Università degli Studi di Napoli Federico II

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Exploring new avenues at the LHC with lepton-induced processes

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Work done in collaboration with:
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A life in phenomenology: a conference in honour of Paolo Nason
Unimib - 15 September 2022

Lepton pdfs

- Lux method for lepton pdfs: compare two calculations for a cross section

[Manohar, Nason, Salam, Zanderighi, PRL (2016)]
[Manohar, Nason, Salam, Zanderighi, JHEP (2017)]

1. pre QCD calculation: the proton interact via a virtual photon and the corresponding structure functions

2. the lepton and the photon are partons (with zero virtuality)

(for leptons) [Buonocore, Nason, FT, Zanderighi, JHEP (2020)]

- Result:

$$x_\ell f_\ell(x_\ell,\mu_F^2) = \left(\frac{1}{2\pi}\right)^2 \int_{x_\ell}^1 \frac{\mathrm{d}x}{x} z_\ell \int_x^1 \frac{\mathrm{d}z}{z} \int_{\frac{m_\mathrm{p}^2 x^2}{1-z}}^{\frac{\mu_F^2}{1-z}} \frac{\mathrm{d}Q^2}{Q^2} \alpha^2(Q^2)$$

$$\times \Bigg\{ P_{\ell\gamma}(z_\ell) \log \frac{\mu_\mathrm{F}^2}{(1-z_\ell) z_\ell \left(Q^2 + \frac{m_\ell^2}{z_\ell(1-z_\ell)}\right)} \left[F_2 \left(z P_{\gamma q}(z) + \frac{2 m_\mathrm{p}^2 x^2}{Q^2} \right) - F_L z^2 \right]$$

$$+ F_2 \left[4(z-2)^2 z_\ell (1-z_\ell) - (1+4 z_\ell(1-z_\ell))\, z P_{\gamma q}(z) \right]$$

$$+ F_L z^2 P_{\ell\gamma}(z_\ell) - \frac{2 m_\mathrm{p}^2 x^2}{Q^2} F_2 - \left(F_2 \frac{2 m_\mathrm{p}^2 x^2}{Q^2} - z^2 F_L \right) 4 z_\ell (1-z_\ell)$$

$$+ \frac{m_\ell^2 F_2}{m_\ell^2 + Q^2 z_\ell (1-z_\ell)} \left[z P_{\gamma q}(z) - 8 z_\ell (1-z_\ell) \left(1 - z - \frac{m_\mathrm{p}^2 x^2}{Q^2} \right) + \frac{2 m_\mathrm{p}^2 x^2}{Q^2} \right]$$

$$- \frac{m_\ell^2 F_L z^2}{m_\ell^2 + Q^2 z_\ell (1-z_\ell)} \left[2 - P_{\ell\gamma}(z_\ell) \right] \Bigg\}$$

with:

$$z_\ell = x_\ell / x$$

$$x_\mathrm{bj} = x/z$$

$$F_2 = F_2(x_\mathrm{bj}, Q^2)$$

$$F_L = F_L(x_\mathrm{bj}, Q^2)$$

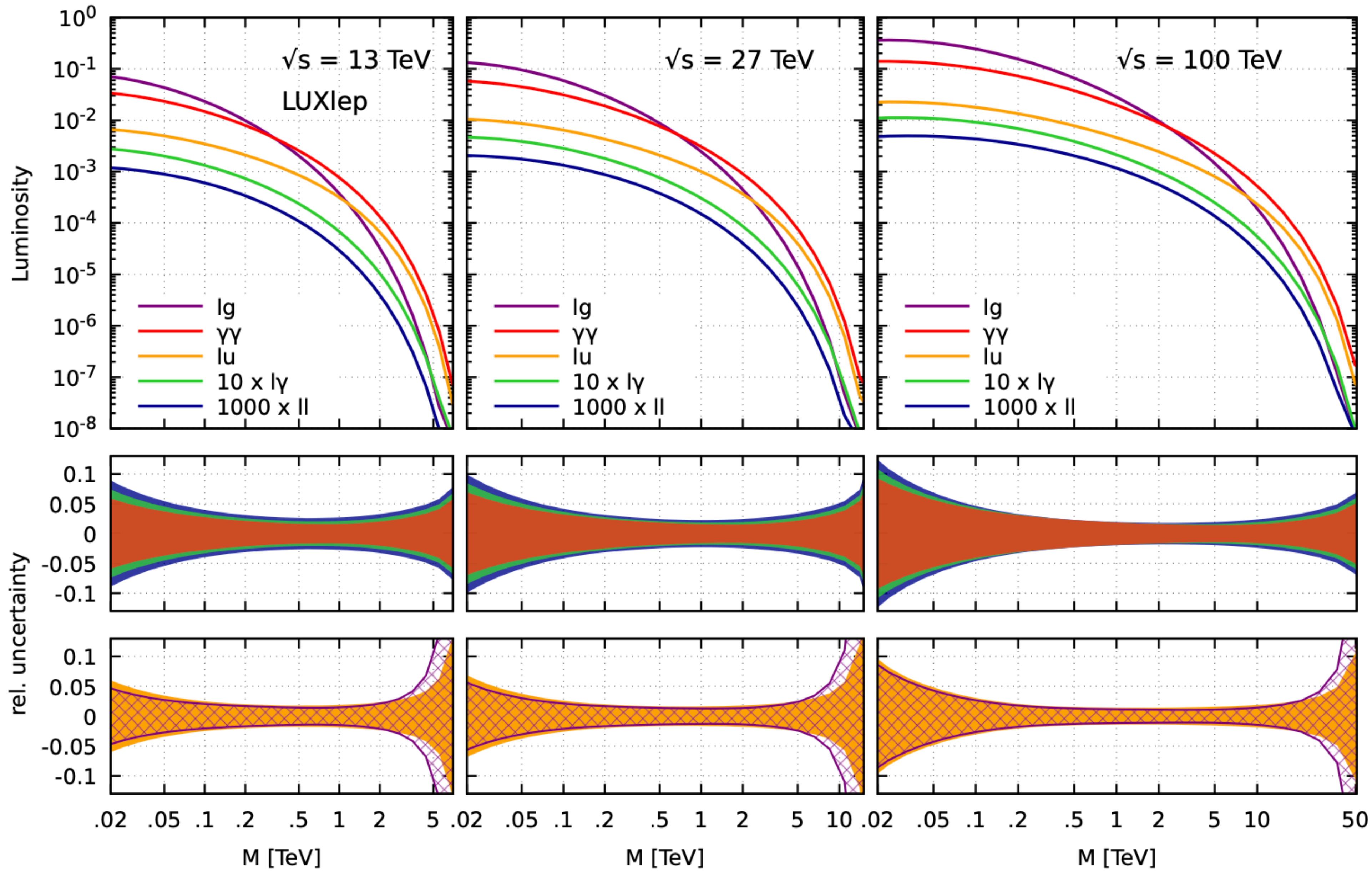
$$P_{\gamma q}(z) = \frac{1 + (1-z)^2}{z}$$

$$P_{\ell\gamma}(z_\ell) = 1 - 2 z_\ell + 2 z_\ell^2$$

Luminosities

$$\mathcal{L}_{ij} \equiv M^2 \int_0^1 \mathrm{d}z\,\mathrm{d}y\, f_i(z, M^2) f_j\left(y, M^2\right) \delta(M^2 - szy)$$

[Buonocore, Nason, FT, Zanderighi, JHEP (2020)]

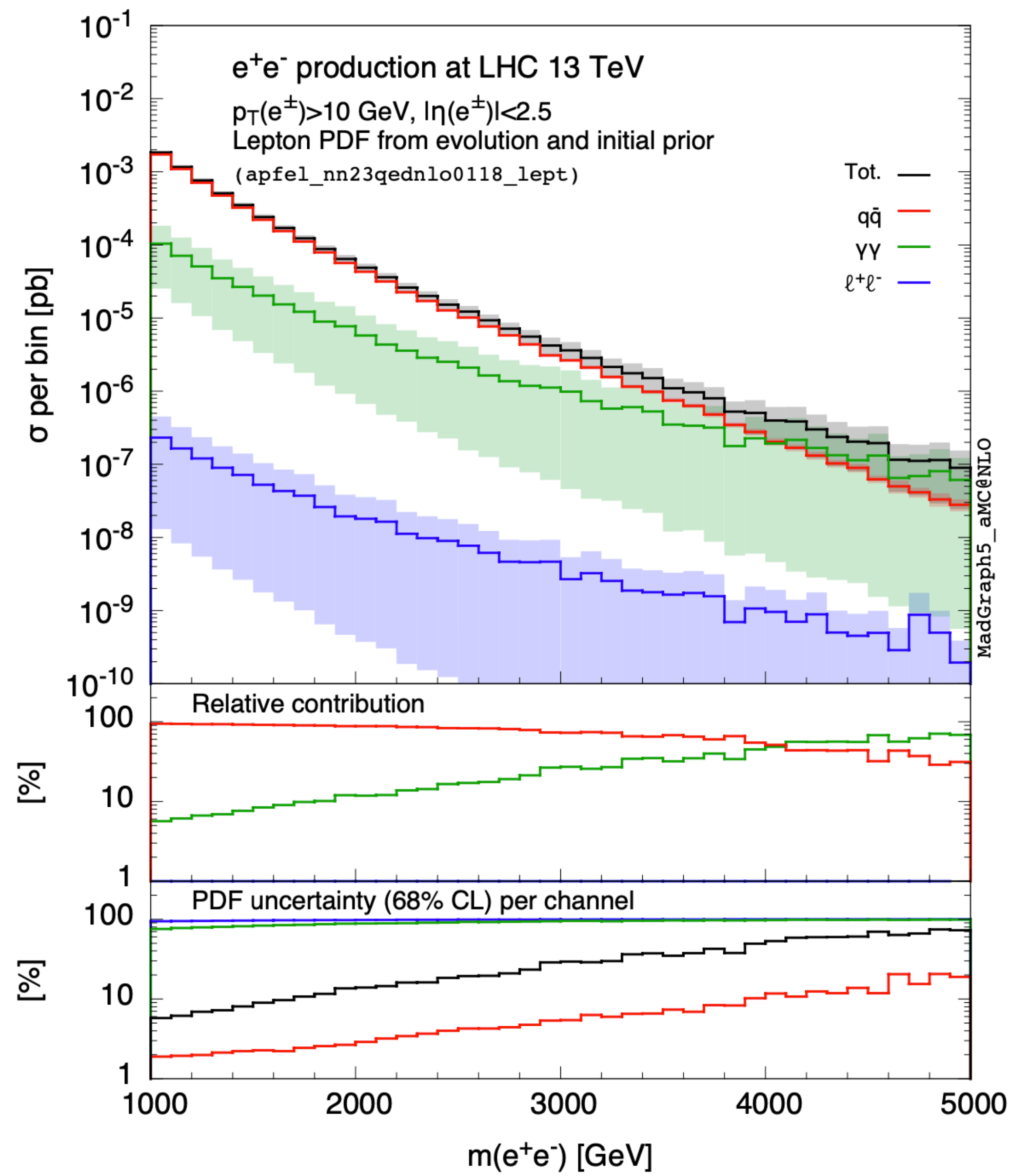


- PDF-Uncertainty under extremely good control → good start for pheno studies with leptons in the initial state
- In principle, all lepton-lepton combinations are available and in a broad energy spectrum
- We have to explore all the physics opportunities offered by the monumental data campaign ongoing at the LHC!

lepton-lepton scattering at the LHC

- A crucial aspect which prevented so far to fully explore the phenomenology offered by lepton initiated processes is **the lack of a precise determination of the lepton densities**

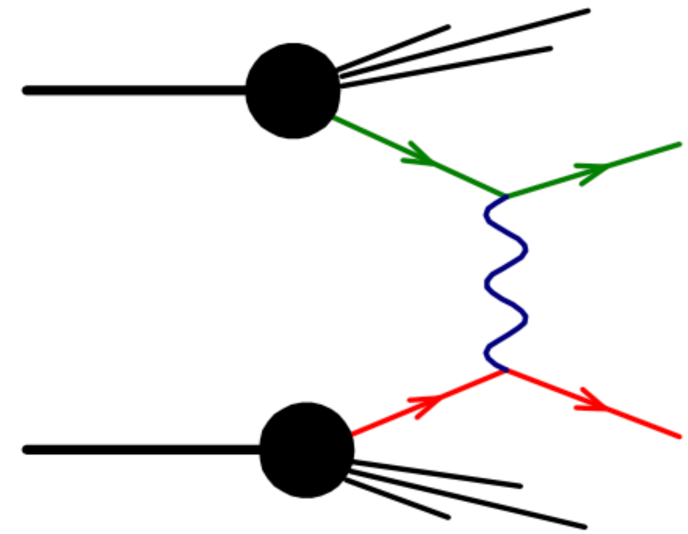
[Bertone, Carrazza, Pagani, Zaro, JHEP (2015)]



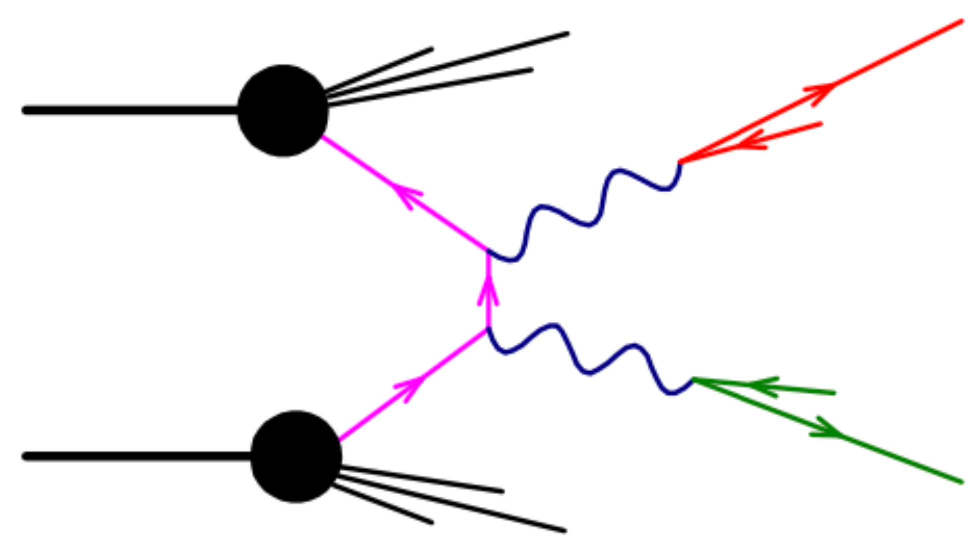
Plan

1. lepton-lepton scattering at the LHC
2. LeptoQuarks

lepton-lepton scattering at the LHC



- Non-DY lepton pair production:
  - opposite sign and different flavor
  - same sign and different flavor
  - same sign and identical flavor
  - Processes with small cross-section, but a typical signature (back-to-back leptons with no radiation)
- On general ground: one could make the partonic computation starting with (on-shell) photons
  - situation analogous as for b quarks (4Fvs5F modes)
  - In this case the balance is among large logs (numerical instabilities) and higher multiplicity vs resummation, good numerical control and simpler calculations



- Main background: double DY
  - we impose cuts to enhance S/B

lepton-lepton scattering at the LHC

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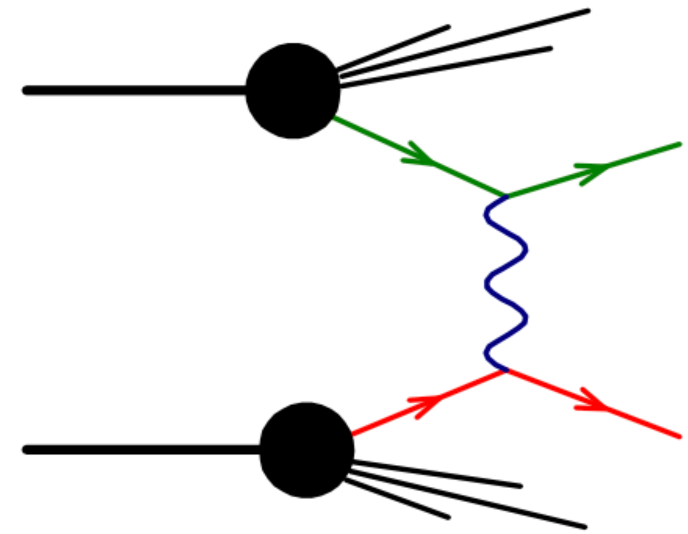
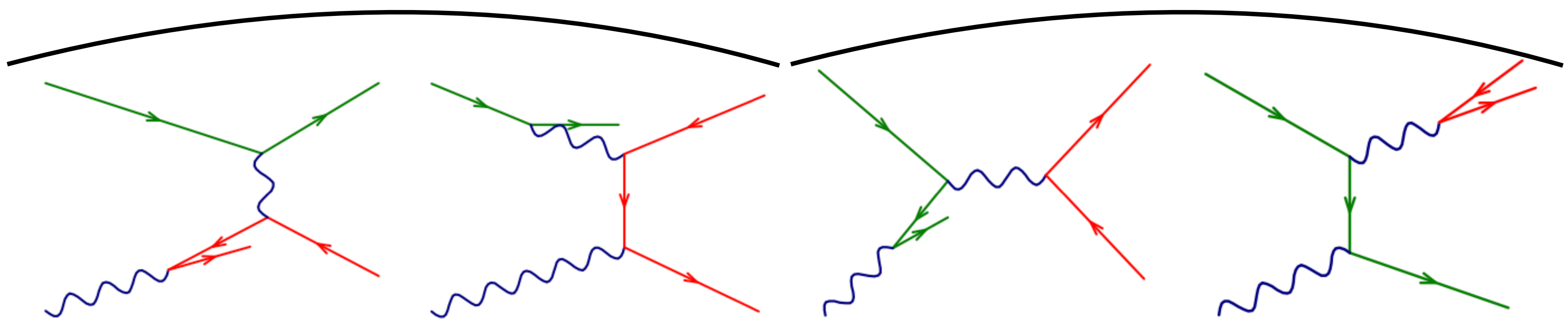




(a) (b) (c) (d)

- Going at NLO: we consider only the leading contribution and apply cuts to reduce double DY bkg
  - lepton pdf is suppressed by αL ($L = \log\left(Q^2/\Lambda\right) \sim 1/\alpha_S$) w.r.t the photon pdf
  - so, photon initiated real corrections (a), (b) and (c) are enhanced by $\alpha/(\alpha L) \sim \alpha_S$
  - (d) is special, collinear region (Compton scattering) suppressed with isolation (we use lepton mass as a natural regulator)
  - virtual contribution (α) are neglected

lepton-lepton scattering at the LHC

[Buonocore, Nason, FT, Zanderighi, JHEP (2021)]

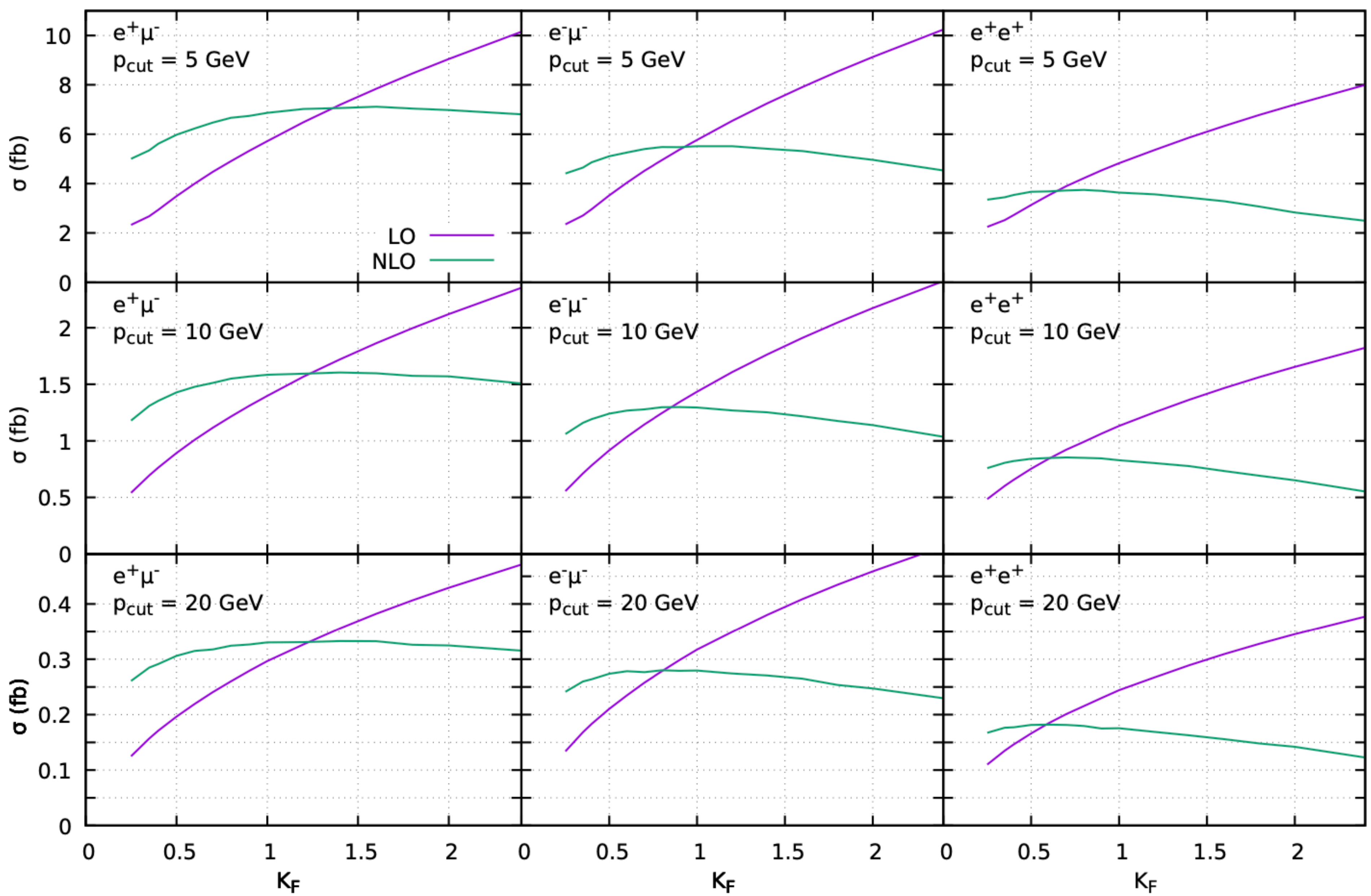
- Scale dependence

$$\mu_0 = \frac{1}{2}\sum_l p_l^T \qquad K_F = \mu/\mu_0$$

$$p_T > p_{cut},\ p_{cut} = 5, 10 \text{ and } 20\,\text{GeV}, \qquad |\eta| < 2.4$$

$$\text{isolation:} \quad \Delta r > 0.3 \quad \text{for leptons } p_T > 0.9\,\text{GeV}.$$

Cross over: $K_F \gtrsim 1$ $K_F \lesssim 1$ $K_F \sim 0.5$



lepton-lepton scattering at the LHC

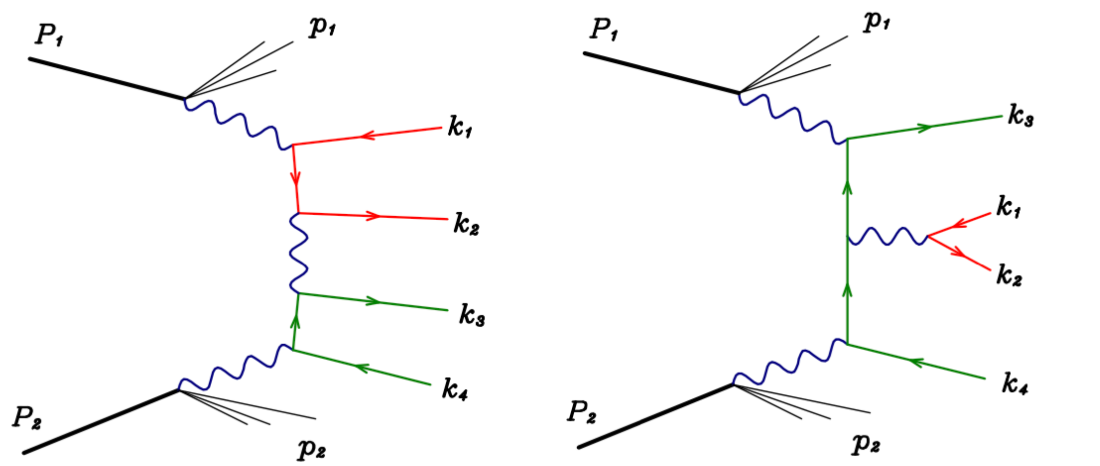
[Buonocore, Nason, FT, Zanderighi, JHEP (2021)]

- Scale dependence: vary by 2 and 1/2 around

$$\mu_{F,max} \mid \sigma_{NLO}(\mu_{F,max}) = \max_{\mu} \sigma_{NLO}(\mu)$$

Cross sections @LHC13 (fb)

Proc.	$p_{\rm cut}$	$K_{\rm F}$		NLO		LO		HT
		min	max	min	max	min	max	
$e^+\mu^-$	5	0.80	3.20	6.203	7.113	4.907	12.091	7.41
	10	0.70	2.80	1.451	1.604	1.116	2.563	1.67
	20	0.70	2.80	0.305	0.333	0.241	0.510	0.346
$e^-\mu^-$	5	0.50	2.00	4.961	5.515	3.521	9.127	6.65
	10	0.40	1.80	1.176	1.299	0.784	2.046	1.53
	20	0.40	1.60	0.264	0.280	0.183	0.409	0.322
e^+e^+	05	0.40	1.60	3.285	3.745	2.719	6.338	4.9
	10	0.35	1.40	0.777	0.853	0.602	1.363	1.05
	20	0.25	1.20	0.167	0.182	0.110	0.267	0.213



$$\sigma = \frac{1}{2S}\int \frac{d^4 q_1}{(2\pi)^4}\frac{1}{q_1^4}(4\pi)W^{(1)}_{\mu\mu'}(P_1,q_1)\frac{d^4 q_2}{(2\pi)^4}\frac{1}{q_2^4}(4\pi)W^{(2)}_{\nu\nu'}(P_2,q_2)$$
$$\times T^{\mu\mu';\nu\nu'}(-q_1,-q_2,k_l)d\Gamma(2\pi)^4\delta\left(-q_1-q_2-\sum k_l\right),$$

$$W_{\mu\mu'}(P,q) = F_1\left(-g_{\mu\mu'}+\frac{q_\mu q_{\mu'}}{q^2}\right)+\frac{F_2}{P\cdot q}\left(P_\mu - \frac{P\cdot q q_\mu}{q^2}\right)\left(P_{\mu'} - \frac{P\cdot q q_{\mu'}}{q^2}\right)$$

- HT: Hadronic Tenson computation, but also
  Highly non Trivial check!

- strong reduction of (factorization) scale error

- good agreement with full Hadronic Tensor computation (at all orders in QCD)
  - HT result slightly larger: in which kinematic region do they differ? can we improve the agreement?

lepton-lepton scattering at the LHC

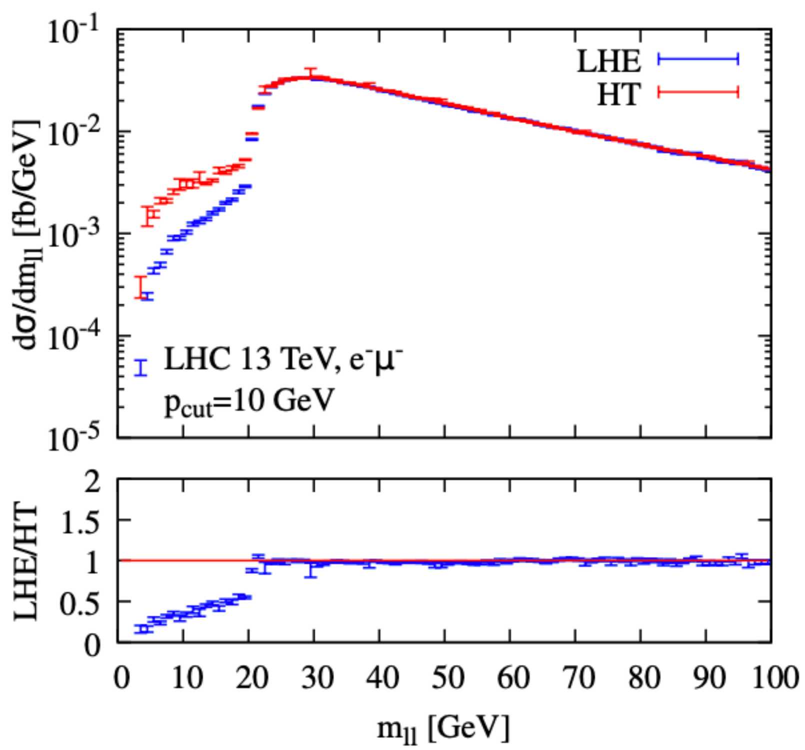
[Buonocore, Nason, FT, Zanderighi, JHEP (2021)]

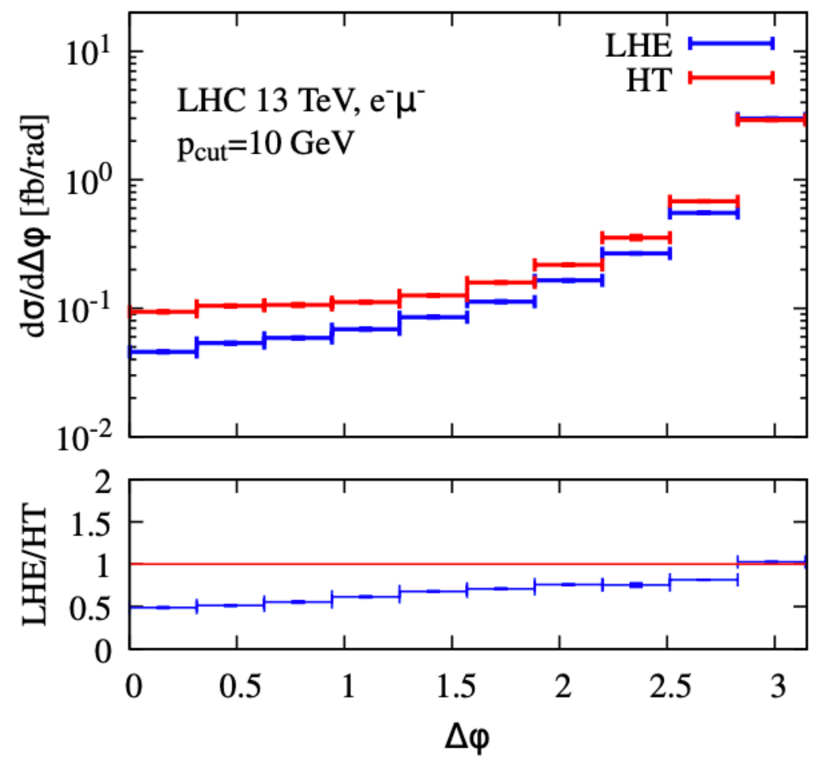
- Where

(cut T)

(i) Both signal leptons must have $|\eta| < 2.4$, $p_t > p_{\rm cut}$.

(ii) We veto events with extra leptons with $p_t > 0.9\,{\rm GeV}$ in a cone of radius $r < 0.3$.

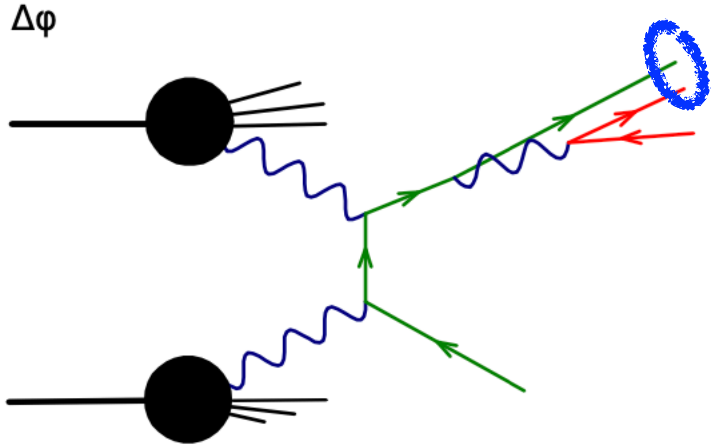




- Why
  - NNLO contribution not included in our partonic computation
  - the effect is strongly reduced by requiring:

$$\text{(iii)}\quad m_{l\ell} > |p_t^{(l)}| + |p_t^{(\ell)}| \quad \text{(cut A)}$$

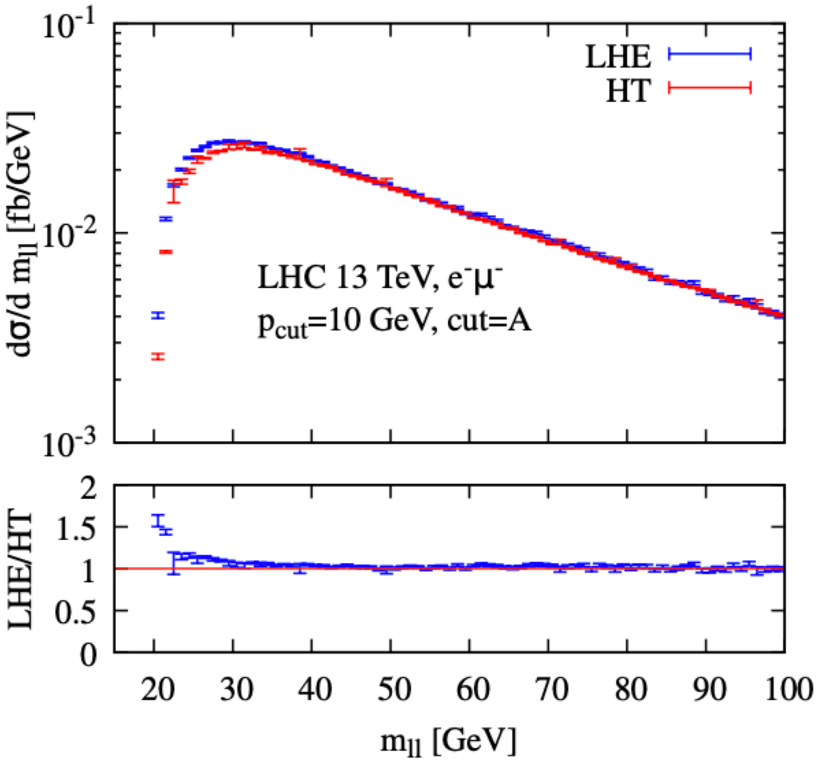
that also reduces double DY bkg

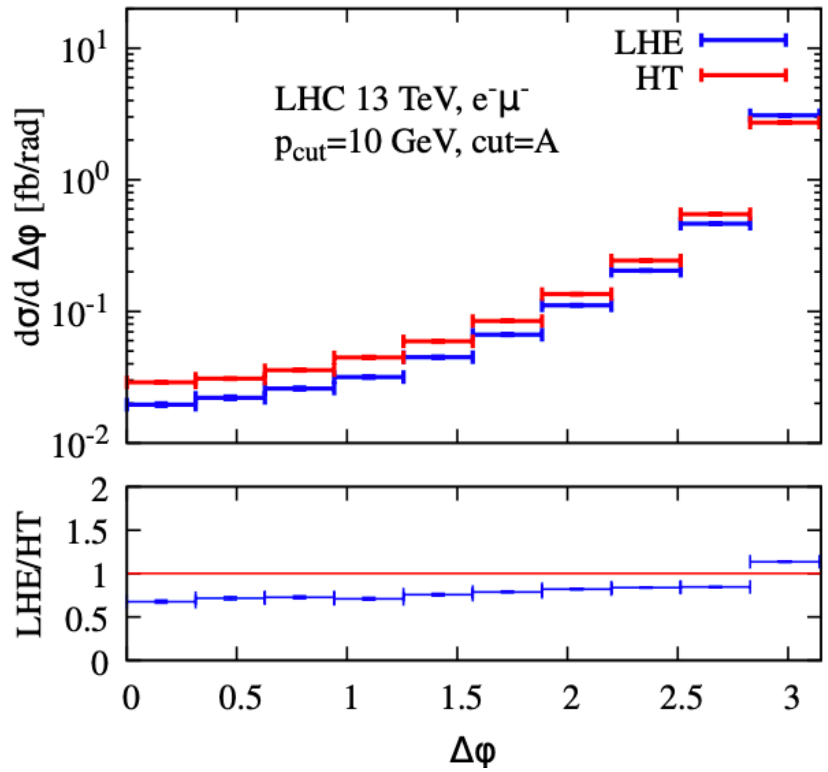


lepton-lepton scattering at the LHC

[Buonocore, Nason, FT, Zanderighi, JHEP (2021)]

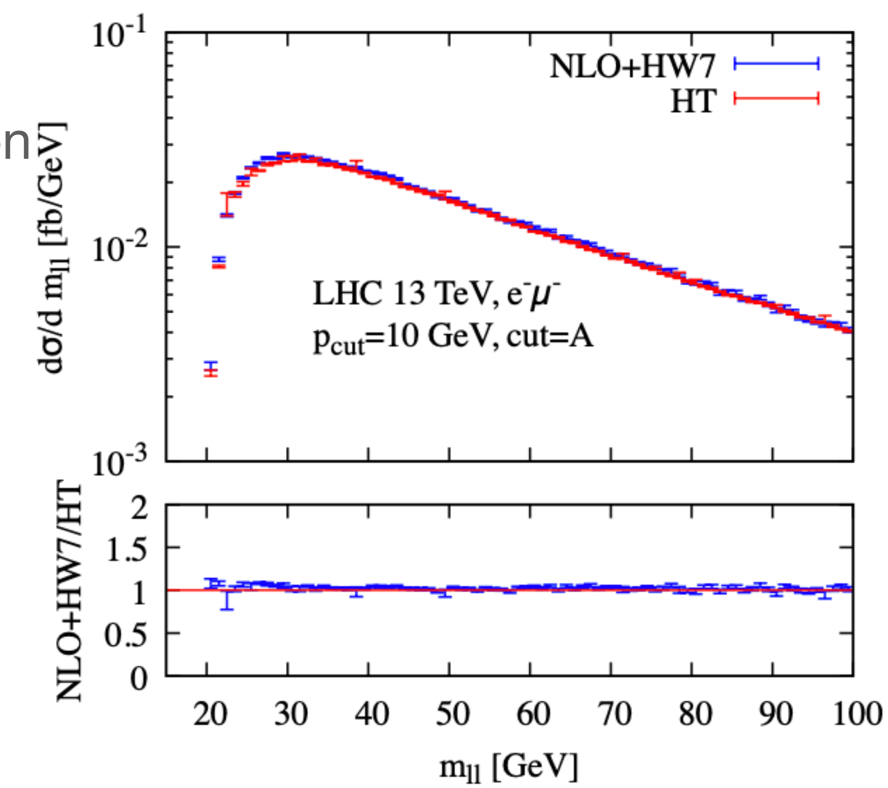
- cut A improves agreement

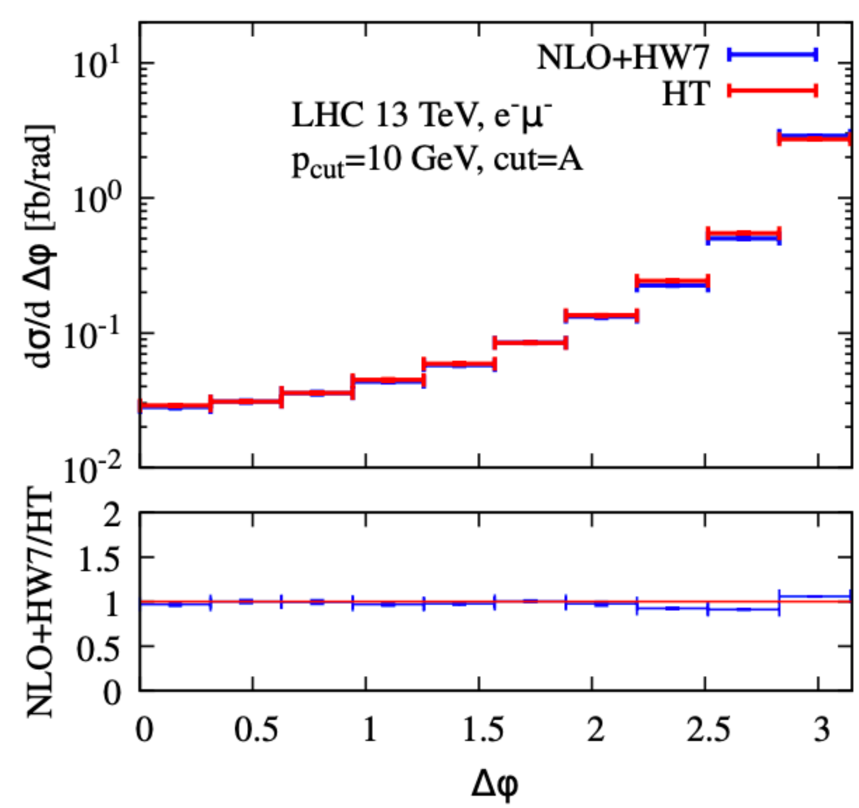




- Thanks to Peter Richardson who provided us with a preliminary version of Herwig that handle incoming leptons and Silvia Ravasio who assisted us in the implementation

- and by including shower effects we have excellent agreement thanks to backward evolution recovering effects already included in HT

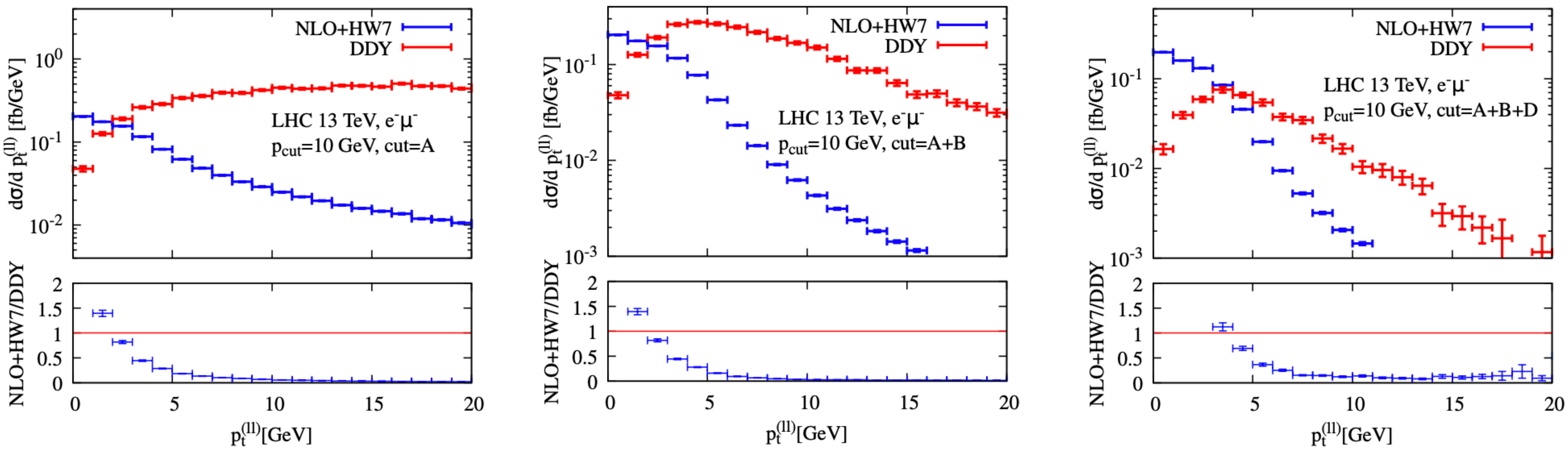




lepton-lepton scattering at the LHC

[Buonocore, Nason, FT, Zanderighi, JHEP (2021)]

- Signal and bkg (DDY) for the transverse momentum of the pair of leptons



(i) Both signal leptons must have $|\eta| < 2.4$, $p_t > p_{\rm cut}$.

(cut T)

(ii) We veto events with extra leptons with $p_t > 0.9\,\text{GeV}$ in a cone of radius $r < 0.3$.

(iii) $m_{l\ell} > |p_t^{(l)}| + |p_t^{(\ell)}|$ (cut A)

(iv) $|p_t^{l\ell}|/(|p_t^{(l)}| + |p_t^{(\ell)}|) < 0.2$ (cut B)

(v) If there is another lepton passing cuts i and ii with $p_t > 3\,\text{GeV}$ the event is vetoed (cut D).

lepton-lepton scattering at the LHC

[Buonocore, Nason, FT, Zanderighi, JHEP (2021)]

- Let's compare signal and bkg (DDY) for the transverse momentum of the pair of leptons

LHC13

$e^-\mu^-$	T	TA	TAB	TABD
σ (fb), $p_{\rm cut} = 5\,\text{GeV}$				
LO	$5.789^{+3.343}_{-2.267}$	$5.789^{+3.343}_{-2.267}$	$5.789^{+3.343}_{-2.267}$	$5.789^{+3.343}_{-2.267}$
NLO	$5.53_{-0.57}$	$4.41_{-1.07}$	$2.21^{+0.59}_{-1.95}$	$1.88^{+0.69}_{-2.08}$
LHE	$6.300_{-0.762}$	$5.493_{-0.591}$	$3.802_{-0.519}$	$3.580_{-0.544}$
NLO+HW7	6.646	5.532	3.255	2.858
HT	6.65	5.232	3.13	2.82
DDY	104.	28.5	4.33	1.22
σ (fb), $p_{\rm cut} = 10\,\text{GeV}$				
LO	$1.432^{+0.734}_{-0.520}$	$1.432^{+0.734}_{-0.520}$	$1.432^{+0.734}_{-0.520}$	$1.432^{+0.734}_{-0.520}$
NLO	$1.28_{-0.14}$	$1.03^{+0.02}_{-0.24}$	$0.56^{+0.15}_{-0.40}$	$0.31^{+0.23}_{-0.49}$
LHE	$1.469_{-0.128}$	$1.281_{-0.093}$	$0.920_{-0.129}$	$0.752_{-0.145}$
NLO+HW7	1.488	1.262	0.847	0.664
HT	1.53	1.234	0.80	0.63
DDY	51.7	17.	3.02	0.47

- Excellent agreement among NLO+PS and HT computations

lepton-lepton scattering at the LHC

[Buonocore, Nason, FT, Zanderighi, JHEP (2021)]

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$$\frac{S}{\sqrt{B}} \sim 2.5$$

$$\frac{S}{\sqrt{B}} \sim 1$$

- Lepton scattering at very high energy measurable at the LHC!

- on going analysis in both ATLAS and CMS

Precision vs New Physics

arXiv > hep-ph

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High Energy Physics - Phenomenology

New submissions

Submissions received from Thu 8 Sep 22 to Fri 9 Sep 22, announced Mon, 12 Sep 22

- New submissions
- Cross-lists
- Replacements

[total of 38 entries: **1-38**]
[showing up to 2000 entries per page: fewer | more]

New submissions for Mon, 12 Sep 22

[1] **arXiv:2209.03968** [**pdf**, **other**]

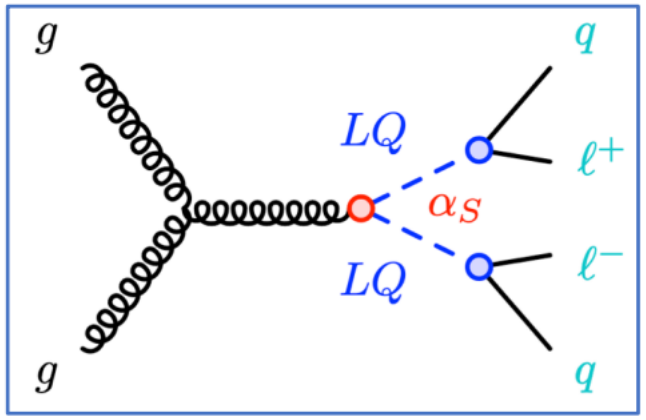
Standard Model Predictions for Rare K and B Decays without New Physics Infection
Andrzej J. Buras
Comments: 26 pages, 1 Figure
Subjects: **High Energy Physics - Phenomenology (hep-ph)**; High Energy Physics - Experiment (hep-ex); High Energy Physics - Lattice (hep-lat)

The Standard Model (SM) does not contain by definition any new physics (NP) contributions to any observable but contains four CKM parameters which are not predicted by this model. We point out that if these four parameters are determined in a global fit that includes processes which are infected by NP, the resulting SM contributions to rare decay branching ratios cannot be considered as true SM contributions to the latter. On the other hand true SM predictions, that are free from the CKM dependence, can be obtained for suitable ratios of the K and B rare decay branching ratios to ΔM_s, ΔM_d and $|\varepsilon_K|$, all calculated within the SM. These three observables contain by now only small hadronic uncertainties and are already well measured so that rather precise true SM predictions for the ratios in question can be obtained. In this context the rapid test of NP infection in the $\Delta F = 2$ sector is provided by a $|V_{cb}| - \gamma$ plot that involves ΔM_s, ΔM_d, $|\varepsilon_K|$, and the mixing induced CP-asymmetry $S_{\psi K_S}$. As with the present hadronic matrix elements this test turns out to be negative, assuming negligible NP infection in the $\Delta F = 2$ sector and setting the values of these four observables to the experimental ones, allows to obtain SM predictions for all K and B rare decay branching ratios that are most accurate to date and as a byproduct to obtain the full CKM matrix on the basis of $\Delta F = 2$ transitions alone. Using this strategy we obtain SM predictions for 26 branching ratios for rare semileptonic and leptonic K and B decays with the $\mu^+\mu^-$ pair or the $\nu\bar{\nu}$ pair in the final state. Most interesting turn out to be the anomalies in the low q^2 bin in $B^+ \to K^+\mu^+\mu^-$ (5.1σ) and $B_s \to \phi\mu^+\mu^-$ (4.8σ).

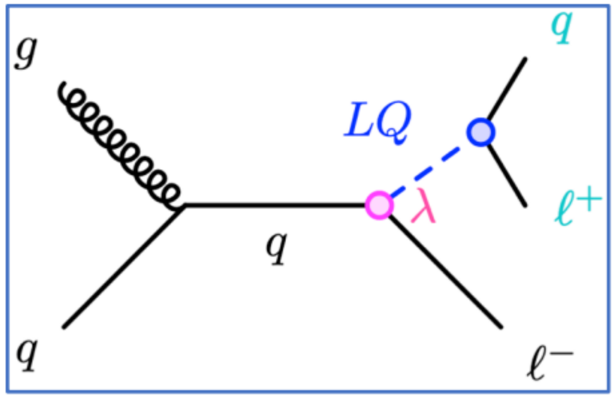
- The way in which BSM Physics is perceived in our community is changing, but still….

LeptoQuarks

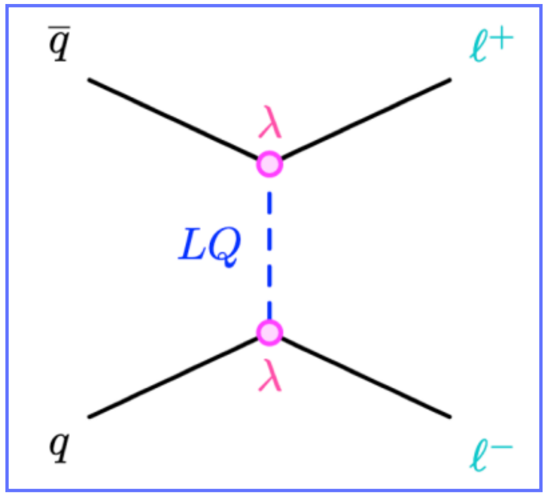
- LQ naturally emerge in unified theories that shed some light on the mystery of fractional charge
- The existence of LQ is also invoked to justify some phenomenological anomalies
- So far LQ searches at the LHC proceed under the assumption of three production mechanisms with signatures made of 2 final state hard leptons, or 1 lepton+MET, plus jet(s) for the resonant searches



- Double production: coupling is α_S

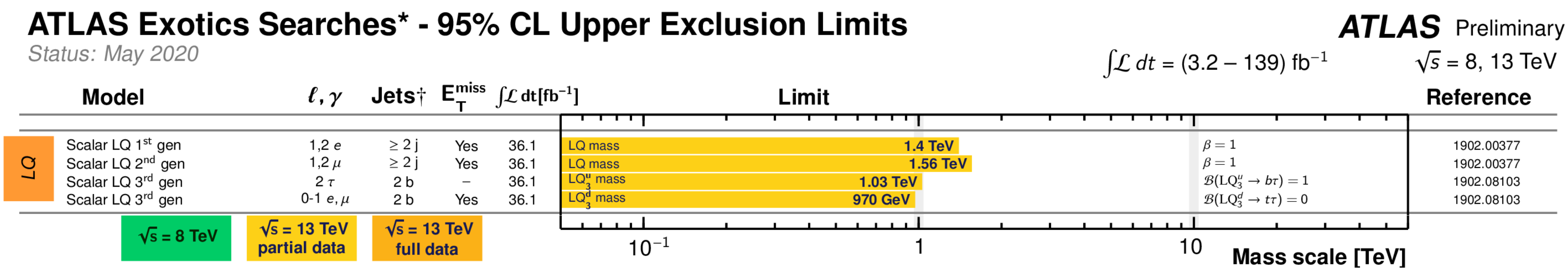


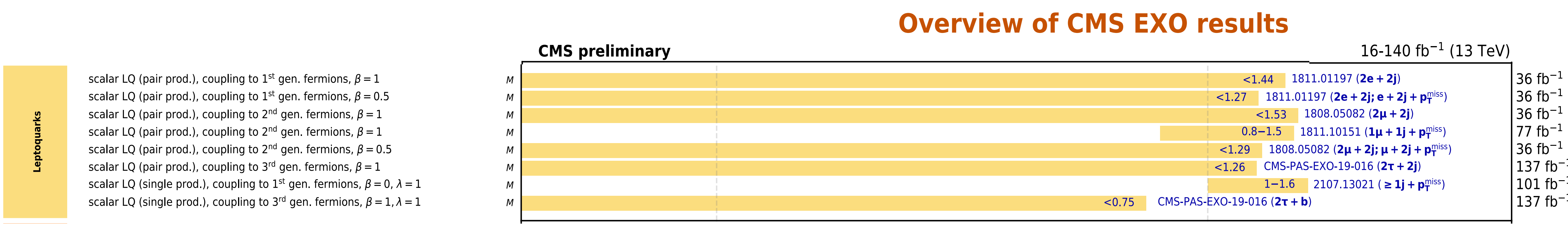
- Single production: lq-coupling λ, wider phase space



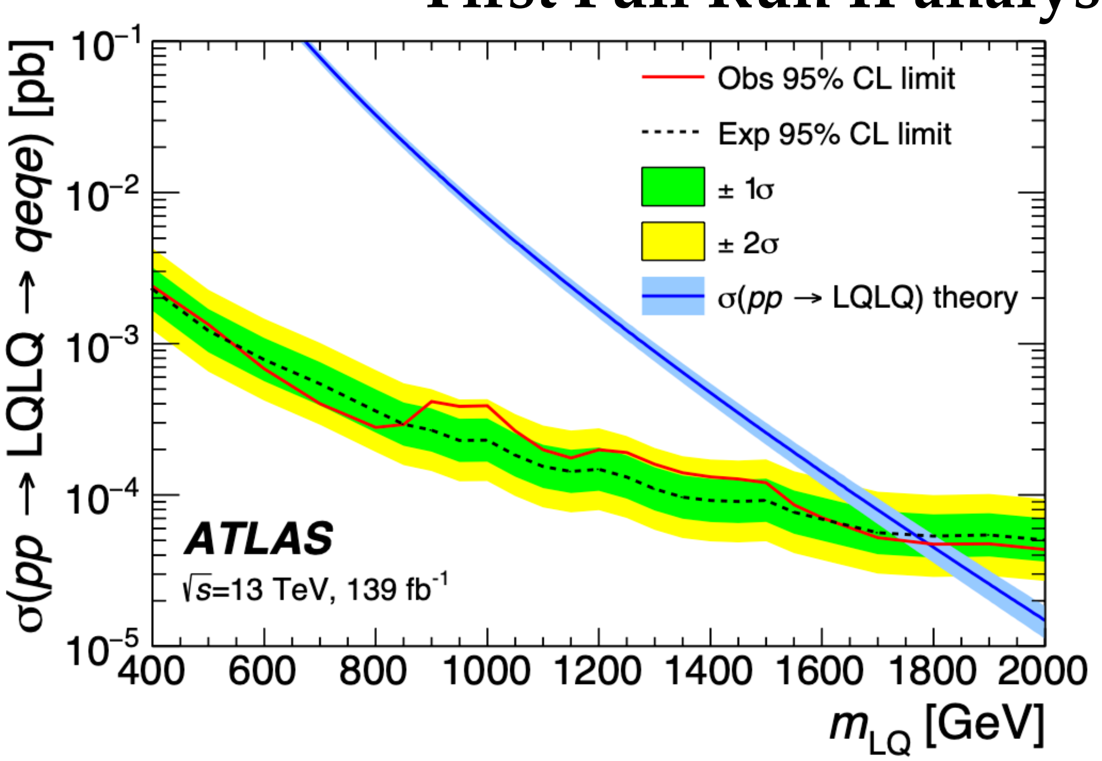
- DY production: non resonant

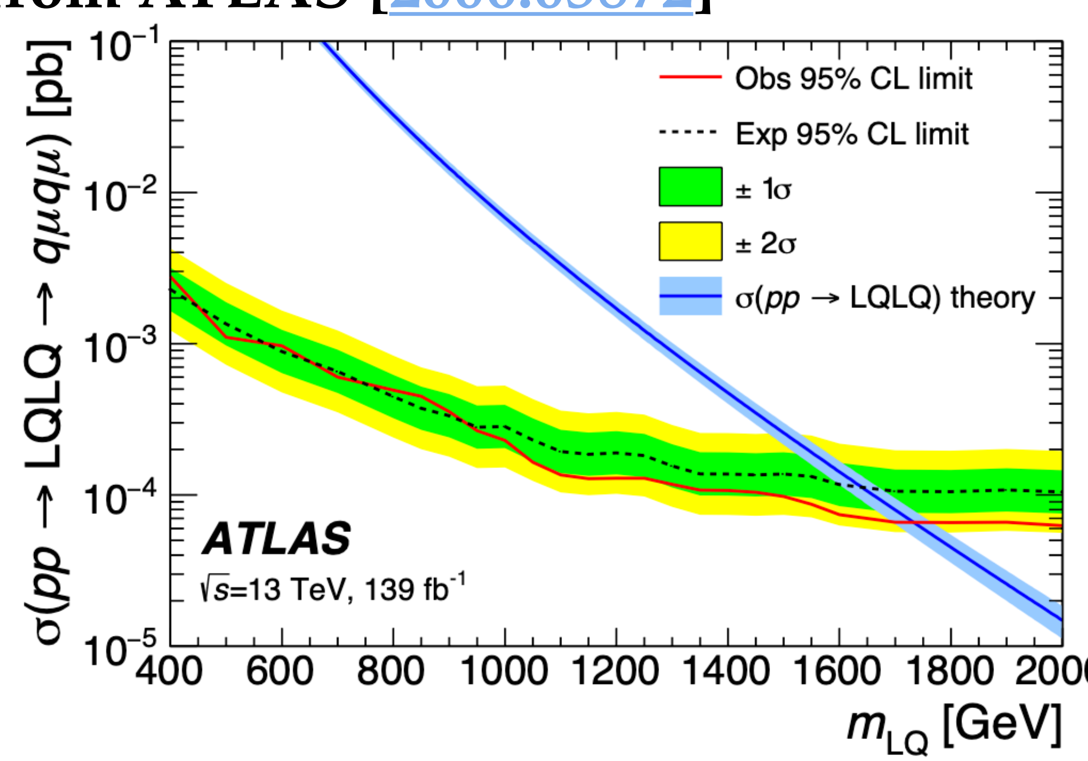
LeptoQuarks





First Full Run II analysis from ATLAS [2006.05872]

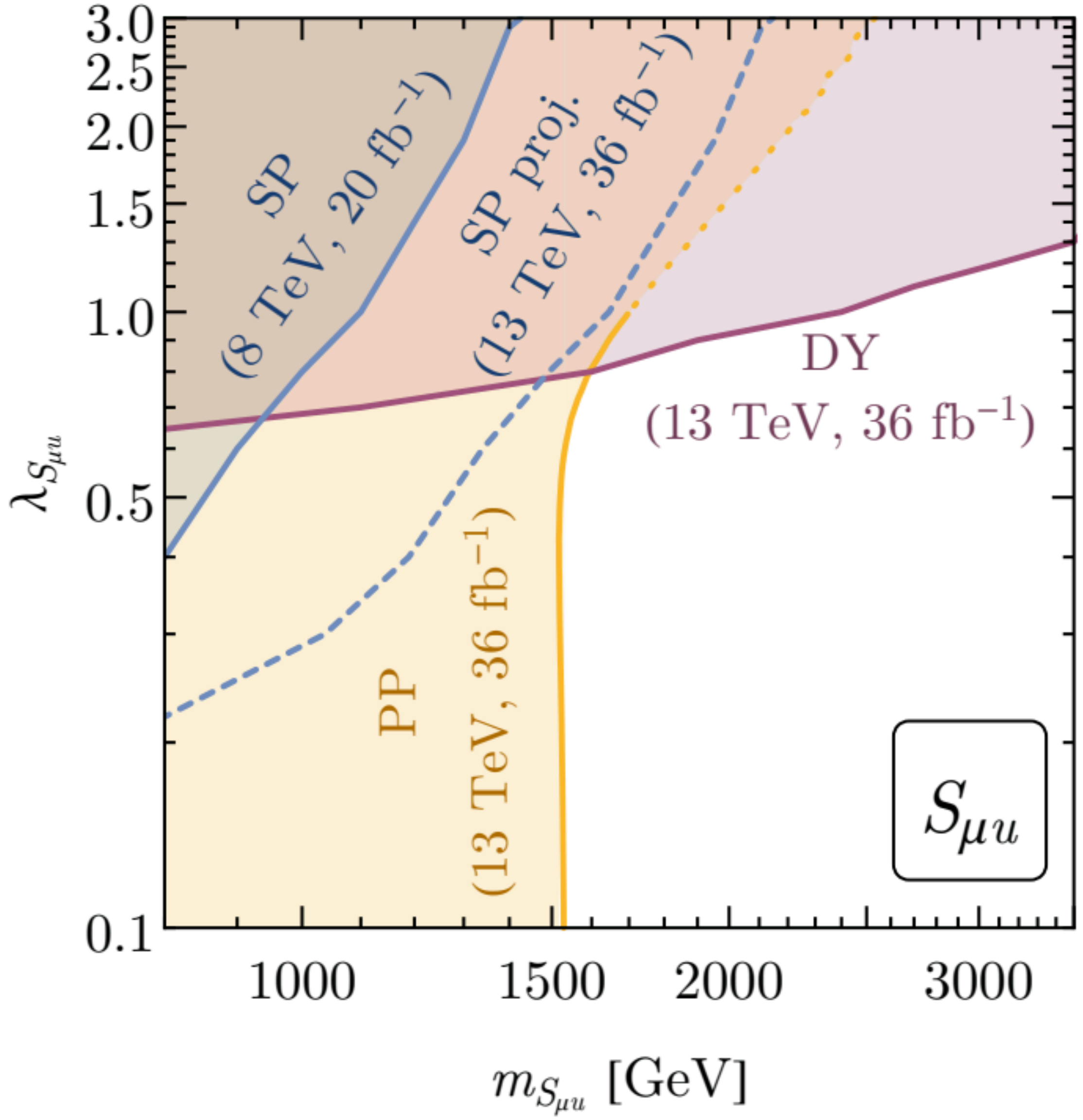




LeptoQuarks

- ATLAS and CMS limits

[Schmaltz and Zhong, JHEP (2019)]



LeptoQuarks

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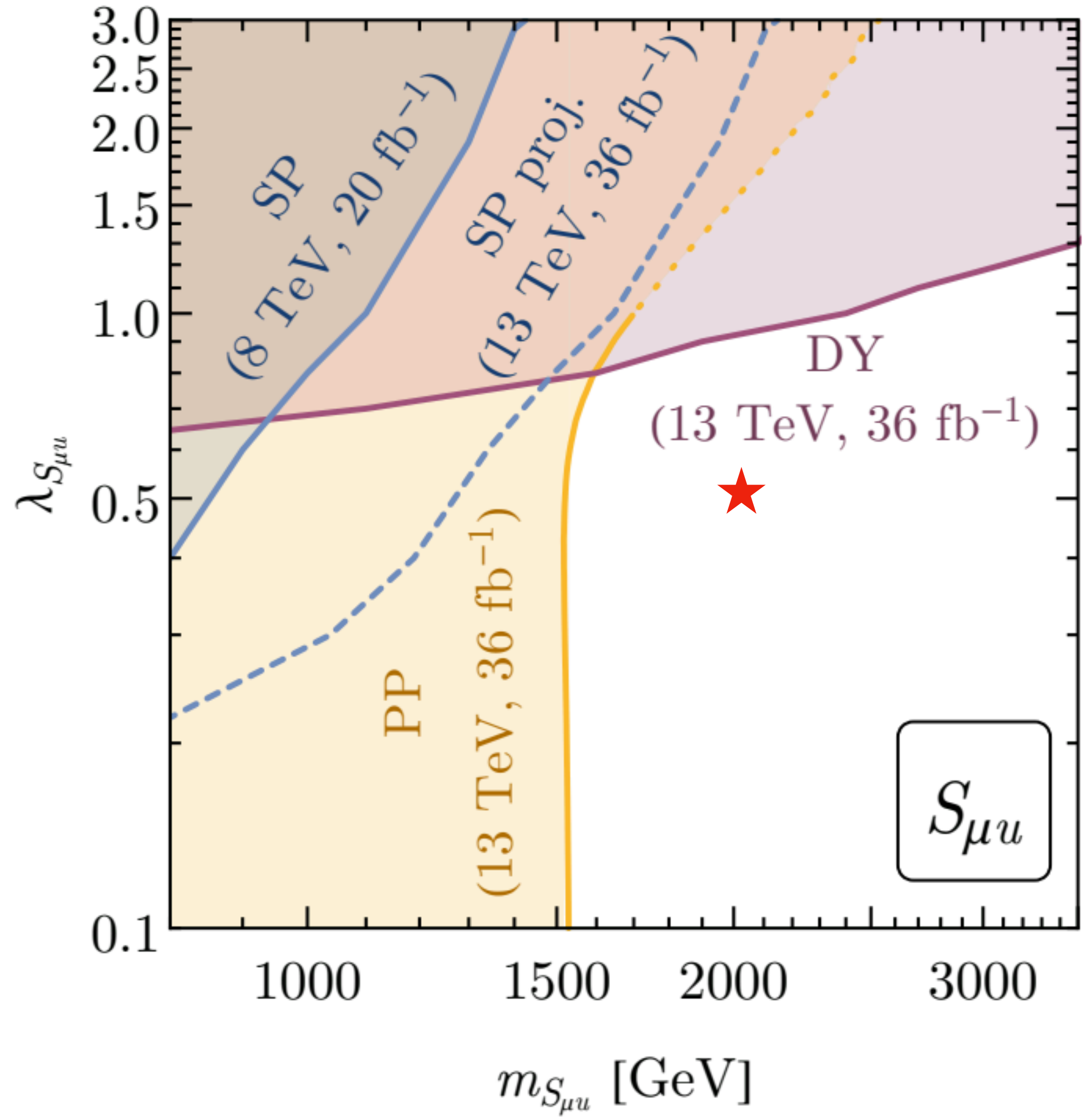
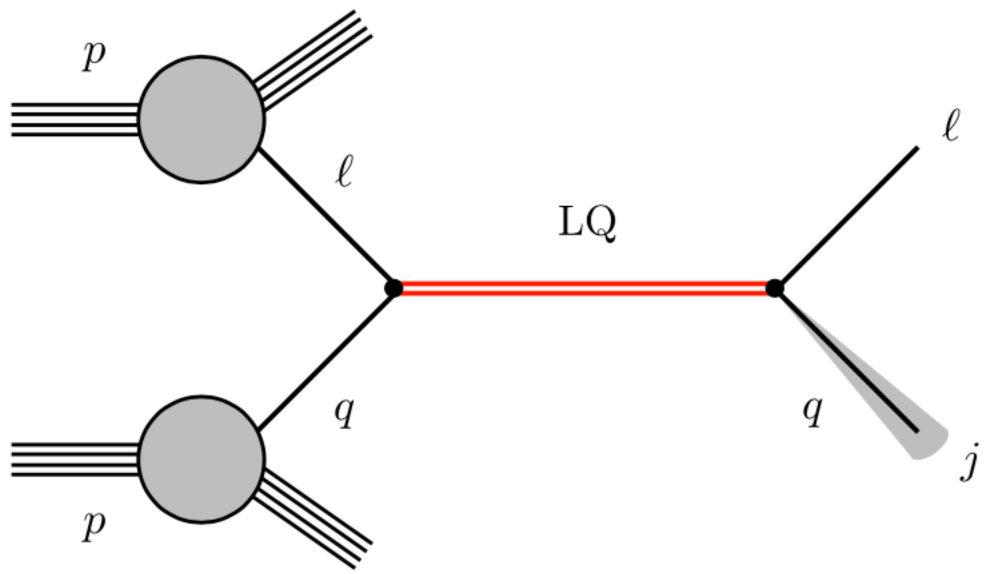


- Let's take for example: $M = 2\,\mathrm{TeV}$ and $\lambda_{S_{\mu u}} = y_{\mu u} = 0.5$ and compute s-channel production rate

LeptoQuarks

[Buonocore, Nason, FT, Zanderighi, JHEP (2021)]

- Let's consider the resonant LQ production as a lepton-quark fusion!



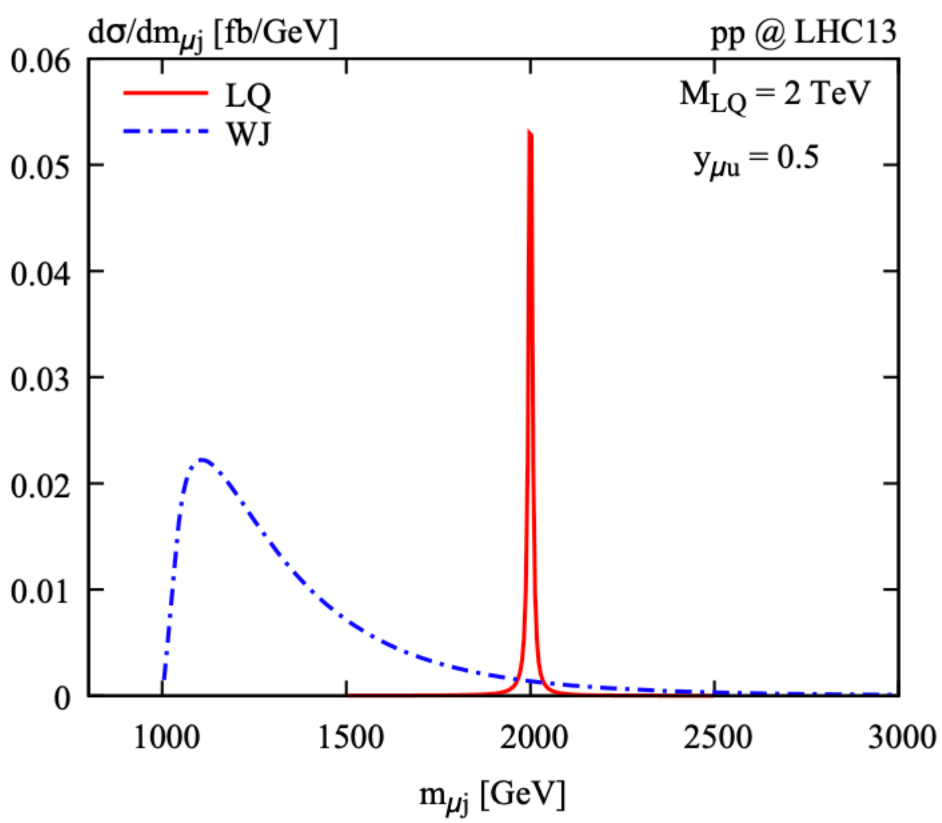
analysis cuts:

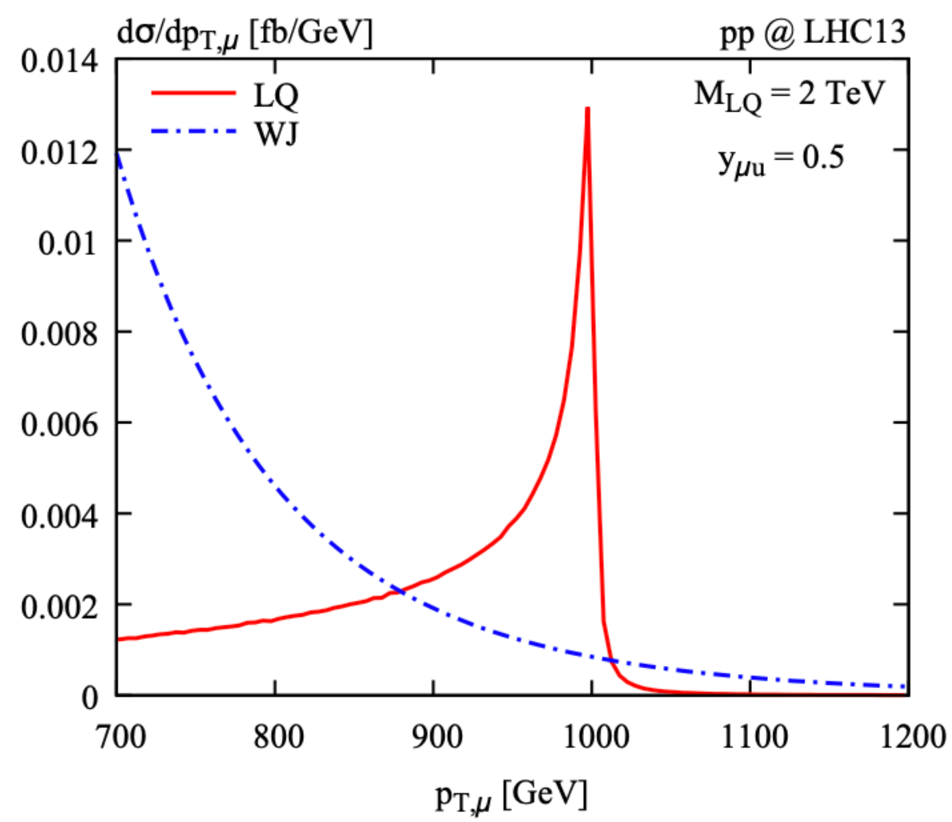
$p_T^l, p_T^j > 500\,\text{GeV}$

$|\eta_l|, |\eta_j| < 2.5$

$p_T^{\text{miss}} < 50\,\text{GeV}$

- Main background is $W(l\nu) + j$





LeptoQuarks

- The second thing we discovered is that: our idea was good, but not new…

arXiv:hep-ph/9406235v1 3 Jun 1994

SINGLE LEPTOQUARK PRODUCTION
AT HADRON COLLIDERS

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Abstract

Leptoquarks can be produced in pairs by gluon–gluon fusion and quark–antiquark annihilation at hadron colliders. While HERA is the proper machine for single production of (eu) and (ed) type leptoquarks, the flavor species of (μu), (μd) and (τu), (τd) type leptoquarks can be produced at hadron colliders very efficiently. Besides exploiting gluon-quark collisions, leptoquarks can also be produced singly by colliding the quarks in one proton beam with leptons e, μ, τ generated by splitting photons which are radiated off the quarks in the other proton beam. For Yukawa couplings of the size α leptoquark masses up to about 300 GeV can be generated at the Tevatron while the LHC can produce leptoquarks with masses up to about 3 TeV. [Leptoquarks involving heavy quarks can be produced singly at a lower rate, determined by the heavy flavor flux in the proton beam.]

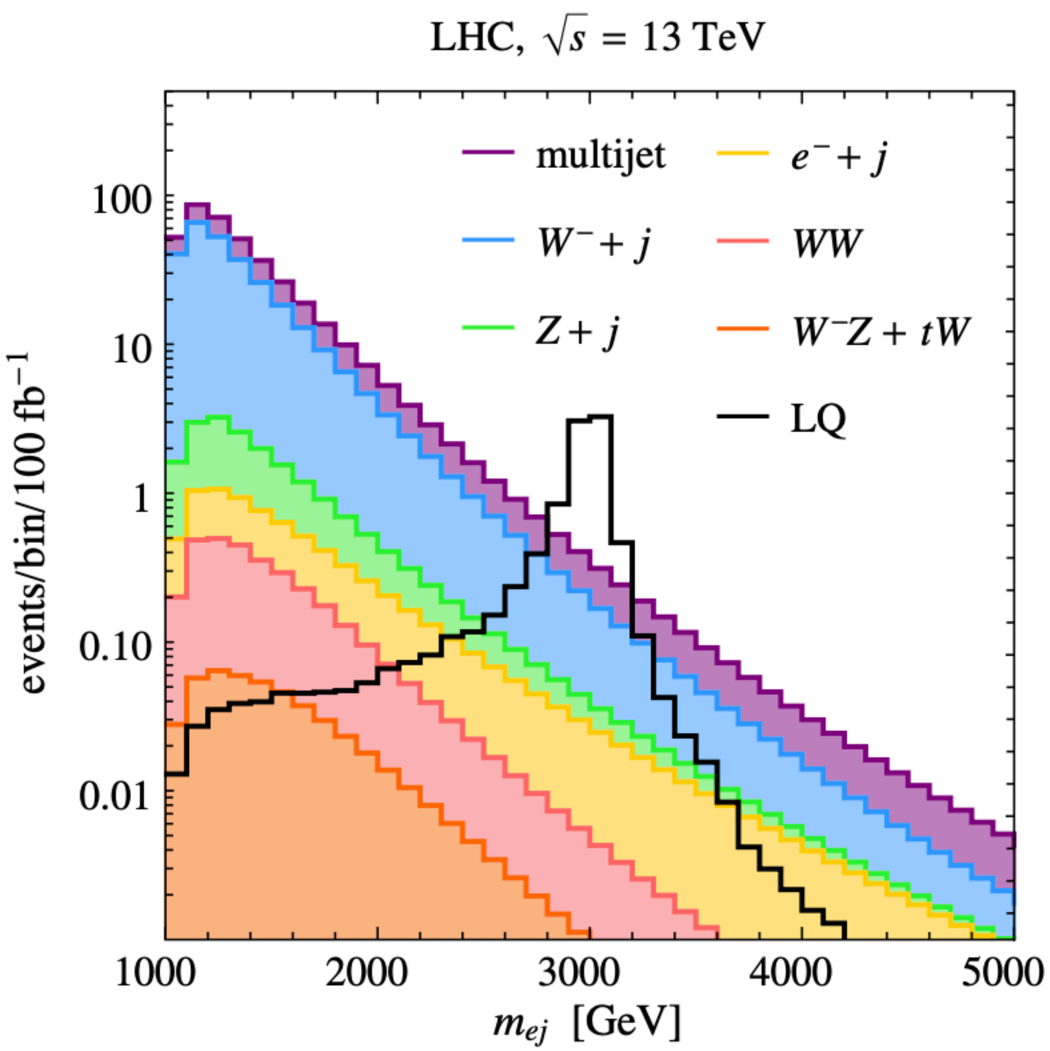
1994 paper: very interesting, but almost forgotten…

- Reasons to forget:
    - Results contain explicit logarithms of the electron and light quark masses
    - No recipe to compute errors

LeptoQuarks

[Buonocore, Haisch, Nason, FT, Zanderighi, PRL (2020)]

- Estimate for signal and bkg



analysis cuts:

$p_T^l, p_T^j > 500\,\mathrm{GeV}$

$|\eta_l|, |\eta_j| < 2.5$

$p_T^{\mathrm{miss}} < 50\,\mathrm{GeV}$

veto additional leptons and jets with:

$|\eta_l|, |\eta_j| < 2.5$

$p_T^l > 7\,\mathrm{GeV}$

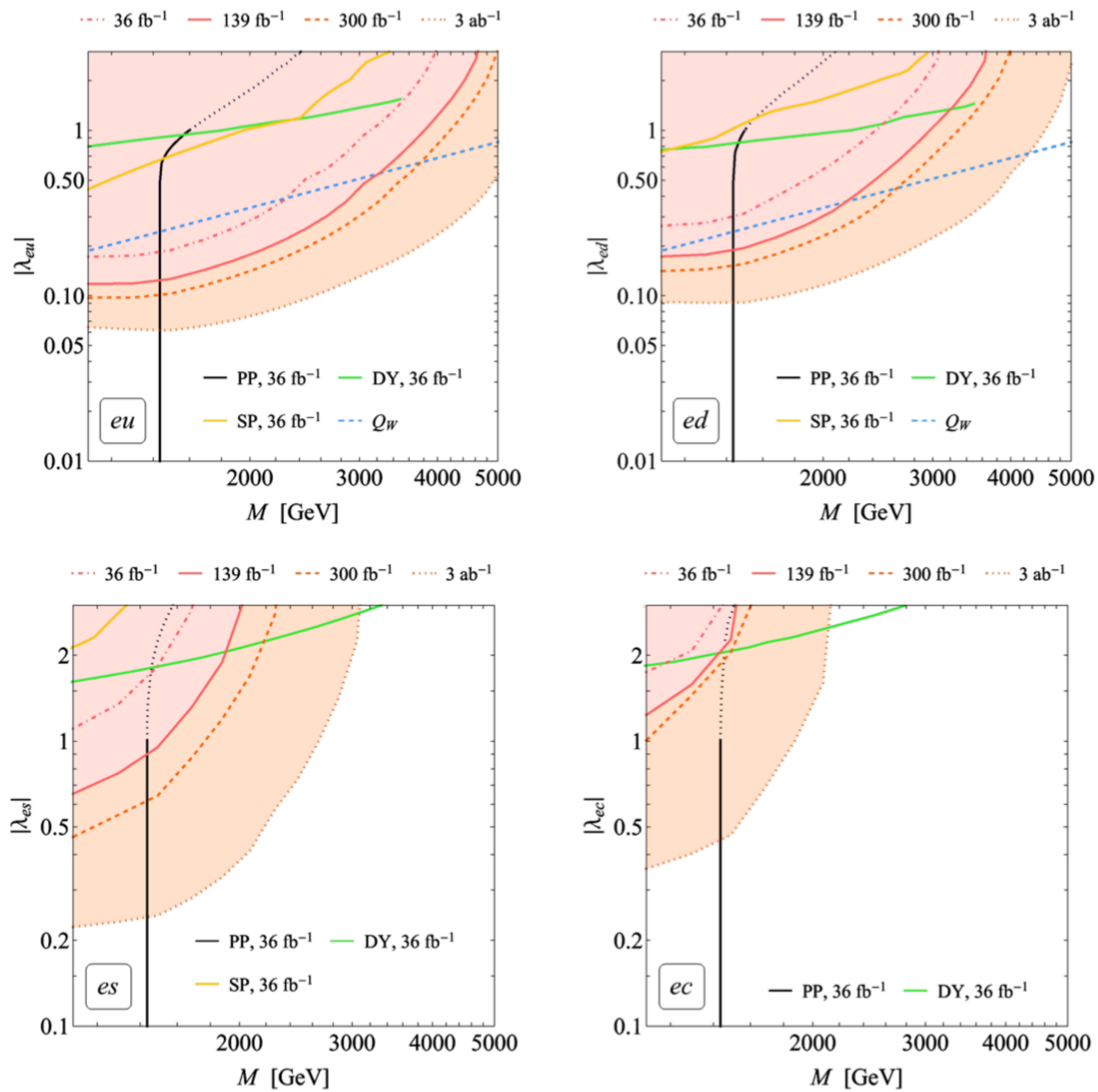
$p_T^j > 30\,\mathrm{GeV}$

LeptoQuarks

[Buonocore, Haisch, Nason, FT, Zanderighi, PRL (2020)]

- 95% exclusion plots @LHC13
- s-channel resonant LQ production provides comparable better limits for large couplings (complementarity)
- But…
  - signal is only LO accurate
  - no shower MC for initial state leptons at the time
  - we used PYTHIA exchanging an initial lepton with a photon (mis-modelling of radiation)
- Similar exercise done for the third generation

  [Haisch, Polesello, JHEP (2021)]



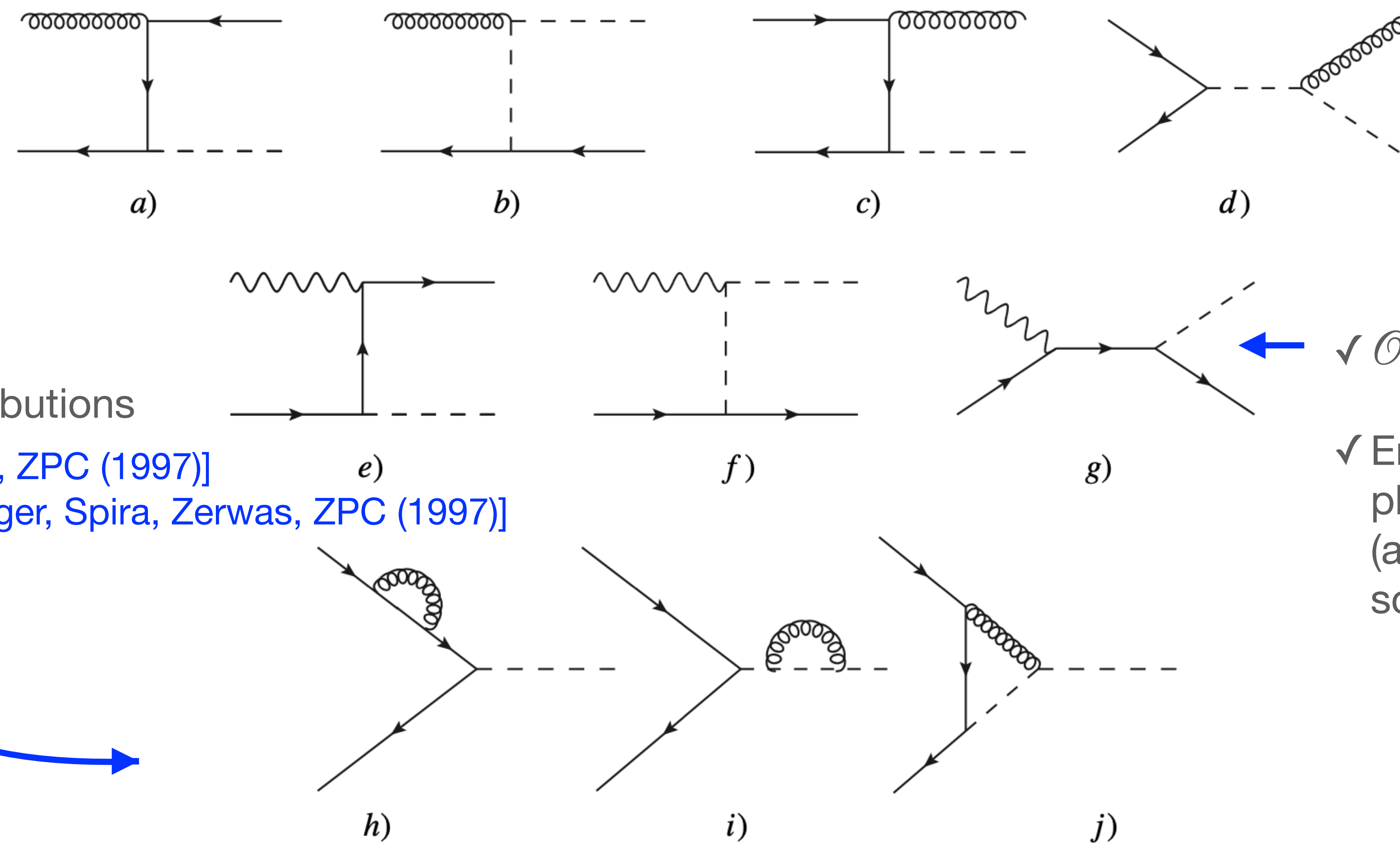
LeptoQuarks

[Buonocore, Greljo, Krack, Nason, Selimović, FT, Zanderighi, 2209.02599 (2020)]

- Relaxing the approximations:

  1. compute NLO corrections in the production stage and let the shower describe all radiation from the decay product (including finite width effects).

[Greljo, Selimović, JHEP (2020)]



✓ $\mathcal{O}(\alpha_S)$ contributions

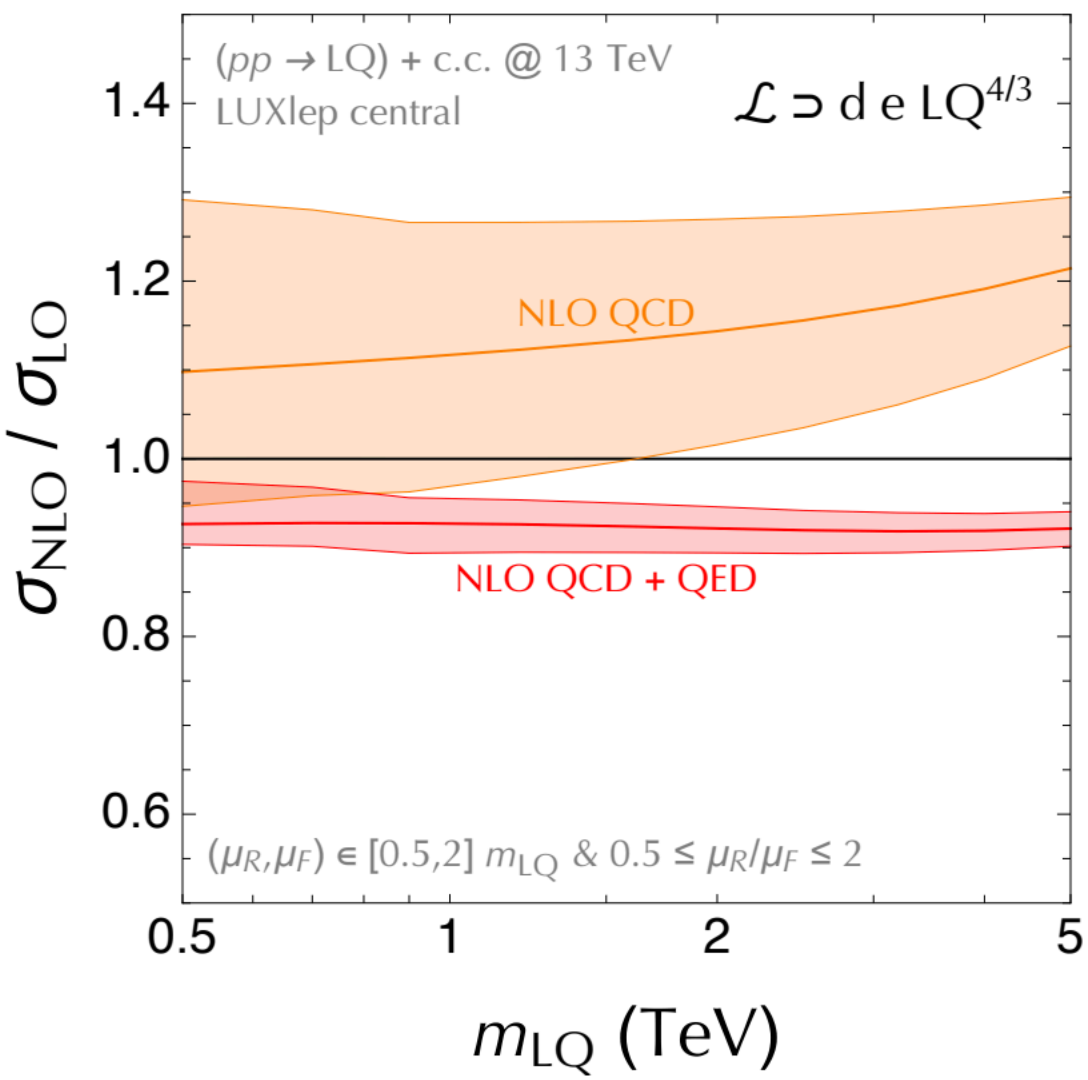
[Kunszt, Stirling, ZPC (1997)]
[Plehn, Spielberger, Spira, Zerwas, ZPC (1997)]

✓ $\mathcal{O}(\alpha)$ at the level of R/B

✓ Enhanced by the photon flux (as for lepton-lepton scattering)

LeptoQuarks

- Inclusive NLO results



In general:

- both QCD and QED corrections are large
- they cancel in part
- strong reduction on the factorization scale dep.

[Greljo, Selimović, JHEP (2020)]

LeptoQuarks

[Buonocore, Greljo, Krack, Nason, Selimović, FT, Zanderighi, 2209.02599 (2020)]

- Relaxing the approximations:

  2. match fixed order computation to Herwig7 that now handle processes initiated by leptons

- Non trivial modification to the POWHEG-BOX
  - possibility to set the color charge ('3', '3bar', 'adj') of possible new (emitter) particles
  - updated logic for the contribution of the collinear remnants
    - ✓ from a constructions based on the LO existing subprocesses to one based on the radiation regions really present in the calculation, that in turn are determined by the analysis of the REAL subprocesses
  - these modifications makes the implementation of new processes much simpler and are very useful for debugging purposes (split of the calculation in subparts)

LeptoQuarks

[Buonocore, Greljo, Krack, Nason, Selimović, FT, Zanderighi, 2209.02599 (2020)]

- Impact on the projected LHC bounds

- photon-quark vs lepton-quark scattering: mis-modeling of the hadronic activity
  First radiation generated by the shower is likely to be a colored parton most of the time while in a true lepton-quark scattering event, the photon splitting process $\gamma \to l\bar{l}$ competes with QCD radiation in the backward evolution

- Benchmark point with $M = 3\,\mathrm{TeV}$ and $y_{eu} = 1$

- analysis cuts:
  - cut A: $|\eta_l|, |\eta_j| < 2.5$
  - cut B: $p_T^l, p_T^j > 500\,\mathrm{GeV}$
    veto additional leptons and jets with:
    $|\eta_l|, |\eta_j| < 2.5\,,\ p_T^l > 7\,\mathrm{GeV}\ ,\ p_T^j > 30\,\mathrm{GeV}$

	cut A (noFSR)	*cut A+B* (noFSR)	*cut A*	*cut A+B*
LO	0.96	0.89	0.96	0.89
LO+PS (HW7)	0.98	0.48	0.98	0.28
NLO_P	0.97	0.42	0.97	0.42
NLO_P+PS (HW7)	0.98	0.37	0.99	0.20
$\mathrm{LO+PS}_{\gamma q}$ (PY8)	0.97	0.51	0.98	0.29

- Inclusion of FSR reduces acceptance by 50%

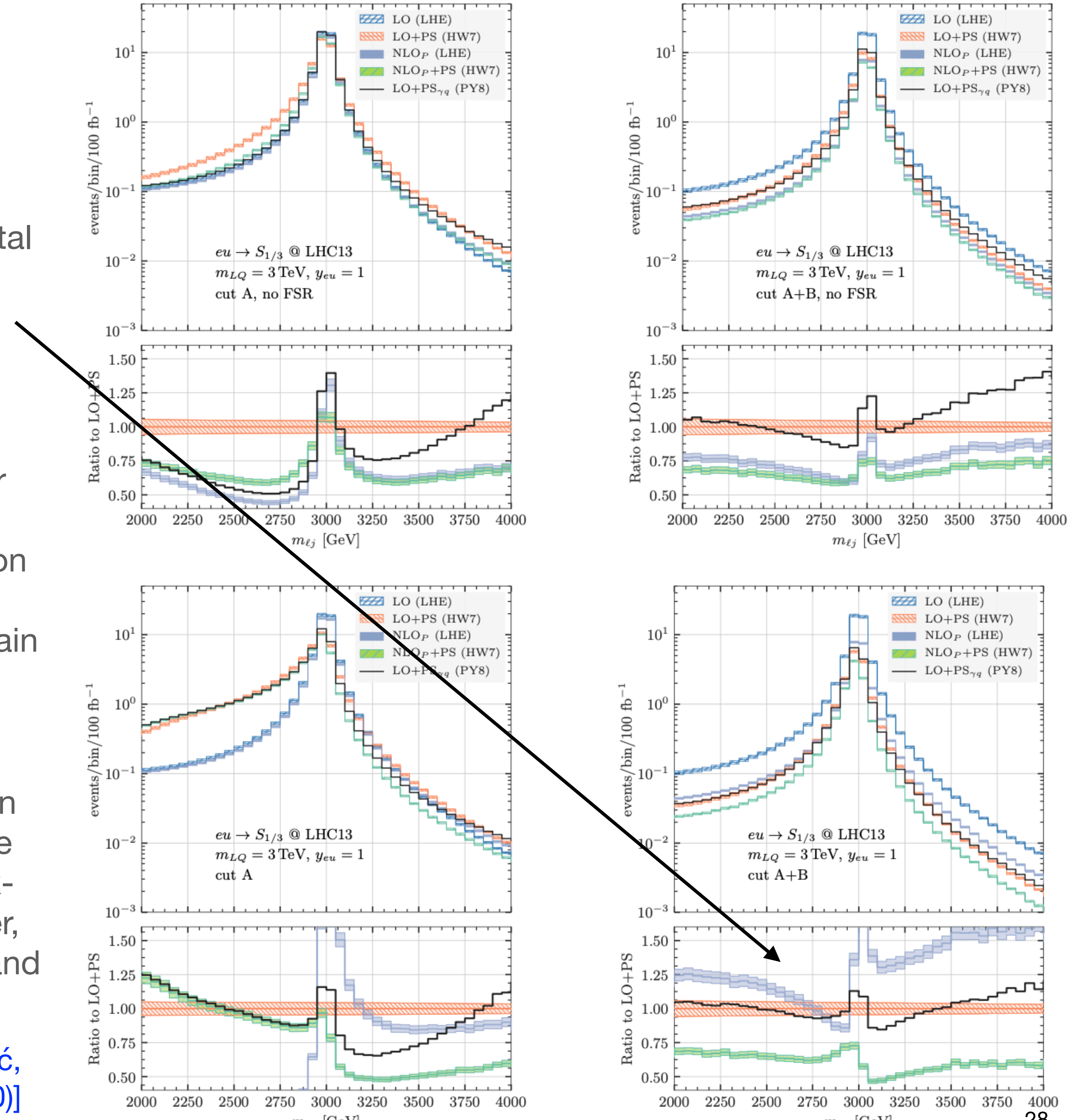
- NLO+PS is 30% lower then LO+PS: ~15% relax on the limits reported in the previous slides)

LeptoQuarks

Differential results: lj-mass system

- Radiation from the decay further reduces the acceptance. Since the NLO_P computation does not contain such effects, it fails to describe the total result.
- LO+PS predictions and the more accurate NLO_P +PS one includes radiative effects from the decay as modeled by FSR of the parton shower
- PS's usually provide a good description of FSR and one may expect that the NLO_P +PS description captures the main radiative effects (ME corrections)
- Nonetheless, given the impact of FSR on the acceptance, a natural extension of the this work would be to match the NLO computation for the 2 → 2 quark-lepton processes to the parton shower, thus including radiation from all legs and (or) resonant intermediate states.

[Buonocore, Greljo, Krack, Nason, Selimović, FT, Zanderighi, 2209.02599 (2020)]



Conclusion

- Lepton pdfs allow for new searches at the LHC and the HL phase
- lepton scattering in proton collisions at very high energy is measurable!
- New BSM searches are possible
- Resonant production relevant in the case of LQ with relatively large coupling
- Simulation for NLO(prod)+PS is done and available on the POWHEG-BOX page

Conclusion

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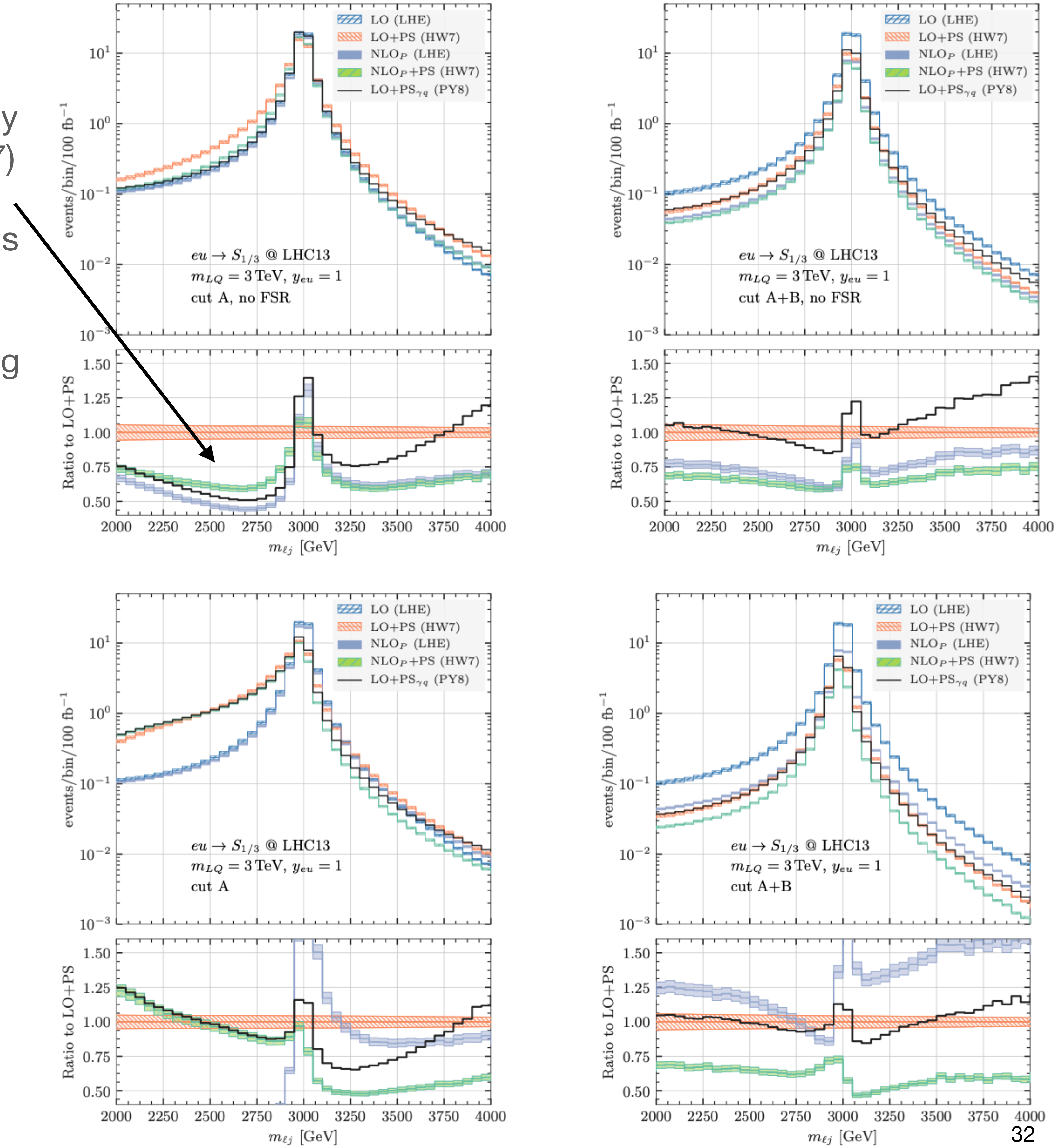
Stay tuned!

Backup slides

LeptoQuarks

Differential results: lj-mass system

- with no FSR, all predictions are close-by among each other except LO+PS (HW7)
- Due to the different shower mechanisms and recoil prescriptions in Pythia8 and Herwig7, whose impact becomes less prominent after performing the matching to the $\mathrm{NLO_P}$ computation

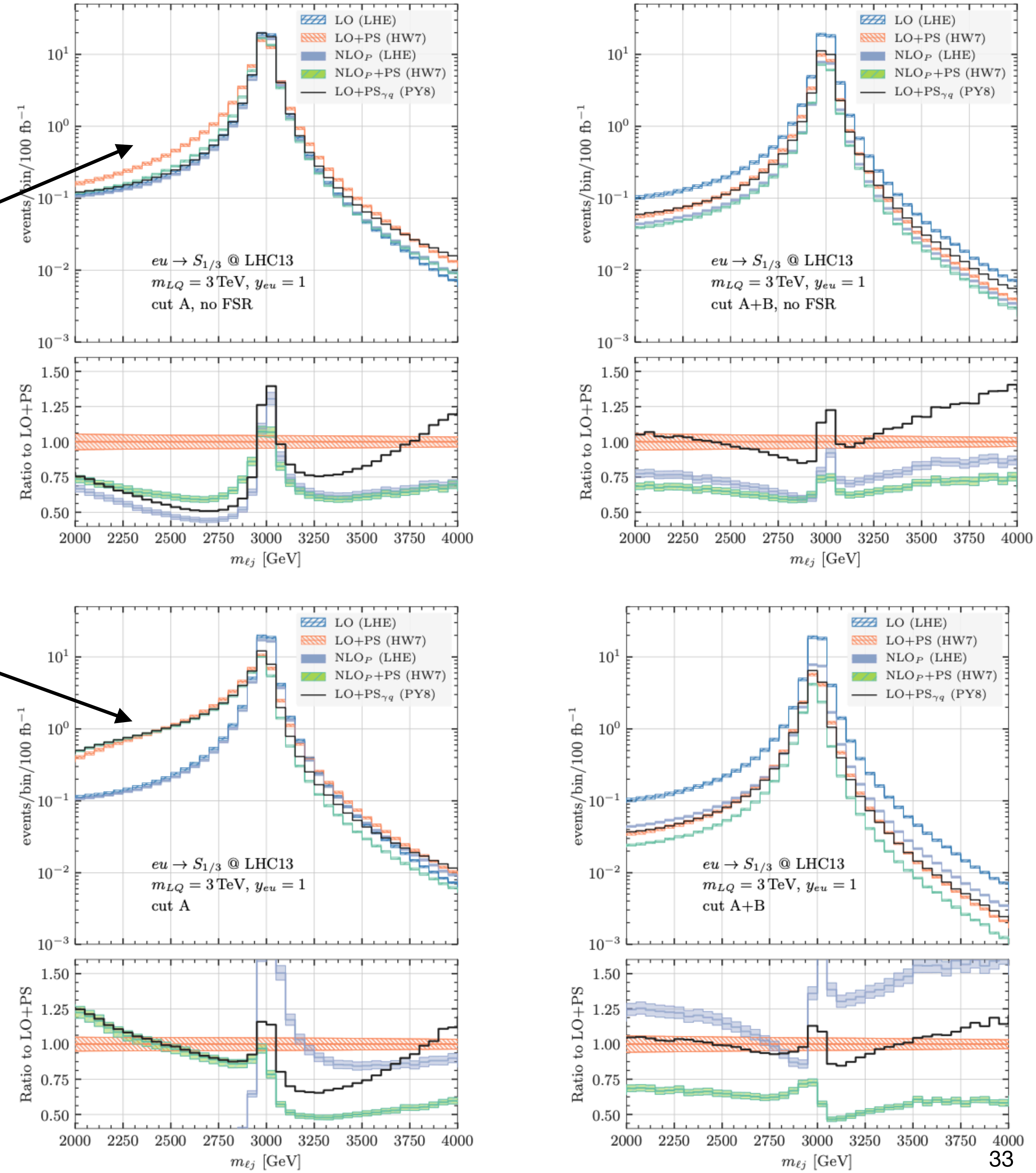


[Buonocore, Greljo, Krack, Nason, Selimović, FT, Zanderighi, 2209.02599 (2020)]

LeptoQuarks

Differential results: lj-mass system

- radiative tail is entirely due to QCD FSR, which forms a separate second jet softening the leading jet, originated by the quark in the leptoquark decay

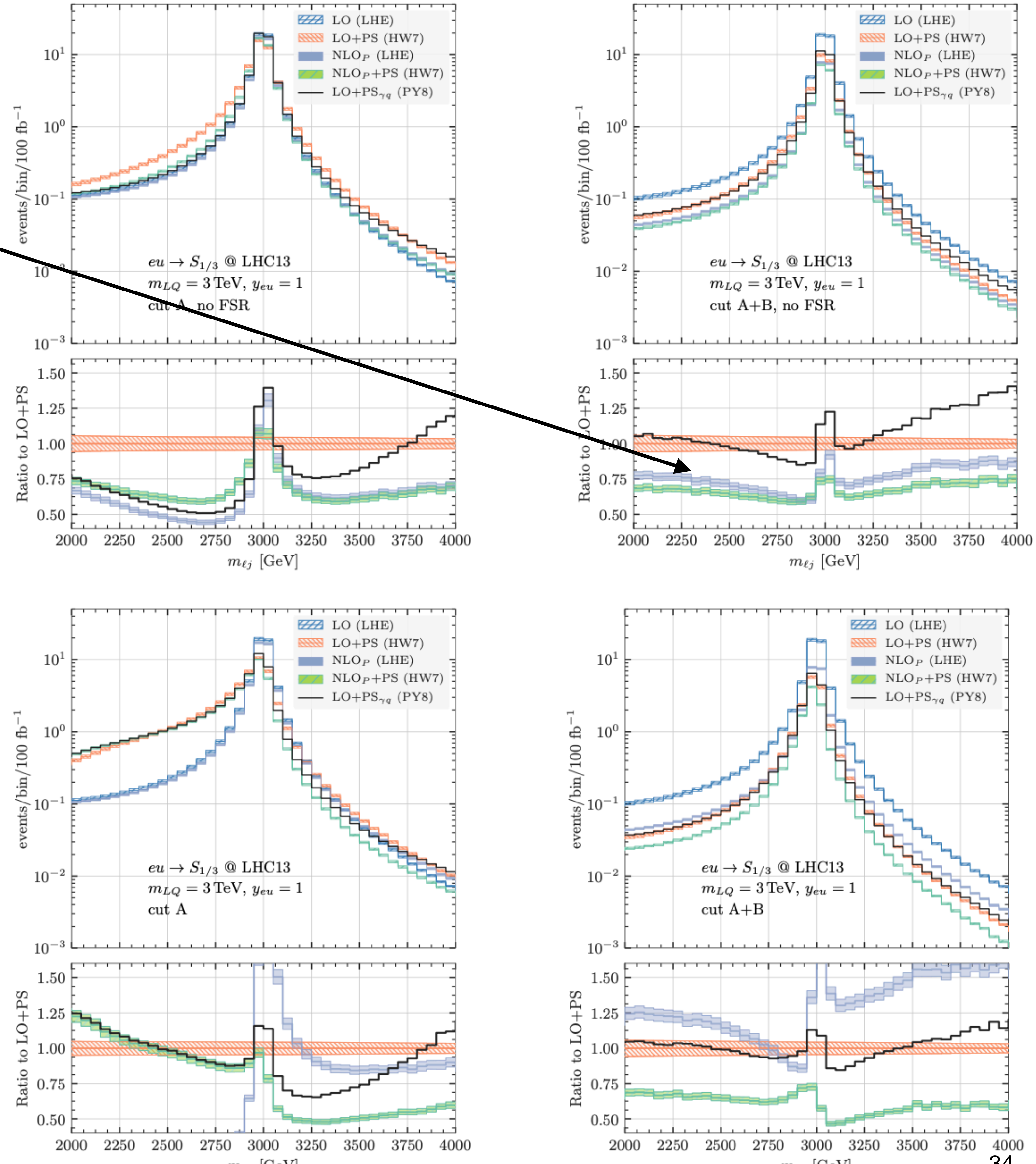


[Buonocore, Greljo, Krack, Nason, Selimović, FT, Zanderighi, 2209.02599 (2020)]

LeptoQuarks

Differential results: lj-mass system

- When FSR is excluded the $\mathrm{NLO_P}$ +PS (HW7) generator only mildly differs from the $\mathrm{NLO_P}$ one.
- Only the first few emissions are relevant for the computation of the acceptance

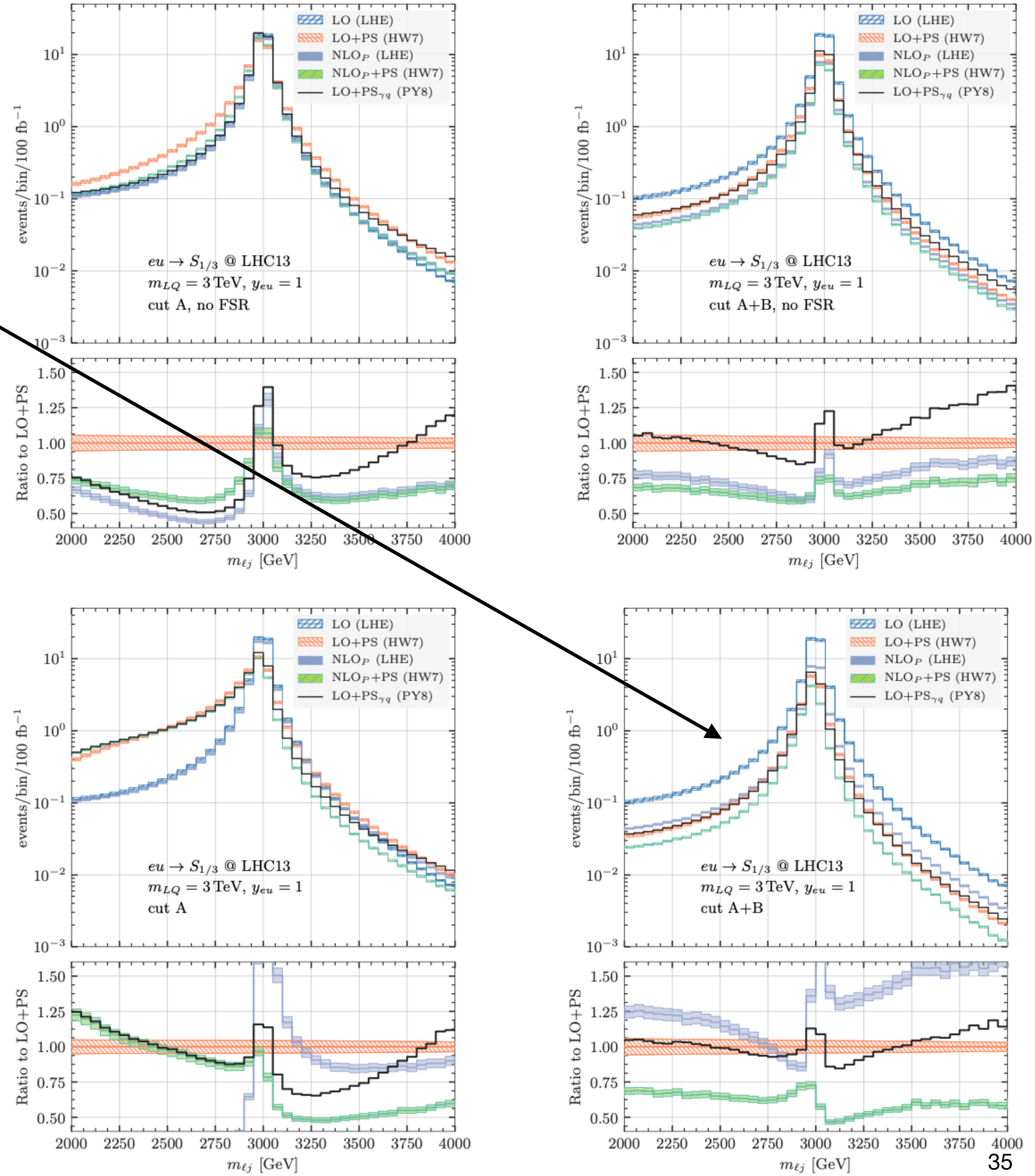


[Buonocore, Greljo, Krack, Nason, Selimović, FT, Zanderighi, 2209.02599 (2020)]

LeptoQuarks

Differential results: lj-mass system

- With full simulation including FSR and vetoes there is a reduction for the predictions that contains effects beyond LO
- The radiative tail is effectively cut out



[Buonocore, Greljo, Krack, Nason, Selimović, FT, Zanderighi, 2209.02599 (2020)]

LeptoQuarks

- Fully inclusive results at FCC-hh

m_{LQ} [TeV]	Partons	$\sigma_{\mathrm{S}^{1/3}}$ [pb]	$\sigma_{\mathrm{S}^{5/3}}$ [pb]
5.0	$u+e$	$(1.06\times10^{-2})^{+3.0\%}_{-3.4\%}\pm1.5\%$	$(1.14\times10^{-2})^{+2.9\%}_{-3.2\%}\pm1.5\%$
	$u+\mu$	$(1.02\times10^{-2})^{+3.0\%}_{-3.4\%}\pm1.5\%$	$(1.1\times10^{-2})^{+2.9\%}_{-3.2\%}\pm1.5\%$
	$u+\tau$	$(8.72\times10^{-3})^{+3.1\%}_{-3.5\%}\pm1.6\%$	$(9.54\times10^{-3})^{+3.0\%}_{-3.3\%}\pm1.6\%$
	$c+e$	$(1.48\times10^{-3})^{+3.7\%}_{-4.2\%}\pm7.5\%$	$(1.59\times10^{-3})^{+3.5\%}_{-3.9\%}\pm7.6\%$
	$c+\mu$	$(1.45\times10^{-3})^{+3.7\%}_{-4.1\%}\pm7.4\%$	$(1.55\times10^{-3})^{+3.5\%}_{-3.9\%}\pm7.5\%$
	$c+\tau$	$(1.23\times10^{-3})^{+3.7\%}_{-4.2\%}\pm7.5\%$	$(1.33\times10^{-3})^{+3.5\%}_{-4.0\%}\pm7.5\%$
	$t+e$	$(3.18\times10^{-4})^{+7.0\%}_{-7.9\%}\pm0.6\%$	$(3.05\times10^{-4})^{+7.3\%}_{-8.3\%}\pm0.6\%$
	$t+\mu$	$(3.12\times10^{-4})^{+7.0\%}_{-7.9\%}\pm0.6\%$	$(2.97\times10^{-4})^{+7.3\%}_{-8.3\%}\pm0.6\%$
	$t+\tau$	$(2.63\times10^{-4})^{+7.3\%}_{-8.2\%}\pm0.6\%$	$(2.49\times10^{-4})^{+7.6\%}_{-8.6\%}\pm0.7\%$

- hierarchical for heavy quarks
- comparable for diff. leptons
- similar behavior for larger LQ masses

- no set with both top and lepton pdfs. top from the NNPDF31_nlo_as_0118_nf_6 set “added” to the LUXlep-NNPDF31_nlo_as_0118_luxqed

- xs involving top quarks are sizable
- promising prospects at the FCC-hh given the luminosity target is up to 30 ab^{-1}

m_{LQ} [TeV]	Partons	$\sigma_{\mathrm{S}^{2/3}}$ [pb]	$\sigma_{\mathrm{S}^{4/3}}$ [pb]
5.0	$d+e$	$(6.93\times10^{-3})^{+3.0\%}_{-3.3\%}\pm1.6\%$	$(7.18\times10^{-3})^{+2.8\%}_{-3.2\%}\pm1.6\%$
	$d+\mu$	$(6.72\times10^{-3})^{+2.9\%}_{-3.3\%}\pm1.6\%$	$(6.98\times10^{-3})^{+2.9\%}_{-3.2\%}\pm1.6\%$
	$d+\tau$	$(5.74\times10^{-3})^{+3.1\%}_{-3.4\%}\pm1.7\%$	$(5.99\times10^{-3})^{+3.1\%}_{-3.3\%}\pm1.7\%$
	$s+e$	$(2.4\times10^{-3})^{+3.2\%}_{-3.6\%}\pm3.8\%$	$(2.48\times10^{-3})^{+3.1\%}_{-3.5\%}\pm3.9\%$
	$s+\mu$	$(2.34\times10^{-3})^{+3.2\%}_{-3.6\%}\pm3.8\%$	$(2.42\times10^{-3})^{+3.1\%}_{-3.5\%}\pm3.9\%$
	$s+\tau$	$(1.99\times10^{-3})^{+3.3\%}_{-3.7\%}\pm3.9\%$	$(2.07\times10^{-3})^{+3.2\%}_{-3.6\%}\pm3.9\%$
	$b+e$	$(1.11\times10^{-3})^{+3.8\%}_{-4.3\%}\pm1.3\%$	$(1.15\times10^{-3})^{+3.7\%}_{-4.2\%}\pm1.3\%$
	$b+\mu$	$(1.09\times10^{-3})^{+3.8\%}_{-4.3\%}\pm1.3\%$	$(1.13\times10^{-3})^{+3.7\%}_{-4.2\%}\pm1.3\%$
	$b+\tau$	$(9.22\times10^{-4})^{+3.9\%}_{-4.5\%}\pm1.4\%$	$(9.62\times10^{-4})^{+3.8\%}_{-4.3\%}\pm1.4\%$

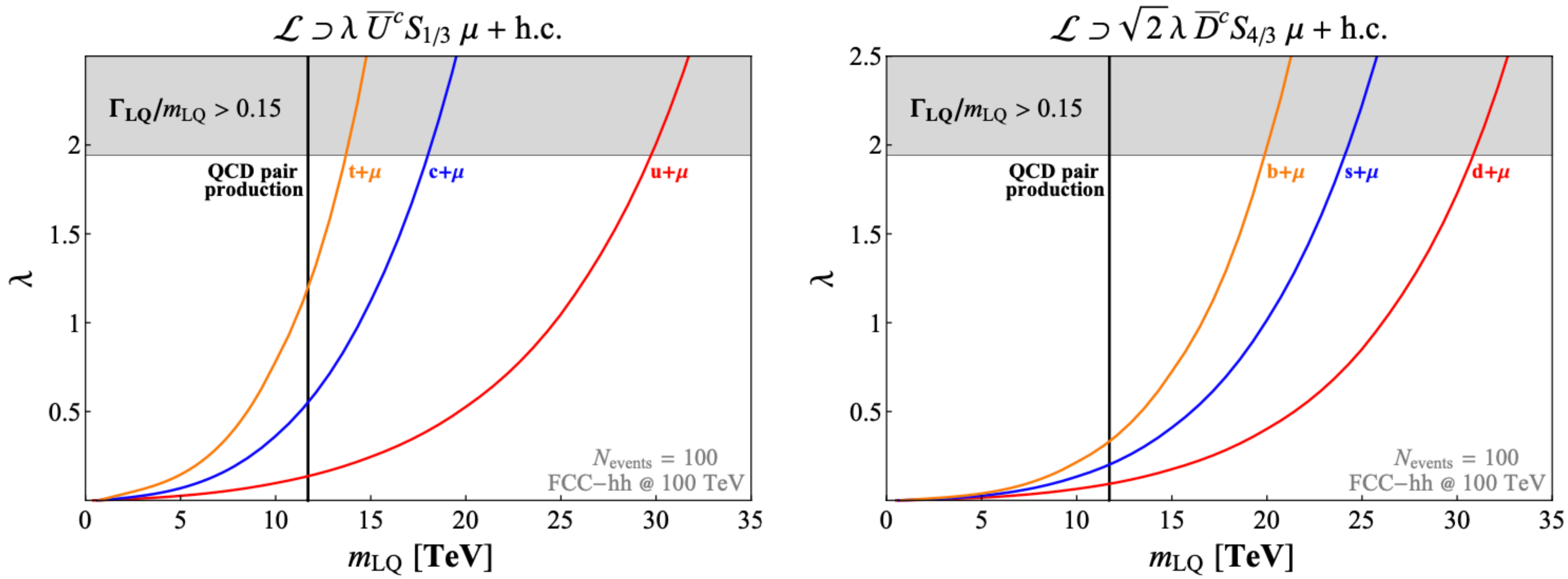
[Buonocore, Greljo, Krack, Nason, Selimović, FT, Zanderighi, 2209.02599 (2020)]

LeptoQuarks

[Buonocore, Greljo, Krack, Nason, Selimović, FT, Zanderighi, 2209.02599 (2020)]

- Example: S_3 model. Scalar leptoquark that is in a $\bar{3}$ of color and in a 3 of $SU(2)_L$ with $Y = 1/3$

$$-\mathcal{L} \supset \lambda_{q\ell}\, \bar{Q}_L^{Ca} \epsilon^{ab} (\sigma^k S_3^k)^{bc} L_L^c + \lambda_{qq}\, \bar{Q}_L^{Ca} \epsilon^{ab} ((\sigma^k S_3^k)^\dagger)^{bc} Q_L^c + \text{h.c.}$$



Simplified analisys:

- relatively narrow resonance
- fully inclusive
- 100 events