# New ideas for Monte Carlo Generators

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# Different types of calculations

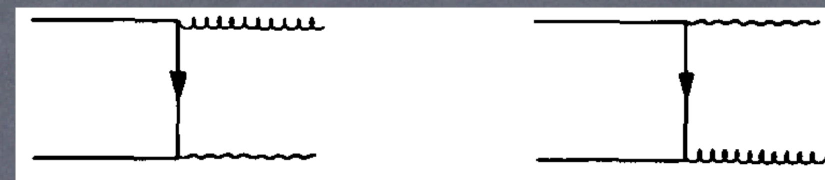
- Three different expansion possible to calculate QCD
  - Straight perturbation theory
  - Logarithmic resummation
  - Kinematic expansion (parton showers)
- Each have their advantages, and can describe physics in different kinematical regions
  - Widely separated jets, only one large scale
  - Widely separated scales
  - Collinear radiation, jet substructure

Best description obtained by combining the different expansions

# Peturbative calculations

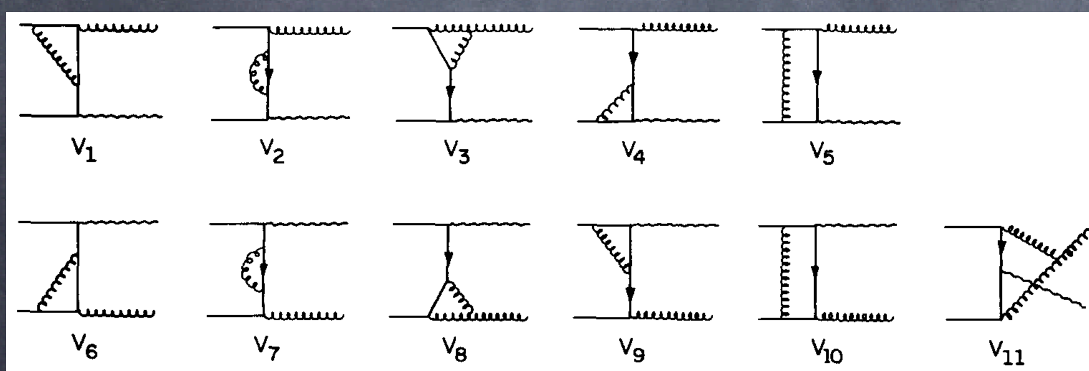
Example: pp → W j

Leading order:

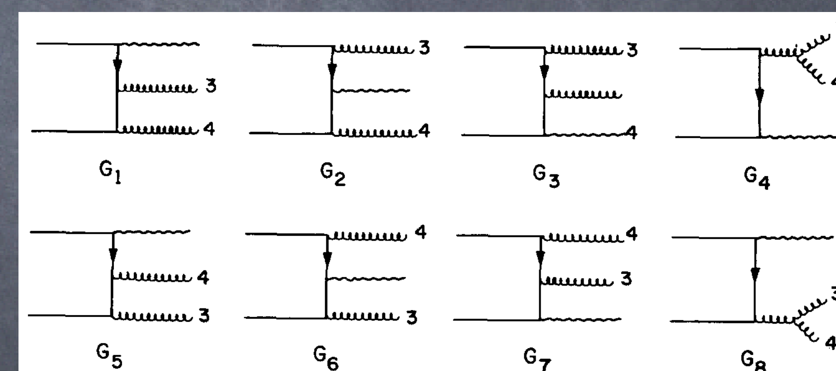


At NLO need:

virtual




real




Both virtual and real divergent, but divergences cancel, finite pieces left over

# Logarithmic resummation

Perturbative expressions at higher order always contain logarithms of ratios of scales in the problem

RGE known to sum all logs in single scale problems

RG Equation (μ d/dμ)

$$\mu \frac{\mathrm{d}}{\mathrm{d}\mu} \frac{\mathrm{d}\sigma_n^{\mathrm{LL}}(\mu)}{\mathrm{d}\Phi_n} = \gamma_n(\mu) \frac{\mathrm{d}\sigma_n^{\mathrm{LL}}(\mu)}{\mathrm{d}\Phi_n}$$

Solution exponentiates

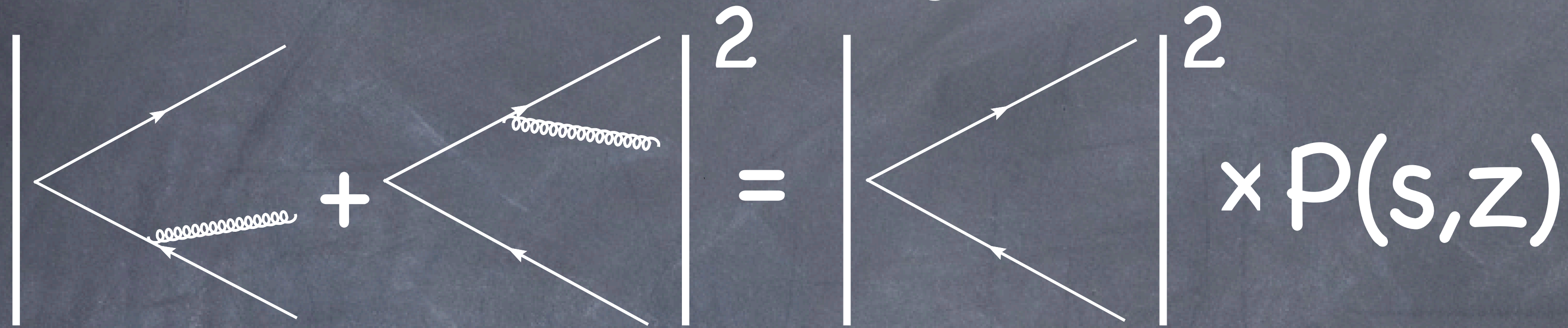
$$\frac{\mathrm{d}\sigma_n^{\mathrm{LL}}(\mu)}{\mathrm{d}\Phi_n} = \frac{\mathrm{d}\sigma_n^{\mathrm{LL}}(\mu_0)}{\mathrm{d}\Phi_n} \Delta_n(\mu_0, \mu)$$

$\Delta_n$ = Sudakov factor

If cross-section factorizes into terms depending on only one scale, resums all logarithms of μ

# Kinetic expansion

In limit of small angle radiation




Another way of writing result: $\sigma_3 = \sigma_2 \times P(s,z)$

Corrections are suppressed by angle of the emission

In general, can show that procedure continue

$\sigma_n = \sigma_{n-1} \times P(s,z)$

Recursive algorithm to build up n-body final state
(Parton Shower)

# The need for combination

- Different expansions are important in different kinematical regions
  - Perturbative expansion: Most important for inclusive observables containing several widely separated jets
  - Logarithmic resummation: Most important if kinematical cuts introduce other small scales in the problem
  - Kinematic expansion: Most important to understand jet substructure and implement high multiplicity final states

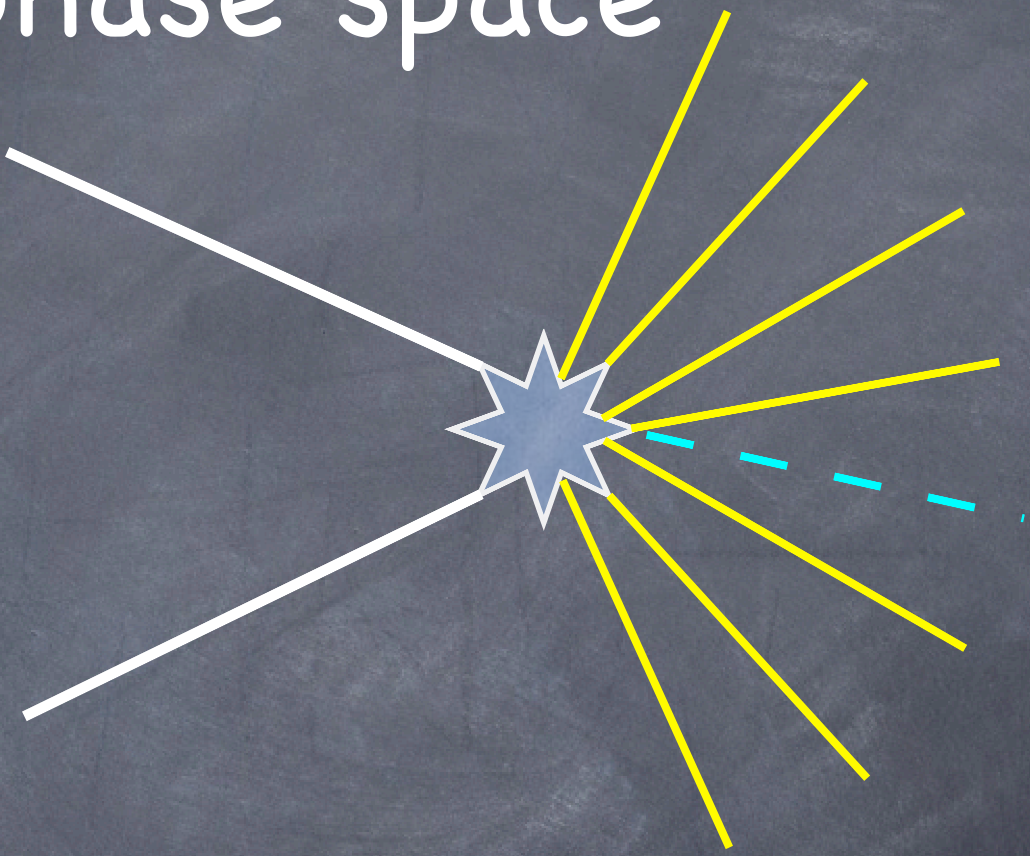
A general calculation needs to combine all three approaches for best accuracy

# Pictorial phase space

$d\Phi_n$

$d\Phi_{n+1}$

$d\Phi_{n+2}$



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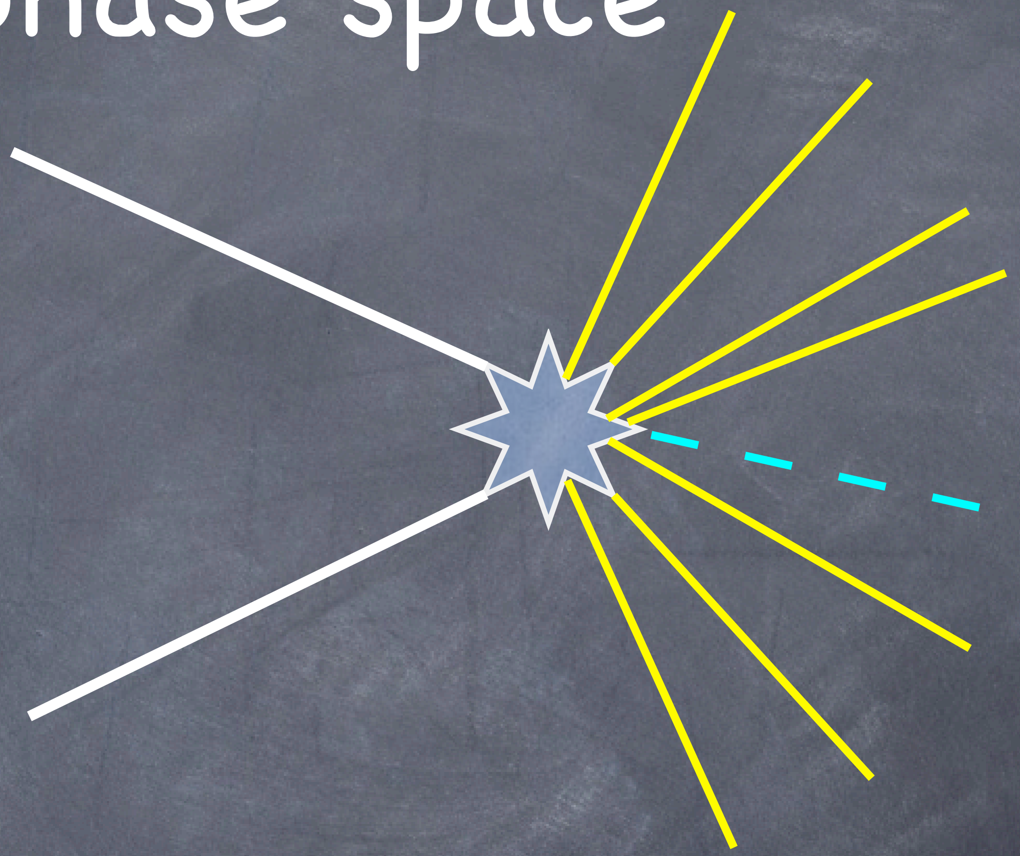

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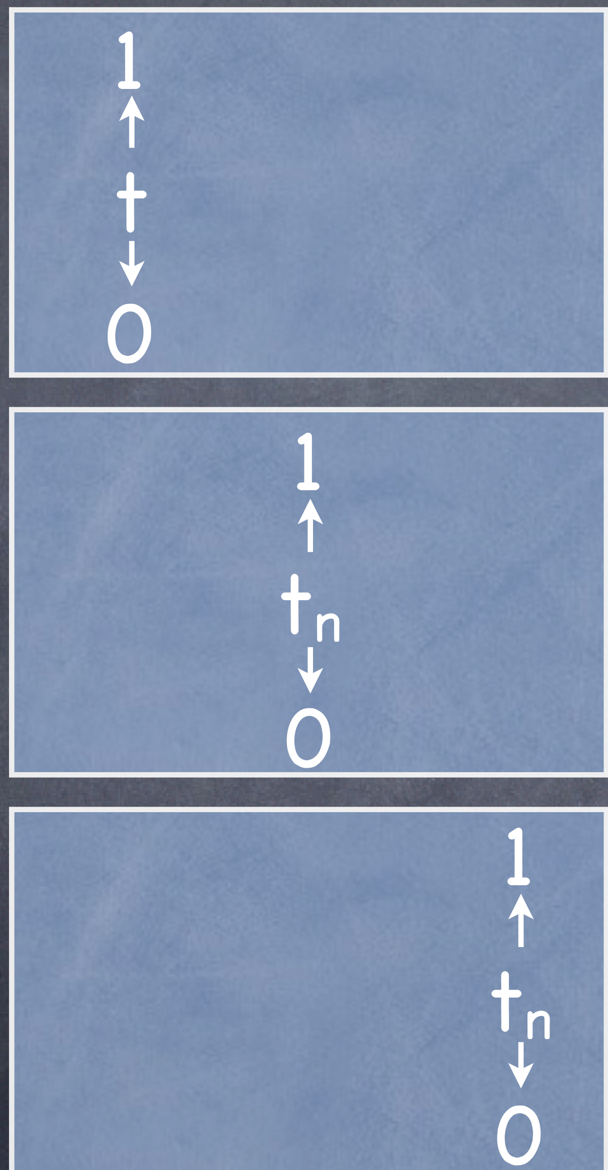
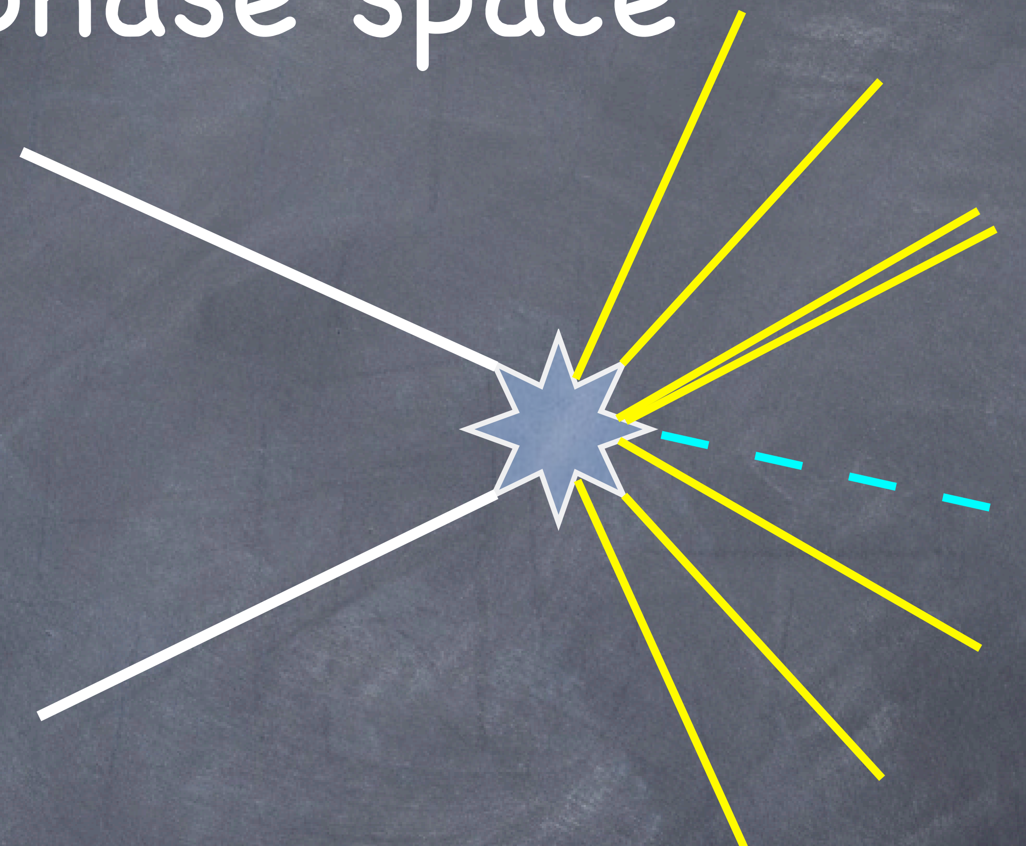


Region of $\Phi_n$ looks like $\Phi_{n-1}$

Define resolution variable $t_n$

($t_n \to 0$ in collinear region)

# The parton shower

$d\Phi_n$

$d\Phi_{n+1}$

$d\Phi_{n+2}$

# The parton shower

$d\Phi_n$ — Perturbative calculation

$d\Phi_{n+1}$

$d\Phi_{n+2}$

Calculated to given order in perturbation theory or logarithmic resummations

# The parton shower

$d\Phi_n$ Perturbative calculation

Calculated to given order in perturbation theory or logarithmic resummations

$d\Phi_{n+1}$ Parton shower

(Good result)

$d\Phi_{n+2}$ Parton shower

(Good result)

Filled by recursive algorithm using $1 \to 2$ AP splitting functions

# Combining FO with PS

| | | |
|---|---|---|
| $d\Phi_n$ | Perturbative calculation | |
| $d\Phi_{n+1}$ | Parton shower | Perturbative calculation |
| $d\Phi_{n+2}$ | Parton shower | Parton shower |

How do I add perturbative calculations for more particles?

Double counting of phase space!

# Combining FO with PS

Main physics question:
What is correct expression for perturbative calculation

$d\Phi_n$

Perturbative calculation

$d\Phi_{n+1}$

Parton shower

Perturbative calculation

$t_{cut}$

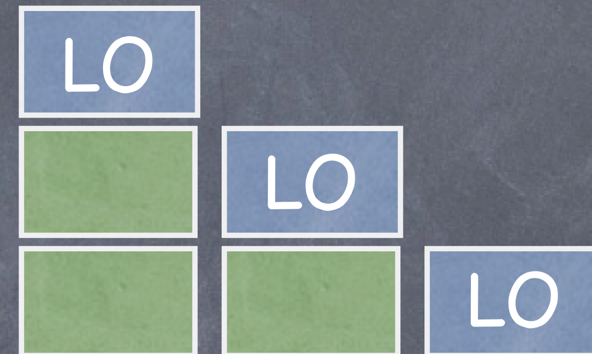
$d\Phi_{n+2}$

Parton shower

Parton shower

# Combining FO with PS

- For LO calculations this problem is essentially solved
  - CKKW matching procedure
  - Different implementations: Madgraph, Sherpa, Alpgen, ...




- For NLO calculations some first attempts exist
  - Go by the name of MC@NLO, POWHEG
  - Only give NLO for one multiplicity


How do I get NLO everywhere

# Development of Geneva

Geneva (Generate NLO Events Analytically) is a new framework developed by my group. It combines


1. Perturbative calculations
2. Logarithmic resummation
3. Parton showers

Goal will be a standalone program available to LHC experiments

Will use latest fixed order calculations (Blackhat, etc)

Interfaces with any parton shower algorithm desired (Pythia, Herwig, Sherpa, ...)

# Development of Geneva

## Main advantages of Geneva

- Can get exclusive cross sections correct (including large logarithmic resummation)
- Get large logarithmic resummation for all observables
- Generate common event sample for different processes
- Easy implementation of new fixed order QCD calculations

## Main difficulties

- Need to have NLO simultaneously with log resummation
- Not accomplished in general using traditional QCD
- SCET allows to derive the required expressions

# Development of Geneva

## The theoretical difficulty

- Main problem is to resum all logarithms while having expression correct to NLO
- Not accomplished yet using traditional QCD methods
- SCET naturally combines both fixed order calculations with logarithmic resummation

It is possible to derive the expressions needed

Allows in principle to go to higher order in fixed and logarithmic calculations

# The SCET framework


1. Perturbative calculations
2. Logarithmic resummation
3. Parton showers

Perturbative calculations come from matching calculations either between QCD and SCET, or different versions of SCET

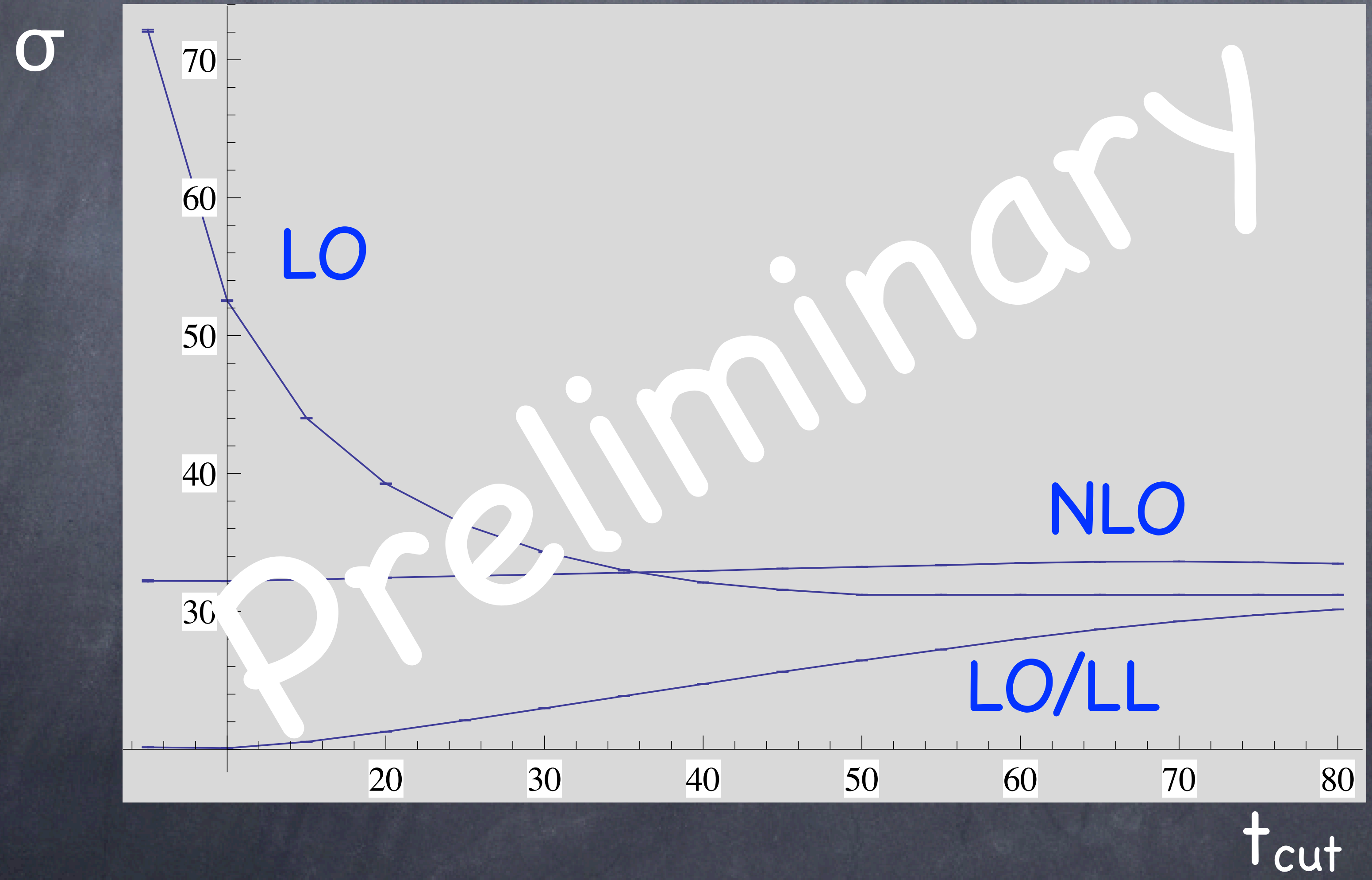
Logarithmic resummation comes from RG evolution in SCET

No need to come up with magic algorithms to achieve this, SCET gives precise predictions

Parton showers can be viewed as performing SCET ME calculations

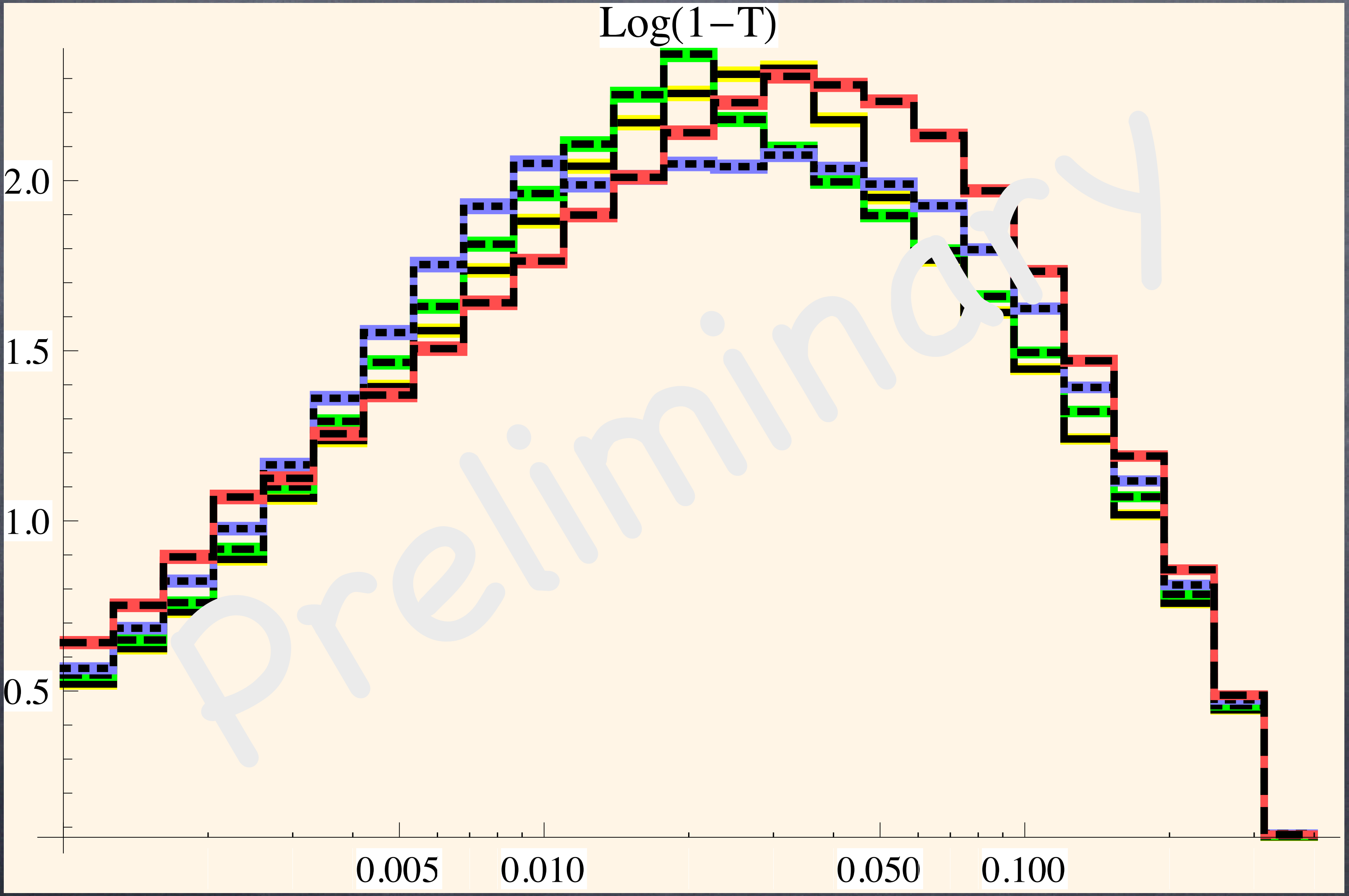
# Some first results

Fixed order calculations



# Some first results

## Interfaced with Pythia 8



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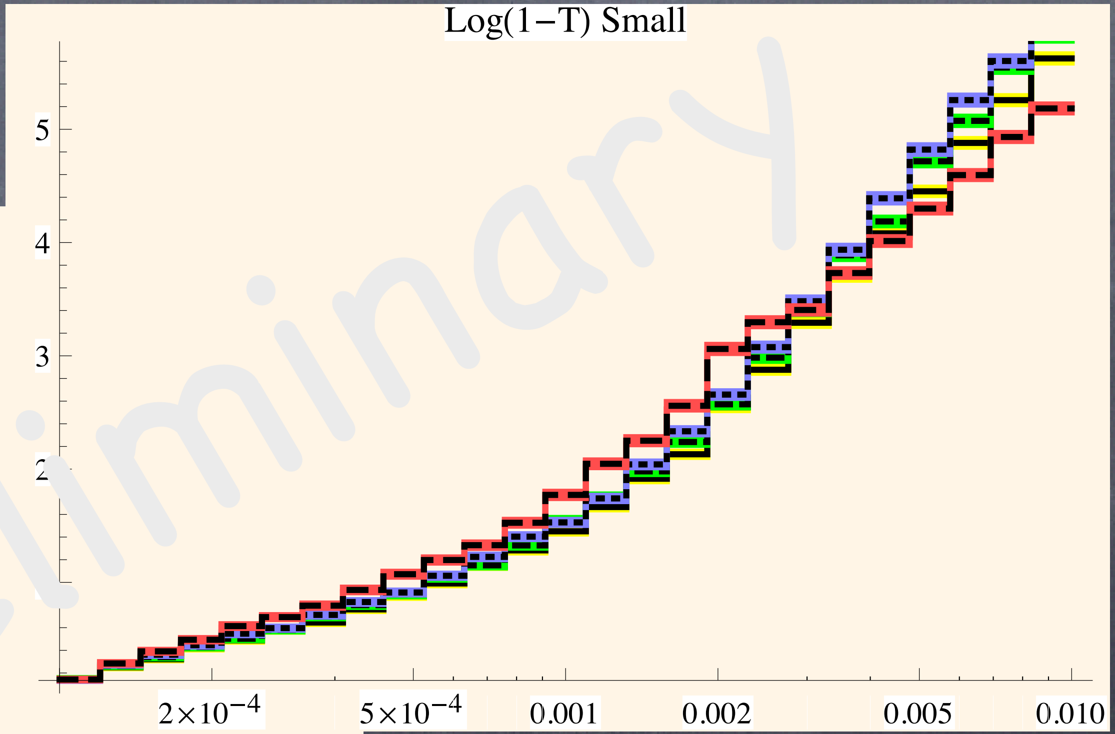


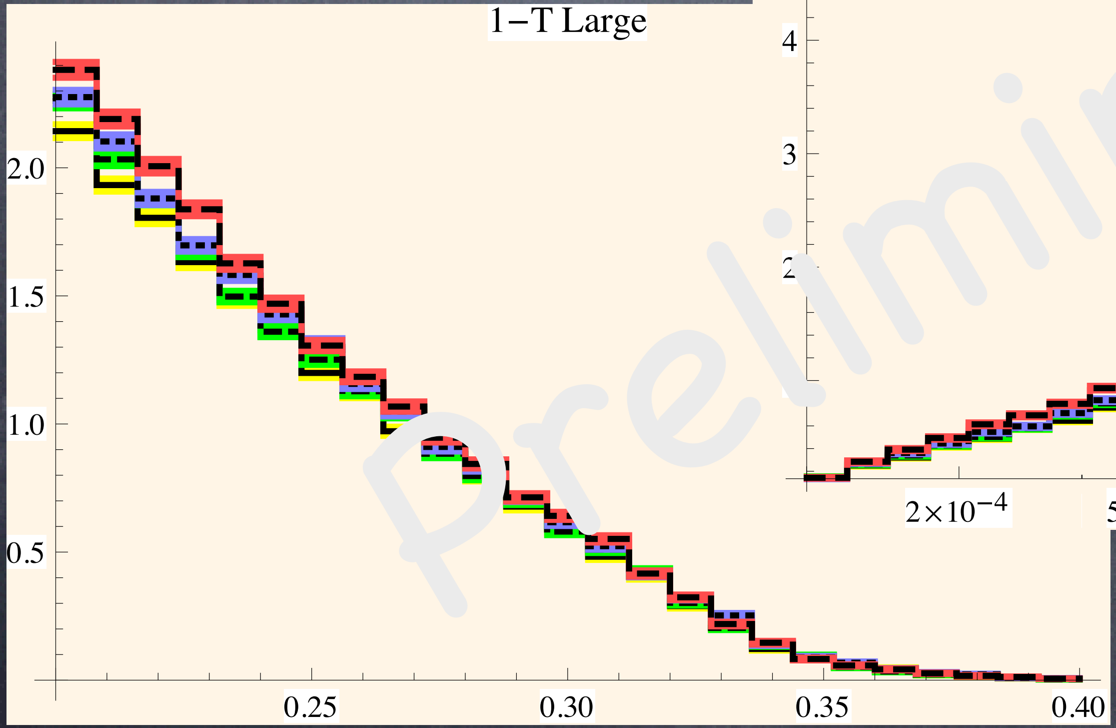

# Conclusions/Outlook

- Event generators are crucial tool to connect theory and experiment
- Much progress over past decade to improve precision of theory in event generators
- Geneva will allow full NLO calculations implemented
- First simple calcs are implemented and working
- Currently implementing full calcs into code

Hopefully can aid LHC when precision become more and more important