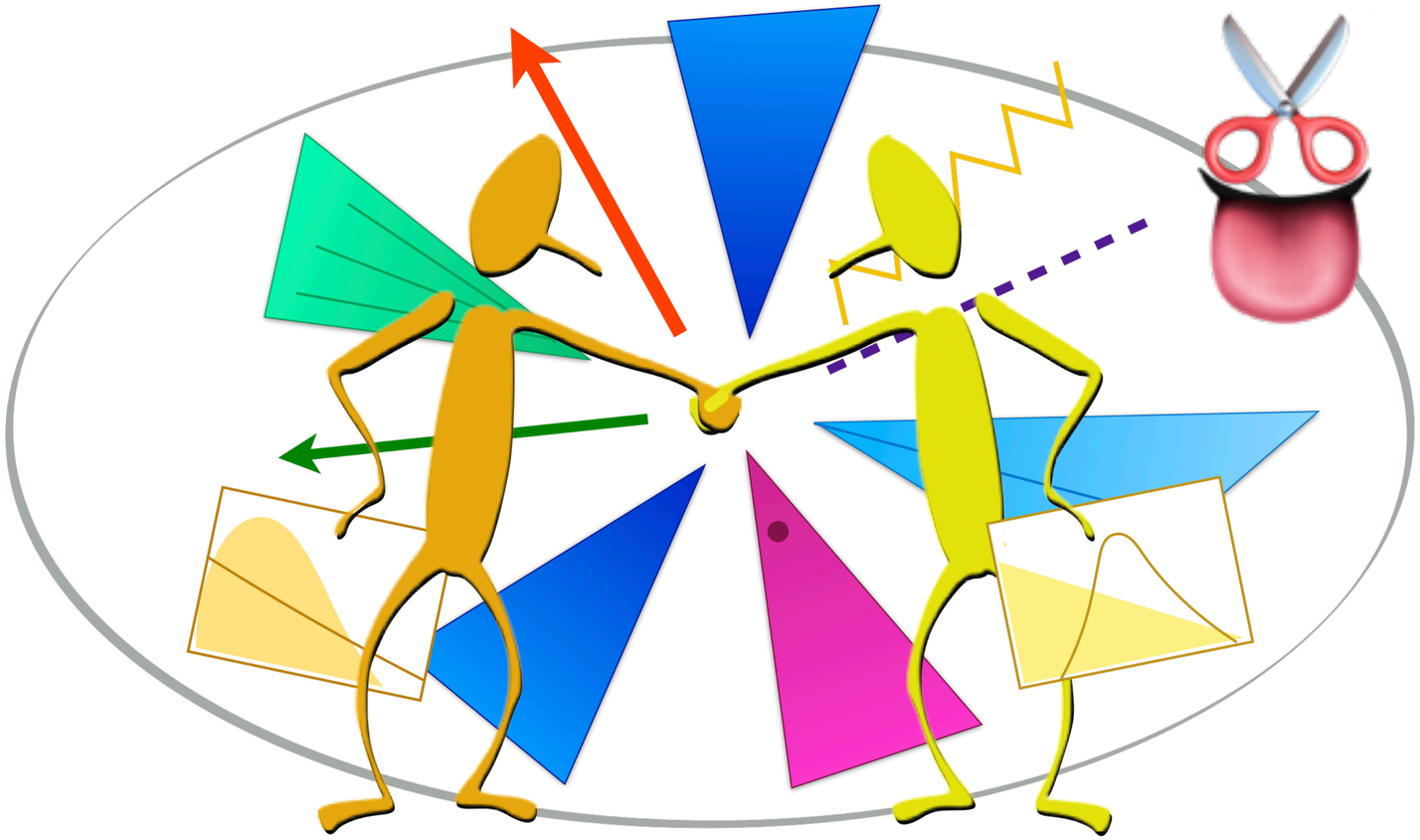

Effective collider data analysis with Analysis Description Language and CutLang

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Welcome to the LHC physics analysis jungle

Inclusive analyses with hundreds of selection regions

Overlaps between different analyses?

Is my control region your signal region???

Multiple analyses exploring similar final states

Many alternative definitions for analysis objects

Many variables, ambiguous definitions

…time to get better organized to work more efficiently!

The “traditional” and the “alternative”

We perform collider analyses for experimental or phenomenological studies.

Analyses are traditionally performed using analysis software frameworks:

- Frameworks based on general purpose languages like C++ / Python.
- Physics content and technical operations are intertwined and handled together.
- Hard to read, maintain and communicate.

Could there be an alternative way?

- Allow more direct interaction with data and
- Decouple the physics information from purely technical tasks?

Analysis description language for collider physics

Analysis Description Language (ADL) is a domain specific and declarative language that describes the physics content of a collider analysis in a standard and unambiguous way.

- Domain specific: Customized to express analysis-specific concepts. Reflects conceptual reasoning of particle physicists.
- Declarative: Tells what to do but not how to do it.
- Designed for everyone: experimentalists, phenomenologists, other enthusiasts…

ADL is a language, independent of software frameworks:

—> Any framework recognizing ADL can run the analysis.

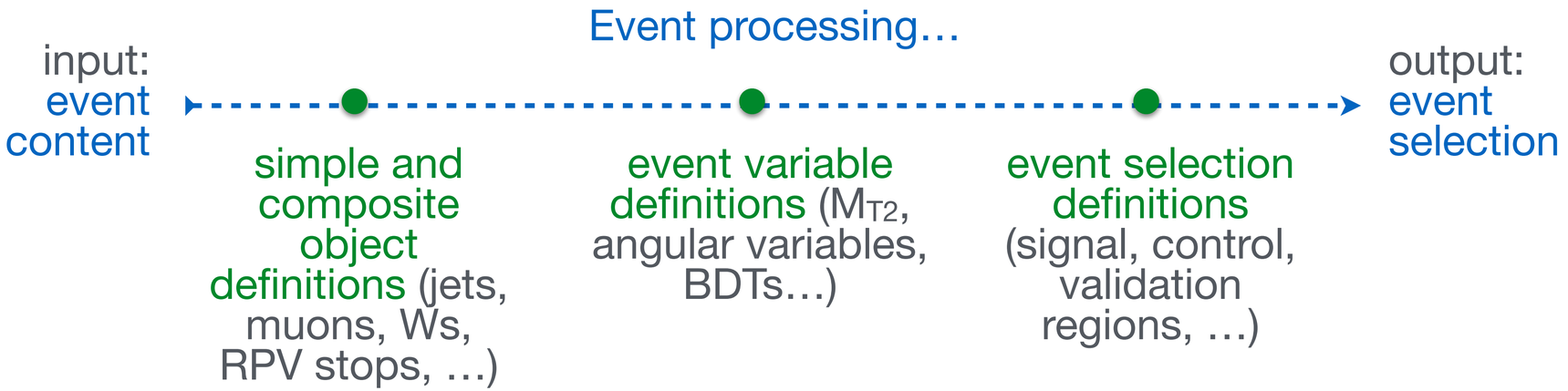
- Focus directly on physics, not on programming.
- Communicate analyses easily between groups, exp & pheno, etc.
- Adapt analyses easily between exp & pheno.

Earlier HEP physics formats/languages have been very useful:

- SUSY Les Houches Accord and Les Houches Event Accord

ADL scope

- Event processing: Priority focus.



- Analysis results, i.e. counts and uncertainties: Available
- Histogramming: Partially available.
- Systematic uncertainties: To be within the scope. Work in progress.
- Operations with selected events, e.g. background estimation, scale factor derivation: Very versatile. Not within the scope yet.

The ADL construct

cern.ch/adl

ADL consists of

- a plain text ADL file describing the analysis algorithm using an easy-to-read DSL with clear syntax rules.
- a library of self-contained functions encapsulating variables that are non-trivial to express with the ADL syntax (e.g. MT2, ML algorithms). Internal or external (user) functions.

- ADL file consists of blocks separating object, variable and event selection definitions. Blocks have a keyword-expression structure.
  - keywords specify analysis concepts and operations.

```
blocktype blockname
  keyword1 value1
  keyword1 value2
  keyword3 value3 # comment
```

- Syntax includes mathematical and logical operations, comparison and optimization operators, reducers, 4-vector algebra and HEP-specific functions (dϕ, dR, …). See backup.

LHADA (Les Houches Analysis Description Accord): Les Houches 2015 new physics WG report (arXiv:1605.02684, sec 17)

CutLang: Comput.Phys.Commun. 233 (2018) 215-236 (arXiv:1801.05727), ACAT 2019 proceedings (arXiv:1909.10621) arXiv:2101.09031

ADL syntax: example

Color legend:

new object,
variable, region
existing object
object attribute
existing variable
existing region
internal function
external function

Objects

```
# AK8 jets
object AK8jets
  take FatJet
  select pt > 200
  select abs(eta) < 2.4

# mass-tagged jets
object WjetsMassTag
  take AK8jets
  select msoftdrop [] 65 105

# W-tagged jets
object Wjets
  take WjetsMassTag
  select tau2 / tau1 <= 0.4
```

Variable definitions

```
define MR = fMR(megajets)
define Rsq = sqrt(fMTR(megajets, met) / MR)
define METl = MET + leptonsVeto[0]
define Rsql = sqrt(fMTR(megajets, METl) / MR)
define MT = fMT(leptonsVeto[0], MET)
define Mll = fMll(leptonsTight[0], leptonsTight[1])
define dphimegajets = dPhi(megajets[0], megajets[1])
```

Event selection regions

```
# preselection region
region preselection
  select size(AK4jets) >= 3
  select size(AK8jets) >= 1
  select MR > 800
  select Rsq > 0.08
```

```
# control region for tt+jets
region ttjetsCR
  select preselection
  select size(leptonsVeto) == 0
  select size(Wjets) >= 1
  select dphimegajets < 2.8
  select MT > 100
  select size(bjetsLoose) >= 1
  bin MR [] 800 1000 and Rsq [] 0.08 0.1
  bin MR [] 800 1000 and Rsq [] 0.1 0.2
  bin ...
```

From CMS SUSY razor analysis CMS-SUS-16-017
Phys.Rev.D97(2018) no.1, 012007, arxiv:1710.11188

Full implementation link

Running analyses with ADL

Experimental / phenomenology analysis model with ADLs

- ADL file
- self-contained functions for complex variables
- events with any format

adl2tnm (transpiler) → **generic c++ analysis code**

CutLang (runtime interpreter)

transpiler / interpreter for any exp/pheno analysis framework (earlier prototypes exist for Rivet and Checkmate)

- Cutflows, counts
- Histograms
- Selected events
- Other results

Running analyses with ADL: adl2tnm

H. B. Prosper,
S. Sekmen

- Python transpiler converting ADL to C++ code.
- C++ code executed within the generic ntuple analysis framework TNM (TheNtupleMaker). Only depends on ROOT.
- Can work with any simple ntuple format.
  Automatically incorporates the input event format into the C++ code:

  ADL + input ntuple ➡ adl2tnm.py ➡ C++ analysis code ➡ compile & run

- Assumes that a standard extensible type is available to model all analysis objects. Uses adapters to translate input to standard types.
- Can be used for experimental or phenomenological analyses.
- Currently moving from proof of principle to the use of formal grammar building and parsing.

adl2tnm ref: Les Houches 2017 new physics WG report (arXiv:1803.10379, sec 23)

adl2tnm Github: https://github.com/hbprosper/adl2tnm

Running analyses with ADL: CutLang

G. Unel, B. Örgen, A. Paul, N. Ravel, S. Sekmen, J. Setpal, A. M. Toon, et.al.

CutLang runtime interpreter:

- No compilation. Directly runs the ADL file on events.
- CutLang itself is written in C++, works in any modern Unix environment.
- Based on ROOT classes for Lorentz vector operations and histograms.
- ADL parsing by Lex & Yacc.

CutLang Github: https://github.com/unelg/CutLang

CutLang publications: arXiv:1801.05727, arXiv:1909.10621
arXiv:2101.09031

CutLang framework: interpreter + tools

- Input events via ROOT files.
  - multiple input formats: Delphes, CMS NanoAOD, ATLAS/CMS Open Data, LVL0, FCC. More can be easily added.
  - All event types converted into predefined particle object types. —> can run the same ADL file on different input types.
- Includes many internal functions.
- Output in ROOT files: ADL file, cutflows, bins and histograms for each region in a separate TDirectory.
- Tools available for parallel processing.

Physics with ADL

Designing new analyses:

- Experimental analyses:
  - 2 ATLAS EXO analyses ongoing with CutLang
- Phenomenology studies:
  - E6 isosinglet quarks at HL-LHC & FCC w/ CutLang (Eur Phys J C 81, 214 (2021))
- Analysis of LHC Open Data:
  - Demo at CMS Open Data workshop: link
  - An example analysis implemented: link
- Analysis optimization via differentiable programming (under development).

Using existing analyses:

ADL analysis database with ~15 LHC analyses:
https://github.com/ADL4HEP/ADLLHCanalyses
(more being implemented)

- Reinterpretation studies:
  - Integrating ADL into the SModelS framework
- Analysis queries, comparisons, combinations:
  - Automated tools under development
- Long term analysis preservation

Making this a community effort

- Discussions and work at the Les Houches PhysTeV workshops among phenomenologists and experimentalists (contributions in Les Houches 2015, 2017, 2019 proceedings).
  - Resulted in prototype language LHADA (Les Houches Analysis Description Accord)
- LHADA workshop, Grenoble, 25-26 Feb 2016
- LHADA workshop, CERN, 16-18 Nov 2016 (link)
- Discussions and activities within HSF data analysis WG and IRIS-HEP.
- 1st dedicated Analysis Description Languages for the LHC workshop (with experimentalists, phenomenologists, computing experts), Fermilab LPC, 6-8 May 2019 (link)
- ADL/CutLang used for training for beginner students with no programming experience:
  - 1st Data Analysis School with ADL+CutLang (3-7 Feb 2020), Istanbul (link, proceedings link)
  - 26th Vietnam School of Physics (VSOP) (Dec 2020) (link)

What is next?

ADL is a promising and feasible approach for practical collider analysis for experiment and phenomenology.

ADL, CutLang and adl2tnm are under constant development!

The language

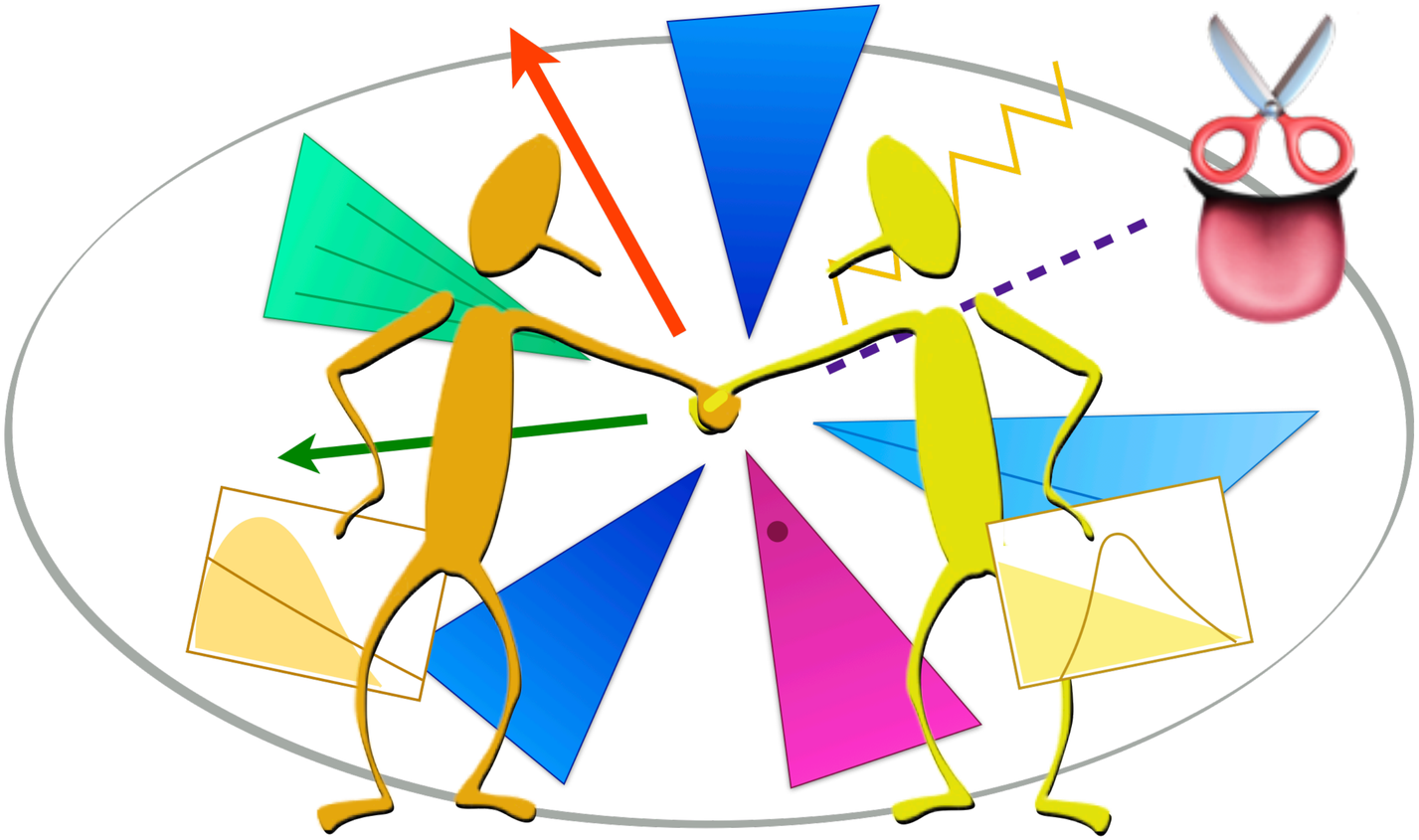
- Develop ADL into a domain-complete language.
- In particular, add sytematic uncertainties.

Tools:

- Unify the transpiler and runtime interpreter through a modern set of tools.
- Further automatize incorporating external functions and new input types.
- Implement static analysis & differentiable programming.

Physics:

- Enlarge the ADL analysis database with new analyses.
- Test ADL & tools in many experimental & pheno studies and get feedback.



Extra slides

ADL core syntax: blocks, keywords, operators

Block purpose	Block keyword
object definition blocks	object
event selection blocks	region
analysis information	info
tables of results, etc.	table

Keyword purpose	Keyword
define variables, constants	define
select object or event	select
reject object or event	reject
define the mother object	take
define histograms	histo
applies object/event weights	weight
bins events in regions	bin

Operation	Operator
Comparison operators	> < => =< == != [] (include)][(exclude)
Mathematical operators	+ - * / ^
Logical operators	and or not
Ternary operator	condition ? truecase : falsecase
Optimization operators	~= (closest to) ~! (furthest from)
Lorentz vector addition	LV1 + LV2 LV1 LV2

ADL syntax rules: https://twiki.cern.ch/twiki/bin/view/LHCPhysics/ADL

ADL core syntax: functions

Standard/internal functions: Sufficiently generic math and HEP operations would be a part of the language and any tool that interprets it.

- Math functions: abs(), sqrt(), sin(), cos(), tan(), log(), …
- Collection reducers: size(), sum(), min(), max(), any(), all(),…
- HEP-specific functions: dR(), dphi(), deta(), m(), ….
- Object and collection handling: sort, comb(), union()…

External/user functions: Variables that cannot be expressed using the available operators or standard functions would be encapsulated in self-contained functions that would be addressed from the ADL file.

- Variables with non-trivial algorithms: M_{T2}, aplanarity, razor variables, …
- Non-analytic variables: Object/trigger efficiencies, variables/efficiencies computed with ML, …

ADL syntax rules: https://twiki.cern.ch/twiki/bin/view/LHCPhysics/ADL