Joon-Bin Lee

Search for new physics inside jets using non-isolated leptons

Information

Meeting Title: 2023 SNU-NAPP workshop
Date: 2023.03.29

Profile

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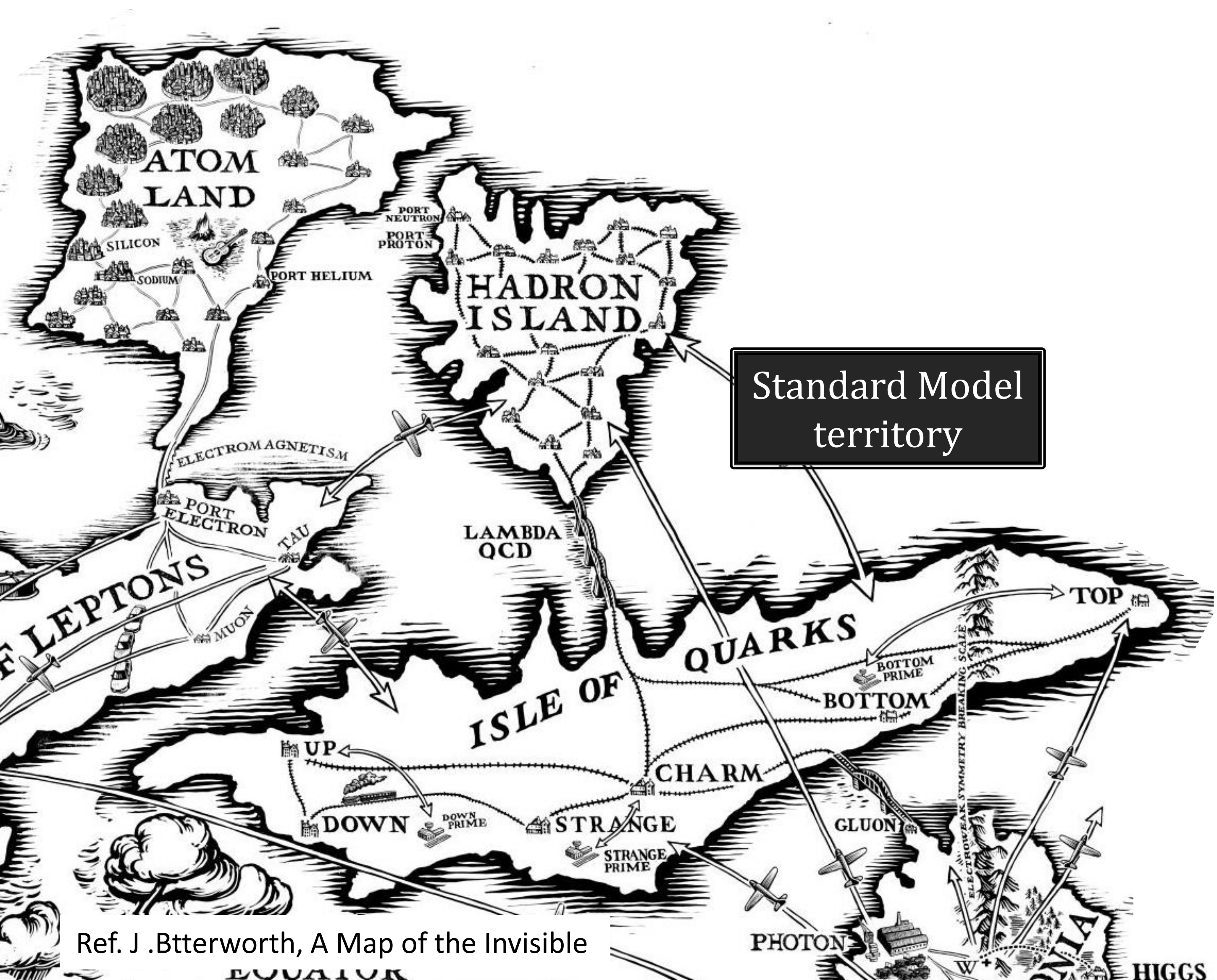
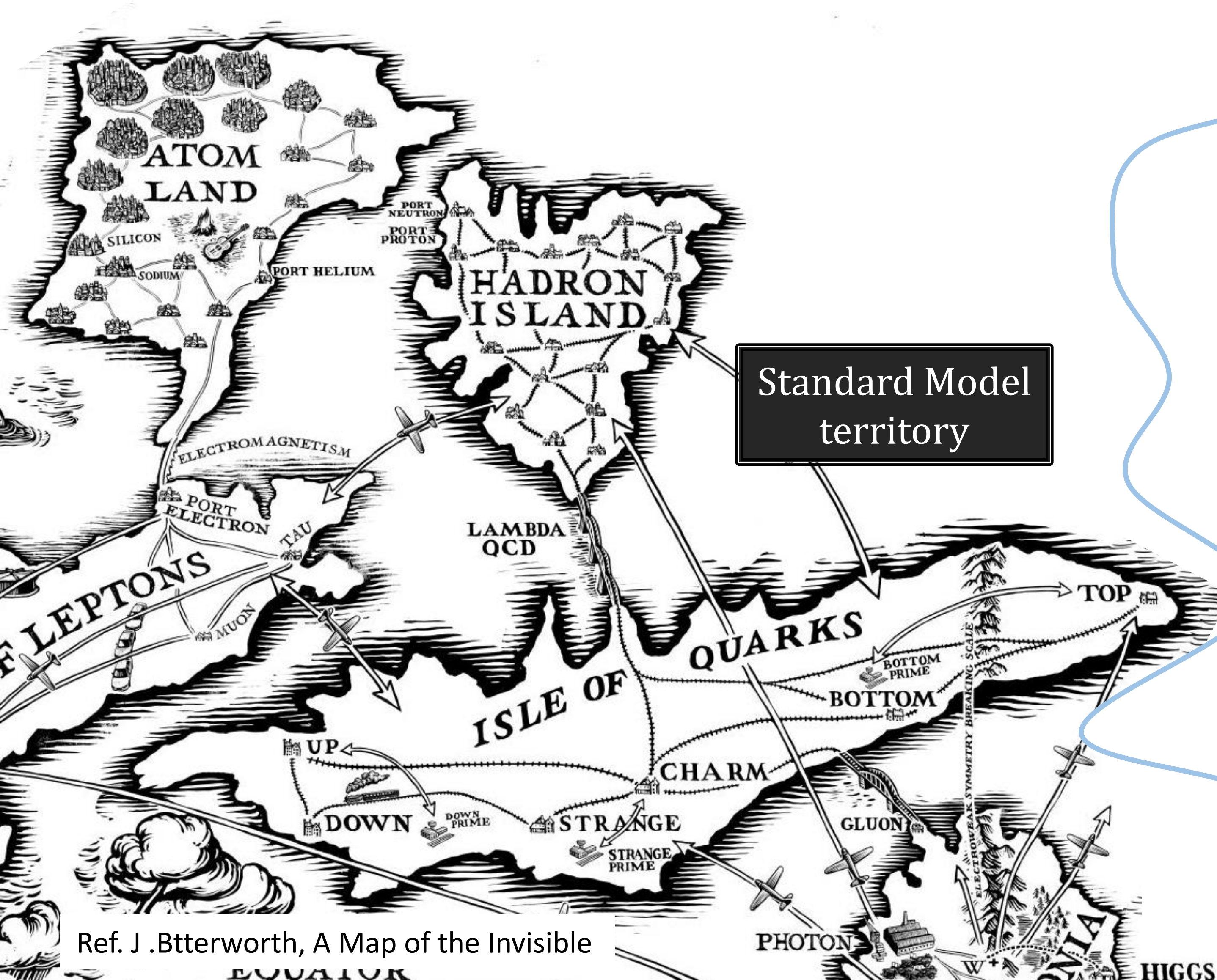
SM can (???) explain everything in the **Universe**



Ref. J .Btterworth, A Map of the Invisible

SM can **NOT** explain everything in the **Universe**



Ref. J .Btterworth, A Map of the Invisible

BSM

Dark Matter/Energy

υ Mass

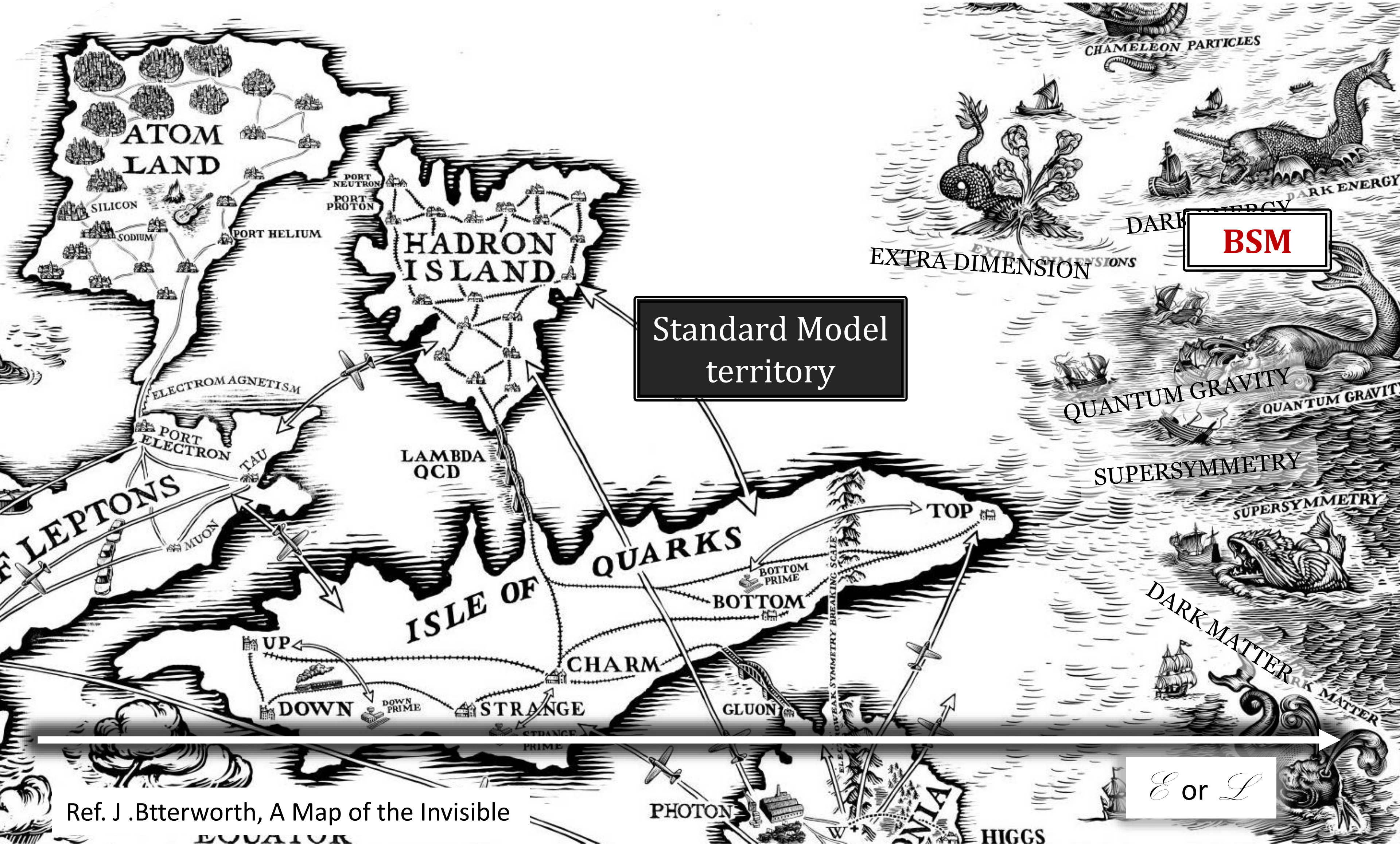
Baryon Asymmetry

Hierarchy Problem

B anomaly

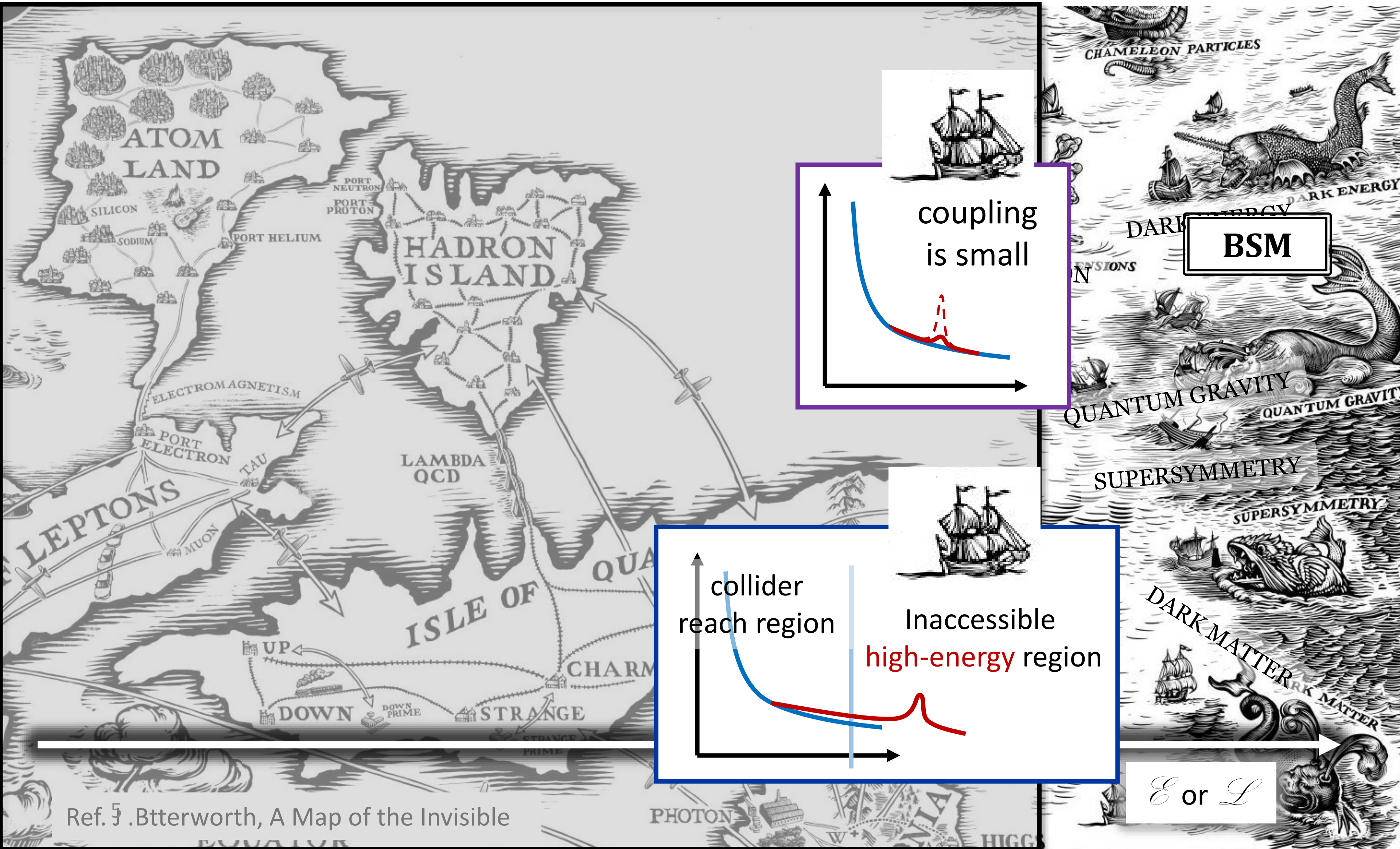
Unexpected W mass

Where is the BSM?



Ref. J .Btterworth, A Map of the Invisible

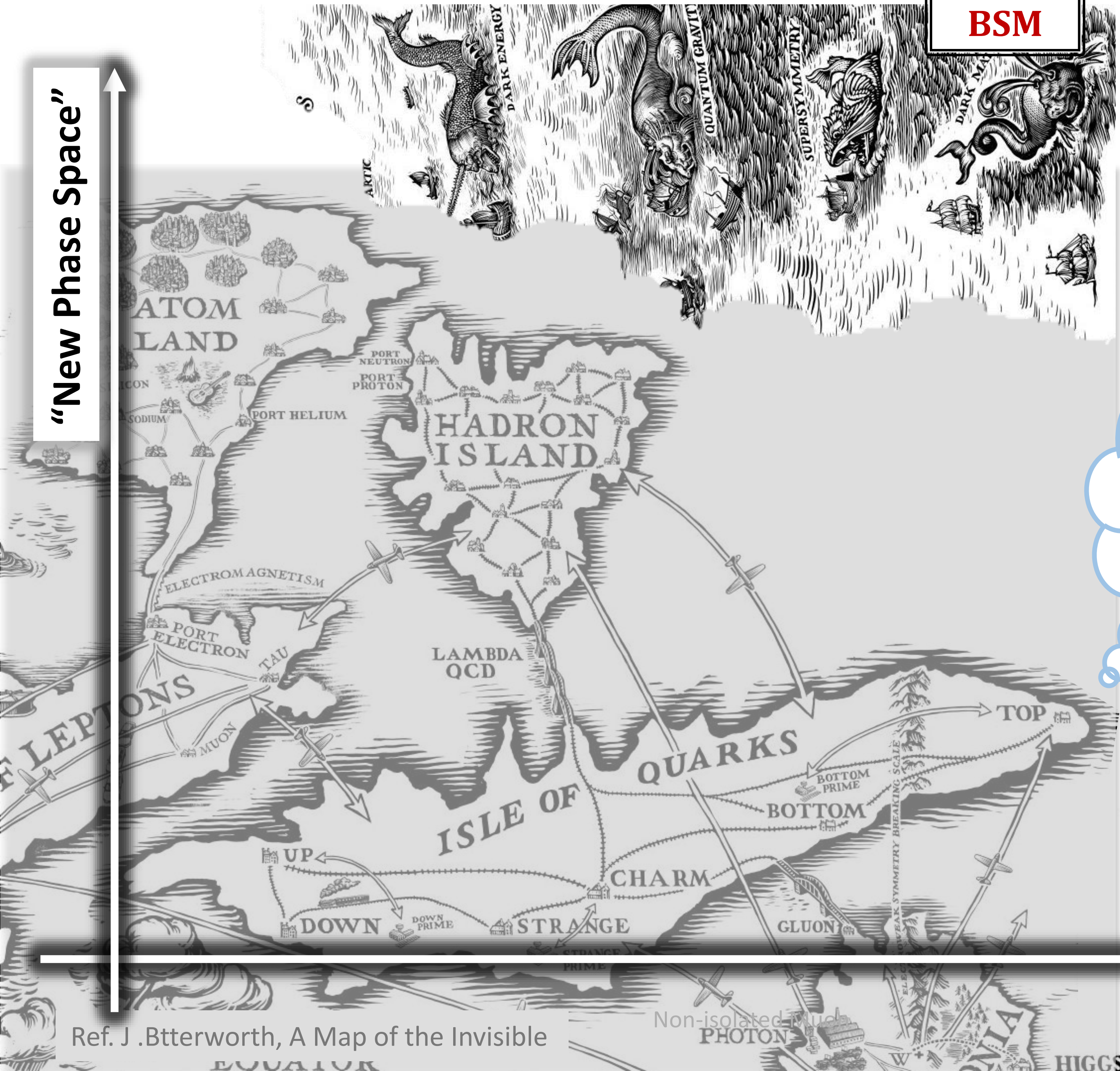
We are exploring **high E & luminosity** regime



Ref. J .Btterworth, A Map of the Invisible

“New Phase Space”

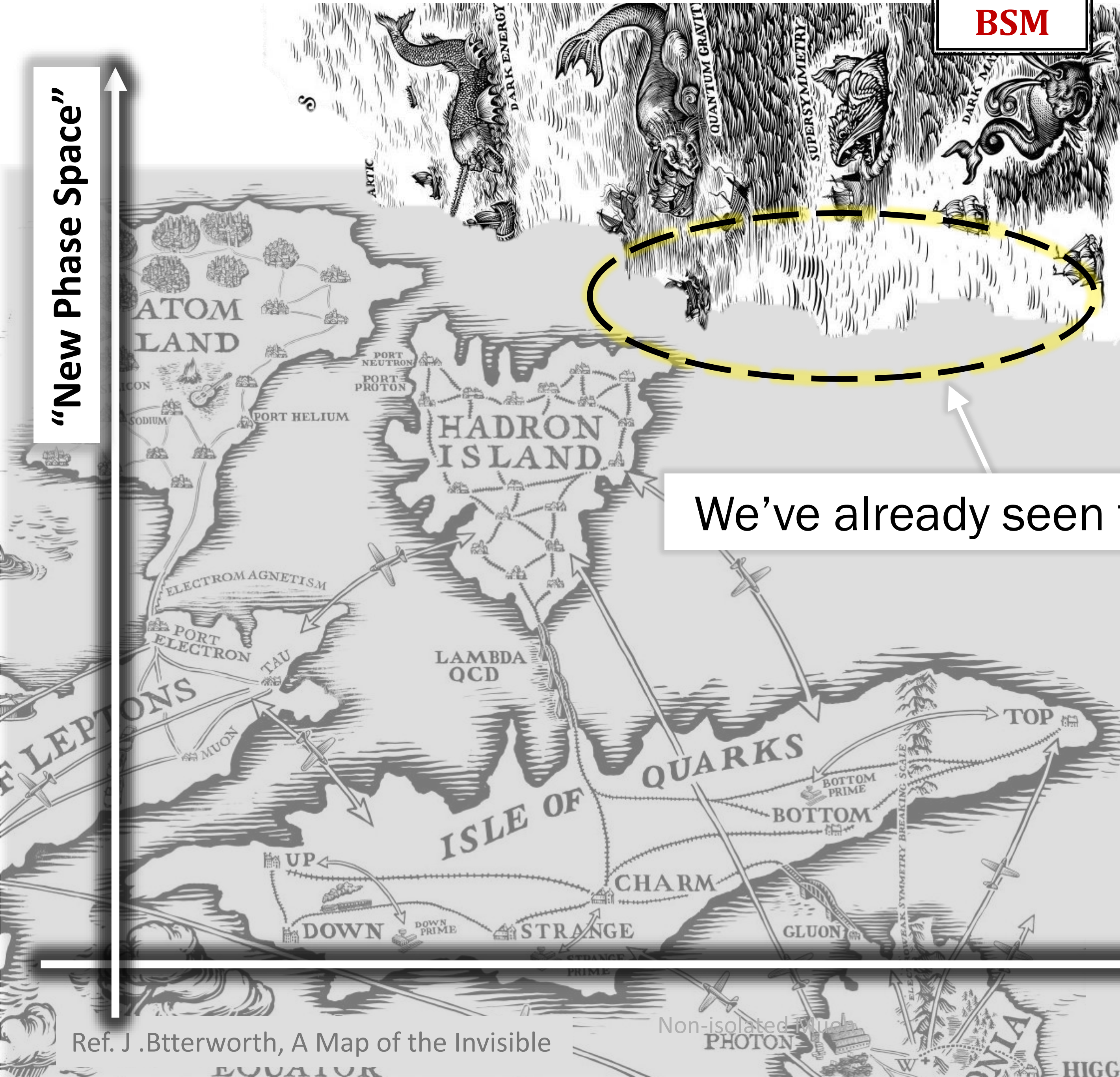
BSM



However,
what if…

$\mathscr{E}$ or $\mathscr{L}$

Ref. J .Btterworth, A Map of the Invisible



BSM

"New Phase Space"

We've already seen the tide of BSM!

Dark Matter/Energy

Baryon Asymmetry

B-anomaly

Muon g-2

Unexpected W mass

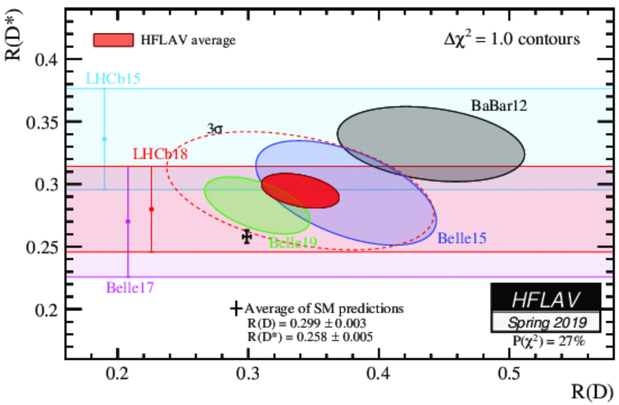
…

$\mathscr{E}$ or $\mathscr{L}$

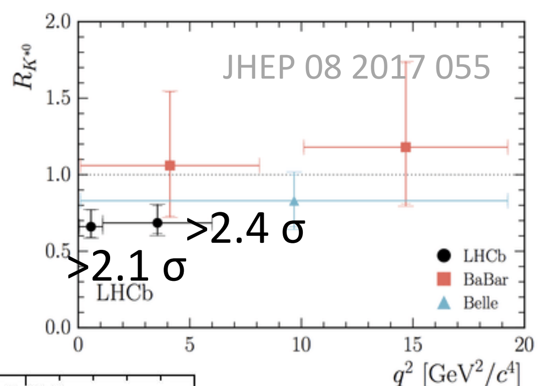
Ref. J .Btterworth, A Map of the Invisible

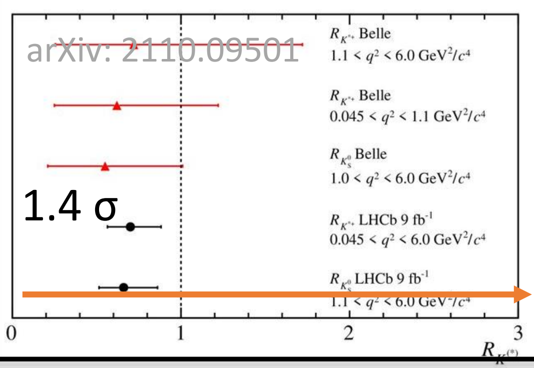
Tide of BSM

“B-anomaly from LHCb experiment”



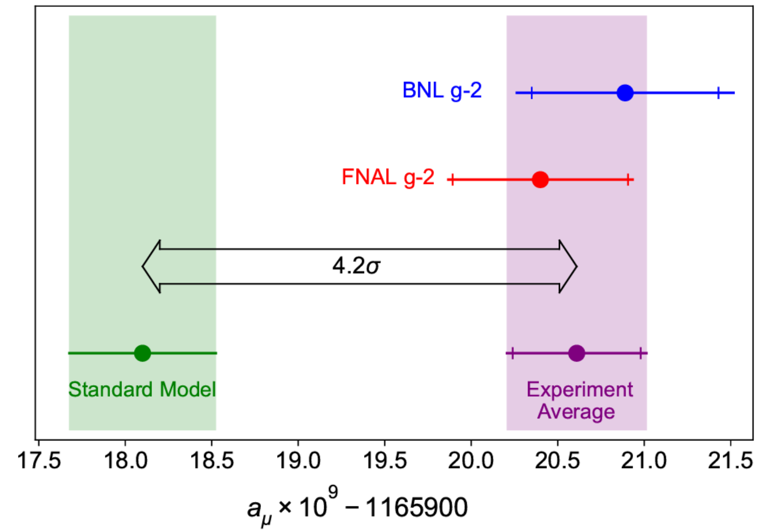
arXiv:1809.06229





3.1 σ deviation at R(K) is disappeared

“Muon g-2 experiment”

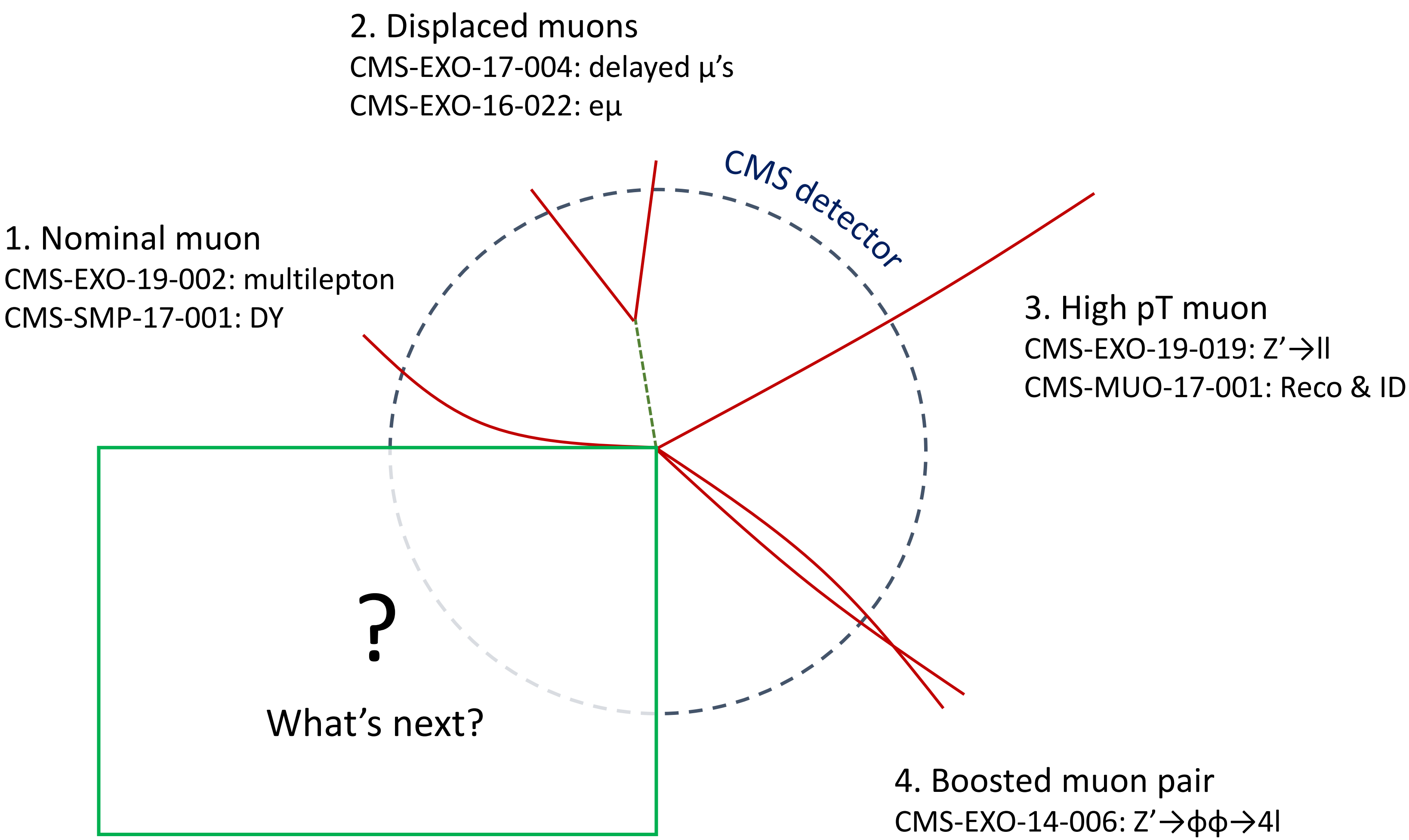


Phys.Rev.Lett. 126 (2021) 14, 141801

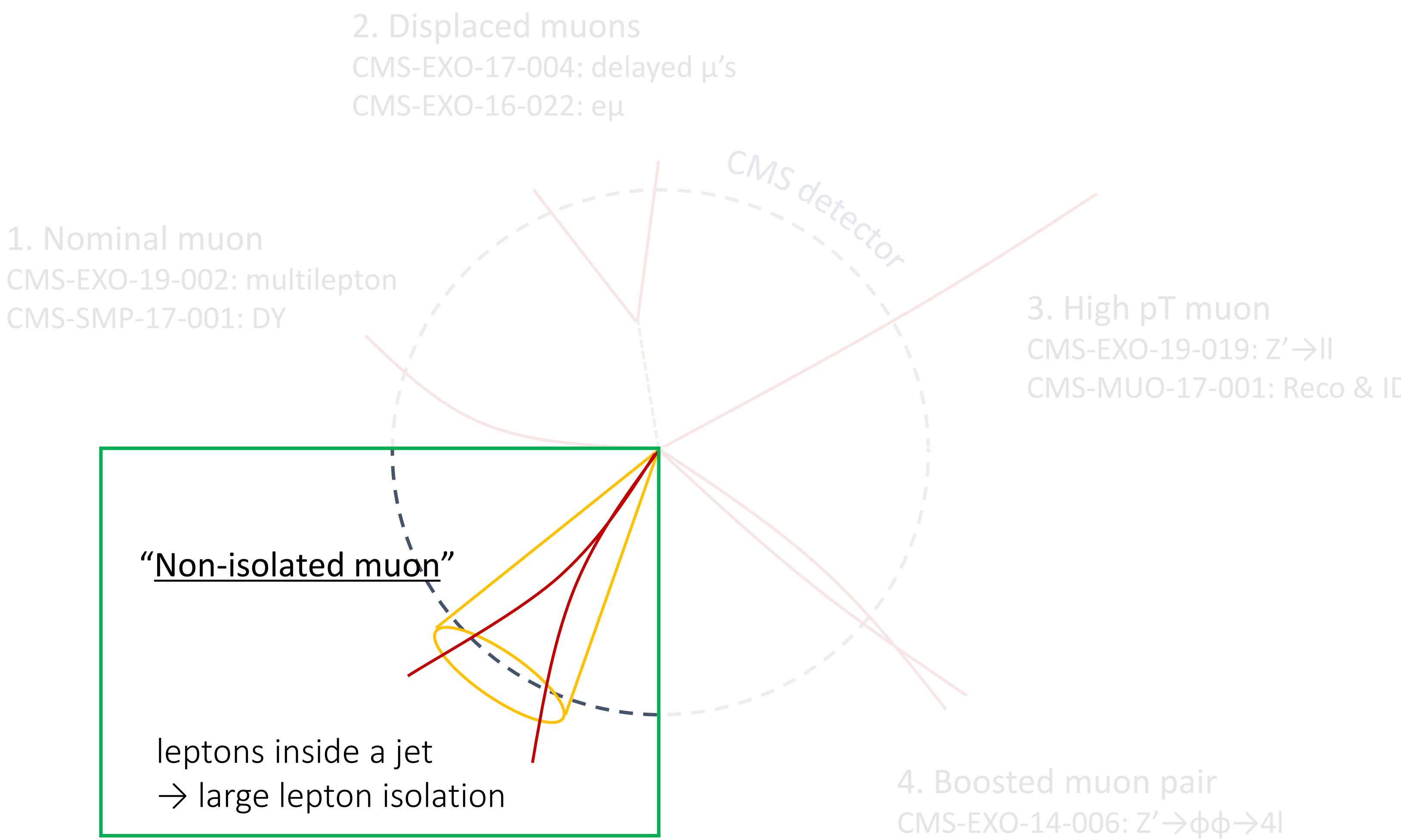
There is something new related with b-jets & muons!

⟹ “*Non-isolated* lepton”

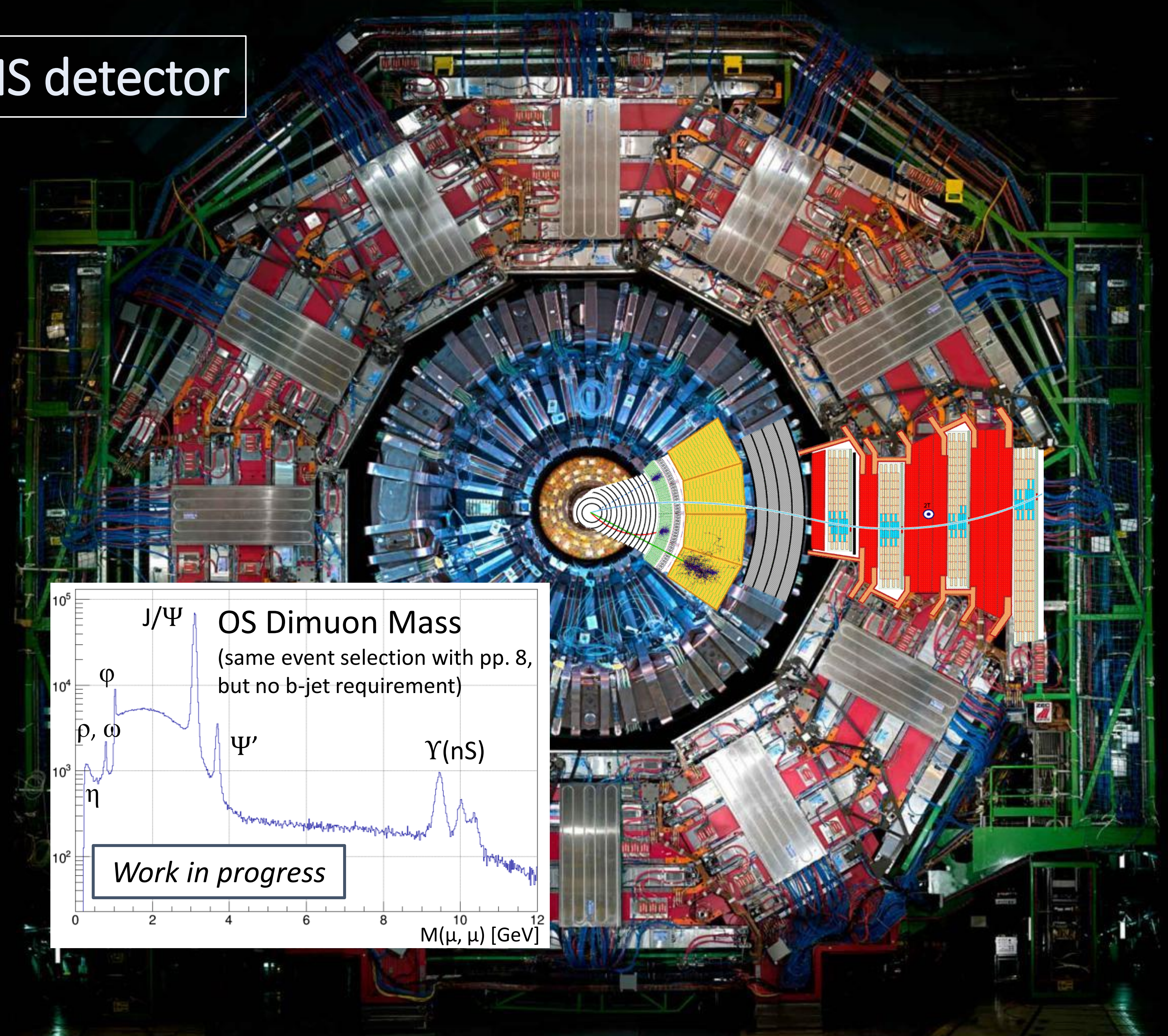
Muon Studies in the CMS Experiment



Muon Studies in the CMS Experiment



CMS detector



Initial difficulty: No generator!!

- How to generate non-isolated signal samples?

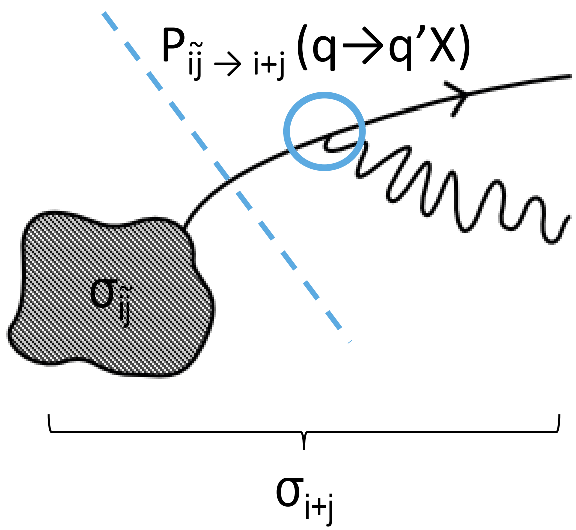
1) Implementing **BSM radiations in Herwig 7** (with Prof. Mike Seymour)

funded by ***Marie Curie Actions***, as a part of ***MCnet project***

2) Goal Calculating as many (general) splitting functions as possible

Parton Shower

- Crop parton shower processes from a hard process



- total cross section

$$d\sigma_{i+j} \simeq \frac{\alpha_{\rm int}(\tilde{q}^2)}{2\pi}\frac{d\tilde{q}^2}{\tilde{q}^2} dz \boxed{P_{\widetilde{ij}\to i+j}(z,\tilde{q})} d\sigma_{\widetilde{ij}},$$

"splitting function"

$$P_{\widetilde{ij}\to i+j}(z,\tilde{q}) = \sum_{\lambda} \left| H_{\widetilde{ij}\to i+j}(z,\tilde{q};\lambda)\right|^2 ,$$

- Iteratively add the splittings using a specific ordering scale($\tilde{q}^2$)

1) <u>Herwig: angular-ordering</u> (θ^2)
2) Pythia 8: pT ordering
3) Pythia 6: virtuality ordering

These orderings are equivalent in soft and collinear region

Spin-0, 1 Splitting functions

- upto $m^2(p_T{}^2)$ order in quasi-collinear limit(m, $p_T \to 0$)

Process	Splitting Function
$q \to q'V$ (same with SM SFs)	$P_{q\to q'V} = \frac{1}{1-z}\Big[(g_L^2\rho_- + g_R^2\rho_+)\Big(\frac{m_0^2(1+z^2)}{z(1-z)\tilde{q}^2} - \frac{(1+z)m_1^2}{z(1-z)\tilde{q}^2} - \frac{m_2^2}{z\tilde{q}^2}\Big) + (g_L^2\rho_+ + g_R^2\rho_-)\frac{m_0^2}{\tilde{q}^2} - (\rho_+ + \rho_-)\frac{2m_0m_1g_Lg_R}{z\tilde{q}^2}\Big]$
$V \to V'V''$	$P^{\text{massive}}_{V\to V'V''}(z,\tilde{q}) = \frac{1}{(1-z)z}(\rho_{-1,-1} + \rho_{1,1})\left[2m_{0,t}^2(1-(1-z)z)^2 - 2m_{1,t}^2\left(1-(1-z)z^2\right) - 2m_{2,t}^2\left(1-(1-z)^2z\right) + 4\rho_{0,0}\, m_{0,t}^2\, z(1-z)^3\right].$
$q \to q'\phi$ (e.g. charged higgs, …)	NEW $P_{q\to q'\phi} = 1 - z + \frac{(m_0+m_1)^2 - m_2^2}{z(1-z)\tilde{(q)}^2}$
$V \to V'\phi$	NEW $P_{V\to V'\phi} = \frac{1}{2}\Big[(\rho_+ + \rho_-)\frac{z(1-z)}{2m_1^2} + \rho_0\frac{1-z}{2m_0^2} + \frac{1}{z(1-z)\tilde{q}^2}\Big\{\frac{\rho_+ + \rho_-}{2}\Big(1 + z + \frac{z(1-z)m_0^2}{m_1^2} - \frac{zm_2^2}{m_1^2} + \frac{\rho_0}{z}\Big(1 - z - \frac{(1-z)m_1^2}{zm_0^2} - \frac{m_2^2}{m_0^2}\Big)\Big\}\Big]$

Spin-0, 1 Splitting functions

- upto $m^2(p_T^2)$ order in quasi-collinear limit($m, p_T \to 0$)

- Upto ~$O(m^0)$ order?

  Ans) VVϕ vertex factor already contain m^2 term

NEW

V→V'ϕ

$$P_{V\to V'\phi} = \frac{1}{2}\Bigg[(\rho_+ + \rho_-)\frac{z(1-z)}{2m_1^2} + \rho_0\frac{1-z}{2m_0^2} + \frac{1}{z(1-z)\tilde{q}^2}\Bigg\{\frac{\rho_+ + \rho_-}{2}\Bigg(1+z + \frac{z(1-z)m_0^2}{m_1^2} - \frac{zm_2^2}{m_1^2}\Bigg) + \frac{\rho_0}{z}\Bigg(1-z-\frac{(1-z)m_1^2}{zm_0^2} - \frac{m_2^2}{m_0^2}\Bigg)\Bigg\}\Bigg]$$

Spin-2 Splitting functions

- Considering Kaluza-Klein excitations of gravitons

Eur.Phys.J.C56:435-447,2008

Fermion-Fermion-Graviton Lagrangian:

$$\mathcal{L}_{\rm FFT} = 4\mathrm{GT}\, T^{\mu\nu *}\Big[-\eta_{\mu\nu}\Big\{\bar{f}(i\gamma^{\rho}\partial_{\rho}-m_F)f-\frac{1}{2}\partial^{\rho}(\bar{f}i\gamma_{\rho}f)\Big\} + \Big\{\frac{1}{2}\bar{f}i\gamma_{\mu}\partial_{\nu}f-\frac{1}{4}\partial_{\mu}(\bar{f}i\gamma_{\nu}f)+(\mu\leftrightarrow\nu)\Big\}\Big], \quad (28)$$

NEW

$$\begin{aligned} P_{q\to qG} = \rho_+ \Bigg[& \Big[\frac{4p_T^2}{\sqrt{z}(1-z)^2}\Big]^2 + \Big[\frac{4p_T(m_1-zm_0)}{(1-z)\sqrt{z}}\Big]^2 \\ & + \Big[2p_T\frac{(1-z)^2(m_1+zm_0)m_1-2z^2m_2^2+(1-z)p_T^2}{(1-z)^2z^{3/2}m_2}\Big]^2 \\ & + \Big[2\frac{m_1\big(m_1^2(1-z)^2-z^2m_2^2+(1+z)p_T^2\big)-zm_0\big((1-z)^2m_1^2-z^2m_2^2+2p_T^2\big)}{(1-z)z^{3/2}m_2}\Big]^2 + \ldots \Bigg] \\ & + \rho_-(\ldots) \end{aligned}$$

1. Why do we calculate it **upto ~O(m^4)** order?

   - **<u>ffG coupling contain 1/M_{Pl} term</u>**

2. Why is it so complicated?

   - We should consider all combinations between m_0, m_1, m_2, and p_T

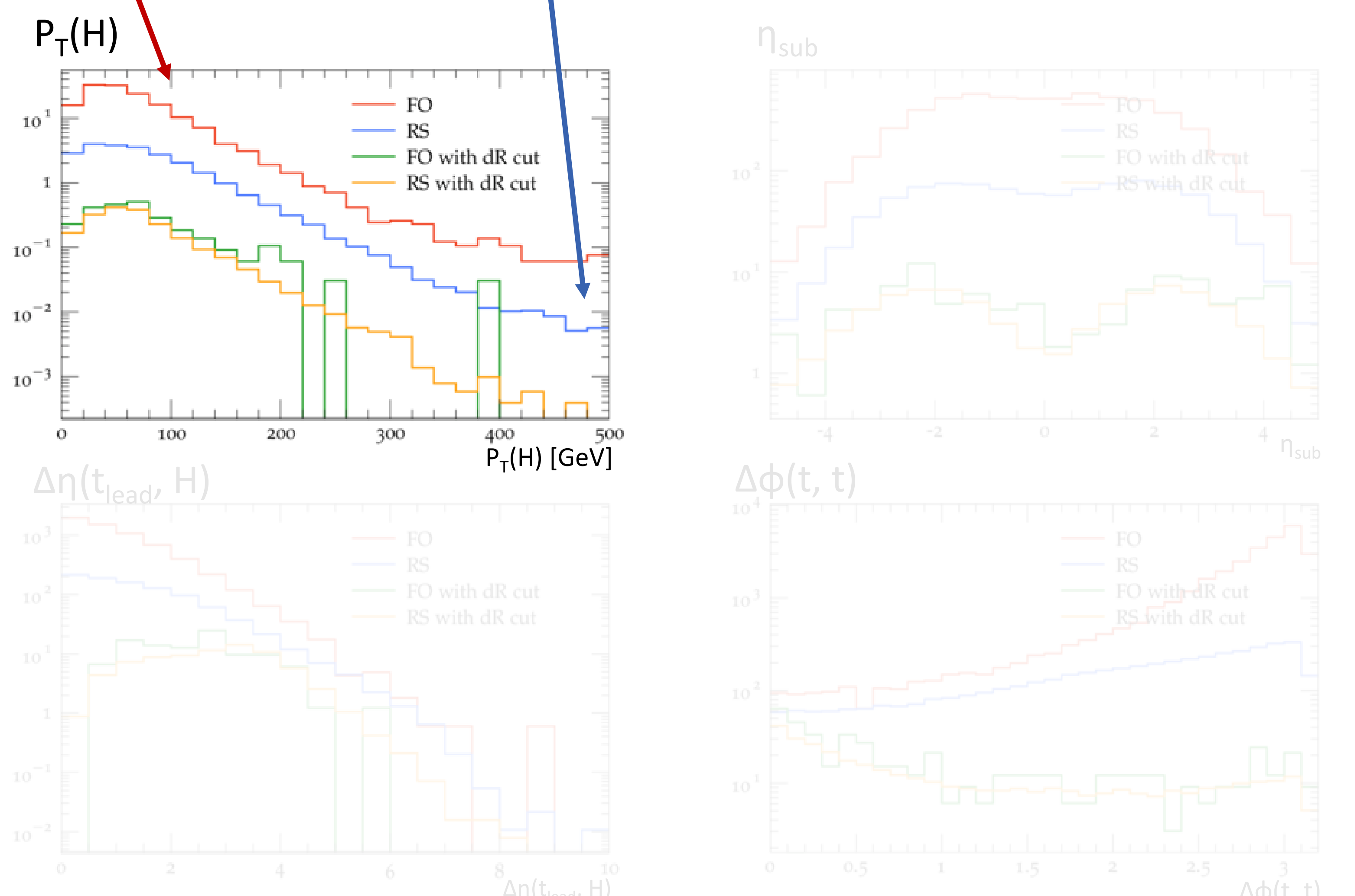
Results

- q → qH splitting is validated using "***ttbar+H_{BSM} sample***" with the type-II 2HDM

- FO: [p p → t t~ H] MG

- RS: [p p > t t~] + [t → t H] MG Herwig7

m(H_{BSM}) = 50 GeV



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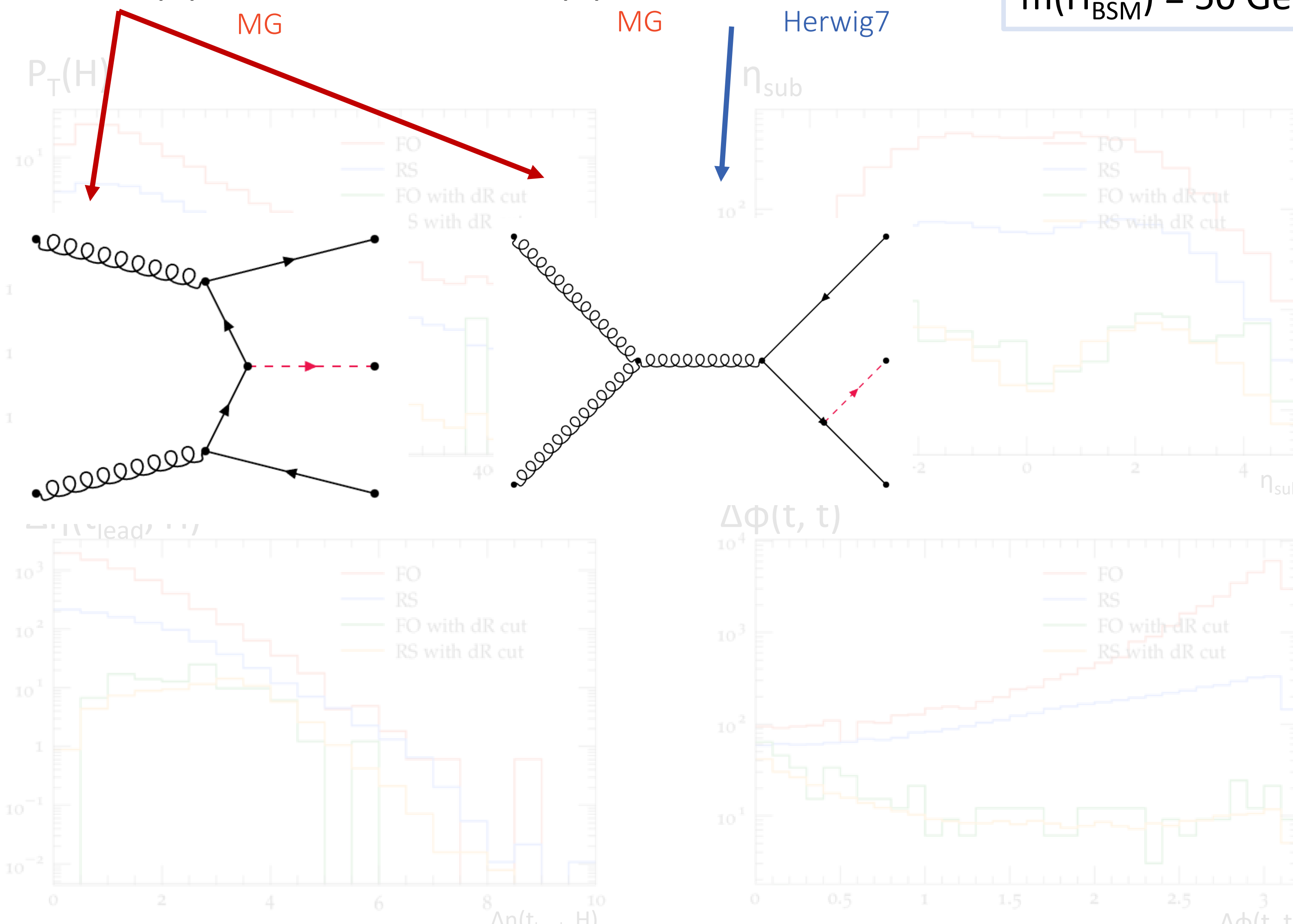

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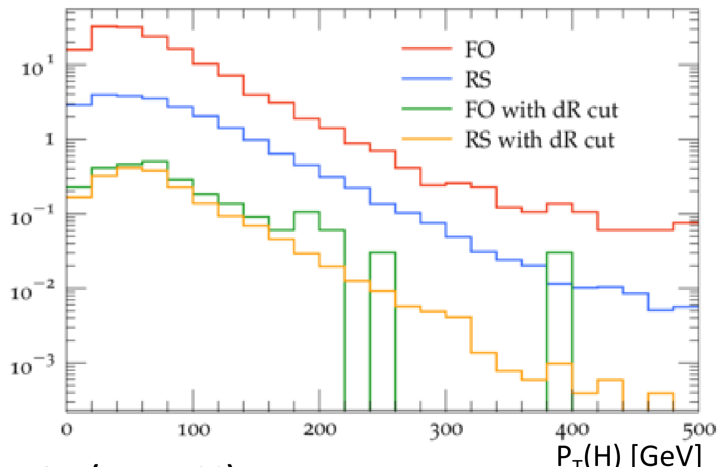
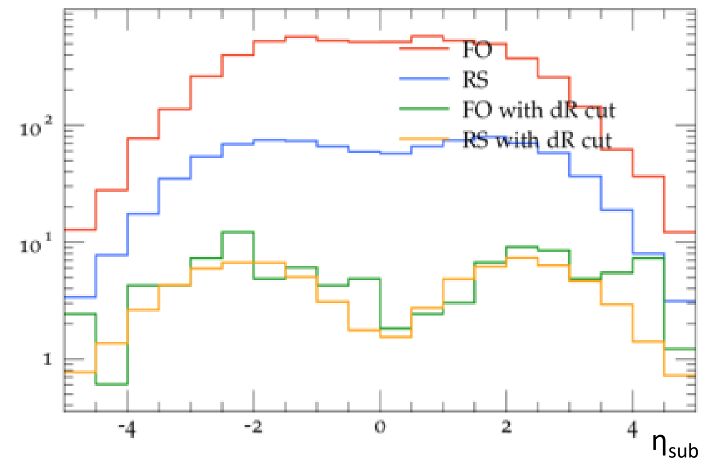
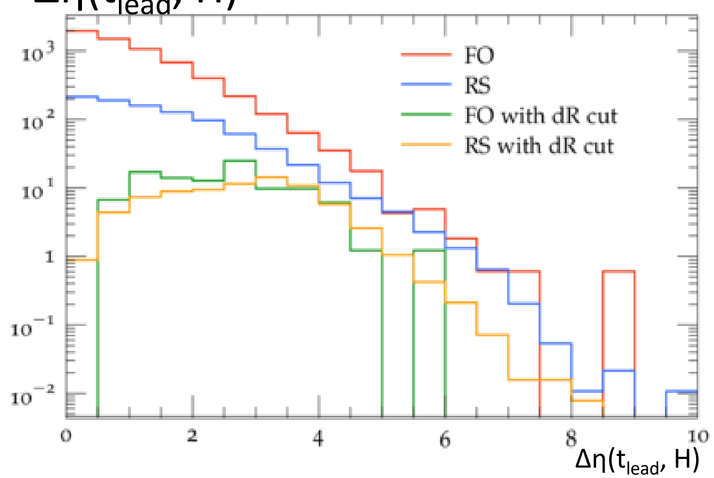
$P_T(H)$



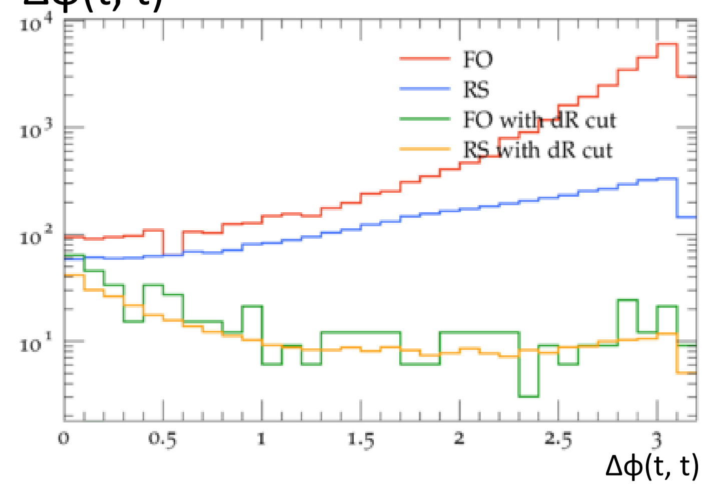
η_{sub}



$\Delta\eta(t_{lead}, H)$



$\Delta\phi(t, t)$



Results

- Splitting function implementation status in Herwig 7

EWK shower in Herwig 7

Prepared for submission to JHEP

Implementation of Angularly Ordered Electroweak Parton Shower in Herwig 7

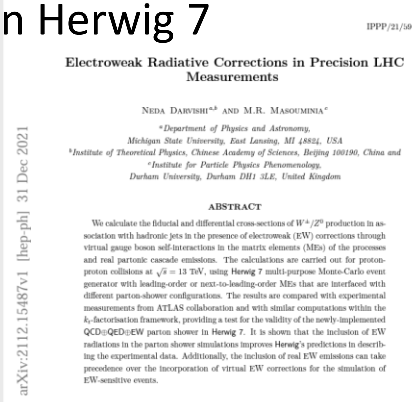
arXiv:2108.10817v1 [hep-ph] 24 Aug 2021

M.R. Masouminia,[a] P. Richardson[a,b]

[a] *Institute for Particle Physics Phenomenology, Durham University, Durham, UK*
[b] *Theoretical Physics Department, CERN, Switzerland*
E-mail: mohammad.r.masouminia@durham.ac.uk, peter.richardson@durham.ac.uk

Abstract: We discuss the necessary steps for implementing an angularly ordered (AO) electroweak (EW) parton shower in Herwig 7 multi-purpose event generator. This includes calculating the helicity-dependent quasi-collinear EW branching functions that correspond to the full range of final-state EW parton shower, in addition to the initial-state EW gauge vector boson radiations. The results are successfully embedded in the AO Herwig 7 shower algorithm and have undergone a set of comprehensive and conclusive performance tests. Furthermore, we have used this EW parton shower algorithm, alongside the existing $QCD + QED$ AO shower, to predict the angular distributions of $W^{\pm}$ bosons in LHC events with high transverse momentum jets. These results are compared against the explicitly generated underlying events as well as the existing ATLAS data to show the effectiveness of the newly implemented $QCD + QED + EW$ AO parton shower scheme.

M.R. Masouminia & P. Richardson, arXiv: 2108.10817 (24.AUG.2021)



IPPP/21/59

Electroweak Radiative Corrections in Precision LHC Measurements

arXiv:2112.15487v1 [hep-ph] 31 Dec 2021

Neda Darvishi[a,b] and M.R. Masouminia[c]

[a] *Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA*
[b] *Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, China and*
[c] *Institute for Particle Physics Phenomenology, Durham University, Durham DH1 3LE, United Kingdom*

ABSTRACT

We calculate the fiducial and differential cross-sections of $W^{\pm}/Z^0$ production in association with hadronic jets in the presence of electroweak (EW) corrections through virtual gauge boson self-interactions in the matrix elements (MEs) of the processes and real partonic cascade emissions. The calculations are carried out for proton-proton collisions at $\sqrt{s} = 13$ TeV, using Herwig 7 multi-purpose Monte-Carlo event generator with leading-order or next-to-leading-order MEs that are interfaced with different parton-shower configurations. The results are compared with experimental measurements from ATLAS collaboration and with similar computations within the k_t-factorisation framework, providing a test for the validity of the newly-implemented QCD⊕QED⊕EW parton shower in Herwig 7. It is shown that the inclusion of EW radiations in the parton shower simulations improves Herwig's predictions in describing the experimental data. Additionally, the inclusion of real EW emissions can take precedence over the incorporation of virtual EW corrections for the simulation of EW-sensitive events.

N. Darvishi & M.R. Masouminia, arXiv: 2112.15487 (31.DEC.2021)

BSM shower

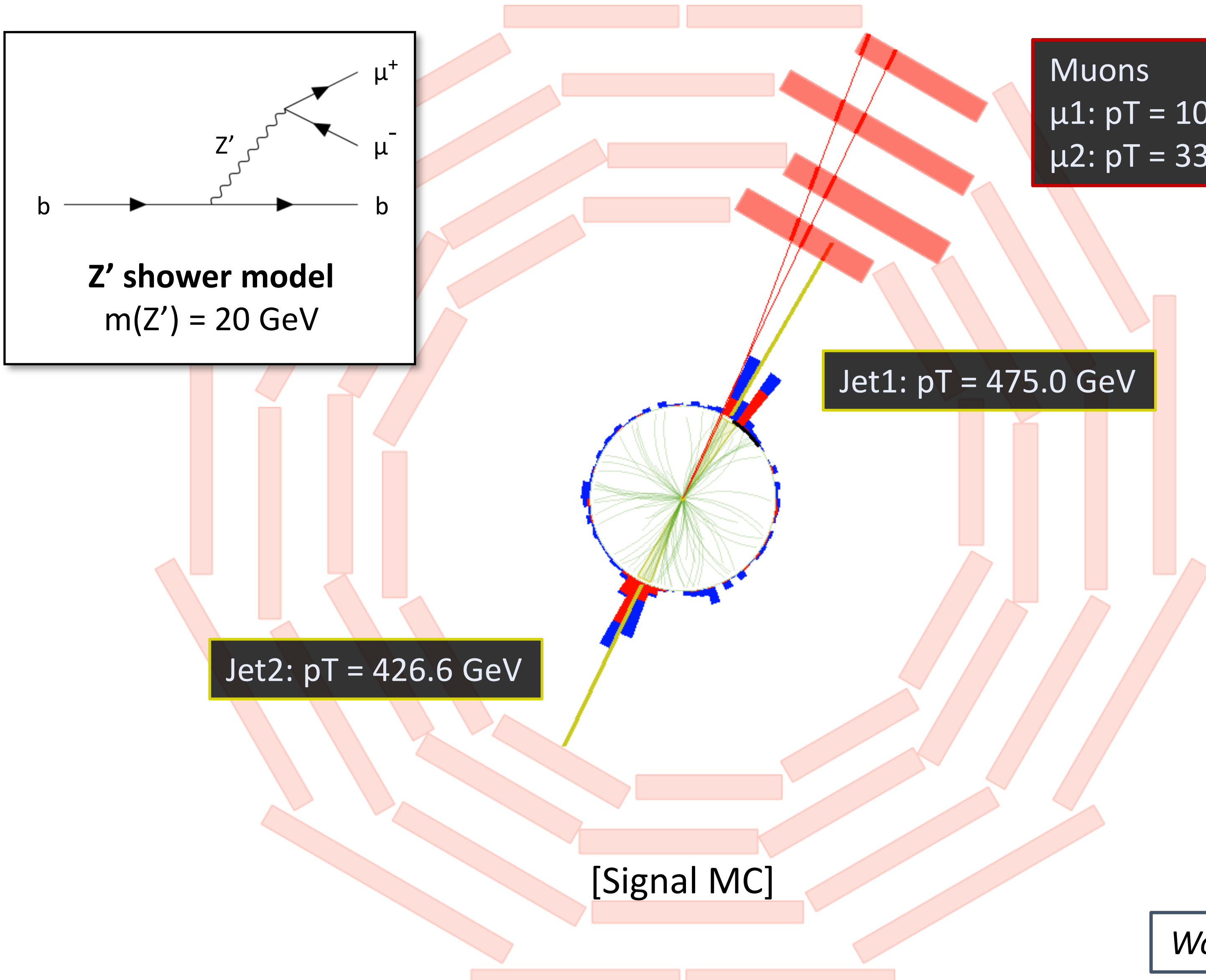
will be published soon!

J.-B. Lee & M. Seymour (2023)

This will be used in…

- Most of low scale BSM searches in future collider experiments
- Dark sector shower, e.g. Hidden Valley model
- BSM search using non-isolated leptons

Signal kinematics



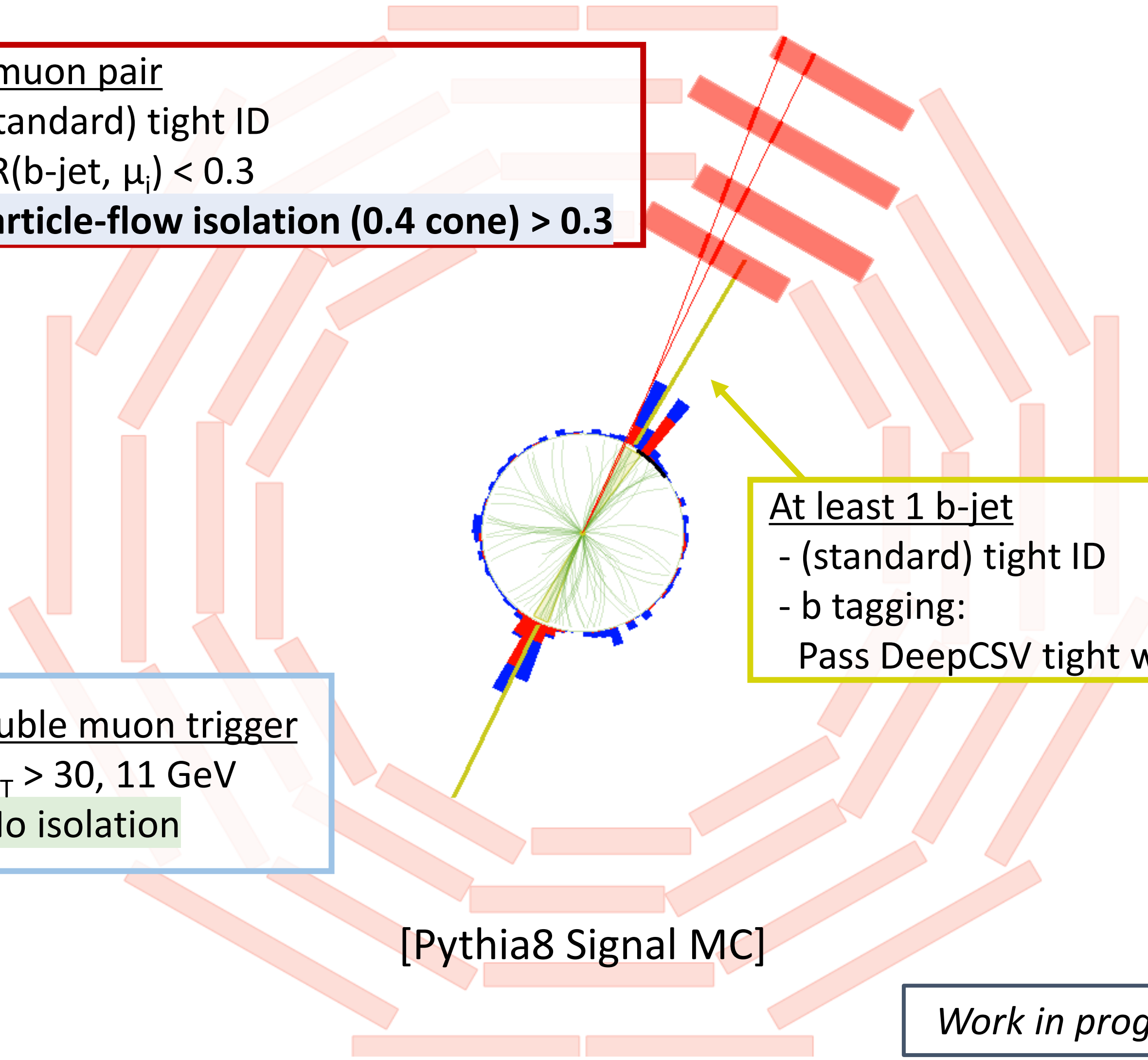
Z' shower model
m(Z') = 20 GeV

[Signal MC]

Work in progress

BSM search using non-isolated dimuon in CMS

- full 2016 CMS datasets (L = 36 /fb, 13 TeV) → will use Full Run2 datasets



OS muon pair
- (standard) tight ID
- ΔR(b-jet, μ_i) < 0.3
- **Particle-flow isolation (0.4 cone) > 0.3**

At least 1 b-jet
- (standard) tight ID
- b tagging:
  Pass DeepCSV tight working point

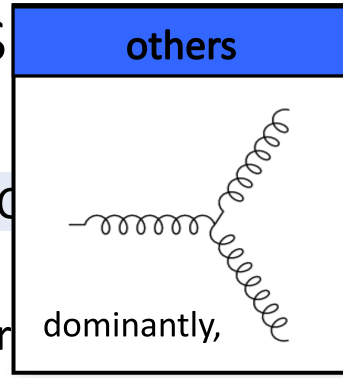
Double muon trigger
- p_T > 30, 11 GeV
- No isolation

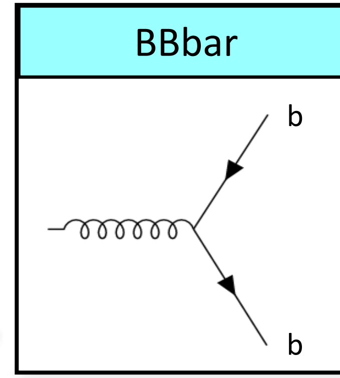
[Pythia8 Signal MC]

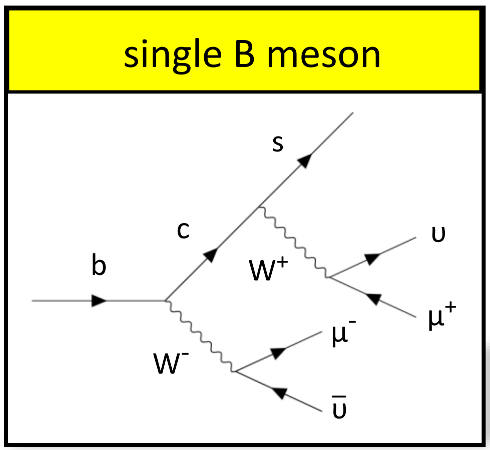
Work in progress

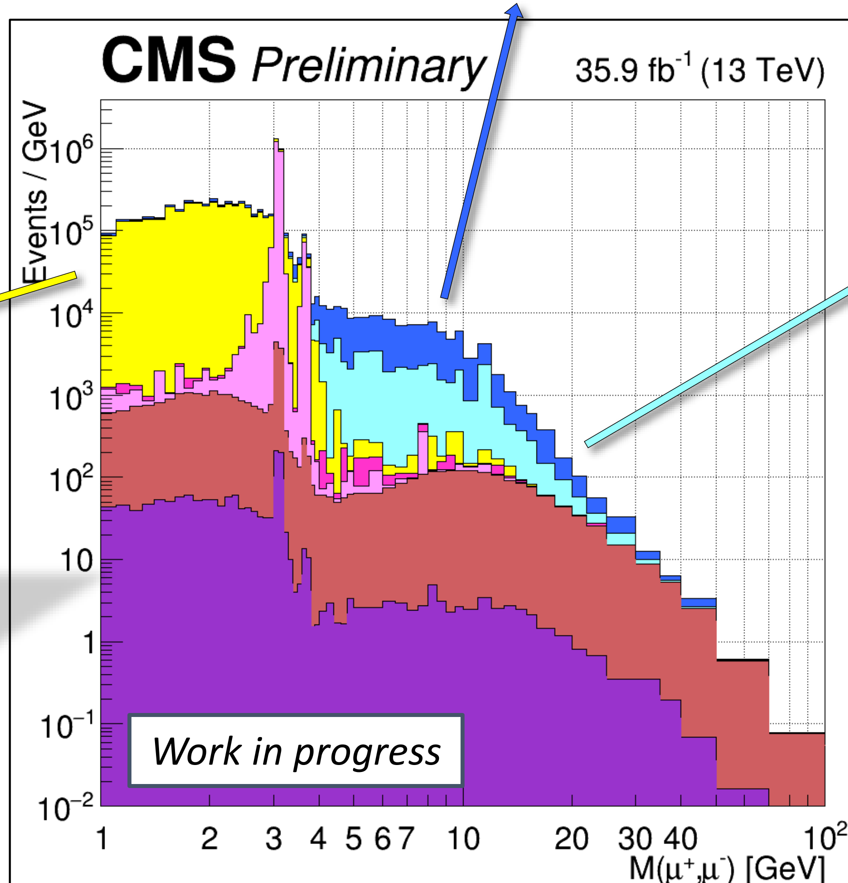
Background Contributions

- Data vs MC
  - Non-isolated lepton study has large QC om non-prompt lepton contributions
  - The sources of the QCD background ar y



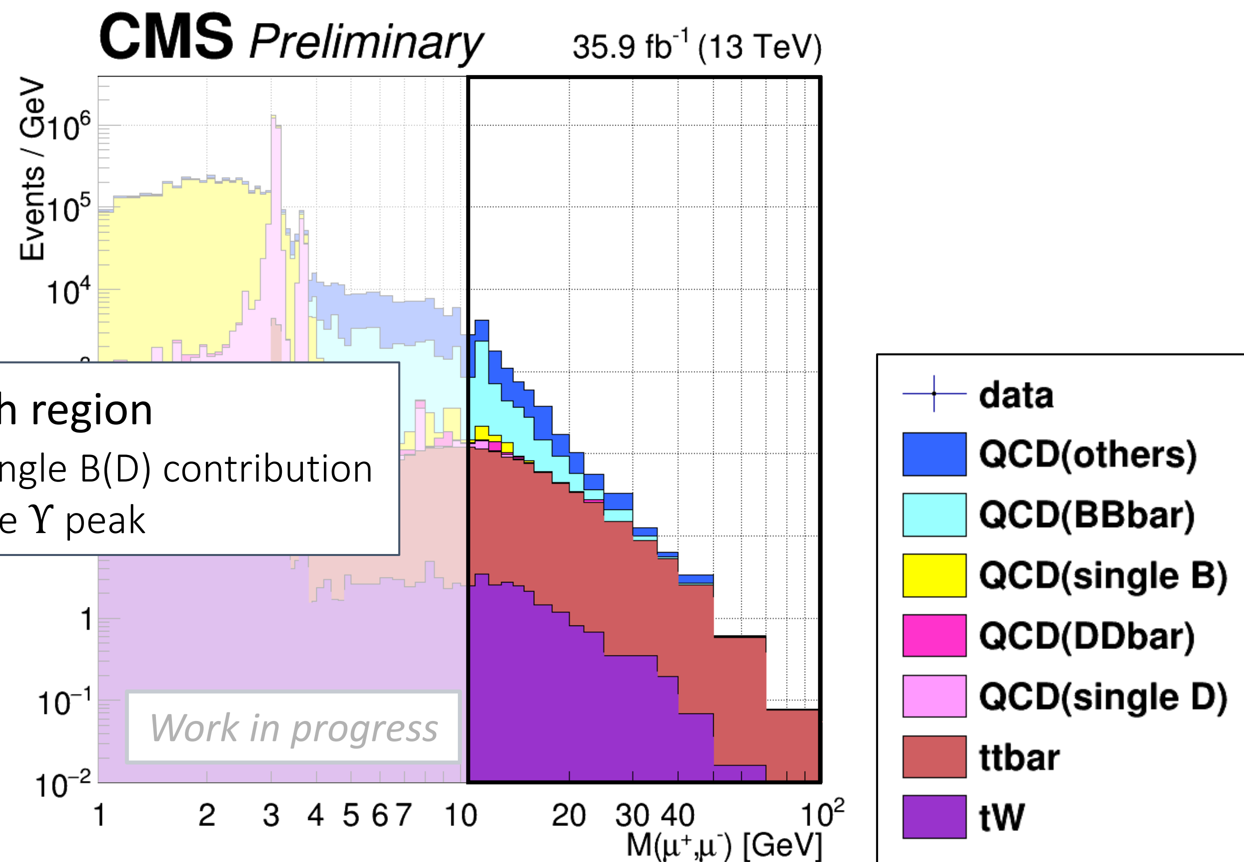






Background Contributions

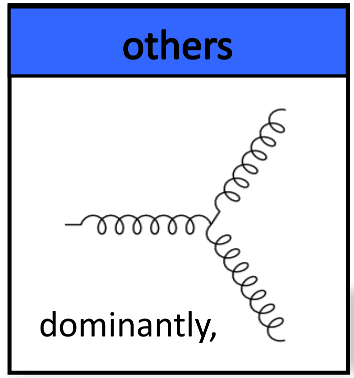
- Data vs MC
  - Non-isolated lepton study has large QCD backgrounds from non-prompt lepton contributions
  - The sources of the QCD background are studied precisely



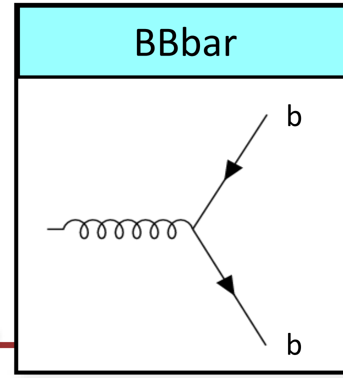
Search region
- No single B(D) contribution
- Above Υ peak

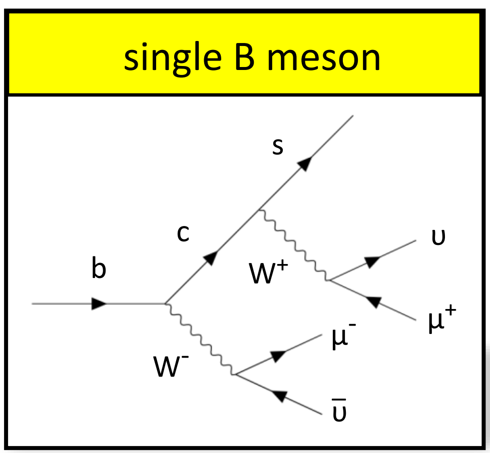
Background Contribution

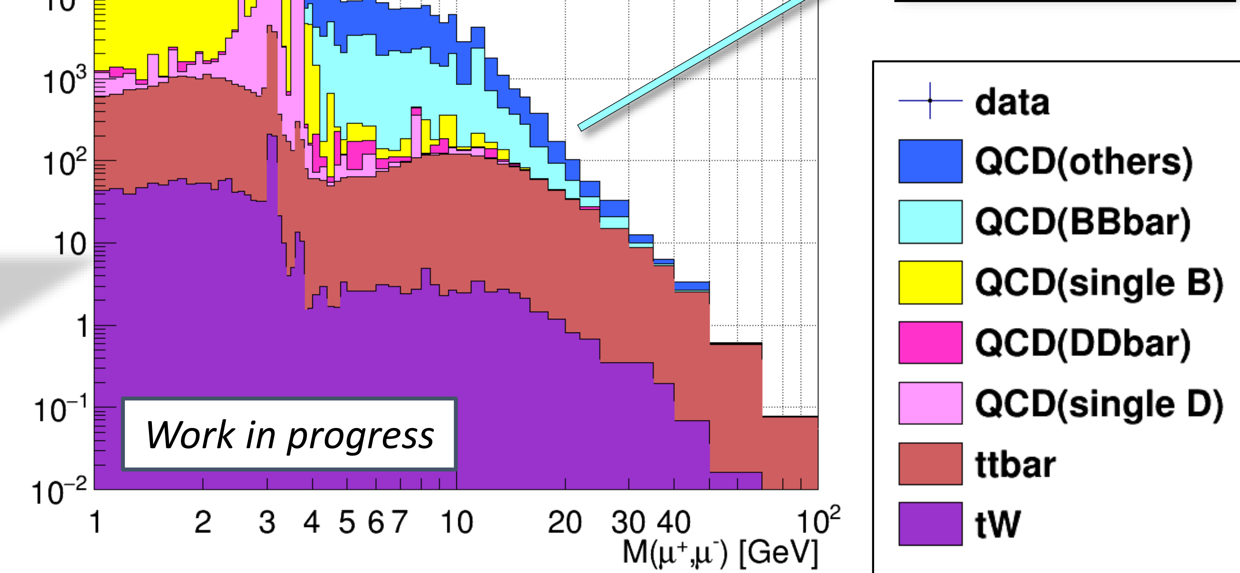
- Data vs MC
  - Non-isolated lepton study has large C
    lepton contributions
  - The sources of the QCD background a



Same distribution shape!
→ Crystal ball function

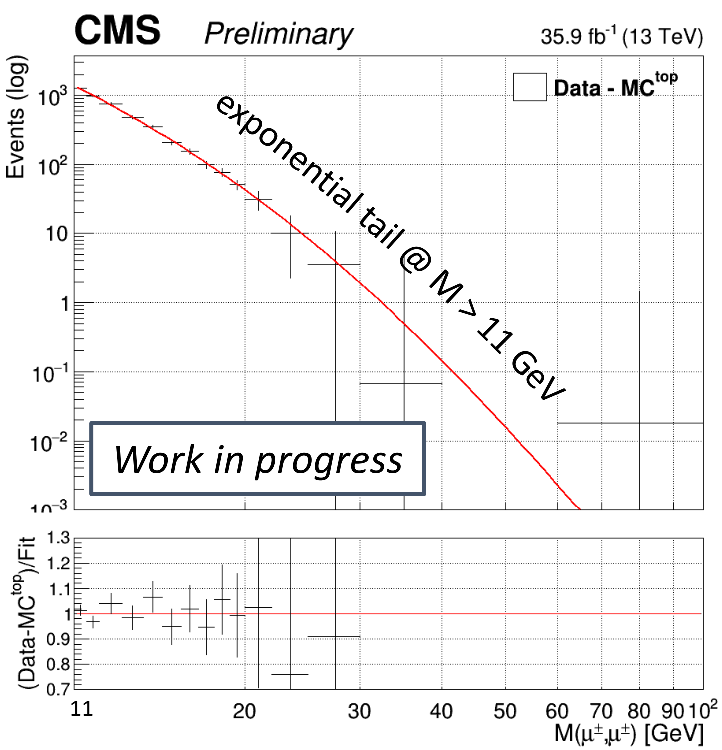






QCD Background Estimation

- Data-driven method
  - QCD shape is ***<u>extracted from the SS dimuon mass distribution</u>*** inside a b-jet
  - ttbar & single top MC events are subtracted



- Crystal ball function

$$f(x) = N \cdot \begin{cases} \exp\left(-\frac{(x-\mu)^2}{2\cdot\sigma^2}\right) & ,\text{for } \frac{x-\mu}{\sigma} < \alpha \\ A\cdot\left(B+\frac{x-\mu}{\sigma}\right)^{-n} & ,\text{for } \frac{x-\mu}{\sigma} \geq \alpha \end{cases}$$

- Crystal ball function describes the QCD background shape very well at ***M > 5 GeV***
- Plan: extend the search region up to 5 GeV (→ backup)

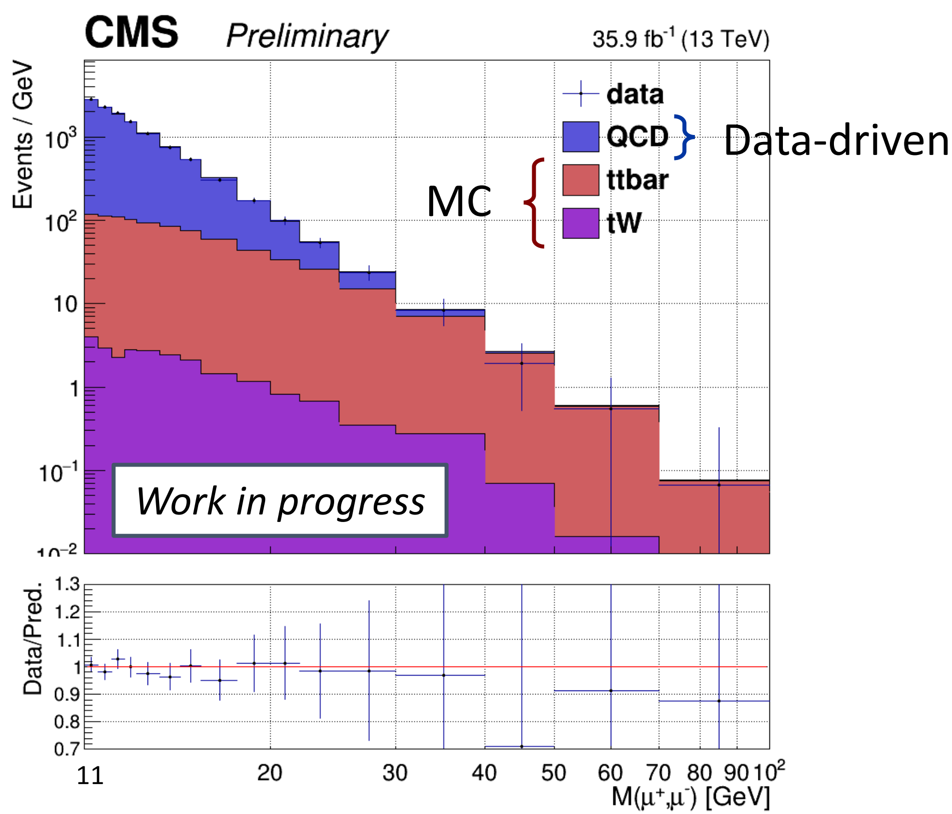
N = 8074.5
μ = 4.2
σ = 3.5
n = 25.2
α = 1.5

Results 1: Mass distribution

- OS dimuon indisde a b-jet
  - Check an anomalous contribution like LHCb
  - The same-sign fit result is normalized by #(OS events)/#(SS events)
  - **Data and prediction agree well** in 1σ(stat.)

- applied corrections -

category	sources
jet	Jet energy resolution
	Jet energy correction
	b-tagging scale factor
	Pile-up reweight
muon	momentum scale (Rochester correction)
	ID scale factor
trigger	trigger scale factor
top	Top pT reweight

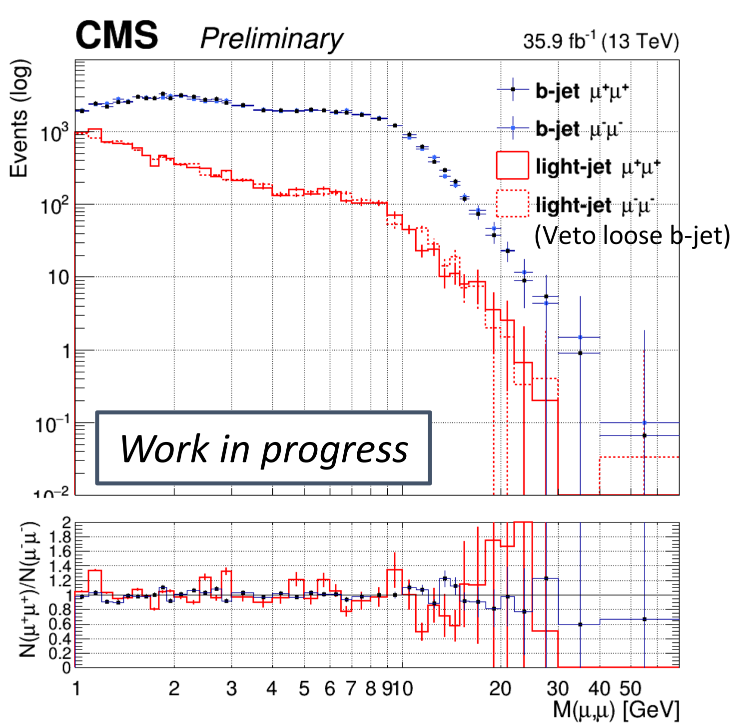


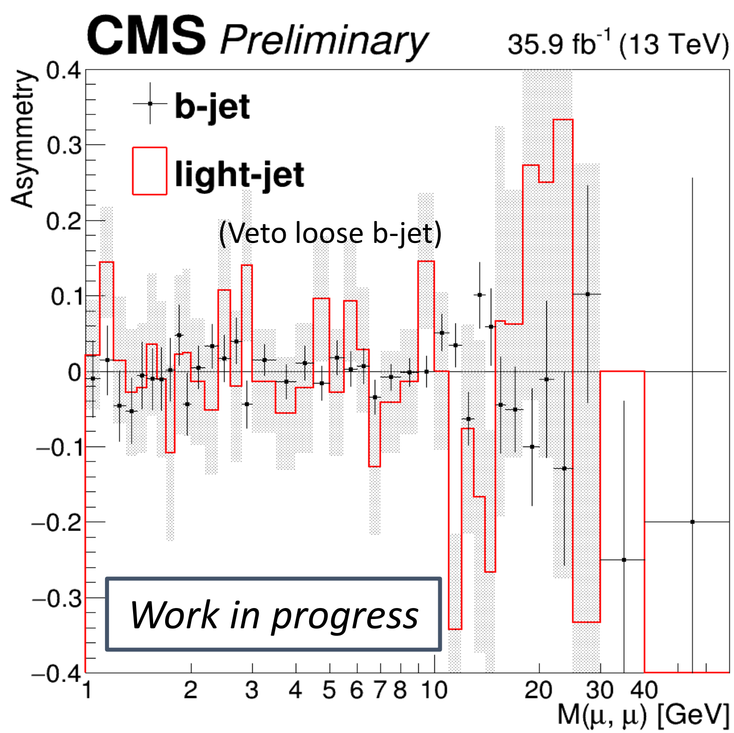
Results 2: Asymmetry

- Dimuon charge asymmetry

$$A = \frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)}$$

  - anomalous production of same-sign dimuon events inside a b-jet
  - **Asymmetry is not observed** considering the uncertainty (within ±2σ)

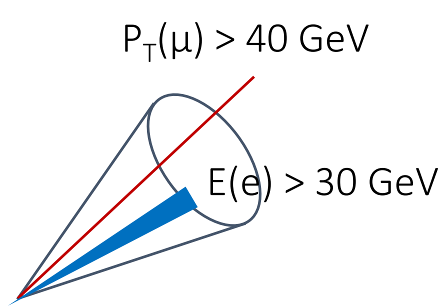


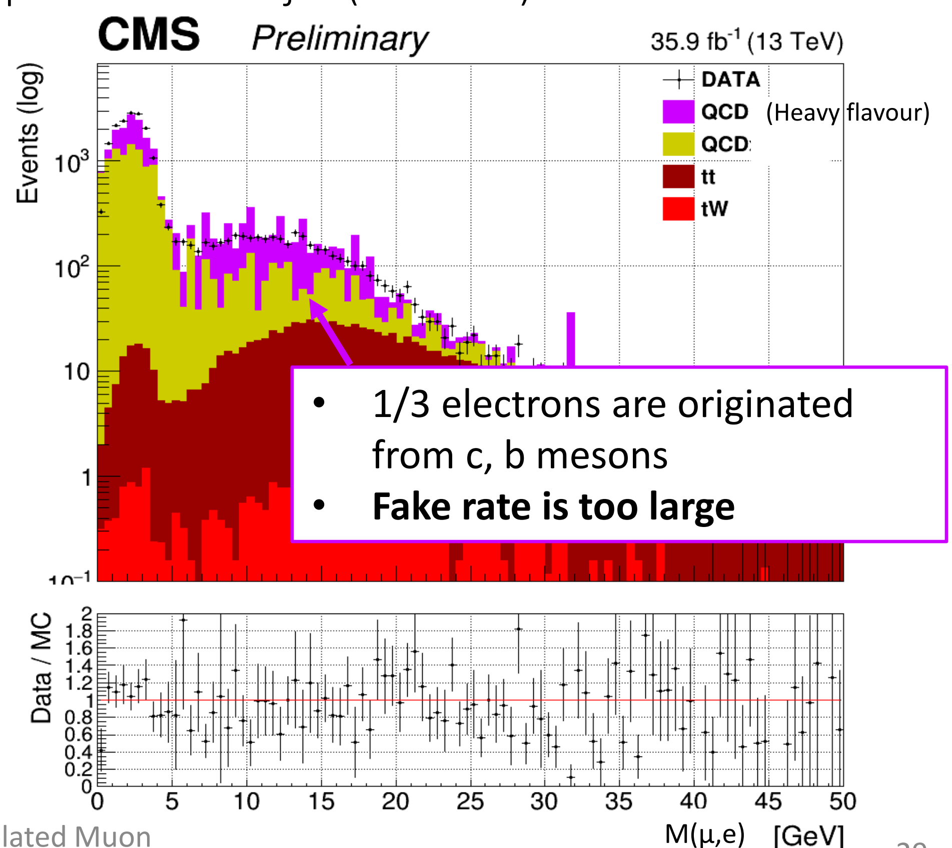


Opposite-sign Dimuon mass distributions

- electron id: medium, vetoing isolation (iso > 0.198+0.506/pT (EB), iso > 0.203+0.963/pT (EE))
- event selection
  - HLT: $P_T(\mu) > 37$, $P_T(e) > 27$ GeV
  - To reduce $\gamma \rightarrow ee$, exactly 1e1μ is required inside a jet ($\Delta R < 0.3$)

OS eμ inside a jet





Non-isolated Muon

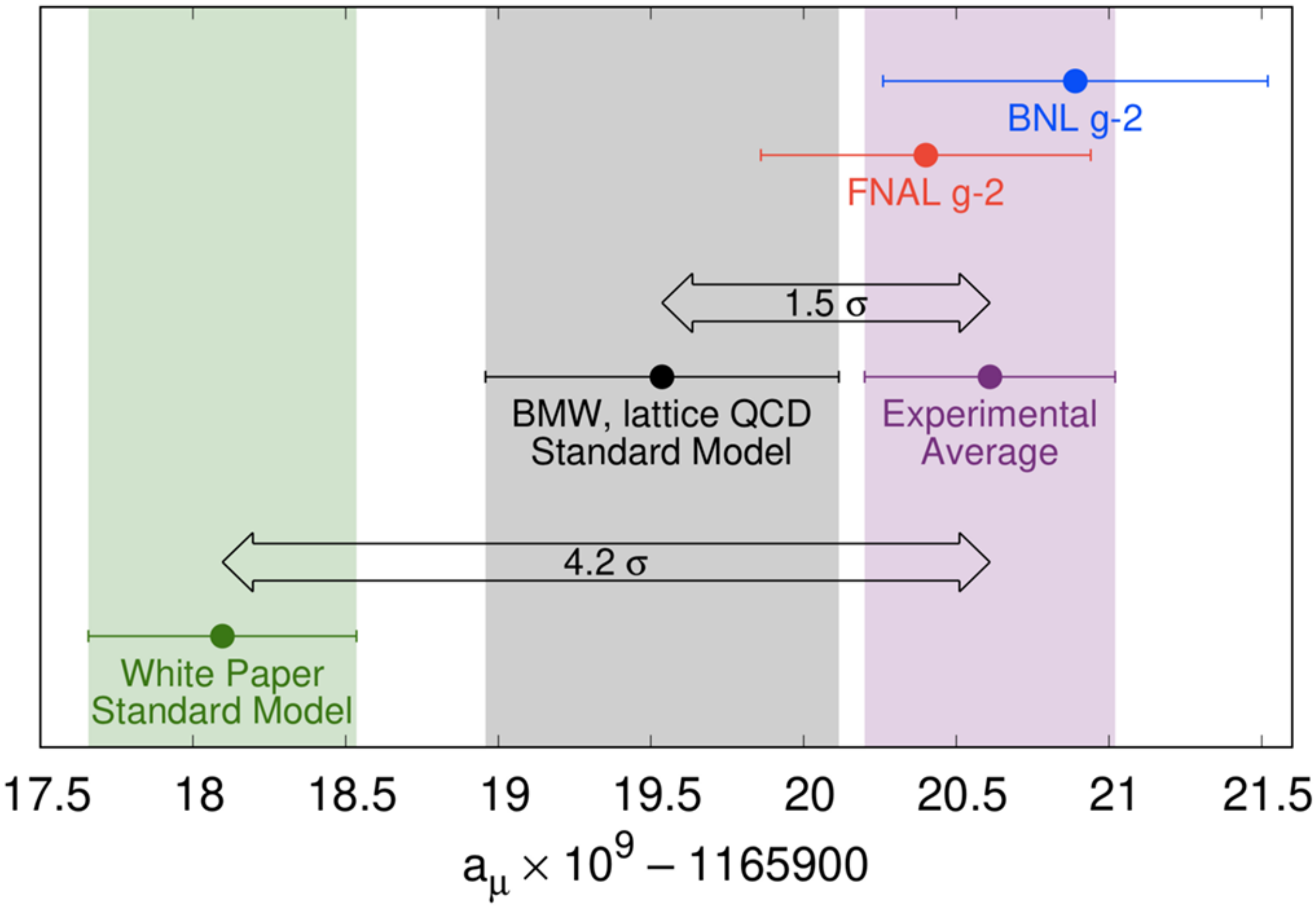
[Thank you for listening]

py **Non-Iso** :D

BACKUP

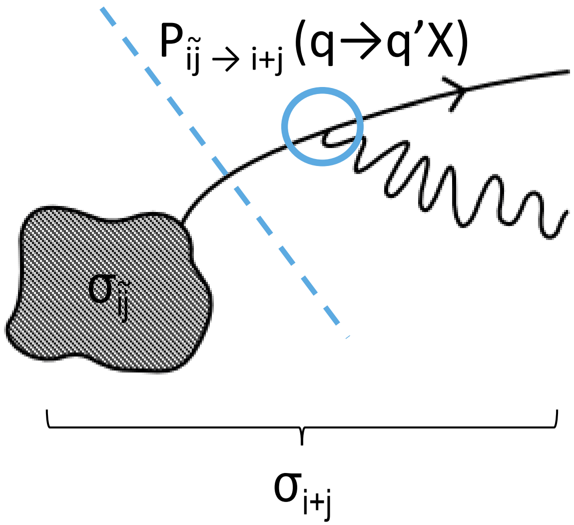
Muon g-2 Theory Initiative, Phys.Rept. 887 (2020) 1-166

Budapest–Marseille–Wuppertal-coll., Nature593(2021)7857



Parton Shower

- Crop parton shower processes from a hard process



- total cross section

$$d\sigma_{i+j} \simeq \frac{\alpha_{\rm int}(\tilde{q}^2)}{2\pi}\frac{d\tilde{q}^2}{\tilde{q}^2} dz \boxed{P_{\tilde{ij}\to i+j}(z,\tilde{q})} d\sigma_{\tilde{ij}}.$$

"splitting function"

$$P_{\tilde{ij}\to i+j}(z,\tilde{q}) = \sum_{\lambda} \left| H_{\tilde{ij}\to i+j}(z,\tilde{q};\lambda)\right|^2 .$$

- Iteratively add the splittings using a specific ordering scale($\tilde{q}^2$)

1) <u>Herwig: angular-ordering</u>
2) Pythia 8: pT ordering
3) Pythia 6: virtuality ordering

$$\begin{aligned}
\tilde{q}^2 &= \frac{q_i^2 - m_i^2}{z(1-z)}; \\
&= \frac{p_T^2 + (1-z)m_j^2 + zm_k^2 - z(1-z)m_i^2}{z^2(1-z)^2}; \\
&= \frac{2q_j \cdot q_k + m_j^2 + m_k^2 - m_i^2}{z(1-z)};
\end{aligned}$$

QCD Background Estimation

❖ Data-driven method

- Same-sign dimuon events are dominated by "others" events, but its distribution shape is same with "BBbar" events
- → ***<u>SS & OS dimuon mass distribuitons have same shape</u>***