Exploiting exotic LHC datasets for long-lived new particle searches

[2211.02171]

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Searching for long-lived particles at the LHC and beyond:
Thirteenth workshop of the LLP Community

Breaking the conventional wisdom

New particles are heavy!

Otherwise we would have found them already
→ Highest possible collision energy
→ High trigger thresholds (to increase S/B)

New particles are infrequently produced!

→ Largest possible luminosity
→ Very large pileup
→ Even higher trigger thresholds

Not always true [See excellent dedicated talks]

- Models with light particles that escaped detection
  e.g. Dark sector models predicting new long-lived particles
- These models gain popularity as the LHC limits on traditional BSM models get tighter

Dedicated detectors [See excellent dedicated talks]

FASER, CODEX-b, milliQan, MATHUSLA, ANUBIS, SHiP, etc.

Dedicated upgrades

e.g. timing layer in CMS

Dedicated triggers

e.g. based on displacement

Special datasets from ATLAS and CMS

- Scouting
- Parking
- Heavy ion collisions
- Low-pileup

Goal and strategy of this study

Benchmark model

Light and long-lived neutral resonance decaying into 2 muons

Light

- Muons have soft spectrum
- Killed by high trigger p_T thresholds

Long-lived

- Large S/B using muon displacement
- Degradation by pileup

Question

Which dataset is most promising?

Purpose

Provide more resources to the right channel

Simplification

- Absolute performance not crucial
  Which significance expected after $n\,\mathrm{fb}^{-1}$?
- Relative performance relevant
  Which dataset performs better?
- Some shortcuts do not affect the answer

Detector simulation

- Using DELPHES
- Applying simplistic analysis/selection

Datasets

Scouting

Idea

Fraction of bandwidth given to data stream with reduced event content

Size reduction (2011 example)

Bandwidth	=	Event Size	·	Event Rate
$\sim 1\,\mathrm{GB/s}$		$\sim 1\,\mathrm{MB}$	·	$\sim 1\,\mathrm{kHz}$
constrained		if reduced		can be larger
$\sim 7.5\,\mathrm{MB/s}$		$\sim 1.5\,\mathrm{kB}$	·	$\sim 5\,\mathrm{kHz}$

Information loss

- No raw data saved
- No offline reconstruction

Run 2

$96.6\,\mathrm{fb}^{-1}$ collected in 2017 and 2018 using a dimuon triggers

Run 3

- Larger bandwidth allocated
- Assumption: Continuous running

→ Threefold increase

Modeled by

- Degrading muon resolution
- Lowering trigger thresholds

Parking

Idea

- Storing a fraction of the triggered data without running the prompt reconstruction algorithms
- Exploit the reduced beam intensity towards end of fill
- Event reconstruction delayed post data taking

Run 2

12 M events collected in 2018
with a non-isolated μ trigger motivated by b-physics

Run 3

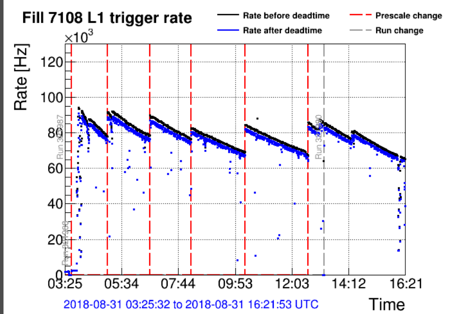
- Difficult to predict since it depends on future available computing resources
- Assumption: Every year as many events as in 2018 will be parked

→ Quadrupled statistics

Simulated using

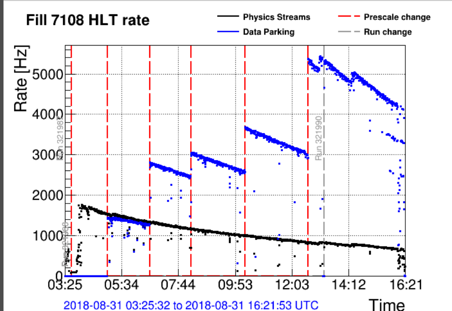
- Low trigger threshold
- Non-isolated muons

L1 trigger rate of example fill



HLT rate

[CMS DP-2019/043]



Low-pileup

Idea

- Motivated by SM measurements that do not need large statistics
- but need the cleanest possible experimental conditions
- in particular very low pileup (e.g. W mass)

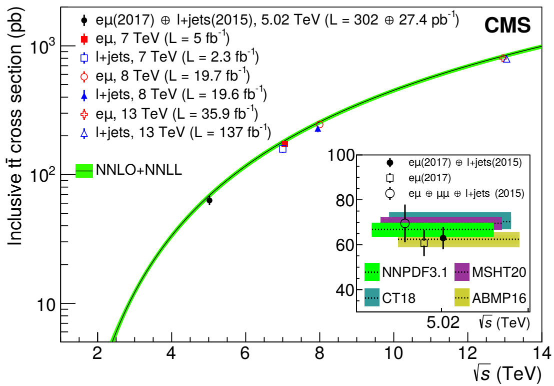
Run 2

- $0.5\,\text{fb}^{-1}$ accumulated in total,
- $0.2\,\text{fb}^{-1}$ at 13 TeV
- $0.3\,\text{fb}^{-1}$ at 5.02 TeV (reference *pp* dataset for heavy-ion studies)

Assumptions for Run 3

- Same luminosity as Run 2
- With energy of 13.6 TeV
- Motivated by higher priority after CDF W mass measurement

Example study [2112.09114]



Modeled by

- No pileup
- Lower trigger thresholds

Heavy ions

Drawbacks

- much shorter running time (1 month per year)
- much smaller instantaneous luminosity (limited by beam disruption)
- smaller collision energy per nucleon

Advantages

- Cross section enhanced by $(208)^2$
- Zero pileup

Run 2 luminosity and energy

$\mathcal{L} = 1.6 \cdot 10^{-6}\,\text{fb}^{-1}$ at $5.02\,\text{TeV/nucleon}$

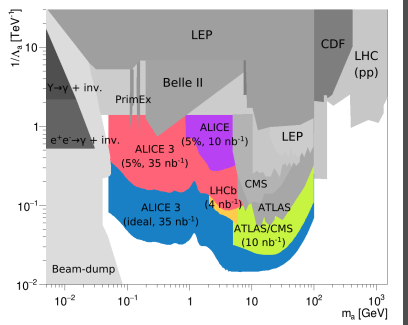
Run 3

- Confirmed plan to accumulate $\mathcal{L} = 9.6 \cdot 10^{-6}\,\text{fb}^{-1}$
- Energy undecided, we assume $5.5\,\text{TeV/nucleon}$

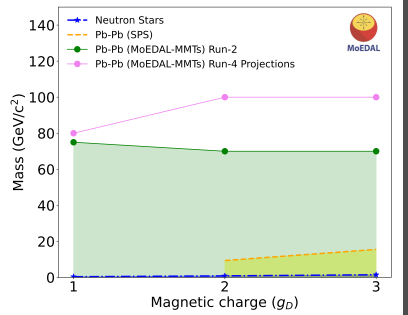
Great for [1812.07688; 2203.05939]

Monopoles, Axion like particles via photon interactions

ALPs



Monopoles [See talk by Mitsou]



Summary of the assumptions for the simulation

Trigger thresholds and luminosities

Dataset	p_T^{min}/GeV		$\mathcal{L}_{int}/fb^{-1}$		MC approximation
	muon	dimuon	Run 2	Run 3	
Standard pp	24	17	140	280	Pileup of 35 and 70
Scouting	–	3	96.6	289.8	
Parking	12	–	48.8	195.2	
Low-pileup	17	8	0.2	0.5	Zero pileup
Heavy ion	–	3	1.6×10^{-6}	9.6×10^{-6}	Only PbPb

To prevent artificially disfavouring one dataset we assume three different trigger scenarios

Trigger scenarios

	Muon	Hybrid	Dimuon
p_T threshold	Single muon		Dimuon
Displaced muons	1	2	

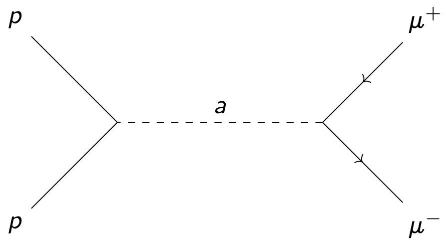
Sensitivity to benchmark model

Benchmark model

Axion like particle interaction

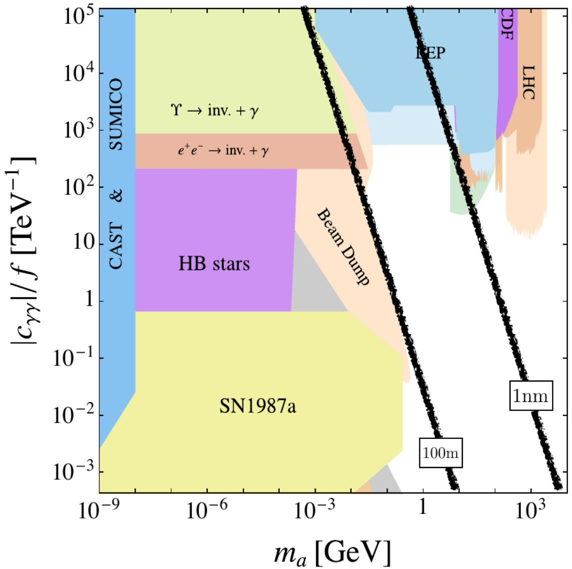
$$\mathcal{L}_a = \frac{1}{2}\partial_\mu a\,\partial^\mu a - \frac{1}{2}m_a a^2 - c_{\tilde{G}}\frac{a}{f_a}G_{\mu\nu}\widetilde{G}^{\mu\nu} - \mathrm{i}c_{a\phi}\frac{a}{f_a}\sum_f m_f(\bar{f}_L f_R - \mathrm{h.c.}) + \dots,$$

Production and decay



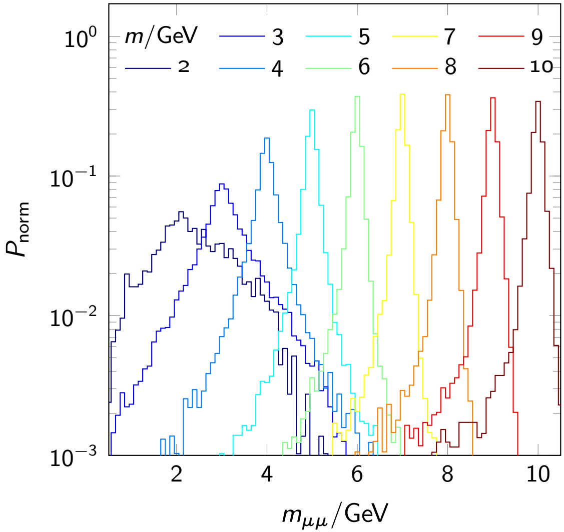
Long-lived ALPs

[Martin's slides]



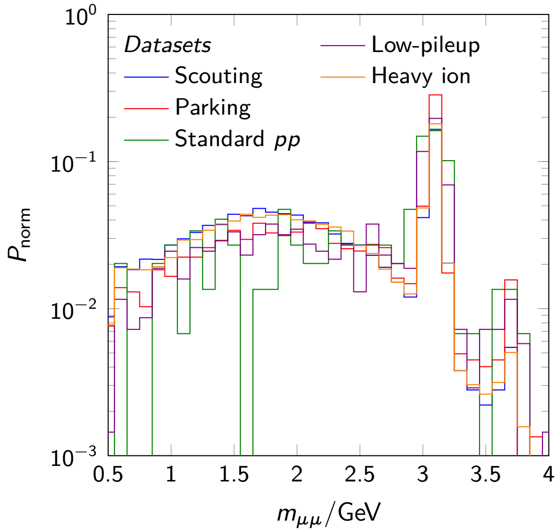
Invariant mass distribution

Signal



Mass peak broadens for smaller masses

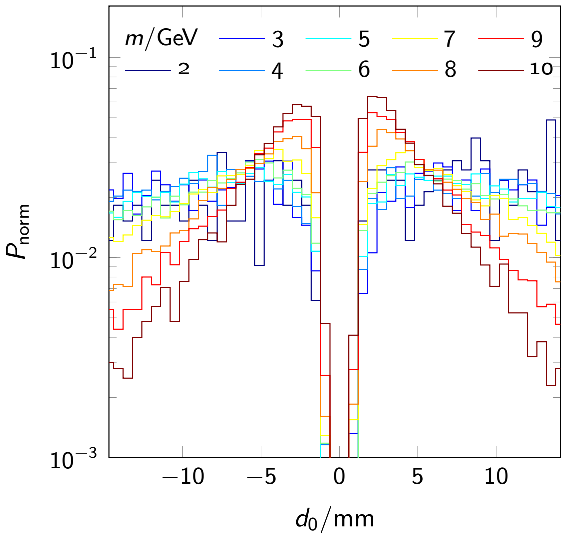
Background



Meson peaks are recognizable

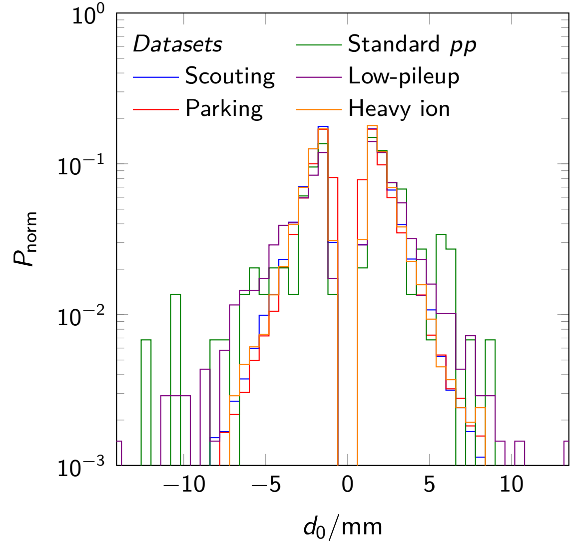
Displacement

Signal



Impact parameter depends on mass

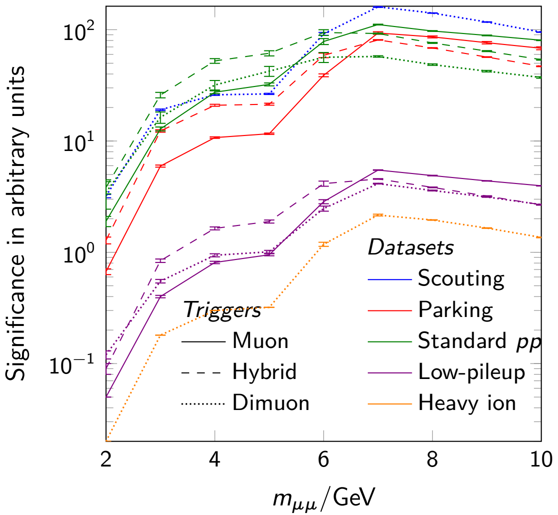
Background



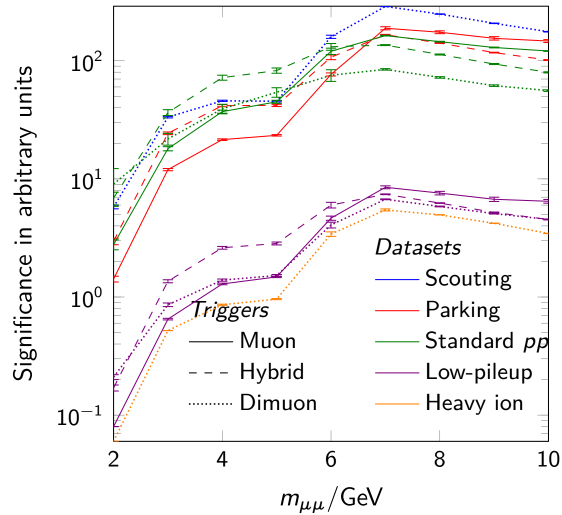
Restriction to long-lived backgrounds

Results

Run 2



Run 3



Trigger Scenarios

- Hybrid trigger scenario better for low masses
- Dimuon trigger scenario better for high masses

Datasets

- Scouting and Parking can outperform standard *pp* dataset
- They can easier be increased than *pp* dataset

HNLs from mesons in heavy ions

[1810.09400; 1905.09828]

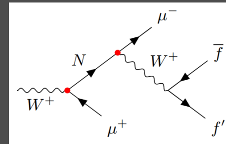
Idea

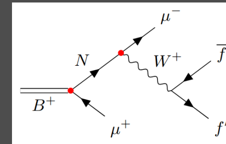
- Exploit low triggers
- Use lighter ions

Lighter ions can have advantage

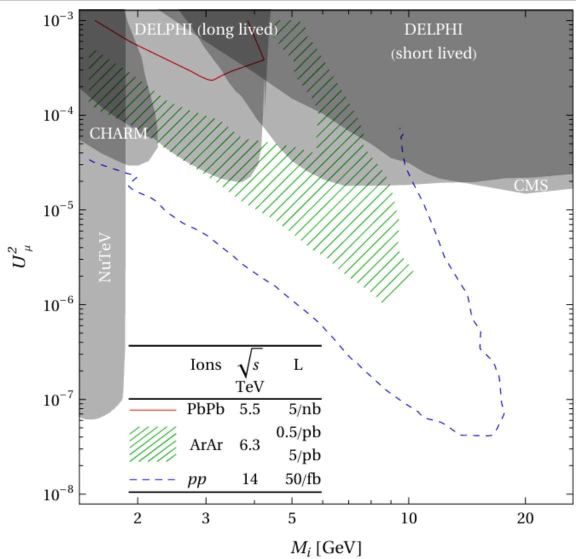
over *pp* collisions

at equal running time

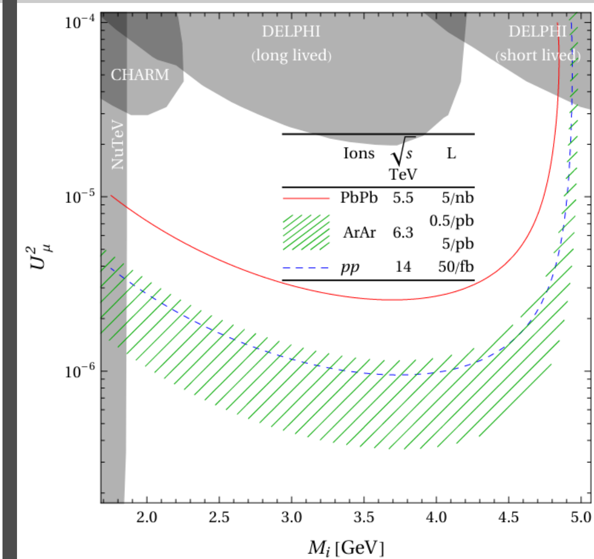




$W^\pm \to \mu^\pm N$



$B^\pm \to \mu^\pm N$



Conclusions

- Scouting and parking are competitive with standard data for this category of signal model
- They might outcompete standard data if significantly larger resources are allocated
- PbPb and low-pileup are considerably less competitive
- Other signal models (monopoles, ALP interacting with γ, ...) lead to different conclusions

References

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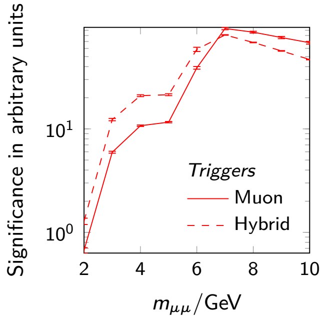
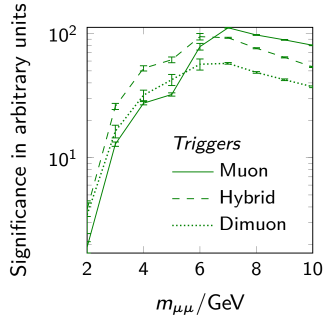
Details

Run 2

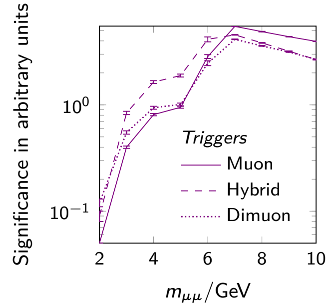
Parking



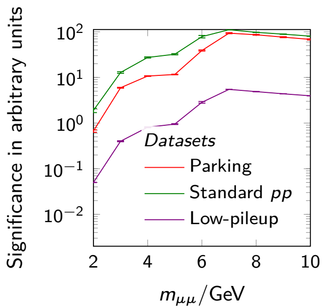
Standard *pp*



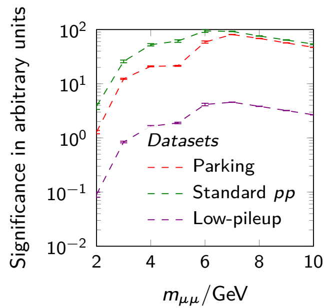
Low-pileup



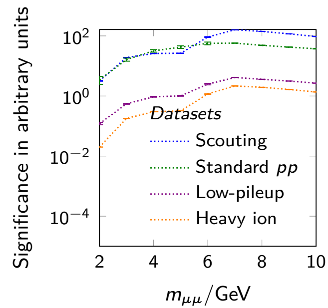
Muon trigger



Hybrid trigger

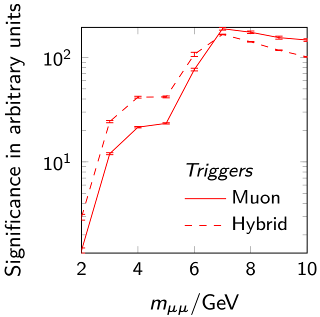


Dimuon trigger

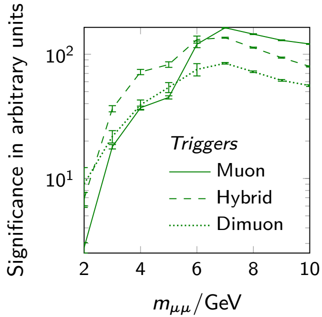


Run 3

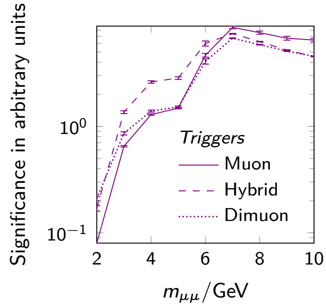
Parking



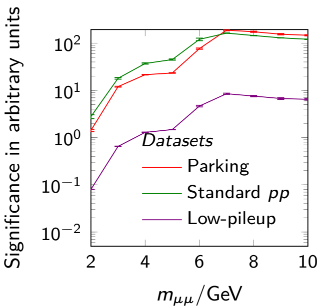
Standard *pp*



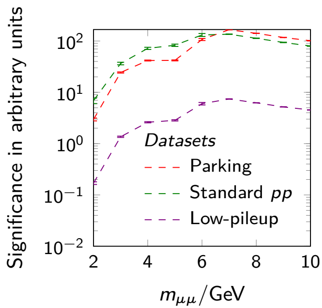
Low-pileup



Muon trigger



Hybrid trigger



Dimuon trigger