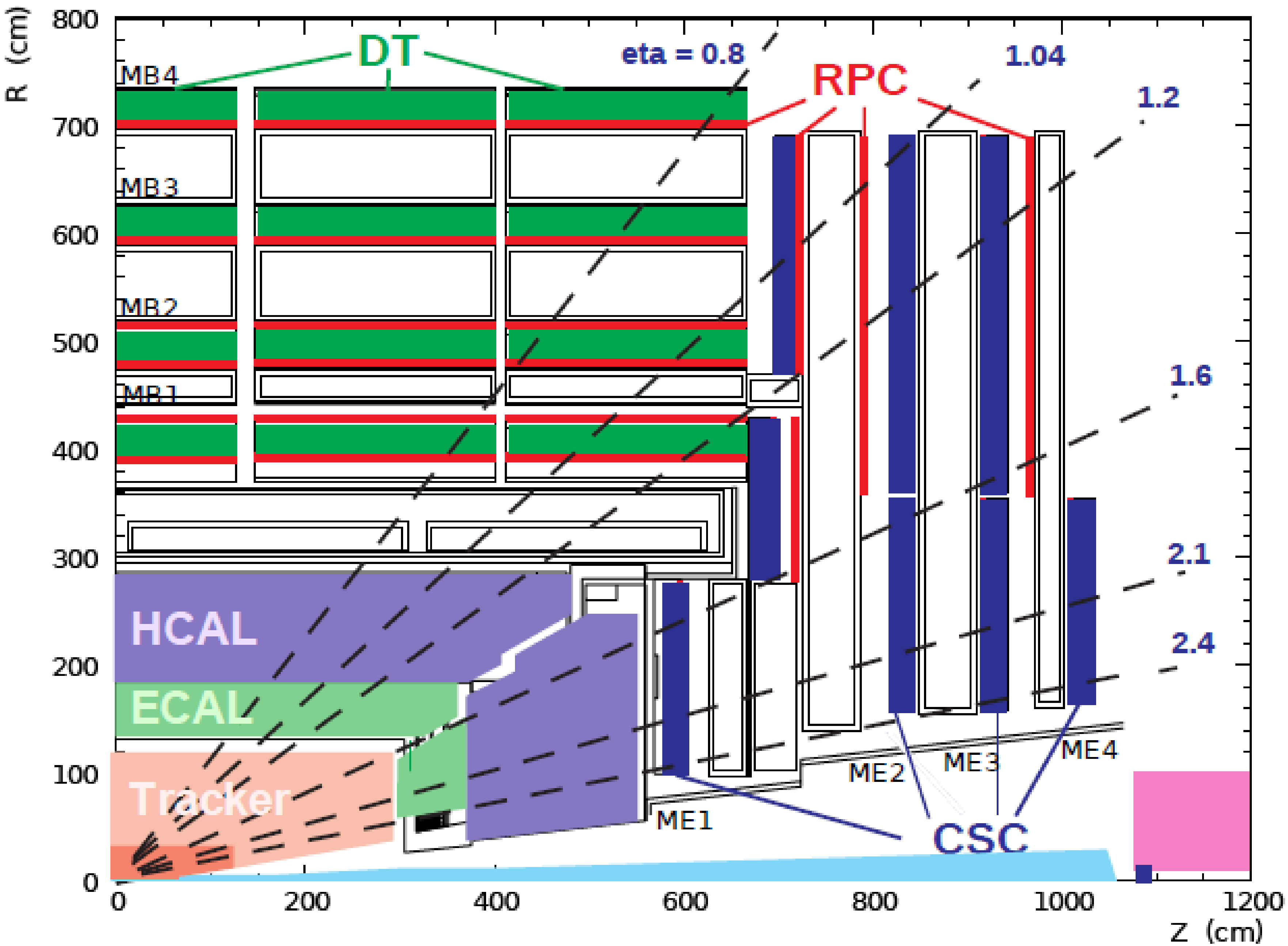
Introduction

- **Aim of the CMS Collaboration** :discover physics underlying electro-weak symmetry breaking with the favoured mechanism being the Higgs mechanism.
- Inner tracker is composed of a pixel detector and a silicon strip tracker
- Drift tube (DT) chambers $|\eta|<1.2$
- Cathode strip chambers (CSC) $0.9<|\eta|<2.4$
- Resistive plate chambers (RPC) $|\eta|<1.6$
- Energy: electromagnetic calorimeter (ECAL),
  hadronic calorimeter (HCAL),
  outer hadronic calorimeter (HO)


R (cm)
800
700
600
500
400
300
200
100
0
DT
MB4
MB3
MB2
MB1
eta = 0.8
1.04
1.2
1.6
2.1
2.4
RPC
HCAL
ECAL
Tracker
ME1
ME2
ME3
ME4
CSC
0
200
400
600
800
1000
1200
Z (cm)

- Region: barrel ($|\eta| < 0{:}9$),
  overlap($0{:}9 < |\eta| < 1{:}2$)
  endcap ($1{:}2 < |\eta| < 2{:}4$)
- Magnet field:3.8T , without making stringent demands on spatial resolution and the alignment of muon chambers.
- Three main task in $|\eta| < 2.5$:
  1. triggering on muons
  2. identifying muons
  3. improving the momentum measurement and charge determination of high-pT muons

triggers

- The zero-bias trigger : defined by the coincidence of signals in two dedicated beam position in the same bunch crossing.

  constant 20Hz, define samples for the study

- Single-muon triggers:detector,inner tracker

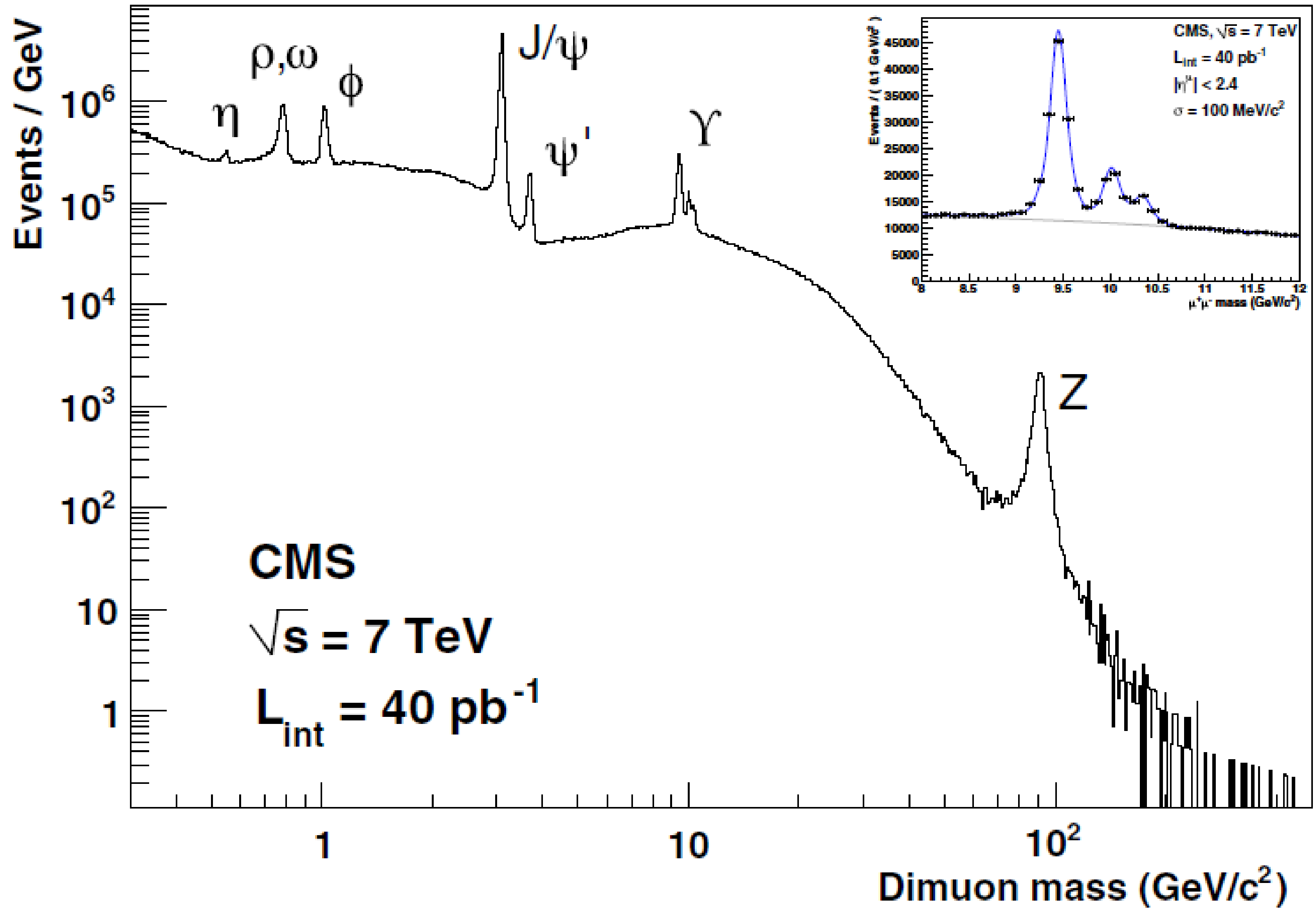
  pT>15Gev/c or lower(depend)

  In 2010, These triggers were the main source of muonic decays of W and Z bosons.

- Muon-plus-track triggers : for J/ ψ event. A muon paired with an inner-tracker track of opposite charge yielding an invariant mass close to that of the for J/ ψ
- Jet and missing transverse energy triggers

  Considering energy
- loose double-muon trigger

  Can span dimuon mass region



Events / GeV
η
ρ,ω
φ
J/ψ
ψ'
ϒ
Z
CMS
√s = 7 TeV
L_int = 40 pb^-1
CMS, √s = 7 TeV
L_int = 40 pb^-1
|η^μ| < 2.4
σ = 100 MeV/c^2
μ+μ- mass (GeV/c^2)
Dimuon mass (GeV/c^2)

Simulate

- Monte Carlo (MC) techniques : CTEQ6L set of parton distribution functions and different event generators.
- tt and QCD multijet events: PYTHIA6 with the Z2 tune
- Samples of prompt J/ ψ from the decays of b hadrons : PYTHIA interfaced to EVTGEN
- W and Z samples and non-resonant Drell-Yan events: POWHEG interfaced with PYTHIA
- W+jets and Z+jets samples: MADGRAPH combined with PYTHIA

Muon reconstruction

- Global Muon reconstruction: For each standalone-muon track, a matching tracker track is found by comparing parameters of the two tracks propagated onto a common surface.
- Tracker Muon reconstruction
- pT >0.5GeV/c and total momentum p > 2.5GeV/c. If at least one muon segment (i.e., a short track stub made of DT or CSC hits) matches the extrapolated track, the corresponding tracker track qualifies as a Tracker Muon.

Muon Identification

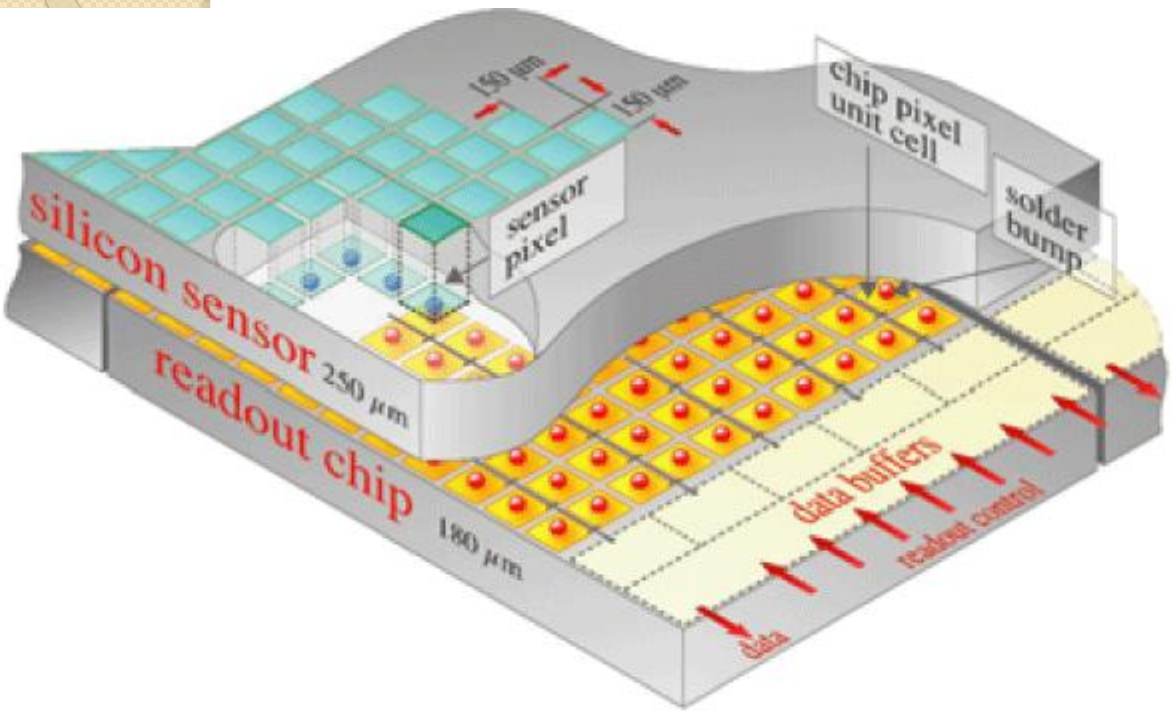
- Soft Muon selection
- candidate to be a Tracker Muon
- muon segment is matched in both x and y coordinates with the extrapolated tracker track track, such that the pull for local x and y is less than 3.
- Particle-Flow Muon selection
- muon candidates reconstructed with the Global and Tracker Muon algorithms(use energy depending on the environmnet)

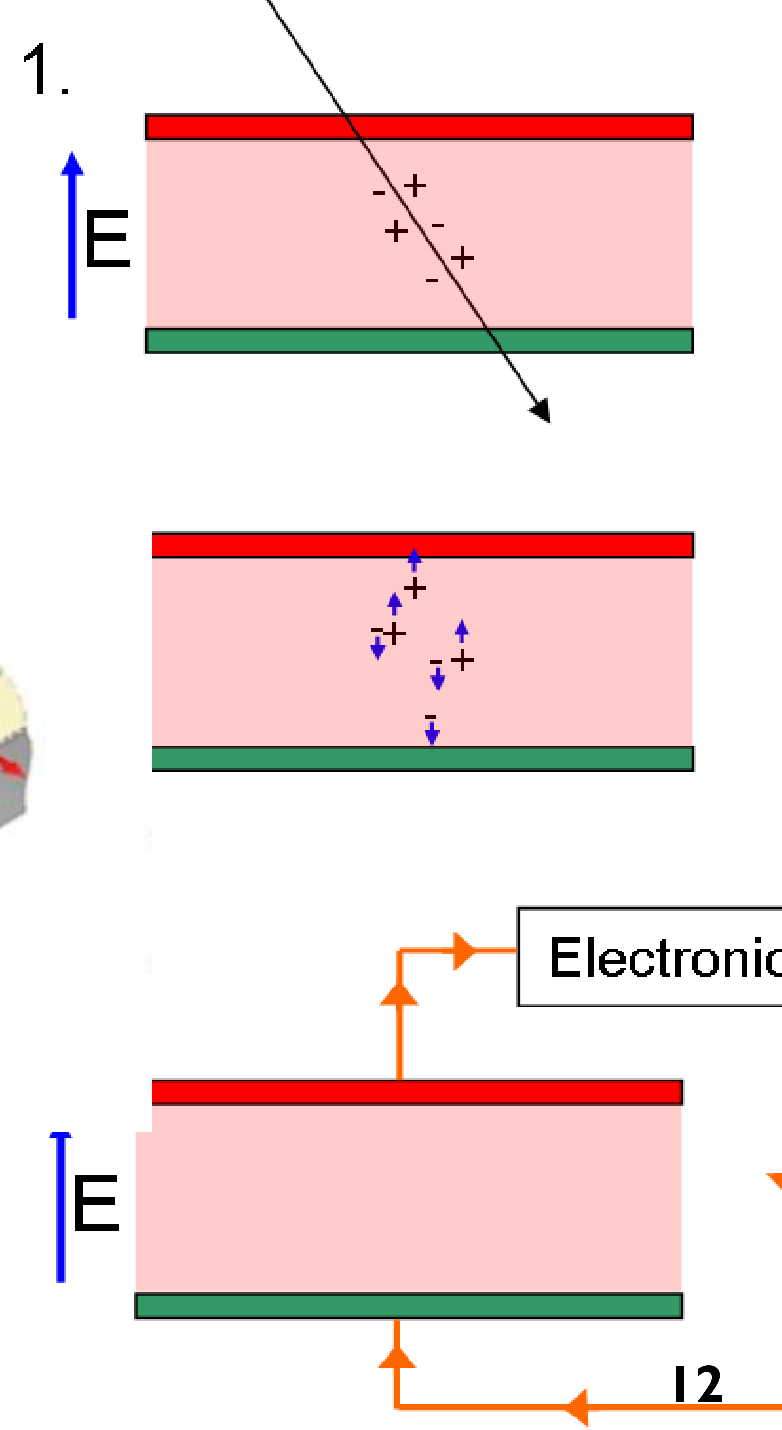
- Tight Muon selection
- candidate must be reconstructed outside-in as a Global Muon
- χ^2/d.o.f of the global-muon track fit less than 10
- at least one muon chamber hit
- to be matched to muon segments in at least two muon stations
- more than 10 inner-tracker hits
- transverse impact parameter |dxy|< 2 mm with respect to the primary vertex

Muon pt

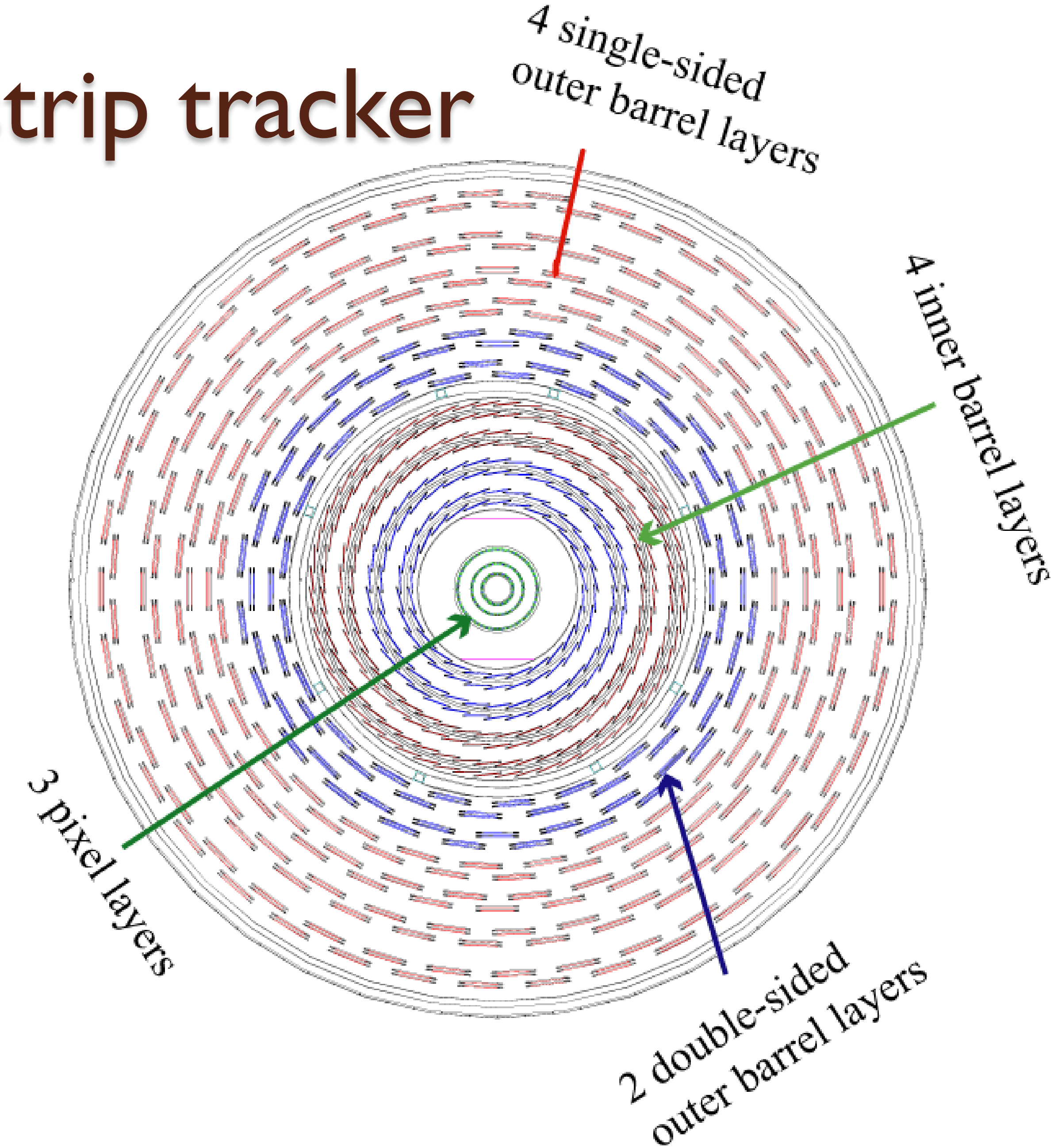
- sigma switch
- If pT above 200GeV/c and give the charge-to-momentum ratios q/p that agree to within $2\sigma q/p$ of the tracker-only fit,use Global fit.
- Or use tracker fit.

pixel detector





silicon strip tracker



Why is the pixel detector closer to beam pipe?

- Reconstructing the tracks of very short-lived particles
- Being made of 2D tiles, rather than strips, and has a number of layers, we can create a three-dimensional picture

Classification of muon sources in simulation

- Prompt muons.

  produced by a muon, arising either from decays of W, Z, and promptly produced quarkonia states, or other sources such as Drell-Yan processes or top quark production.
- Muons from heavy flavour.

  produced by a muon, but the muon's parent particle was a beauty or charmed hadron, or a t lepton.

- Muons from light flavour.

produced by a muon arising from a decay in flight of light hadrons (p and K) or, less frequently, from the decay of particles produced in nuclear interactions in the detector material

- Hadron punch-through.

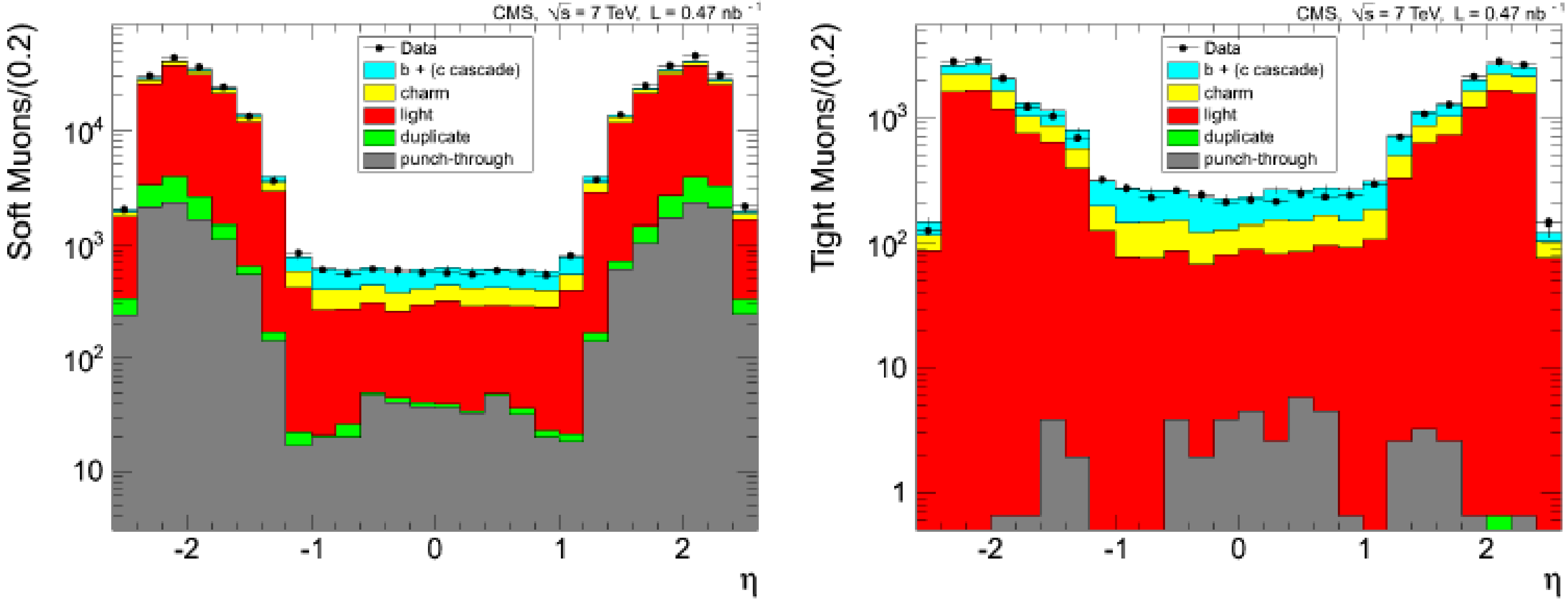
produced by a particle that was not a muon.

- Duplicate.

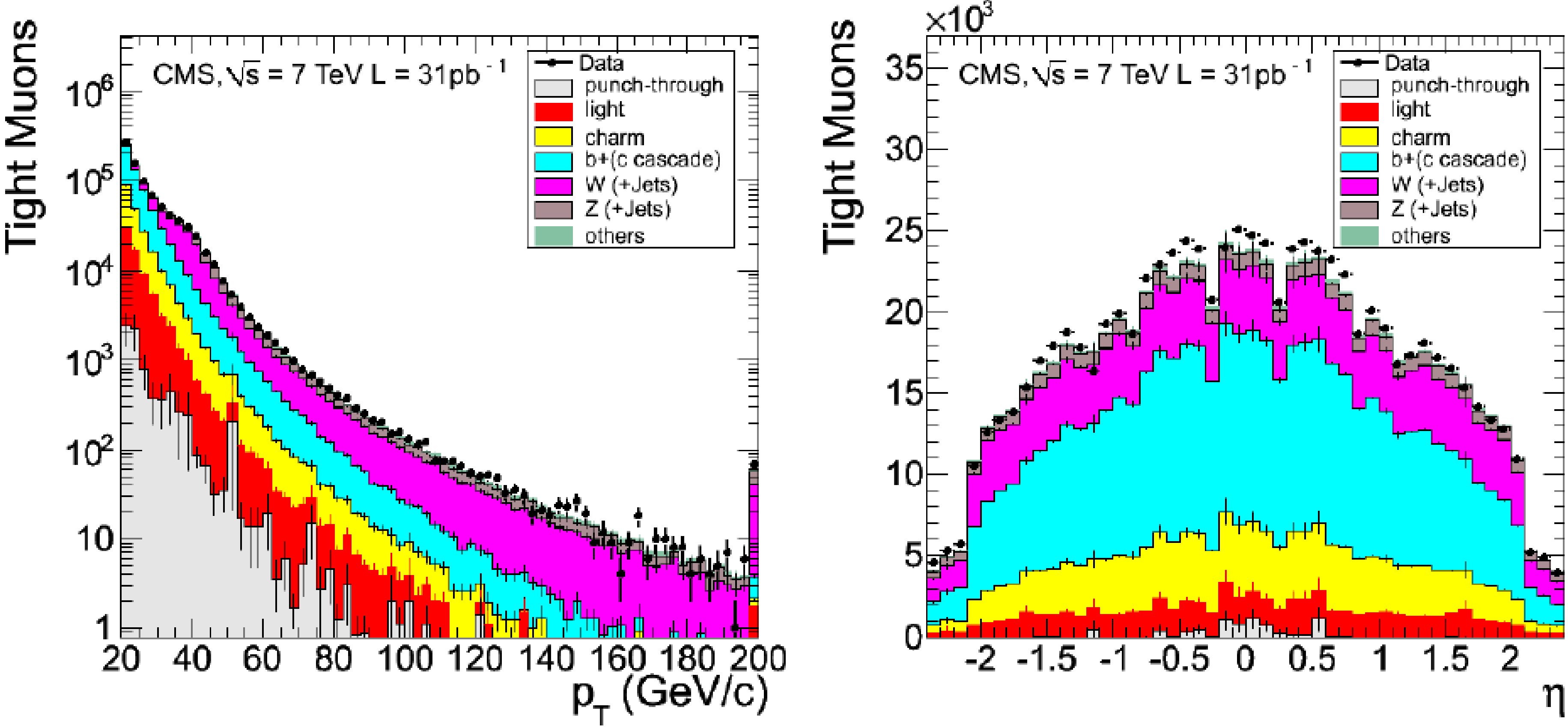
If one simulated particle gives rise to more than one reconstructed muon candidate, that with the largest number of matched hits is assigned to one of the above categories, and any others are labeled as "duplicate".

Table 1. Composition by source of the low-p_T muon candidates reconstructed in zero-bias events, according to simulation for the Soft and Tight Muon selections.

Muon source	Soft Muons [%]	Tight Muons [%]
beauty	4.4	22.2
charm	8.3	21.9
light flavour	79.0	55.7
hadron punch-through	5.4	0.2
duplicate	2.9	<0.01
prompt	$\lesssim 0.1$	$\lesssim 0.1$

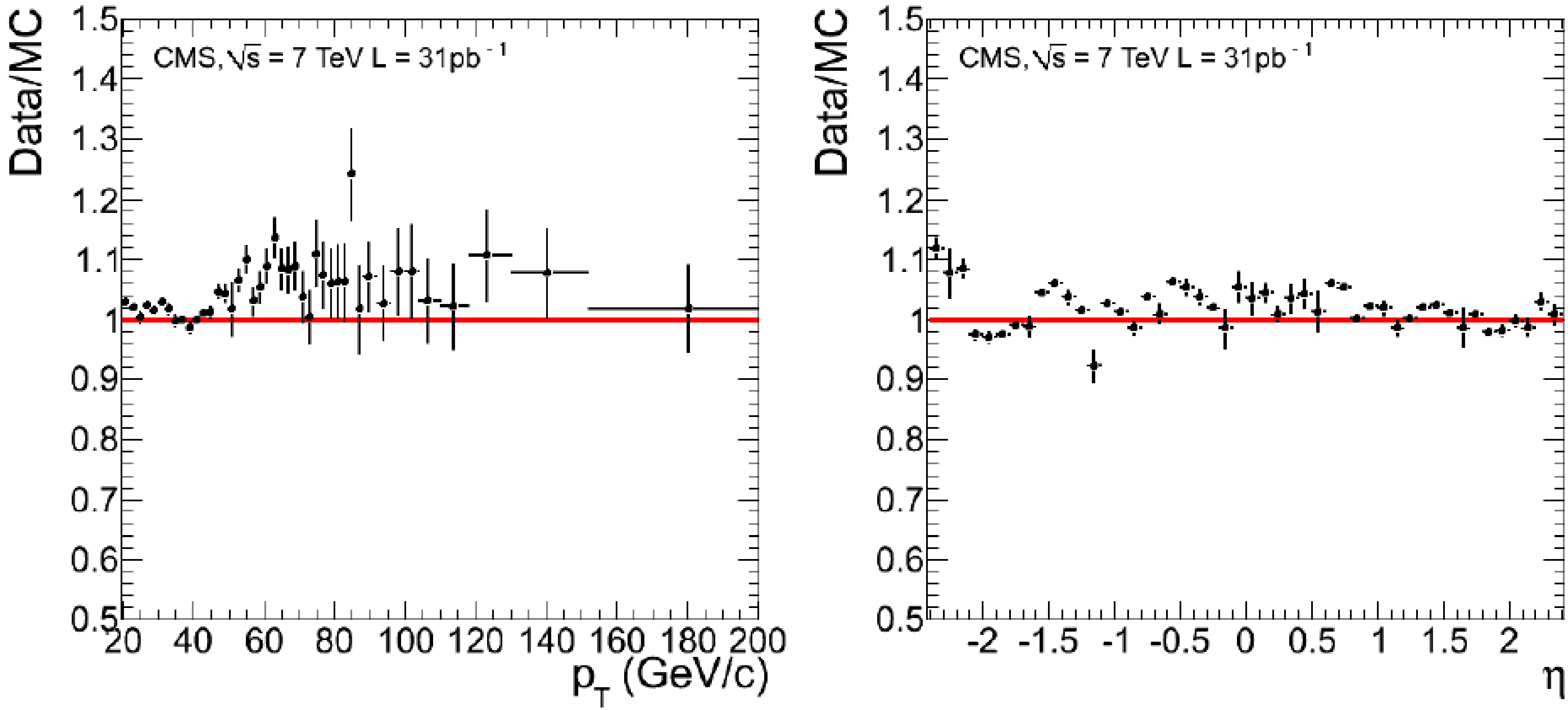


the minimum pT required to reach the muon stations is lower than in the barrel: in the endcaps the threshold in pT is about 0.5GeV/c, while in the barrel it is about 3–4GeV/c.



- The beauty contribution dominates up to muon transverse momentum of about 30GeV/c ,where the W contribution starts to prevail, leading to a shoulder in the falling pT spectrum.
- Dips in the η distribution

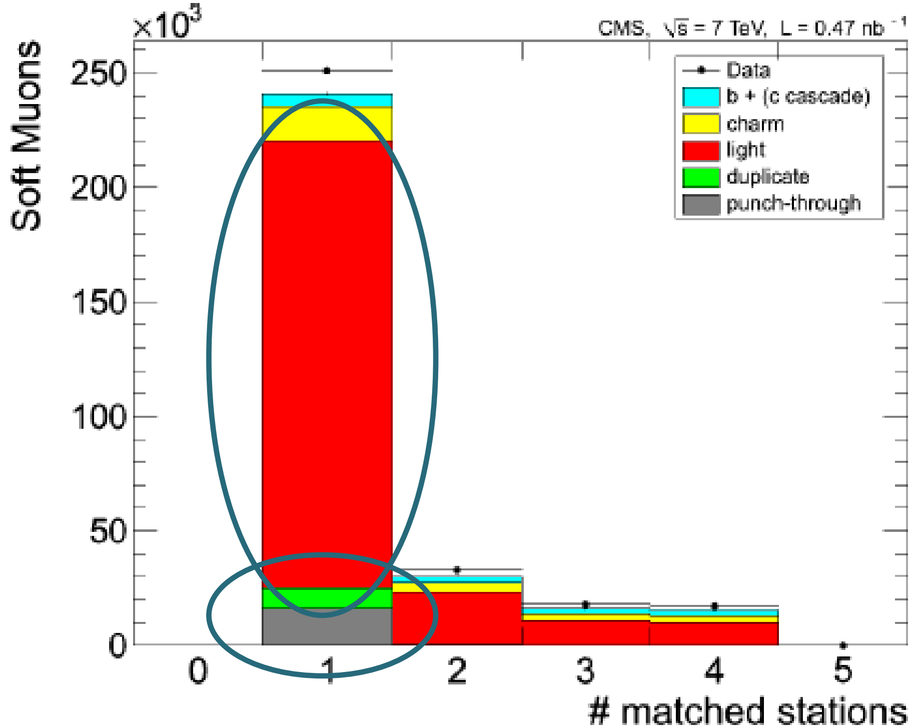
are due to inefficiencies related to the muon detector geometry.



- The inclusive muon yield agrees with the expectations within a few percent up to a transverse momentum of 50GeV/c.
- In this pT region, the data agree with the predictions within 10%

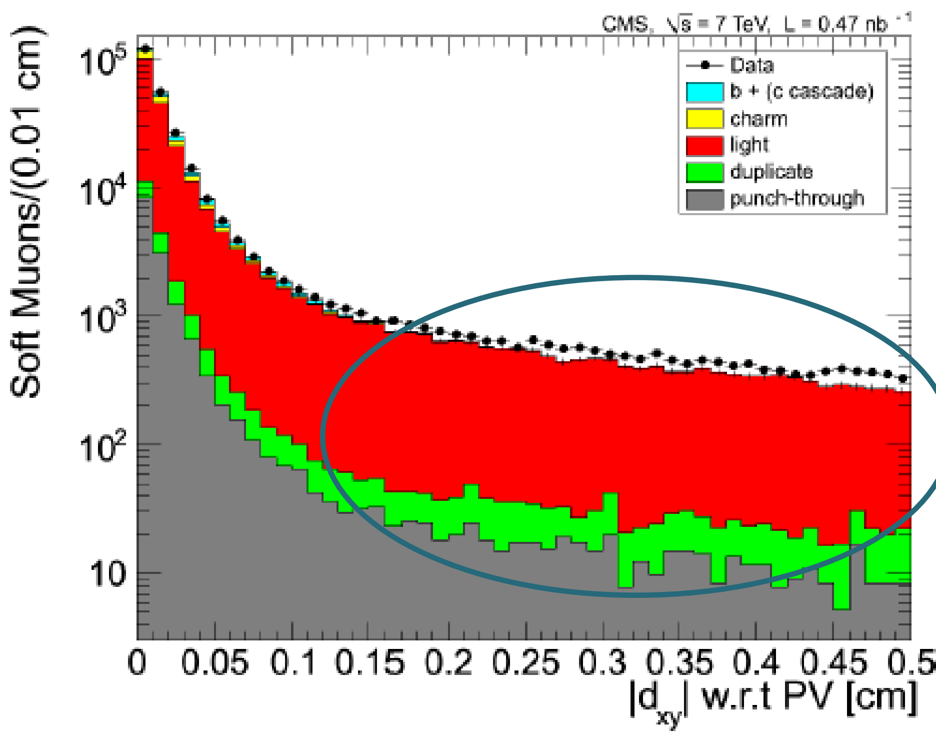
Table 2. Composition by source of Tight Muons with $p_T > 20\,\mathrm{GeV}/c$ according to simulation.

Muon source	Tight Muons with $p_T > 20\,\mathrm{GeV}/c$ [%]
W (+ jets)	20.8
Z/Drell-Yan (+ jets)	4.7
top	0.1
quarkonia	0.7
beauty	47.6
charm	17.4
light flavour	7.8
hadron punch-through	0.9
duplicate	<0.01



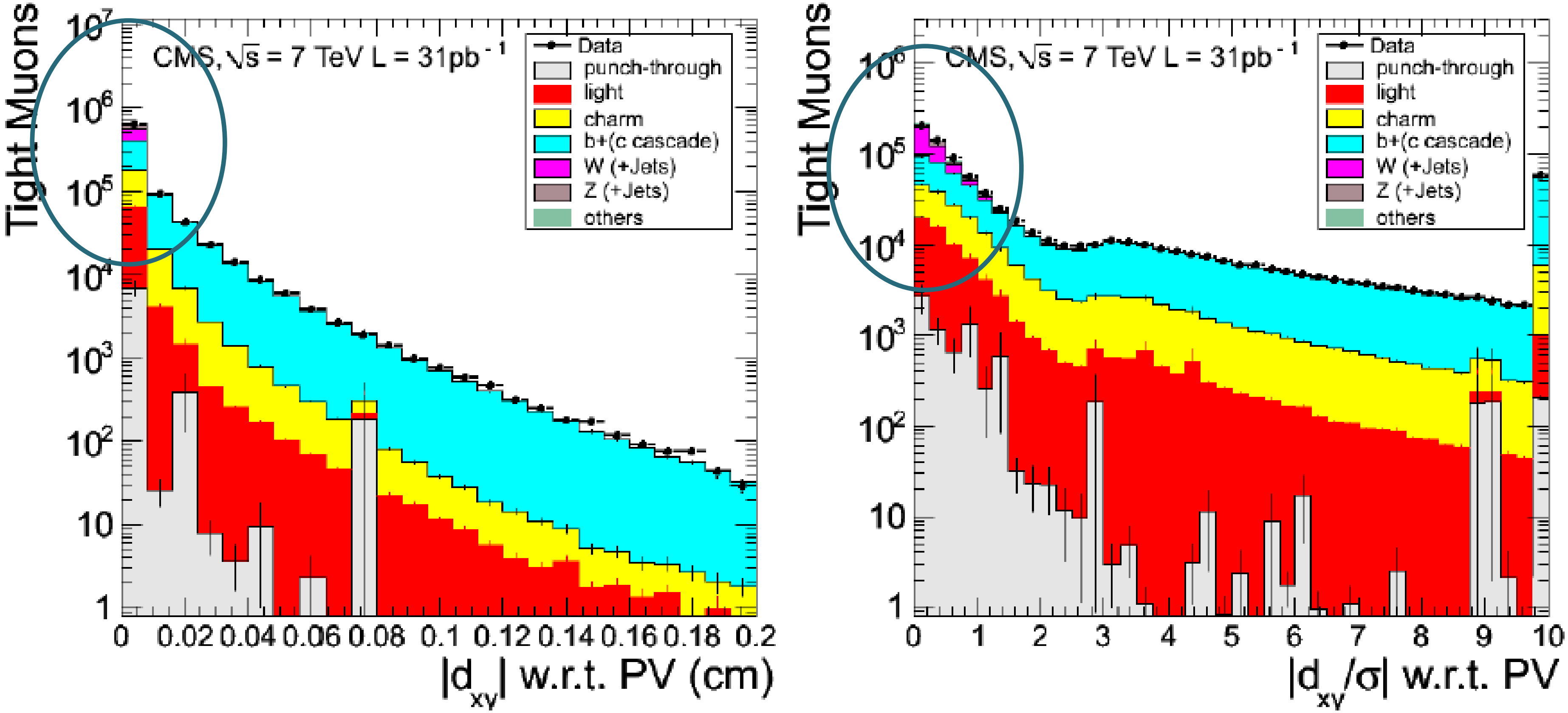
×10^3
CMS, √s = 7 TeV, L = 0.47 nb^-1
Soft Muons
Data
b + (c cascade)
charm
light
duplicate
punch-through
matched stations

(a)

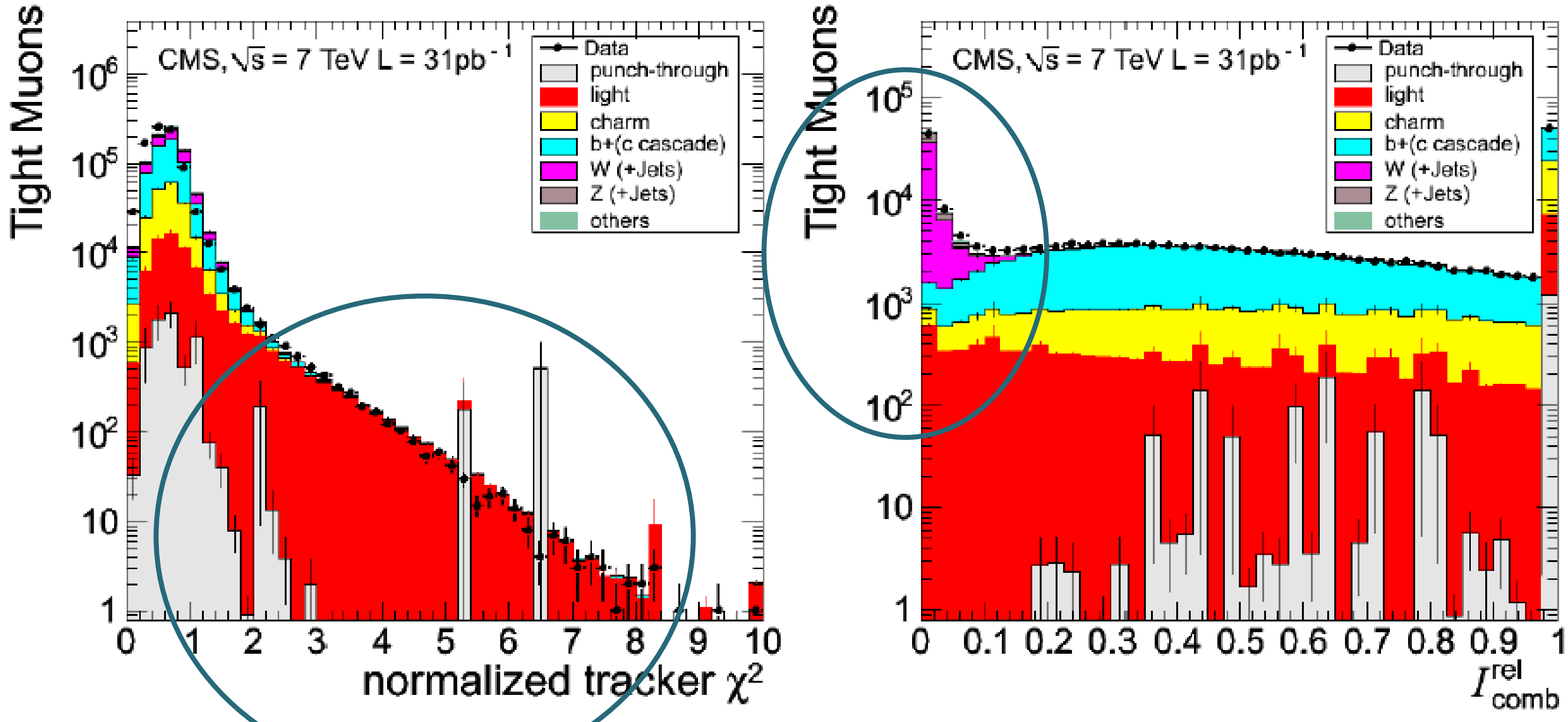


CMS, √s = 7 TeV, L = 0.47 nb^-1
Soft Muons/(0.01 cm)
Data
b + (c cascade)
charm
light
duplicate
punch-through
|d_xy| w.r.t PV [cm]

(b)



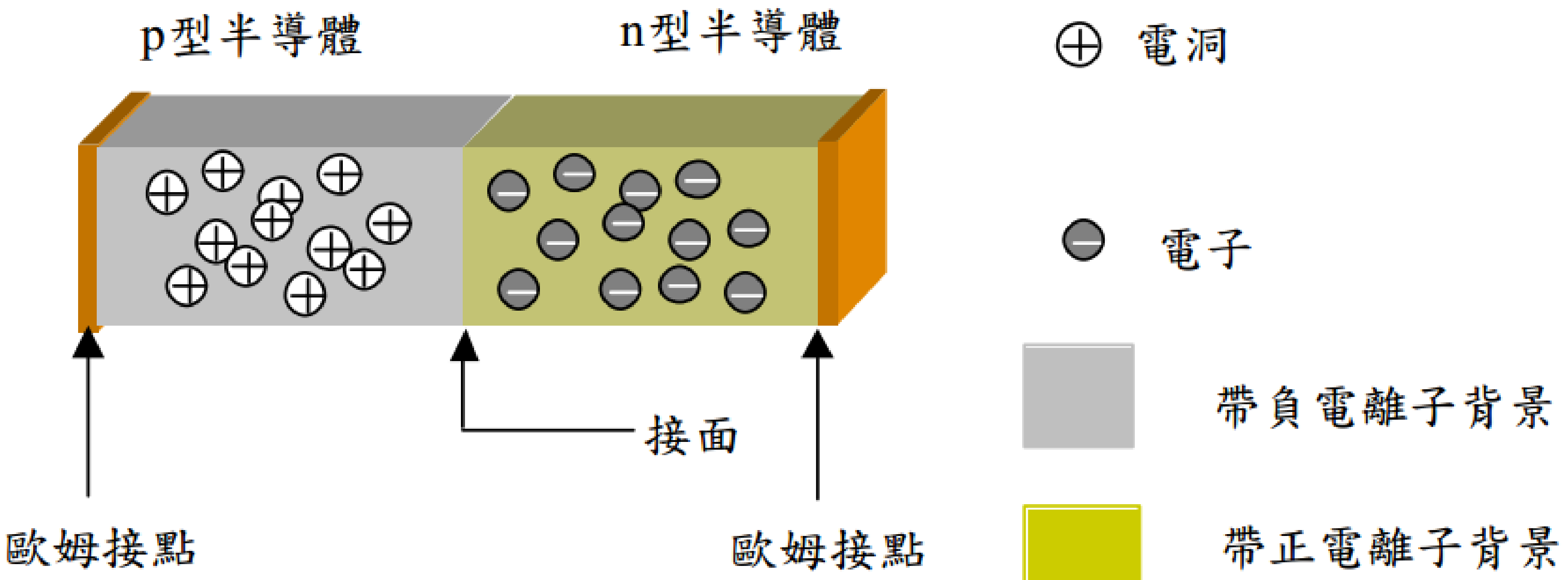
Tight Muons
CMS, √s = 7 TeV L = 31pb⁻¹
Data
punch-through
light
charm
b+(c cascade)
W (+Jets)
Z (+Jets)
others
|d_xy| w.r.t. PV (cm)
|d_xy/σ| w.r.t. PV

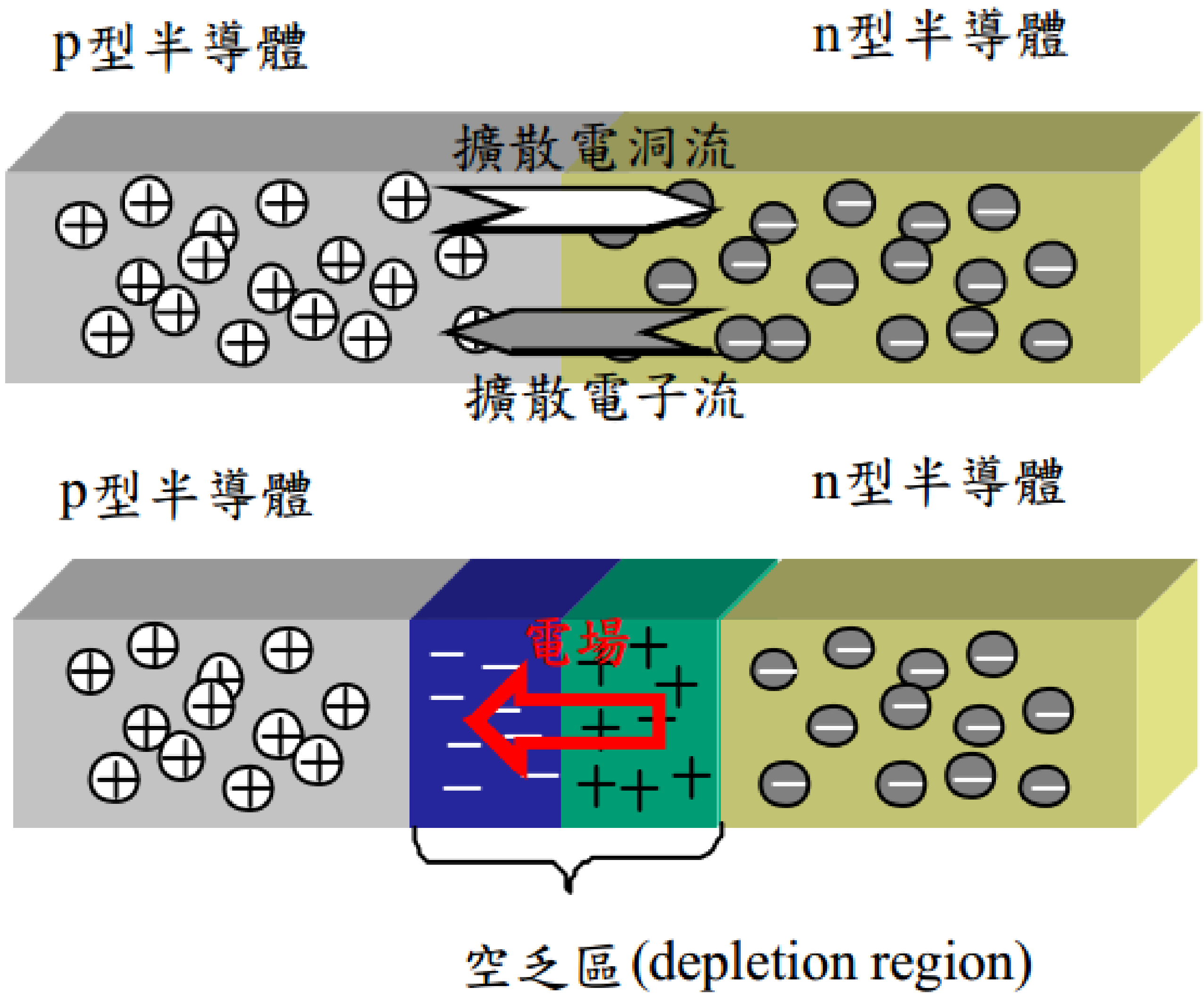


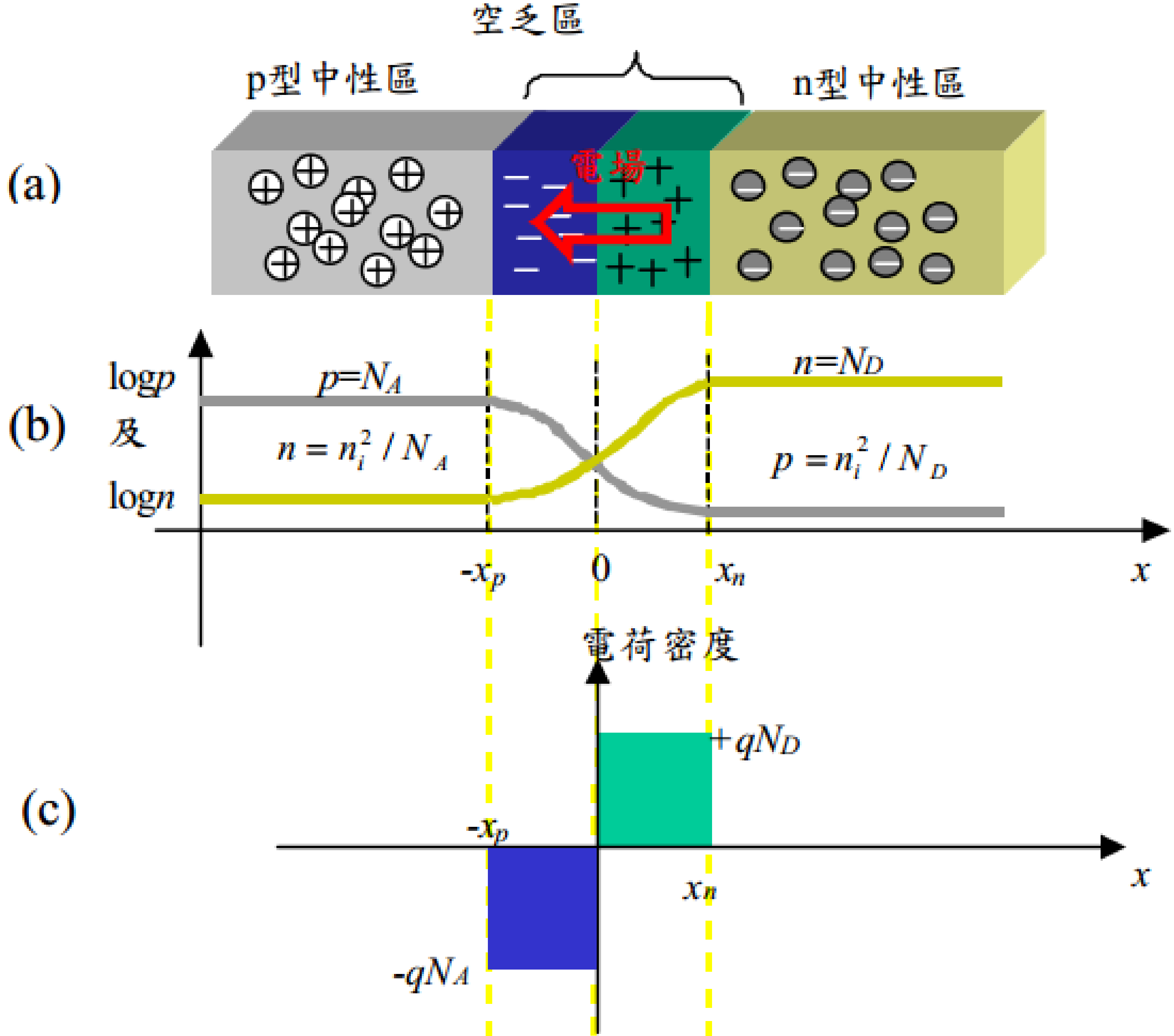
- The scalar sum of the transverse momenta of tracks in the inner tracker and the transverse energies in calorimeter cells within a cone of radius $\Delta R = \sqrt{(\Delta\varphi)^2 + (\Delta\eta)^2} = 0.3$ centred on the direction vector of the muon candidate is calculated,excluding the contribution from the candidate itself
- The relative combined isolation is defined as the ratio of this scalar sum to the transverse momentum of the muon candidate

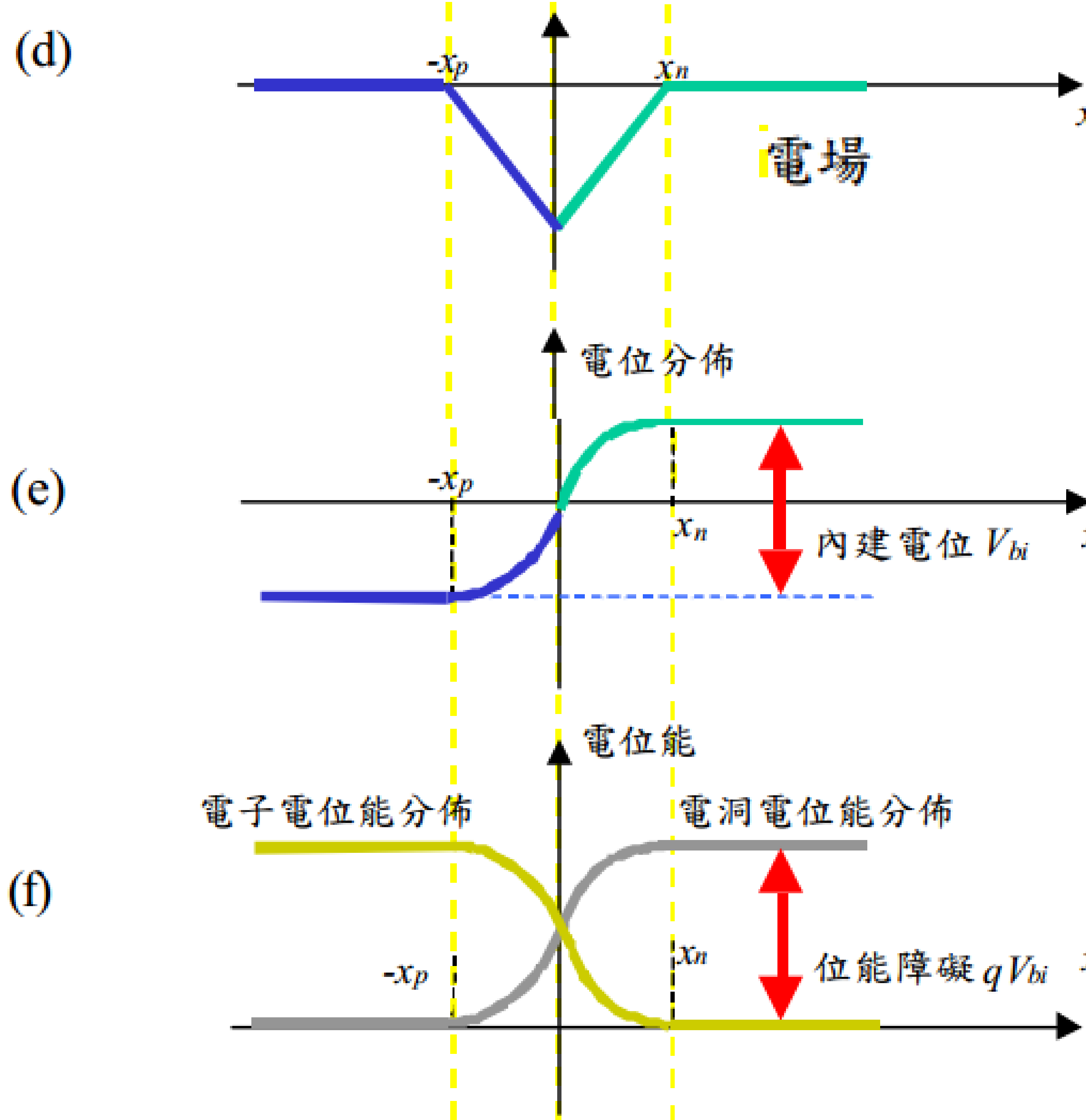
二極體

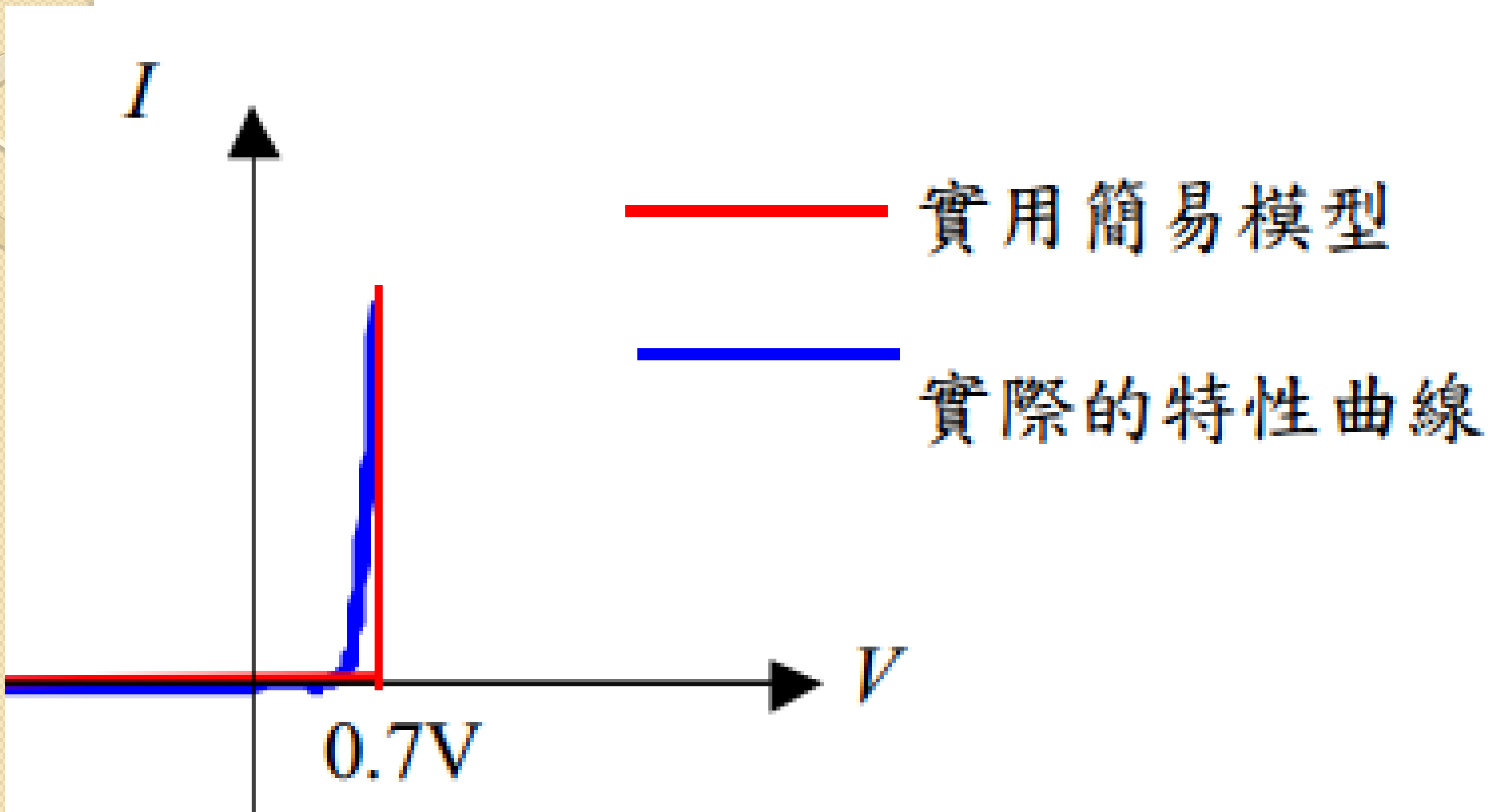
圖 1　pn 二極體的基本結構




p型半導體
n型半導體
擴散電洞流
擴散電子流
p型半導體
n型半導體
電場
空乏區 (depletion region)


空乏區
p型中性區
n型中性區
(a)
電場
(b)
logp
及
logn
p=N_A
n=N_D
n = n_i^2 / N_A
p = n_i^2 / N_D
-x_p
0
x_n
x
電荷密度
(c)
+qN_D
-x_p
x_n
x
-qN_A


(d)
-xp
xn
x
電場
(e)
電位分佈
-xp
xn
x
內建電位 Vbi
(f)
電位能
電子電位能分佈
電洞電位能分佈
-xp
xn
x
位能障礙 q Vbi


I
實用簡易模型
實際的特性曲線
V
0.7V

Sagitta

- B=3.8T
- Pt=200GeV/c

$=1.783 \times 10^{-27}$ kg $\times$ 299 792 458 m / s $\times 200$

$=5.344 \times 10^{-19}$ kg.m/s $\times 200$

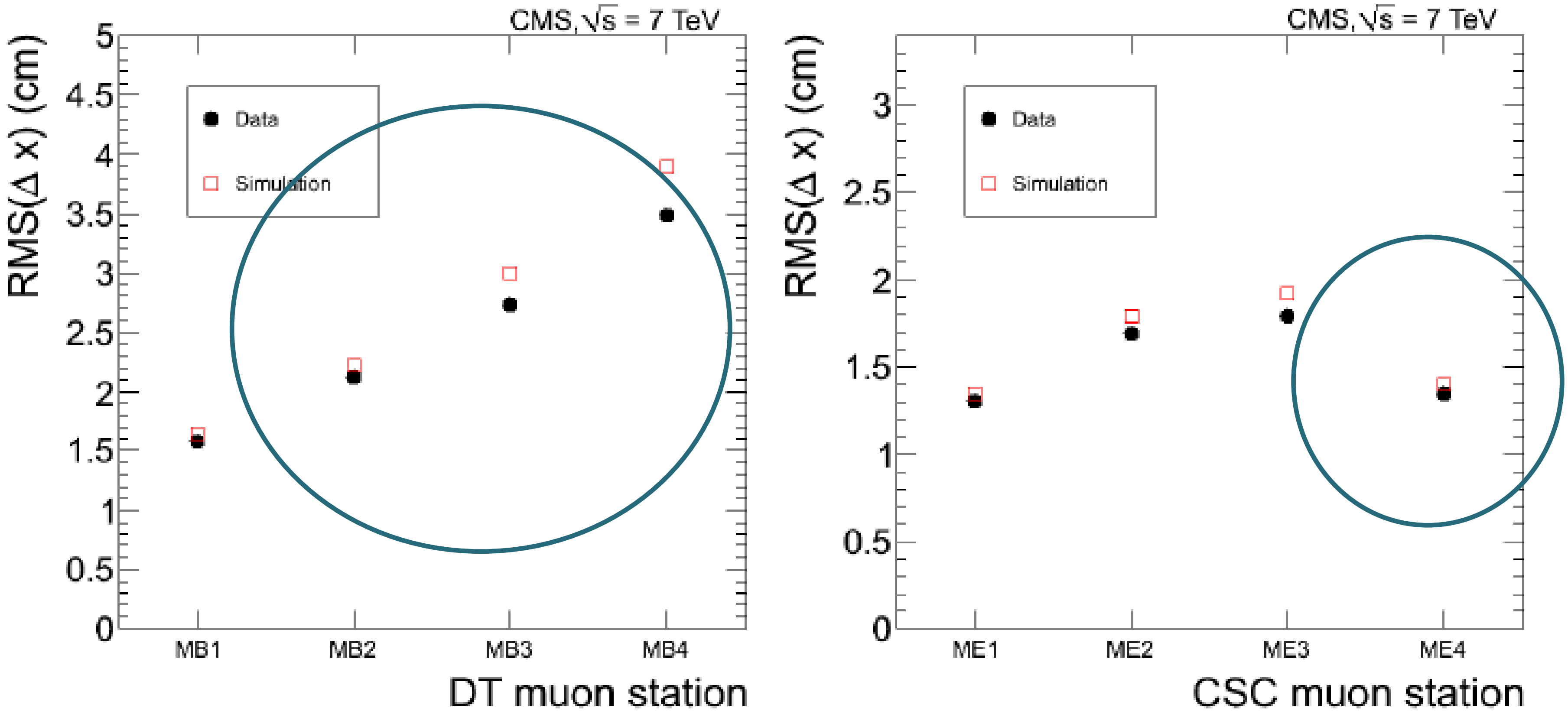
- F=qvB=m(v^2)/r
- qB=mv/r=pt/r
- r=pt/qB

- r=pt/qB

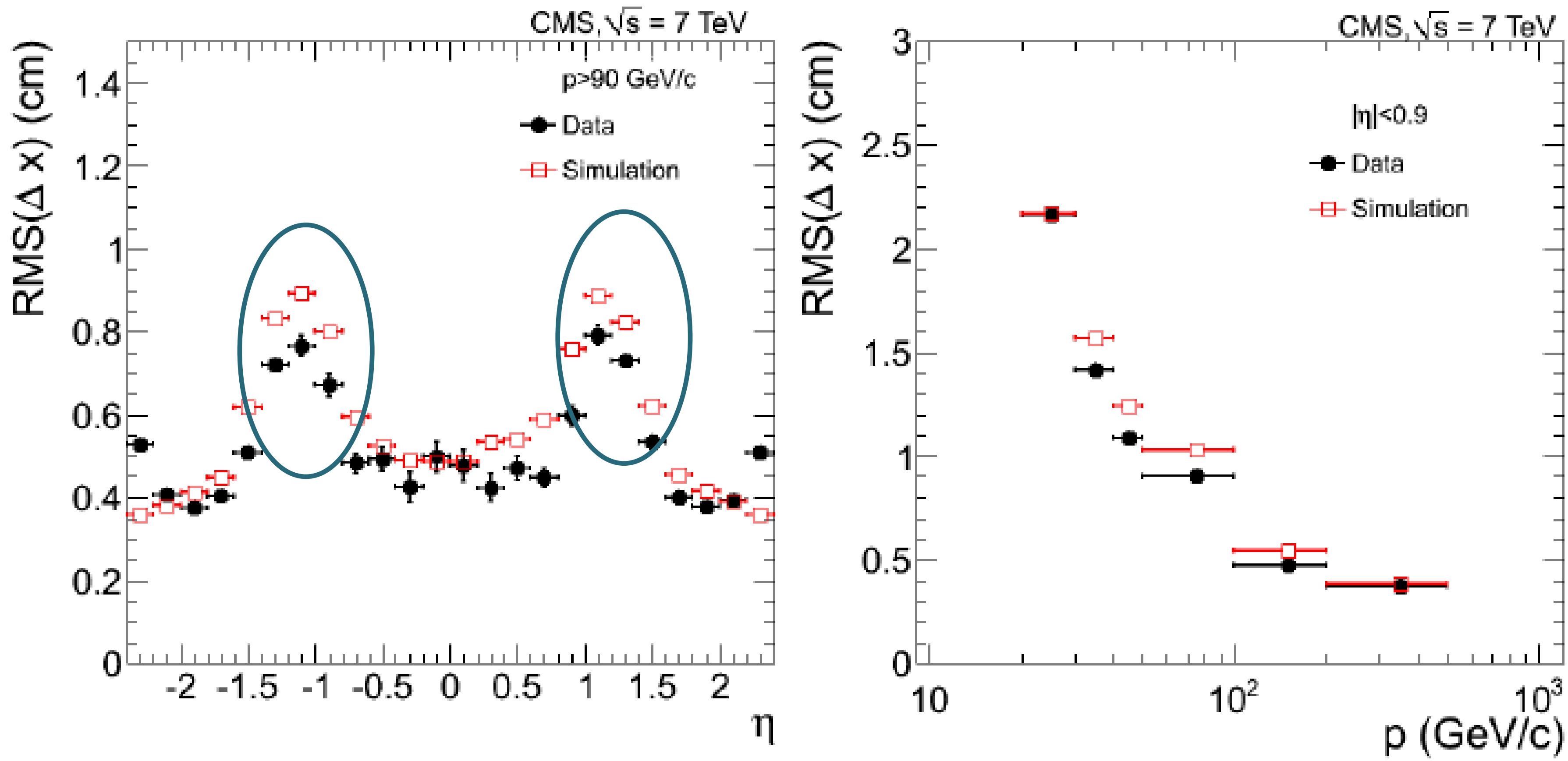
= 5.344 × 10^{-19} (kg.m/s)/[1.6021892×10^{-19} (C)× 3.8 (T)] ×200

=0.877m ×200=175.5m

- Inner tracker =1m
- S= $r-\sqrt{r^2-l^2}$=175.5-175.49928=0.0072m
- Chamber=7m
- S= $r-\sqrt{r^2-l^2}$=175.5-175.46509=0.0349m

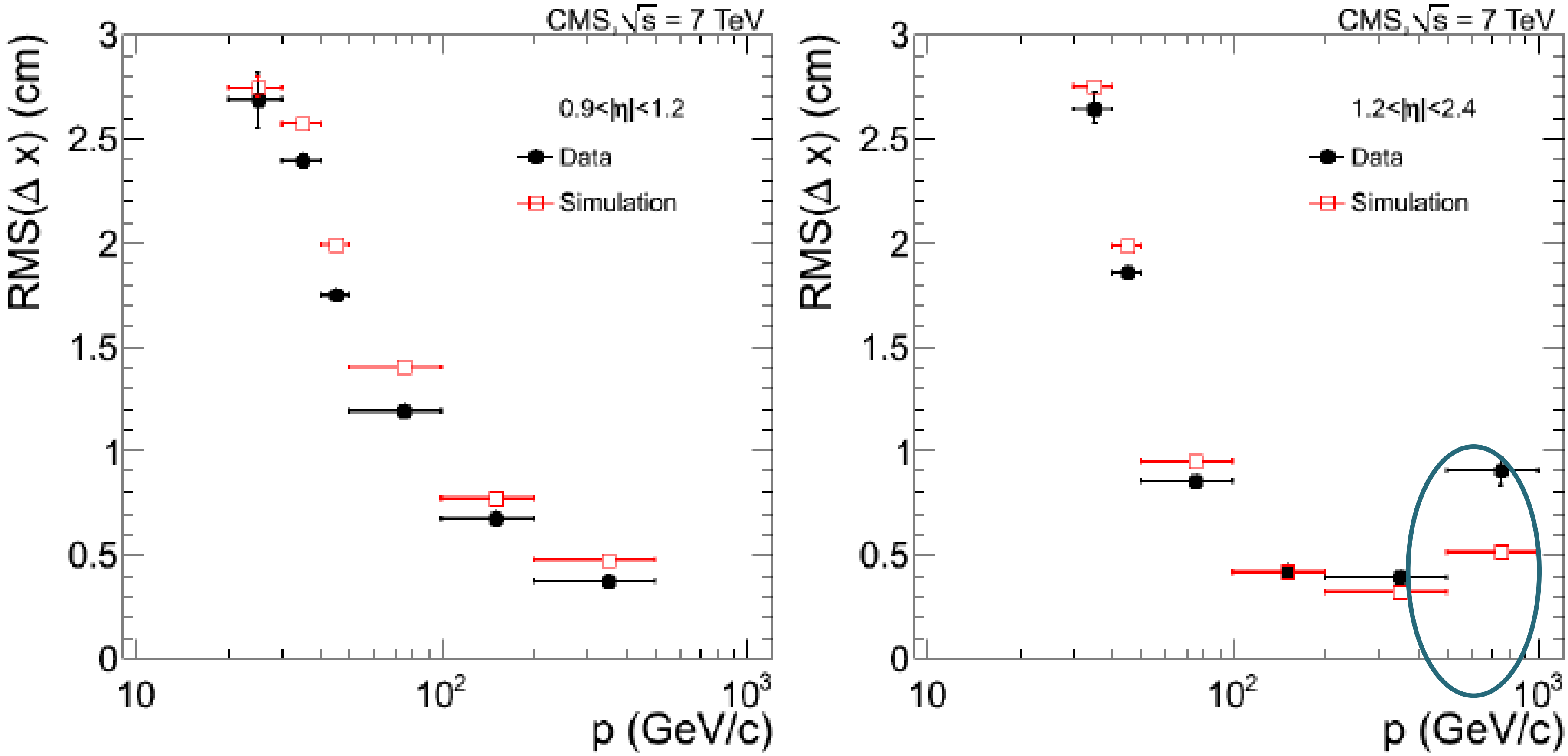


- the residual for ME4 is not directly comparable with the measurements in the other stations because muons traversing the installed ME4 chambers have a higher average momentum



CMS, $\sqrt{s}$ = 7 TeV
p>90 GeV/c
Data
Simulation
RMS(Δ x) (cm)
η
CMS, $\sqrt{s}$ = 7 TeV
|η|<0.9
Data
Simulation
RMS(Δ x) (cm)
p (GeV/c)

(a) (b)



(c) (d)

- The only exception

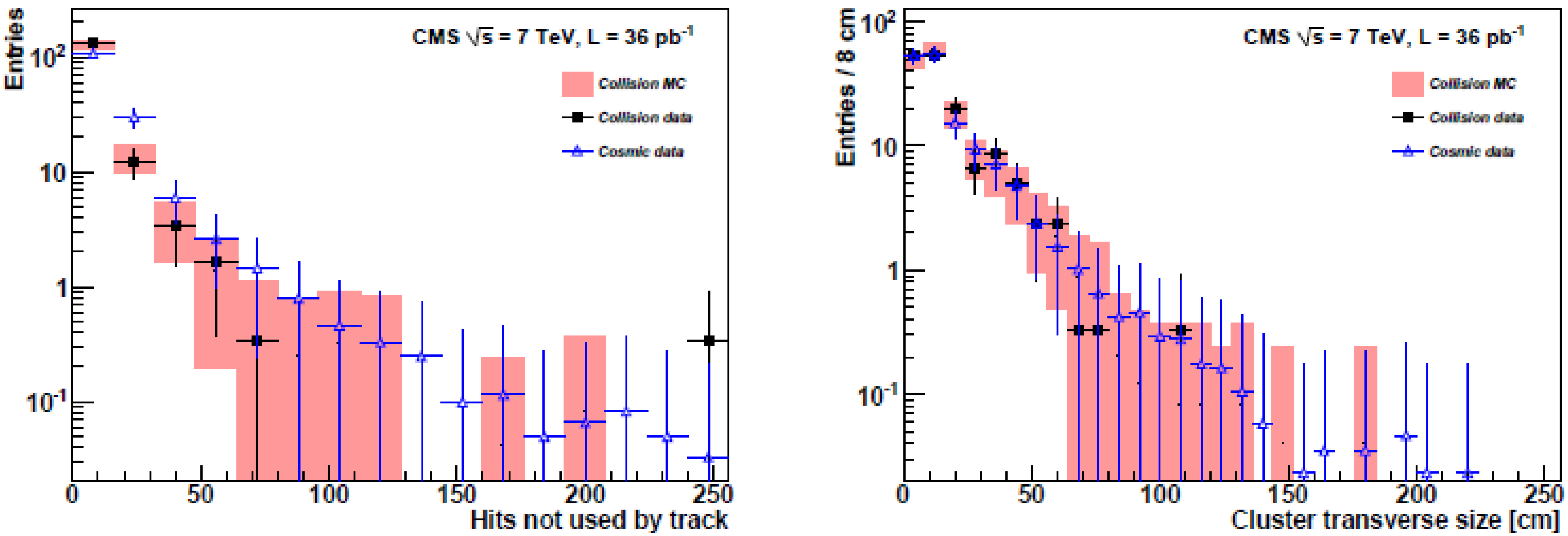


Figure 10. Comparison of data and simulation for variables characterizing electromagnetic showers, for muons with $p > 150\,\mathrm{GeV}/c$ in the barrel region: the number of reconstructed muon hits not used in a track fit (left); the transverse size of the cluster of hits around a track (right). All distributions are normalized to the number of muons per muon station in the collision data sample.

the number of hits reconstructed in the DT chamber crossed by a track but not used in the track fit

- The cluster of hits is defined iteratively, starting from the impact point of the extrapolated muon track and successively adding any hit if it lies within $\Delta\phi < 0.05$ rad of the hit in the existing cluster with largest radial distance from the impact point

transverse size of the cluster of hits around a track

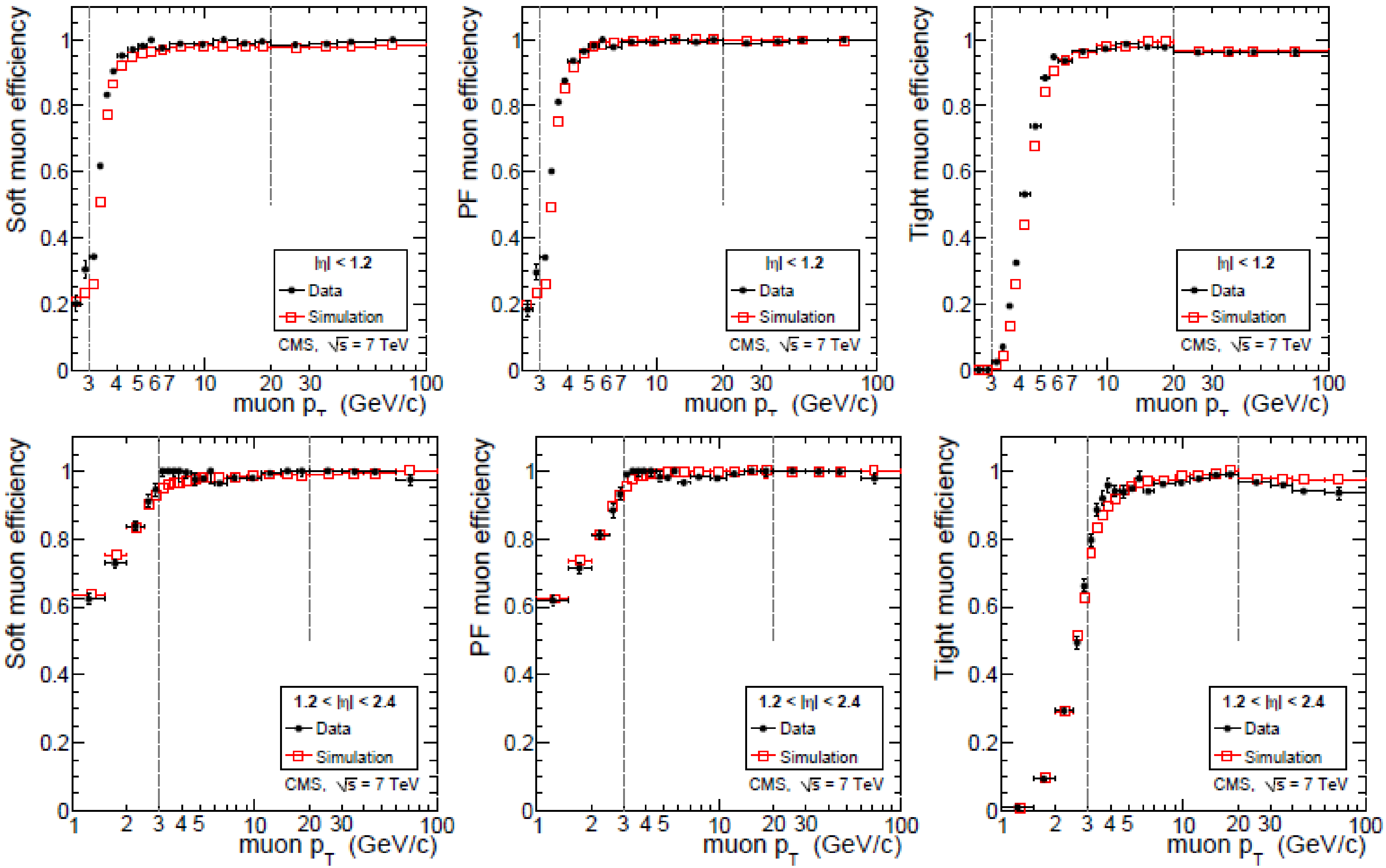
- The transverse size of a cluster is defined as the maximum distance in the local x-y plane between the impact point of the track and any hit in the cluster

Why to use cosmic muon

- To decrease the hit by other charged particles which are not belong to electromegnetic shower.

Muon reconstruction and identification efficiency

- $\varepsilon_{\mu} = \varepsilon_{track} \times \varepsilon_{rec+id} \times \varepsilon_{iso} \times \varepsilon_{trig}$
- muon efficiencies ε_{rec+id} are measured with tag-and-probe technique



- J/ ψ events for pT <20GeV/c and Z events for pT > 20GeV/c

Why to use Tag and Probe method?

- The method uesd to calculate the efficiency of reconstruction and idenification is to divide the number of reconstructed and idenified particles (muon) by the total number of particles passing through .However,we do not know how many muons were generated by collision. The Tag and Probe method insure that another muon would be generate with the muon which passes the Tag selection.

minimum-ionizing particle (MIP) in the calorimeters

- In the case of the J=y events, combinatorial backgrounds from other tracks in the event are generally high, particularly at low pT
- n physics, a minimum ionizing particle (or mip) is a particle whose mean energy loss rate through matter is close to the minimum

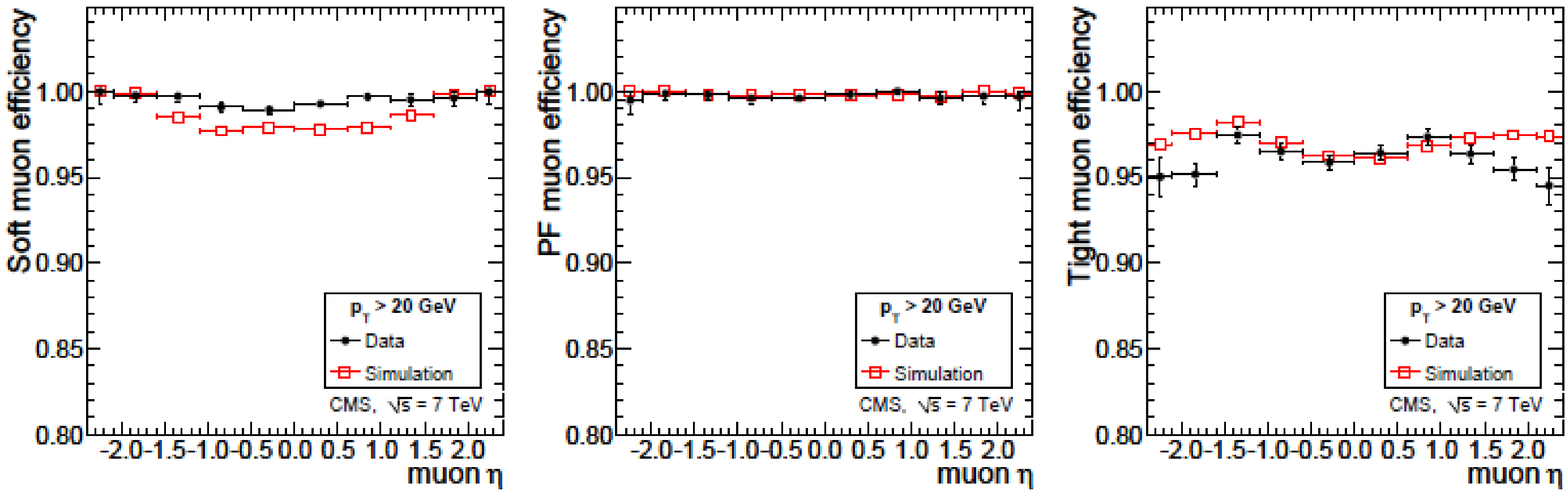


Figure 12. Muon efficiency $\varepsilon_{\text{rec+id}}$ in data and simulation as a function of muon pseudorapidity for Soft Muons (left), Particle-Flow Muons (middle), and Tight Muons (right). The efficiencies were calculated relative to the tracker tracks with $p_T > 20\,\text{GeV}/c$ by applying the tag-and-probe technique to $Z \rightarrow \mu^+\mu^-$ events.

- The data and simulation agree to better than 2%.

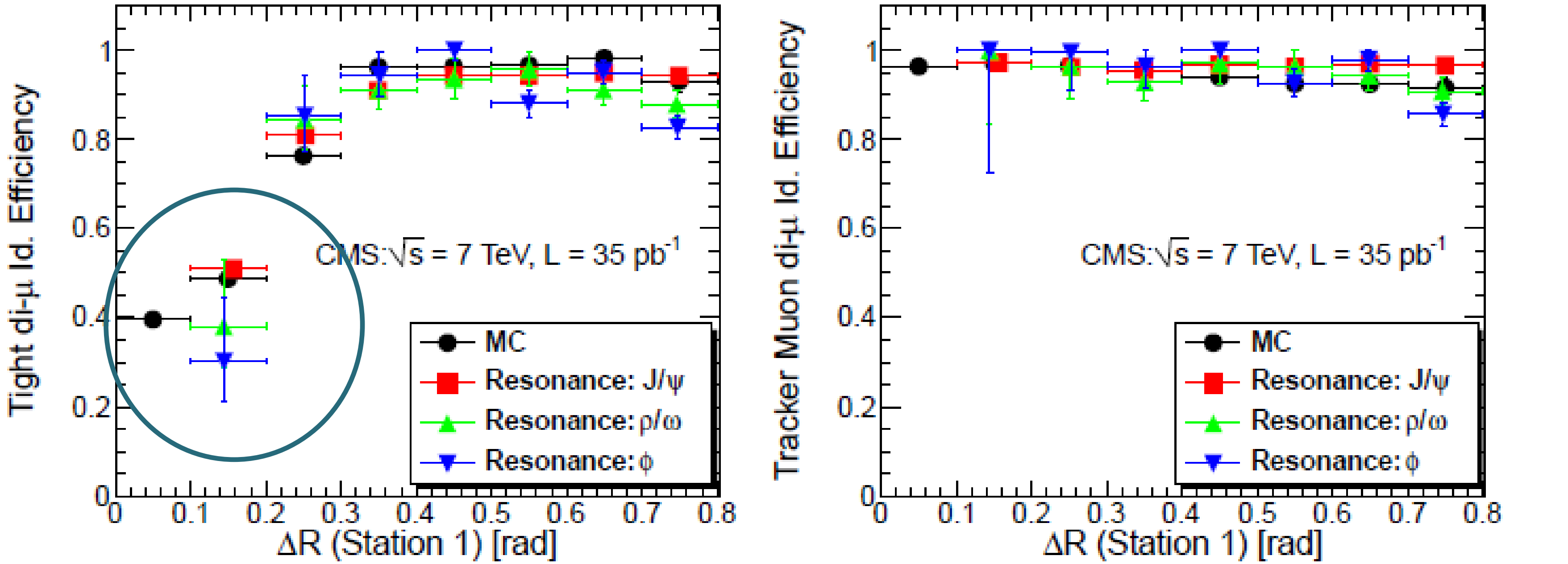


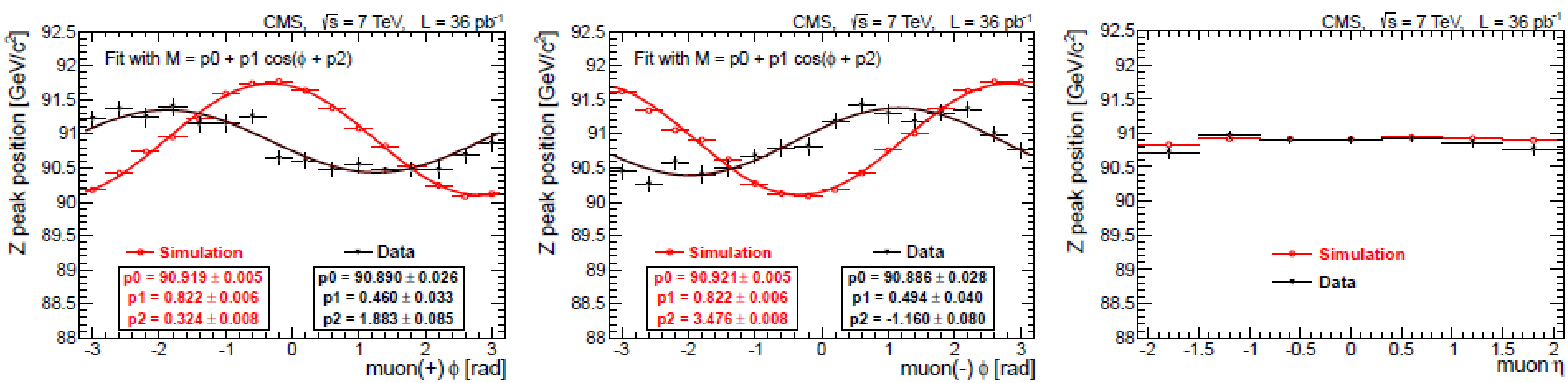
Figure 13. Efficiency for identifying both muons in the dimuon pair as Tight (left) and Tracker (right) Muons as a function of the angular separation of the two tracks computed at the surface of the first muon station. Measurements obtained using J/ψ (squares), ϕ (inverted triangles), and ρ/ω (triangles) are compared with the expectations from the simulation (circles).

$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

this inefficiency is introduced by a cleaning procedure used at the seeding stage of the global muon reconstruction to eliminate muon seeds leading to duplicate muons.

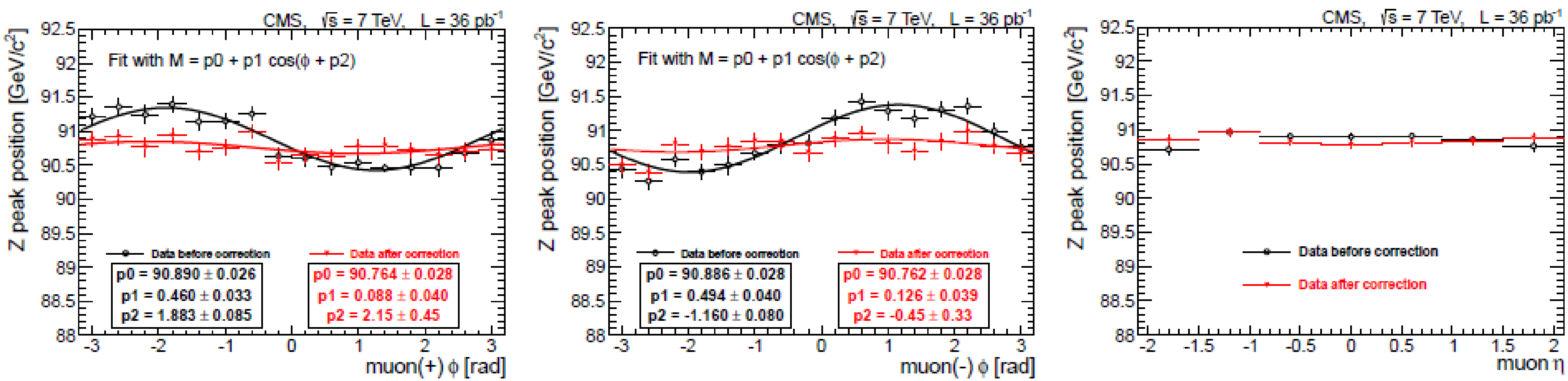
Muon momentum scale

- the biases in the reconstructed muon pT are determined from the position of the Z mass peak as a function of muon kinematic variables



MuScleFit

$$p'_{\mathrm{T}} = p_{\mathrm{T}}(1 + b \cdot p_{\mathrm{T}} + c \cdot \eta^2 + q \cdot d \cdot p_{\mathrm{T}} \cdot \sin(\phi + e)),$$



SIDRA method

- This means that unlike the MuScleFit method, the SIDRA method calibrates only relative biases between data and simulation.

$$\frac{1}{p'_{\mathrm{T,sim}}} = \frac{1}{p_{\mathrm{T,sim}}} + \delta_{\kappa_{\mathrm{T}}}(q,\phi,\eta) + \sigma_{\kappa_{\mathrm{T}}}(q,\phi,\eta)\ \mathrm{Gauss}(0,1)\,,$$

the reconstructed transverse momentum p_{T} of the simulated muons, $p_{\mathrm{T,sim}}$

$$\delta_{\kappa_{\mathrm{T}}}(q,\phi,\eta) = A + B\eta^2 + qC\sin(\phi - \phi_0)\,;$$

$$\sigma_{\kappa_{\mathrm{T}}}(q,\phi,\eta) = A' + B'\eta^2\,,$$

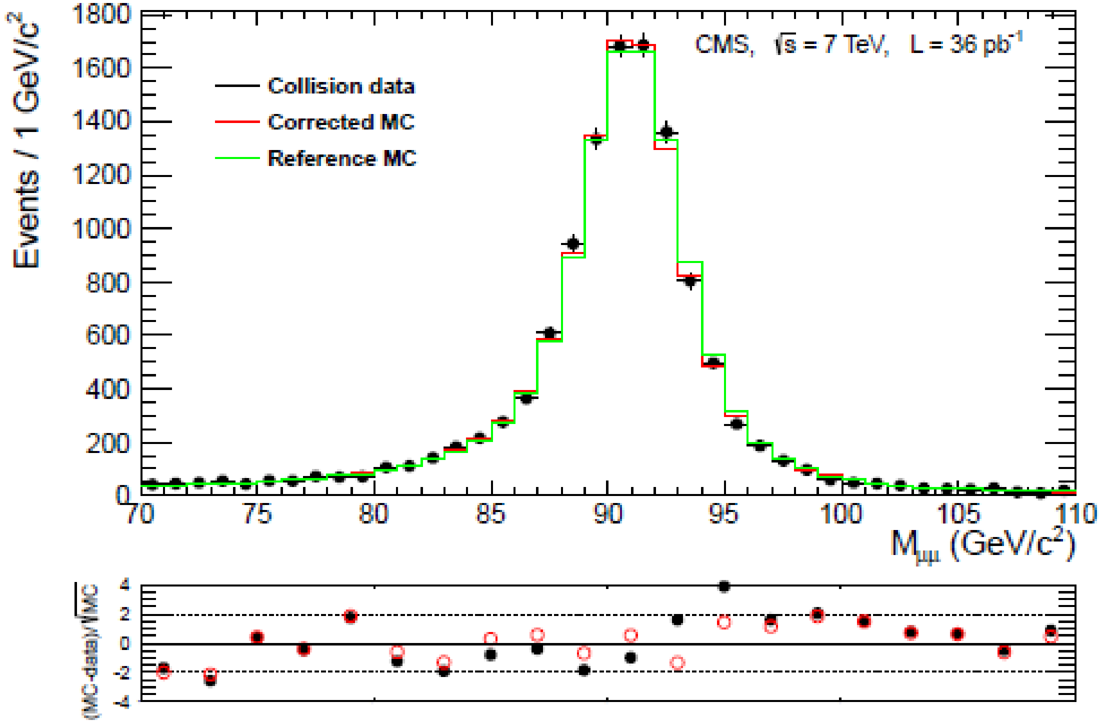
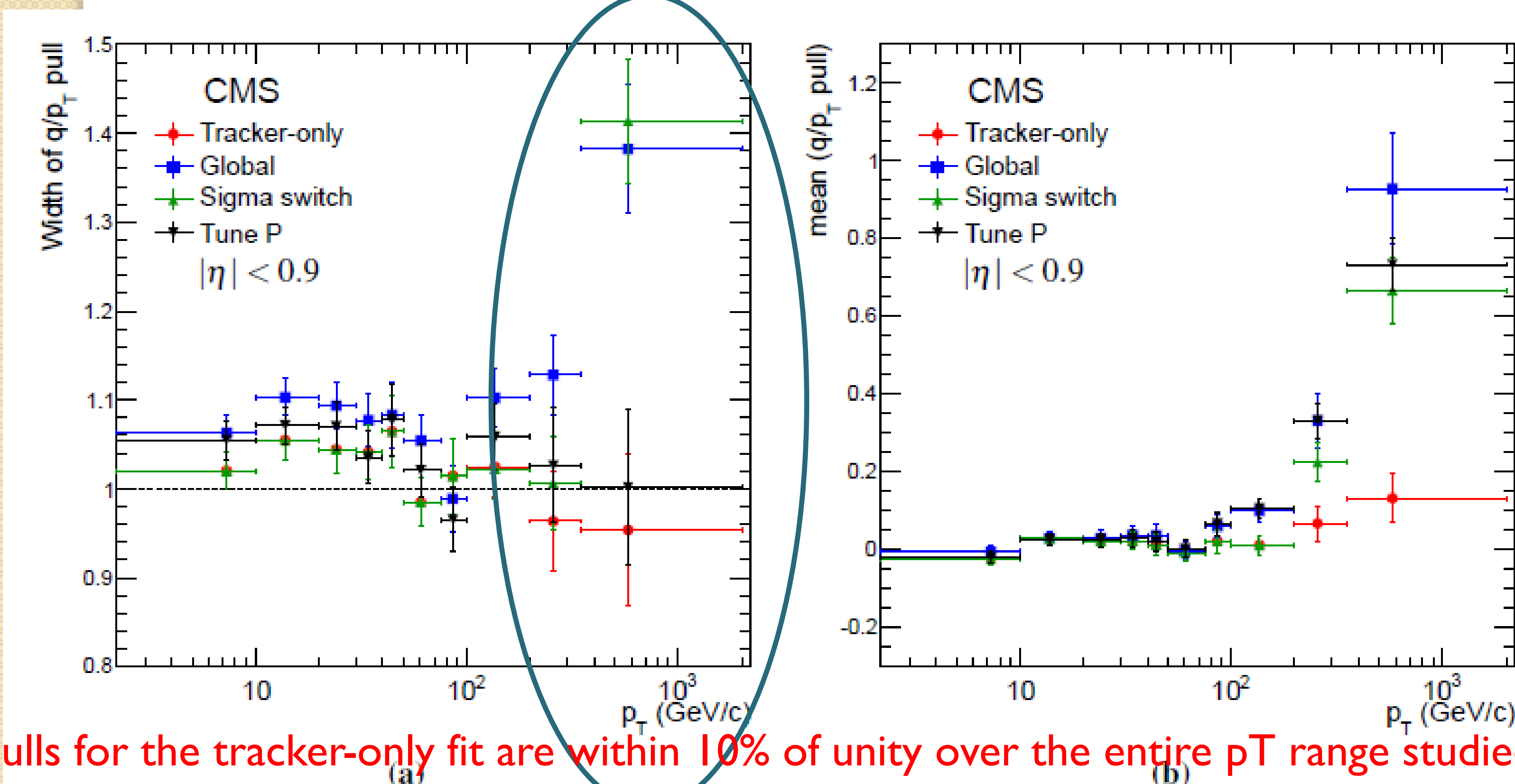


Figure 19. Top: distributions of the dimuon invariant mass for the selected $Z \to \mu^+\mu^-$ candidates in data (points with error bars) and in simulation without ("reference MC") and with ("corrected MC") corrections from SIDRA applied. Bottom: bin-by-bin difference (rebinned for clarity) between the simulation and the data, divided by the expected statistical uncertainty, for MC samples without (filled black circles) and with (open red circles) the SIDRA corrections. The uncertainties are statistical only.

Muon momentum resolution from cosmic-ray muon data

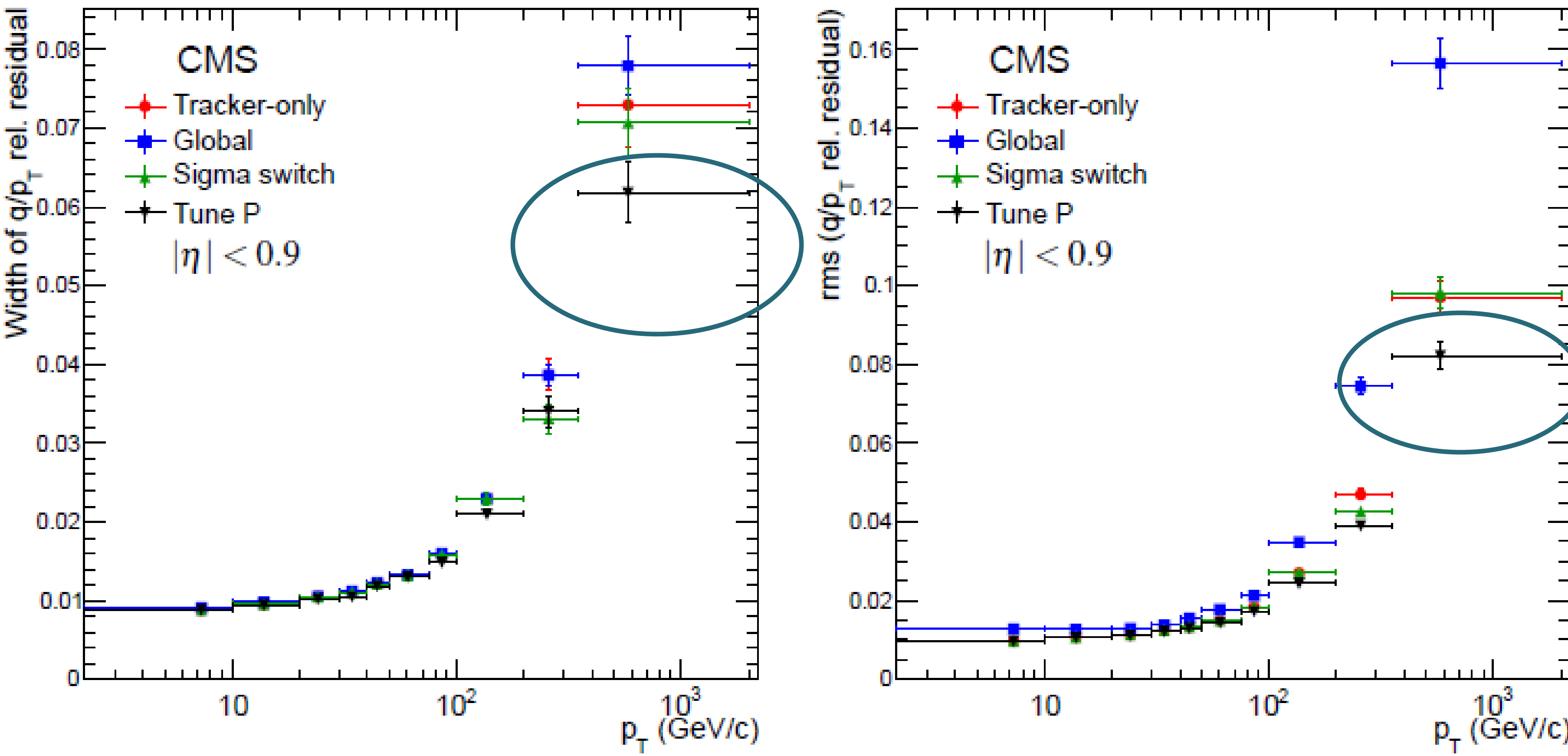
- We define the normalized residual (pull) as $$P(q/p_T) = \frac{(q/p_T)^{\text{upper}} - (q/p_T)^{\text{lower}}}{\sqrt{\sigma^2_{(q/p_T)^{\text{upper}}} + \sigma^2_{(q/p_T)^{\text{lower}}}}},$$ we examine a Gaussian fit to the distributions of P(q/pT)



pulls for the tracker-only fit are within 10% of unity over the entire pT range studied

To estimate the muon q/p_T resolution, we define the relative residual,

$$R(q/p_T) = \frac{(q/p_T)^{\text{upper}} - (q/p_T)^{\text{lower}}}{\sqrt{2}(q/p_T)^{\text{lower}}},$$



(a) (b)

Tracker-Plus-First-Muon-Station (TPFMS) fit

- This algorithm refits the global-muon track ignoring hits in all muon stations except the innermost one containing hits, for reduced sensitivity to possible showering deeper in the muon system.

The Picky fit.

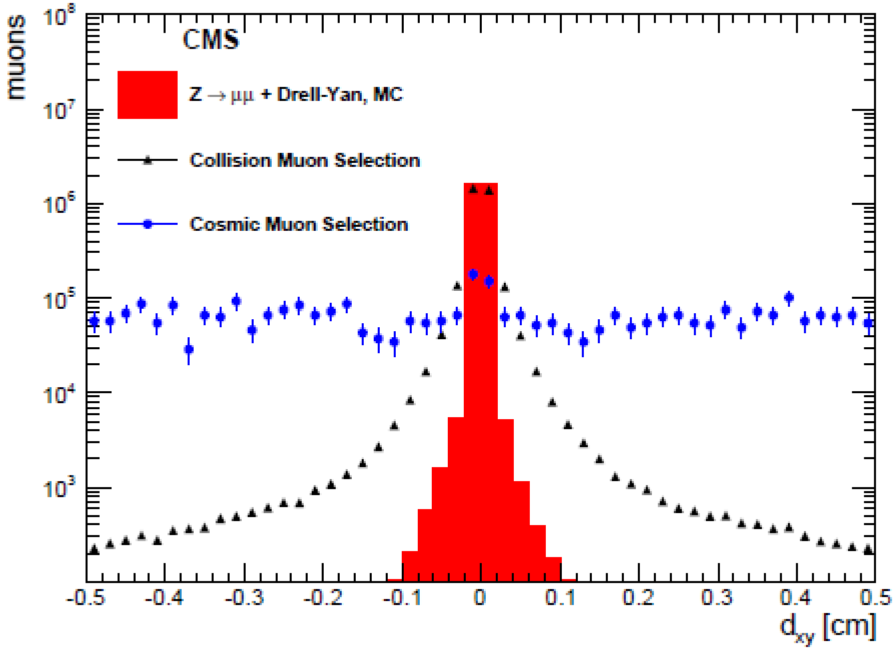
- This algorithm again starts with the hit list of the global-muon track, but, in chambers appearing to have hits from showers (determined by the hit occupancy of the chamber), retains only the hits that, based on a χ^2 comparison, are compatible with the extrapolated trajectory.

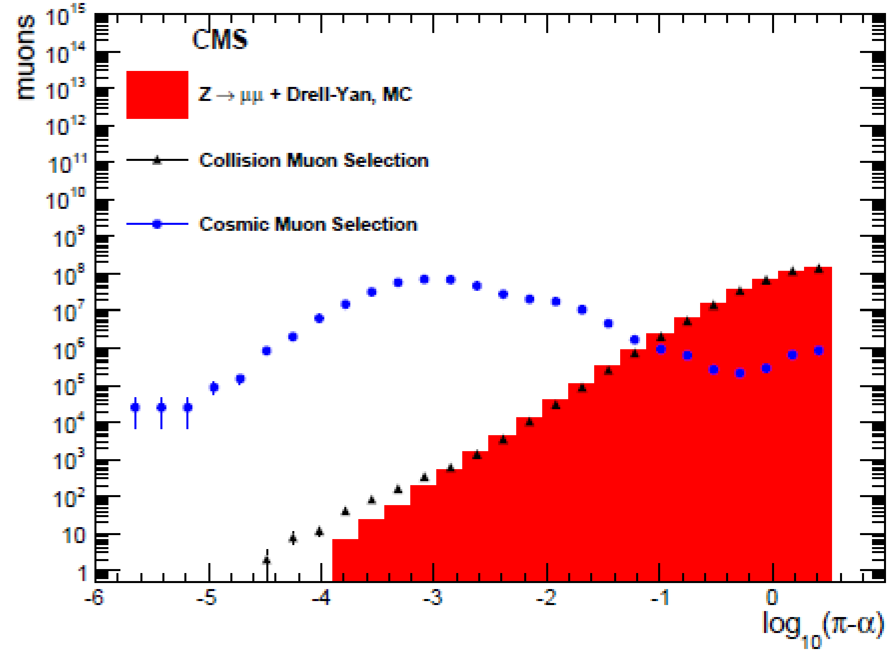
Tune P

- The algorithm starts with the Picky fit, then switches to the tracker-only fit if the goodness of fit of the latter is significantly better. Then it compares the goodness of fit of the chosen track with that of TPFMS; TPFMS is chosen if it is found to be better.
- For high-pT muons, TPFMS and Picky algorithms are selected by Tune P in most of the cases, in approximately equal amounts, while the tracker-only fit is selected only in a few percent of events

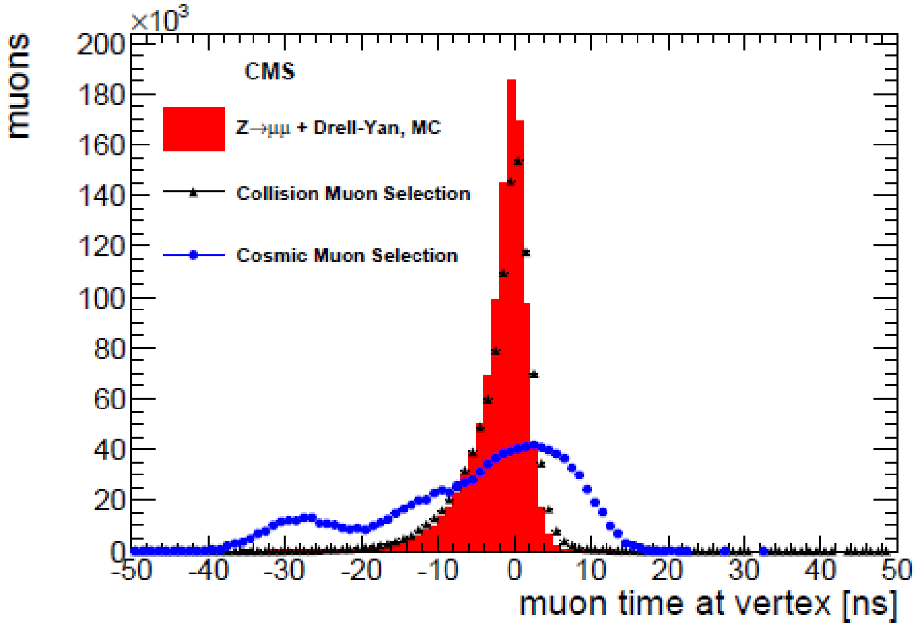
several types of background in physics analyses

- A cosmic-ray muon passing close to the interaction point can be reconstructed as a collision muon, or as a pair of oppositely charged muons in the upper and lower halves of CMS.
- A muon that is not reconstructed in the tracker (either because it is out-of-time or passes too far from the interaction point) can still be reconstructed as a standalone muon in the muon system and accidentally matched to a tracker track, forming a mismeasured global muon.
- A cosmic-ray muon can deposit energy in the calorimeters but avoid detection in the tracking detectors, which would result in, e.g., mismeasured missing transverse energy.

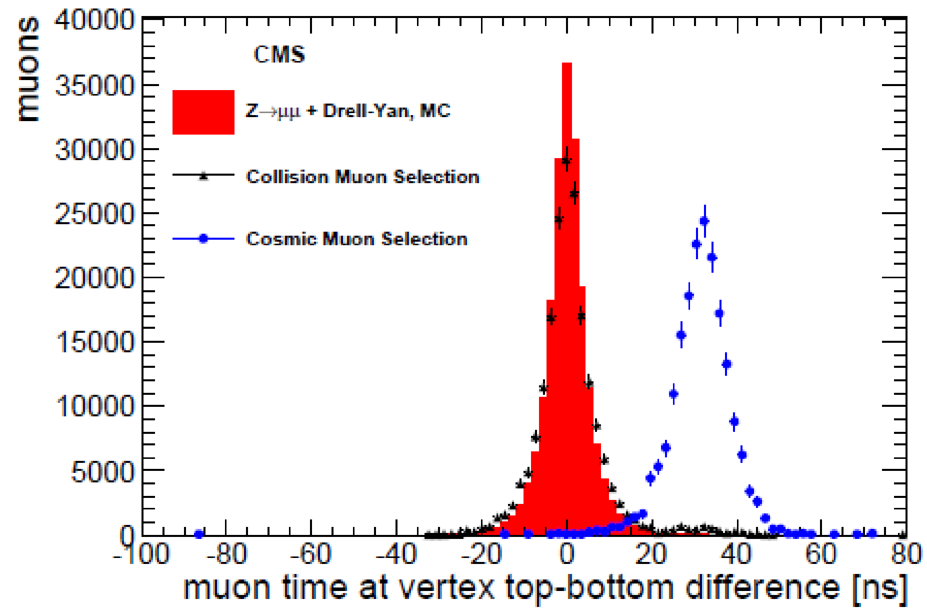




- angle a, defined as the largest angle between the inner-tracker track of a muon and any other track



(c)



(d)

- The muon timing is defined as the time at which a muon would pass the interaction point relative to the time of the bunch crossing

typical individual selections

	Efficiency (%)	Misidentification (%)
Back-to-back	89.97 ± 0.13	0.153 ± 0.002
$\lvert d_{xy} \rvert > 0.2$ cm	99.05 ± 0.04	0.0045 ± 0.0003
Cosmic ID tight	97.58 ± 0.07	0.0001 ± 0.0001
Cosmic ID loose	99.52 ± 0.03	0.153 ± 0.002

Back –to -back

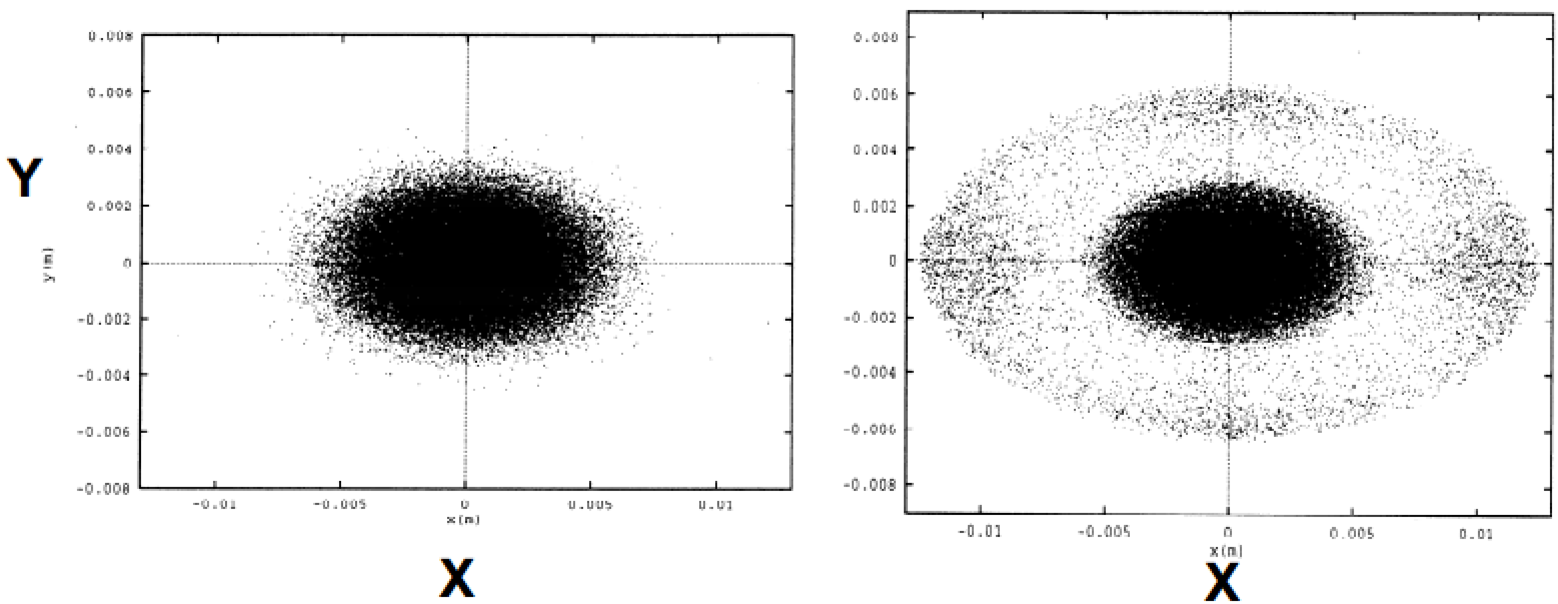
$\alpha > (\pi - 0.1)$ rad and that $|p_{T1} - p_{T2}|/\sqrt{p_{T1} \cdot p_{T2}} < 0.1$

Beam-halo muons

- Accelerator-induced backgrounds ("beam halo") contribute to a variety of physics analyses.
- The CMS detector can identify beam-halo muons that overlap with collision events and might otherwise be considered as part of the collision itself.

Simulations showed beam mismatch is a major source of halo.

Mismatched beam (on right) develops larger amplitudes than matched beam (on left).



Isolation

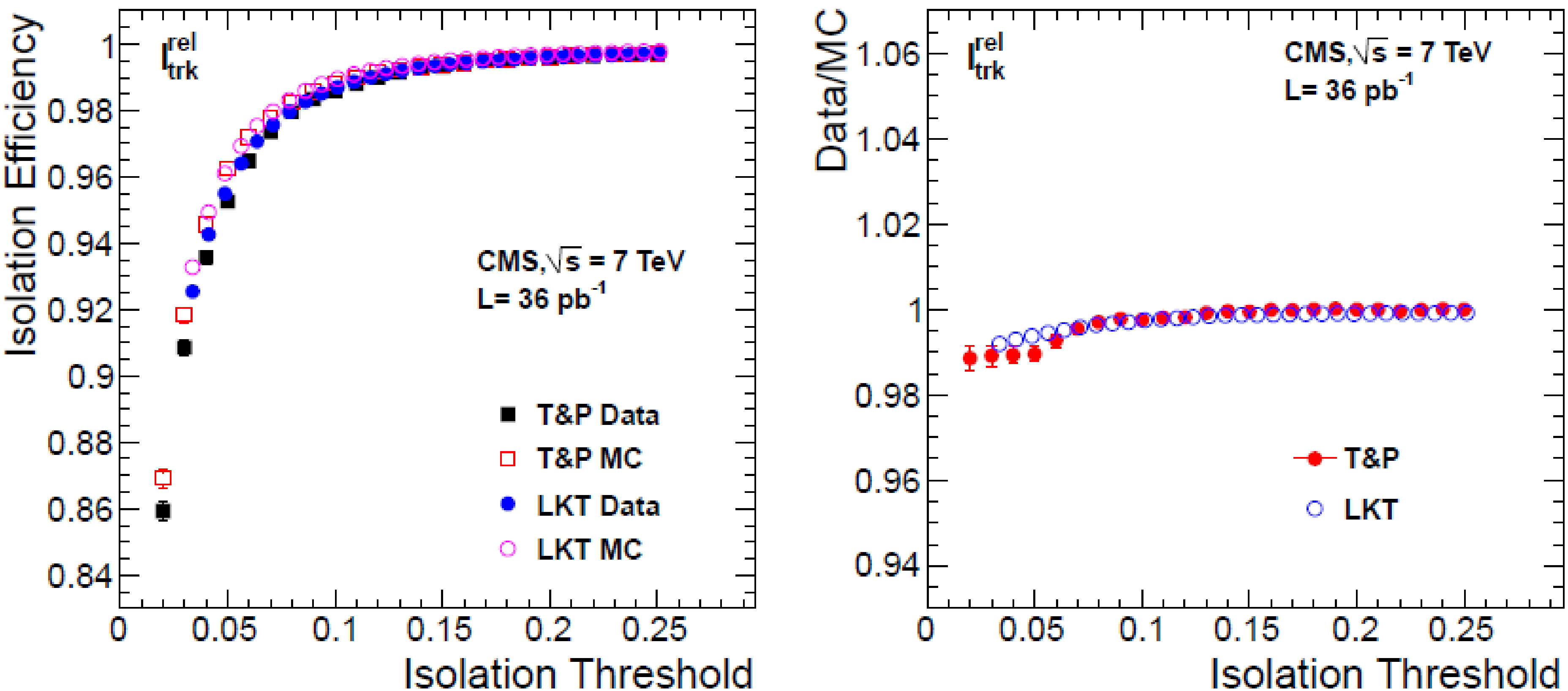
- Tracker relative isolation: calculates the scalar sum of the pT of all tracker tracks reconstructed in a cone of radius $\Delta R \equiv \sqrt{(\Delta\varphi)^2 + (\Delta\eta)^2} < 0.3$
- Tracker-plus-calorimeters (combined) relative isolation
- Particle-flow relative isolation: The discriminating variable is the sum of the pT of all charged hadrons, the transverse energies ET of all photons, and ET of all neutral hadrons reconstructed by the particle-flow algorithm within a cone of radius $\Delta R < 0.4$

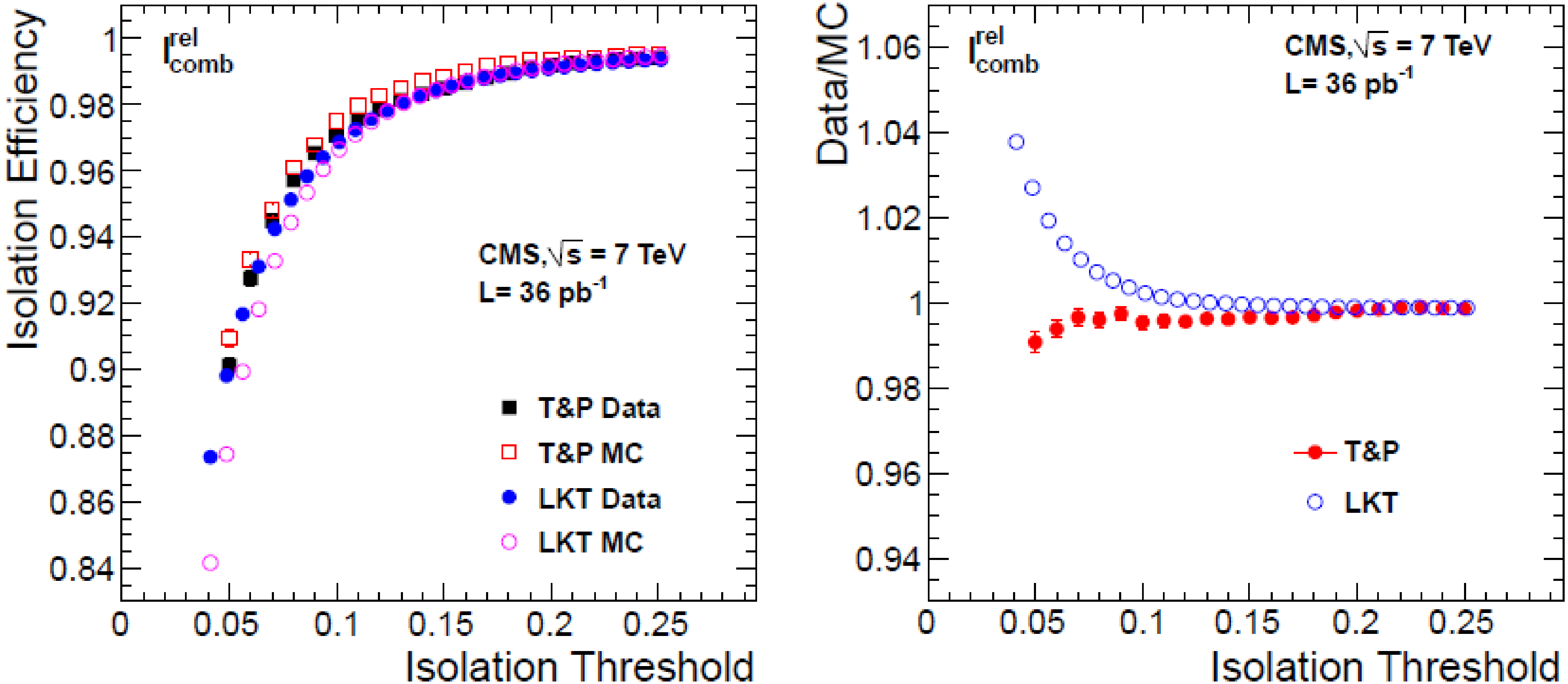
- For the muon to be considered isolated, the ratio of the pT sum to the muon track pT is required to be below a certain threshold.

Lepton Kinematic Template

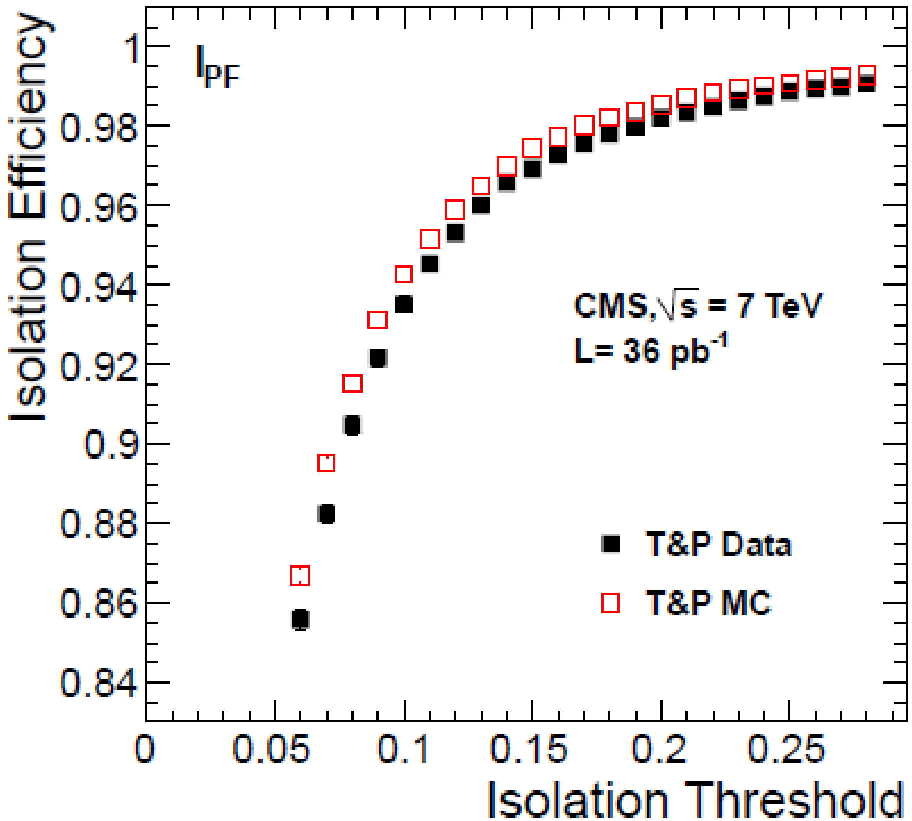
- It relies on the assumption that the kinematics of muons from decays of W or Z bosons produced in the hard parton scattering is unrelated to accompanying interactions of the other partons in the colliding protons, which are responsible for the energy flow around the muons.
- An isolation variable can then be computed relative to any specific direction in an event with underlying event activity similar to that of a signal event. Events containing a Z decaying into a pair of muons, with the reconstructed muon tracks and activity associated with them discarded, were used as approximations to underlying events. Directions were drawn from template kinematic distributions of muons obtained from simulation.
- Directions were drawn from template kinematic distributions of muons obtained from simulation

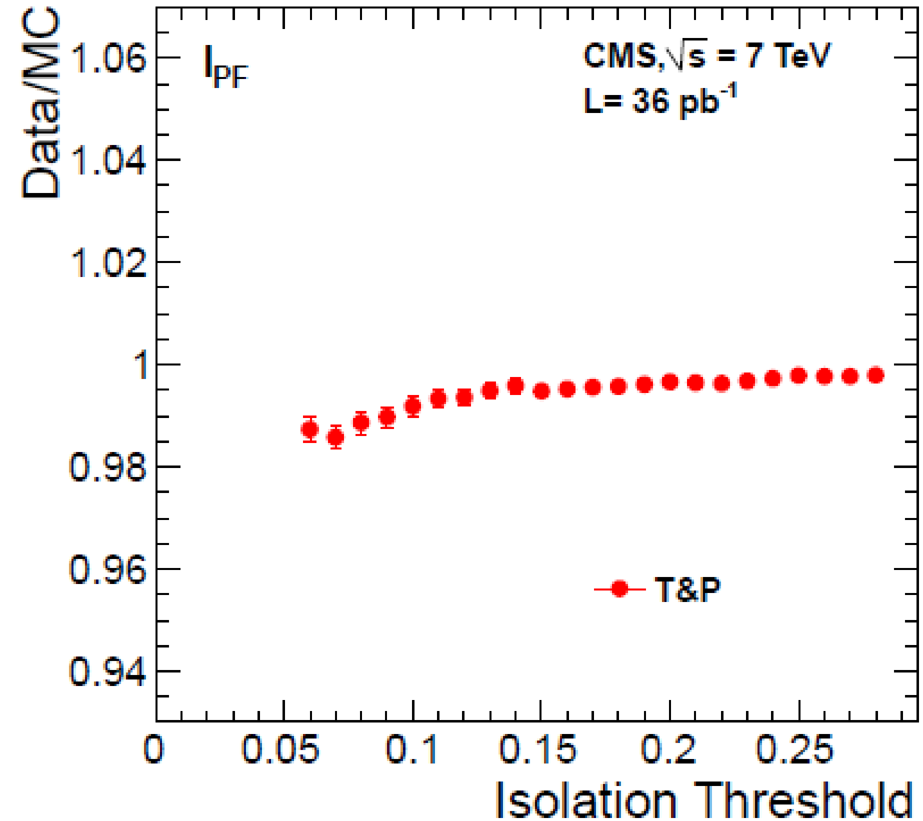
Figure 26. Left: efficiencies of various isolation algorithms for muons with $20 < p_T < 50\,\mathrm{GeV}/c$ from Z decays as a function of the isolation threshold. Results are shown for both data and simulation using the tag-and-probe ("T&P") and Lepton Kinematic Template ("LKT") methods; the LKT method is not used for the particle-flow algorithm. Right: data to simulation ratios. Plots are shown for tracker relative (I^{rel}_{trk}, top), tracker-plus-calorimeters relative (I^{rel}_{comb}, middle), and particle-flow relative (I^{rel}_{PF}, bottom) isolation algorithms. The MC samples include simulation of pile-up events.



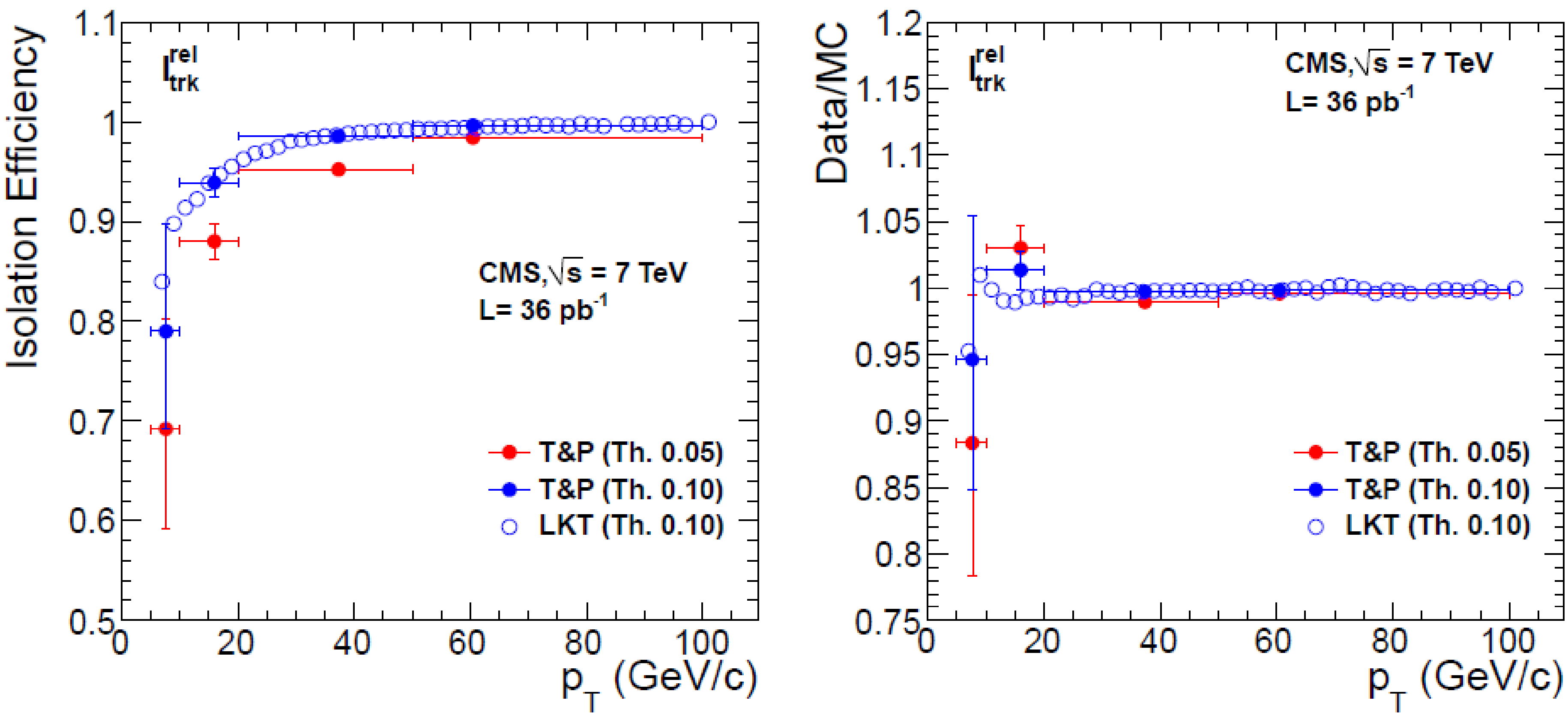


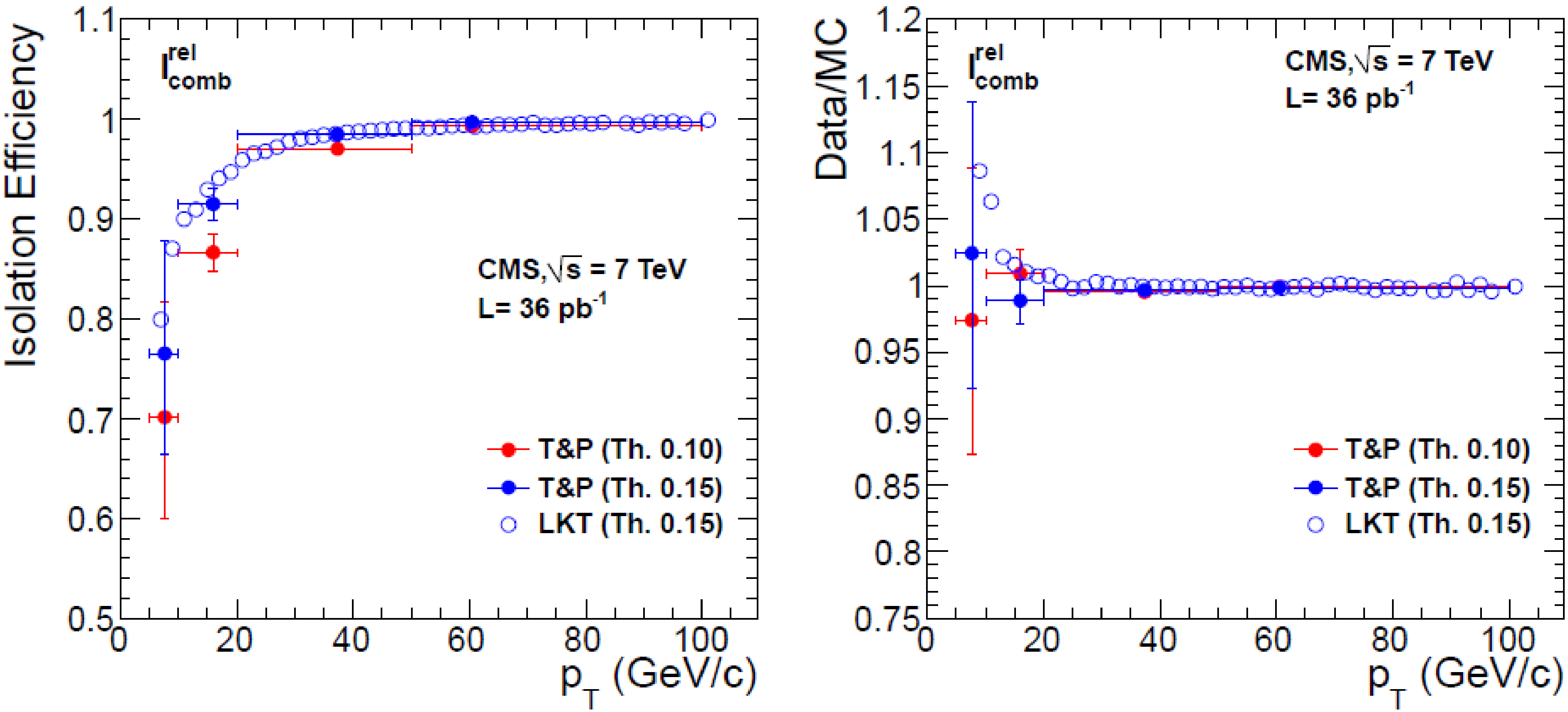
I^{rel}_{comb}
CMS, $\sqrt{s}$ = 7 TeV
L= 36 pb^{-1}
T&P Data
T&P MC
LKT Data
LKT MC
Isolation Efficiency
Isolation Threshold
I^{rel}_{comb}
CMS, $\sqrt{s}$ = 7 TeV
L= 36 pb^{-1}
T&P
LKT
Data/MC
Isolation Threshold


Isolation Efficiency
I_{PF}
CMS, $\sqrt{s}$ = 7 TeV
L= 36 pb^{-1}
T&P Data
T&P MC
Isolation Threshold
1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0
0.05
0.1
0.15
0.2
0.25

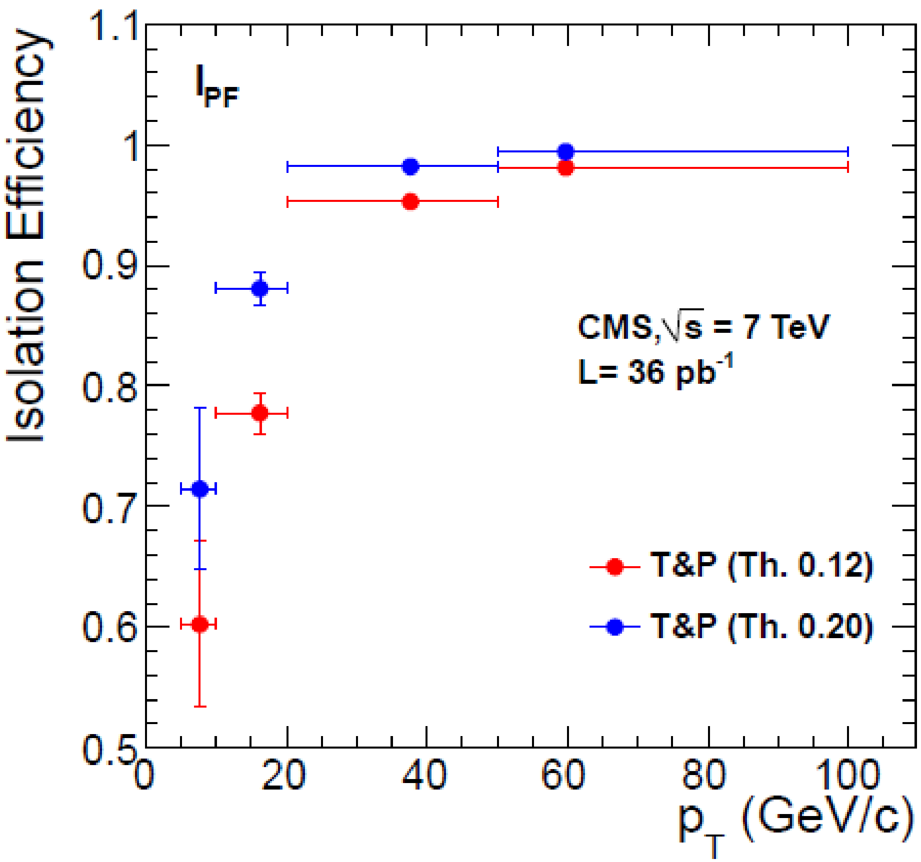

Data/MC
I_{PF}
CMS, $\sqrt{s}$ = 7 TeV
L= 36 pb^{-1}
T&P
Isolation Threshold
1.06
1.04
1.02
1
0.98
0.96
0.94
0
0.05
0.1
0.15
0.2
0.25

- Efficiencies in data and MC simulation are generally in good agreement, with the difference between the two not exceeding 1.5%.
- A single exception is the results from the LKT method for low values of the $I^{\mathrm{rel}}_{\mathrm{comb}}$
- threshold, where efficiencies from MC simulation are lower than those from data by up to 4%.(The origin of this discrepancy is under study)

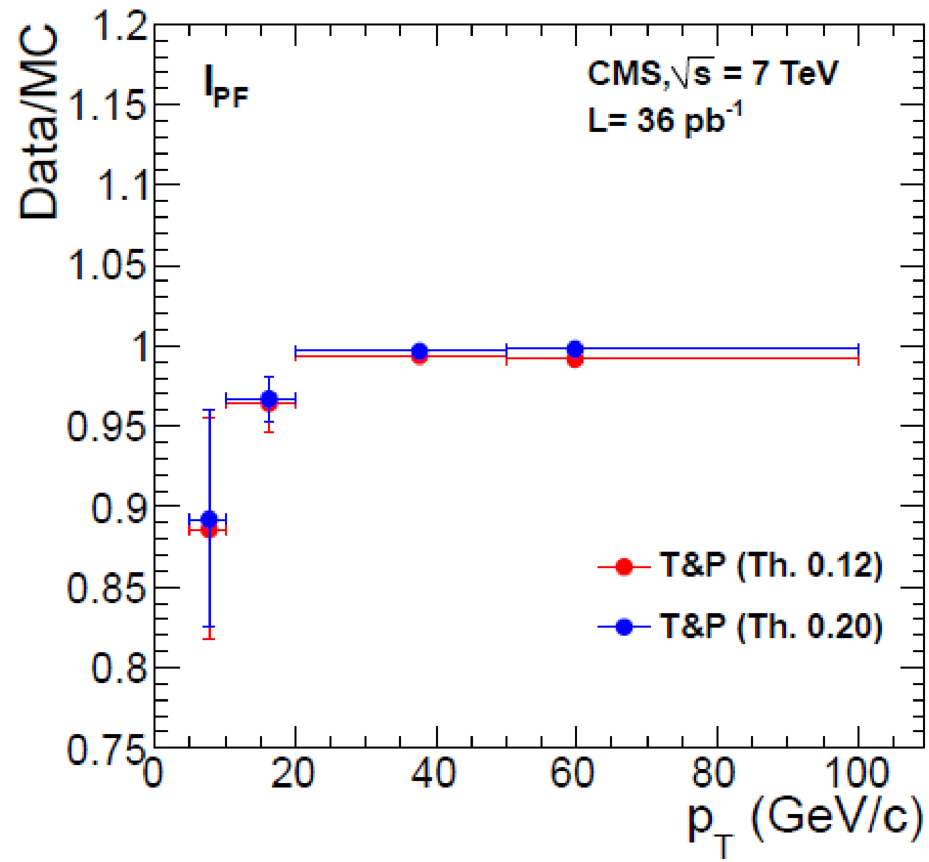

Isolation Efficiency
I_{trk}^{rel}
CMS, $\sqrt{s}$ = 7 TeV
L= 36 pb^{-1}
T&P (Th. 0.05)
T&P (Th. 0.10)
LKT (Th. 0.10)
p_T (GeV/c)
Data/MC
I_{trk}^{rel}
CMS, $\sqrt{s}$ = 7 TeV
L= 36 pb^{-1}
T&P (Th. 0.05)
T&P (Th. 0.10)
LKT (Th. 0.10)
p_T (GeV/c)



Isolation Efficiency
I^{rel}_{comb}
CMS, $\sqrt{s}$ = 7 TeV
L= 36 pb^{-1}
T&P (Th. 0.10)
T&P (Th. 0.15)
LKT (Th. 0.15)
p_T (GeV/c)
Data/MC
I^{rel}_{comb}
CMS, $\sqrt{s}$ = 7 TeV
L= 36 pb^{-1}
T&P (Th. 0.10)
T&P (Th. 0.15)
LKT (Th. 0.15)
p_T (GeV/c)



Isolation Efficiency
I_{PF}
CMS, $\sqrt{s}$ = 7 TeV
L= 36 pb^{-1}
T&P (Th. 0.12)
T&P (Th. 0.20)
p_T (GeV/c)



Data/MC
I_{PF}
CMS, $\sqrt{s}$ = 7 TeV
L= 36 pb^{-1}
T&P (Th. 0.12)
T&P (Th. 0.20)
p_T (GeV/c)

- The results obtained with the tag-and-probe and LKT methods agree within the statistical uncertainties down to the lowest tested muon pT (5GeV/c)
- The LKT results, which have very small statistical uncertainties, indicate that for muon pT as low as 5GeV/c, the agreement between data and MC efficiencies I^{rel}_{trk} (I^{rel}_{comb}) is within 5% (10%), while for pT greater than 15GeV/c the agreement is within 1%.

Pt of Muon to loop

- $qv \times B = mv^2/R$
- $P_t = qRB$
- $R = 1m$
- $q = 1e$
- $B = 3.8$ Tesla
- $P_t = 1.6021892 \times 10^{-19}$ (C) $\times$ 3.8 (T) $\times 0.5$(m) $= 3.04415948 \times 10^{-19}$ (kg.m/s) $= 0.56964$ GeV/c

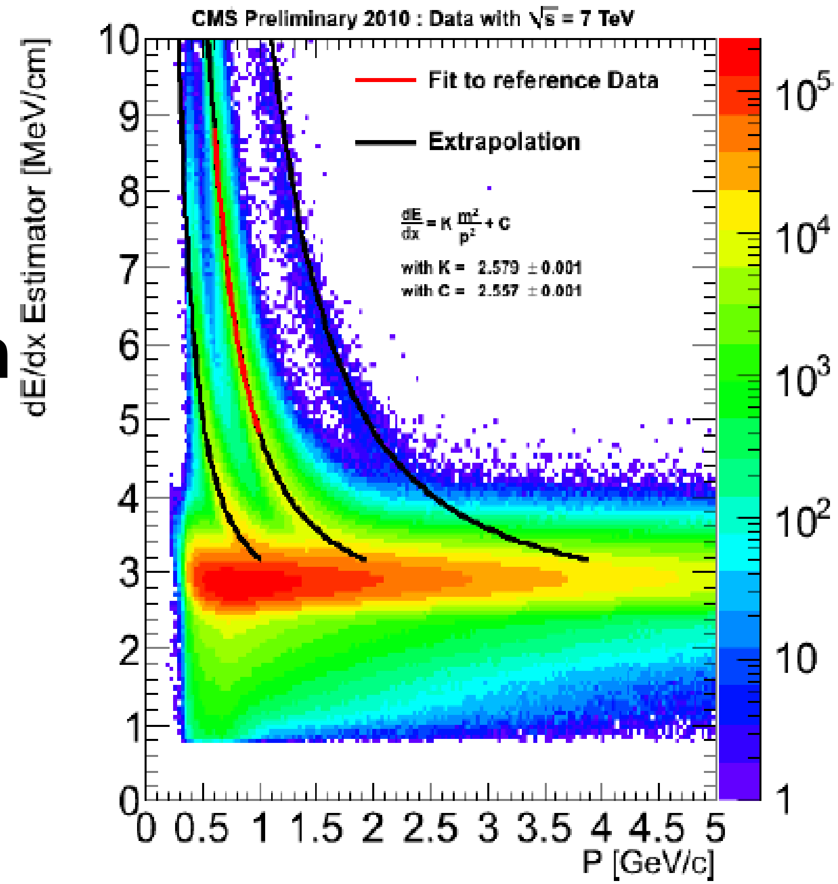
energy loss

$\beta\gamma = p/Mc$

- Particle identication is therefore possible in the region $0.2 \leq \beta\gamma \leq 0.9,$, where large dierences in the energy loss are observed for small variations of the incident particle momentum.
- In the restricted region of where identication is possible, the Bethe-Bloch formula can be linearized around m2=p2 with a few percent agreement with respect to the com- plete parametrization.

$$\left\langle \frac{dE}{dx} \right\rangle = K \frac{m^2}{p^2} + C$$

- Injecting the proton mass in the equation , the constants have been measured to be K = 2.545 and C = 2.642 for the observed data
- Three mass lines from the parametrization, assuming kaon, proton and deuteron mass, are also visible on gure 2.



Calculating time of flight

- Get the E ,Pt
- **float** calE **=** genParE **->**at(0) ;
- **float** calPt **=** genParPt **->**at(0);
- Get the P
- $$E^2 = (pc)^2 + (m_0c^2)^2$$
- Get the Pz
- **float** calPz **=** sqrt(calE*****calE**-**calPt*****calPt**-**0.01);

- Get velosity
- $$\mathbf{p} = \gamma m \mathbf{u}$$
- $$\gamma = \frac{1}{\sqrt{1 - u^2/c^2}},$$
- **float** calVz **=** sqrt((calPz* calPz)/(calPz* calPz**+**0.01));
- **float** calVt **=** sqrt((calPt* calPt)/(calPt* calPt**+**0.01));
- Get distance of the Vertex and the xy coordinate of the tracker
- **float** gloXY **=** sqrt(

hitGlobalX**->**at(i)*hitGlobalX**->**at(i)

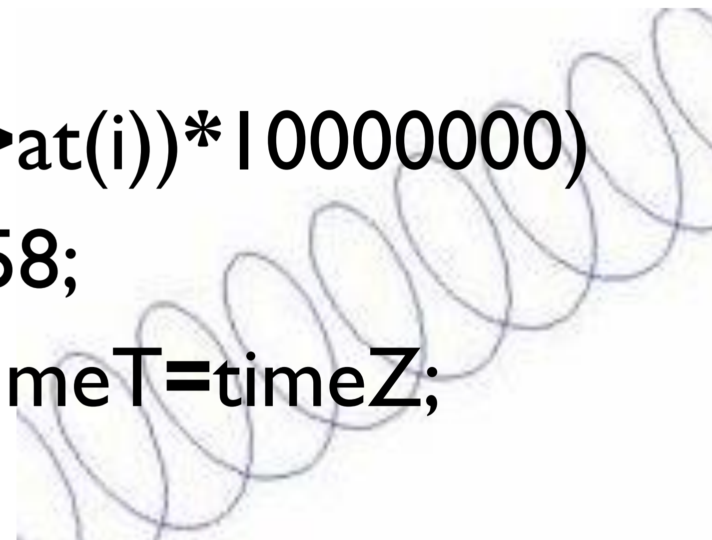
+hitGlobalY**->**at(i)*hitGlobalY**->**at(i)

) ;

- Get the radius of the circle
- **float** BR **=** calPt*0.877;
- (r=Pt/qB

  For Pt=1Gev/c ,q=1e ,B=3.8t,r=0.877m)
- Get the half of the angle
- **float** angle **=**gloXY/BR/200;
- (gloXY (cm)/100(cm/m))
- **float** arcsin **=**asin(angle);
- Get the arch
- **float** calR **=**arcsin*BR*2;

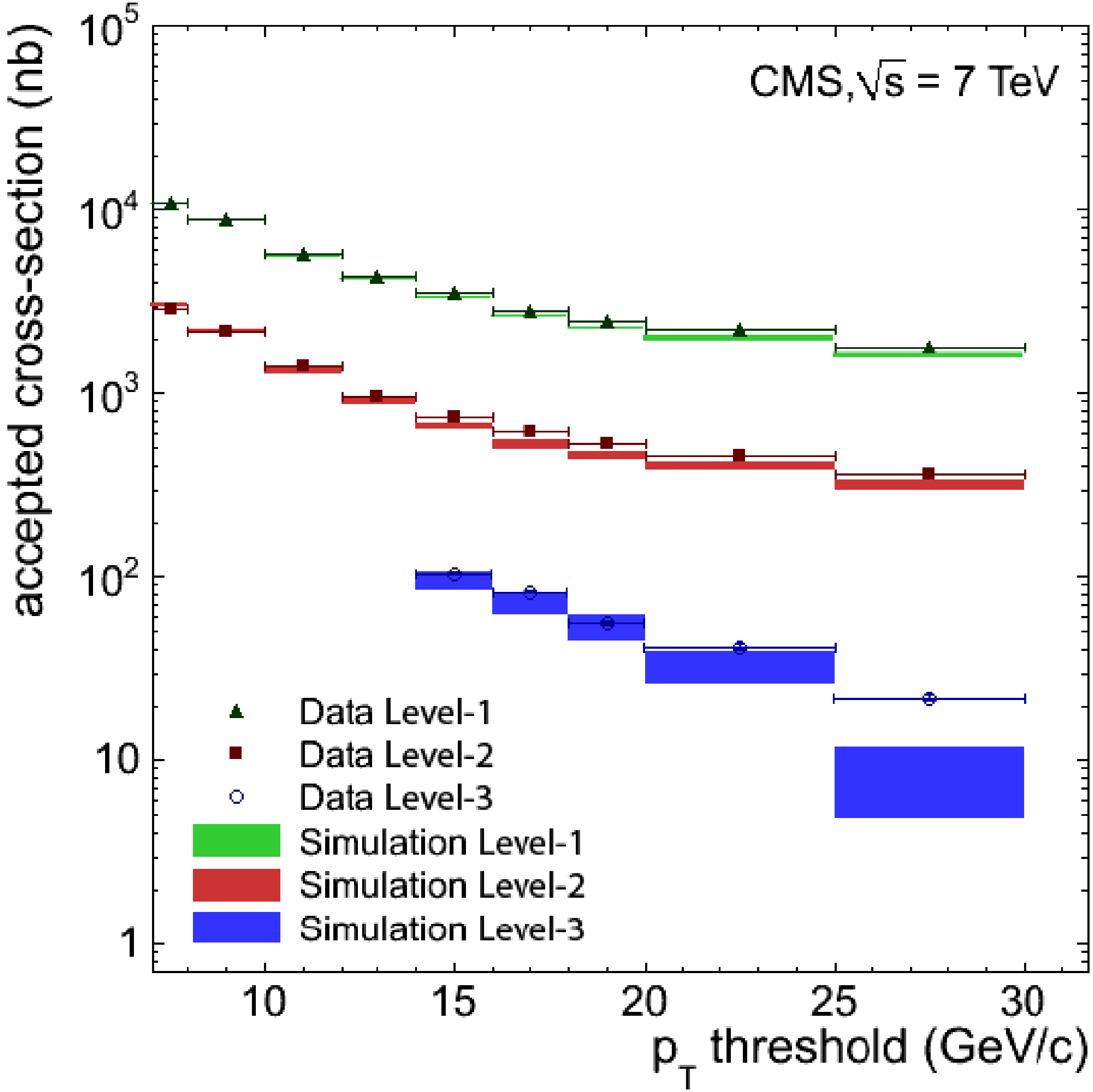
- Time
- **float** timeT **=** (calR*1000000000)/calVt/299792458;
- If muon loop more the one circle
- **float** timeZ **=**(abs(hitGlobalZ**>**at(i))*10000000) /calVz/299792458;
- **if** (timeZ**>**timeT)timeT**=**timeZ;



Muon trigger

- the hardware-based Level-1 trigger
- The Level-1 muon trigger uses signals from all three CMS muon detector systems: DT,CSC, and RPC.
- It has a latency of 3.2 ms
- and reduces the rate of inclusive muon candidate eventsread-out from detector front-end electronics to a few kHz by applying selections on the estimatedmuon pT and quality.

- the software-based high-level trigger (HLT)
- first a Level-1 trigger object is used as a seed
- At this point, pT threshold filters are applied to the standalone (also called Level-2) muon.
- Then seeds in the inner tracker are generated in the region around the extrapolated Level-2 muon, and tracker tracks are reconstructed.
- If a successful match is made between a tracker track and the Level-2 muon, a global fit combining tracker and muon hits is performed, yielding a Level-3 muon track on which the final pT requirements are applied
- processing time of the HLT reconstruction is about 50 ms.



accepted cross-section (nb)
CMS, √s = 7 TeV
Data Level-1
Data Level-2
Data Level-3
Simulation Level-1
Simulation Level-2
Simulation Level-3
p_T threshold (GeV/c)

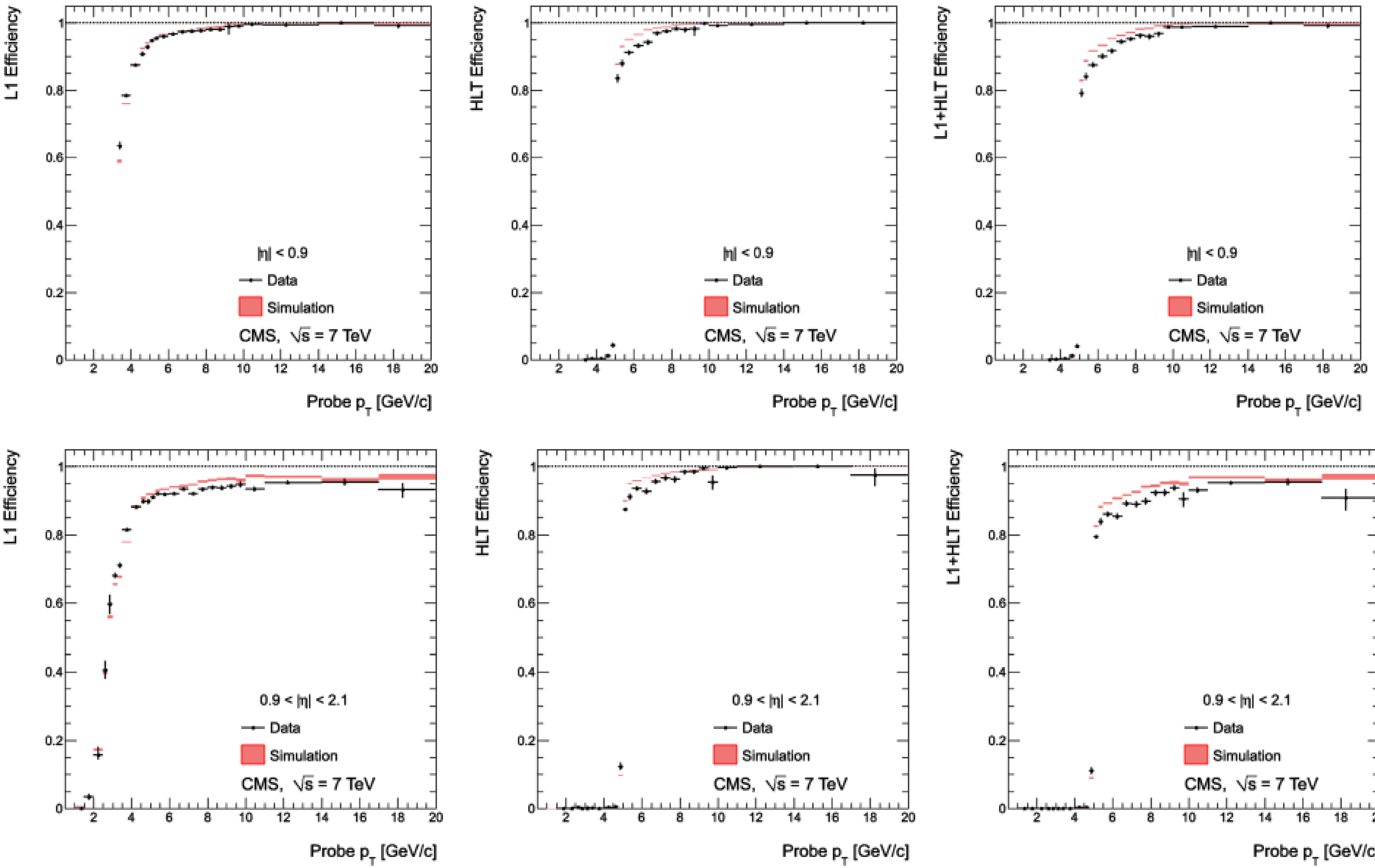
Trigger efficiency using the tag-and-probe method on dimuon resonances

- use Soft Muons and Tight Muons as probes
- also required to be isolated by requiring $I^{\text{rel}}_{\text{comb}}$ to be smaller than 0.15.

Trigger Level	Region	Tag-and-Probe $J/\psi \to \mu^+\mu^-$ Eff. [%]	Data/MC
Level-1	$\|\eta\| < 2.1$	97.1 ± 0.2	0.990 ± 0.002
	$\|\eta\| < 0.9$	99.2 ± 0.1	0.995 ± 0.001
	$0.9 < \|\eta\| < 2.1$	94.5 ± 0.3	0.978 ± 0.004
HLT	$\|\eta\| < 2.1$	99.1 ± 0.2	0.995 ± 0.002
	$\|\eta\| < 0.9$	99.2 ± 0.2	0.993 ± 0.002
	$0.9 < \|\eta\| < 2.1$	99.0 ± 0.3	0.997 ± 0.004
Level-1+HLT	$\|\eta\| < 2.1$	96.2 ± 0.2	0.985 ± 0.003
	$\|\eta\| < 0.9$	98.5 ± 0.2	0.989 ± 0.002
	$0.9 < \|\eta\| < 2.1$	93.6 ± 0.5	0.975 ± 0.005

Trigger efficiency for Soft Muons

- In the region of pT > 20GeV/c, the efficiency was measured using a sample of $Z \rightarrow \mu^+\mu^-$ events collected with single-muon triggers. In the region of pT < 20GeV/c, the $J/\psi \rightarrow \mu^+\mu^-$ events collected
- the Level-1 trigger with pT threshold at 3GeV/c, the HLT with pT threshold at 5GeV/c, and for the full Level-1-HLT online selection


L1 Efficiency
|η| < 0.9
Data
Simulation
CMS, √s = 7 TeV
Probe p_T [GeV/c]
HLT Efficiency
|η| < 0.9
Data
Simulation
CMS, √s = 7 TeV
Probe p_T [GeV/c]
L1+HLT Efficiency
|η| < 0.9
Data
Simulation
CMS, √s = 7 TeV
Probe p_T [GeV/c]
L1 Efficiency
0.9 < |η| < 2.1
Data
Simulation
CMS, √s = 7 TeV
Probe p_T [GeV/c]
HLT Efficiency
0.9 < |η| < 2.1
Data
Simulation
CMS, √s = 7 TeV
Probe p_T [GeV/c]
L1+HLT Efficiency
0.9 < |η| < 2.1
Data
Simulation
CMS, √s = 7 TeV
Probe p_T [GeV/c]

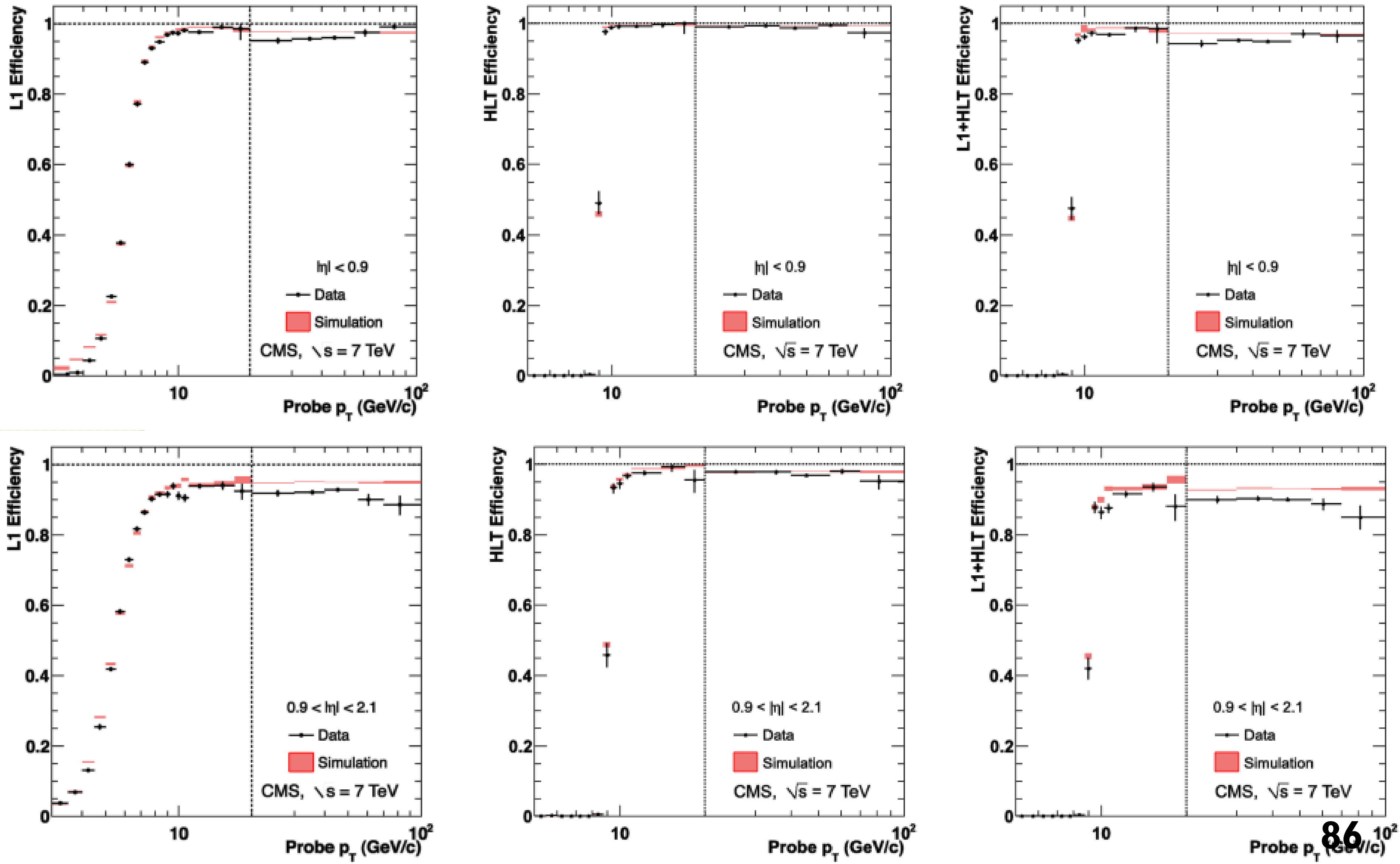
- a sharp "turn-on" at the trigger pT threshold
- turn-on is sharper for the HLT, due to an improved pT resolution
- 99% for the Level-1 trigger in the barrel region,overlap-endcap region is slightly lower, at about 95%.
- 5% efficiency loss is due to stringent quality criteria used in the selection(these criteria were further optimized during the 2010–11 winter technical stop of the LHC)
- Measured efficiencies are generally in good agreement with those expected(within 1%)
- The only exception is a slightly larger, about 2%, difference between data and simulation in the overlap-endcap region due to a few non-operational CSCs not accounted for in the simulation

The very forward region

$2.1 < |\eta| < 2.4,$

- higher rates of low-pT muons and poorer momentum resolution
- At the nominal LHC luminosity, this region is intended to be used to improve trigger efficiency for events with multiple muons. In 2010, the luminosity the rates of low-pT muons were sufficiently low to allow the single-muon trigger to be extended to the entire acceptance of muon detectors
- The algorithm to resolve this ambiguity was configured withthe goal to reduce the rate of muons with overestimated pT to a minimum
- the efficiency of the Level-1 triggers in the very forward region was high for triggers with low pT thresholds

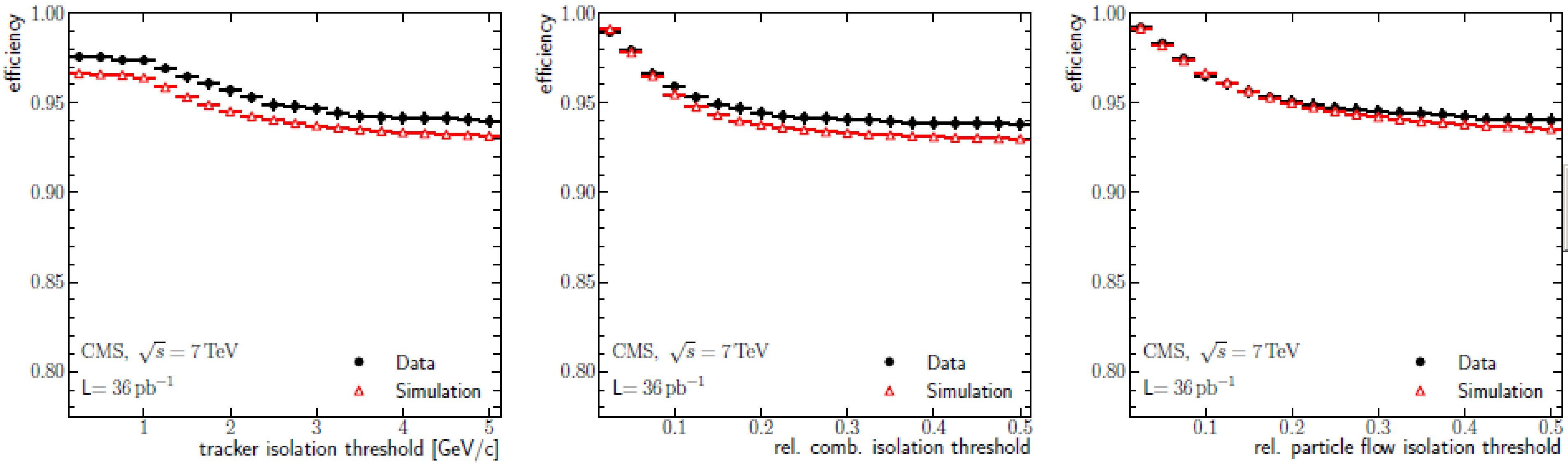
Trigger efficiency for Tight Muons



- rapid turn-on of efficiencies:near the applied threshold: for Level-1 threshold at pT = 7GeV/c and HLT threshold at pT = 9GeV/c,
- Most of the efficiency loss occurs at Level-1 and, in particular, in the overlap-endcap region
- very forward region,trigger efficiency is
- about 45%. Most of the losses are due to the underestimation of pT by the Level-1 pT-assignment algorithm

Efficiency of online muon isolation requirements

- To further reduce the trigger rate, isolation criteria can be applied at the HLT
- The probes are Tight Muons with $|\eta| < 2.1$ and pT > 20GeV/c, matched with the muon trigger candidates that passed the Level-1 trigger with a pT threshold of 7GeV/c and HLT with a pT threshold of 9GeV/


efficiency
1.00
0.95
0.90
0.85
0.80
CMS, $\sqrt{s} = 7$ TeV
L= 36 pb^{-1}
Data
Simulation
1
2
3
4
5
tracker isolation threshold [GeV/c]
0.1
0.2
0.3
0.4
0.5
rel. comb. isolation threshold
rel. particle flow isolation threshold

Muon trigger efficiencies from jet-triggered samples

- samples recorded with jet triggers, which use only energy measurements in the calorimeters.
- To reduce background, the probes are required to be Tight Muons.
- Mismatches are reduced by requiring that only one reconstructed muon be present in the event.

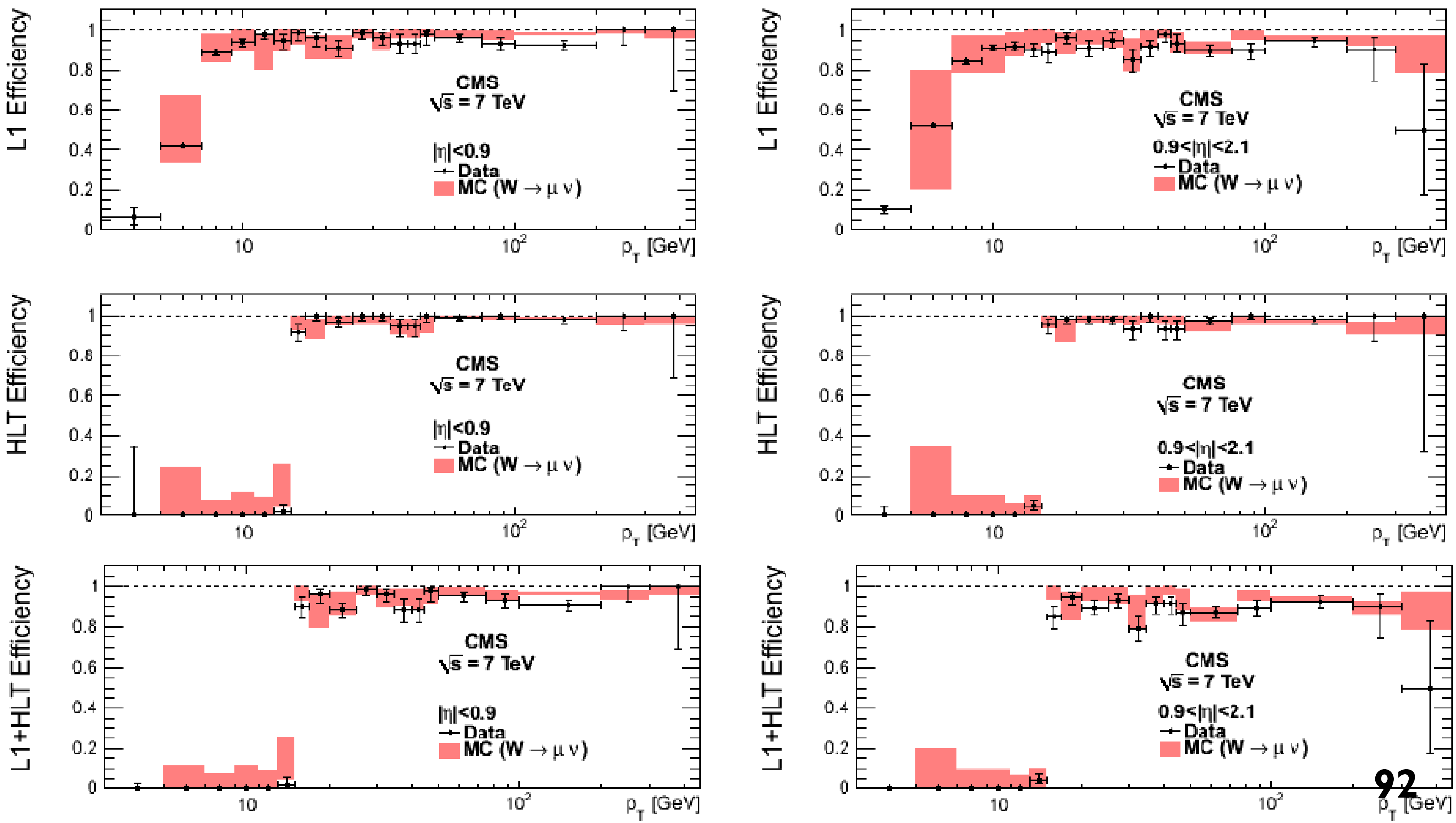
- Backgrounds from pion and kaon decays, as well as remaining hadron punch-through, lower the estimated efficiency
- A higher rejection of these backgrounds can be achieved by applying two alternative and independent additional selections
- Isolation, which selects mainly muons from W decays and suppresses the heavy-flavour contributions that are typically non-isolated.

$W \to \mu \nu$ decays.

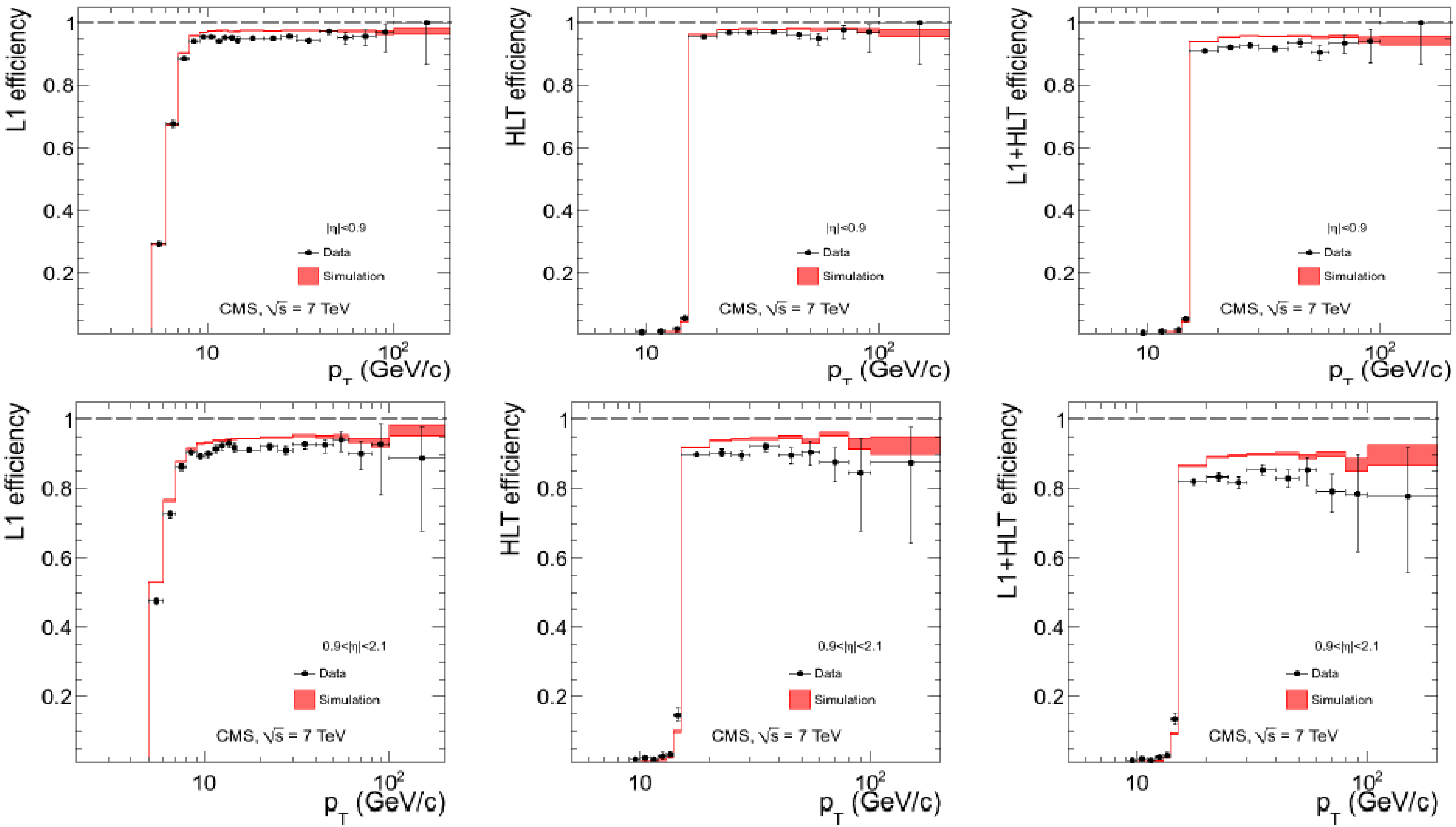
$$I^{\mathrm{rel}}_{\mathrm{comb}} < 0.15.$$

- B tagging, which selects muons from semileptonic heavy-flavour decays

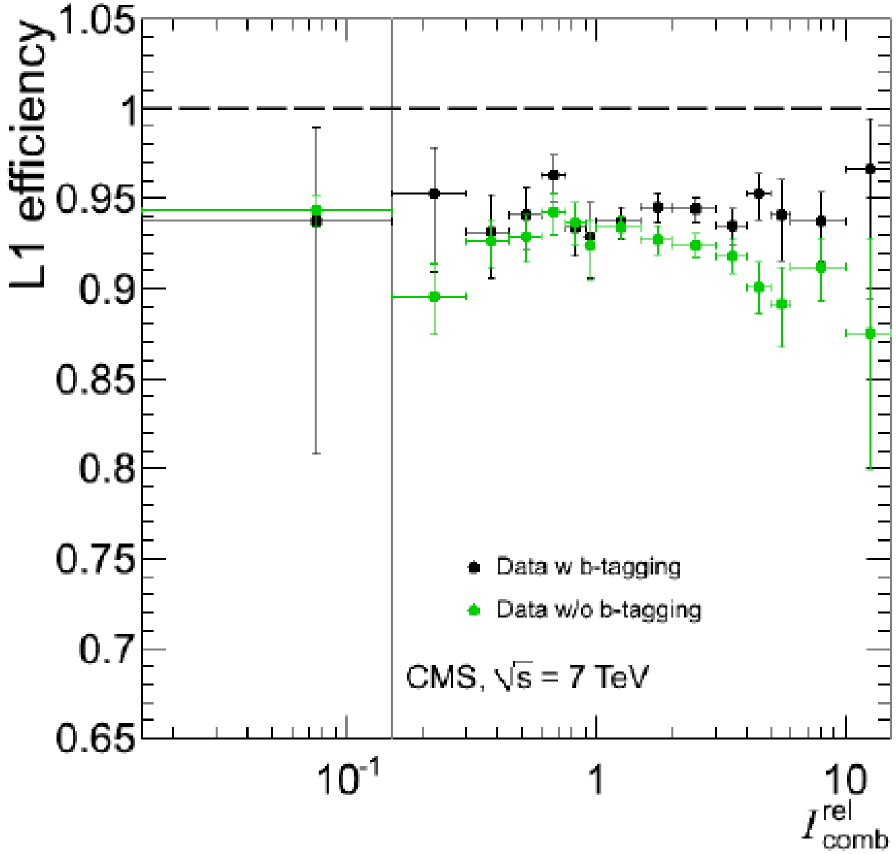
Isolation approach

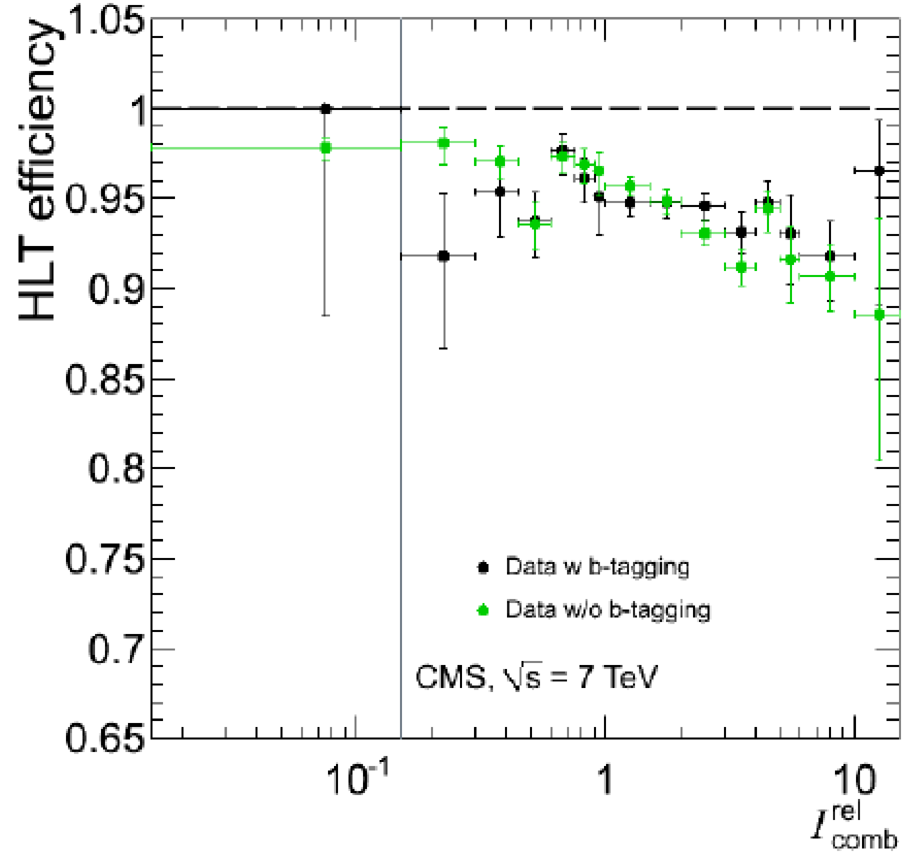


b-tagging approach



In the plateau above 20GeV/c
the data and simulation agree to about the 5% level





- A worse performance of the single-muon trigger at HLTfor muons within high-multiplicity jets is not unexpected
- remains greater than 90% even in the most unfavourable environment