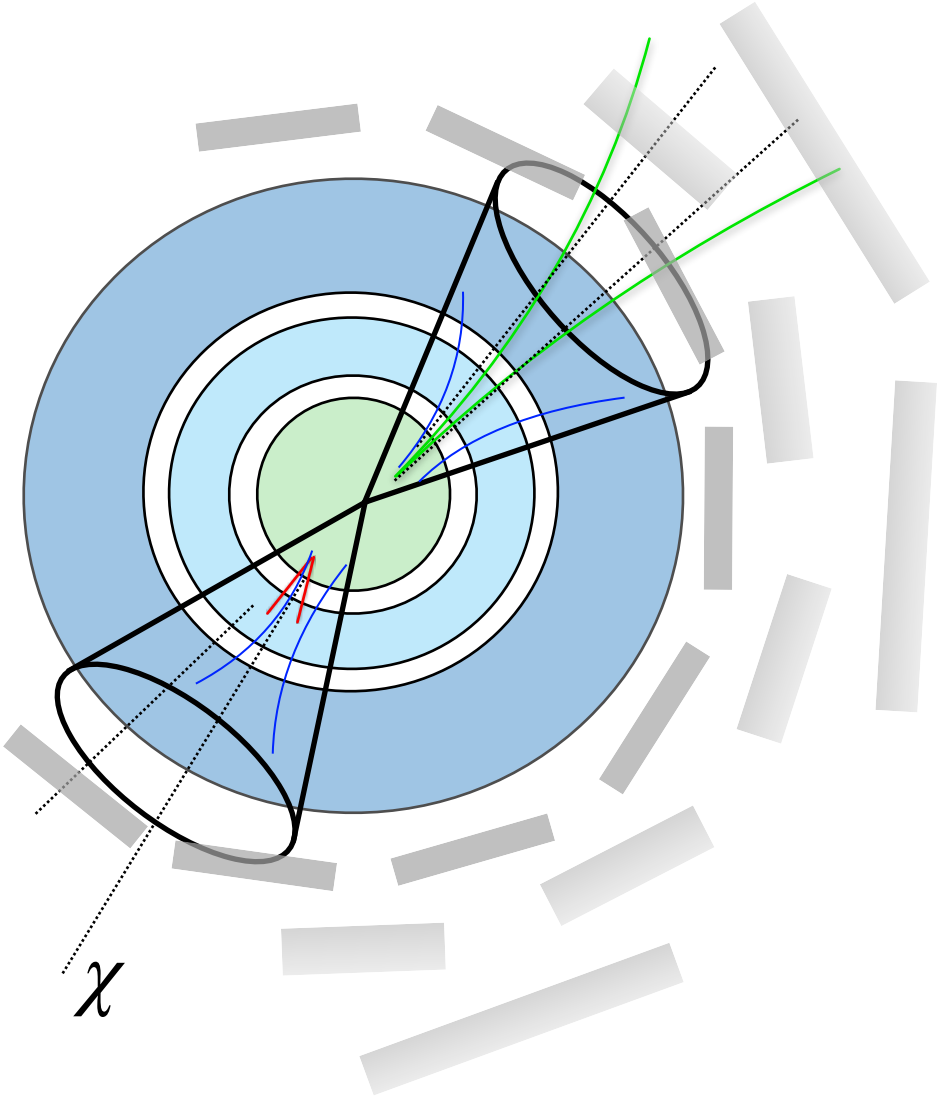
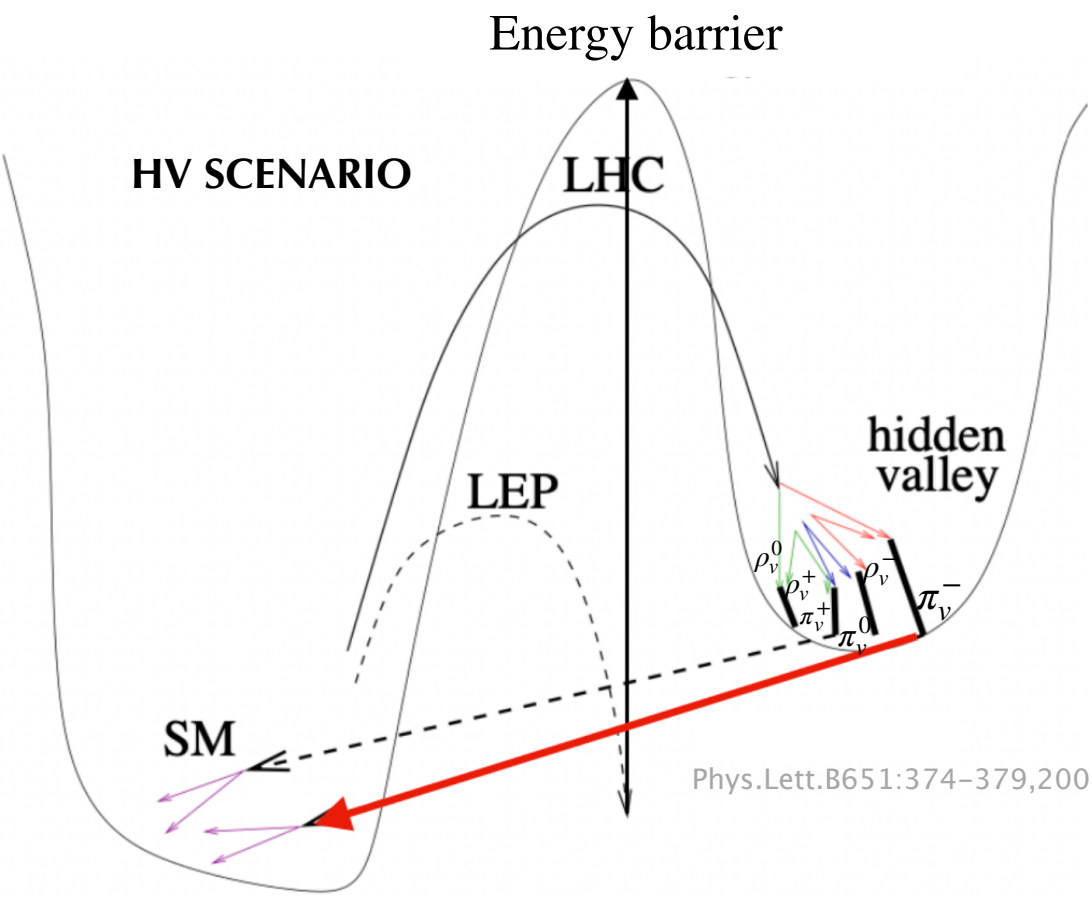


Leptons-Enriched Signatures For Semi-Visible Jets

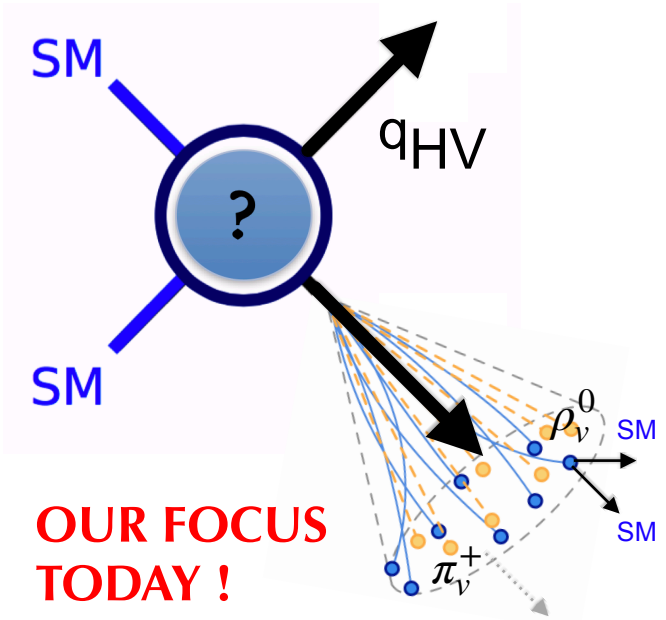
Cesare Cazzaniga

HIDDEN VALLEYS AND QCD-LIKE HIDDEN SECTORS



Phys.Lett.B651:374-379,2007

DARK QCD @ COLLIDERS

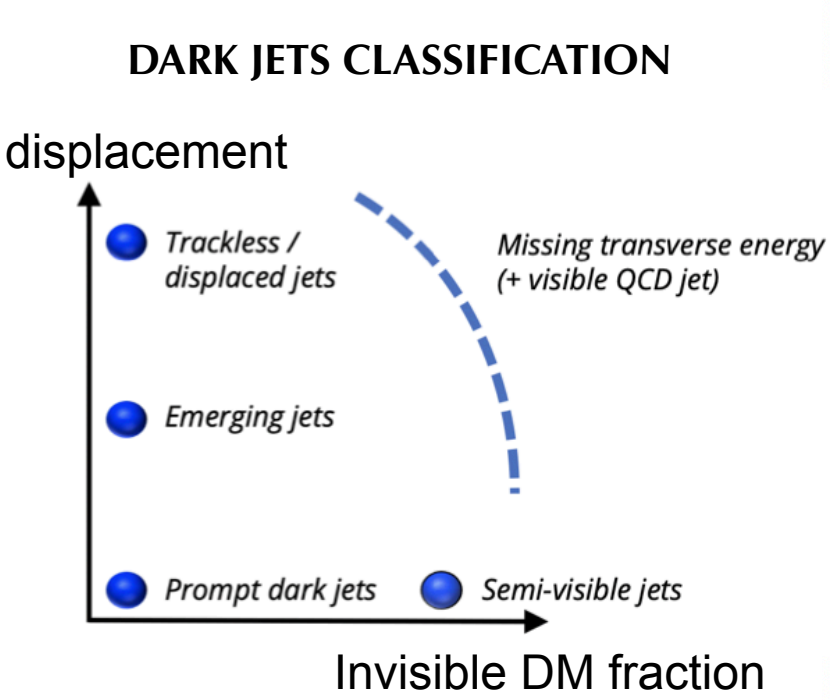


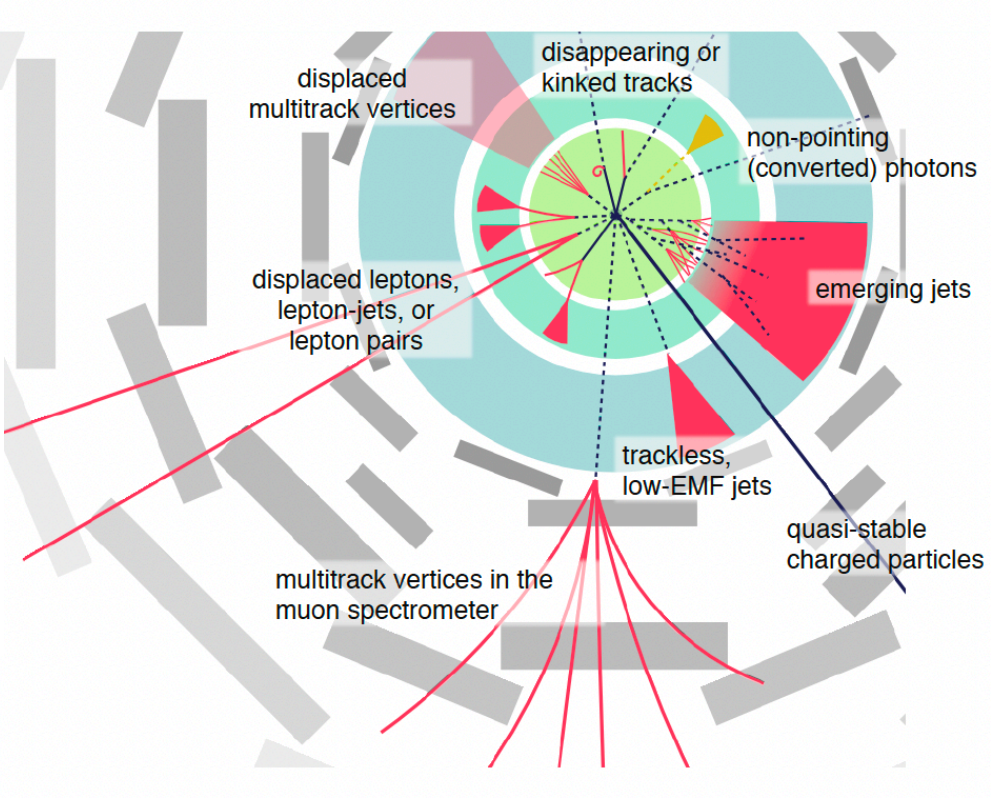
OUR FOCUS TODAY !

Stable/metastable (DM candidates)

CLASS OF MODELS WITH UNCONVENTIONAL COLLIDER SIGNATURES !

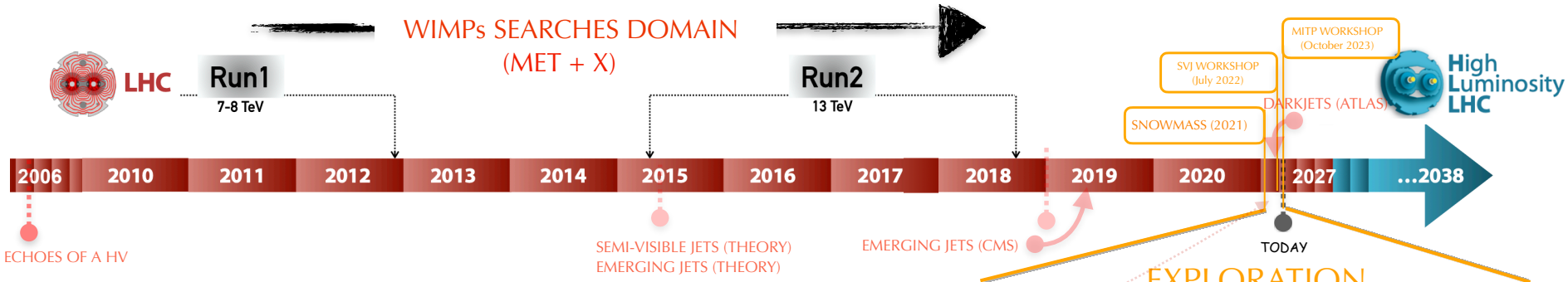
BEYOND CONVENTIONAL SIGNATURES





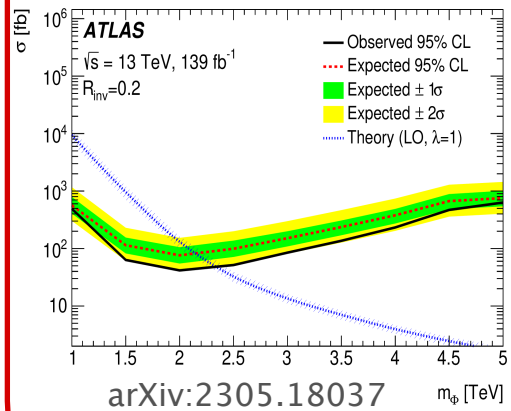
HIDDEN VALLEYS: NEW UNEXPLORED SIGNATURES ACCORDING TO BOUND STATES LIFE-TIMES AND DECAY MODES

QCD-LIKE DARK SECTORS @ THE LHC



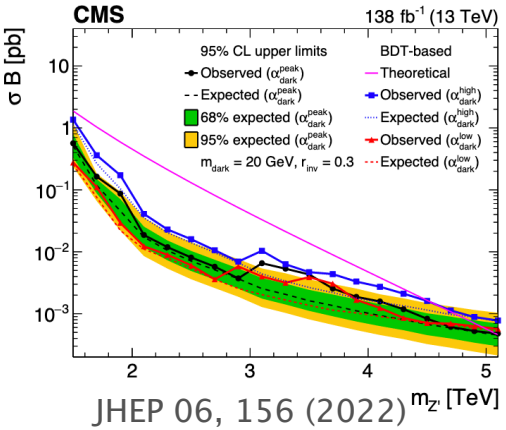
SEMI-VISIBLE JETS (SVJ)

t-channel



arXiv:2305.18037

s-channel



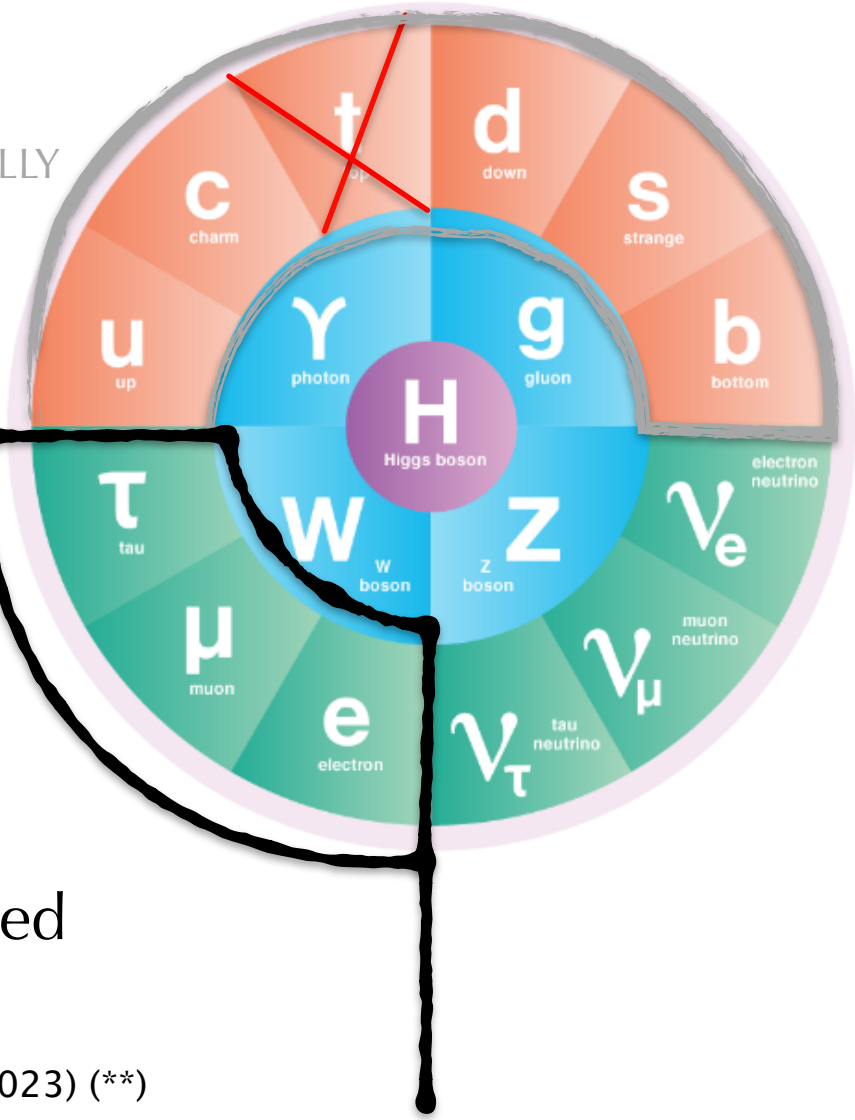
JHEP 06, 156 (2022)

EXPLORATION

Vast landscape of models being investigated,
many others waiting in the drawer,
and lots of others still not being thought of …

OUTLINE

EXPLORED THEORETICALLY
& EXPERIMENTALLY



OUR FOCUS

Leptons-enriched signatures

Eur. Phys. J. C 82, 793 (2022) (*)

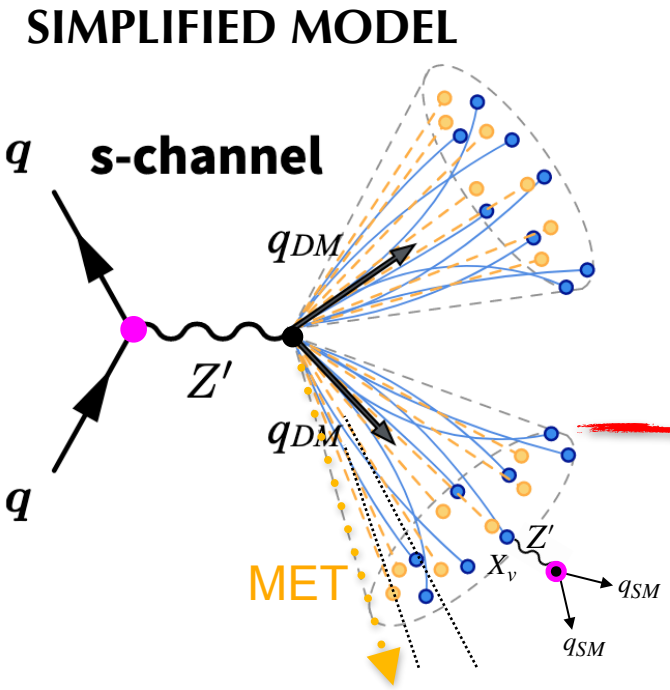
(*) Publication with:
A. de Cosa

τ leptons-enriched signatures

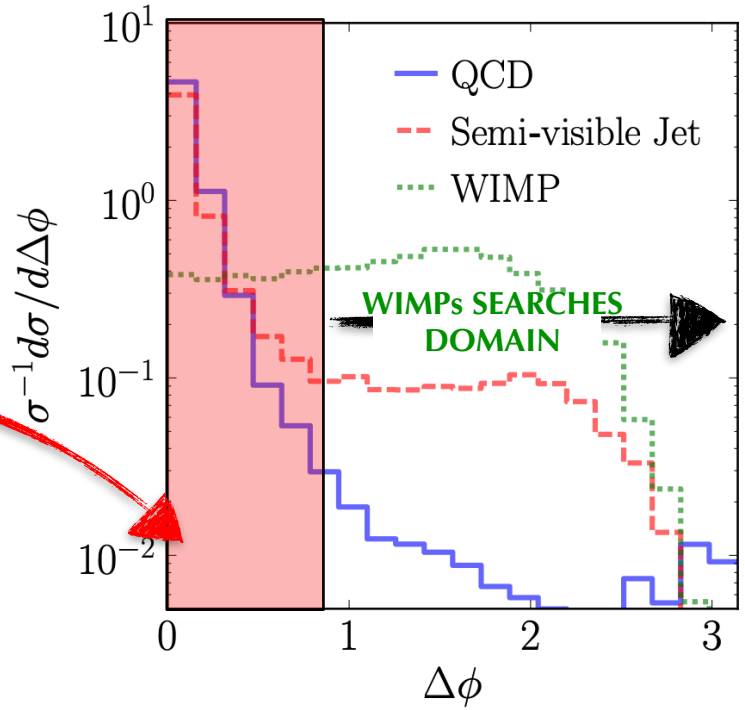
Eur. Phys. J. C 83, 599 (2023) (**)

(**) Publication with:
H. Beauchesne, A. de Cosa, C. Doglioni, T. Fitschen, G. Grilli di Cortona, Z. Zhou

THE IDEA BEHIND SEMI-VISIBLE JETS



RESONANT PRODUCTION OF SVJs

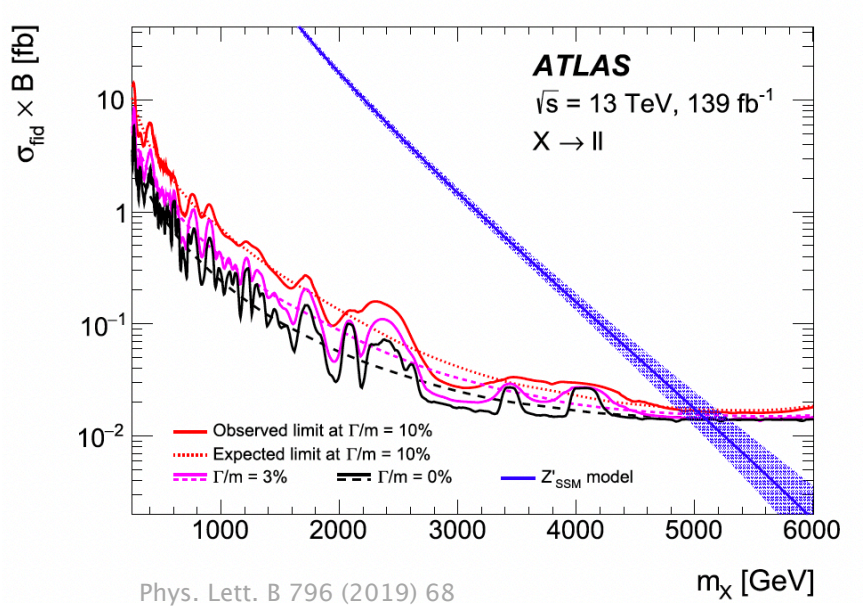


Phys. Rev. Lett. **115**, 171804

SV jets lays in a region orthogonal to WIMPs searches and largely affected by QCD background : challenging signature !

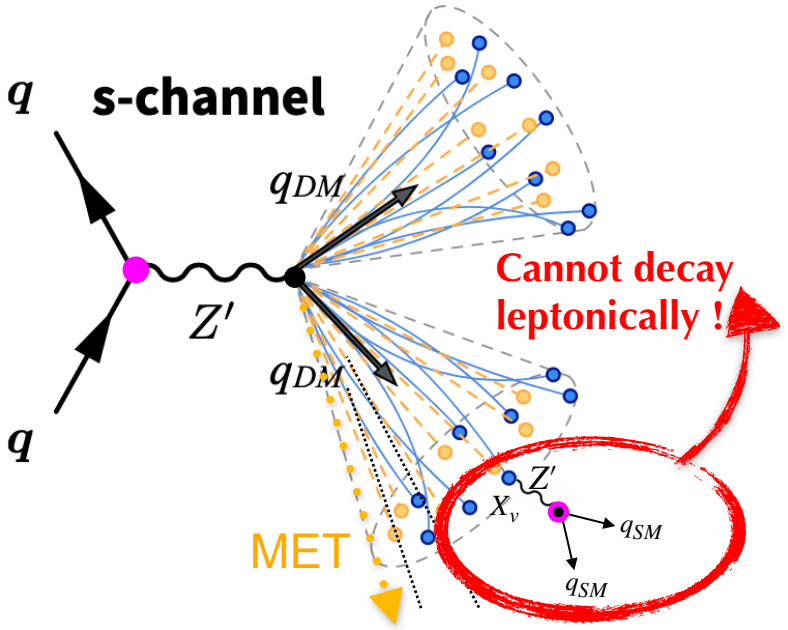
LIMITATIONS OF THE ORIGINAL SVJ MODEL

HIGH MASS DI-LEPTON SEARCH



Phys. Lett. B 796 (2019) 68

SIMPLIFIED MODEL



FULLY HADRONIC SVJ (MULTI-JET + $\not{E}_T$)

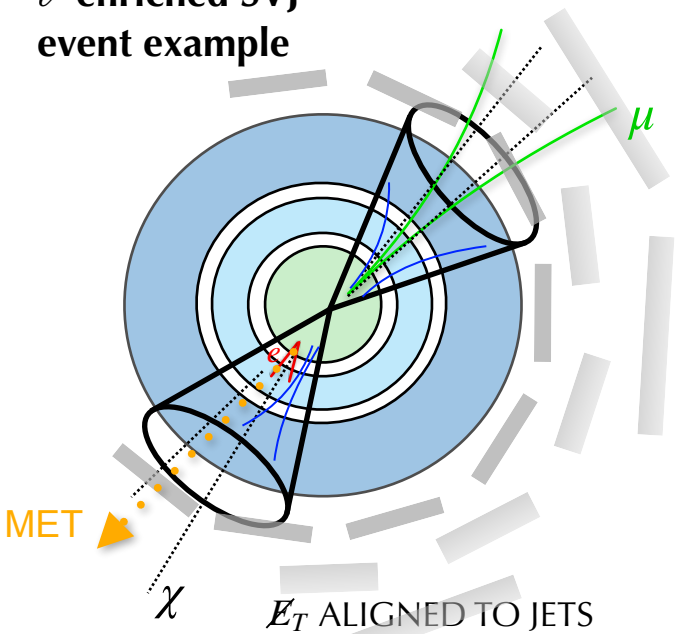
LEPTOPHOBIC (*) Z′ AS MEDIATOR TO EVADE HIGH MASS DI-LEPTON SEARCHES
CONSTRAINTS: FULLY HADRONIC DARK BOUND STATES DECAYS (OFF-SHELL Z′)

(*) constraints on Z′ coupling to leptons (backup)

SIGNATURE-DRIVEN MODEL BUILDING

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

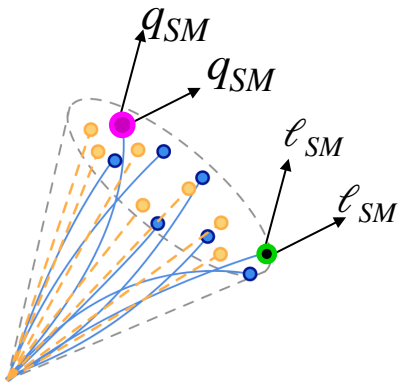
ℓ-enriched SVJ event example



$\not{E}_T$ ALIGNED TO JETS

+ PROMPT LEPTON PAIRS PRODUCED INSIDE HADRONIC JETS

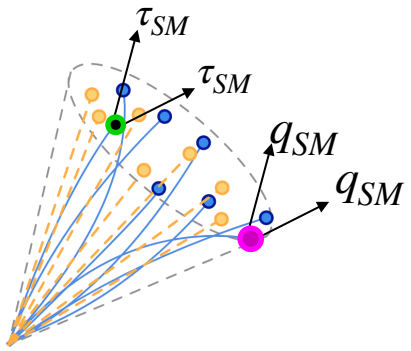
resonant e/μ (τ)
(Model 1 / SVJℓ)



SVJ ℓ-ENRICHED

Eur. Phys. J. C 82, 793 (2022)

"non-resonant"
(Model 2 / SVJτ)



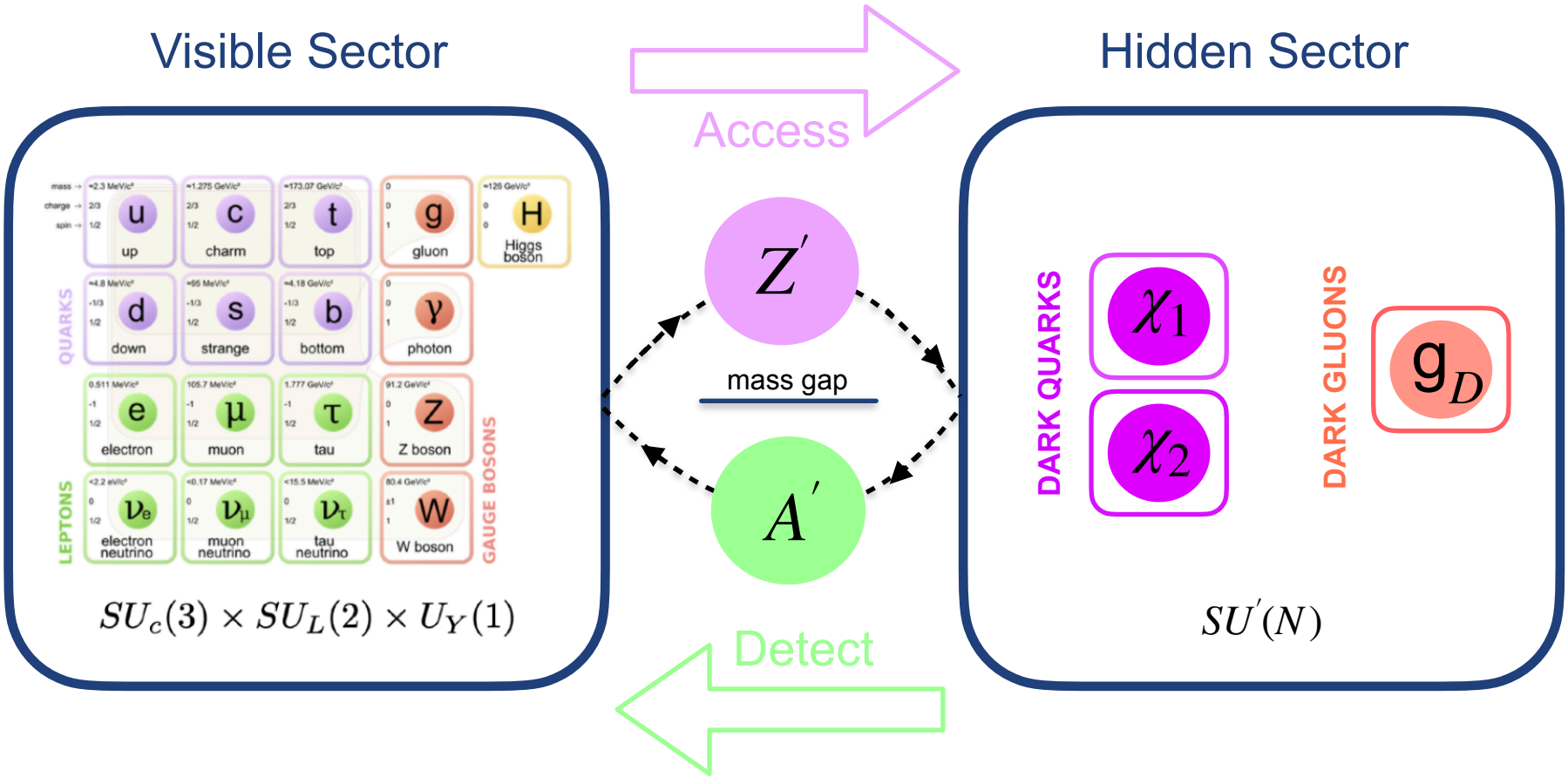
SVJ τ-ENRICHED

Eur. Phys. J. C 83, 599 (2023)

SIMPLIFIED MODEL(S) ?

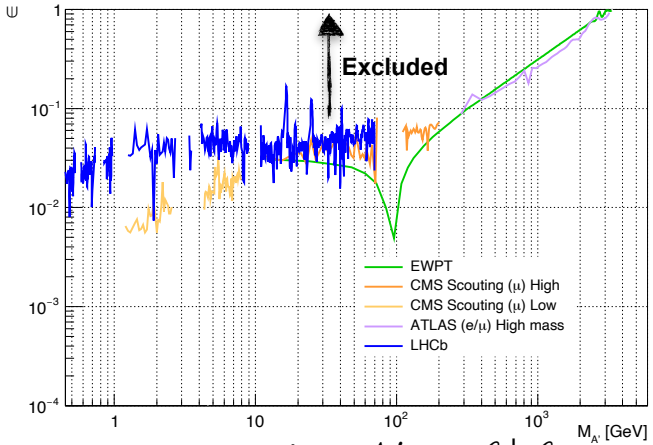
Eur. Phys. J. C 82, 793 (2022)
PRD 103, 115013 (2021)

MODEL 1: TWO MESSENGER FIELDS



MODEL 1: PARAMETERS & CONSTRAINTS

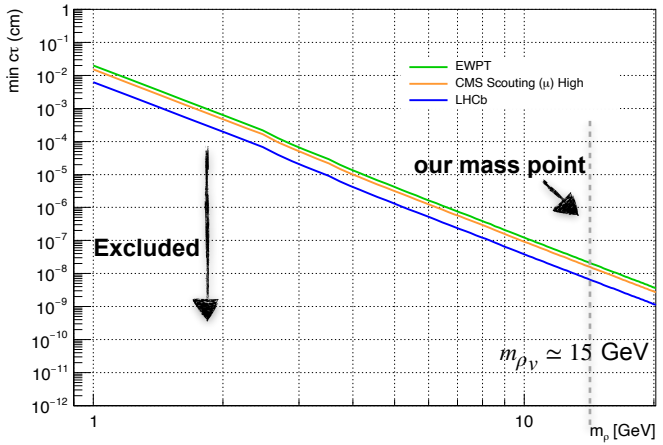
Parameter	Description	Benchmark
$M_{Z'}$	Z' pole mass	1.5–5 TeV
$\epsilon_{\text{eff,v}}$	Effective mixing	0.03
r_{inv}	Invisible fraction	0.3, 0.5, 0.7
Λ_v	Dark confinement scale	5 GeV
m_{π_v}/Λ_v (*)	Pseudo-scalar mass ratio	1.6



constraints $A' \to \ell^+\ell^-$

- **~ 15% democratic decay** of unstable ρ to <u>all lepton flavours</u>
- **Z′ COUPLINGS SETTINGS**: $g^v_{Z'} = 0.4$, $g^q_{Z'} = 0.25$

[Phys. Dark Univ. 27, 100365 (2020)
JHEP 06, 156 (2022)]



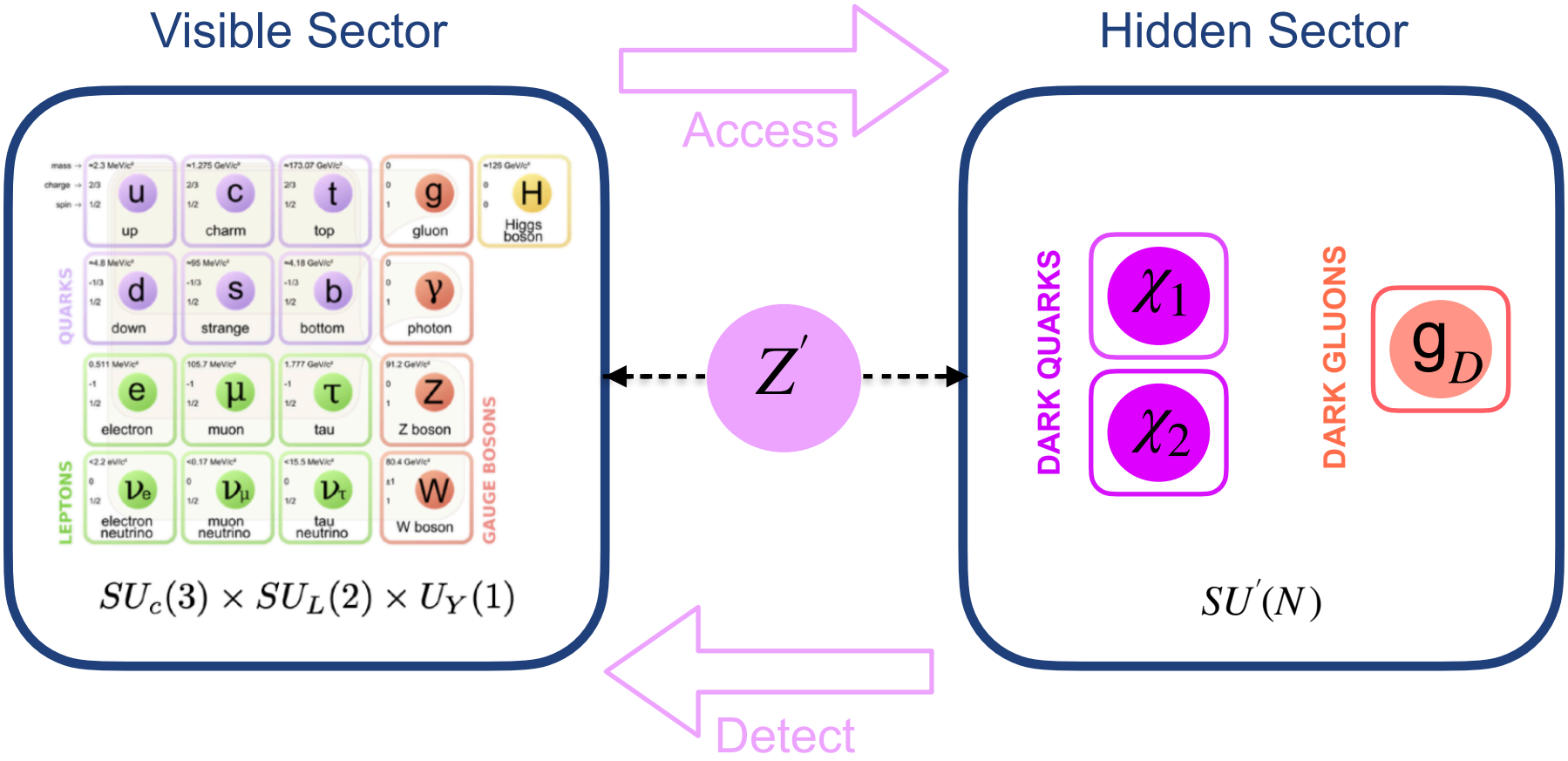
* effective mixing fixed saturating $A' \to \ell^+\ell^-$ bounds

** dark hadron masses set using Lattice QCD fits (Nf = 2, Nc = 3):

$m_{\pi_v} = 8$ GeV $m_{\rho_v} \simeq 15$ GeV $\rho \to \pi\pi$ closed

Eur. Phys. J. C 83, 599 (2023)

MODEL 2: SINGLE MESSENGER FIELD



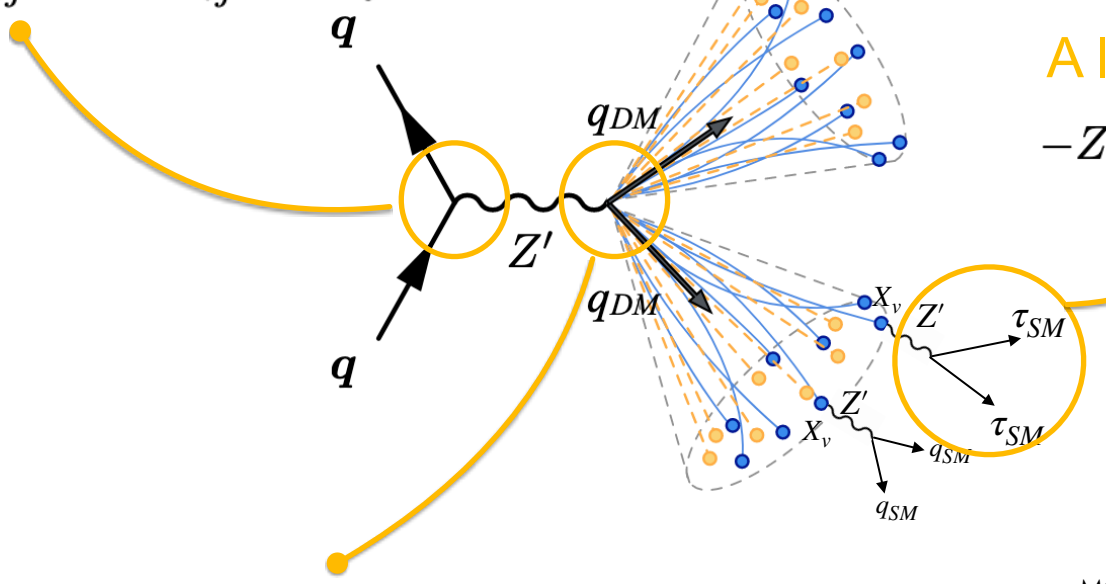
Eur. Phys. J. C 83, 599 (2023)

MODEL 2: SINGLE MESSENGER FIELD

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 leptonic decay mode

$$-Z'_\mu \bar{e}_i \gamma^\mu (g_{ij}^{e_R} P_R + g_{ij}^{e_L} P_L) e_j$$

A coupling to the dark sector

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

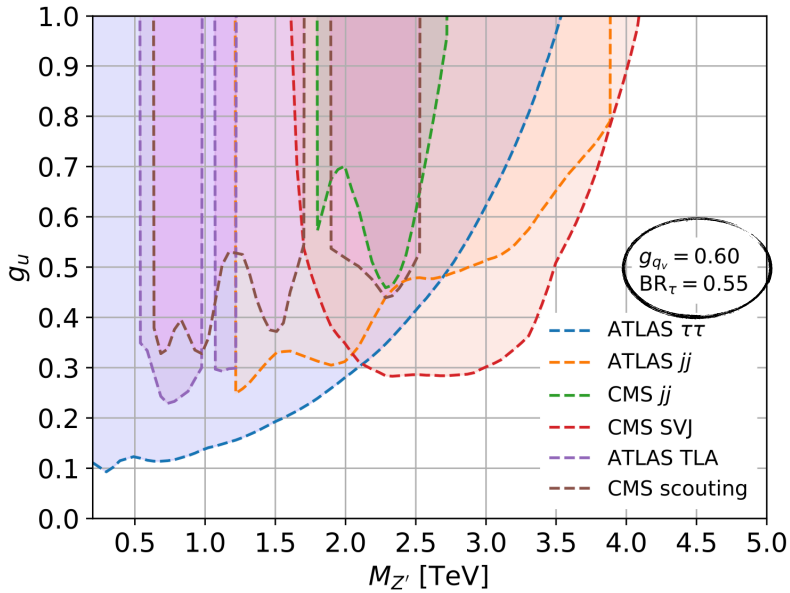
MODEL BASED ON:

Phys. Rev. D 84, 115006 (2011)

Phys. Rev. D 89, 095033 (2014)

MODEL 2: PARAMETERS & CONSTRAINTS

Parameter		Description	Benchmark
$M_{Z'}$		Z' pole mass	0.5-5 TeV
r_{inv}	(*)	invisible fraction	0.3
Λ_v		dark confinement scale	10 GeV
m_{π_v}/Λ_v	(**)	pseudo-scalar mass ratio	0.8
BR_τ	(***)	branching to τ leptons	0.15, 0.3 0.55, 0.7



* Neutrinos can be included adding a term $\propto \text{BR}_\tau \times (1 - r_{inv})$

** dark hadron masses set using Lattice QCD fits (Nf = 2, Nc = 3):

$m_{\pi_v} = 8$ GeV $\quad m_{\rho_v} \simeq 25$ GeV $\quad \rho \to \pi\pi$ open

see Eur. Phys. J. C (2022) , and backup

*** effective parameter controlled by the ratio: g_u/g_τ

Constrained by high mass di-lepton searches

COUPLINGS SETTINGS

$$g_{ij}^{d_R} = g_{ij}^{d_L} = g_{ij}^{u_L} = g_{ij}^{e_L} = 0, \quad g_{ij}^{u_R} = g_u \delta_{ij},$$
$$g_{ij}^{e_R} = g_\tau \delta_{i3}\delta_{j3}, \quad g_{ij}^{q_v R} = g_{ij}^{q_v L} = g_{q_v}\delta_{ij}.$$

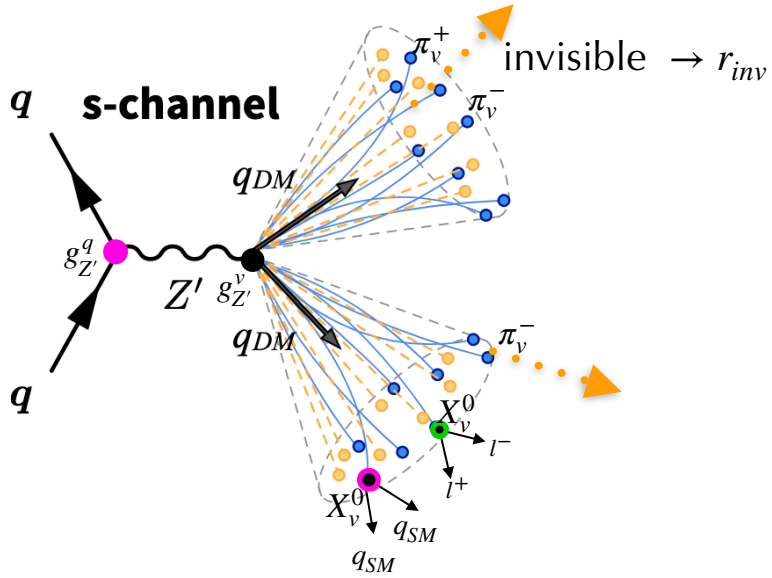
respect NWA

Allow coupling to third generation leptons

[Phys. Dark Univ. 27, 100365 (2020) JHEP 06, 156 (2022)]

SIGNAL AND BACKGROUND PROCESSES

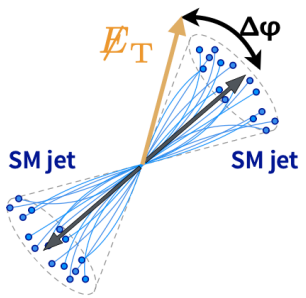
Signal Process



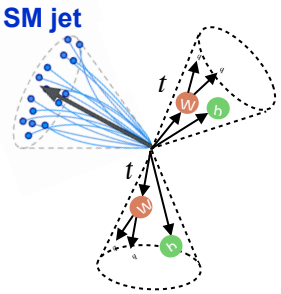
- Signals and backgrounds generated via (MadGraph5_aMC@NLO +) Pythia8 + Delphes3 (*)
- ➡ Signal model dark shower and hadronization simulated with dedicated Pythia8 module (**Hidden Valley Module**)

Background Process

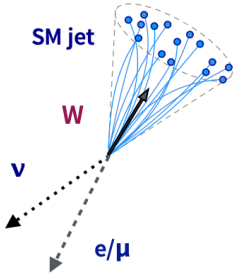
QCD - DIJET



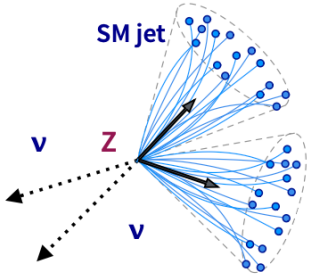
$t\bar{t}$ + jets



W + JETS



Z + JETS



(*) more details in backup

RESONANT HADRONIC SVJ INCLUSIVE ANALYSIS

GOOD OBJECTS

- ≥ 2 AK8 Jets with $p_T > 200$ GeV & $|\eta| < 2.4$
- $p_T(e,\mu) > 10$ GeV & $|\eta(e,\mu)| < 2.4$

SELECTIONS

- $R_T > 0.15$: $\not{E}_T$-like cut, no M_T sculpting
- $\Delta\eta(j_1, j_2) < 1.5$: removes t-channel QCD
- $M_T > 1500$ GeV : trigger requirement
- $\Delta\phi_{min}(j_{1,2}, \not{E}_T) < 0.8$: W/Z + jets suppression
- Veto mini-isolated leptons

LIMITATION MAINLY FOR MODEL 1 (SVJℓ)!

VARIABLES LEGEND

M_T : di-jet transverse mass

R_T : $\not{E}_T/M_T$

IS IT EFFICIENT FOR OUR SIGNATURES ?

Our standard candle to evaluate LHC constraints !

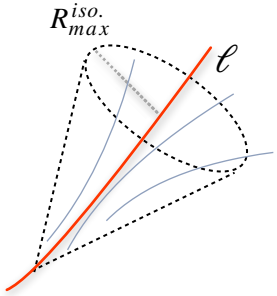
SELECTIONS BASED ON: JHEP 06, 156 (2022)

BUMP HUNT ON A FALLING BACKGROUND IN M_T SPECTRUM : 1.5 - 5 TeV (HIGH MASS SEARCH)

LIMITATIONS: CLASSICAL LEPTONS ISOLATIONS

RELATIVE STANDARD ISOLATION (FIXED R)

$$I(\ell) = \frac{1}{p_{T,l}} \sum_{i \neq \ell}^{\Delta R < R_{max}^{iso.}} p_t(i)$$

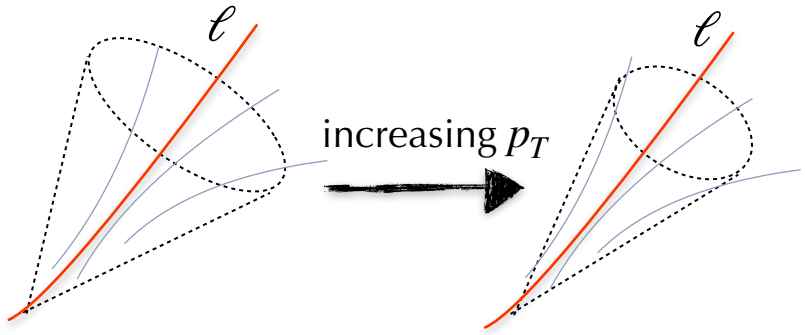


ISOLATION VETO: LIMITATION FOR ELECTRONS AND MUONS PRODUCED INSIDE JETS

RELATIVE MINI-ISOLATION (VARIABLE R) JHEP 1103:059,2011

$$I_{mini} = \frac{1}{p_{T,l}} \sum_{i \neq l}^{\Delta R < R_{max}^{mini\ iso.}} p_t(i)$$

$$R_{\text{max}}^{\text{mini iso.}} = \begin{cases} 0.2, & p_{\text{T}}^{\ell} \leq 50\,\text{GeV} \\ \frac{10\,\text{GeV}}{p_{\text{T}}^{\ell}}, & 50\,\text{GeV} < p_{\text{T}}^{\ell} < 200\,\text{GeV} \\ 0.05, & p_{\text{T}}^{\ell} \geq 200\,\text{GeV} \end{cases}$$



USED IN CMS SVJ AS A VETO

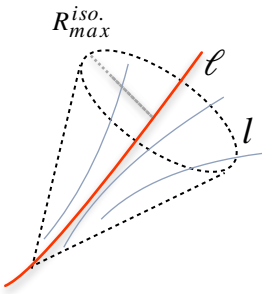
MINI-ISOLATION VETO: LIMITATION FOR e/μ FROM DIRECT DARK BOUND STATES DECAYS (RESONANT SIGNATURE)

BEYOND CLASSICAL ISOLATION: INTER-ISOLATION

RELATIVE INTER-ISOLATION (FIXED R)

Eur. Phys. J. C 82, 793 (2022)

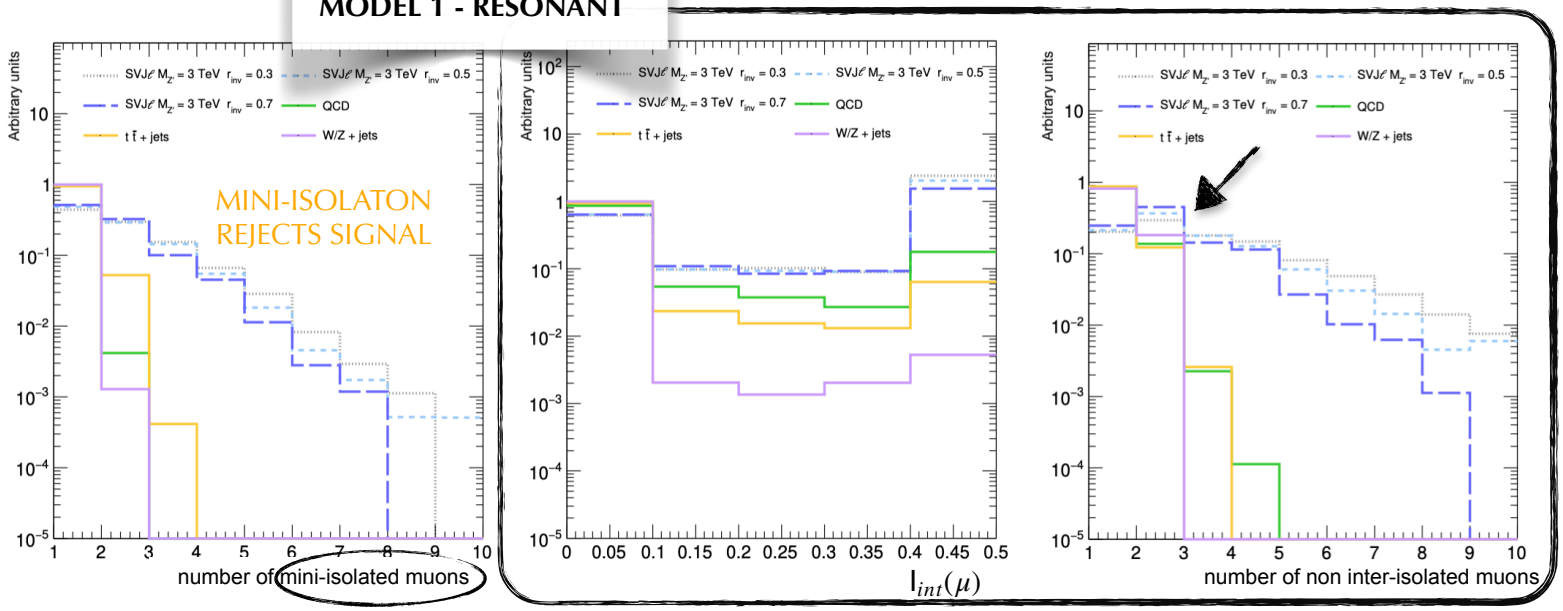
$$I_{int}(\ell) = \frac{1}{p_{T,\ell}} \sum_{l \neq \ell}^{\Delta R < R_{max}^{iso.}} p_t(l)$$



- CAPTURES NEARBY NON-ISOLATED LEPTONS INSIDE JETS (LEPTONIC ACTIVITY)
- BACKGROUNDS ARE EXPECTED TO BE MORE INTER-ISOLATED

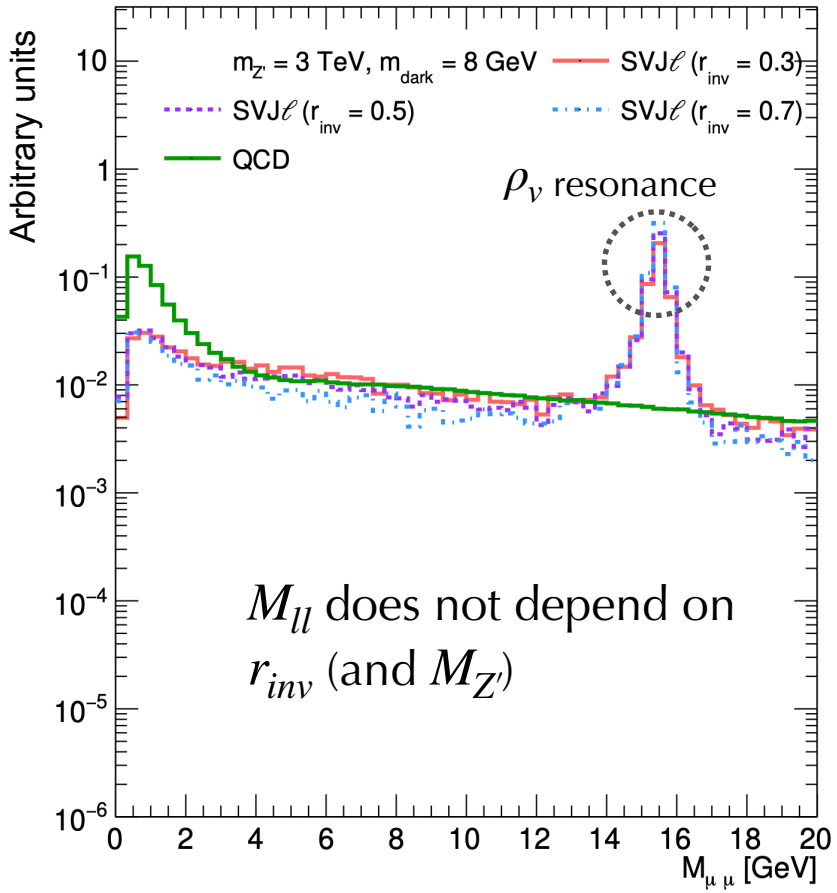
➡ Remove mini-isolated leptons veto and **select opposite sign non inter-isolated leptons pairs (*)**

MODEL 1 - RESONANT



(*) detailed selections in backup

EXPLOITING DI-LEPTON RESONANCE

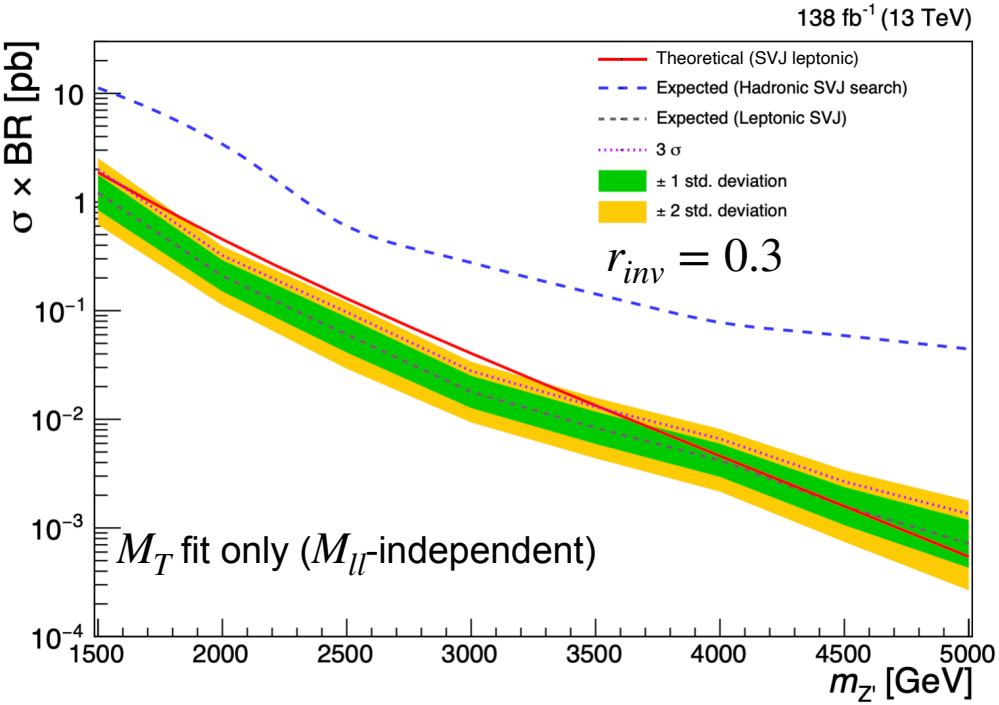


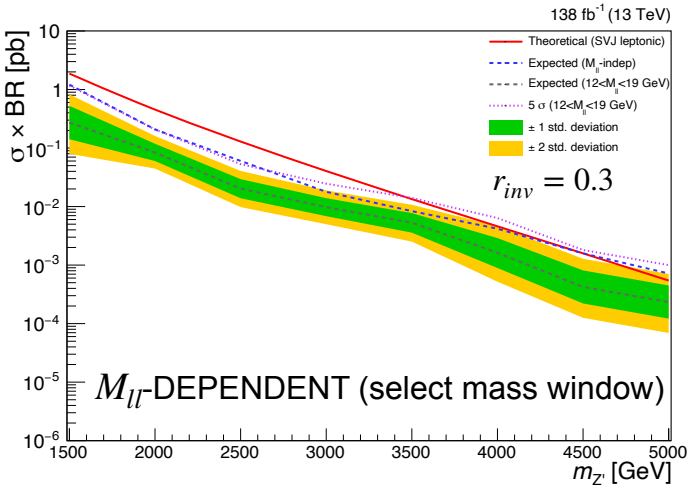
POSSIBLE STRATEGIES

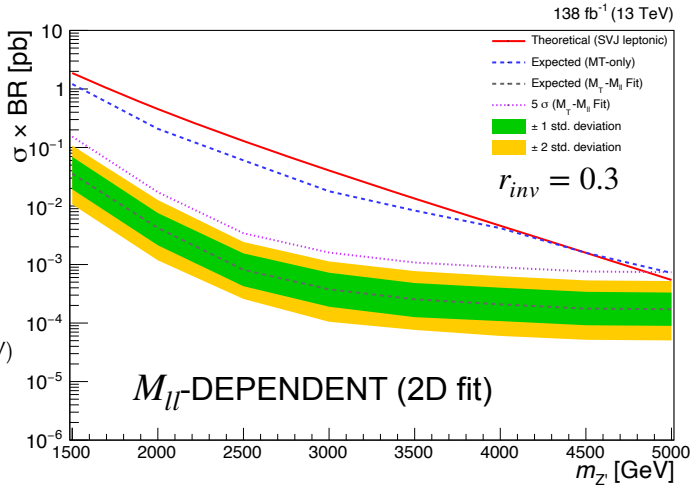
- Can select a mass window in M_{ll} and fit M_T
- Can perform 2D fit $M_{ll} - M_T$
- Can look independently for low mass resonance(s) in the non-isolated di-lepton spectrum

DI-LEPTON MASS SPECTRUM IS MODEL-DEPENDENT AND MULTIPLE RESONANCES ARE POSSIBLE (DARK QUARKS FLAVOURS & POSSIBLE MASS SPLITTING …)

SVJℓ-TARGETED INCLUSIVE ANALYSIS SENSITIVITY







- ✦ CMS INCLUSIVE HADRONIC STRATEGY: NO SENSITIVITY
- ✦ SVJℓ-INCLUSIVE STRATEGY : EXCLUSION REACH (EVIDENCE) UP TO ~ 4.5 TeV (~ 3.5 TeV)
- ✦ IMPROVEMENT EXPLOITING DI-LEPTON RESONANCE - METHOD-DEPENDENT (MODEL-DEPENDENT)

(*) more on limits varying r_{inv} in backup

RESONANT HADRONIC SVJ INCLUSIVE ANALYSIS

GOOD OBJECTS

- ≥ 2 AK8 Jets with $p_T > 200$ GeV & $|\eta| < 2.4$
- $p_T(e,\mu) > 10$ GeV & $|\eta(e,\mu)| < 2.4$

SELECTIONS

- $R_T > 0.15$: $\not{E}_T$-like cut, no M_T sculpting
- $\Delta\eta(j_1, j_2) < 1.5$: removes t-channel QCD
- $M_T > 1500$ GeV : trigger requirement
- $\Delta\phi_{min}(j_{1,2}, \not{E}_T) < 0.8$: W/Z + jets suppression
- Veto mini-isolated leptons

LIMITATION MAINLY FOR MODEL 2 (SVJτ)!

LIMITATION MAINLY FOR MODEL 1 (SVJℓ)!

VARIABLES LEGEND

M_T : di-jet transverse mass

R_T : $\not{E}_T/M_T$

IS IT EFFICIENT FOR OUR SIGNATURES ?

Our standard candle to evaluate LHC constraints !

SELECTIONS BASED ON: JHEP 06, 156 (2022)

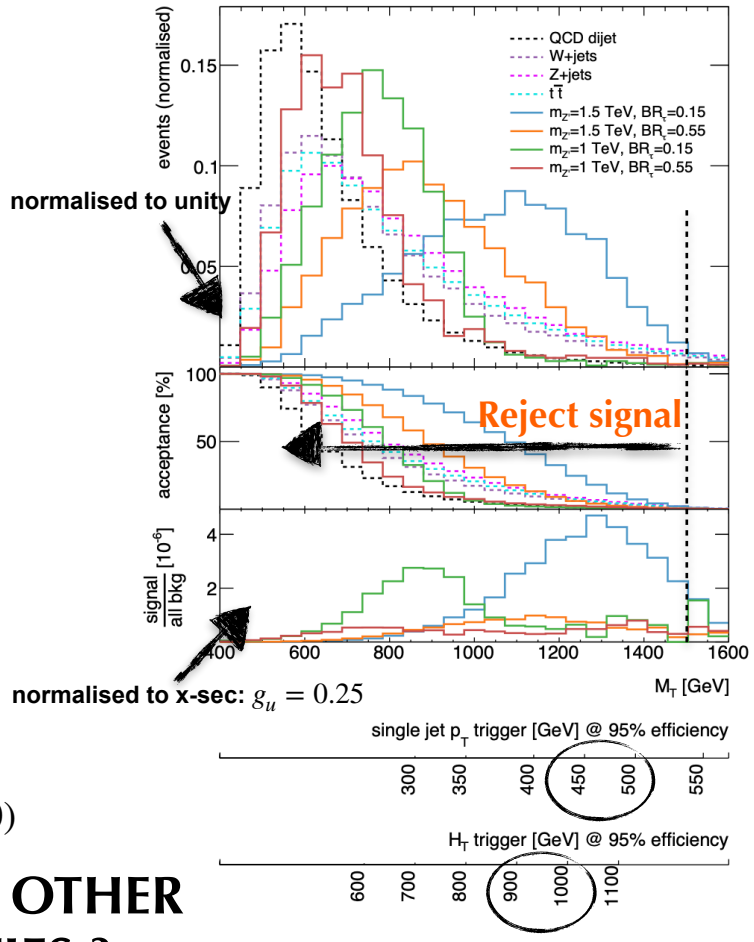
BUMP HUNT ON A FALLING BACKGROUND IN M_T SPECTRUM : 1.5 - 5 TeV (HIGH MASS SEARCH)

LIMITATIONS: JET PT AND HT TRIGGERS

CMS SVJ SEARCH SELECTIONS

Selection	BR_τ :	Signal efficiency (%) 0.7	0.55	0.15
$N(AK8jets) \geq 2$		71.8	76.5	85.7
$\Delta\eta(j_1, j_2) < 1.5$		51.5	53.5	56.6
$M_T > 1500$ GeV		16.2	25.5	42.7
$R_T > 0.15$		10	14.3	20.2
$\Delta\phi_{min}(\not{E}_T, j) < 0.8$		9.3	13.6	19.5
$N_{\mu,e} = 0$		5.7	9.2	17.3

Benchmark mass point: $M_{Z'} = 3\ TeV$

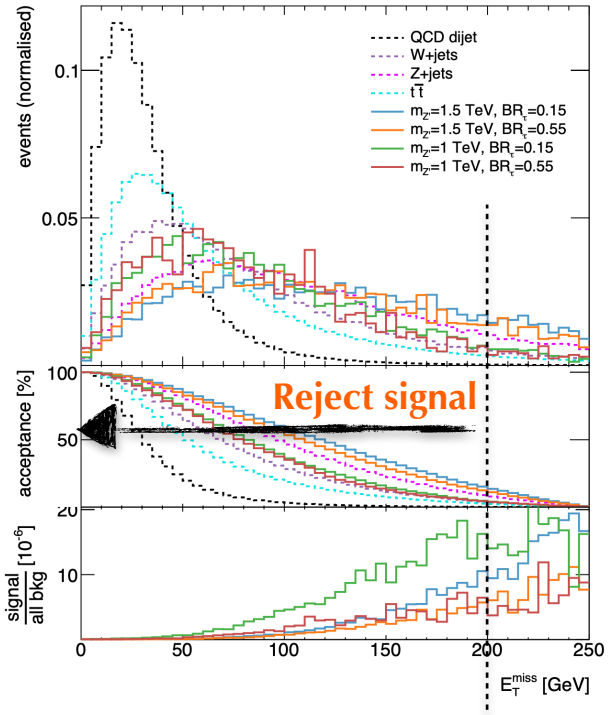


- ✦ Jet HT || pT triggers used by CMS: inherited from high mass di-jet search JHEP 06, 156 (2022)
- ✦ CMS fully efficient trigger requirement $M_T > 1.5$ TeV limits sensitivity for $SVJ\tau$ (effect of neutrinos from τ decays shifts M_T to lower values)
- ✦ Hadronic triggers below current thresholds $p_T(500)$ /$H_T(1050)$ are prescaled (limited statistics)

ARE THERE OTHER POSSIBILITIES ?

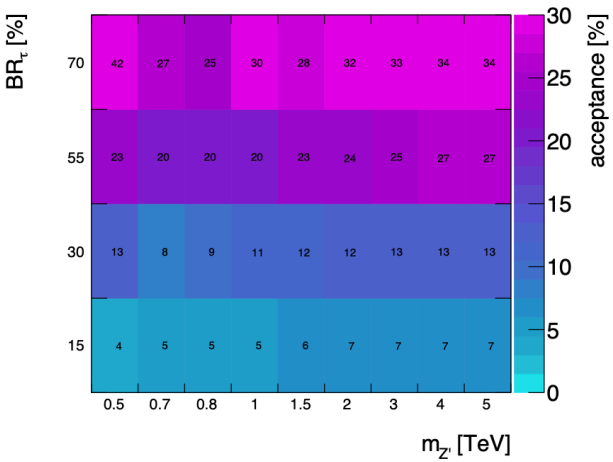
CLASSICAL MET AND TAU TRIGGERS

MET TRIGGERS

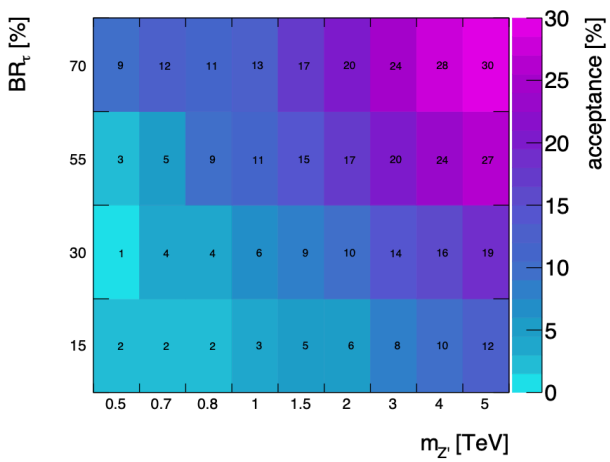


lowest unprescaled threshold $\mathcal{O}(200\ GeV)$

SINGLE TAU TRIGGER



DI-TAU TRIGGER



- MET triggers: too high threshold for lowest unprescaled
- Single tau triggers: limited by isolation criteria
- Di-tau triggers: isolation applied to τ candidates $p_T < 25$ GeV
  no significant improvement (relatively soft τ leptons in signal)

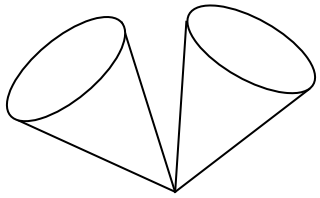
TOPOLOGICAL TRIGGERS AND BEYOND

TOPOLOGICAL TRIGGERS

- Exploit the s-channel topology at L1:
  ≥ 2 AK4 $p_T > 100$ GeV & $\Delta\eta(j_1, j_2) < 2$
  reduce hadronic rates prior to HLT
- Promising for lowering HT threshold
- Hypothetical target: HT > 600 GeV
  (MT > 800 GeV) [need full sim]

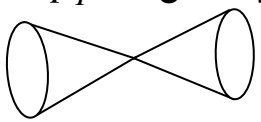
… AND BEYOND ?

- Alternative data-taking: Data Parking and Scouting
- Partial Event Building (PEB): can retain full jet substructure for tagging (but fully reconstructing only part of the event)

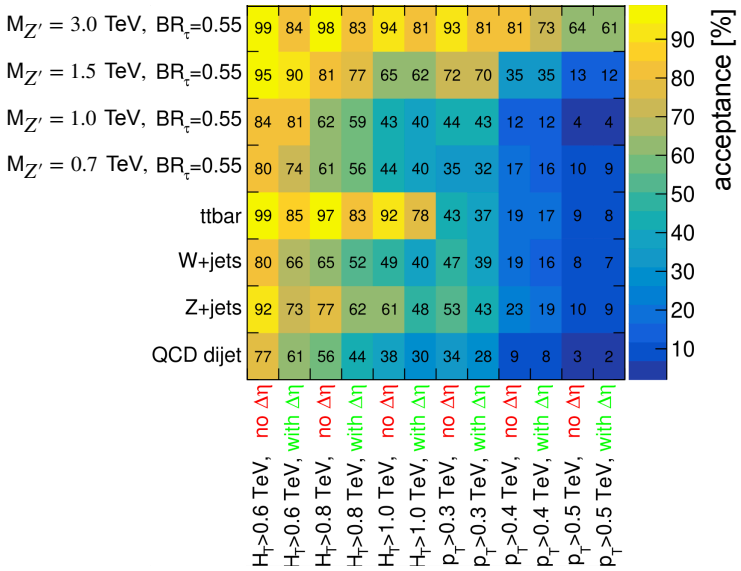


Passes:
high p_T , low $\Delta\eta$

Fails:
low p_T , high $\Delta\eta$



TOPOLOGICAL TRIGGERS

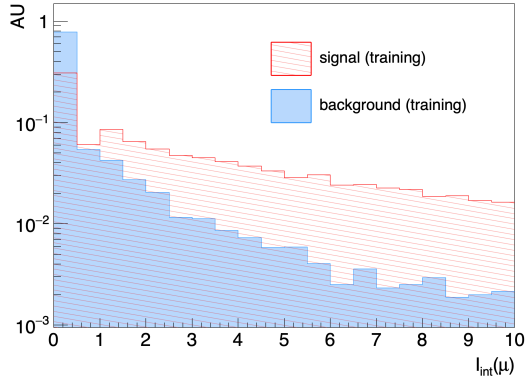


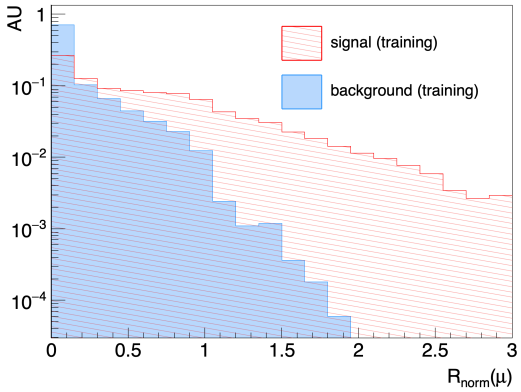
LEPTON FLAVOUR-BASED JET TAGGER FEATURES

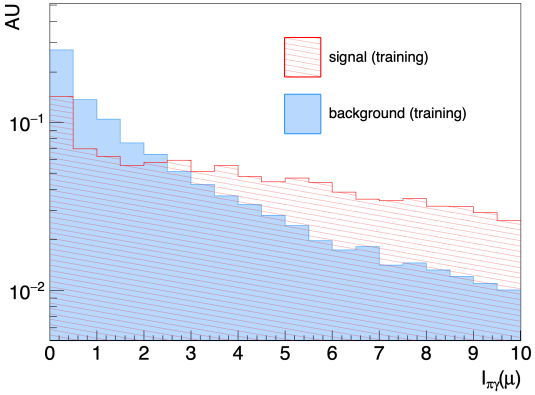
- Set of variables to exploit e/μ enriched jet content from leptonic τ decays (~ 35 %)
- 3 main classes of features (per e/μ):
  1. Energy/momentum flow,
  2. Spatial distributions,
  3. Specific isolations (capture leptonic and hadronic boosted di-τ decays)
- Adaptive BDT (TMVA) trained on a mixture of signal jets hypo (scan over Z′ mass and BR_τ)

JET-TAGGER INPUT FEATURES

Rank	Variable	Separation
1	$I_{inter}(\mu)$	2.703×10^{-1}
2	$R_{Norm}(\mu)$	2.601×10^{-1}
3	$I_{\gamma\pi}(\mu)$	2.164×10^{-1}
4	$R_{Norm}(e)$	1.786×10^{-1}
5	$I_{inter}(e)$	1.632×10^{-1}
6	$Energyfraction(e)$	7.500×10^{-2}
7	$I_{\gamma\pi}(e)$	7.175×10^{-2}
8	$p_{T,Norm}(\mu)$	6.272×10^{-2}
9	$Energyfraction(\mu)$	6.220×10^{-2}

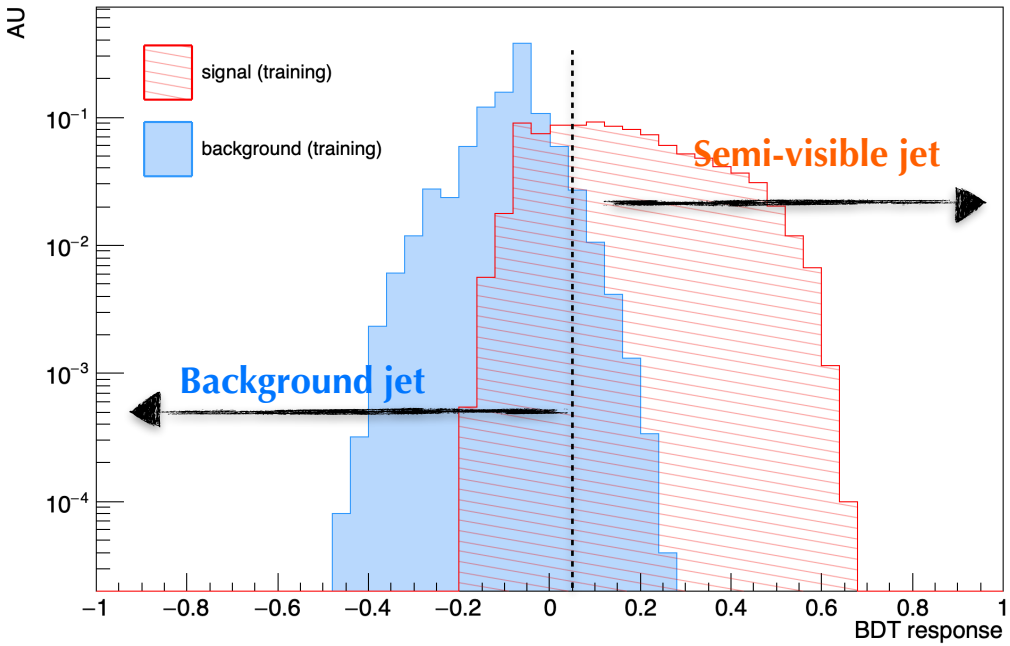


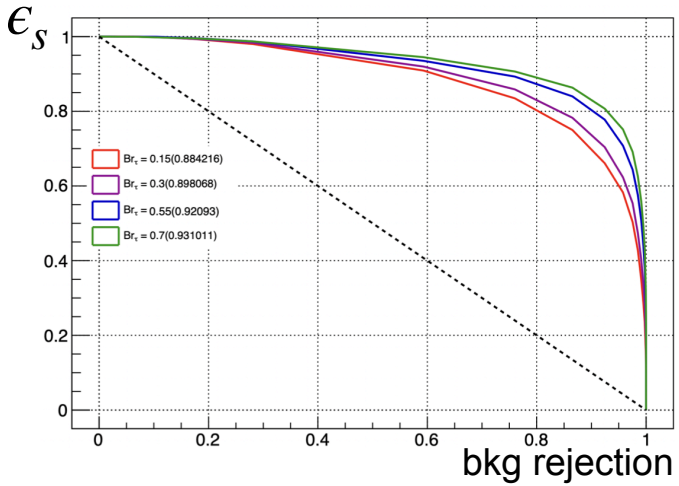


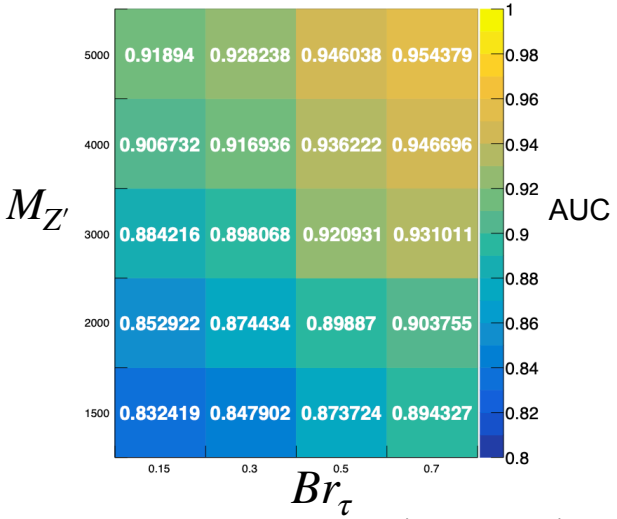


(*) all distributions shown are for training datasets

LEPTON FLAVOUR-BASED JET TAGGER PERFORMANCE

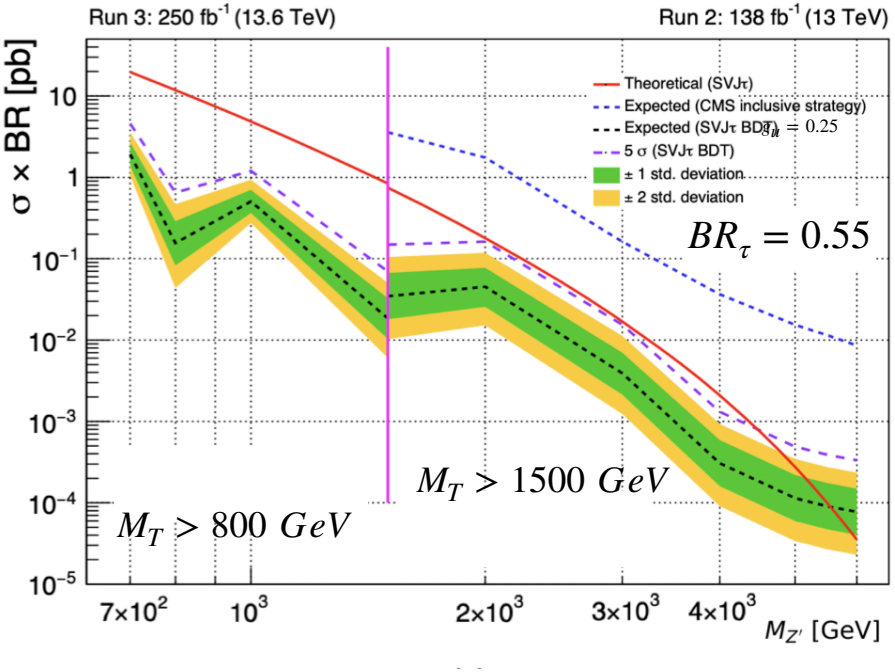


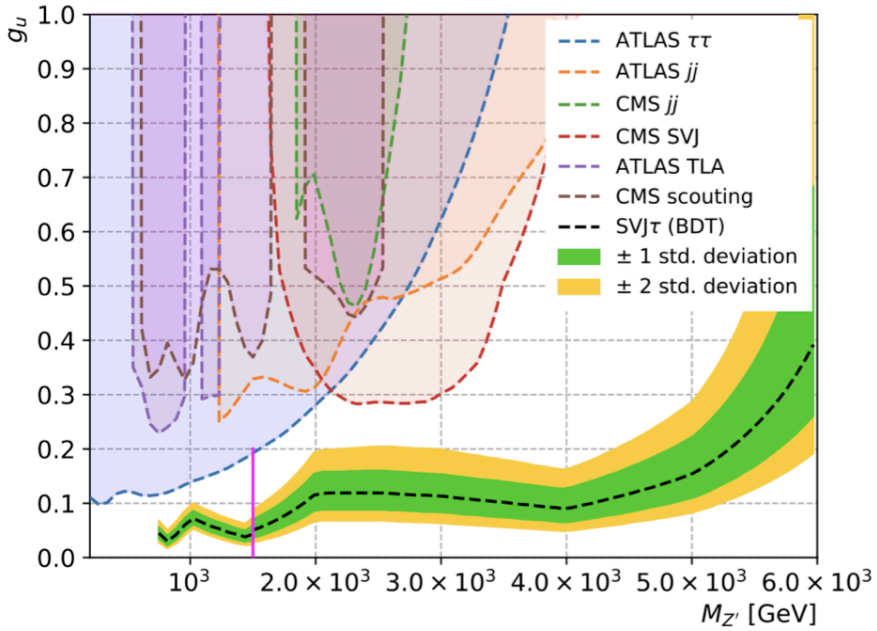




- ✦ BDT working point: maximise $s/\sqrt{s+b}$
- ✦ Rejects ~97% of background jets, tags:
  80%, 84%, 90%, 93% signal jets ($BR_\tau = 0.15, 0.3, 0.55, 0.7$)

SVJτ-TARGETED ANALYSIS SENSITIVITY





- NO SENSITIVITY FOR CMS INCLUSIVE HADRONIC STRATEGY : NEED A JET TAGGER-BASED APPROACH
- EXPLOITING BDT JET-CLASSIFICATION : EXCLUSION REACH (DISCOVERY) UP TO ~ 5.5 TeV (~ 4.5 TeV)
- RESULT OUTPERFORMS ANY EXISTING SEARCH: PROBE UNEXPLORED g_u COUPLING VALUES

(*) more on limits varying BR_τ in backup

CONCLUSIONS AND OUTLOOKS

LEPTONS-ENRICHED SIGNATURES: NEW PROMISING SEARCHES FOR CONFINING DARK SECTORS

→ Investigated models for resonant and non-resonant leptonic decays

→ Provided possible search strategies based on: new lepton-based variables (possible inputs for jet taggers)

→ Examined triggers limitations and explored new possibilities

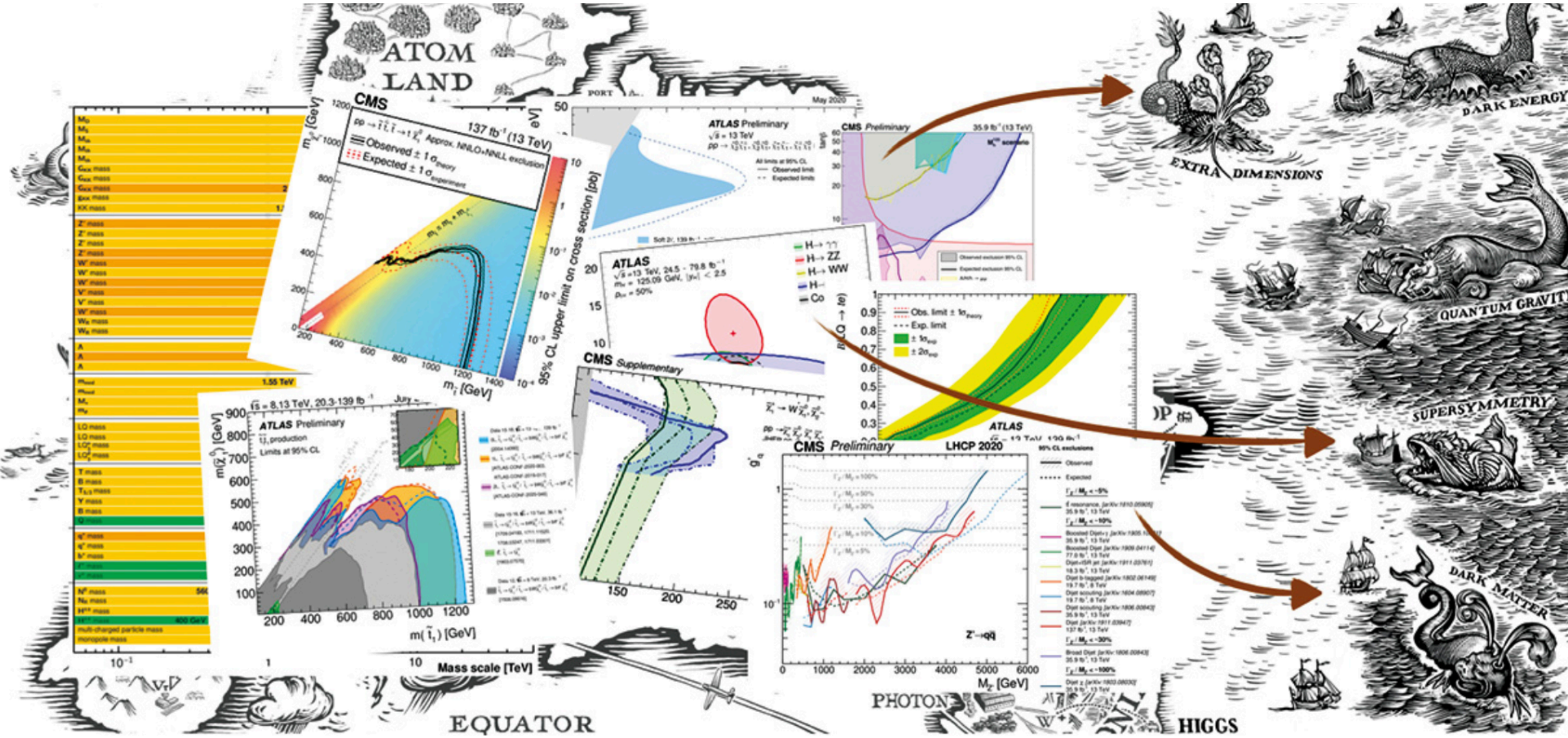
→ These signatures are currently mildly constrained and offer Hidden Valleys discovery opportunities

…. WHAT IS NEXT ?

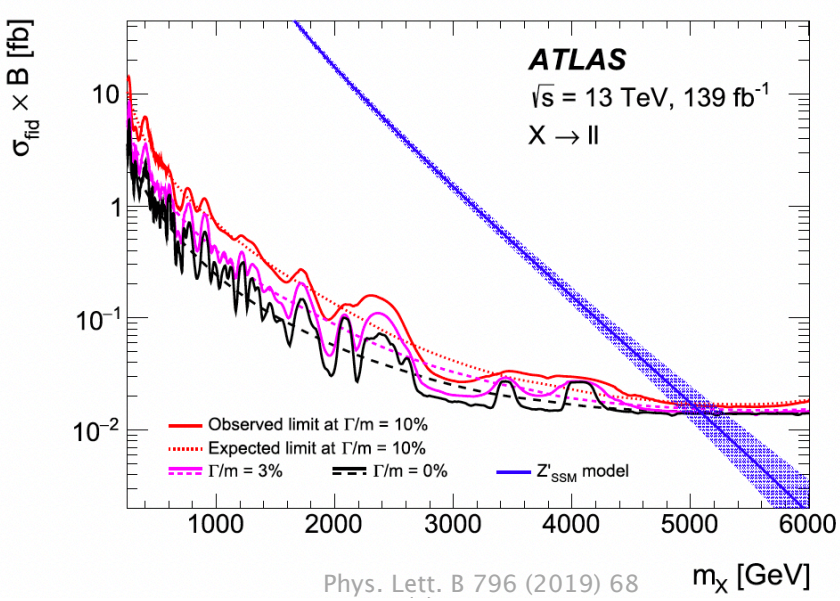
→ Ongoing analysis of both signatures with full Run 2, and Run 3 data (CMS experiment)

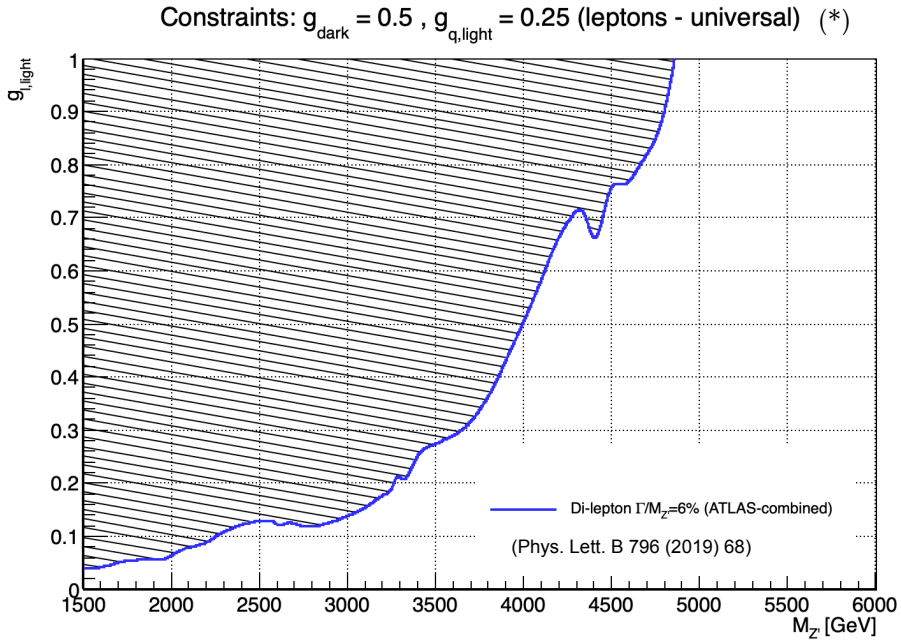
→ Not excluded further pheno studies on uncharted territories

BACKUP


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

CONSTRAINTS ON Z′ COUPLING TO LEPTONS



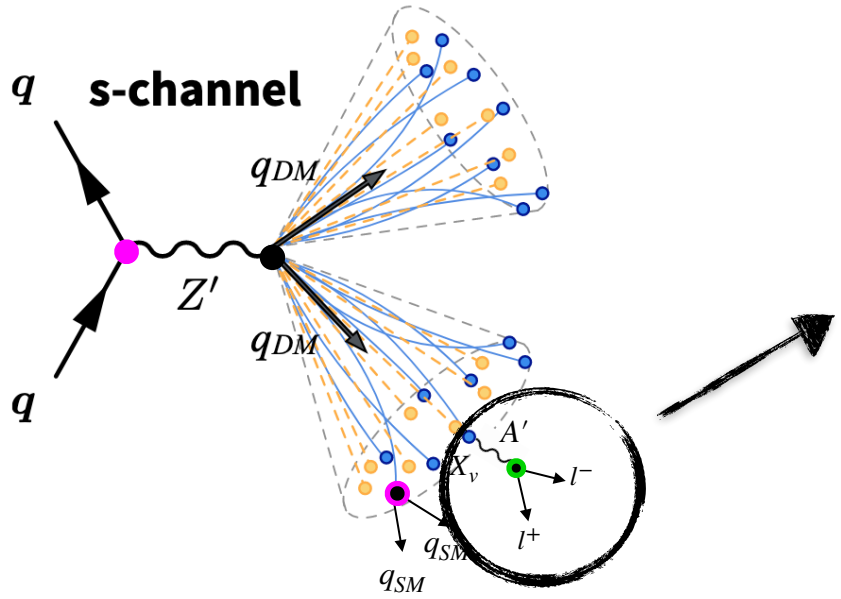


ALLOWING IN THE CURRENT SVJ MODEL FOR Z′ COUPLING TO LEPTONS WOULD INTRODUCE IMPORTANT CONSTRAINTS FROM HIGH MASS DI-LEPTON SEARCHES

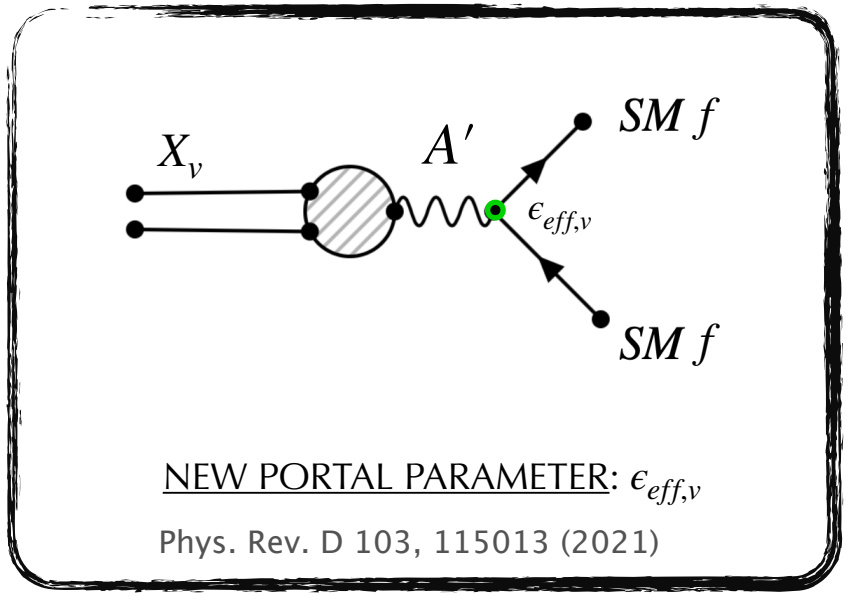
(*) parameters are set consistently with CMS Z′ model

MODEL 1: LEPTONIC DECAYS IN SVJ VIA A′

PROMPT LEPTONIC DECAYS OF DARK BOUND STATES ALLOWED BY LOWER MASS MEDIATOR A′



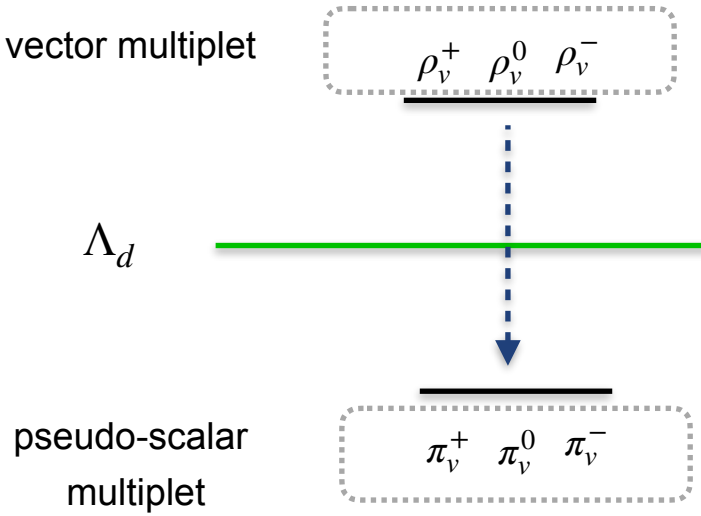
HADRONS + LEPTONS SVJ



LOWER MASS MEDIATOR: OFF-SHELL Z′ SUPPRESSED IN DARK BOUND STATES DECAYS ~ $1/M_{Z'}^4$

SIMPLIFIED HIDDEN VALLEY SPECTRUM

SIMPLE Nf = 2 HV SPECTRUM
(mass degenerate dark quarks)



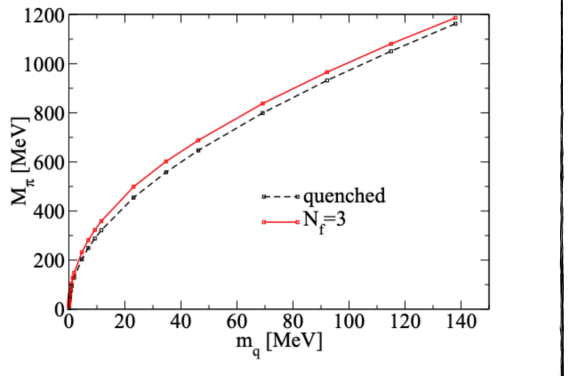
HOW TO FIX THE MASSES ?

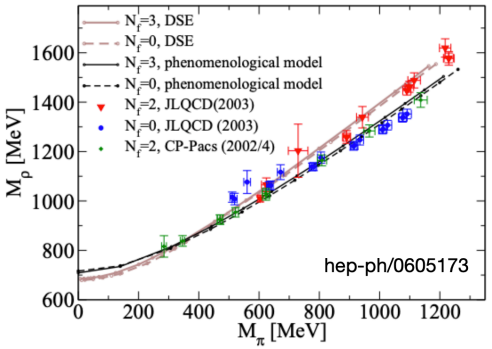
FULL HADRONIC SEARCH ASSUMES ONE DARK HADRON MASS SCALE

DEVELOPMENTS IN SNOWMASS 2021-2022 Eur. Phys. J. C (2022)

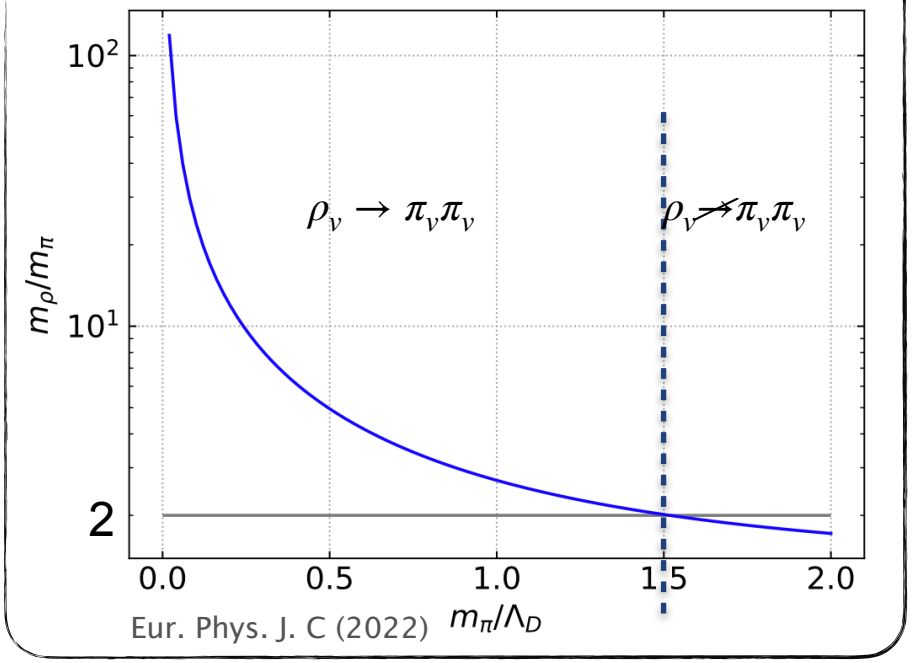
DARK SECTOR HADRON MASSES

LATTICE CALC





DM SPECTRUM PREDICTION

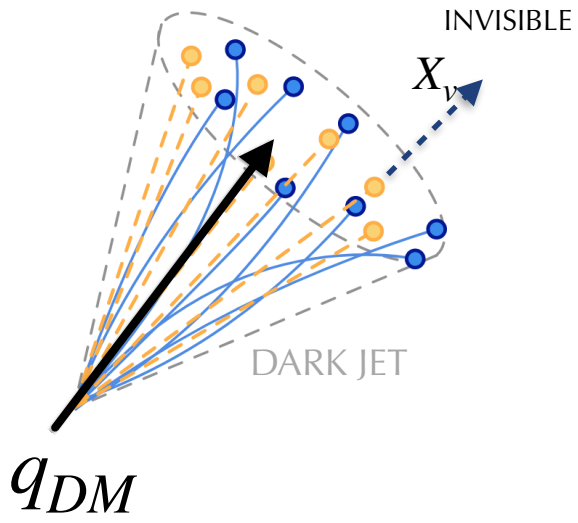


LATTICE CALCULATION: INPUT DARK CURRENT QUARK MASS AND GET DARK HADRON MASSES (BOTH DIVIDED BY OVERALL SCALE Λ_d)

(*) Predictions DM spectrum independent from Nc and Nf

INVISIBLE FRACTION

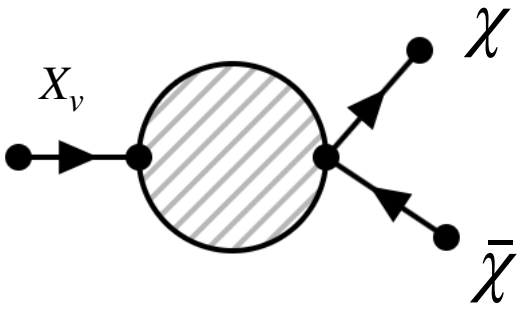
NUMBER OF INVISIBLE DM STATES IMPLEMENTED AS A BRANCHING RATIO



EFFECTIVE INVISIBLE FRACTION

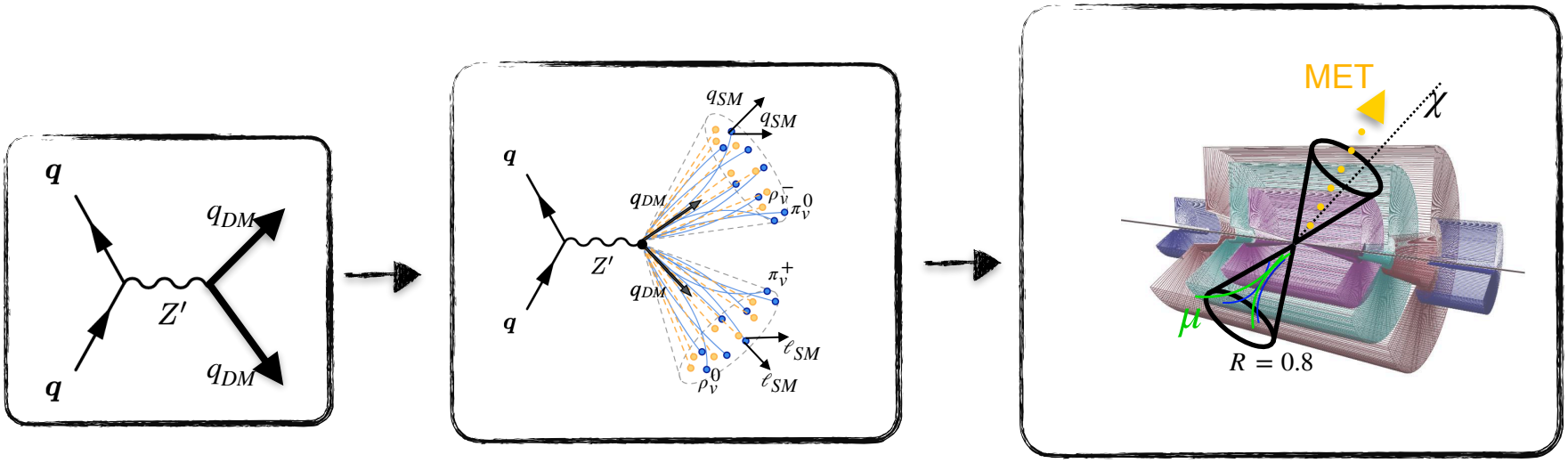
$$r_{\text{inv}} \equiv \left\langle \frac{\#\text{ of stable hadrons}}{\#\text{ of hadrons}} \right\rangle$$

BR_{inv} :



CAPTURES VARIATION IN NUMBER OF DARK FLAVOURS (N_f), NUMBER OF DARK COLORS (N_c) & DARK QUARKS MASS SPLITTING (LUND STRING)

SIGNAL MODELS GENERATION CHAIN



Madgraph5

- ✦ Generation of matrix element
- ✦ Cross-section computation
- ✦ Inputs: couplings, $M_{Z'}$ mass

PYTHIA8

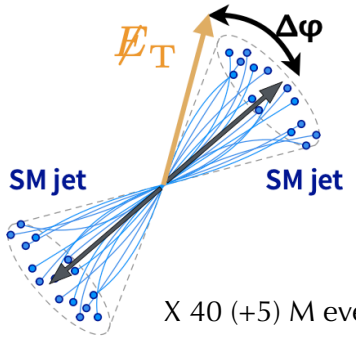
- ✦ HV MODULE : dark sector parton shower, hadronization, dark hadrons decays to SM
- ✦ Inputs: dark sector parameters and dark hadrons decay modes

FASTJET/DELPHES3

- ✦ Clustering AK8 jets with $p_T > 200$ GeV
- ✦ Filter out from AK8 invisible final states (DM, neutrinos)
- ✦ Fast detector simulation: parametric response

BACKGROUNDS SAMPLES

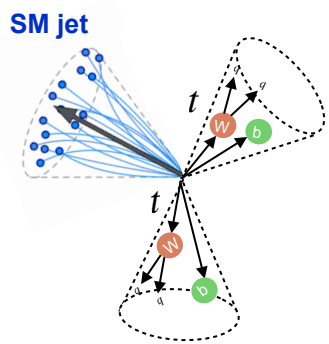
QCD - DIJET



- 2 HARD PARTONS IN ME
- GEN PT CUT: 500 GeV (200 GeV - trigger study)

X 40 (+5) M events

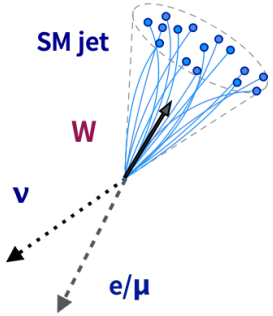
$t\bar{t}$ + jets



- MAXIMUM 2 ADDITIONAL PARTONS IN ME

X 50 M events

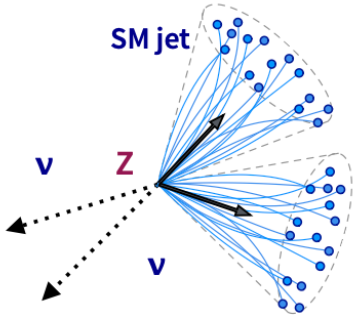
W + JETS



- MAXIMUM 3 ADDITIONAL PARTONS IN ME
- GEN HT CUT: 100 GEV

X 25 M events

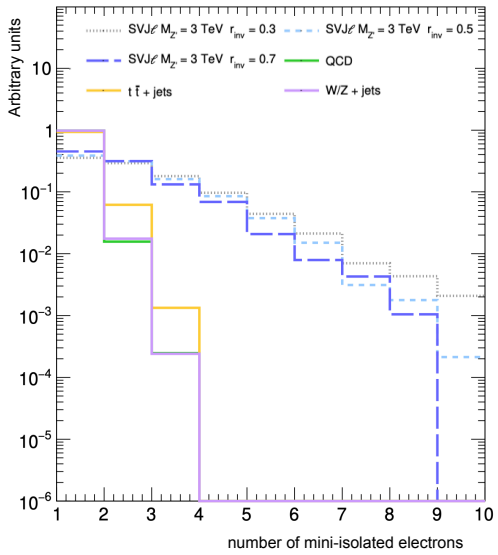
Z + JETS

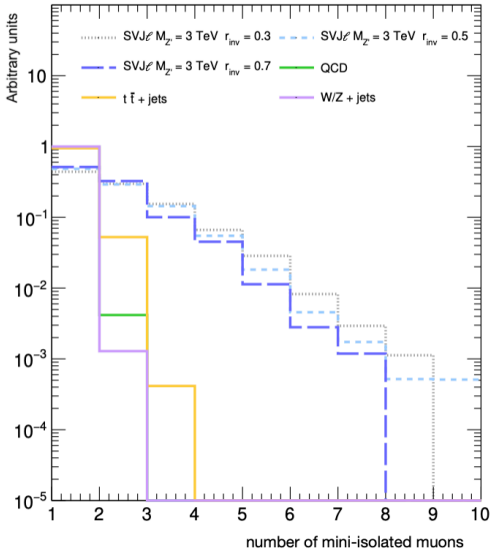


- MAXIMUM 3 ADDITIONAL PARTONS IN ME
- GEN HT CUT: 100 GEV

X 25 M events

MINI-ISOLATION VETO





SIGNAL BENCHMARK : MZ′ = 3 TeV

Variable	Selection	ϵ_{sig}, r_{inv} : 0.3	ϵ_{sig}, r_{inv} : 0.5	ϵ_{sig}, r_{inv} : 0.7
$n(good\ AK8)$	≥ 2	67.53	46.69	22.42
$\Delta\eta_{j0,j1}$ $(AK8)$	≤ 1.5	45.25	32.80	16.53
M_T $(AK8)$	≥ 1500	31.01	18.11	7.45
R_T $(AK8)$	≥ 0.15	19.22	13.41	6.00
$\Delta\Phi_{\min}(\not{E}_T, Jets)$	≤ 0.8	17.61	11.58	4.51
n Good Mini Iso leptons	$N_\mu = N_e = 0$	2.84	2.42	1.37

MINI-ISOLATION LEPTONS VETO USED IN CMS SVJ ANALYSIS IS EXPECTED TO REJECT MOST OF THE SIGNAL
(STATEMENT VALID FOR DIFFERENT INVISIBLE FRACTIONS AND MEDIATOR MASSES)

SVJℓ TARGETED INCLUSIVE APPROACH

GOOD OBJECTS

- ≥ 2 AK8 Jets with $p_T > 200$ GeV & $|\eta| < 2.4$
- $p_T(e,\mu) > 10$ GeV & $|\eta(e,\mu)| < 2.4$
- ✦ $d_0(\mu, e) < 100\ \mu m$: prompt dark hadrons leptonic decays

SELECTIONS

- $R_T > 0.15$: $\not{E}_T$-like cut, no M_T sculpting
- $\Delta\eta(j_1, j_2) < 1.5$: removes t-channel QCD
- $M_T > 1500$ GeV : trigger requirement
- $\Delta\phi_{min}(j_{1,2}, \not{E}_T) < 0.8$: W/Z + jets suppression
- ✦ Veto events with at least 2 isolated leptons
- ✦ Opposite sign non inter-isolated ($I_{int} > 0.1$) leptons pairs

VARIABLES LEGEND

M_T : di-jet transverse mass

R_T : $\not{E}_T/M_T$

d_0 : transverse impact param.

SVJℓ CUT EFFICIENCIES

SIGNAL BENCHMARK : MZ′ = 3 TeV

Variable	Selection	ϵ_{sig}, r_{inv} : 0.3	ϵ_{sig}, r_{inv} : 0.5	ϵ_{sig}, r_{inv} : 0.7
$n(good\ AK8)$	≥ 2	67.53	46.69	22.42
$\Delta\eta_{j0,j1}$ $(AK8)$	≤ 1.5	45.25	32.80	16.53
M_T $(AK8)$	≥ 1500	31.01	18.11	7.45
R_T $(AK8)$	≥ 0.15	19.22	13.41	6.00
$\Delta\Phi_{\min}(\not{E}_T, Jets)$	≤ 0.8	17.61	11.58	4.51
n non-interIso Good OS lepton pairs	> 0	14.01	8.70	2.83

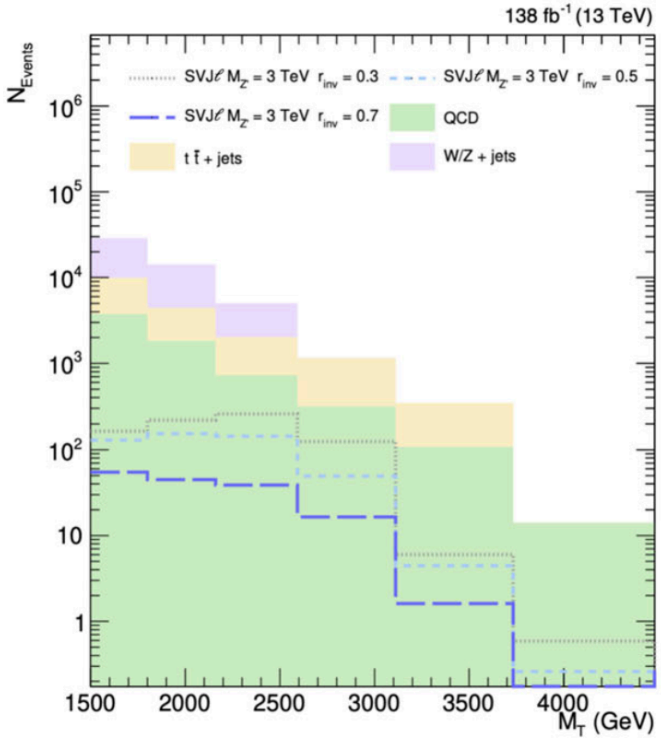
BACKGROUNDS

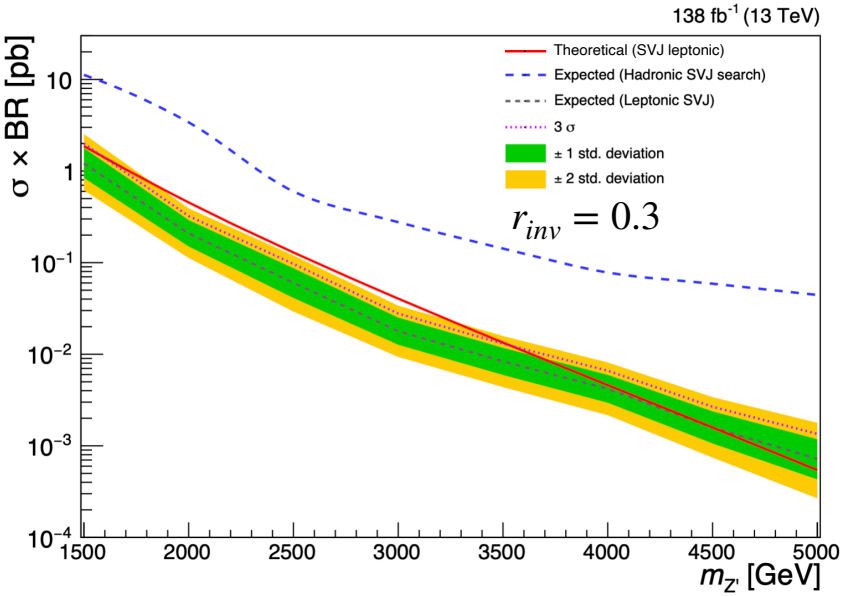
Variable	Selection	$\epsilon_{QCD}\%$	$\epsilon_{t\bar{t}}\%$	$\epsilon_{Zj}\%$	$\epsilon_{Wj}\%$
$n(good\ AK8)$	≥ 2	98.16813	7.18502	1.02670	1.58200
$\Delta\eta_{j0,j1}$ $(AK8)$	≤ 1.5	66.54385	5.31659	0.66615	1.09866
M_T $(AK8)$	≥ 1500	15.00132	0.15060	0.03025	0.0227
R_T $(AK8)$	≥ 0.15	0.70012	0.03026	0.01346	0.00692
$\Delta\Phi_{\min}(\not{E}_T, Jets)$	≤ 0.8	0.68872	0.02722	0.00753	0.00535
(*) n non-interIso Good OS lepton pairs	> 0	0.05426	0.00243	0.00030	0.00036

→ REMAINING MAJOR BACKGROUND: QCD (HADRONS PROMPT LEPTONIC DECAYS)

(*) all good lepton pairs are non-isolated

SENSITIVITY ESTIMATION



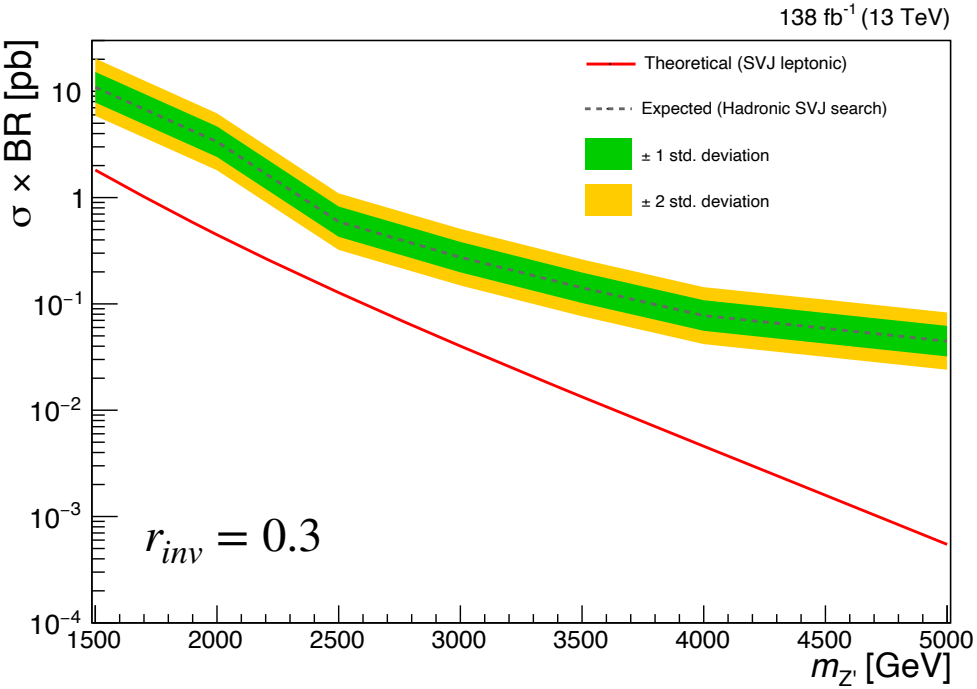


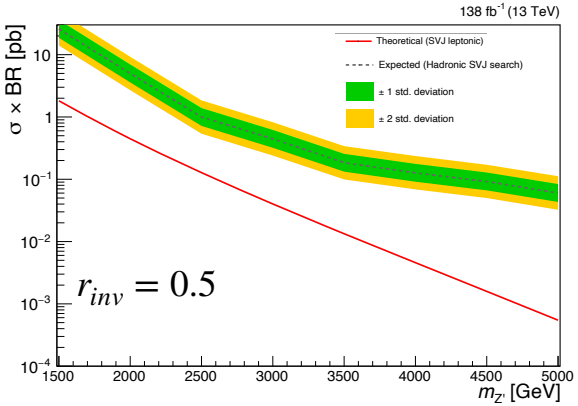
BUMP HUNT ON A FALLING BACKGROUND IN M_T SPECTRUM : 1.5 - 5 TeV (HIGH MASS SEARCH)

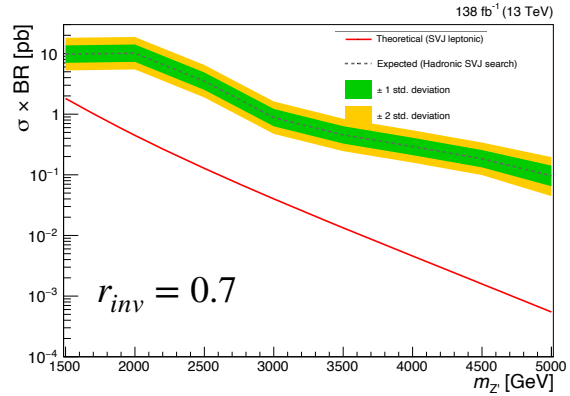
ASYMPTOTIC CLs (J.Phys.G 28 (2002) 2693–2704 , Eur. Phys. J. C (2011) **71**: 1554)

MINIMAL SYSTEMATICS (LOG-NORMAL): LUMINOISITY (2.6 %) & TRIGGER (2 %)

HADRONIC SVJ ANALYSIS SENSITIVITY ON SVJℓ-RESONANT

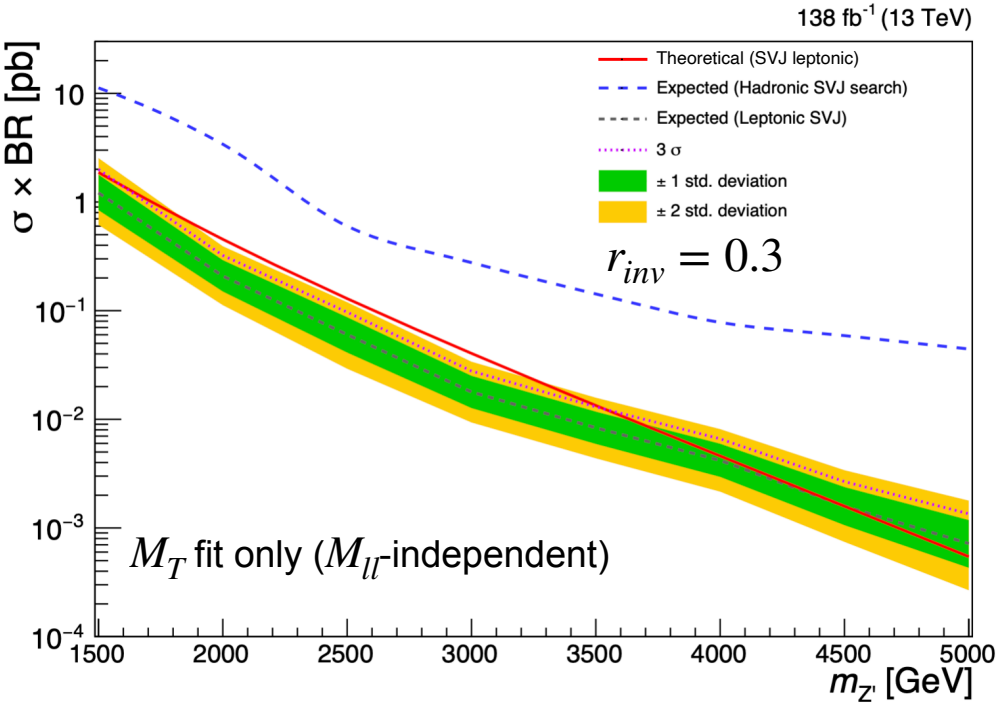


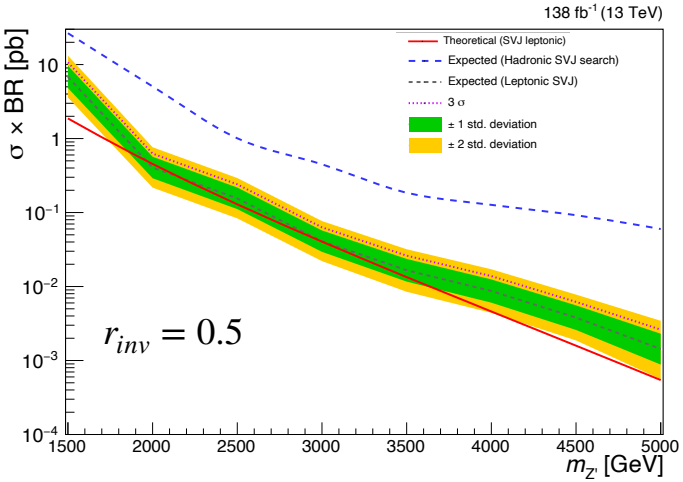


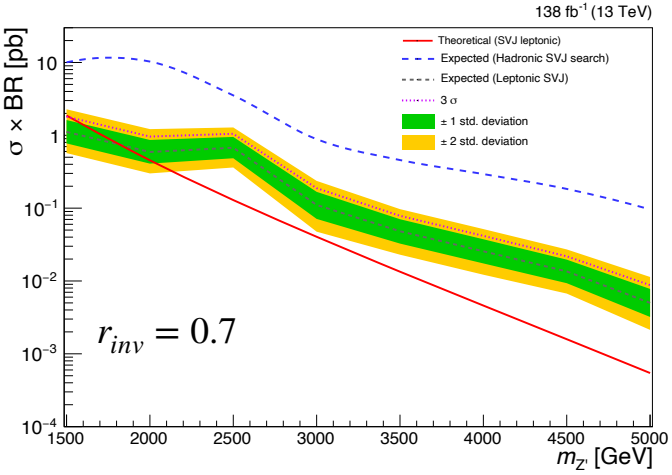


NO EXCLUSION REACH FROM FULL HADRONIC ON SVJℓ (NOR DISCOVERY) IN THE FULL MASS RANGE AND ALL TESTED VALUES OF INVISIBLE FRACTION

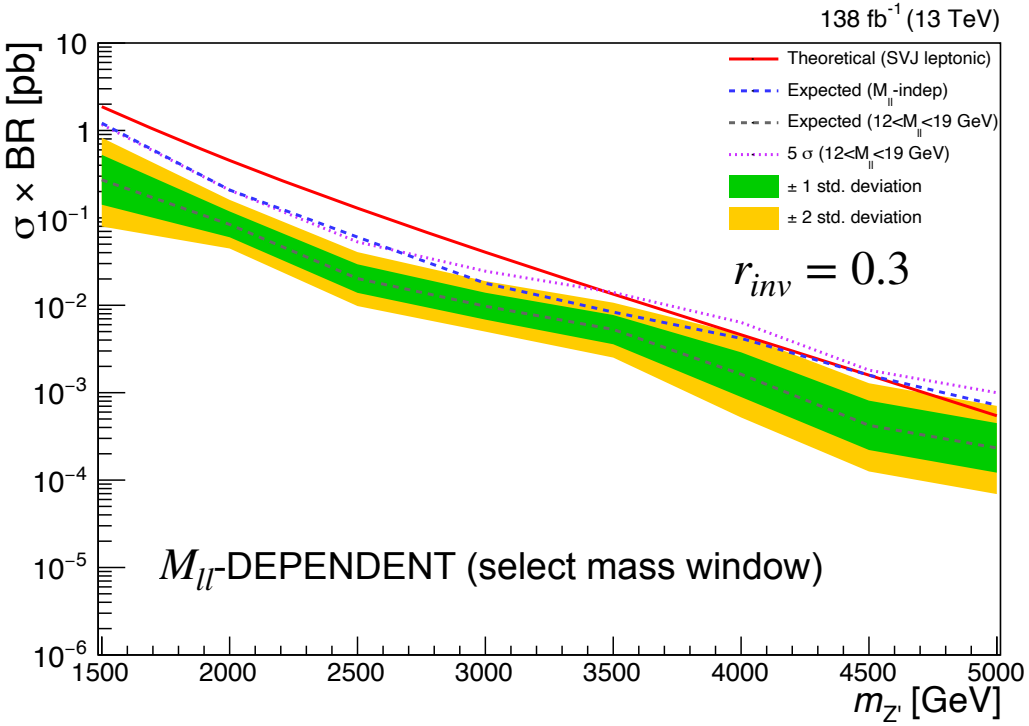
SVJℓ-TARGETED ANALYSIS SENSITIVITY (m_{ll}-INDEPENDENT)

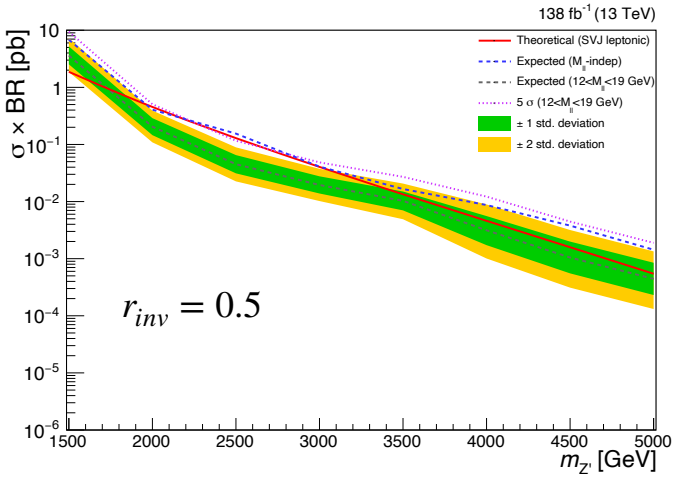


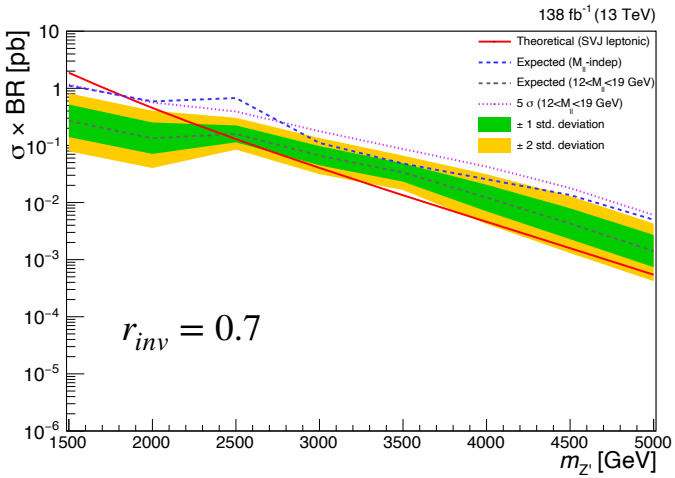




SVJℓ-TARGETED ANALYSIS SENSITIVITY (M_{ll}-CUT)

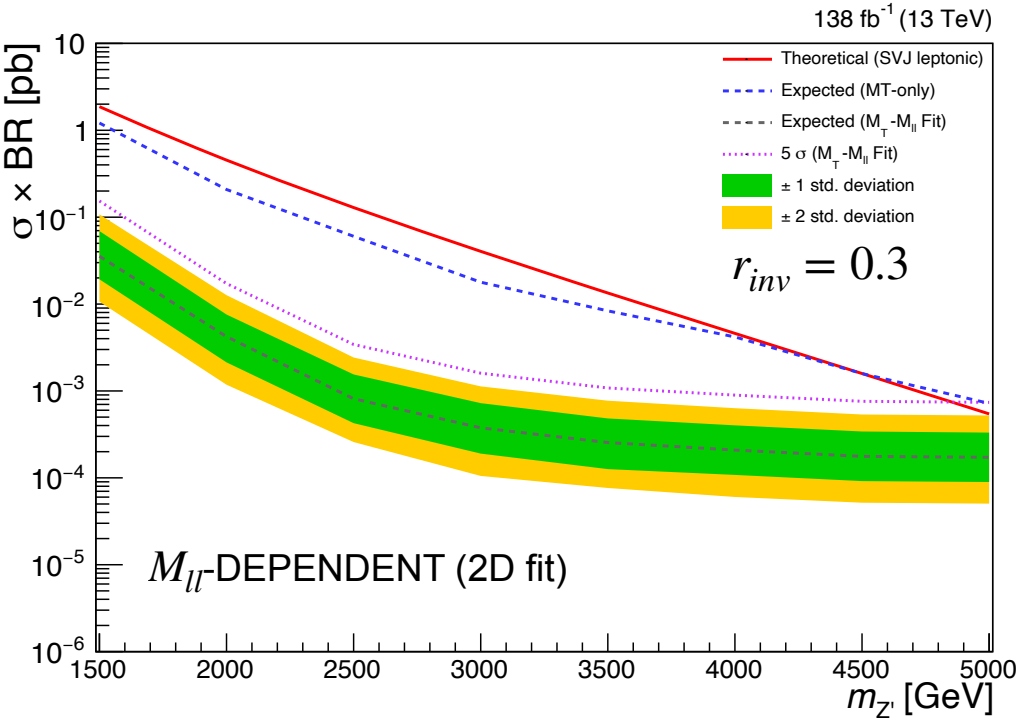


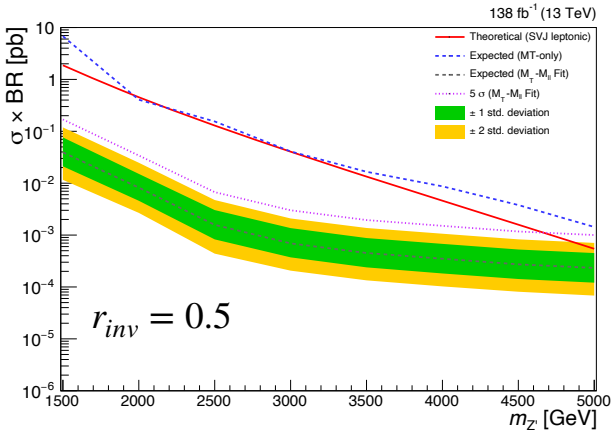


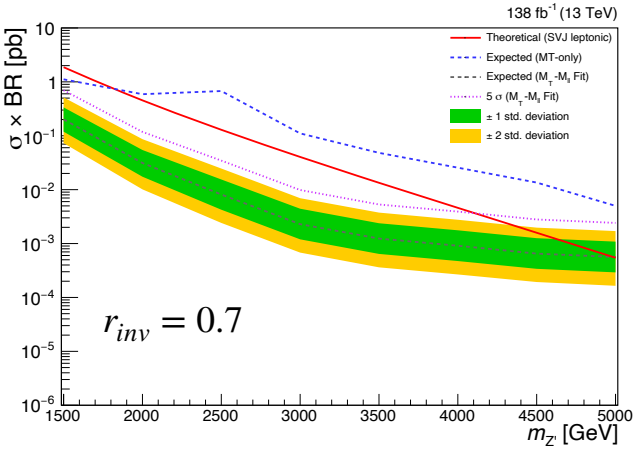


ETH zürich

SVJℓ-TARGETED ANALYSIS (M_T vs M_{ll} 2D FIT)







SVJτ-TARGETED ANALYSIS SENSITIVITY