MadGraph/ MadEvent v4

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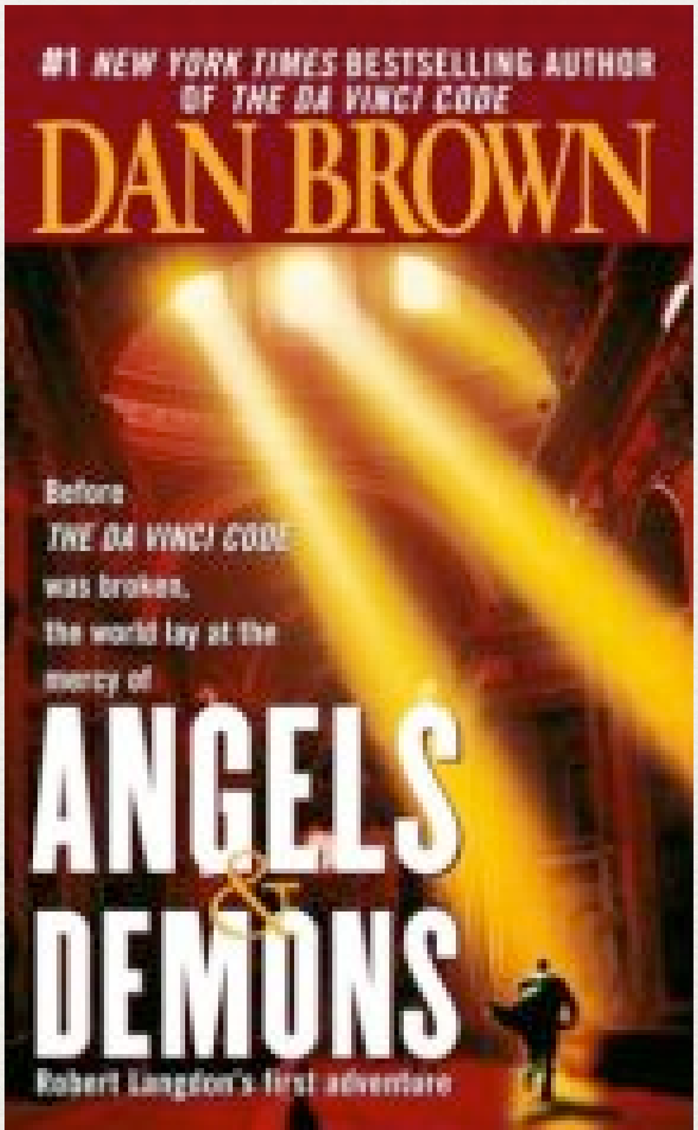
Time line (2:15-6:45)

- First contact (20’+40’)
- How does it work ? (15’+45’)
- Going Beyond the Standard Model (10’+50’)
- World is not perfect: backgrounds and detector simulation (10’+50’)

Part I:
First contact

Reading Assignment



Outline Part I

- Questions to answer :
  - What is MadGraph/MadEvent ? How can it help you ?
  - What are the fundamental concepts behind it ?
- Technical skills to develop :
  - Connect and register on a MG/ME online cluster
  - Create your first process, compute a cross section and produce some events

An imaginary discussion

- Theo: "*I have a fantastic model for TeV physics and I would like you to test it*"
- Elsa: "*Great! How the signal events look like ?*"
- Theo: "*No idea... But here is the Lagrangian*"
- Elsa (looking at the paper): "*What do you want me to do with... this ?*"
- Theo: "*Well, I don't know, it's your job!*"
- Elsa: "*No, it's yours!*"
- Theo: "*Ok, let's meet... later...*"

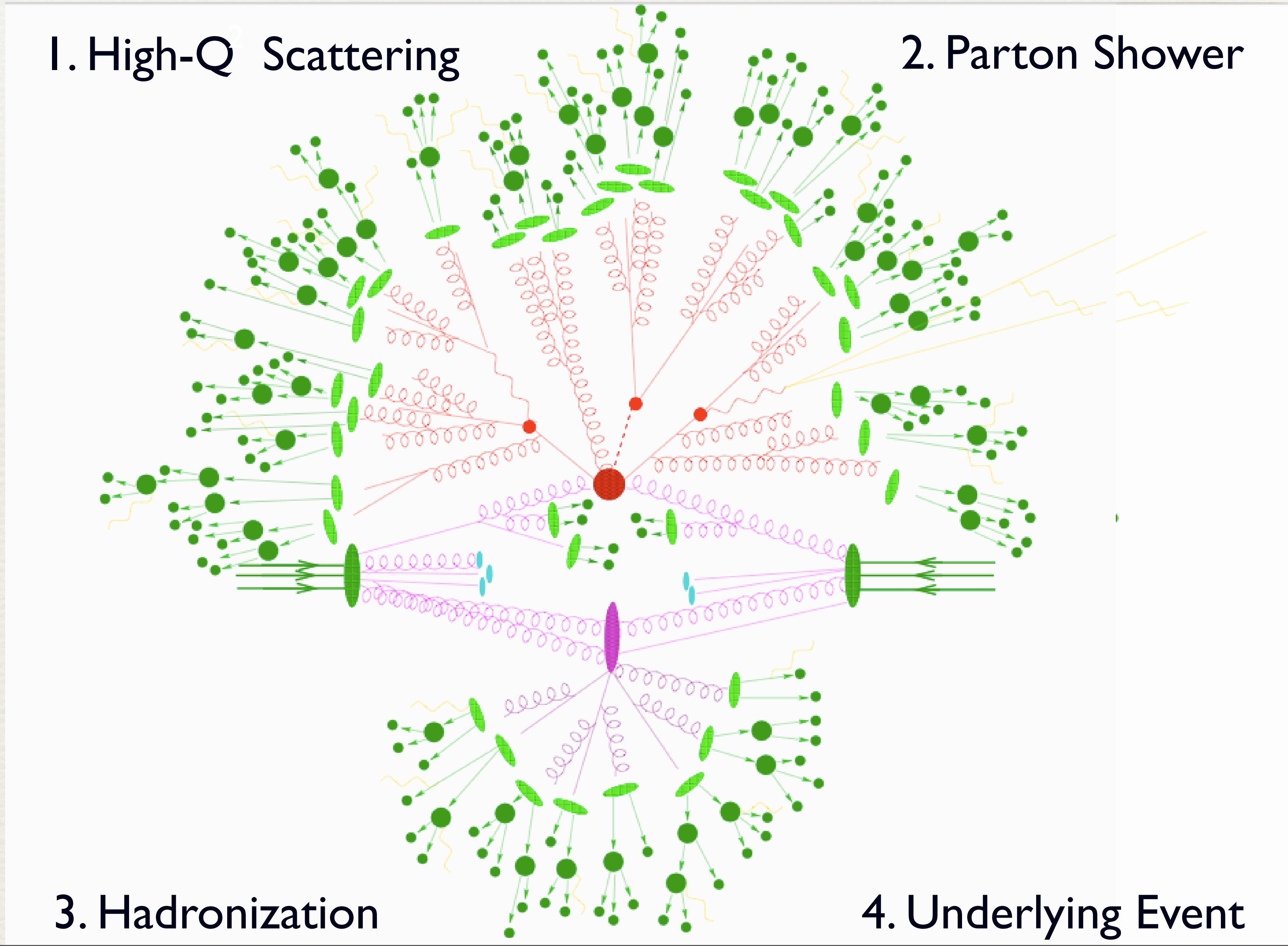
Building bridges

- Bad news : going from a Lagrangian to events in a detector is **not** a trivial task
- Good news : a large part of the process can be automatized, so physicists can **focus on interesting physics** and avoid spending time on painstaking tasks
- Warning: automatization does not exempt users from understanding what's going on in the box

"*Make everything as simple as possible, but not simpler.*"

Fortune cookie message found in a chinese restaurant somewhere in NYC by the MadGraph Team

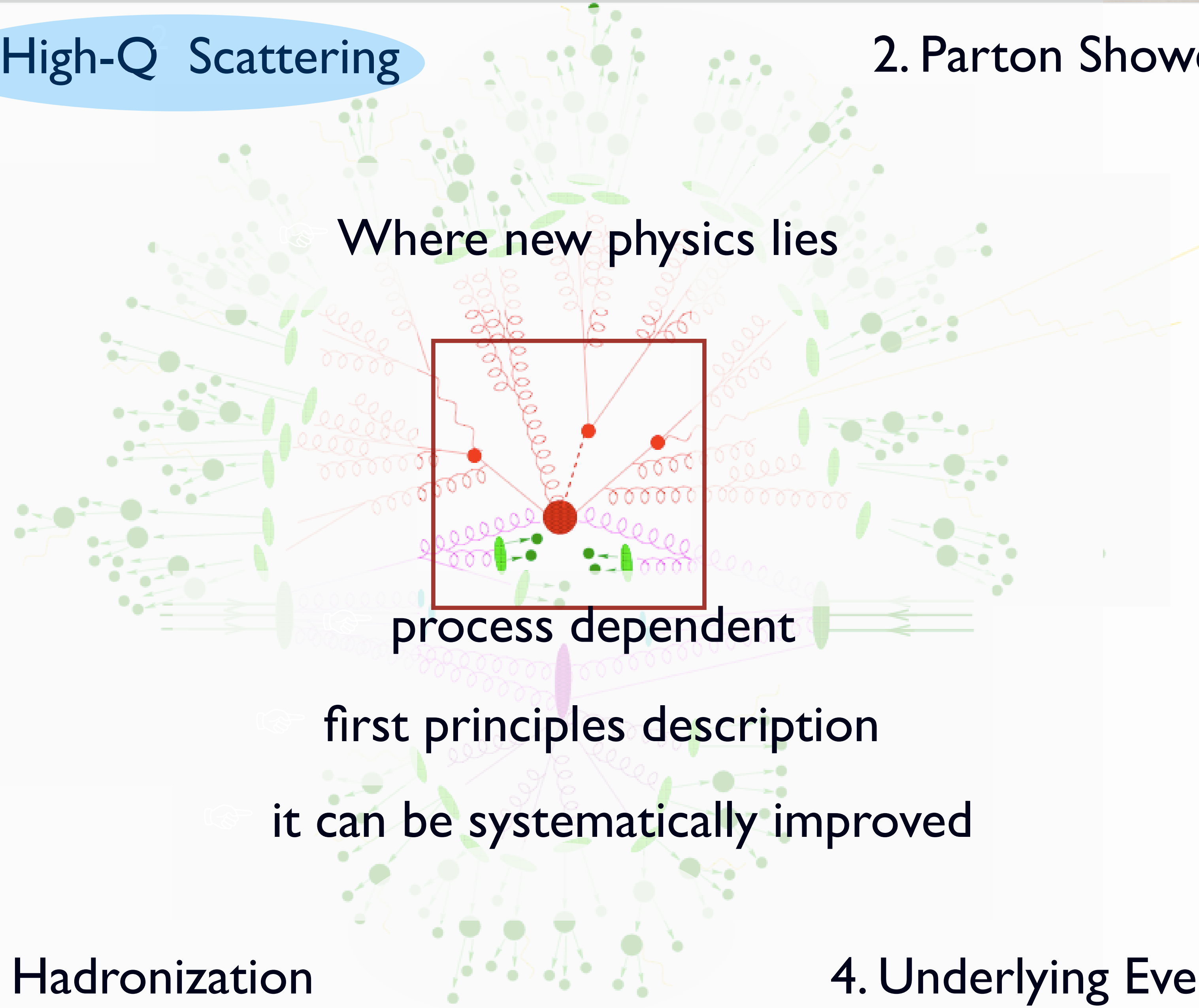
Anatomy of an event



Anatomy of an event

1. High-Q Scattering

2. Parton Shower

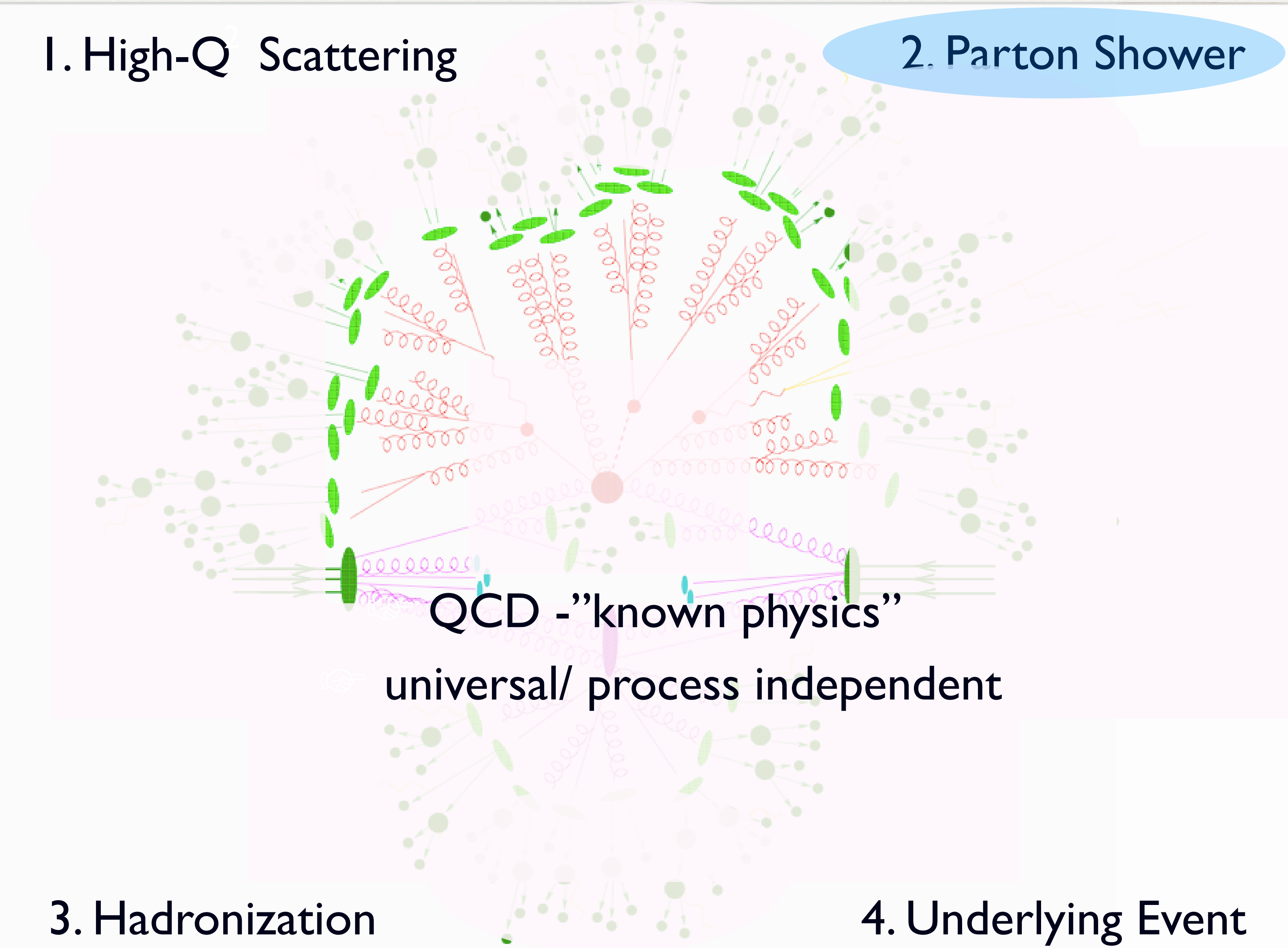


- Where new physics lies
- process dependent
- first principles description
- it can be systematically improved

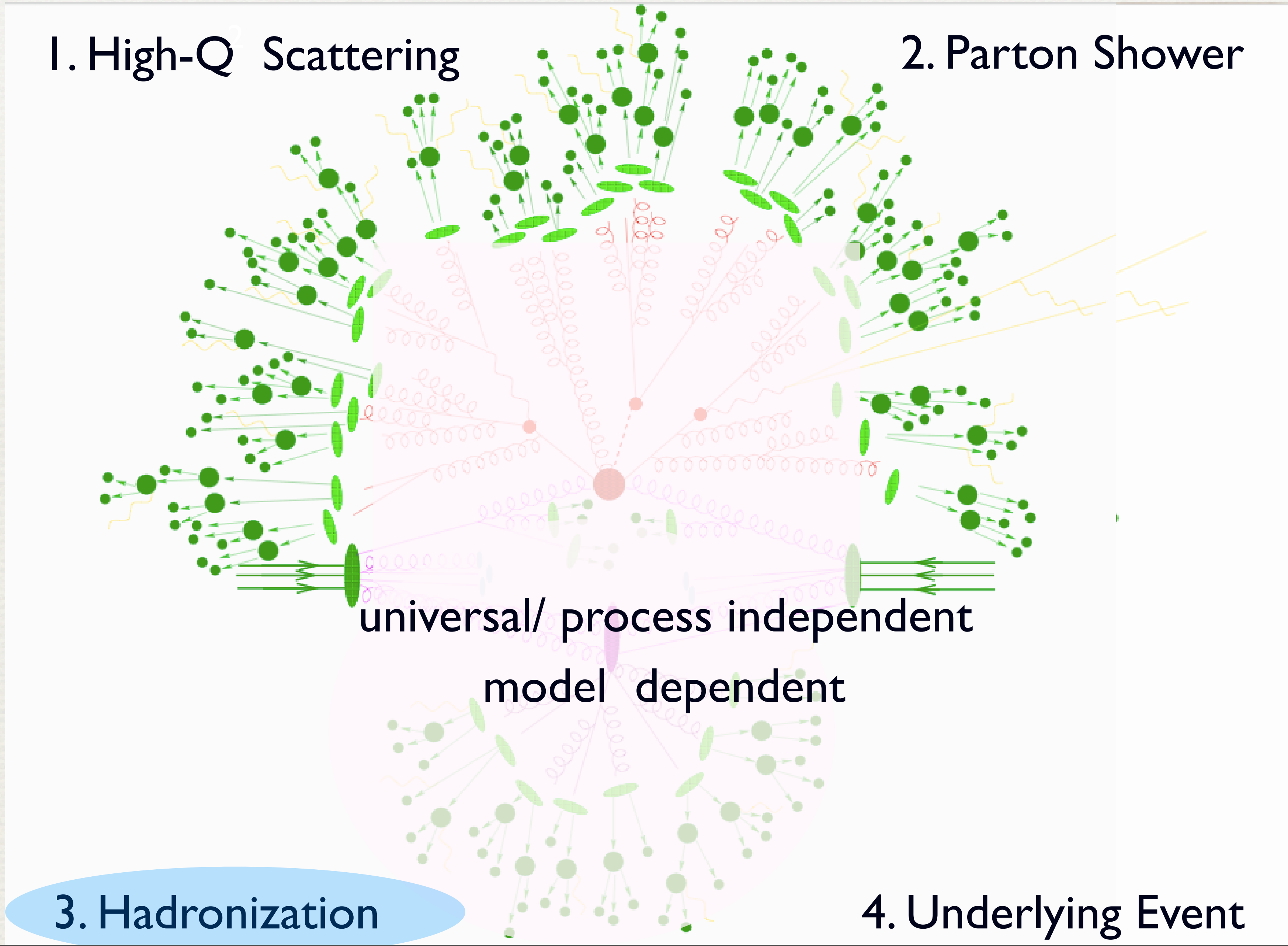
3. Hadronization

4. Underlying Event

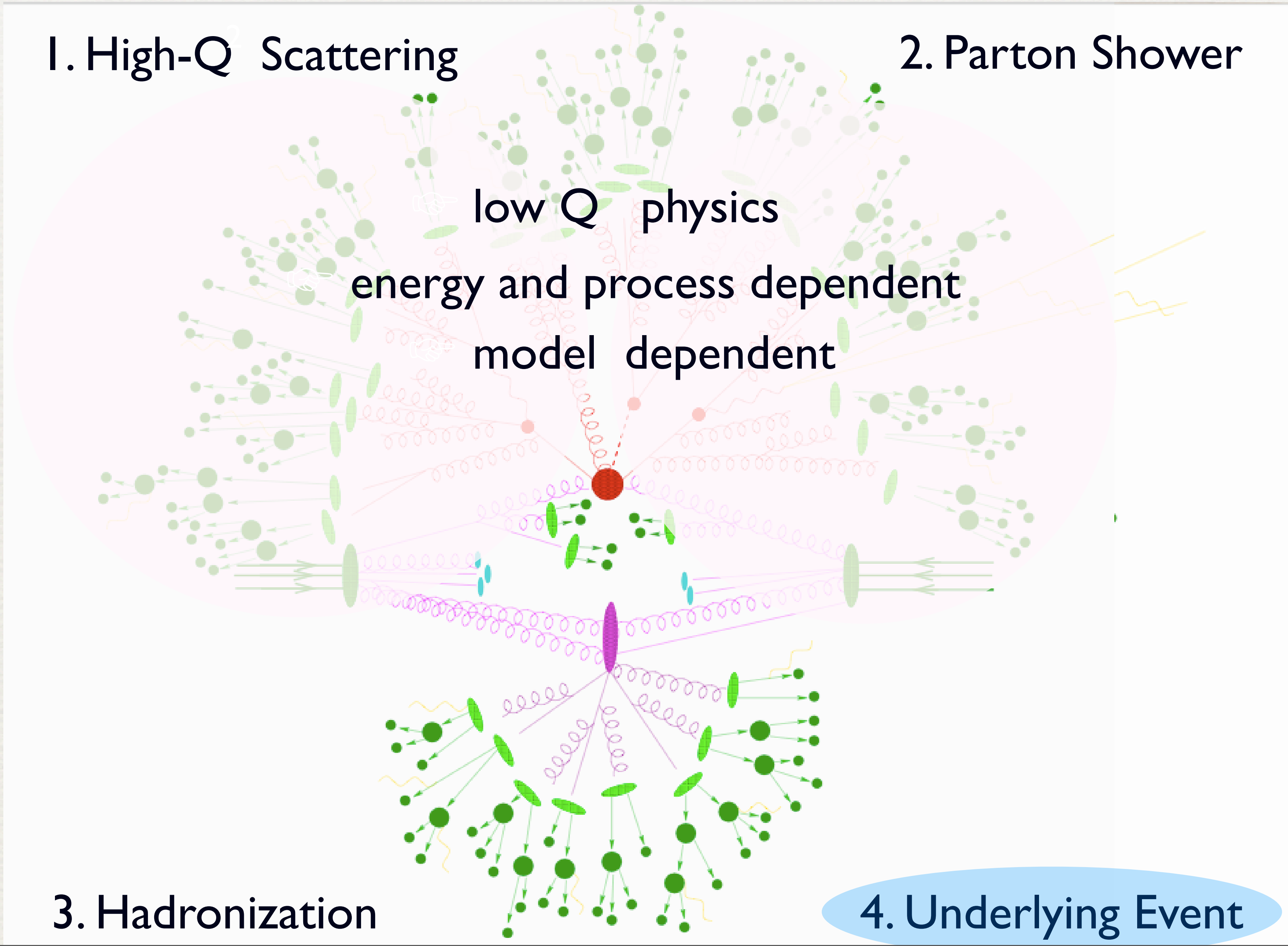
Anatomy of an event



Anatomy of an event



Anatomy of an event



Matrix Elements

- Good news : the Standard Model is the most successful theory in Physics !
- Bad news : we can't solve it!!!
  - Cross sections : $$\sigma = \frac{1}{2s}\int |M|^2 \mathrm{d}\Phi$$
  - Matrix elements : $$M = \langle \mu^+ \mu^- | T\left(e^{-i\int H_I \mathrm{d}t}\right)|e^+ e^-\rangle$$

  cannot be computed exactly because interactions change wave functions
- Solution : perturbation theory: start with free particles and assume small perturbations

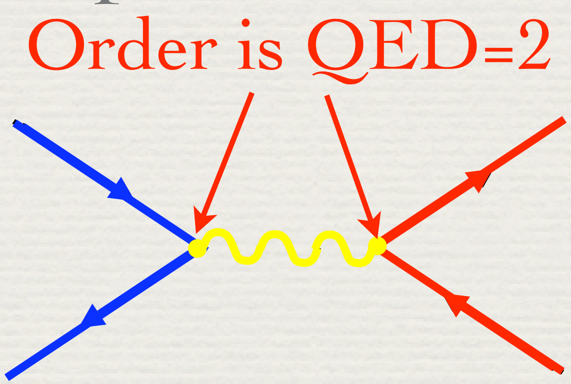
$$M \approx \langle \mu^+ \mu^- | H_I | e^+ e^- \rangle + \frac{1}{2}\langle \mu^+ \mu^- | H_I^2 | e^+ e^- \rangle + \ldots$$

Feynman rules

- Feynman rules are the building blocks used to generate allowed diagrams and the associated amplitudes

γ	QED	$q\bar{q}\gamma$ $l^-l^+\gamma$	$W^+W^-\gamma$	
Z	QED	$q\bar{q}Z$ $l\bar{l}Z$	W^+W^-Z	
W^{+-}	QED	$q\bar{q}'W$ $l\nu W$		WWWW
g	QCD	$q\bar{q}g$	ggg	gggg
h	QED HIG	$q\bar{q}h$ $l\bar{l}h$	W^+W^-h	ZZh

- Example :



$$M \approx \overline{\nu}(e^+)(-iq\gamma^\mu)\nu(e^-)\frac{-ig_{\mu\nu}}{p^2}\overline{u}(\mu^+)(-iq\gamma^\nu)u(\mu^-)$$

MadGraph

- Generates **all tree-level diagrams** and produces **code to compute the associated |M|²**
- Exercise 1.a :
  - On a sheet of paper, draw all Feynman diagrams associated with $e^+e^- \to e^+e^-b\bar{b}$
  - Browse to http://madgraph.phys.ucl.ac.be
  - Register or use the username "Angels" and guess the password (6 letters)
  - Use MadGraph to check your answer

MadEvent

- Uses code produced by MadEvent to **compute cross sections** and **generate events**
- Exercise 1.b :
  - Generate events for the previous process using the web interface (for a e+e- collider @ 500 GeV and for default parameters / cuts)
  - Look at the results page, how can you interpret them ?
  - Give a look at the plot page. Download the LHE event file & open it with a text editor. What do you see ?

Part II:
How does it work ?

Outline Part II

- Questions to answer :
  - What are the basic principles used in MadGraph ? MadEvent ?
  - How to deal with hadron collisions ? Why do we need production cuts ?
- Technical skills to develop :
  - Understand the structure of a self contained MadEvent directory
  - Start the Higgs hunt at Tevatron ! Produce Higgs signal events for a hadron collider

MadGraph

- Generates "empty" topologies for m>n diagrams and "fill" them using valid interaction vertices (listed in the `interactions.dat` file)

```
e-  e-  z GZL QED
mu- mu- z GZL QED
ta- ta- z GZL QED
```

- Knowing particles properties (listed in the `particles.dat` file), produces suitable calls to the HELAS library

```
#Name anti_Name  Spin    Linetype Mass Width Color Label Model
 a         a        V        W       ZERO  AWIDTH  S    A     22
 w-        w+       V        W       WMASS WWIDTH  S    W    -24
 h         h        S        D       HMASS HWIDTH  S    h     25
```

MadGraph

- Sample matrix.f file (for the $e^+e^- \to e^+e^-b\bar{b}$ process)

```
CALL OXXXXX(P(0,1   ),ZERO ,NHEL(1   ),-1*IC(1   ),W(1,1   ))
CALL IXXXXX(P(0,2   ),ZERO ,NHEL(2   ),+1*IC(2   ),W(1,2   ))
CALL IXXXXX(P(0,3   ),ZERO ,NHEL(3   ),-1*IC(3   ),W(1,3   ))
CALL OXXXXX(P(0,4   ),ZERO ,NHEL(4   ),+1*IC(4   ),W(1,4   ))
CALL OXXXXX(P(0,5   ),BMASS ,NHEL(5   ),+1*IC(5   ),W(1,5   ))
CALL IXXXXX(P(0,6   ),BMASS ,NHEL(6   ),-1*IC(6   ),W(1,6   ))
CALL JIOXXX(W(1,2   ),W(1,4   ),GAL ,ZERO    ,AWIDTH  ,W(1,7   ))
CALL FVIXXX(W(1,3   ),W(1,7   ),GAL ,ZERO    ,ZERO    ,W(1,8   ))
CALL JIOXXX(W(1,8   ),W(1,1   ),GAL ,ZERO    ,AWIDTH  ,W(1,9   ))
CALL IOVXXX(W(1,6   ),W(1,5   ),W(1,9   ),GAD ,AMP(1   ))
CALL JIOXXX(W(1,8   ),W(1,1   ),GZL ,ZMASS   ,ZWIDTH  ,W(1,10  ))
CALL IOVXXX(W(1,6   ),W(1,5   ),W(1,10  ),GZD ,AMP(2   ))
CALL JIOXXX(W(1,2   ),W(1,4   ),GZL ,ZMASS   ,ZWIDTH  ,W(1,11  ))
CALL FVIXXX(W(1,3   ),W(1,11  ),GZL ,ZERO    ,ZERO    ,W(1,12  ))
CALL JIOXXX(W(1,12  ),W(1,1   ),GAL ,ZERO    ,AWIDTH  ,W(1,13  ))
CALL IOVXXX(W(1,6   ),W(1,5   ),W(1,13  ),GAD ,AMP(3   ))
CALL JIOXXX(W(1,12  ),W(1,1   ),GZL ,ZMASS   ,ZWIDTH  ,W(1,14  ))
CALL IOVXXX(W(1,6   ),W(1,5   ),W(1,14  ),GZD ,AMP(4   ))
CALL JIOXXX(W(1,3   ),W(1,1   ),GAL ,ZERO    ,AWIDTH  ,W(1,15  ))
```

MadEvent

- Cross section integration is a **hard job** !
  - 3n-4+2 dimensions
  - Many peaks from propagators

- The only option is **Monte-Carlo integration**

$$\int_a^b f(x)\mathrm{d}x \approx \frac{b-a}{N} \sum_{i=1,N} f(x_i)$$

  - Advantages : large number of dimensions, complicated cuts, event generation
  - Limitations : only works for $f(x) \approx 1$, errors scale as $1/\sqrt{N}$

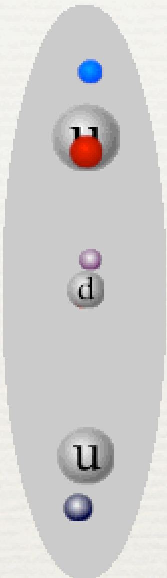
MadEvent

- Adaptive methods like VEGAS adjust a "grid" to numerically flatten peaks
  - But : time expensive, peaks must lie on integration variables
- Solutions exist : Multi-Channel Integration (Amegic, Nextcalibur, Whizard), **Single Diagram Enhanced MCI** (MadEvent) :

$$|\sum_i A_i|^2 = \sum_i \left(\frac{|A_i|^2}{\sum_j |A_j|^2} |\sum_k A_k|^2 \right)$$

  - One peaked function per diagram
  - Parallel in nature

Hadron collisions



- Initial State: Protons
  - Made of **quarks/gluons in bound state**
  - Approximately **free at very short times**
  - **Measure distributions** in experiments
- Final State: Hadrons
  - Made of **quarks/gluons in bound state**
  - **Combine into jets** and evolve back to partons
  - **Measure hadronization** in experiments
- Many parton level sub processes contribute to same hadron level event, e.g several hundred for

$$pp \to e^+ \nu_e jjjj$$

Hadron collision

- Parton distribution functions (**PDFs**) must be taken into account when calculating cross sections :

$$\sigma = \frac{1}{2s}\sum_{p_1,p_2}\int f_{p_1}(x_1)f_{p_2}(x_2)|M|^2\mathrm{d}\Phi\mathrm{d}x_1\mathrm{d}x_2$$

- MadGraph automatically deals with **summations over multiple partons** (p, j and l symbols)

- MadEvent automatically integrates over PDFs

- MG/ME can deal with several processes inclusively, e.g.

$$pp \to X, X+1j, X+2j, \ldots, X+nj$$

Generation cuts

- Cuts at the event generation level are both **essential** and **useful** :
    - Tree-level amplitudes often contain s**oft and/or colinear singularities**
    - Real-life analysis often focus on **specific kinematic regions** : generation cuts improve efficiency
- Standard ME cuts include: pT, energy, rapidity, invariant masses, ΔR, ...
- User defined cuts are easy to implement

Exercise 2

- Create the following process online

$$pp \to Z, h^0 \to l^+ l^- b\bar{b} \quad \text{with} \quad l^\pm = e^\pm, \mu^\pm$$

- Download the code, expand it and take a look at the files, especially
    - `particles.dat, interactions.dat, couplings.f in ./Source/MODEL`
    - `proc_card.dat, param_card.dat, run_card.dat in ./Cards`
    - `cuts.f, matrix.f in ./SubProcesses/P_*_*`
- Generate 20k events for a Higgs mass of 140 GeV, using the command line. What is the integrated luminosity needed to see 10 such events at Tevatron ?

Part III : Going beyond the SM

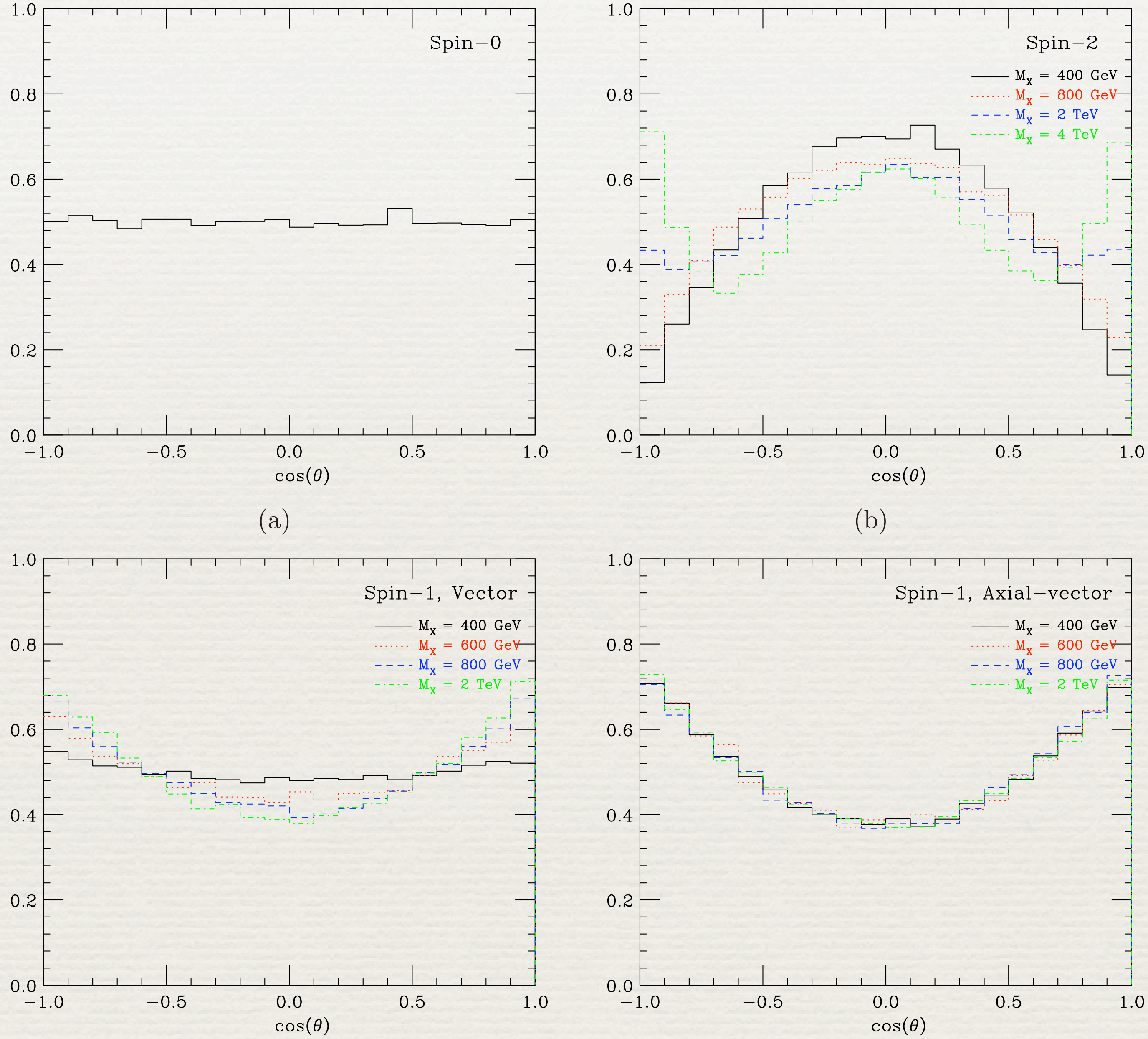
Outline Part III

- Questions to answer :
  - What are the different ways to implement BSM models in MG/ME v4 ?
  - How matrix elements simulations can help to disentangle different types of BSM physics ?
- Technical skills to develop :
  - Add a new particle to the SM and generate signal events involving it
  - Use the MadAnalysis program to generate plots to disentangle two BSM hypothesis

BSM models

- Several common BSM models are already implemented in MG/ME v4: MSSM, 2HDM, HEFT, UED, LH, ...
- Users can implement new models using the USRMOD framework :
  - Advantage : well adapted for simple SM extensions
  - Limitation : requires Feynman rules, which can be hard to extract for complex/realistic models
- The FeynRules Mathematica module solves this issue by allowing the user to start directly from the Lagrangian

Advantages of ME simulations



from arXiv:0712.2355, Frederix & Maltoni

Exercise 3

- Go to the local directory where the full MG/ME v4 package stands
- Use the USRMOD template to create a spin-1 "Higgs" model
- Generate 20k events with this new model
- Use MadAnalysis to create a plot to discriminate between this model and the usual SM.

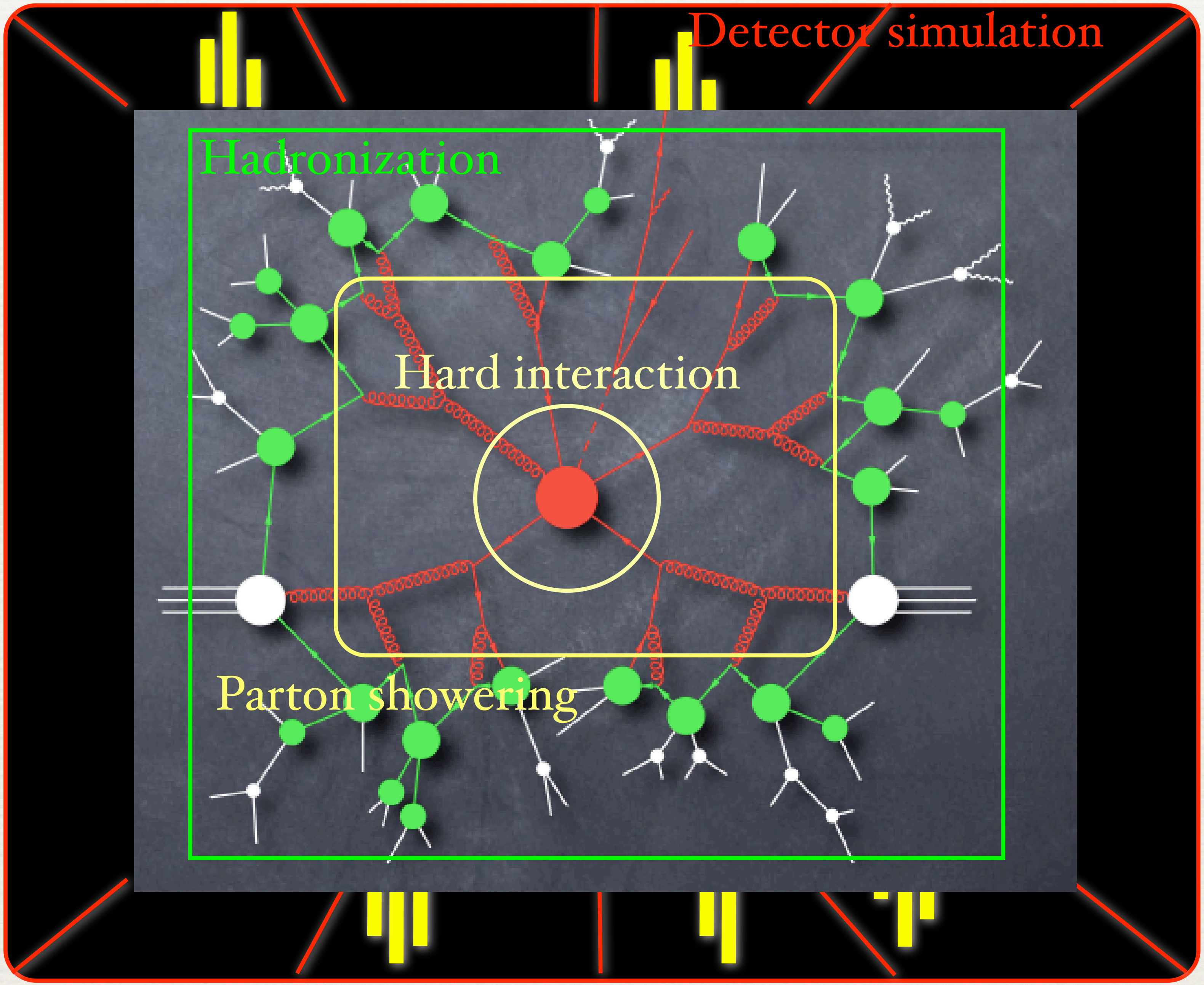
Part IV : World is not perfect

(Good news, this is the very last one)

Outline Part IV

- Questions to answer :
  - How to go from parton level events to detector events ?
  - What's the main issue when trying to merge matrix elements and parton showers ?
- Technical skills to develop :
  - Use the online interface to generate parton level, hadron level and detector level events in one go
  - Understand the production of a matched sample with MG/ME + Pythia

Going to the detector



Going to the detector

- For realistic simulations, **parton showering**, **hadronization** and **detector response** must be simulated accurately
- A full chain MG/ME+Pythia+PGS is available online
- Many other possibilities exist : HERWIG for PS/hadronization, collaboration tools for detector simulation, ...

Merging ME with PS

- Merging Matrix Elements with Parton Showers is **not** a trivial issue
  - Both descriptions have **different validity ranges**
  - Possible **double counting**! E.g. Z+1j + one jet from PS can overlap with Z+2j
  - **Solutions exists**, e.g. CKKW & MLM algorithms
  - A modified version of the MLM algorithm is implemented in the MG/ME - Pythia interface
- **More on this tomorrow** with Frank !

Exercise 4

- Generate the Higgs signal in Exercise 2 online, up to the detector simulation with PGS
- Browse to the MG wiki page:

  http://cp3wks05.fynu.ucl.ac.be/twiki/bin/view/Physics/YETI08

  and follow instructions in handout notes to understand how the inclusive Z+jets sample has been generated
- Homework: Investigate signal and background PGS files with MadAnalysis to understand why b-tagging is essential

Conclusion
(stolen from Tim Stelzer)

- Standard Model is Amazing (good news)
- SM (and BSM!) is tough to Solve (good news)
    - Factorization allows use of Perturbation Theory
    - Feynman Diagrams help
    - MadGraph/MadEvent can help too
- Good Luck !

Thanks !!!