University of Zurich[UZH]

Measurement of the Low Mass Drell-Yan Production Cross-Section with the LHCb Experiment

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University of Zurich

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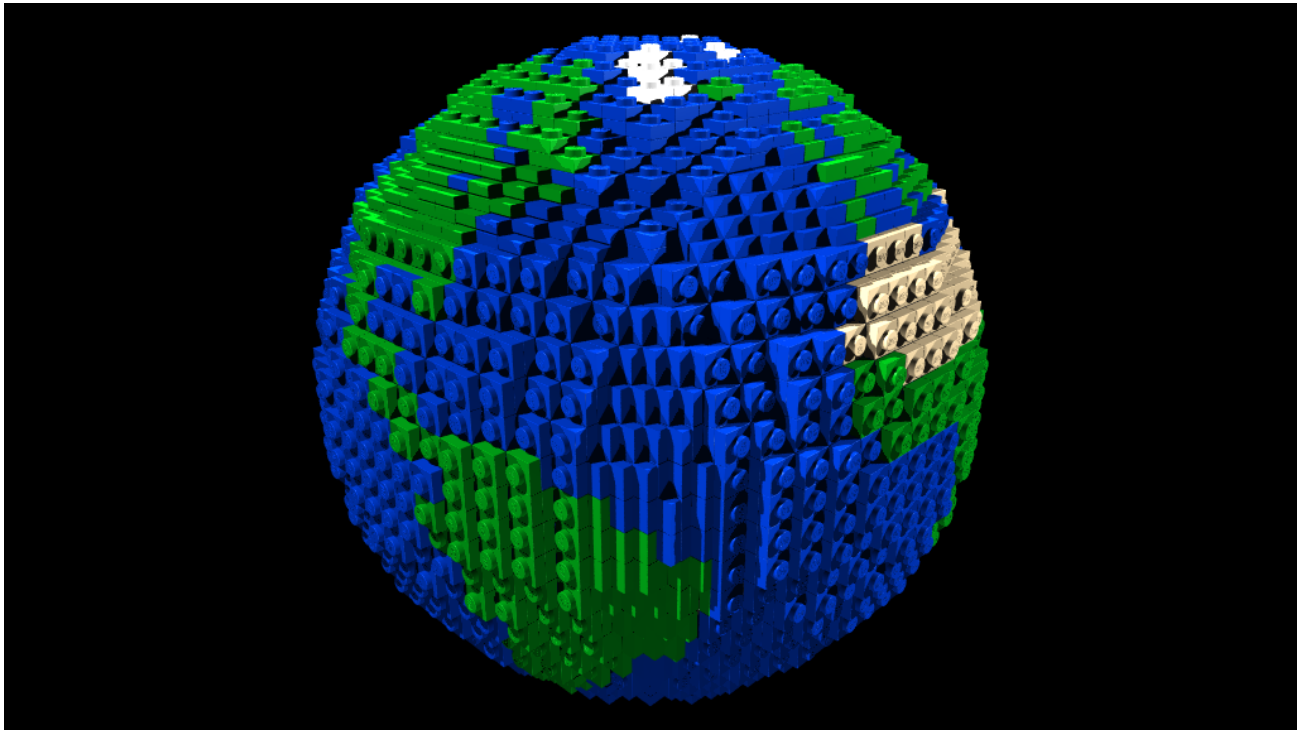
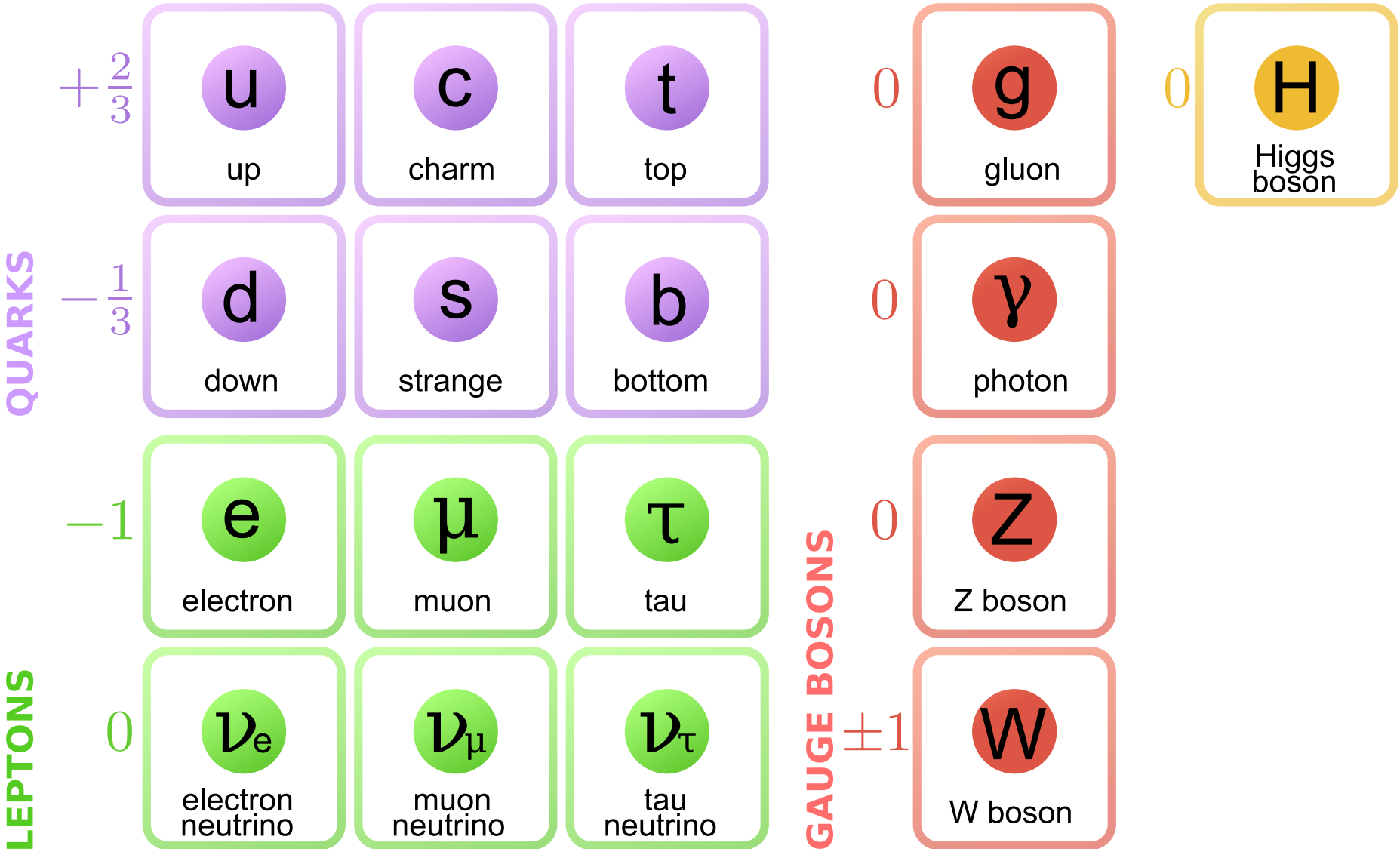
Life, The Universe and Everything



- built with a relatively small set of building blocks and rules.
- particle physics is the study of these blocks and rules.

The Standard Model



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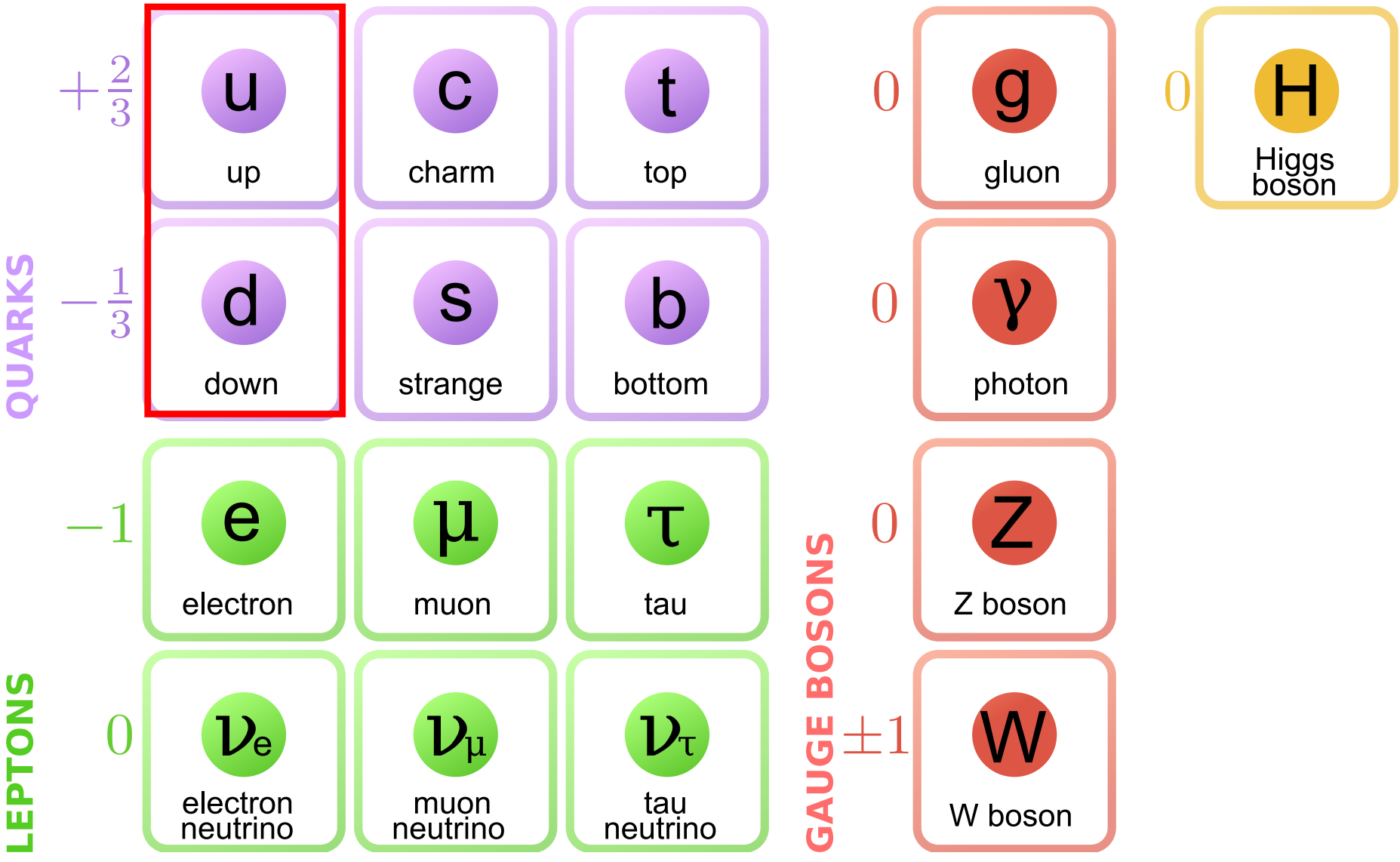


The Standard Model

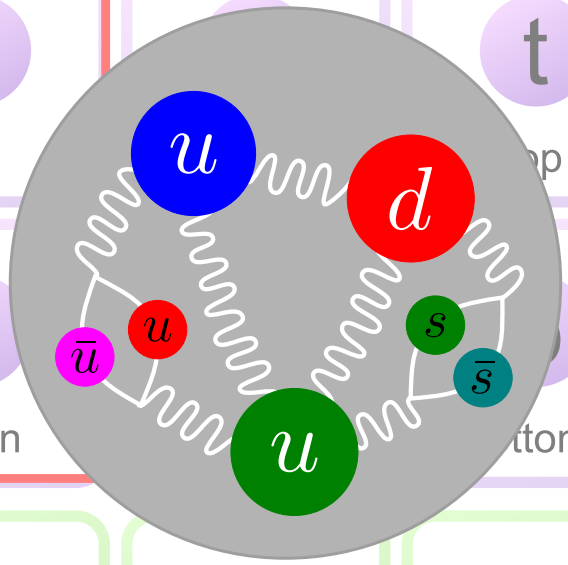
QUARKS

$+\frac{2}{3}$ u up

t top

$-\frac{1}{3}$ d down

b bottom



-1 e electron

μ muon

τ tau

LEPTONS

0 ν_e electron neutrino

ν_μ muon neutrino

ν_τ tau neutrino

GAUGE BOSONS

0 g gluon

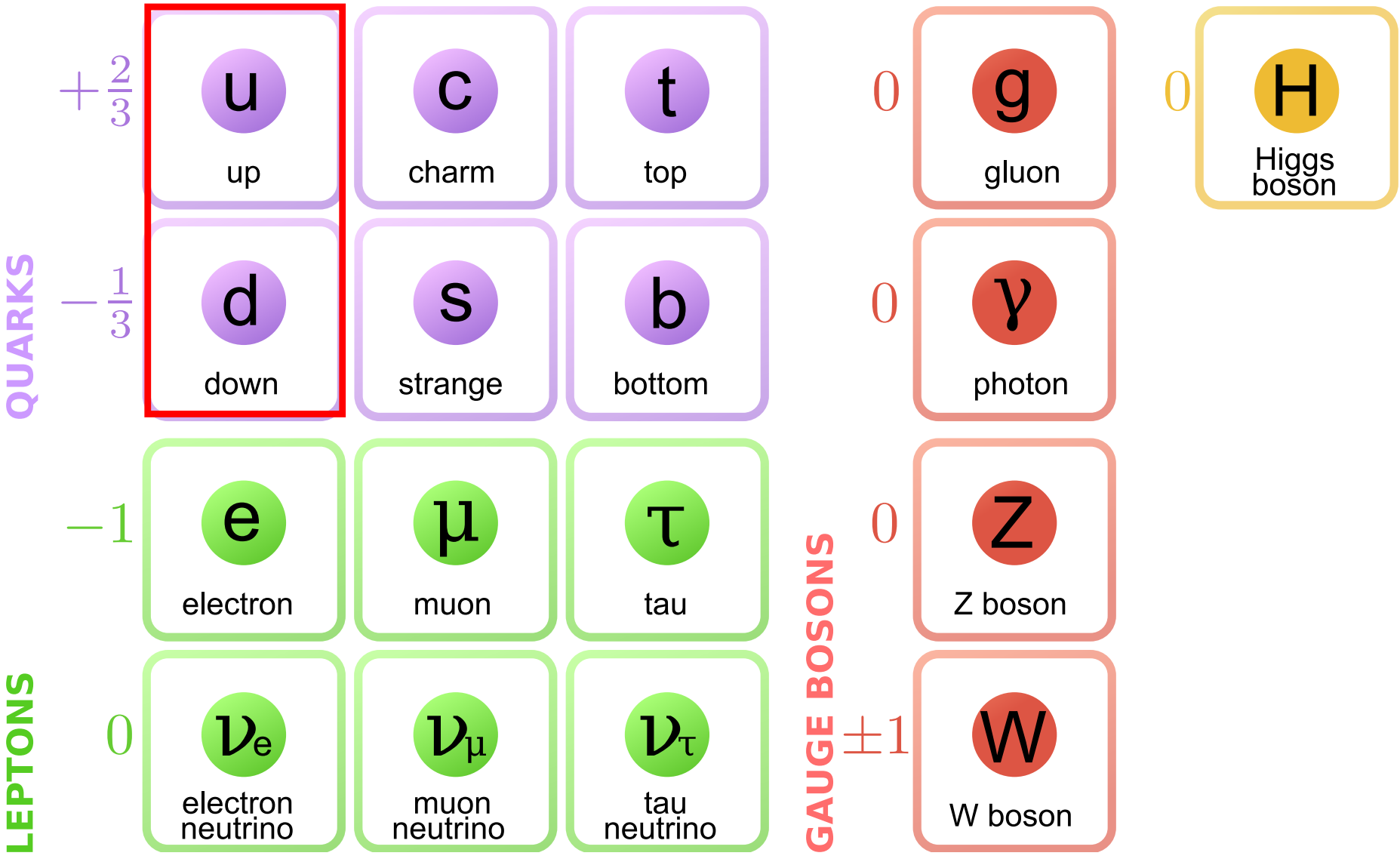
0 H Higgs boson

0 γ photon

0 Z Z boson

± 1 W W boson

The Standard Model



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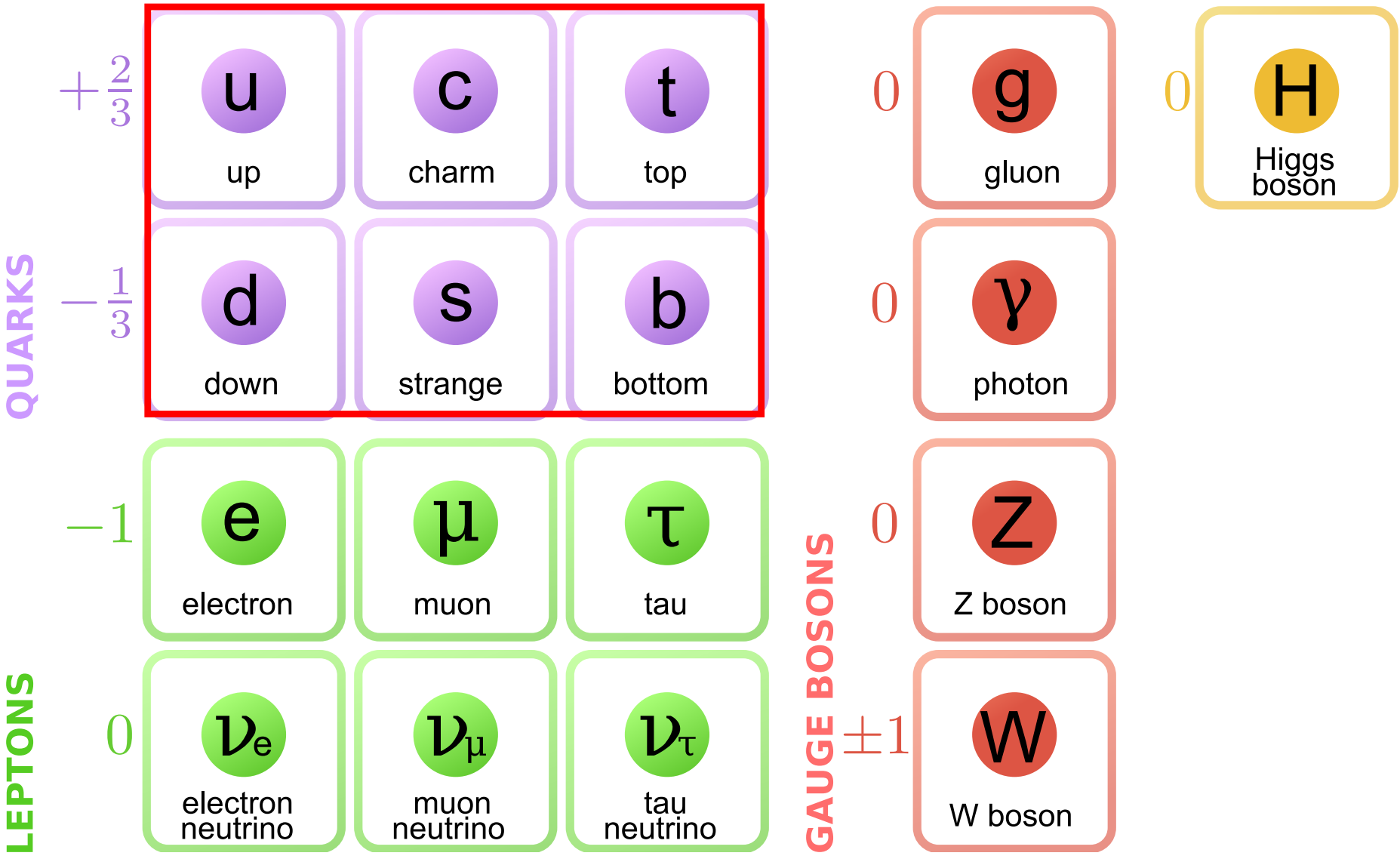

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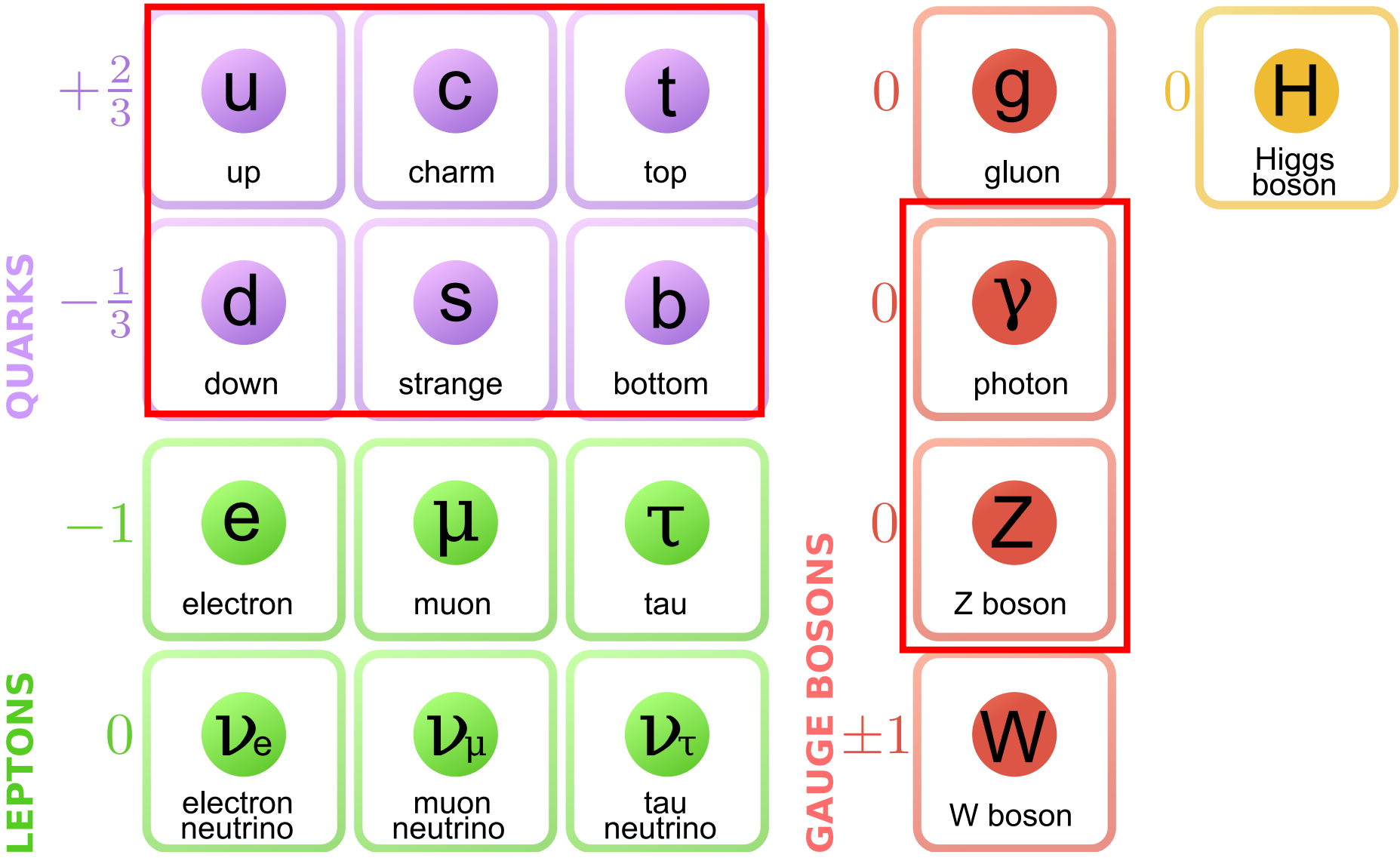

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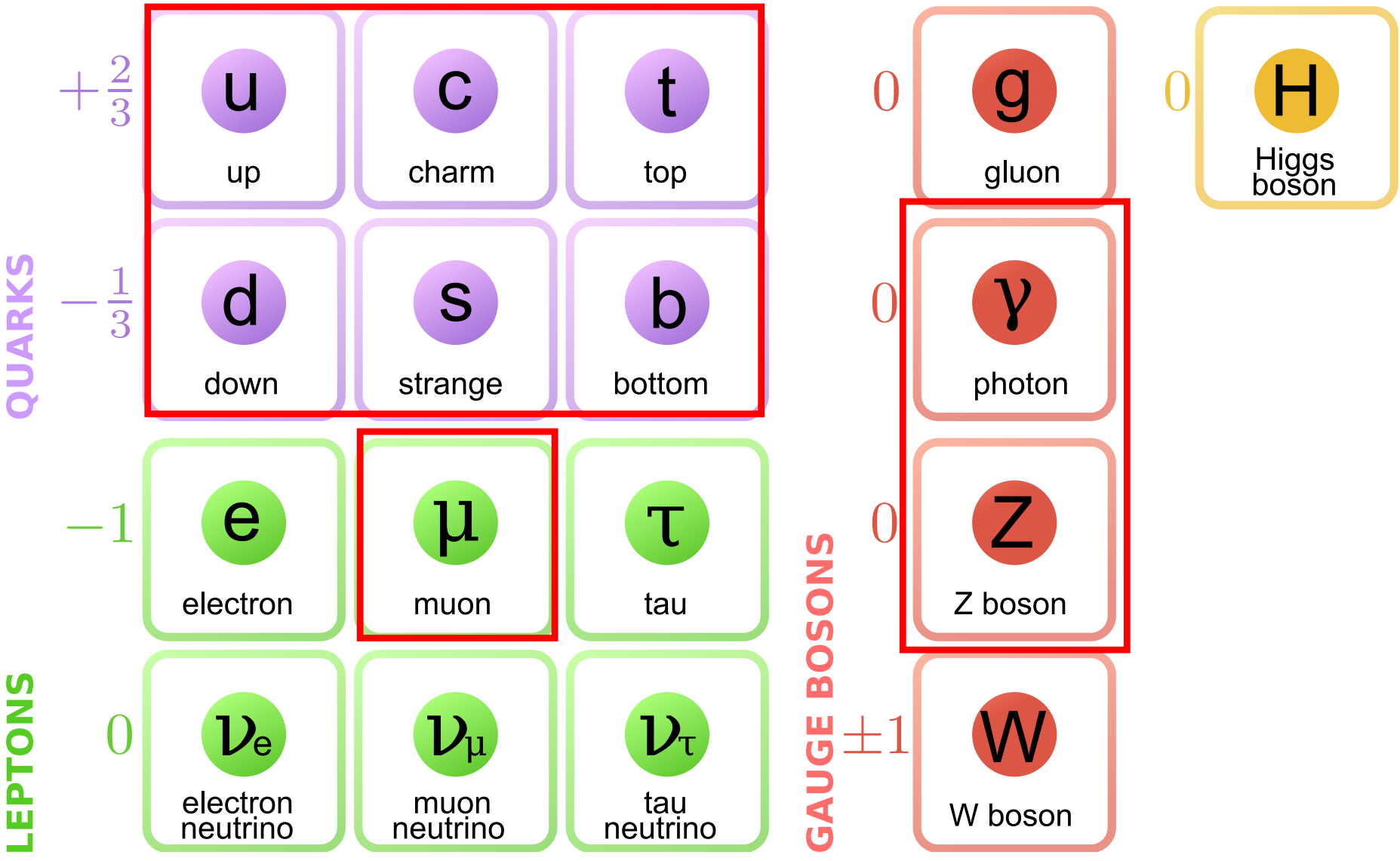
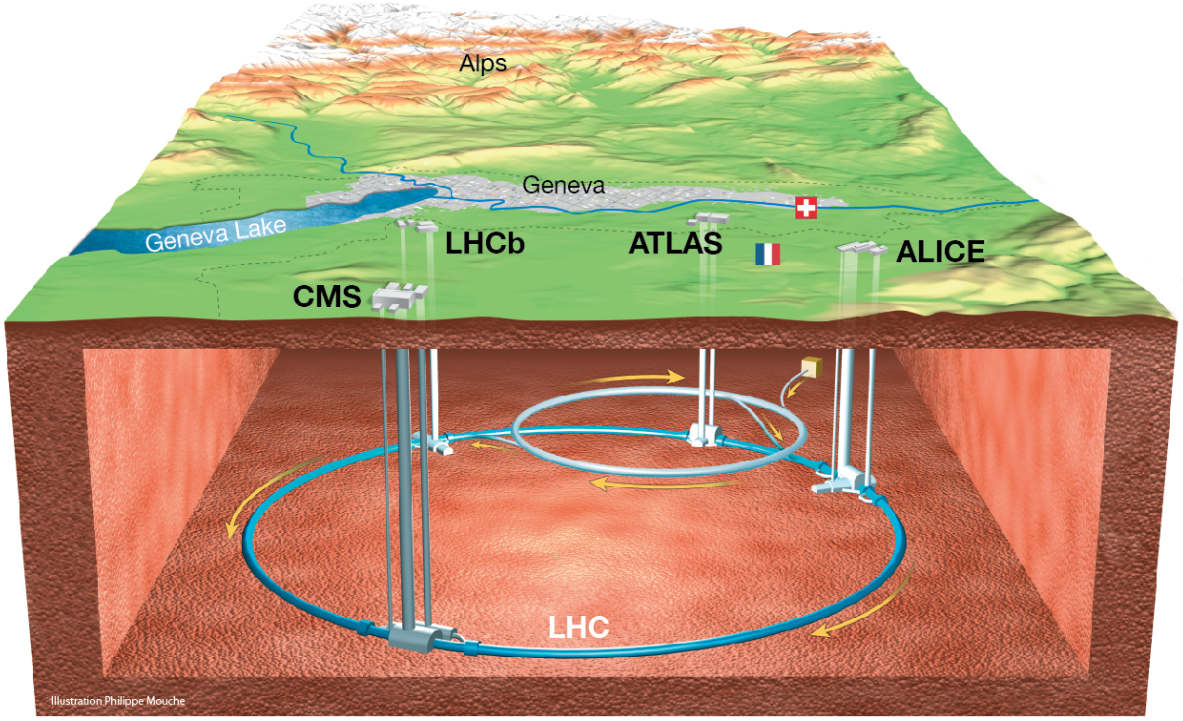
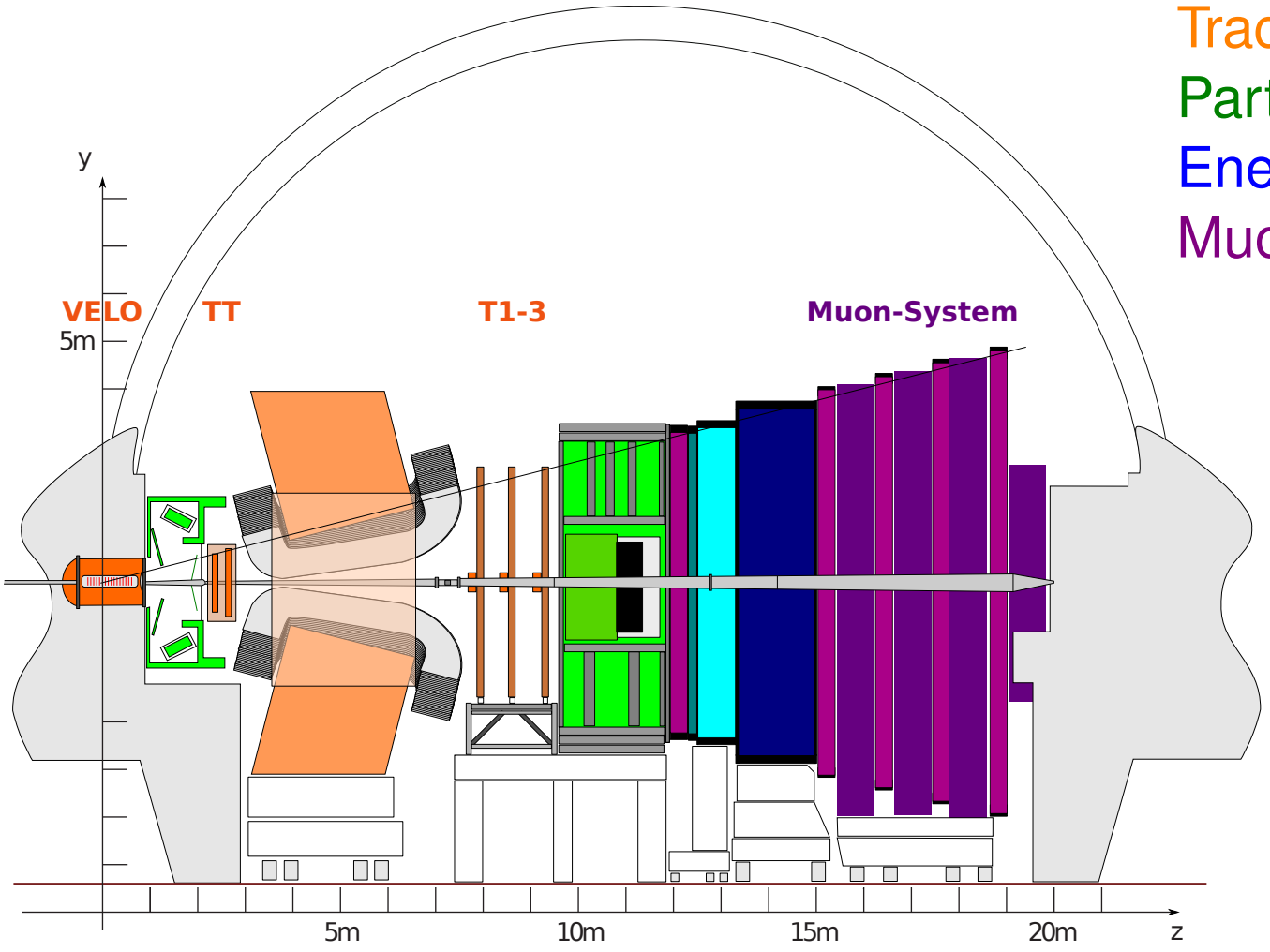


How do we study these particles?



- smashing protons together
- measuring the resulting particles

Measuring: LHCb



Tracking System
Particle Identification
Energy Measurement
Muon Identification

Acceptance

pseudo-rapidity (η)

$2 < \eta < 5$

Trigger & Reconstruction

Trigger

- select interesting collisions
- reduce amount of data
- based on signal from specific sub-detectors (Muon-System)

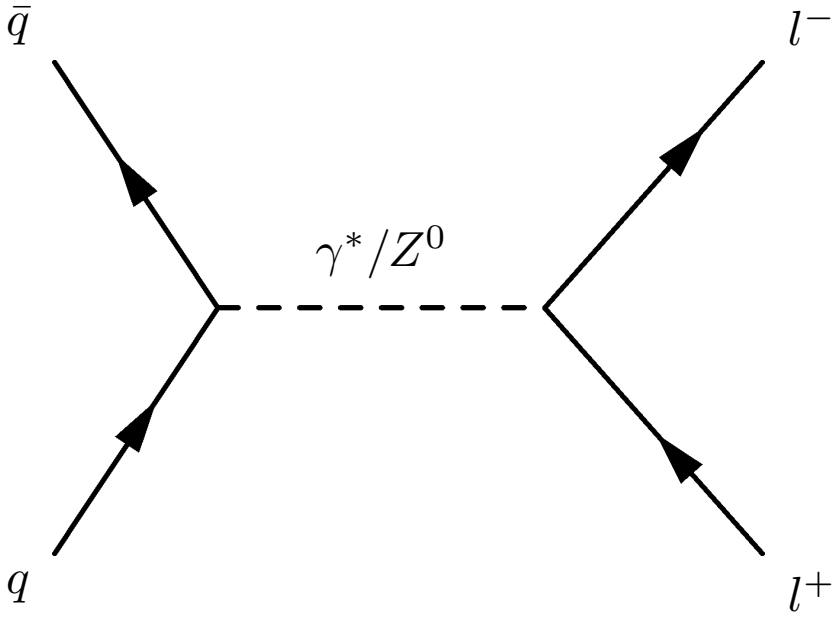
Reconstruction

- use information from all sub-detectors
- combine individual measurements
- create data-objects

Track	flight path of a particle
Particle	Track, energy, particle type
Event	result of one primary interaction

Drell-Yan Process

Drell-Yan Process

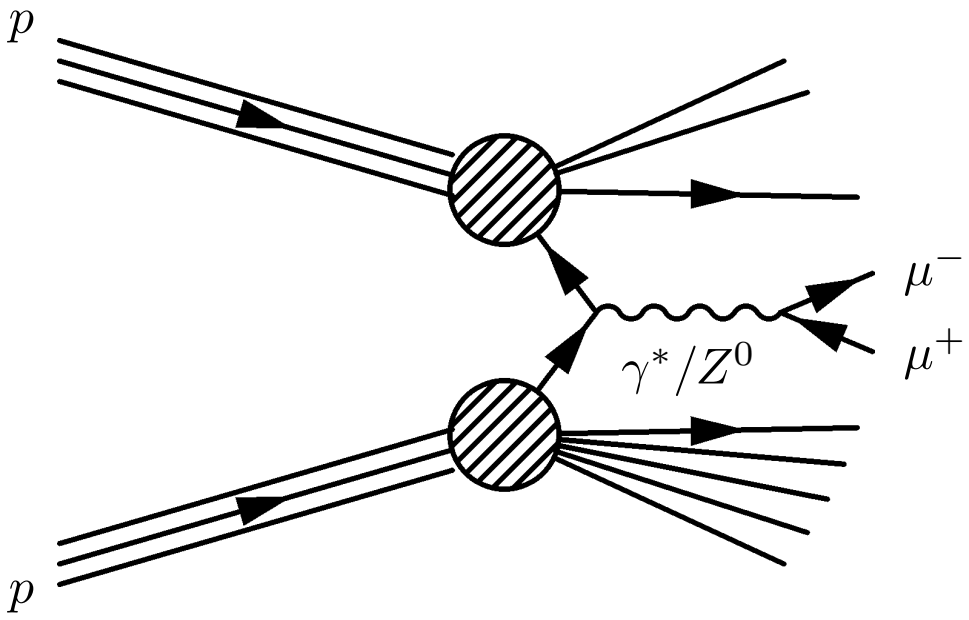


- quark/anti-quark annihilation
- production of γ or Z
- decay into two leptons

- decay into two muons
- quarks from protons
- anti-quarks from sea

Cross Section (σ) measure for probability of process

Drell-Yan Process



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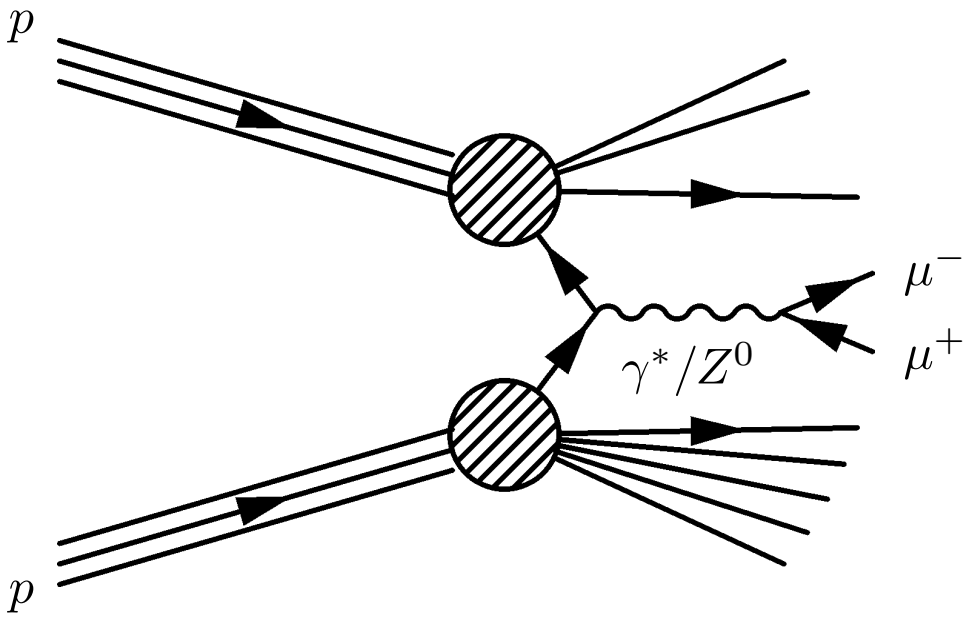

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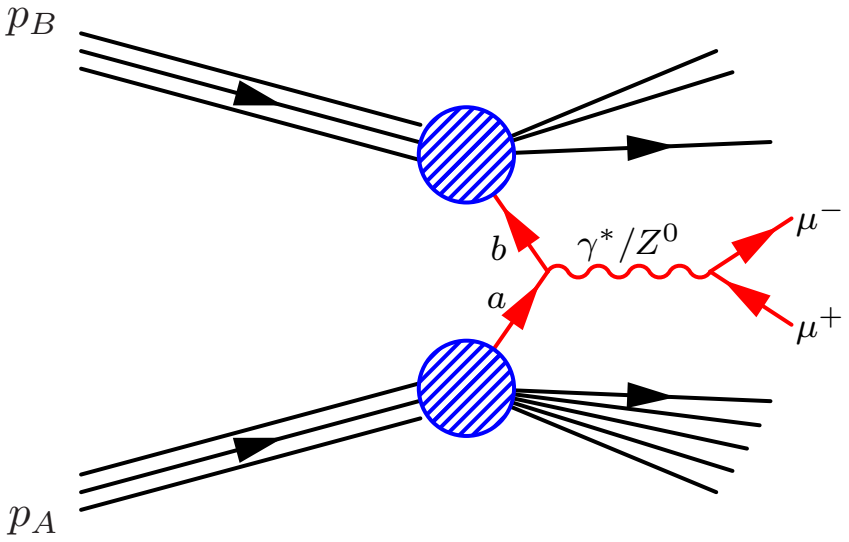
Cross Section (σ) measure for probability of process

Calculations: Factorisation Theorem



Hard Process

- perturbative QCD
- at NNLO

$$\sigma_{AB\to X} = \int dx_a dx_b \cdot f_{a/A} f_{b/B} \cdot \hat{\sigma}_{ab\to X}$$

Parton Distribution Function $f_{q/P}$

- structure of the proton
- probability to find quark (q) in proton (P)
- as a function of momentum fraction (x)

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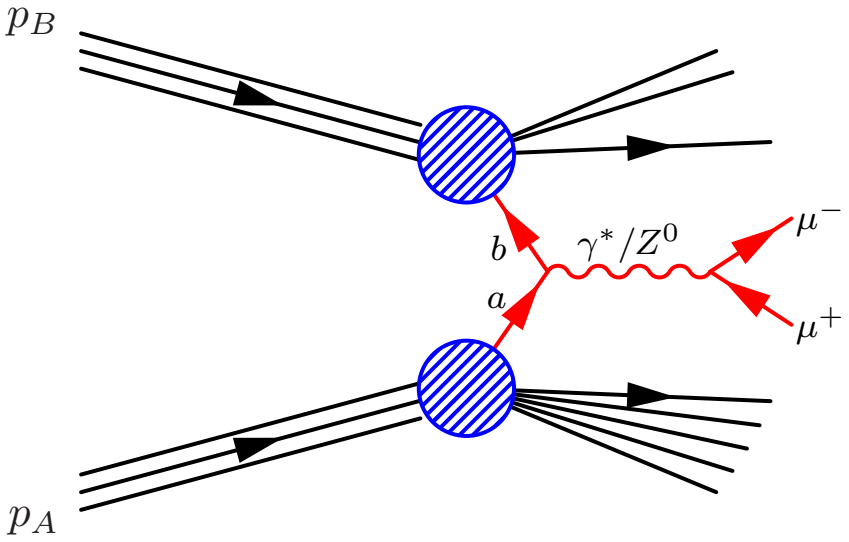

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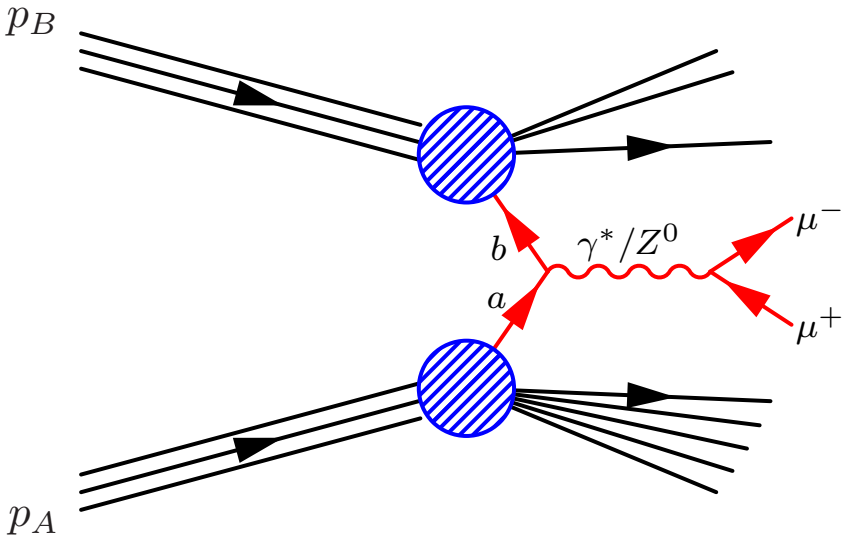

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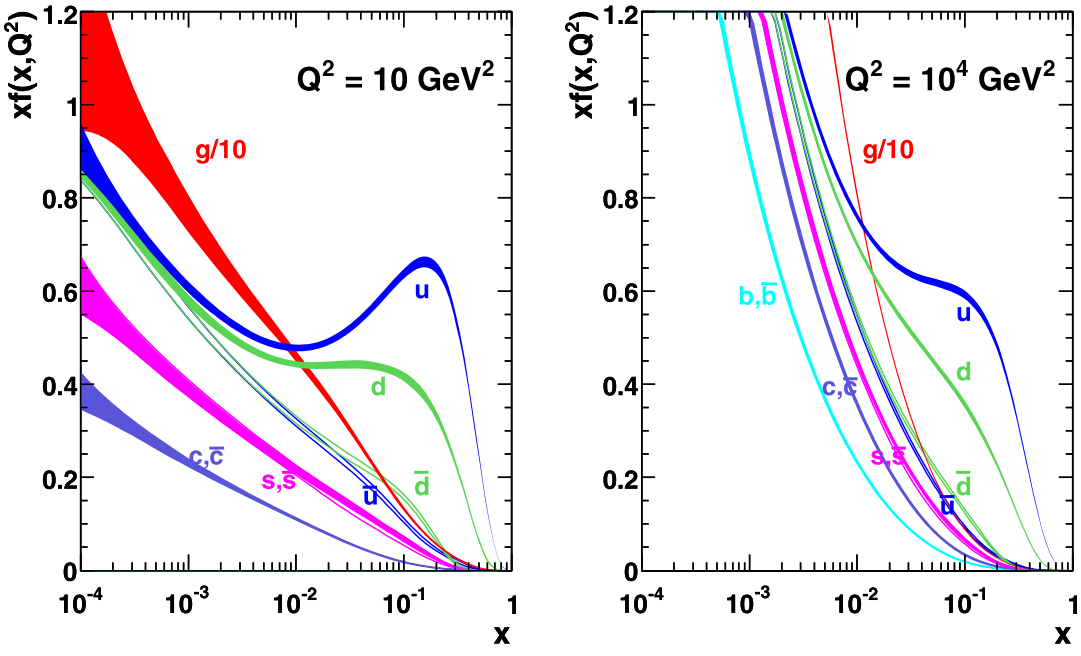
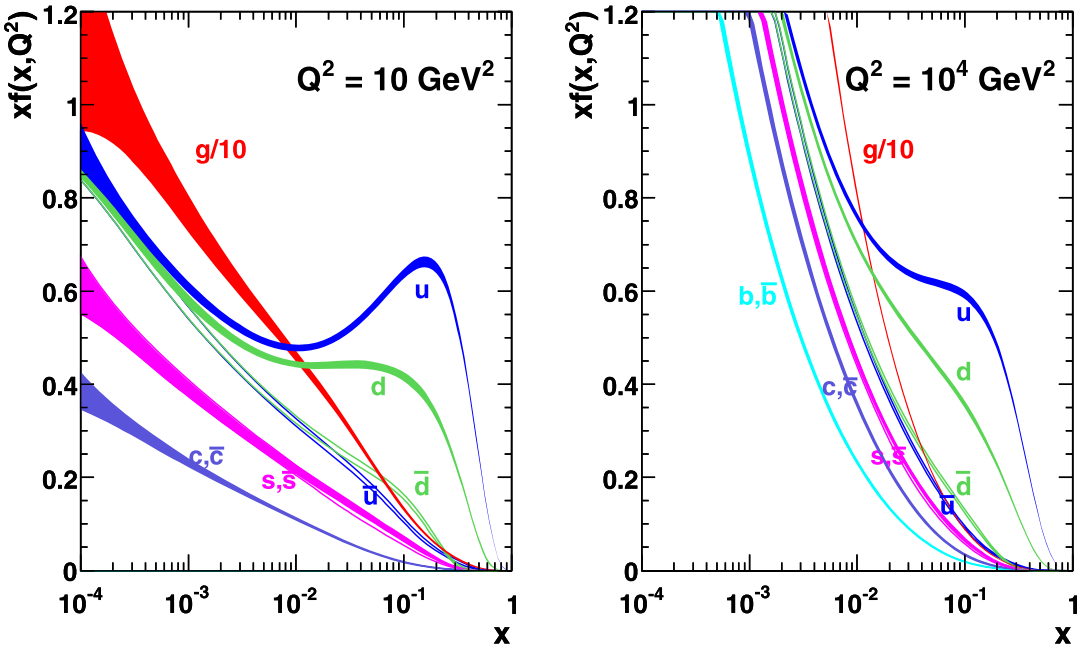


- Q energy scale
- x momentum fraction

- set of 7 functions
- no theoretical model

- determined from measurements by different collaborations
- valid at given energy scale
- evolved with DGLAP equations
- uncertainties increase for low x

Parton Distribution Functions



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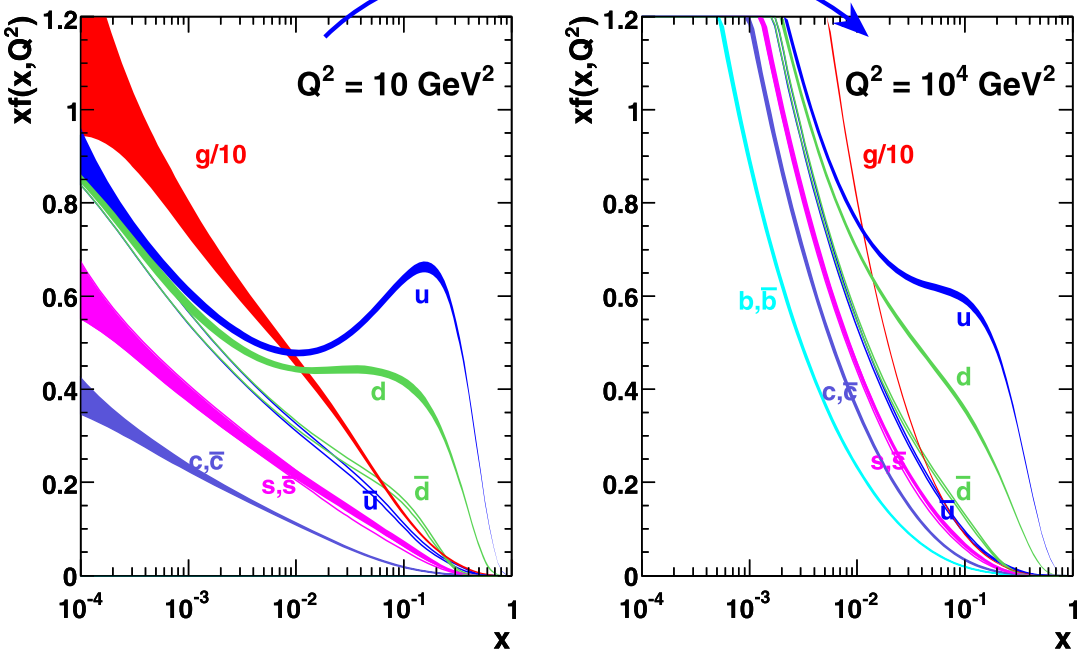
Parton Distribution Functions

DGLAP



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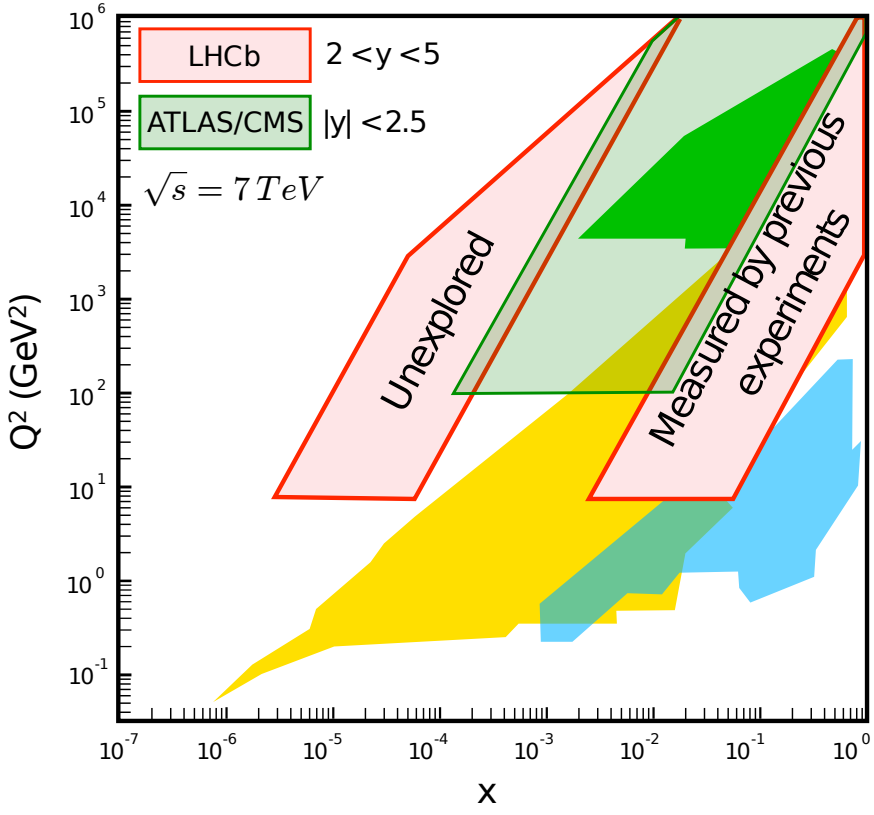
$x - Q^2$ Plane



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- large DGLAP evolution HERA $\rightarrow$ LHCb
- measurement uncertainty large for low x

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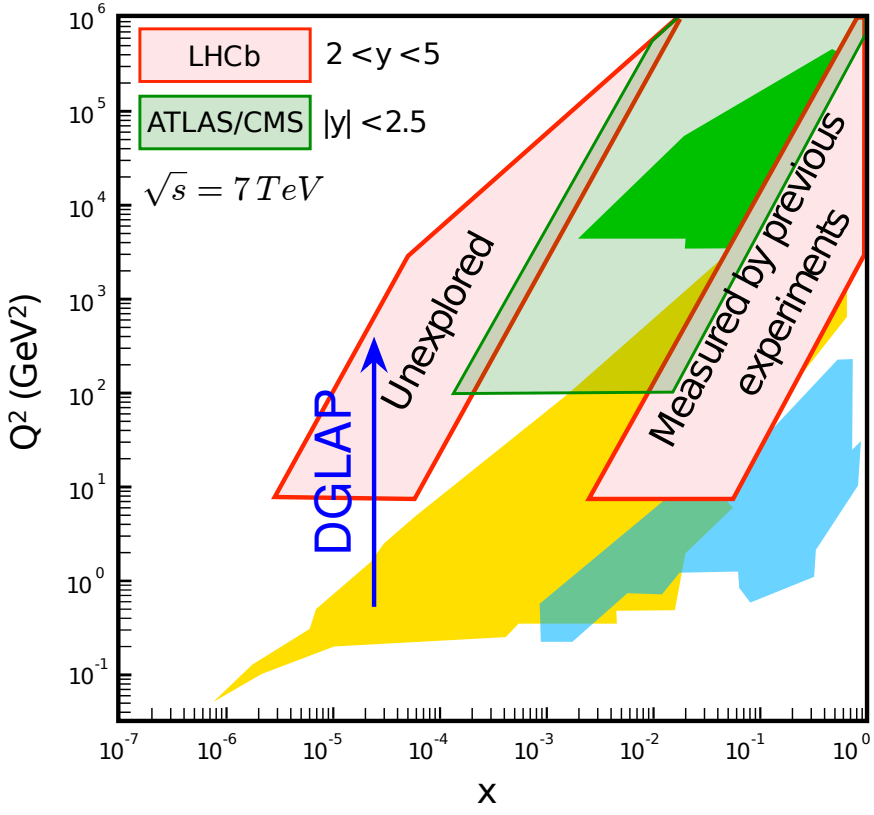

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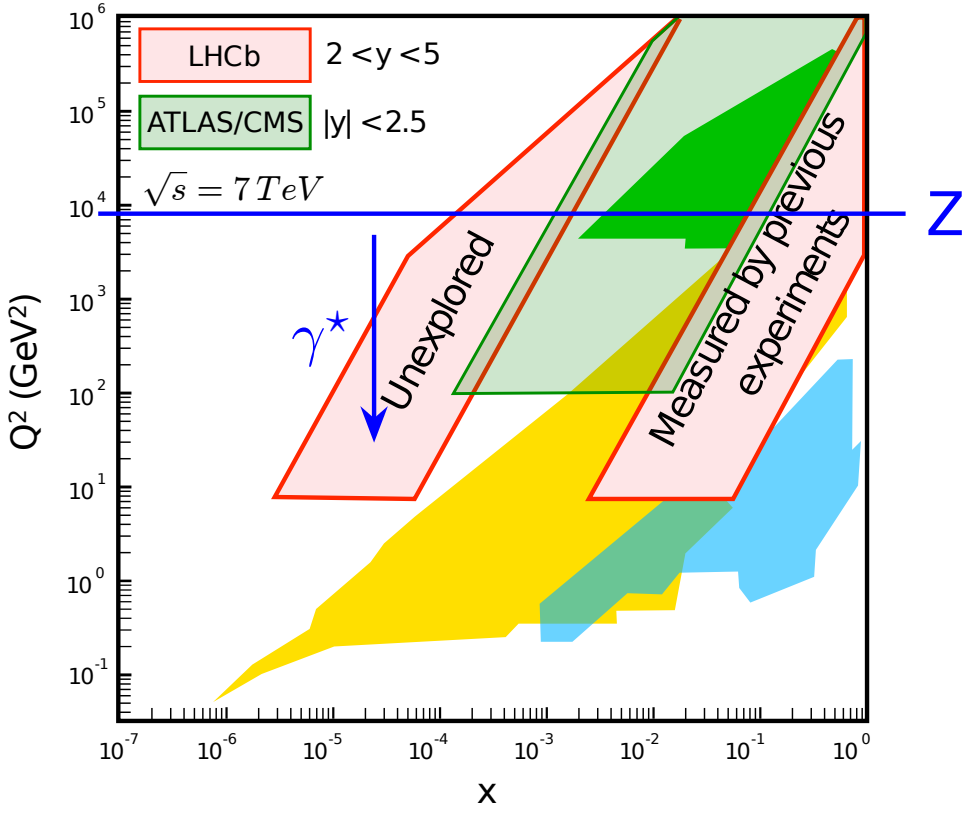

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The Measurement

Experimental Approach

$$\sigma = \frac{N_{\mathrm{DY}}}{\mathcal{L}}$$

- $\mathcal{L}$ integrated luminosity
- ρ signal fraction
- $\varepsilon^{\mathrm{TRIG}}$ trigger efficiency
- $\varepsilon^{\mathrm{TRACK}}$ tracking efficiency
- $\varepsilon^{\mathrm{GEC}}$ global event cut efficiency
- $\varepsilon^{\mathrm{MUID}}$ muon identification efficiency
- $\varepsilon^{\mathrm{SEL}}$ efficiency of the vertex quality requirement
- f^{MIG} correction for bin-to-bin migrations

Analysis Details

Data Set

- collected in 2011
- $\sqrt{s} = 7$ TeV
- $\mathcal{L} = 1018.8$ pb^{-1}

Selection

- triggered on two oppositely charged muons
- muons with common vertex
- $10 < M_{\mu\mu} < 120$ GeV/c^2
- $2 < \eta < 4.5$
- $p_T > 3$ GeV/c

Binning

- 18 mass bins, full rapidity range
- 4 mass bins, 9 rapidity bins

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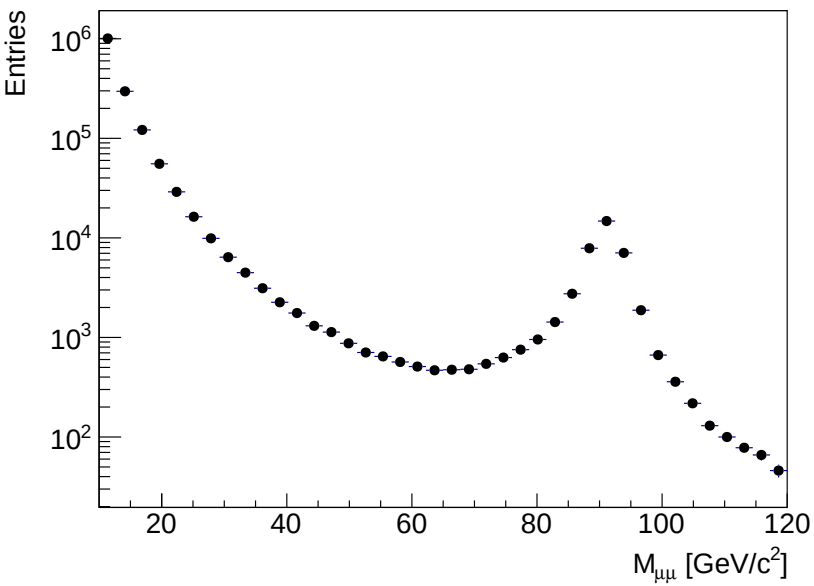

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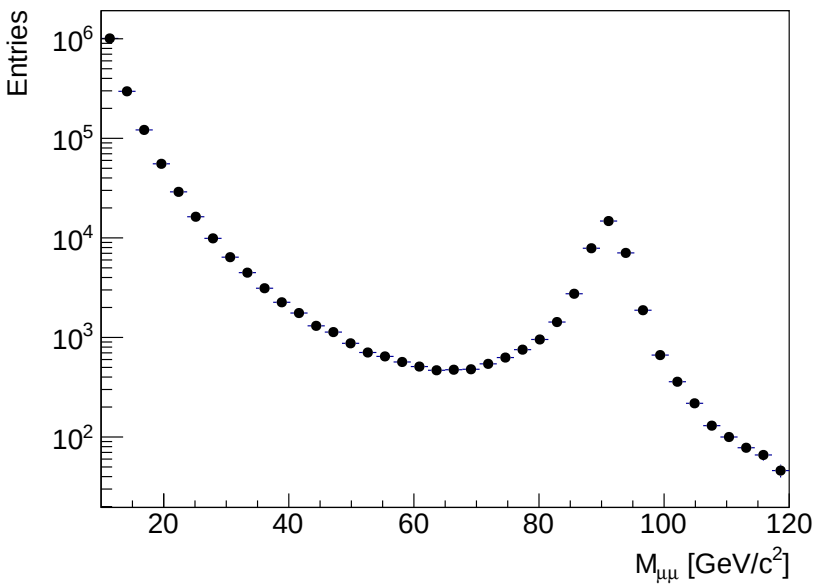

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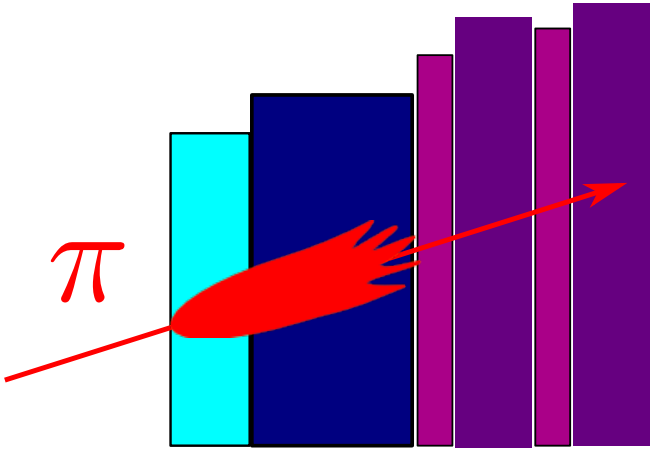
Signal Extraction

selection not pure Drell-Yan events

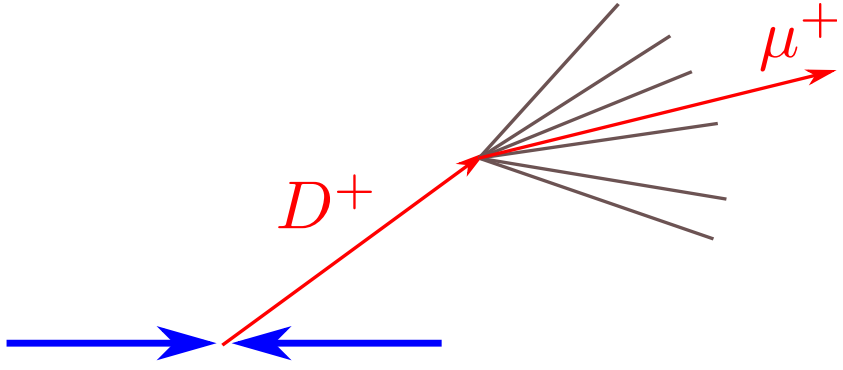
Mis-Identification

- pions or kaons
- decay in flight
  or punch through



Heavy Flavour

- hadrons with c or b quarks
- decay semileptonically



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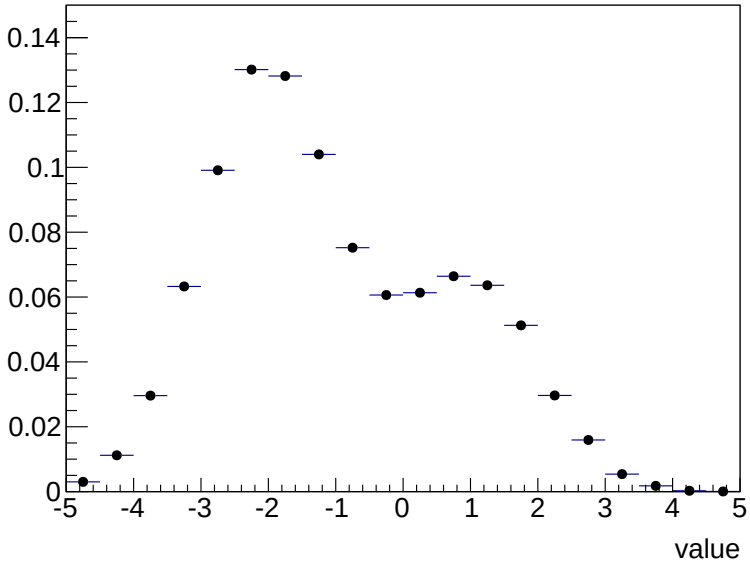
Fraction-Fitter: Example



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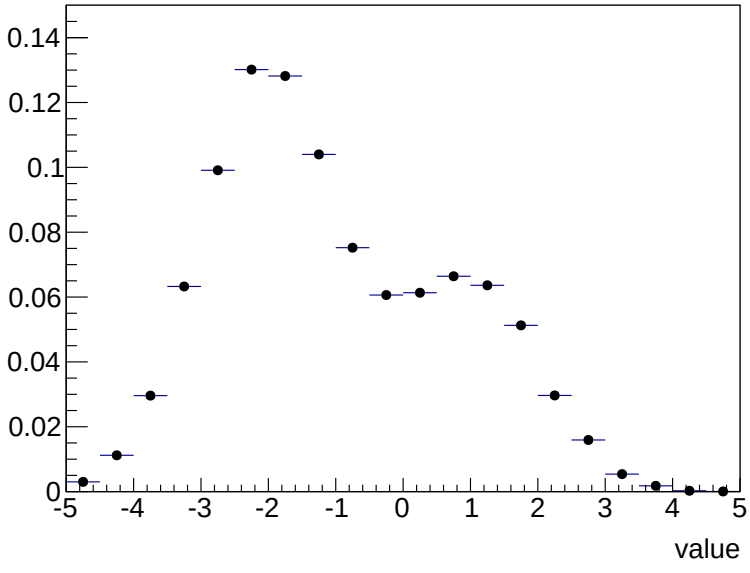

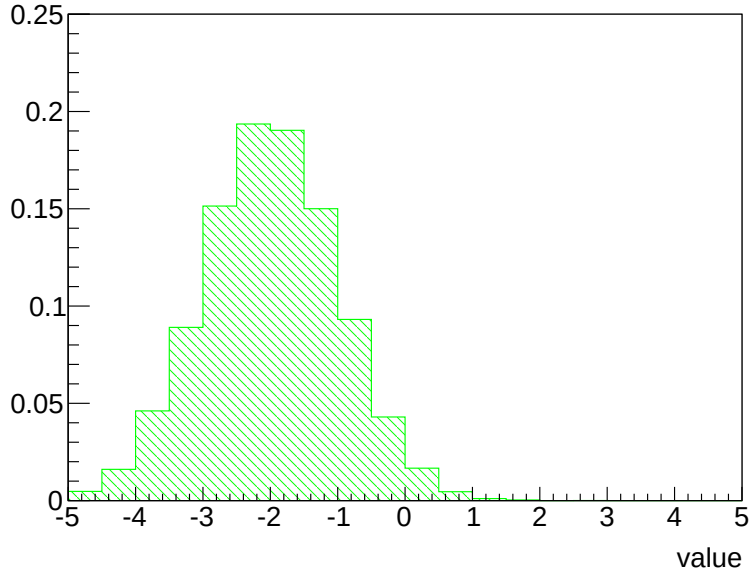

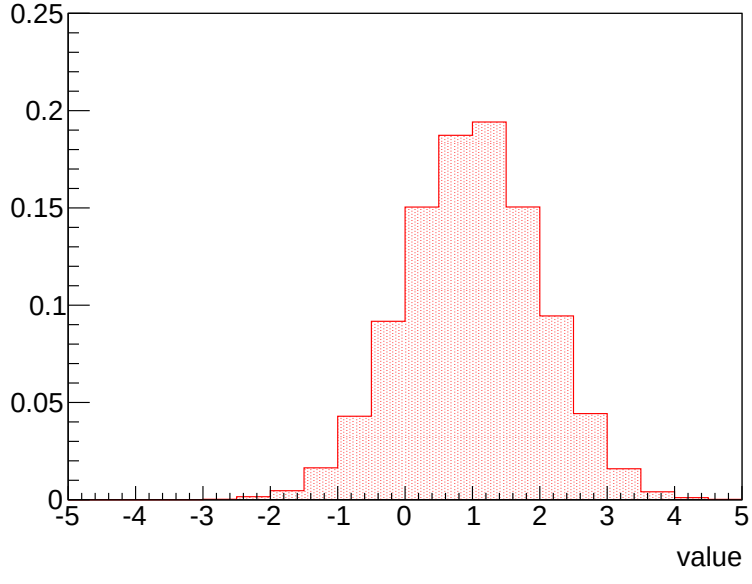

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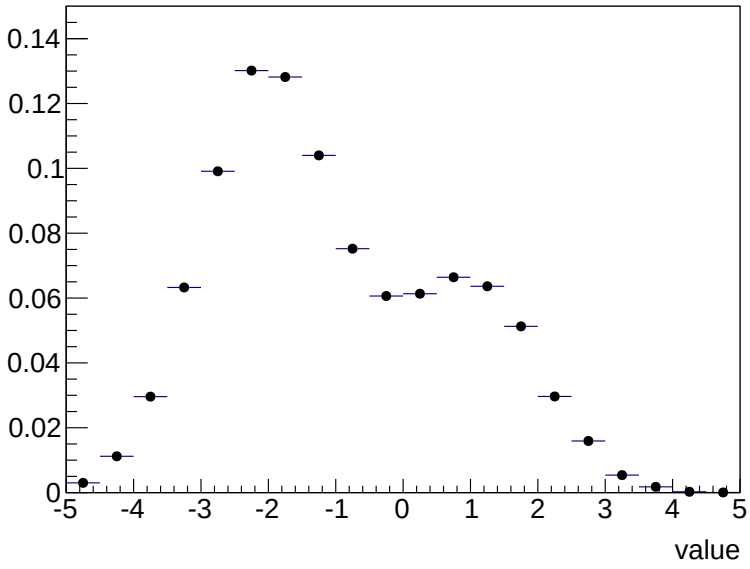
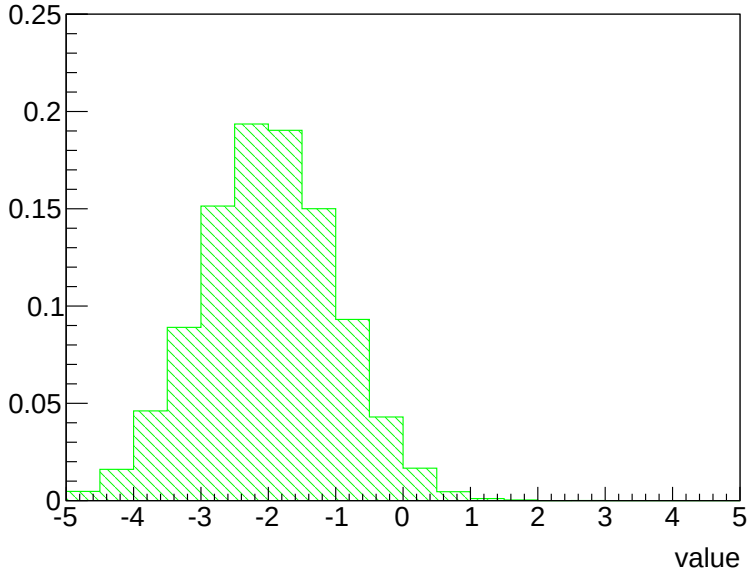
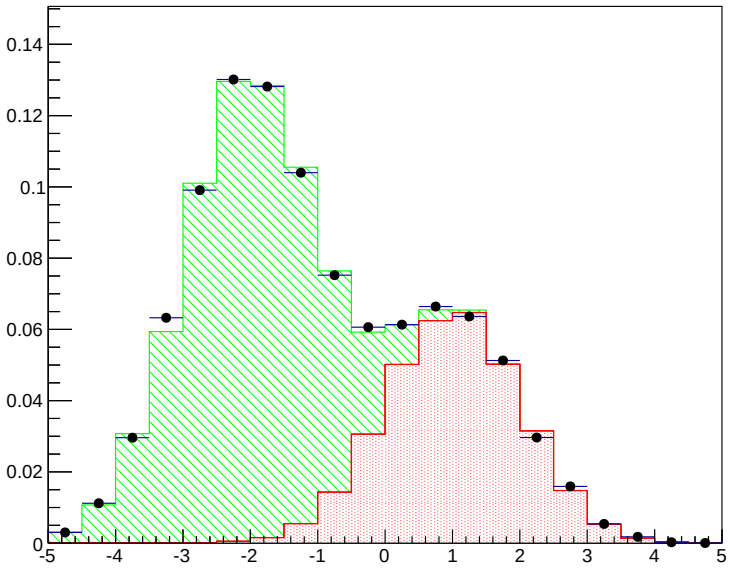
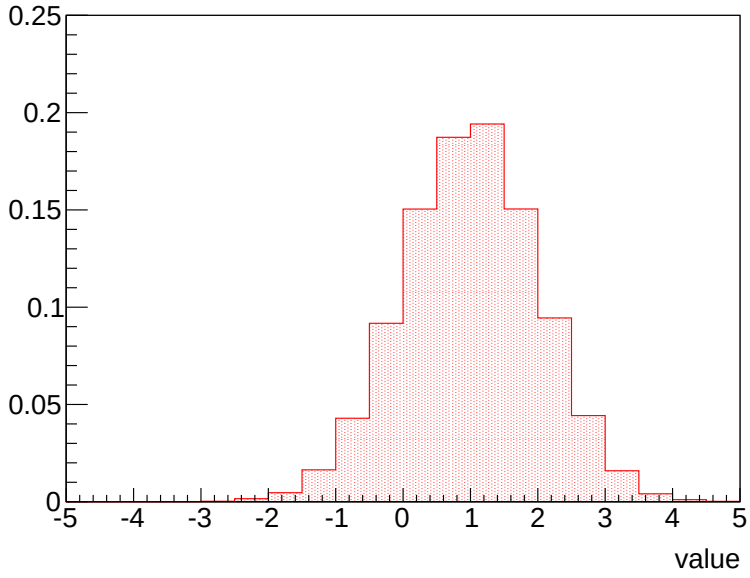








Sources for Templates

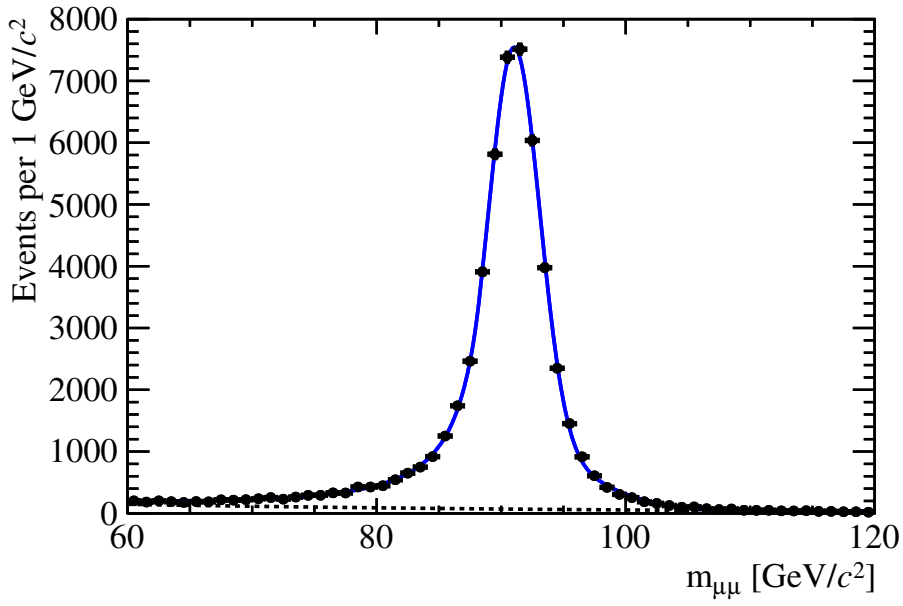
Simulation unsure if underlying event is modelled well

Data needs mass independent variable

Why Mass Independent?

- Z region background free
- shown by several analyses

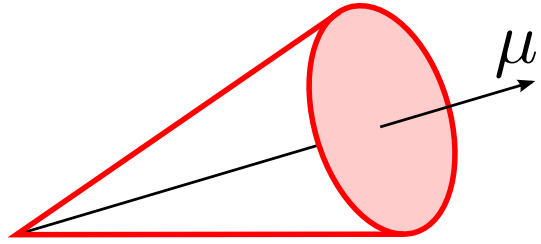
$\rightarrow$ signal template from Z region



[LHCB-PAPER-2014-033]

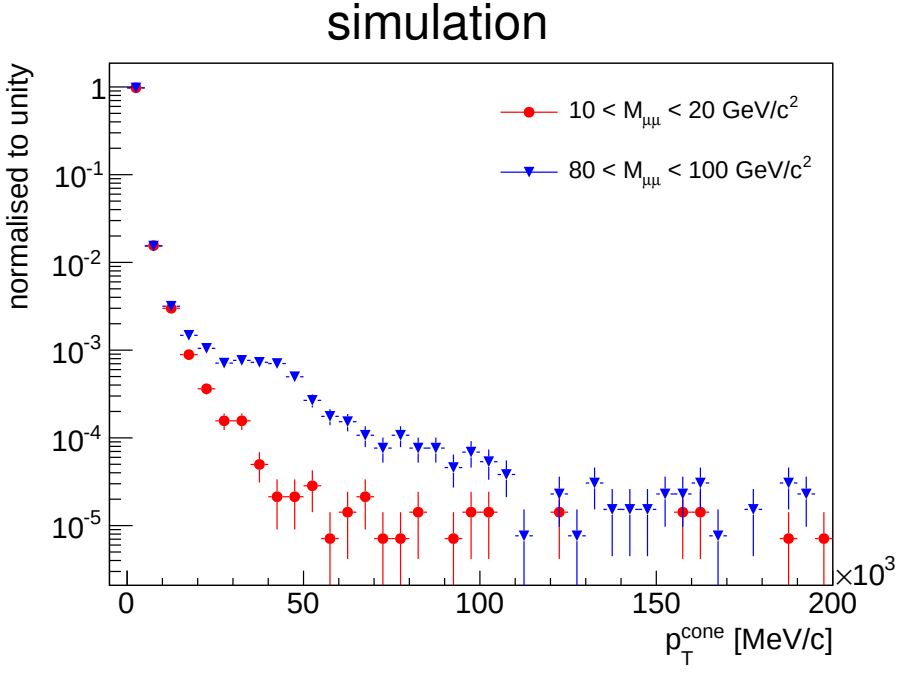
Variable

- mass independent for signal
- discriminating sig./bkg.



Muon Isolation

- transverse momentum (p_T) in cone around muon
- difference between 2 cones
- take logarithm
- take least isolated muon
- mass dependent scale factor



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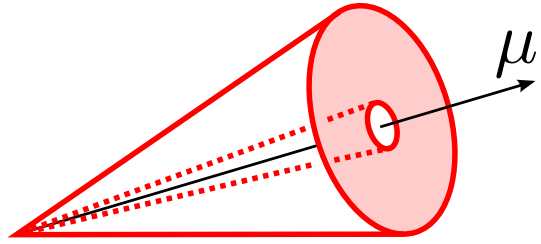

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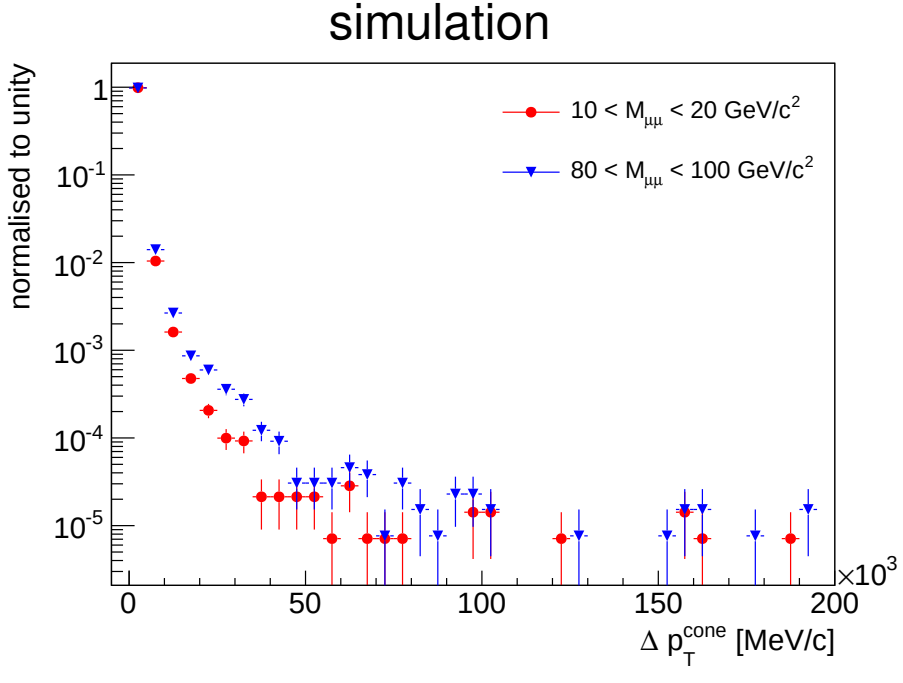

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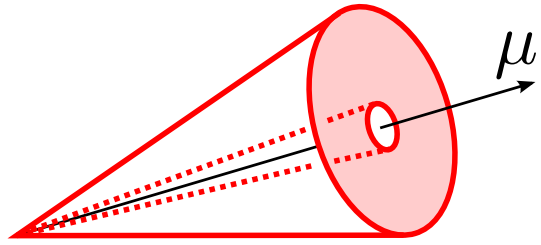

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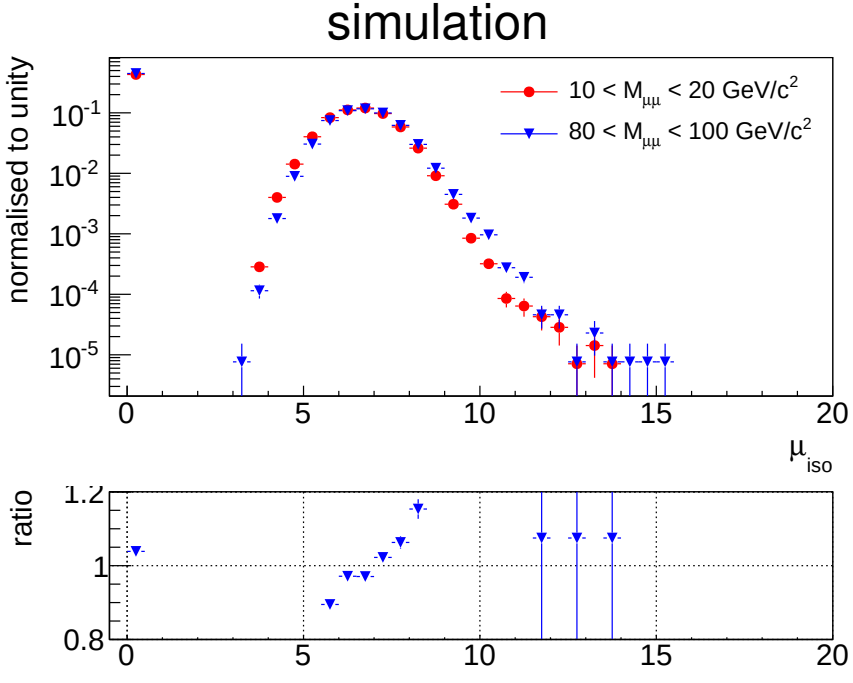

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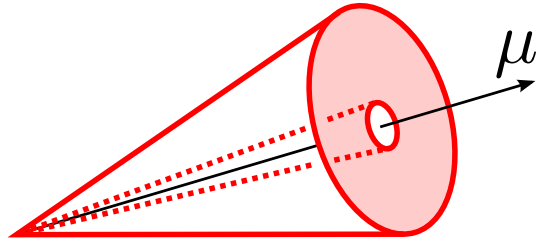
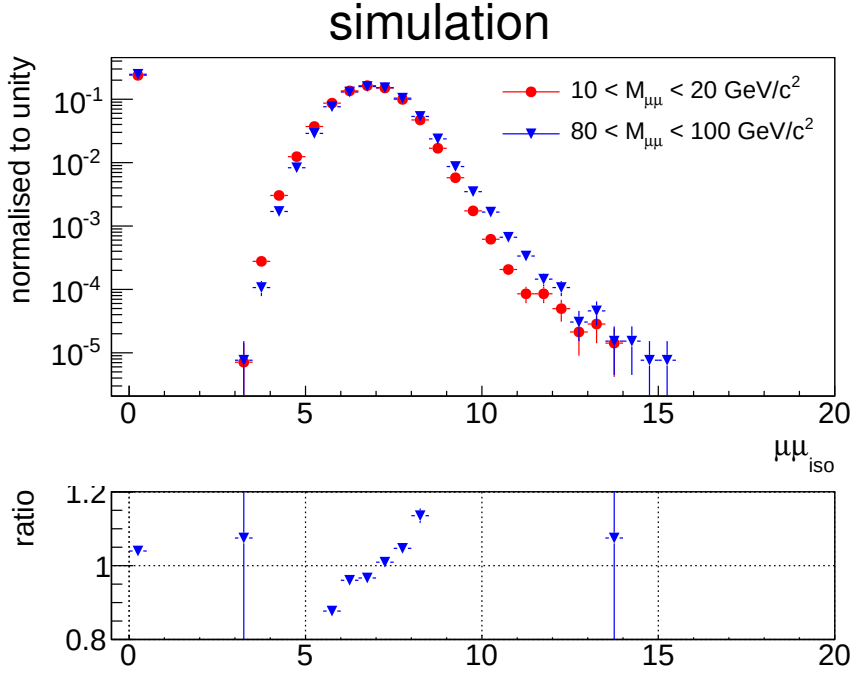


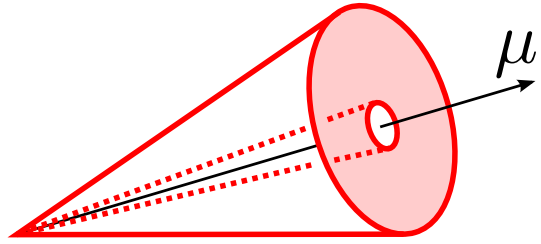
Muon Isolation

- transverse momentum (p_T) in cone around muon
- difference between 2 cones
- take logarithm
- take least isolated muon
- mass dependent scale factor



Variable

- mass independent for signal
- discriminating sig./bkg.



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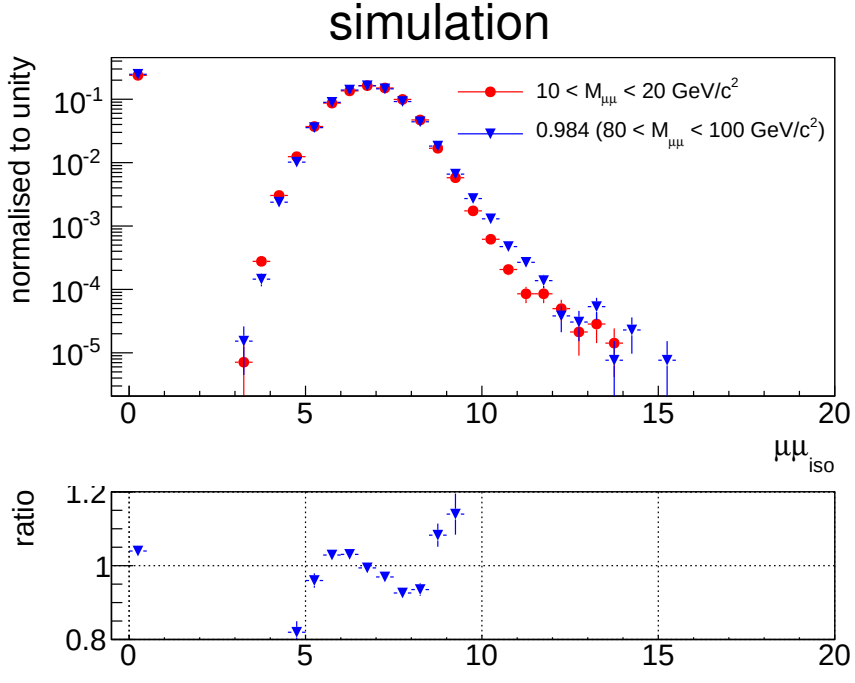
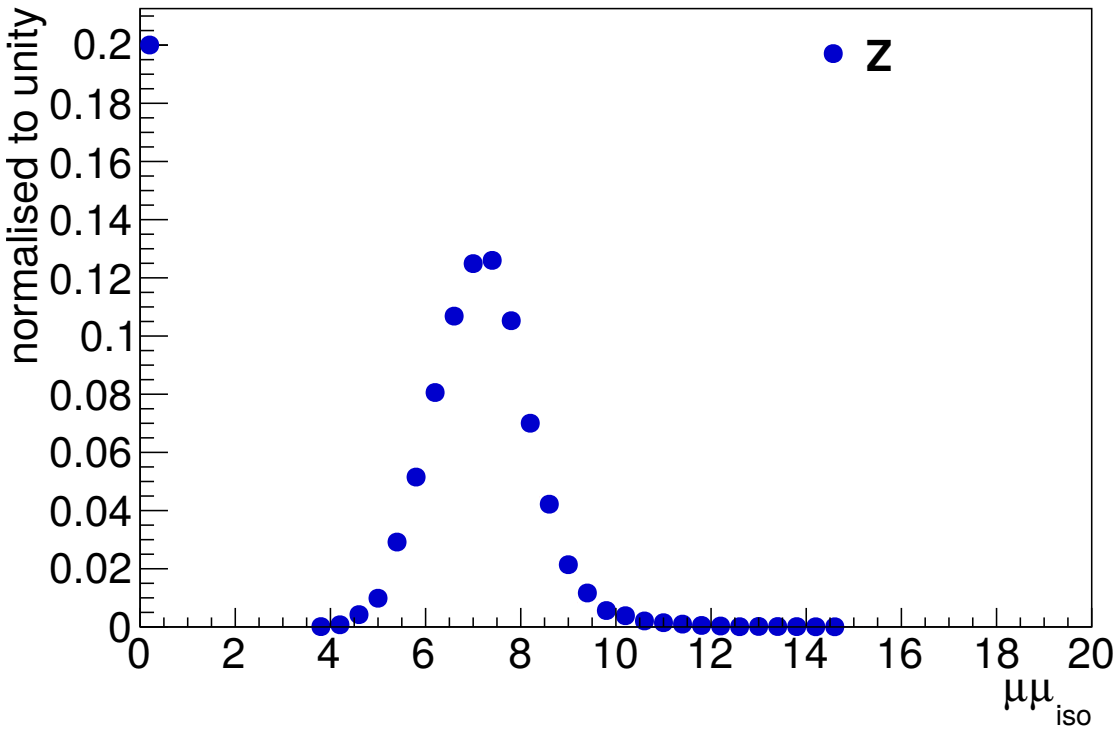


Signal Shape in Data

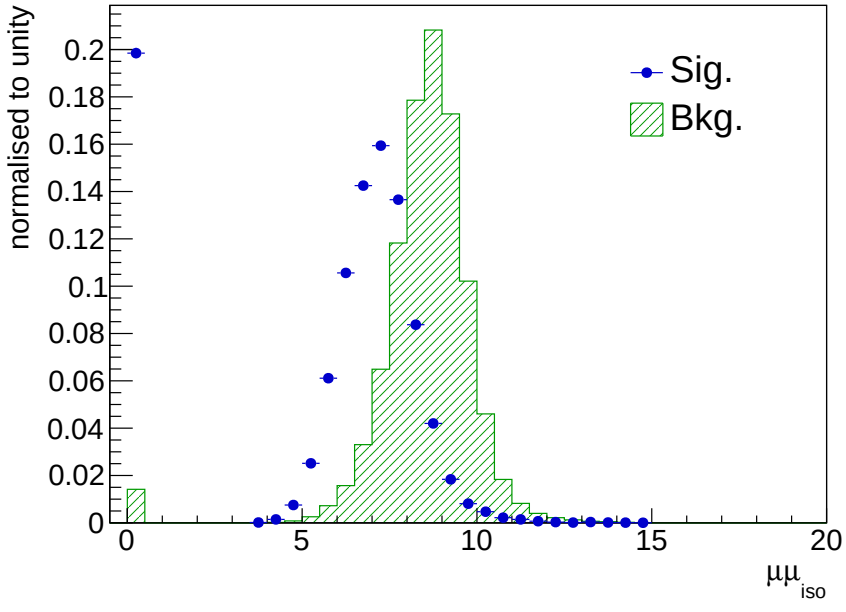


- signal template
- from Z region
- unscaled

Background Shape

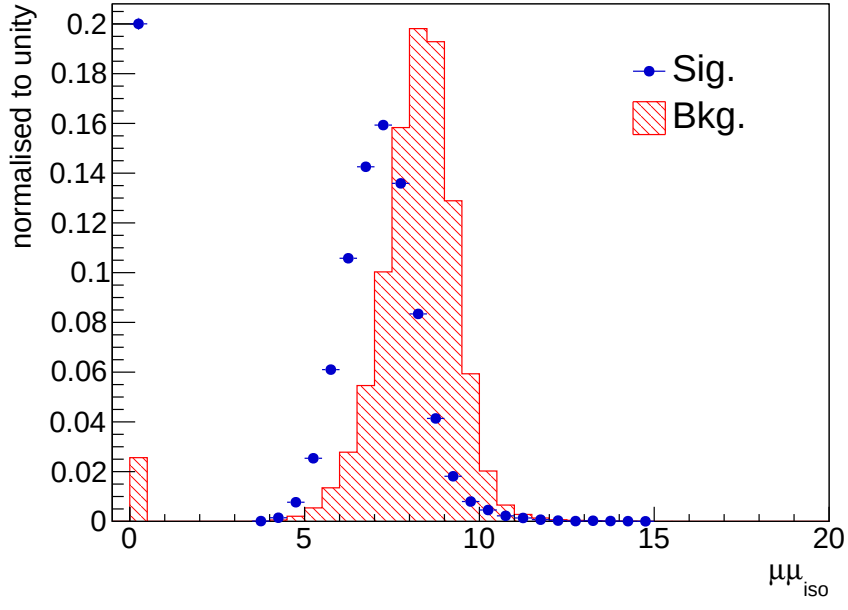
Mis-Identification

1. randomly triggered events
2. same sign events



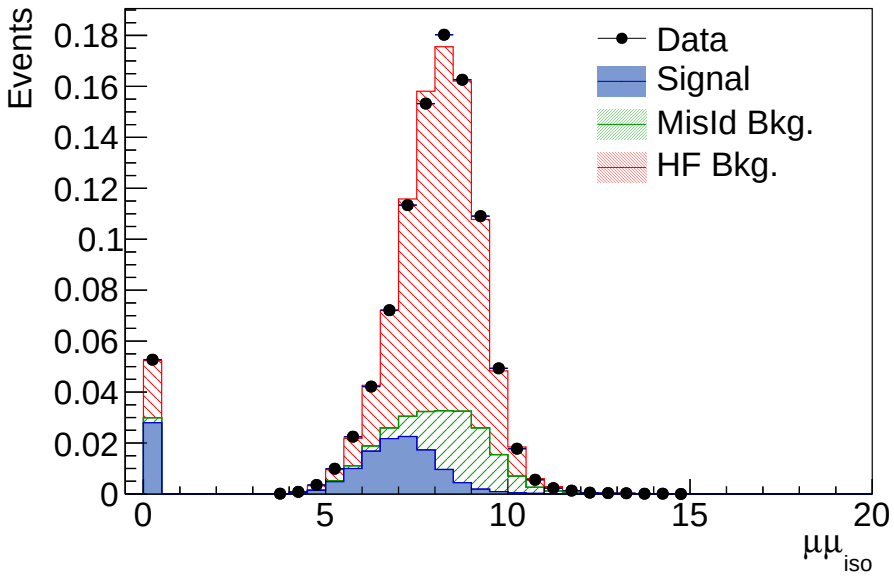
Heavy Flavour

1. badly reconstructed vertex
2. large impact parameter



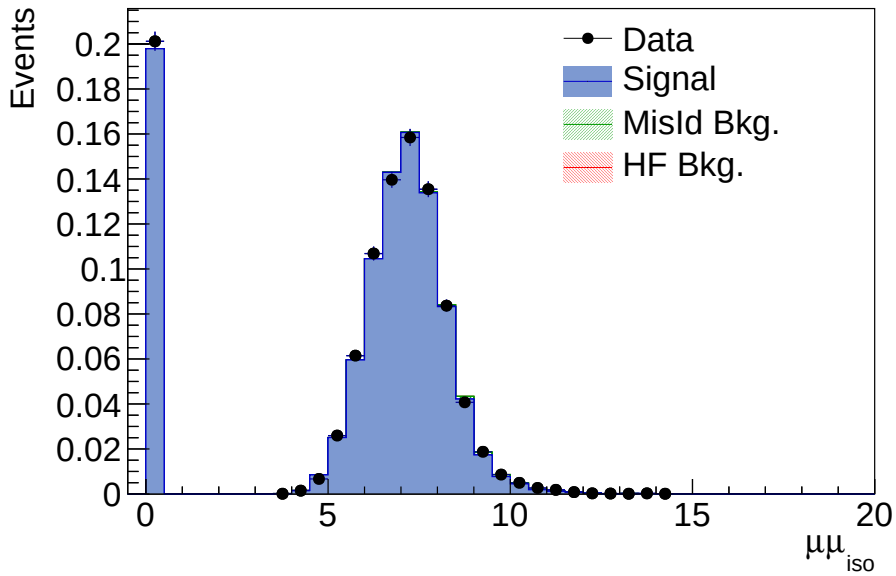
Fits

$10.5 < M_{\mu\mu} < 11.0\ \mathrm{GeV/c^2}$



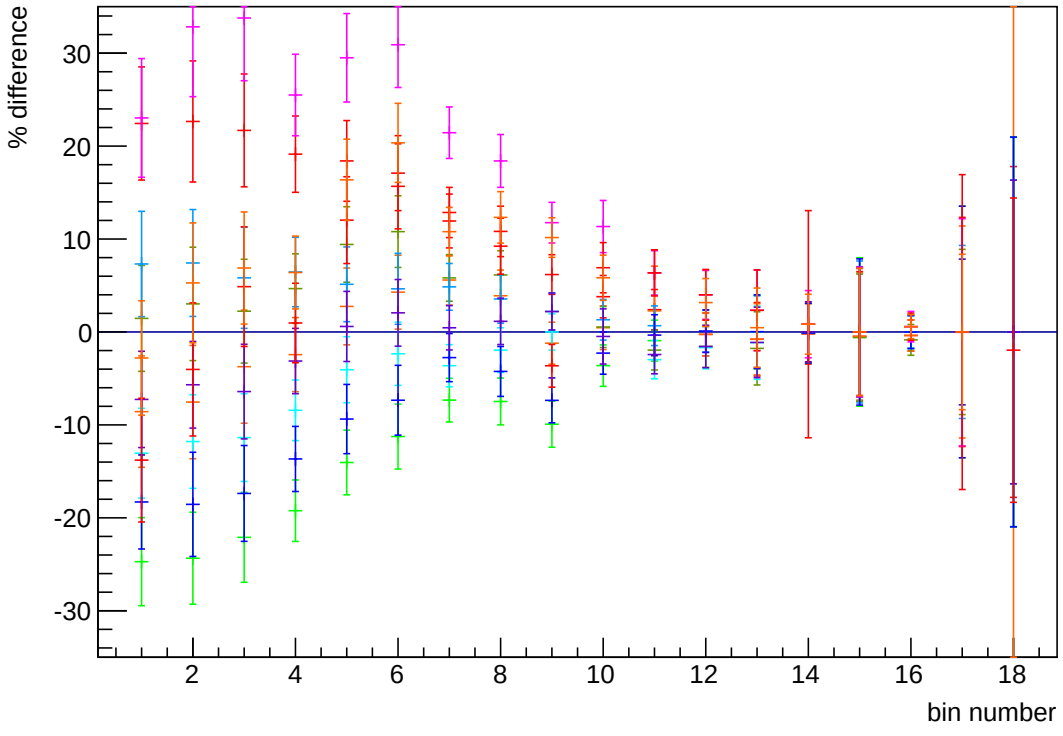
$\rho = 0.140 \pm 0.005$

$90.0 < M_{\mu\mu} < 100.0\ \mathrm{GeV/c^2}$



$\rho = 0.994 \pm 0.012$

Template Combinations



low mass

high mass

→ mean and standard deviation

Signal

- Z, scaled
- Z, unscaled
- Υ (9.4 - 9.5 $\mathrm{GeV/c^2}$)
- simulation

Heavy Flavour

- bad vertex
- large IP

Mis-Identification

- same sign
- random trigger

Corrections

not all events registered correctly

- events rejected by global cuts
- events missed by trigger
- tracks not found in reconstruction
- muons not recognised
- events failing selection
- wrong boson mass reconstructed

Experimental Approach: Corrections

$$\sigma = \frac{\rho \cdot N_{\text{cand}}}{\mathcal{L}}$$

- $\mathcal{L}$ integrated luminosity ✓
- ρ signal fraction ✓
- $\varepsilon^{\text{TRIG}}$ trigger efficiency
- $\varepsilon^{\text{TRACK}}$ tracking efficiency
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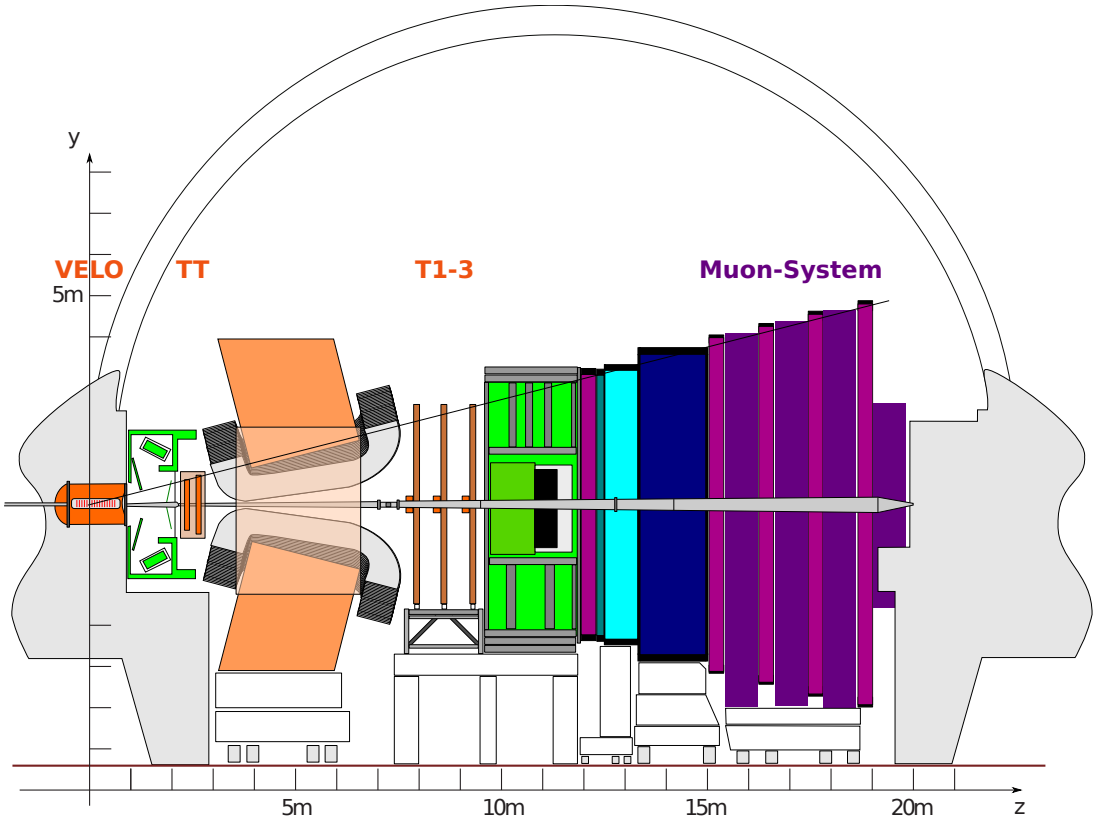
Trigger Efficiency

$$\varepsilon^{\text{TRIG}} = \frac{N_{\text{post-trigger}}}{N_{\text{pre-trigger}}}$$



Pre-Trigger?

- simulation
- tag-and-probe

Tag-and-Probe

- for single muon trigger
- di-muon trigger as product
- compared to simulation
- only for $p_T > 5\ \mathrm{GeV/c}$

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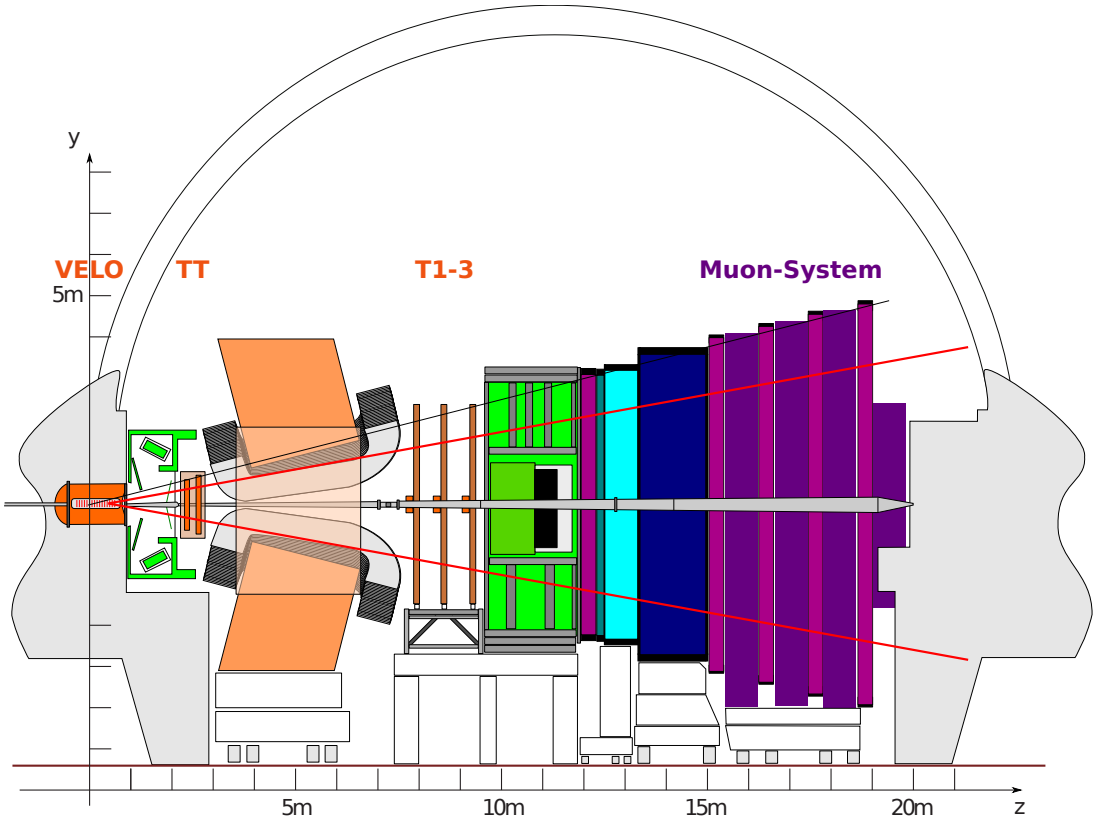

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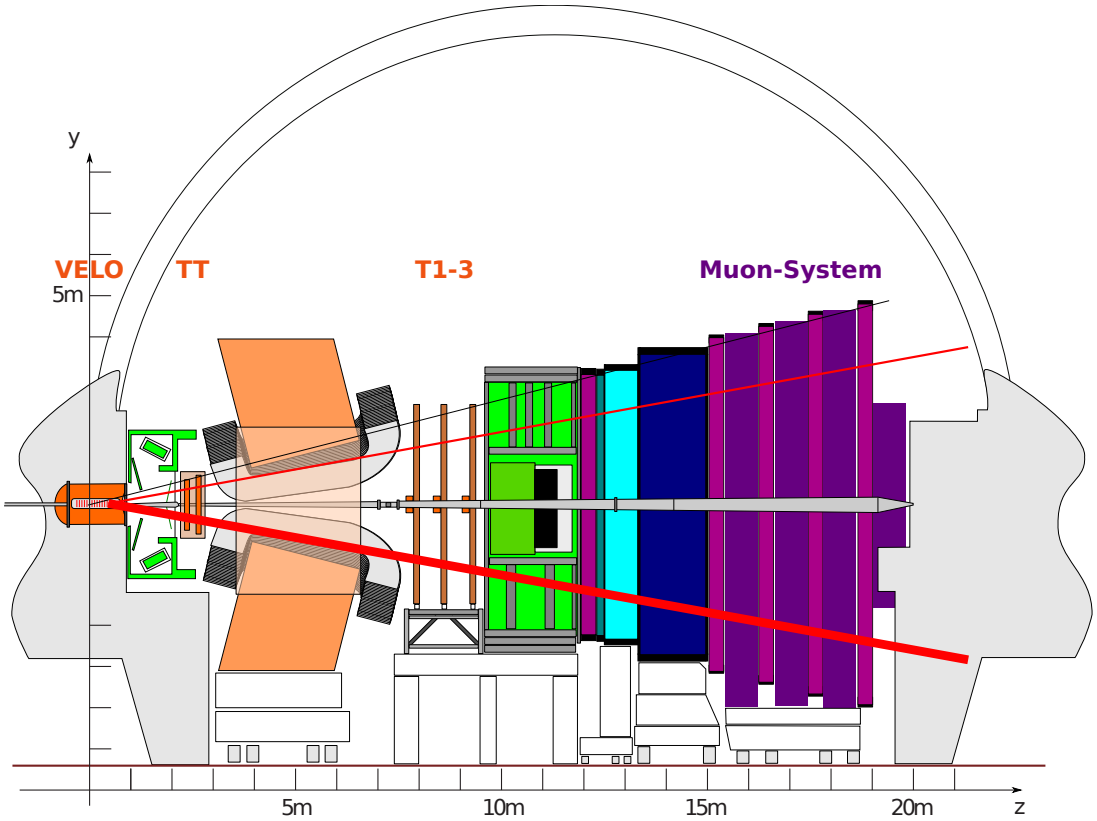

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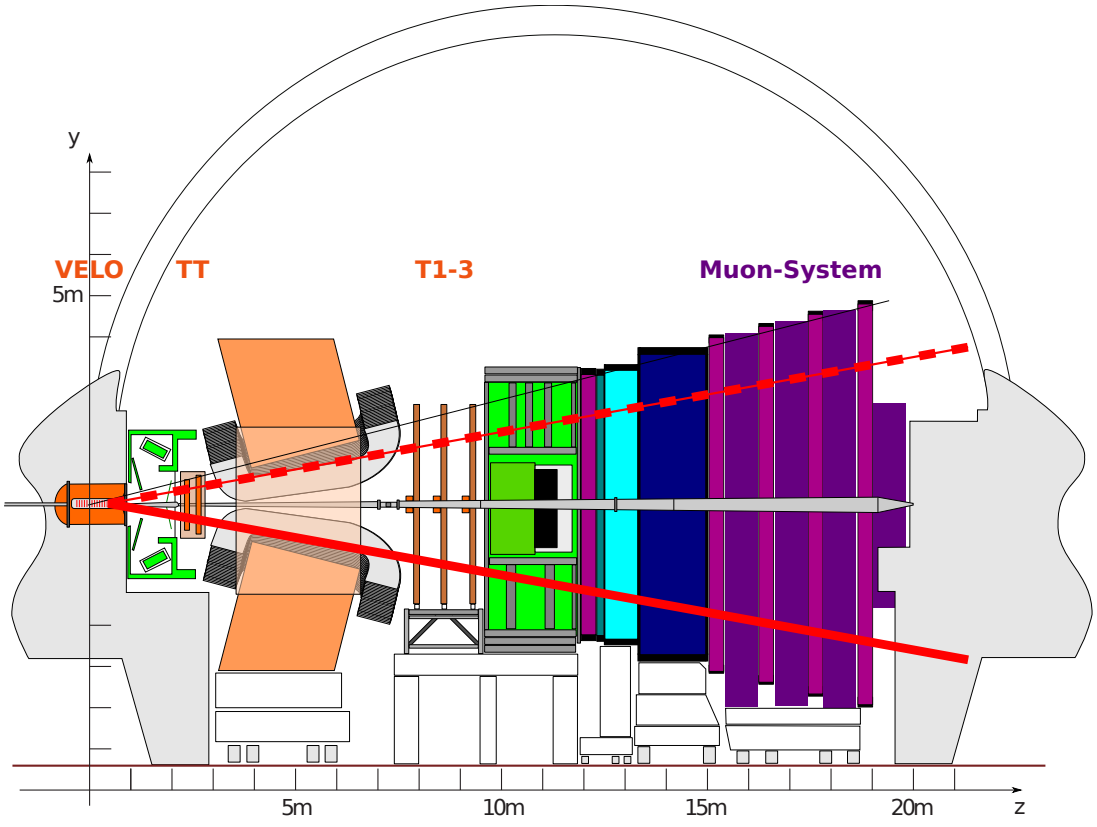

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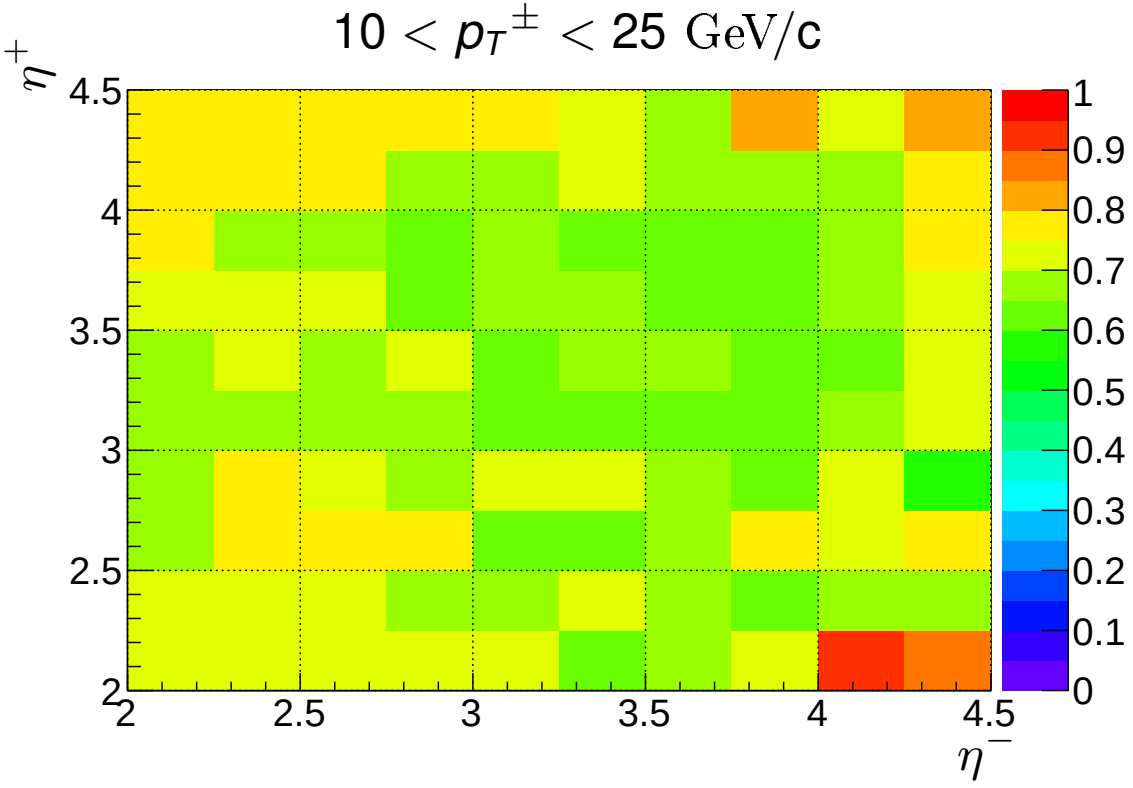
Trigger Efficiency: Result



Efficiency

- from simulation
- 9 efficiency maps

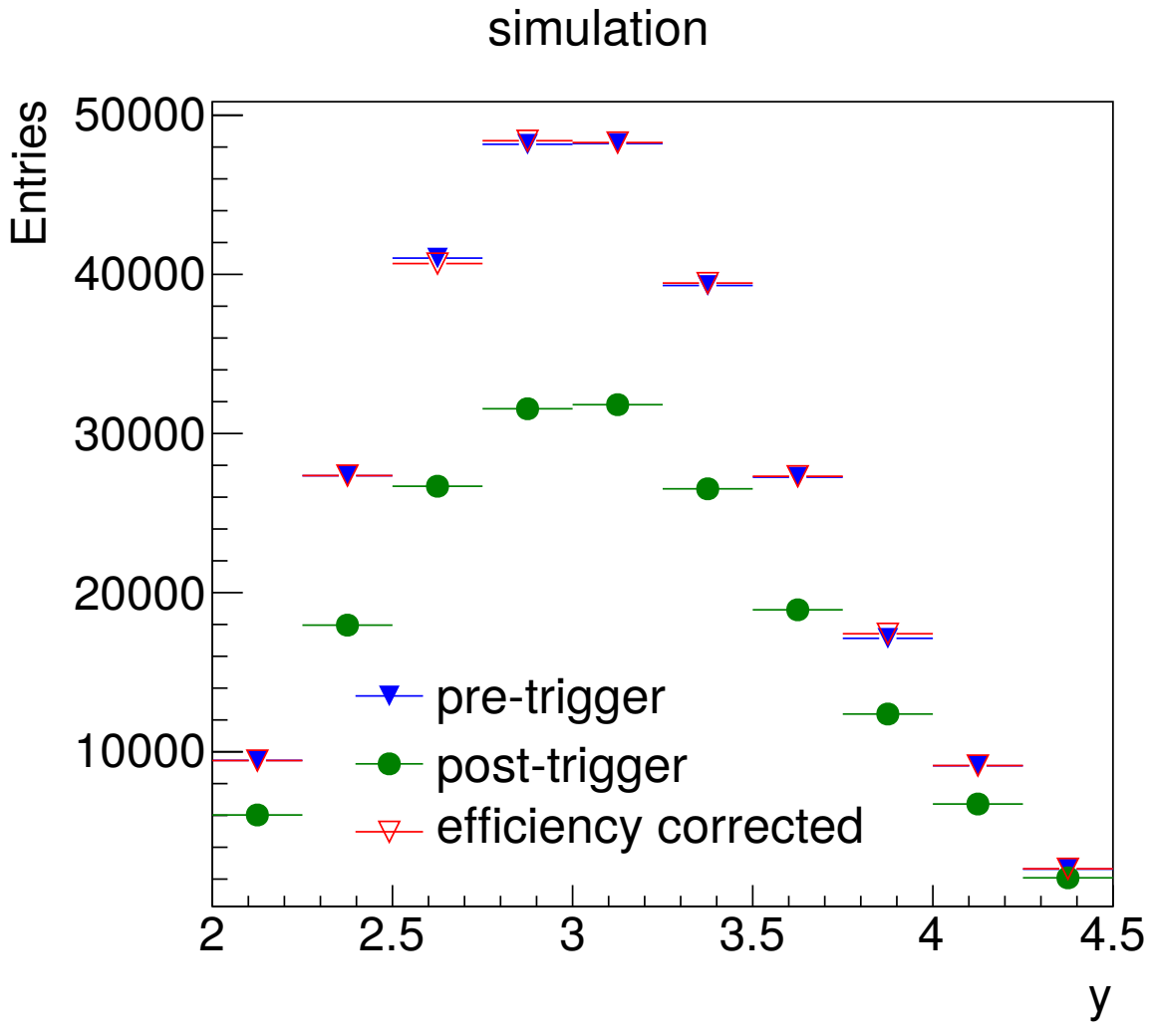
As Function of

- pseudo-rapidity (η)
- transverse momentum (p_T)

Average Efficiency

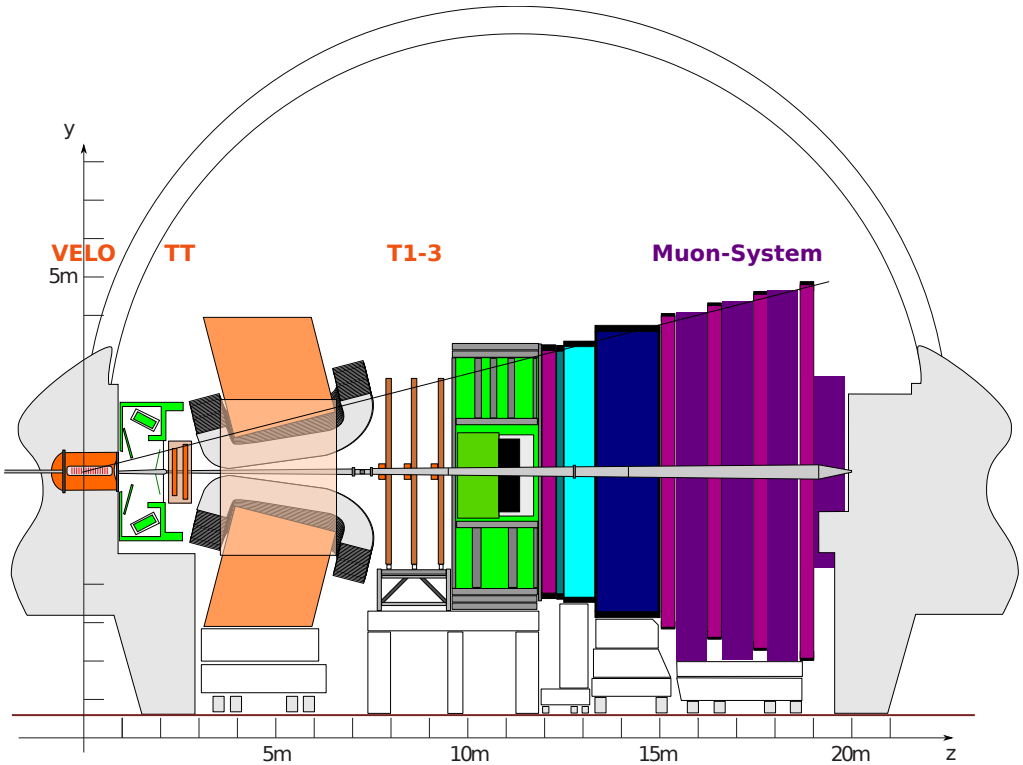
0.693 ± 0.009

Trigger Efficiency: Closure Test



Track Reconstruction Efficiency

Tag-and-probe method developed by M. De Cian



Track Reconstruction

Long VELO, T-Stations

MuonTT TT, Muon-System

Efficiency

- look at di-muon decays
- tag with Long+MuonTT
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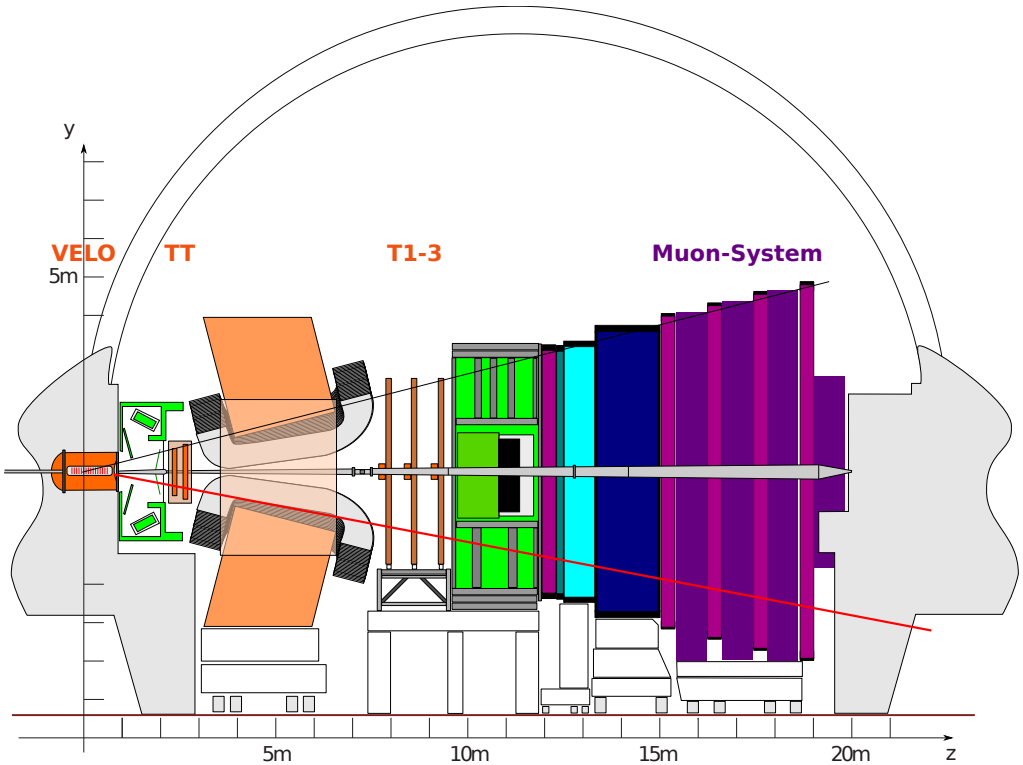

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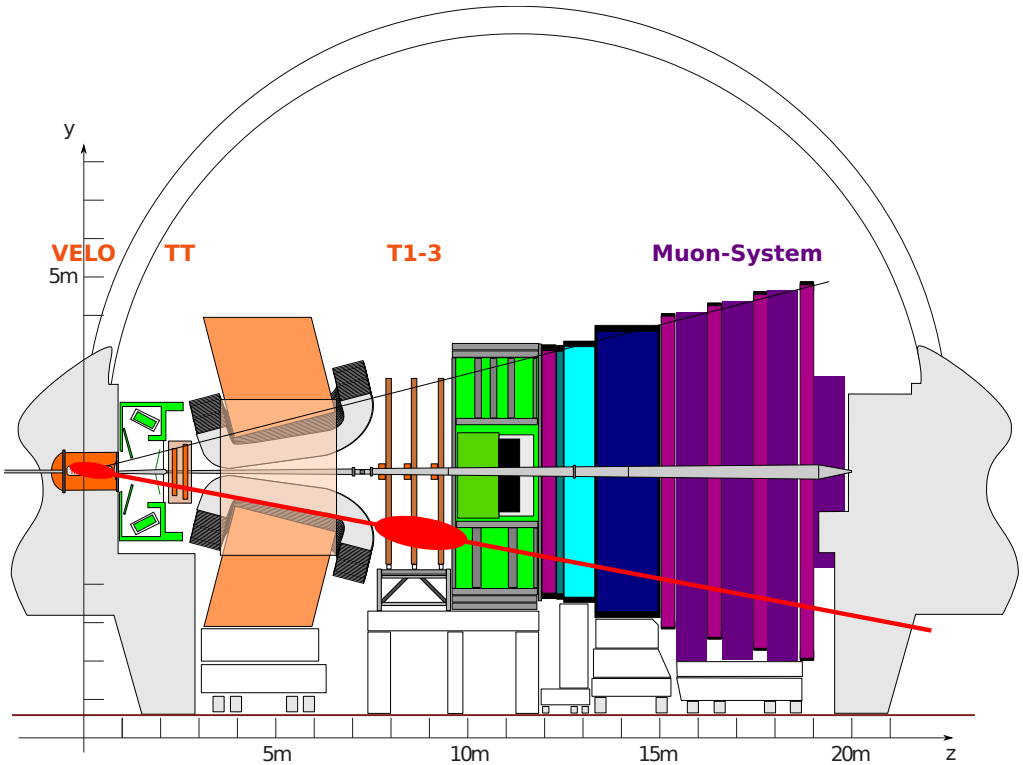

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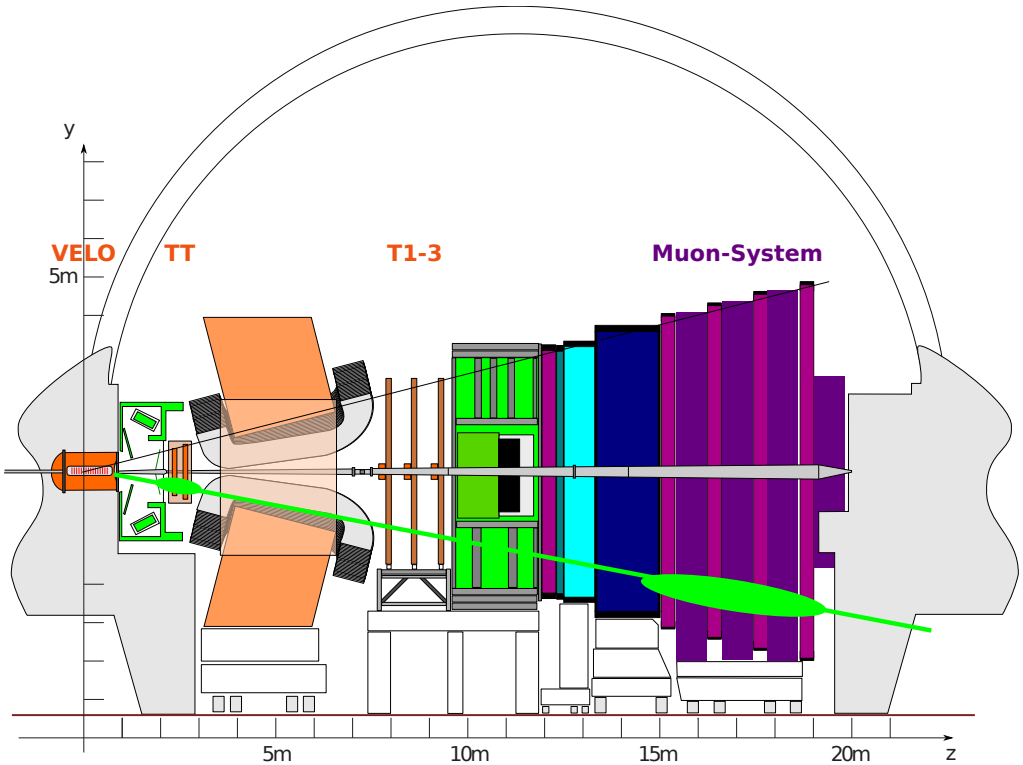

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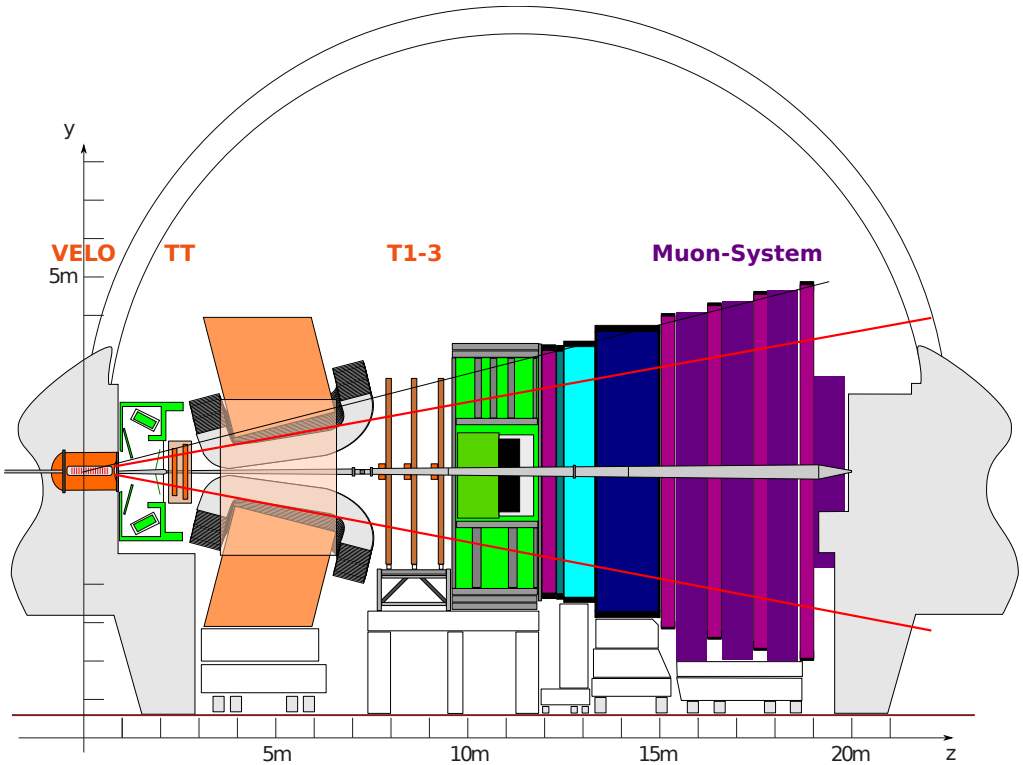

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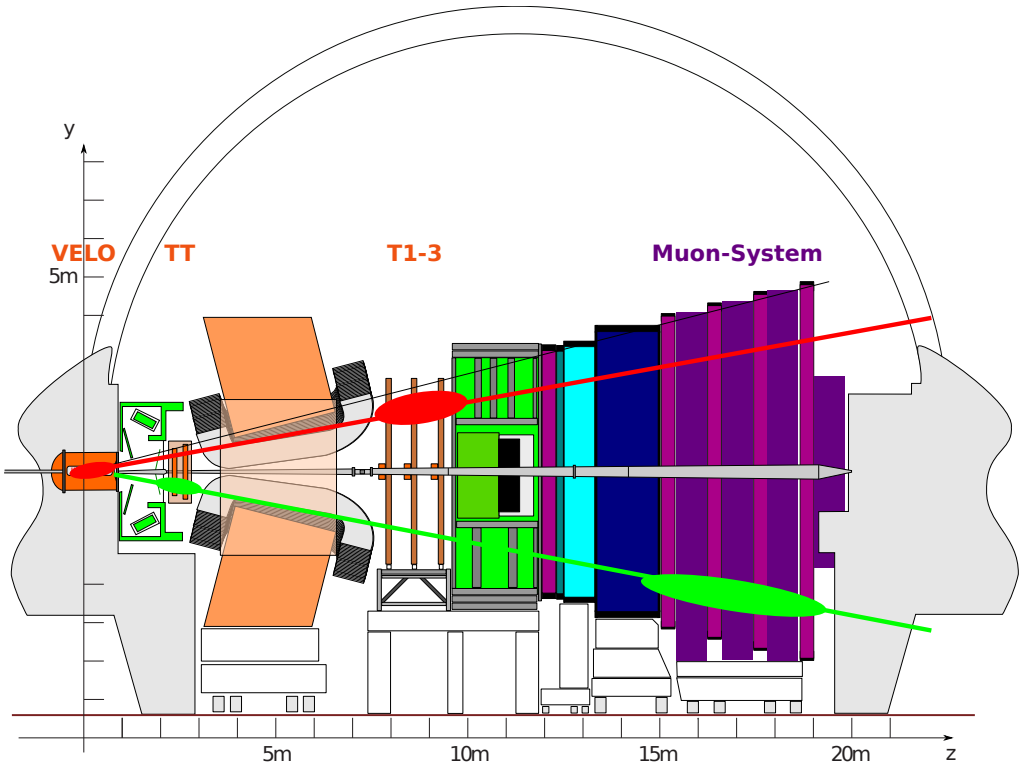

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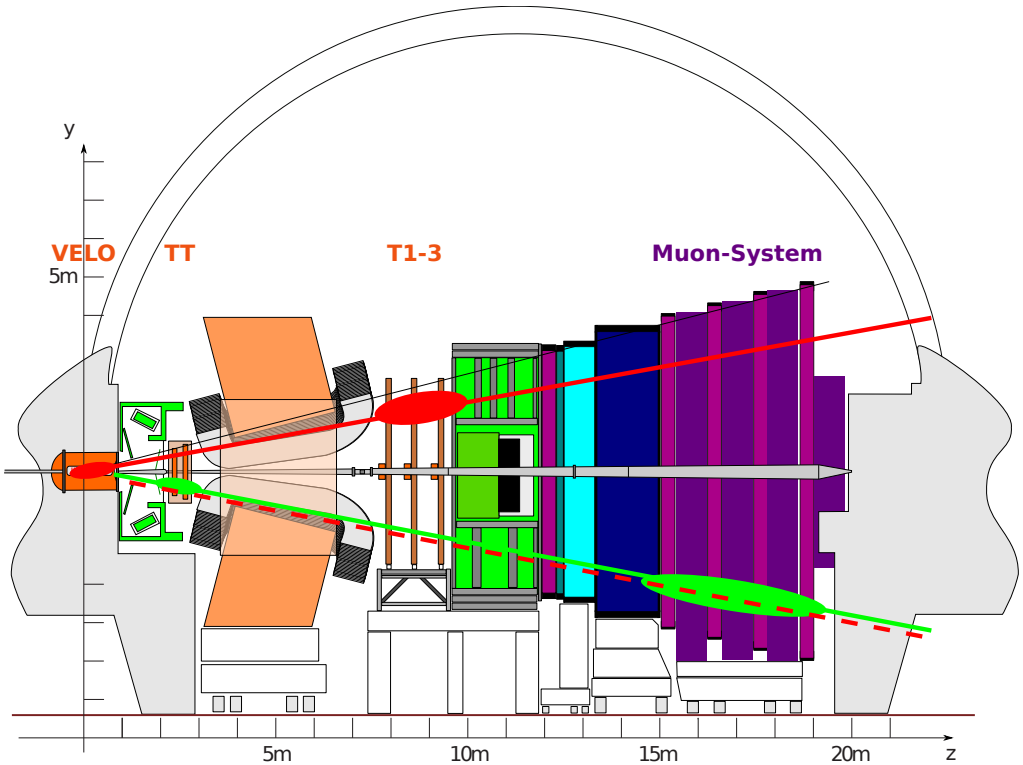

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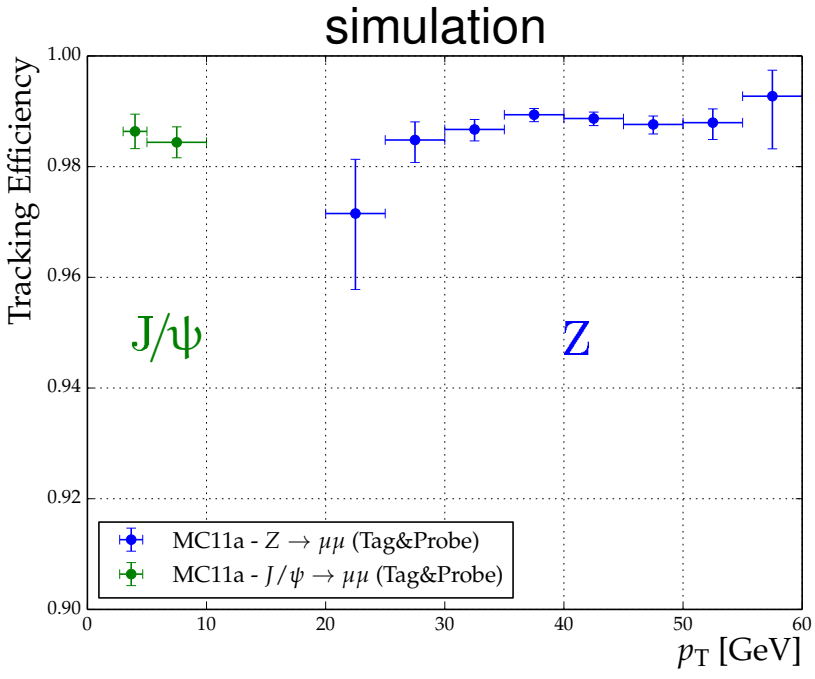
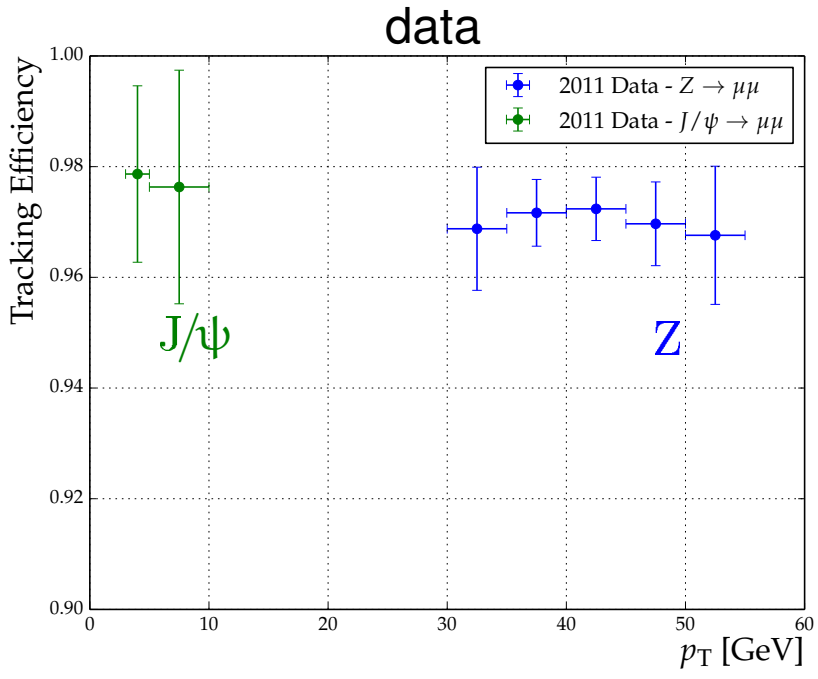
Track Reconstruction Efficiency: Result





- determined with Z and J/ψ decays
- in data and simulation
- constant as function of p_T

$\to$ high-p_T numbers from Z analysis can be used.

Putting Everything Together

$$\sigma = \frac{\rho}{\mathcal{L}} \cdot \frac{f^{\mathrm{MIG}}}{\varepsilon^{\mathrm{SEL}}} \sum_{i=1}^{N} \frac{1}{\varepsilon_i^{\mathrm{TRIG}} \cdot \varepsilon_i^{\mathrm{TRACK}} \cdot \varepsilon_i^{\mathrm{GEC}} \cdot \varepsilon_i^{\mathrm{MUID}}}$$

- $\mathcal{L}$ integrated luminosity ✓
- ρ signal fraction ✓
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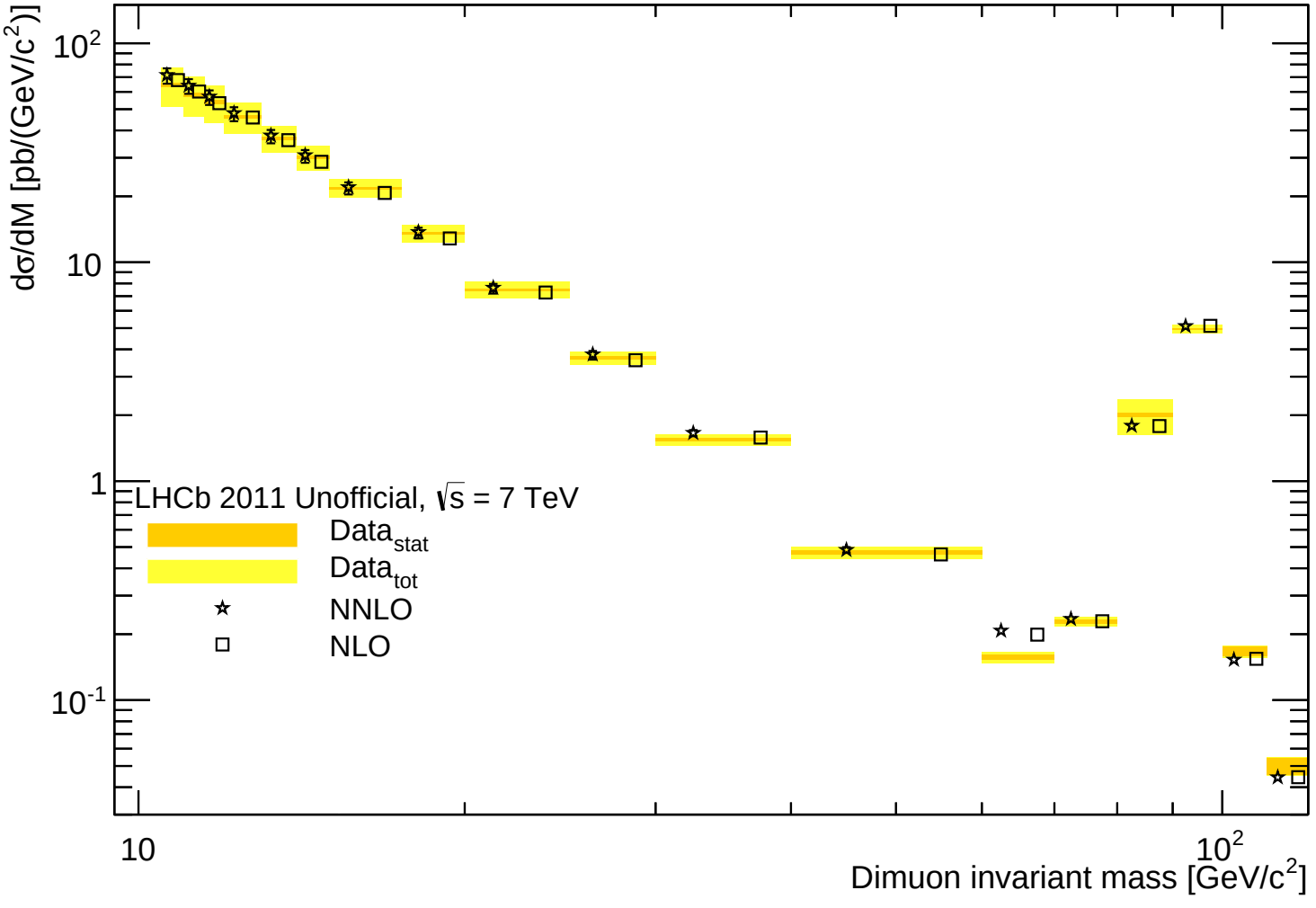
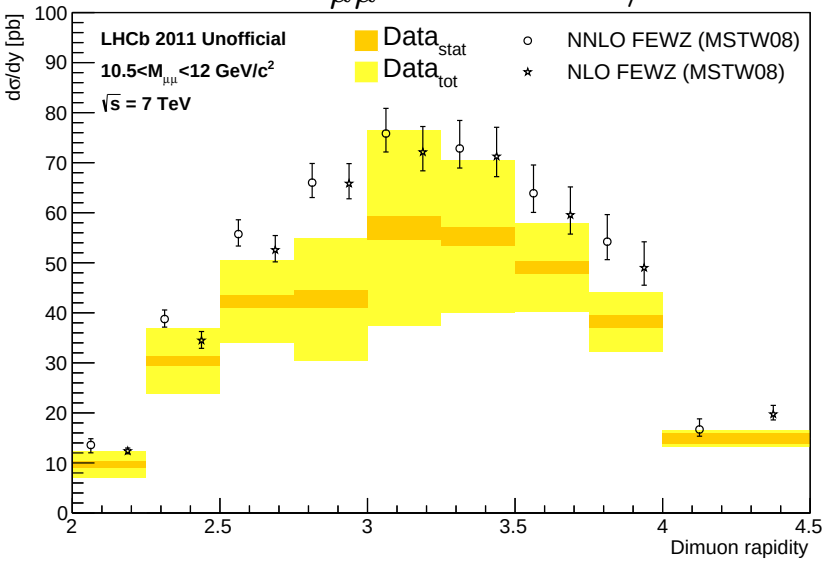
Cross-Section as a Function of Mass

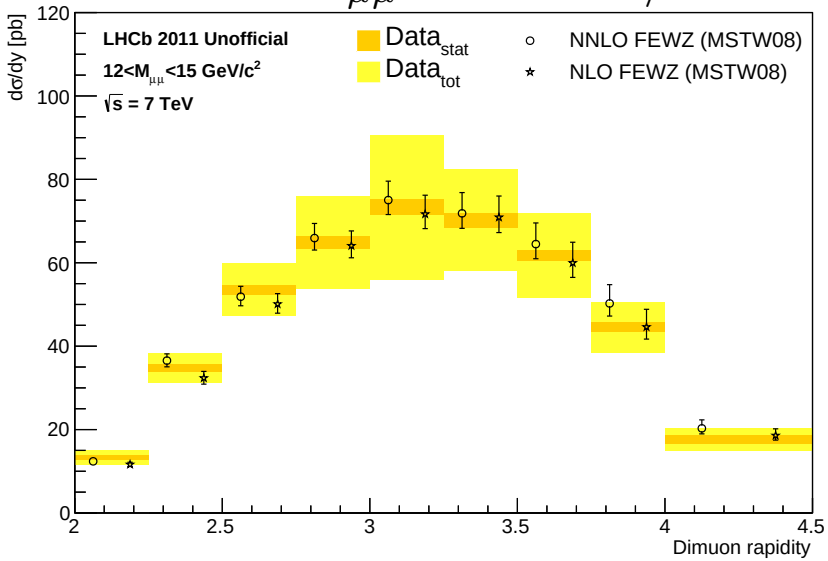


Cross-Section as a Function of Rapidity

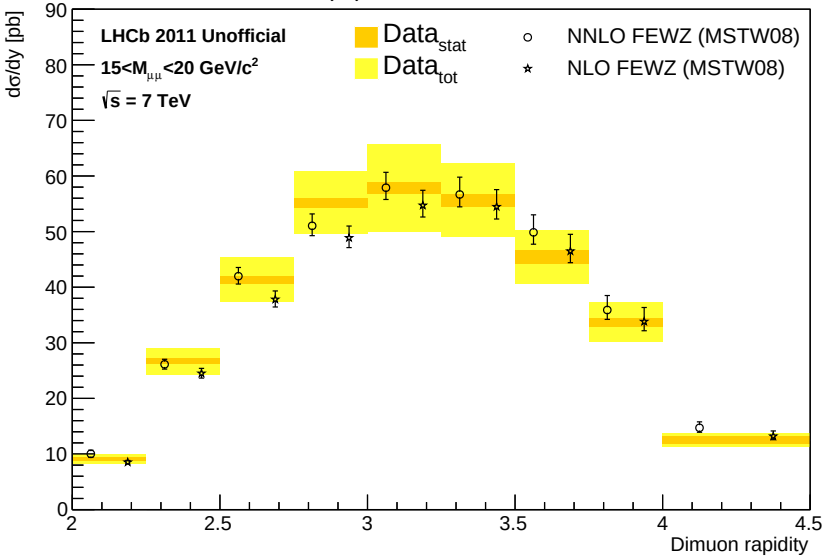
$10.5 < M_{\mu\mu} < 12.0$ GeV/c^2



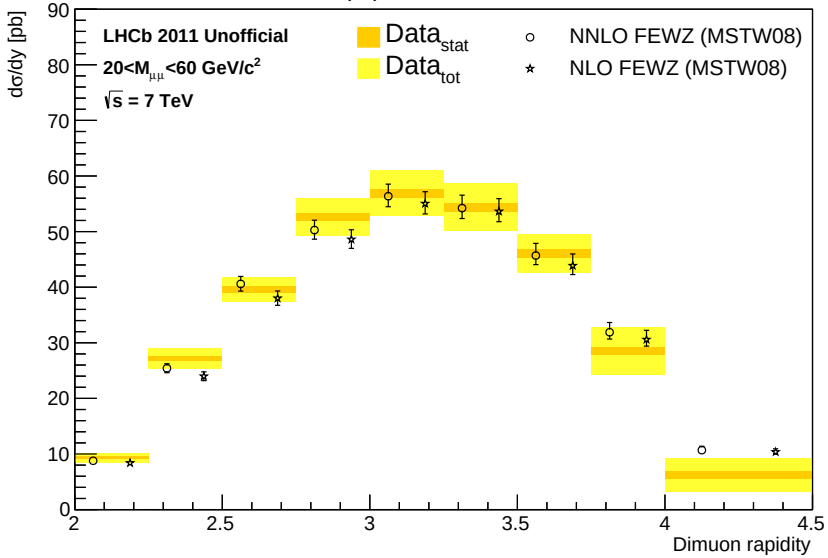
$12.0 < M_{\mu\mu} < 15.0$ GeV/c^2



$15.0 < M_{\mu\mu} < 20.0$ GeV/c^2

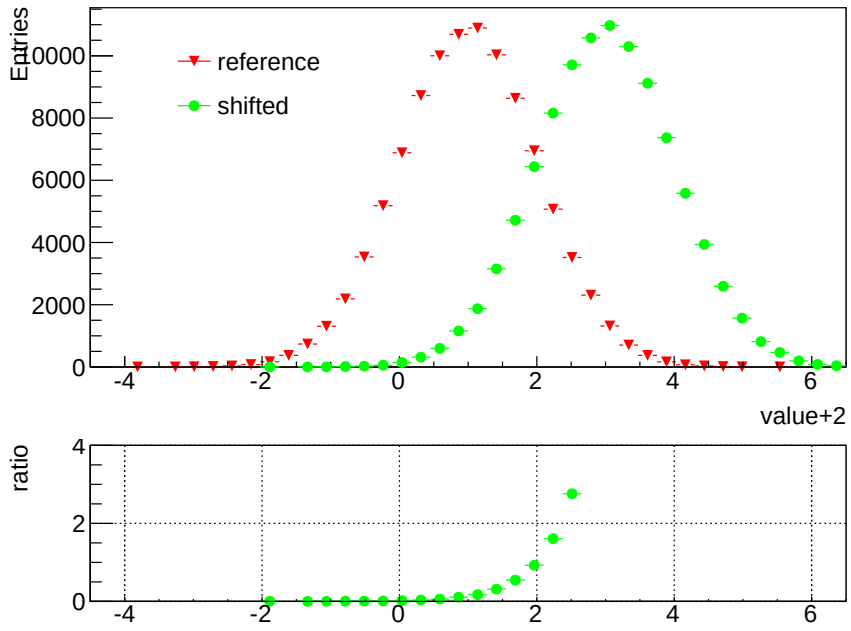


$20.0 < M_{\mu\mu} < 60.0$ GeV/c^2



Closing Remarks

An Advertisement




```
load("gauss_tree")
h = draw("value")
h.SetMarkerStyle(23)
draw("value+2")
draw_ratio()
gCanvs[-1].set_yrange(0, 4, "ratio")
put_texts(ylabel="Entries")
l = legend(["reference", "shifted"],
           pos=(0.2, 0.7, 0.4, 0.9))
l.SetBorderSize(0)
gCanvs[-1].SaveAs("illustration")
```

https://github.com/nchiapol/lookat

Conclusion and Outlook

Result

- differential cross section ($M_{\mu\mu}$, $y_{\mu\mu}$) measured
- mostly good agreement with theory predictions
- result awaited by PDF-fitting collaborations

Possible Improvements

- uncertainty correlations
- understanding of the templates
- correction factors

Thank you for your attention.

and a big Thank You
to all who contributed
to the success of this project

Sources

Lego Globe	WWWally, https://ideas.lego.com/projects/16205
Standard Model	based on Illustration by MissMJ [CC-BY-3.0], via Wikimedia Commons
LHC Overview	Philippe Mouche, http://cds.cern.ch/record/1708847
LHCb	redone; based on Rolf Lindner, http://cds.cern.ch/record/1087860
Feynman Diagrams	done with FeynDiag, http://www.physik.uzh.ch/ che/FeynDiag/
PDF Diagram	Martin, A., W. Stirling, et al. (2009). doi: 10.1140/epjc/s10052-009-1072-5
$x - Q^2$ Plane	based on Anderson, J. S. (2008). CERN-THESIS-2009-020
Z peak	based on LHCB-PAPER-2014-033

Backup

Project Planning

The last thing one knows in constructing a work is what to put first.

$\mathcal{L}$	integrated luminosity
ρ	signal fraction
$\varepsilon^{\text{TRIG}}$	trigger efficiency
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ε^{GEC}	global event cut efficiency
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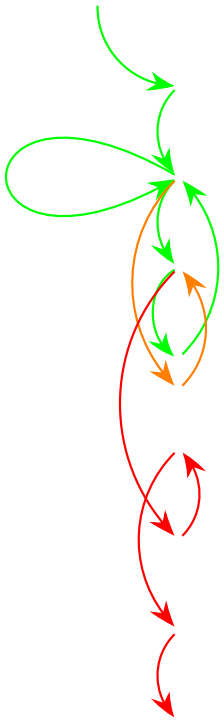

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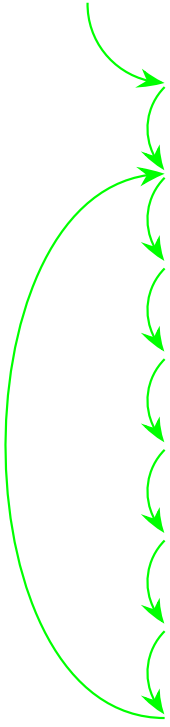

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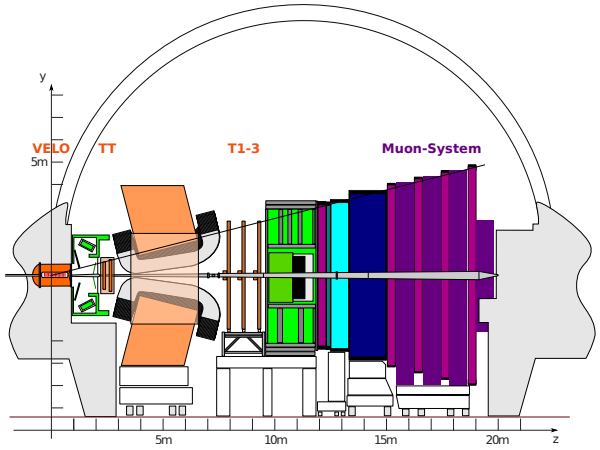
Angular Variables

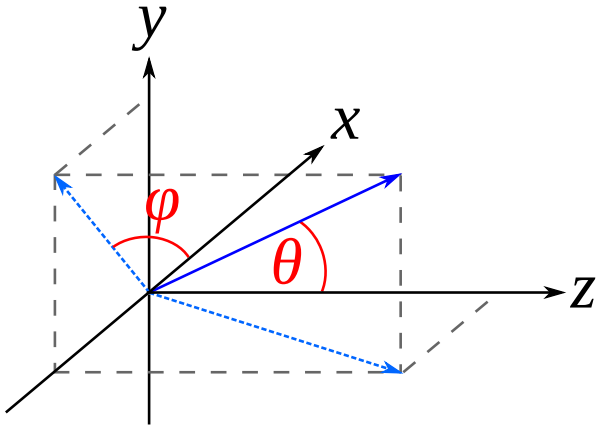
Rapidity

$$y \equiv \frac{1}{2} ln \left(\frac{E + p_z}{E - p_z} \right)$$



Pseudorapidity

$$\eta \equiv -ln \left(tan \left(\frac{\theta}{2} \right) \right)$$



Cone Size

$$\sqrt{\Delta\eta\left(t,\mu\right)^2 + \Delta\phi\left(t,\mu\right)^2} < R$$