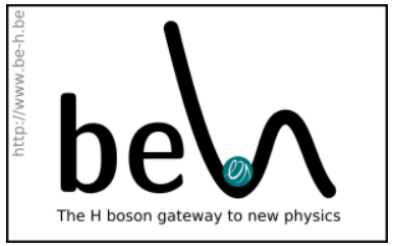
Soft Displaced Leptons at the LHC

HEP@VUB: PhD Event

A.R.Sahasransu

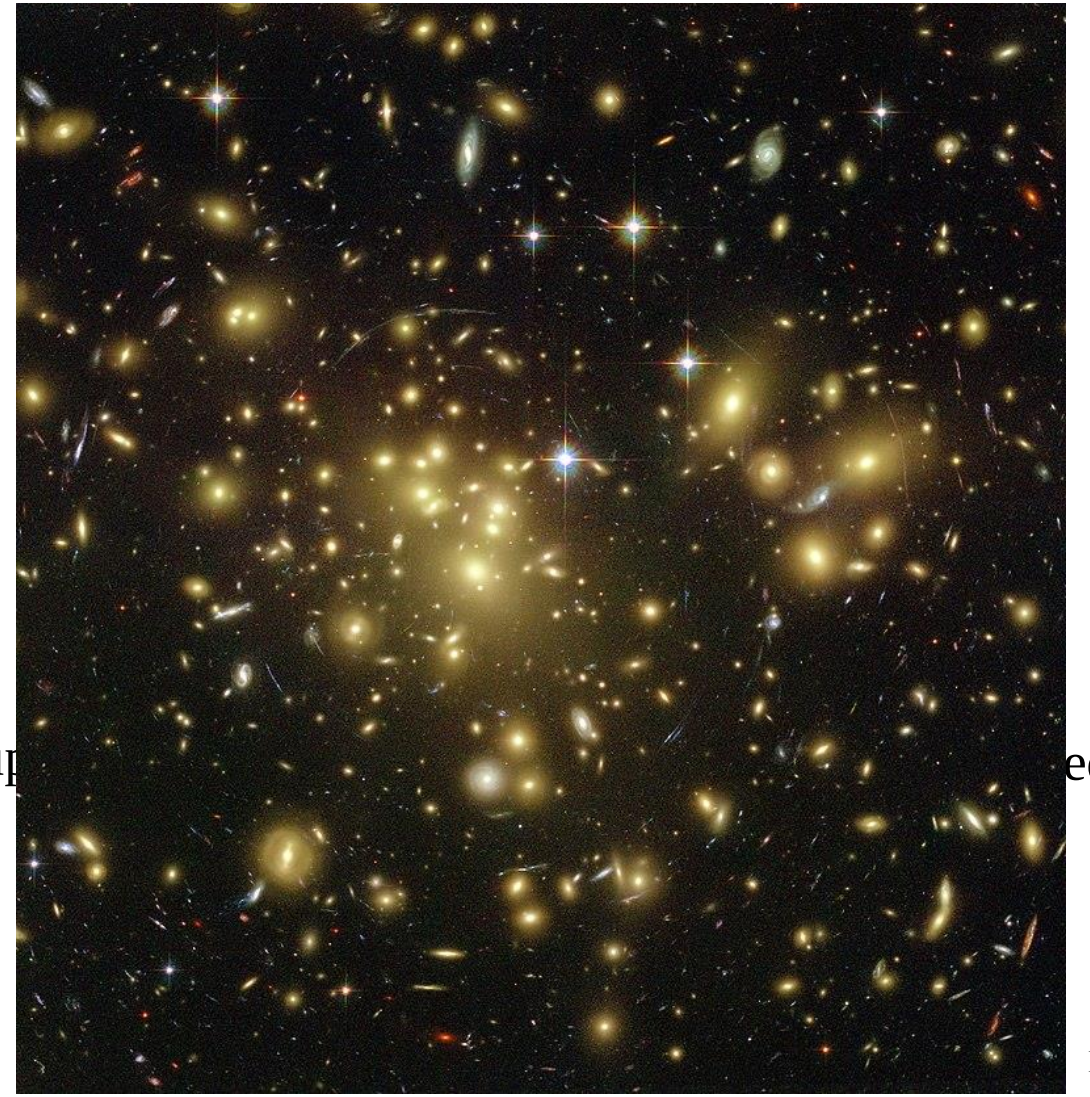
Based on paper arxiv[2007.03708], accepted by JHEP

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



Thermal higgs portal dark matter at the LHC

Thermal relic:
Co-annihilating
dark matter



Compressed mass spectrum:
process exponentially supressed by

$$\frac{m_{Xi} - mXj}{T}$$

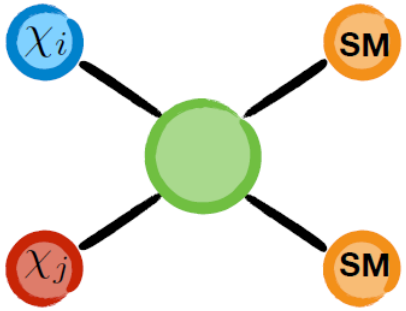
Weak coup ed particle

Image by Hubble

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

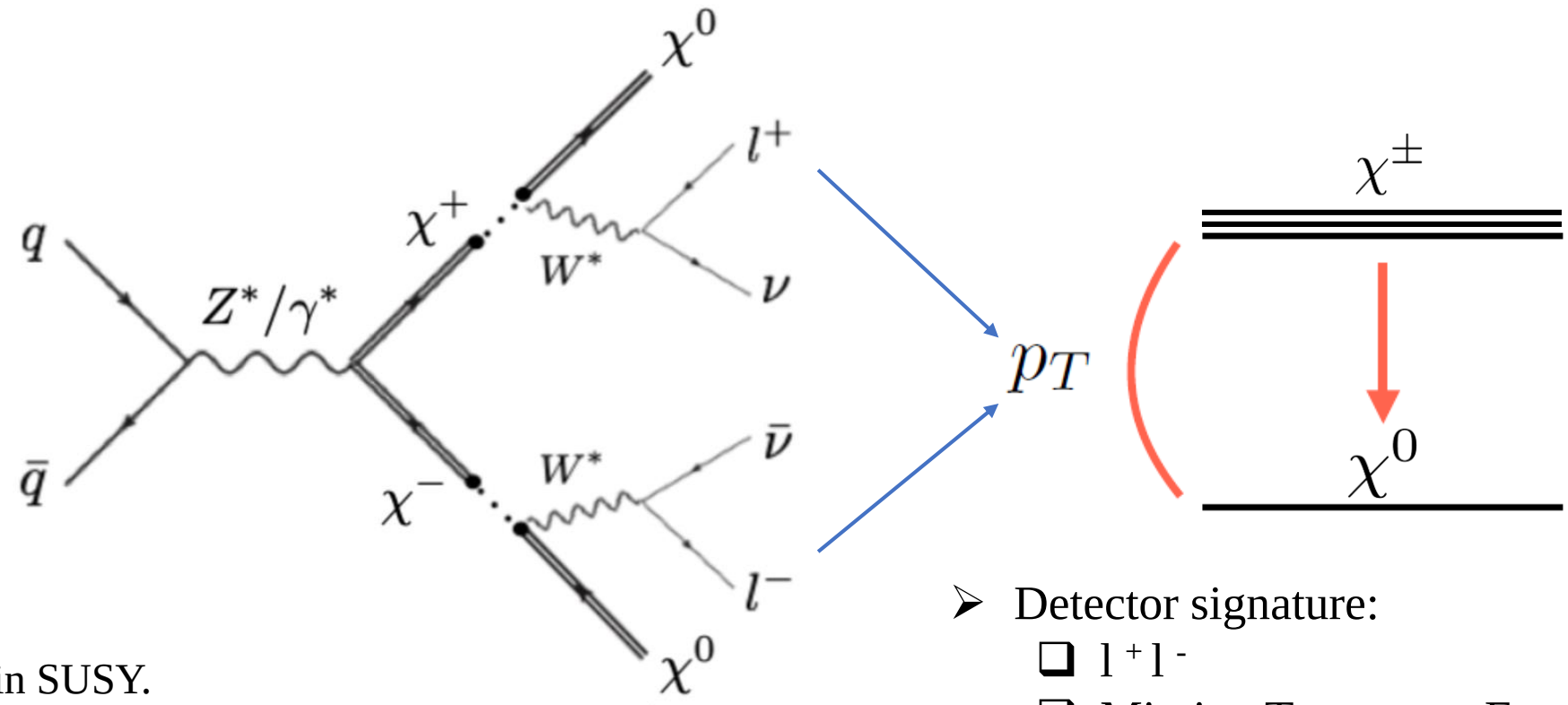
$$\frac{m_{Xi} - mXj}{T}$$

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



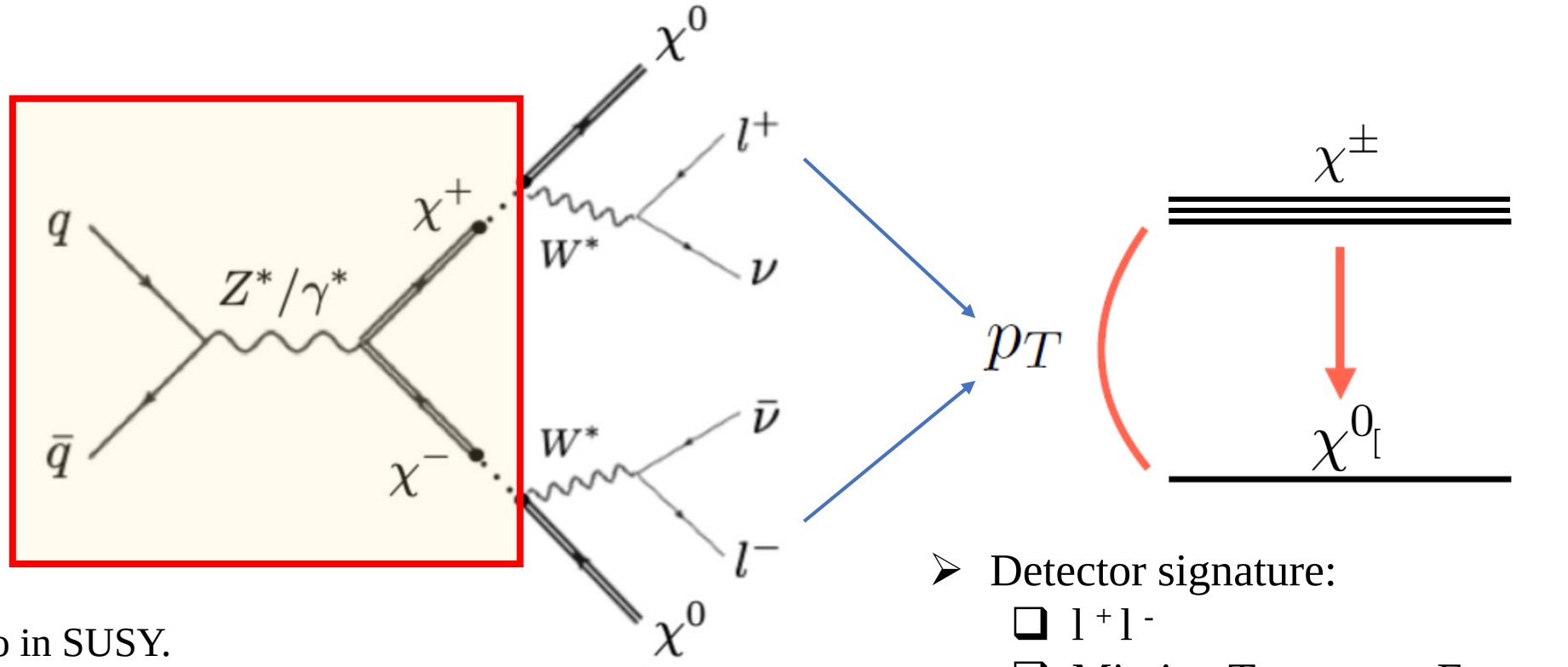
- Similar to bino-wino scenario in SUSY.

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

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

Soft leptons from singlet-triplet model

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



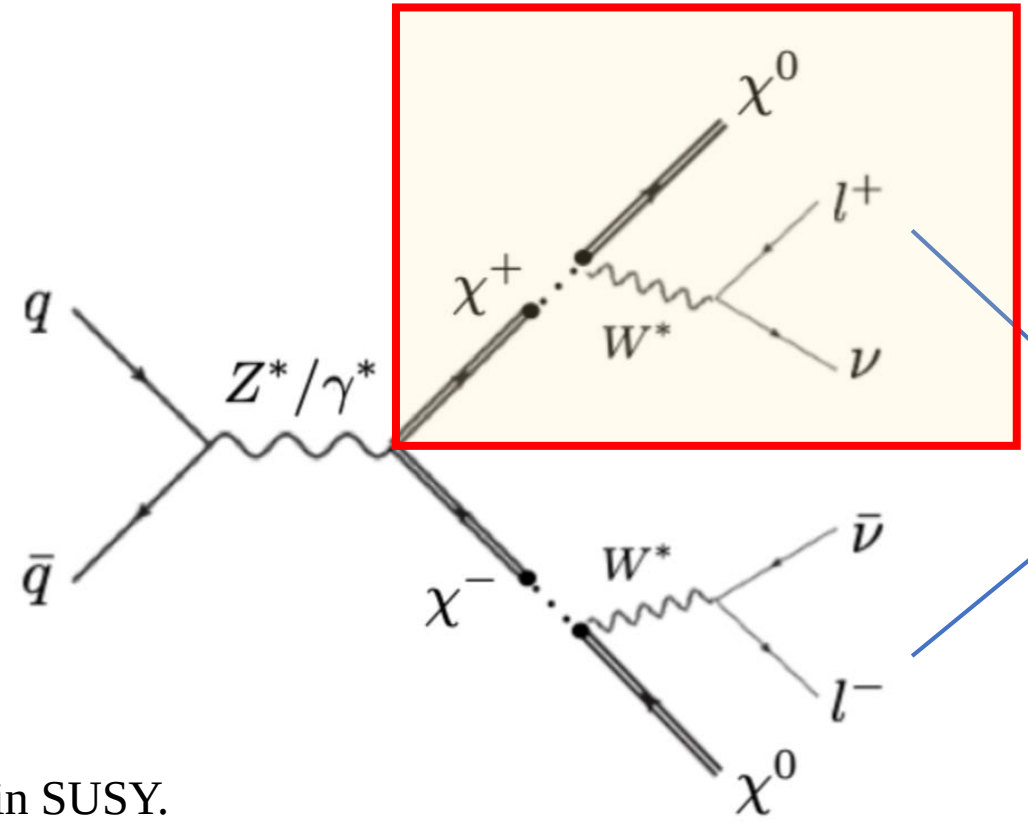
- Similar to bino-wino scenario in SUSY.

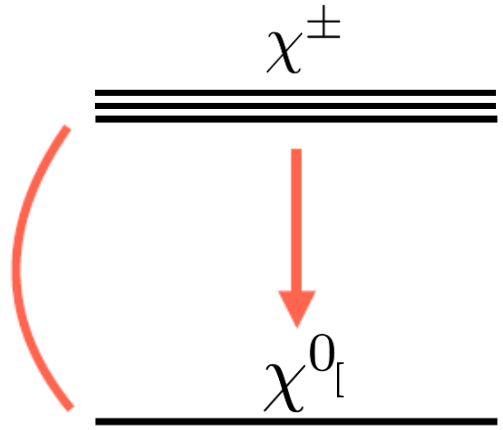
- Detector signature:
  - l^+l^-
  - Missing Transverse Energy

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

Soft leptons from singlet-triplet model

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





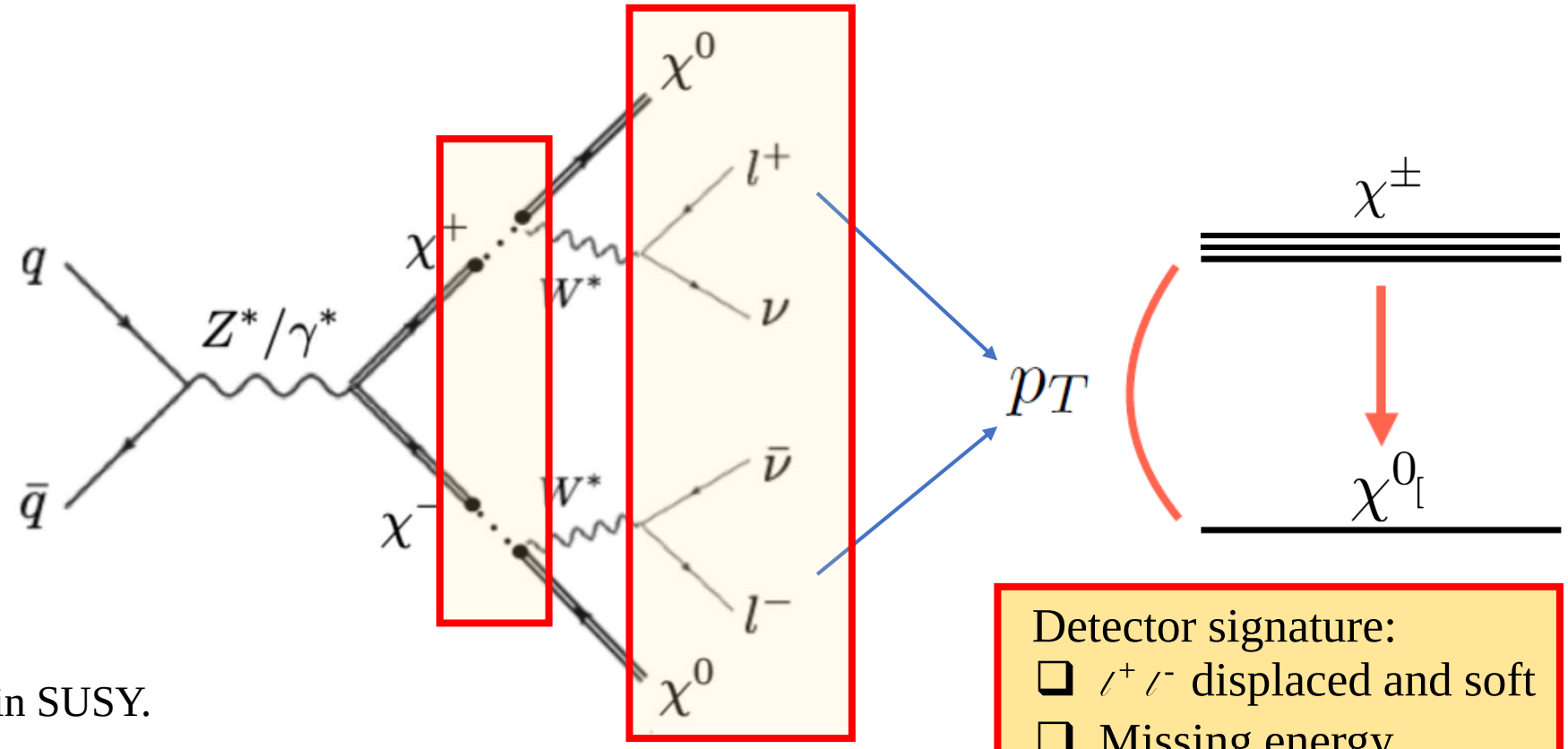
- Similar to bino-wino scenario in SUSY.

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

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

Soft leptons from singlet-triplet model

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



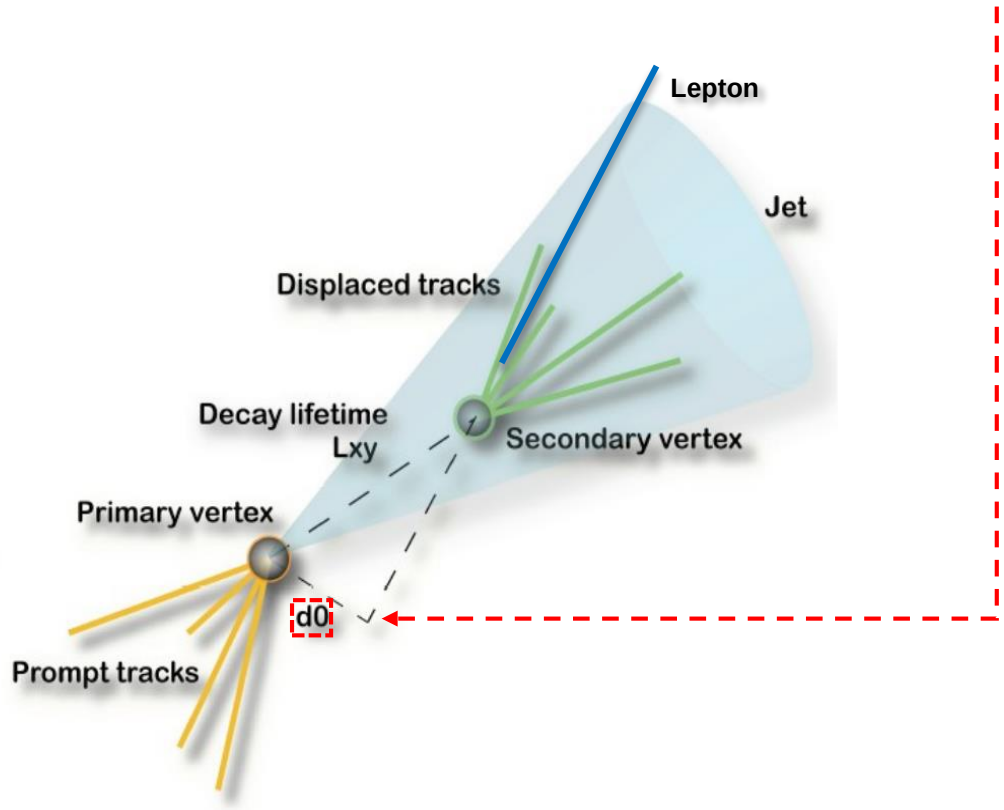
Detector signature:
- $l^+ l^-$ displaced and soft
- Missing energy

- Similar to bino-wino scenario in SUSY.

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

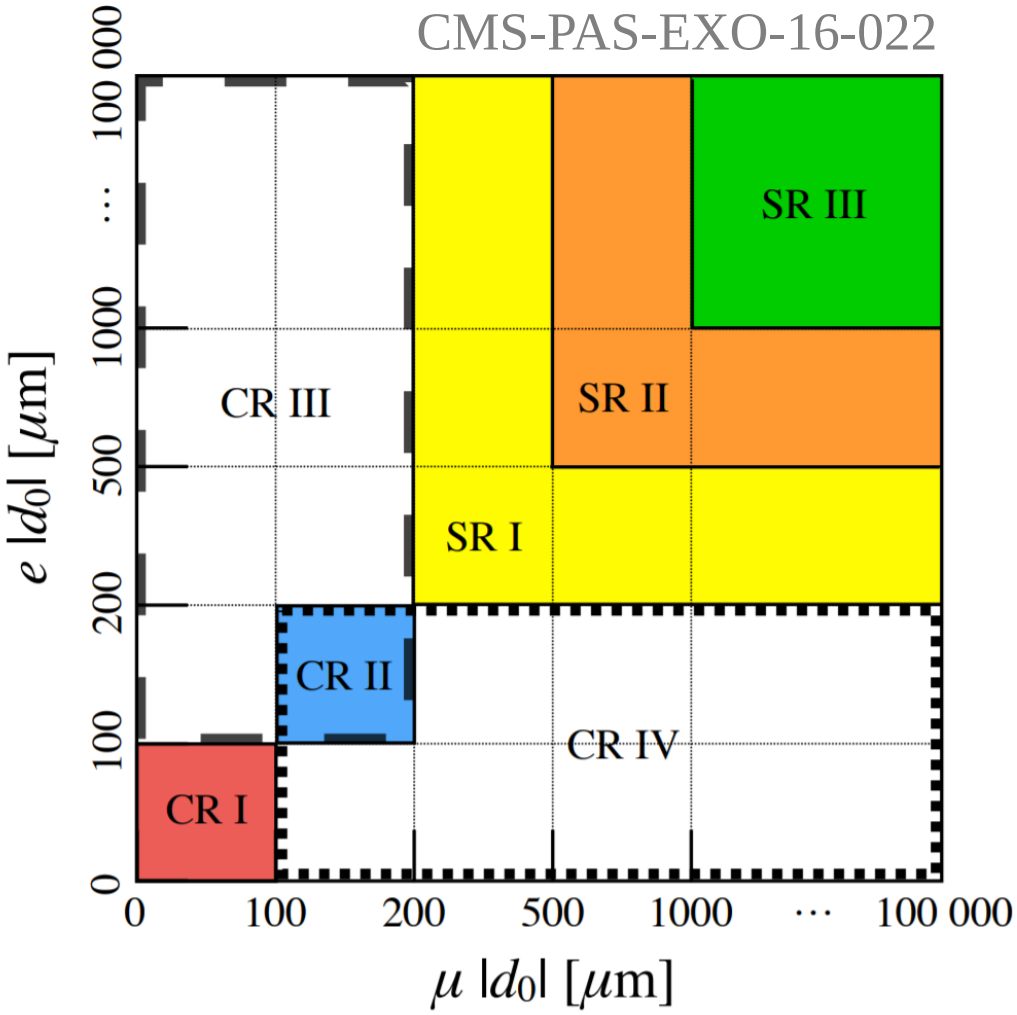
Background: Displaced di-lepton analysis at 13 TeV

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



PhD Thesis 2019, VUB: Q. Python

CMS-PAS-EXO-16-022



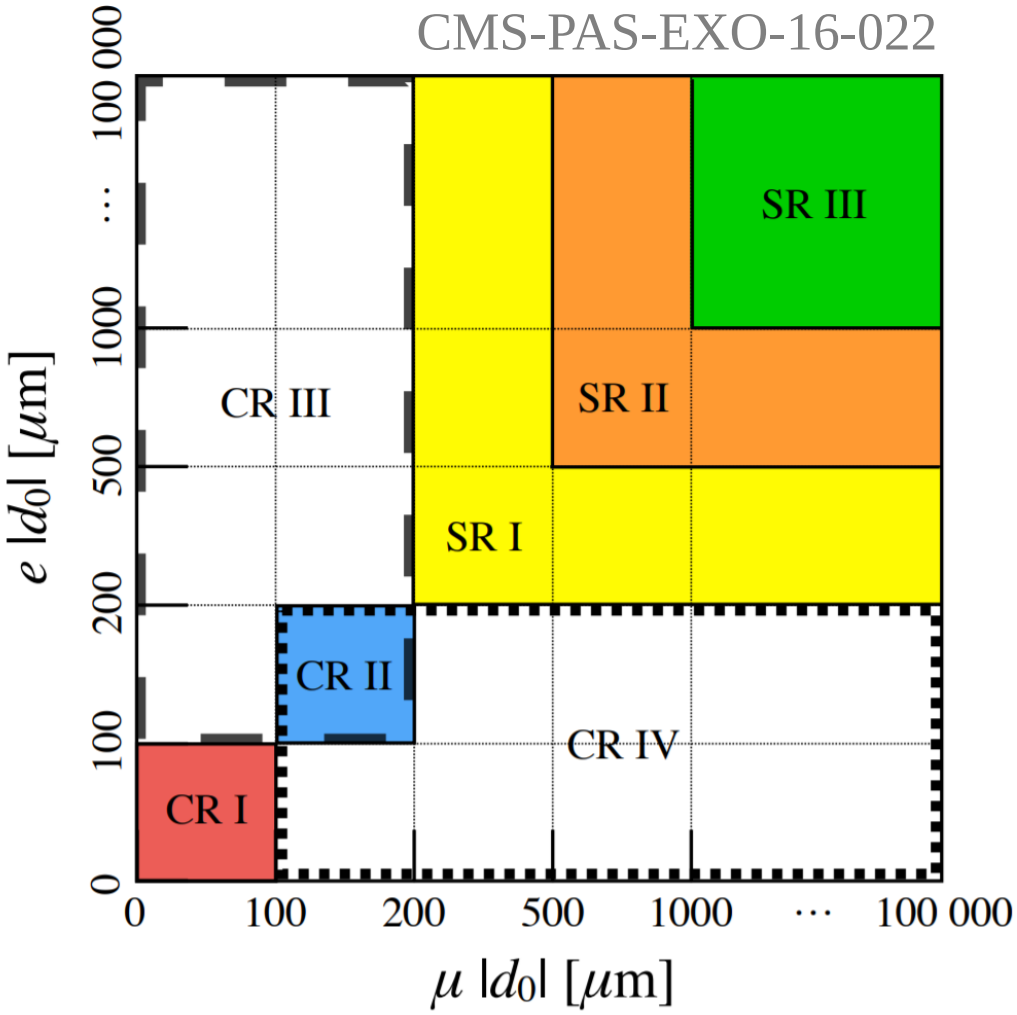
Background: Displaced di-lepton analysis at 13 TeV

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

1 electron
p_T > 42 GeV
1 muon
p_T > 40 GeV
Opp. charge

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

PhD Thesis 2019, VUB: Q. Python
CMS-PAS-EXO-16-022



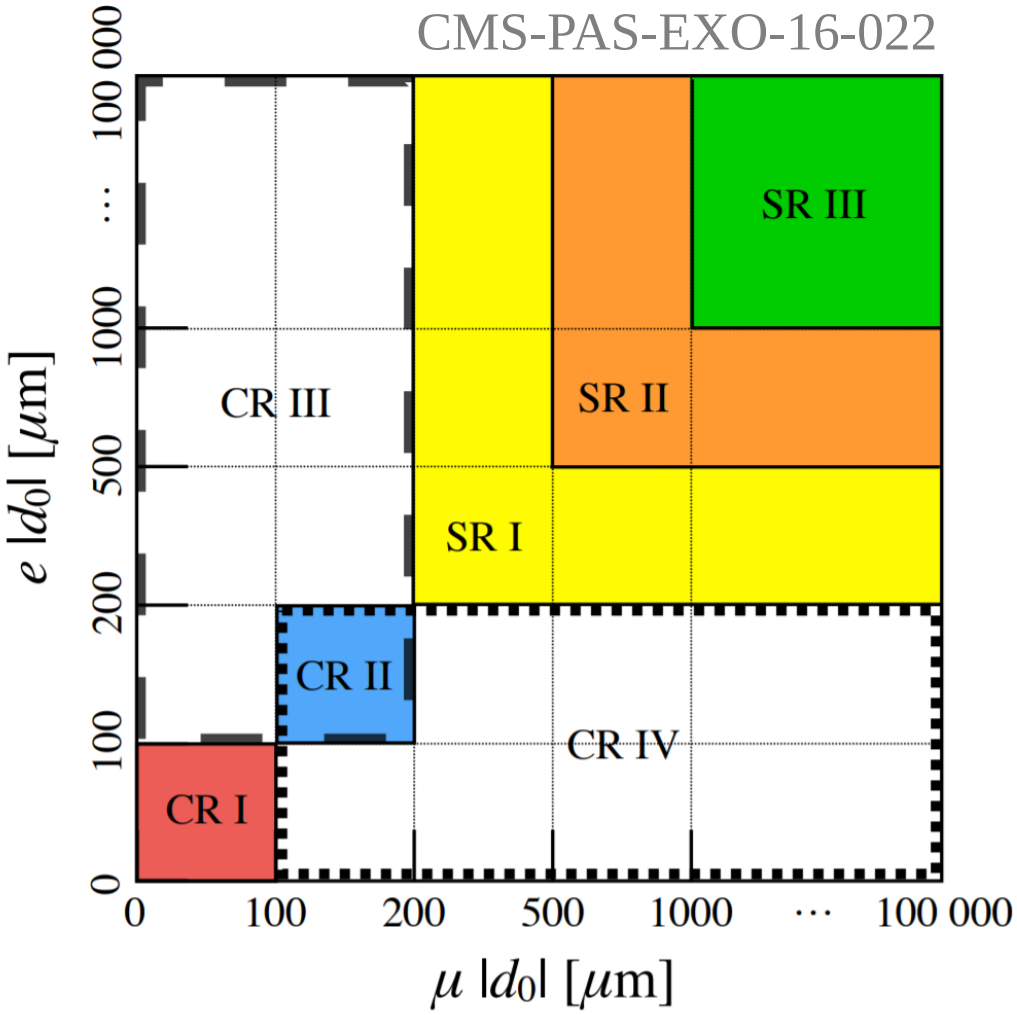
Background: Displaced di-lepton analysis at 13 TeV

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

1 electron
$p_T >$ **42 GeV**
1 muon
$p_T >$ **40 GeV**
Opp. charge

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

PhD Thesis 2019, VUB: Q. Python
CMS-PAS-EXO-16-022



Background estimation

arxiv[2007.03708]

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

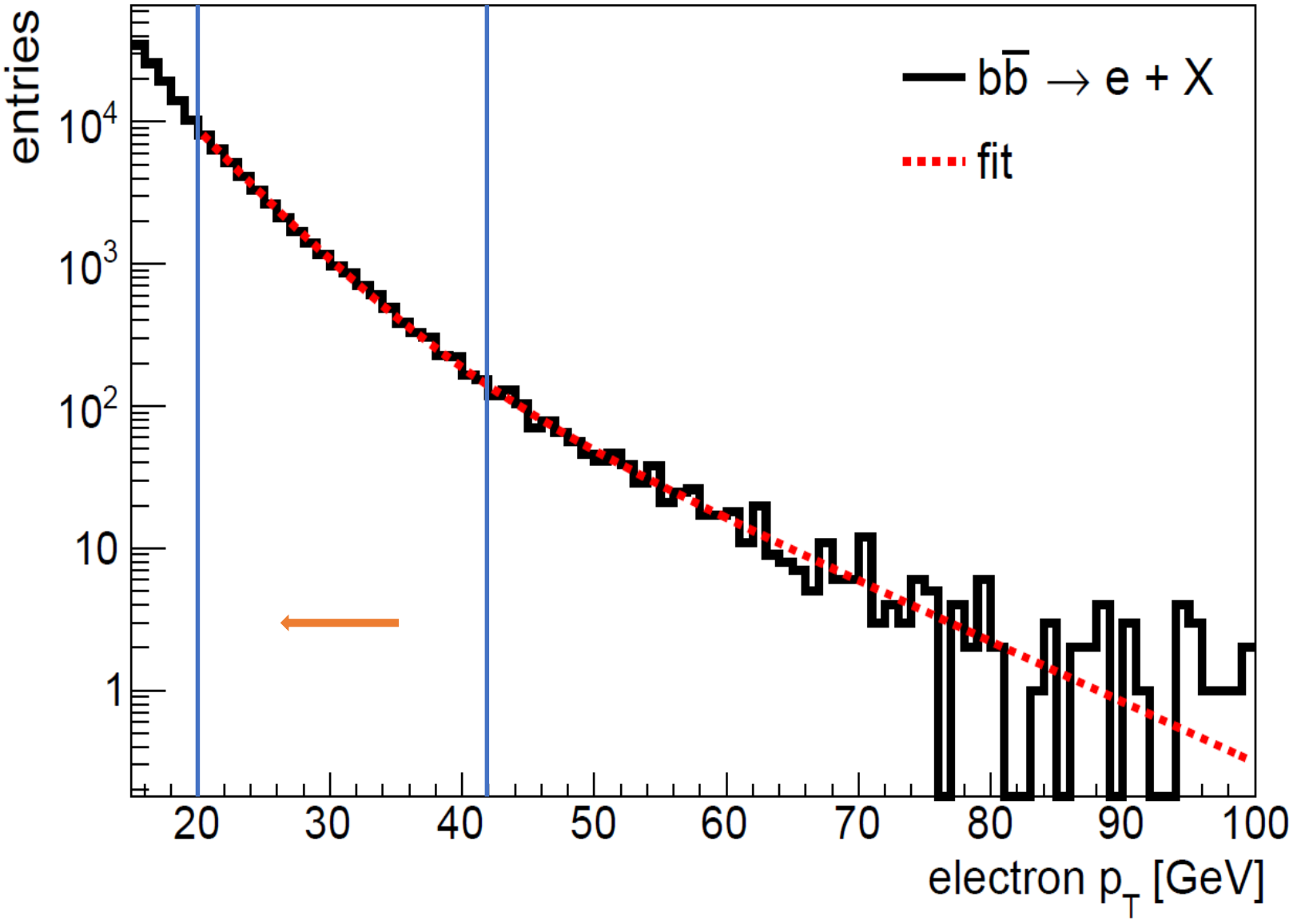
CMS-PAS-EXO-16-022

p_T: (42, 40)

$S_I < 3.2$

$S_{II} < 0.5$

$S_{III} < 0.019$



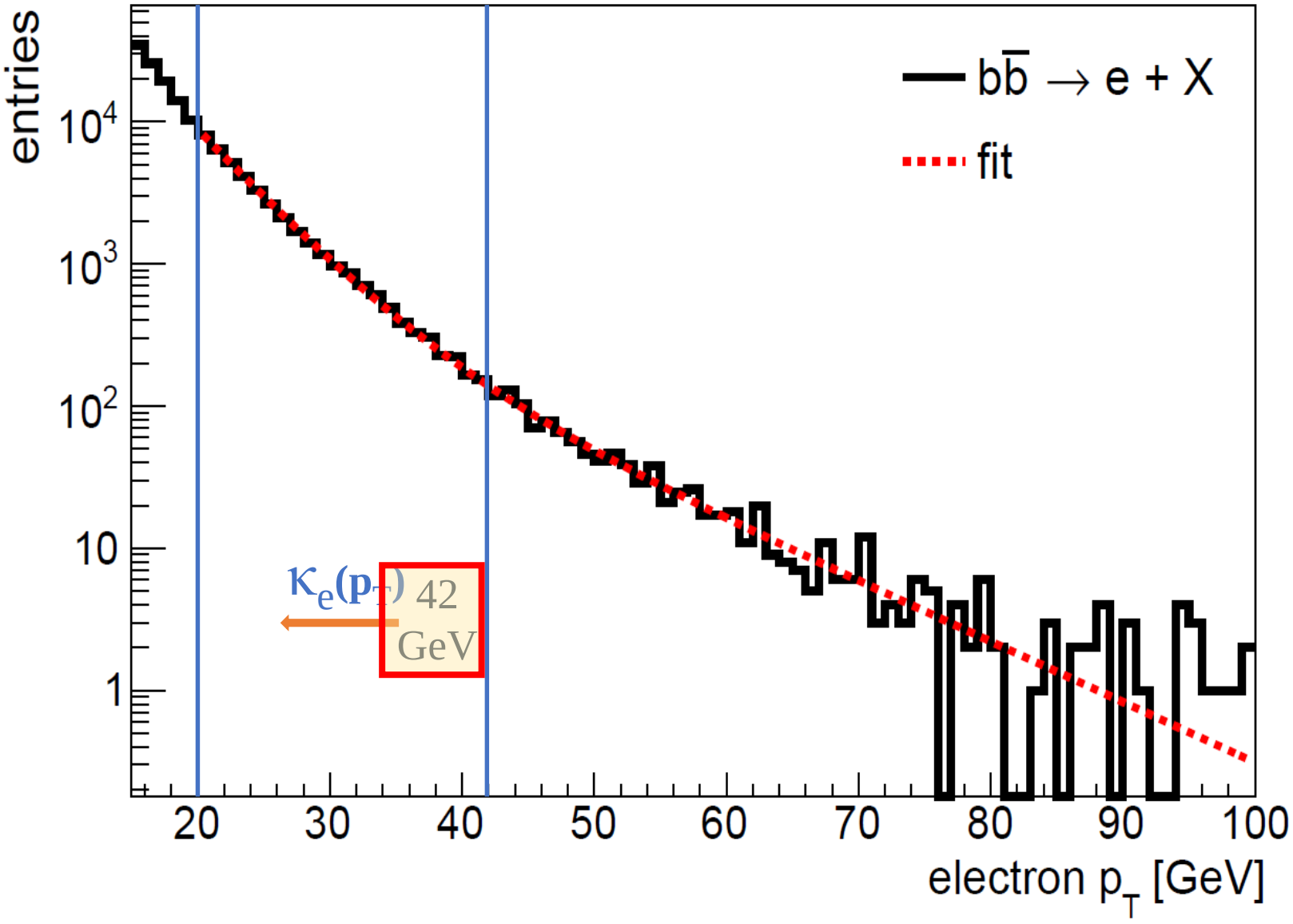
Background estimation

arxiv[2007.03708]

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

CMS-PAS-EXO-16-022
p_T: (42, 40)
$S_I < 3.2$
$S_{II} < 0.5$
$S_{III} < 0.019$

$\kappa_e \times \kappa_\mu$



Background estimation

arxiv[2007.03708]

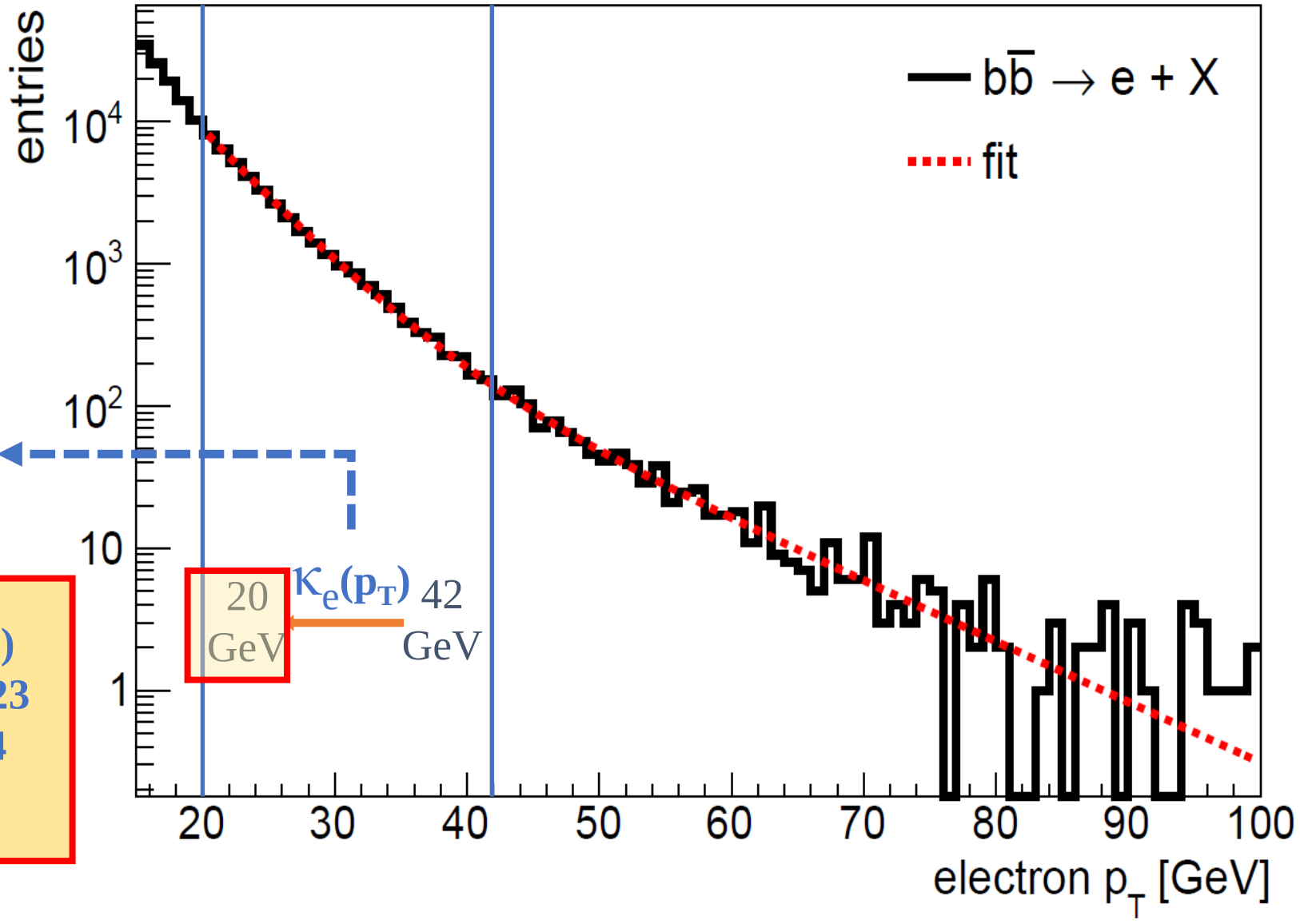
- Lepton enriched $b\bar{b}$ sample.
- e and μ transfer factor measured separately to keep statistic.

CMS-PAS-EXO-16-022

p_T: (42, 40)
S_I < 3.2
S_{II} < 0.5
S_{III} < 0.019

κ_e X κ_μ

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



Background estimation

arxiv[2007.03708]

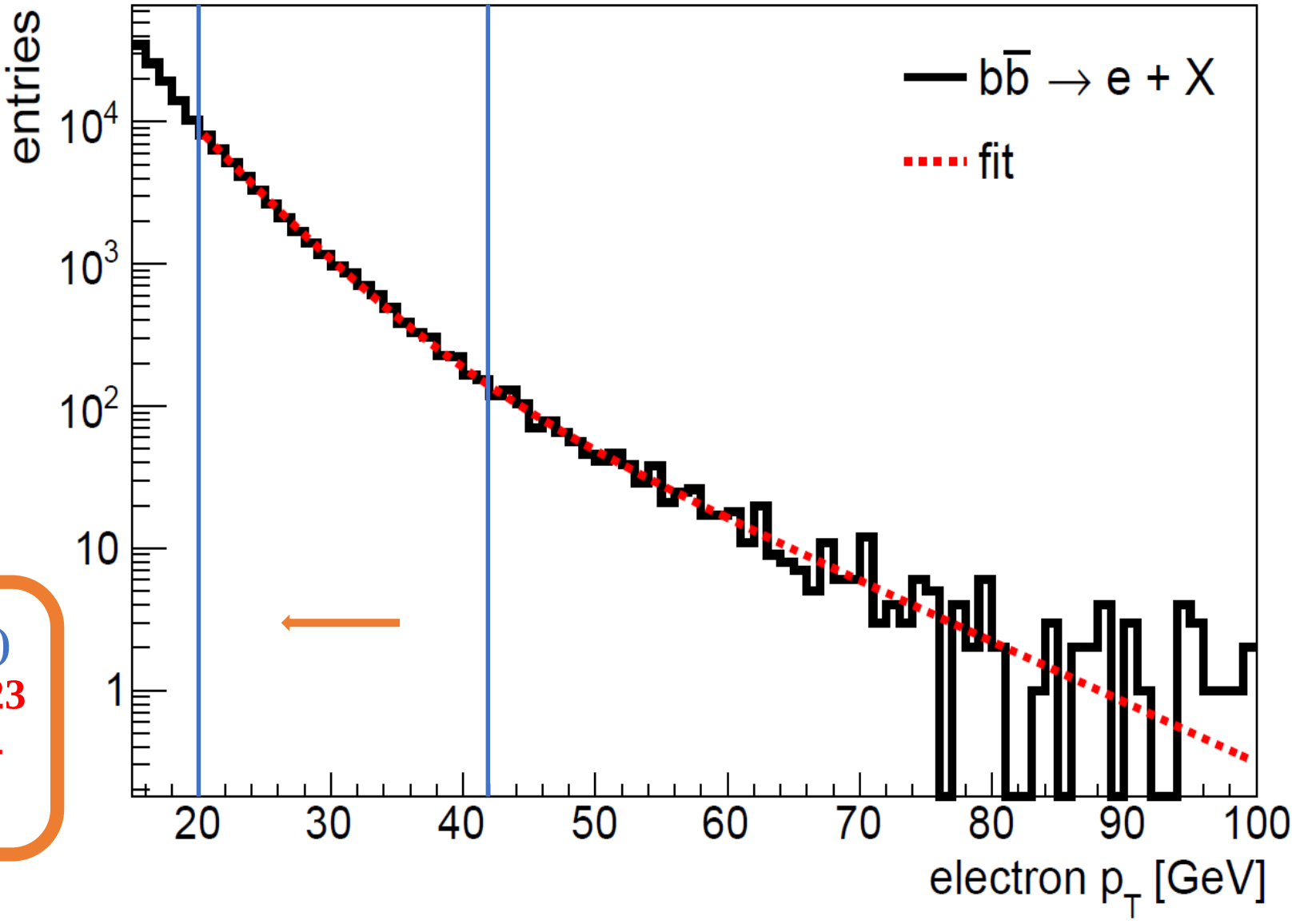
- Lepton enriched $b\bar{b}$ sample.
- e and μ transfer factor measured separately to keep statistic.

CMS-PAS-EXO-16-022

p_T: (42, 40)
$S_I < 3.2$
$S_{II} < 0.5$
$S_{III} < 0.019$

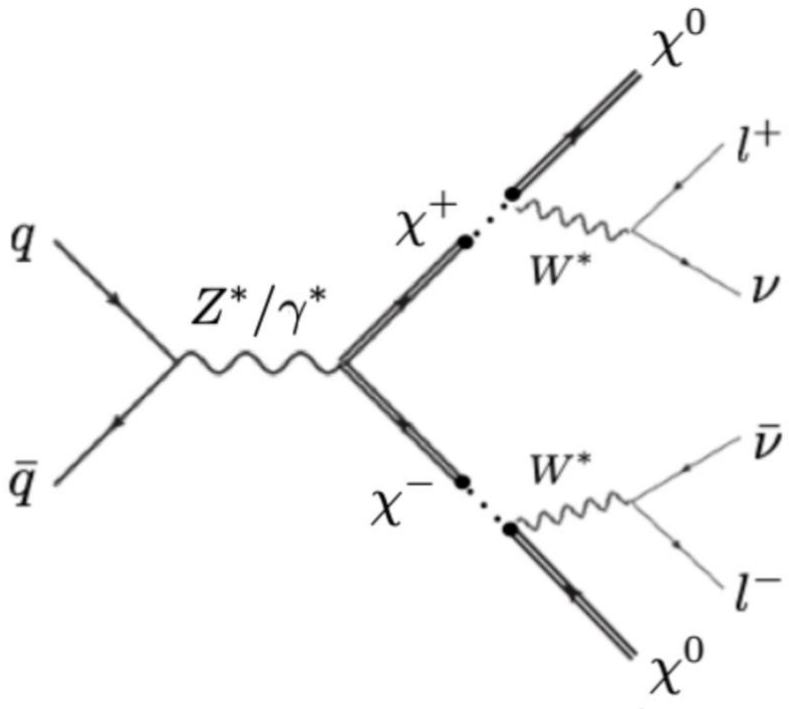
- **Large background!**

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



Signal model parameters

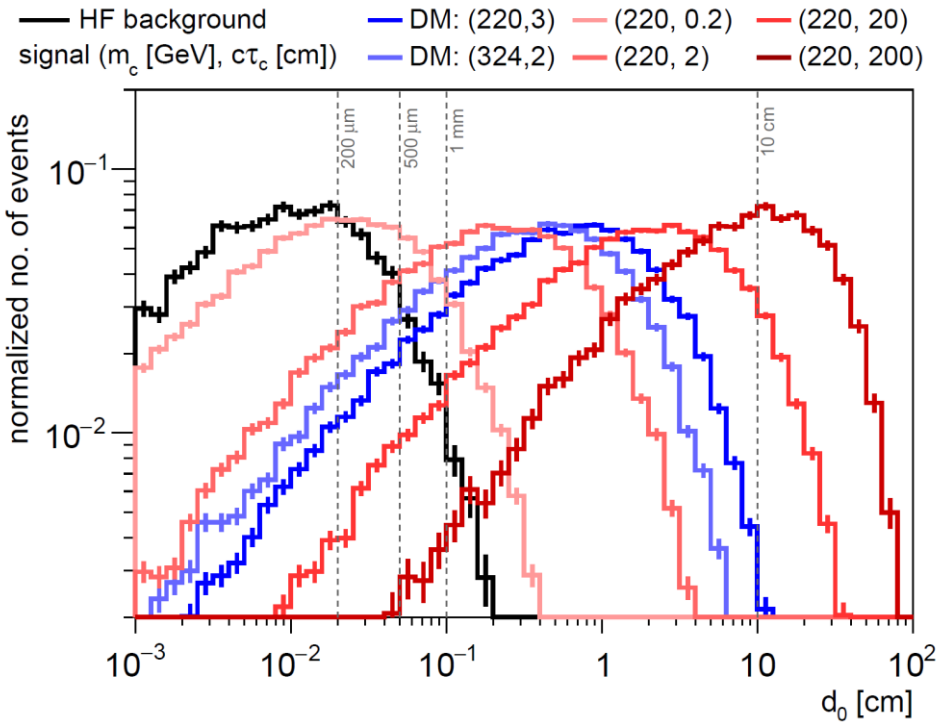
- Detector acceptance is affected by $c\tau_c$.
- Lepton kinematics depends on Δm.



#	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

Signal model parameters

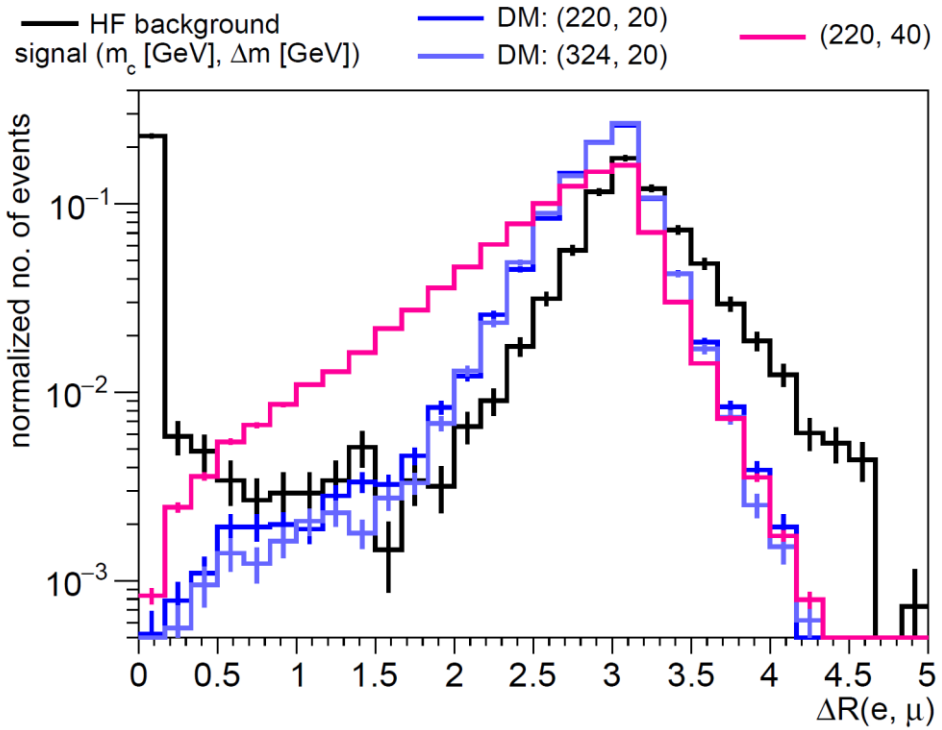
- **Detector acceptance is affected by $c\tau_c$.**
- Lepton kinematics depends on Δm.



#	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

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

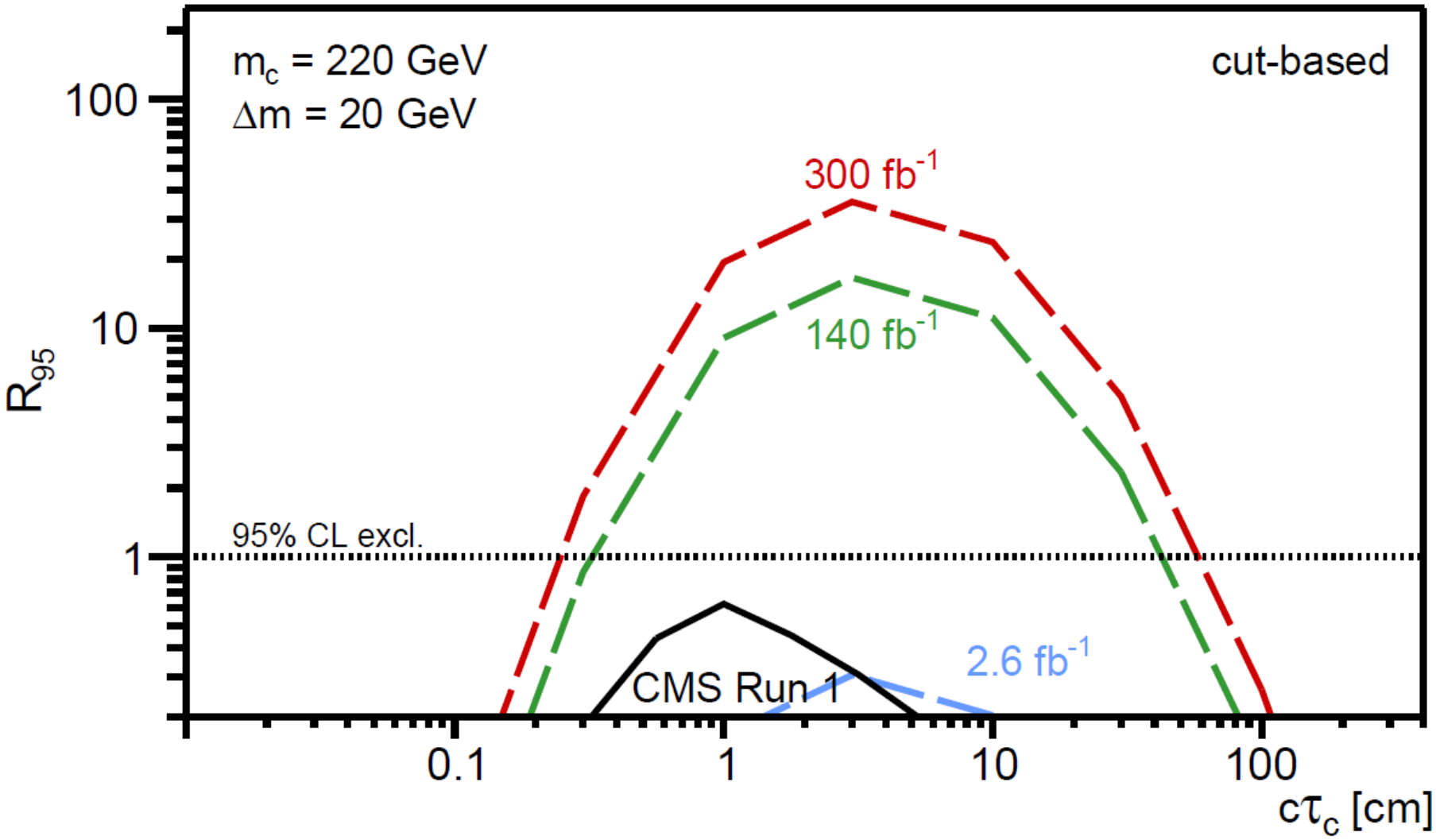
Signal Yield (For $\mathscr{L}$= 140 fb^{-1})

	HF background ($\mathscr{L}$= 2.6fb^{-1})	**4123**	**644**	**25**
#	$(m_c\,[\text{GeV}],\ \Delta m\,[\text{GeV}],\ c\tau_c\,[\text{cm}])$	S_{I}	S_{II}	S_{III}
1	(324, 20, 2)	0.38	0.43	1.18
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

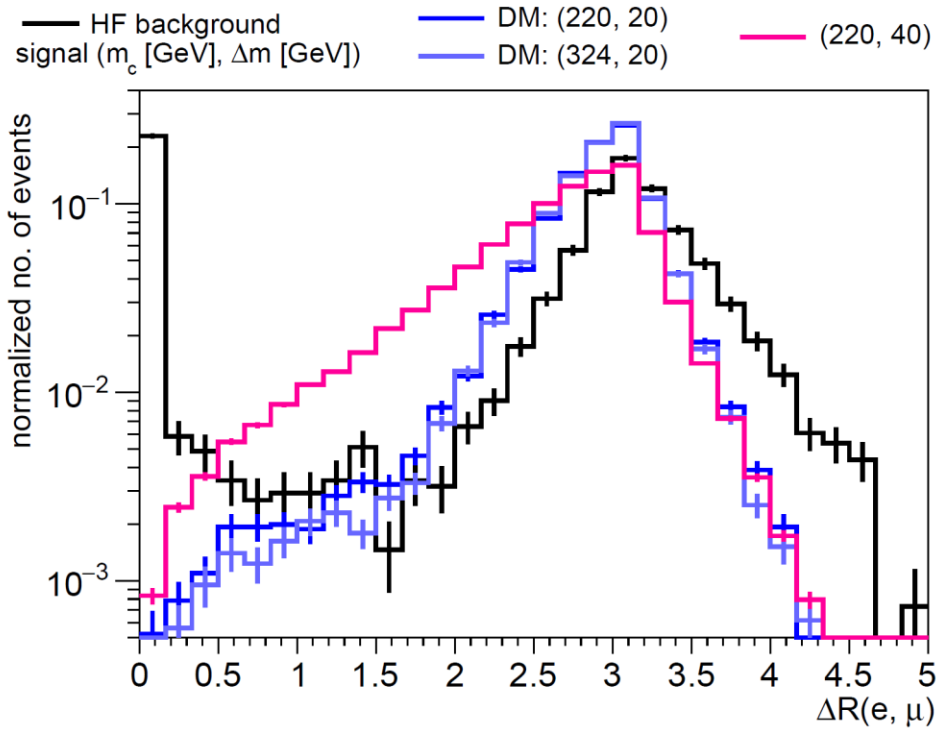
Signal Yield (For $\mathscr{L}$= 140 fb^{-1}) : Limit plot

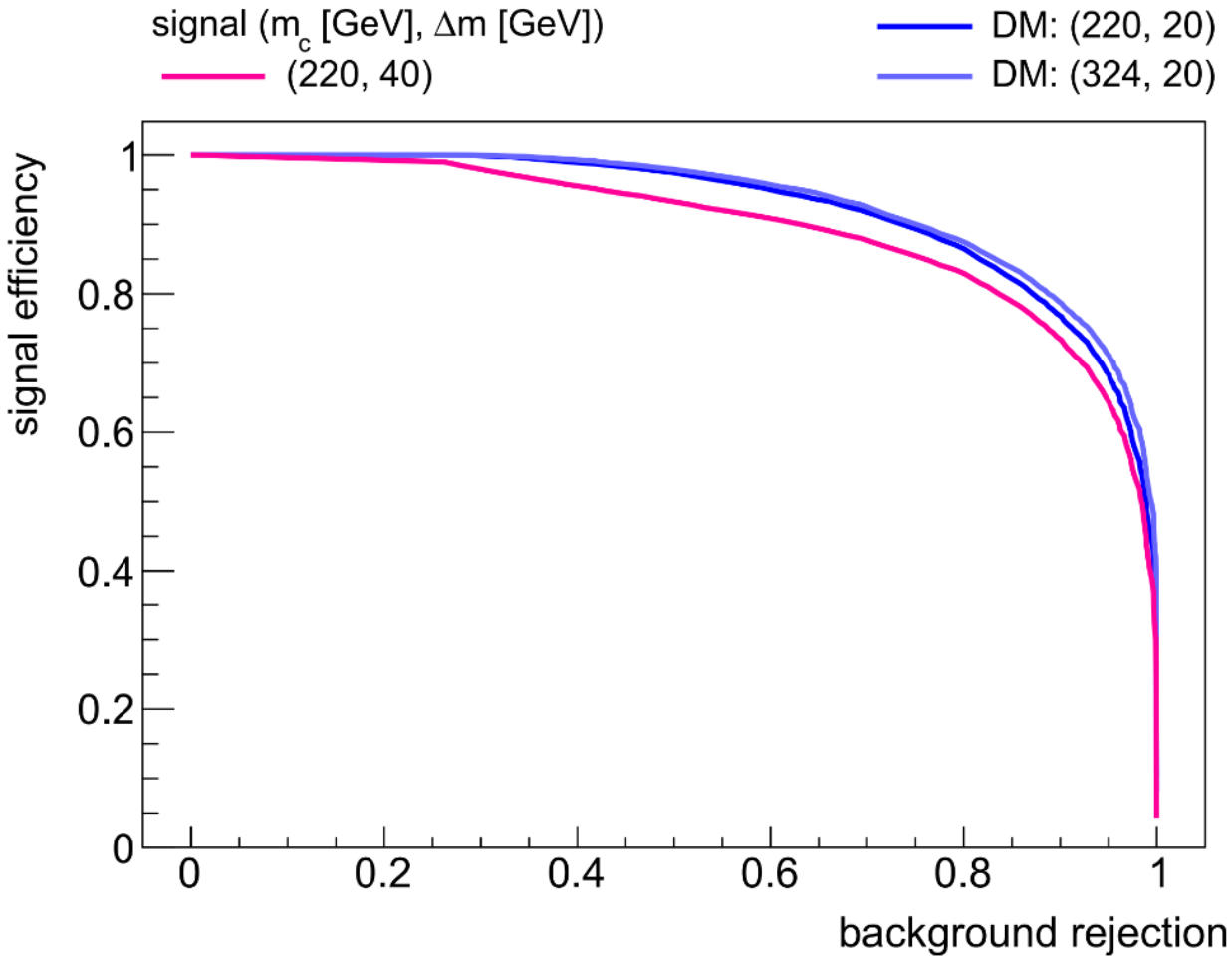


- Background with luminosity scaling is 200000!
- Signal yield relatively very low for Δm = 20 GeV.
- Δm = 40 GeV is already excluded.

Model independent neural network to improve signal vs background

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

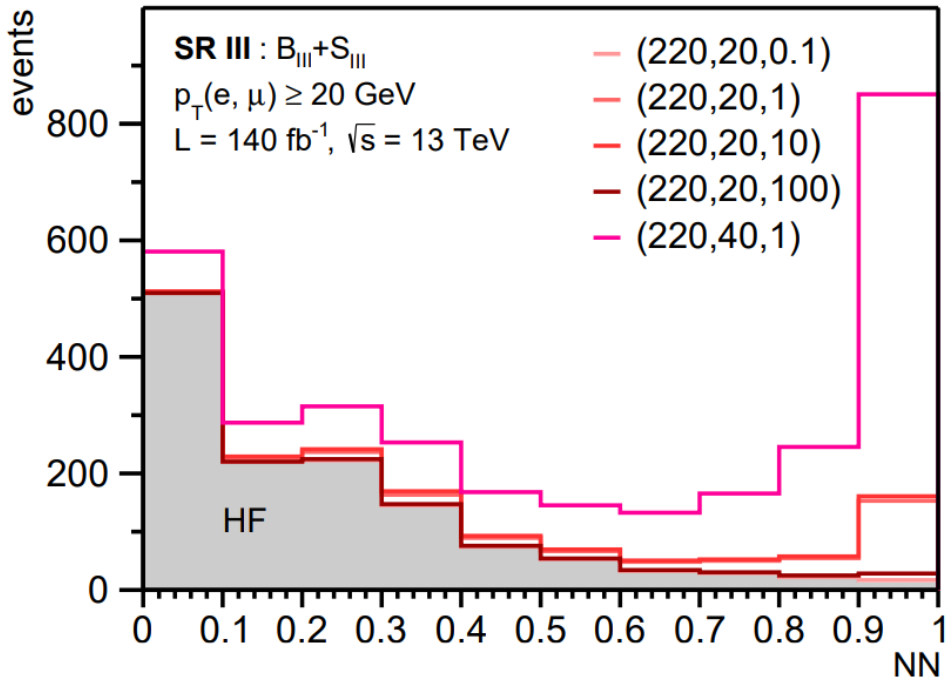


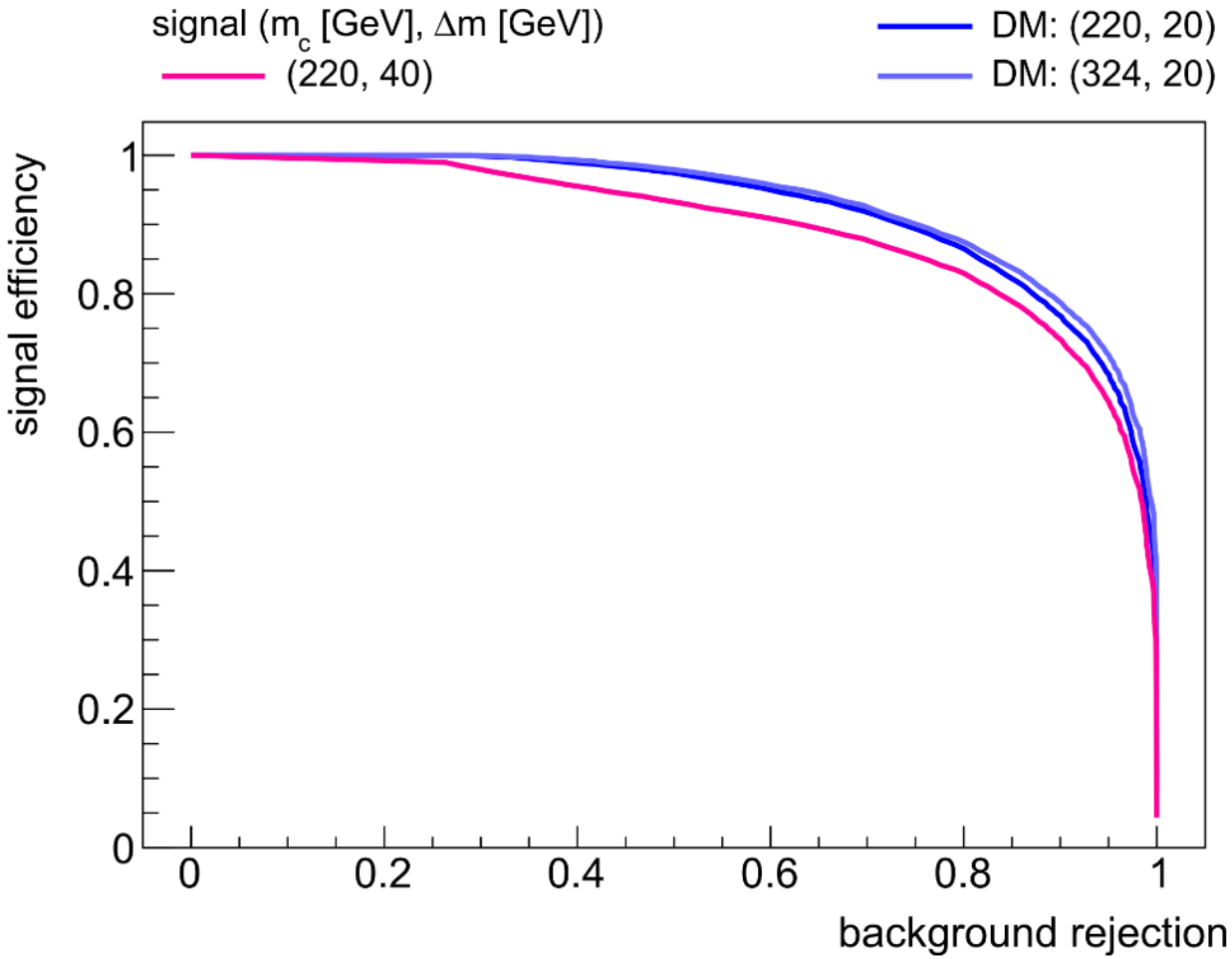


- One classifier for all benchmarks.

Model independent neural network to improve signal vs background

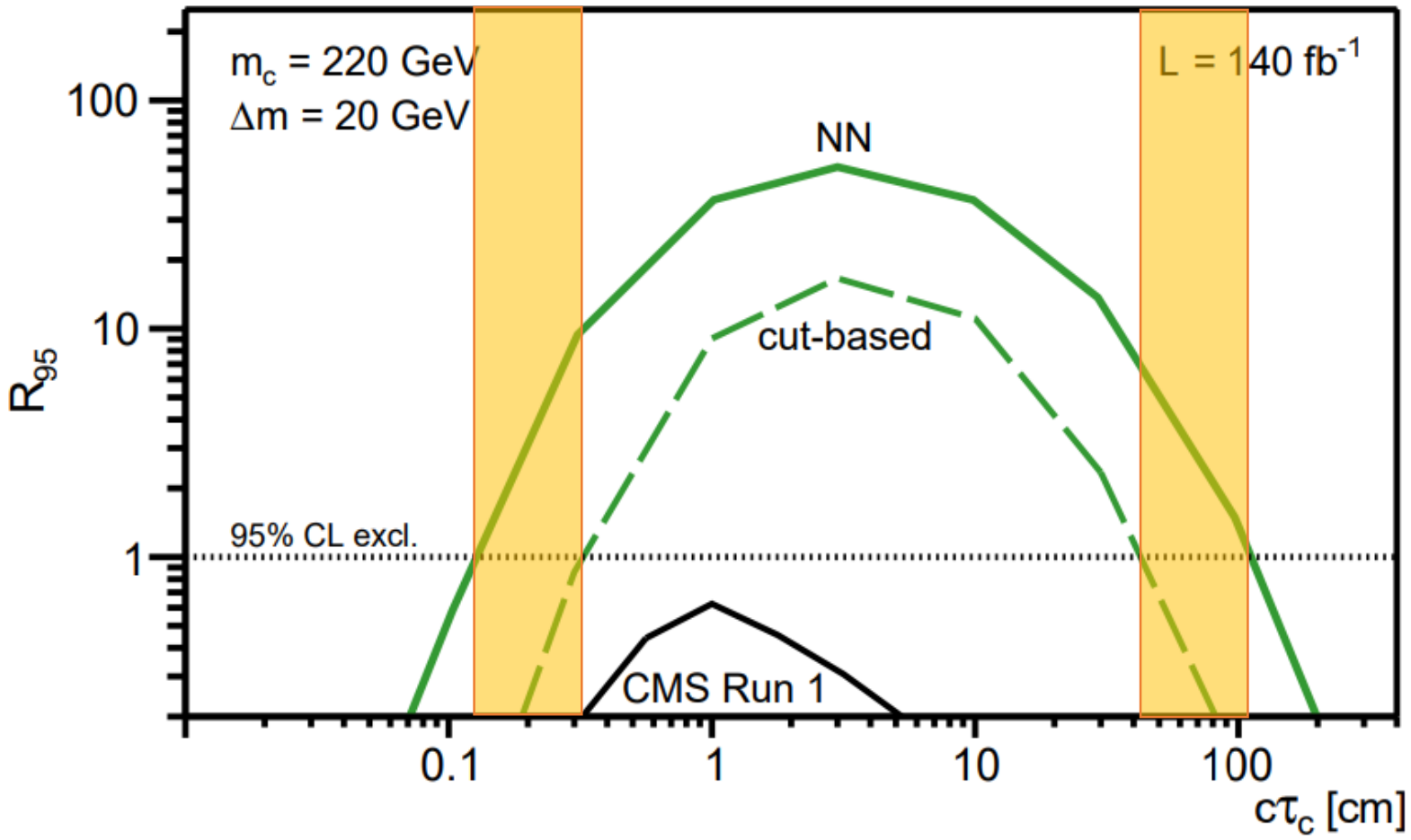
- Trained (80%) and tested (20%) on (324, 20, 2).



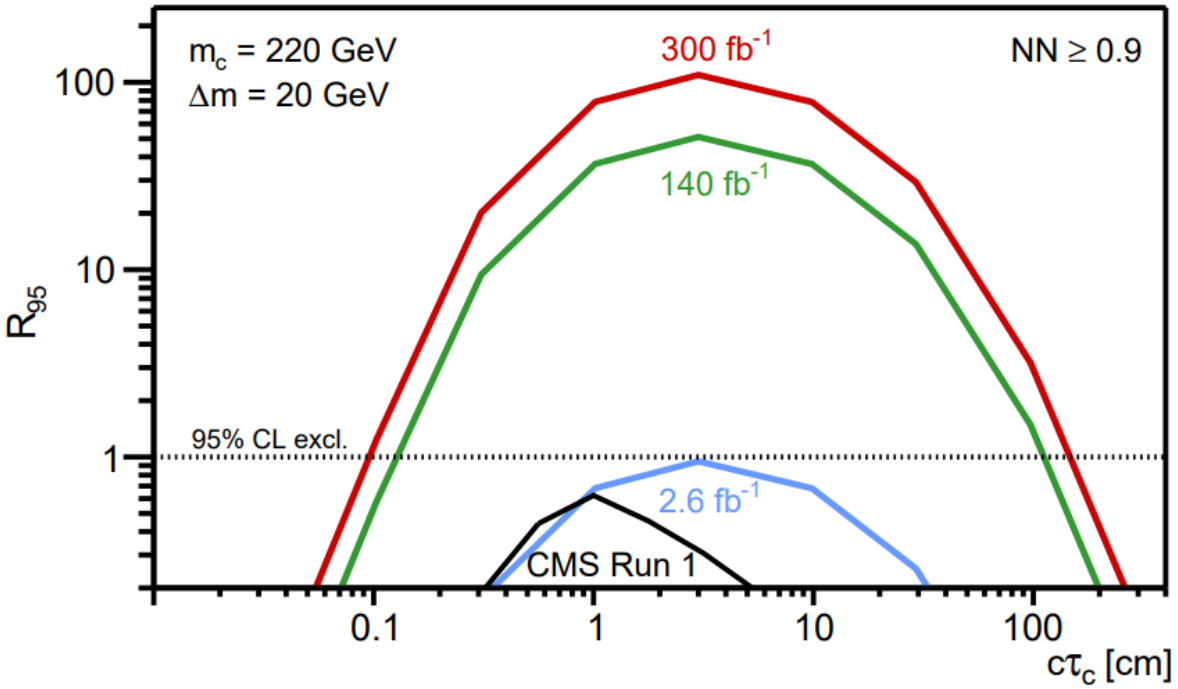


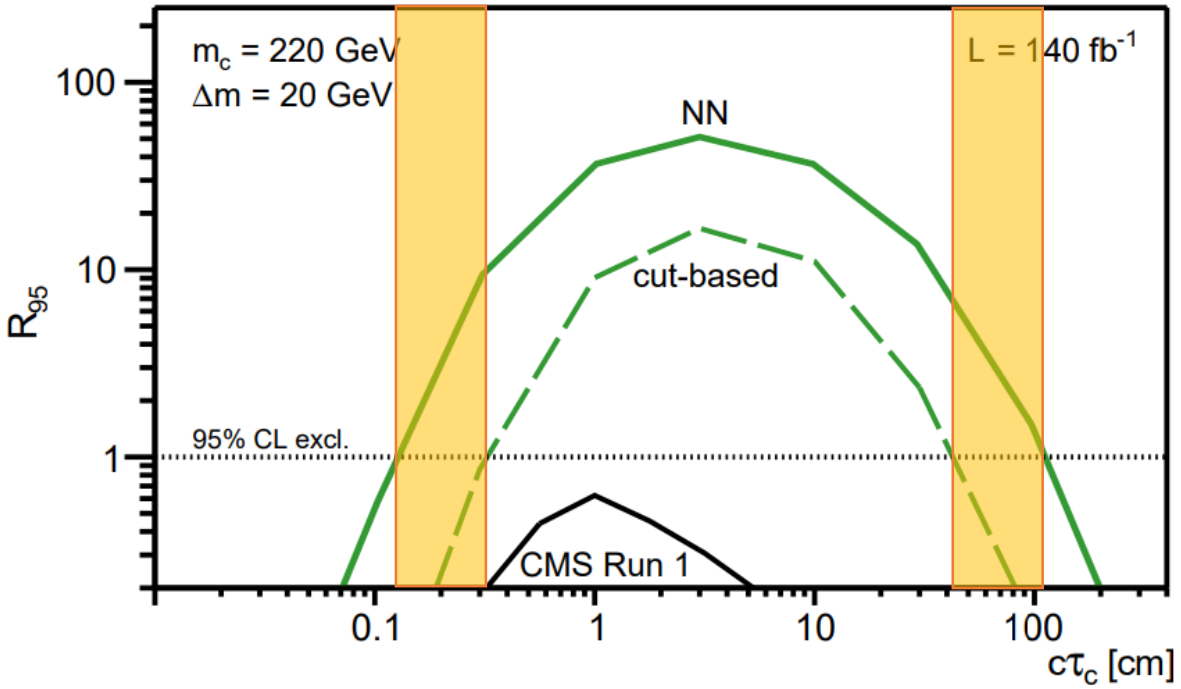
- One classifier for all benchmarks.

Exclusion limit for the benchmarks



Exclusion limit for the benchmarks



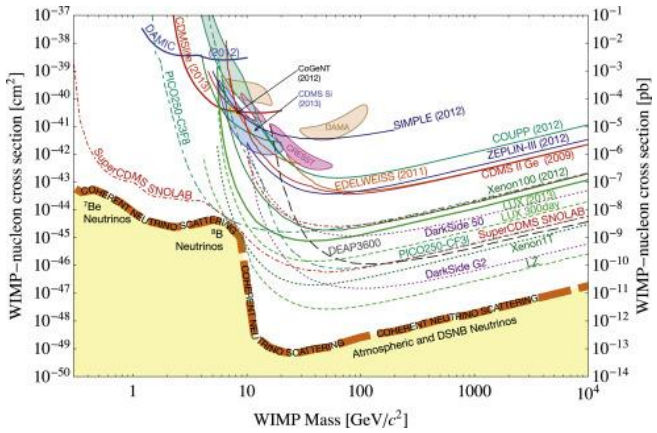


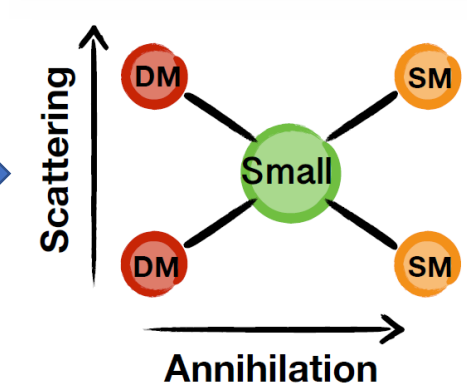
Conclusion and Outlook

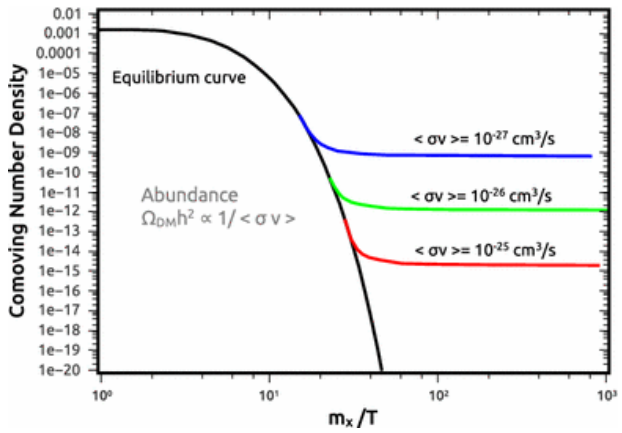
- Soft displaced leptons are typical signs of dark matter from co-scattering and co-annihilation.
  - To observe these signatures at the LHC, events with soft leptons need to be selected.
- LHC signal with soft displaced leptons are challenged by large heavy flavour background.
- Multivariate analysis 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.
- 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.

BACK-UP

Higgs portal dark matter

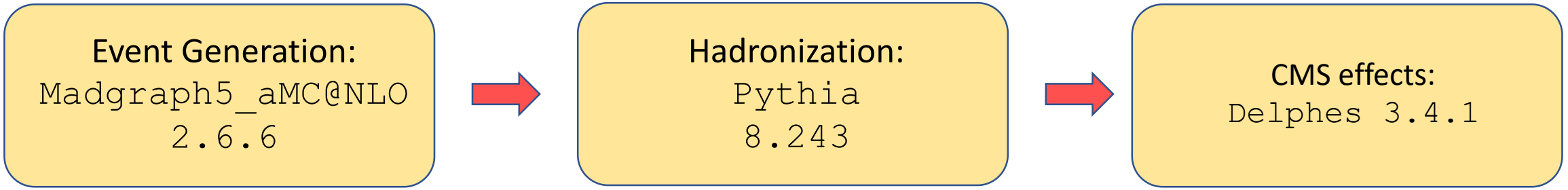






Over-Abundant DM

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**.

Accuracy of NN classifier