BSM searches at colliders long term prospects

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Searching for new physics: what

Standard Model of Elementary Particles



Today: Evidence of NP BSM (Dark Universe, neutrinos, baryogenesis..)

- ... but not of **where/what** BSM is !
- \rightarrow arguments as naturalness/tuning possibly pushed to boundaries
- \rightarrow precision tests perfectly healthy (so far), no need for NP at the EW scale

Searching for new physics: what

Standard Model of Elementary Particles



conservation or violation..)
mostly heavy super-partners, prompt or longlived, several Higgs bosons

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Searching for new physics: where



LHC (and future pp colliders) offer a unique place where to look directly for new particles:

possibility to search for excesses in number of events in a plethora of kinematic regions and for resonances from new heavy particles

[The main focus of this talk]

 perform precision measurements of SM parameters → Each deviation could be an hint of new physics! [not really covered here]

• Other colliders/experiments give alternative but fundamental opportunities:

 hidden sector particles (NA62), precision measurements leading to loop-induced deviations (g-2, EDM); LFV experiments (m2e, m3e); BC experiments for ALPs. @ colliders: EWK SUSY, Higgs precision (ee), LQ and contact interactions (ep), and more

Why colliders

- access a WIDE and BROAD exploration potential \rightarrow target well justified BSM scenarios but also have sensitivity to the unknown
- guarantee flexibility \rightarrow if (indirect) hints of NP arise somewhere, need to be able to re-direct efforts
- guarantee deliverables \rightarrow if not a discovery, precision measurements!
- have the potential to provide conclusive and quantitative answers to the relevant questions

Physics at Colliders fulfill all of the above conditions so it is mandatory to guarantee a continuous progression in this direction with sufficient complementarity



HL-LHC

- 14 TeV com energy, 2025-2038, up to 3000 or 4000/fb (300/fb for LHCb)
 - > The only one really approved, on which most studies have been made
- ATLAS, CMS and LHCb detectors upgrade well on-going
- Start time 2025
- Yellow Report for EU strategy expected in December 2018 summarize studies and projections by experiments and theory community on SM&Top, Higgs, BSM, Heavy Flavor and Heavy Ions
- WG3 (=BSM) has more than 80 contributions foreseen
 - Half and half between experiments and theorists

Section 1: Intro and review Section 2: SUSY Section 3: DM Section 4: LLP Section 5: Dark sectors Sections 6 and 7: Resonances, VLQ (to be decided on possible merging) Section 8: Flavor-related and Miscellanea HE projections studies also included

https://twiki.cern.ch/twiki/bin/view/ LHCPhysics/HLHEWG3

Conveners: MD (ATLAS) Keith Ulmer (CMS), Xabier Vidal (LHCb), Riccardo Torre (TH), Paddy Fox (TH)

Status of WG3 document so far

 113 pages, theoretical contributions only, experimental results in preparation for september
 and the UNISM

https://www.overleaf.com/14722141bbfgfvqrrvbp#/56185127/

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Other (future?) "colliders"

Proton-proton

- **HE-LHC** \rightarrow 27 TeV com energy, beyond 2038
- FCC-hh \rightarrow 100 TeV com energy, beyond 2045 (so far, after FCC-ee), up to 30/ab

Electron-positron

- Linear collider:
 - ILC \rightarrow E_{cm} \approx 500 GeV with staging at 250 GeV,
 - CLIC → three stages E_{cm}≈ 380 GeV, 1.5 TeV and 3 TeV for 500/fb, 1.5/ab and 3/ab respectively, data taking after HL-LHC for ~ 20 yrs

Circular collider:

- CepC → At least two stages, E_{cm} ≈ 91 and 240 GeV, 2IP, data-taking 2030-2040 [Upgradable to pp collision 50-100 TeV, with ep and HI option)
- FCC-ee → 2IP, beyond 2045, Operation model foresees, 5 different stages and lumi

Electron-proton

- LHeC \rightarrow E_e = 60 GeV, p from LHC, up to 1/ab, running at the same time as HL-LHC
- **HE-LHeC** \rightarrow upgrade in parallel to HL-LHC
- FCC-eh \rightarrow E_e = 60 GeV vs 50 TeV, up to 3/ab



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outline

- At the LHC, hundreds of searches for new physics are on-going targeting many models proposed in the past thirty years.
- HL LHC studies on-going
- This is not a review talk, rather a discussion about goals and synergies
 - Will illustrate what data might tell us at the end of HL-LHC and complementarities with other facilities (e.g. e+e-, e-p)
 - Consider some benchmark routes
 - New heavy resonances and high p_T physics
 - Supersymmetry
 - Dark matter
 - Long-lived particles and their role in hidden/ dark sectors, sterile neutrinos



New resonances (and high p_T searches)

Where high luminosity and high center of mass energy help the most

- Sensitive to many BSM scenarios Heavy higgses (A/H), Extra-dimensions, new gauge bosons... without mentioning the role of dijet searches for DM
- Consider <u>all relevant combinations</u> of final state objects
- Example of flexibility/synergy: strong focus on 3rd generation: can help explaining anomalies in B-sector and beyond → Leptoquarks, Z', W'

Reach with HL-LHC: Z' →ttbar

- Resolved and boosted top systems
- ► Large **R-jets** considered







ATL-PHYS-PUB-2017-002



Reach: beyond 4 TeV (I TeV gained with HL-LHC)

Reach with HL-LHC: W'→tb

 Projections performed assuming NWA using 2015 and 2016 analyses

3000 fb⁻¹ (14 TeV) **CMS** Preliminary Simulation $σ(pp→W'_{B}) × B(W'_{B} → tb→lvbb) [pb]$ $1 P_{-0} 0 P_{-0} 1 P_{-0} 0 P_{-0} P_{$ "heory M_ << M_w Theory $M_{\rm o} > M_{\rm w}$ 95% CL expected ±1σ expected $\pm 2\sigma$ expected "no" unc. **Invariant Mass Analysis** e/μ +jets N_{b tags} = 1 or 2 3500 2500 3000 4000 1000 1500 2000 W' Mass [GeV]

Again, dependence on assumptions on uncertainties CMS DP016_064

Three possibilities for the evolution of systematic uncertainties with integrated luminosity are considered

- (Flat) All systematic uncertainties are assumed to remain unchanged
- (Scaled) All systematic uncertainties are assumed to improve
- (None) No systematic uncertainties are included?



Reach: beyond 4 TeV For W' in ev and $\mu v \rightarrow$ reach up to 7 TeV

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W

Reach with HL-LHC: $Z' \rightarrow II$

ATLAS and CMS update for Yellow Report in progress

ATLAS

- Search in the ee and µµ final states using MC truth + smearing
- Exclusion limits shown in LAr TDR
- Also plans for property studies

For Z'→ee, exclusion up to 6.4 TeV, discovery reach ~ 5.9 TeV

CMS (CMS-PAS-EXO-14-007)

- Study ee final state
- Existing full sim property study using A_{FB} in 2014
- \rightarrow updates on the possibility to characterize signals being followed up by ATLAS and CMS and for HE-LHC



The (far) future

On the optimistic side: if deviations are observed in Run 3, HL-LHC will allow to study new physics properties with high statistics in characteristic distributions, e.g. A_{FB} .

- Clearly, the higher c.o.m. energy, the better
 - If nothing is found by HL-LHC, only option for direct observation
 - @100 TeV collider would increase the reach of a factor 10 with full dataset (30/ab) [question: to discover an m=6-10 TeV new particle produced via gluonfusion, do we wait for FCC-hh or is HE-LHC enough? What do we need?]



Indirect constraints on Z'

- If mZ'>>5 TeV, main contributions from interference effects modifying DY
- HL-LHC can do a lot \rightarrow but need very precise predictions of SM DY again PDF!

Alioli, Farina, Pappadopulo, JTR, Phys. Rev. Lett. 120, no. 10, 101801 (2018)



Other resonances: di-higgs

- > NP in the higgs sector can manifest in various ways
 - E.g.: heavy particles decaying into higgs
 - Very recent result from CMS released for the HL-LHC Yellow Report



VBF signatures: very good potential at HL-LHC

Search for di-higgs resonance in the 4b channel
 → Substructure + boosted b-tagging helps to suppress large QCD multijets background.

 \rightarrow Bump-hunt on mJJ (J = Large R jet from h \rightarrow bb)



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Follow the anomalies ?

- B-physics anomalies could be explained by LQ-like or Z'-like mediators
 - TeV-scale and 3rd generation favored
- LQ could also explain g-2

 $\begin{array}{l} \textbf{Quark level transition b} \rightarrow c\ell\bar{\nu} \\ \textbf{R}_{D}, \textbf{R}_{D^{*}} \colon \text{combined} \sim 4\sigma \text{ deviation} \\ \textbf{R}_{D^{(*)}}^{\tau/\ell} = \frac{\Gamma(\bar{B} \rightarrow D^{(*)}\tau\bar{\nu})}{\Gamma(\bar{B} \rightarrow D^{(*)}\ell\bar{\nu})} \end{array}$

Quark level transition $\mathbf{b} \to \mathbf{s}\ell\bar{\ell}$ $R_{K}, R_{K^{*}}: \sim 2.5 \ \sigma \ \text{deviation (LHCb)}$ $R_{K^{(*)}} = \frac{\Gamma(\bar{B} \to \bar{K}^{(*)}\mu^{+}\mu^{-})}{\Gamma(\bar{B} \to \bar{K}^{(*)}e^{+}e^{-})}$

 $B^0 \rightarrow K^{\star 0} \mu^+ \mu^-$ angular analysis: 3.4 σ deviation (LHCb)







Possible new contribution in the $b \rightarrow s\ell\ell$ transition in BSM scenarios involving Z'



LQ: $\rightarrow \tau$ + b and beyond

- Projections for HL-LHC not yet available, but likely to cover part of the interesting phase-space regions
 - ~2.9-3 TeV in mass, according to back-of the envelope extrapolations



Pure 3G (scalar) LQ are not the only option:

- → Mixed generation LQ models have also been proposed to explain LFV anomalies
- → Left-, right- handed muons-top coupling could explain g-2 (arXiv:1612.06858) (e.g. see A. Crivellin talk at Moriond 2018)

→CMS HL-LHC studies and projections expected for September

Note: depending on mixture and mass, studies could be also possible at e-p (limited by c.o.m energy)

Supersymmetry

Lot of interesting consequences, theoretically sound, predictive framework, what about naturalness ?

- Current LHC: m(gluino)>2 TeV, m(stop)>1 TeV
 compare: Barbieri-Giudice 3% naturalness:
 → m(gluino)<~1000 GeV; m(t1)<~500 GeV
 LHC limits way beyond paturalness bounds
- LHC limits way beyond naturalness bounds
 → is SUSY unnatural? Is SUSY dead? NO
 (and it's not me saying that ...)

Using electroweak fine-tuning (Δ_{EW}), SUSY is natural (3-10%) with: gluinos up to 5-6 TeV, stop up to 2-3 TeV, squarks up to 10-20 TeV, + need low μ_{H} ~ 100-300 GeV



H. Baer, FNAL HL/HE-LHC workshop

higgsino is LSP, higgsino-like WIMP~100-300 GeV thermally under-produced as DM candidate: augment with e.g. axion

SUSY @ HL-LHC: strong sector

- In strong production, can push the reach to much higher masses
 - Question: is this sufficient to exclude natural SUSY? Probably not
- With HL-LHC, gain several hundred GeV in discovery potential for pair-produced gluinos or squarks (including stop).



Large uncertainties from PDF \rightarrow improvements expected with LHC data and, possibly, new facilities (LHeC)

Analyses being re-assessed: Exp. gluino reach up to 3 TeV

Baer et al., EPJC77 (2017) 499



M(stop) can range up to 3 TeV with little cost to naturalness. HL-LHC Stop reach: 1.4-1.5 TeV (1.9 TeV with new analyses, but for compressed scenarios ~ 700 GeV)

Expected reach with HE-LHC in strong sector

HB, Barger, Gainer, Huang, Savoy, Serce, Tata, PRD96 (2017) 115008



SUSY @ HL-LHC: challenging scenarios (stop)

- Target compressed scenarios and use ISR jets
- m_{T2} as discriminating quantity, 2l + 2b + MET
 - Not simple to target those!

$$(m_{\widetilde{t}_1}, m_{\widetilde{\chi}_1^0}) \cong m_t$$



Cut-and-count, optimized for discovery



ATL-PHYS-PUB-2016-022

Others

80

900 1000

m_t [GeV]

60

100

120

140

m_τ, [GeV]

160

••••• t̃,t̃, m(t̃, χ̃)=(350, 177) GeV ••••• τ̃, t̃,, m(t̃,, χ̃)=(700, 527) GeV

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Events / 10 GeV

10⁶

10⁵

10⁴

 10^{3}

10²

10

10

ATLAS Preliminarv

 $\sqrt{s} = 14 \text{TeV}$. L = 3000 fb⁻¹. u= 200

Simulation

SUSY@ HL-LHC: EWK sector

ATLAS and CMS update for Yellow Report in progress

- EWK SUSY fundamental e.g. for DM
- HL-LHC dataset has the potential to increase the sensitivity to EWK SUSY enormously
- HE-LHC at 27 TeV can lead to a ~2x increase of signal xs for sub-TeV EKW-inos
 - But unclear if it is really an advantage
- Sensitivity strongly depends on EWK-inos composition and consequent decay
- Decays via higgs very challenging



10^{6} 10^{12} 10 Followed prescriptions in 1206.2892 [hep-ph] 10^{11} 10^{4} 10^{3} $pp \rightarrow \tilde{\chi}_1^{\pm} \tilde{\chi}$ 10^{2} 10^{1} 10^{0} 10^{-} 10^{-2} 10^{-3} 10- 10^{-5} SS Section cro 10^{-} 2000 2500 3000 500 1000

Mass [GeV]

SUSY@ HL-LHC: EWK sector (II)

- EWK SUSY fundamental e.g. for DM
- HL-LHC dataset has the potential to increase the sensitivity to EWK SUSY enormously
- HE-LHC at 27 TeV can lead to a ~2x increase of signal xs for sub-TeV EKW-inos
 - But unclear if it is really an advantage
- Sensitivity strongly depends on EWK-inos composition and consequent decay
- Slepton production also very challenging

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E.g. current LHC stau results DO NOT provide constraints



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ATLAS and CMS update for Yellow **Report in progress**



SUSY@ HL-LHC: EWK sector (III)

ATLAS update for Yellow Report in progress

- SUSY higgsino-like scenarios also difficult (and very relevant for DM)
 - Low x-section, compressed \rightarrow decay products are soft/invisible (for pro



little sensitivity at the LHC for higgsino scenarios \rightarrow new ideas coming in! p $\tilde{\chi}_{1}^{\pm}$ W $\tilde{\chi}_{1}^{0}$ $\tilde{\chi}_{1}^{0}$ $\tilde{\chi}_{2}^{0}$ Z ℓ

Search for events with Higgsinos produced in association with an ISR jet





Profit of additional charginos and neutralinos

- And if you wonder about
 higgsino-DM and direct detection ...
 - ~ I TeV: maximum mass for the Higgsinos such that their relic abundance is at most Ω_{DM}





A brief outlook on SUSY reach



 Sleptons projections not yet available everywhere. Potential at ILC and CLIC (not for higgsinos).

are still through an s-channel

- using mono-jet signatures
 - A signature relevant for many
 NP models (DM-oriented)
 - \rightarrow 1 TeC boundary reached only by FCC-hh



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Invisible

Invisible

dark matter candidates

Most wanted after the higgs!



Foreseen by full theories as SUSY but nowdays searched under 'simplified models' assumptions

Complementarities with non-collider experiments to be exploited more

Dark matter searches at HL-LHC (I)



Simplified models with few free parameters:

 $m_{med},\,m_{DM},\,med\math{-}quark$ coupling, med-DM coupling

The classic: monojet



Strategy: Search for associated production with one of many SM tags: Jet, photon, Z, single/double top, b, H

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ATLAS update for Yellow Report in progress

ATLAS and CMS update for Yellow Dark matter searches at HL-LHC (II) **Report in progress** g t (b) محوووووو **DM + heavy flavor**: great potential, lot of studies in progress (CMS, ATLAS, theory) ¢/a لففقففففف arXiV:1611.09841v2 Ľ, Ī(b) 10 pseudoscalar 10 scalar events/bin/(100 fb⁻¹) 10 1-bin, 20%, 300 fb⁻¹ 1-bin, 20%, 300 fb⁻¹ 10 10shape, 30%, 300 fb⁻¹ shape, 30%, 300 fb⁻¹ scalar, 100 GeV shape, 20%, 300 fb⁻¹ shape, 20%, 300 fb⁻¹ pseudoscalar, 100 GeV shape, 20%, 3 ab-1 shape, 20%, 3 ab⁻¹ SM background 50 100 150 200 250 300 350 400 450 500 50 100 150 200 250 300 350 400 450 500 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 lcos0"l

Also including DM + single-top

▶ E.g.:



Forward tracking will increase sensitivity to DM+HF



Dark Matter searches at HL-LHC (III)

ATLAS update for Yellow Report in progress

- Can also target models with pure wino DM.
- Studied using various signatures (monojet, disappearing tracks, photons, VBF...)
- Monophoton:



Complementarities

 Just two examples to show the complementarities with DM direct detection experiments



Long-lived particle, dark sectors and sterile neutrinos

LLP \rightarrow Hot topic of the past 2-3 years

Great discovery potential: many NP models predict LLPs

- small couplings: RPV decays, dark sector coupling
- small mass-splittings: degenerate next-LSP
- heavy messengers, split SUSY, hidden valley

Signature space quite complex \rightarrow joined exp/theory efforts to review all modes

Long-lived particles

Particles decaying non-promptly are one of the major targets of HL-LHC experiments and beyond



Lifetime

Decay

Long-lived higgsinos

ATLAS and CMS update for Yellow Report in progress

 π^{\pm}

- If DM(charg-neut) ~ 200 MeV, higgsinos might be long-lived
- charged particle with lifetime ~10 ps 10 ns which decays to "invisible"
 - pure higgsino case: ~0.05 ns (wino: 0.2 ns)
- Studies for HL-LHC are in progress
 - Current results promising, but challenging need excellent tracking!
 - Results so far for pure Wino models
 - Higher cross sections wrt higgsinos



@higgsinos: expect to exclude up to 250
GeV for pure higgsino (τ = 0.05 ns)

p



Tracking efficiency versus decay radius

Long-lived higgsinos: long term future?

• At FCC-hh, sensitivity will depend on the bkg (very high PU)



 Also possible at ep-colliders: advantage from low bkg and low PU





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 π^{\pm}

Long-lived higgsinos: long term future?

> At FCC-hh, sensitivity will depend on the bkg (very high PU)



 Also possible at ep-colliders: advantage from low bkg and low PU



disappearing track analyses Maybe optimistic on Pile Up MARCARO Only sensitive to $c\tau > 10^{-2}$ p π^{\pm} FCC-eh 10-1 0.3 10-2 -0.5 10-3 ∆m (GeV) cr (m) 10-4 FCC-eh-60 1ab-1 10-5 $\mu > 0$ 10⁻⁶ з $N_{1+LLP} > 10$ 10^{-7} N_{1+LLP} > 100 10⁻⁸ 200 100 300 400 500 m_{χ^*} (GeV) Curtin, Deshpande, Fischer, Zurita arXiV: 1712.07135

p

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HL-LHC and FCC-hh bound from

3/07/2018

 π^{\pm}

Displaced muons



- \rightarrow Vertex constrains reduce efficiency
- → Dedicated algorithms needed for displaced muons to recover efficiency

Quite an improvement in sensitivity!

800

1000

 10^{-3}

200

400

600

1400

M_{ii} (GeV)

1200

Displaced jets

- Aim to exploit at best the complementarities among detectors
 - LHCb sensitive to lighter mass and low τ wrt ATLAS and CMS
- E.g. hidden valley dark pions from Higgs



For short-lifetimes, this could be complemented by CepC !

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Cand C

 π_V

h

%

LLP and Dark sectors

arXiv:1708.09395

Higgs-portal models

- B and exotic decays
 φ = light CP-even scalar
 mixing with the higgs
- Projections promising !
- Additional gain from proposal for a new detector (CodeX-b)

Significant extension of LHCb coverage



Relation between Dark sector and Long-lived particle have led to many new ideas for new detectors and experiments \rightarrow big interplay with Physics Beyond collider experiments

LLP and Dark sectors: PBC proposals



Target complementary life-time and kinematic regions (forward and central, short and long) Note: CepC and FCC could incorporate the basic of these experiments from the beginning

Dark photons @ HL-LHC

- Dedicated worldwide effort to search for dark photons
- E.g., can exploit the A' $\rightarrow \mu\mu$ mode: at LHCb impressive prospects:
 - curves assume Run 3 performance with more luminosity [triggerless detector readout in Run 3 will have a huge impact on low-mass BSM searches, including dark photons]
 - Magnet chambers would help with soft A' decays to e+e- (efficiency and/or resolution).



LLP and heavy sterile neutrinos

- Low-scale type I seesaw with sterile neutrinos
 - heavy neutrino mass eigenstates with M ~ vEW
 - Neutrino mixing $|\theta_{\alpha}|, \alpha = e, \mu, \tau \Rightarrow$ Weak current production.
 - Present constraints: $|\theta_e| \le 10^{-3}$, can be long-lived
- Projections (LHCb)



arXiv:1612.00945



LLP and heavy sterile neutrinos

- Low-scale type I seesaw with sterile neutrinos
 - heavy neutrino mass eigenstates with M ~ vEW
 - Neutrino mixing $|\theta_{\alpha}|, \alpha = e, \mu, \tau \Rightarrow$ Weak current production.
 - > Present constraints: $|\theta_e| \le 10^{-3}$, can be long-lived
- Potential at e-e colliders, complementarities of FCC-hh, eh, ee



A long way before constraining the full mass/mixing ranges A good news worth further investigation: Heavy neutrinoantineutrino oscillations could be resolvable and hh and eh

Fischer, Cazzato, arXiV: 1709.03797



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Summary

- In the past years, experiments have focused on the completion of the detector proposals and optimization of performance
 - Lot of benchmark studies have been carried out, with continued efforts to evaluate the prospects of BSM searches in parallel to data analyses
 - New ideas are being explored
 - Never underestimate physicists ingenuity ⁽²⁾ We did not find NP yet, but pushed the boundaries well beyond initial projections

• There is huge potential also in terms of complementarities:

- Push for a synergic approach across HL-LHC experiments i.e. in NP scenarios characterized by long-lived particles and dark sectors
- Work to fully exploit the HL-LHC potential also considering new detectors/ facilities (e.g. for long-lived particles)
 - In YR WG3, more than 80 contributions being finalized

Lot of exciting physics can be done at HL-LHC and 'around', and a great physics case is being developed

Outlook

- At the moment, it is not possible to define a preferred direction
 - Direct searches limited by kinematic reach, indirect searches limited (e.g.) by precisions → not a unique recipe
- Directions: HARD until we see some deviations from SM predictions!
 - Not necessarily at LHC, could be on any other related field (cosmo, neutrino...)
 - Correlations LHC/non-LHC signals could be pursued, hints of DM candidates and more could indicate the scale
- A proton-proton machine provides a wide range for exploration of NP
- Is that enough ?





Reach with HL-LHC: Z'→ee (ATLAS)

- > LAr calorimeter has a direct impact on the ee invariant mass resolution
- Consider Sequential SM Z' as benchmark
- 2 electrons with p_T>25 GeV
 - exclusion up to to 6.4 TeV, discovery reach ~ 5.9 TeV



• Constraints are about 200 GeV more stringent than for muons, thanks to the resolution for high $p_{\rm T}$ electron

SUSY @ electron-positron machines (II)

[GeV]

160

140

100

80

60

40

40

60

80

5[™]120



Chargino/neut @ CLIC (Stage 2: 1.5 TeV)

50

40

30

20

10



∍ hh

hZ

120 140 160

M_{ii 1} [GeV]

Precision on the measured chargino/ neutralino masses (few hundred GeV): 1 - 1.5%

0 (M(charg/neut2)=487 GeV)

Similar studies in progress for circular colliders

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100

Heavy Stable charged particles

- Dedicated studies showed the need to keep good dE/dx capabilities
- New 200 PU studies:

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- consider stau and gluinos models
- pT>55 GeV tracks, show also N of high threshold clusters with HI particle





Additional CMS studies on performance for Heavy stable charged particle via muon system also available (more in dedicated talk)

CMSTDR (NEW)

Dark photons: future potential

FASER predictions



I. Galon at FNAL workshop on HL/HE-LHC (4-6 April 2018)

CepC potential

 $e^+e^- \to \tilde{Z}H_0$ Study $\tilde{Z} \to \ell\ell$ and semi-visible $H_0 \to (\ell\ell)_Z \chi \chi$ $e^+e^- \to \tilde{Z}\tilde{K}$ Study $\tilde{Z} \to \ell\ell$ and $\tilde{K} \to \bar{\chi}\chi$ or $\ell\ell$ $e^+e^- \to \gamma \tilde{K}$ Study \tilde{K} inclusive decays, and exclusive $\tilde{K} \to \bar{\chi}\chi$ or $\ell\ell$



Indirect constraints on Z'

- If mZ'>>5 TeV, main contributions from interference effects modifying DY
- The precision of e^+e^- colliders help but LHC (and HL-LHC) can do a lot

Alioli, Farina, Pappadopulo, JTR, Phys. Rev. Lett. 120, no. 10, 101801 (2018)



potential @ electron-positron machines

Sensitive to EWK processes and useful to target compressed scenarios

Higgs

charginos

neutralinos

squarks

SM

 10^{3}

 10^{2}

cross section (fb) 10¹ 10¹

 10^{0}

 10^{-1}

Caveat: depends on the center of of mass energy



Sparticle σ for unpolarized beams at e+e- for ILC

Sparticle σ at e+e- for one CLIC benchmark point



120 GeV Higgs

CLIC CDR

High cross section for χ^{\pm}_1 and χ_0 production and sleptons: clean environment to access very compressed scenarios

too low also for CLIC? arXiV:1801.05192

Sensitivity for sleptons and charg/neut up to $\sim \sqrt{s/2}$

A comment on high p_T / mass searches

Already at HL-LHC, limitations arise from difficulties to identify high p_{τ} / boosted objects, but also from modeling of SM processes



more for DM in Wt+MET final states





Studies in 1712.03874 performed using 1L and 2L channels

10

120 140 160 180 200 220 240 260





 $C_{\rm em} \equiv m_{\rm T2} + 0.2 \cdot E_{\rm T}^{\rm miss}$

√s = 14 TeV, L = 300 fb⁻¹



3/07/2018

2L channel

Wt/single-t

Total SM

tī

tī+V

Other

 $(m(H^{\pm}), m(a), tan\beta)$

DM with 2HDM+a models

One more final states being considered: 4-top



Look for final state with at least one lepton, multi-bjets and MET

Scan various sets of parameters: - e.g. scan in m(a) for benchmark values of $m_{\rm H}$ Analysis for Run 2 released with 3.2/fb



ttbar+bb main background

Difficult to model with MC but we can assume a better understanding of this process at HL-LHC!