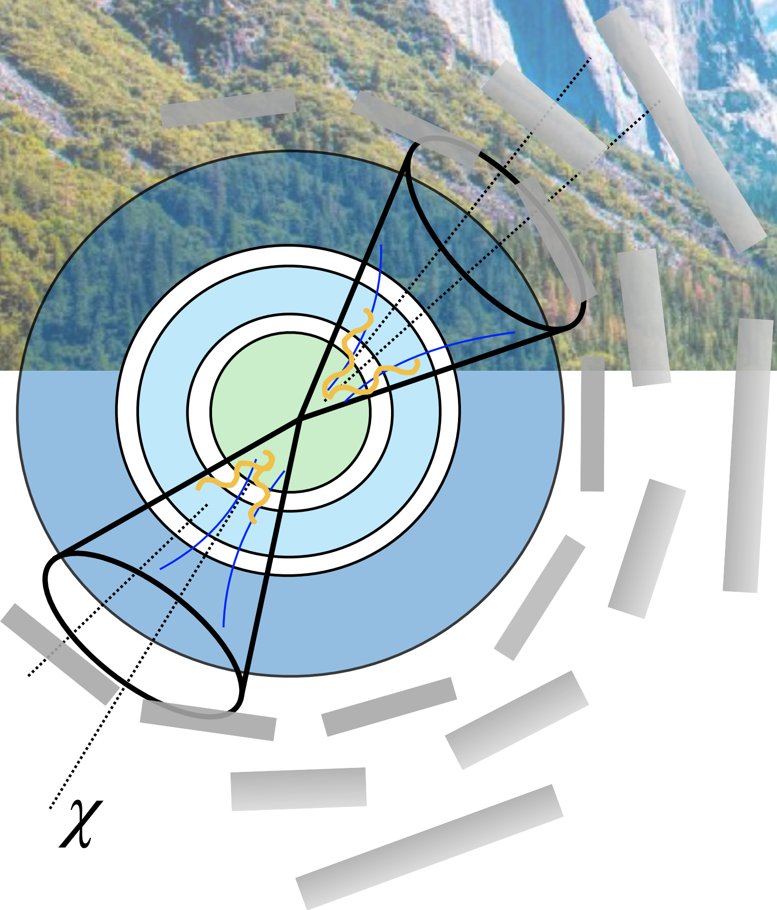


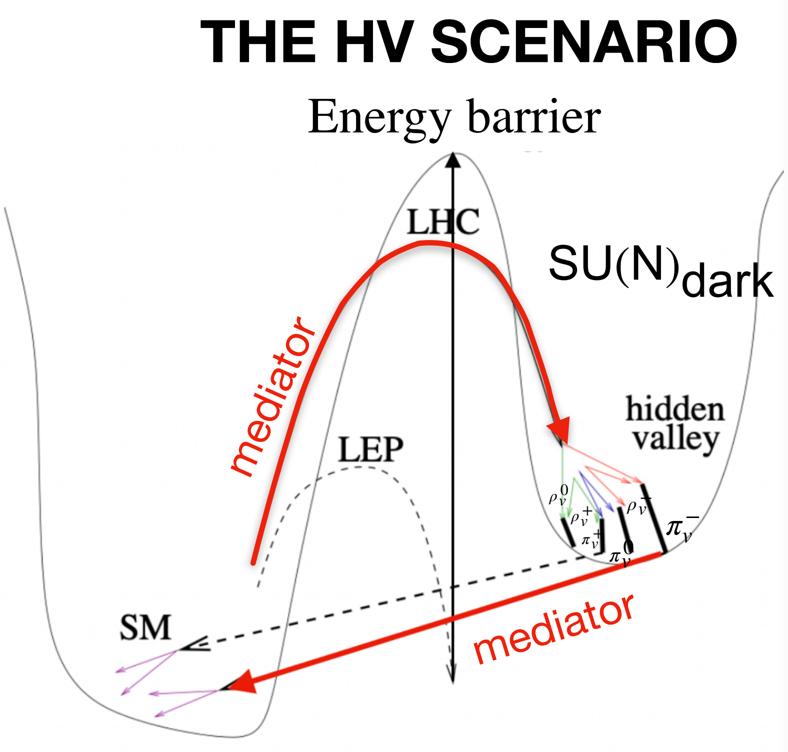
PROBING PHOTONS-ENRICHED SIGNATURES FOR SEMI-VISIBLE JETS AT THE LHC

C. Cazzaniga[1], A. Russo[2], E.Sitti[1], A. De Cosa[1]

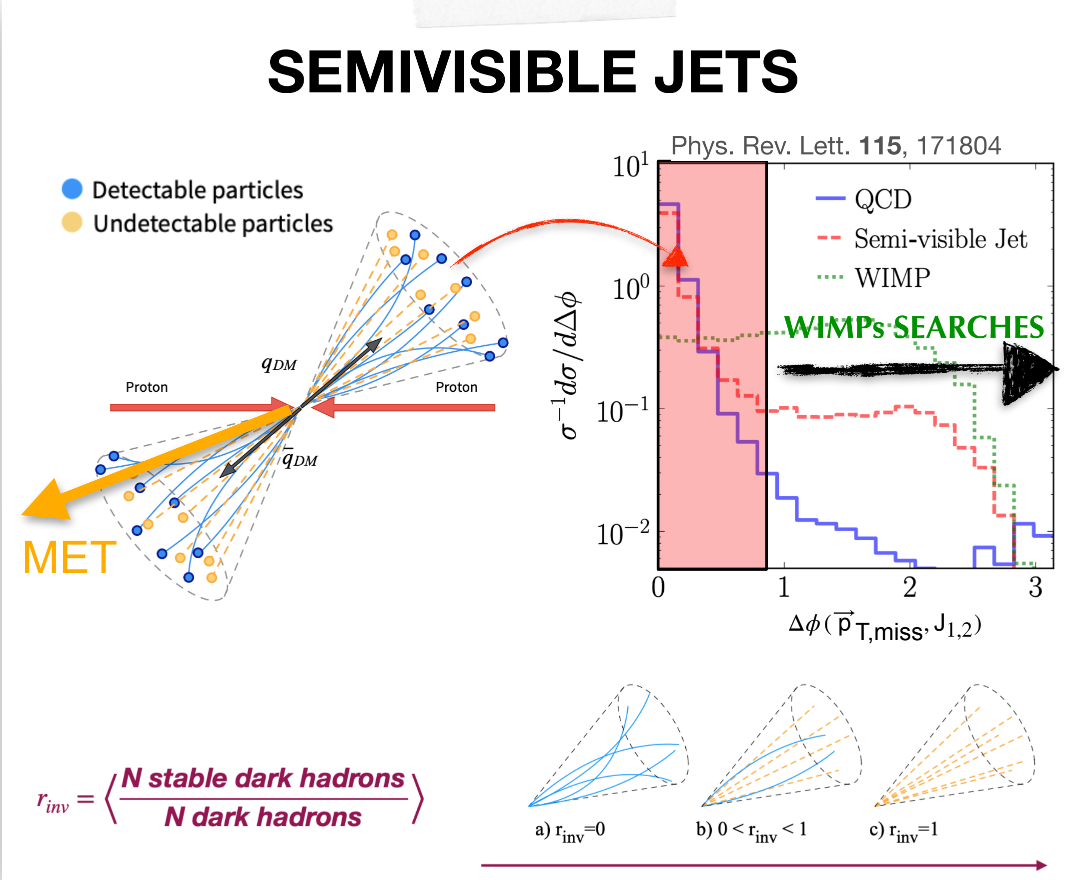
[1] ETH Zurich, [2] Stanford University

Based on Eur. Phys. J. C 84, 1223 (2024)

Hidden Valleys And SVJs



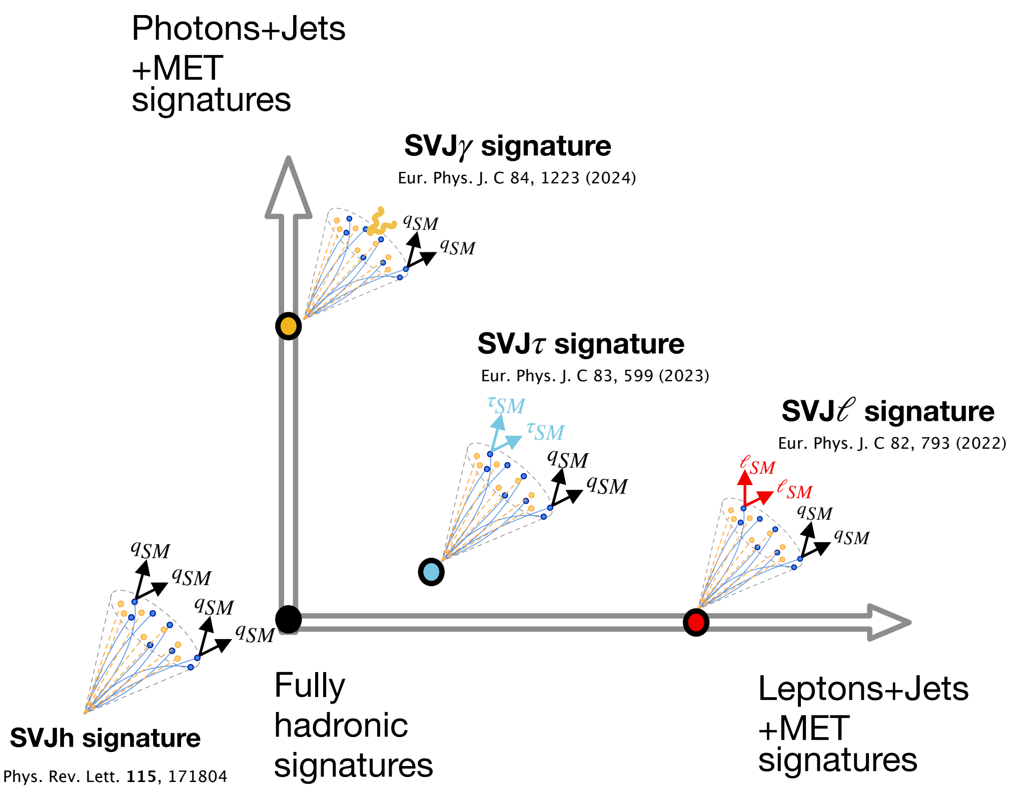
Adapted from Phys.Lett.B651:374-379,2007

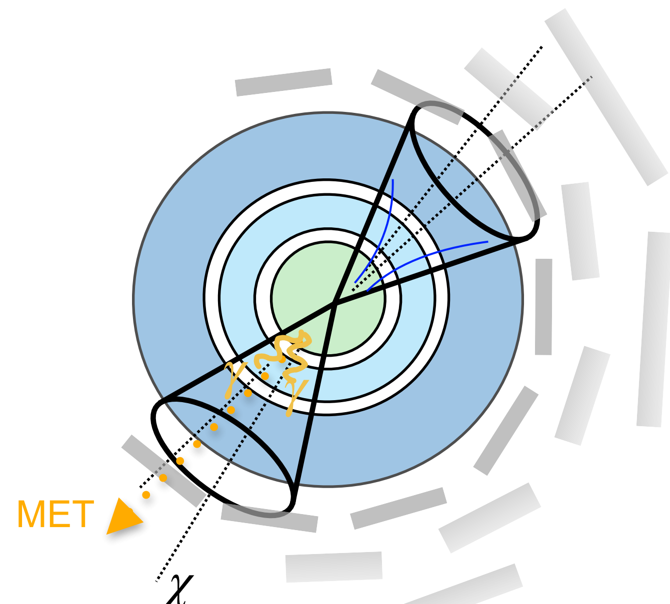


SVJs are exotic signatures emerging from Hidden Valleys complementary to di-jet and WIMPs searches: broader resonances (if present), dominated by QCD background (detector effects) → challenging signature!

Photons-enriched SVJ Signatures

EXTEND SVJ SIGNATURE: ALLOW **DS DECAYS TO PHOTONS** AND EXPLOIT NEW EXPERIMENTAL HANDLES





$\not{E}_T$ ALIGNED TO JETS

+ **(PROMPT)*** **NON-ISOLATED PHOTON PAIRS** PRODUCED INSIDE HADRONIC JETS

Eur. Phys. J. C 84, 1223 (2024)

C.Cazzanaiga, A. Russo, E. Sitti, A. De Cosa

(*) also non-prompt signatures can appear in this scenario

SVJγ Model In A Nutshell

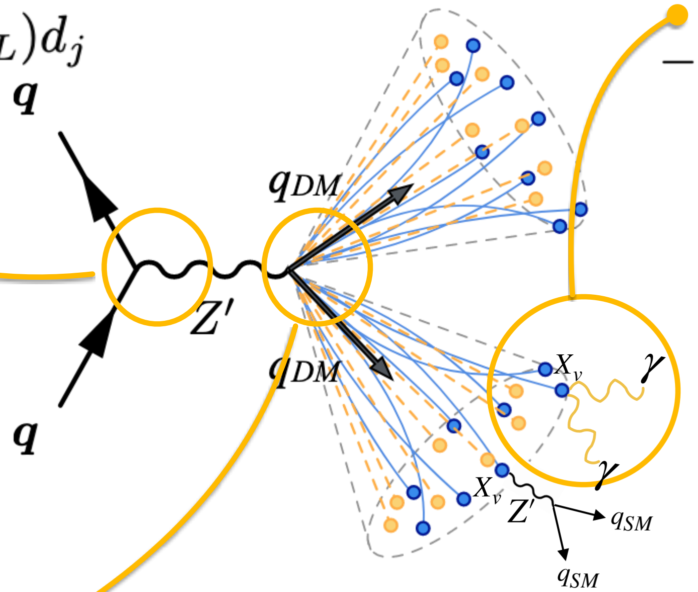
A portal for pp colliders

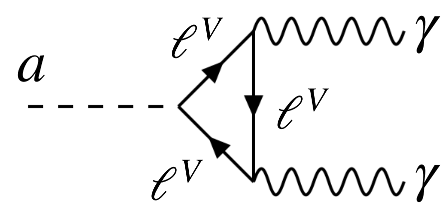
$$-Z'_\mu \bar{u}_i \gamma^\mu (g_{ij}^{u_R} P_R + g_{ij}^{u_L} P_L) u_j$$

$$-Z'_\mu \bar{d}_i \gamma^\mu (g_{ij}^{d_R} P_R + g_{ij}^{d_L} P_L) d_j$$

A decay mode to photons

$$-\frac{\alpha}{4\pi}\frac{y_Q N_Q}{M_Q} a F\tilde{F} - i y_\psi a \bar{q}_v \gamma_5 q_v$$





Axion + VLL portal

MODEL BASED ON:

Phys. Rev. D 84, 115006 (2011)

Phys. Rev. D 89, 095033 (2014)

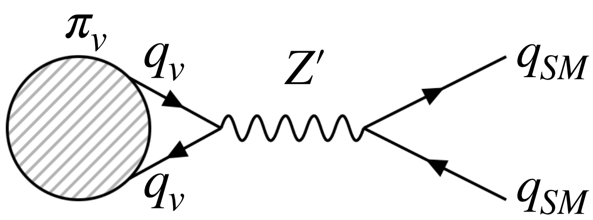
Phys. Rev. D 103, 115013 (2021)

A coupling to the dark sector

$$-Z'_\mu \bar{q}_{vi} \gamma^\mu (g_{ij}^{q_v R} P_R + g_{ij}^{q_v L} P_L) q_{vj}$$

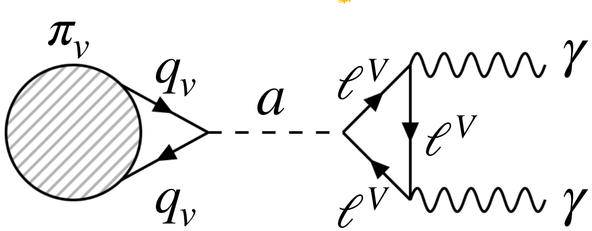
Model Parameters And Branchings

Hadronic decay channel



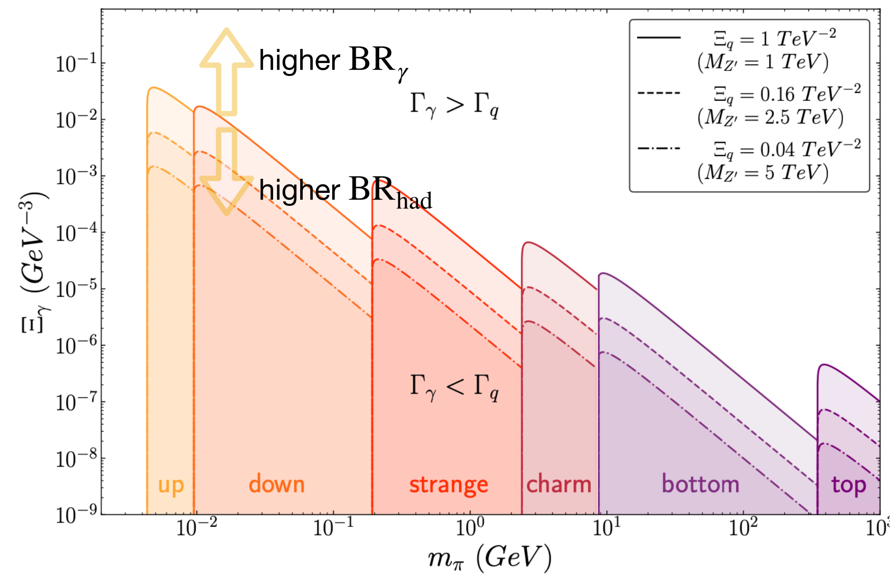
$$\Gamma(\pi_v \to \bar{q}_i q_i) = \frac{N_c}{32\pi} m_{q_i}^2 m_{\pi_v}^3 \sqrt{1 - \frac{4m_{q_i}^2}{m_{\pi_v}^2}}\, \Xi_q^2$$

Photons decay channel



$$\Gamma(\pi_v \to \gamma\gamma) = \frac{\alpha_{EM}^2}{64\pi^2} m_{\pi_v}^7 \Xi_\gamma^2$$

ISOCURVES FOR $\mathrm{BR}_\gamma = \mathrm{BR}_{\mathrm{had}} = 0.5$

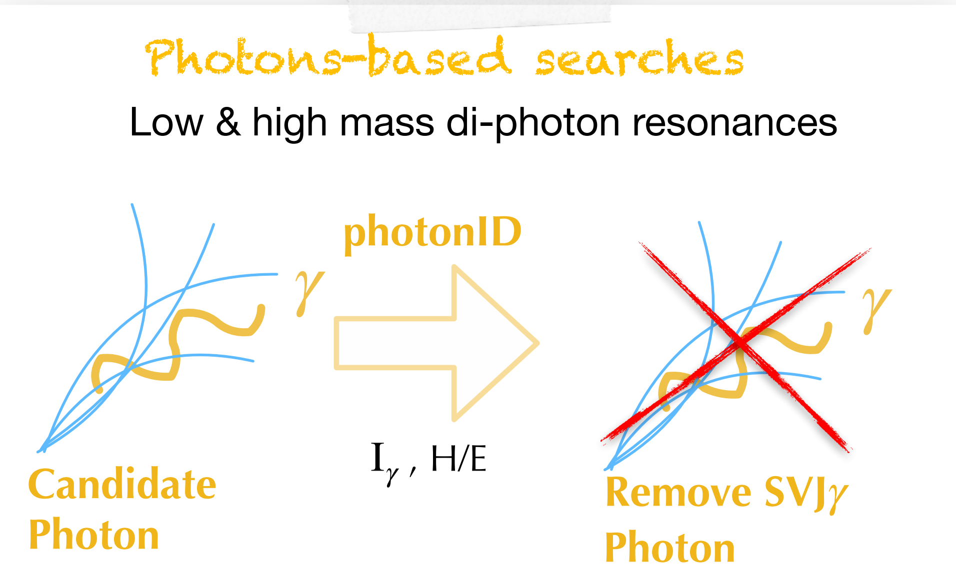


Effective parameters

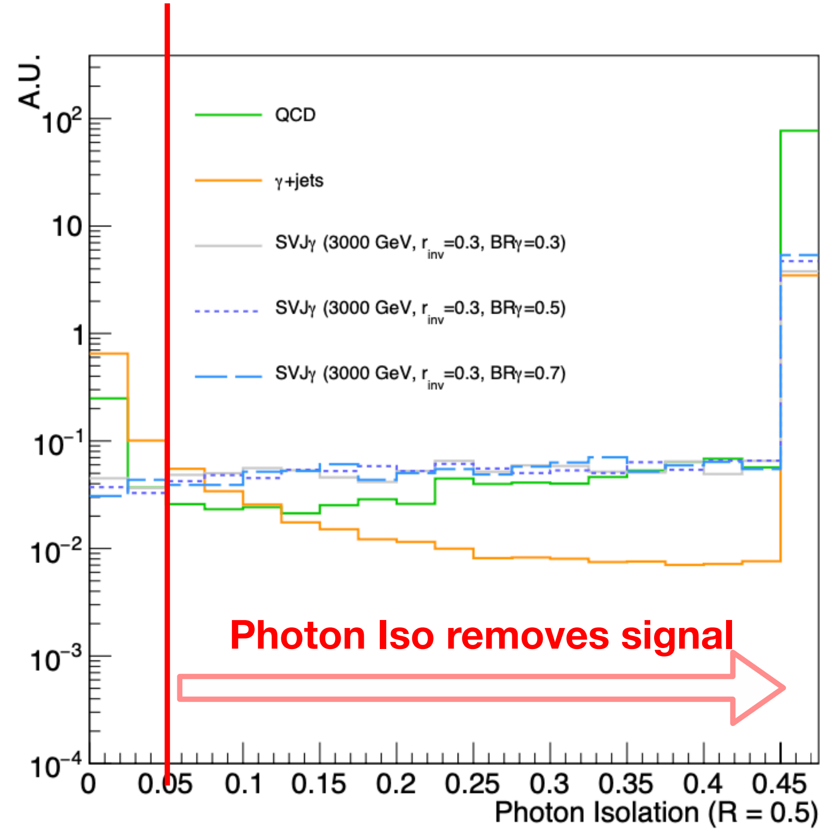
$$\Xi_q := \frac{(\Delta_{ii}^f \Delta_a^{q_v})}{M_{Z'}^2} \qquad \Xi_p := \frac{y_Q y_\psi}{m_a^2 M_Q}$$

- Allow to tune branching to hadrons ($\mathrm{BR}_{\mathrm{had}}$) and photons ($\mathrm{BR}_\gamma$)
- Able to define a **parametric model** that can be mapped to the simplified one

Photons-based Searches Inefficiencies

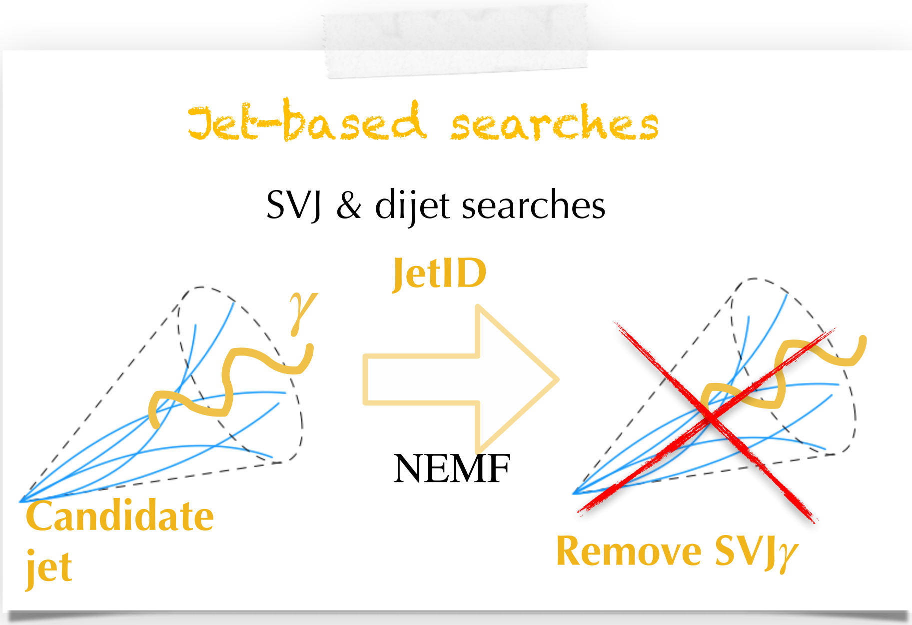


I_γ = photons isolation, H/E = hadronic vs electromagnetic Calo tower energy

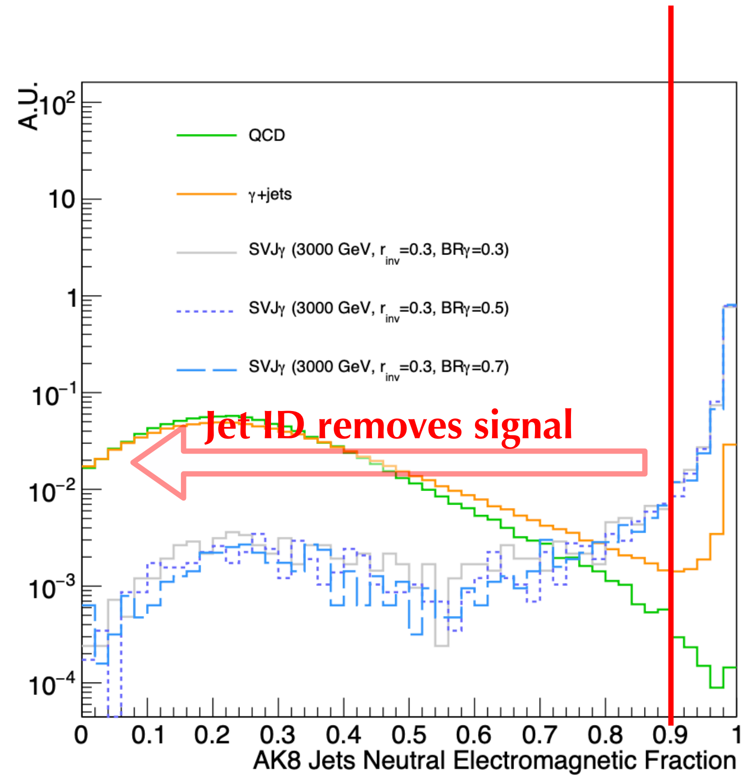


Typical photons-based searches not sensitive to SVJγ due to tight isolation criteria applied to remove jets faking photons

Jet-based Searches Inefficiencies



NEMF = Neutral ElectroMagnetic Fraction



Typical jets-based searches not sensitive to SVJγ due to identification requirements to remove photons faking jets

Applying SVJh CMS Search Selections

Standard SVJ Hadronic Analysis

Selections
1. At least 2 good jets (R = 0.8)
2. Large missing momentum: $R_T > 0.15$
3. Maximum $\Delta\eta(\mathrm{J}_1, \mathrm{J}_2)$: $\Delta\eta < 1.5$
4. Trigger plateau ($\mathrm{m_T} > 1.5$ TeV)
5. Jets aligned with MET: $\Delta\phi(\not{E}_T, J_{1,2}) < 0.8$

SELECTIONS BASED ON CMS ANALYSIS : JHEP 06, 156 (2022)

Variables Legend

: di-jet transverse mass

: $\not{E}_\mathrm{T}/\mathrm{m_T}$

Selection	Signal efficiency (%) BR$_\gamma$: 0.7	0.5	0.3
N(AK8 jets without NEMF) ≥ 2	1.60	1.51	1.54
$\Delta\eta(j_1, j_2) < 1.5$	1.00	1.05	1.08
$M_\mathrm{T} > 1500\,\mathrm{GeV}$	0.74	0.74	0.73
$R_\mathrm{T} > 0.15$	0.47	0.50	0.60
$\Delta\phi_{\min}(\not{E}_\mathrm{T}, j) < 0.8$	0.39	0.38	0.38

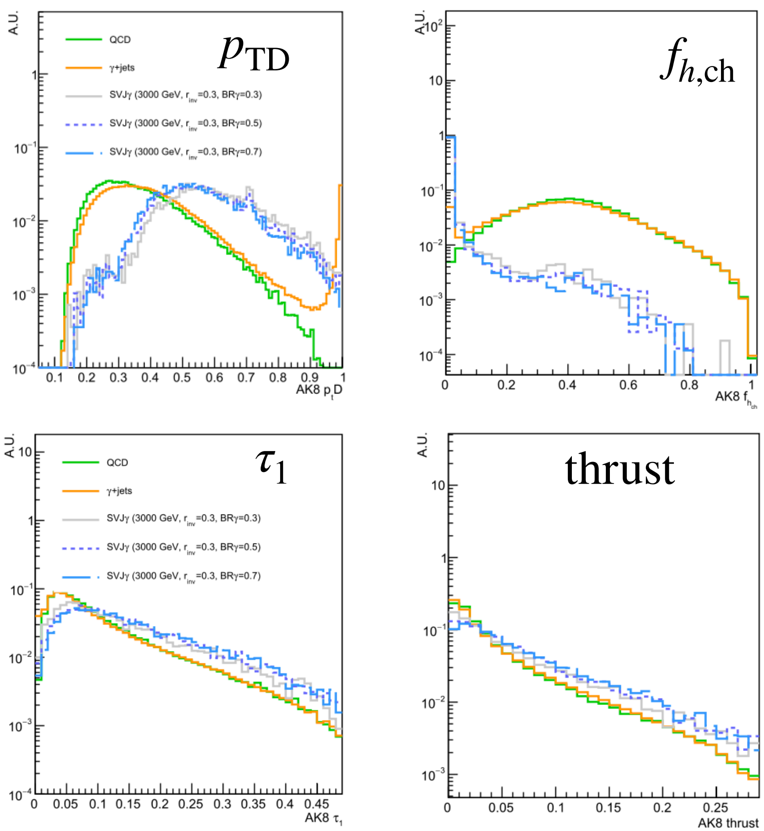
Remove JetID

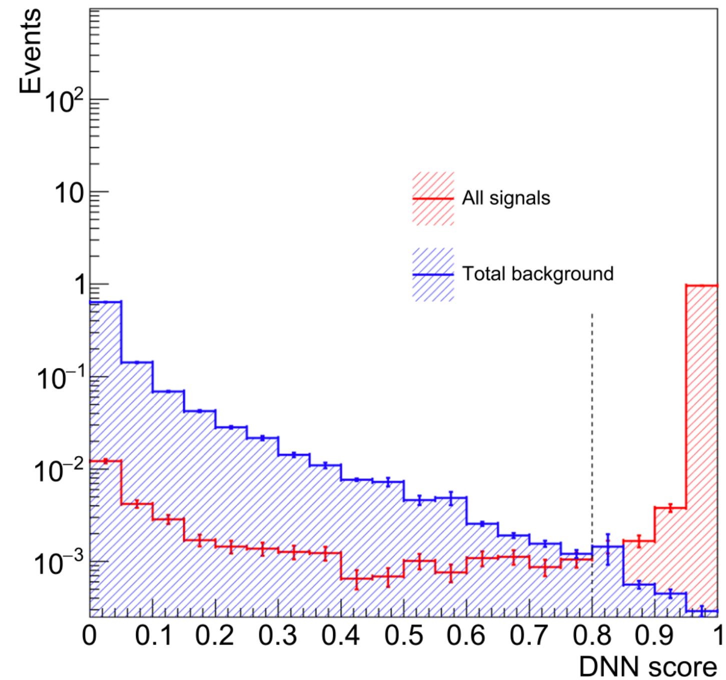
Selection	Signal efficiency (%) BR$_\gamma$: 0.7	0.5	0.3
N(AK8 jets with NEMF) ≥ 2	78.00	69.34	52.71
$\Delta\eta(j_1, j_2) < 1.5$	52.70	47.74	37.59
$M_\mathrm{T} > 1500\,\mathrm{GeV}$	42.66	35.62	23.84
$R_\mathrm{T} > 0.15$	23.38	22.12	16.79
$\Delta\phi_{\min}(\not{E}_\mathrm{T}, j) < 0.8$	21.04	19.43	13.98

BUT expected to retain 10% more $\gamma + \mathrm{jets}$

SVJγ Tagging Algorithm

Powerful DNN features

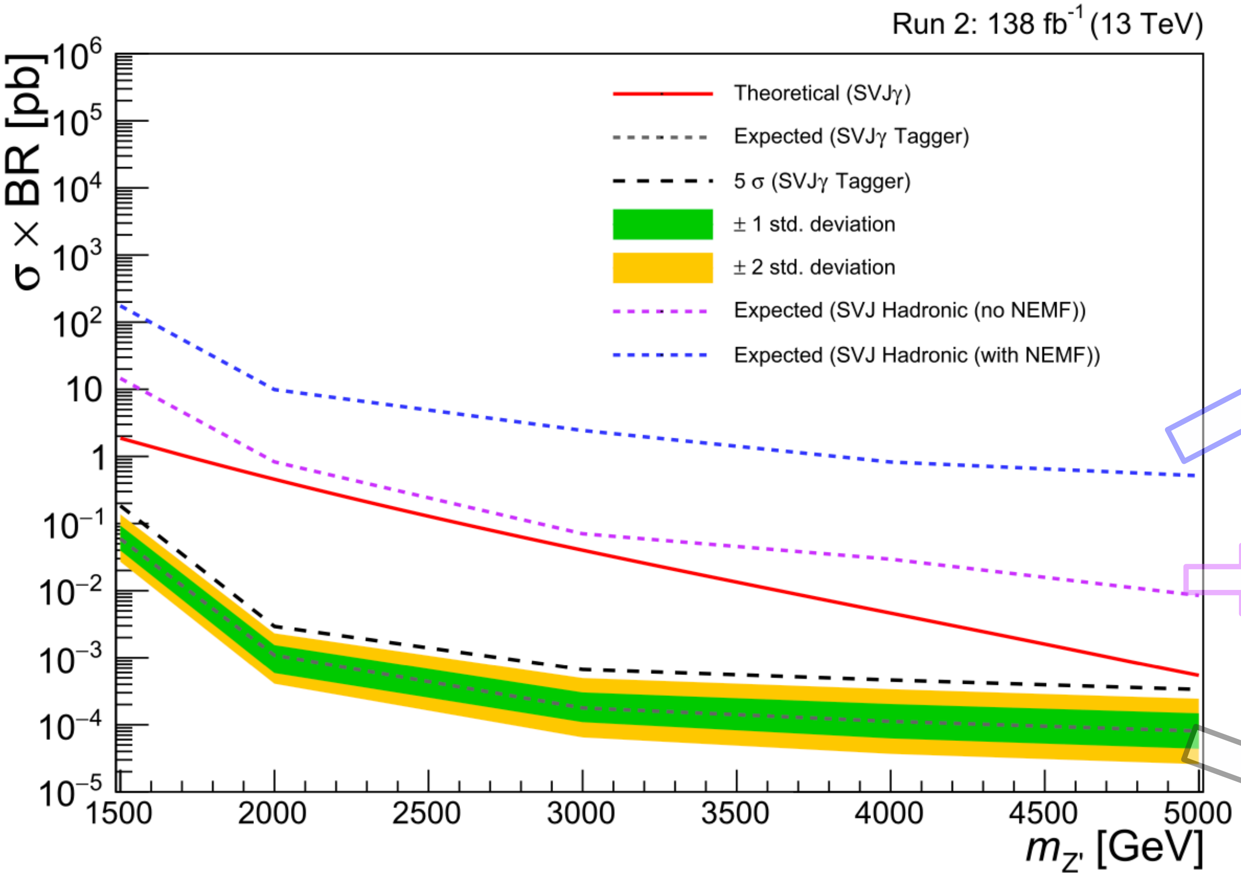




Trained Deep Neural Network on **jet substructure features** to identify SVJγ against QCD and $\gamma + \text{jets}$

(*) more performance plots in backup

SVJγ Expected Sensitivity



Sensitivity of a standard hadronic search

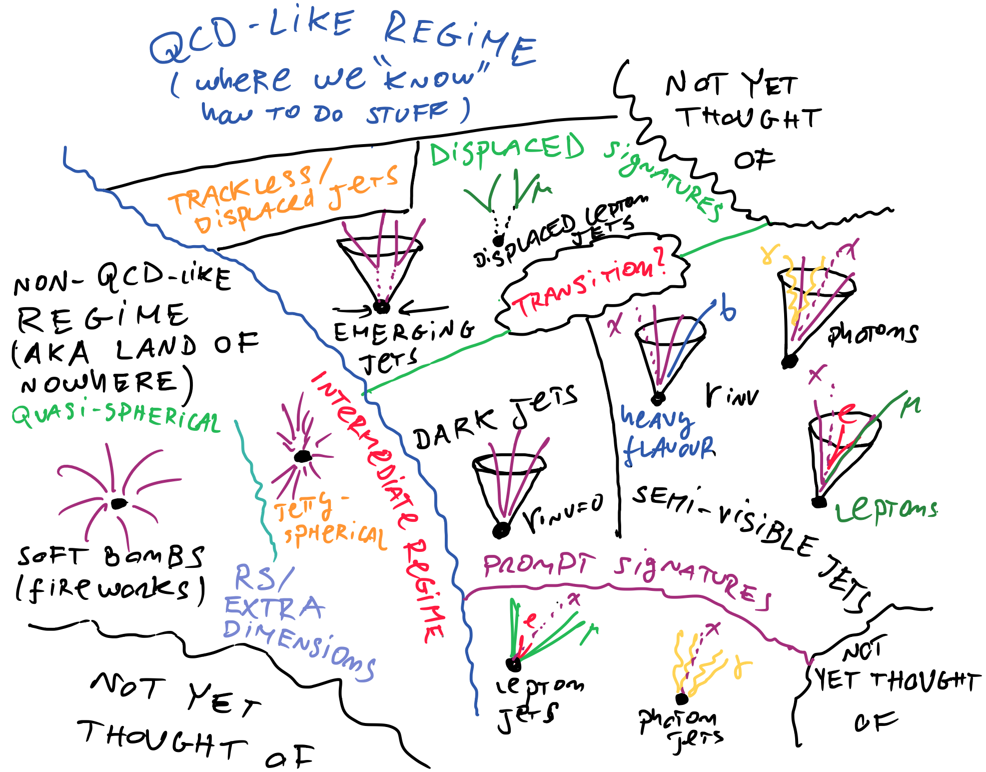
Sensitivity of a modified hadronic search without jet id

Sensitivity of a hadronic search **without jet id + jet tagger**

Photons-enriched semi-visible jets can be discovered in Run2 data collected at the LHC but need to remove standard jet id and employ a dedicated jet tagger exploiting jet substructure

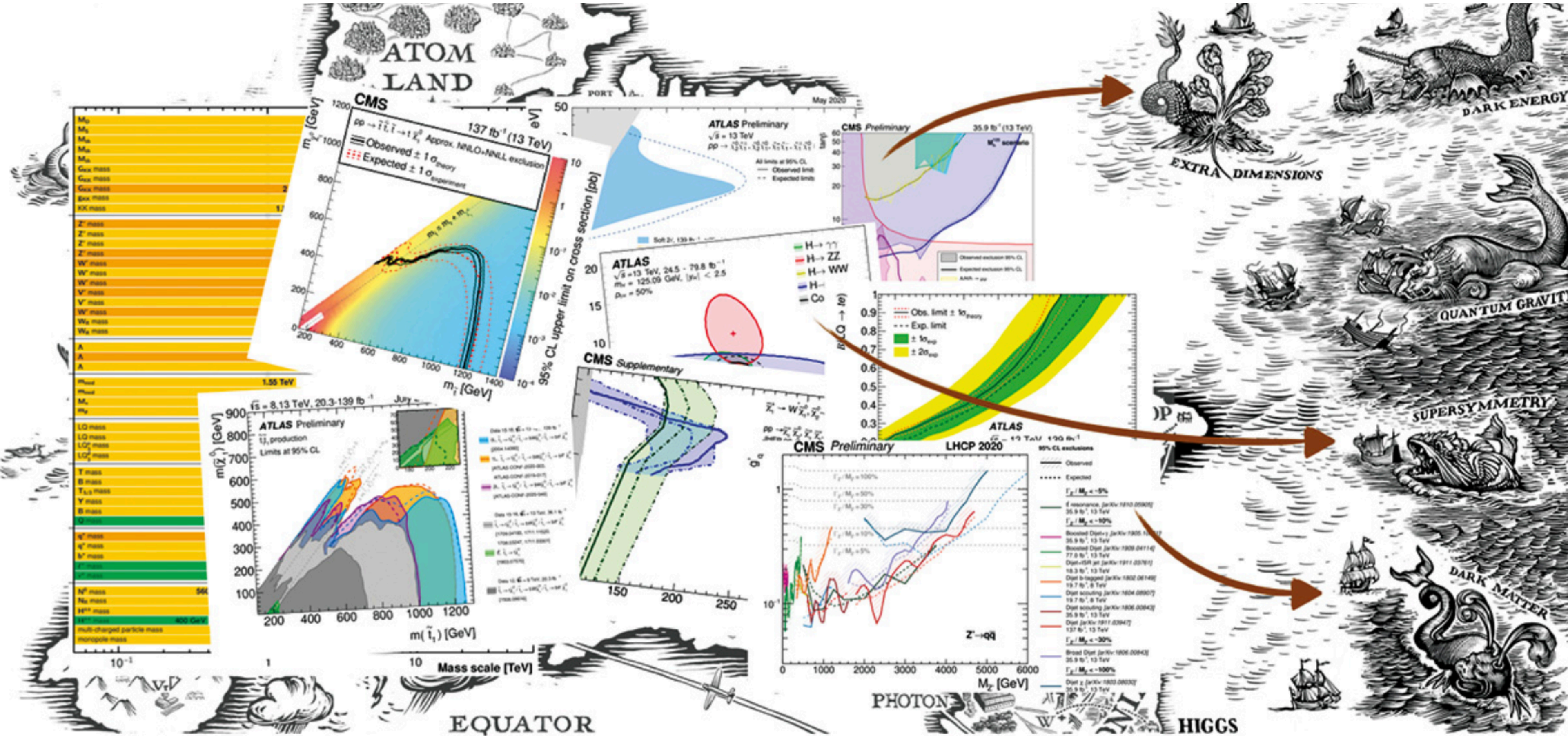
Summary And Conclusions

- Presented new signature for semi-visibler jets at the LHC characterised by enhanced fraction of photons
- Current jet identification/quality criteria tailored for SM objects discard the signal
- New SVJγ algorithm based on jet substructure can be employed to enhance signal sensitivity and Discover/exclude these signals at the LHC !



GROWING FIELD & UNCHARTED TERRITORIES STILL TO BE EXPLORED !

BACKUP


ATOM LAND
EXTRA DIMENSIONS
DARK ENERGY
QUANTUM GRAVITY
SUPERSYMMETRY
DARK MATTER
EQUATOR
PHOTON
HIGGS
CMS
ATLAS Preliminary
CMS Preliminary
CMS Supplementary
LHCP 2020
Mass scale [TeV]

Backgrounds Efficiencies

Selection	Backgorund efficiency (%)				
	QCD	$t\bar{t}+\text{jets}$	$Z(\nu\bar{\nu})+\text{jets}$	$W(\ell\nu)+\text{jets}$	$\gamma+\text{jets}$
$N(\text{AK8 jets with NEMF}) \geq 2$	98.17	7.19	1.04	1.59	98.55
$\Delta\eta(j_1, j_2) < 1.5$	66.53	5.33	0.67	1.11	68.40
$M_T > 1500\,\text{GeV}$	14.98	0.15	0.04	0.03	17.37
$R_T > 0.15$	0.69	0.03	0.02	0.01	0.81
$\Delta\phi_{\min}(\not{E}_T, j) < 0.8$	0.68	0.03	0.01	0.01	0.79

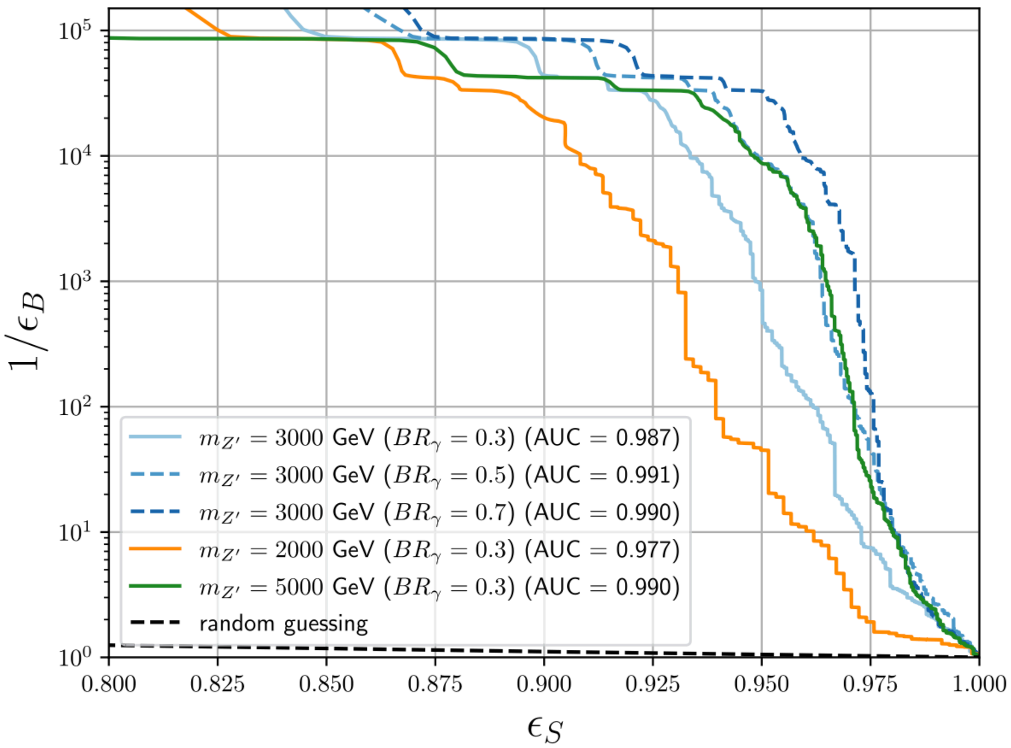
Table 3: Event selections (without the NEMF requirement in the JetID for AK8 jets) applied to the backgrounds.

Selection	Backgorund efficiency (%)				
	QCD	$t\bar{t}+\text{jets}$	$Z(\nu\bar{\nu})+\text{jets}$	$W(\ell\nu)+\text{jets}$	$\gamma+\text{jets}$
$N(\text{AK8 jets with NEMF}) \geq 2$	98.03	7.19	1.04	1.57	89.16
$\Delta\eta(j_1, j_2) < 1.5$	66.44	5.33	0.67	1.10	60.86
$M_T > 1500\,\text{GeV}$	14.96	0.15	0.03	0.03	15.68
$R_T > 0.15$	0.69	0.03	0.02	0.01	0.76
$\Delta\phi_{\min}(\not{E}_T, j) < 0.8$	0.68	0.03	0.01	0.01	0.75

Table 4: Event selections (including the NEMF requirement in the JetID for AK8 jets) applied to the backgrounds. The JetID applied here consists only of a requirement on the NEMF (NEMF is required to be less then 0.9 (0.99) for $\eta < 2.6$ ($2.6 < \eta < 2.7$)).

Jet Identification Algorithm Performance

ROC Curves at $\Lambda_{dark} = 20$ GeV



AUC Scanning over Λ_{dark} and $M_{Z'}$