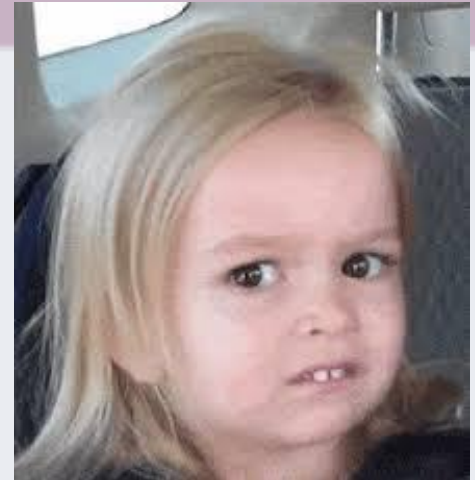


Tuning the Primordial Transverse Momentum in PYTHIA

Yiannis Polychronakos

Supervisors: Korinna Zapp, Christian Bierlich

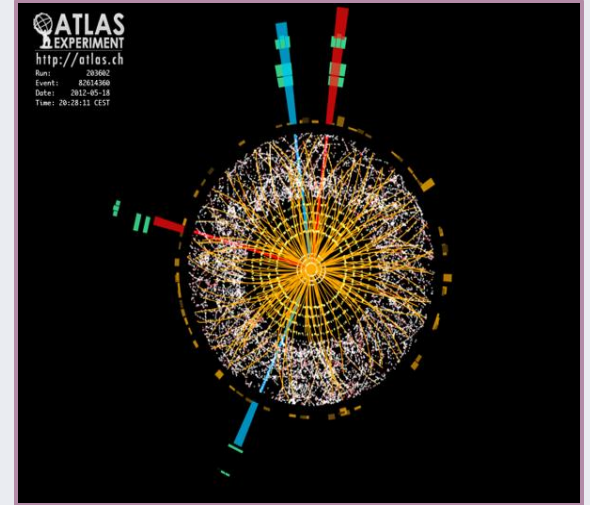
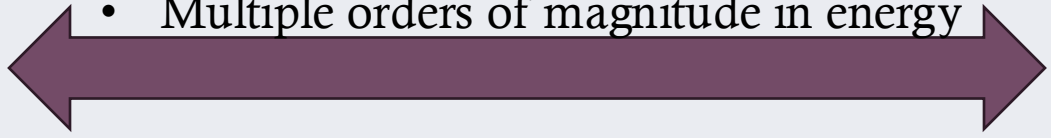
Tuning the Primordial Transverse Momentum in PYTHIA



General-Purpose Monte Carlo Event Generator

$$\begin{aligned}
 \mathcal{L}_{SM} = & -\frac{1}{2}\partial_\mu g_\nu^2 \partial_\mu g_\nu^2 - g_s f^{abc} \partial_\mu g_\nu^a g_\mu^b g_\nu^c - \frac{1}{2}g_1^2 f^{abc} f^{def} g_\mu^a g_\nu^b g_\mu^c g_\nu^d - \partial_\mu W_\nu^+ \partial_\mu W_\nu^- \\
 & - M^2 W_\mu^+ W_\mu^- - \frac{1}{2}\partial_\mu Z_\nu^0 \partial_\mu Z_\nu^0 - \frac{1}{2}M^2 Z_\mu^0 Z_\mu^0 - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - ig_{em}(\partial_\mu Z_\nu^0(W_\mu^+ W_\nu^- - \\
 & W_\mu^- W_\nu^+) - Z_\mu^0(W_\mu^+ \partial_\nu W_\nu^- - W_\mu^- \partial_\nu W_\nu^+) + Z_\mu^0(W_\mu^+ \partial_\nu W_\nu^+ - W_\mu^- \partial_\nu W_\nu^-)) \\
 & + A_\mu(W_\mu^+ \partial_\nu W_\nu^- - W_\mu^- \partial_\nu W_\nu^+) - A_\mu(W_\mu^+ \partial_\nu W_\nu^+ - W_\mu^- \partial_\nu W_\nu^-) \\
 & + ig_{em}(\partial_\mu A_\nu(W_\mu^+ W_\nu^- - W_\mu^- W_\nu^+) - A_\nu(W_\mu^+ \partial_\mu W_\nu^- - W_\mu^- \partial_\mu W_\nu^+) + A_\nu(W_\mu^+ \partial_\mu W_\nu^+ - \\
 & W_\mu^- \partial_\mu W_\nu^-)) - \frac{1}{2}g^2 W_\mu^+ W_\nu^- W_\mu^- W_\nu^+ + \frac{1}{2}g^2 W_\mu^+ W_\nu^- W_\mu^- W_\nu^- + g^2 c_{bc}^2 (Z_\mu^0 W_\nu^+ Z_\mu^0 W_\nu^- - \\
 & Z_\mu^0 Z_\nu^0 W_\mu^+ W_\nu^-) + g^2 c_{bc}^2 (A_\mu W_\nu^+ A_\mu W_\nu^- - A_\mu A_\nu W_\mu^+ W_\nu^-) + g^2 c_{bc}^2 (Z_\mu^0 Z_\nu^0 (W_\mu^+ W_\nu^- - \\
 & W_\mu^- W_\nu^+) - 2A_\mu Z_\nu^0 W_\mu^+ W_\nu^-) - \frac{1}{2}\partial_\mu H \partial_\mu H - 2M^2 \alpha_h H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - \frac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \\
 & \beta_h \left(\frac{2M^2}{\Lambda^2} H + \frac{1}{\Lambda^2} (H^2 + \phi^0 \phi^0 + 2\phi^+ \phi^-) \right) + \frac{2M^2}{\Lambda^2} \alpha_h - \\
 & \frac{1}{2}g^2 \alpha_h (H^2 + (\phi^0)^2 + 4(\phi^+ \phi^-)^2 + 4(\phi^0)^2 \phi^+ \phi^- + 4H^2 \phi^+ \phi^- + 2(\phi^0)^2 H^2) - \\
 & \frac{1}{2}g M W_\mu^+ W_\nu^- H - \frac{1}{2}g \frac{M^2}{\Lambda^2} Z_\mu^0 Z_\nu^0 H - \\
 & \frac{1}{2}ig (W_\mu^+ (\phi^0 \partial_\nu \phi^- - \phi^- \partial_\nu \phi^0) - W_\mu^- (\phi^0 \partial_\nu \phi^+ - \phi^+ \partial_\nu \phi^0)) + \\
 & \frac{1}{2}g (W_\mu^+ (H \partial_\nu \phi^- - \phi^- \partial_\nu H) + W_\mu^- (H \partial_\nu \phi^+ - \phi^+ \partial_\nu H)) + \frac{1}{2}ig \frac{1}{\Lambda^2} (Z_\mu^0 (H \partial_\nu \phi^0 - \phi^0 \partial_\nu H) + \\
 & M (\frac{1}{\Lambda^2} Z_\mu^0 \partial_\nu \phi^0 + W_\mu^+ \partial_\nu \phi^- + W_\mu^- \partial_\nu \phi^+) - ig \frac{M^2}{\Lambda^2} Z_\mu^0 (W_\mu^+ \phi^- - W_\mu^- \phi^+)) + ig_{em} M A_\mu (W_\mu^+ \phi^- - \\
 & W_\mu^- \phi^+) - ig \frac{1}{\Lambda^2} Z_\mu^0 Z_\nu^0 (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) + ig_{em} A_\mu (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) - \\
 & \frac{1}{2}g^2 W_\mu^+ W_\nu^- (H^2 + (\phi^0)^2 + 2\phi^+ \phi^-) - \frac{1}{2}g^2 \frac{1}{\Lambda^2} Z_\mu^0 Z_\nu^0 (H^2 + (\phi^0)^2 + 2(2s_\theta^2 - 1)^2 \phi^+ \phi^-) - \\
 & \frac{1}{2}g^2 \frac{1}{\Lambda^2} Z_\mu^0 Z_\nu^0 (W_\mu^+ \phi^- - W_\mu^- \phi^+) - \frac{1}{2}ig^2 \frac{1}{\Lambda^2} Z_\mu^0 Z_\nu^0 H (W_\mu^+ \phi^- - W_\mu^- \phi^+) + \frac{1}{2}g^2 s_{2\theta} A_\mu \phi^0 (W_\mu^+ \phi^- + \\
 & W_\mu^- \phi^+) + \frac{1}{2}ig^2 s_{2\theta} A_\mu H (W_\mu^+ \phi^- - W_\mu^- \phi^+) - g^2 s_{2\theta} (2c_\theta^2 - 1) Z_\mu^0 A_\nu \phi^+ \phi^- - \\
 & g^2 s_\theta^2 A_\mu A_\nu \phi^+ \phi^- + \frac{1}{2}ig_s \lambda_3^2 (g_1^2 \gamma^0 g_1^2) g_\mu^a g_\nu^a - e^2 (\gamma^0 + m_2) \epsilon^{\mu\nu\alpha\beta} - \nu^\alpha (\gamma^0 + m_2) \nu^\beta - u_2^2 (\gamma^0 + \\
 & m_2) u_2^\beta - d_2^2 (\gamma^0 + m_2) d_2^\beta + ig_{em} A_\mu (-e^\alpha \gamma^\mu e^\alpha + \frac{2}{3}(u_1^\alpha \gamma^\mu u_1^\beta) - \frac{1}{3}(d_1^\alpha \gamma^\mu d_1^\beta)) + \\
 & \frac{1}{2}M^2 Z_\mu^0 ((\nu^\alpha \gamma^\mu (1 + \gamma^5) \nu^\beta) + (e^\alpha \gamma^\mu (4s_\theta^2 - 1 - \gamma^5) e^\beta) + (d_1^\alpha \gamma^\mu (\frac{2}{3}s_\theta^2 - 1 - \gamma^5) d_1^\beta) + \\
 & (u_1^\alpha \gamma^\mu (1 - \frac{2}{3}s_\theta^2 + \gamma^5) u_1^\beta)) + \frac{1}{2}M^2 W_\mu^+ ((\nu^\alpha \gamma^\mu (1 + \gamma^5) U^{\mu\nu} \nu^\beta) + (u_1^\alpha \gamma^\mu (1 + \gamma^5) C_{3a} d_1^\beta)) + \\
 & \frac{1}{2}M^2 W_\mu^- ((e^\alpha U^{\mu\nu} \nu^\beta (1 + \gamma^5) \nu^\beta) + (d_1^\alpha C_{3a} \gamma^\mu (1 + \gamma^5) u_1^\beta)) + \\
 & \frac{1}{2M^2 g^2} \phi^+ (-m_2^2 (e^\alpha U^{\mu\nu} \nu^\beta (1 - \gamma^5) e^\beta) + m_2^2 (\nu^\alpha U^{\mu\nu} \nu^\beta (1 + \gamma^5) e^\beta) - \frac{2}{3} \frac{M^2}{\Lambda^2} H (\nu^\alpha \nu^\beta) - \\
 & \frac{2}{3} \frac{M^2}{\Lambda^2} H (e^\alpha e^\beta) + \frac{2}{3} \frac{M^2}{\Lambda^2} \phi^0 (\nu^\alpha \gamma^\mu \nu^\beta) - \frac{2}{3} \frac{M^2}{\Lambda^2} \phi^0 (e^\alpha \gamma^\mu e^\beta) - \frac{1}{3} \nu_1 M_{1a}^2 (1 - \gamma_5) \nu_a - \\
 & \frac{1}{3} \nu_1 M_{1a}^2 (1 - \gamma_5) \nu_a + \frac{1}{2M^2 g^2} \phi^0 (-m_2^2 (u_1^\alpha C_{3a} (1 - \gamma^5) d_1^\beta) + m_2^2 (u_1^\alpha C_{3a} (1 + \gamma^5) d_1^\beta) + \\
 & \frac{1}{2M^2 g^2} \phi^+ (m_2^2 (d_1^\alpha C_{3a} (1 + \gamma^5) u_1^\beta) - m_2^2 (d_1^\alpha C_{3a}^* (1 - \gamma^5) u_1^\beta) - \frac{2}{3} \frac{M^2}{\Lambda^2} H (u_1^\alpha u_1^\beta) - \\
 & \frac{2}{3} \frac{M^2}{\Lambda^2} H (d_1^\alpha d_1^\beta) + \frac{2}{3} \frac{M^2}{\Lambda^2} \phi^0 (u_1^\alpha \gamma^\mu u_1^\beta) - \frac{2}{3} \frac{M^2}{\Lambda^2} \phi^0 (d_1^\alpha \gamma^\mu d_1^\beta) + C^{\mu\nu} C^{\mu\nu} + g_s f^{abc} \partial_\mu C^a C^b C^c g_\mu^c + \\
 & X^+ (\partial^\mu - M^2) X^+ + X^+ (\partial^\mu - M^2) X^+ - X^0 (\partial^\mu - \frac{M^2}{\Lambda^2}) X^0 + Y^\mu Y^\mu + ig_{em} W_\mu^+ (\partial_\mu X^0 X^- - \\
 & \partial_\mu X^+ X^0) + ig_{em} W_\mu^- (\partial_\mu Y^+ X^- - \partial_\mu X^+ Y^-) + ig_{em} W_\mu^0 (\partial_\mu X^- X^0 - \\
 & \partial_\mu X^0 X^+) + ig_{em} A_\mu (\partial_\mu X^- X^+ - \partial_\mu X^+ X^-) + ig_{em} Z_\mu^0 (\partial_\mu X^- X^+ - \\
 & \partial_\mu X^+ X^-) + ig_{em} A_\mu (\partial_\mu X^- X^+ - \\
 & \partial_\mu X^+ X^-) - \frac{1}{2}ig M (X^+ X^+ H + X^- X^- H + \frac{1}{\Lambda^2} X^0 X^0 H) + \frac{1}{2}ig M (X^+ X^0 \phi^- - X^- X^0 \phi^-) + \\
 & \frac{1}{2}ig M (X^0 X^- \phi^- - X^0 X^+ \phi^-) + ig M s_\theta (X^0 X^- \phi^+ - X^0 X^+ \phi^+) + \\
 & \frac{1}{2}ig M (X^- X^- \phi^0 - X^- X^+ \phi^0) .
 \end{aligned}$$

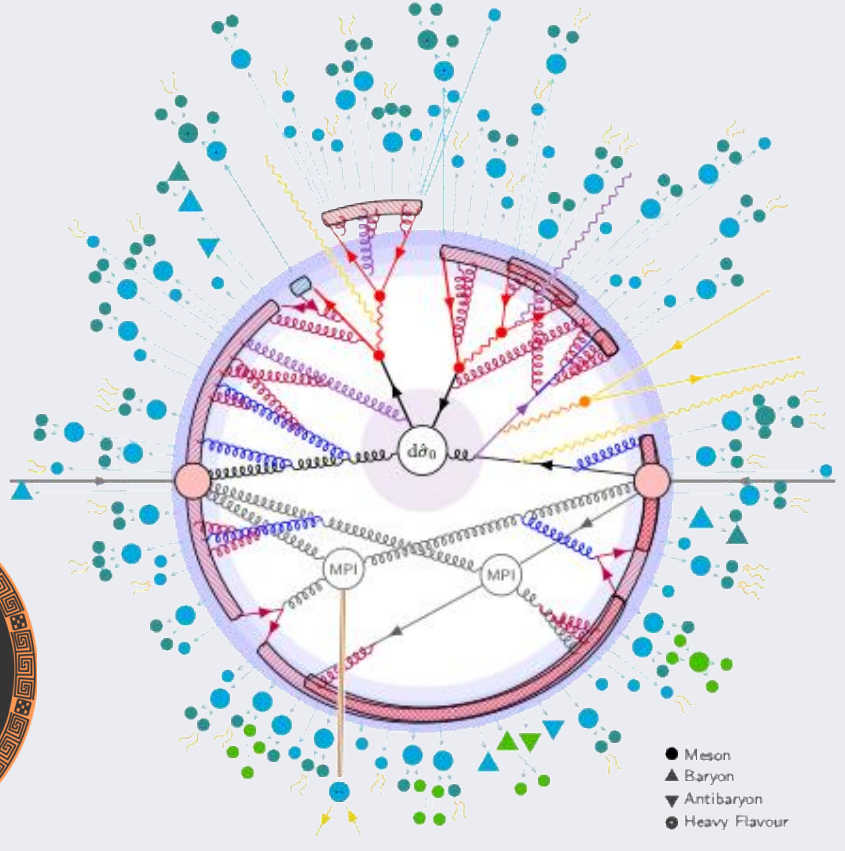
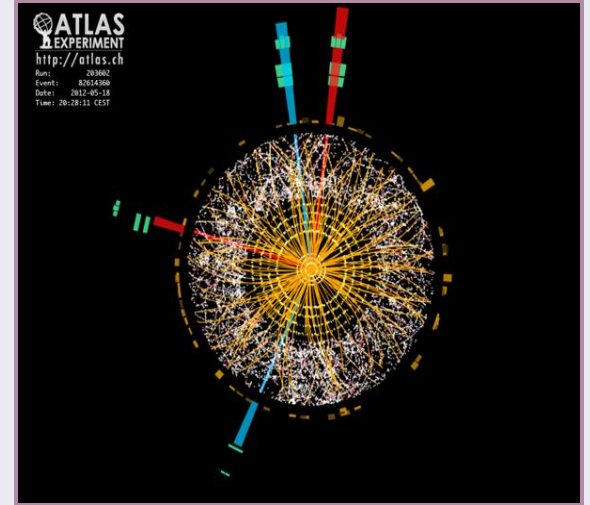
- Hundreds of Final State Particles
- Non-perturbative Physics
- Multiple orders of magnitude in energy



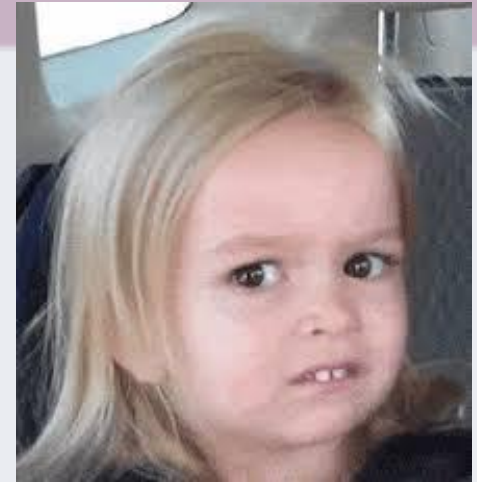
General-Purpose Monte Carlo Event Generator

$$\begin{aligned}
 \mathcal{L}_{SM} = & -\frac{1}{2}\partial_\mu\phi^i\partial_\mu\phi^i - g_s f^{abc}\partial_\mu\phi^i\partial_\mu\phi^j - \frac{1}{2}g_2 f^{abc}\partial_\mu\phi^i\partial_\mu\phi^j - \partial_\mu W_\nu^i\partial_\mu W_\nu^j - \\
 & M^2 W_\nu^i W_\nu^i - \frac{1}{2}\partial_\mu Z_\nu^i\partial_\mu Z_\nu^i - \frac{1}{2}M^2 Z_\nu^i Z_\nu^i - \frac{1}{2}\partial_\mu A_\nu\partial_\mu A_\nu - ig_{cc}(W_\nu^+ W_\nu^- - \\
 & W_\nu^- W_\nu^+) - Z_\nu^i(W_\nu^+ W_\nu^- - W_\nu^- W_\nu^+) + Z_\nu^i(W_\nu^+ \partial_\mu W_\nu^- - W_\nu^- \partial_\mu W_\nu^+) - \\
 & ig_{su}(\partial_\mu A_\nu(W_\nu^+ W_\nu^- - W_\nu^- W_\nu^+) - A_\nu(W_\nu^+ \partial_\mu W_\nu^- - W_\nu^- \partial_\mu W_\nu^+) + A_\nu(W_\nu^+ \partial_\mu W_\nu^- - \\
 & W_\nu^- \partial_\mu W_\nu^+)) - \frac{1}{2}g^2 W_\nu^+ W_\nu^- W_\nu^+ W_\nu^- + \frac{1}{2}g^2 W_\nu^+ W_\nu^- W_\nu^- W_\nu^+ + g^2 c_{cc}(Z_\nu^i W_\nu^+ Z_\nu^i W_\nu^- - \\
 & Z_\nu^i Z_\nu^i W_\nu^+ W_\nu^-) + g^2 c_{su}(A_\nu W_\nu^+ W_\nu^- - A_\nu A_\nu W_\nu^+ W_\nu^-) + g^2 c_{sc}(A_\nu Z_\nu^i W_\nu^+ W_\nu^- - \\
 & W_\nu^+ W_\nu^-) - 2A_\nu Z_\nu^i W_\nu^+ W_\nu^- - \frac{1}{2}\partial_\mu H\partial_\mu H - 2M^2\alpha_\mu H^2 - \partial_\mu\phi^i\partial_\mu\phi^i - \frac{1}{2}\partial_\mu\phi^i\partial_\mu\phi^i - \\
 & \beta_\alpha\left(\frac{2M^2}{\Lambda^2}H + \frac{1}{\Lambda^2}(H^2 + \phi^i\phi^i + 2\phi^+\phi^-)\right) + \frac{2M^2}{\Lambda^2}\alpha_\mu - \\
 & \frac{1}{2}g\alpha_\mu(H^2 + (\phi^i)^2 + 4(\phi^+)^2\phi^+\phi^- + 4H\phi^+\phi^- + 2(\phi^+)^2H^2) - \\
 & \frac{1}{2}ig(W_\nu^+(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - W_\nu^-(\phi^+\partial_\mu\phi^+ - \phi^-\partial_\mu\phi^-)) + \\
 & \frac{1}{2}g(W_\nu^+(H\partial_\mu\phi^- - \phi^-\partial_\mu H) + W_\nu^-(H\partial_\mu\phi^+ - \phi^+\partial_\mu H)) + \frac{1}{2}ig\left(\frac{1}{2}Z_\nu^i(H\partial_\mu\phi^i - \phi^i\partial_\mu H) + \right. \\
 & M\left(\frac{1}{2}Z_\nu^i\partial_\mu\phi^i + W_\nu^+\partial_\mu\phi^- + W_\nu^-\partial_\mu\phi^+\right) - ig\frac{1}{2}MZ_\nu^i(W_\nu^+\phi^- - W_\nu^-\phi^+)\left. + ig_{su}MA_\nu(W_\nu^+\phi^- - \right. \\
 & \left. W_\nu^-\phi^+)\right) - ig\frac{1}{2}Z_\nu^i Z_\nu^i(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) + ig_{su}A_\nu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \\
 & \frac{1}{2}g^2 W_\nu^+ W_\nu^- (H^2 + (\phi^i)^2 + 2\phi^+\phi^-) - \frac{1}{2}g^2\frac{1}{2}Z_\nu^i Z_\nu^i (H^2 + (\phi^i)^2 + 2(2s_\mu^2 - 1)^2\phi^+\phi^-) - \\
 & \frac{1}{2}g^2\frac{1}{2}Z_\nu^i Z_\nu^i (W_\nu^+\phi^- + W_\nu^-\phi^+) - \frac{1}{2}ig^2\frac{1}{2}Z_\nu^i Z_\nu^i H(W_\nu^+\phi^- - W_\nu^-\phi^+) + \frac{1}{2}g^2 s_{su}A_\nu\phi^i(W_\nu^+\phi^- + \\
 & W_\nu^-\phi^+) + \frac{1}{2}ig^2 s_{su}A_\nu H(W_\nu^+\phi^- - W_\nu^-\phi^+) - g^2 c_{cc}(2s_\mu^2 - 1)Z_\nu^i A_\nu\phi^i - \\
 & g^2 c_{su}^2 A_\nu A_\nu\phi^i\phi^i + \frac{1}{2}ig_\mu\lambda_2^i(g^2\gamma^i\phi^i\phi^i) - e^2(\gamma^i\partial + m_i)^2 - \frac{1}{2}(d_i^2\gamma^i\phi^i\phi^i) - \frac{1}{2}(d_i^2\gamma^i\phi^i\phi^i) + \\
 & \frac{1}{2}Z_\nu^i Z_\nu^i\left\{(\omega^i\gamma^i(1+\gamma^i)\nu^i) + (e^i\gamma^i(4s_\mu^2 - 1 - \gamma^i)e^i) + (d_i^2\gamma^i(\frac{1}{2}s_\mu^2 - 1 - \gamma^i)d_i^2) + \right. \\
 & \left. (u_i^2\gamma^i(1 - \frac{1}{2}s_\mu^2 + \gamma^i)u_i^2)\right\} + \frac{1}{2}Z_\nu^i Z_\nu^i\left\{(\omega^i\nu^i(1+\gamma^i)U_{\mu\nu}^{\mu\nu}) + (u_i^2\gamma^i(1+\gamma^i)C_{\mu\nu}^{\mu\nu})\right\} + \\
 & \frac{1}{2}Z_\nu^i Z_\nu^i\left\{(e^i U_{\mu\nu}^{\mu\nu}\gamma^i(1+\gamma^i)\nu^i) + (d_i^2 C_{\mu\nu}^{\mu\nu}\gamma^i(1+\gamma^i)u_i^2)\right\} + \\
 & \frac{1}{2}Z_\nu^i Z_\nu^i\left\{(-m_i^2(e^i U_{\mu\nu}^{\mu\nu}(1+\gamma^i)\nu^i) + m_i^2(u_i^2 U_{\mu\nu}^{\mu\nu}(1+\gamma^i)u_i^2) + \right. \\
 & \left. \frac{1}{2}Z_\nu^i Z_\nu^i H(m_i^2(e^i U_{\mu\nu}^{\mu\nu}(1+\gamma^i)\nu^i) - m_i^2(e^i U_{\mu\nu}^{\mu\nu}(1-\gamma^i)\nu^i) - \frac{1}{2}Z_\nu^i H(u_i^2\nu^i) - \right. \\
 & \left. \frac{1}{2}Z_\nu^i H(e^i\nu^i) + \frac{1}{2}Z_\nu^i H(u_i^2\nu^i) - \frac{1}{2}Z_\nu^i H(\omega^i\gamma^i\nu^i) - \frac{1}{2}Z_\nu^i H(e^i\gamma^i\nu^i) - \frac{1}{2}Z_\nu^i M_{\mu\nu}^{\mu\nu}(1-\gamma^i)\nu^i - \right. \\
 & \left. \frac{1}{2}Z_\nu^i M_{\mu\nu}^{\mu\nu}(1-\gamma^i)\nu^i + \frac{1}{2}Z_\nu^i H\phi^i - (m_i^2(u_i^2 C_{\mu\nu}^{\mu\nu}(1-\gamma^i)u_i^2) + m_i^2(u_i^2 C_{\mu\nu}^{\mu\nu}(1+\gamma^i)u_i^2) + \right. \\
 & \left. \frac{1}{2}Z_\nu^i H\phi^i - (m_i^2(d_i^2 C_{\mu\nu}^{\mu\nu}(1+\gamma^i)u_i^2) - m_i^2(d_i^2 C_{\mu\nu}^{\mu\nu}(1-\gamma^i)u_i^2) - \frac{1}{2}Z_\nu^i H(u_i^2u_i^2) - \right. \\
 & \left. \frac{1}{2}Z_\nu^i H(d_i^2 d_i^2) + \frac{1}{2}Z_\nu^i H(u_i^2 u_i^2) - \frac{1}{2}Z_\nu^i H(d_i^2 \gamma^i d_i^2) + C^{\mu\nu}C^{\mu\nu} + g_s f^{abc}C^{\mu\nu}C^{\mu\nu}g_s^2 + \right. \\
 & \left. X^+(\partial^\mu - M^2)X^+ + X^-(\partial^\mu - M^2)X^- + X^0(\partial^\mu - \frac{M^2}{\Lambda^2})X^0 + Y^i\partial^\mu Y^i + ig_{su}W_\nu^+(X^0 X^+ X^- - \right. \\
 & \left. \partial_\nu X^+ X^0) + ig_{su}W_\nu^-(X^0 X^- X^+) + ig_{cc}Z_\nu^i(\partial_\nu X^+ X^0 - \right. \\
 & \left. \partial_\nu X^0 X^+) + ig_{su}W_\nu^-(\partial_\nu X^- X^0 - \partial_\nu X^0 X^-) + ig_{cc}Z_\nu^i(\partial_\nu X^- X^+ - \right. \\
 & \left. \partial_\nu X^+ X^-) + ig_{su}A_\nu(\partial_\nu X^+ X^- - \partial_\nu X^- X^+) - \frac{1}{2}igM(X^+ X^0 H + X^- X^0 H) + \frac{1}{2}igM(X^+ X^0\phi^- - X^- X^0\phi^+) + \right. \\
 & \left. \frac{1}{2}igM(X^0 X^+\phi^- - X^0 X^-\phi^+) + igM_{su}(X^+ X^-\phi^+ - X^0 X^+\phi^-) + \right. \\
 & \left. \frac{1}{2}igM(X^- X^-\phi^- - X^- X^+\phi^+)\right.
 \end{aligned}$$

- Hundreds of Final State Particles
- Non-perturbative Physics
- Multiple orders of magnitude in energy



Tuning the Primordial Transverse Momentum in PYTHIA



Find the parameters that fit the most data

Every model has free parameters that need to be "tuned" by experiment.

Standard Model: 19 free parameters

- Fermion Masses (9)
- Gauge Couplings (3)
- CKM matrix (4)
- θ_{QCD} (1)
- Higgs vev (1)
- Higgs mass (1)

PYTHIA: ~ 60 free parameters (from Monash Tune)

- Final State Radiation (6)
- Initial State Radiation (15)
- PDF and Matrix Elements (3)
- Multiple Parton Interactions (12)
- Hadronization (23)

How do we tune so many parameters?

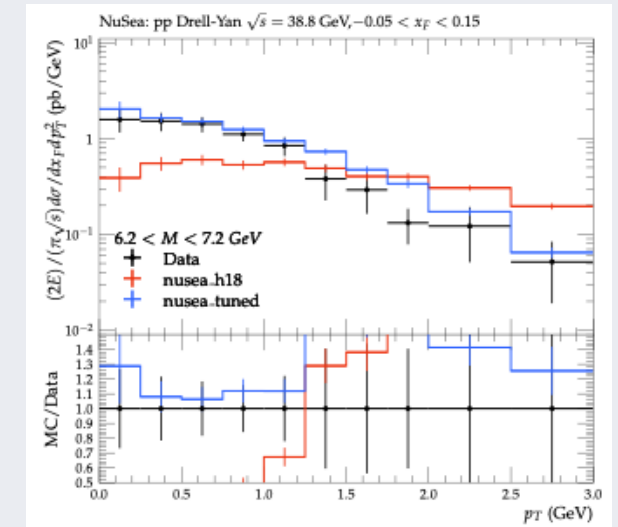
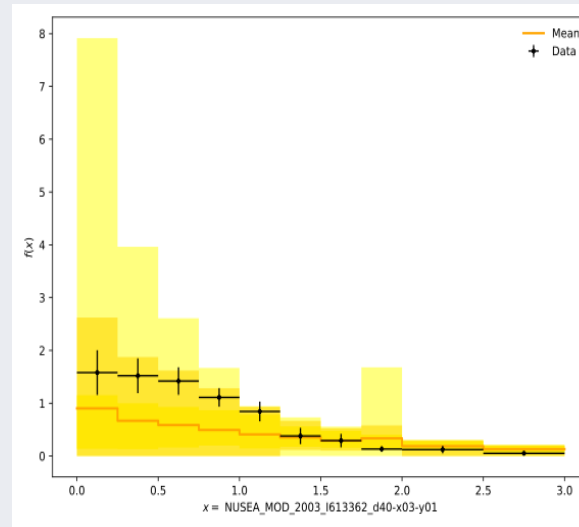
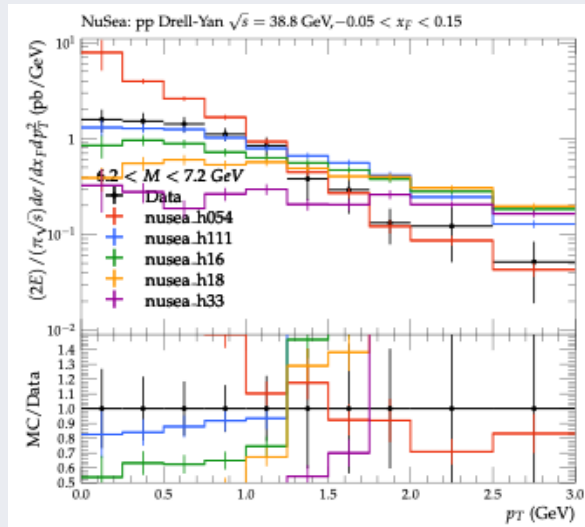
Surrogate Models with PROFESSOR
(at least for now)

Parameter Space
Sampling

Bin by bin
Polynomial
Interpolation

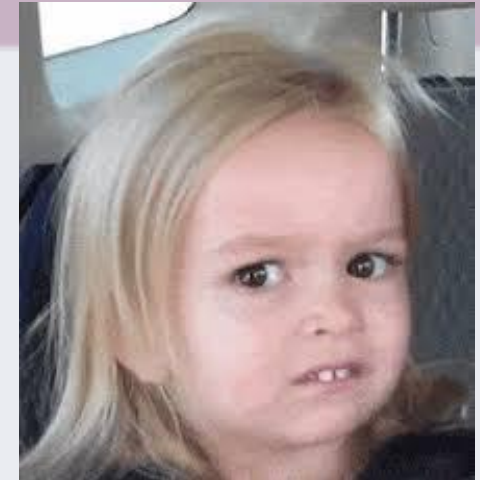
χ^2 minimization

Prediction



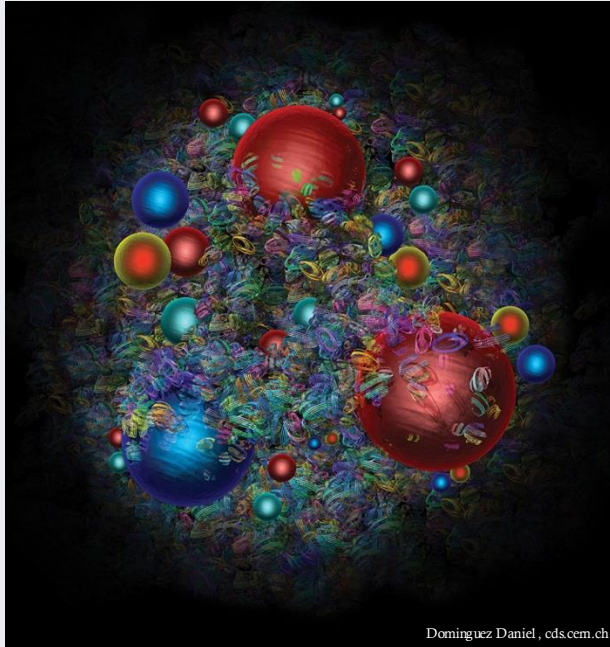


Tuning the **Primordial Transverse Momentum** in PYTHIA



Initial momentum transverse to the beam direction

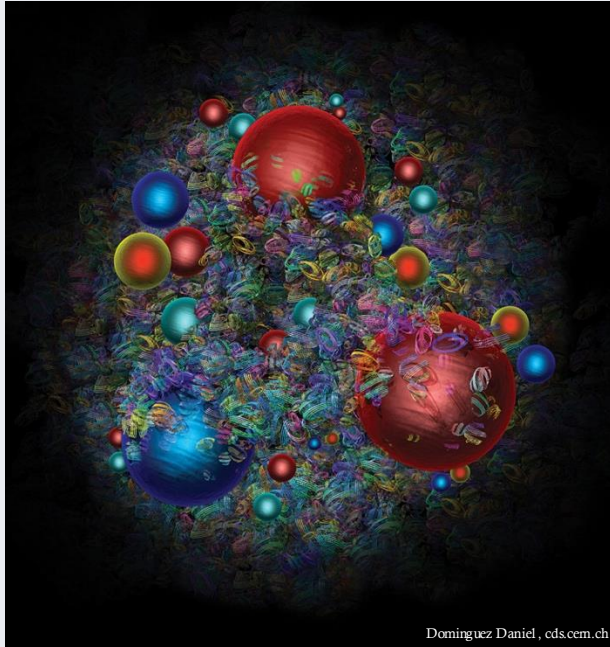
Proton at Rest



We expect the partons to have, at least, an average momentum of the order of $\Lambda_{QCD} \sim 300 \text{ MeV}$

Initial momentum transverse to the beam direction

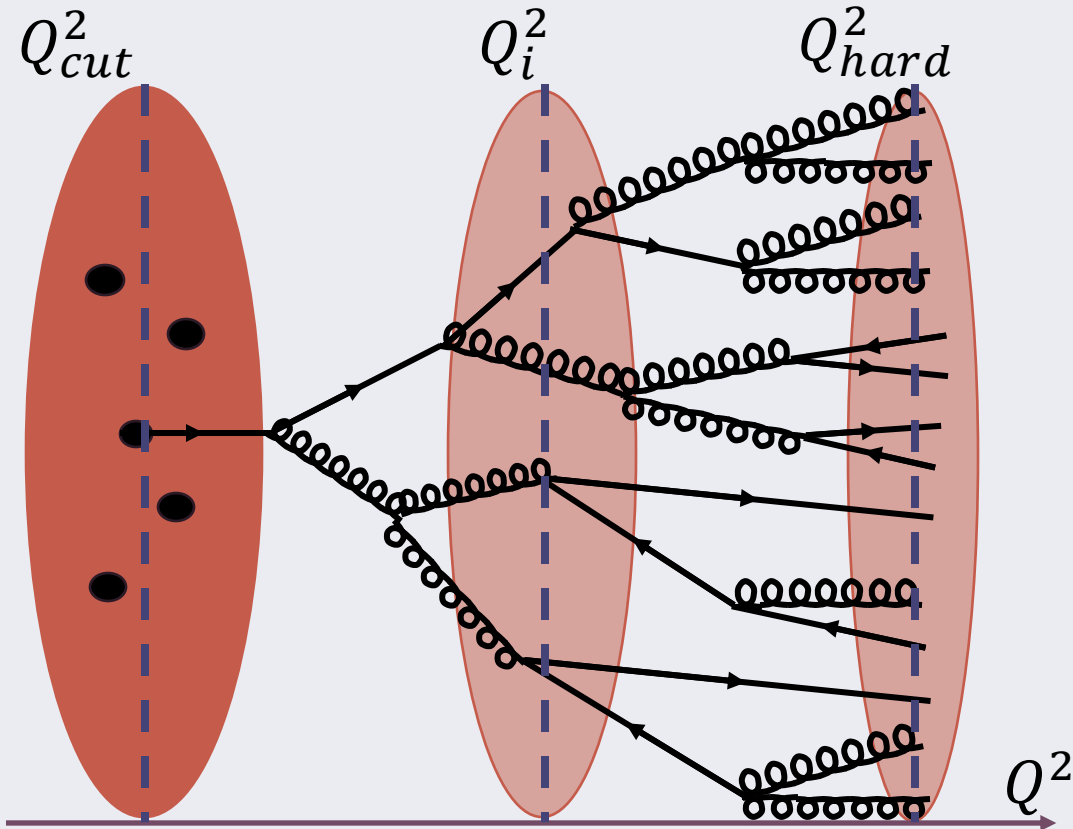
Proton at Rest



Dominguez Daniel, cds.cern.ch

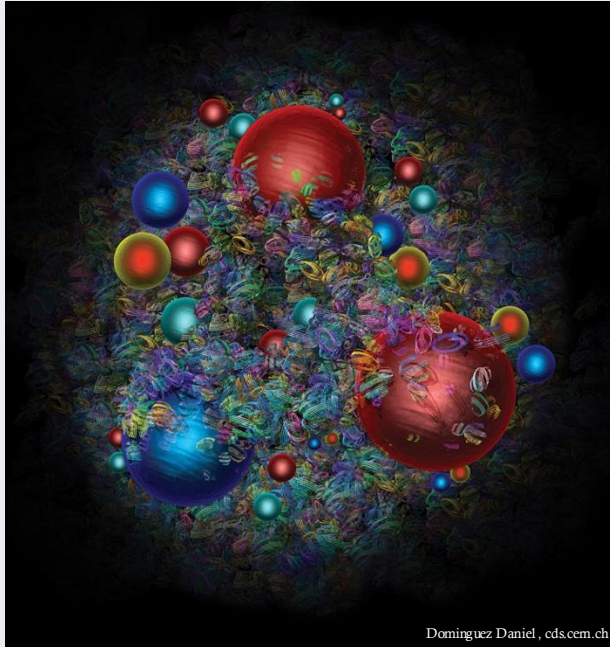
We expect the partons to have, at least, an average momentum of the order of $\Lambda_{QCD} \sim 300 \text{ MeV}$

Initial State Radiation (Space-like Parton Shower)



Initial momentum transverse to the beam direction

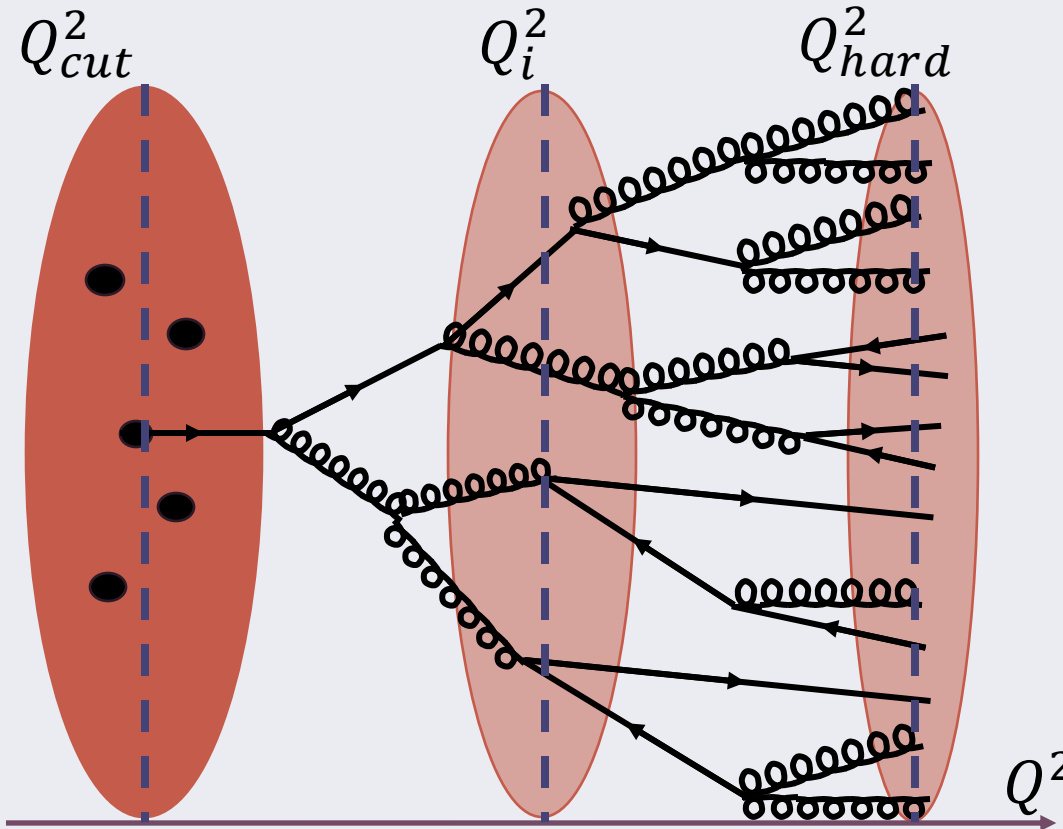
Proton at Rest



Dominguez Daniel, cds.cern.ch

We expect the partons to have, at least, an average momentum of the order of $\Lambda_{QCD} \sim 300 \text{ MeV}$

Initial State Radiation (Space-like Parton Shower)



Role of
Primordial k_T

Fermi motion of
partons below the
ISR cut-off.

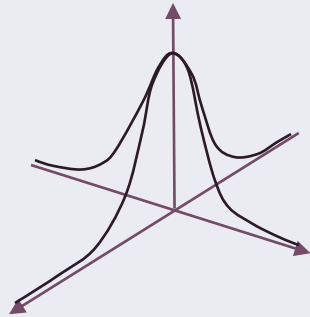
Radiation not
accounted for by
the parton shower
evolution.

Primordial k_T in PYTHIA

In PYTHIA the primordial k_T is applied as a correction on the transverse momentum that the space-like parton shower produces.

Parametrization is two gaussians: $\propto e^{-k_i^2/\sigma^2}$

All the parameters are in the width!



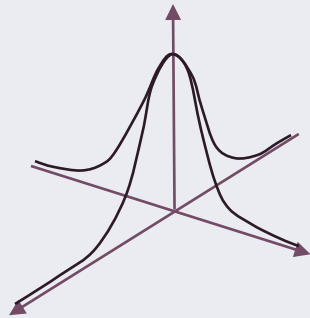
$$\sigma(Q, m) = \frac{m}{m + m_{1/2} y_{damp}} \frac{\sigma_{soft} Q_{1/2} + \sigma_{hard} Q}{Q_{1/2} + Q}$$

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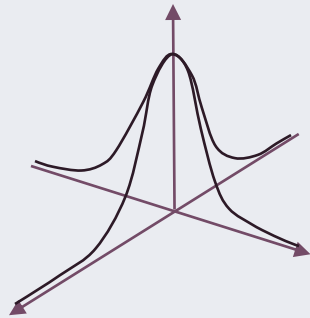
“Technical
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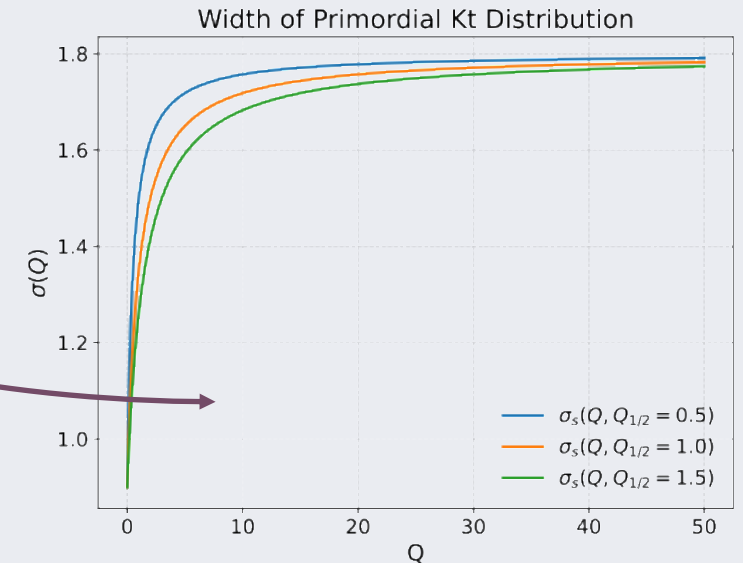
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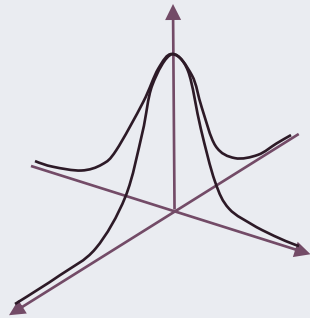


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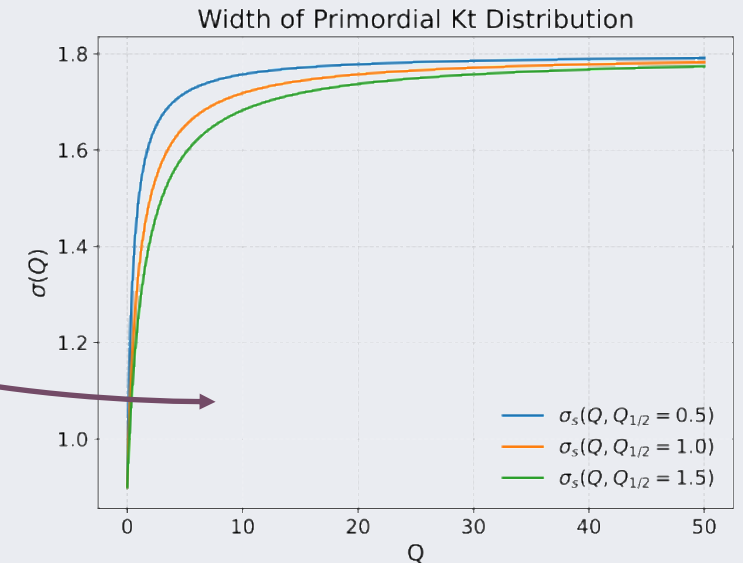
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“Technical Dampening Factor”

Default values:

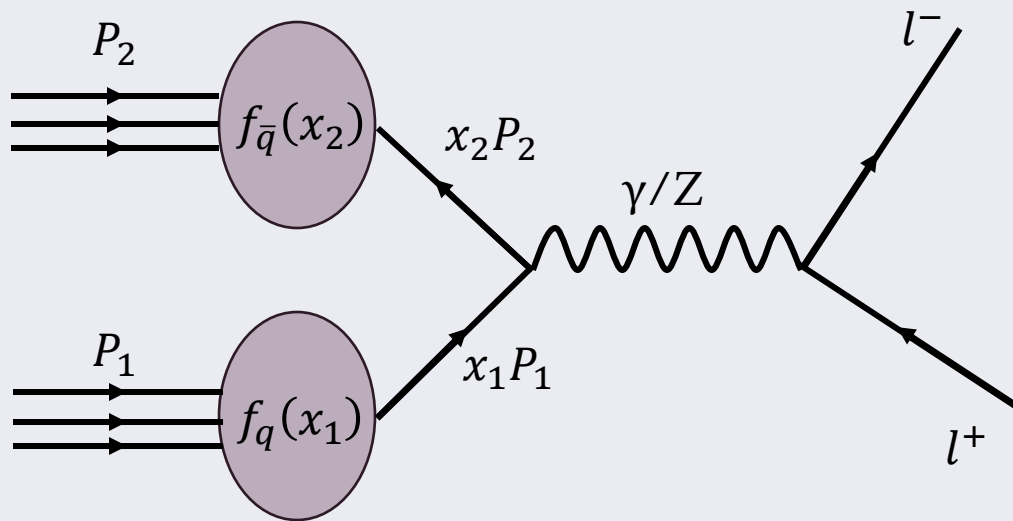
$$Q_{1/2} = m_{1/2} = 0$$

$$\sigma = \sigma_{hard}$$



Drell –Yan Process as Primordial kT Probe

Collinear Factorization: $\sigma_{AB} = \sum_q \int dx_1 dx_2 f_q(x_1, Q^2) f_{\bar{q}}(x_2, Q^2) \sigma_{q\bar{q} \rightarrow l^+ l^-}$



We generalize the PDFs:

$$dx f(x) \rightarrow d^2 k_T dx P(\vec{k}_T, x) = d^2 k_T dx h(\vec{k}_T) f(x)$$

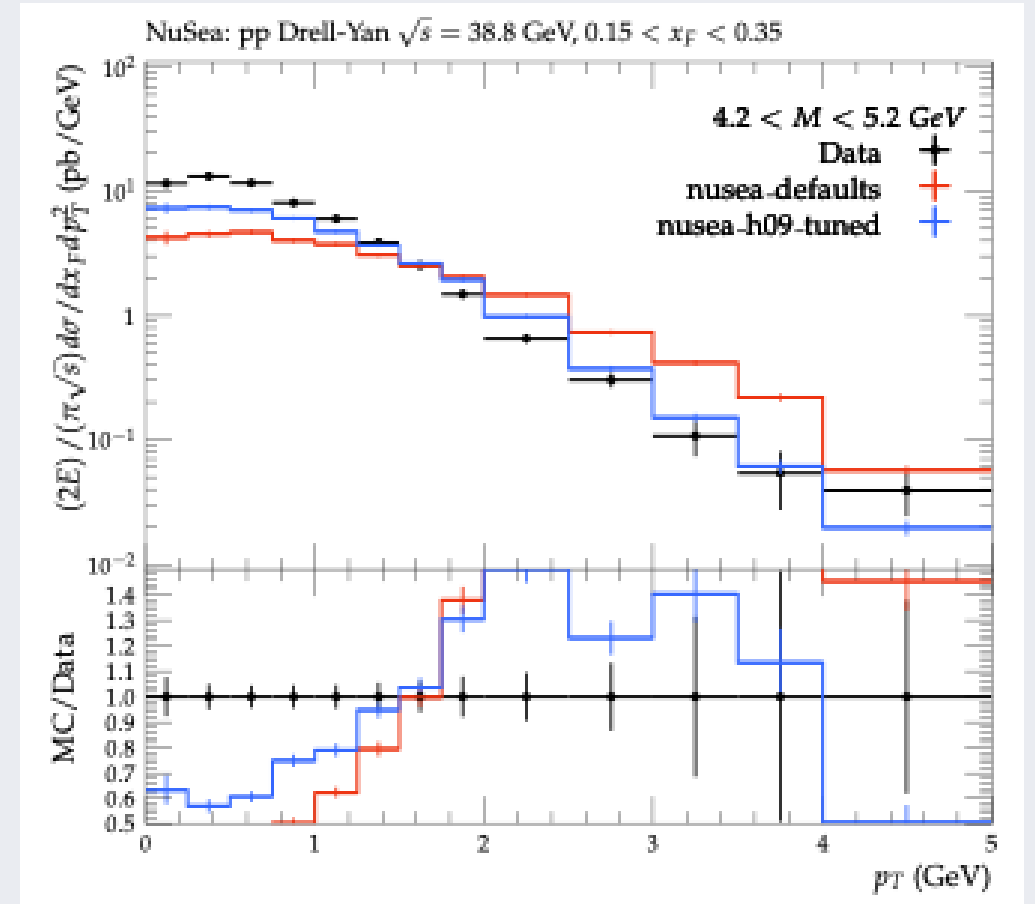
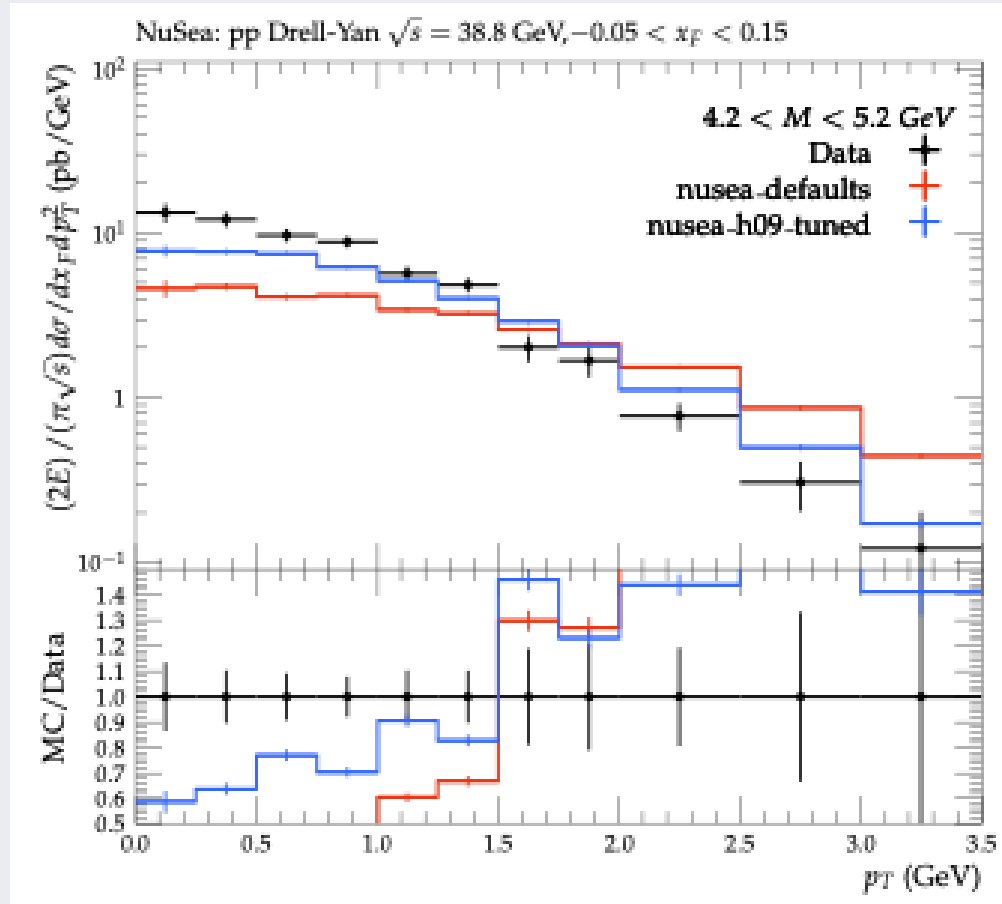
In the simple model of a Gaussian Distribution:

$$h(\vec{k}_T) = \frac{1}{\pi\sigma^2} e^{-k_T^2 / \sigma^2}$$

$$\frac{M^4}{\sigma} \frac{d^4 \sigma}{dM^2 dy d^2 p_T} = \frac{1}{2\pi\sigma^2} e^{-p_T^2 / 2\sigma^2}$$

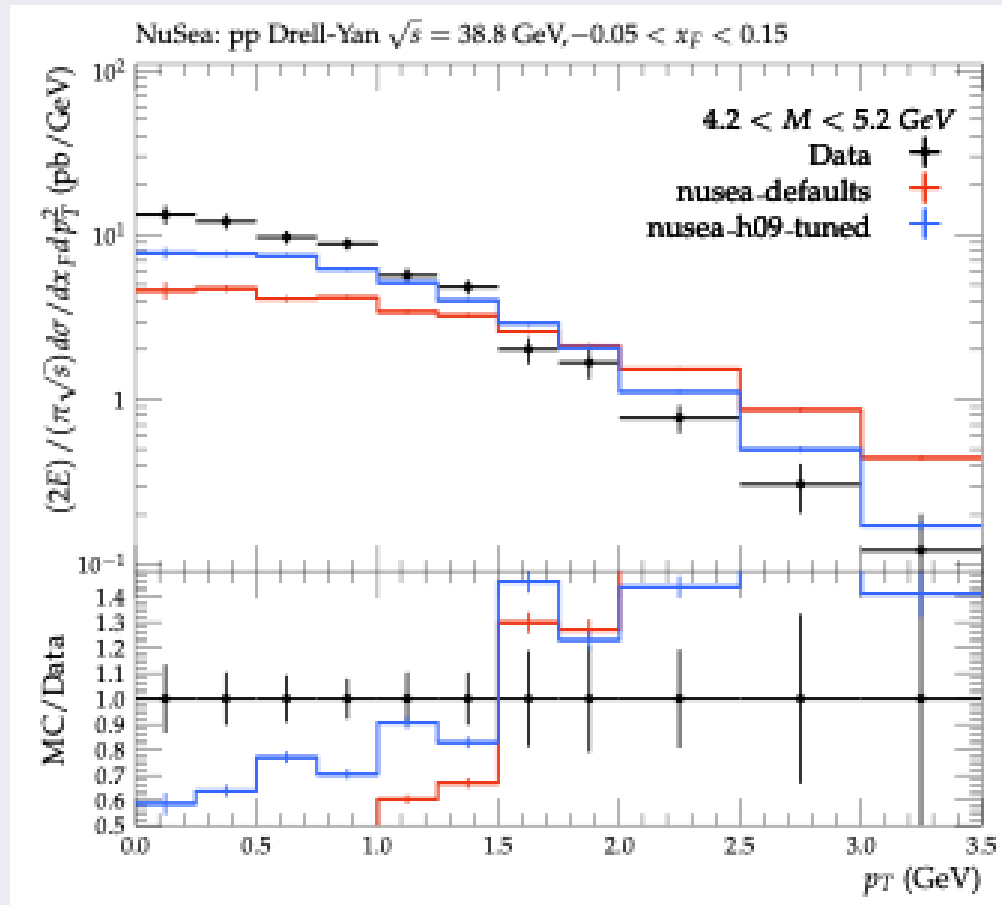
Some Tuning Results

NuSea Data: Drell-Yan dimuon production ($pp \rightarrow \mu^- \mu^+ + X$) at $\sqrt{s} = 38.8$ GeV.

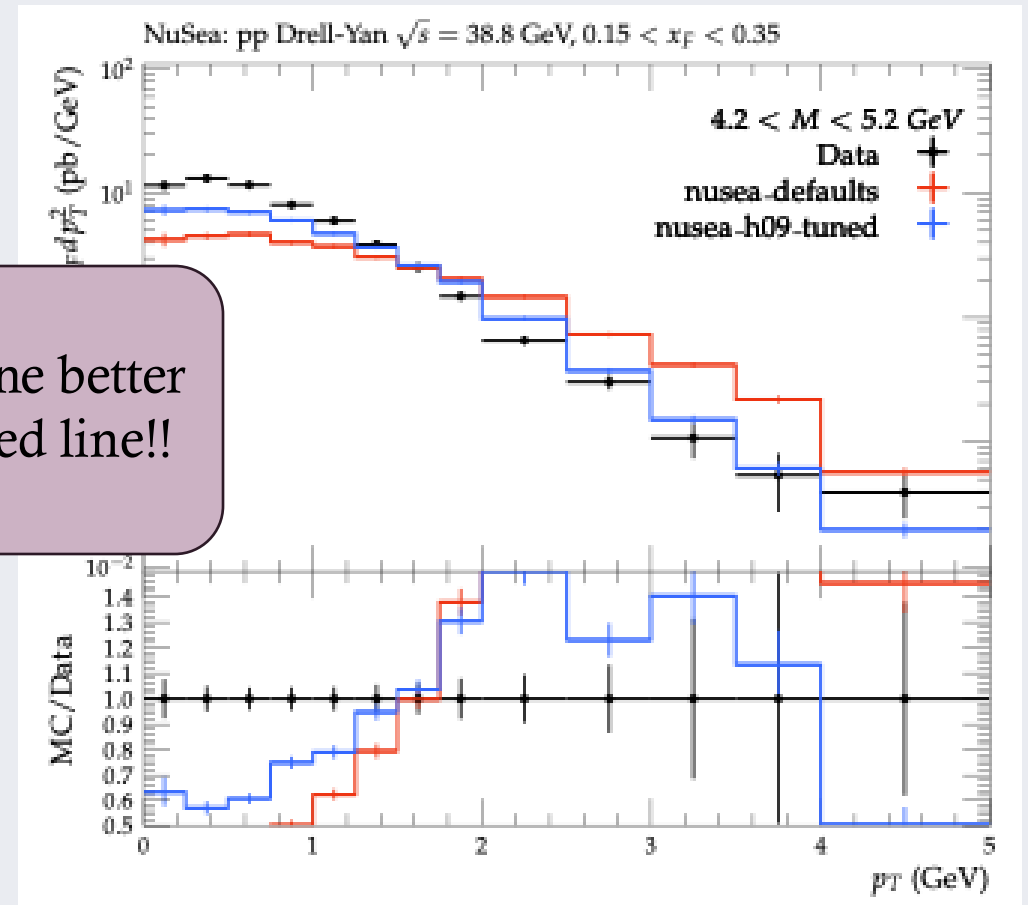


Some Tuning Results

NuSea Data: Drell-Yan dimuon production ($pp \rightarrow \mu^- \mu^+ + X$) at $\sqrt{s} = 38.8$ GeV.



Blue line better than red line!!

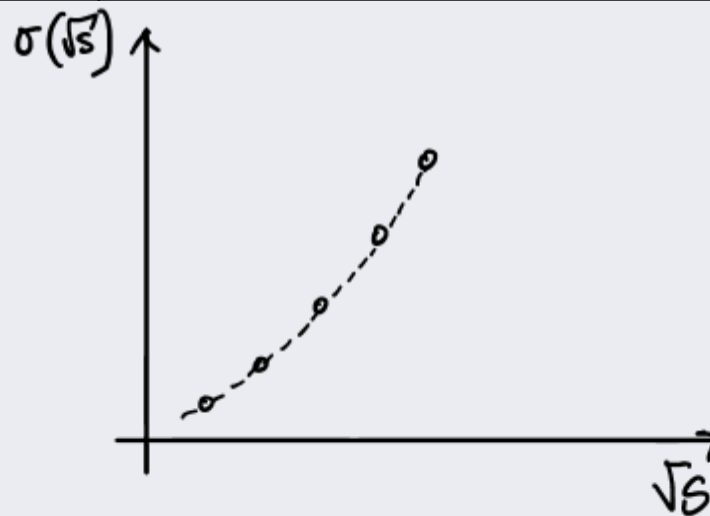
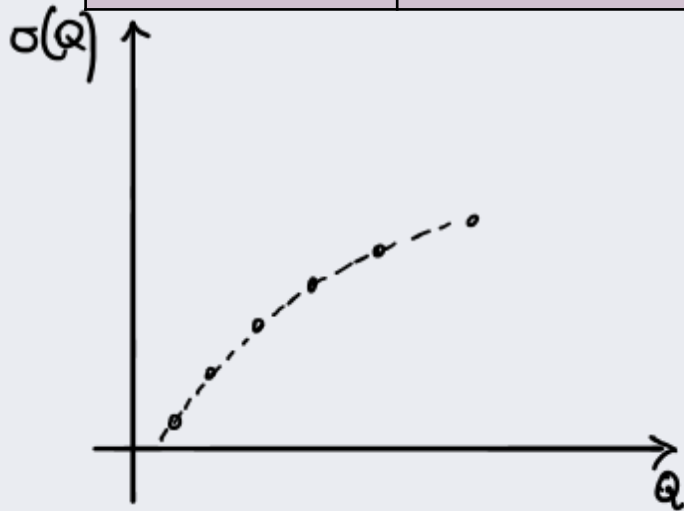


Work in Progress

Experiment:	\sqrt{s}	Q (GeV)
NUSEA	38.8 GeV	[4.2 , 6.2, 7.2, 8.7, 10.9, 12. 9]
PHENIX	200 GeV	[4.8 , 8.2]
CDF	1.96 TeV	[66, 116]
ATLAS	7 TeV	[66, 116]
CMS	13 TeV	[50, 1000]
ATLAS	13 TeV	[66, 116]

Last tune was Monash 2013 with very few data points

New tune bound to happen and maybe re-parametrization of the primordial kT in PYTHIA!



THANK YOU FOR LISTENING!

Division of Particle and Nuclear Physics –
PhD Day

