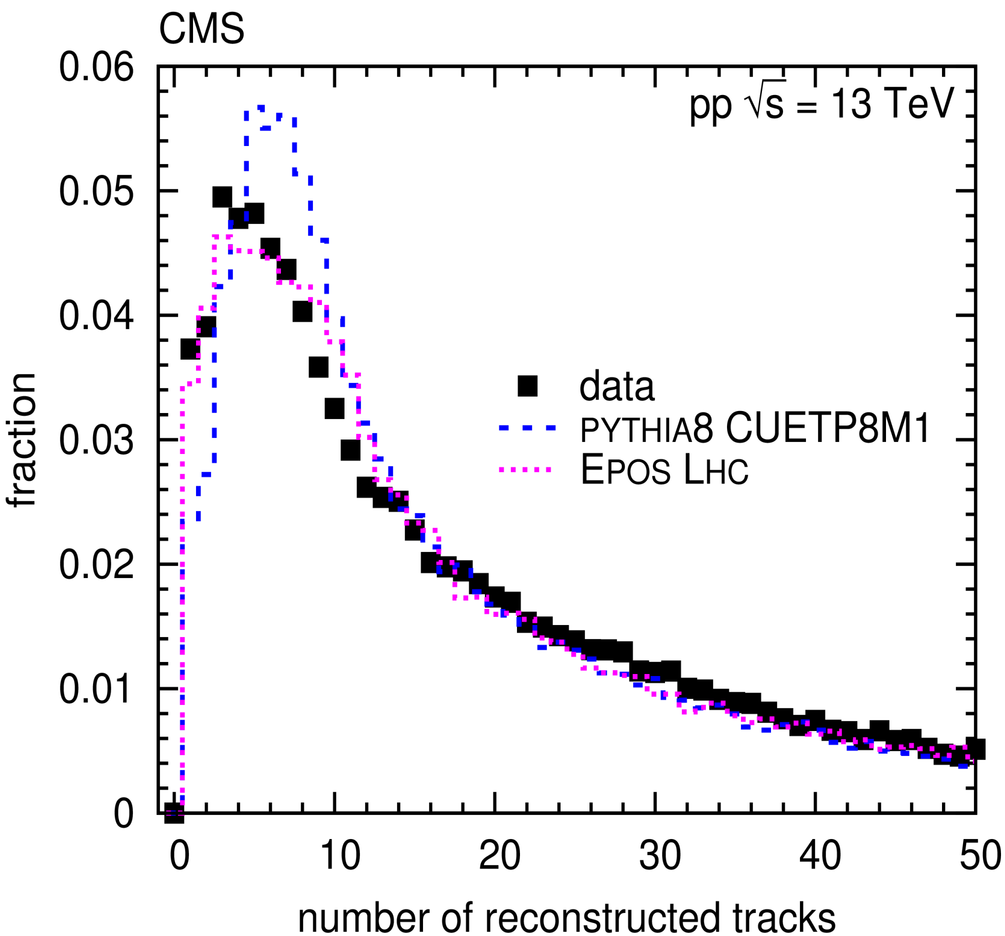
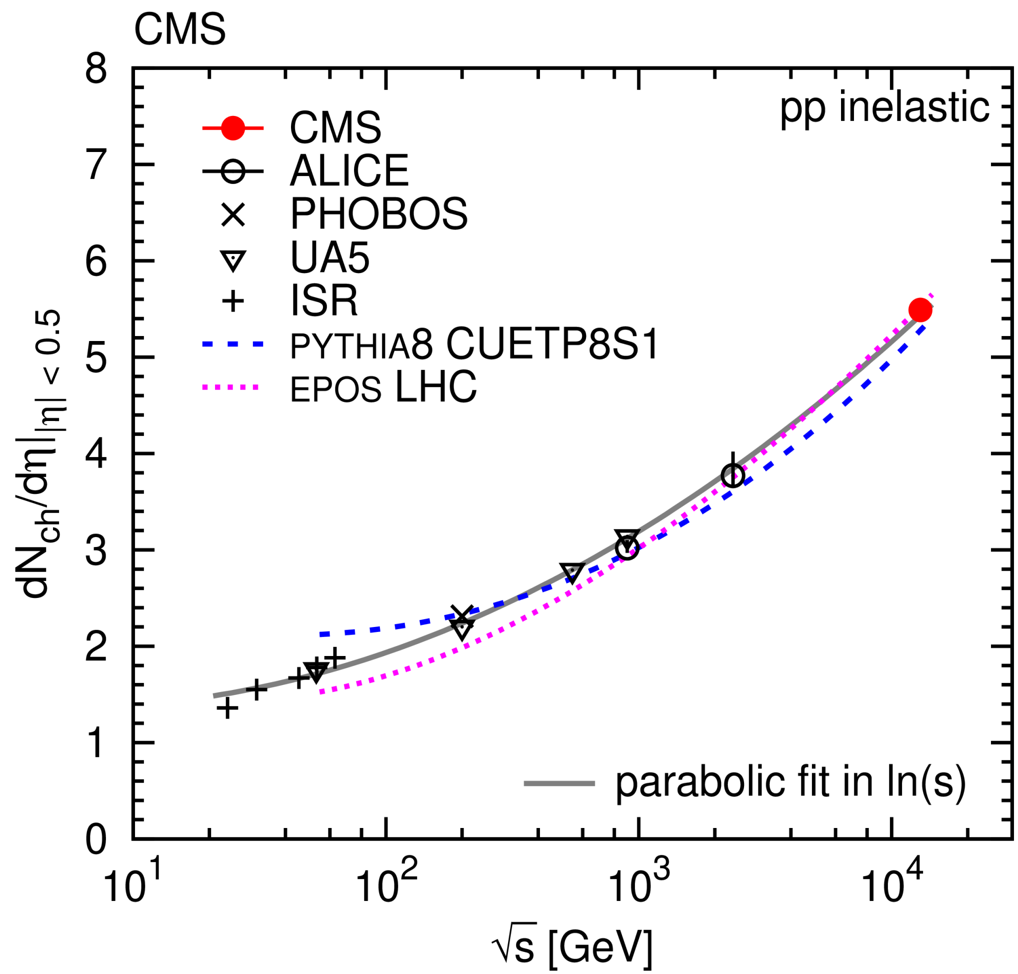
Run /I in CMS

P.Harris

One result so far

- In the midst of calibrating/fixing the detector





We can still do physics without a magnet!

arxiv/1507.05915

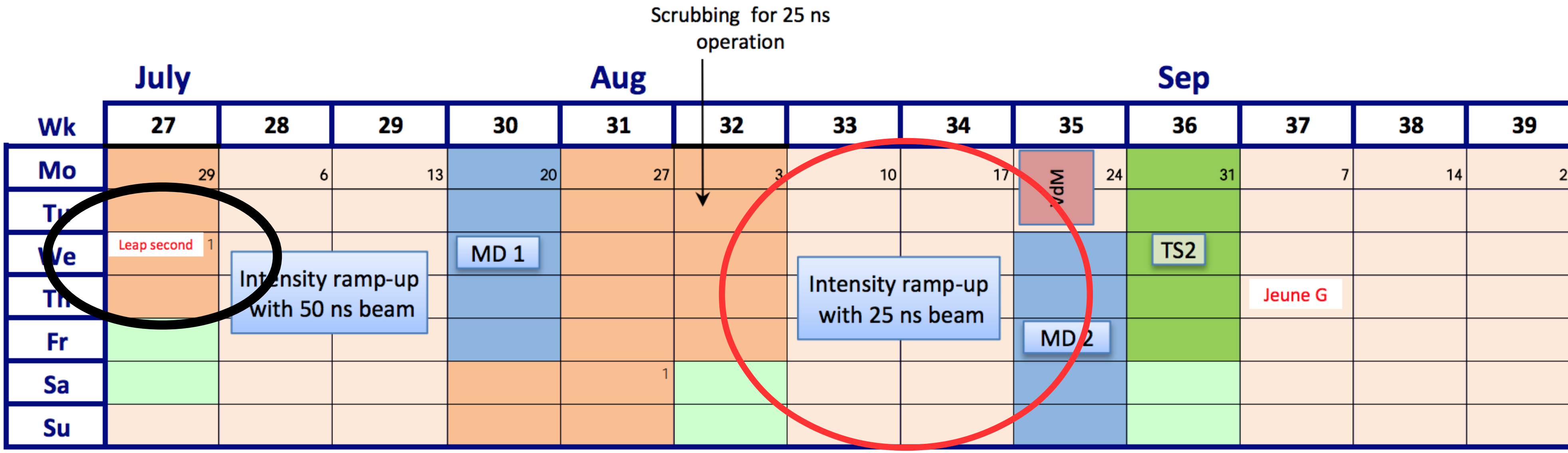
Whats happened to get to Run ||I

- Main questions :
  - Can we deal with higher pileup? (Satoshi's talk)
  - Can we deal with higher p_T?

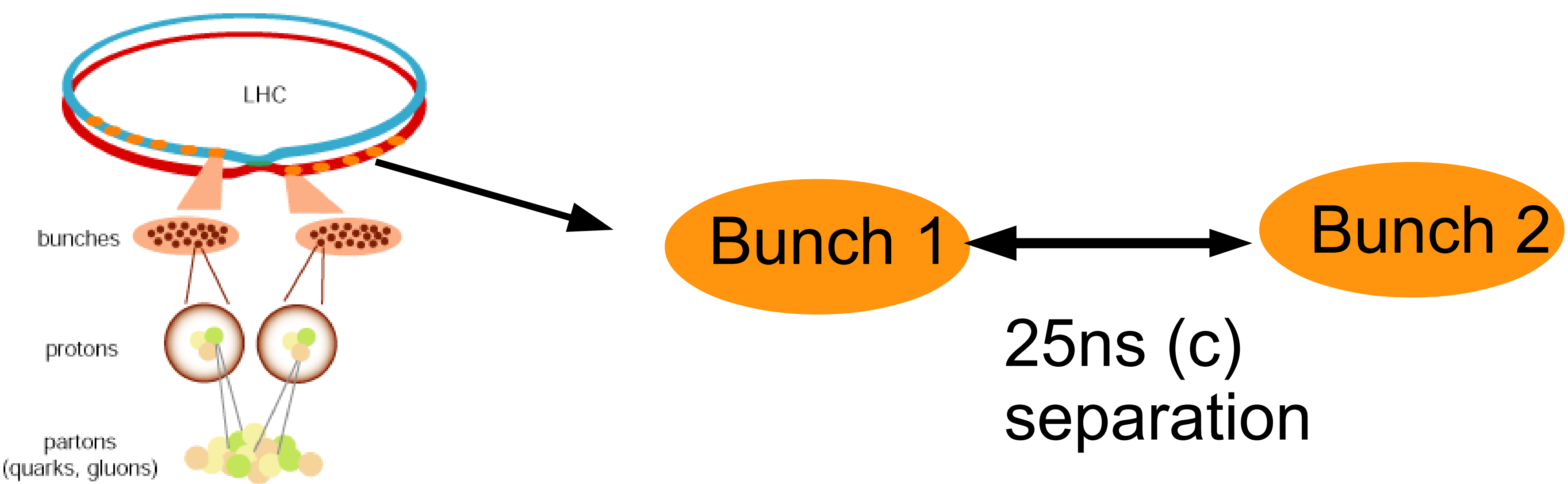
    (Andreas' talk from last boost)
  - Can we deal with 25ns running? (this talk)
  - How does this all project to the future (this talk)
  - Are we ready for run II?

Running at 25ns Spacing

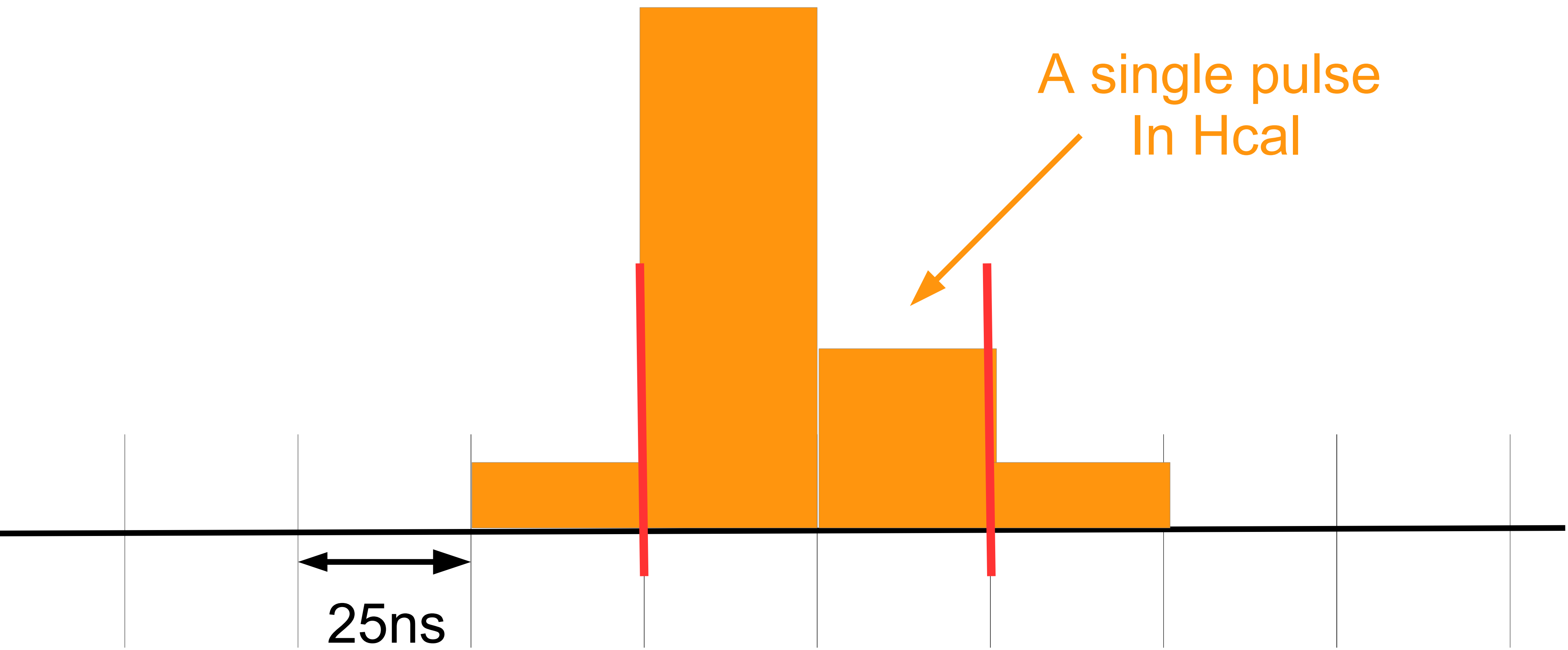
LHC running schedule



This week collider is going to run with 25ns spacing



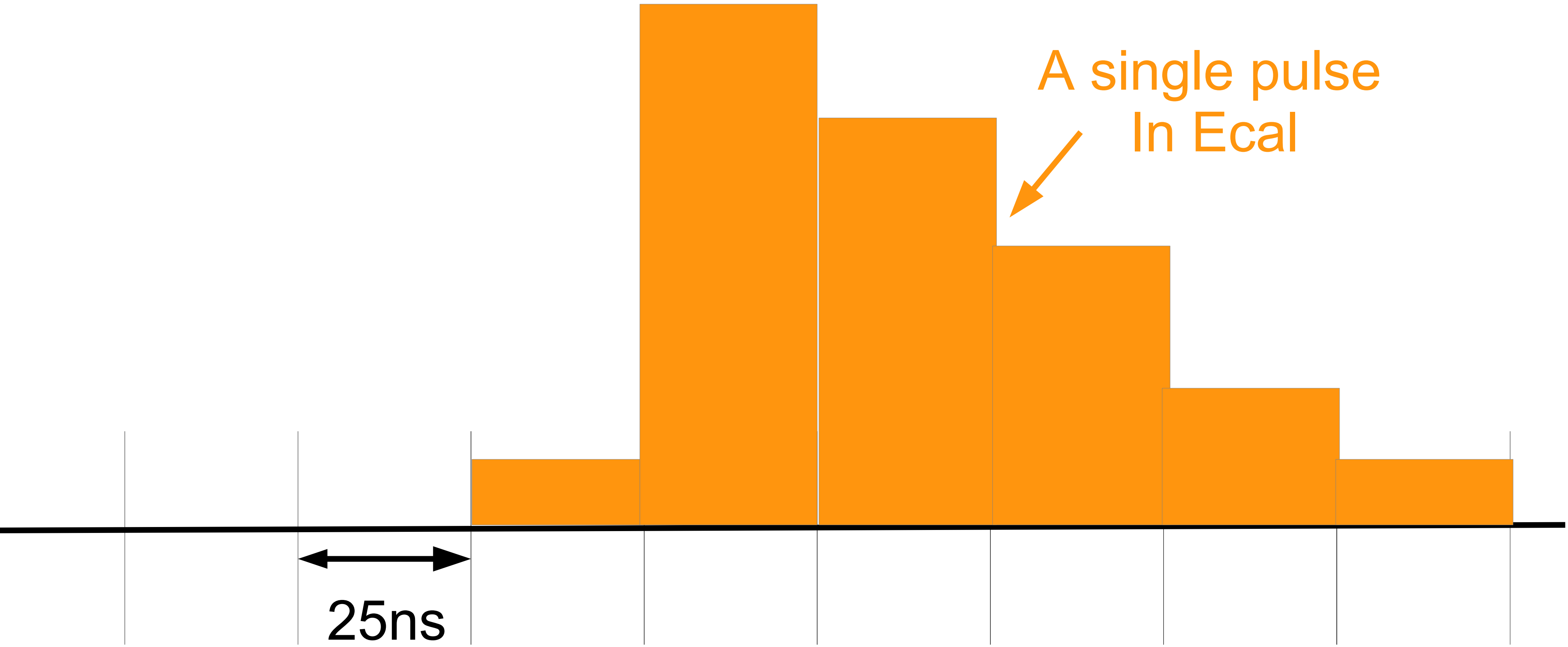
What does a pulse look like?



Total energy = Correction (Integration in a 50ns window)

Total Energy = $\int_{50ns\ range} dt$

What does a pulse look like?

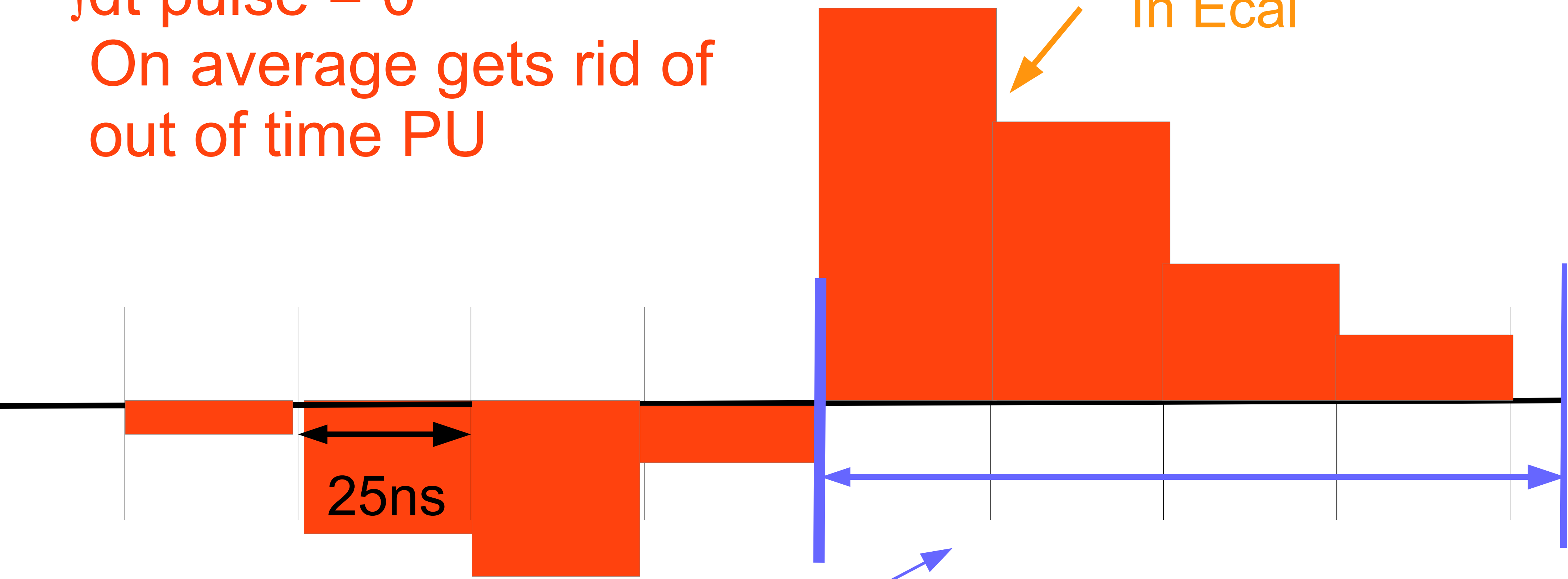


Pulse shape driven by electronics & physical energy recovery
Total Energy = Peak energy of transformed pulse

What does a pulse look like?

Pulse transformed to have
$\int dt$ pulse = 0
On average gets rid of
out of time PU

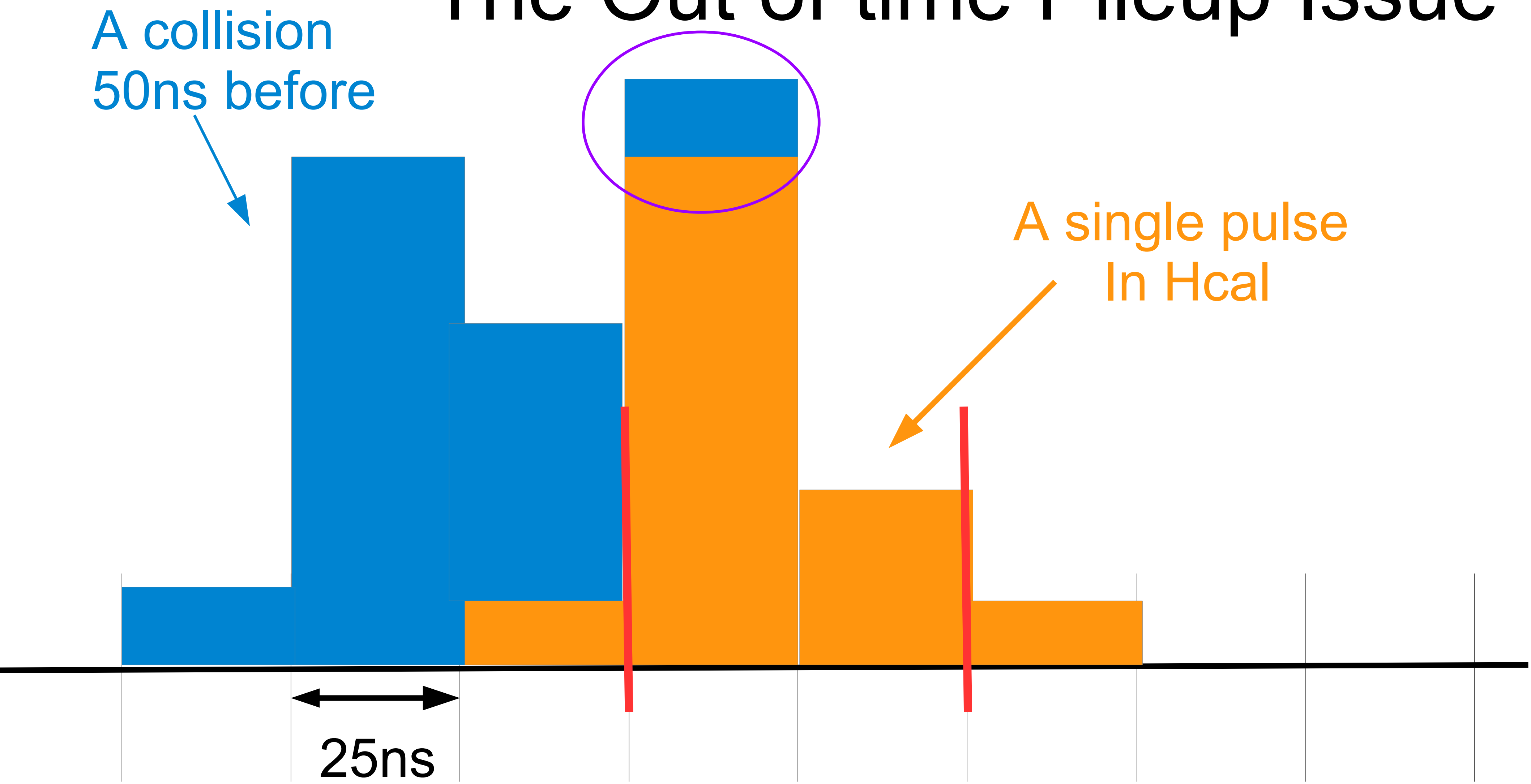
A single pulse
In Ecal



Pulse shape driven by electronics & physical energy recovery

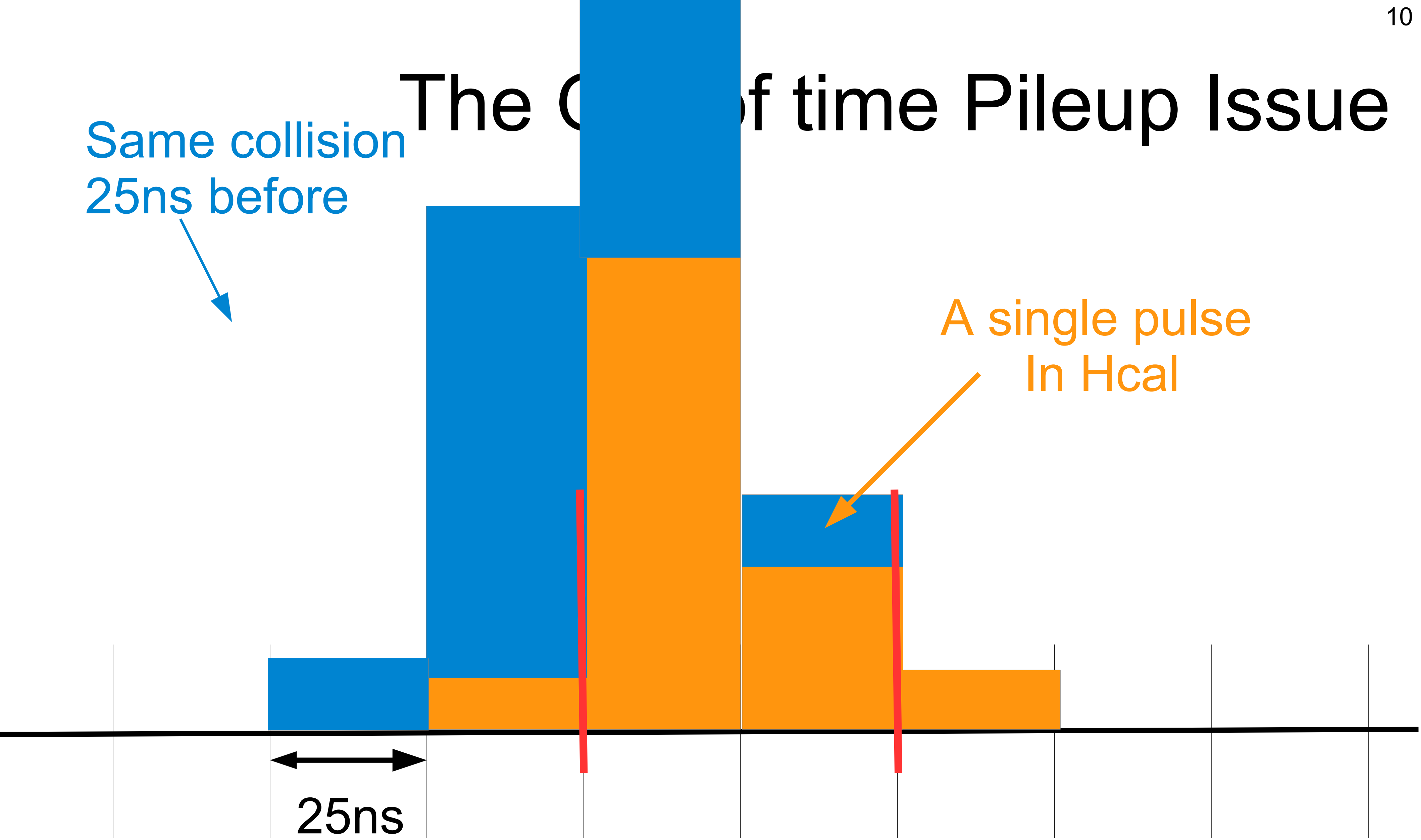
Total Energy = $\int_{125\text{ns range}} dt$

The Out of time Pileup Issue



With 50ns ouf ot time pileup we have small bias

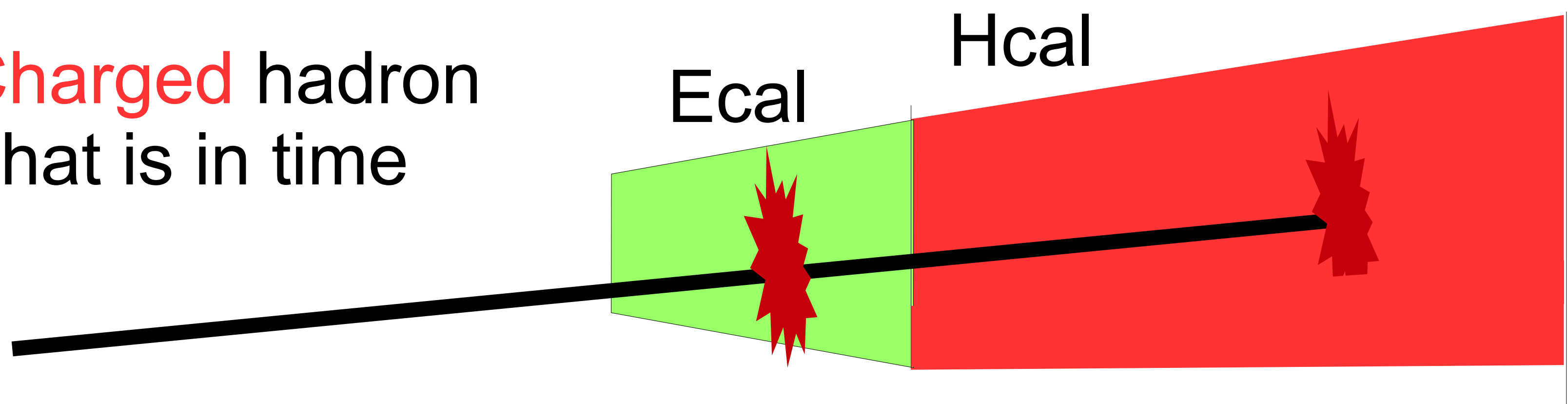
The Out of time Pileup Issue



With 25ns ouf ot time pileup we have large bias

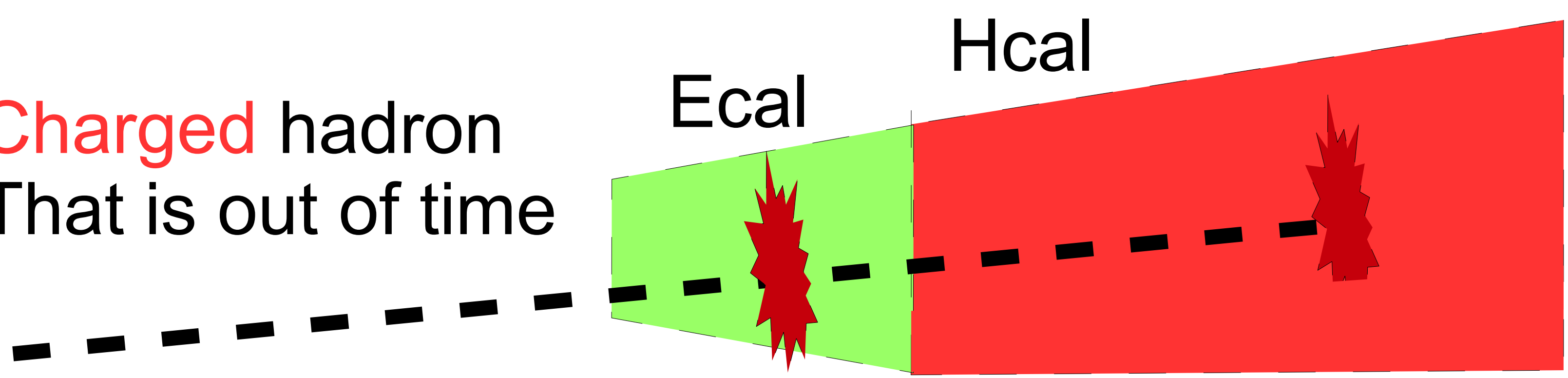
Why is out of time pileup important?

Charged hadron
That is in time



Track + Ecal + Hcal => Track dominates energy measurement

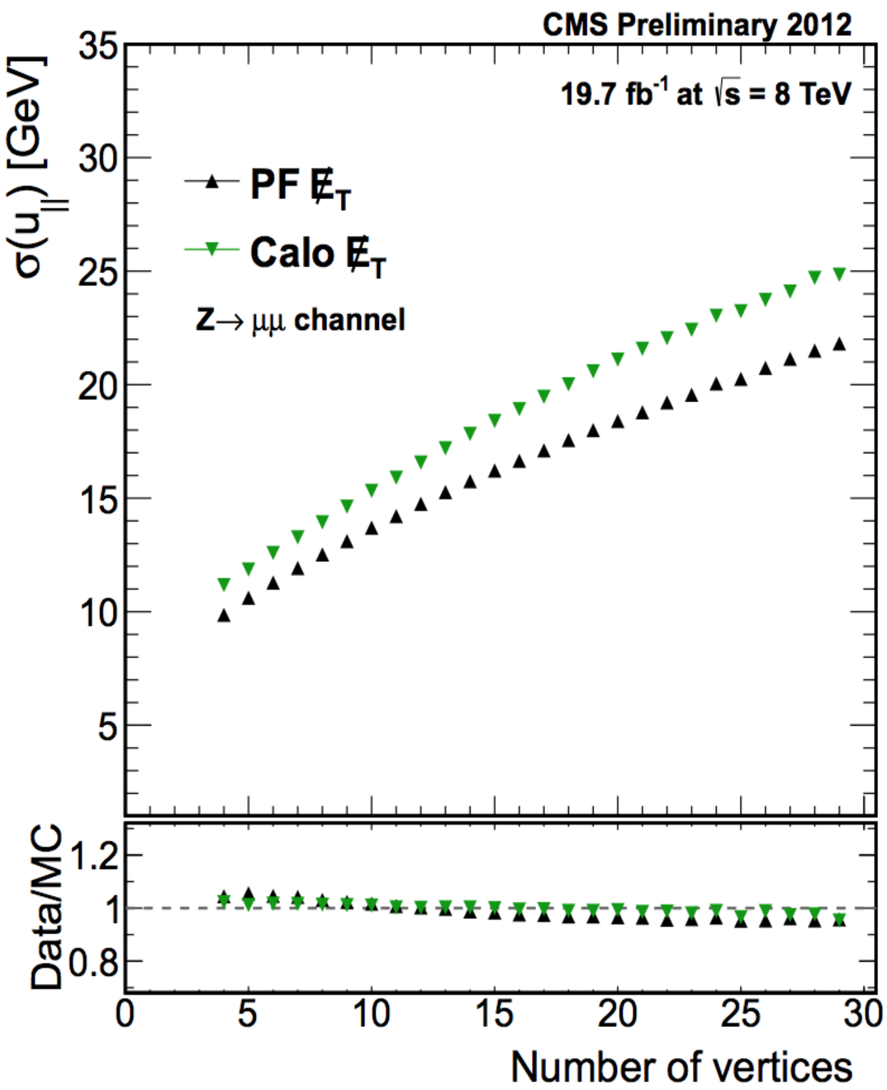
Charged hadron
That is out of time



No Track

Ecal + Hcal => Calorimeters dominate out of time

Affect of OOT in Particle flow



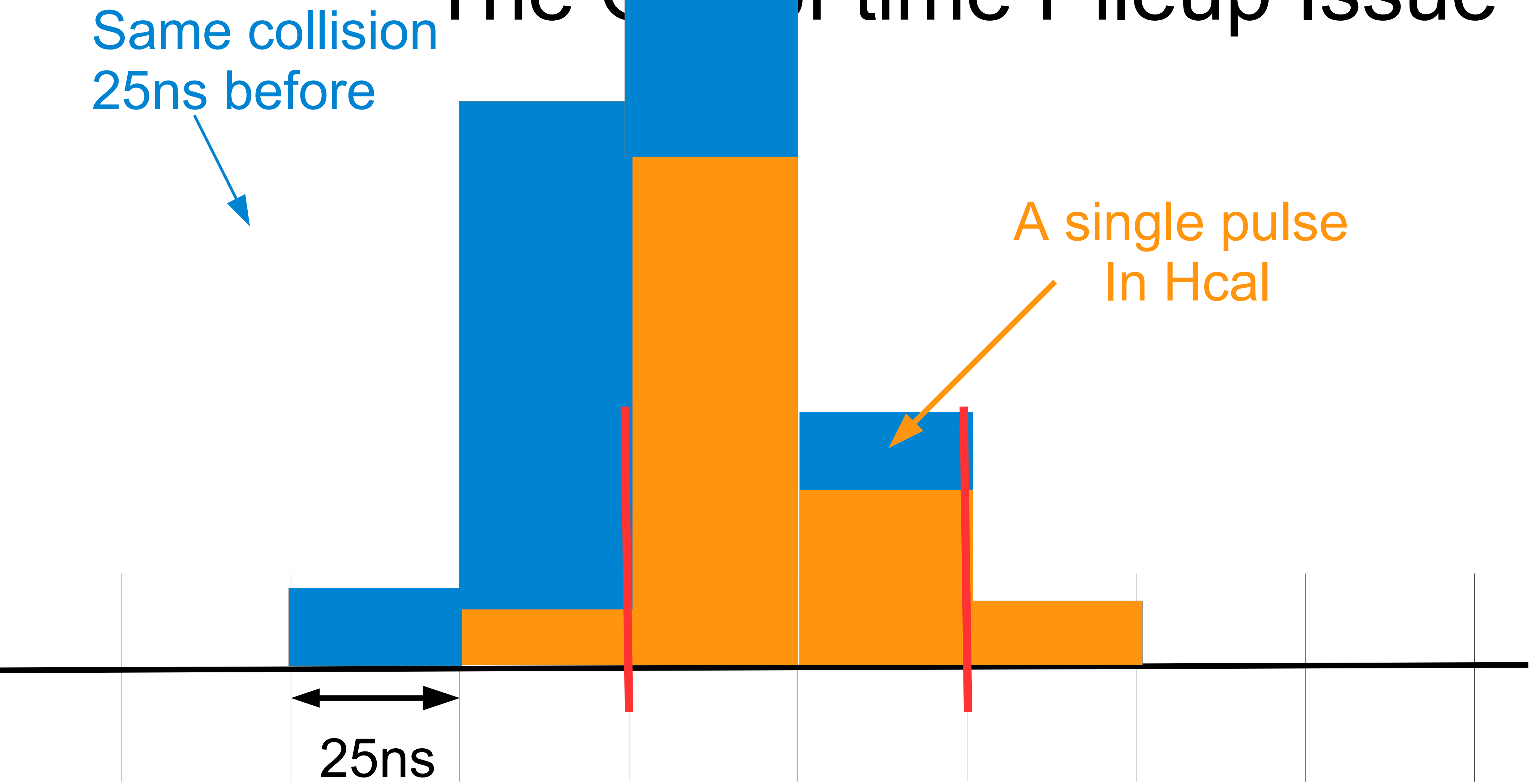
For no OOT cleaning
(as was the case for Hcal) :

$$\sigma_{MET} = \sigma_{PF}(N_{PU}) \oplus \sigma_{Calo}(N_{OOTPU})$$

Out of time pileup
Rapidly degrades *MET*

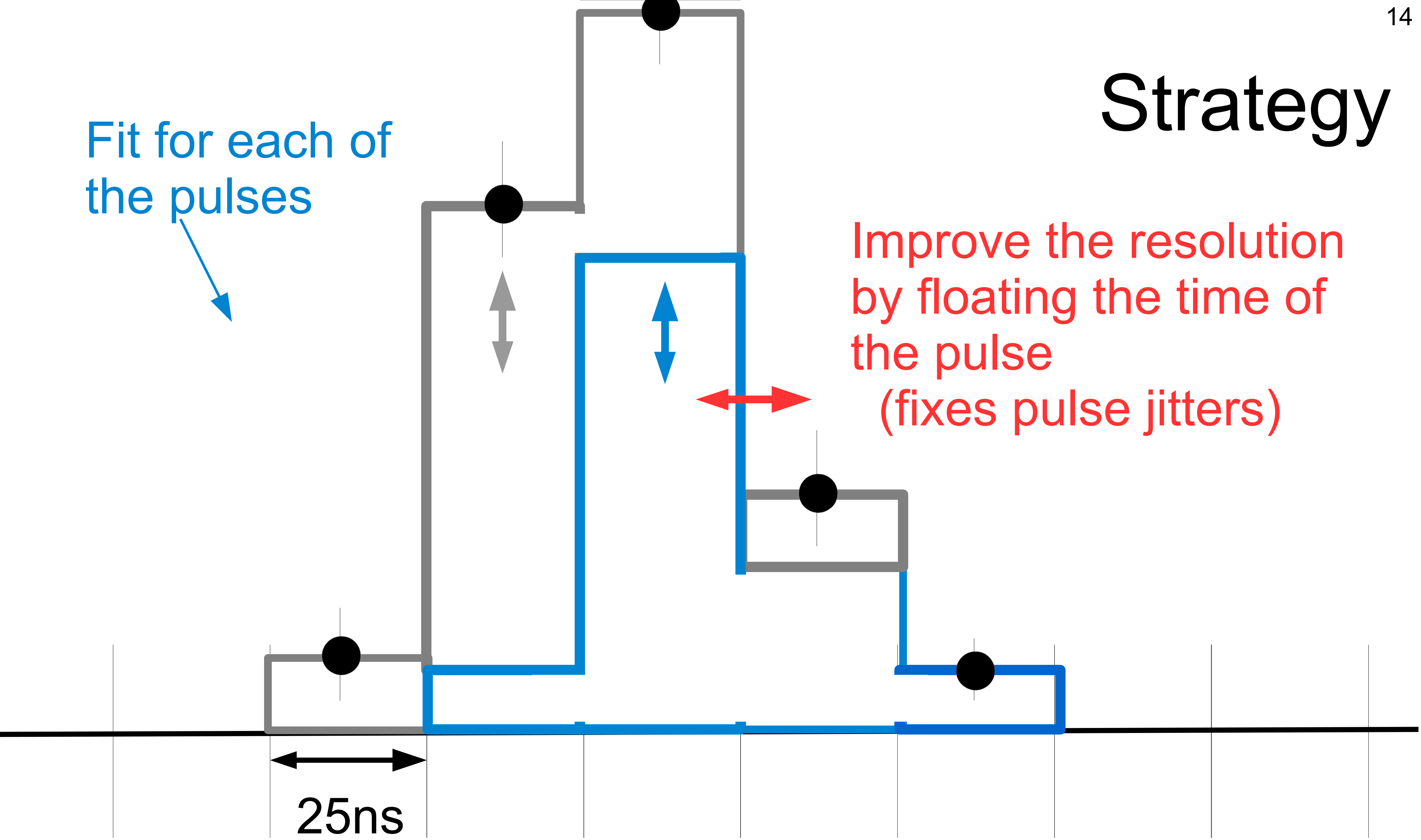
CMS-JME-13-003

The C[illegible]f time Pileup Issue



With 25ns ouf ot time pileup we have large bias

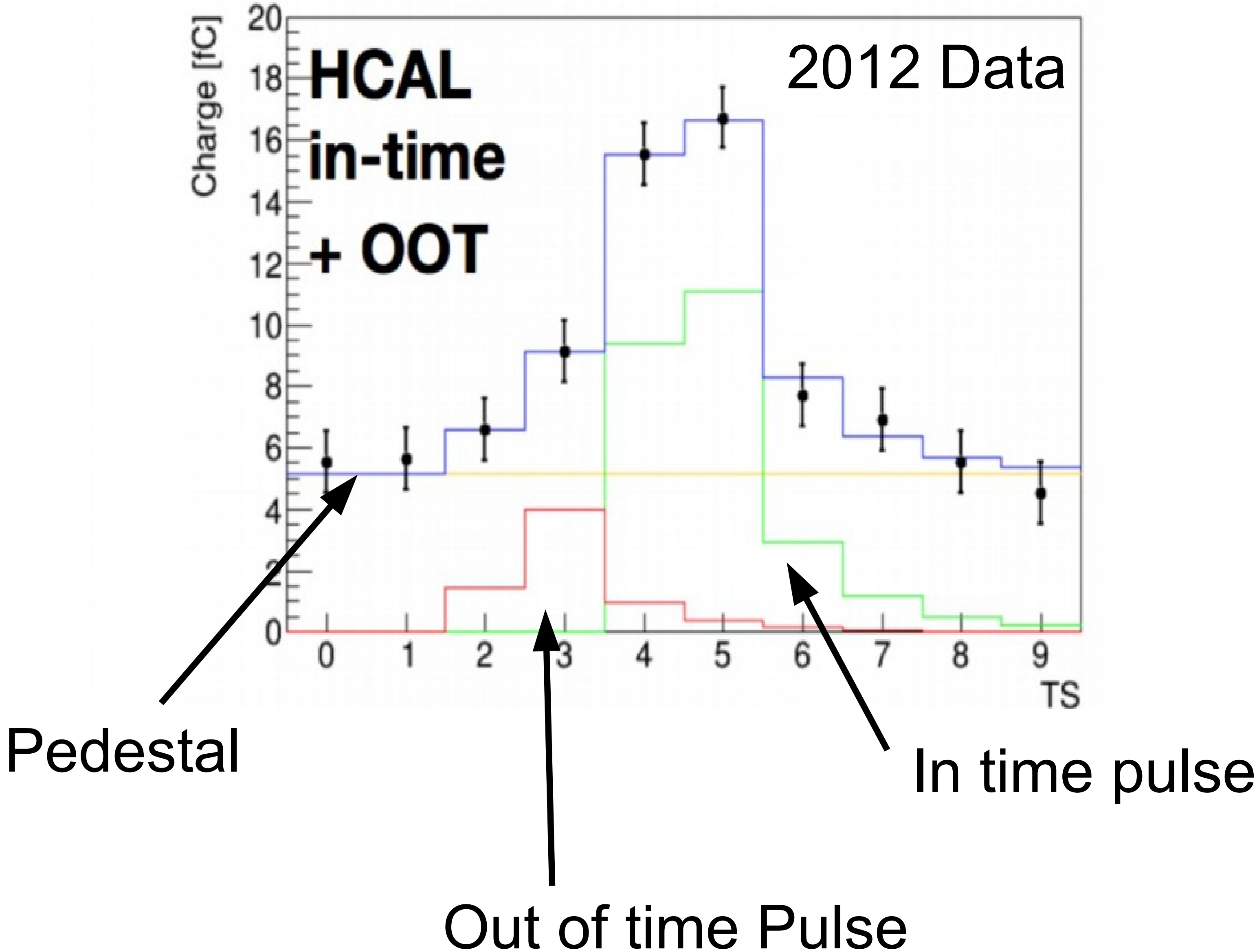
Strategy



Fitting for the pulses requires we know their shapes

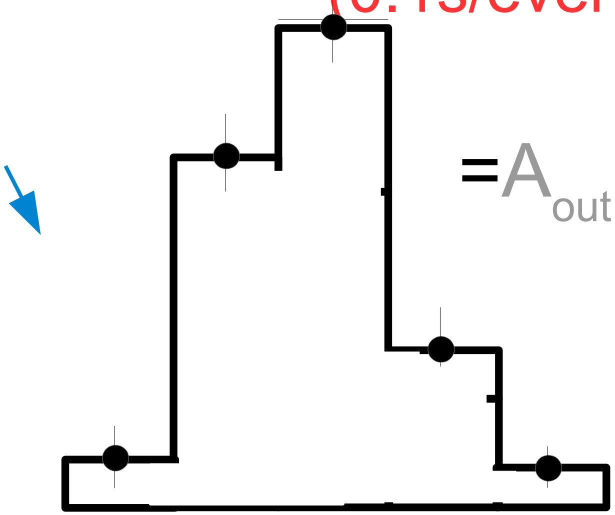
How does it look?

- Example Hcal Pulse

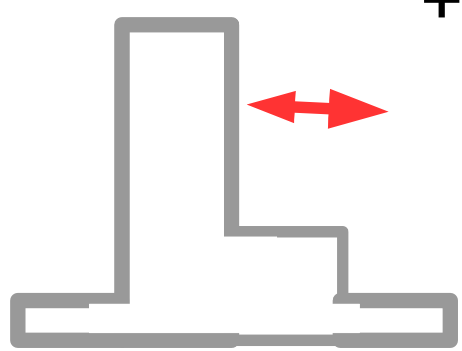


Challenge

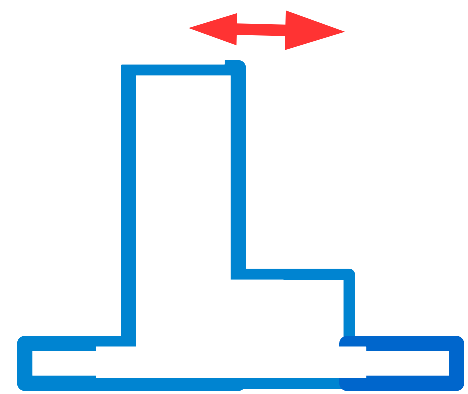
- Challenge of fitting the pulse :
  - There are O(>10,000) crystals in Ecal
  - There are O(1000) towers in Hcal
  - Need to fit pulse for all of these cells in time to trigger (0.1s/event)



$= A_{\text{out of time}}$



$+ \ldots + A_{\text{intime}}$



Simplest form minimize :

$$X^2 = \frac{(s_i - \Sigma_j A^i_j)^2}{\sigma_i^2}$$

Hcal Approach

- Pulses have a time jitter (roughly 3ns)
  - Pulses are quite narrow
  - Additional amplitude dependent time variation
  - Baseline(Pedestal) variations of 0.2-0.5 GeV
- Perform full minimization of 3/4 central pulse
  - For b_i basline (pedestal)

$$\chi^2 = \frac{(s_i - A^j p^j_i - b_i)^2}{\sigma^2_p} + \frac{(t-t_i)^2}{\sigma^2_{time}} + \frac{(b_i - b_i^{mean})^2}{\sigma^2_{pedestal}}$$

$$\sigma_p^2 = \sigma_{noise}^2 + A^j p^j \sigma_{pulse}^2$$

Fast fitting: linearize fit in 1ns intervals

All pulse take < 0.5s (time constrainted for HLT)

Ecal Approach

- With wide pulses : solve for a pulse in each bunch
- Can reduce this to a system of 10 linear equations
  - By requiring A > 0 we constrain the full system

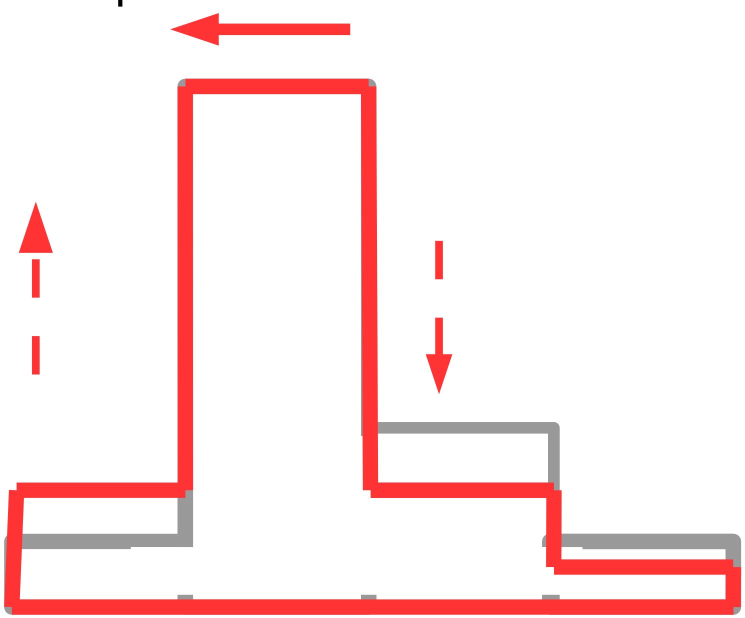
$$\begin{pmatrix} S_1 \\ S_2 \\ \cdots \\ \\ \\ S_{10} \end{pmatrix} = A_1 \begin{pmatrix} P^1{}_1 \\ P^1{}_2 \\ \cdots \\ \\ \\ P^1{}_{10} \end{pmatrix} + A_2 \begin{pmatrix} P^2{}_1 \\ P^2{}_2 \\ \cdots \\ \\ \\ P^2{}_{10} \end{pmatrix} + \ldots A_{10} \begin{pmatrix} P^{10}{}_1 \\ P^{10}{}_2 \\ \cdots \\ \\ \\ P^{10}{}_{10} \end{pmatrix} + \text{Pedestal}$$

Solve the system given the full uncertainty constraints

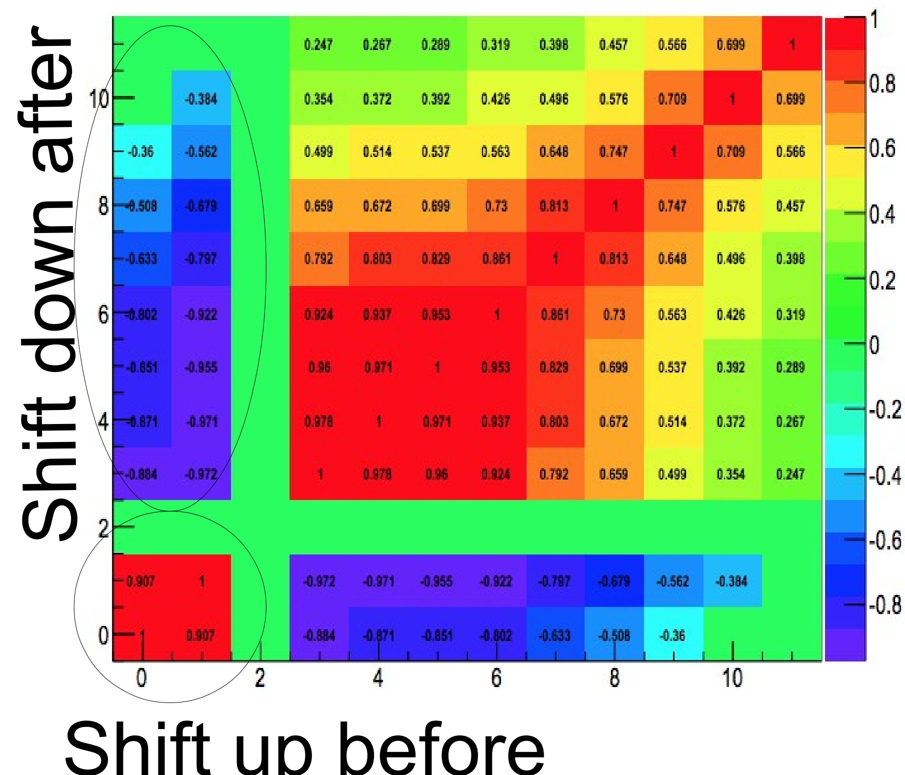
Constructing the Uncertainty

- Ecal pulses are well understood
  - Robust well understood time jitter (< 500ps)
  - Well established database of pulses
  - Keep a fast minimization by linearizing the fit

Shift in time corresponds to a shift up before peak and shift down after



Pulse covariance for peak at 2

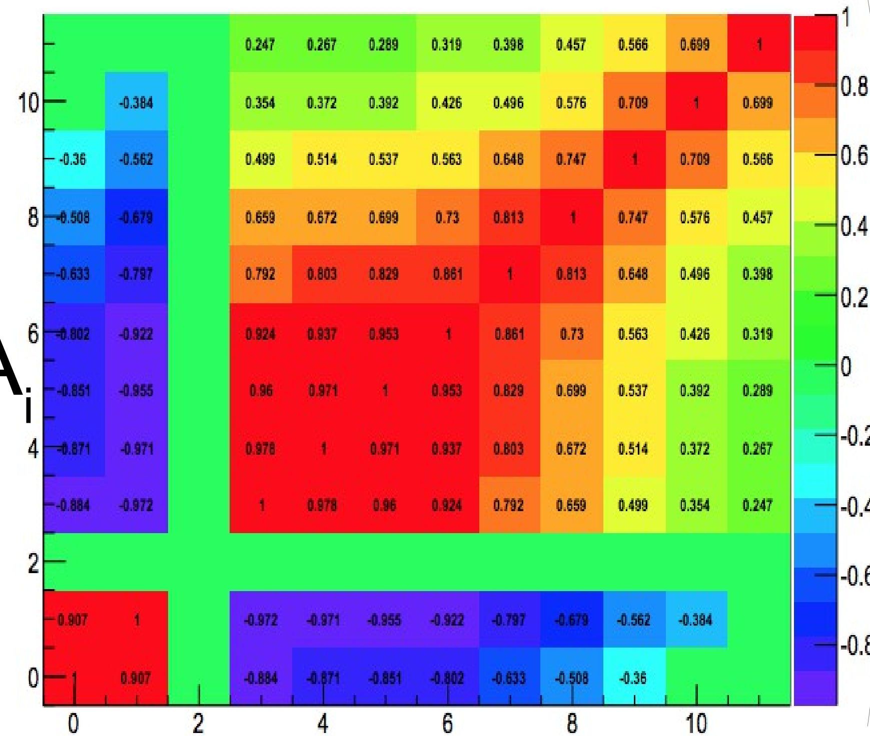


Fast Linearized fit for Ecal

- X^2 can be minimized quickly using NNLS
  - Pulse covariance unique to each ecal cell

$\delta_i = (A_j p_j)_i - s_i$

$$X^2 = \begin{pmatrix} \delta^1_1 \\ \delta^1_2 \\ \dots \\ \delta^1_{10} \end{pmatrix}^T \left(\Sigma_i A_i \right)^{-1} \begin{pmatrix} \delta^1_1 \\ \delta^1_2 \\ \dots \\ \delta^1_{10} \end{pmatrix}$$

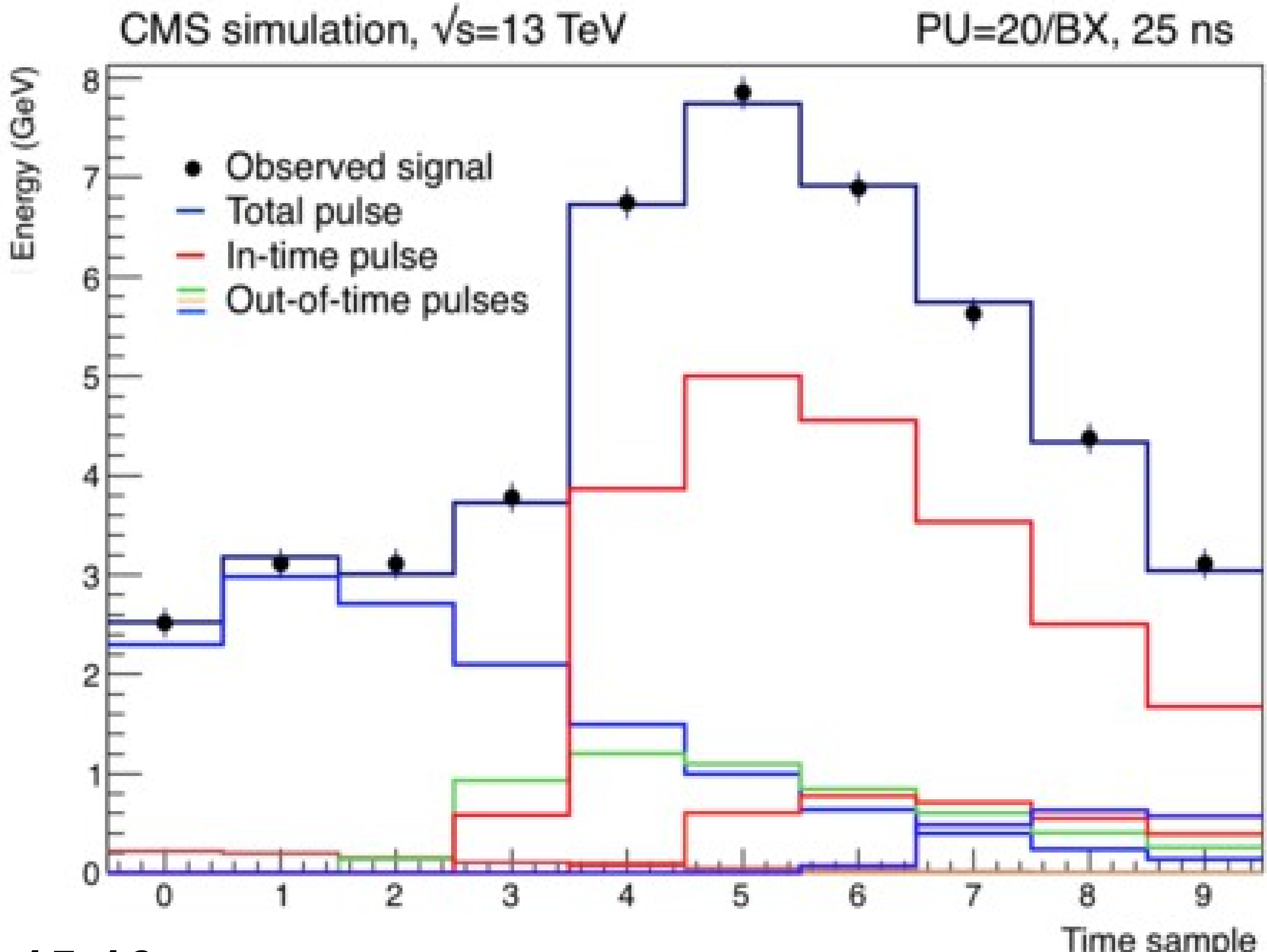


The full minimiation over all channels < 0.5s/event

Reduced version is used at HLT (10ms/event!)

25ns Calorimeter Strategy

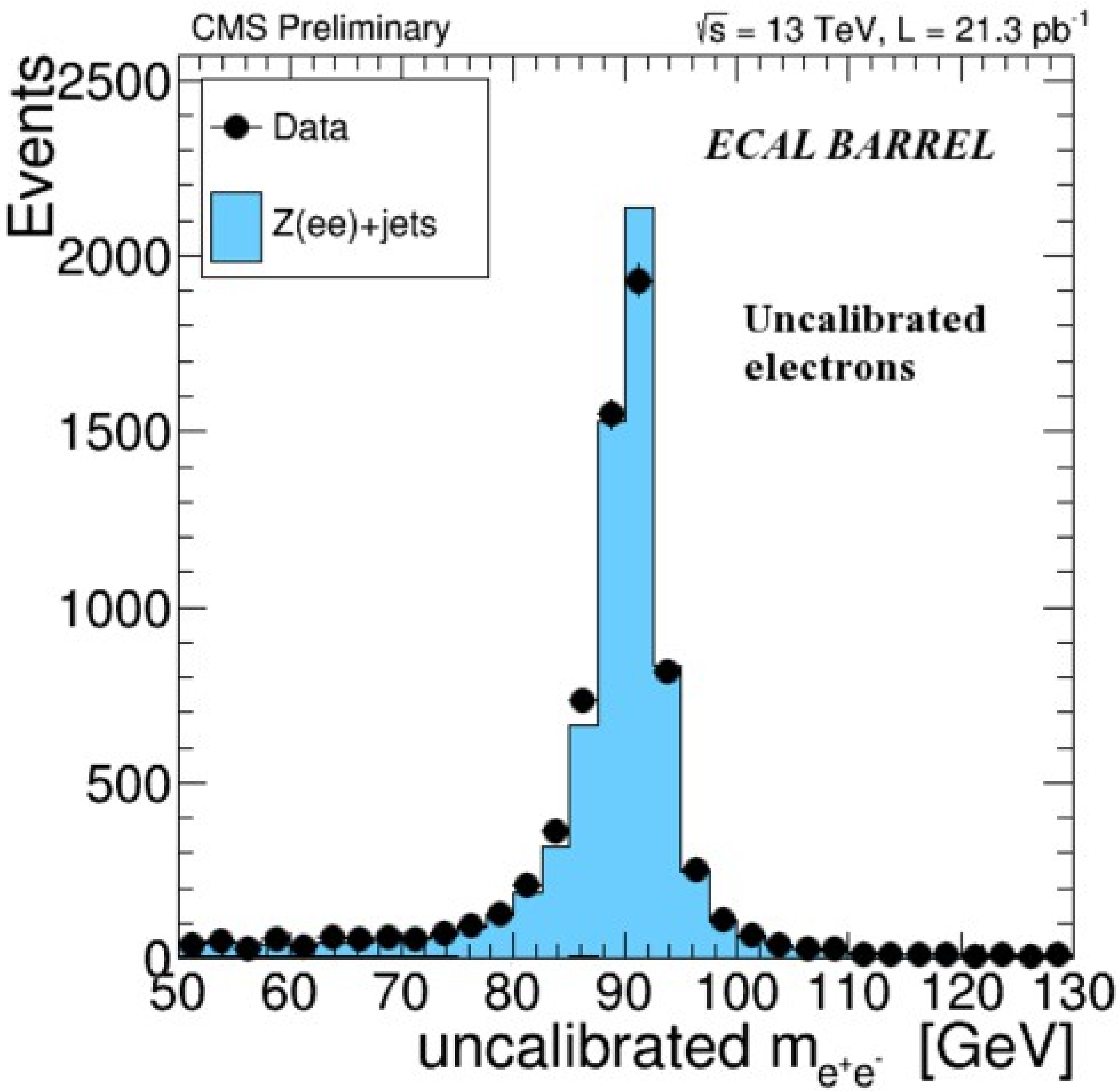
- Fit for the pulses



CMS-DP-15-16

Putting it all Together

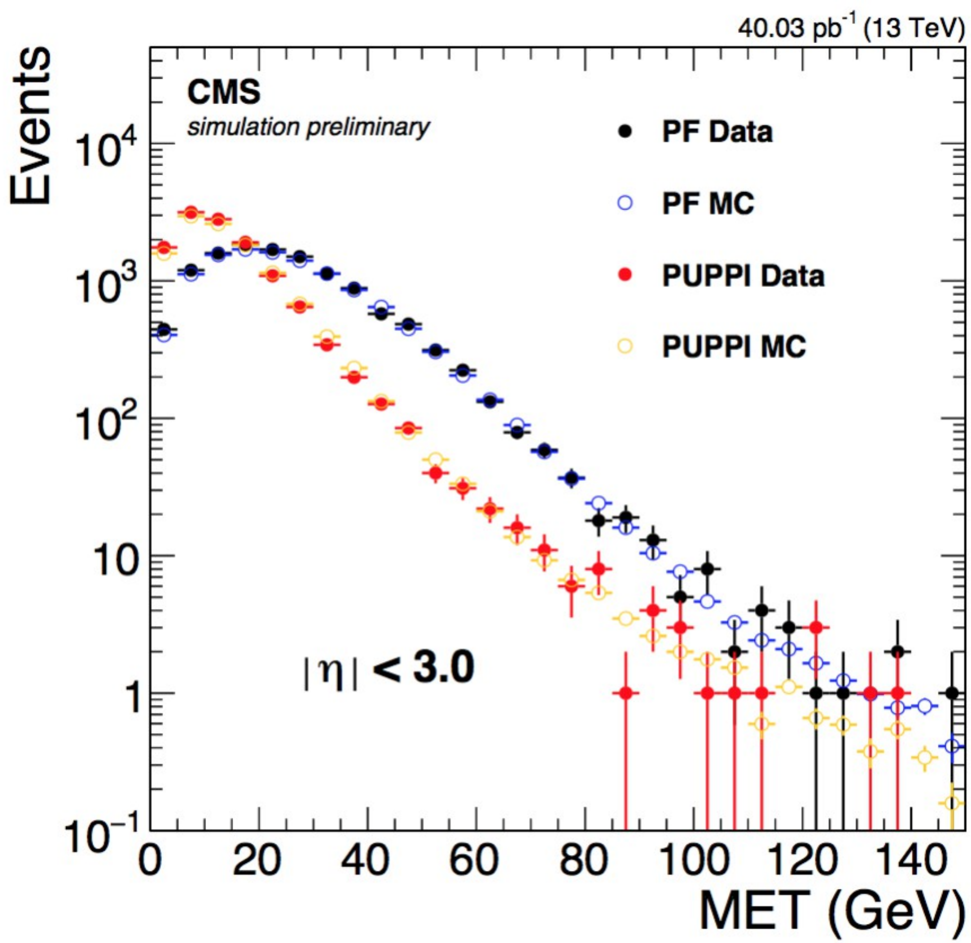
- The uncalibrated Z peak not far off from prediction

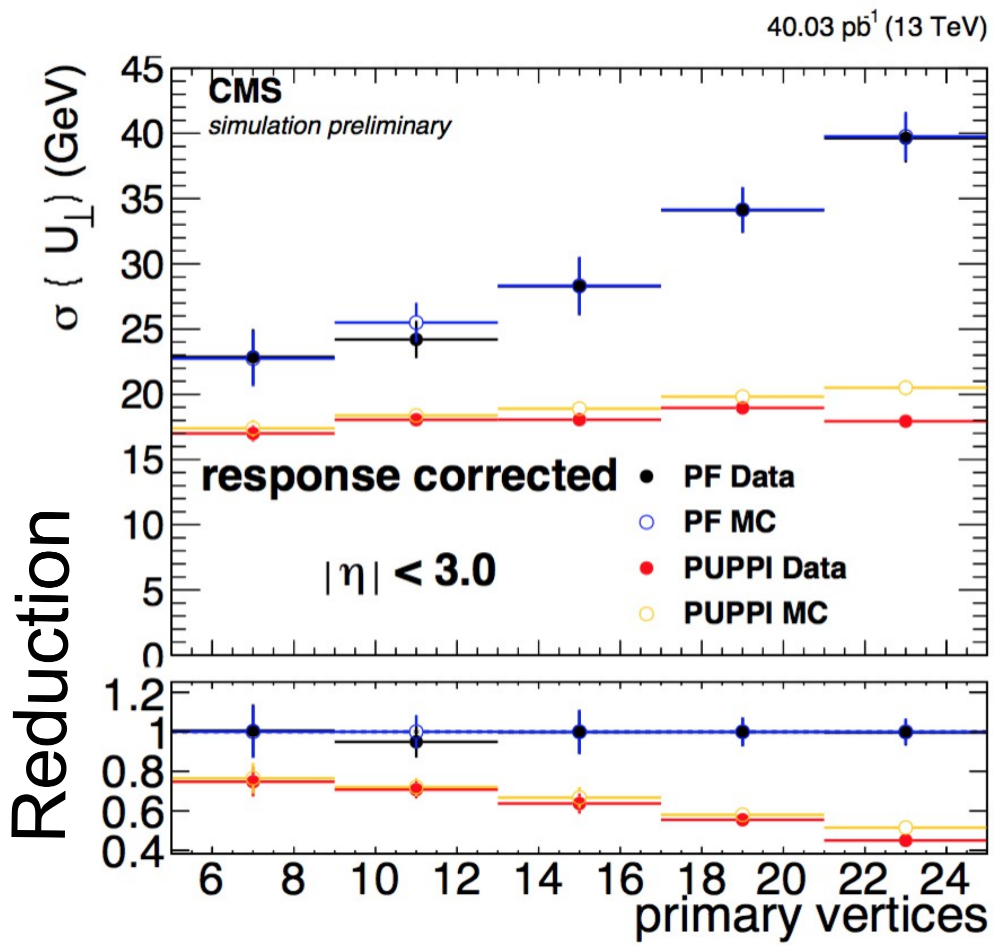


CMS-DP-15-16

What about in *MET*?

- Modelling of the *MET* and resolutions is good



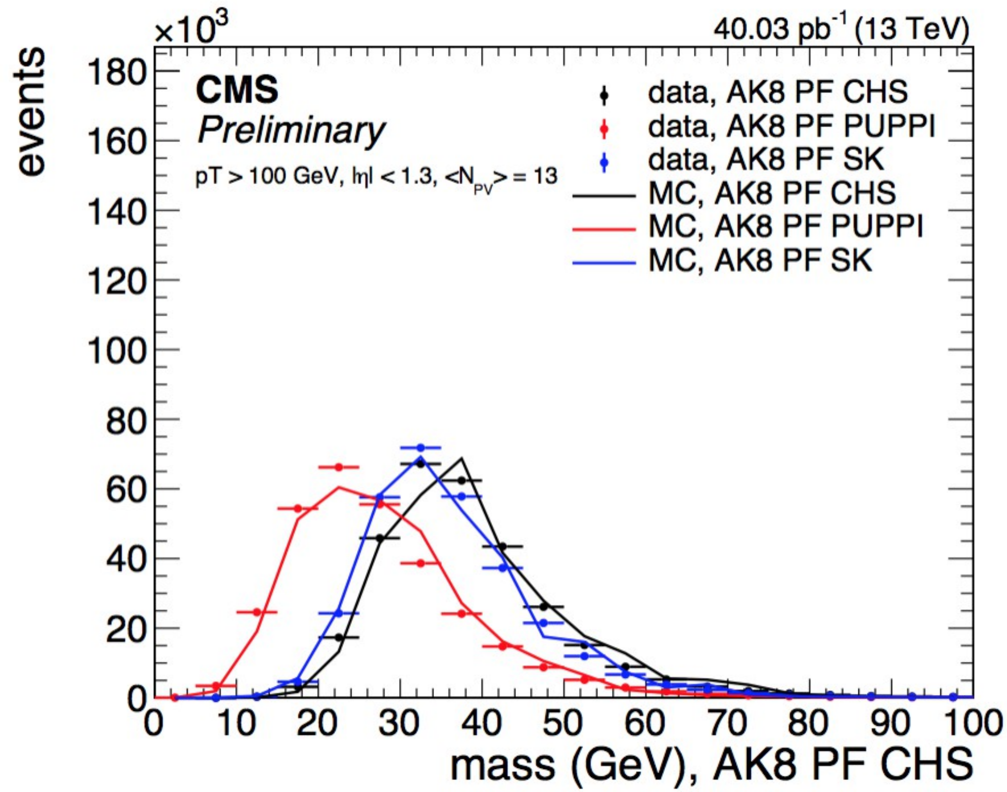


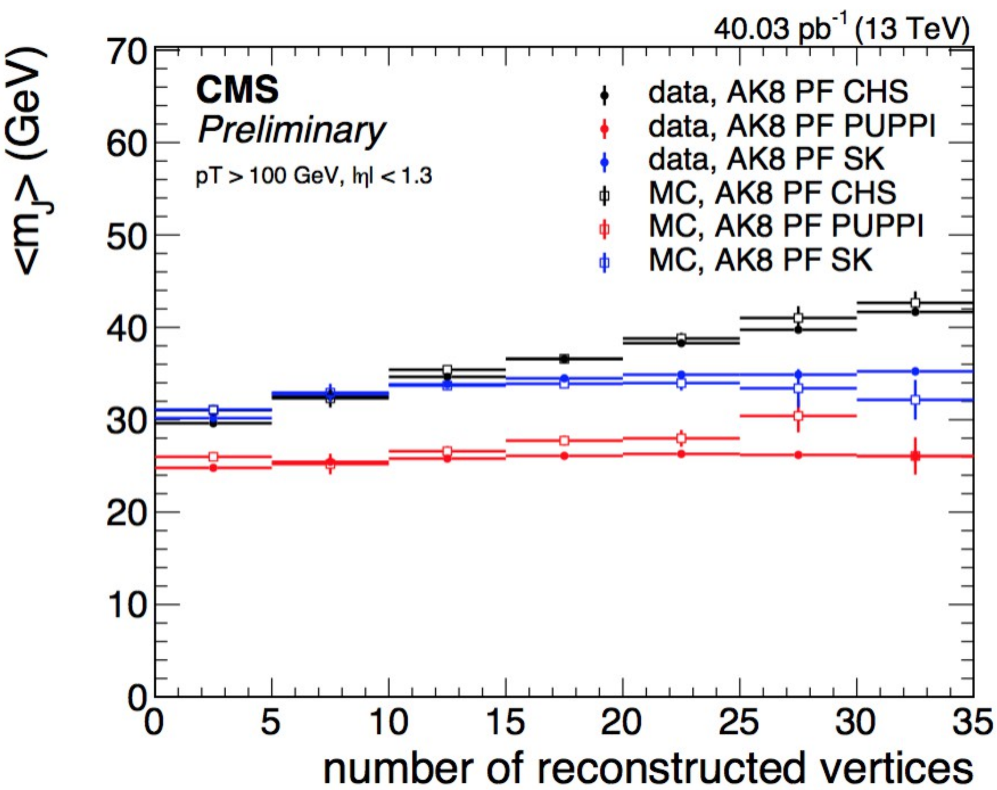
Works in the context of Puppi as well

CMS-DP-15-Puppi

What about in Jets?

- Jet Performance looks good





Works in the context of Puppi as well

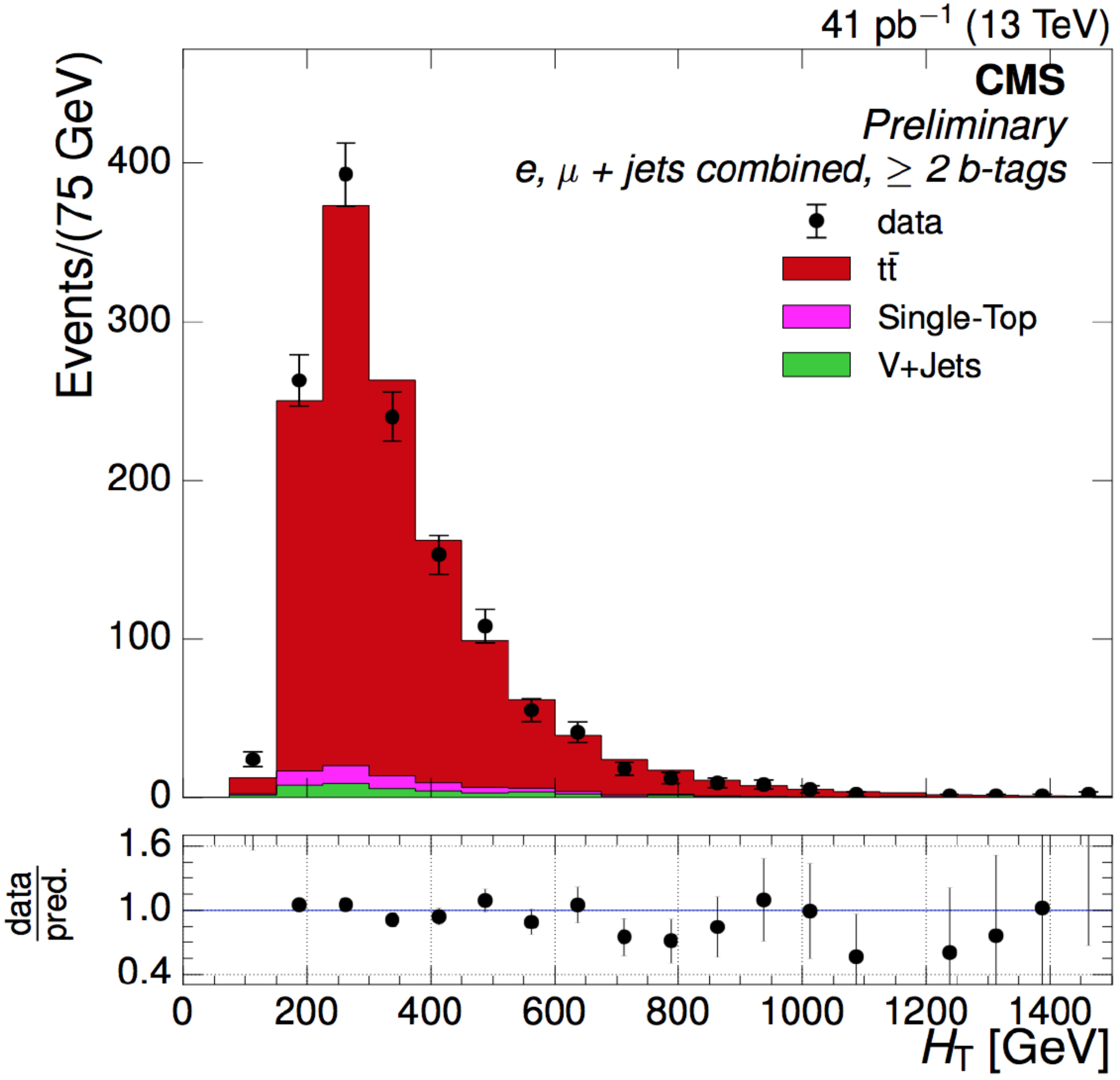
CMS-DP-15-Puppi

Fantastic Stochastics

- Effect from 25ns running
  - Post multi-pulse fit impact on calo is relatively small
  - Expect very similar performance for 25ns running
    - Improved pileup jet dependence at 25 and 50ns
- Large rate reduction on all hadronic triggers
  - Roughly 50% reduction in rate at same threshold
  - No loss in performance
- Ecal/Hcal reconstruction performs as in data
  - Validation of what we expect

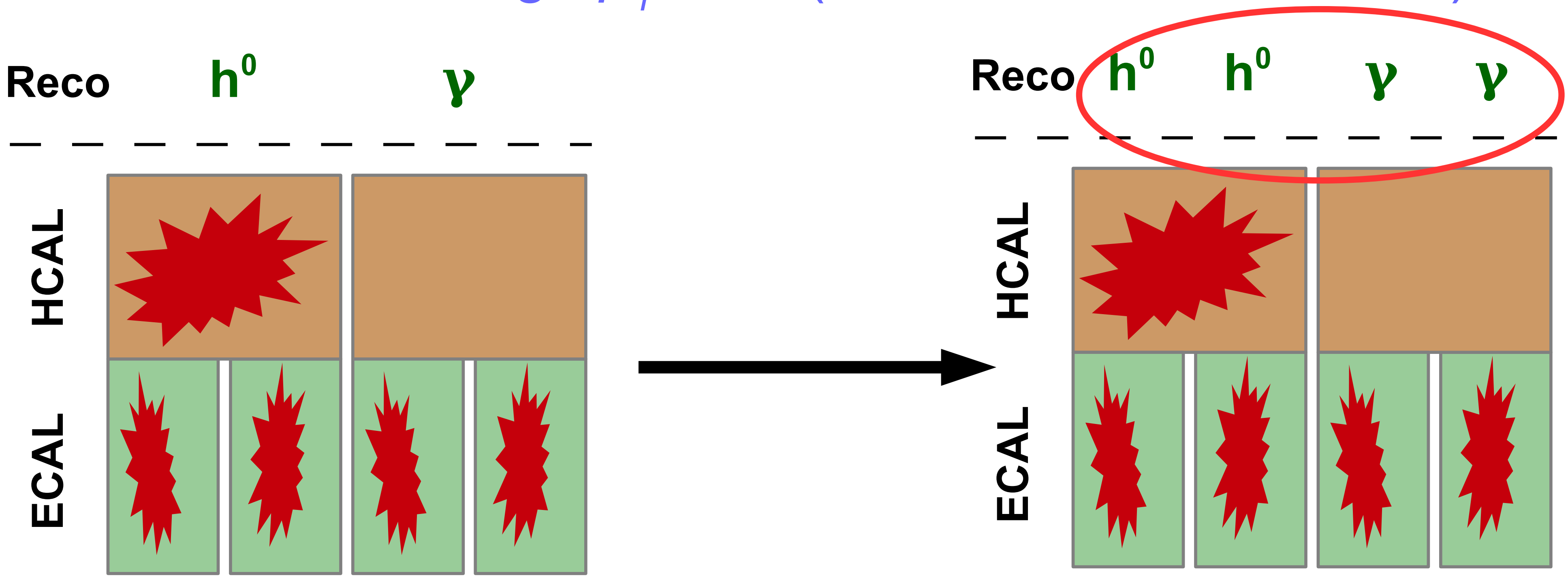
Going to Higher p_T

Looking to high energies



Going to High p_T

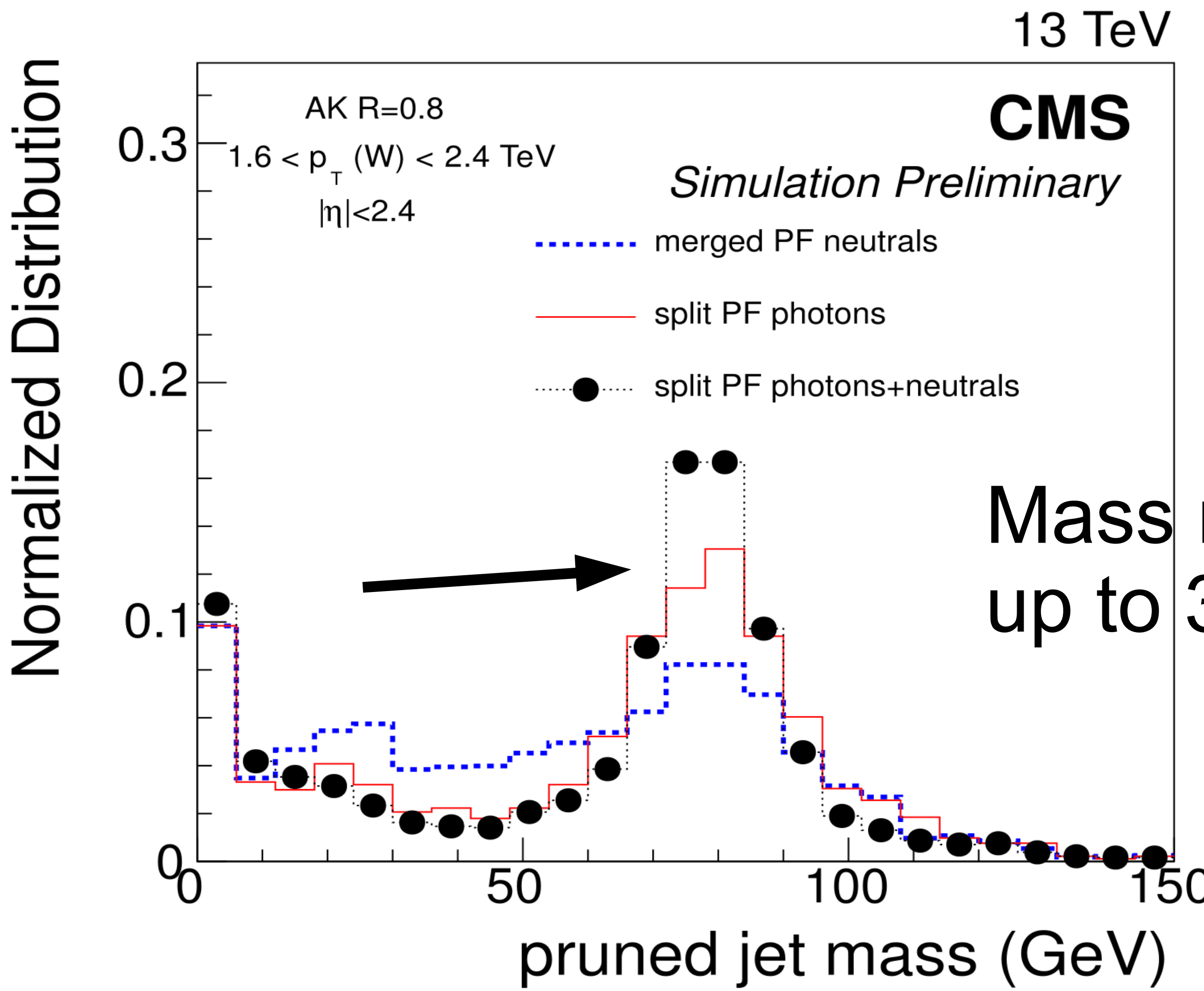
- Reminder we have tuned the particle flow
  - Modified reco to take into account maximal granularity
  - Critical for high p_T reco (Andreas' talk last boost)



Split Neutrals
Assign number of h^0, γ based on number of ECAL clusters

Going to High p_T

- At high p_T this reconstruction is critical

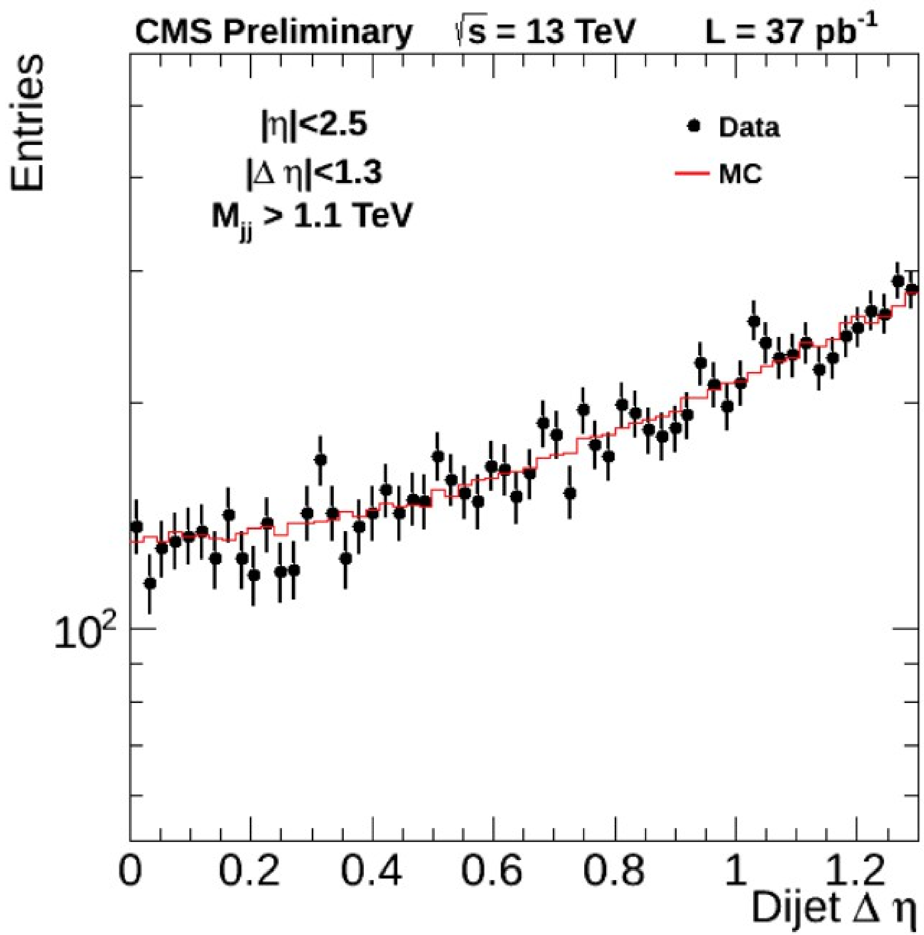


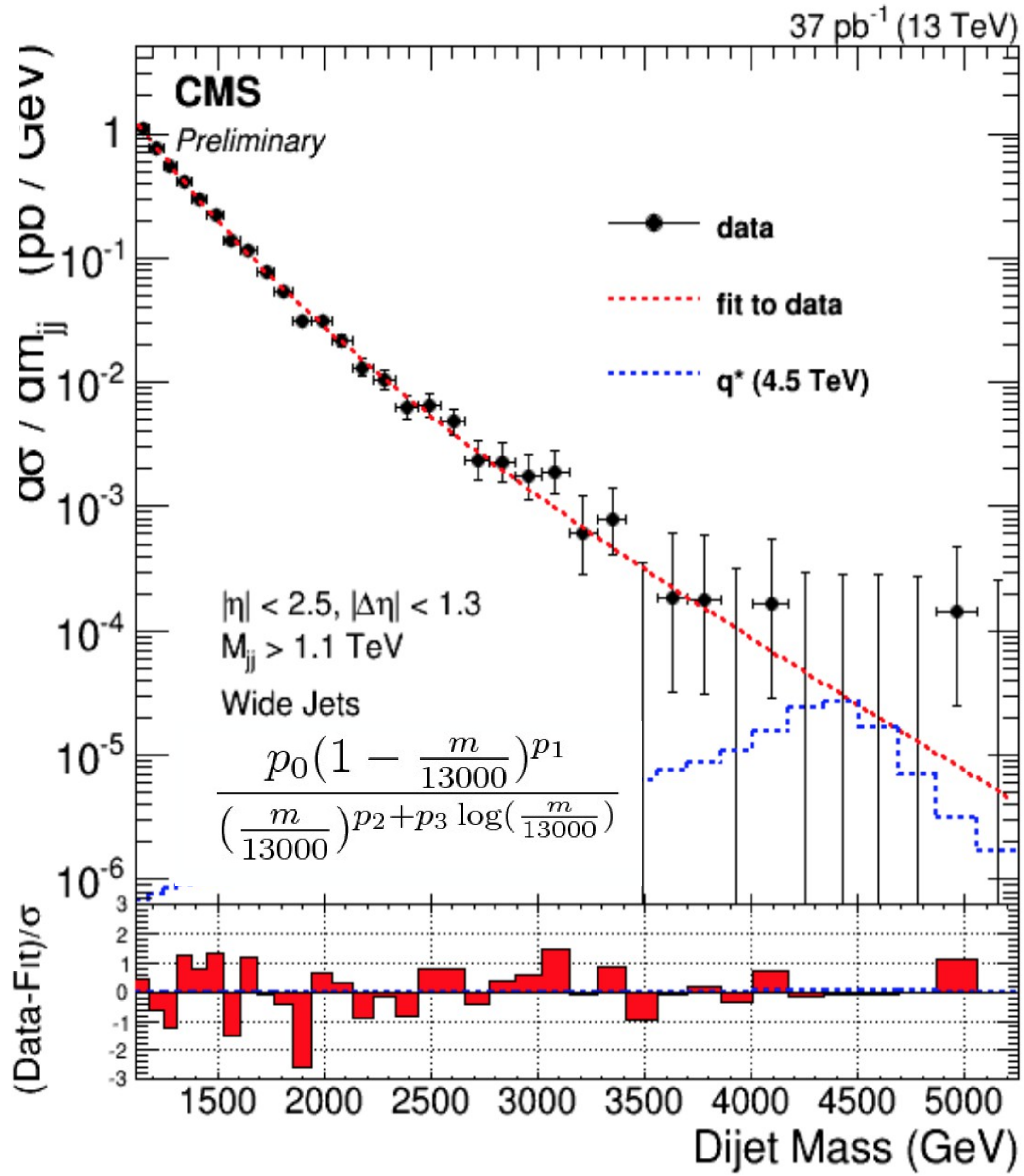
Mass recovered up to 3TeV

CMS-JME-14-002

13 TeV @ High p_T

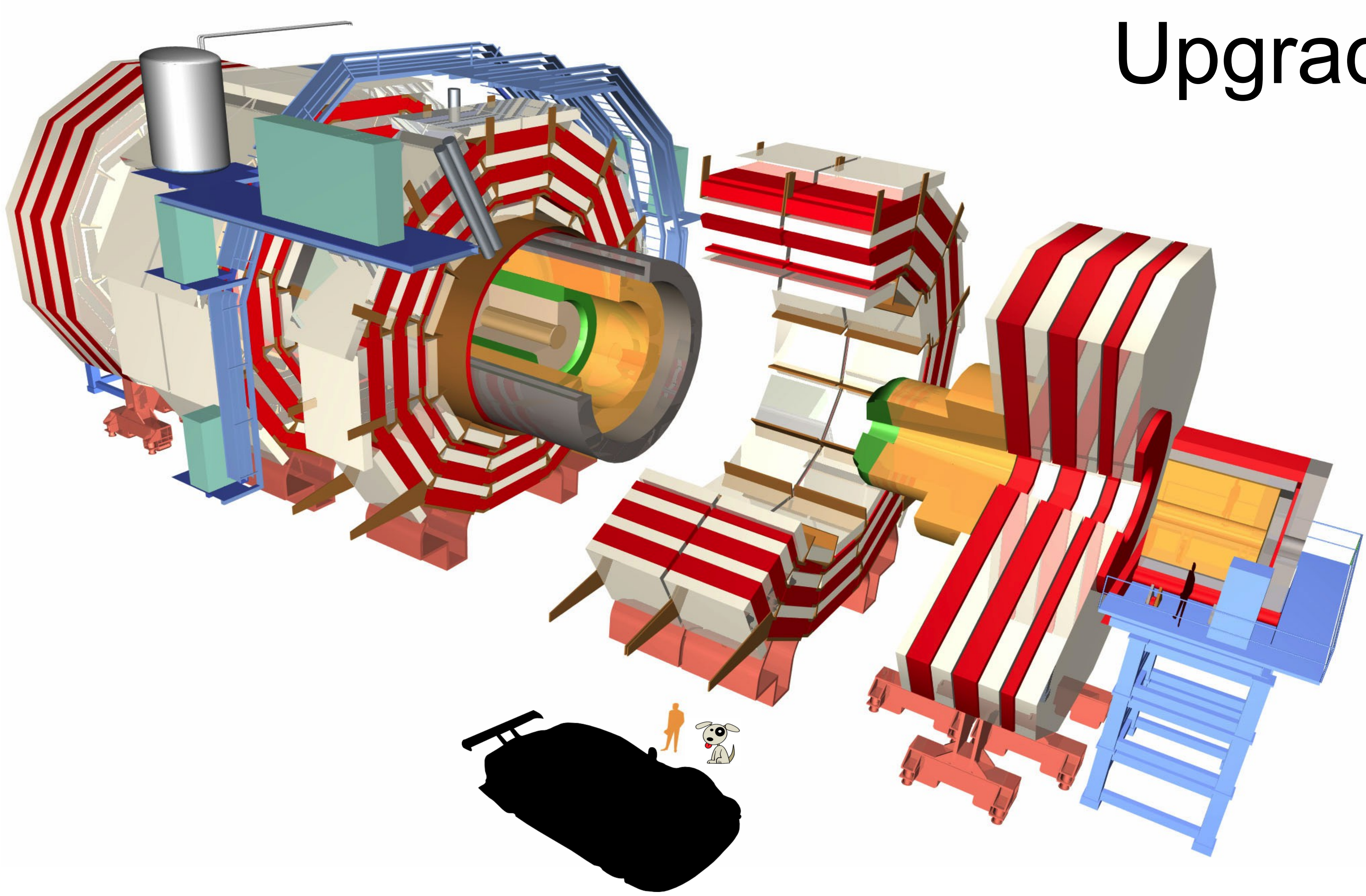
- We can start to see events up to 2.5 TeV in jet p_T



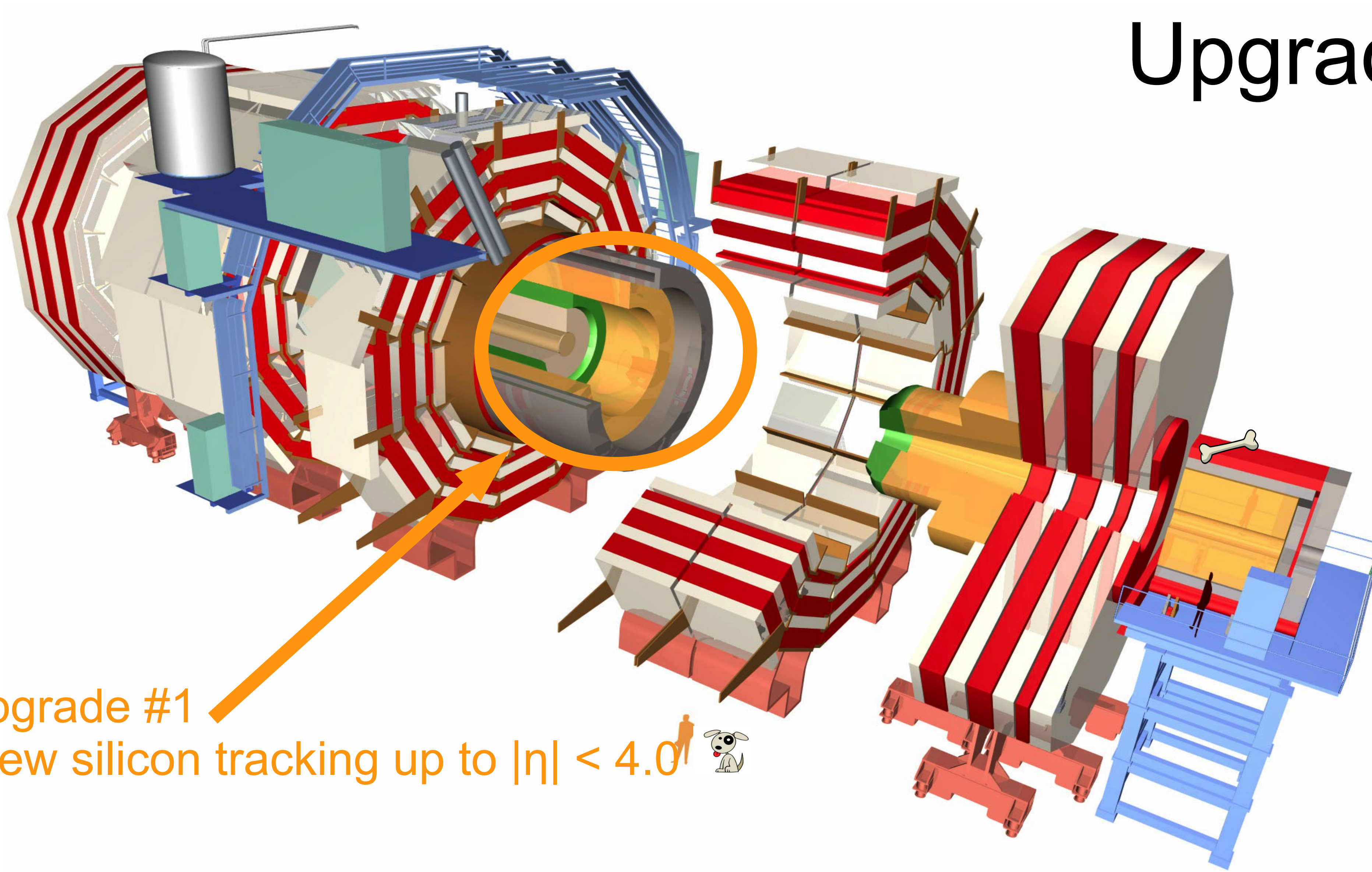


CMS-DP-15-017

Upgrade

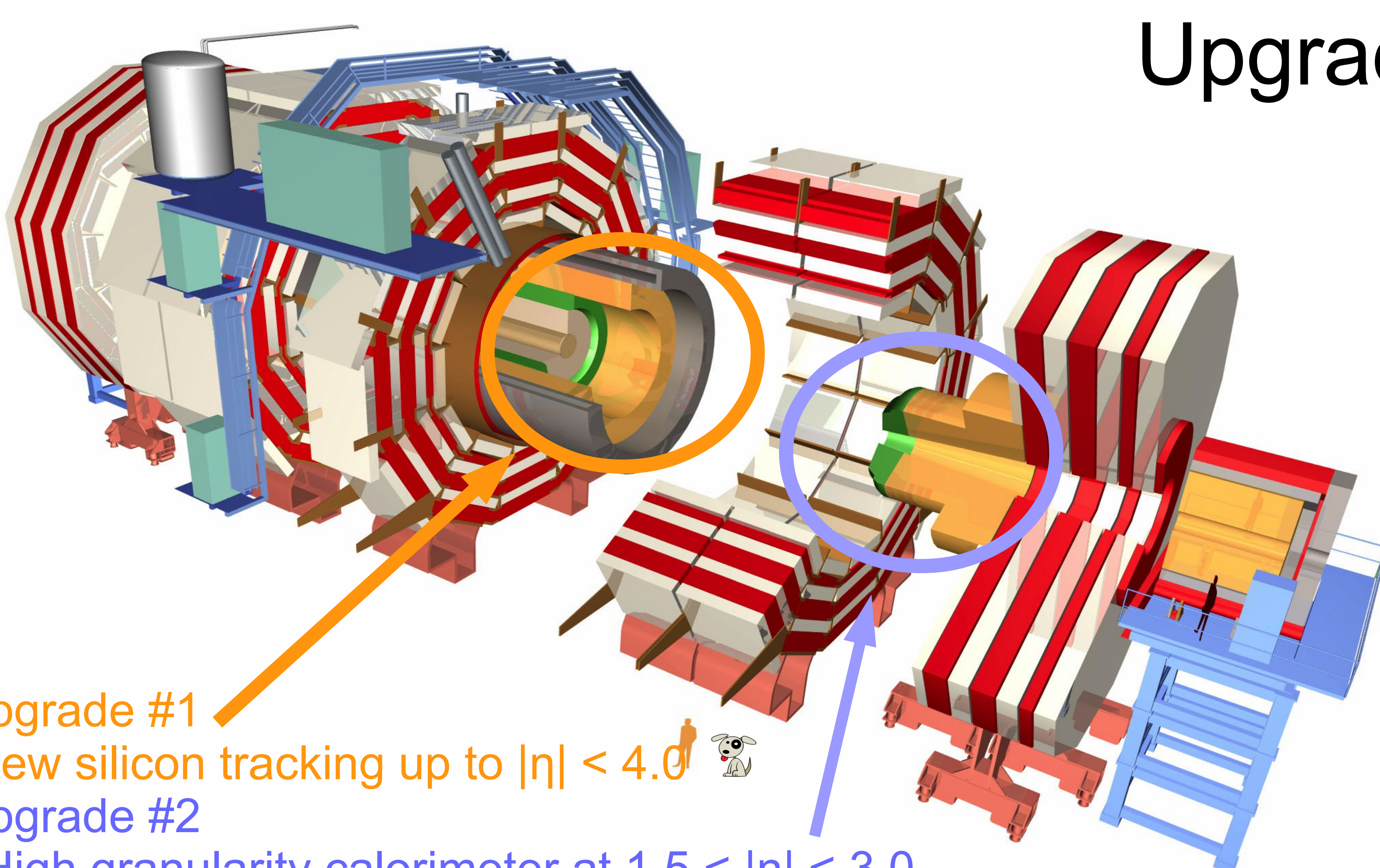


Upgrade



Upgrade #1
New silicon tracking up to $|\eta| < 4.0$

Upgrade



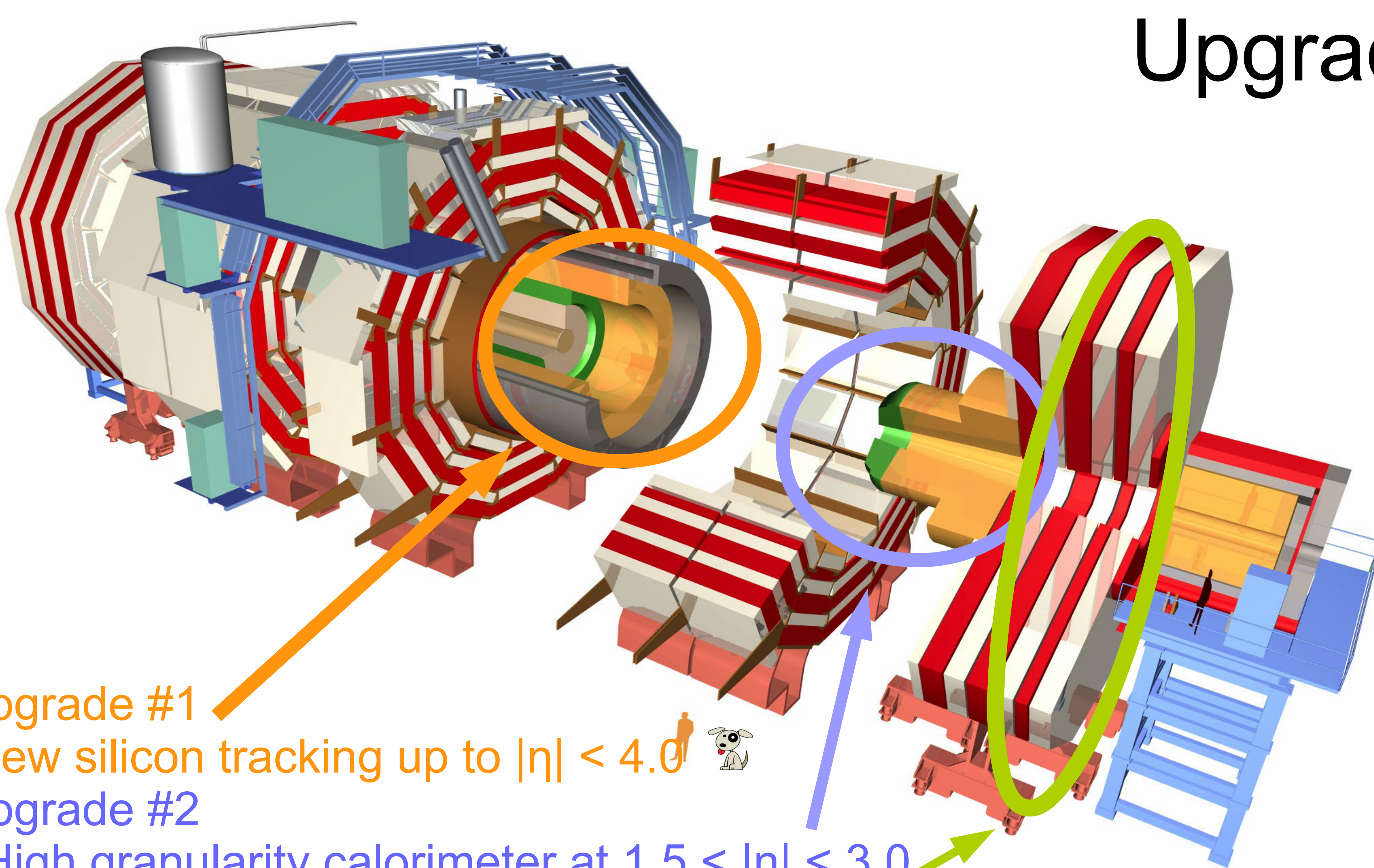
Upgrade #1

New silicon tracking up to |η| < 4.0

Upgrade #2

High granularity calorimeter at 1.5 < |η| < 3.0

Upgrade

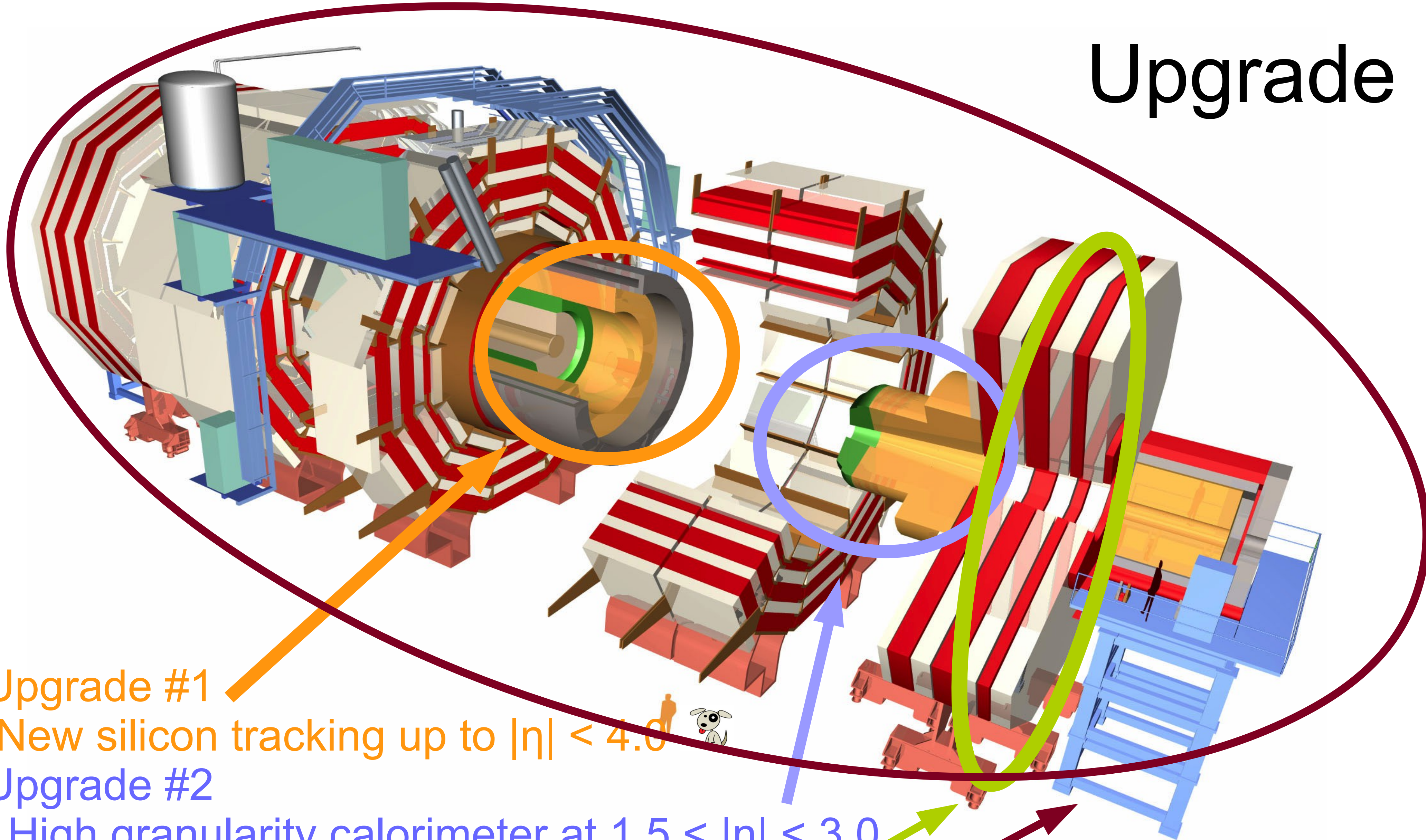


Upgrade #1
New silicon tracking up to |η| < 4.0

Upgrade #2
High granularity calorimeter at 1.5 < |η| < 3.0

Upgrade #3
Muon chambers extedend to |η| < 4.0

Upgrade



Upgrade #1
New silicon tracking up to $|\eta| < 4.0$

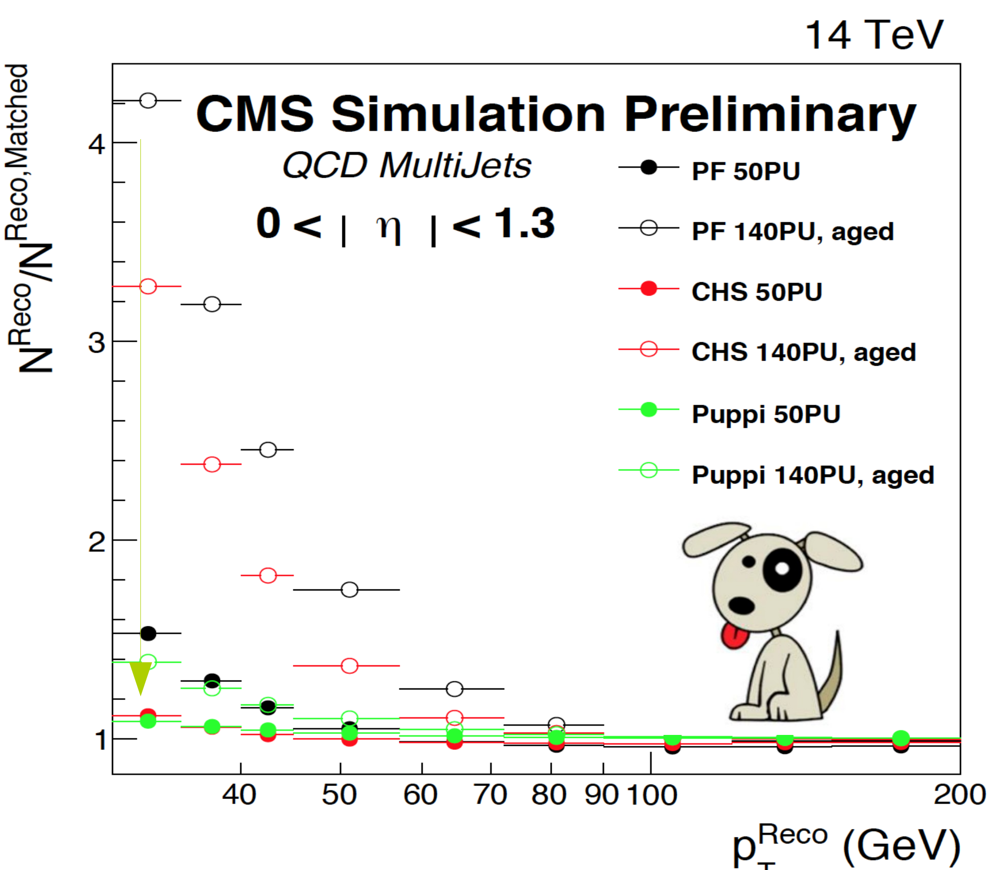
Upgrade #2
High granularity calorimeter at $1.5 < |\eta| < 3.0$

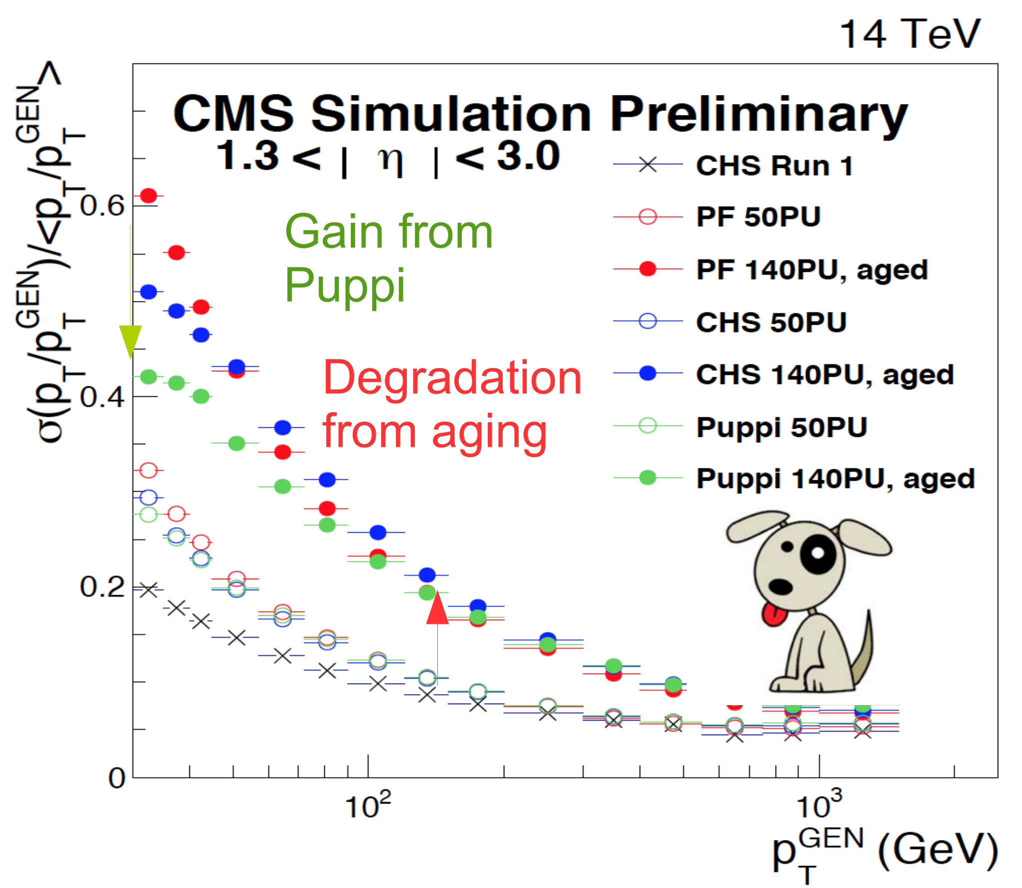
Upgrade #3
Muon chambers extedend to $|\eta| < 4.0$

Upgrade #4
Track trigger/faster HLT rate

Approach to Upgrade

- Put in the most advanced algorithms
  - Consider the design improvements against the best
  - In some instances allows us to rethink design
    - ex. PUPPE_T resolution improves with forward tracking

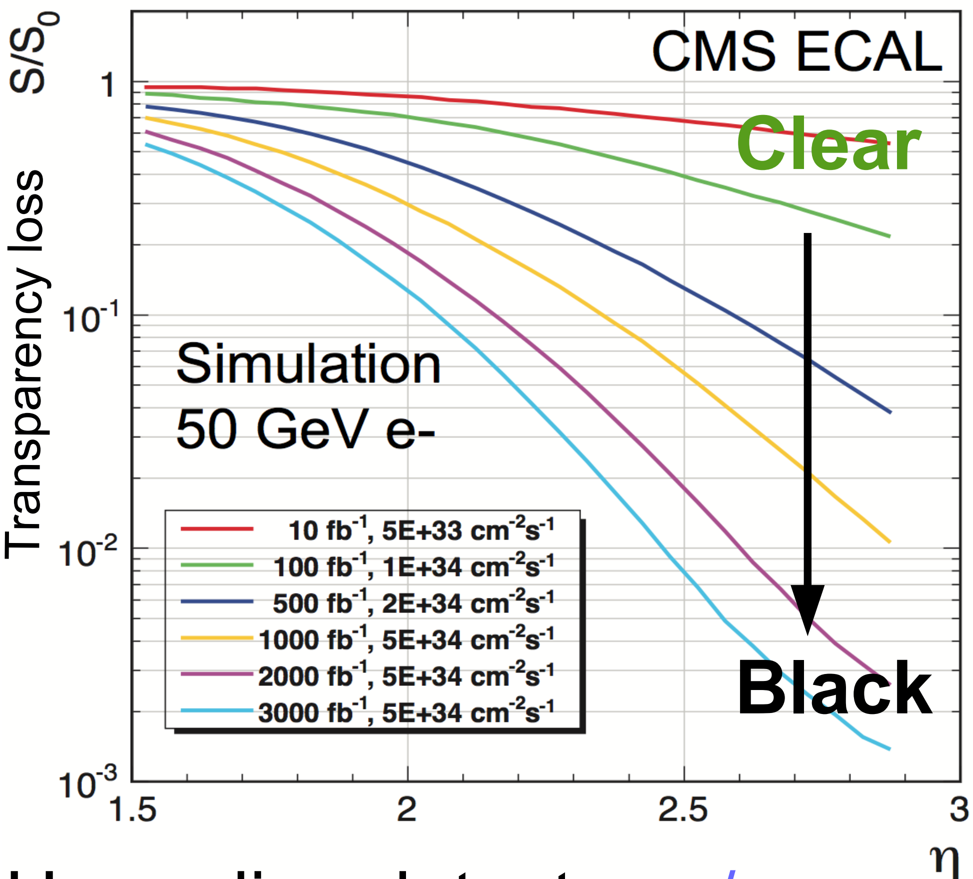


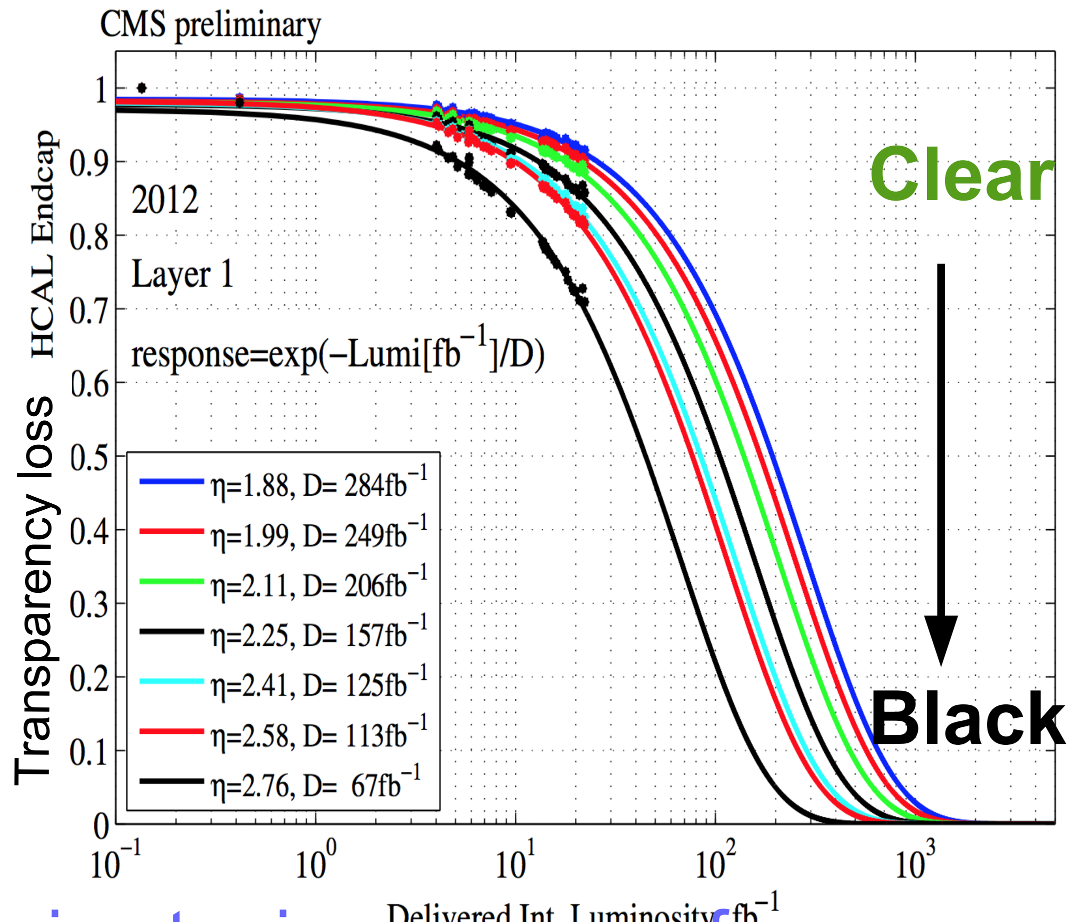


CMS-DP-ECFA

What we known will happen

- Hcal and Ecal endcaps are **going black**
  - A result of radiation damage to the fibers/crystals

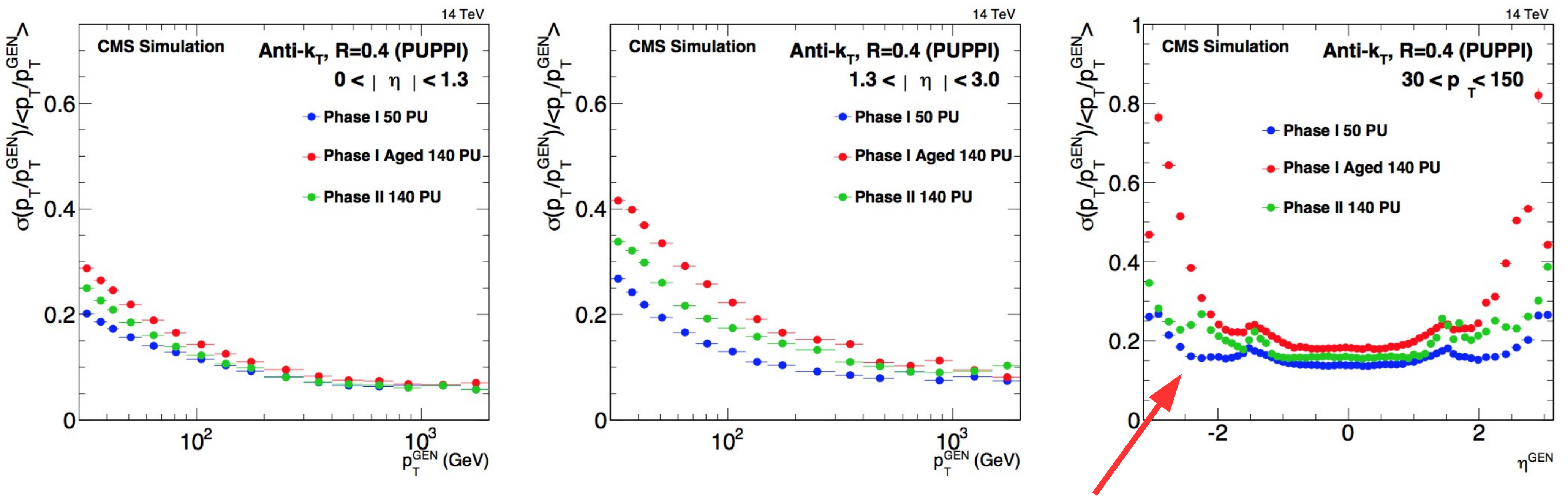




Upgrading detector w/new calorimeter improves performance
HGCal will fix improvement with many new handles to use
LHCC-P-008

Puppi Performance in Upgrade

- Comparing the detectors
  - Phase I 50 PU => End of Run II
  - Phase I Aged 140 PU => No upgrade
  - Phase II 140 PU => Upgrade
    - Includes calorimeter/forward tracking/muons

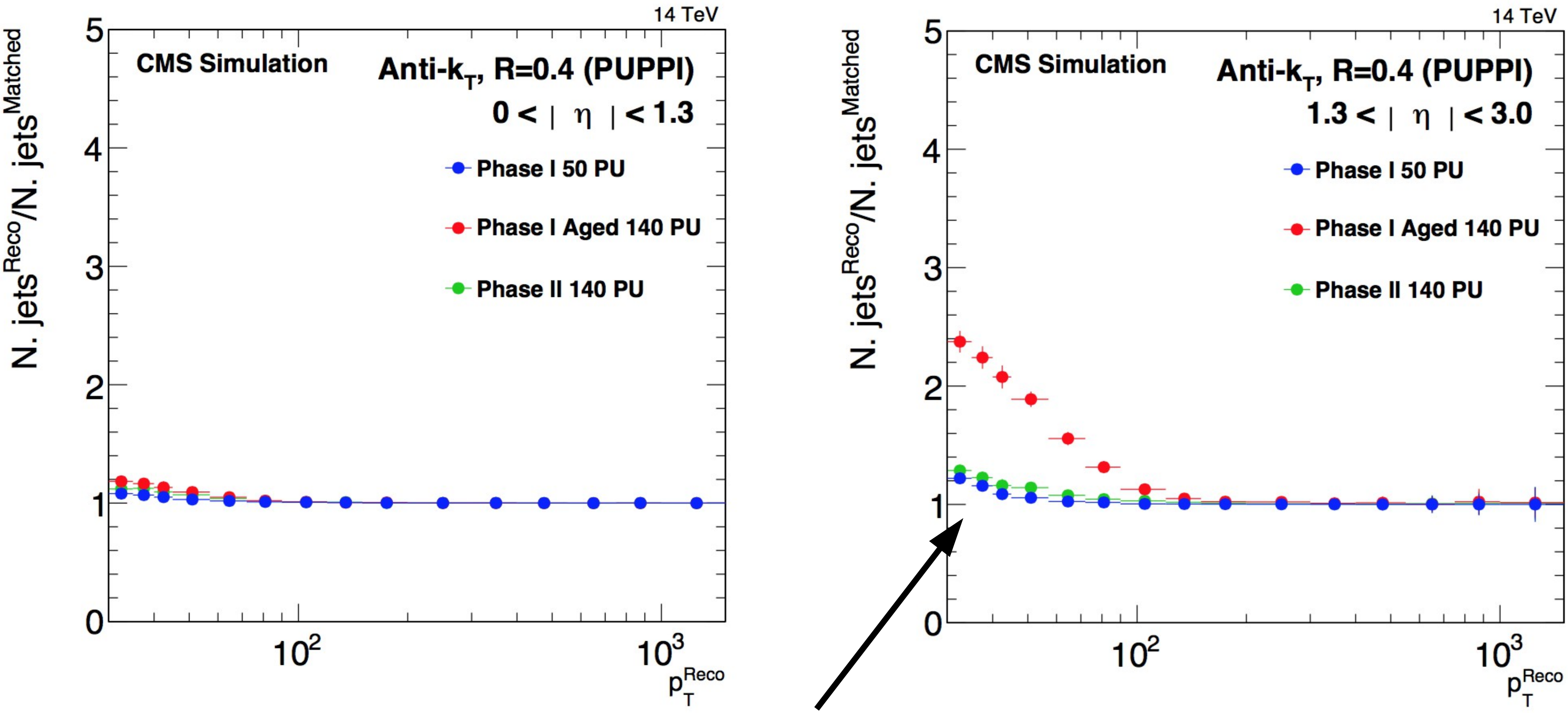


Calorimeter upgrade drastically improves resolution

LHCC-P-008

Pileup Jet Performance

- The upgraded calorimeters make a big difference

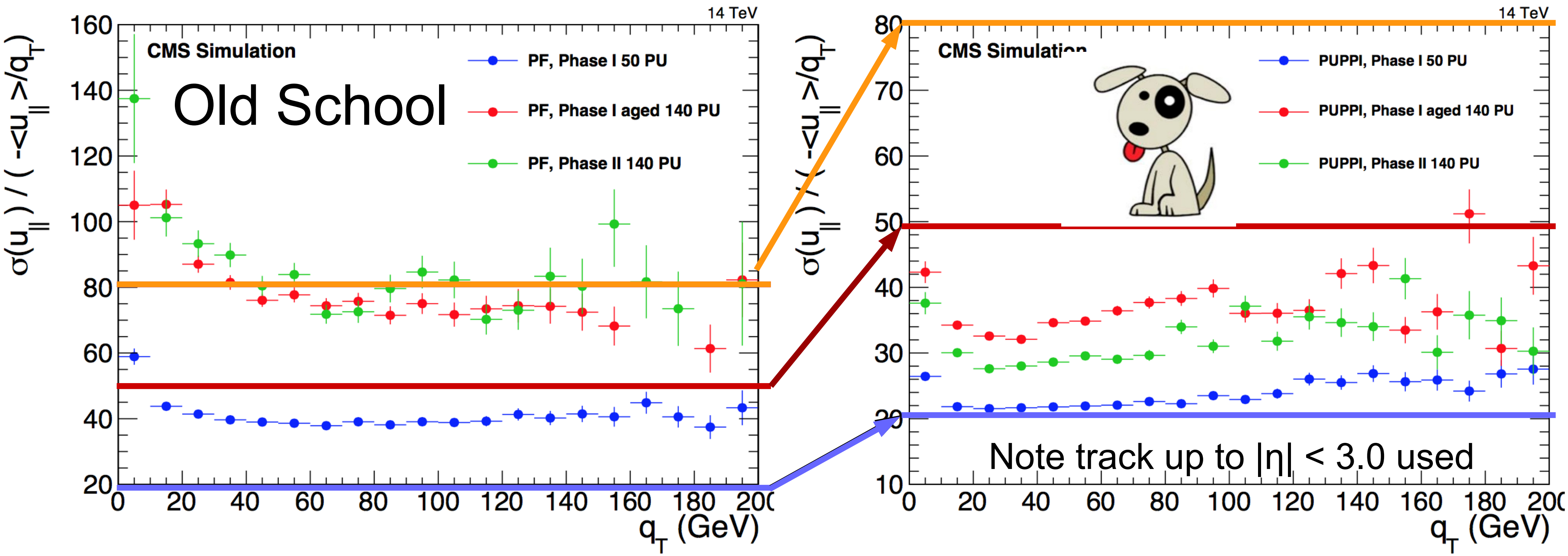


Can restore PU Jet rate for 50 PU by upgrading calorimeters

LHCC-P-008

PuppE_T performance

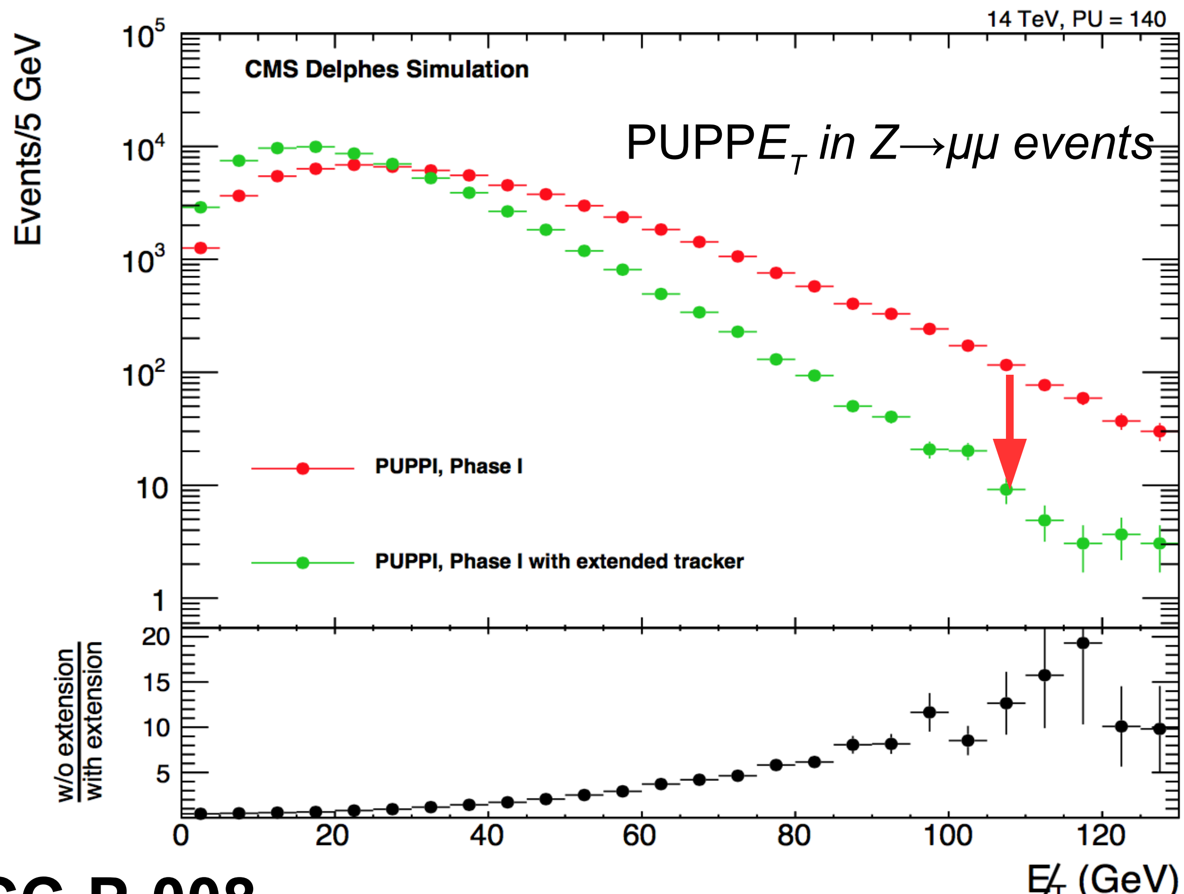
- No gain is present for when puppE$_T$ is not used
  - Upgrade does nothing to improve the *MET*
- With *PuppE_T* upgrade can reduce resolution by 1/3
  - Has a substantial impact on searches



LHCC-P-008

Impact of Forward Tracking

- Extending the tracker to the forward region
  - Improves *MET* resolution with PUPPE_T
  - 30% better resolution than without forward tracking

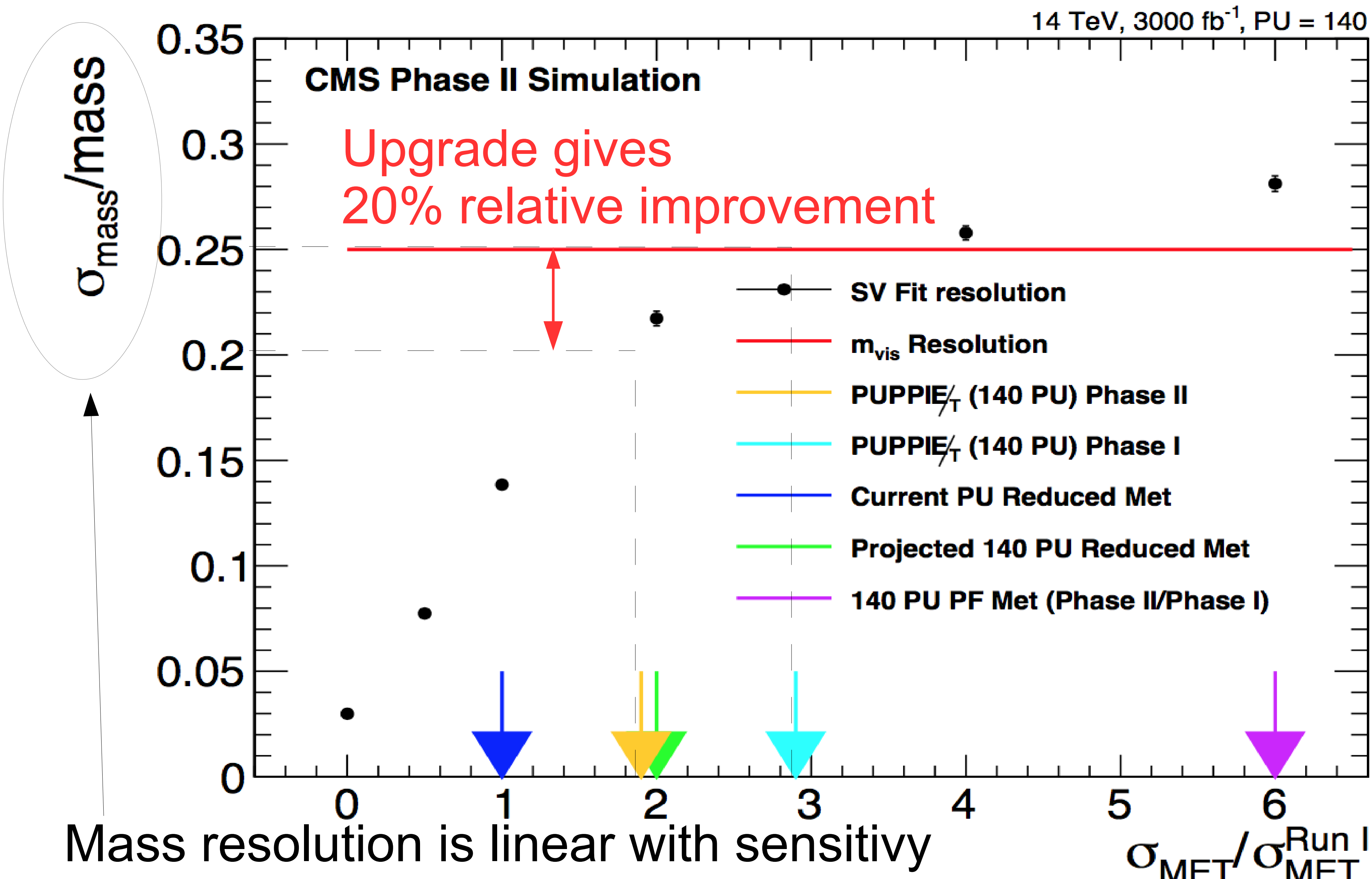


Tails from backgrounds are improved considerably

LHCC-P-008

PUPP$\not{E}_T$ on anlaysis

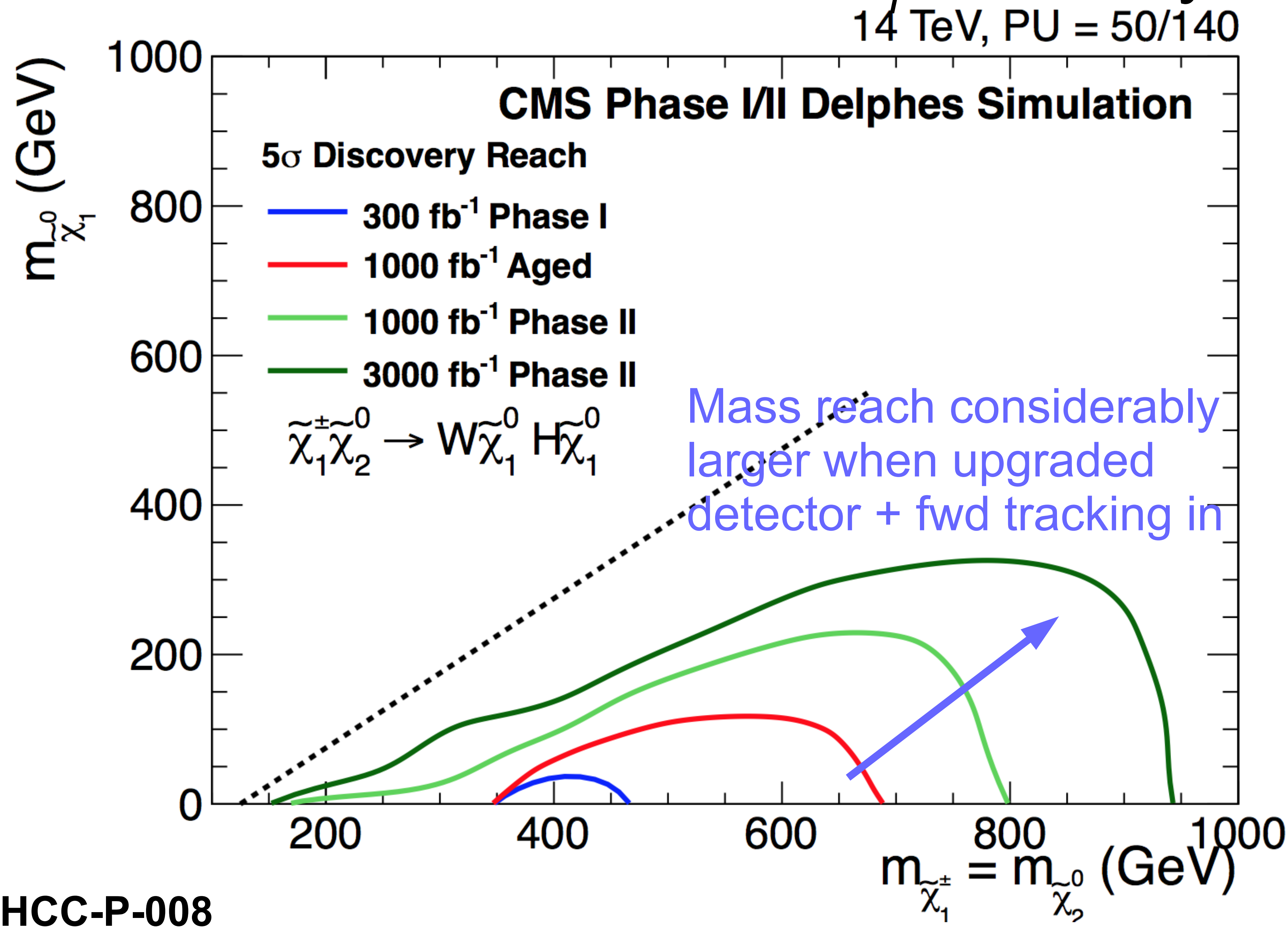
CMS H→ττ analysis



Mass resolution is linear with sensitivy

LHCC-P-008

PUPPE_T on analysis



LHCC-P-008

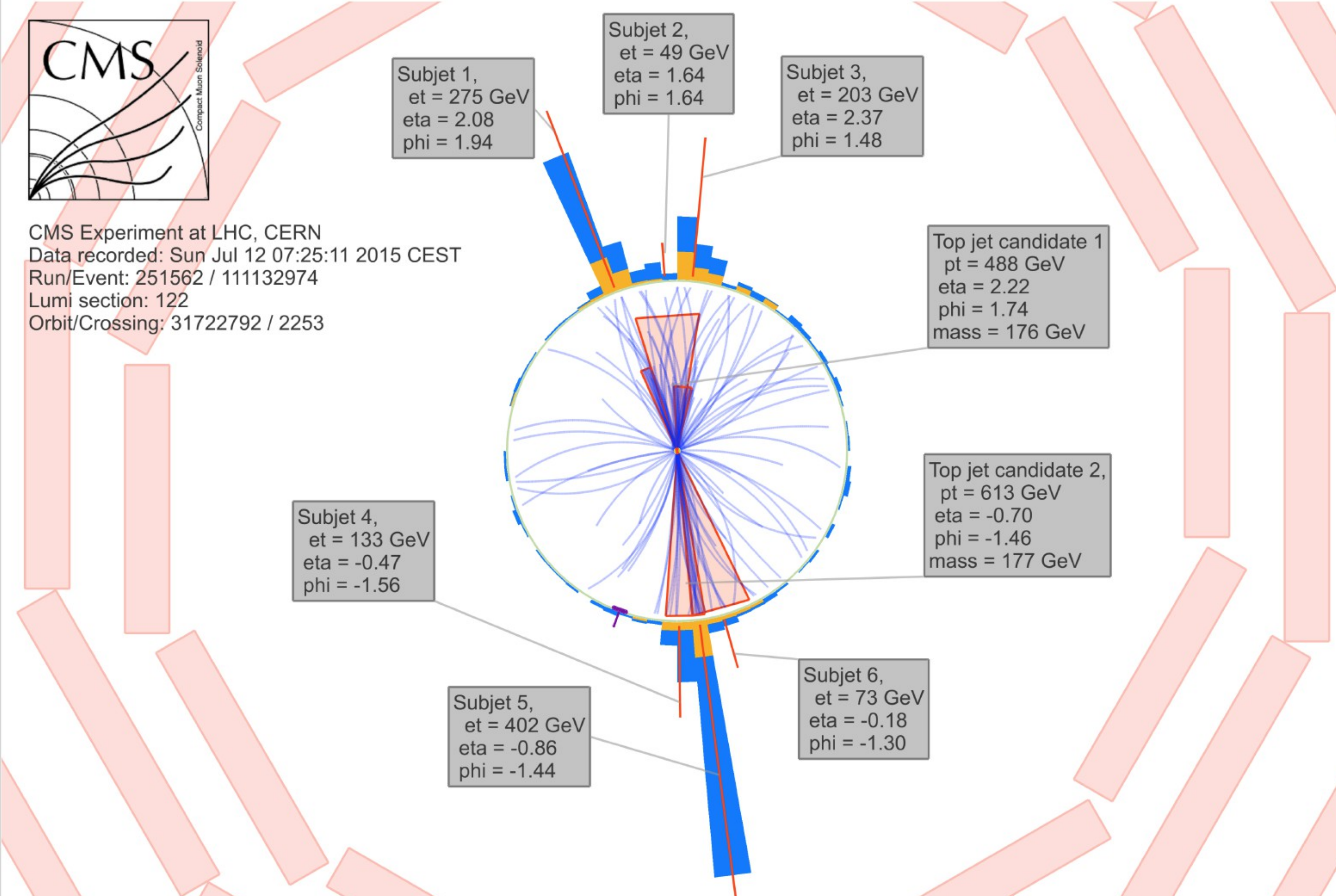
After one year of Puppi school

- Preparing for the onslaught
  - CMS has revamped their calorimeter reconstruction
  - Aim has been to dynamically take pileup away
    - Use all information that we can
  - Showing good performance in Run II data

- Learned how reconstruction obeys in higher pileup
  - Pileup techniques drive how we build a future detector

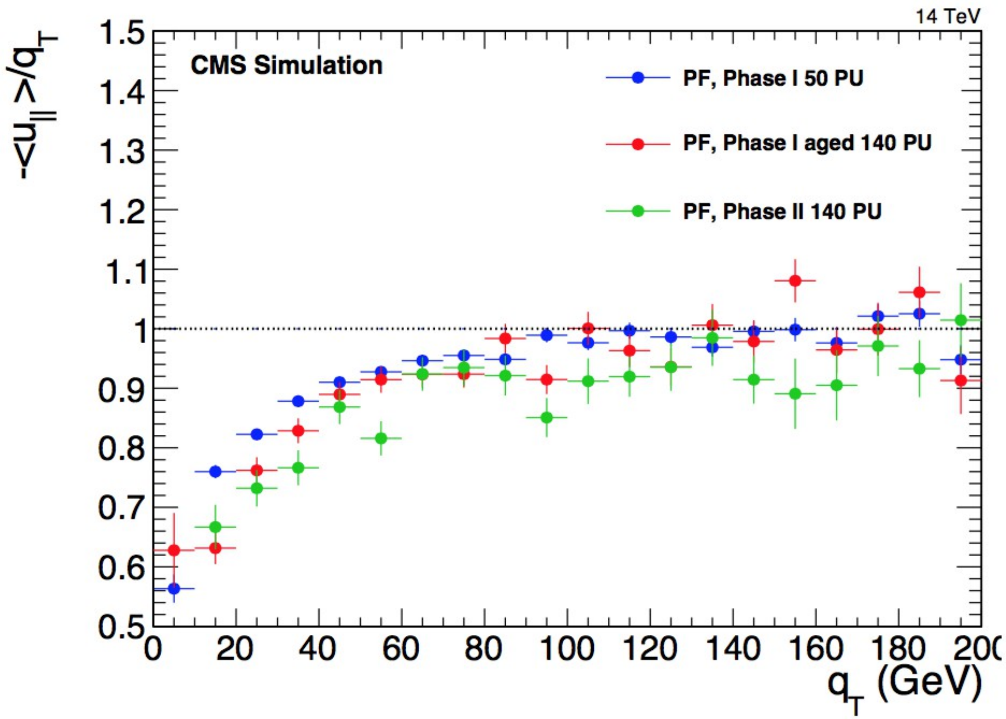
- Can we teach our dog new tricks?

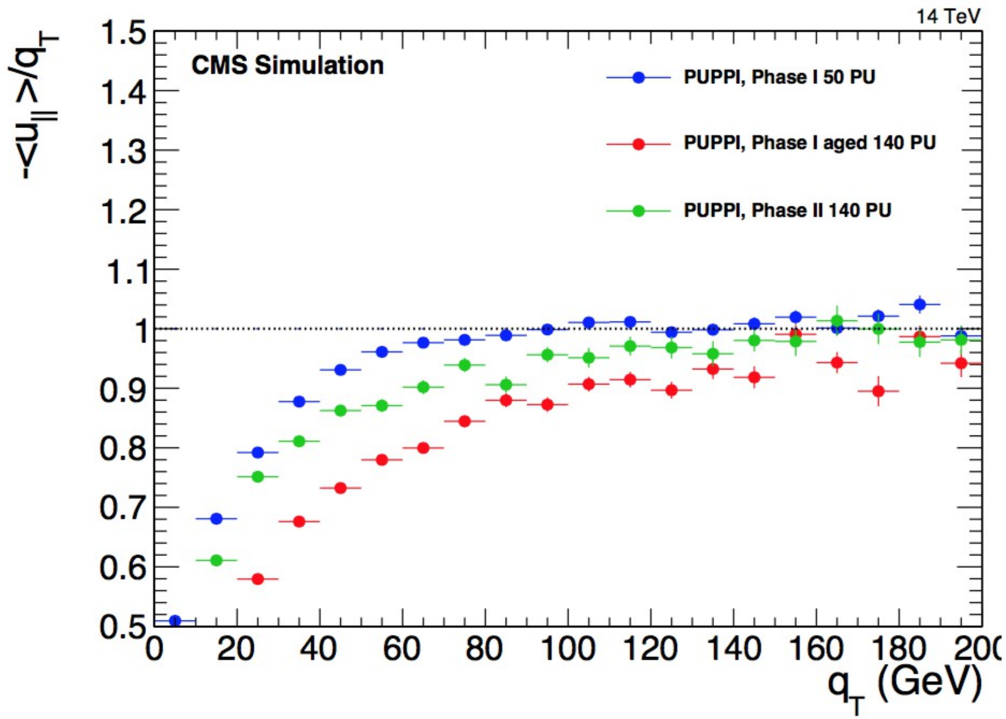
Thanks!


CMS
Compact Muon Solenoid
CMS Experiment at LHC, CERN
Data recorded: Sun Jul 12 07:25:11 2015 CEST
Run/Event: 251562 / 111132974
Lumi section: 122
Orbit/Crossing: 31722792 / 2253
Subjet 1, et = 275 GeV eta = 2.08 phi = 1.94
Subjet 2, et = 49 GeV eta = 1.64 phi = 1.64
Subjet 3, et = 203 GeV eta = 2.37 phi = 1.48
Top jet candidate 1 pt = 488 GeV eta = 2.22 phi = 1.74 mass = 176 GeV
Top jet candidate 2, pt = 613 GeV eta = -0.70 phi = -1.46 mass = 177 GeV
Subjet 4, et = 133 GeV eta = -0.47 phi = -1.56
Subjet 5, et = 402 GeV eta = -0.86 phi = -1.44
Subjet 6, et = 73 GeV eta = -0.18 phi = -1.30

Backup

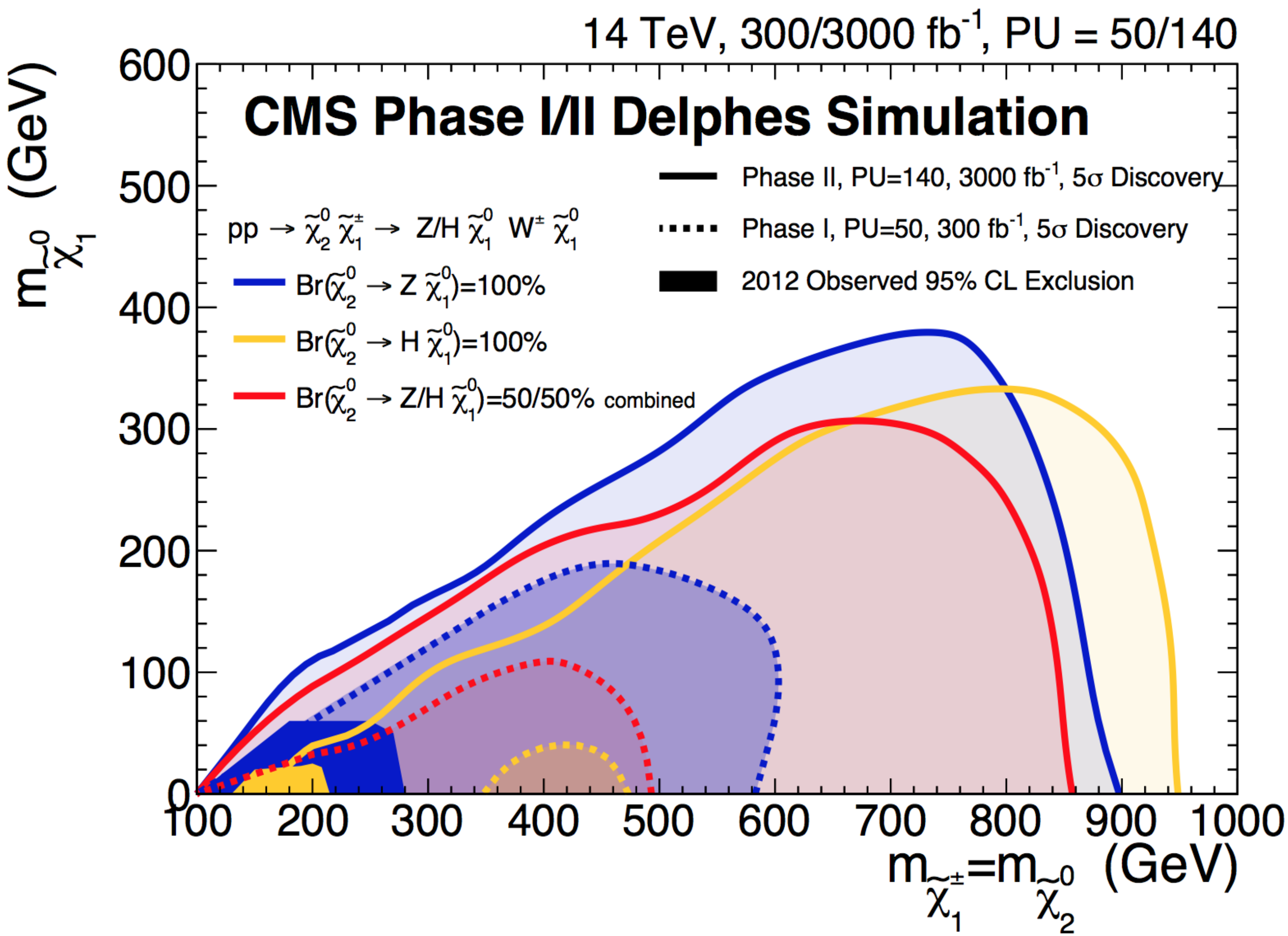
PuppE_T response plots



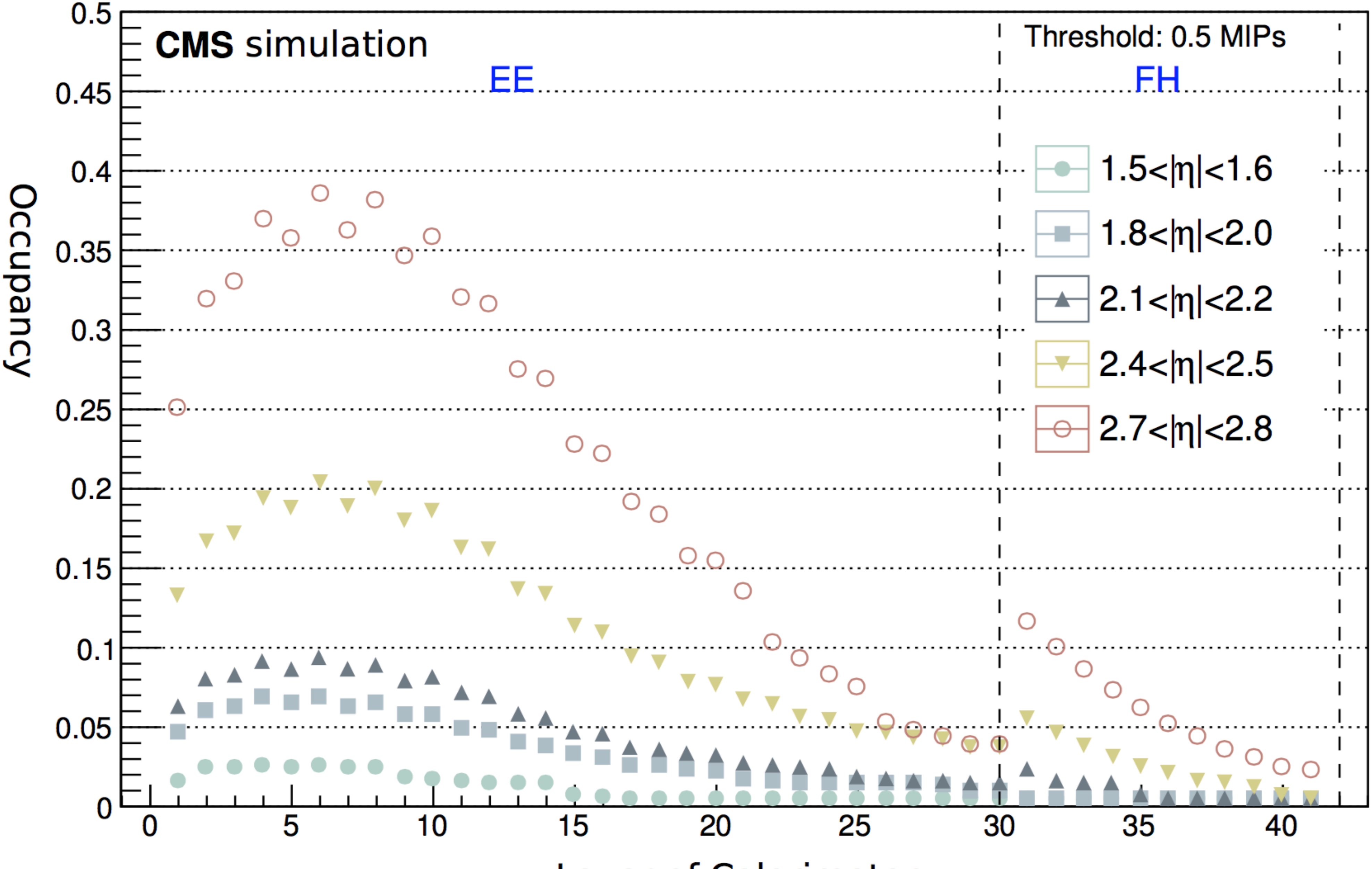


SUSY reach

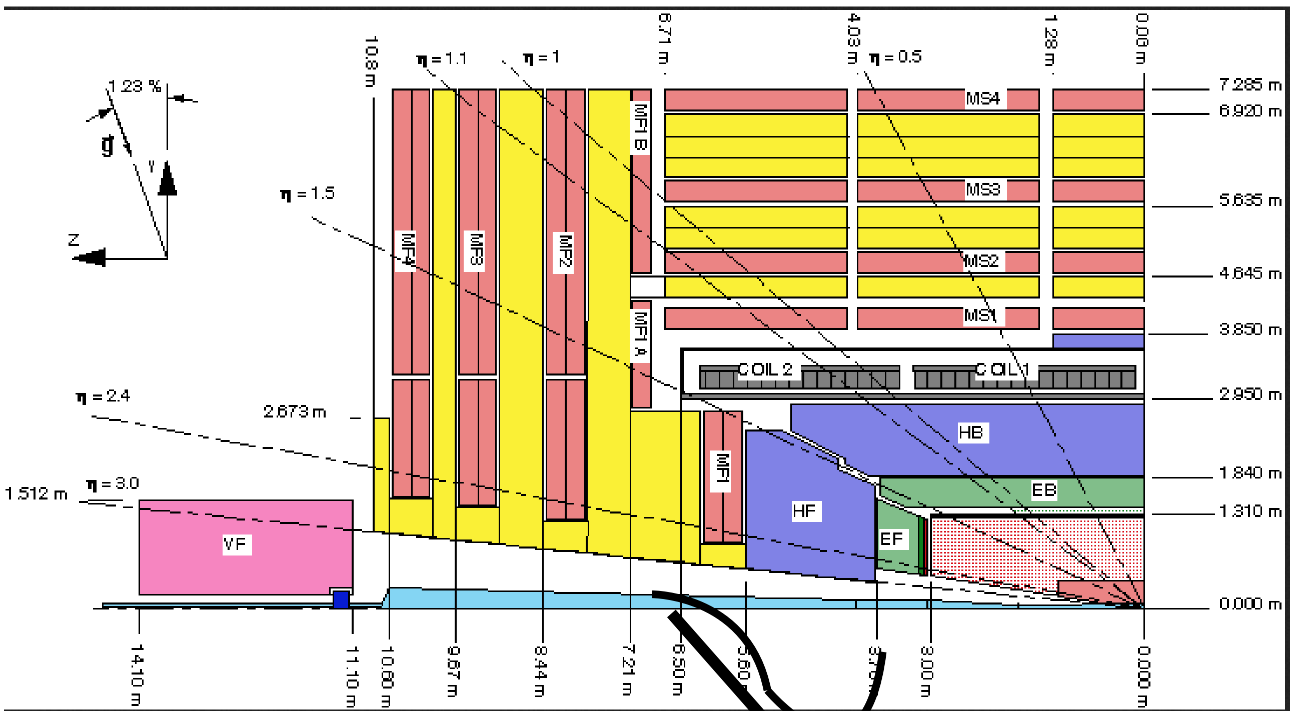
- Reach of SUSY w/upgrade

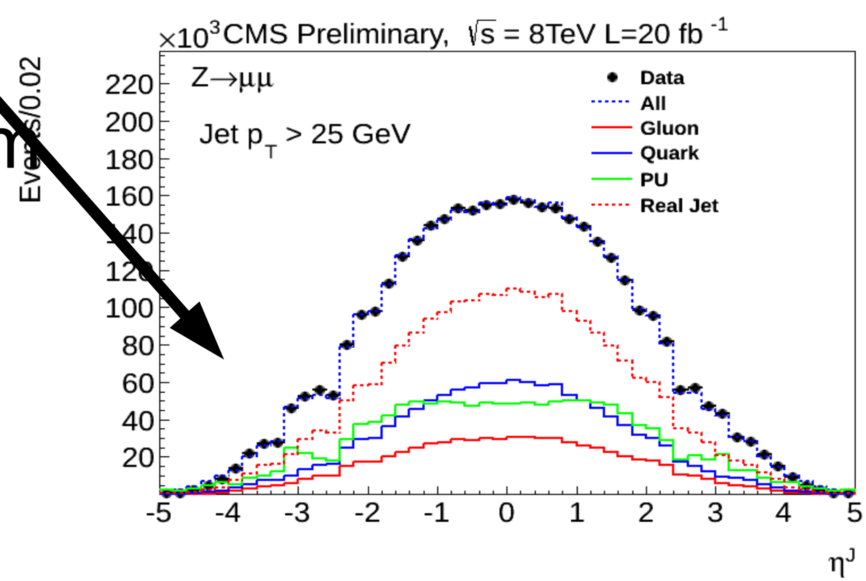


HGCal Depth Layers



Pileup Jet Phenomenon

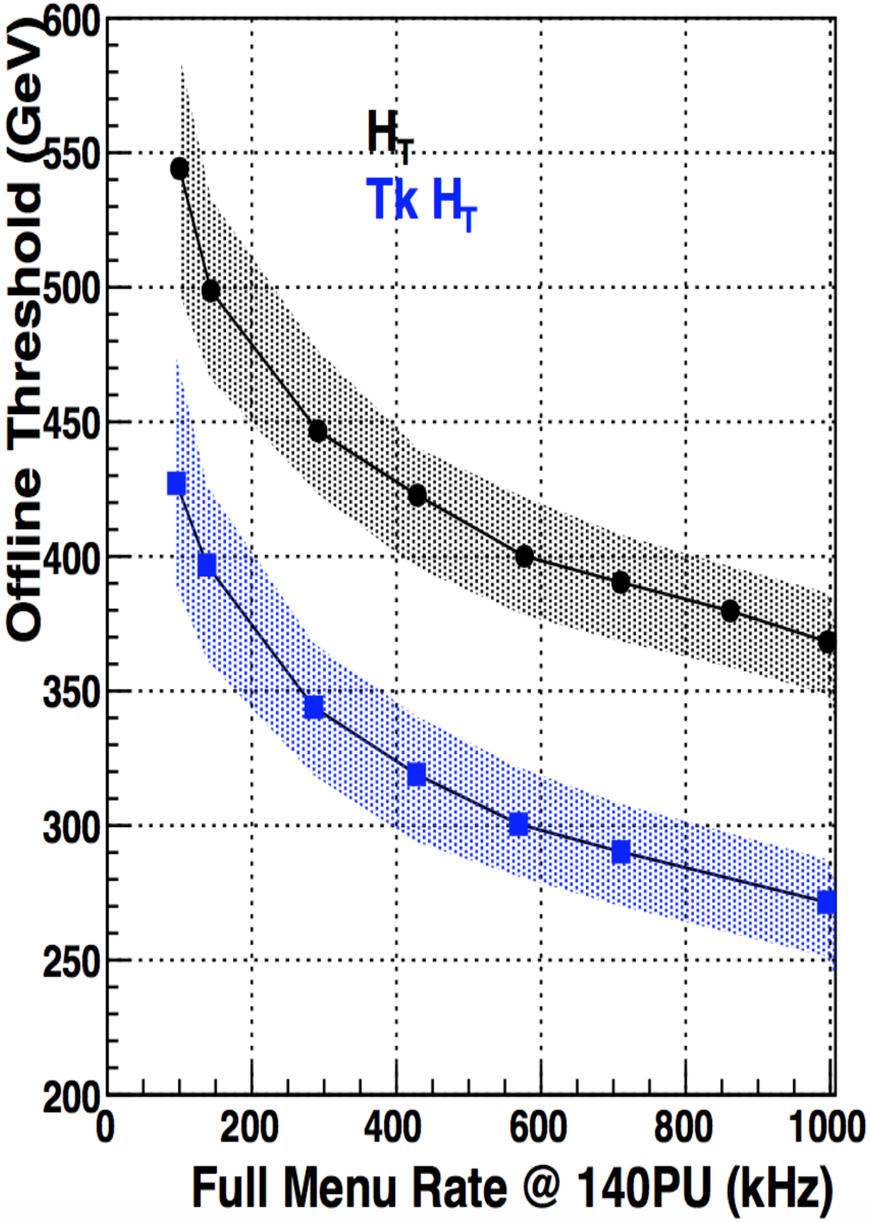


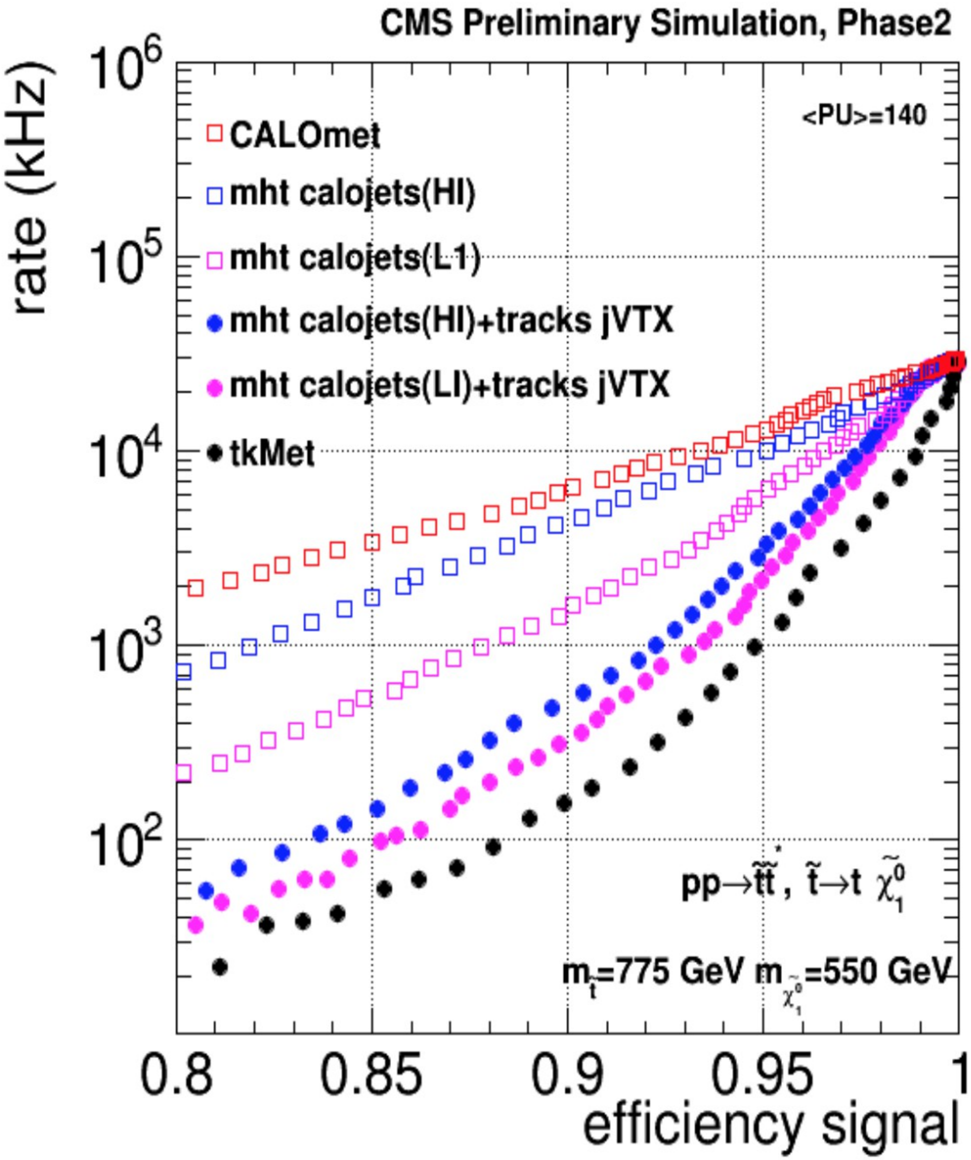


η edge yields PU Jets from low energy particles

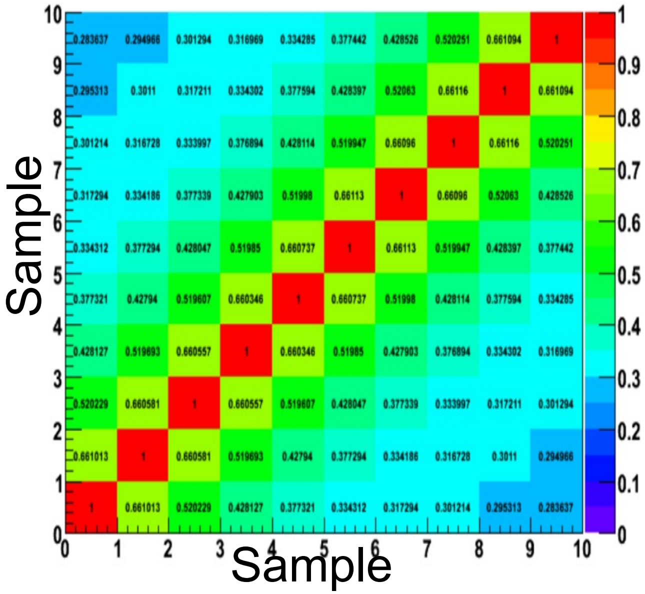
These PU Jets go away with Hcal pulse fits

Track Trigger

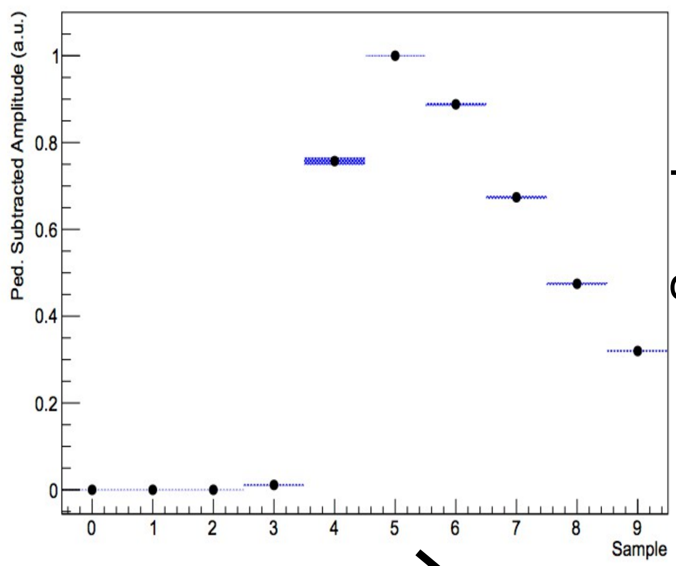




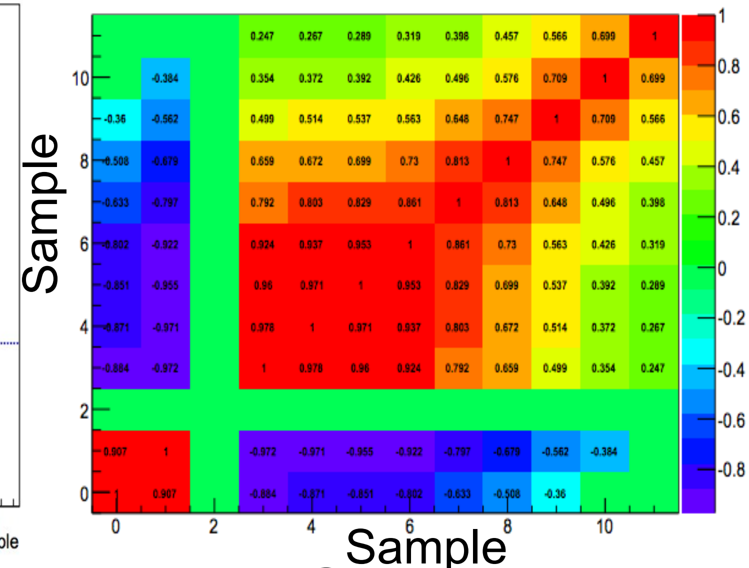
Full Form of behavior



Noise covariance



Pulse shapes



Pulse Covariance

Minimize $$\chi^2 = \left(\sum_j^{N_{\text{pulse}}} A_j \mathbf{p}_j - \mathbf{s}\right)^T \left(\boldsymbol{\Sigma}_s + \sum_j^{N_{\text{pulse}}} A_j^2 \boldsymbol{\Sigma}_{p_j}\right)^{-1} \left(\sum_j^{N_{\text{pulse}}} A_j \mathbf{p}_j - \mathbf{s}\right)$$