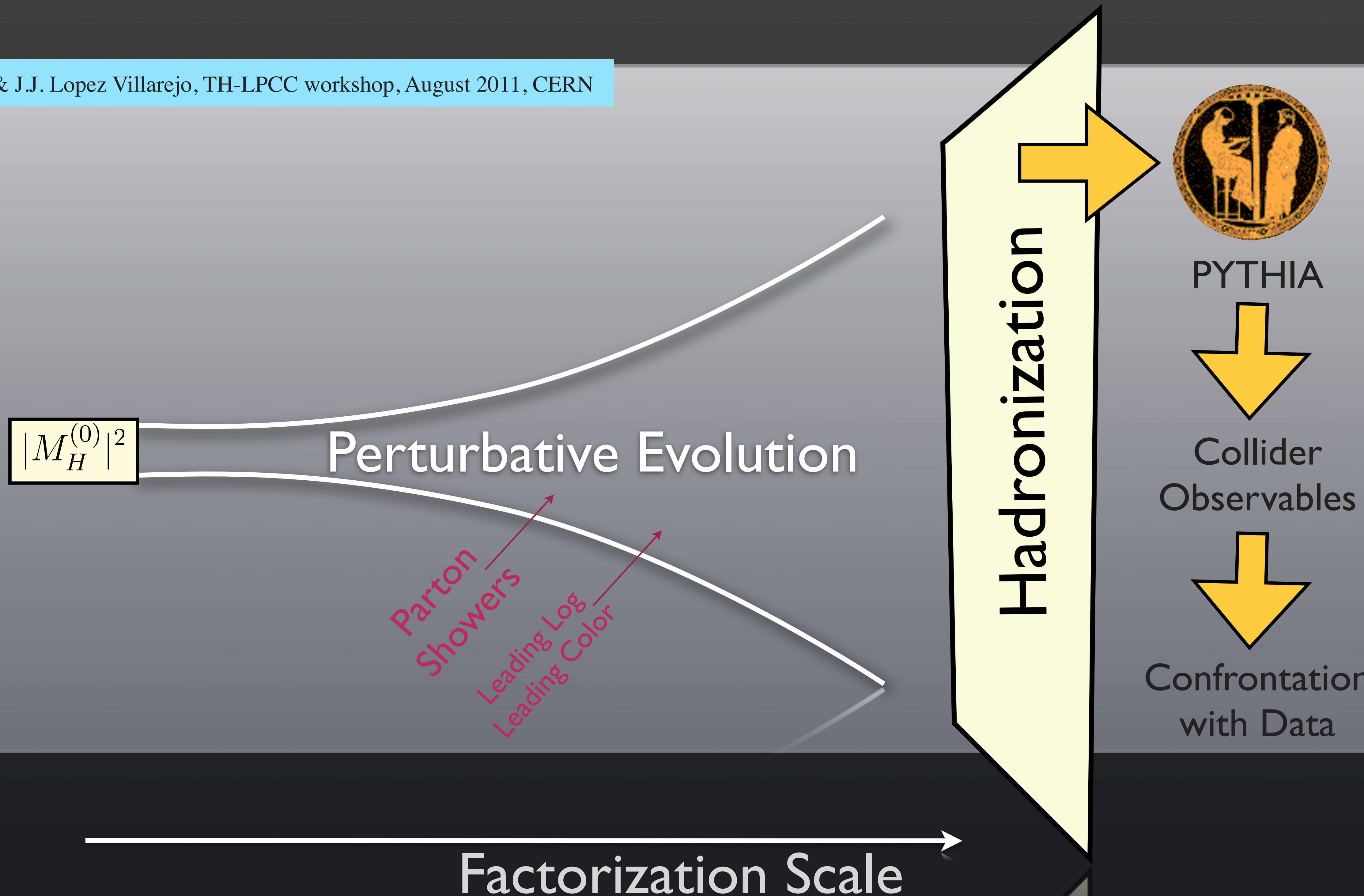
VINCIA: MC event generator for the LHC

Juanjo Lopez-Villarejo (CERN & Dpto. Física Teórica, UAM)

Slides from P. Skands & J.J. Lopez Villarejo, TH-LPCC workshop, August 2011, CERN



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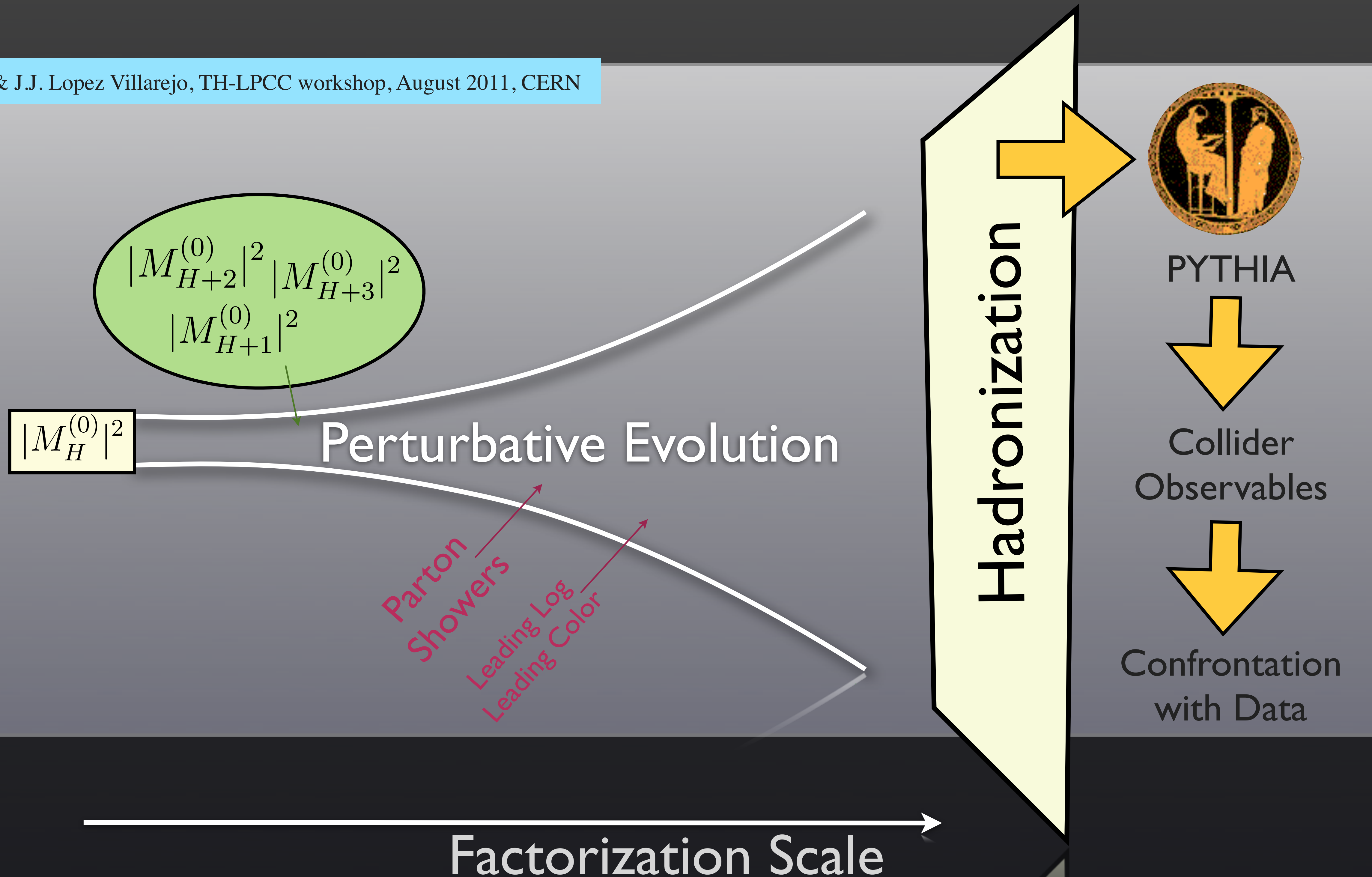

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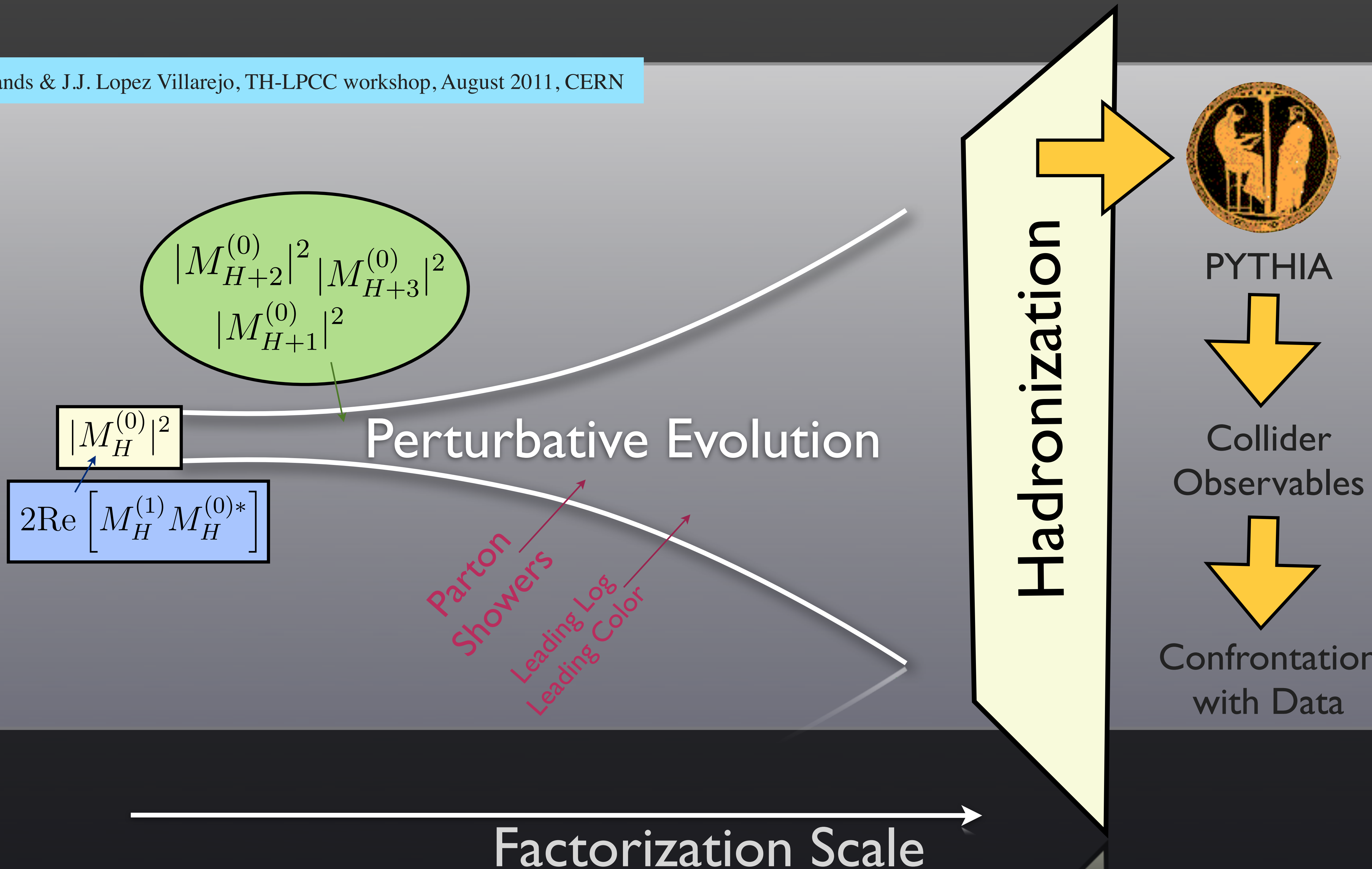

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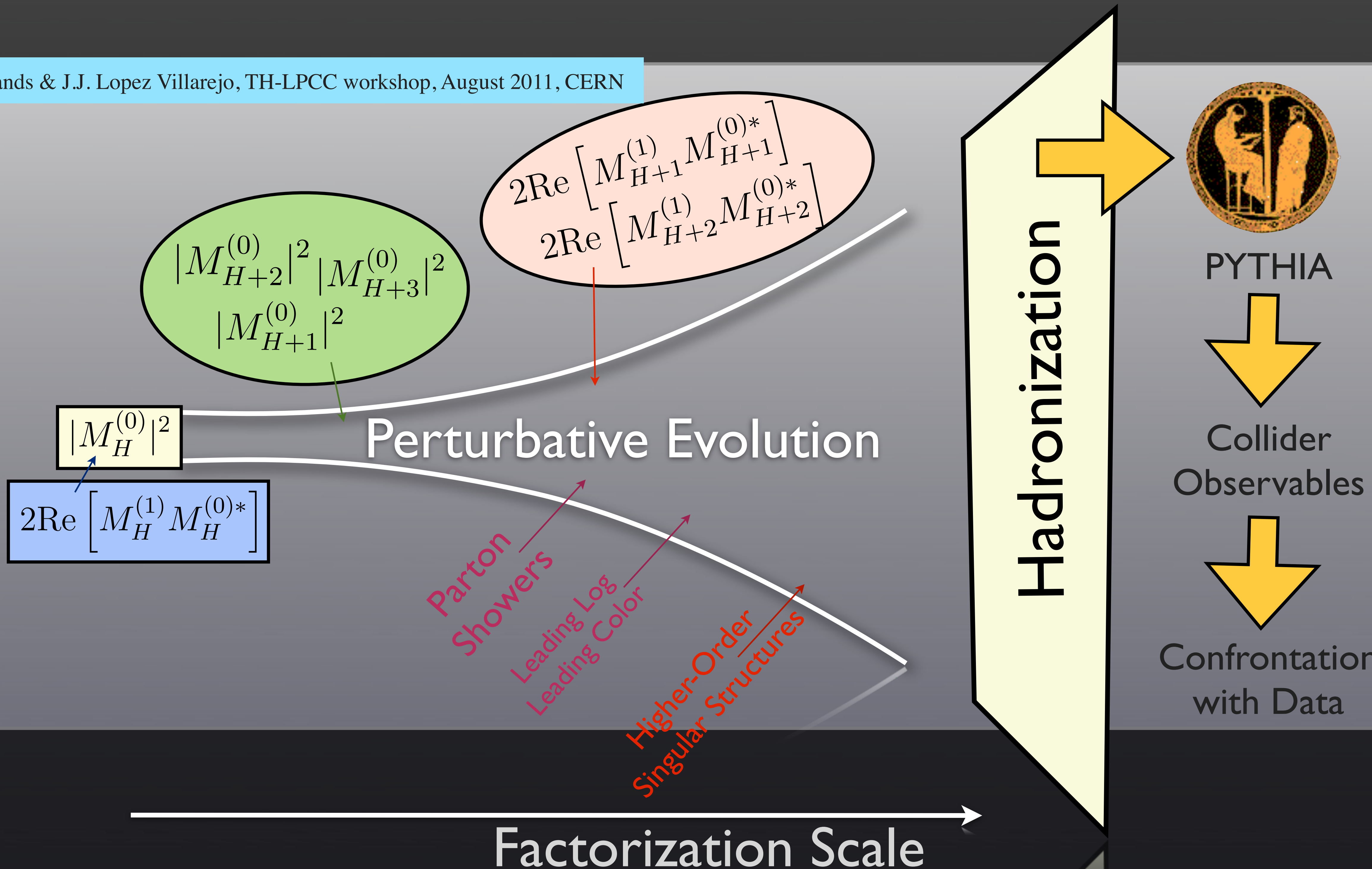

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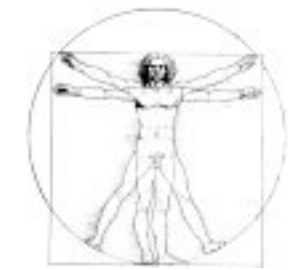
VINCIA


The VINCIA Code

What is it?

Plug-in to PYTHIA 8 http://projects.hepforge.org/vincia

What does it do?

"Matched Markov antenna showers"

Improved parton showers

+ Re-interprets tree-level matrix elements as 2→n antenna functions

+ Extends matching to soft region (no "matching scale")

Extensive *(and automated)* uncertainty estimates

Systematic variations of shower functions, evolution variables, μ_R , etc.

→ A vector of output weights for each event (central value = unity = unweighted)

Who is doing it?

Giele, Kosower, Skands (GKS)

+ Collaborations with Gehrmann-de-Ridder & Ritzmann *(mass effects)*, Lopez-Villarejo *("sector showers")*, Hartgring & Laenen *(NLO multileg)*, Diana *(ISR)*, Larkoski *(Polarization)*, Bravi & Volunteers *(Tuning)*

What is new ?

For matching to the first emission:

= PYTHIA scheme Sjöstrand & Bengtsson, Phys.Lett. B185 (1987) 435, Nucl.Phys. B289 (1987) 810

(reformulated for antennae)

For matching to the first loop:

= POWHEG scheme Nason, JHEP 0411 (2004) 040; Nason, Ridolfi, JHEP 0608 (2006) 077; …

(real-emission part same as PYTHIA, hence compatible)

What is new (apart from antennae): Giele, Kosower, Skands, arXiv:1102.2126 (accepted, PRD)

Repeating this for the next emission, and the next, …

GKS ~ multileg scheme (unitary) that reduces to PYTHIA/POWHEG at 1st order

Unitarity → No "matching scale" needed

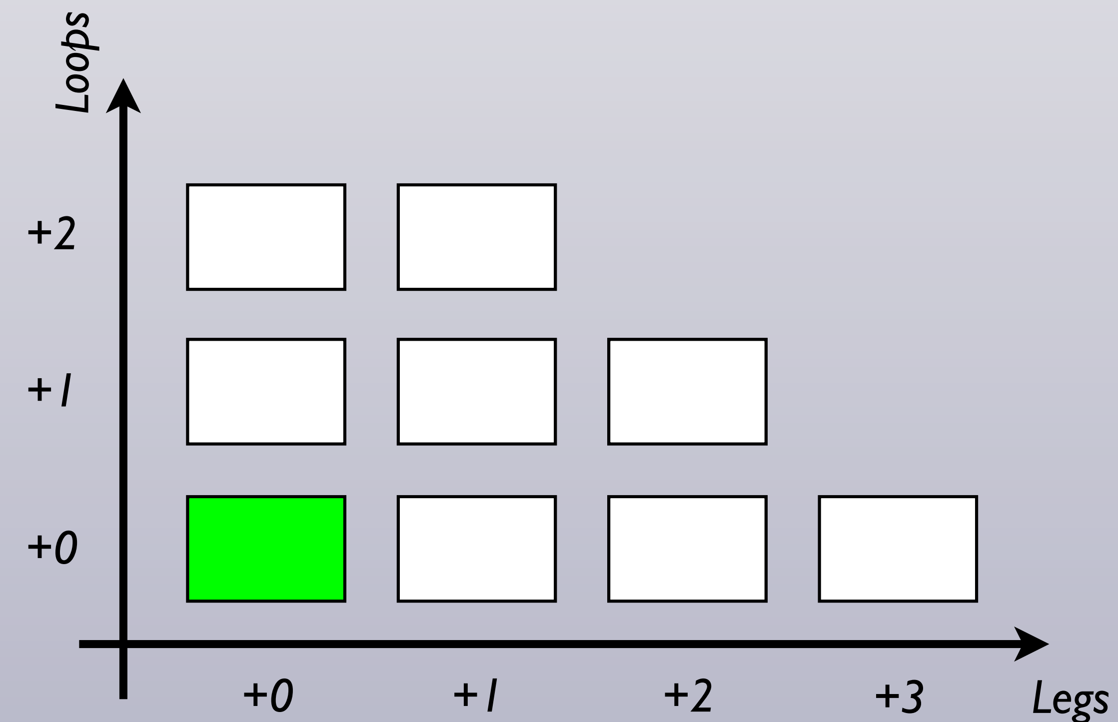
Substantially faster than MLM, CKKW (no initialization, no separate n-parton phase-spaces)

The calculation also yields ~10 automatic uncertainty estimates at a moderate speed penalty (less than running the program twice)

Markov pQCD

Start at Born level

$$|M_F|^2$$



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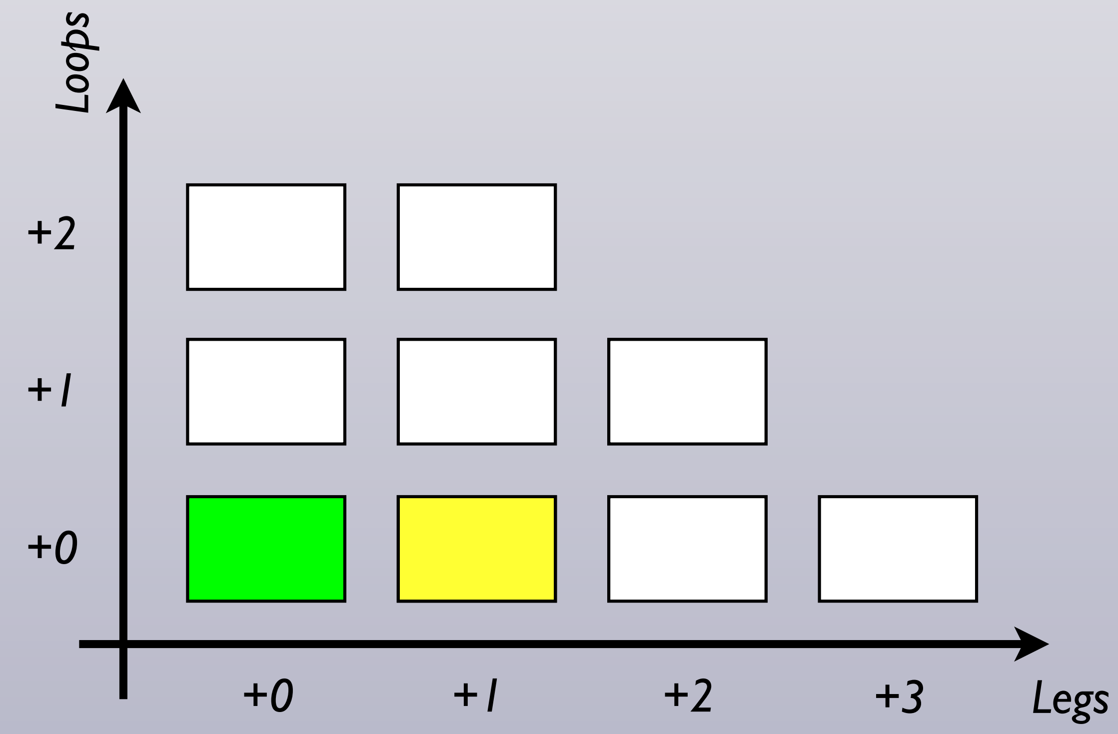
$$|M_{F+1}|^2 \overset{LL}{\sim} \sum_{i \in \mathrm{ant}} a_i \, |M_F|^2$$



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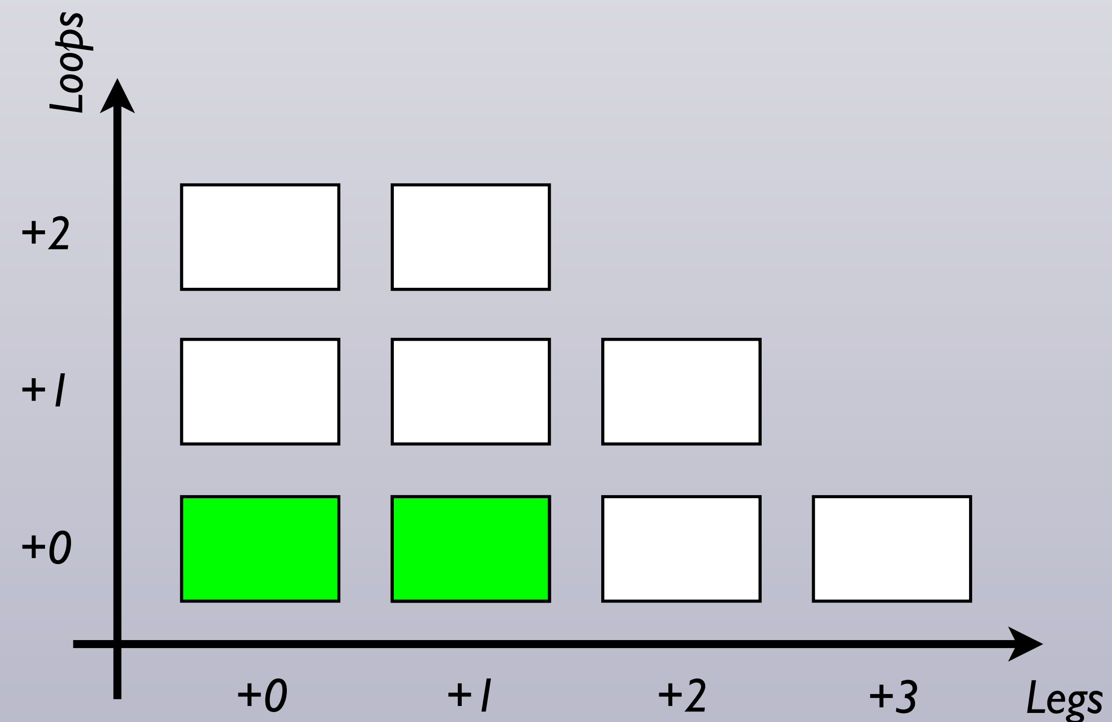
Correct to Matrix Element

PYTHIA trick

$$a_i \to \frac{|M_{F+1}|^2}{\sum a_i |M_F|^2}$$



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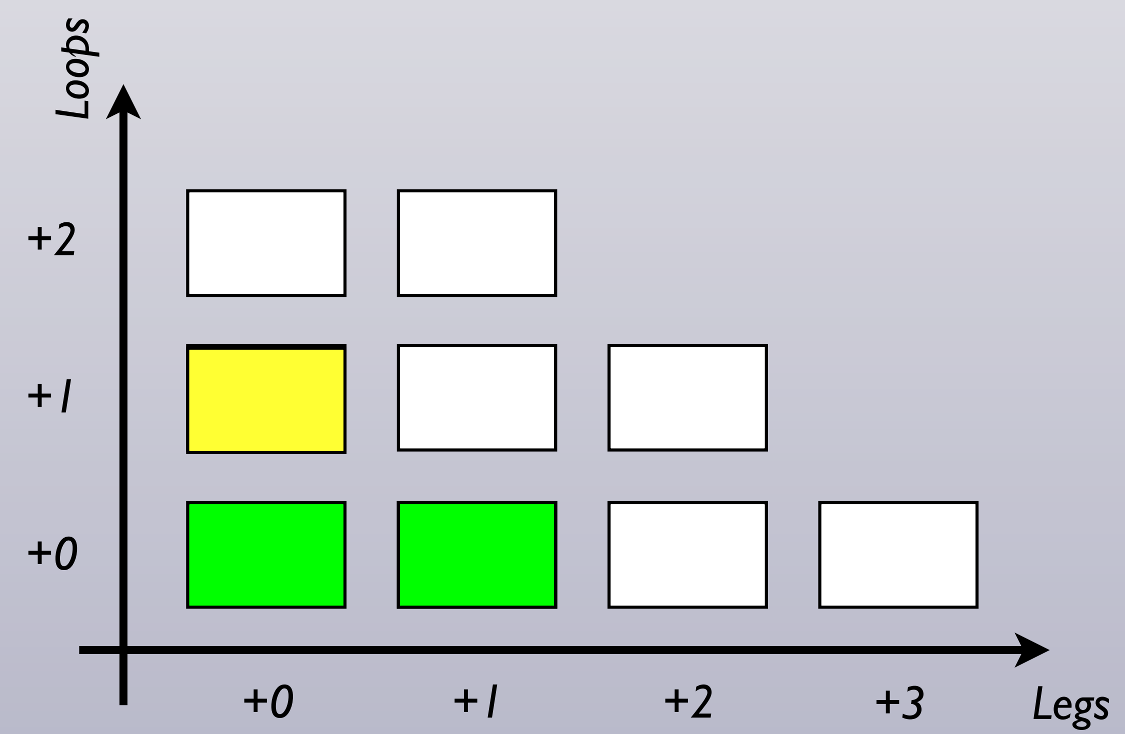
Unitarity of Shower

$$\mathrm{Virtual} = -\int \mathrm{Real}$$



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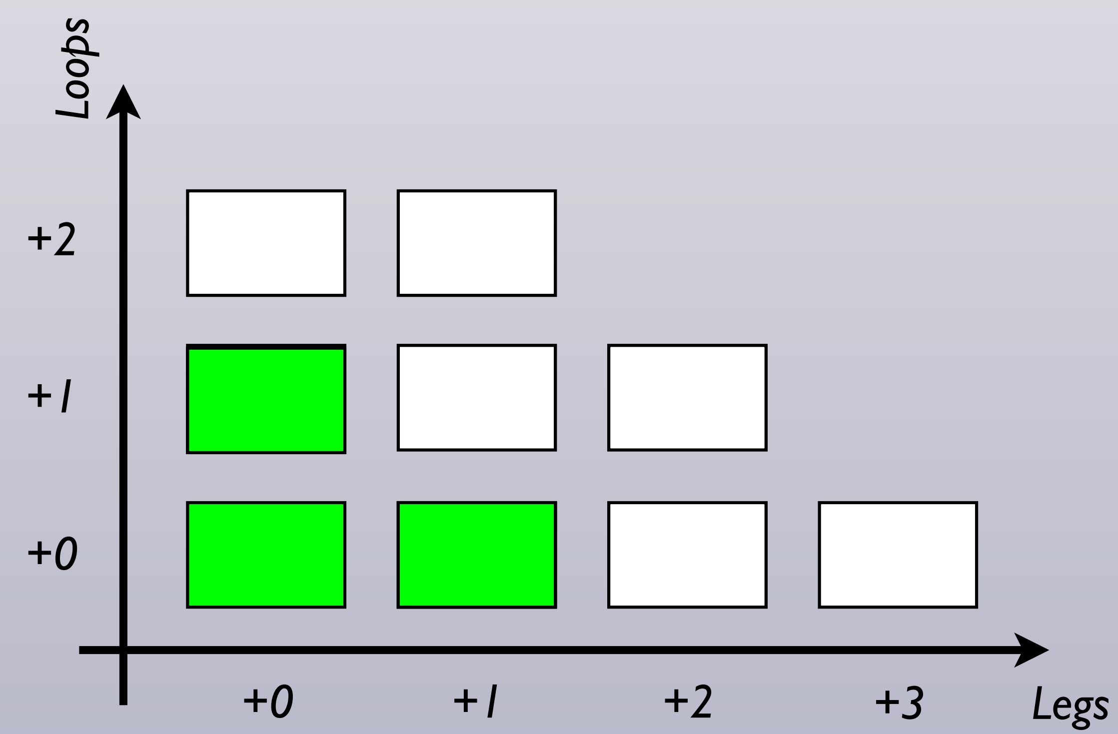

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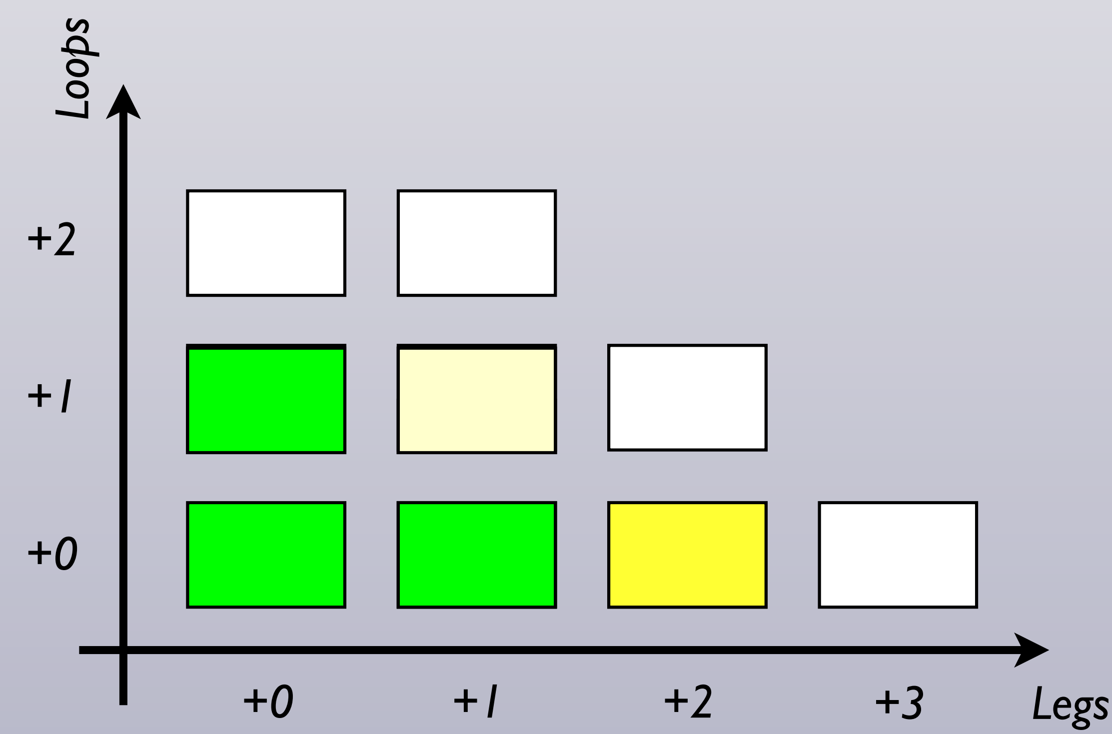

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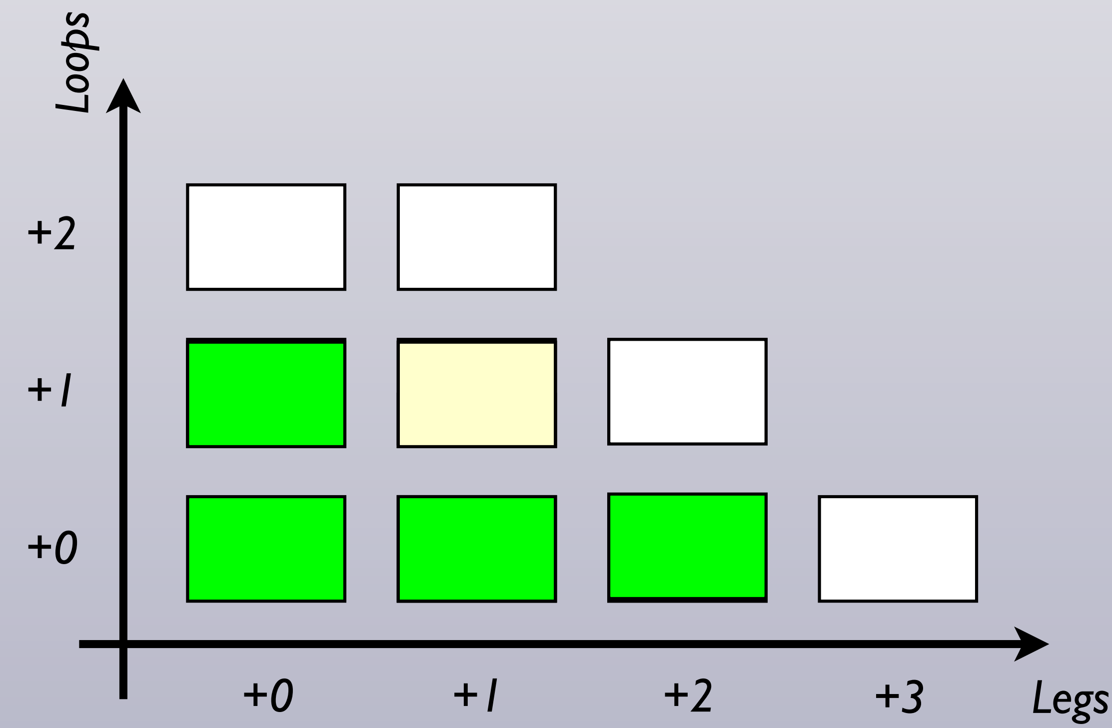

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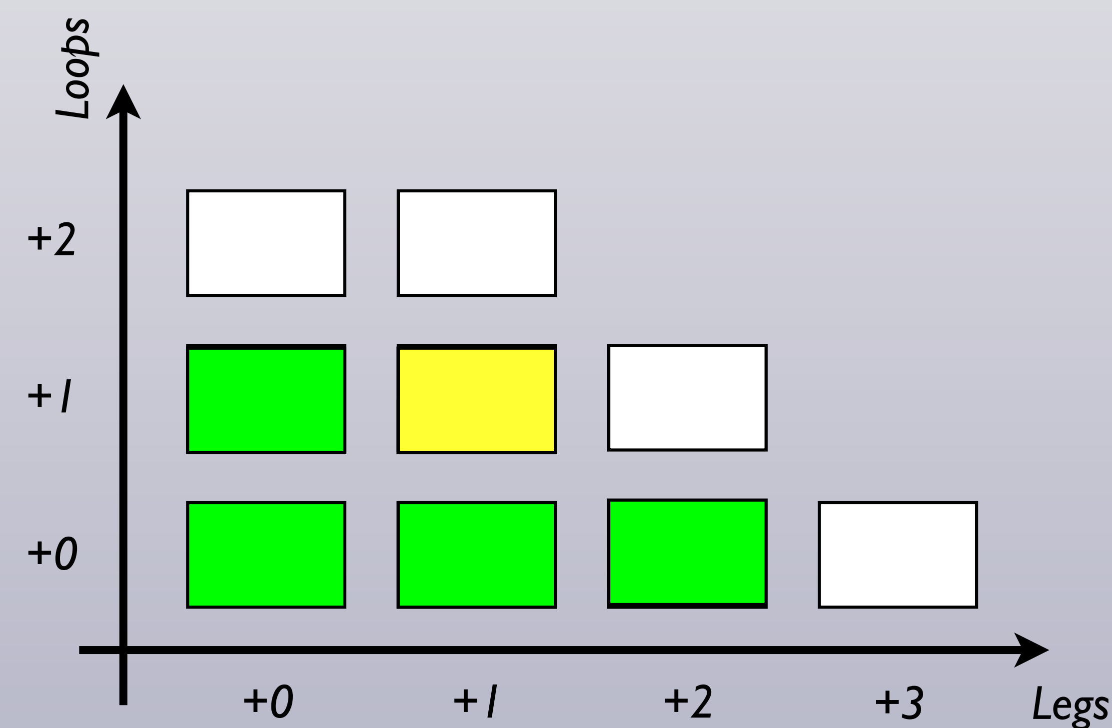

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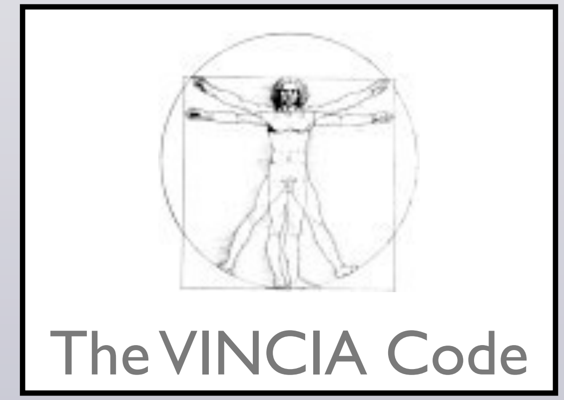

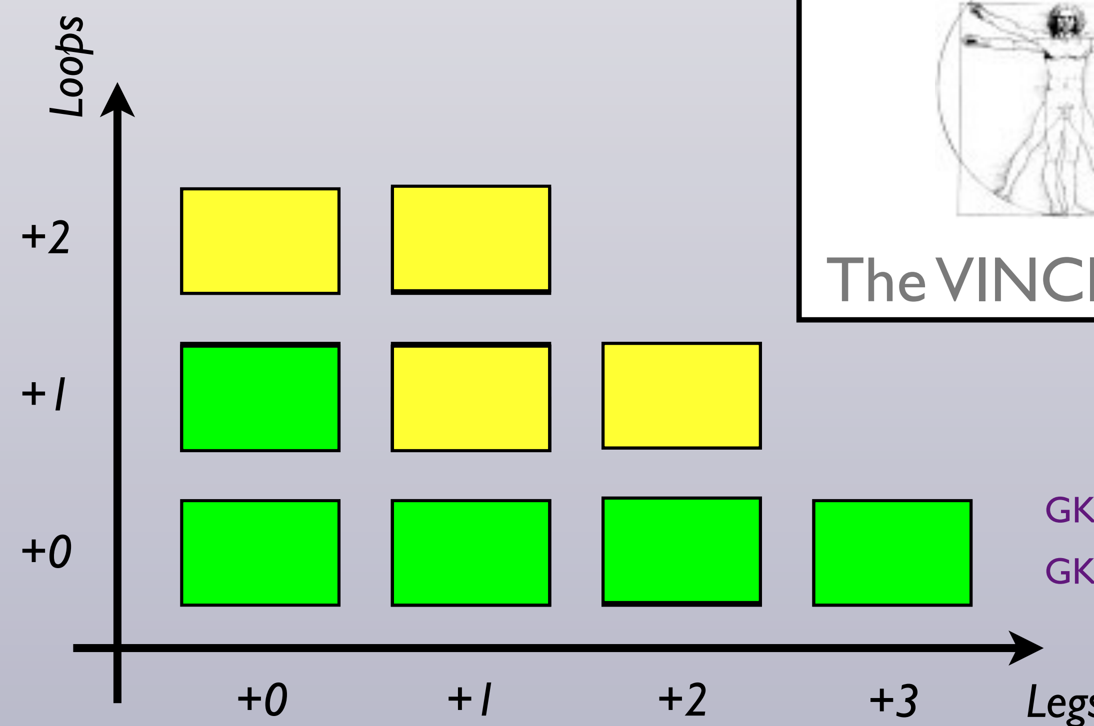

GKS, PRD78(2008)014026

GKS, PRD84(2011)054003

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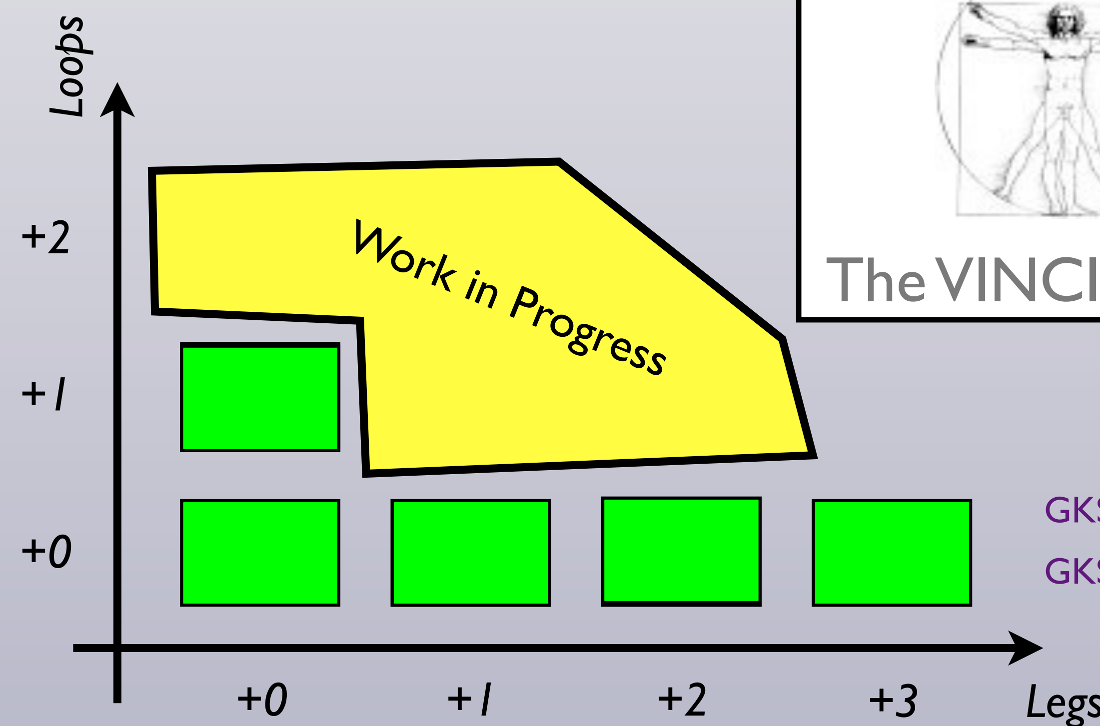

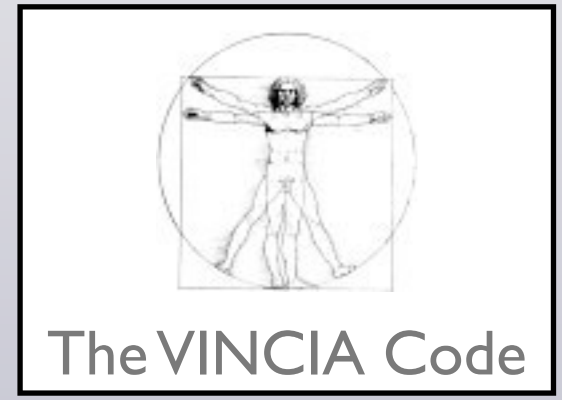

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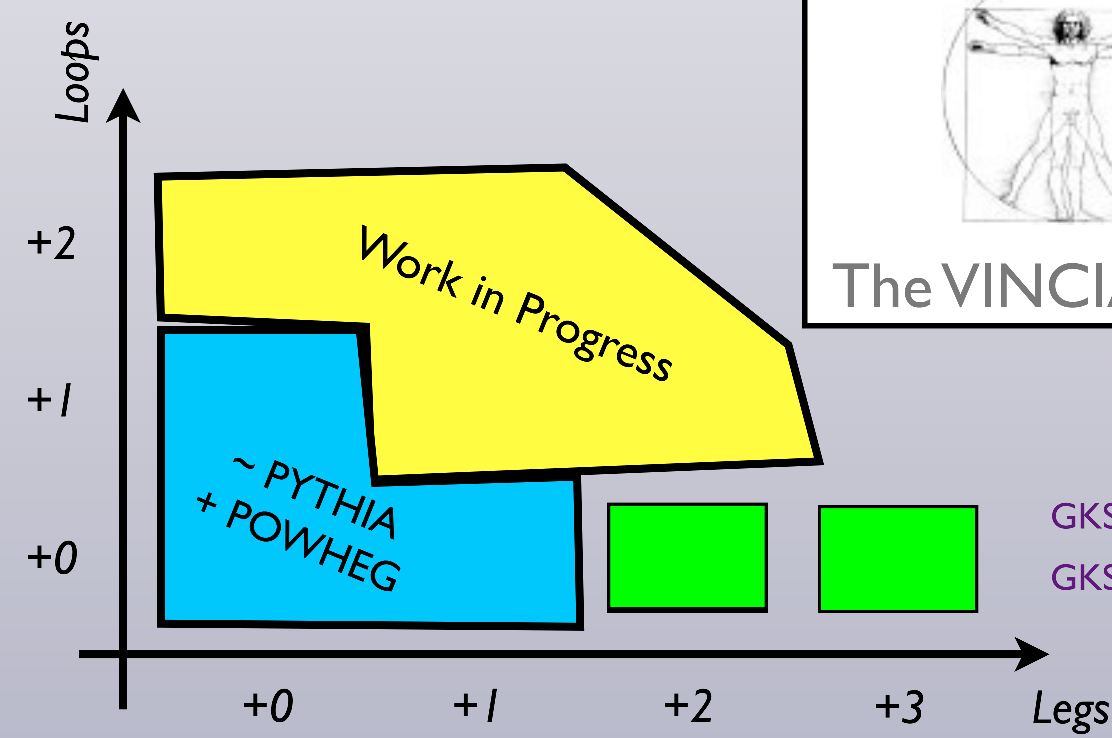

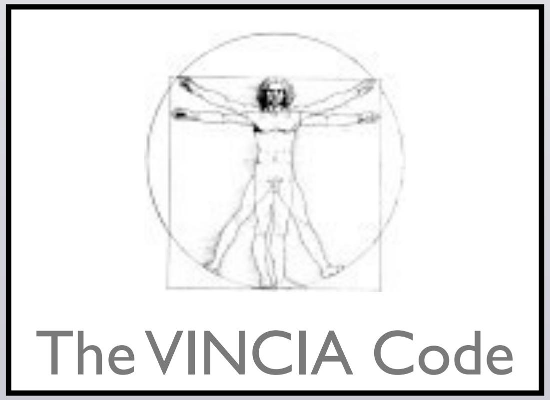

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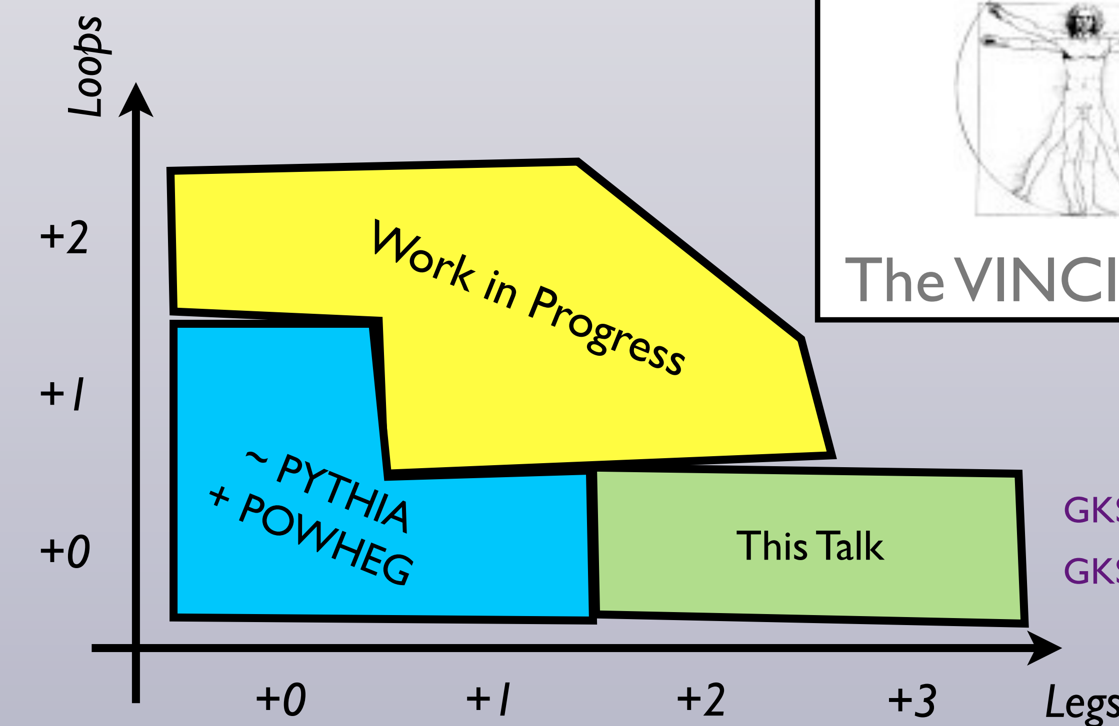

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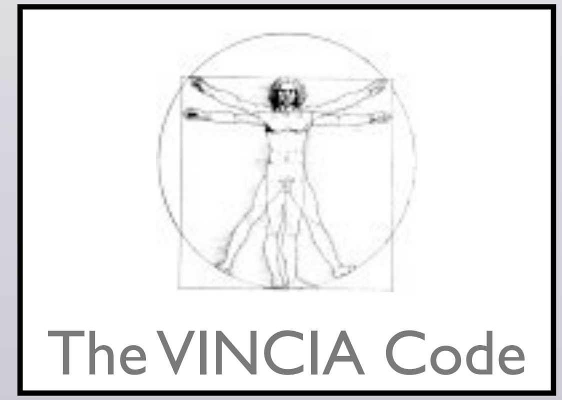

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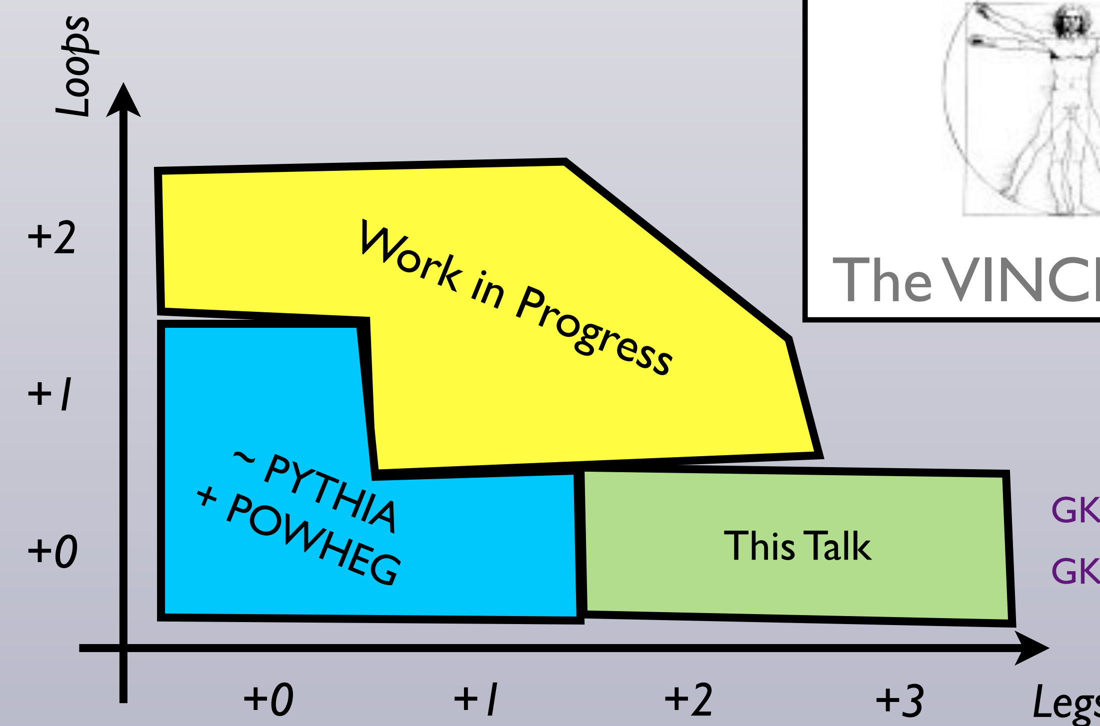

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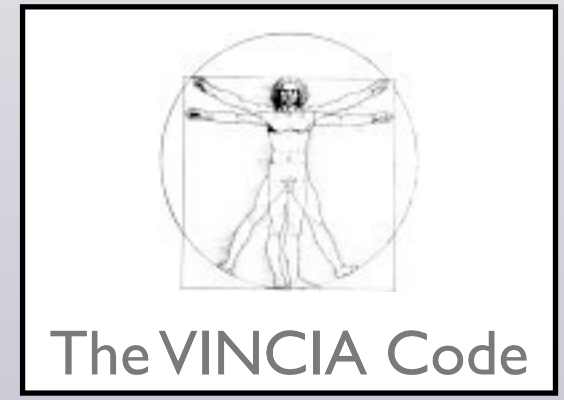
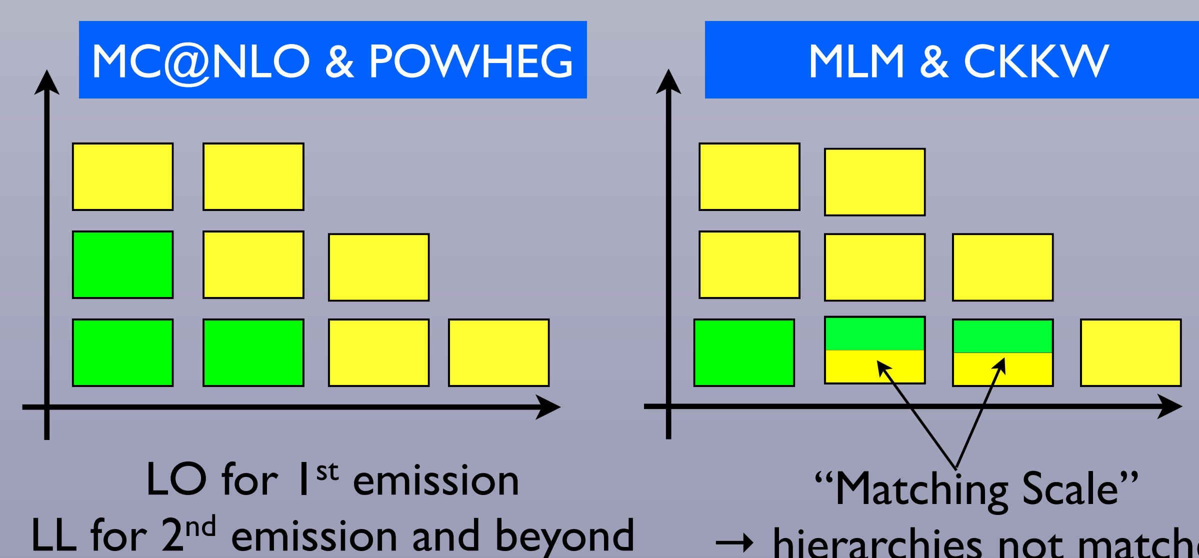




The Denominator

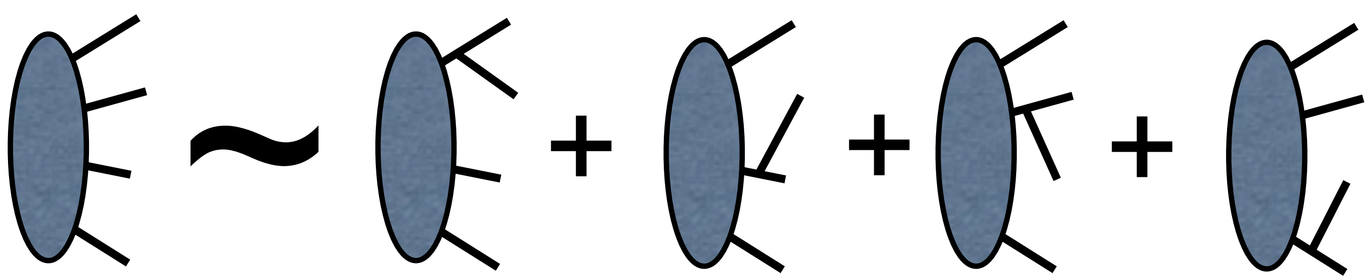
$$a_i \to \frac{|M_{F+1}|^2}{\sum a_i |M_F|^2}$$

In a traditional parton shower, you would face the following problem:

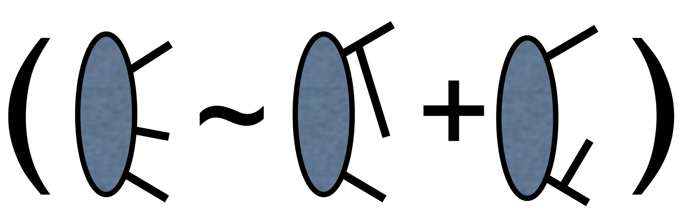
Existing parton showers are *not* really Markov Chains

Further evolution (restart scale) depends on which branching happened last → proliferation of terms

Number of histories contributing to n^{th} branching ∝ $\mathbf{2^n n!}$



j = 2
→ 4 terms



j = 1
→ 2 terms

(+ parton showers have complicated and/or frame-dependent phase-space mappings, especially at the multi-parton level)

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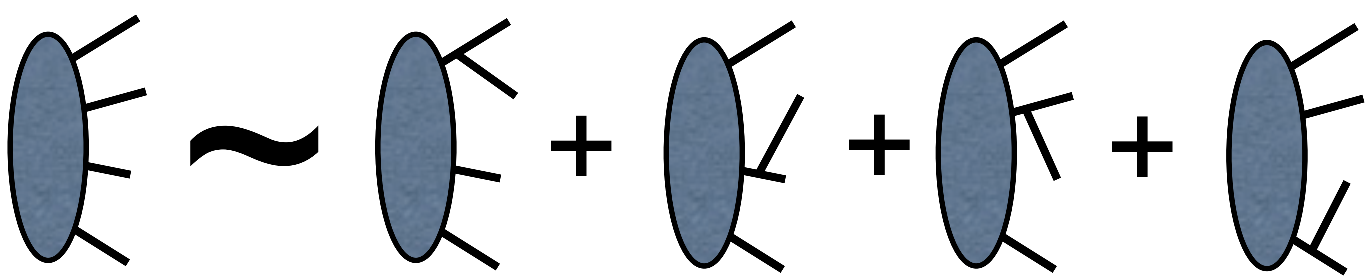

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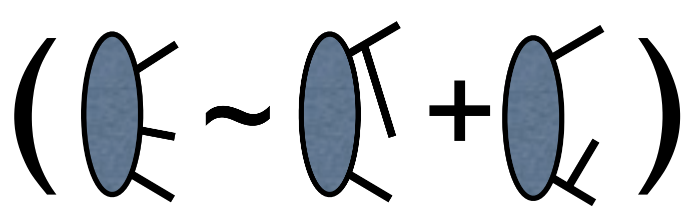


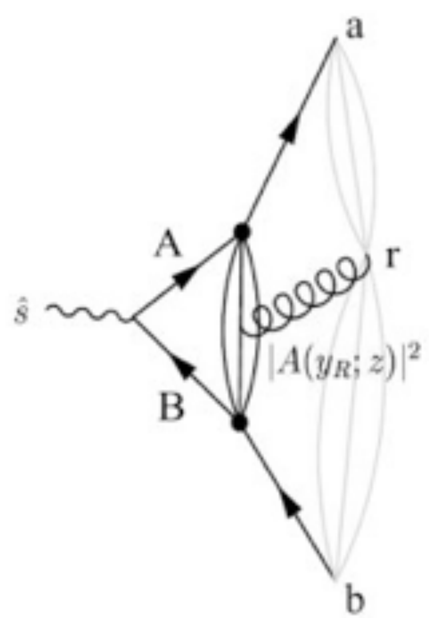
j = 1
→ 2 terms

Parton- (or Catani-Seymour) Shower:
After 2 branchings: 8 terms
After 3 branchings: 48 terms
After 4 branchings: 384 terms

(+ parton showers have complicated and/or frame-dependent phase-space mappings, especially at the multi-parton level)

Matched Markovian Antenna Showers

Antenna showers: one term per parton *pair* **$2^n n! \rightarrow n!$**



(+ generic Lorentz-invariant and on-shell phase-space factorization)

+ Change "shower restart" to Markov criterion:

Given an *n*-parton configuration, "ordering" scale is

$$Q_{ord} = min(Q_{E1}, Q_{E2}, ..., Q_{En})$$

Unique restart scale, independently of how it was produced

+ Matching: $n! \rightarrow n$

Given an *n*-parton configuration, its phase space weight is:

$|M_n|^2$: *Unique weight, independently of how it was produced*

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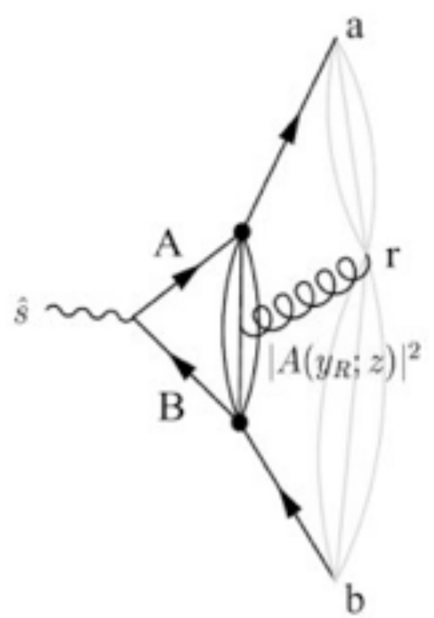

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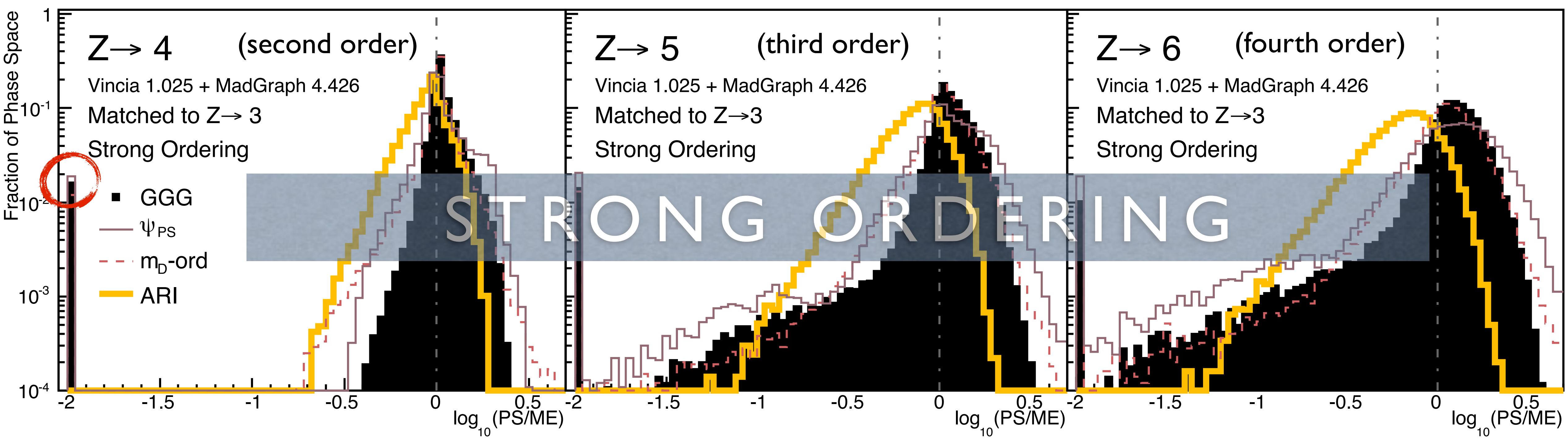
Matched Markovian Antenna Shower:	Parton- (or Catani-Seymour) Shower:
After 2 branchings: 2 terms	After 2 branchings: 8 terms
After 3 branchings: 3 terms	After 3 branchings: 48 terms
After 4 branchings: 4 terms	After 4 branchings: 384 terms

+ J. Lopez-Villarejo → 1 term at *any* order

Approximations

Distribution of **$\text{Log}_{10}(\text{PS}_{LO}/\text{ME}_{LO})$** (inverse ~ matching coefficient)

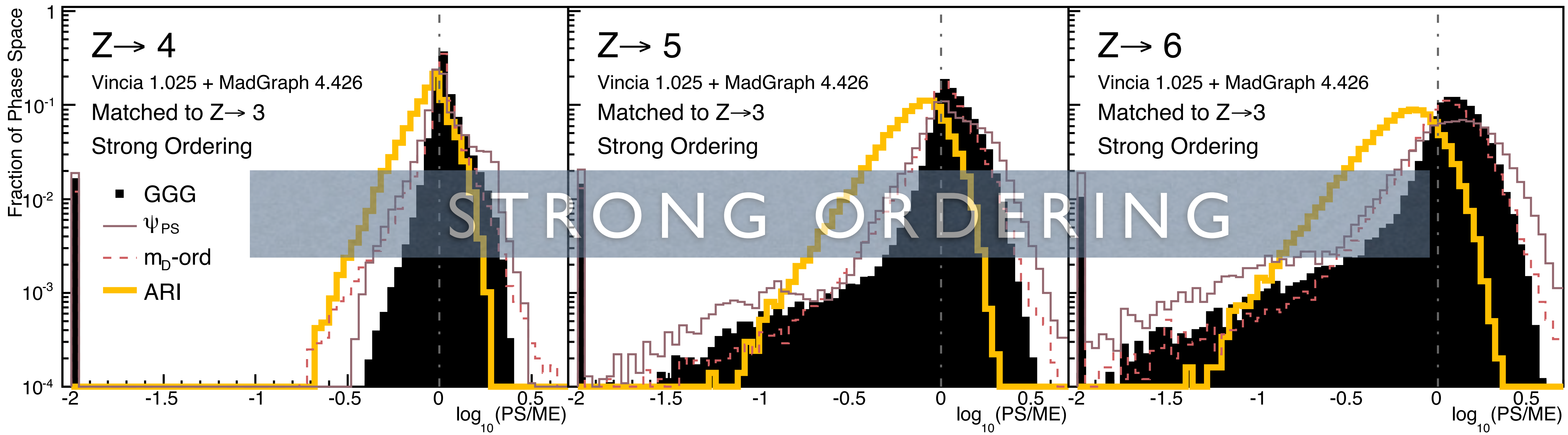


Dead Zone: 1-2% of phase space have no strongly ordered paths leading there*

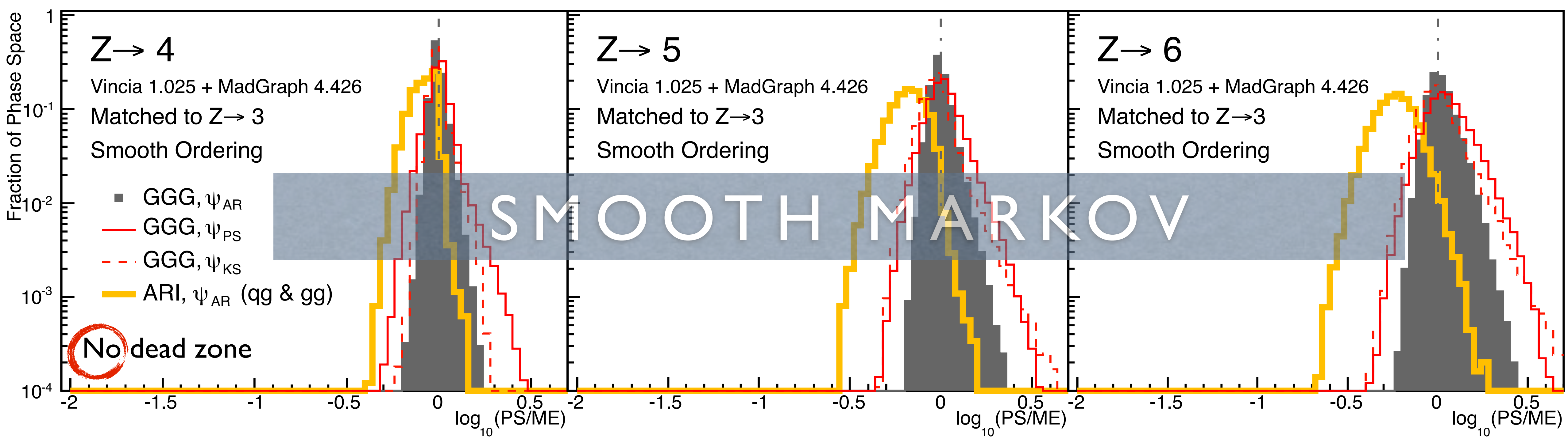
*fine from strict LL point of view: those points correspond to "unordered" non-log-enhanced configurations

→ Better Approximations

Distribution of **$\log_{10}(PS_{LO}/ME_{LO})$** (inverse ~ matching coefficient)

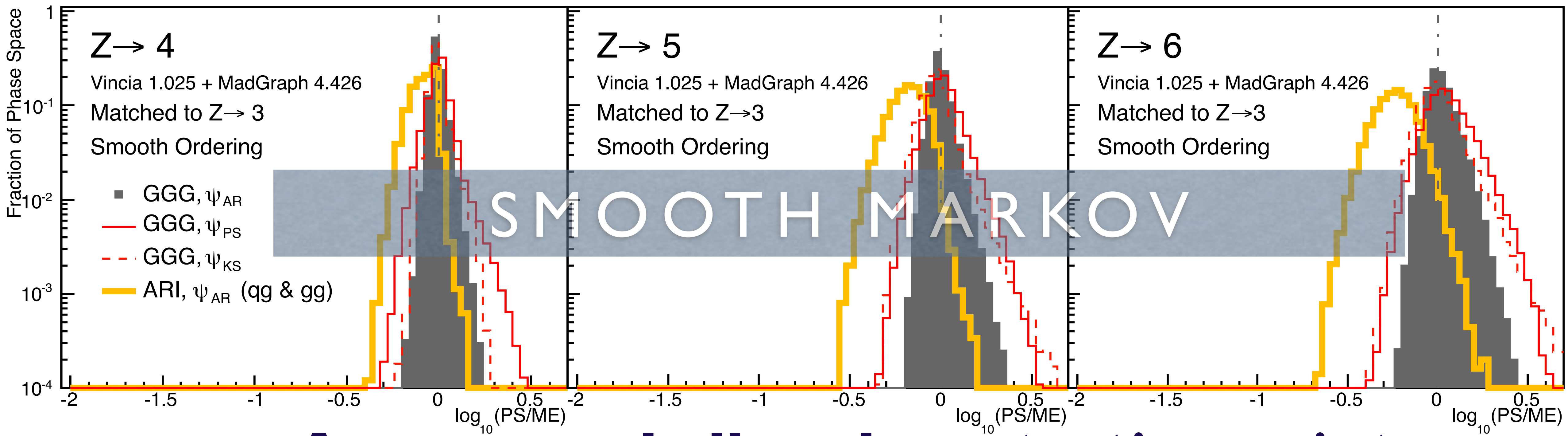


Leading Order, Leading Color, Flat phase-space scan, over **all of phase space** (no matching scale)

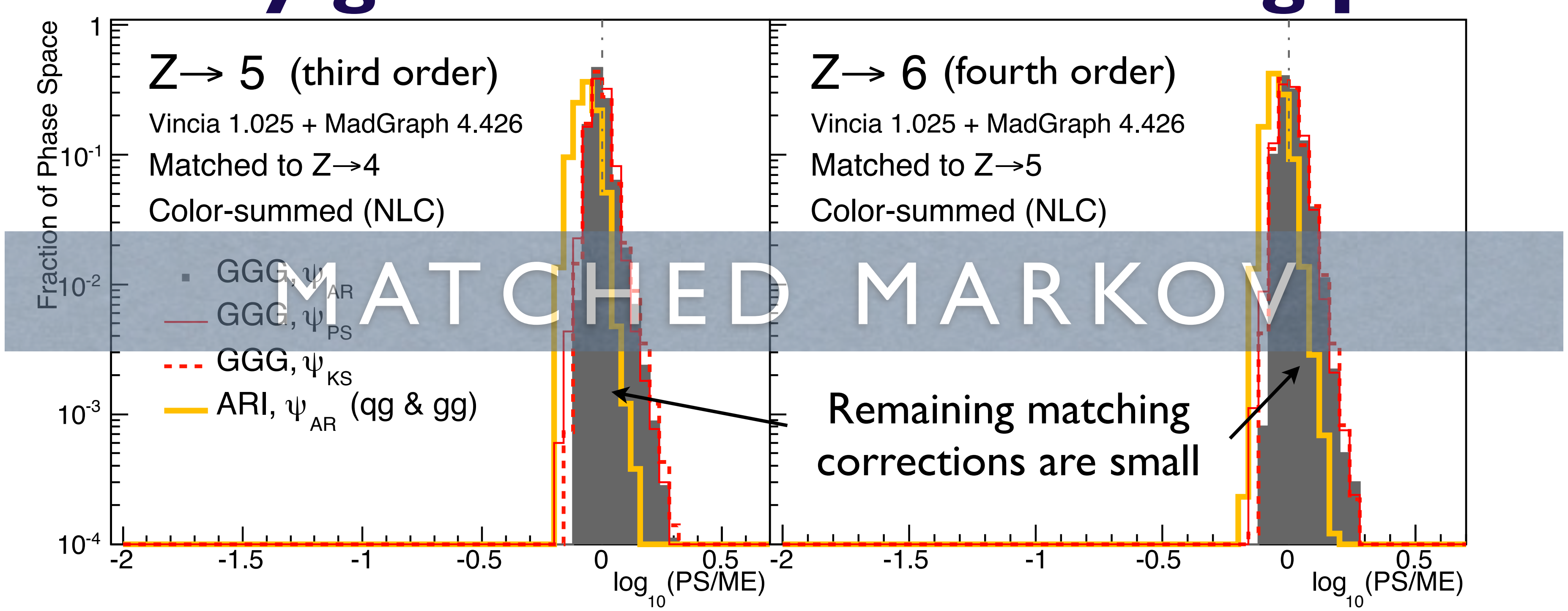


GEEKS (Giele, Kosower, Skands): arXiv:1102.2126

+ Matching (+ NLC)



→ A very good all-orders starting point




Uncertainties

Uncertainty Variations

A result is only as good as its uncertainty

- Normal procedure:
  - *Run MC 2N+1 times (for central + N up/down variations)*
    - Takes 2N+1 times as long
    - + uncorrelated statistical fluctuations

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Normal procedure:

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Takes 2N+1 times as long

+ uncorrelated statistical fluctuations

Automate and do everything in one run

VINCIA: all events have weight = 1

Compute *unitary* alternative weights on the fly

→ *sets of alternative weights representing variations (all with <w>=1)*

Same events, so only have to be hadronized/detector-simulated ONCE!

MC with Automatic Uncertainty Bands

Uncertainties

For each branching, recompute weight for:

- Different renormalization scales
- Different antenna functions
- Different ordering criteria
- Different subleading-color treatments

	Weight
Nominal	1
Variation	$P_2 = \frac{\alpha_{s2} a_2}{\alpha_{s1} a_1} P_1$

Uncertainties

For each branching, recompute weight for:

- Different renormalization scales
- Different antenna functions
- Different ordering criteria
- Different subleading-color treatments

	Weight
Nominal	1
Variation	$P_2 = \frac{\alpha_{s2} a_2}{\alpha_{s1} a_1} P_1$

+ Unitarity

For each *failed* branching:

$$P_{2;\mathrm{no}} = 1 - P_2 = 1 - \frac{\alpha_{s2} a_2}{\alpha_{s1} a_1} P_1$$

Uncertainties

For each branching, recompute weight for:

- Different renormalization scales
- Different antenna functions
- Different ordering criteria
- Different subleading-color treatments

	Weight
Nominal	1
Variation	$P_2 = \frac{\alpha_{s2} a_2}{\alpha_{s1} a_1} P_1$

+ Matching

Differences explicitly matched out

(Up to matched orders)

(Can in principle also include variations of matching scheme…)

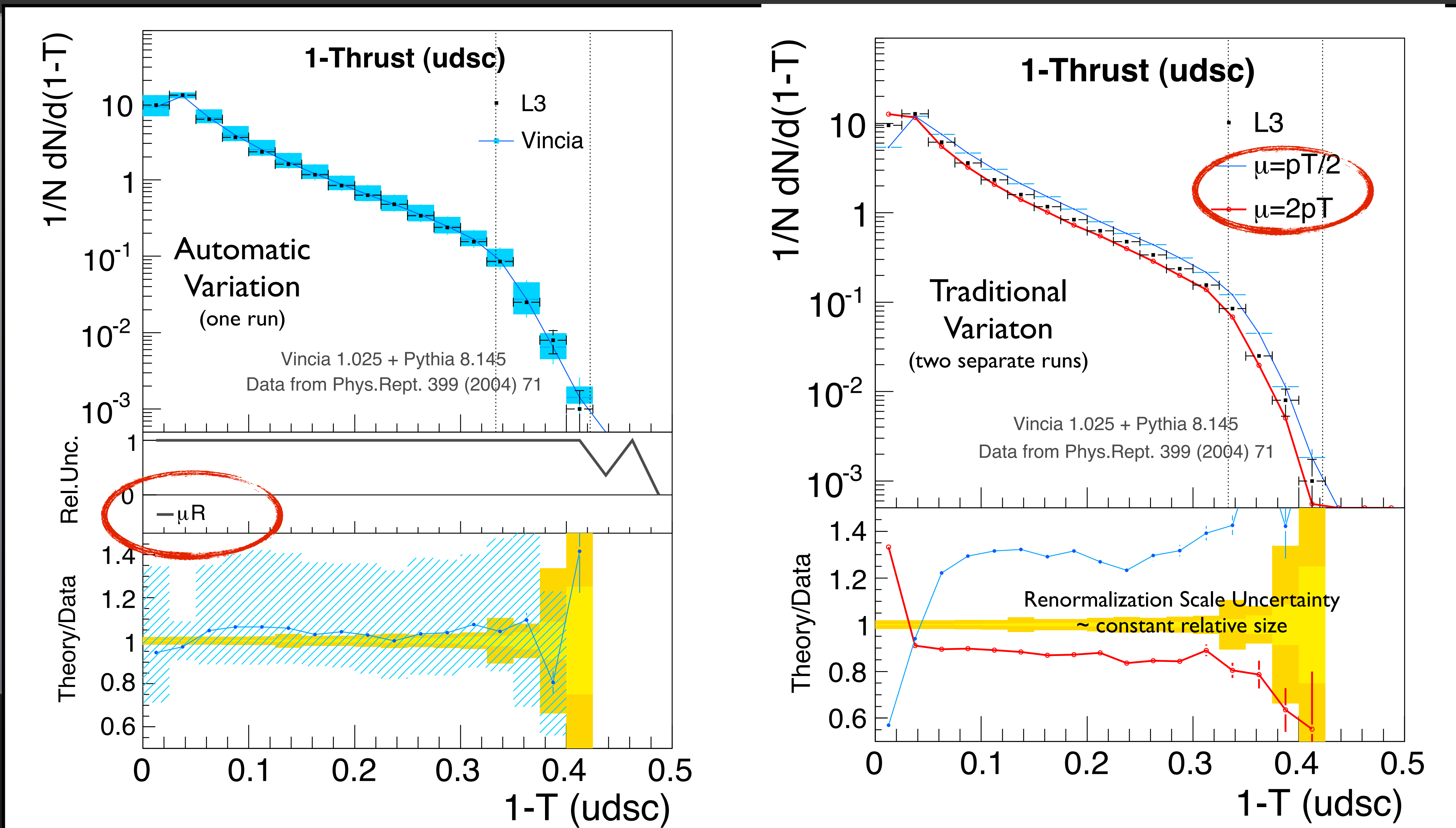
+ Unitarity

For each *failed* branching:

$$P_{2;\mathrm{no}} = 1 - P_2 = 1 - \frac{\alpha_{s2} a_2}{\alpha_{s1} a_1} P_1$$

Automatic Uncertainties

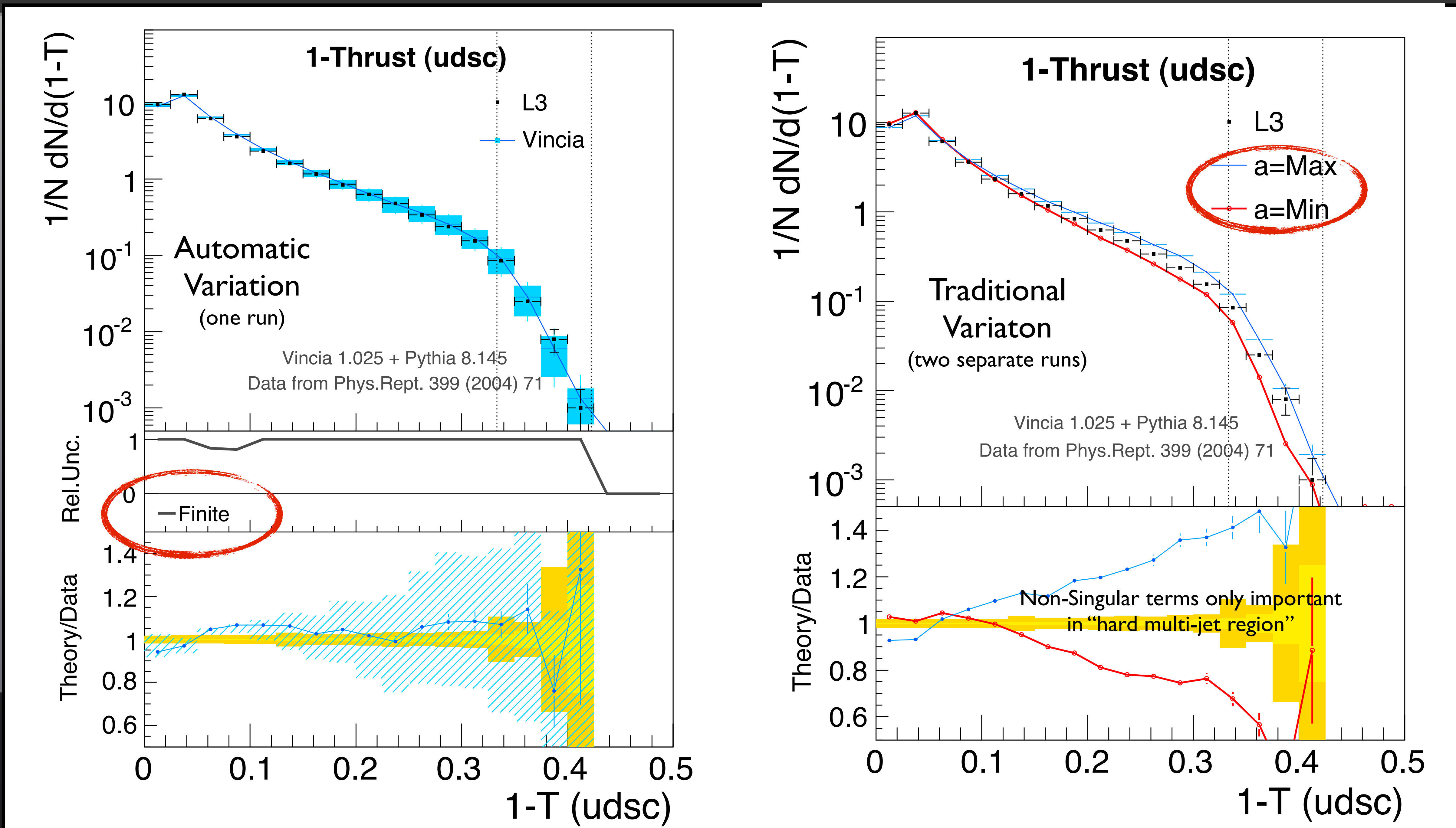
Vincia:uncertaintyBands = on



Variation of renormalization scale (no matching)

Automatic Uncertainties

Vincia:uncertaintyBands = on

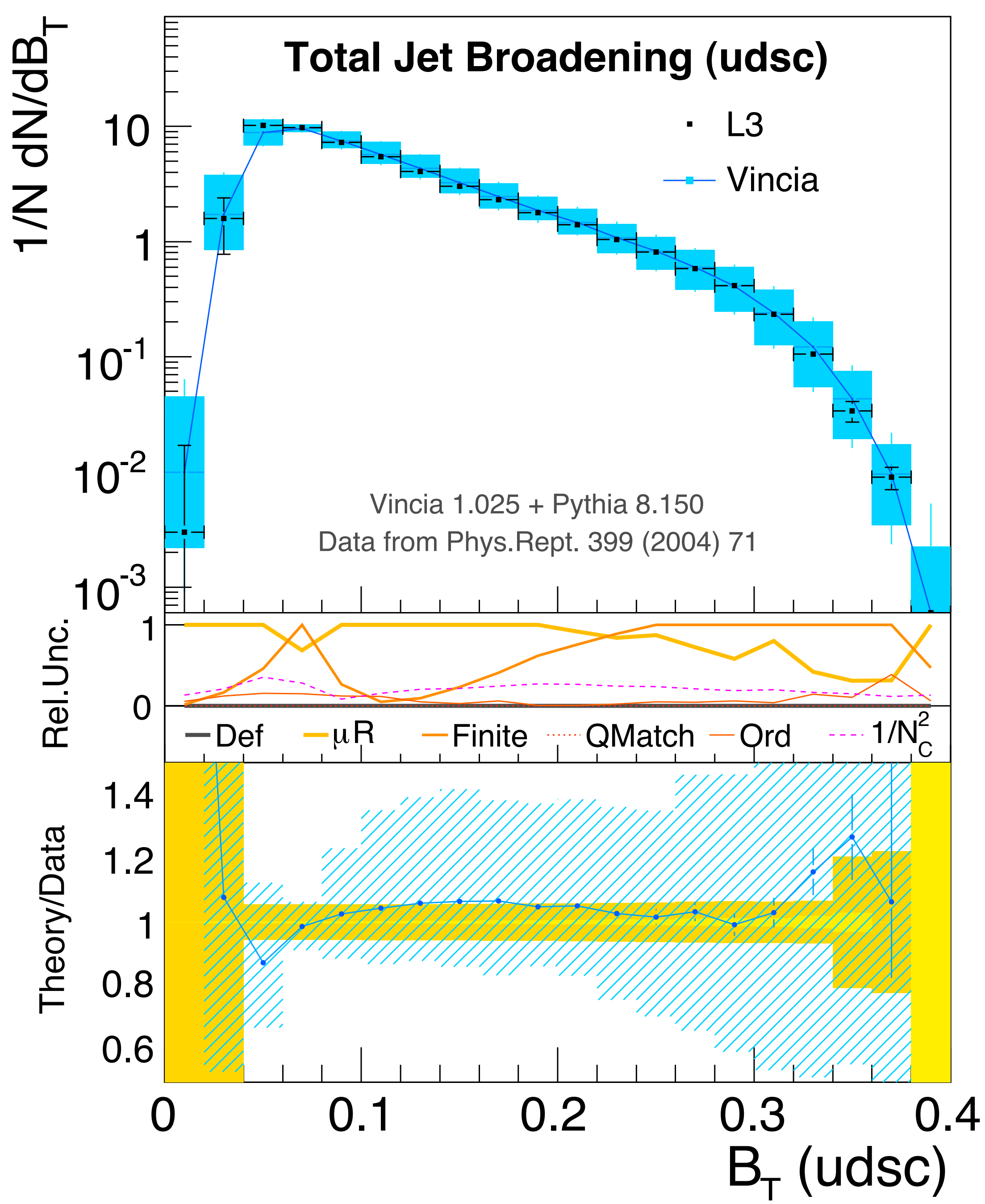


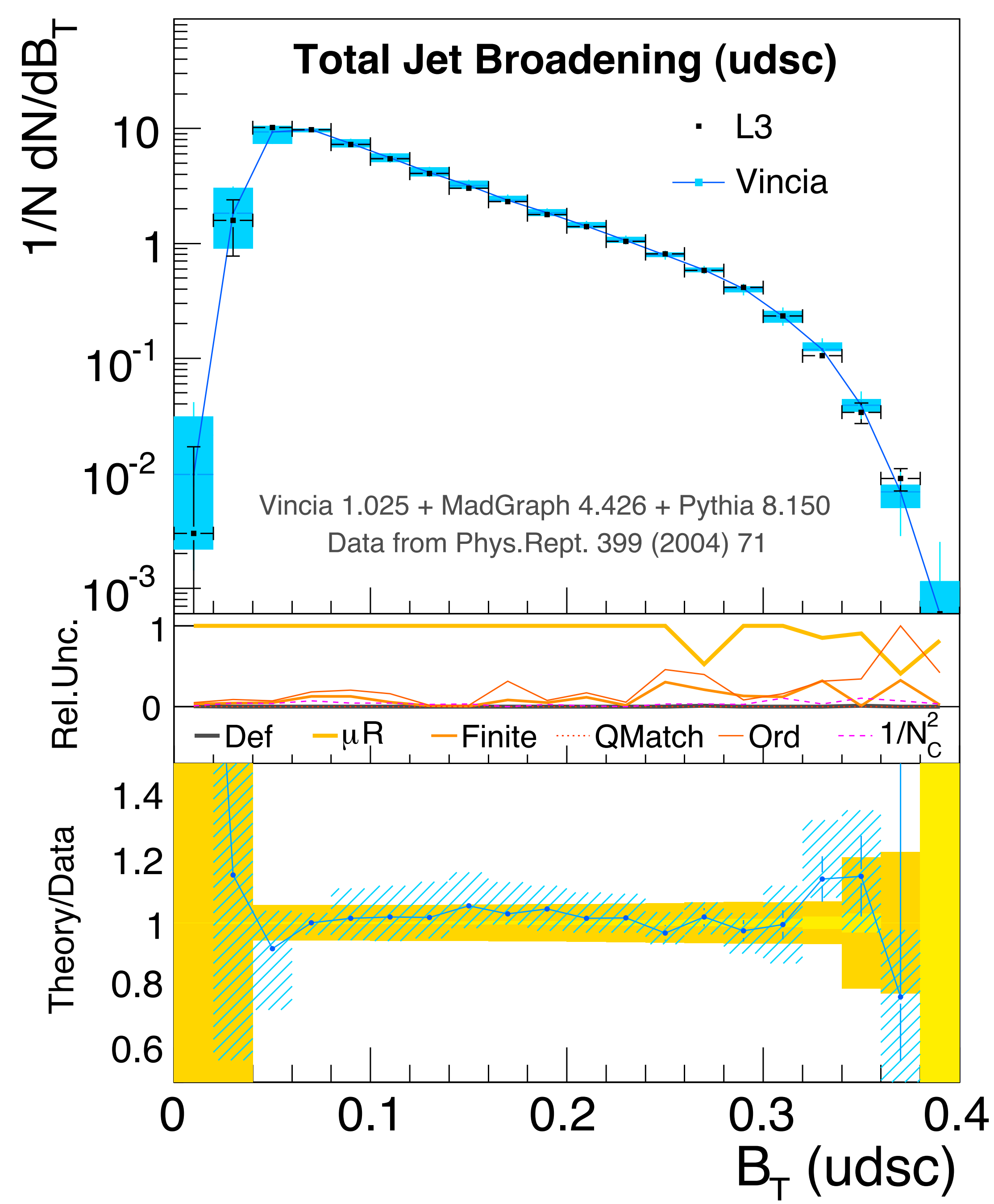
Variation of "finite terms" (no matching)

Putting it Together

VinciaMatching:order = 0

VinciaMatching:order = 3

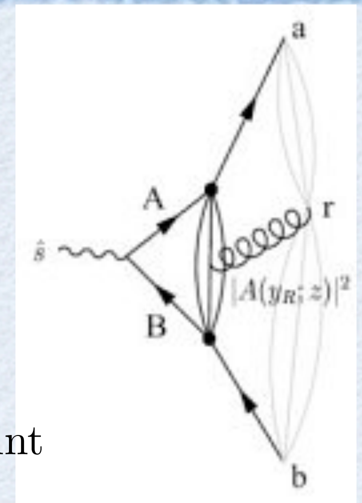




Sector Showers

J. Lopez-Villarejo & PS, arXiv:1109.3608

Also discussed in Larkoski & Peskin, PRD81(2010)054010, PRD84 (2011)034034



- Dipole-antenna formalism (2 -> 3)
- Two types:
  - Global (Lund, GGG, GKS) $$|M^{(n)}|^2 \sim \sum_{i \in \text{clust.}} a_i |M_i^{(n-1)}|^2 \quad \text{for any P.S. point}$$
  - Sector (Kosower PRD 57 (1998) 5410) $$|M^{(n)}|^2 \sim \sum_{i \in \text{clust.}} \tilde{a}_i |M_i^{(n-1)}|^2 \; \Theta_i(\text{P.S.}) \sim \tilde{a}_j |M_j^{(n-1)}|^2$$

Sector Showers

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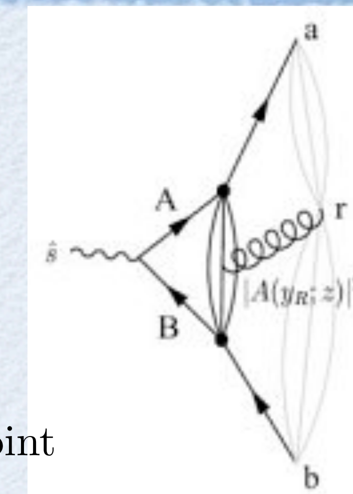

- Dipole-antenna formalism (2 -> 3)
- Two types:
  - Global (Lund, GGG, GKS): $|M^{(n)}|^2 \sim \sum_{i \in \text{clust.}} a_i |M_i^{(n-1)}|^2$ for any P.S. point
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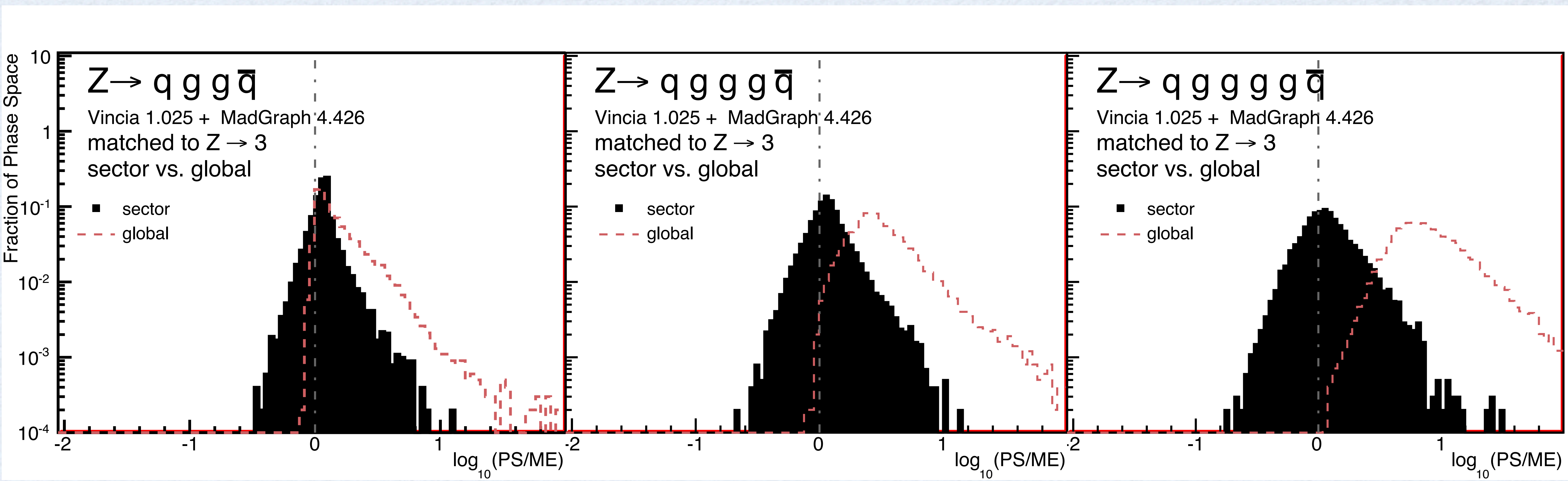


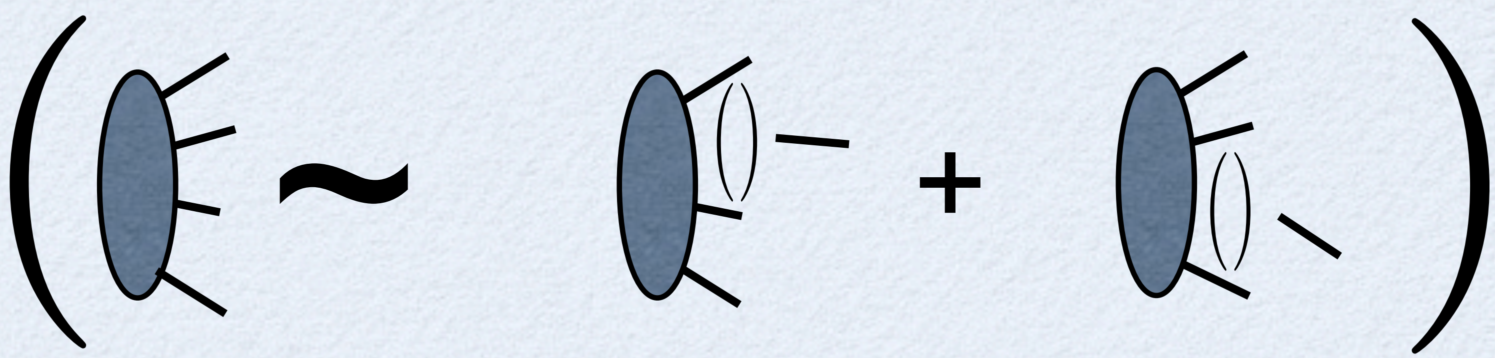
*) shows Global *without* any ordering condition imposed → overcounting

Number of terms

Global FSR shower (default VINCIA)

	"Traditional" parton shower	Vincia Markov global antenna shower	Vincia Markov sector antenna shower
# of terms produced in the shower	$2^N N!$	N	1

N = number of emitted partons



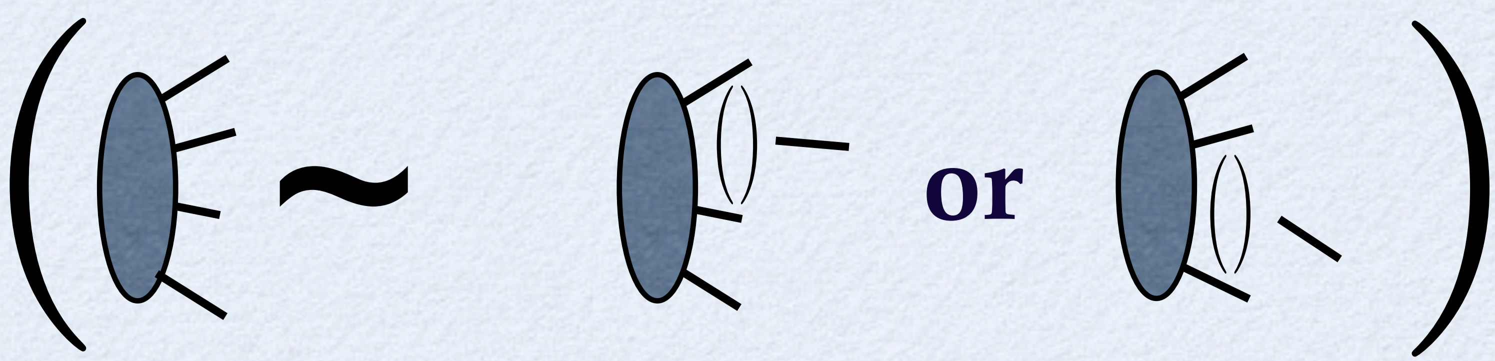
3→4
2 terms per phase-space point

Number of terms

→ Sector shower

	"Traditional" parton shower	Vincia Markov global antenna shower	Vincia Markov sector antenna shower
# of terms produced in the shower	$2^N N!$	N	1

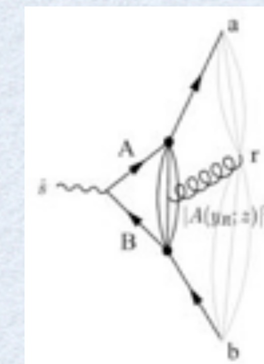
N = number of emitted partons



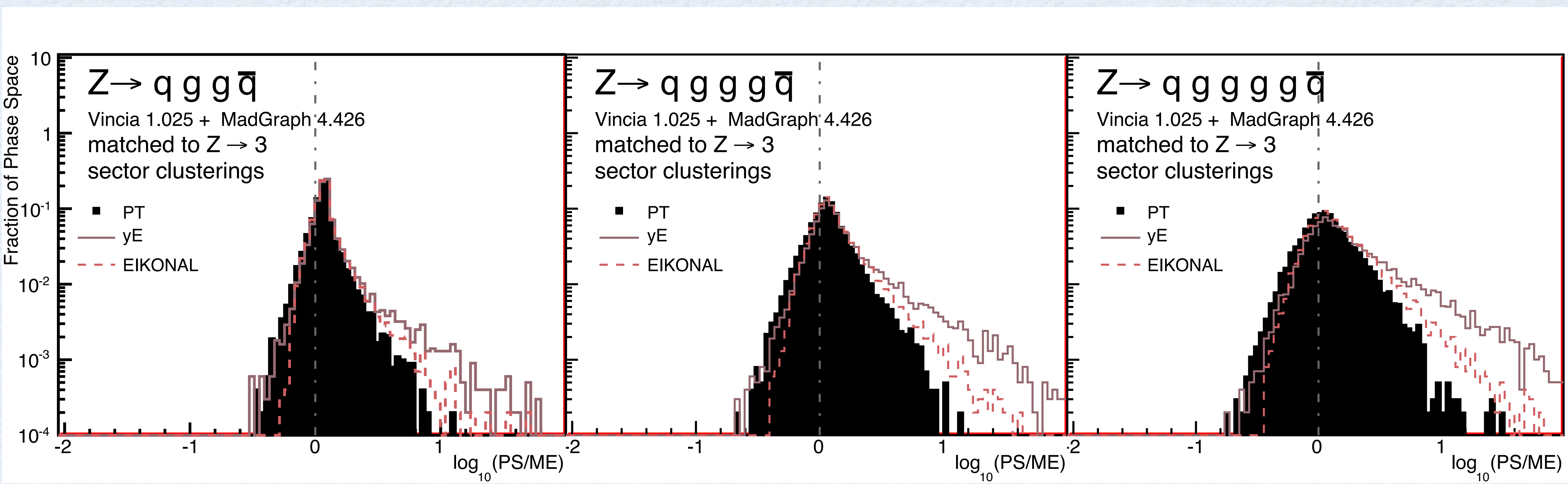
3→4
1 term per phase-space point

Sector implementation

- Implementation based on the global shower setup.
- Antenna functions are different than in the global case.
  → Challenges (partitioning of collinear radiation singularities)



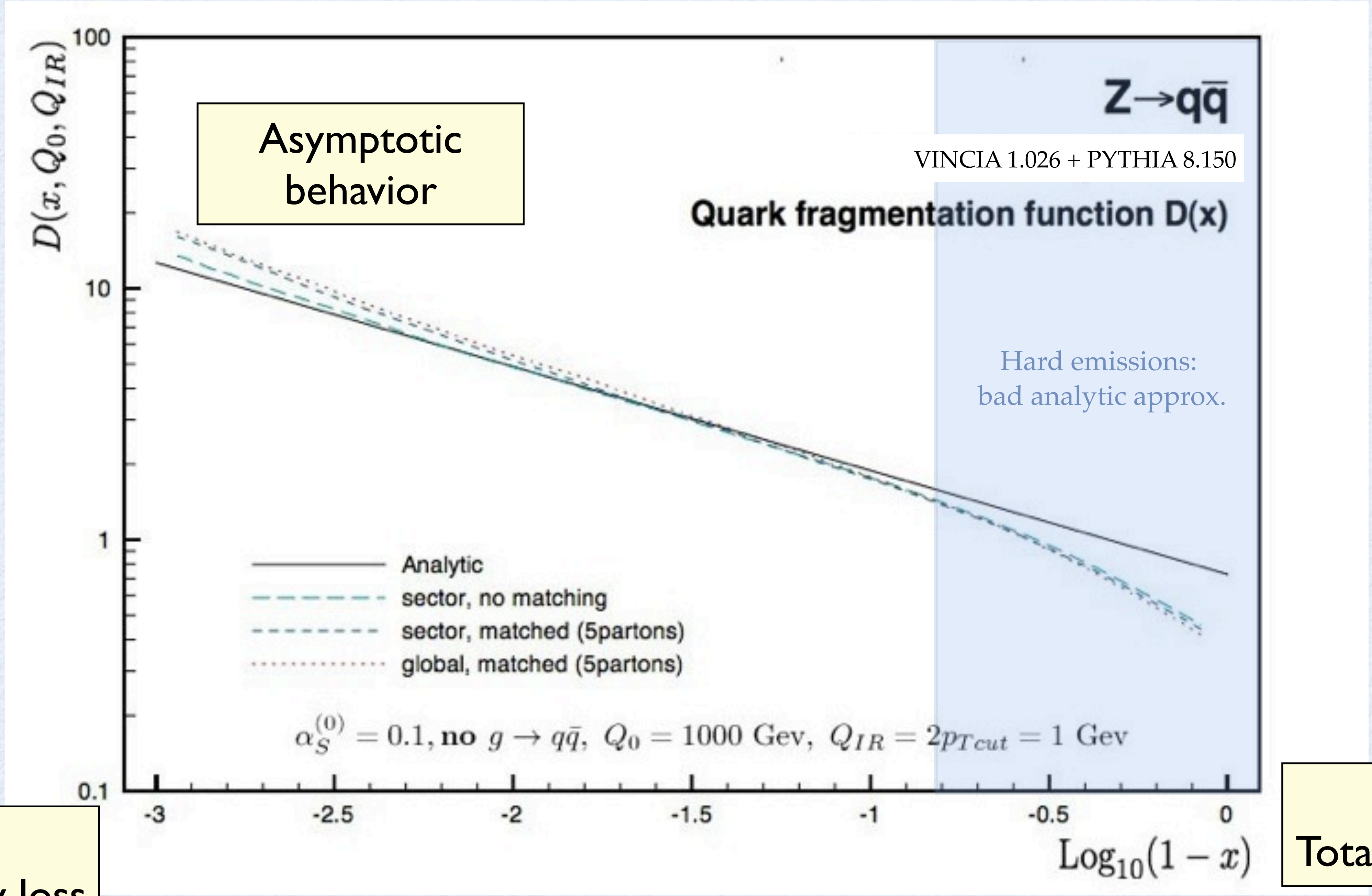
- Different criteria for separating sectors in phase space
  Looking for "best" sub-LL behavior.



RESULTS->FF

PS, Weinzierl: Phys.Rev.D79 (2009) ; Nagy, et al. JHEP 0905 (2009) 088

Test: fragmentation function for a quark



x→1
No energy loss

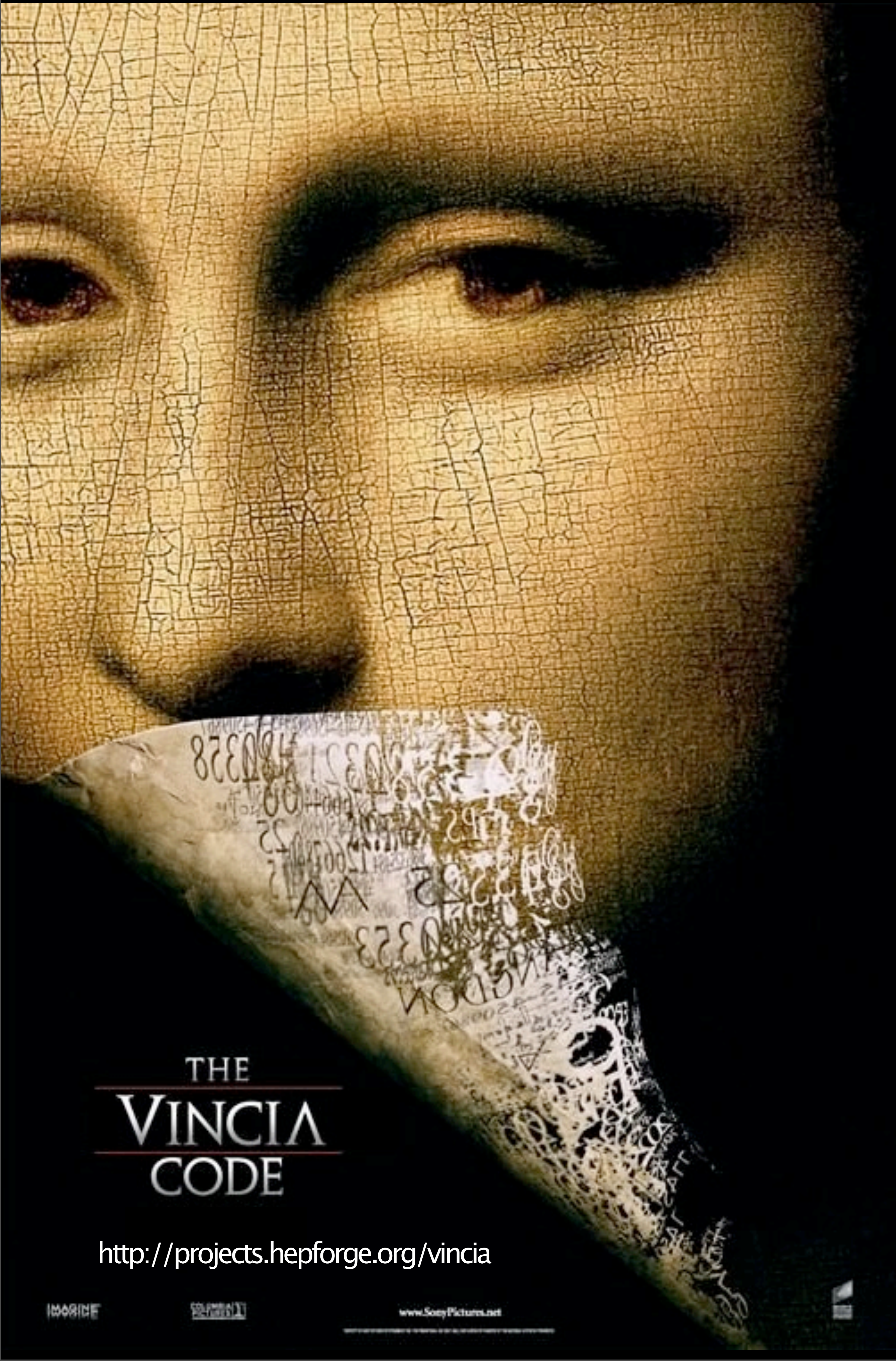
x→0
Total energy loss

Results -> Speed

Matched through:	Z→3	Z→4	Z→5	Z→6
Pythia 6	0.20	ms/event Z→qq *(q=udscb)* + shower. Matched and unweighted. Hadronization off *gfortran/g++ with gcc v.4.4 -O2 on single 3.06 GHz processor with 4GB memory*		
Pythia 8	0.22			
Vincia Global	0.30	0.77	6.40	130.00
Vincia Sector	0.27	0.63	6.90	52.00
Vincia Global *(Q_{match} = 5 GeV)*	0.29	0.60	2.40	20.00
Vincia Sector *(Q_{match} = 5 GeV)*	0.26	0.50	1.40	6.70
Sherpa *(Q_{match} = 5 GeV)*	5.15*	53.00*	220.00*	400.00*
* + *initialization time*	1.5 minutes	7 minutes	22 minutes	2.2 hours

Generator Versions: Pythia 6.425 *(Perugia 2011 tune)*, Pythia 8.150, Sherpa 1.3.0, Vincia 1.026 *(without uncertainty bands, NLL/NLC=OFF)*

J. Lopez-Villarejo & PS, arXiv:1109.3608



VINCIA Status

- Plug-in to PYTHIA 8
- Stable and reliable for Final-State Jets
  (E.g., LEP)
  - Automatic matching and uncertainty bands
  - improvements in shower
    (smooth ordering, NLC, Matching, …)
- Paper on mass effects ~ ready
  (with A. Gehrmann-de-Ridder & M. Ritzmann)

Next steps

- Multi-leg one-loop matching
  (with L. Hartgring & E. Laenen, NIKHEF)
- Polarized Showers
  (with A. Larkoski, SLAC, & J. Lopez-Villarejo, CERN)
- → Initial-State Showers
  (with W. Giele, D. Kosower, G. Diana, M. Ritzmann)