Measurement of direct Photons in pp and Pb-Pb Collisions with ALICE

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on behalf of the ALICE Collaboration

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H-QM | Helmholtz Research School Quark Matter Studies

EMMI

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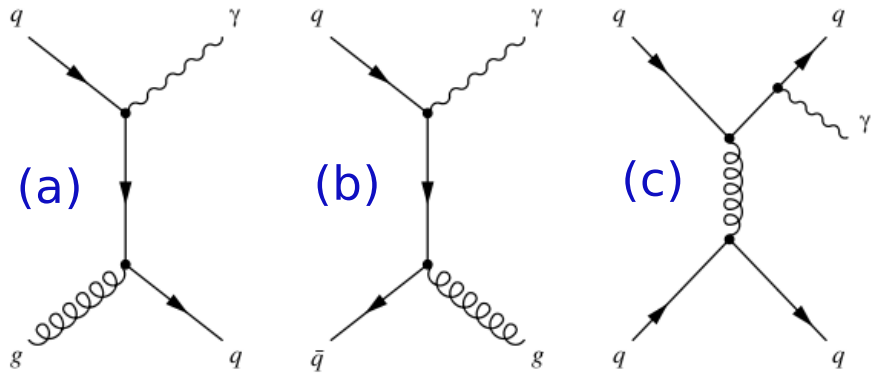
Direct Photons in pp and Pb-Pb Collisions

Direct Photons - Definition

Photons that are not produced by particle decays



Prompt Photons: In pp and Pb-Pb

- Calculable within NLO pQCD
- Predominant source in pp
- Signal scales with number of binary collisions in Pb-Pb
- Fragmentation photons may be modified by parton energy loss in the medium

(a) Quark-gluon Compton scattering

(b) Quark-Anti-quark annihilation

(c) Fragmentation photons (bremsstrahlung)

Measurement of direct photons in pp is an ideal test for pQCD

Direct Photons in Pb-Pb Collisions

Additional sources of direct photons in Pb-Pb collisions

Jet-Medium Interactions:

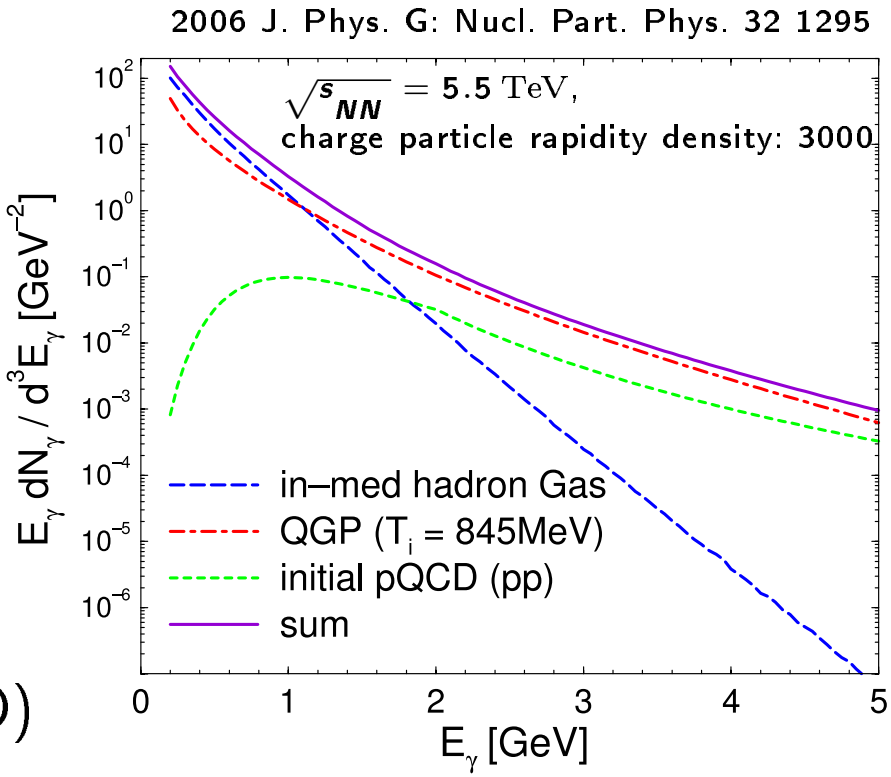
- Scattering of hard partons with thermalized partons
- In medium (photon) bremsstrahlung emitted by quarks

Thermal Photons:

- Scattering of thermalized particles

  QGP: $q\bar{q} \rightarrow g\gamma$ and $qg \rightarrow q\gamma$ (+NLO)

  HHG (hot hadronic gas): Hadronic interactions (e.g. $\pi^+\pi^- \rightarrow \gamma\rho_0$)
- Exponentially decreasing but dominant at low p_T



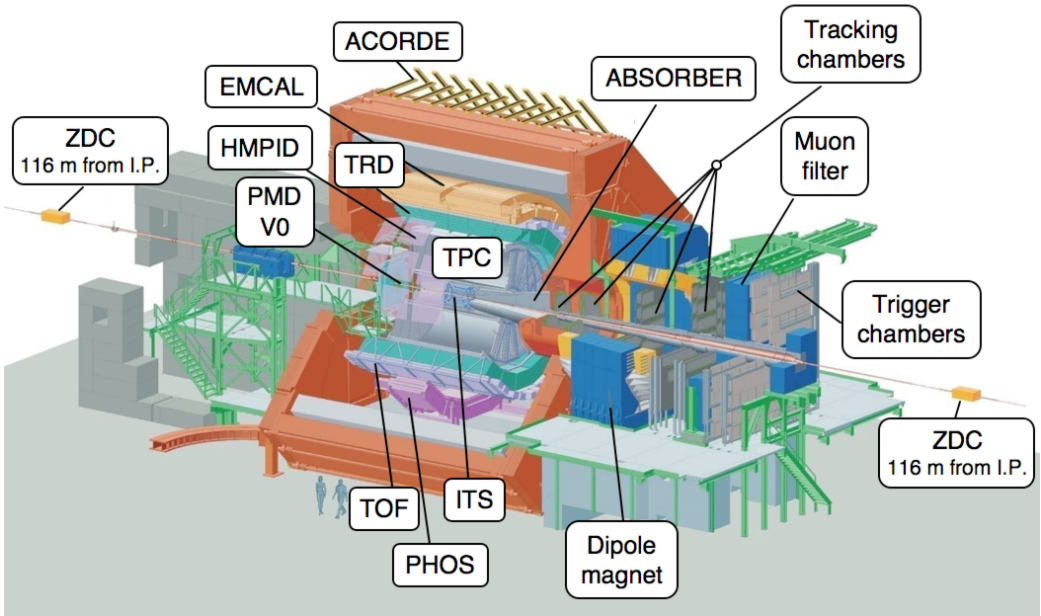
Photons leave medium unaffected, an ideal probe to study HI collisions

General Strategy of the Analysis

Subtraction Method

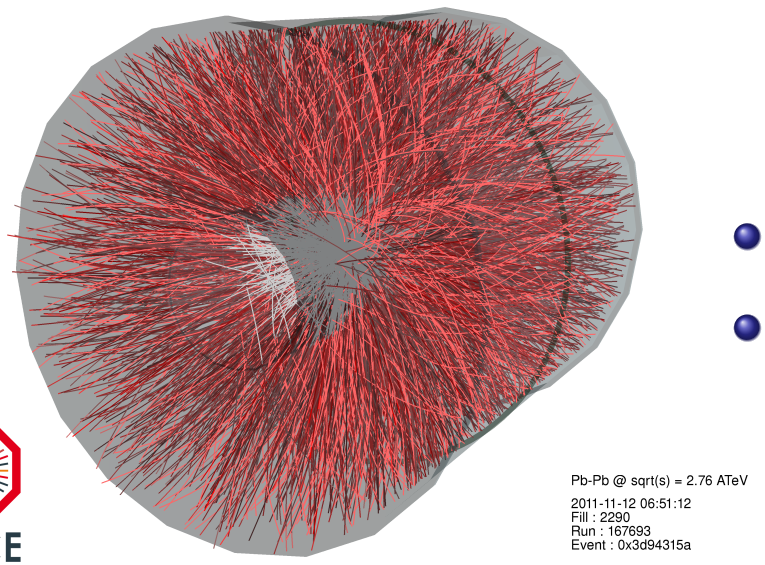
- Direct Photon Signal: $\gamma_{direct} = \gamma_{inc} - \gamma_{decay} = (1 - \frac{\gamma_{decay}}{\gamma_{inc}}) \cdot \gamma_{inc}$
- Double Ratio: $\frac{\gamma_{inc}}{\pi^0} / \frac{\gamma_{decay}}{\pi^0_{param}} \approx \frac{\gamma_{inc}}{\gamma_{decay}}$ if > 1 direct photon signal
  $\rightarrow$ cancellation of uncertainties
- Numerator: Inclusive γ spectrum per π^0
- Denominator: Sum of all decay photons per π^0
  Decay photons are obtained by a cocktail calculation
- Photons and π^0s are measured via conversion method
  $\pi^0 \rightarrow \gamma + \gamma$, $\gamma \rightarrow e^+ e^-$

The ALICE Detector and Data Sample



pp, $\sqrt{s} = 7\,\mathrm{TeV}$:

- Data sample: 3.54×10^8 events (min. bias)
- Monte Carlo: Pythia-Perugia0 and Phojet



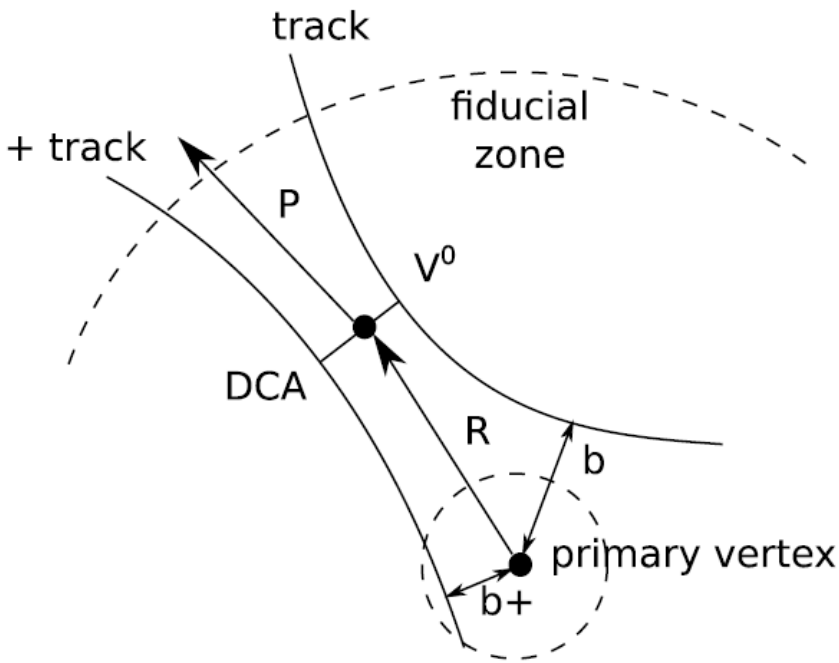
Pb-Pb, $\sqrt{s_{NN}} = 2.76\,\mathrm{TeV}$:

- Data sample: 17×10^6 min. bias events
- Monte Carlo: Hijing (min. bias plus enriched events with high p_T π^0)

Photon Reconstruction with ITS and TPC

Secondary Vertex Algorithm - V0 Particles

- Charged tracks with large impact parameter are paired
- Candidates with a small DCA
  $\rightarrow$ V0 candidate
- Most abundant particle species:
  K^0_s, Λ, $\bar{\Lambda}$ or γ
- Photon conversion probability in
  $|\eta| < 0.9$ up to $R = 180\,\mathrm{cm}$ at 8.5%

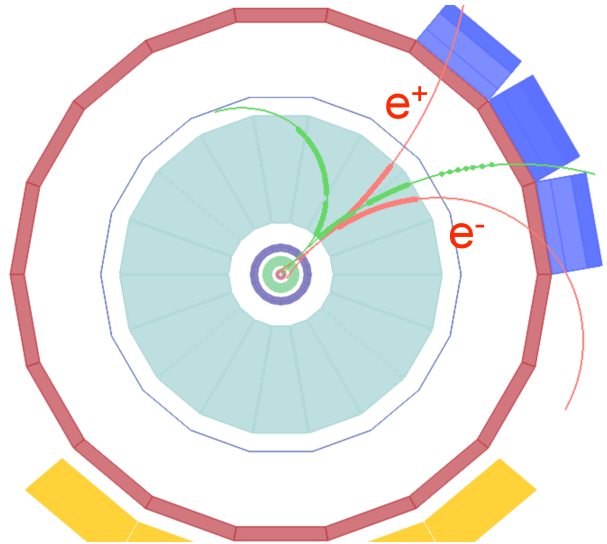


- Cuts on the decay topology of photons and electron track properties
  $\rightarrow$ Purity at 90% at $2\,\mathrm{GeV/c}$ for 0-40% Pb-Pb events
- Background is mainly combinatorial - Strange particle contribution negligible

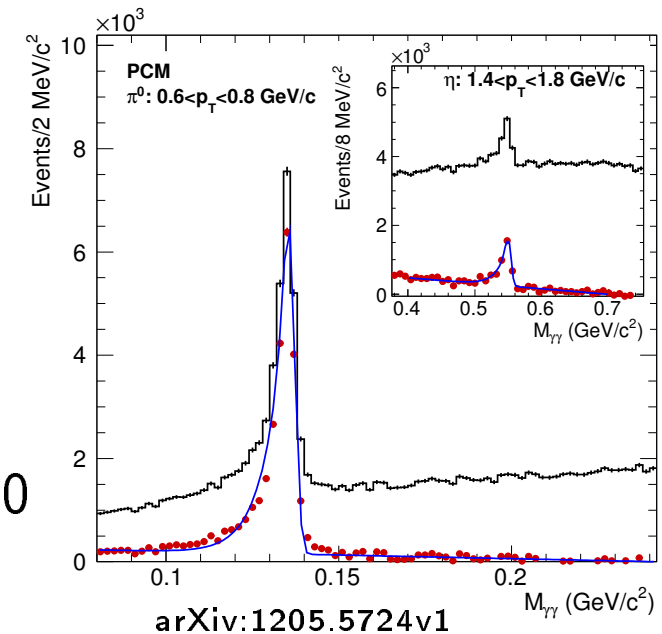
π^0 and η Reconstruction via Conversion

Neutral pion and η (pp only) based on converted photons

Measurement based on identical set of photons as used for photon results



- Inv. mass calculated for all photon pairs in an event
- Combinatorial background obtained via mixed event technique
- Raw π^0 spectrum obtained by peak integration
- Efficiency and acceptance estimated with MC simulations



Details on π^0 measurement see:

D. Peresounko, Session: 4B Jets, 2012-08-15, 12:00

Photon Corrections and Invariant Cross Section for pp

- Raw γ spectrum in pp and Pb-Pb corrected for:
  - purity ($\mathcal{P}$)
  - efficiency ($\mathcal{E}$)
  - conversion probability ($\mathcal{C}$)

  and secondary photon candidates subtracted
- Inclusive photon cross section in pp: $$E\frac{\mathrm{d}^3\sigma}{\mathrm{d}p^3} = \frac{1}{2\pi}\frac{\sigma_{MB_{OR}}}{N_{events}}\frac{1}{p_T}\frac{\mathcal{P}}{\mathcal{C}\mathcal{E}}\frac{N^{\gamma prim}}{\Delta y \Delta p_T}$$

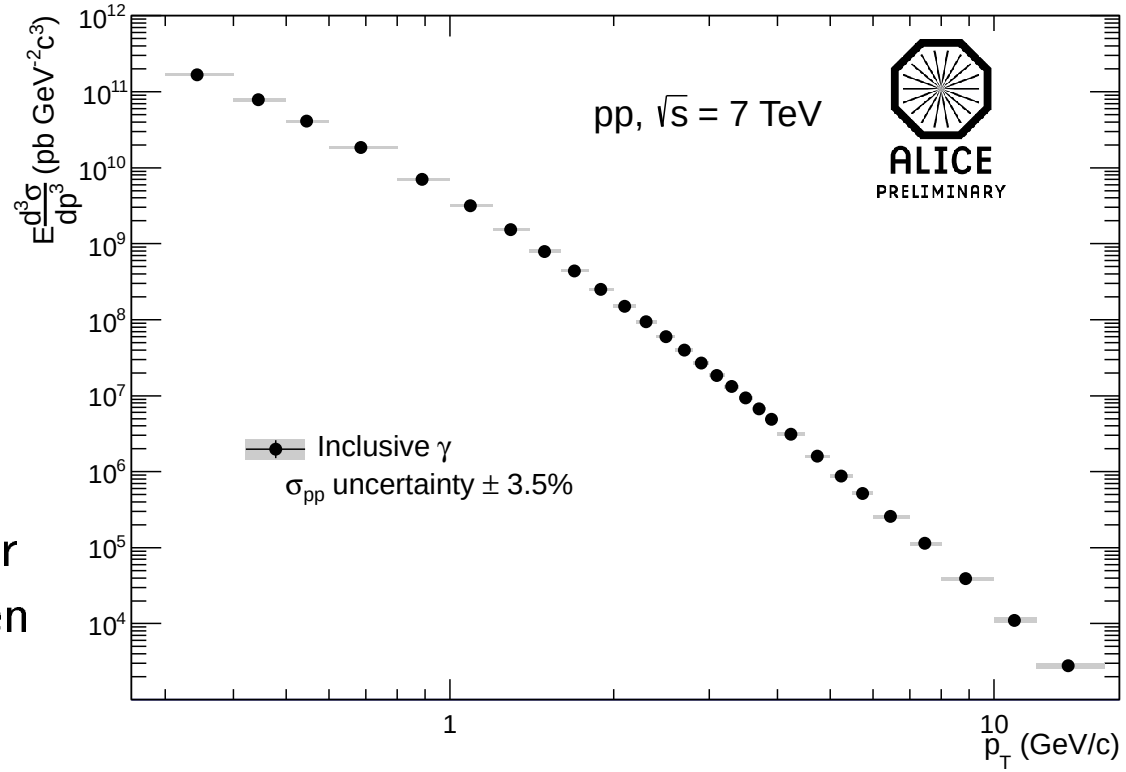
Main sources of uncertainty:

- Material budget of the detector $\sim$ 4.5%
- Efficiency estimation by cut variations

  $p_T < 5$ GeV: pp $\sim$ 3%, Pb-Pb $\sim$ 6%

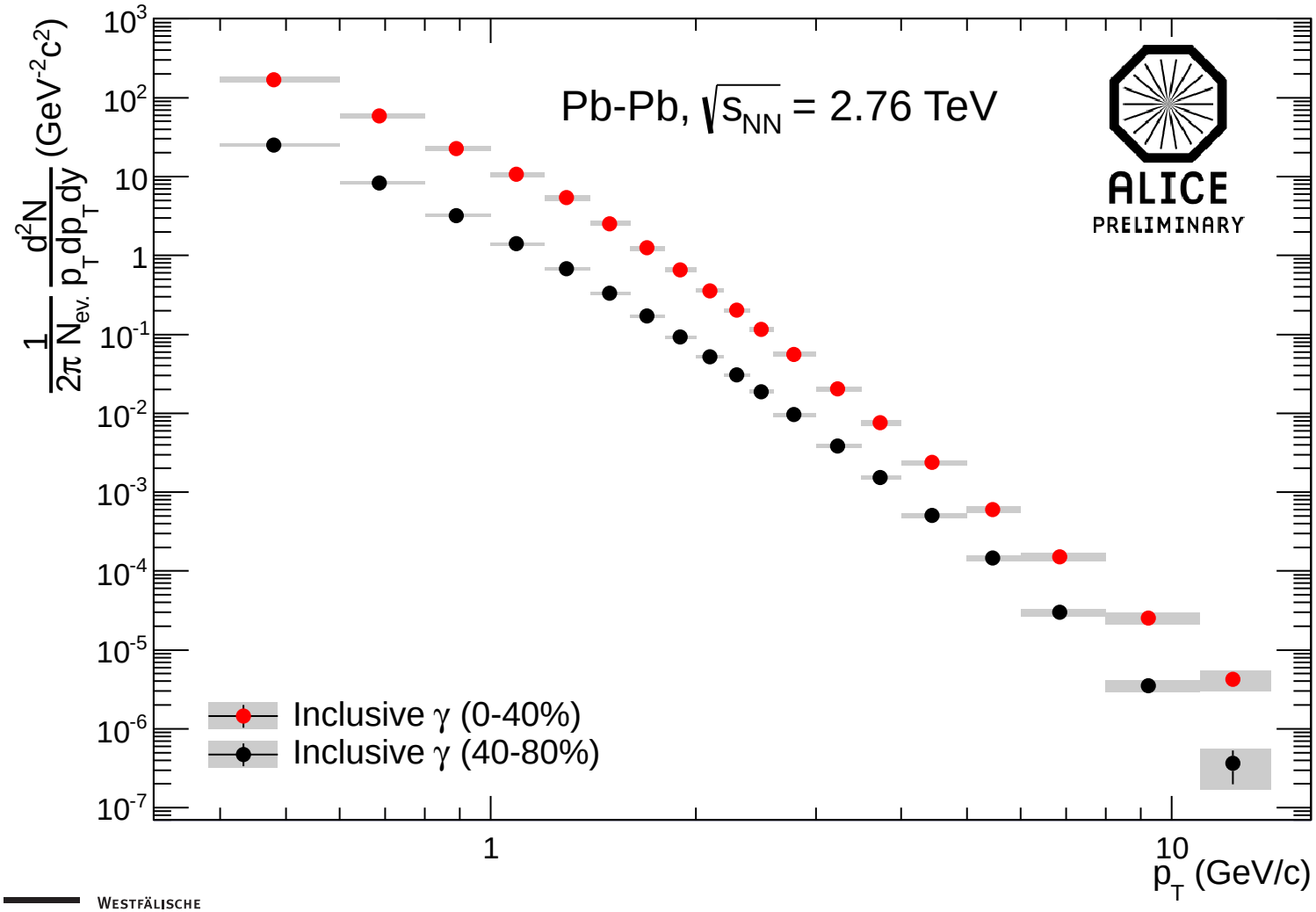
  $p_T > 5$ GeV: pp $\sim$ 6%, Pb-Pb $\sim$ 15%

  e.g. geometrical cuts, detector PID, sharing of tracks between sec. vertices



Inclusive Photon Invariant Yield in Pb-Pb

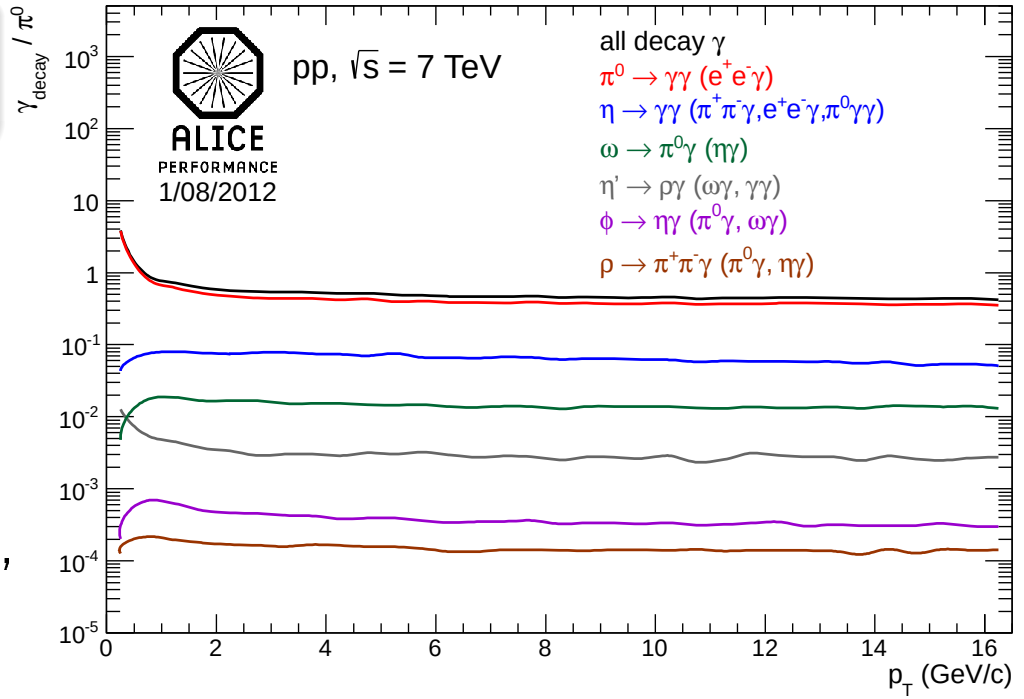
- Two centrality selections: 0-40% and 40-80% (central and peripheral)



Cocktail Generator

Decay photon spectra are obtained via calculation

- Based on a fit to measured π^0 and η (in pp)
- Other meson spectra obtained via m_T-scaling
- Incorporated mesons: π^0, η, η', ω, ϕ and ρ_0



m_T-Scaling:

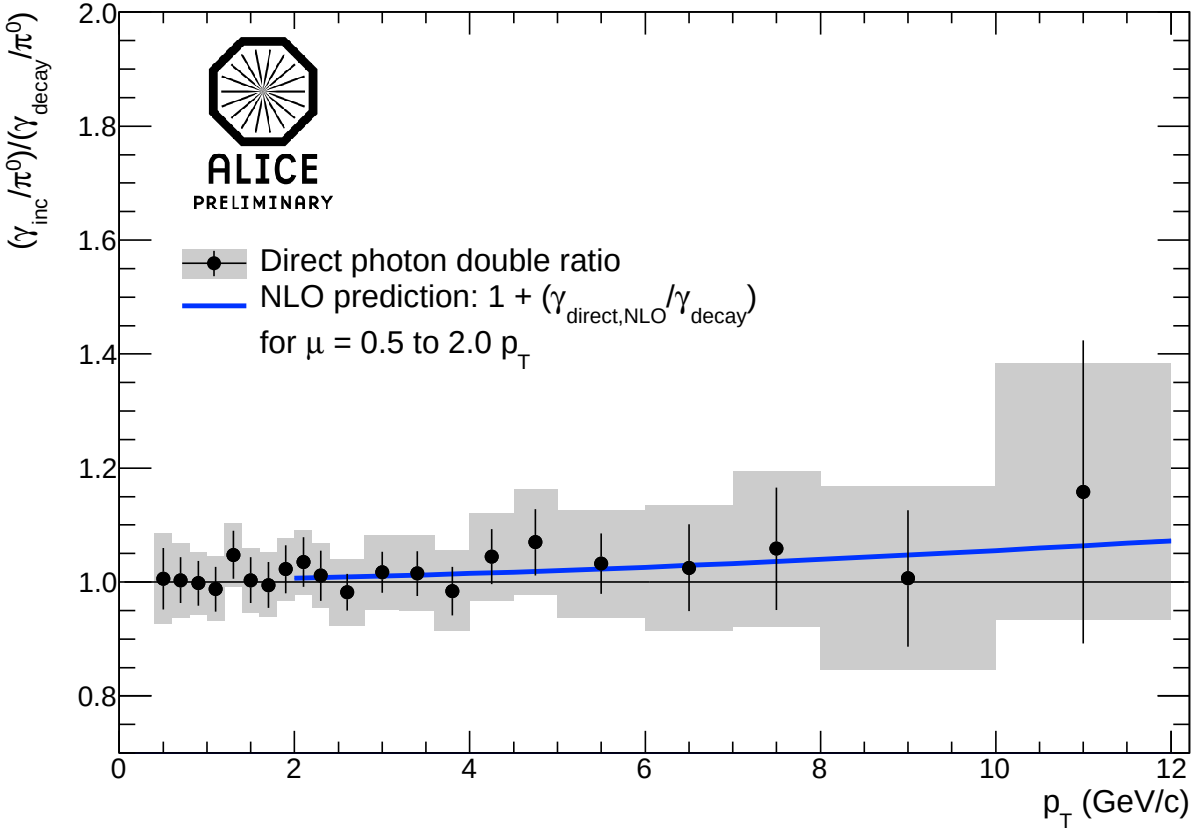
- Same shape of cross sections, $f(m_T)$, of various mesons

  transv. mass: $m_T = \sqrt{m_0^2 + p_T^2}$
- Normalization factors C_m

$$E\frac{d^3\sigma_m}{dp^3} = C_m \cdot f(m_T)$$

Meson (C_m)	Mass	Decay Branch	B. Ratio
π^0	134.98	$\gamma\gamma$	98.789%
		$e^+e^-\gamma$	1.198%
η	547.3	$\gamma\gamma$	39.21%
		$\pi^+\pi^-\gamma$	4.77%
(0.48)		$e^+e^-\gamma$	$4.9 \cdot 10^{-3}$
ρ^0	770.0	$\pi^+\pi^-\gamma$	$9.9 \cdot 10^{-3}$
(1.0)		$\pi^0\gamma$	$7.9 \cdot 10^{-4}$
ω	781.9	$\pi^0\gamma$	8.5%
(0.9)		$\eta\gamma$	$6.5 \cdot 10^{-4}$
η'	957.8	$\rho^0\gamma$	30.2%
		$\omega\gamma$	3.01%
(0.25)		$\gamma\gamma$	2.11%

Direct Photons in pp Collisions at 7 TeV



In the ratio uncertainties related to:

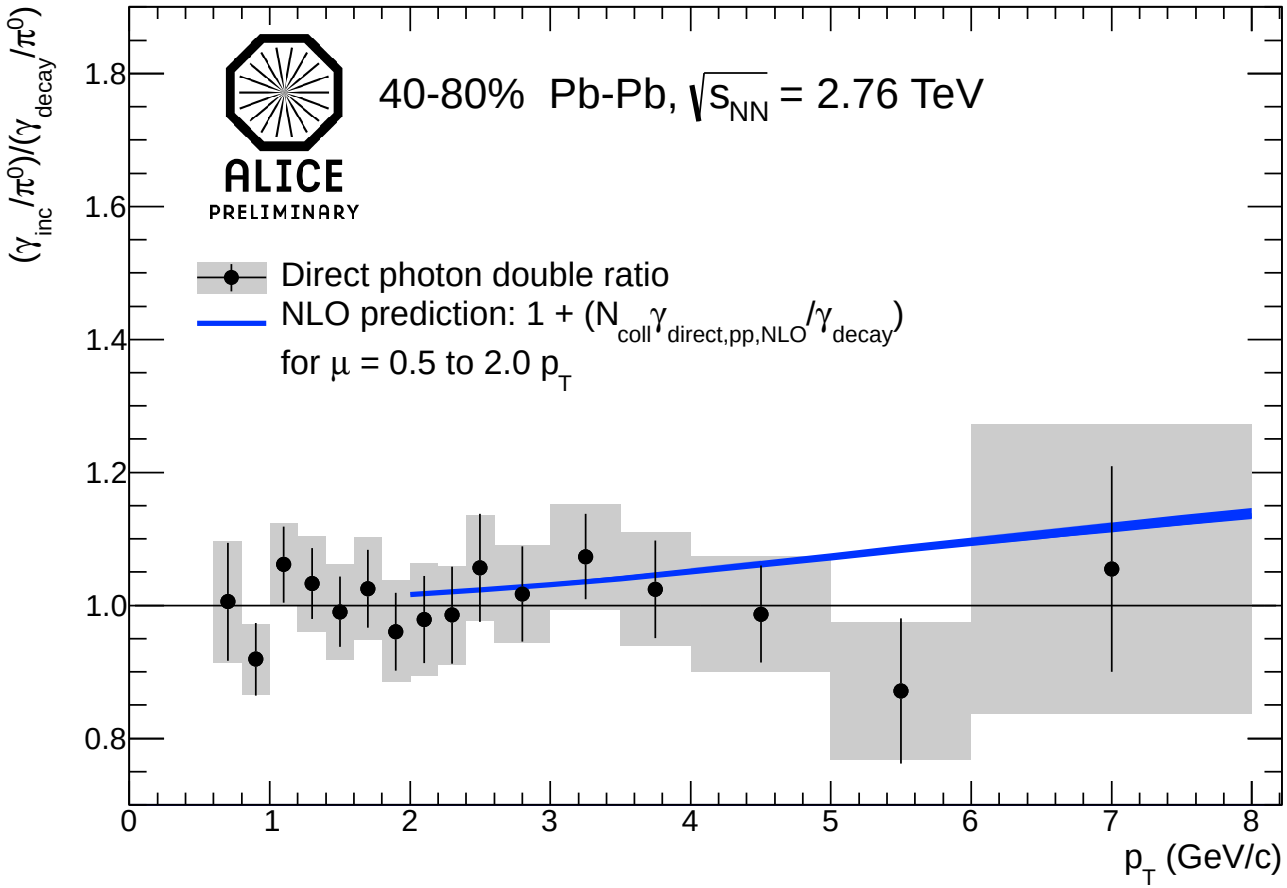
- normalization
- π^0 measurement
- rec. efficiency

partially or exactly canceled

Direct photon signal in pp at 7 TeV is consistent with zero

- The NLO double ratio prediction is plotted as $\mathcal{R}_{NLO} = 1 + \frac{\gamma_{direct,NLO}}{\gamma_{cocktail}^{decay}}$
- Measurement is consistent with the expected direct photon signal

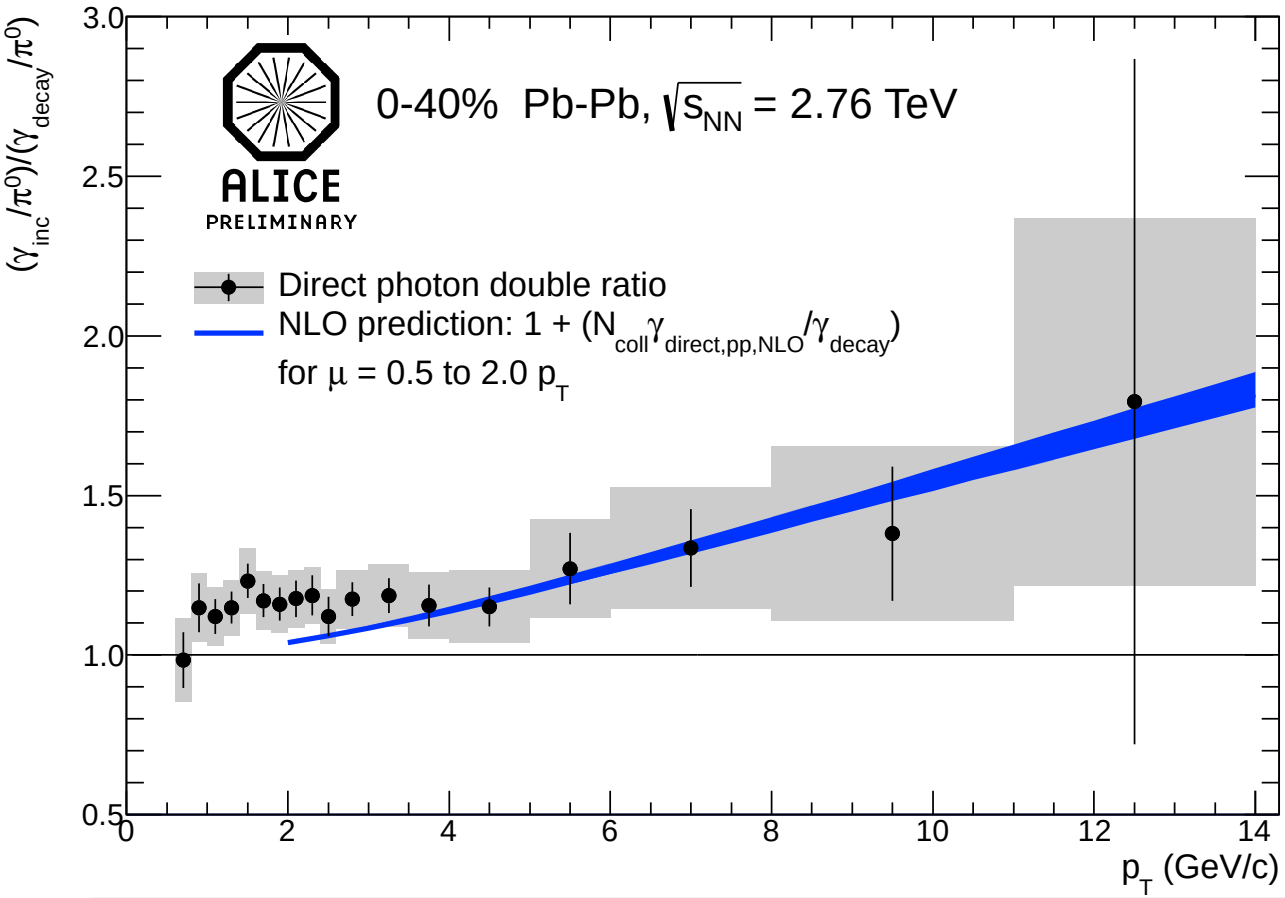
Double Ratio - Pb-Pb 2.76 TeV - peripheral



Double ratio for peripheral events shows no excess at any value of p_T

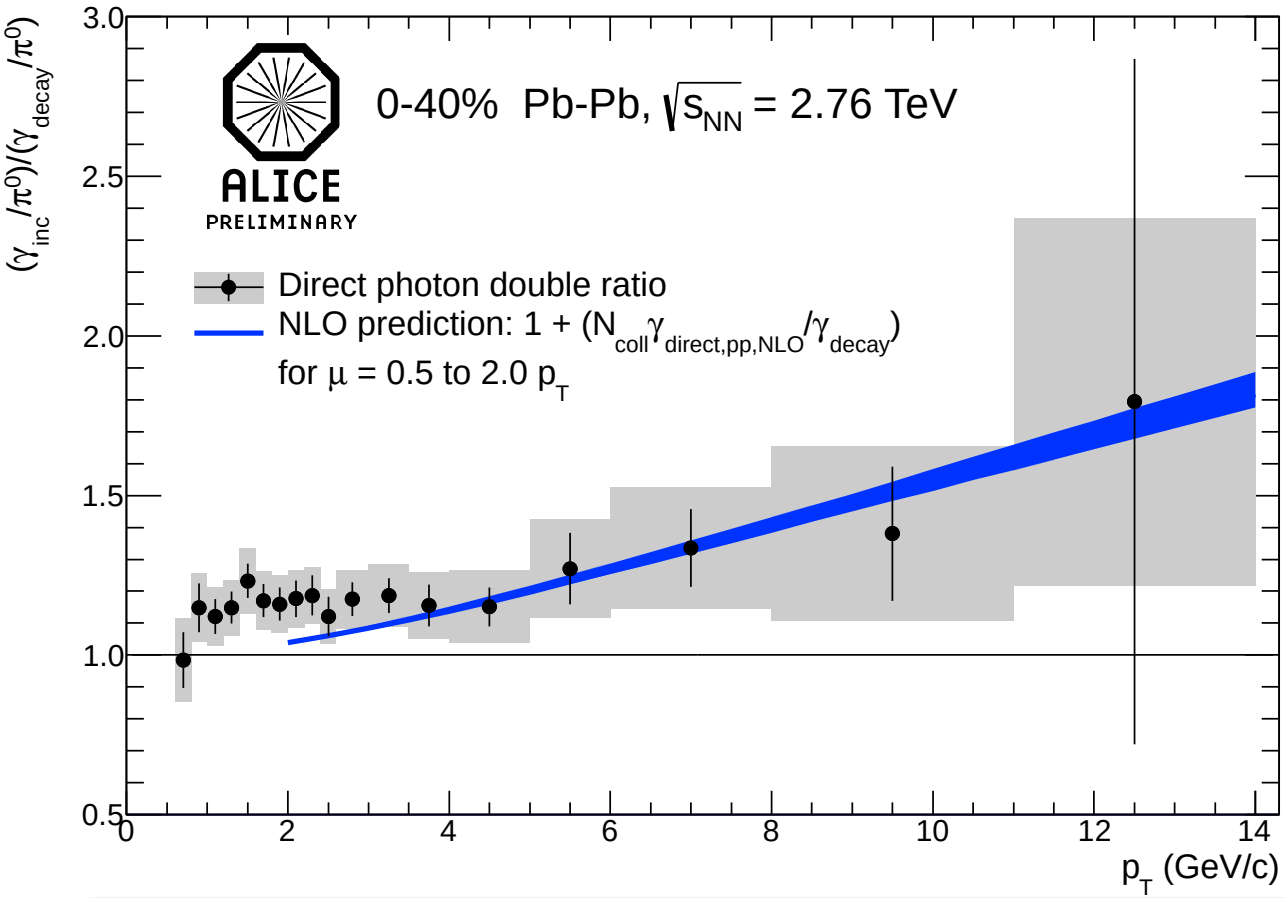
- Measurement is consistent with the expected direct photon signal
- pp NLO predictions scaled with N_{coll}

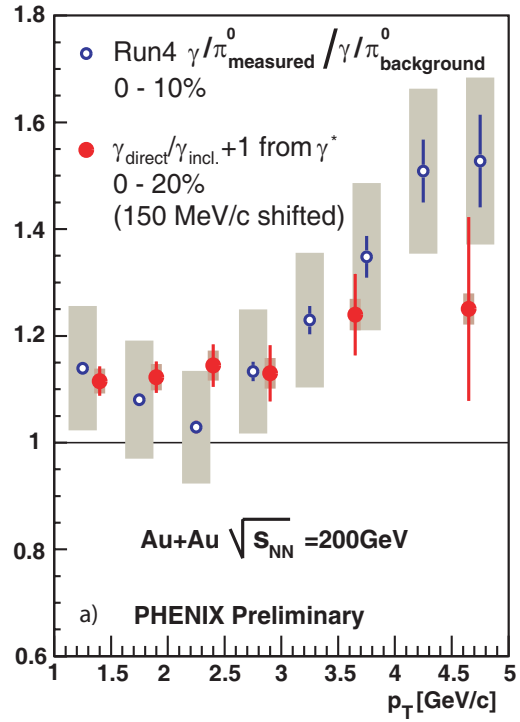
Double Ratio - Pb-Pb 2.76 TeV - central



Clear extra yield of 20% for $p_T < 2\,\mathrm{GeV/c}$
N_{coll} scaled pp NLO in agreement with high p_T direct photons

Double Ratio - Pb-Pb 2.76 TeV - central

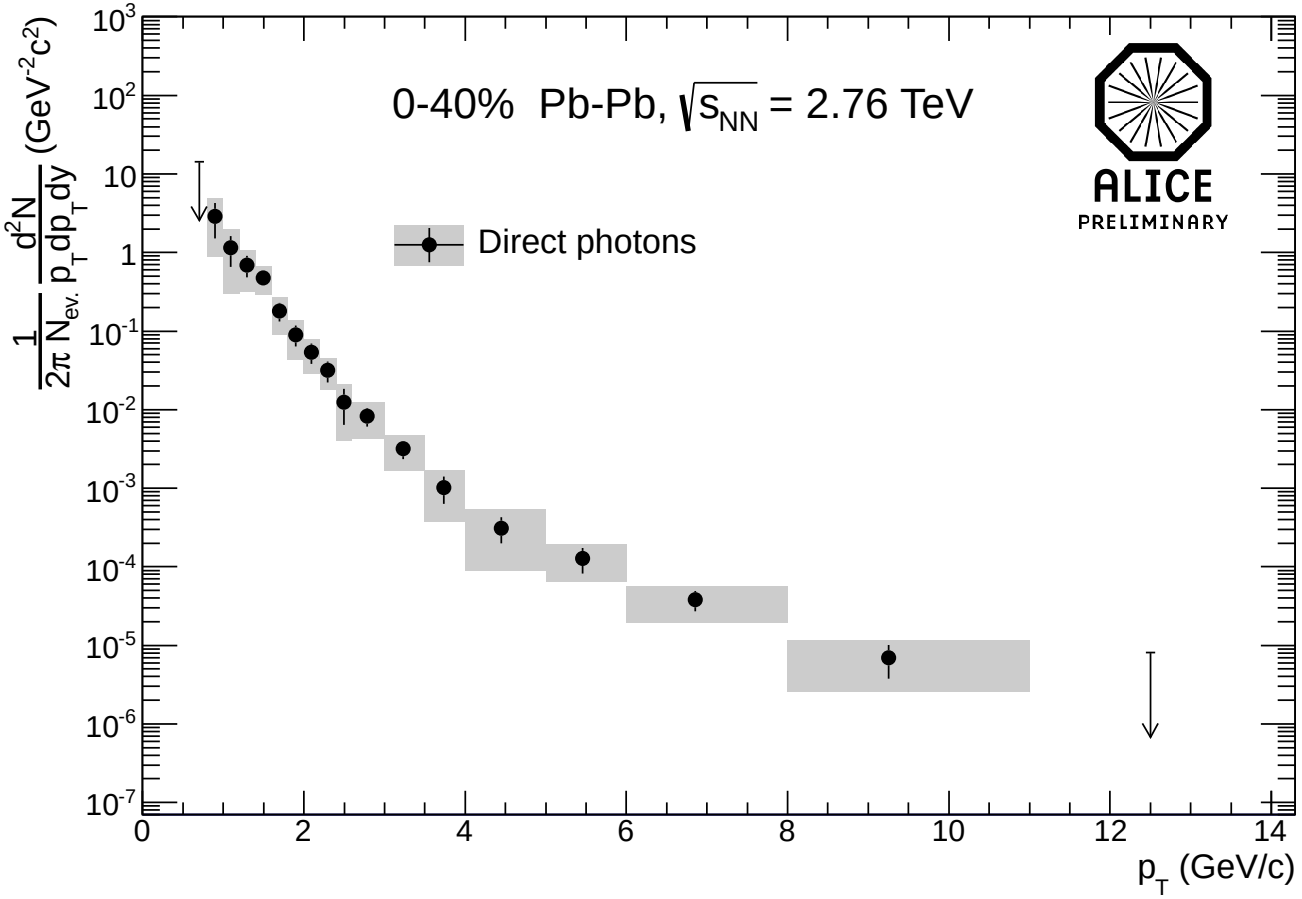




Clear extra yield of 20% for $p_T < 2\,\mathrm{GeV}/c$
N_{coll} scaled pp NLO in agreement with high p_T direct photons

- Similar to low p_T direct photon observation by PHENIX

Results of Pb-Pb Direct Photons at 2.76 TeV

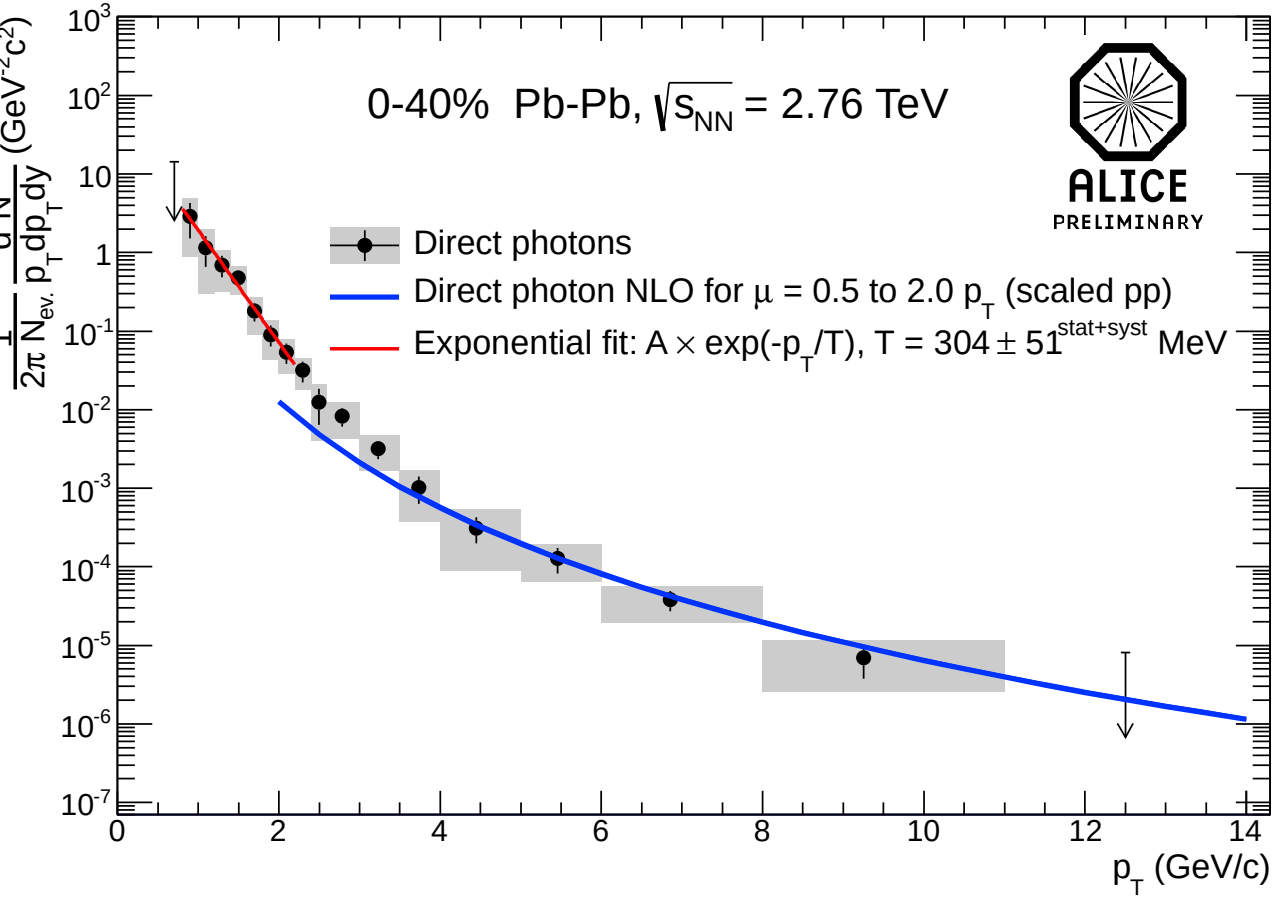


Direct Photon Spectrum for central Pb-Pb events

Spectrum derived from double ratio by:

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

Results of Pb-Pb Direct Photons at 2.76 TeV



Direct Photon Spectrum for central Pb-Pb events

Spectrum derived from double ratio by:

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

- NLO predictions in agreement with spectrum ($p_T > 4\,\mathrm{GeV/c}$)
- At low p_T ($< 2.2\,\mathrm{GeV/c}$) spectrum fitted with an exponential
  $\rightarrow$ slope parameter $T = 304 \pm 51^{\mathrm{stat+syst}}\,\mathrm{MeV}$
- Intermediate region: superposition of low and high p_T direct photons

Conclusions

- Statistical analysis of direct photons based on converted photons via double ratio
- With current uncertainties no significant direct photon signal in pp and peripheral Pb-Pb
- Direct photon signal is consistent with expectation from NLO pQCD

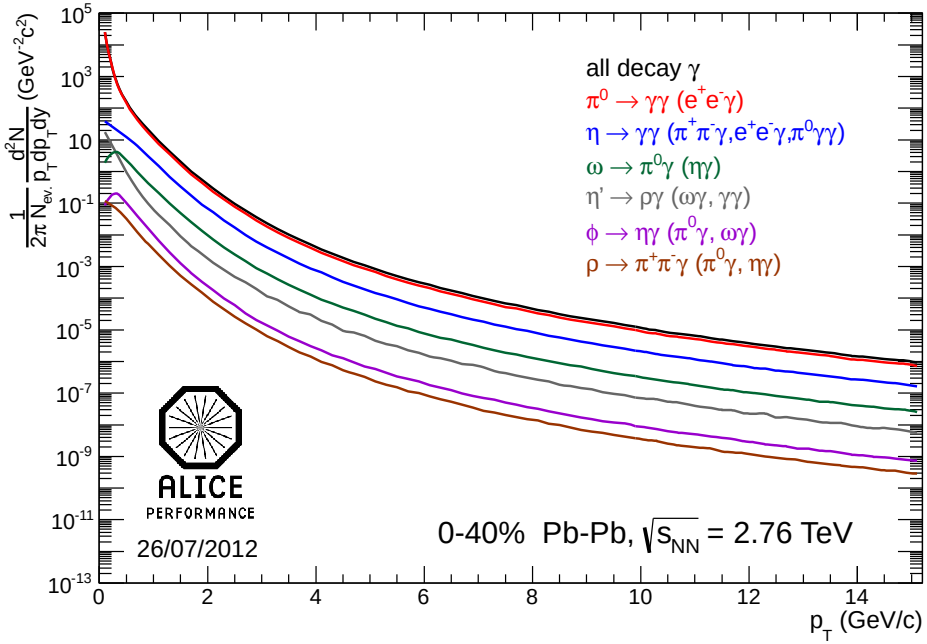
- In central Pb-Pb:
  Low p_T direct photon signal, exponential in shape
- Similar excess measured at RHIC interpreted as thermal signal

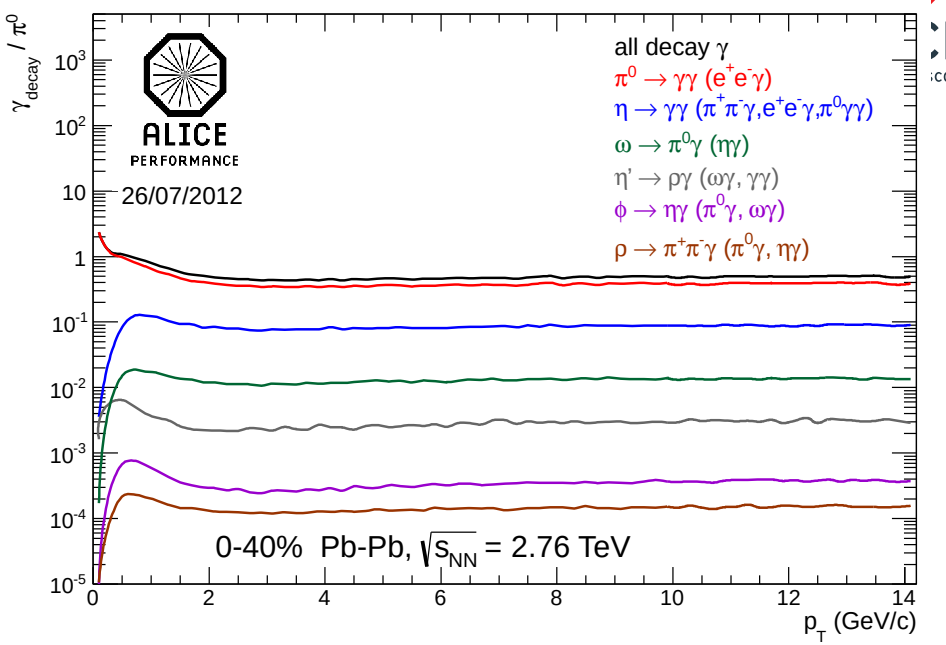
  Slope parameter:
  - $T_{ALICE} = 304 \pm 51^{\mathrm{stat+syst}}\ \mathrm{MeV}$ (0-40%)
  - $T_{PHENIX} = 221 \pm 19^{\mathrm{stat}} \pm 19^{\mathrm{syst}}\ \mathrm{MeV}$ (0-20%)

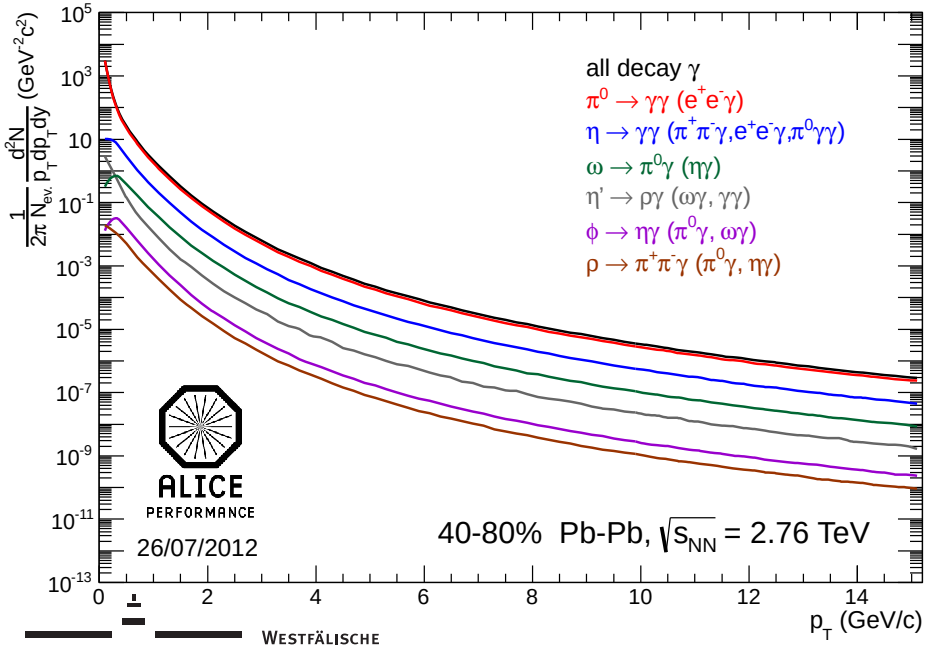
  arxiv:0804.4168 PRL 104 (132301) 2010

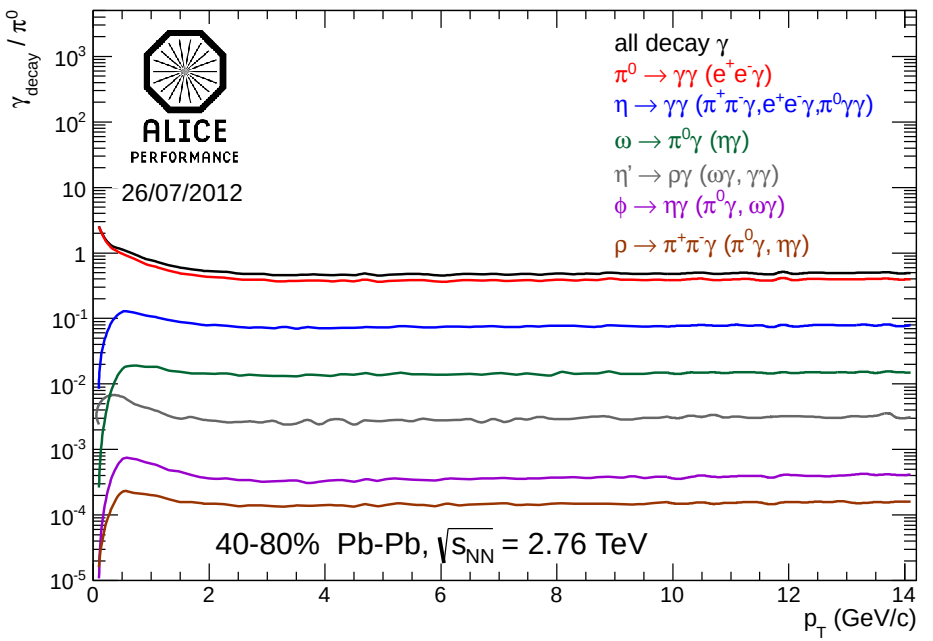
Backup Slides

Denominator Ratio: Cocktail Generator Pb-Pb Results

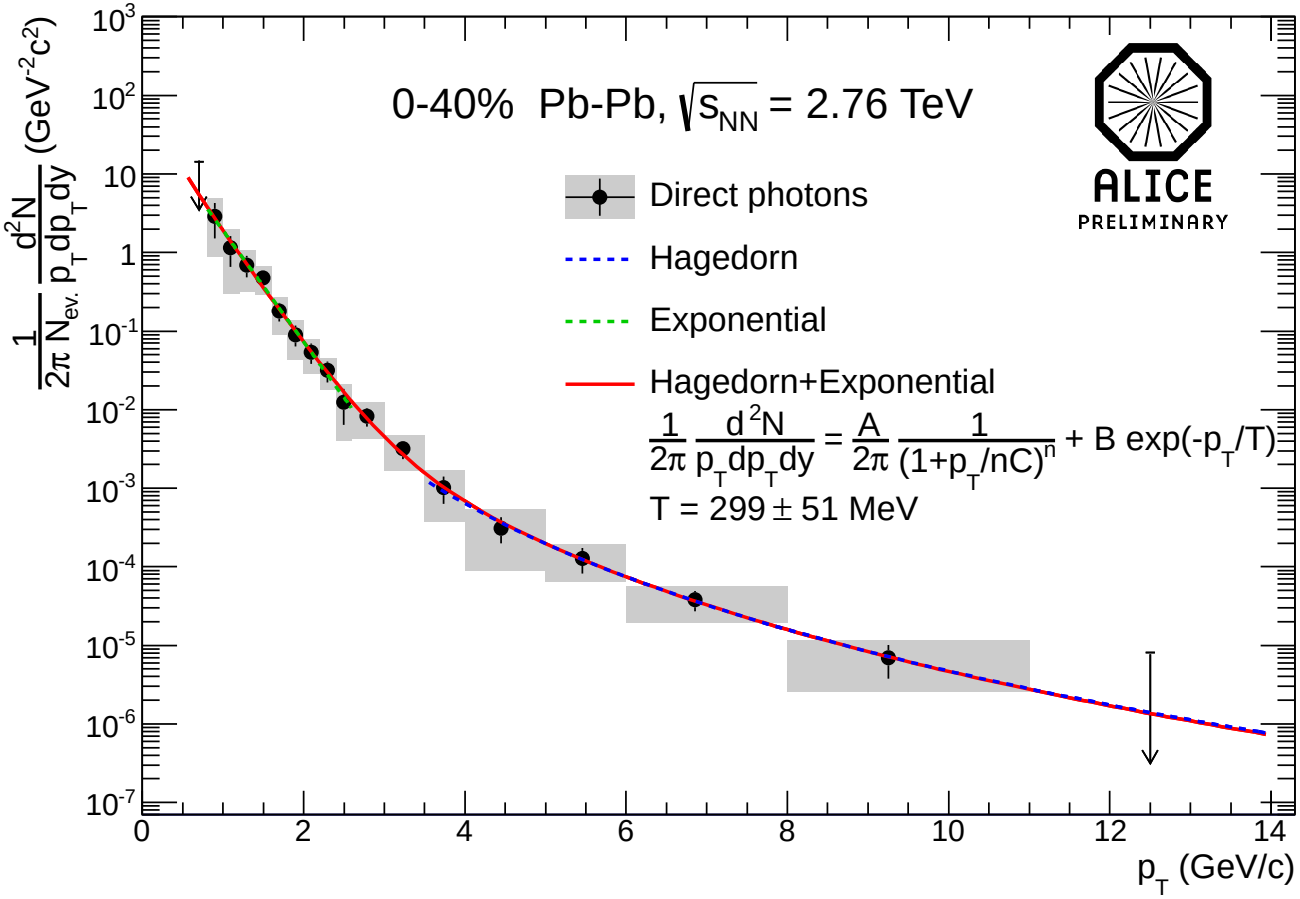








Combined Fit for Direct Photons



Combined fit (Hagedorn + Exponential) gives similar result for the inverse slope parameter T as for the exponential only fit

Systematic Cut Studies pp

- Cut Variations for γ and π^0:

Cut Name	Std. value	Variation 1	Variation 2	Variation 3
Electron dEdx	-4,5σ	-4,4σ	-3,4σ	-
Pion dEdx	1,-10σ	2,1σ	2,0.5σ	2,0.5σ
Min. p e^+/e^-	0.4 GeV/c	0.4 GeV/c	0.4 GeV/c	0.3 GeV/c
Find. Cls. TPC	0.35	0.6	-	-
Photon χ^2	20	30	10	-
q_t	0.05	0.07	0.03	-
min. p_t e^+/e^-	50 MeV/c	75 MeV/c	100 MeV/c	-
photon η, π^0 y	0.9, 0.8	0.8, 0.7	1.2, 0.9	-
min. R	5 cm - 180 cm	2.8 cm - 180 cm	10 cm - 180 cm	-

  - V0s with shared electrons rejected
  - Purity for different centralities used
  - TOF and α cut not used for pp
  - R cut already considered for material budget
- π^0 yield extraction:
  - Three different integration windows
  - Different Numbers of mixed events for bg, different mixed event bins (n V0s, n tracks)
- Cocktail simulation:
  - Two different fits
  - Variation of the m_t scaling factors (η measured)

Systematic Cut Studies Pb-Pb

- Cut Variations for γ and π^0:

Cut Name	Std. value	Variation 1	Variation 2	Variation 3
Electron dEdx	-3,5σ	-4,5σ	-2.5,4σ	-
Pion dEdx Min. p e^+/e^-	3,-10σ 0.4 GeV/c	2.5,-10σ 0.4 GeV/c	3.5,-10σ 0.4 GeV/c	3,-10σ 0.3 GeV/c
Find. Cls. TPC	0.6	0.7	0.35	-
Photon χ^2	10	5	20	-
q_t	0.05	0.03	0.07	-
min. p_t e^+/e^-	50 MeV/c	75 MeV/c	100 MeV/c	-
photon η, π^0 y	0.75, 0.7	0.9, 0.8	0.8, 0.7	-
min. R	5 cm - 180 cm	2.8 cm - 180 cm	10 cm - 180 cm	-
α meson central	0.65	1.00	-	-
α meson peripheral	0.8	1.00	-	-
TOF	-5,-5σ	-3,-5σ	-2,-5σ	-

  - V0s with shared electrons rejected
  - Purity for different centralities used
- π^0 yield extraction:
  - Three different integration windows
  - Different Numbers of mixed events for bg, different mixed event bins (n V0s, n tracks)
- Cocktail simulation:
  - Two different fits, with and without blast wave
  - Variation of the m_t scaling factors