Analysis Chain Overview

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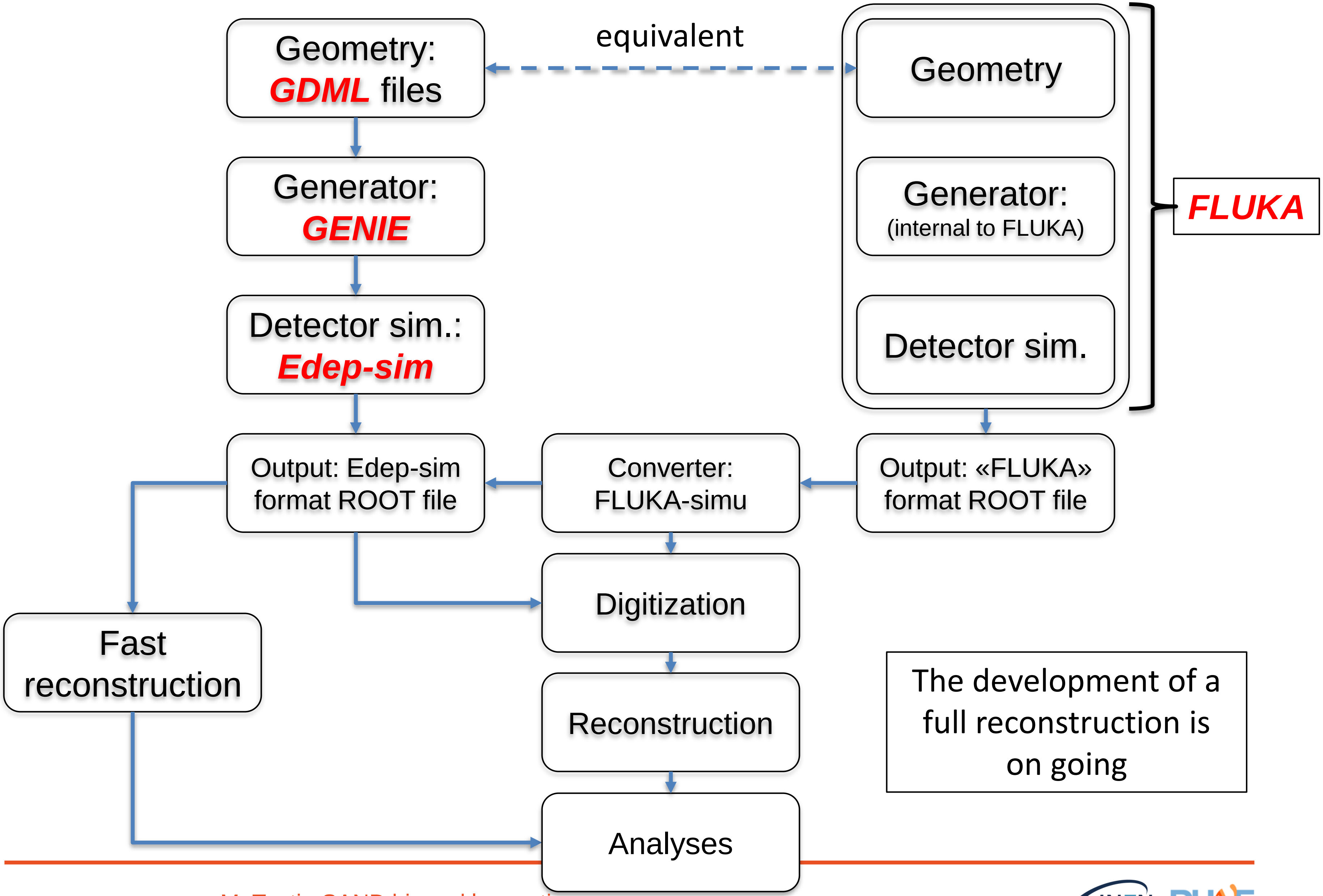
SAND bi-weekly meeting

14/07/2020

Status of the software in a nutshell



Geometry: *GDML* files

equivalent

Geometry

Generator: ***GENIE***

Generator:
(internal to FLUKA)

FLUKA

Detector sim.: ***Edep-sim***

Detector sim.

Output: Edep-sim format ROOT file

Converter: FLUKA-simu

Output: «FLUKA» format ROOT file

Digitization

Fast reconstruction

Reconstruction

Analyses

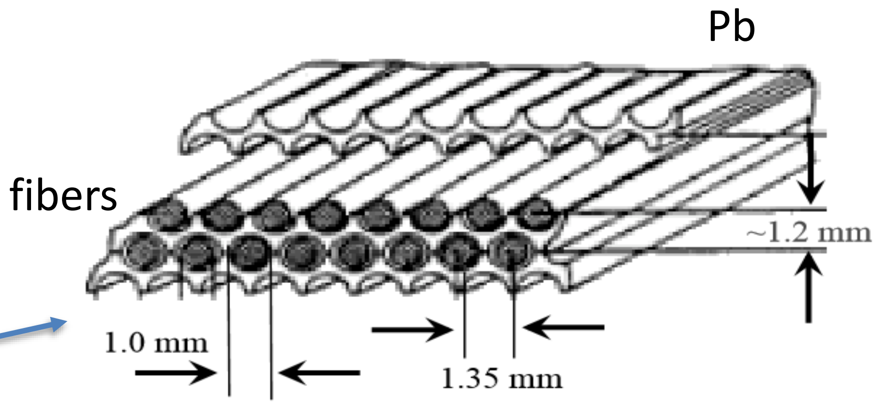
The development of a full reconstruction is on going

GEOMETRIES

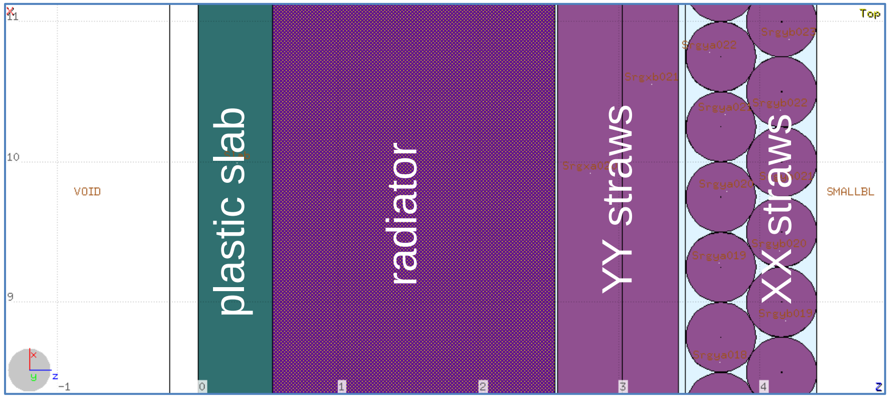
- ECAL + 3DST + TPC → GDML (from Guang…Thank you!!)
- ECAL + 3DST + STT → GDML and FLUKA
- ECAL + STT only → GDML and FLUKA

FLUKA geometry

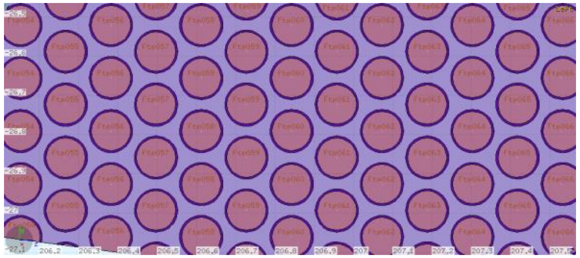
Full simulation of the magnet, tracker (STT), electromagnetic calorimeter (ECAL)



Kloecal fine structure



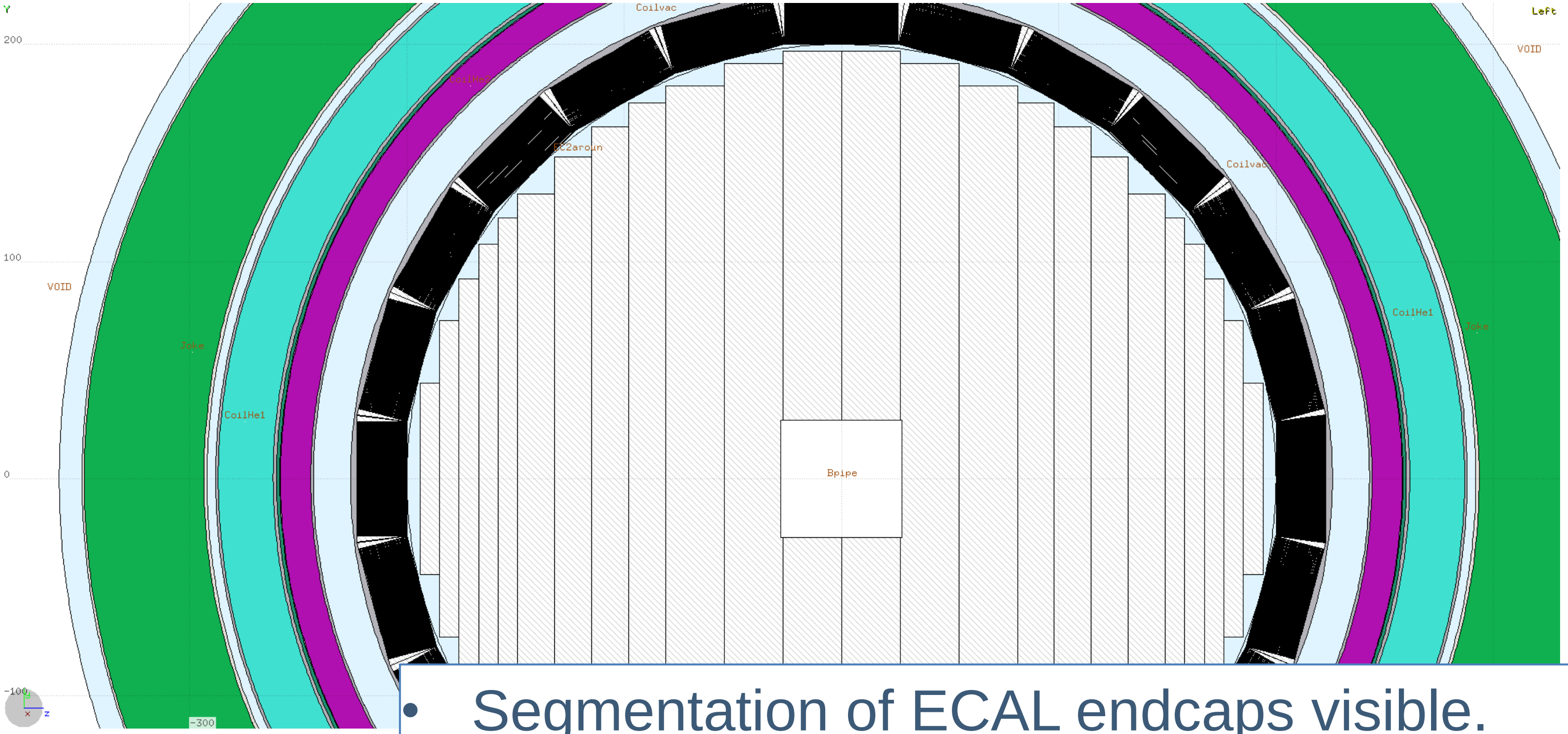
Detail of a STT module



Detail of a ECAL barrel module implemented in FLUKA: fibers, glue, lead

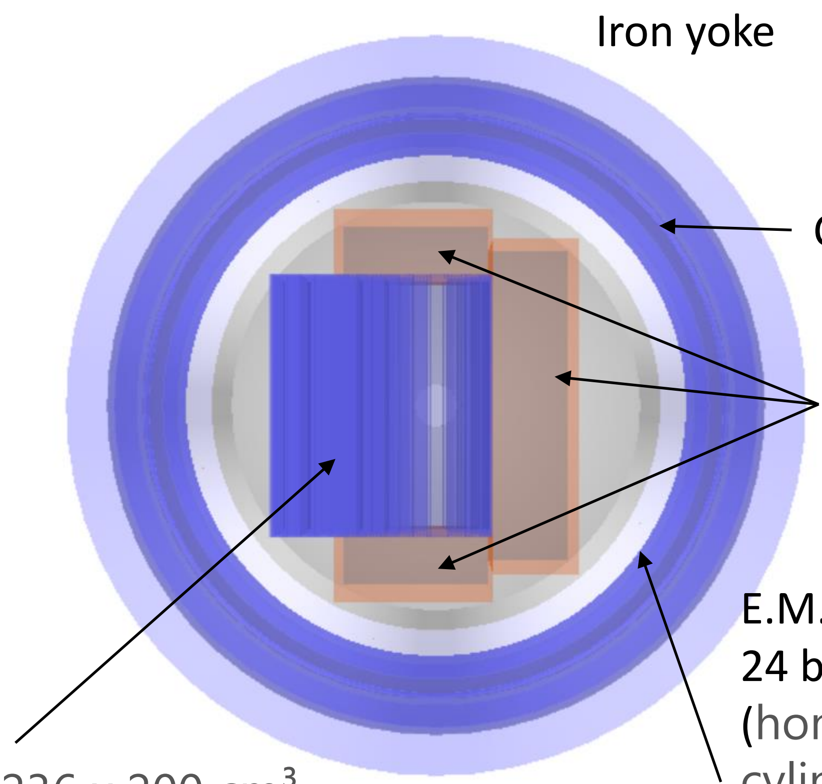
Recent: detailed ECAL extended to endcaps

Detail of the SAND cross section at the level of the ECAL endcap



- Segmentation of ECAL endcaps visible. Inner structure equal to the barrel module
- Analogue geometry available with 3DST inside

GDML geometry: 3DST + TPC



Iron yoke

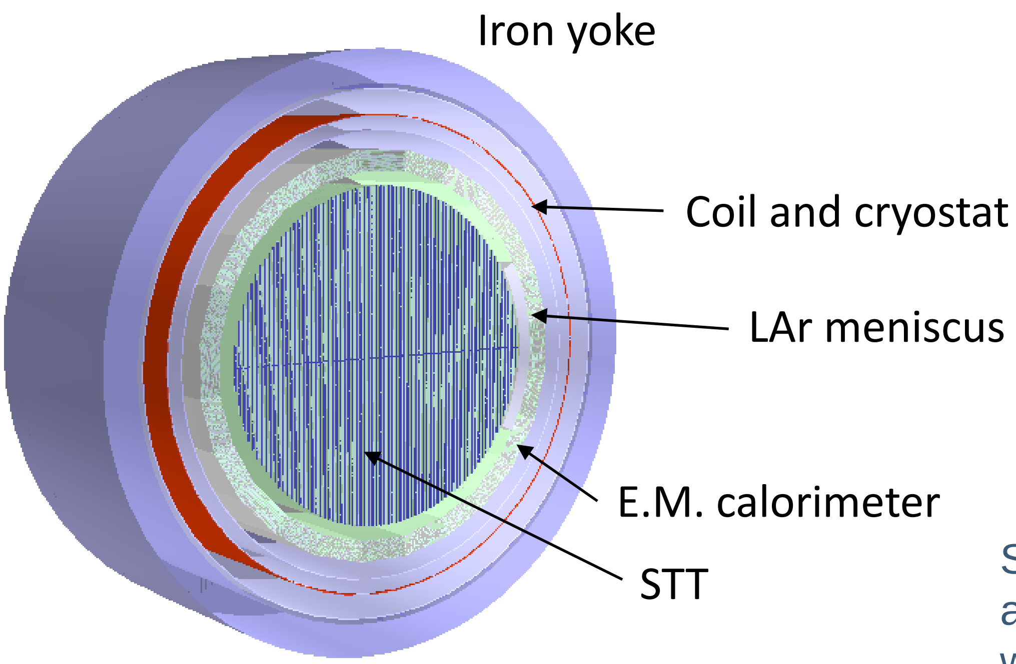
Coil and cryostat

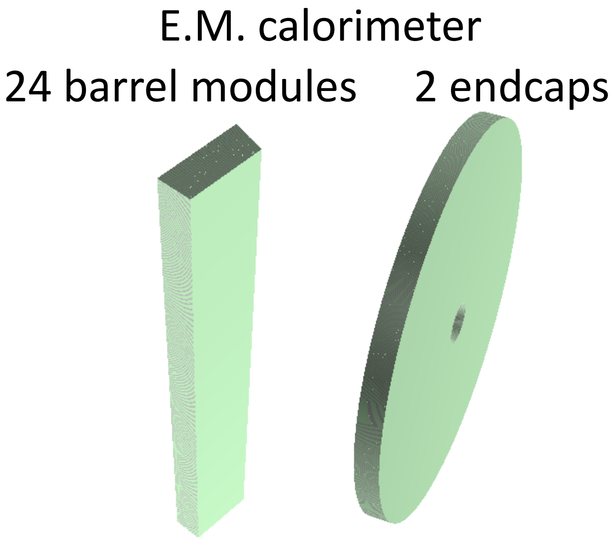
GAr TPCs

E.M. calorimeter:
24 barrel modules
(homogeneous hollow cylinder segments)
2 endcaps:
(homogeneous cylinders)

3DST: 252 x 236 x 200 cm^3

GDML geometry: STT-only

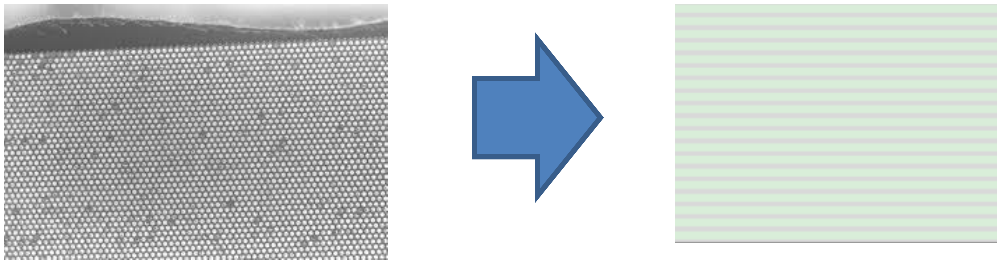




Spaghetti calorimeter approximated as 209 scintillation layers alternated with 209 lead layers

~ 90 STT modules:

- target (CH2 or C)
- radiator (plastic foils)
- XX straw tube plane
- YY straw tube plane



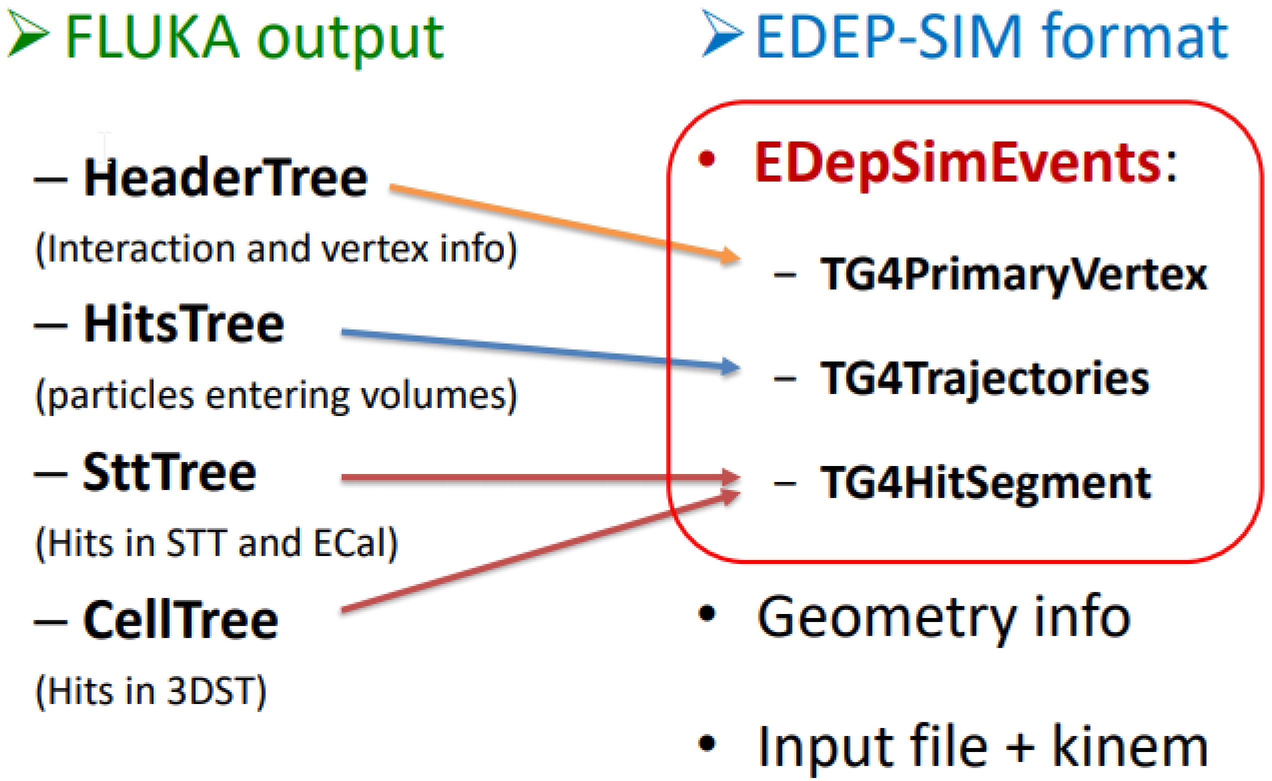
0.7 mm scintillation layer (green)

0.4 mm lead layer (gray)

GENIE

- We developed a dedicated code based on GENIE 3 (GENIE 3.00.06) to generate neutrino events in the detector. The code:
  - accepts geometry files in gdml format
  - accepts DUNE beam spectrum files in root format
  - takes into account the beam direction (theta=0.101 rad). Beam size set to 3 m.
  - generates any neutrino flavors in the beam and all possible interactions but it is possible to change:
    - the neutrino flavor list
    - the GENIE tune (default: G18_02a_00_000)
    - the GENIE event generator list (default: Default)

From FLUKA output to Edep-sim output



- FLUKA output
  - **HeaderTree**
    (Interaction and vertex info)
  - **HitsTree**
    (particles entering volumes)
  - **SttTree**
    (Hits in STT and ECal)
  - **CellTree**
    (Hits in 3DST)

- EDEP-SIM format
  - **EDepSimEvents:**
    - **TG4PrimaryVertex**
    - **TG4Trajectories**
    - **TG4HitSegment**
  - Geometry info
  - Input file + kinem

In the FLUKA OUTPUT the geometry information are partially in the SttTree and the info about the generated events are all in the HeaderTree

Digitization (for FLUKA files)

- A proper and distinct from GEANT4 process is necessary
  - since the geometry information are stored in different way (from SttTree)
  - since for ECAL the simulation details are different

→the parameters for p.e./MeV and the p.e. time distribution were tuned accordingly to the measured values for MIP particle crossing the middle of the barrel module (as done for geant4)

THE OUTPUT from digitization is the same as from edepsim!
→ the reconstruction will be the same for fluka and genie+edepsim chains

Digitization: ECAL

NIM A 482 (2002) 364-386

- Detailed digitization of the ECAL response takes into account:
  - Number of photons per deposited energy; scintillation time; attenuation and propagation time along the fibers; response of PMT
- Reproduction of measured performances:

Time resolution

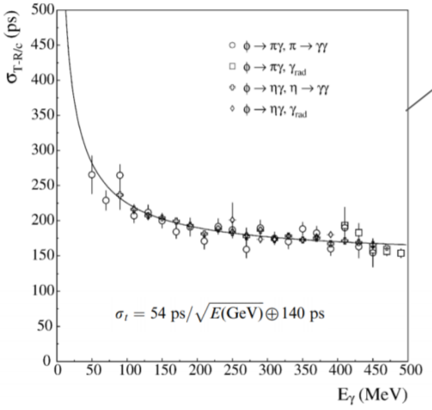
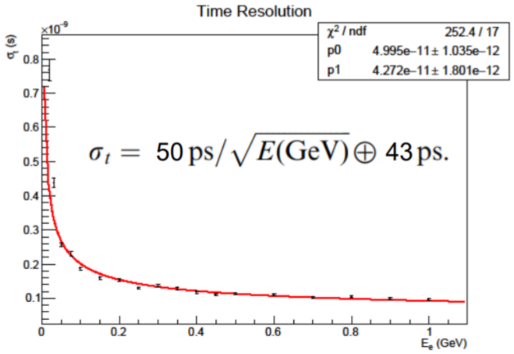


Fig. 32. Time resolution as a function of E_γ for ϕ radiative decays.

Intrinsic resolution:
$\sigma_t = 54\ \mathrm{ps}/\sqrt{E(\mathrm{GeV})} \oplus 50\ \mathrm{ps}.$



$\sigma_t = 50\,\mathrm{ps}/\sqrt{E(\mathrm{GeV})} \oplus 43\,\mathrm{ps}.$

Energy resolution

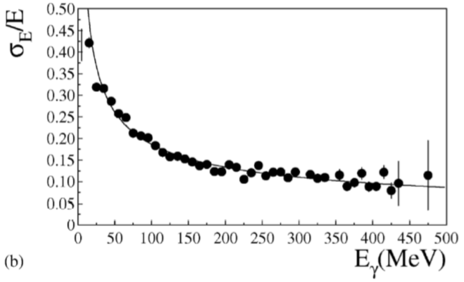
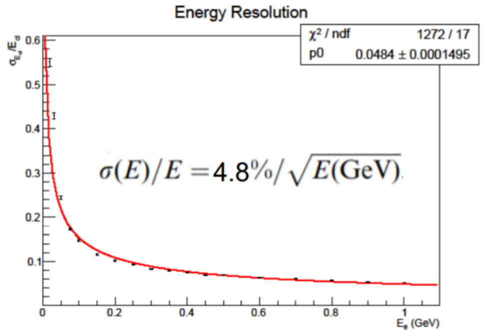


Fig. 20. $(E_{cl} - E_\gamma)/E_\gamma$ (a) and resolution (b) vs. E_γ for $e^+e^-\gamma$ events. The fit gives $\sigma(E)/E = 5.7\%/\sqrt{E(\mathrm{GeV})}$.



$\sigma(E)/E = 4.8\%/\sqrt{E(\mathrm{GeV})}$

Digitization: STT

- STT space-resolution (0.2 mm for X and Y coordinates, 0.1 mm for Z coordinate) simulated by means of Gaussians
- Energy threshold for STT-hits: 0.1 keV
- For any charged particle in MC-tracks, hits for each STT plane are grouped to get the “STT-digits” in X-Z and Y-Z views
  - Digit coordinates from the average of hit coordinates
  - Time-resolution on STT digits: 1 ns (Gaussian smearing)

Reconstruction strategy (without MC truth)

- **Step 0** - Vertex reconstruction based on STT-hit topology
- Track finding (global transform method)
- Linear or circle fits of the tracks
- **Step 1** - Vertex reconstruction from crossing of 2 most rigid tracks
- Possible repetition of the procedure
- Track matching ⇒ 3D track

in both views (Y-Z and X-Z)

- $p_\perp$ from Larmor radius
- dip-angle λ from x-vs-ρ fit

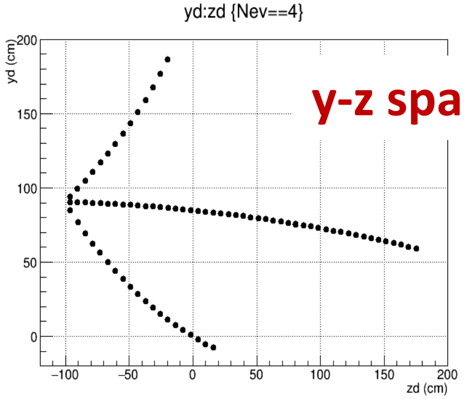
momentum estimate $p = p_\perp / \cos \lambda$

- ECal hits compatible with tracks ⇒ ToF measurement ⇒ β estimate for each track ⇒ charged particle Id …

From Vertex to Track reconstruction

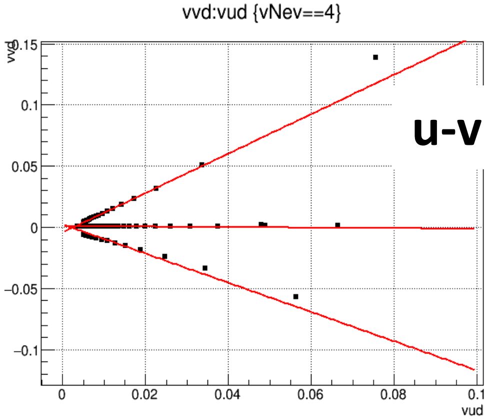
Coordinate transformation by using reco-Vertex ((z_V,y_V)):

$$u = +(z-z_V) / [(z-z_V)^2 + (y-y_V)^2]$$
$$v = -(y-y_V) / [(z-z_V)^2 + (y-y_V)^2]$$



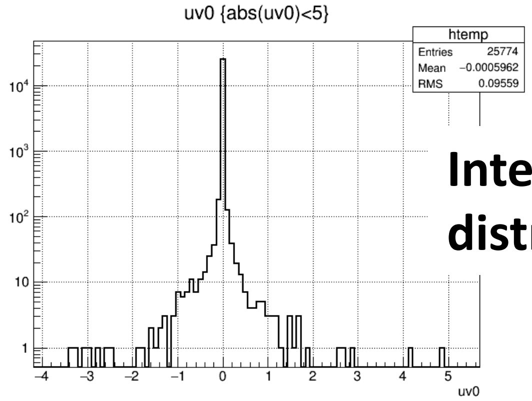
y-z space

Curved trajectories become straight lines



u-v space

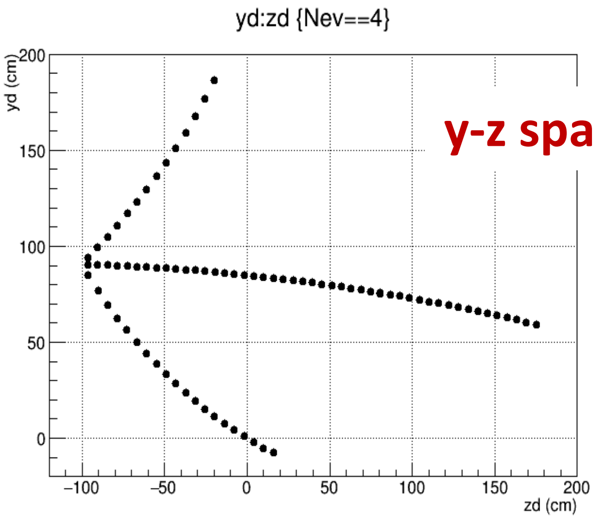
Parameters of tracks in u-v space



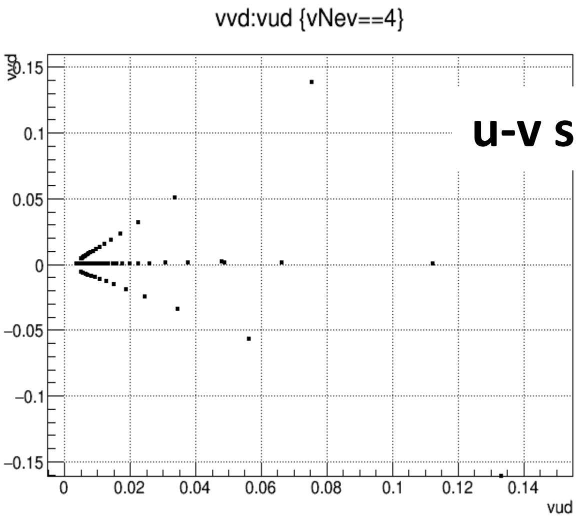
Intercept distribution

Intercepts more peaked at 0 if Vertices are well reconstructed

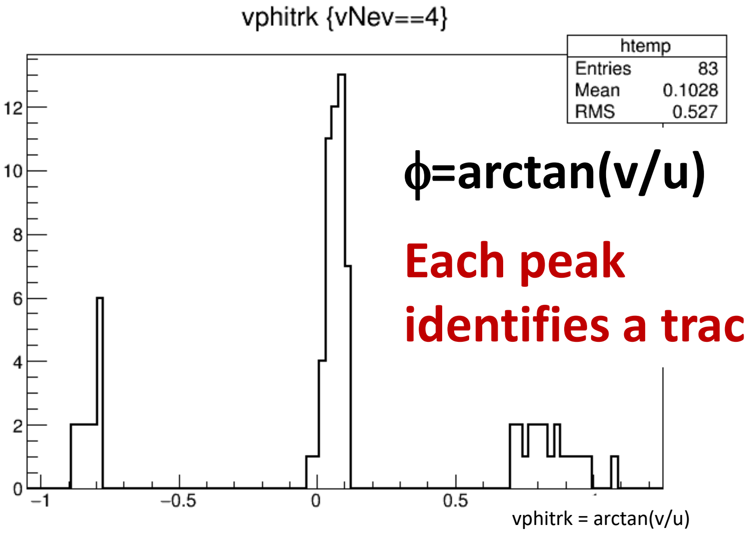
Track reconstruction by fits



y-z space

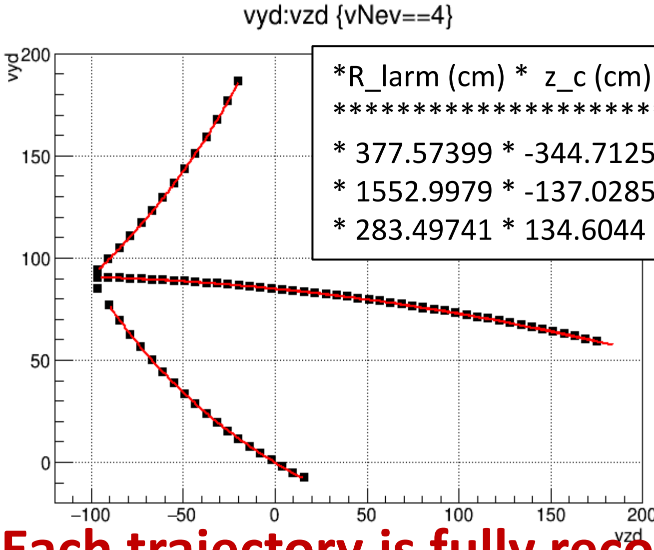


u-v space



ϕ=arctan(v/u)

Each peak identifies a track



```
*R_larm (cm) *  z_c (cm) *  y_c (cm) *
******************************
* 377.57399 * -344.7125 *  378.457
* 1552.9979 * -137.0285 * -1462.071
* 283.49741 * 134.6044  *  249.4256
```

Track finding and fits

Each trajectory is fully reconstructed!

Identification of charged tracks

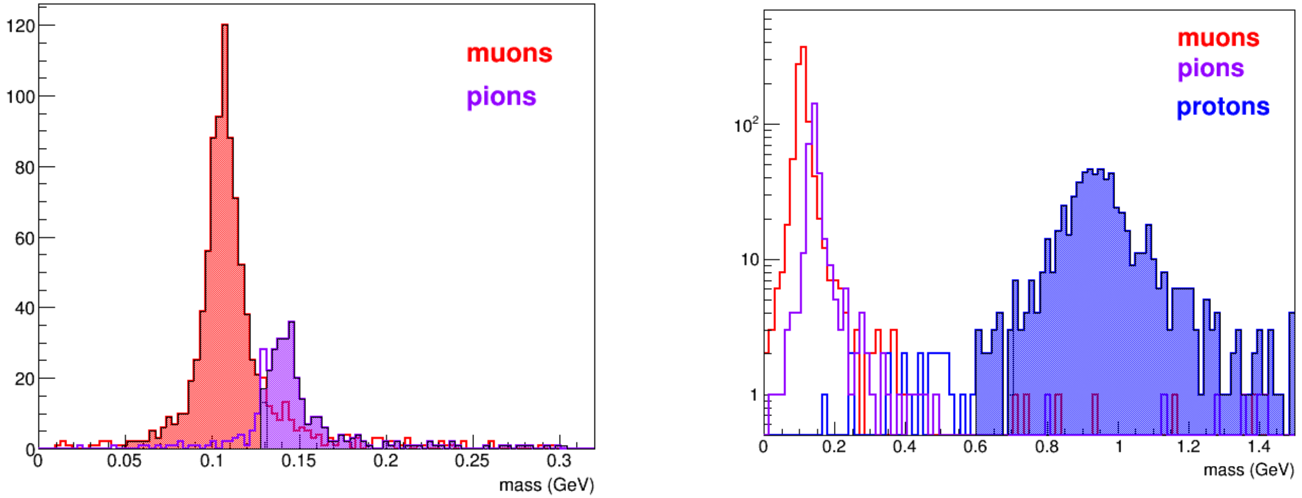
From 3D-track: evaluation of Track-Length (L) and Time of Flight (ToF)

⇒ velocity estimate: $\beta = L / ToF$

- ✓ L from sum of distances between STT-digits along the 3D-trajectory
- ✓ ToF from MC-times of STT-digits … → time resolution NOT included!

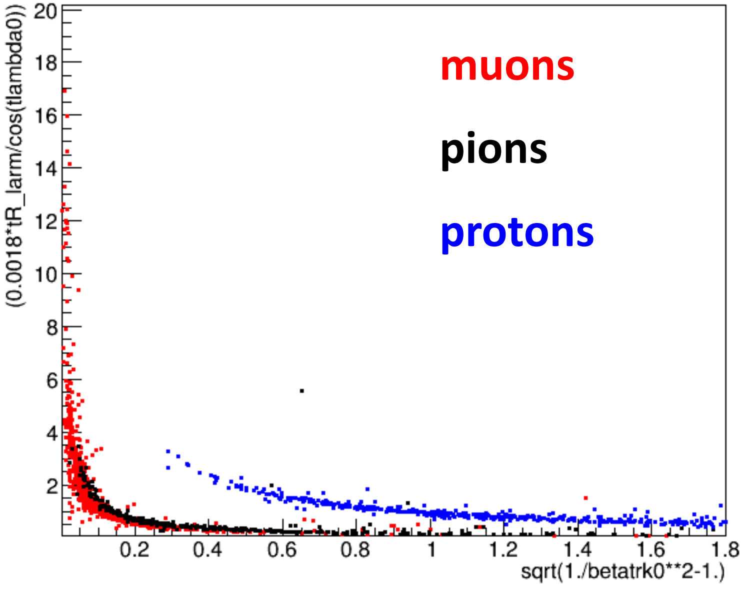
Particle identification: $\boxed{m = p / \beta\cdot\gamma = p\cdot\sqrt{(1/\beta^2 - 1)}}$

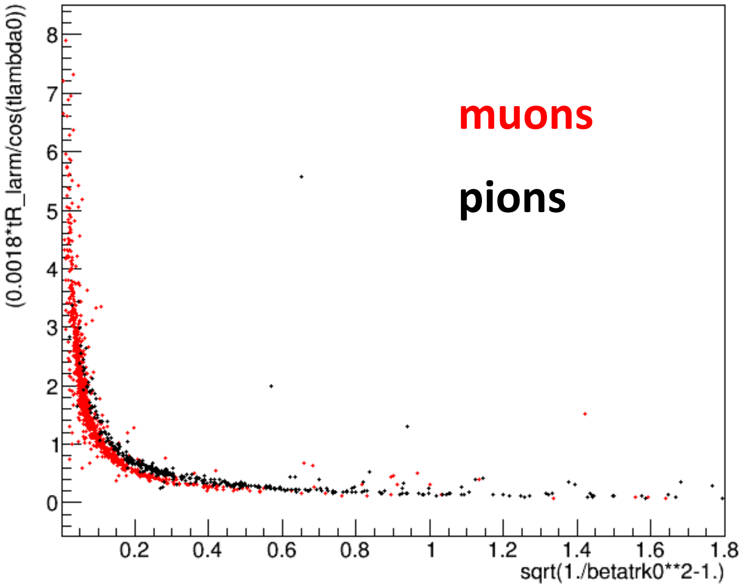
Events with no more than 3 matched tracks in the two views:



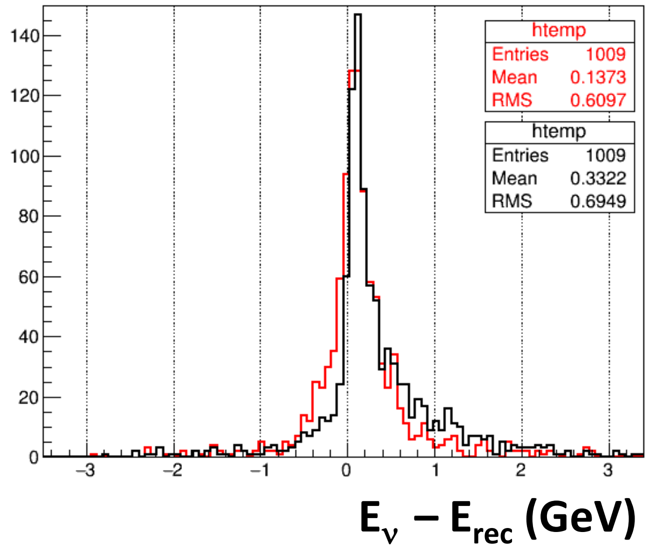
Identification of charged tracks

p vs $1/(\beta \cdot \gamma)$



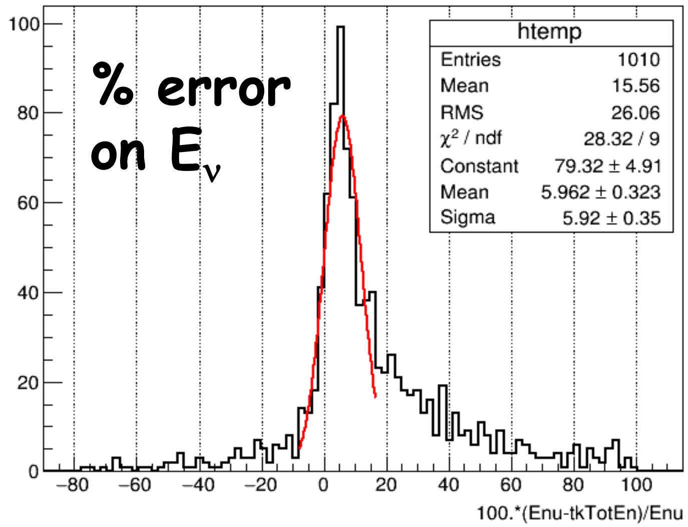


ν energy reconstruction (preliminary)

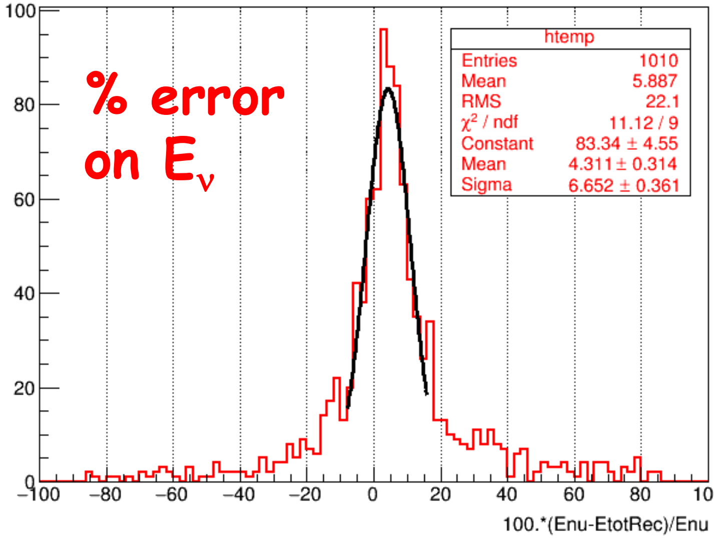


'All-tracks' energy only

'All-tracks' energy + Off-track ECal energy



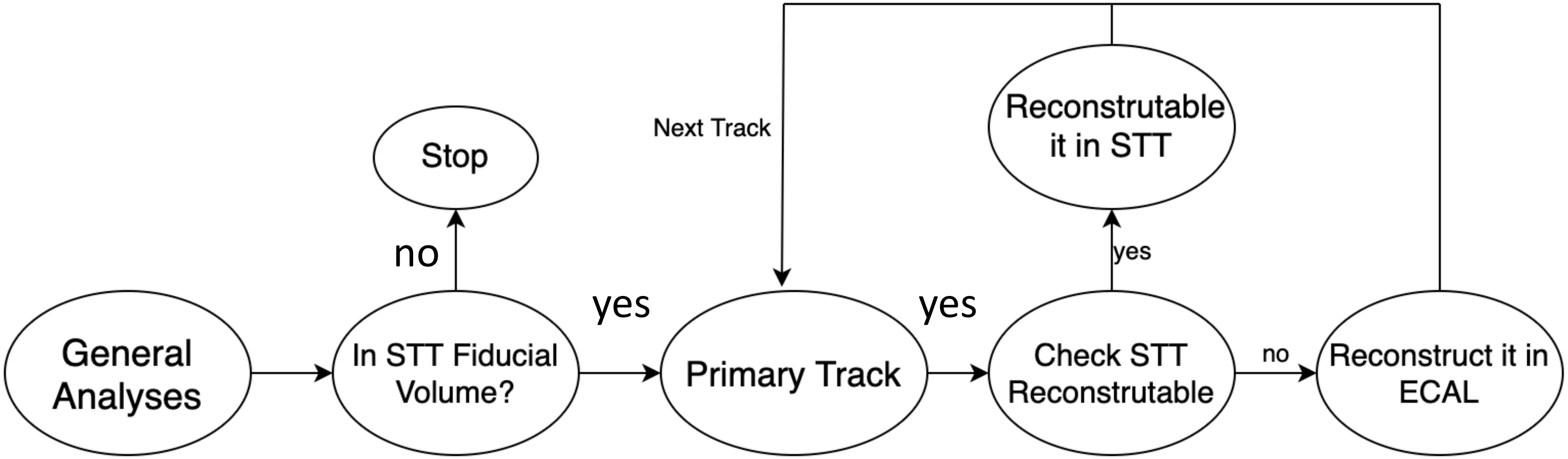
% error on E_ν



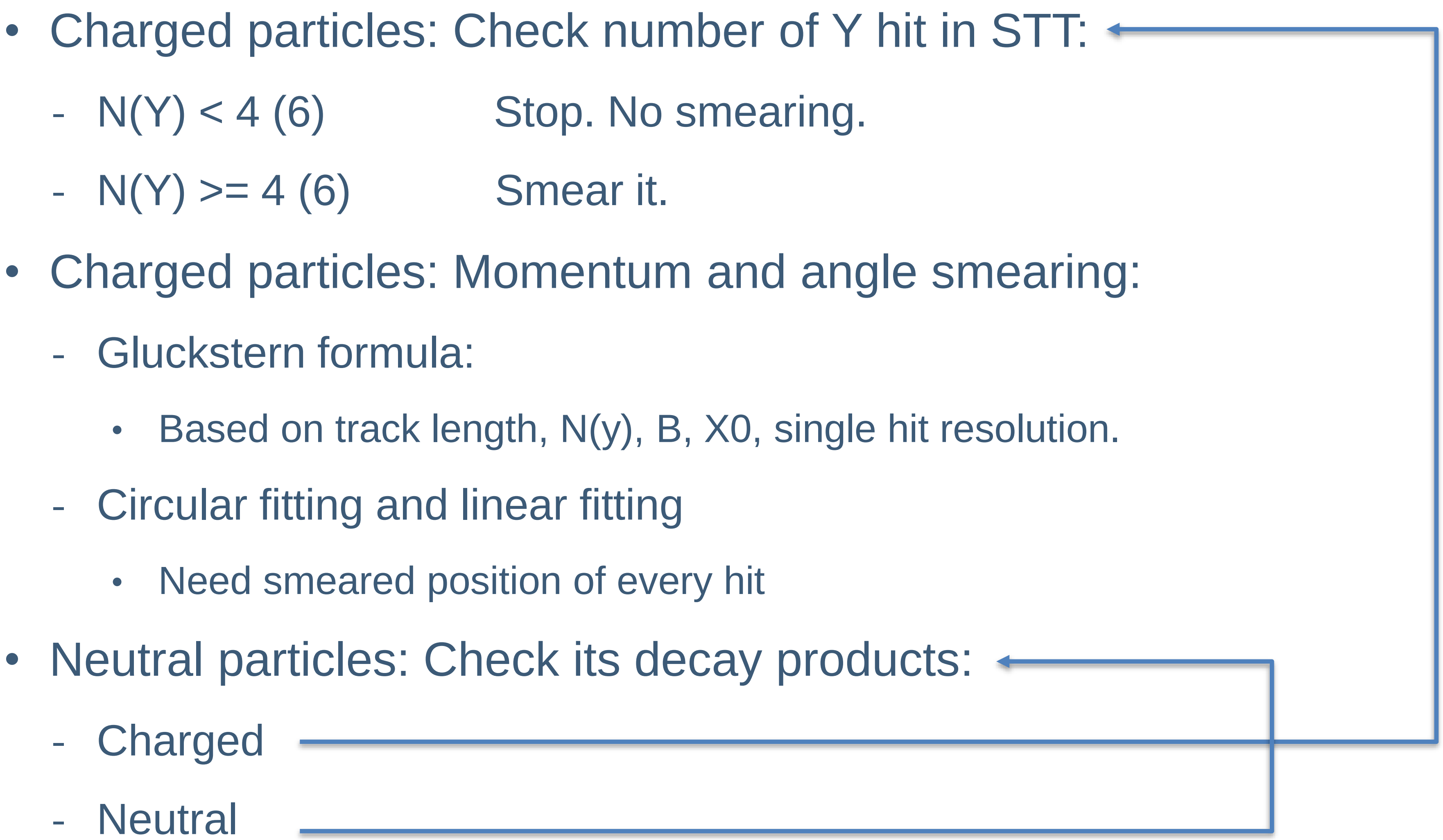
% error on E_ν

Fast Reconstruction

- Based on full detector simulation edep-sim (GEANT4)
- Treat events originating in different detector region differently
- Algorithm depends on specific analysis considered
- Single-particle smearing based on dedicated analysis/reconstruction



Fast Reconstruction in STT



- Charged particles: Check number of Y hit in STT:
  - N(Y) < 4 (6) Stop. No smearing.
  - N(Y) >= 4 (6) Smear it.
- Charged particles: Momentum and angle smearing:
  - Gluckstern formula:
    - Based on track length, N(y), B, X0, single hit resolution.
  - Circular fitting and linear fitting
    - Need smeared position of every hit
- Neutral particles: Check its decay products:
  - Charged
  - Neutral

Neutral Particles Reconstruction

- $\pi^0 \rightarrow 2\gamma$ or $\pi^0 \rightarrow \gamma + e^- e^+$
  - Reconstruct each daughter particle's momentum separately then summing up.
- γ: $e^- e^+$ pair in STT or e.m. shower in ECAL.
  - Convert in STT: Reconstruct $e^- e^+$ track in STT
  - Convert in ECAL: find calibrated energy deposition of the e.m. shower
    - Smear earliest hit position by its resolution, connecting with vertex gives momentum direction
- Neutron: hits/cells detached from primary vertex.
  - Interaction in STT: connecting first hit (smeared) to vertex (or first hit for single track) gives direction, reconstructing the daughter tracks gives momentum.
  - Interaction in ECAL: detached cells are used to define neutral clusters, calibrated energy deposition in the cluster is summed up, connecting earliest cell to the vertex (or first hit for single track) gives momentum direction.
  - Neutron energy in CC: time-of-flight from smeared timing at primary vertex (or first hit) and earliest hit of detected neutron candidate and reconstructed direction.
  - Neutron energy in CC on Hydrogen: calculated analytically from energy-momentum conservation.

Conclusions e outlook

- Quite mature analysis chain
- Official tools for geometry, generator and detector simulation
- Equivalent flow with FLUKA: enforce result reliability specially for neutrons and low energy processes
- Converter from FLUKA to edep-sim format to use same reconstruction software
- Detailed ECAL digitization
- Smearing for STT digits
- Event reconstruction without (or minimal) use of MC info; work in progress to avoid use of MC info at all.
- Fast reconstruction to speed-up analysis
- Code in INFN baltig repositories

Backup

p_{yz}, p and dip-angle estimations

- p_{yz} from curvature radius after circle fit in the bending plane
- p reconstruction: $p = p_{yz}/\cos(\lambda)$ λ: dip-angle
- Dip-angle reconstruction from linear fit of x-ρ correlation

where $\rho = z*\cos(\phi) + y*\sin(\phi)$

$\phi = \mathrm{atan}(-(z_0-z_C)/(y_0-y_C))$

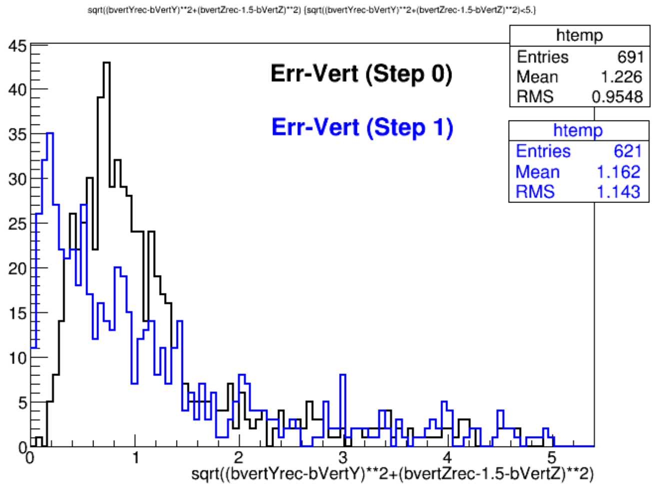
(z_0,y_0 : coordinates of 1st point on the track
z_C,y_C : coordinated of the center of fit circle)

x coordinate from track reconstruction in x-z view

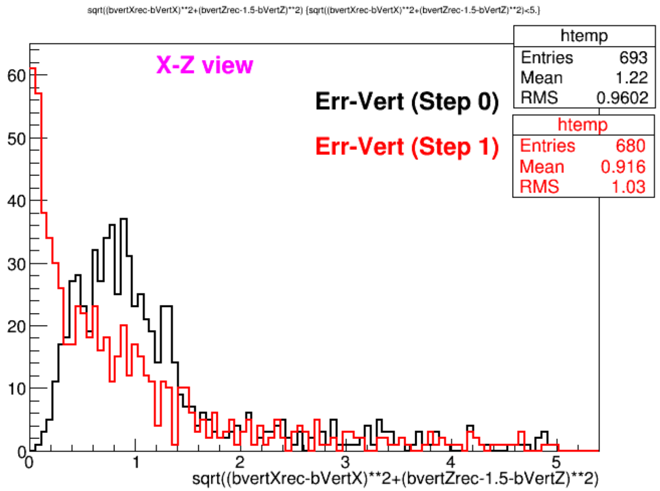
⇒ Match of tracks in y-z and x-z views to get 3D-track

"ECal+STT": Error on Vertex reconstruction (step 1)

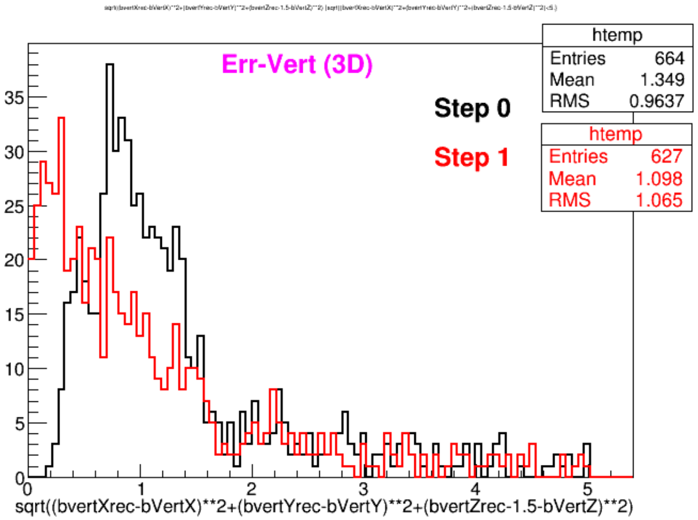
On Y-Z plane:



On X-Z plane



In the space:

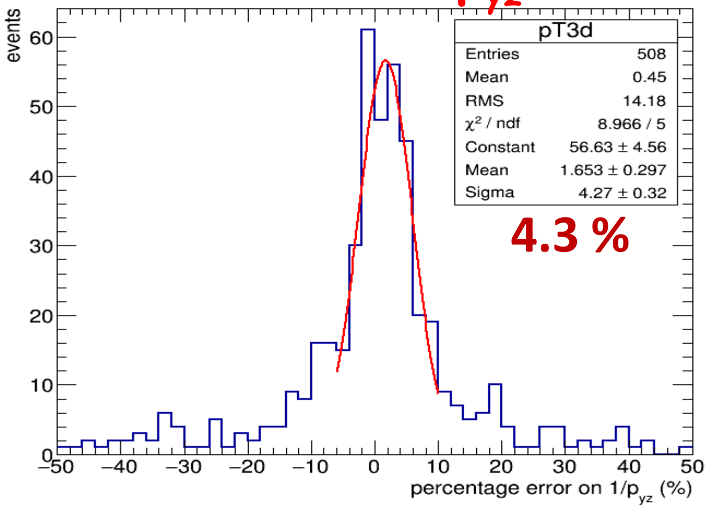


From crossing of the 2 most rigid tracks

ECal+STT layout: muon track

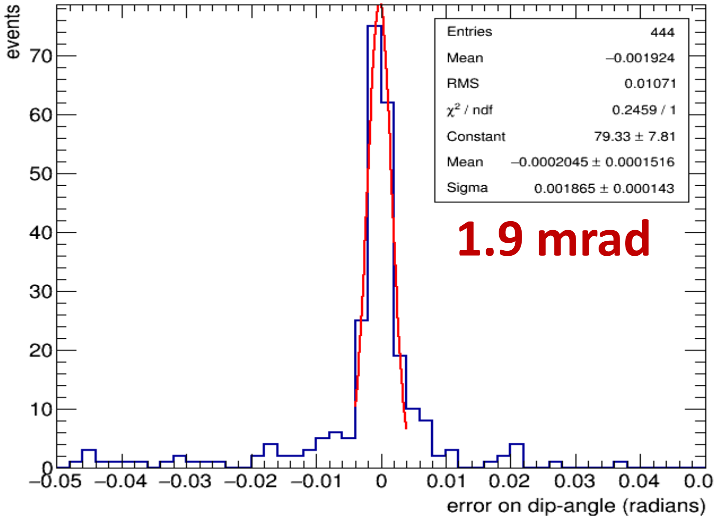
Vertices in STT

Error on p_{yz}



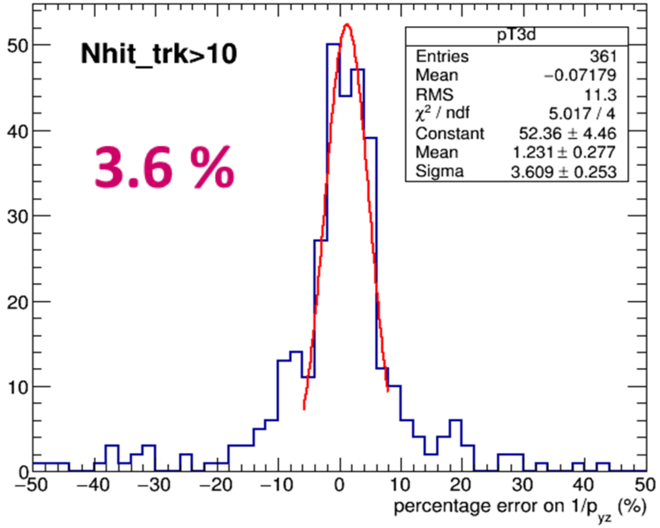
4.3 %

Error on dip-angle (λ)



1.9 mrad

Error on $p = p_{yz} / \cos \lambda$

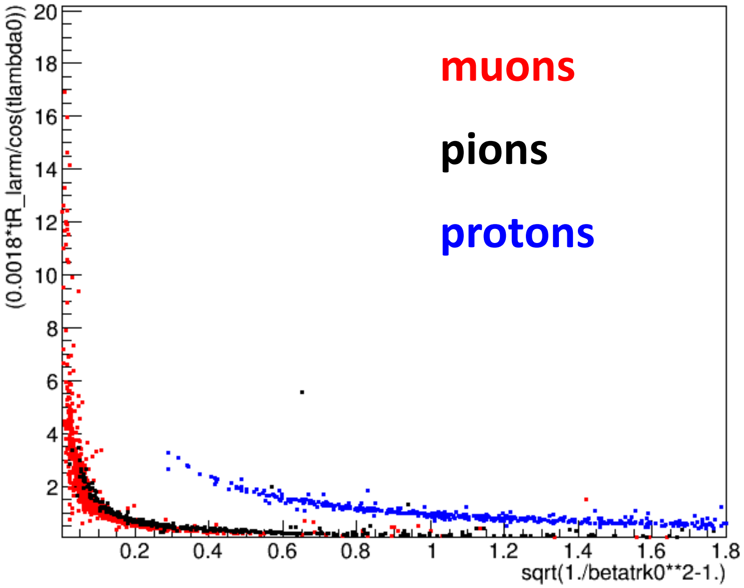


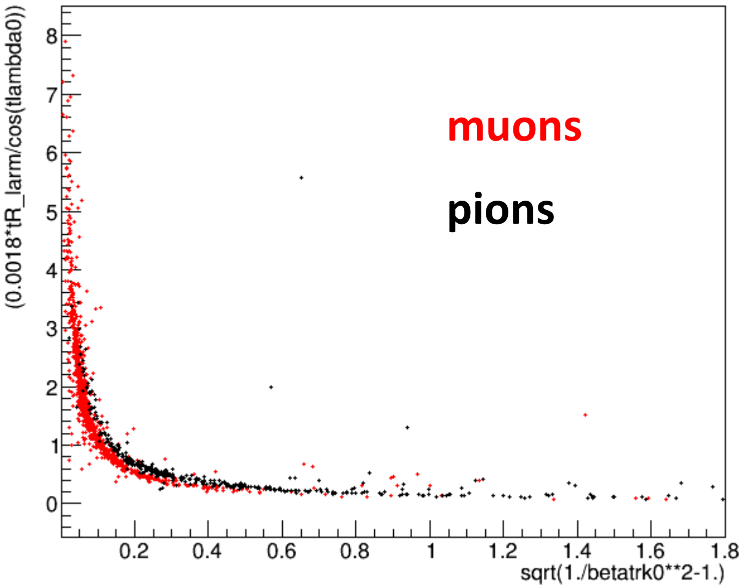
Nhit_trk>10

3.6 %

Identification of charged tracks

p vs 1/(β · γ)





Muon (~10% contamination from pions)

Charged Pion (~65% contam. from μ's)

Proton (few % contaminations)