Monte Carlos for pp Scattering:

An Overview

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with contributions from
T. Pierog, S. Ostapchenko, C. Bierlich, F. Riehn, P. Tribedy, A. Fedynitch.

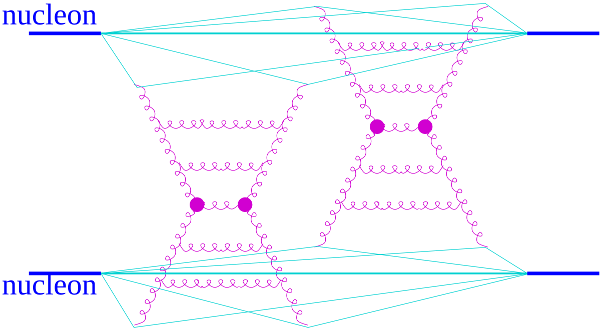
model	Gribov Regge	Dipole	Facto risation	authors
QGSJETII	X			Ostapchenko
EPOSLHC	X			Pierog, Werner
EPOS3	X			Werner, Pierog
DIPSY		X		Flensburg, Bierlich
IP-Glasma		X		Tribedy
SIBYLL			X	Engel, Riehn
DPMJETIII			X	Engel, Fedynitch
PYTHIA			X	
HERWIG			X	

To discuss: Intial state treatment / non-linear effects

Multiple scattering

Gribov-Regge multiple scattering approach

EPOS, QGSJETII



S-Matrix based on Pomerons

Pomerons :
Parton ladders (initial and final state radiation, DGLAP)

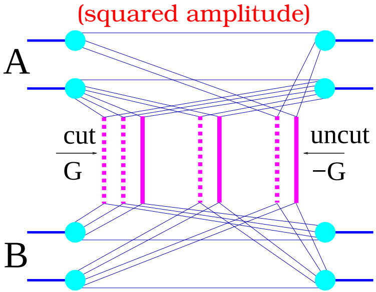
Cutting rules to get inelastic cross sections.

Same principle for AA

Explicite formulas for cross sections

(even partial cross sections)

$$\sigma^{\mathrm{tot}} = \underbrace{\sum_{\mathrm{cut\,P}} \int \sum_{\mathrm{uncut\,P}} \int}_{d\sigma_{\mathrm{exclusive}}}$$



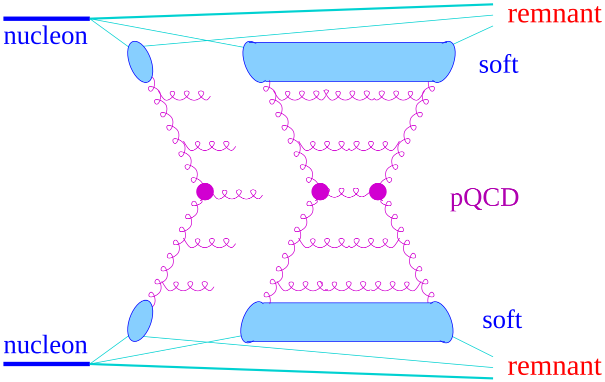
$d\sigma_{\mathrm{exclusive}}$

Soft evolution, remnants

EPOS, QGSJETII

Semihard Pomerons :
soft - pQCD - soft

Continuing evolution
into soft sector
=> large x Pomerons
(important for
forward physics)

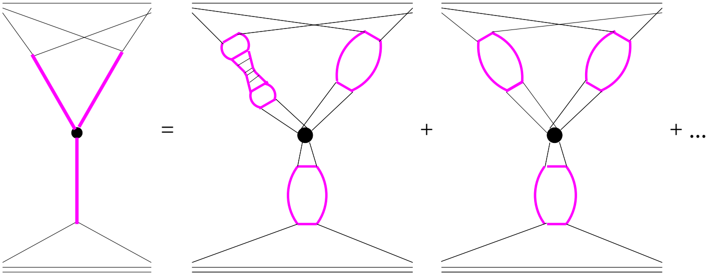


☐ Remnants ☐ Partonic final state => strings

☐ EPOS: high string density => core => hydro

Nonlinear effects in QGSJET

Pomeron-Pomeron coupling



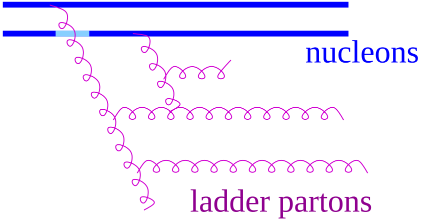
- ☐ Summing of **all orders**
- ☐ No energy conservation
- ☐ (in EPOS full energy conservation, but effective treatment of nonlinear effects)

Nonlinear effects in EPOS

Parton-ladders[1] are perfectly fitted[2] as $G = \alpha\,(x^+)^\beta (x^-)^\beta$.
G depends on the vituality cutoff: $G = G(Q_0)$.

To mimic the effects of gluon fusion, the fits are modified as $\alpha\,(x^+)^\beta (x^-)^{\beta+\varepsilon}$, referred to as G_{eff}.

The exponent $\varepsilon = \varepsilon(s)$ is chosen to reproduce the energy dependence of cross sections.



(1) Imaginary part G of the corresponding amplitude in $b-$space
(2) x^+, x^-: light cone momentum fractions of the Pomeron end

Adding an exponent ε

- □ **must be accompanied by a corresponding modification of the internal structure of the Pomeron**

This can be done by defining a **saturation scale Q_s** via

$$G_{\text{eff}} = kG(Q_s)$$

and then considering the parton ladder with the cutoff Q_s (thus changing the internal structure! => consistent!)

We find (with $x = x^+x^-$ being the energy fraction of the Pomeron)

$$Q_s = Q_s(x) \propto x^{0.30}$$

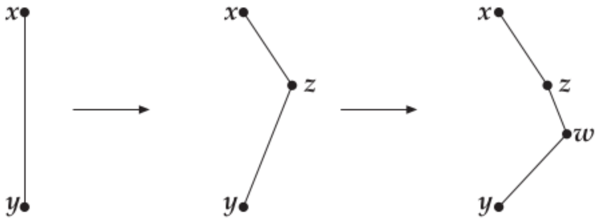
Dipole approach

Initial state radiation in DIPSY (from Christian Bierlich)

Initial nucleon: Three dipoles

LL BFKL in b-space + corrections: A dipole $(\vec{x},\vec{y})$ can emit a gluon at position $\vec{z}$ with probability (P) per unit rapidity (Y)

$$\frac{dP}{dY} = \frac{\bar{\alpha}}{2\pi} d^2\vec{z} \frac{(\vec{x}-\vec{y})^2}{(\vec{x}-\vec{z})^2(\vec{z}-\vec{y})^2}$$

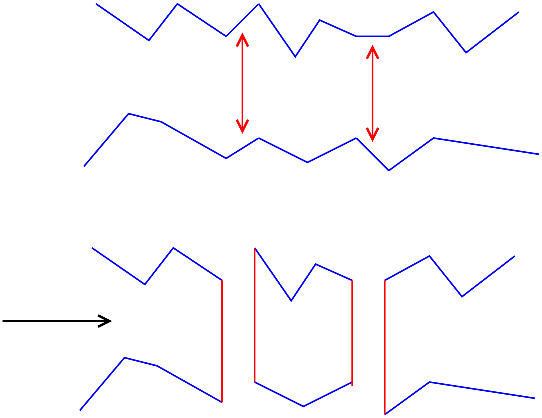


Multiple scattering

Multiple color exchange
between dipoles i and j
with probabilities

$$\frac{\alpha_s^2}{4}\left[\log\left(\frac{(\vec{x}_i-\vec{y}_j)^2(\vec{y}_i-\vec{x}_j)^2}{(\vec{x}_i-\vec{x}_j)^2(\vec{y}_i-\vec{y}_j)^2}\right)\right]^2$$

-> kinky strings



☐ **Two “leading“ strings**

☐ **Additional strings from loops**

☐ **No Remnants**

Many strings:
Lund strings may overlap

=> color ropes
(Larger eff. string tension)

Initial state in IP-Glasma (from Prithwish Tribedy)

IP-Sat dipole model ($r_\perp$ =dipole size):

$$\frac{d\sigma}{d^2b} = 2\left[1 - \exp\left(-F(r_\perp, x, b\right)\right], \; F \propto r_\perp^2 \alpha_s(\mu^2) xg(x, \mu^2) T(b)$$

$T(b)$: Gaussian profile, $\mu^2 = 4/r_\perp^2 + \mu_0^2$, xg : DGLAP evolution

Saturation scale Q_s defined via

$$F\left(r_\perp, x = \frac{2}{Q_s^2}, b\right) = \frac{1}{2}$$

IP-Glasma: Color charge squared for projectile A and target B :

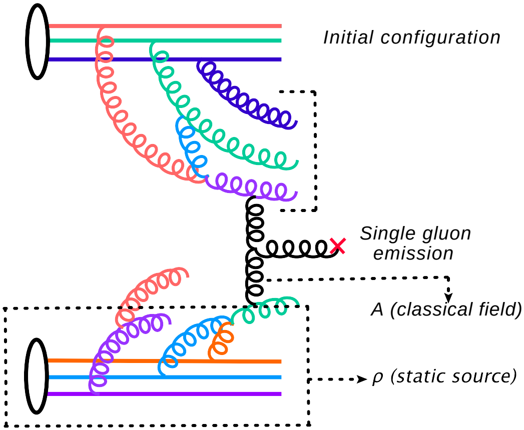
$g^2\mu_A^2 = \sum_{nucleons} g^2\mu_i^2$, with $g^2\mu_i^2 \propto Q_s^2$ with Q_s^2 from IP-Sat model.

Multiple Scattering

Color charge density $\rho_{A/B}$
generated from Gaussian distribution with variance $g^2\mu_A^2$ (contains DGLAP, saturation)

Current
$J^\nu = \delta^{\nu\pm}\rho_{A/B}(x^\mp, x_\perp)$

Field from $[D_\mu, F_{\mu\nu}] = J_\nu$
Numerical (lattice) solution, fields can be expressed in terms of initial ones:
$A^i = A^i_A + A^i_B,\ A^\eta = \frac{ig}{2}[A^i_A, A^i_B]$

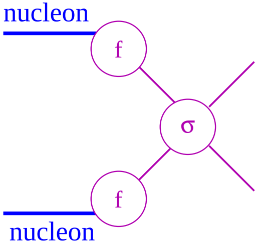


Multiple scattering:
Nonlinearity in terms of A:
Infinite number of $g + g \to g$ processes

Fields→Gluons→Pythia strings

Models based on factorization

$$\sigma_{\rm jet} = \int dx_1 dx_2 \int dp_t^2 \sum f_i(x_1, p_t^2)\, f_j(x_2, p_t^2)\, \frac{d\sigma_{ij}}{dp_t^2}(\hat{s}, \hat{t}) \qquad (1)$$



PYTHIA (->P.Ilten)

HERWIG (->P.Ilten)

SIBYLL

DPMJETIII

First step: Generation of partons according to (1)

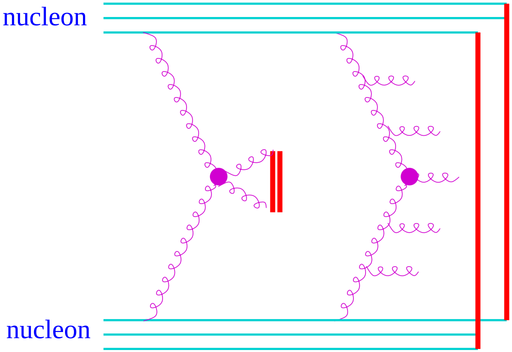
Second step: Multiple scattering scheme via eikonal formula

$$prob(n) = \frac{[\sigma_{\rm jet}(s)\, T(s,b)]^n}{n!} \exp\left(-\sigma_{\rm jet}(s)\, T(s,b)\right)$$

Multiple scattering in SIBYLL

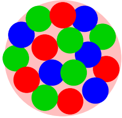
From F. Riehn

Multiple scattering via eikonal model with soft and hard component



- ☐ No Remnants
- ☐ Main scattering
  => qq-q strings
- ☐ Further scatterings
  => strings between gluon pairs

Saturation scale from



$$\frac{\alpha_s N_c}{Q^2} \times \frac{1}{N_c^2-1}\,\frac{xG}{\pi R^2} = 1$$

Some results

DIPSY, EPOS LHC

(not presented here)

Plots provided by from Christian Bierlich and Tanguy Pierog

EPOS Versions
(from Tanguy Pierog)

EPOS 1.99 (public 2009)

- ☐ Tuned to fit data up to Tevatron
- ☐ Effective flow, parametrized using SPS and RHIC data

EPOS LHC (public 2012)

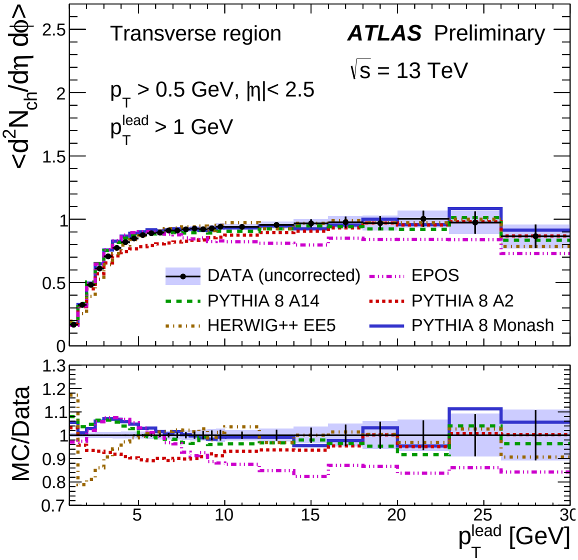
- ☐ Tuned to fit pp and pA data up to early LHC data
- ☐ Effective flow, parametrized using LHC data

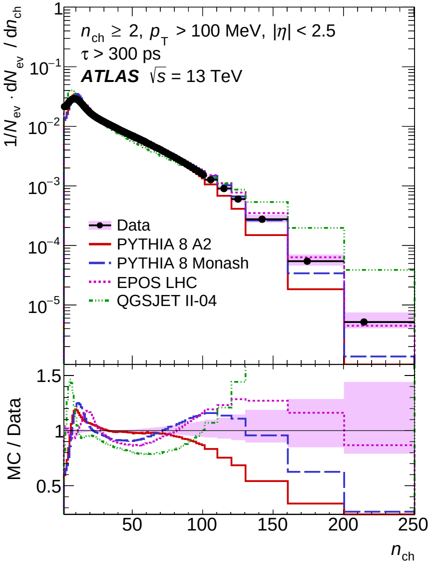
EPOS 2.x (semi-public)

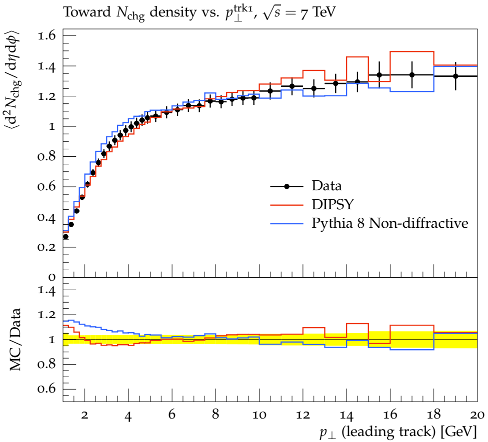
- ☐ True 3D+1 ideal hydro + hadronic cascade (heavy ions)

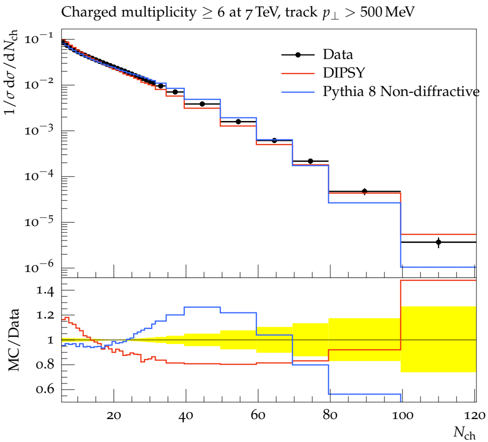
EPOS 3.x (to be public 2017 ...)

- ☐ All data from LHC run 1 (incl. diffraction, UE, ...)
- ☐ True 3D+1 viscous hydro (slow) OR (fast) effective flow treatment, new saturation treatment (HM pp, pA and AA)

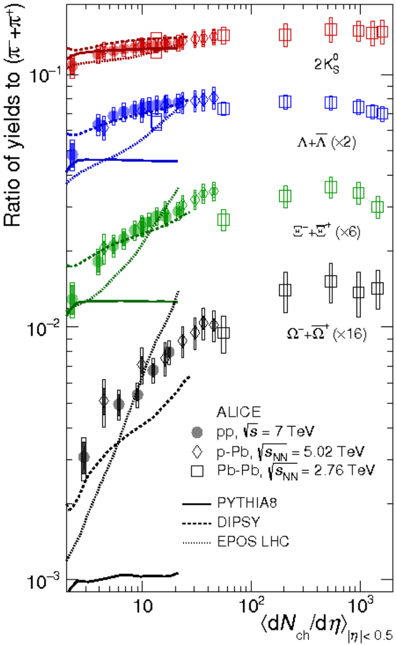

Transverse region
ATLAS Preliminary
√s = 13 TeV
p_T > 0.5 GeV, |η|< 2.5
p_T^lead > 1 GeV
<d²N_ch/dη dϕ>
DATA (uncorrected)
EPOS
PYTHIA 8 A14
PYTHIA 8 A2
HERWIG++ EE5
PYTHIA 8 Monash
MC/Data
p_T^lead [GeV]


n_ch ≥ 2, p_T > 100 MeV, |η| < 2.5
τ > 300 ps
ATLAS √s = 13 TeV
1/N_ev · dN_ev / dn_ch
Data
PYTHIA 8 A2
PYTHIA 8 Monash
EPOS LHC
QGSJET II-04
MC / Data
n_ch





Data by ATLAS, many more comparisons at `http://home.thep.lu.se/DIPSY`



Ratio of yields to $(\pi^- + \pi^+)$
10^{-1}
10^{-2}
10^{-3}
$2K^0_S$
$\Lambda + \bar{\Lambda}$ (×2)
$\Xi^- + \bar{\Xi}^+$ (×6)
$\Omega^- + \bar{\Omega}^+$ (×16)
ALICE
pp, $\sqrt{s}$ = 7 TeV
p-Pb, $\sqrt{s_{NN}}$ = 5.02 TeV
Pb-Pb, $\sqrt{s_{NN}}$ = 2.76 TeV
PYTHIA8
DIPSY
EPOS LHC
10
10^2
10^3
$\langle dN_{ch}/d\eta \rangle_{|\eta|<0.5}$