Faking The Diphoton Signal by Displaced Dark Photon Decays

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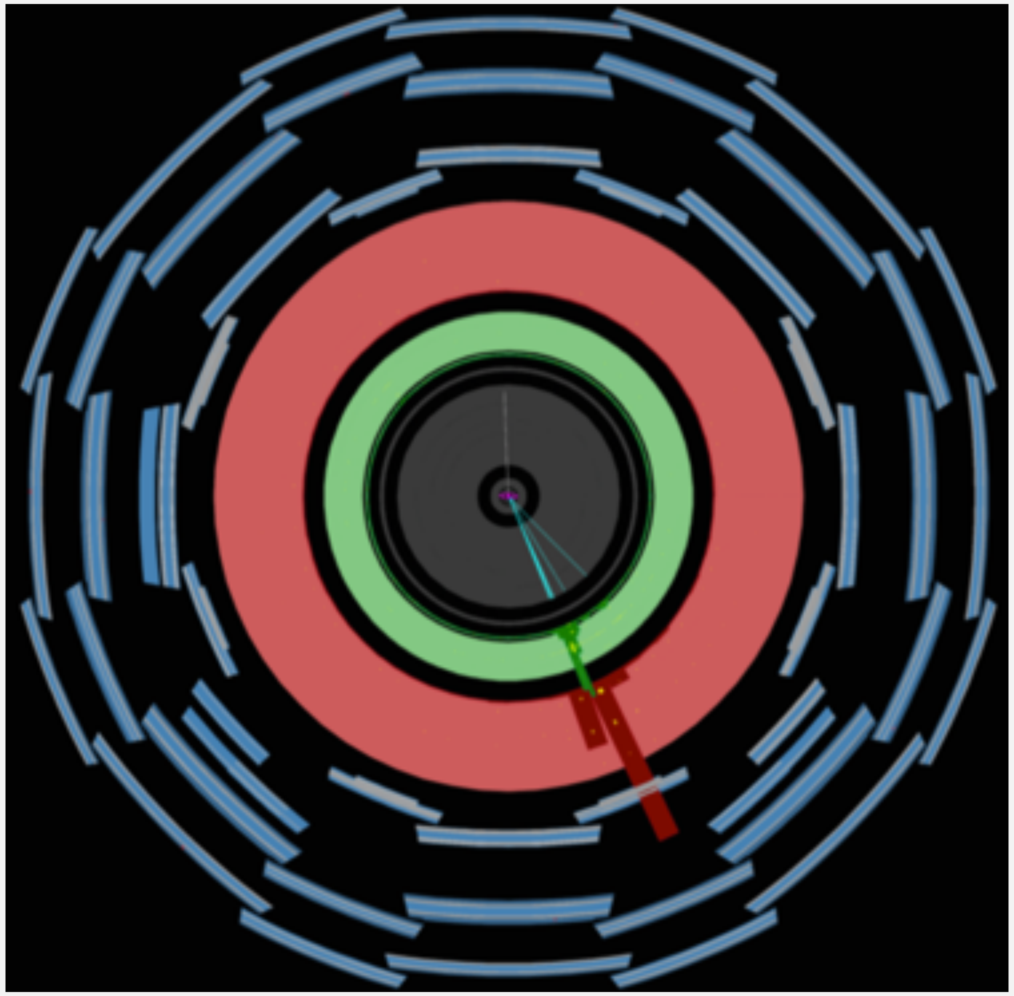
1603.00024 YT, Liantao Wang, Yue Zhao

Light Dark World, July 14 2016

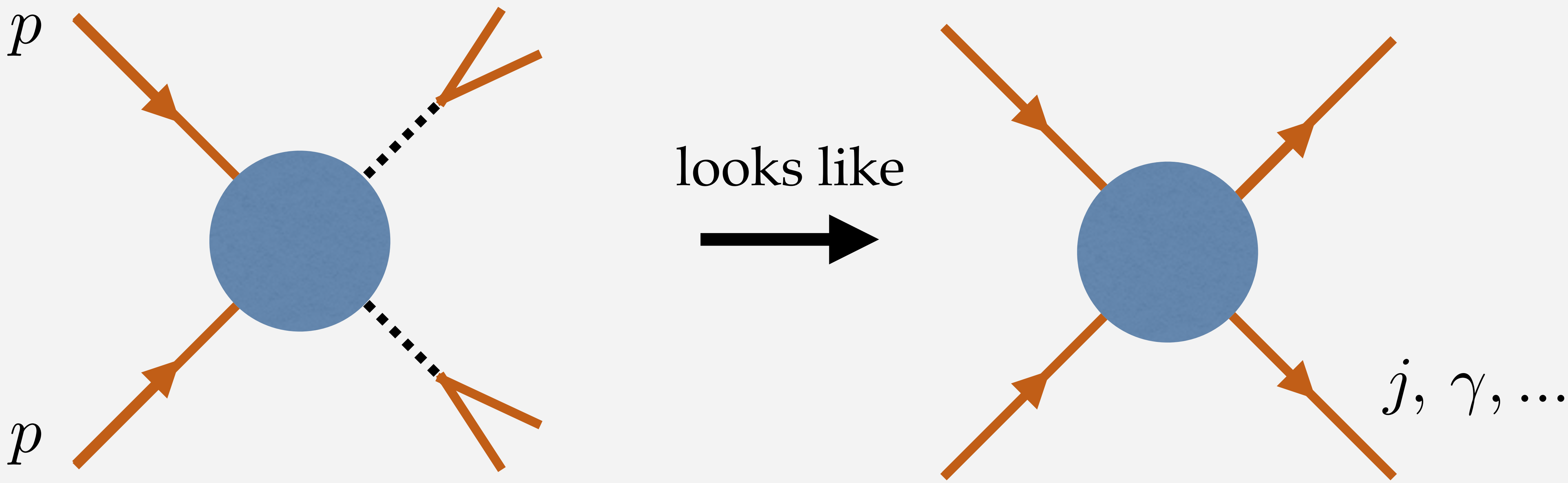
Collider Signals from a Dark Sector



Missing energy , displaced decays

hidden valley, twin hadrons,…

In this talk: BSM signals fake SM objects



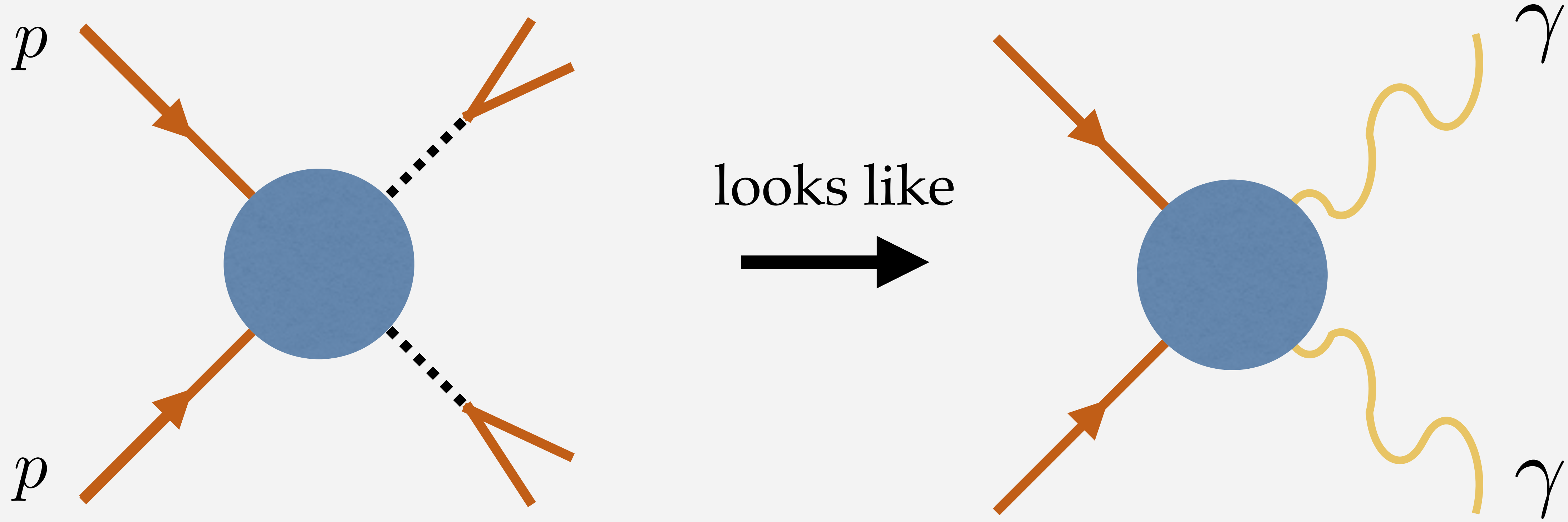
Why complicating things?

There are good motivations to think about the FAKE signals

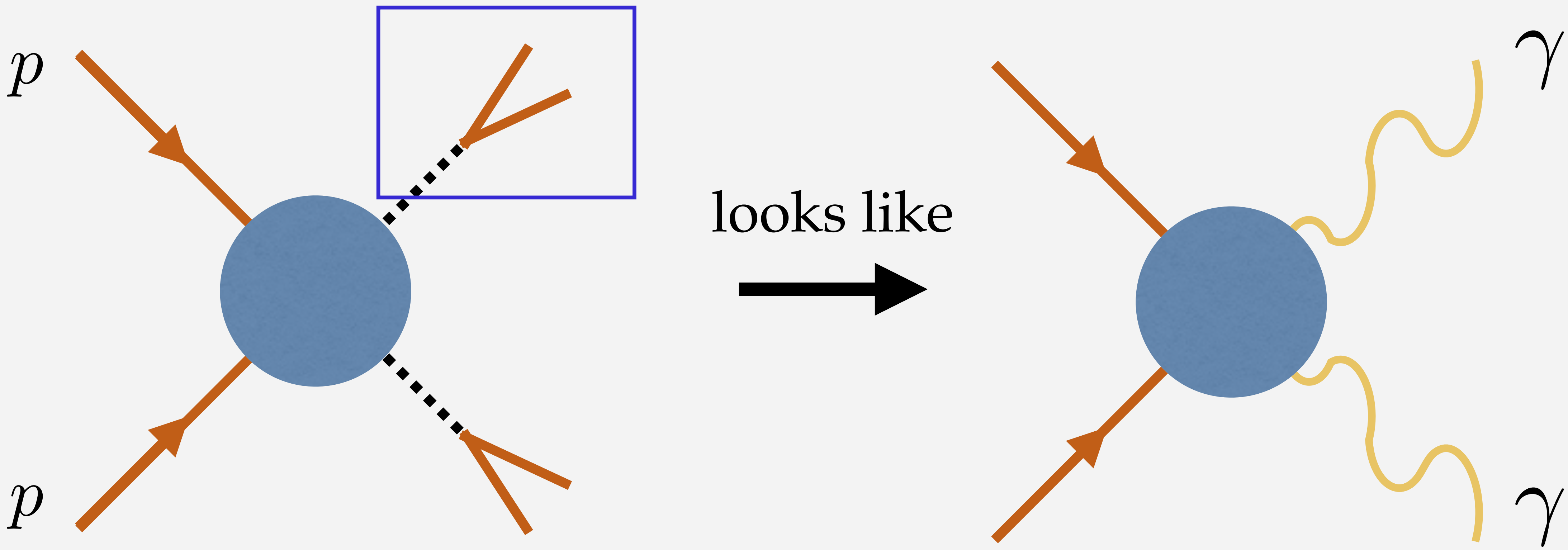
The inconsistency between one searching result to the others may come from the mis-identification of FAKE particles

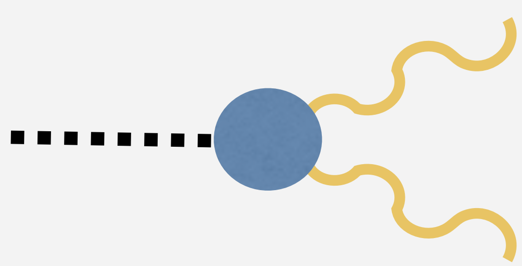
When studying exotic collider objects (like displaced decays), the detector may seem an exotic signal to be ``normal”

In this talk: BSM signals fake SM photon



In this talk: BSM signals fake SM photon

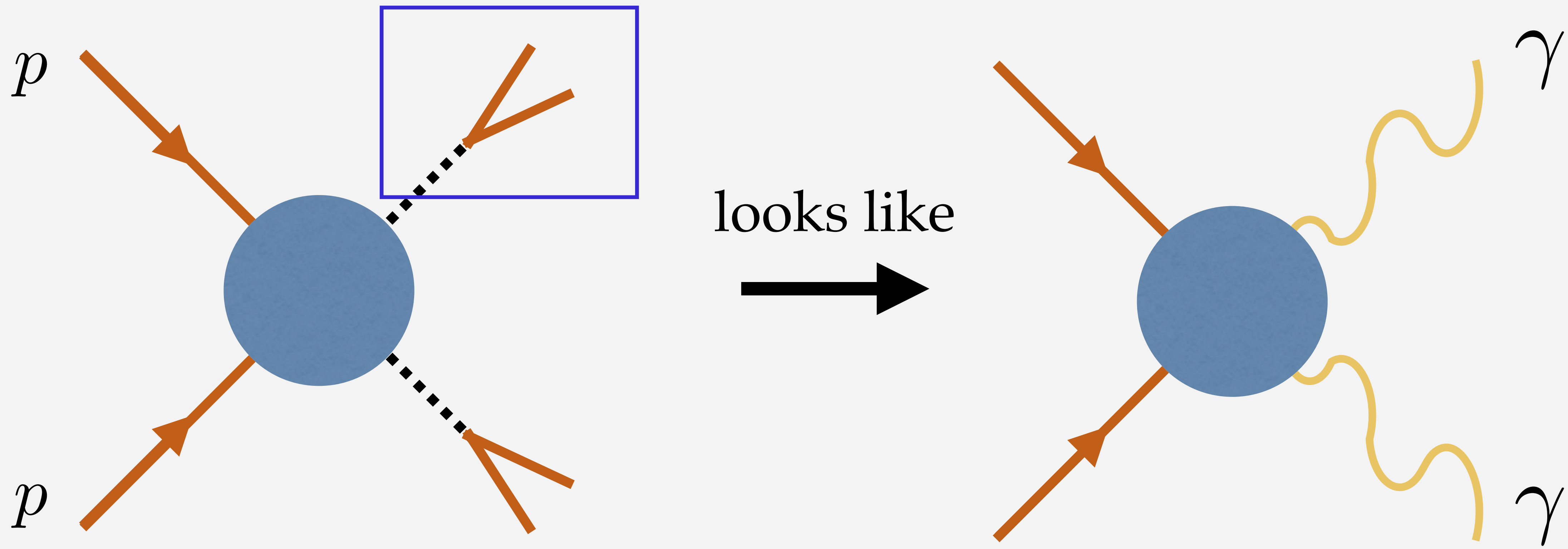


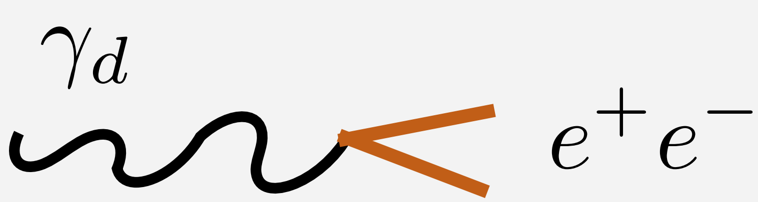


$$\frac{\alpha}{4\pi f}\phi F_{\mu\nu}\tilde{F}^{\mu\nu}$$

Require f ~< 10 GeV for the decay to be inside detector. This is challenging for an electrically charged mediator

In this talk: BSM signals fake SM photon





$$\frac{\epsilon}{4} F_{\mu\nu} F'^{\mu\nu}$$

fake both converted / unconverted photons, easier to realize

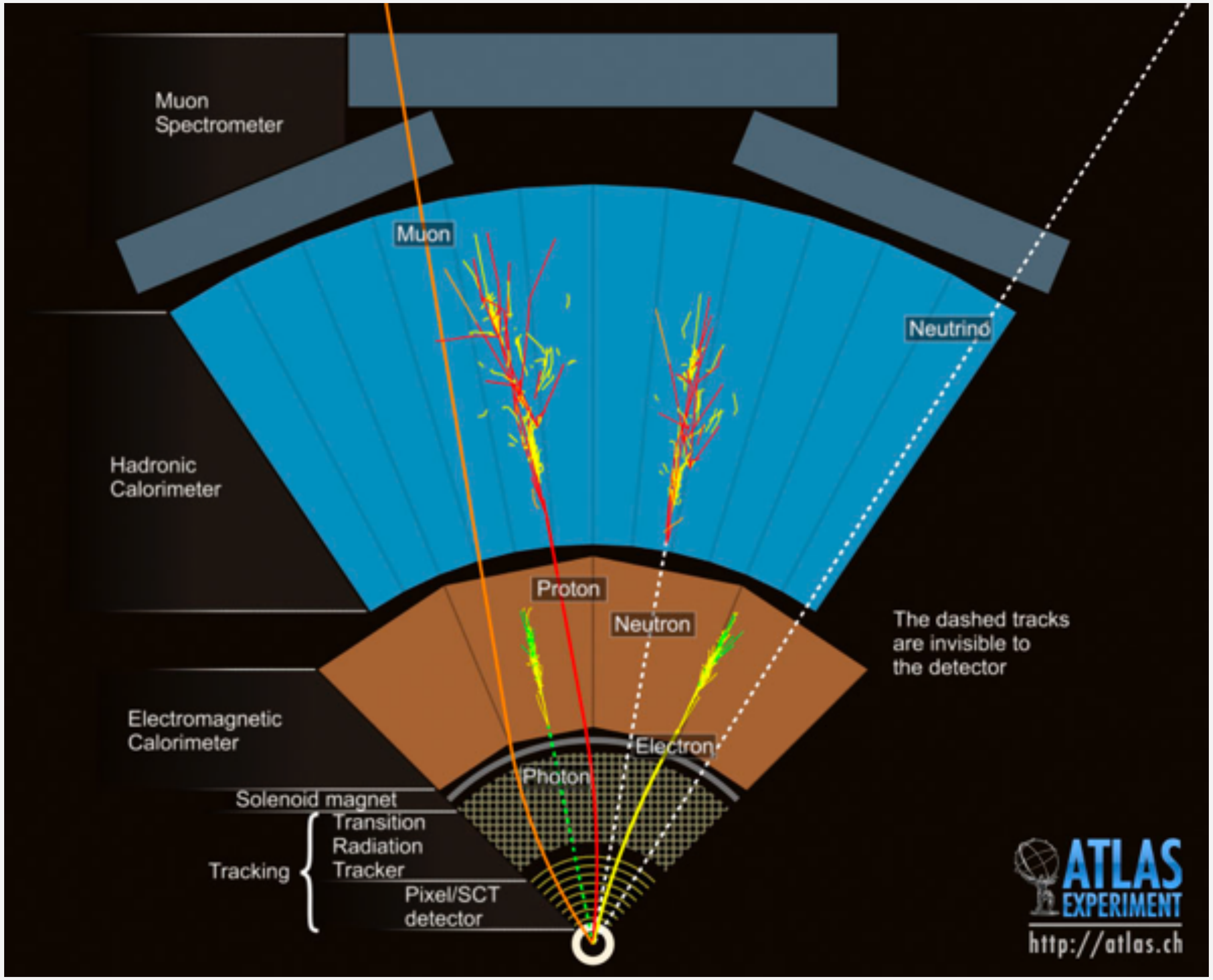
$$\epsilon \sim 10^{-4}, \;\; m_{\gamma'} = \mathcal{O}(100)\,\text{MeV}$$

$$c\tau_{\text{lab}} > 1\,\text{cm}$$

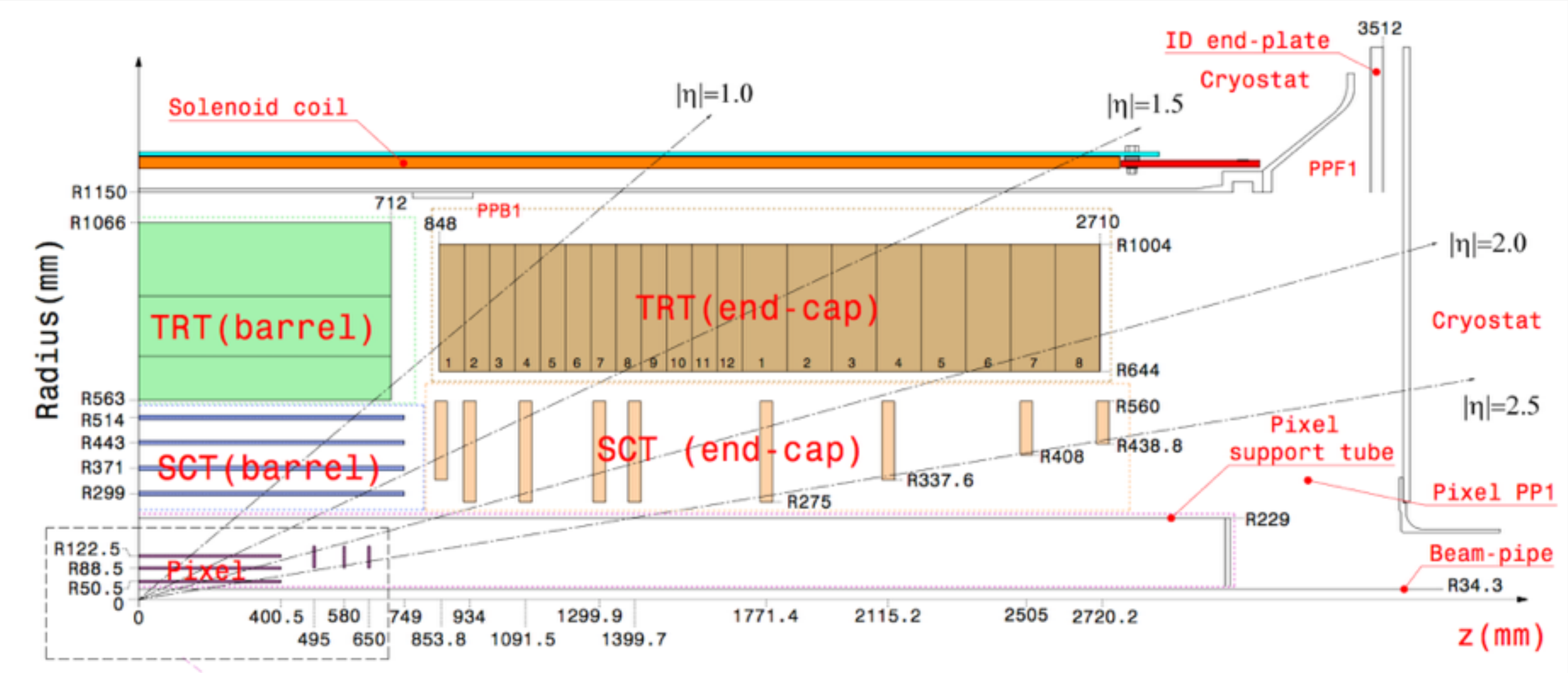
See also Agrawal et al. (15'), Dasgupta et al. (16')

Dark Photon Fakes A SM Photon

Tight photon identification at ATLAS



Photon-id at ATLAS: before ECAL



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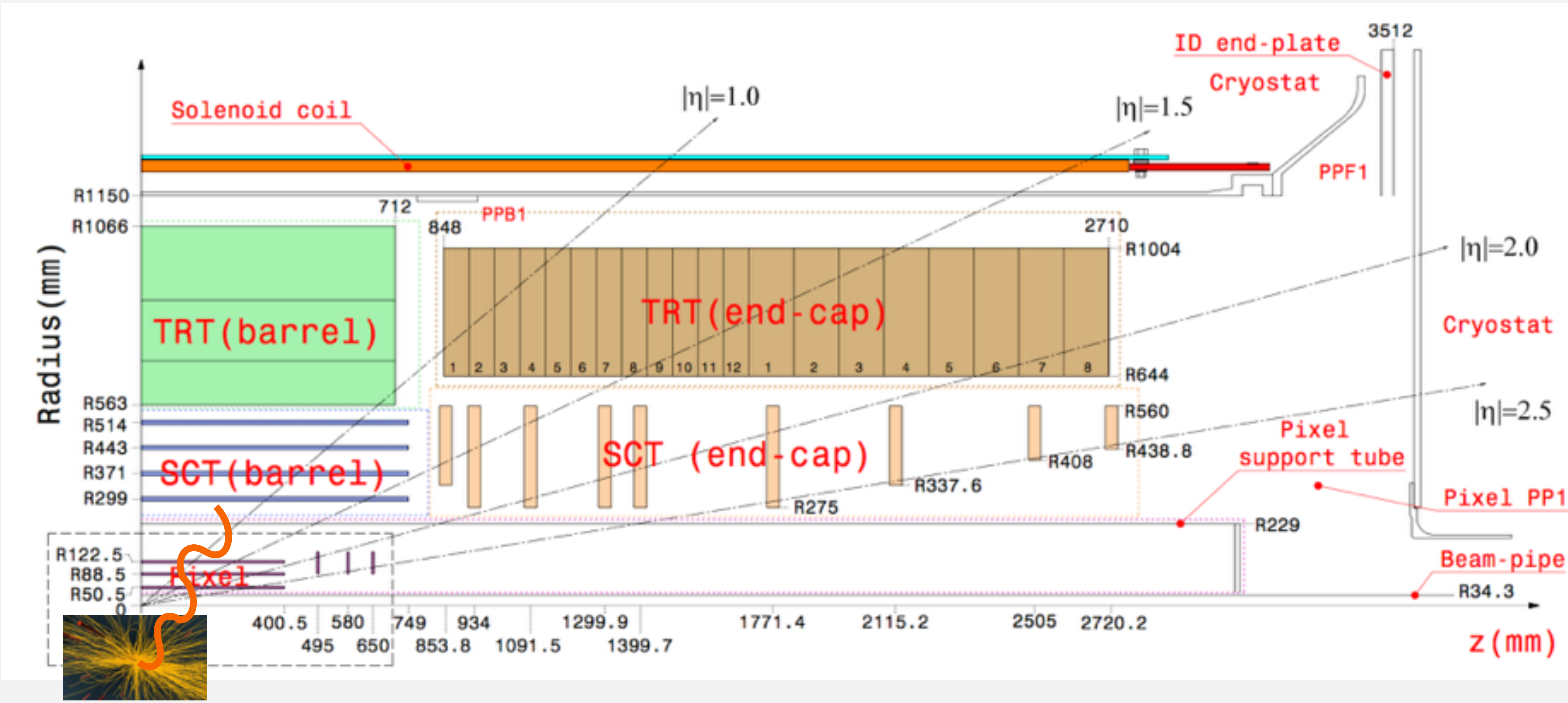
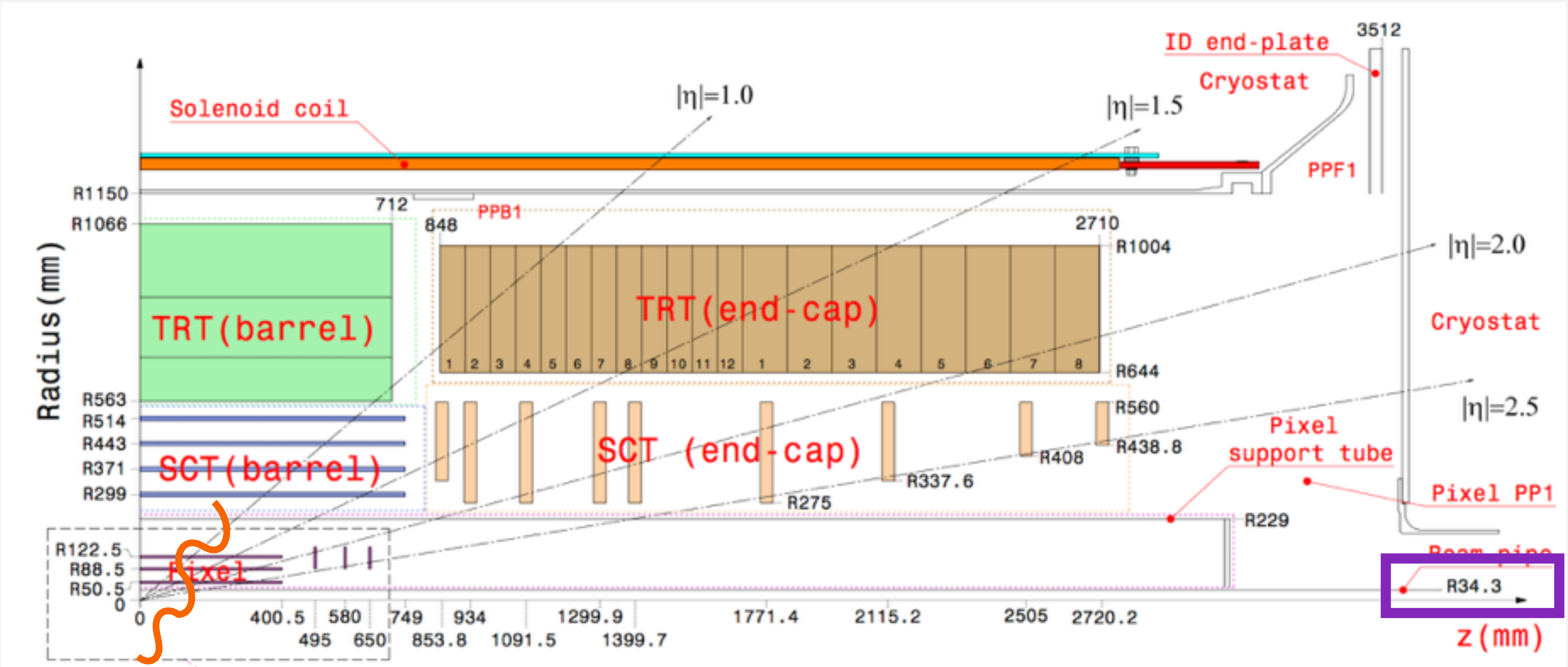


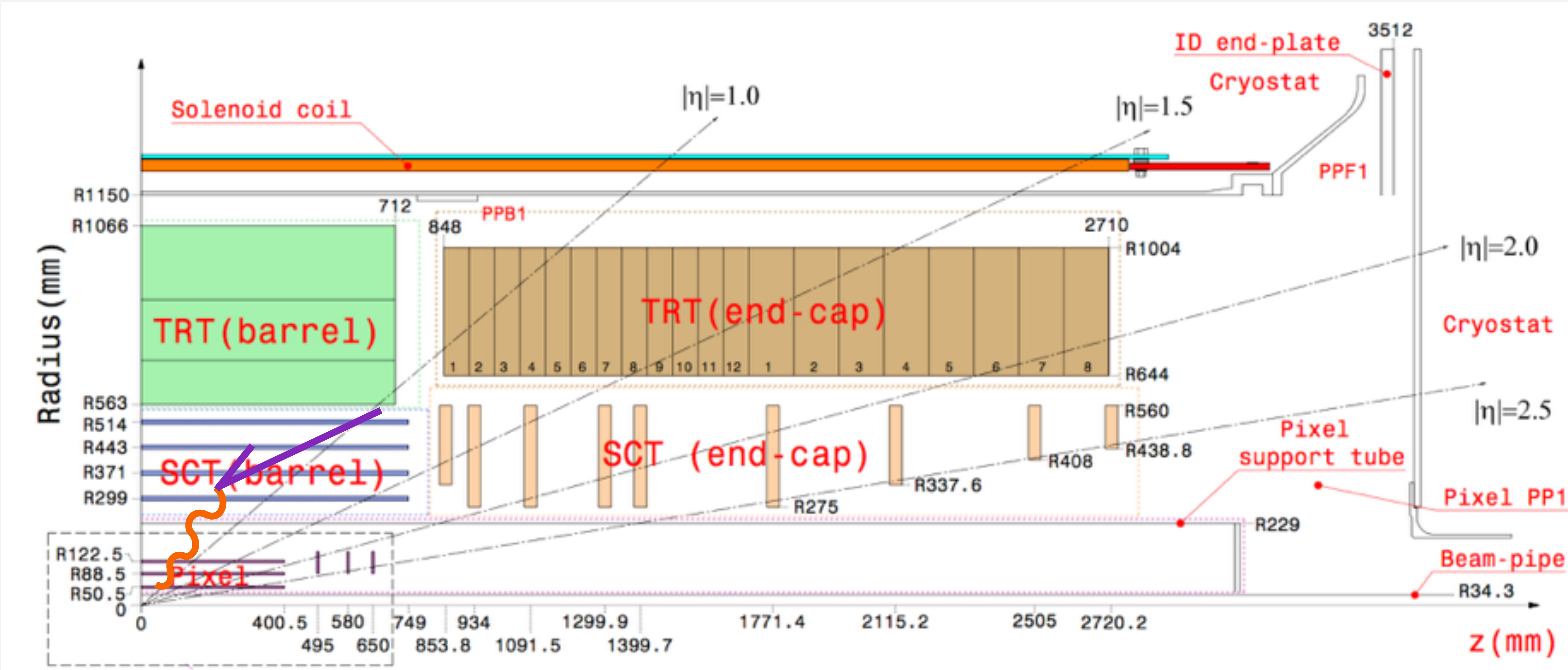
γ

Photon-id at ATLAS: r < 34 mm



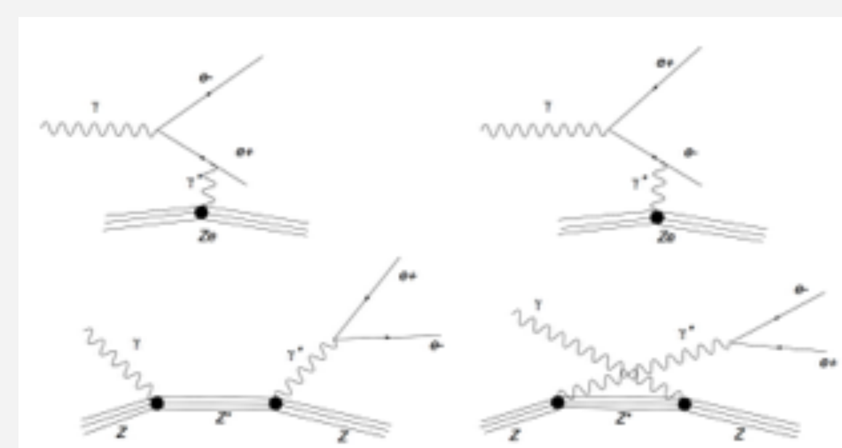
No hit at the 1st layer of Pixel detector

Photon-id at ATLAS: 34 < r < 400 mm

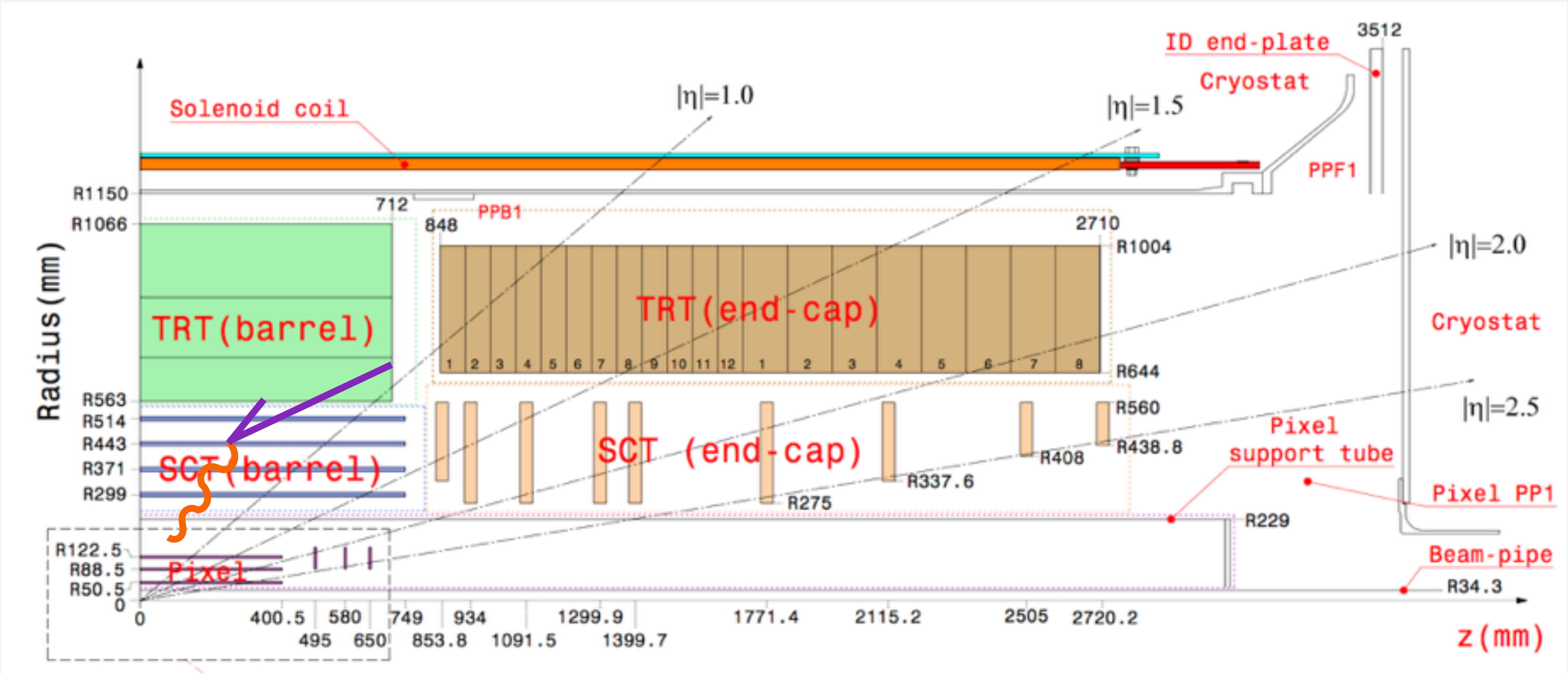


If converted, needs to leave > 3 space points at Pixel or SCT

There can be either 1 or 2 tracks

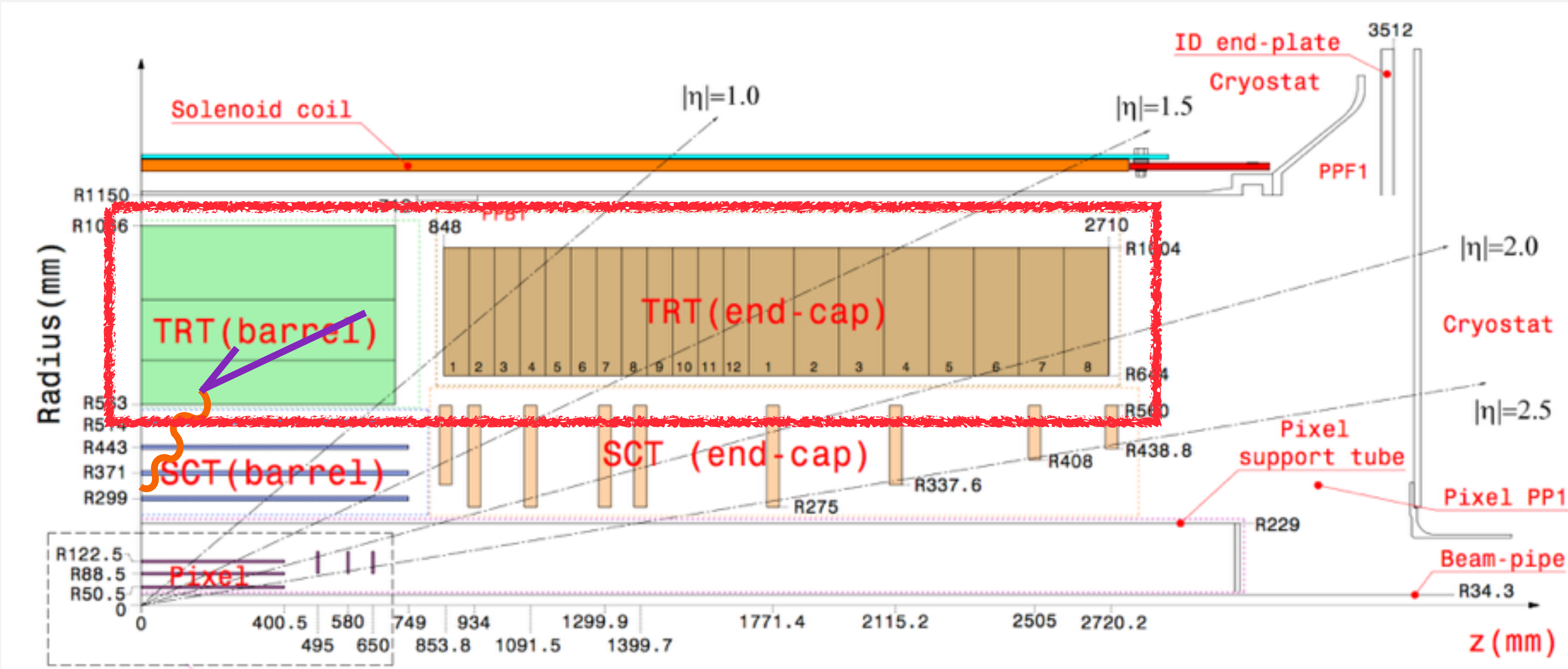


Photon-id at ATLAS: 400 < r < 1500 mm



If < 3 hits before TRT: identified as an unconverted photon

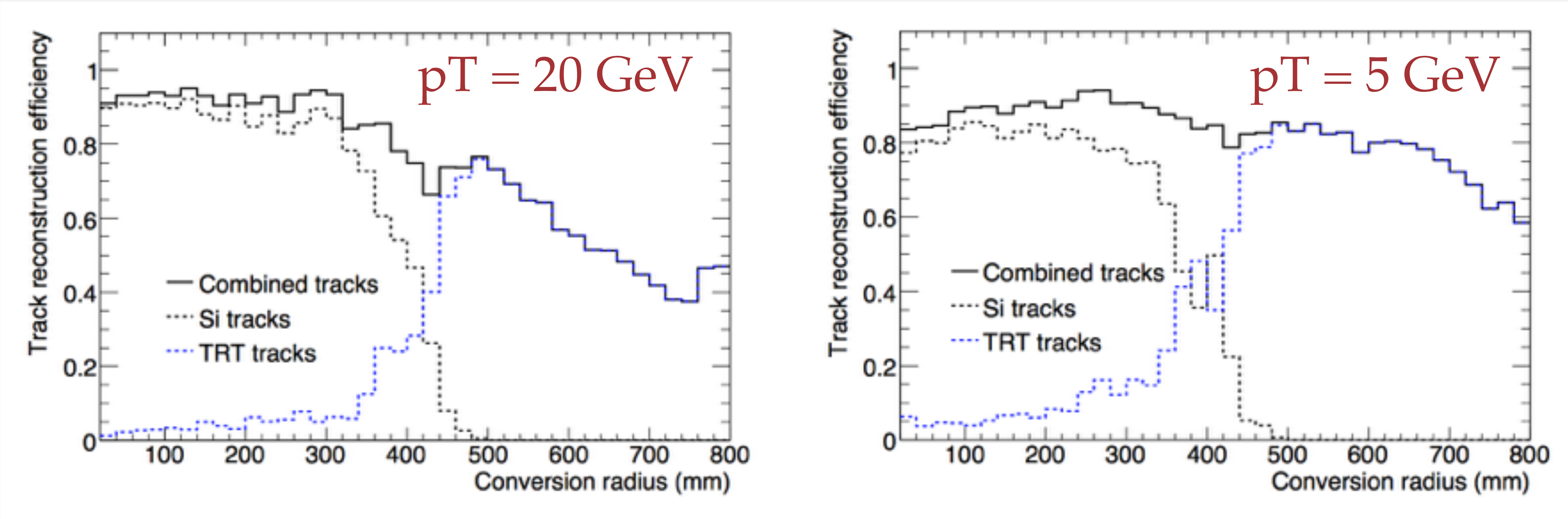
Photon-id at ATLAS: in TRT (Transition Radiation Tracker)



Converted photon can in principle be identified in the TRT but with a much worse resolution

=> need well-separated e+e- tracks, difficult for a high pT photon

Photon-id at ATLAS: in TRT (Transition Radiation Tracker)



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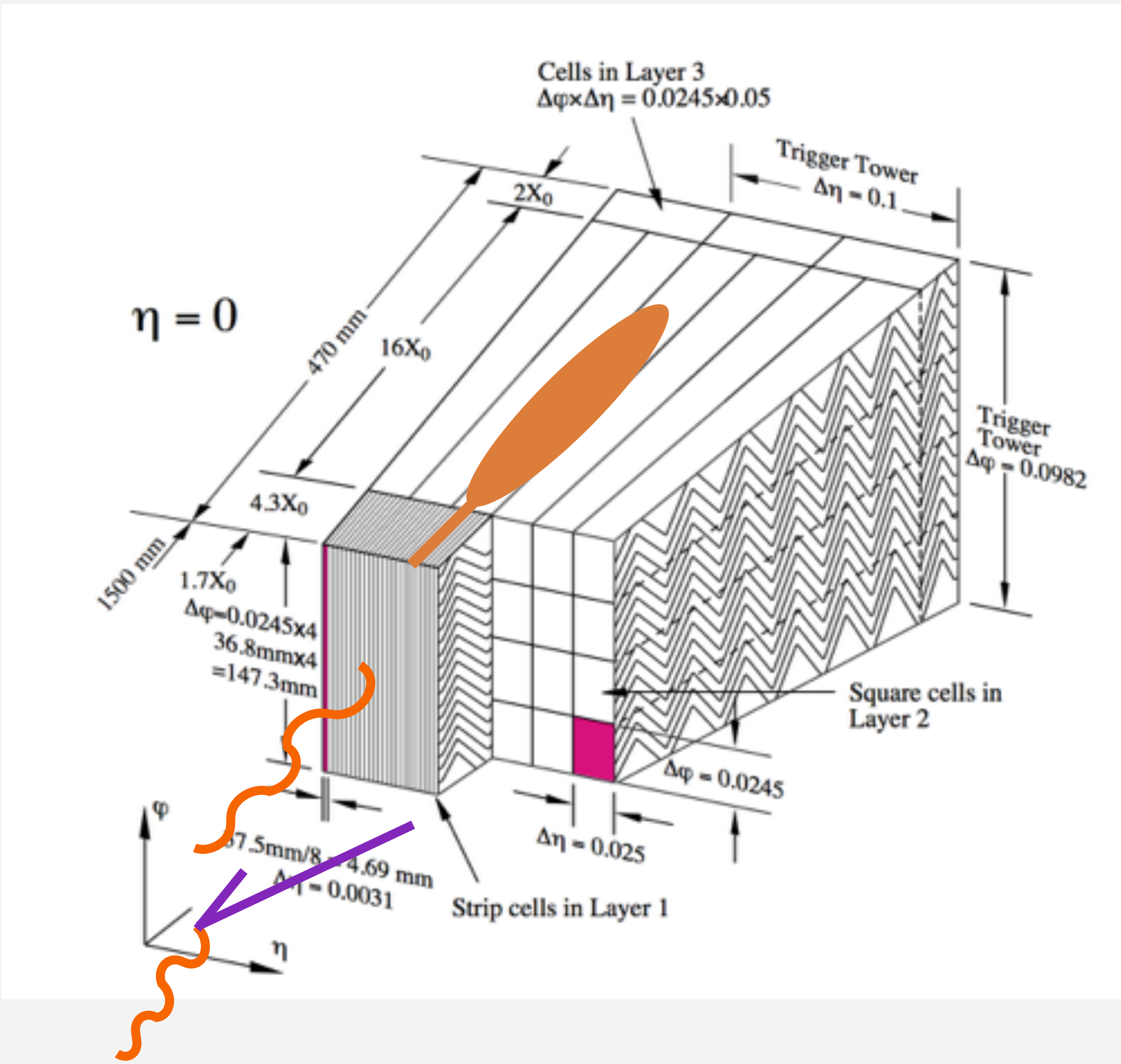
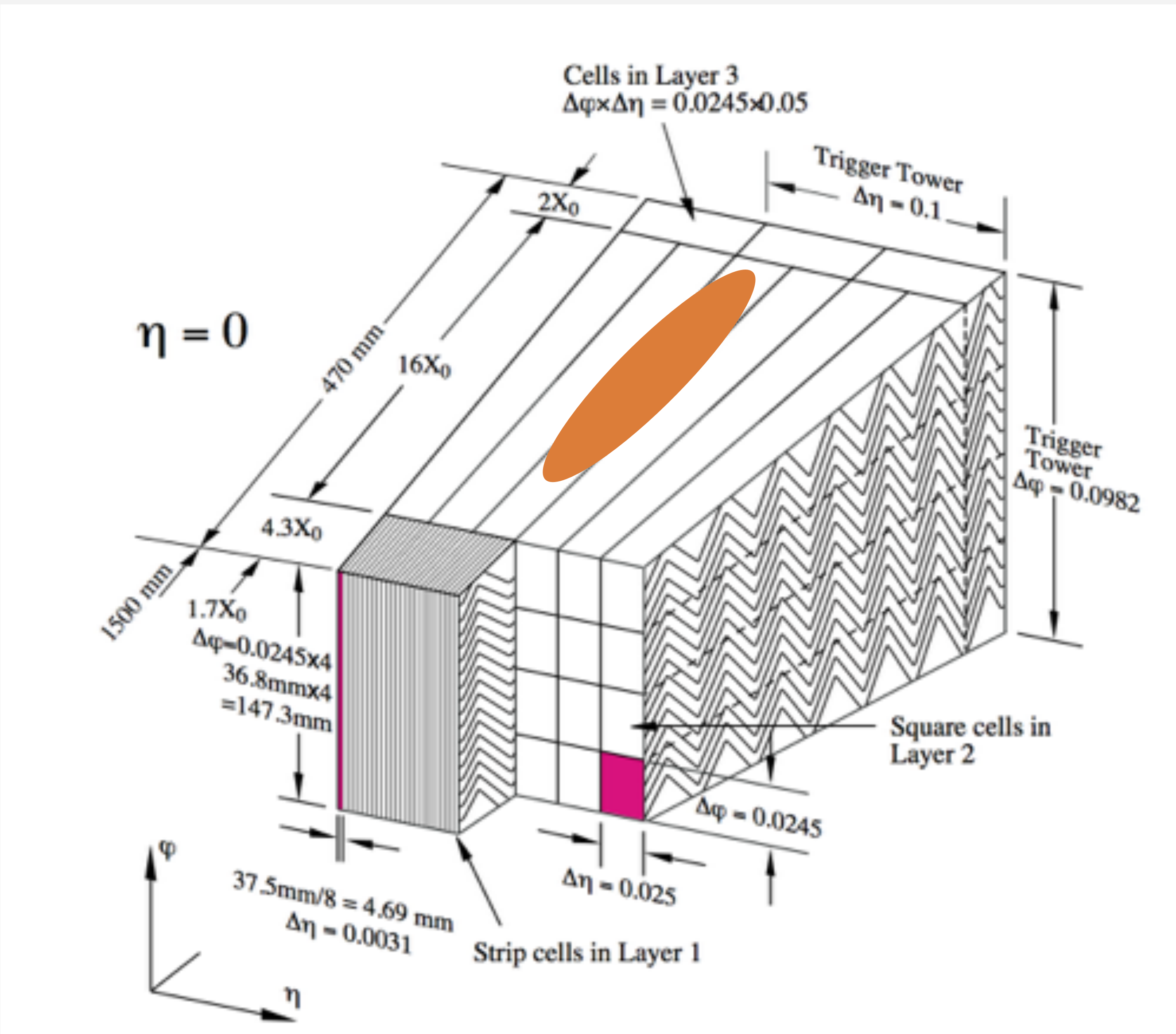
Photon-id at ATLAS: ECAL Layer 1



Both converted / unconverted photons deposit energy in ECAL with a specific shower shape

In the 1st layer of ECAL, the energy needs to be within few strip cells to be identified as a single photon

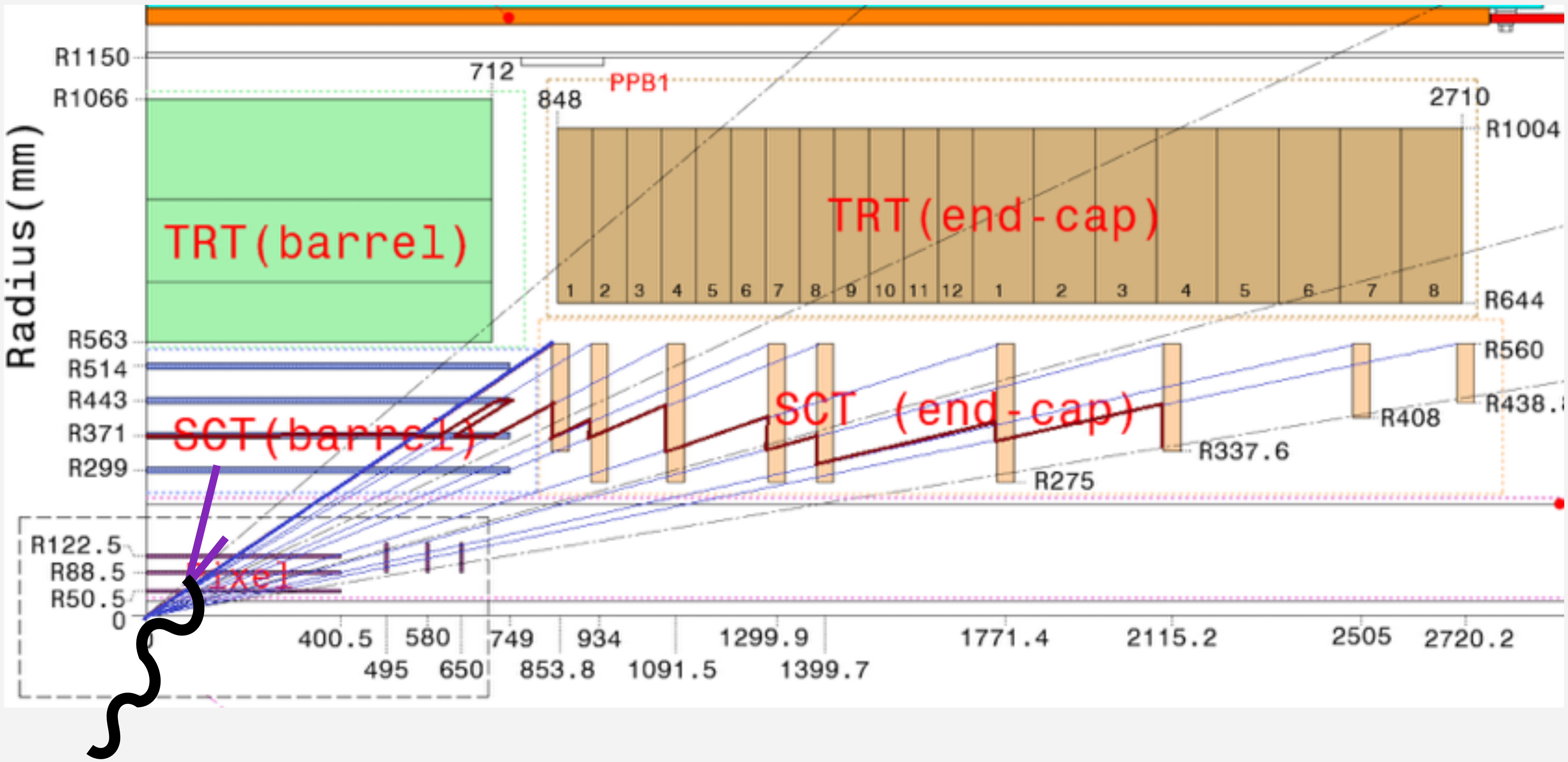
Photon-id at ATLAS: ECAL Layer 2



If it's not registered at layer 1, the showering will not be identified as a photon

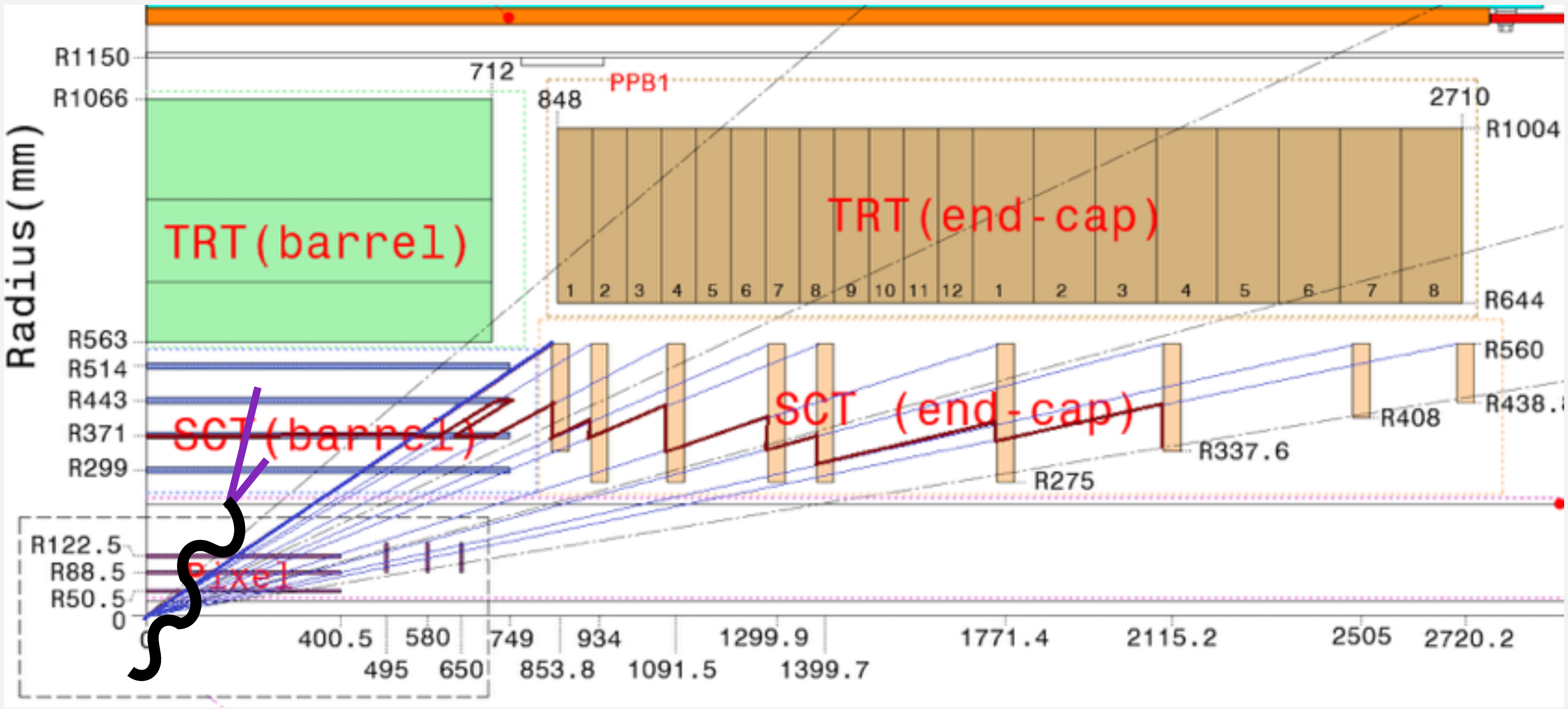
No more than 20% energy should be inside the HCAL

Faking Photon by a displaced dark photon



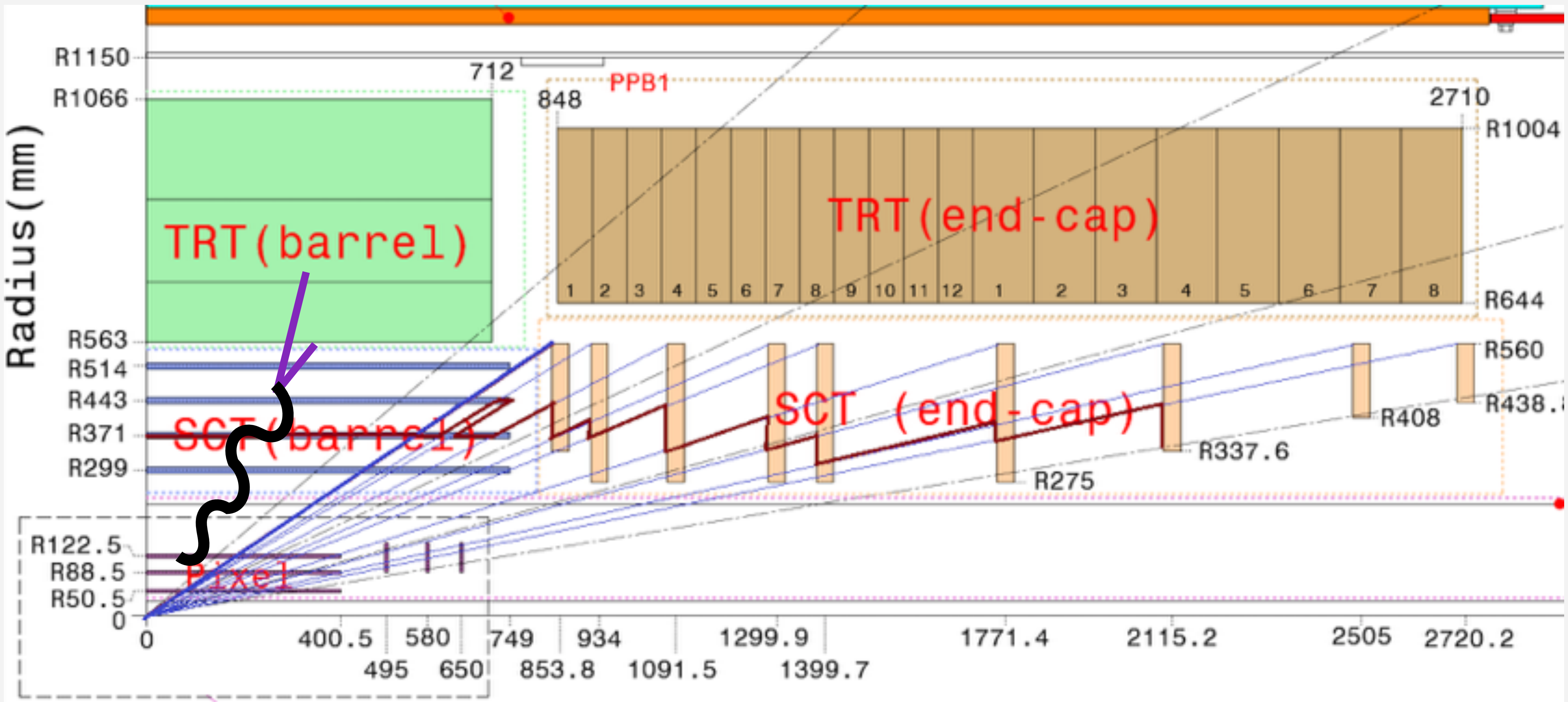
Need to decay after the 1st layer of Pixel

Decay between 34 < r < 400 mm



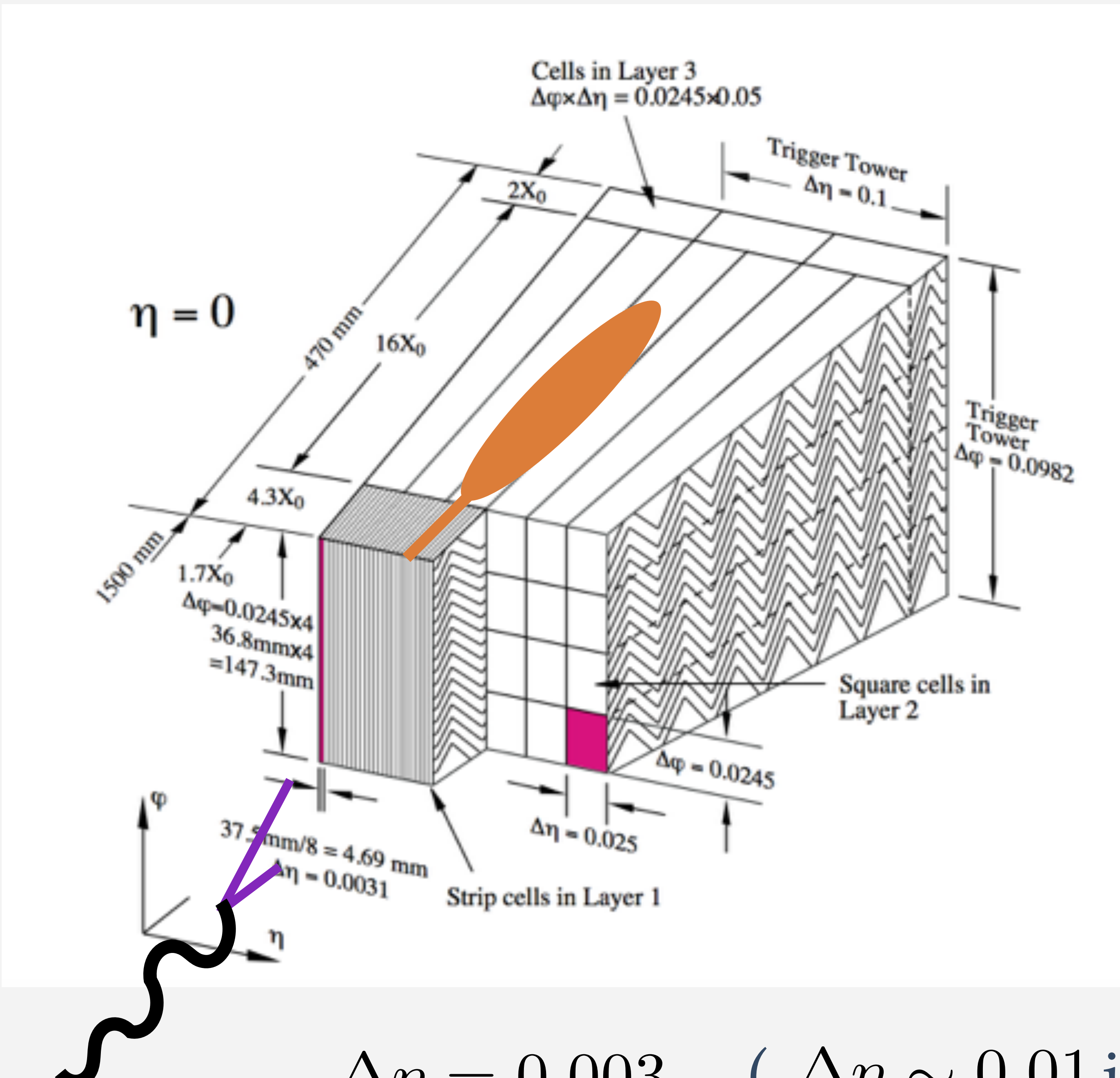
A fake converted photon

Decay between $400 < r < 1500$ mm



Converted photon if the e+e- separation is small

Decay before the ECAL Layer 1



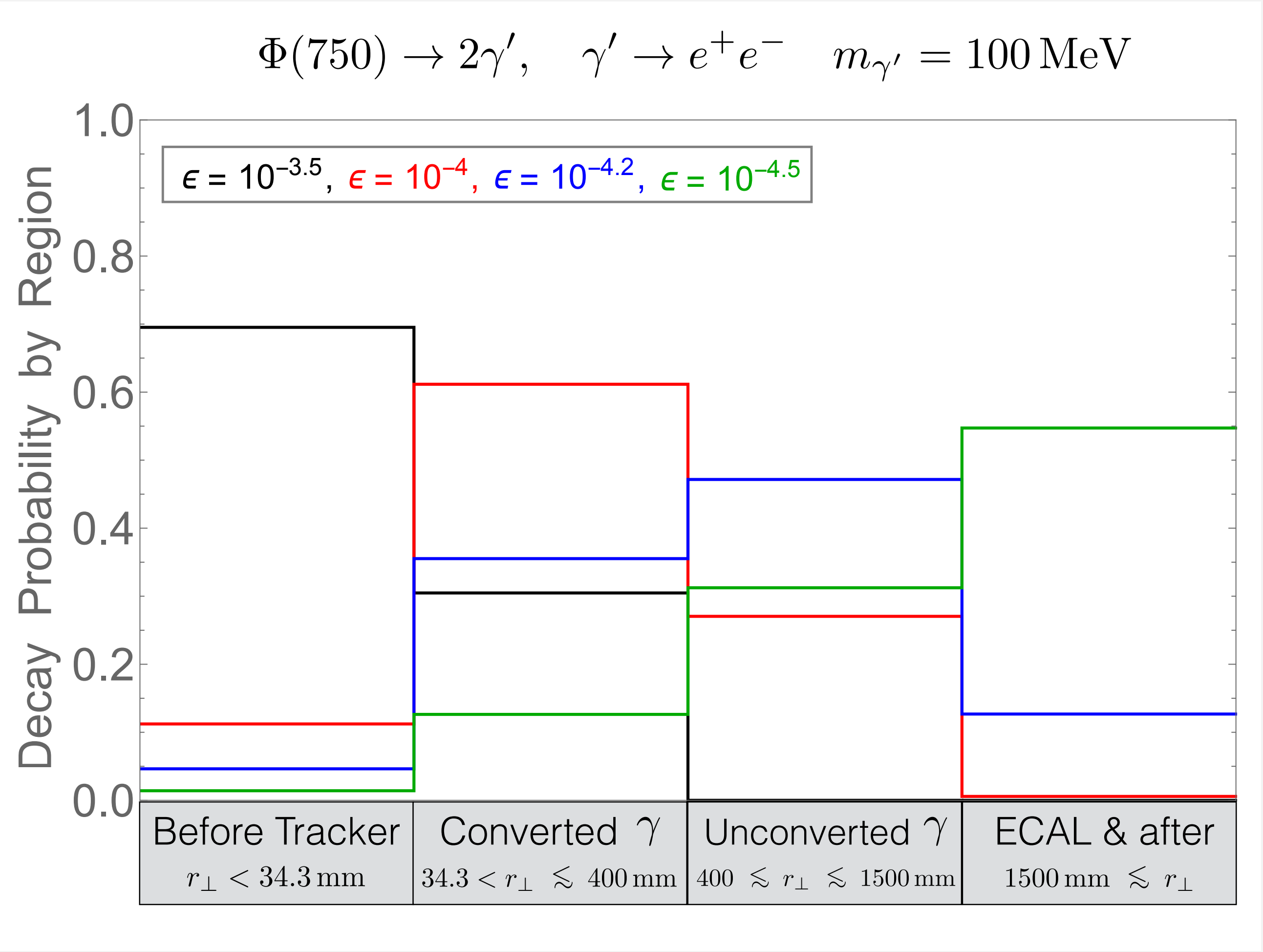
If e+e- is within a strip cell, it will definitely be identified as a single object

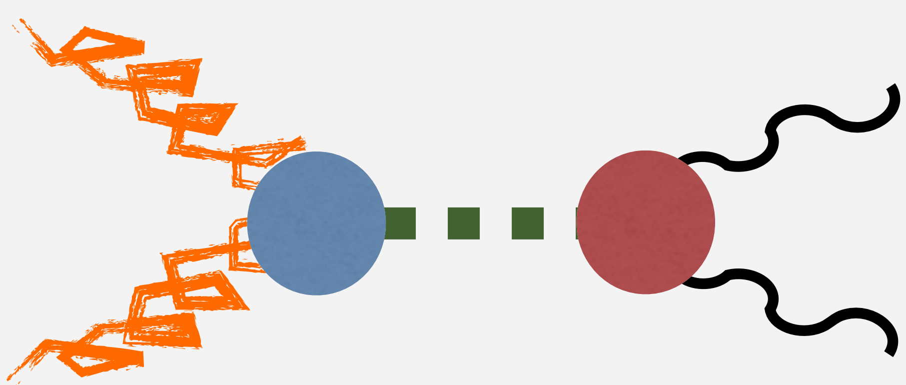
Dark photon can decay close to the strip cells, making it easier to enter a single strip cell

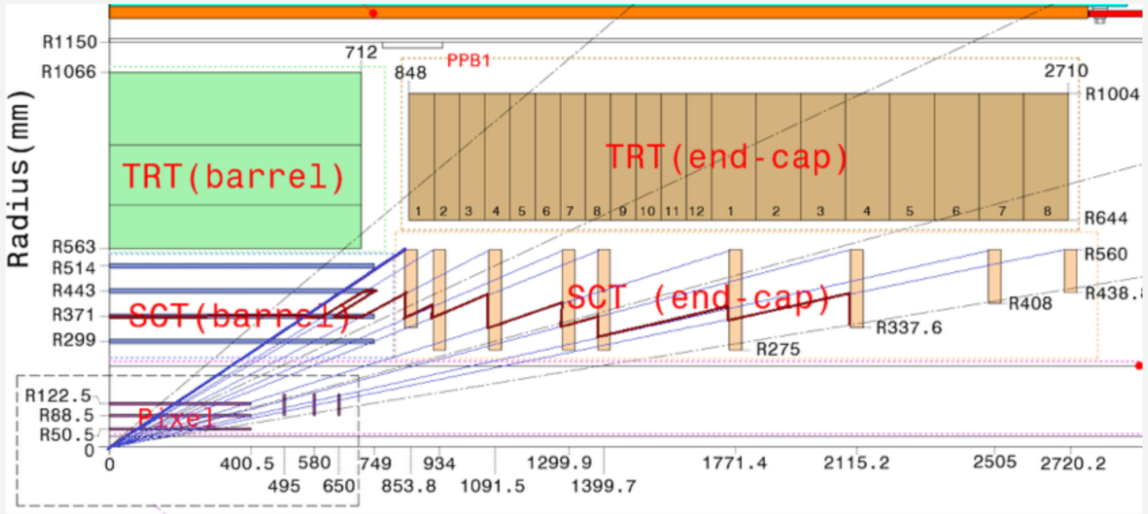
Magnetic bending ~< 1 cm

$\Delta\eta = 0.003$ ($\Delta\eta \sim 0.01$ in CMS)

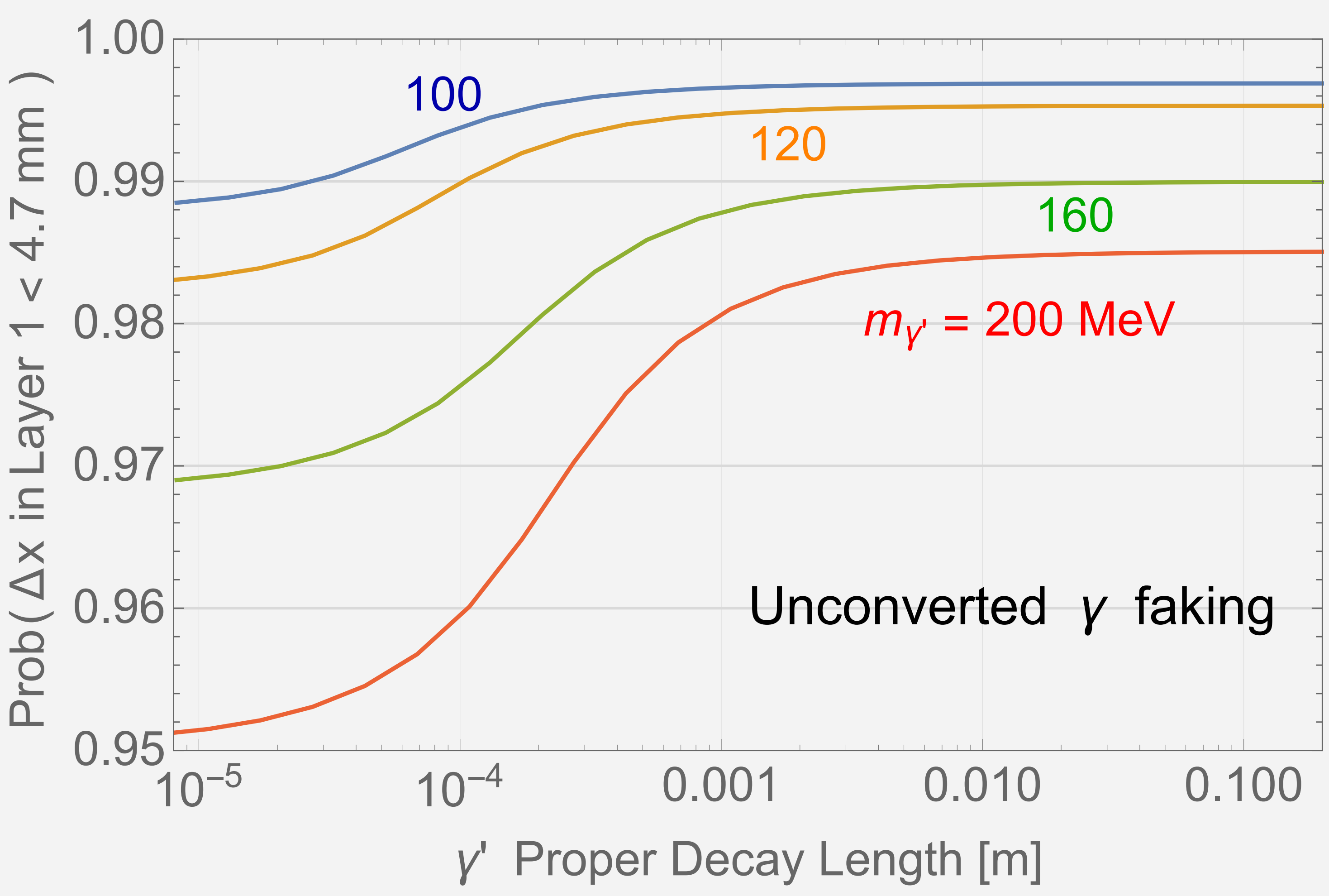
Decay probability by region



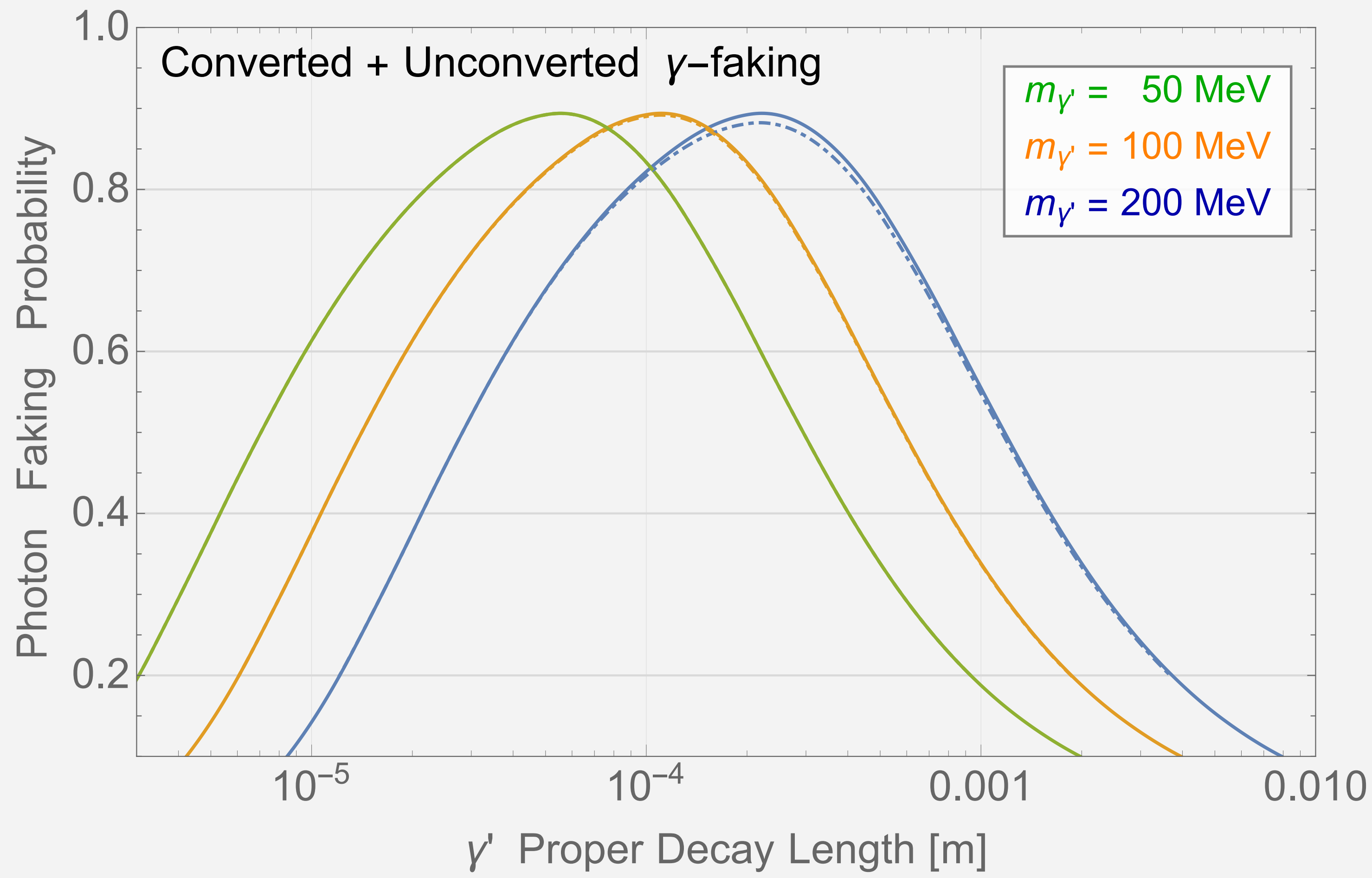




Probability of e+e- entering one strip cell

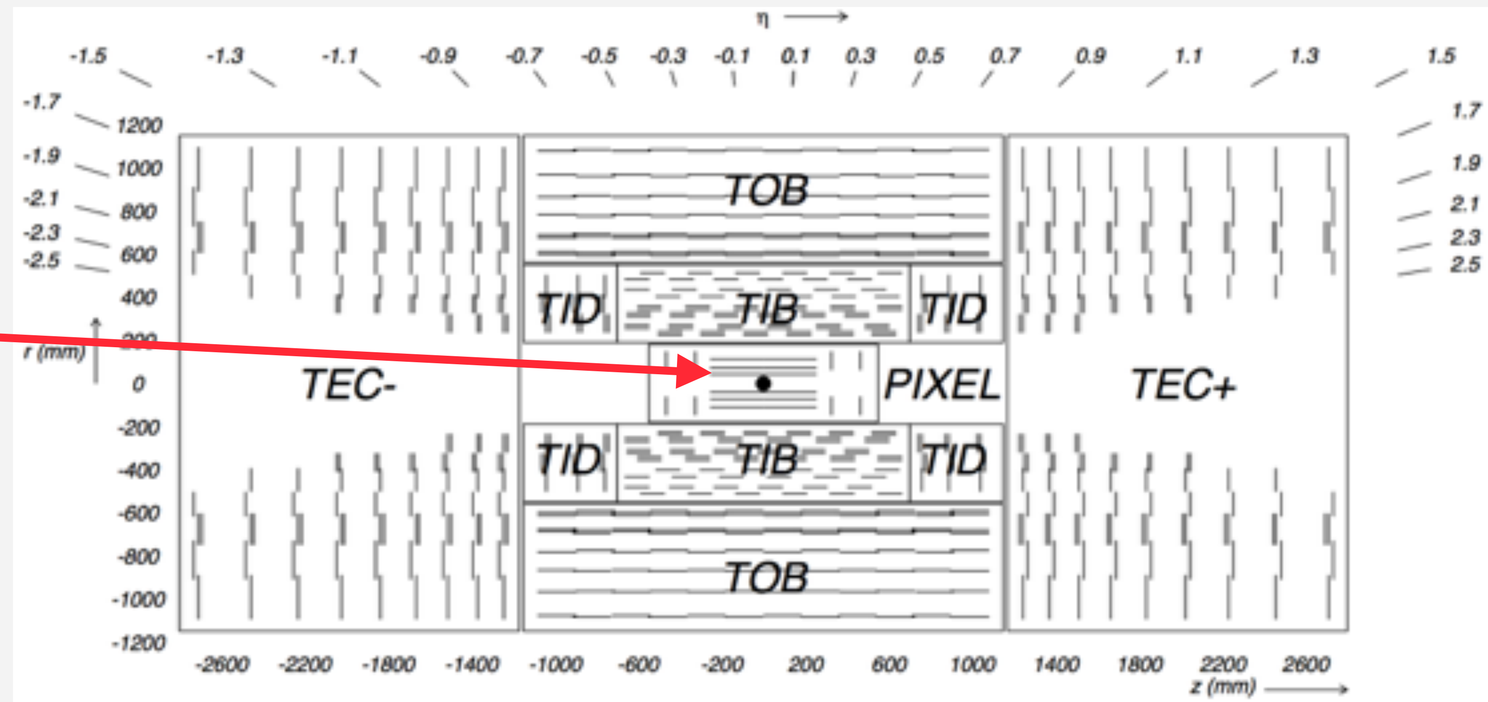


Photon faking probability



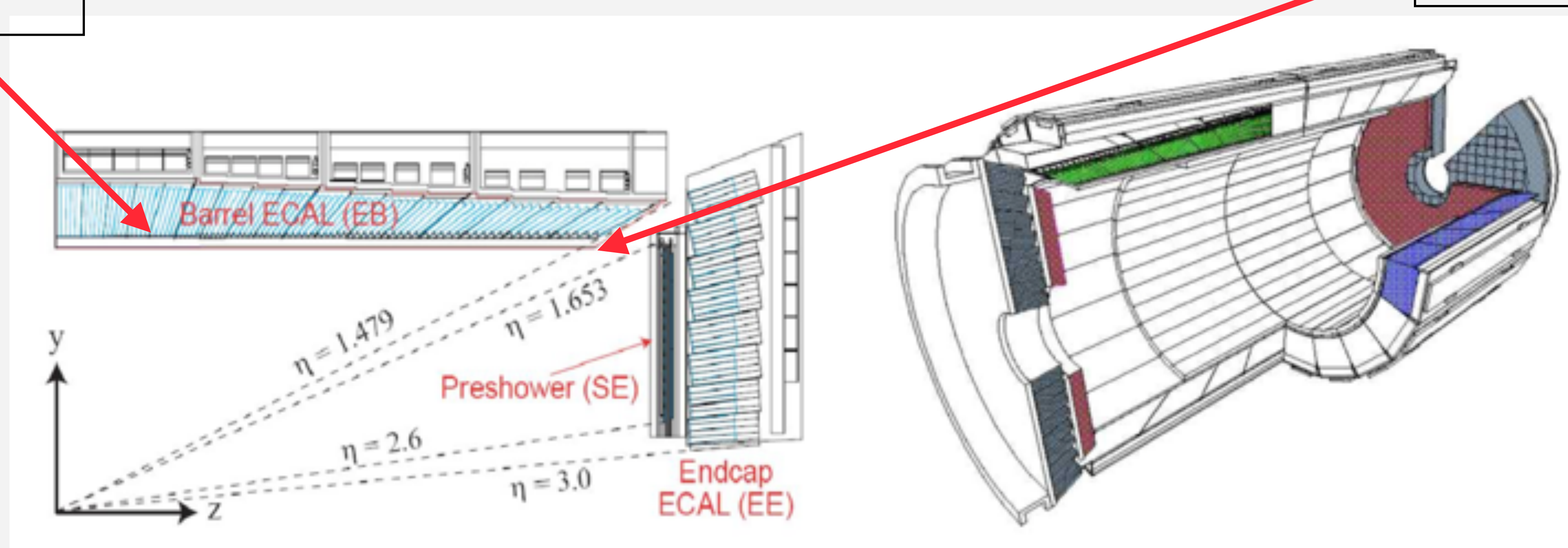
Faking a photon at CMS: it's easier

1st layer Pixel
44 mm (34)

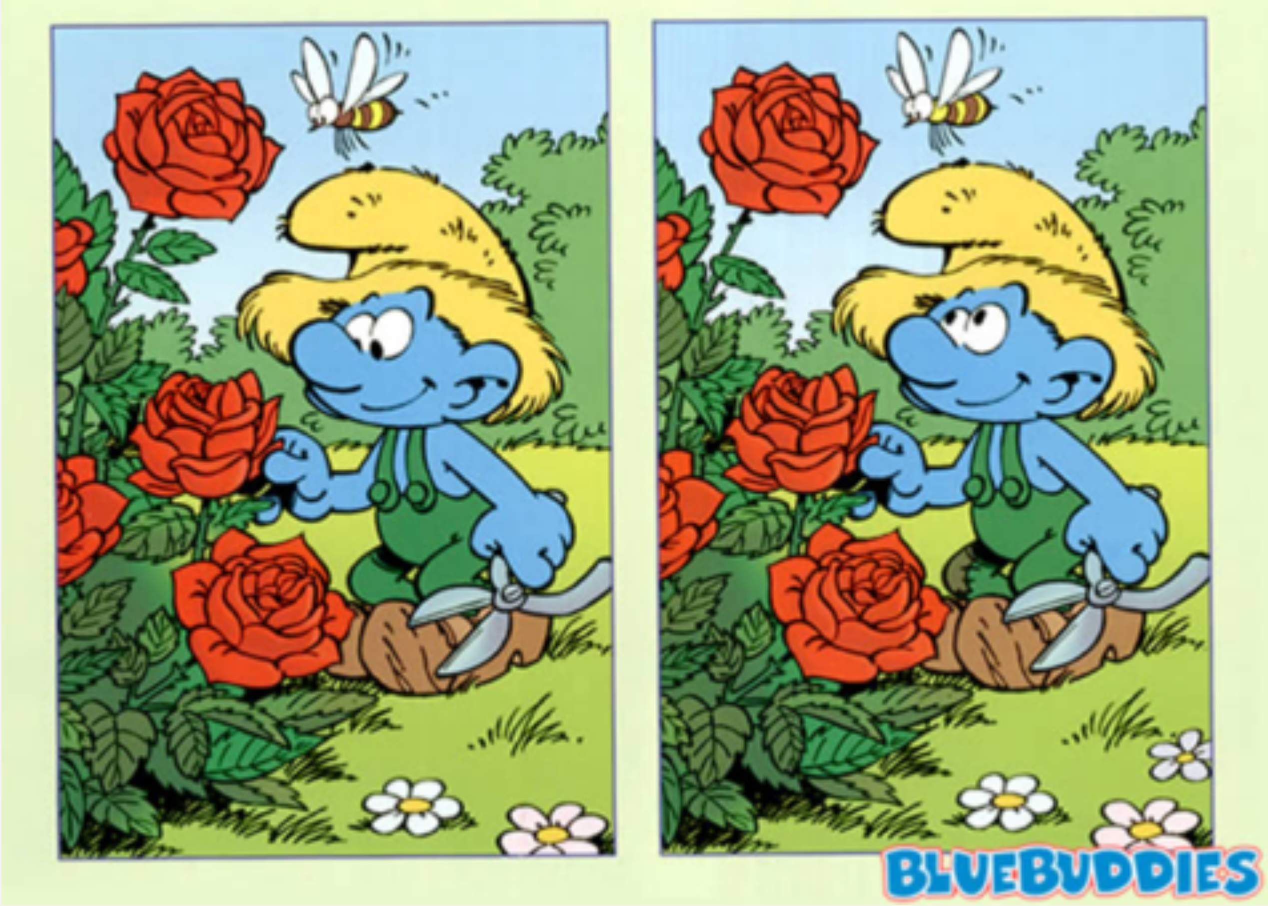


Resolution
$\Delta\eta \sim 0.01$

ECAL location
1.79 m (1.59)



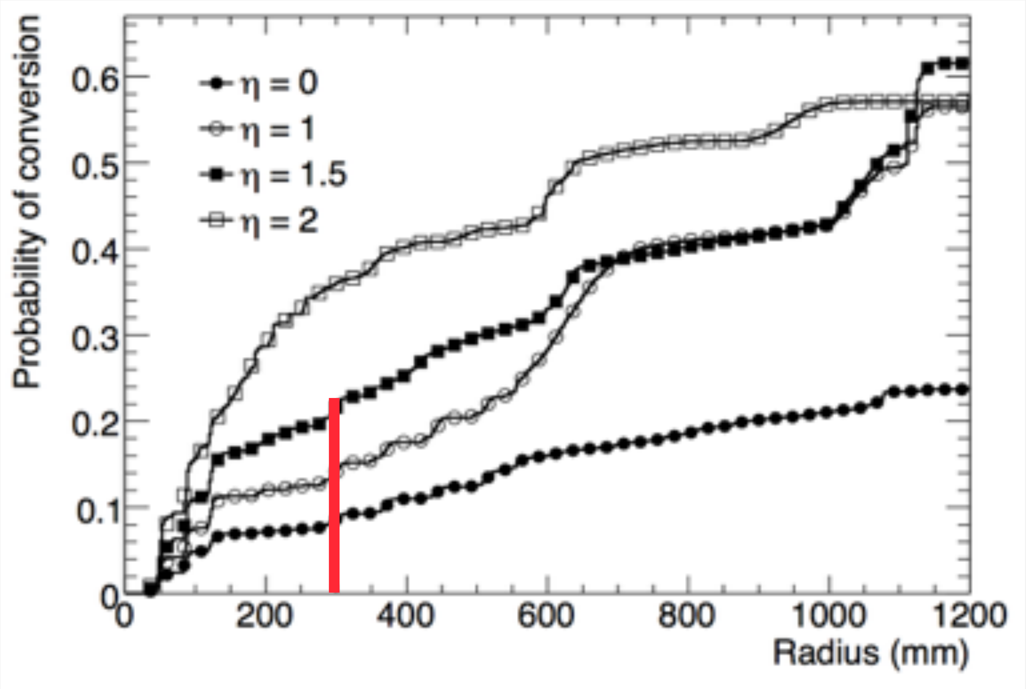
Distinguish the Dark & SM photons



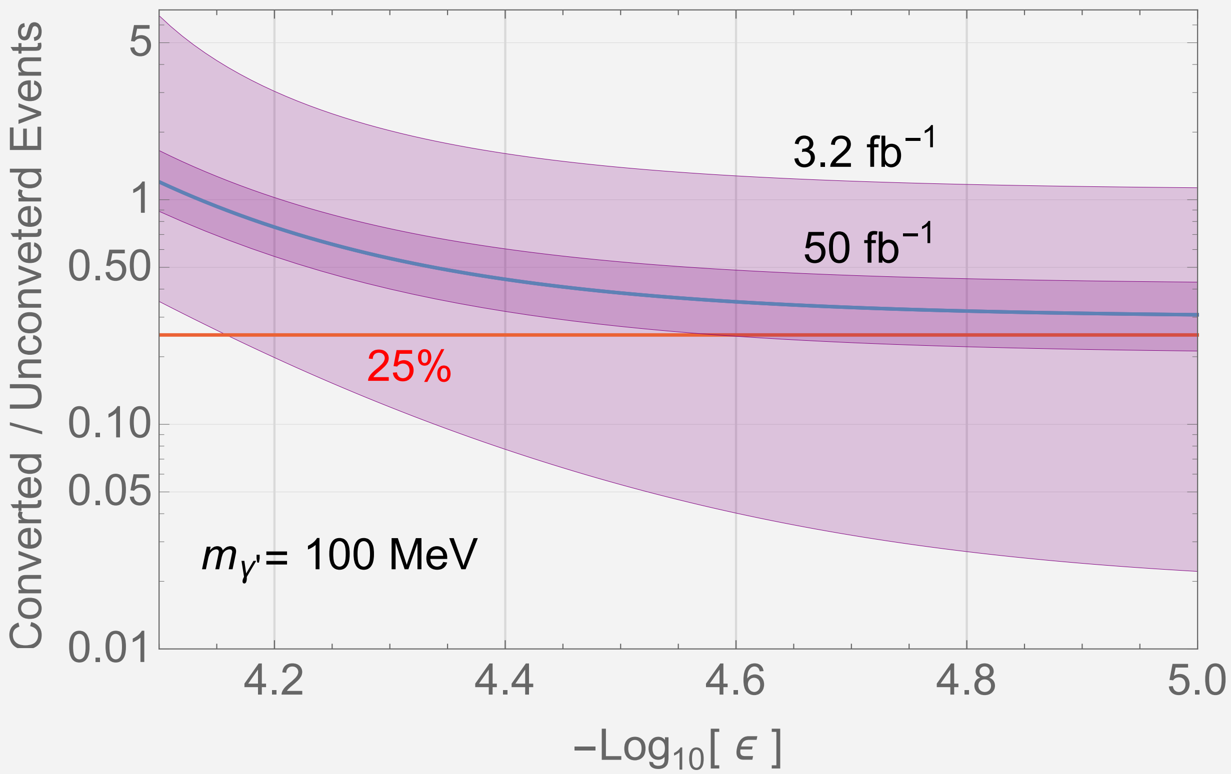
Number ratio of converted vs. unconverted

SM conversion depends on the material,
the dark photon conversion depends on lifetime

CSC NOTE - PHOTON CONVERSIONS IN ATLAS



Assume $N_{\rm sg}^{\gamma'} = N_{\rm bg}^{\gamma} = 11$ at $3.2\,{\rm fb}^{-1}$

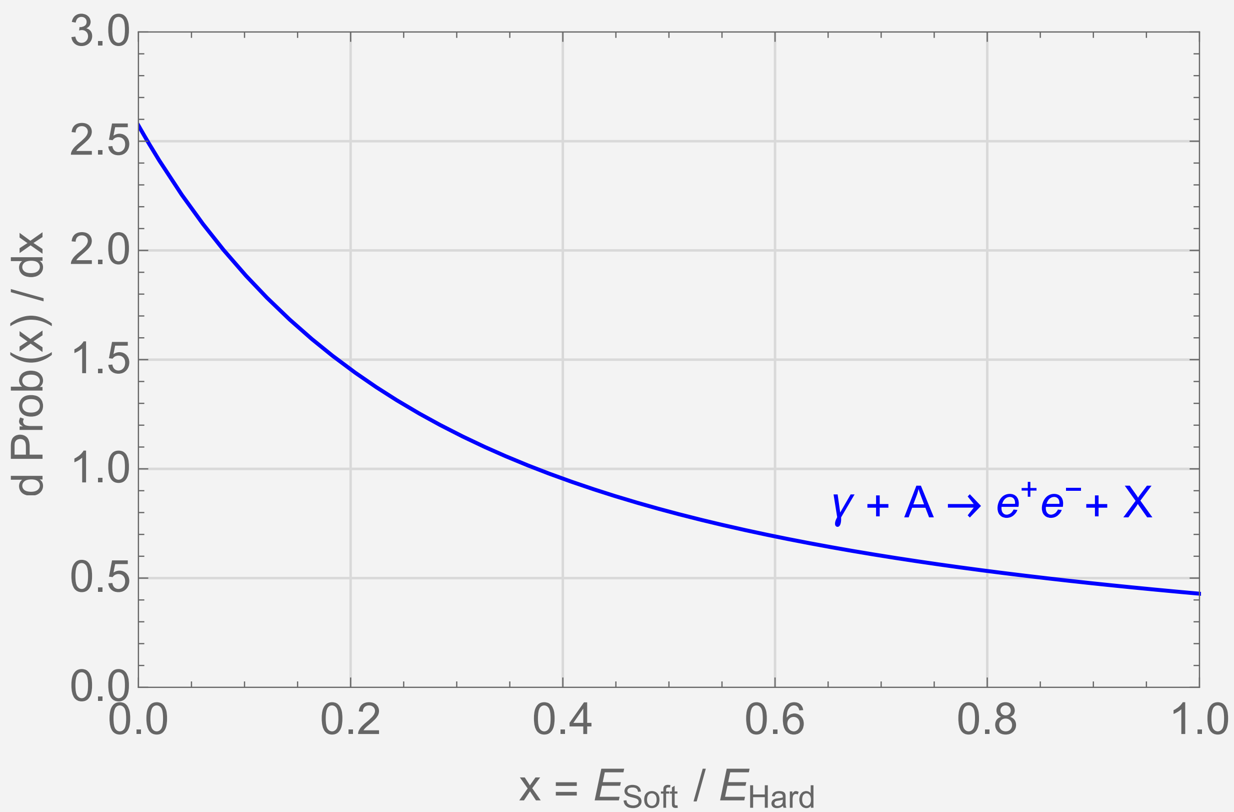


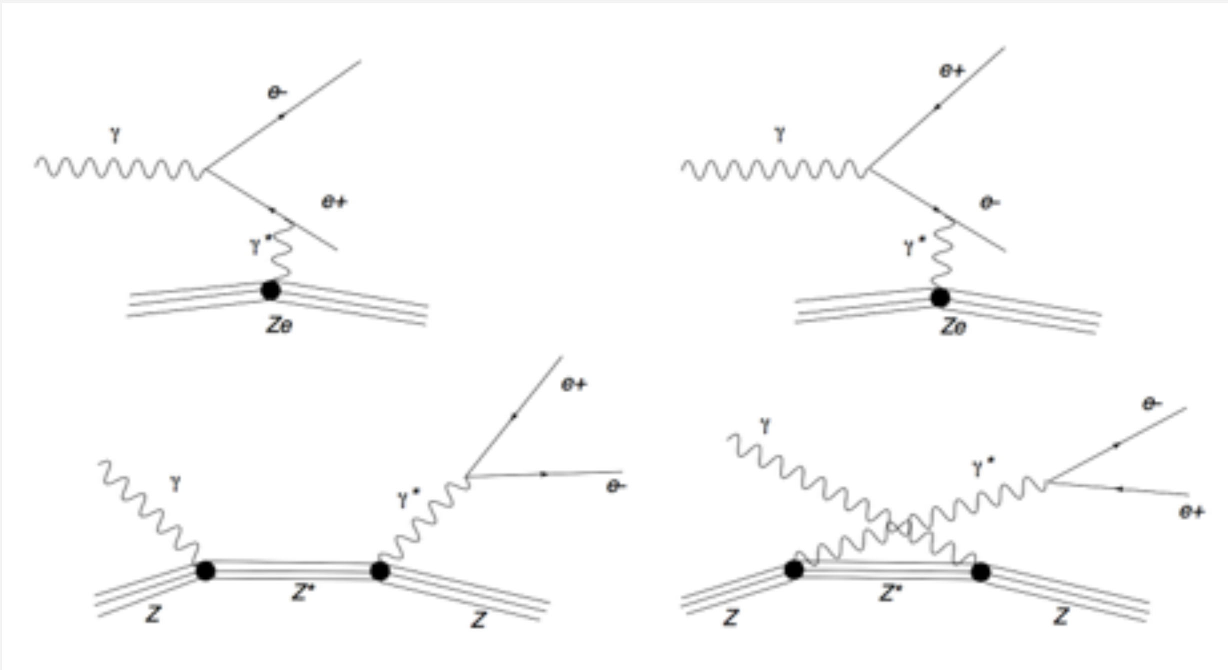
Photon conversation rate ~ 20%

Can eventually tell the difference

Energy ratio between the converted e+e-

SM photon conversion tends to give leptons with asymmetric energy



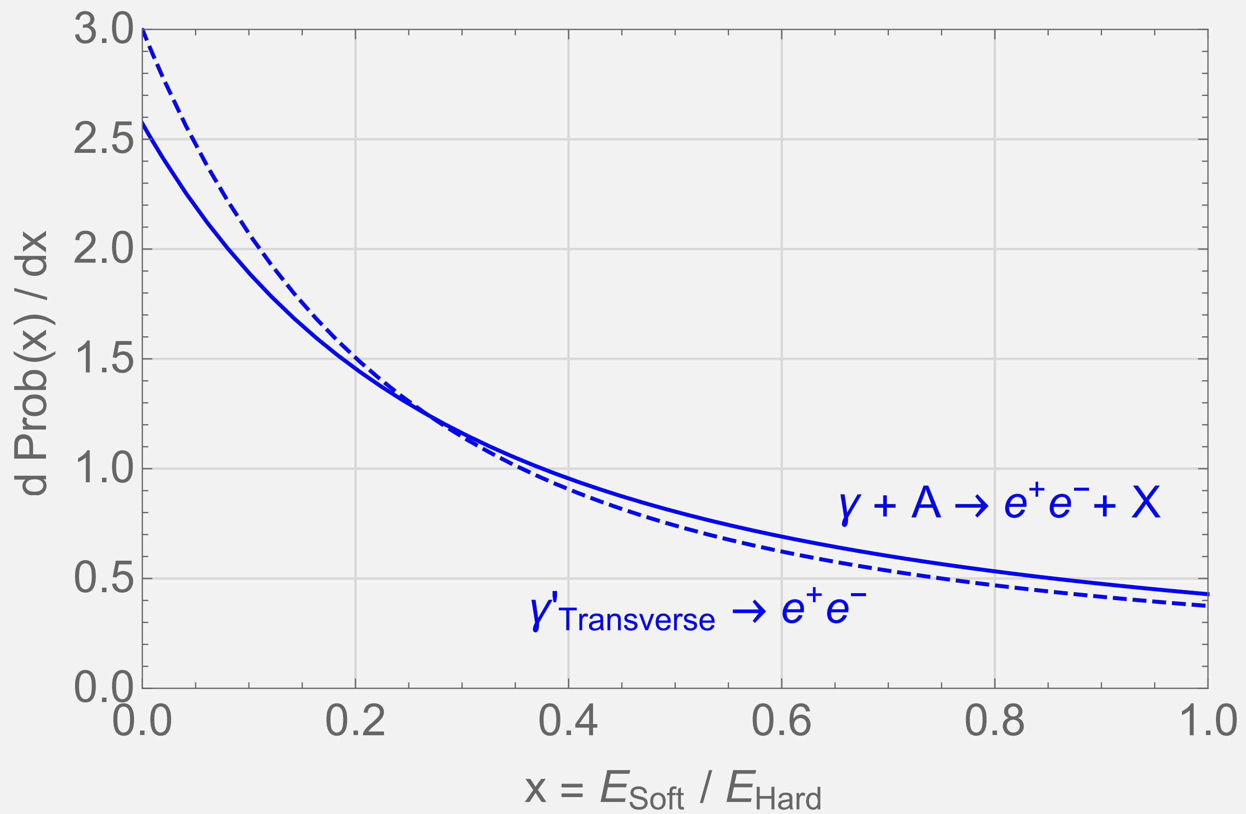


$$\frac{d\,\mathrm{Prob}_\gamma}{dx} \propto \left[1 - \frac{4x}{3(1+x)^2}\right] / (1+x)^2$$

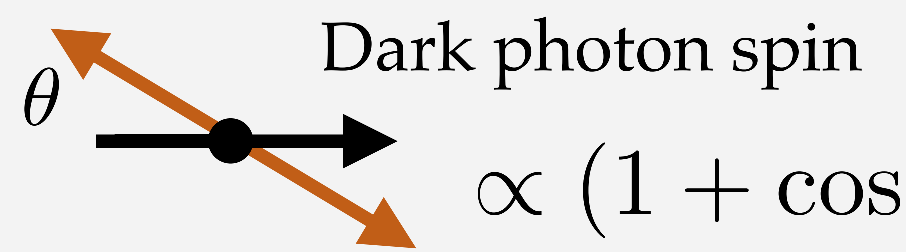
Can we use this to distinguish the SM/Dark photon decays?

Not that easy…

When the dark photon is mainly produced in the transverse mode, its decay also generates an asymmetric electron energy

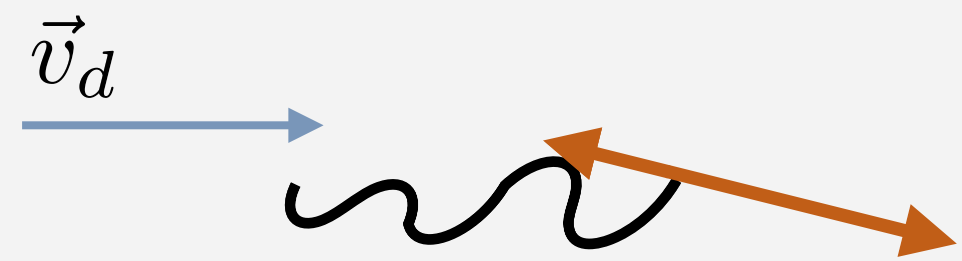


CM frame



$$\propto (1 + \cos\theta^2)$$

Lab frame



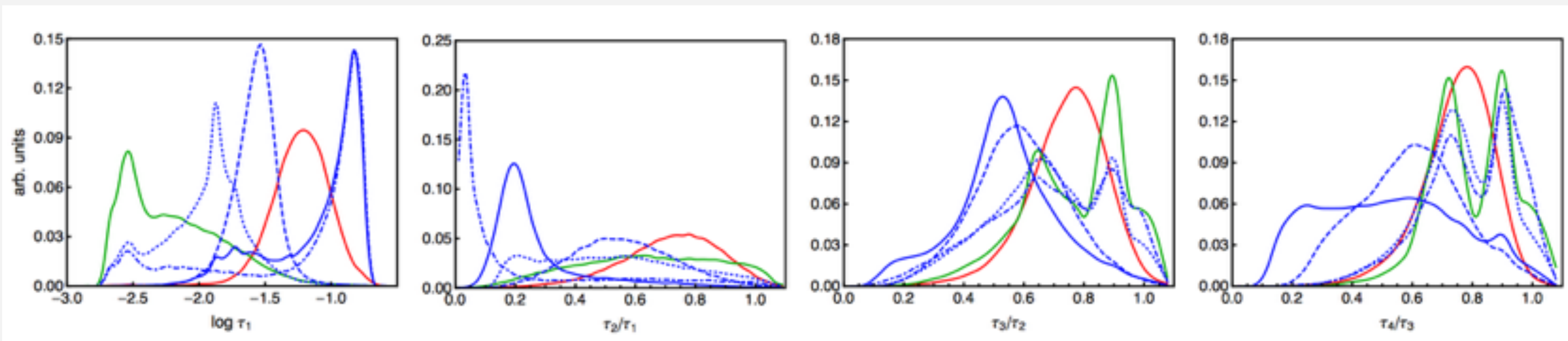
$$\frac{d\,\text{Prob}_\gamma}{dx} \propto \left[1 - \frac{4x}{3(1+x)^2}\right]/(1+x)^2$$

$$\frac{d\,\text{Prob}_\gamma}{dx} \propto \left[\frac{2}{3} - \frac{4x}{3(1+x)^2}\right]/(1+x)^2$$

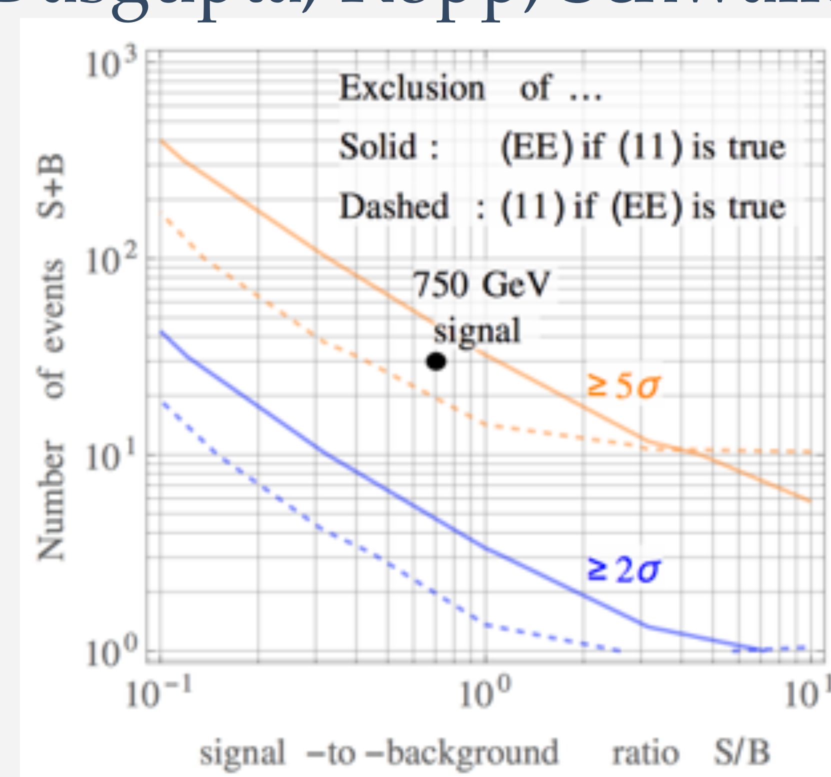
If dark photon decays cannot fake the unconverted

e.g. ECAL only exclusion from the photon jet information

Ellis, Roy, Sholtz (12') $\eta F_{\mu\nu}F^{\mu\nu}$, τ N-subjettiness variable



Dasgupta, Kopp, Schwaller

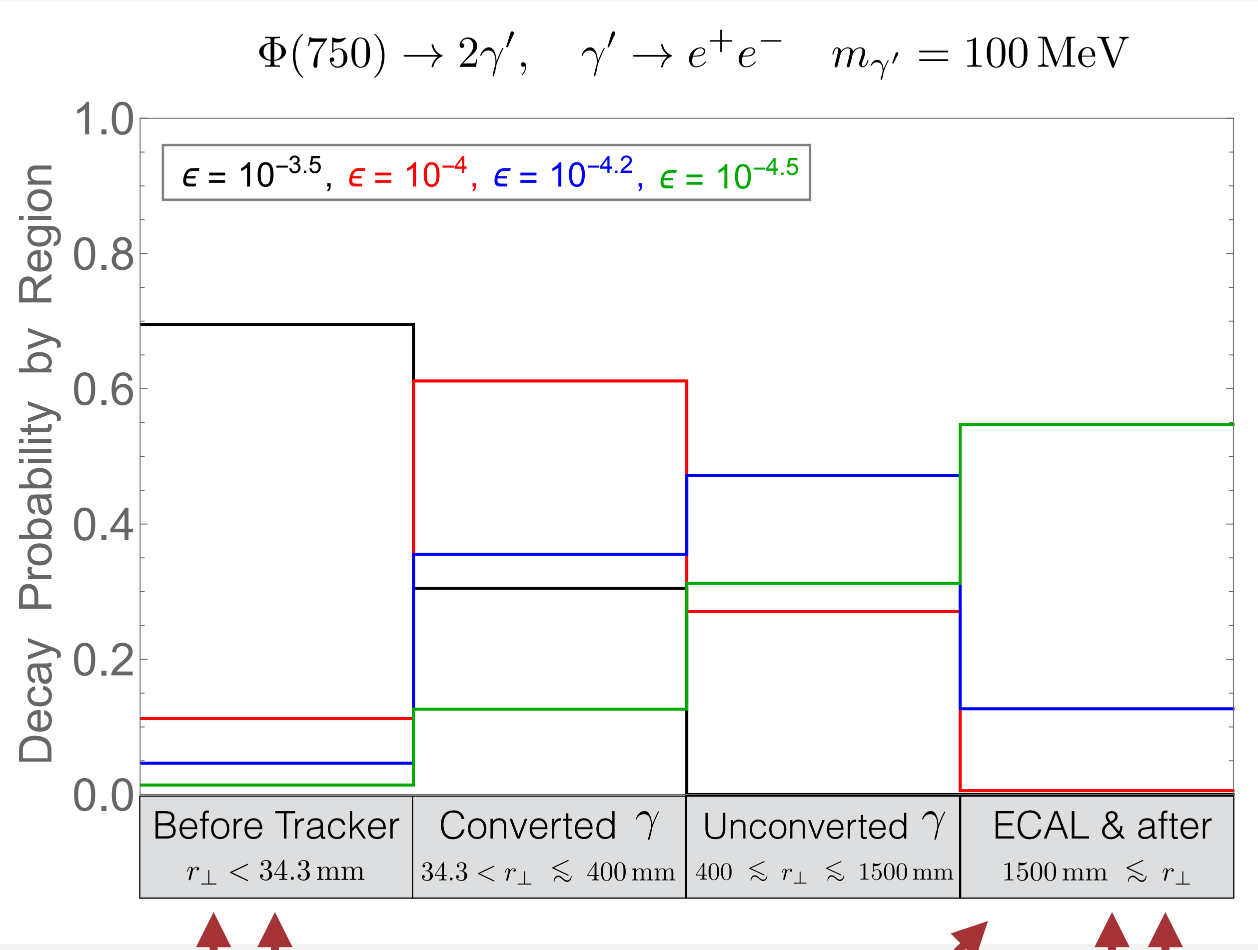


The bound can be much stronger

However, it is not clear how well does the same bound apply to the dark photon case, since the e+e- from the dark decay carrying asymmetric energy

Complimentary search

Constrain decays outside the photon id region



Prompt lepton jet

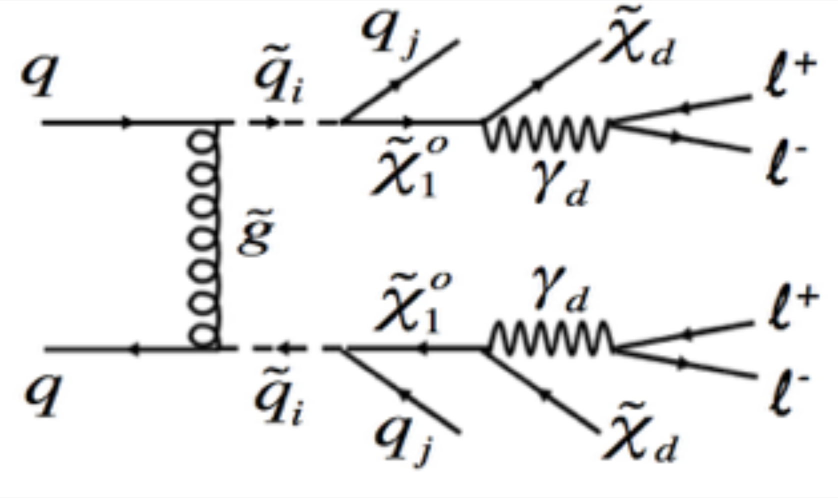
Displaced lepton jet

Monophoton + MET

2 γ_d before Pixel: prompt lepton-jet

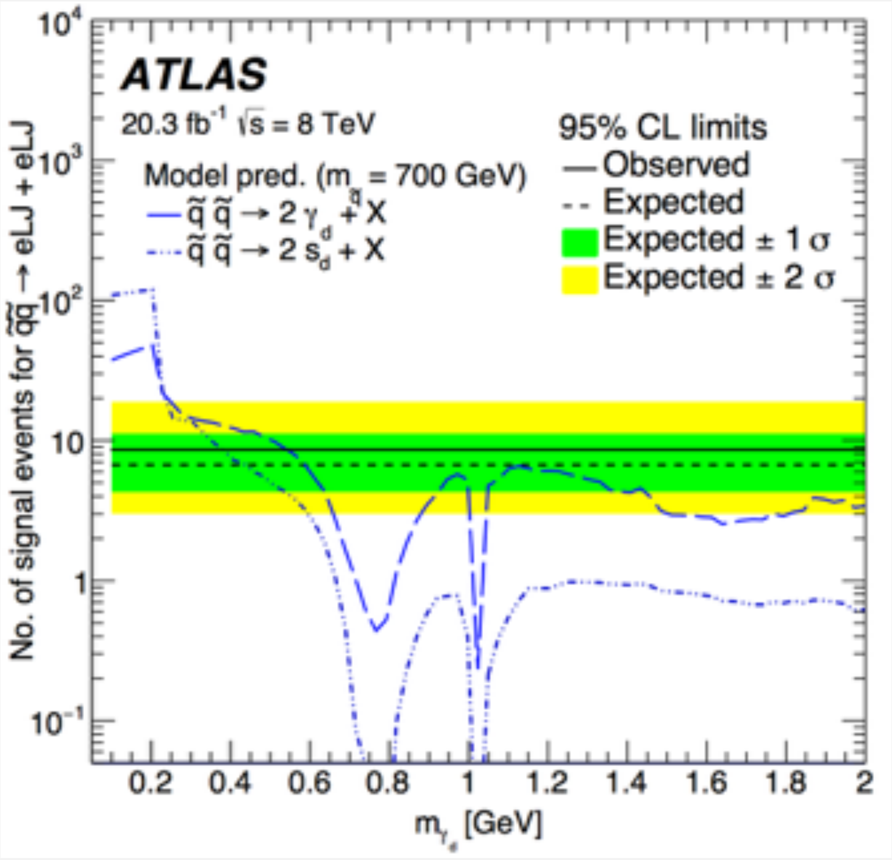
When dark photons decay before the Pixel, there are jets of highly collimated electrons

The search of ``lepton jets" can be applied

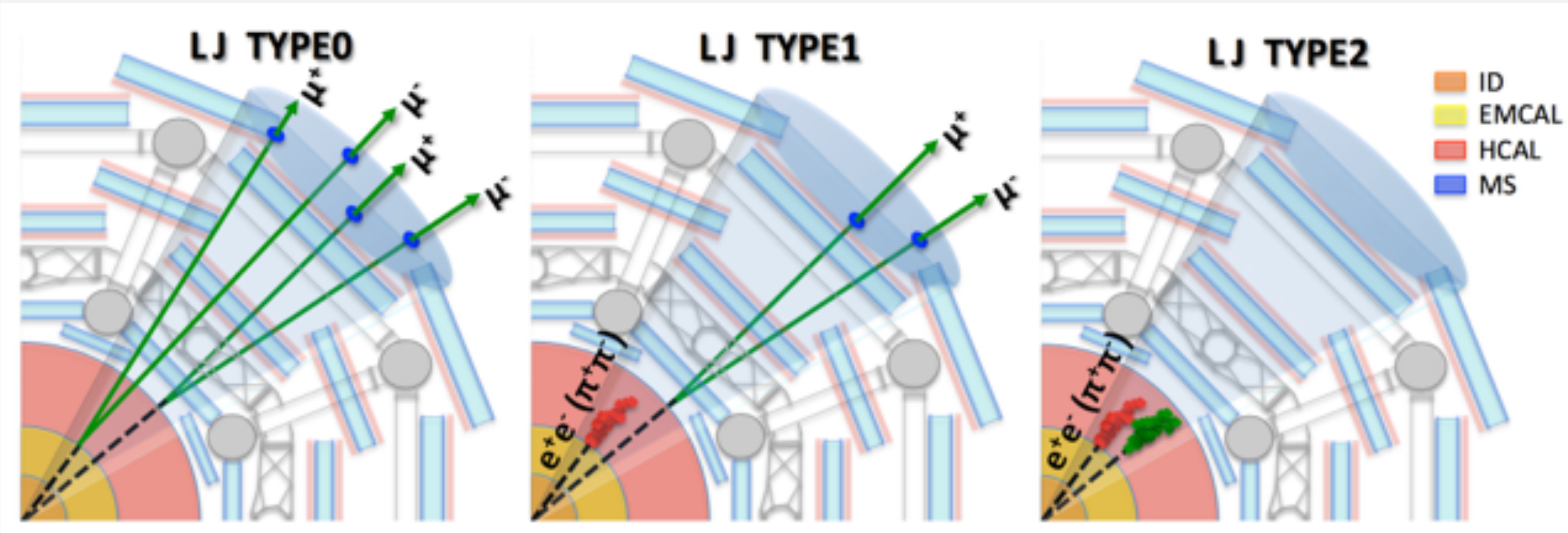


Reconstruction efficiency of two 100 GeV LJs ~ 0.36. We estimate the bound by requiring < 15 2eLJs events (90%CL) @ 8 TeV

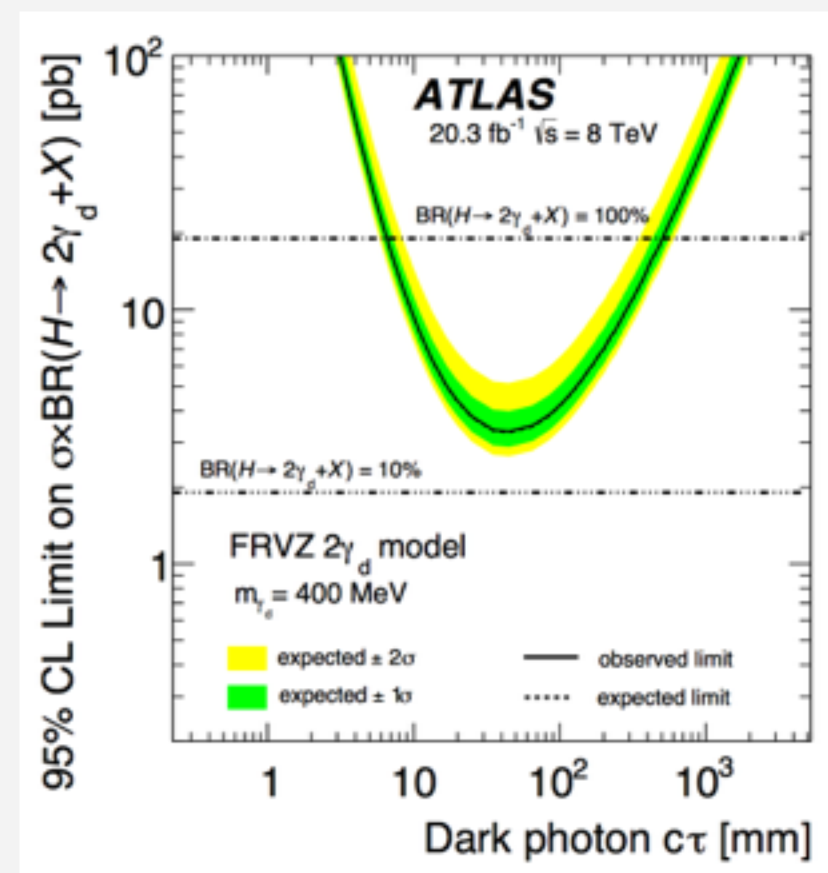
CERN-PH-EP-2015-242



2 γ_d after ECAL: displaced lepton-jet



CERN-PH-EP-2014-209

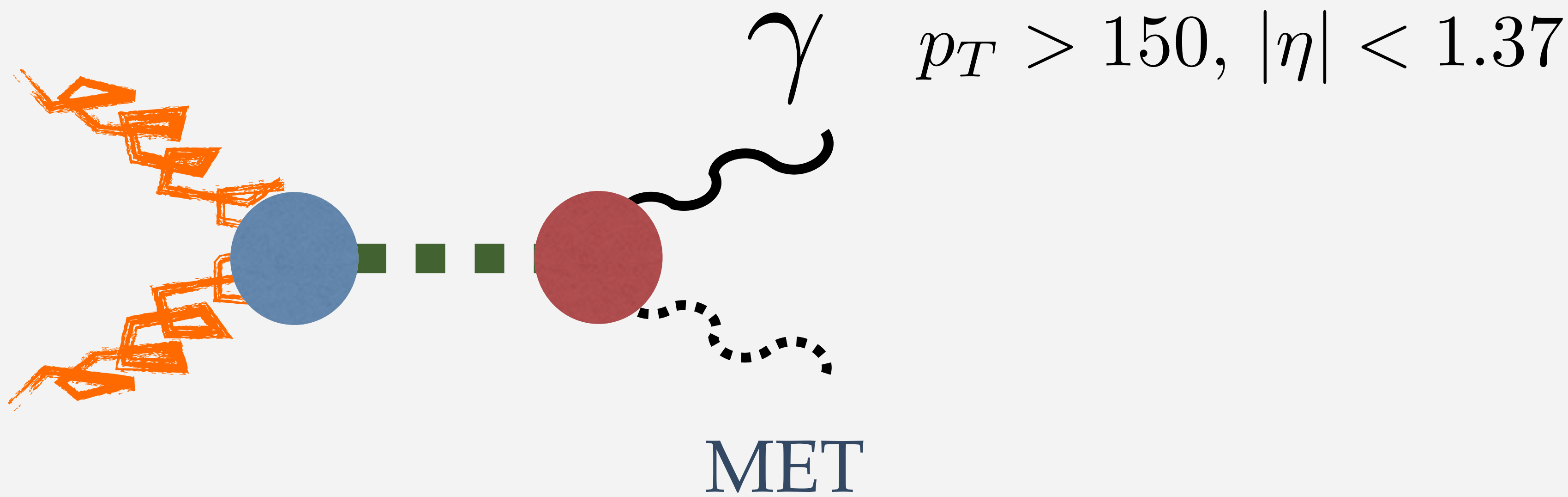


Reconstruction efficiency of 30 GeV LJs ~ 0.1

100 GeV LJs ~ 0.5

Even for 750 GeV decays into 2 LJs, the bound is still much weaker than 10 fb @ 8 TeV (corresponds to 45 fb @ 13 TeV if it's diphoton)

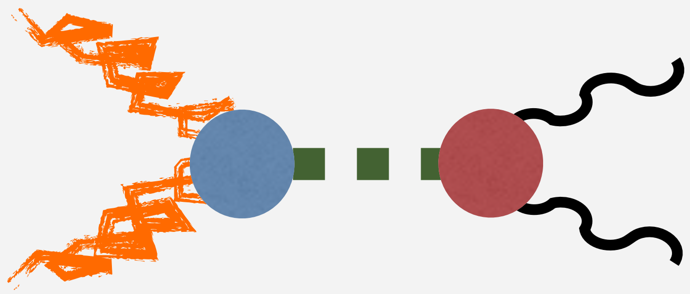
1 fake $\gamma + \gamma_d$ after ECAL: mono-photon + MET

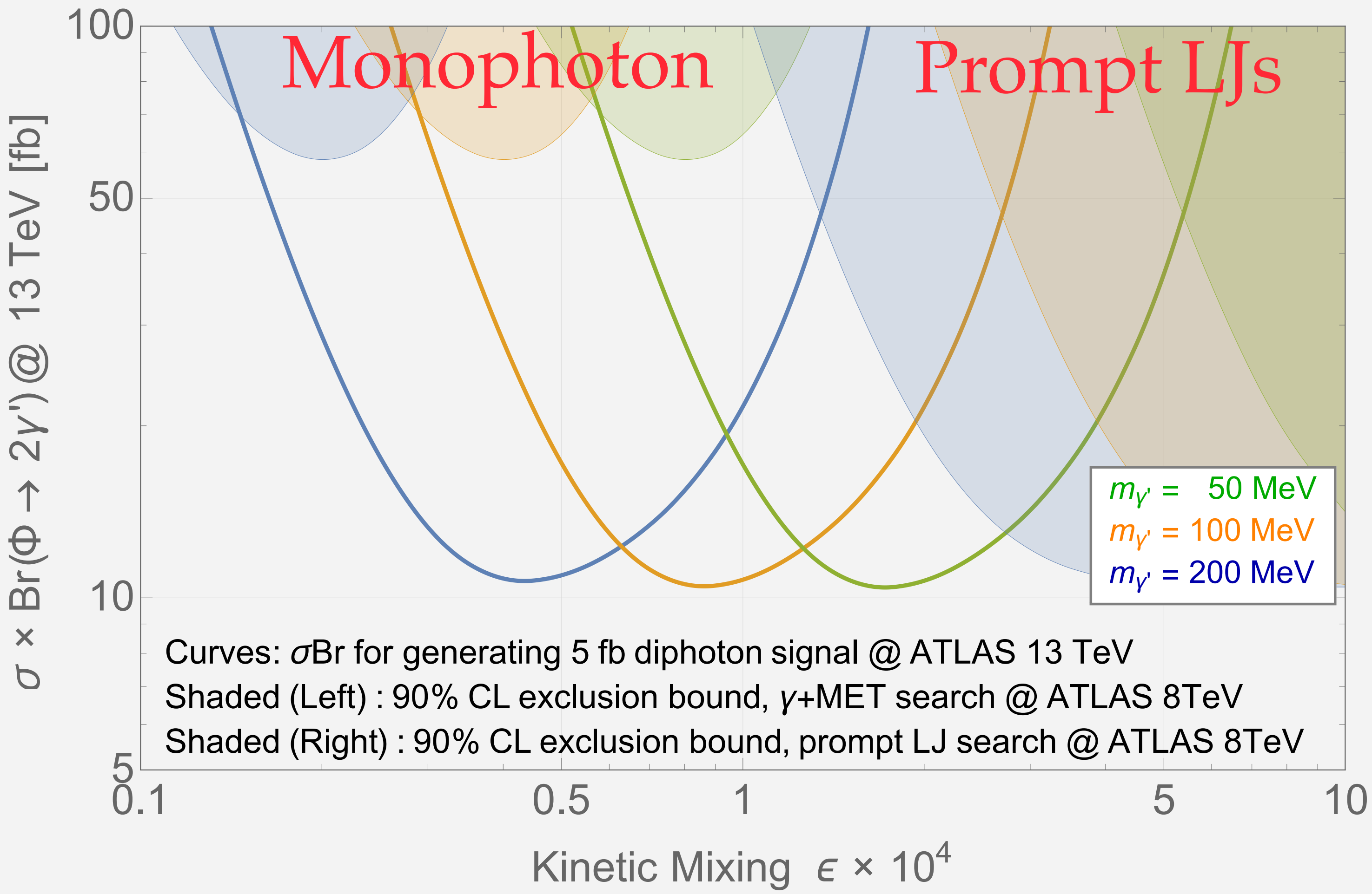


CERN-PH-EP-2014-245 (ATLAS 8 TeV monophon)

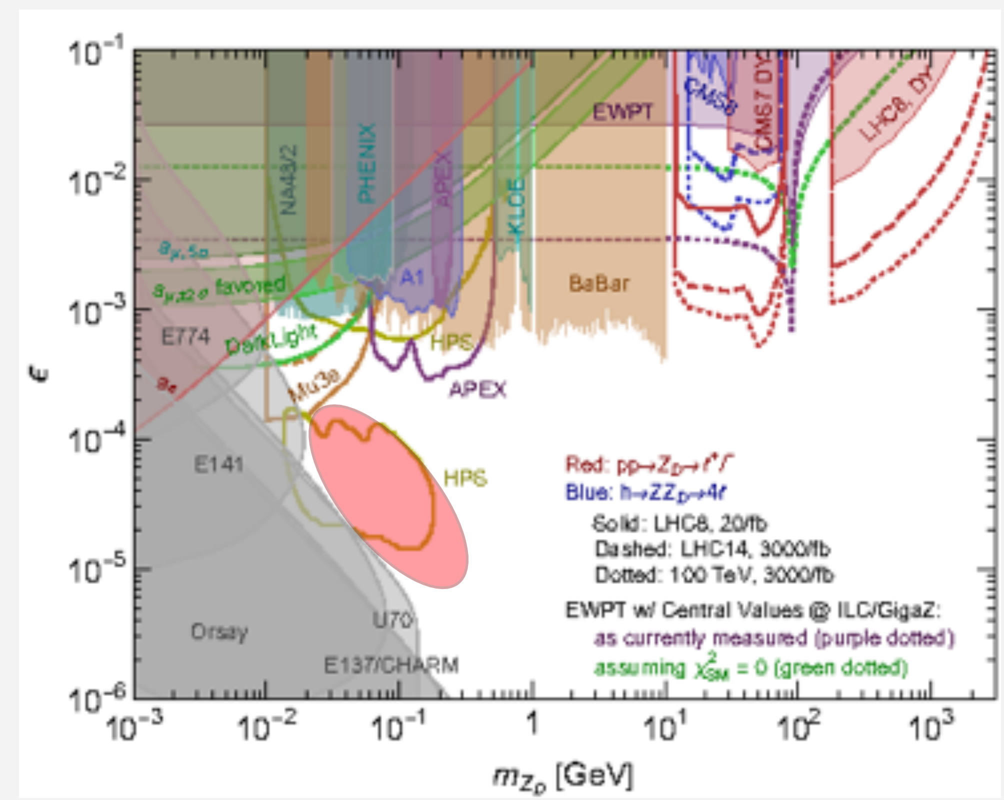
The vector momentum imbalance in the transverse plane is obtained from the negative vector sum of the reconstructed and calibrated physics objects and is referred to as missing transverse momentum, $\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$. The sym-

Apply to the 750 GeV diphoton



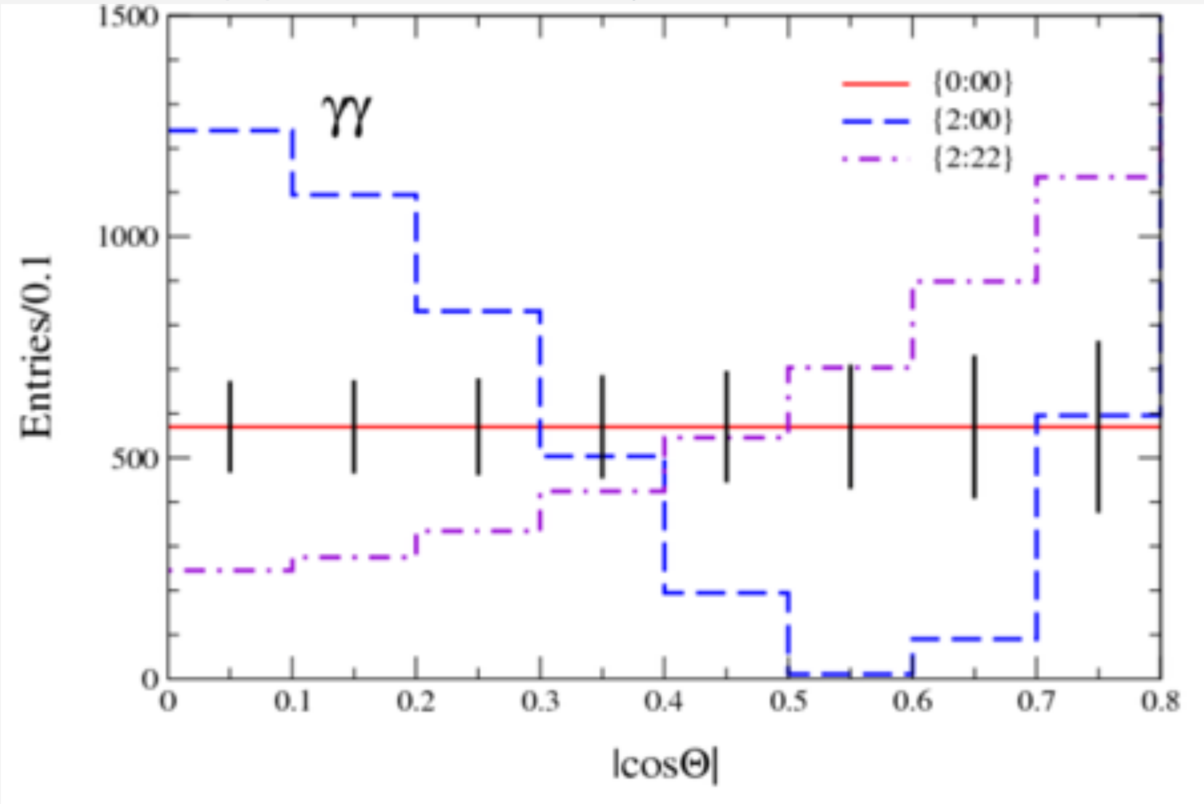


Curtin, Essig, Gori, Shelton 1412.0081

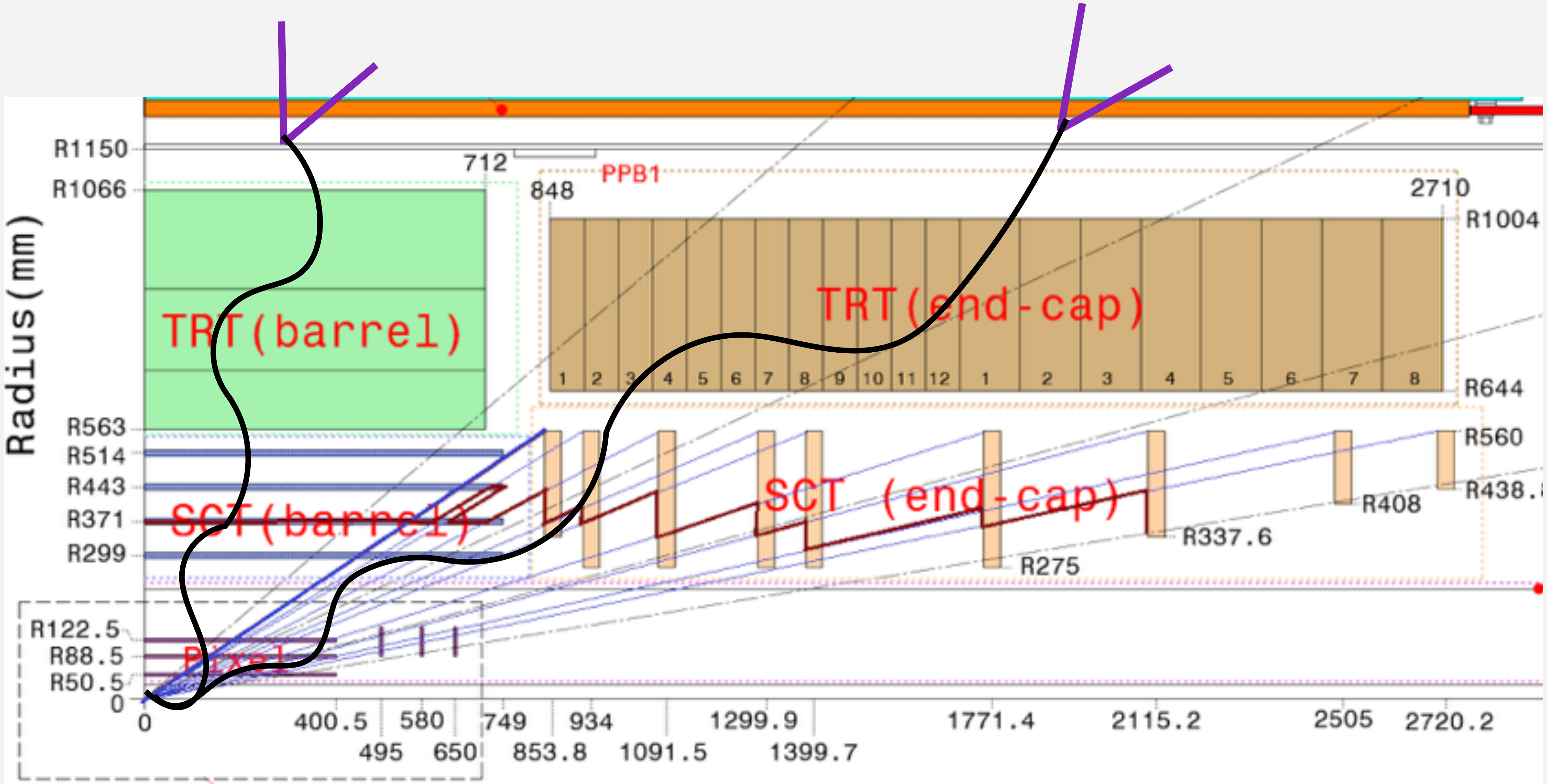


Lifetime-dependent Angular Distribution

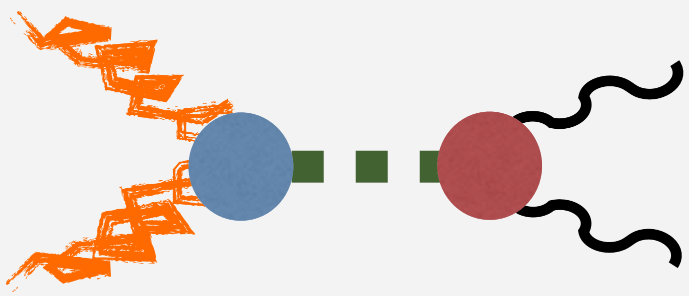
Higgs spin analysis 1209.5263

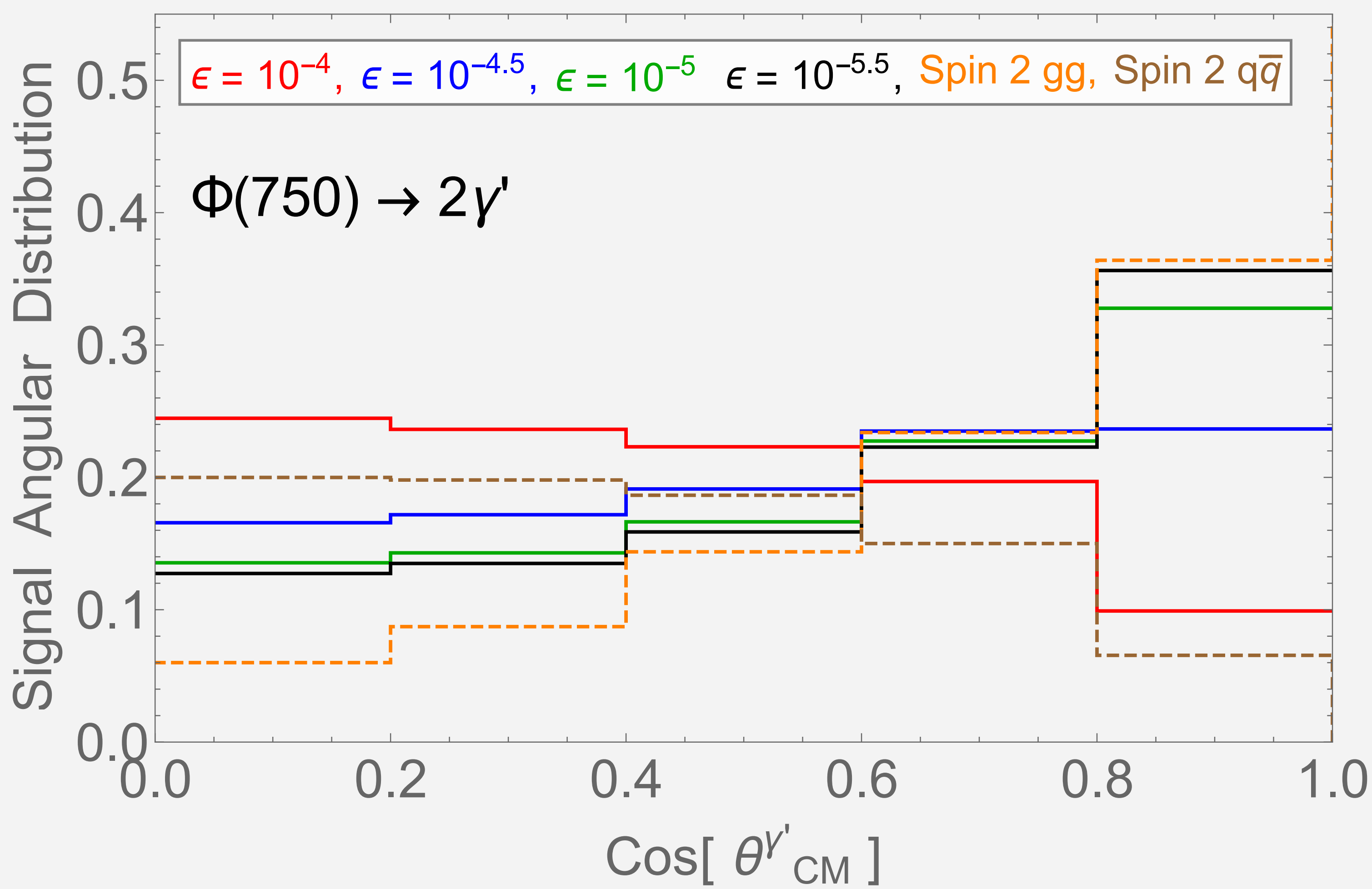


Slower decay fakes more forward signal

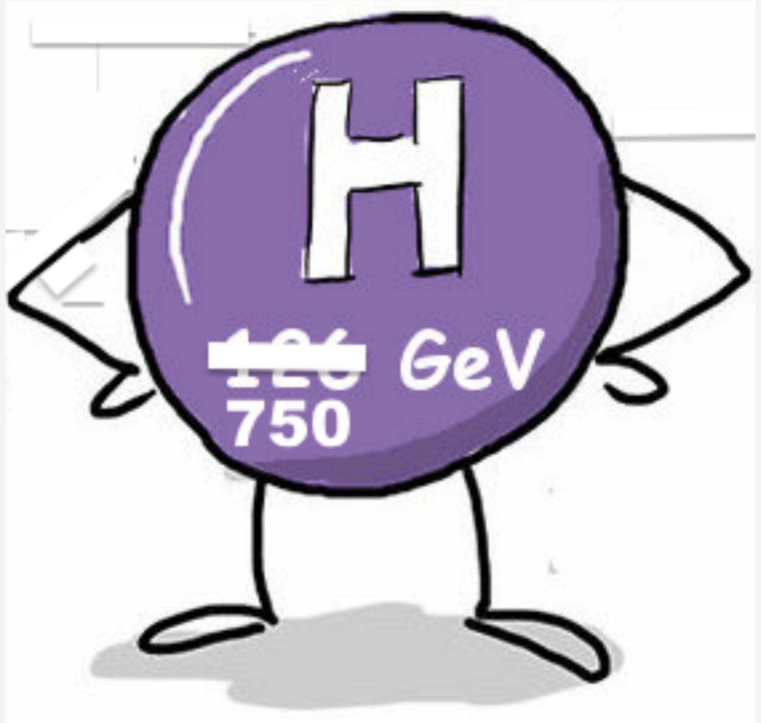


Fake a higher spin resonance from a lower spin





Application to the 750 GeV physics



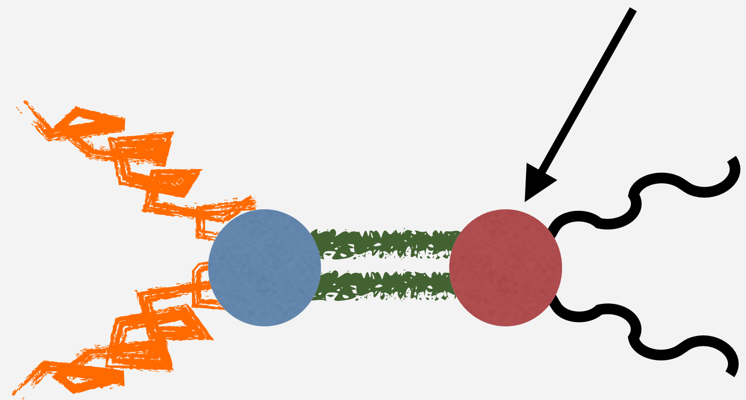
?

Roberto Vega-Morales

Challenges in generating the 750 GeV signal

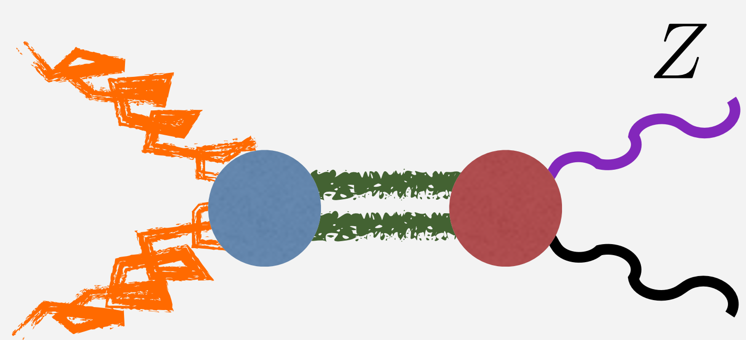
Large signal requires light or largely e-charged mediators

Much weaker constraints on darkly-charged mediators



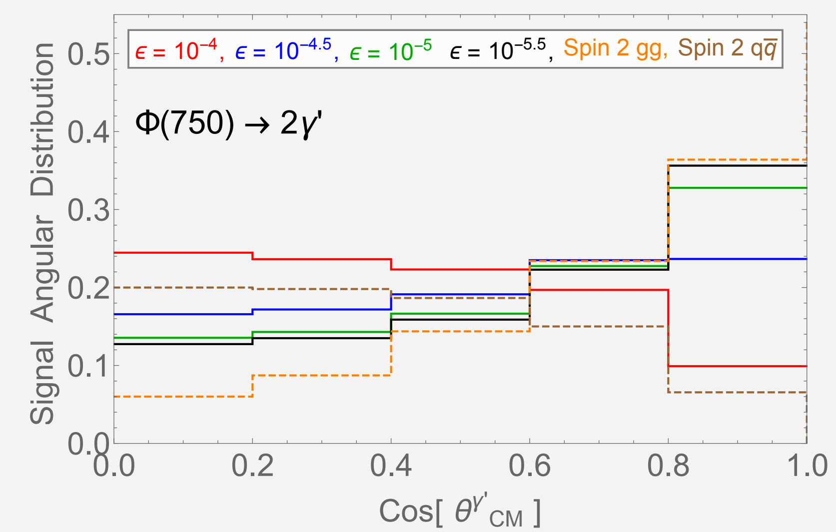
Bound from the Z+gamma search

The resonance can have a highly suppressed coupling to Z



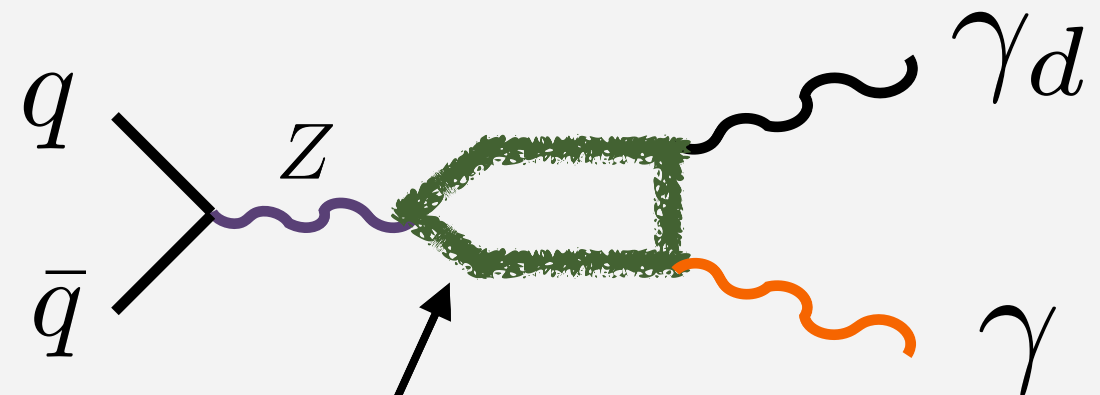
Additional feature

Fake the higher spin resonance



Allows the spin-1 resonance decay

$$\frac{e\, g_d\, g_H}{16\pi^2 M^2} F^{\mu\nu}_{V_H} F^{\alpha}_{\nu} F'_{\alpha\nu}$$



Vector bound state of EW-charged quirks, usually suffers a strong e+e- constraint if 750 is the pseudo-scalar

Conclusion

Dark signals may be around us!

Fake photons from the dark photon decays is a good example

The fake SM signals can explain the weird signals

e.g., easier 750 explanation, non-trivial angular distribution

We can distinguish these signals eventually,

but some works are required

When study collider constraint on dark photon decays,

part of the signals may be identified as SM photons