BSM searches at LHeC

and some prospects for FCC-he

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ATLAS Exotics Searches* - 95% CL Exclusion

Status: March 2015

ATLAS Preliminary

$\int \mathcal{L}\, dt$ = (1.0 - 20.3) fb^{-1} $\sqrt{s}$ = 7, 8 TeV

	Model	ℓ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt$[fb^{-1}]	Mass limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	–	≥ 1 j	Yes	20.3	M_D 5.25 TeV	$n = 2$	1502.01518
	ADD non-resonant $\ell\ell$	2e,μ	–	–	20.3	M_S 4.7 TeV	$n = 3$ HLZ	1407.2410
	ADD QBH $\rightarrow \ell q$	1 e,μ	1 j	–	20.3	M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD QBH	–	2 j	–	20.3	M_{th} 5.82 TeV	$n = 6$	1407.1376
	ADD BH high N_{trk}	2 μ (SS)	–	–	20.3	M_{th} 4.7 TeV	$n = 6$, $M_D = 3$ TeV, non-rot BH	1308.4075
	ADD BH high $\sum p_T$	≥ 1 e,μ	≥ 2 j	–	20.3	M_{th} 5.8 TeV	$n = 6$, $M_D = 3$ TeV, non-rot BH	1405.4254
	ADD BH high multijet	–	≥ 2 j	–	20.3	M_{th} 5.8 TeV	$n = 6$, $M_D = 3$ TeV, non-rot BH	Preliminary
	RS1 $G_{KK} \rightarrow \ell\ell$	2 e,μ	–	–	20.3	G_{KK} mass 2.68 TeV	$k/\overline{M}_{Pl} = 0.1$	1405.4123
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2 γ	–	–	20.3	G_{KK} mass 2.66 TeV	$k/\overline{M}_{Pl} = 0.1$	Preliminary
	Bulk RS $G_{KK} \rightarrow ZZ \rightarrow qq\ell\ell$	2 e,μ	2 j / 1 J	–	20.3	G_{KK} mass 740 GeV	$k/\overline{M}_{Pl} = 1.0$	1409.6190
	Bulk RS $G_{KK} \rightarrow WW \rightarrow qq\ell\nu$	1 e,μ	2 j / 1 J	Yes	20.3	W' mass 700 GeV	$k/\overline{M}_{Pl} = 1.0$	1503.04677
	Bulk RS $G_{KK} \rightarrow HH \rightarrow b\bar{b}b\bar{b}$	–	4 b	–	19.5	G_{KK} mass 590-710 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2014-005
	Bulk RS $g_{KK} \rightarrow t\bar{t}$	1 e,μ	≥ 1 b, ≥ 1J/2j	Yes	20.3	g_{KK} mass 2.2 TeV	BR = 0.925	ATLAS-CONF-2015-009
	2UED / RPP	2 e,μ (SS)	≥ 1 b, ≥ 1 j	Yes	20.3	KK mass 960 GeV		Preliminary
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	2 e,μ	–	–	20.3	Z' mass 2.9 TeV		1405.4123
	SSM $Z' \rightarrow \tau\tau$	2 τ	–	–	19.5	Z' mass 2.02 TeV		1502.07177
	SSM $W' \rightarrow \ell\nu$	1 e,μ	–	Yes	20.3	W' mass 3.24 TeV		1407.7494
	EGM $W' \rightarrow WZ \rightarrow \ell\nu\,\ell'\ell'$	3 e,μ	–	Yes	20.3	W' mass 1.52 TeV		1406.4456
	EGM $W' \rightarrow WZ \rightarrow qq\ell\ell$	2 e,μ	2 j / 1 J	–	20.3	W' mass 1.59 TeV		1409.6190
	HVT $W' \rightarrow WH \rightarrow \ell\nu bb$	1 e,μ	2 b	Yes	20.3	W' mass 1.47 TeV	$g_V = 1$	Preliminary
	LRSM $W'_R \rightarrow t\bar{b}$	1 e,μ	2 b, 0-1 j	Yes	20.3	W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \rightarrow t\bar{b}$	0 e,μ	≥ 1 b, 1 J	–	20.3	W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	17.3	Λ 12.0 TeV	$\eta_{LL} = -1$	Preliminary
	CI $qq\ell\ell$	2 e,μ	–	–	20.3	Λ 21.6 TeV	$\eta_{LL} = -1$	1407.2410
	CI $uutt$	2 e,μ (SS)	≥ 1 b, ≥ 1 j	Yes	20.3	Λ 4.35 TeV	$\lvert C_{LL}\rvert = 1$	Preliminary
DM	EFT D5 operator (Dirac)	0 e,μ	≥ 1 j	Yes	20.3	M_* 974 GeV	at 90% CL for $m(\chi) < 100$ GeV	1502.01518
	EFT D9 operator (Dirac)	0 e,μ	1 J, ≤ 1 j	Yes	20.3	M_* 2.4 TeV	at 90% CL for $m(\chi) < 100$ GeV	1309.4017
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	1.0	LQ mass 660 GeV	$\beta = 1$	1112.4828
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	1.0	LQ mass 685 GeV	$\beta = 1$	1203.3172
	Scalar LQ 3rd gen	1 e,μ, 1 τ	1 b, 1 j	–	4.7	LQ mass 534 GeV	$\beta = 1$	1303.0526
Heavy quarks	VLQ $TT \rightarrow Ht + X, Wb + X$	1 e,μ	≥ 1 b, ≥ 3 j	Yes	20.3	T mass 785 GeV	isospin singlet	ATLAS-CONF-2015-012
	VLQ $TT \rightarrow Zt + X$	2/≥3 e,μ	≥2/≥1 b	–	20.3	T mass 735 GeV	T in (T,B) doublet	1409.5500
	VLQ $BB \rightarrow Zb + X$	2/≥3 e,μ	≥2/≥1 b	–	20.3	B mass 755 GeV	B in (B,Y) doublet	1409.5500
	VLQ $BB \rightarrow Wt + X$	1 e,μ	≥ 1 b, ≥ 5 j	Yes	20.3	B mass 640 GeV	isospin singlet	Preliminary
	$T_{5/3} \rightarrow Wt$	1 e,μ	≥ 1 b, ≥ 5 j	Yes	20.3	$T_{5/3}$ mass 840 GeV		Preliminary
Excited fermions	Excited quark $q^* \rightarrow q\gamma$	1 γ	1 j	–	20.3	q^* mass 3.5 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1309.3230
	Excited quark $q^* \rightarrow qg$	–	2 j	–	20.3	q^* mass 4.09 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1407.1376
	Excited quark $b^* \rightarrow Wt$	1 or 2 e,μ	1 b, 2 j or 1 j	Yes	4.7	b^* mass 870 GeV	left-handed coupling	1301.1583
	Excited lepton $\ell^* \rightarrow \ell\gamma$	2 e,μ, 1 γ	–	–	13.0	ℓ^* mass 2.2 TeV	$\Lambda = 2.2$ TeV	1308.1364
	Excited lepton $\nu^* \rightarrow \ell W, \nu Z$	3 e,μ,τ	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LSTC $a_T \rightarrow W\gamma$	1 e,μ, 1 γ	–	Yes	20.3	a_T mass 960 GeV		1407.8150
	LRSM Majorana ν	2 e,μ	2 j	–	2.1	N^0 mass 1.5 TeV	$m(W_R) = 2$ TeV, no mixing	1203.5420
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	2 e,μ (SS)	–	–	20.3	$H^{\pm\pm}$ mass 551 GeV	DY production, BR($H_L^{\pm\pm} \rightarrow \ell\ell$)=1	1412.0237
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	3 e,μ,τ	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, BR($H_L^{\pm\pm} \rightarrow \ell\tau$)=1	1411.2921
	Monotop (non-res prod)	1 e,μ	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{non-res} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	multi-charged particle mass 785 GeV	DY production, $\lvert q\rvert = 5e$	Preliminary
	Magnetic monopoles	–	–	–	2.0	monopole mass 862 GeV	DY production, $\lvert g\rvert = 1g_D$	1207.6411

$\sqrt{s}$ = 7 TeV $\sqrt{s}$ = 8 TeV

10^{-1} 1 10 **Mass scale [TeV]**

*Only a selection of the available mass limits on new states or phenomena is shown.

Prelude

- Clearly, the LHC results of the next 2-3 years will be crucial to re-focus the BSM program at the LHeC in terms of
  - Characterization of hints for new physics if some excess or deviations from the SM are found
  - Constraints of new physics models and complementary searches wrt the LHC
  - Exploration of new scenarios
- Not an easy task at the moment
- Spent some time to re-evaluate what is worth pursuing and what is already excluded:
  - E.g. excited leptons boundaries from LHC are already excluding most of the scenarios where LHeC could be sensitive
- Wish: engage more also the theory community!

Outline

" The LHC is the primary machine to search for physics beyond the SM at the TeV scale. The role of the LHeC is to complement and possibly resolve the observation of new phenomena…"

LHeC CDR

- New Physics searches investigated for LHeC
  - CDR studies and some updates:
    - Contact interactions, Extra Dimension Leptoquarks
  - "New" ideas and topics:
    - Anomalous couplings VVV
    - Majorana neutrinos
    - R-parity conserving and R-parity violating SUSY: stop, sbottom and beyond
- Prospects for FCC-he

Contact interactions

- **if new physics enters at higher scales: Λ>> √s**
- such indirect signatures can be seen as effective 4-fermion interaction

$$\mathcal{L} = \frac{4\pi}{2\Lambda^2} j_\mu^{(e)} j^{\mu(q)}; \quad j_\mu^{(f=e,q)} = \eta_L \, \bar{f}_L \gamma_\mu f_L + \eta_R \, \bar{f}_R \gamma_\mu f_R + h.c.$$

$$\Rightarrow \text{ all combinations of couplings } \eta_{ij} = \eta_i^{(e)} \eta_j^{(q)}; \quad q = u, d$$

- may be applied very generally to new phenomena

Λ
- LQ mass >> √s
- Planck scale (Ms) of extra dimensional models
- compositeness scale
- …

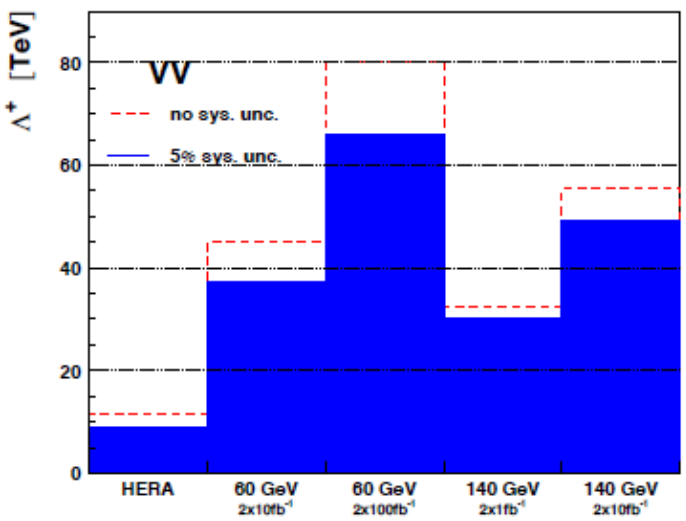
- sensitivity to fermion radius below 10^{-19}–10^{-20}m at LHeC (FCC-eh) $\frac{\hbar c}{1.3\,\text{TeV}} = 1.5 \times 10^{-4}\,\text{fm}$

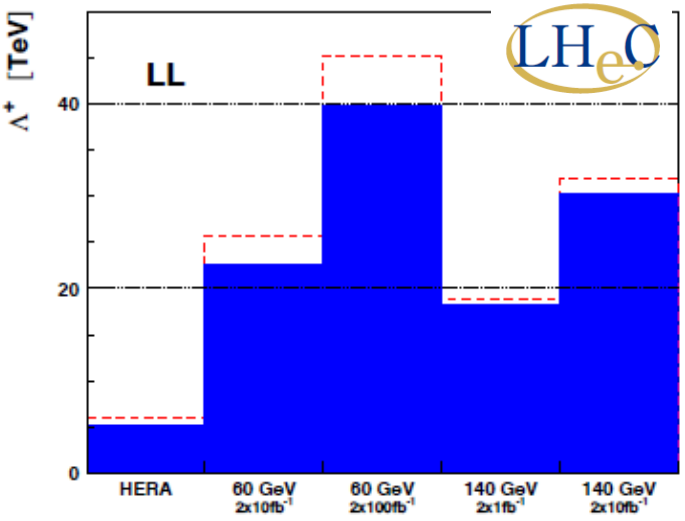
$$\text{form factor: } f(Q^2) = 1 - \frac{1}{6}\langle r^2 \rangle Q^2$$

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma_{SM}}{dQ^2} f_e^2(Q^2) f_q^2(Q^2)$$

Contact interactions (eeqq)

- New currents or heavy bosons may produce indirect effect via new particle exchange interfering with γ/Z fields.
- Reach for Λ (CI eeqq): 25-45 TeV with 10 fb^{-1} of data depending on the model





CI *qqqq*	–	2 j	–	17.3	Λ 12.0 TeV $\eta_{LL} = -1$
CI *qqℓℓ*	2 e, μ	–	–	20.3	Λ 21.6 TeV $\eta_{LL} = -1$
CI *uutt*	2 e, μ (SS)	≥ 1 b, ≥ 1 j	Yes	20.3	Λ 4.35 TeV $\lvert C_{LL} \rvert = 1$

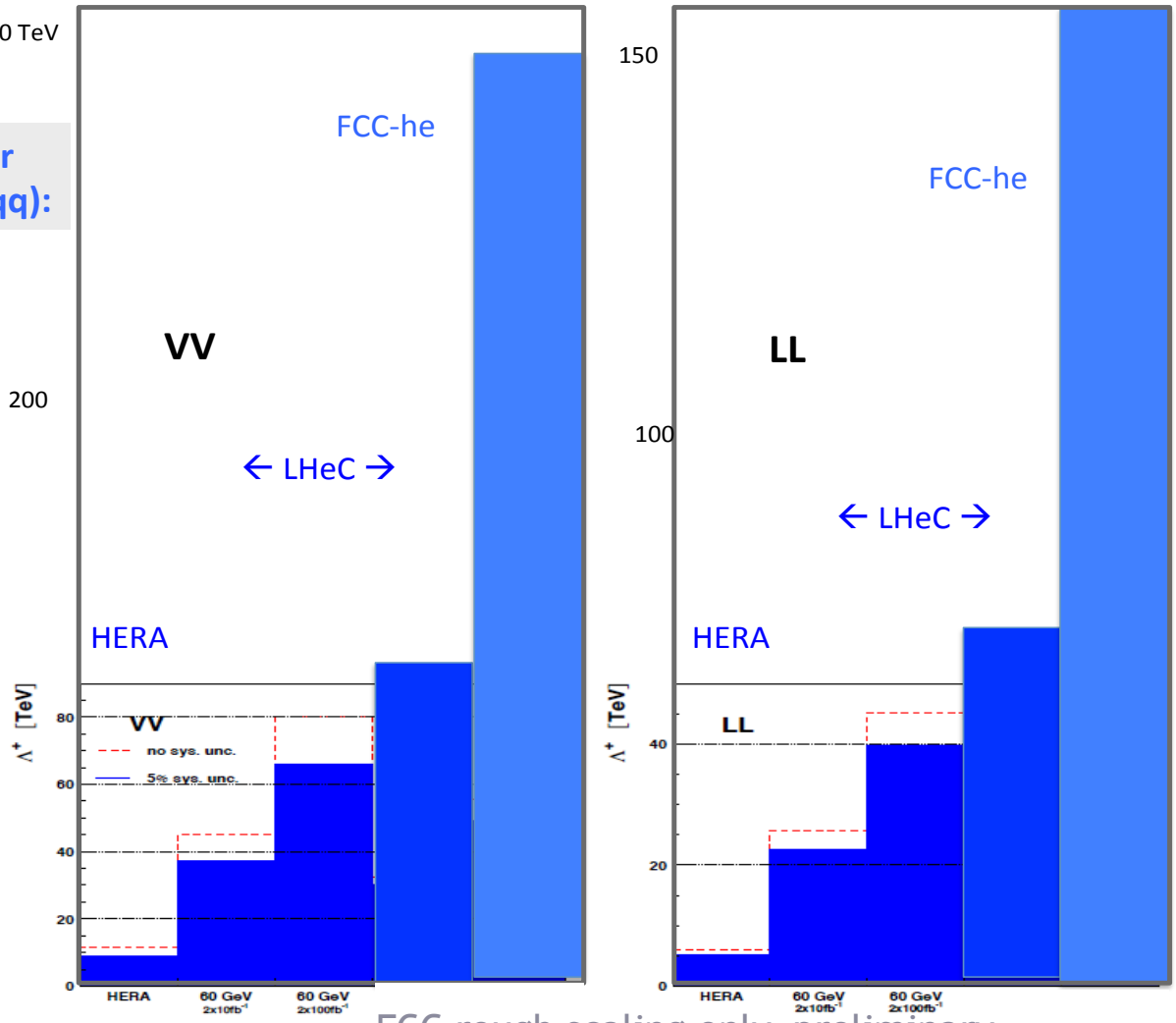
Relevant for quark radius

ATLAS and CMS constraints on eeqq CI ~ 22 TeV (expected up to 40 TeV at c.o.m. 14 TeV HL-LHC) ~ equivalent sensitivity at the LHeC at least for some of the couplings but will have to see 13 TeV results !

Contact Interactions at FCC-he

- **if new physics enters at higher scales: Λ>> √s**

Reach for Λ (CI eeqq):



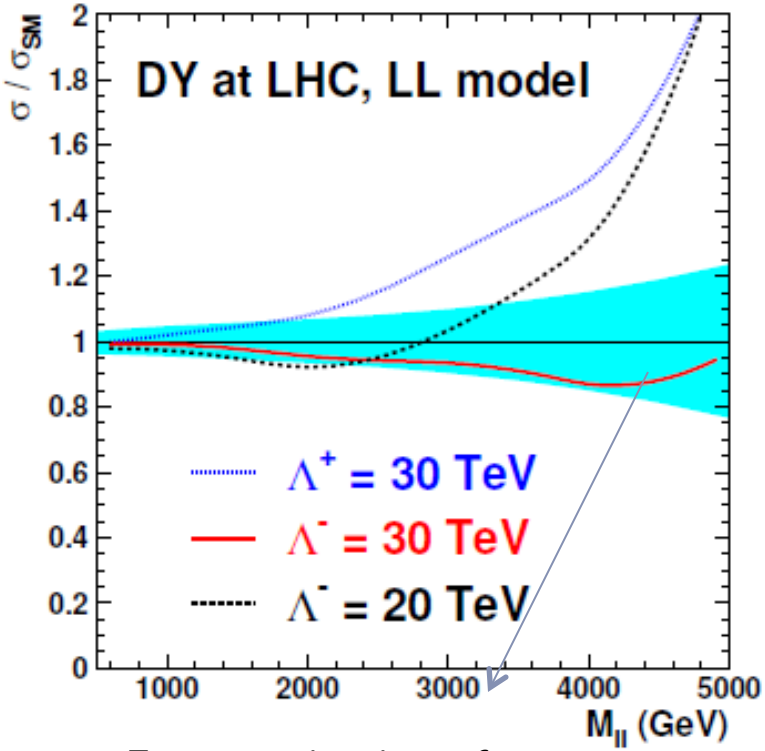
FCC rough scaling only, preliminary

LHeC: see CDR 2012

also advantages over, and complementarities with, pp (and e+e-) in characterising nature of new physics

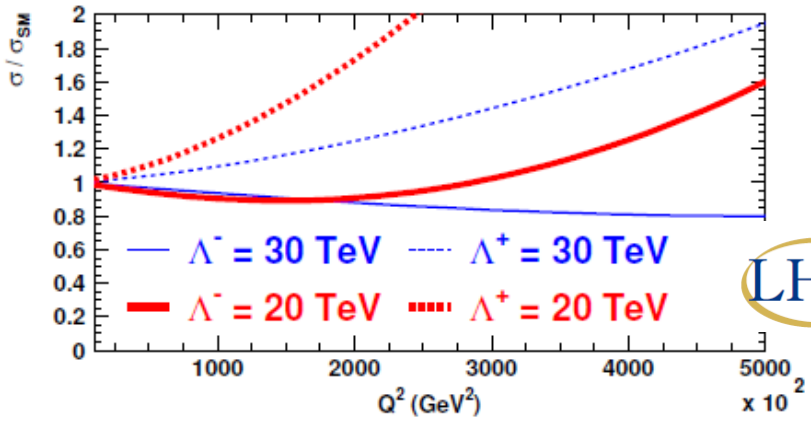
CI at LHC and LHeC

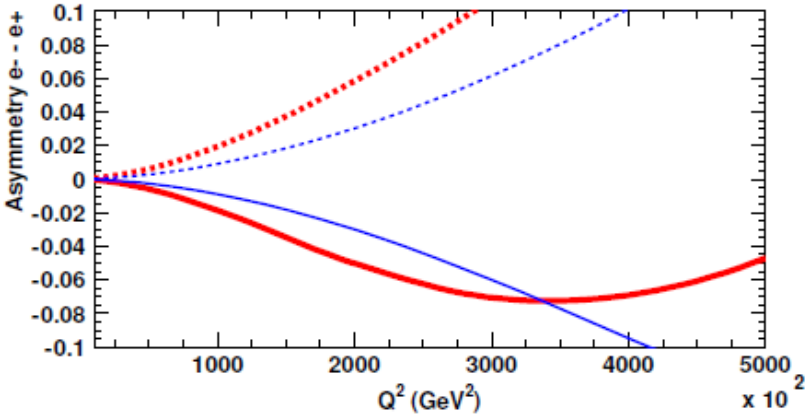
- LHC: Variation of DY cross section for CI model
  - Cannot determine simultaneously Λ and sign of interference of the new amplitudes wrt SM (ε)



Ex: negative interference too small to be disentagled

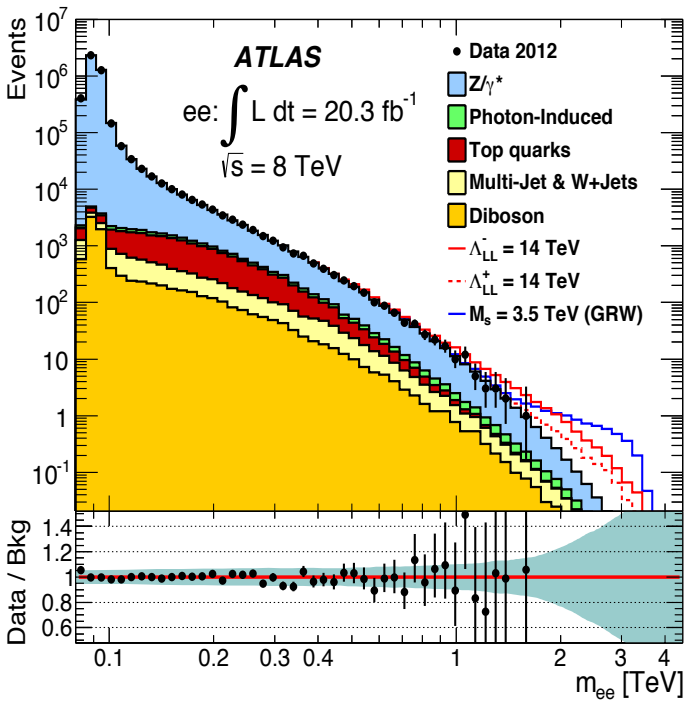
LHeC: sign ε from asymmetry of σ/σ_{sm} in e+p and e-p data





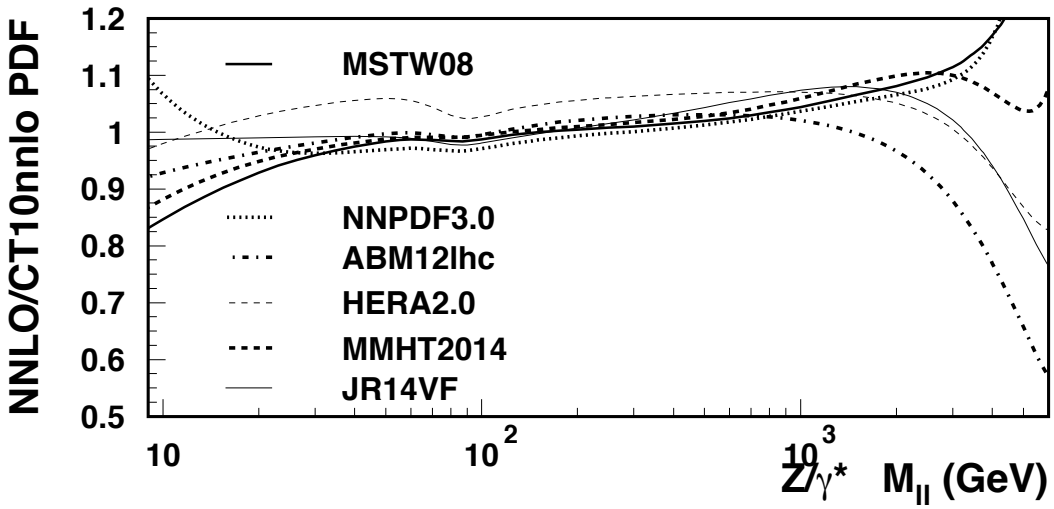
ED: High mass Drell-Yan

Both CMS and ATLAS searching for deviations in m(ll) tails



- Non resonant searches for ED (interference) sensitive to tails of DY distributions thus to PDF
- For HL-LHC need to study in context with experimental uncertainties (calibrations)

LHC@13 TeV

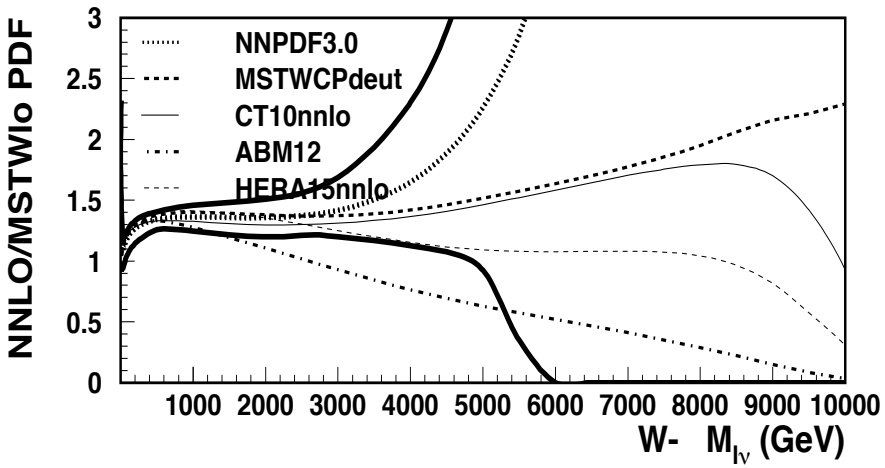


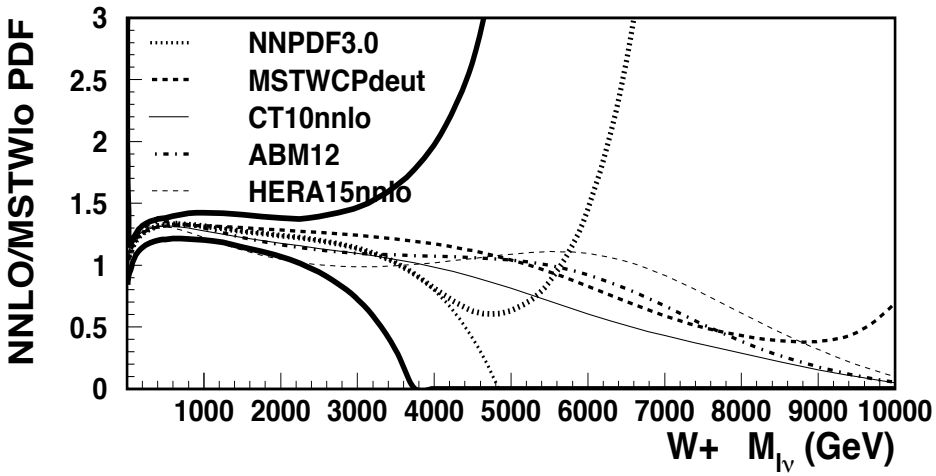
U. Klein using VRAP0.9

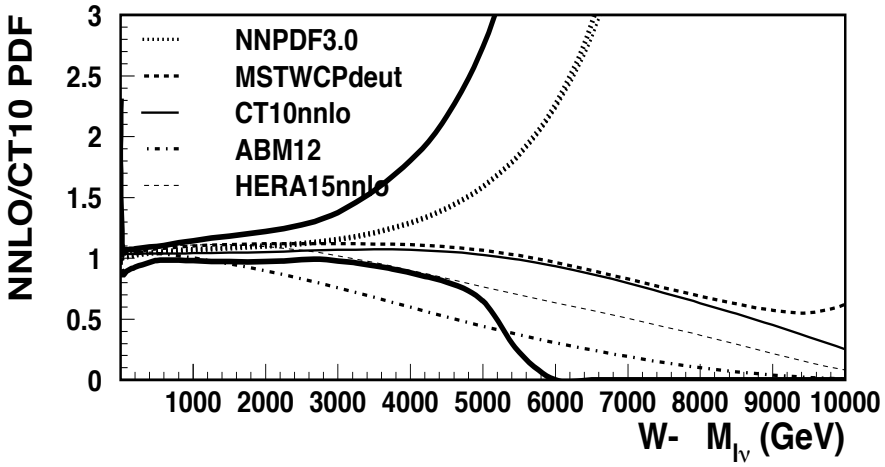
W+/W- uncertainties high mass

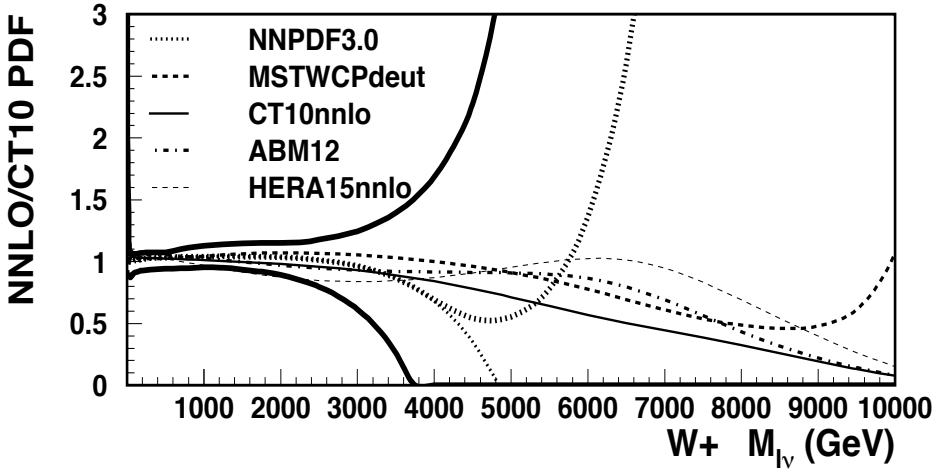
MET+lepton final states also sensitive to ED and other BSM models…

LHC@13 TeV







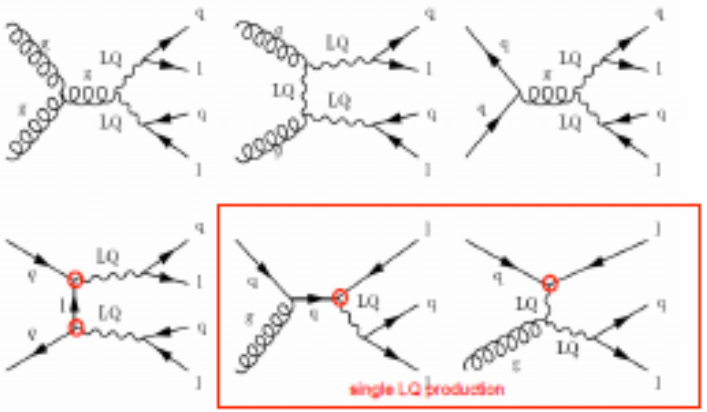


Thick lines represent 99% NNPDF3.0 C.L.

U. Klein using VRAP0.9

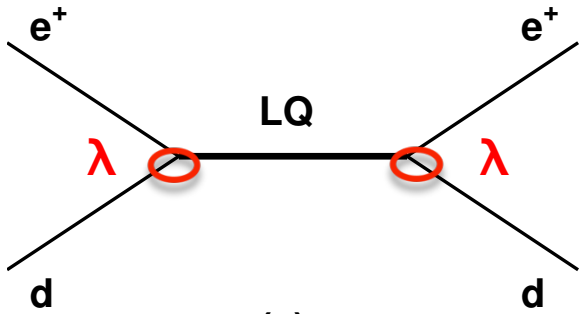
LQ production at LHC ad LHeC

- **leptoquarks (LQs)** appear in several extensions to SM: production $\sigma \sim \lambda^2 q(x)$
- can be **scalar** or **vector**, with fermion number 0 (e^-qbar) or 2 (e^-q)
- At LHC, mostly pair production (from gg or qq)
  - if λ not too strong (0.3 or lower), cross section independent on λ
  - Exclude up to 900 GeV for 1° generation
  - Expect to exclude up to 1.2 (1.5) TeV at 14 TeV 300 fb^{-1} for scalar (vector)-LQ



At the LHC, pair production is essentially independent of the LQ-q-e coupling λ → pair production abundant

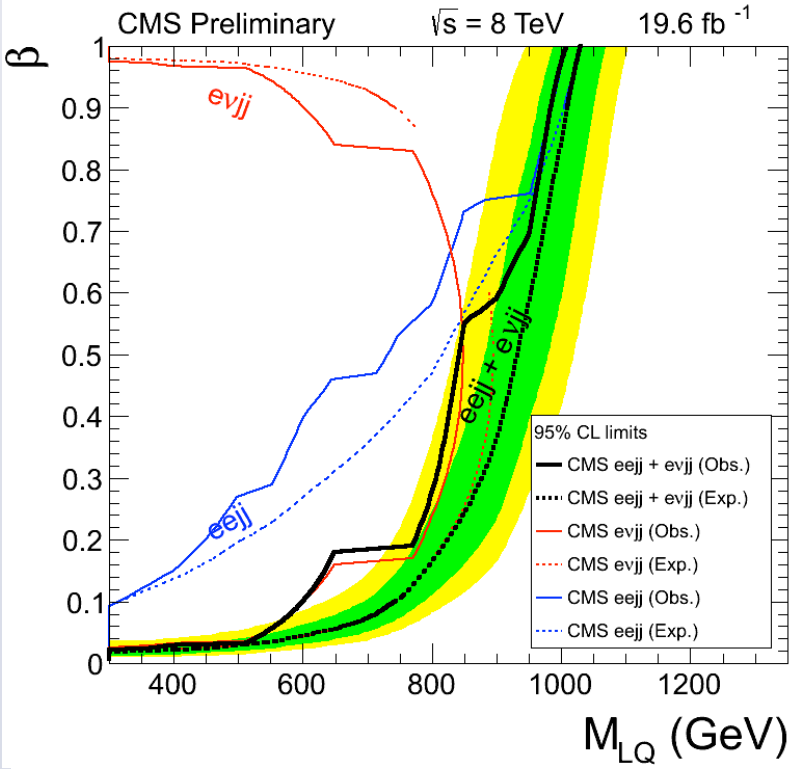
- **At the LHeC**: both baryon and lepton quantum numbers – ideally suited to search for and study properties of new particles coupling to both leptons and quarks

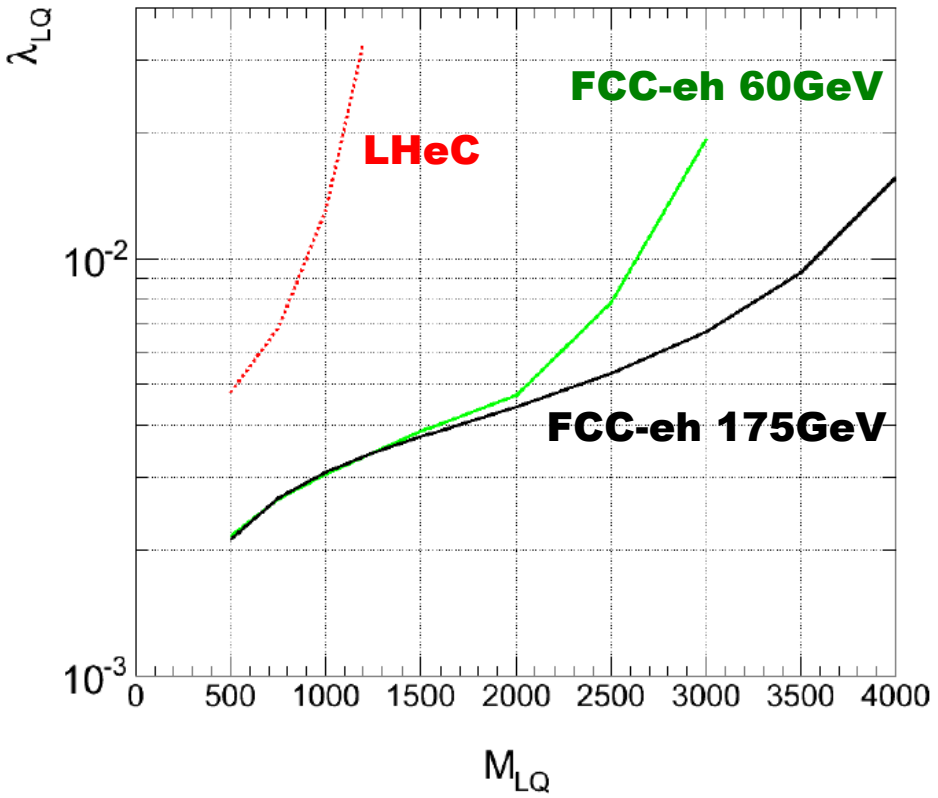


- single, resonant production; sensitive to **λ**

LQs: comparison with current LHC bounds

PAS-EXO-12-041





1st generation LQs; ß=BR(LQ→eq)=1

ATLAS+CMS (20fb^{-1}): $m_{LQ} \leq 1000$ GeV

expect up to 1.2 (1.5)TeV (pair production) with 300fb^{-1} at LHC@14TeV for scalar (vector)

ep scenarios:

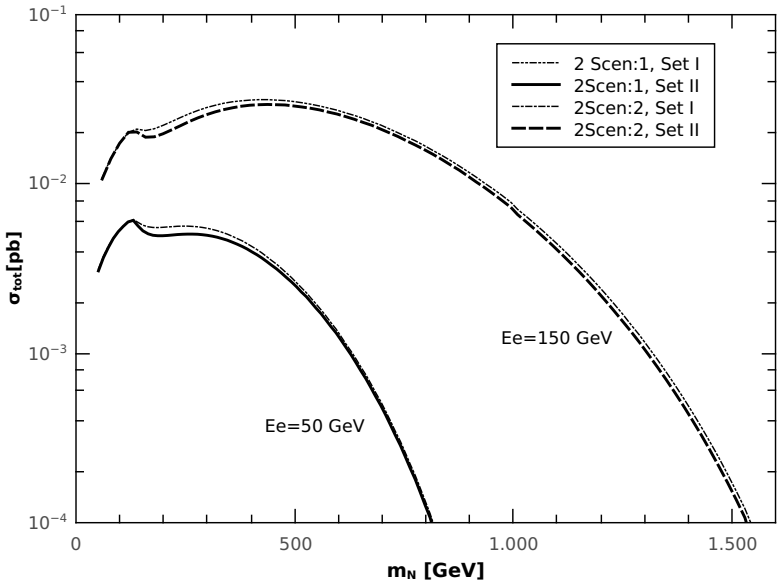
also sensitive to $\lambda << e=\sqrt{4\pi\alpha}=0.3$

preliminary study: in progress

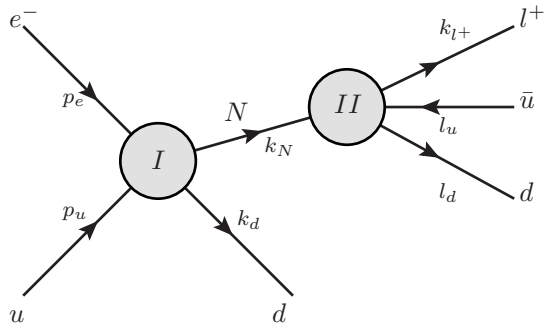
Majorana neutrinos

- Trace the existence and nature of neutrino masses
  - Recent paper: http://arxiv.org/pdf/1412.1433v2.pdf
  - Other papers in the past studying Seesaw models at LHeC
- Study l+3jets signature in 2 scenarios (E(e)=50 and 150 GeV)
- Use effective Lagrangian approach
- Signature much cleaner than at LHC (Same-sign leptons analyses)

$ep \to NX$



(a) Signal cross section.



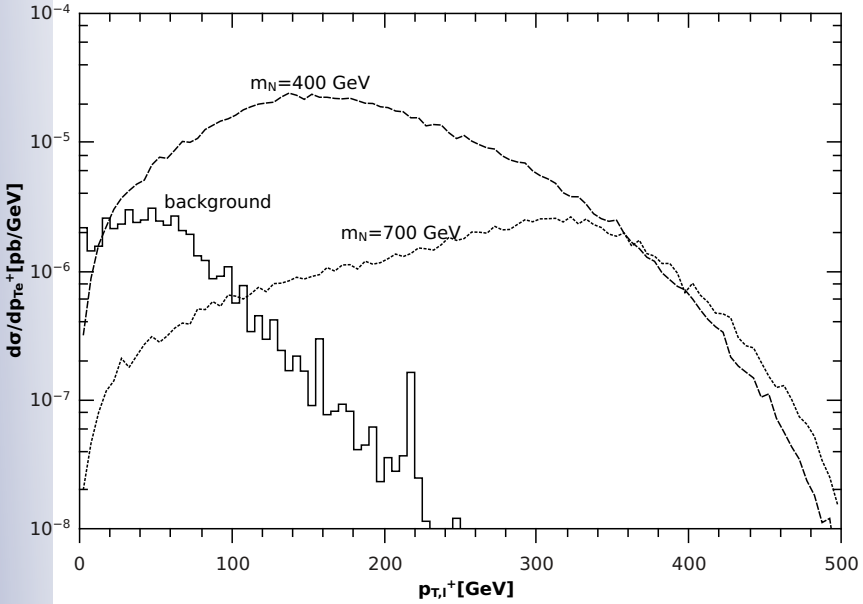
Constraints from other experiments (LEP, low-energy, and neutrinoless double β decay) also taken into account

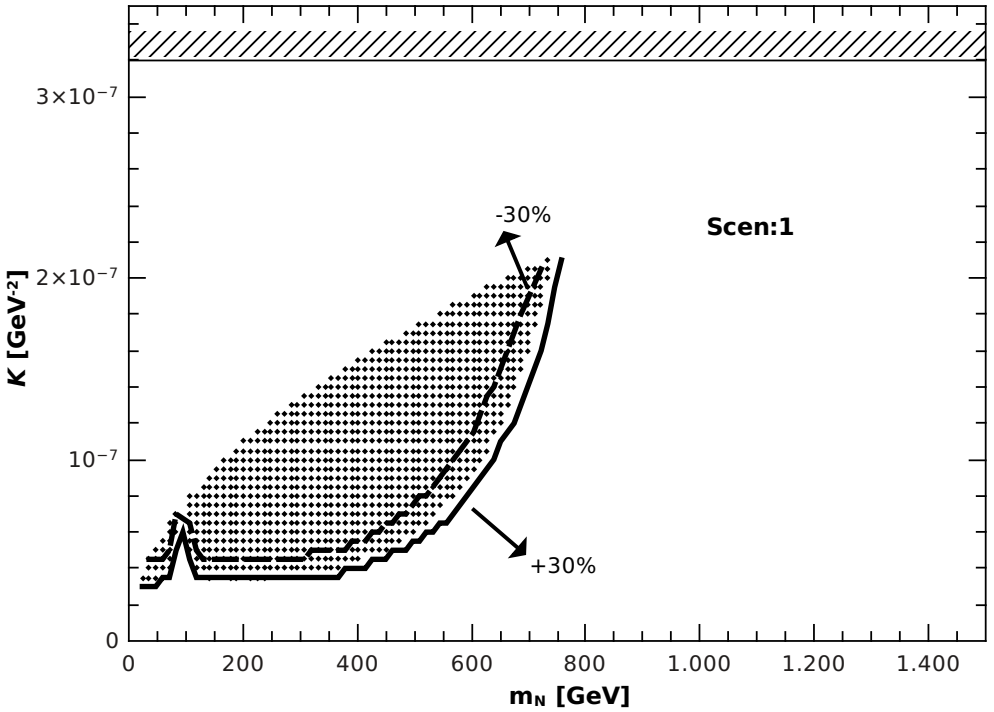
Majorana neutrinos

- Dominant background: W production
- Strongly reduced with cuts on Missing E_T and minimum pT of the lepton
- Can be further improved!

$$ep \to NX$$

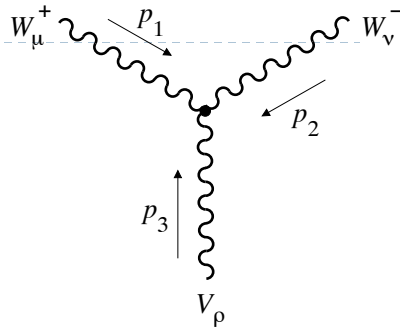
Discovery potential for E(e)=50 GeV hypothesis: up to 700 GeV





Anomalous couplings WWV

- Triple gauge boson vertices WWV, V=γ,Z:
  - Precisely defined in SM
  - Parametrise possible new physics contributions to this vertex $(\Delta\kappa_\gamma, \lambda_\gamma)$
  - Current constraints (best from LEP) use various assumptions



	LEP [9]	CDF [12]	D0 [13]	ATLAS [10]	CMS [11]
$\Delta\kappa_\gamma$	[-0.099, 0.066]	[-0.460, 0.390]	[-0.158, 0.255]	[-0.135, 0.190]	[-0.210, 0.220]
λ_γ	[-0.059, 0.017]	[-0.180, 0.170]	[-0.036, 0.044]	[-0.065, 0.061]	[-0.048, 0.037]

Table 1: Allowed ranges, at 95% C.L., on the anomalous $WW\gamma$ couplings from the data collected at the LEP, Tevatron and LHC experiments. In each case, the most restrictive of the reported measurements is taken.

http://arxiv.org/pdf/1405.6056v1.pdf

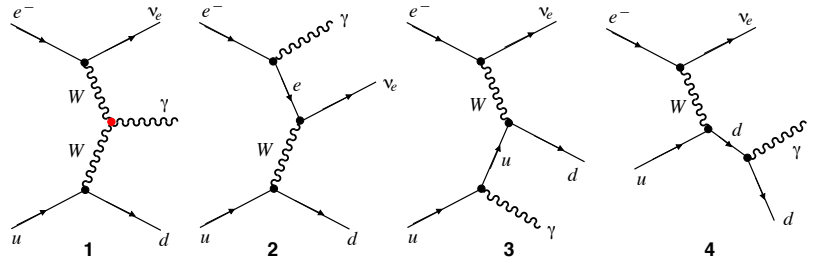
At the LHeC:

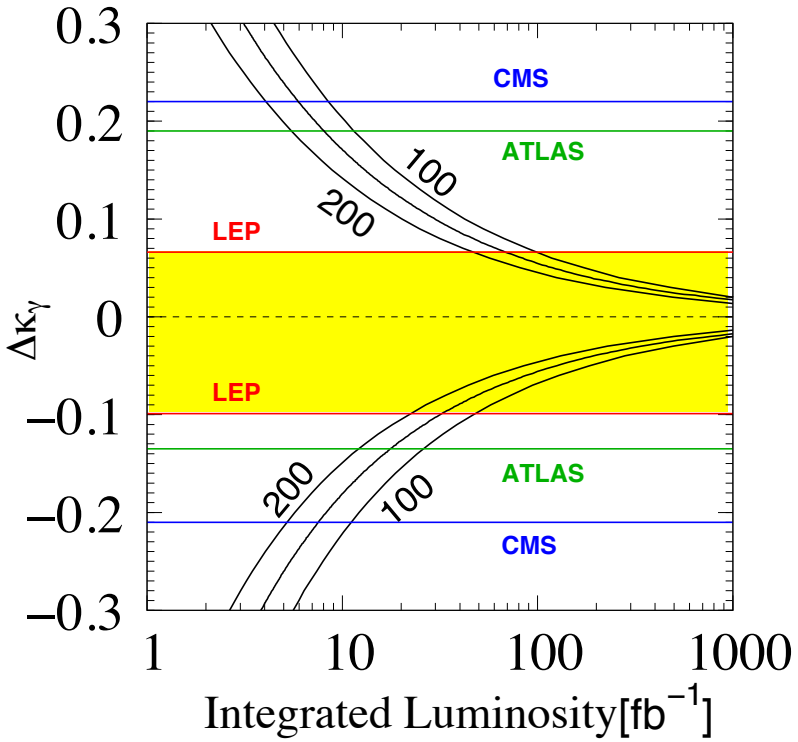
- can clearly distinguish between CC events e + p → ve + jet (W-exchange) and NC events e + p → e + jet (photon or Z boson exchange)
- triggering on a final state photon, can provide very clean bounds on the anomalous TGV's!

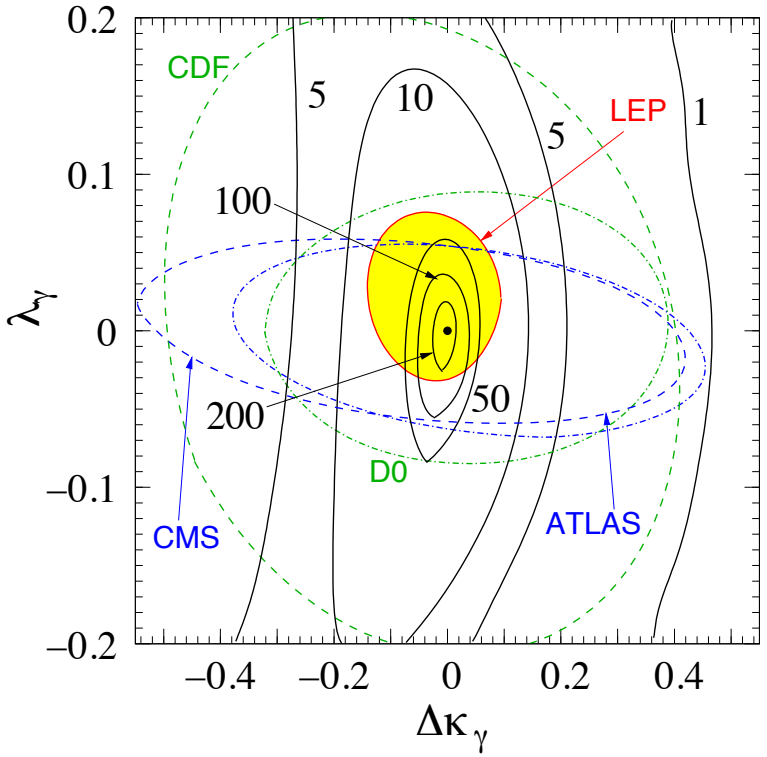
Prospects for WWγ

http://arxiv.org/pdf/1405.6056v1.pdf

- Select on p_T of γ and jet
- Sensitivity to Δφ (γ-jet)







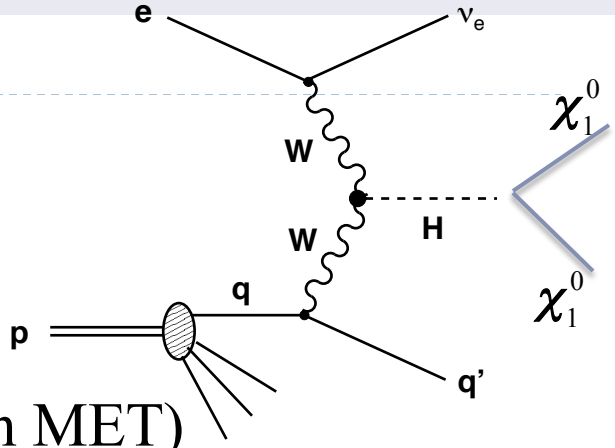
Competitive constraints at LHeC already for ~ 100 fb^{-1}

Can access a space inaccessible for LEP

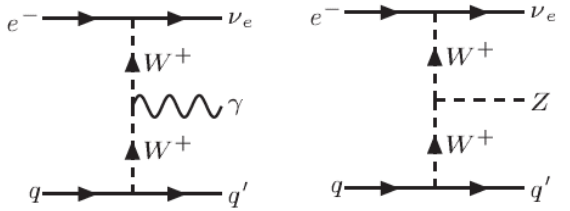
(Note: E(e)=100 GeV → expect slightly worse for 60 GeV, but not much)

BSM in Vector Boson (VB) scattering

- VB Higgs production with BSM decay
  - explore SUSY-R-parity Violating cases. E.g.
    $$H \rightarrow \chi_1^0 \chi_1^0 \rightarrow 3j\,3j \text{ (resonances)}$$
  - BUT need to understand background as well as RPV-UDD vs LDQ constraints
    $$H \rightarrow \chi_1^0 \chi_1^0 \rightarrow jjjjvv \text{ (non-resonant, with MET)}$$



- VB scattering at high mass (more for FCC-he) :
  - Mass dependence of cross section
  - anomalous TGC, QGC couplings in VVV, VVVV ?

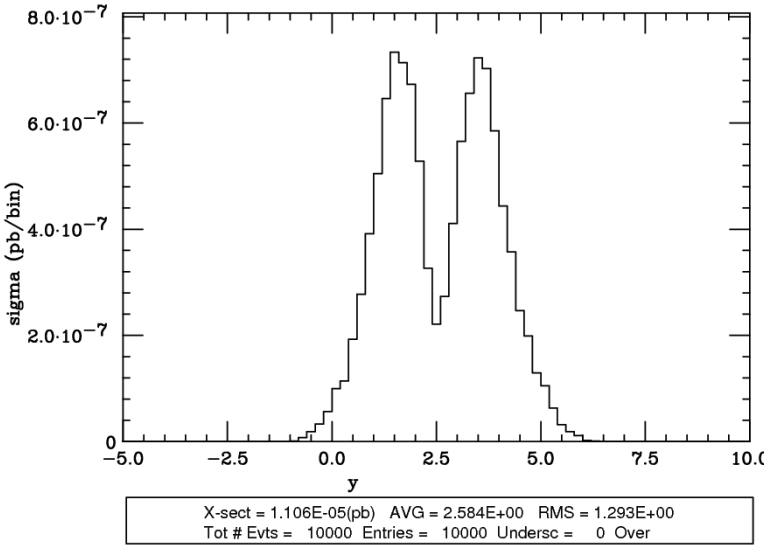


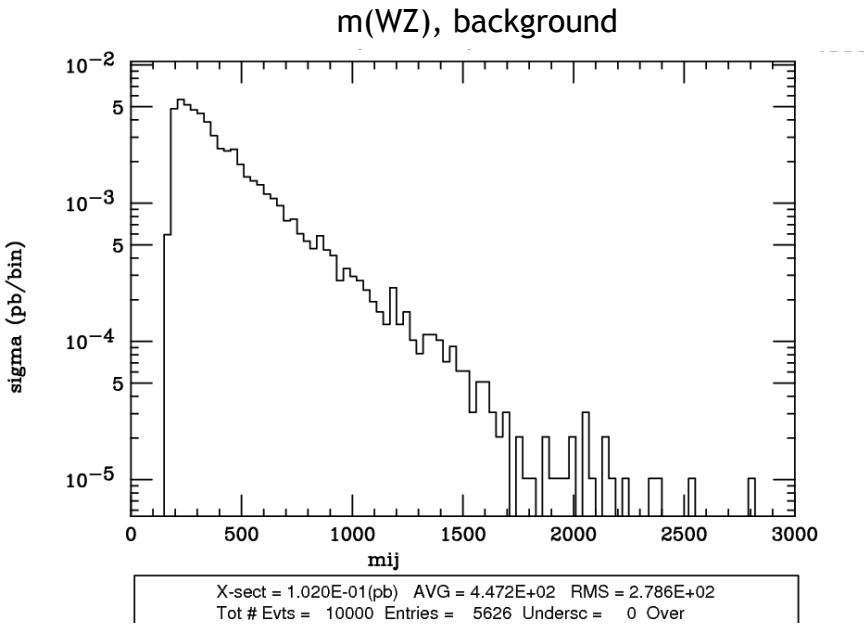
I.T. Cakir et al, 1406.7696 → *sensitivity comparable to LHC*

  - Is unitarity restored only by Higgs? Are there new resonances (CH model) ?
    - expect below ~ 2-3 TeV $e^- q \rightarrow e^-(q)WZ, \quad (\nu q)WZ$
      → *look for deviations from SM predictions:*
    - high background from QCD diagrams at LHC, absent at FCC-eh
    - challenging at LHC if no lepton trigger is used, and because of pileup

Vector Boson Scattering

FCC-he





preliminary !!

typical cross sections for 2 TeV resonance (c_F=0, c_H=1, g_V=3, 120GeV x 50 TeV)

Heavy Vector Triplet model, D. Pappadopoulo et al., JHEP 1409 (2014) 060, 1402.4431

- highly dependent on acceptance and performance of detector)
- LHC14: S = 0.12 fb B_{QCD} = 4.2 pb B_{EW} = 300 fb
- FCC-eh S = 0.01 fb B_{EW} = 100 fb

low cross section, but kinematics of signal distinct from background
need v. good detector performance

possibly use hadronic decay of W and Z (boosted, high mass object)?

R-parity violating SUSY

Squarks in RPV models could be an example of 'Leptoquarks'

- R-parity = $(-1)^{3(B-L)+2s}$ (R = 1 for SM particles, -1 for MSSM partners)

If not conserved (RPV)→ different terms, couplings constraint by proton decay

L-number violating terms

$$W_{\not R p} = \lambda_{ijk}\hat{L}_i\hat{L}_j\hat{E}^C_k + \lambda'_{ijk}\hat{L}_i\hat{Q}_j\hat{D}^C_k + \epsilon_i\hat{L}_i\hat{H}_u + \lambda''_{ijk}\hat{U}^C_i\hat{D}^C_j\hat{D}^C_k$$

bilinear terms

B-number violating terms

ΔL =1, 9 λ couplings, 27 λ' couplings

Plethora of new couplings, only partially constraints (m/100 GeV)

	$\lambda_{ijk}L_iL_j\bar{E}_k$	$\lambda'_{1jk}L_1Q_j\bar{D}_k$	$\lambda'_{2jk}L_2Q_j\bar{D}_k$	$\lambda'_{3jk}L_3Q_j\bar{D}_k$
weakest	0.07	0.28	0.56	0.52
strongest	0.05	$5.\cdot 10^{-4}$	0.06	0.11

Various strong constraints from LHC on Lambda and Lambda'' (from multilepton and multijet searches)

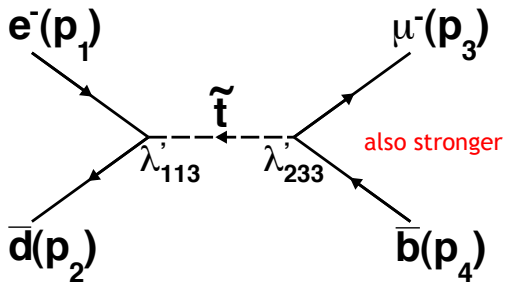
SUSY – R-parity violating

single squark production, in RPV SUSY (signal like leptoquarks, with generation mixing)

[general LQ studies and more - in back-up]

http://arxiv.org/pdf/1107.4461v2.pdf

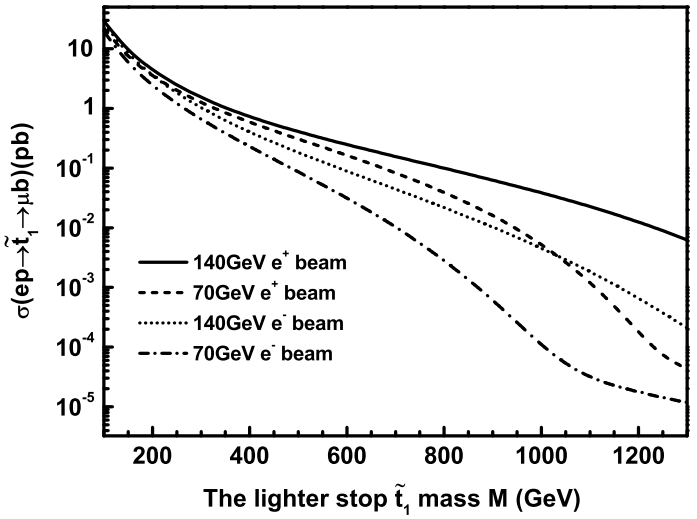
stop

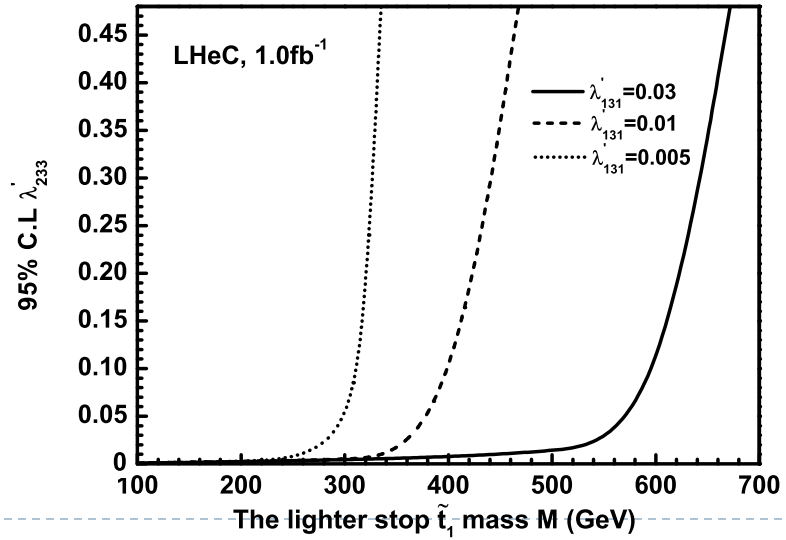


$\lambda'_{131} < 0.03$

also stronger bounds from ßß0ν

- sensitivity up to 700 – 800 GeV with only 1fb^{-1}
- very promising with high luminosity, 100 fb^{-1}
- requires good b-tagging





Update with high lumi scenario
In progress ! Expect to be strongly competitive with LHC

RPV interaction can be probed at unprecedented levels

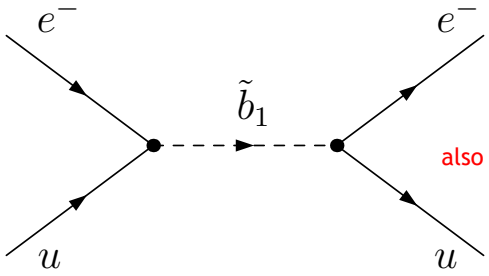
SUSY - R-parity violating

single squark production, in RPV SUSY (signal like leptoquarks, with generation mixing)

[general LQ studies and more - in back-up]

http://xxx.tau.ac.il/abs/1401.4266

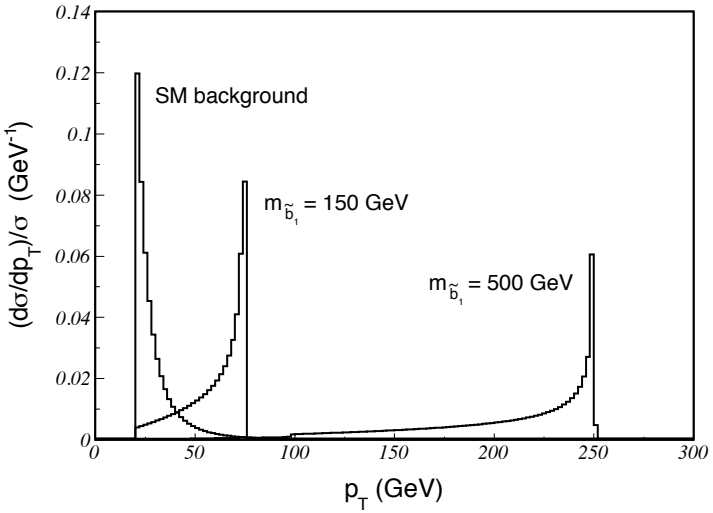
sbottom

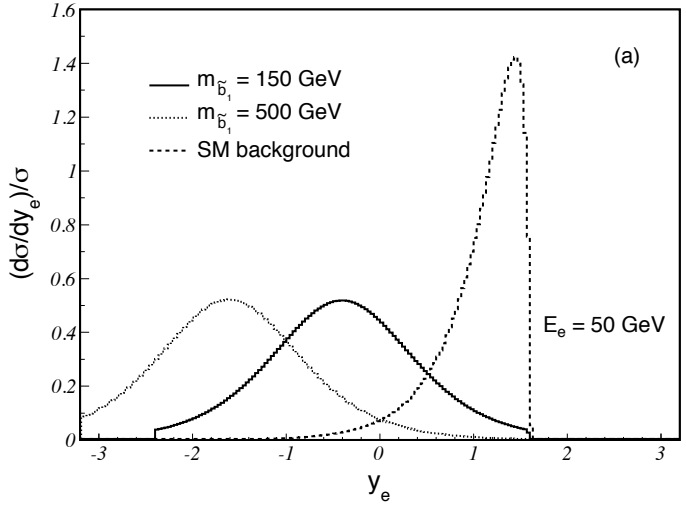


$\lambda'_{131} < 0.02$

also stronger bounds from $\beta\beta 0\nu$

Several handles to get extremely good sensitivity (e rapidity, pT(e/jet)~1/2 m(sbottom))

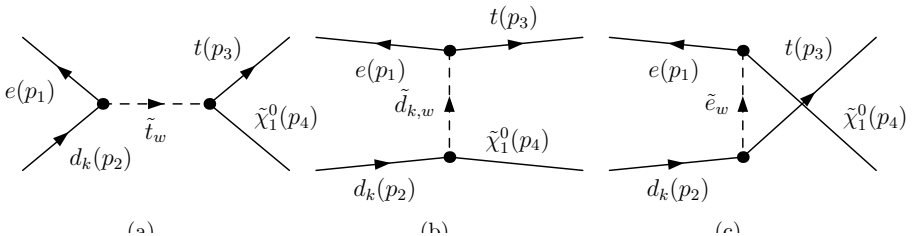


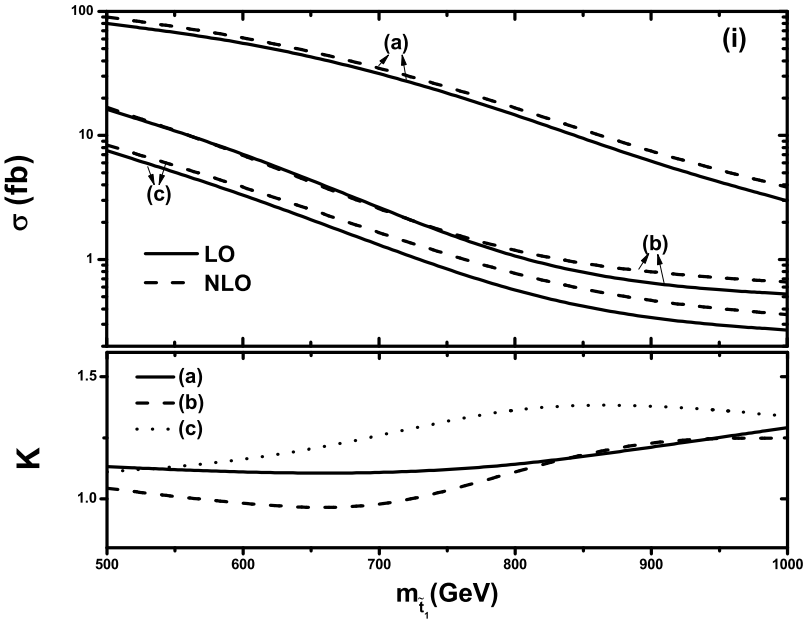


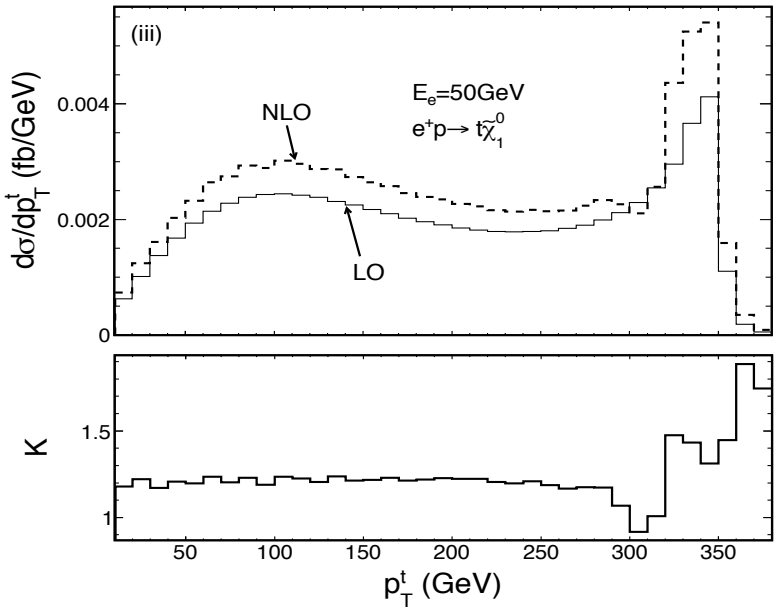
- At LHeC: < 100 fb^{-1} needed for 1TeV RPV sbottom discovery
- More updates in progress

Single-top + neutralino

- http://arxiv.org/pdf/1307.2308v2.pdf
- Show the relevance of NLO corrections for these processes
- Could lead to interesting discovery e.g. **neutralinos in qqMissingET from RPV scenarios**

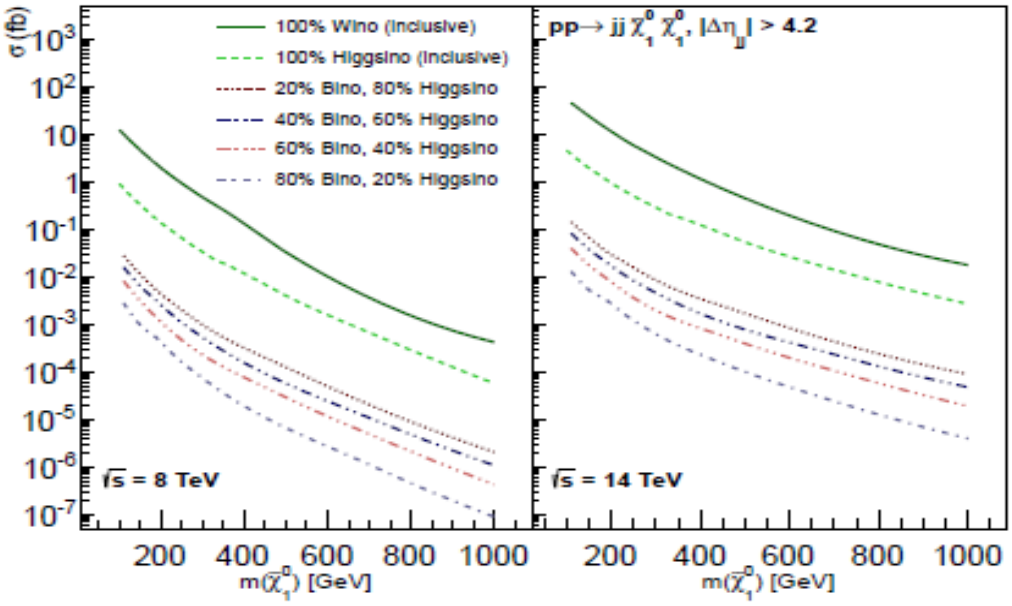






Hopes for RPC SUSY? EWK RPC

- Charginos (C) and Neutralinos (N) fundamental for SUSY
  - Expected to be light in most scenarios (C1, N1, N2 in particular)
  - N1 is often the LSP and one of the preferred DM candidate
- One of the most difficult scenarios for the LHC: medium-compressed N1, C1, N2 (DM few GeV)
  - Not visible in direct searches, mono-photon and mono-jet searches possibly not sensitive because of systematic unceratinties VS tiny xsect.
  - VBF scenarios investigated for 14 TeV LHC



$pp \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 jj, \ \tilde{\chi}_1^\pm \tilde{\chi}_1^\mp jj, \ \tilde{\chi}_1^\pm \tilde{\chi}_1^0 jj$

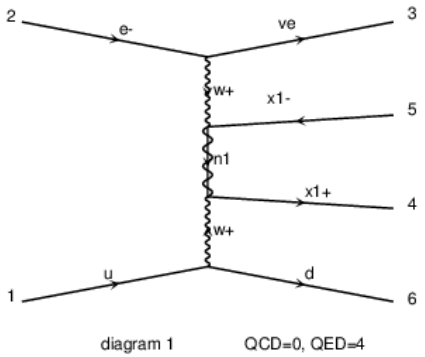
50 fb xsection for pure Wino-like N1

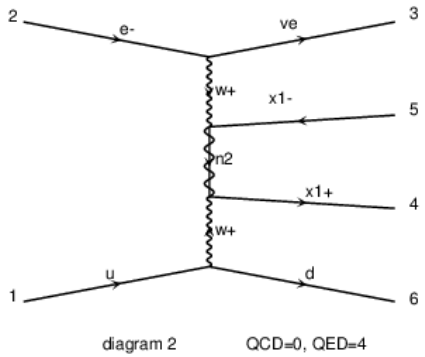
Promising for low N1, but possibly large bkg from SM (ie Z,higgs production)

EWK RPC-SUSY production

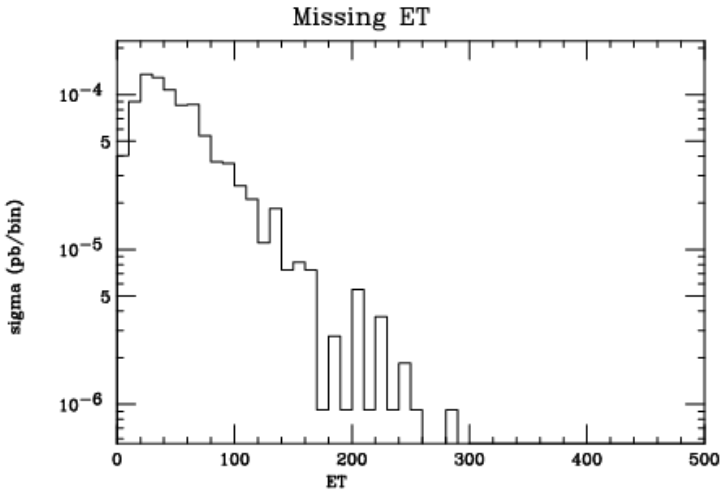
Need inputs from theorists!

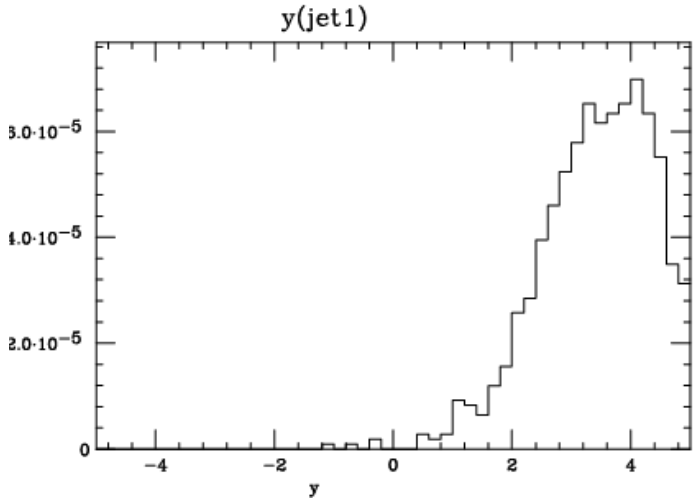
- Question: can anything be done at the LHeC ?
- Completely uncharted territory, nothing in the literature
- Very first look, using Madgraph:





- Example of diagram for C1C1. Production of N1N1 and C1N2 equivalent for almost degenerate masses
- Coupling strenghts depend on the Wino-Higgsino mixture

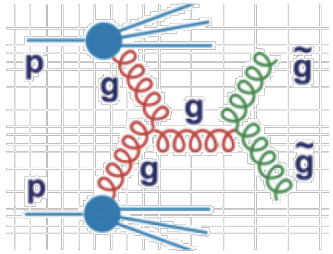


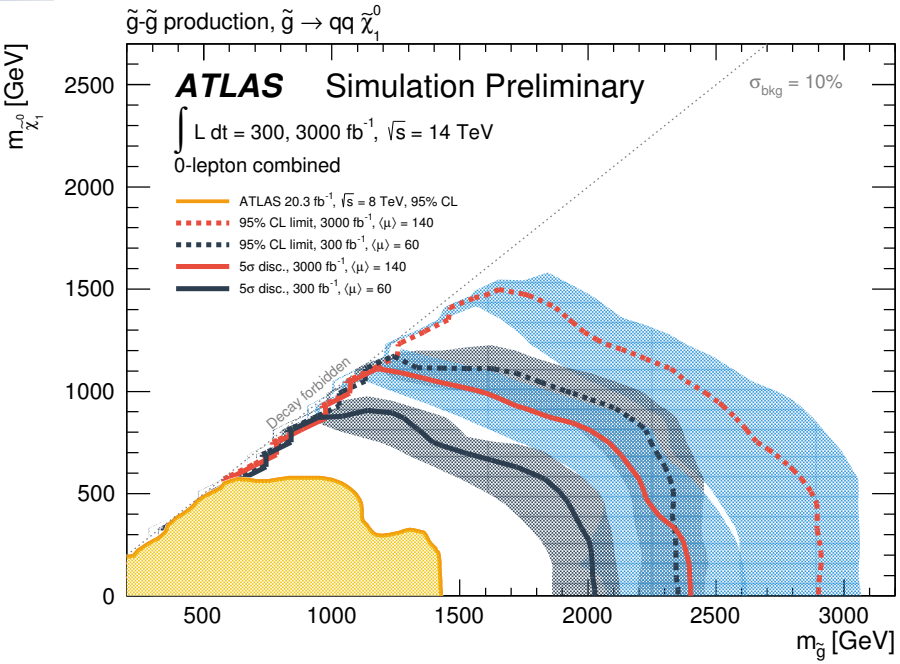


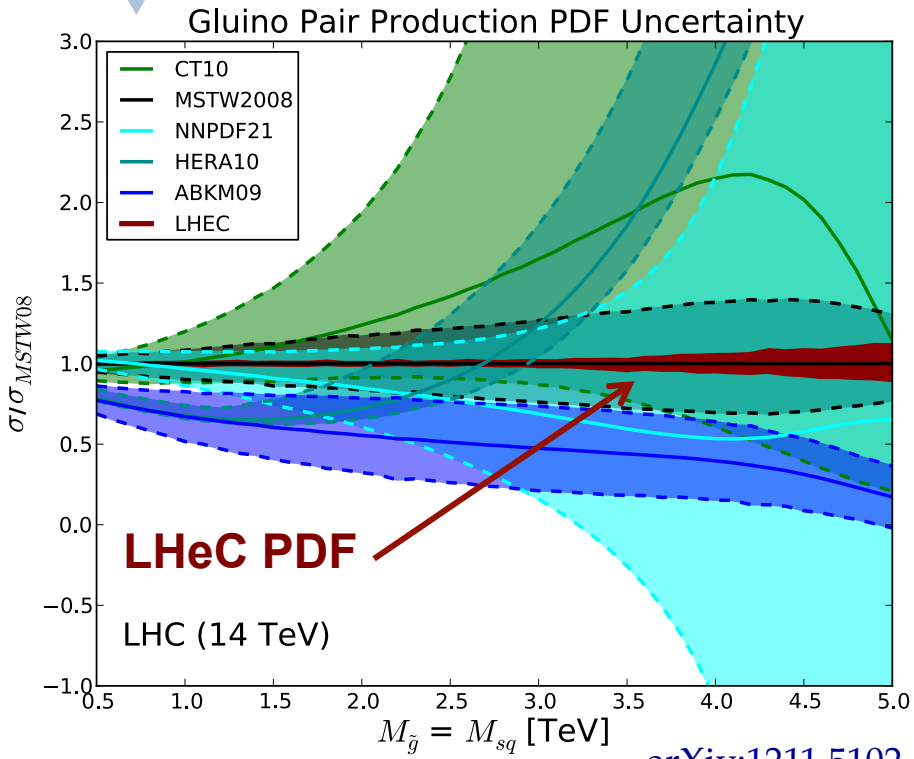
High x PDFs: link to LHC

- large uncertainties in high x PDFs limit searches for new physics at high scales

  many interesting processes at LHC are gluon-gluon initiated: top, Higgs, … and BSM processes, such as gluino pair production







arXiv:1211.5102

High x PDFs: link to LHC

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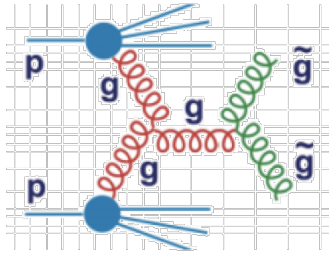
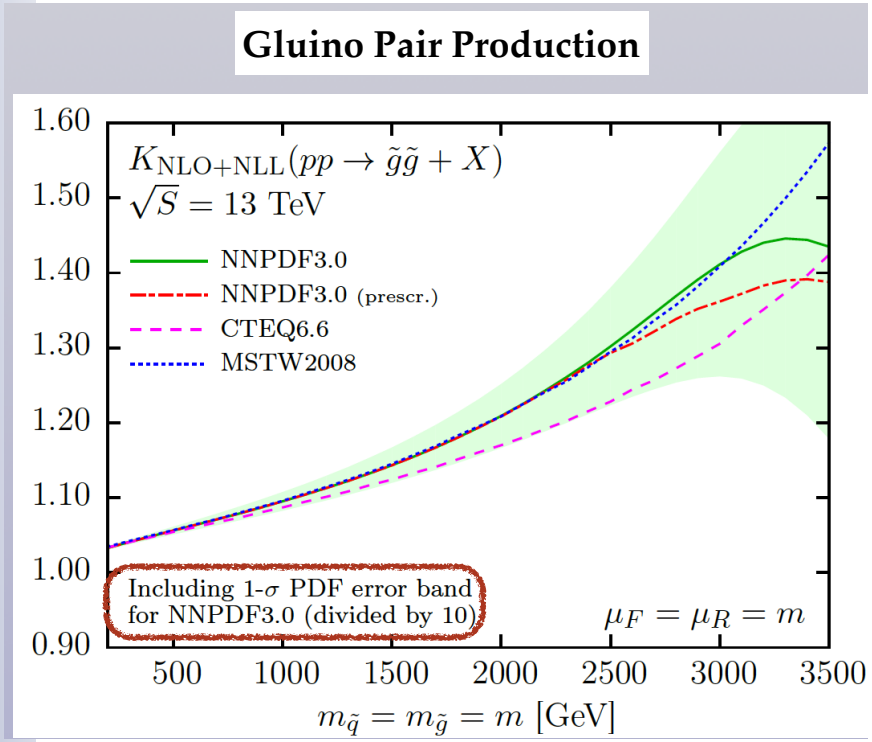
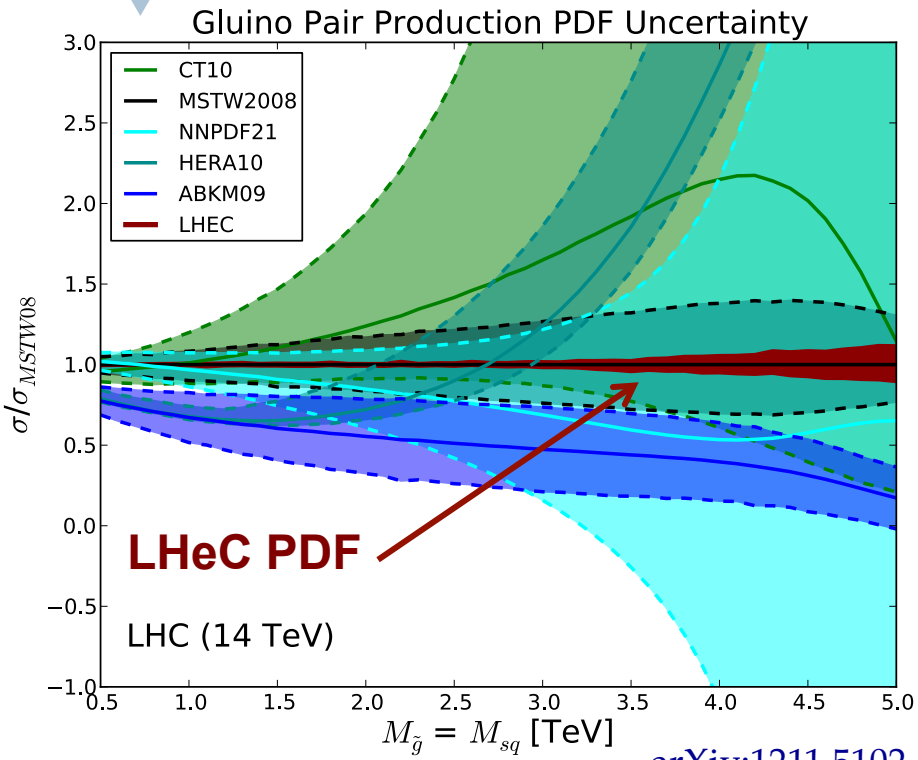


NLO+NLL calculations by Kulesza et al,





Still large uncertainty!

arXiv:1211.5102

Summary and outlook

- LHeC provides complementarities to the LHC SUSY search program in the twenties
  - Ideal to search and study properties of new bosons with couplings to electron-quark
  - Direct searches for CI, excited fermions, leptoquark, RPV SUSY, RPC SUSY in specific scenarios estabilished
    - More studies are needed to improve the BSM physics case → currently very short person-power!
    - Engagement from theory community is really important: uncharted terrotories, and very very promising results where there are!!

Back-up

LQ isospin family

- Classification used here (BRW framework)

$F=2$	Prod./Decay	β_e	$F=0$	Prod./Decay	β_e
Scalar Leptoquarks					
${}^{1/3}S_0$	$e_L^- u_L \to e^- u$	1/2	${}^{5/3}S_{1/2}$	$e_L^- \bar{u}_L \to e^- \bar{u}$	1
	$e_R^- u_R \to e^- u$	1		$e_R^- \bar{u}_R \to e^- \bar{u}$	1
${}^{4/3}\tilde{S}_0$	$e_R^- d_R \to e^- d$	1	${}^{2/3}S_{1/2}$	$e_R^- \bar{d}_R \to e^- \bar{d}$	1
${}^{4/3}S_1$	$e_L^- d_L \to e^- d$	1	${}^{2/3}\tilde{S}_{1/2}$	$e_L^- \bar{d}_L \to e^- \bar{d}$	1
${}^{1/3}S_1$	$e_L^- u_L \to e^- u$	1/2			
Vector Leptoquarks					
${}^{4/3}V_{1/2}$	$e_R^- d_L \to e^- d$	1	${}^{2/3}V_0$	$e_R^- \bar{d}_L \to e^- \bar{d}$	1
	$e_L^- d_R \to e^- d$	1		$e_L^- \bar{d}_R \to e^- \bar{d}$	1/2
${}^{1/3}V_{1/2}$	$e_R^- u_L \to e^- u$	1	${}^{5/3}\tilde{V}_0$	$e_R^- \bar{u}_L \to e^- \bar{u}$	1
${}^{1/3}\tilde{V}_{1/2}$	$e_L^- u_R \to e^- u$	1	${}^{5/3}V_1$	$e_L^- \bar{u}_R \to e^- \bar{u}$	1
			${}^{2/3}V_1$	$e_L^- \bar{d}_R \to e^- \bar{d}$	1/2

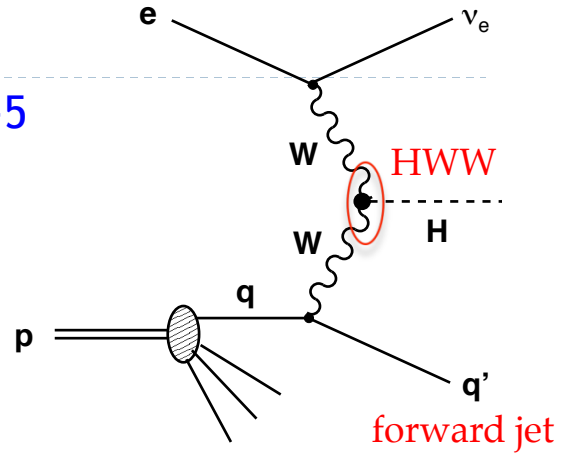
Table 5.1: Leptoquark isospin families in the Buchmüller-Rückl-Wyler model. For each leptoquark, the superscript corresponds to its electric charge, while the subscript denotes its weak isospin. β_e denotes the branching ratio of the LQ into $e+q$.

CP properties of Higgs

- LHC has shown that discovered Higgs boson consistent with 0+ state, but: are there small additional dimension-5 anomalous couplings to the HWW vertex?

$$i\Gamma^{\mu\nu}(p_-, p_+)\varepsilon_\mu(p_-)\varepsilon^*_\nu(p_+)$$

$$\Gamma^{\mu\nu} = g M_W \left(-g^{\mu\nu} + \frac{1}{M_W^2}\left[\lambda\left(p_- \cdot p_+ \, g^{\mu\nu} - p_-^\nu p_+^\mu \right) + i\lambda' \varepsilon^{\mu\nu\rho\sigma} p_{-\rho} p_{+\sigma} \right] \right)$$



(BSM will modify CP even (λ) and odd (λ') states differently)

- measure **azimuthal angular distribution** between $E_T$miss and forward jets
- sensitive probe of nature of **HWW vertex** and hence **CP properties**

with 50 fb^{-1}, sensitivity up to λ ~ 0.05 and λ' ~ 0.2

(T. Plenh et al, hep-ph/0105325
S. Biswal et al, arXiv:1203.6285, and update)