Introduction to Muons in CMS

Achim Geiser CMS Hamburg/DESY meeting 16.12.09

thanks to I. Bloch for template slides

- What is a muon?
- What is a muon in CMS?
- Example muon physics topics
- How to reconstruct muons?
- How to analyze muons?

What is a muon ?

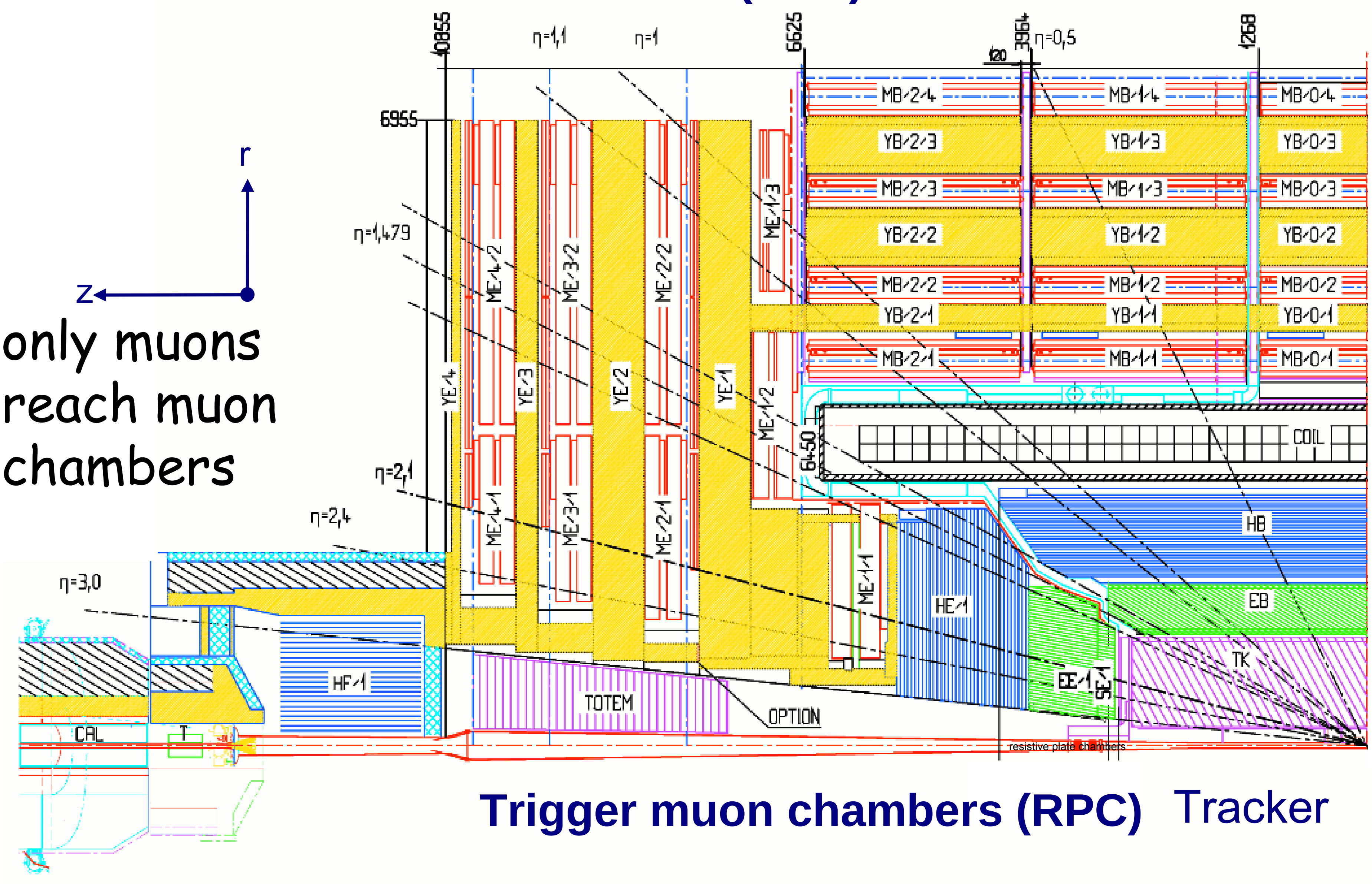
Minimum Ionizing Particle (MIP) with high penetration power

„rule of thumb":
Range in iron: ~ 1 m / GeV

to be compared to nuclear interaction length of l~17 cm (e.g. for pions)

What is a muon in CMS?

Forward muon chambers (CSC) **Central muon chambers (DT)**



only muons reach muon chambers

HO

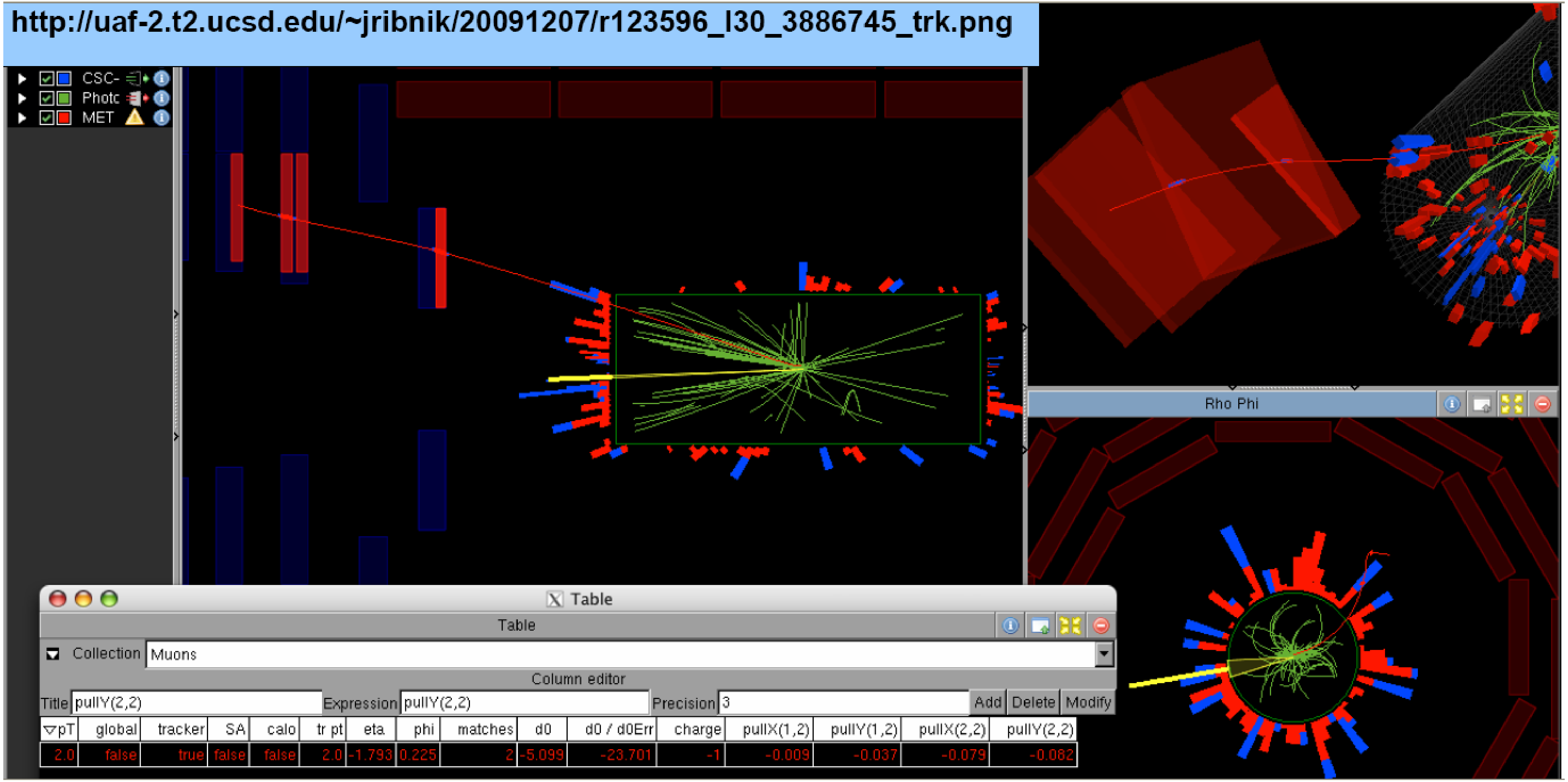
HCAL

ECAL

Trigger muon chambers (RPC) Tracker

Muon event display

From talk J. Ribnik



Example muon physics topics

- Beauty and charm production from semileptonic decays, b->J/ψ

  -> muons in jets (non-isolated muons)
- Direct charmonium/bottomonium production (J/ψ , Υ, ...)
- Drell-Yan muon pair production (Z, γ*)

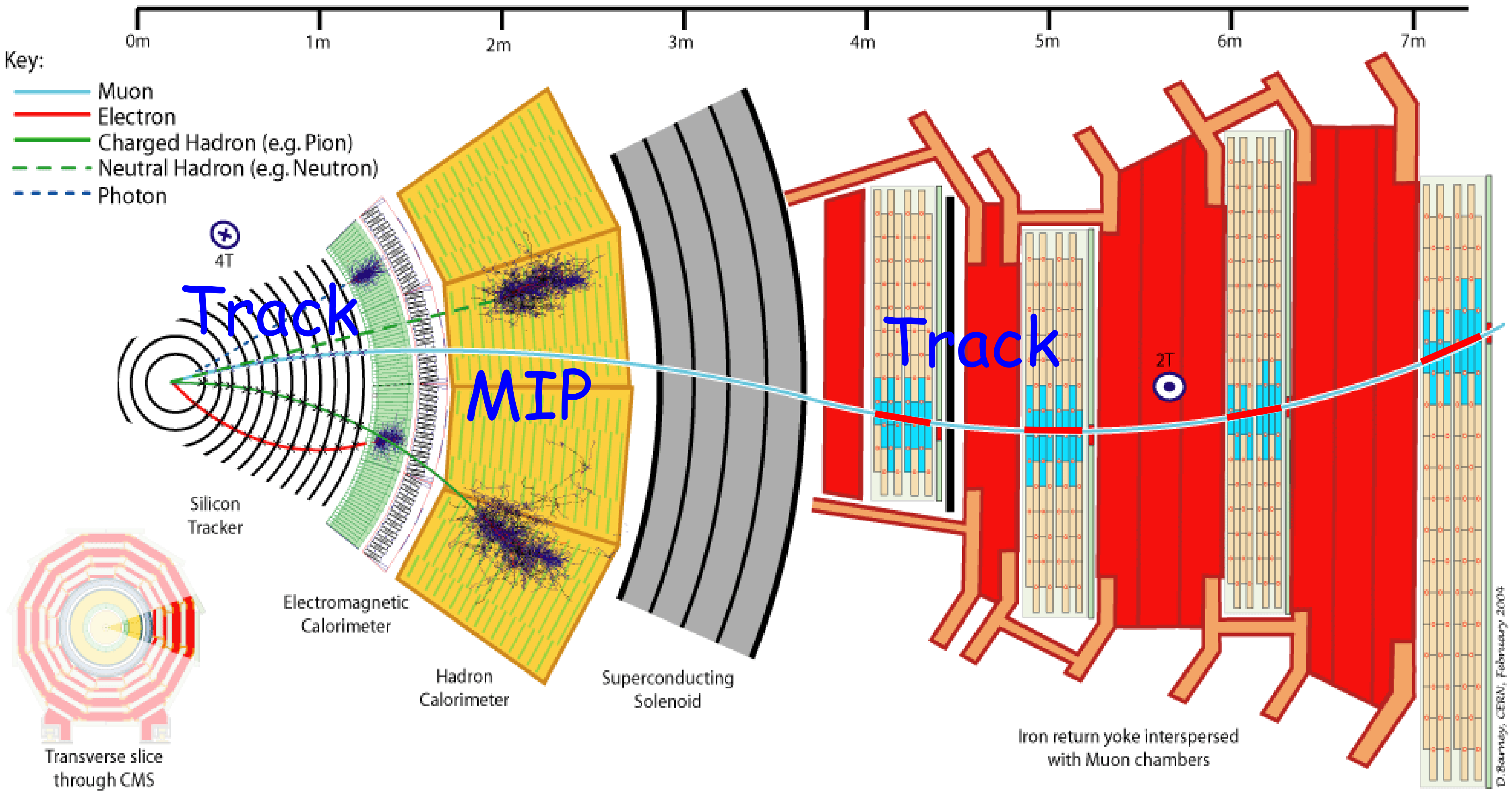
  -> isolated muon pairs
- High pt isolated muons

  (W, t, SUSY, ...)
- ...

How to reconstruct a muon in CMSSW?

Tracker μ (Calo μ), inside-out →

Standalone μ and Global μ outside-in ←



Main detectors involved in muon ID

- Magnets
  - -> provide bending power (opposite directions inside/outside coil)
  - -> provide absorber
- Tracking detectors (Pixel, SiStrip)
  - -> measure momentum/charge, track isolation, vtx association
- Calorimeters (ECAL,HCAL,HO)
  - -> measure minimum ionization, isolation
  - -> provide absorber
- Central (DT) and forward (CSC) muon chambers, RPC

  -> measure
  - penetration power,
  - momentum and momentum consistency,
  - timing

Redundancy !

Muon backgrounds

- muonic K and π decays
  - -> mainly low momentum non-isolated muons,
  - sometimes detectable kink/not vertex associated
- hadronic shower leakage/punchthrough
  - -> mainly non-isolated muons,
  - often momentum/range inconsistency
- matching ambiguities
  - -> only nonisolated muons
  - match wrong central track to real muon hits/tracks
- cosmic ray muons through nominal vertex
  - -> mainly isolated muons,
  - sometimes mistaken for back-to-back muon pair

Standalone Muons

built from muon chamber information only.

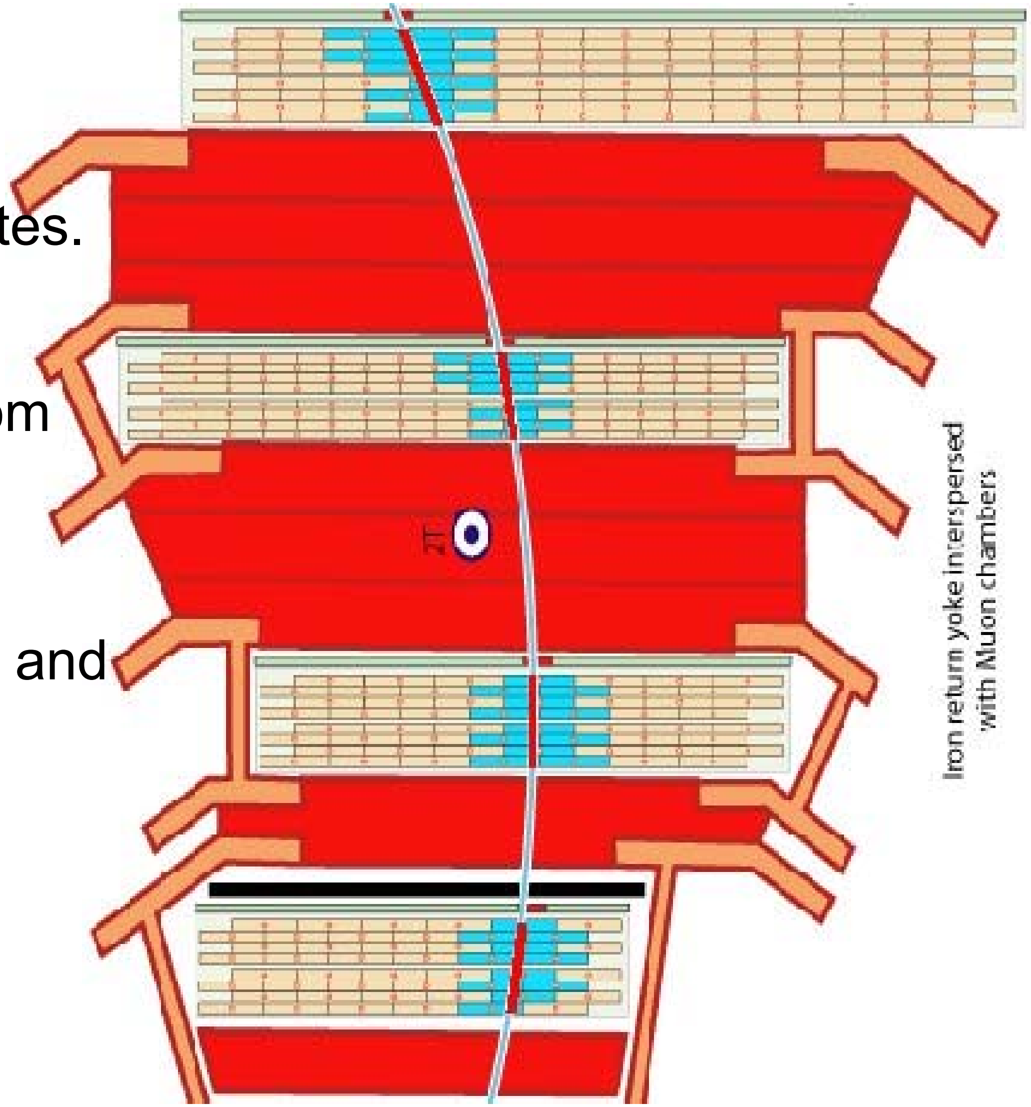
Seed:

Seeds are initial trajectory estimates. Formed by matching up pairs of local DT and CSC segments and estimating the momentum from the bending.

Fit:

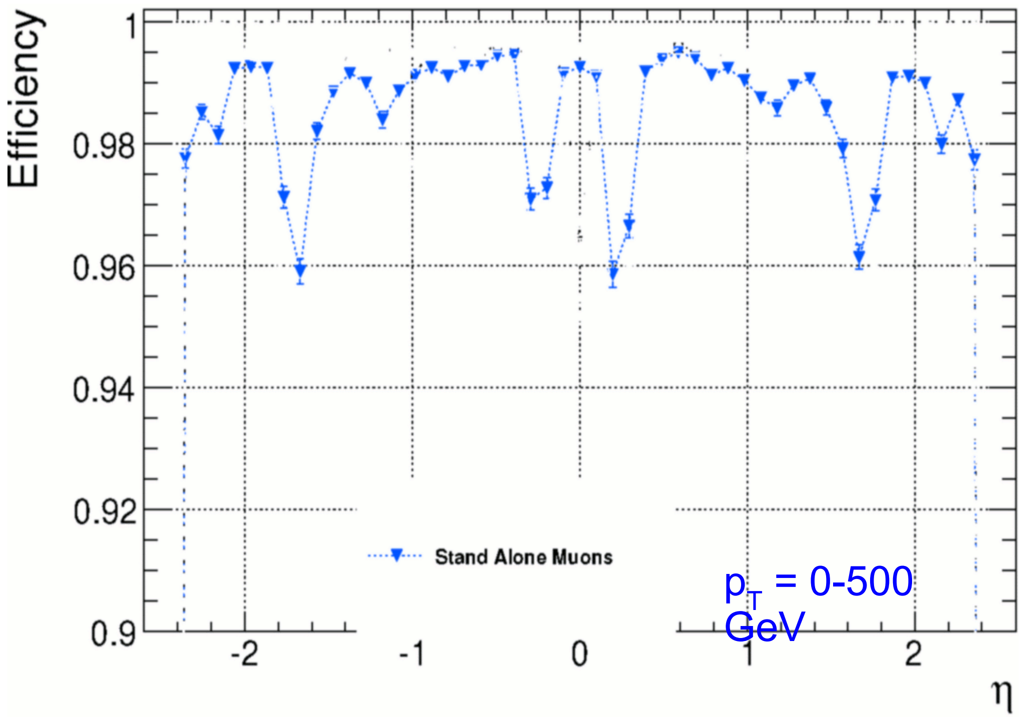
Pick up and fit CSC and RPC hits and DT segments along the trajectory using Kalman technique.

Additional Kalman smoothing is applied to equalize the fitted track errors.

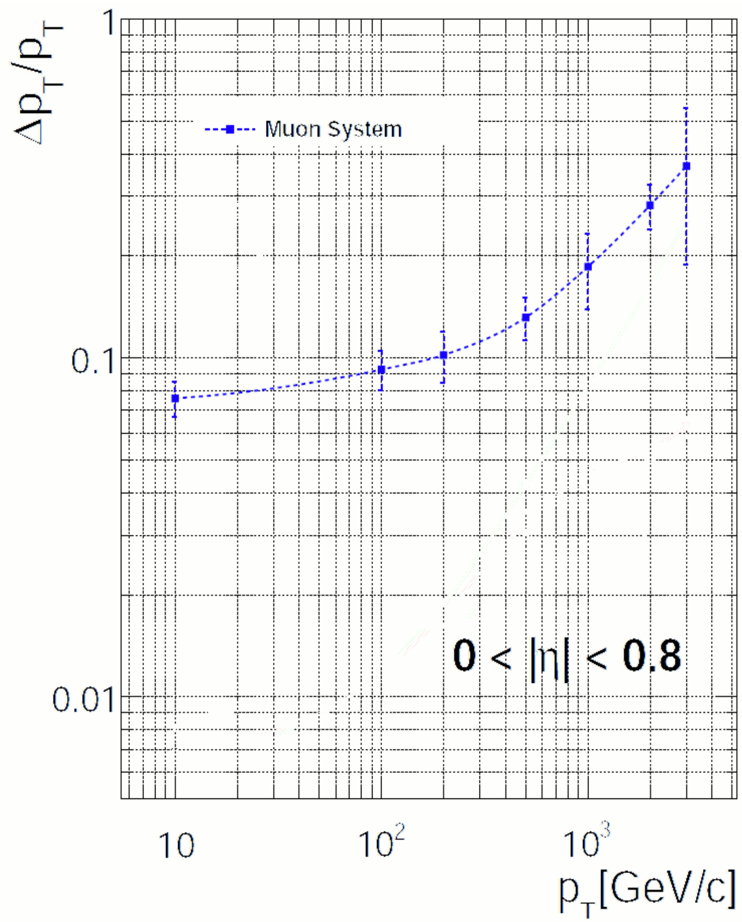


Standalone Muons

Single S/A-μ p_T resolution $\Delta p_T/p_T$

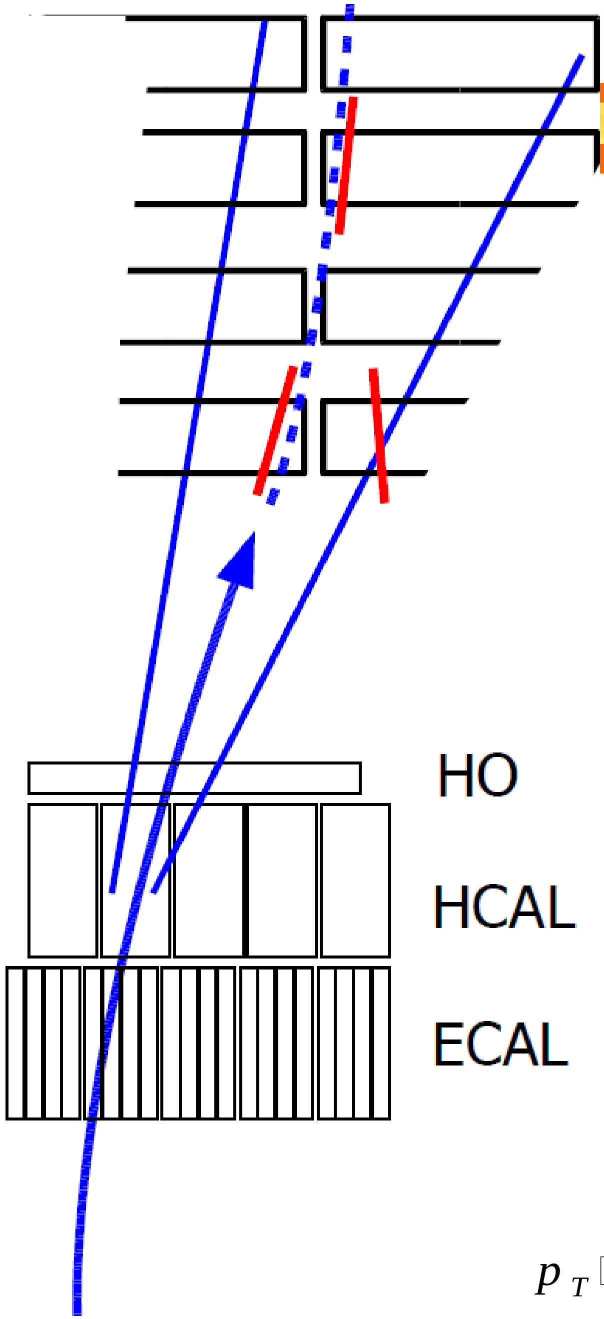


Single S/A-μ efficiency



High reconstruction efficiency at good resolution of about 10% for S/A Muons.

Tracker Muons



Inside-out approach, alternative to starting from the S/A muons, **combine muon signatures with tracks**:

Seed: use each reconstructed track as seed

Associate: pick up corresponding muon signatures:

- **energy in calorimeter cells** crossed by extrapolation (ECAL, HCAL, HO)
- **segments close to track extrapolation** directions relative to / distances to extrapolation
- **distances between extrapolations and chamber edges** → expected segments

(Pre-)Select:

By definition every track is a TrackerMuon
⇒ need simple pre-selection for collection.

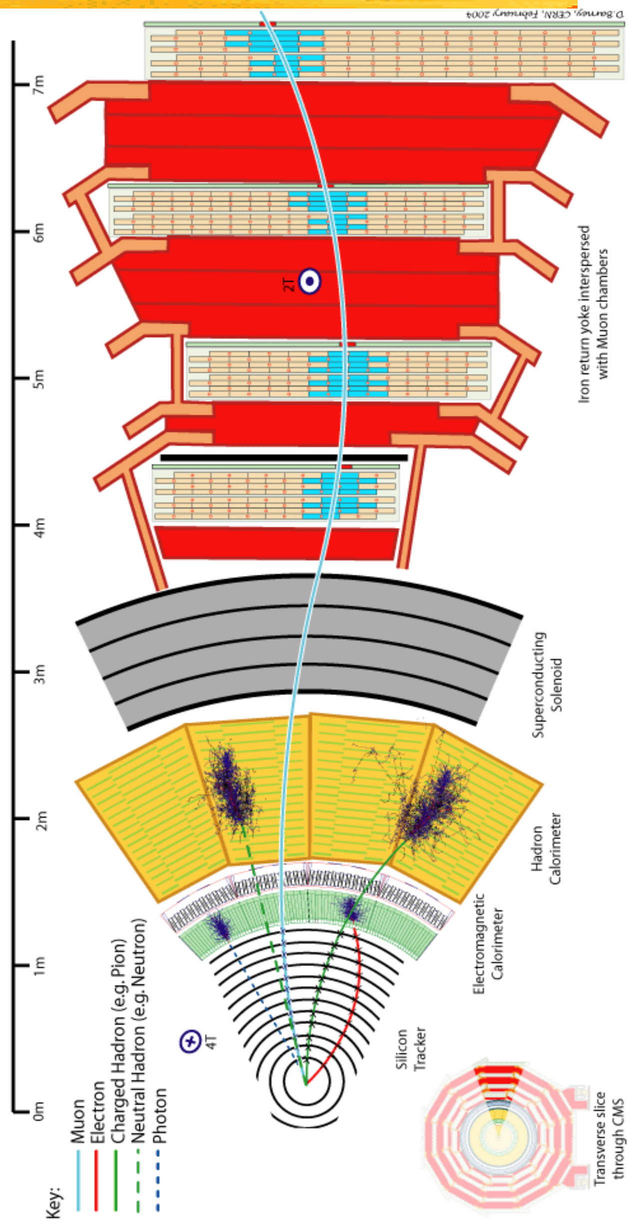
Current (spring 09) pre-selection:

$$p_T \square 1.5\,GeV \square p \square 3\,GeV \square nSeg \square 0 \square pullX_{seg} \square 4 \square distX_{seg} \square 3\,\mathrm{cm}$$

Global Muons

Outside-in approach:

Global Muons are a combination of standalone muons with silicon tracks



Standard procedure to find a Global Muon track:

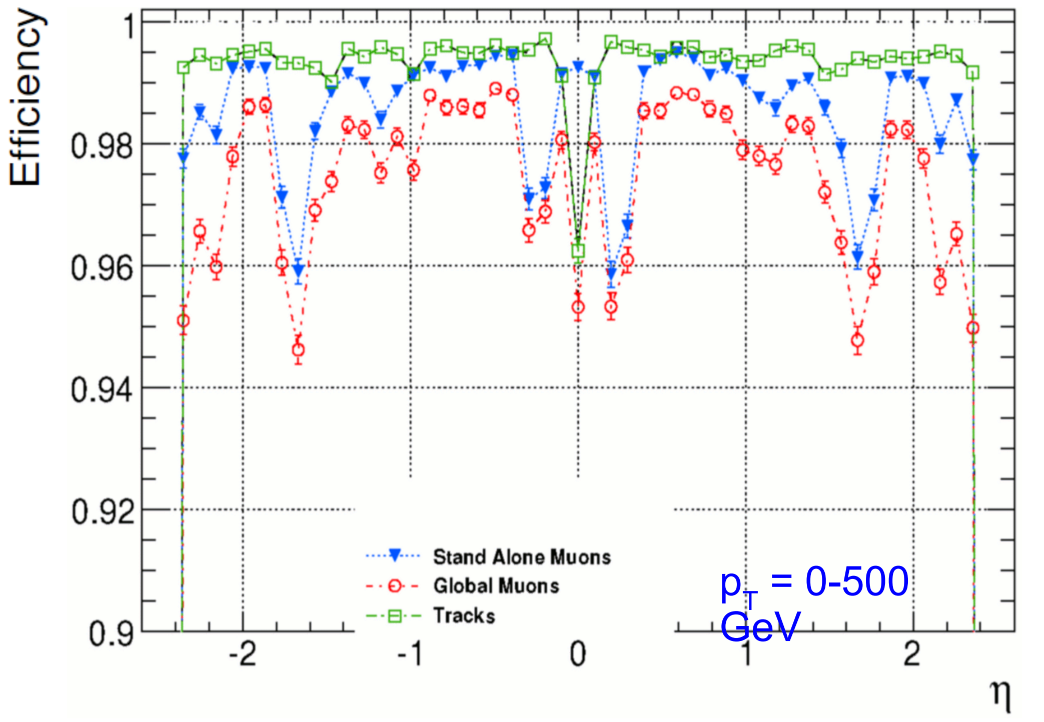
Seed: for each S/A-μ, find matching tracks.
(compare on common surface (χ^2))

(Re)fit: Perform Kalman fit using track candidate hits and hits from all layers that were crossed by the S/A-μ

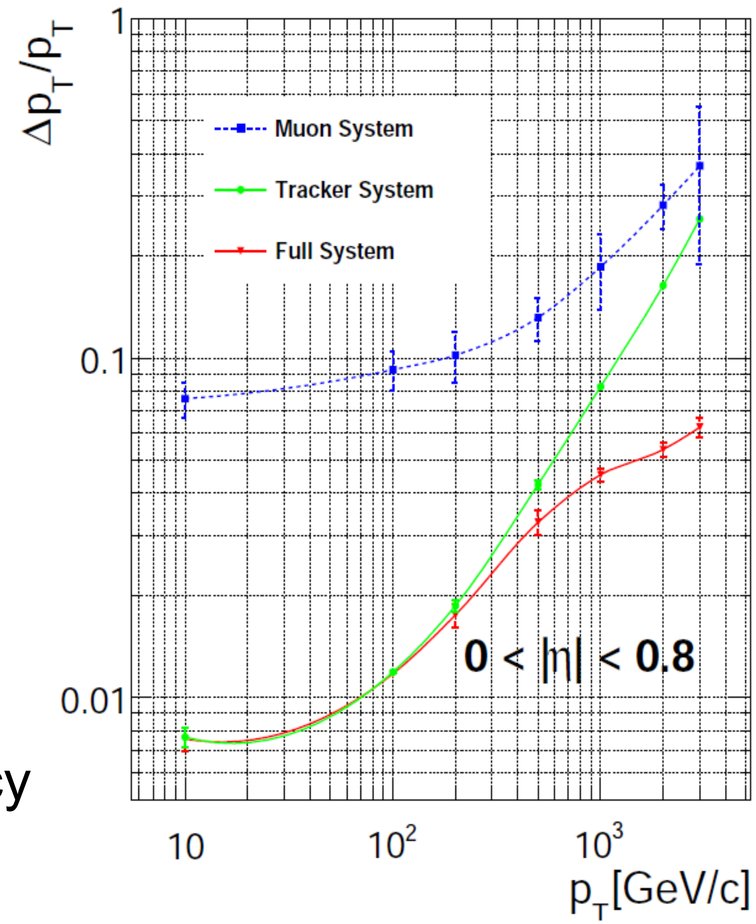
(Pre-)Select: select Global Muon candidate with best fit probability (default)

Global Muons

Single S/A, Si-Tracker and Global-μ p_T resolution $\Delta p_T/p_T$



Single S/A, Si-Tracker and Global-μ efficiency



High reconstruction efficiency at very good resolution of about 1% for Global Muons.

reco:Muon collection (“muons”)

Three different muon types are **merged in one common muon collection**:

Tracker Muons

Global Muons

S/A Muons

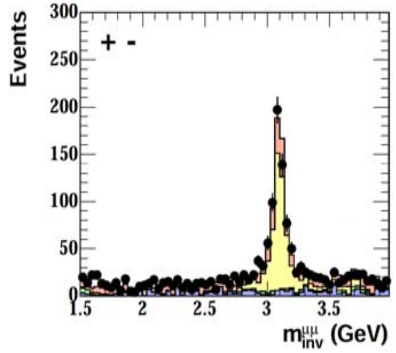
Handle double counting
loose pre-selection
select candidate information

One merged Muon Collection

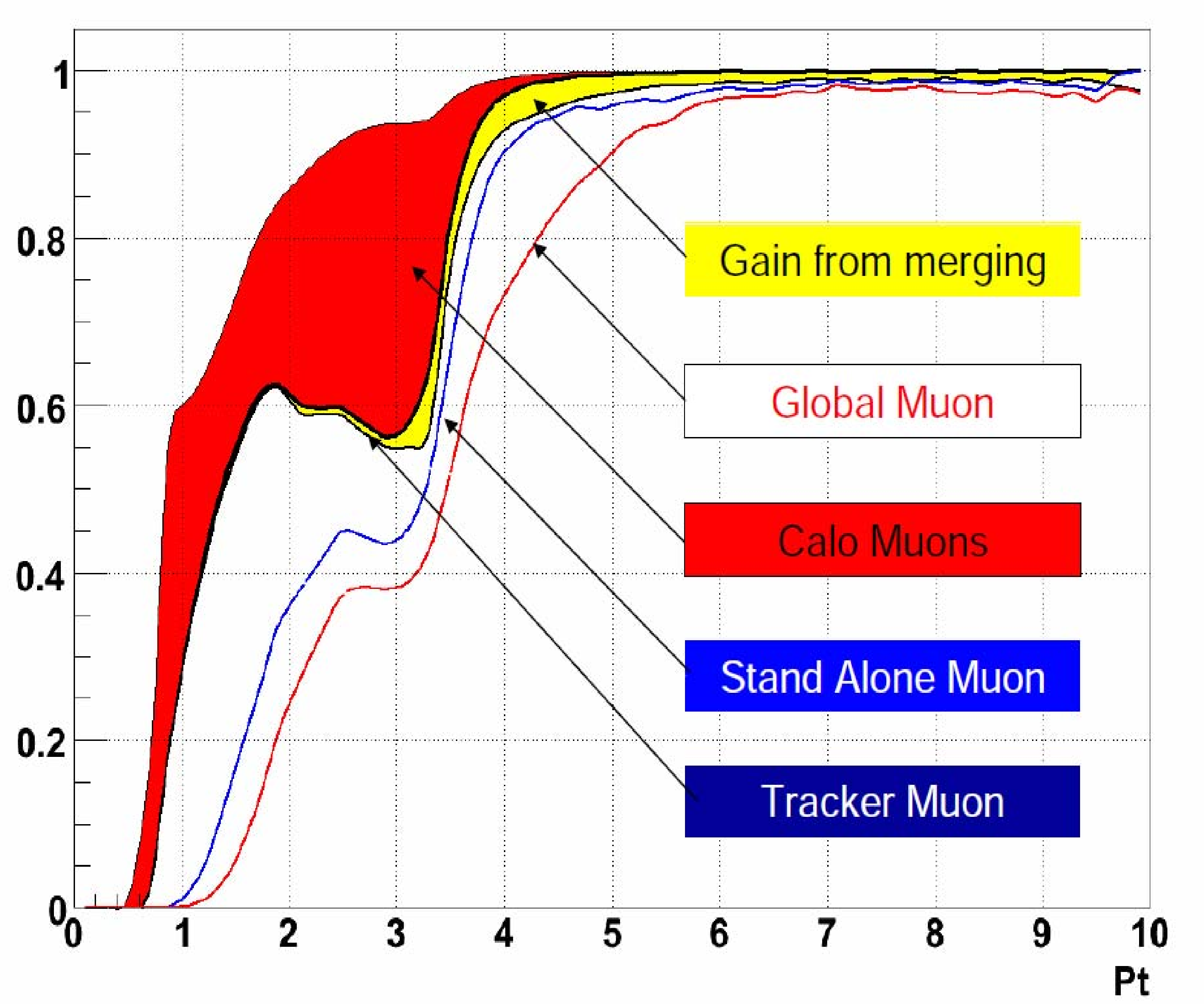
with Flag “Muon Type”

Selection Methods

μ



Signal efficiency - muon candidate collection



Benchmark plot:

Merging collections gains in efficiency, especially at low p_T.

These are the plain candidate collections. Further selection required to improve purity. Trigger also limits the selection efficiency

$\Rightarrow$ this plot gives an upper limit on the selection efficiency

CMSSW Muon object content

reco::Muon

Track block
references to *inner (Si)*, *outer (Mu)* and *global* tracks

Energy block
ECAL, HCAL, HO energy associated with muon

Segment Match block
Information on segment - track matching for muon id

Compatibility block
Track calo compatibility with muon hypothesis

Isolation block
Brief summary of muon isolation for two cones

Timing block
e.g. beta of muon assuming it came from the IP (DT only)

Muon Type
Bitmap of algorithms that made contribution

Muon collection ("muons") **contains 3 types of muons**:

- S/A muon
- global muon
- tracker muon

Special muon collections:

- Calorimeter based muons
- TeV optimized muons
- Cosmic muons

As pat::Muon inherits from reco::Muon complete info also available there.

Conclusions

- The CMS detector is very well suited for muon detection (a lot of redundancy)
- Global muons, using the information from (almost) all detectors, offer the best resolution and purity, with some loss of efficiency.
- Other options: Tracker muons (Calo muons), Standalone muons
  -> better efficiency, especially at low momentum, but higher background
- Quality cuts, Isolation cuts, Muon trigger … -> another time