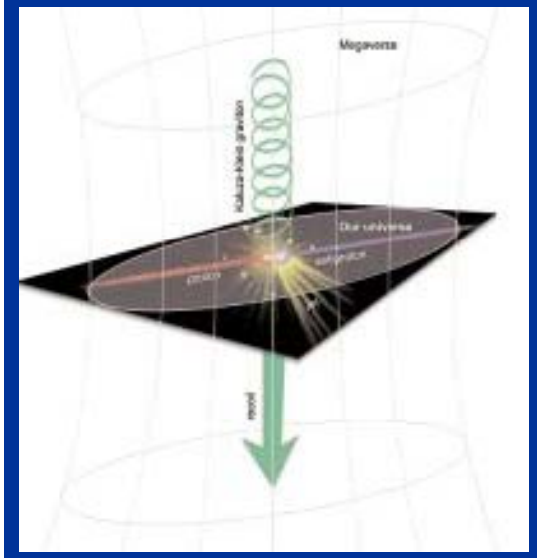
Models ⟺ Experiment
Bridging the Gap

Tim Stelzer
Fabio Maltoni + CP^3

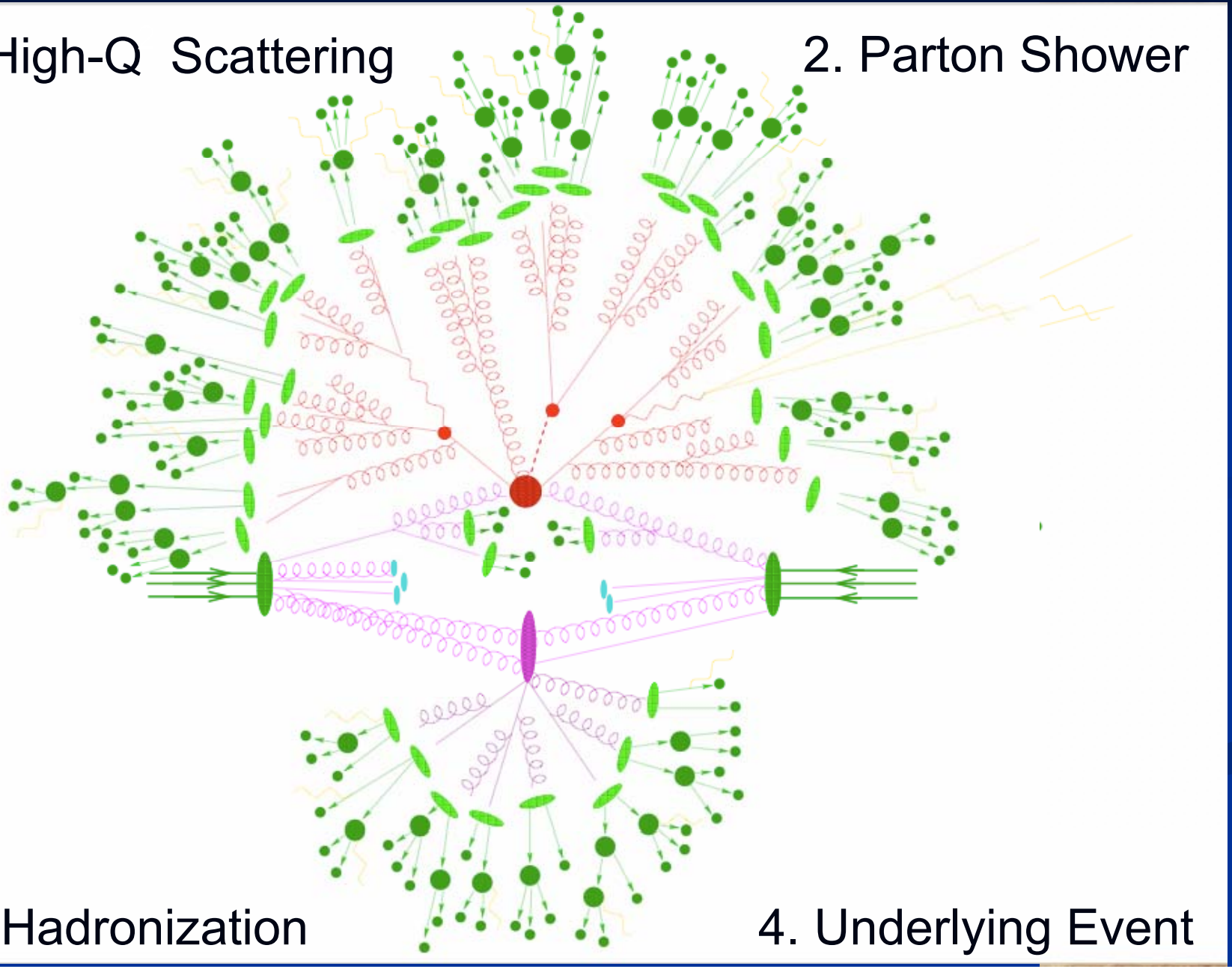


Outline

- Anatomy of an Event
- Parton Shower MC
- Matrix Element Corrections
- Current Tools
- Outlook

A Top Quark Event

Anatomy of an Event

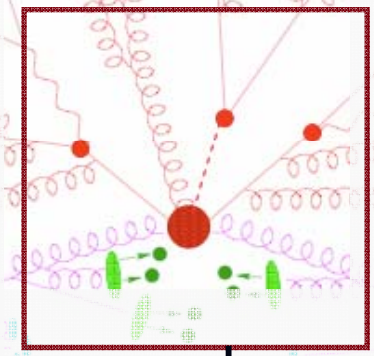


Hard Scattering

1. High-Q Scattering

2. Parton Shower

Where new physics lies



process dependent

first principles description

it can be systematically improved

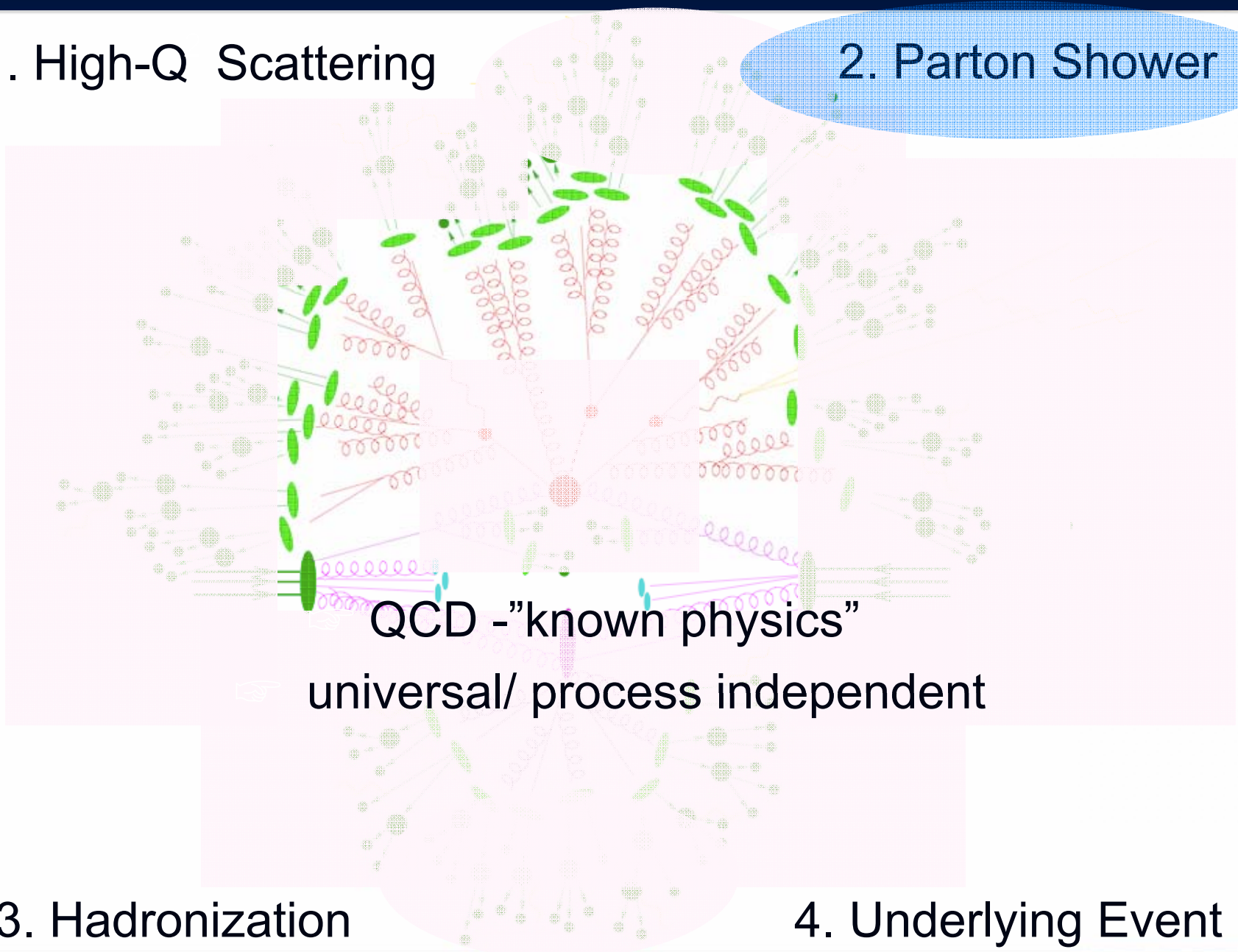
3. Hadronization

4. Underlying Event

Parton Shower

1. High-Q Scattering

2. Parton Shower



QCD -"known physics"

universal/ process independent

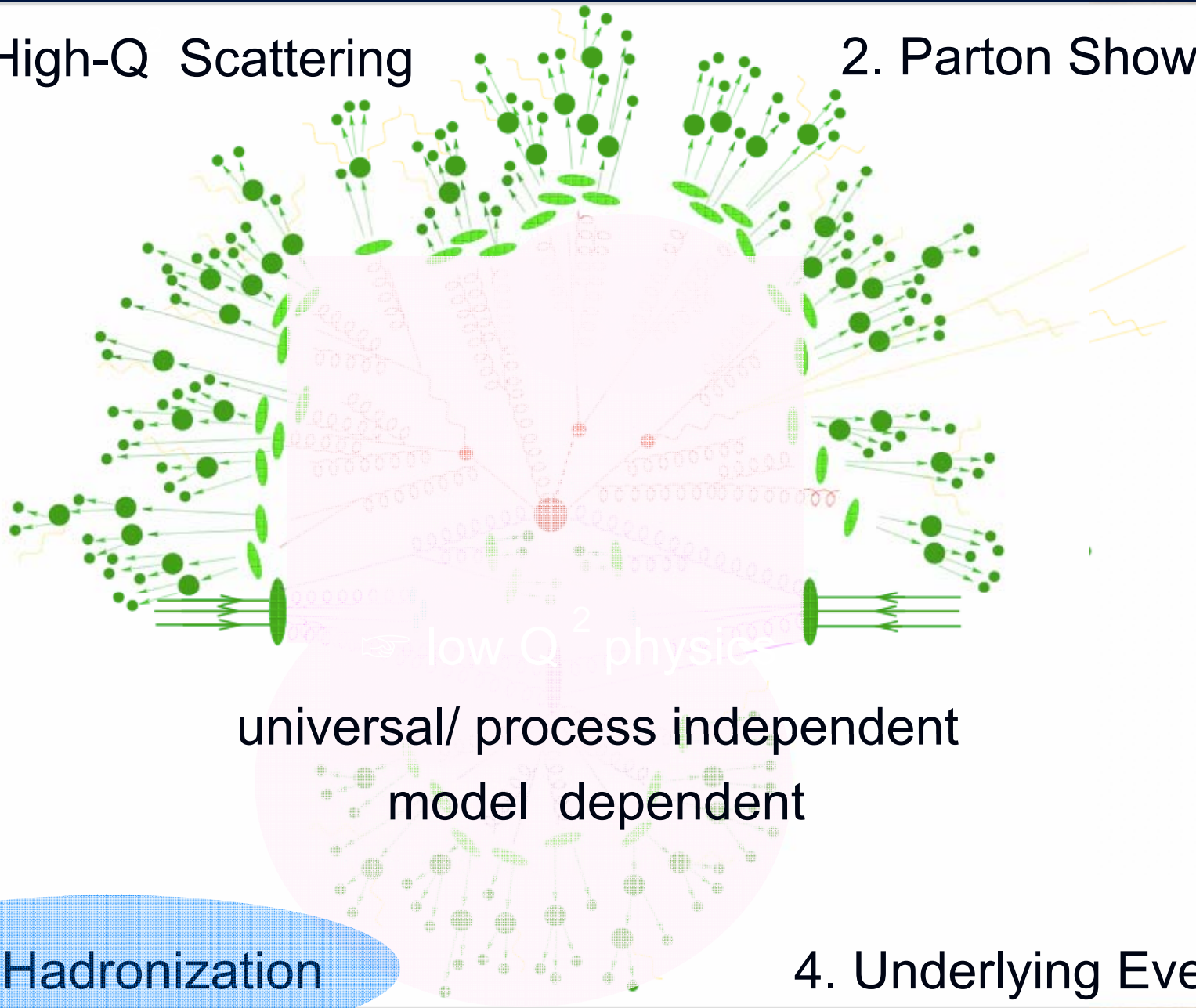
3. Hadronization

4. Underlying Event

Hadronization

1. High-Q Scattering

2. Parton Shower



☞ low Q^2 physics

universal/ process independent

model dependent

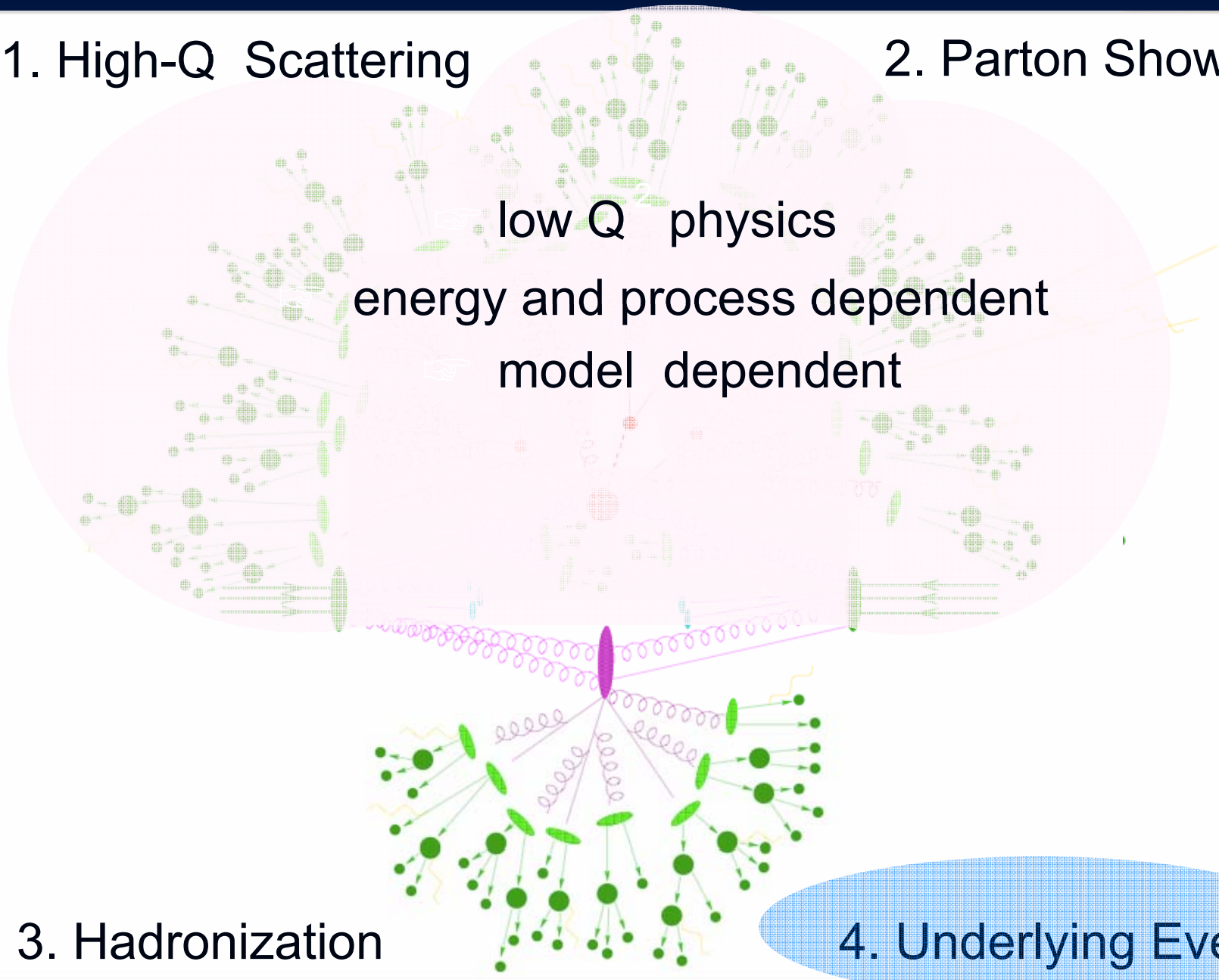
3. Hadronization

4. Underlying Event

Underlying Event

1. High-Q Scattering

2. Parton Shower



low Q physics

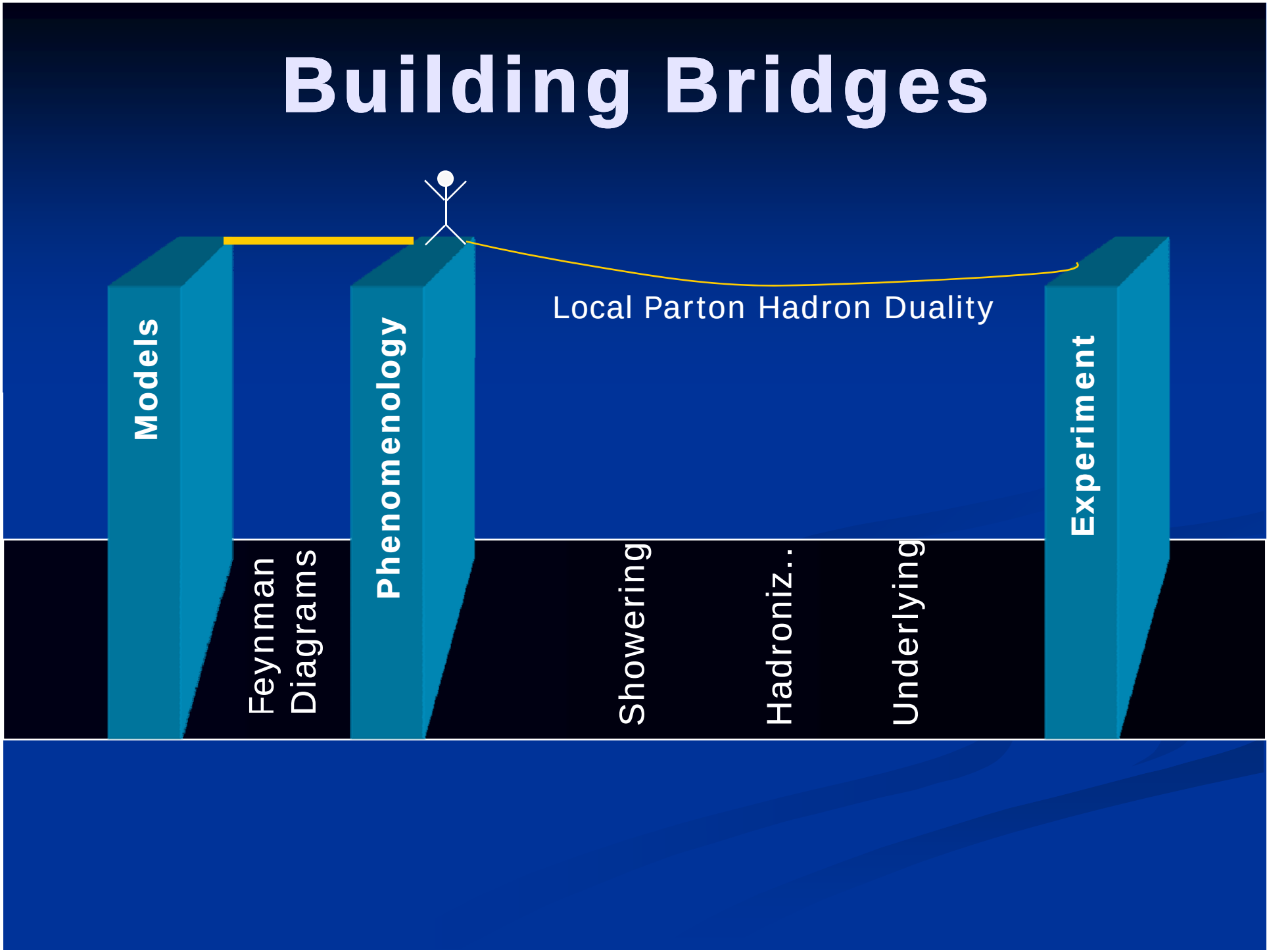
energy and process dependent

model dependent

3. Hadronization

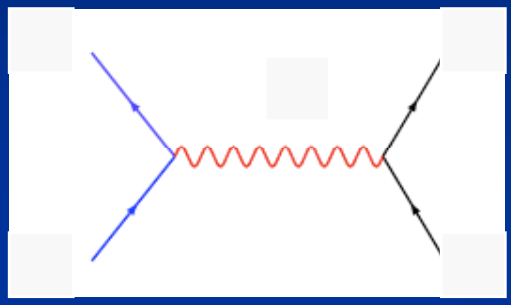
4. Underlying Event

Building Bridges



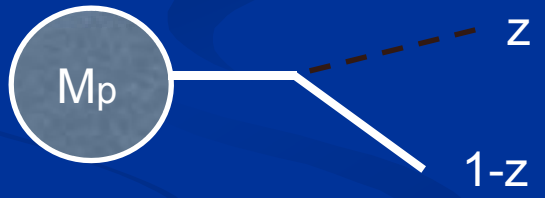
Parton Shower MC
HERWIG / Pythia

Start with Hard Process* then allow to radiate



ME involving q →q g (or g → gg) are strongly enhanced when they are close in the phase space:

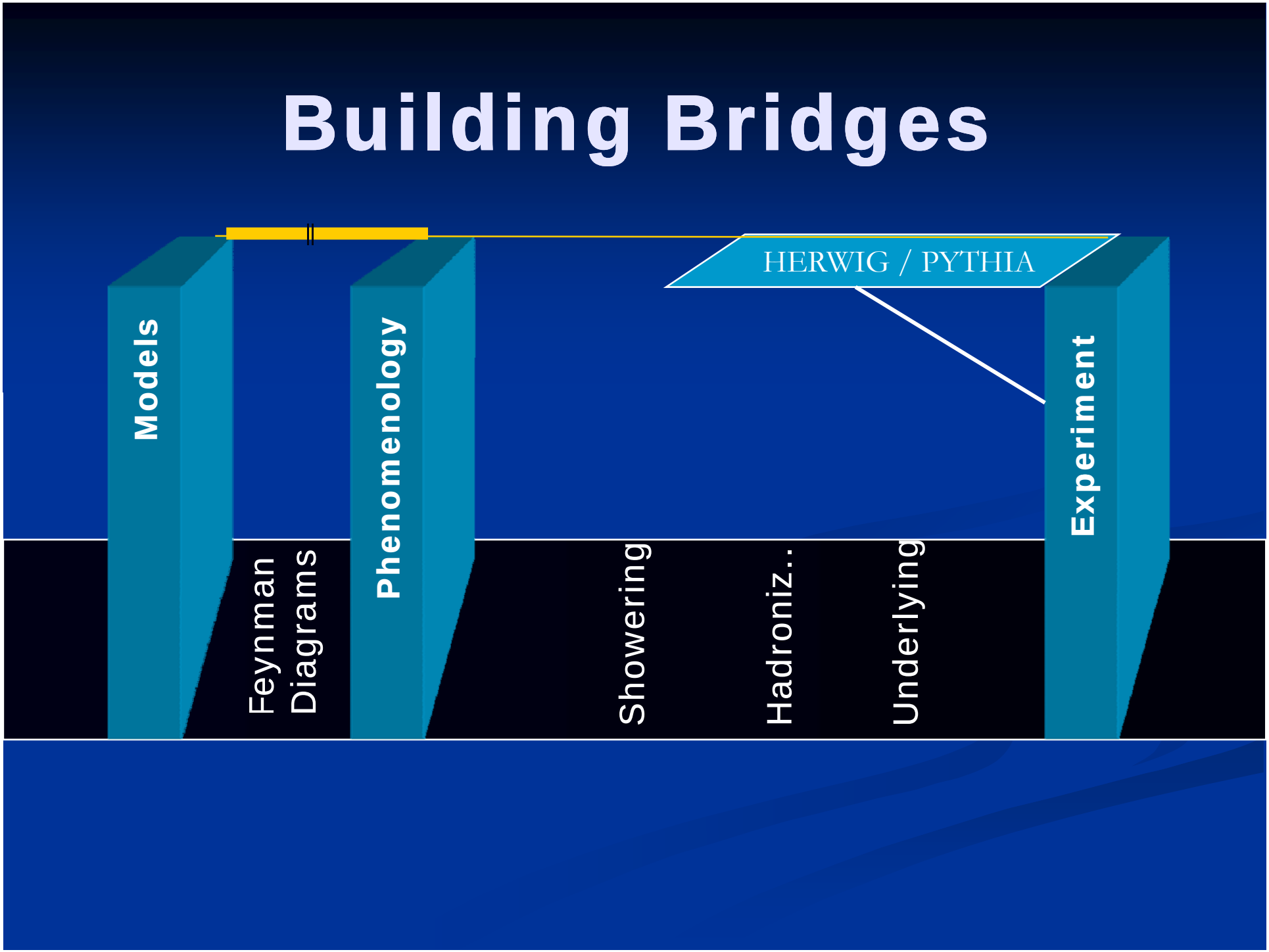
$$\frac{1}{(p_q + p_g)^2} \simeq \frac{1}{2E_q E_g(1-\cos\theta)}$$



Collinear factorization:

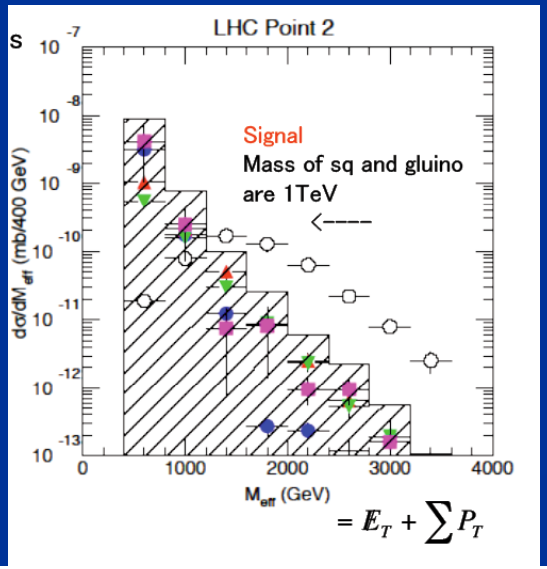
$$|M_{p+1}|^2 d\Phi_{p+1} \simeq |M_p|^2 d\Phi_p \frac{dt}{t} \frac{\alpha_S}{2\pi} P(z) dz d\phi$$

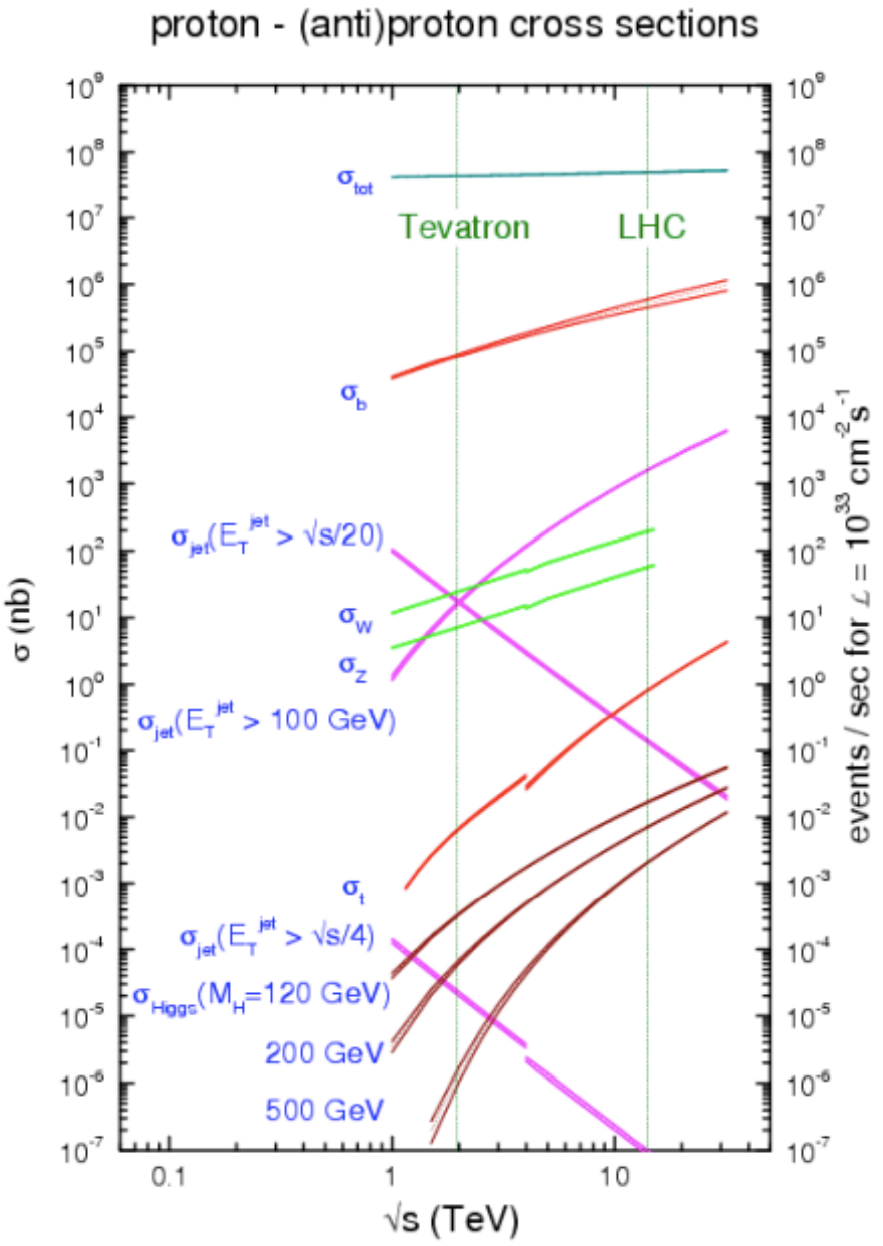
Building Bridges



Tevatron to LHC

- Backgrounds
  - Multi-parton (tt)
  - Study first
  - Key to Signal
- Require better event generators





Improve Hard Scattering

1. Identify all suprocesses (gg-> ggg, gq -> ggq, etc) in $$\sigma(pp \to 3j) = \sum_{ijk} \int f_i(x_1) f_j(x_2) \hat{\sigma}(ij \to k_1 k_2 k_3)$$

Easy

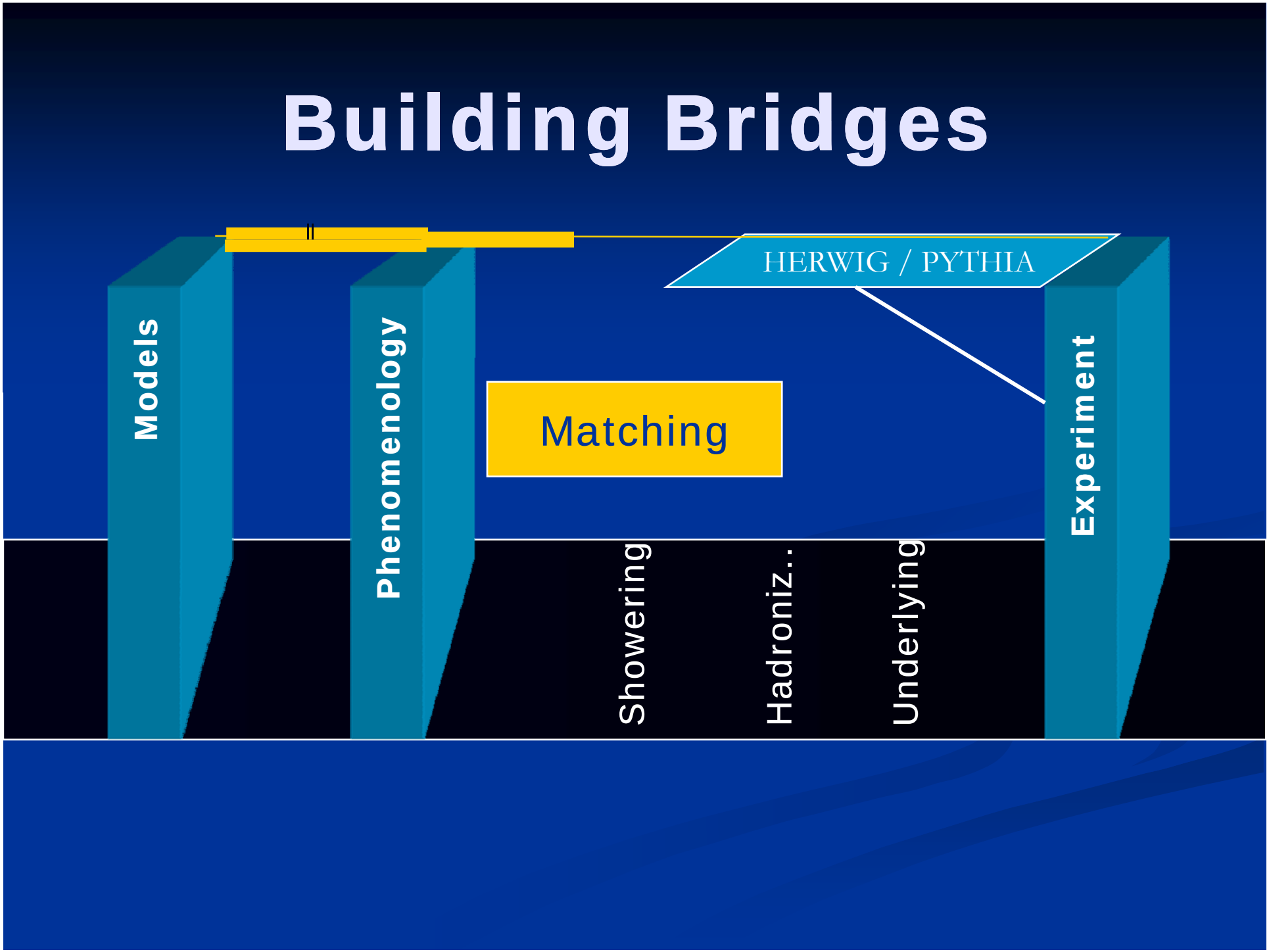
2. For each one calculate amplitude $$\mathcal{A}(\{p\},\{h\},\{c\}) = \sum_i D_i$$

Hard

3. Square amplitude, sum over spins & color, integrate over phase space $$\hat{\sigma} = \frac{1}{2\hat{s}} \int d\Phi_p \sum_{h,c} |\mathcal{A}|^2$$

Very hard

Building Bridges



M.E. / Shower Matching

ME

1. parton-level description
2. fixed order calculation
3. quantum interference exact
4. valid when partons are hard and well separated
5. needed for multi-jet description

Shower MC

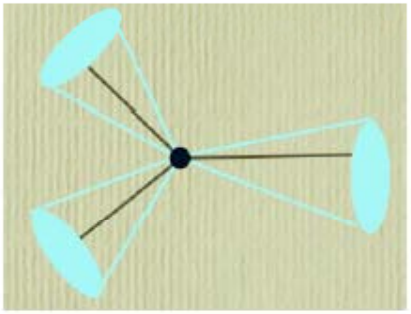
1. hadron-level description
2. resums large logs
3. quantum interference through AO
4. valid when partons are collinear and/or soft
5. needed for realistic studies

Approaches are complementary!

But double-counting has to be avoided!

Avoid Double Counting

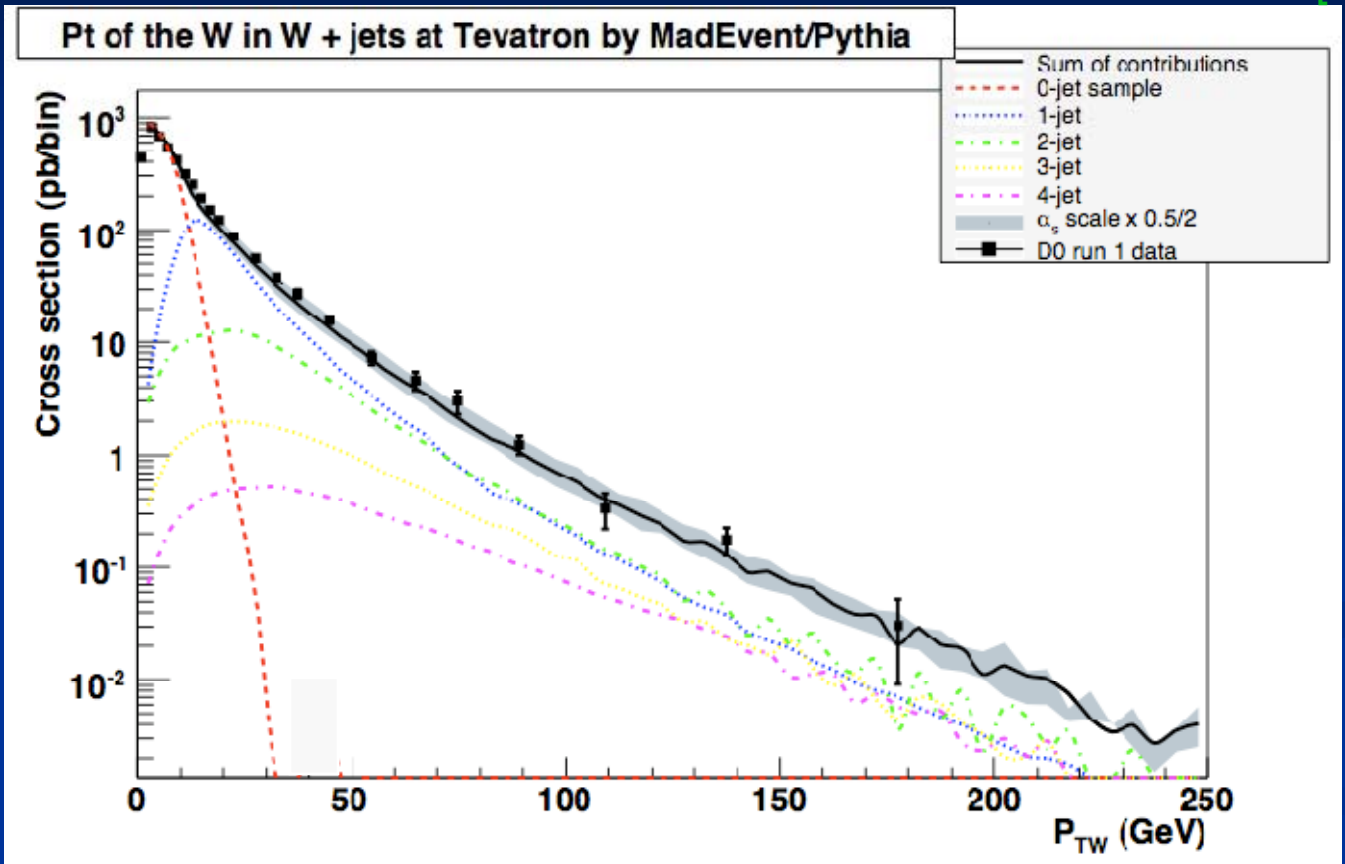
Jet-parton matching



Event matched, $N_{\text{jet}} = N_{\text{part}} = 3$
– Keep event

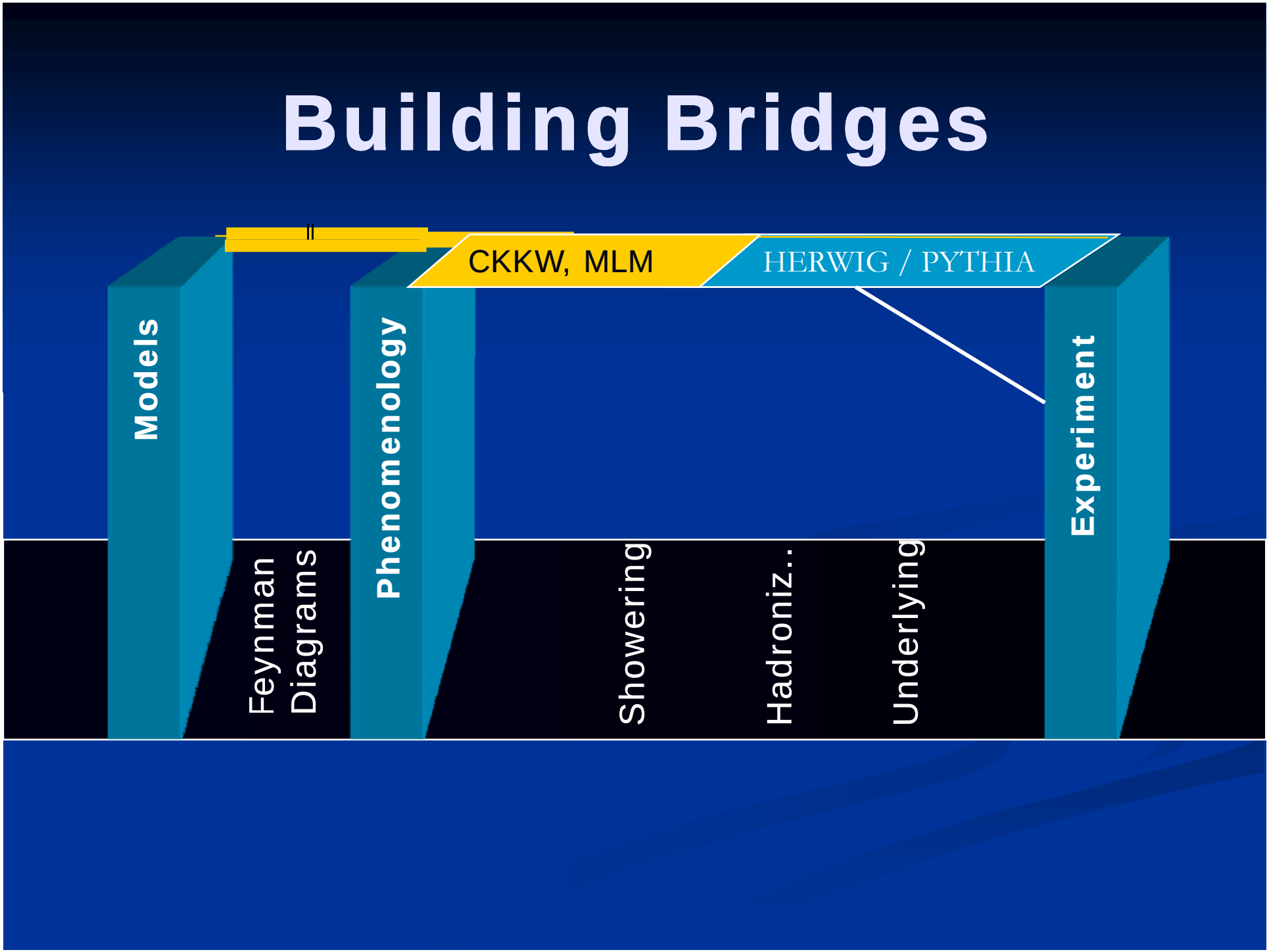
Matching Results

[J. Alwall]



1. The most inclusive observable.
2. All parton multiplicities contribute.
3. Excellent agreement with TeV data (validation)

Building Bridges



Available Tools

- Showering/Hadronization
  - HERWIG
  - Pythia
  - SHERPA
- Hard Scattering
  - Alpgen (Multi parton)
  - AMEGIC (SHERPA integration)
  - Comphep/Calchep (User Interface)
  - MadGraph/MadEvent (see next slide)

MadGraph Home Page

http://madgraph.phys.ucl.ac.be/

SPINS Java Homepage | Dictionary.com | Free Online Translator | CP3 | Il Blog di Beppe Grillo | sole24radio

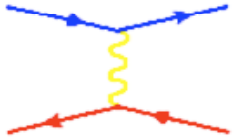
Center for Particle Physics and Phenomenology - CP3

MadGraph Version 4

UCL UIUC Fermi

by Fabio Maltoni, Tim Stelzer

and the CP3 Development team



Generate Process | Register | Tools | My Database | Cluster Status | Manual | News | Downloads | Documents | Admin

Code can be generated either by:

I. Fill the form:

Model: SM — Particle names

Input Process: — Examples

Max QCD Order: 99

Max QED Order: 99

p and j definitions: p=j=d u s c d~ u~ s~ c~ g

sum over leptons: l+ = e+, mu+ ; l- = e-, mu- ; vl = ve, vm ; vl~ = ve~, vm~

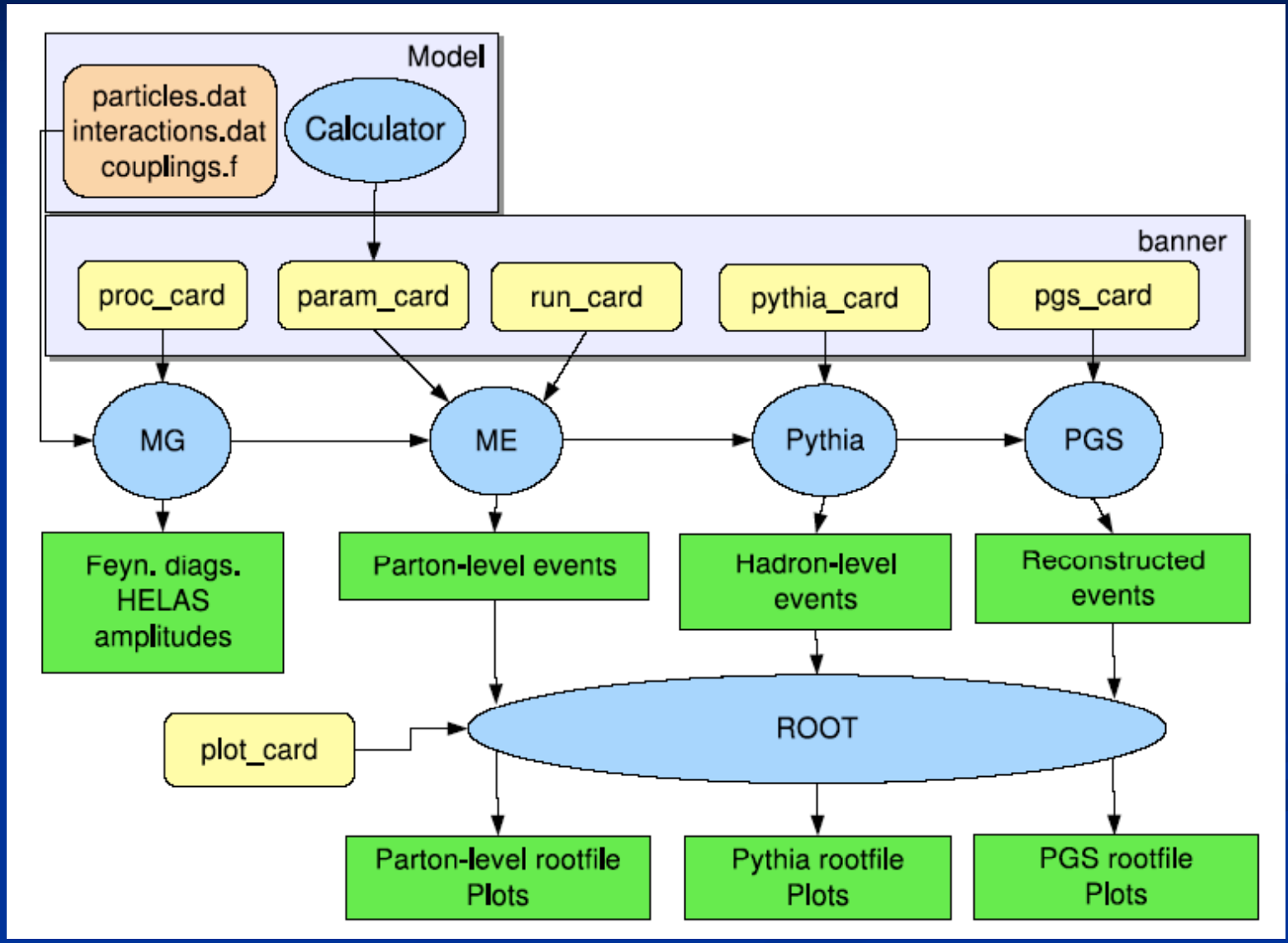
Submit

II. Upload the proc_card.dat

Process card examples

Choose File | no file selected | and | send | it to the server.

Structure


Model
particles.dat
interactions.dat
couplings.f
Calculator
banner
proc_card
param_card
run_card
pythia_card
pgs_card
MG
ME
Pythia
PGS
Feyn. diags.
HELAS
amplitudes
Parton-level events
Hadron-level
events
Reconstructed
events
plot_card
ROOT
Parton-level rootfile
Plots
Pythia rootfile
Plots
PGS rootfile
Plots

Models in MadGraph

- Standard Mod

- MSSM
  Rainwater+Plehn+Alwall

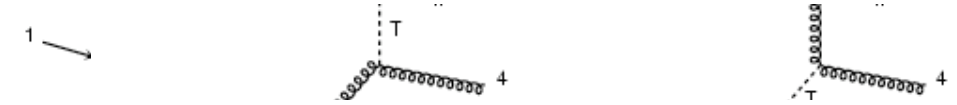
- General 2 H
  Model (inclu
  Herquet, De Viss

- Higgs EFT
  Frederix

-New: General framework for user-defined models

```
#Name anti_Name  Spin     Linetype Mass Width Color Label Model
#xxx   xxxx      SFV       WSDC     str  str   STO    str  PDG code

#
# Quarks
#

d       d~        F        S       ZERO  ZERO    T     d     1
u       u~        F        S       ZERO  ZERO    T     u     2
s       s~        F        S       ZERO  ZERO    T     s     3
c       c~        F        S       ZERO  ZERO    T     c     4
b       b~        F        S       BMASS ZERO    T     b     5
t       t~        F        S       TMASS TWIDTH  T     t     6
```

particles.da

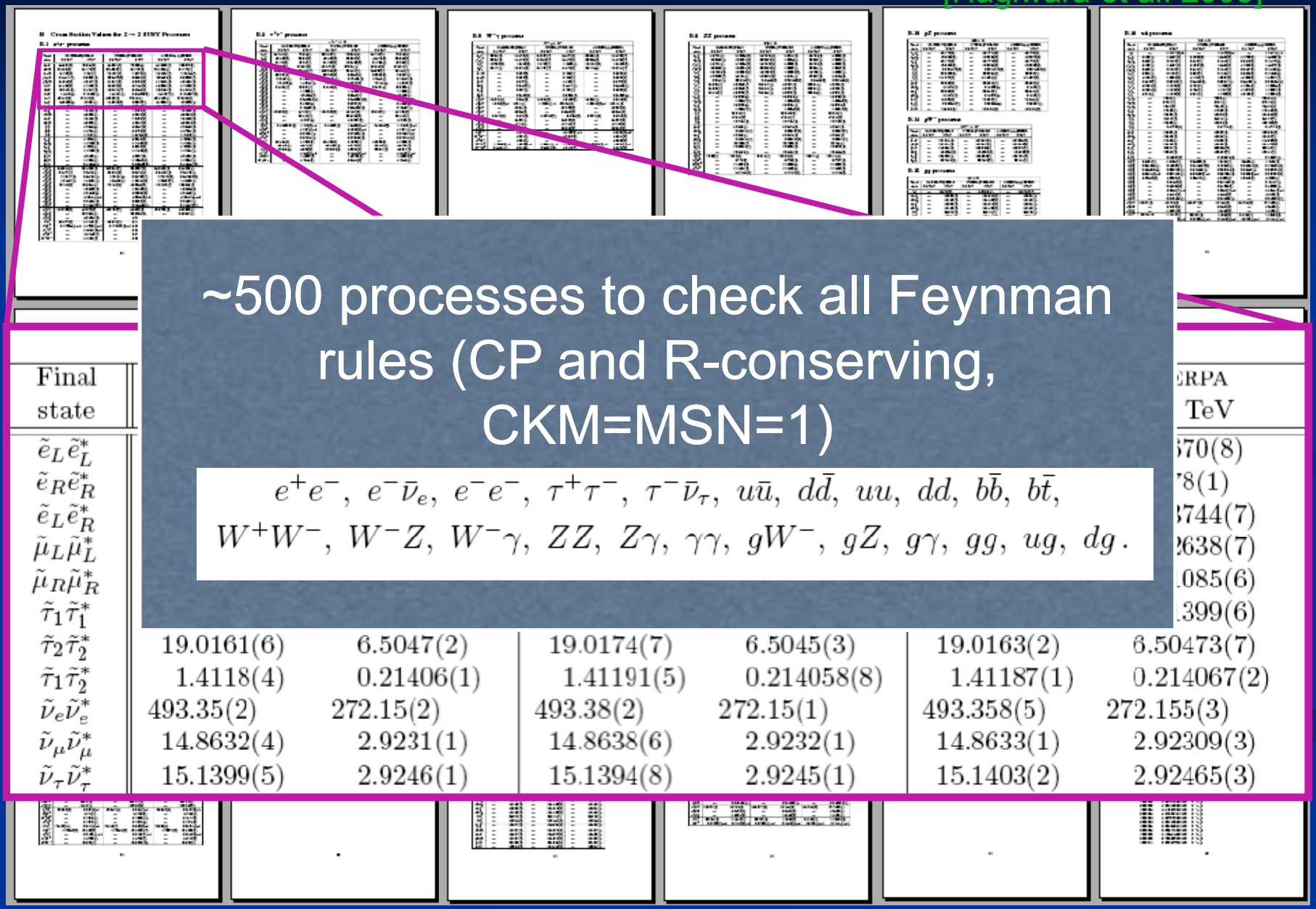



```
#
# QCD interactions
#

d d g GG QCD
u u g GG QCD
s s g GG QCD
c c g GG QCD
b b g GG QCD
t t g GG QCD

g g g G  QCD
```

interactions.dat

MadGraph/Sherpa/Whizard SUSY comparison

[Hagiwara et al. 2005]



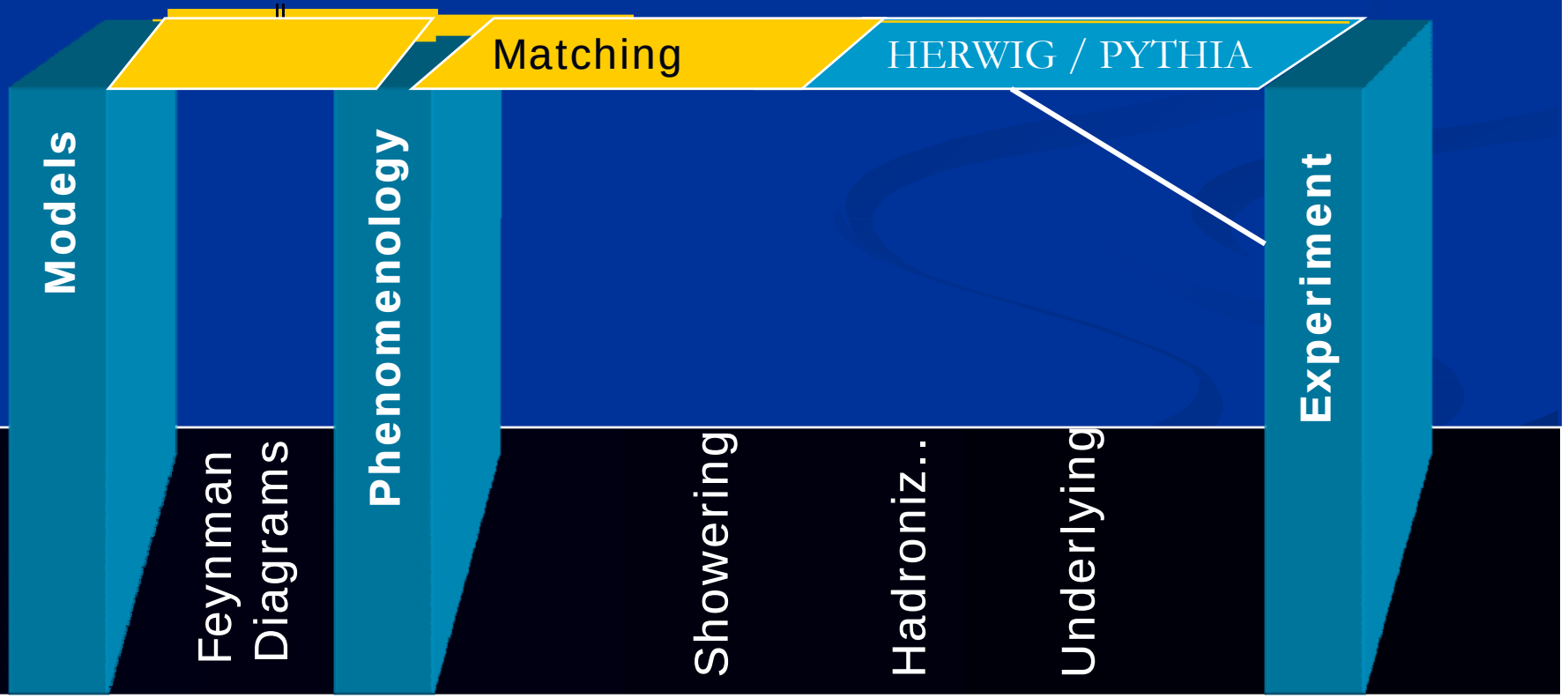
~500 processes to check all Feynman rules (CP and R-conserving, CKM=MSN=1)

$$e^+e^-,\ e^-\bar{\nu}_e,\ e^-e^-,\ \tau^+\tau^-,\ \tau^-\bar{\nu}_\tau,\ u\bar{u},\ d\bar{d},\ uu,\ dd,\ b\bar{b},\ b\bar{t},$$
$$W^+W^-,\ W^-Z,\ W^-\gamma,\ ZZ,\ Z\gamma,\ \gamma\gamma,\ gW^-,\ gZ,\ g\gamma,\ gg,\ ug,\ dg\,.$$

Final state						
$\tilde{e}_L\tilde{e}_L^*$						
$\tilde{e}_R\tilde{e}_R^*$						
$\tilde{e}_L\tilde{e}_R^*$						
$\tilde{\mu}_L\tilde{\mu}_L^*$						
$\tilde{\mu}_R\tilde{\mu}_R^*$						
$\tilde{\tau}_1\tilde{\tau}_1^*$						
$\tilde{\tau}_2\tilde{\tau}_2^*$	19.0161(6)	6.5047(2)	19.0174(7)	6.5045(3)	19.0163(2)	6.50473(7)
$\tilde{\tau}_1\tilde{\tau}_2^*$	1.4118(4)	0.21406(1)	1.41191(5)	0.214058(8)	1.41187(1)	0.214067(2)
$\tilde{\nu}_e\tilde{\nu}_e^*$	493.35(2)	272.15(2)	493.38(2)	272.15(1)	493.358(5)	272.155(3)
$\tilde{\nu}_\mu\tilde{\nu}_\mu^*$	14.8632(4)	2.9231(1)	14.8638(6)	2.9232(1)	14.8633(1)	2.92309(3)
$\tilde{\nu}_\tau\tilde{\nu}_\tau^*$	15.1399(5)	2.9246(1)	15.1394(8)	2.9245(1)	15.1403(2)	2.92465(3)

Coming Soon

- New Tools for Adding New Models
- Decay Chains



Summary

- Accurate simulation of SM backgrounds and New Physics is essential for LHC
- Significant progress has been made in last 5 years
- New era in communication between Model builders and experimentalists