Hard probes in pp collisions and the event generator EPOS

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Outline

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Our project

EPOS is an event generator for Heavy Ions Collisions with a unified formalism for pp pA and AA collisions:

- Good results for collective behavior observables
  $\Rightarrow$ see Klaus's talk
- Missing ingredient : heavy flavors, prompt photons
  $\Rightarrow$ Couldn't be done like in pythia which is based on factorization formula

Our project : implementation of hard probes in EPOS

- Useful for experimentalists
- Test for theories/models :

Study of the QGP :

- Heavy quark correlation
- Isolated photon/ charged particles correlation
  $\rightarrow$modification of fragmentation functions by the medium
- γ jet

Small x study (includes cold matter effects):

- Multiplicity of D mesons
- Gluon distribution
- R_{pA} for D mesons

Test of "basic QCD" :

- partonic cascades
- QCD cross sections

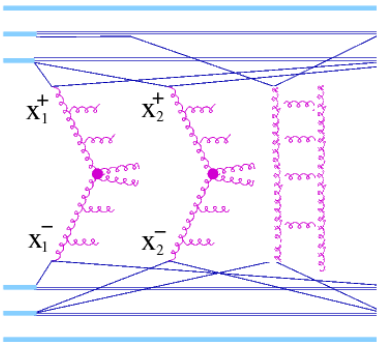
Outline

Multiple scattering in EPOS

Multiple scattering : pQCD and Gribov-Regge theory + Saturation

1. Seen in experiments at high energy (*Ref : X.N. Wang and M. Gyulassy, Phys. Rev D 45, 844 (1992)*)
2. Needed for theoretical reasons : $\sigma_{tot}(s)$ violates the Froissart bound with just one interaction

- Multiple pomerons exchange :



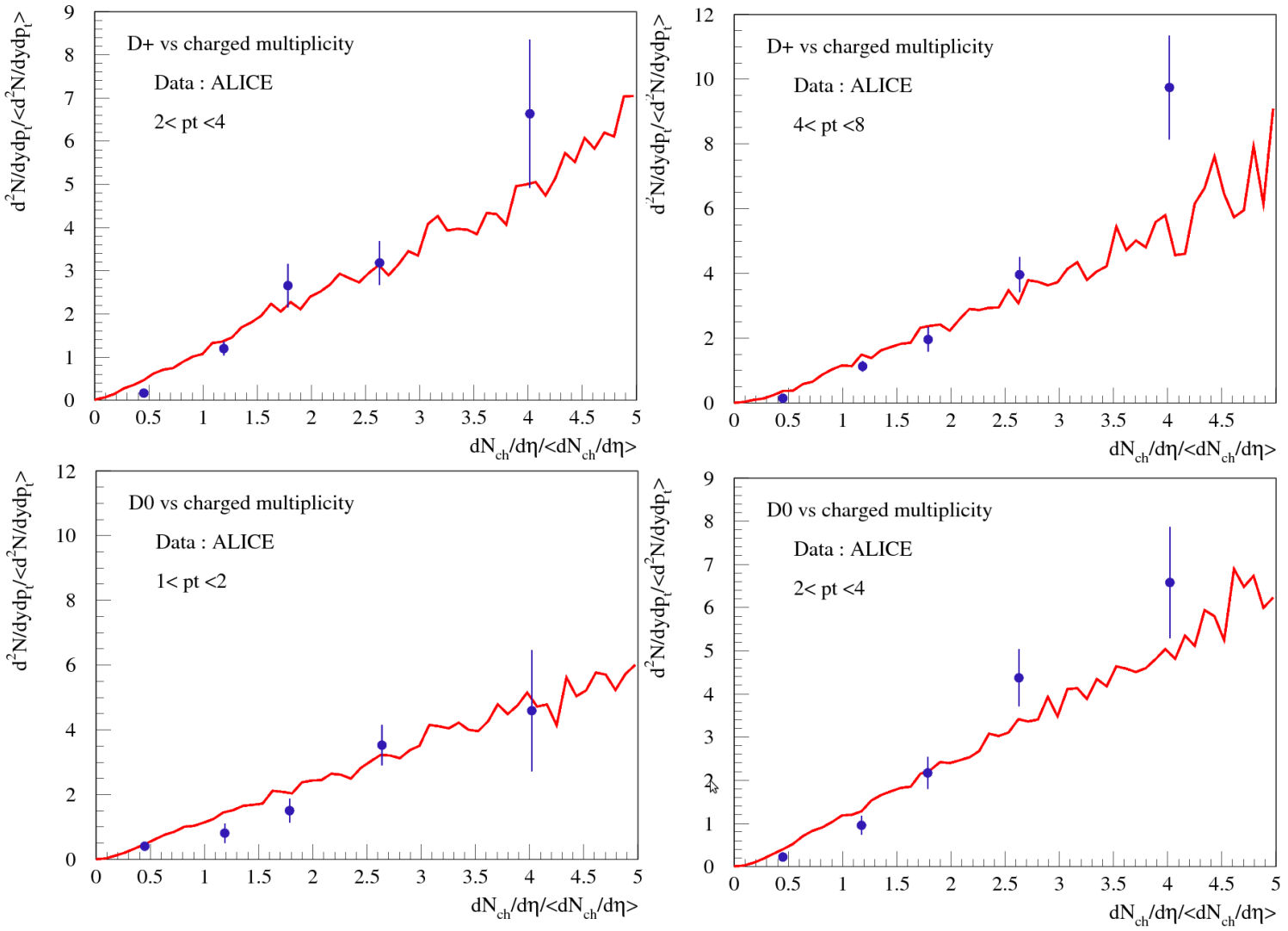
Multiple scatterings
(in parallel !!)
in pp, pA, or AA

Cut pomeron → particles production :

- Multiplicity ∝ # of cut pomerons
- hard probes ∝ # of cut pomerons

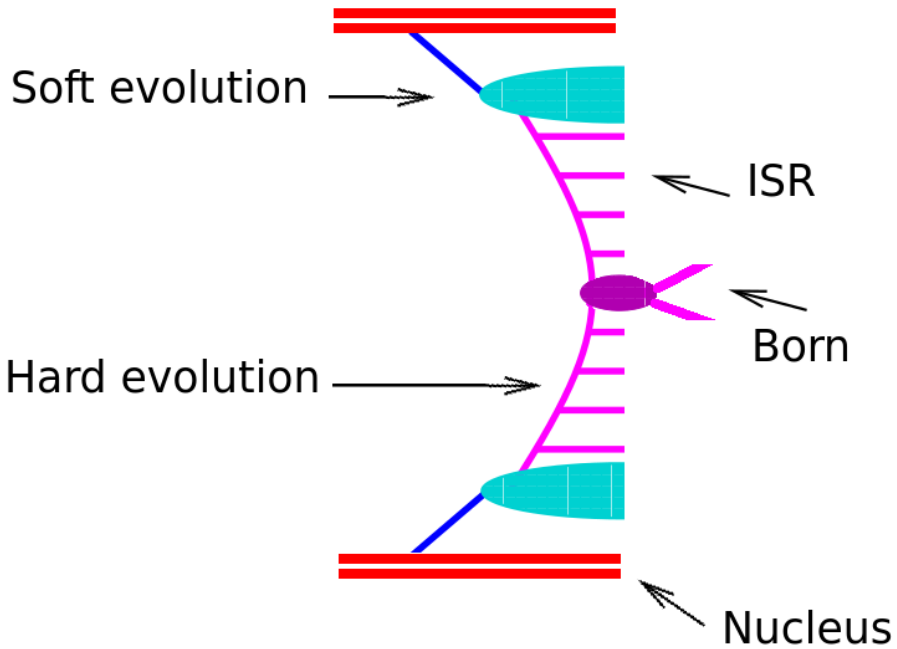
Linear rise of hard probes with the multiplicity of charged particles

D mesons vs multiplicity



Hard probes production

dissection of a pomeron :



Hard probes produced during :

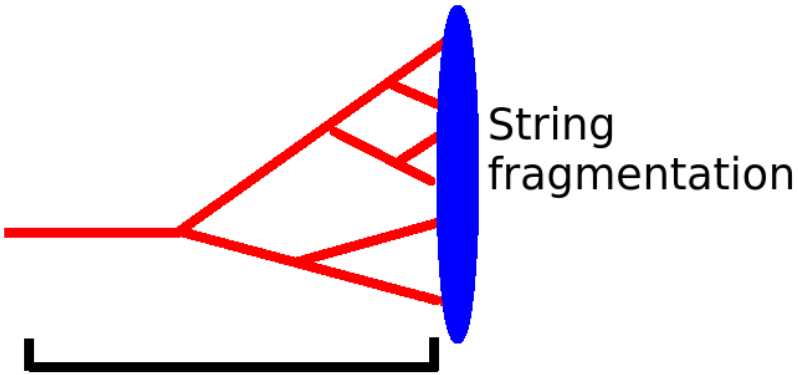
- Hard evolution
- Born process = σ_{QCD} at L.O

emission probability :
$dP(z, Q^2) \propto \frac{\alpha}{2\pi} \frac{p(z)}{Q^2} \Delta(Q_0^2, Q^2)$

- The same formalism (and parameters) for prompt photons and heavy quarks

... and timelike cascade ⊗ fragmentation

ISR and out born particles have $Q^2 \neq 0 \Rightarrow$ timelike cascade



Relevant processes :

$g \to c\bar{c}$ $\qquad$ $q \to q\gamma$

$c \to cg$

- Emissions at small angle $dP(z, Q^2) \propto \frac{\alpha}{2\pi} \frac{p(z)}{Q^2} \Delta(Q_0^2, Q^2) +$ **angular ordering**

EPOS : a "real" event generator

1 LHC event = 1 EPOS event

1. All kind of particles produced and registered in final tables
   - Not the case in Pythia (where one has to choose processes of interest) or Jetphox
2. We can (and have to) do the same experimental treatment for our final particles
   $\Rightarrow$ anti-kt for jets, isolation, background subtraction ...

$\Rightarrow$ **Ideal for comparison with experiments**

- *Remark : Even in that case, not easy to be sure that we are looking at exactly the same observable*

Outline

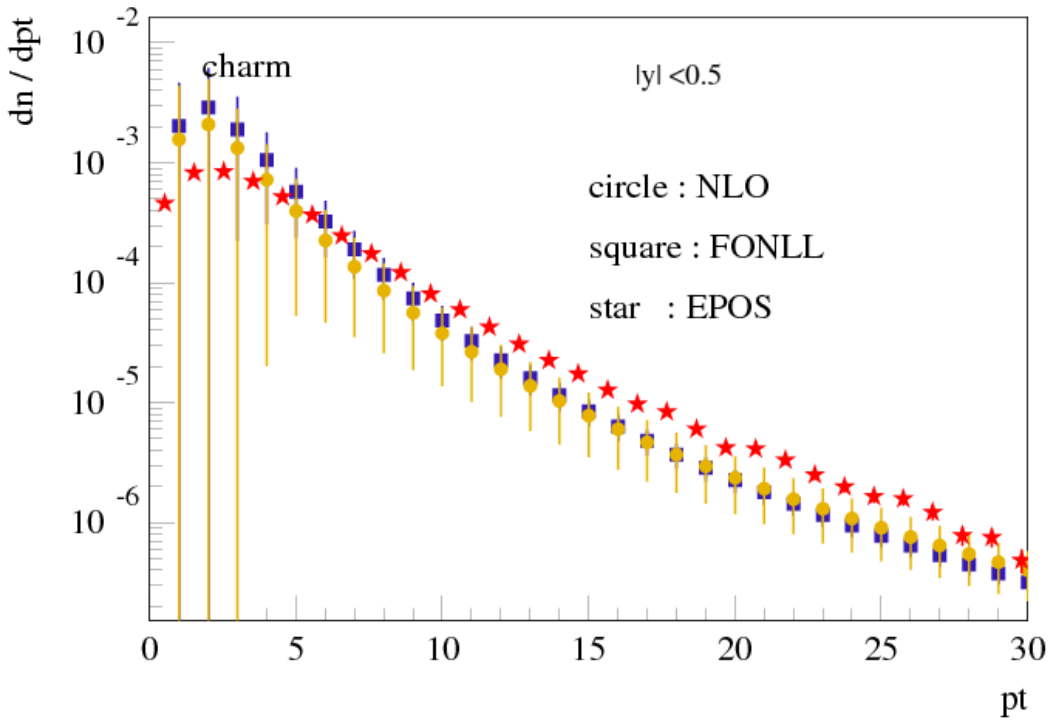
Goals

1. Test of charm implementation : Try to reproduce experimental results for D mesons
2. Later, charms could be used for the study of the QGP
   - R_{pA} , R_{AA}
   - Heavy quarks correlations $\rightarrow$ Information on energy loss mechanisms.

   $\Rightarrow$Project with J. Aichelin, P.B Gossiaux, K. Werner, M. Nahrgang and Vitalii Ozvenchuk.

Charm vs NLO and FONLL

- **A precise treatment of timelike cascade is essential for heavy quarks**



More splitting ≡ harder slope and more charms at low pt

Satisfying result but not enough splittings during timelike cascade

⇒ **Work in progress**

D mesons measurement

No additional or modified parameter for D mesons and photons

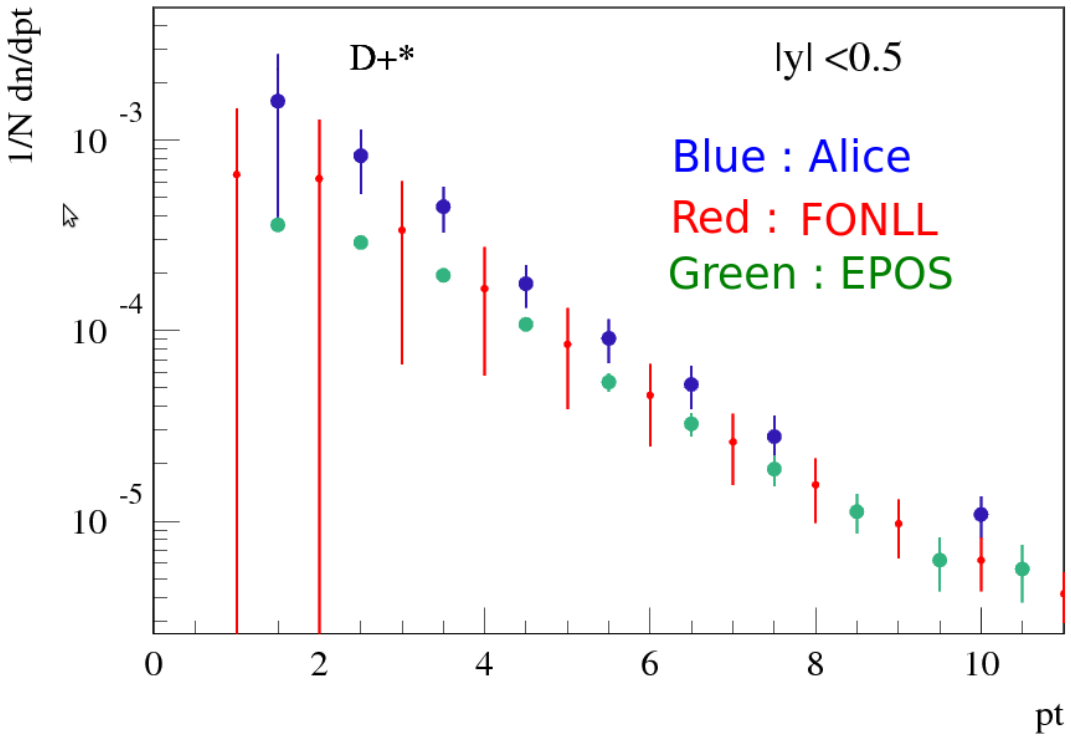
Alice collaboration 2012, arXiv 1312.1233. Measurement of :

- D^{+*}
- D^{+}= prompt D^{+} and decays from D^{+*}
- $D0$ = prompt $D0$ and decays from D^{+*} and $D0^{*}$

D^{*+} contributes to the $D0$ and D^{+} p_t spectrum. The spectrum of the D^{*+} need to be well reproduced

- *Rem : $\sum$ of D meson fractions > 1*

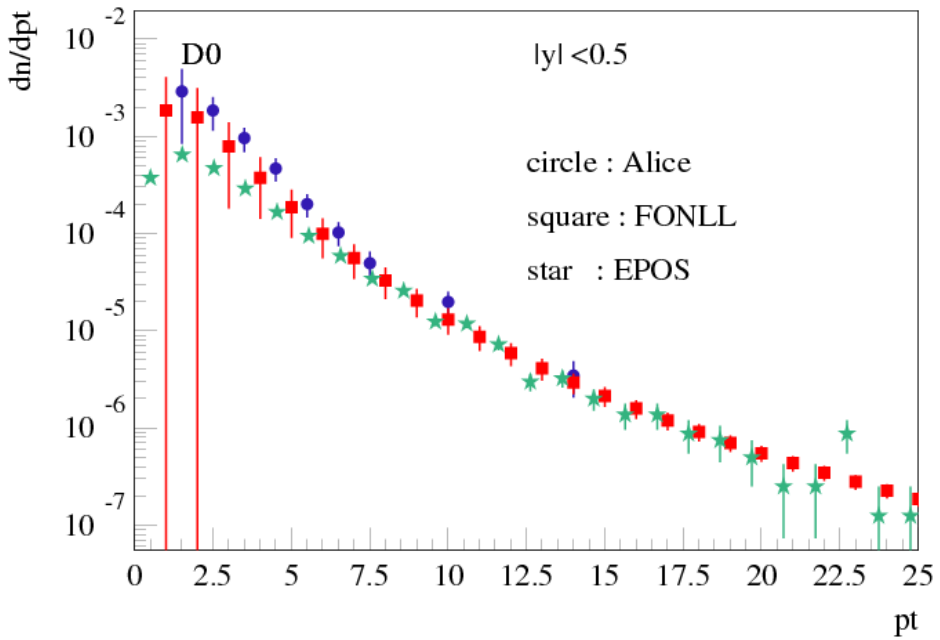
(unavoidable) D^{+*}

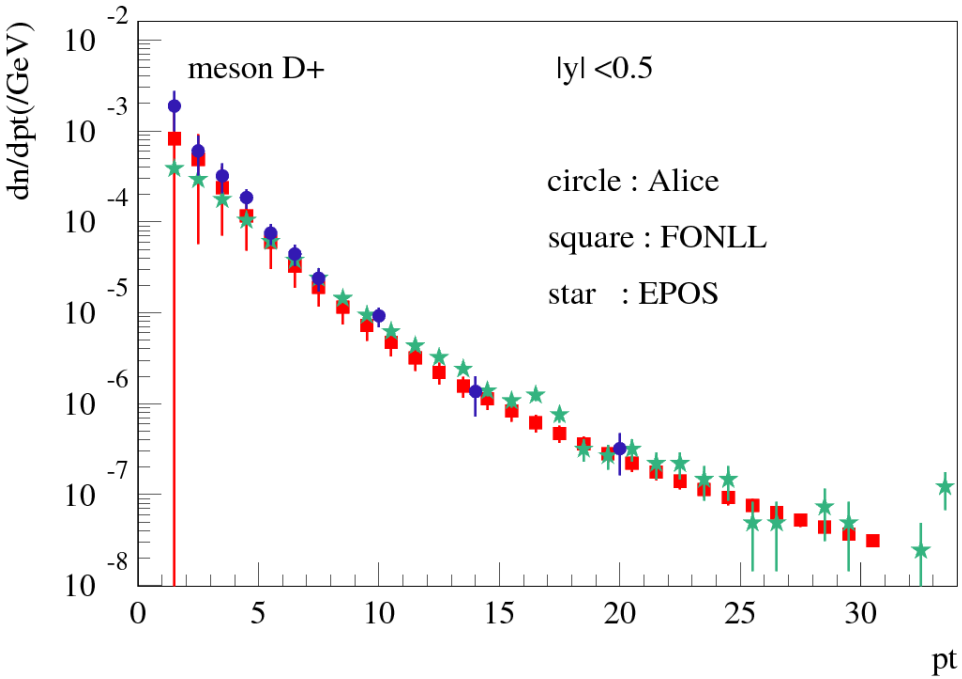


- IN agreement with FONLL and data, except at low pt
- $M_{charm} = 1.5$ GeV for both EPOS and FONLL

D0 and D+ mesons

- Good agreement with FONLL and ALICE data
- Not enough D mesons at low pt





www.lpthe.jussieu.fr/∼cacciari/fonll/fonllform.html
arXiv : 1111.1553v2, 2012

Outline

Goals

Some definitions (in pp collisions)

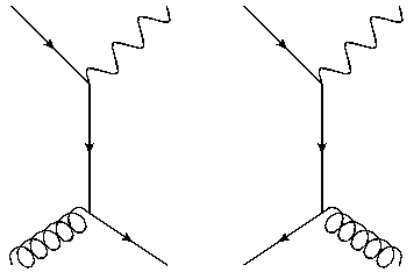
- Direct photon : produced during the born process
- fragmentation photon : produced in spacelike/timelike cascade
- prompt photon = Fragmentation + direct photons

- Test of γ implementation : Try to reproduce experimental
- Direct photons/charged particles correlations : provides an (approximate) measurement of quark fragmentation functions
  - Could be used for the study of the QGP

$\Rightarrow$ **Need to separate contributions from direct and fragmentation photon...**

Isolated photons

- Direct photons : produced at $\sim \pi$ of the rest of the matter



  - Fragmentation photons : produced at small angle during the final timelike cascade $\rightarrow$ surrounded by several particles

Isolation criteria :

1. Define a cone $R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$ around the photon
2. Isolated if $\sum p_t < p_t^{MAX}$ GeV, p_t : transverse momentum of particles in the cone

$\rightarrow$ **Strong suppression of fragmentation photons**

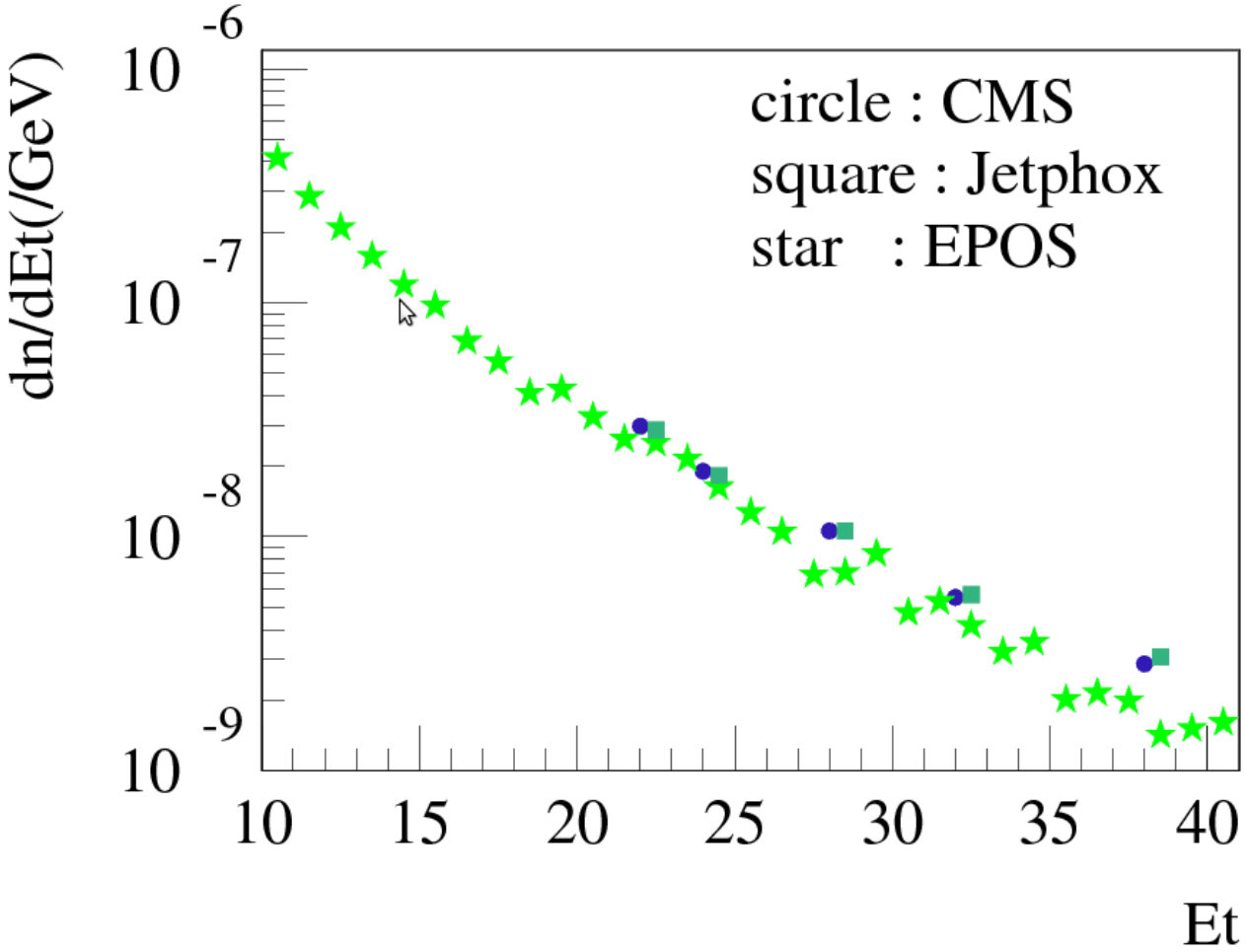
Implementation of isolated photons

- Isolation subroutine : like in experiments, we define a cone $R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$ around a triggered photon

Event generator with a complete particles production :

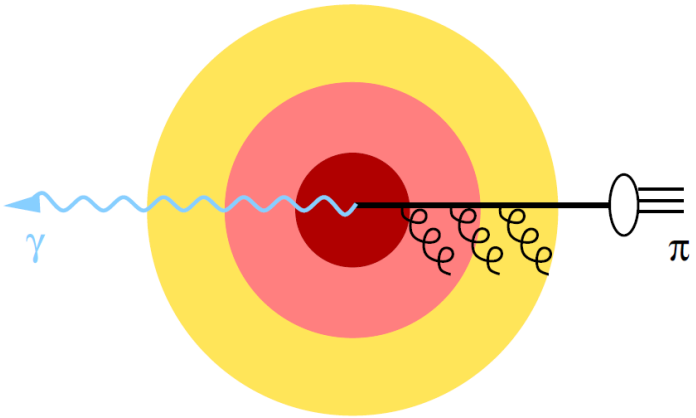
$\Rightarrow$ realistic isolation (In Jetphox done by calculation $\rightarrow$ non-physical effect)
$\Rightarrow$ Able to reproduce sophisticated observables

Isolated photon distribution



- In good agreement with Jetphox and CMS

Isolated photon/charged particle correlation : ALICE



Measurement :

Aim :

- $xe = -\frac{p_t{}^{asso}}{p_t^{trig}} \cos(\Delta\phi) \simeq$ quark fragmentation function
- Comparison of xe for pp and PbPb collisions

Isolation :

$R = 0.4$

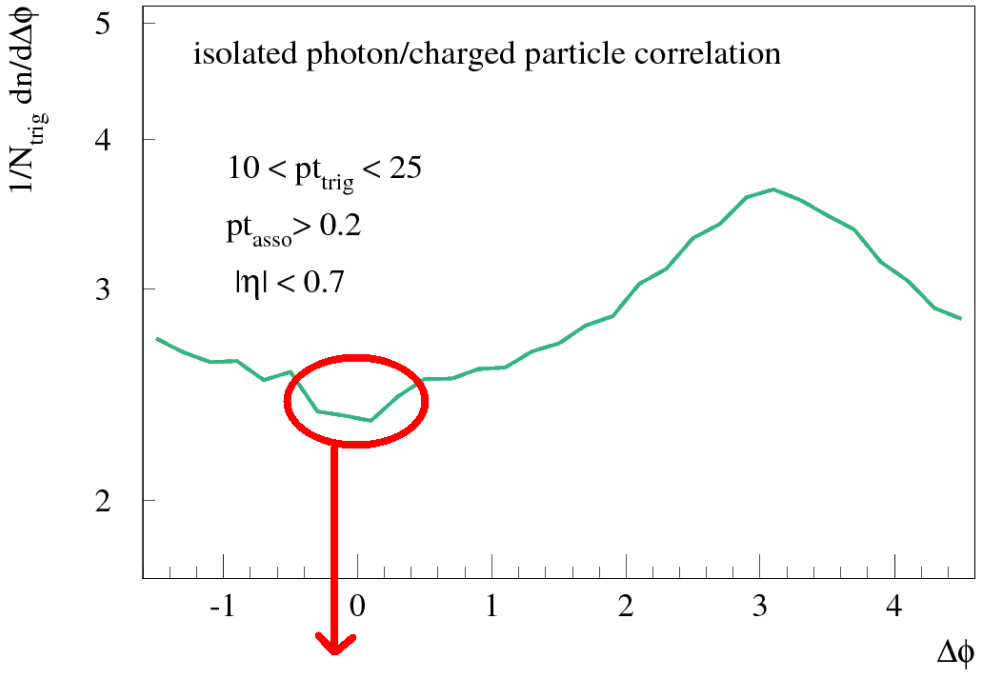
$\sum p_t > 1$ GeV

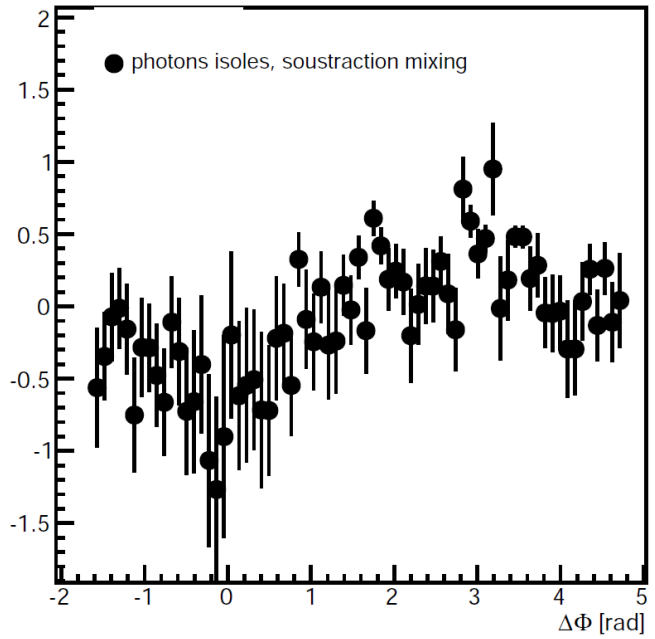
Additional criteria :

$p_t^{trig} \in [10, 25]$ + highest p_t of the event

$p_t^{asso} > 0.2$ GeV

Azimuthal correlations

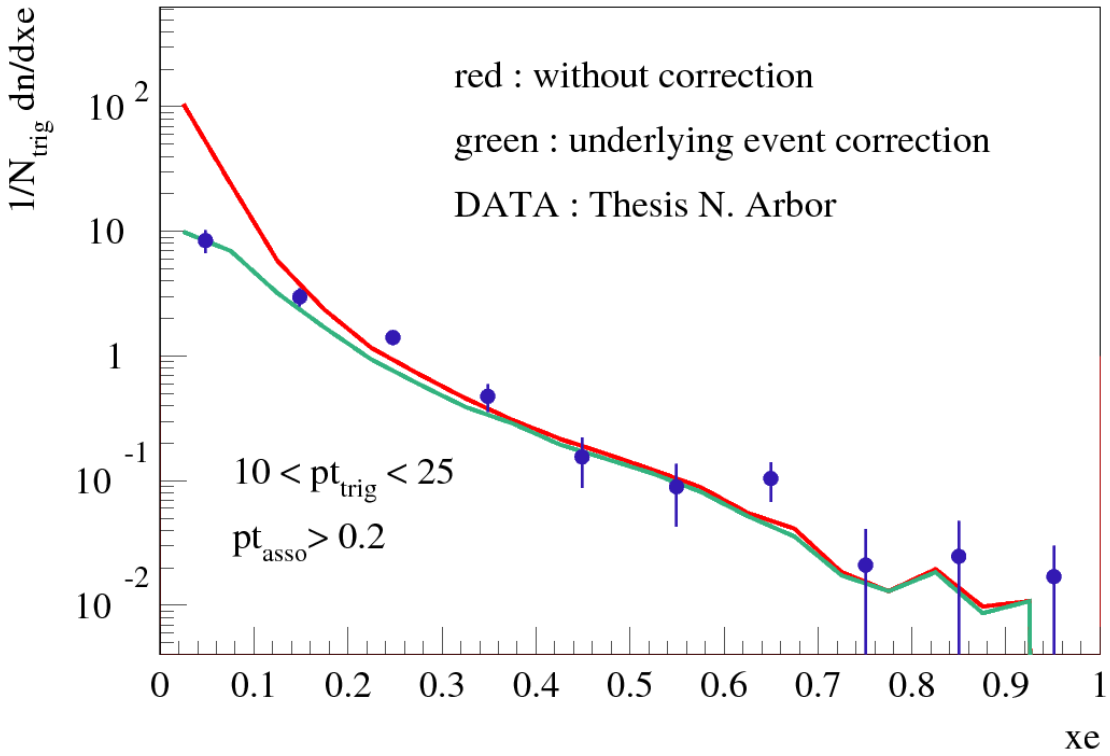




- "Anti-correlation" reproduced : less particles around the **isolated** photon
- The two plots are comparable

(*ref : thesis, N. Arbor, 2013*)

Xe Alice



- Regions for underlying event evaluation : $[\pi/3,2\pi/3]$ and $[4\pi/3,5\pi/3]$

(*ref : thesis, N. Arbor, 2013*)

Isolated photon/charged particle correlation : Phenix

Aim :

- Comparison of fragmentation functions in pp and AuAu collisions
- Evaluation of k_t effect (correction to the back to back picture)

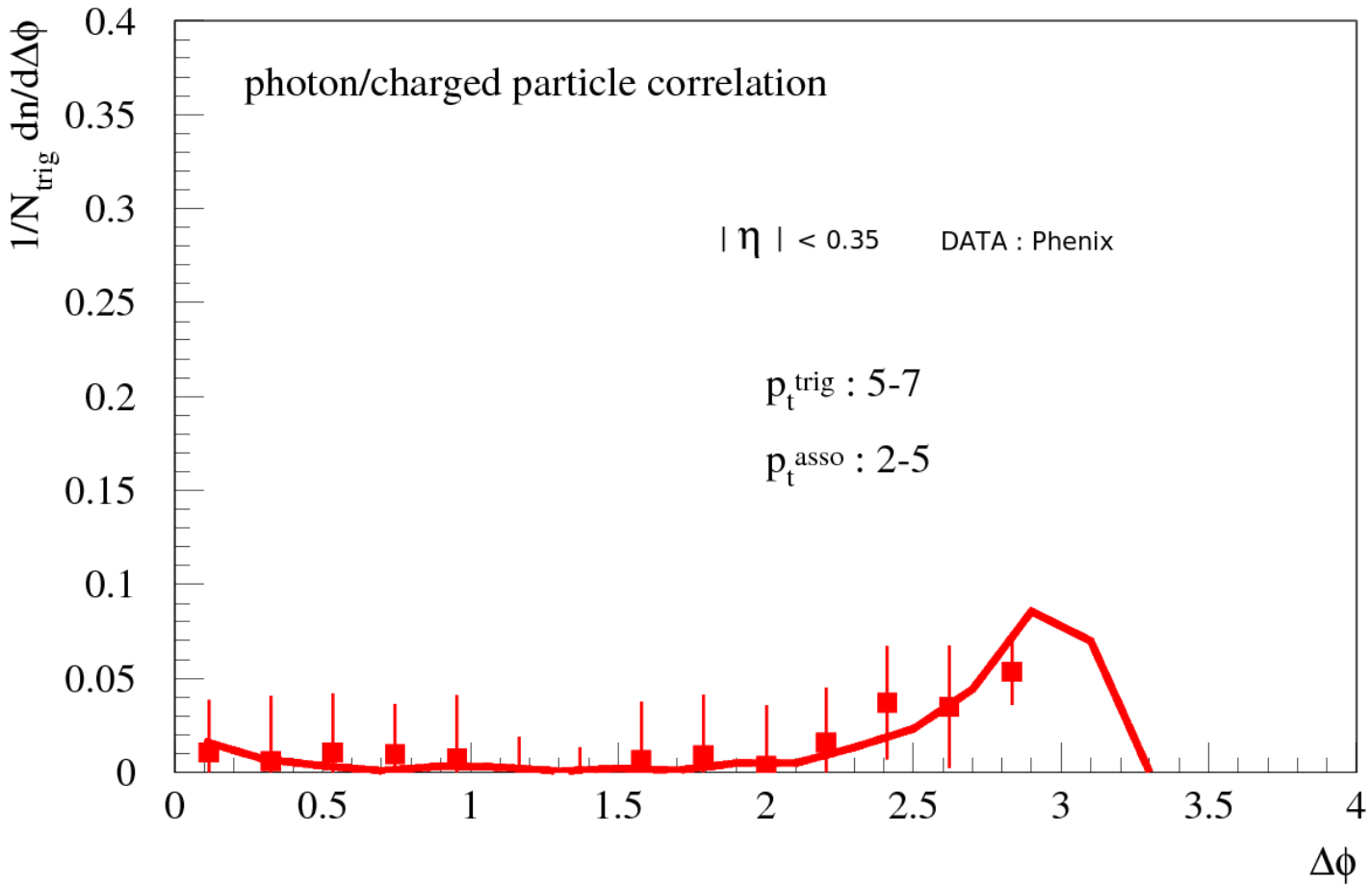
Isolation :

- $R = 0.3$
- $\sum E < 0.1 * E_{photon}$

Simulation with EPOS :

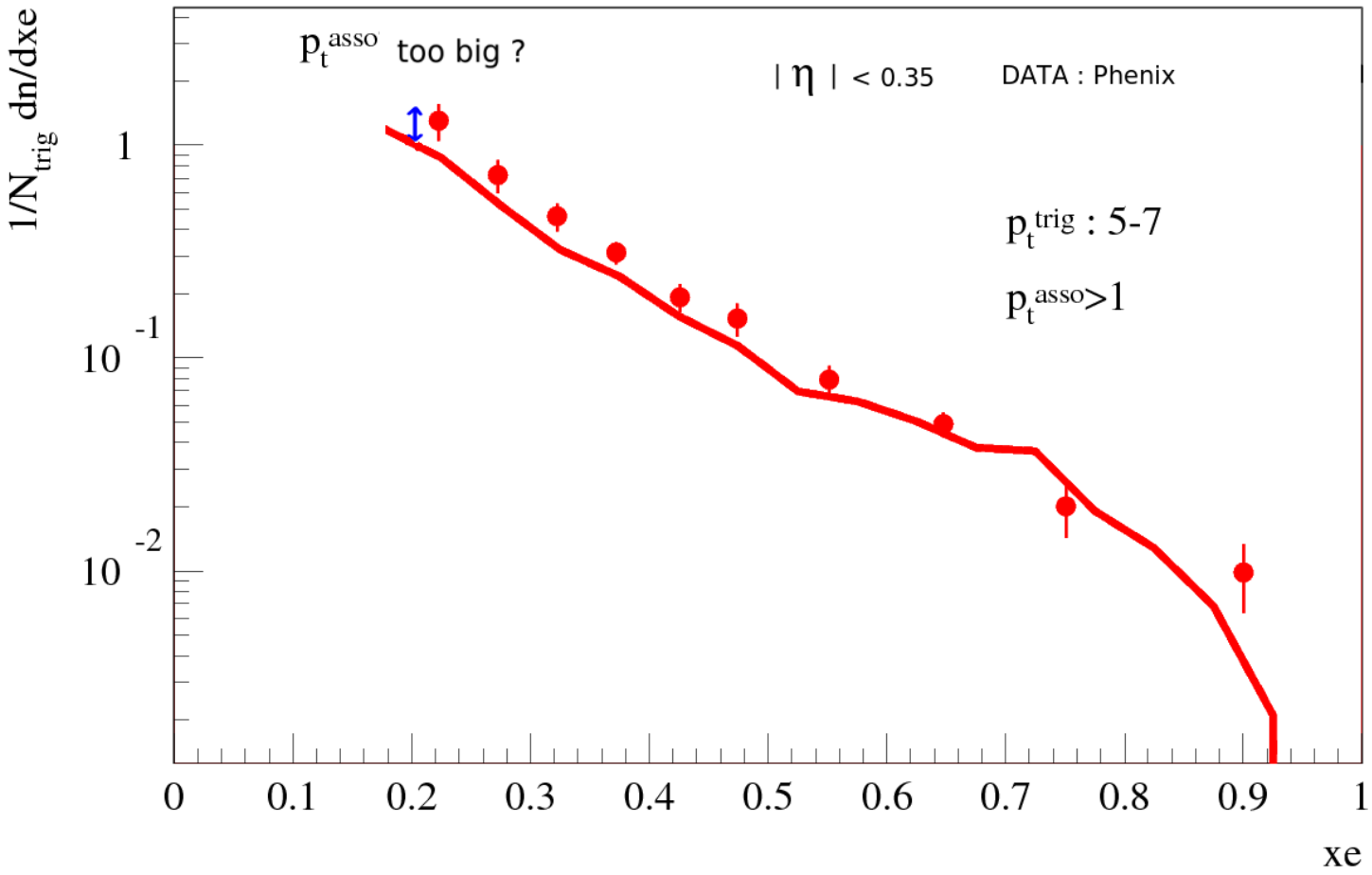
- Just try to reproduce data to test our model
- Could be interesting to look at fragmentation functions or k_t effect directly inside EPOS

Photon/charged particles correlation



- Done for $p_t^{trig} = [7,9]$, [9,12] and [12, 15] $\Rightarrow$ good agreement

Xe Phenix


p_t^{asso} too big ?
| η | < 0.35
DATA : Phenix
p_t^{trig} : 5-7
p_t^{asso}>1
$1/N_{trig}$ dn/dxe
1
10^{-1}
10^{-2}
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
xe

Summary

1. Good results for D mesons, except at low pt
   $\Rightarrow$ The partonic cascade need to be improved
2. pt spectra and correlations of photons with charged particles in good agreement with data
   - a "real" event generator makes comparison with experiments easier/possible

Hard probes could now be used for all kind of studies

- Outlook :
  - Implementation of new particles : bottom, J/ψ
  - Heavy quarks correlation (work in progress)

acknowledgment : projet together, Region des pays de la Loire

Study of isolation criteria