Recent photon physics results from the ALICE experiment at LHC

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for the ALICE collaboration

9th High p_T Physics at LHC – Grenoble – 25/09/2013

ALICE
A JOURNEY OF DISCOVERY

cnrs dépasser les frontières
IN2P3 Les deux infinis

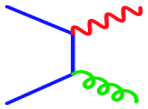
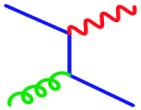
LPSC Grenoble
Laboratoire de Physique Subatomique et de Cosmologie

Photons in pp and Pb-Pb collisions

- Direct photons (not produced by decay)

  proton-proton and Pb-Pb :

  - prompt photons → test of pQCD (gluon PDF)

Annihilation  Compton 

  Pb-Pb:

  - Thermal photons → QGP properties
  - Photons from parton interactions → parton energy loss

- Neutral mesons (π^0,η,ω) via decay photons :
  - Spectra in proton-proton → test of NLO pQCD
  - Medium suppression in Pb-Pb → parton energy loss
  - Needed for direct photon measurements ($\gamma_{direct} = \gamma_{inclusive} - \gamma_{decay}$)

- Correlations photon-hadrons/jets :
  - Medium effects on parton fragmentation in Pb-Pb
  - See Catherine's talk

Photon reconstruction with ALICE

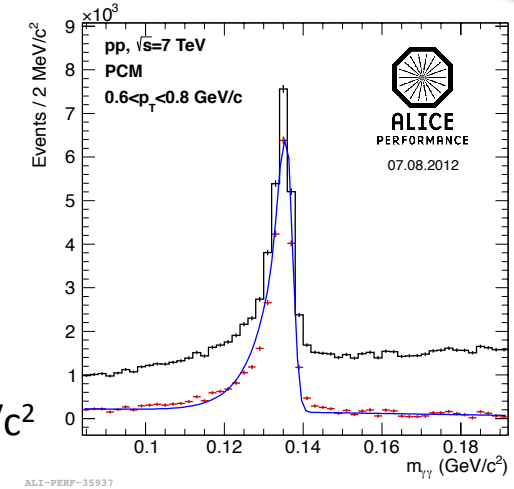
3 different sub-systems :

→ complementary to each other
→ independent measurements
→ different systematics

Photon conversion + tracking (PCM)

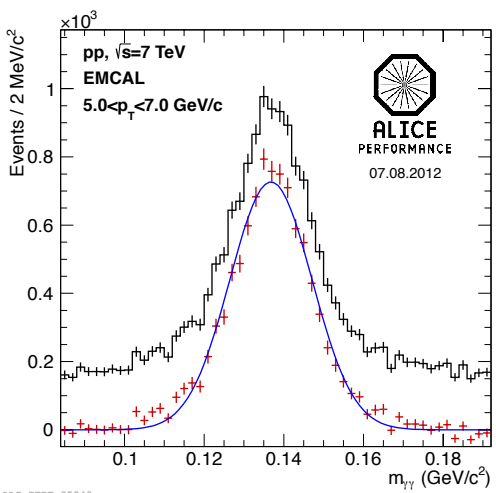
γ's converted into $e^{\pm}$ pairs
(conversion *probability* ≈ 8.5%)

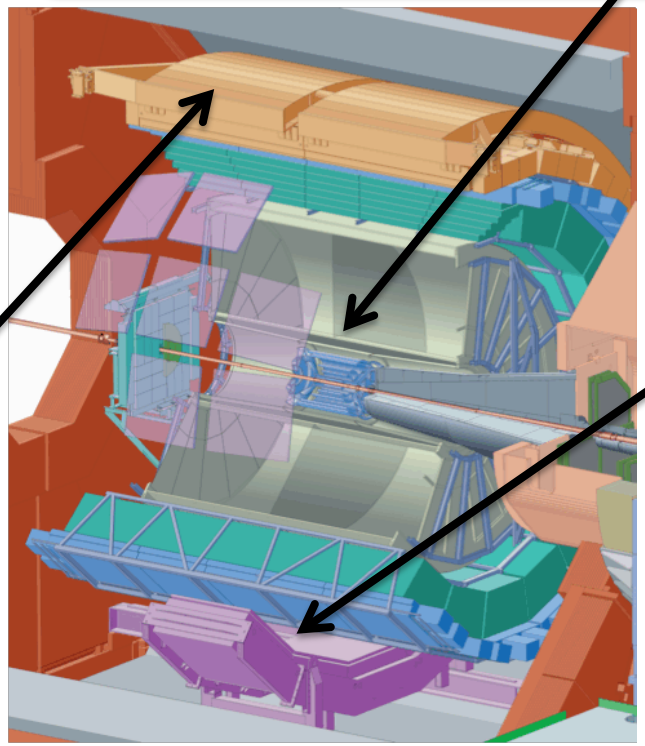
$|\eta| < 0.9$, $\Delta\phi = 360º$
π^0 mass resolution in pp : $\sigma_\pi \approx 4$ MeV/c^2



EMCAL

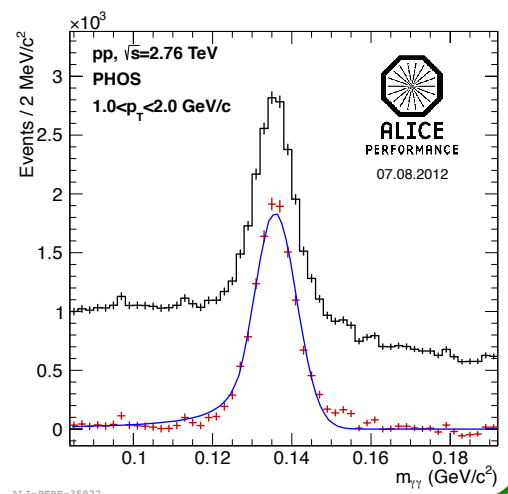
Sandwich Pb-Scintillator
$|\eta| < 0.7$, $\Delta\Phi = 107°$ (in 2012)
$\sigma_\pi \approx 10$ MeV/c^2 (pp)





PHOS

$PbWO_4$ crystals
$|\eta| < 0.12$, $\Delta\Phi = 60°$
$\sigma_\pi \approx 5$ MeV/c^2 (pp)



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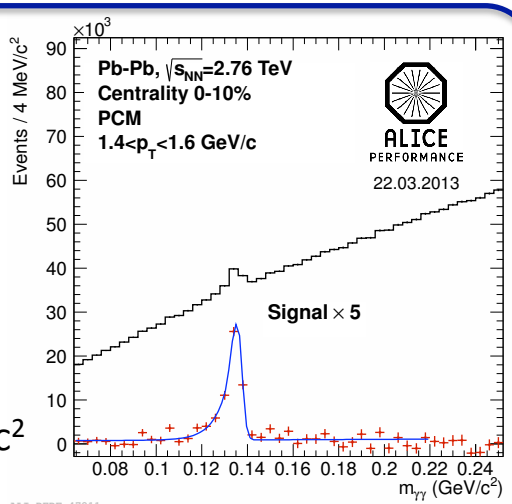

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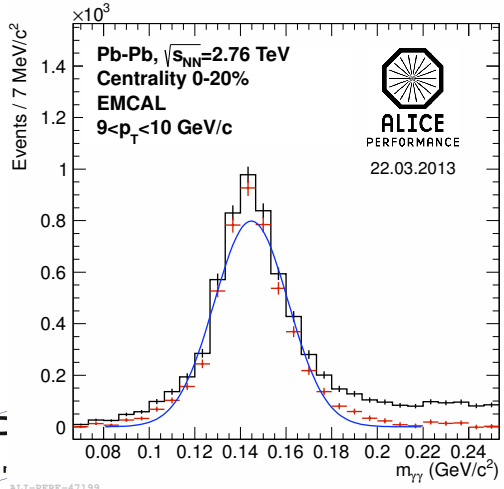

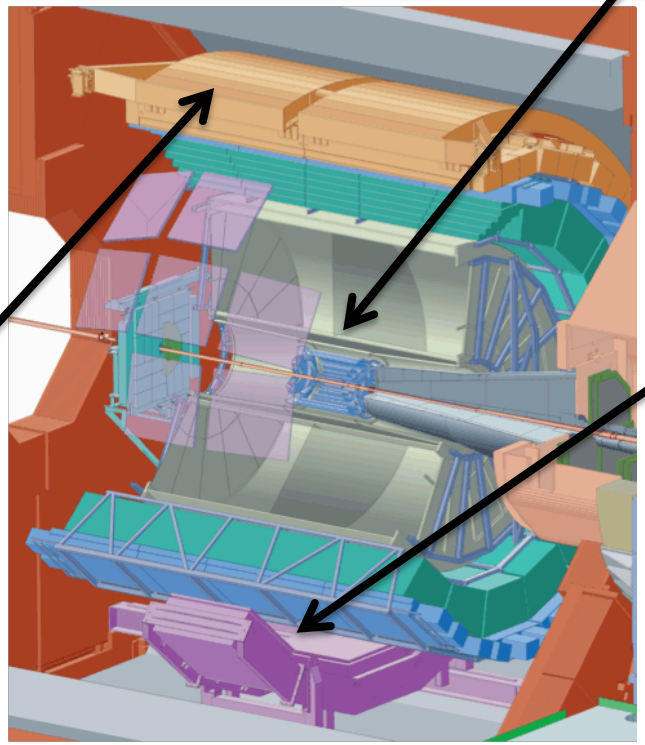

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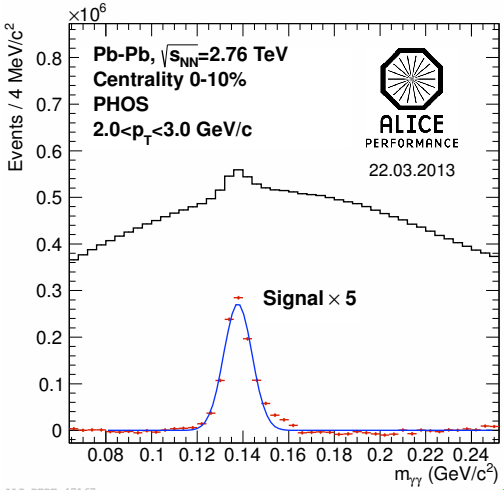
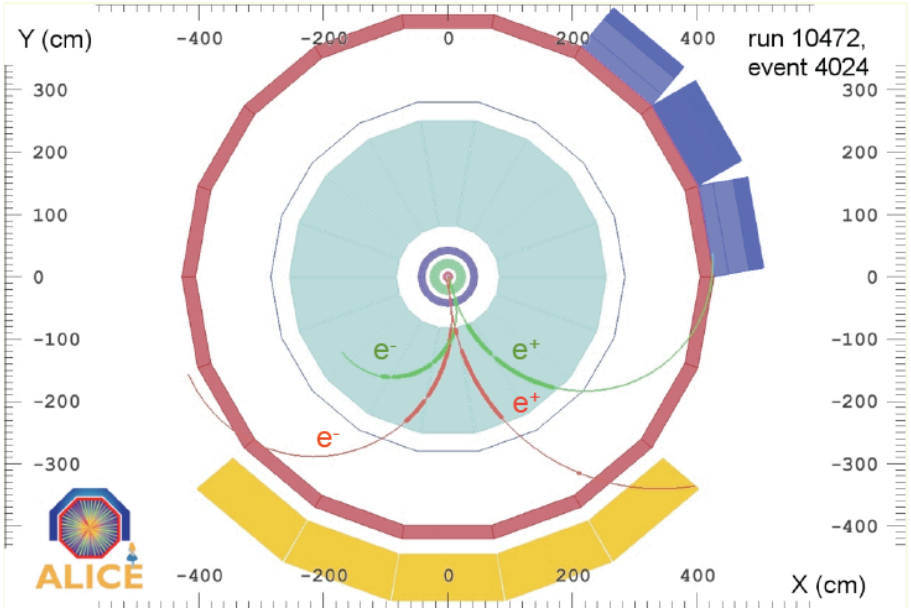
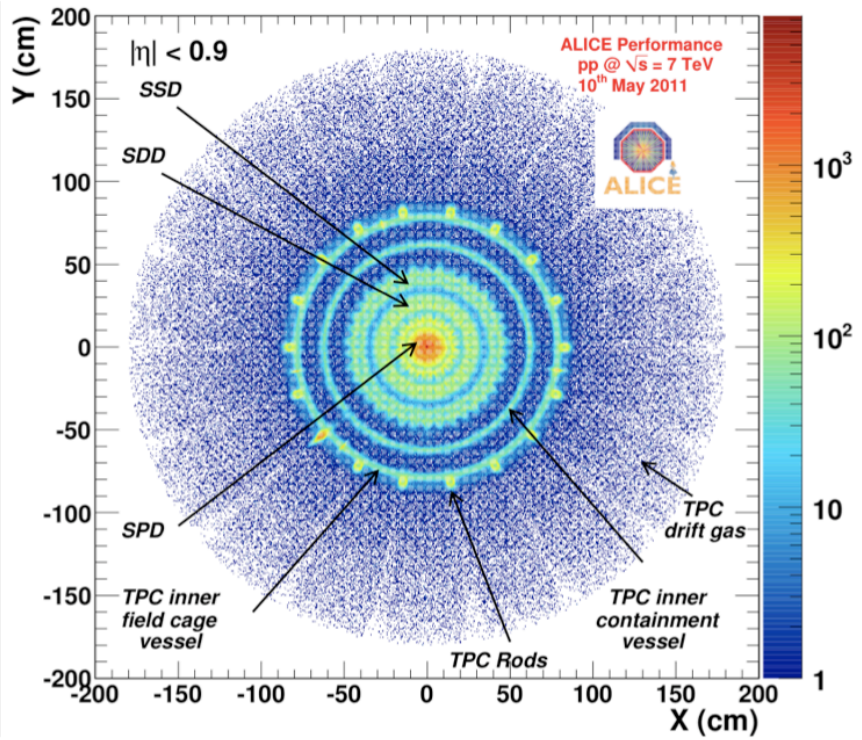


PCM: Photon Conversion Method

- Photons converted in ALICE material (2 opposite charged tracks).
- Reconstruct neutral mesons using invariant mass method.
- Cuts on tracks energy loss in TPC (to separate e^{+-} from p,K,π,μ).

$\pi^0 \rightarrow \gamma\gamma \rightarrow e^+e^-e^+e^-$



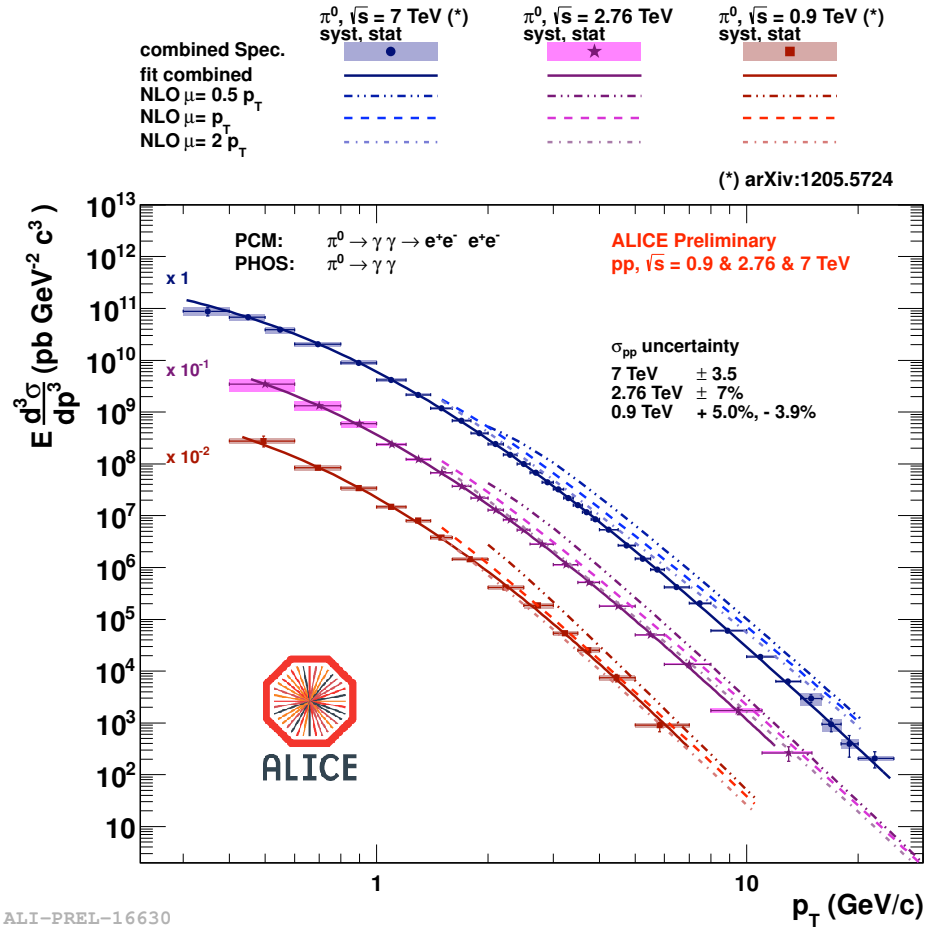


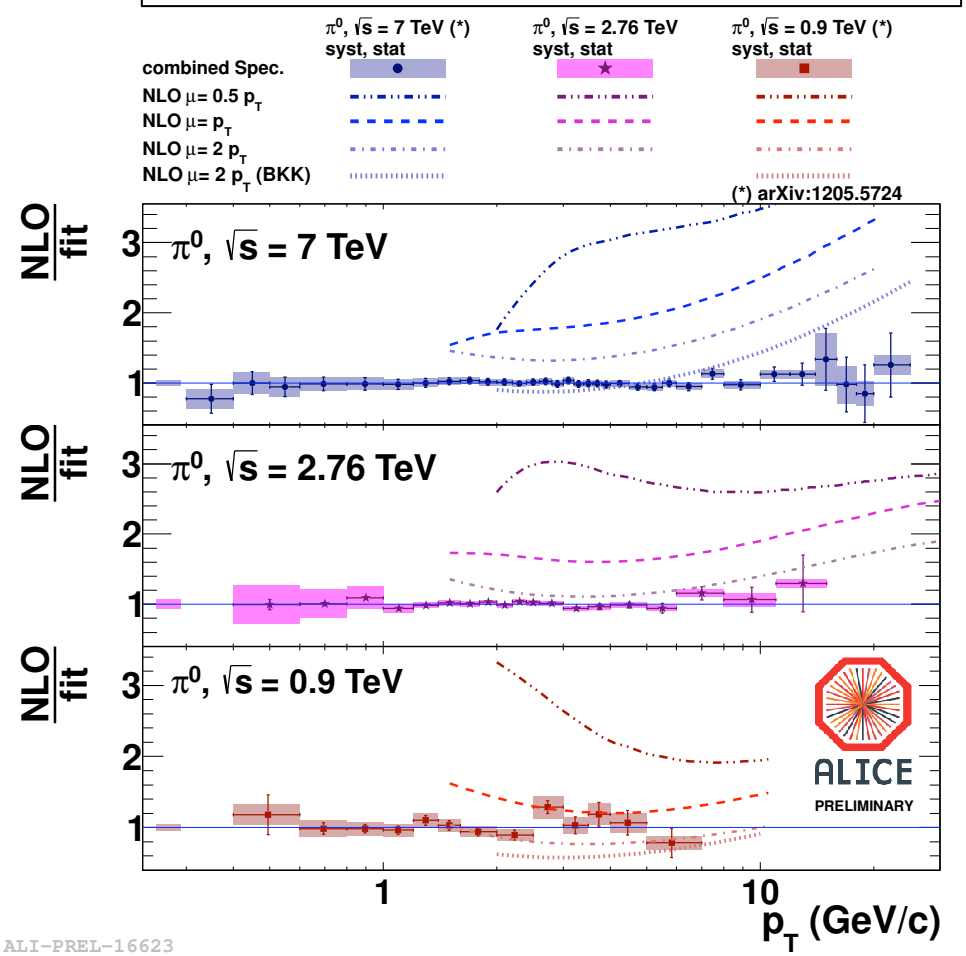
Distribution of photon conversion points

Neutral meson production in pp collisions

π^0 spectra in pp at 0.9, 2.76 and 7 TeV

ALICE data: Phys. Lett. B 717 (2012), pp. 162-172





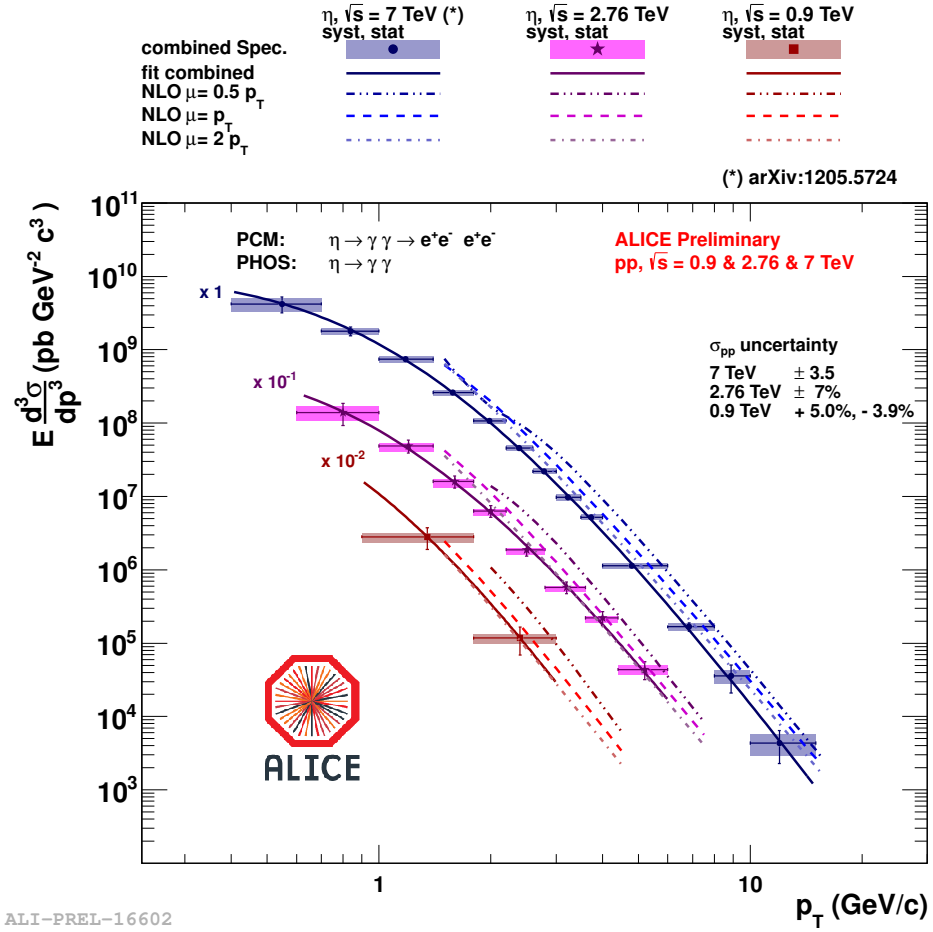
- Good agreement PHOS/PCM.
- Use Tsallis fit function as parametrization.

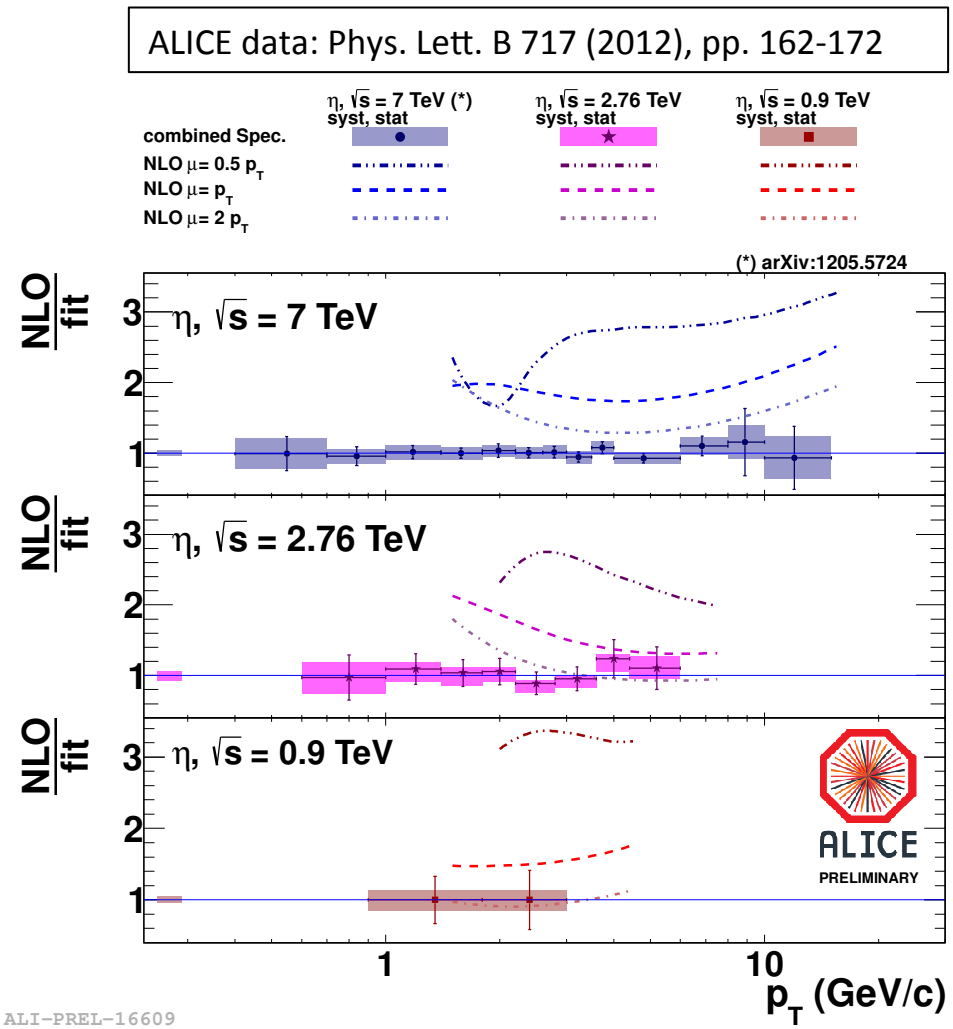
- Compare data with NLO pQCD (*), results can help to tune PDF and FF.
- Calculations overestimate cross section and predict different slope for 2.76 and 7 TeV col.

(*) P. Aurenche et al., Eur. Phys. J. C13, 347-355 309 (2000)

η spectra in pp at 0.9, 2.76 and 7 TeV

ALICE data: Phys. Lett. B 717 (2012), pp. 162-172





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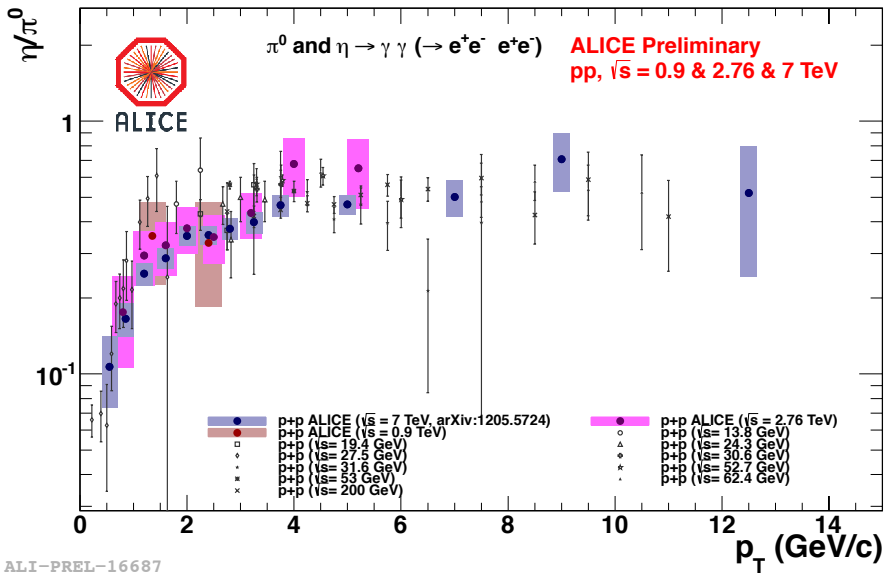
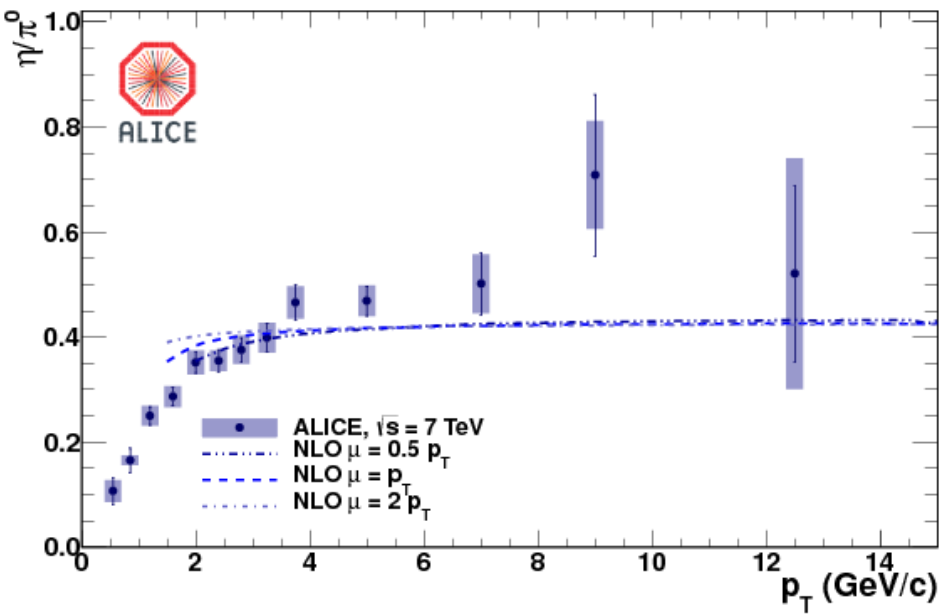
η/π^0 ratio

ALICE data: Phys. Lett. B 717 (2012), pp. 162-172

Compilation of η/π^0 in pp at $\sqrt{s}$=13-7000 GeV



Comparison with NLO pQCD



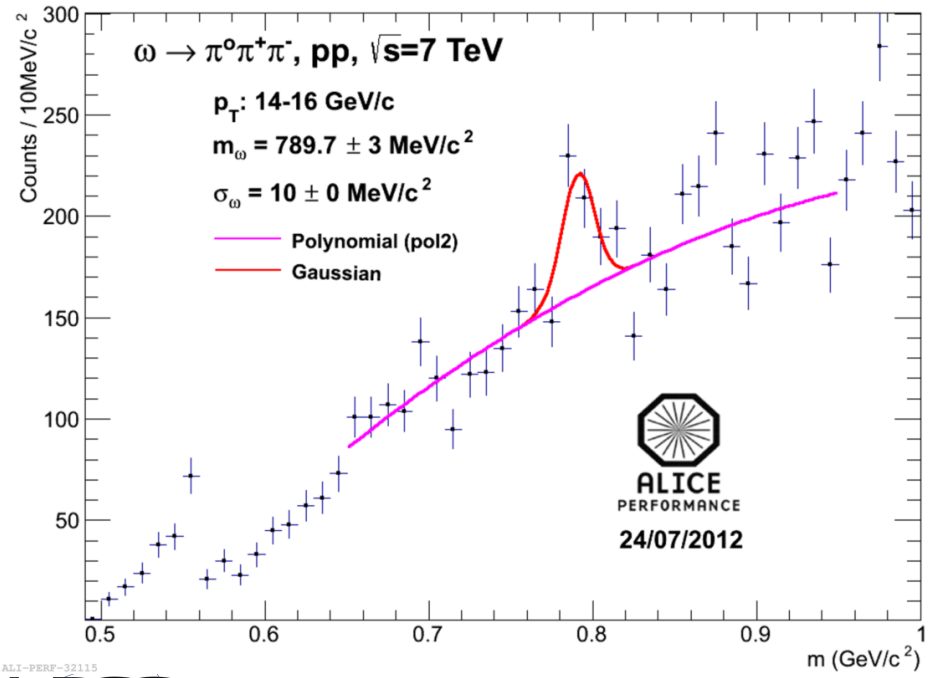
- The measured ratio η/π^0 in a wide collision energy range $\sqrt{s}$ = 13 to 7000 GeV shows an universal behavior.
- The measured η/π^0 ratio is reproduced by pQCD.

ω mass peak in pp at 7 TeV

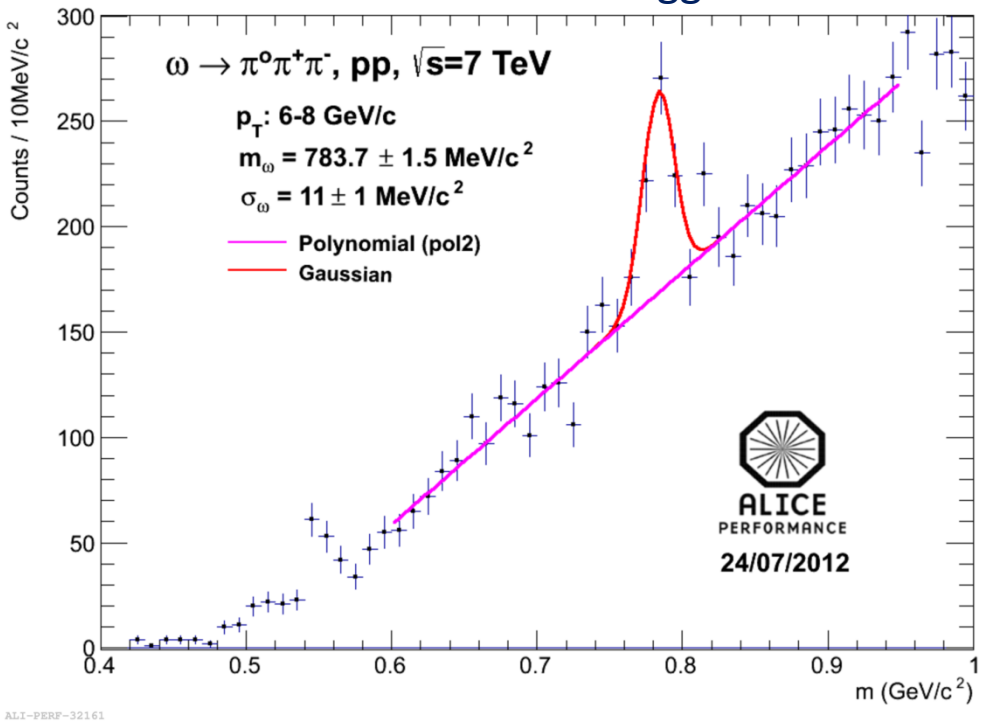
$\omega \rightarrow \pi^+\pi^-\pi^0$

- Using $\pi^{\pm}$ reconstructed in Central Tracking System and π^0 – in PHOS.
- Data collected in 2010: ~400 M events, ~ 6 nb^{-1}.

PHOS trigger data



Minimum Bias trigger



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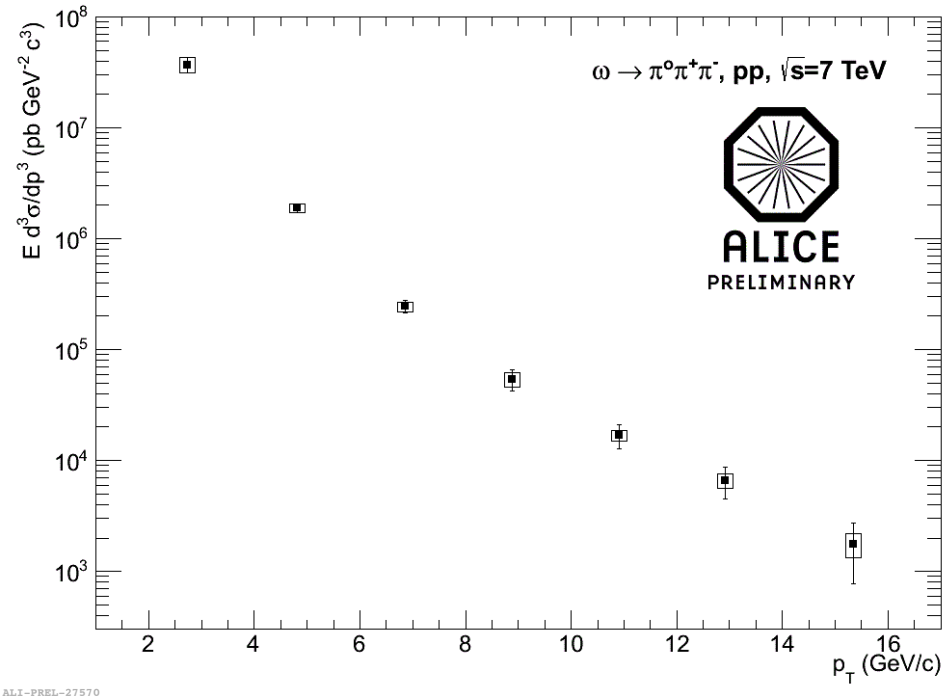
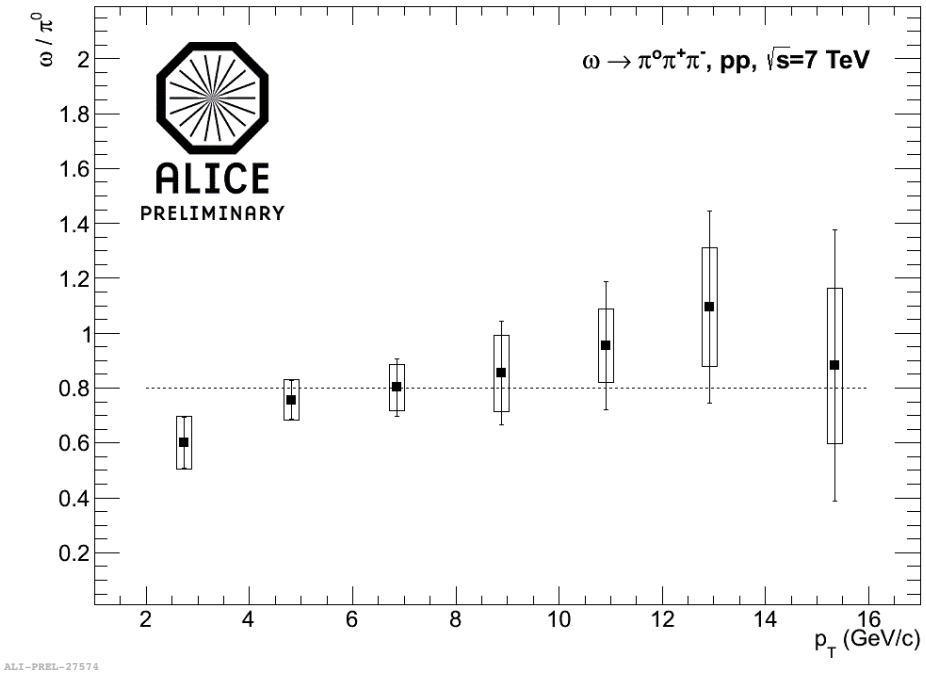
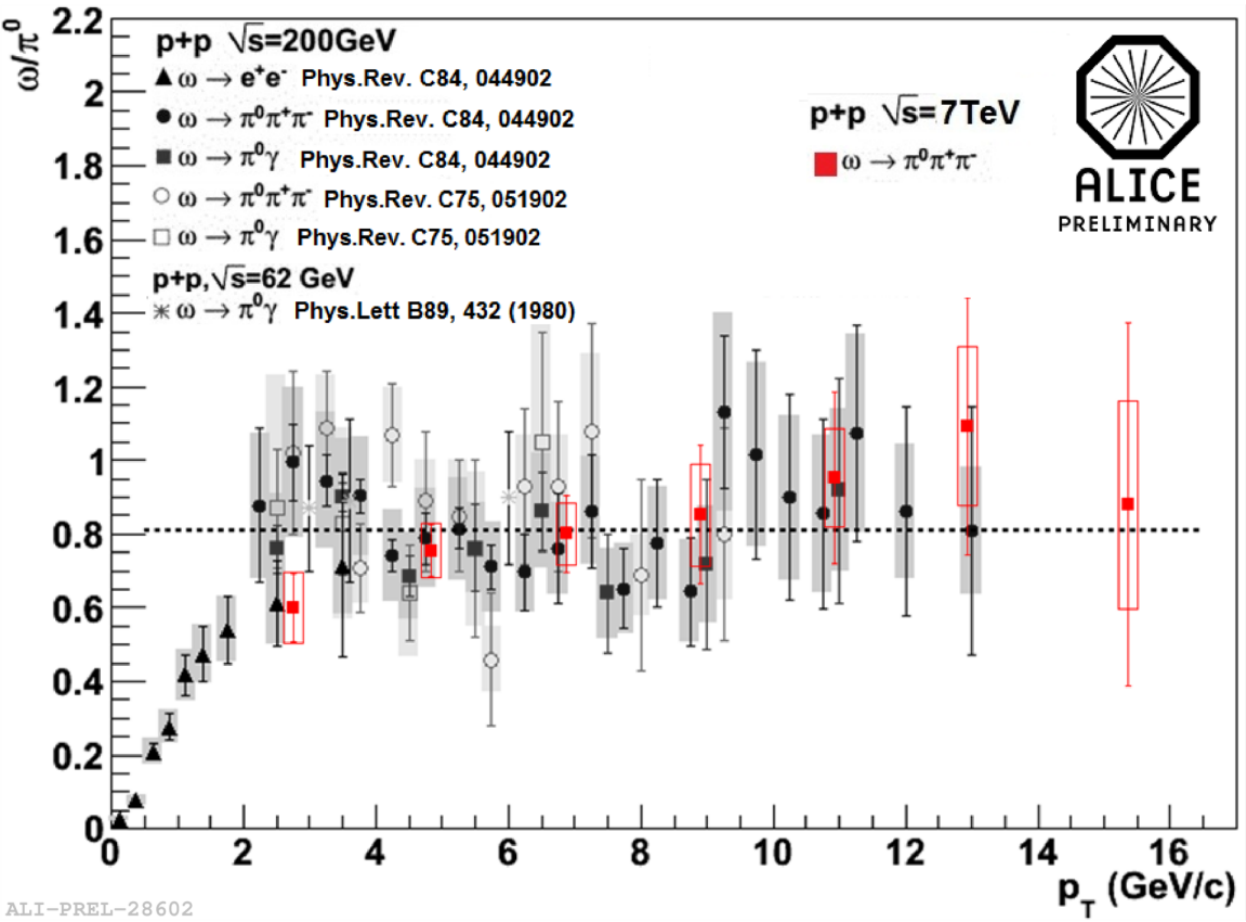
ω spectrum in pp 7 TeV





Spectrum of ω has a slope consistent with that of π^0 above 4 GeV/c.

ω/π^0 spectra ratio in pp at 7 TeV

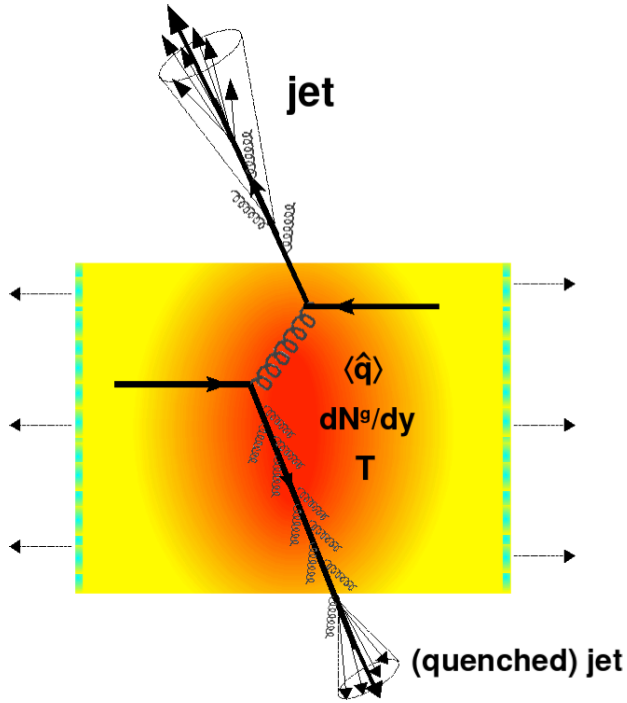


- The measured ratio ω/π^0 in a wide collision energy range √s = 62 to 7000 GeV shows an universal behavior.
- Comparison to theory prediction would be interesting (NLO Fragmentation Function for ω is missing…).

Neutral meson suppression
Parton energy loss in QGP

Tomography of the QGP

- Make a tomography of strongly interacting QCD matter produced in Pb-Pb collisions.



Medium features :

- mean free path λ
- gluon density dN^g/dy
- temperature T
- transverse size (L)

- **Single hadron suppression**

$$R_{AA}(p_T, y) = \frac{d^2N_{AA}/dydp_T}{\langle N_{coll}\rangle \times d^2N_{pp}/dydp_T}$$

→ Particle identification can help to understand energy loss dependences (quark vs gluon, quark mass, …).

- **Parton fragmentation**

→ Fragmentation function modified due to parton energy loss.

→ Gather observables to constrain models:

- hadron-hadron correlations.
- jet reconstruction.
- gamma-hadron correlations.

(see Catherine's talk)

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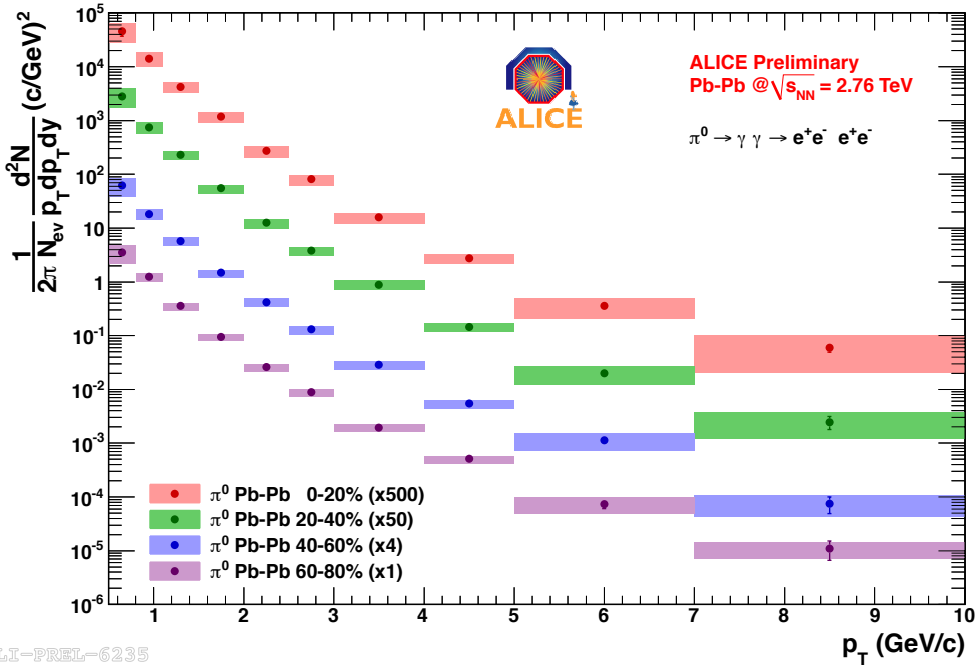
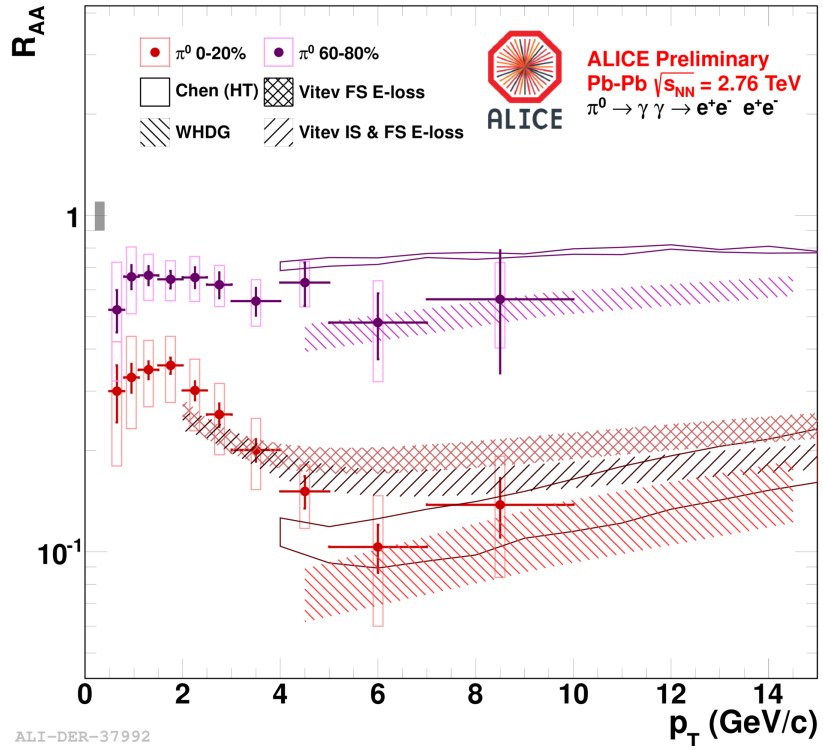
π^0 R_{AA} Pb-Pb 2.76 TeV

- π^0 spectra measured from conversion photons for different centralities.
- π^0 R_{AA} strength and shape described by theoretical models.
- Next step : higher p_T by using calorimeter reconstruction.



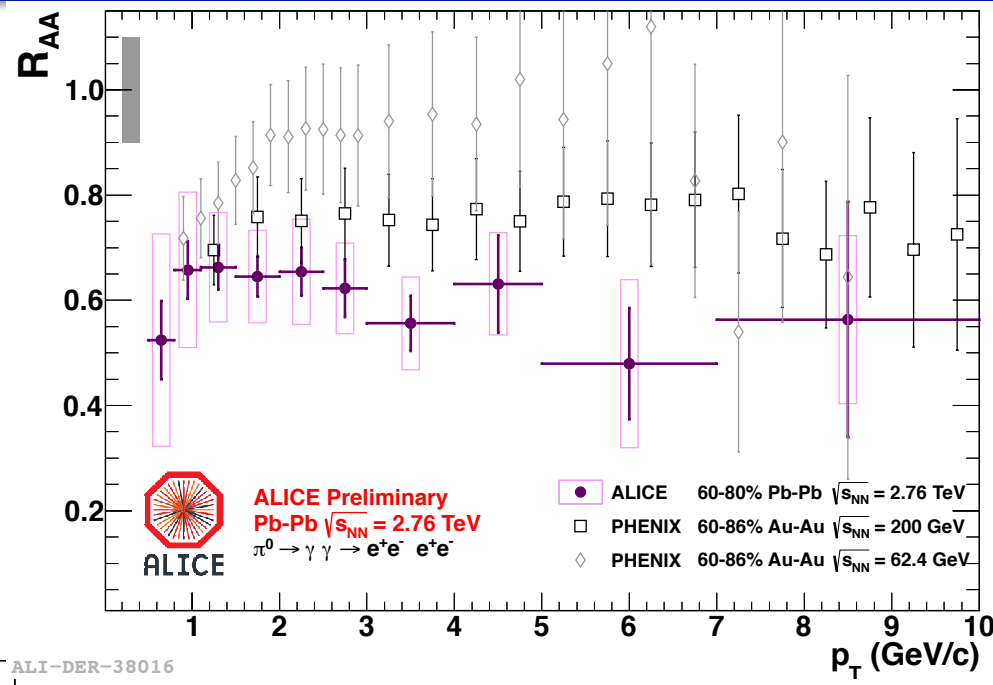


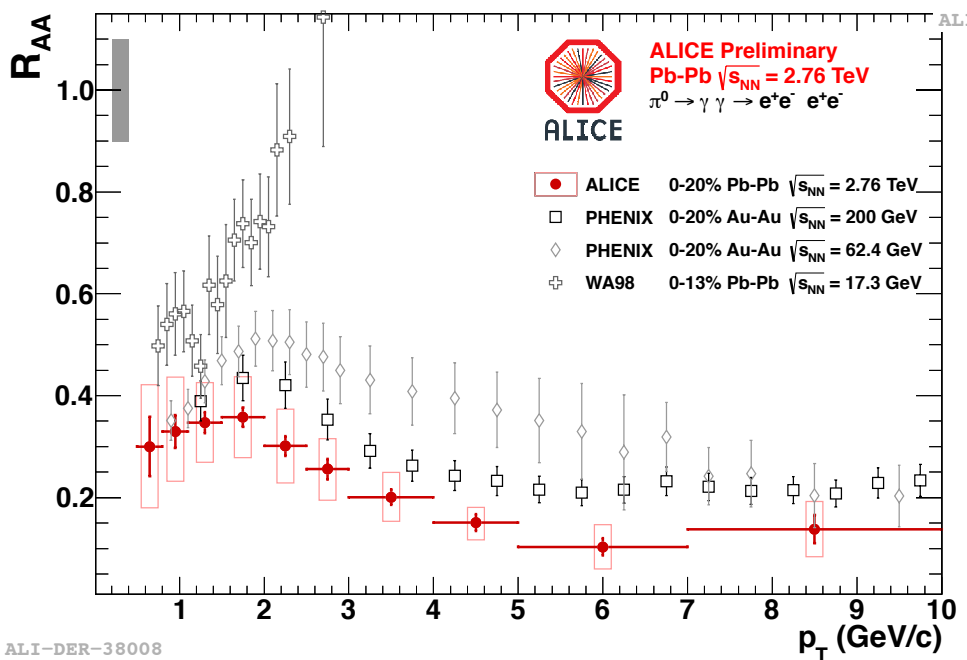
See D. Peresunko talk QM 2012, arXiv:1210.5749 (nucl-ex)

- (**WHDG**) W. A. Horowitz. Int.J.Mod.Phys. E16 (2007) 2193–2199, arXiv:nucl-th/0702084 [nucl-th]
- X.-F. **Chen**, T. Hirano, E. Wang, X.-N. Wang, and H. Zhang. Phys.Rev. C84 (2011) 034902, ArXiv:1102.5614 [nucl-th]
- R. Sharma, I. **Vitev**, and B.-W. Zhang. Phys.Rev. C80 (2009) 054902, arXiv:0904.0032[hep-ph]

π^0 R_{AA} LHC vs RHIC

- Suppression follows the energy dependence seen at RHIC energies.
- Suppression agrees with charged pion R_{AA} within errors.





[S.Bathe et al., PHENIX collaboration.
J. Phys. G: Nucl. Part. Phys. 38 (2011) 124001]

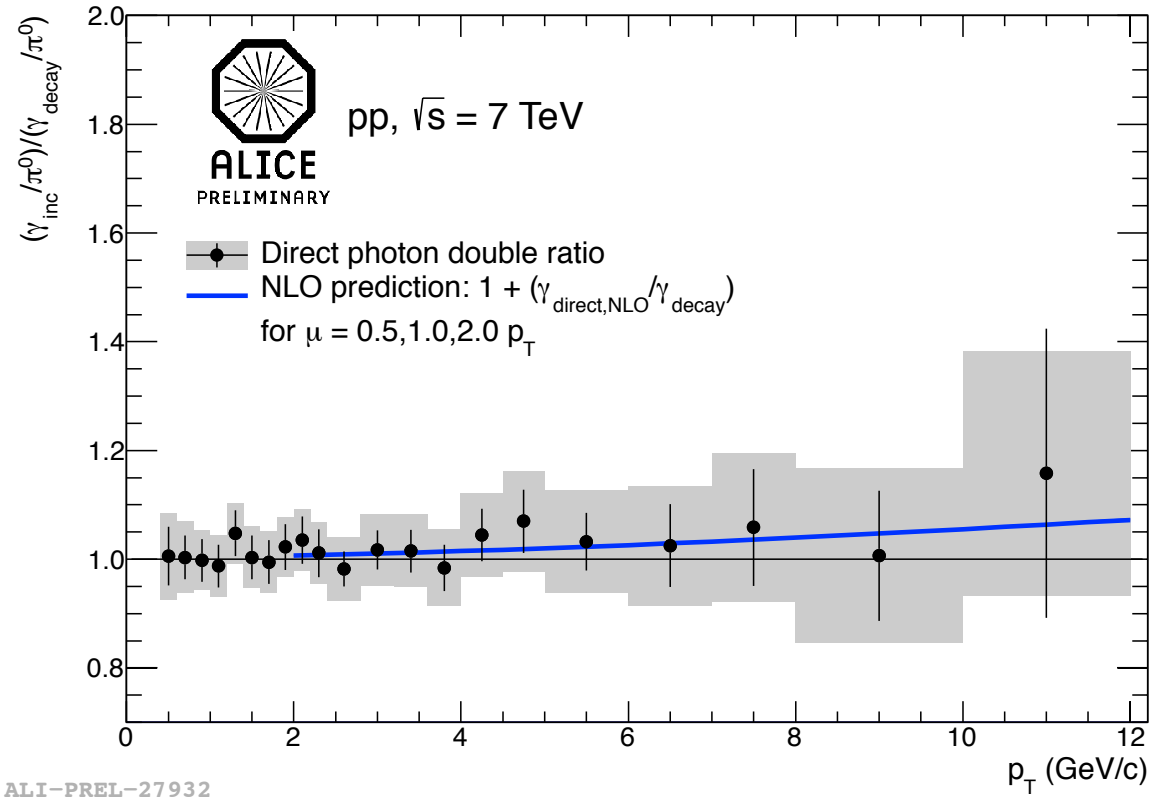
Low p_T direct photons

Direct photons in 7 TeV pp

- Direct photons from inclusive spectrum : $\gamma_{dir} = \gamma_{inc} - \gamma_{decay}$
- Double ratio: R= $\frac{\gamma_{inc}}{\gamma_{decay}} \approx \frac{\gamma_{inc}}{\pi^0} / \frac{\gamma_{decay}}{\pi^0}$, if > 1 direct photon signal.

From converted photon measurements

From cocktail generator (π^0 data+simulation)



The NLO double ratio is
$R_{NLO} = 1 + \gamma_{NLO} / \gamma_{decay\ cocktail}$

The measured direct photon signal in pp collisions at √s=7 TeV shows no excess

See M. Wilde talk QM 2012, arXiv:1210.5958 (hep-ex)

Direct photons in 40-80% 2.76 TeV Pb-Pb

- Direct photons from inclusive spectrum : $\gamma_{dir} = \gamma_{inc} - \gamma_{decay}$
- Double ratio: $R = \frac{\gamma_{inc}}{\gamma_{decay}} \approx \frac{\gamma_{inc}}{\pi^0} / \frac{\gamma_{decay}}{\pi^0}$, if > 1 direct photon signal.

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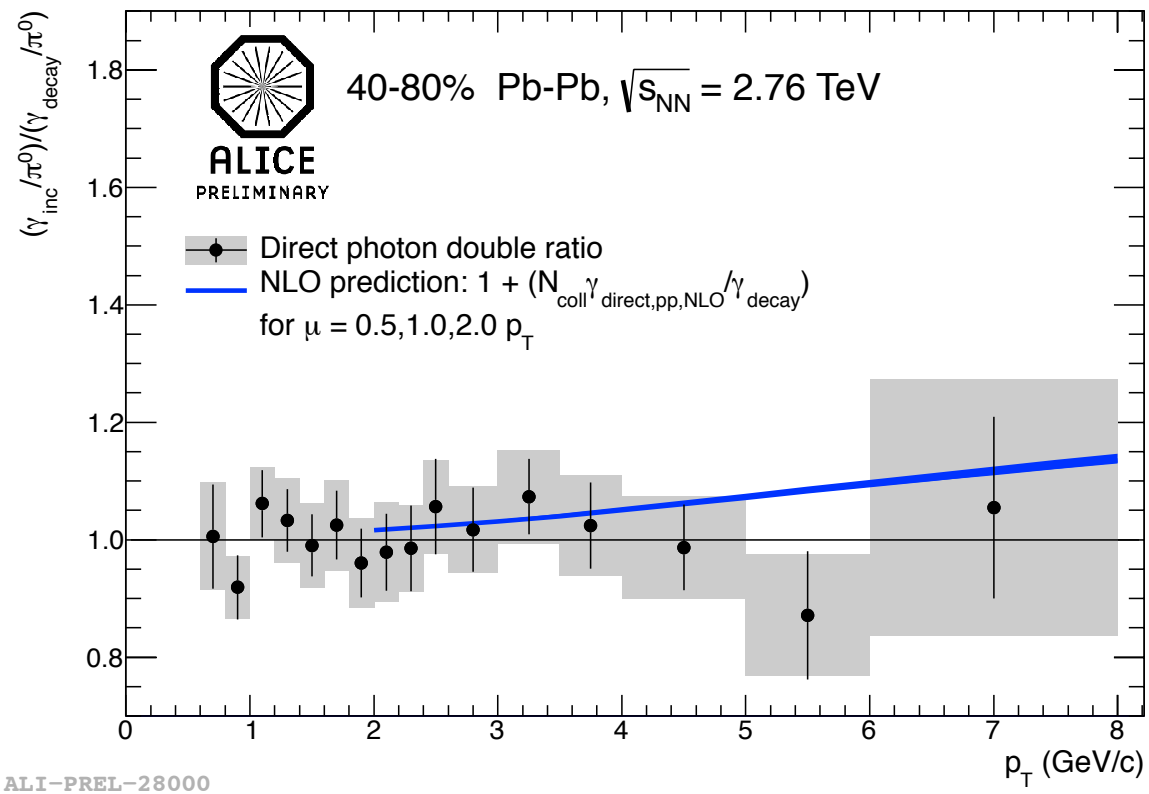


The NLO double ratio is
$R_{NLO} = 1 + N_{coll}\gamma_{NLO}/\gamma_{decay\ cocktail}$

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

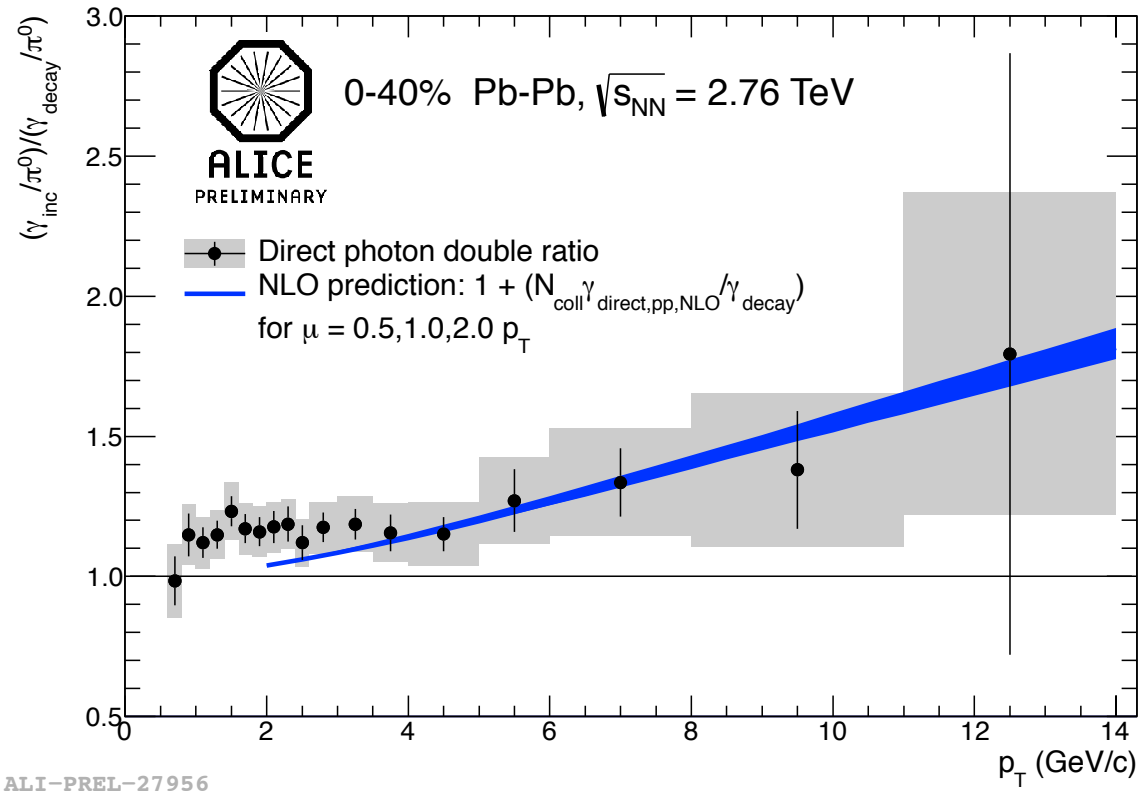
See M. Wilde talk QM 2012, arXiv:1210.5958 (hep-ex)

Direct photons in 0-40% 2.76 TeV Pb-Pb

- Direct photons from inclusive spectrum: $\gamma_{dir} = \gamma_{inc} - \gamma_{decay}$
- Double ratio: $R = \frac{\gamma_{inc}}{\gamma_{decay}} \approx \frac{\gamma_{inc}}{\pi^0} / \frac{\gamma_{decay}}{\pi^0}$, if > 1 direct photon signal.

From converted photon measurements

From cocktail generator (π^0 data+simulation)



The NLO double ratio is

$R_{NLO} = 1 + N_{coll}\gamma_{NLO}/\gamma_{decay\ cocktail}$

Clear extra yield of 20% for $p_T < 2$ GeV/*c*. High p_T direct photon measurement agrees with the NLO prediction scaled by N_{coll}

See M. Wilde talk QM 2012, arXiv:1210.5958 (hep-ex)

Direct photons in 2.76 TeV Pb-Pb

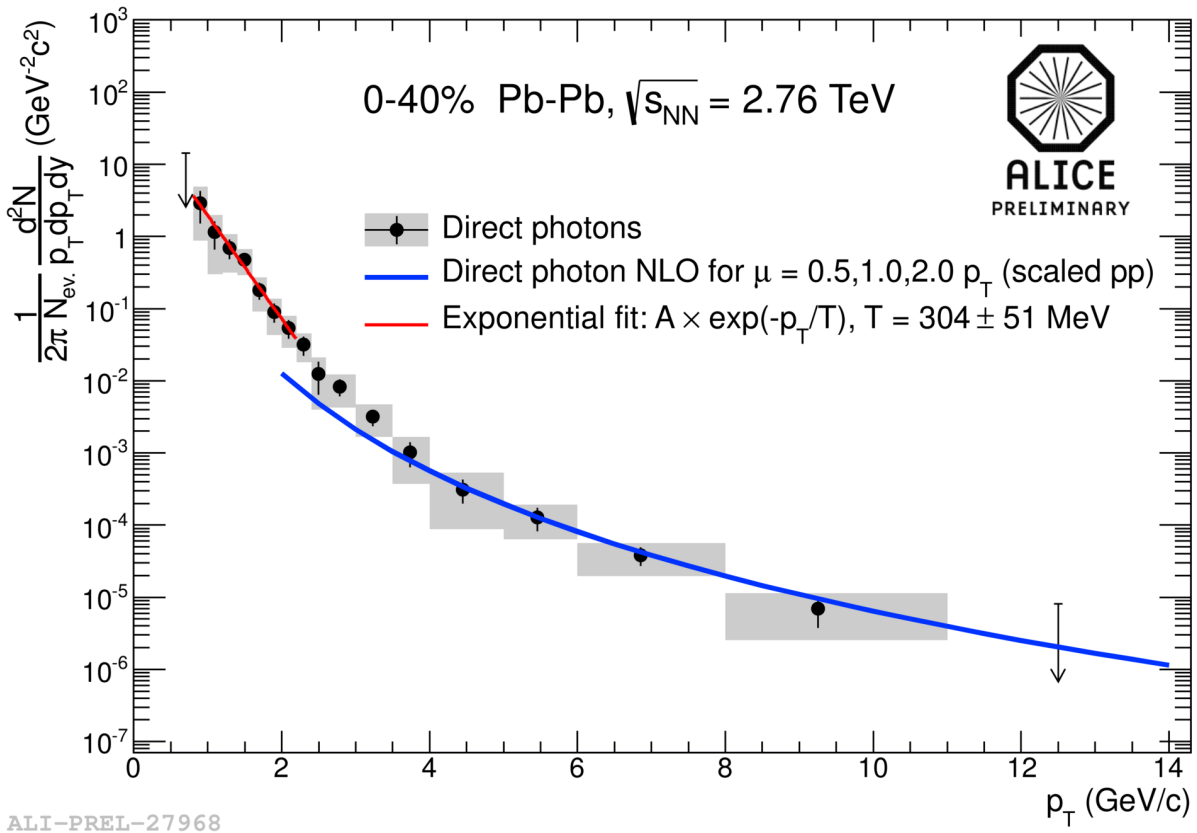
- Spectrum derived from double ratio:

$$\gamma_{dir} = \gamma_{inc} \times \left(1 - \gamma_{decay} / \gamma_{inc}\right)$$

→ NLO predictions in agreement with data for $p_T > 4$ GeV/c.

→ Exponential fit for $p_T < 2$ GeV/c slope **: T = 304 ± 51 $^{sys+stat}$ MeV (Cen: 0-40%).**

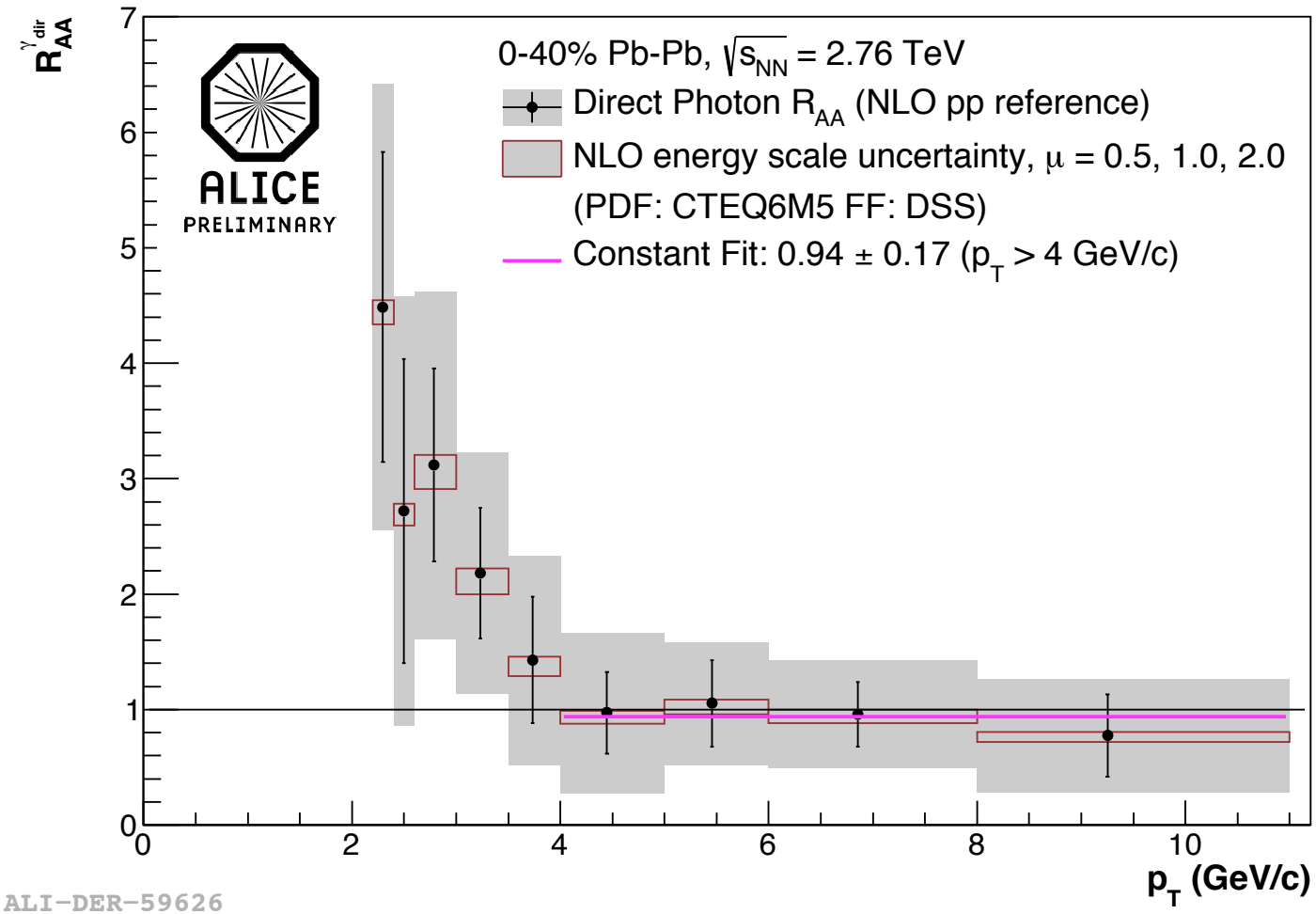
→ **RHIC : T = 221 ± 19 ^{stat} ± 19 ^{sys} MeV (Cen: 0-20-%).**



See M. Wilde talk QM 2012, arXiv:1210.5958 (hep-ex)

Direct photons in 2.76 TeV Pb-Pb: R_{AA}

- Ratio of measured direct photon yield to NLO prediction, scaled with N_{coll}:
  - → $p_T > 4$ GeV/c : Clear scale of NLO with N_{coll} and data.
  - → $2 < p_T < 4$ GeV/c : Clear enhancement.

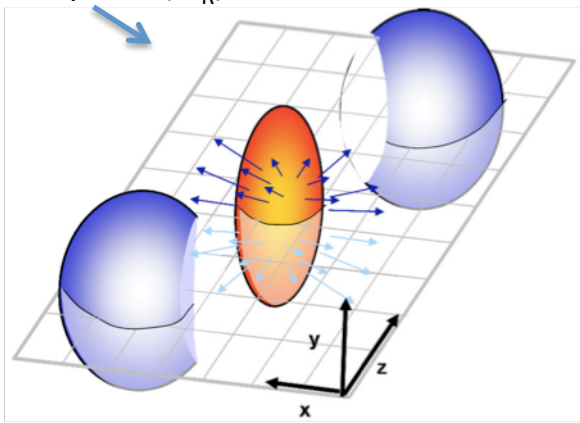


ALI-DER-59626

Direct photons v_2 in Pb-Pb 2.76 TeV

- space asymmetry ⇔ momentum asymmetry,
- Fourier series : $E\frac{d^3N}{d^3p} = \frac{d^2N}{2\pi p_T dp_T dy}(1+\sum_{n=1}^{\infty} 2v_n cos[n(\Phi-\Psi_r)])$
- v_2 (elliptic flow) ⇔ onset of direct photon production (early(QGP) : small v_2, late(HG) : large v_2).

Reaction plane (Ψ_R)



Experimental method :

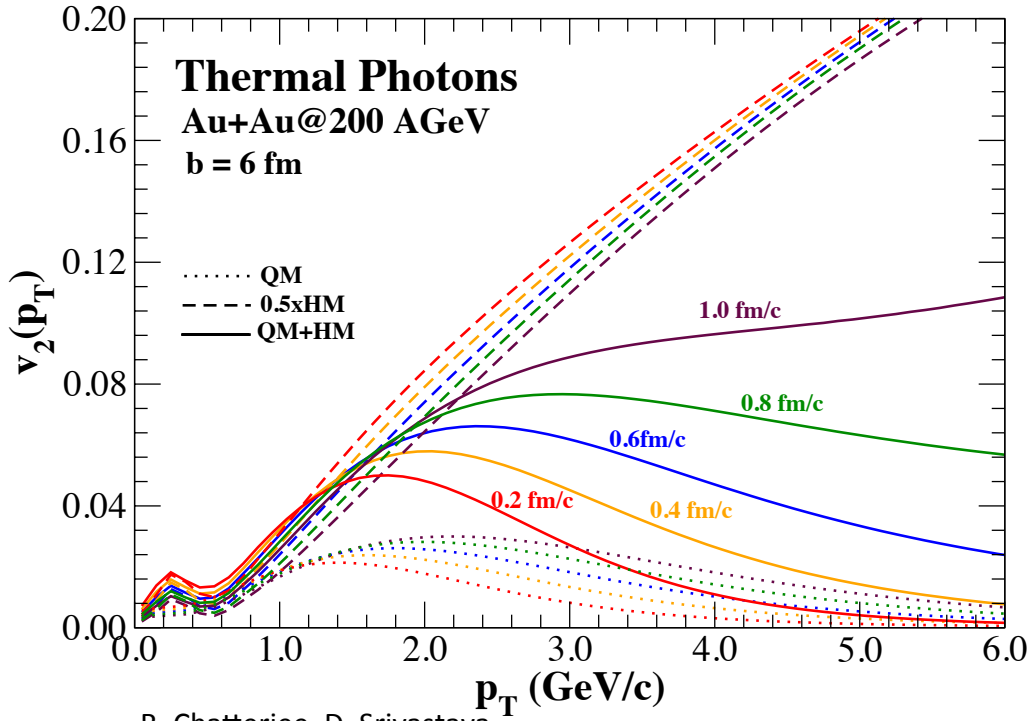
- v_2 direct photon :

$$v_2^{\gamma\ direct} = (Rv_2^{\gamma\ inc} - v_2^{\gamma\ decay})/(R-1)$$

with double ratio $R = N^{\gamma\ inc}/N^{\gamma\ decay}$

- Get event plane (Ψ_2^{EP})
- Extract $v_2 \approx \langle\cos[2(\Phi-\Psi_2^{EP})]\rangle$

See D. Lohner talk HQ 2012, arXiv:1212.3995(hep-ex)



R. Chatterjee, D. Srivastava
arXiv:0809.0548 [nucl-th]

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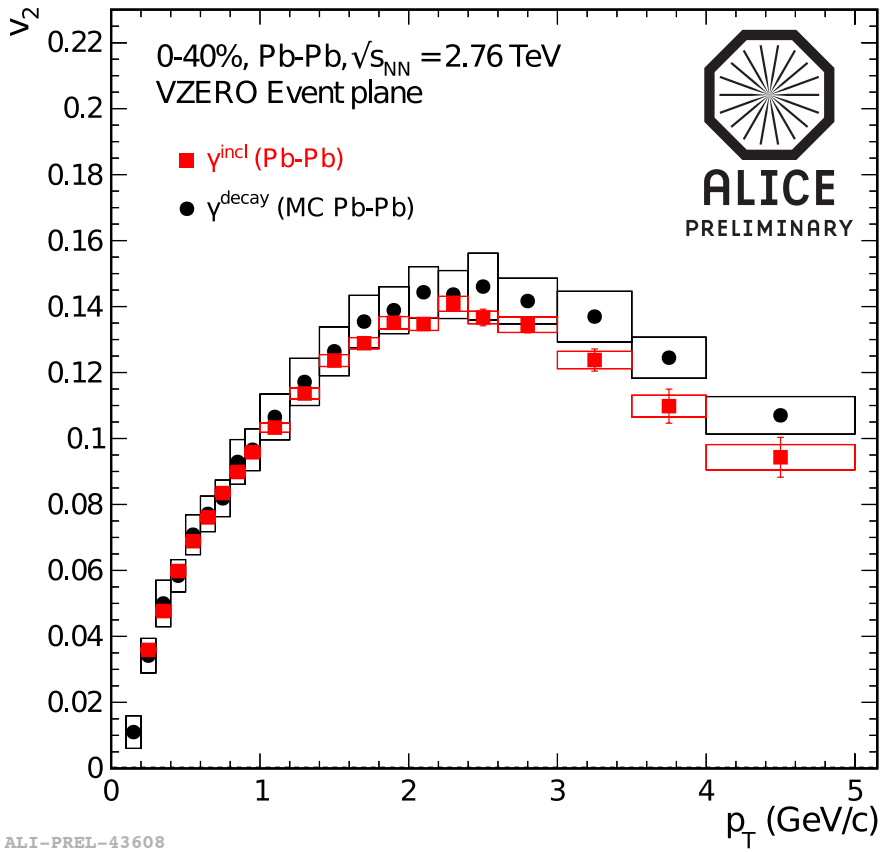
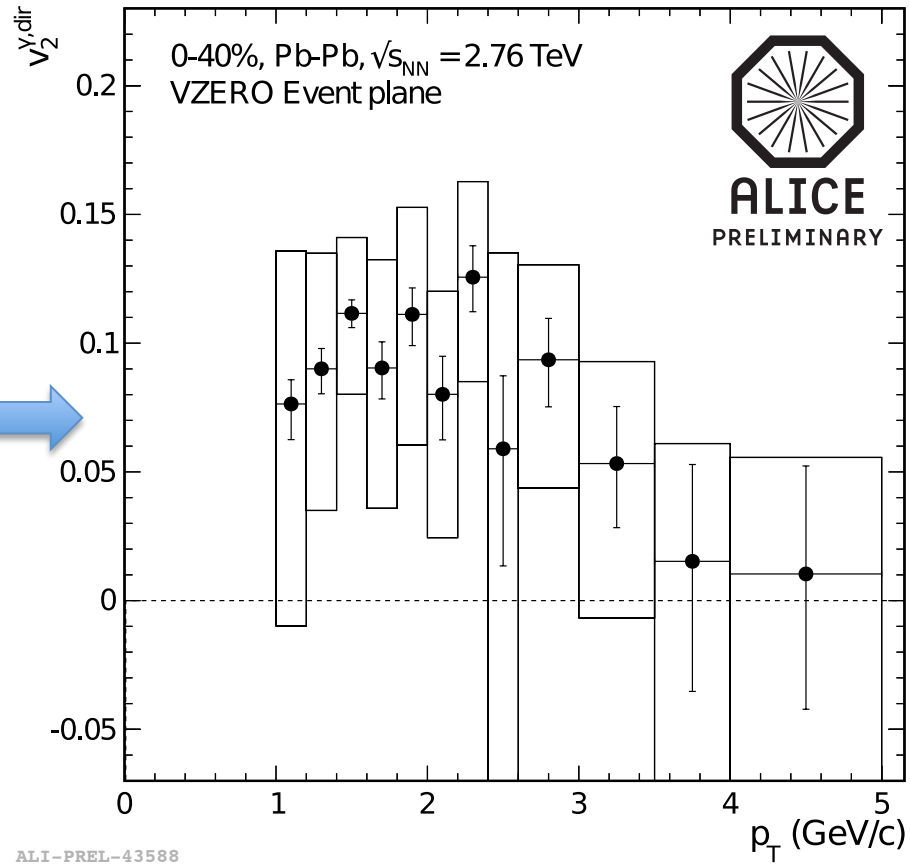
Direct photons v_2 in Pb-Pb 2.76 TeV

$$v_2^{\gamma\ direct} = (R v_2^{\gamma\ inc} - v_2^{\gamma\ decay})/(R-1)$$



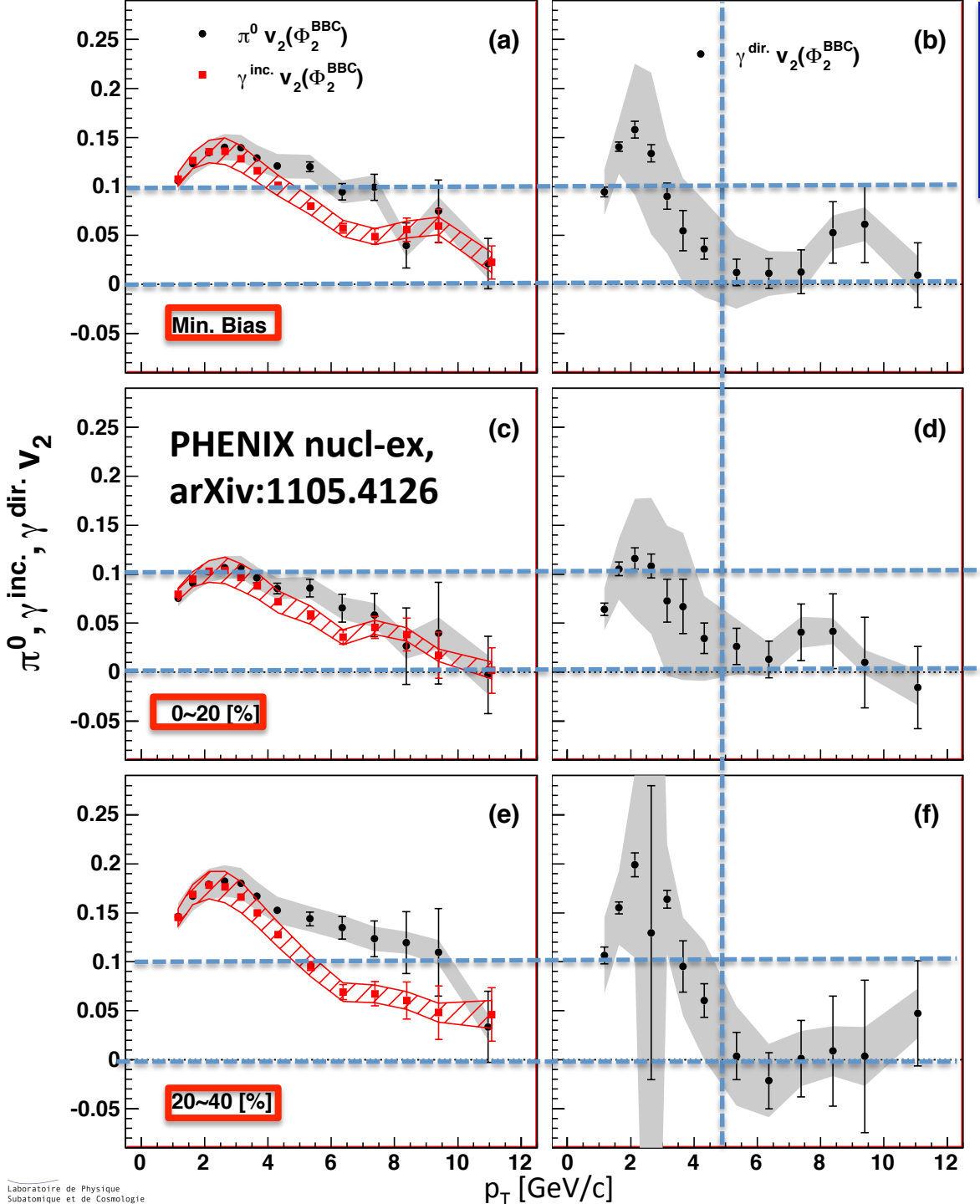


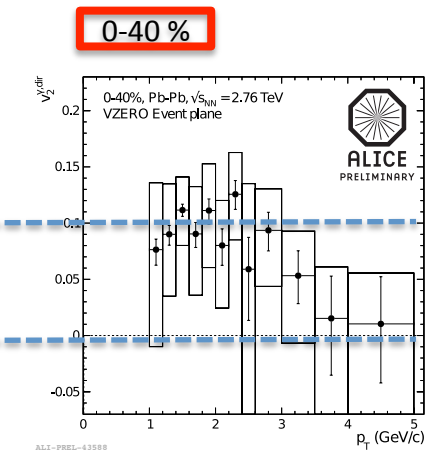
- Inclusive γ's $\mathbf{v_2}$ has same behavior to hadrons $\mathbf{v_2}$ with centrality.
- Decay γ's $\mathbf{v_2}$ obtained from cocktail spectra, different mesons decay scaled via m_T and quark number.

- Significant flow of direct γ below 3 GeV/c
- Magnitude comparable to pion flow.
- Unexpected from high T^{eff} measurement.

See D. Lohner talk HQ 2012, arXiv:1212.3995(hep-ex)

PHENIX vs ALICE direct photon v_2





The strength of the v_2 is similar in both experiments, but the different centrality ranges do not allow to do a full comparison.

Summary and Outlook

- ALICE reconstructs photons with 3 complementary methods :
  - → Tracking (conversion photon) + 2 calorimeters (EMCal, PHOS).
  - → Large p_T range with useful overlap (from 1 to 50 GeV/c).
  - → Independent measurement with different systematics.

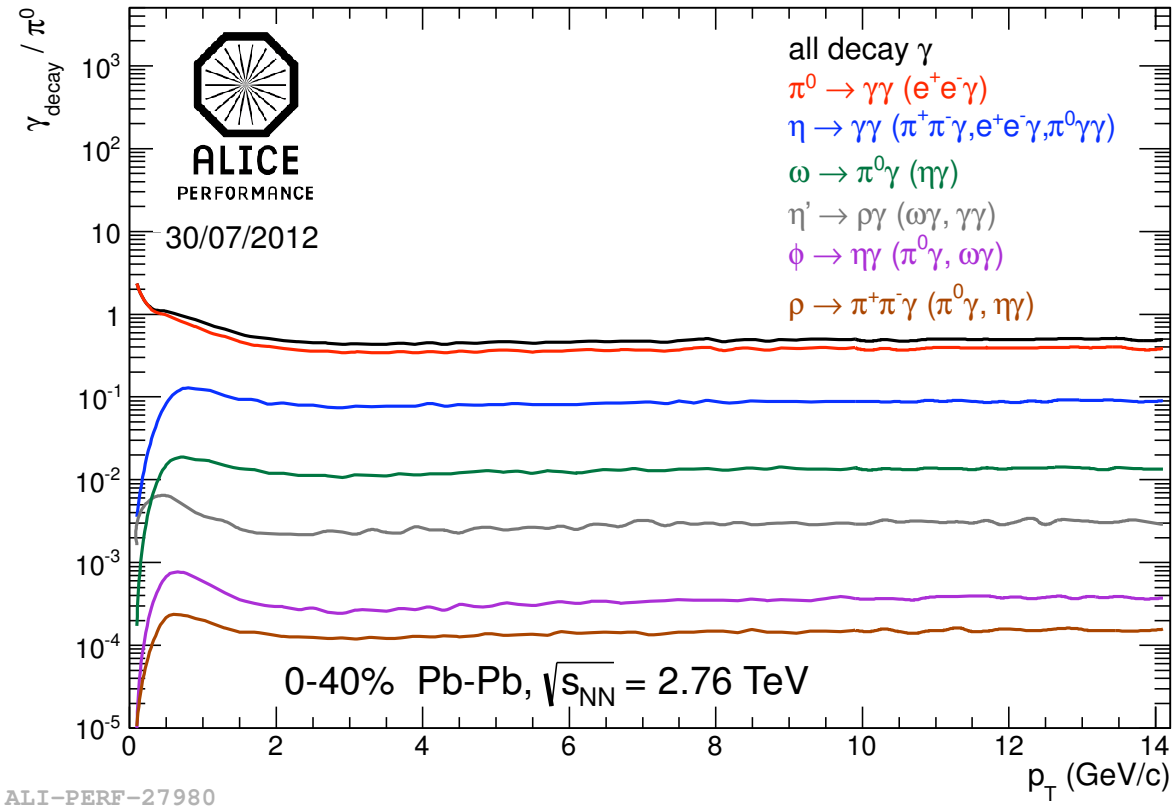
- Photon measurements provide wide-ranging results :
  - → Global QGP features (apparent temperature, direct photon flow v_2).
  - → Parton energy loss (neutral meson suppression R_{AA}).
  - → Besides in pp, tuning of NLO pQCD with neutral mesons.

- More results to come from pp, p-Pb and Pb-Pb analysis :
  - → Photon/π^0-hadron correlations (see Catherine's talk).
  - → Neutral mesons R_{AA} from calorimeters measurement.
  - → Direct photon spectrum from calorimeters measurement.


Welcome
Bienvenus

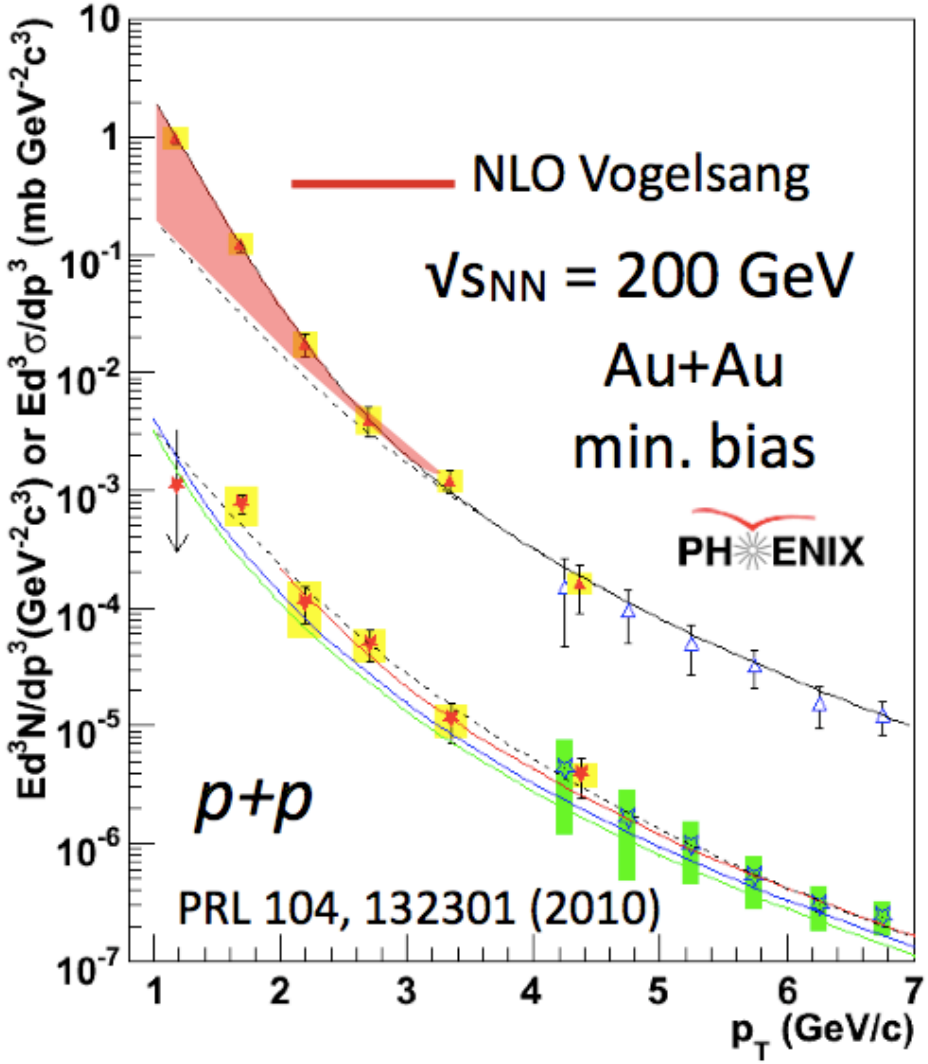
Cocktail simulation

- π^0 parametrized from 0-40% spectrum measurement
- other resonances from m_T-scaling



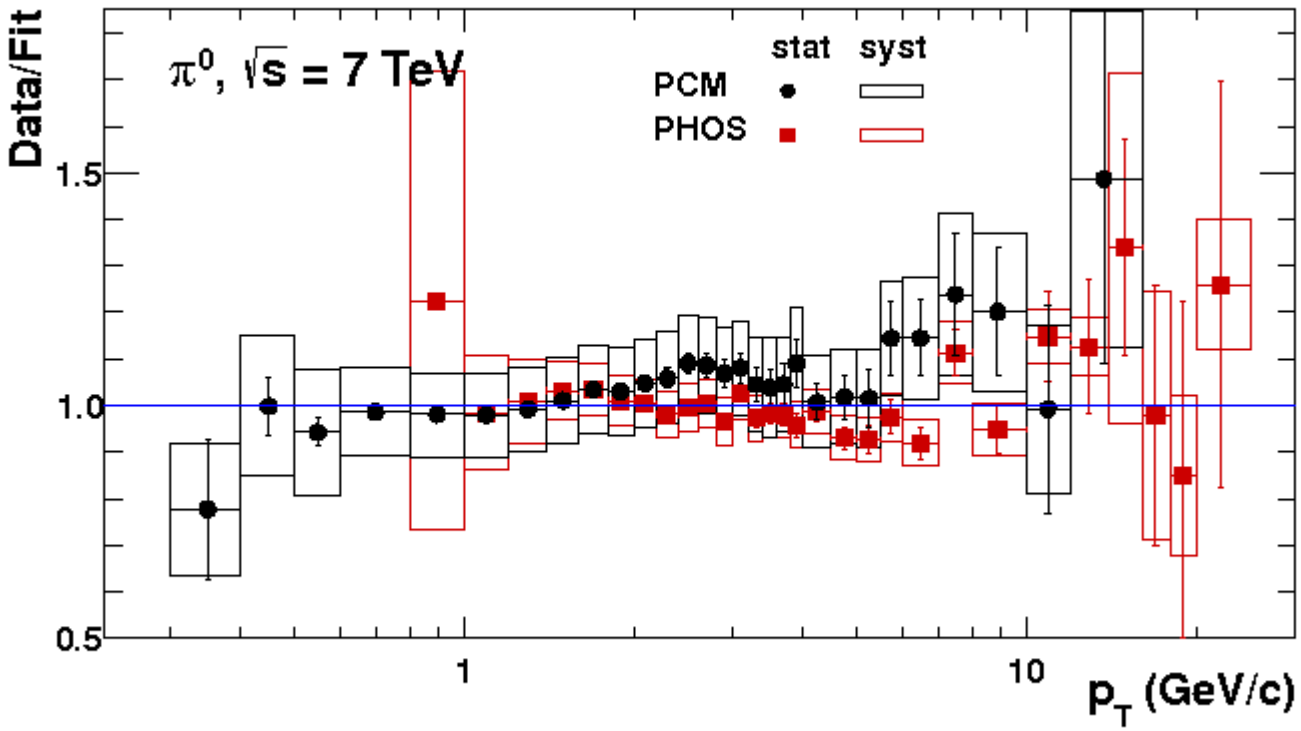
PHENIX thermal photons

- Exponential fit : T^{eff} = 220 ± 20 MeV



Comparison of spectra measured in PHOS and with conversion method

ALICE data: CERN-PH-EP-2012-001, arXiv.1205.5724

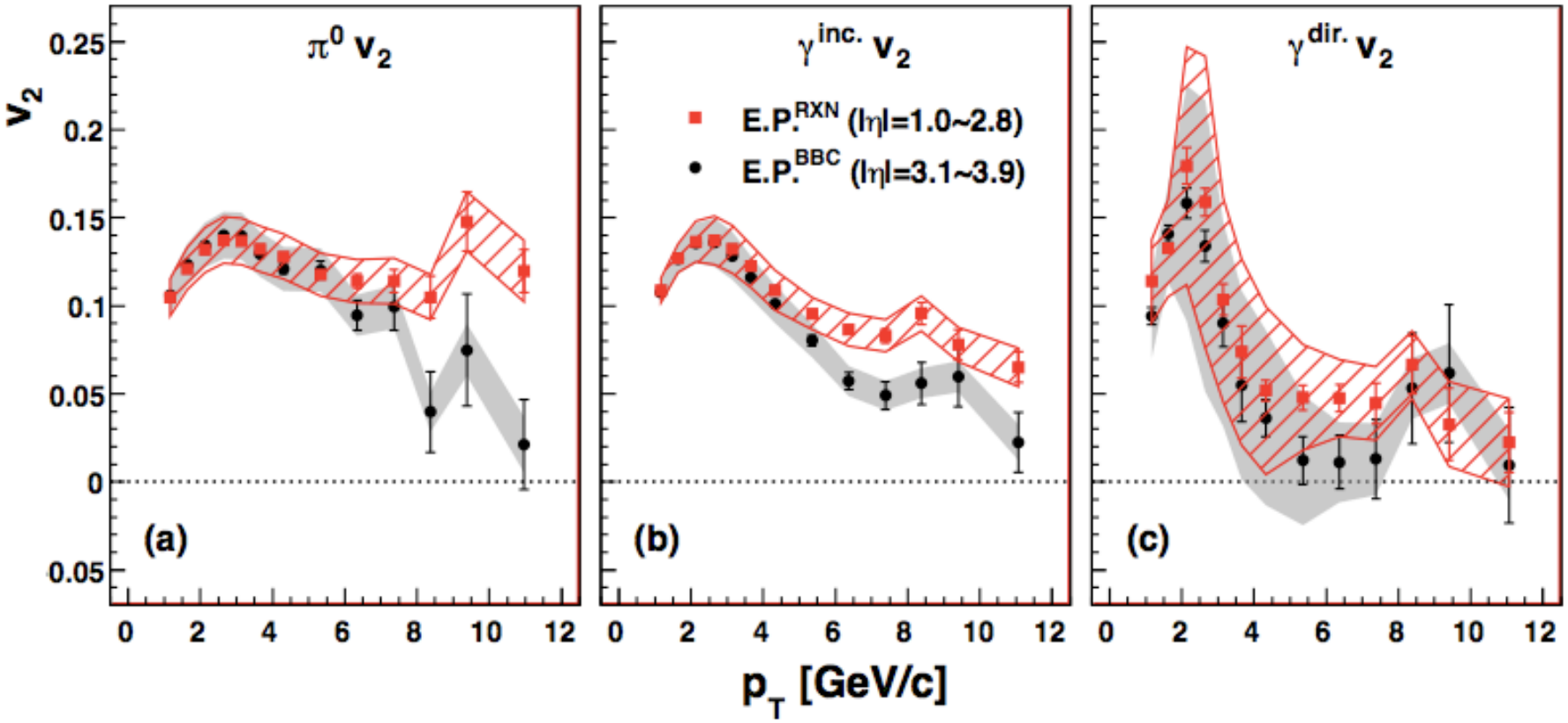


Neutral pion spectra measured in PHOS and Photon Conversion Method (PCM) agree within errors

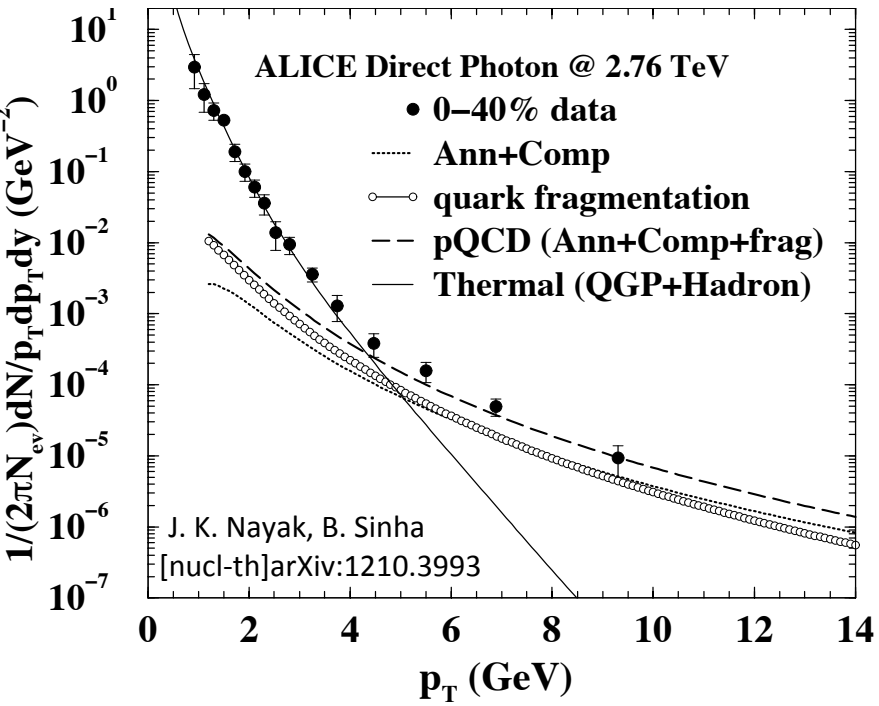
PHENIX direct photon v_2

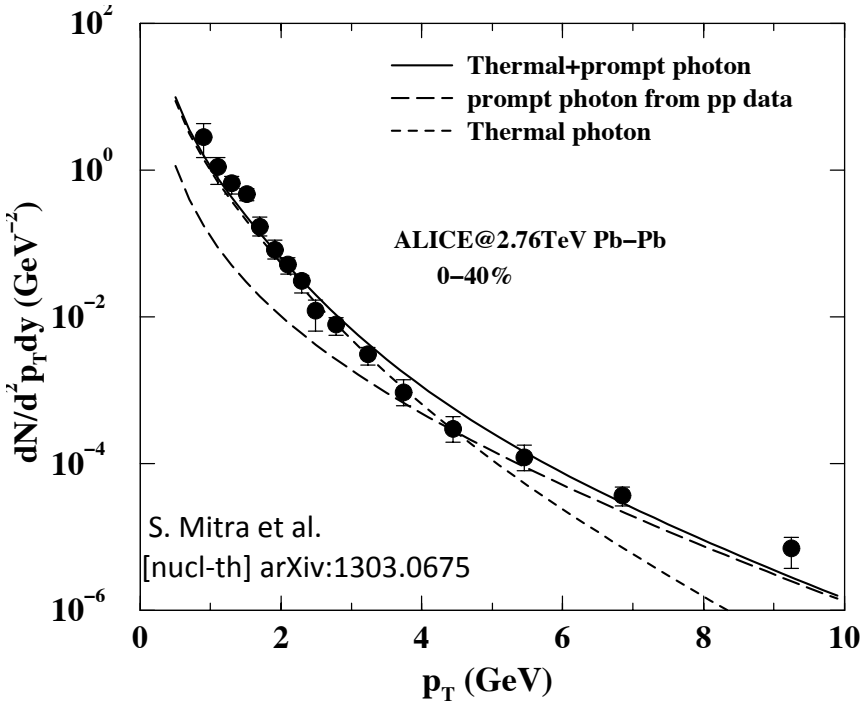
PHENIX nucl-ex, arXiv:1105.4126

Minimum bias



Direct photons in 2.76 TeV Pb-Pb





- Thermal: (2+1) dimensional relativistic hydrodynamics, prompt: CTEQ6M
- EoS: crossover like transition
  - Initial temperature: T_i = 546 MeV
  - Formation time: τ_i = 0.1 fm

- Thermal: lattice QCD EoS + resonance gas
- Prompt: photons from 7 TeV pp
  - Initial temperature: T_i = 553 MeV
  - Formation time: τ_i = 0.1 fm

Both calculations ignore jet-plasma photons