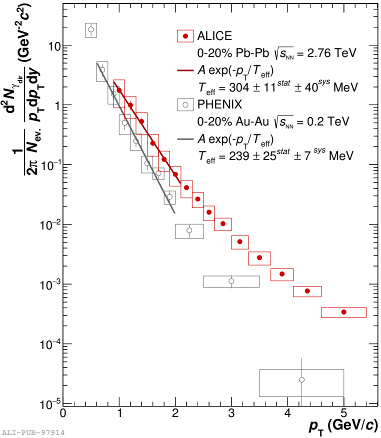


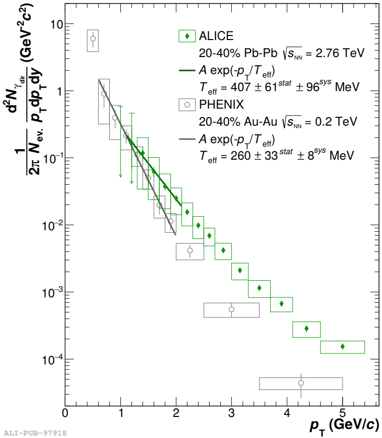


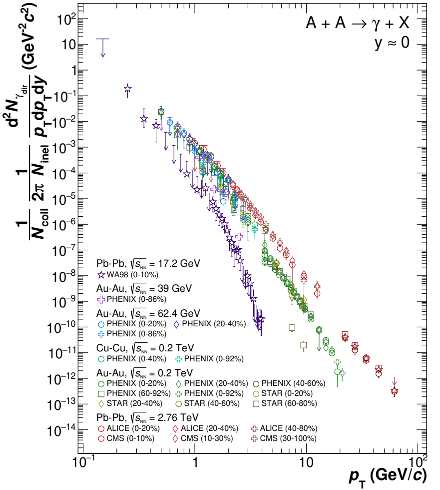
- Photon yield increased by $\approx$ factor 2 for $p_T < 3$ GeV$/c$
- Larger T_{eff} for direct photons at LHC energies
- Direct photon measurements available from $\sqrt{s_{NN}} = 0.017 - 2.76$ TeV
  $\rightarrow$ **Are there any scaling relations which might help us understand better the direct photon productions mechanisms?**

PLB 754 (2016) 23-248, PRC 91 6, (2015) 064904

Direct Photons in A–A collisions





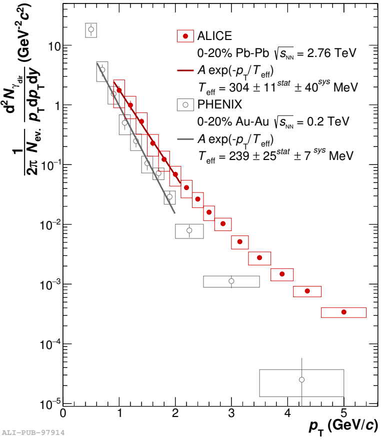


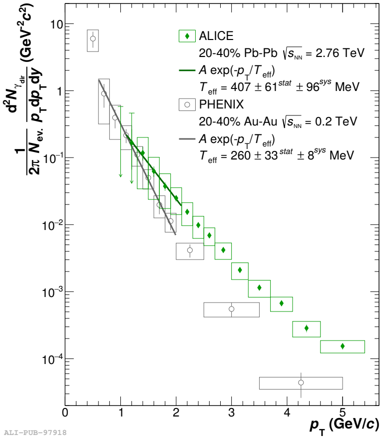
- Photon yield increased by ≈ factor 2 for $p_T < 3$ GeV/c
- Larger T_{eff} for direct photons at LHC energies
- Direct photon measurements available from $\sqrt{s_{NN}} = 0.017 - 2.76$ TeV

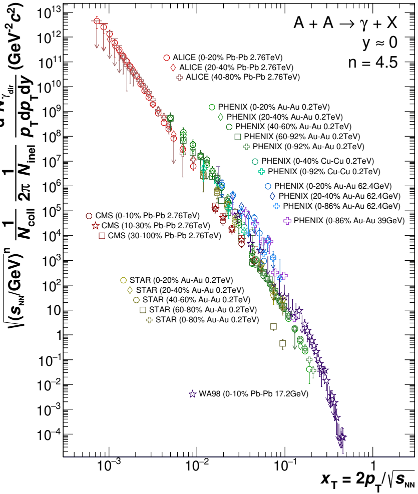
  → Are there any scaling relations which might help us understand better the direct photon productions mechanisms?

PLB 754 (2016) 23-248, PRC 91 6, (2015) 064904

Direct Photons in A–A collisions







- Photon yield increased by ≈ factor 2 for $p_T < 3$ GeV$/c$
- Larger T_{eff} for direct photons at LHC energies
- Direct photon measurements available from $\sqrt{s_{NN}} = 0.017 - 2.76$ TeV
  → **Are there any scaling relations which might help us understand better the direct photon productions mechanisms?**

PLB 754 (2016) 23-248, PRC 91 6, (2015) 064904

Summary

γ_{dir} production in pp & p–Pb collisions:

- First direct photon measurements at the LHC for pp and p–Pb collisions at low transverse momenta
- No significant direct photon excess observed in thermal photon region ($p_{\mathrm{T}} < 3$ GeV/c)
- Consistent with NLO pQCD calculations at higher p_{T}
- All pp and p(d)–A data seem to align on a common x_{T}-curve within $\pm(20-50)\%$, if scaled with $(\sqrt{s})^n$ with $n = 4.5$

γ_{dir} production in Pb–Pb Collisions:

- Direct photon excess for $p_{\mathrm{T}} < 3$ GeV/c observed with 2.6σ for 0-20% and 1.5σ in 20-40% consistent with theory expectations
- Spectra consistent with NLO pQCD calculations at high p_{T}
- High p_{T} spectra seem to scale with x_{T} from $\sqrt{s_{\mathrm{NN}}} = 0.017 - 2.76$ TeV