ECL reconstruction and K_L ID Update

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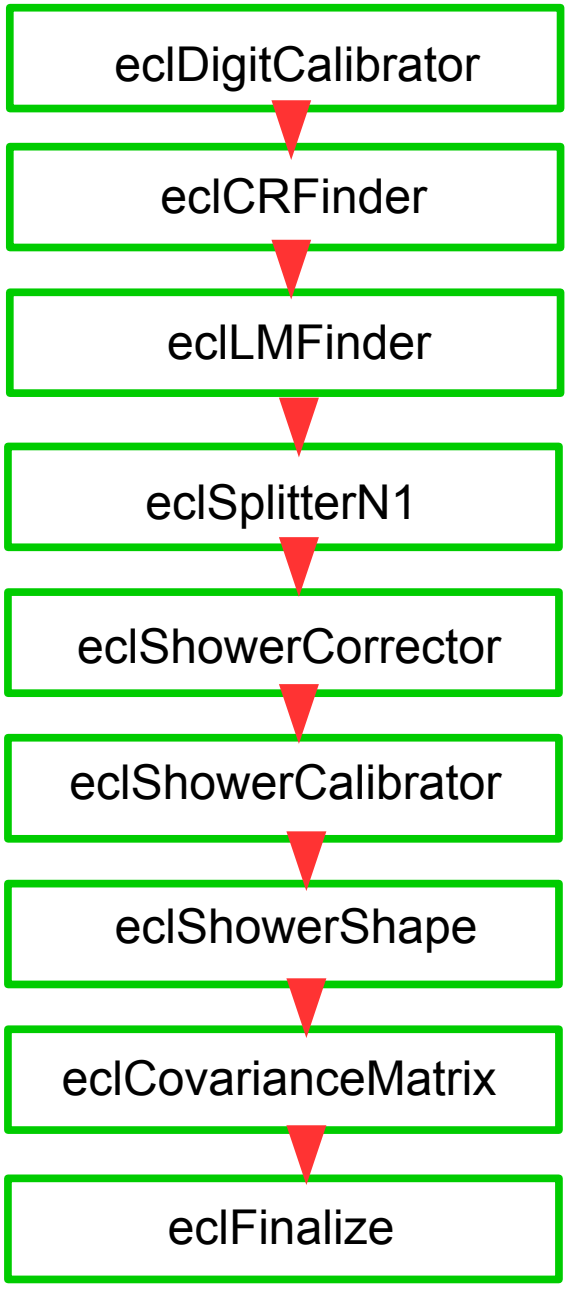
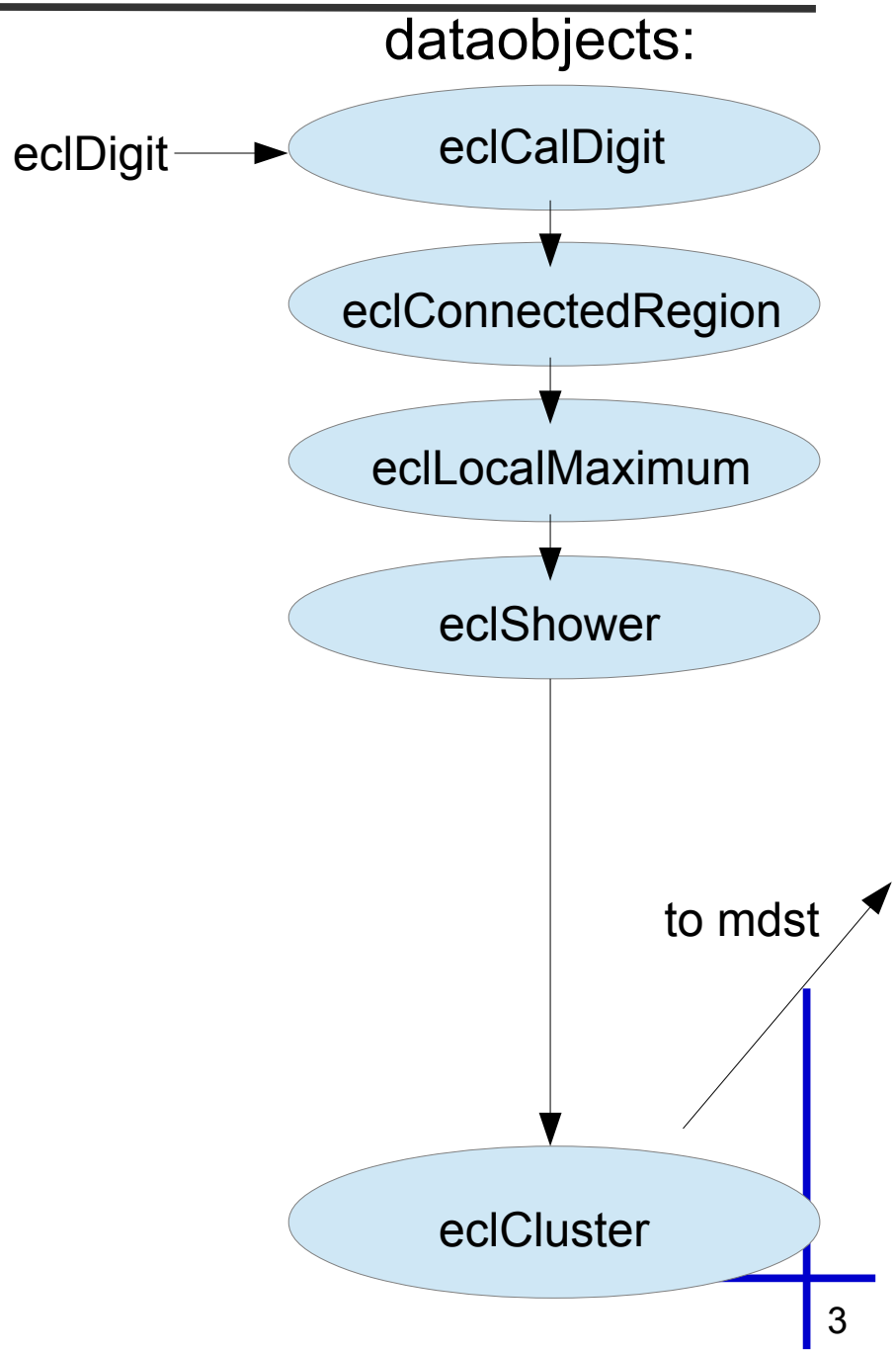
Outline

- Overview of current ECL reconstruction
- K_L ID & eclN2Splitter
- Pulse Shape Discrimination for hadron ID

ECL Reconstruction Chain

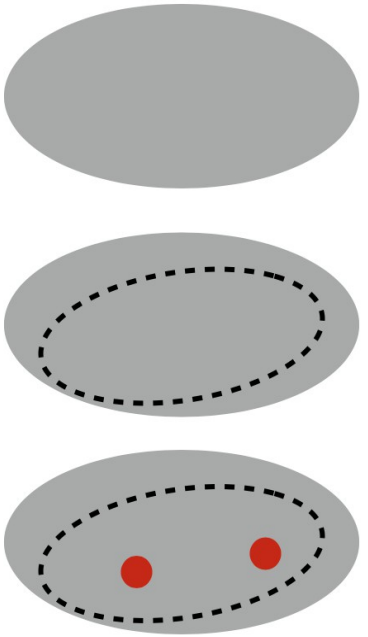
basf2 module path:





ECL Reconstruction

CalDigits, i.e. single crystal signals



Connected Region Finder

Local Maximum Finder

Make hypothesis about particle ID

Splitter N1

Splitter N2

Showers Hp. 1

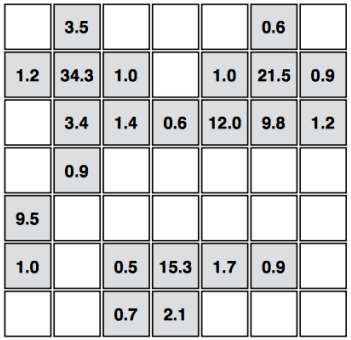
Showers Hp. 2

Currently 3 different neutral hp. are foreseen:
1 - n photons
2 - neutral hadron
3 - (merged)pi0

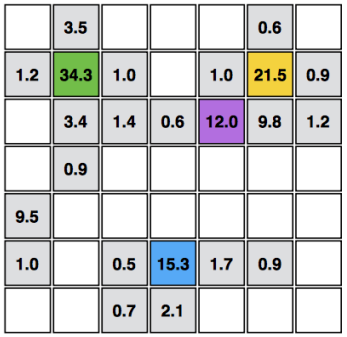
+ 3 chrged hp.:
1 – electron (+n photons)
2 - MIP
3 – charged hadron

Graphics & plots in this & following slides by T. Ferber

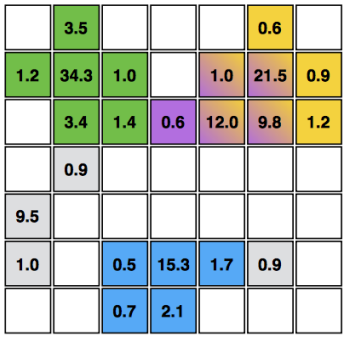
CR Finder



Use only digits with E>0.5MeV.

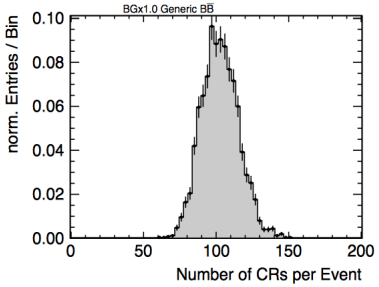


Digits with E>10MeV are seeds.

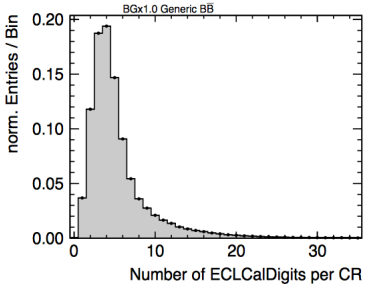


Neighbours are grouped with the seed.

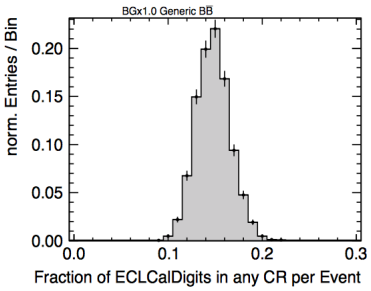
Overlapping CRs are merged.



~100 CRs per event.



Most CRs with few Digits. Large CRs are very rare.

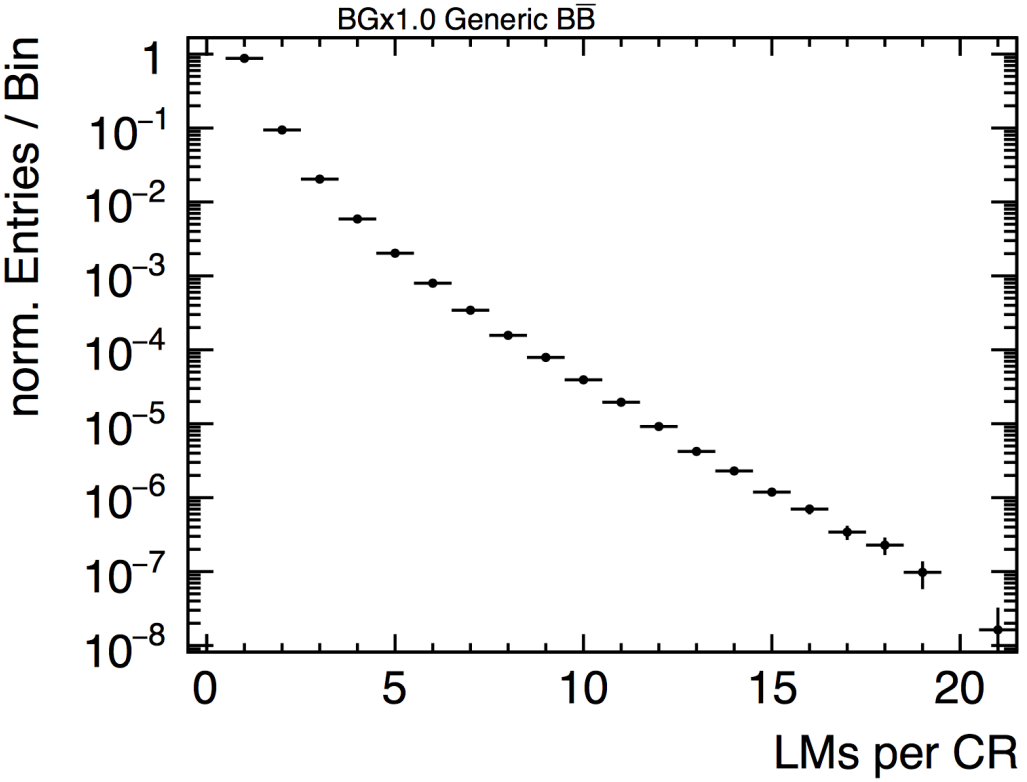


CR Finder removes ~85% of all digits.

Neighbours of digits with E>1.5MeV are added as well (continued).

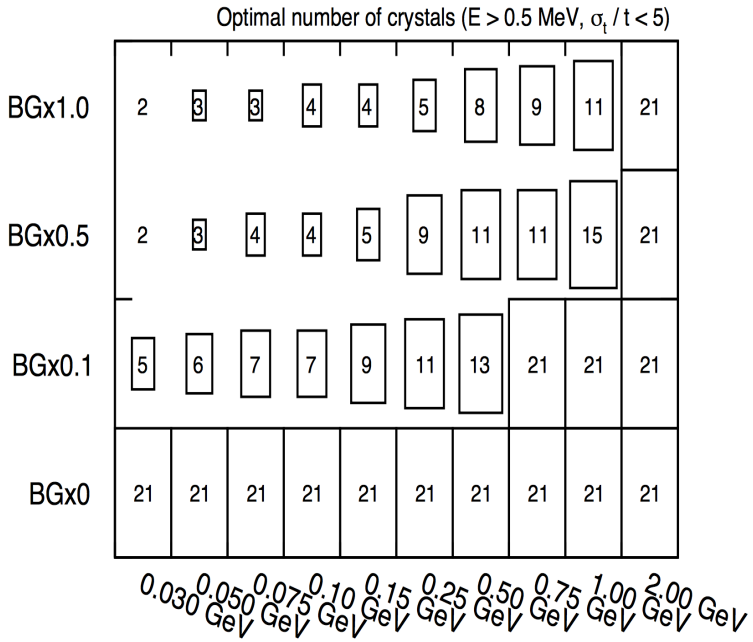
Local Max Finder

- The connected region can contain energy deposits from more than one particle and/or there are many digits that do not belong to a particle
- If a CR contains multiple particles (including beam background) we have to split the energy → search for local maxima (LM)



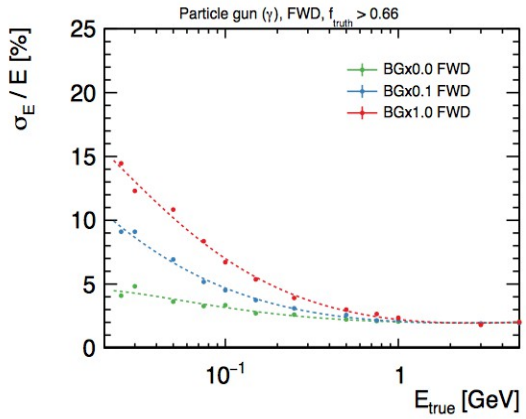
Splitter N1 (n photons)

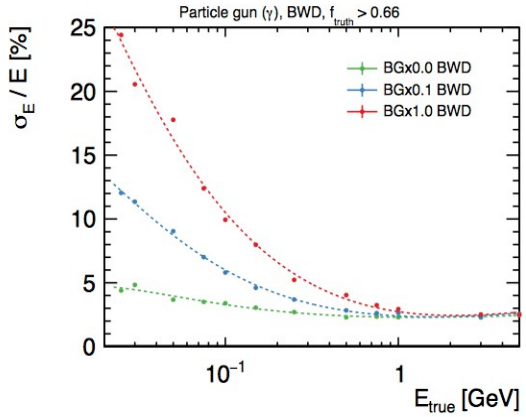
- The digit energy within a CR is shared between different LMs based on the distance to the LM. Iterative procedure via recalculation of the shower positions (BaBar-like)
- For each LM within a CR, we choose an optimal number of neighbor crystals within the nearest “5x5 minus corners” crystals
- The optimal number of neighbors depend on the BG level and a raw energy estimation from 3x3 crystals: optimal number per crystal position as f(BG, E_{raw})
- The optimal number minimizes the energy resolution for true photons, the mean will be corrected later

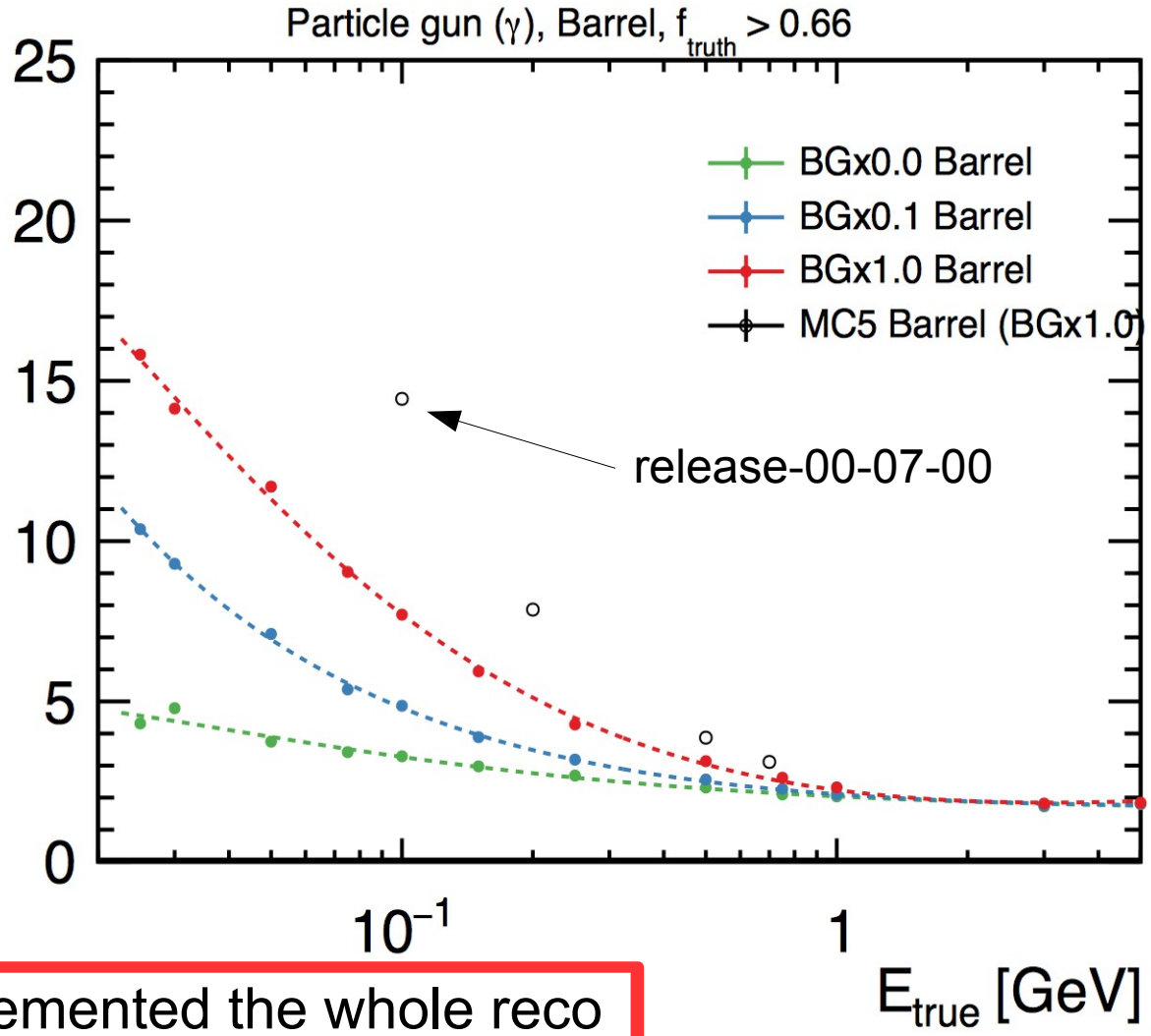


Energy Resolution (rel-00-08-00)

More details in Mario's talk

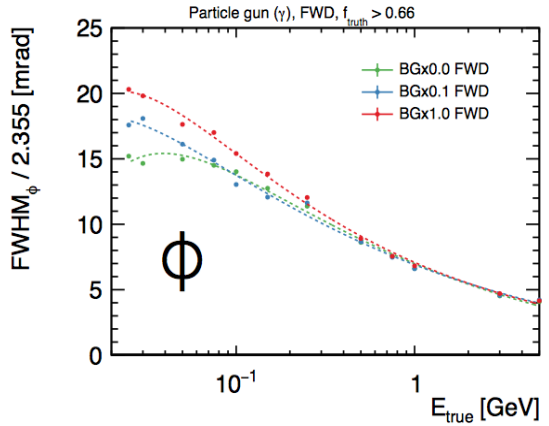


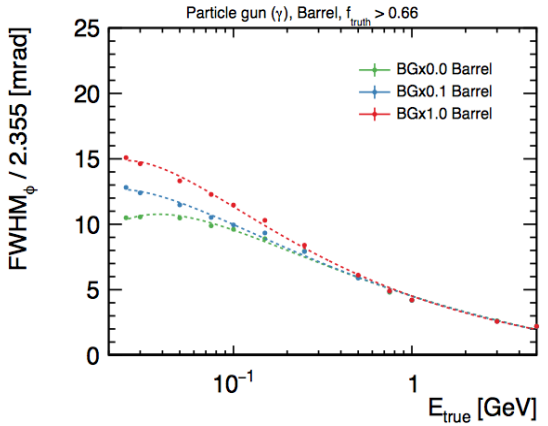


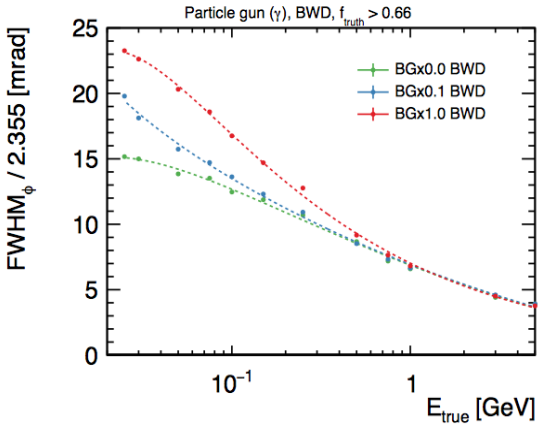


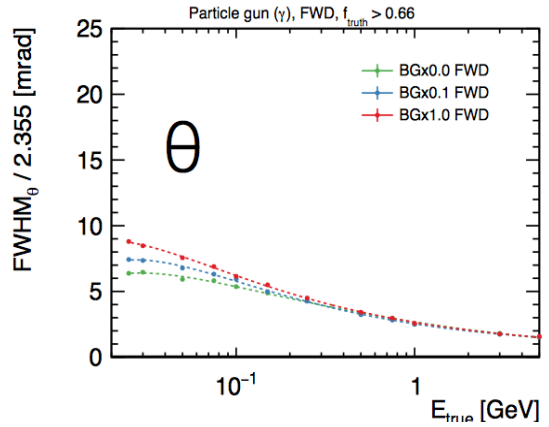
Note: we have recently implemented the whole reco chain also for Pure CsI option for final performance comparison. Tuning & testing is ongoing.

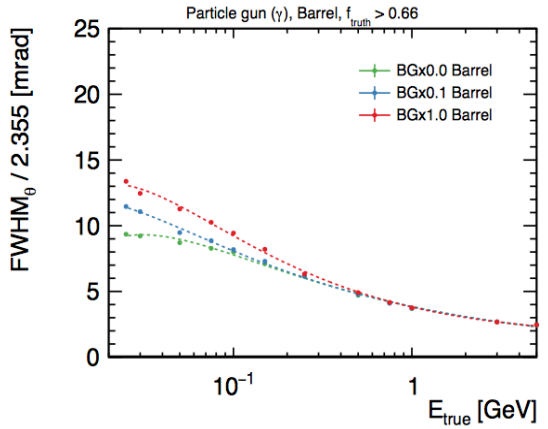
Position Resolution (rel-00-08-00)

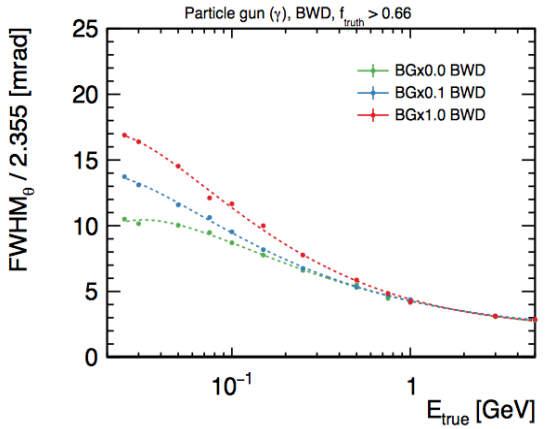




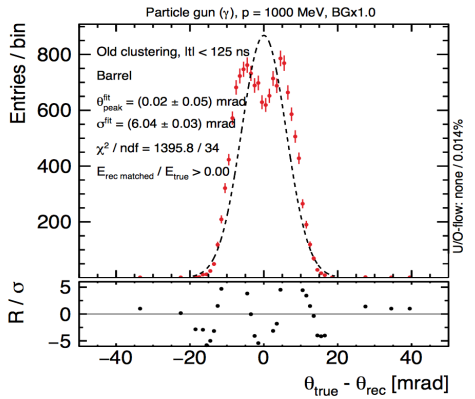




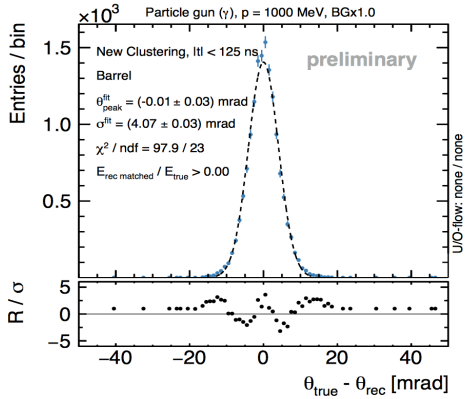




release-00-07-00



release-00-08-00



More details in Mario's talk

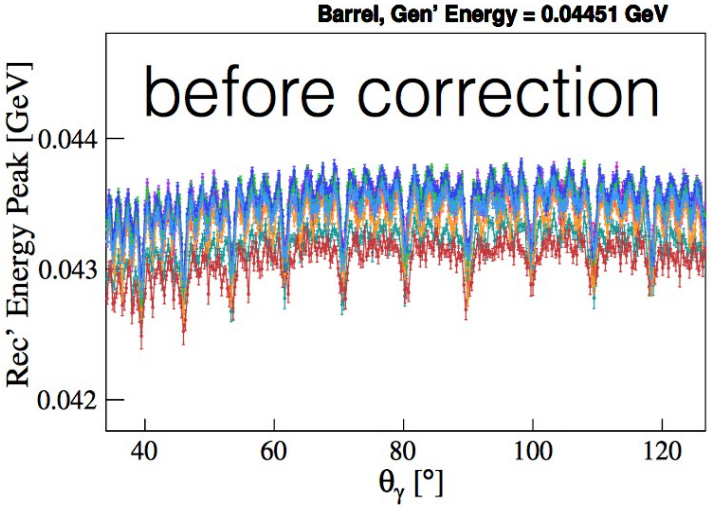
Shower Energy Correction

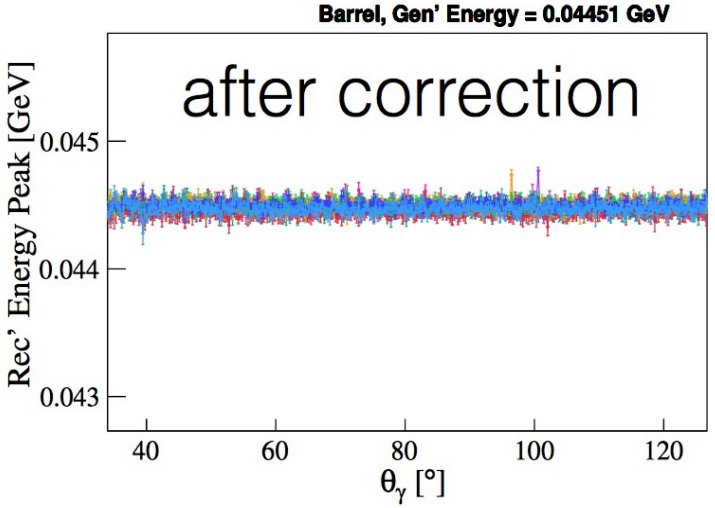
- Bkg, theta and phi dependent, currently provided for BGx0.0 and BGx1.0

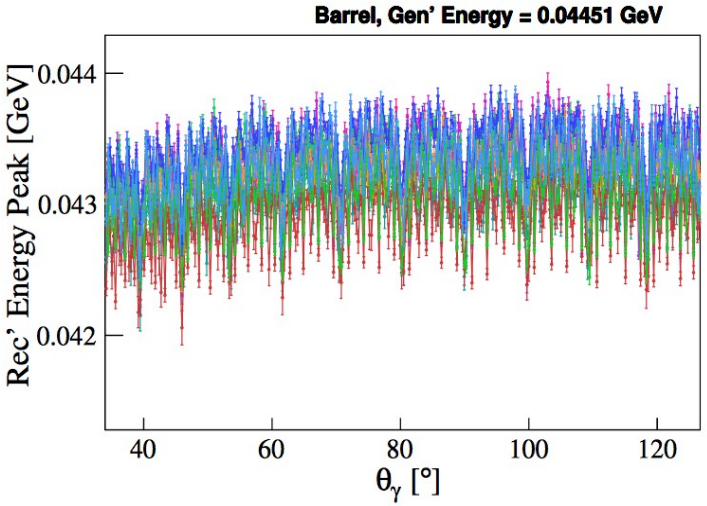
BGx0

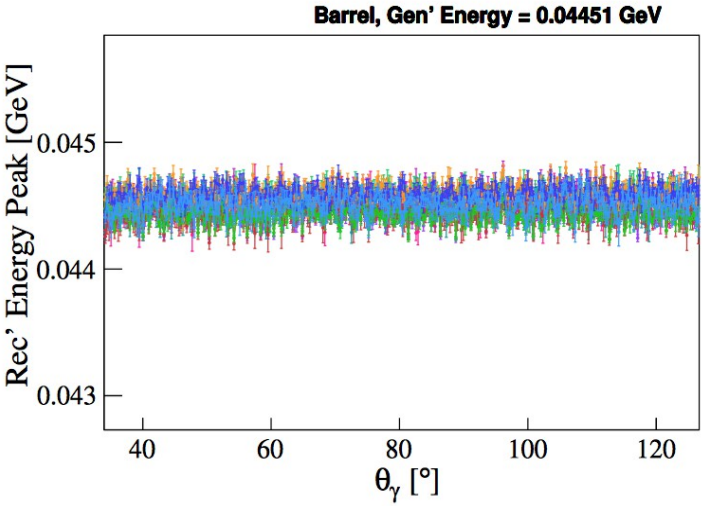
Different colors = different ϕ bins.

BGx1.0







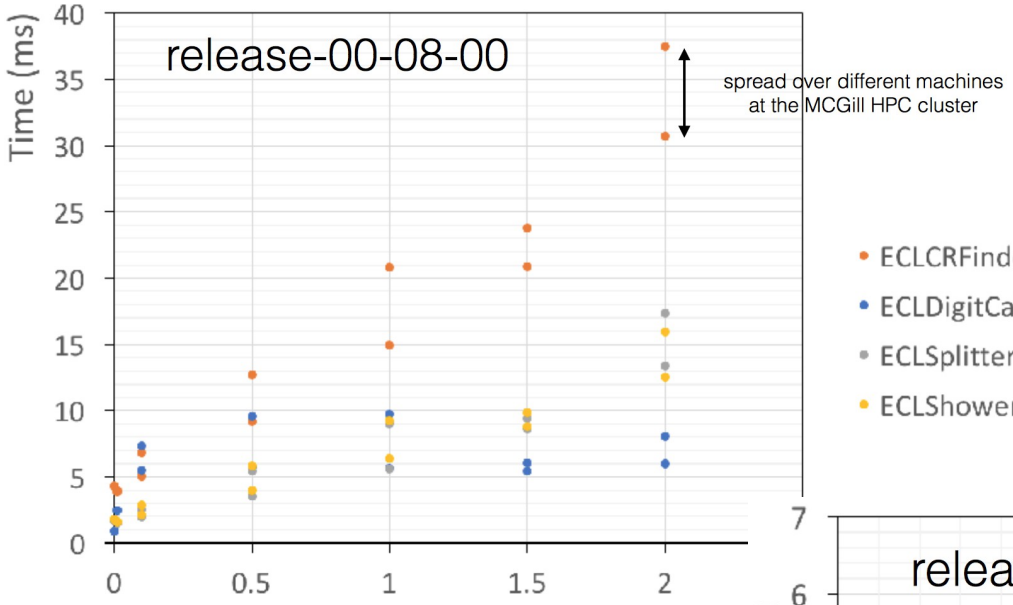


Suman Koirala

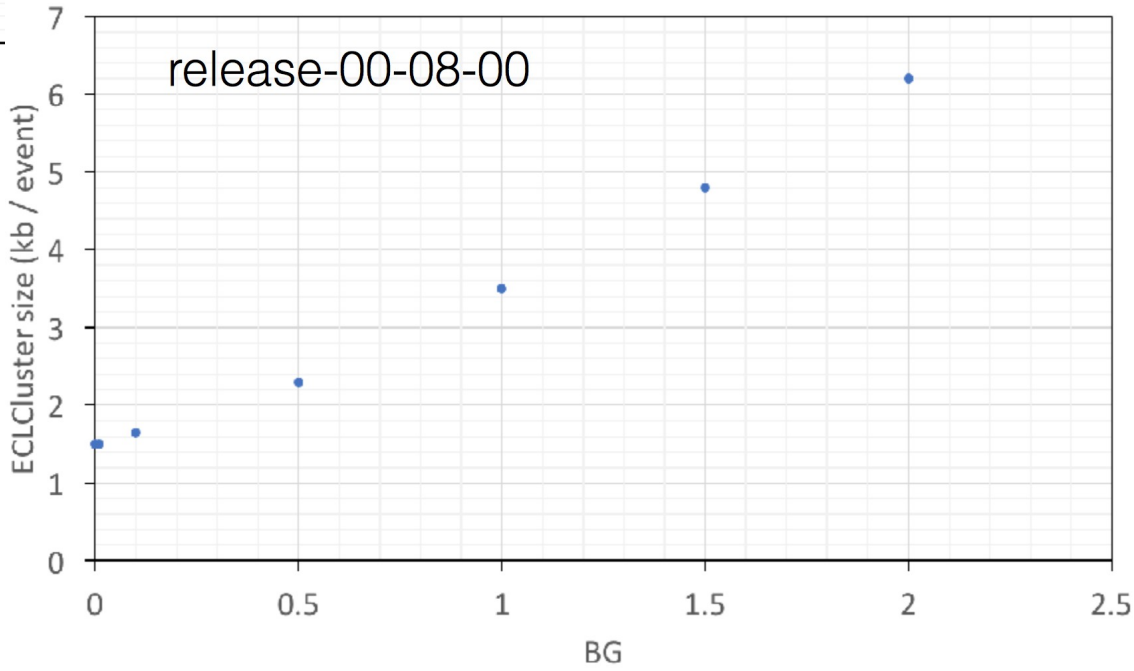
More details in Mario's talk

Exec. Time & Memory Consumption

- ECL reconstruction time and file size increase is almost linear with bkg



Generic $B\bar{B}$ events



K_L ID int the ECL: Foreword

- Previous results:
  - Using full Connected Region (CR) information we get improved K_L ID w.r.t. Belle-like showers
  - Improved resolution on K_L direction is easily obtained already by "cluster reduction" in a similar way as is done for photons

- Unfortunately, the main question, however, was left open:

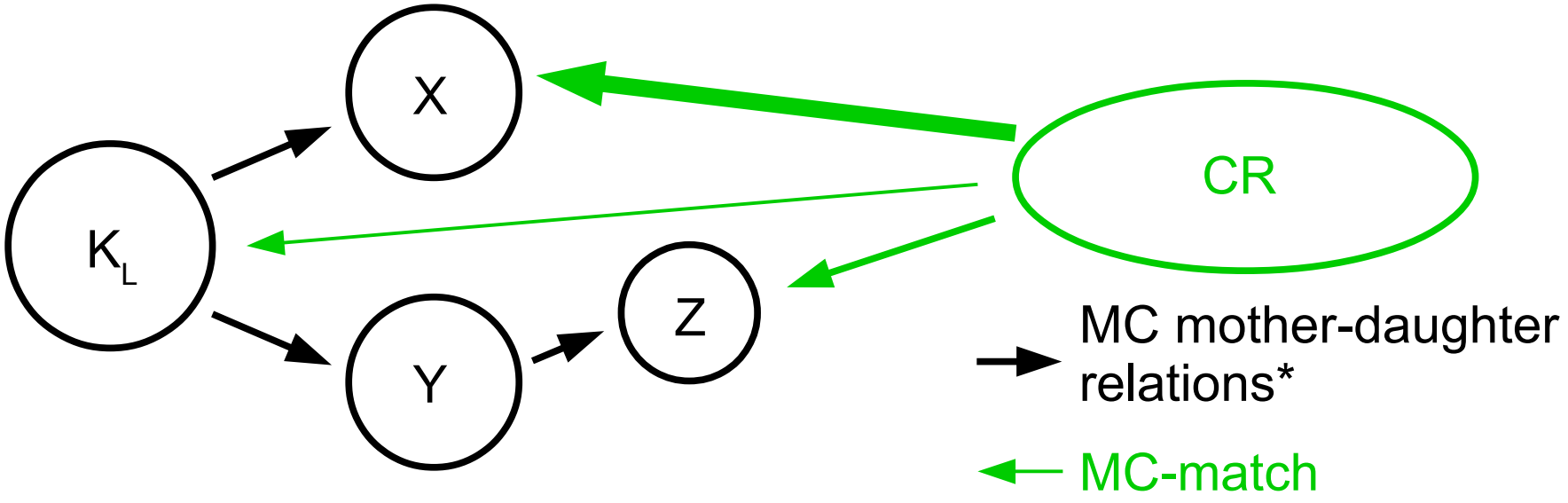
  Do we actually really need a splitter for N2 hypothesis?

- Which can be translated as:

  How many times do we have more than one local maximum (LM) in a CR which is matched to a K_L which come from other (i.e. non-K_L related) physics processes?

CR-MC Match

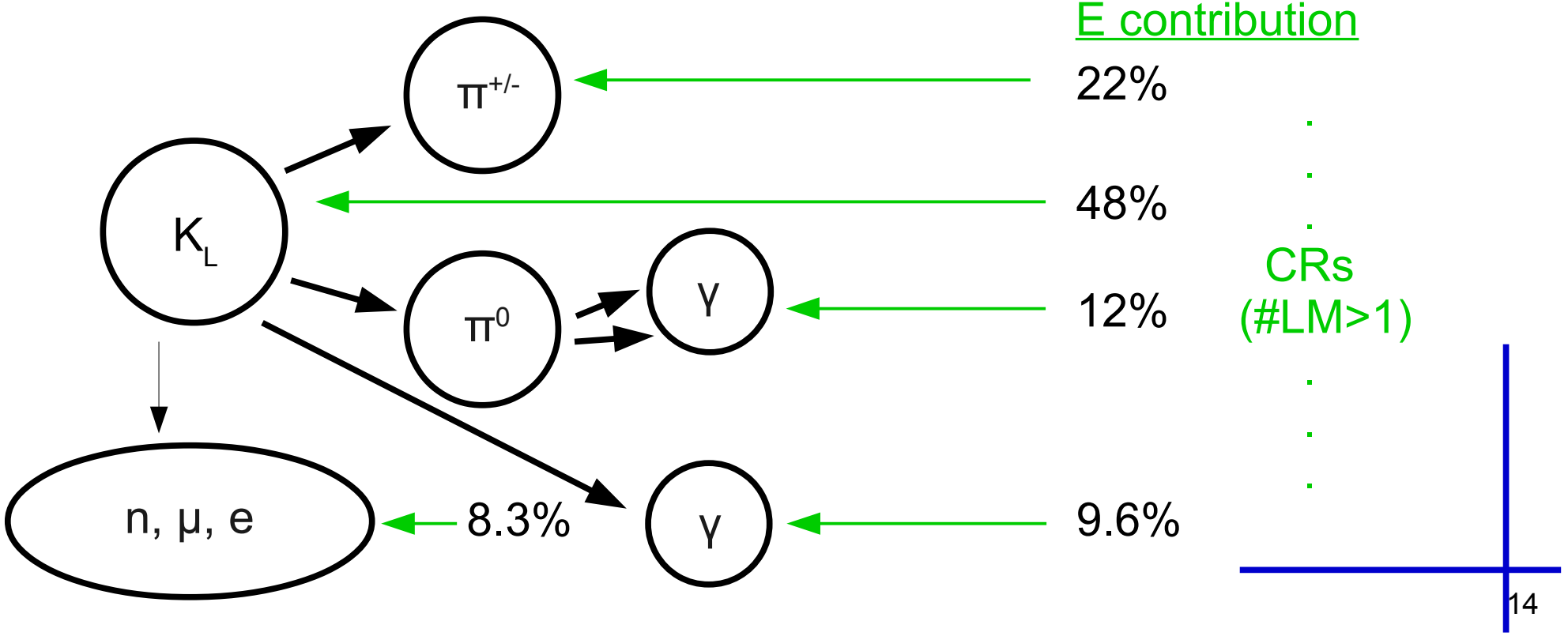
- MC relations in K_L-CR matching are non-trivial, direct matches are (mostly) not sufficient to understand the interaction
- Not necessarily most significant match is to K_L
- We look for CR with > 1 LM and study associated MC-matches
- Selection: CR Energy > 40 MeV, “strong” MC-match (i.e. MC-match + K_L interaction in TOP or ECL), basic timing cut (same as cluster)



*mostly “daughters” produced interaction, not decay

pGun KL (w/o bkg)

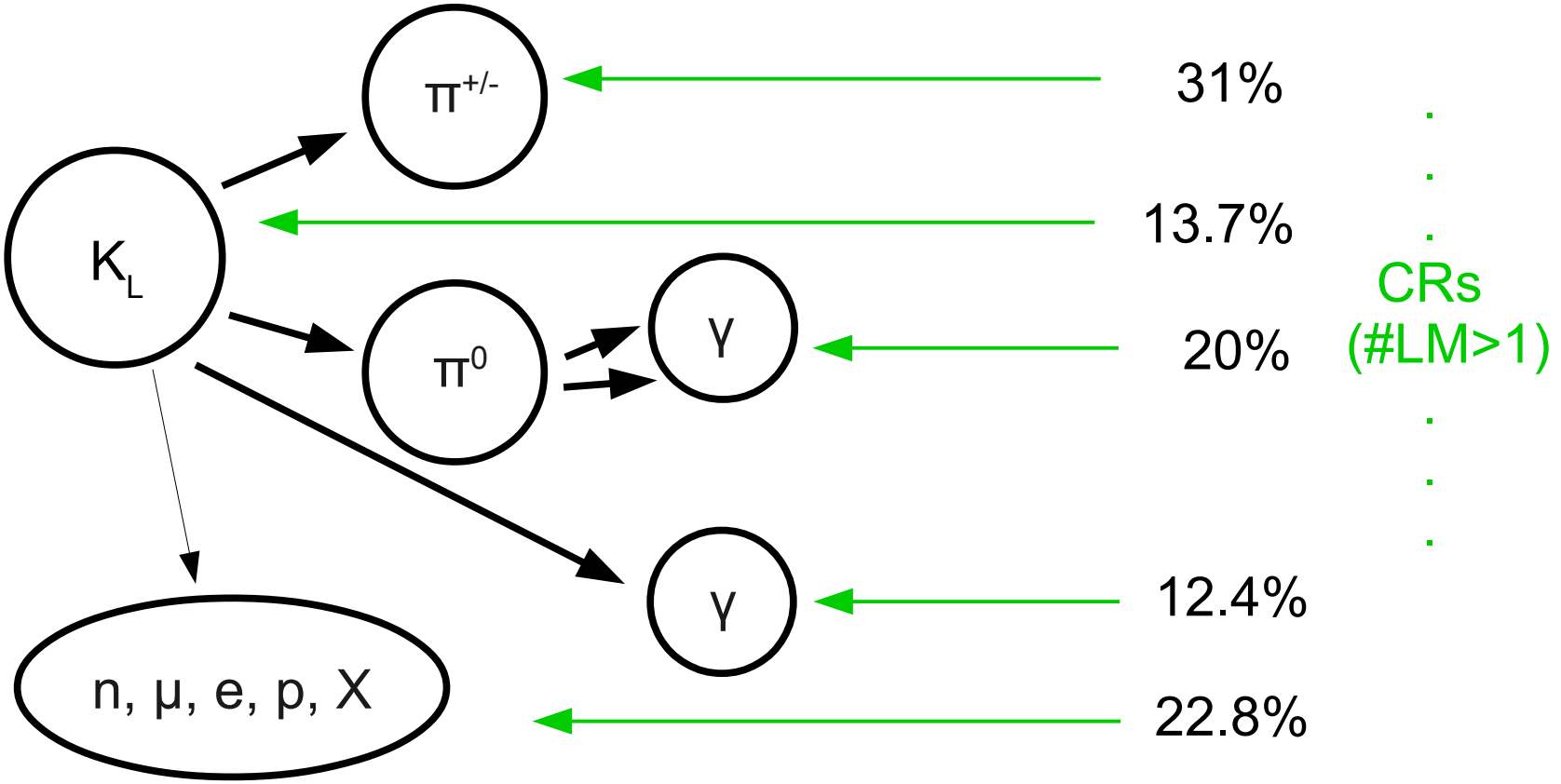
- Benchmark: single K_L with E, theta spectrum as K_L from generic $B\overline{B}$
- From 1000 events:
  - K_L interaction rate (ECL+TOP, geometry factorized out): 60.5%
  - #CRs: 570 (1077 w/o any selection)
  - #CRs > 1 LM: 162
  - #CRs > 2 LM: 27



pGun KL (w/o bkg) (2)

← MC-match of second highest E contribution

→ MC mother-daughter relations



- Going back 2 levels every CR-matched MC particle is seen to originate from the K_L as it should

Bkg effect

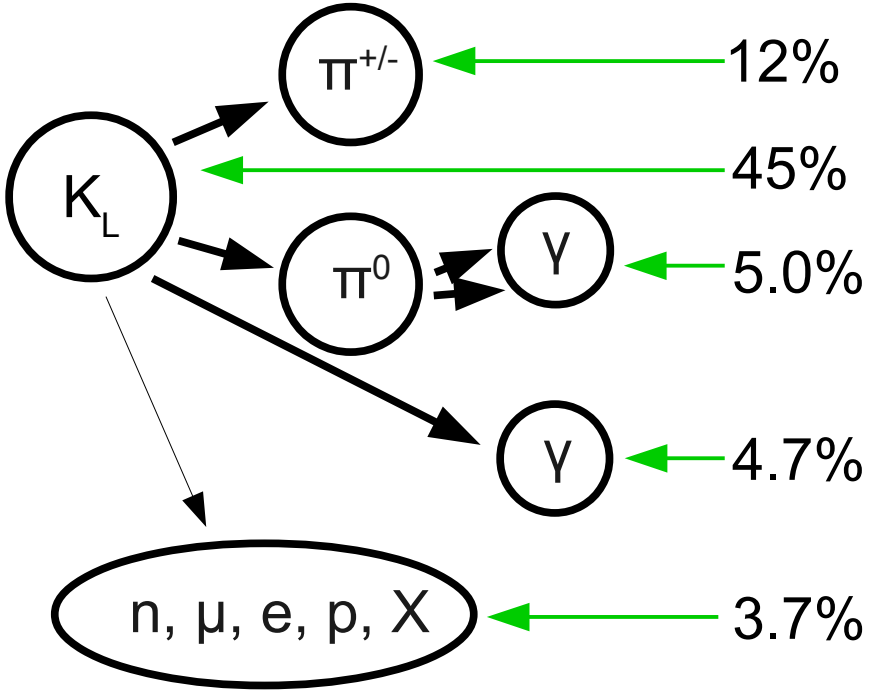
- From 1000 pGun K_L events + 12th campaign beam bkg:

no beam bkg	w beam bkg
#CRs: 570	-> 979
#CRs > 1 LM: 162	-> 537
#CRs > 2 LM: 27	-> 207

- # of multi-bump CRs grows as function of #bumps
- The effect is energy dependent, i.e. grows with K_L energy
- No significant change in matching relations for 1st peak
- 2nd most energetic peak in > 50% cases due to bkg photon
- We interpret this as a pile-up effect

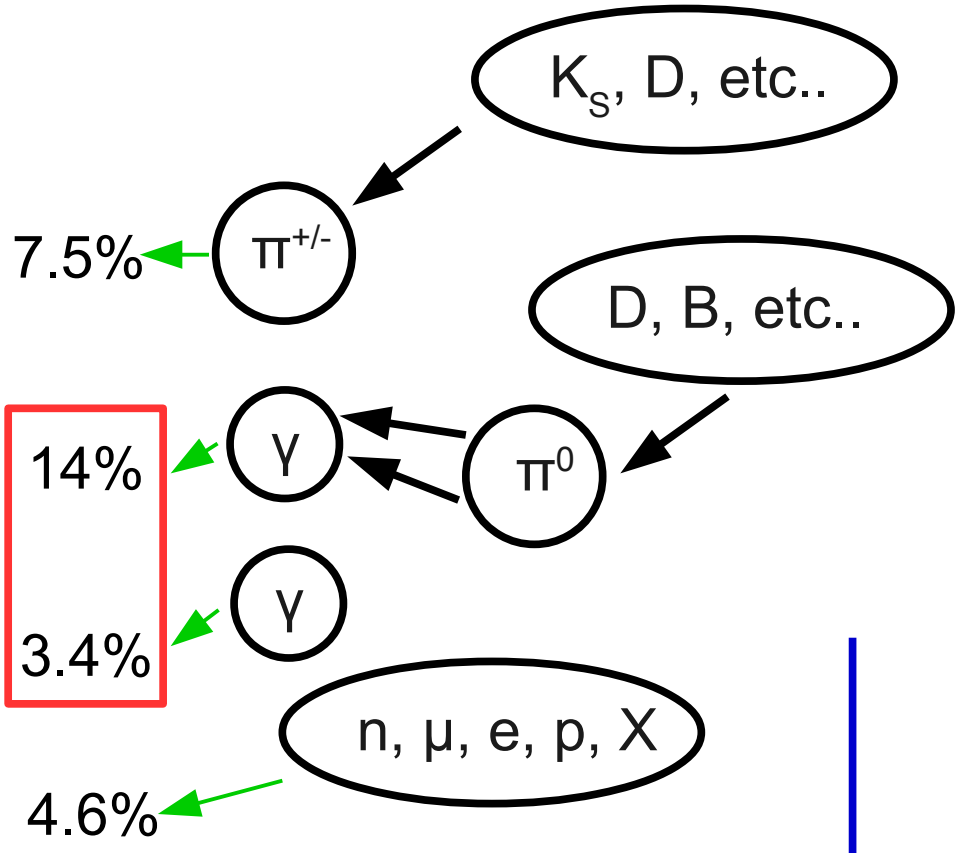
genericB$\overline{B}$ (w bkg)

- From 100000 events:
  - #K_L (mcTruth): 60869
  - #CRs (w match): 72491
  - #CRs (w match) > 1 LM: 34816
  - #CRs (w match) > 2 LM: 12578

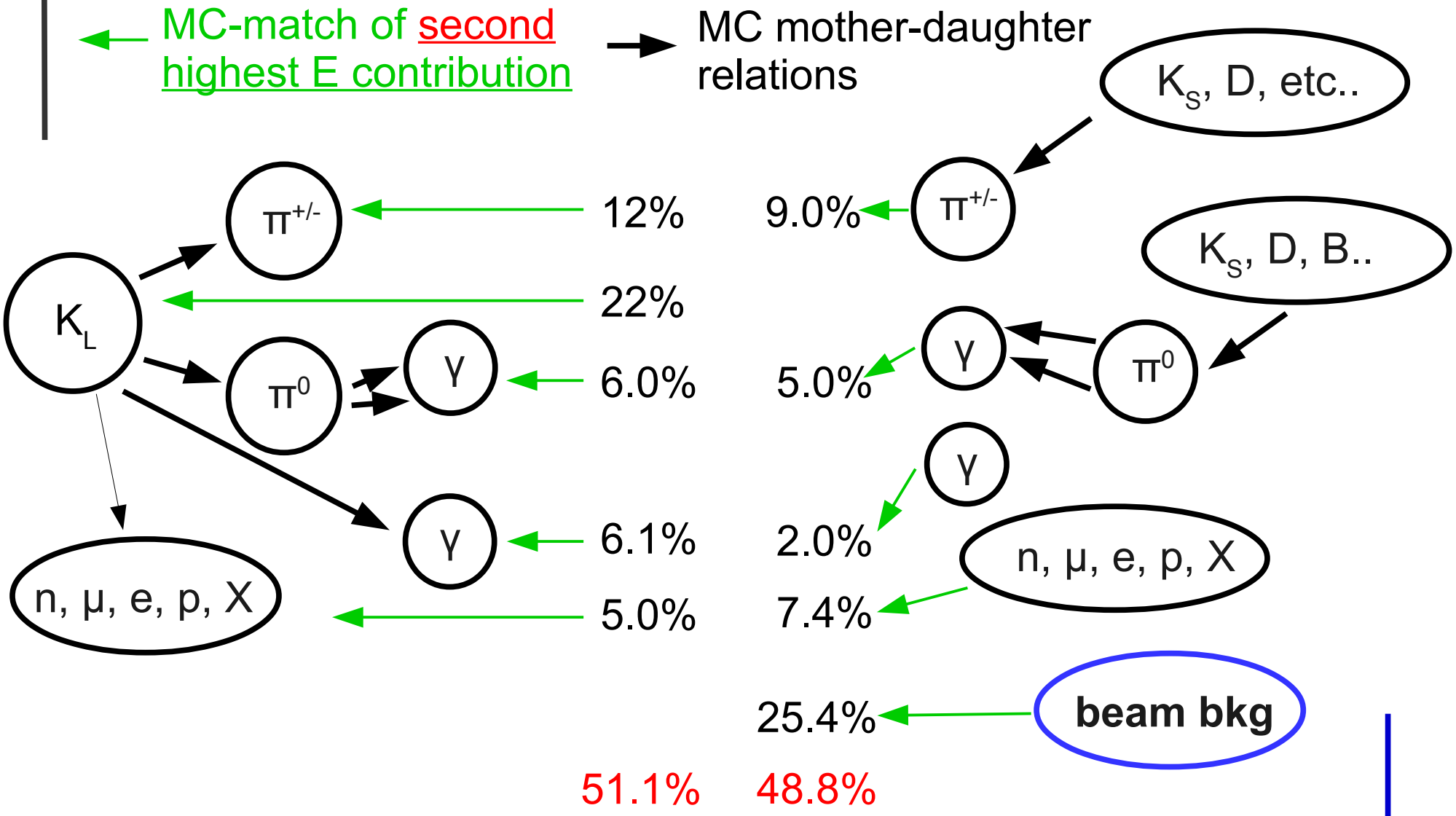


MC mother-daughter relations

MC-match of highest E contribution



genericBB̄ (w bkg) (2)



- Most important contribution to 2nd peak from beam bkg

Simulation results: overview

- In generic $B\bar{B}$ events + 12th campaign beam-bkg, for CR with at least 2 LM, for a K_L truth-matched CR:

  - in 17.2% events the most energetic deposit in the CR is due to a photon
  - in 6.9% the photon gives 2nd most energetic deposit
  - (photons mostly from π^0)

    -> most interesting case

  - in 25% of cases the 2nd most energetic peak is from a bkg-photon

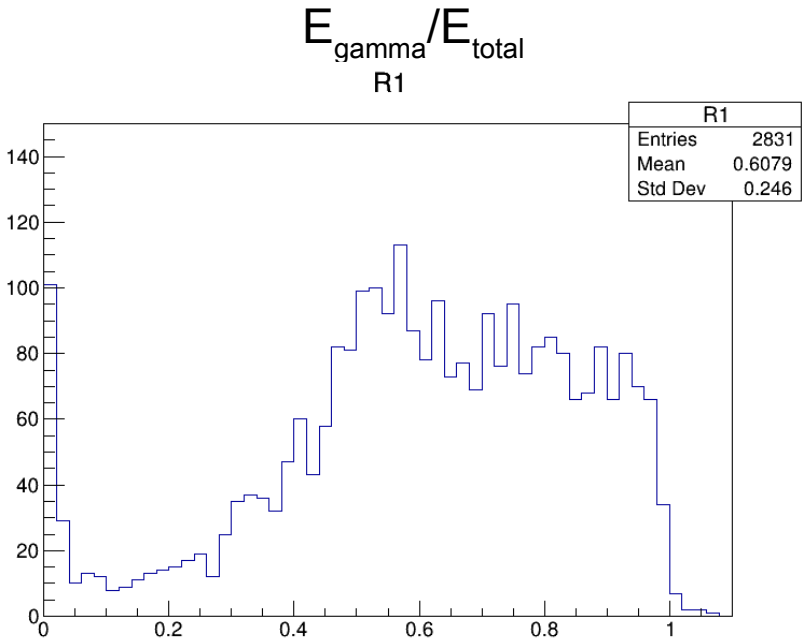
    -> a splitter could help to clean-up

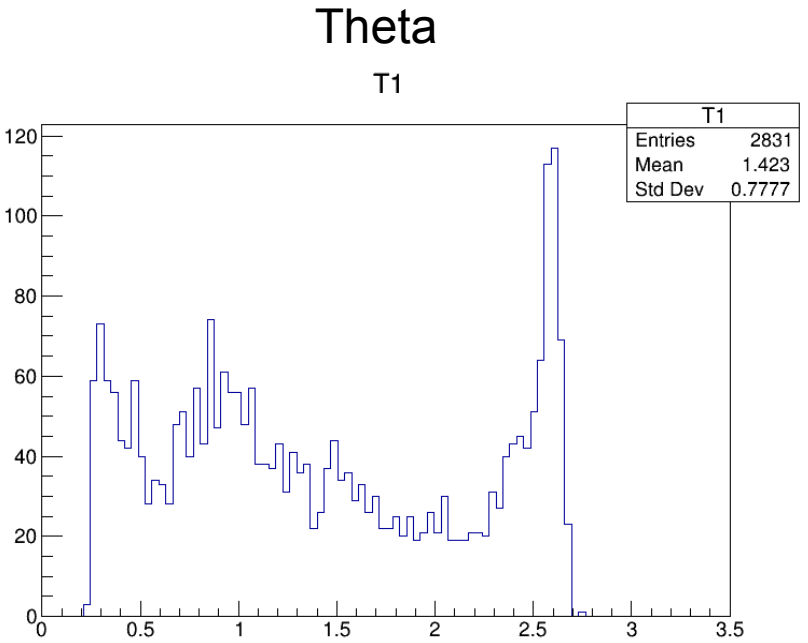
  - on average 8.2% of contributions is from a $\pi^{+/-}$ (most likely split-offs)
  - on average 6% of contributions is from a mix of (n, μ, e, p, X)

    -> hopeless to recover any useful information

Cross check

- To check whether the previously determined overlap probabilities are reasonable we compare mu/gamma overlap probabilities in generic $B\overline{B}$ (this time make no requirement on track/match)
- We get 9.7% probability that a CR matched to a muon get its most energetic deposit from a π^0 photon, in reasonable agreement with the previous result

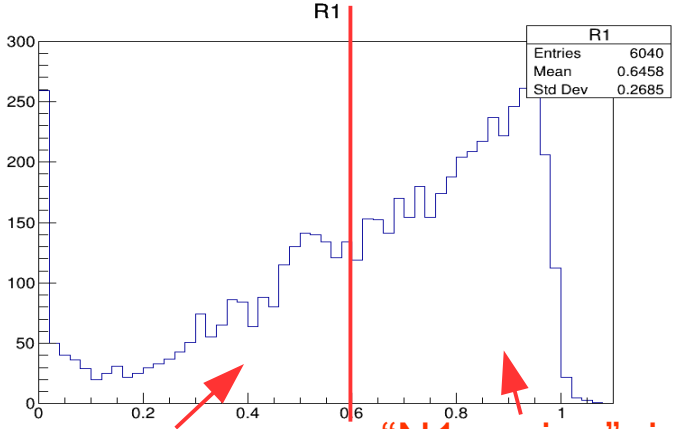




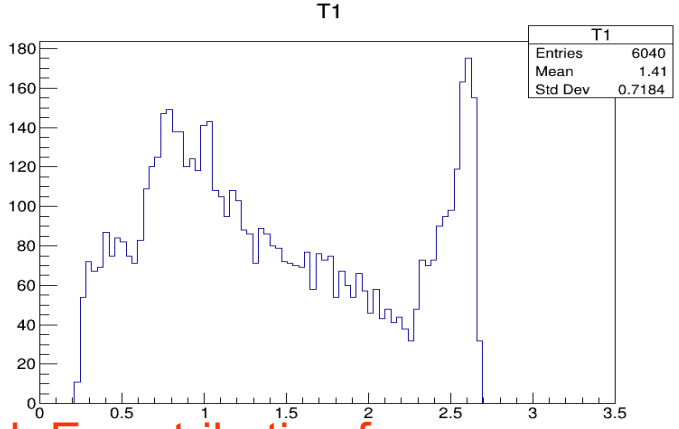
N2Splitter, prel. conclusions

- KL/gamma overlap might be the (only?) physics case to justify an N2Splitter
- Makes sense only in the “N2 region” where $E_{gamma}/E_{CR,tot}$ is low (see picture)

E_{gamma}/E_{total}



Theta



“N2” region

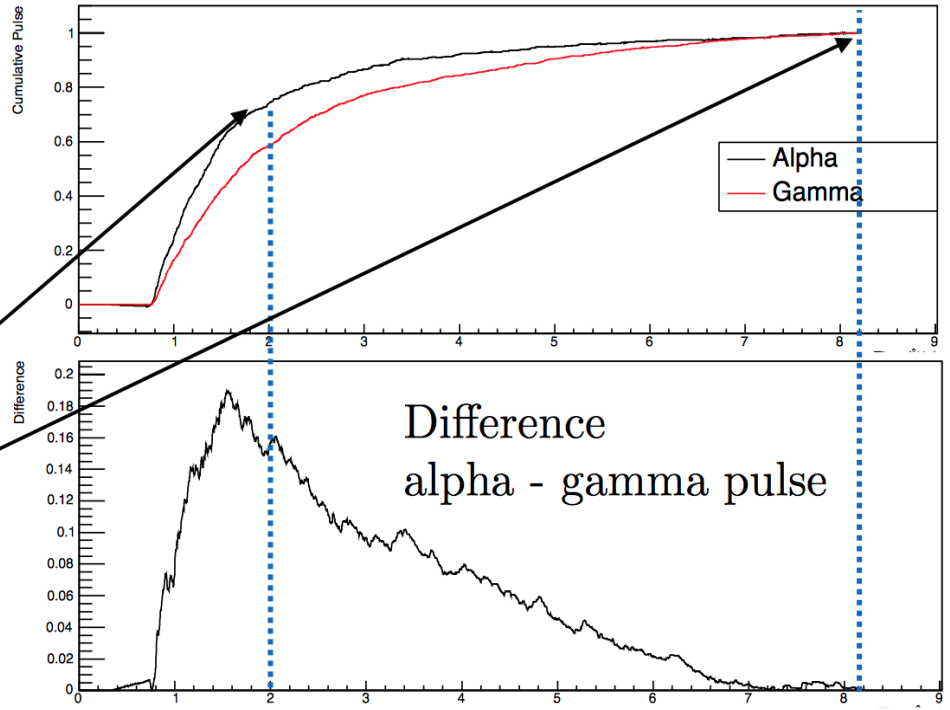
“N1 region”, i.e. high E contribution from a photon, no chance to recover the K_L

- Basic option could be a sort of “photon/hadron” splitter, e.g.:
  - under N2 hypothesis try to find a photon in the CR
    - If you find it (with P > x) keep it and assign the remaining of the CR to K_L
    - Otherwise assign everything to the K_L
- Would also remove beam-bkg
- At a later step we would do dedicated clustering to improve K_L direction resolution

Pulse Shape Discrimination

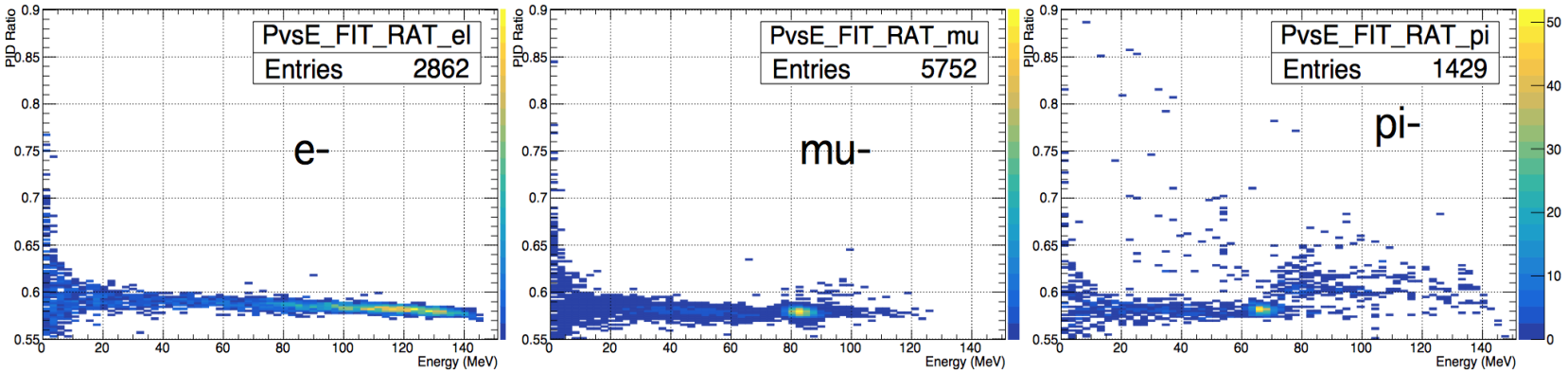
- Basic idea: scintillation response of CsI(Tl) varies with particle type for protons and alphas and electrons
- Use this information to improve particle ID in Belle II
- Known to work at low energies O(10 MeV) and for neutron ID @ 100-700 MeV, what about typical BelleII energies?

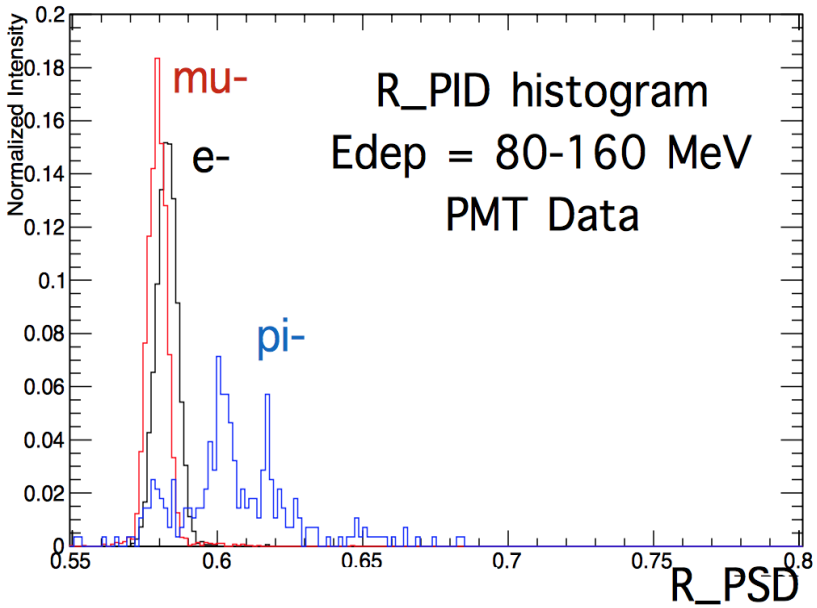
$$R_{\mathrm{PSD}} = \frac{Q(1.2\mu s)}{Q(7.4\mu s)}$$



Hadron ID using PSD

- First successful test at higher energies made @ TRIUMF M11 test facility using CsI(Tl) crystal + PMT on p=100-300 MeV e, mu, pi beam (fall 2016)



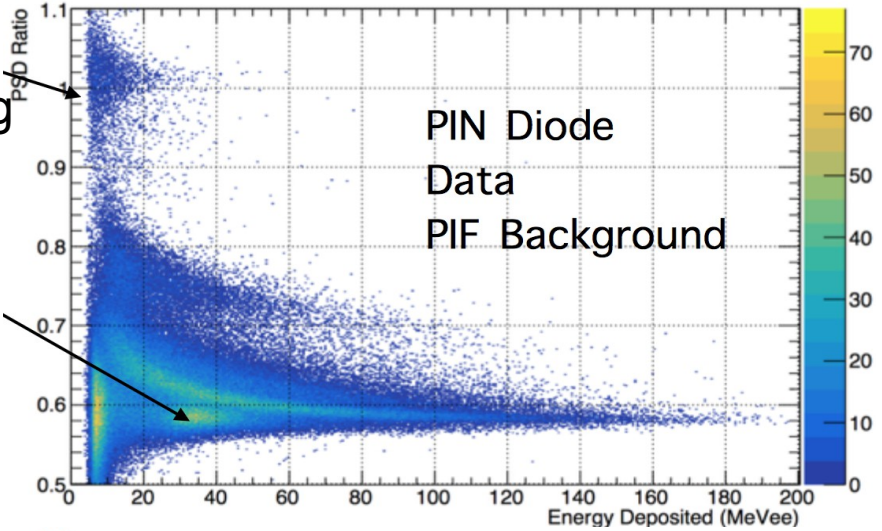


PSD, CsI(Tl) w PIN diodes

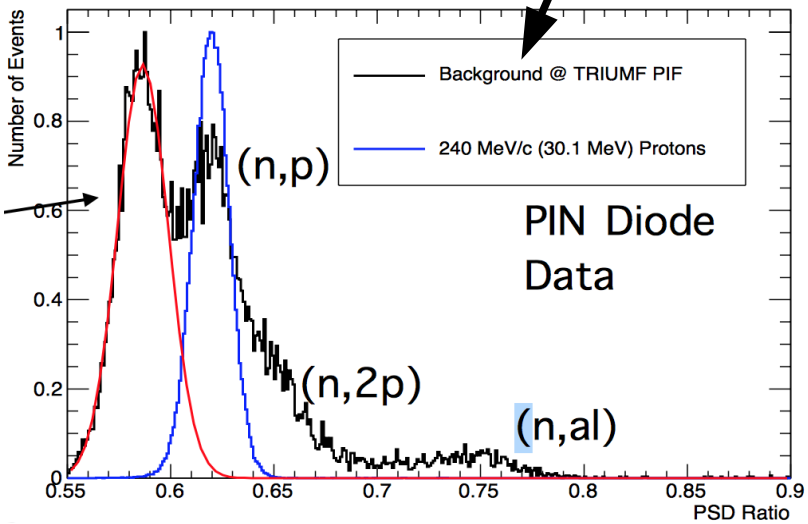
- 2nd test at TRIUMF PIF using both PMT and PIN diode readout
- Proton momentum: 195, 240, 277, 334, 361 MeV/c

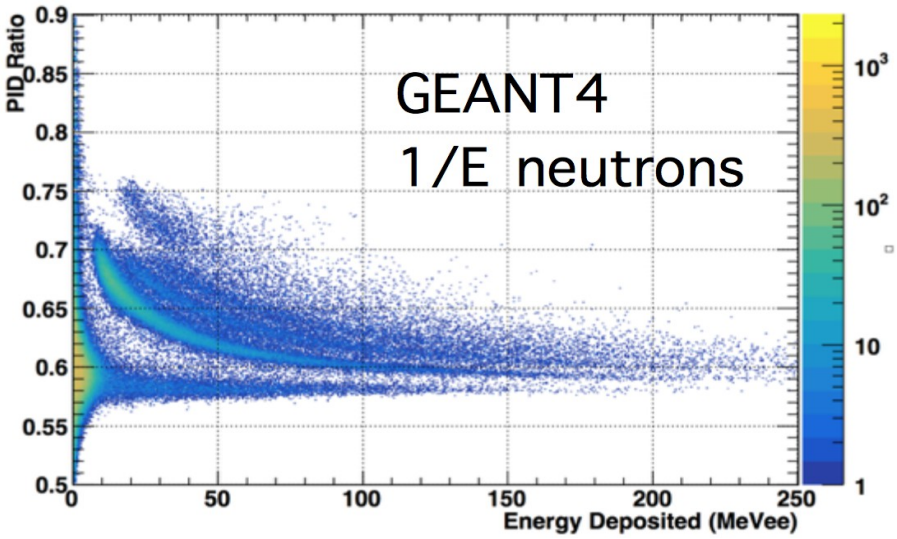
Diode crossing

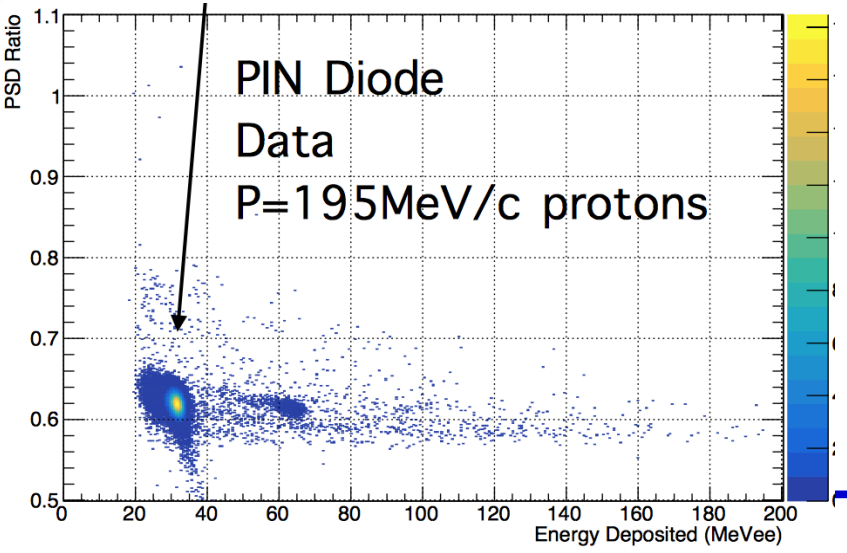
Cosmics



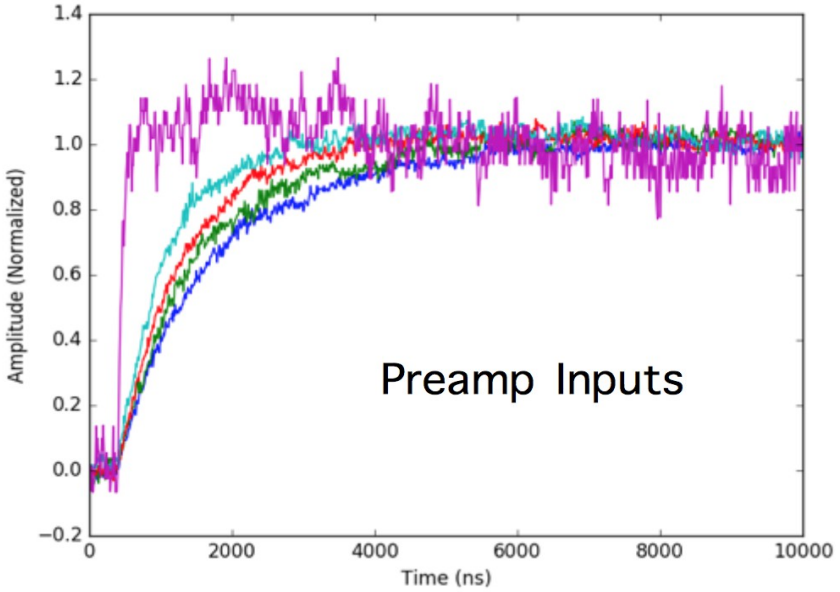
Projection on 30-35 MeV slice

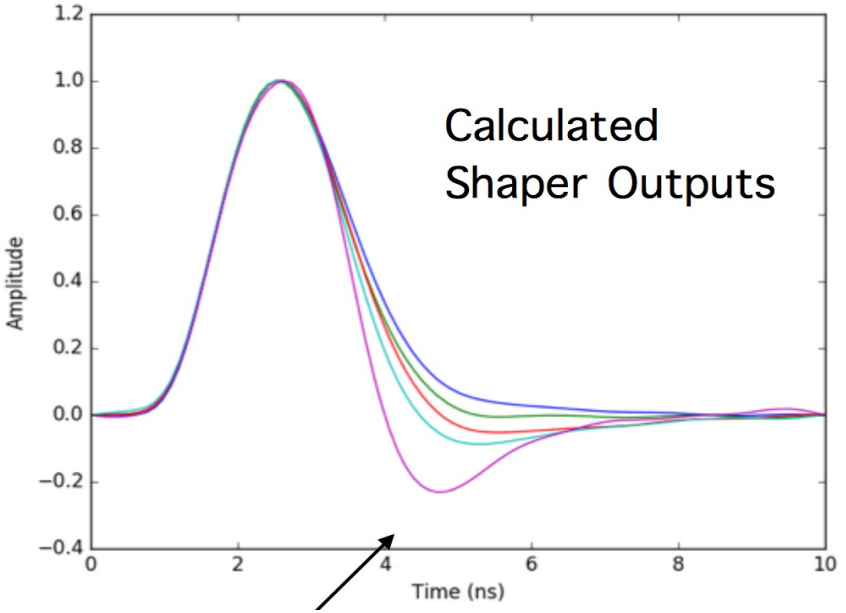






PSD, Shaper



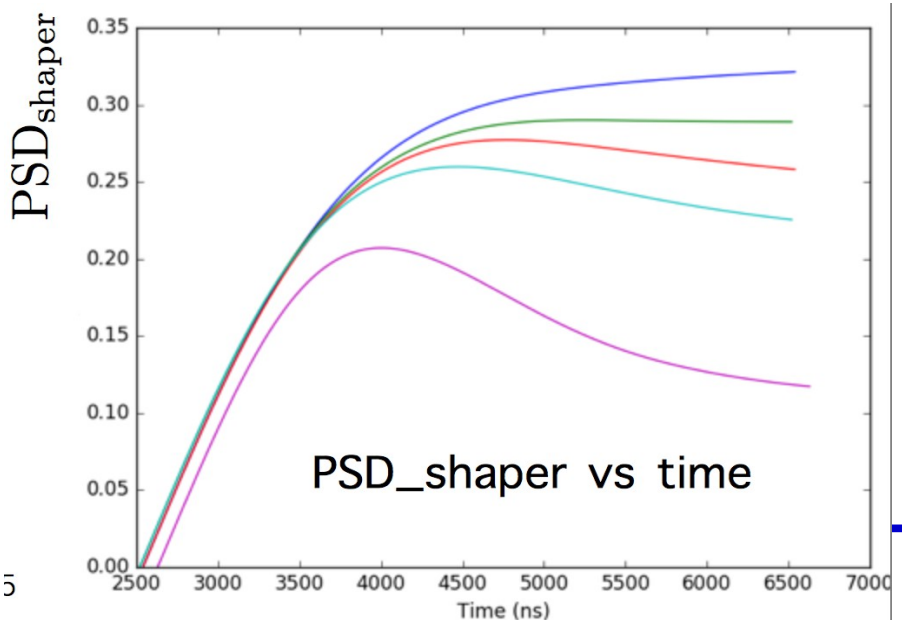


Output for: mu / e / p / alpha / diode

$$\mathrm{PSD_{shaper}} = \frac{1}{E * \mathrm{NMAX}} \sum_{i=0}^{\mathrm{NMAX}} V(t_i)$$

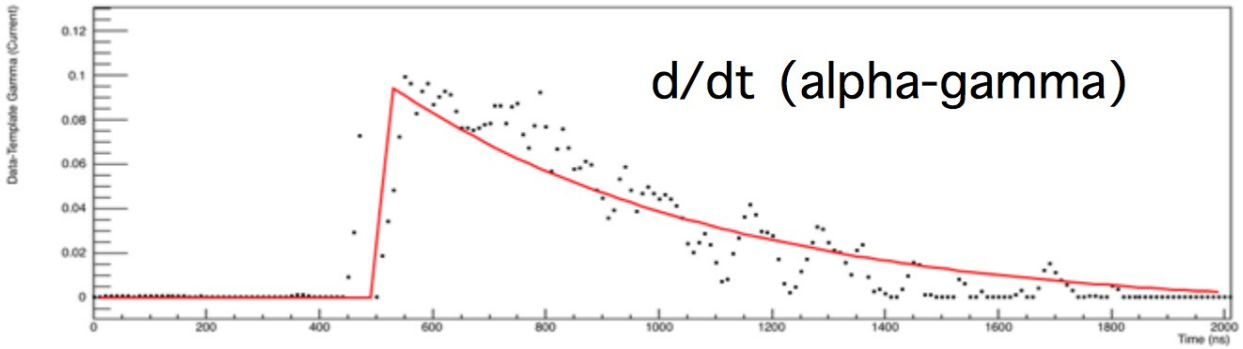
$$t_i = t_{\max} + \frac{i(4\mu s)}{\mathrm{NMAX}}$$

$$E = V(t_{\max})$$



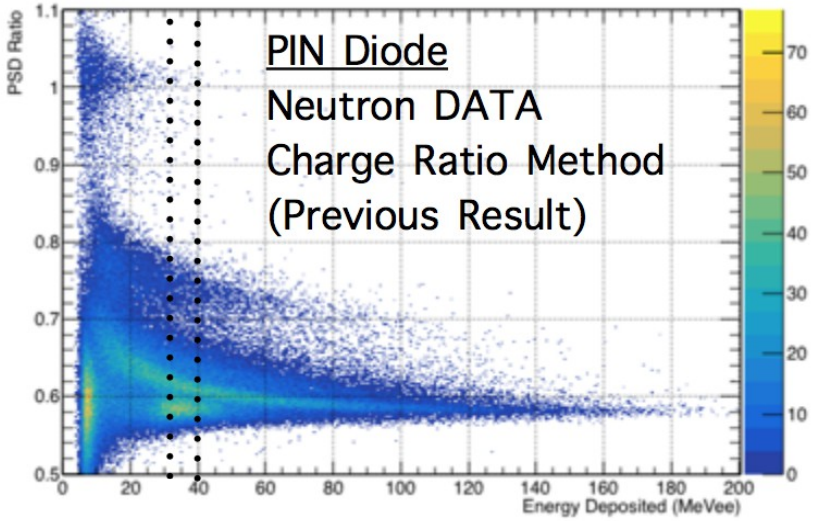
PSD, recent development

- Method has been improved by using 3-component model based on data
- 3rd (fast) component is called PSD component

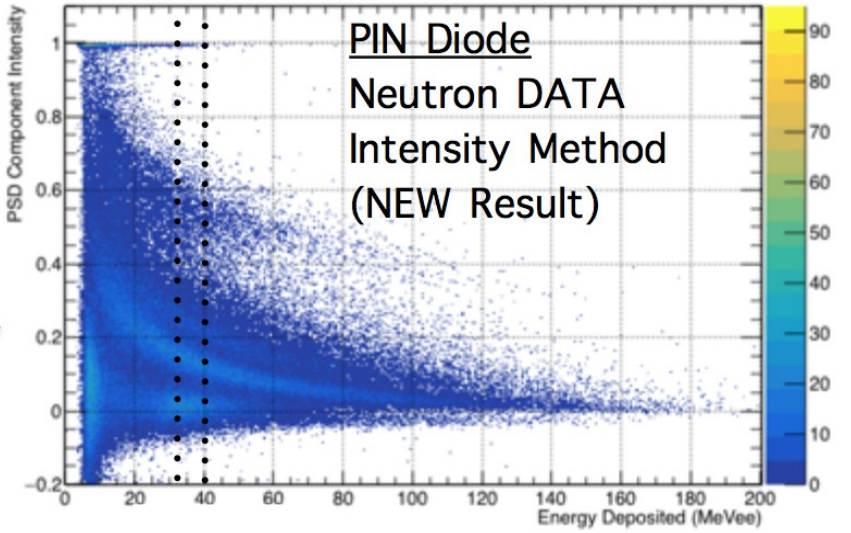


Fit function:
$$I(t) = N_3 e^{-\frac{t-t_0}{580\ \mathrm{ns}}}$$

Charge Ratio Method (old method)

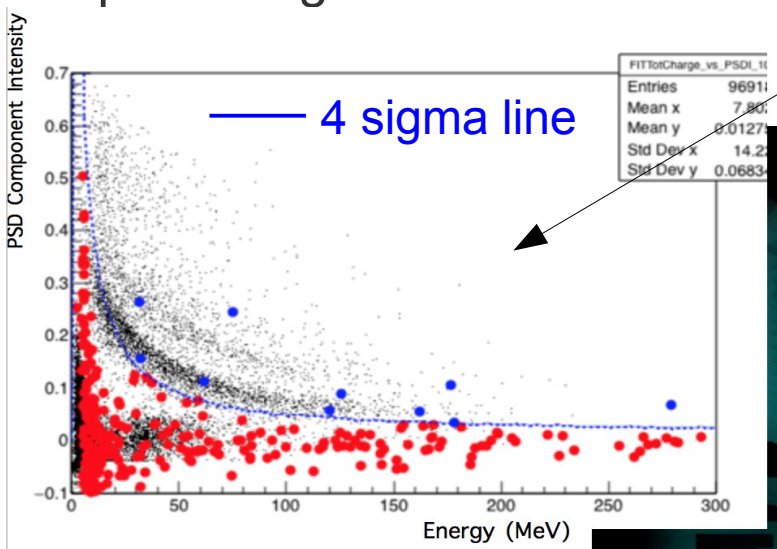


3 Component Method (NEW)



PSD outlook

- Feature branch feature/ecl-PSD with (particle dependent) signal shape simulation and PSD signal extraction now available in git
- First promising result on cosmic data



Black dots is TRIUMF data

Cosmic event with hadron-like topology

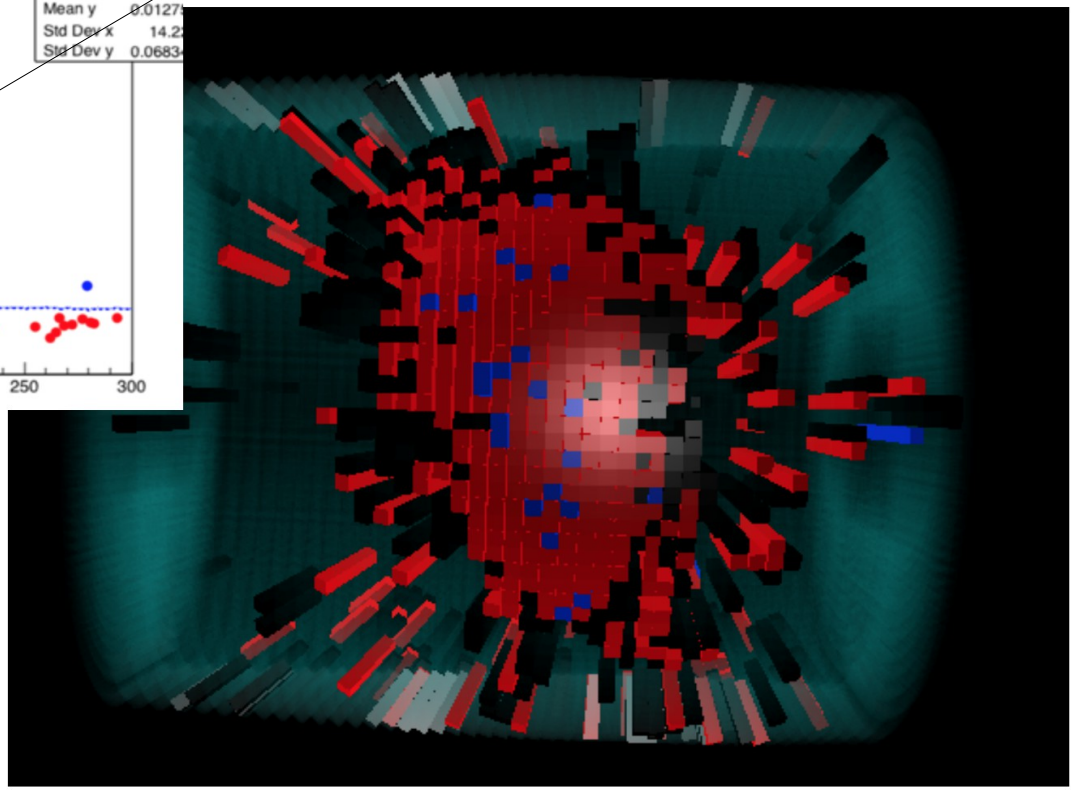


Image Legend:

Red crystals below 4 sigma threshold (electromagnetic)
Blue crystals above 4 sigma threshold (hadronic)
Black crystals have noise (triggered but no pulse)

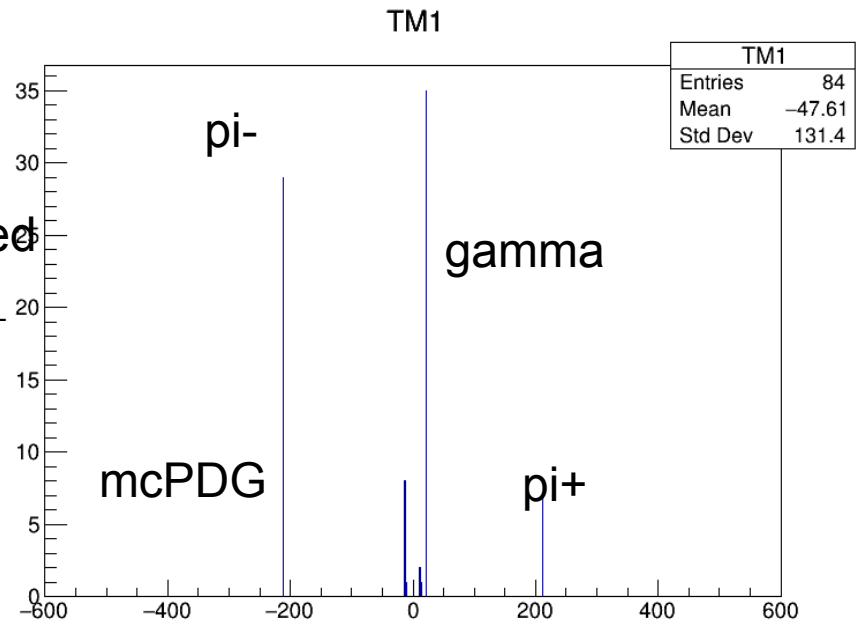
- @LNF we will collaborate to develop new clustering algorithms which use PSD information to improve particle ID

Backups

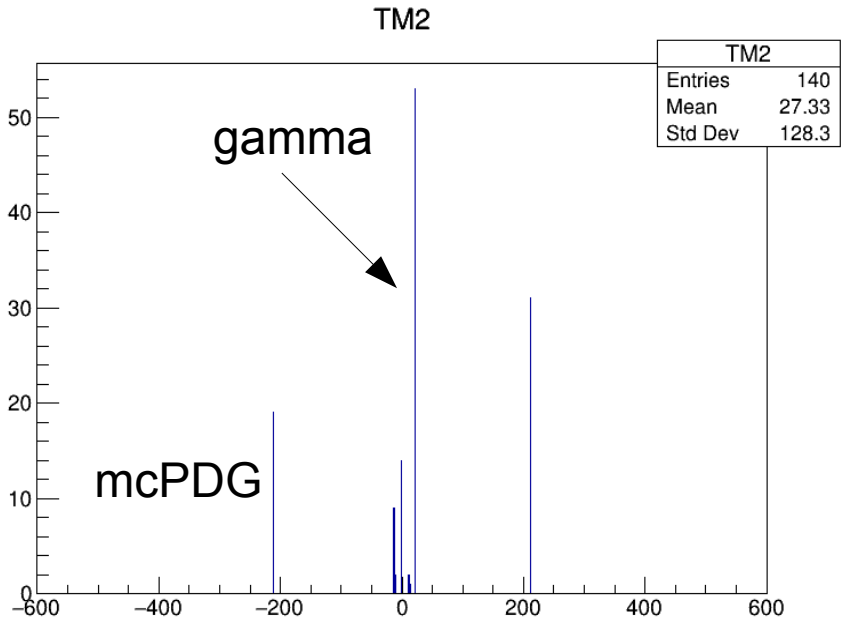
Contributors for LM > 2, single K_L

- We look for MC-matches of 1st and 2nd most energetic deposits in CR if they are not matched to the K_L, in previously defined sample:
- Total CR = 570 (1077) (without any selection)
- CR LM > 1 = 162
- CR LM > 2 = 27

Most E deposit



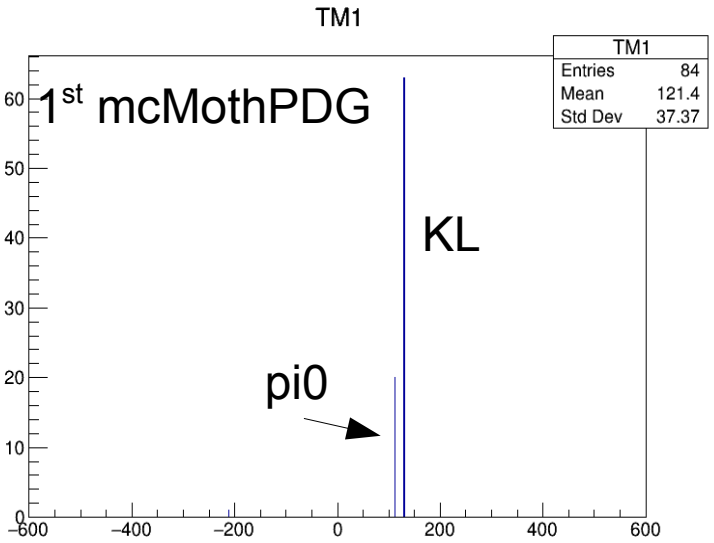
Second most E deposit

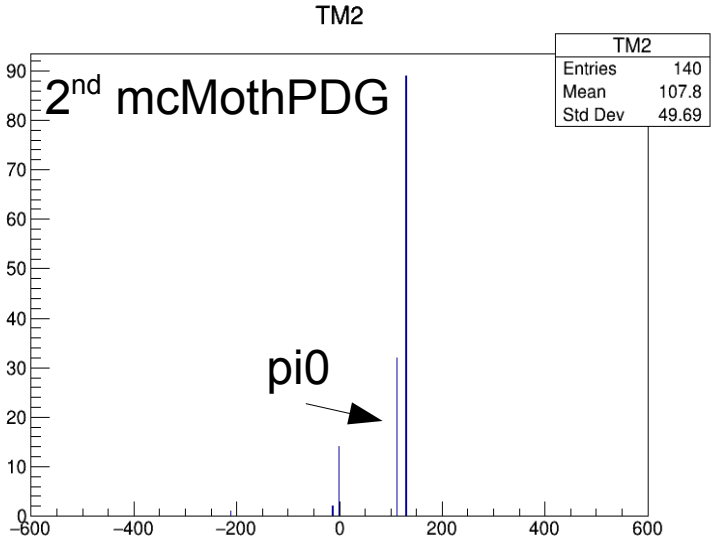


Single KL

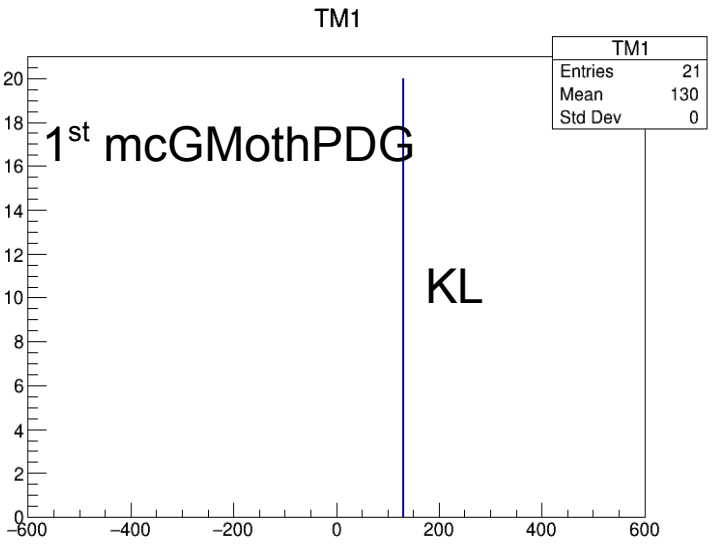
- Now we look for mcMothPDG and mcGMothPDG of 1st and 2nd mostE
- At 2nd generation (almost) all contributors are seen to come from KL (as expected)

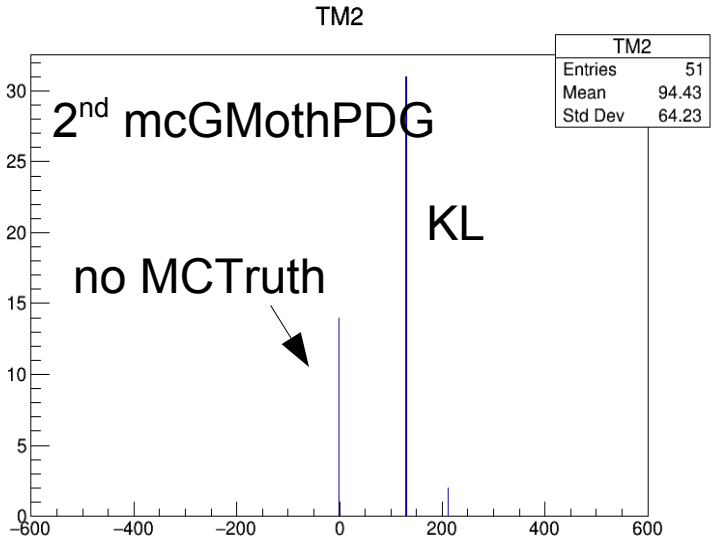
MCMother of matched particle if !=K_L





MCGMother of matched particle if !=K_L && MCMother !=K_L

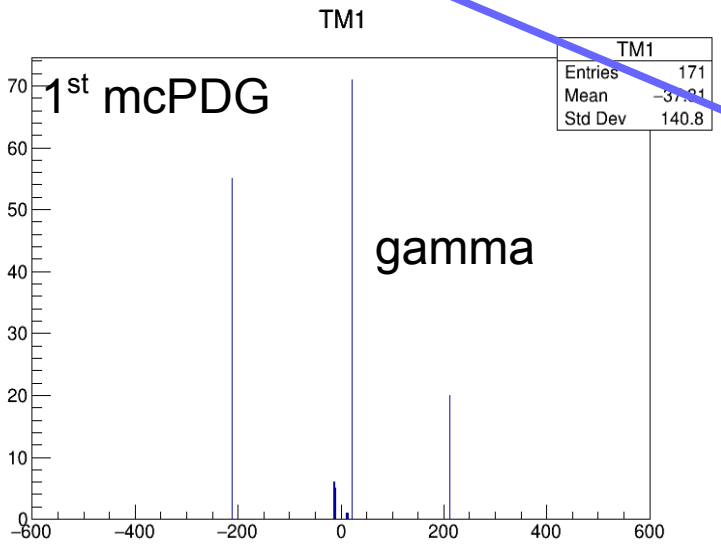


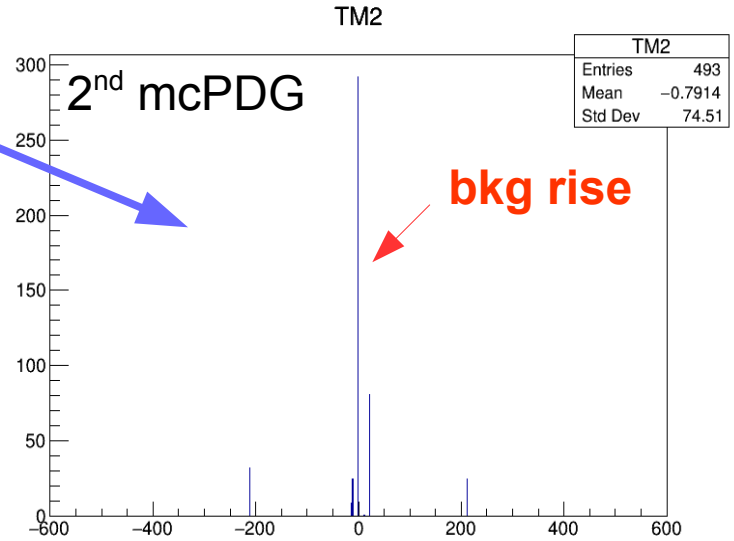


Single KL + bkg

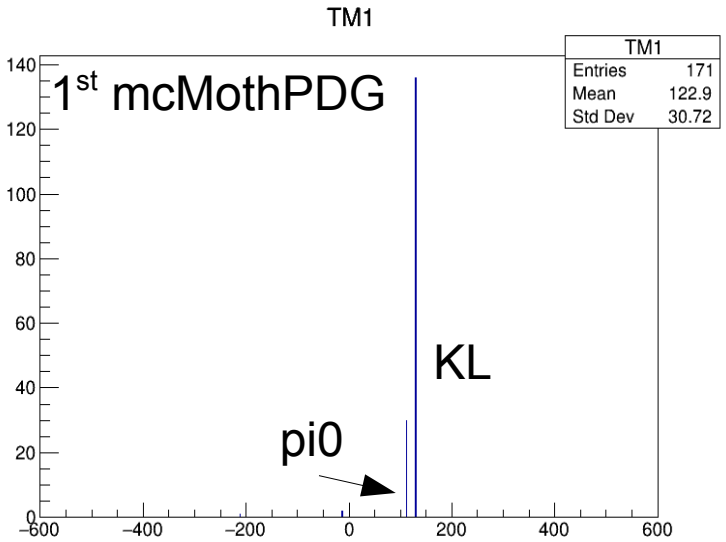
- Increase in cluster number (all) : 570 -> 979
- LM > 1 : 162 -> 537

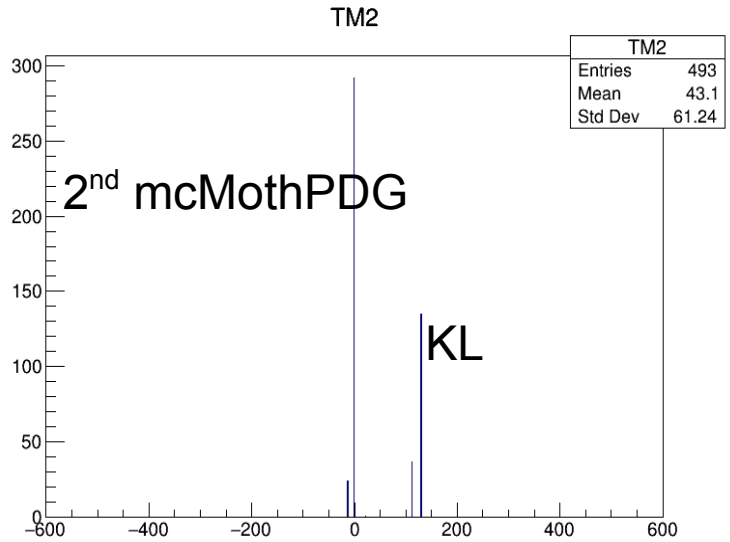
PDG of matched particle if !=K_L





MCMother of matched particle if !=K_L

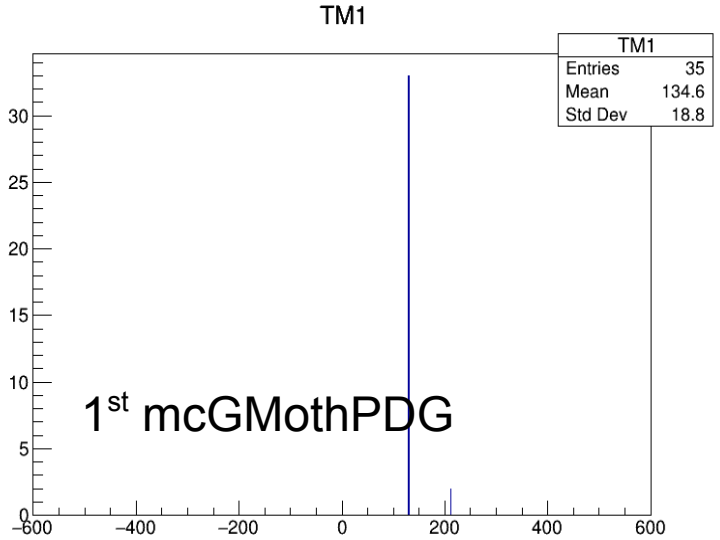


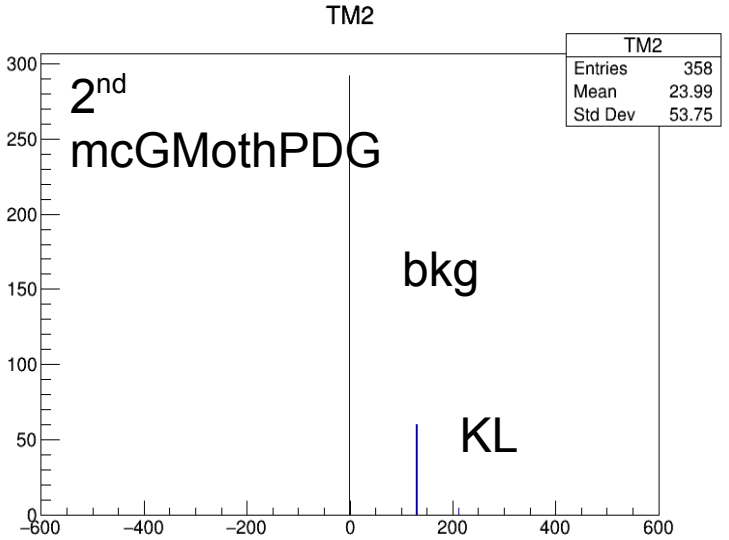


Single KL + bkg (2)

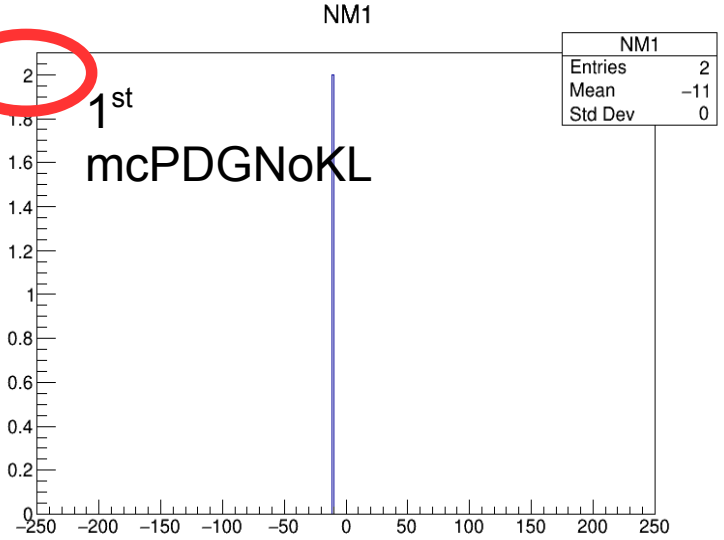
- Bkg has a pile-up effect on particle deposits, no bkg-bkg CRs found
- All contribution coming either from KL or bkg, as expected

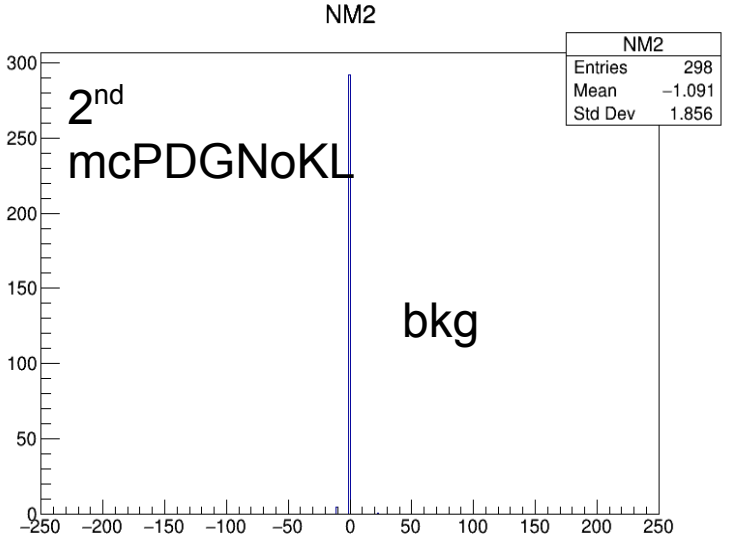
MCGMother of matched particle if !=K_L && MCMother !=K_L





mcPDG of particles not matched K_L relatives

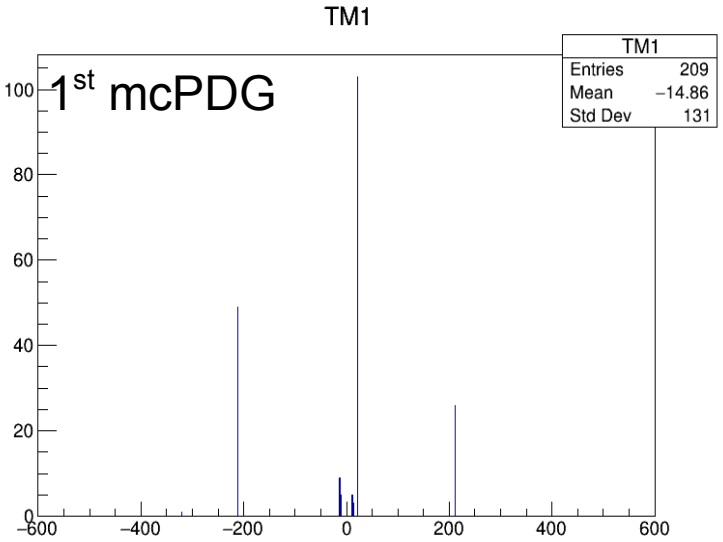


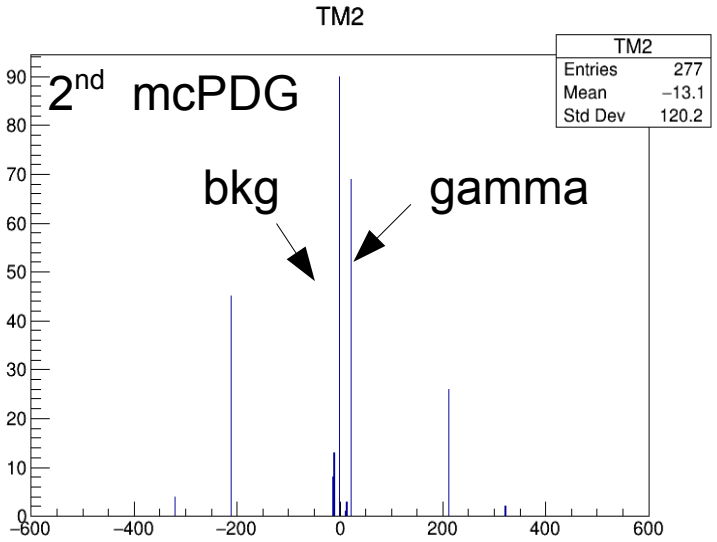


Generic $B\bar{B}$ (w bkg) (1000 evts)

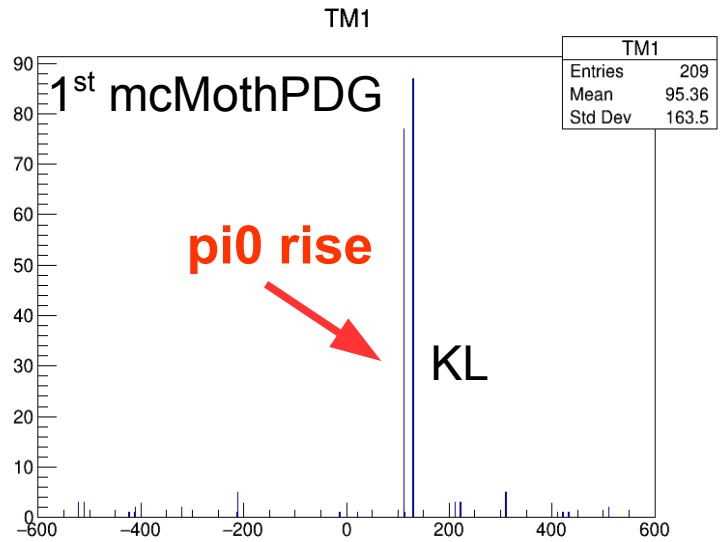
- True KL CRs (i.e. w KL-Match) : 707
- LM > 1 : 339

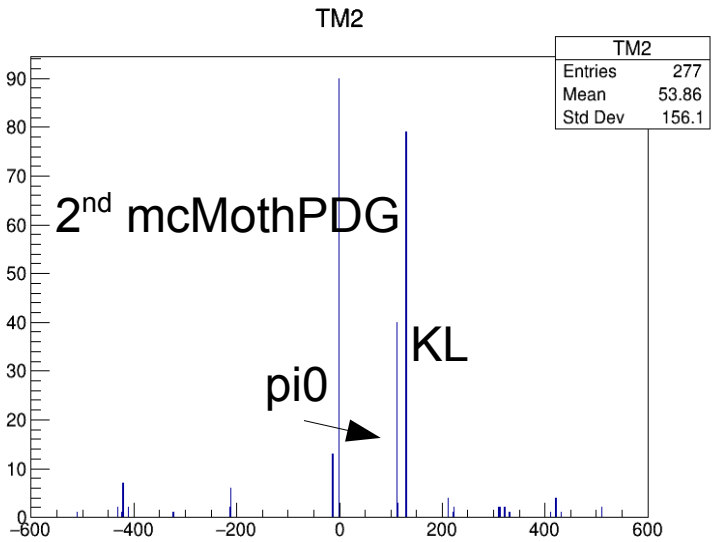
PDG of matched particle if !=K_L





MCMother of matched particle if !=K_L

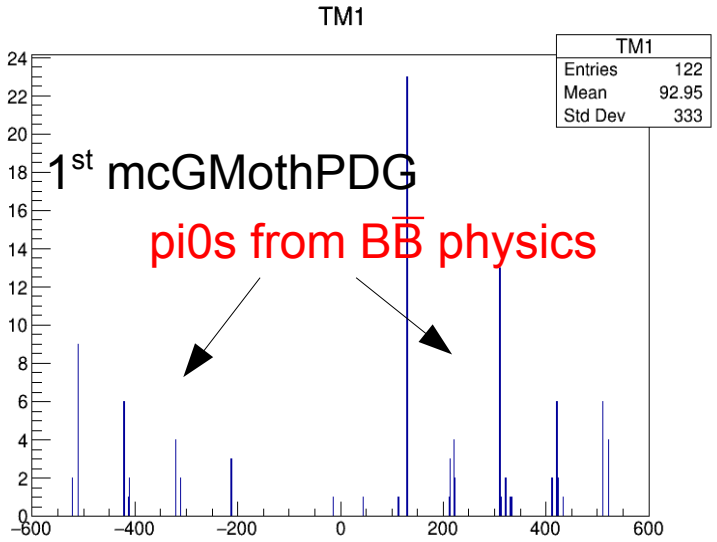


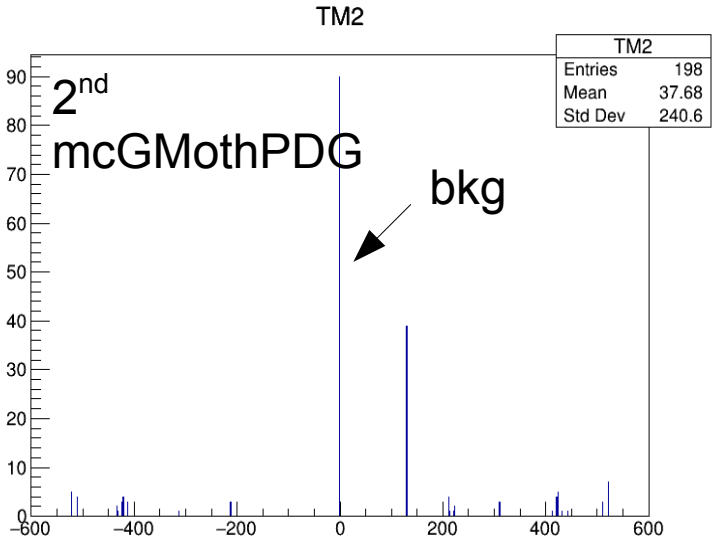


Generic $B\bar{B}$ (w bkg) (1000 evts) (2)

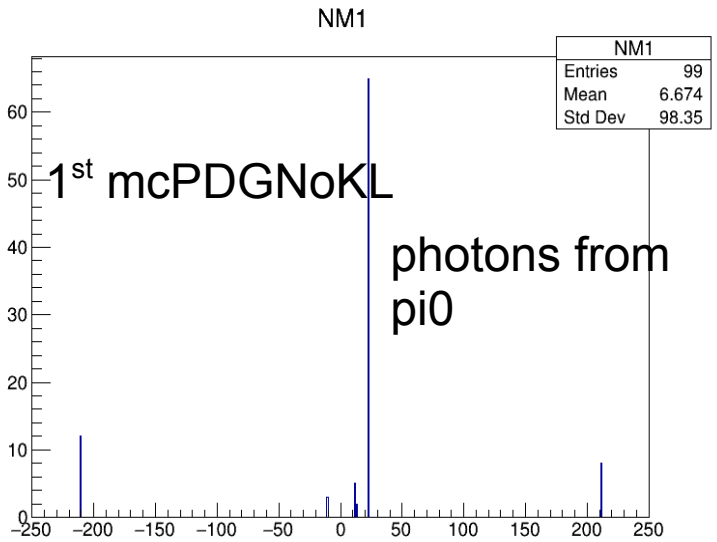
- Main contribution from physical photons coming from pi0s and bkg
- Residual contribution from pi+/pi-

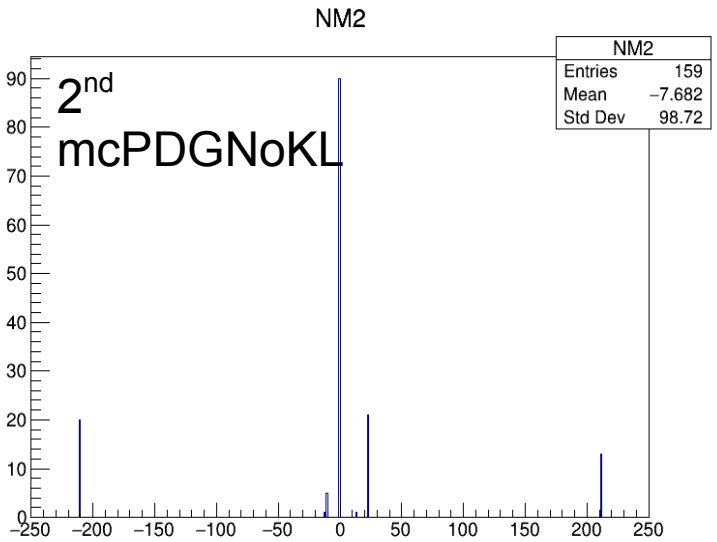
MCGMother of matched particle if !=K_L && MCMother !=K_L



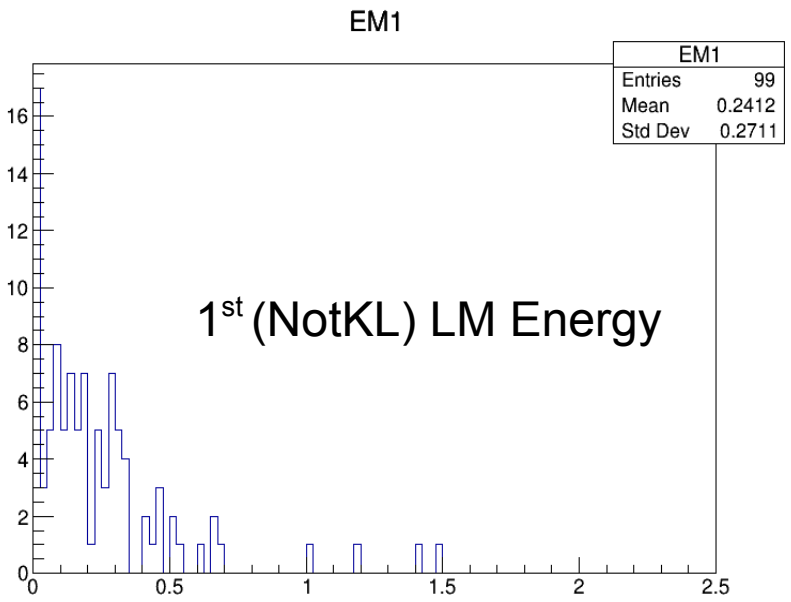


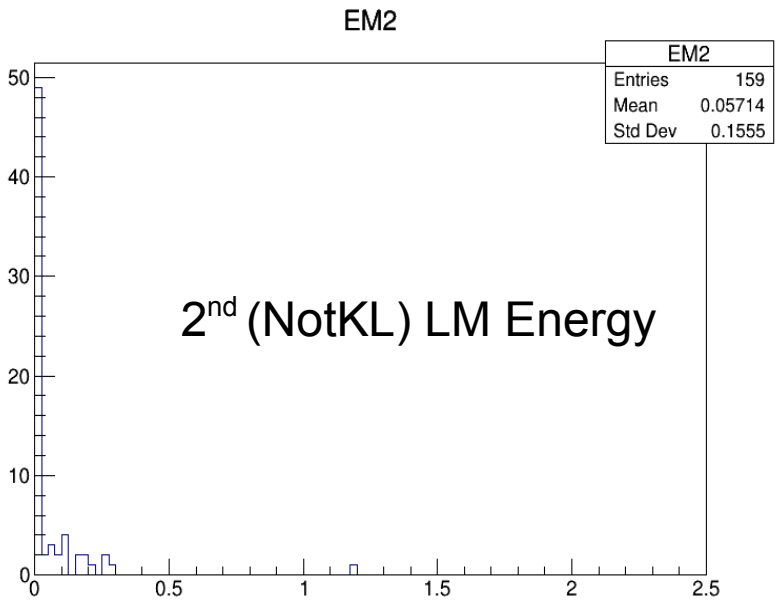
mcPDG of particles not matched to K_L





Generic $B\bar{B}$ (w bkg) (3)

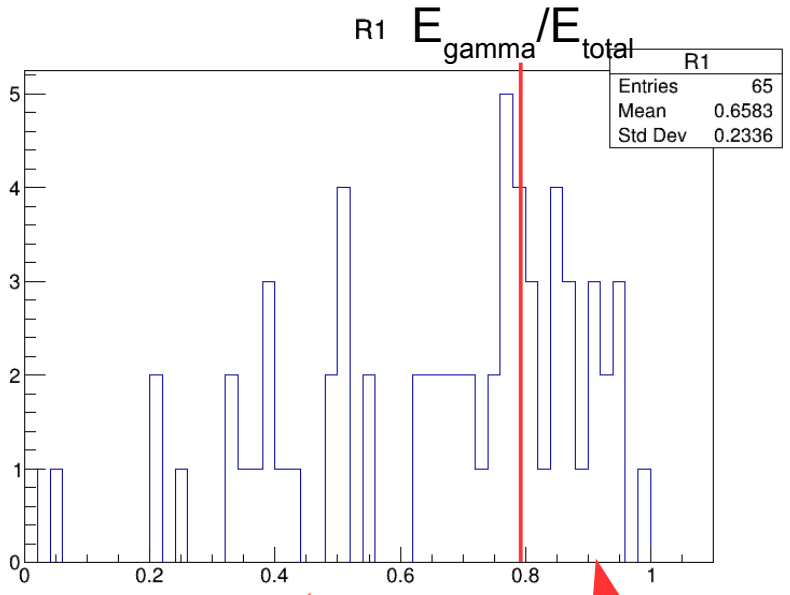




- Main non-KL matches to CR in generic BB are:

  photons from pi0s, bkg photons, pi+/pi-
  - pi+/pi-: most likely split-offs (we require trackMatch==0 during selection), no useful information from splitting (and difficult to do)
  - bkg: is it useful for K_L reconstruction to split the CR in order to separate the (low E) bkg contribution?
  - photons from pi0s: interesting case

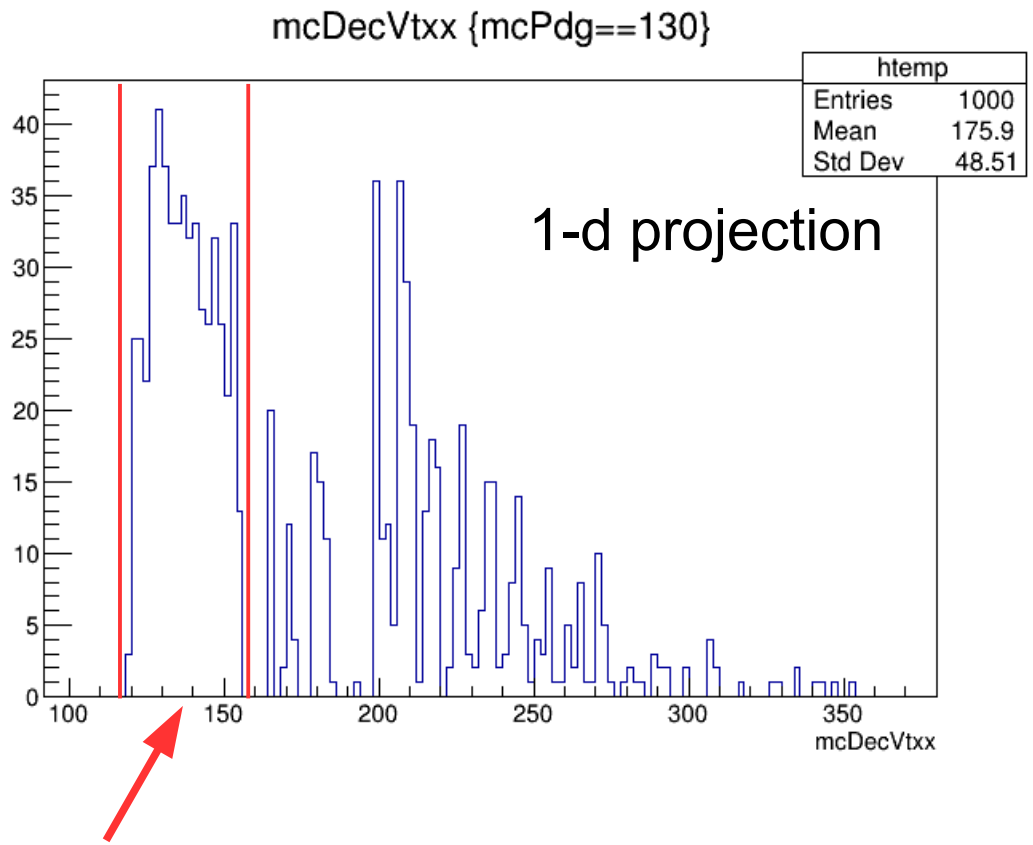
Conclusion at October B2GM



- This study suggests K_L/gamma overlap might be the physics case to justify a splitter for neutral hadron hypothesis
- Usefulness for a splitter to subtract bkg contribution has also to be understood (also in higher bkg environment)
- A "photon/hadron N2splitter": would do both jobs

“Strict” MC match

- To remove annoying multiple associations due to interactions or to distant split-offs
- We require the CR to be matched either to a KL which has interacted in the TOP or the ECL or to a daughter of a KL which has interacted in the TOP or the ECL



Resolution

- pGun KL + bkg (EvtGenLike E spectrum)