DIS 2004 Theory Highlights

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Overview

DIS2004, Strbskie Pleso, Slovakia, 14-18 April 2004.

Six working groups:

- Structure functions, low x
- Diffraction and Vector Meson
- Hadronic Final States
- Heavy Flavors
- Electroweak and Physics Beyond SM
- Spin Physics

~ 230 presentations

Available at:
http://www.saske.sk/UEF/OSF/DIS/sciprog.html

Selected topics

- Proton structure function: global fits
- Higher order calculations: NNLO splitting function
- BFKL Pomeron at non-zero temperature
- Dipole picture and saturation at low x
- Diffractive Higgs production
- Pentaquarks
- Heavy quark production
- Automated event shape resummation
- Matching MC with NLO
- Monte Carlo generators: Pythia and Herwig

Proton structure function: global fits

Good news: MRST analysis based on approximate NNLO splitting functions should be very accurate.
Careful analysis of pdf uncertainties using various methods.

Problems: MRST analysis shows that data require negative gluon at very low Q^2.
Finds tension between HERA F_2 data and jets and NMC data.

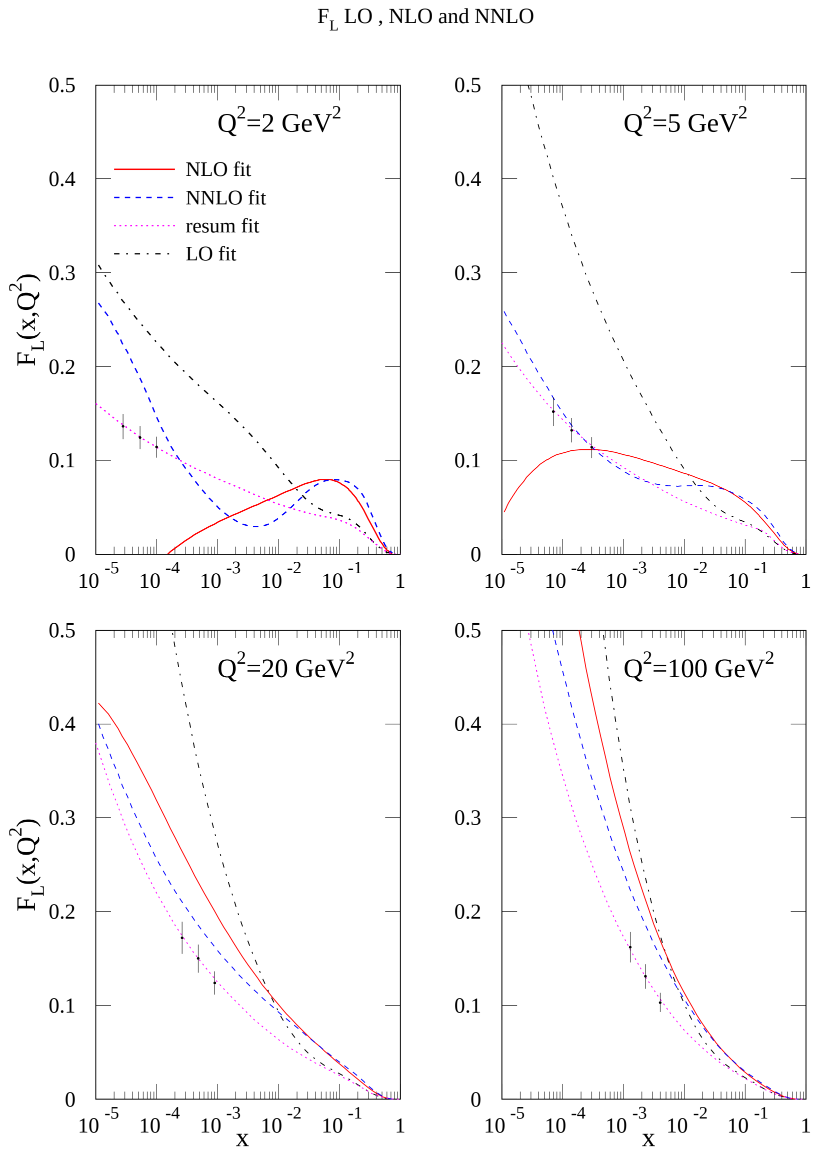
Tests: Vary kinematic cuts $W^2_{\rm min}, Q^2_{\rm min}, x_{\rm min}$, and refit the data. Observe if the χ^2 changes, proceed until it stabilizes.

Cuts in Q^2: raising cut from 2 to $10\ \mathrm{GeV}^2$ leads to slow continuous improvement $\rightarrow$ suggest that most corrections mainly higher order and not higher twist.
Cuts in x: continuous and significant improvement. Gluon becomes positive.

Two sets of partons: standard and conservative (higher cuts).
Significant impact on the exclusive observables like rapidity distribution of W boson.

Prediction for F_L structure function

Prediction for $F_L(x,Q^2)$ at LO,NLO,NNLO and $\ln 1/x$-resummed prediction (R.Thorne).



Desperate need of F_L measurement, which possibly could discriminate between NNLO and resummed predictions.

Splitting function at NNLO

A.Vogt: Complete results for next-to-next-to-leading order (NNLO) non-singlet and singlet splitting functions.

Small x limit of nonsinglet functions:

$$P^i_{(x\to 0)}(x) = D^i_0 \ln^4 x + D^i_1 \ln^3 x + D^i_2 \ln^2 x + D^i_3 \ln x$$

where

$$D_0^+ \simeq 1.58, \qquad D_1^+ \simeq 29.63 - 2.37 n_f,$$
$$D_2^+ \simeq 295.04 - 32.20 n_f + 0.59 n_f^2, \qquad D_3^+ \simeq 1261.11 - 152.60 n_f + 4.35 n_f^2$$

Strongly increasing coefficients of small x terms.

New, unpredicted small x term in P^s_{ns} :

$$\sim d^{abc} d_{abc} n_c \alpha_s^3 \ln^4 x$$

Splitting function at NNLO

Small x limit in singlet case:

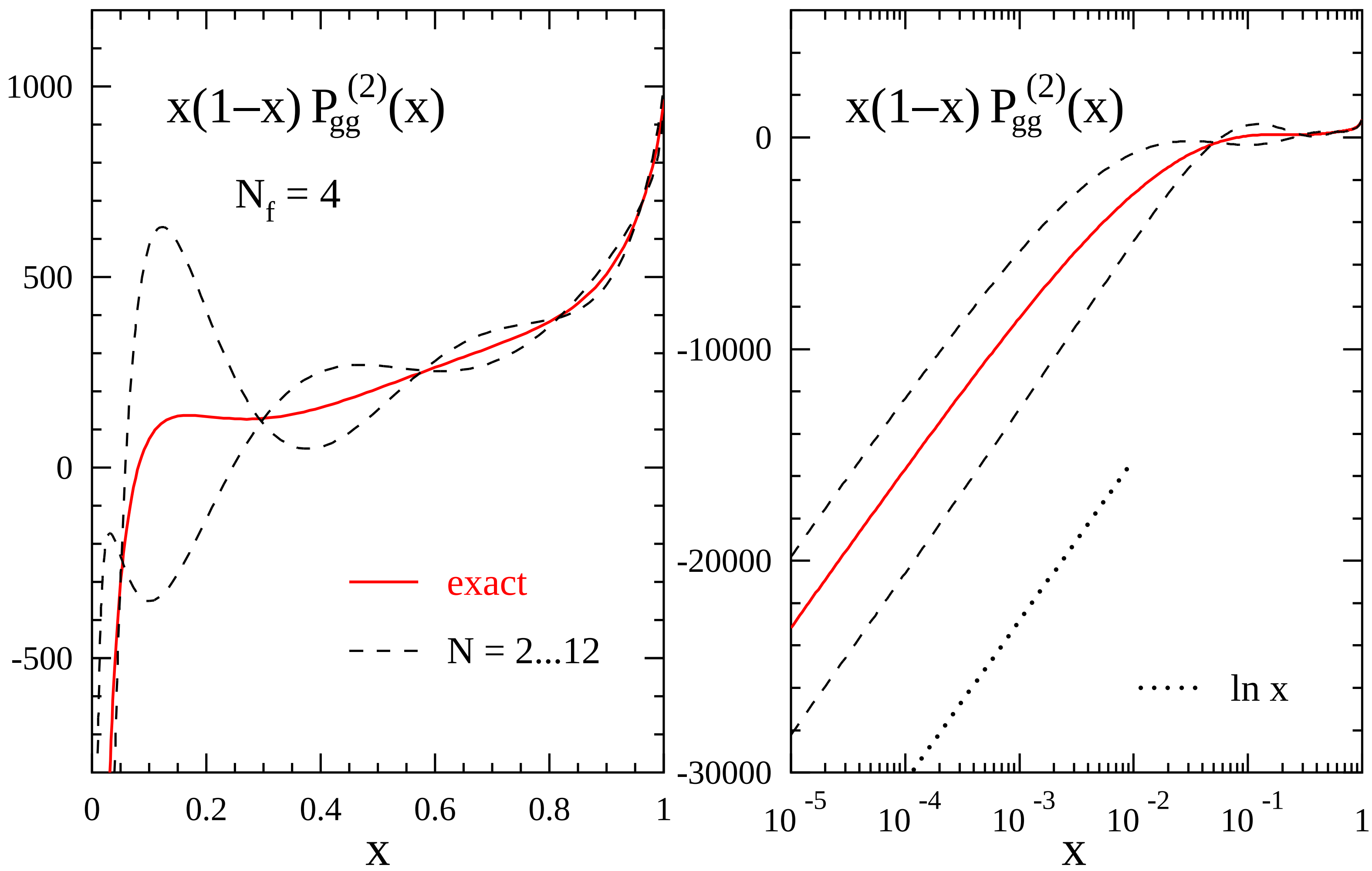
$$P_{ab}^{(2)} = E_1^{ab}\frac{\ln 1/x}{x} + E_2^{ab}\frac{1}{x} + \ldots$$

Small x terms E_1^{gg}, E_1^{qg} consistent with previous calculations: NLLx BFKL and Catani-Hautmann.

Exact values of P_{ab} within the error bands of the previous estimates.

One should not expect big differences from previous NNLO MRST estimates.

Splitting function at NNLO



Note: P_{gg} is negative

BFKL Pomeron at $T > 0$

Collision of heavy nuclei $\rightarrow$ formation of quark-gluon plasma

Parton-parton scattering leads to thermalisation of plasma

The confining potential between $q\bar{q}$ disappears, which leads to J/Ψ suppression.

A similar mechanism could occur for glueballs.

L. Lipatov: Study of influence of $T > 0$ on a Pomeron: cylinder topology

Results:

- resulting equation still has conformal symmetry, despite the presence of additional scale T
- energy dependence of the Pomeron the same as at $T = 0$
- extension to nonlinear equation
- different topologies $\rightarrow$ connection with string dynamics

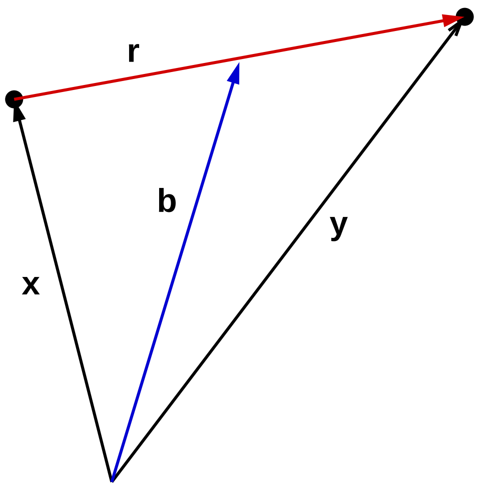
Balitsky-Kovchegov non-linear equation

$$\frac{\partial N_Y(\underline{x}_0,\underline{x}_1)}{\partial Y} = \bar{\alpha}_s \int \frac{d^2\underline{x}_2}{2\pi} \frac{(\underline{x}_0-\underline{x}_1)^2}{(\underline{x}_0-\underline{x}_2)^2(\underline{x}_1-\underline{x}_2)^2} \left[N_Y(\underline{x}_0,\underline{x}_2) + N_Y(\underline{x}_2,\underline{x}_1) - N_Y(\underline{x}_0,\underline{x}_1) - N_Y(\underline{x}_0,\underline{x}_2)N_Y(\underline{x}_2,\underline{x}_1)\right]$$

$N_Y(\underline{x}_0,\underline{x}_1)$ forward amplitude for scattering of the $q\bar{q}$ dipole on a nucleus target. Linear + rescattering term.

$$Y = \ln\left(\frac{1}{x}\right) \qquad \mathbf{r} = \underline{x}_0 - \underline{x}_1$$

$$\bar{\alpha}_s = \frac{\alpha_s N_c}{\pi} \qquad \mathbf{b} = \frac{\underline{x}_0+\underline{x}_1}{2}$$



Travelling waves and Saturation scale

In the approximation of large nucleus $R \gg r$, impact parameter b in BK equation can be neglected leading to 1+1 dim. problem

$$\partial_Y N = \bar{\alpha}_s \chi(-\partial_L) N - \bar{\alpha}_s N^2$$

with χ BFKL eigenvalue.

R.Peschanski: BK equation falls into class of nonlinear equation with general properties:

- $N = 0$ is unstable fixed point w.r.t. linear evolution
- nonlinearity tames the growth when $N \sim \mathcal{O}(1)$
- the initial condition must be sufficiently steep at large k, ($N \sim 1/k^2$)

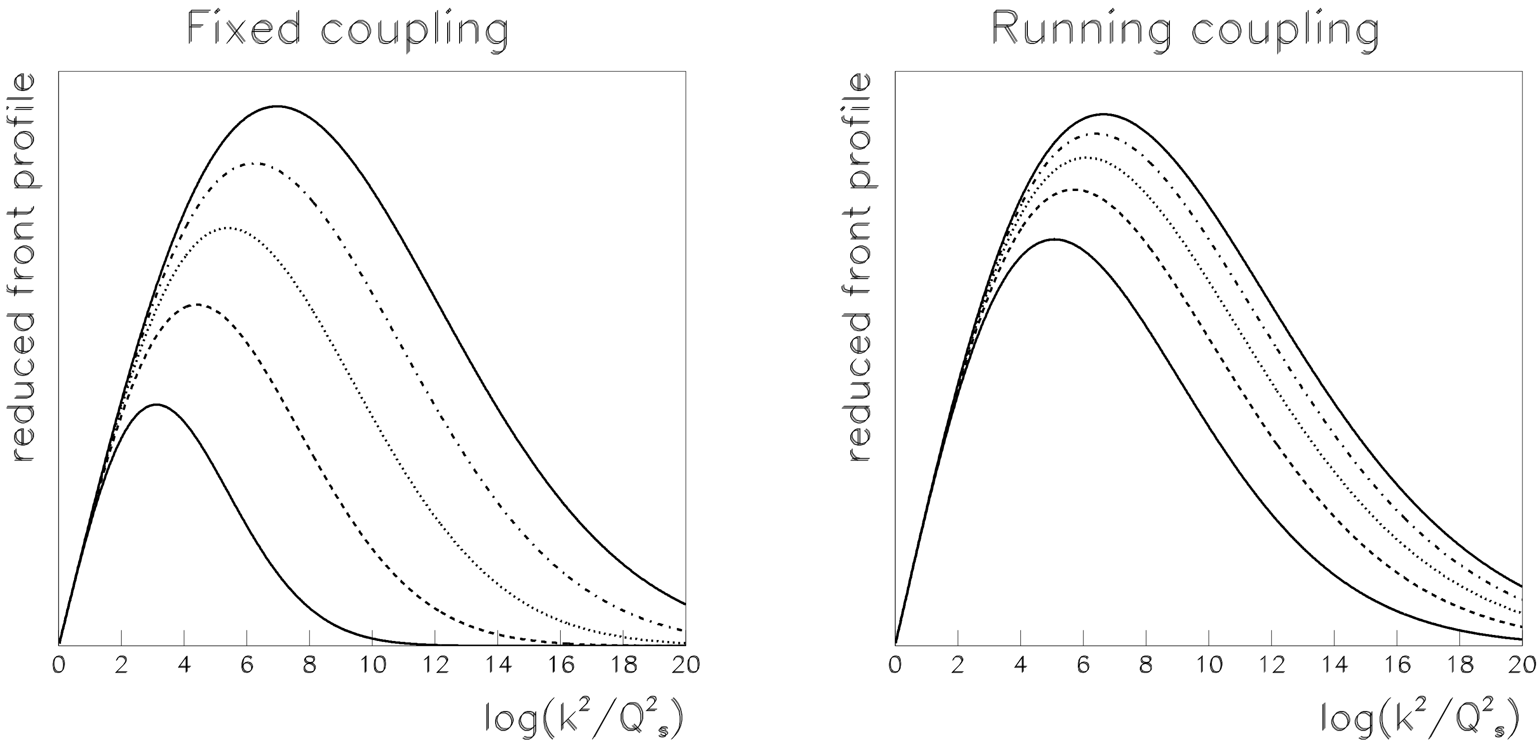
Relation with other fields in physics: Disordered phenomena, spin glass phase transitions, polymer diffusion

Travelling wave fronts

N is a travelling wave which moves with constant velocity

$$N(\ln k^2 - \ln Q_s^2(Y))$$

This corresponds to geometric scaling.



Rigorous results for $Q_s(Y)$ and $N(Y, k)$ also in the running coupling case.

Diffractive Higgs production

A.Martin: Exclusive double-diffractive Higgs production is a valuable process for Higgs production at LHC

$$\mathrm{pp} \longrightarrow \mathrm{p} + \mathrm{H} + \mathrm{p}$$

$$M_H = M_{b\bar{b}} (\sim 10\,\mathrm{GeV\ resol.}) \qquad \text{or} \qquad M_H = M_{miss} (\sim 1\,\mathrm{GeV\ resol.})$$

In the latter case: if proton taggers installed at $420\,\mathrm{m}$.

Example: $\mathcal{L} = 30\ \mathrm{fb}^{-1}$, $M_H = 120\ \mathrm{GeV}$
then $11\ \ H \to b\bar{b}$ events can be seen and $4\ \ b\bar{b}$ background.

Rate can be checked by observing:

$$\mathrm{pp} \longrightarrow \mathrm{p} + \mathrm{dijet} + \mathrm{p}$$

So far consistent with CDF bound.

Diffractive Higgs production

$$\Lambda_{QCD}^2 \ll Q_t^2 \ll M_H^2$$

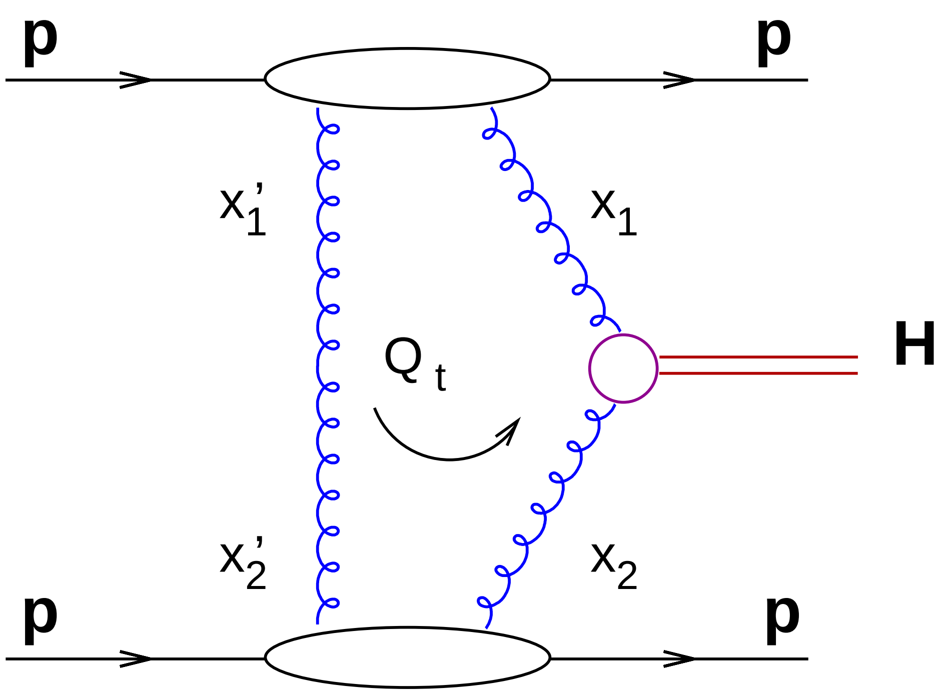
Use of pQCD justified

$$x' \sim \frac{Q_t}{\sqrt{s}} \ ,$$

$$x \sim \frac{M_H}{\sqrt{s}}$$

$$x' \ll x \ll 1$$

Need to use uninte-grated skewed gluon pdfs.



Diffractive Higgs production

$$\mathcal{M} \sim \frac{1}{M_H^2} \int \frac{d^2 Q_t}{Q_t^4} f(x_1, x_1', Q_t^2, \frac{M_H^2}{4})\, f(x_2, x_2', Q_t^2, \frac{M_H^2}{4})$$

where

$$f(x_1, x_1', Q_t^2, \mu^2) \simeq R \frac{\partial}{\partial \ln Q_t^2} \left[\sqrt{T(Q_t, \mu)}\, xg(x, Q_t^2) \right]$$

R is a skewed effect.
$T(Q_t, \mu)$ Sudakov form-factor, strongly suppress the infrared Q_t region

$$Q_t^2 \sim 4 \text{ GeV}^2$$

Need to evaluate additional suppression factor
$\longrightarrow$ no soft rescattering.

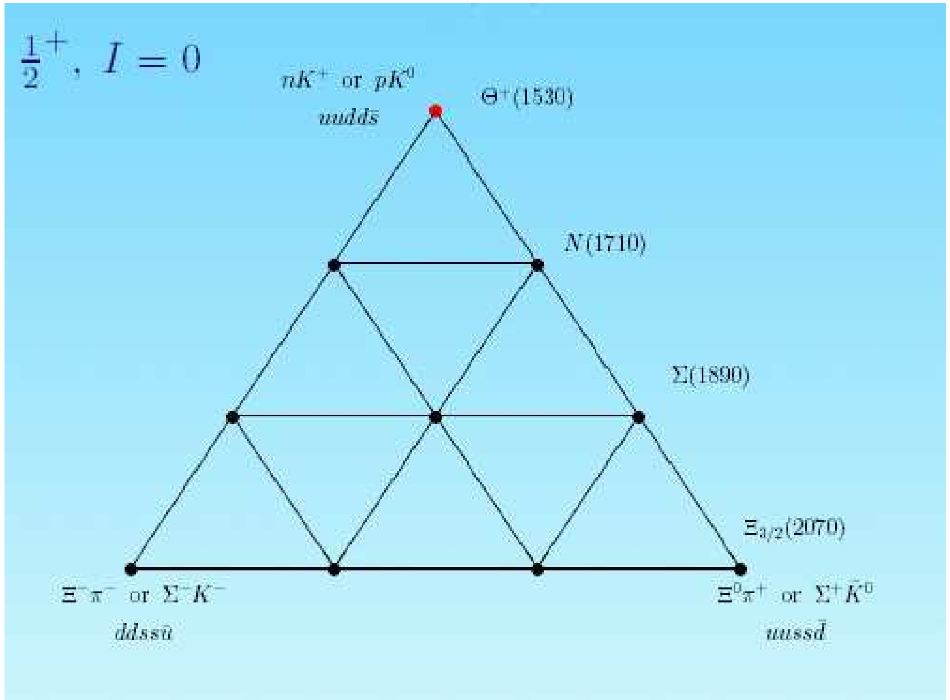
$$S^2 = 0.05 \text{ at Tevatron} \qquad S^2 = 0.026 \text{ at LHC}$$

Pentaquarks

Prediction on Θ^+ (Praszałowicz 87', Diakonov,Petrov, Polyakov 97'):

- $m_{\Theta^+} \simeq 1530\mathrm{MeV}$
- $\Gamma_{\Theta^+} < 10\mathrm{MeV}$
- $J^P = \frac{1}{2}^+$
- $I = 0$

Θ^+ is a member of $\overline{10}$ of $SU(3)_f$:



Pentaquarks

M.Karliner: Θ^+ in terms of quark language.

$$|\Theta^+\rangle = |uudd\bar{s}\rangle$$

Constituent quark model:

$$M = \sum_i m_i - \sum_{i>j} V(\lambda_i \cdot \lambda_j) \frac{\sigma_i \cdot \sigma_j}{m_i m_j}$$

where m_i quark mass, λ_i $SU(3)_c$ generator, σ_i Pauli spin matrices

Algebra of color $\times$ spin

symmetric in color $\times$ spin $\leftrightarrow$ attractive
antisymmetric in color $\times$ spin $\leftrightarrow$ repulsive

Θ^+ quark structure

- Identical fermions need to be antisymmetric $\rightarrow$ hyperfine repulsion
- Maximize $u-u$ and $d-d$ distances
- Minimize hyperfine interaction
- Mate swapping $\{udd\}\{u\bar{s}\} \rightarrow \{ud\bar{s}\}\{ud\}$
- System is in P wave

Resulting configuration of diquark-triquark

Computation of mass from this configuration:

$$m_{\Theta^+} \simeq 1592 \pm 50 \text{ MeV}$$

vs

$$m_{\Theta^+} = 1542 \pm \ 5\text{MeV}$$

from Experiment.

Predictions for other pentaquarks

Analogous diquark-triquark configurations give:

- $m_{\Xi^{--}} = 1720\mathrm{MeV}$
- $m_{\Theta_c} = 2985 \pm 50$ MeV, $\Theta_c : \{ud\}\{du\bar{c}\}$, $\Gamma(\Theta_c \to DN) \sim 20 - 40\mathrm{MeV}$
- $m_{\Theta_b} = 6398 \pm 50$ MeV, $\Theta_b : \{ud\}\{du\bar{b}\}$, $\Gamma(\Theta_b \to BN) \sim 4 - 8\mathrm{MeV}$

Look for narrow peaks in $D^- p, \bar{D}^0 n, B^0 p, B^+ n$

Interesting possibility: pentaquark production in B decays.

Progress in bottom production

S.Frixione:
In principle well posed perturbative problem: $m_b \gg \Lambda_{QCD}$. Partonic cross section computable in pQCD:

$$d\hat{\sigma}_{ij\to Q\bar{Q}} = \sum_{i=2}^{\infty} a_i \alpha_s^i = \overbrace{a_2 \alpha_s^2}^{LO} + \overbrace{a_3 \alpha_s^3}^{NLO} + \ldots$$

Possible uncertainties:

- Large logs: $a_i = \sum_{k=0}^{i-2} a_i^{(i-2-k)} \log^{i-2-k} \mathcal{O}$, with $\alpha_s \log^2 \mathcal{O} \geq 1$
  - large p_T: $\mathcal{O} = \frac{p_T(Q)}{m_Q}$
  - threshold logs: $\mathcal{O} = 1 - \frac{4m_Q^2}{\hat{s}}$
  - small-x logs: $\mathcal{O} = \frac{m_Q^2}{\hat{s}}$
- quark to hadron fragmentation

Progress in bottom production

To match the resummed calculation with the fixed one FONLL scheme (Cacciari, Greco, Nason):

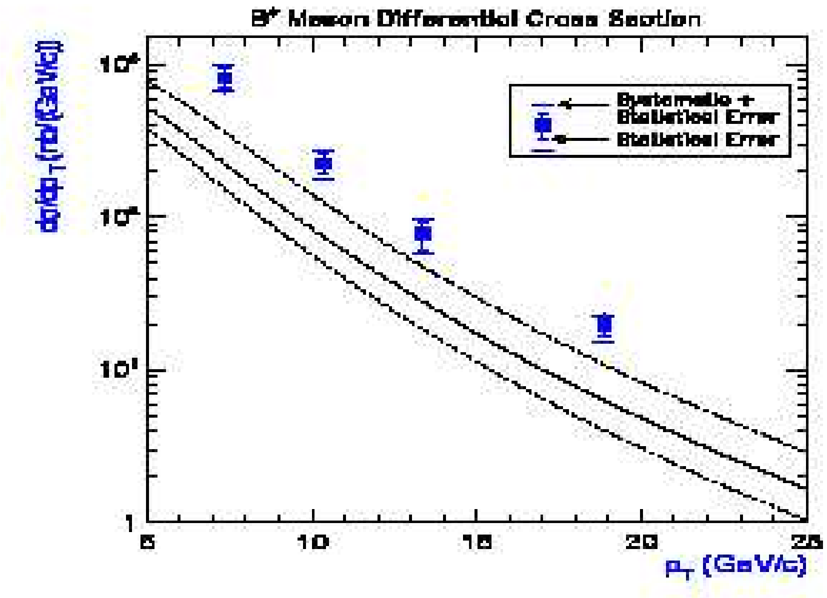
$$\frac{d\sigma}{dp_T^2} = a_2\alpha_s^2 + a_3\alpha_s^3 + \alpha_s^2 \sum_{i=2}^{\infty} r_i^{(0)} \left(\alpha_s \log \frac{p_T^2}{m^2}\right)^i + \alpha_s^3 \sum_{i=1}^{\infty} r_i^{(1)} \left(\alpha_s \log \frac{p_T^2}{m^2}\right)^i$$

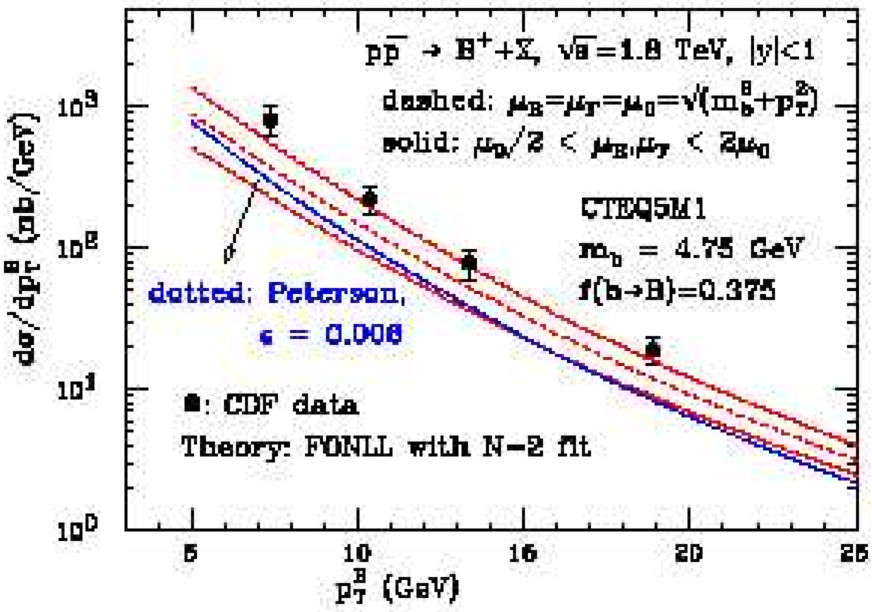
- Better than NLO computations
- Better than resummed computations
- Introduces matching uncertainty

Additionally new treatment of fragmentation function, fitting the Mellin moments.

Bottom production

QCD description of bottom production: before and after





Data/Theory=$2.9 \pm 0.2 \pm 0.4$

Data/Theory=$1.7 \pm 0.5 \pm 0.5$

Improvement due to NLO $\rightarrow$ FONLL (20%), and to correct treatment of the fragmentation (45%). Data are consistent with the upper end of the QCD band. No need to invoke new physics.

Resummation in event shapes

Study of event shapes is fundamental for

- measurements of coupling α_s and its renormalization group running
- measurements/cross checks of the values of the colour factors in QCD
- study of the transition from parton to hadron level

Resummation: accounts for multiple soft/collinear radiation.
Perturbative expansion is poorly convergent:

$$P(1-T<\tau) \equiv \Sigma(\tau) = 1 + \sum_{n=1} R_{n,2n} \alpha_s^n \ln^{2n} \tau + \ldots$$

Exponentiation and resummation of LL and NLL terms:

$$\Sigma(\tau) \simeq \exp\left[\sum_{n=1}\left(\overbrace{G_{n,n+1}\alpha_s^n \ln^{n+1}\tau}^{LL} + \overbrace{G_{n,n}\alpha_s^n \ln^n \tau}^{NLL} + \ldots\right)\right]$$

Event shapes, resummation

However, resummation done for each observable separately.
G.Salam: alternative analytical & numerical approach to resummation.

- derive analytically a resummed result for a general observable in terms of clearly identifiable properties of that observable
- derive associated applicability conditions to ensure that result is applied only to observables for which it is valid
- use computer subroutine for observable & high precision numerics to
  - test applicability conditions
  - determine observable-specific 'properties' needed for the explicit resummed answer

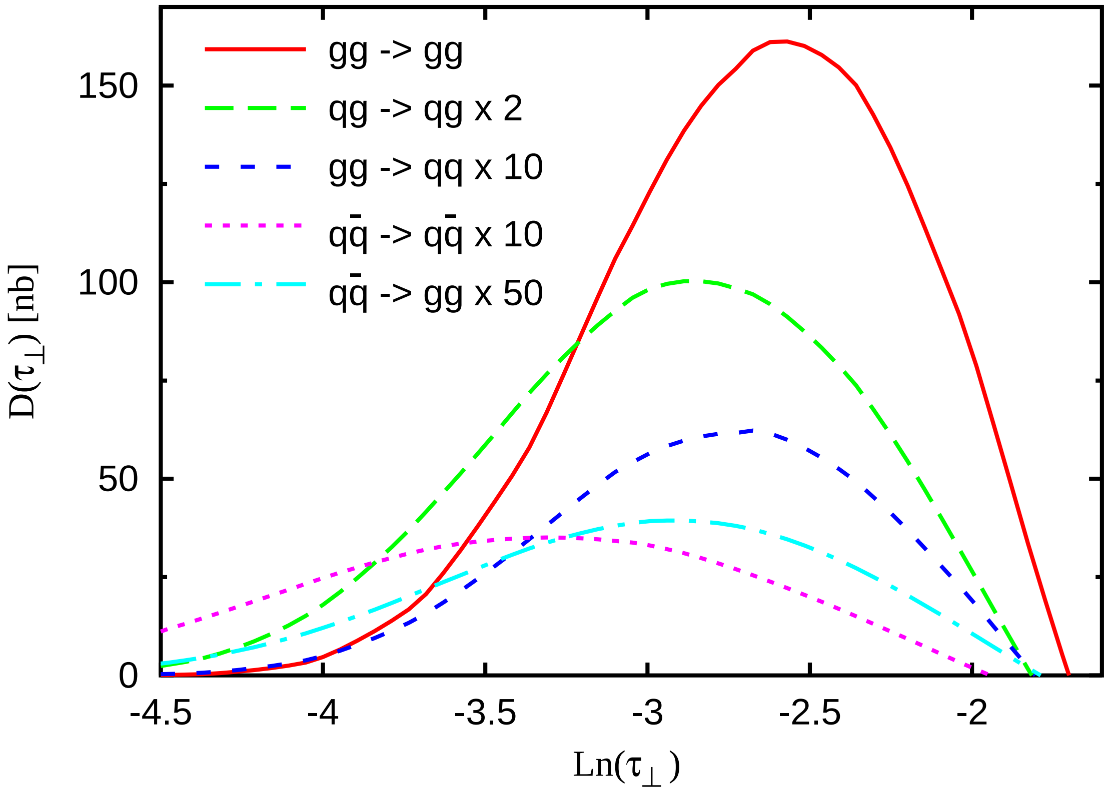
Computer Automated Expert Semi-Analytical Resummation
CAESAR

In practice: user provides the routine with the observable, the program returns the observable's distribution $\Sigma(v)$ at NLL accuracy.

Example of THRUST distribution

$$\tau_\perp \equiv 1 - \max_{\mathbf{n}_\perp} \frac{\sum_i |\mathbf{p}_{\perp i} \cdot \mathbf{n}_\perp|}{\sum_i p_{\perp i}}$$

- run II Tevatron, $\sqrt{s} = 1.96\text{TeV}$
- cut on jet transverse energy $E_T > 50$ TeV
- cut on rapidity $|\eta| < 1$



MC@NLO

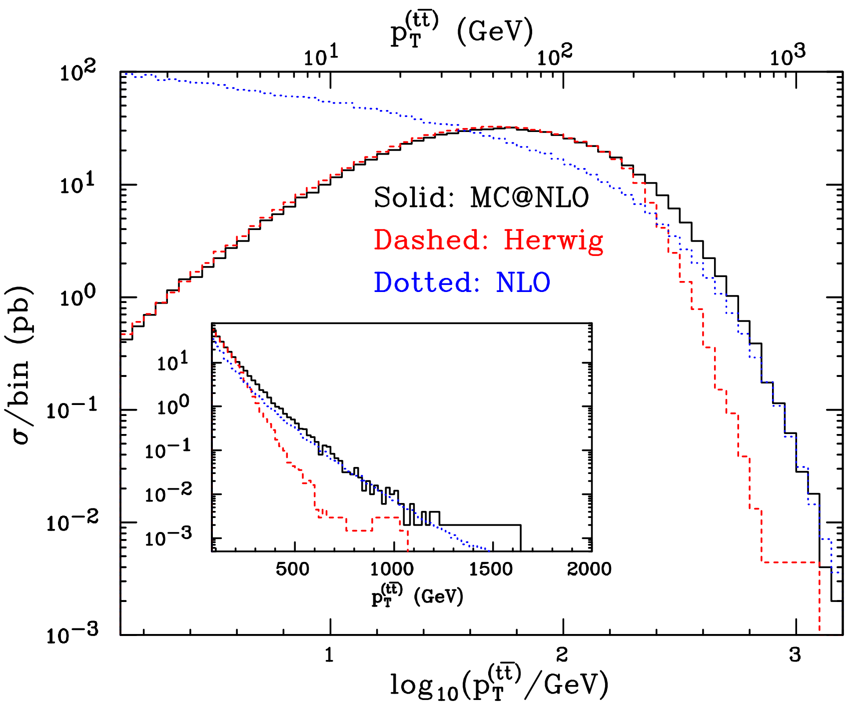
S.Frixione: Problem of matching the Monte Carlo Parton Showers with the fixed order NLO calculations.

- Fixed order calculations:good $\rightarrow$ best treatment of hard emissions, accurate for total rates. bad $\rightarrow$ hadronization; soft,collinear emissions
- MC with PS: good $\rightarrow$ hadronization implemented, access to exclusive states, soft and collinearly safe. bad $\rightarrow$ high p_T, total rates

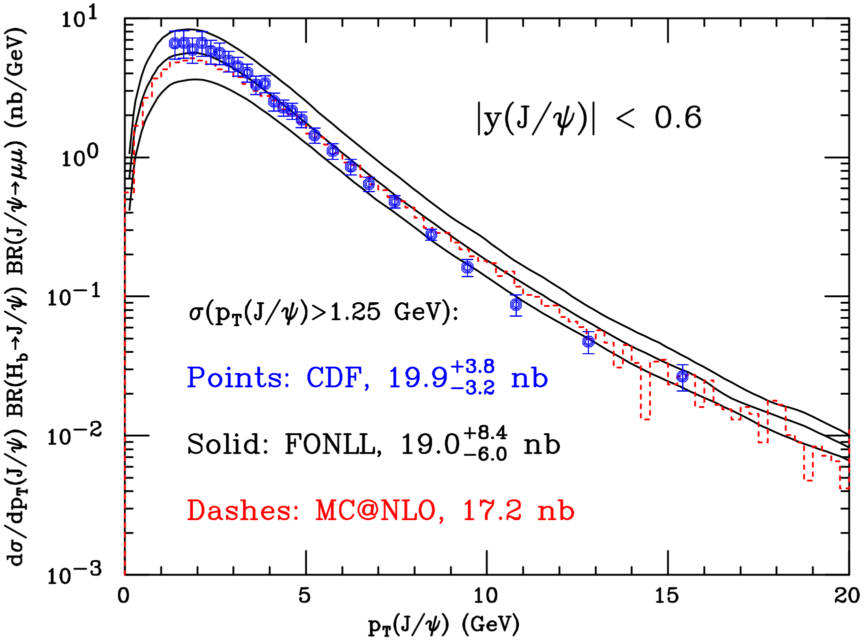
MC@NLO combines the features of both:

- The output is a set of events which are fully exclusive
- Total rates are accurate up to NLO
- NLO results for all observables are recovered upon expansion of MC@NLO results to α_s (no double counting)
- hard emissions are treated as in NLO calculations
- Soft and collinear emissions are treated as in MC
- Matching between soft and hard region is smooth

MC@NLO



p_T spectrum of $t\bar{t}$ pair from HERWIG, MC@NLO and NLO calculations. MC@NLO matches MC at small p_T and NLO calculations at high p_T.



Spectrum of J/Ψ at CDF from B decays. No PTMIN dependence from MC@NLO and good agreement with FONLL.

Monte Carlo: HERWIG and PYTHIA

PYTHIA7 and HERWIG++ are based on one framework: ThePEG.

ThePEG (Toolkit for high energy Physics Event Generation) is a general and modular C++ framework for implementing event generator models.

Cons:

- Lack of total independence
- Miss the possibility to test codes against each other

Pros:

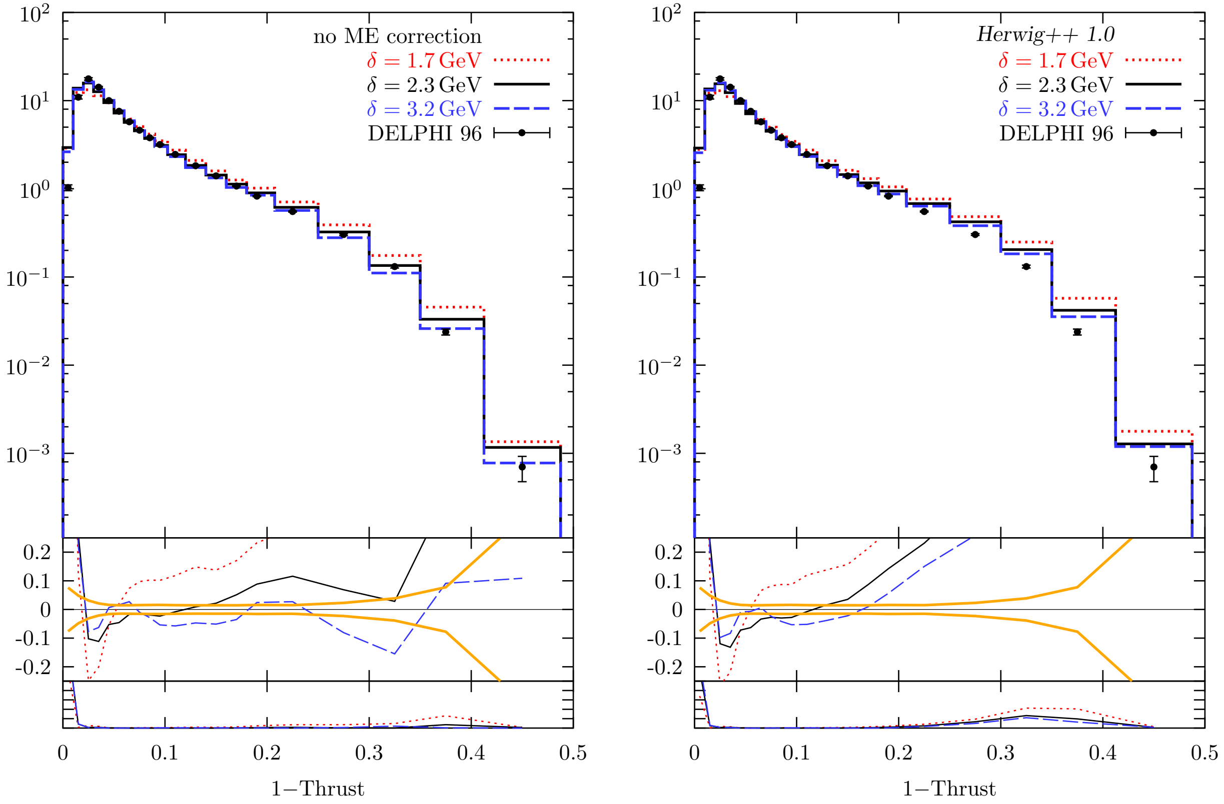
- Physics implementation is still independent
- Beneficial for the user to have the same framework
- Running Herwig++ with Lund String Fragmentation from Pythia7 is now very simple

HERWIG++ and Pythia7

Pythia7/ThePEG includes some basic $2 \to 2$ matrix elements, a couple of PDF parametrizations, initial and final-state parton showers, Lund String fragmentation and particle decays.

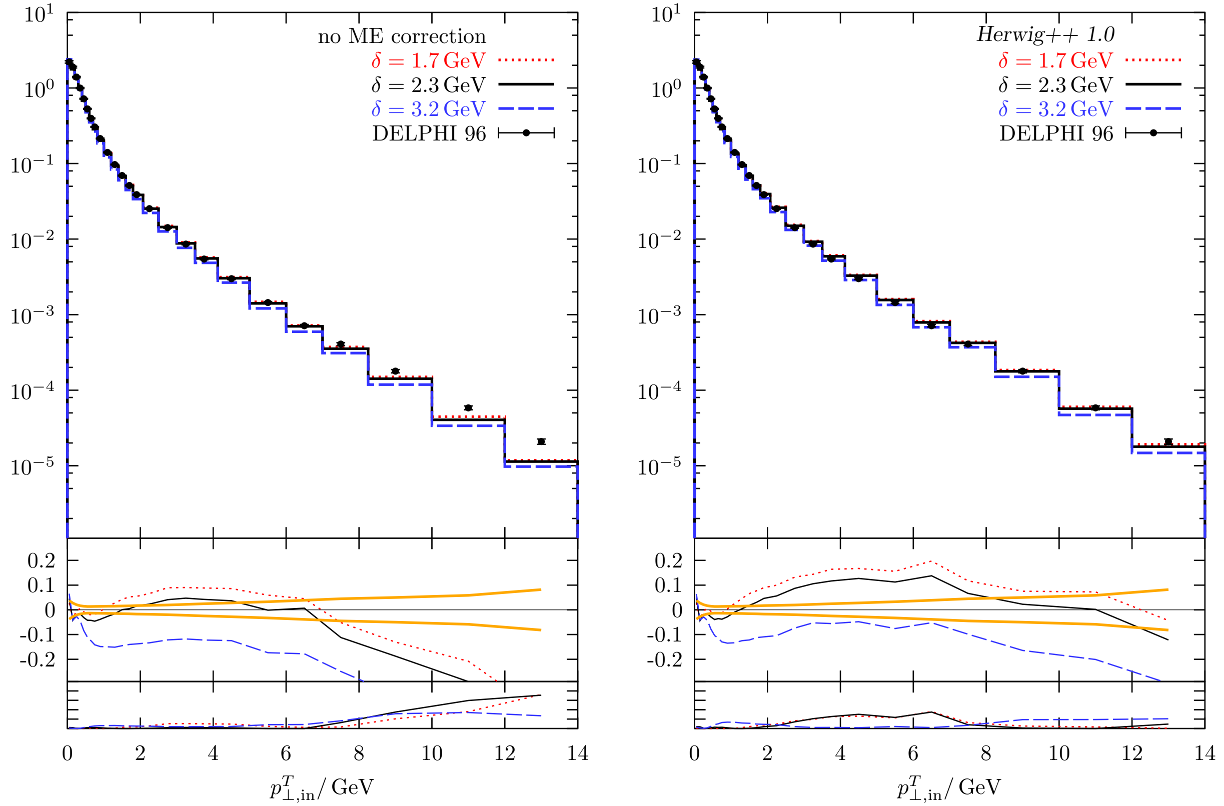
HERWIG++ includes a new parton shower algorithm, matrix element corrections, improved cluster fragmentation. Mainly e^+e^-

Example of Herwig++ results



Thrust without (left) and with (right) matrix element corrections.

Example of Herwig++ results



Momentum distributions of charged particles with respect to the thrust axis, $p_{\perp,\mathrm{in}}^{T}$ (with and without matrix element corrections).

Overall agreement with the data is very good.

Plans for future

Pythia7:

- rework fragmentation to include junction strings
- multiple interactions

Herwig++:

- initial state PS
- SUSY/BSM
- tests of Drell-Yan and jets in pp collisions

ARIADNE:

- dipole shower with ME matching
- LDC model with multiple interactions