UCLouvain
Institut de recherche en mathématique et physique
Centre de Cosmologie, Physique des Particules et Phénoménologie
Centre de Calcul Intensif et Stockage de Masse

MCnet

MadGraph

Olivier Mattelaer (for the full team)

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MadGraph5

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~~MadGraph~~
~~MadGraph5~~
MadGraph5_aMC@NLO

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MCnet

~~MadGraph~~
~~MadGraph5~~
~~MadGraph5_aMC@NLO~~
MadGraph6

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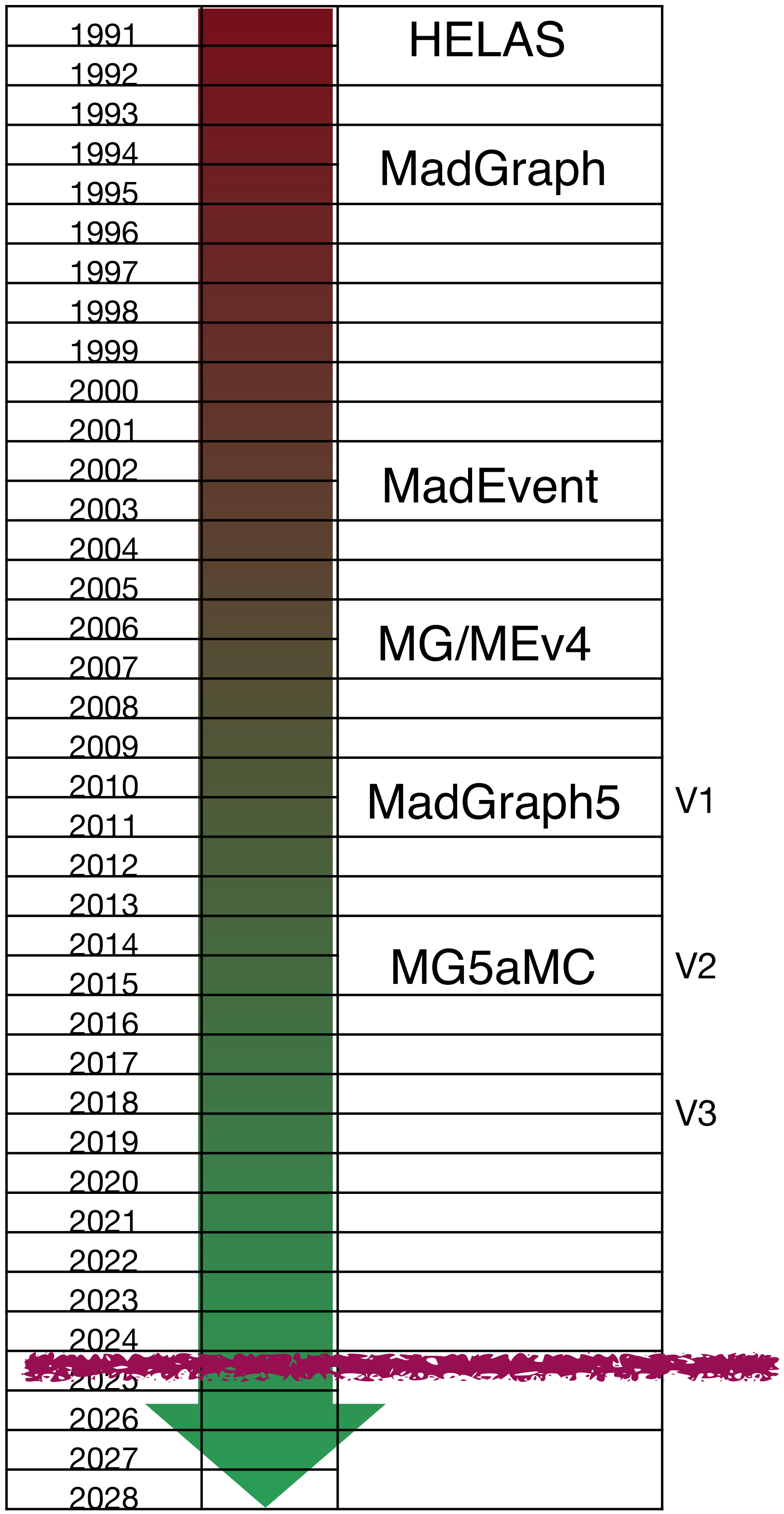
MCnet

MG5aMC

Olivier Mattelaer (for the full team)

The Past



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2028
HELAS
MadGraph
MadEvent
MG/MEv4
MadGraph5
V1
MG5aMC
V2
V3

The Past

1991	HELAS	
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1994	MadGraph	
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2002	MadEvent	
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2006	MG/MEv4	
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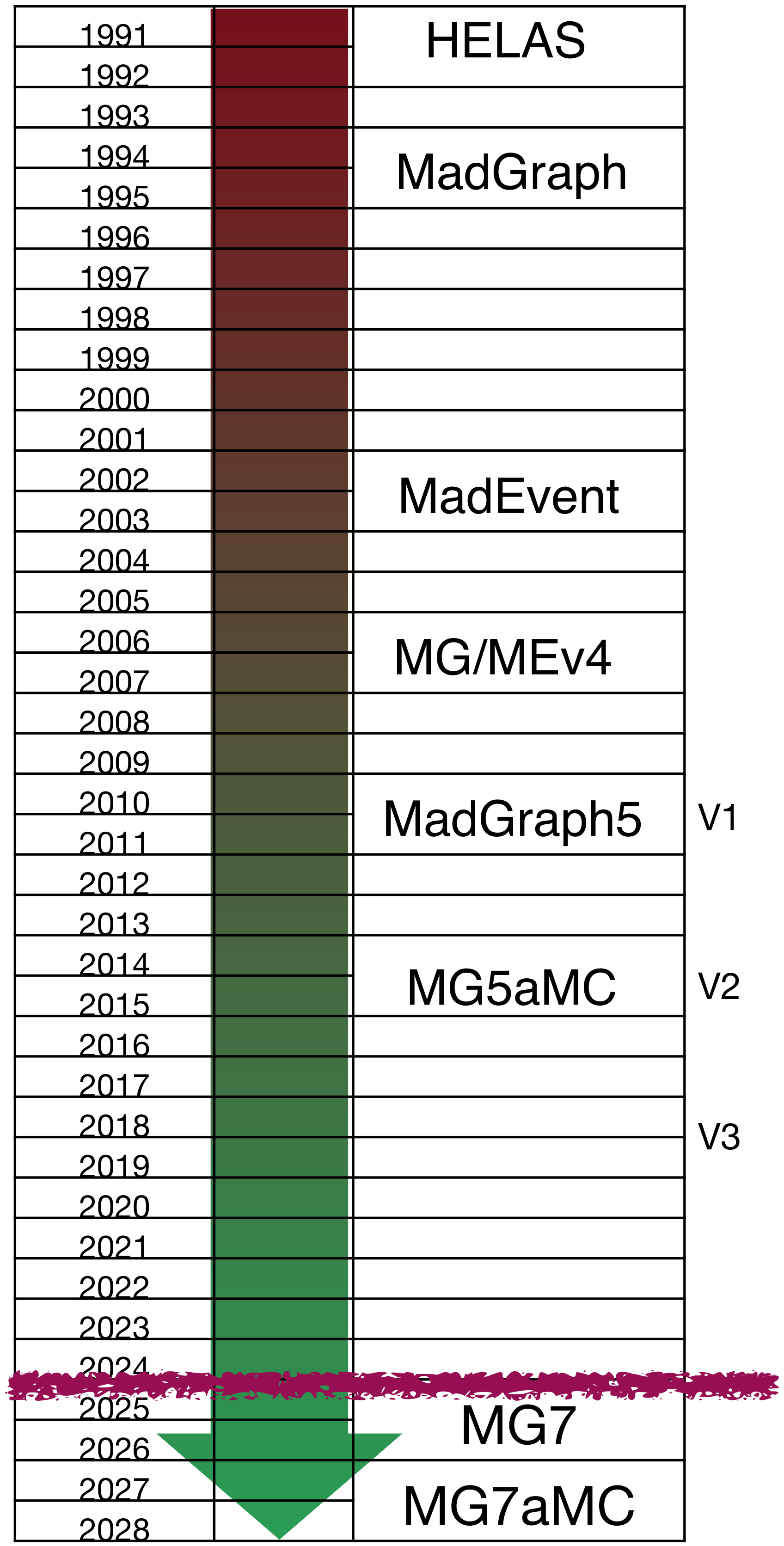
Future



- New Big release begin of 2026
  - MadGraph7
  - Focussing on LO rewriting
- Next One in 2027
  - MadGraph7@NLO
  - Focussing on NLO Improvment

Plan of my talk

- What is MG5aMC?
  - ➡ What can it help you with?
- What is the goal of MG7?
  - ➡ Why focussing on LO?
- MadGraph7 Plan
  - ➡ GPU and better hardware support
  - ➡ Machine Learning
  - ➡ Avoid scaling of matrix-element with multiplicity
  - ➡ Recursion Relation for color /hght jet multiplicity

What is it ?

(With the Full MG5aMC team)

It is a vending machine!

It is a Matrix-Element Provider!

- Choose your model (UFO)
  - Meat / drinks / ...
- Choose your process
  - Wine/ Vodka/...
- Get $|M|^2$
  - What you want, when you want!
  - And do what you want!

Use our Restaurant!

Use our Restaurant!

$$\int d\Phi f_1(x_1) f(x_2) \,|\, M \,|^2$$

- Cross-section computation
- Differential cross-section
  - LO
  - Fixed order NLO (EW and QCD)
  - NLO+PS (QCD)
- Onshell Decay/ Reweighting / systematics/ ...

Features

BSM

BSM re-weighting

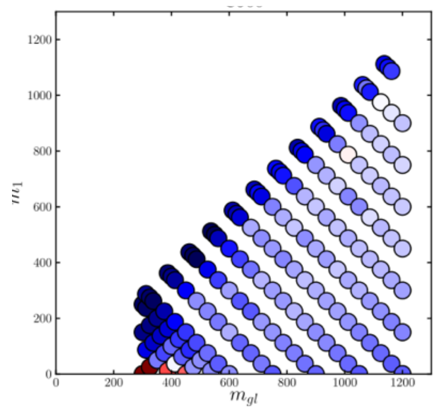
$$|M_{new}|^2 / |M_{old}|^2$$

Features

Auto-Width

$$\Gamma = ?$$

Parameter scan



BSM

BSM re-weighting

$$|M_{new}|^2 / |M_{old}|^2$$

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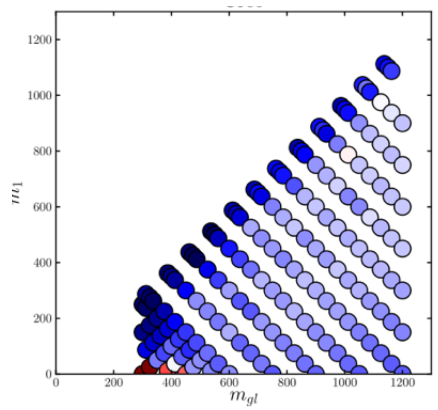
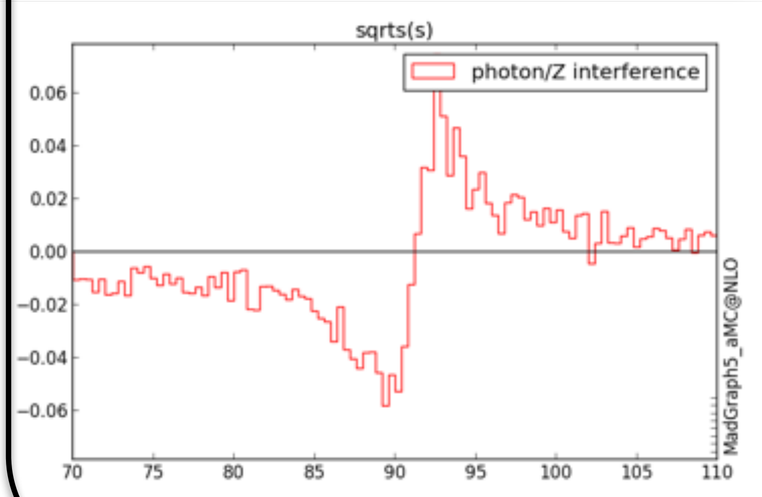


Interference



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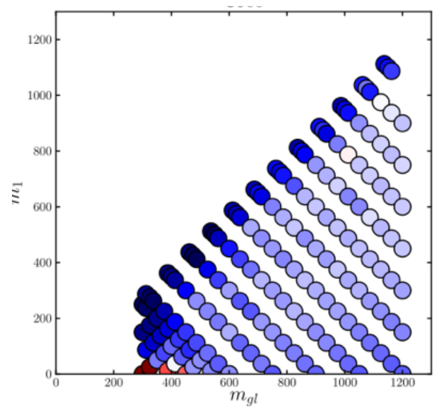
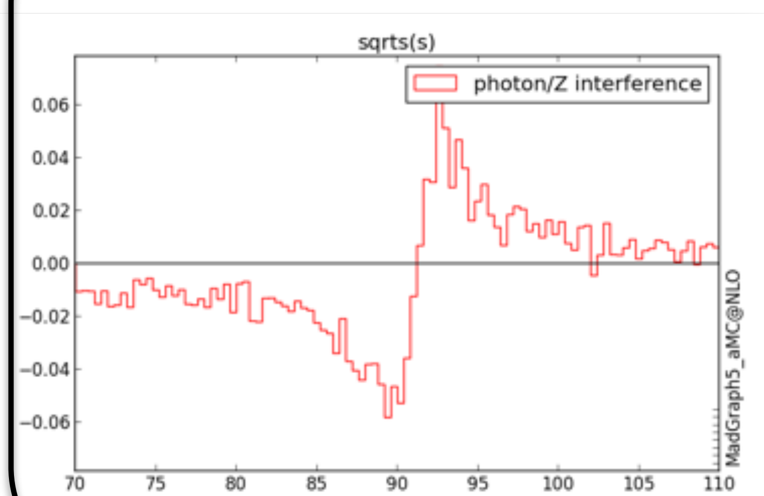
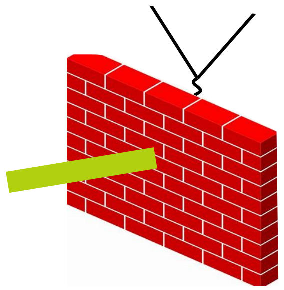


Interference



Plugin



Interface

MAD Analysis 5

BSM

BSM re-weighting

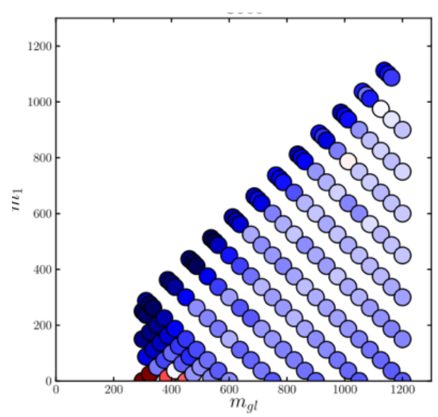
$$|M_{new}|^2 / |M_{old}|^2$$

Features

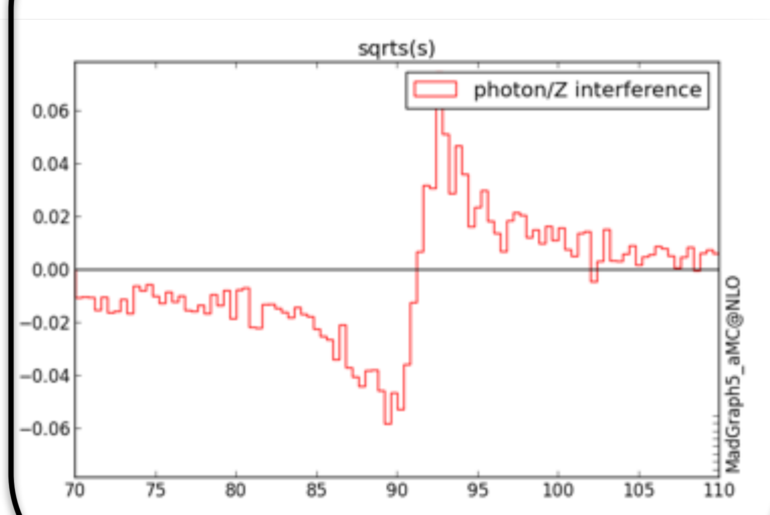
Auto-Width

$$\Gamma = ?$$

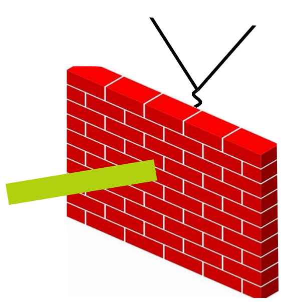
Parameter scan



Interference



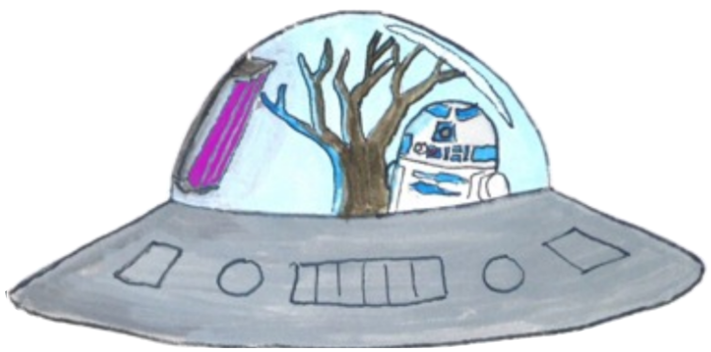
Plugin



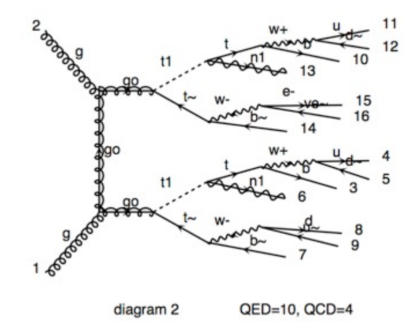
Interface

MADAnalysis 5

BSM



Onshell Decay



BSM re-weighting

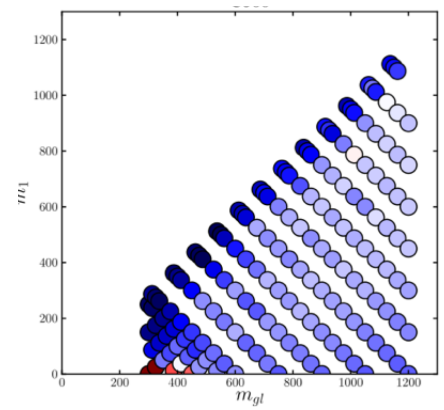
$$|M_{new}|^2 / |M_{old}|^2$$

Features

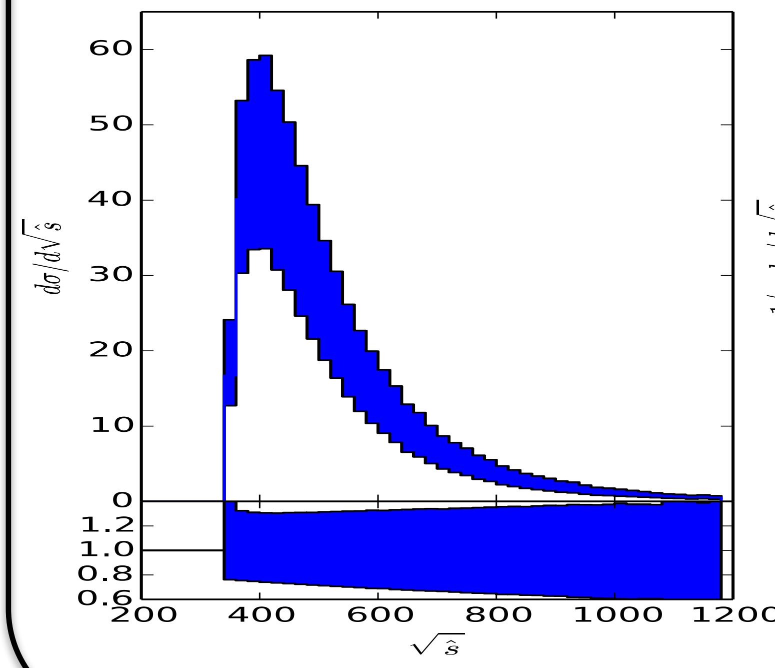
Auto-Width

$$\Gamma = ?$$

Parameter scan

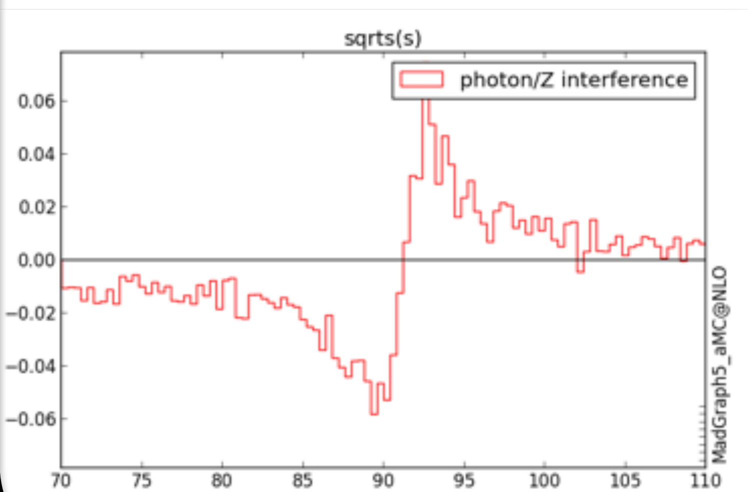


Systematics

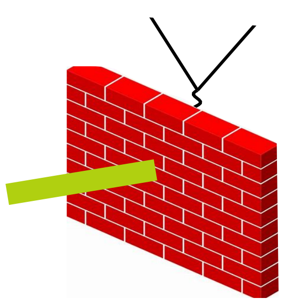


BSM

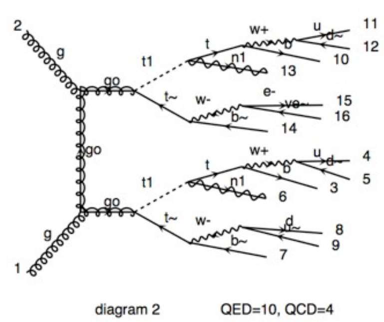
Interference



Plugin



Onshell Decay



Interface

MAD Analysis 5

BSM re-weighting

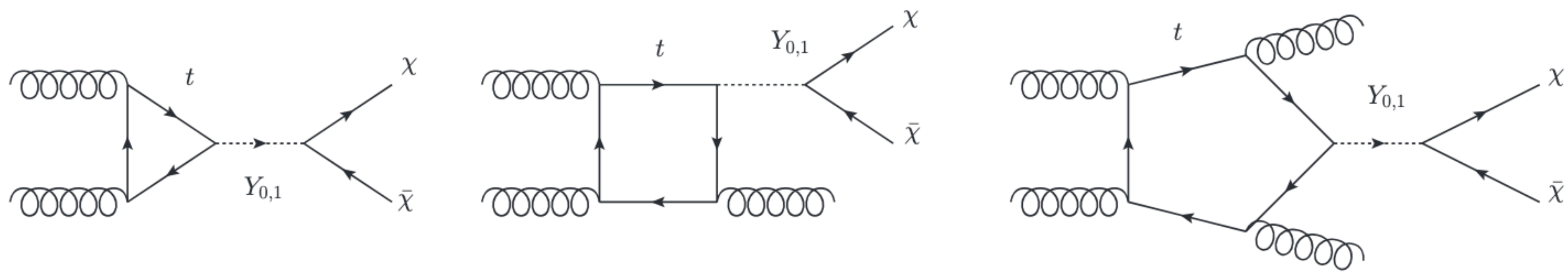
$$|M_{new}|^2 / |M_{old}|^2$$

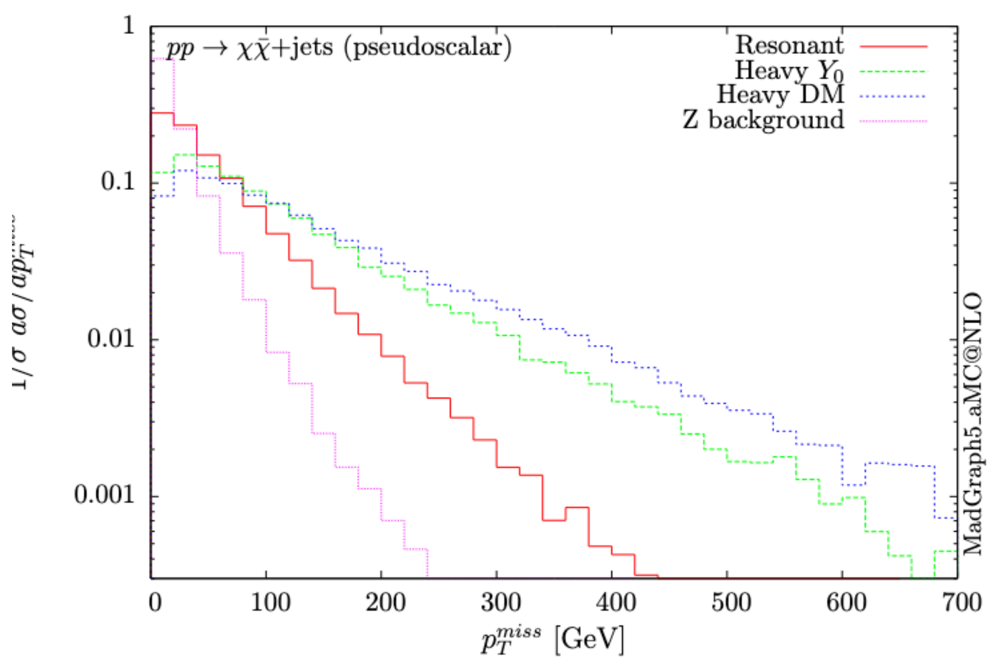
Dark Matter

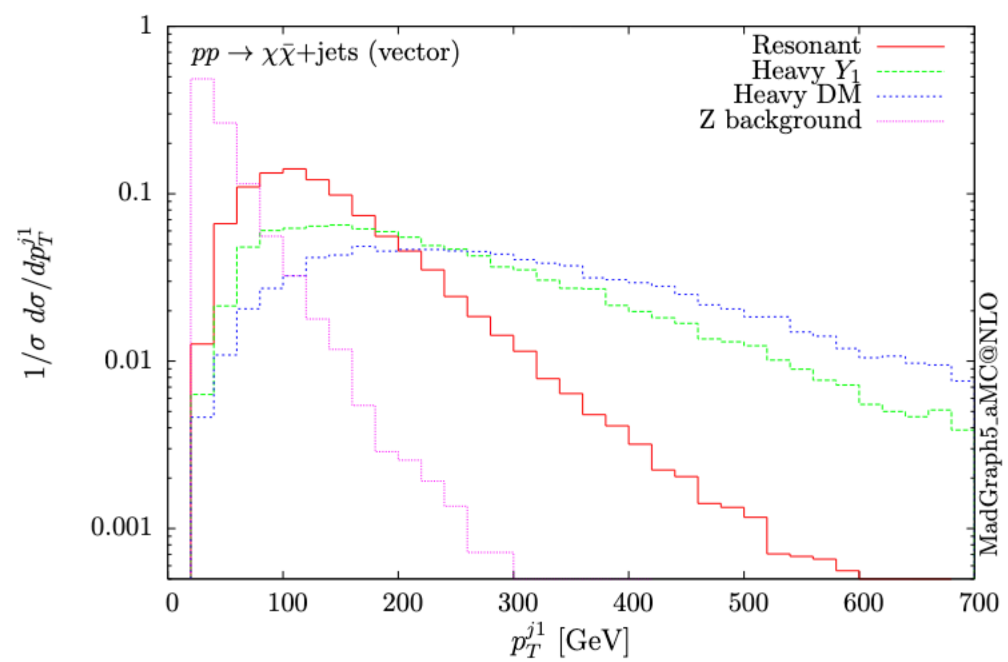
- What about DM? (Not MadDM)
  - Can (help) to search for it at LHC

Dark Matter

- What about DM? (Not MadDM)
    - Can (help) to search for it at LHC
    - Like MonoJet searches:



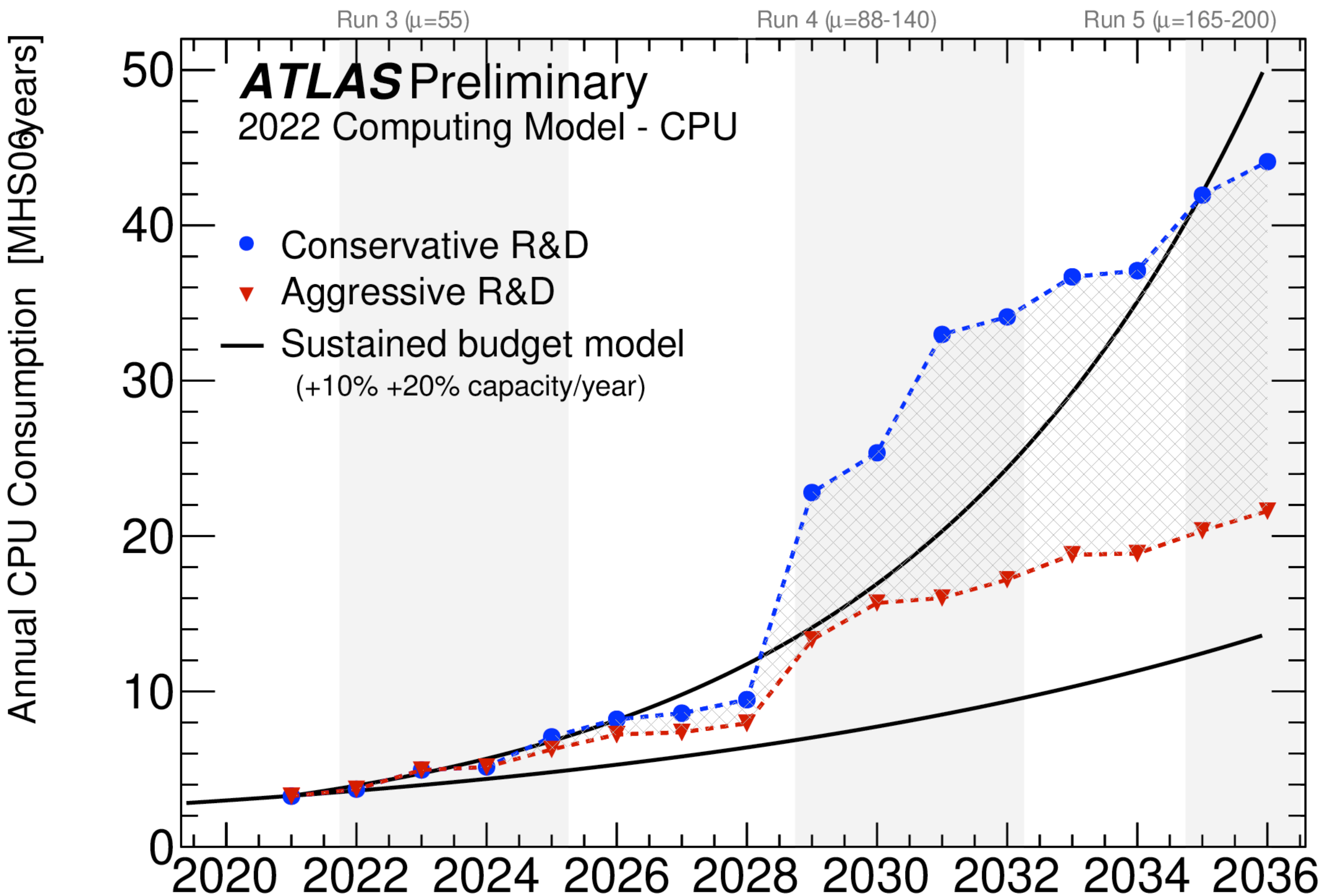




OM and E. Vryonidou: 1508.00564

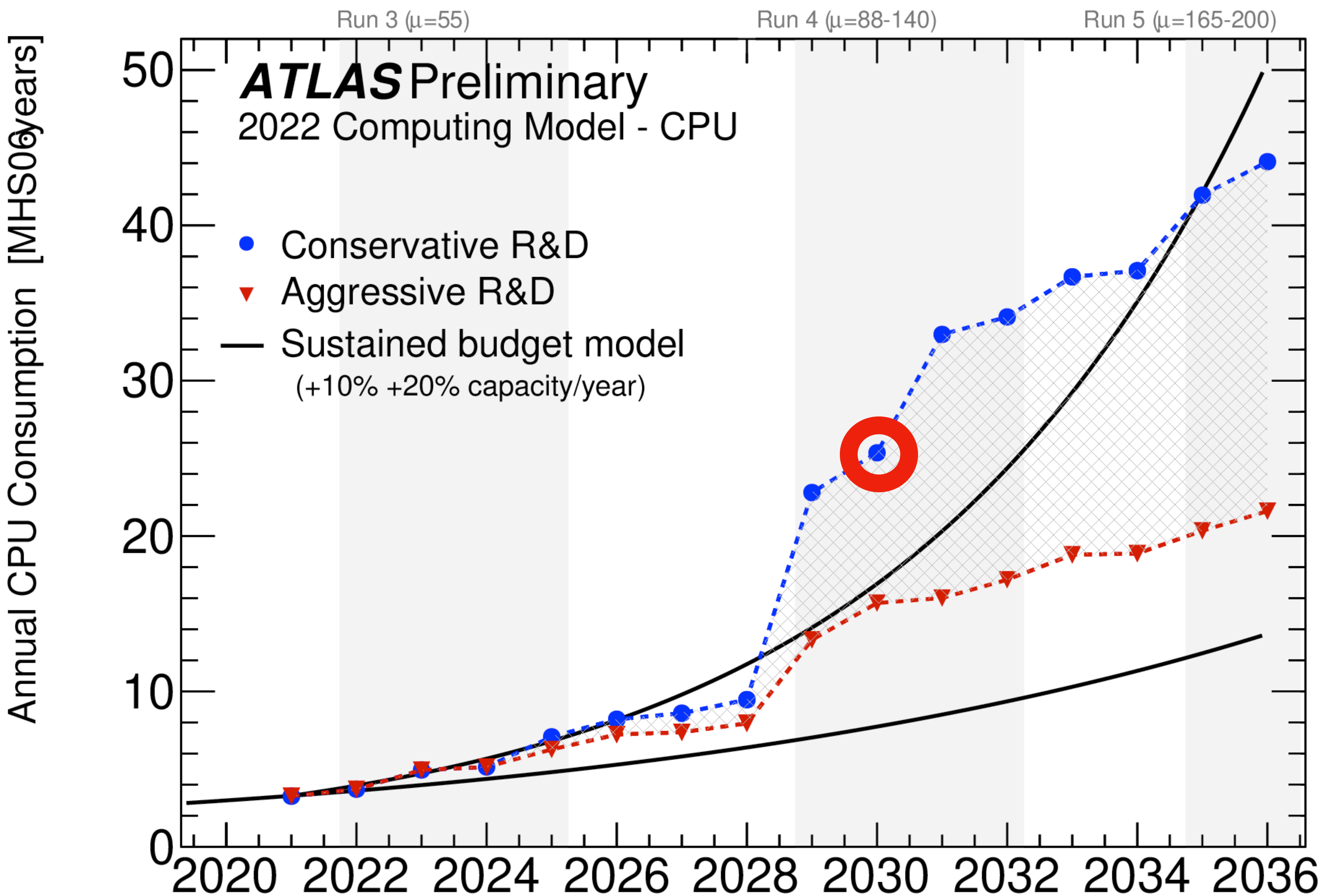
Why LO focus?

Computing planning II



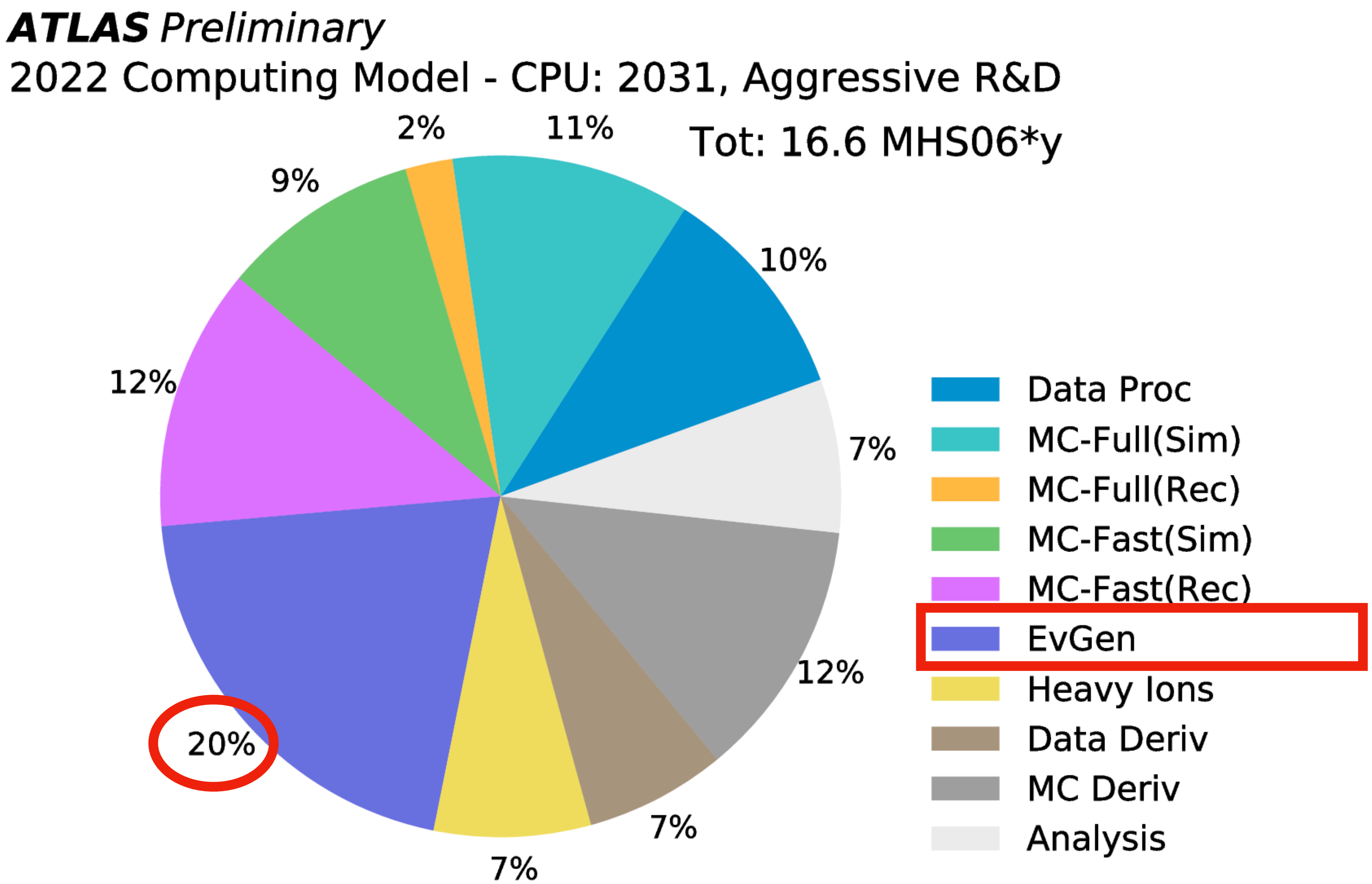
~ 2029 is the most critical period

Computing planning II



~ 2029 is the most critical period

Computing planning III



LO here dominates (multi-jet)

They ask us to go parallel!

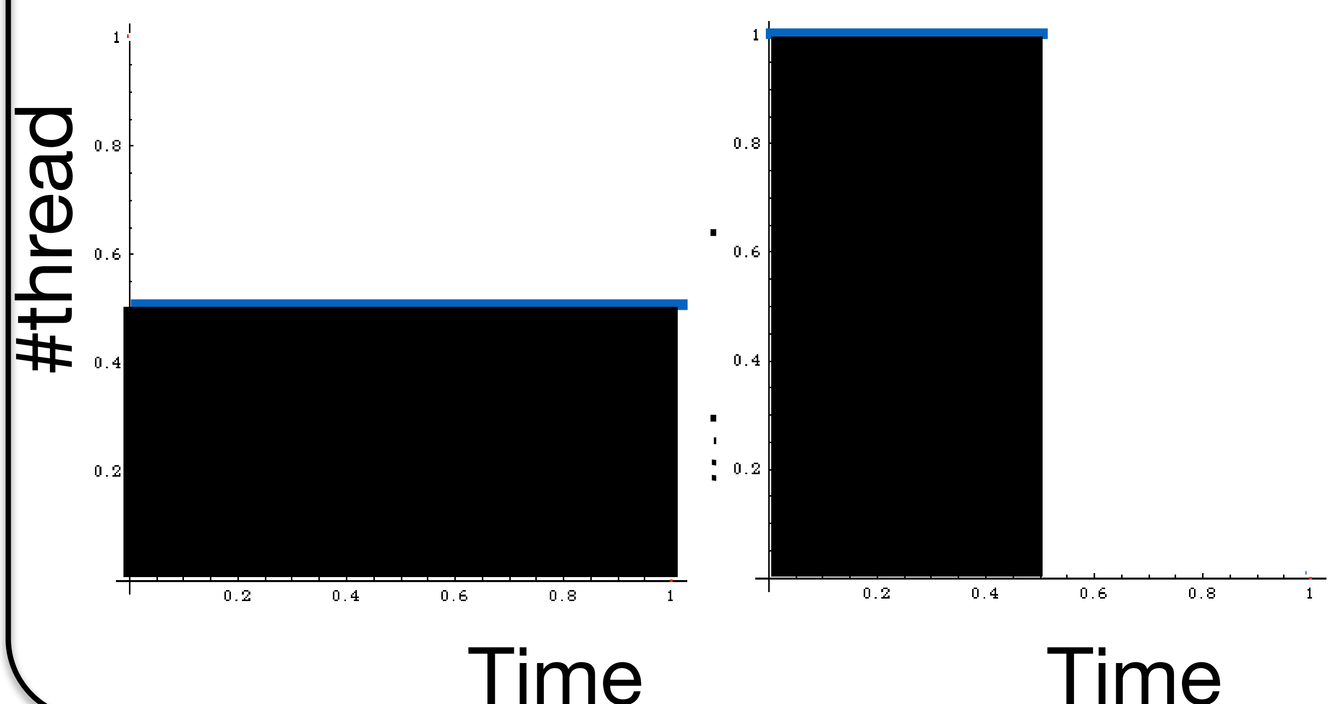
GPU/ hardware

With support from CERN IT:
S. Roiser, A. Valassi, D. Massaro, Z. Wettersten, S. Hageboeck

Going Parallel

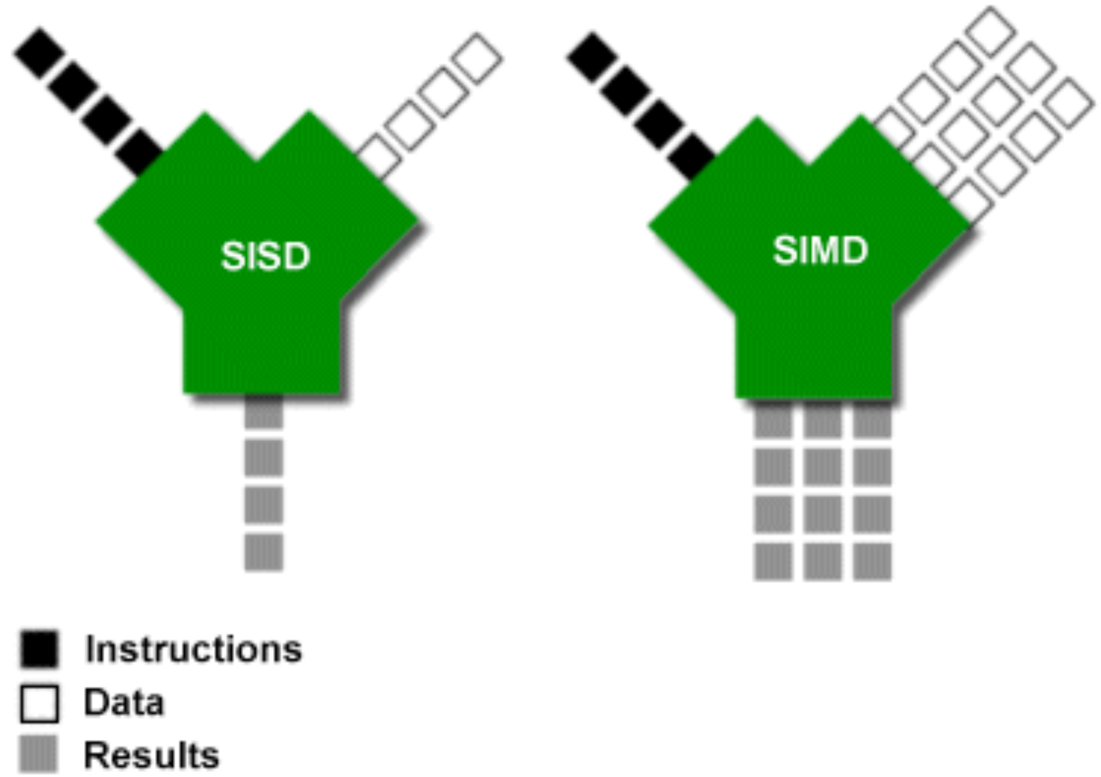
- Multi-processes
  - ➡ We fit here!
- OpenMP
- OpenMPI

➡ Great as a user: The more you use the less you wait



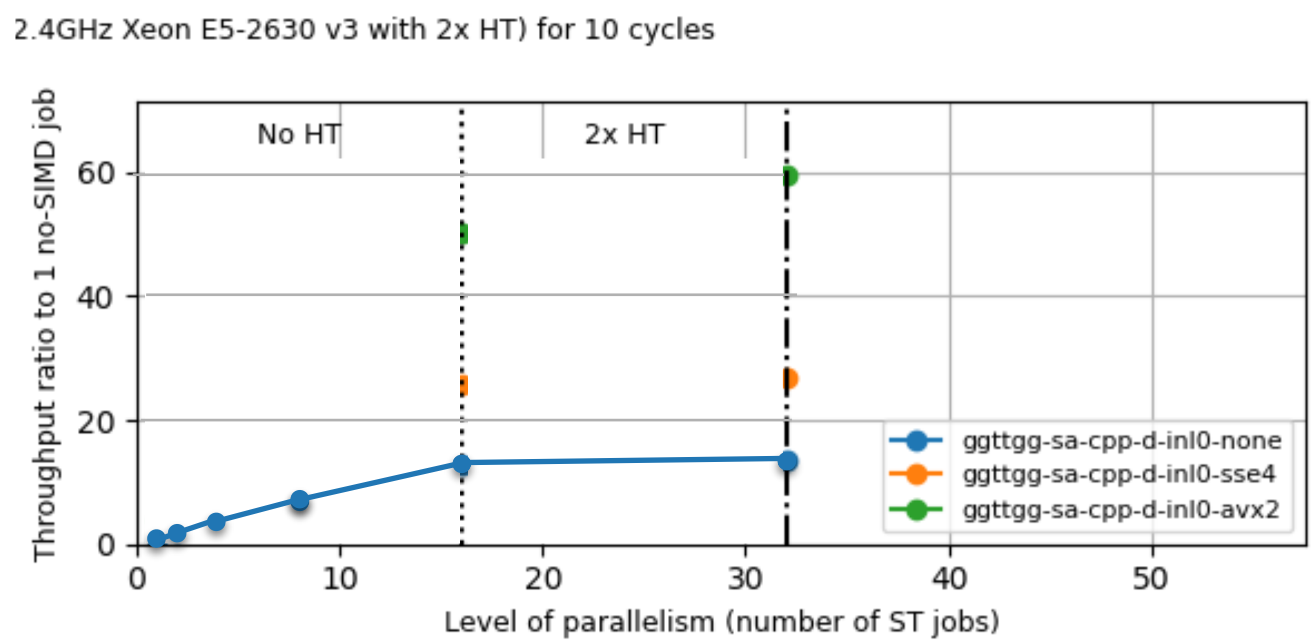
➡ Bad/Useless for Clusters: the integral is the same (in the best case)

Data parallelism



- SIMD (Single Instruction Multiple data):
  - ➡ Also named code vectorisation
  - ➡ Need dedicated memory pattern to allow it
  - ➡ Speed-up on the same hardware
    - All CPU have it

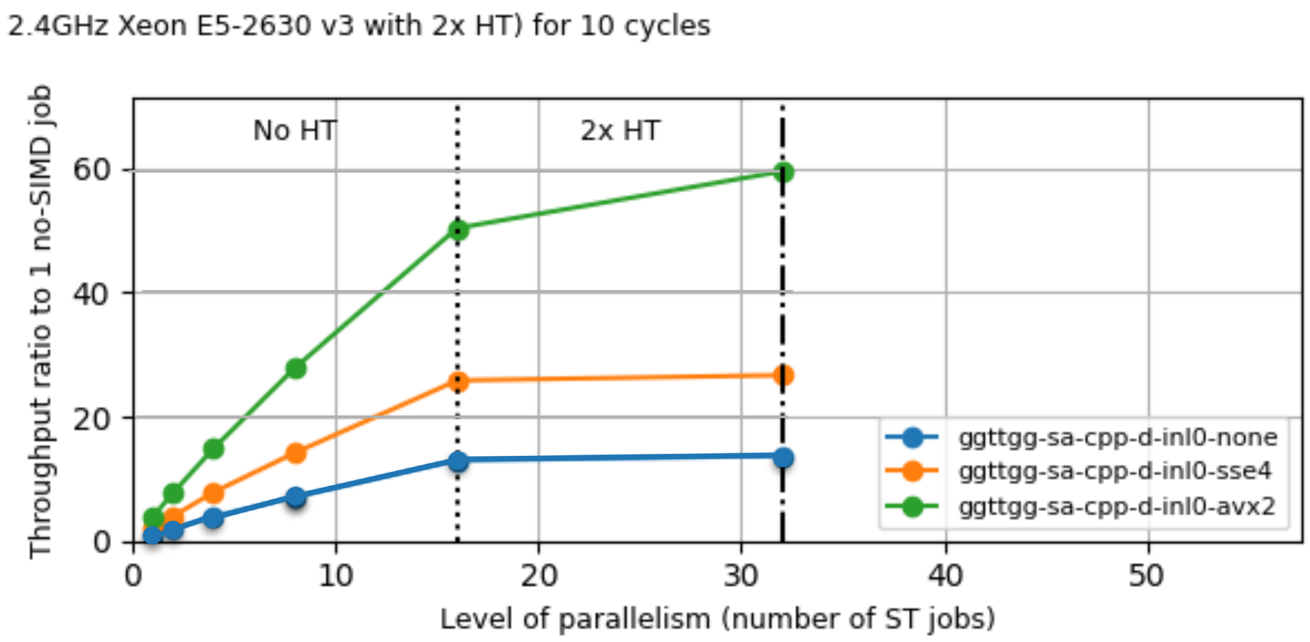
Multi-process



- Pure matrix-element evaluation (no pdf/…)
- X-axis number of process submitted on the node
  - Multi-process mode (boringly parallel)
- Machine has 16 core
  - Above 16 the hyper-threading is used
  - Small gain from hyper-threading

➡The more you use the less you wait

Haswell Computer



- Orange line (SSE4.2: All computers since 2008)
  - 2x faster
- Green line (AVX2: All x65 based since 2011)
  - 4x faster
- 8x theoretically possible on
  - AMD since 2024
  - intel since 2018

Going Parallel (GPU)

- GPU are $\simeq$ many and large SIMD unit
  - Development are similar
  - But they prefer single precision

- CUDA implementation:
  - Same code as the SIMD C++
  - kernel is the FULL matrix-element

- Abstraction Layer:
  - Kokkos, sycl, alpaka
  - Allow portability

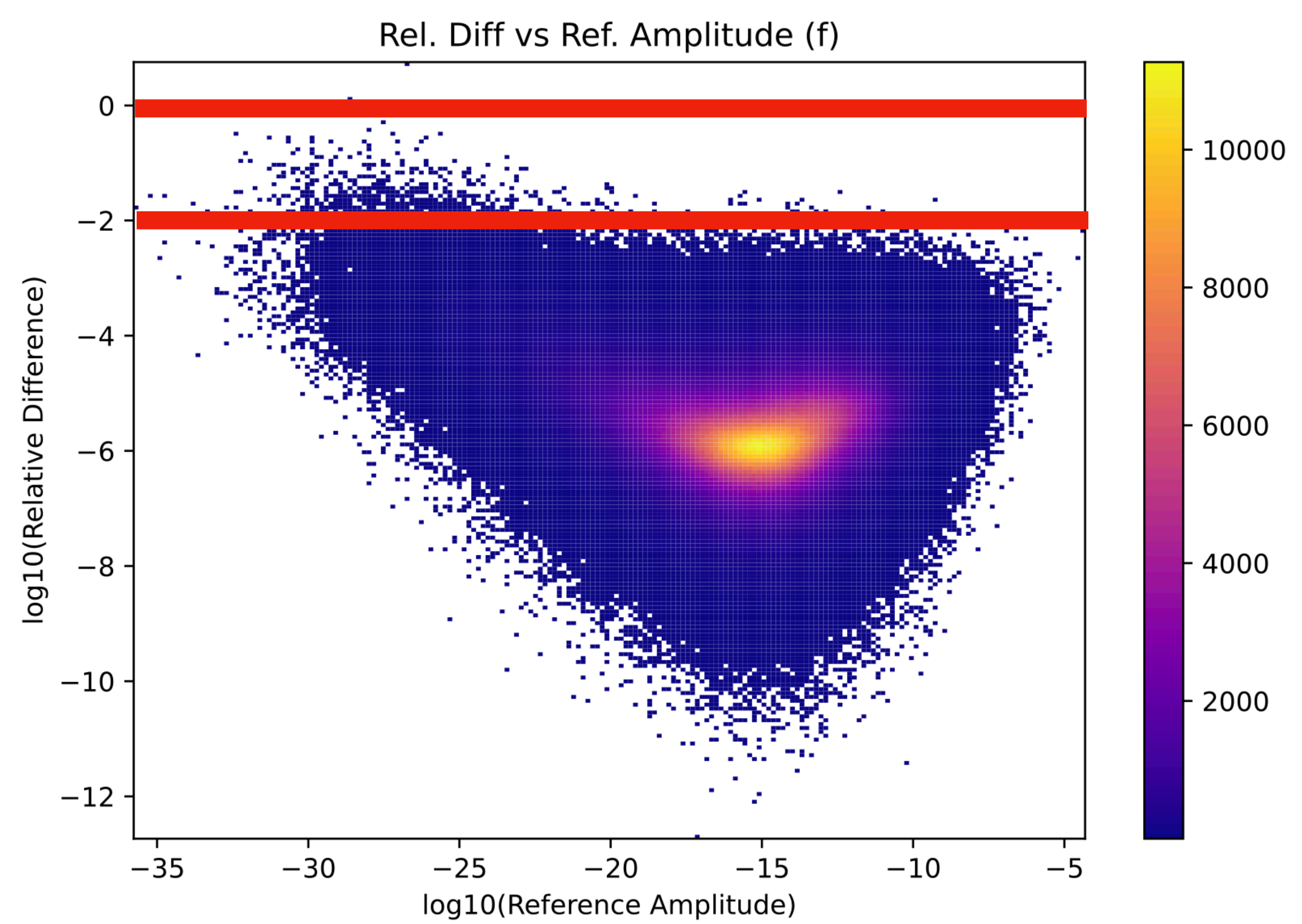
- Other work:
  - MadFlow
  - Old MadGPU

Can we use single precision?

Issue:

- (Very) Few events have large numerical issues
- Some does not even agree on the leading digit

$$u\,\bar{u} \rightarrow hgggg$$

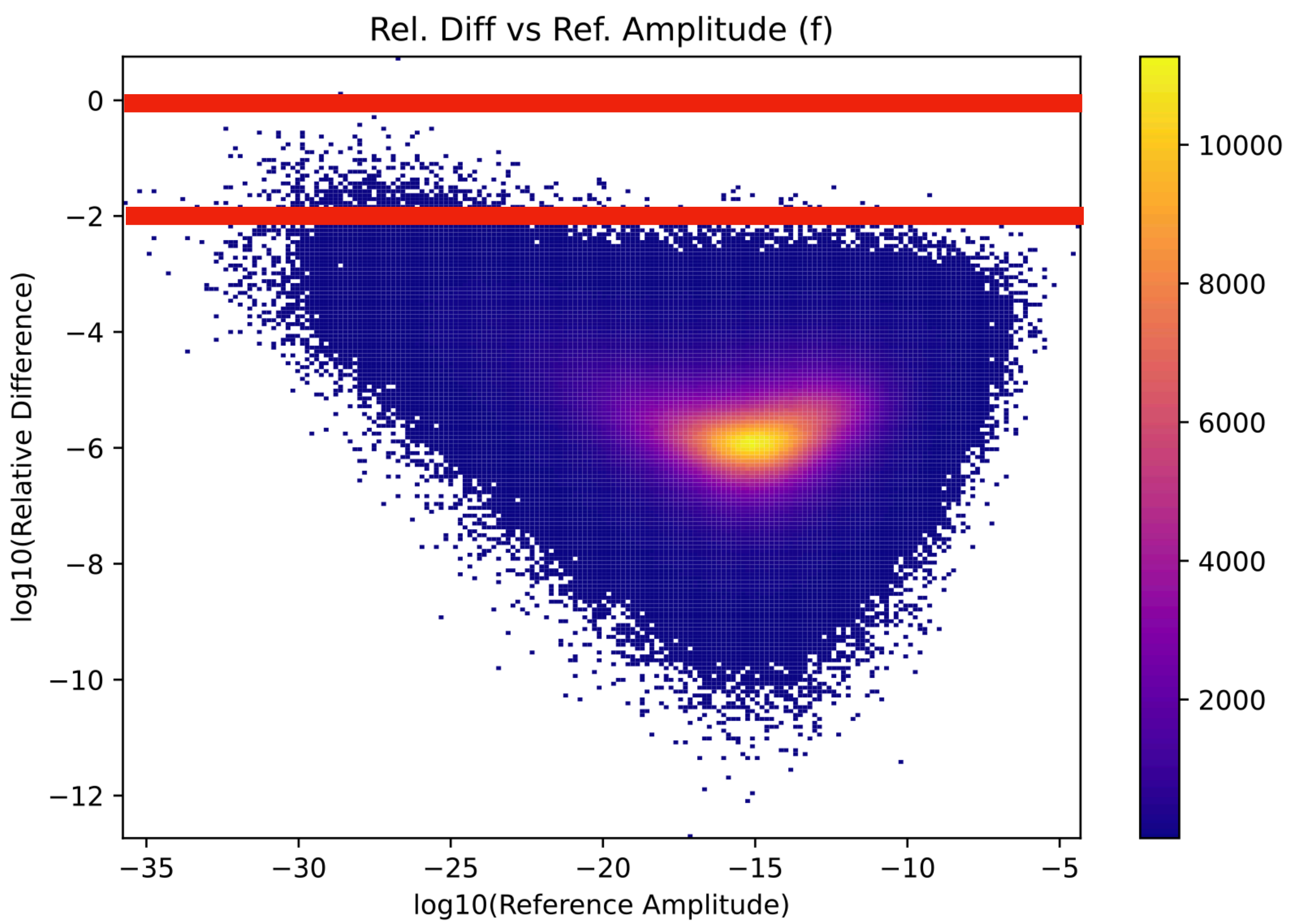


Can we use single precision?

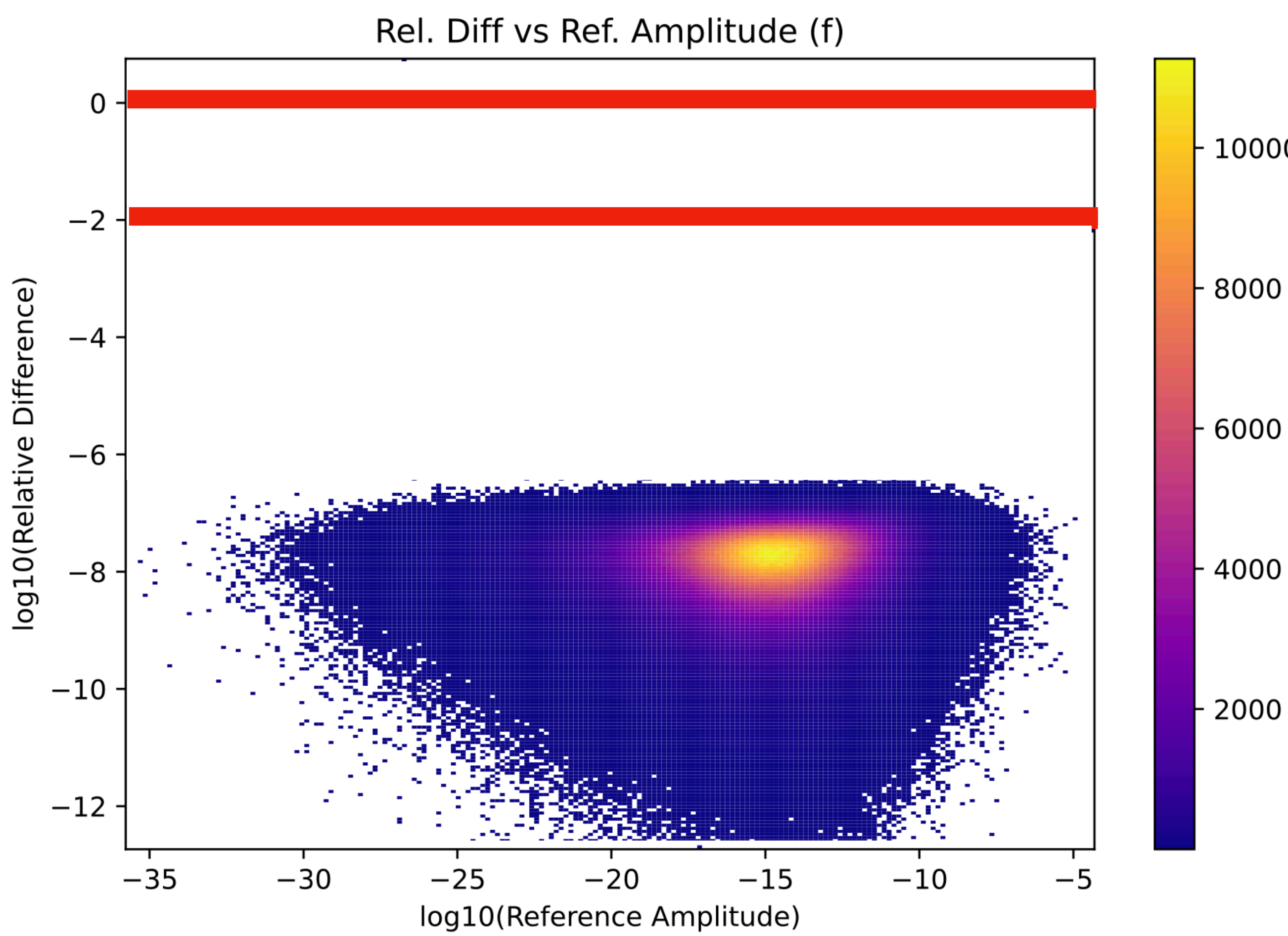
Compromised:

- compute amplitude in double
- Compute color part in single

$u\,\bar{u} \to hgggg$

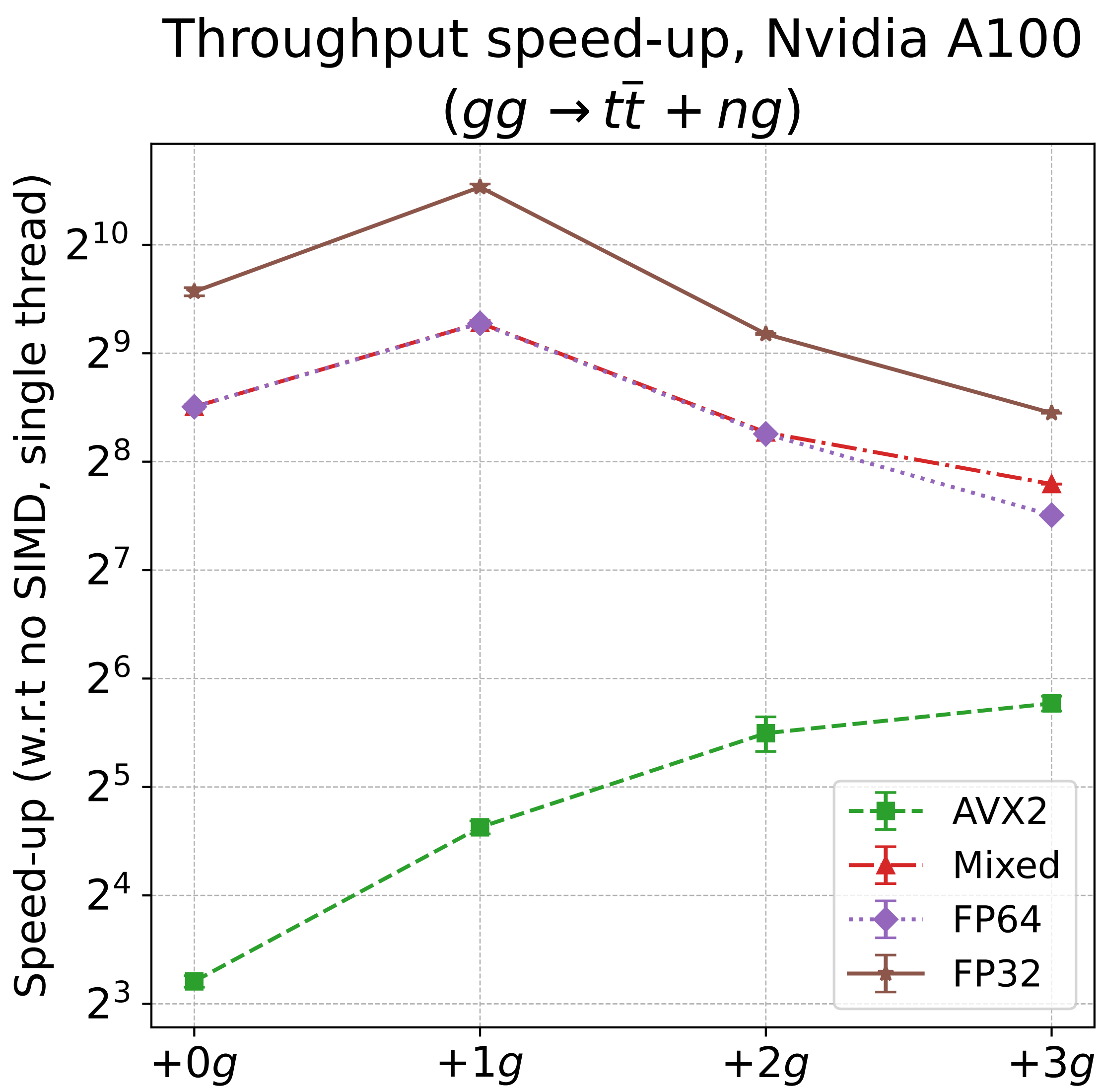


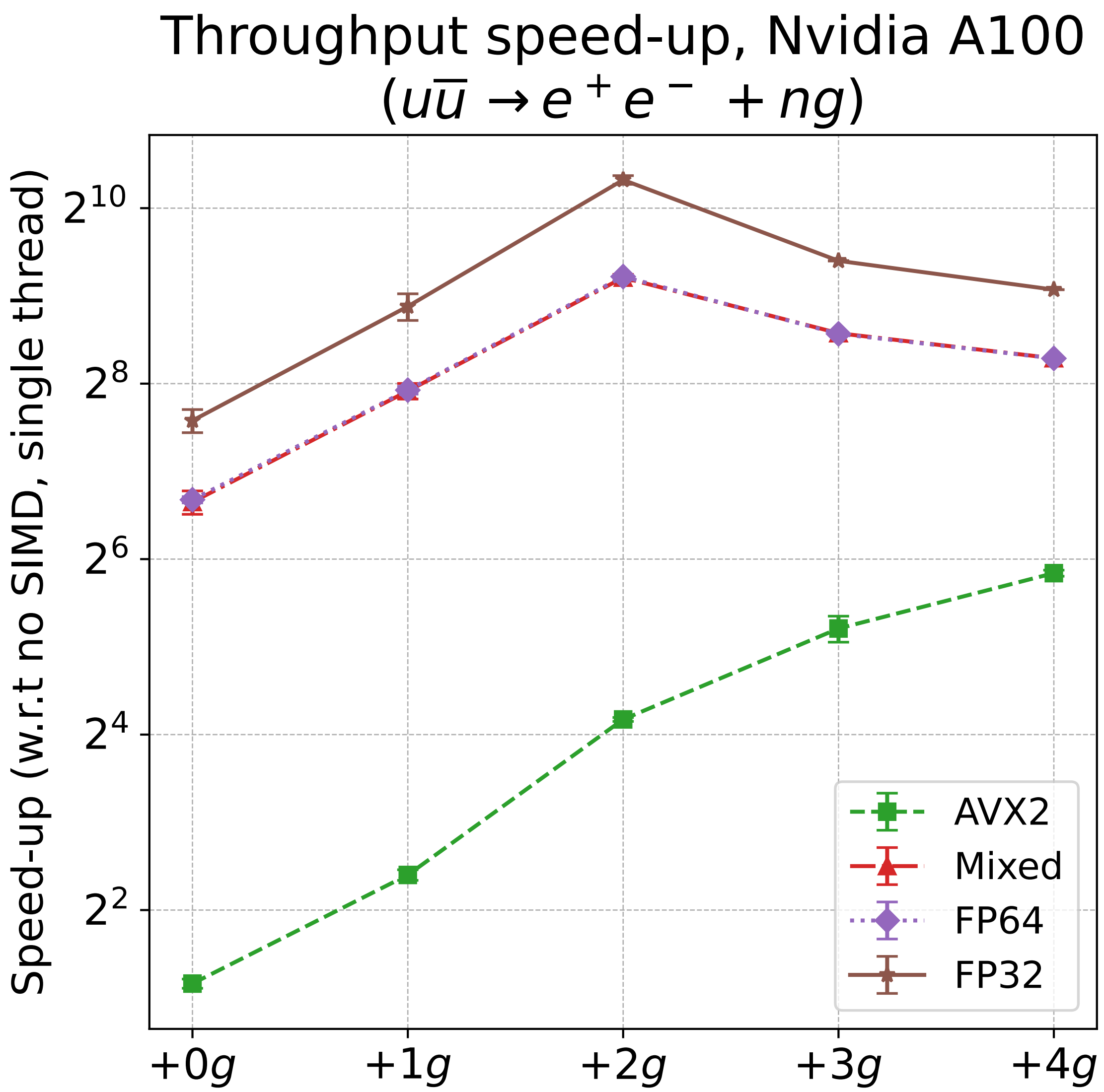
$u\,\bar{u} \to hgggg$



Phase-Space results

(Preliminary)





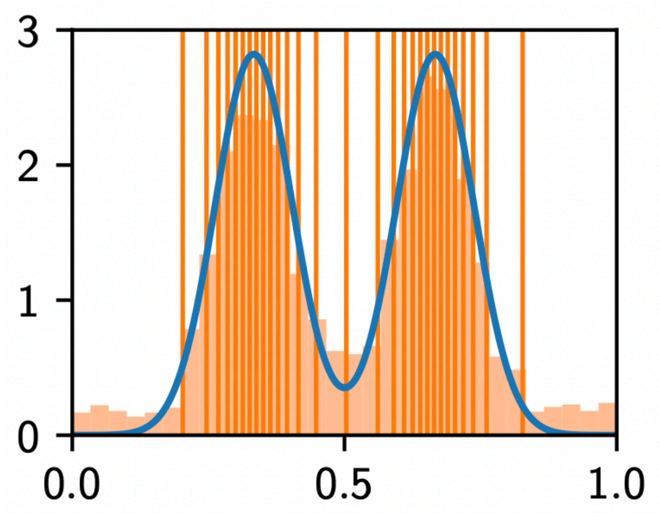
ML Phase-Space

Work with T. Heimel, R. Winterhalder, T. Plehn, F. Maltoni

Importance sampling — Vegas

Factorize probability

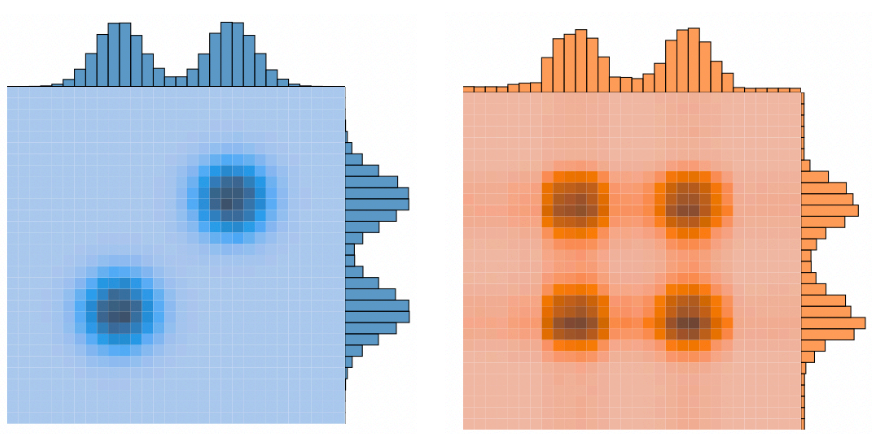
Fit bins with equal probability and varying width



Computationally cheap

High-dim and rich peaking functions
→ slow convergence

Peaks not aligned with grid axes
→ phantom peaks



Importance sampling — Flow

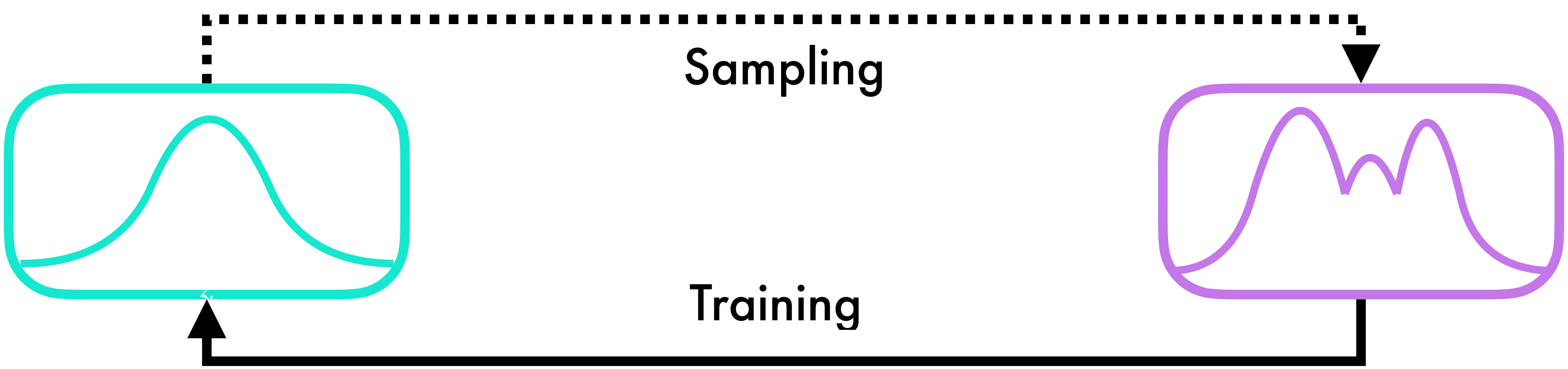
Using a Normalizing Flow

⊕ Invertibility

→ **bijective mapping**

⊕ tractable Jacobians

→ **fast training and evaluation**



[2001.05478, 2001.05486, 2001.10028,2005.12719, 2112.09145]

MadNIS

Basic Functionality

- Neural Channel Weights
- Normalizing Flow
- MadGraph matrix elements
- MadEvent channel mappings

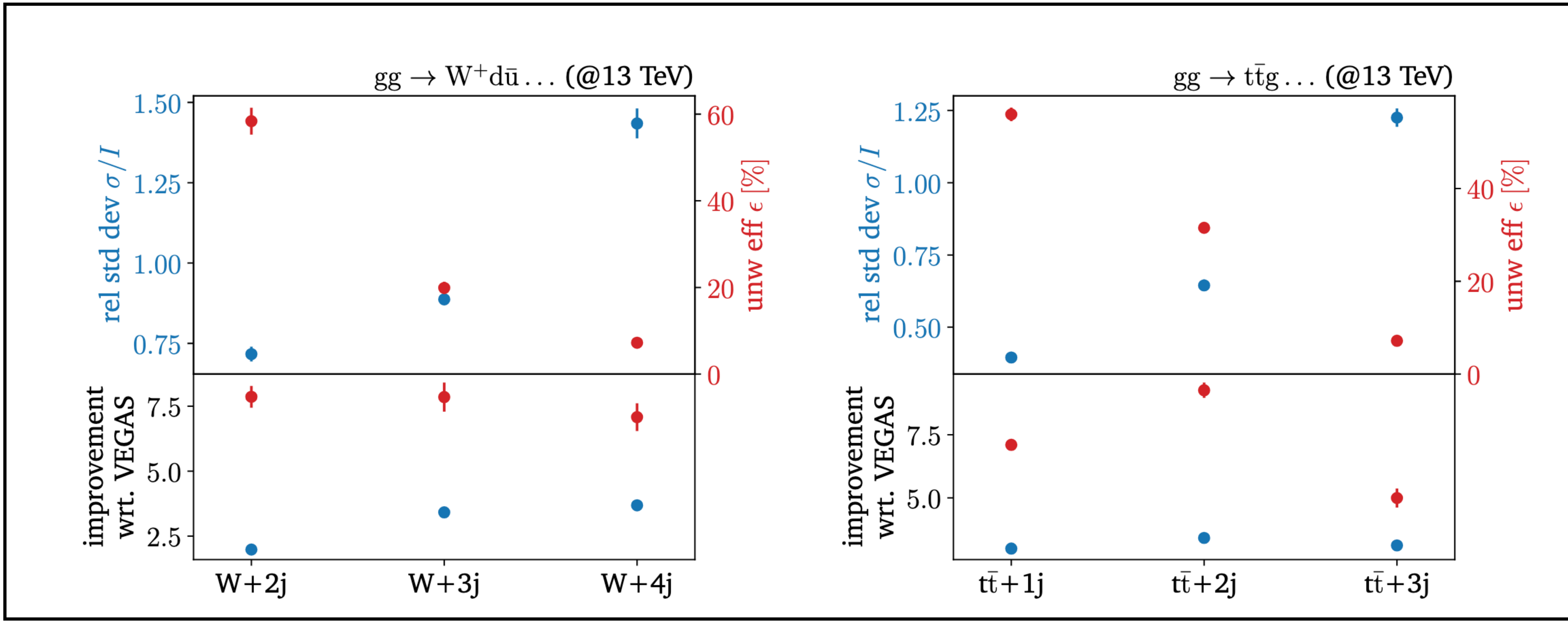
Improved multi-channeling

- Conditional flows
- Overflow Channels
- Symmetries between channels
- Stratified Sampling/ Training

Improved training

- Vegas Initialization
- Buffered Training
- Trainable Rotations

LHC Example



Unweighting efficiency 8 times more efficient

Matrix-Element Grouping

MadGraph5 @LO

- How do you handle u u > w+ g u d and u c > w+ g u s ?
  - MG4 : Fully separate directory
  - MG5: Same directory, MC over flavor

Process	Subproc. dirs.		Channels		Directory size	
	MG 4	MG 5	MG 4	MG 5	MG 4	MG 5
$pp \to W^+j$	6	2	12	4	79 MB	35 MB
$pp \to W^+jj$	41	4	138	24	438 MB	64 MB
$pp \to W^+jjj$	73	5	1164	120	842 MB	110 MB
$pp \to W^+jjjj$	296	7	15029	609	3.8 GB	352 MB
$pp \to W^+jjjjj$	-	8	-	2976	-	1.5 GB
$pp \to l^+l^-j$	12	2	48	8	149 MB	44 MB
$pp \to l^+l^-jj$	54	4	586	48	612 MB	83 MB
$pp \to l^+l^-jjj$	86	5	5408	240	1.2 GB	151 MB
$pp \to l^+l^-jjjj$	235	7	65472	1218	5.3 GB	662 MB
$pp \to t\bar{t}$	3	2	5	3	49 MB	39 MB
$pp \to t\bar{t}j$	7	3	45	17	97 MB	56 MB
$pp \to t\bar{t}jj$	22	5	417	103	274 MB	98 MB
$pp \to t\bar{t}jjj$	34	6	3816	545	620 MB	209 MB

Example W+ 3j

No grouping

53 directories

Directory	# Diagrams	# Subprocesses
P1_udx_wpgddx	24	2
P1_uc_wpgcd	12	4
P1_ug_wpdddx	24	2
P1_gd_wpddux	24	2
P1_uxu_wpgscx	12	4
P1_ud_wpgdd	24	2
P1_gux_wpduxux	24	2
P1_gdx_wpggux	50	2
P1_ug_wpuscx	12	4
P1_dxc_wpgcux	12	4
P1_udx_wpgccx	12	4
P1_dxux_wpguxux	24	2
P1_du_wpgdd	24	2
P1_dxu_wpguux	24	2
P1_uxg_wpsuxcx	12	4
P1_dxg_wpggux	50	2
P1_dxu_wpgccx	12	4
P1_uxsx_wpguxcx	12	4
P1_gu_wpudux	24	2
P1_ug_wpggd	50	2
P1_udx_wpguux	24	2
P1_gu_wpcdcx	12	4
P1_uux_wpgscx	12	4
P1_gg_wpgdux	50	2
P1_usx_wpgucx	12	4
P1_gux_wpsuxcx	12	4
P1_uxc_wpgsux	12	4
P1_uxg_wpduxux	24	2
P1_dxu_wpgddx	24	2
P1_gu_wpggd	50	2
P1_ug_wpudux	24	2
P1_uxdx_wpguxux	24	2
P1_ug_wpcdcx	12	4
P1_dxd_wpgdux	24	2
P1_uxu_wpgdux	24	2
P1_dxg_wpcuxcx	12	4
P1_gdx_wpcuxcx	12	4
P1_gu_wpdddx	24	2
P1_ddx_wpgdux	24	2
P1_dxu_wpggg	50	2
P1_uc_wpgus	12	4
P1_udx_wpggg	50	2
P1_uux_wpgdux	24	2
P1_dg_wpddux	24	2
P1_dxcx_wpguxcx	12	4
P1_dxdx_wpguxdx	24	2
P1_uu_wpgud	24	2
P1_gdx_wpduxdx	24	2
P1_dxg_wpduxdx	24	2
P1_gdx_wpuuxux	24	2
P1_dxg_wpuuxux	24	2
P1_gu_wpuscx	12	4
P1_ucx_wpgdcx	12	4

MG5 Grouping

5 directories

30 matrix-elements

Directory	# Diagrams	# Subprocesses
P1_qq_wpggg	50	4
P1_gg_wpgqq	50	2
P1_gq_wpggq	50	4
	50	4
P1_qq_wpgqq	24	2
	24	4
	24	4
	24	4
	24	4
	24	4
	24	4
	24	2
	12	2
	12	6
	12	8
	12	8
	12	8
	12	8
	12	6
	12	2
P1_gq_wpqqq	24	4
	24	4
	24	4
	24	4
	24	4
	24	4
	12	8
	12	8
	12	8
	12	8

Example W+ 3j

No grouping

53 directories

Directory	# Diagrams	# Subprocesses
P1_udx_wpgddx	24	2
P1_uc_wpgcd	12	4
P1_ug_wpdddx	24	2
P1_gd_wpddux	24	2
P1_uxu_wpgscx	12	4
P1_ud_wpgdd	24	2
P1_gux_wpduxux	24	2
P1_gdx_wpggux	50	2
P1_ug_wpuscx	12	4
P1_dxc_wpgcux	12	4
P1_udx_wpgccx	12	4
P1_dxux_wpguxux	24	2
P1_du_wpgdd	24	2
P1_dxu_wpguux	24	2
P1_uxg_wpsuxcx	12	4
P1_dxg_wpggux	50	2
P1_dxu_wpgccx	12	4
P1_uxsx_wpguxcx	12	4
P1_gu_wpudux	24	2
P1_ug_wpggd	50	2
P1_udx_wpguux	24	2
P1_gu_wpcdcx	12	4
P1_uux_wpgscx	12	4
P1_gg_wpgdux	50	2
P1_usx_wpgucx	12	4
P1_gux_wpsuxcx	12	4
P1_uxc_wpgsux	12	4
P1_uxg_wpduxux	24	2
P1_dxu_wpgddx	24	2
P1_gu_wpggd	50	2
P1_ug_wpudux	24	2
P1_uxdx_wpguxux	24	2
P1_ug_wpcdcx	12	4
P1_dxd_wpgdux	24	2
P1_uxu_wpgdux	24	2
P1_dxg_wpcuxcx	12	4
P1_gdx_wpcuxcx	12	4
P1_gu_wpdddx	24	2
P1_ddx_wpgdux	24	2
P1_dxu_wpggg	50	2
P1_uc_wpgus	12	4
P1_udx_wpggg	50	2
P1_uux_wpgdux	24	2
P1_dg_wpddux	24	2
P1_dxcx_wpguxcx	12	4
P1_dxdx_wpguxdx	24	2
P1_uu_wpgud	24	2
P1_gdx_wpduxdx	24	2
P1_dxg_wpduxdx	24	2
P1_gdx_wpuuxux	24	2
P1_dxg_wpuuxux	24	2
P1_gu_wpuscx	12	4
P1_ucx_wpgdcx	12	4

MG5 Grouping

5 directories

30 matrix-elements

Directory	# Diagrams	# Subprocesses
P1_qq_wpggg	50	4
P1_gg_wpgqq	50	2
P1_gq_wpggq	50	4
	50	4
P1_qq_wpgqq	24	2
	24	4
	24	4
	24	4
	24	4
	24	4
	24	4
	24	2
	12	2
	12	6
	12	8
	12	8
	12	8
	12	8
	12	6
	12	2
P1_gq_wpqqq	24	4
	24	4
	24	4
	24	4
	24	4
	24	4
	12	8
	12	8
	12	8
	12	8

GPU grouping

30 directories

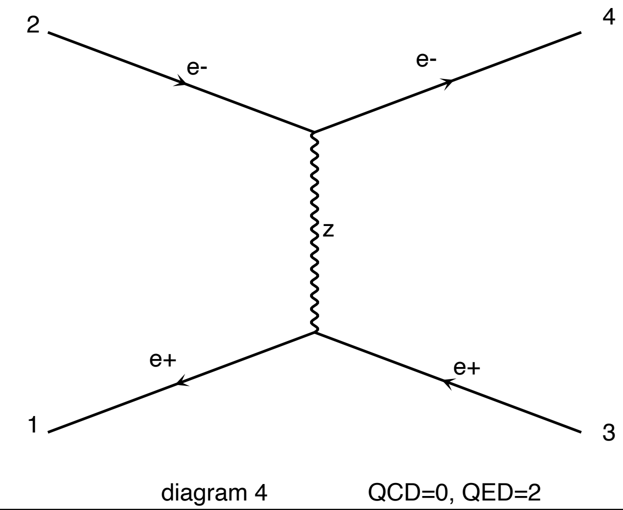
Directory	# Diagrams	# Subprocesses
P1_udx_wpgddx	24	4
P1_uc_wpgcd	12	6
P1_gd_wpddux	24	4
P1_ud_wpgdd	24	4
P1_gux_wpduxux	24	4
P1_gdx_wpggux	50	4
P1_udx_wpgccx	12	8
P1_uxsx_wpguxcx	12	6
P1_gu_wpudux	24	4
P1_udx_wpguux	24	4
P1_gu_wpcdcx	12	8
P1_uux_wpgscx	12	8
P1_gg_wpgdux	50	2
P1_usx_wpgucx	12	8
P1_gux_wpsuxcx	12	8
P1_gu_wpggd	50	4
P1_uxdx_wpguxux	24	4
P1_gdx_wpcuxcx	12	8
P1_gu_wpdddx	24	4
P1_dxsx_wpguxsx	12	2
P1_ddx_wpgdux	24	4
P1_uc_wpgus	12	2
P1_udx_wpggg	50	4
P1_uux_wpgdux	24	4
P1_dxdx_wpguxdx	24	2
P1_uu_wpgud	24	2
P1_gdx_wpduxdx	24	4
P1_gdx_wpuuxux	24	4
P1_gu_wpuscx	12	8
P1_ucx_wpgdcx	12	8

Why so many?

Identical particle

e+ e- > e+ e- : 4 diagrams

e+ e- > mu+ mu- : 2 diagrams

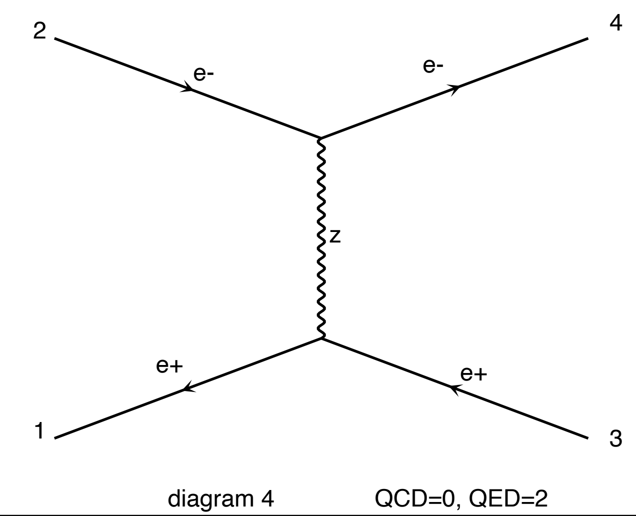


Why so many?

Identical particle

e+ e- > e+ e- : 4 diagrams

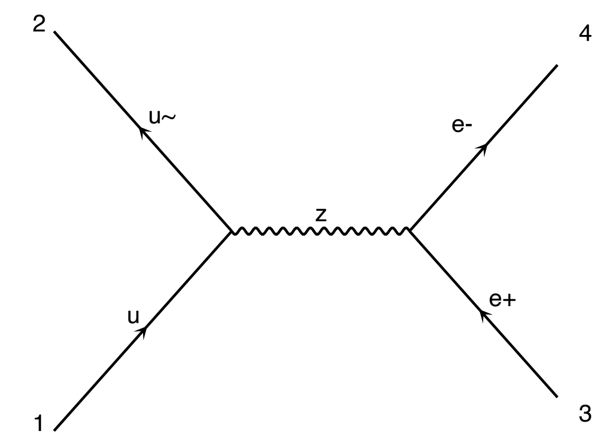
e+ e- > mu+ mu- : 2 diagrams



Different Coupling

u u~ > e+ e-

d d~ > e+ e-

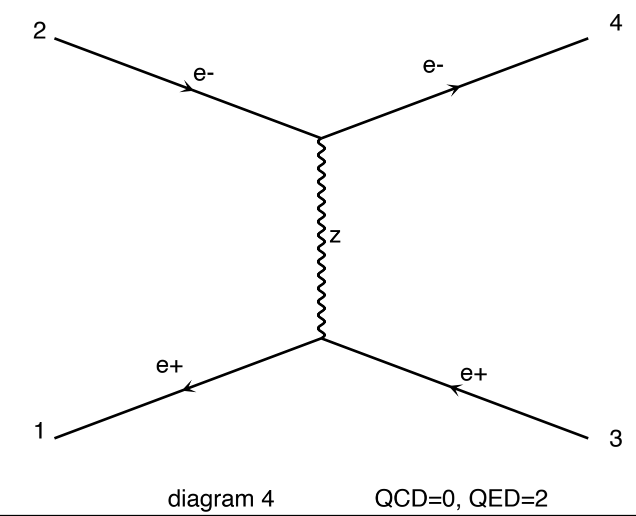


Why so many?

Identical particle

e+ e- > e+ e- : 4 diagrams

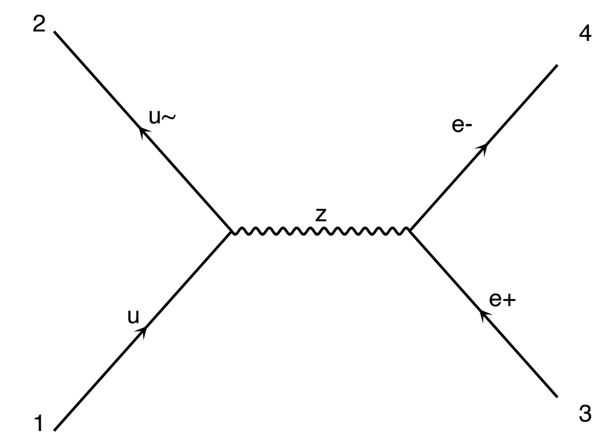
e+ e- > mu+ mu- : 2 diagrams



Different Coupling

u u~ > e+ e-

d d~ > e+ e-



No use of C-parity

g u > g u

g u~ > g u~

No initial/final state flipping

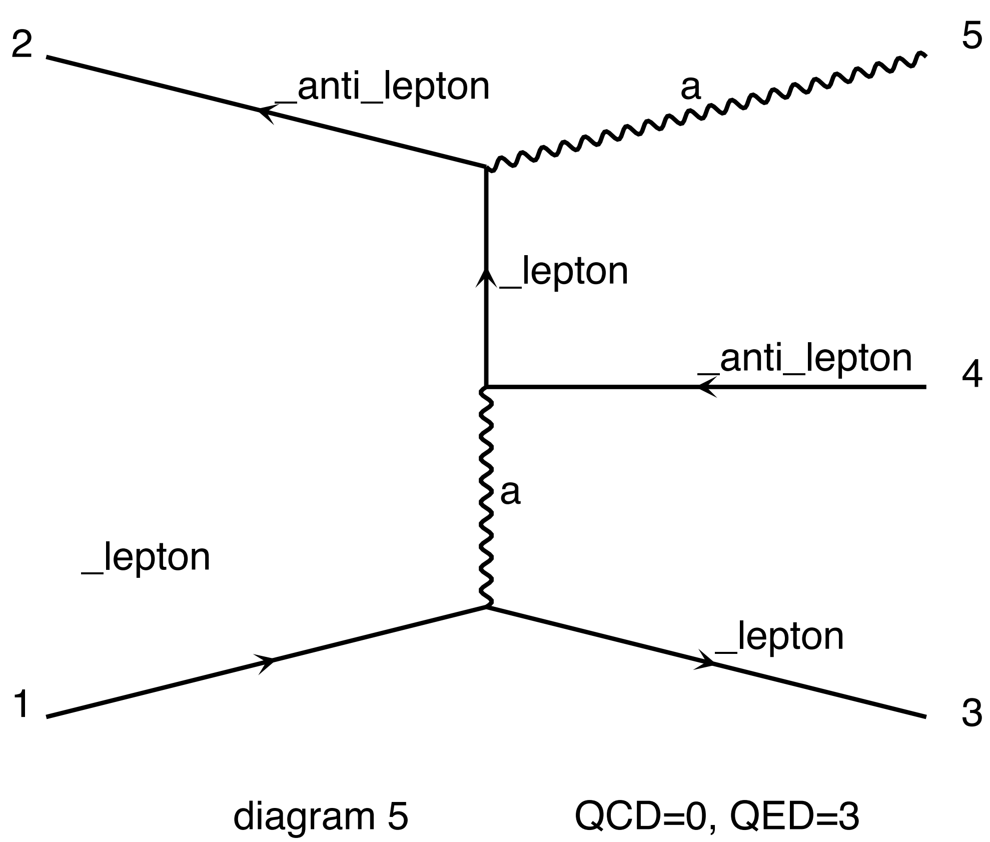
g g > u u~

u u~ > g g

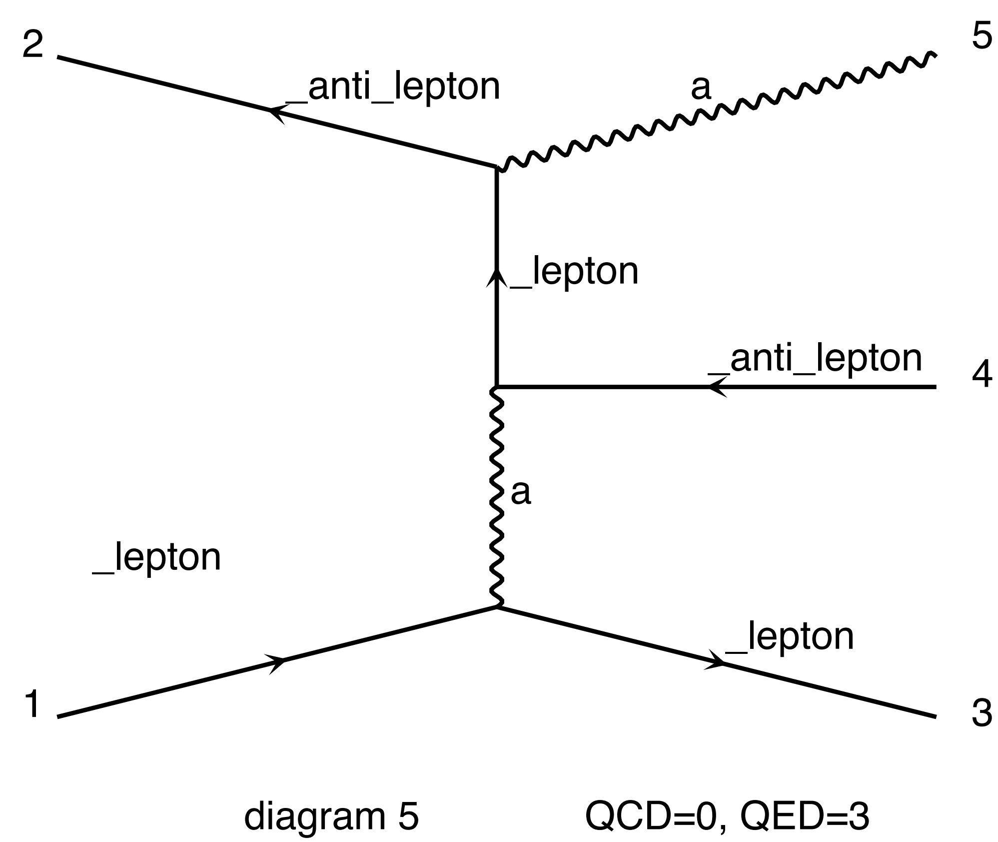
Example l+ l- > l+l- a

Flavor is propagated trough the diagram from final state:

e+ e- > e+ e- a



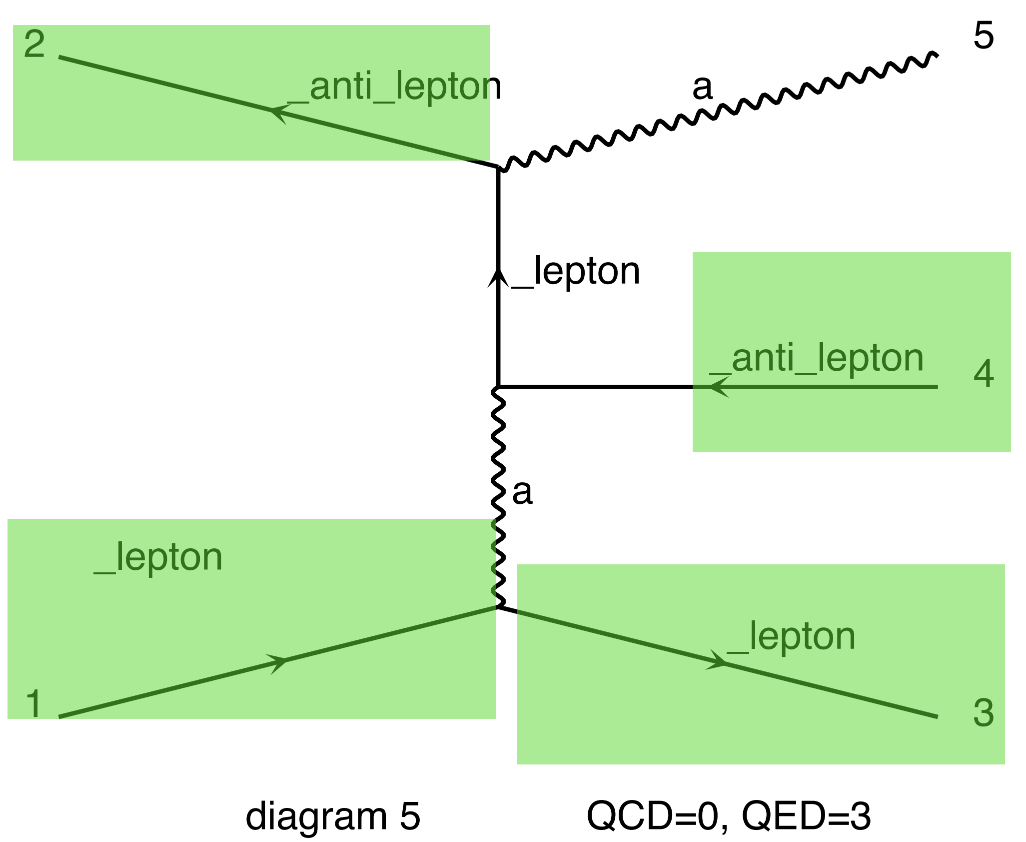
e+ e- > mu+ mu- a



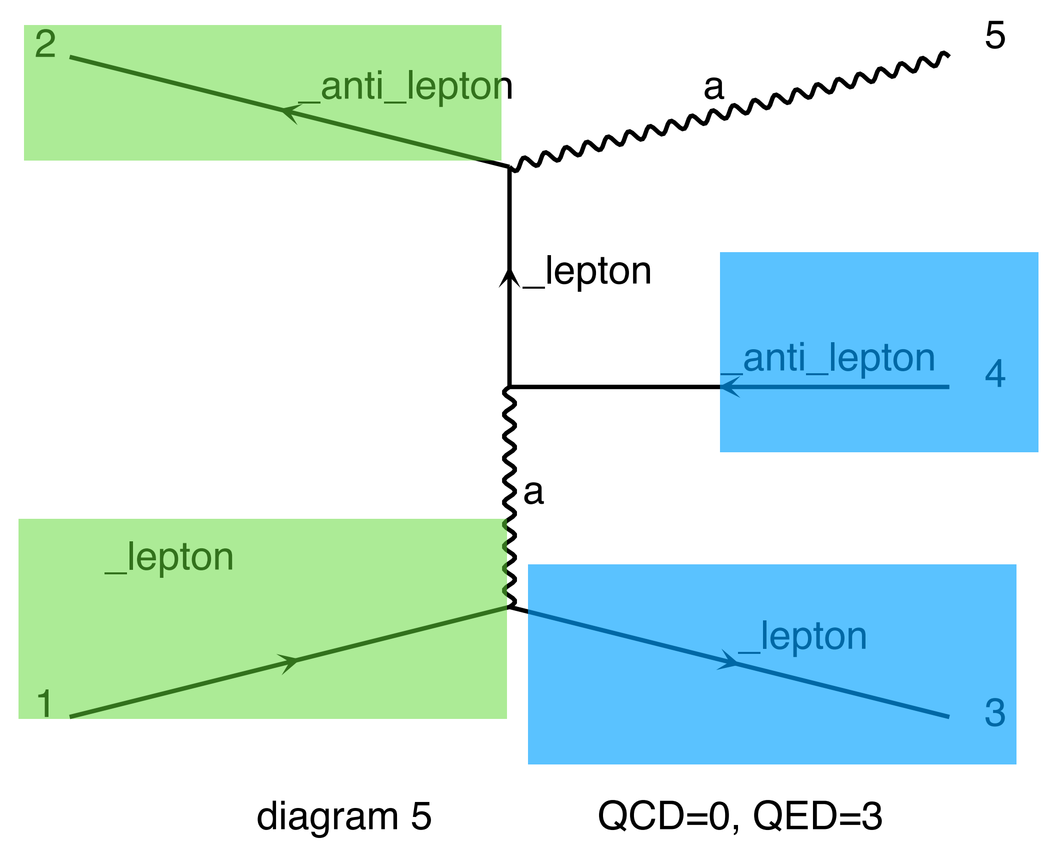
Example l+ l- > l+l- a

Flavor is propagated trough the diagram from final state:

e+ e- > e+ e- a



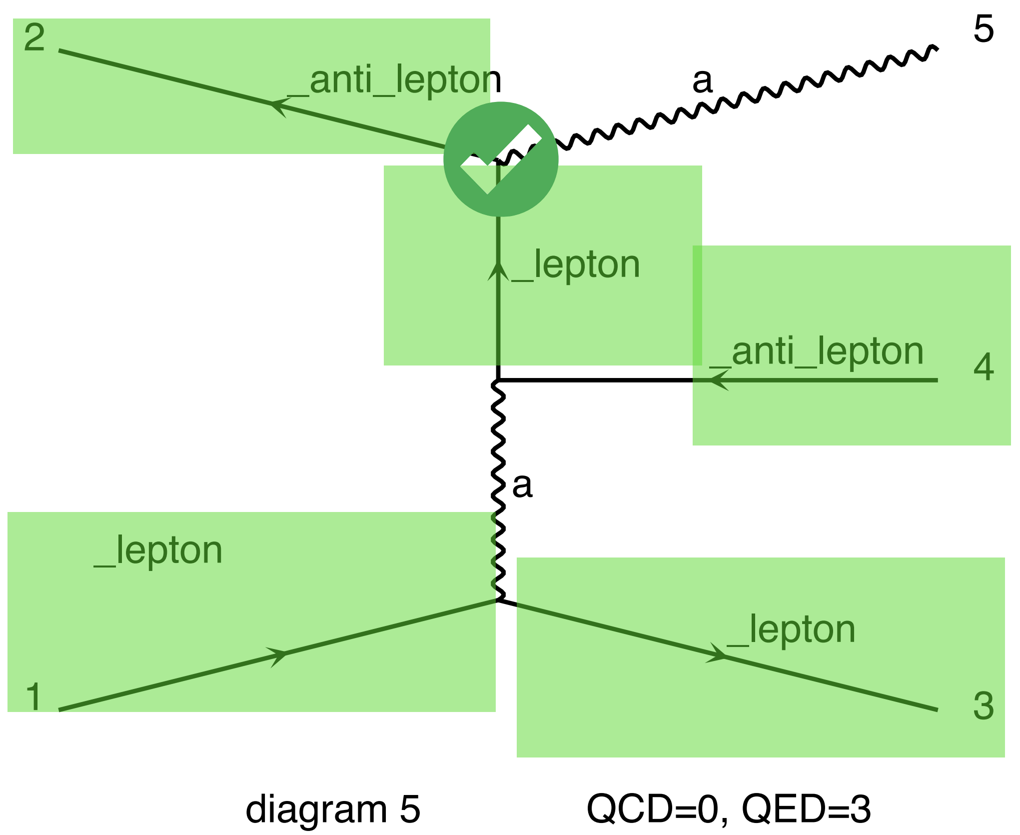
e+ e- > mu+ mu- a



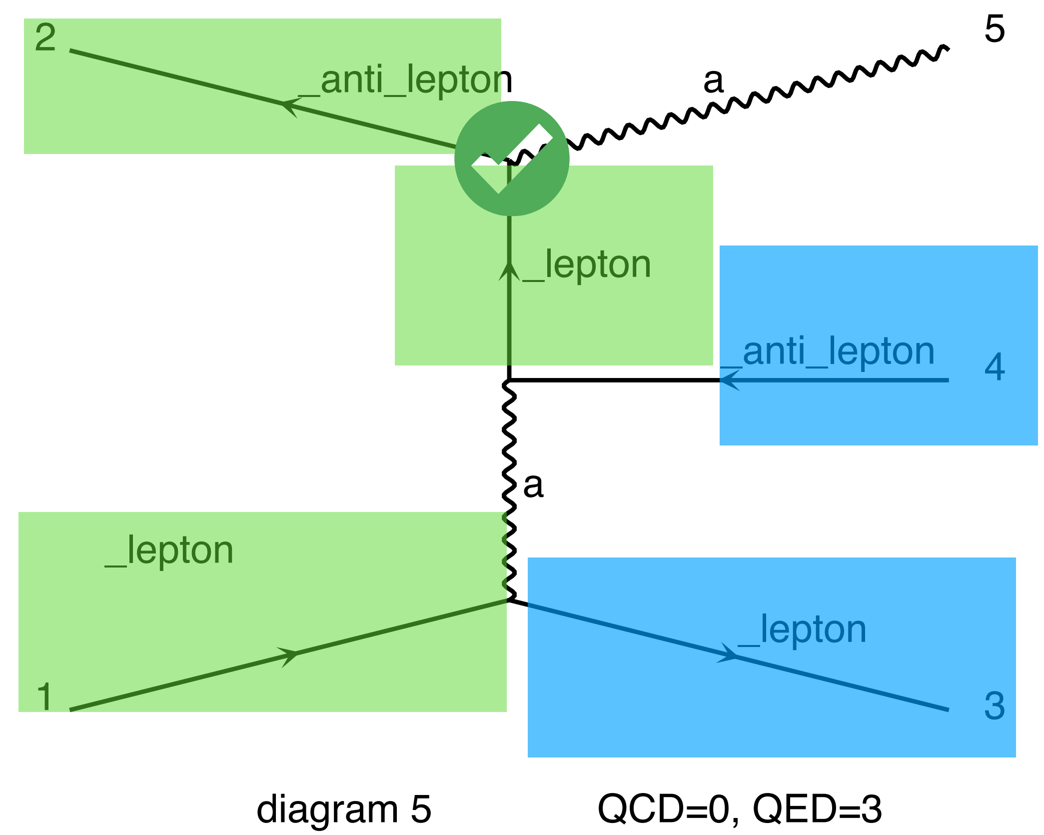
Example l+ l- > l+l- a

Flavor is propagated trough the diagram from final state:

e+ e- > e+ e- a

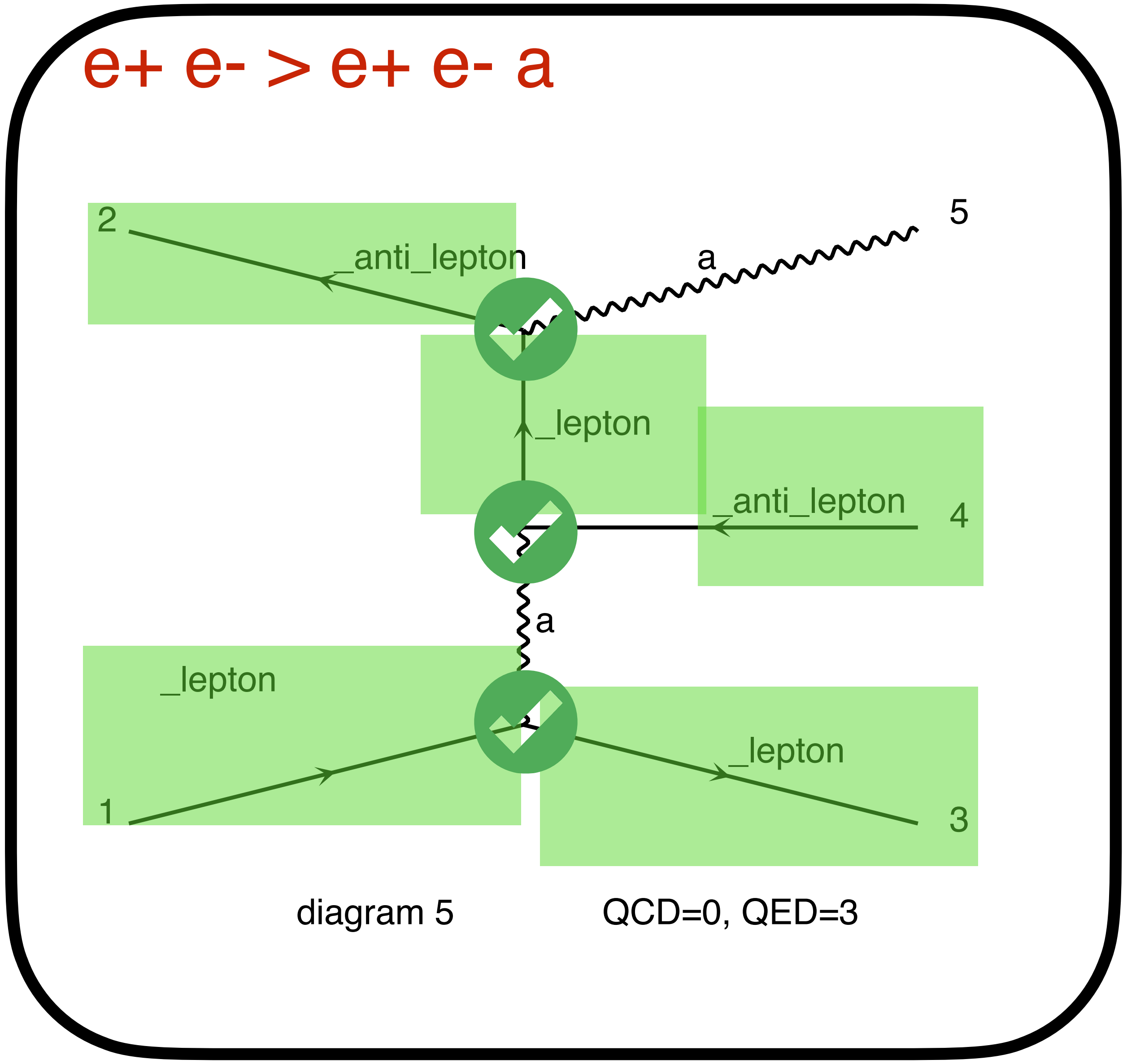


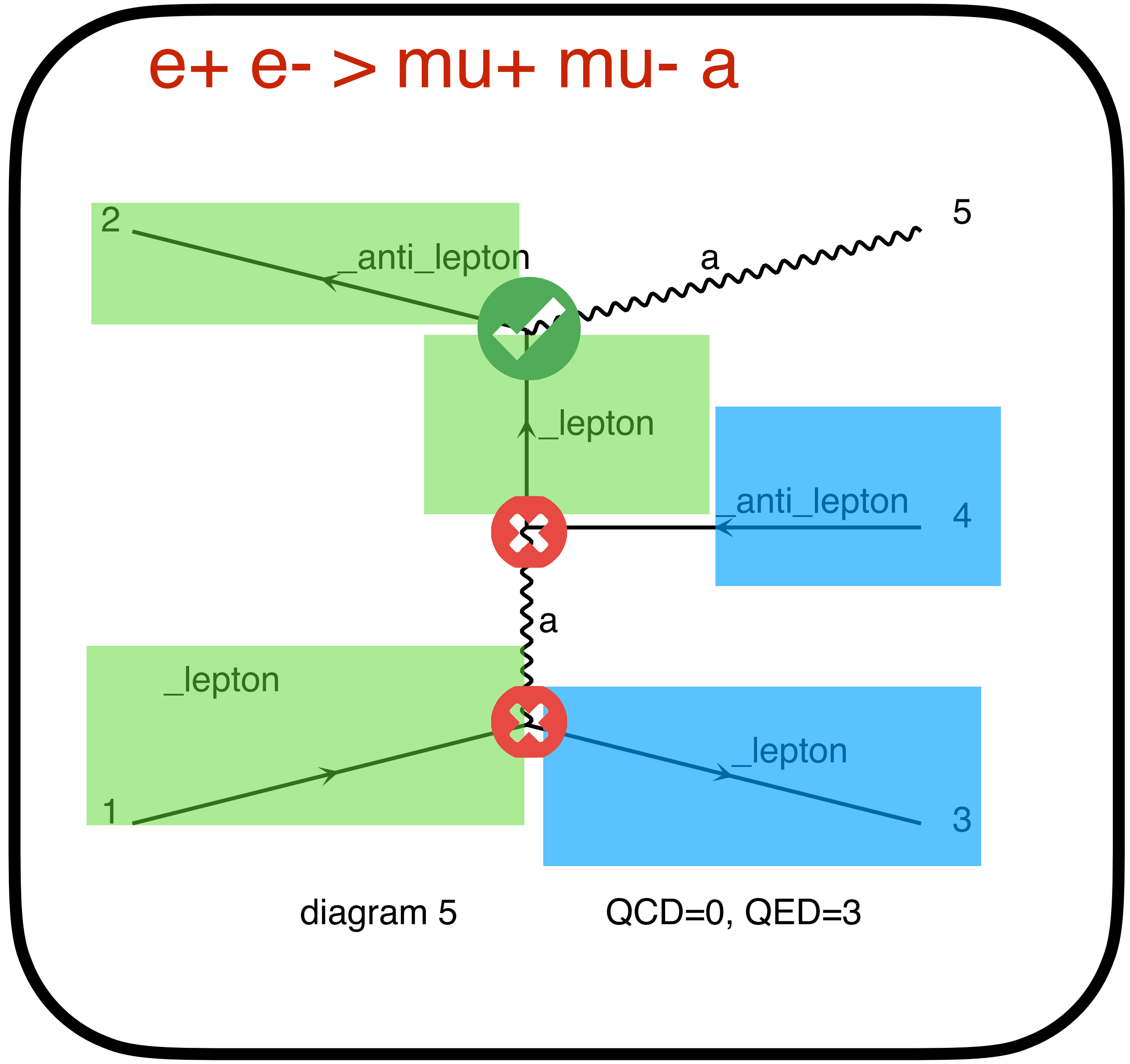
e+ e- > mu+ mu- a



Example l+ l- > l+l- a

Flavor is propagated trough the diagram from final state:

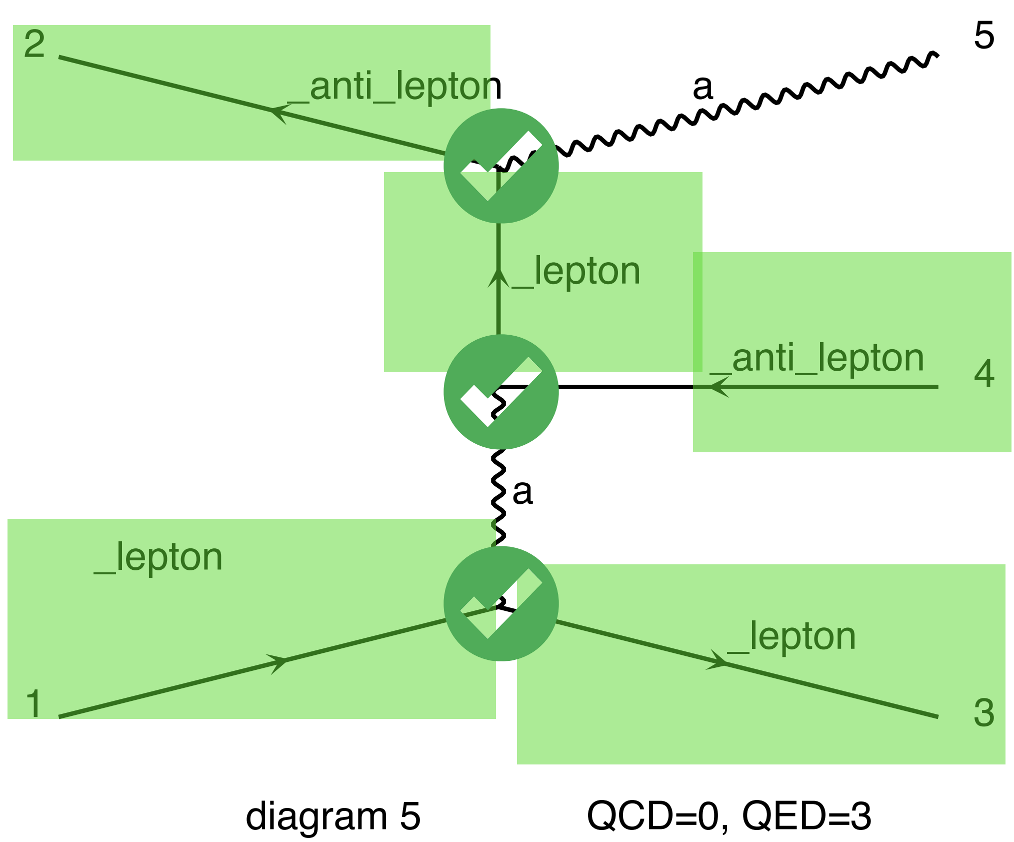




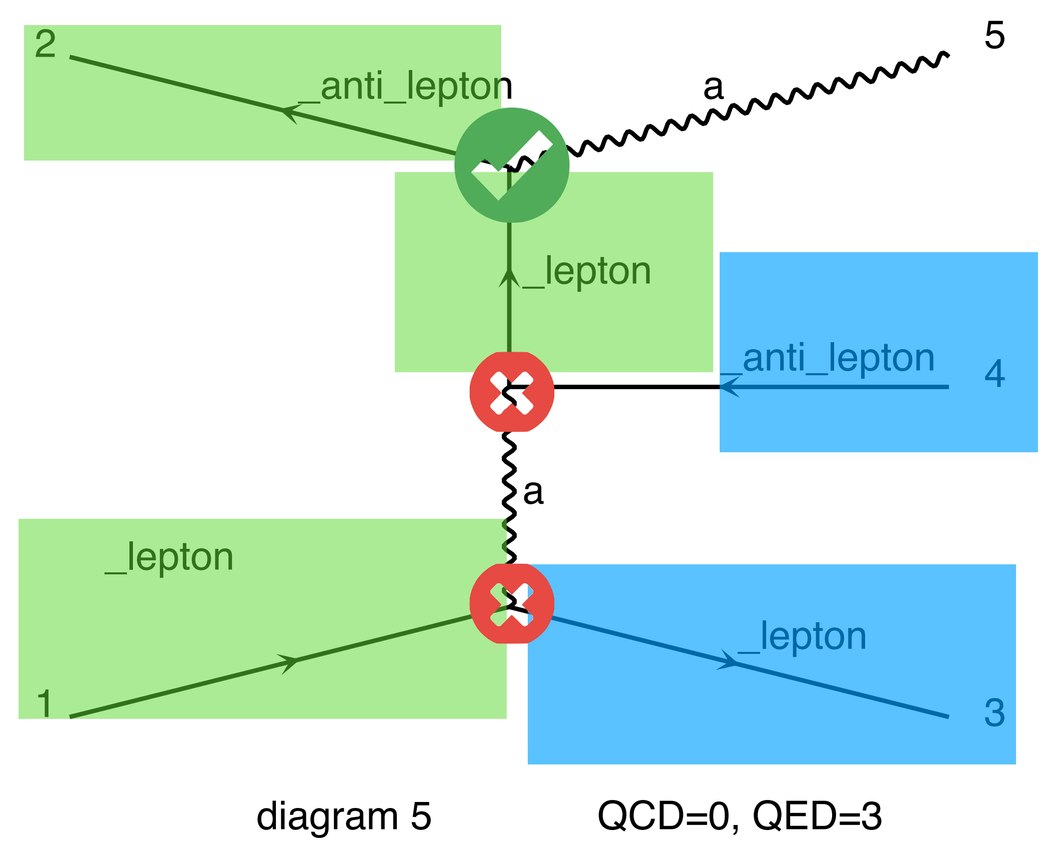
Example l+ l- > l+l- a

Flavor is propagated trough the diagram from final state:

e+ e- > e+ e- a



e+ e- > mu+ mu- a



Easy to support different coupling depending on the flavor in such framework.

Example W+ 3j

No grouping

53 directories

Directory	# Diagrams	# Subprocesses
P1_udx_wpgddx	24	2
P1_uc_wpgcd	12	4
P1_ug_wpdddx	24	2
P1_gd_wpddux	24	2
P1_uxu_wpgscx	12	4
P1_ud_wpgdd	24	2
P1_gux_wpduxux	24	2
P1_gdx_wpggux	50	2
P1_ug_wpuscx	12	4
P1_dxc_wpgcux	12	4
P1_udx_wpgccx	12	4
P1_dxux_wpguxux	24	2
P1_du_wpgdd	24	2
P1_dxu_wpguux	24	2
P1_uxg_wpsuxcx	12	4
P1_dxg_wpggux	50	2
P1_dxu_wpgccx	12	4
P1_uxsx_wpguxcx	12	4
P1_gu_wpudux	24	2
P1_ug_wpggd	50	2
P1_udx_wpguux	24	2
P1_gu_wpcdcx	12	4
P1_uux_wpgscx	12	4
P1_gg_wpgdux	50	2
P1_usx_wpgucx	12	4
P1_gux_wpsuxcx	12	4
P1_uxc_wpgsux	12	4
P1_uxg_wpduxux	24	2
P1_dxu_wpgddx	24	2
P1_gu_wpggd	50	2
P1_ug_wpudux	24	2
P1_uxdx_wpguxux	24	2
P1_ug_wpcdcx	12	4
P1_dxd_wpgdux	24	2
P1_uxu_wpgdux	24	2
P1_dxg_wpcuxcx	12	4
P1_gdx_wpcuxcx	12	4
P1_gu_wpdddx	24	2
P1_ddx_wpgdux	24	2
P1_dxu_wpggg	50	2
P1_uc_wpgus	12	4
P1_udx_wpggg	50	2
P1_uux_wpgdux	24	2
P1_dg_wpddux	24	2
P1_dxcx_wpguxcx	12	4
P1_dxdx_wpguxdx	24	2
P1_uu_wpgud	24	2
P1_gdx_wpduxdx	24	2
P1_dxg_wpduxdx	24	2
P1_gdx_wpuuxux	24	2
P1_dxg_wpuuxux	24	2
P1_gu_wpuscx	12	4
P1_ucx_wpgdcx	12	4

MG5 Grouping

5 directories

30 matrix-elements

Directory	# Diagrams	# Subprocesses
P1_qq_wpggg	50	4
P1_gg_wpgqq	50	2
P1_gq_wpggq	50	4
	50	4
P1_qq_wpgqq	24	2
	24	4
	24	4
	24	4
	24	4
	24	4
	24	4
	24	2
	12	2
	12	6
	12	8
	12	8
	12	8
	12	8
	12	6
	12	2
P1_gq_wpqqq	24	4
	24	4
	24	4
	24	4
	24	4
	24	4
	12	8
	12	8
	12	8
	12	8

Example W+ 3j

No grouping

53 directories

Directory	# Diagrams	# Subprocesses
P1_udx_wpgddx	24	2
P1_uc_wpgcd	12	4
P1_ug_wpdddx	24	2
P1_gd_wpddux	24	2
P1_uxu_wpgscx	12	4
P1_ud_wpgdd	24	2
P1_gux_wpduxux	24	2
P1_gdx_wpggux	50	2
P1_ug_wpuscx	12	4
P1_dxc_wpgcux	12	4
P1_udx_wpgccx	12	4
P1_dxux_wpguxux	24	2
P1_du_wpgdd	24	2
P1_dxu_wpguux	24	2
P1_uxg_wpsuxcx	12	4
P1_dxg_wpggux	50	2
P1_dxu_wpgccx	12	4
P1_uxsx_wpguxcx	12	4
P1_gu_wpudux	24	2
P1_ug_wpggd	50	2
P1_udx_wpguux	24	2
P1_gu_wpcdcx	12	4
P1_uux_wpgscx	12	4
P1_gg_wpgdux	50	2
P1_usx_wpgucx	12	4
P1_gux_wpsuxcx	12	4
P1_uxc_wpgsux	12	4
P1_uxg_wpduxux	24	2
P1_dxu_wpgddx	24	2
P1_gu_wpggd	50	2
P1_ug_wpudux	24	2
P1_uxdx_wpguxux	24	2
P1_ug_wpcdcx	12	4
P1_dxd_wpgdux	24	2
P1_uxu_wpgdux	24	2
P1_dxg_wpcuxcx	12	4
P1_gdx_wpcuxcx	12	4
P1_gu_wpdddx	24	2
P1_ddx_wpgdux	24	2
P1_dxu_wpggg	50	2
P1_uc_wpgus	12	4
P1_udx_wpggg	50	2
P1_uux_wpgdux	24	2
P1_dg_wpddux	24	2
P1_dxcx_wpguxcx	12	4
P1_dxdx_wpguxdx	24	2
P1_uu_wpgud	24	2
P1_gdx_wpduxdx	24	2
P1_dxg_wpduxdx	24	2
P1_gdx_wpuuxux	24	2
P1_dxg_wpuuxux	24	2
P1_gu_wpuscx	12	4
P1_ucx_wpgdcx	12	4

MG5 Grouping

5 directories

30 matrix-elements

Directory	# Diagrams	# Subprocesses
P1_qq_wpggg	50	4
P1_gg_wpgqq	50	2
P1_gq_wpggq	50	4
	50	4
P1_qq_wpgqq	24	2
	24	4
	24	4
	24	4
	24	4
	24	4
	24	4
	24	2
	12	2
	12	6
	12	8
	12	8
	12	8
	12	8
	12	6
	12	2
P1_gq_wpqqq	24	4
	24	4
	24	4
	24	4
	24	4
	24	4
	12	8
	12	8
	12	8
	12	8

Flavor grouping

5 directories

9 matrix-elements

Directory	# Diagrams	# Subprocesses
P1_qq_wpggg	50	2
P1_gg_wpgqq	50	1
P1_gq_wpggq	50	2
	50	2
P1_qq_wpgqq	48	1
	48	2
	48	1
P1_gq_wpqqq	48	2
	48	2

Number of matrix-element

	# matrix (LTS)	# matrix (Flavor)
pp>jj QED=0	12	8
pp> jj QCD=0	31	3
DY3j	30	9
Tt~3j	16	10
W+w-jj QCD=0	32	3

Number of matrix-element

	# matrix (LTS)	# matrix (Flavor)	# matrix C inspired	# matrix Crossing
pp>jj QED=0	12	8	5	3
pp> jj QCD=0	31	3	2	1
DY3j	30	9	5	2
Tt~3j	16	10	6	3
W+w-jj QCD=0	32	3	2	1

Conclusion

- We provide Matrix-Element
  - Tree, loop, NLO subtraction term,...
- We have use those ourselves
  - LO / NLO event generation
  - Post-processing tools (MadSpin/...)
- We help external tools (MadDM, MadDump)
- Currently focus on LO speed-up:
  - ➡ Better software (ML, multiplicity,color)
  - ➡ Better use of hardware (SIMD/GPU)