PHENO 2020

FROM THE INFRARED TO THE ULTRAVIOLET

Long-lived particle Searches at LHC

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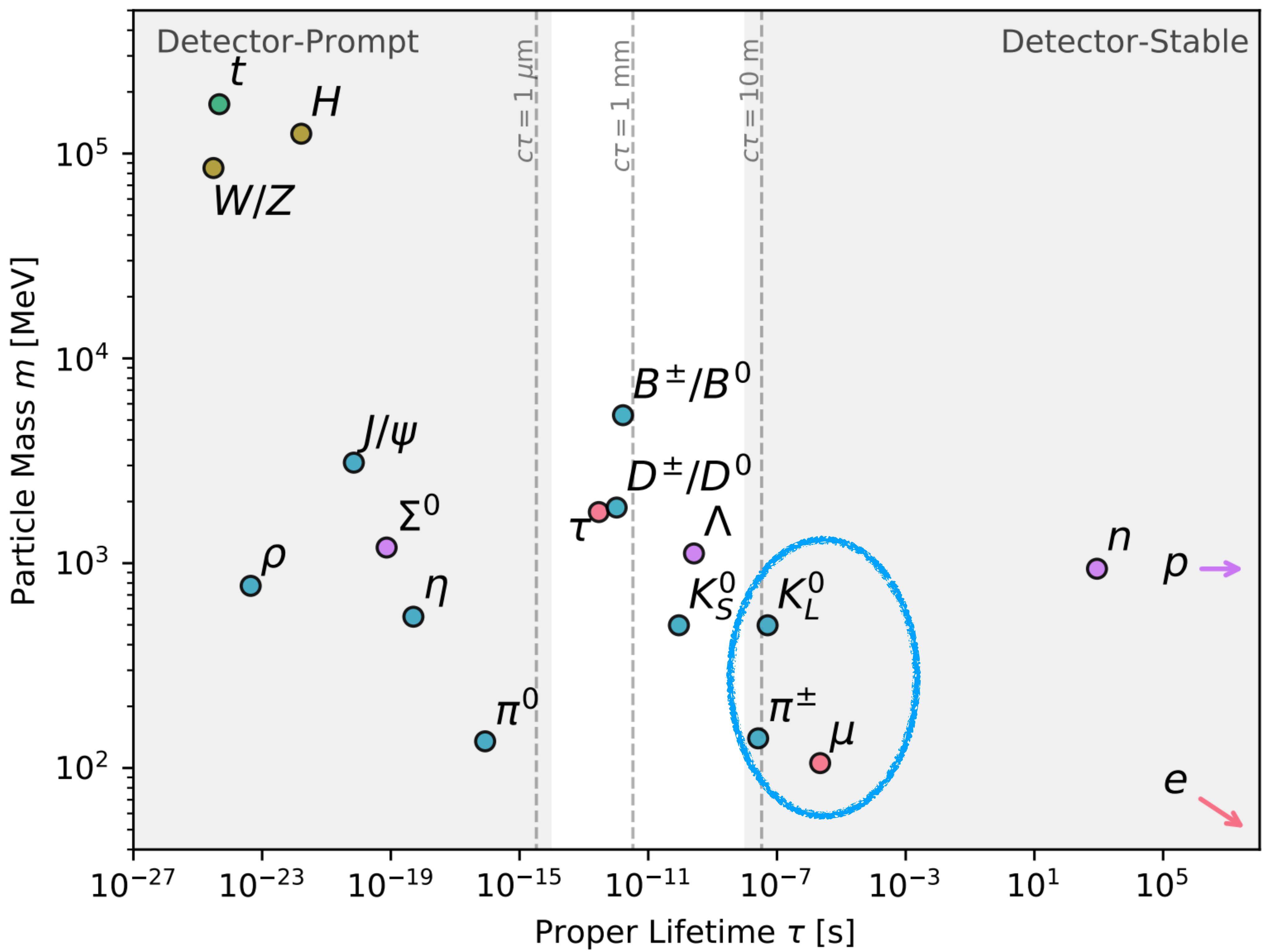
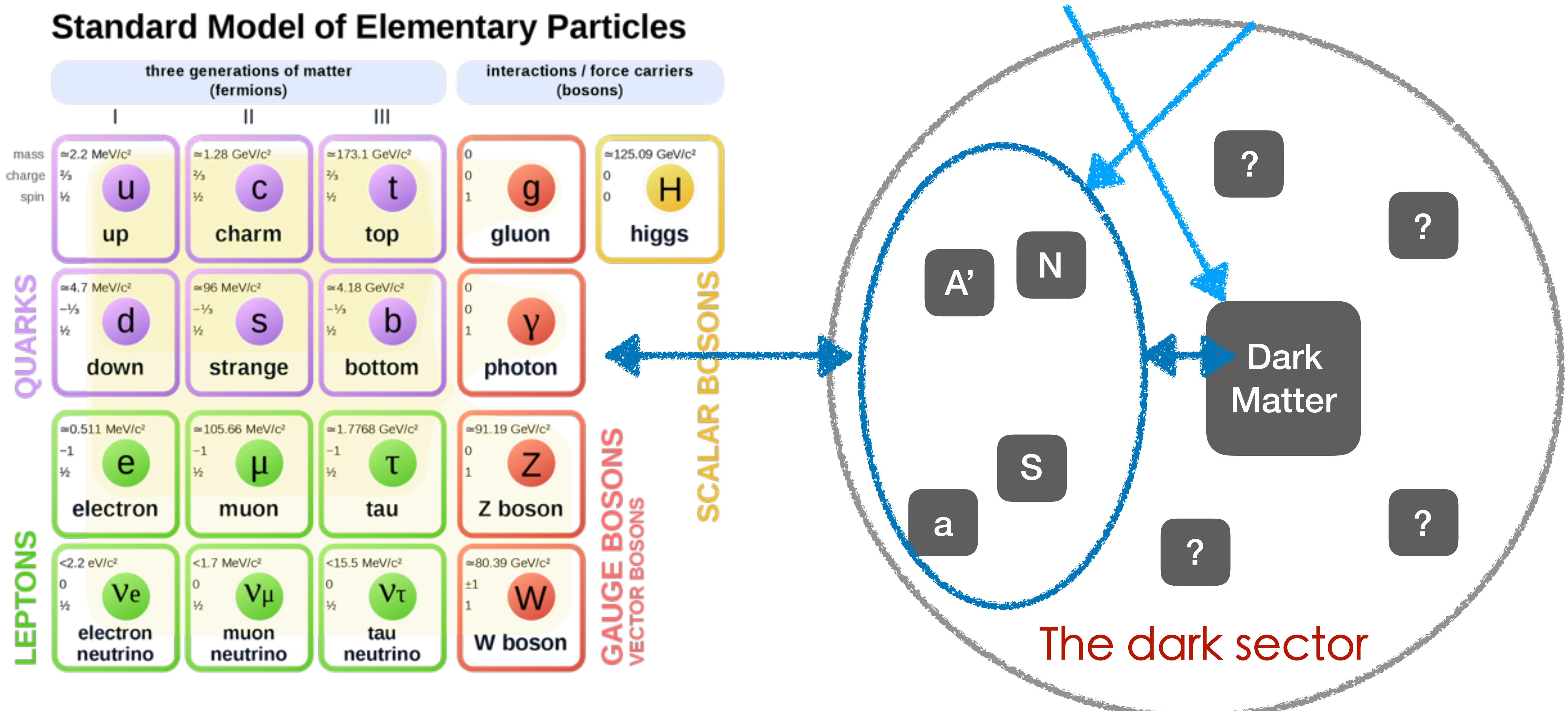
Why Long-lived Particles?



Xiao-Ping Wang, Argonne National Lab

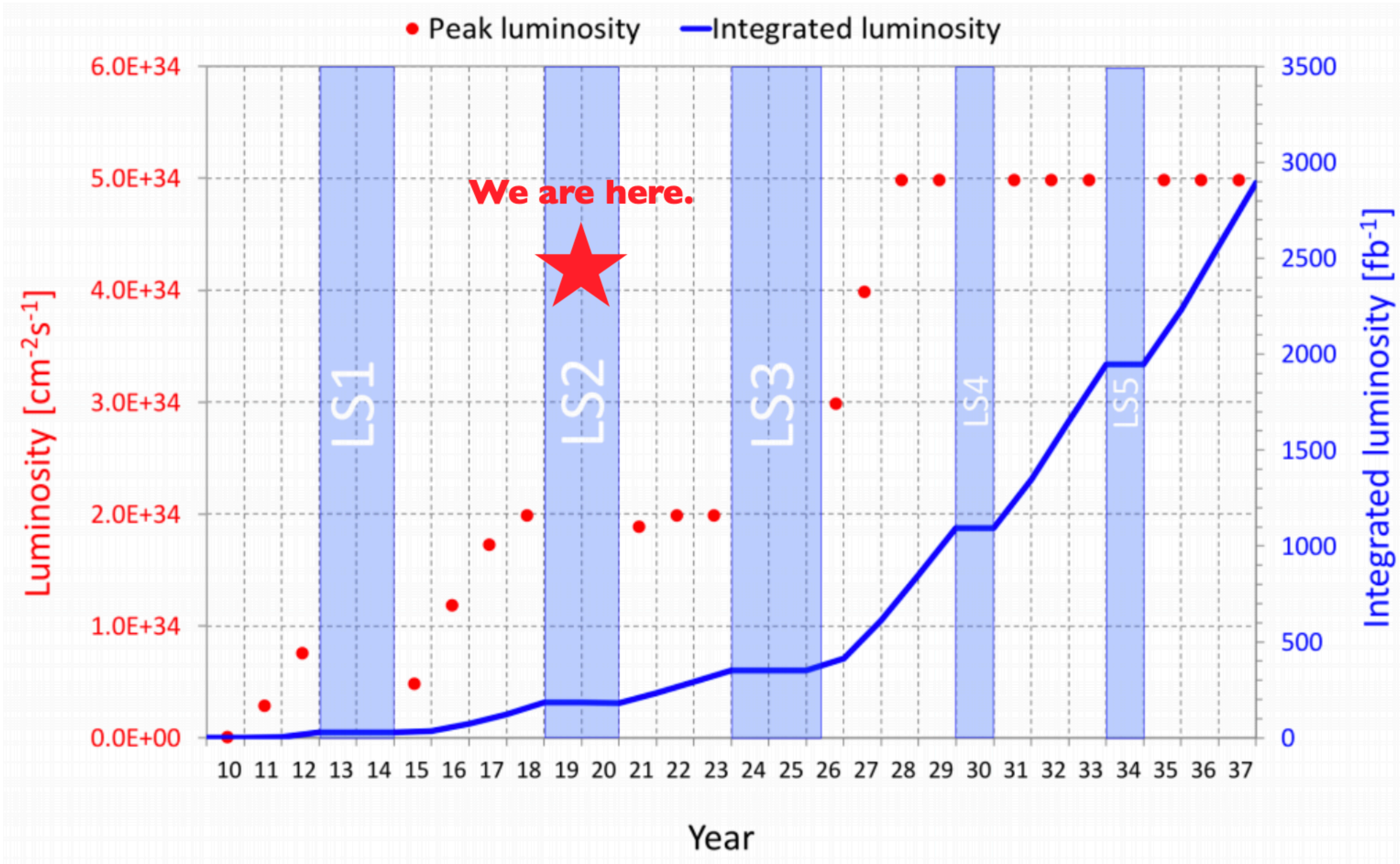
Why Long-lived Particles?

- Standard Model
  =fermions+force mediators
- Dark sector
  =DM+dark mediators



- **Not a surprise: dark sector particles have a wide spread in lifetime**

Why Looking for Long-lived Particle at LHC?



- LHC will accumulate more data
- Exp collaborations have broad physics programs: SUSY, composite H, extra Dim, etc.
- New directions?

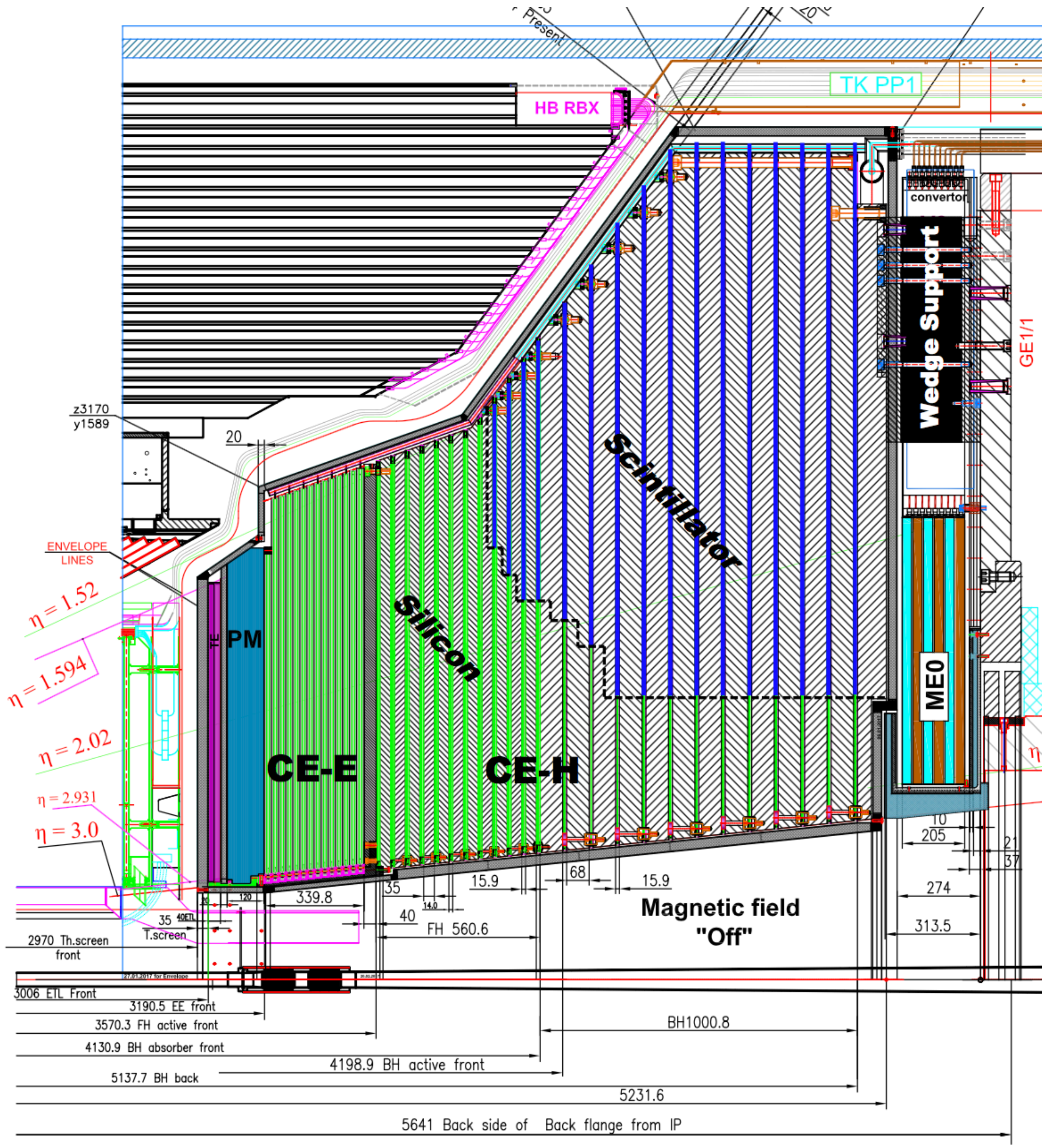
Why Looking for Long-lived Particle at LHC?

- Physics potential from a lot of new data
  - Very rare signal
    - E.g. dark sector, rare decays, ...
  - More data can help reducing systematics
    - Precision measurements

An important example:
Long-lived particles

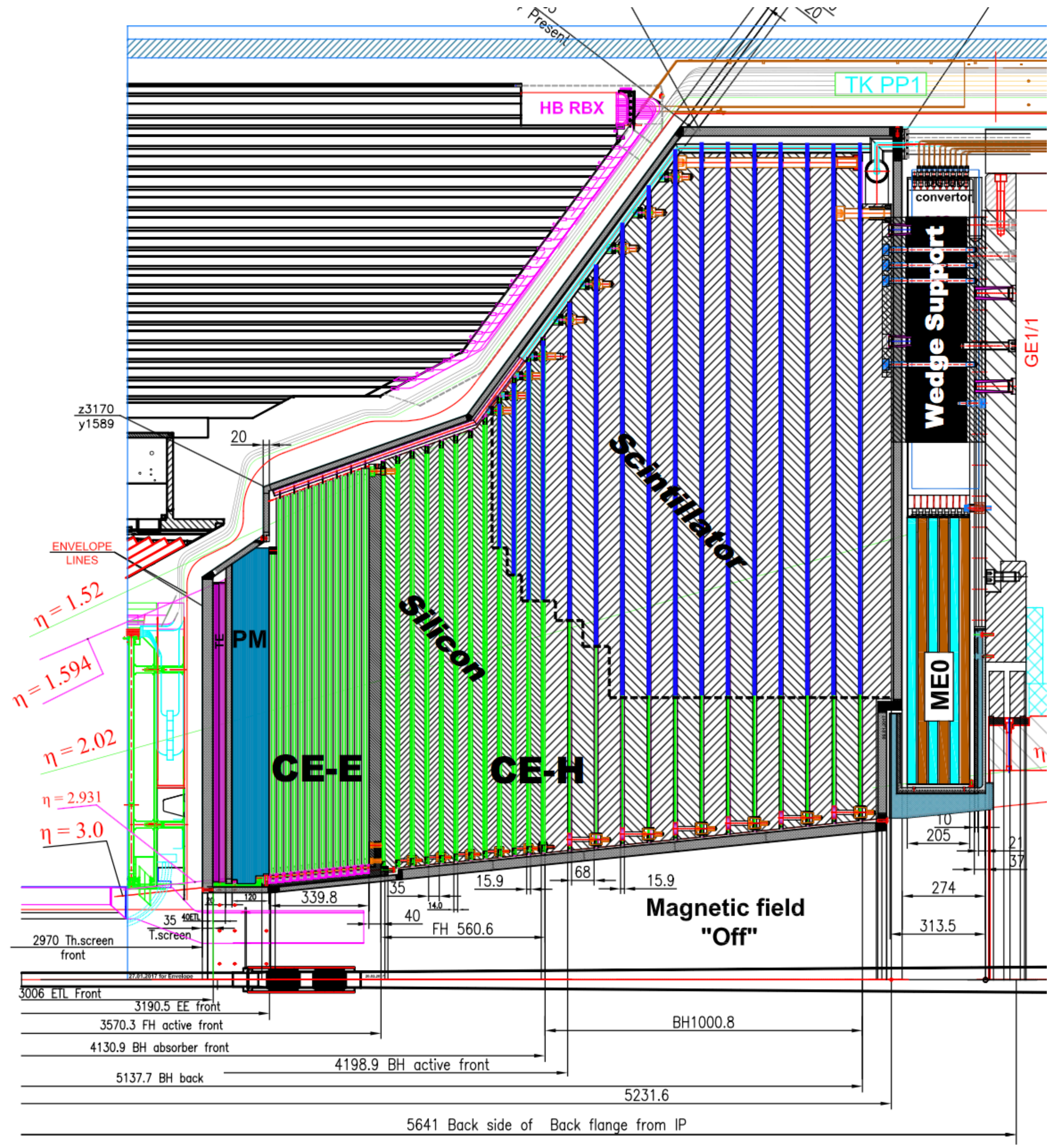
CMS High Granularity Calorimeter

- Motivation
  - Upgrade for radiation tolerance and pile-up
  - Tracker, calorimeter and timing integrated in one detector
  - Will provide much more information than any previous calorimeters



LLP motivation @ HGCAL

- Own triggers
- Tracker with silicon cell 0.5~1 cm^2 for EM
- Angular resolution of 5x10^{-3} rad stand-alone from high granularity (improvement by combining with ID trackers)
- Timing resolution ~ 25 ps from silicon sensor
- Semi-central coverage good for forward LLP
  Collinear enhancement
  Pt PS suppression



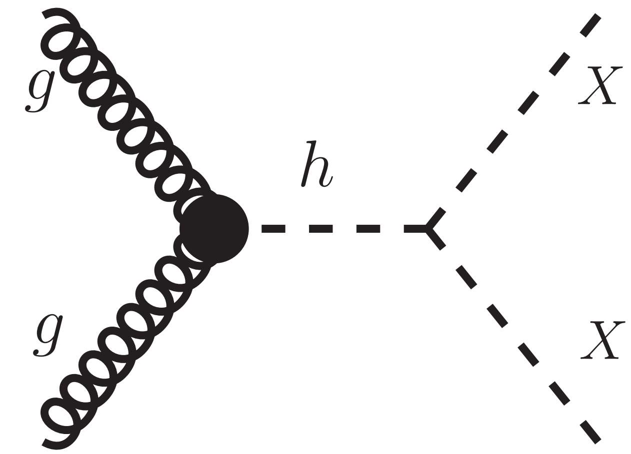
What is the HGCAL sensitivity for LLP?

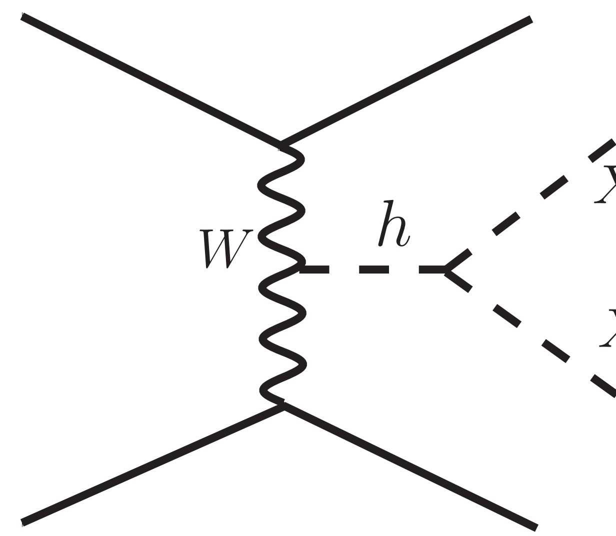
LLP Model

- Higgs portal LLP: a very small mixing

$$\mathscr{L} \supset \lambda X^2 H^\dagger H$$

- LLP production from Higgs decay
  - Gluon fusion
  - Vector boson fusion





- LLP decay

$$X \to \bar{b}b$$

- Trigger: displaced track trigger with/without large H_T requirement, and traditional VBF trigger

The Search Strategy

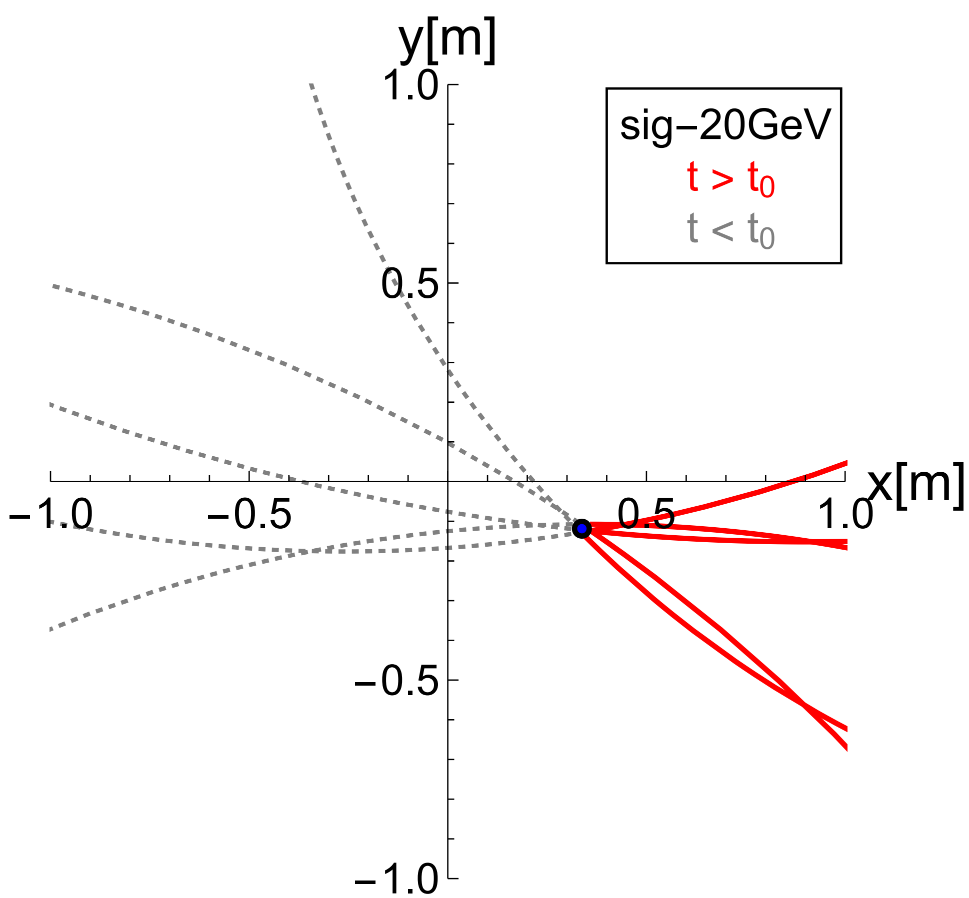
- Choose the leading 5 tracks (Pythia, p_T, hitting HGCAL) and calculate the 4D trajectories (including angular resolution effect)
- Perform a 2D track bundle vertex finder by minimizing the quantity

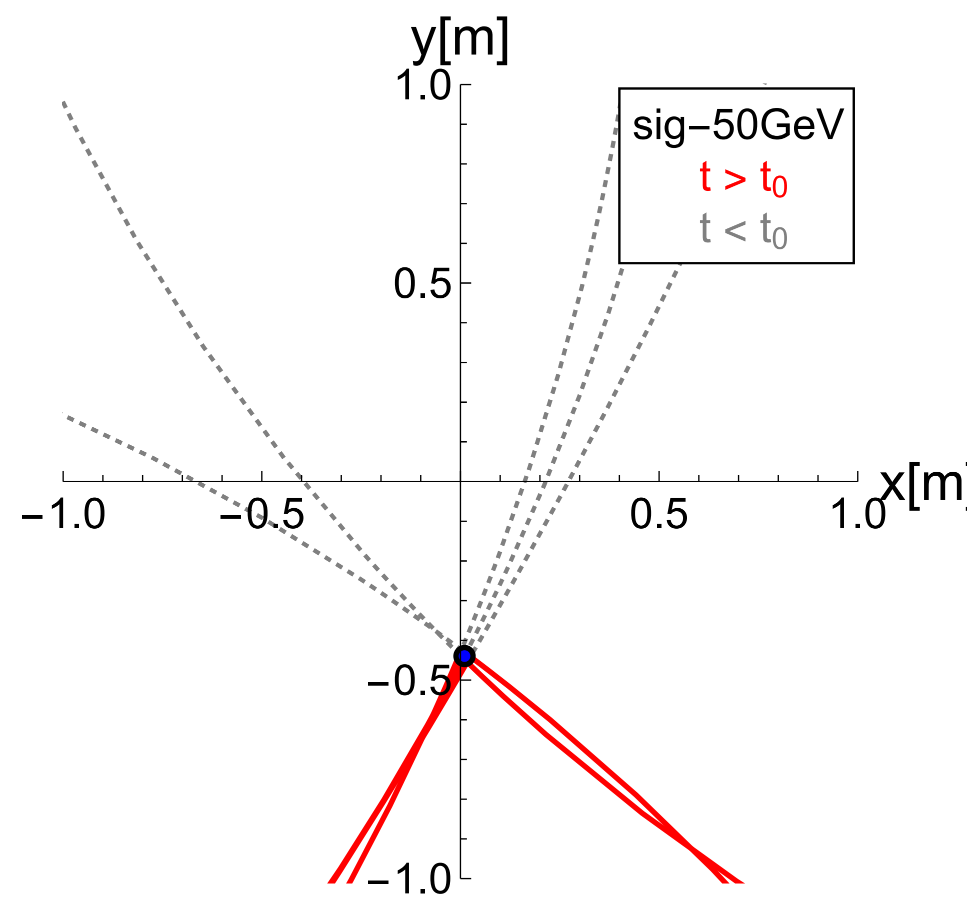
$$\Delta \mathrm{D} \equiv \sqrt{\sum_{i=1}^{5}\left(\sqrt{(x-x_i^{\mathrm{cen}})^2+(y-y_i^{\mathrm{cen}})^2}-R_i\right)^2}$$

  - R_i is the curvature of the ith track, $\{x^{cen}, y^{cen}\}$ are the center of the track
  - We obtain the fitted DV {x, y}, and define $r_{\mathrm{DV}} = \sqrt{x^2+y^2}$
  - The goodness of fit ΔD_{min}
- With the angular velocity of the track, we can determine the referencing point to DV for each track $\{x_i, y_i, z_i, t_i\}$
- A time delay quantity can be defined $\Delta t_i = t_i - \sqrt{x_i^2+y_i^2+z_i^2}$

The signature of the signal

- Multiple tracks with large impact parameters from the same displaced origin

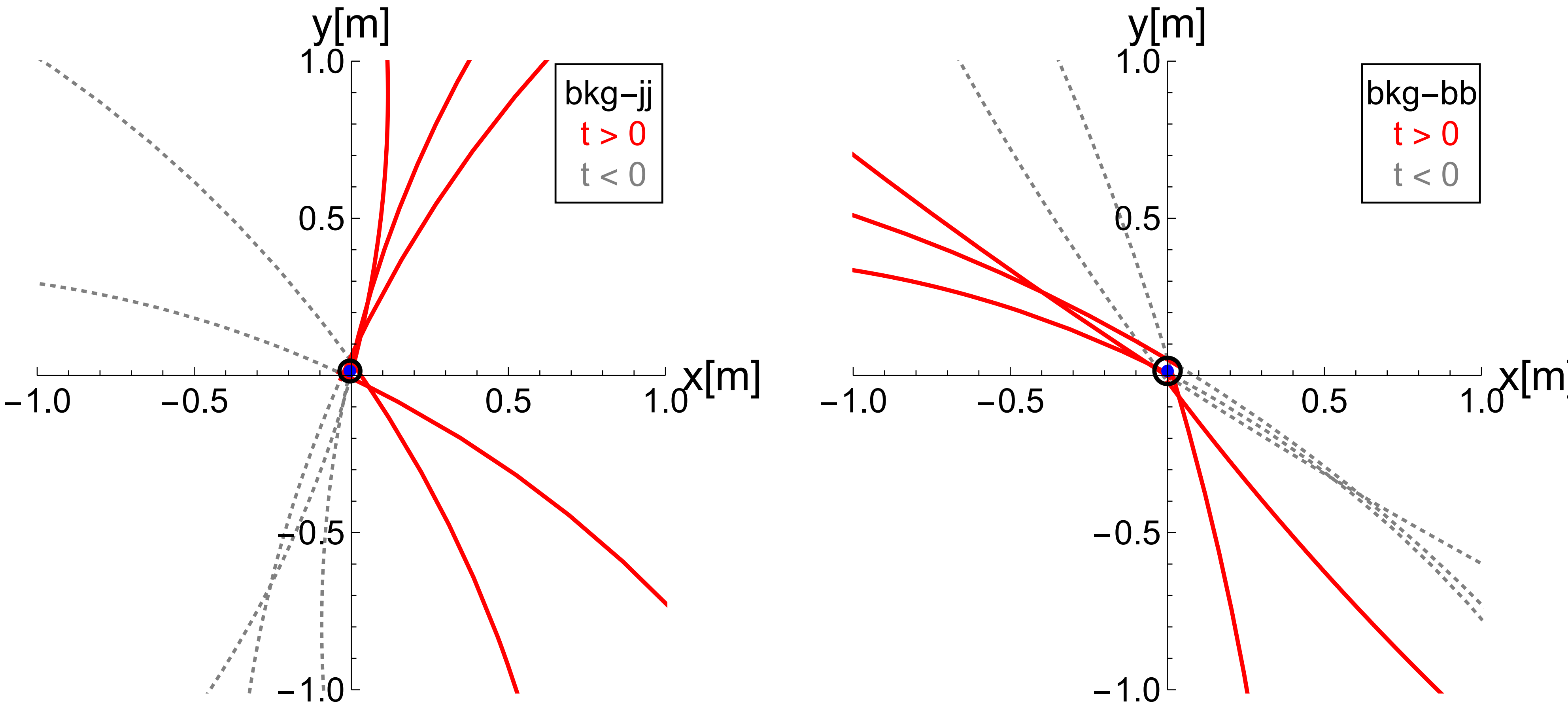




B=3.8T
X decay |Z|<1.5m
Tracks arrive at |Z|=3.2m

The SM Backgrounds

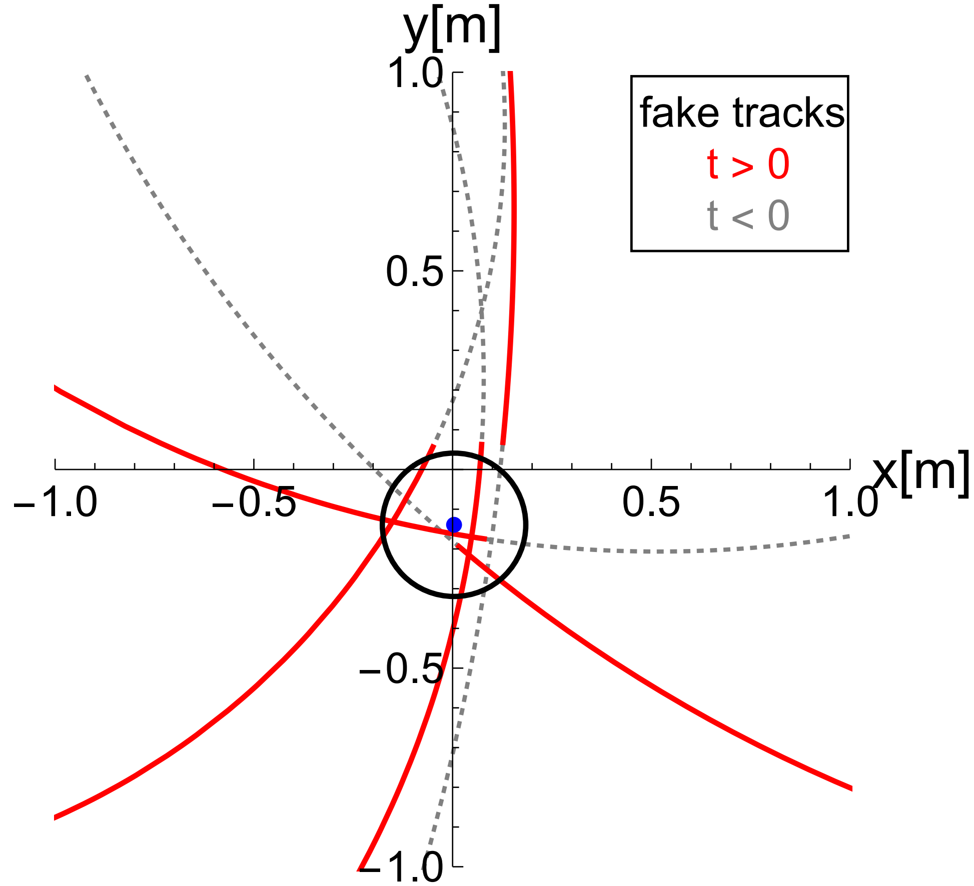
- QCD backgrounds
  - Most of them are prompt



- Large impact parameter dominantly from K_S ($c\tau$ ~ 2.7 cm)
  - B ($c\tau$ ~ 0.045 m) and D meson ($c\tau$ ~ 0.03 m) too small

The SM Backgrounds

- Fake track backgrounds
  - wrong connection of the hitting points in the tracker system



Flat distributions in

$\phi_0,\ d_0^T,\ 1/R,\ z_0, t_0, \eta$

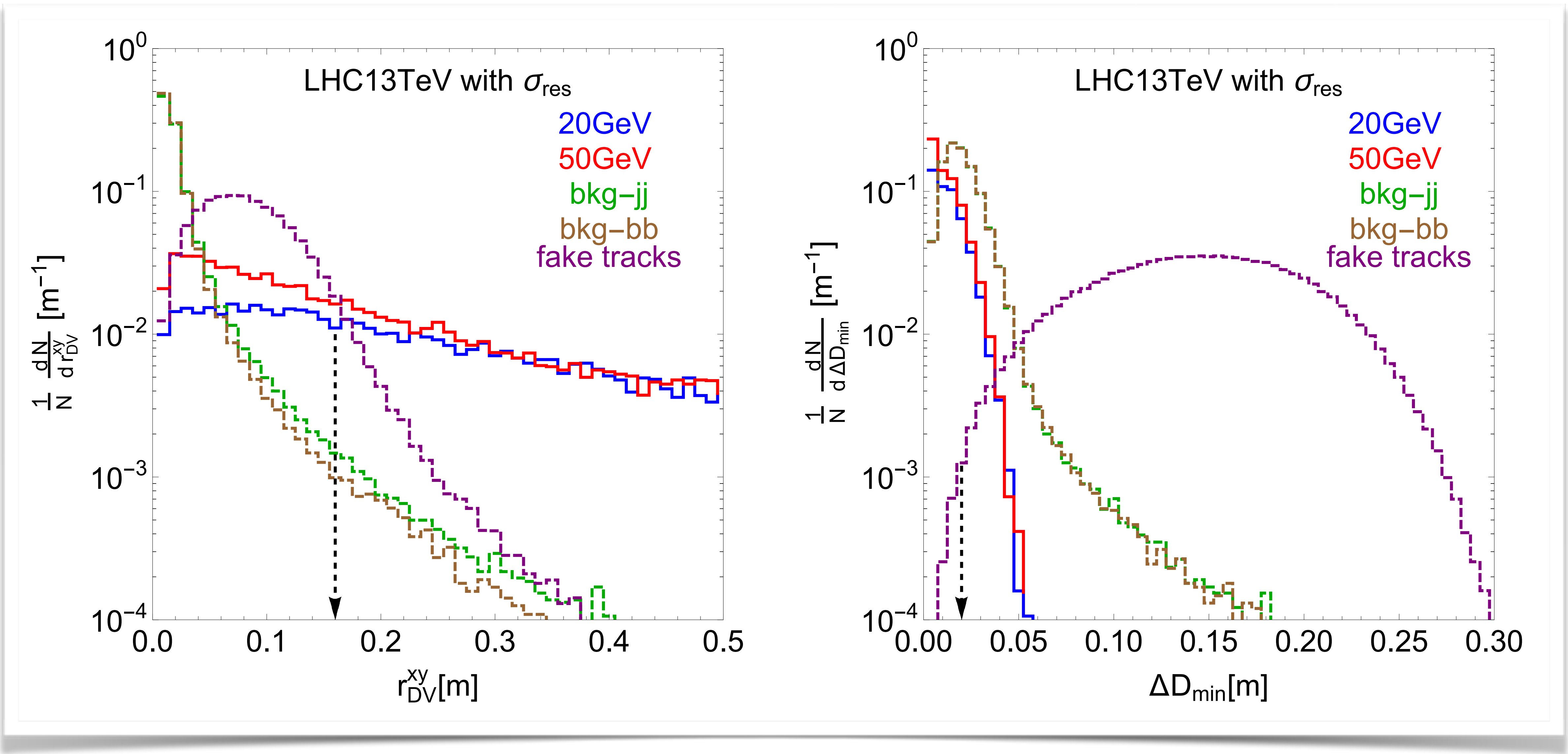
Generated following
Y. Gershtein and S. Knapen
1907.00007

- Very distinct features comparing with QCD backgrounds
  - Easy to have large impact parameter
  - Poorly fit to the same origin

Kinematic Features

- Check the kinematic distribution for

$$r_{DV},\ \Delta D_{min},\ \bar{t},\ \bar{z},\ \overline{\Delta t},\ SD_t,\ SD_z,\ SD_{\Delta t}.$$

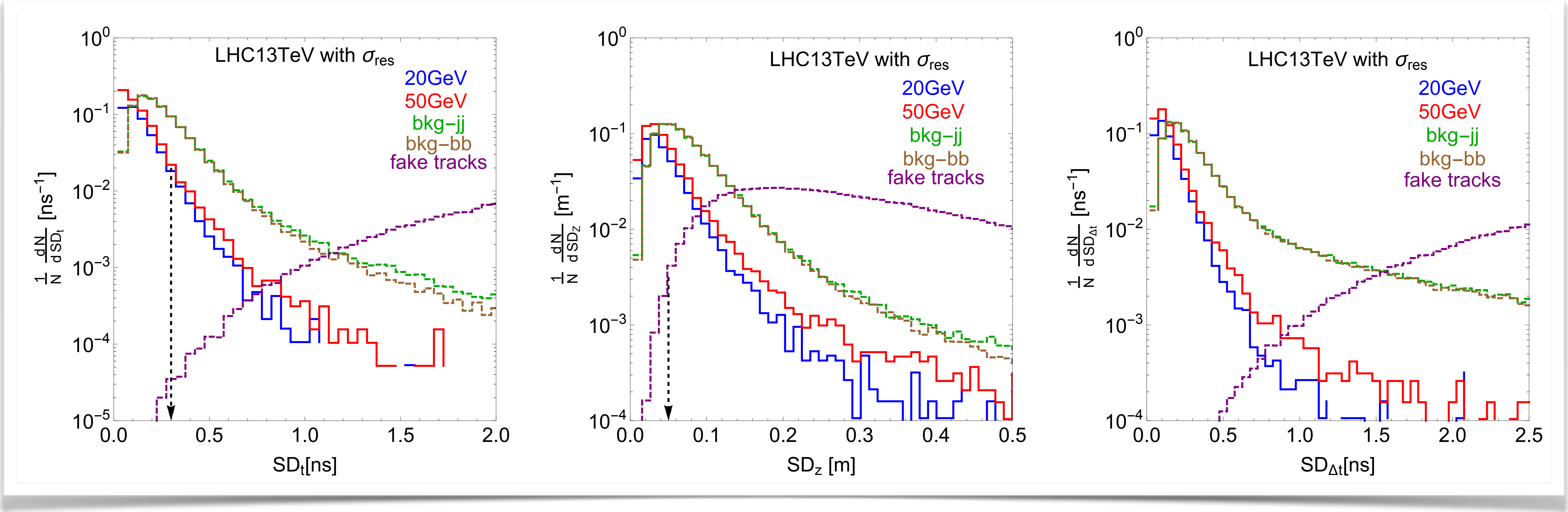


Kinematic Features

- Check the kinematic distribution for

$$r_{DV},\ \Delta D_{min},\ \bar{t},\ \bar{z},\ \overline{\Delta t},\ SD_t,\ SD_z,\ SD_{\Delta t}.$$

- Standard Deviation of the tracks quantities



The Cut Flow Table

- QCD bkg: p_T>20GeV with jet matching
- Fake track bkg: five displaced tracks and H_T>100GeV
  L1 trigger rate of 10 kHz (same as Yuri and Simon), HL-LHC 10^8 sec

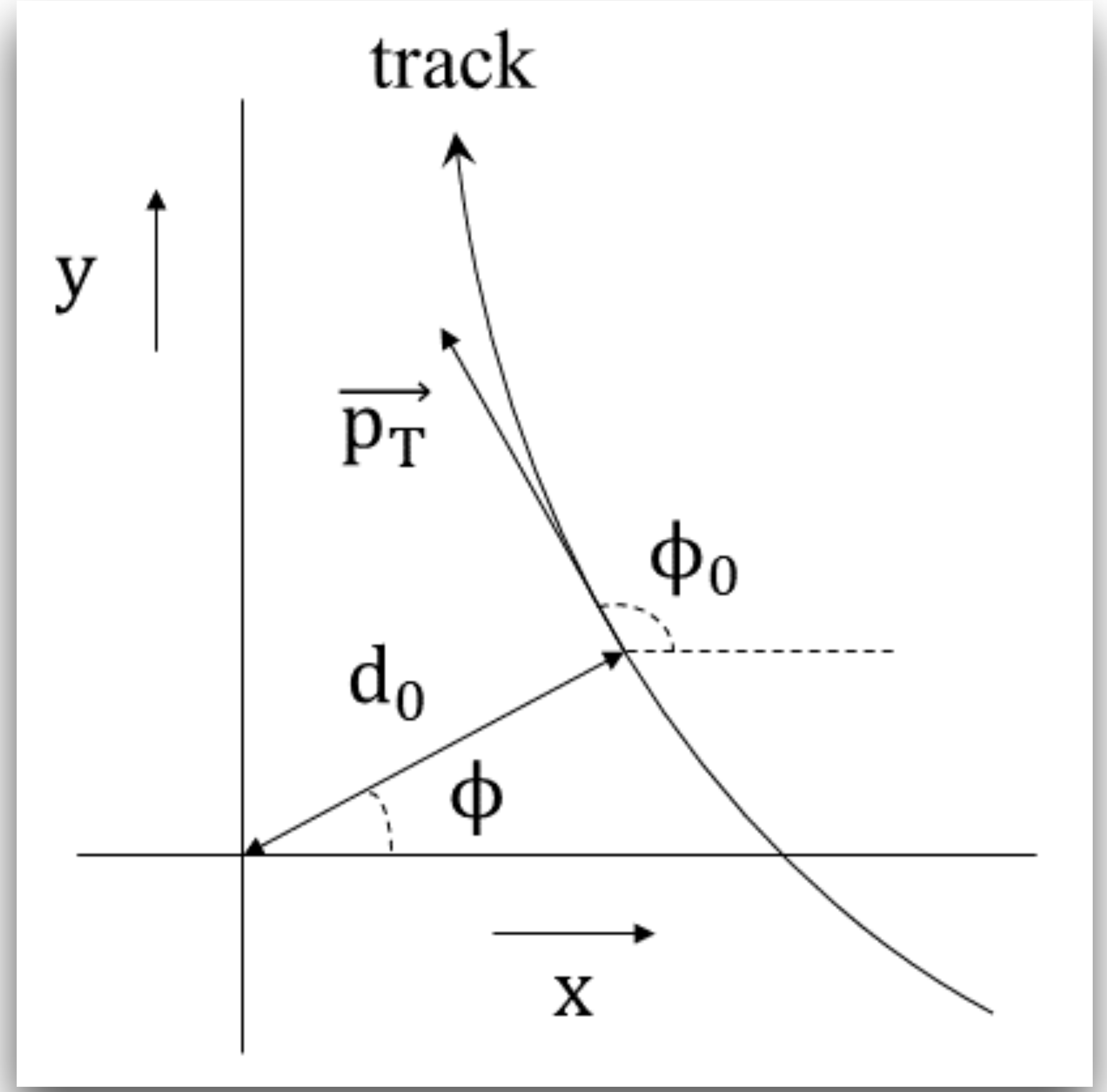
type of bkg	$N_{\rm ini}$	5 tracks	$r_{\rm DV}^{\rm xy} > 0.16$ m	$\Delta D_{\rm min} < 0.02$ m	$\bar{t} > 1$ ns	$SD_t < 0.3$ ns
jj dijet	5.1×10^{14}	9.4×10^{-1}	1.0×10^{-2} $(*)$	8.7×10^{-1}	3.0×10^{-2} $(*)$	7.3×10^{-1}
$b\bar{b}$ dijet	1.1×10^{13}	1.0	7.7×10^{-3} $(*)$	9.2×10^{-1}	2.4×10^{-2} $(*)$	7.4×10^{-1}
fake track	1×10^{12}	5.6×10^{-1}	4.6×10^{-2}	2.2×10^{-3}	2.8×10^{-2}	6.2×10^{-5}
ggF $m_s = 20$ GeV	1.3×10^8BR	$0.36 \times 3.1 \times 10^{-1}$	5.3×10^{-1}	8.6×10^{-1}	9.9×10^{-1}	9.6×10^{-1}
ggF$m_s = 50$ GeV	1.3×10^8BR	$0.8 \times 3.5 \times 10^{-1}$	3.5×10^{-1}	8.8×10^{-1}	9.8×10^{-1}	9.5×10^{-1}

Pre-cuts for DV fitting

type of bkg	N_{ini}	5 tracks	$r_{\mathrm{DV}}^{xy} > 0.16$ m	$\Delta D_{\mathrm{min}} < 0.02$ m	$\bar{t} > 1$ ns	$SD_t < 0.3$ ns	$\bar{z} > 0.4$ m	$SD_z < 0.05$ m	ϵ_{vtc}	$(d_0^T > 0.03\ \mathrm{m})^5$	N_{fin}
jj dijet	5.1×10^{14}	9.4×10^{-1}	1.0×10^{-2} $(*)$	8.7×10^{-1}	3.0×10^{-2} $(*)$	7.3×10^{-1}	3.4×10^{-2} $(*)$	4.9×10^{-1}	3.0×10^{-1}	$(7.2 \times 10^{-4})^5$	2.8×10^{-2}
$b\bar{b}$ dijet	1.1×10^{13}	1.0	7.7×10^{-3} $(*)$	9.2×10^{-1}	2.4×10^{-2} $(*)$	7.4×10^{-1}	2.7×10^{-2} $(*)$	4.9×10^{-1}	2.9×10^{-1}	$(6.5 \times 10^{-4})^5$	3.7×10^{-4}
fake track	1×10^{12}	5.6×10^{-1}	4.6×10^{-2}	2.2×10^{-3}	2.8×10^{-2}	6.2×10^{-5}	5.9×10^{-2}	5.4×10^{-3}	5.8×10^{-13}	3.4×10^{-1}	1.1×10^{-1}
ggF $m_s = 20$ GeV	1.3×10^8BR	$0.36 \times 3.1 \times 10^{-1}$	5.3×10^{-1}	8.6×10^{-1}	9.9×10^{-1}	9.6×10^{-1}	9.8×10^{-1}	8.6×10^{-1}	1.2×10^{-1}	2.9×10^{-1}	$4.3 \times 10^6 \times$ BR
ggF$m_s = 50$ GeV	1.3×10^8BR	$0.8 \times 3.5 \times 10^{-1}$	3.5×10^{-1}	8.8×10^{-1}	9.8×10^{-1}	9.5×10^{-1}	8.9×10^{-1}	8.6×10^{-1}	9.0×10^{-2}	8.0×10^{-1}	$9.5 \times 10^6 \times$ BR

- Fake track bkg suppressed because its random origin

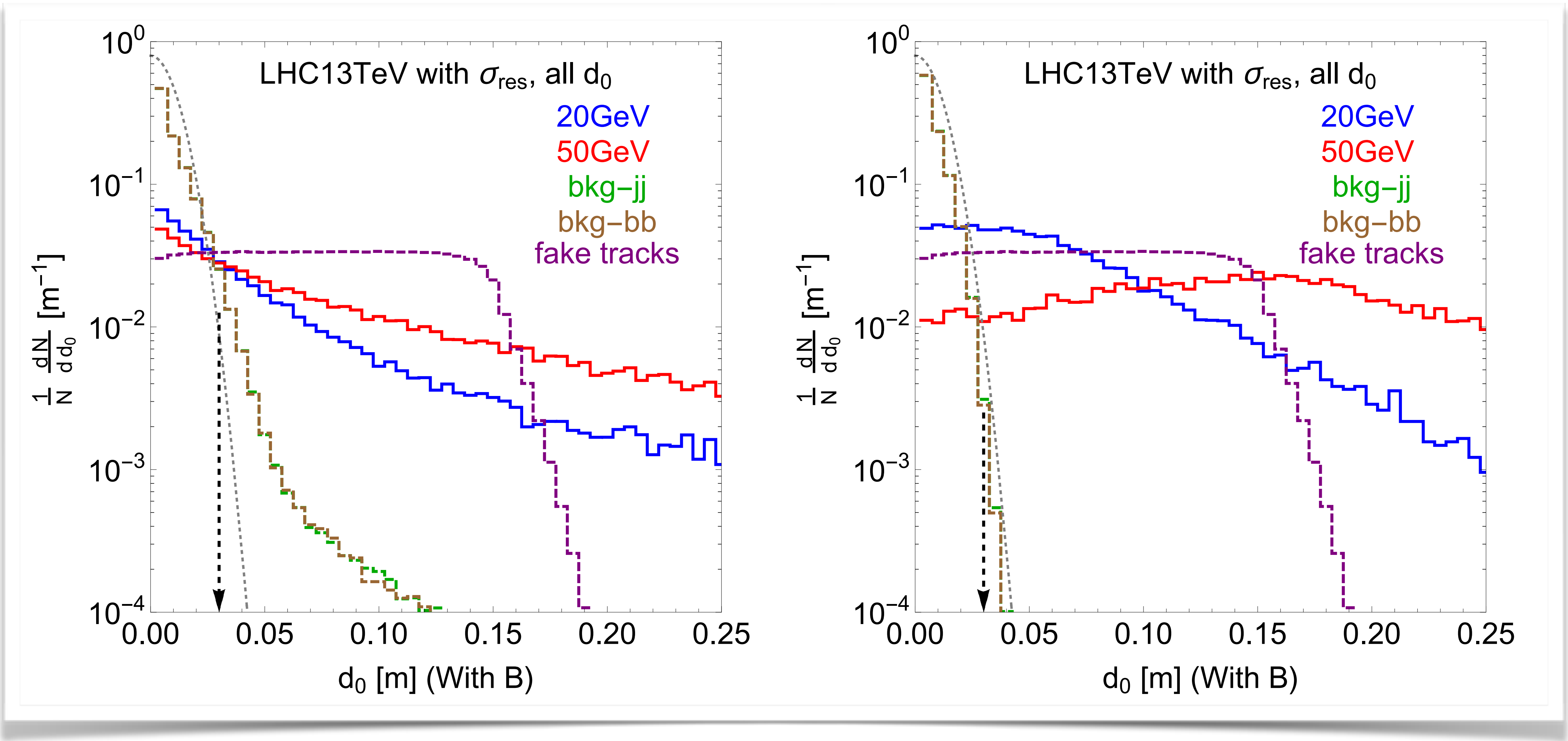
Impact Parameter



$$d_0 = \sqrt{x^2 + y^2 - \frac{(xp_x + yp_y)^2}{p_x^2 + p_y^2}}$$

Kinematic Features

- Transverse impact parameters



- QCD bkg has a good Gaussian shape because pre-cuts excludes K_S meson decays

- Gaussian width comes from angular resolution
  3 m x 5×10^{-3} rad = 0.015 m

Independence Check is Necessary

- QCD bkg: impact parameter cuts are independent?
    - Should be, because they are from angular resolution smearing

type of bkg	$N_{\rm ini}$	5 tracks	$\rm r_{DV}^{xy} > 0.16$ m	$\Delta \rm D_{min} < 0.02$ m	$\bar{t} > 1$ ns	$\rm SD_t < 0.3$ ns	$\bar{z} > 0.4$ m	$\rm SD_z < 0.05$ m	$\epsilon_{\rm vtc}$	$(d_0^T > 0.03\ \rm m)^5$	$N_{\rm fin}$
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ggF $m_s = 20$ GeV	1.3×10^8BR	$0.36 \times 3.1 \times 10^{-1}$	5.3×10^{-1}	8.6×10^{-1}	9.9×10^{-1}	9.6×10^{-1}	9.8×10^{-1}	8.6×10^{-1}	1.2×10^{-1}	2.9×10^{-1}	$4.3 \times 10^6 \times$ BR
ggF$m_s = 50$ GeV	1.3×10^8BR	$0.8 \times 3.5 \times 10^{-1}$	3.5×10^{-1}	8.8×10^{-1}	9.8×10^{-1}	9.5×10^{-1}	8.9×10^{-1}	8.6×10^{-1}	9.0×10^{-2}	8.0×10^{-1}	$9.5 \times 10^6 \times$ BR

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ggF $m_s = 20$ GeV	1.3×10^8BR	$0.36 \times 3.1 \times 10^{-1}$	5.3×10^{-1}	8.6×10^{-1}	9.9×10^{-1}	9.6×10^{-1}	9.8×10^{-1}	8.6×10^{-1}	1.2×10^{-1}	2.9×10^{-1}	$4.3 \times 10^6 \times$ BR
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- Independence check

$$\mathrm{IDd}_n \equiv \frac{\epsilon^n(1\ \text{track}\ d_0^T > 0.03\text{m})}{\epsilon(\text{n tracks}\ d_0^T > 0.03\text{m})}$$

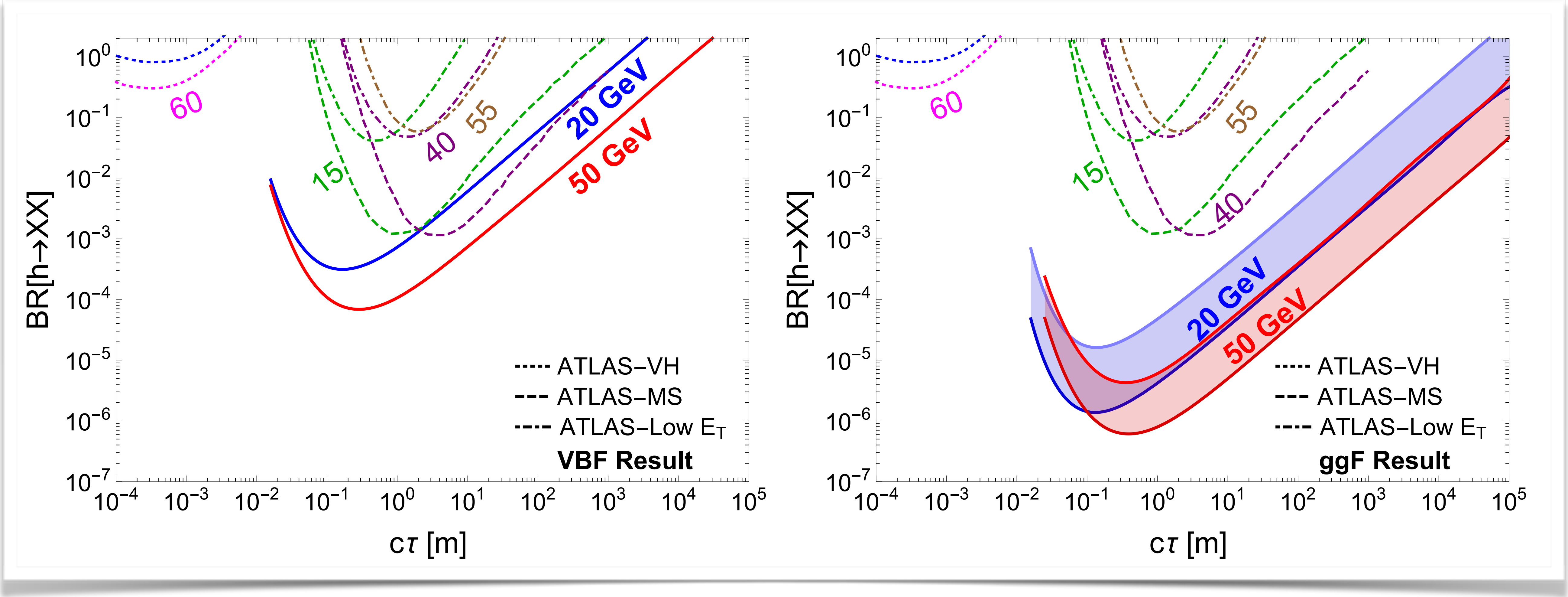
  - ~1 independent, >1 conservative
  - In summary, ≥ 1 is conservative for bkg estimation

Independence Check

- QCD bkg: impact parameter for tracks are independent
  - angular resolution smearing is independent for each track

jj dijets	$d_0^T > 0.01$ m	$d_0^T > 0.015$ m	$d_0^T > 0.02$ m	$d_0^T > 0.025$ m	$d_0^T > 0.03$ m
IDd_1	0.96	0.95	1.0	1.1	1.3
IDd_2	1.0	1.1	0.87	-	-
IDd_3	1.2	0.95	-	-	-
IDd_4	1.1	-	-	-	-
IDd_5	0.9	-	-	-	-
$\bar{b}b$ dijets	$d_0^T > 0.01$ m	$d_0^T > 0.015$ m	$d_0^T > 0.02$ m	$d_0^T > 0.025$ m	$d_0^T > 0.03$ m
IDd_1	0.96	0.95	0.98	1.12	1.8
IDd_2	1.1	1.2	1.1	-	-
IDd_3	1.3	0.90	-	-	-
IDd_4	1.2	1.1	-	-	-
IDd_5	1.1	-	-	-	-

The Preliminary Results for HL-LHC



- ggF result: with/without high H_T trigger requirement
- VBF result: standard VBF trigger

Thank you!