Muon Identification software upgrade

Marco Santimaria

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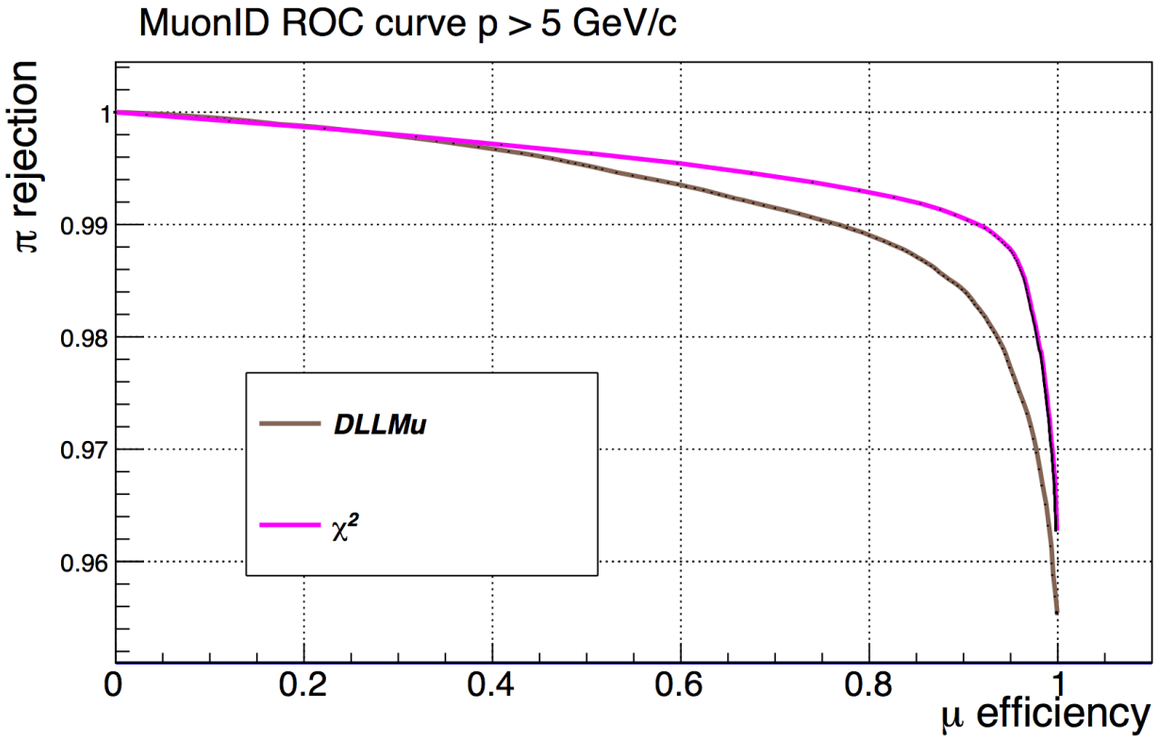
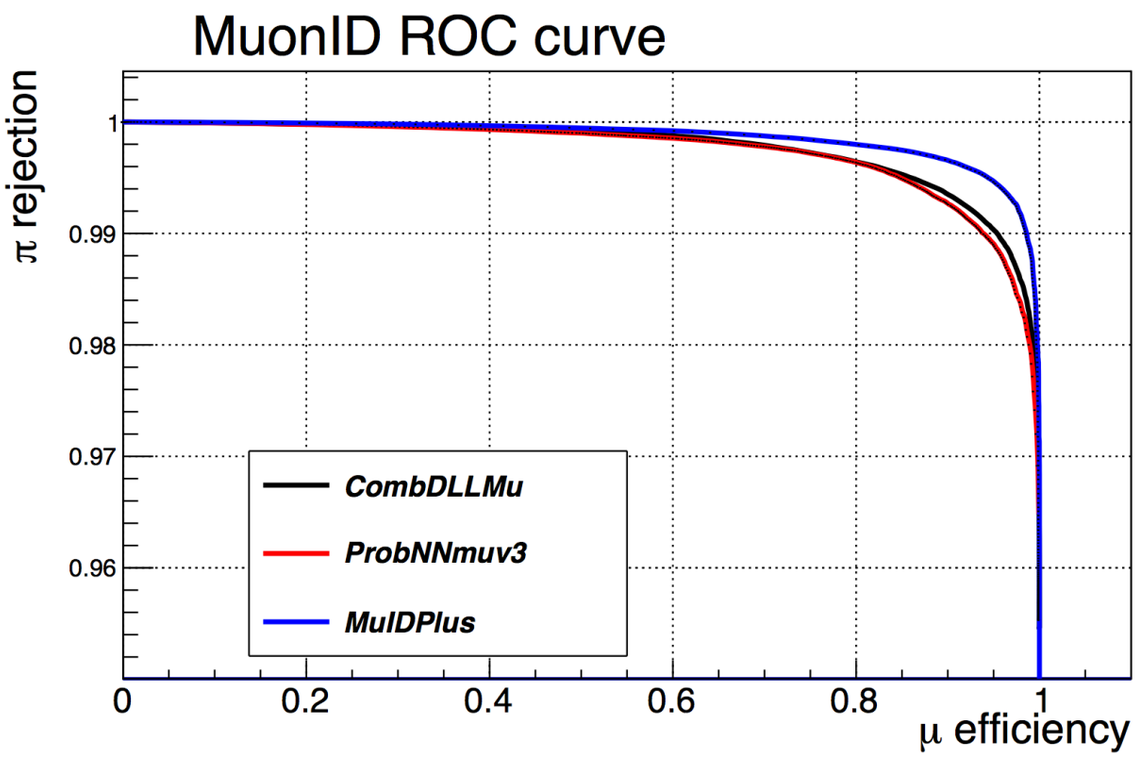
The Muon Identification @ $2x10^{33}$ $cm^{-2}s^{-1}$

A factor of **~2 more background** is expected with isMuon at upgrade conditions.

What we developed to increase background rejection:

- **BDT:** to exploit full muon detector informations and correlations (space residuals, multiple scattering contributions, times, shared hits…)
- **best $\chi 2$:** accounts for correlations induced by multiple scattering
- **MuonIDPlus:** developed by Giacomo Graziani to reduce backgrounds in KsMuMu. Larger search window + BDT combining best $\chi 2$, Isolation, match variables, cluster size, hit time





Building a new muID

muIDPlusAlg is available under Muon/MuonID and can be used in reconstruction
but computation time needs to be reduced:

- MuonIDAlgLite ~ **1ms/ev** (current muID: isMuon + muDLL)
- MuonIDPlusAlg ~ **120 ms/ev**

TOWARDS A NEW muID ALGORITHM

All these “offline” studies show encouraging results and we are now updating the muID reconstruction code.

1) Five new words have been added into the muonPID event model (Ricardo Vazquez Gomez)

- muonChi2Corr, muonMVA1, muonMVA2, muonMVA3, muonMVA4

with the aim of filling them with best $\chi 2$, BDT, MuonIDPlus and possible future developments

-> best $\chi 2$ already filled, can be added to ProbNN
-> New Packer has been developed for the MVA variables (Chris Jones)

2) MuonIDAlgLite **porting to GaudiFunctional** framework -> merge request (Nikita Kazeev + Roel Aaij)

3) A **bug has been fixed** in the computation of NShared and merged into `master` (Nikita Kazeev)

4) $\chi 2$ tool has been rewritten (Marco Santimaria + Manuel Schiller) -> see next slide

The new $\chi 2$ tool

- MuonIDAlgLite + $\chi 2$ tool ~ **1.5 ms/ev**

Profiting from a fruitful hackathon week and the valuable and kind help of Manuel Schiller, the **$\chi 2$ tool underwent a major rewrite:**

1. Some “cosmetic” changes: `++i` vs `i++`, const correctness, **modularity** (-> easier to debug)
2. **“Basic” loops speed-up**: repeated identical calculations carried out, replaced pow(x,2) with x*x etc…
3. wrote a “MultiIndex” class to evaluate hit combinations faster
4. **calcChi2 method: Cholesky decomposition to perform matrix inversion** (=LL^T, with L=Lower triangular matrix) **-> this decreases the computation time by a factor 2**
5. **Thread safety and vectorisation**

Result:

The new tool produces the same $\chi 2$ with no impact on the timing performance
-> MuonIDLite + New $\chi 2$ tool ~ 1 ms/ev

The new tool is ready and has been implemented along with the event model changes.

Conclusions & Plans

- ☑ PID event model modified to include recent and future developments
- ☑ muID algorithm is being ported to GaudiFunctional
- ☑ Fast Chi2 tool ready

- ☐ Write a **tool for the BDT**
- ☐ Write tools for each variable entering the **muIDPlus** with almost negligible **impact on the timing**
  -> now working on **cluster size**, which has large impact on the CPU time (~18 ms)
- ☐ Performance evaluation of the new algorithms with Run2 data

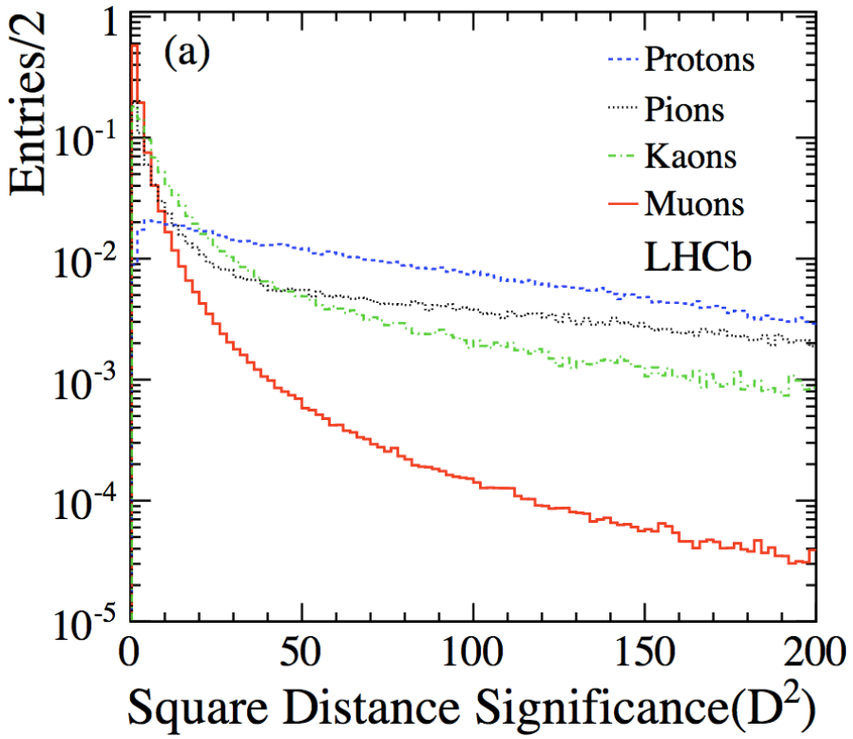
backup slides

The Muon Identification - basics

The current **muID** algorithm is a two-step procedure:

1) isMuon: Hits in a search window (FOI) around track extrapolation are searched in each muon station -> a coincidence of stations is required as a function of momentum.
(isMuonTight requires both X and Y view)

Momentum range	Muon stations
$3\ \text{GeV}/c < p < 6\ \text{GeV}/c$	M2 and M3
$6\ \text{GeV}/c < p < 10\ \text{GeV}/c$	M2 and M3 and (M4 or M5)
$p > 10\ \text{GeV}/c$	M2 and M3 and M4 and M5

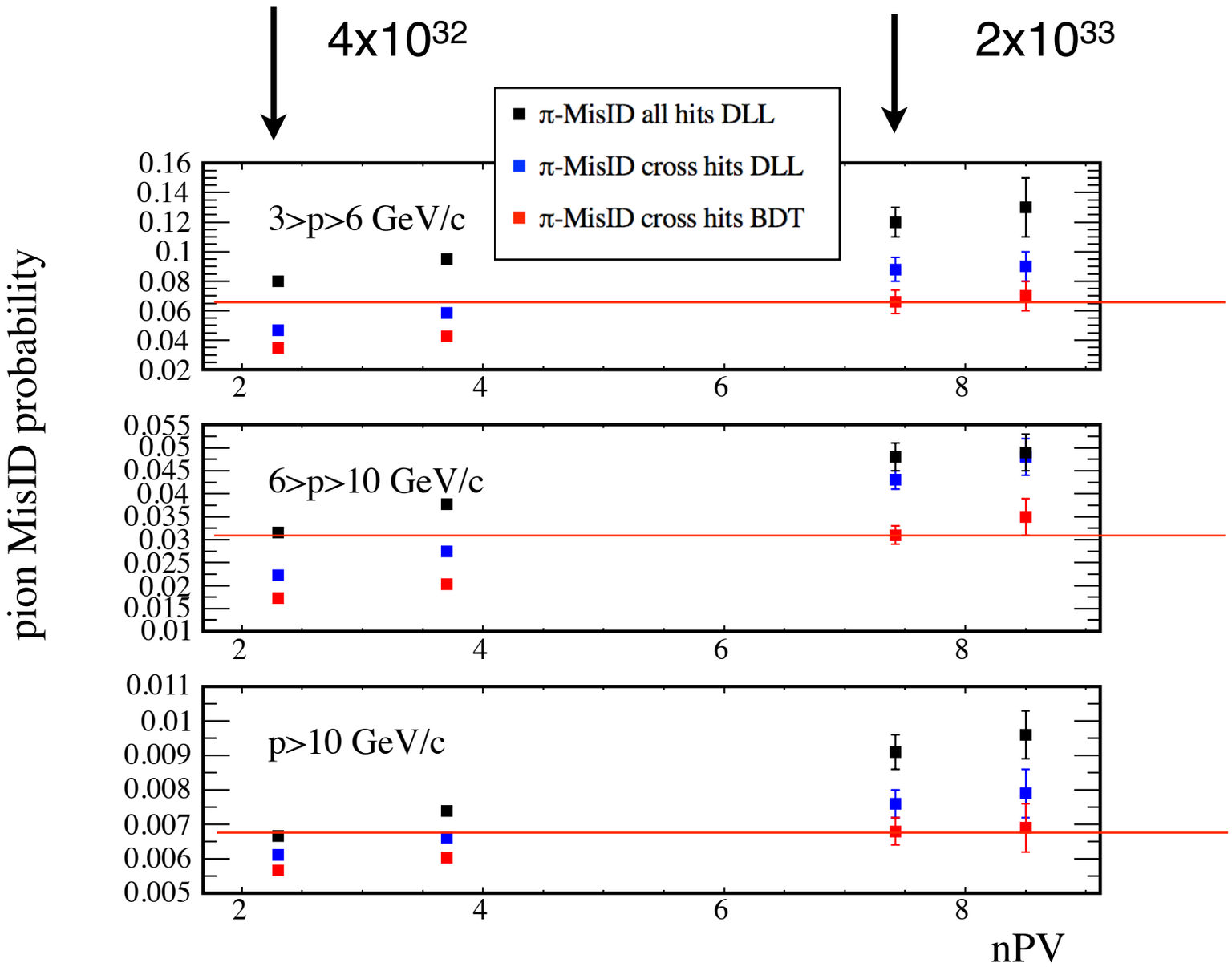


2) Muon likelihood (muDLL): based on average squared distance (D^2) of muon hits to the track extrapolation points

$$D^2 = \frac{1}{N}\sum_i \left\{ \left(\frac{x^i_{closest} - x^i_{track}}{pad^i_x} \right)^2 + \left(\frac{y^i_{closest} - y^i_{track}}{pad^i_y} \right)^2 \right\}$$

- muDLL is then combined with other subdetector informations (**combDLL**, **ProbNN**)

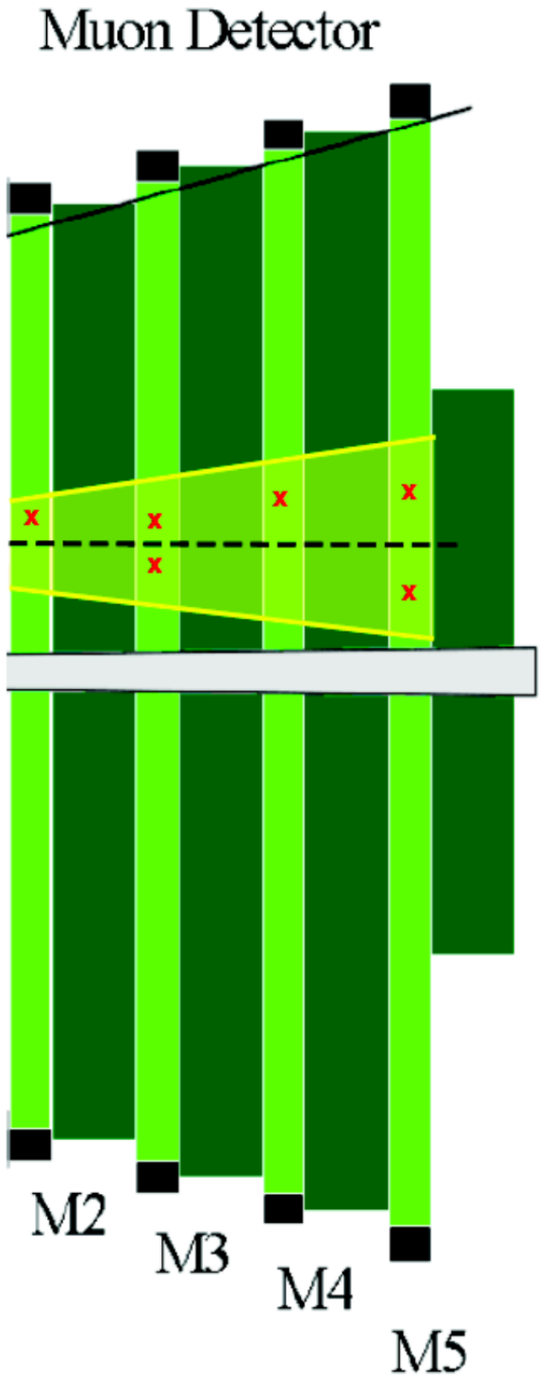
Pion MisID vs nPV



pion misID vs momentum at low and high luminosity:

1. **isMuon + muDLL** (current muID)
2. **IsMuonTight + muDLL**
3. **IsMuonTight + BDT**

The new $\chi 2$



$$\chi^2_{cor} = \delta\vec{x}^T Var^{-1} \delta\vec{x}$$

where

$$\begin{cases} Var^{MS}_{jk} = \sum_{z_i<z_j,z_k} (z_j - z_i)(z_k - z_i)\sigma^2_{MS,i} \\ \sigma_{MS,i} \approx \frac{13.6mrad}{p/GeV} \sqrt{\frac{\Delta z_i}{X_0}} \end{cases}$$

	z position (m)	$\Delta z/X_0$
ECAL+SPD+PS	12.8	28
HCAL	14.3	53
M23 filter	15.8	47.5
M34 filter	17.1	47.5
M45 filter	18.3	47.5

$$\begin{cases} Var^{RES}_{jj} = \sigma^2_{RES,j} \\ \sigma_{RES,j} = padsize_j / \sqrt{12} \end{cases}$$

$$\chi^2_{unc} \Rightarrow Var_{ij,i\neq j} = 0$$