Production of Neutral Pions and Eta-Mesons in pp Collisions Measured with ALICE

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Why p_T Spectra of Neutral Pions and η Mesons in pp?

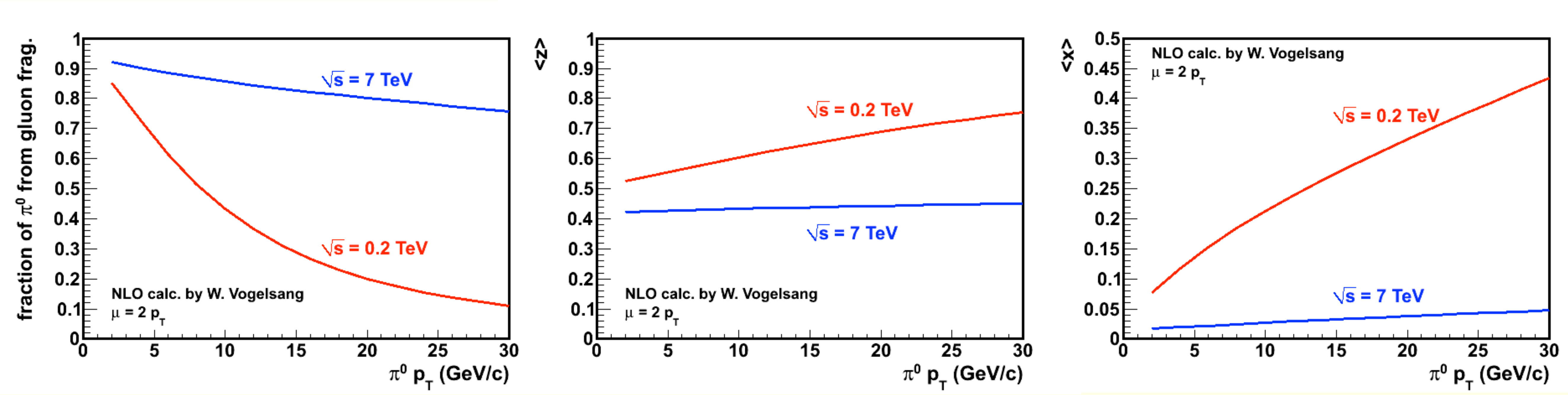
- Characterization of particle production in pp in a new energy regime
  - Test phenomenological rules observed at lower $\sqrt{s}$ (e.g., m_T scaling, x_T scaling)
- Test perturbative QCD at highest energies
  - π^0 and η measurements in the current p_T range mainly test $g \rightarrow \pi, \eta$ fragmentation functions
- Particular interest in η meson
  - large contribution of strange quarks and gluons to η mass
- π^0 and η p_T spectra needed
  - for the extraction of direct-photon spectrum
  - as a reference to study nuclear effects in Pb+Pb

In this talk: π^0 and η p_T spectra at $\sqrt{s}$ = 0.9, 2.76, and 7 TeV

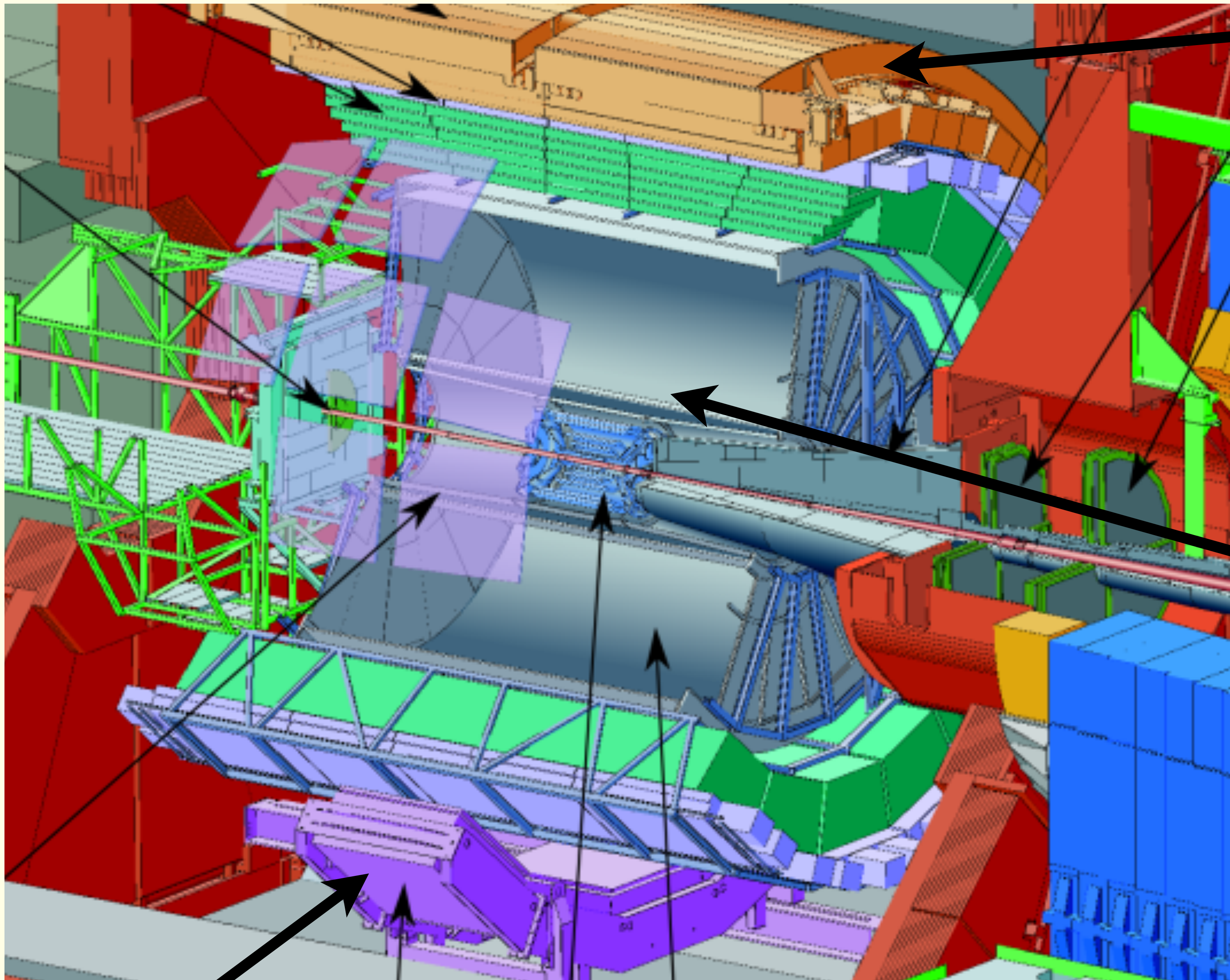
More on Gluon Fragmentation Functions

QCD factorization: $$E_h \frac{d^3\sigma}{d^3 p_h} = \sum_{a,b,c} f_a \otimes f_b \otimes d\hat{\sigma}^c_{ab} \otimes D^h_c$$

- Parton Distributions *f* in the *x* range relevant for ALICE data believed to be well under control
- Gluon fragmentation in e^+e^- not well constrained as gluon jets in e^+e^- are a subleading NLO correction $\Rightarrow$ π^0,η spectra in p+p important constraint for gluon FF
- π^0 spectra in pp at RHIC favor large $g \to \pi$ FF's (AKK and DSS favored over KRE)
- Gluon fragmentation at LHC more important than at RHIC



Photons and Neutral Mesons with ALICE: Conversion Method, PHOS, EMCAL



EMCAL

- Lead scintillator sandwich calorimeter
- $|\eta| < 0.7$, $\Delta\phi = 40°$ (now $\Delta\phi = 100°$)

Photon conversion + tracking

- γ's between beam pipe and middle of TPC can be detected ($p_{conv} \approx 8.5$ %)
- $p_T(e^{-/+})_{min} \approx 50$ MeV/c
- $|\eta| < 0.9$, full azimuth

PHOS

- Lead tungstate crystals
- $|\eta| < 0.13$, $\Delta\phi < 60°$

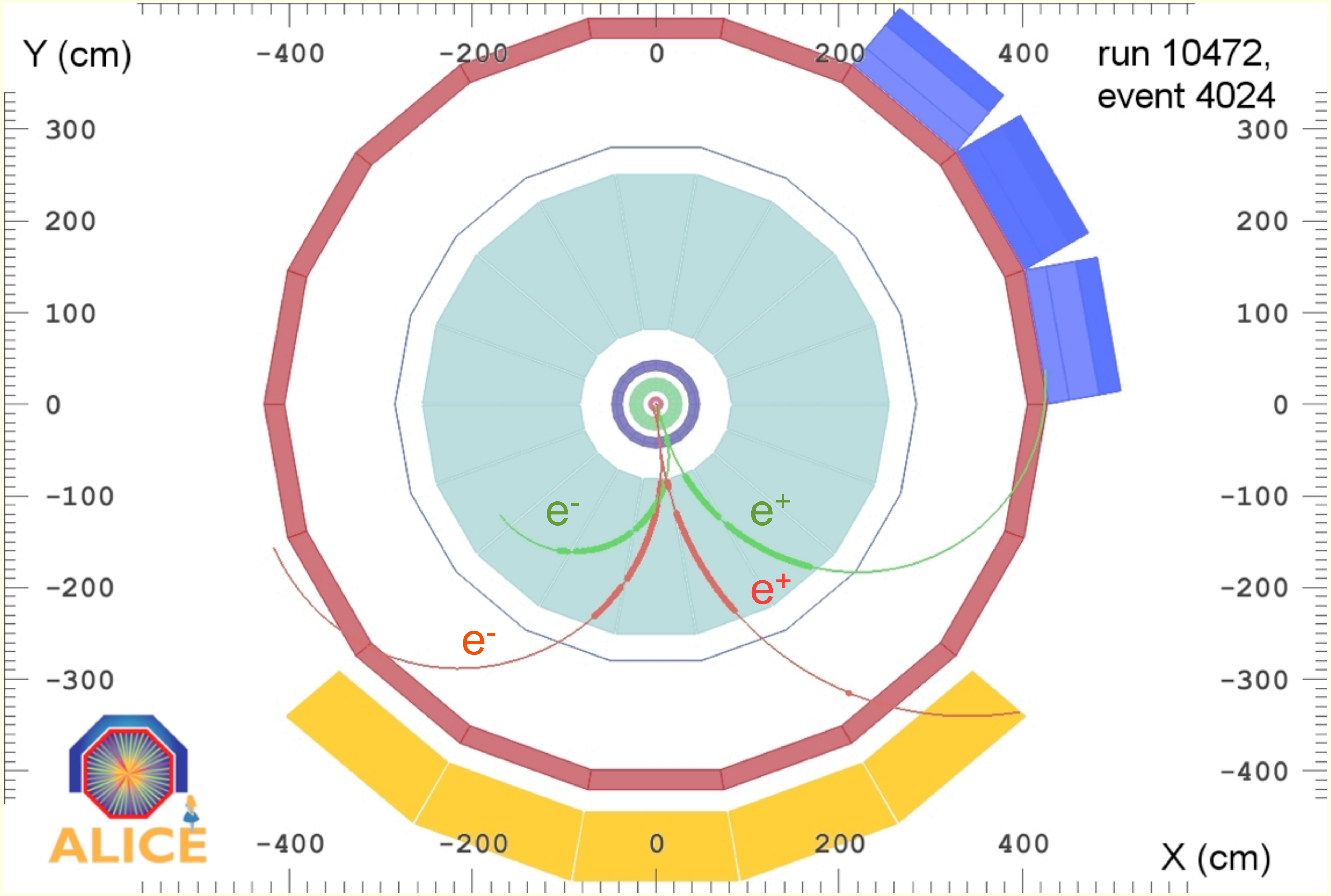
Posters:
Yuri Kharlov: π^0 and η in pp with PHOS
Alexander Borissov: π^0 via (Υ_{calo}, Υ_{conv}) pairs

Pb+Pb results: G. Conesa Balbastre, Thursday

Visualizing Neutral Pions

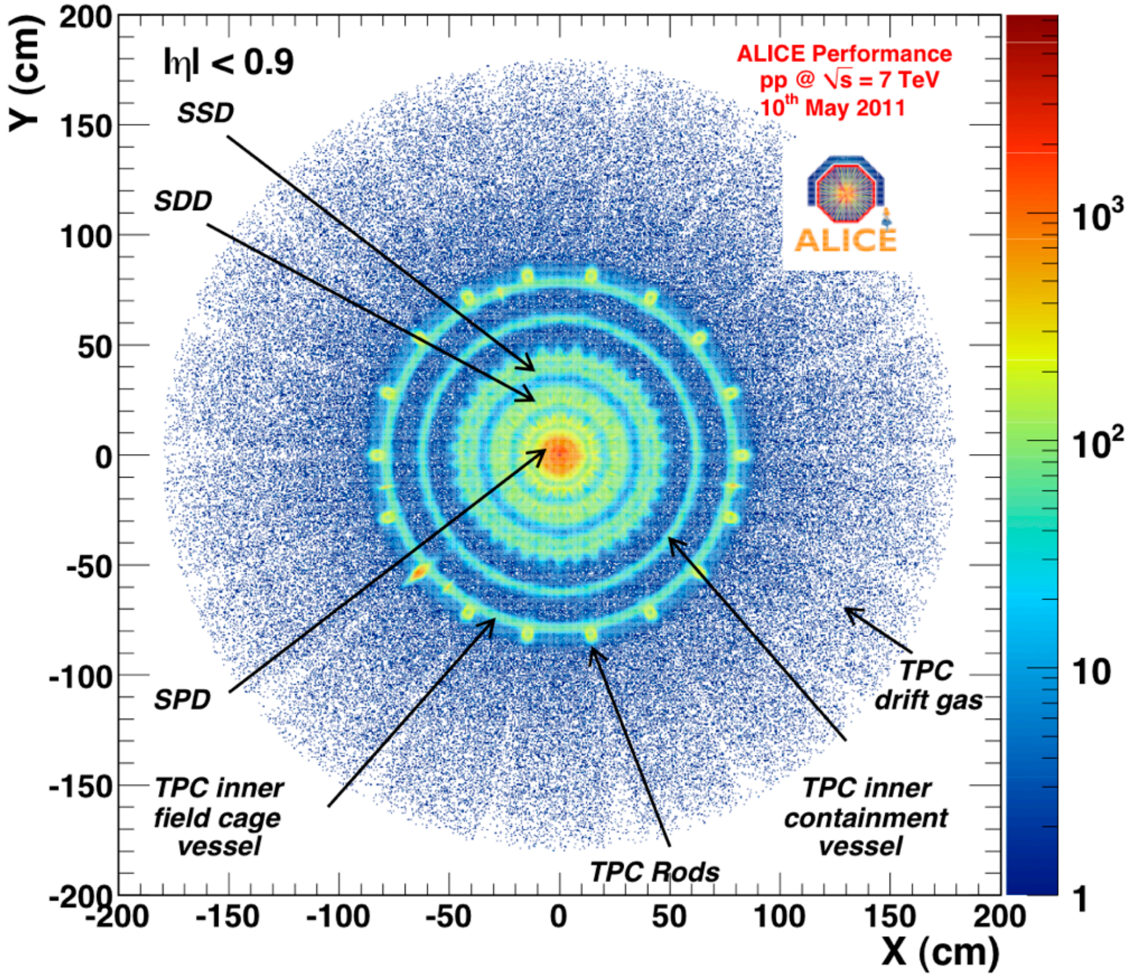
ca. 1950

2011

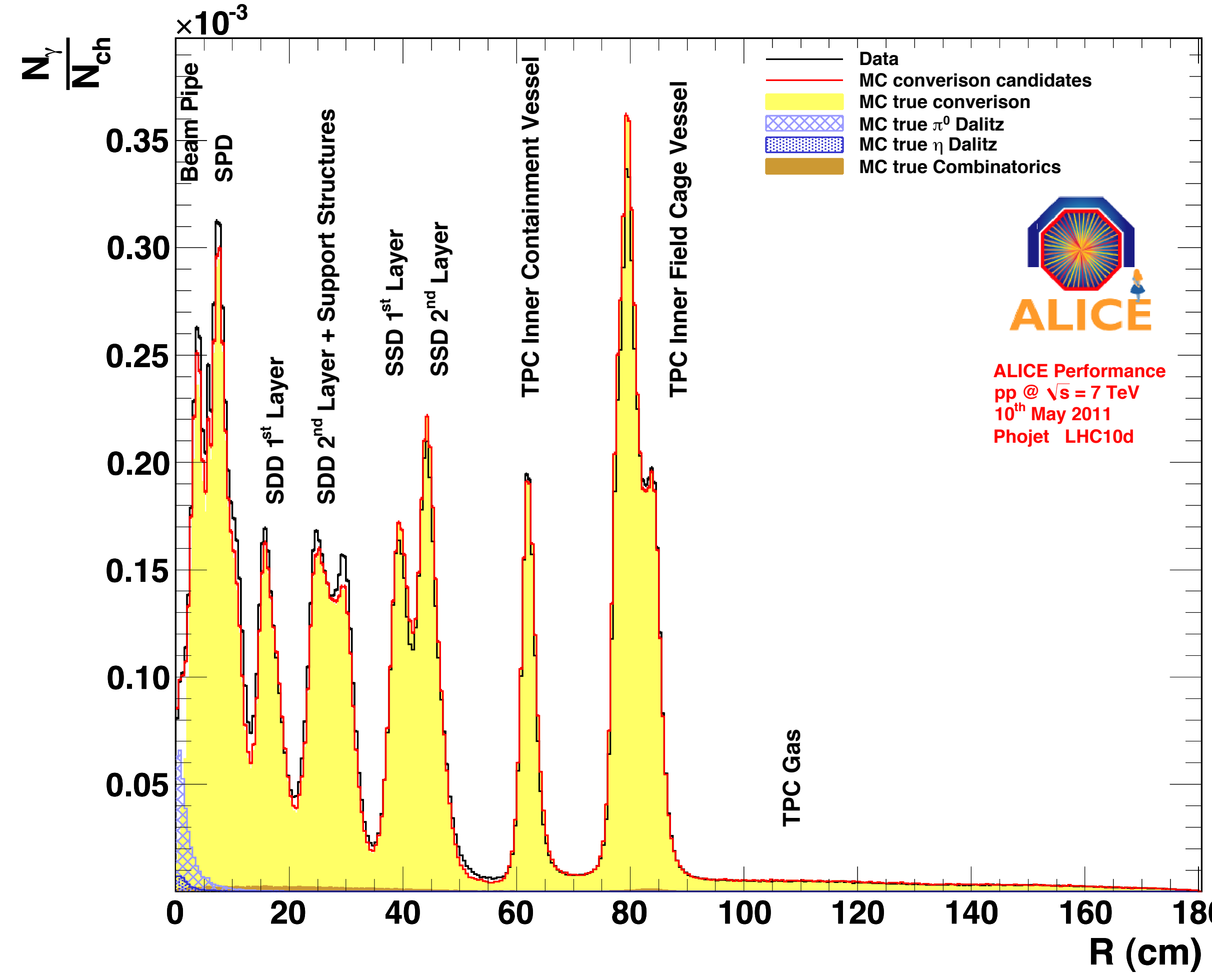


ALICE's Material Budget Studied with Conversions

Map of photon conversion points



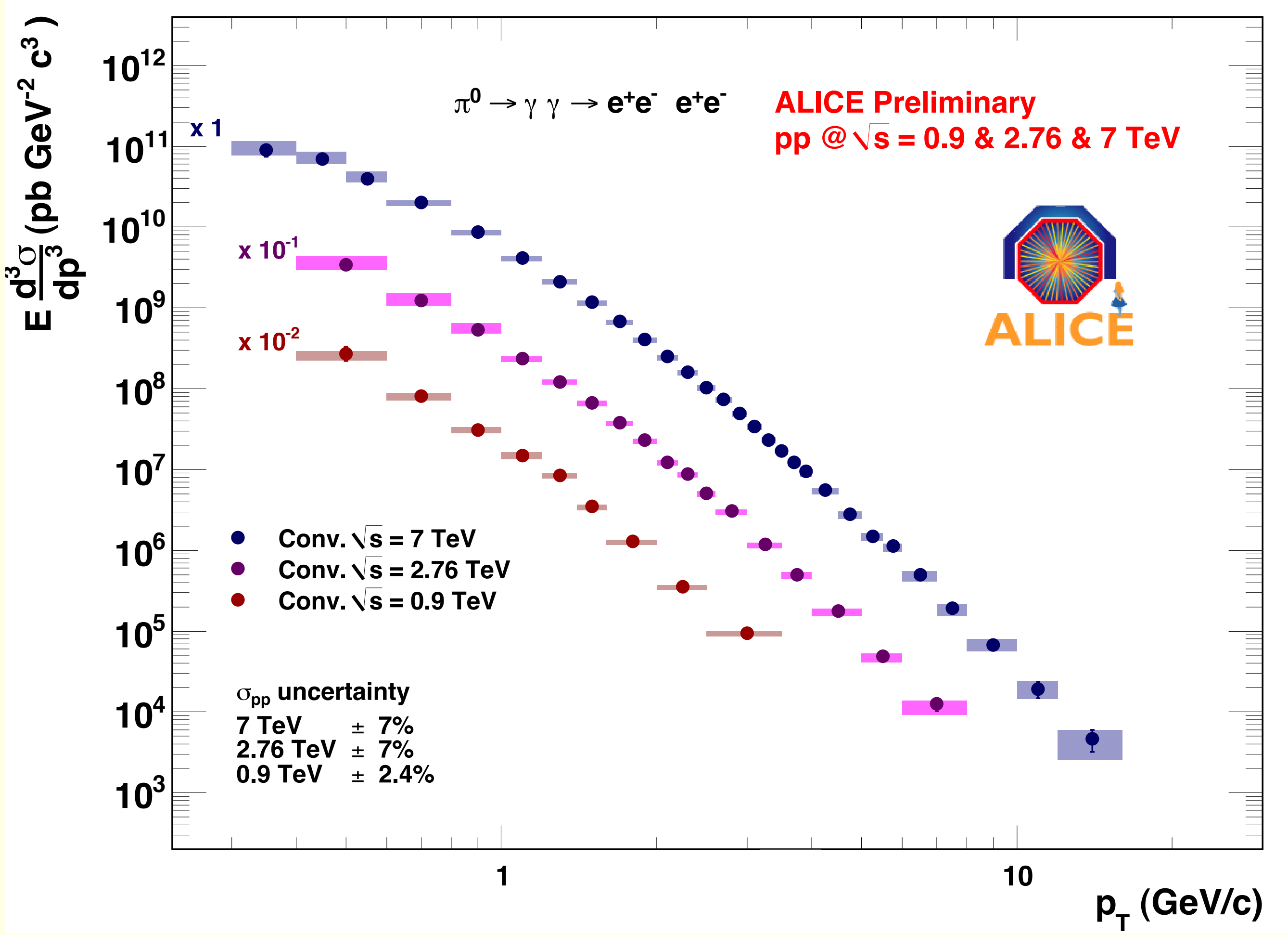
#conversions as fct. of *R*: Data vs. MC

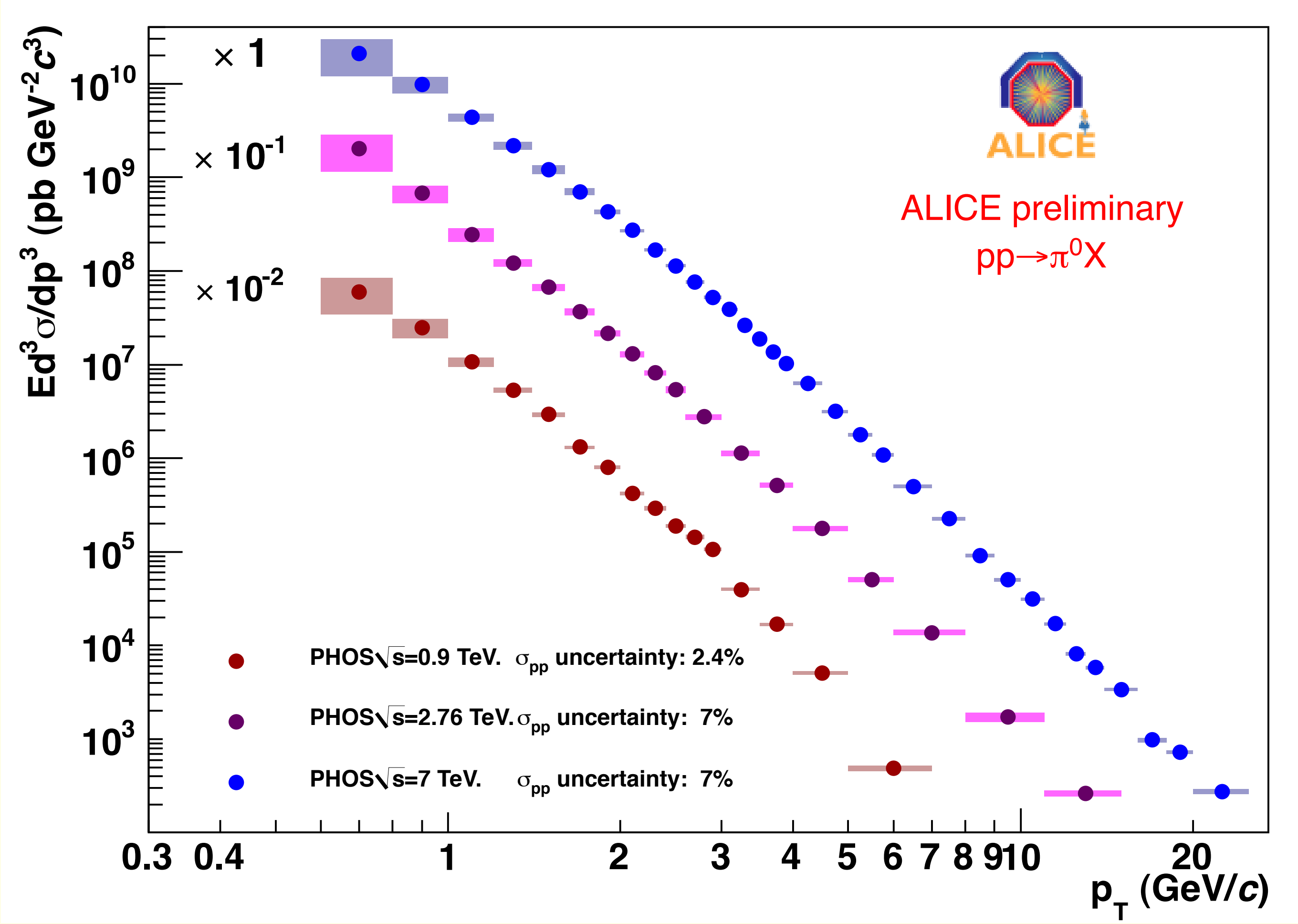


resolution of conversion point reconstruction: 1.5 cm in z, 3 cm in radial direction R, 2.5 mrad in ϕ

ALICE material budget (11.4% X_0 up to middle of TPC) agrees within +3.4%/-6.2% with its implementation in GEANT

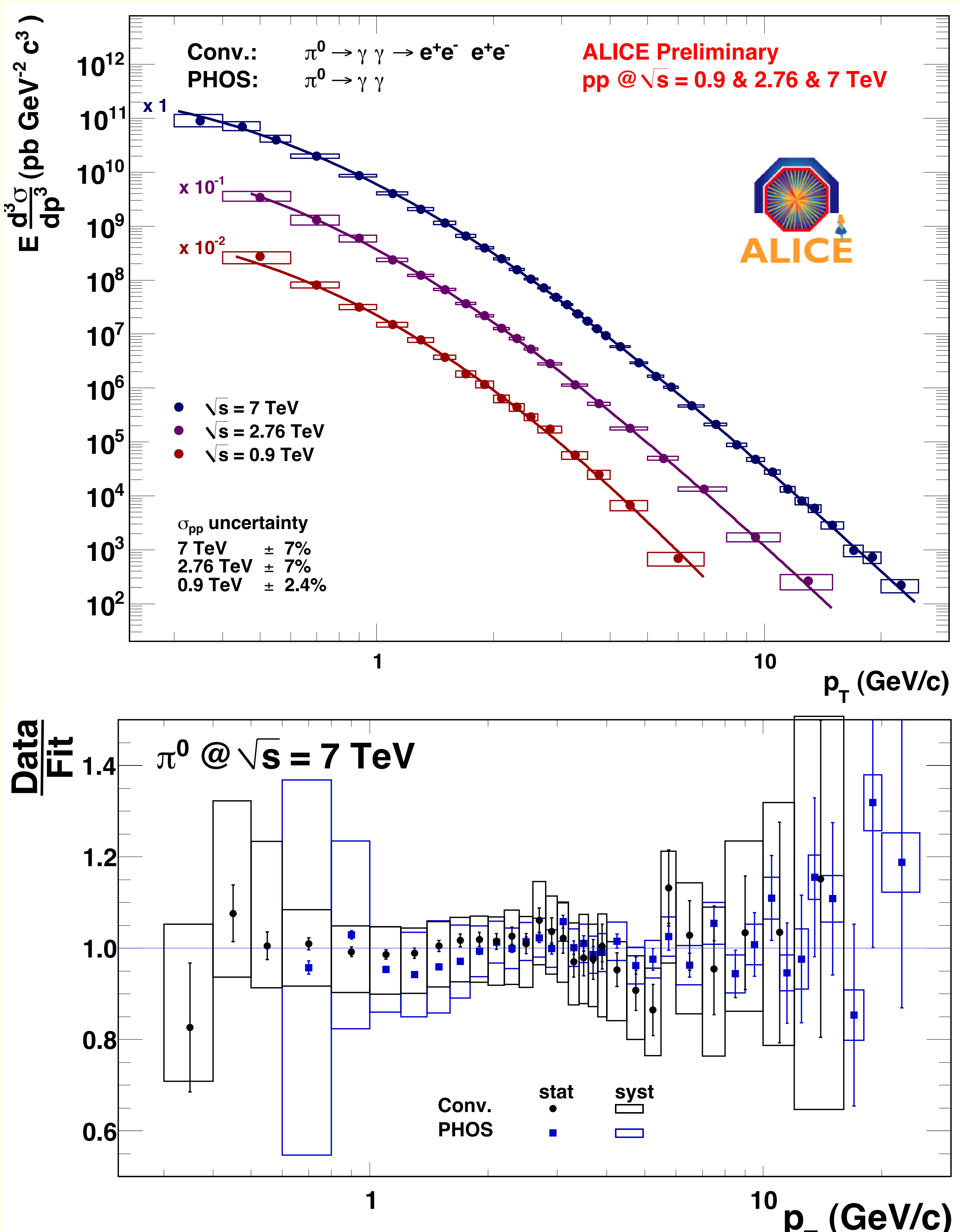
Invariant π^0 Cross Section at 0.9, 2.76, and 7 TeV (Conversions, PHOS)





- PHOS/conversions: Methods with different systematics: perfect cross check
- Conversion method provides very good inv. mass resolution at low p_T
- PHOS: better statistics at high p_T

Invariant π^0 Cross Section at 0.9, 2.76, and 7 TeV: ALICE Combined Result (Conversions + PHOS)

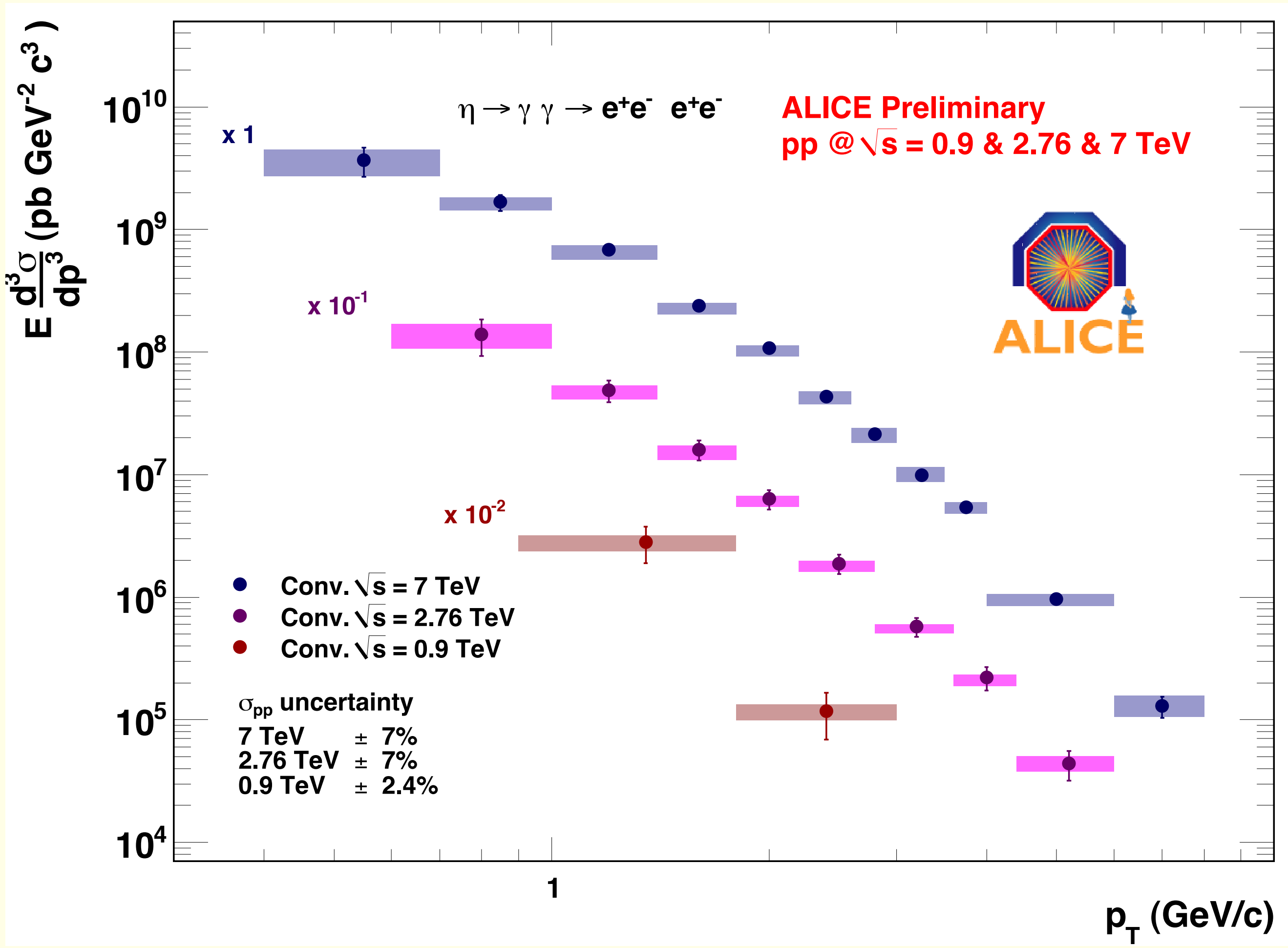


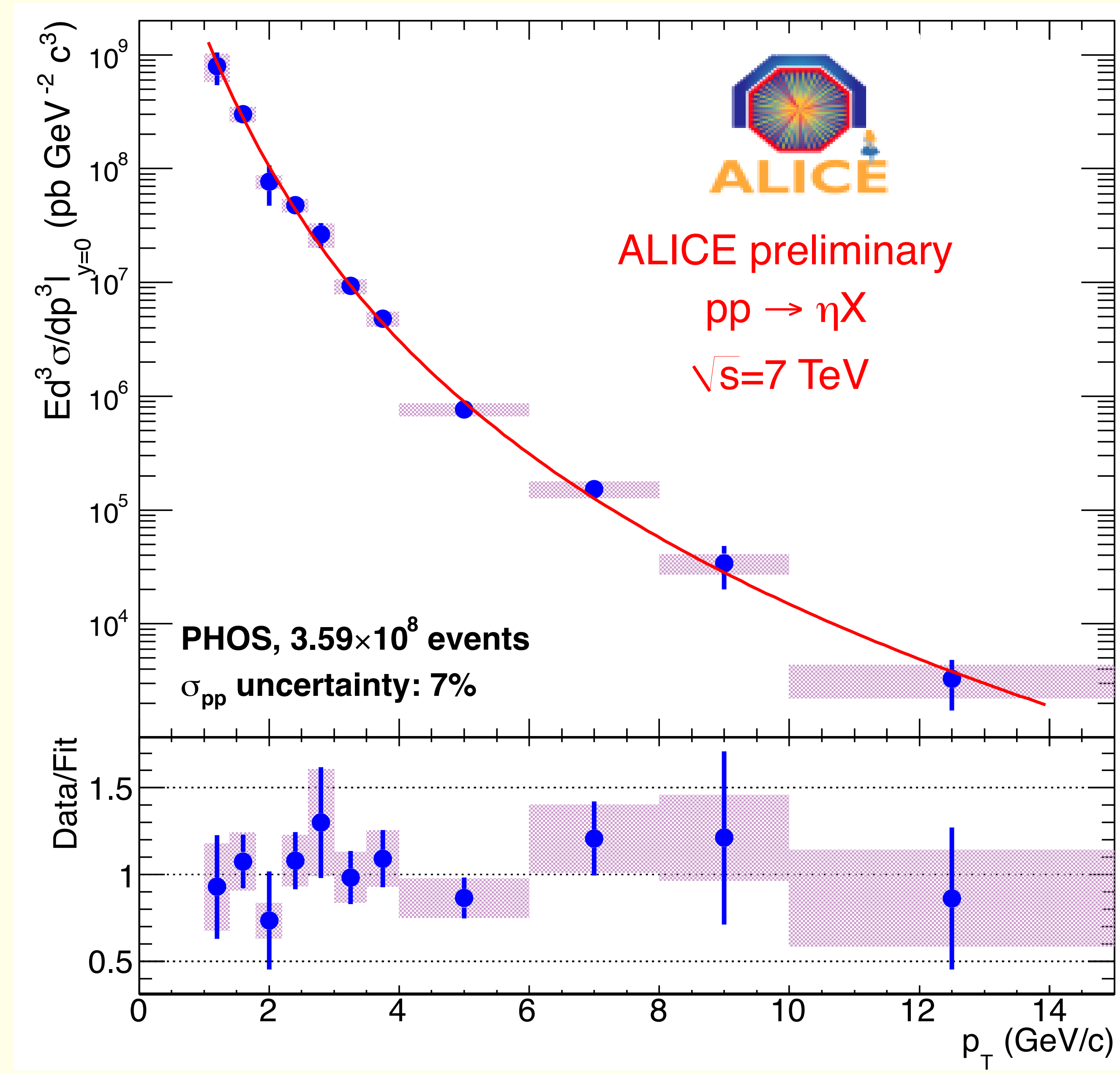
Tsallis function:

$$E\frac{d^3\sigma}{dp^3} = \frac{1}{2\pi}\frac{d\sigma}{dy}\frac{(n-1)(n-2)}{nT(nT+m(n-2))}\left(1+\frac{m_T-m}{nT}\right)^{-n}$$

- Good agreement between results from PHOS and conversion method
- Tsallis function provides a good parameterization of the spectra

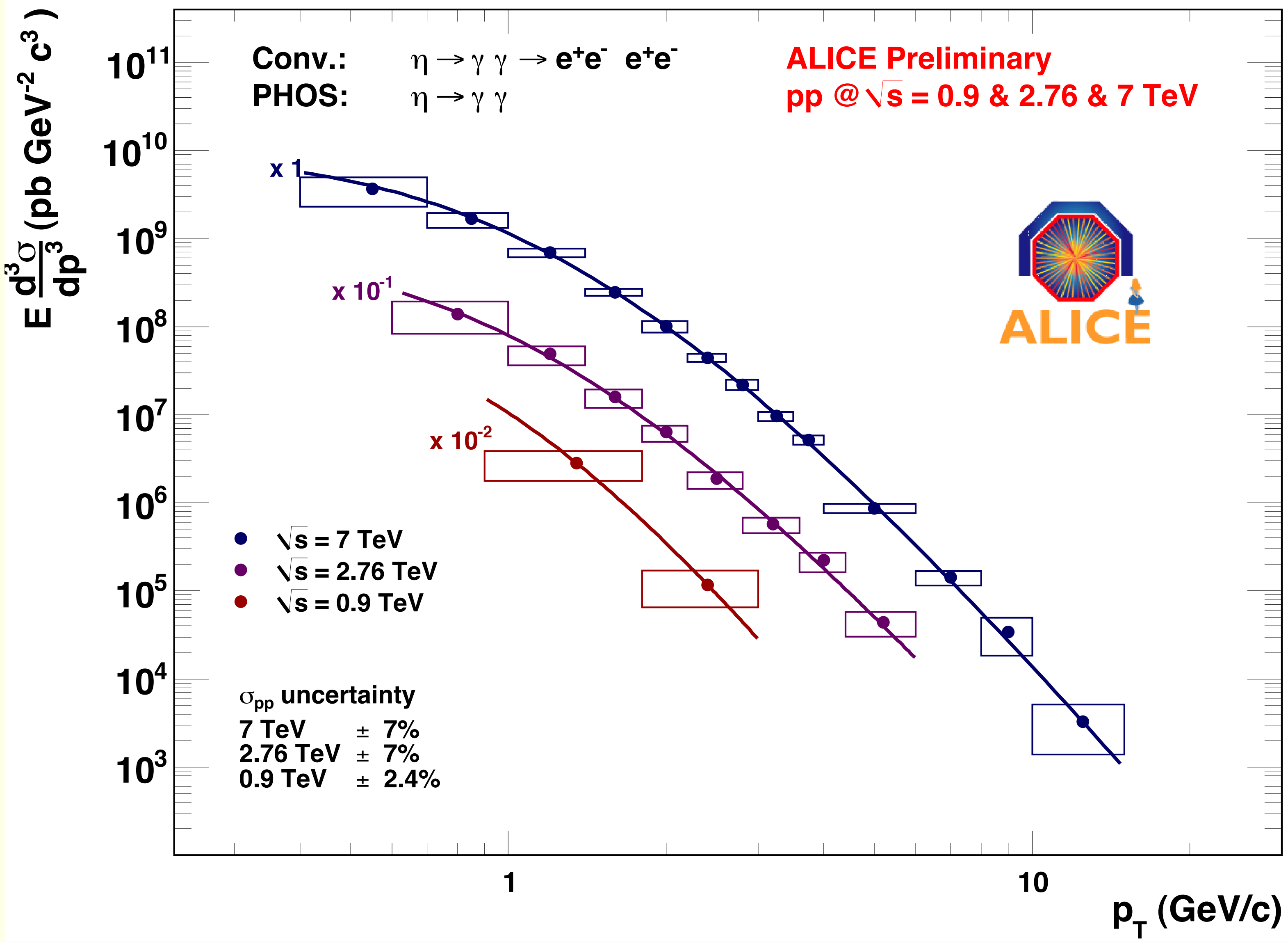
Invariant η Cross Section at 0.9, 2.76, and 7 TeV (Conversions, PHOS)

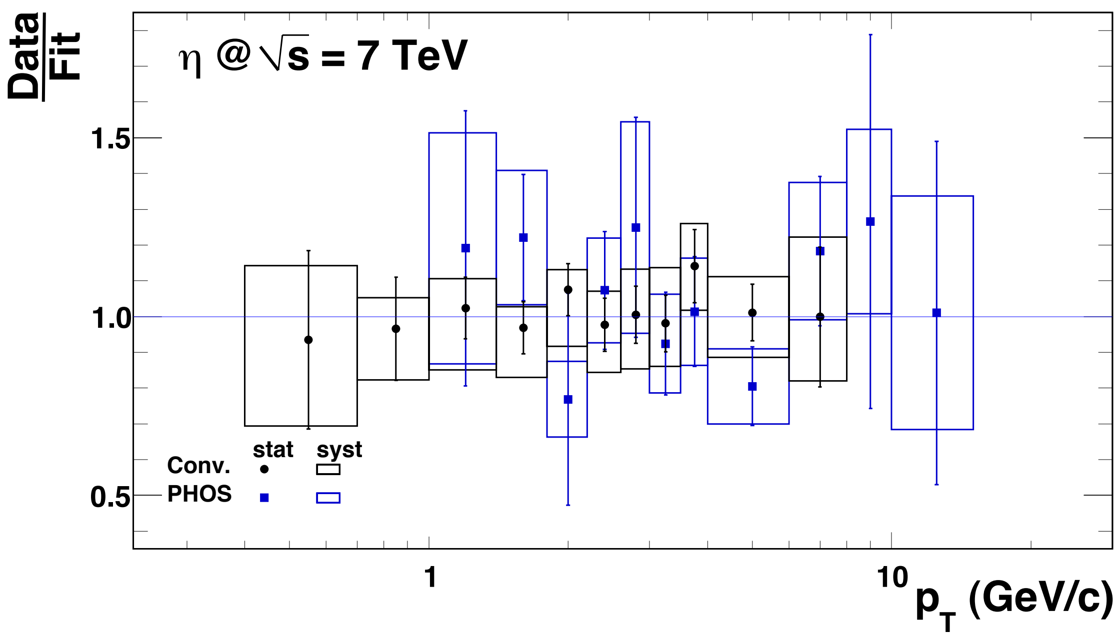




η at √s = 7 TeV measured up to $p_T \approx 7$ GeV/c with conversion method and up to $p_T \approx 12$ GeV/c with PHOS

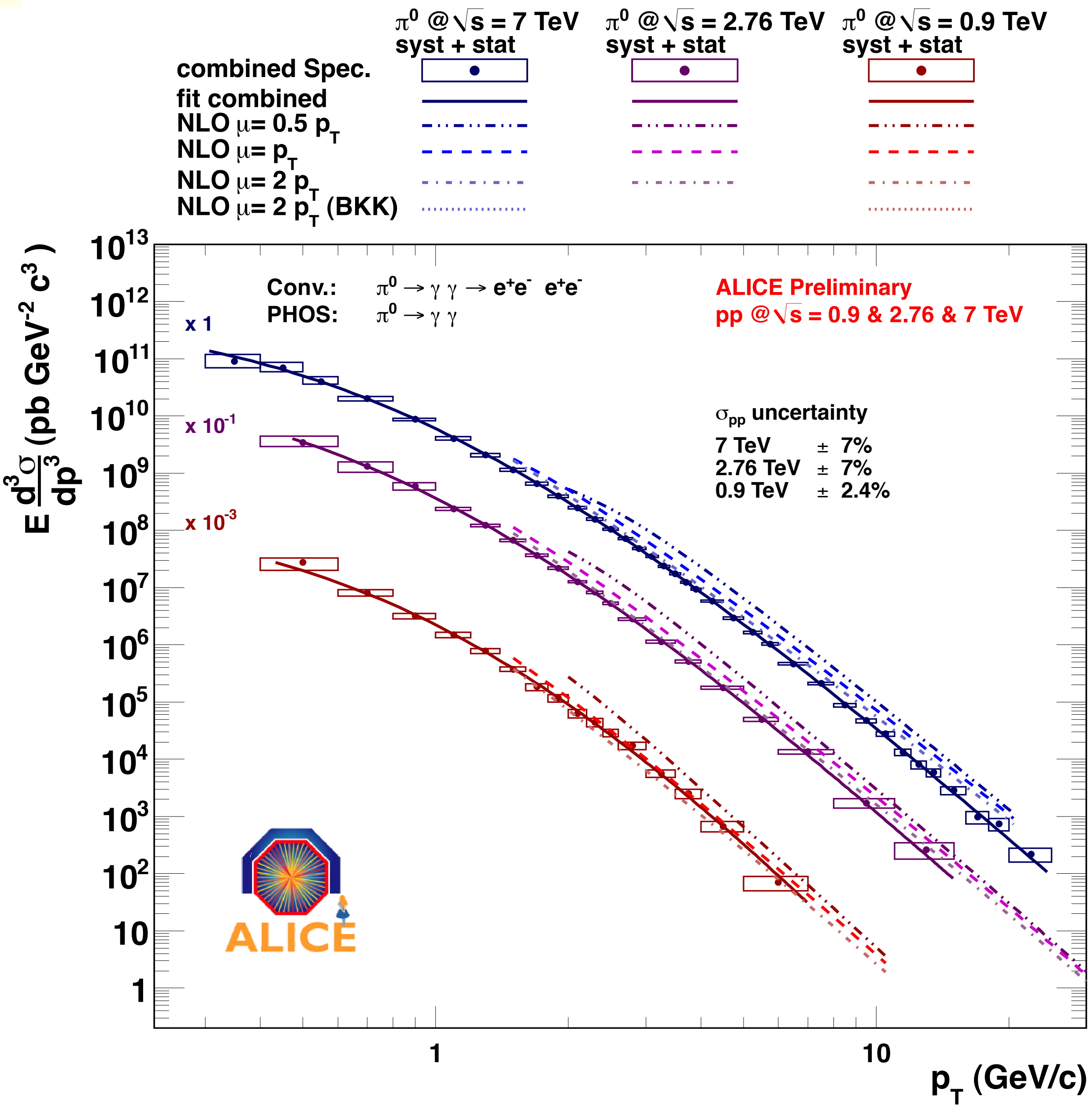
Invariant η Cross Section at 0.9, 2.76, and 7 TeV: ALICE Combined Result (Conversions + PHOS)



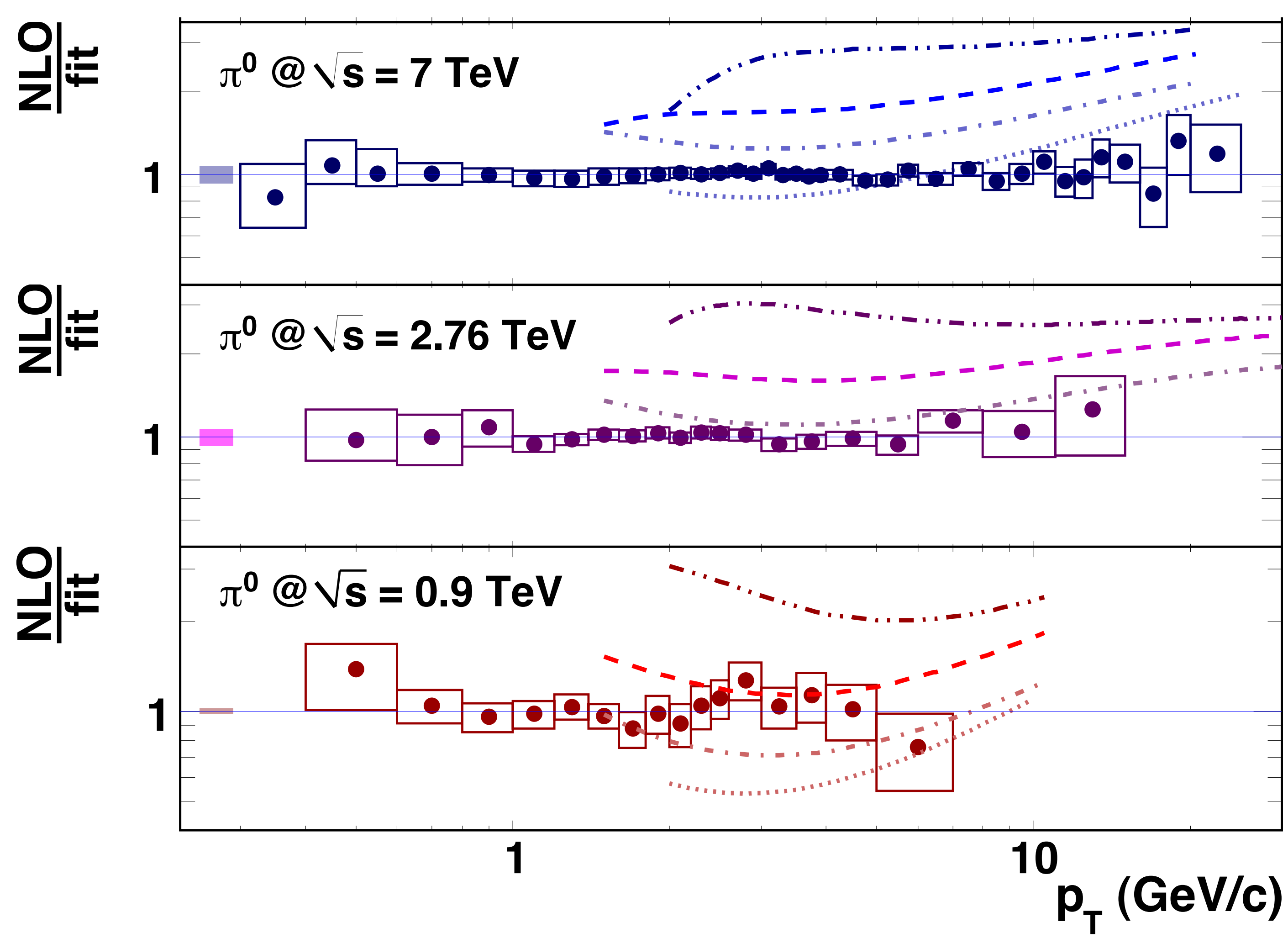


- Same conclusions as for π^0:
  - Good agreement between conversion method and PHOS
  - Tsallis function provides a useful parameterization

π^0 at 0.9, 2.76, and 7 TeV vs. NLO pQCD



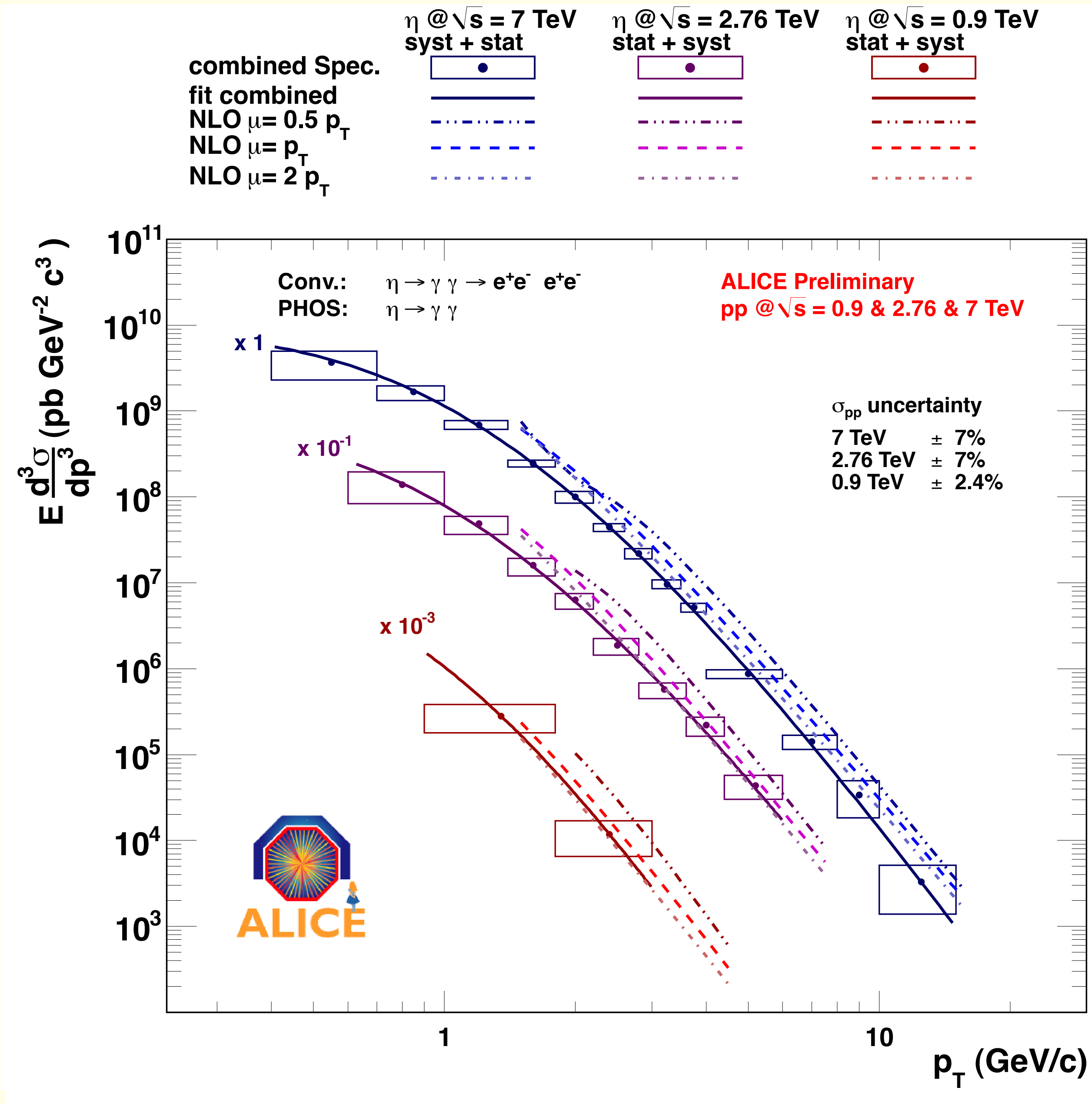
NLO pQCD (W. Vogelsang):
PDF: CTEQ6M5, FF: DSS, scales, μ = 0.5 p_T, p_T, 2 p_T
Also: INCNLO with BKK FF



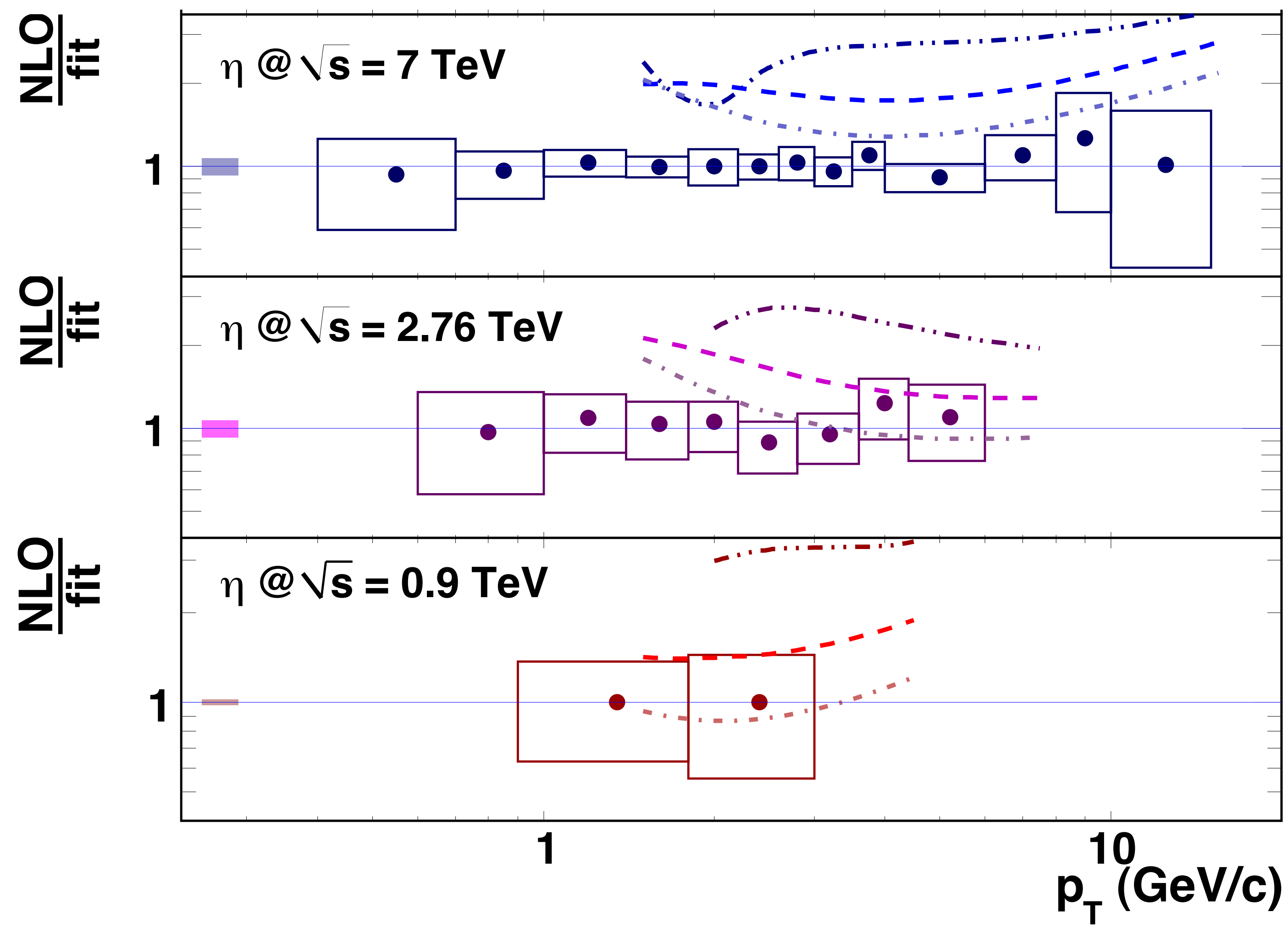
- NLO pQCD with DSS FF describes 0.9 TeV data, but overestimates cross sections at 2.76 TeV and 7 TeV for all scales
- Better agreement with 7 TeV data with BKK FF

DSS FF's: Phys. Rev. D75, 114010 (2007)

η at 0.9, 2.76, and 7 TeV vs. NLO pQCD



NLO pQCD (W. Vogelsang):
PDF: CTEQ6M5, FF: AESSS,
scales: μ = 0.5 p_T, p_T, 2 p_T



Same trend as for the π^0:

- Agreement with pQCD at 0.9 TeV, and, at least for $p_T > 3$ GeV/*c* also at 2.36 TeV
- 7 TeV data overestimated

AESSS FF's: Phys. Rev. D83, 034002 (2011)

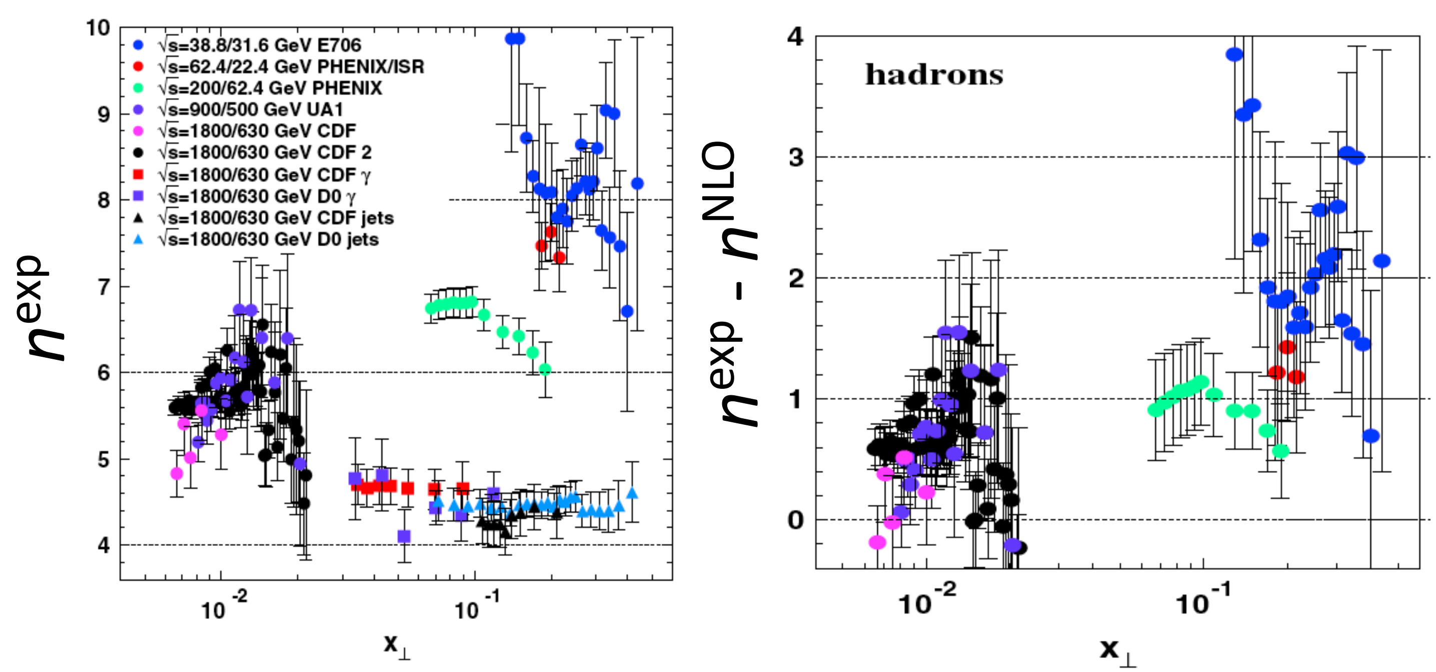
x_T Scaling of π^0 Cross Sections

- **Motivation:**
  - x_T scaling: Invariant cross sections at fixed $x_T = 2\,p_T/\sqrt{s}$ scale as $(\sqrt{s})^n$
  - Significant deviations from leading-twist perturbative QCD predictions at NLO for $n(x_T)$ are observed in p+p(bar) collisions
  - Indication for higher-twist processes?

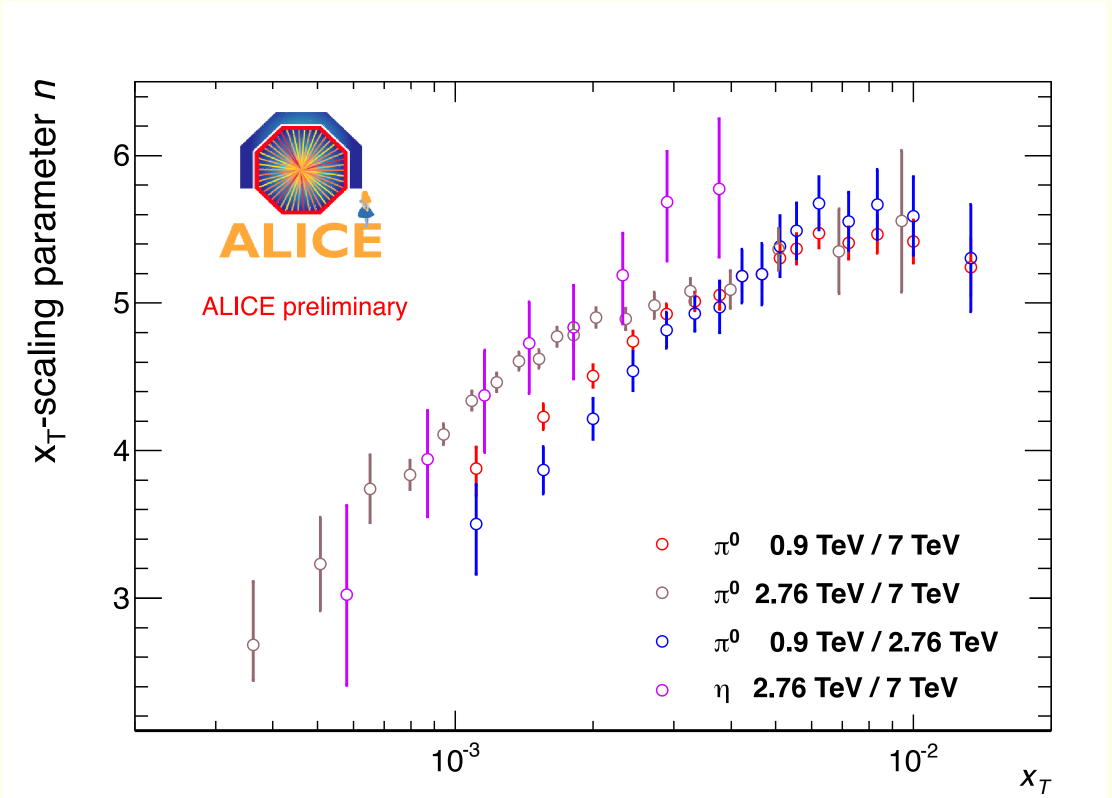
$$E\frac{d^3\sigma}{d^3p} = \left(\sqrt{s}\right)^n F(x_T), \qquad x_T = 2p_T/\sqrt{s}$$

$$n(x_T) = -\ln\left(\frac{\sigma(x_T,\sqrt{s_1})}{\sigma(x_T,\sqrt{s_2})}\right) \Bigg/ \ln\left(\frac{\sqrt{s_1}}{\sqrt{s_2}}\right)$$

$n(x_T)$ world data (so far)

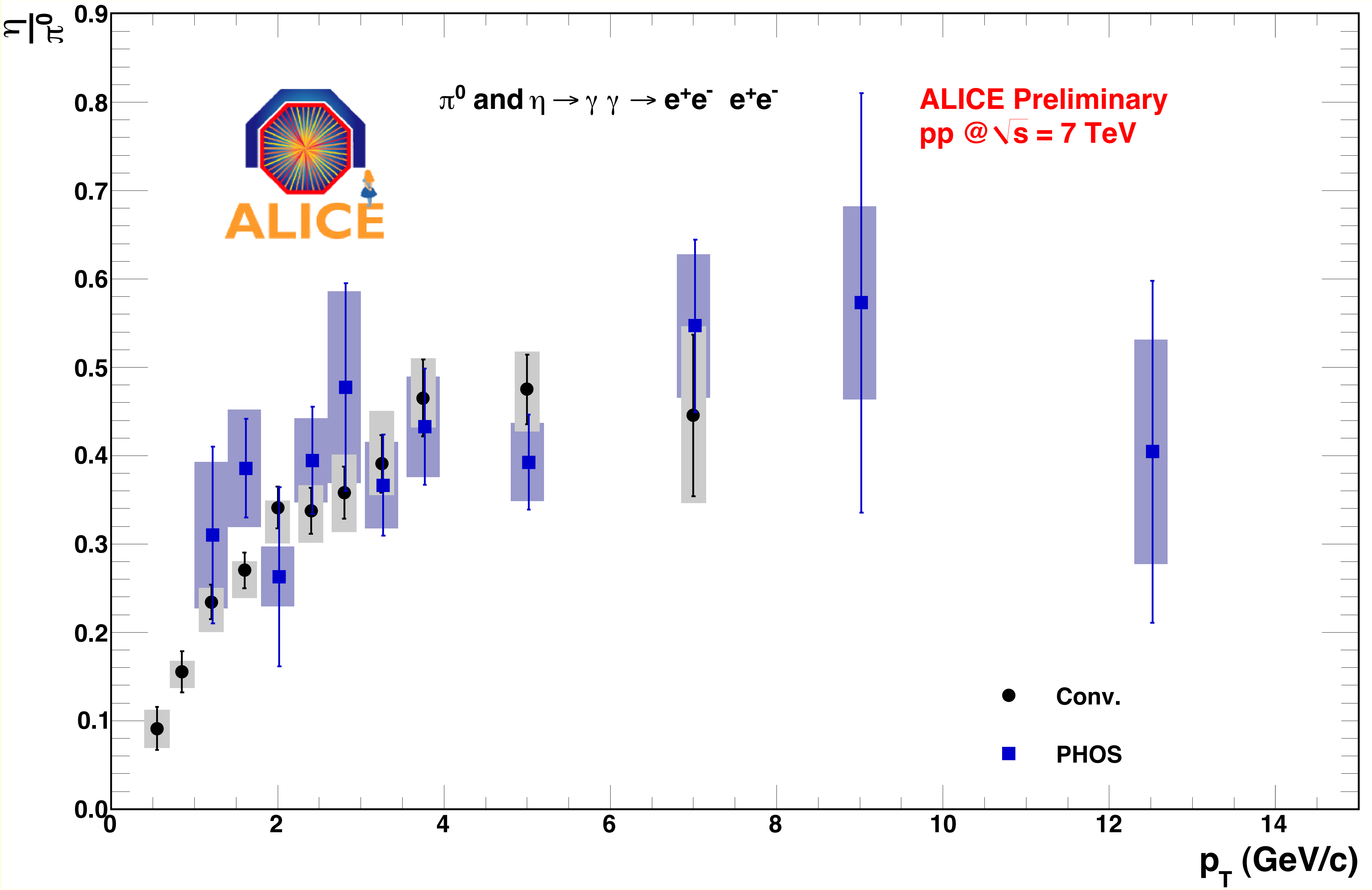


Arleo et al., PRL 105, 062002 (2010)



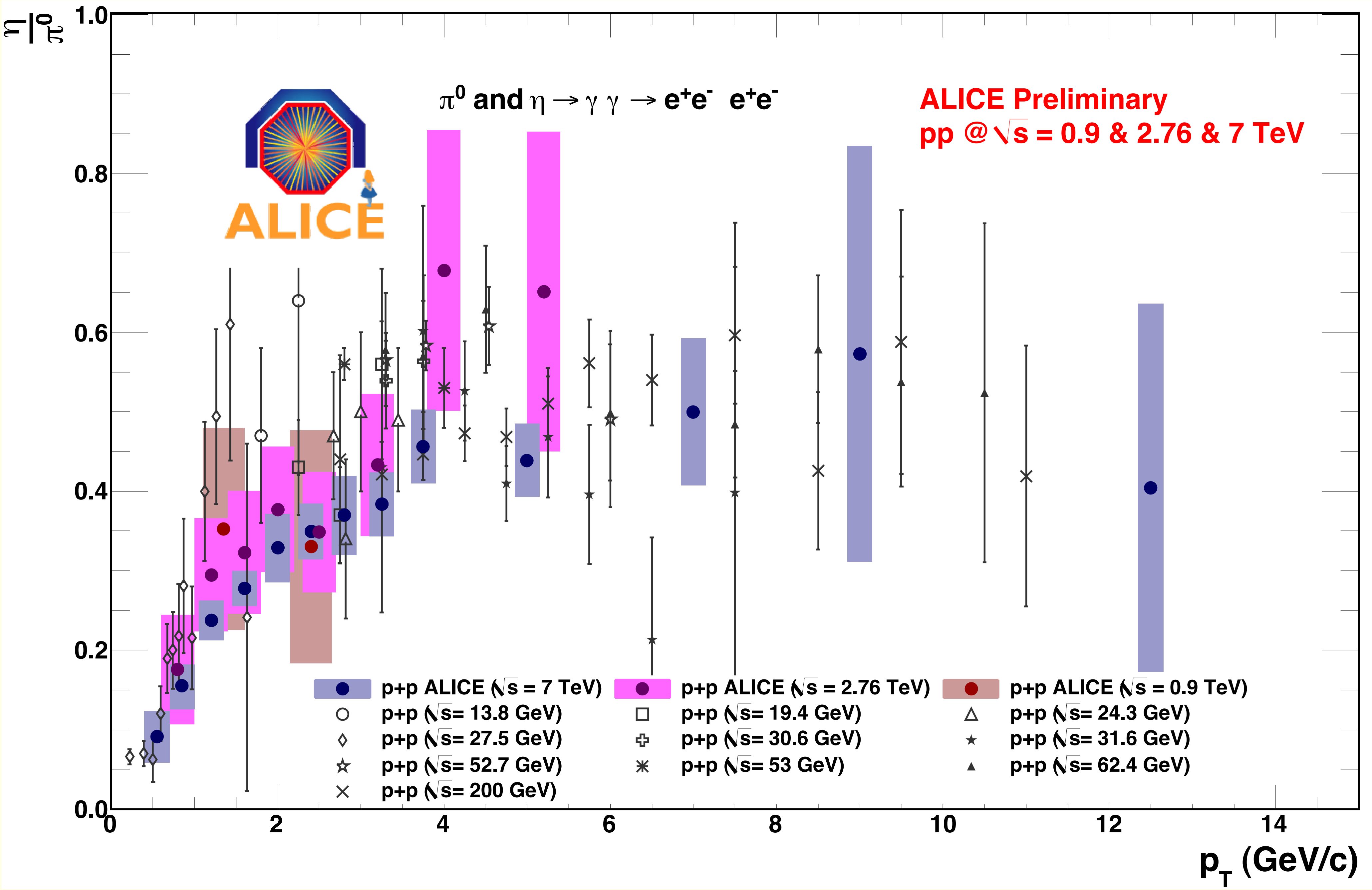
- **Conclusions:**
  - $n \approx 5.2$ at $x_T \approx 0.01$ for p+p at $\sqrt{s}$ = 0.9, 2.76, and 7 TeV
  - No obvious difference between n^{exp} and n^{NLO} at LHC energies

η/π^0 Ratio (I): Conversions + PHOS



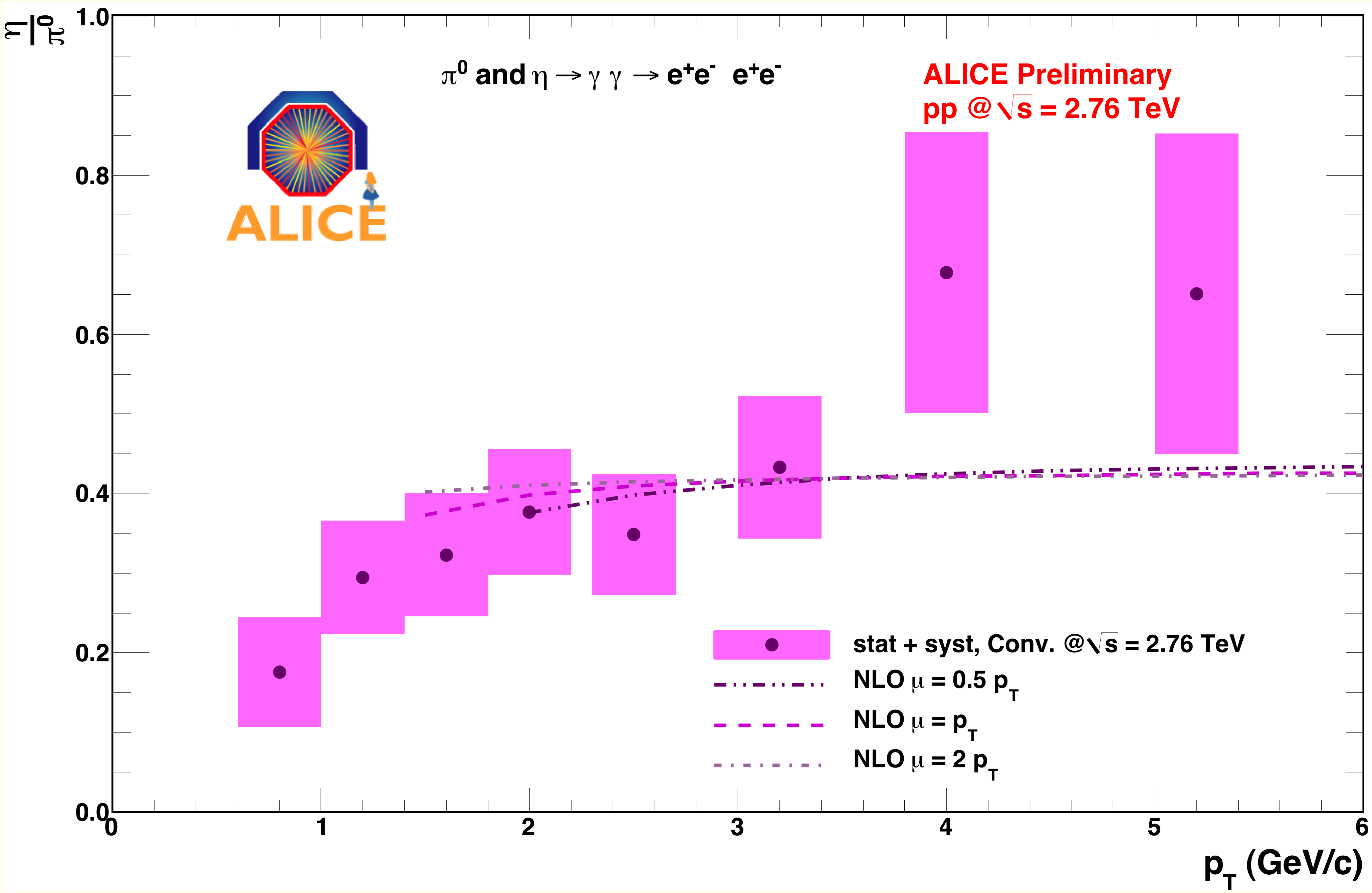
Data from PHOS and conversion method agree

η/π^0 Ratio (II): Comparison with World Data



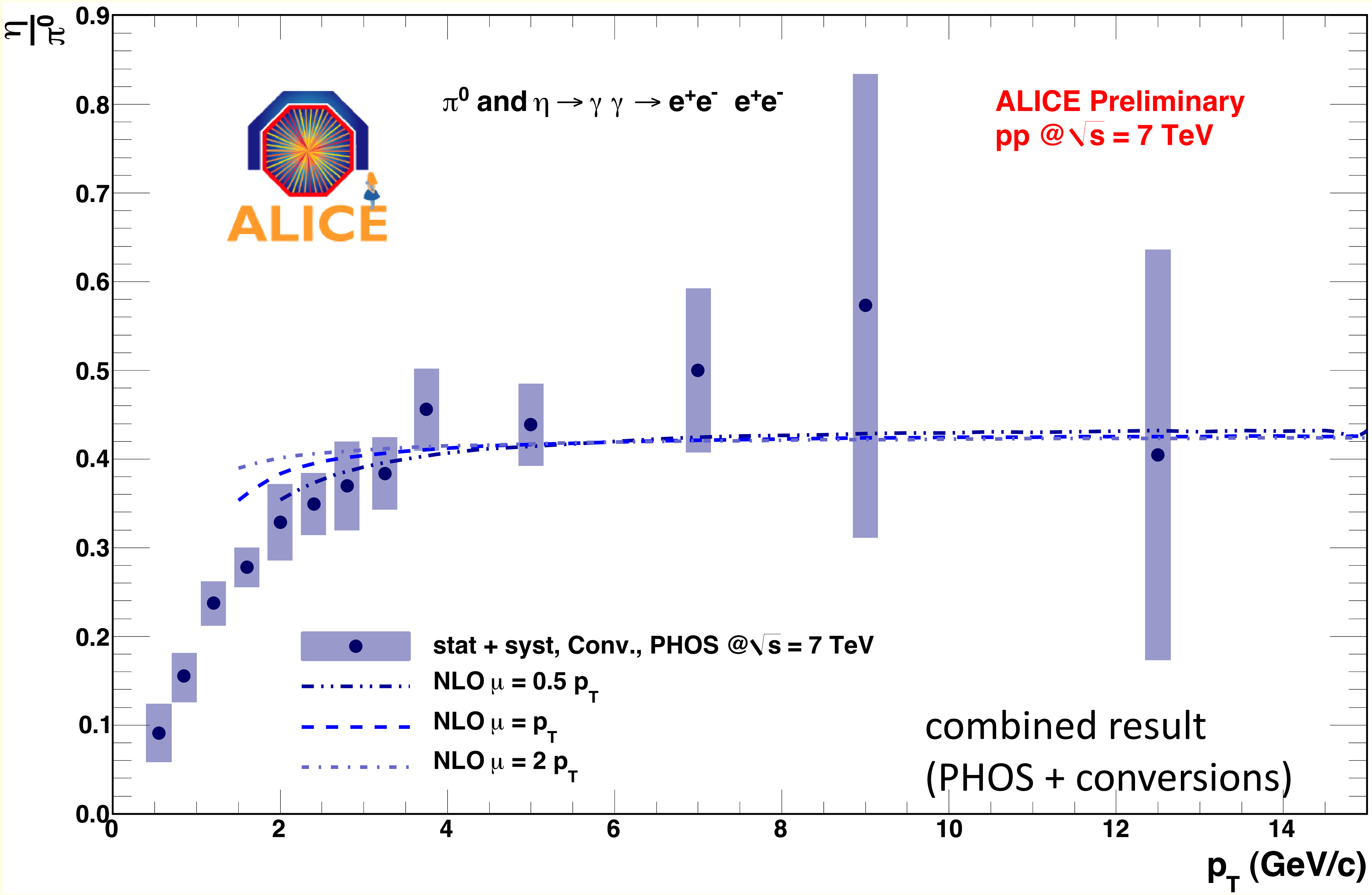
LHC data follow trend observed at lower √s

η/π^0 Ratio (III): Comparison with NLO pQCD ($\sqrt{s}$ = 2.76 TeV)



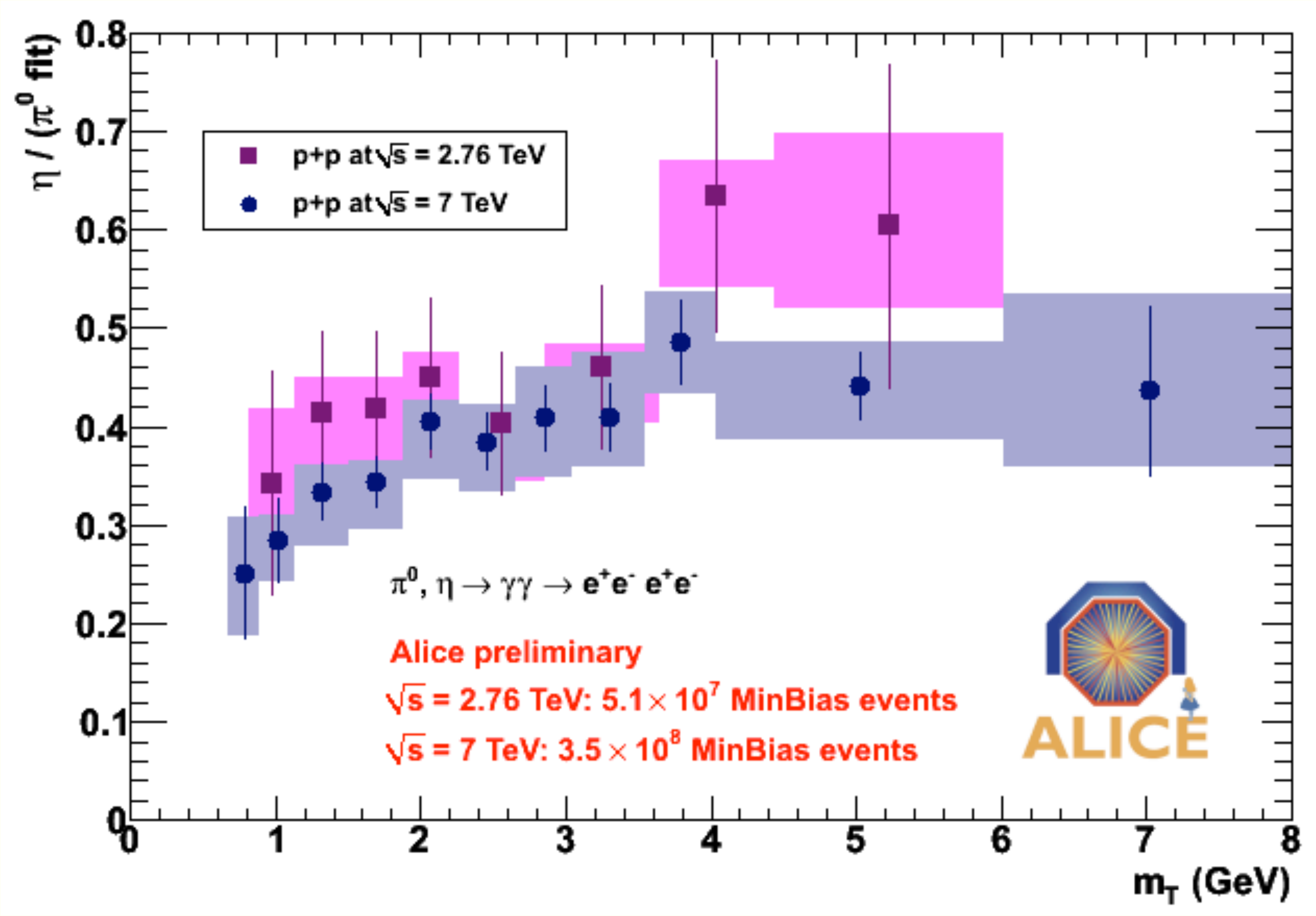
η/π^0 ratio at $\sqrt{s}$ = 2.76 TeV agrees with NLO pQCD

η/π^0 Ratio (IV): Comparison with NLO pQCD ($\sqrt{s}$ = 7 TeV)



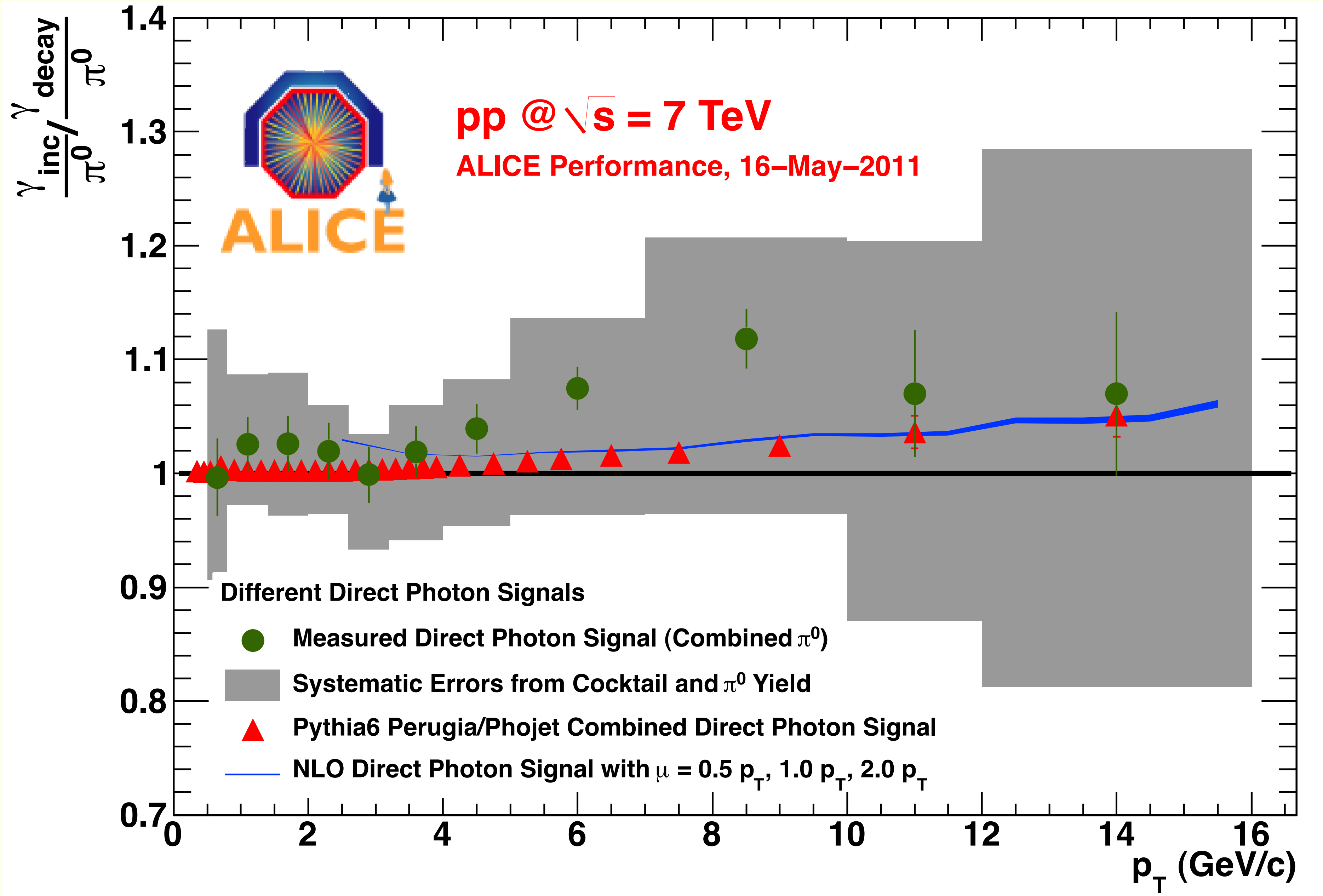
η/π^0 ratio at $\sqrt{s}$ = 7 TeV agrees with NLO pQCD

η/π^0 Ratio (V): Test of m_T Scaling



- $\sqrt{s}$ = 2.76 TeV: consistent with m_T scaling
- $\sqrt{s}$ = 7 TeV: Indication of m_T scaling violation

Cross Check:
Inclusive Photons over Expected Decay Photons

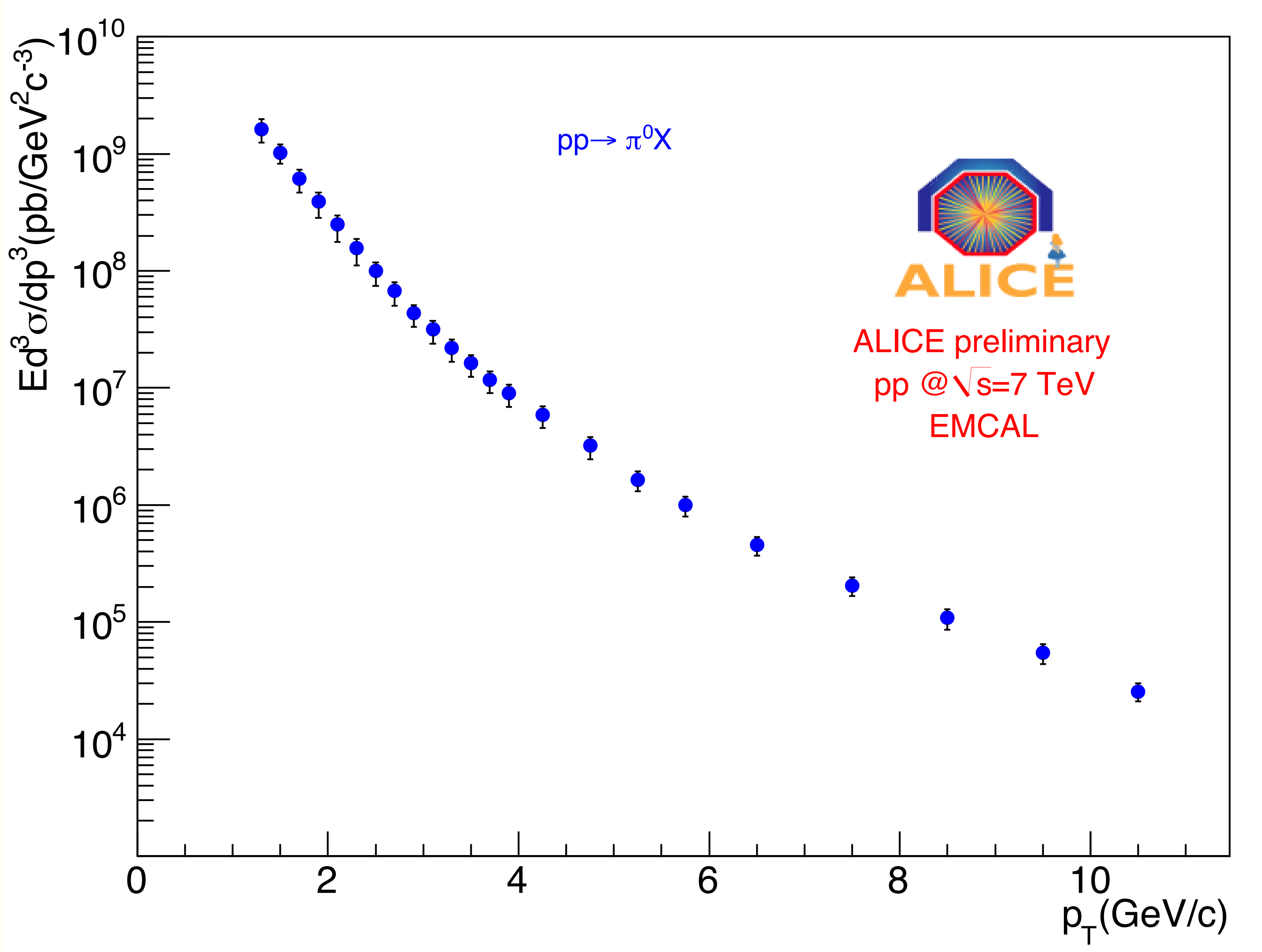


Measured inclusive photons in agreement with expected decay photons (in a p_T range where the direct photon contribution is negligible)

Conclusions

- π^0 p_T spectra at 0.9, 2.76, and 7 TeV: x_T scaling observed (with $n \approx 5.2$ at $x \approx 0.01$)
- Comparison with NLO pQCD
  - NLO pQCD with DSS FF, which describes RHIC data, overestimates π^0 and η spectra at 2.76 TeV and 7 TeV (for all scales $\mu = 0.5\ p_T$, p_T, $2\ p_T$)
- Indication of m_T scaling violation in p+p at $\sqrt{s}$ = 7 TeV for $m_T < 1.5$ GeV/c

Outlook: EMCAL Enters the Stage



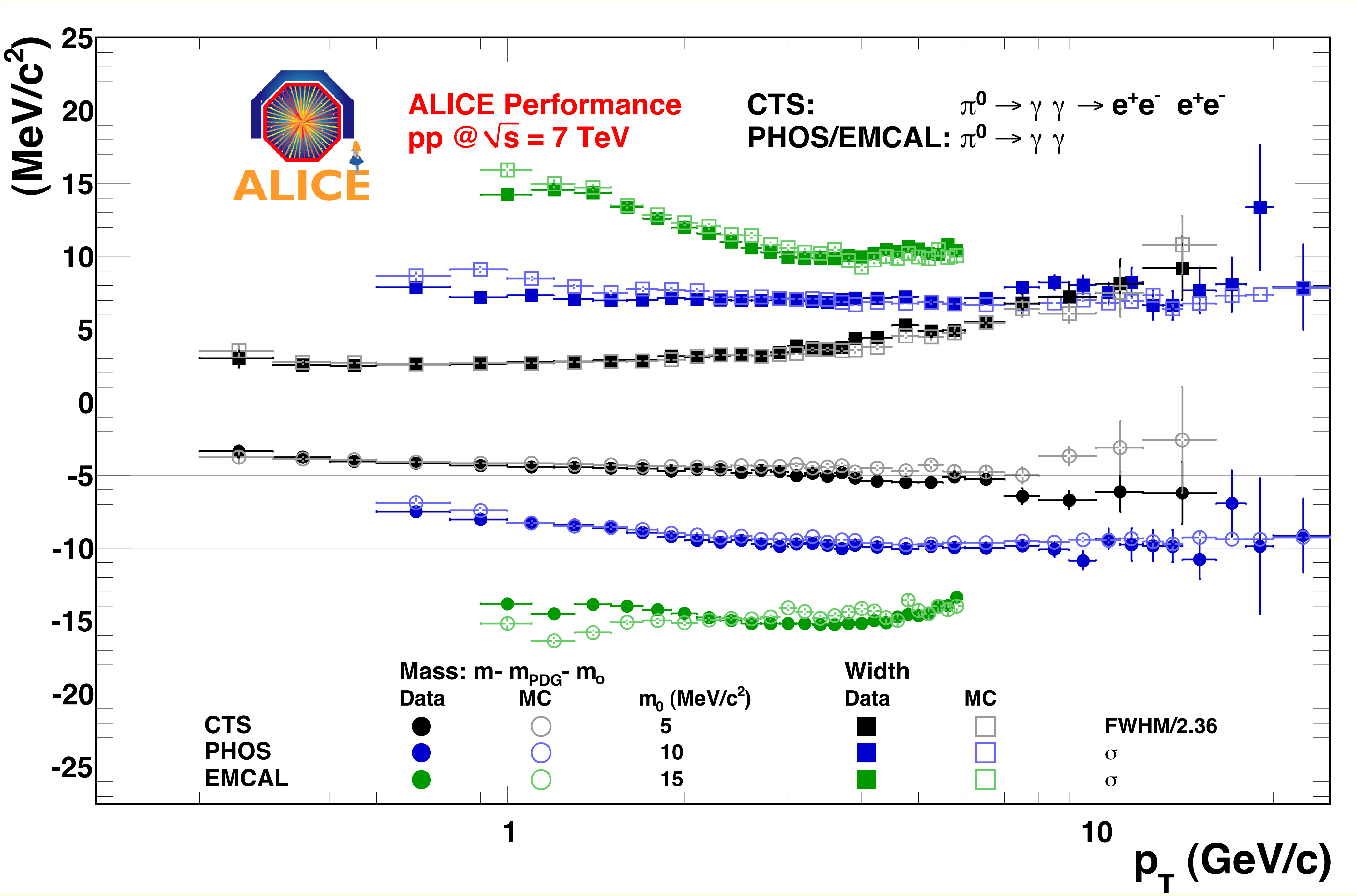
π^0 Spectrum from EMCAL (p+p @ 7 TeV)

Extra Slides

Results of Tsallis Fits for π^0 and η

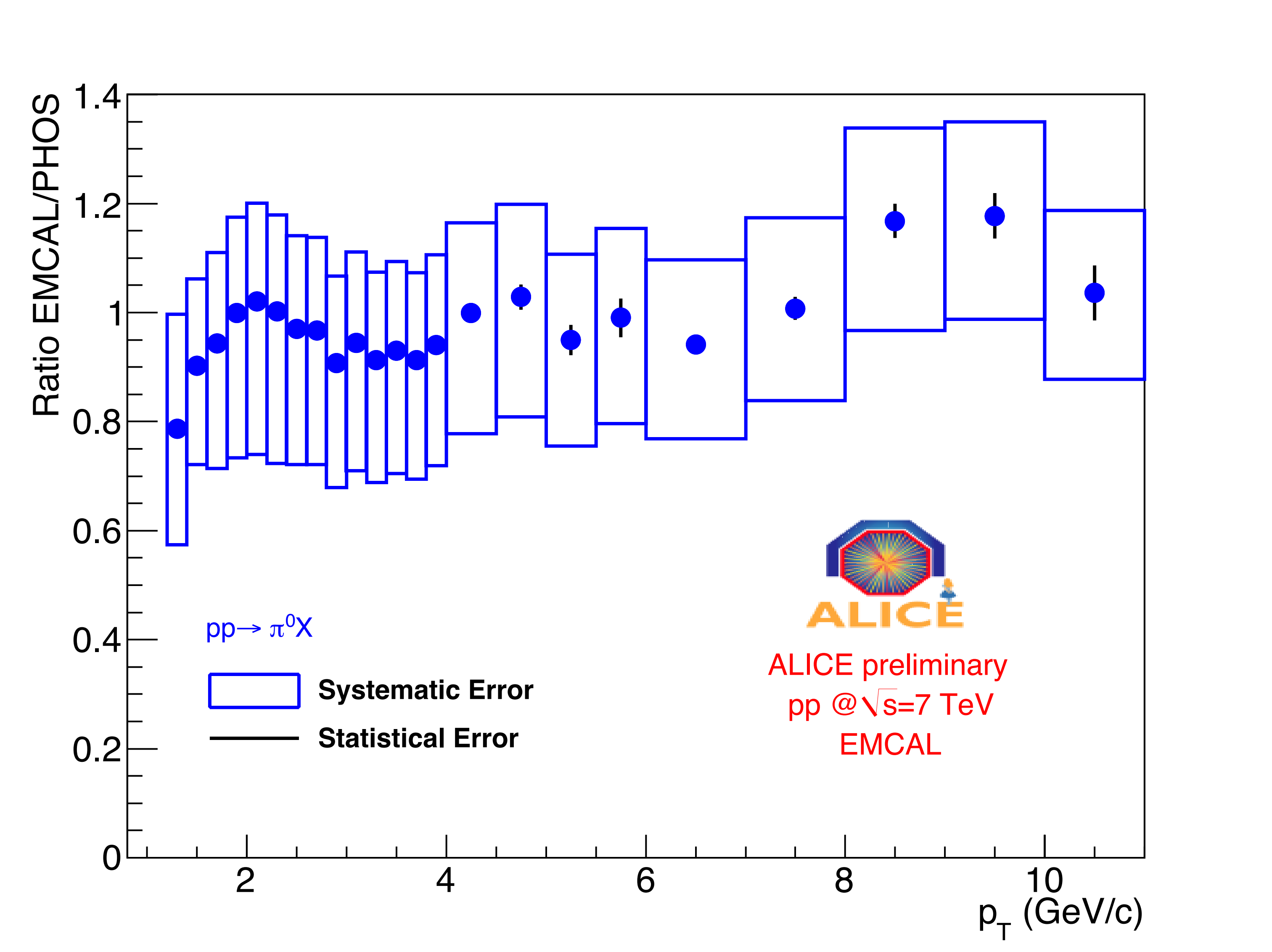
	Fit	value	sys Error	χ^2	ndf	χ^2/ndf
7 TeV:	$d\sigma^{\pi^0}/dy$ (pb)	$1.72 \cdot 10^{11}$	$0.096 \cdot 10^{11}$	12.8	33.00	0.39
	n	6.79	0.06			
	$T_{Tsallis}$ (GeV/c)	0.140	0.004			
2.76 TeV:	$d\sigma^{\pi^0}/dy$ (pb)	$1.24 \cdot 10^{11}$	$0.16 \cdot 10^{11}$	7.9	16.00	0.49
	n	7.05	0.18			
	$T_{Tsallis}$ (GeV/c)	0.130	0.008			
0.9 TeV:	$d\sigma^{\pi^0}/dy$ (pb)	$6.51 \cdot 10^{10}$	$1.12 \cdot 10^{10}$	7.5	13.00	0.57
	n	8.4	0.6			
	$T_{Tsallis}$ (GeV/c)	0.151	0.015			

	Fit	value	sys Error	χ^2	ndf	χ^2/ndf
7 TeV:	$d\sigma^{\eta}/dy$ (pb)	$1.48 \cdot 10^{10}$	$0.17 \cdot 10^{10}$	2.0	10.00	0.2
	n	7.2	0.5			
	$T_{Tsallis}$ (GeV/c)	0.239	0.021			
2.76 TeV:	$d\sigma^{\eta}/dy$ (pb)	$1.08 \cdot 10^{10}$	$0.3 \cdot 10^{10}$	1.31	6.00	0.22
	n	7.05	fixed as π^0			
	$T_{Tsallis}$ (GeV/c)	0.215	0.020			
0.9 TeV:	$d\sigma^{\eta}/dy$ (pb)	$2.1 \cdot 10^{10}$	$2.3 \cdot 10^{10}$	-	-	-
	n	8.4	fixed as π^0			
	$T_{Tsallis}$ (GeV/c)	0.152	0.057			

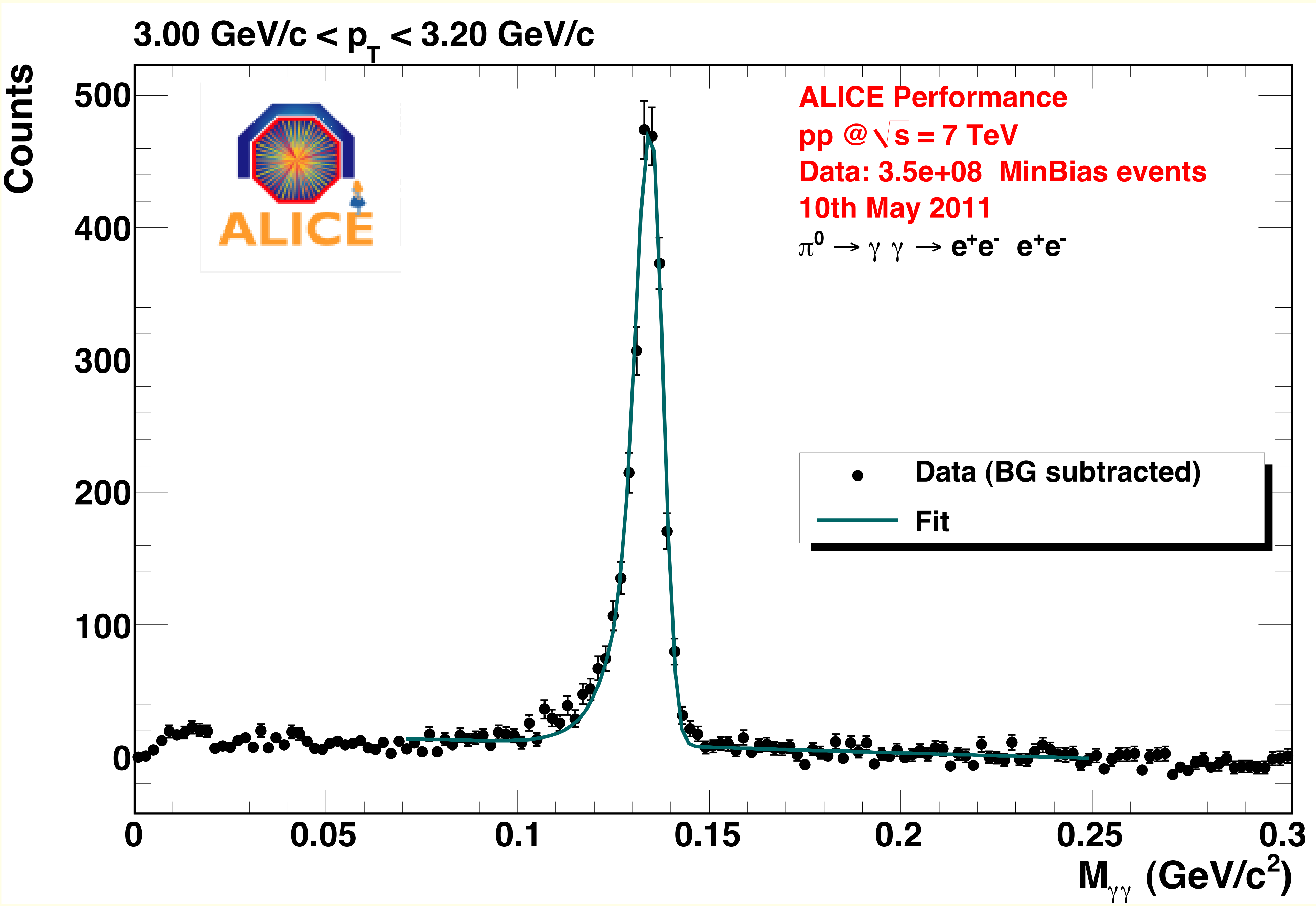


ALICE Performance
pp @ √s = 7 TeV
CTS: π⁰ → γ γ → e⁺e⁻ e⁺e⁻
PHOS/EMCAL: π⁰ → γ γ
(MeV/c²)
Mass: m- m_PDG- m_0
Data
MC
m_0 (MeV/c²)
Width
Data
MC
CTS
PHOS
EMCAL
5
10
15
FWHM/2.36
σ
σ
p_T (GeV/c)

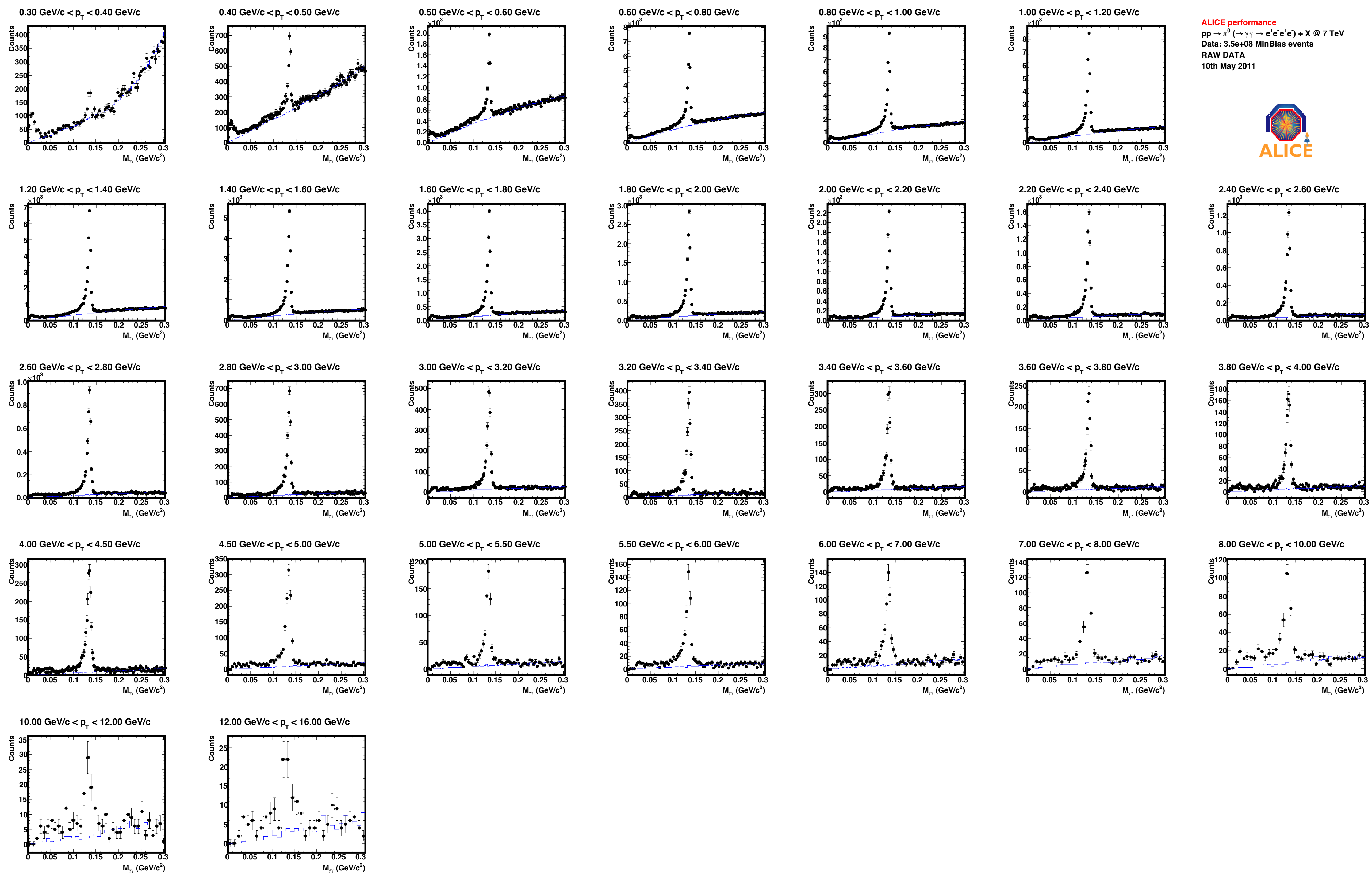
Comparison EMCAL vs. PHOS (π^0, p+p @ 7 TeV)



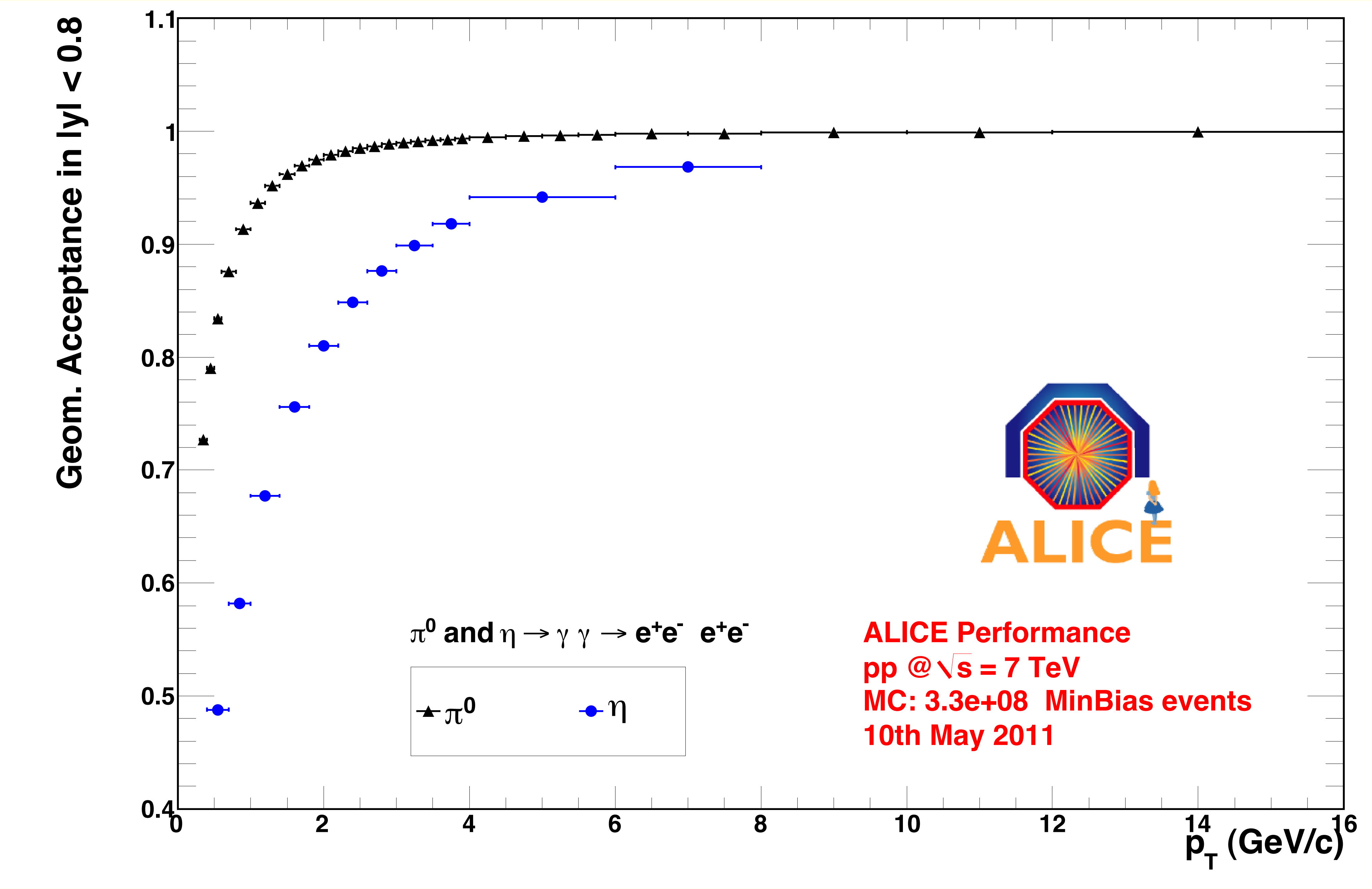
Conversion analysis at √s = 7 TeV: Sample π^0 Peak



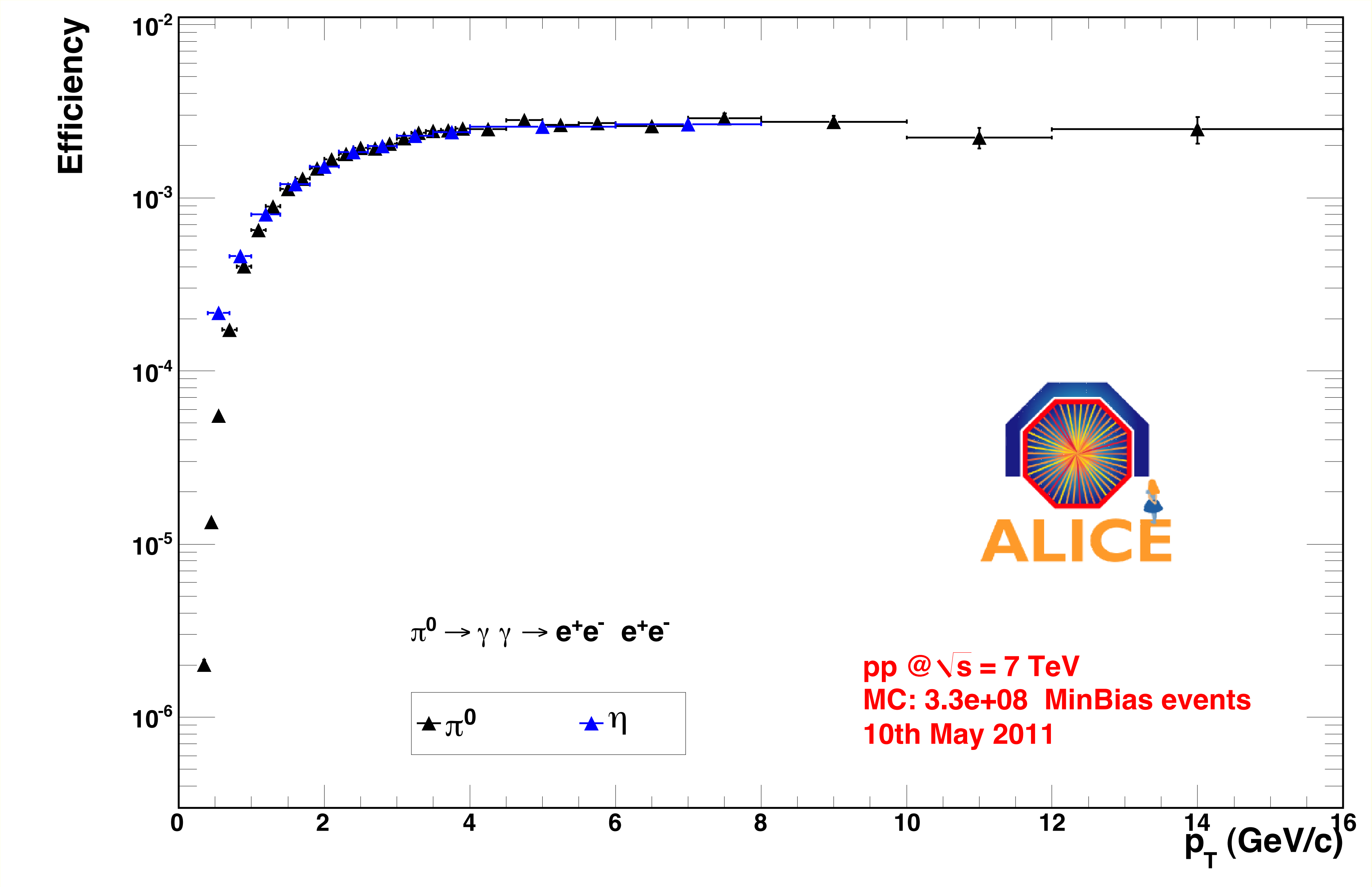
Conversion analysis at √s = 7 TeV: π^0 Peaks



Conversion analysis at √s = 7 TeV: Geometrical Acceptance



π^0 Reconstruction Efficiency



$$\varepsilon_{\max}^{\pi^0} = p_{\text{conv}}^2 \times \varepsilon_{\max}^{\gamma} = 0.085^2 \times 0.65^2 = 0.3\%$$

About 0.3% of the π^0 with $|y| < 0.8$ are detected