Hard probes in pp collisions and the event generator EPOS

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NeD/TURIC, 2014
Outline

1. Our project
2. Pomerons and hard probes production
3. Charms
4. Prompt photons
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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**
  ⇒ see Klaus’s talk

- **Missing ingredient : heavy flavors, prompt photons**
  ⇒ 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 → modification of fragmentation functions by the medium
- $\gamma$ 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
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Multiple scattering in EPOS

Multiple scattering: pQCD and Gribov-Regge theory + Saturation


2. Needed for theoretical reasons: \(\sigma_{tot}(s)\) violates the Froissart bound with just one interaction

- Multiple pomerons exchange:

\[
\text{Cut pomeron } \rightarrow \text{particles production}
\]

  - Multiplicity \(\propto\) # of cut pomerons
  - Hard probes \(\propto\) # of cut pomerons

Linear rise of hard probes with the multiplicity of charged particles

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D mesons vs multiplicity

D+ vs charged multiplicity
Data: ALICE
2< pt <4

D0 vs charged multiplicity
Data: ALICE
1< pt <2

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Hard probes production

**dissection of a pomeron:**

- **Soft evolution**
- **Hard evolution**
- ISR
- Born
- Nucleus

**Hard probes produced during:**
- Hard evolution
- Born process $= \sigma_{QCD}$ 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

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

**Relevant processes:**
- $g \rightarrow c\bar{c}$
- $q \rightarrow q\gamma$
- $c \rightarrow cg$

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
   ⇒ anti-kt for jets, isolation, background subtraction ...
   ⇒ Ideal for comparison with experiments

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

Satisfying result but not enough splittings during timelike cascade

⇒ Work in progress
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
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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

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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 $\gamma$ 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 $\sum p_t < p_t^{\text{MAX}}$ 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:**

⇒ realistic isolation (In Jetphox done by calculation → non-physical effect)
⇒ Able to reproduce sophisticated observables
Isolated photon distribution

\[ \frac{dn}{dEt}/(\text{GeV}) \]

-6
-7
-8
-9
10
20
30
40
Et

circle: CMS
square: Jetphox
star: EPOS

In good agreement with Jetphox and CMS

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Isolated photon/charged particle correlation: ALICE

**Aim:**
- \[ xe = - \frac{p_t^{asso}}{p_t^{trig}} \cos(\Delta \phi) \simeq \text{quark fragmentation function} \]
- Comparison of \( xe \) for pp and PbPb collisions

**Measurement:**

**Isolation:**
- \( R = 0.4 \)
- \( \sum p_t > 1 \text{ GeV} \)

**Additional criteria:**
- \( p_t^{trig} \in [10, 25] + \text{highest } p_t \text{ of the event} \)
- \( p_t^{asso} > 0.2 \text{ GeV} \)
Azimuthal correlations

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

(ref: thesis, N. Arbor, 2013)
Regions for underlying event evaluation: \([\pi/3, 2\pi/3]\) and \([4\pi/3, 5\pi/3]\)

\((ref: \text{thesis, N. Arbor, 2013})\)
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:
- $R = 0.3$
- $\sum E < 0.1 \times E_{\text{photon}}$

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
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Photon/charged particles correlation

\[ \frac{1}{N_{\text{trig}}} \frac{dN}{d\Delta \phi} \]

| \( \eta \) | < 0.35  
DATA : Phenix

\[ p_t^{\text{trig}} : 5-7 \]

\[ p_t^{\text{asso}} : 2-5 \]

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

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Xe Phenix

\[ \frac{1}{N_{\text{trig}}} \frac{dN}{dx} \]

- \( p_t^{\text{asso}} \) too big?
- \( |\eta| < 0.35 \)
- DATA: Phenix
- \( p_t^{\text{trig}} : 5-7 \)
- \( p_t^{\text{asso}} > 1 \)
Summary

1. Good results for D mesons, except at low pt
   ⇒ 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