Space-time model for colour reconnection

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in collaboration with
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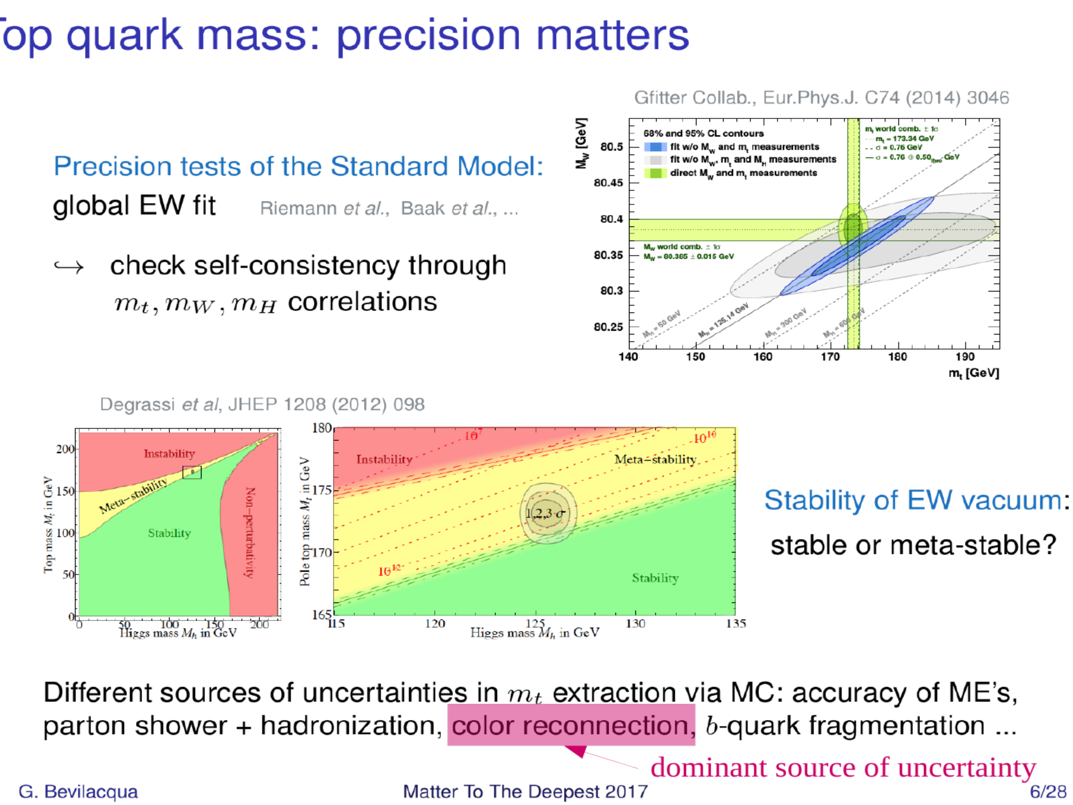
Outline

1. Introduction and motivation
2. Basic building blocks of MPI in Herwig
3. MPI and Parton Shower space-time models
4. Preliminary results
5. Summary and outlook

Motivation

- Non perturbative effects like colour reconnection start to be important source of uncertainties in precise LHC measurements (for example top mass).

e.g.
S. Argyropoulos , T. Sjöstrand,
Effects of color reconnection on $t\bar{t}$
final states at the LHC
JHEP 1411 (2014) 043



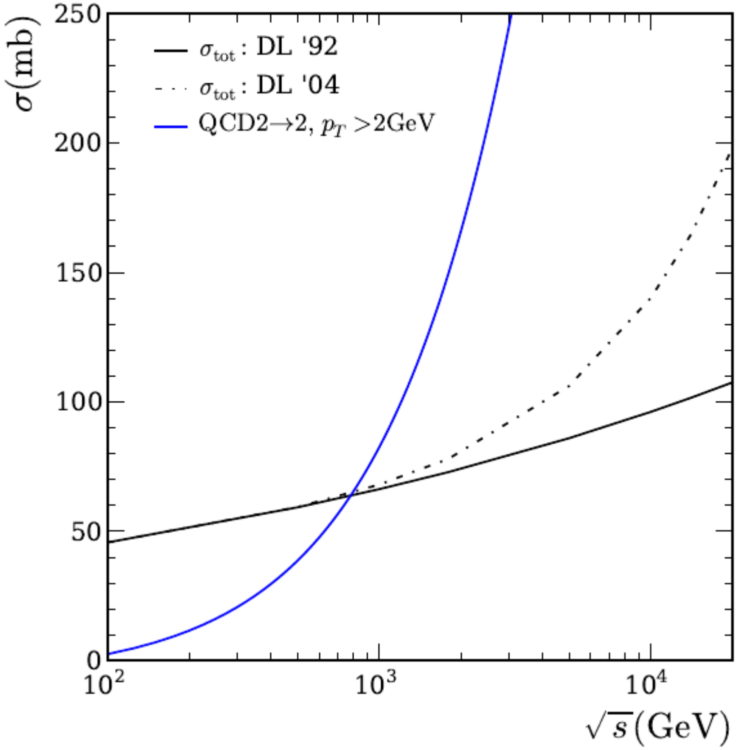
- Our aim is to introduce the space-time picture in Herwig 7

- notice a similar effort in Pythia [S. Ferreres-Solé, T. Sjöstrand, **Eur.Phys.J. C78 (2018) no.11, 983**]

Basic building blocks of MPI in Herwig

Inclusive hard jet cross section in pQCD:

$$\sigma^{\mathrm{inc}}(s, p_t^{\min}) = \sum_{i,j} \int_{p_t^{\min 2}} \mathrm{d}p_t^2 \int \mathrm{d}x_1 \mathrm{d}x_2 \; f_i(x_1, Q^2)\, f_j(x_2, Q^2) \; \frac{\mathrm{d}\hat{\sigma}_{ij}}{\mathrm{d}p_t^2}$$



$\sigma^{\mathrm{inc}} > \sigma_{\mathrm{tot}}$ eventually

Interpretation:

- σ^{inc} counts all partonic scatters in a single *pp* collision
- more than a single interaction

$$\sigma^{\mathrm{inc}} = \langle n_{\mathrm{dijets}} \rangle \sigma_{\mathrm{inel}}$$

Basic building blocks of MPI in Herwig

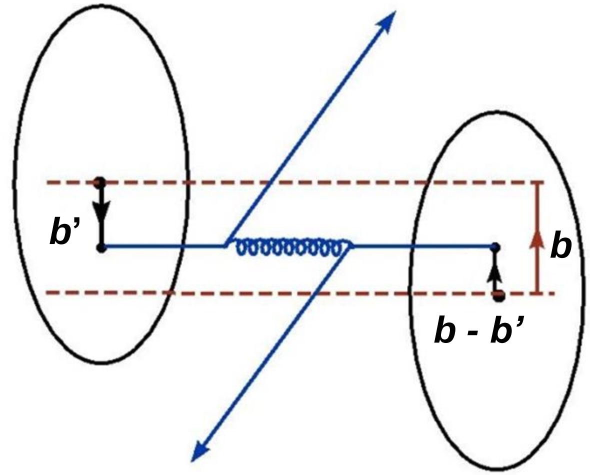
Assumptions:

- the distribution of partons in hadrons factorizes with respect to the b and x dependence ⇒ average number of parton collisions:

$$
\begin{aligned}
\bar{n}(\vec{b},s) &= L_{\text{partons}}(x_1,x_2,\vec{b}) \otimes \sum_{ij} \int \mathrm{d}p_t^2 \frac{\mathrm{d}\hat{\sigma}_{ij}}{\mathrm{d}p_t^2} \\
&= \sum_{ij} \frac{1}{1+\delta_{ij}} \int \mathrm{d}x_1 \mathrm{d}x_2 \int \mathrm{d}^2\vec{b}' \int \mathrm{d}p_t^2 \frac{\mathrm{d}\hat{\sigma}_{ij}}{\mathrm{d}p_t^2} \\
&\quad \times D_{i/A}(x_1,p_t^2,|\vec{b}'|) D_{j/B}(x_2,p_t^2,|\vec{b}-\vec{b}'|) \\
&= \sum_{ij} \frac{1}{1+\delta_{ij}} \int \mathrm{d}x_1 \mathrm{d}x_2 \int \mathrm{d}^2\vec{b}' \int \mathrm{d}p_t^2 \frac{\mathrm{d}\hat{\sigma}_{ij}}{\mathrm{d}p_t^2} \\
&\quad \times f_{i/A}(x_1,p_t^2) G_A(|\vec{b}'|) f_{j/B}(x_2,p_t^2) G_B(|\vec{b}-\vec{b}'|) \\
&= A(\vec{b})\sigma^{\text{inc}}(s;p_t^{\text{min}}) \; .
\end{aligned}
$$

- at fixed impact parameter b, individual scatterings are independent (leads to the Poisson distribution)

Basic building blocks of MPI in Herwig



From assumptions:

- independent scatters at fixed impact parameter ***b***
- factorization of ***b*** and ***x*** dependence

$$\langle n(b,s)\rangle = A(b)\sigma^{inc}(s)$$

where ***A(b)*** is partonic **overlap function** of the colliding hadrons

$$\sigma_{\text{eff}} = \frac{28\pi}{\mu^2}$$

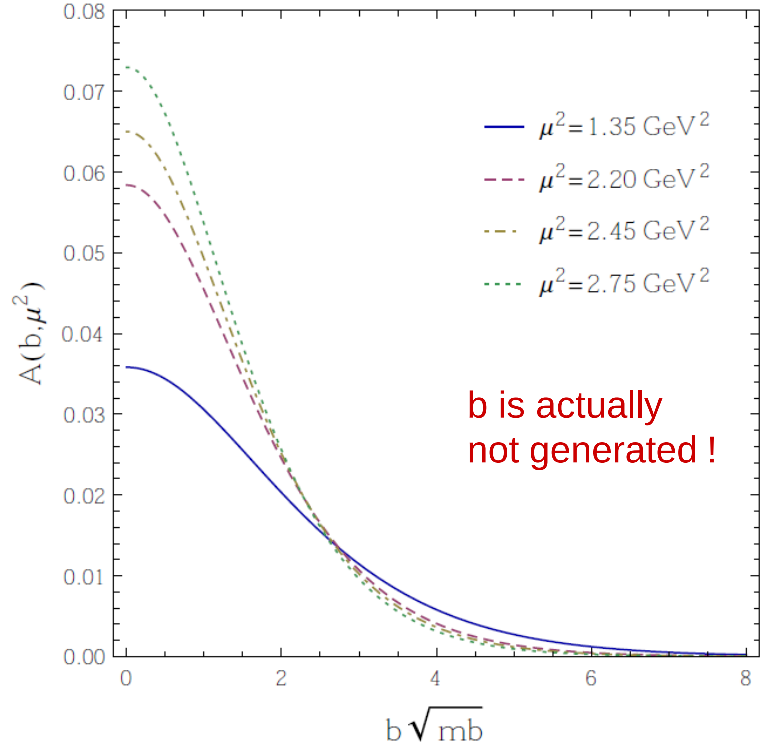
$$A(\vec{b}) = \int d^2\vec{b'} g(\vec{b'}) g(\vec{b}-\vec{b'})$$

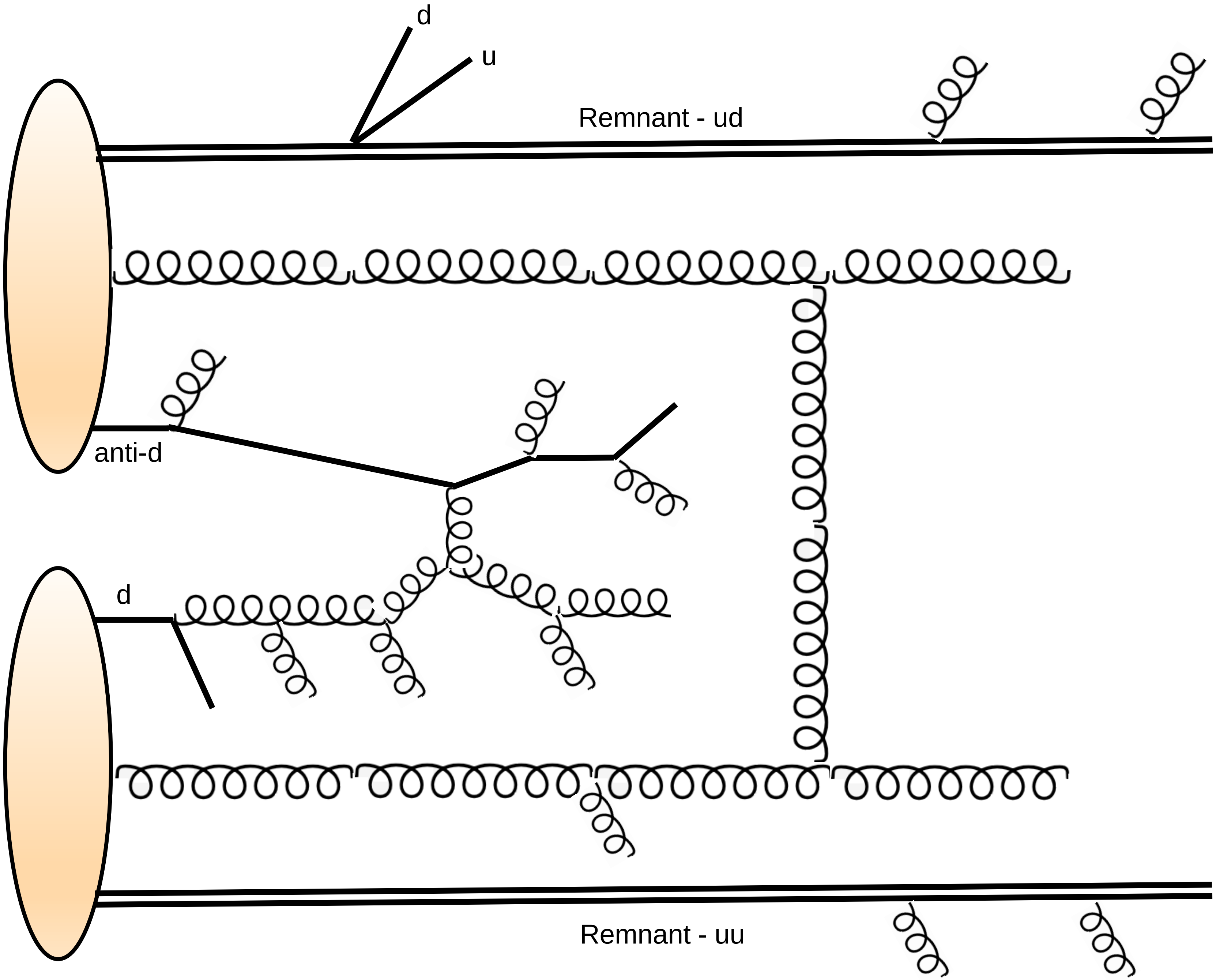
with ***g(b')*** being EM FF

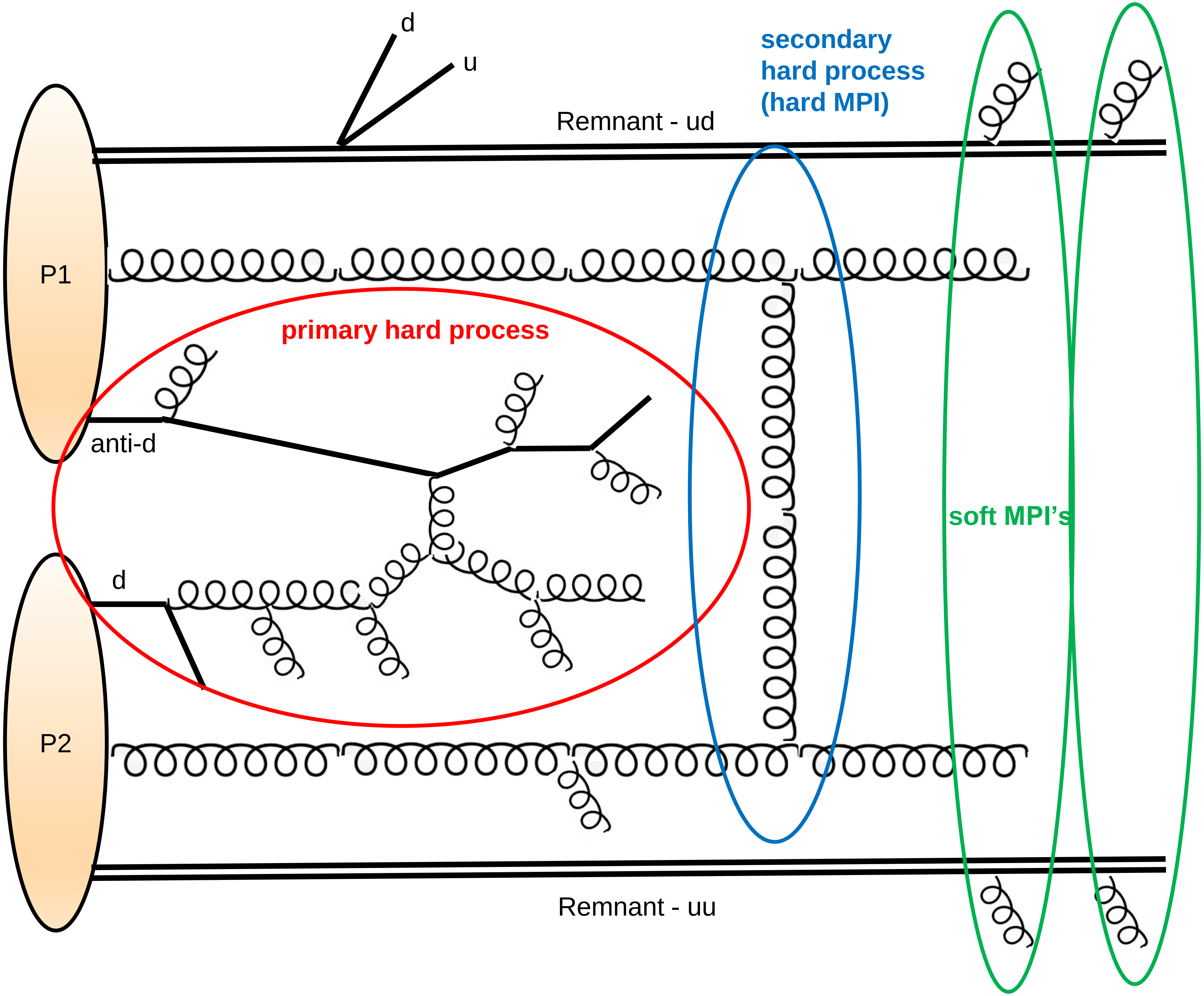
$$g(\vec{b'}) = \frac{1}{(2\pi)^2}\int d^2\vec{k}\frac{e^{i\vec{k}\vec{b'}}}{\left(1+\frac{|\vec{k}|^2}{\mu^2}\right)^2}$$

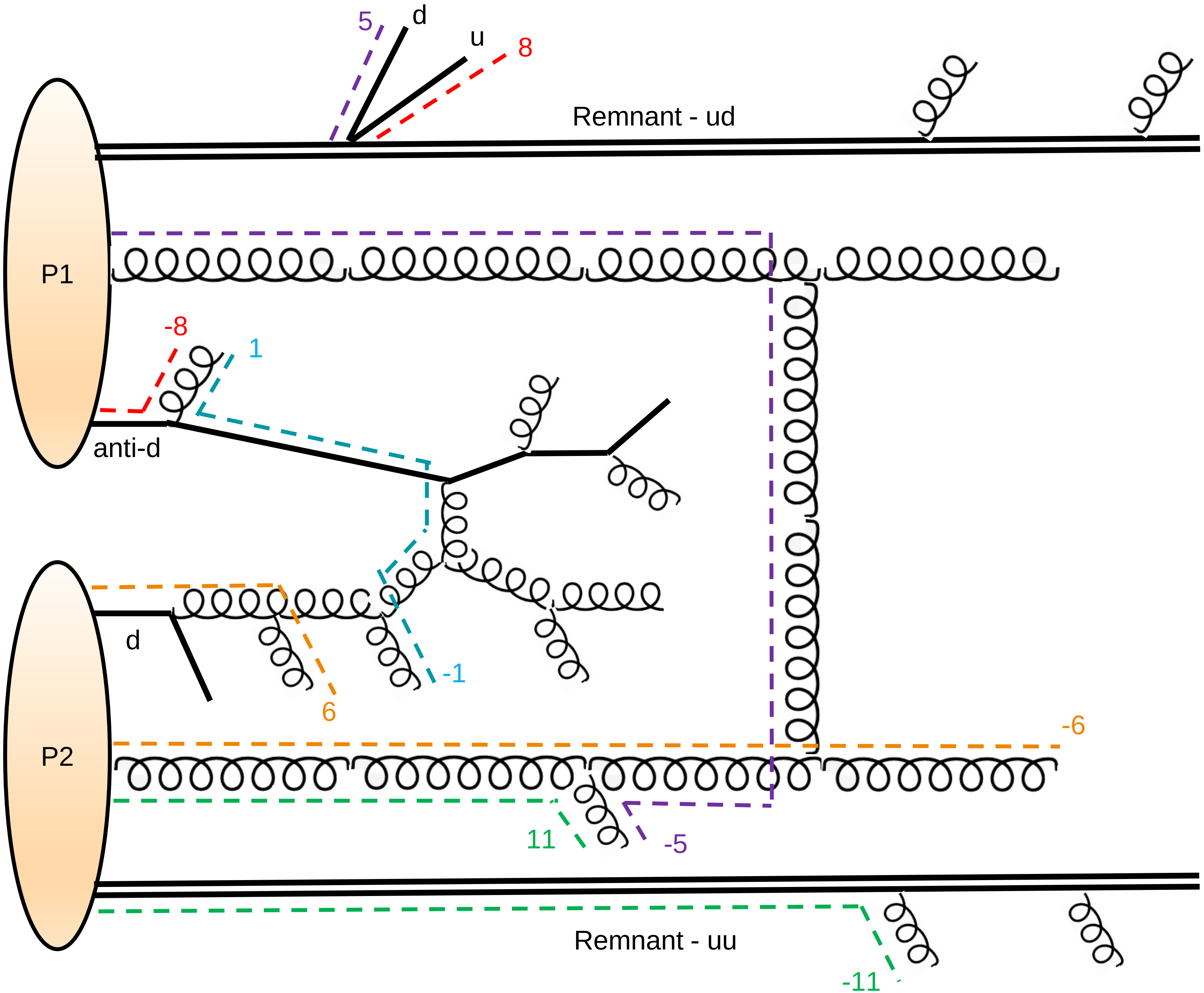
and ***μ*** as a free parameter
(i.e. not fixed at EM value of 0.71 GeV^2)

=> two main parameters ***μ***, ***p_t^{min}***




d
u
Remnant - ud
anti-d
d
Remnant - uu


d
u
Remnant - ud
secondary
hard process
(hard MPI)
P1
primary hard process
anti-d
d
P2
soft MPI's
Remnant - uu


5
d
u
8
Remnant - ud
P1
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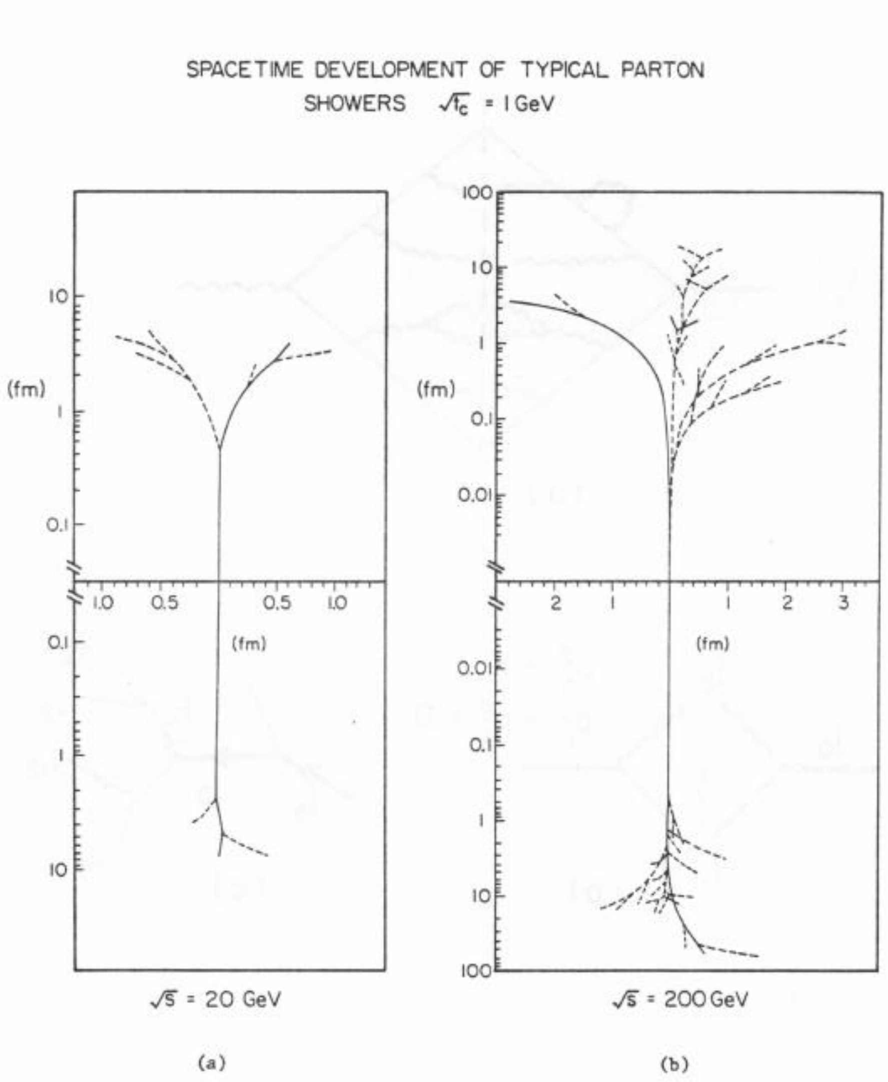
anti-d
P2
d
6
-1
-6
11
-5
Remnant - uu
-11

Space-time Model - shower



G. C. Fox, S. Wolfram,
A Model for Parton Showers in QCD
Nucl. Phys. B168 (1980) 285

Herwig7:

- fortranHerwig-like algorithm

G. Corcella et al., JHEP 0101 (2001) 010, chapter 3.8

- **Mean lifetime**
  virtuality dependence - interpolation between on-shell and high virtuality

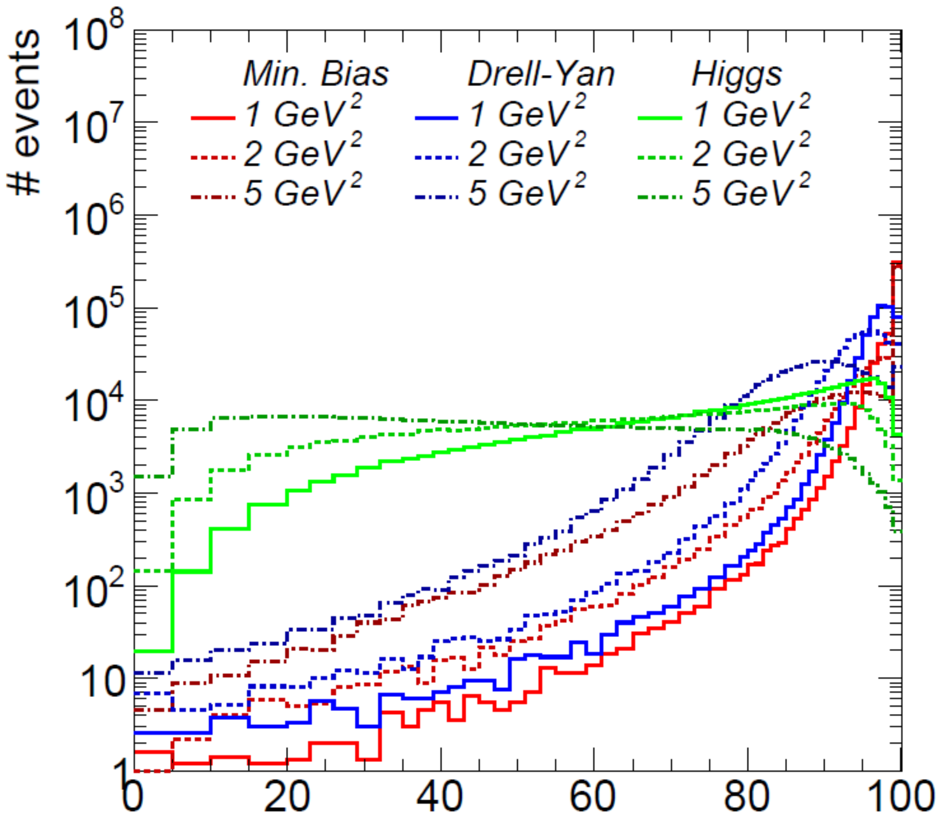
$$\tau(q^2) = \frac{\hbar\sqrt{q^2}}{\sqrt{(q^2 - M^2)^2 + (\Gamma q^2/M)^2}}$$

- **Distance travelled for proper lifetime *d***

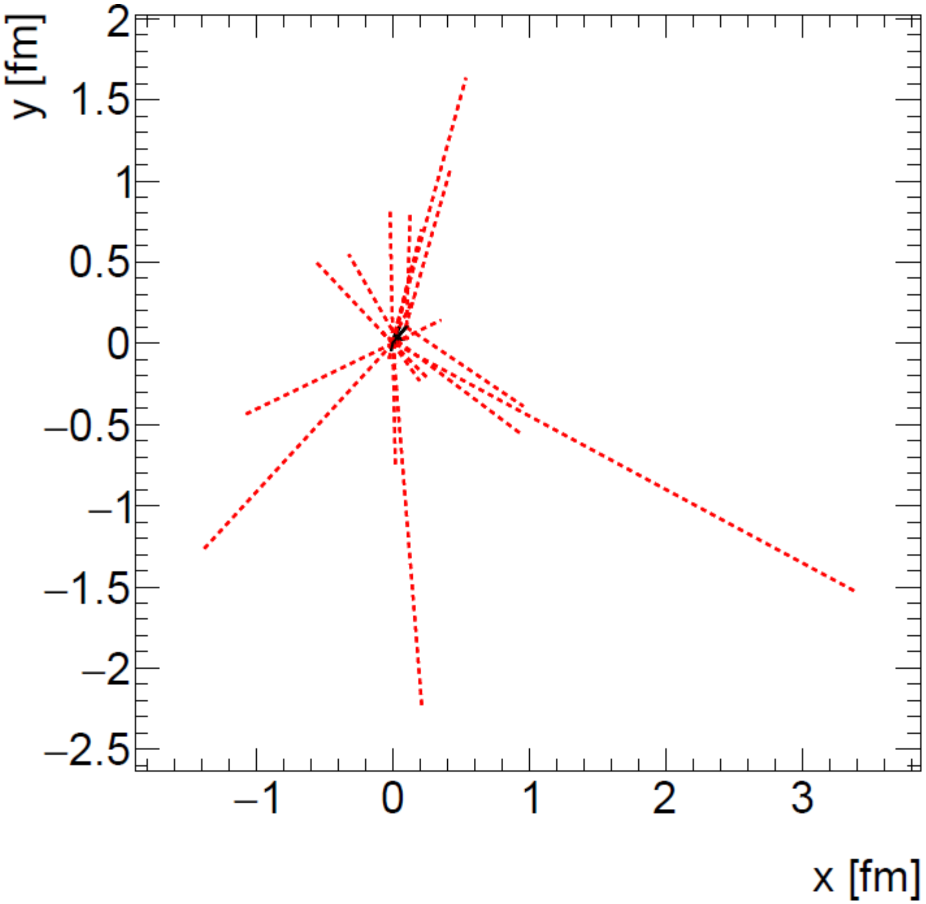
$$\mathrm{Prob}(\text{proper time} > t^*) = \exp(-t^*/\tau)$$

$$t = \gamma t^*, \boldsymbol{d} = \boldsymbol{\beta}\gamma t^*$$

Space-time Model - shower

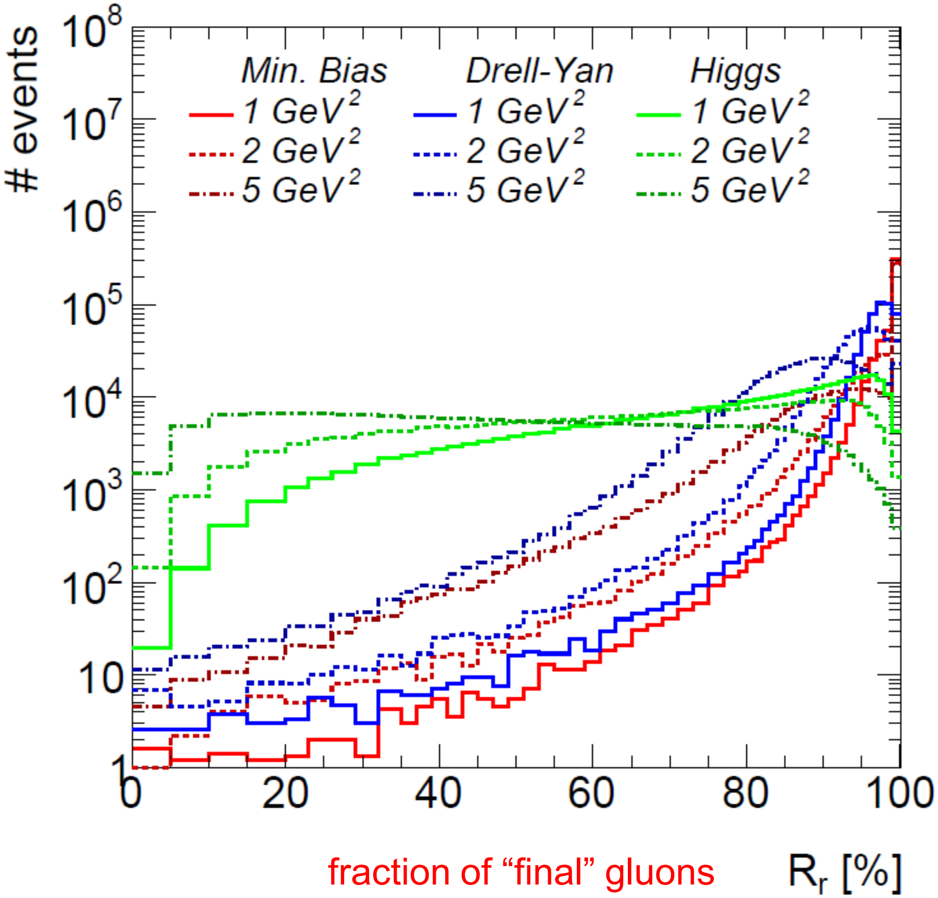


fraction of “final” gluons

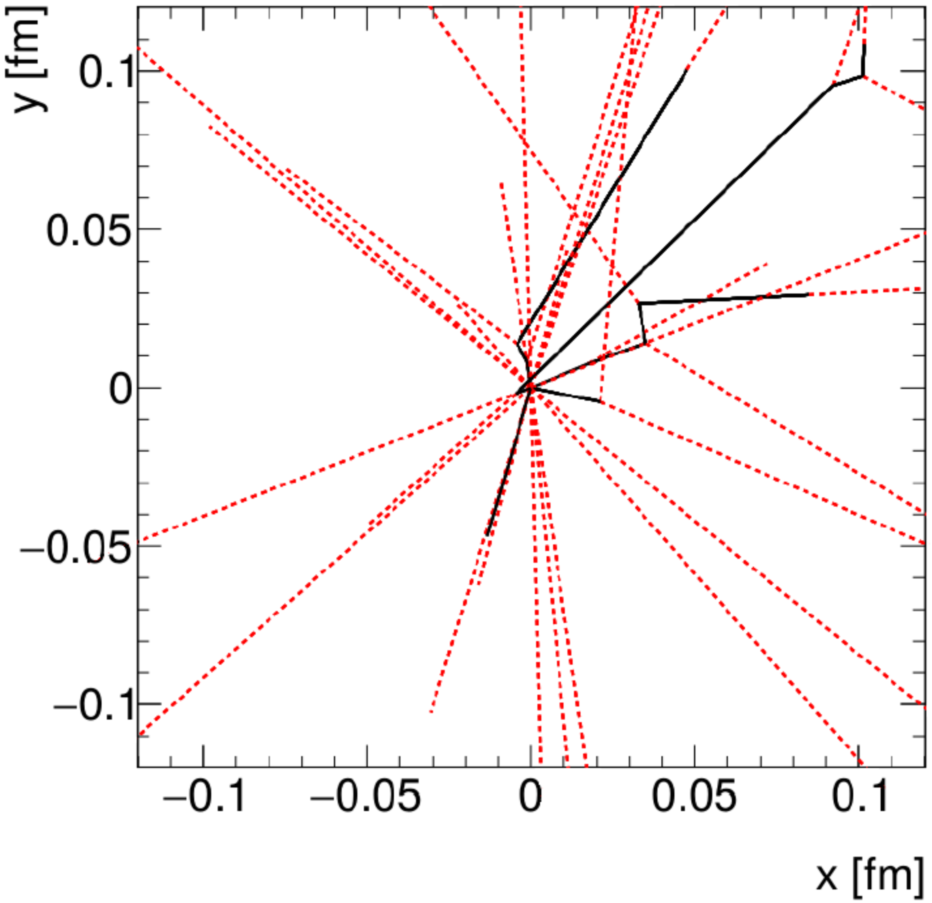


- Most of ISR/FSR has very small chance to travel far away
- “final” gluons however can “fly” even several fermi

Space-time Model - shower



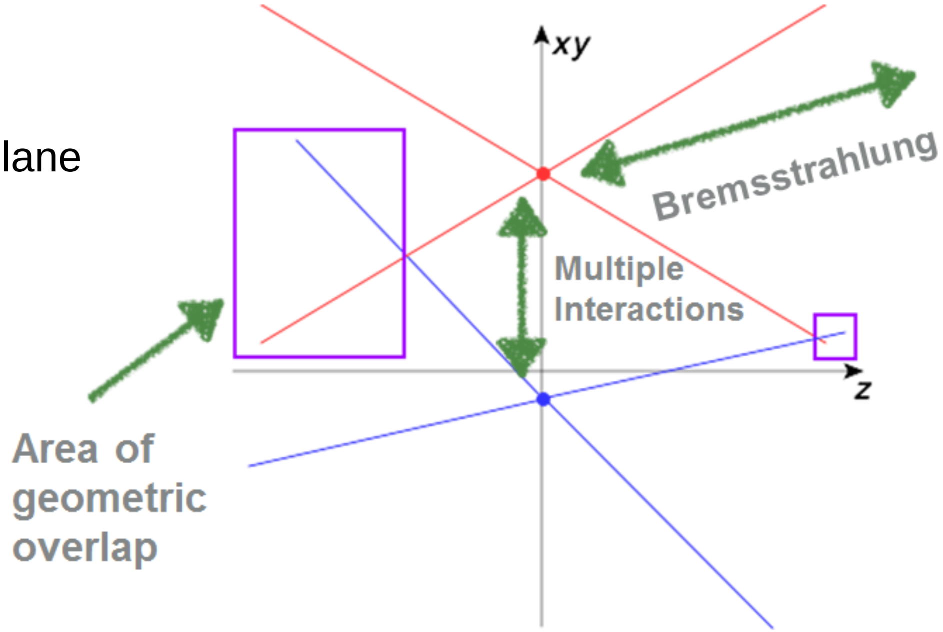
fraction of “final” gluons



- ➢ Most of ISR/FSR has very small chance to travel far away
- ➢ “final” gluons however can “fly” even several fermi

Space-time Model - smearing of scatter points in *b* space

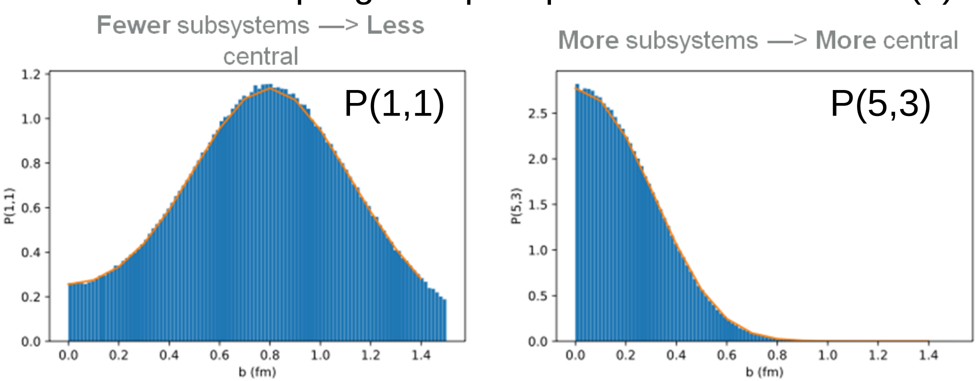
- ➢ Each scatter (MPI) gets its point in xy plane (inspired by heavy ion collision)
- ➢ Shower evolves partons further in xyz
- ➢ Motivation to cluster “close” partons



Issues:

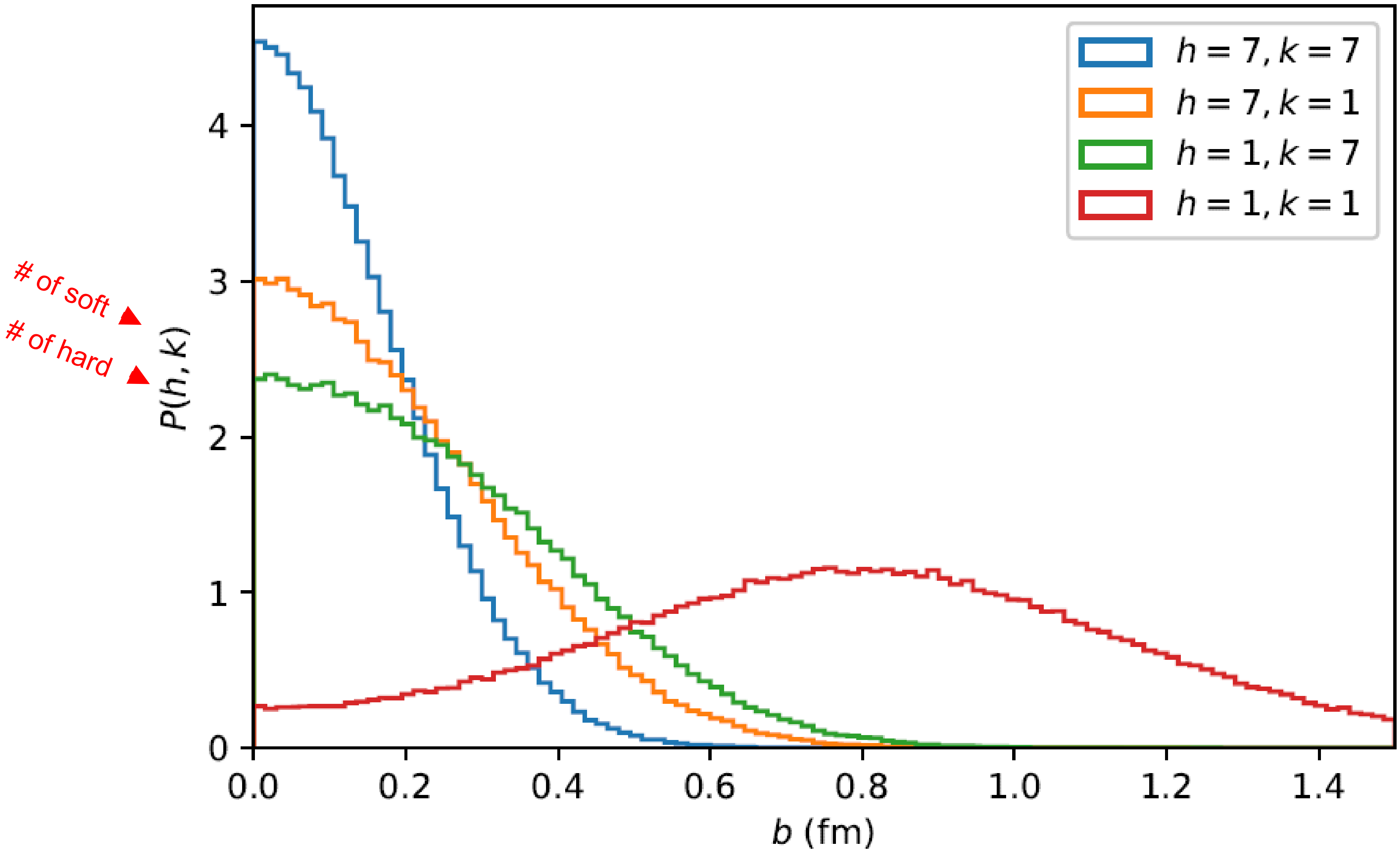
- ➔ Impact parameter
- ➔ Proton profile
  - ◆ Black disk
  - ◆ Gaussian
  - ◆ Overlap function (Bessel)
- ➔ Proton mean radius (r_0)
- ➔ Proton remnants

Poisson sampling of impact parameter of collision (b)

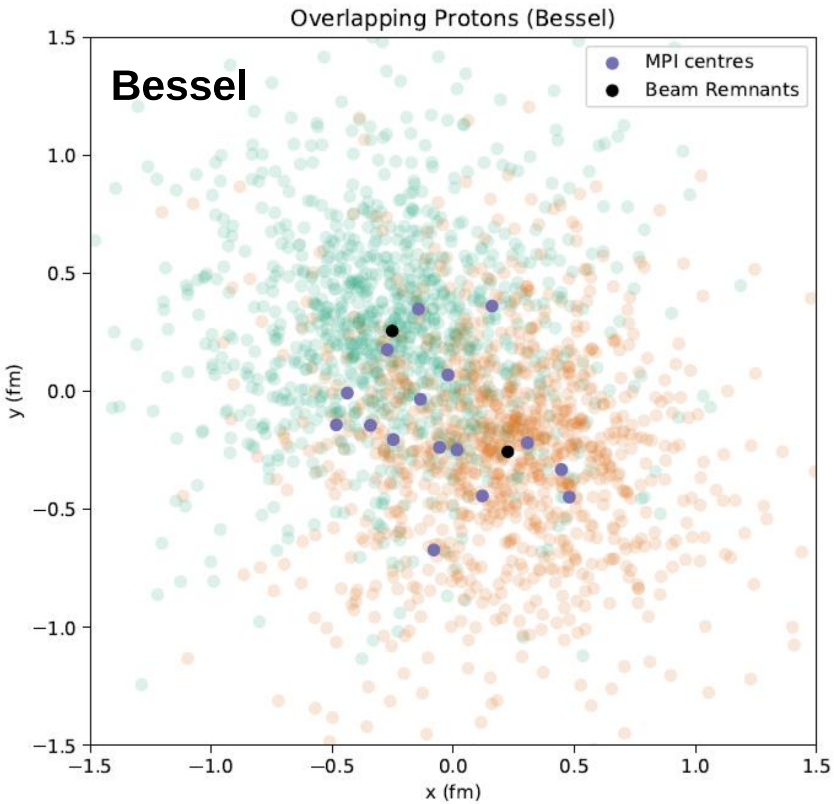


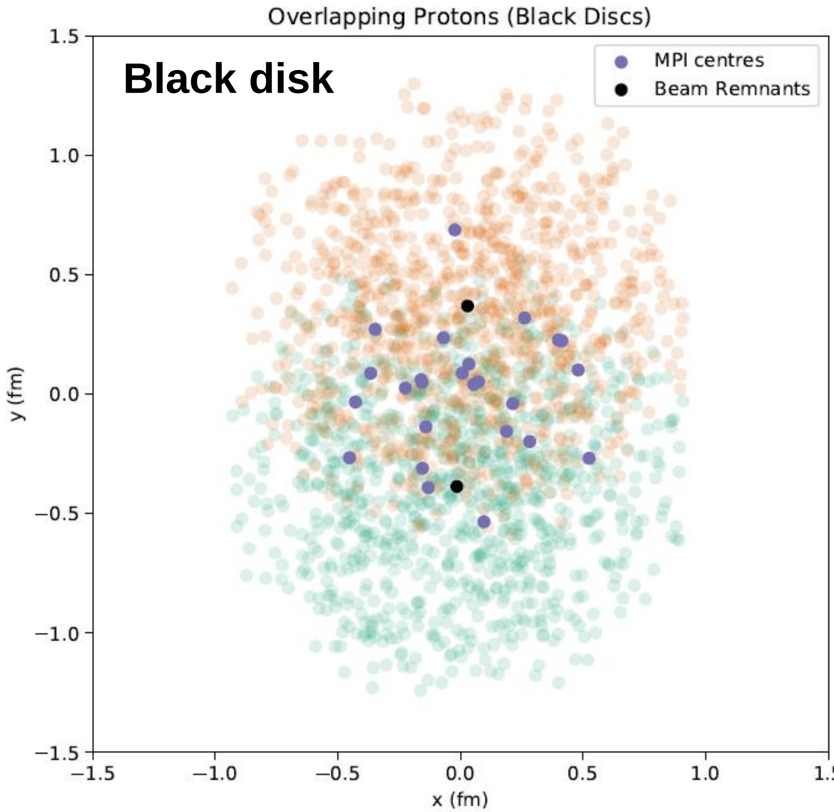
$$\mathcal{P}_{h,k} = \frac{\langle n_h(b)\rangle^h}{h!}\frac{\langle n_k(b)\rangle^k}{k!}\exp[-(\langle n_h(b)\rangle + \langle n_k(b)\rangle)]$$

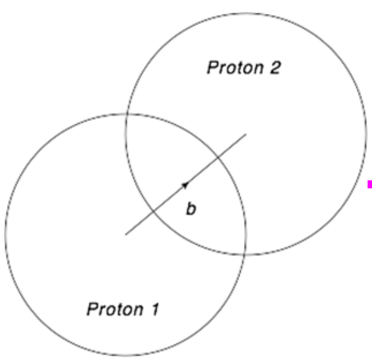
Space-time Model - smearing of scatter points in *b* space

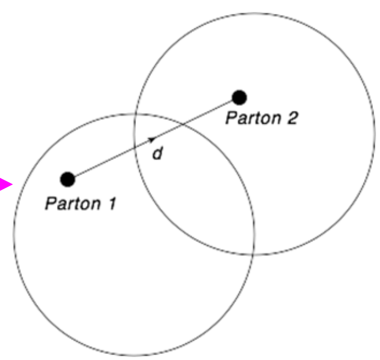


Space-time Model - smearing of scatter points in *b* space



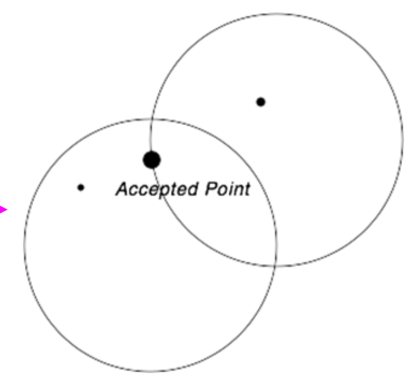






Probability to accept or reject the points

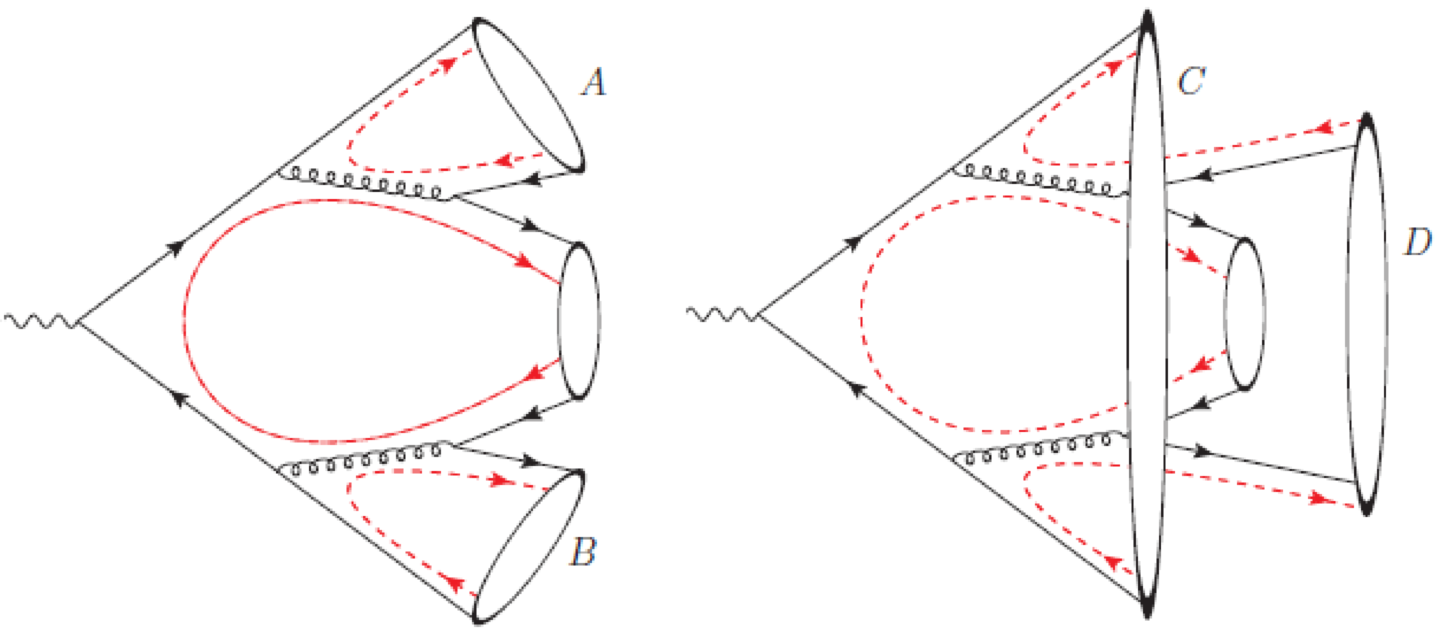
$$P = \exp\left(\frac{-d}{r_0}\right)$$



iterated N times; discarded points → remnants

Space-time Model – re-connection

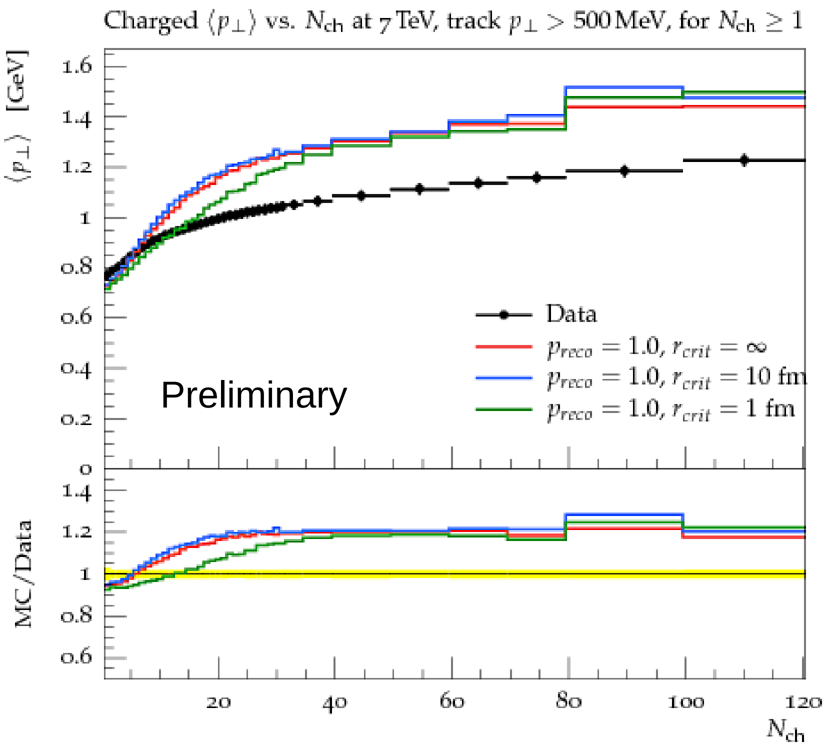
- “Final” partons = forming clusters
- Motivation: 1) interconnect MPI’s
  2) correct for errors in leading-color approximation of parton shower
- Needs a “measure” and law to set probability to decide YES/NO, p_{RC} – to tune

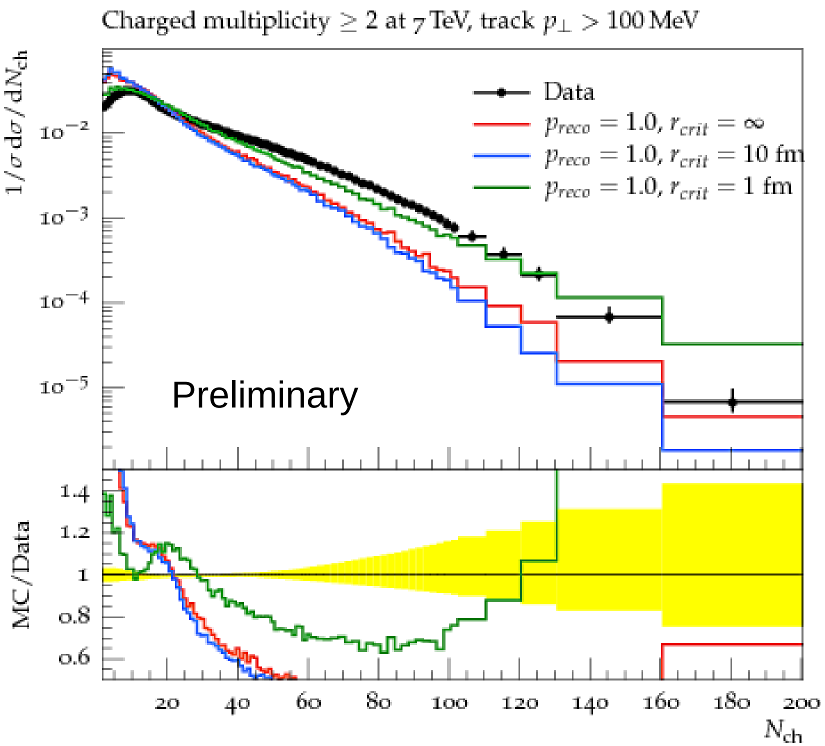


Space-time Model - preliminary results

First idea: critical radius

→ plain CR + critical radius (new parameter)



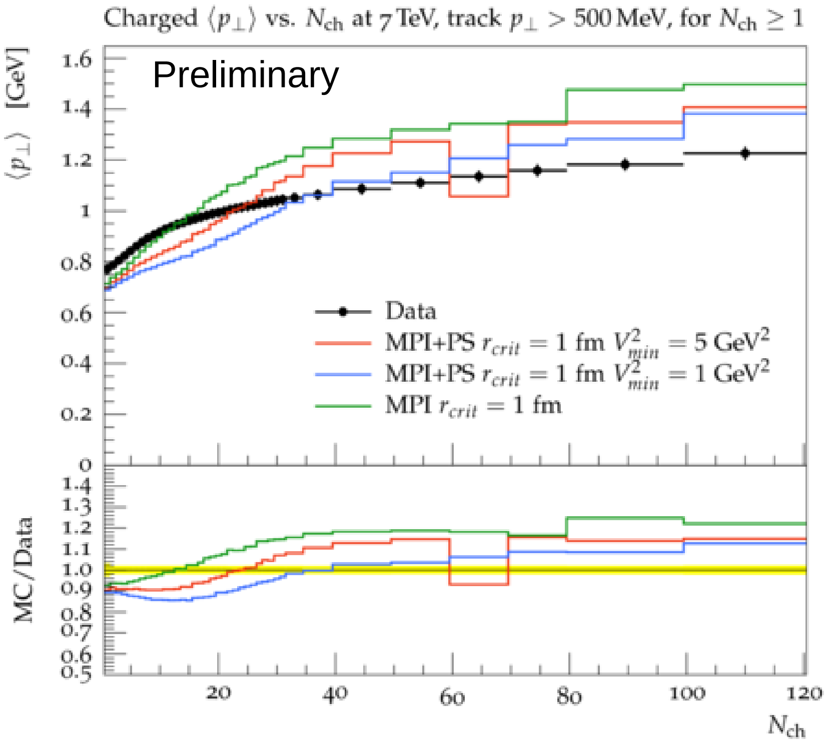


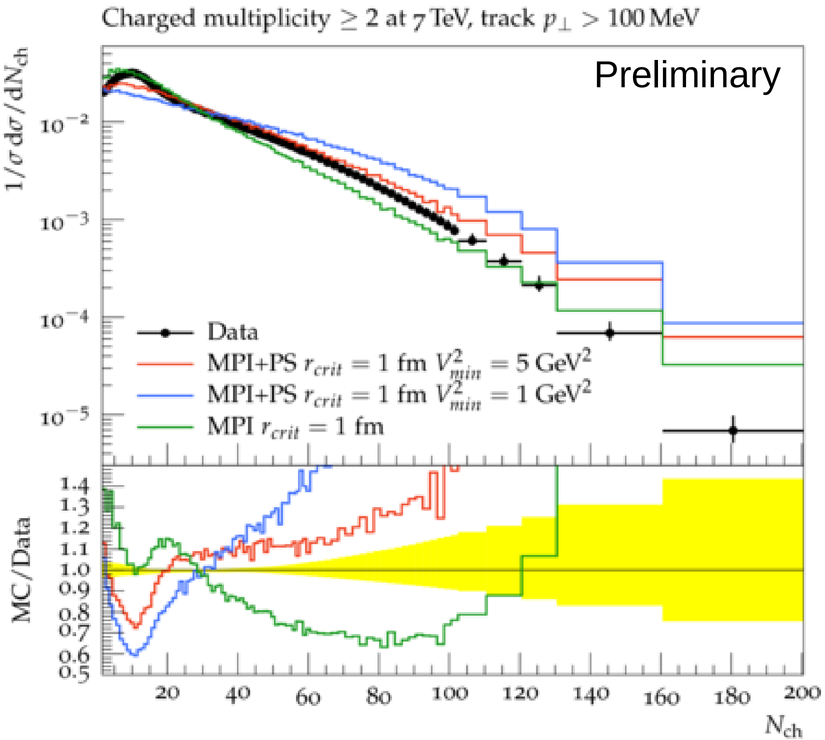
Not tuned (just to see the effect), **MPI smearing only** - no shower ST

Space-time Model - preliminary results

First idea: critical radius

→ plain CR + critical radius (new parameter)



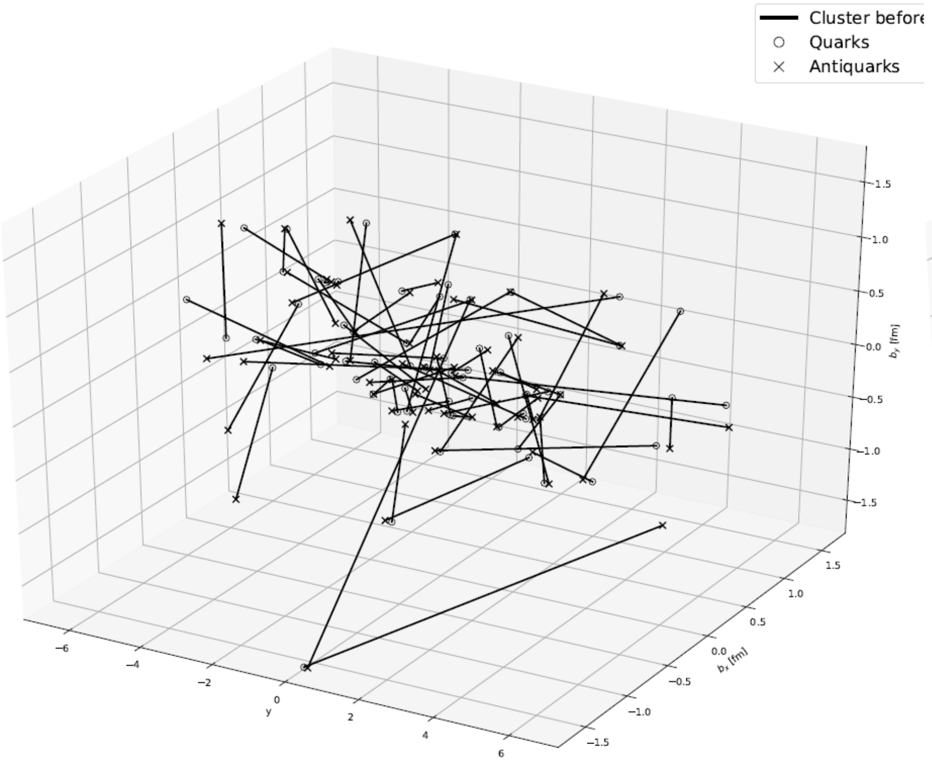


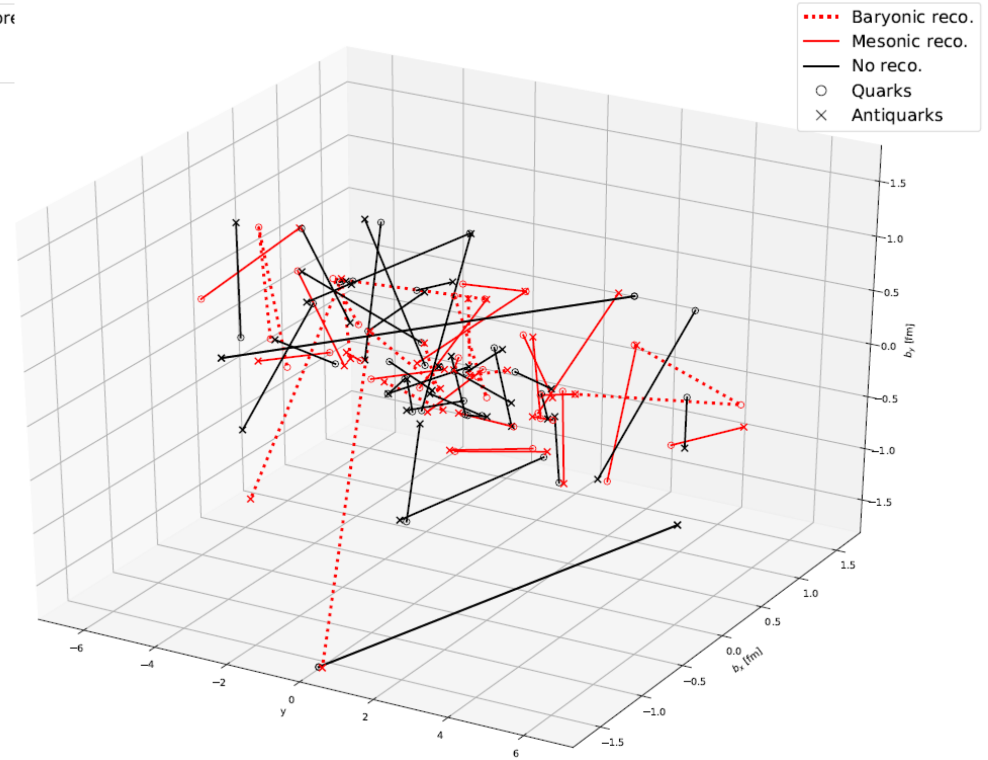
Not tuned (just to see the effect), **MPI + shower ST**, p_{reco} = 1 (same as previous slides)

Space-time Model – preliminary results

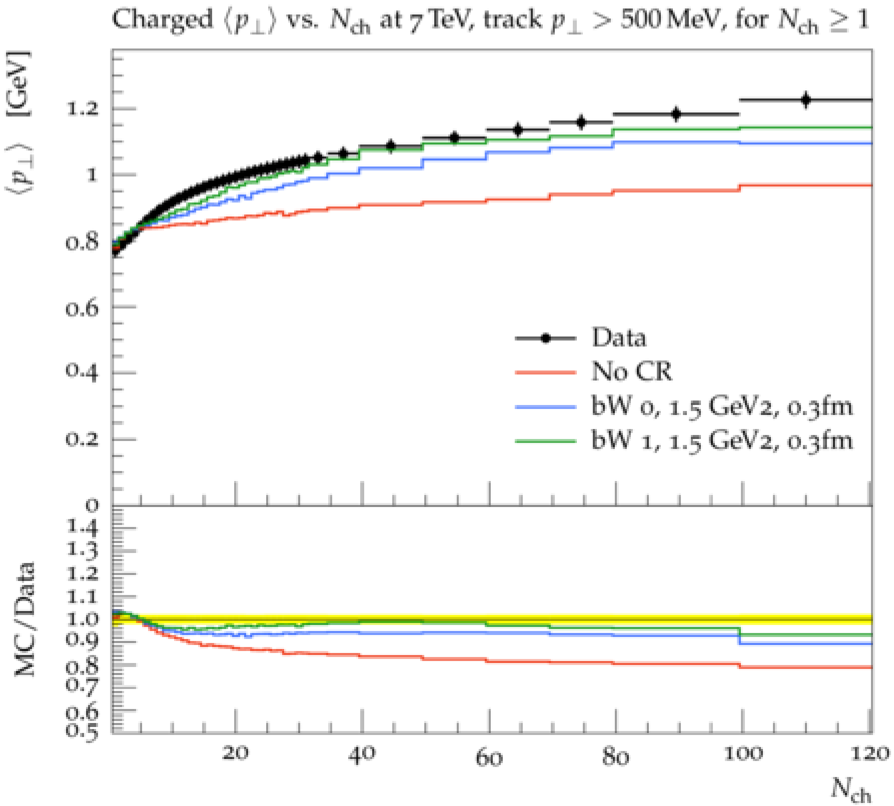
$$R_{ij}^2 = \frac{\Delta d_{\perp ij}^2}{d_0^2} + \Delta y_{ij}^2$$

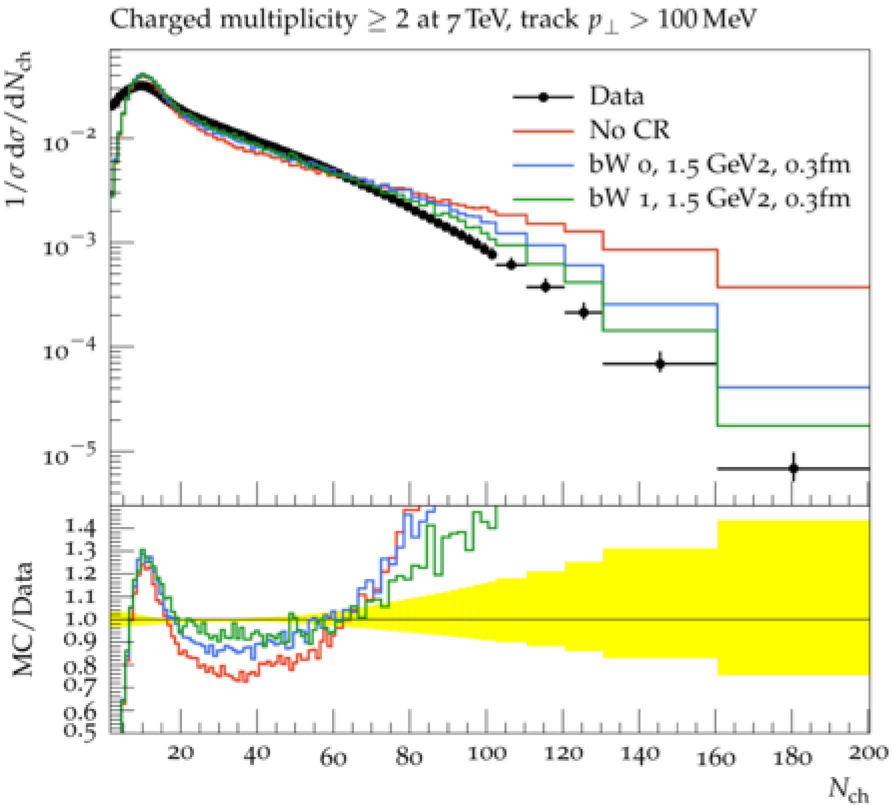
$$p_{\mathrm{M,reco}} = \exp\left(-\frac{R_{14}+R_{23}}{R_{12}+R_{34}}\right) = \exp\left(-\frac{\sum R_{\mathrm{new}}}{\sum R_{\mathrm{old}}}\right)$$





Space-time Model – preliminary results





Summary and outlook

- We introduced space-time picture to MPI (probe b from the overlap function) and to the Parton Shower (based on mean life-time)
- We study sources of displacement and its dependence on the main parameters
- We introduced space-time information to the CR model in Herwig and studied its influence on MB and UE event data (now tuning).
- Space-time picture could serve us as a starting point to study collective effects in p-p collisions