The Abdus Salam
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International Atomic
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Fifth International Conference on
PERSPECTIVES IN HADRONIC PHYSICS
Particle-Nucleus and Nucleus-Nucleus Scattering at Relativistic Energies

22 - 26 May 2006

Direct photon detection in pp and PbPb collisions in the ALICE experiment at LHC

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Yuri Kharlov
For the ALICE PHOS collaboration

5th International Conference on Perspectives in Hadronic Physics

22-26 May 2006

Outline

- ALICE photon detectors
- Physics motivation
- Photon sources
- Expected rates
- Experimental methods

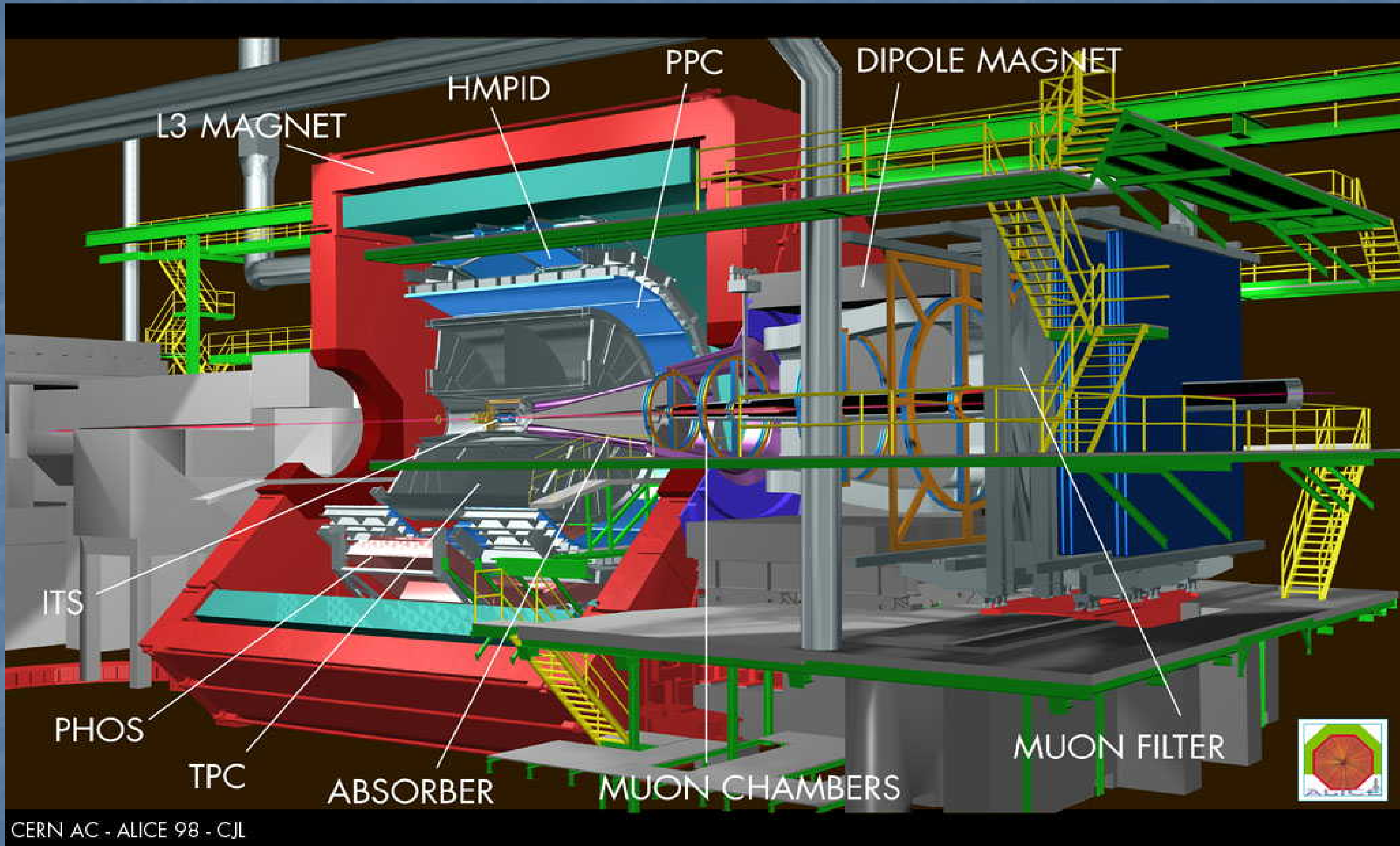
ALICE experiment at LHC

ALICE is a dedicated heavy-ion experiment at LHC.

Our aim is to study the physics of strongly interacting matter at extreme energy densities.

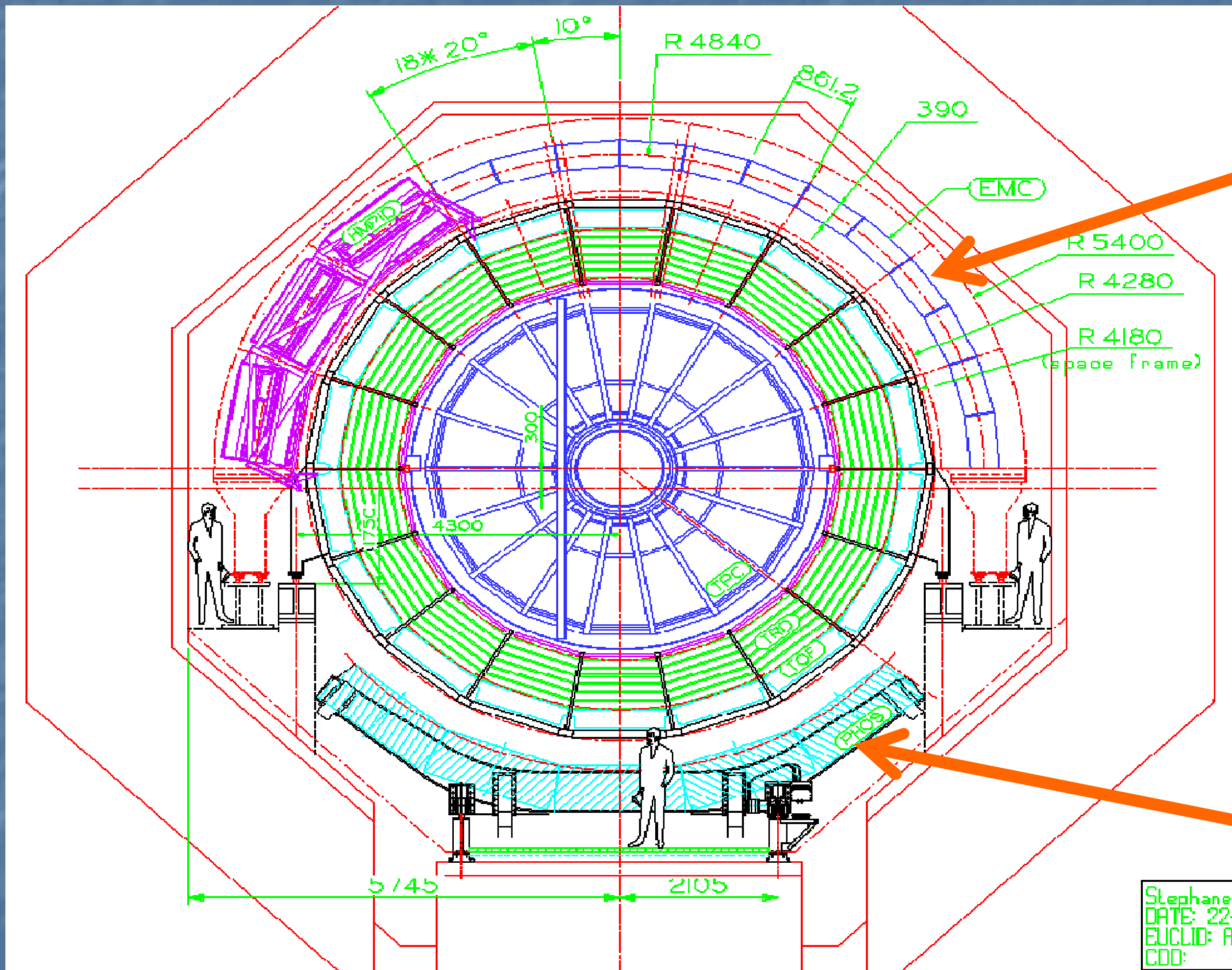
1000 scientists from 30 countries.

ALICE setup



On ALICE physics see a talk by M.Monteno on 24 May

Photon detectors in ALICE

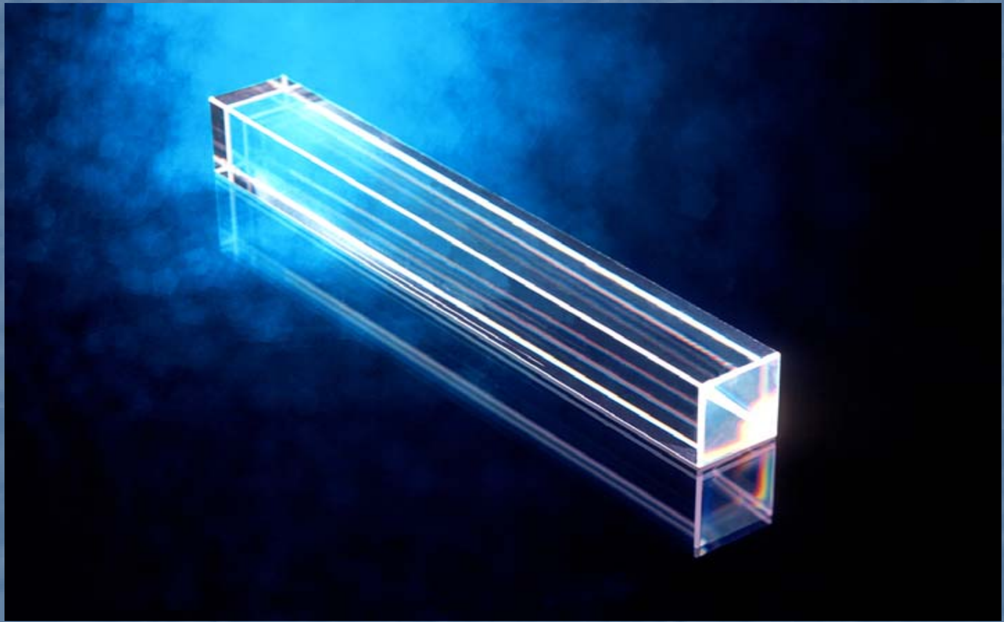


EMCAL

See a talk by N.Bianchi on 23 May

PHOS

PHOS crystals



Base element: $PbWO_4$ crystal grown at "North Crystals" enterprise in Russia

R_M=2.0 mm

X_0=8.9 mm

ρ=8.28 g/cm^3

n=2.16

size: 22$\times$22$\times$16 cm^3

PHOS has 5 modules installed at 4.6 m apart from the ALICE interaction point.

Each module contains 3584 crystals

Total number of crystals: 17920

PHOS aperture: $|\eta|<0.13$, $\Delta\phi=100°$

Energy range: E<100 GeV

First PHOS module is assembled in April-May 2006

Main physics interests

- Photon are highly penetrating particles which escape from the hot nuclear matter almost intact and, therefore, carry undistorted information from any stage of the nuclear matter evolution
- Direct photons are produced in elementary interactions acts in the nuclear matter:
  - in hard QCD processes, observed mainly at high p_T;
  - In emission of thermalized nuclear matter, observed mainly at low p_T

  serve as a probe for thermal properties of the early phase of the nuclear reaction. Aka "*thermal photons*".
- Fragmentation photons
- Decay photons reveal medium-induced modifications of hadron properties.
- Interferometry of photons can be used as a tool to measure geometrical size of the source.

See a talk by F.Arleo on 24 May

Photon sources (1)

Prompt γ [$\mathcal{O}(\alpha\alpha_s)$]: interaction of initial partons

$$q + g \rightarrow q + \gamma$$

$$q + \bar{q} \rightarrow g + \gamma$$

- Parton in-medium-modification imprinted in the final hadronic state
- Prompt photons are not perturbed by the medium

Medium-induced γ [$\mathcal{O}(\alpha\alpha^2_s)$]: multiple scattering of final-state partons

$$q + g_{\text{medium}} \rightarrow q + \gamma$$

$$\bar{q} + q_{\text{medium}} \rightarrow q + \gamma$$

Photon sources (2)

Thermal photons from QGP:

$$q + g \to q + \gamma \qquad \frac{dN}{d^4x d^3p} = a\alpha\alpha_s \ln\frac{0.23E}{\alpha_s T}\exp\left(-\frac{E}{T}\right)\frac{T^2}{E},\ E >> T$$

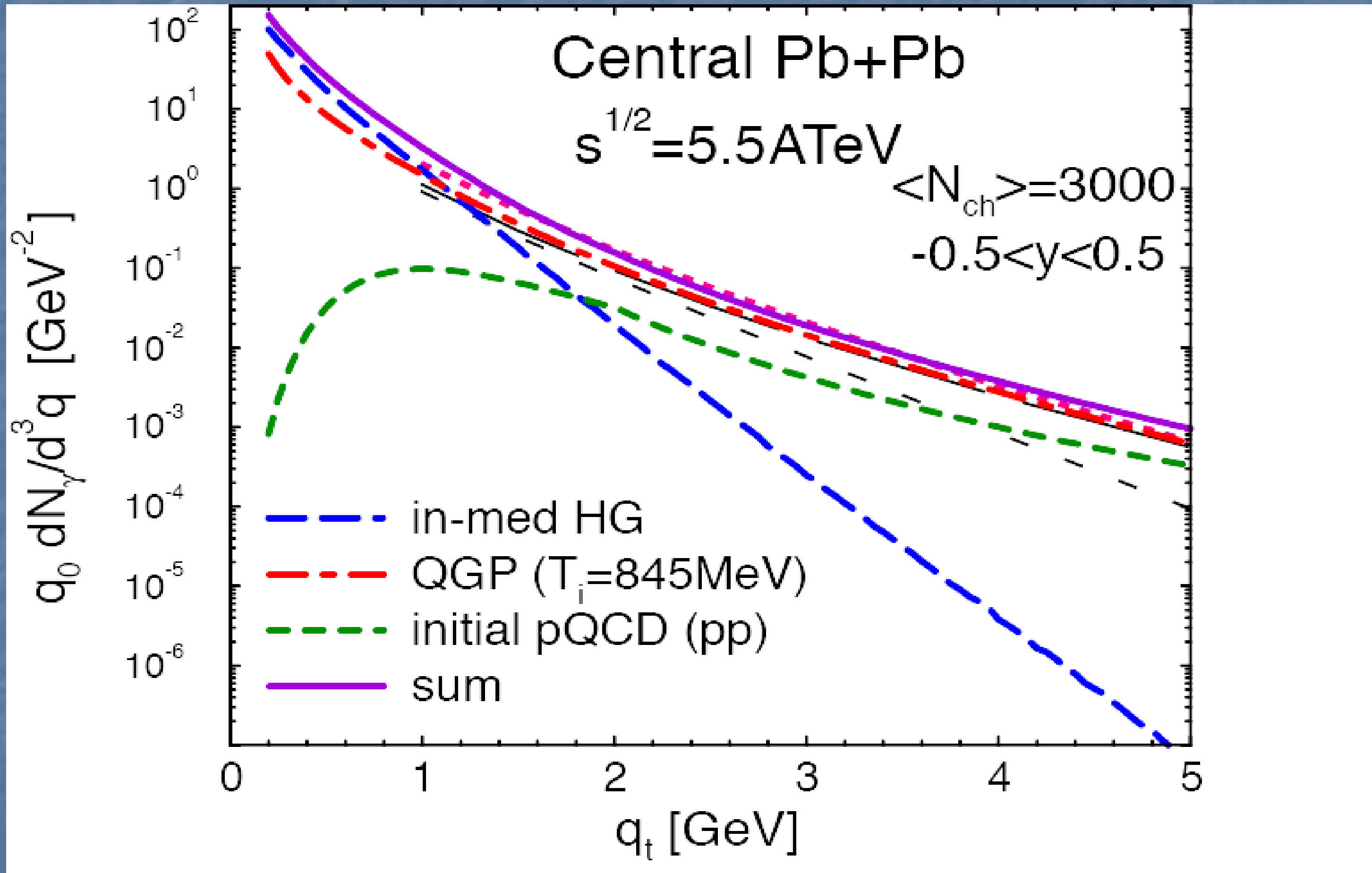
$$q + \bar{q} \to g + \gamma \qquad \frac{dN}{d^2x d^3p} = b\alpha\alpha_s \exp\left(-\frac{E}{T}\right)\frac{T^2}{E},\ E >> T$$

Photons from HG: $\pi\rho\to\pi\gamma$, $\pi\pi\to\rho\gamma$, $\omega\to\pi^0\gamma$

$$\frac{dN}{d^4x d^3p} = 4.8T^{2.15}\exp\left(-\frac{1}{(1.35T)^{0.77}}\right)\exp\left(-\frac{E}{T}\right)$$

Photon rates from QGP and HG might be similar, but can be distinguishable due to different space-time evolution

Contributions to direct photon spectrum



Photon predictions for p+p at LHC

Start up scenario :

2 PHOS modules

($\Delta\phi=40°$, $\Delta y=0.25$)

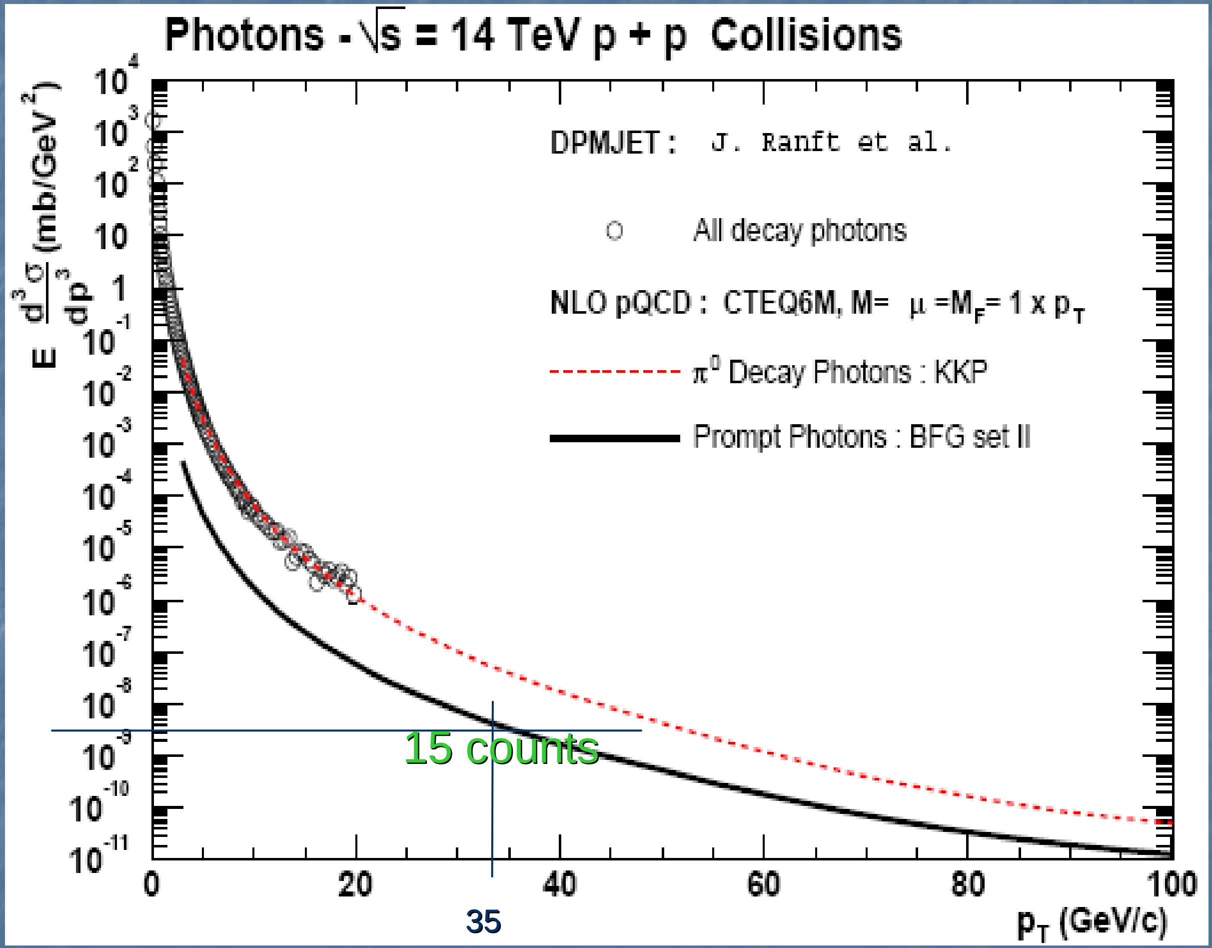
$L=10^{30}$ cm^{-2}s^{-1}

$T=10$ days$=8.6\cdot10^{5}$ s

$LT= 8.6\cdot 10^{8}$ mb^{-1}

$3\cdot10^{6}$ events/GeV at 1-2 GeV/c

15 events/GeV at 35 GeV/c



π^0 predictions for p+p at LHC

Start up scenario :

2 PHOS modules

($\Delta\phi$=40°, Δy=0.25)

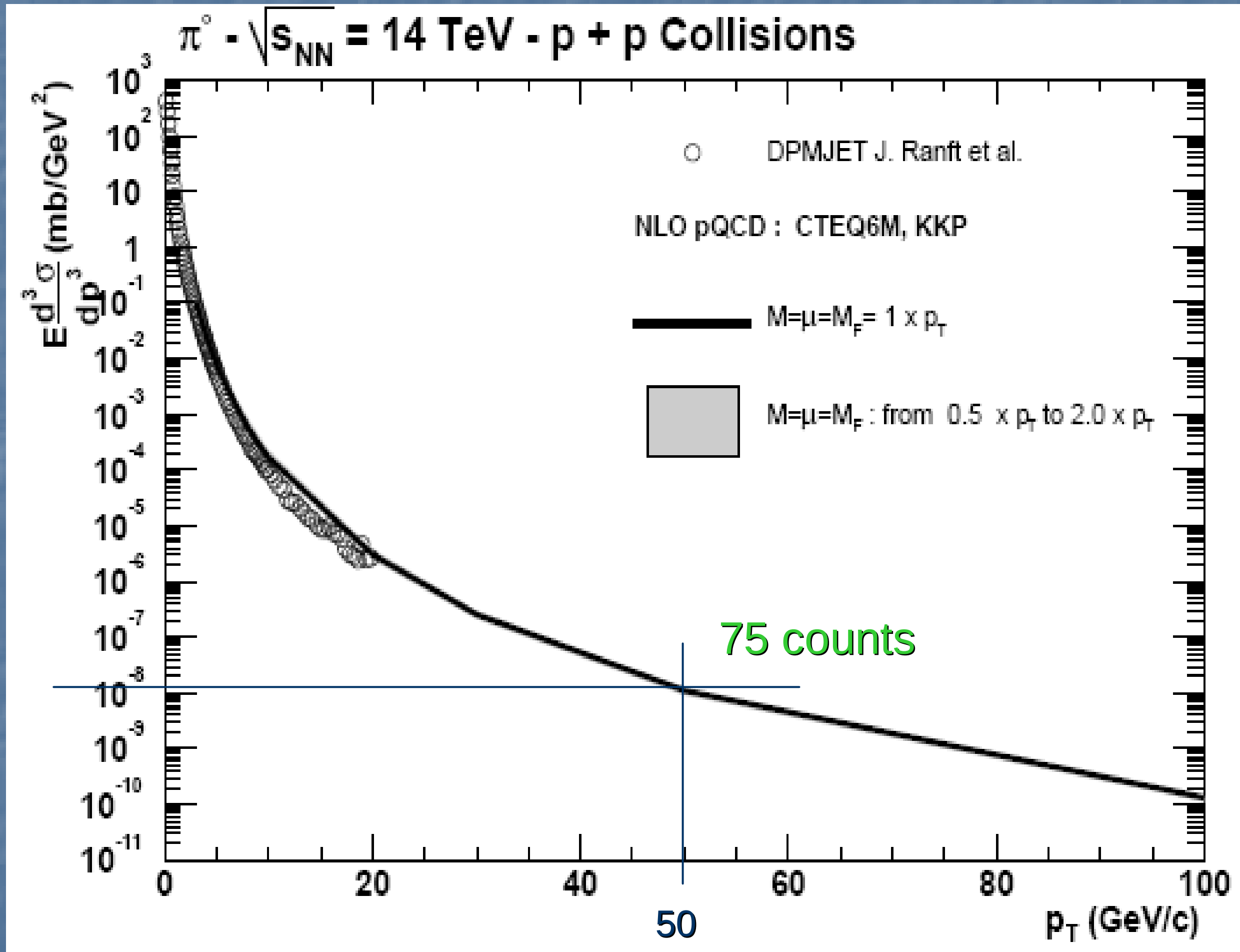
$L=10^{30}\ cm^{-2}s^{-1}$

T=10 days=$8.6\cdot10^5$ s

$LT= 8.6\cdot 10^8\ mb^{-1}$

$3\cdot10^8$ events/GeV at 1-2 GeV/c

75 events/GeV at 50 GeV/c



Decay γ vs Direct γ

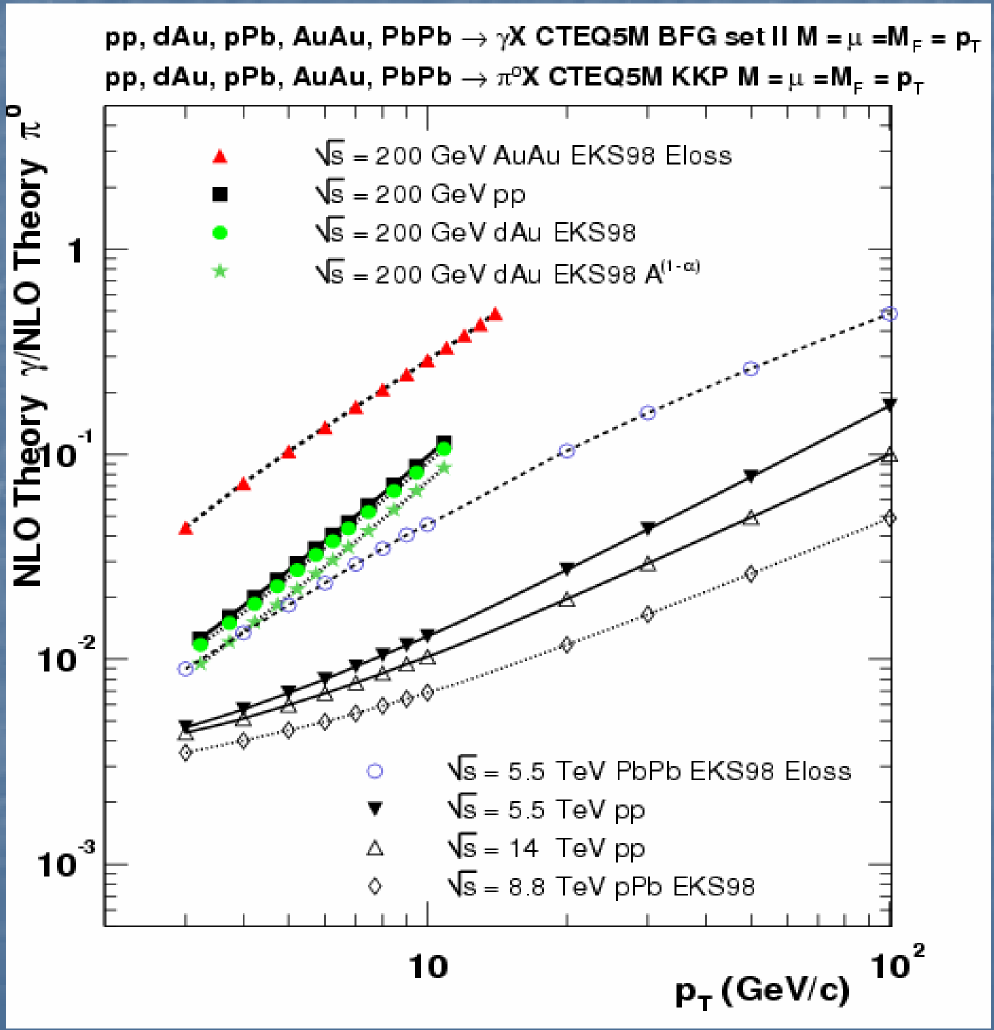
Photon Yellow Report **hep-ph/0311131**

p+p collisions:

- π^0 dominates at all p_T

A+A collisions:

- Jet quenching suppress π^0
- RHIC:
  - $N_\gamma > N_\pi$ for $p_T > 10$ GeV/*c*
- LHC:
  - $N_\gamma > N_\pi$ for $p_T > 100$ GeV/*c*



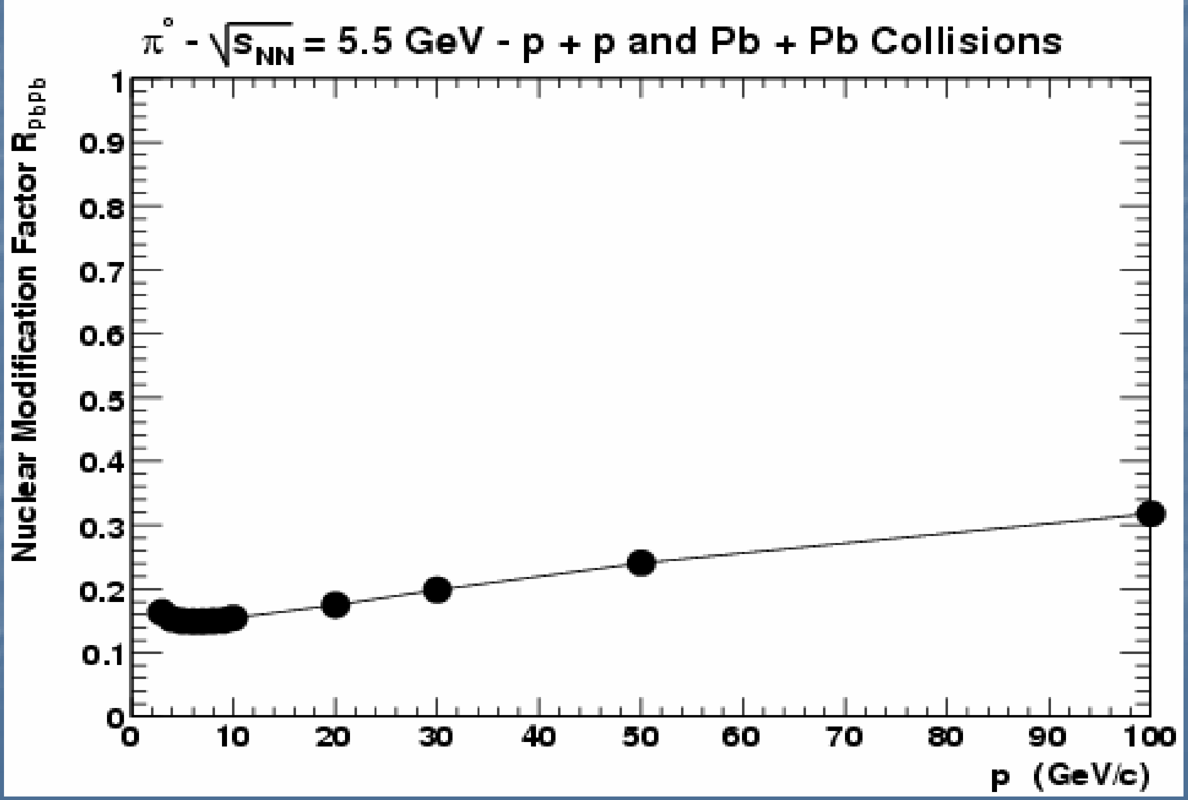
π^0 nuclear modification factor

- R_{AA} for the 5% most central Pb+Pb collisions at $\sqrt{s_{NN}}$ = 5.5*A* TeV with respect to p+p system.

$$R_{AA}(p_T) = \frac{(1/N^{evt}_{AA})\, d^2N^{\pi^0}_{AA}/dp_T dy}{\langle N_{coll}\rangle/\sigma^{inel}_{pp} \times d^2\sigma^{\pi^0}_{pp}/dp_T dy}$$

- Points obtained with NLO pQCD approximation

  Photon Yellow Report
  hep-ph/0311131



Photon predictions for Pb+Pb at LHC

Start up scenario :

2 PHOS modules

($\Delta\phi$=40°, Δy=0.25)

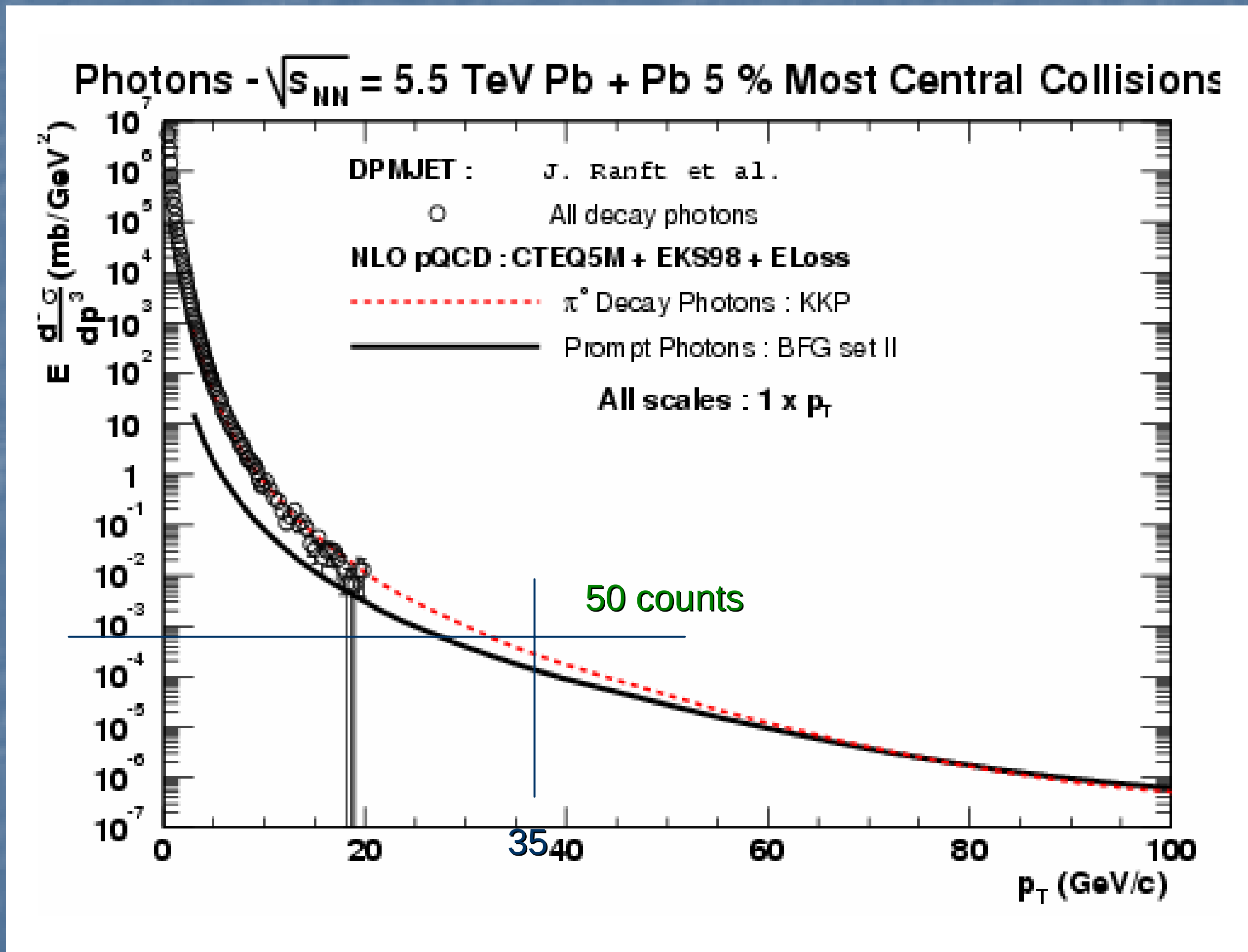
$L=10^{26}$ $cm^{-2}s^{-1}$

T=10 days=$8.6 \cdot 10^5$ s

LT= $8.6 \cdot 10^4$ mb^{-1}

$7 \cdot 10^7$ events/GeV at 1-2 GeV/c

50 events/GeV at 35 GeV/c



π^0 predictions for Pb+Pb at LHC

Start up scenario :

2 PHOS modules

($\Delta\phi$=40°, Δy=0.25)

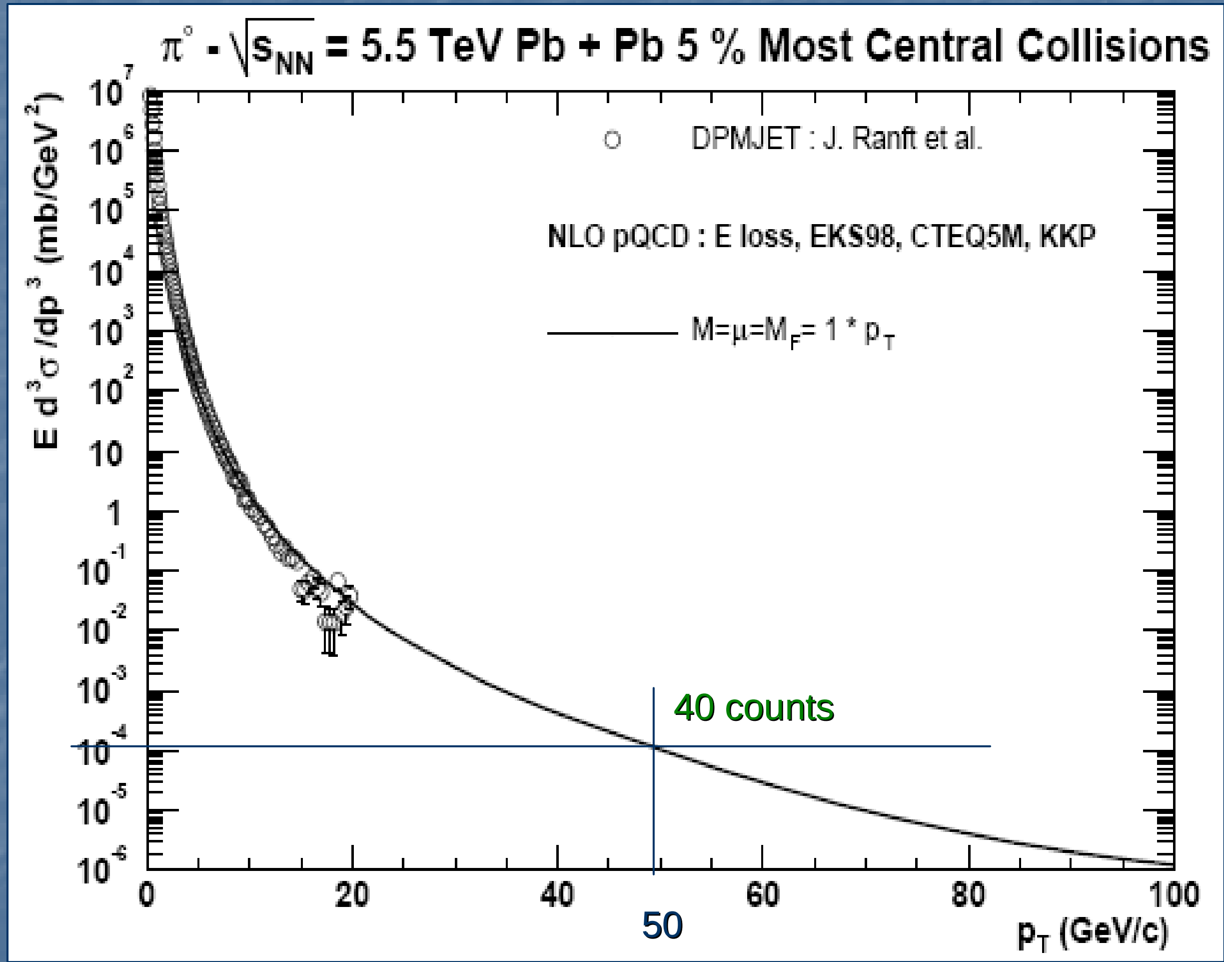
$L=10^{26}$ cm^{-2}s^{-1}

T=10 days=$8.6\cdot10^5$ s

LT= $8.6\cdot 10^4$ mb^{-1}

$2\cdot10^9$ events/GeV at 1-2 GeV/c

40 events/GeV at 50 GeV/c



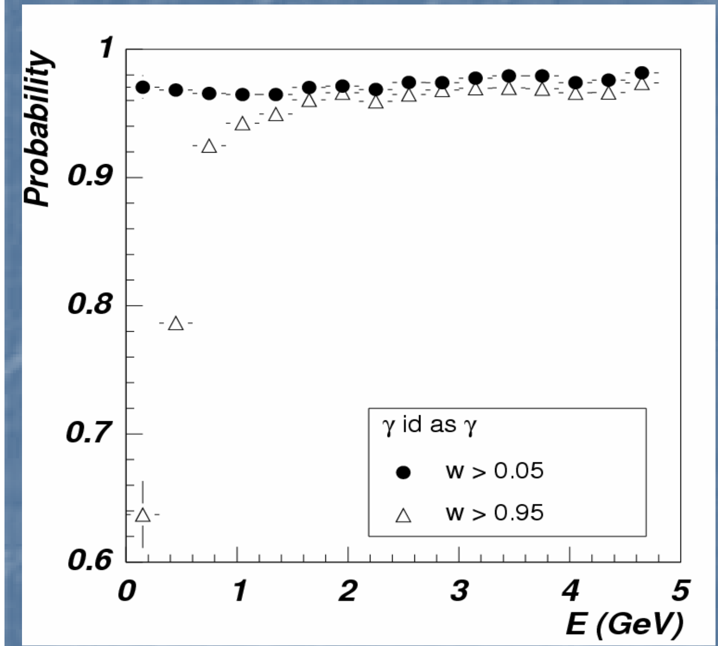
Particle identification in PHOS

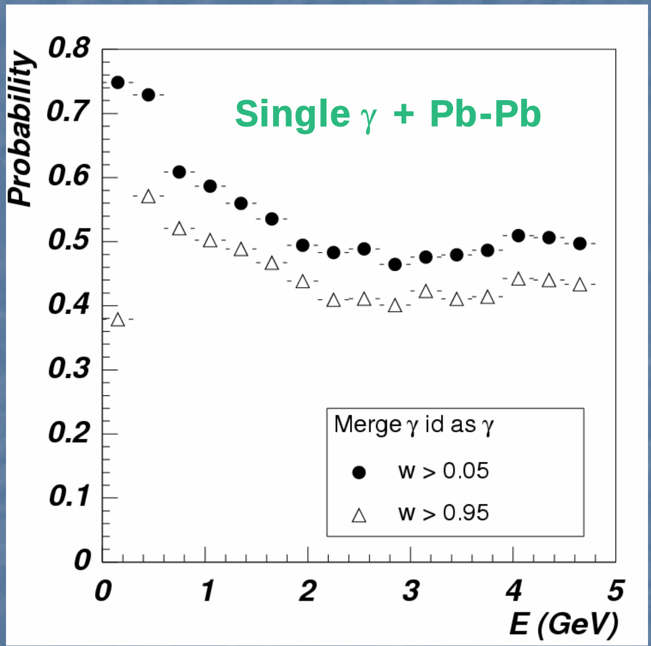
Photon are identified by 4 criteria:

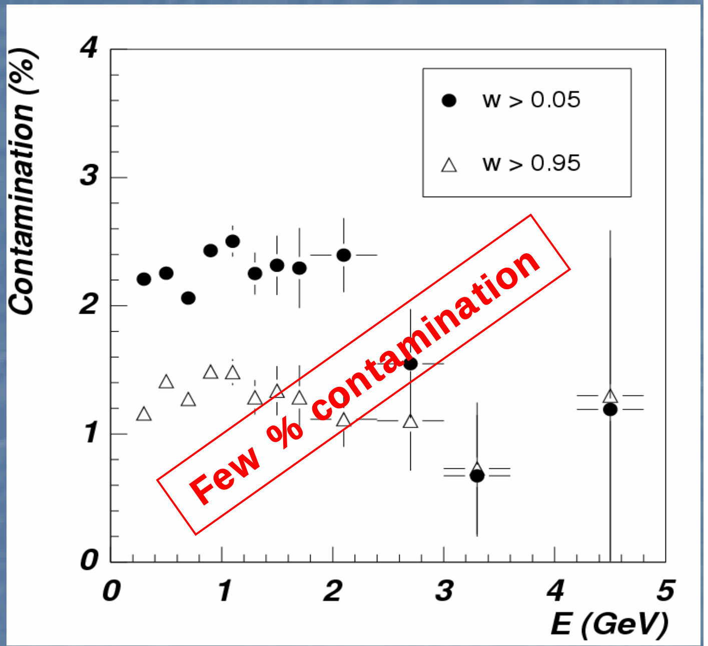
1. Shape of the showers (e.m. or hadronic)
2. Charged particle matching by CPV detector
3. Time of flight measured by FEE
4. Photon isolation

Photon efficiency and hadron contamination

Single γ | **Central Pb+Pb collisions** | **Hadron contamination**







Direct photons: experimental methods

Direct photons spectrum at low p_T can be measured statistically:

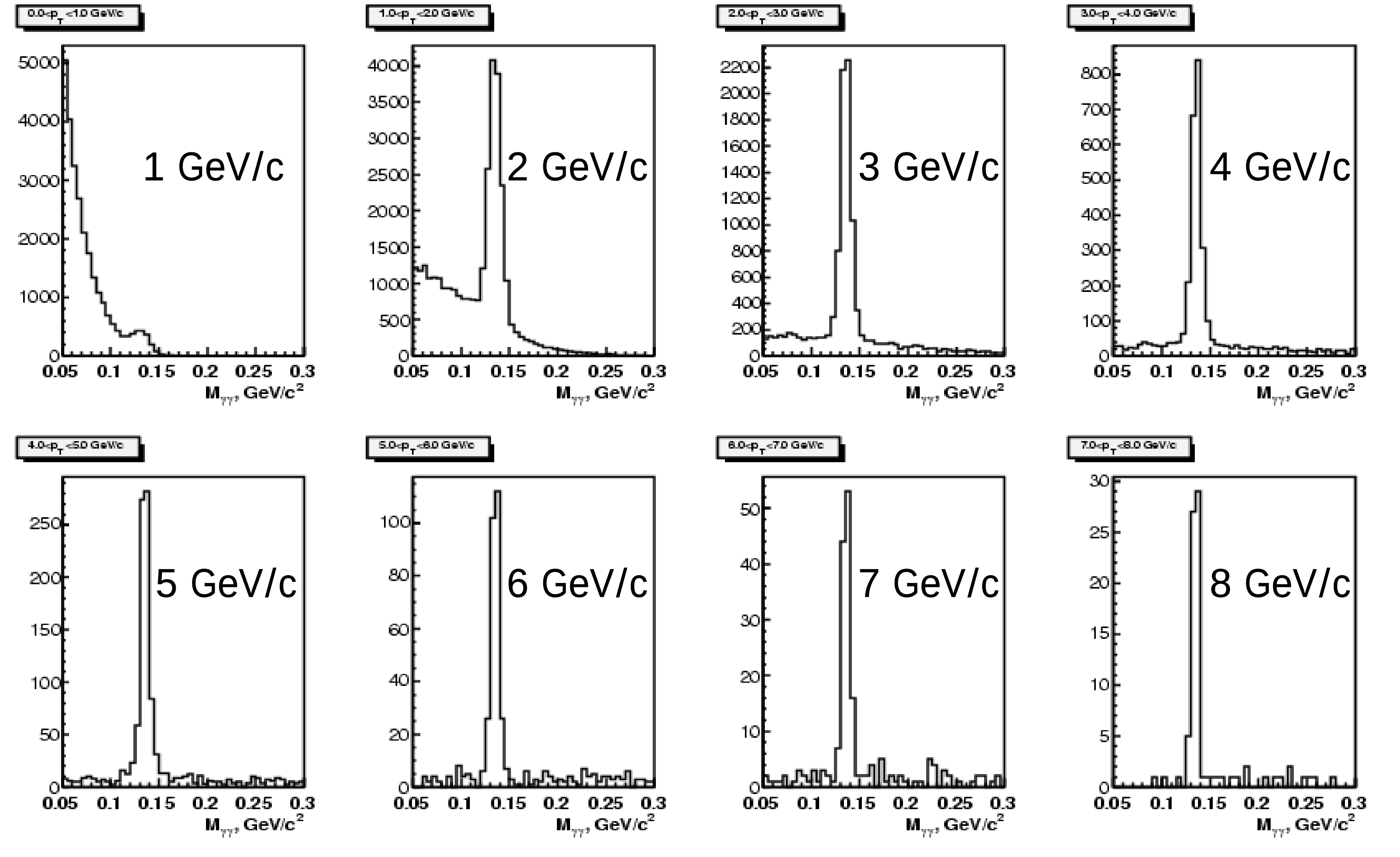
- Raw spectrum of reconstructed and identified photons is accumulated
- This raw spectrum is to be corrected for
  - hadron contamination
  - photon conversion
  - reconstruction and identification efficiencies
  - geometrical acceptance

Experimental methods (cont'd)

Decay photon spectrum is to be reconstructed:

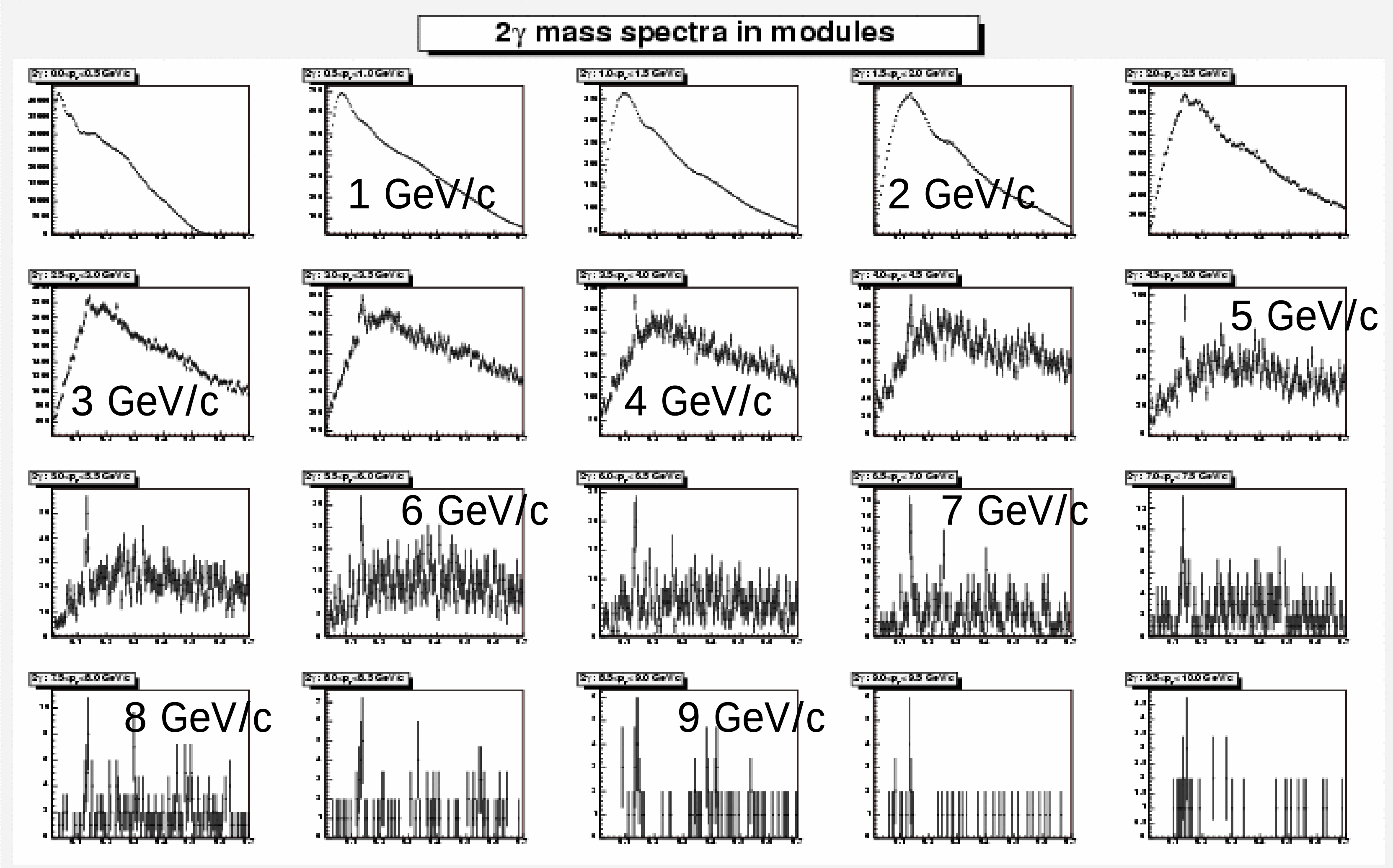
- π^0 spectrum is reconstructed by 2-photon invariant mass distributions for each p_T-bin
- Combinatorial background is evaluated by event-mixing techniques
- π^0 spectrum is corrected for
  - reconstruction efficiency
  - photon conversion
  - geometrical acceptance
- Similar procedures should be done for η and other neutral mesons if possible, heavy mesons contribution is evaluated by m_T scaling
- Reconstructed neutral meson spectra should be put into simulation to produce decay photon spectra

π^0 detection in pp via 2γ inv.mass



Practically no combinatorial background at p_T>1 GeV/c

π^0 detection in Pb+Pb via 2γ inv.mass



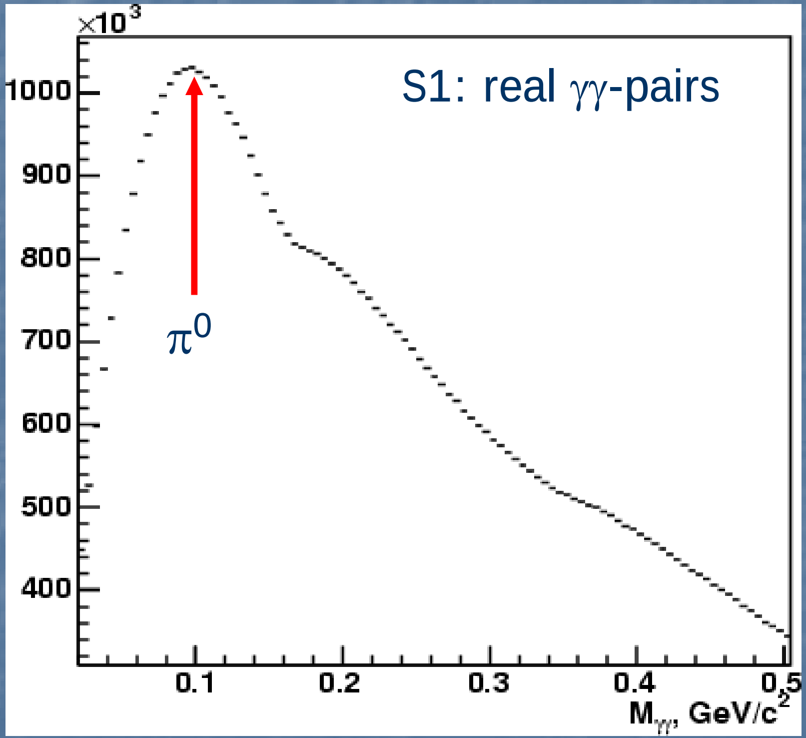
π^0 becomes visible over combinatorial background at p_T>5 GeV/c

π^0 reconstruction in central Pb-Pb collisions: $\gamma\gamma$-mass spectrum

Invariant mass spectrum of photon pairs has too high combinatorial background at low p_T which obscures the π^0 peak

Example: $\gamma\gamma$-mass at p_T=1 GeV/c in 200,000 central Pb-Pb collisions in PHOS

Number of combinations: N(N-1)/2

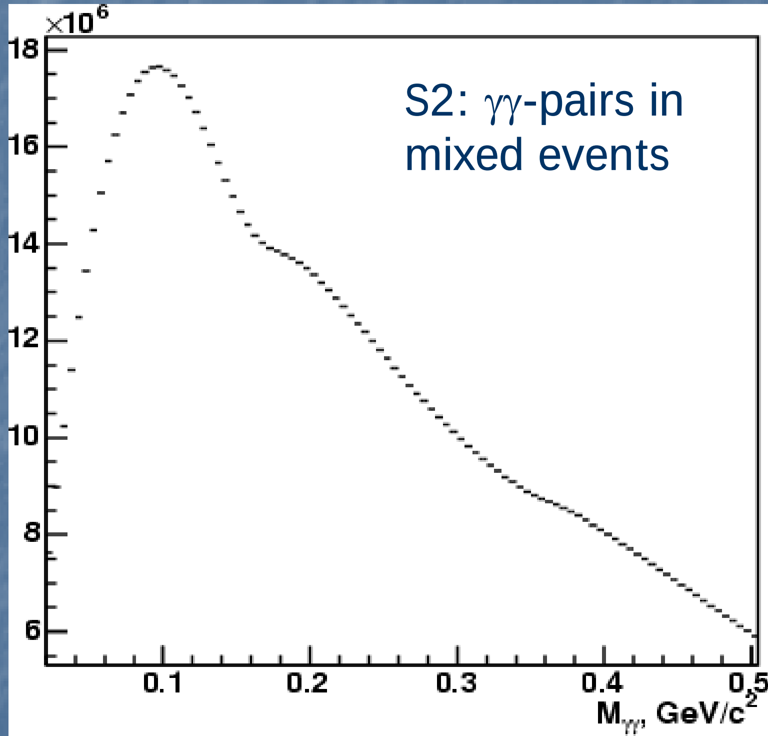


$\gamma\gamma$-mass spectrum in mixed events

Combinatorial background can be constructed from totally uncorrelated photons from different events

Example: $\gamma\gamma$-mass at p_T=1 GeV/c_of all combinations from 10 consequent events

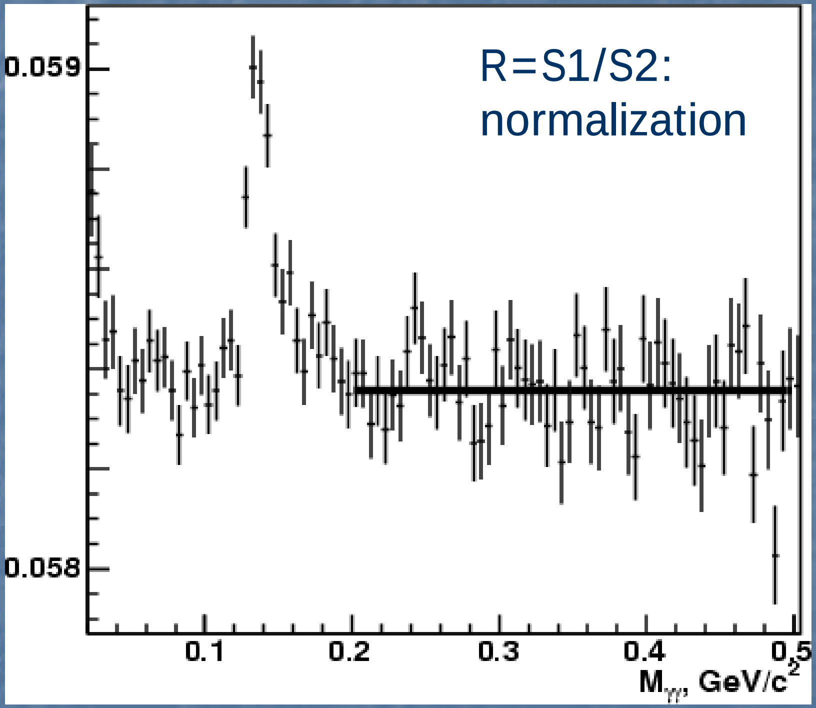
Number of combinations: $10\langle N \rangle^2$



Combinatorial background normalization

Normalization of real-pair spectrum and mixing-event pair spectrum can be obtained in the mass region of uncorrelated pairs

($200<M_{\gamma\gamma}<400$ MeV/c^2)



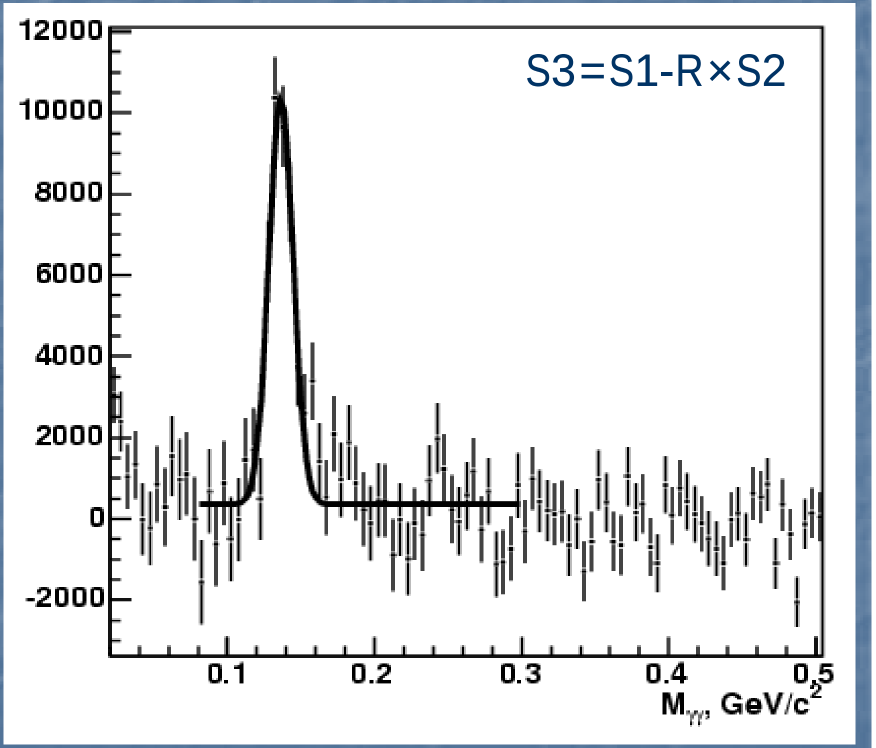
Combinatorial background subtraction

After subtraction the π^0 peak is revealed above almost zero background

But:

•residual correlated pairs are observed at low $M_{\gamma\gamma}$ which gives a background for photon interferometry studies (see later)

•Statistical errors are higher due to subtraction of two large numbers

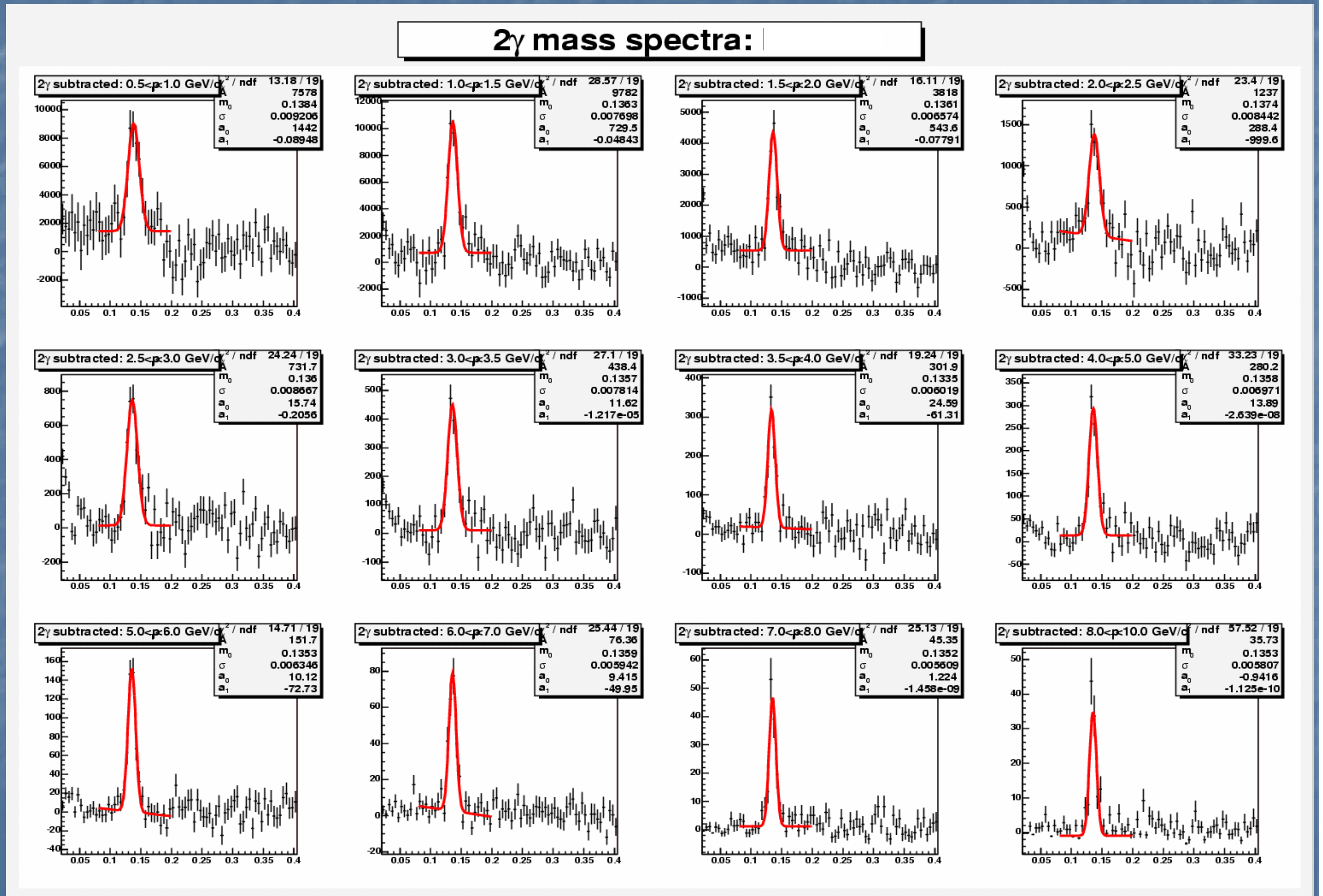


π^0 detection in central Pb-Pb collisions

200,000 central Pb-Pb collisions (b<2 fm)

4 minutes of the LHC run at the nominal luminosity

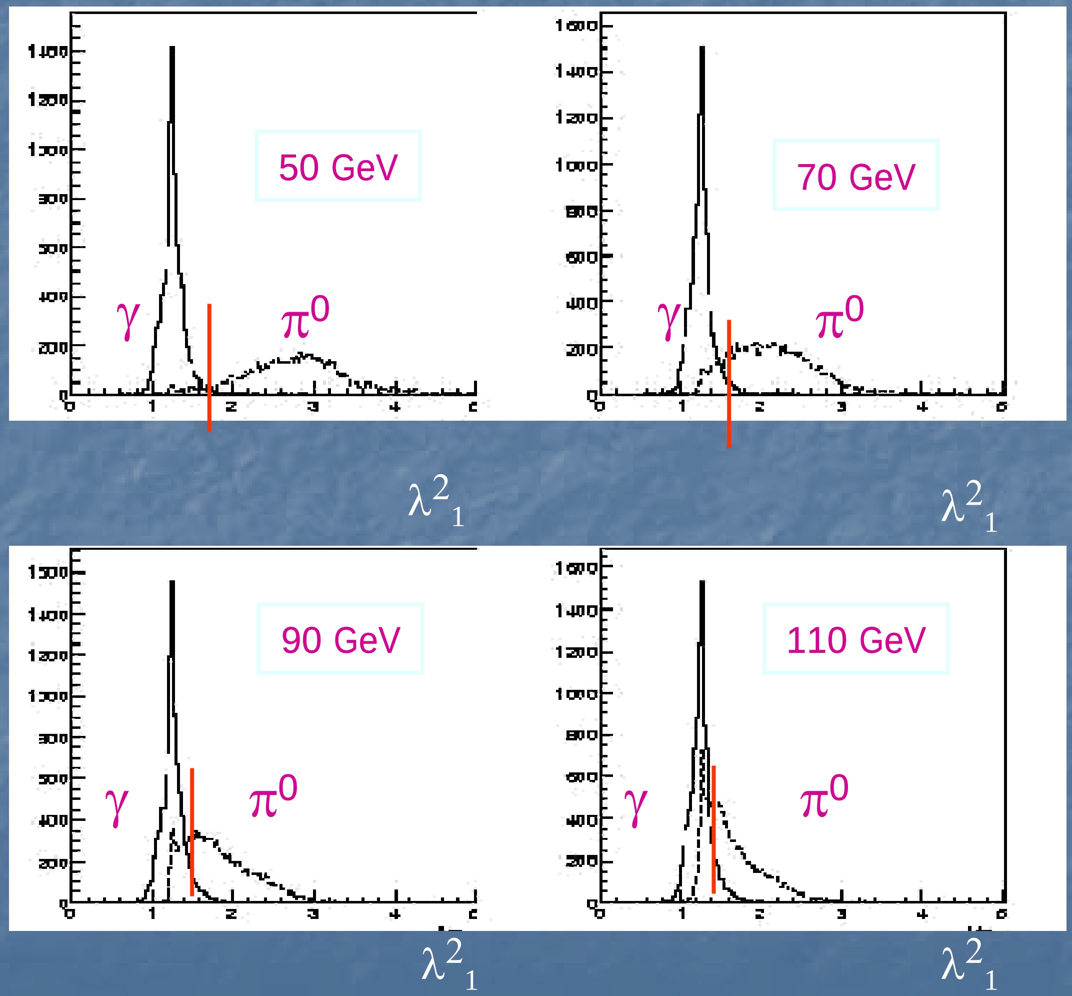
$L=5\cdot10^{26}$ cm^{-2}s^{-1}

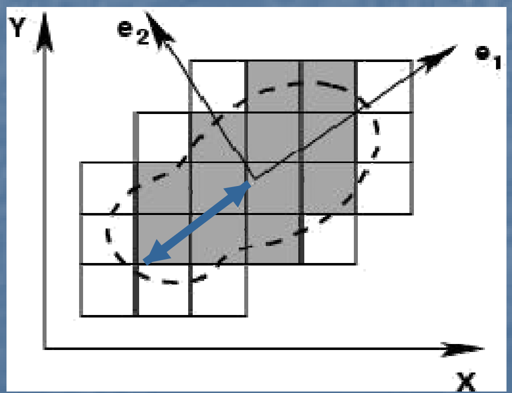


Direct photons at high p_T

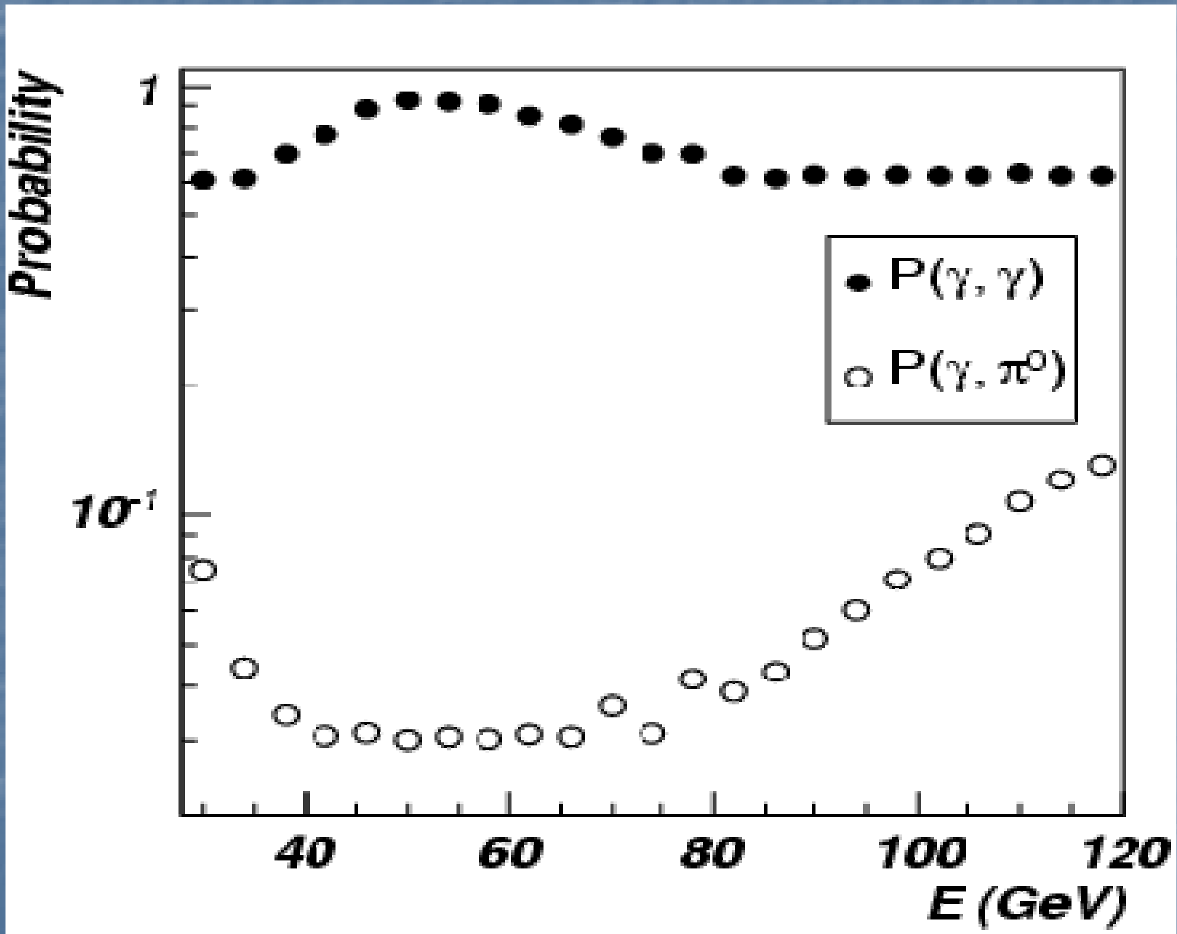
Direct photons at high p_T can be identified E-by-E

by the shape of the shower





Direct photons at high p_T: efficiency and contamination



p_T = 90 GeV/c:

$P(\gamma,\gamma)$ = 60 %

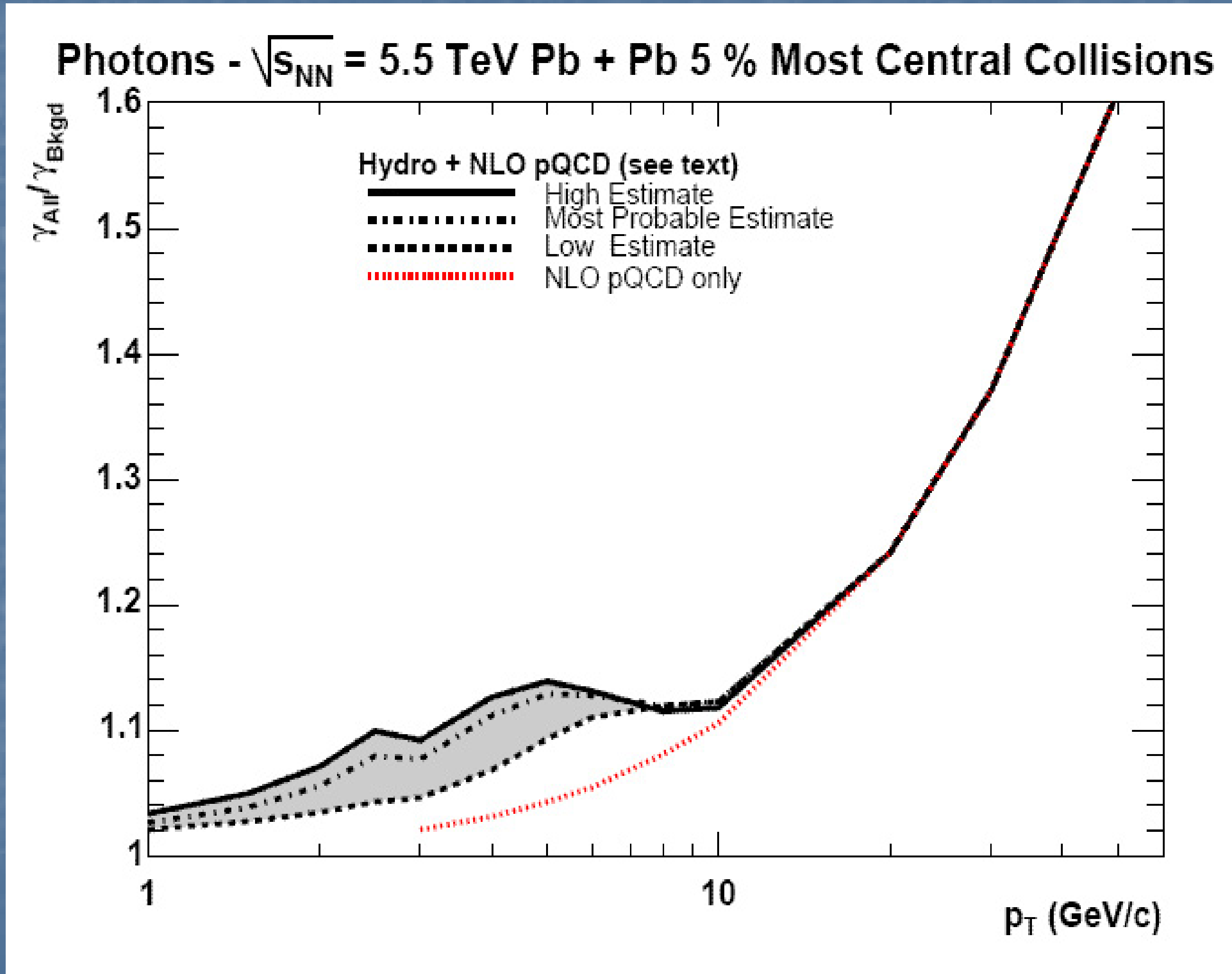
$P(\gamma,\pi^0)$ = 5%

Direct photons: sources of systematical errors

- Errors in inclusive photon spectrum
- Errors in decay photon spectrum
- Errors in theoretical assumptions on background

Error	p_T=1.5 GeV/c	p_T=5 GeV/c
γ detection	3%	3%
π^0 detection	5%	5%
η detection	3%	3%
Hadron contamination	2.5%	1%
Non-vertex background	2%	1%
Total	7.3%	6.7%

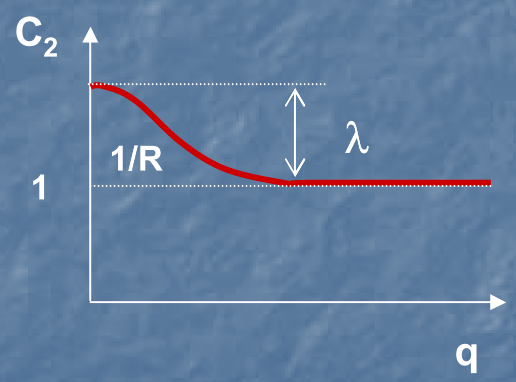
Expected direct photon excess over decay photons



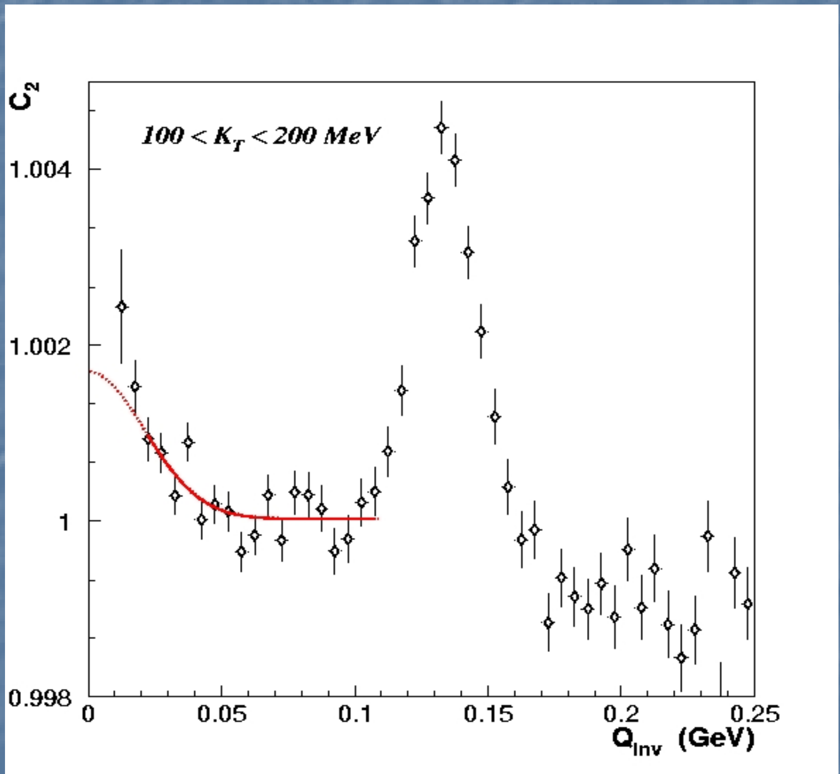
Photon interferometry

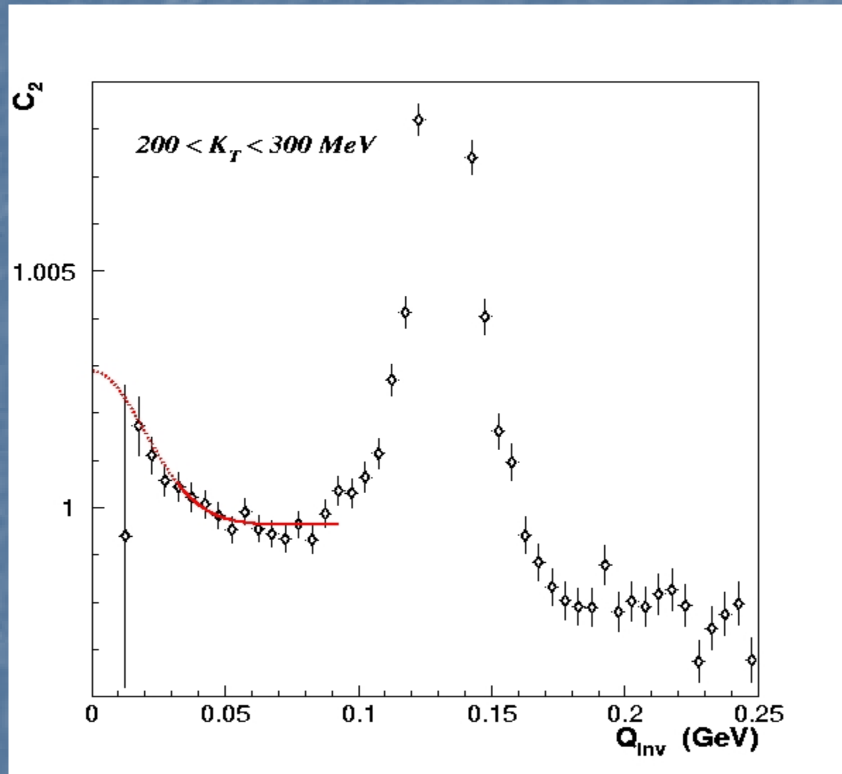
$$C_2(k_1,k_2)=\frac{P(k_1,k_2)}{P(k_1)P(k_2)}=1+\lambda\frac{\left|\int d^4xS(x,K)e^{iqx}\right|^2}{\left|\int d^4xS(x,K)\right|^2}\approx 1+\lambda e^{-q^2R^2}$$

$$q=k_1-k_2,\quad K=\left(k_1+k_2\right)/2$$



C_2 in Pb-Pb at 158 AGeV/c (WA98)



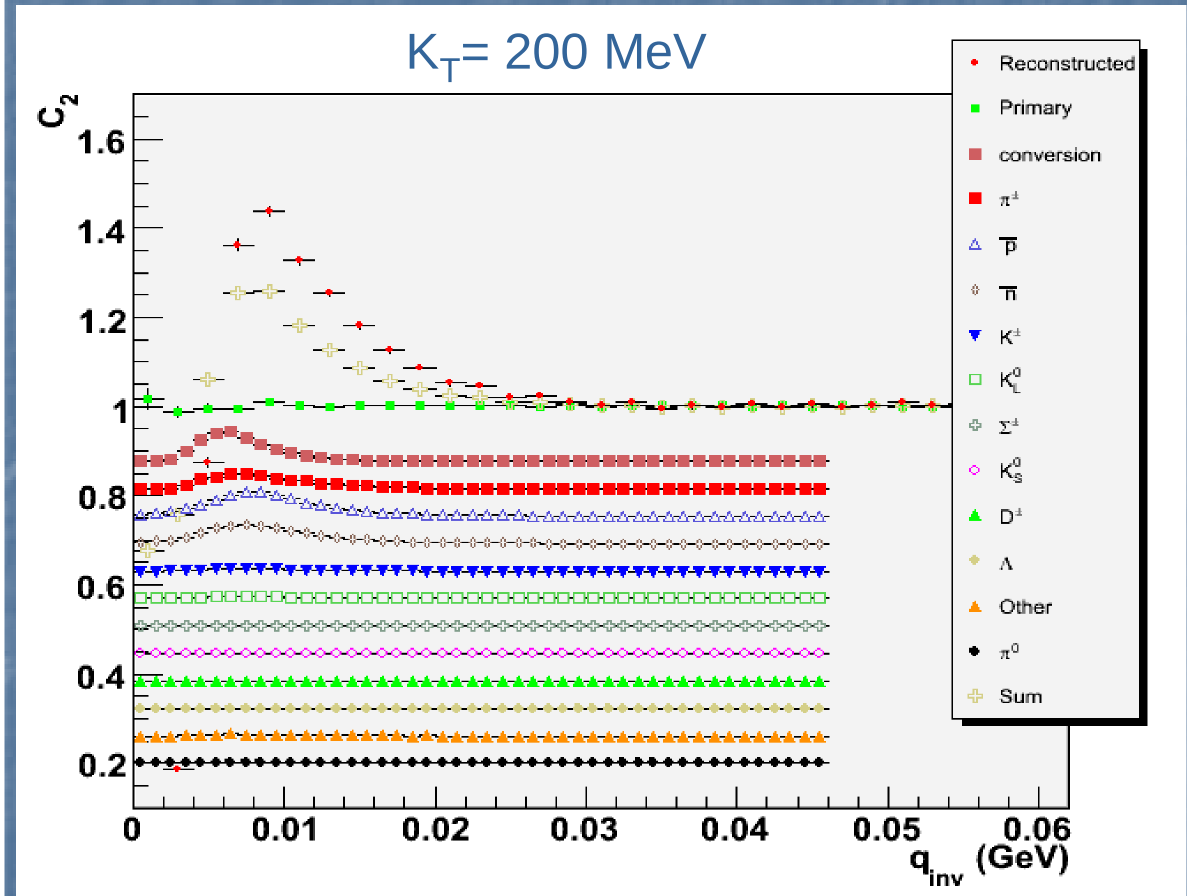


Photon correlations: sources of systematical errors

Systematic errors in photon HBT extration.

- Apparatus effects: close cluster interference, cluster merging and splitting
- Photon spectrum contamination and admixture of the hadron (electron) correlations
- Background photon correlations due to
  - Residual correlation from Bose-Einstein correlated hadrons ($\pi^0\pi^0$)
  - Resonance decays and conversion on material in front of PHOS
  - Residual correlations from collective flow, jets, etc.
- Experimental resolution of the relative momentum

Two-photon correlations:
HIJING event



Comparison of two-photon correlation function of primary photons and reconstructed one as well as decomposition of correlations due to decays of heavy resonances.

Each contribution is shifted for clarity (all they go to zero at q_{inv} > 30 MeV/c)

Both apparatus effects and background correlations are negligible at q_{inv}>30 MeV/c

Summary

- ALICE PHOS can measure direct photons and π^0 in pp and PbPb collisions with reasonable statistics during first 10 days up to p_T=30-50 GeV/c.
- PHOS is able to measure thermal photons with the uncertainties better than 10%
  - Main uncertainties come from photon identification efficiency and decay photon reconstruction.
- PHOS can measure prompt photons at high p_T with the uncertainties better then a few %
  - Main contamination is due to π^0 misidentification
- PHOS provides an opportunity to measure two-photon correlations, and in particular, direct photon HBT correlations
  - Background correlations and apparatus effects distort two-photon correlation function at q<20-30 MeV/c.