# *Report from the Analysis Center Monte Carlo Group*

***Albert Knutsson***

**Co-conveners and contact persons:**
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**Outline**

- **The MC Group**
- **Activities and projects**
  - **PDFs and unintegrated PDFs for Monte Carlo**
  - **HEPMCAnalyser**
  - **OOPDFs**
  - **Parton showers**
- **Summary and Future Plans**

# The MC group

**The Monte Carlo group is an international meeting place for theorist and experimentalists, a link between experiments, and a training center for students and post-docs.**

***Theorists and experimentalists work together for an improved understanding of the Standard Model, especially QCD.***

- **Mission → An improved understanding of (QCD) LHC events:**

  *Event = PDF × (hard part × shower + MPI/UE × shower) × hadronisation*

  - ***Parton showers: Theoretical improvements and tuning to data of existing models.***
  - ***Parton density functions. Standard and unintegrated PDFs, and their use together with MC generators.***
  - ***The understanding of the UE. Tuning of MPI models.***
  - ***Understanding of the hard process in higher order calculations.***

- **Education:**
  - ***Yearly MC school, and typically 1-2 QCD/MC block courses with exercises/year***
  - ***Diploma, PhD, Post Docs.***
  - ***This (last) year we had 3 (2) summer students connected to the MC group.***

# Projects

- **CASCADE**. MC generator based on kt-factorization and unintegrated PDFs. Used as framework for developments of parton showers and PDFs.
- **PDF4MC**. An attempt to refine the PDFs and unintegrated PDF for MC event generators.
- **Fitting tool** for faster and high statistical fits (PROFFIT).
- PDF framework **OOPDF** (complementary to LHAPDF)
- **Tuning efforts** within ATLAS (and CMS), and across the experiments (PROFFIT tool). (ATLAS tuning: see separate talk by M. Warsinsky)
- Validation efforts and tools - **HEPMCAnalyser**, application to GENSER validation.
- Improving existing tools and frameworks, e.g. HZTOOL in C++

# PDFs for MC

The standard PDFs have so far all been fitted in a semi-analytic approach.

- PDFs @ starting $Q_0^2$: $f(x, Q_0^2)$ $\xrightarrow{\text{DGLAP}}$ PDFs @ measured $Q^2$: $f(x, Q^2)$
- calculate e.g. x-section @ $Q^2$ using these PDFs

$$\frac{d^2\sigma(x,Q^2)}{dQ^2dx} \sim ME \bigotimes PDF \bigotimes D_{frag}$$

- fit these theoretical predictions to data by changing parameters of starting PDFs

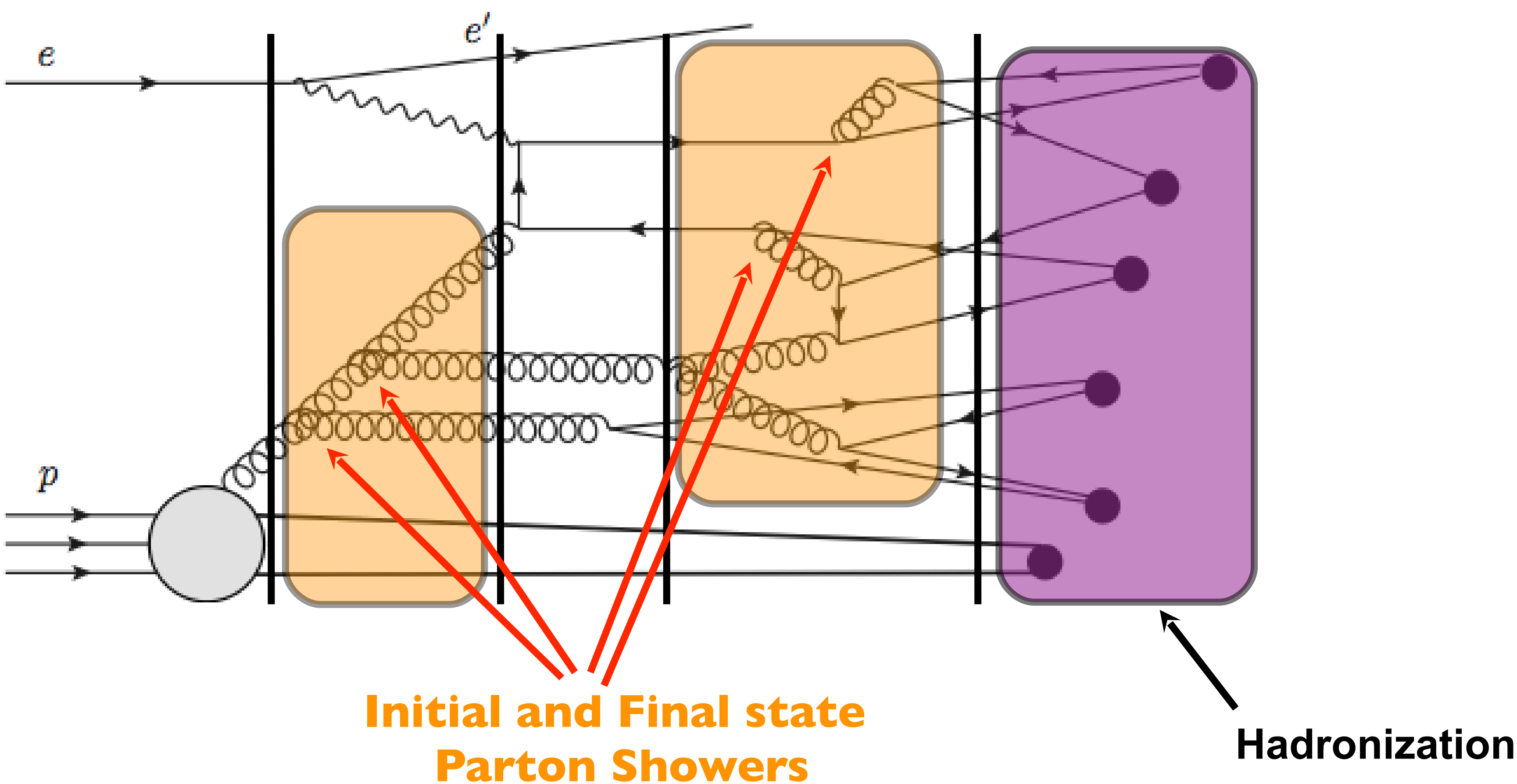
$$f(x, Q_0^2) = A_0\, x^{A_1} (1-x)^{A_2} (1 + A_3\, x^{A_4})$$

$A_i$ **are parameters to be determined by fits.**

# *PDFs for MC*

**However, a full MC event includes part not considered in the standard PDF fits.**

***Event = PDF × (hard part × shower + MPI/UE × shower) × hadronisation***




**Need to refine PDF to work better together with the MC.**

→ **Fit the the PDF using MC event generator.**

# Determine PDFs for MC

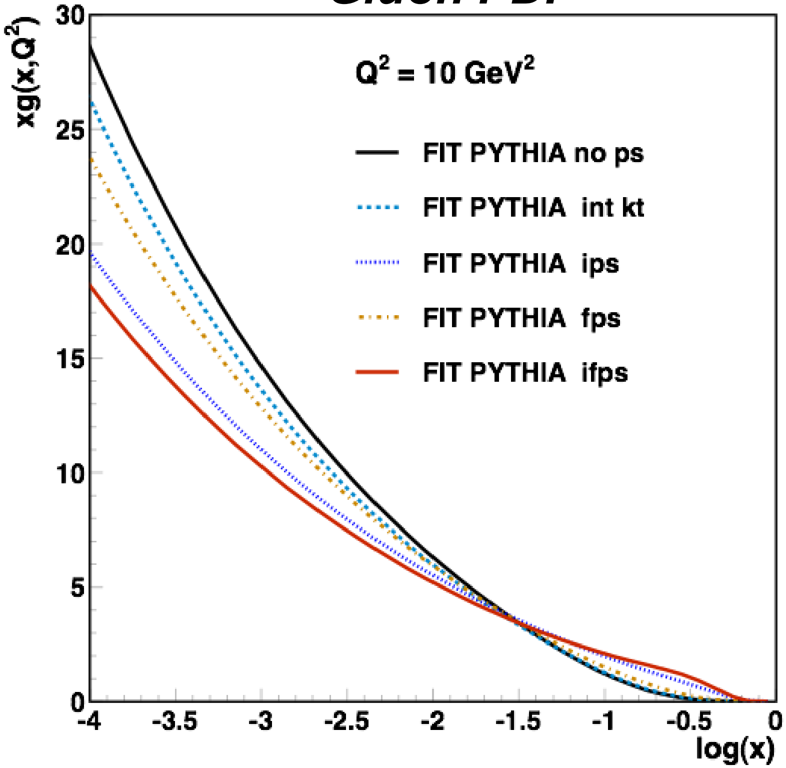


F. Himmelstjerna

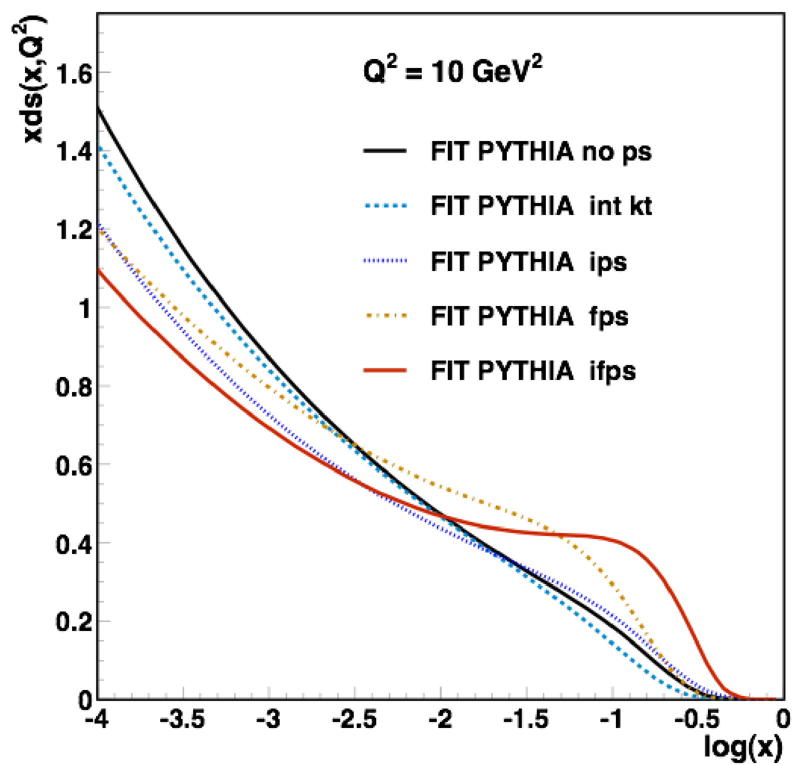
- **CTEQ6L refitted with PYTHIA to $F_2$ measurements from HERA**
- **Refitted PDFs for different MC settings:**

  **Black line – no parton showers, Red line – initial and final state PS**

***Gluon PDF***




***Down Sea PDF***




| generator and ordering | in.+fin. state p.s. CTEQ6L | in.+fin. state p.s. fitted |
|---|---|---|
| PYTHIA, $k_\perp$-ord. | 2180.42 | 182.40 |
| PYTHIA, $Q^2$-ord. | 920.11 | 134.73 |

**Refitting the PDF improves the data description by more than a factor of 10 in $\chi^2$ when the parton showers are turned on in PYTHIA**

# Unintegrated PDFs

- Standard PDFs: $k_t$-"integrated". Evolved with e.g. DGLAP. Final state partons ordered in $k_t$. For example PYTHIA MC generator. Typically CTEQ, MRST or GRV PDFs. (As on previous slides.)

# *Unintegrated PDFs*

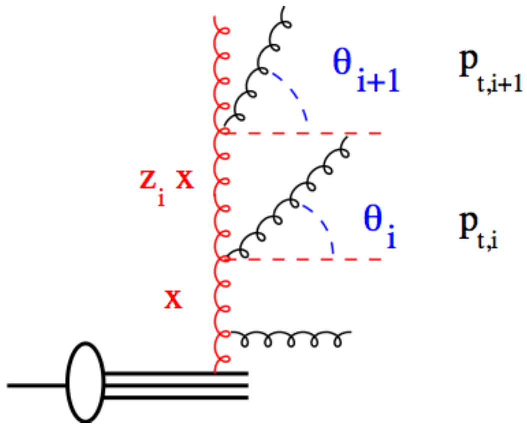


- Standard PDFs: $k_t$-"integrated". Evolved with e.g. DGLAP. Final state partons ordered in $k_t$. For example PYTHIA MC generator. Typically CTEQ, MRST or GRV PDFs.

- **Unintegrated PDFs: $k_t$-dependent. uPDF starting distribution (example):**

$$xA_0(x, k_T, \bar{q}_0) = N \cdot x^{-B} \cdot (1-x)^C \cdot exp(-\frac{(k_T - \mu)^2}{2\sigma^2})$$

- **Defined at some starting scale and evolved to higher scales by emissions of gluons according to the *CCFM* evolution scheme. Angular ordering of emitted gluon (Color coherence). No explicit $k_t$-ordering.**




- **CCFM and uPDFs are fully implemented in the general purpose LHC MC generator CASCADE (H. Jung, *Comput.Phys.Commun.143:100-111,2002*).**

**More complicated calculations make event generation time consuming. Need exclusive final states to be sensitive to $k_t$.**

→ **Fitting of uPDFs more time consuming**

# *A new approach for fitting*

**Former fitting method:** Based on running the generator in an **iterative procedure** in parameter space.
→ **Time consuming for exclusive final states. A high statistics MC run can take more than 24h, and ~100 iterations are needed.**

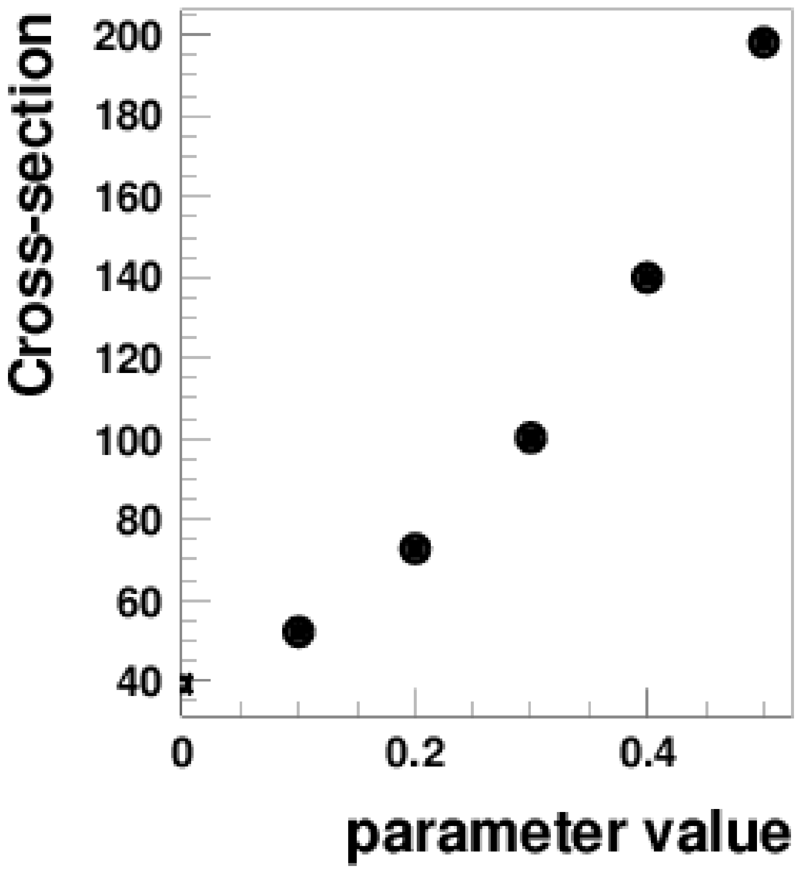
**New Approach:** Describe **parameter dependence** **before parameter fitting**, by building up a ***grid in parameter space***.
The MC grid points can be calculated simultaneously.
The fitting itself then takes a few seconds.

# 1-dim Example

**Simplest possible example**

**1 parameter, 1 data cross-section**

## 1. Build the MC grid



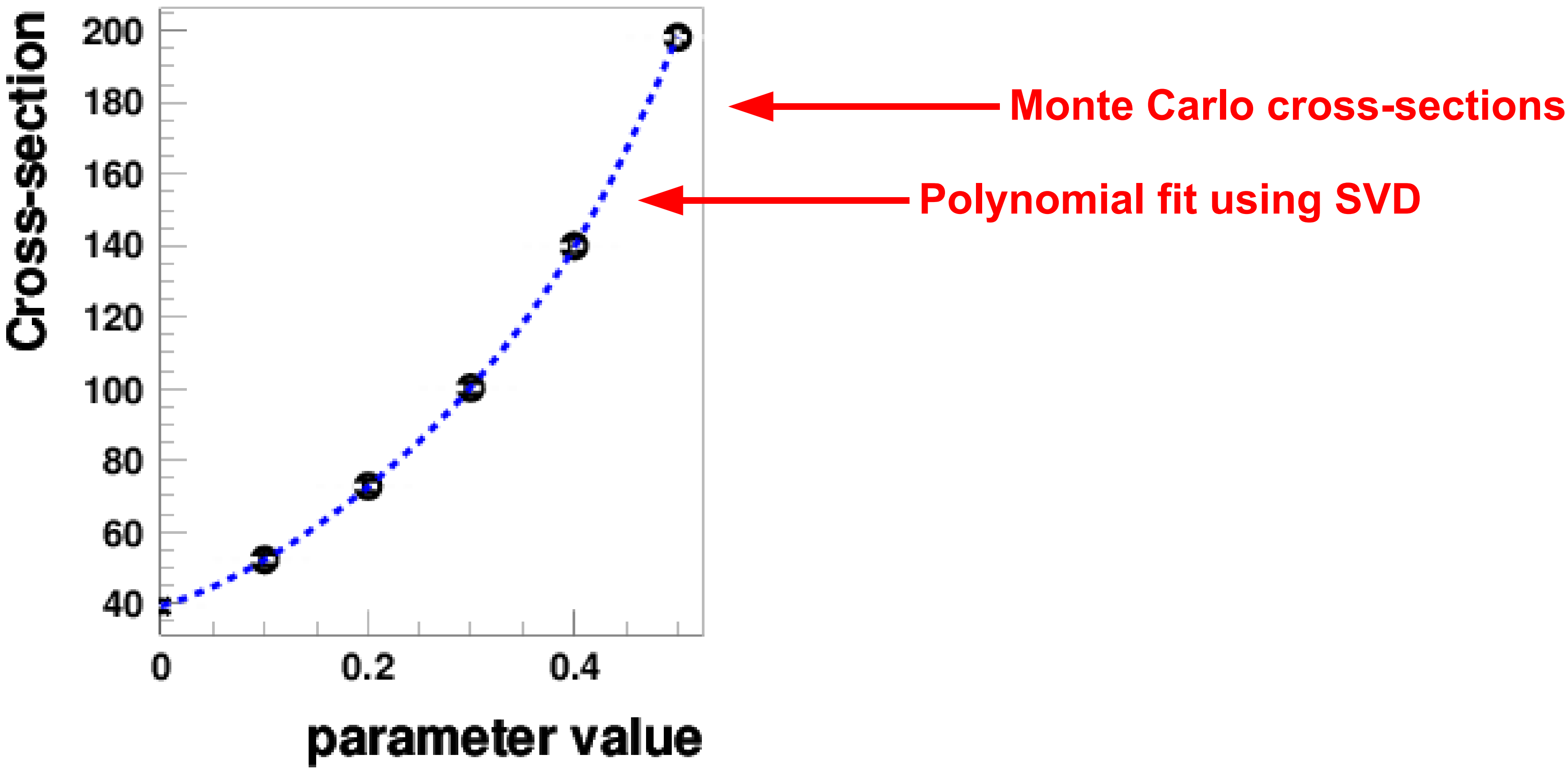

**Monte Carlos cross-sections**

# Simple Example

**Simplest possible example**

**1 parameter, 1 data cross-section**

## 2. Approximate MC with polynomial

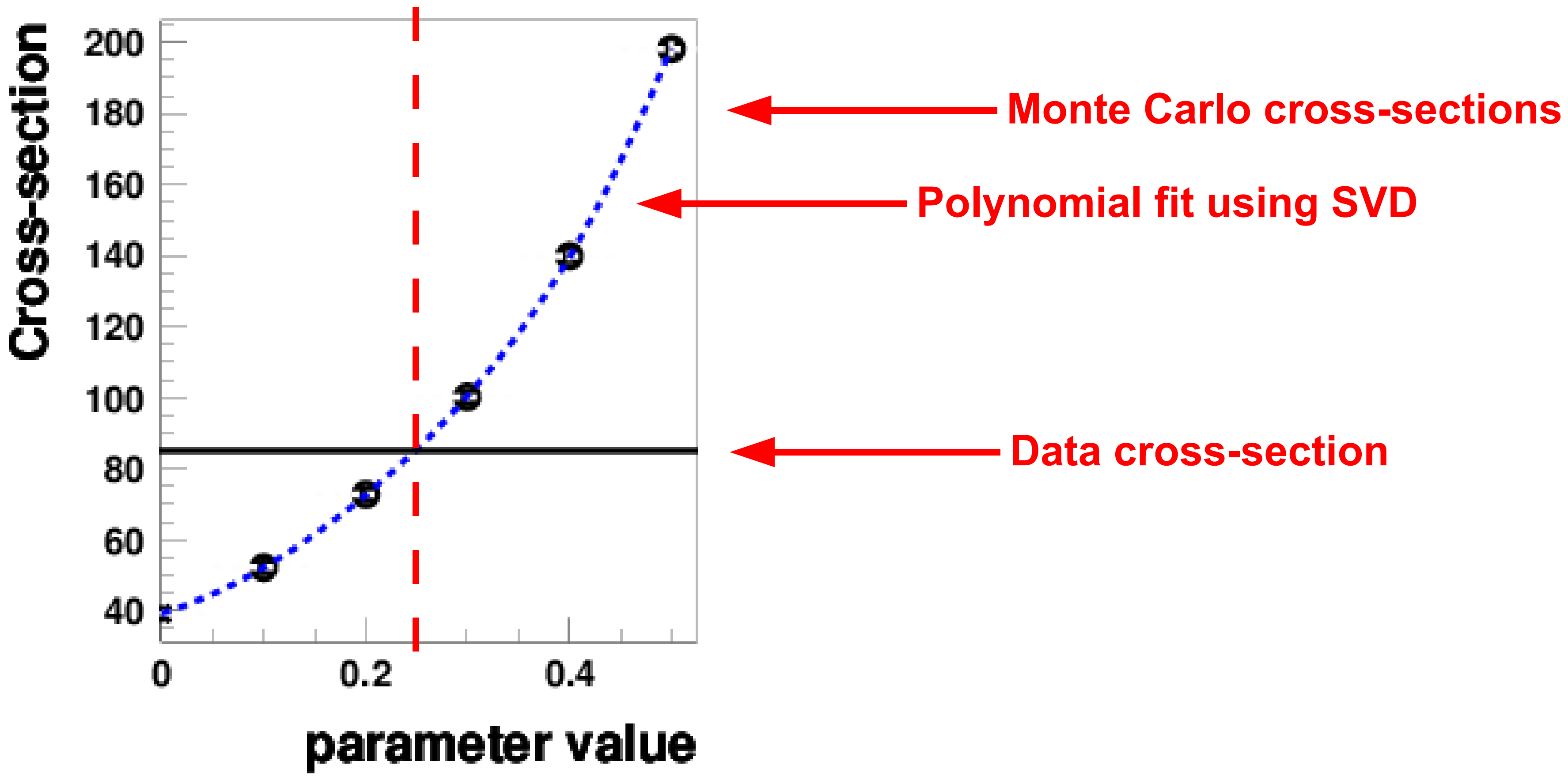


# Simple Example

**Simplest possible example**

**1 parameter, 1 data cross-section**

## ***3. Minimize Chi2 with a fit to data***




**Similar approach used in the program PROFESSOR by the MCNet people.**
**Future collaboration in the pipe-line.**

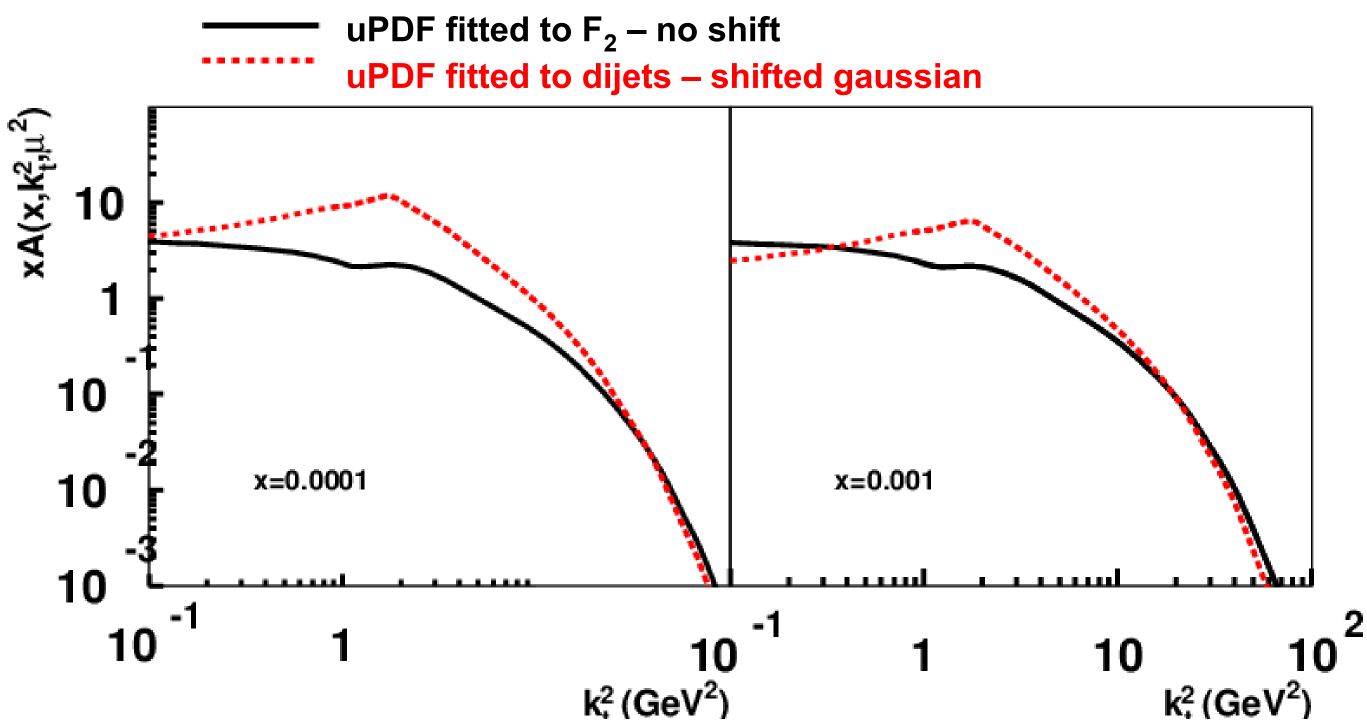
Use this method to for multidimensional fits of the parameters in the uPDFs.

# Fitting unintegrated PDF (4MC)

- **Determine the parameters in the uPDF starting distribution. Fit using PROFFIT and CASCADE with full evolution, PS and hadronisation.**

$$xA_0(x, k_T) = N \cdot x^{-B} \cdot (1-x)^C \cdot exp(-\frac{(k_T-\mu)^2}{2\sigma^2})$$

- **Fitting the MC to di-jet data suggests a gluon PDF which is suppressed at low $k_t$ (shifted Gaussian, $\mu = 3$ )**



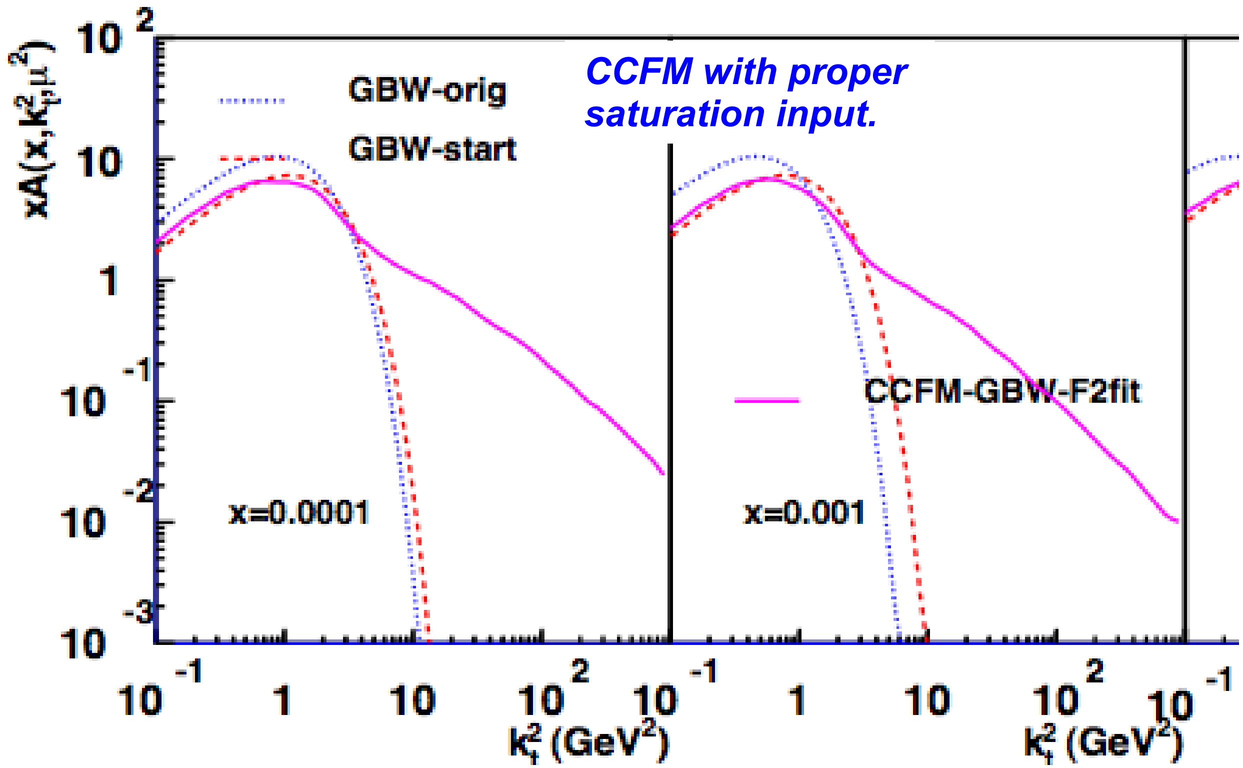

*A. Bacchetta (External collaborator/Guest Researcher)*
*H. Jung, A. Knutsson, A. Kutak*

Research still ongoing....

# *Saturation effects?*

• *Saturation effects mimicked?*
The suppression at low $k_t$ is **also seen when using saturated PDFs**.

Saturation of parton density due to recombination of partons.

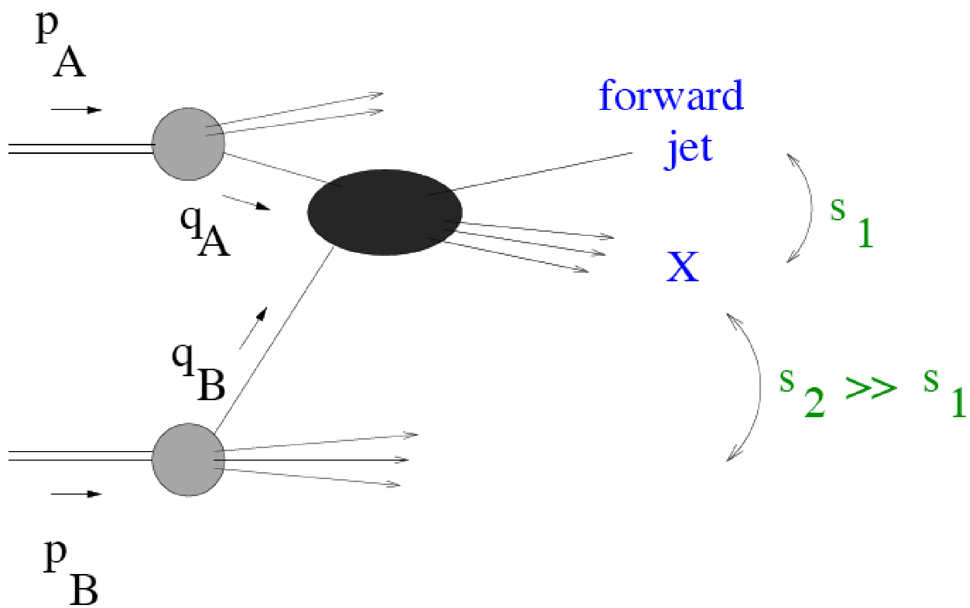



*Jung, Kutak. arXiv 0812.4082*
*(Also work within the MC group.)*

# Implementation of valence quarks in CASCADE



- So far only unintegrated gluons (i.e. indirectly also sea quarks) in CASCADE.
- Valence quarks expected to be relevant for LHC. For example high Pt production:




Two scale process. With relevant physics for both *x* → *0* and *x* → *1*. High sensitivity to parton dynamics.

Quarks successfully implemented.
The $k_t$ dependent quark PDF is taken from derivated CTEQ5.1.

*Deak, Hautmann (MC group external collaborator), Jung, Kutak*.
Published in JHEP within short.
arXiv:0908.0538

# Object Oriented PDFs

## What is wrong with LHAPDF?

- ✗ Not object oriented
  - ➪ only one pdf available (*more pdf can be hard wired*)
  - ➪ harder to add new pdf sets with different parameterization, evolution code or interpolation table
- ✗ Not thread safe
  - ➪ **ONLY ONE** pdf in a multi threaded program
- ✗ Hard wired pdfs use lots of memory
- ✗ ......

## Object Oriented PDF

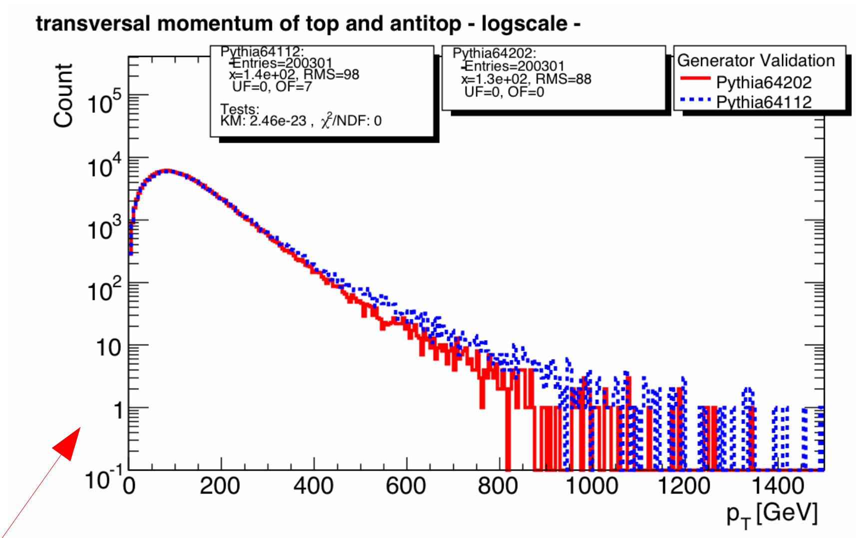
- ✓ It is an ANSI-C library
  - ➪ easy to use in C++ code
  - ➪ can be interfaced to Fortran
  - ➪ dynamic linkage of the pdf sets
- ✓ Fully object oriented (*even in F77*)
- ✓ Thread safe
- ✓ All cteq6.x pdfs are already implemented (table based)
- ✓ and some QCDNUM based: Alekhin 2002, Botje 1999, Fermi 2002, HERA 2001, ZEUS 200x,...
- ✓ Modern MRST/MSTW are not yet implemented.
- !!! Please support the idea!

*CTEQ version is available from* http://www.desy.de/~znagy/Site/CTEQ_PDF.html

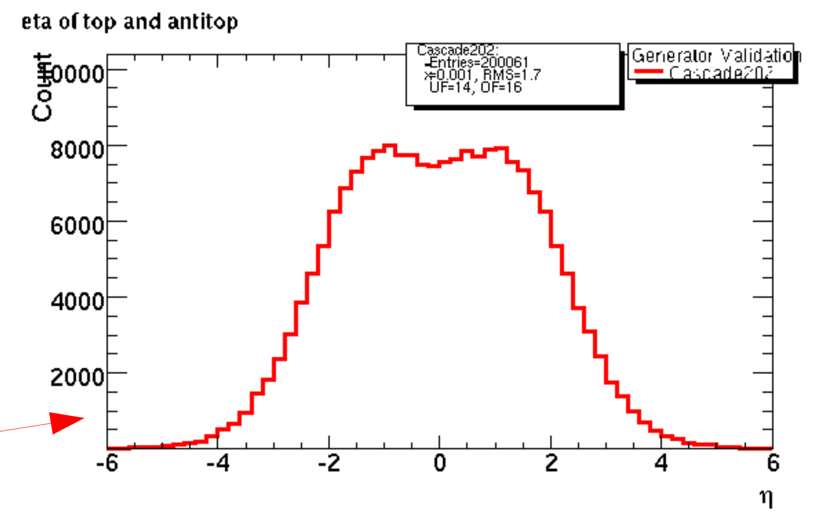
# HEPMC + Genser

**HEPMCAnalysis**: a tool for ***generator validation and comparisons***

- **Developed in the Statistics Tools group,**
- **used in the MC group**
- **Used for validation of the GenSer (GeneratorService) library of all generators used by LHC collaborations**
- **usable for all LHC generators!**




- **Example 1: validation of different PYTHIA versions (predictions for top-antitop pair transverse momentum).**




- **Example 2: top-antitop pseudorapidity distribution with CASCADE generator.**

*J. Katzy, S. Johnert*

# Parton Shower Development

## Parton shower development

- Developing parton shower algorithm based only on the soft and collinear approximation of the tree and 1-loop matrix elements.
  - Must be systematically improvable
  - Quantum effects (color and spin)
  - Better kinematics in the shower.
  - Non-global observables ➠ *super leading logarithms*
- Developing a matching scheme fro LO and NLO matching
  - Proper matching of color and spin
  - Proper treatment of the 1-loop effects

## Validating the parton shower algorithms against known QCD results

- ✓ DGLAP evolution in the final state (Dokshitzer & Marchesini problem)
- ✓ Validate the shower against known QCD results *e.g.*: *Drell-Yan pT distribution*
- Developing general procedure for validation
- Validating the matching scheme against QCD

*Z. Nagy*

# Summary and Future Plans

## Summary

- PDFs and *unintegrated* PDFs for Monte Carlo generators at LHC, and OOPDF.
- PROFFIT tuning tool.
- HEPMCAnalysis validation tool.
- Work on CASCADE. Preparations for LHC: Valence quarks, uPDFs, saturation.
- Parton showers – theory.

## Other Achievements not mentioned earlier

- Parton Shower and Resummation institute (May 2009, several speakers and discussions)
- Pheno weeks (Typically two days meetings with talks, discussions, lectures, exercises)
  e.g. Tuning, Low x, Rivet tutorial.
- MC School once a year.

## Future Plans

- Increase the collaboration with CMS. Tuning. PDFs. MI. Tools. (Already work with ATLAS.)
- Combined efforts with MCNet:
  - MC School: Next MC School together with MCNet
  - Tuning: Collaboration between PROFFIT and PROFFESOR
- Continue with the bi-weekly meeting. At least one speaker and discussion each time on a MC related topic. Everyone is welcome to participate. EVO exist.
- Student ships. ~ 3 month. We are searching for money...

## Web-page

http://www.terascale.de/research_topics/rt1_physics_analysis/monte_carlo_generators

# Backups

**BACK UPS**

# Fitting unintegrated PDF (4MC)

- **Use PROFFIT to determine the x-dependence in the starting distribution of the uPDF. Fit the uPDF using CASCADE with full evolution, PS and hadronisation.**

(1) $xA_0(x, k_T, \bar{q}_0) = N \cdot x^{-B} \cdot (1-x)^C \cdot G(k_T)$

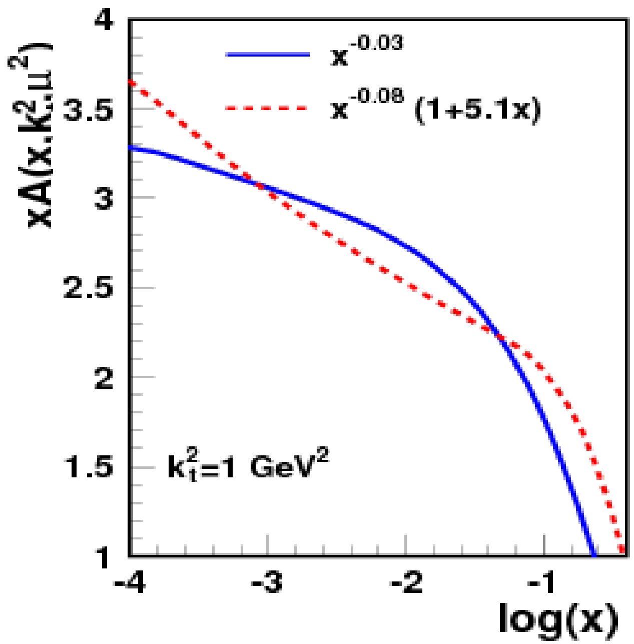
**After fit to $F_2$ data: Chi2/ndf = 5.4**

*The research on fitting the uPDFs resulted in the introduction of an addition factor in the PDF (Inspired by CTEQ)*

(2) $xA_0(x, k_T, \bar{q}_0) = N \cdot x^{-B} \cdot (1-x)^C \cdot (1-Dx) \cdot G(k_T)$

**After fit to $F_2$ data: Chi2/ndf = 2.8**

The additional freedom allows for a steeper PDF at low x.




*A. Bacchetta (External collaborator/Guest Researcher)*
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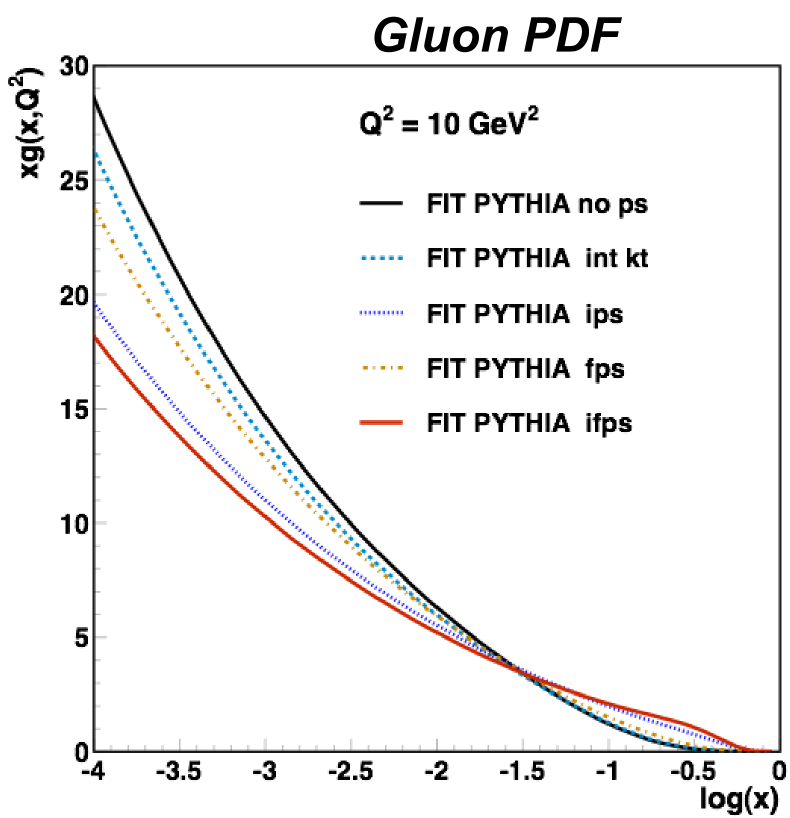
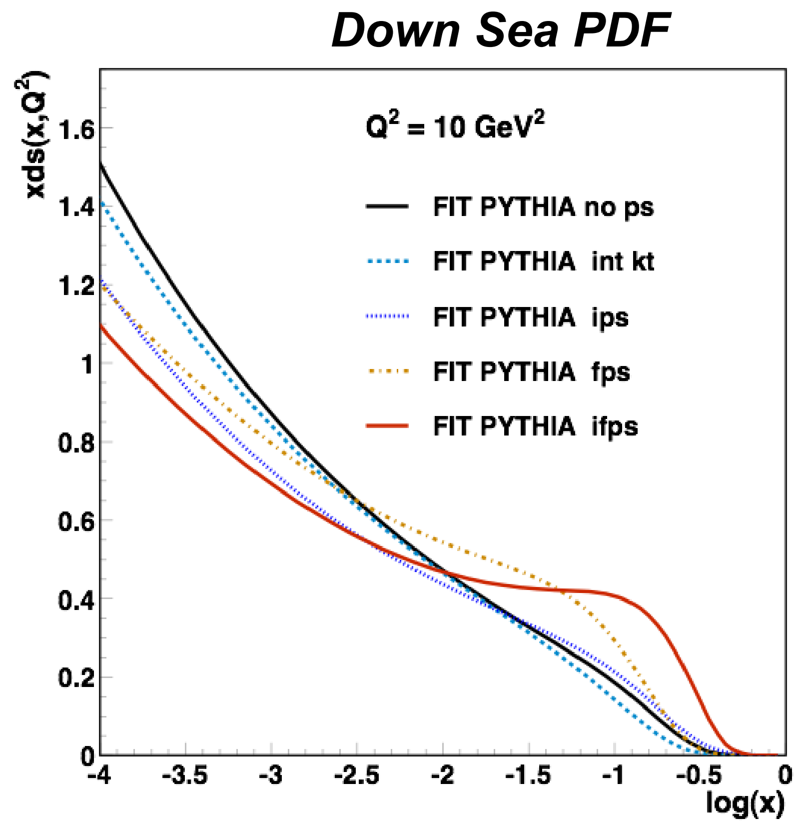
# Chi2 PYTHIA fits - detailed



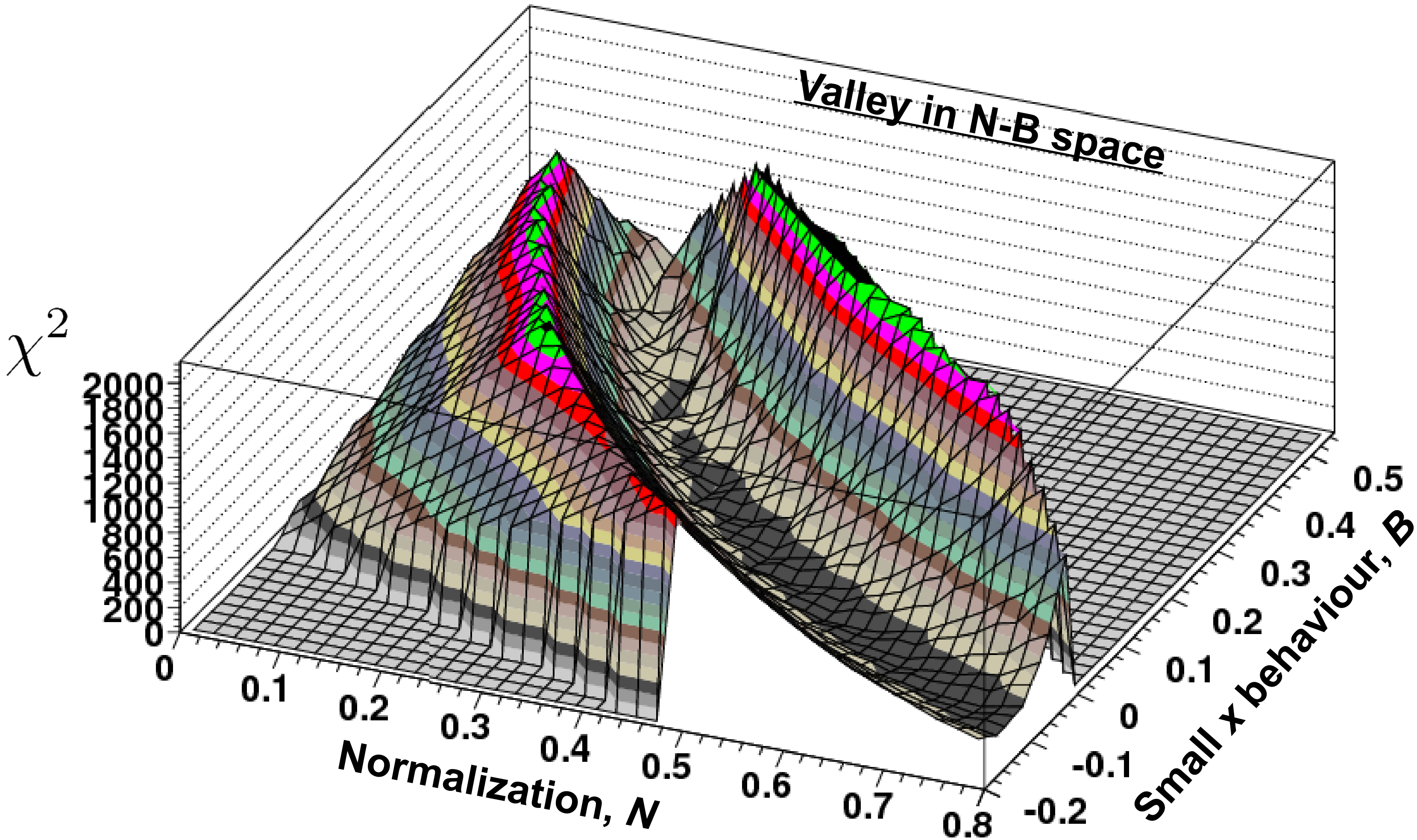

| generator and ordering | parton shower and PDF set | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | no p.s. | | intr. $k_\perp$ | | in. state p.s. | | fin. state p.s. | | in.+fin. state p.s. | |
| | CTEQ6L | fitted | CTEQ6L | fitted | CTEQ6L | fitted | CTEQ6L | fitted | CTEQ6L | fitted |
| PYTHIA, $k_\perp$-ord. | 139.12 | 105.03 | 283.34 | 157.96 | 1162.28 | 211.52 | 773.66 | 112.68 | 2180.42 | 182.40 |
| PYTHIA, $Q^2$-ord. | 97.61 | 77.18 | - | - | 268.46 | 113.81 | 740.65 | 145.09 | 920.11 | 134.73 |
| RAPGAP | 106.29 | 89.81 | - | - | 134.97 | 74.06 | 108.00 | 77.78 | 113.72 | 87.52 |

Table 9.1: Values of $\chi^2$ for RAPGAP and the two parton shower orderings of PYTHIA running with no parton shower, intrinsic $k_\perp$, initial state parton shower, final state parton shower and the combination of initial and final state parton shower. The $chi^2$ is calculated when the Monte Carlo event generators were running with the CTEQ6L PDF set (left subdivision) and with the fitted PDF (right subdivision).

# Di-jet data insensitivity to the x behavior of uPDF

$$xA_0(x, k_T, \bar{q}_0) = N \cdot x^{-B} \cdot (1-x)^C \cdot exp(-\frac{(k_T - \mu)^2}{2\sigma^2})$$

The small *x* behaviour (**B)** is roughly arbitrary as long as we choose (fit) the correct normalization, N.



# HZTOOL in C++



**Summerstudent projects 2009:**

- **3- and forward-jet cross sections at HERA.**
- **Analysis of charm in photoproduction at HERA**
- **Analysis of pt spectrum in Drell-Yan production at LHC**

**Extensive work in the HZTOOL framework.**

*"HZTool is a library of routines which will allow you to reproduce an experimental result using the four-vector final state from Monte Carlo generators."*

*Large collection of data and analyses implemented, but less frequently updated by experiments recent years due to old programming language.*

**Thanks to these students we for the first time code HZTOOL in C++ !**

# *Fitting unintegrated PDF*

**1. Build up a grid in parameter – cross section space using Monte Carlo.**

**If you have a CPU farm (or use the *G R I D* ) this ultimately takes the time of running the MC generator once.**

**2. Fit polynomials to the Monte Carlo grid.**

$$\sigma_{\text{poly}} = A + \sum_{1}^{N} B_i \cdot p_i + \sum_{1}^{N} C_i \cdot p_i^2 + \sum_{i=1}^{N} \sum_{j=i+1}^{N} D_{ij} \cdot p_i p_j + H.O.$$

$A, B, C$ **and** $D$ **are determined by fitting the polynomial to the parameter grid.**

***Step 1. and 2. are done for each data point in the measurement.***

**3. Determine PDF parameters,** $p_i$ **, by fitting all the polynomials to data simultaneously**

**Also this takes only a few seconds.**

# Object Oriented PDFs



## User example code

*Create the objects*

*Use them simultaneously, without reinitialization*

*Destroy them*

```
int main()
{
  /*   Creating and initializing the pdf object   */
  unsigned int i;
  cteq_pdf_t *pdf[41];

  for(i = 0; i < 41; i++)
    pdf[i] = cteq_pdf_alloc(&oopdf_cteq60m, i);


  /*   we plot all the 41 pdfs */
  int iprtn = 0;
  double x, q = 1000.0;

  printf("#  q = %f   iprtn = %d\n", q, iprtn);
  printf("#  x     and the result of the 41 pdfs \n");

  for(x = 1.0; x > 0.01; x-=0.1) {
    printf("%f  ", x);
    for(i = 0; i < 41; i++)
      printf("  %e", cteq_pdf_evolvepdf(pdf[i], iprtn, x, q));
    printf("\n");
  }

  /*   Before exit destroy the pdf objects   */
  for(i = 0; i < 41; i++)
    cteq_pdf_free(pdf[i]);

  return 0;
}
```

# A new approach for fitting

**Former fitting method:** Based on running the generator in an **iterative procedure** in parameter space.

→ **Time consuming for exclusive final states. A high statistics MC run can take more than 24h, and ~100 iterations are needed.**

**Also a challenge: Fitting several "event types" simultaneously, e.g. Charm production and inclusive di-jet production**

***Above method makes separated event generation difficult.***

**New Approach:** Describe **parameter dependence before parameter fitting**, by building up a ***grid in parameter space***.
The MC grid points can be calculated simultaneously.
The fitting itself then takes a few seconds.