POLISH NATIONAL AGENCY FOR ACADEMIC EXCHANGE

ELECTROWEAK PDFS FOR FUTURE LEPTON COLLIDERS

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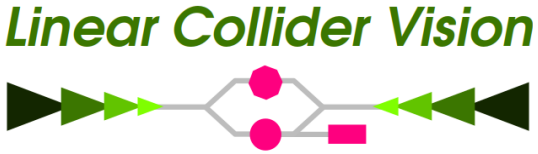
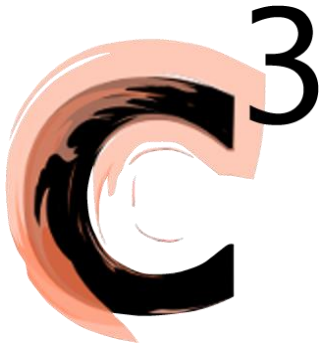
based on work with T. Han, W. Kilian, Y. Ma, J. Reuter, K. Xie

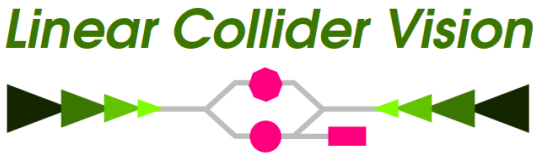
Pheno'26, May 12th, 2026

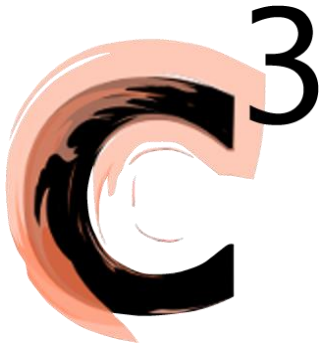
FUTURE LEPTON COLLIDERS





FUTURE LEPTON COLLIDERS

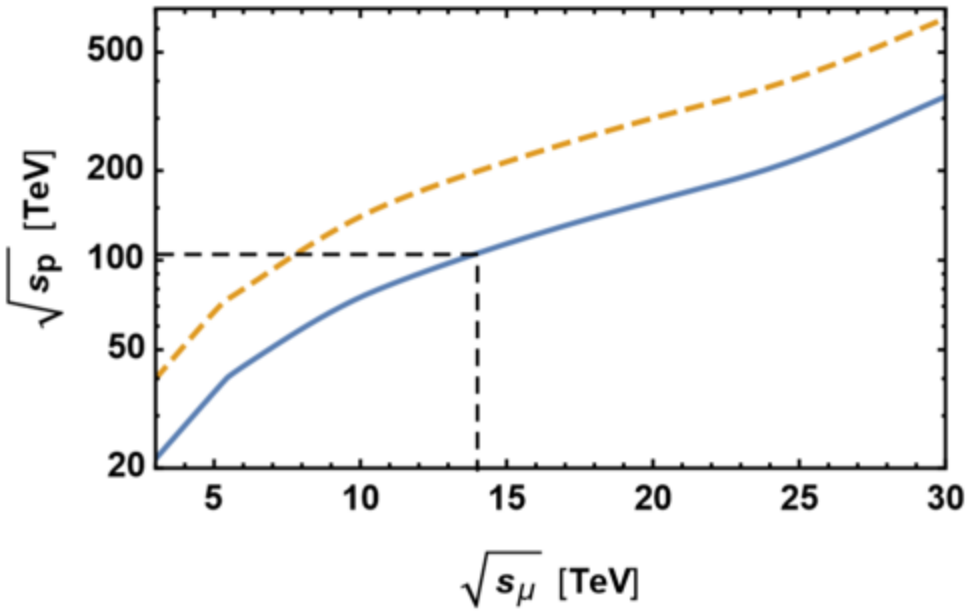




MUON COLLIDER BASICS

Muons can be accelerated to energies comparable to those of protons:

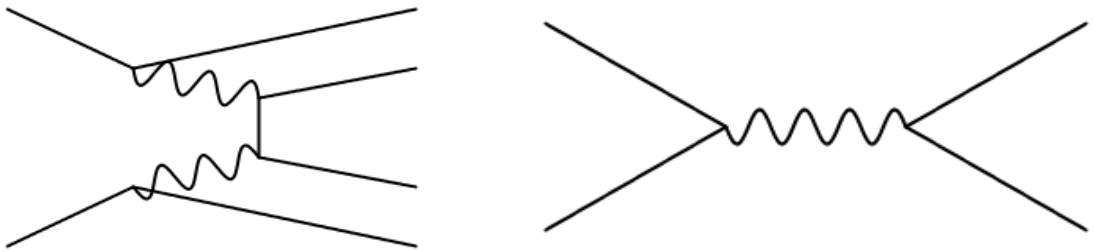
- As they are point-like particles, the *entire* nominal centre-of-mass energy is available for interactions.
- For protons, only a part of the energy is available, since it is distributed statistically among partons.



[1901.06150]

HIGH-ENERGY SM: VECTOR-BOSON FUSION

- At sufficiently high energies, VBF processes start to appear: they are suppressed by additional powers of couplings, but at the same time enhanced by soft/collinear logs.
- VBF topologies are naturally *contaminated* by annihilation topologies.



ANNIHILATION VS. VECTOR-BOSON FUSION

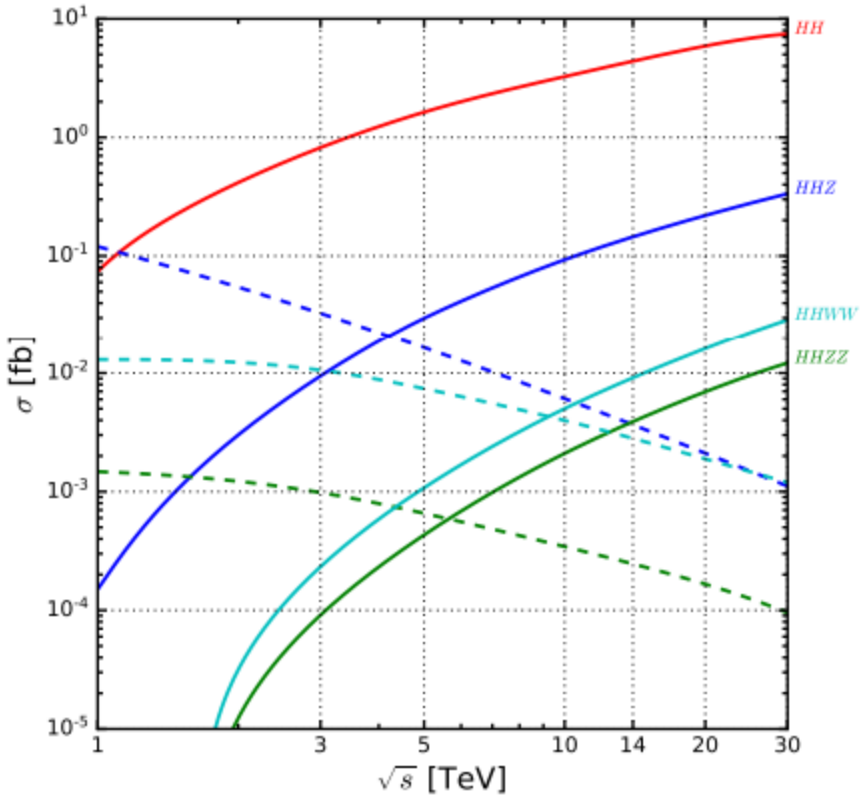
For SM processes well above treshold:

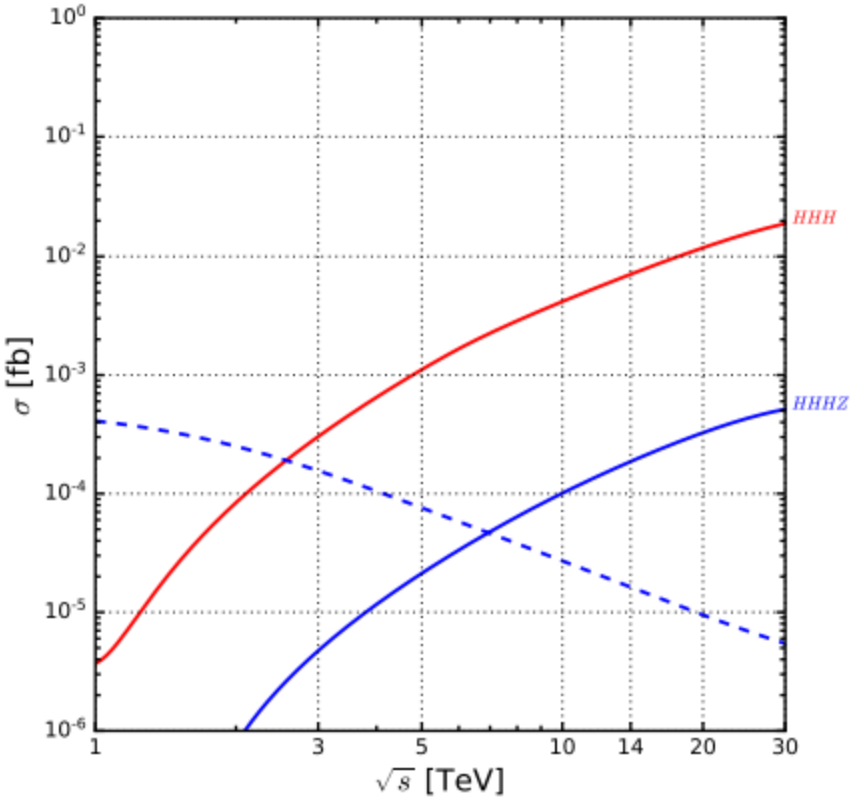
$$\frac{\sigma_{\mathrm{VBF}}^{\mathrm{SM}}}{\sigma_{\mathrm{ann}}^{\mathrm{SM}}} \propto \alpha_W^2 \frac{s}{m_V^2} \log^3 \frac{s}{m_V^2}$$

VBF subprocesses grow with *s*!

[2005.10289]

ANNIHILATION VS. VECTOR-BOSON FUSION II



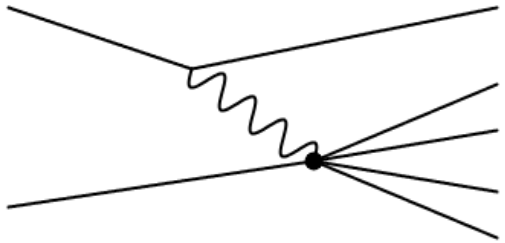


[2005.10289]

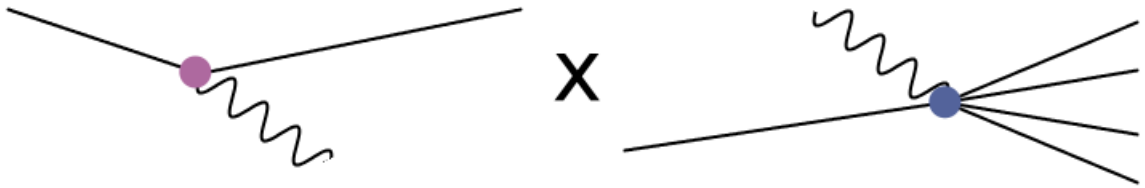
ELECTROWEAK FACTORISATION

Dawson'84

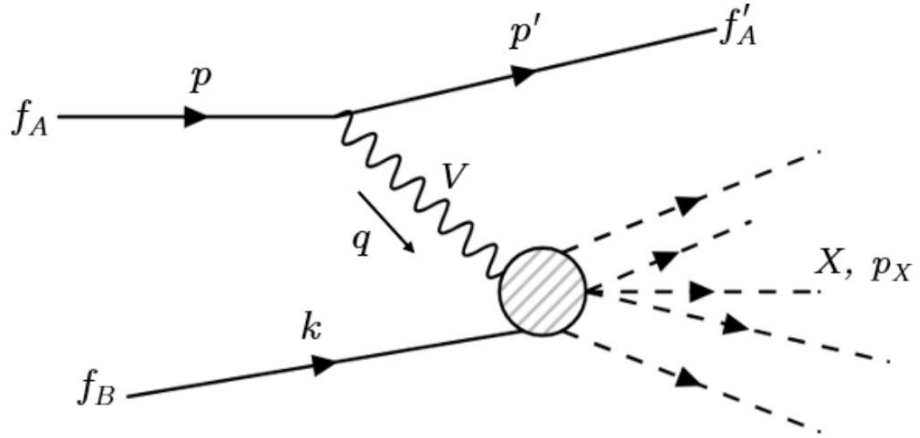
- Let us consider a boson-initiated process, for example:



- We would like to factorise the process into some universal structure function describing the emission and a hard-process Matrix Element.



EQUIVALENT VECTOR-BOSON APPROXIMATION



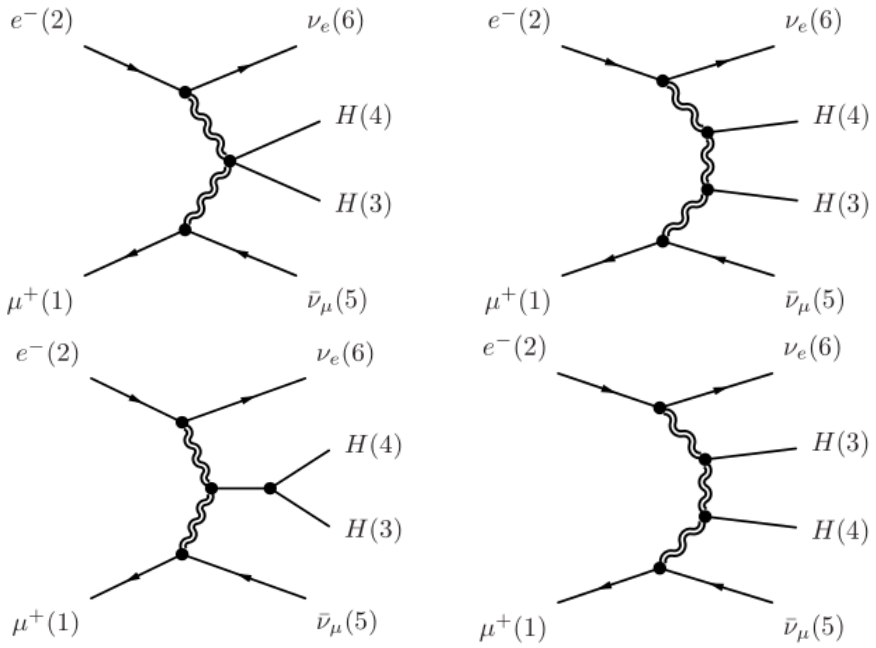
In the collinear approximation:

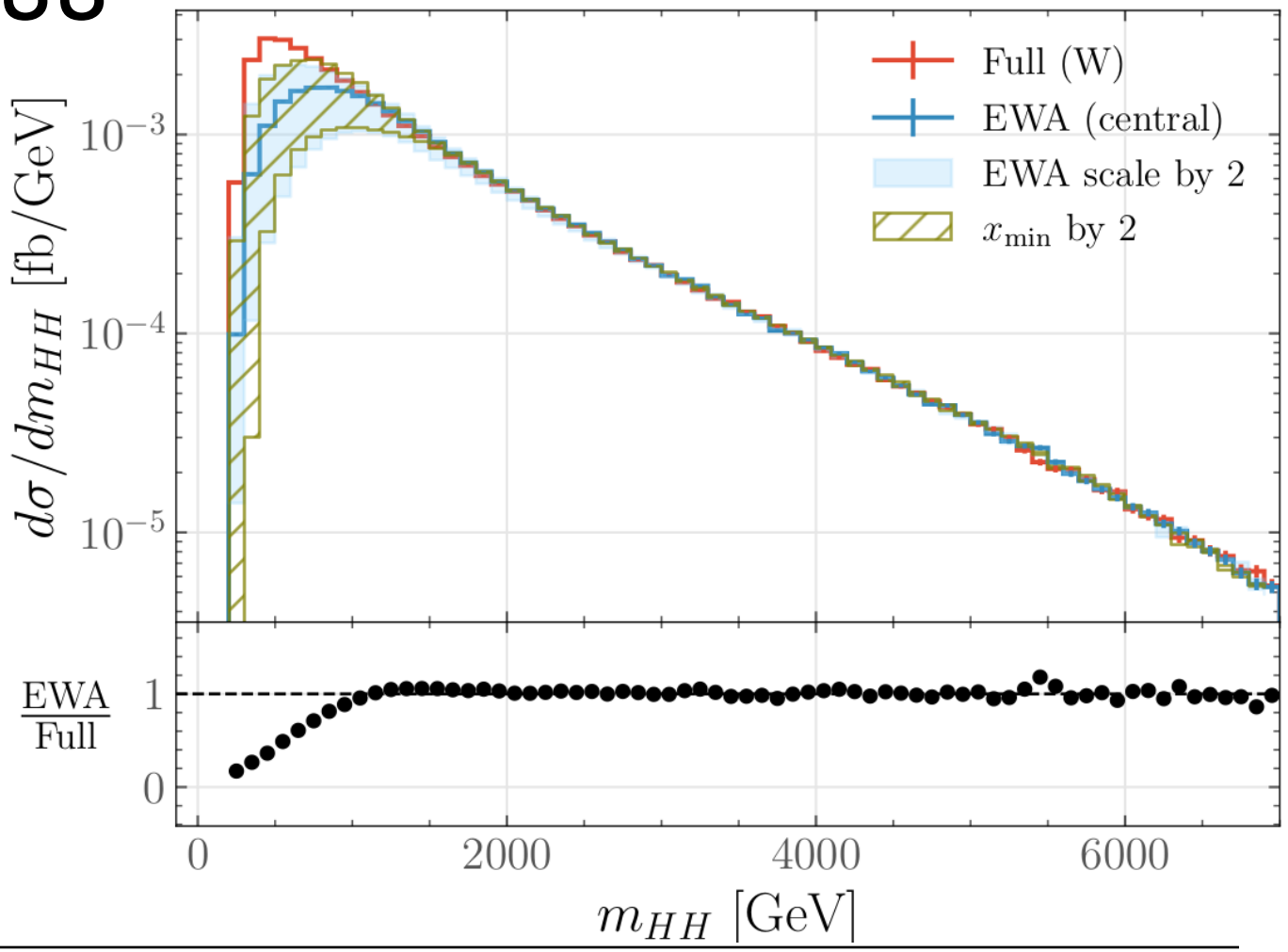
$$\sigma(f_A f_B \to f'_A X) = \sum_{\lambda_V} \int_{x_{min}}^{1} \mathrm{d}x F_{\lambda_V}(x, p_T^{max}) \times \hat{\sigma}(f_B V_{\lambda_V} \to X)$$

EVA VS. FULL PROCESS

[2507.19285]

Double-Higgs production at a 10-TeV μ^+e^- collider*

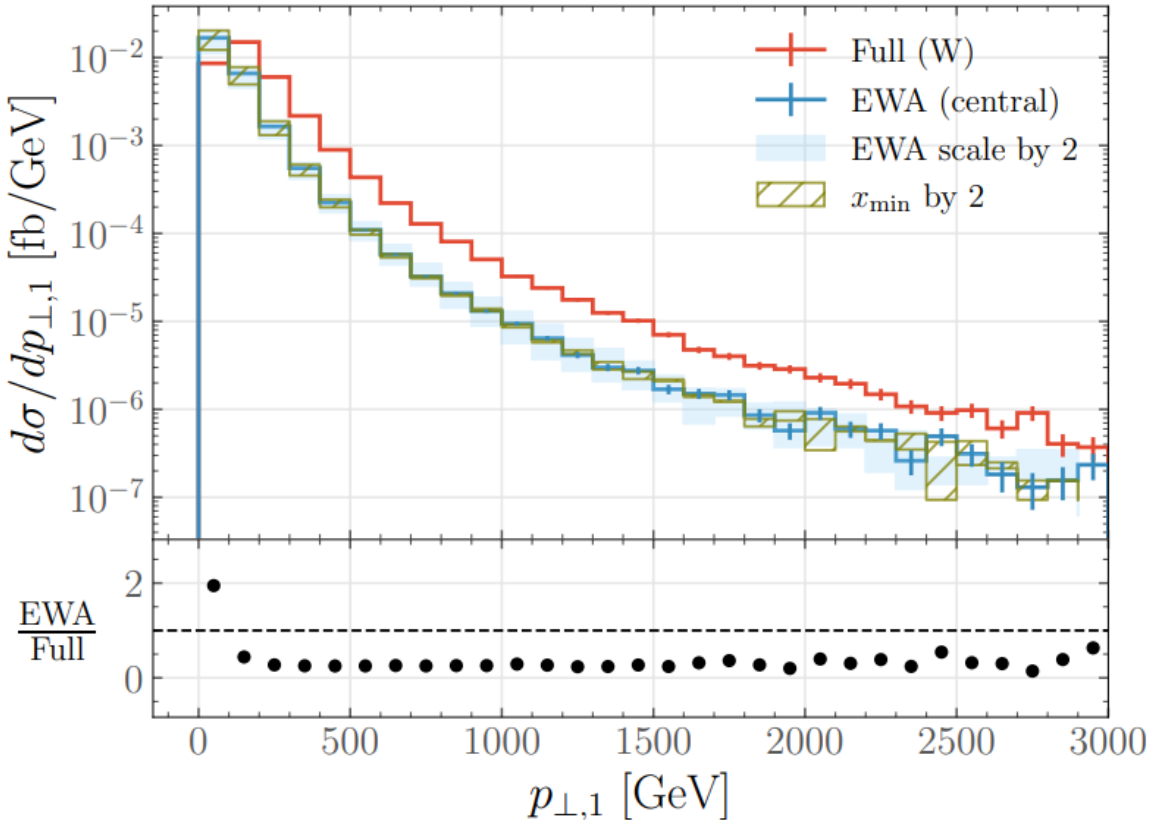


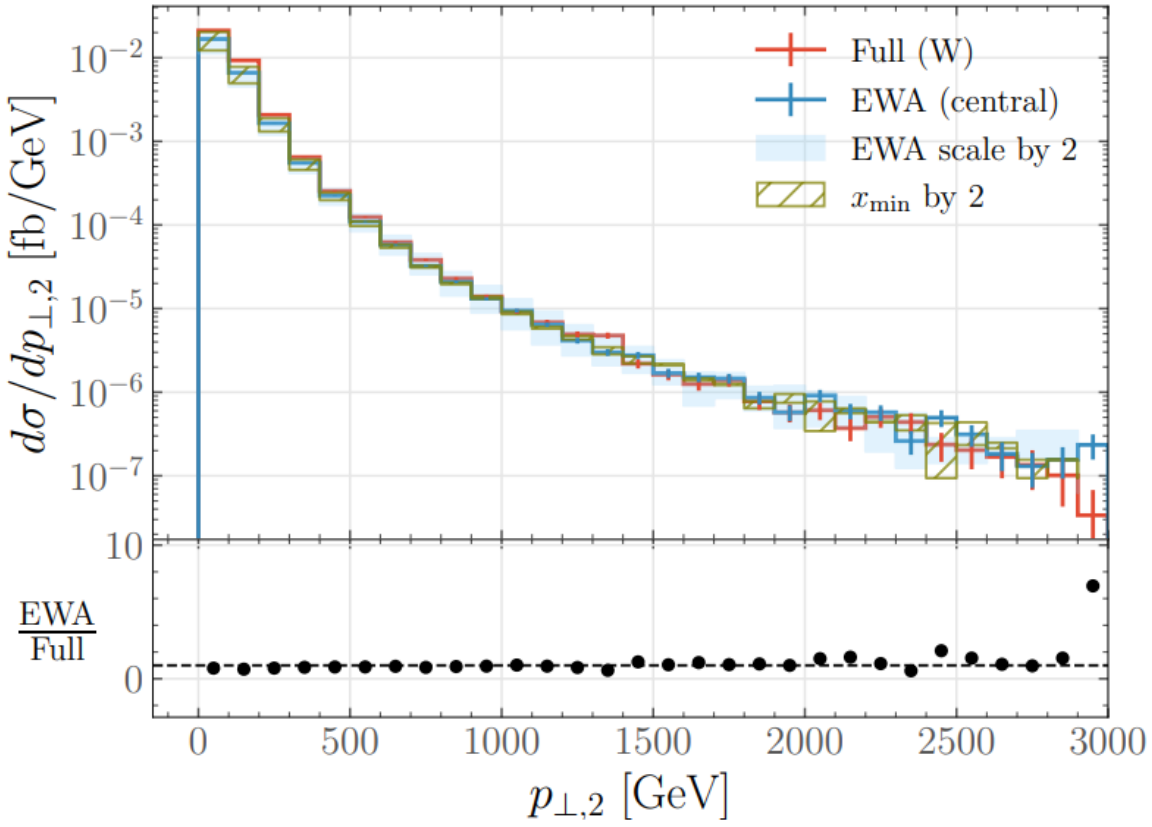


*- for validation purposes

DOUBLE-HIGGS PRODUCTION

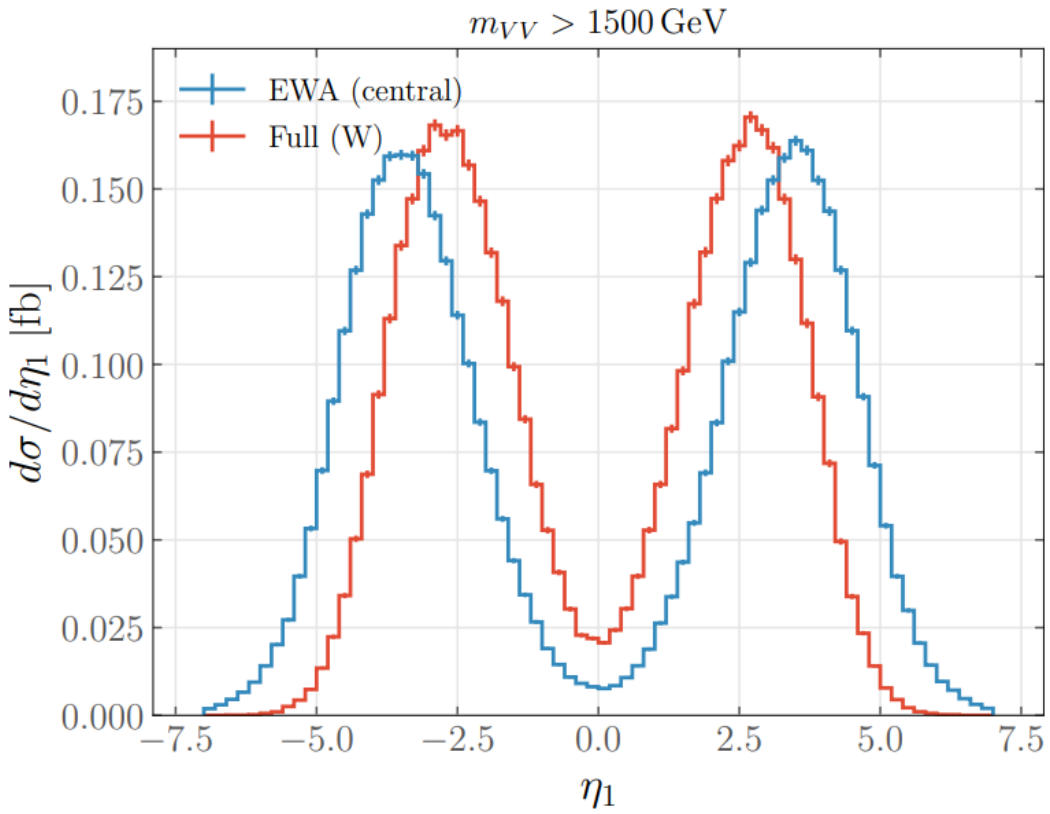
[2507.19285]

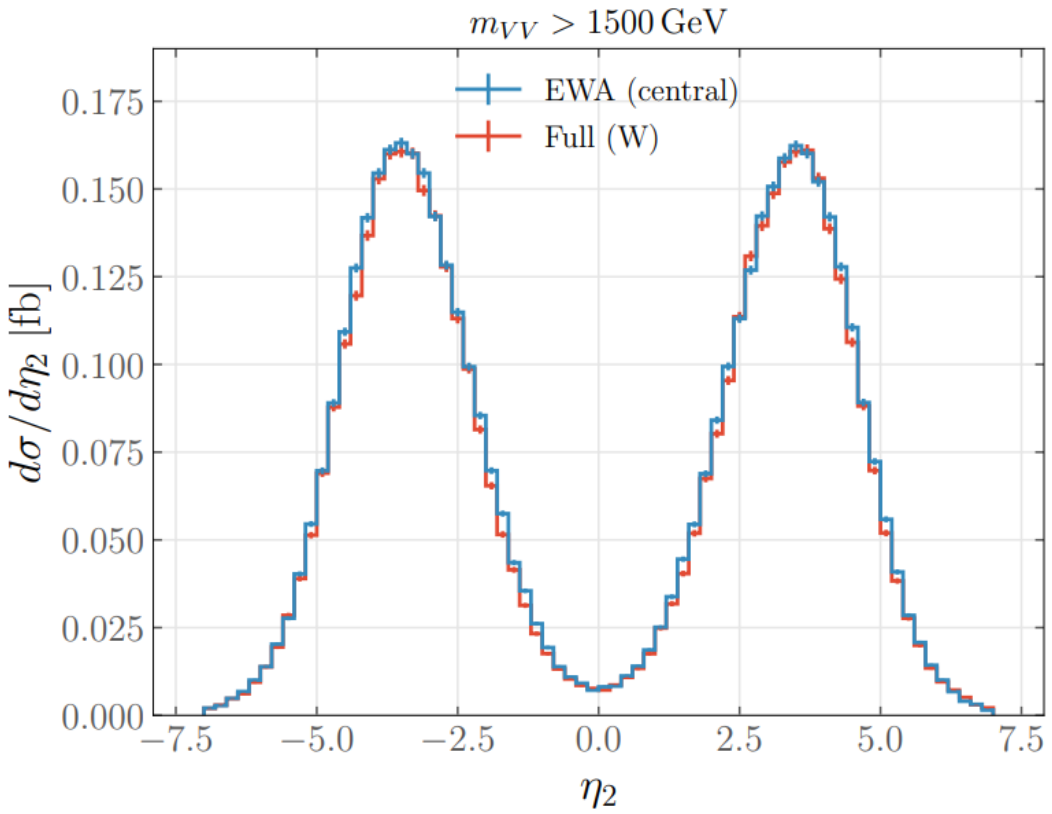




DOUBLE-HIGGS PRODUCTION

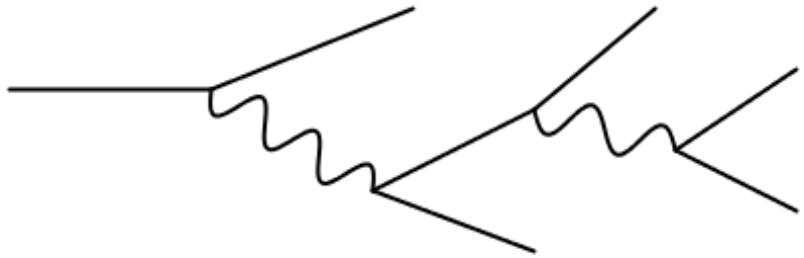
[2507.19285]



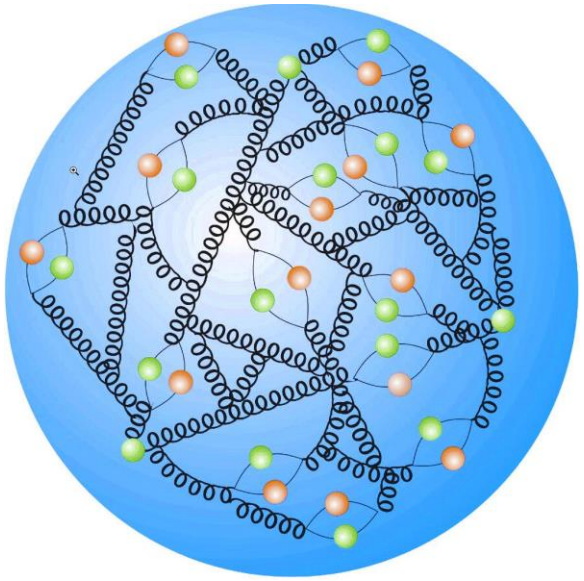


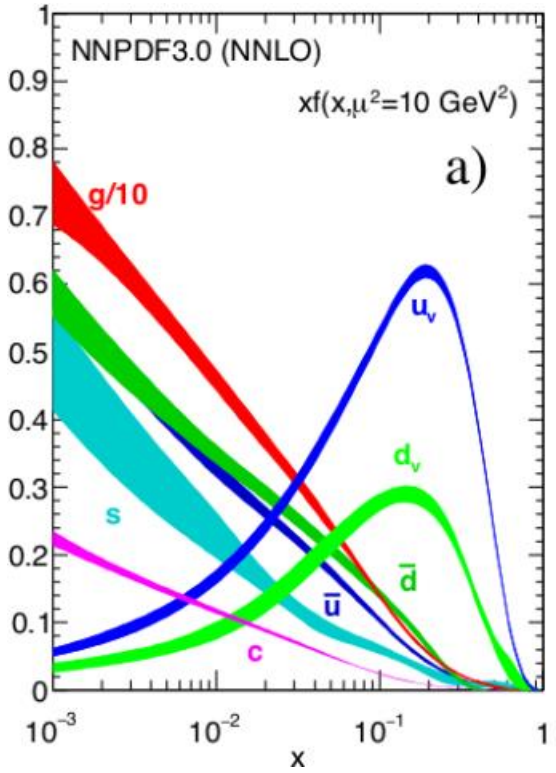
EW RADIATION AT VERY HIGH ENERGIES

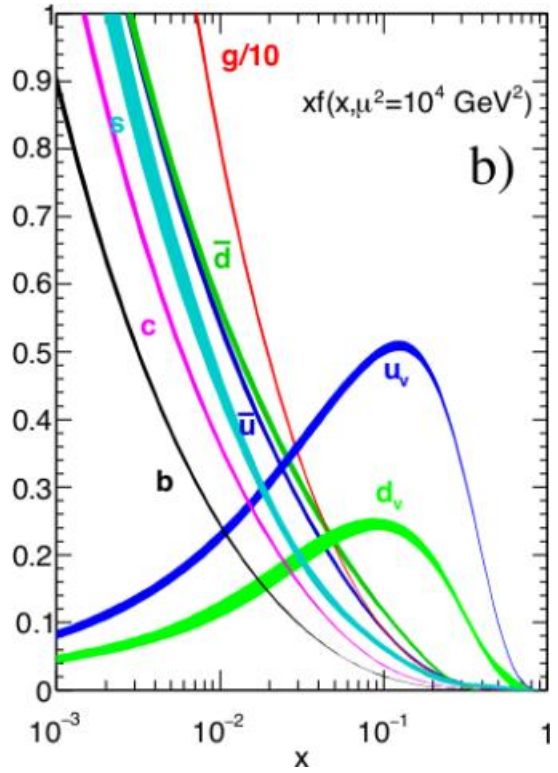
- At high energies, muons emit multiple EW bosons: the coupling suppresion is compensated by logs of the ratios of scales between the energy and masses.
- The emitted bosons can initiate a hard collision or split. The products of the splitting can initiate a hard collision or split. The products of this splitting can also initiate a hard collision or further split...



QCD PICTURE




NNPDF3.0 (NNLO)
xf(x,μ²=10 GeV²)
a)
g/10
u_v
d_v
s
ū
d̄
c
x


xf(x,μ²=10⁴ GeV²)
b)
g/10
s
c
d̄
ū
b
u_v
d_v
x

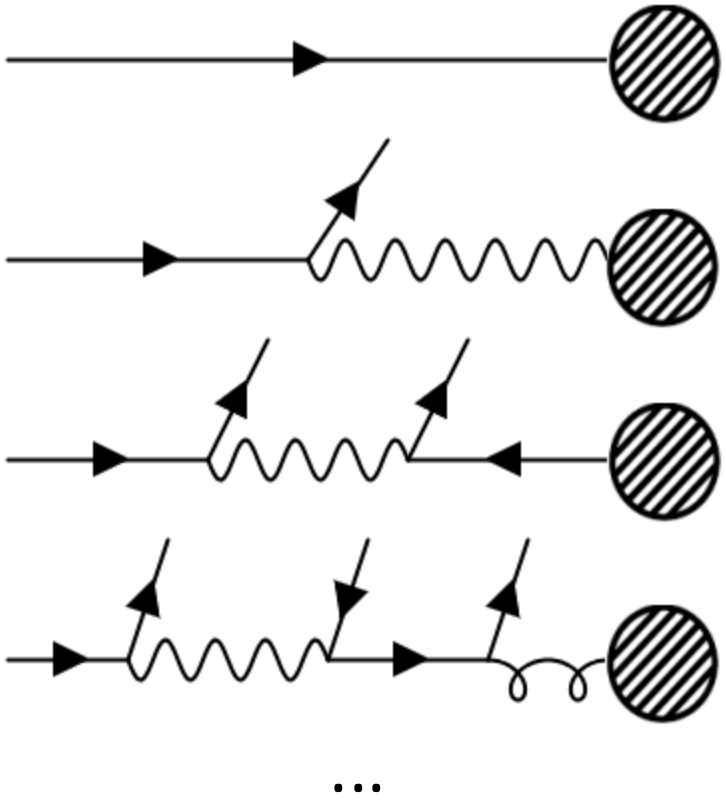
PARTON DISTRIBUTION FUNCTIONS IN THE SM

- This leads to a PDF-like picture of a muon. Large logs of scales have to be resummed for reliable predictions. $\alpha^n \log^k(E^2/m_\ell^2)$
- The full EW DGLAP equation has to be employed:

$$\frac{\mathrm{d}f_i}{\mathrm{d}\ln Q^2} = \sum_I \frac{\alpha_I}{2\pi} \sum_j P^I_{i,j} \otimes f_j$$

- At the EW scale and above, all states in the **unbroken** SM are dynamically activated.
- As the SM is a chiral theory, **parton polarisation** emerges naturally.

FULL PARTICLE SPECTRUM IN EWPDFS



...

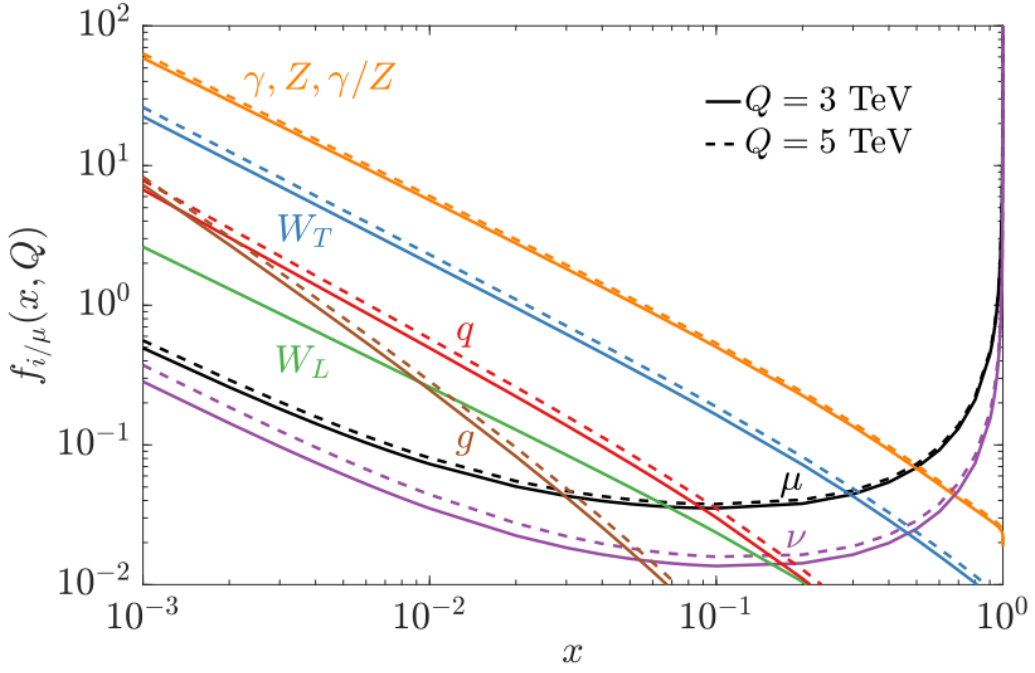
e_L	eL	11	-
e_R	eR	11	+
ν_e	nue	12	-
μ_L	muL	13	-
μ_R	muR	13	+
ν_μ	numu	14	-
τ_L	taL	15	-
τ_R	taR	15	+
ν_τ	nuta	16	-
$\bar{e}_L$	eLb	-11	+
$\bar{e}_R$	eRb	-11	-
$\bar{\nu}_e$	nueb	-12	+
$\bar{\mu}_L$	muLb	-13	+
$\bar{\mu}_R$	muRb	-13	-
$\bar{\nu}_\mu$	numub	-14	+
$\bar{\tau}_L$	taLb	-15	+
$\bar{\tau}_R$	taRb	-15	-
$\bar{\nu}_\tau$	nutab	-16	+

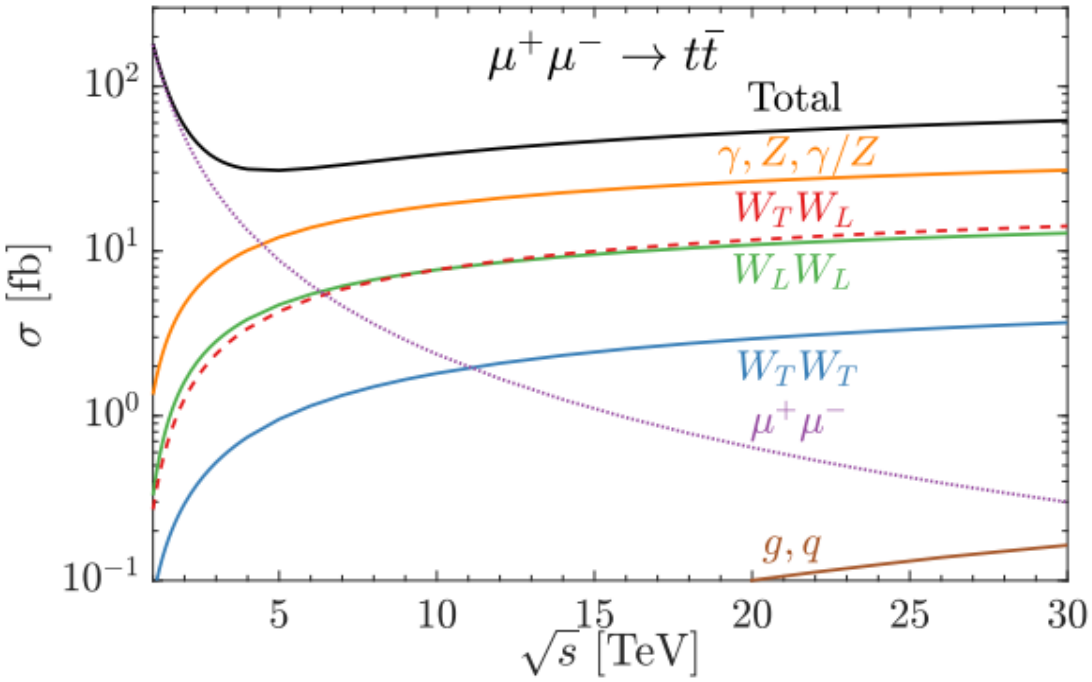
d_L	dL	1	-
d_R	dR	1	+
u_L	uL	2	-
u_R	uR	2	+
s_L	sL	3	-
s_R	sR	3	+
c_L	cL	4	-
c_R	cR	4	+
b_L	bL	5	-
b_R	bR	5	+
t_L	tL	6	-
t_R	tR	6	+
$\bar{d}_L$	dLb	-1	+
$\bar{d}_R$	dRb	-1	-
$\bar{u}_L$	uLb	-2	+
$\bar{u}_R$	uRb	-2	-
$\bar{s}_L$	sLb	-3	+
$\bar{s}_R$	sRb	-3	-
$\bar{c}_L$	cLb	-4	+
$\bar{c}_R$	cRb	-4	-
$\bar{b}_L$	bLb	-5	+
$\bar{b}_R$	bRb	-5	-
$\bar{t}_L$	tLb	-6	+
$\bar{t}_R$	tRb	-6	-

g_+	gp	21	+
g_-	gm	21	-
γ_+	gap	22	+
γ_-	gam	22	-
Z_+	Zp	23	+
Z_-	Zm	23	-
Z_L	ZL	23	0
Z/γ_+	Zgap	2223	+
Z/γ_-	Zgam	2223	-
W_+^+	Wpp	24	+
W_-^+	Wpm	24	-
W_L^+	WpL	24	0
W_+^-	Wmp	-24	+
W_-^-	Wmm	-24	-
W_L^-	WmL	-24	0
h	h	25	0
h/Z_L	hZL	2523	0

[2303.16964]

PARTON DISTRIBUTION FUNCTIONS FOR MUONS





[2007.14300]

EWPDF IMPLEMENTATION IN WHIZARD

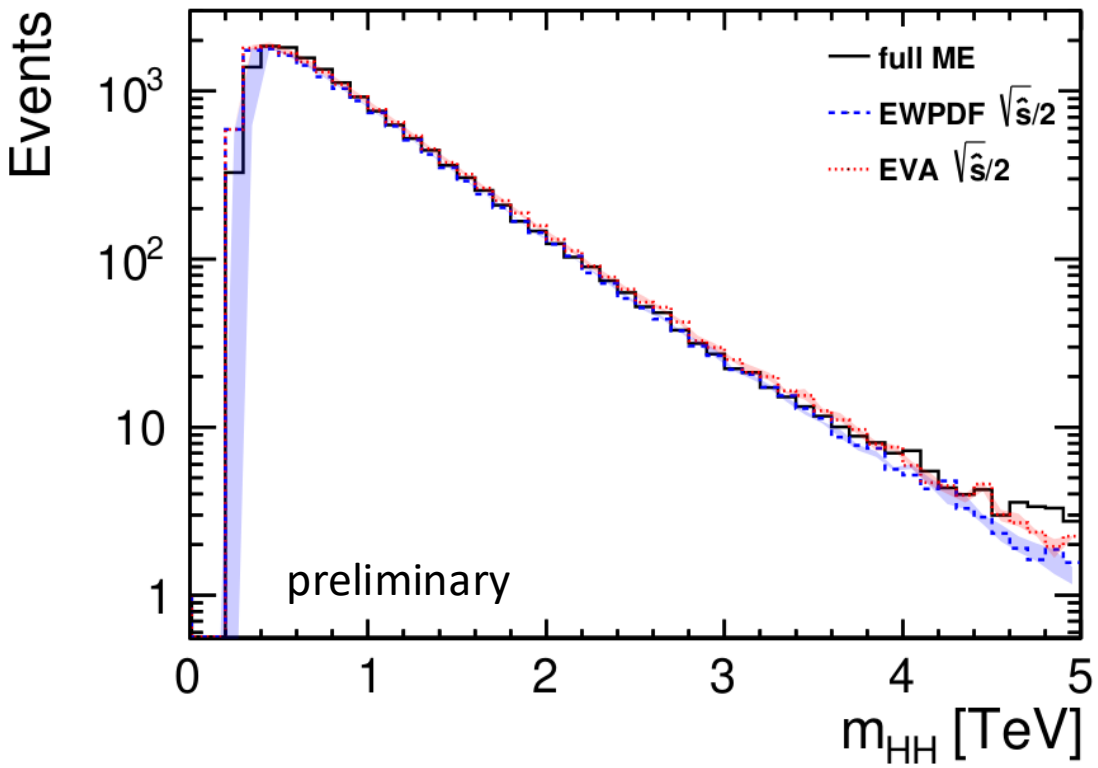
- almost complete, to be released *soon*
- inspired by LHAPDF, able to handle various PDF sets
- some limitations (e.g. H/Z_L mixing missing)

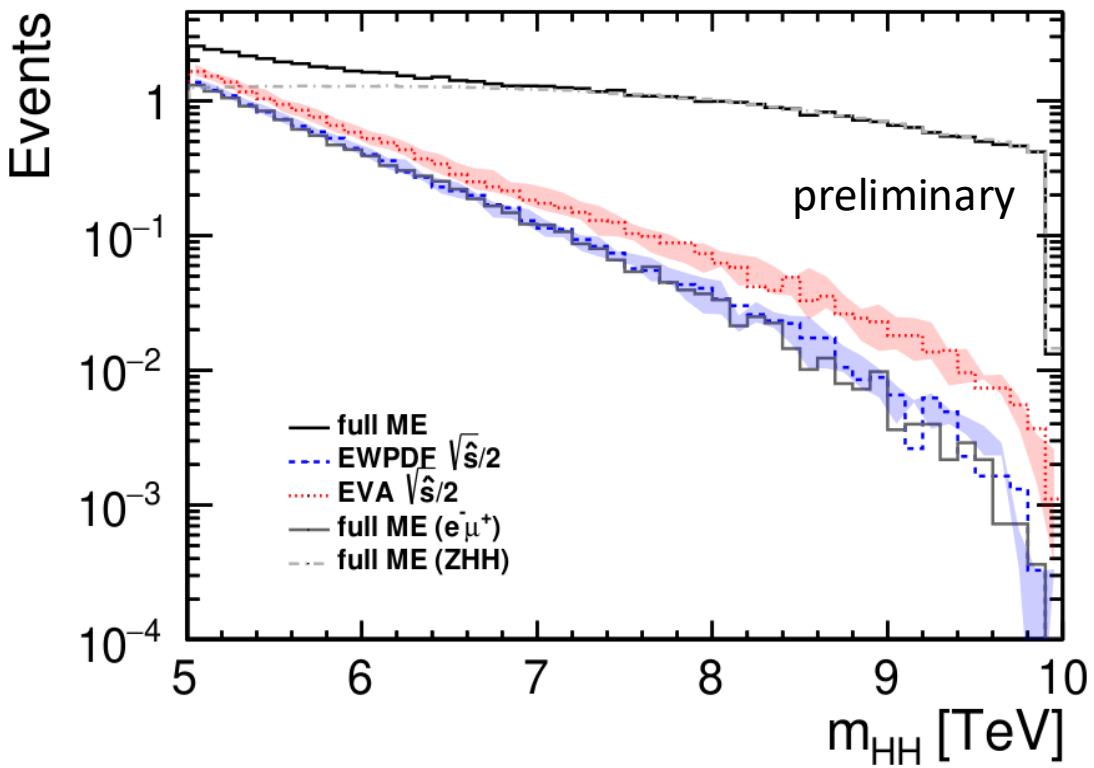
```
model = SM
sqrts = 10 TeV
beams = "e+", "mu-" => lhapdf_ew
scale = eval 0.25*M [H, H] #Scale corresponding to sqrt(s-hat)/4

process procEWPDF = "W+", "W-" => H, H
integrate (procEWPDF)
```

[2606.xxxxx]

DOUBLE-HIGGS PRODUCTION

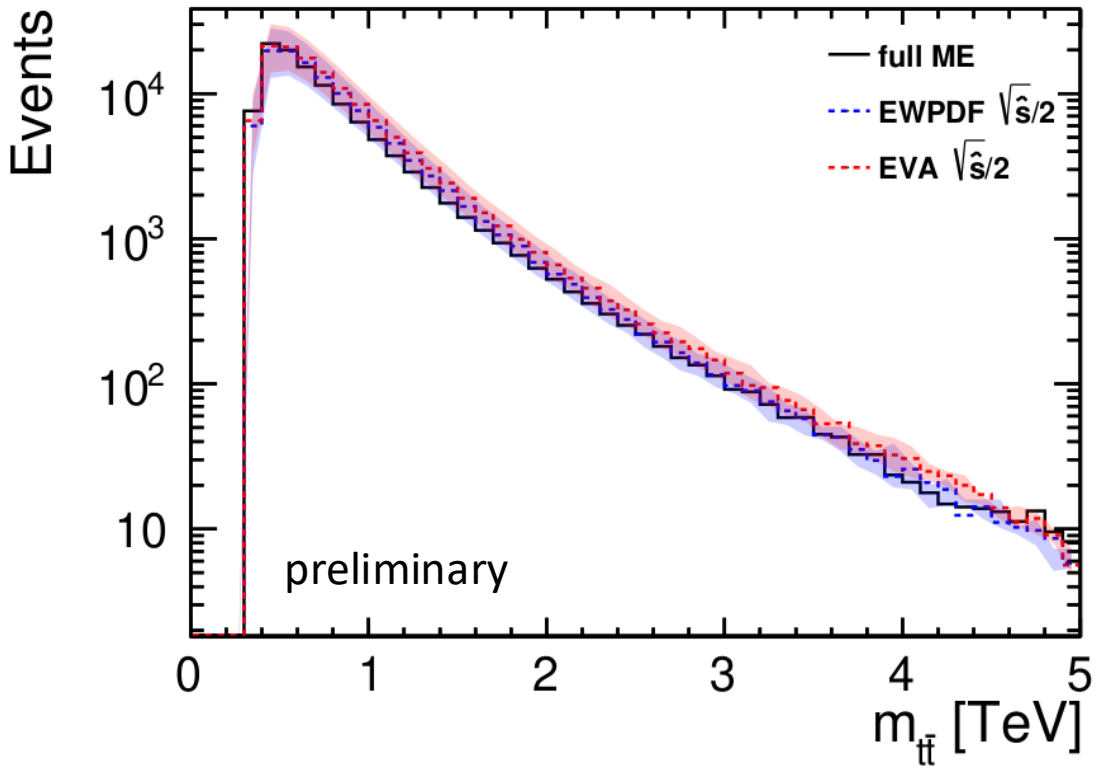
WW -> HH @ 10-TeV MuC, $|\eta_{sub}| < 2.44$

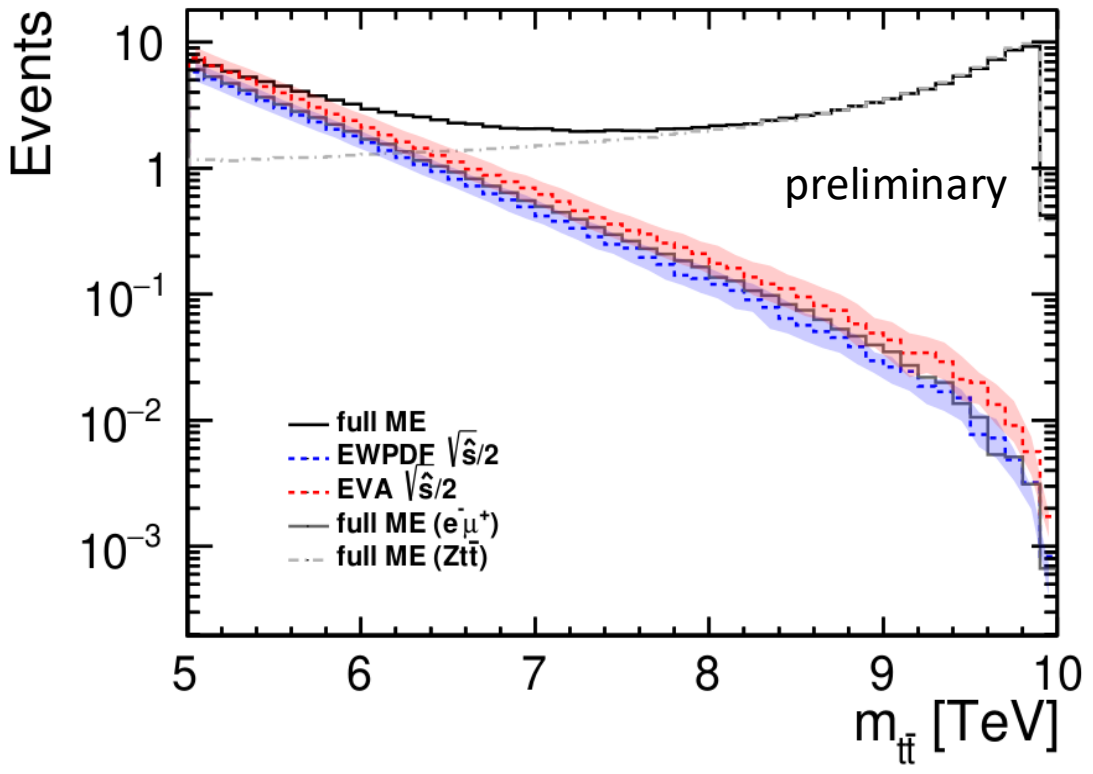




TOP-PAIR PRODUCTION

WW -> ttbar @ 10-TeV MuC, $|\eta_{sub}| < 2.44$





CONCLUSIONS & OUTLOOK

- The collinear emission of nearly on-shell massive vector bosons makes any multi-TeV machine a **vector-boson collider**.
- EVA and EWPDFs offer a framework to study physics in the collinear regime.
- EWPDFs resum certain large logs and potentially improve the description of physics at low angles.
- Many new results expected soon!