Long-lived particles: unconventional signatures in collider experiments

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New physics searches

Many BSM models and a large number of possible signatures

No hint of BSM physics so far …..

Where is BSM physics hiding ?

Three Possibilities:

- BSM particles are very heavy -> Not accessible at the LHC
- BSM particles are just above the current limit -> LHC will discover soon
- New particles are within the reach of LHC, search methods are not very sensitive

Nature of the new physics is completely unknown
Probably very unconventional, exotic final states

NOT YET SEARCHED FOR ?
EXPERIMENTALLY CHALLENGING ?

One such interesting possibility : Long-lived particles(LLPs)

Recipe for conventional search at the LHC

Goal: Find a new particle X

STEP I : Production

a). Single production $pp \to X$

b). Pair production $pp \to XX$

c). From decay $pp \to Y_{SM/BSM} \to XX$

STEP II : Decay

Various Decay modes possible : X to 2,3,4 body decays to SM particles and also BSM particles

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STEP III : Final State

At the LHC we can identify electron, muon, photon, jets(from quarks and gluons)

Indirect identification of invisible particles like neutrinos, dark matter etc. possible (in terms of MET)

Classify the signatures based on the production mechanisms and decay modes

Example : di-muon final state, multiple jets + missing transverse energy, photons + leptons etc.

Analysis techniques

Define variable(s) which can separate signal process from the SM backgrounds.

Use sophisticated statistical techniques, ML etc.

A concrete example of conventional signature

Goal: Search for gluino ($\tilde{g}$) of MSSM

STEP I : Production

Pair production $pp \to \tilde{g}\tilde{g}$

STEP II : Decay

$\tilde{g} \to q\bar{q}\tilde{\chi}$

STEP III : Final State

Gluino can decay to quarks and dark matter (LSP in MSSM)

Final State : Multiple jets + Missing transverse energy

Analysis techniques

Missing transverse energy, effective mass , H_T etc

Use techniques to separate signal and backgrounds

Null results from different experiments put stringent limits on the conventional BSM scenarios

Unconventional signature: Long-lived Gluino

Goal: Search for long-lived gluino ($\tilde{g}$) of MSSM

STEP I : Production

Pair production $pp \to \tilde{g}\tilde{g}$

STEP II : Decay

$\tilde{g} \to q\bar{q}\tilde{\chi}$ decay width is suppressed

$\tilde{g}$ will be produced at the collision point but not decay instantaneously

=> Long-lived gluino !!!

Unconventional signature: Long-lived Gluino

Goal: Search for long-lived gluino ($\tilde{g}$) of MSSM

STEP I : Production

Pair production $pp \to \tilde{g}\tilde{g}$

STEP II : Decay

$\tilde{g} \to q\bar{q}\tilde{\chi}$ decay width is suppressed => long lived gluino

STEP III : Final State

Gluino may not decay to quarks and dark matter (LSP in MSSM)

Gluino will hadronize and form heavy hadron

Gluino is now semi-stable and will travel through the detector

The signature is no longer multi-jet + MET

Analysis techniques

Questions : Is it possible to make gluino long-lived ?
Is such a possibility rare ? Or too much fine-tuned ?

LLPs in the Standard Model

Presence of LLP is not unnatural

Many long-lived particles are present in our world

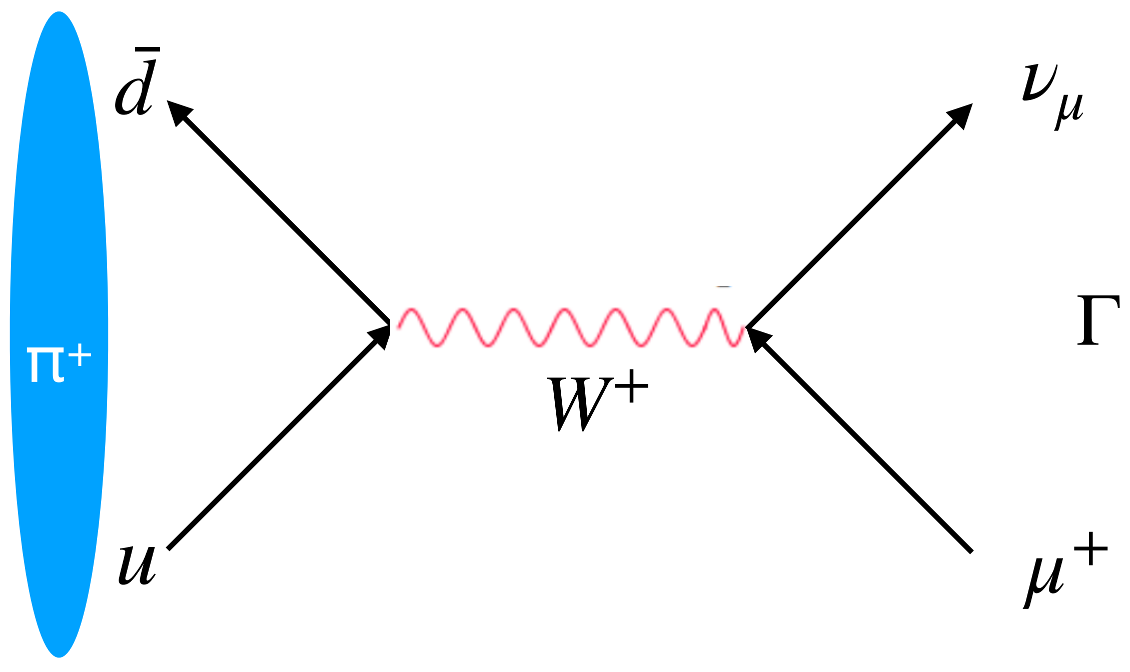
Particle	Lifetime
Muon	2.2 picosecond
Proton	$> 10^{30}$ year
Neutron	878 second
B^+	1600 femtosecond
π^+	26 nanosecond

LLPs in the Standard Model

Particle	Lifetime
Neutron	878 second
B+	1600 femtosecond
π +	26 nanosecond

Case I

Pion decay in the SM

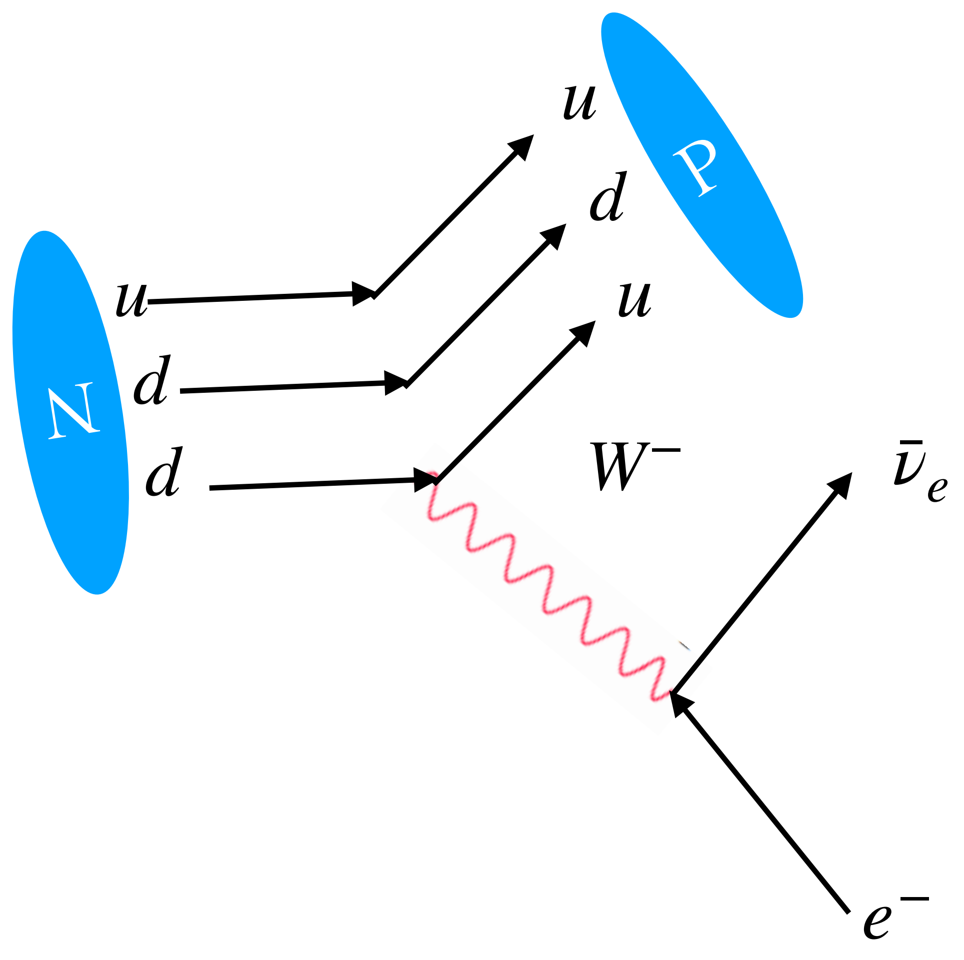


$$\Gamma \sim \frac{m_\pi^5}{m_W^4}$$

Huge suppression from the W boson propagator

Case II

Neutron decay in the SM

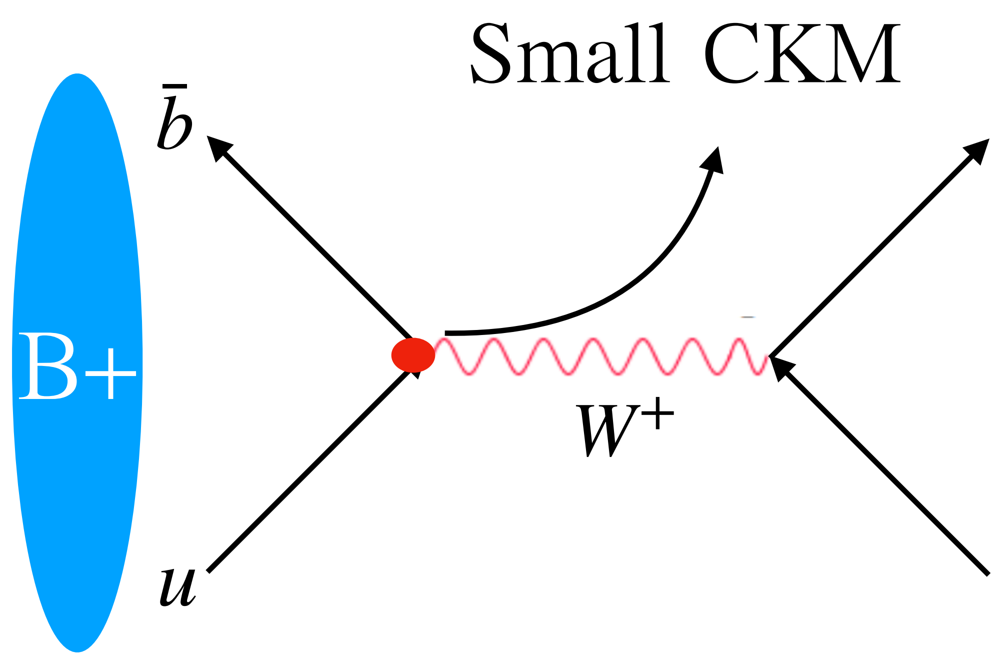


$\Delta = M_n - M_p \sim 1.3$ **MeV**

Decay is highly phase space suppressed

Case III

B+ decay in the SM

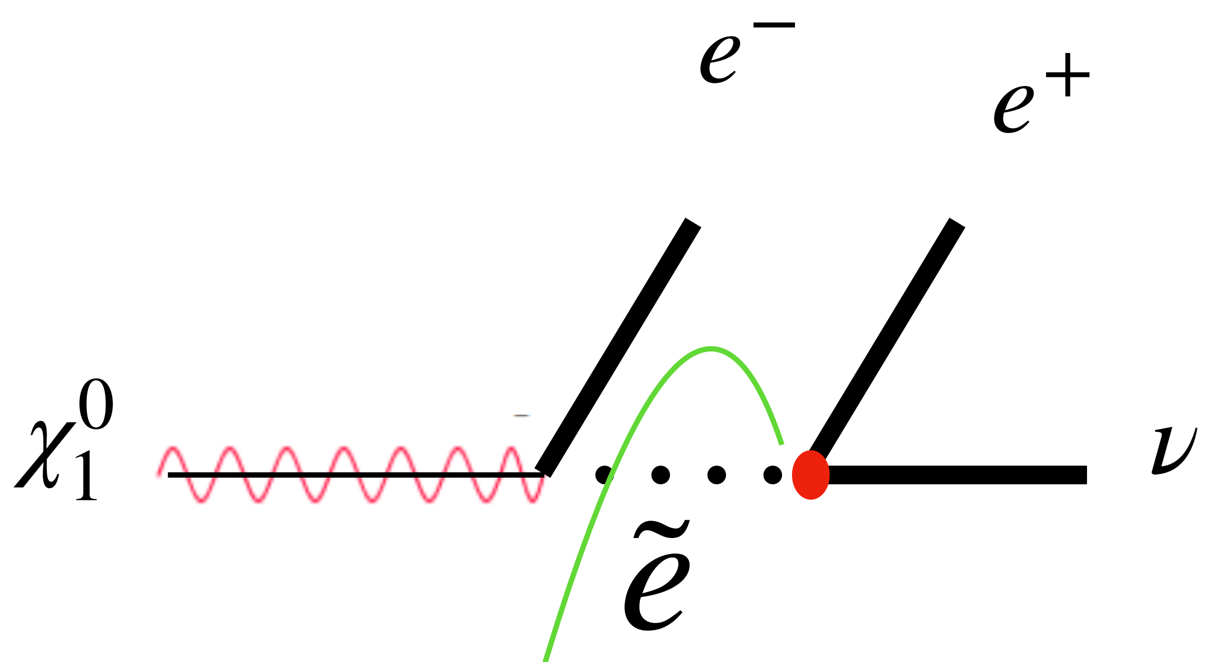


V_{ub} small, gives additional suppression

Long-lived BSM particles

Case 1: Small Coupling

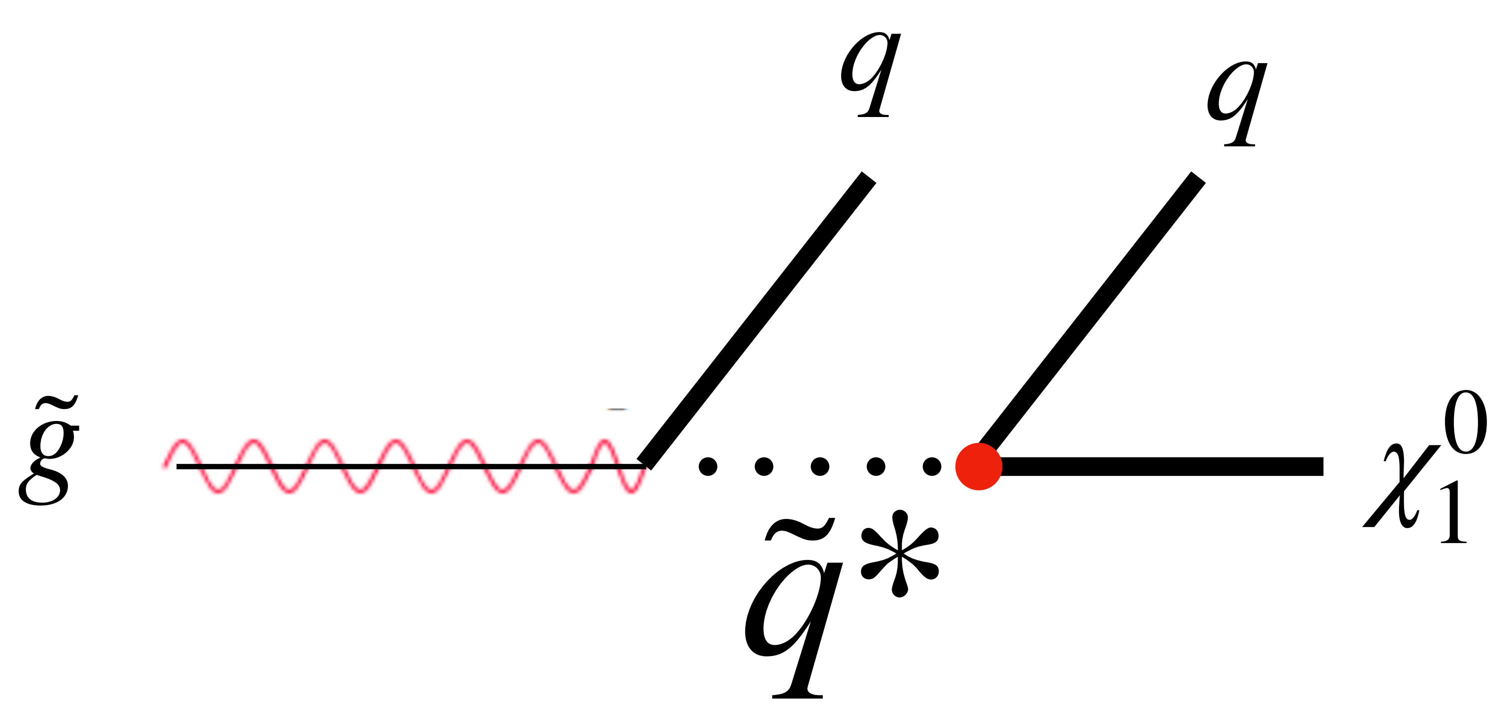
$$\chi_1^0 \rightarrow e^- e^+ \nu$$



R parity violating coupling can be Arbitrarily small

Case 2: Heavy Propagator

$$\tilde{g} \rightarrow q\bar{q}\chi_1^0$$



Case 3: Small mass difference

$$\chi^\pm \rightarrow \chi^0 + \pi^\pm$$

$$\chi^\pm \rightarrow \chi^0 + l^\pm + \bar{\nu}_l$$

$$\Delta M = M_{\tilde{W}^\pm} - M_{\tilde{W}^0} \sim 160 \text{ MeV}$$

MSSM with neutral wino as the lightest supersymmetric particle

Charged wino becomes heavier than the neutral wino because of electroweak radiative corrections

Dark Sector

Dark sector particles talk to the SM particles through a portal

Lowest dimensional operator

Vector Portal: $\epsilon B^{\mu\nu} X_{\mu\nu}$

Scalar Portals: $\kappa(H^\dagger H)S + \lambda(H^\dagger H)S^2$

Neutrino Portal: $yHLN$

Higher dimensional operator also possible

ALP: $\epsilon a F^{\mu\nu} \tilde{F}_{\mu\nu}$

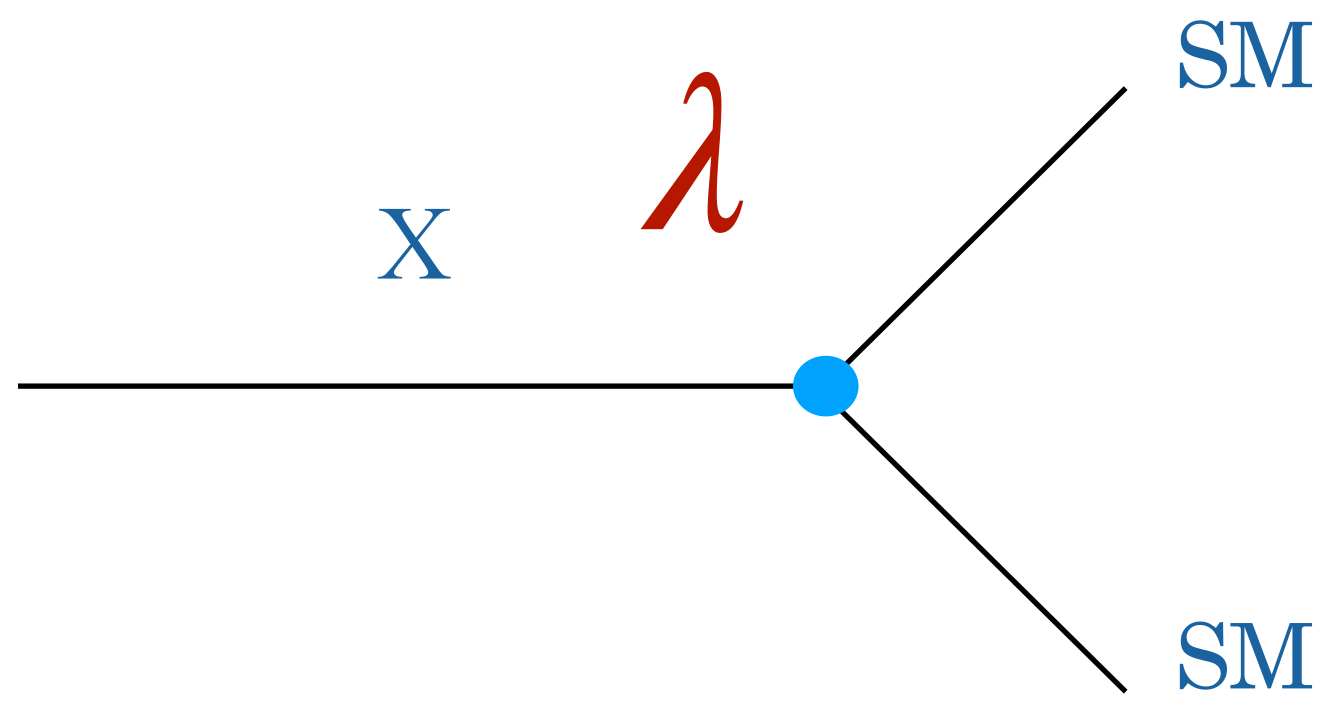
The new couplings can be very small in principle

Possibility of small decay width => LLP !!

Recent survey: Exploring Dark Sector Portals with High Intensity Experiments [arXiv:2207.06905]

Minimal model of LLPs: small coupling

Decay



Suppose the coupling λ is small: X is LLP

Easy to make X an LLP

Minimal model of LLPs: small coupling

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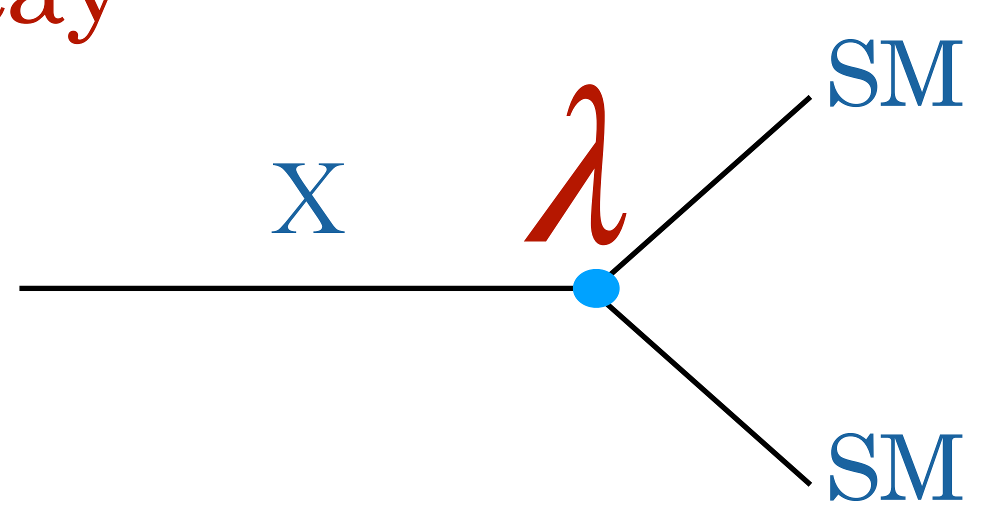
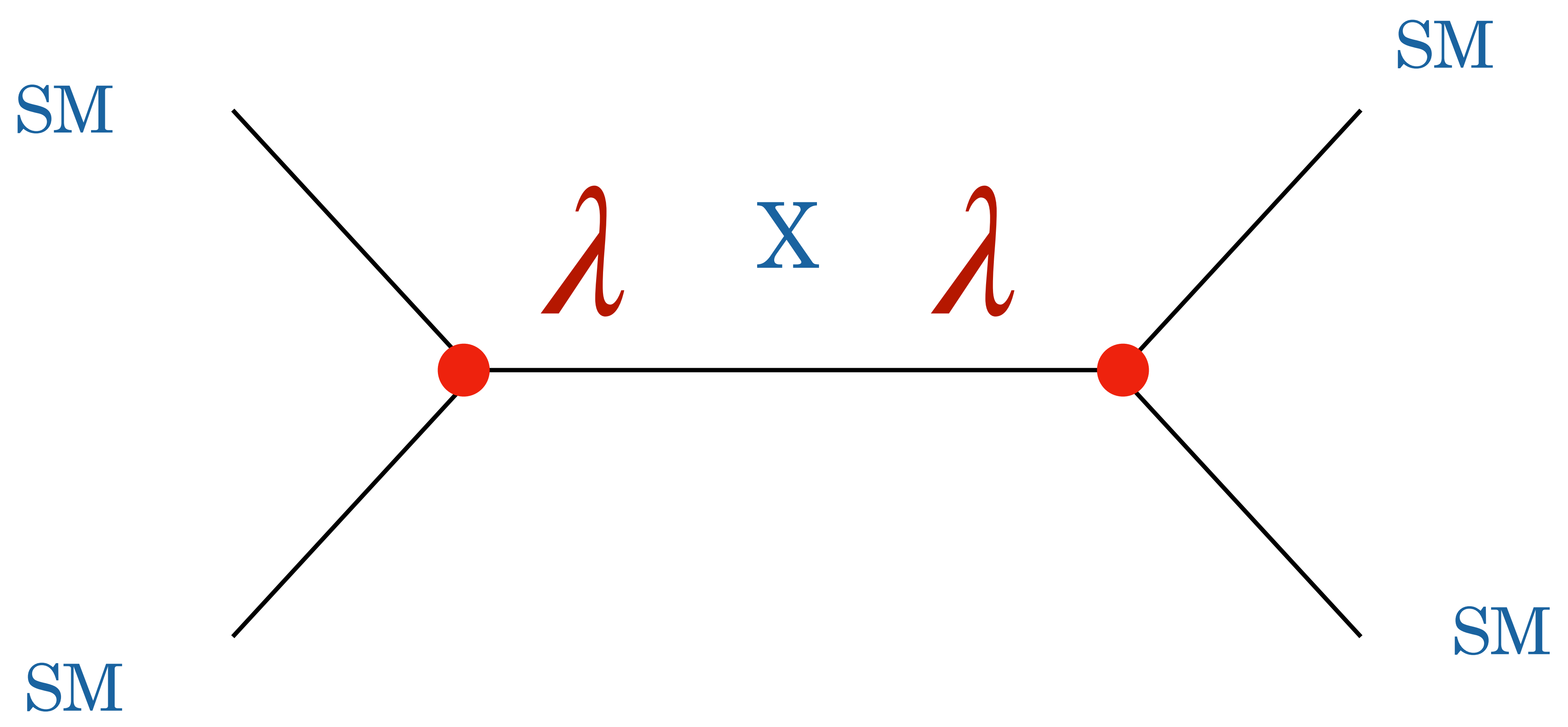


Suppose the coupling λ is small: X is LLP

Easy to make X an LLP

Production mode



Minimal model : decay and production determined by the same coupling

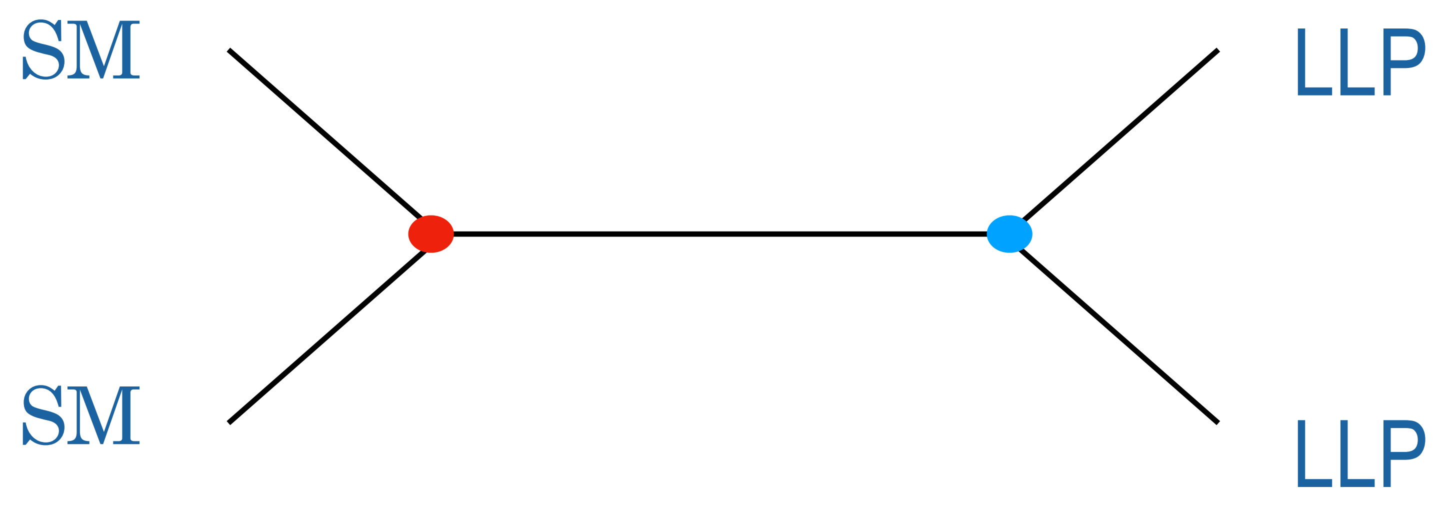
Single production cross section $\propto \lambda^2$

For very small coupling X will have high decay length and small cross section

"High" and "small" will depend on the process and the detector

More possibilities

LLP may come from the decay of SM or other BSM particles, we are using two different couplings



Single production of LLP is suppressed but not the pair production

Non-minimal model : decay width and production cross section determined by the different couplings

Decay of phase space suppressed LLPs

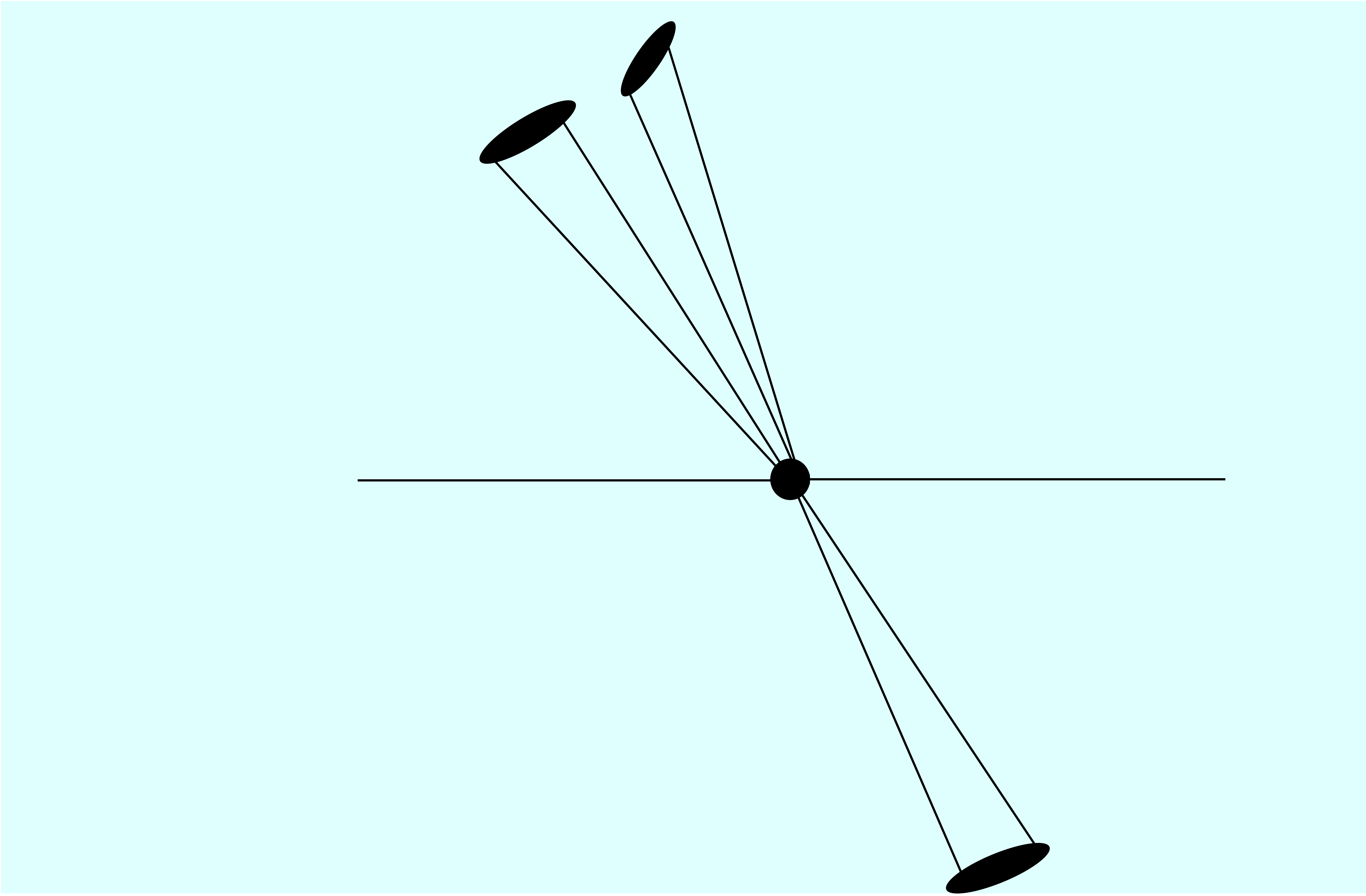
$$\chi^{\pm} \rightarrow \chi^{0} + \pi^{\pm}$$

No suppression in the coupling, LLP decay length is small because of the phase space suppression
=> production cross section can be large

Search Using prompt particles

$$pp \to \tilde{g}\tilde{g}, \tilde{g} \to qq^{'} X^{\pm}_{LLP}$$ Multiple prompt jets + MET

Tracker Volume



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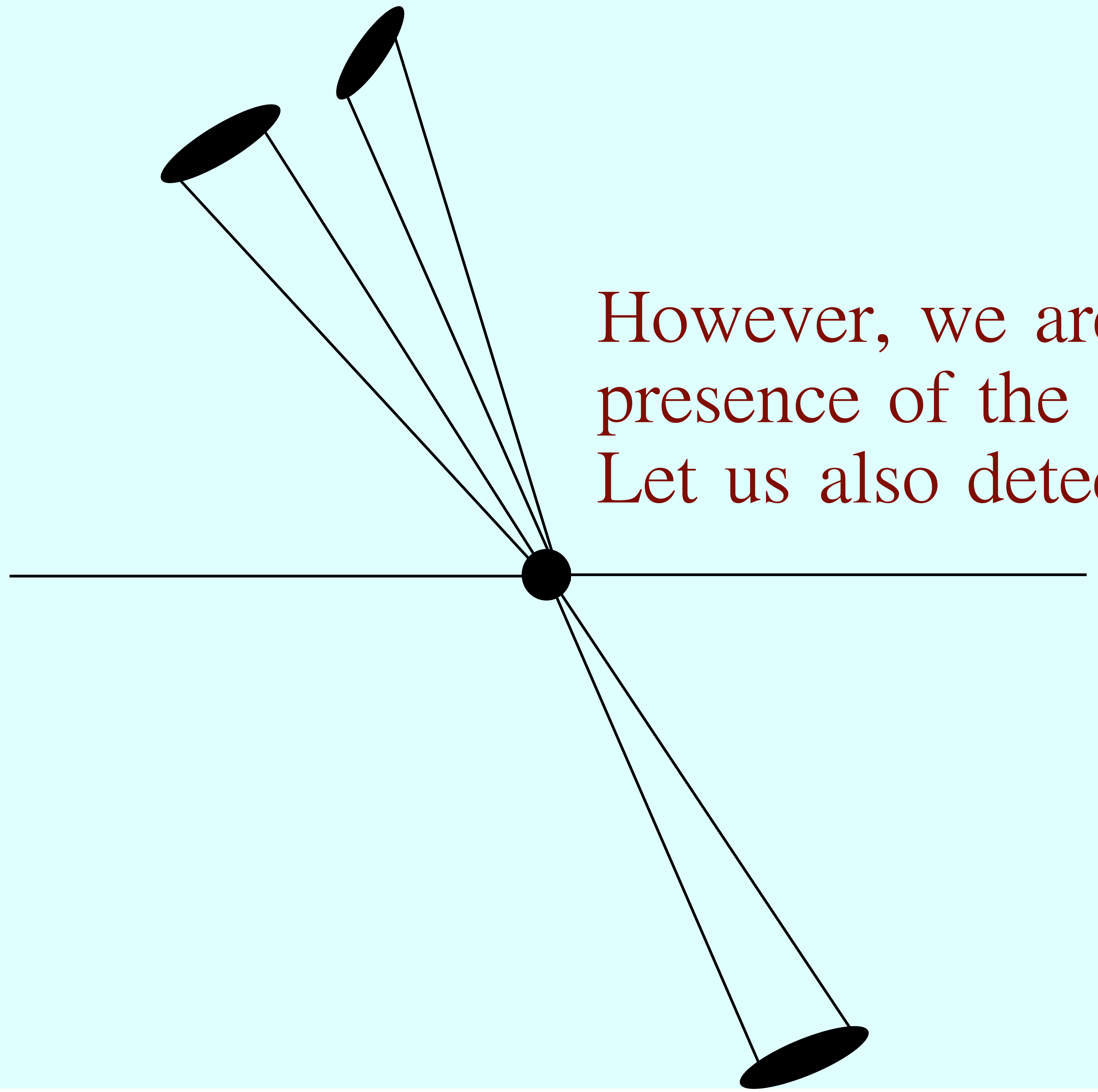
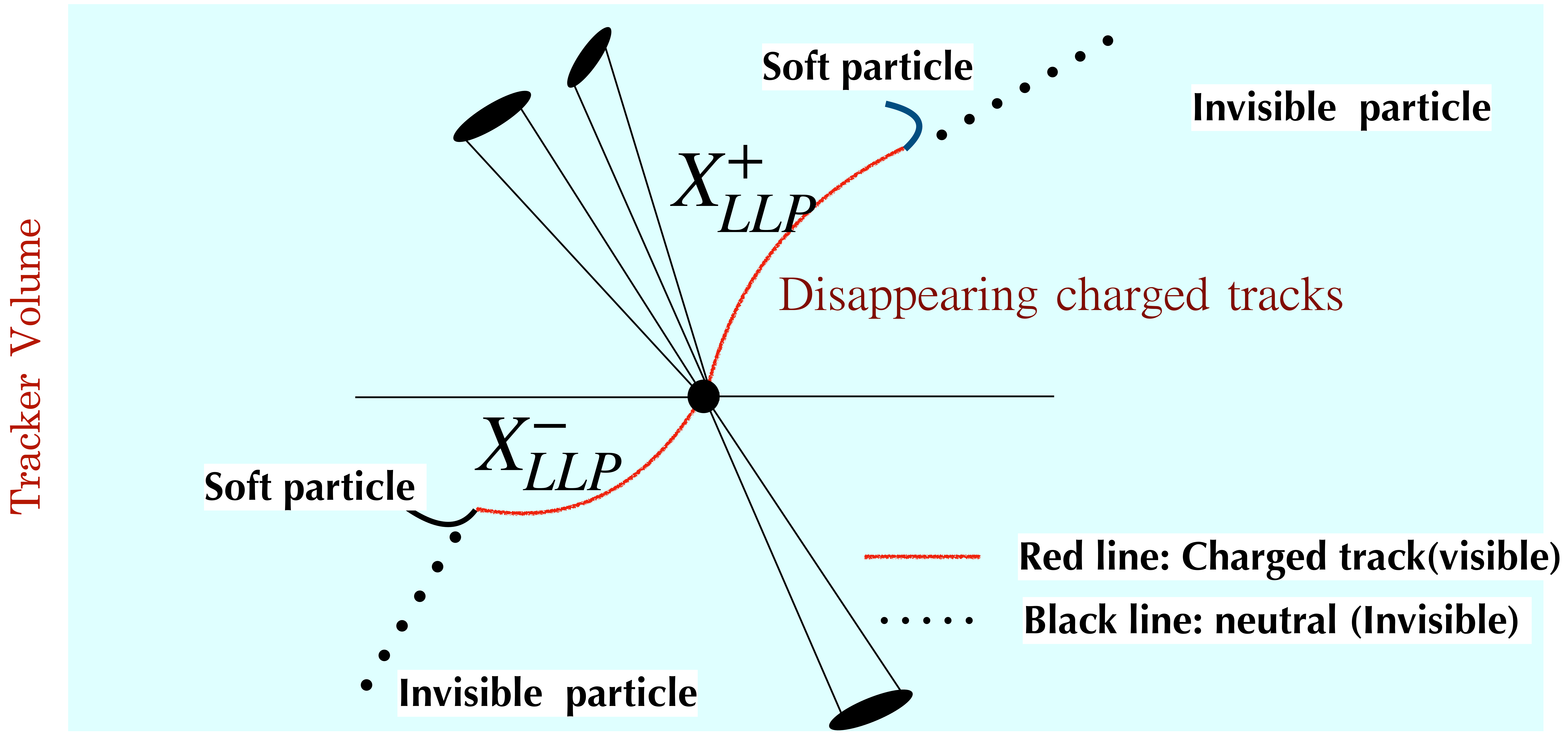


However, we are not fully utilising the presence of the charged LLP.
Let us also detect charged LLPs

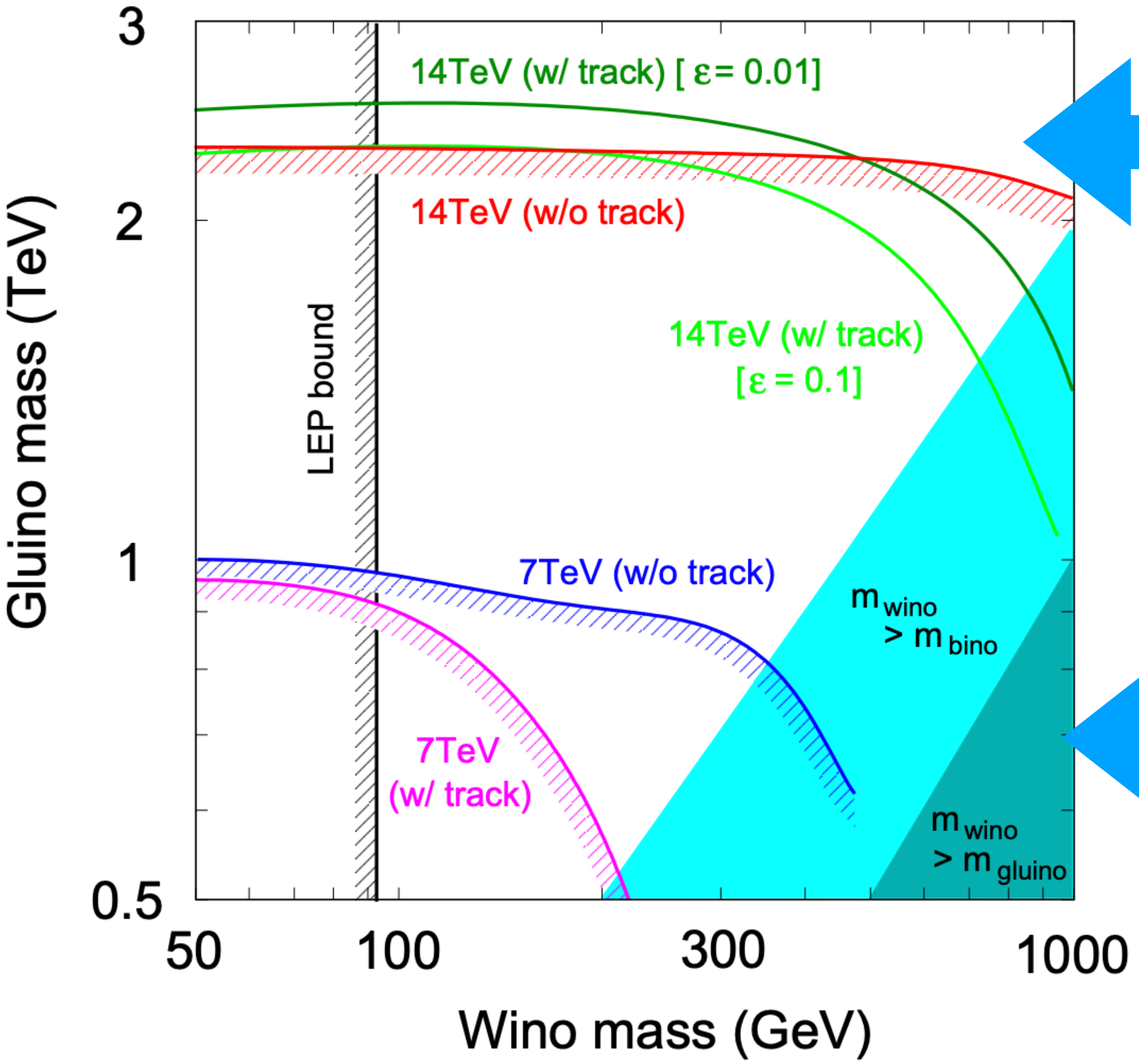
Search Using prompt particles

$pp \to \tilde{g}\tilde{g}, \tilde{g} \to qq^{'} X^{\pm}_{LLP}$ Multiple prompt jets + MET



Significant improvements in the analysis techniques

$$\tilde{g} \to qq^{'}\chi_1^{\pm}$$



BB, Brian Feldstein, Masahiro Ibe, Shigeki Matsumoto, Tsutomu T. Yanagida
arXiv:1207.5453, PRD 2013

Our Proposal : shorter tracks

- The selected track must disappear between 142 mm and 520 mm, i.e. between the inner pixel detectors and the semiconductor detector (SCT).

7 TeV searches: Longer tracks

- The selected track must disappear between 514 mm and 863 mm, i.e. within the first and second layers of the transition radiation tracker (TRT).

ATLAS-CONF-2012-034

Current Situation (Huge improvement in the analysis)

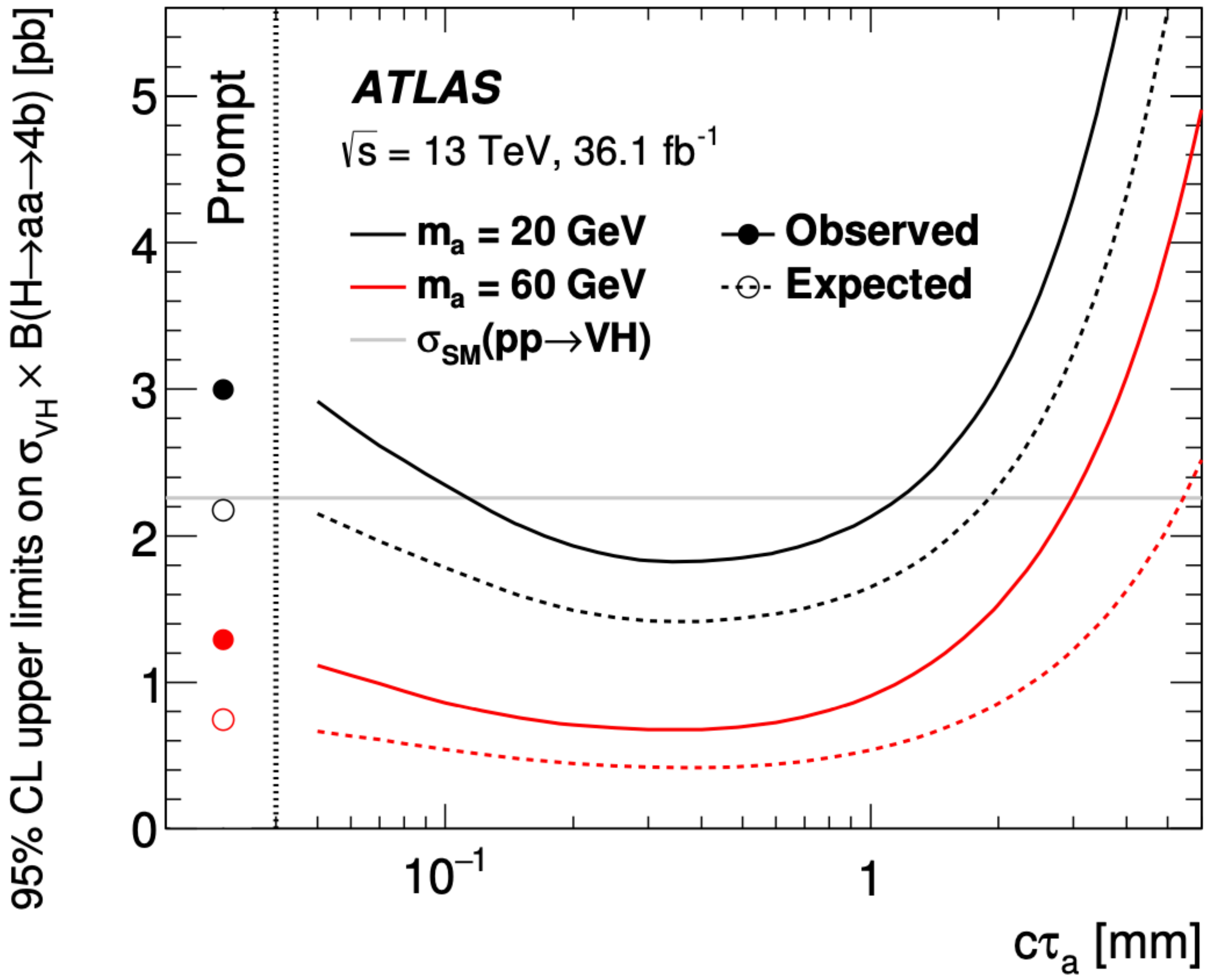
Pixel tracklet searches By ATLAS 2201.02472

Also by CMS collaboration

ATLAS 4b analysis : LLP vs Prompt

$$PP \to VH, H \to \phi\phi, \phi \to \bar{b}b$$

1806.07355



b-jets(Jets including b-hadrons) :

multivariate b-tagging algorithm that combines information from an impact-parameter-based algorithm and from a multi-vertex fitter that tries to identify the b- to c-hadron decay chain

The b-tagging algorithm is also works in identifying b-jets that do not originate from the primary vertex(Prompt).

Slight displacement enhances the sensitivity => drops after ~ 1mm

Prompt searches are not optimal for highly displaced LLPs => need dedicated analysis

Unusual features of LLPs

$$pp \rightarrow XX,\ X_{LLP} \rightarrow e^{+}e^{-}$$

X is the long-lived particle

Unusual features of LLPs

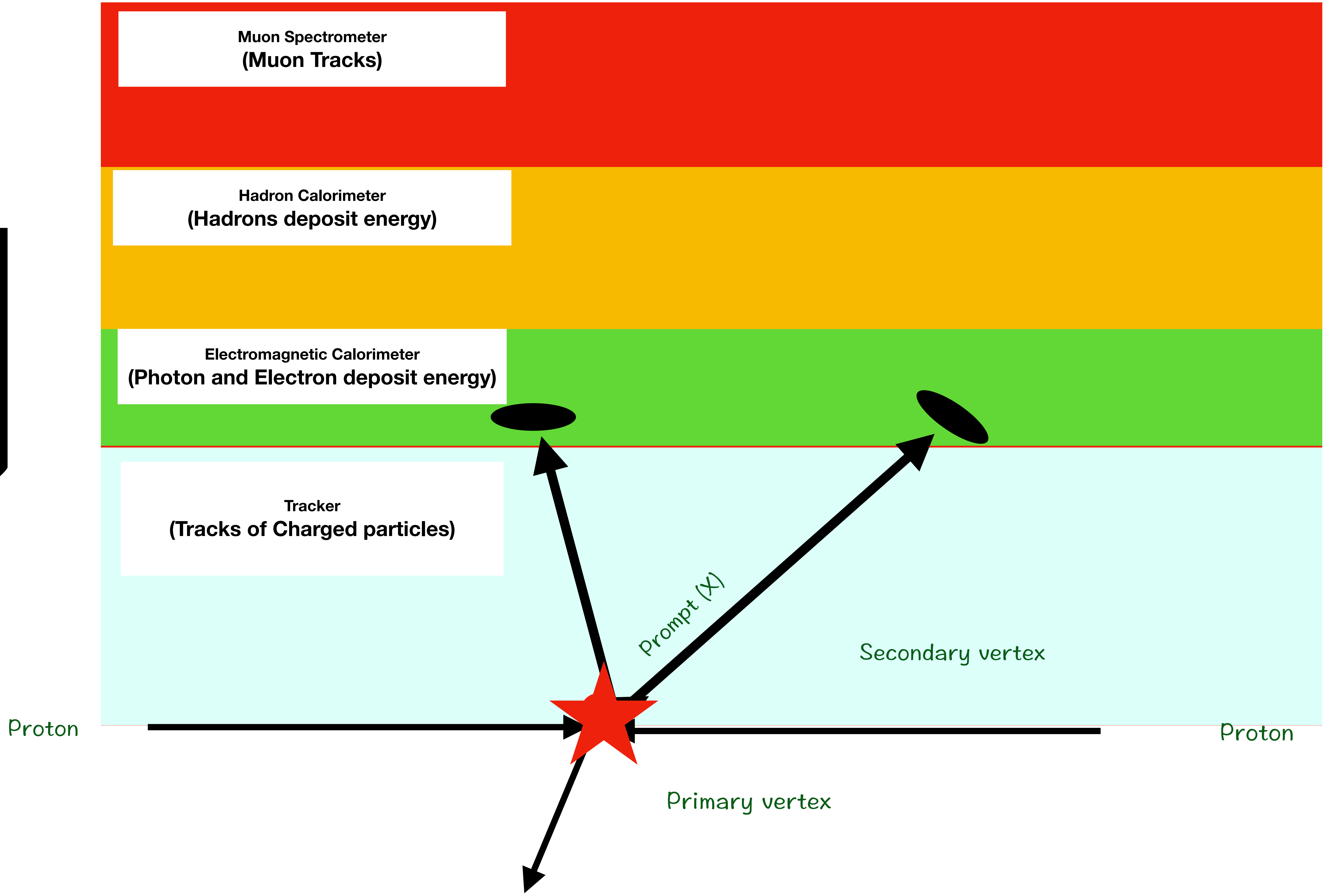
Suppose X decays promptly

Electron Identification :

Tracker: Track
ECAL: energy deposits
HCAL : No energy deposition

X decays promptly

$$pp \to XX,\ X \to e^+e^-$$



Unusual features of LLPs

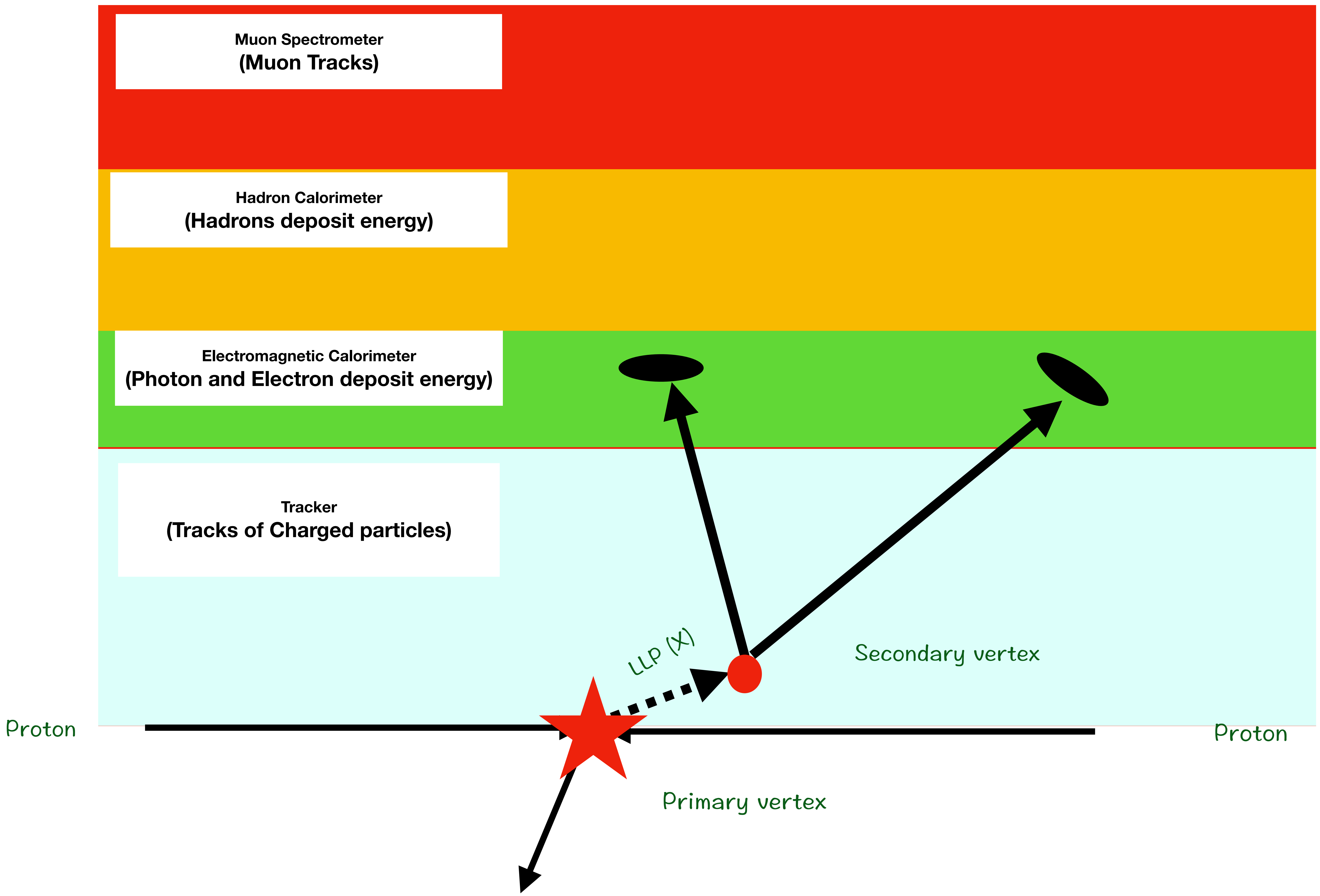
Electron Identification :

Tracker: May not be any reconstructed tracks
ECAL: energy deposits
HCAL : No energy deposition

Looks like a photon !!!

LLP decays inside the tracker

$$pp \to XX,\ X \to e^+e^-$$



Unusual features of LLPs

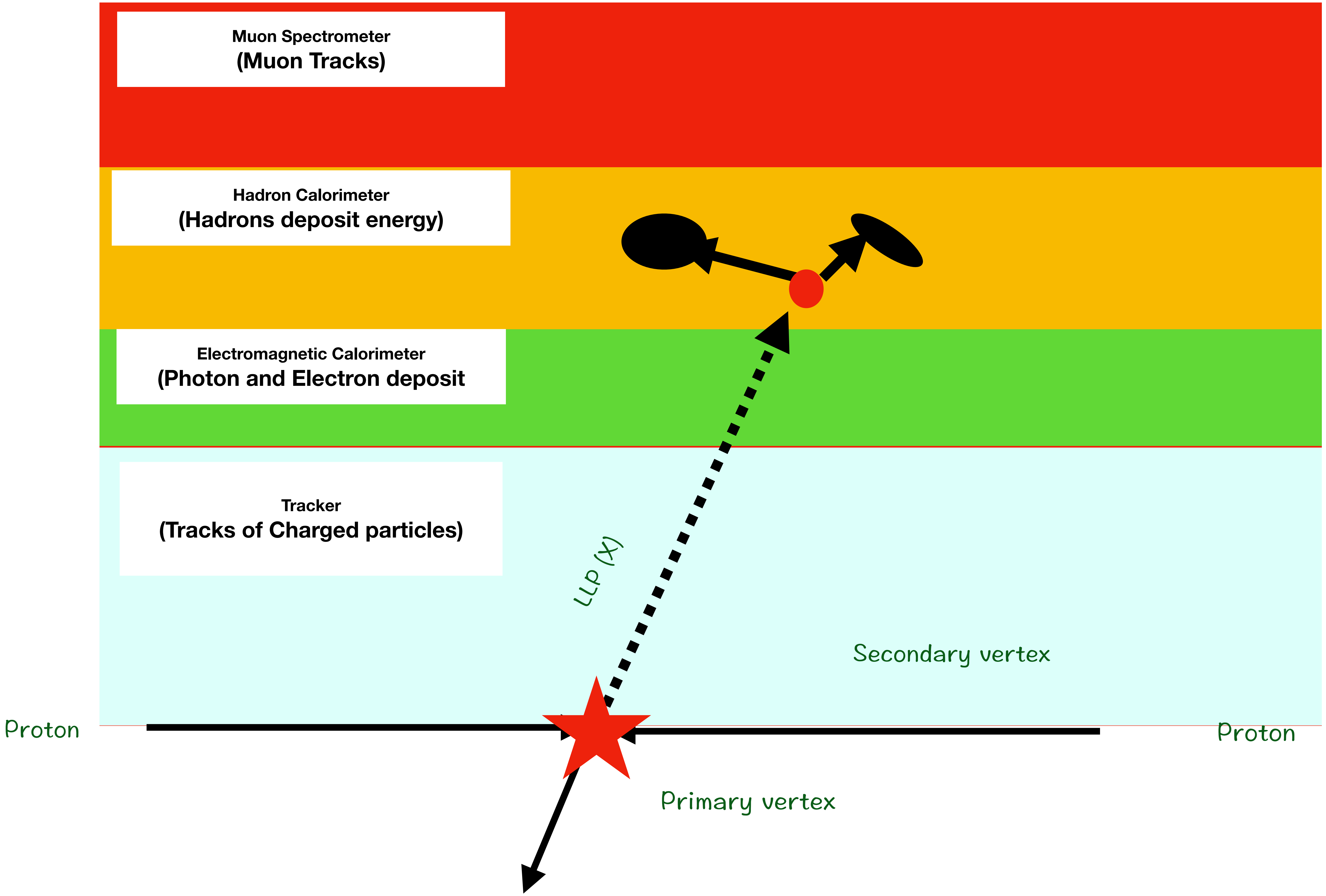
Electron Identification :

Tracker: No track
ECAL: No energy deposit
HCAL : energy deposition

Looks like a neutral hadron !!!

LLP decays inside the hadronic calorimeter

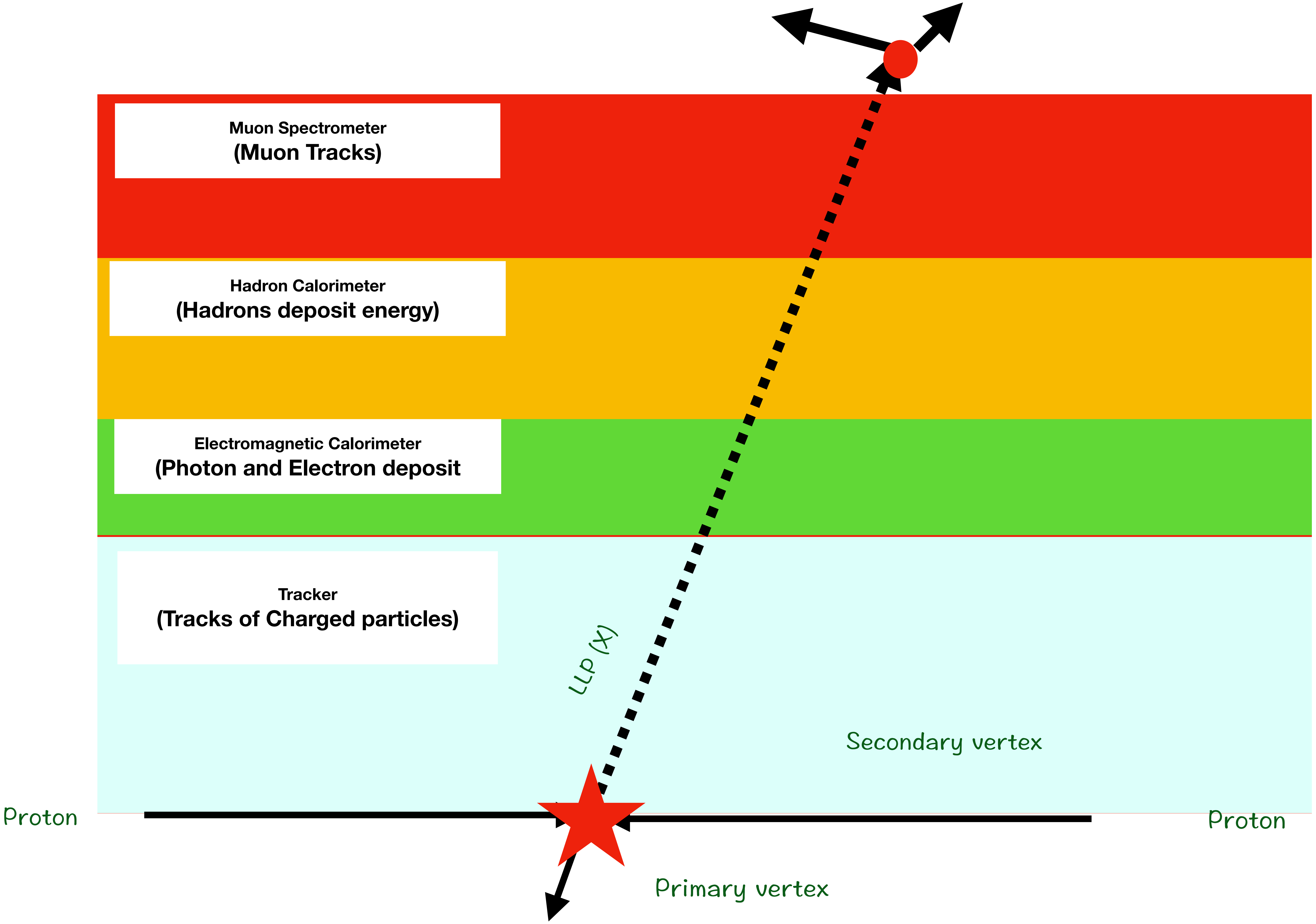
$$pp \to XX,\ X \to e^+e^-$$



Unusual features of LLPs

LLP decays outside the detector

$$pp \to XX,\, X \to e^+e^-$$



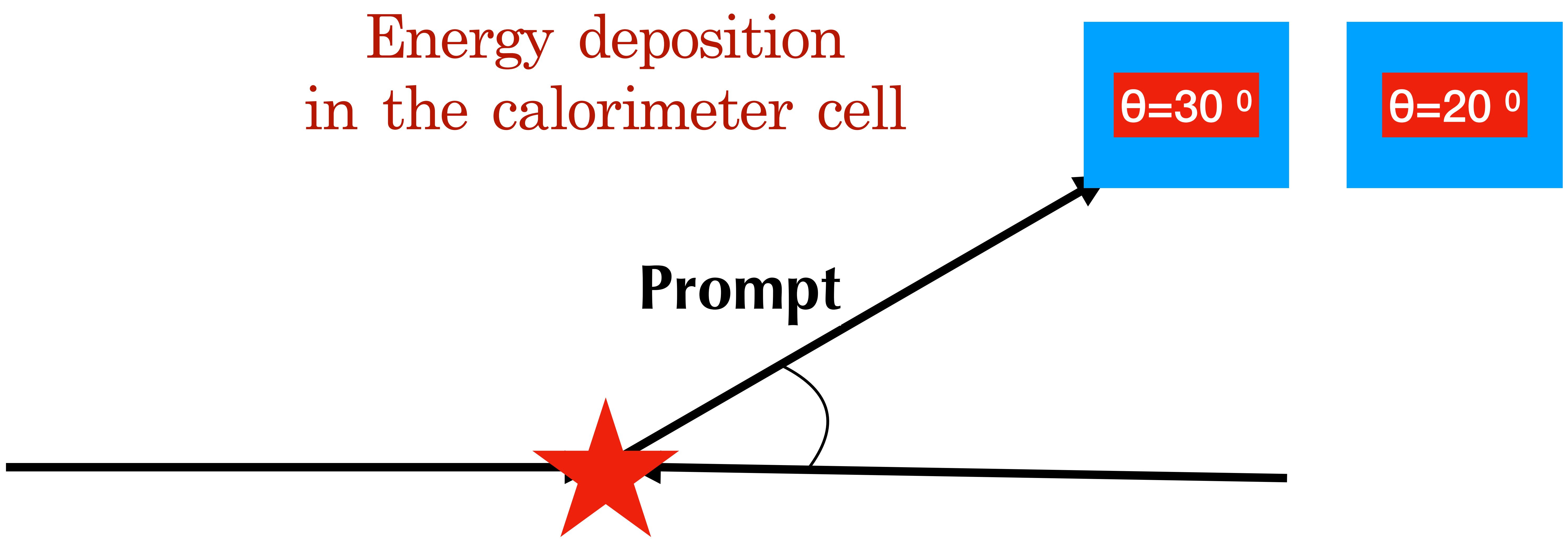
Electron Identification :

Tracker: No track
ECAL: No energy deposits
HCAL : No energy deposits

Looks like an invisible particle !!!

Observation: signature depends where LLP decays Lifetime dependent search required

Unusual features of LLPs : Non-pointing nature

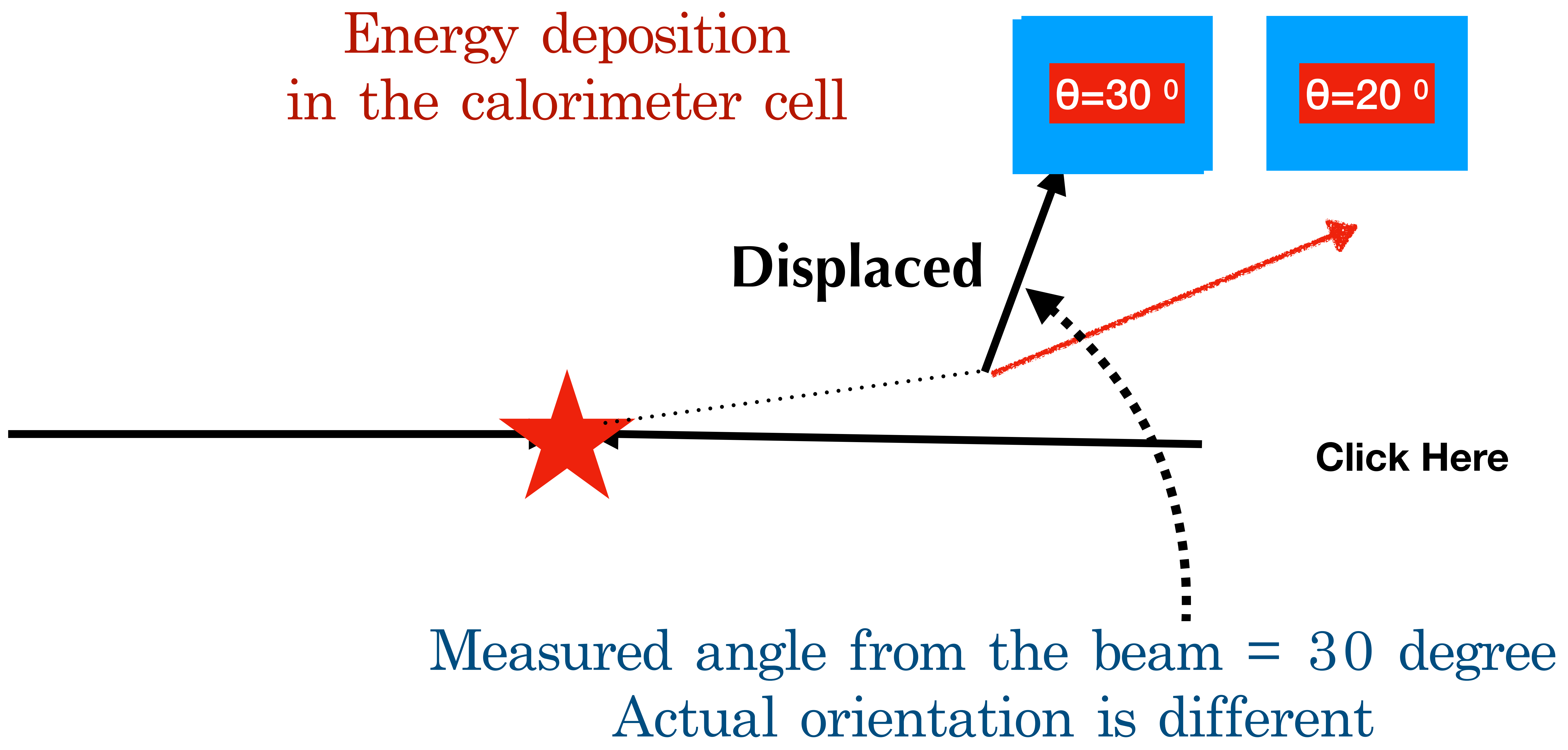


Orientation from the beam axis of the particle = 30 degree

Unusual features of LLPs : Non-pointing nature

In experiment, particle's η-ϕ corresponds to the η-ϕ of the detector cell where it deposits its energy

Mismatch of displaced particle's η-ϕ direction with η-ϕ segmentation of the detector



layered structure/depth segmentation needed to visualise the effect

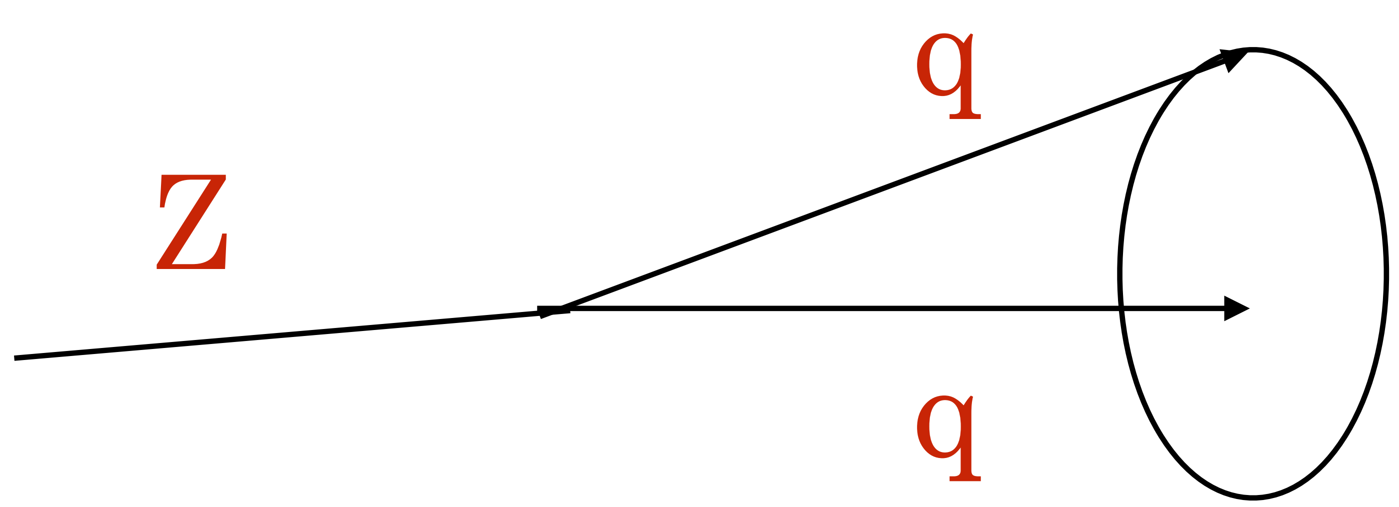
Fast detector simulations do not have such layered structure (e.g. Delphes)

See non-pointing photon search by CMS collaboration

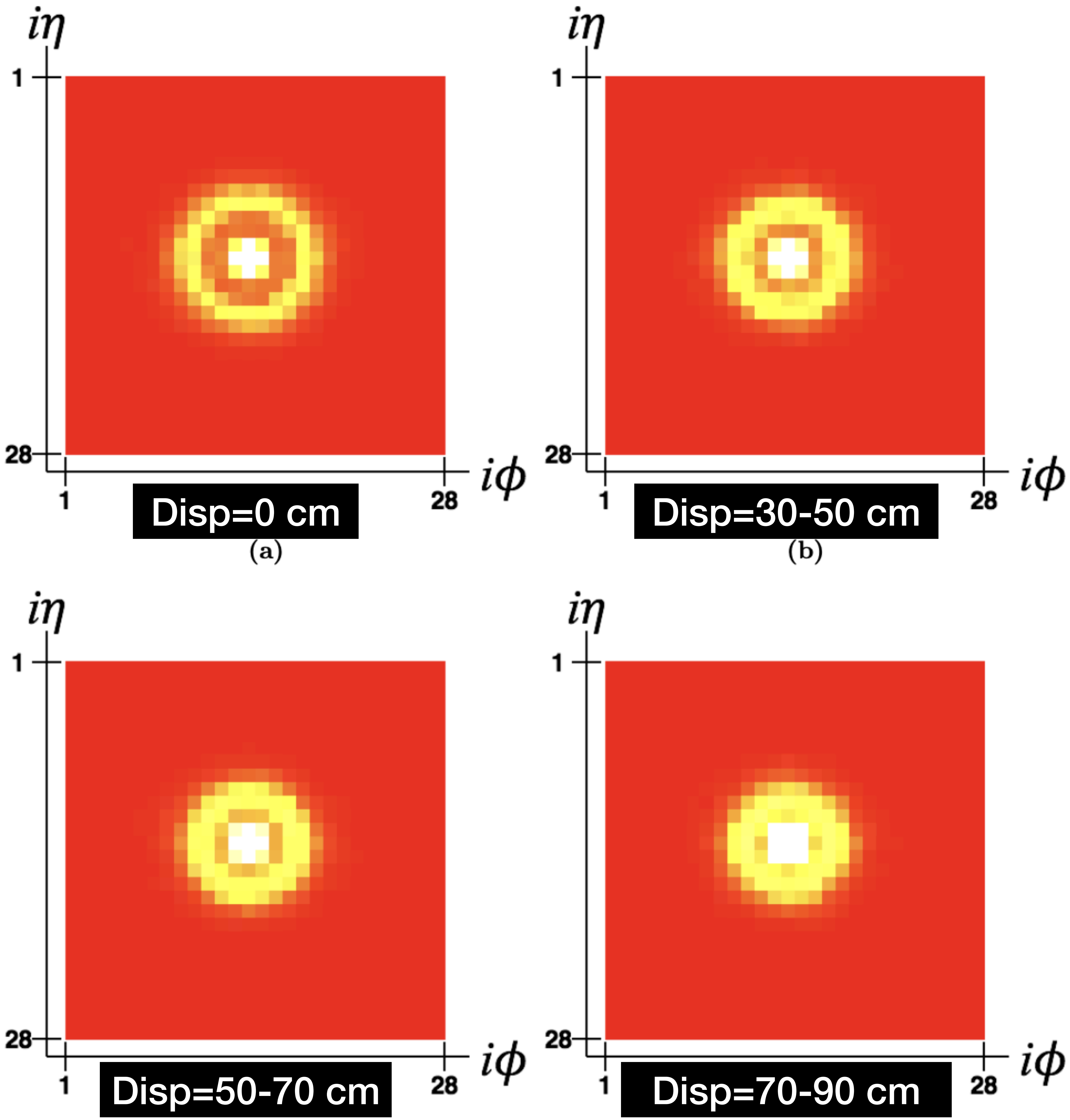
Unusual features of LLPs : Non-pointing nature

$X(\mathrm{LLP}) \to Z + \mathrm{inv}$

Energy ~400 -500 GeV



average of images: prompt vs displaced

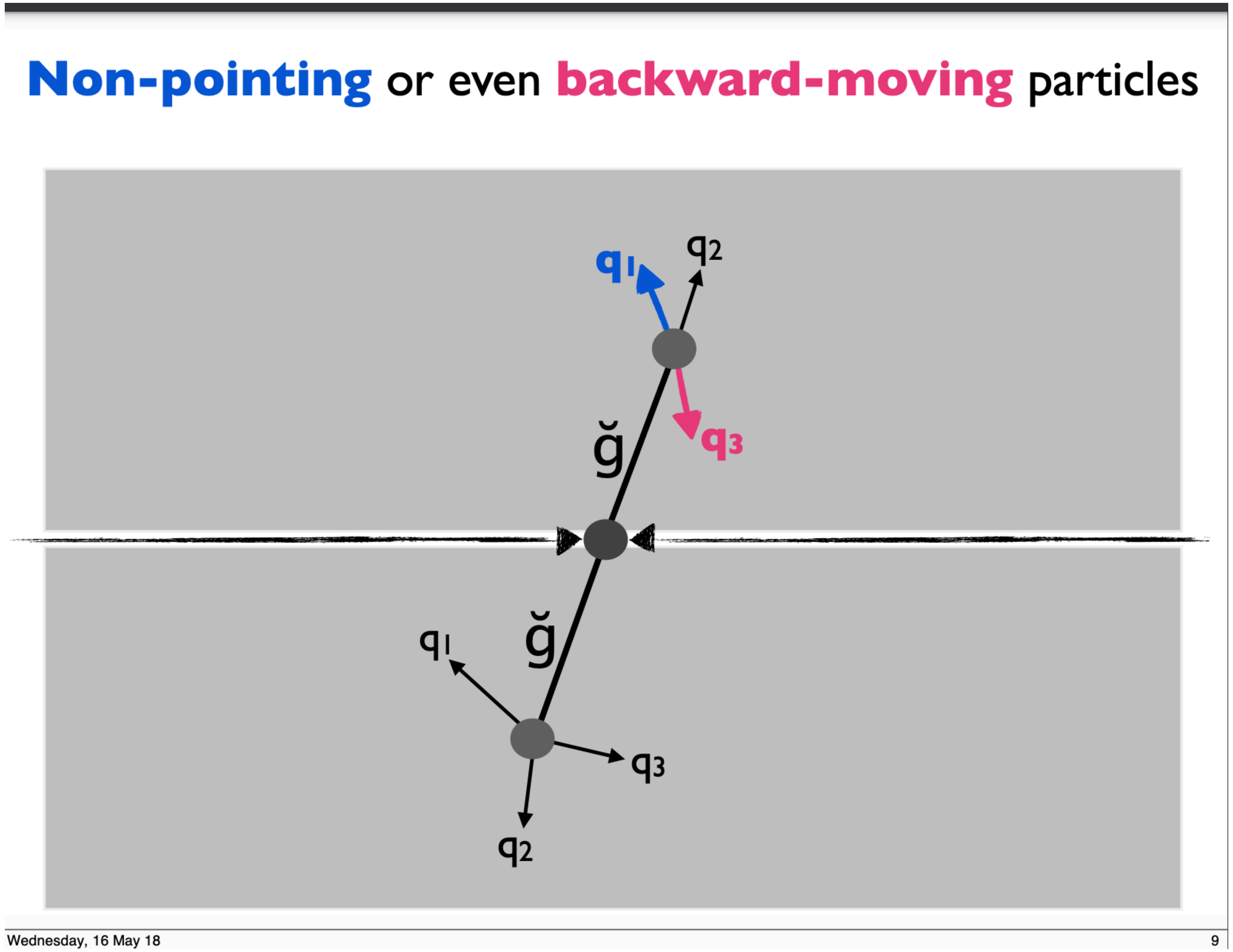


CNN can discriminate displaced vs prompt energy deposition

Physical area taken by the decay products become small with distance and they mostly get contained within fewer $\eta - \varphi$ towers.

BB, Swagata Mukherjee and Rhitaja Sengupta
arXiv:1904.04811, JHEP 2019

Unusual features of LLPs : backward moving particle



Talk by Swagata Mukherjee
LHC LLP Workshop 16-18 May, 2018 CERN

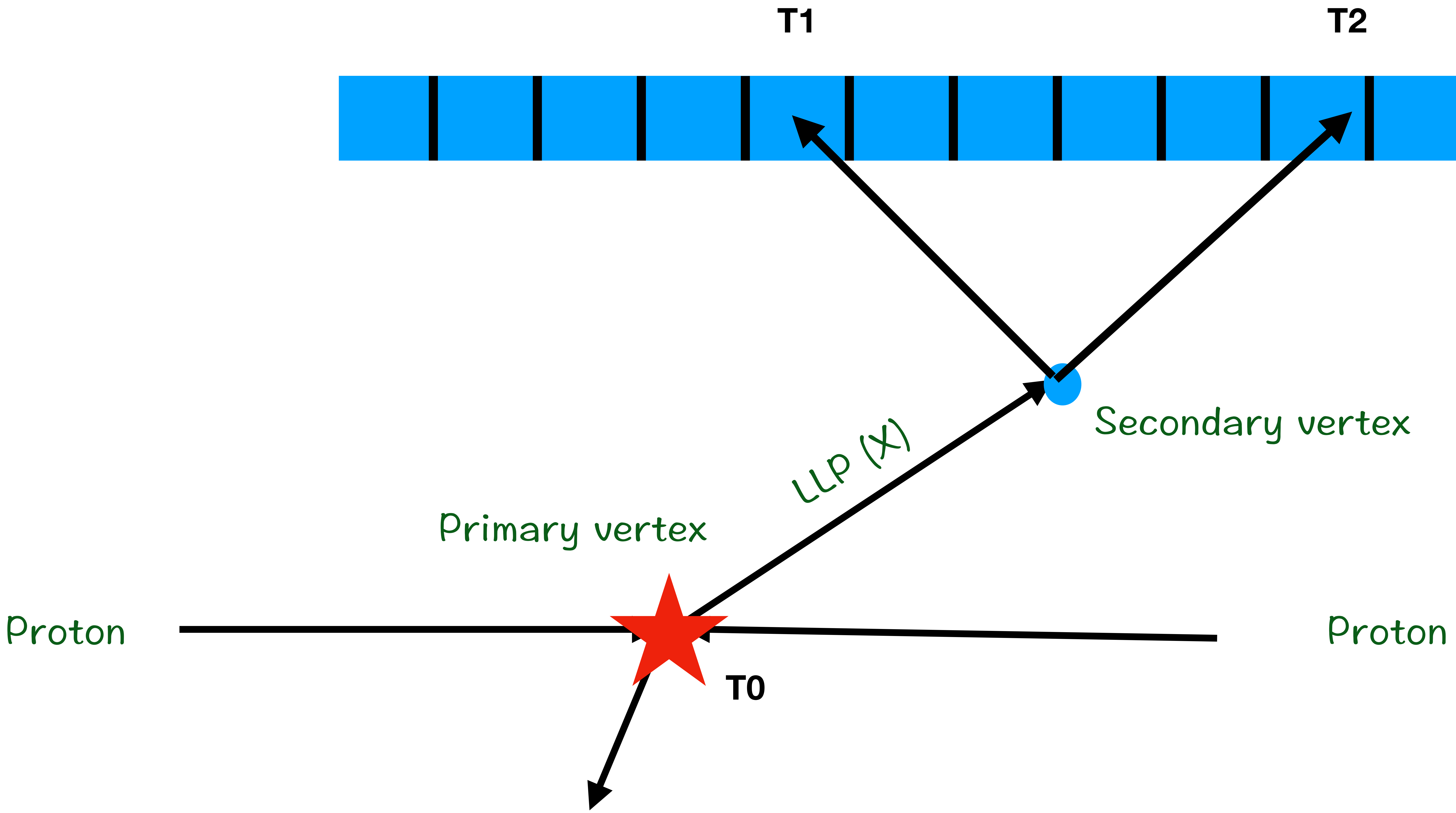
S. Banerjee, G. Bélanger, BB, F. Boudjema, R. Godbole and S. Mukherjee Phys.Rev.D 98 (2018) 11, 115026

Timing Information

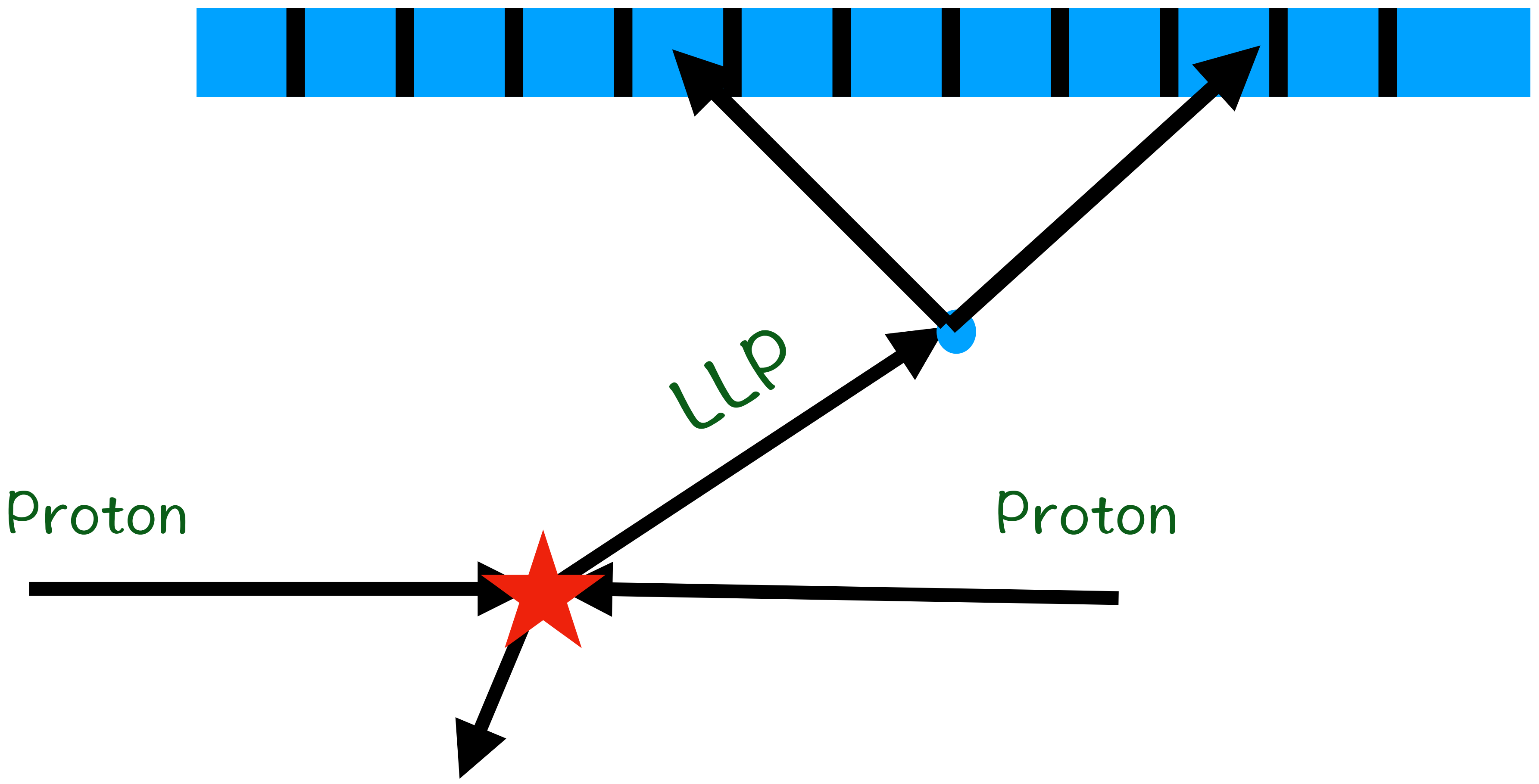
$$pp \to \phi\phi,\ \phi \to e^+e^-$$

Decay products of heavy LLPs will reach late compared to the prompt particles

T1 -T0 can be used as a discriminant



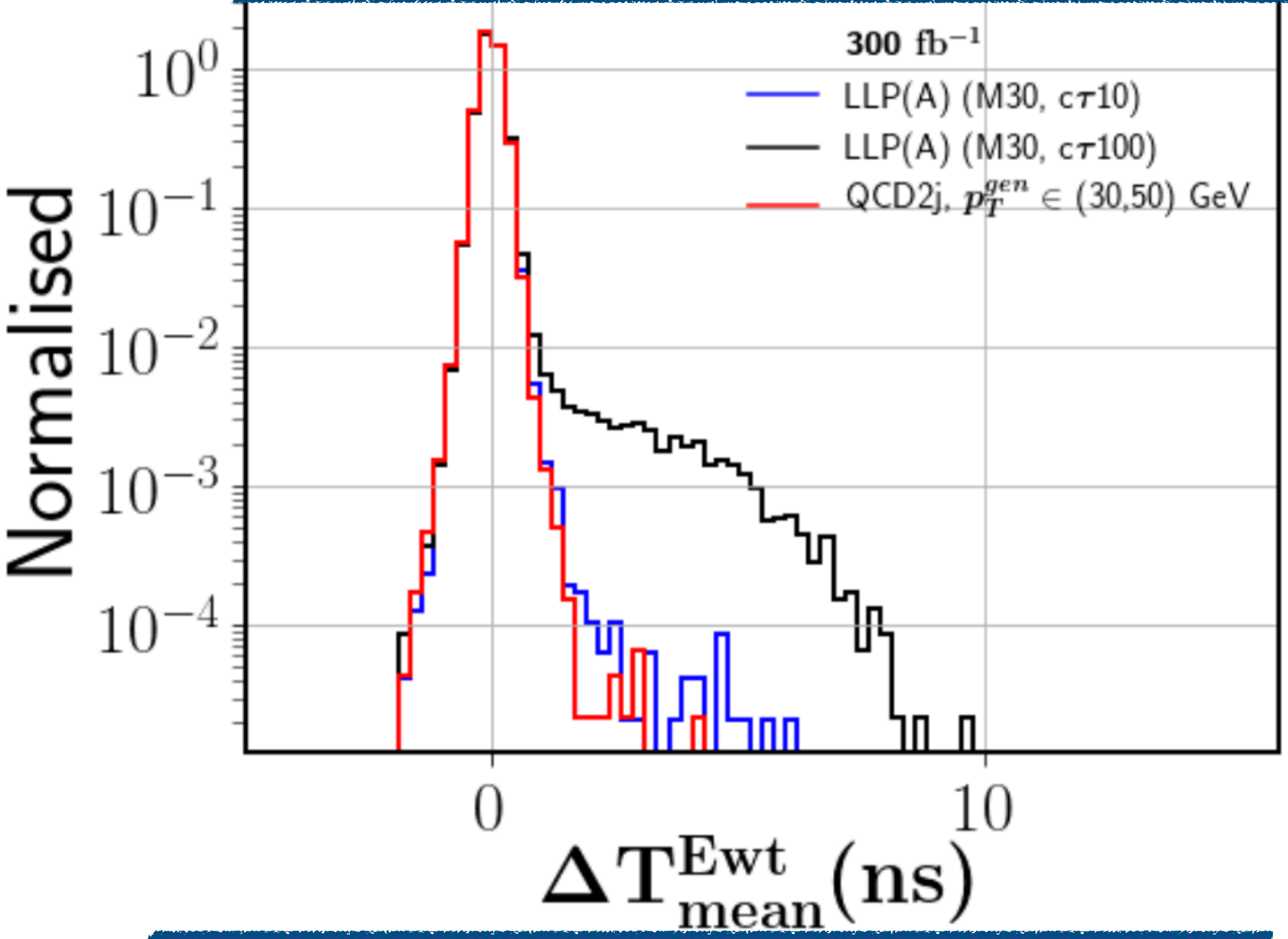
Jet timing



ECAL barrel detector will also provide precise timing information

30ps timing resolution for 20 GeV energy deposition at the beginning of HL-LHC

LLP Model: $pp \to h \to XX, X \to q\bar{q}$



$$\Delta T^{Ewt}_{mean} = \frac{\sum \Delta T_i \times E_i}{\sum E_i}, \quad i \equiv \text{crystals inside the jet}$$

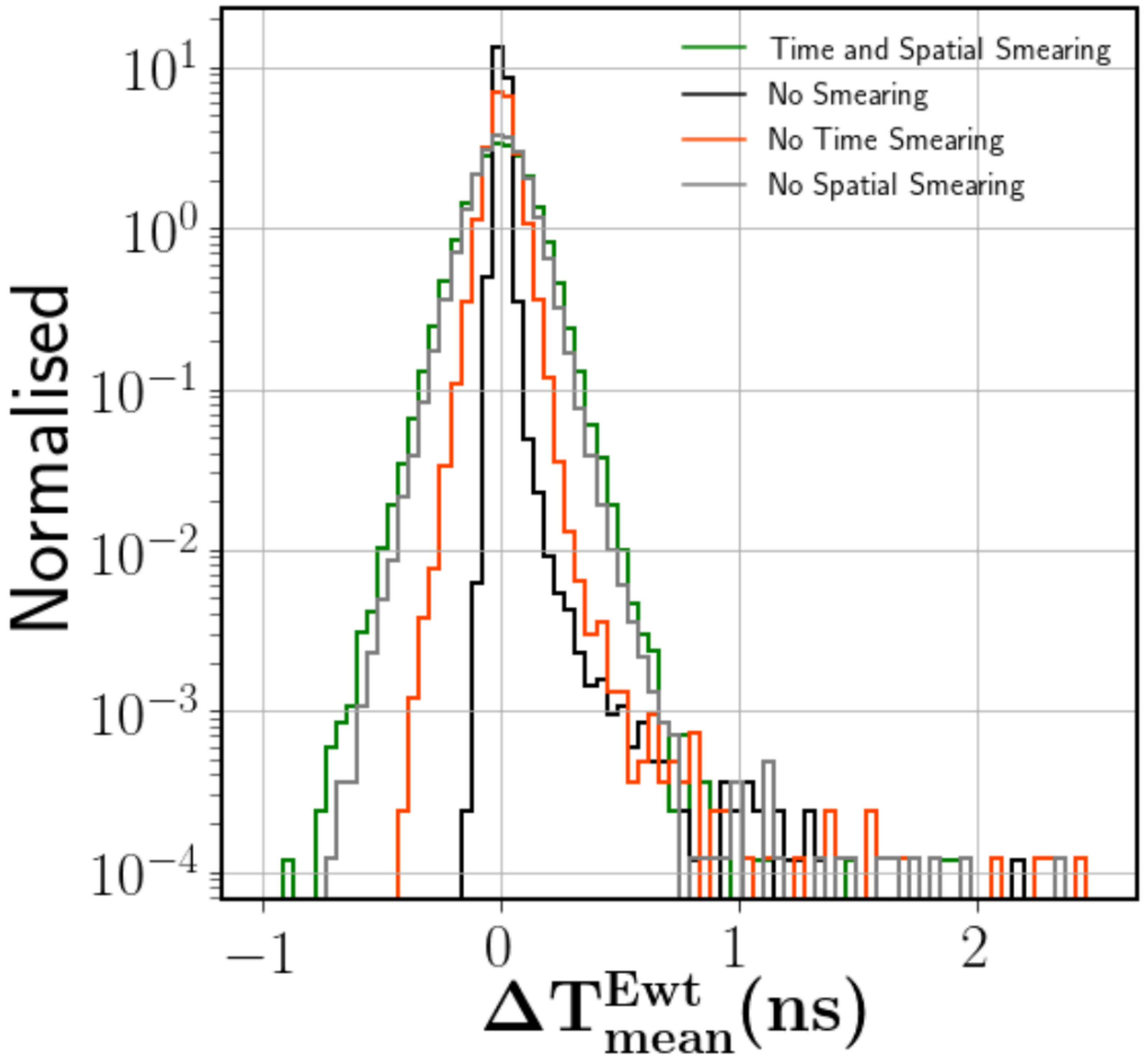
distribution is different for high decay length

QCD jets can also have a long tail

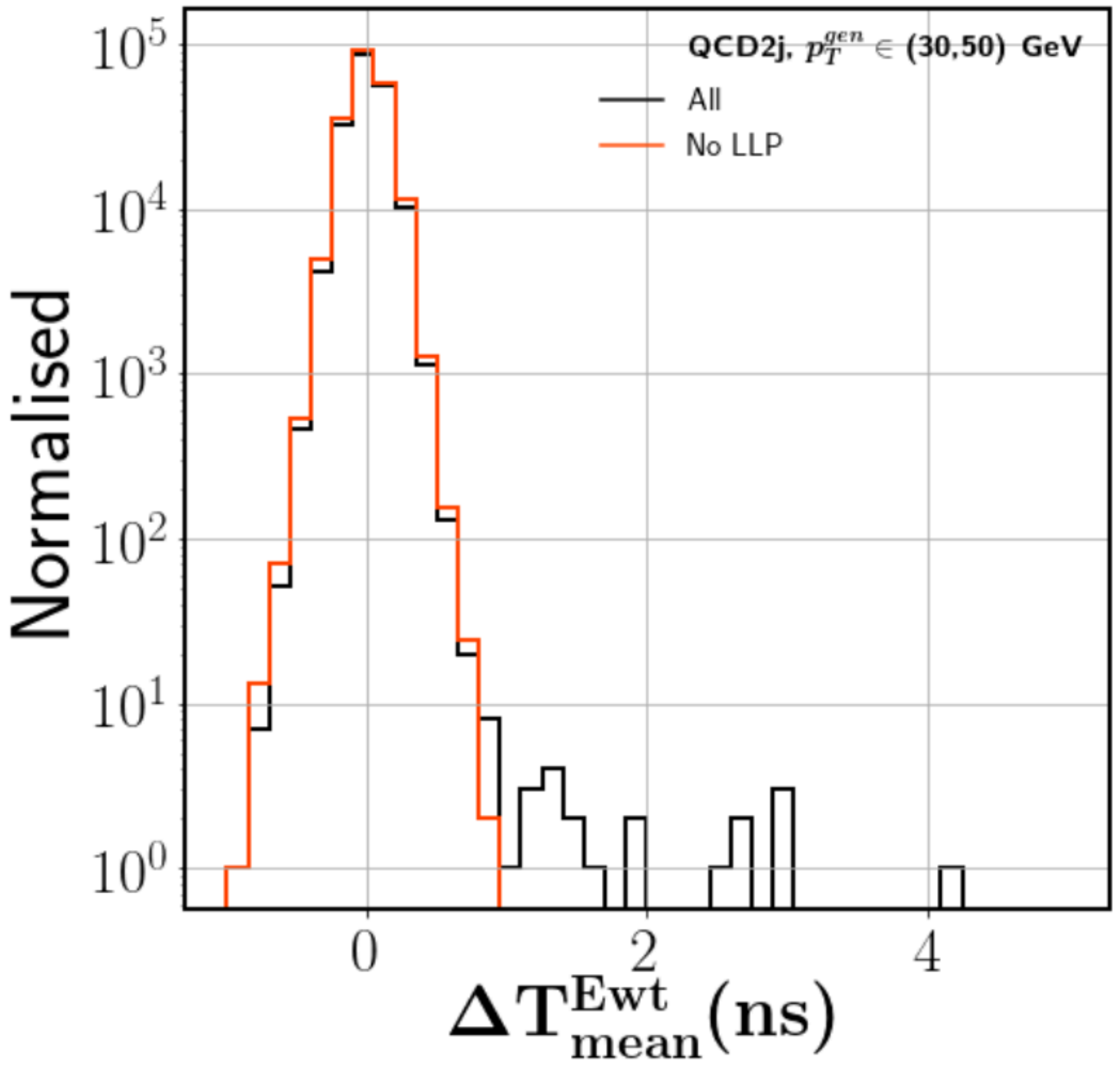
BB, Tapasi Ghosh , Rhitaja Sengupta , Prabhat Solanki
e-Print: 2112.04518, JHEP 2022

Time-delayed QCD jets

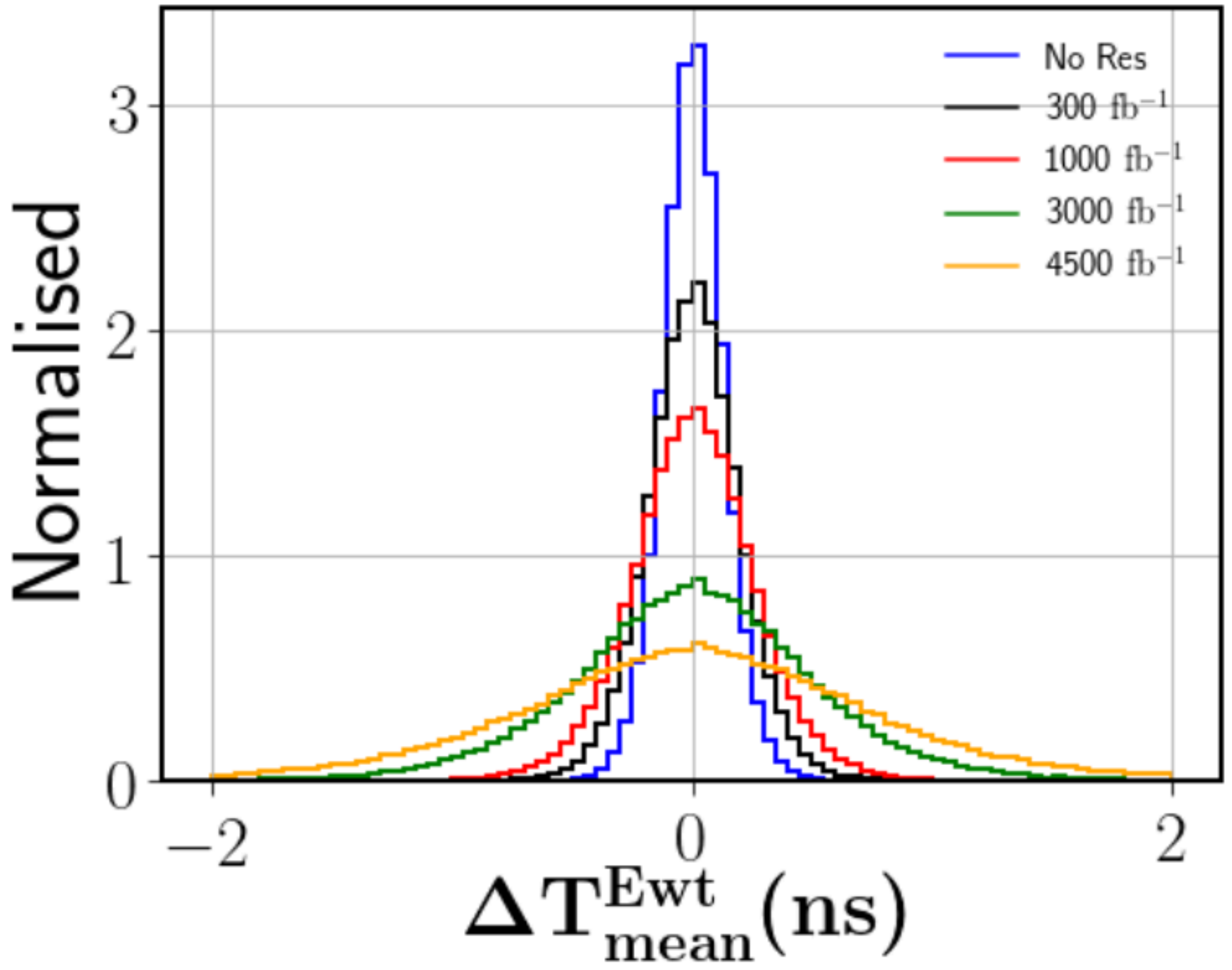
BB, Tapasi Ghosh , Rhitaja Sengupta , Prabhat Solanki
e-Print: 2112.04518, JHEP 2022



Smearing effect



LLPs in SM



ECAL resolution

Intrinsic spread of the beam-spot in both the temporal and longitudinal direction

Particles like KS, Λ , Ω etc. are long lived in the detector

ECAL resolution changes with time

Displaced Jets

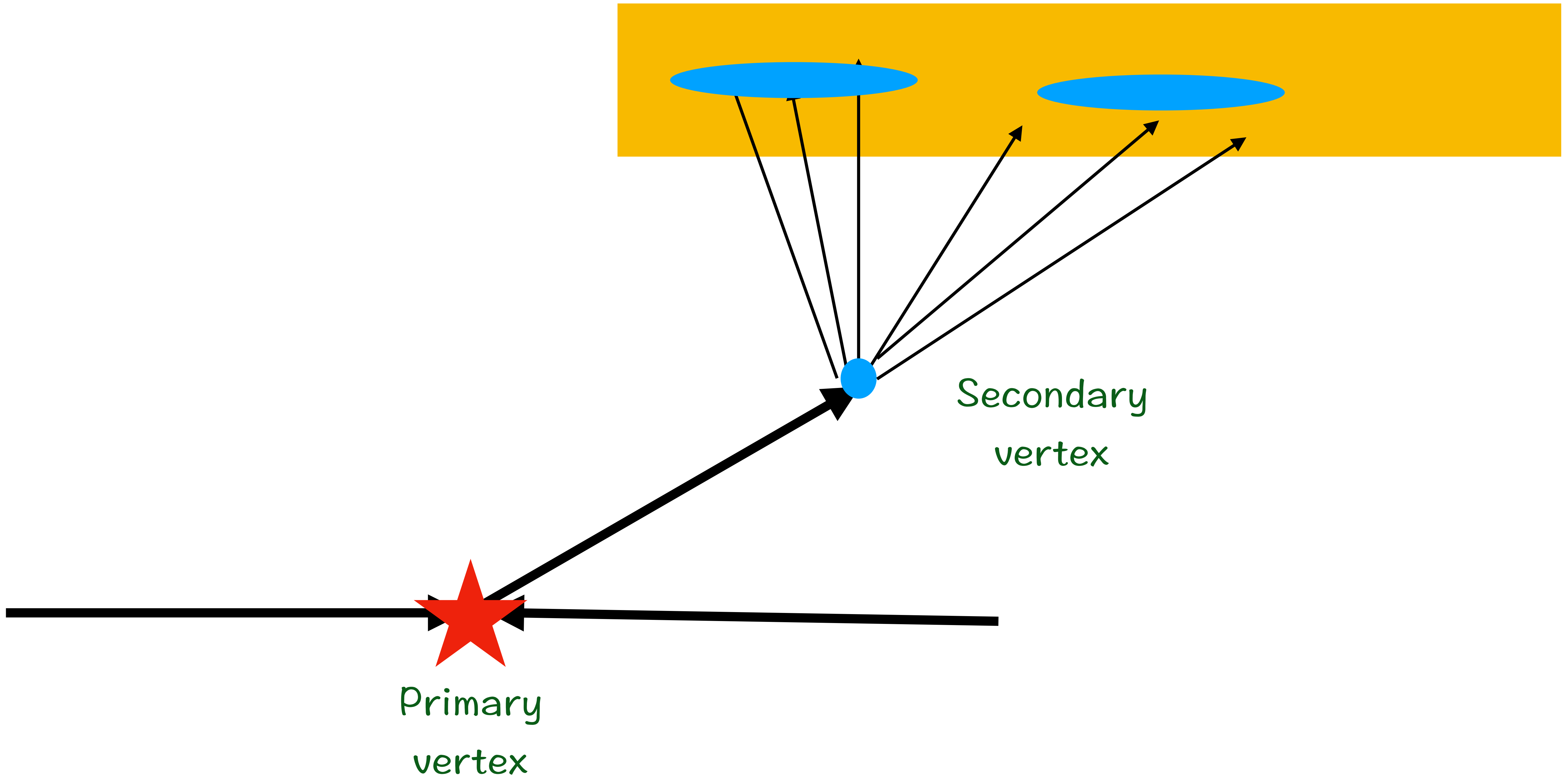
$$pp \to X_{LLP} X_{LLP},\ X_{LLP} \to q + \bar{q}$$ **(jets)**

Nice features

- Displaced multiple tracks
- Secondary vertices
- Calorimeter energy deposits are not associated with tracks from primary vertex=> trackless jet

Displaced jets

Energy deposit in the calorimeter, no associated tracks from the primary vertex



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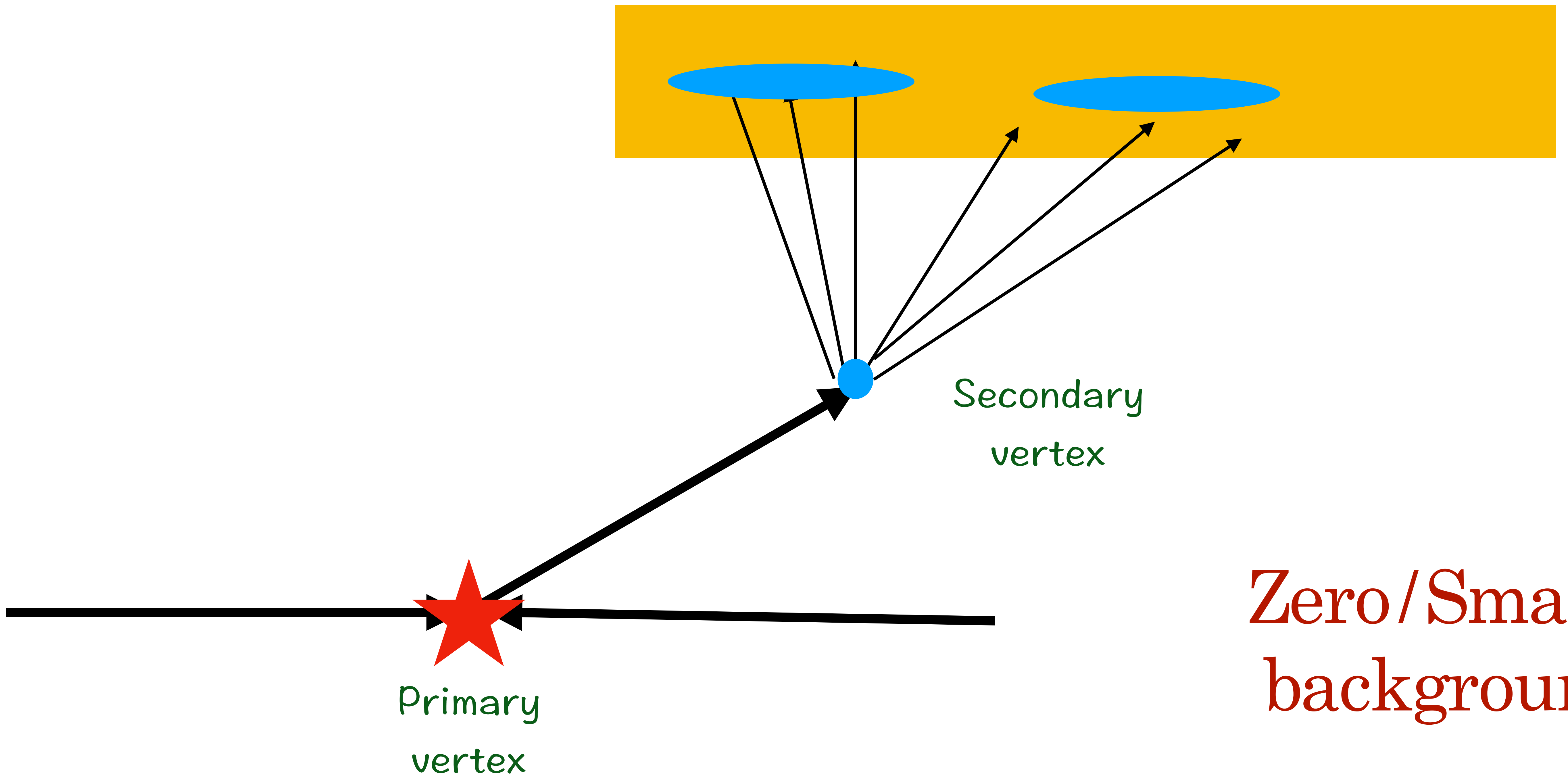
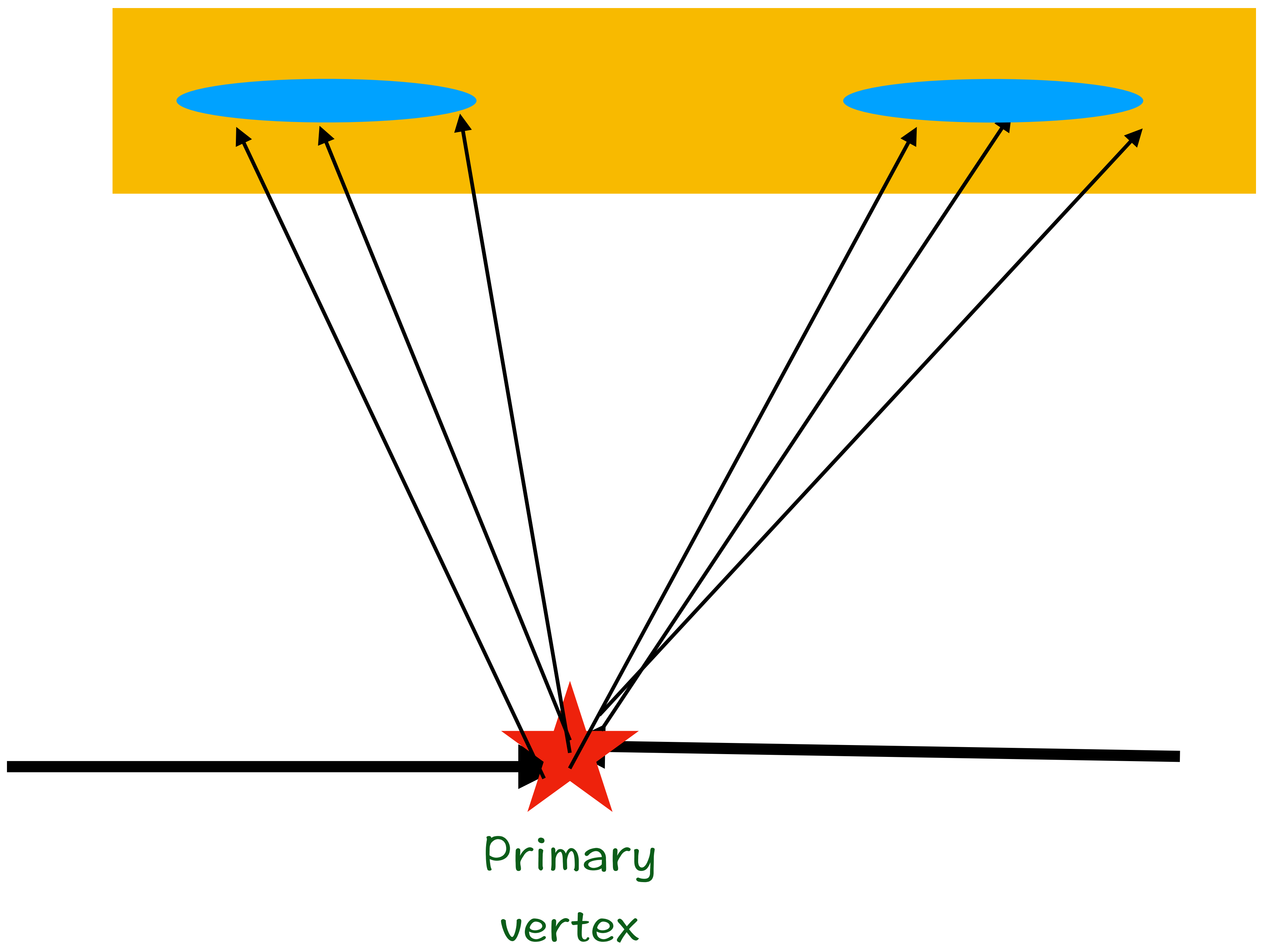


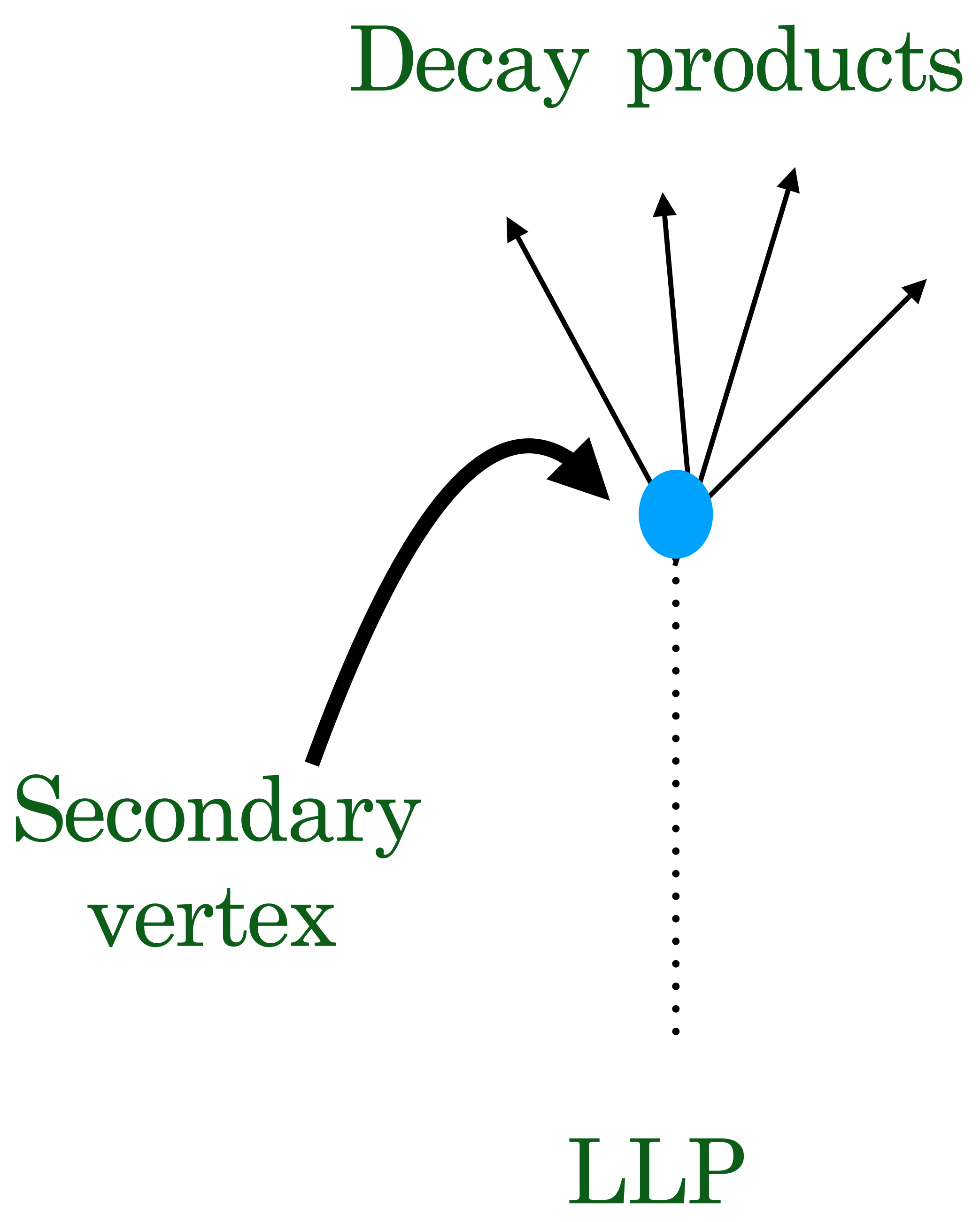
Prompt QCD jets

Energy deposit in the calorimeter, associated tracks from the primary vertex



Zero/Small SM background ??

Displaced Vertex search

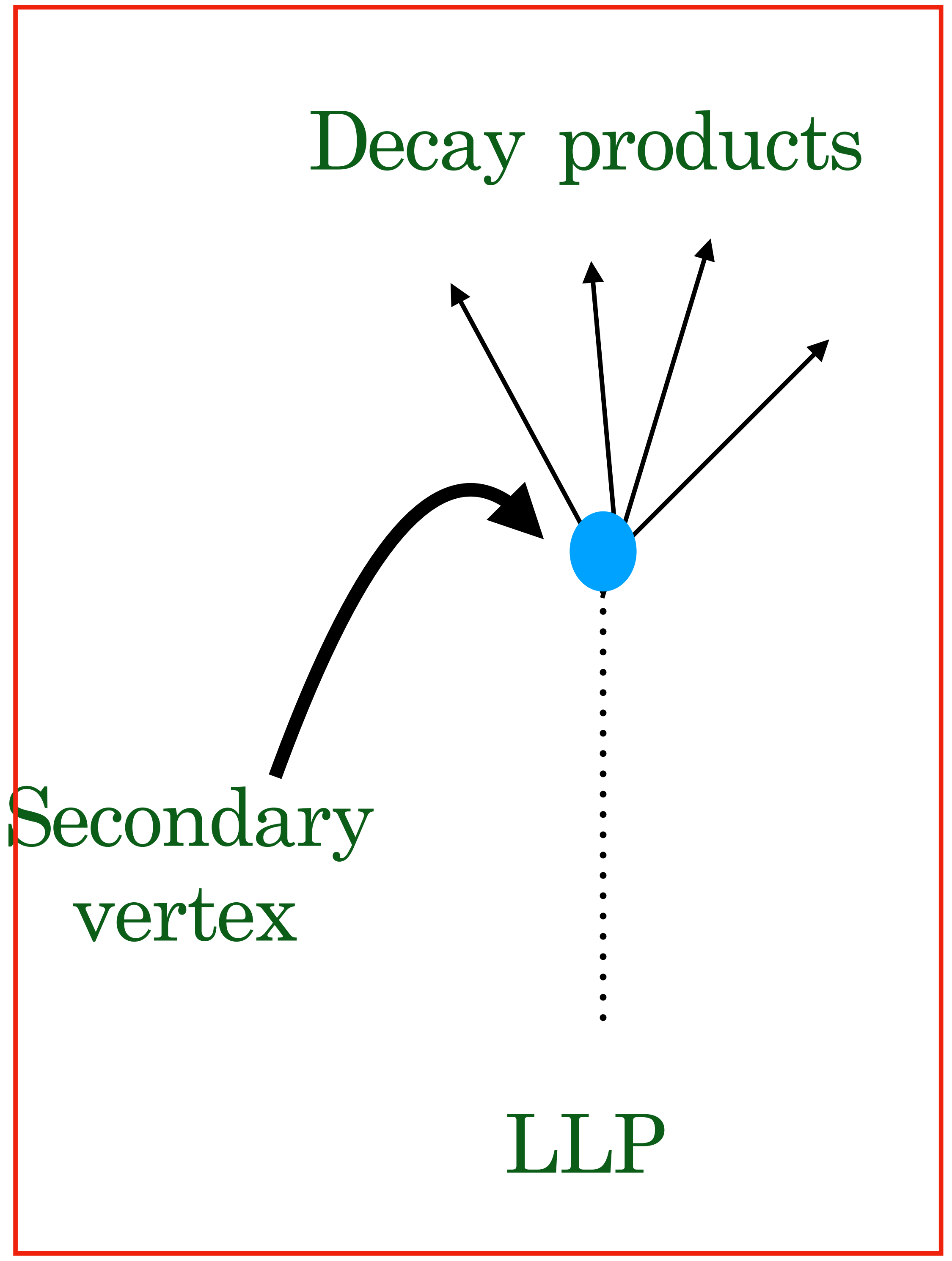


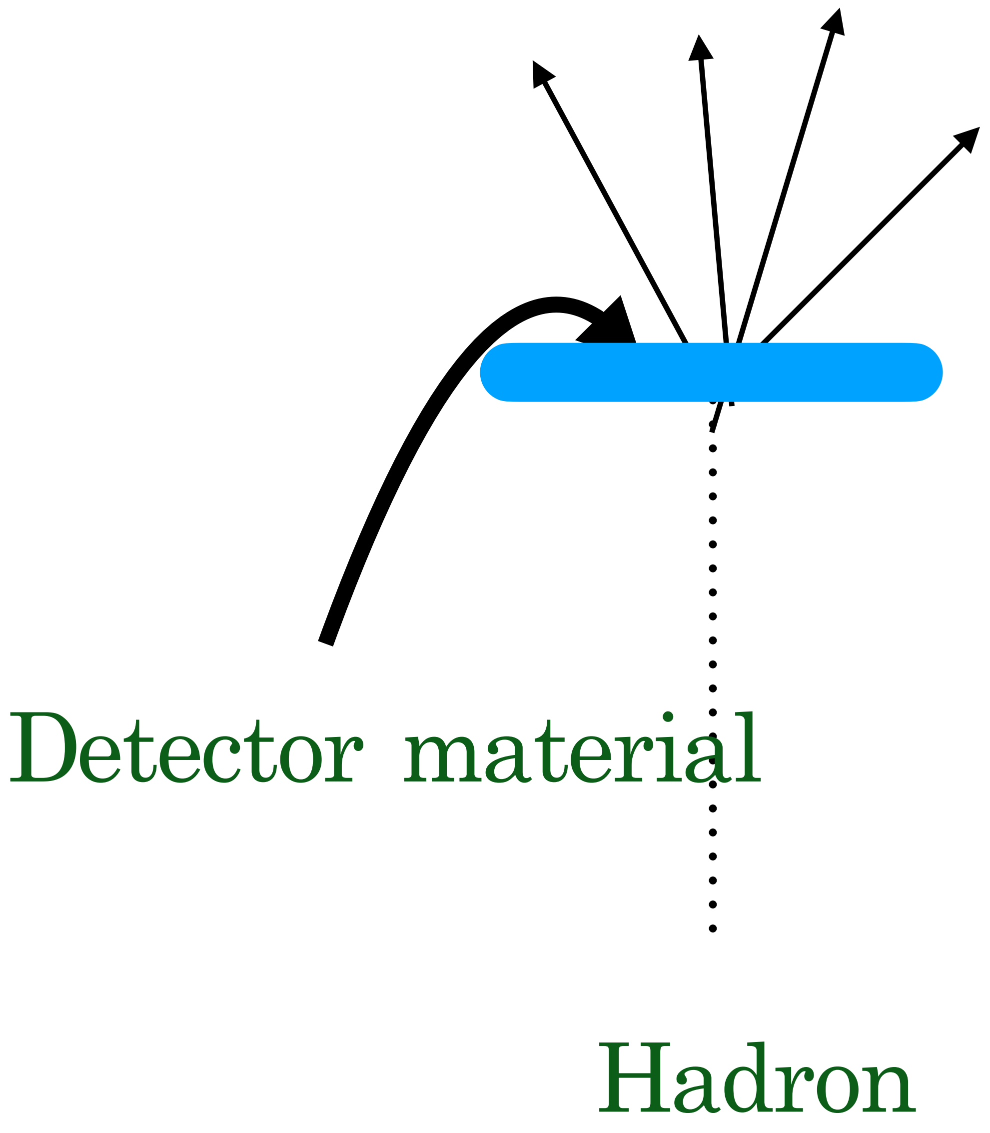
Displaced Vertex search

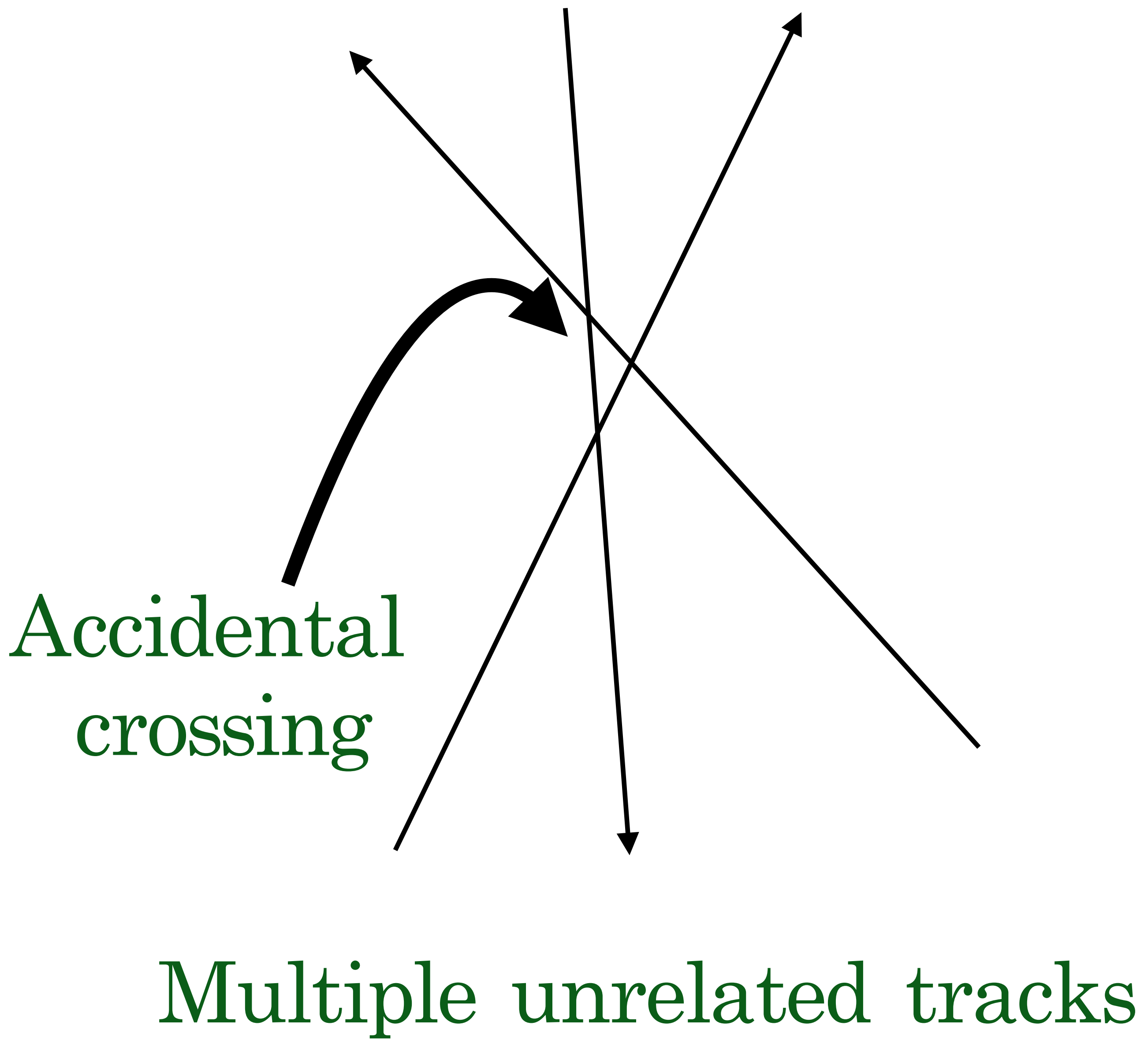
- There are a few SM hadrons which can also give rise to displaced vertex signature
    - their lifetimes and masses are known => better handle

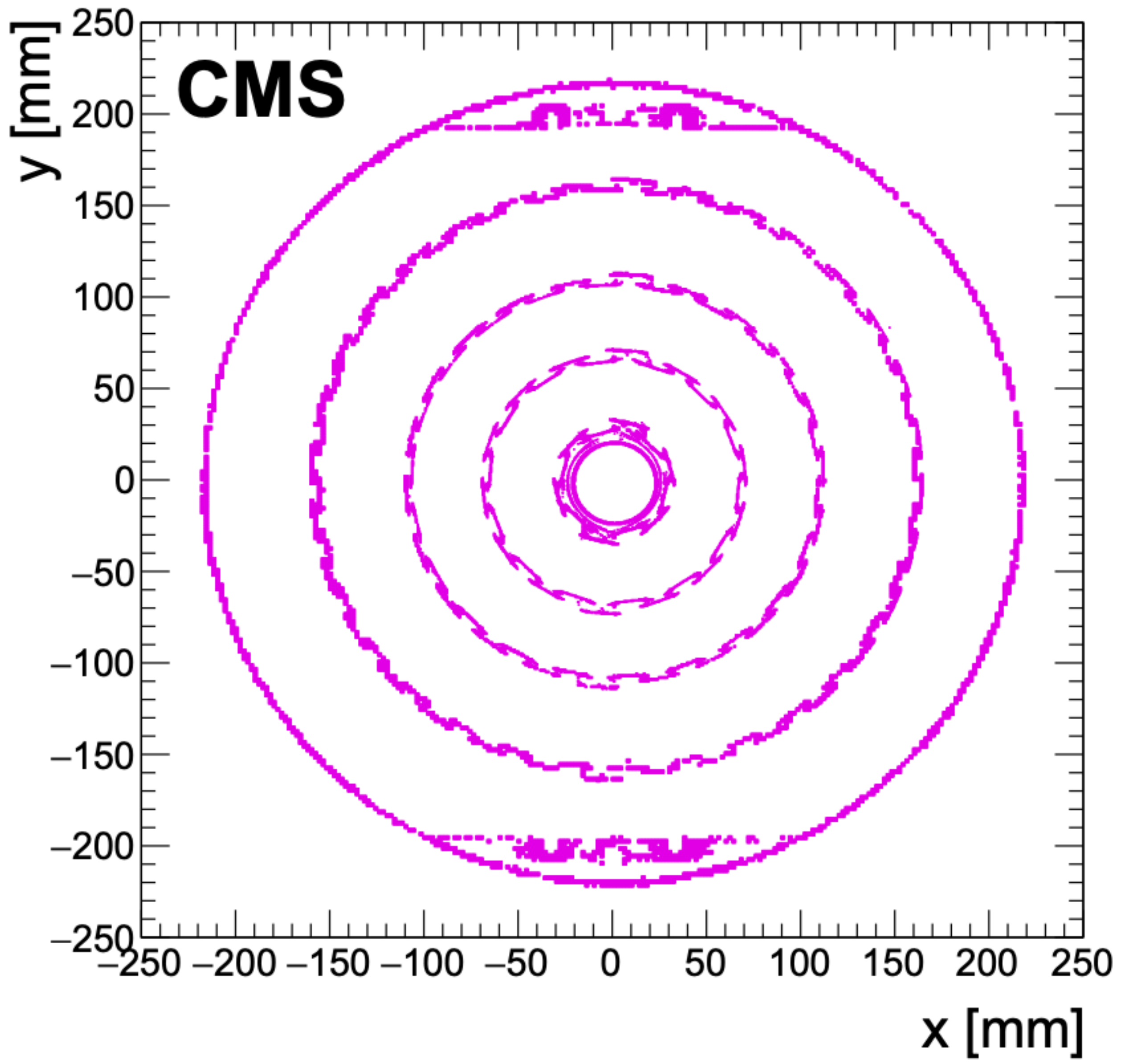
- Highly energetic hadrons can interact with the material of the detector

- Accidental crossing of tracks and merged vertices







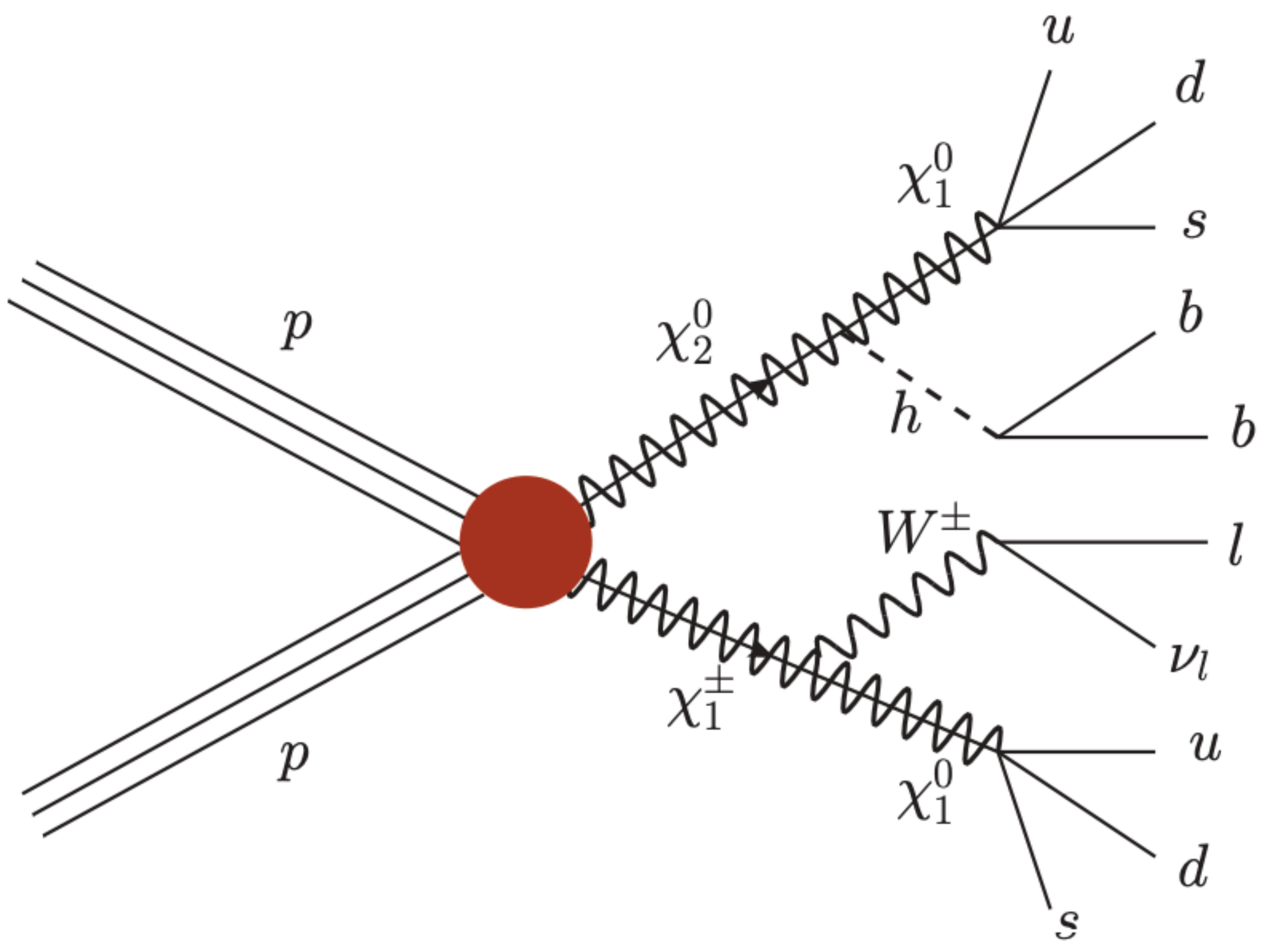


Material veto map (CMS)
2012.01581

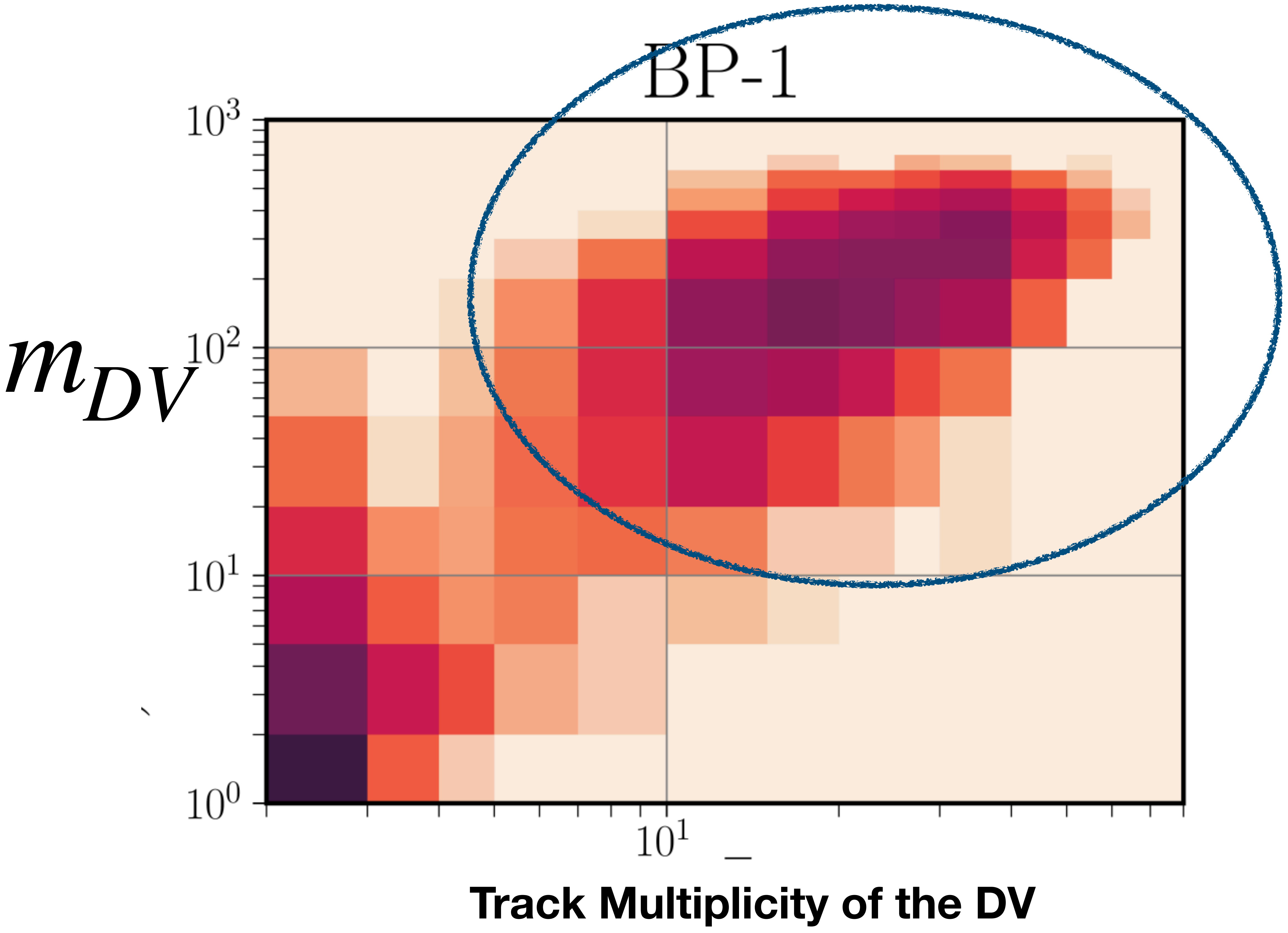
Displaced Vertex search

- Use material map veto : reject displaced vertices if it falls on the veto region(dense region)
  => residual backgrounds come from less dense region, LLP hadrons and accidental crossing
  => mostly peaks in the low invariant mass low multiplicity region

See ATLAS paper 2301.13866 for example



BB and Prabhat Solanki
arXiv:2308.05804, JHEP 23



Identification of light LLPs with low multiplicity final states may be difficult !!
(Exception : Muon final state)

Dedicated Forward detector: FASER Experiment

The flux of light hadrons produced at the interaction points of ATLAS/CMS in the forward direction is very high.

Mediators produced from the decay of such hadrons will have significant boost.

If the mediator are long-lived, it can travel ~O(100 m) before it decays.

=> Need for a forward detector
the ForwArd Search ExpeRiment(FASER)

REF: The FASER Detector: 2207.11427

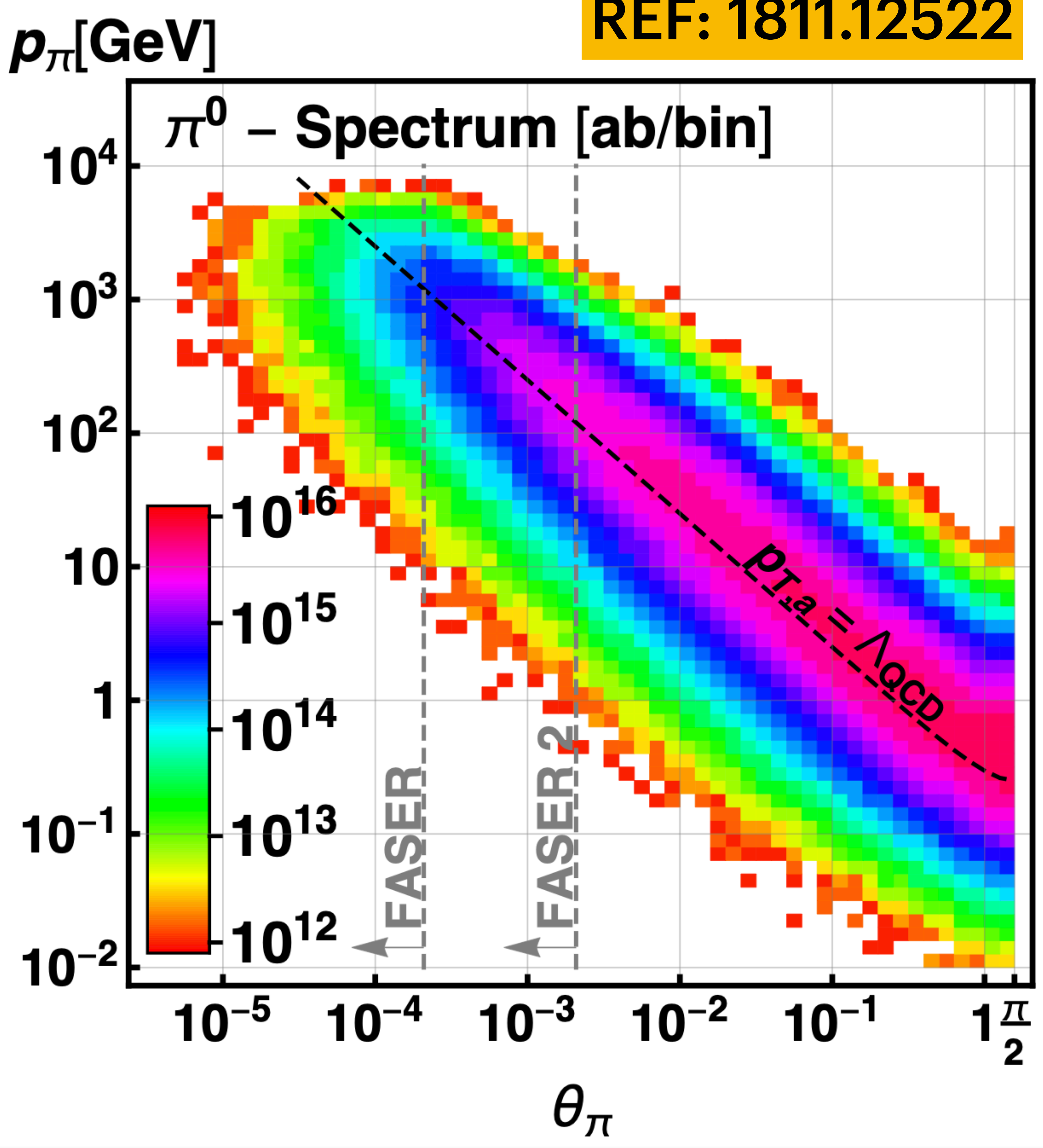
The FASER detector is located at ~480 m from the ATLAS detector.

It has about 1.5 m long decay volume followed by tracking stations and calorimeter.

Four Scintillator stations: in front of FASERnu(veto), decay volume, tracking station and Calorimeter

Decay volume and tracking stations are surrounded by 0.57 T Magnetic field.

REF: 1811.12522



FASER Experiment : Backgrounds

Trigger: Signals form Scintillators or Calorimeter

Dark photon search strategy: $Z_D \rightarrow e^+e^-$

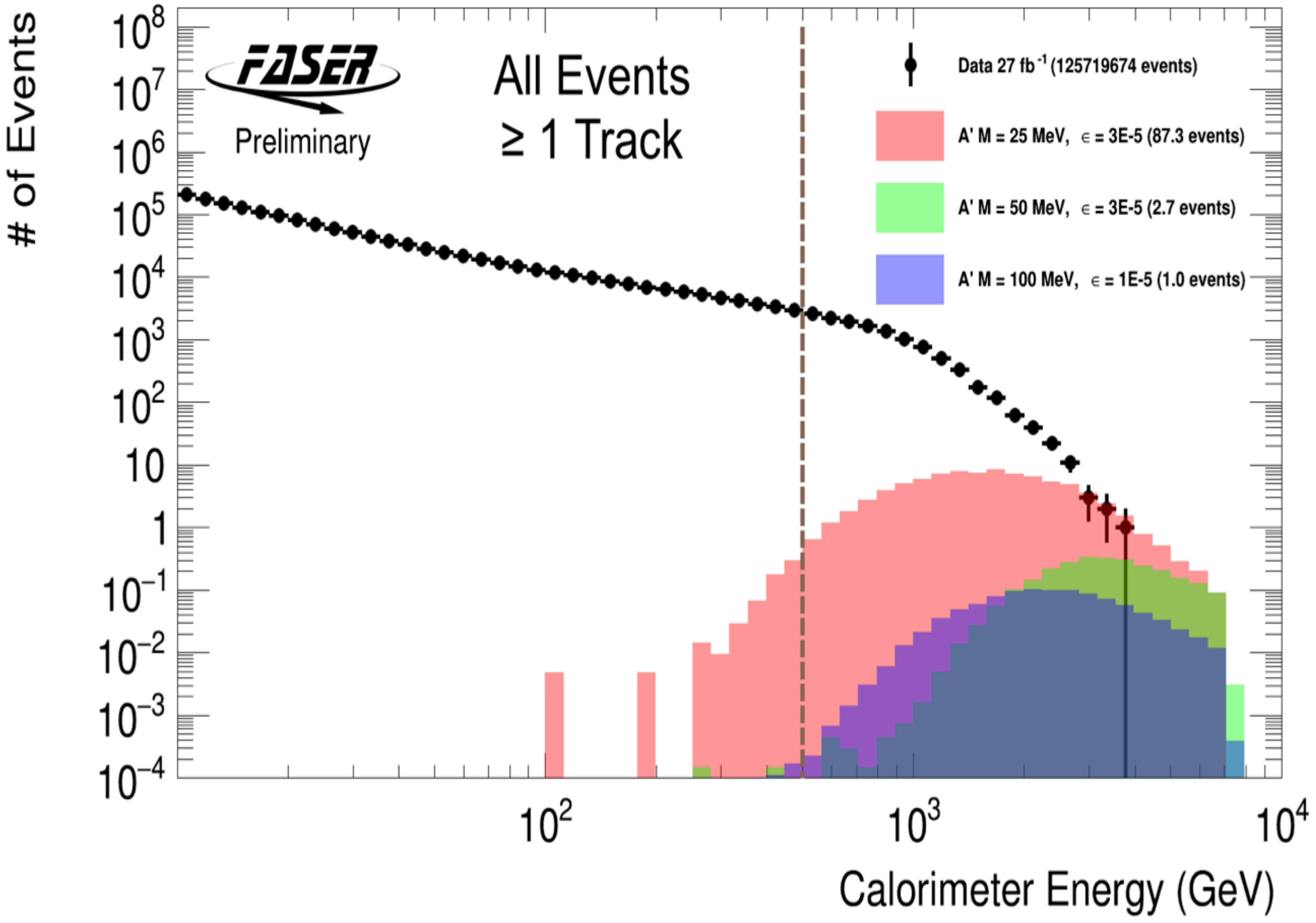
two collimated charged tracks in the tracker, large energy deposit in the calorimeter

Trigger Rate : ~ 1KHz mostly from muons

Other backgrounds : Neutral hadrons from muon in the rock, cosmic muon and neutrino

no signal in the scintillator, Each Scintillator efficiency > 99.99% => 4 scintillators can effectively suppress muon background, two good quality reconstructed tracks and more than 500 GeV energy in the calorimeter

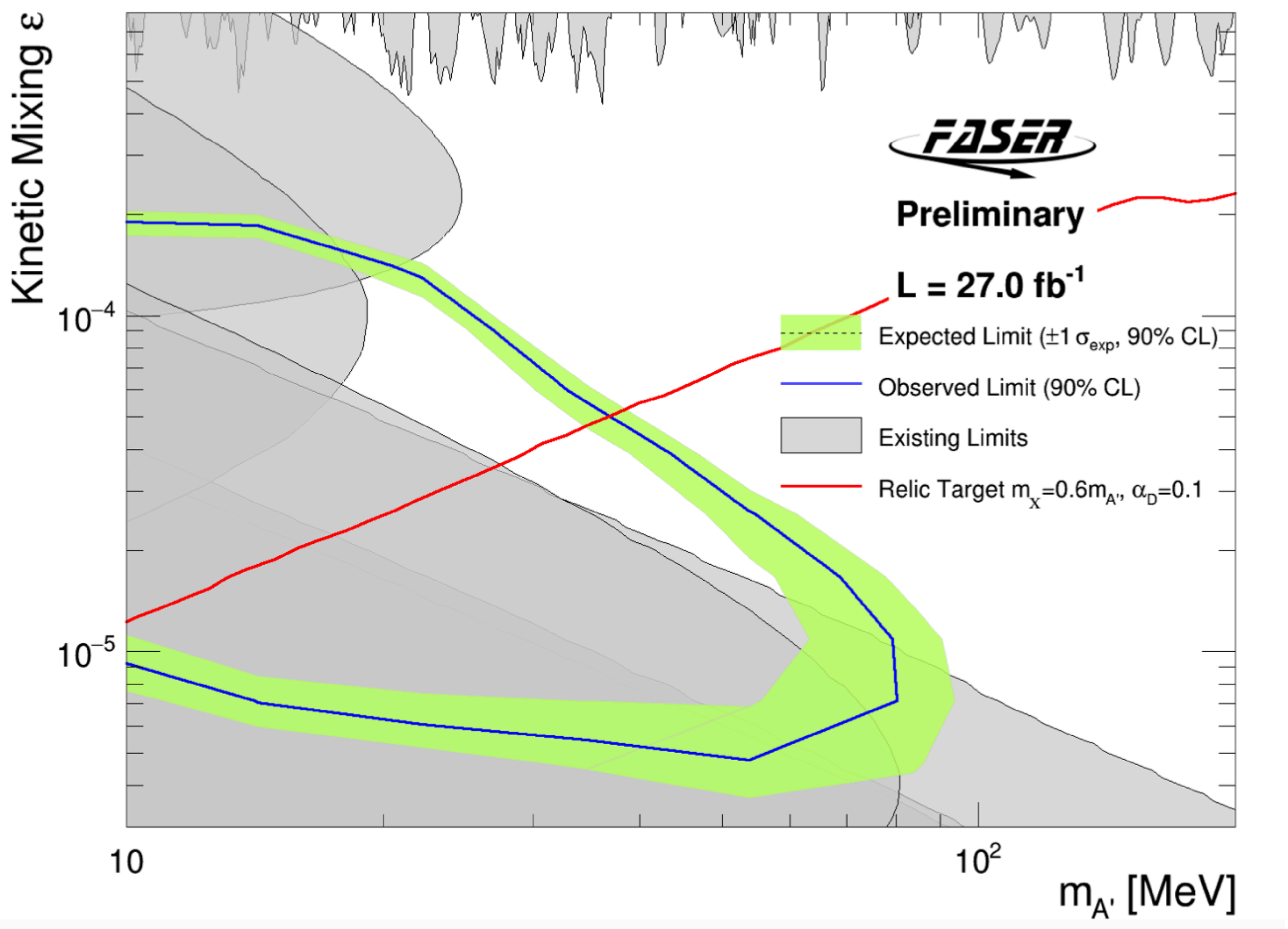
Total estimated background less than 1 (~2 X 10^-3)



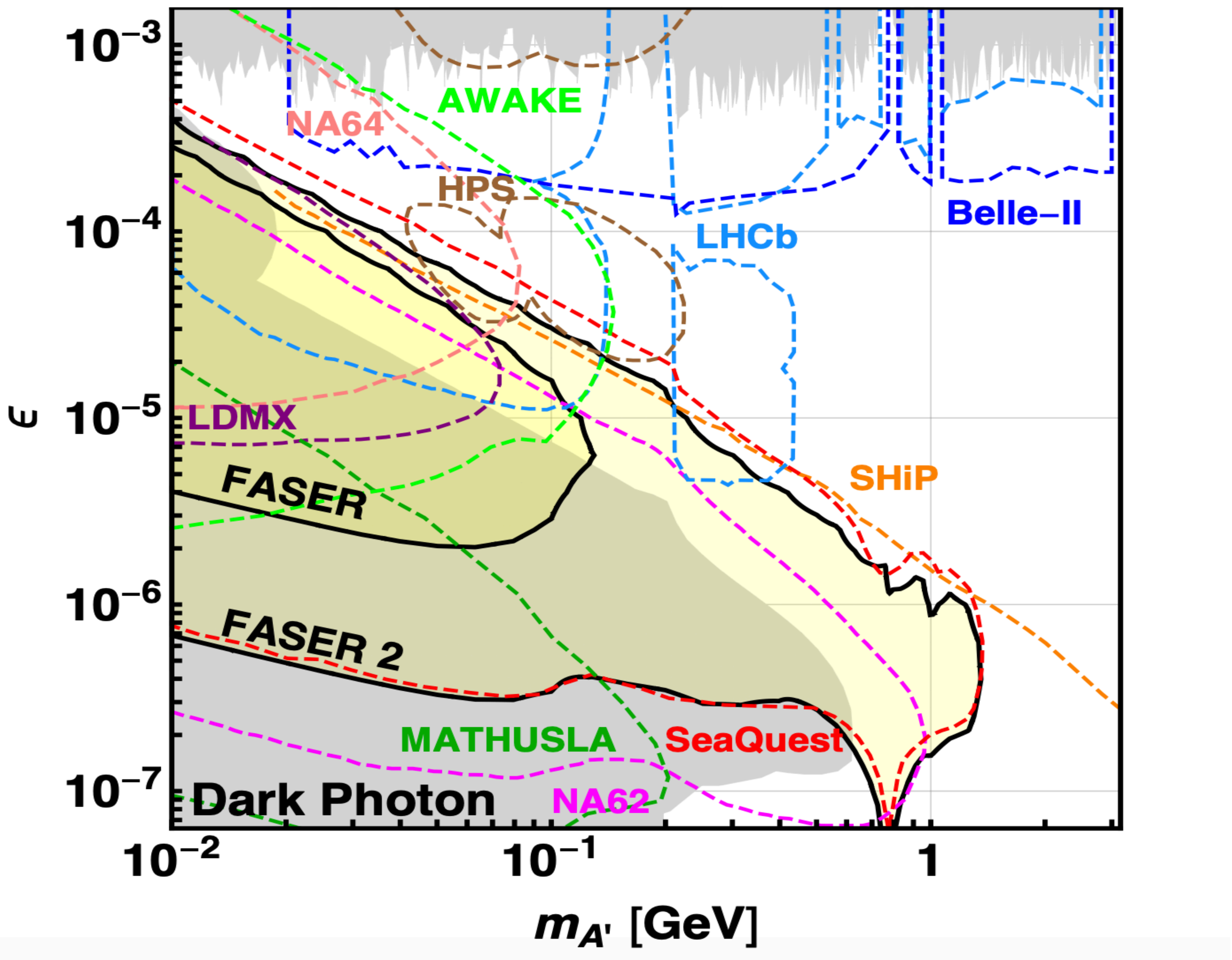
Background@FASER
COM 13.6 TeV , LHC Run 3
REF: CERN-FASER-CONF-2023-001

FASER: Limits and Future Projections:

$$pp \to Z_D + X$$
$$\pi \to Z_D\gamma$$



First result on dark photon
COM 13.6 TeV , LHC Run 3
CERN-FASER-CONF-2023-001

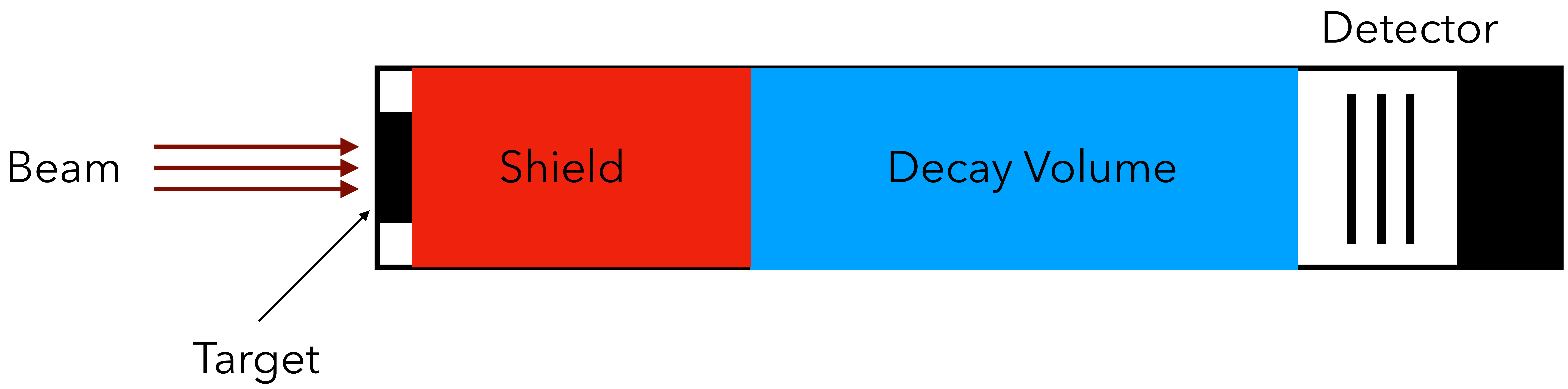


Future projection
1811.12522

Fixed Target/ Beam Dump Experiment

Fixed target experiment: a beam is dumped mostly on a heavy target(absorb the hadronic cascade quickly)

Produce LLPs from rare meson decay, bremsstrahlung etc.



Disadvantage :COM energy is small compared to collider experiment

Advantage: High Intensity beam, long decay volume => particularly effective for light LLPs

Various past/existing/proposed Fixed target/Beam dump experiments :

Past : E137,E141, KEK, Orsay ..

Existing : NA64e, NA64mu,NA62-BD Proposed : NA64h, Ship, HIKE, SHADOW

Future : ILC beam dump : 2105.13768

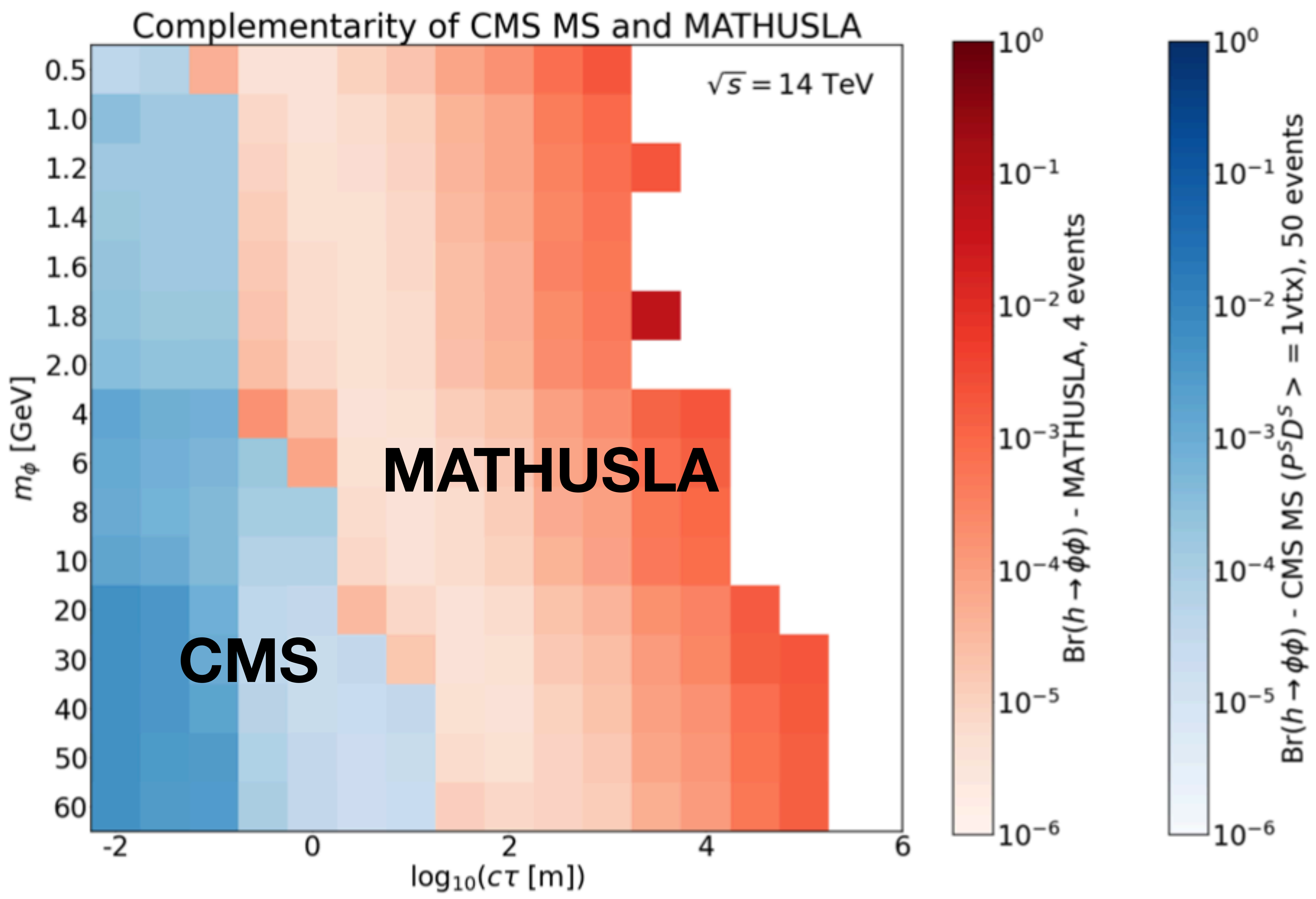
CMS vs MATHUSLA

BB, Shigeki Matsumoto, Rhitaja Sengupta
e-Print: 2111.02437, PRD 2022

LLP Model: $pp \to h \to \phi\phi$

$25 \times 100 \times 100\,\mathrm{m}^3$

$$60 < x < 85\,\mathrm{m}$$
$$-50 < y < 50\,\mathrm{m}$$
$$68 < z < 168\ \ \mathrm{m},$$



Complementarity of the CMS analyses using the muon spectrometer and the MATHUSLA LLP detector at 14 TeV with an integrated luminosity of 3000 fb^{-1}

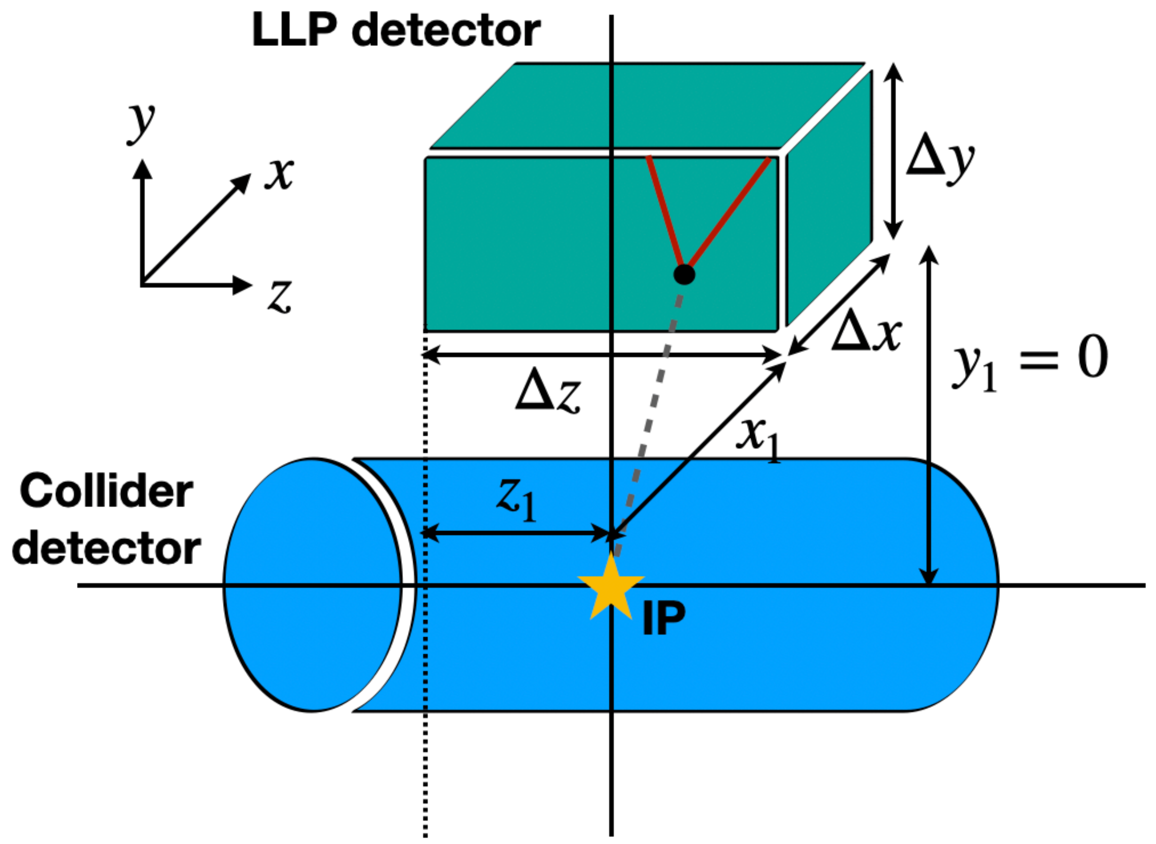
- The dedicated detectors placed far away from the IP might be sensitive to a range of lifetimes which is complementary to the CMS MS.
- These proposed detectors will be placed a few tens of meters away from the IP of the pp collision.
- Enough shielding of rock or concrete as well as active veto to guarantee very little or almost no backgrounds.
- Therefore, observation of even a few events ($\sim$ 4) can be claimed as a discovery of displaced decays of particles.

A dedicated Transverse Detector for FCC-hh

BB, Shigeki Matsumoto
and Rhitaja Sengupta
e-Print: 2111.02437, PRD 2022

Advantage: The collider, as well as the detectors, are not yet constructed, possible to optimise the position as well as the size of the detector to maximise its sensitivity, rather than finding empty spaces near the various IPs to place and fit the LLP detectors for the HL-LHC experiment.

We here propose three designs of a dedicated LLP detector
DELIGHT (Detector for long-lived particles at high energy of 100 TeV),
a box-type detector in the periphery of the FCC-hh collider



DELIGHT (A): The same as the dimensions of the MATHUSLA detector, i.e. $\Delta x \times \Delta y \times \Delta z = 25 \times 100 \times 100\,\mathrm{m}^3$.

DELIGHT (B): Four times bigger than the MATHUSLA detector, i.e. $\Delta x \times \Delta y \times \Delta z = 100 \times 100 \times 100\,\mathrm{m}^3$.

DELIGHT (C): The same decay volume as the MATHUSLA detector with different dimensions, i.e. $\Delta x \times \Delta y \times \Delta z = 200 \times 50 \times 50\,\mathrm{m}^3$.

A position starting at around 25 m in the x-direction around η = 0 region can be kept empty for placing a dedicated LLP detector.

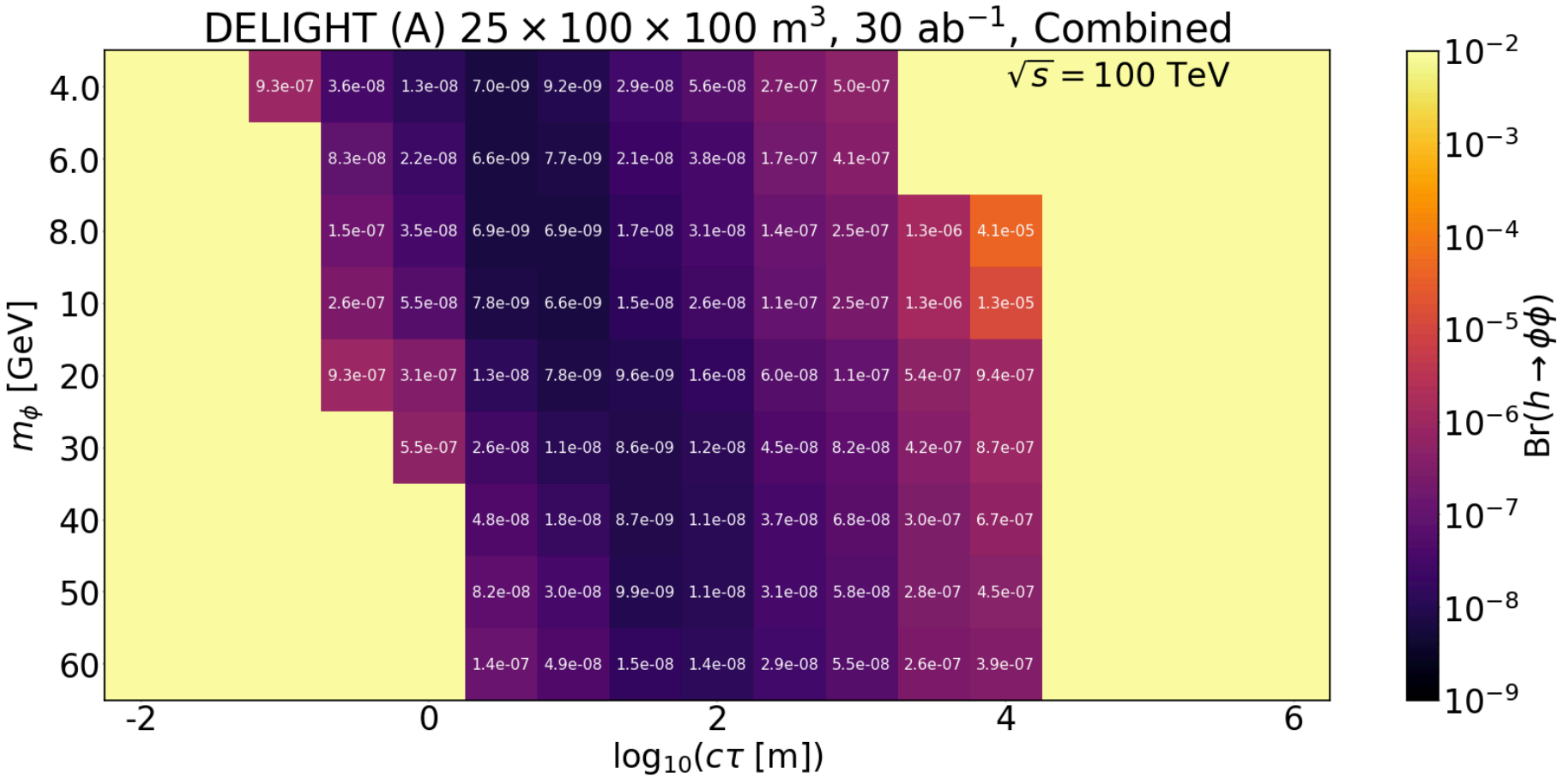
LLP detectors for FCC-ee is proposed here : 2011.01005

DELIGHT-A

DELIGHT (A): The same as the dimensions of the MATHUSLA detector, i.e. $\Delta x \times \Delta y \times \Delta z = 25 \times 100 \times 100\,\mathrm{m}^3$.

BB, Shigeki Matsumoto
and Rhitaja Sengupta
e-Print: 2111.02437, PRD 2022

LLP Model: $pp \to h \to \phi\phi$



DELIGHT(A) vs MATHUSLA: an improvement by a factor of ~ 540,

around ~ 150 from increased cross-section and integrated luminosity,

another factor of ~ 3 - 4 is gained by moving the detector close to the IP.

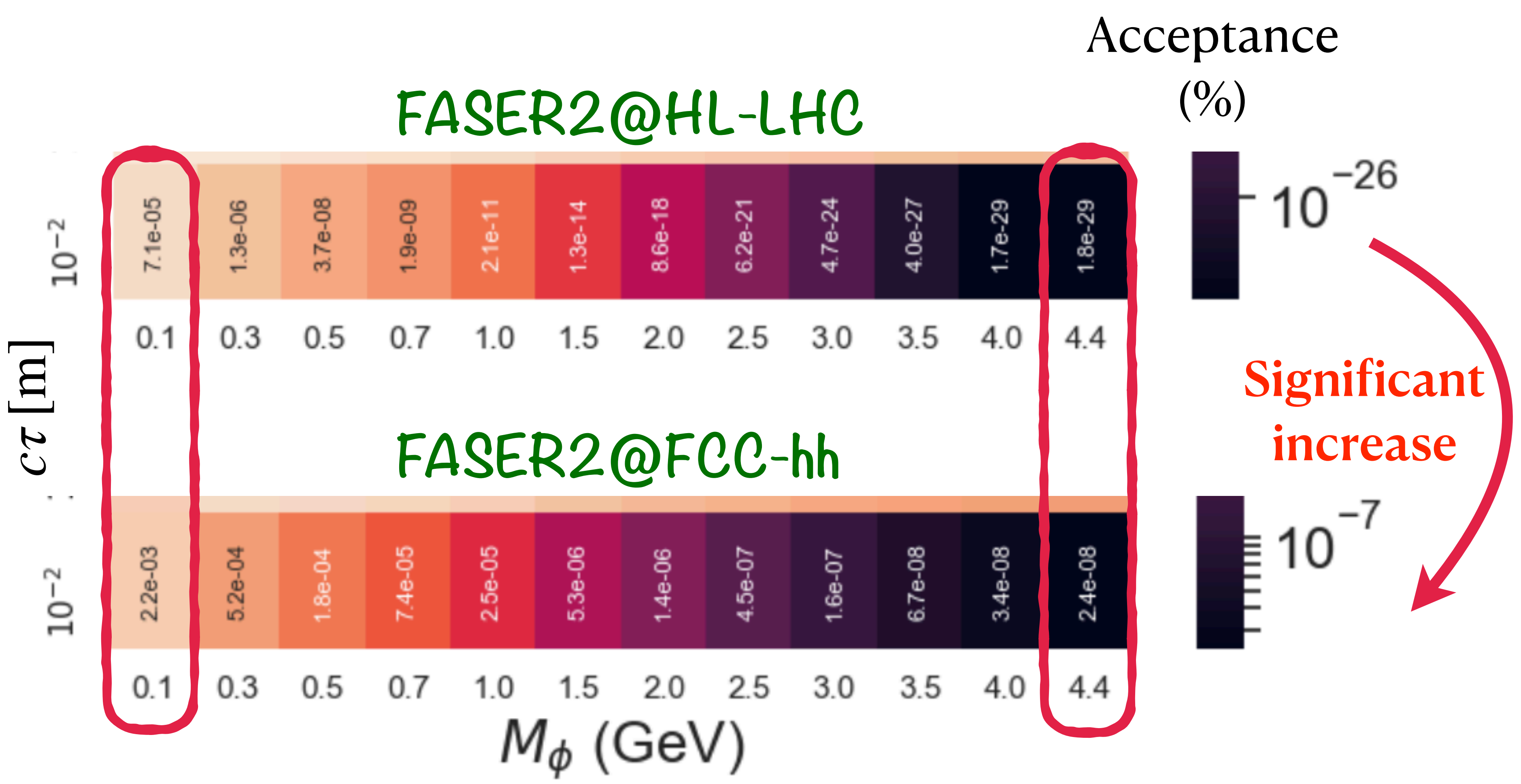
Central position of the detector can benefit light LLPs.

Proposal for a dedicated forward detector@FCC-hh

Proposal for a dedicated forward detector, **FOREHUNT (FORward Experiment for HUNdred TeV),** for 100 TeV FCC-hh

$B^{\pm} \to K^{\pm}\phi$

FASER2 $L_s = 480$ m, $R = 1$ m, $L_d = 5$ m, $p_{\phi} > 100$ GeV



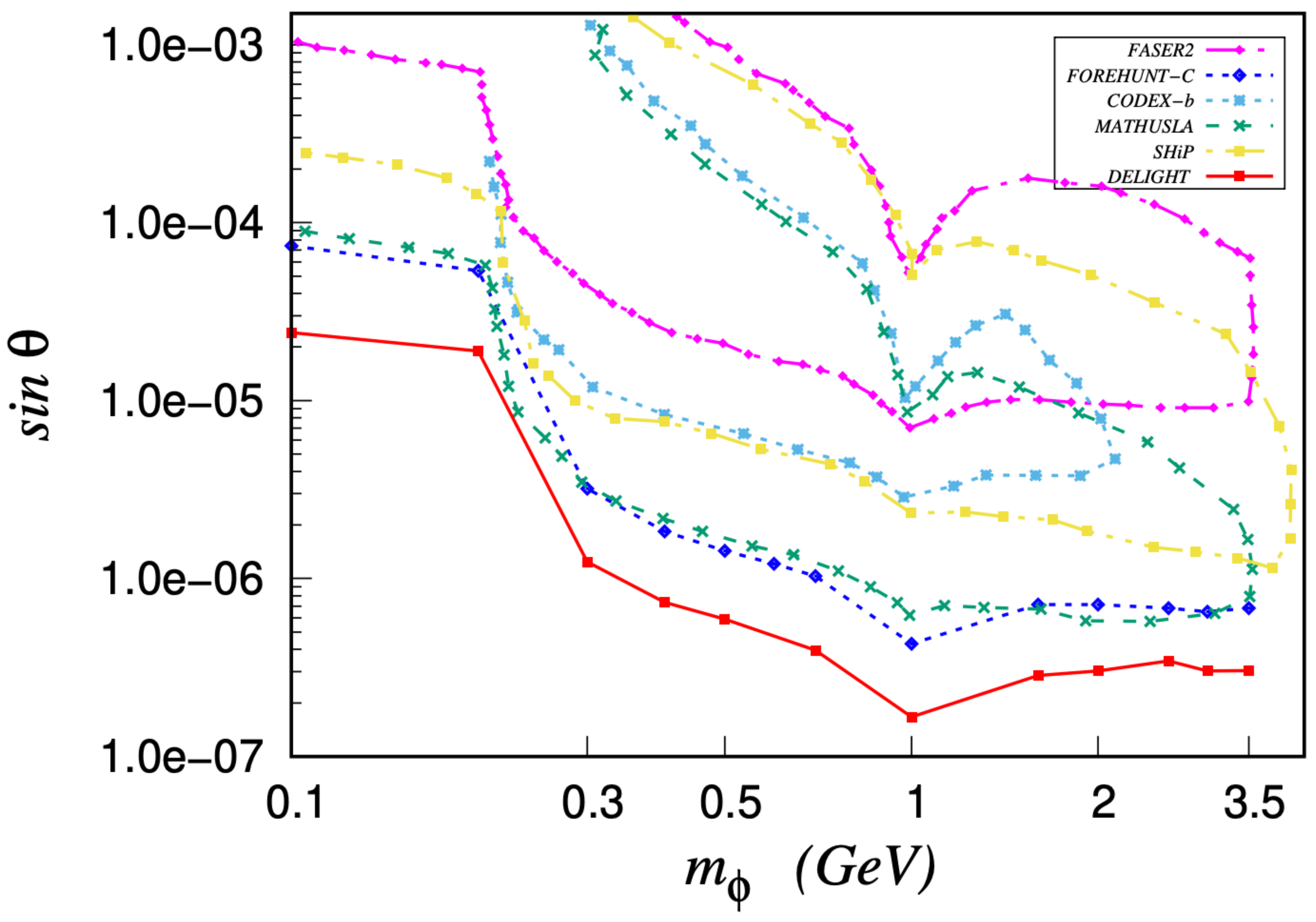
B-mesons more energetic at 100 TeV collider

The LLP coming from B-meson decay has larger boost

Increased efficiency for smaller decay lengths and heavier masses

Taken from Rhitaja Sengupta's Talk

Dark Scalar



BB, Herbi Dreiner, Nivedita Ghosh, Shigeki Matsumoto, Rhitaja Sengupta , Prabhat Solanki PRD 2024

Collaborators :

1. Dr. Rhitaja Sengupta (Graduated in 2023, now at Bonn Univ.)
2. Dr. Prabhat Solanki (Graduated in 2024, Now in INFN Pisa, CMS experiment)
3. Dr. Nivedita Ghosh (Postdoc @IISc)
4. Dr. Swagata Mukherjee (IIT Kanpur)
5. Prof. Shigeki Matsumoto(Kavli IPMU)
6. Shankha Banerjee (IMSc) + ….

Directions :

1. Trigger developments for LLPs
2. ECAL and MTD Timing
3. ML for LLPs
4. Dedicated detector for FCC-hh
5. Parameter estimation for LLPs

Summary

- Long-lived particles are well-motivated in BSM theories
- Signature of LLP not only depends on the decay products also depend where it decays
- Various unusual signatures are possible : understanding of detector is required for estimation of backgrounds
- General purpose detectors like CMS/ATLAS are capable to identify the presence of LLPs in many cases
- Dedicated detectors will be required to probe light LLPs
- FCC-hh will be able to improve the search sensitivity as expected
- Optimization of the location and size of the dedicated detectors will be possible for the future collider unlike LHC
- Two proposals for dedicated detectors : FOREHUNT and DELIGHT are made by our group. => More studies are ongoing

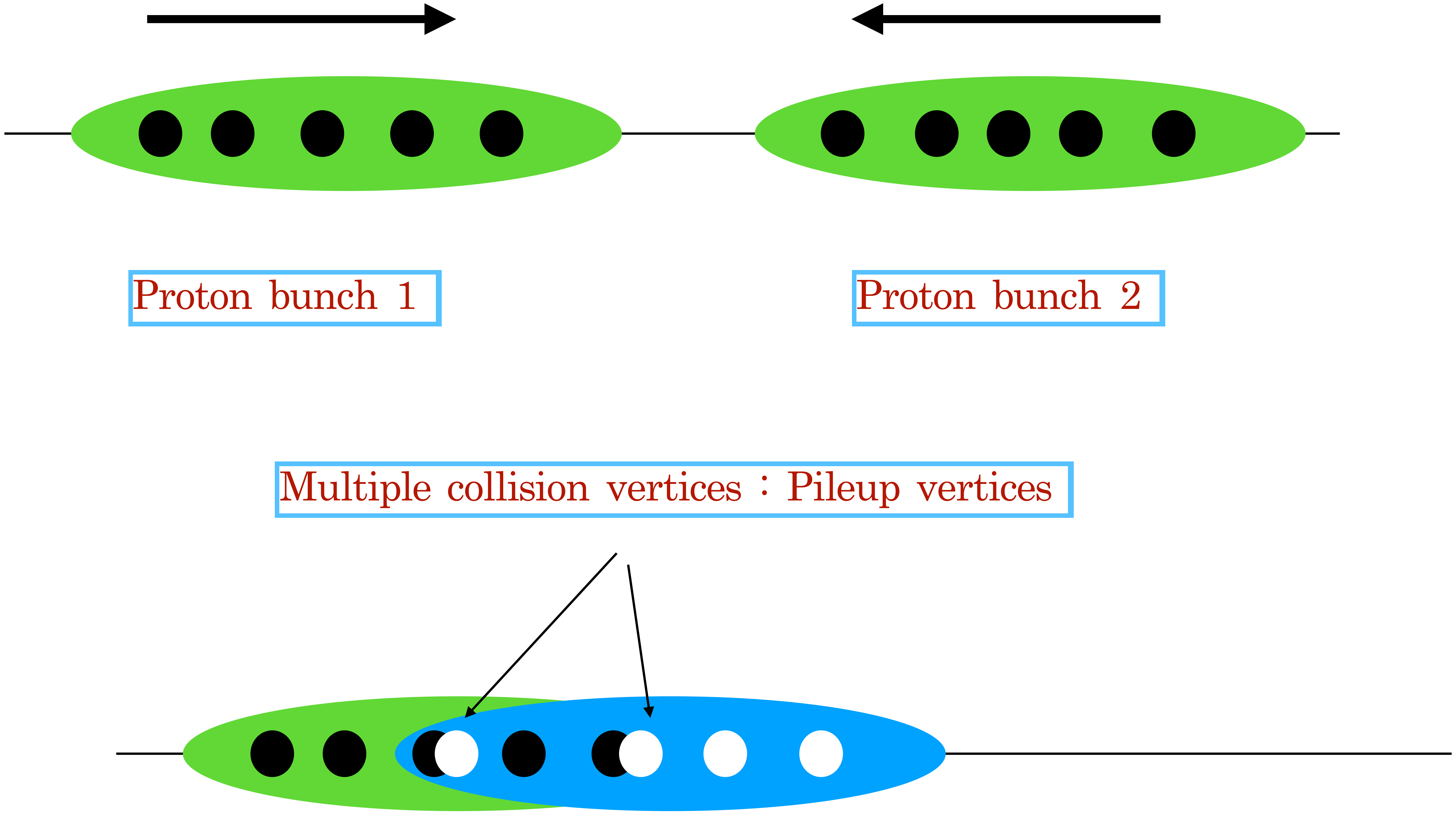
Thank you

Extra Slides

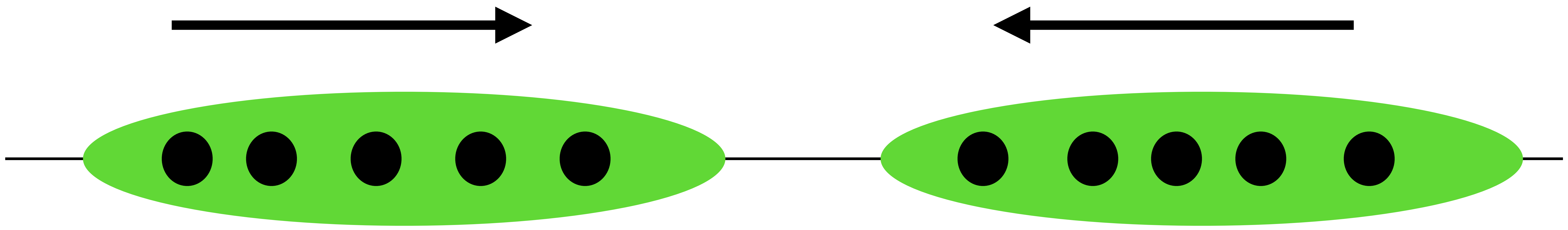
Pile up

Not a collision between two protons

Collision between proton bunches



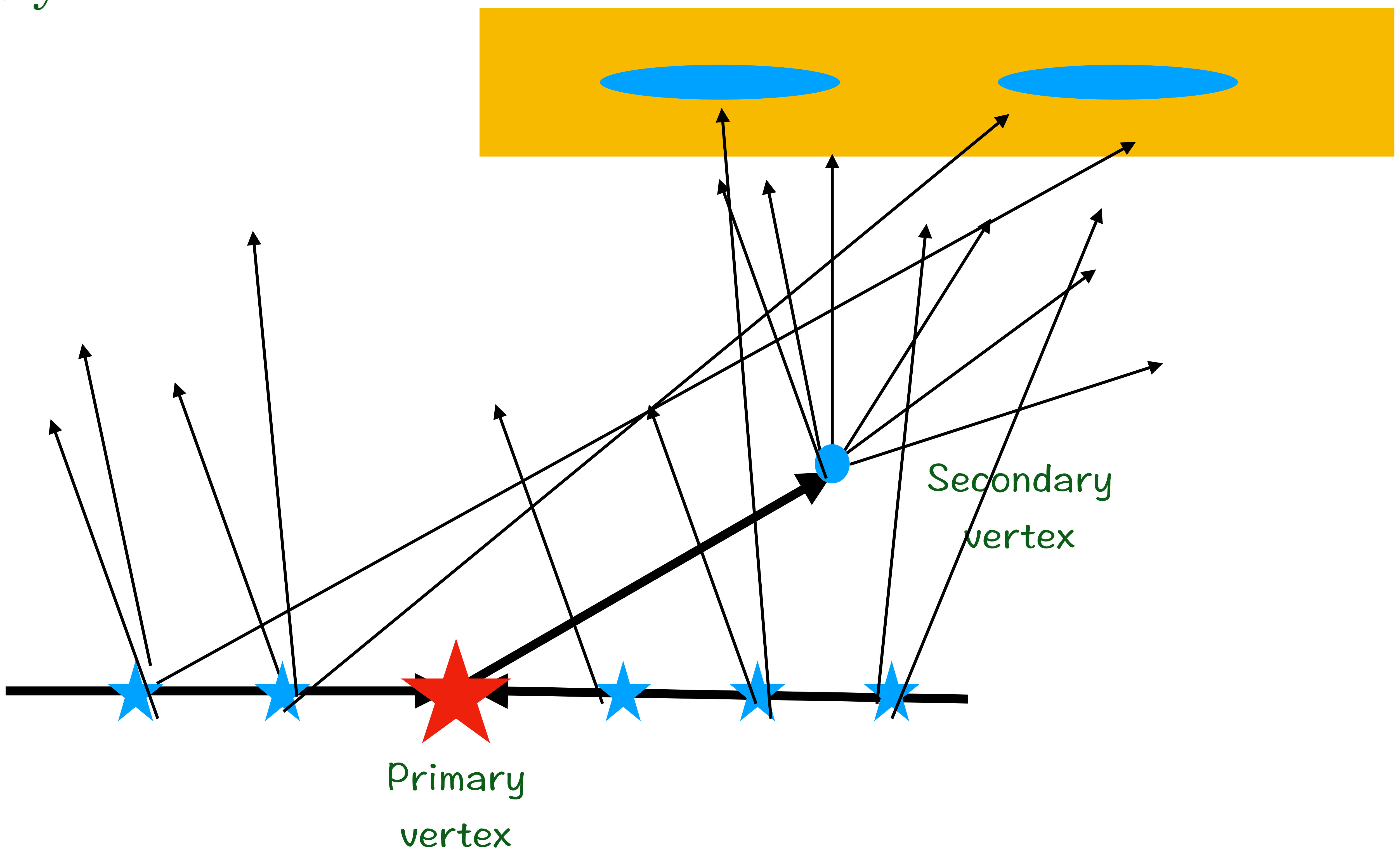
Displaced jets



Expected features

- Displaced multiple tracks
- Secondary vertices
- Calorimeter energy deposits are not associated with tracks from primary vertex=> trackless jet

Pile up vertex ★

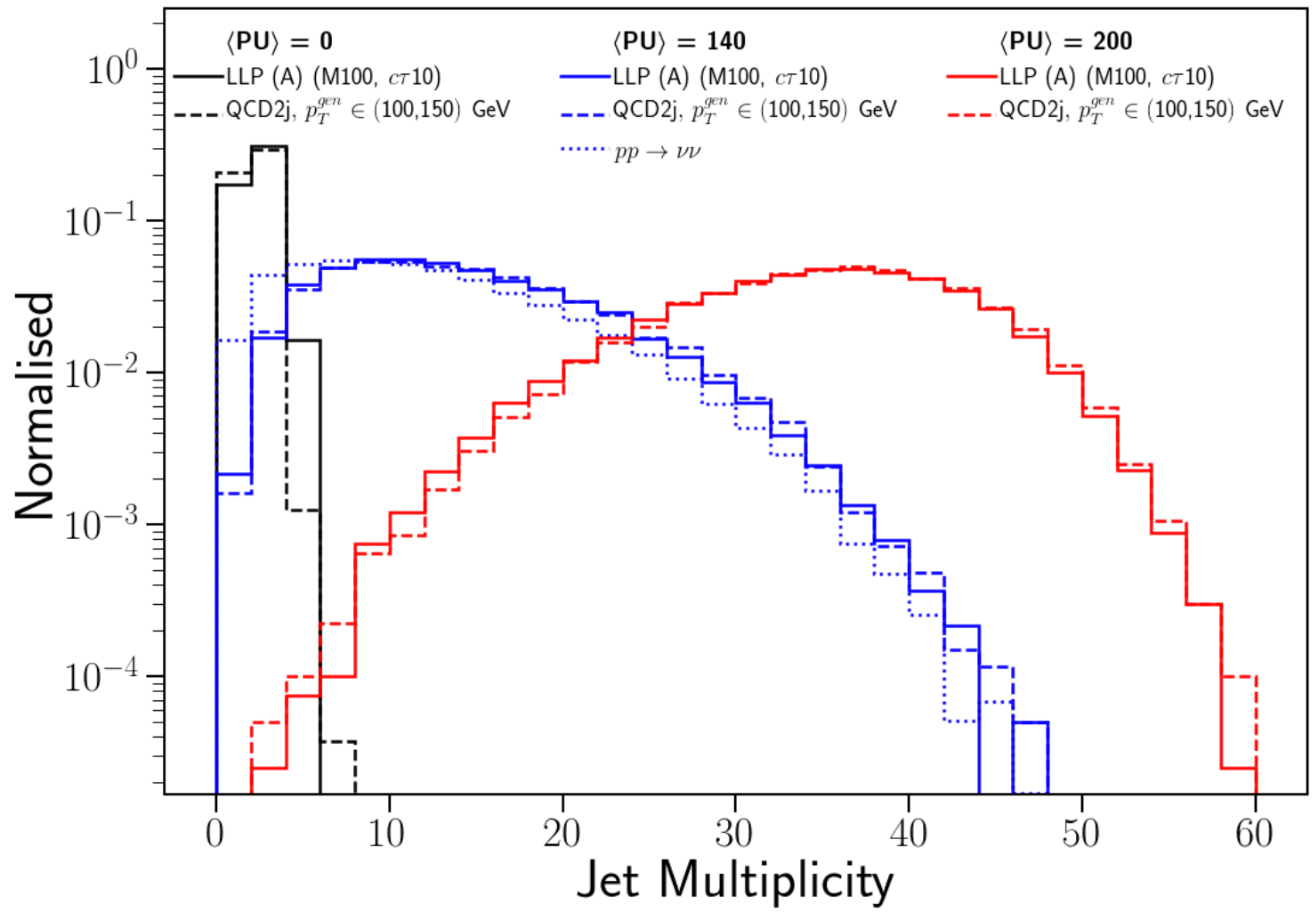


Current Run of LHC: average number of pileup ~50

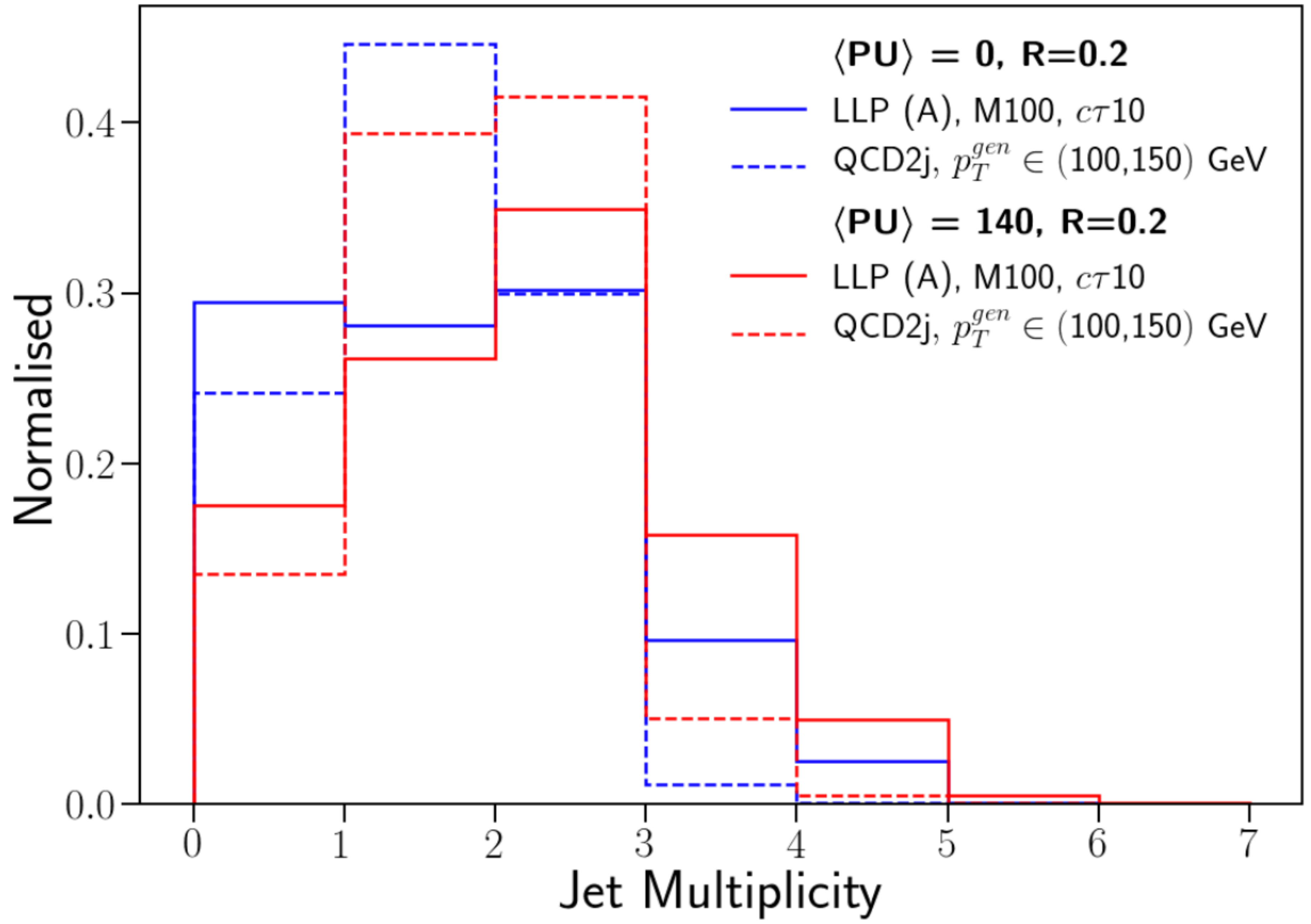
Narrow jets for LLP

BB, Swagata Mukherjee, Rhitaja Sengupta, Prabhat Solanki
e-Print: 2003.03943, JHEP 2020

LLP Model: $pp \to XX, X \to q\bar{q}$



Narrow jets !!



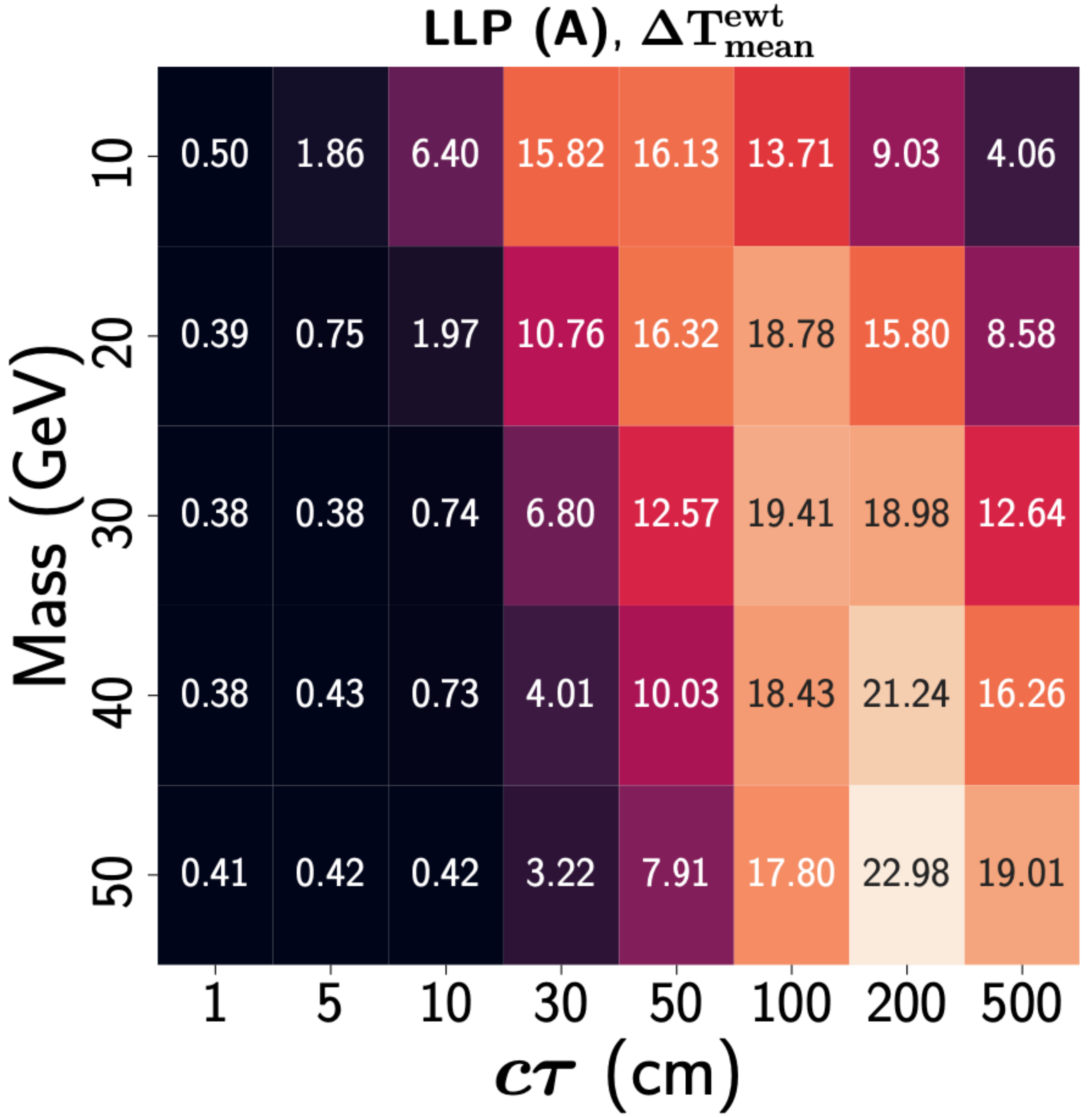
Only narrow jet will not be sufficient to suppress background
Many Variables can be constructed
Single narrow jet trigger with pT >60 GeV with strict cuts on tracking variables may be used.

ECAL timing

$$pp \to h_{125} \to \phi\phi, \phi \to b\bar{b}$$

BB, Tapasi Ghosh , Rhitaja Sengupta , Prabhat Solanki
e-Print: 2112.04518, JHEP 2022

$\Delta T^{Ewt}_{mean} > 1.1\text{ns}$ and $p_T^{jet} > 35\text{GeV}$



Other variables can be constructed.

Future sensitivity
(50 events at L1)

- $\text{Br}(h \to XX) \lesssim 6.2 \times 10^{-6}$ for $M_X = 10\,\text{GeV}$, $c\tau = 50\,\text{cm}$
- $\text{Br}(h \to XX) \lesssim 5.1 \times 10^{-6}$ for $M_X = 30\,\text{GeV}$, $c\tau = 100\,\text{cm}$
- $\text{Br}(h \to XX) \lesssim 4.3 \times 10^{-6}$ for $M_X = 50\,\text{GeV}$, $c\tau = 200\,\text{cm}$

Tracker vs Muon Spectrometer

The ratio increases with the decay length

$$\frac{\epsilon_{MS}}{\epsilon_{Tracker}}$$

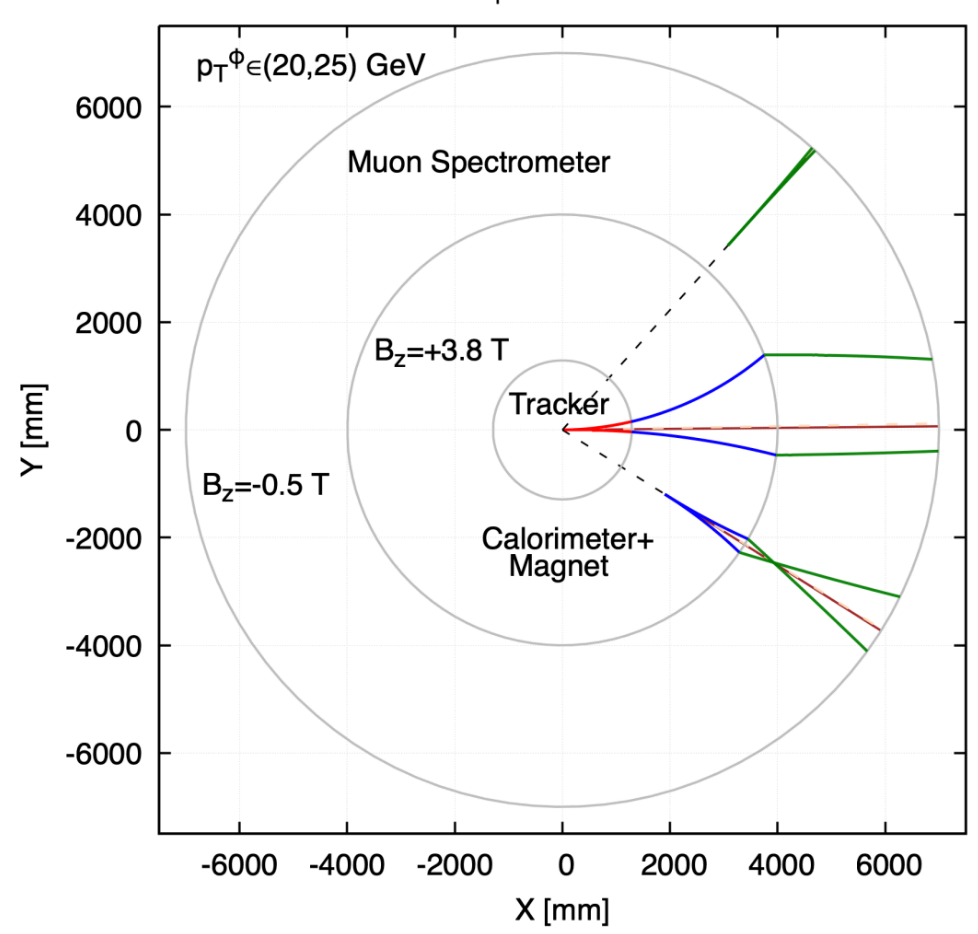
The ratio of efficiencies for the LLP (the mediator particle) which decays inside the muon spectrometer and the tracker of the CMS detector

$c\tau_\phi$ \ m_ϕ	0.5 GeV	5 GeV	50 GeV
0.01 m	0.09	0.00	0.00
0.1 m	1.10	0.09	0.00
1.0 m	1.68	1.07	0.07
10.0 m	2.04	1.67	0.85
100.0 m	-	1.59	1.53
1000.0 m	-	-	1.52

MS volume : $d_T > 4$m or $|d_Z| > 7$m, and, $d_T < 7$m and $|d_Z| < 10$m

tracker volume : ($d_T < 1.29$m and $|d_Z| < 3$m)

LLP Model: $pp \to h \to \phi\phi$



Why Muon spectrometer ?

- **Muon spectrometer is least affected by the increased PU rate (farthest from the IP)**
- **Large decay volume, suitable for LLPs**
- **MS has the capability to detect various final states from the mediator decay other than muons**
- **There exists a range of decay lengths where this ratio is equal to or greater than one**

LLP searches using MS by CMS/ATLAS collaborations: 1811.07370, 1911.12575, CMS PAS EXO-20-015, 2107.04833

Activity in the Muon Spectrometer

Particles except muons will look different in the CMS MS due to their interactions with the iron yokes, i.e., they shower and give rise to a cluster of hits.

Experimental Questions : how they exactly look in the MS ? whether these hits can be reconstructed ? whether the position of the dSV can be identified with such clusters of hits

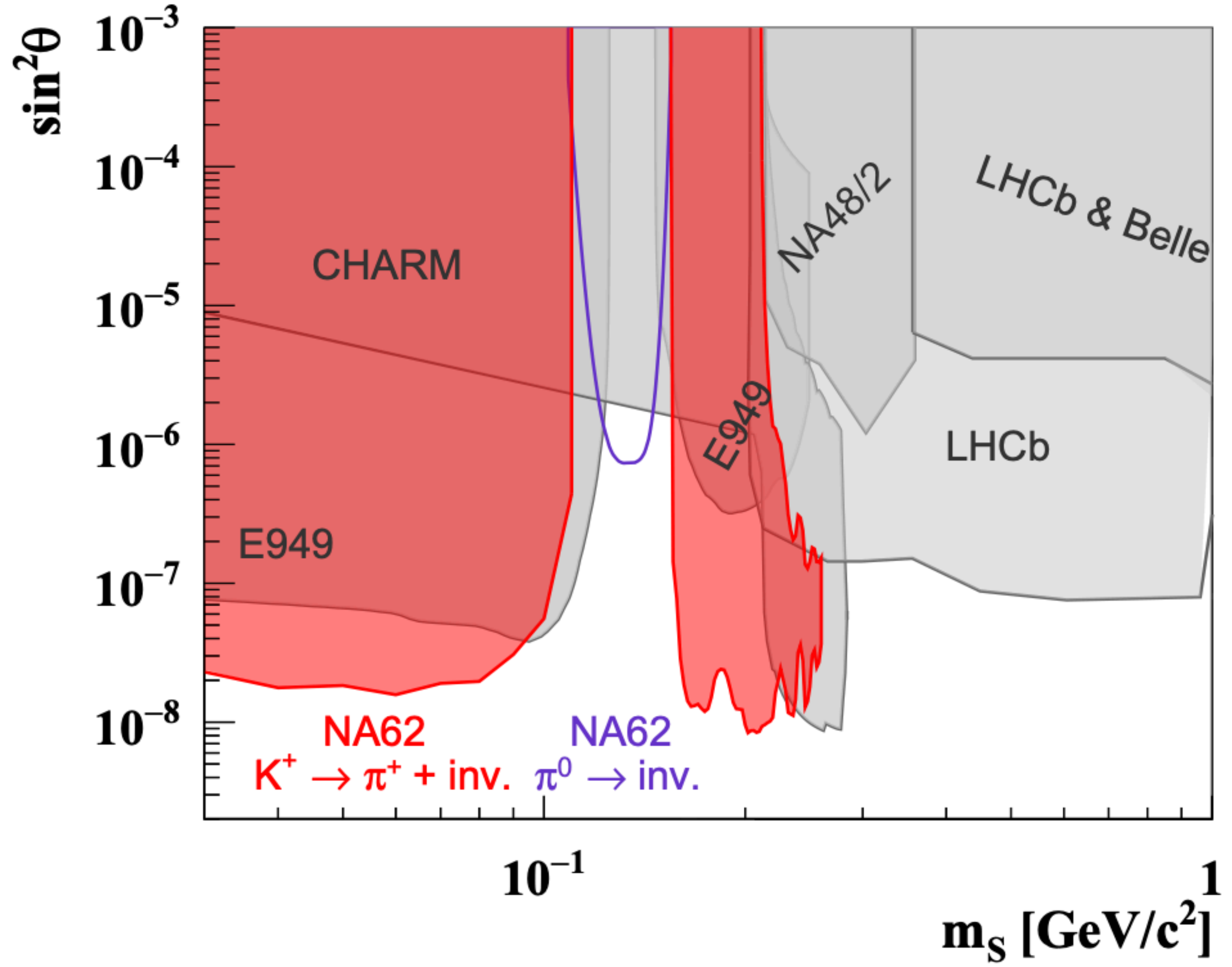
NA62 Experiment

Fixed-target experiment at CERN SPS

Goal : measure $K^+ \to \pi^+ \nu \bar{\nu}$

NA62: 2103.15389

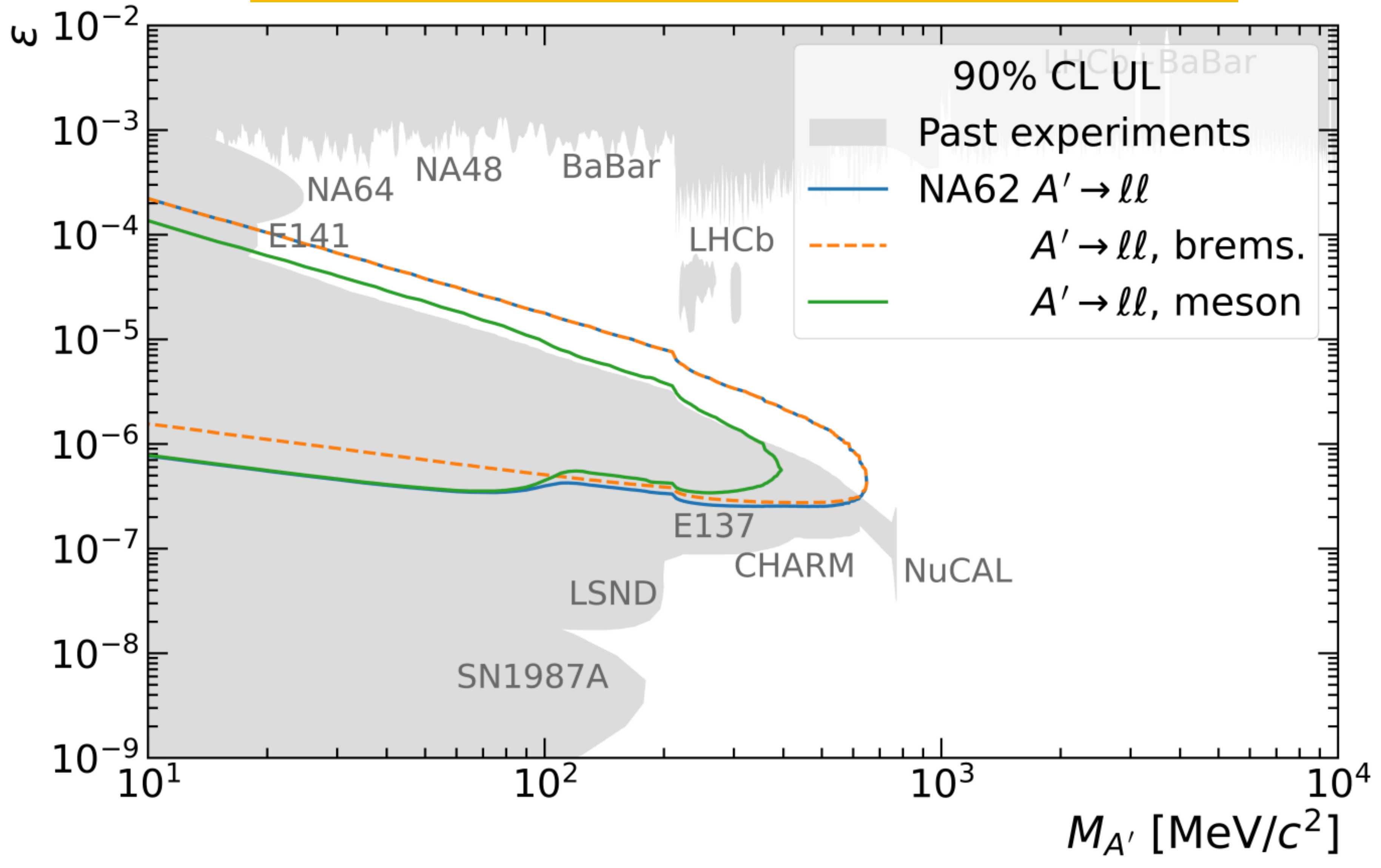
400 GeV proton on Beryllium target=> 75 GeV K+ is selected



Kaon is tagged by KTAG, momentum measured by GTK => decay volume is 60 m
Decay products are measured by several detectors (and veto on photons)

The result can be translated to $K^+ \to \pi^+ X_{LLP}$

https://pos.sissa.it/445/073/pdf



It can also run in a beam-dump mode:
Limit on dark-photon model

SHiP Experiment

The Search for Hidden Particles Collaboration

Proposed general purpose beam dump experiment at CERN SPS

SPS is capable of delivering 4 x 10^{19} protons with energy 400 GeV (per year)

The detector consists of heavy target, hadron stopper, active muon shield followed by Scattering and Neutrino detector and Hidden sector spectrometer (Total length ~ 120 m).

HS spectrometer will be able to detect the decay products of the long-lived mediator which decays inside the 50m long decay volume between SND and HS.

SHiP Experiment

The decay spectrometer will have tracker, muon detector and calorimeter=> possible to identify various decay products of the mediator and also for background suppression

Various backgrounds can be reduced below 1 event

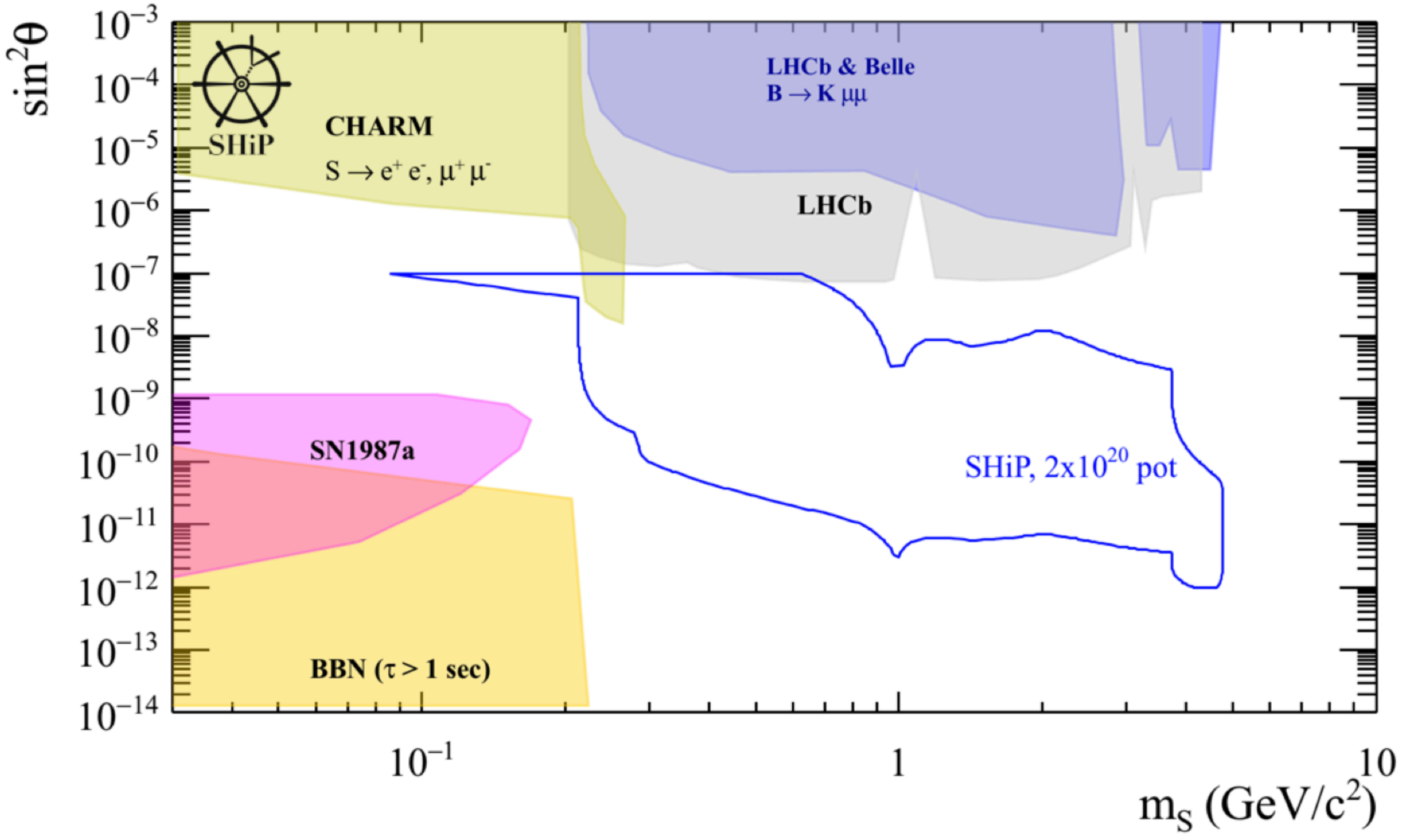
SHiP is sensitive to wide range of models

	Physics model	Final state
HSDS	HNL, SUSY neutralino	$\ell^{\pm}\pi^{\mp}$, $\ell^{\pm}K^{\mp}$, $\ell^{\pm}\rho^{\mp}(\rho^{\mp}\to\pi^{\mp}\pi^{0})$
	DP, DS, ALP (fermion coupling), SUSY sgoldstino	$\ell^{+}\ell^{-}$
	DP, DS, ALP (gluon coupling), SUSY sgoldstino	$\pi^{+}\pi^{-}$, $K^{+}K^{-}$
	HNL, SUSY neutralino, axino	$\ell^{+}\ell^{-}\nu$
	ALP (photon coupling), SUSY sgoldstino	$\gamma\gamma$
	SUSY sgoldstino	$\pi^{0}\pi^{0}$

2112.01487

K -> X , B -> X

DARK SCALAR



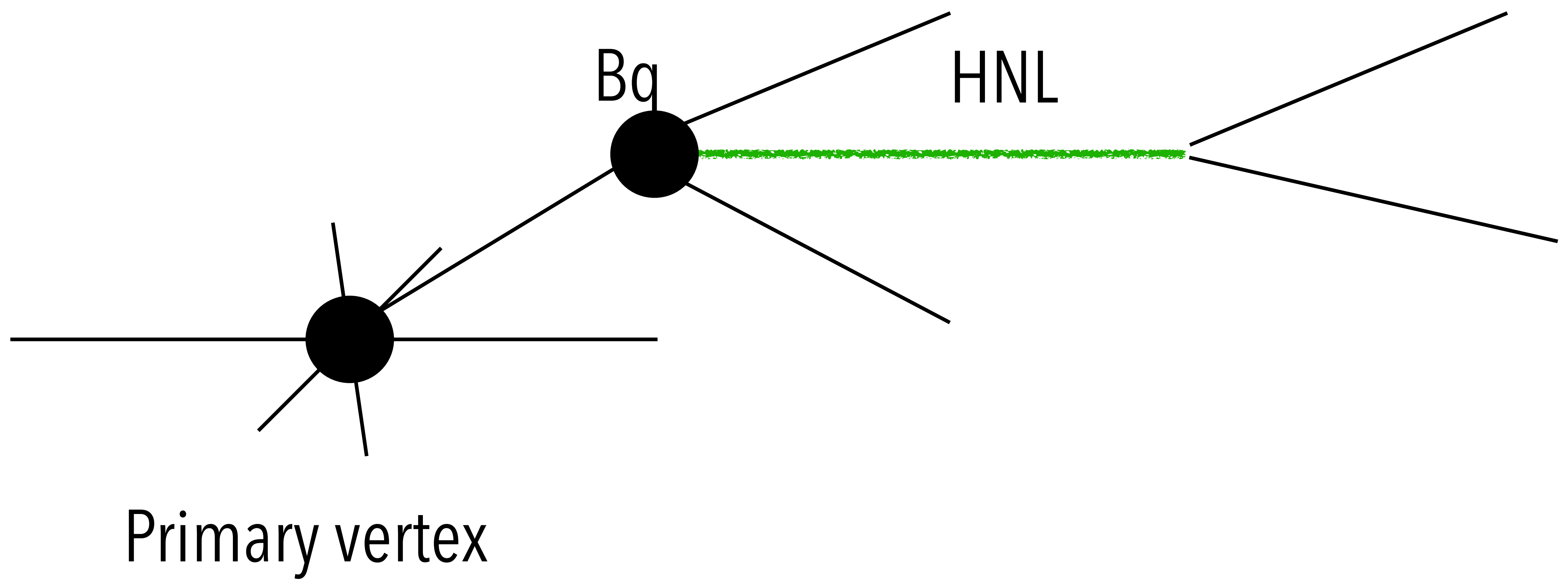
SHiP Progress report SPSC-SR-248

Projected sensitivity for dark photon and HNL are also available here SPSC-SR-248

LHCb

It uses the high production rate in the forward direction.

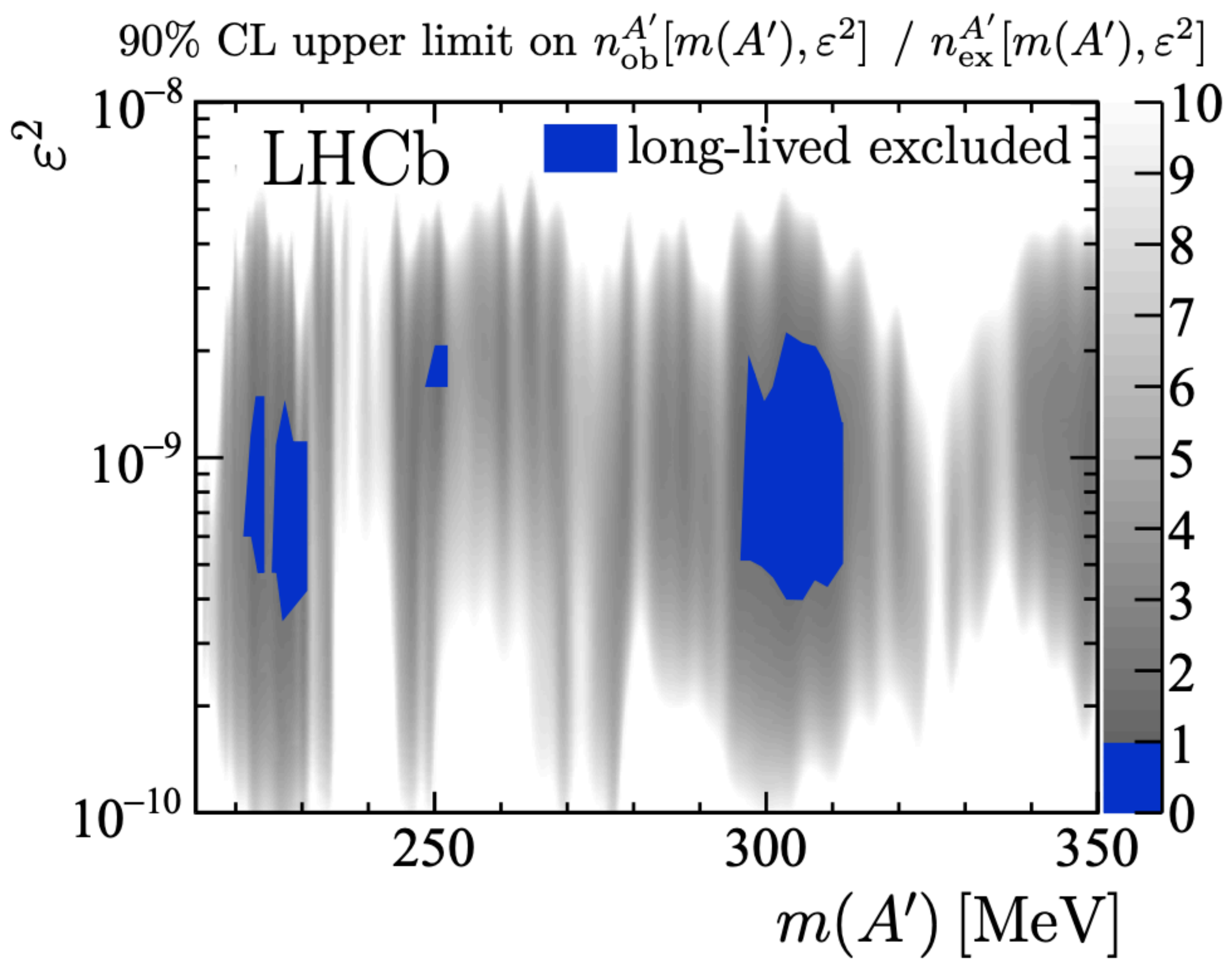
Detection of low p_T event possible



1710.02867

Dark Photon search in the di-muon channel => Peak search above SM continuum bkg. PT of muon >1 GeV Resonance regions excluded

Some patches for LL dark photon also excluded



Standard analysis : $pp \to W \to lN \to lljj$ also possible

Light scalar : $B \to \phi K, \phi \to \mu\mu$

From Run 3, LHCb is using full software trigger

LHCb future sensitivity without VELO 2312.14016

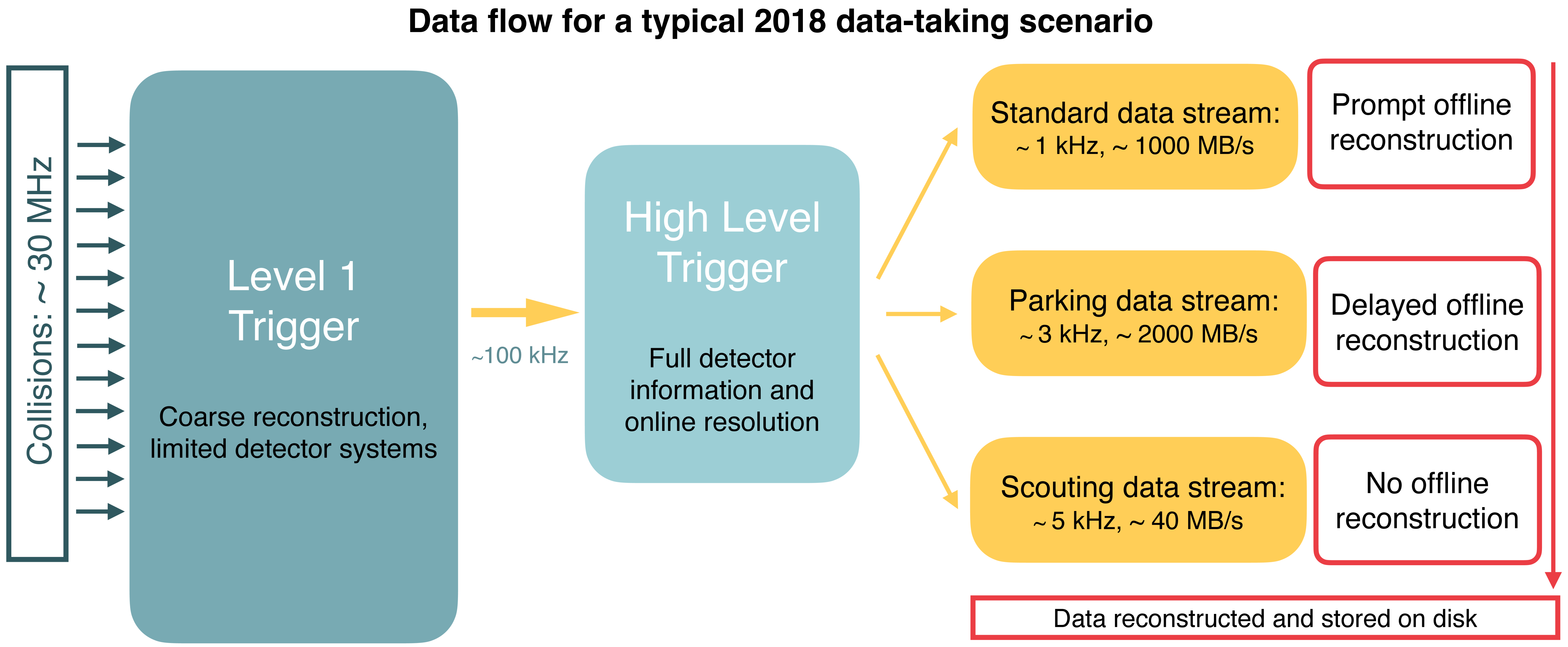
Light dark photon below 200 MeV can be studied in future from pion decay $\pi \to Z_D + \gamma$

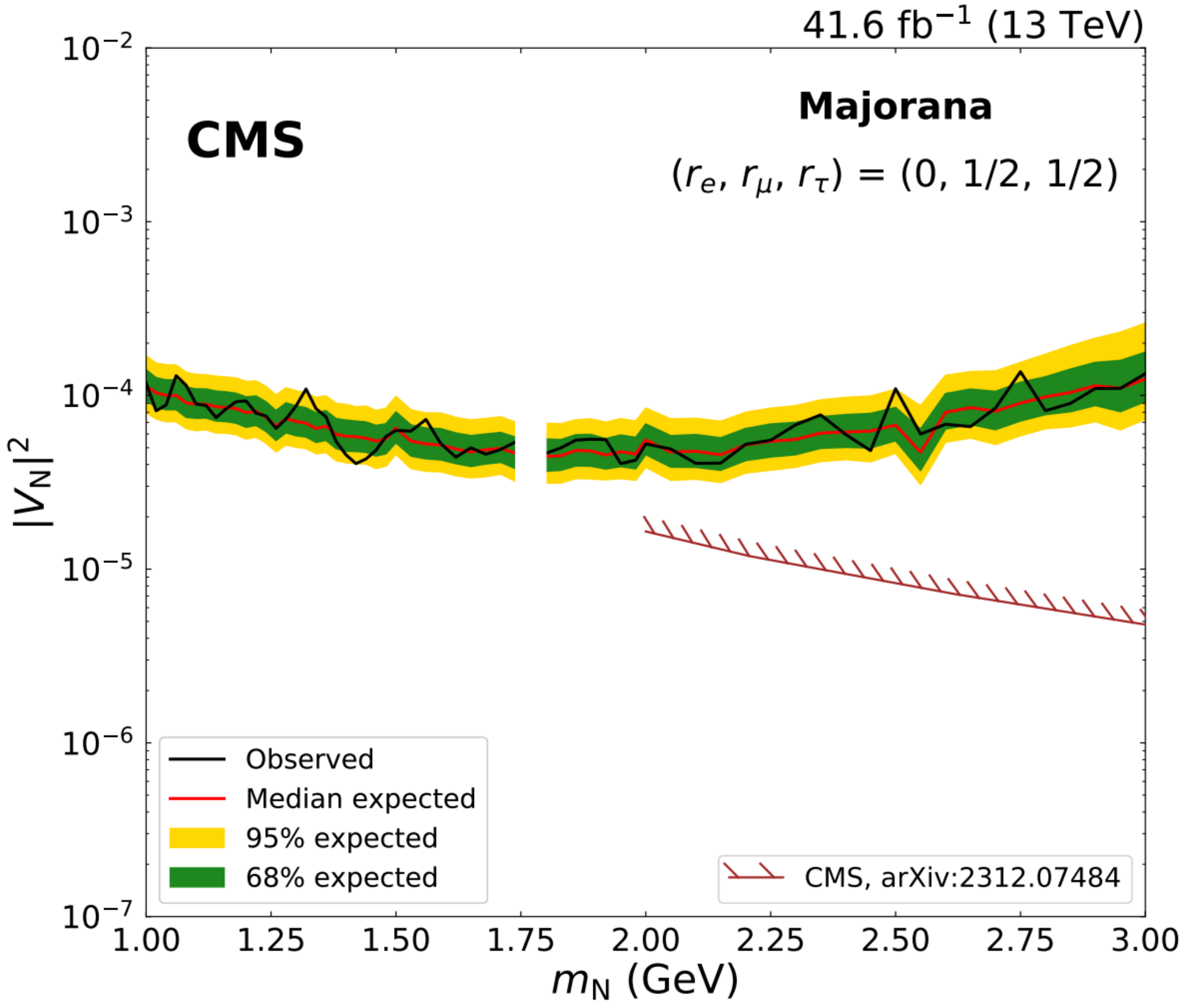
B-parking@CMS

2018: CMS collected 10^{10} $b\bar{b}$ events using a dedicated data stream

Events with muons with pT > 7 to 12 GeV recorded

Raw data stored and later processed





CMS-EXO-23-007

2403.04584

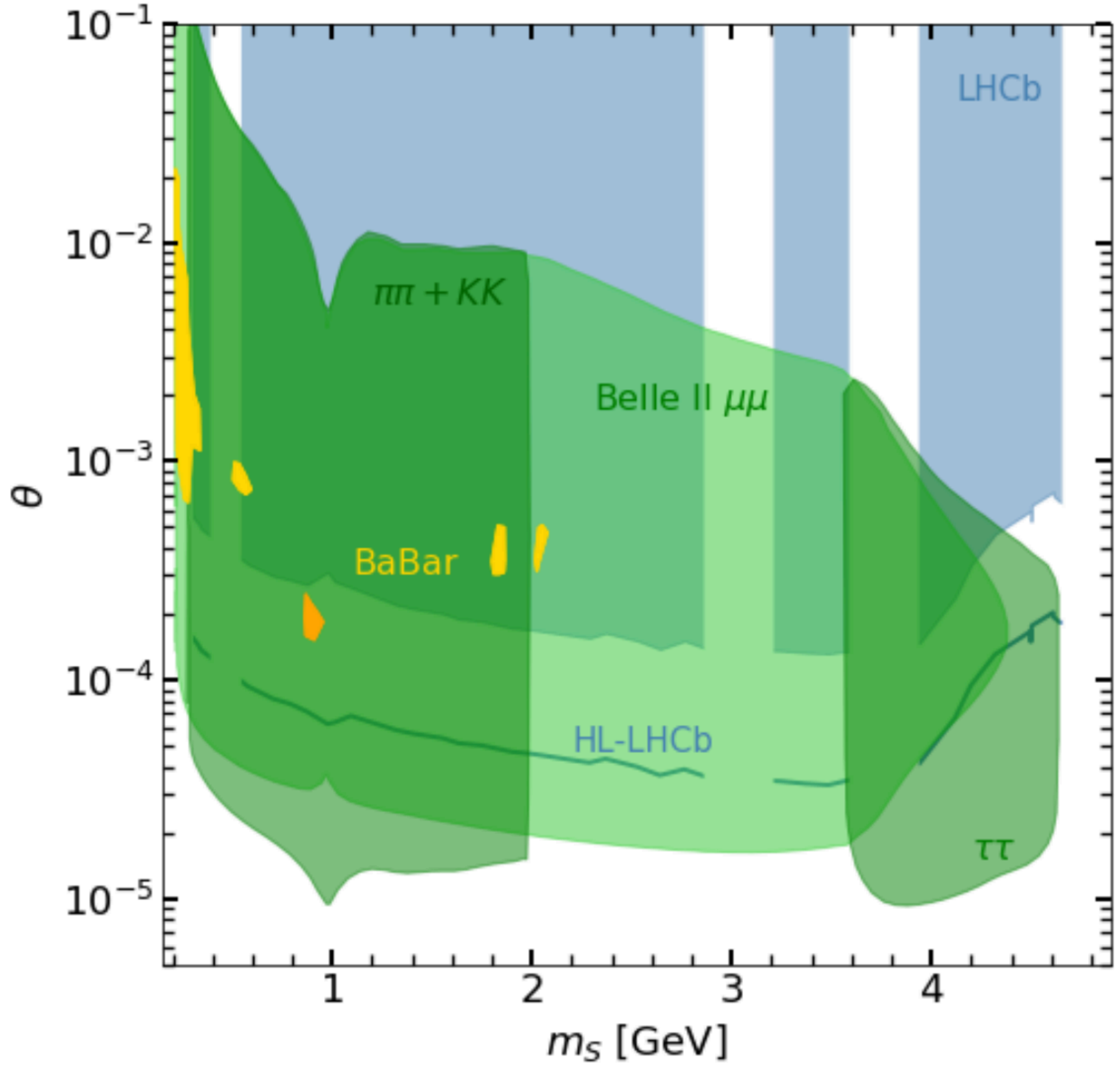
CMS Scouting

Future projection@BELLE-II

10 GeV electron-positron collider at the SuperKEKB (KEK)   Capable of collecting 50 ab-1 of data in future

Smaller background compared to LHC experiments (no Pileup)

Reconstruction of charged and neutral hadrons possible



1911.03490

Future projection for dark scalars from BELLE-II(Green) : B + → K+ Phi
Phi -> pion, Kaon, Mu and tau