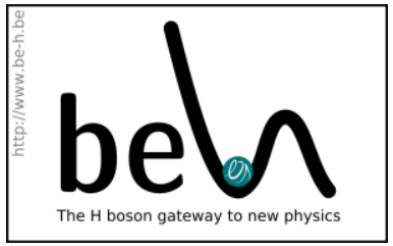
Soft Displaced Leptons at the LHC

EOS PhD Day 2020

A.R.Sahasransu

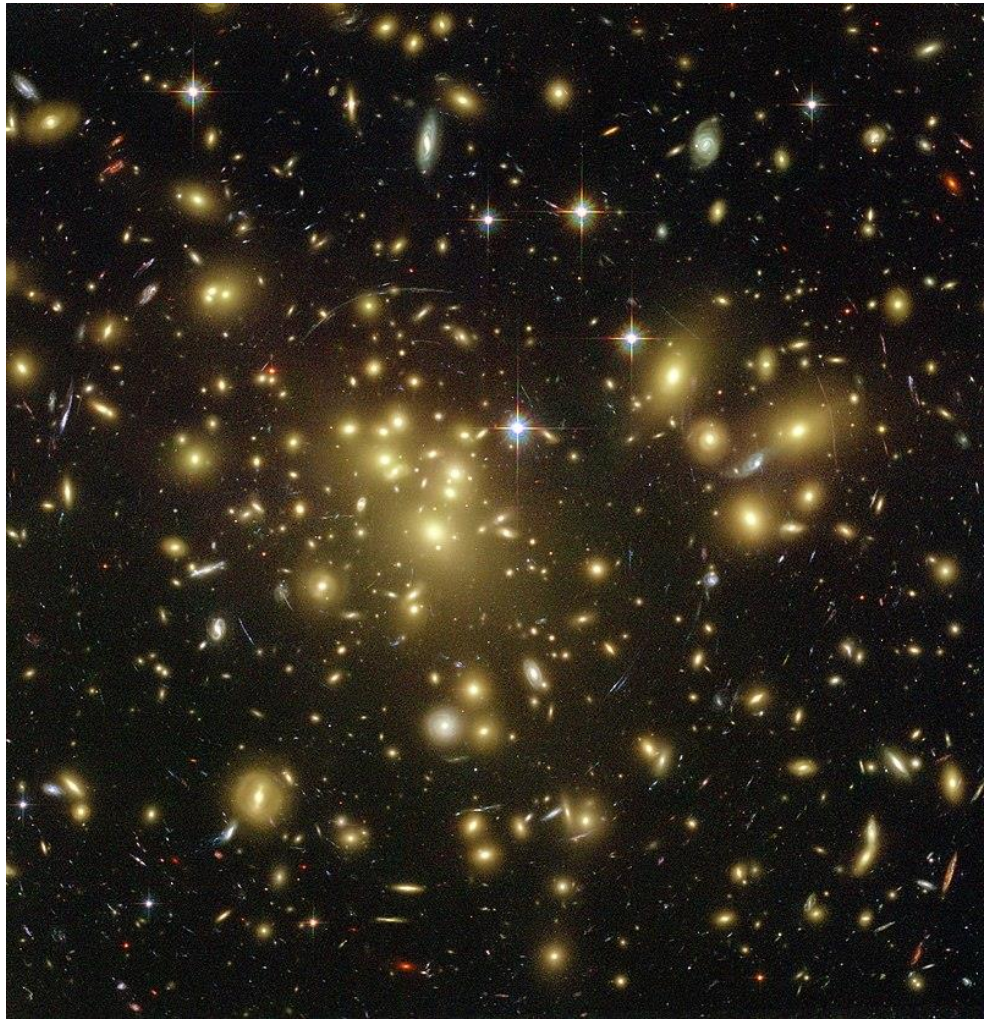
Based on paper arxiv[2007.03708], accepted by JHEP

With F. Blekman, N. Desai, A. Filimonova and S. Westhoff



Dark matter !!

Image by Hubble



- Cosmological observations
- Baryon asymmetry

→ Dark Matter Exists!!!

? Other interactions ?

? Mass ?

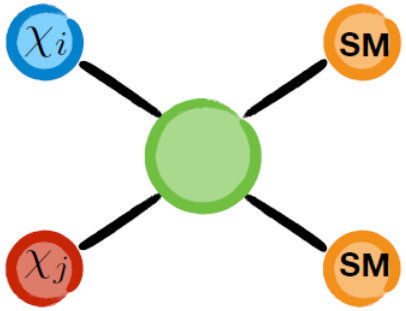
? Spin ?

? Several Species ?

Thermal higgs portal dark matter at the LHC

Thermal relic: Co-annihilating dark matter

$$\sum_{ij}$$



$\langle \sigma v \rangle_{eff}$ at decoupling

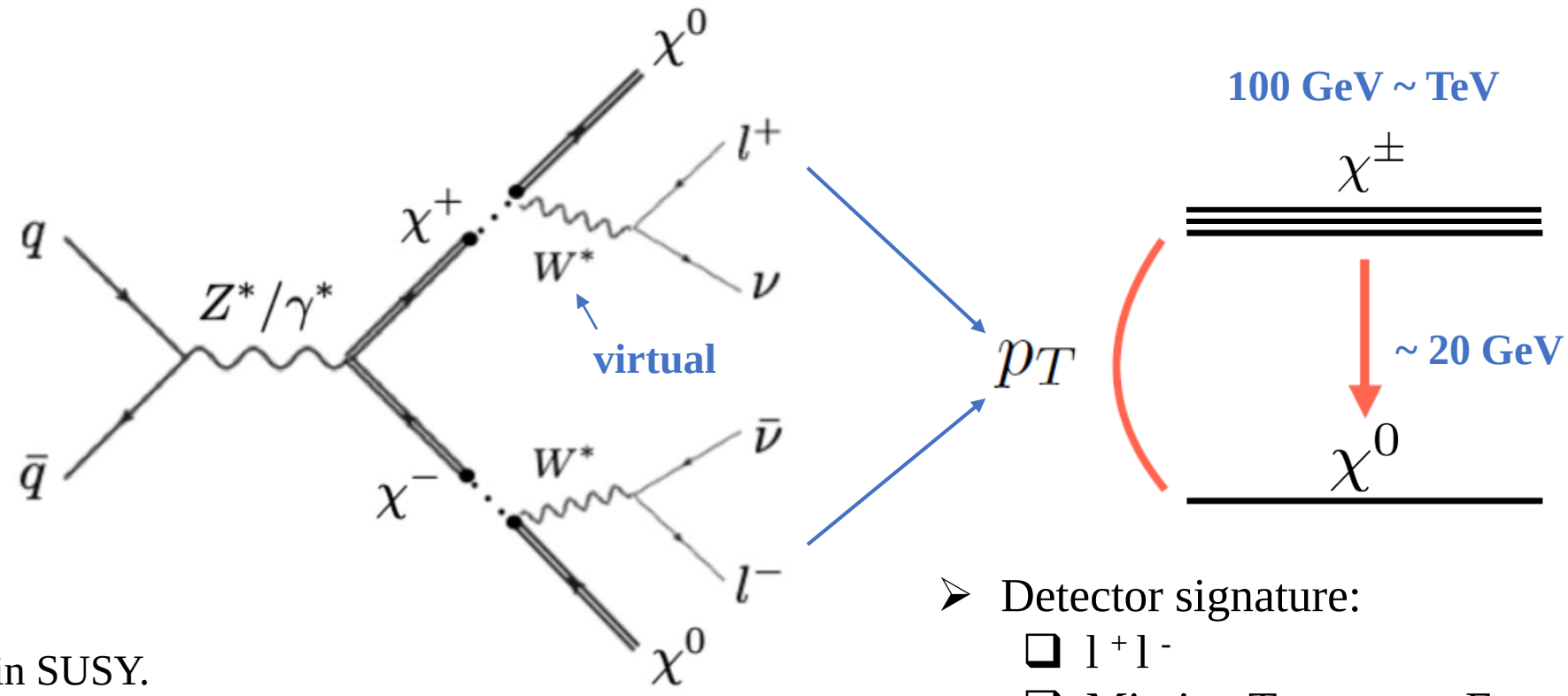
Compressed mass spectrum: process exponentially supressed by $\frac{m_{Xi} - m_{Xj}}{T}$

Image by A. Filimonova

Weak coupling with standard model → Long-lived particle

Soft leptons from singlet-triplet model

- At colliders:
  - Produce mediators
  - M → DM + SM



- Similar to bino-wino scenario in SUSY.

- Detector signature:
  - $l^+ l^-$
  - Missing Transverse Energy

Filimonova and Westhoff [1812.04628]
Bharucha, Bruemmer and Desai [1804.02357]

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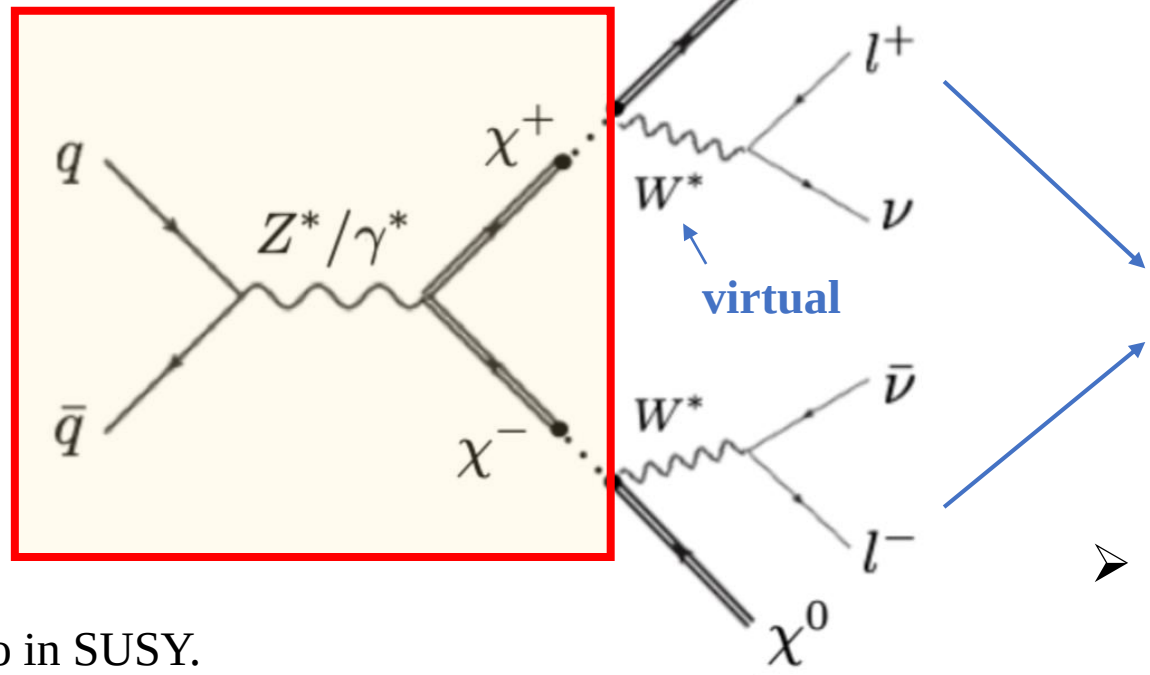
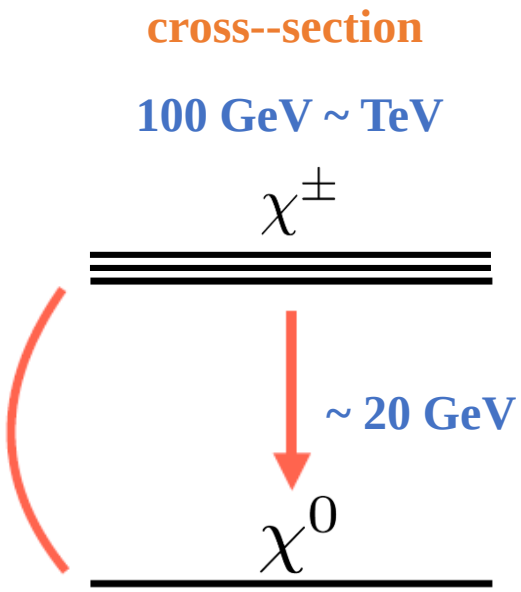


p_T



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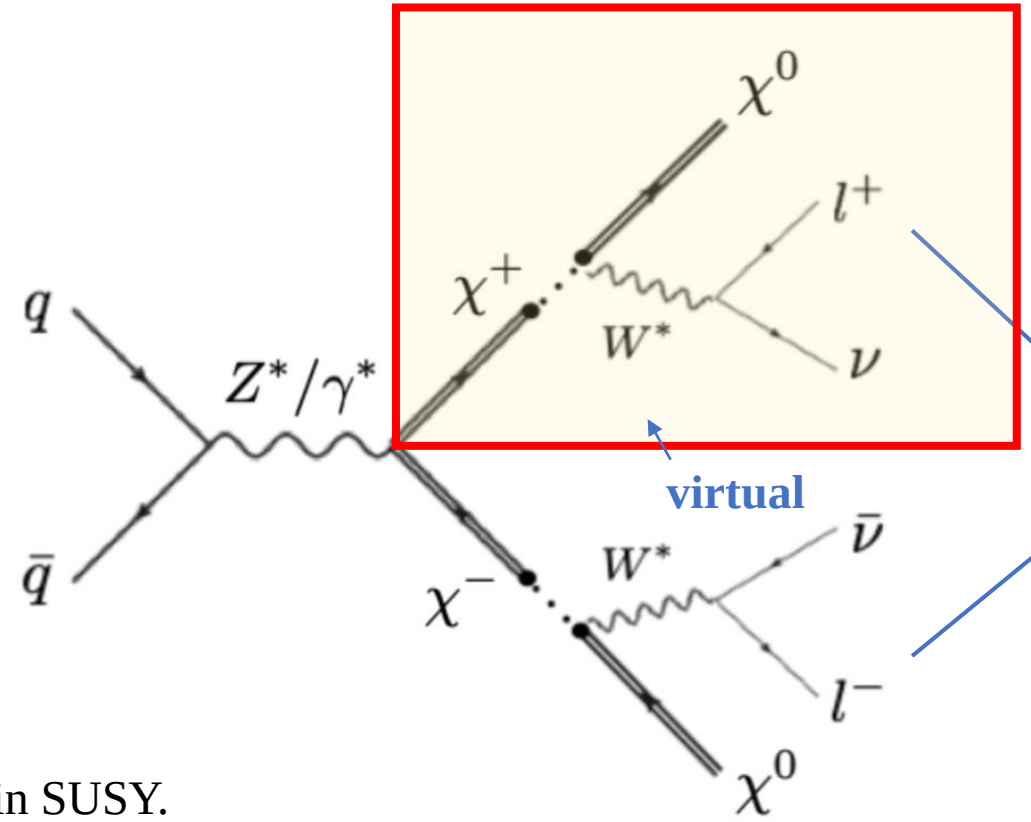
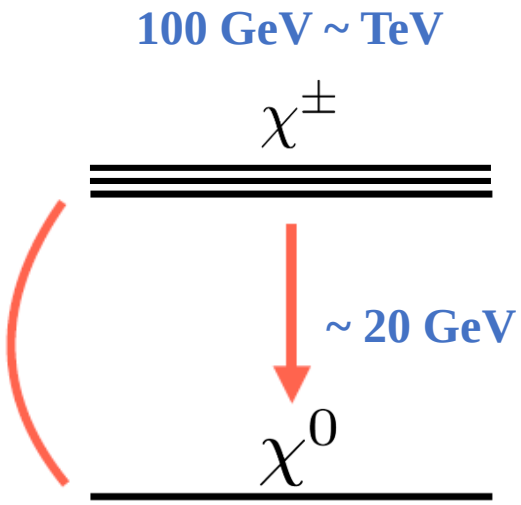


how soft lepton?

p_T



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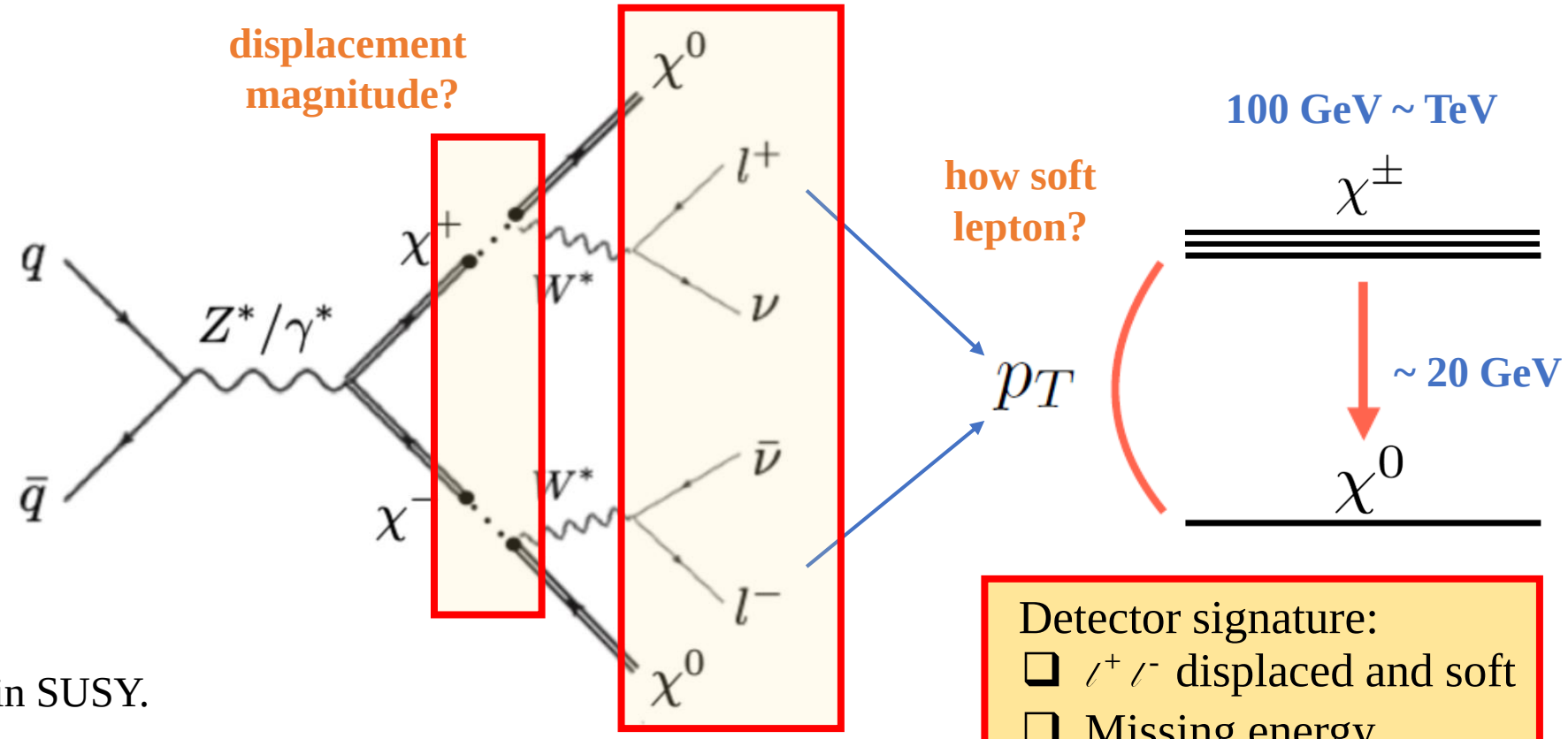

- Similar to bino-wino scenario in SUSY.

Detector signature:
- l^+l^- displaced and soft
- Missing energy

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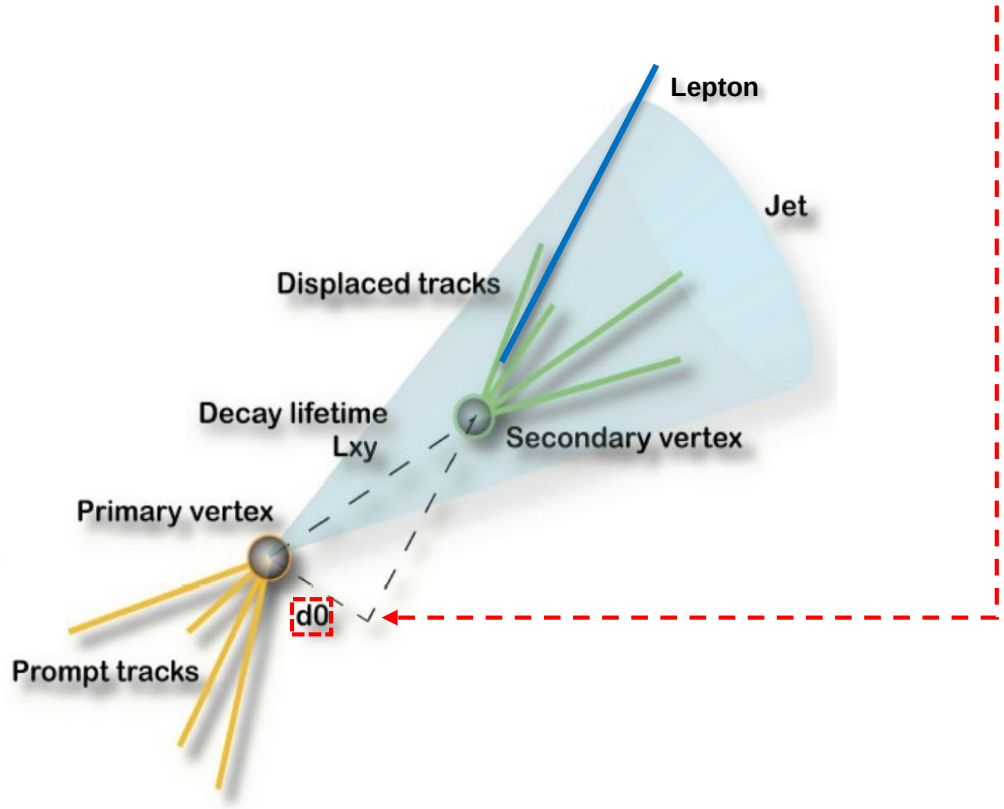
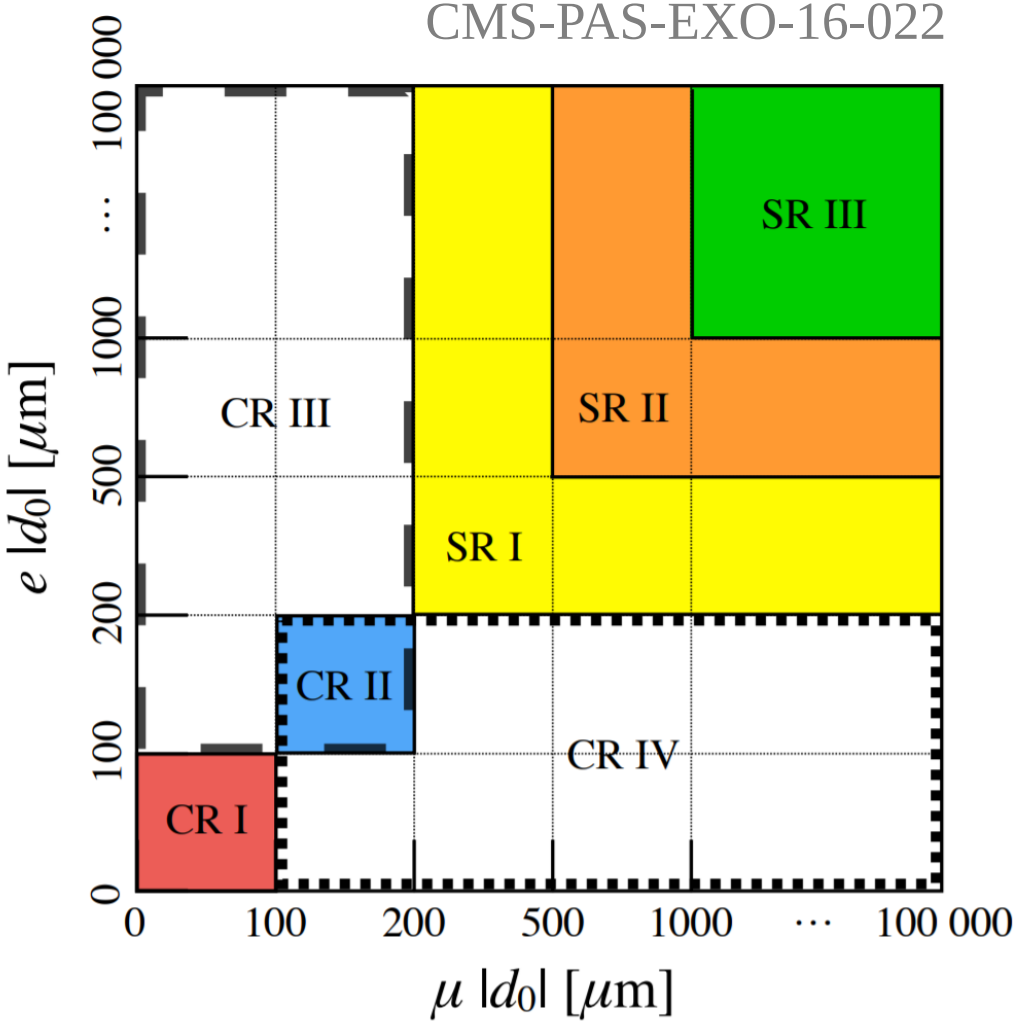
Background: Displaced di-lepton analysis at 13 TeV

- Data driven background estimate for displaced leptons.
- Estimates in regions based on the **impact parameter** (d_0).



CMS-PAS-EXO-16-022



Background: Displaced di-lepton analysis at 13 TeV

- Data driven background estimate for displaced leptons.
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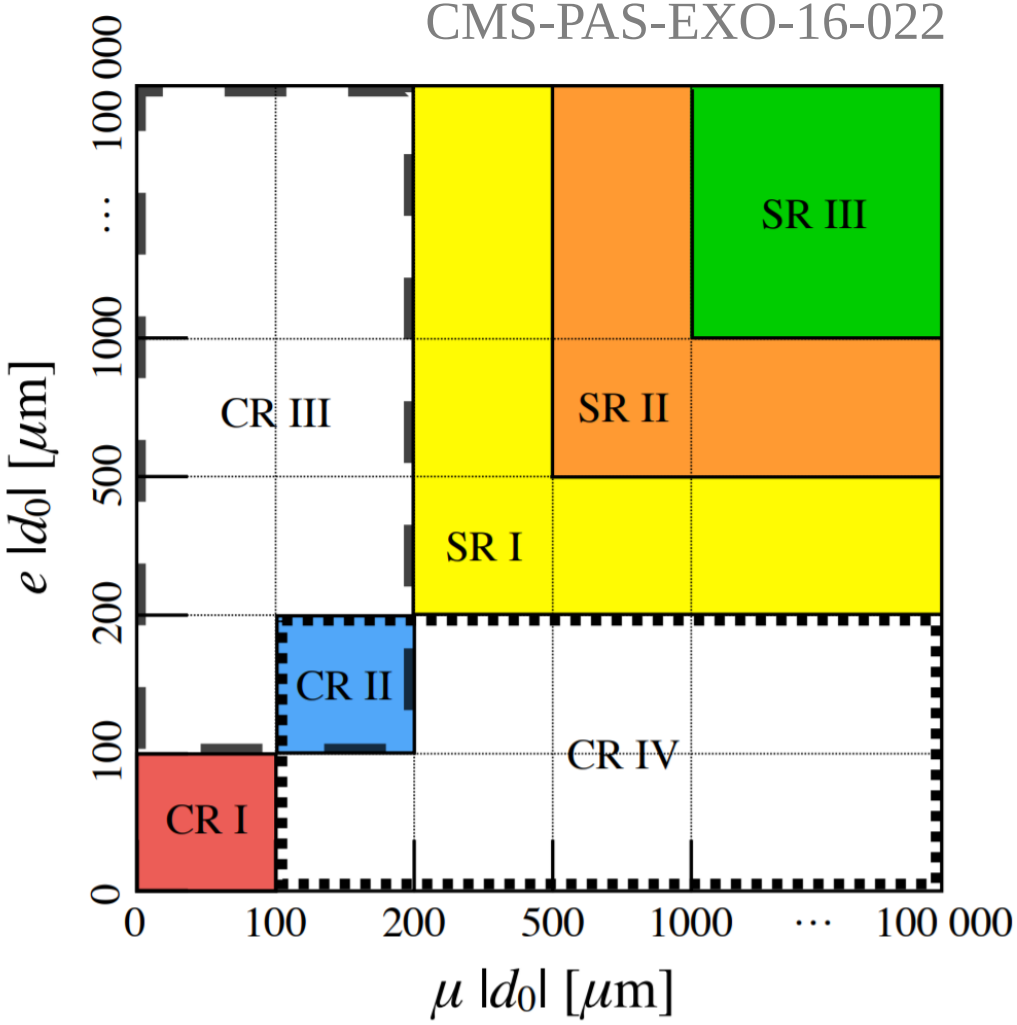
1 isolated electron
p_T > 42 GeV
1 isolated muon
p_T > 40 GeV
Opp. charge

- p_T cut is driven by trigger constraints to reduce background.
- **Too tight for our model.**

CMS-PAS-EXO-16-022



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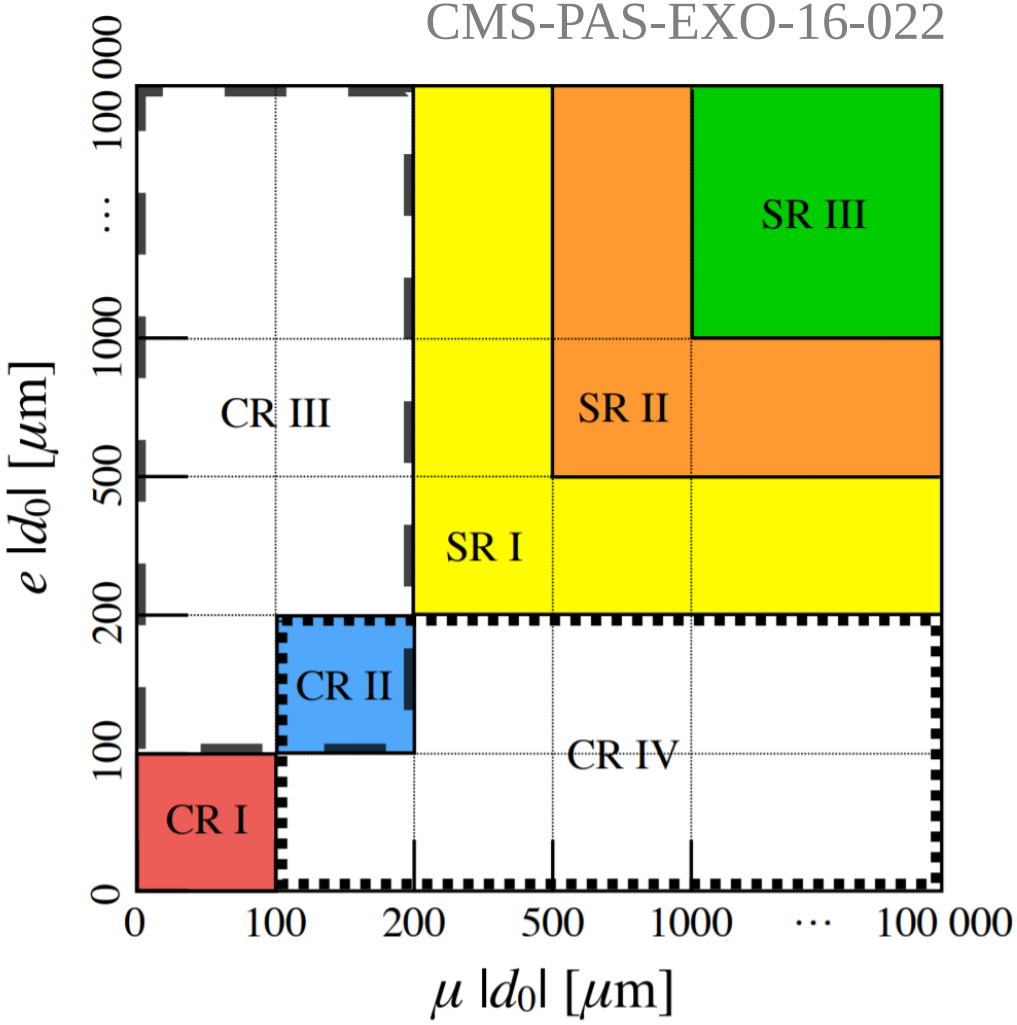

Background: Displaced di-lepton analysis at 13 TeV

- p_T is independent of d_0 and isolation in the background sample.

CMS-PAS-EXO-16-022

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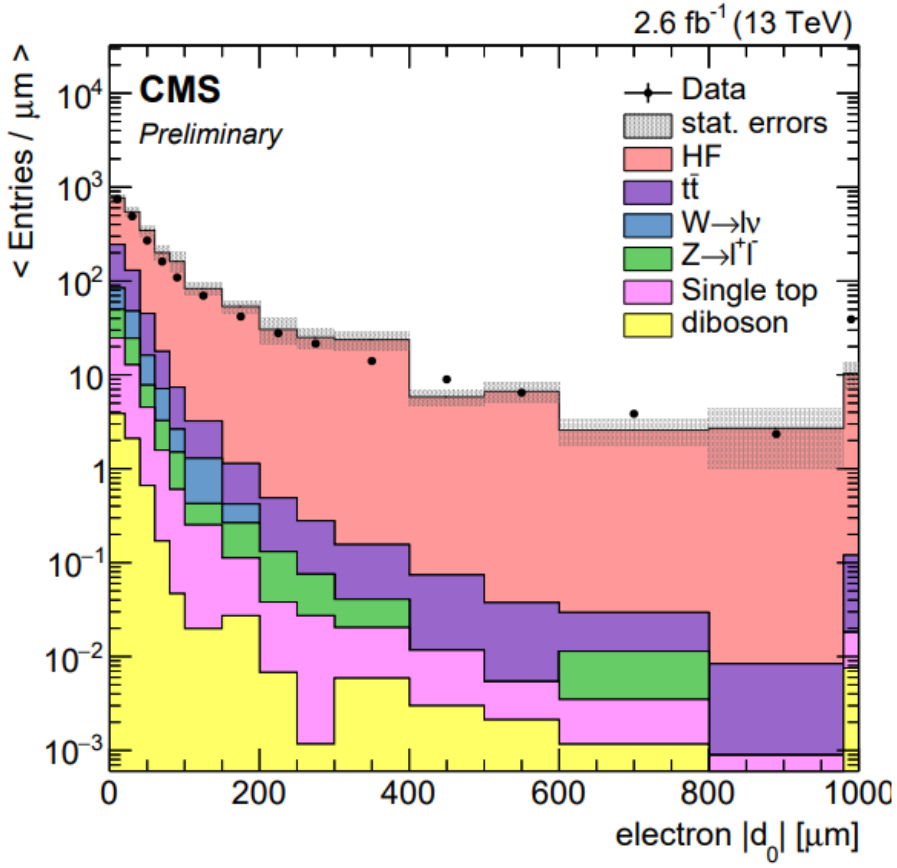
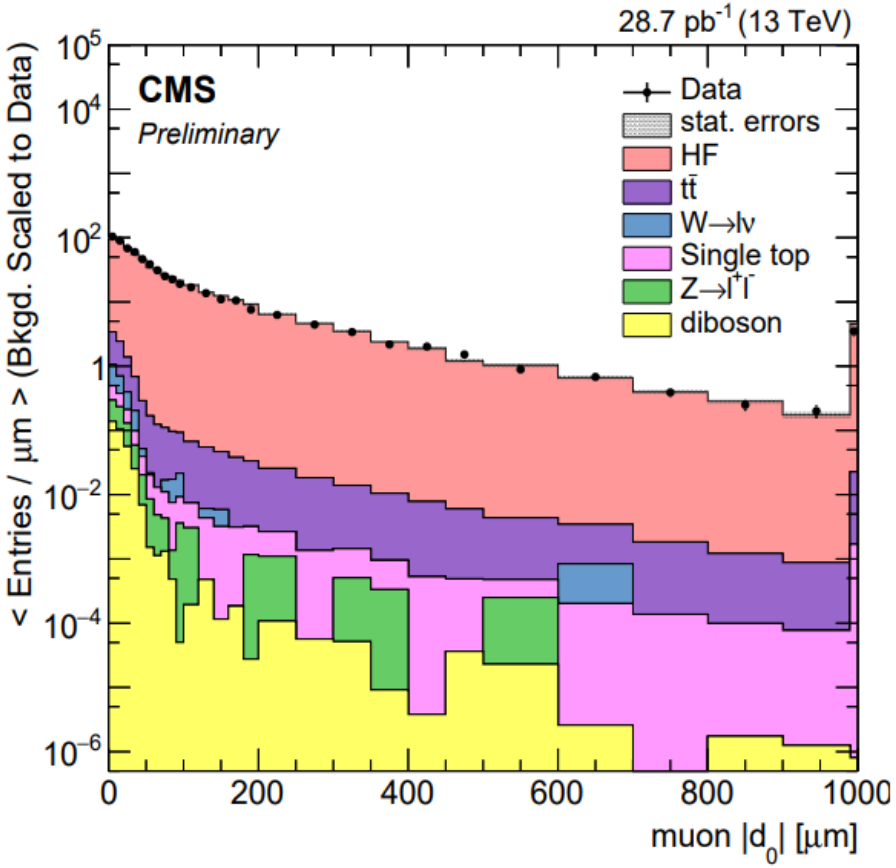
p_T: (42, 40)

$S_I < 3.2$

$S_{II} < 0.5$

$S_{III} < 0.019$





Background estimation

arxiv[2007.03708]

- Lepton enriched $b\bar{b}$ sample.
- e and μ transfer factor measured separately to keep statistic.

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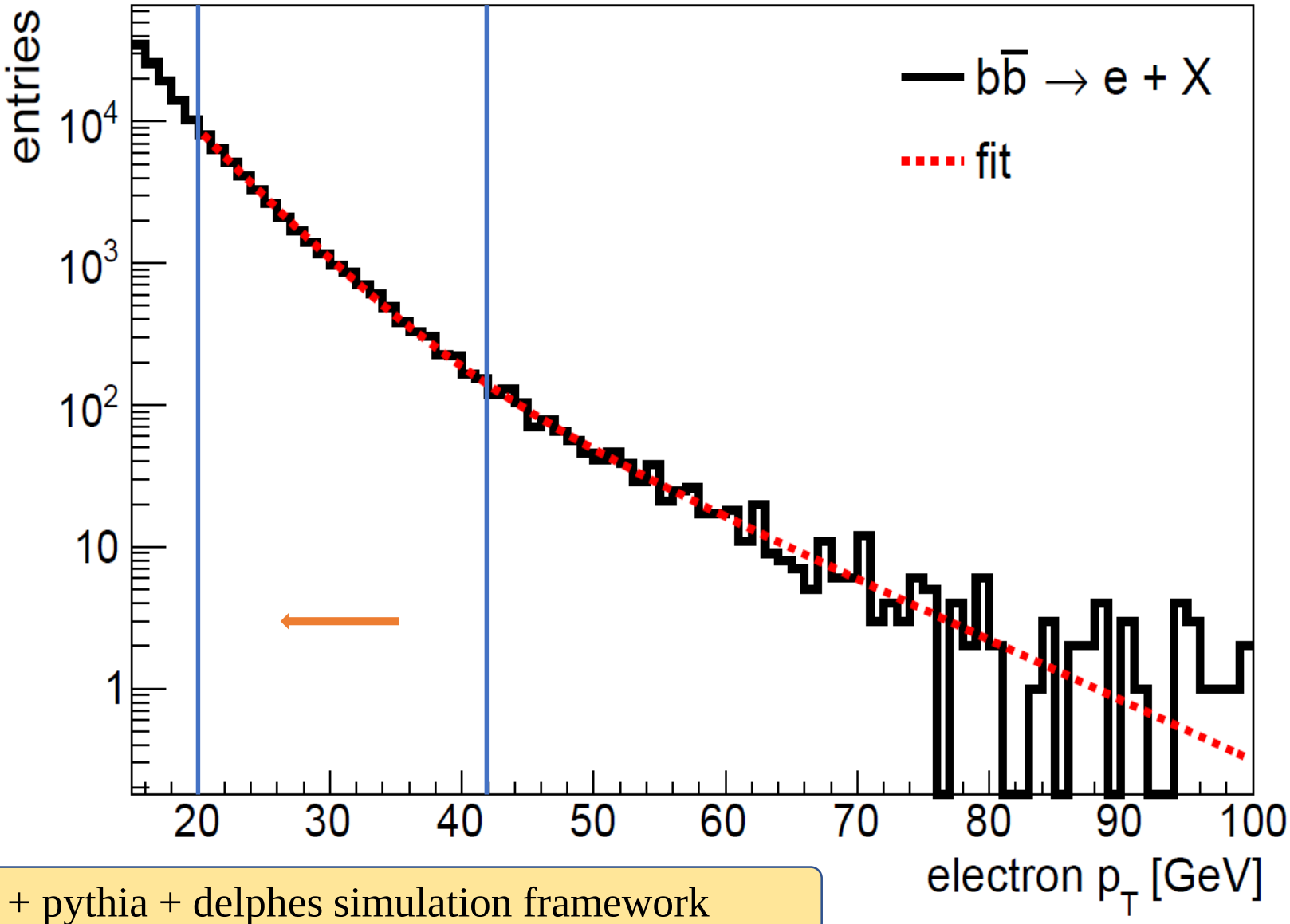
$\mathscr{L}$ = **2.6 fb^{-1}**



madgraph + pythia + delphes simulation framework

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$\kappa_e \times \kappa_\mu$

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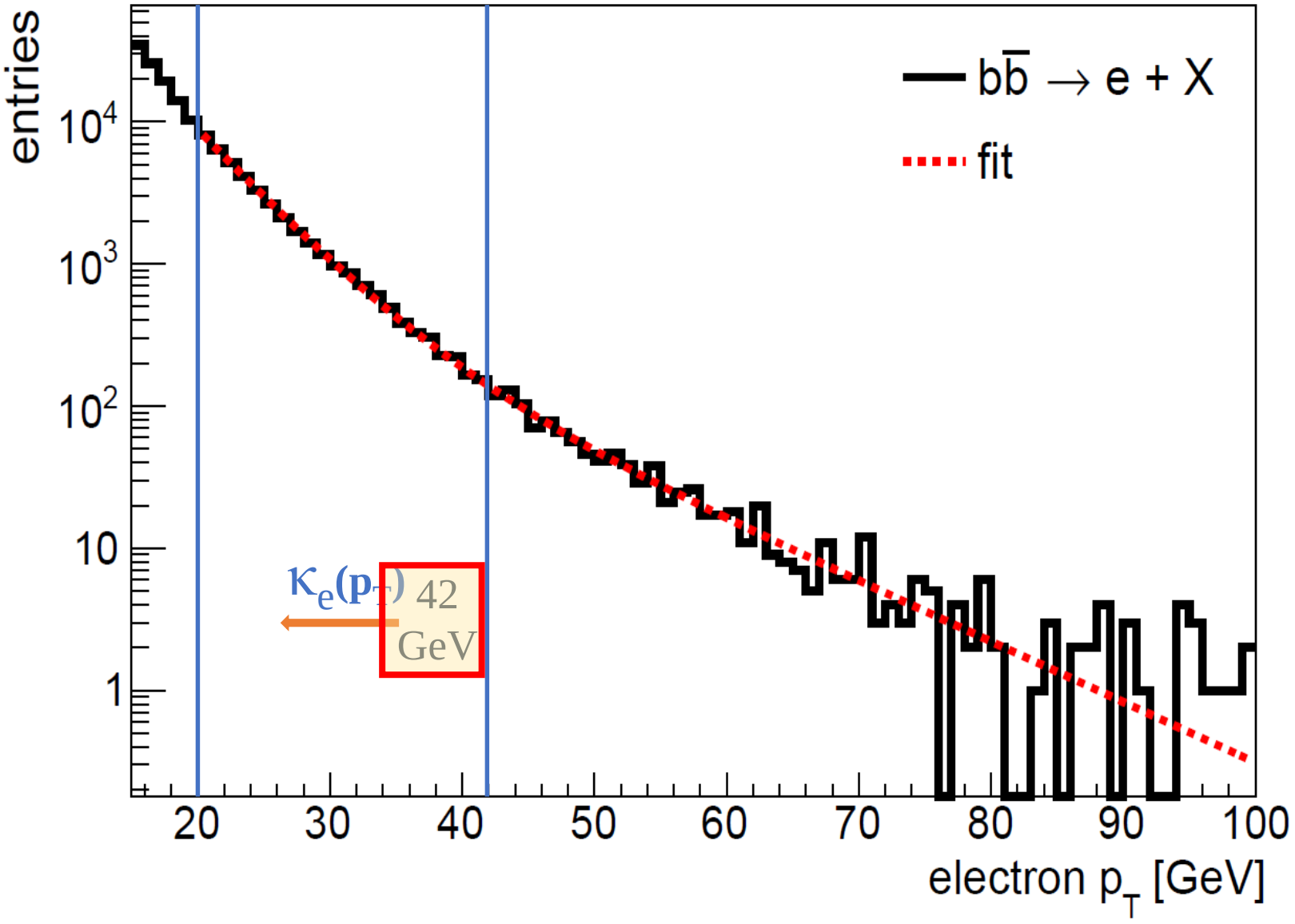

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κ_e X κ_μ

p_T: (20, 20)
S_I < 4123
S_{II} < 644
S_{III} < 25

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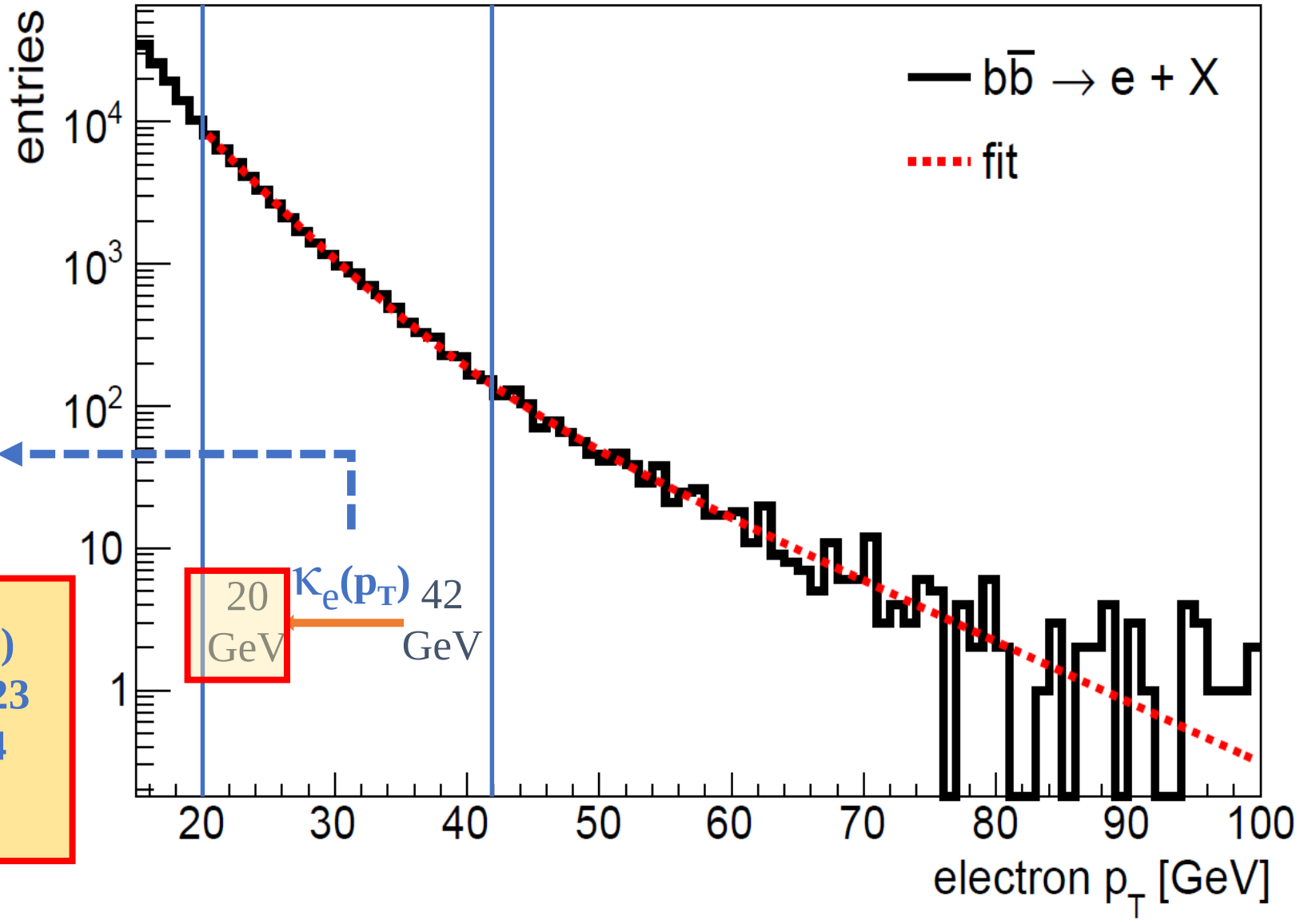

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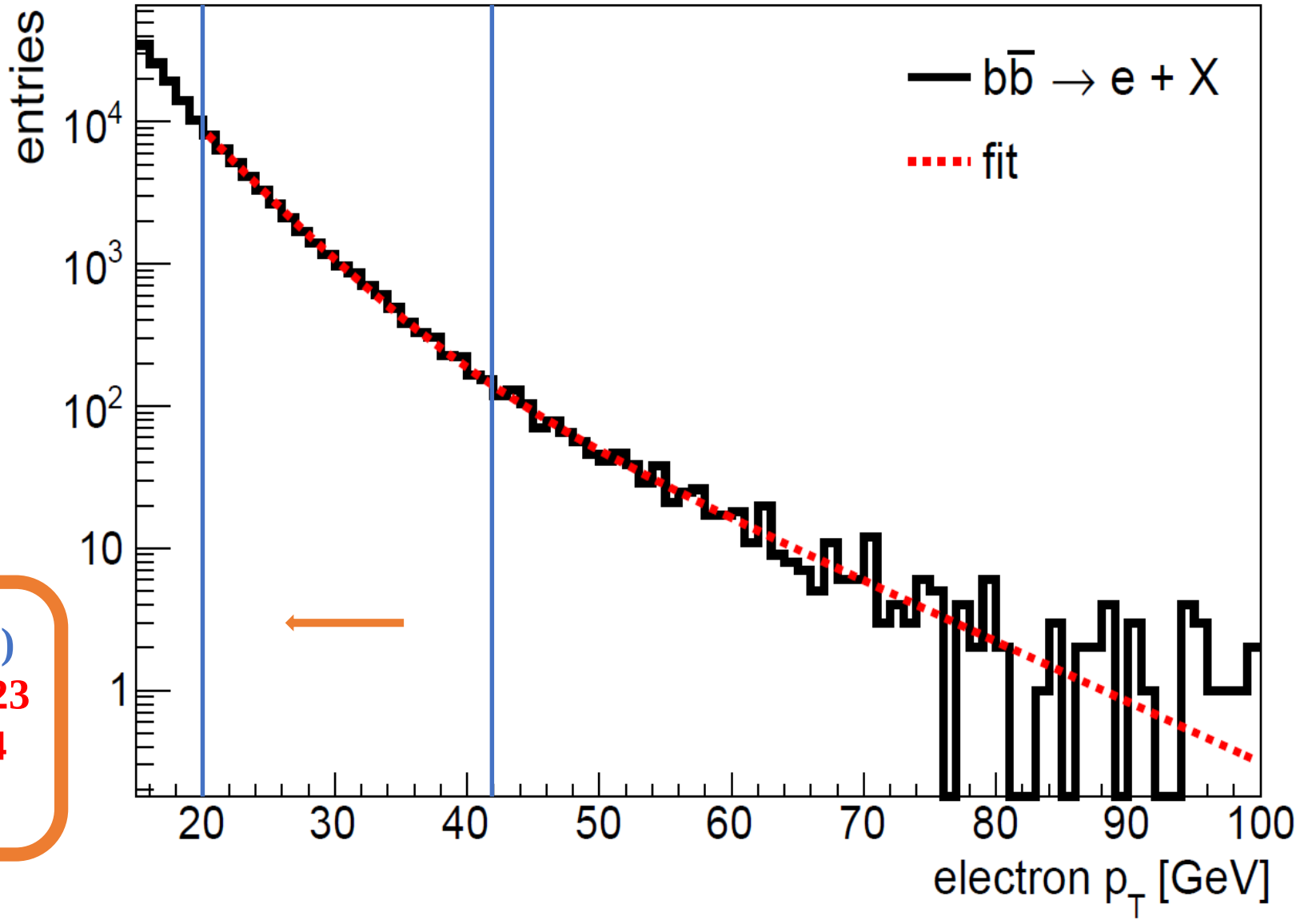
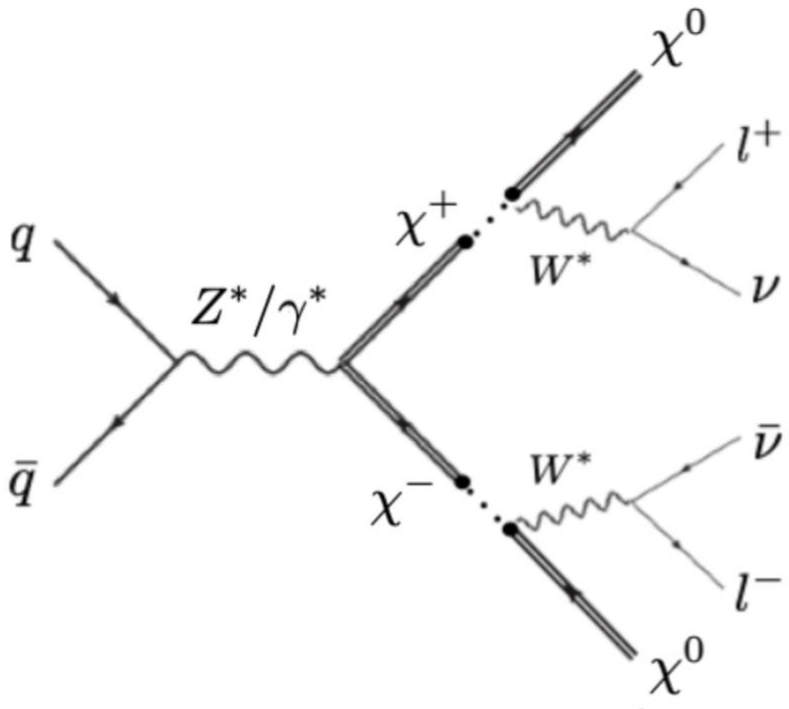
- **Large background!**

$\mathscr{L} = 2.6\ fb^{-1}$



Signal model parameters

- Detector acceptance is affected by $c\tau_c$.
- Lepton kinematics depends on Δm.



#	m_c [GeV]	Δm [GeV]	$c\tau_c$ [cm]	$\mathcal{B}(\ell^+\ell^-)$
1	324	20	2	0.025
2	220	20	3	0.014
3	220	20	0.1	1
4	220	20	1	1
5	220	20	10	1
6	220	20	100	1
7	220	40	1	1

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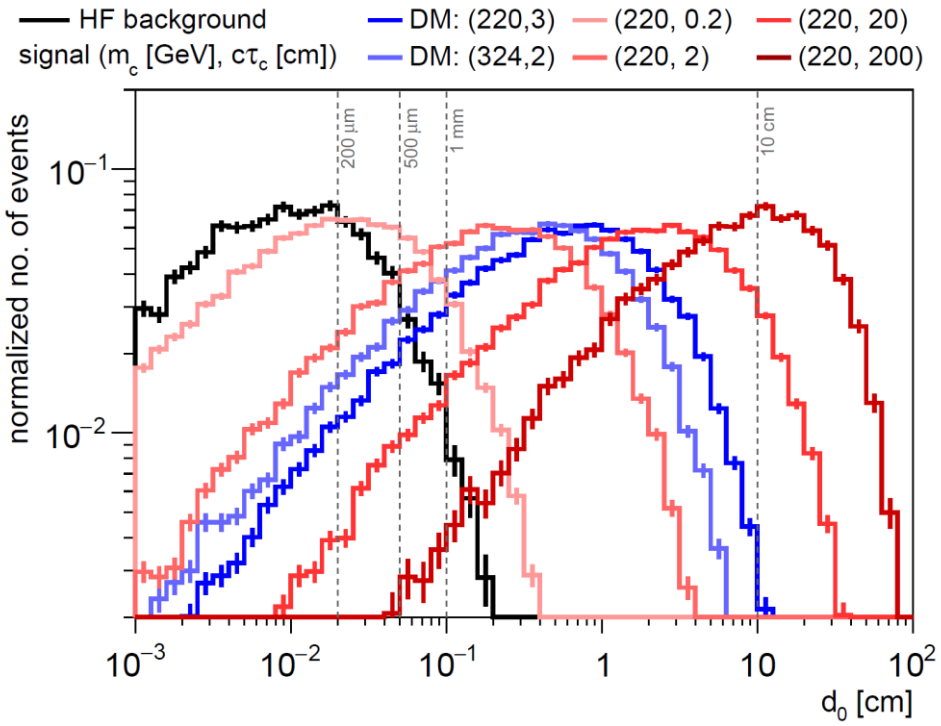

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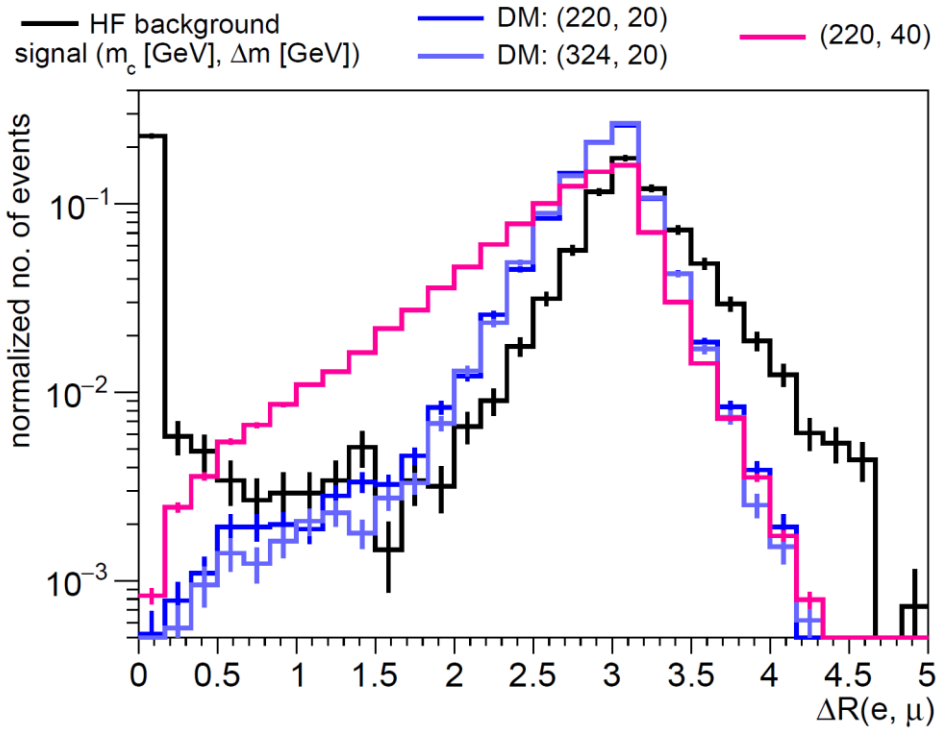

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Signal Yield (For $\mathscr{L}$= 140 fb^{-1})

	HF background ($\mathscr{L}$= 2.6fb^{-1})	**4123**	**644**	**25**
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2	(220, 20, 3)	1.18	1.40	5.55
3	(220, 20, 0.1)	139	37	5.98
4	(220, 20, 1) ($\mathscr{L}$= 140fb^{-1})	174	157	283
5	(220, 20, 10)	32	93	318
6	(220, 20, 100)	1.35	2.15	31
7	(220, 40, 1)	1067	980	1826
	HF background ($\mathscr{L}$= 140fb^{-1})	221997	34688	1318

- Background with luminosity scaling is 200000!
- Signal yield relatively very low for Δm = 20 GeV.
- Δm = 40 GeV is already excluded.

Scaled with luminosity

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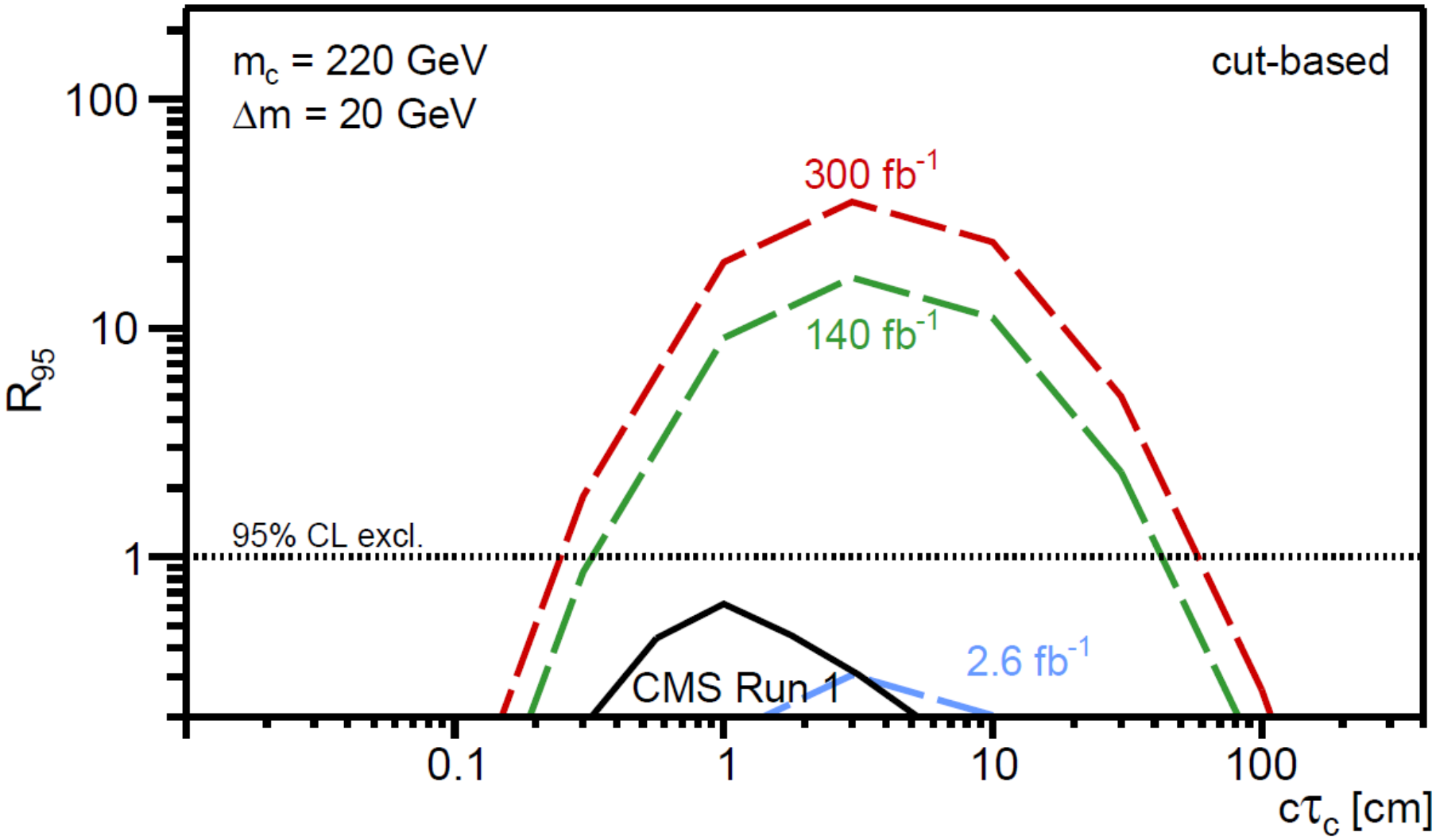
($\mathscr{L}$= 140fb^{-1})

95% CL for a background only hypothesis

Signal Yield (For $\mathscr{L}$ = 140 fb^{-1}) : Limit plot



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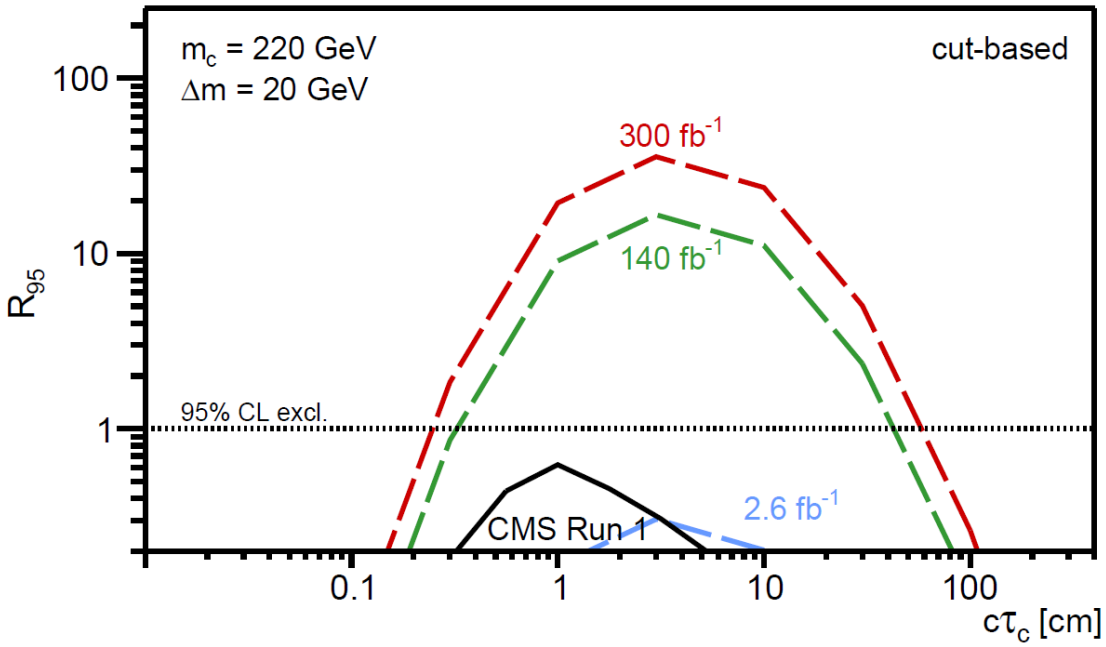
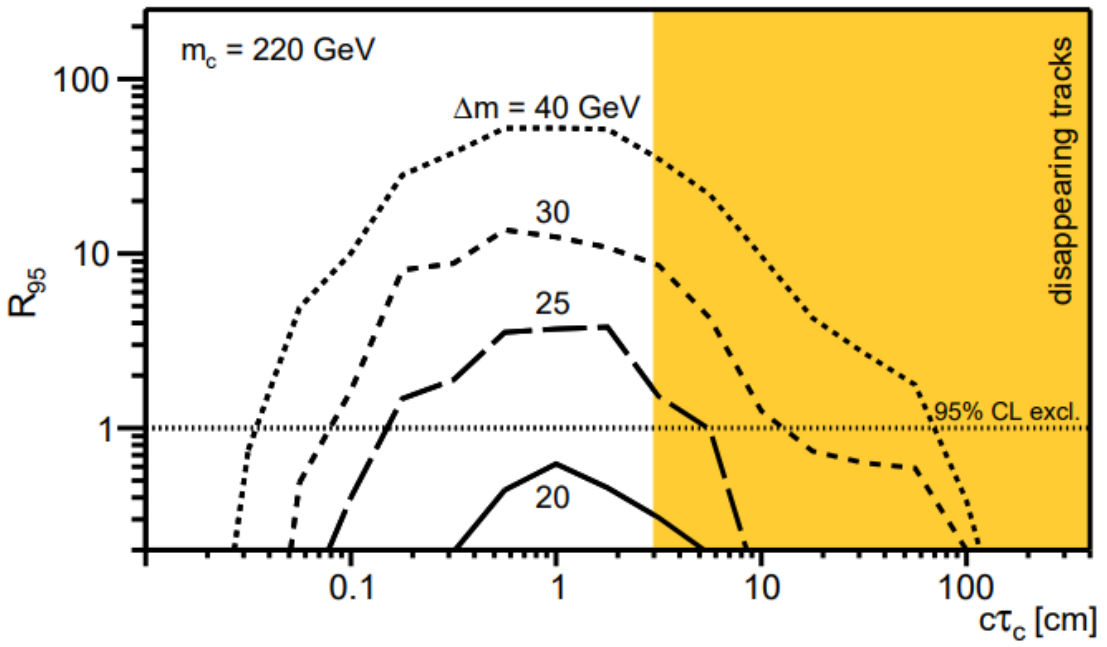
Relaxation of p_T enables exclusion in displaced phase space over 4 orders of lifetime of the BSM particle.

Significant possible improvement over LHC bounds

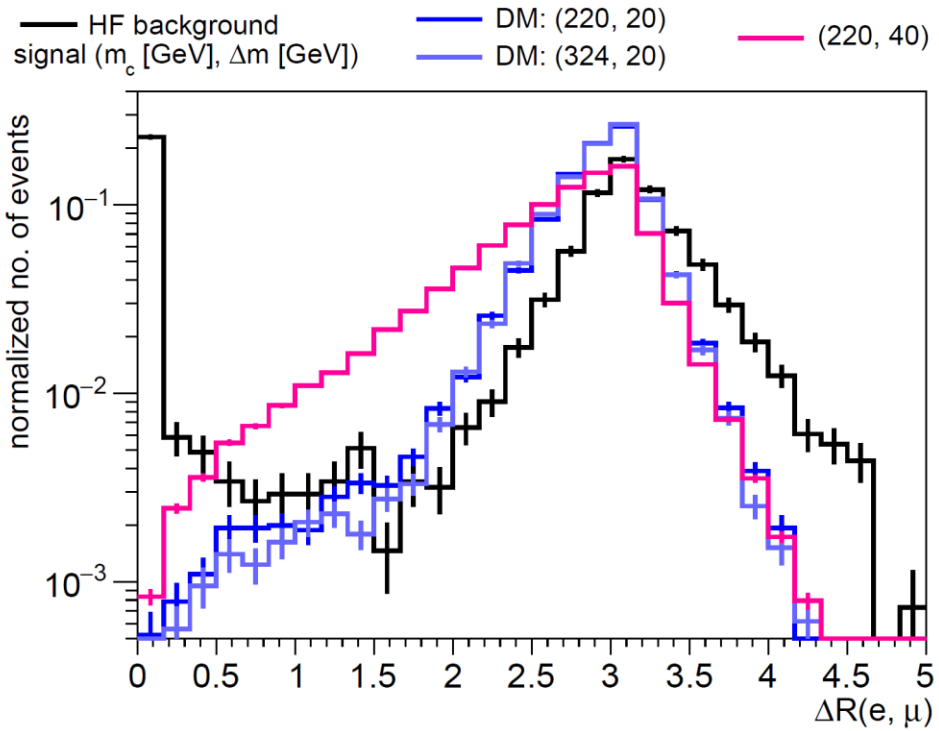
- Right plot: LHC bounds on co-scattering dark matter.
- Concentric circles – 8 TeV CMS disappearing track search.
- Yellow shaded region – most recent result on disappearing tracks.
- Possible to further improve results by classifying between signal and background based on event kinematics.

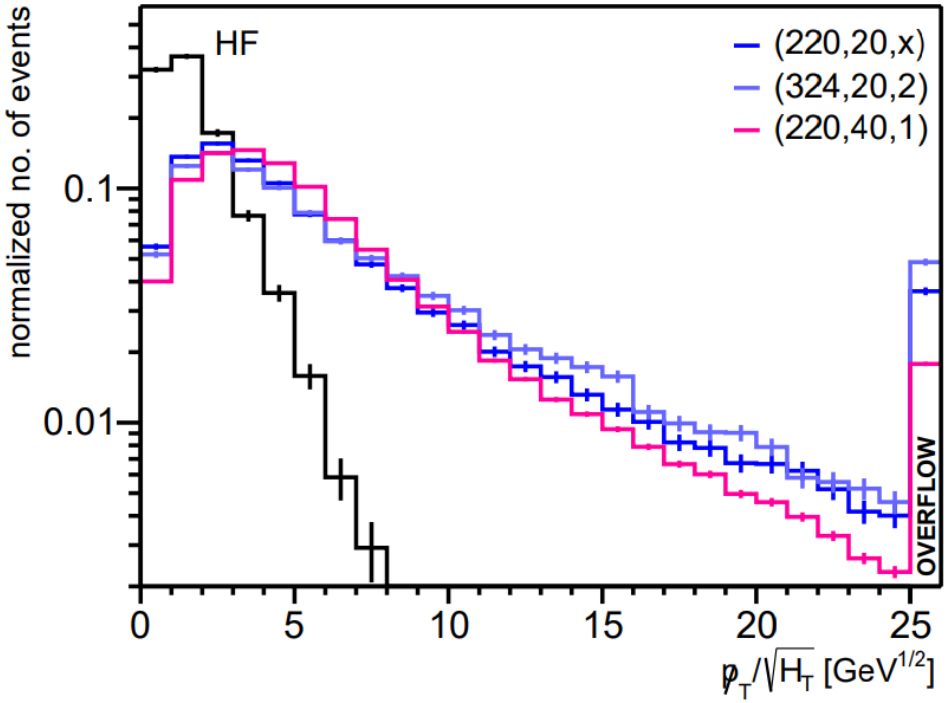




Model independent neural network to improve signal vs background: Input

- Multi-variate analysis – 9 variables
- Simply connected neural network

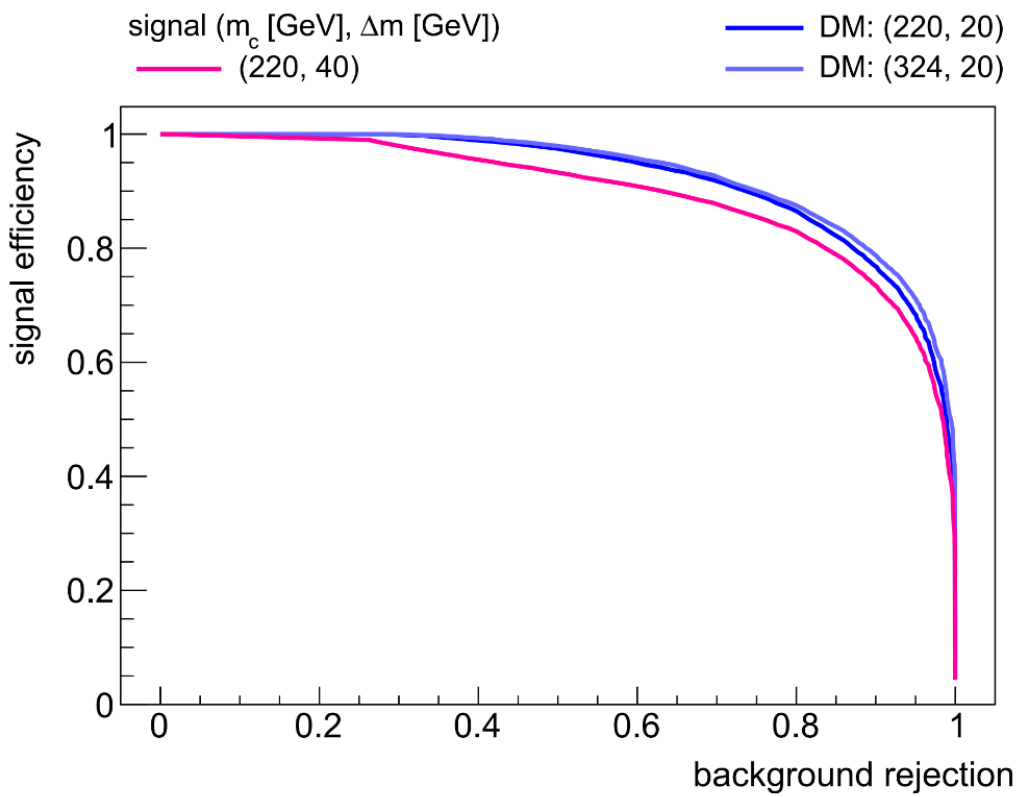


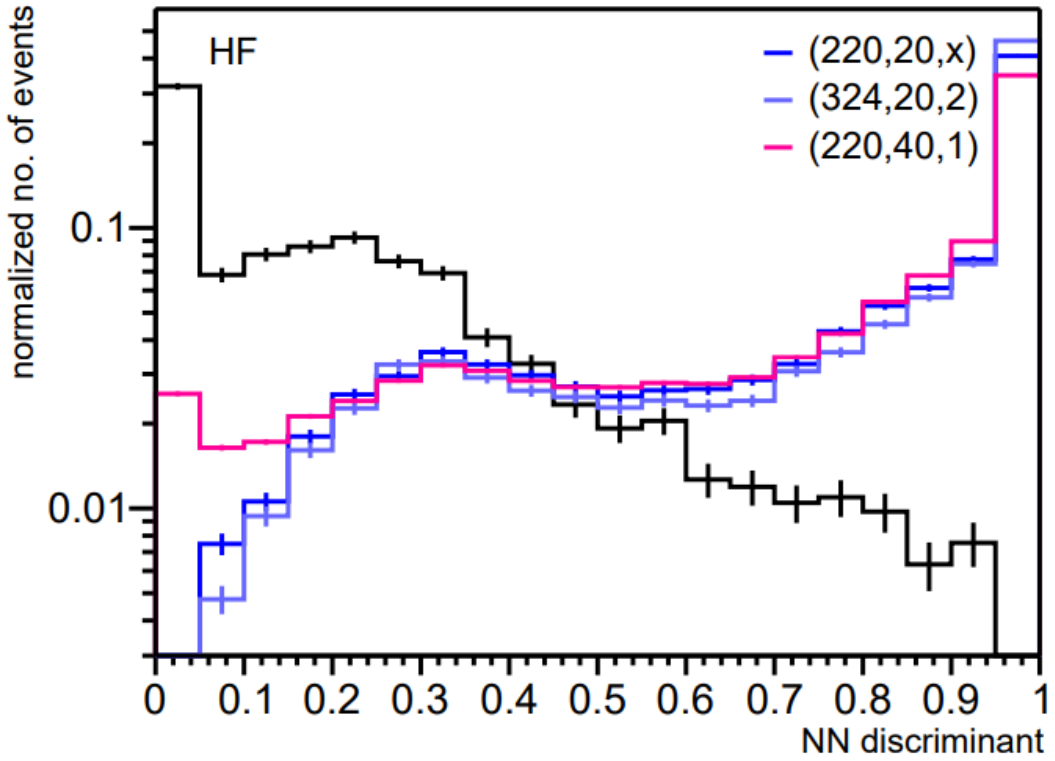


$$\not{p}_T/\sqrt{H_T},\ H_T,\ \Delta R(e,\mu),\ m_T(\ell_1,\not{p}_T),\ (\not{p}_T/\sqrt{H_T})_{\ell,j},\ \Delta\phi(\ell_1,\not{p}_T),$$
sphericity, α_T, spherocity

Model independent neural network to improve signal vs background: Output

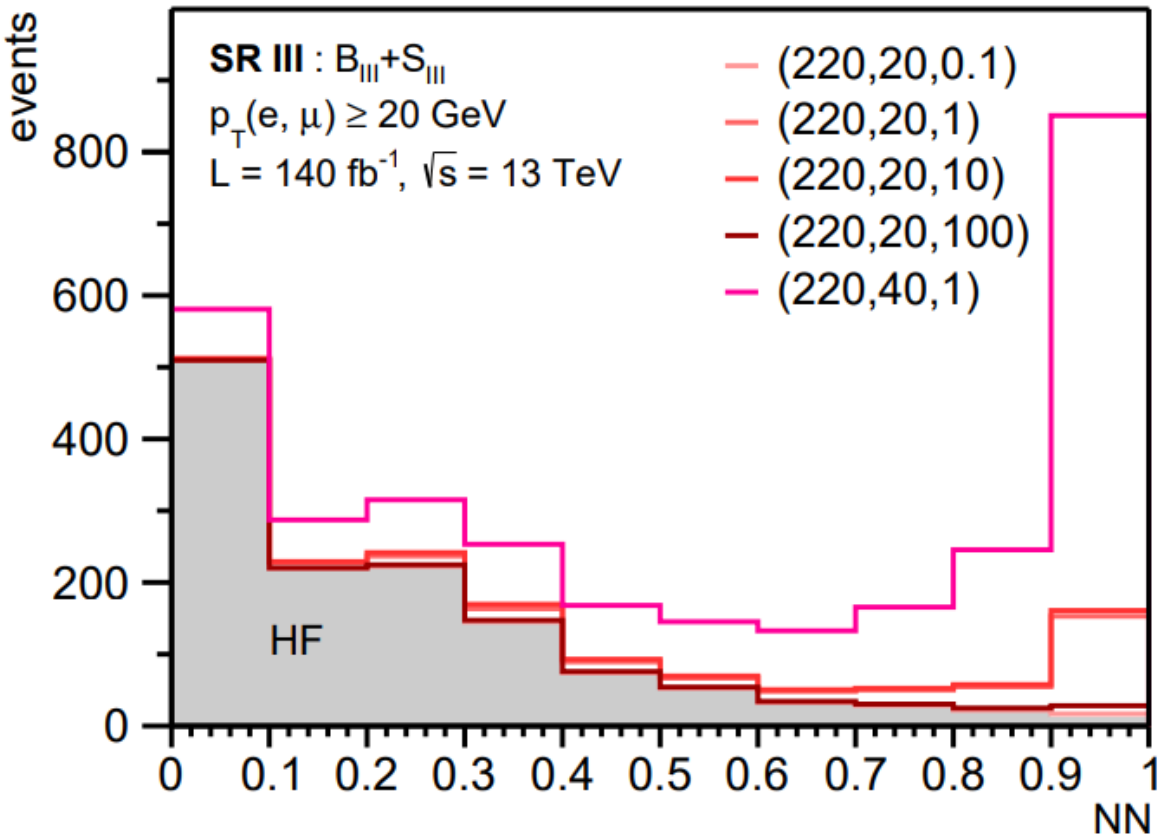
- Trained (80%) and tested (20%) on (324, 20, 2).

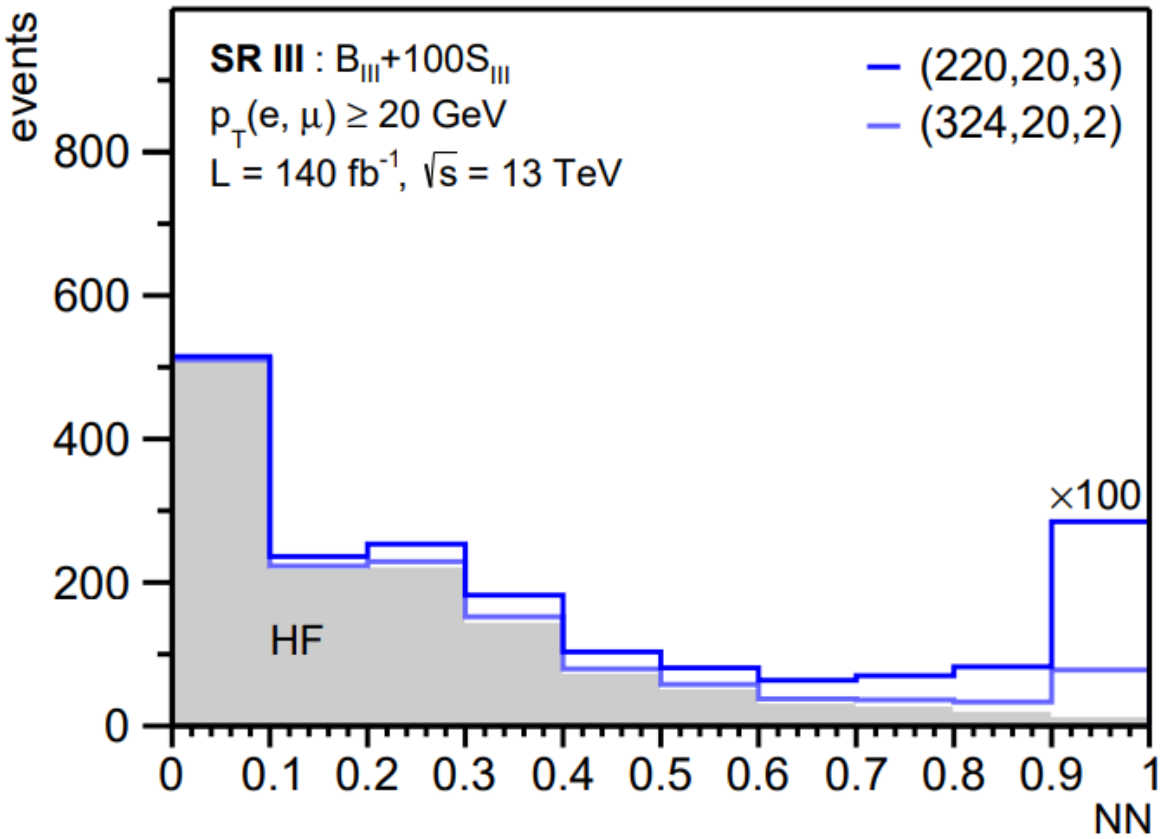




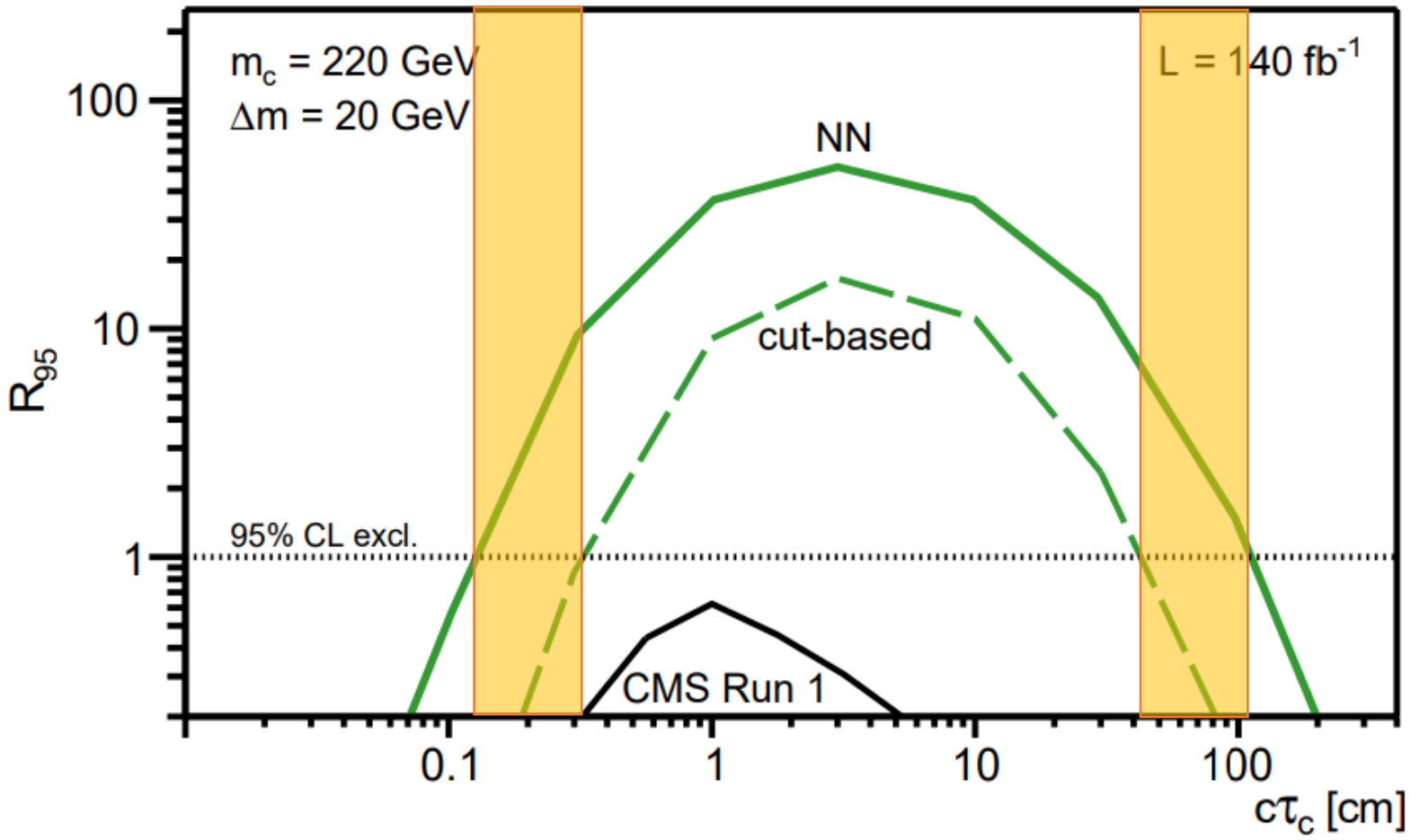
- One classifier for all benchmarks.

Signal Regions

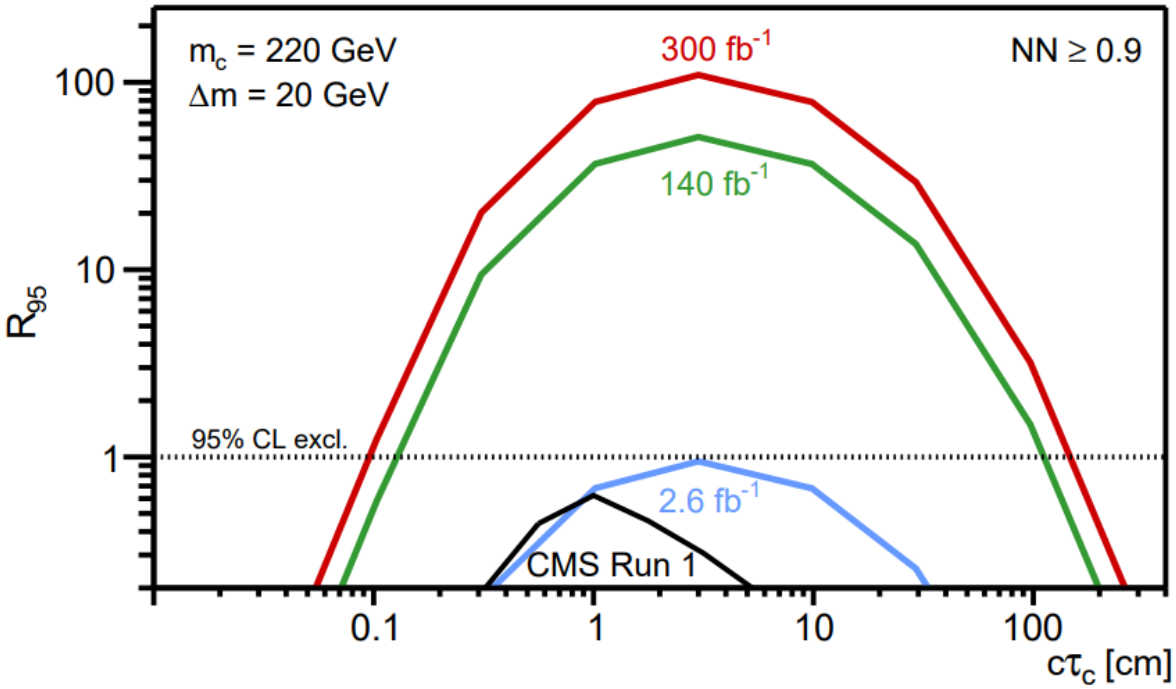


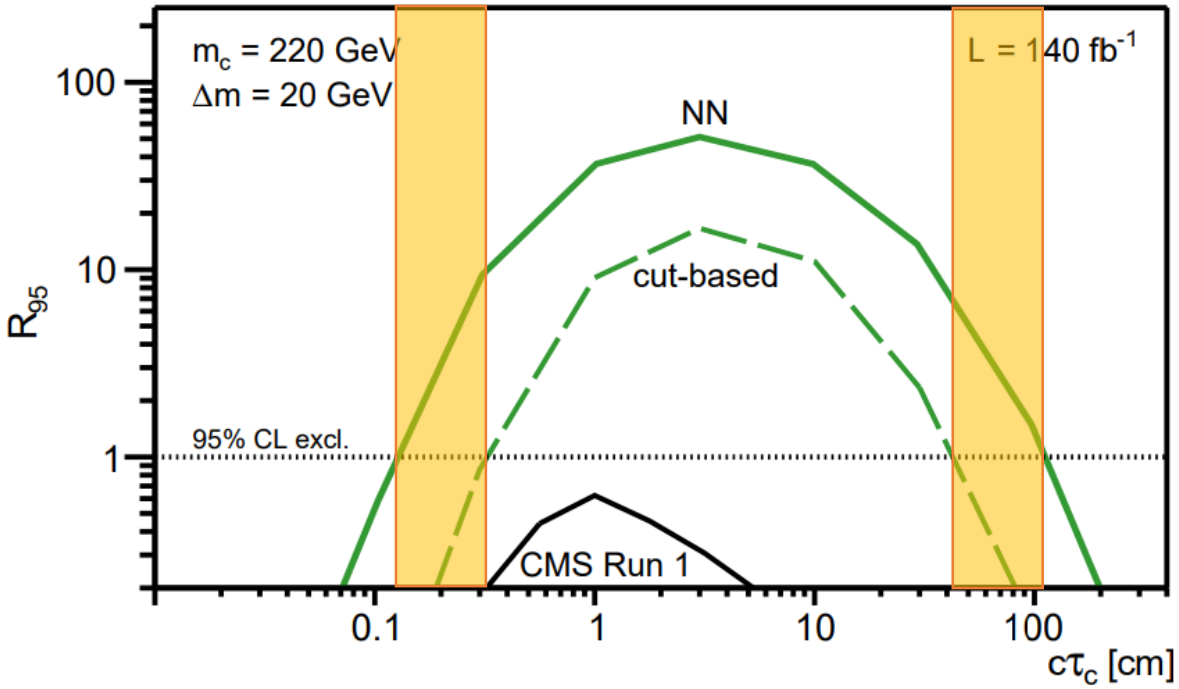


NN shows one order improvement in limits



Exclusion limit: variation with lumi





Conclusion

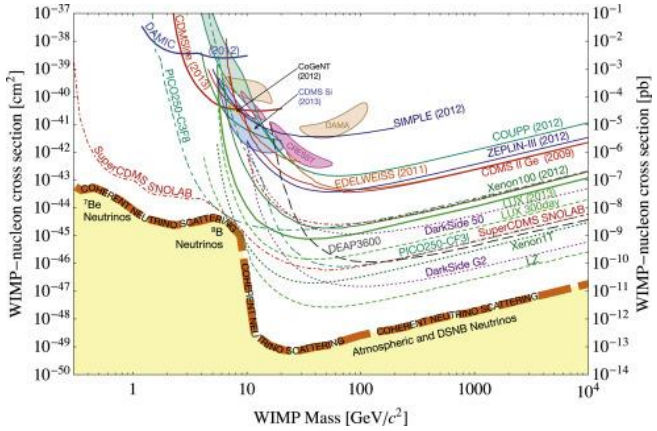
- Soft displaced leptons are typical signs of dark matter from co-scattering and co-annihilation.
  - To observe these signatures at the LHC, events with soft leptons need to be selected.
- LHC signal with soft displaced leptons are challenged by large heavy flavour background.
- Multivariate analysis effectively discriminates between signal and HF background.
  - Neural network reduces background by two orders of magnitude.
  - With 140 fb^{-1} $c\tau_c$ values between 2 mm and 2 m can be excluded.

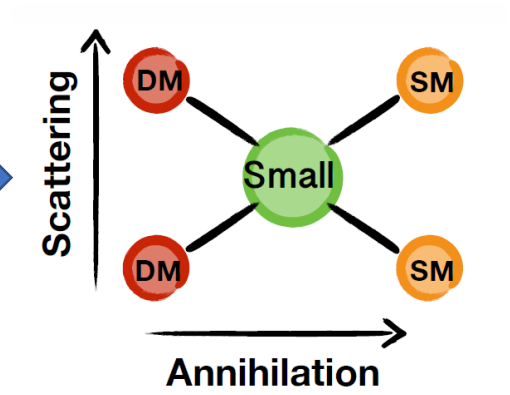
Outlook and overview of activities

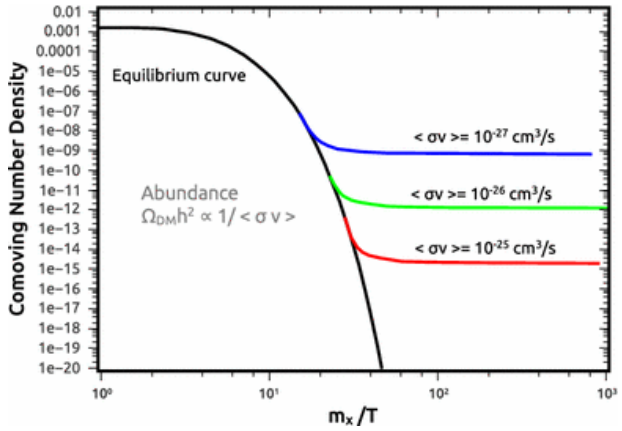
- Analysis with LHC Run 2 data involving displaced lepton and MET.
- Can be discovered with LHC data.
  - Requires cross triggers with lower p_T threshold and other objects.
- CMS author since 30th August, 2020.
- L3 Validation manager in PPD-PDMV in CMS collaboration.
- Teaching assistant for Sub-Atomic Physics at VUB.
- Bachelor Thesis assistant with Prof. Freya Blekman at VUB.

BACK-UP

Higgs portal dark matter

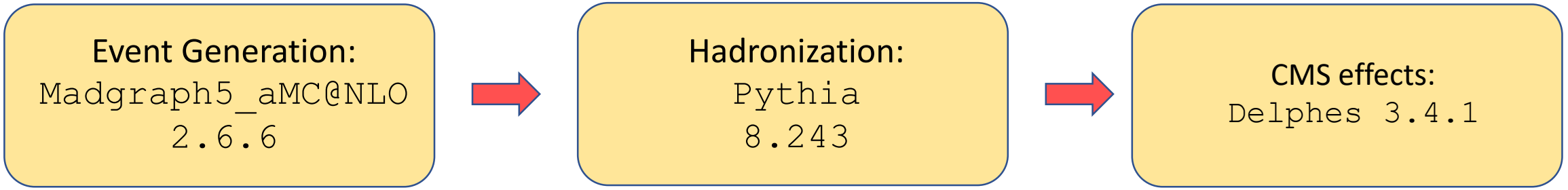






Over-Abundant DM

Standard simulation framework



Event Selection in CMS-PAS-EXO-16-022

Oppositely charged
e and μ
with
ΔR>0.5

1 muon
p_T > 40 GeV
η < 2.4
Isolation < 0.15

1 electron
p_T > 42 GeV
η < 2.4
Isolation < 0.12

- Dominant background: **Leptons from heavy flavour jet misidentified as isolated leptons**.

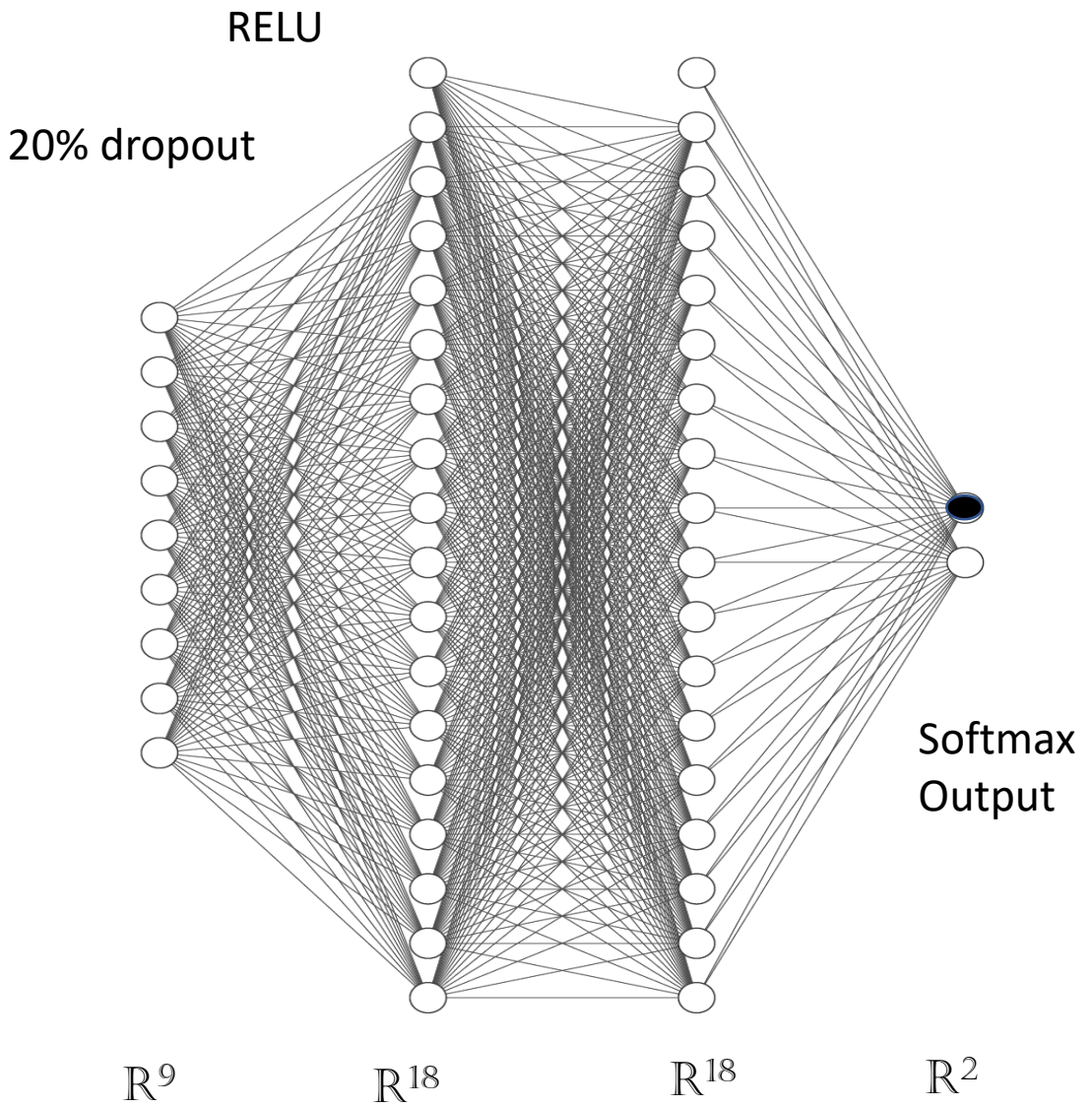
Ranking of Variables

List of variables

The ranking of the variables is based on overlapping co-efficient of the normalized histograms on each other.

1. YDelpObj - 0.4764
2. dRLL - 0.596
3. dPhiLepMET - 0.6138
4. Sphericity - 0.7042
5. Spherocity - 0.7516
6. YUserObj - 0.7547
7. dPhiLepMETSelObj - 0.7705
8. alphaT - 0.7822
9. EtaEl - 0.8486
10. EtaMu - 0.8696

Neural Network



Accuracy of NN classifier