

LPC JTERM III

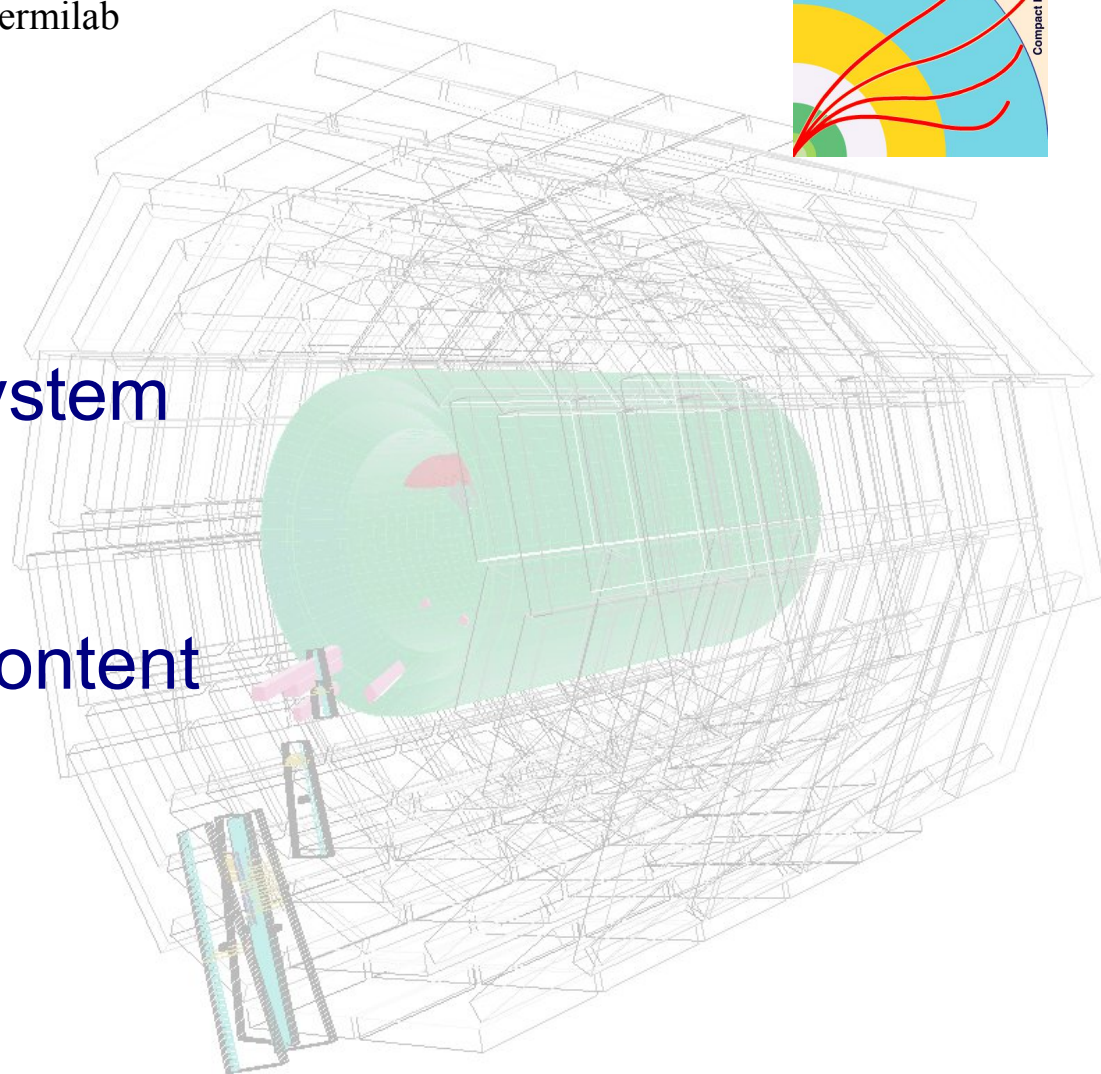
Muons



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Fermilab



- Introduction - Muon system
- Muon types
- Muon event format / content
- Isolation
- Summary



Introduction

Muon reconstruction goals:

Highest possible reconstruction efficiency with high resolution for all categories of muons:

- Low, medium and high p_T^μ (1-10/10-300/>300 GeV)
- Prompt and non-prompt
- isolated and non-isolated

Provide uniform coverage over full η - ϕ range of muon detectors

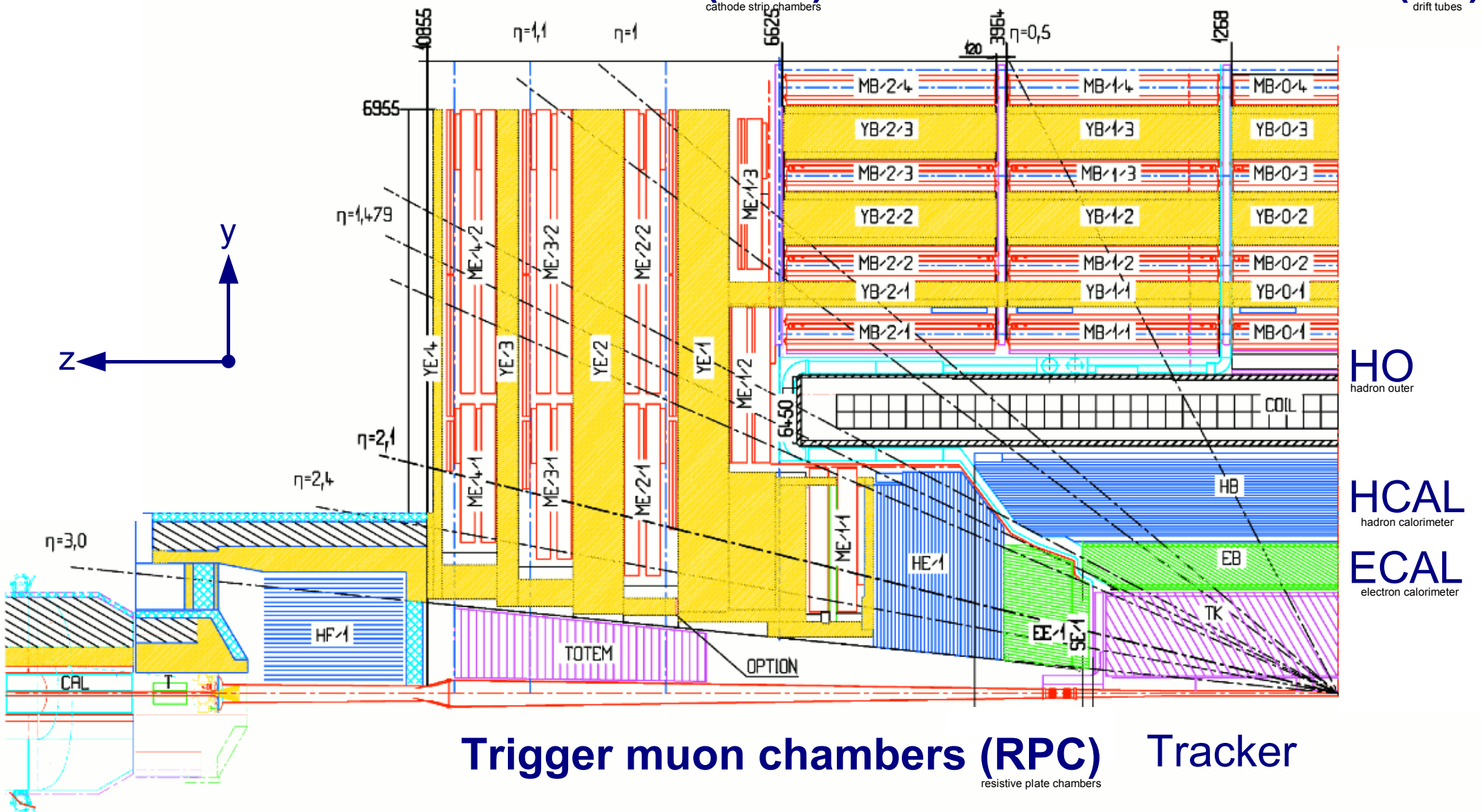
Take advantage of redundancy to increase purity of candidate samples.

(Use in HLT is not discussed here)

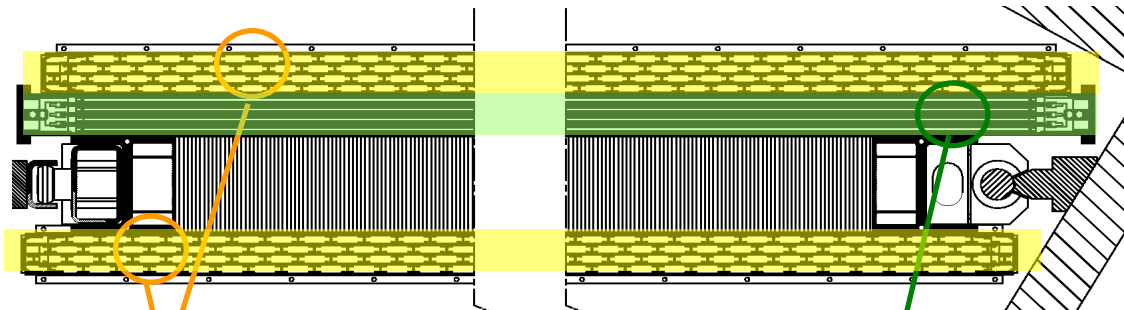
Muon coverage

Forward muon chambers (CSC)

Central muon chambers (DT)

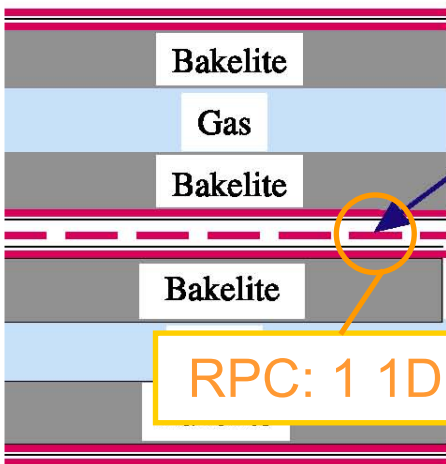
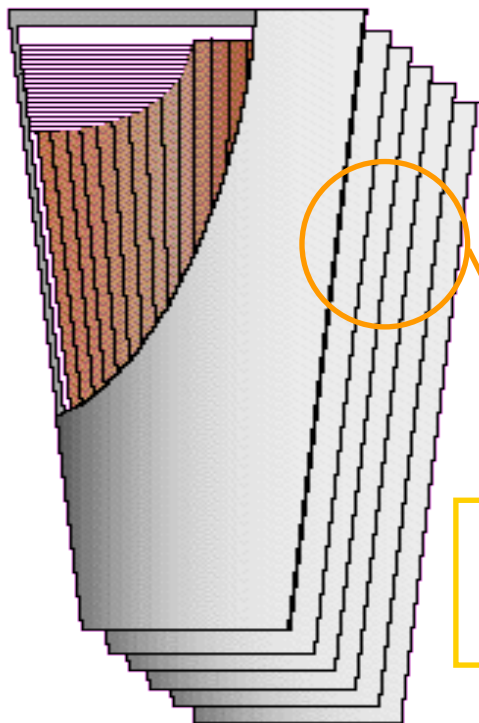


Muon systems



2 x 4 1D hits in ϕ (bending)

4 1D hits in θ (non-bending)



RPC: 1 1D hit in ϕ

CSC: 6 2D hits in $r-\phi$ (more precise in ϕ)

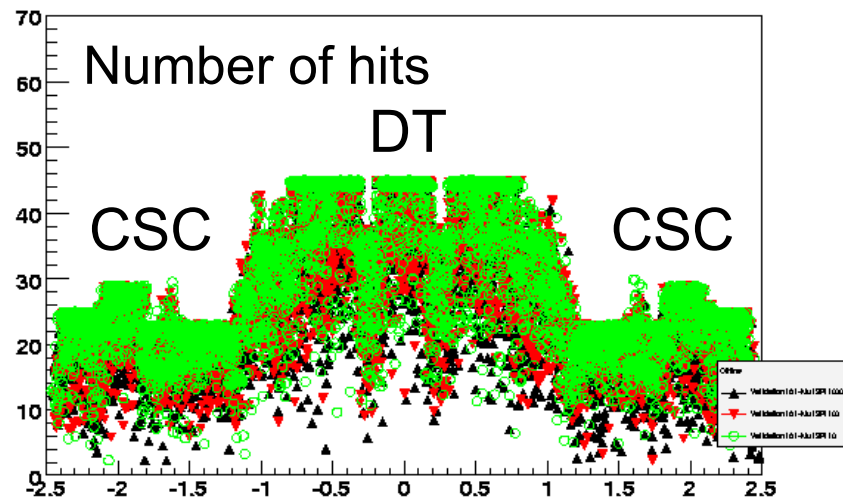
Along a muon track:

4 **DT** stations w/ 12 hits
= **48 1D hits**

4 **CSC** stations w/ 6 hits
= **24 2D hits**

4 or 6 **RPC** stations w/ 1 hit
= **4 or 6 1D hits**
(ignoring overlaps)

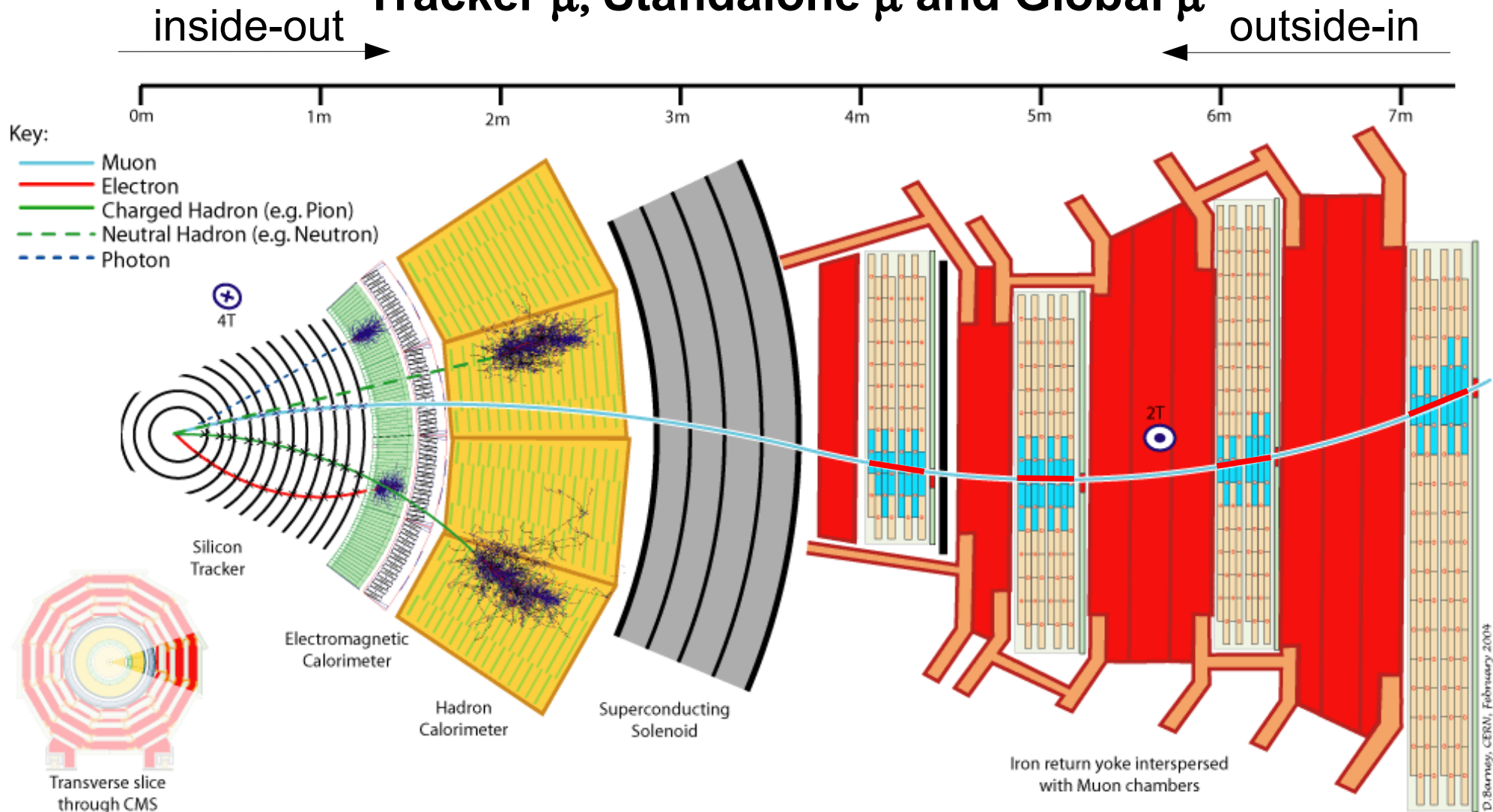
Sta η vs NHits



3 Muon types in CMSSW

Two independent approaches for muon reconstruction leading to three different types of muon candidates:

Tracker μ , Standalone μ and Global μ



Standalone Muons

Standalone muons are built from muon chamber information only.

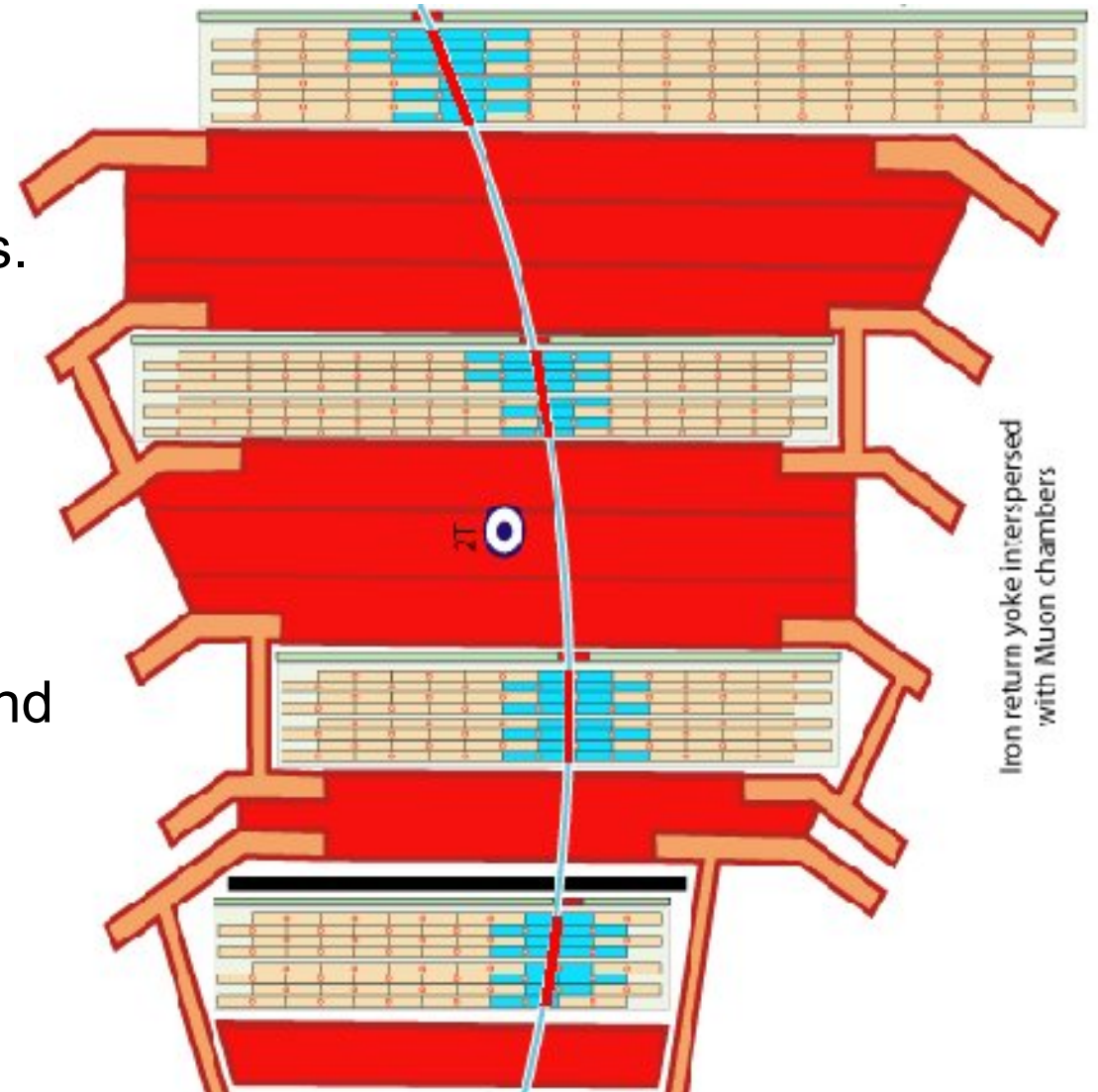
Seed:

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

Fit:

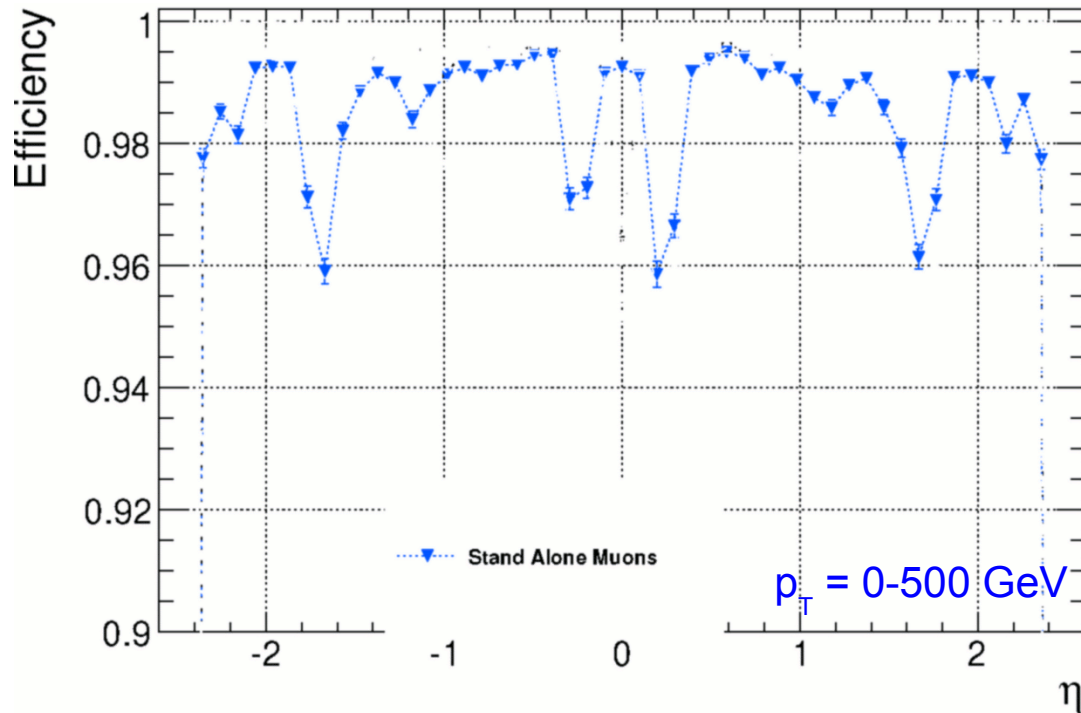
Pick up and fit CSC and RPC hits and DT segments along the trajectory using Kalman technique.

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

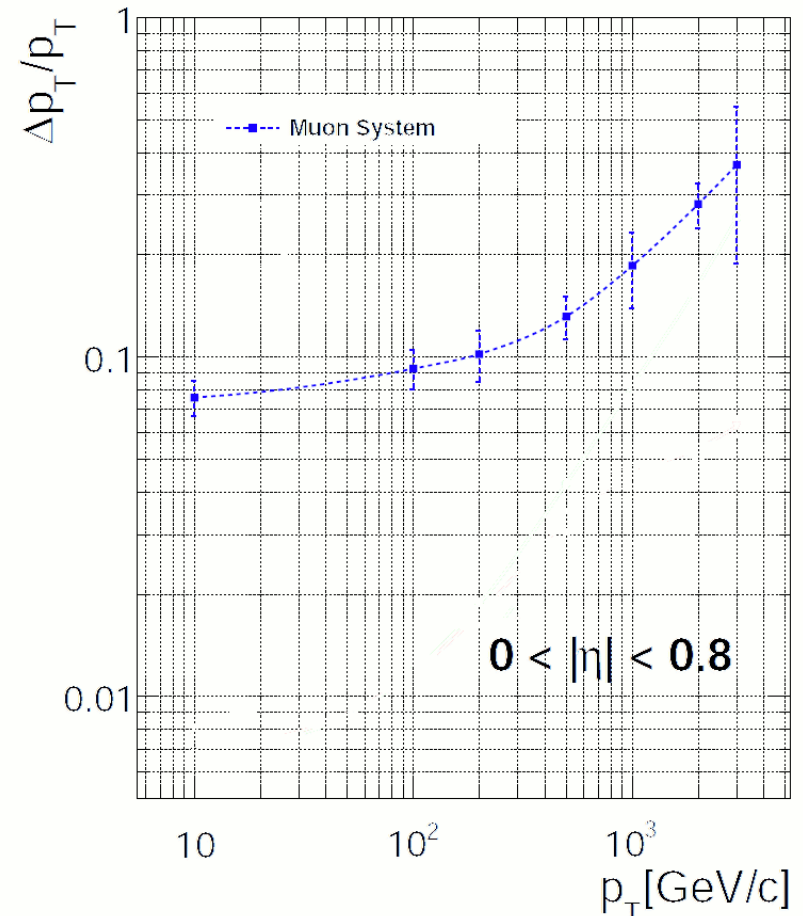


Standalone Muons

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.

Global Muons

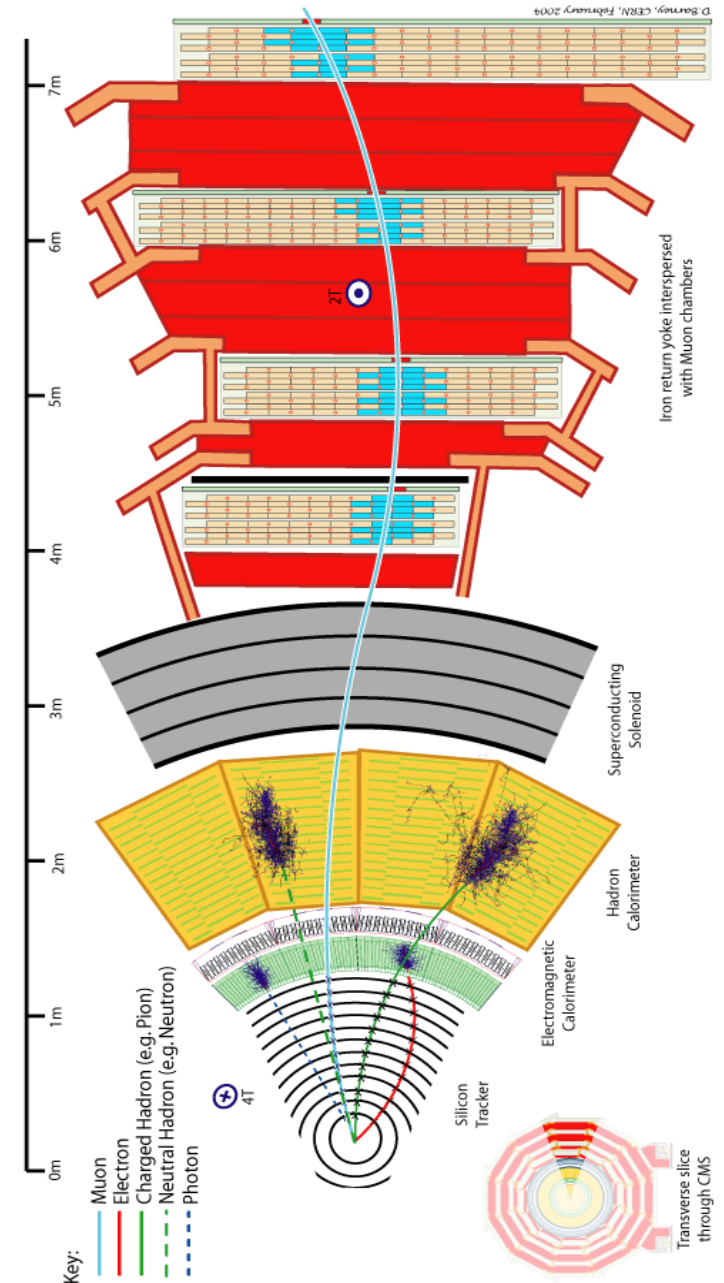
Outside-in approach:
Global Muons are a combination
of standalone muons with
silicon tracks

Standard procedure to find a Global Muon track:

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

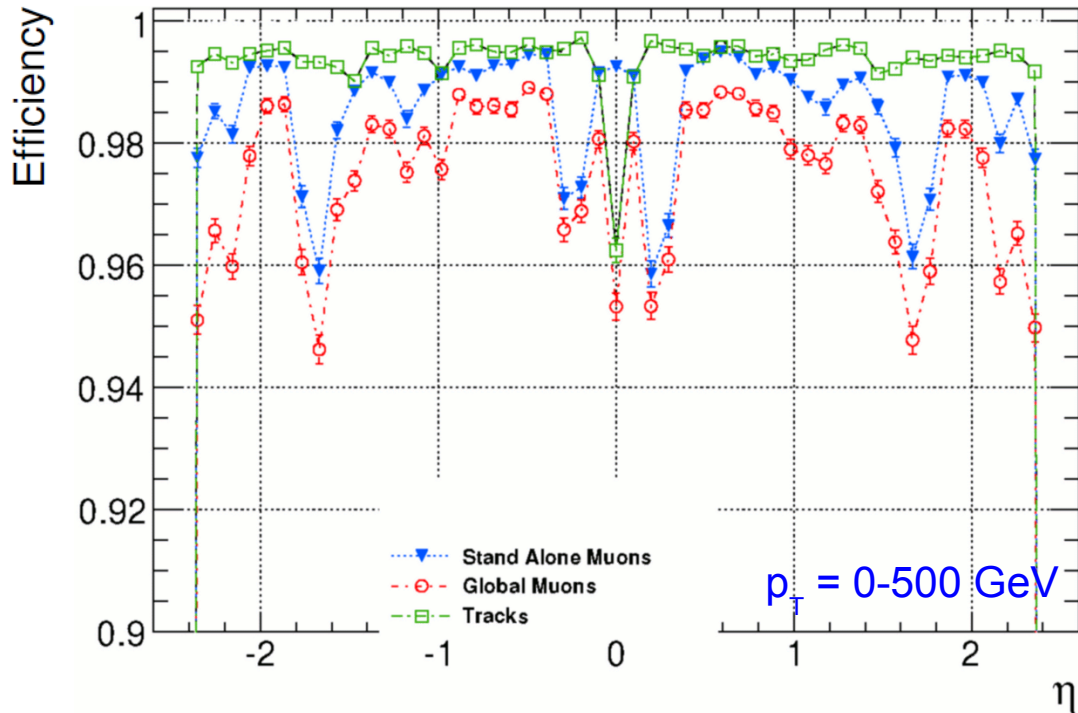
(Re)fit: Perform Kalman fit using track
candidate hits and hits from all
layers that were crossed by the S/A- μ

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

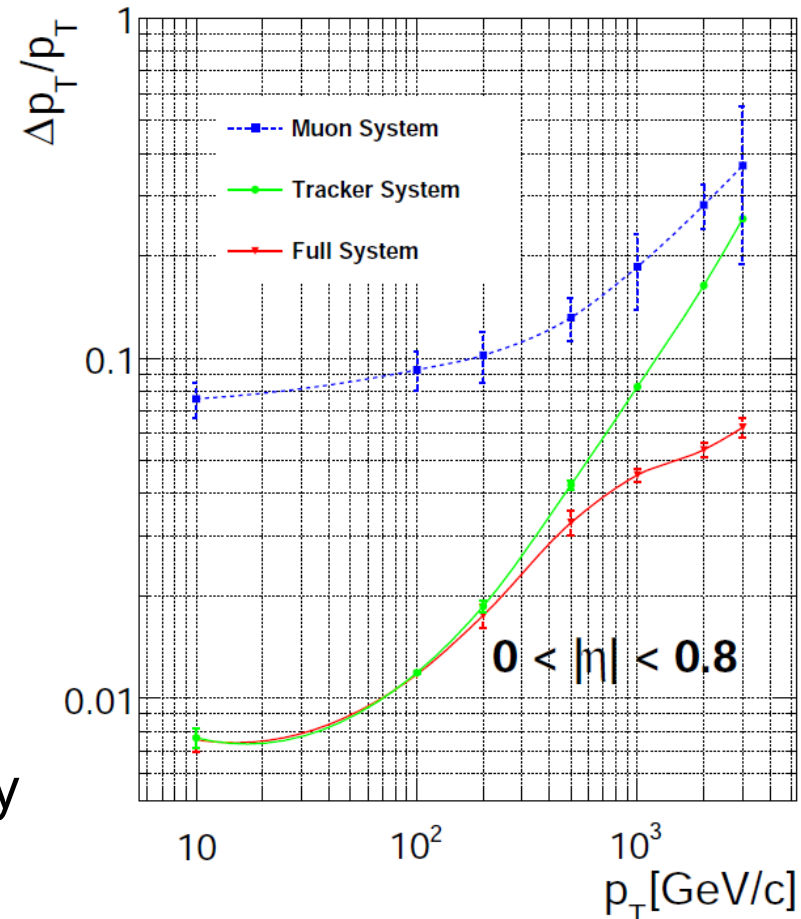


Global Muons

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

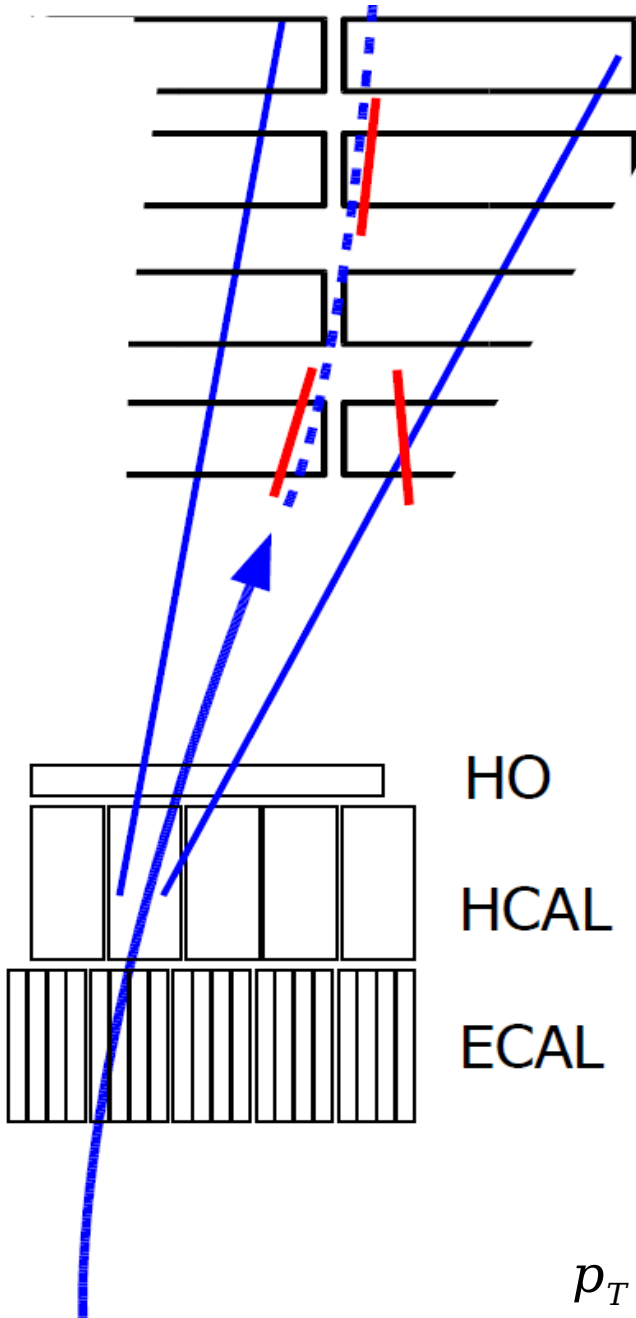


Single S/A, Si-Tracker and Global- μ efficiency



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

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 pre-selection:

$$p_T > 1.5 \text{ GeV} \wedge p > 3 \text{ GeV} \wedge nSeg > 0 \wedge pullX_{seg} < 4 \wedge distX_{seg} < 3 \text{ cm}$$

Muon - Selections

Full list of muons is optimized for maximum efficiency.
Most analyses will need **selections to require a given muon quality** on top of full set of muons.

Different **selections are made available in reco::Muon**.

The **global muon selection, GlobalMuonPromptTight**, is simple:

- Global fit normalized- $\chi^2 < 10$

additionally recommended are:

- Si track $|d_0| < 2$ mm
- Si track Nhits ≥ 11

In the following will describe the Tracker Muon selections.

For complete set of available selections see this [twiki](#).

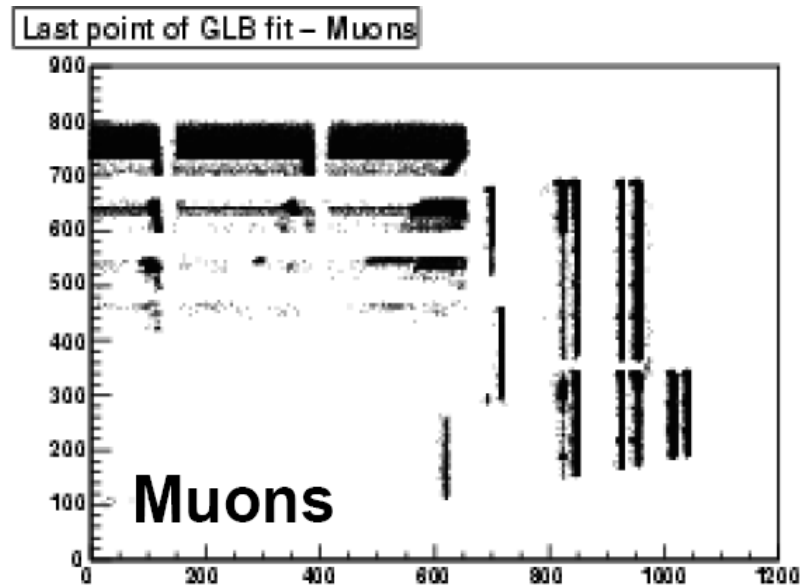
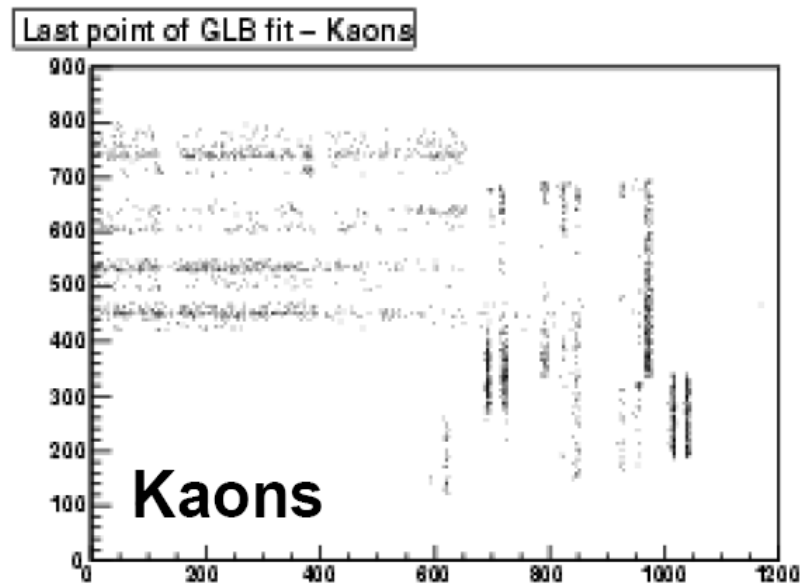
Tracker Muons - Selections

Currently providing two selection types for tracker muons:

- 1) **Cut based**, using segment information
- 2) **Compatibility based**, using segment & calorimeter information

1) **Cut based** approach:

- cut on **# of matched segments**
- cut on **match quality of last matched segment**
thus putting **full weight on last expected station**
or cut on best matched segment



Tracker Muons - Selections

1) **Cut based** approach - Currently available options are:

TMLastStationLoose

$$nSeg > 1 \wedge |x^\mu - x^{track}|_{outermost\ station} < Max(3\sigma, 3cm)$$

TMLastStationTight

$$\text{Loose} \wedge |y^\mu - y^{track}|_{outermost\ station} < Max(3\sigma, 3cm)$$

TMOneStationLoose

Same as LastStation but using the best matching

TMOneStationTight

segment for selection cuts

Optimized combined use of above two cut based approaches:

TMLastStationOptimizedLowPt[Loose | Tight]:

TMOneStation[Loose | Tight] for $|\eta| < 1.2$ and $p_T < 8$ GeV

TMLastStation[Loose | Tight] at higher η and/or higher p_T

Tracker Muons - Selections

2) **Compatibility based**, using segment & calorimeter information

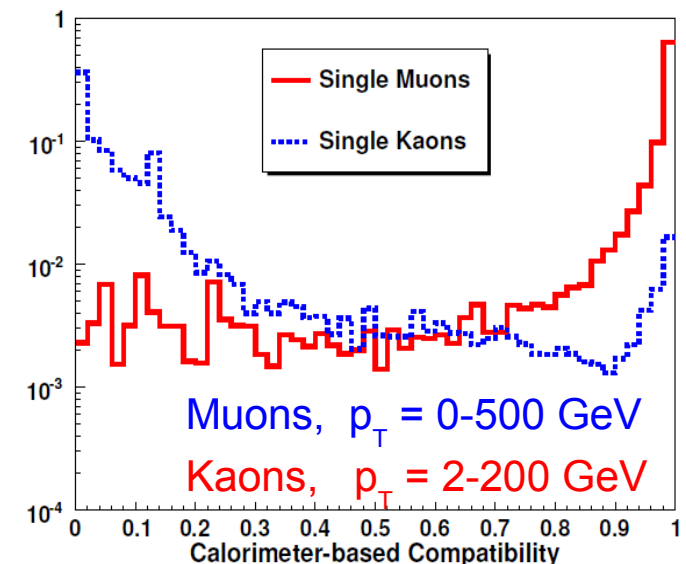
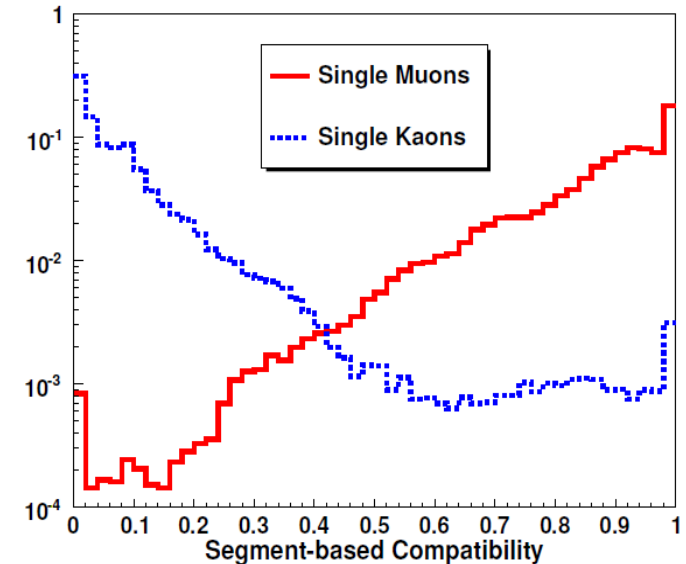
Segment Compatibility - quantify how well associated segments match expectation for a real muon

- which expected muon stations contain segments (lower weight to inner, more to outer stations)
- weight reduction for poor matches
- less weight reduction if extrapolation is close to chamber boundary

Calorimeter Compatibility:

- 3D calorimeter energy likelihood ratio for muons (signal) vs. hadrons (background)

Resulting Compatibility distributions for single muons and kaons:



Tracker Muons - Selections

Use **2D cut** to **select muons** and suppress hadrons:

$$0.8 \cdot Calo + 1.2 \cdot Seg > 1.0 \quad \text{TM2DCompatibilityTight}$$

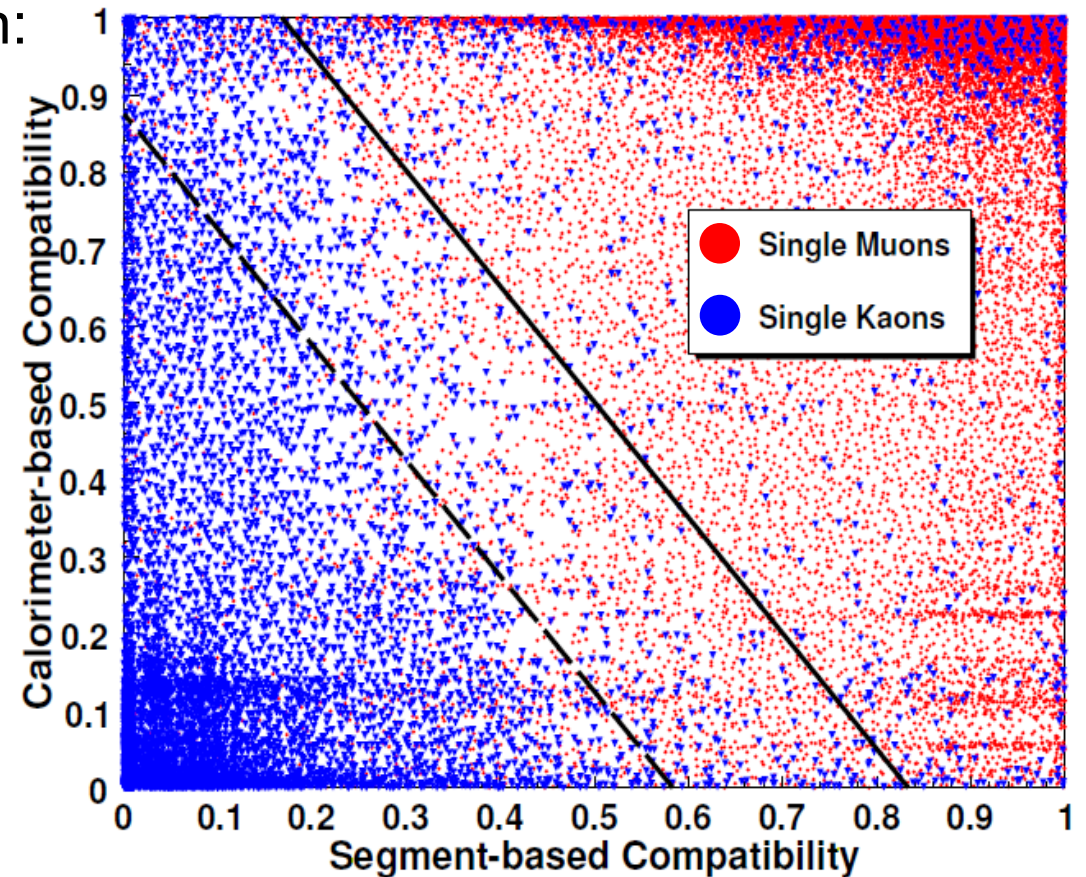
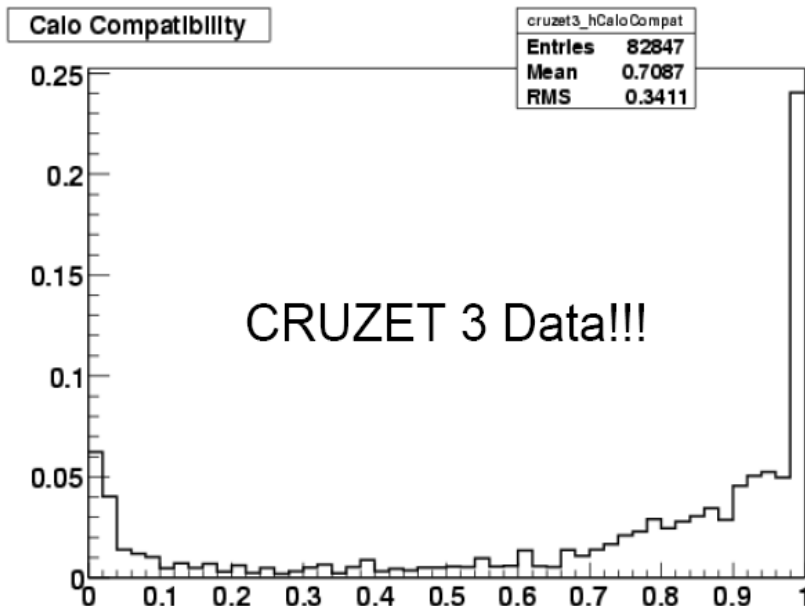
$$0.8 \cdot Calo + 1.2 \cdot Seg > 0.7 \quad \text{TM2DCompatibilityLoose}$$

Muons, $p_T = 0-500$ GeV

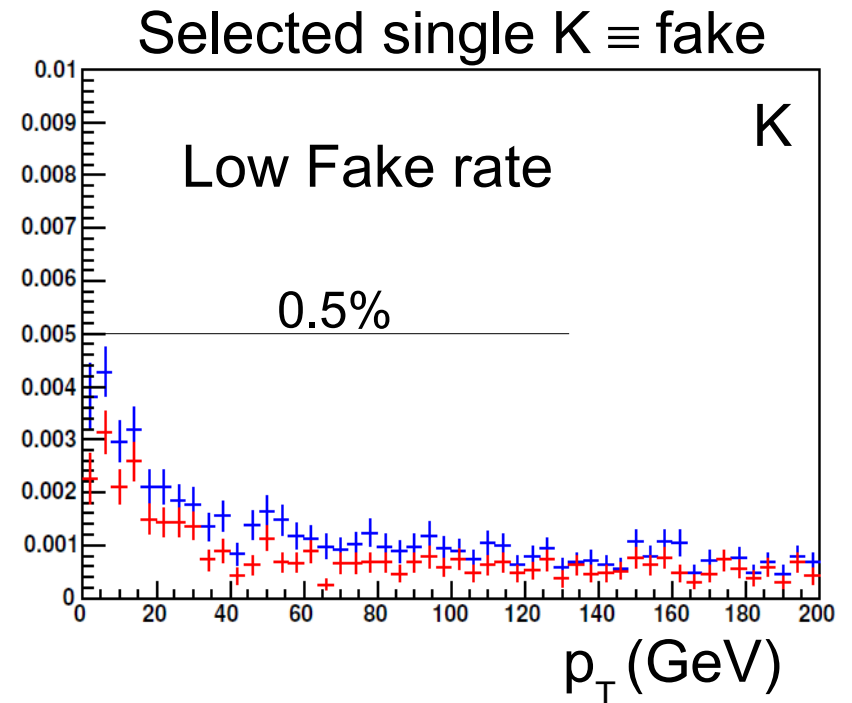
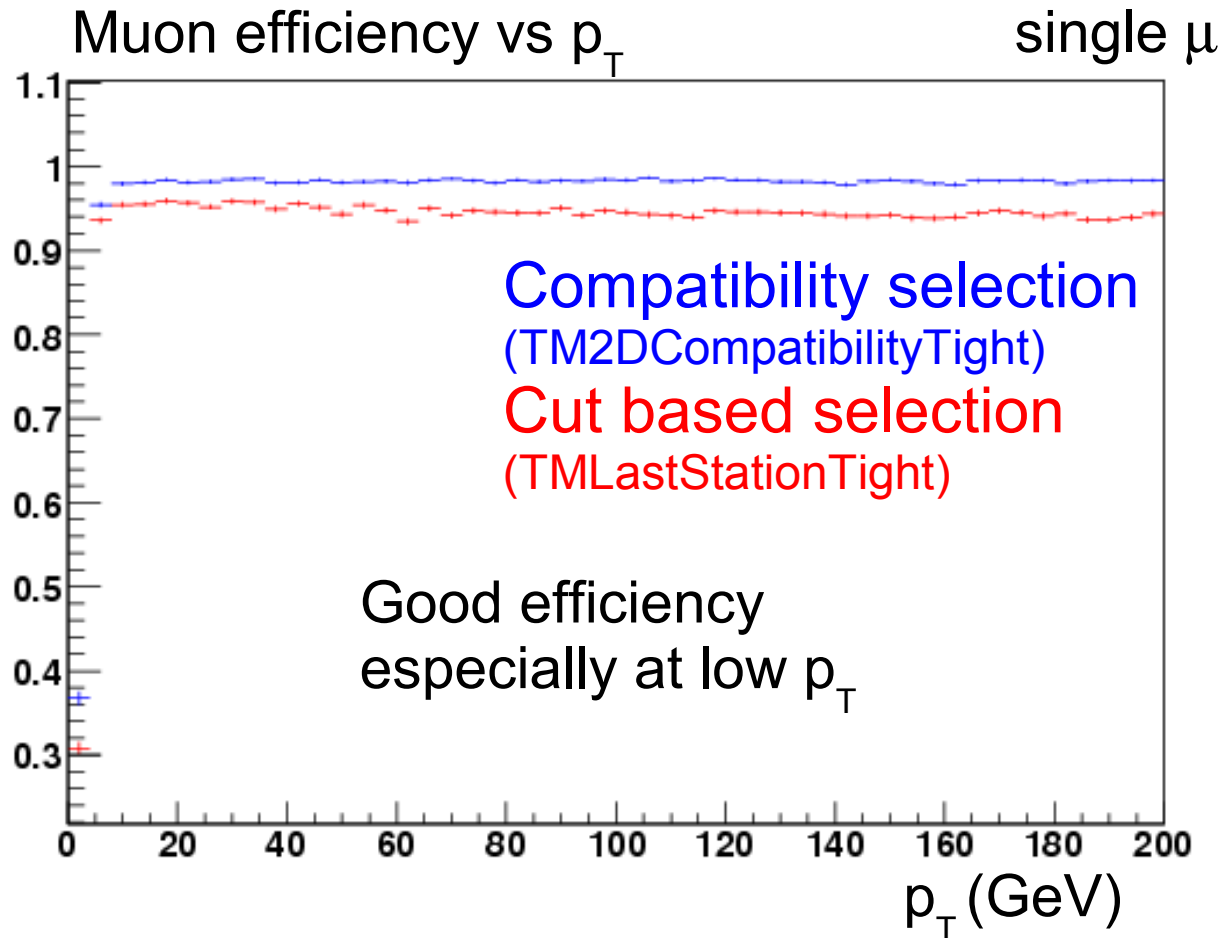
Kaons, $p_T = 2-200$ GeV

Gives good muon hadron separation:

MuonID also works in the real world:



Tracker Muons - Selection performance

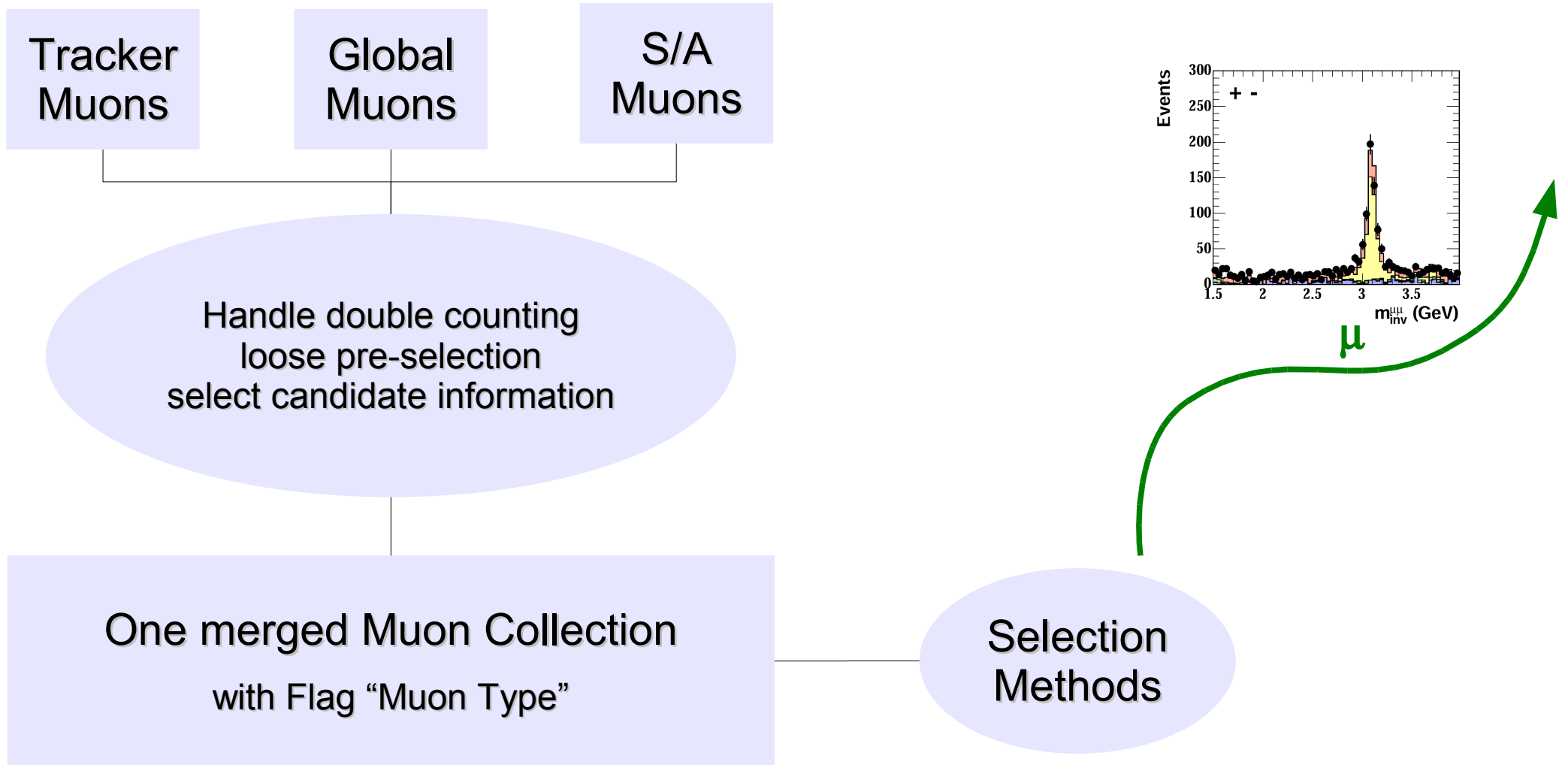


Compatibility selection is slightly more efficient than **Cut based selection** with slightly higher fake rate.

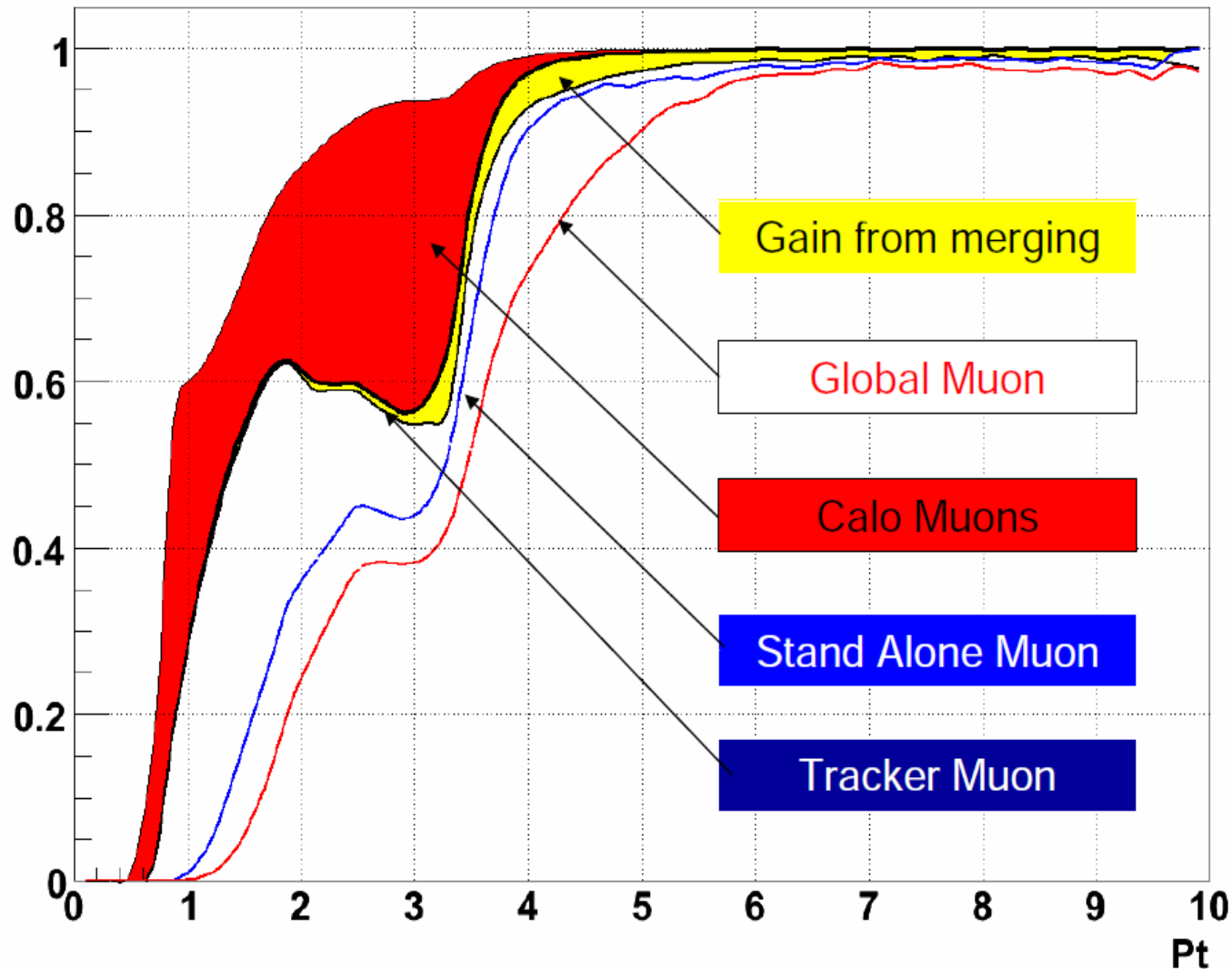
(fakes here include “real muons” from decays in flight)

reco:Muon collection (“muons”)

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



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

⇒ 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.

Muon Isolation

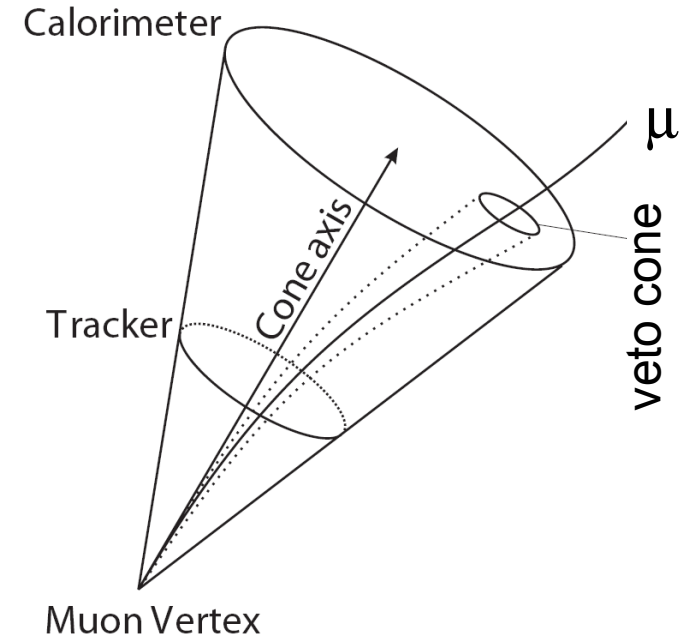
Isolation Muon Object quantities

in cone around muon (excluding the muon), e.g.:

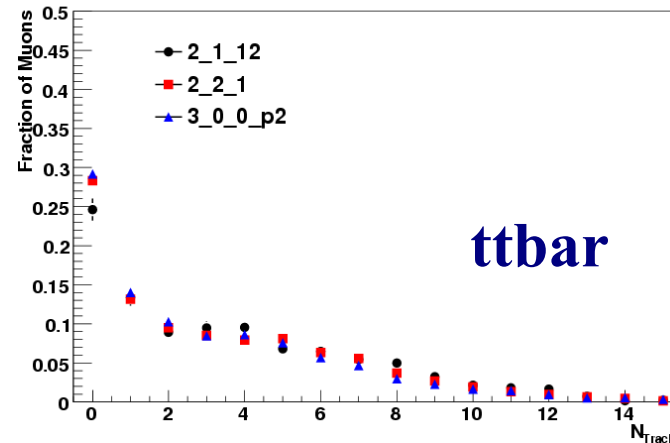
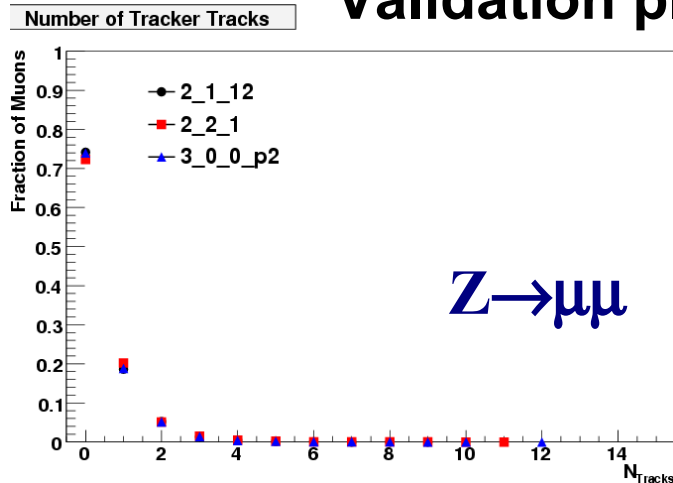
- summed track p_T
- number of tracks
- summed Ecal- / Hcal- / HO- E_T
- *New:* energy in veto cone (from 300pre3 onwards)

in cones with $\Delta R < 0.3$ and $\Delta R < 0.5$

Other cone radii etc. available in the muon isolation deposit collections.
Find further information on the [Muon Isolation twiki](#)



Validation plots for $\Delta R < 0.3$ cones:



Summary

- 3 different muon types available in one common format and collection
- Standard selectors efficiently select muons with good purity
- Extracted muon associated information allows further selection optimization
- Additional muon collections for special cases
- Snapshot of current status available in recent notes:
 - [Muon Reco note \(AN-2008-97\)](#)
 - [Muon ID note \(AN-2008-098\)](#)
- More info → discussion