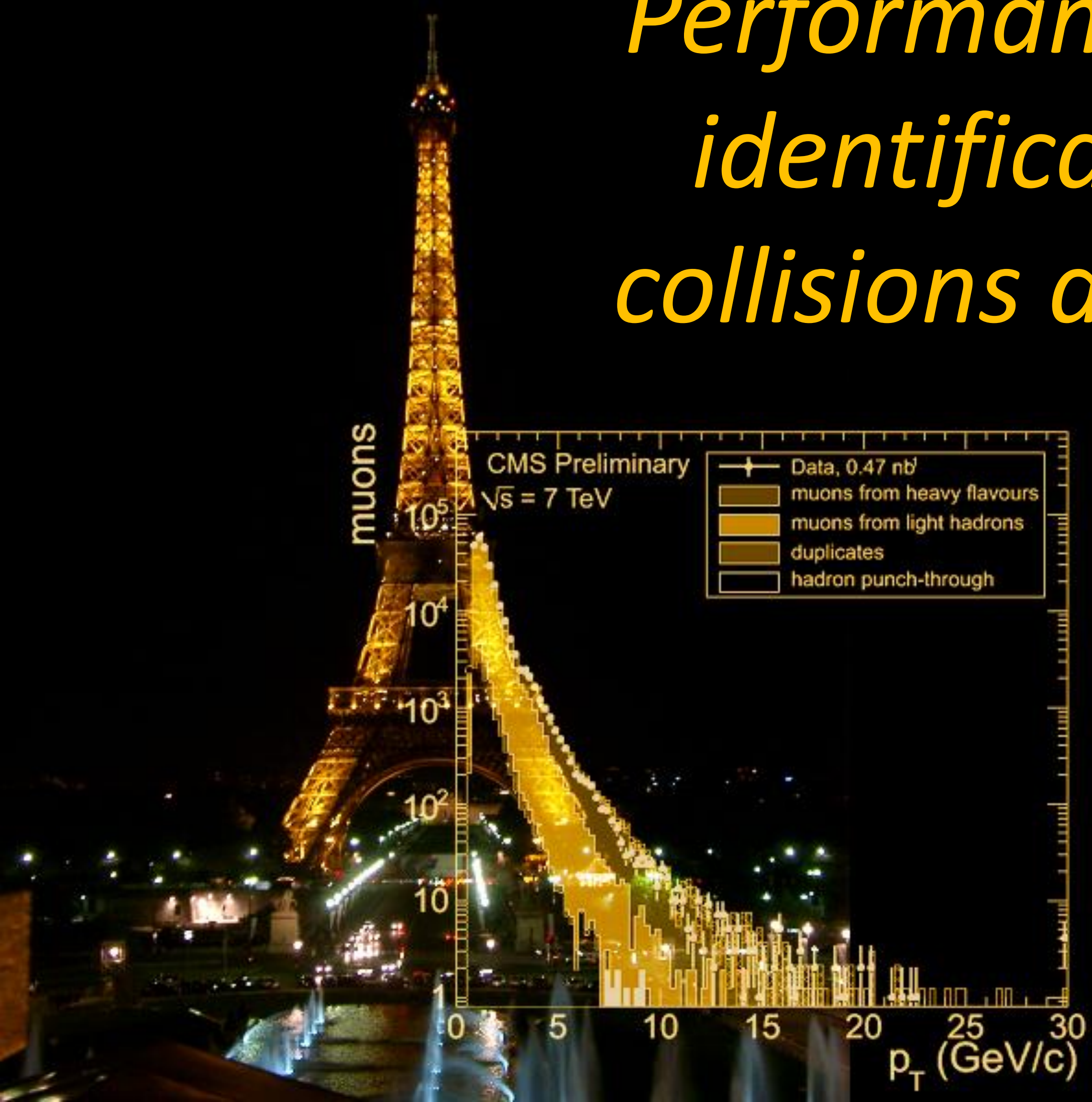
Performance of muon identification in pp collisions at $\sqrt{s}$ = 7 TeV



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CMS Collaboration

Introduction

- Muons play a central role in the CMS physics program, from very low luminosity (e.g. J/Ψ->μμ) to the future discovery channels (e.g. H->ZZ->4μ, Z'->μμ, ...)
- Topic of this talk: our understanding of "inclusive" muons from 7 TeV pp collisions, with an integrated luminosity up to 84/nb.

Outline

- **Overall rates and properties of the muons**, comparing the data with the expectations from simulations.
- Highlights from the individual measurements:
  - Identification efficiency for prompt muons
  - Mis-identification efficiency for hadrons
  - Trigger efficiencies
  - Momentum scale and resolution
- First results for higher p_T muons from W, Z.

CMS Muon System and Tracker

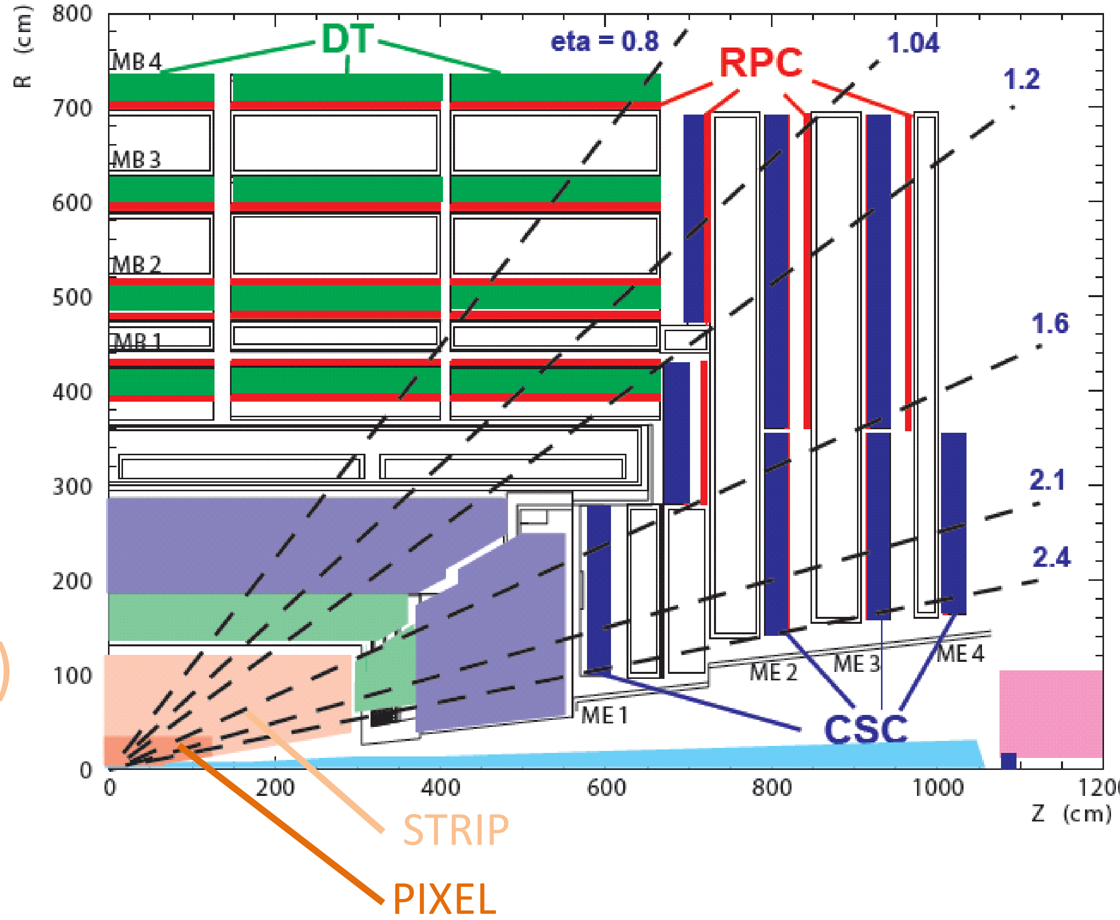
Muon system:

- Drift Tubes (DT)
- Cathode Strip Chambers (CSC)
- Resistive Plate Chambers (RPC)

Silicon Tracker:

- Pixels (3 layers)
- Strips (10-12 layers)

Magnet: B = 3.8 T

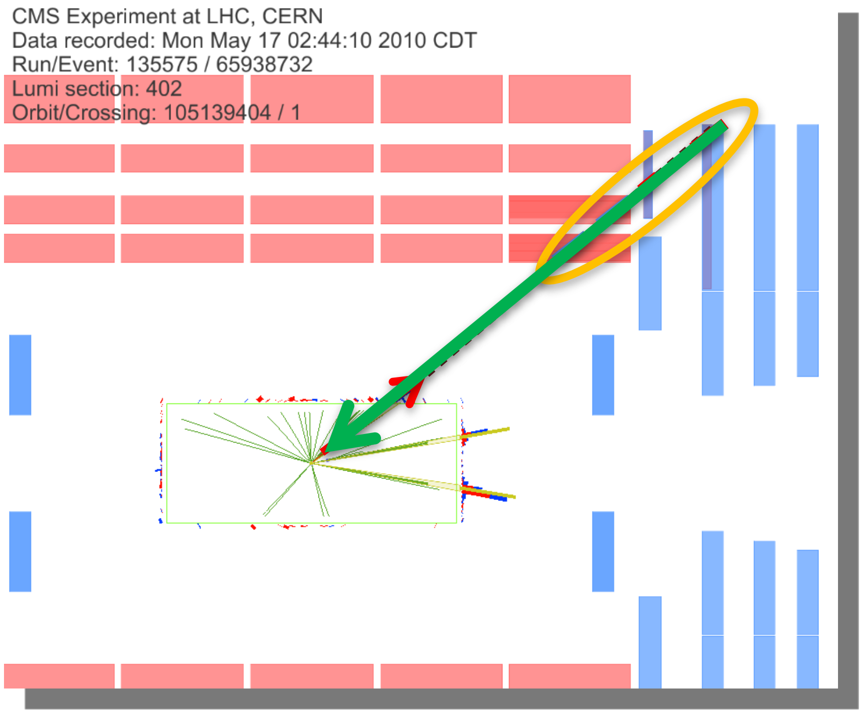


Part I
overall picture

Muon identification

Different algorithms and working points are available.
Two types will be used in this presentation:

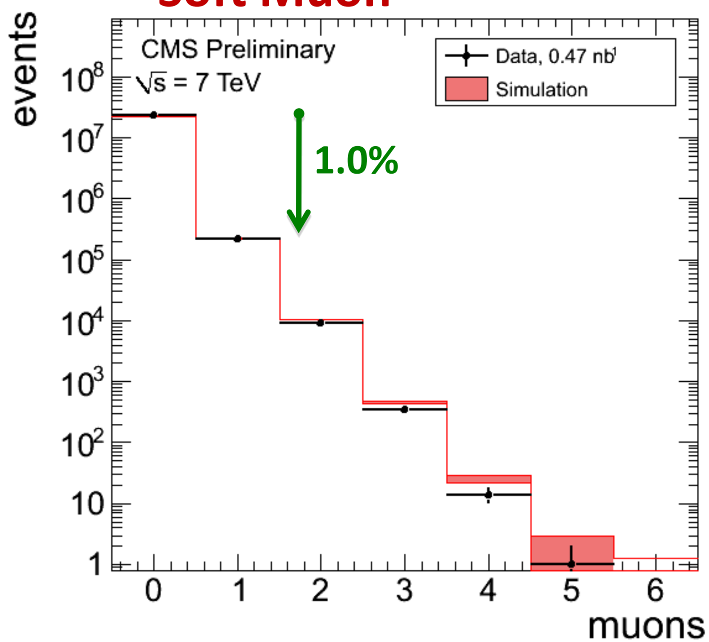
- "**Soft muon**": a tracker track **matched** to at least **one** CSC or DT stub, to collect muons down to p_T about 500 MeV in the endcaps (e.g. for J/Ψ)
- "**Tight muon**": a good quality track from a **combined fit** of the hits in the tracker and muon system, requiring signal in at least **two** muon stations to improve purity. Used e.g. for W, Z analyses.



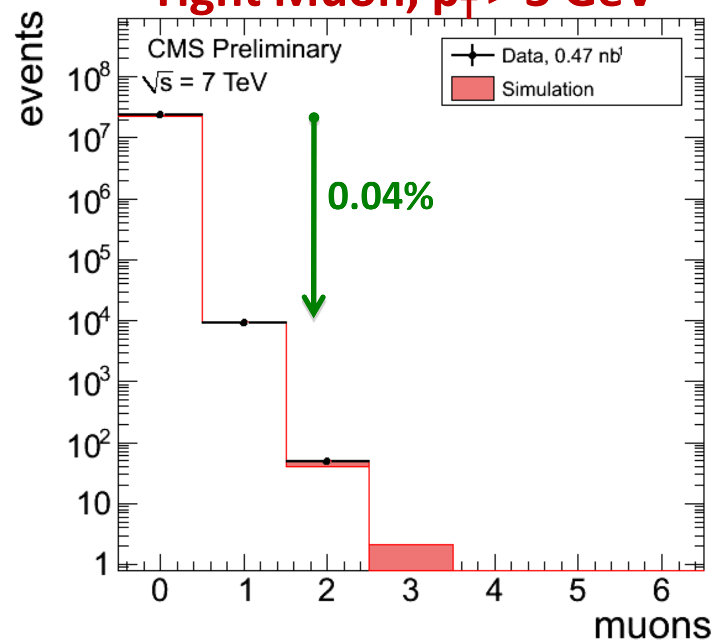
Muon counts in 7 TeV pp collisions

Data from **prescaled "minimum bias" triggers**, compared to simulation (Pythia D6T "minimum bias")
Good agreement across different muon identification working points, and at a few % level for the overall rate.

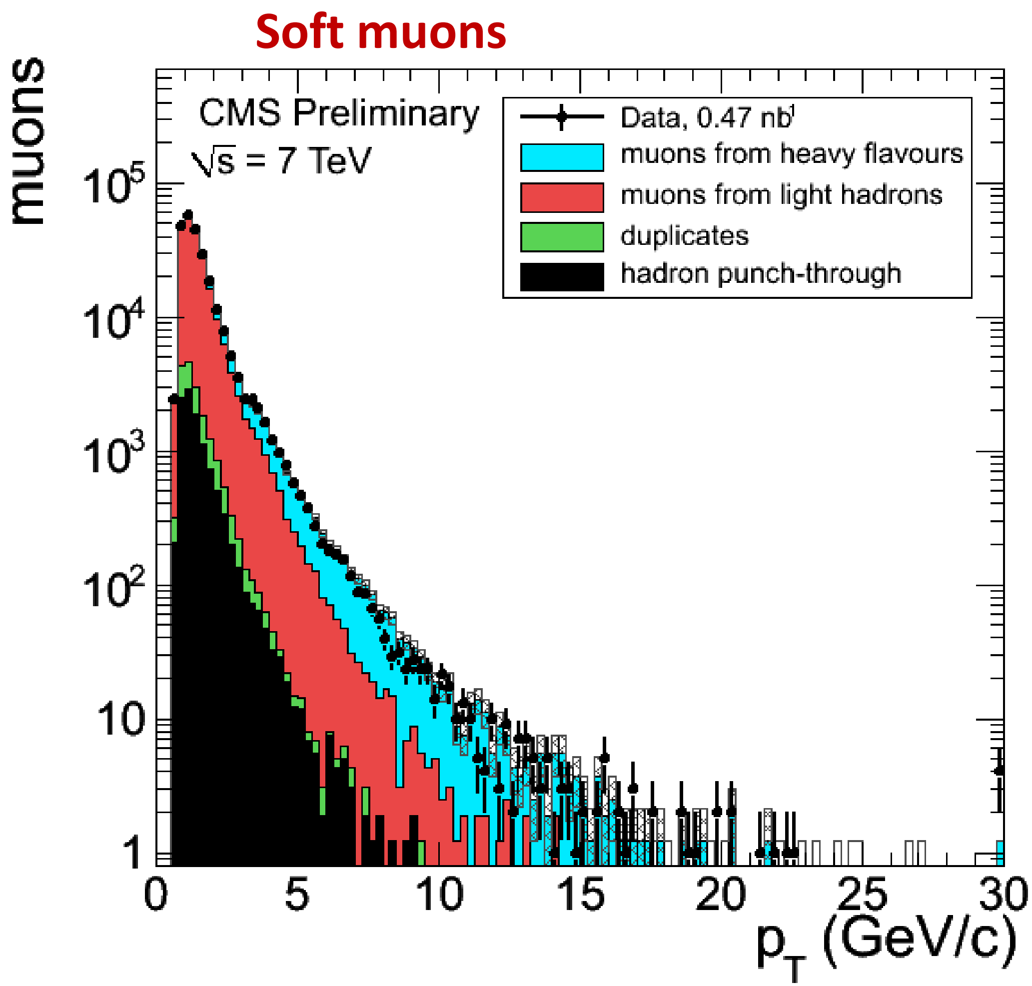
Soft Muon



Tight Muon, $p_T > 3$ GeV



Soft muons: kinematics



Data collected with a minimum bias trigger

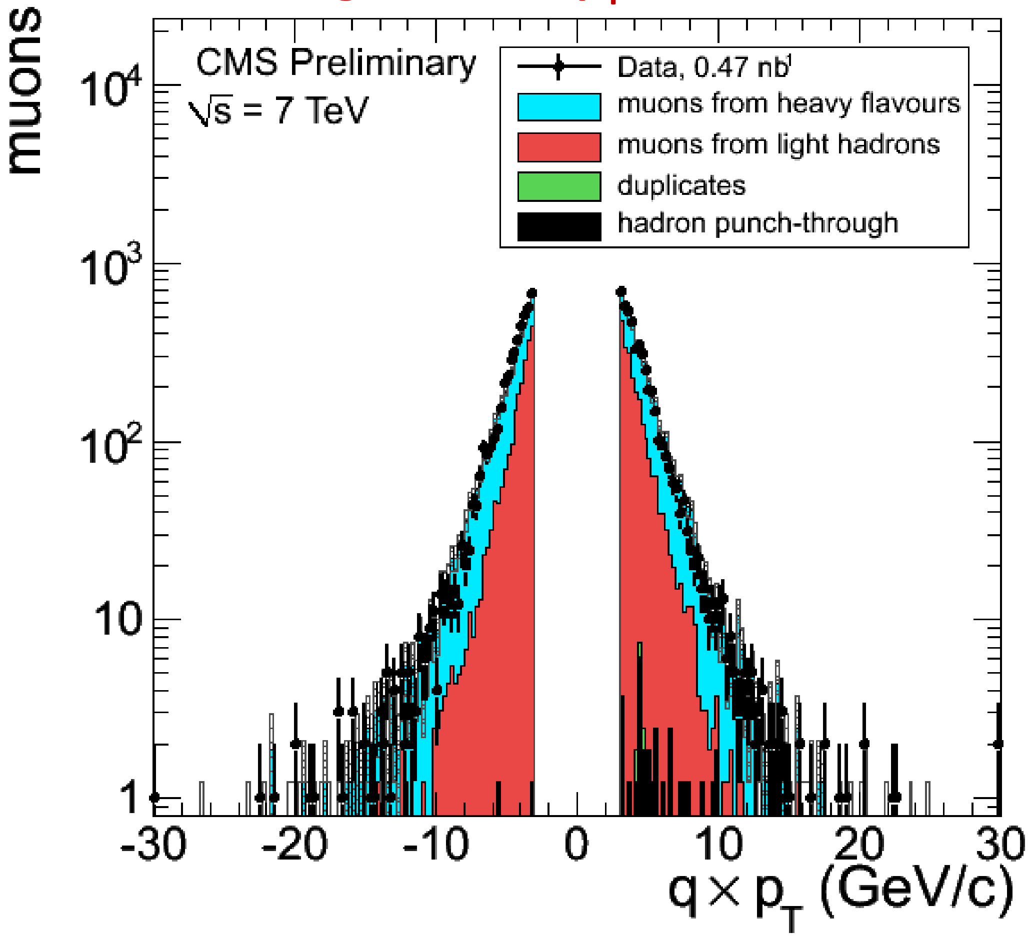
compared to

Simulation of min. bias events; muons separated according to their origin:

- **84% from π/K decays**
- **9% from b/c decays**
- **4.4% from hadron punch-through**
- **2.8% duplicates (1 sim. particle giving >1 reco. muons)**

Tight muons: kinematics

Tight Muon, $p_T > 3$ GeV



Data collected with a minimum bias trigger

compared to

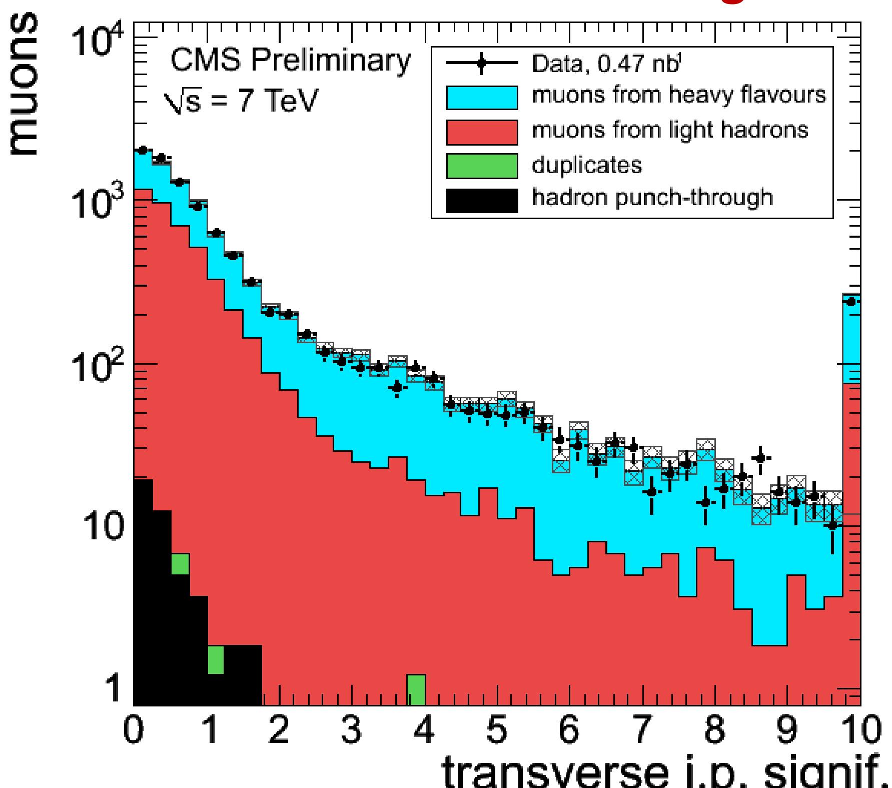
Simulation of min. bias events; muons separated according to their origin:

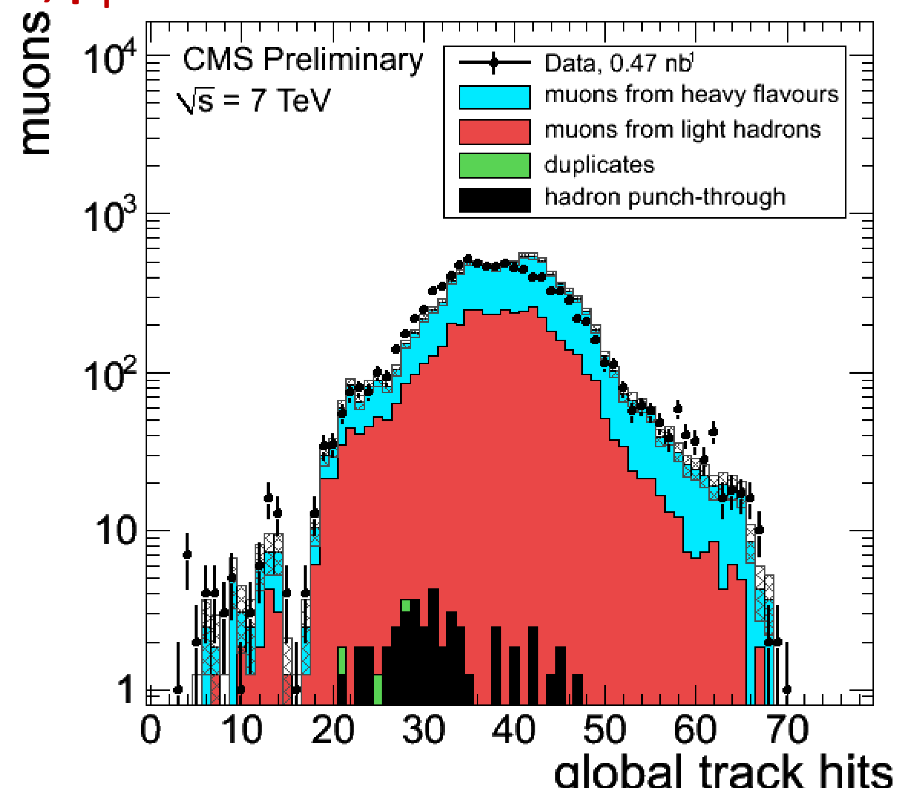
- **52.0% from b/c decays**
- **47.5% from π/K decays**
- **0.5% from hadron punch-through (mostly K^+/π^+)**
- **≤ 0.1% duplicates**

Other muon observables

Other data/sim. comparisons, with different sensitivities to the performance of the identification algorithms, the modelling of the detector, and to the sample composition.

Tight Muon, p_T > 3 GeV



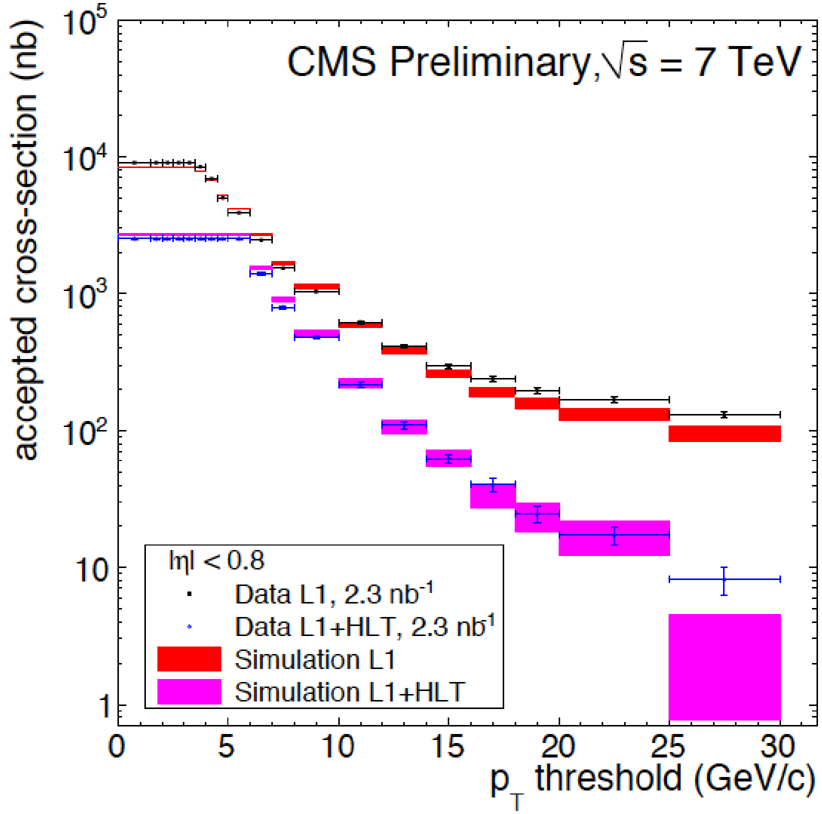


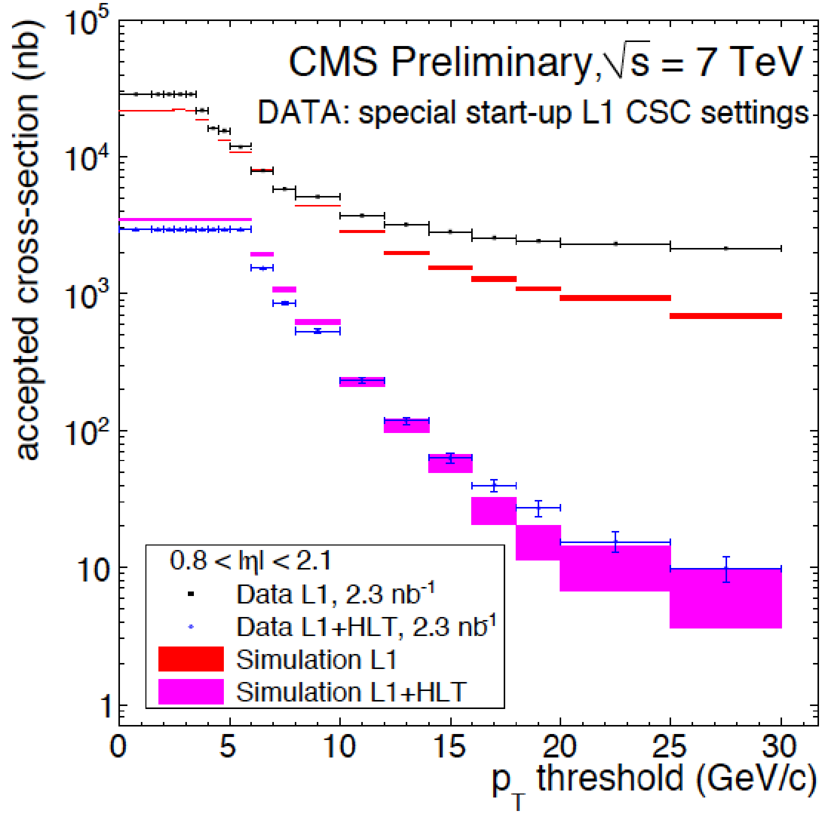
Muon trigger

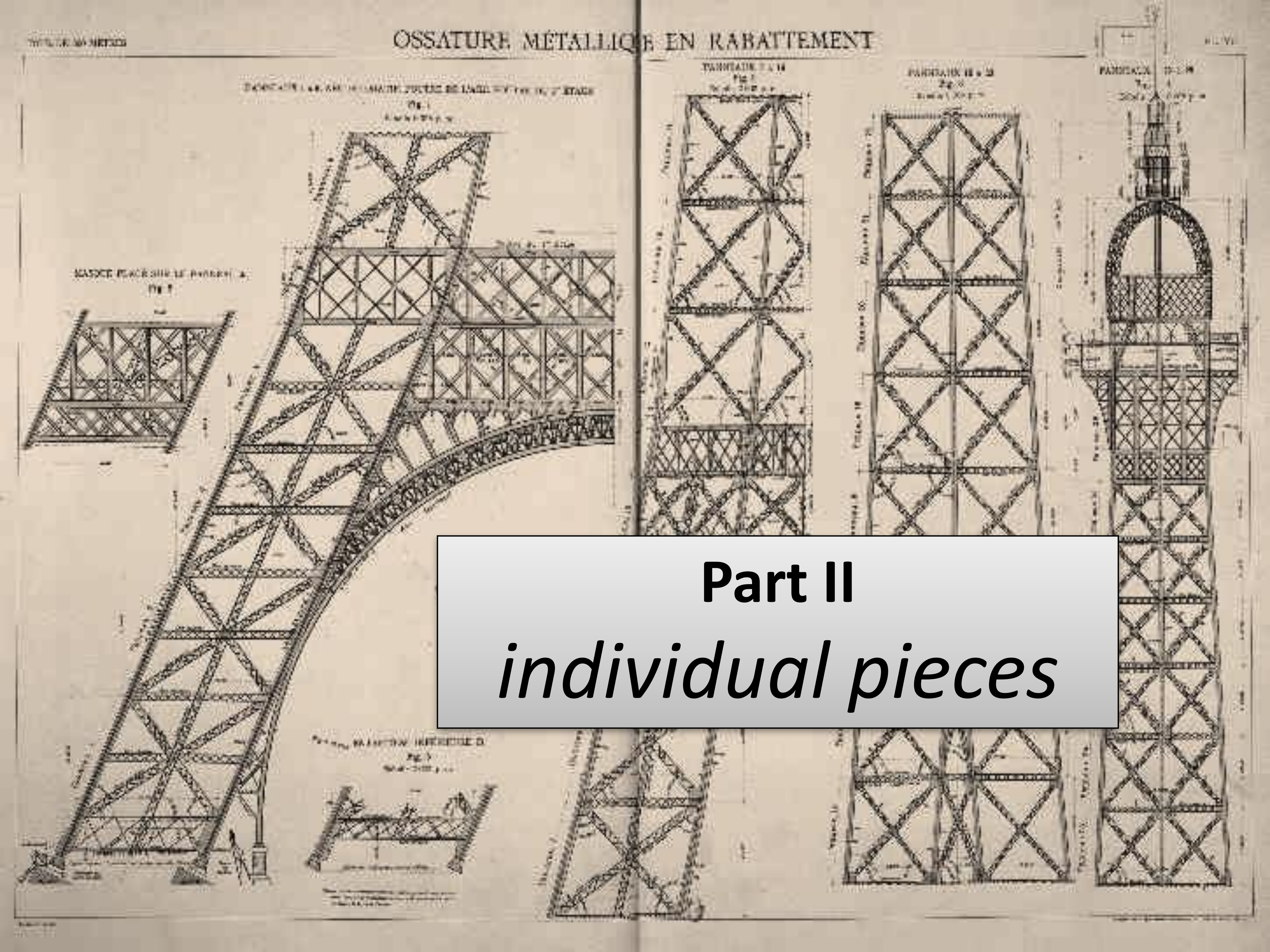
- L1, implemented in hardware, based on:
  - Tracks combining stubs from two DT/CSC stations
  - Patterns of hits in the RPCs
  - Single station stubs in the first CSC disk
    (Special startup configuration for soft muons)
- HLT, implemented in software:
  - Full muon reconstruction, including the silicon tracker

Muon trigger rates: Data vs Sim.

- Barrel: very good agreement at L1 and HLT
- Endcaps: the start-up L1 is not in the simulation, so the discrepancy is expected. Better agreement at HLT.







Part II

individual pieces

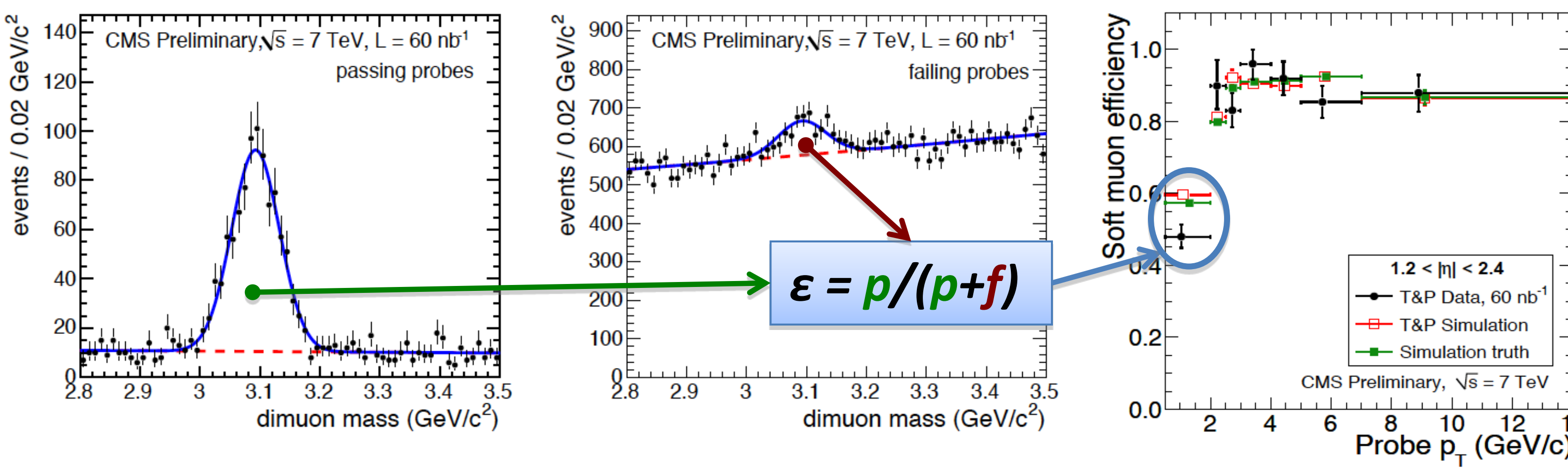
Performance measurements on Data

- I will show only the results more directly connected to the data/sim. comparisons shown in the previous slides.
- Many other approved CMS results not included here are available, e.g.
  - Isolation efficiencies using random cones
  - Investigations on the background from cosmics
  - Efficiencies for muons from W, Z
  - Results related only to single subdetectors

Reconstruction efficiency from J/Ψ

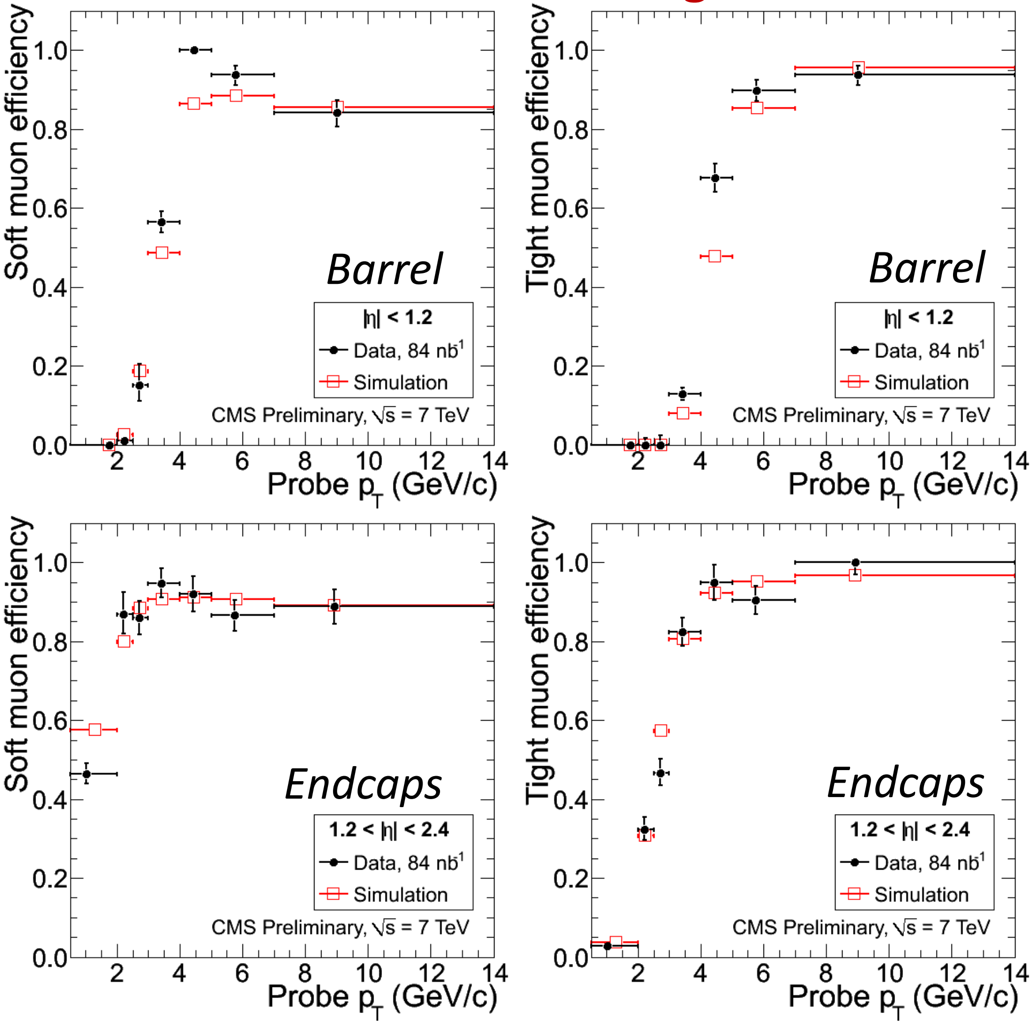
Tag & Probe method:

- Select track pairs in a mass window around the J/Ψ peak
  - Tag: a muon passing tight id. and firing the trigger
  - Probe: a tracker track, MIP-like in the calorimeters but with no requirements on the muon system
- Test if the probe passes muon reco. and identification
- Subtract the background using the lineshape fit.



Identification efficiency from J/Ψ

Soft Muon **Tight Muon**



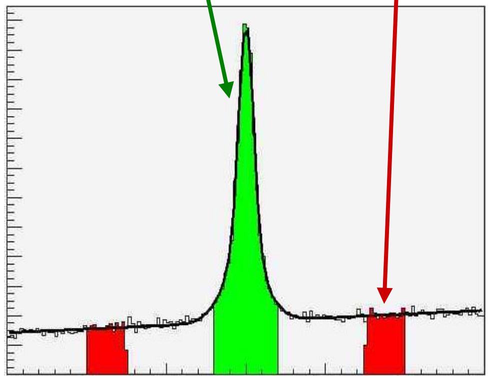
Results from data in agreement with expectations from simulation at the 5-10% level almost everywhere

... just a few months after the startup!

Mis-id. efficiency for hadrons

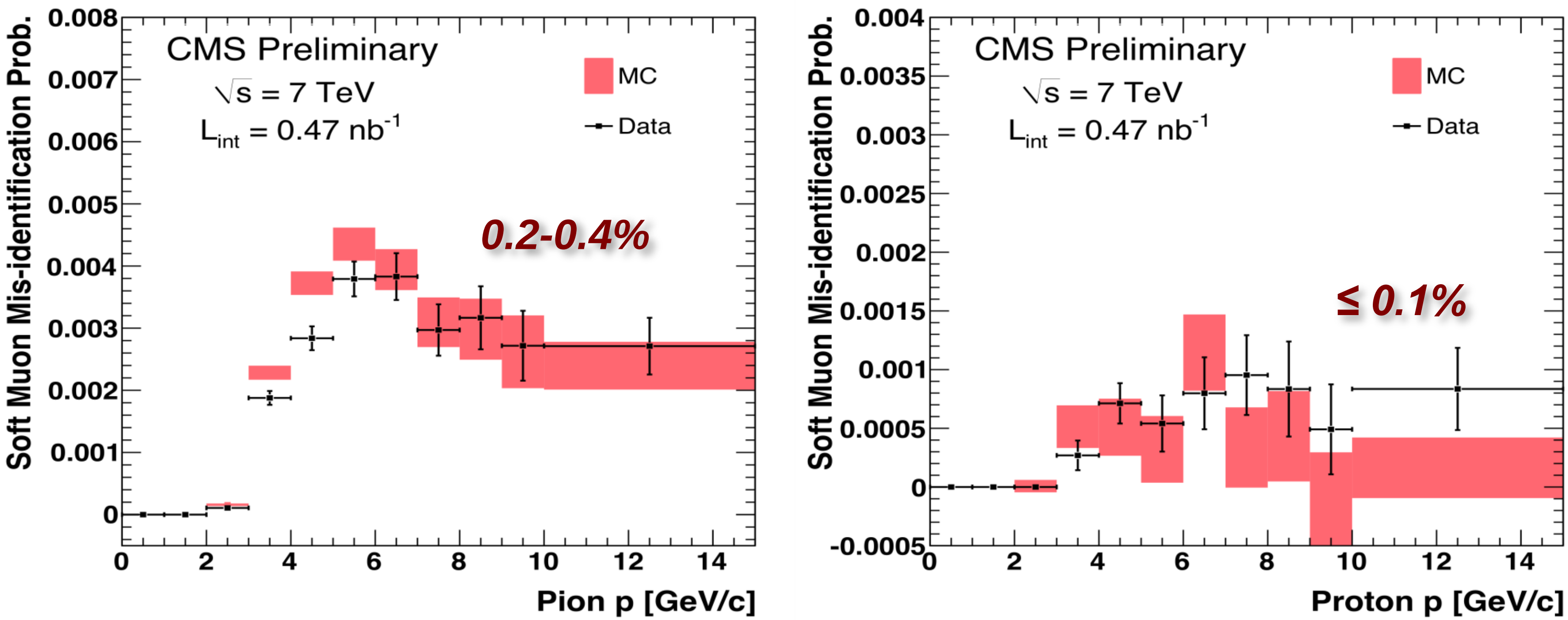
- Select π/K/p tracks from identified K_S, ϕ, Λ resonances (from minimum bias triggers)
- Measure the probability that they are identified as muons:
  - for protons, this is the punch-through probability
  - for π/K, this is the sum of decay in flight and punch-through probabilities

$$\varepsilon = \frac{N_S^{\mu} - N_B^{\mu}}{N_S^{\mathrm{trk}} - N_B^{\mathrm{trk}}}$$



Mis-id. efficiency for hadrons

Mis-id probability for soft muons from pions and protons (after background subtraction from mass sidebands)



Smaller prob. for tight muons: 0.1% for π, 0.02% for p

Momentum scale and resolution

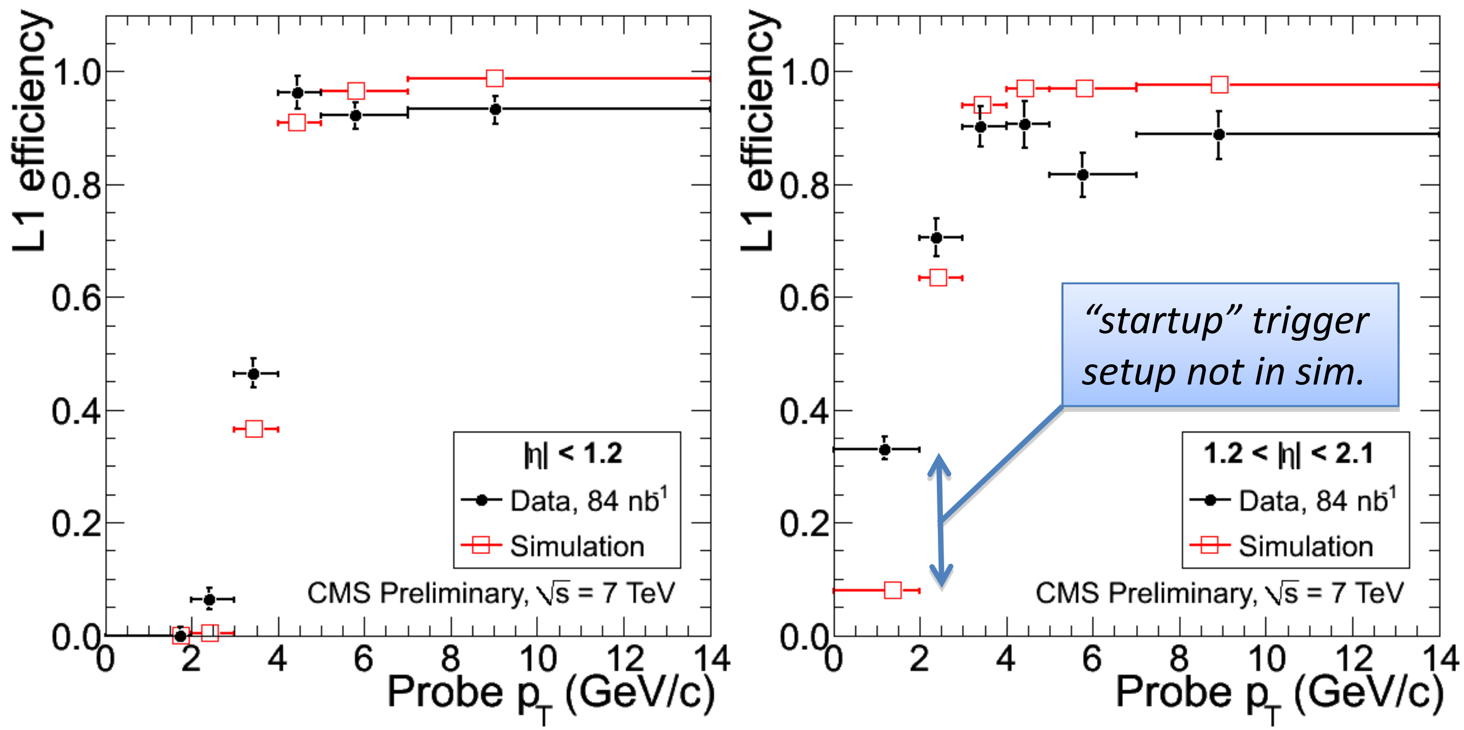
- The momentum measurement for muons is dominated by the silicon tracker for p_T < 200 GeV/c
- Measurement on data using muons from J/Ψ
  - momentum scale bias: (2±1) × 10^{-3}
  - momentum resolution agrees with expectations from simulation within 5%
- More details in the CMS tracking performance talk by B. Mangano in this morning's session, or in the CMS Physics Analysis Summary TRK-10-004

Trigger efficiencies

- Two definitions can be used:
  - **Relative to muons which are reconstructed offline:** Used in analysis when factorizing $\varepsilon = \varepsilon_{Offl} \times \varepsilon_{Trig}$ Can be measured from di-muons (“tag & probe”) or from single muons taken from minbias triggers.
  - **Absolute**: for assessing the trigger performance. Can be measured from di-muons, using silicon tracker tracks as probes not biased by the muon system.

"Absolute" Trigger Efficiency

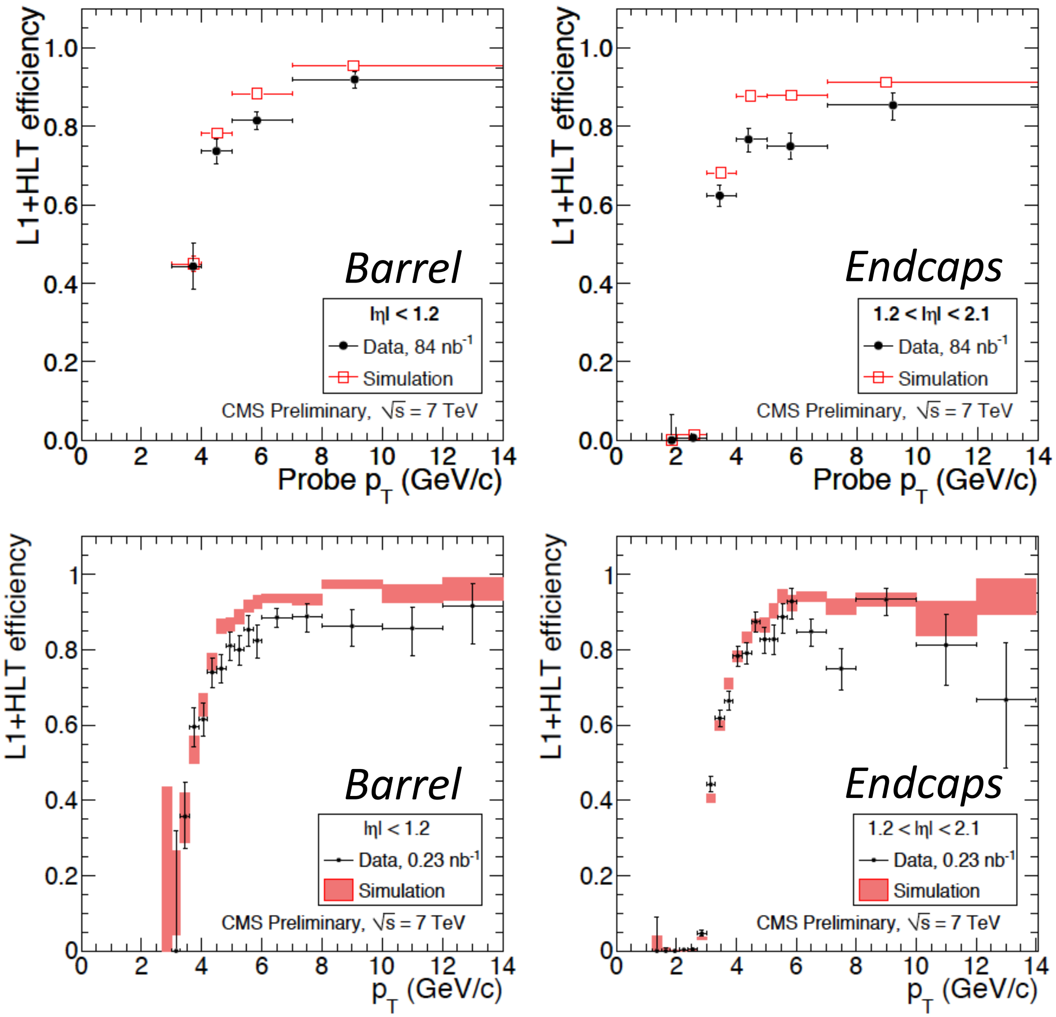
From "tag & probe" method on J/Ψ using probes with no muon requirement (MIP-like tracker tracks).
At low p_T, higher efficiency in data from the "startup" trigger settings, not included in the simulation.



Trigger efficiency w.r.t. tight muons

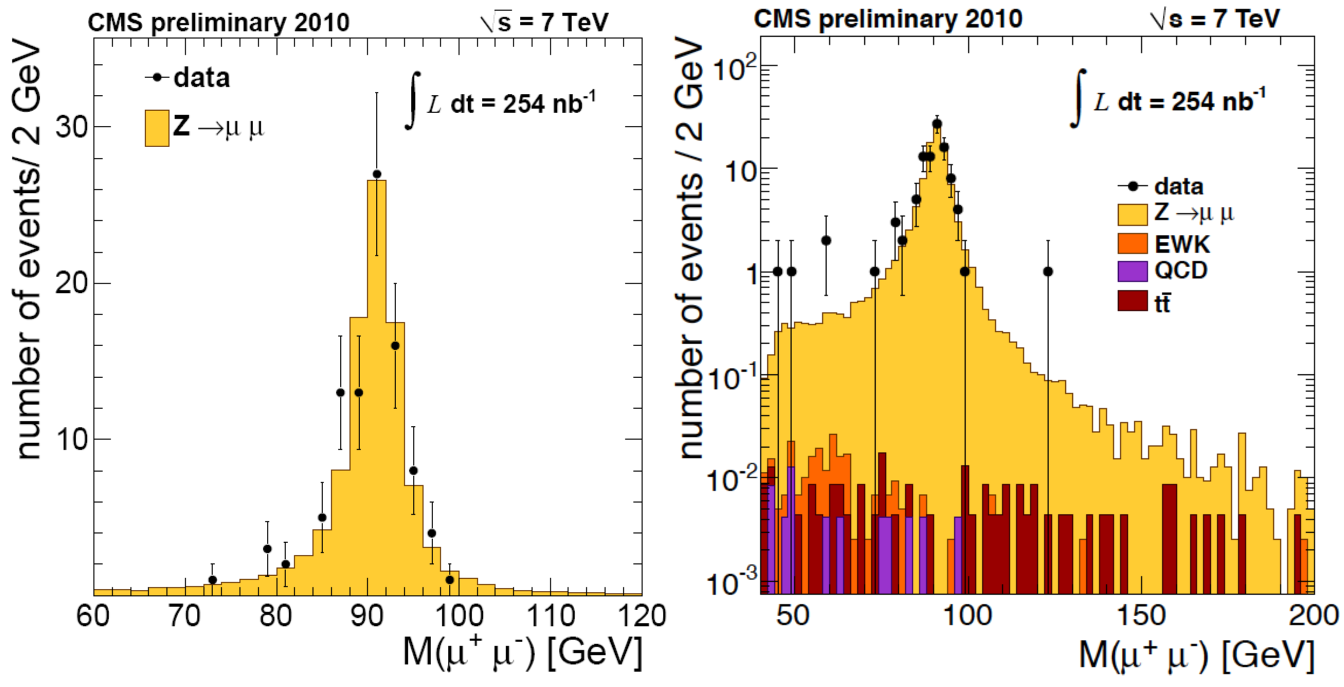
tag & probe on J/Ψ di-muons

Single muons in minbias events



Higher momentum muons

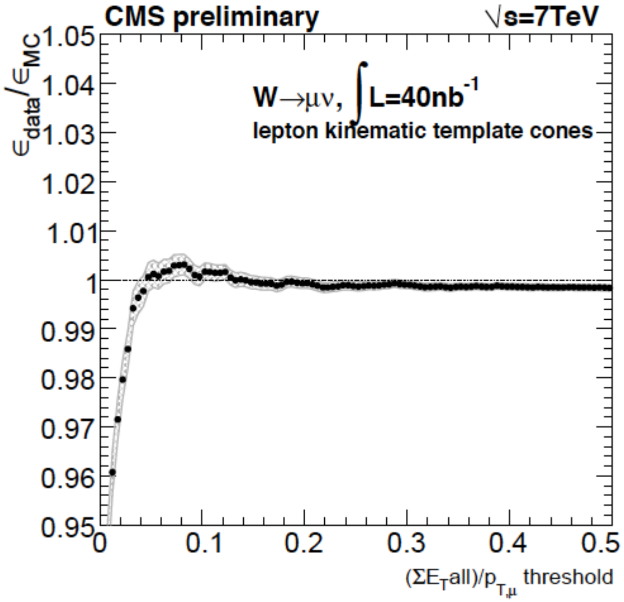
- Shortly before ICHEP we started to have a sizable sample of higher momentum muons.
- Just like for lower energies, the agreement between data and simulations is remarkably good



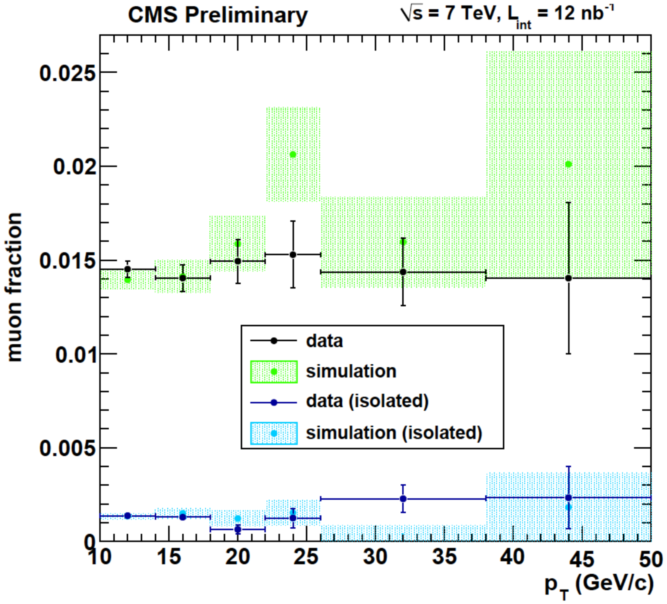
Higher momentum muons

- Good data/sim. agreement also for muon performance measurements at higher p_T

Data/sim. ratio of isolation efficiencies for W muons



Fraction of tracker tracks identified as tight muons



Conclusions

- The CMS muon reconstruction and trigger has been studied on pp collisions at 7 TeV.
- The agreement with the expectations from simulations is very good, both in the overall picture and in the individual performance measurements: efficiencies, resolutions, …

… just a few months since the startup!

(and work is ongoing to make it even better)

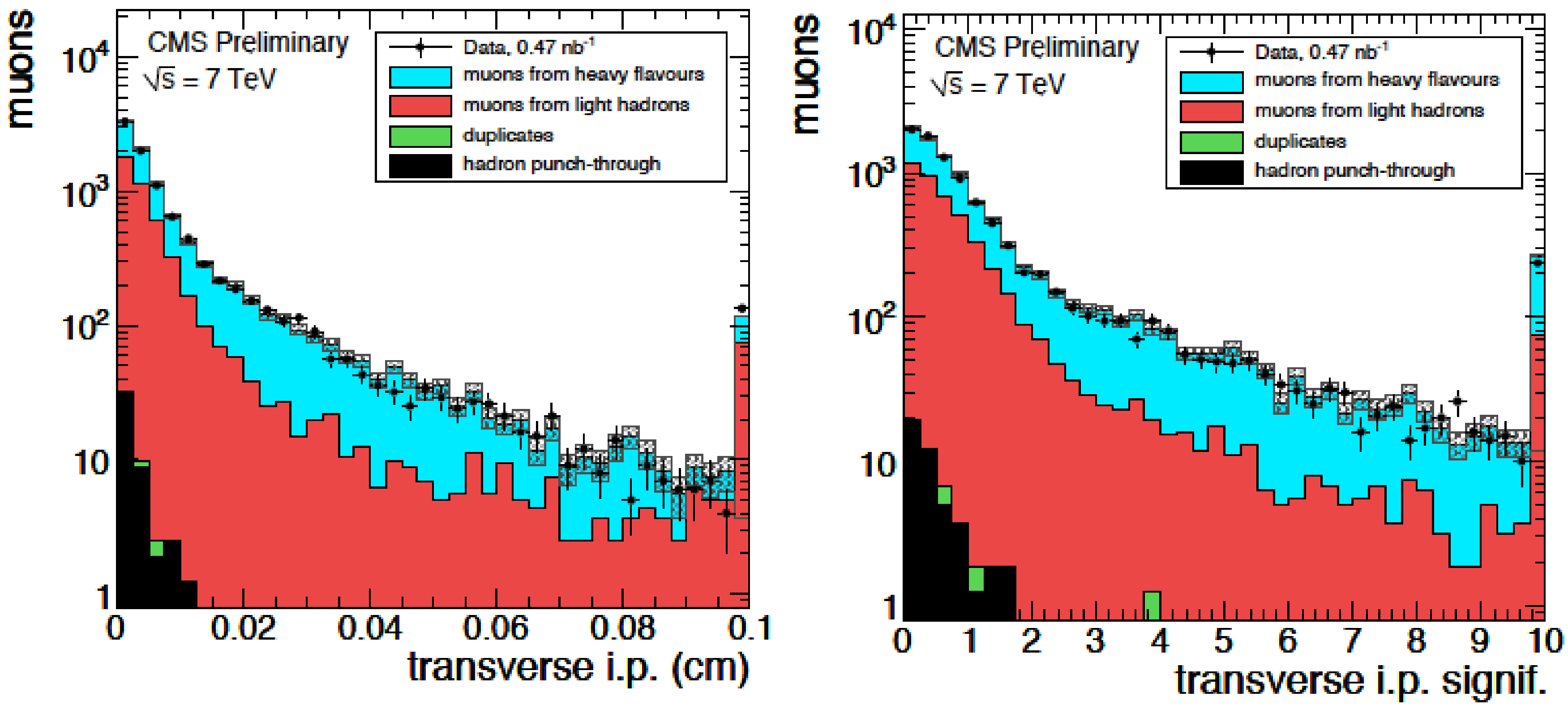
References

- CMS Muon Physics Results page https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsMUO
- CMS Physics Analysis Summaries:
  - MUO-10-002: “Performance of muon identification in pp collisions at √s = 7 TeV”
  - TRK-10-004: “Measurement of Momentum Scale and Resolution using Low-mass Resonances and Cosmic-Ray Muons”

Support Material

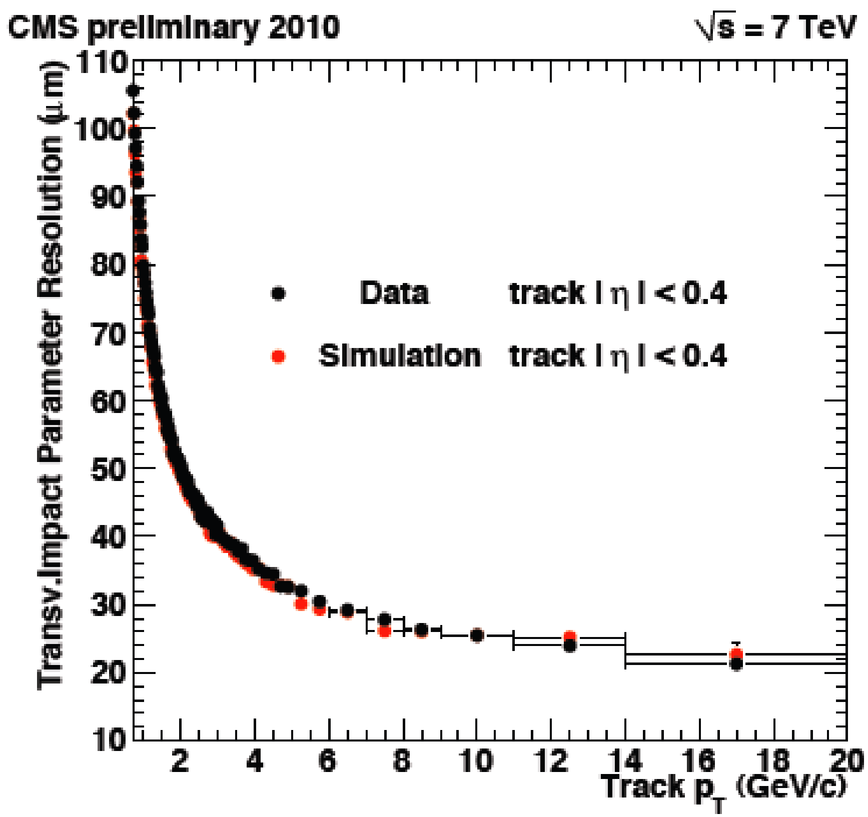
Muon impact parameter

Transverse impact parameter for tight muons

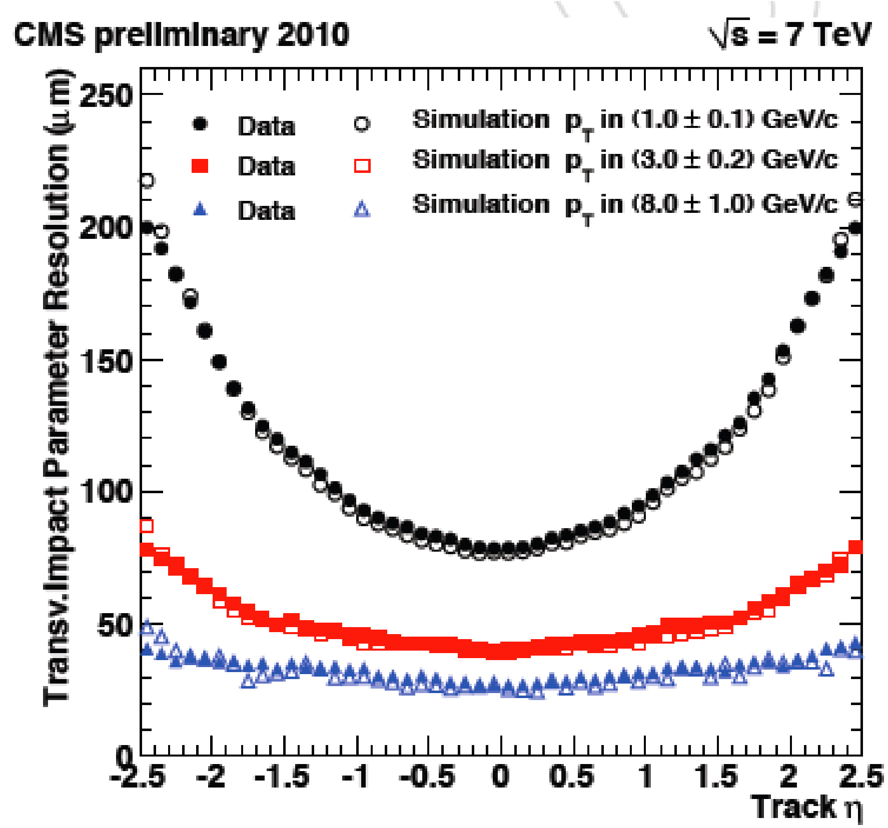


Impact parameter resolution

σ(dxy) vs p_T, in the barrel



σ(dxy) vs η, for different p_T bins



from CMS PAS TRK-10-005

Muon yields, and compositions

Yields in data vs sim. (L = 0.47/nb)

overall yield [no. of muons]	Soft Muon	Global Muon	Tight Muon
data	241 381	46 742	9 435
simulation $\times 10^3$	245.7 ± 0.4	46.12 ± 0.17	9.66 ± 0.08
ratio data/simulation	0.982 ± 0.002	1.014 ± 0.006	0.977 ± 0.013

(note: uncertainties are statistical only)

Sample composition from simulation

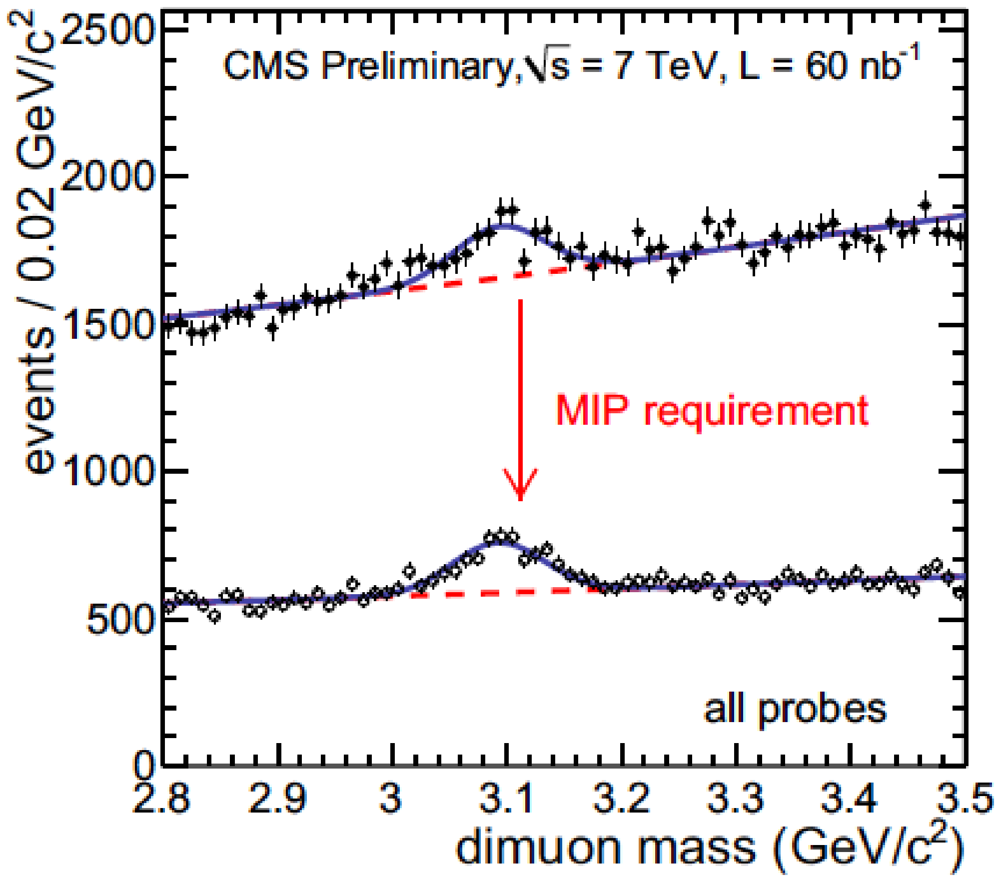
muon source [%]	Soft Muon	Global Muon	Tight Muon
heavy flavour	8.83	23.9	52.0
light flavour	83.9	73.6	47.5
duplicate	2.82	0.65	0.03
hadron punch-through	4.44	1.84	0.49

(Global muon: another muon id working point; see PAS MUO-10-002)

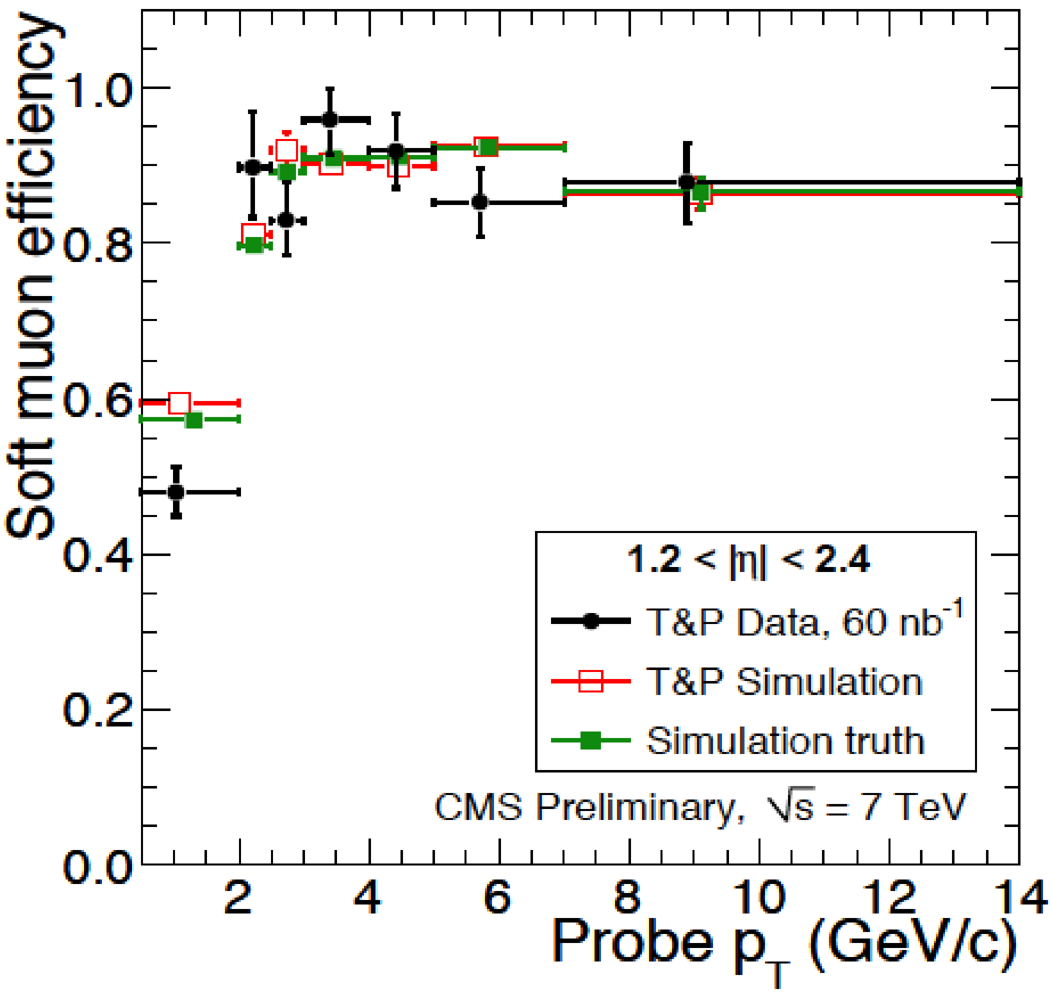
Efficiencies from Tag & Probe

How the calorimetric MIP identification reduces the inclusive background in the muon+track lineshape.

This figure is for the endcaps, for probes in p_T range [0, 2] GeV



Efficiencies from Tag & Probe



Comparison of:

T&P in Data

T&P on Sim.

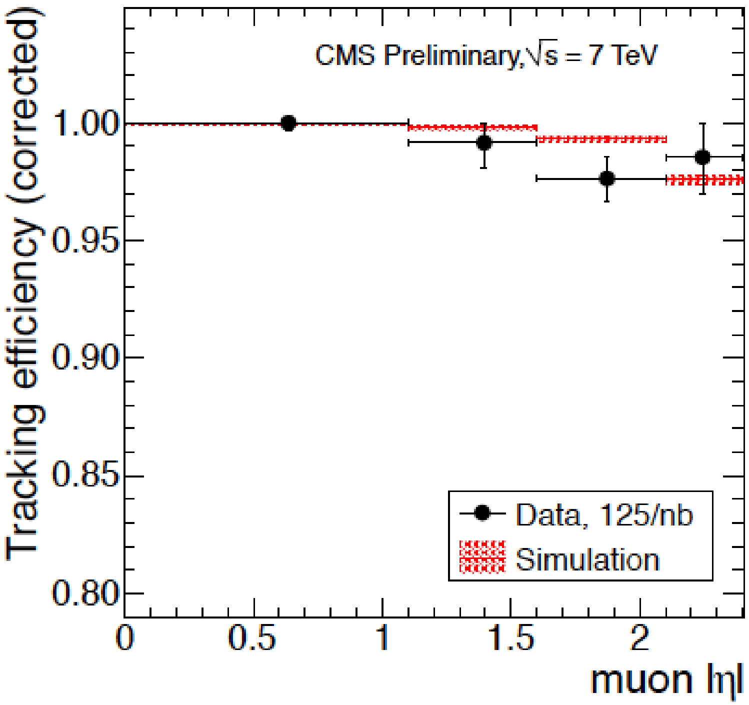
Sim. truth (= perfect background subtraction)

No systematic bias from the mass fit

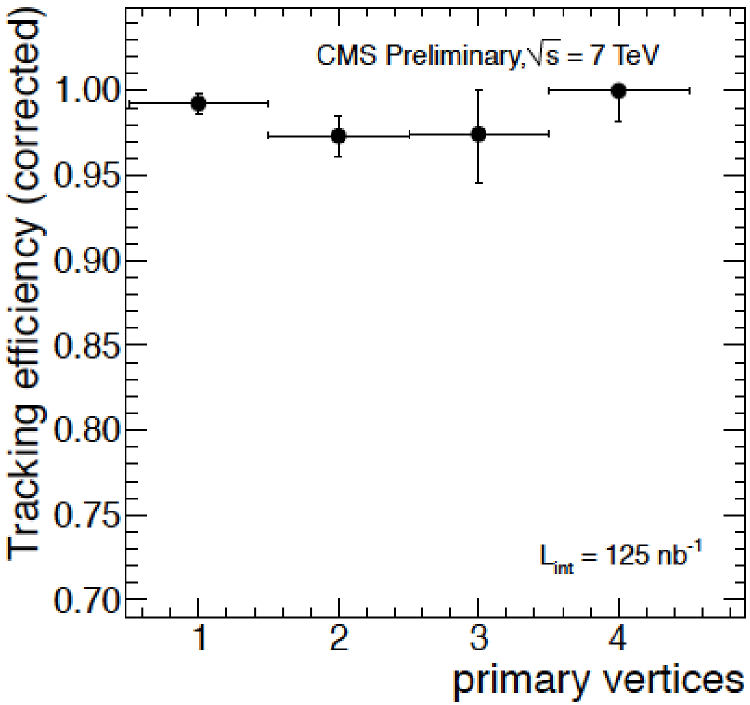
Silicon tracker reco. efficiency

Tag & probe method on muons from J/Ψ, using as probes "standalone" tracks from muon system only

Efficiency vs |η|

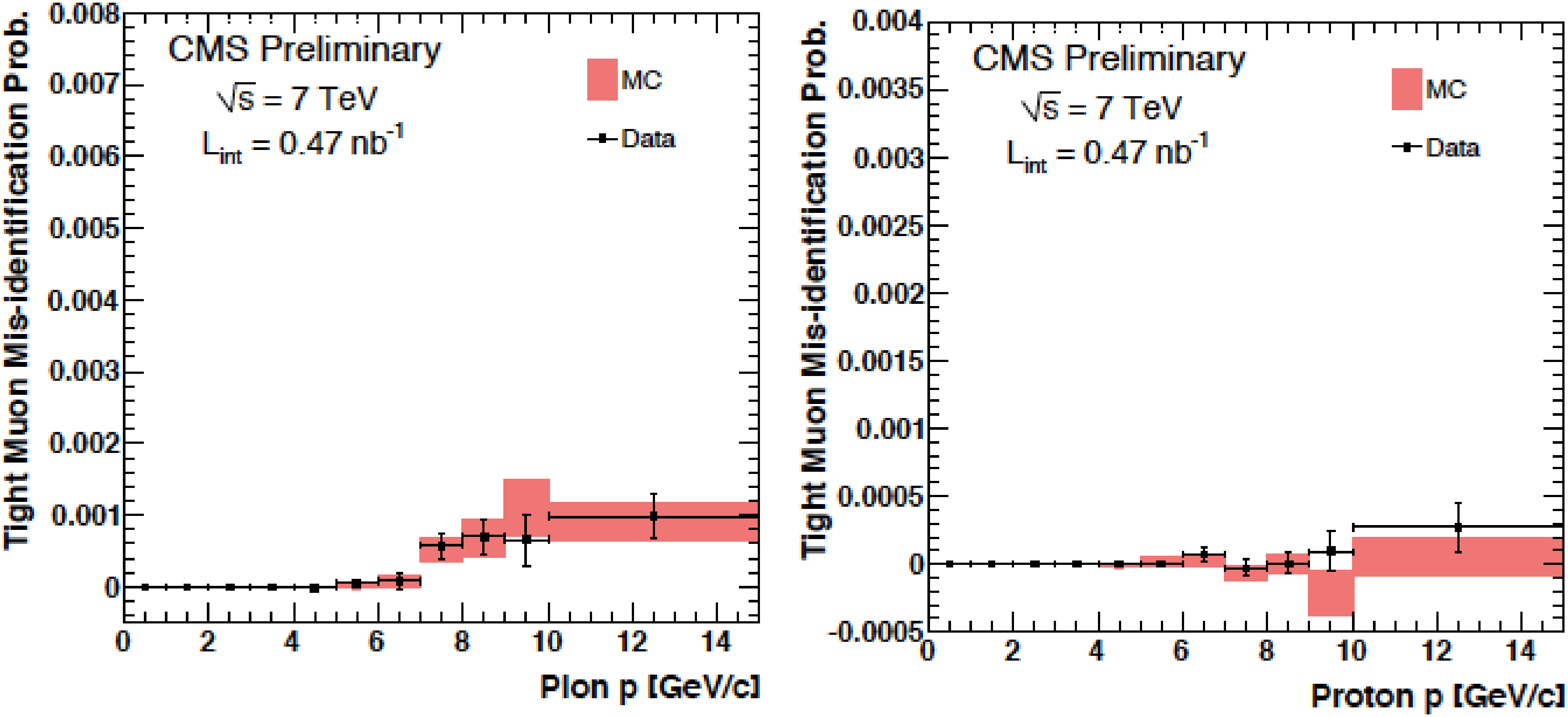


Efficiency vs pile-up



from CMS PAS TRK-10-002

Mis-id efficiencies for tight muons



Mis-id efficiencies: figures

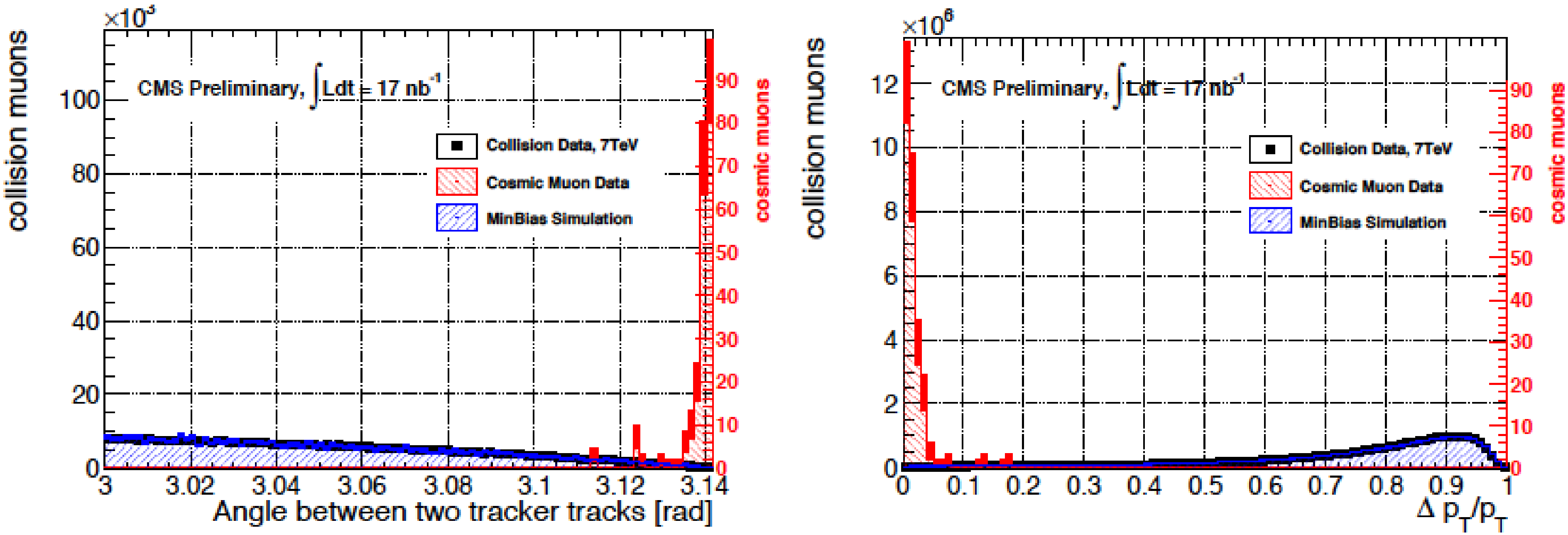
integrated over momenta 0-10 GeV

	Soft Muon		Tight Muon	
$(\times 10^{-4})$	data	simulation	data	simulation
protons	5.3 ± 0.8	4.9 ± 0.9	0.17 ± 0.13	0.04 ± 0.14
pions	26 ± 1	31 ± 1	1.0 ± 0.2	1.0 ± 0.2
kaons	30 ± 4	31 ± 4	2.3 ± 1.0	4.0 ± 1.0

(uncertainties are statistical only)

(No) background from cosmics

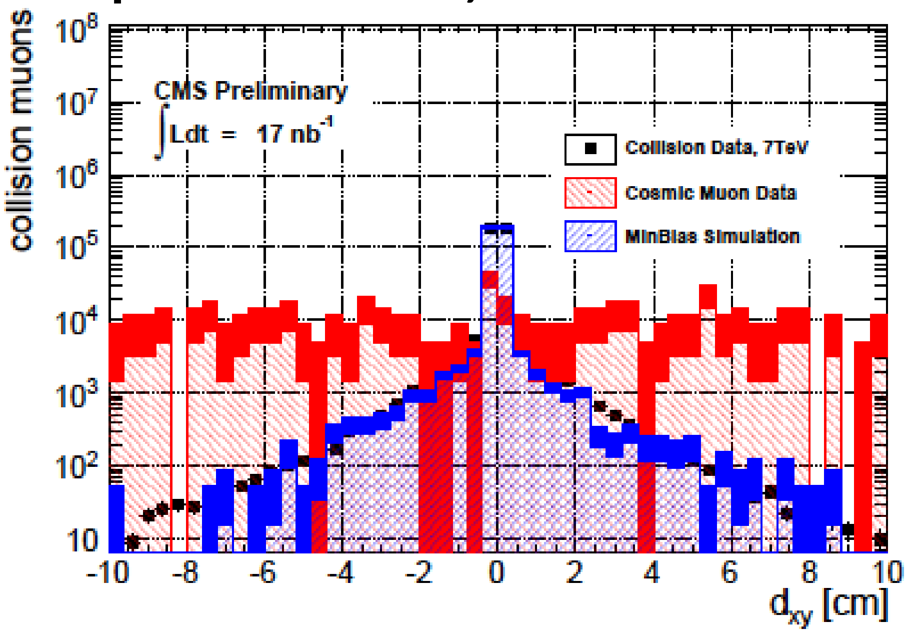
- Pointing cosmic muons can be identified by searching for a silicon track back to back with the reco. muon

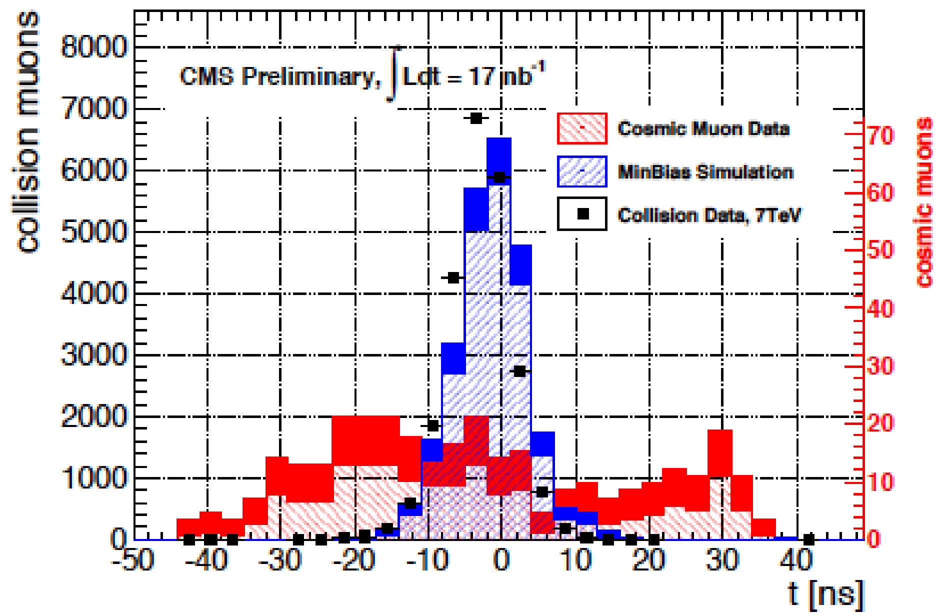


Data points follow the distribution expected from **collision simulation**. No visible contamination from **cosmic muons**

(No) background from cosmics

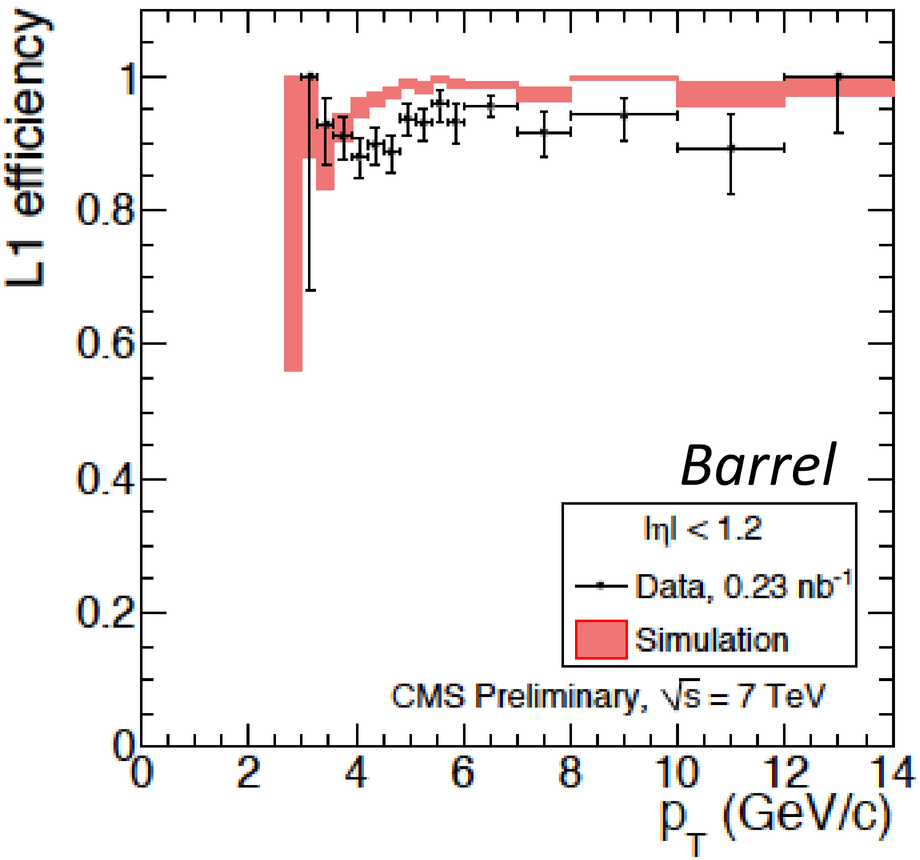
Other discriminating variables: track impact parameter, time measurement from DTs

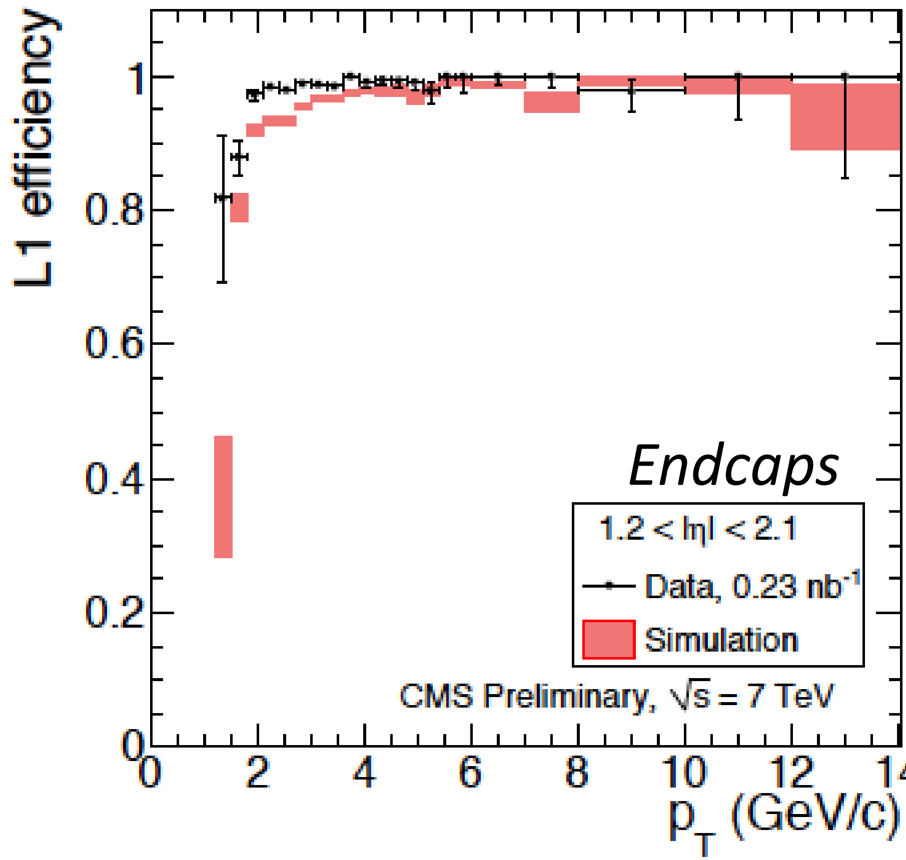




Data points follow the distribution expected from **collision simulation**. No visible contamination from **cosmic muons**

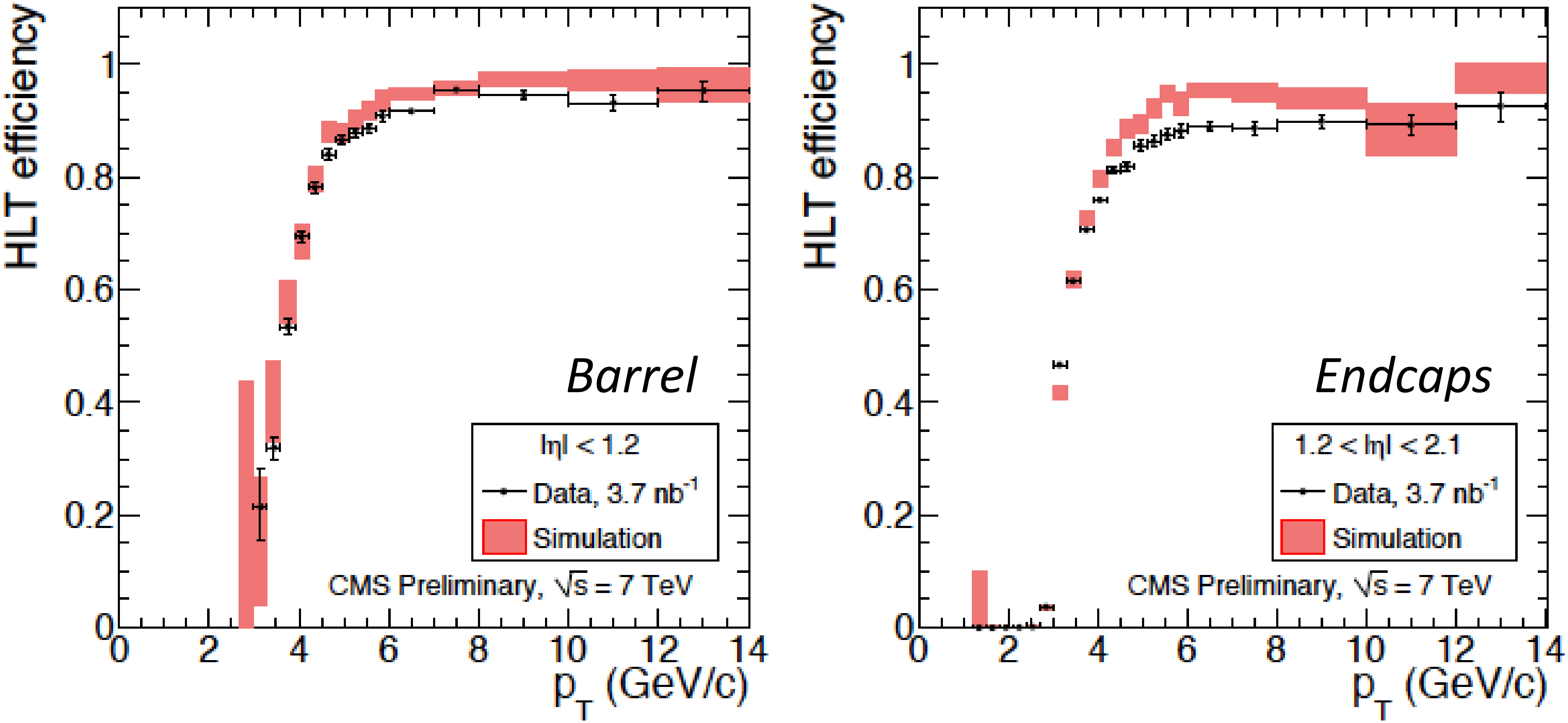
L1 efficiency w.r.t. tight muons





Good agreement. Effect of the “startup” L1 setting in data is less visible for muons with signal in ≥2 stations

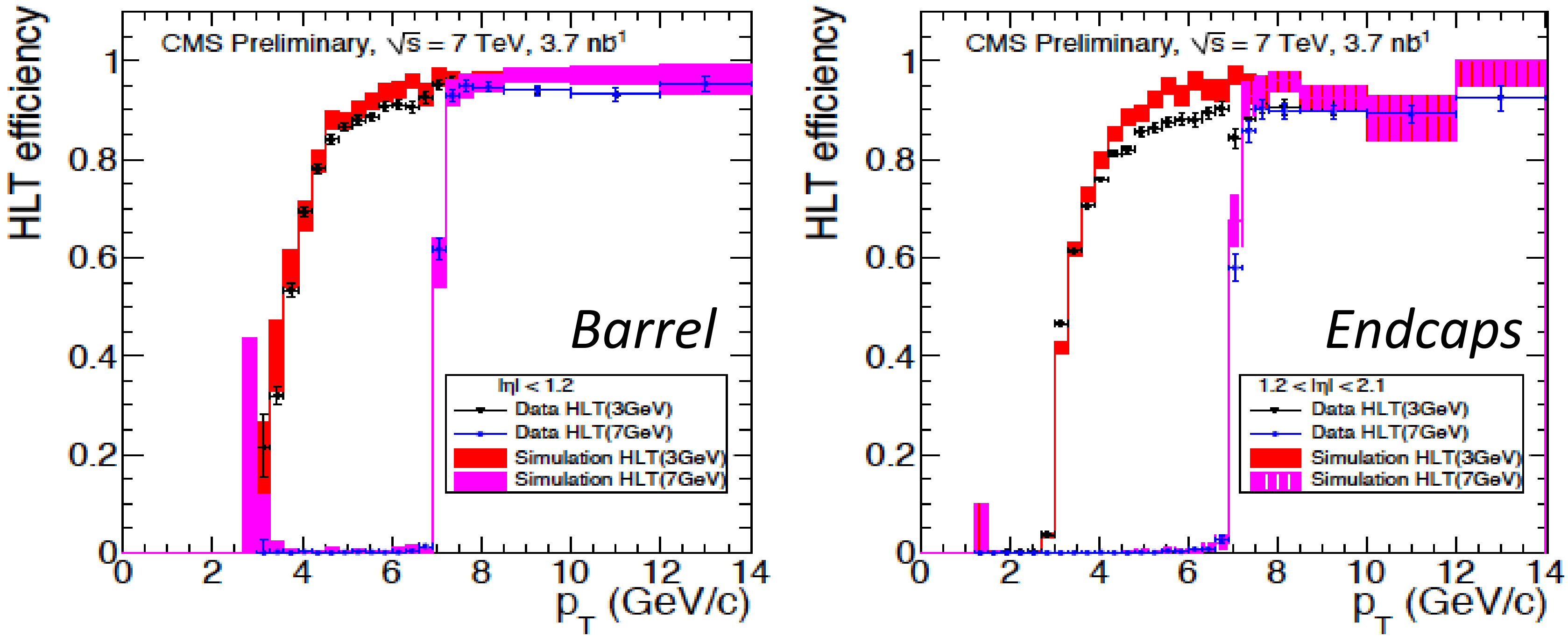
HLT-only efficiency wrt tight muons



HLT turn-on for a threshold of 7 GeV

Turn-on curve for the HLT with 3 GeV threshold is slow because of the 3 GeV cut at “L2” (muon system only).

When the final HLT cut is tighter than the L2 one, the turn on is much sharper thanks to the inner tracker.



Efficiencies for W/Z muons

Muon identification:

- "tag & probe" on the Z, averaged over p_T, η:

  Values from data and agrees with expectations within the statistical uncertainties (3%)

Muon trigger:

- "tag & probe" on the Z, averaged over p_T, η:

  Eff(data) / Eff(sim.) = 98 ± 3 %

- high pT tight muons in events from jet trigges

  Eff(data) / Eff(sim.) = 92 ± 3 %

from CMS PAS EWK-10-002

DT Trigger improvements since startup

Local trigger efficiency: efficiency to have at least 2 trigger primitives in different stations, with same bunch crossing id.