Long-Lived Stau Kink Signature at the LHC

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27th Feb. 2012
@ KEK, Tsukuba

NOTE
'cause of the time limitation,
I'll rush a bit.
Plz interrupt & gimme Q's
if something unclear!

Based on

ATLAS collaboration

Asai, Azuma, Endo, Hamaguchi, and Iwamoto.

Theory group (Phenomenologists)

Stau Kinks at the LHC.
JHEP 1112 (2011) 077. [arXiv: 1103.1881] (hep-ph)

Motivation

"How can we discover

SUSY with

$\widetilde{G}$-LSP, $\widetilde{\tau}_1$-NLSP

at the LHC?"

- The NLSP is charged and decays as $\widetilde{\tau}_1 \to \widetilde{G}\tau$.
- expected in the GMSB framework etc.

(gauge-mediated SUSY breaking)

SUSY with $\widetilde{G}$-LSP, $\widetilde{\tau}_1$-NLSP

- The NLSP $\widetilde{\tau}_1 \Longrightarrow$ decay: $\widetilde{\tau}_1 \to \widetilde{G}\tau$.

$$\Downarrow$$

- LHC signature $\Longleftarrow c\tau(\widetilde{\tau}_1 \to \widetilde{G}\tau)$

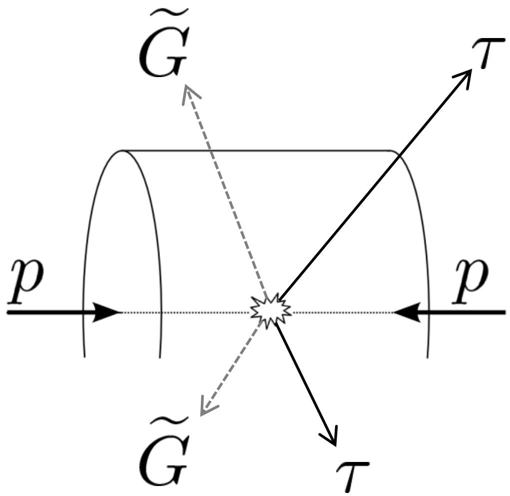
$$c\tau \simeq 0.55\,\mathrm{m} \left(\frac{200\,\mathrm{GeV}}{m_{\widetilde{\tau}_1}}\right)^5 \left(\frac{m_{\widetilde{G}}}{1\,\mathrm{keV}}\right)^2$$

$c\tau \lesssim 1\,\mathrm{mm} \cdots$ multi τ-lepton signature

$c\tau \gtrsim 1\,\mathrm{m} \cdots$ "heavy long-lived charged particle"

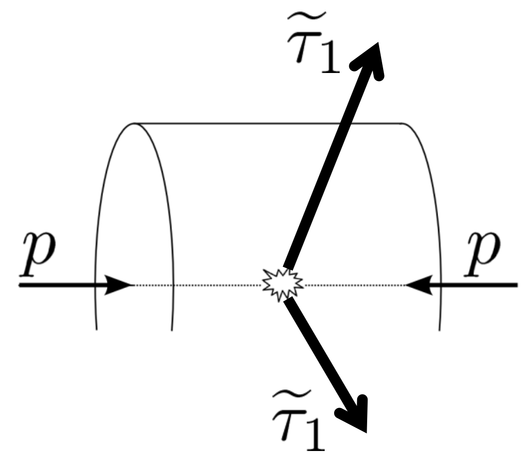
SUSY with $\widetilde{G}$-LSP, $\widetilde{\tau}_1$-NLSP

$c\tau \lesssim 1\,\mathrm{mm}$



multi τ-lepton

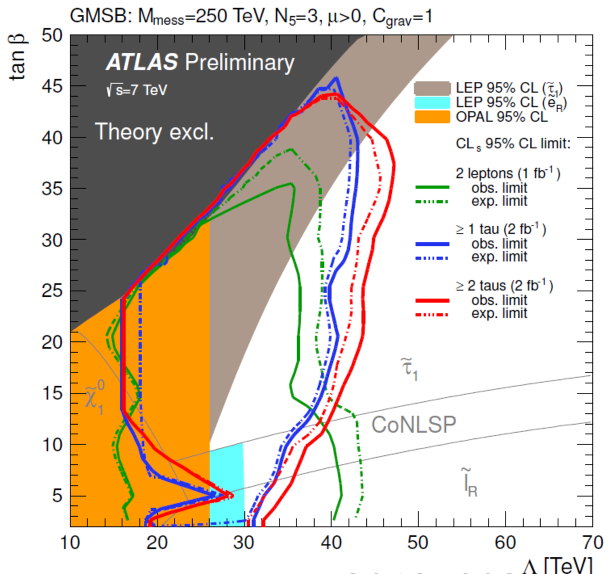
$c\tau \gtrsim 1\,\mathrm{m}$



"heavy long-lived charged particle"

SUSY with $\widetilde{G}$-LSP, $\widetilde{\tau}_1$-NLSP

$c\tau \lesssim 1\,\mathrm{mm}$

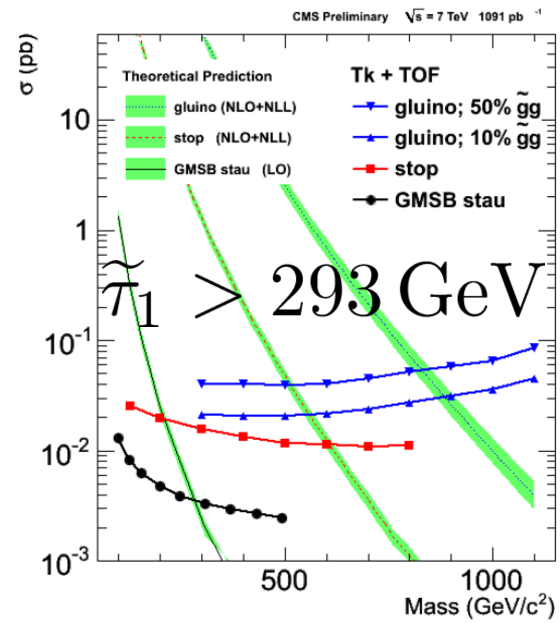


ATLAS-CONF-2012-002
ATLAS-CONF-2012-005

multi τ-lepton

What will happen between these?

$c\tau \gtrsim 1\,\mathrm{m}$

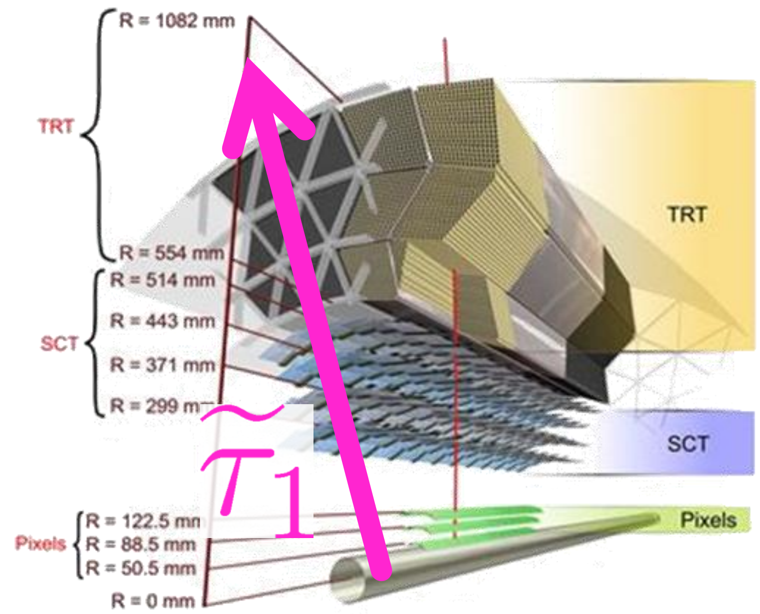


$\widetilde{\tau}_1 > 293\,\mathrm{GeV}$

CMS-PAS-EXO-11-022
(1.1fb^{-1}, assuming a GMSB model)

"heavy long-lived charged particle"

Stau = Charged
$\Rightarrow$ a track in detectors



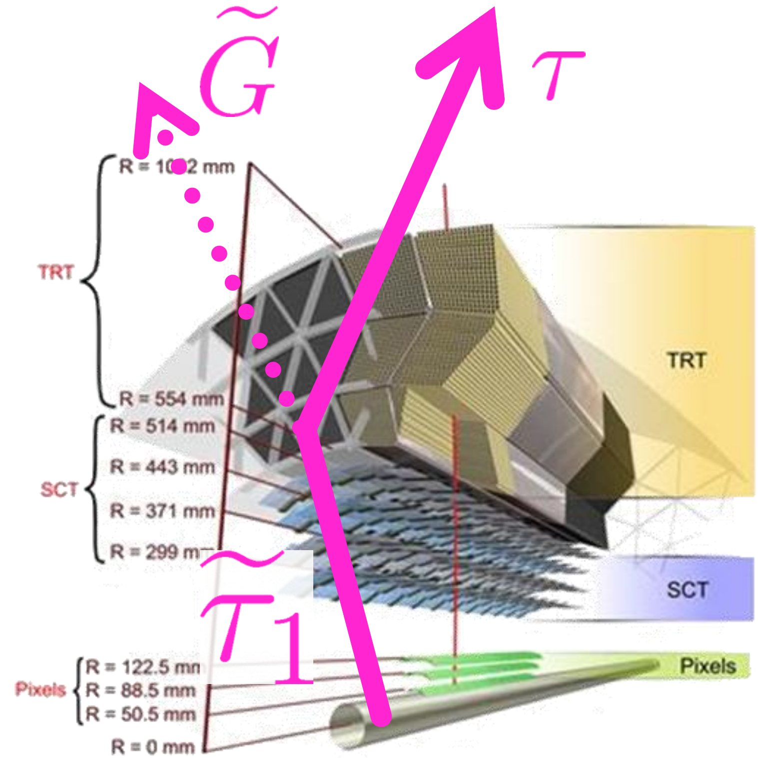
ATLAS detectors (in the LHC)

Stau = Charged
$\Longrightarrow$ a track in detectors

If $c\tau \sim \mathrm{O}(1\,\mathrm{cm})$,
"defay inside detectors"

$\Longrightarrow$ track bends!

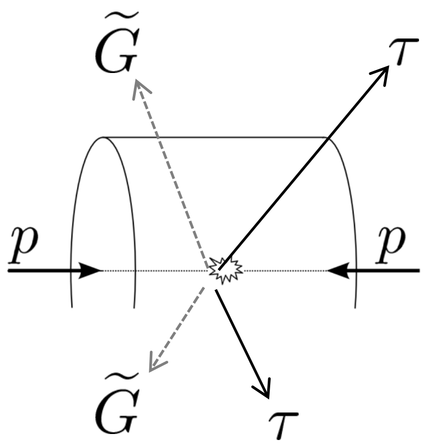
"Kink track"



ATLAS detectors (in the LHC)

SUSY with $\widetilde{G}$-LSP, $\widetilde{\tau}_1$-NLSP

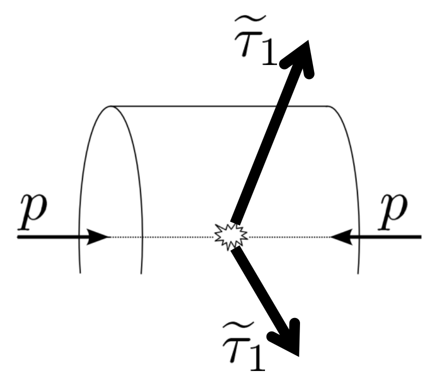
$c\tau \lesssim 1\,\mathrm{mm}$



multi τ-lepton

What will happen between these?

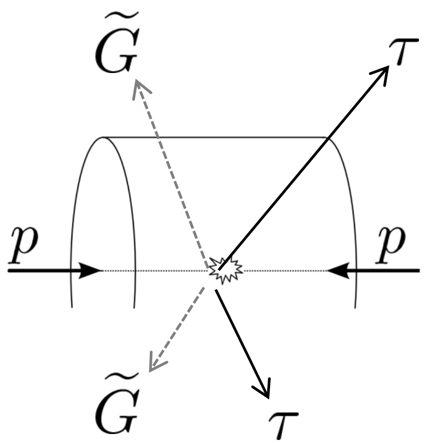
$c\tau \gtrsim 1\,\mathrm{m}$



"heavy long-lived charged particle"

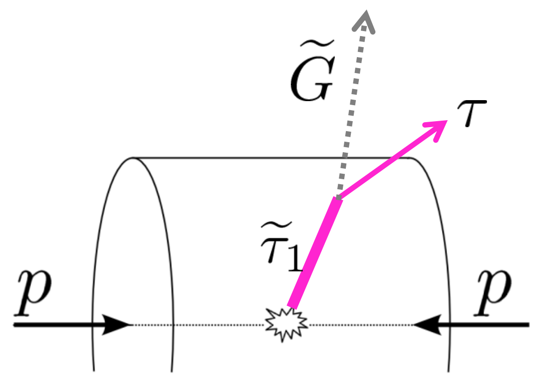
SUSY with $\widetilde{G}$-LSP, $\widetilde{\tau}_1$-NLSP

$c\tau \lesssim 1\,\mathrm{mm}$



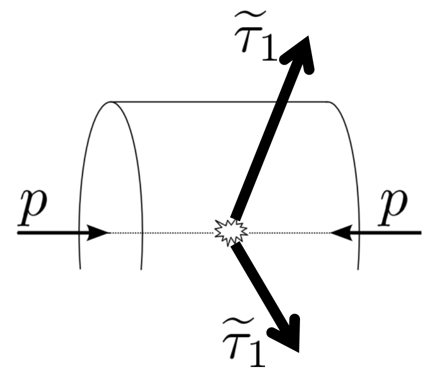
multi τ-lepton

$c\tau \sim 1 - 100\,\mathrm{cm}$



stau
kink track

$c\tau \gtrsim 1\,\mathrm{m}$

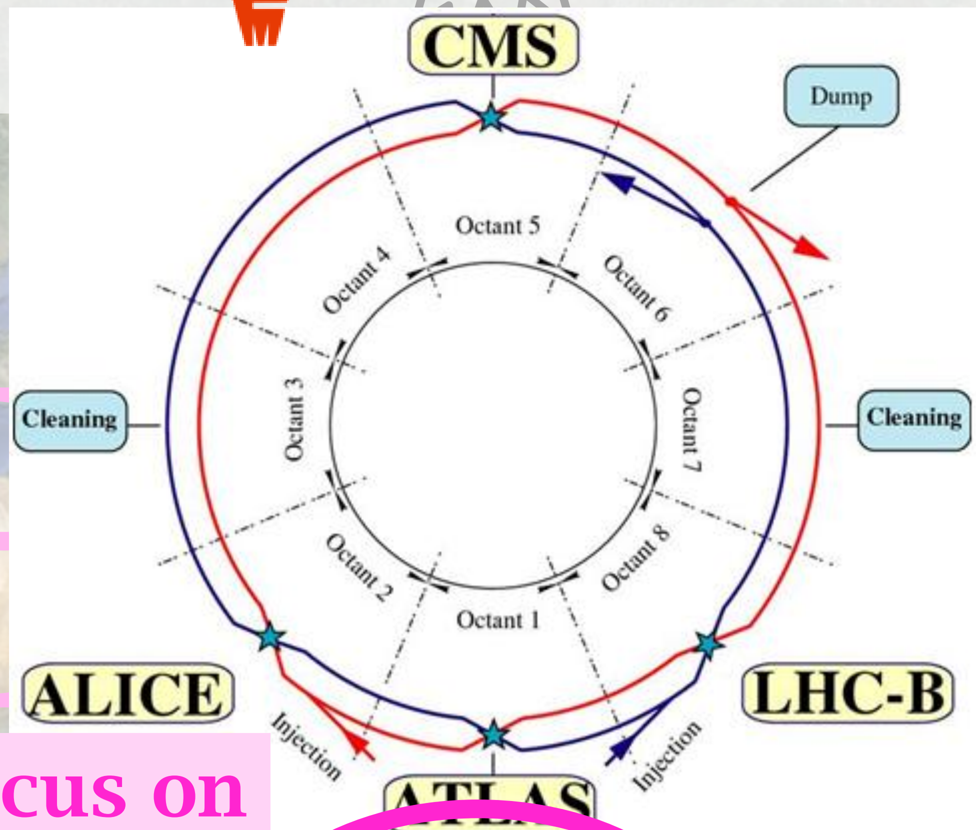


"heavy long-lived
charged particle"

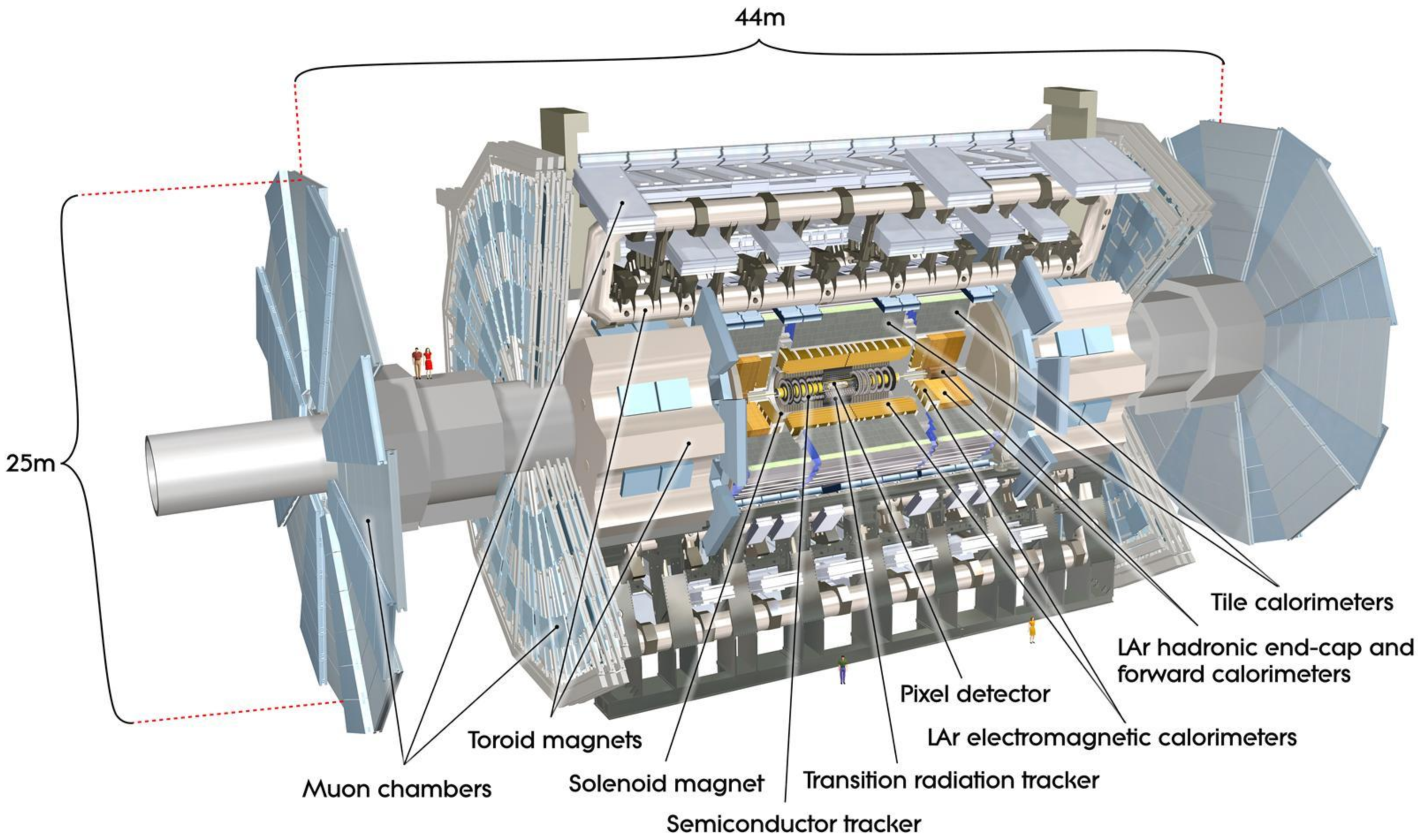
2. How can we detect “stau-kink”?

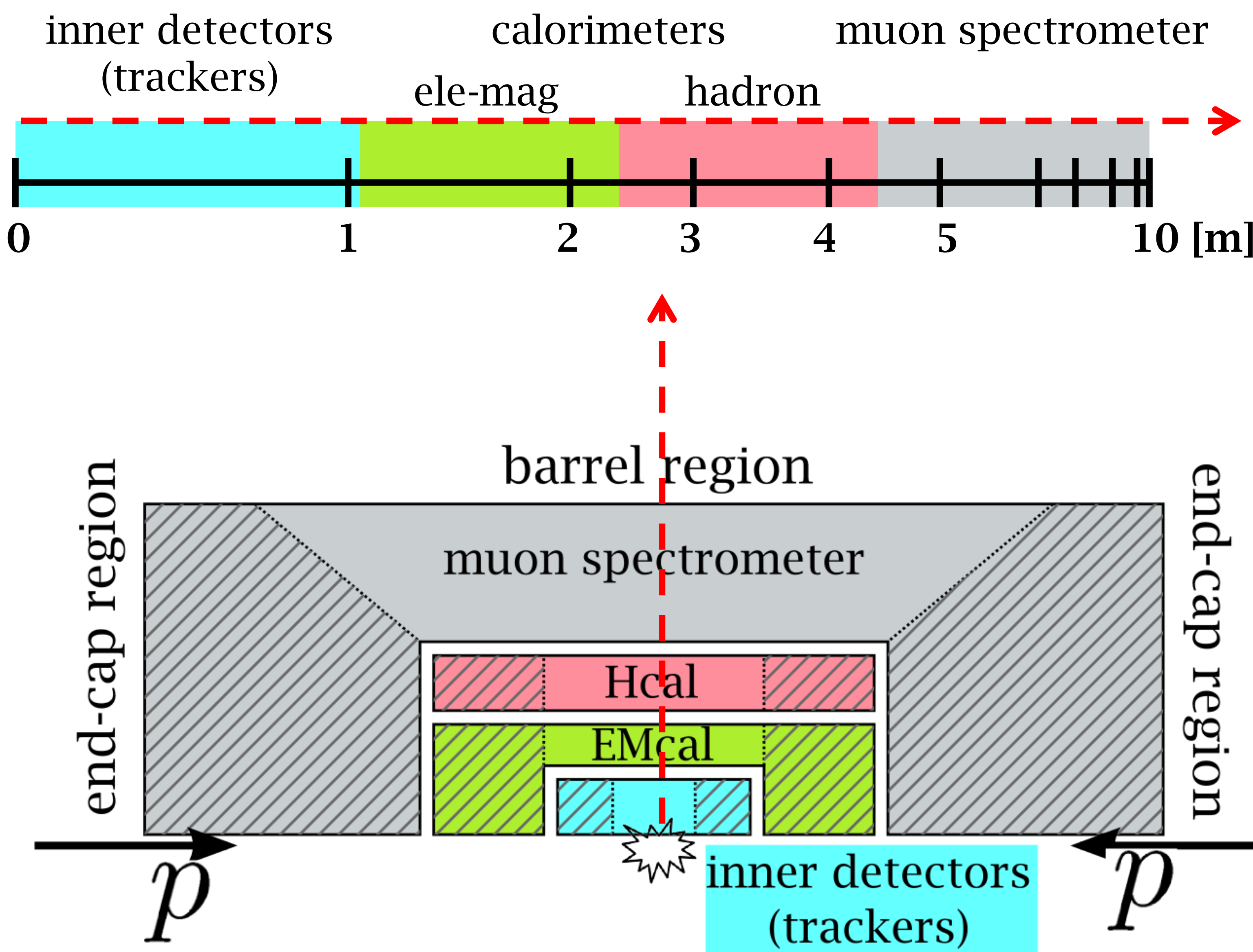

$p \longrightarrow \quad \longleftarrow p$
LHC
つくば

$p \longrightarrow \quad \longleftarrow p$



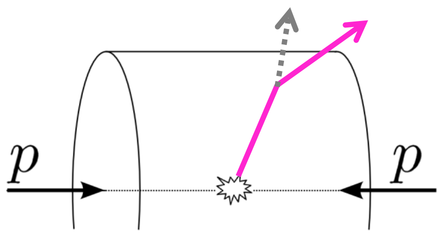
We focus on


44m
25m
Tile calorimeters
LAr hadronic end-cap and
forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker

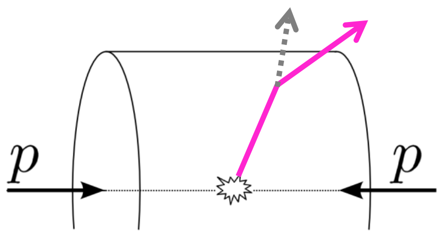


[sectional (cut-away) view]

Kink track = stau track + daughter track

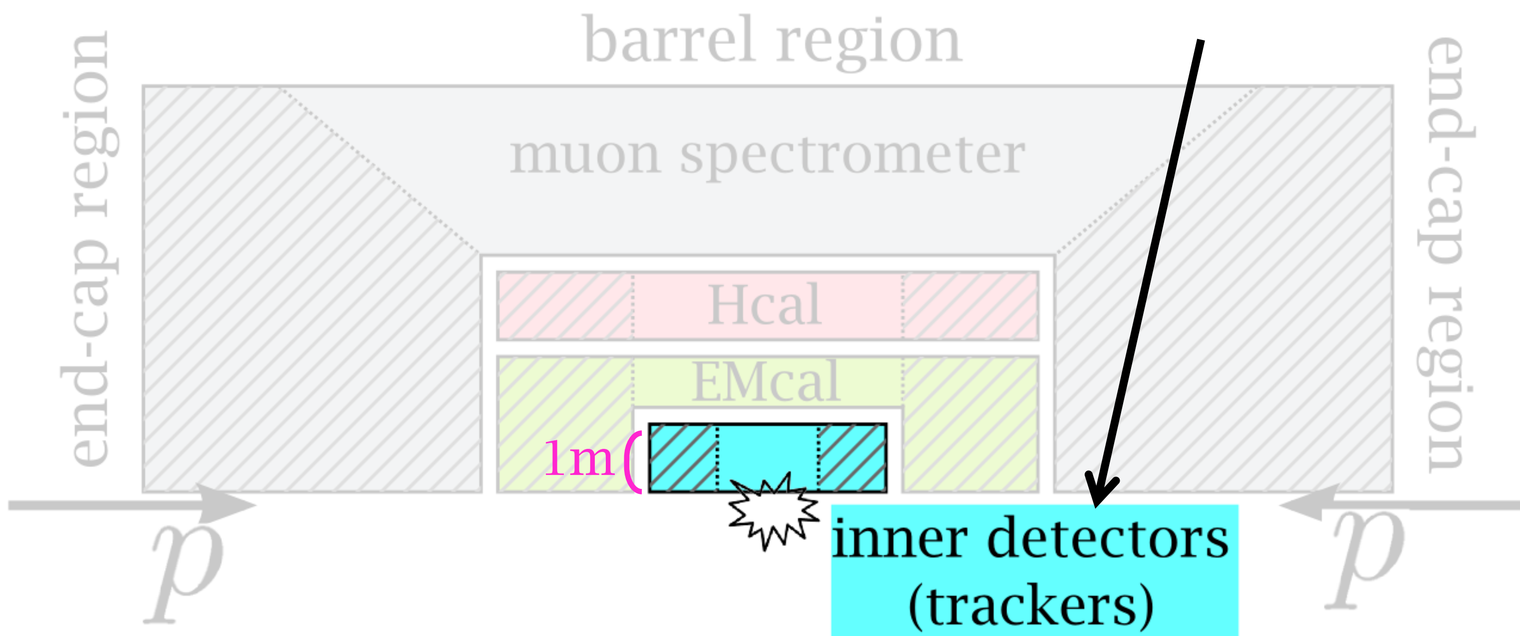


Kink track id. = id. of **stau** track
by a tracker
+
id. of **daughter** track
by a tracker



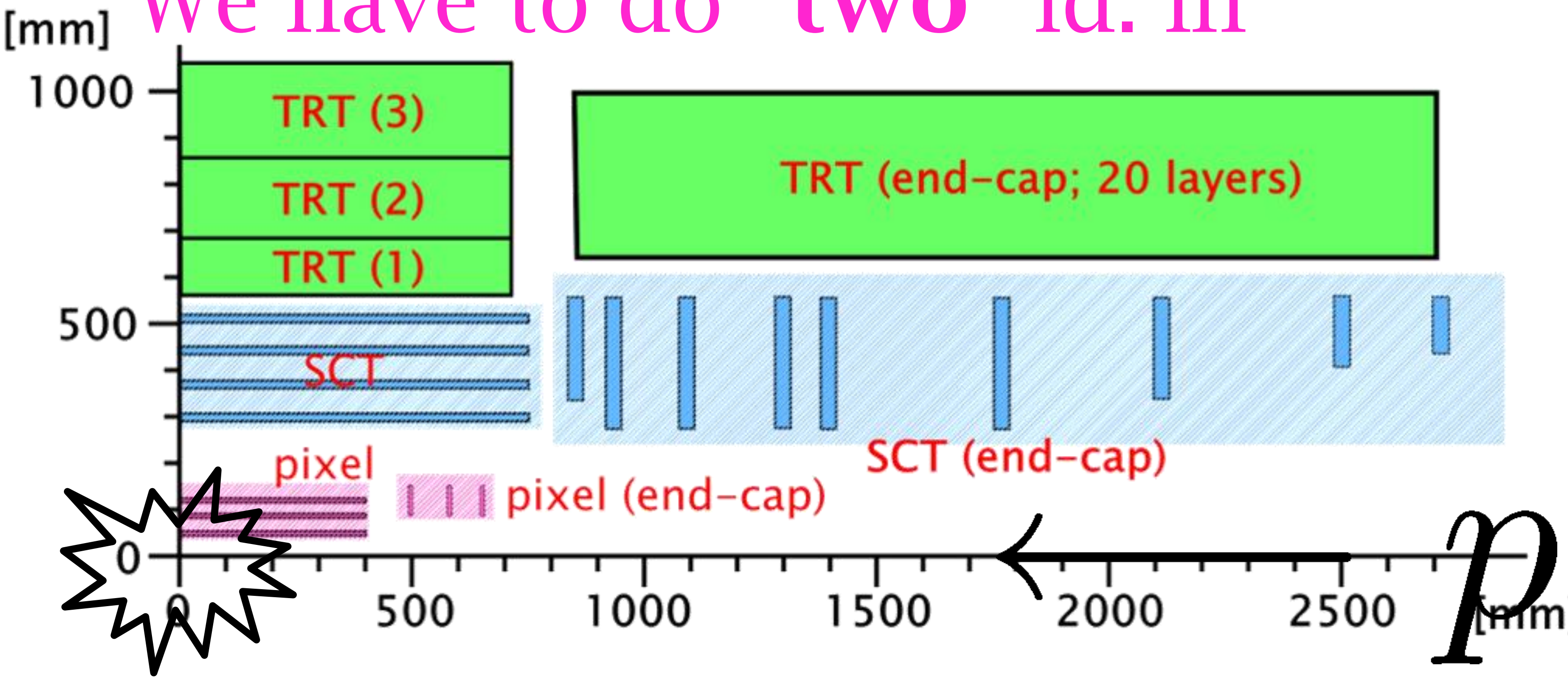
Kink track id. = id. of **stau** track by a tracker + id. of **daughter** track by a tracker

We have to do "**two**" id. in



Kink track id. $=$ id. of **stau** track (by a tracker) $+$ id. of **daughter** track (by a tracker)

We have to do “**two**” id. in



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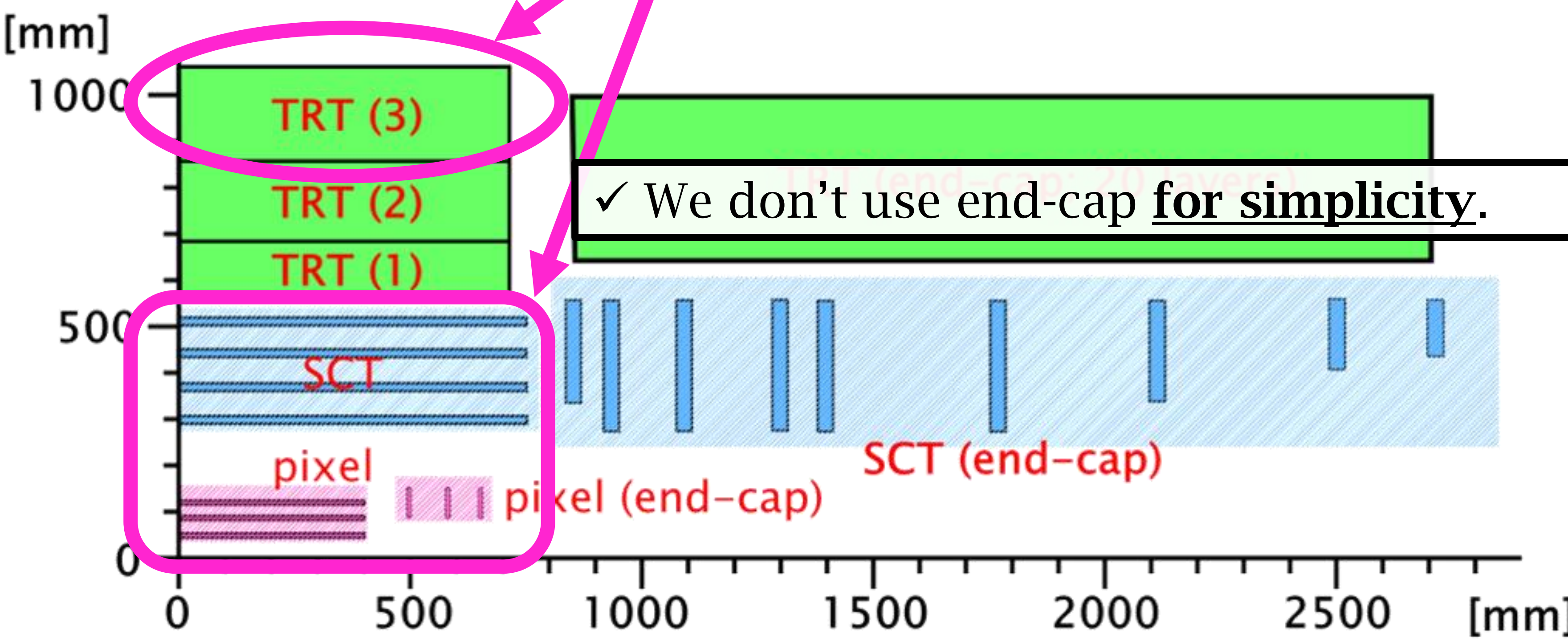
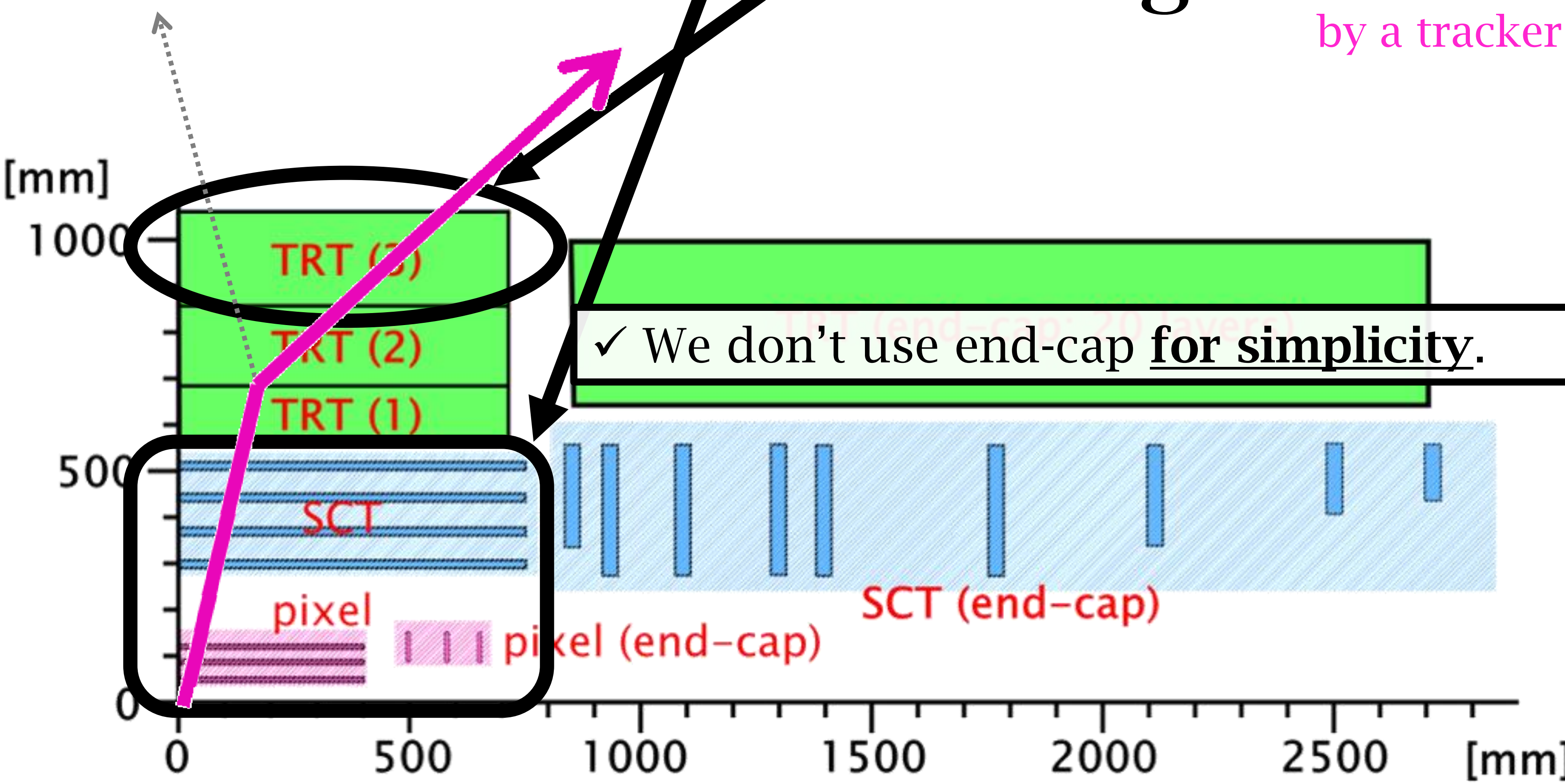


✓ We don’t use end-cap **for simplicity**.

Kink track id. = id. of **stau** track (by a tracker) + id. of **daughter** track (by a tracker)



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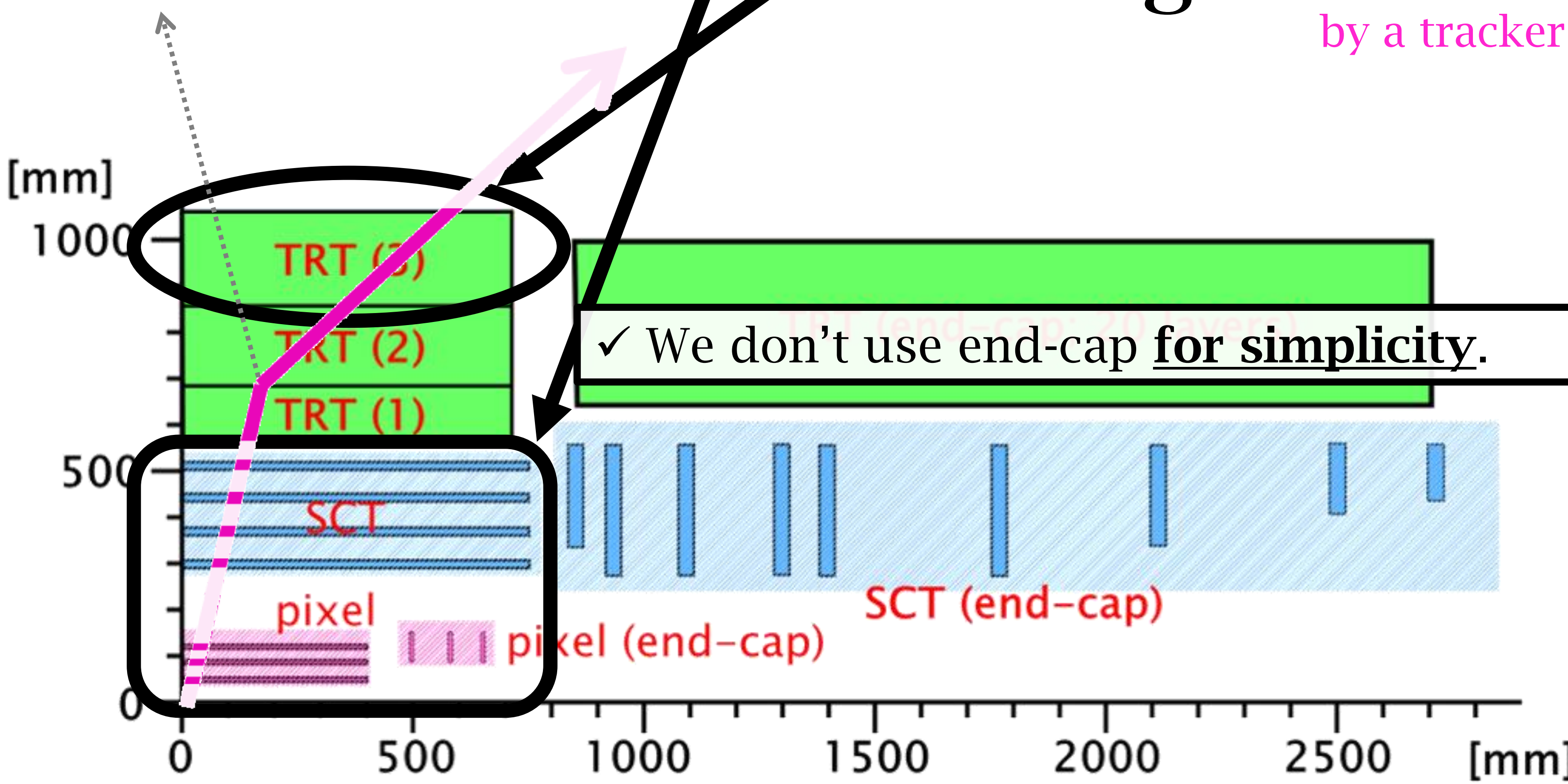
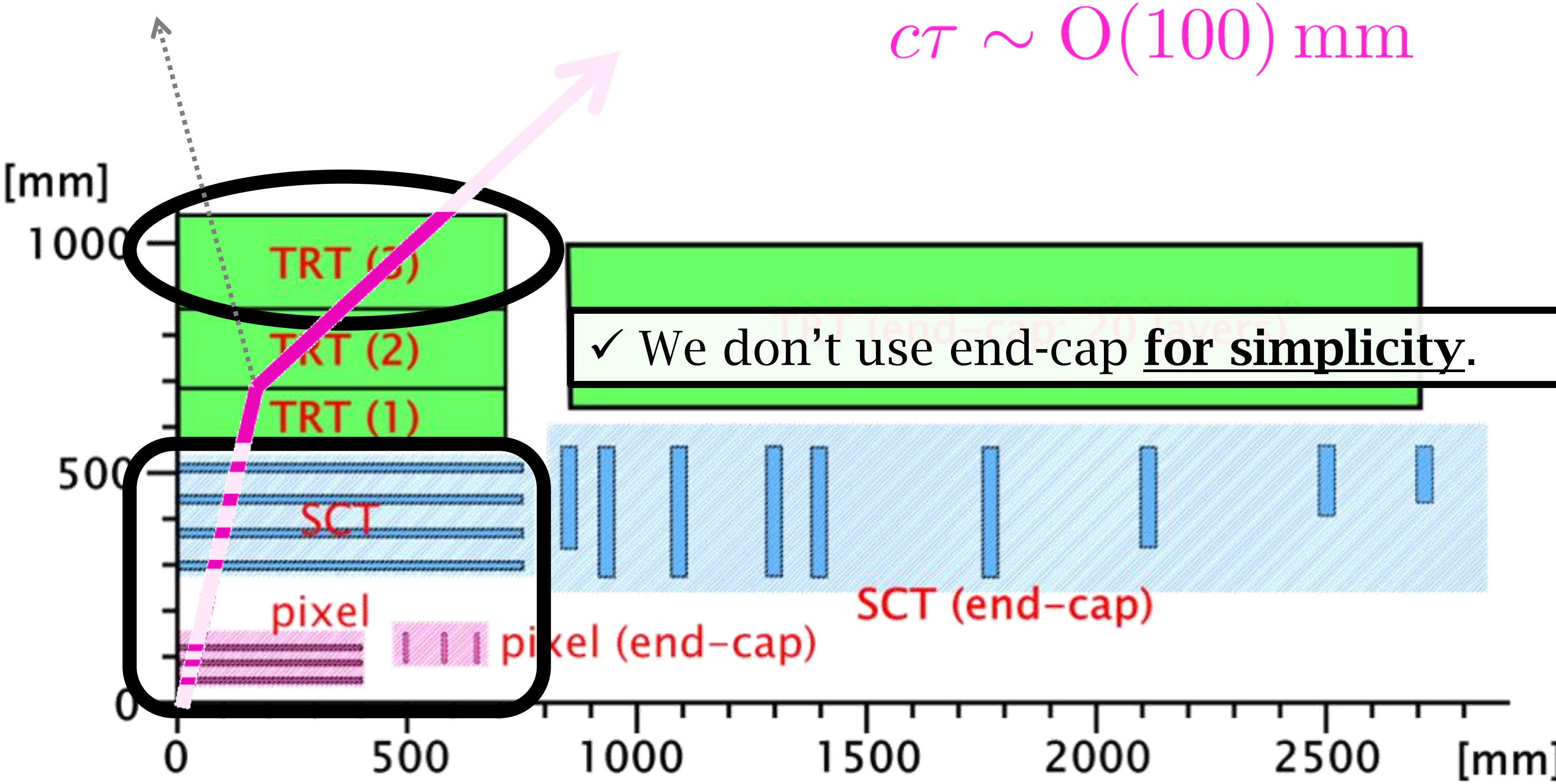


✓ We don't use end-cap **<u>for simplicity</u>**.

Kinks at **TRT 1st or 2nd module** can be observed.

$c\tau \sim \mathrm{O}(100)\ \mathrm{mm}$



✓ We don't use end-cap **for simplicity**.

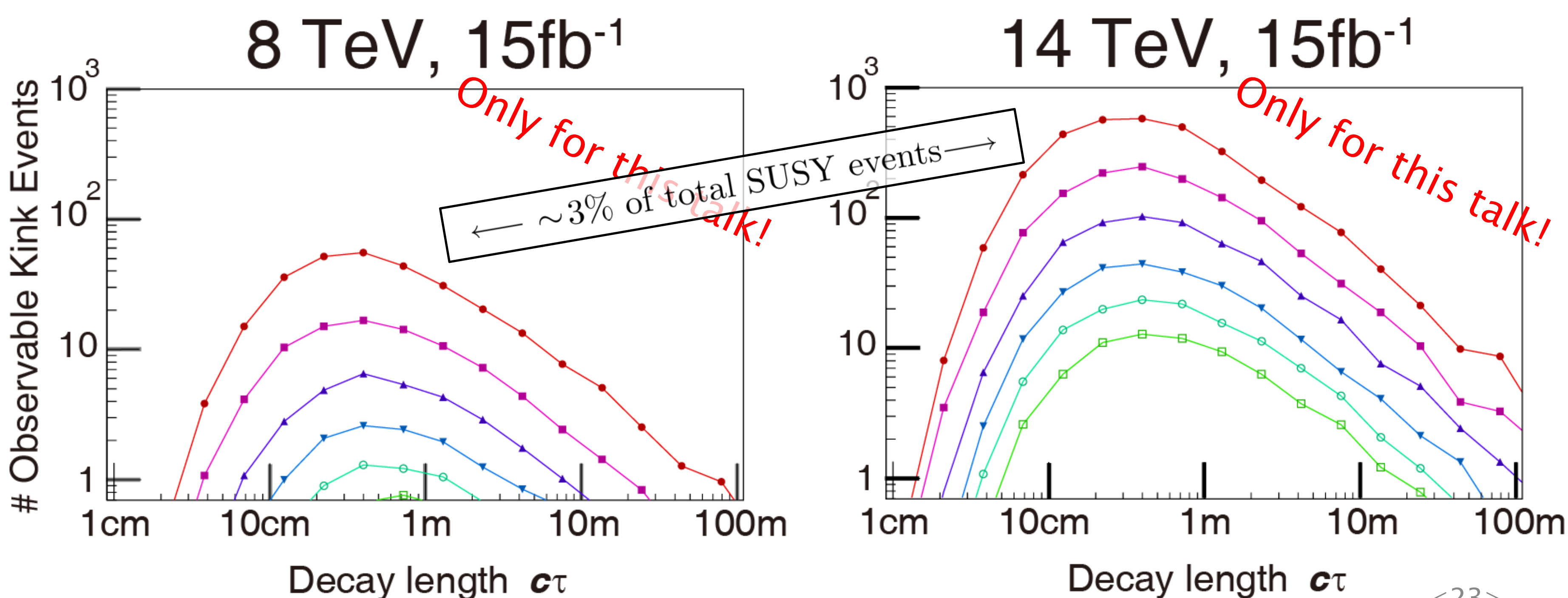
N_{mess}	M_{mess}	$\tan\beta$	μ	Λ, c_{grav}
3	250 TeV	30	+	varied

Result (GMSB)

	Λ	m_{stau}	$m_{colored}$
●	50 TeV	134 GeV	~1.1 TeV
■	60	166	~1.3
▲	70	198	~1.5
▼	80	229	~1.7
○	90	290	~1.9
□	100	320	~2.1

We can observe kinks.

- Sweet $c\tau$ (of stau) $\sim \mathrm{O}(0.1-10)\,\mathrm{m}$
  $(m_{\tilde{G}} \sim 0.1-10\,\mathrm{keV})$
- $\tilde{\tau}_1 \lesssim$ 300 GeV can be observed.



3. Model Discrimination

"Stau kink" is expected in...

- $\widetilde{G}$-LSP, $\widetilde{\tau}_1$-NLSP model ::: $\widetilde{\tau}_1 \to \tau$ kink
-

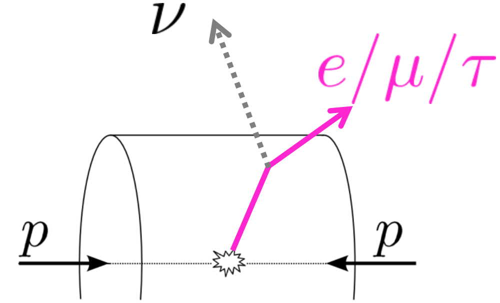
“Stau kink” is

$$W=\frac{1}{2}\lambda_{ijk}L_iL_j\bar{E}_k+\lambda'_{ijk}L_iQ_j\bar{D}_k+\frac{1}{2}\lambda''_{ijk}\bar{U}_i\bar{D}_j\bar{D}_k$$

- $\widetilde{G}$-LSP, $\widetilde{\tau}_1$-NLSP model ::: $\widetilde{\tau}_1 \to \tau$ kink

- $\widetilde{\tau}_1$-LSP with tiny R-parity viol.

$$\lambda_{i3k},\lambda_{ij3} \Longrightarrow \widetilde{\tau}_1 \to e\nu,\ \mu\nu,\ \tau\nu$$



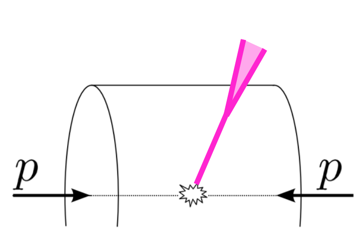
✓ **Applicable to RpV case :::** $\lambda \sim \mathrm{O}(10^{-8}-10^{-9})$

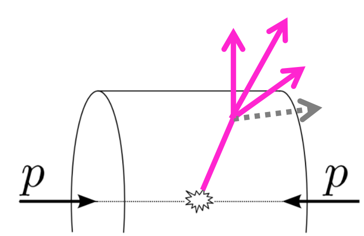
(complicated for the other couplings...)

$\lambda_{121},\lambda_{122} \Longrightarrow$ 4-body decay

$\lambda' \Longrightarrow$ hadron or 4-body

$\lambda'' \Longrightarrow$ 4-body decay





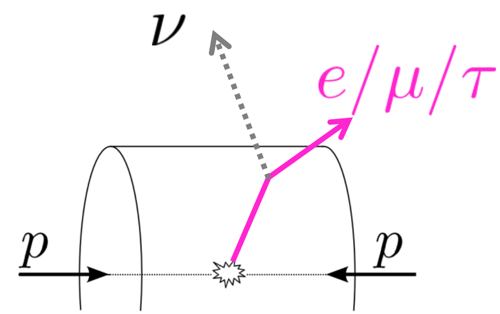
“Stau kink” is

$$W = \frac{1}{2}\lambda_{ijk}L_iL_j\bar{E}_k + \lambda'_{ijk}L_iQ_j\bar{D}_k + \frac{1}{2}\lambda''_{ijk}\bar{U}_i\bar{D}_j\bar{D}_k$$

- $\widetilde{G}$-LSP, $\widetilde{\tau}_1$-NLSP model ::: $\widetilde{\tau}_1 \rightarrow \tau$ kink

- $\widetilde{\tau}_1$-LSP with tiny R-parity viol.

$$\lambda_{i3k}, \lambda_{ij3} \Longrightarrow \widetilde{\tau}_1 \rightarrow e\nu, \mu\nu, \tau\nu$$

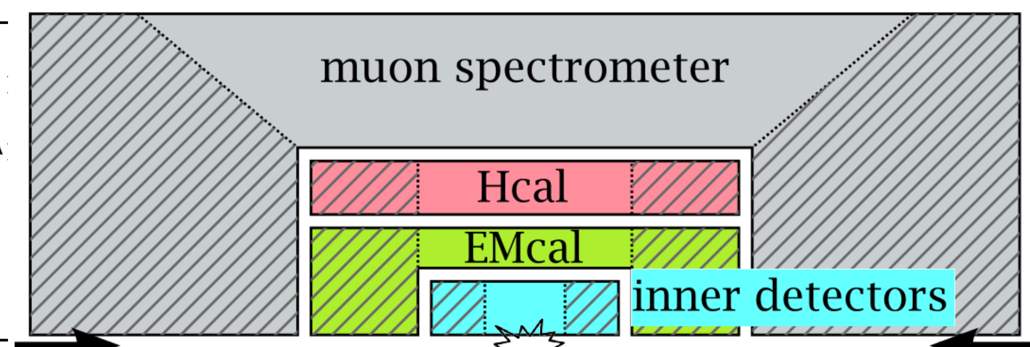


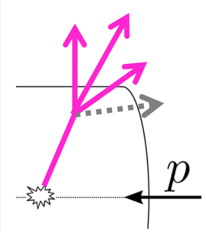
✓ **Applicable to RpV case :::** $\lambda \sim \mathrm{O}(10^{-8} - 10^{-9})$

✓ **We can distinguish these two models!**

(complicated

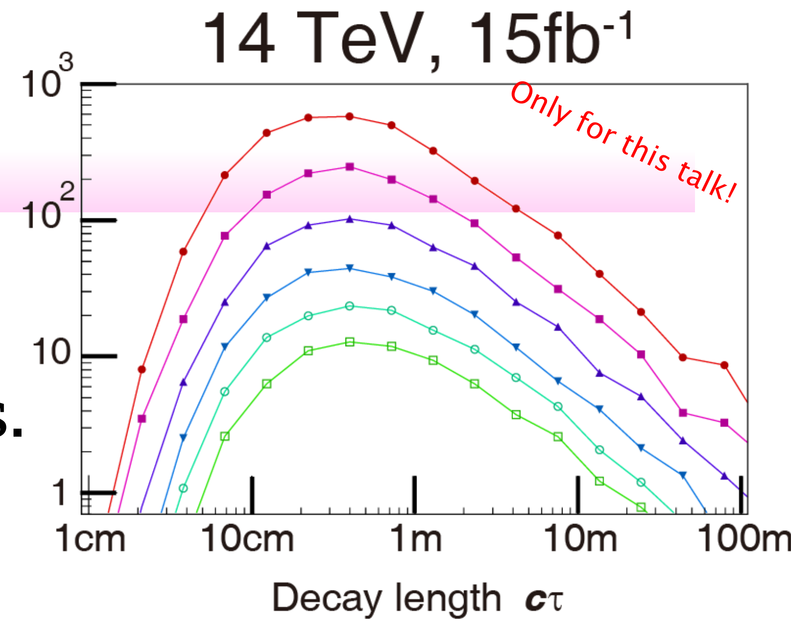
λ_{121}, λ





4. Conclusion

Conclusion



- Stau (slepton) in-flight-decay

  $\Longrightarrow$ observable as kink events.

  - $c\tau \sim \mathrm{O}(0.1 - 100)\mathrm{m}$
  - $\tilde{\tau}_1 \lesssim 300\,\mathrm{GeV}$ (for $14\,\mathrm{TeV}, 15\,\mathrm{fb}^{-1}$)

■Gravitino-LSP model with $m_{\tilde{G}} \sim \mathbf{0.1 - 10}\,\mathrm{keV}$

■R-parity violation case with $\lambda \sim \mathrm{O}(\mathbf{10^{-8} - 10^{-9}})$

can be **discovered** by stau kink search,

and underlying models can be discriminated.

Monte Carlo SYSTEM

Monte Carlo Simulation

mass spectrum:	SUSY-HIT
event generation:	Pythia6
fast detector sim.:	PGS4

Event selection

- triggering issue
  - 1 jet with $P_{\mathrm{T}} > 120\,\mathrm{GeV}$.
  - $\not{E}_{\mathrm{T}} > 100\,\mathrm{GeV}$.
- $\widetilde{\tau}_1$ must be
  - $|\eta| < 0.63$.
  - $P_{\mathrm{T}} > 100\,\mathrm{GeV}$.
  - decay in TRT 1st or 2nd module.
- The kink must be
  - azimuthal opening angle $0.1 < \Delta\phi < \pi/2$.
- daughter particle must be
  - not into end-cap; stay in barrel region.
  - $P_{\mathrm{T}} > 10\,\mathrm{GeV}$ (efficiency 0.6) or $> 20\,\mathrm{GeV}$ (0.7).

Monte Carlo Simulation

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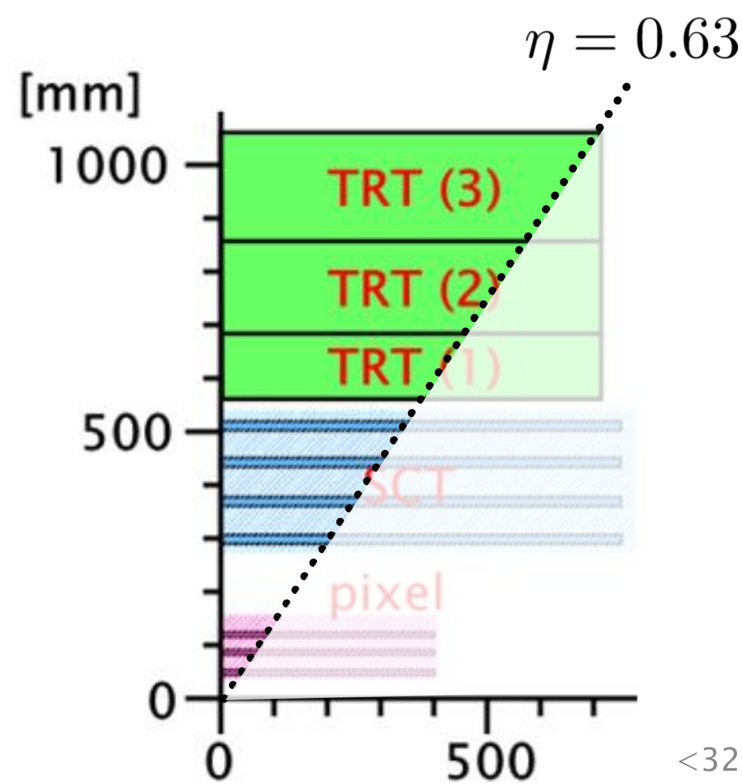
Trigger: 1jet(70) + MET(40) is "stable" (90% eff.) above this point.



Monte Carlo Simulation

TRT = r-ϕ information

(know nothing about on z-direction.)

⇩

"azimuthal opening angle" can be measured.

- ◦ $|\eta| < 0.63$.
- ◦ $P_{\mathrm{T}} > 100\,\mathrm{GeV}$.
- ◦ decay in TRT 1st or 2nd module.
- The kink must be
  - ◦ azimuthal opening angle $0.1 < \Delta\phi < \pi/2$.
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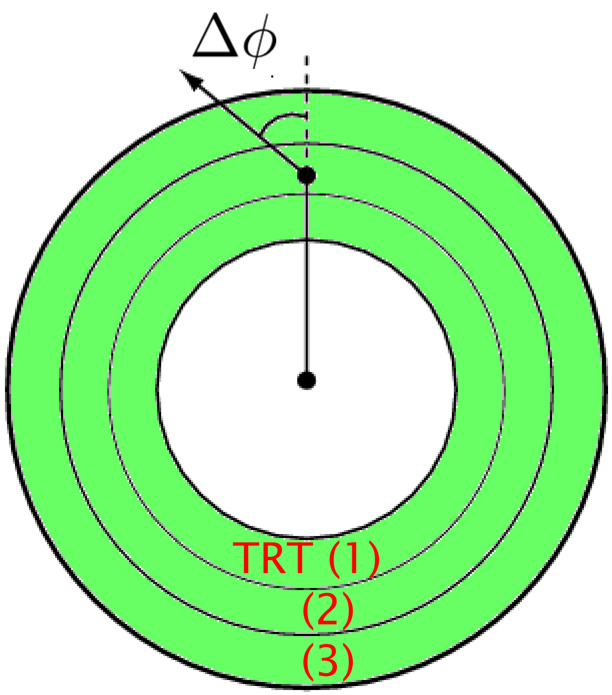

r-ϕ projected plane view

Monte Carlo Simulation

Event selection

- triggering issue
  - 1 jet with $P_{\mathrm{T}} > 120\,\mathrm{GeV}$.
  - $\not{E}_{\mathrm{T}} > 100\,\mathrm{GeV}$.
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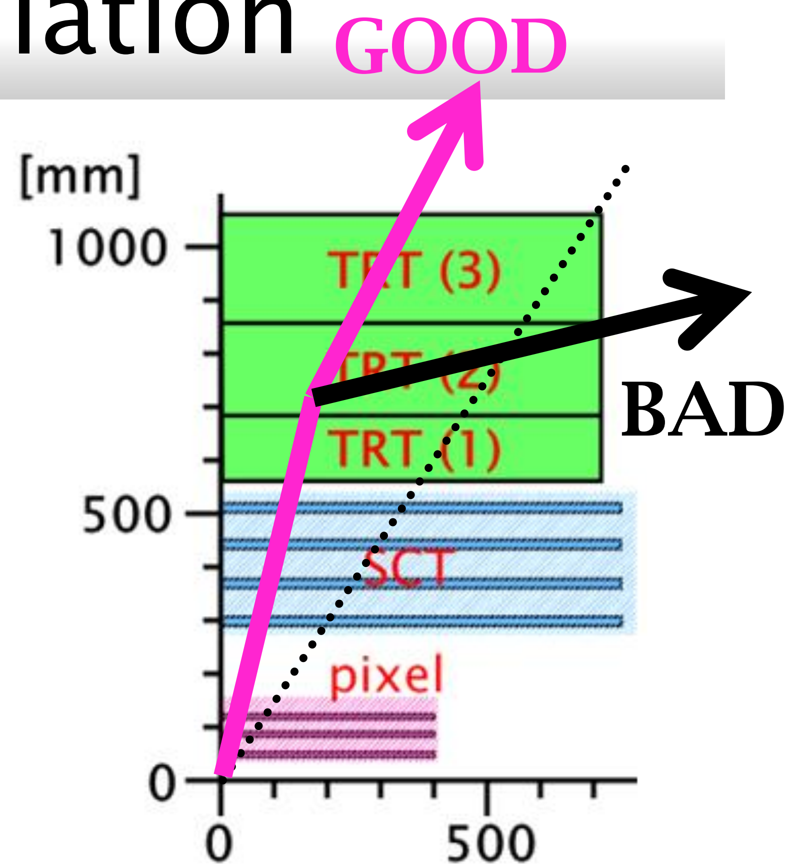
in order to the daughter reconstruction.



Daughter must go through TRT (3).

Monte Carlo Simulation

Event selection 100%

- triggering issue
  - 1 jet with $P_{\mathrm{T}} > 120\,\mathrm{GeV}$.
  - $\not{E}_{\mathrm{T}} > 100\,\mathrm{GeV}$.

$\sim 85\%$

- $\widetilde{\tau}_1$ must be
  - $|\eta| < 0.63$. $\sim 35\%$
  - $P_{\mathrm{T}} > 100\,\mathrm{GeV}$. $\sim 33\%$
  - decay in TRT 1st or 2nd module.

$\sim 4\%$

- The kink must be
  - azimuthal opening angle $0.1 < \Delta\phi < \pi/2$.

$\sim 3\%$

- daughter particle must be
  - not into end-cap; stay in barrel region.
  - $P_{\mathrm{T}} > 10\,\mathrm{GeV}$ (efficiency 0.6) or $> 20\,\mathrm{GeV}$ (0.7).

$\sim 2\%$