SAND-DUNE: Simulations and reconstruction

DUNE-doc-13262

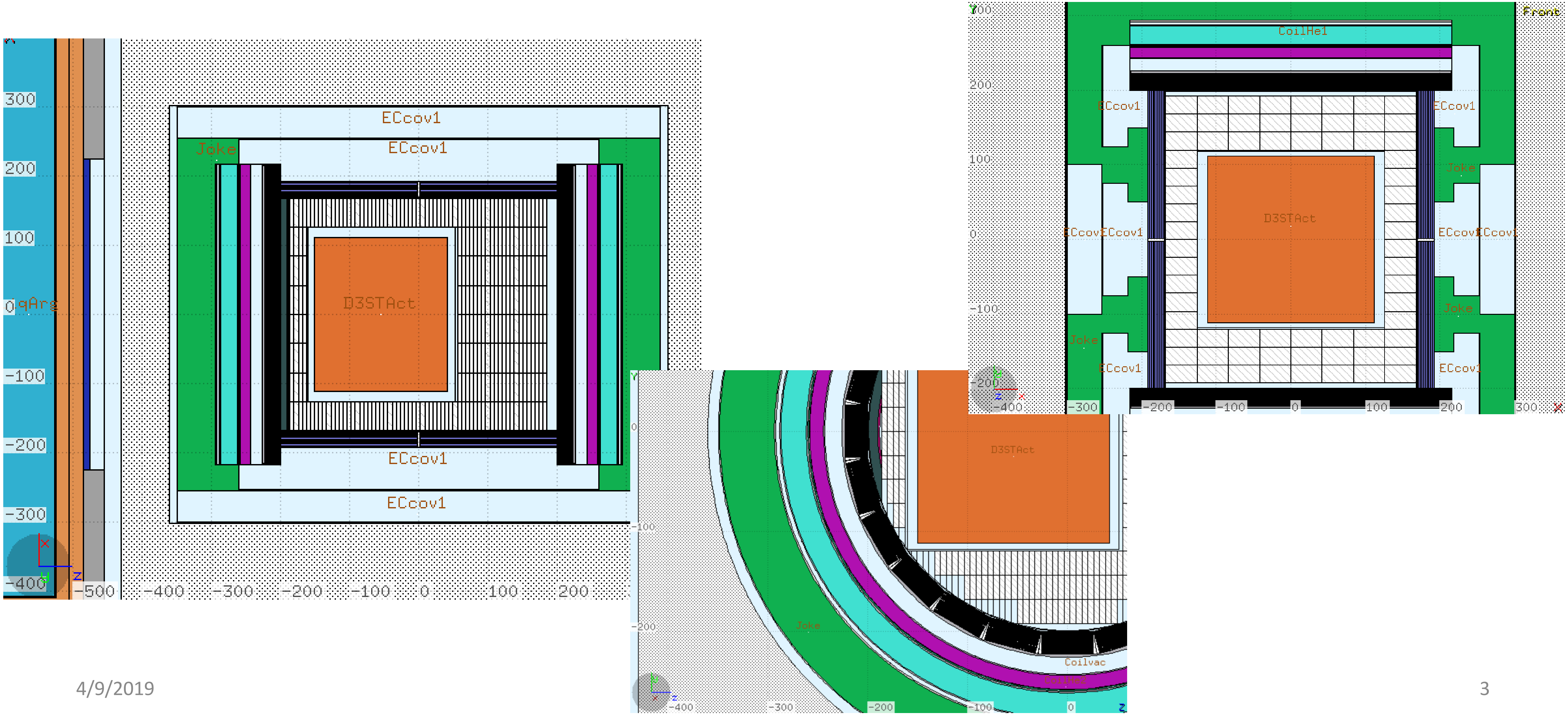
SAND: Solenoid for Accurate Neutrino Detection, for DUNE

Status of simulations and analysis

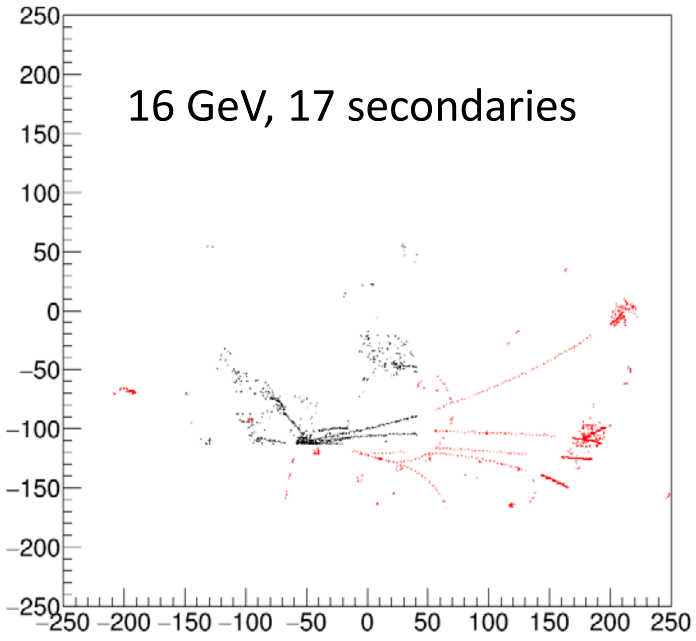
- Summary of performance study for
- KLOE + STT + LAr
- Full simulations and reconstruction to demonstrate performances
- Perspectives in new proposed configuration, KLOE +3DST +…

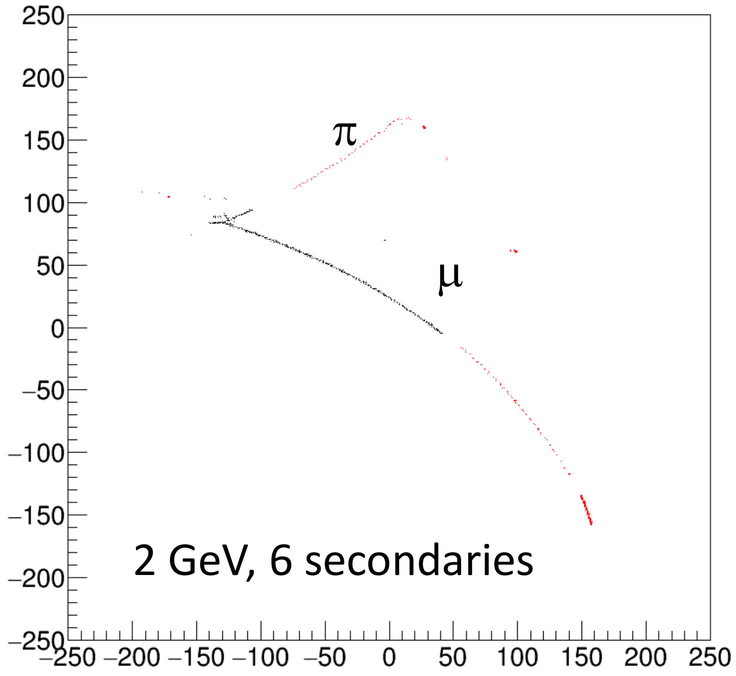
New

Integration of 3DST, surrounded by tracking devices. Work in progress.

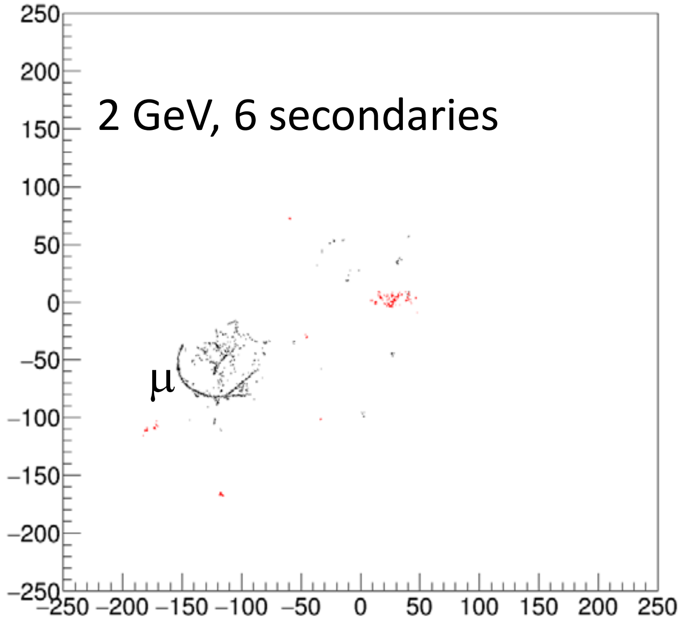


Example events



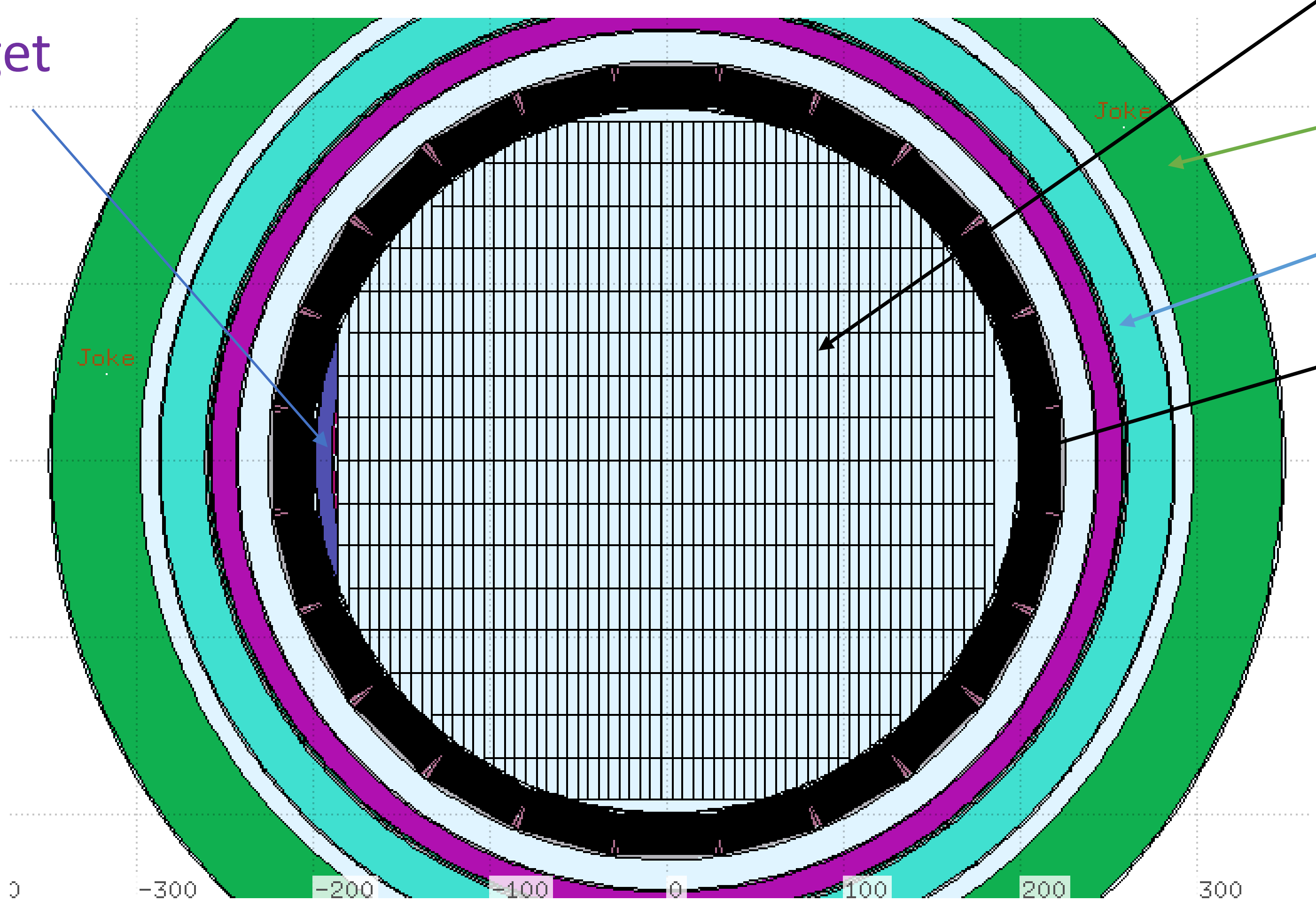


Output: energy in 1cm cubes, and time
Will reuse 3DST software for light yield and digitization.



Black: Edep in 3DST
Red: tracker and Calo

Old Layout (a reminder)



STT (5tons CH_2, "compact" version)

LAr active target ~1 ton

Joke

B: solenoid 0.6T

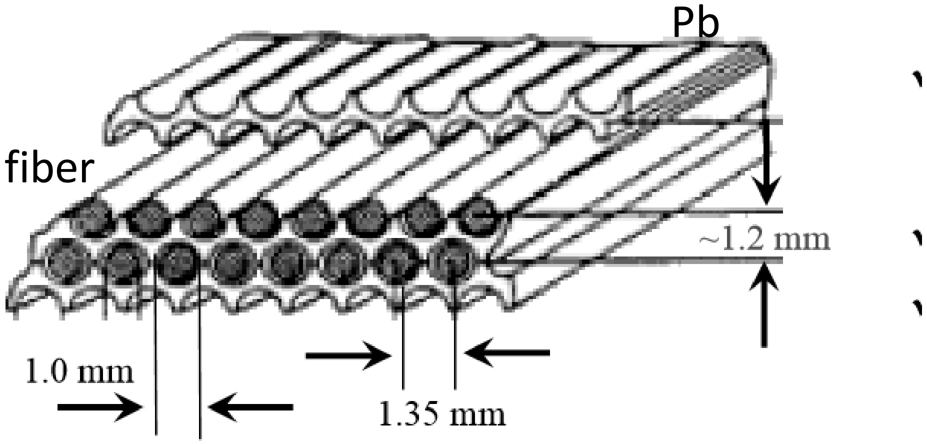
Coils and cryo

EM-CALO Barrel +Endcap Pb +SciFi No separation from tracker

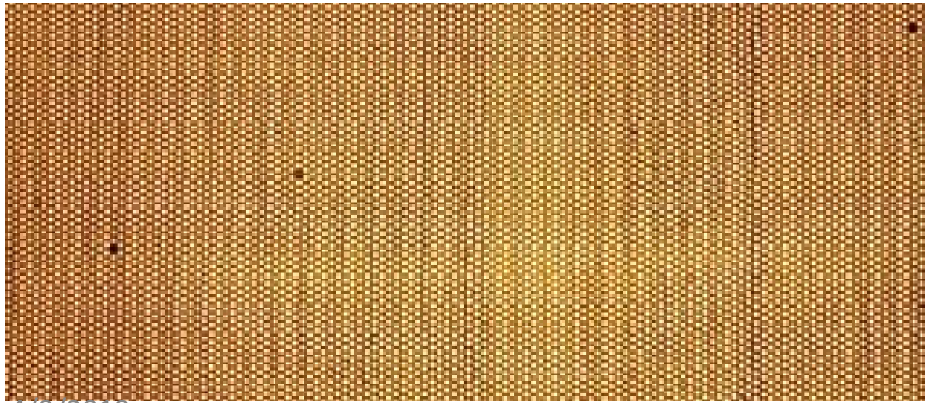
Inner volume~45m^3

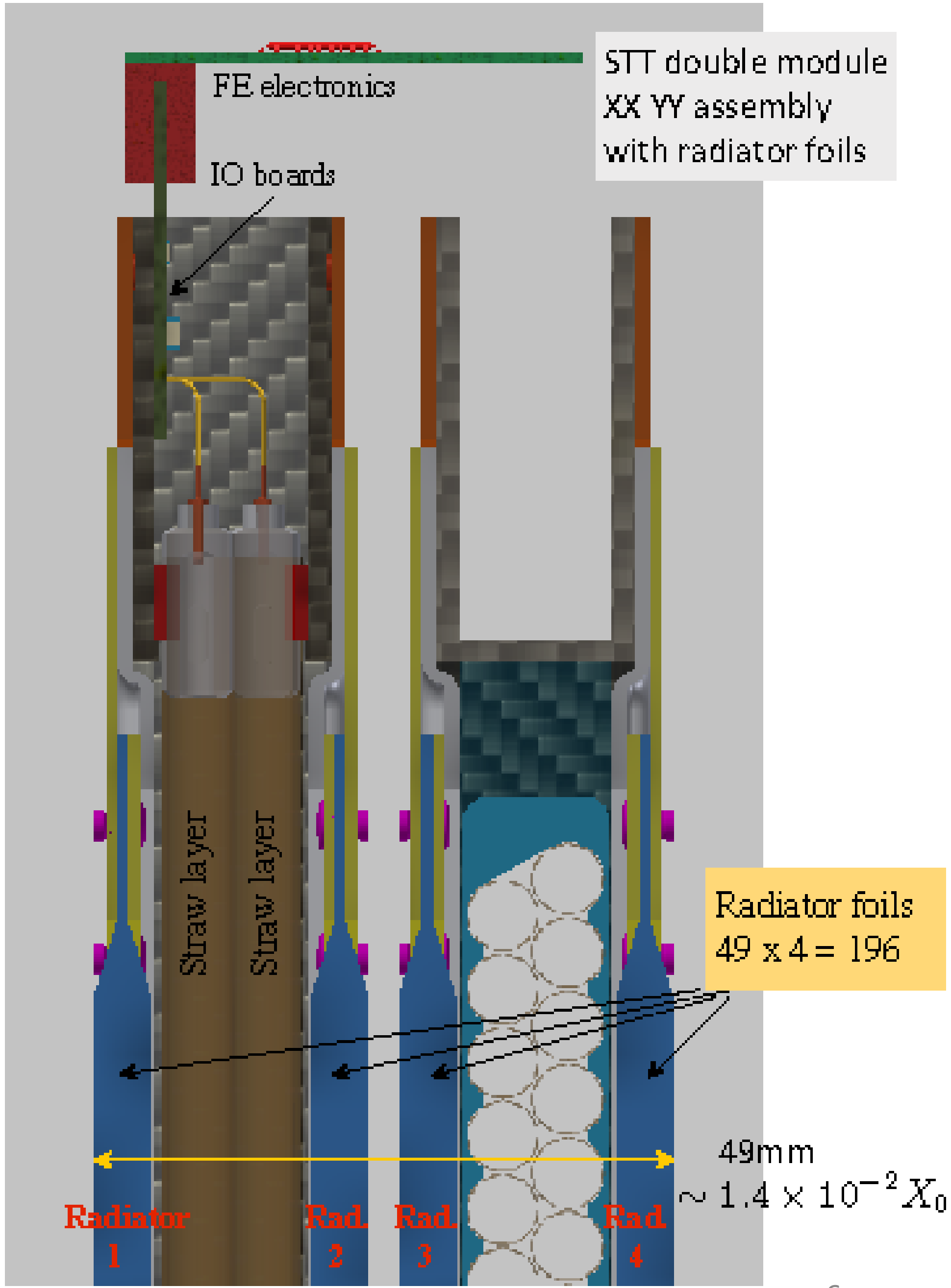
ν

Details



Kloecal fine structure

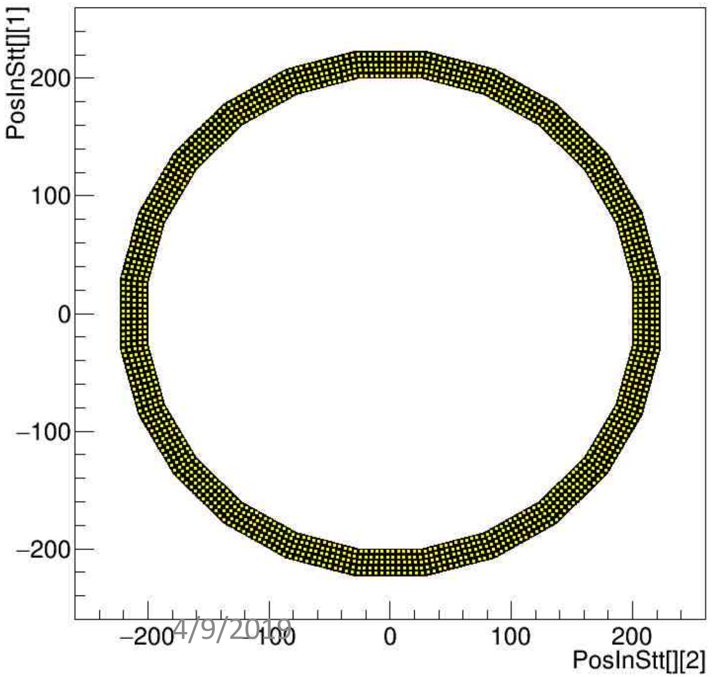


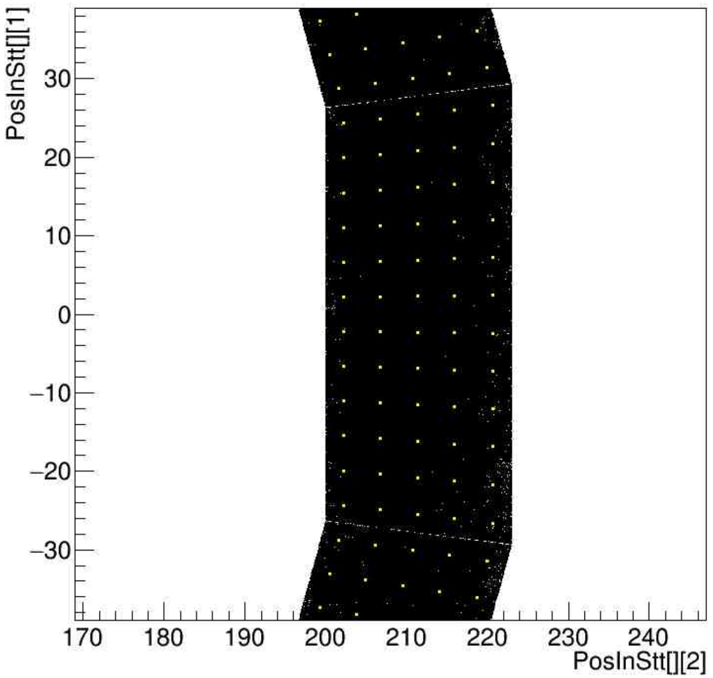


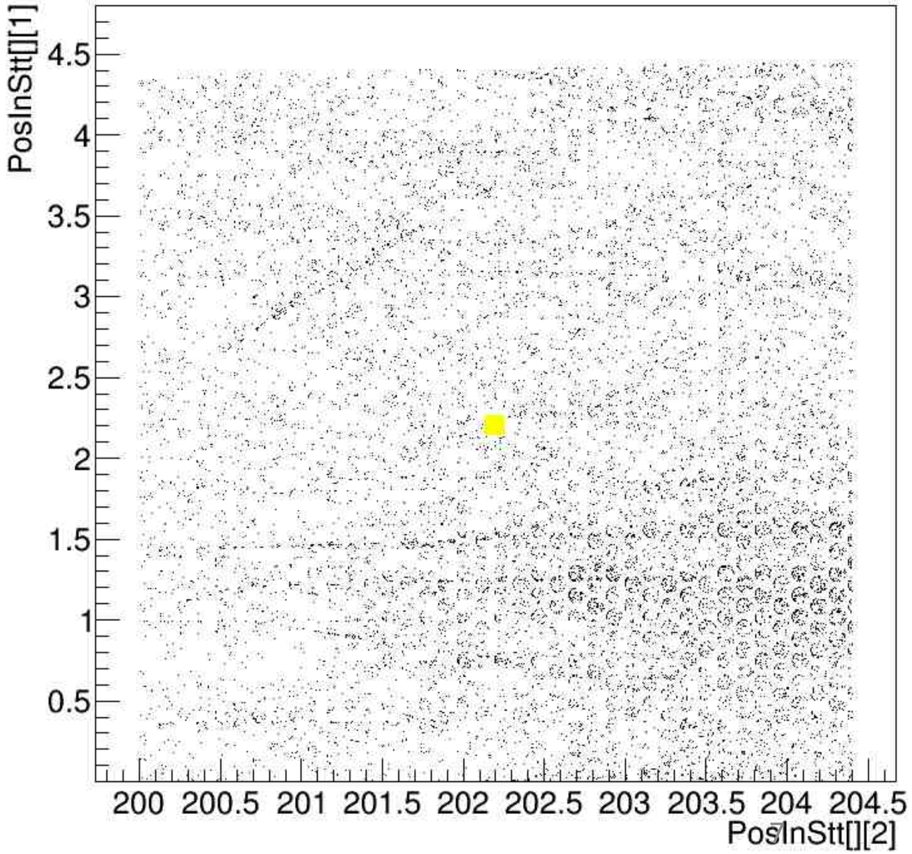
Simulations

- Two parallel streams
- GEANT4 + GENIE + dunendggd
- FLUKA (with internal generator) + ROOT
- Same neutrino fluxes from http://home.fnal.gov/ ljf26/DUNEFluxes/
- Same STT configuration and LAr meniscus
- In FLUKA: detailed EM Calo geometry+readout

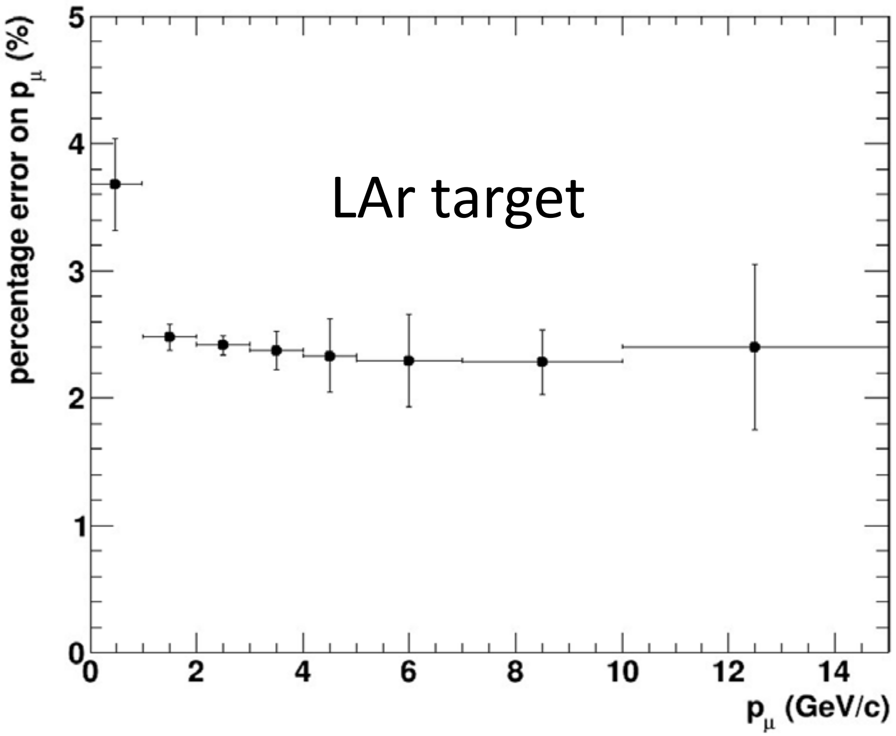
Plots: em-calo hits (black) and readout cell centres (yellow) (integrated over many events)

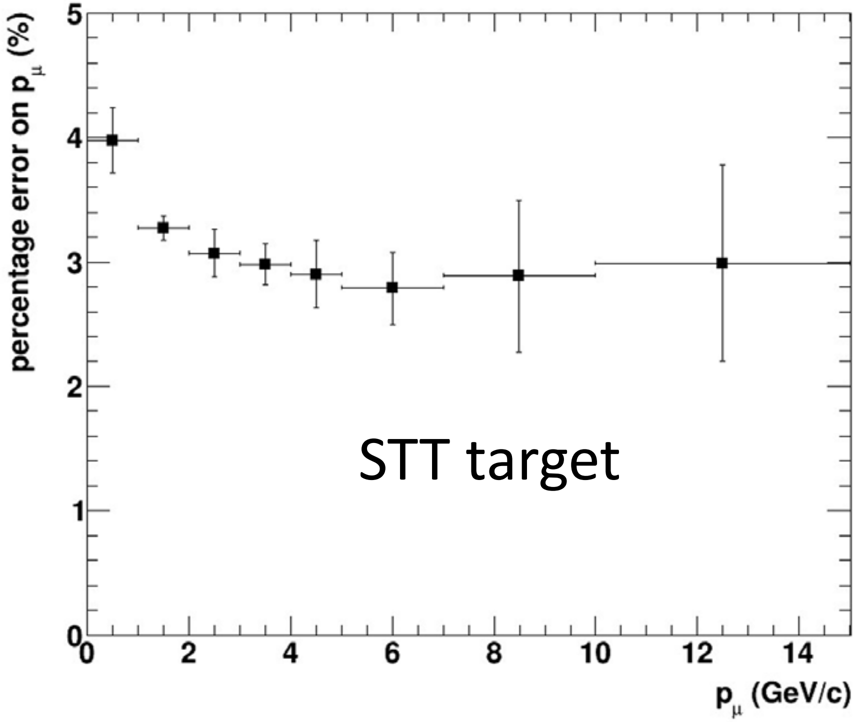






Results –Muons





FLUKA sim: muon-track reconstruction based on STT hits, assuming a spatial resolution of 0.2 mm on y and x axes and 0.01 mm on z axis (beam axis).

Improvements ongoing

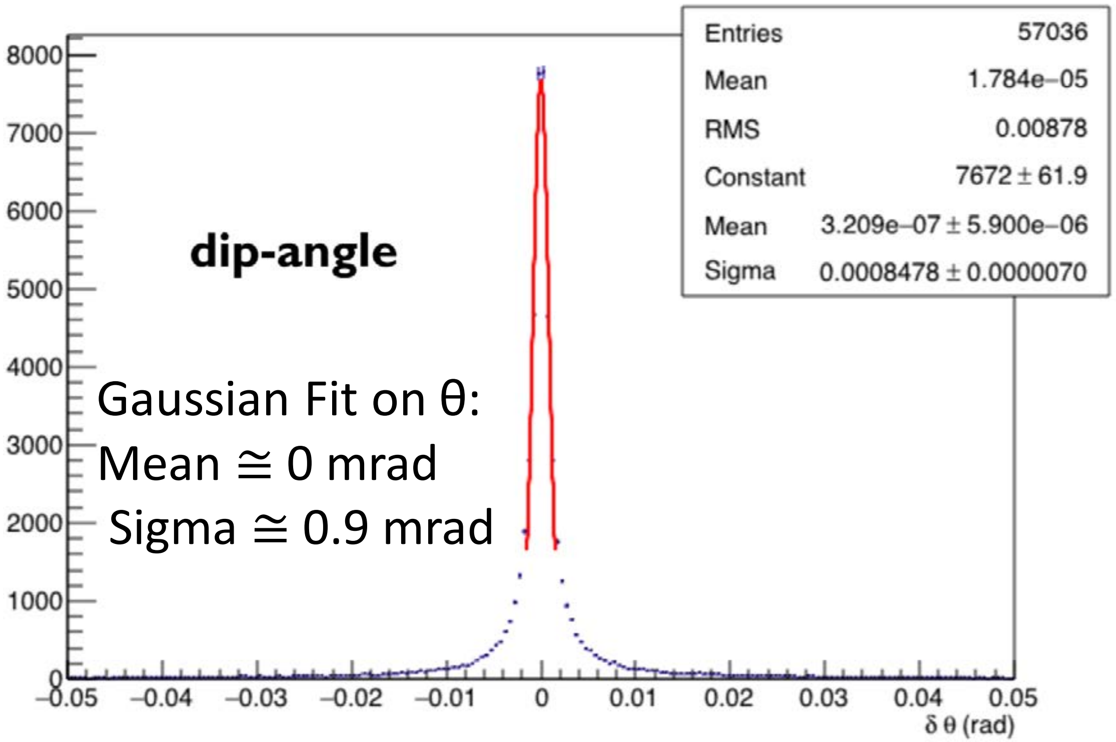
Good resolution on p (~3%) for both targets

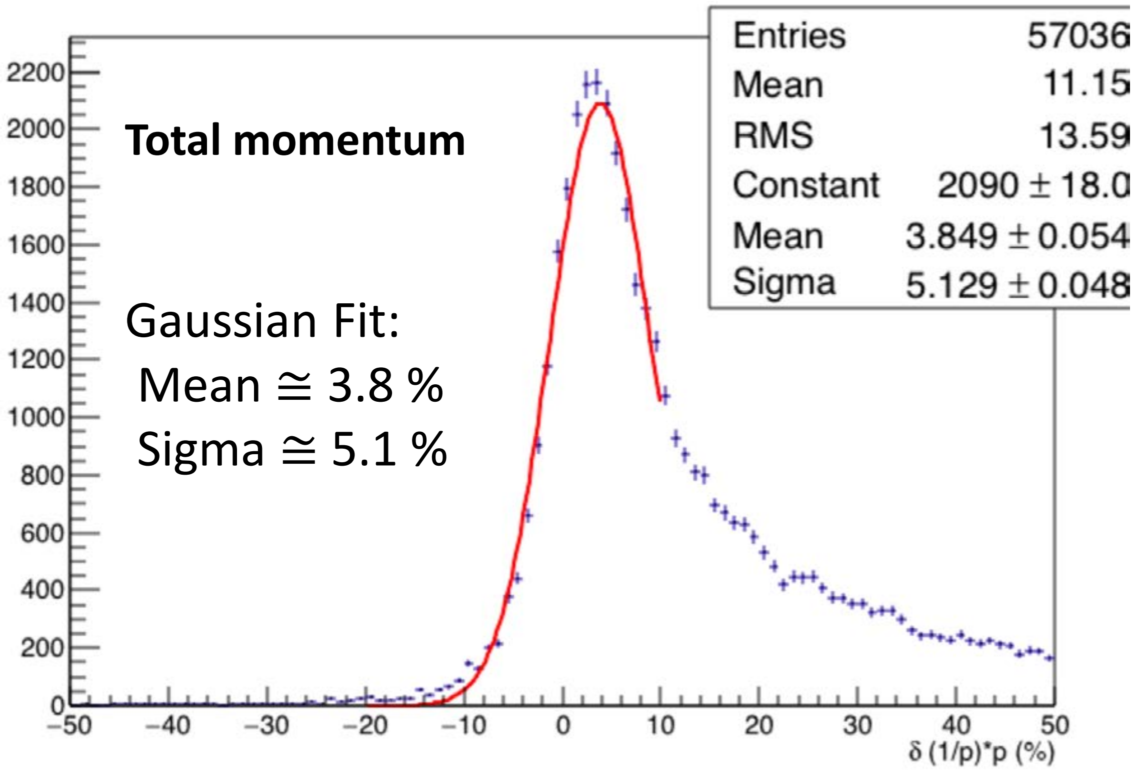
Good resolution on dip angle ~1.7 mrad

Charge mis-id ~0.02%

Results: - electrons

Generated in STT with GENIE+GEANT4. Very good resolutions, tails due to circular fit approximation to be improved i.e. with Kalman filter.





Wrong sign 1.3%

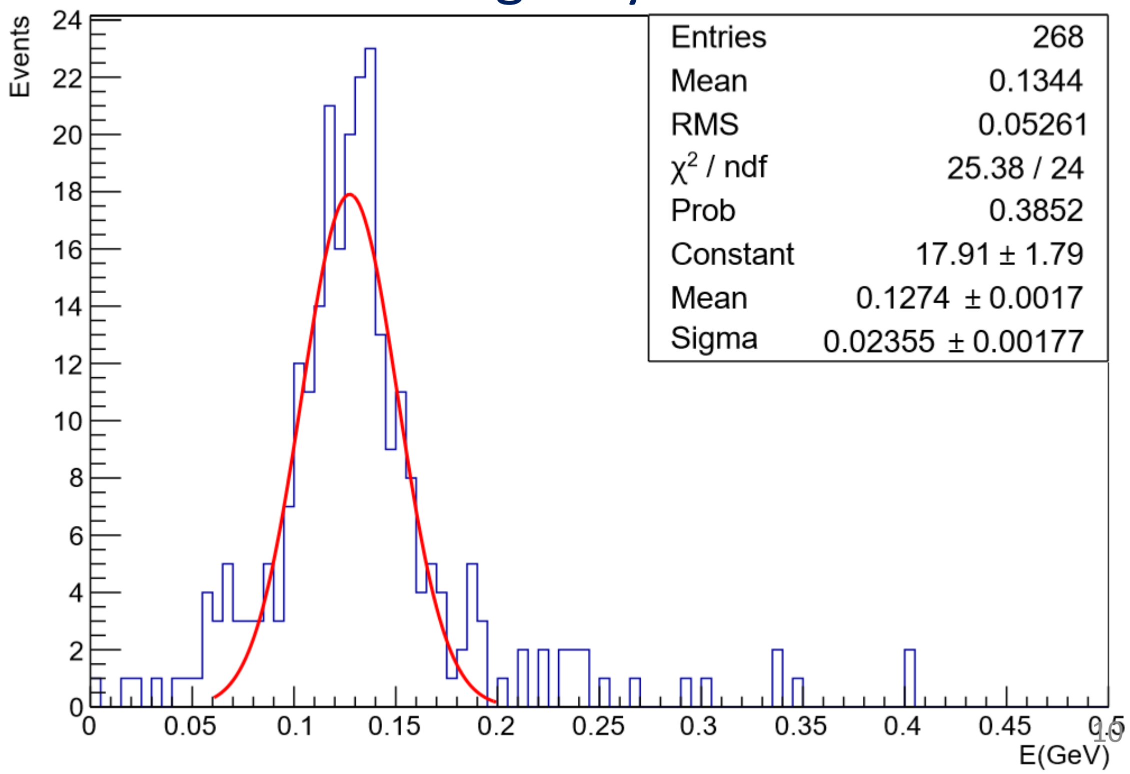
Results- π^0

Reconstructed CC sample:
4000 events
1 π^0 25% of events
2 π^0 8% of events
> 2 π^0 2.5 % of events

Resolutions:
1 π^0 16%
2 π^0 18%

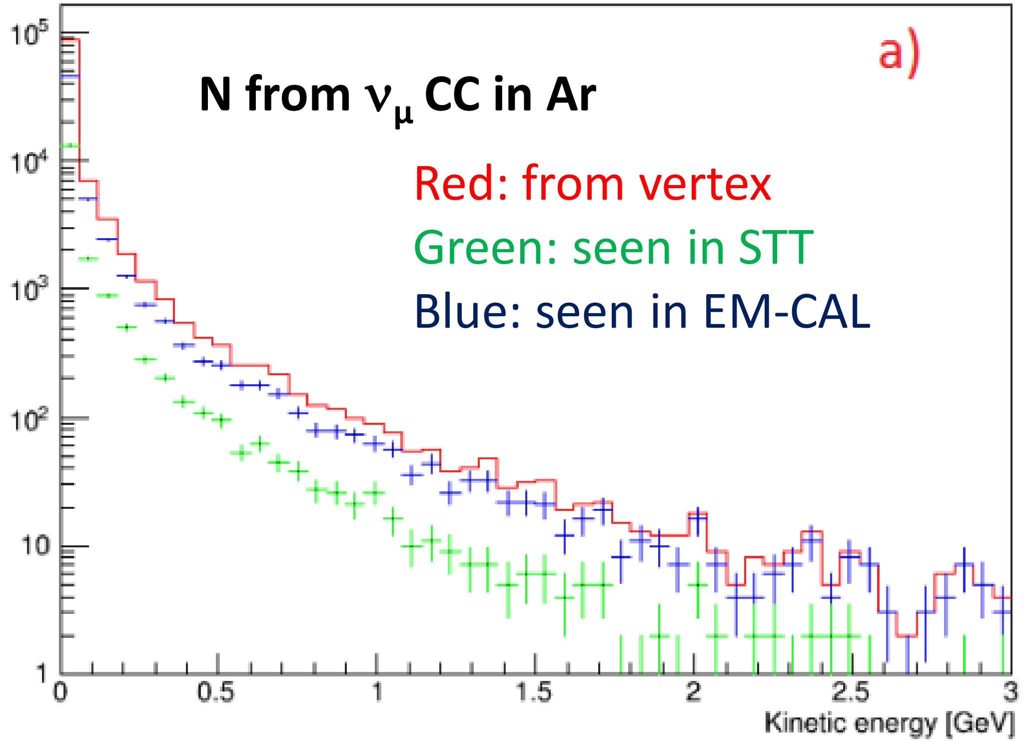
Reconstruction from EM CALO clusters
Dimensions Δx = 20 cm and $\Delta\phi$ = 5 deg.
Energy smearing $\sigma_E/E \approx 5.7\%/\sqrt{E(GeV)}$
Position from hit barycentre +
resolution of the KLOE calorimeter (4.5 mm).

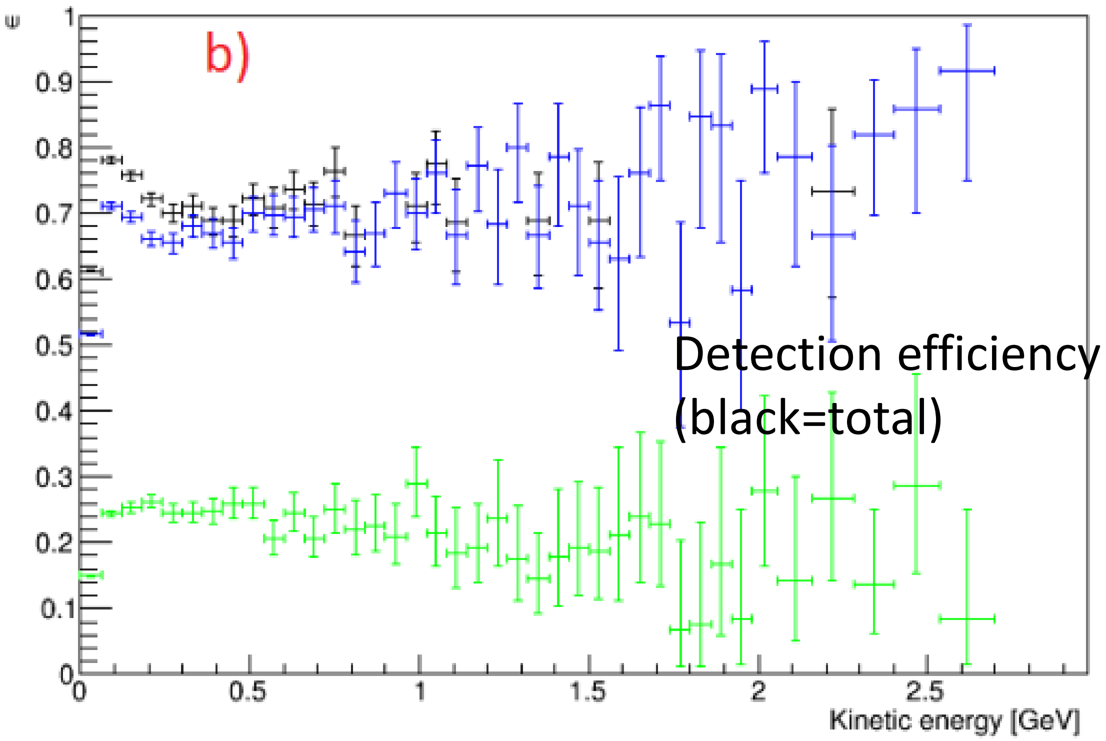
2 π^0 sample: π^0 invariant mass,
Considering only 4-cluster events



Results: - Neutrons : efficiency

FLUKA simulation, detailed EM-CAL. Reconstruction uses real calo segmentation+ measured signal attenuation and time delay in fibres. Combined with STT hits as for muons





Global efficiency 64% (17% STT, 55% EM-CAL, 8%overlap)

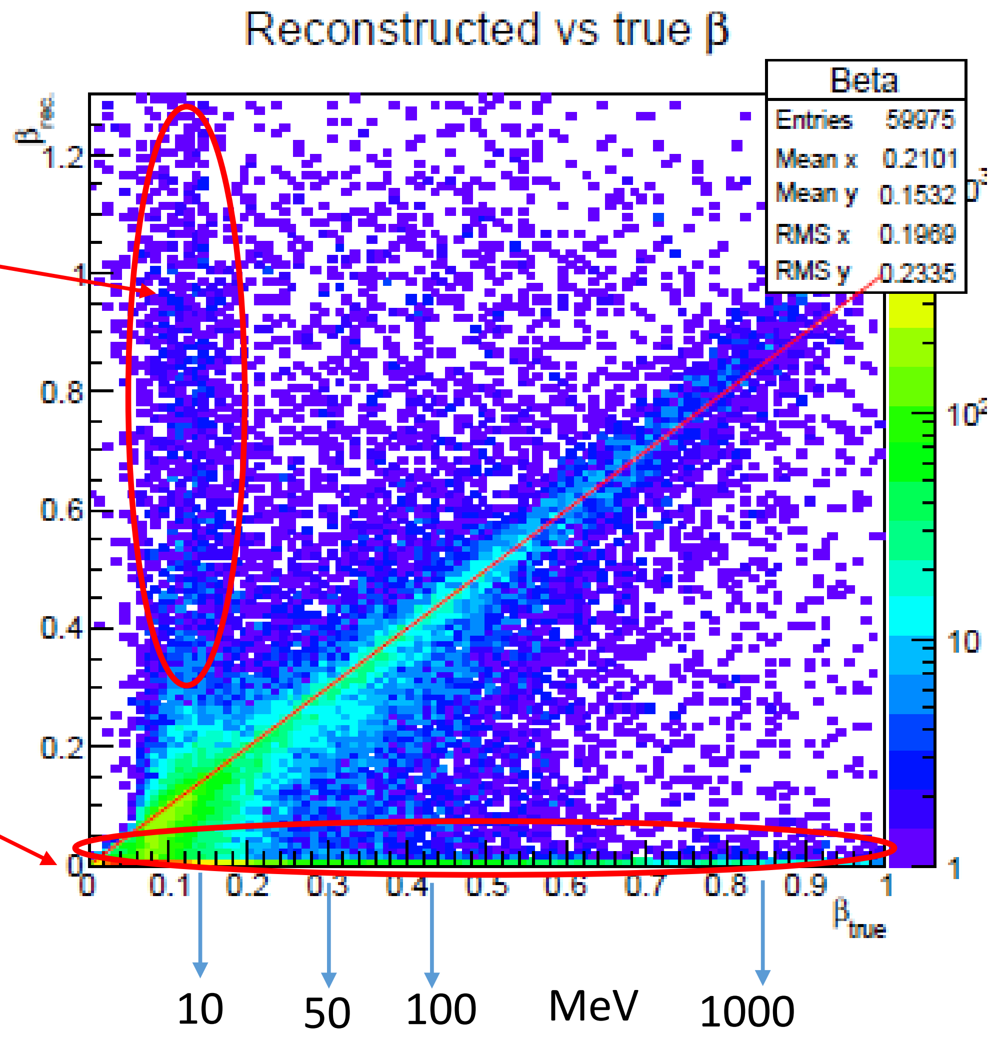
Efficiency > 72% for E_{kin} > 100 MeV

Results: - Neutrons: energy from ToF

FLUKA simulation. Reconstructed ToF from vertex in Ar to hit in STT or EM-CALO

Early interaction not detected. ToF from fast secondary (photons)

Many scatterings not detected. Path much longer than straight line



On full spectrum:
the neutron kinetic energy can be reconstructed with about 30% precision for about 23% of the detected neutrons.

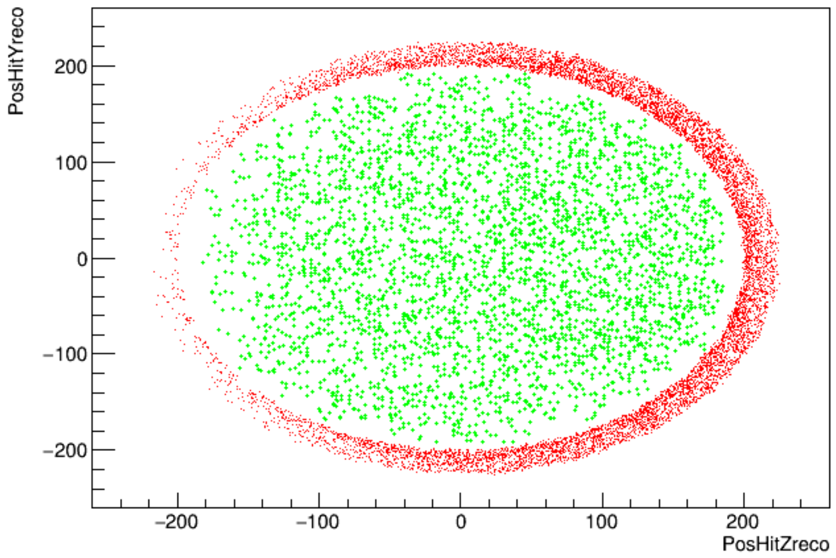
Situation improves quickly with energy:
On E> 50 MeV 47% of detected neutrons are reconstructed within 30% accuracy

Next: try to add calorimetric information

Angle reconstruction for QE interactions on H

$$\bar{\nu} + p \rightarrow \mu^{+} + n$$

- first hit (minimum time) of neutron or neutron daughters track
- Smearing of MC vertex position and hit position

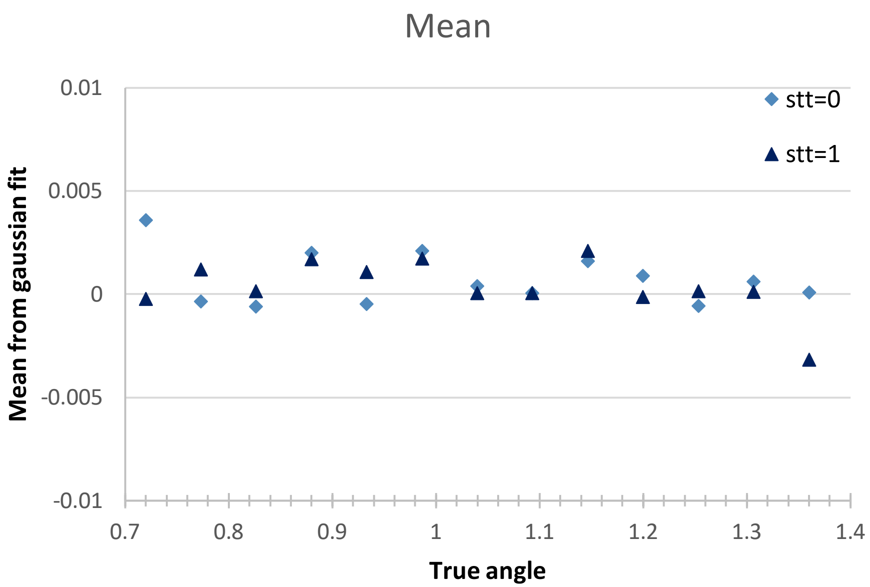


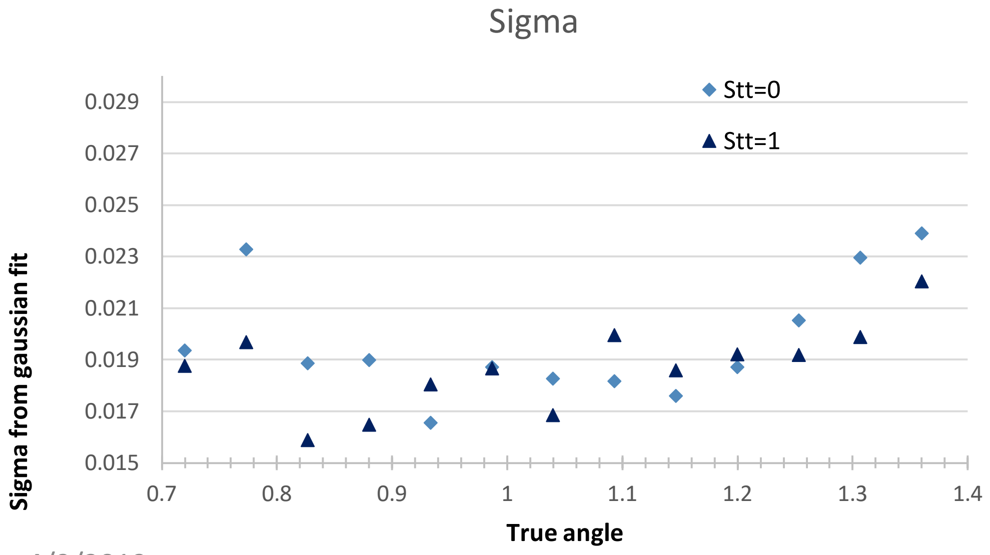
Stthit=1 events in stt

Stthit=0 events in barrel calorimeter

Stthit=2 events in endcap calorimeter

Resolution vs true angle





(Reco-true)/true :

average within 0.5%

sigma ~2%

Full reconstruction –no MC truth

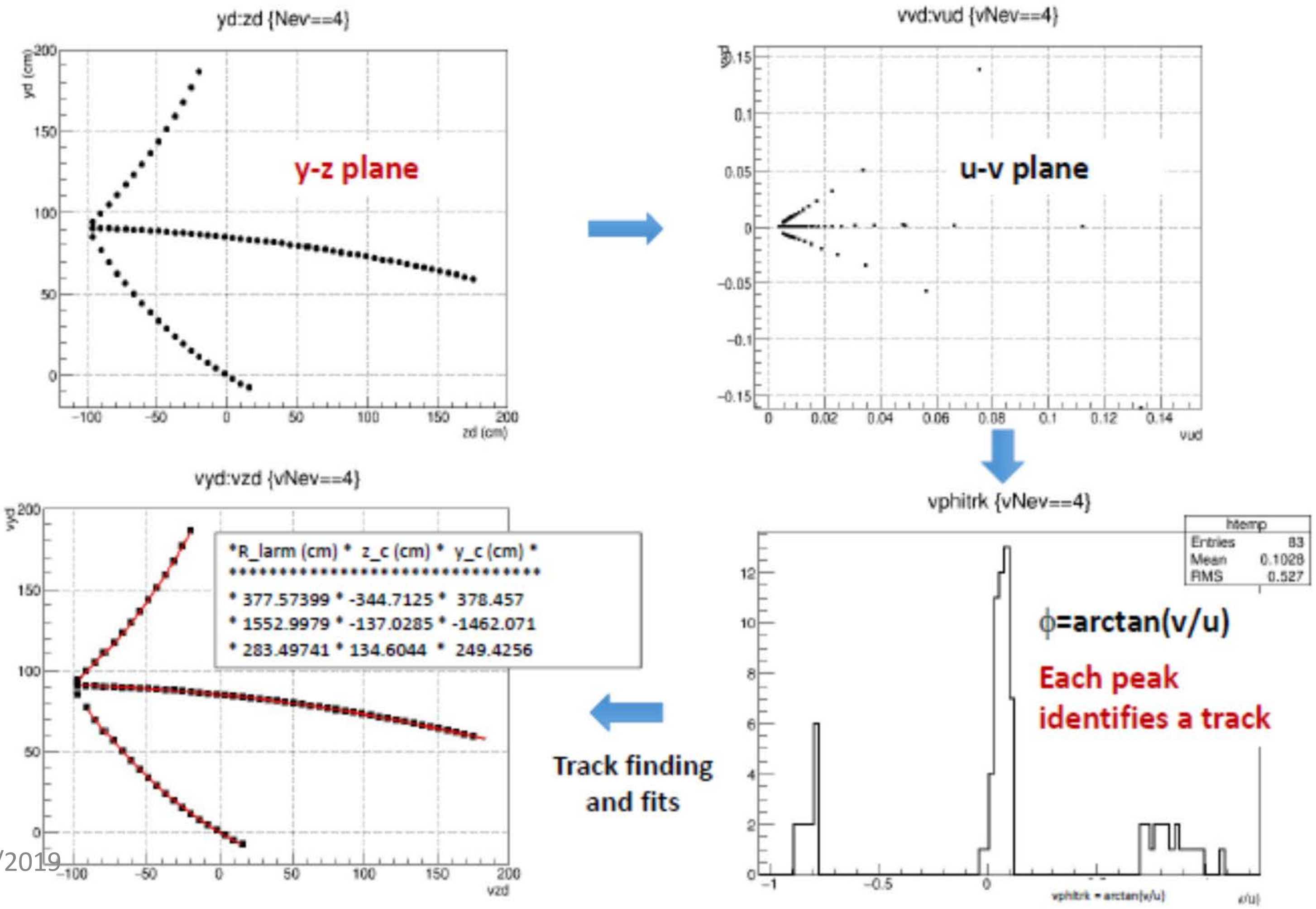
- Interaction Vertex based on STT-hit topology (Step 0)
- Track finding (Global transform method)
- Linear or circle fits to track
- Vertex reco from crossing on two most rigid tracks (Step 1)
- Iteration…

On two views

- Matching of tracks in the two views → tracks in 3D
- Evaluation of $p_\perp$ and dip-angle → p estimate
- Ecal hit compatible with tracks → ToF measurement
- → β estimate→ PiD

vertex and track finding

- A full realistic event reconstruction based only on detected quantities, avoiding to use MC true information, is under development using FLUKA simulated events



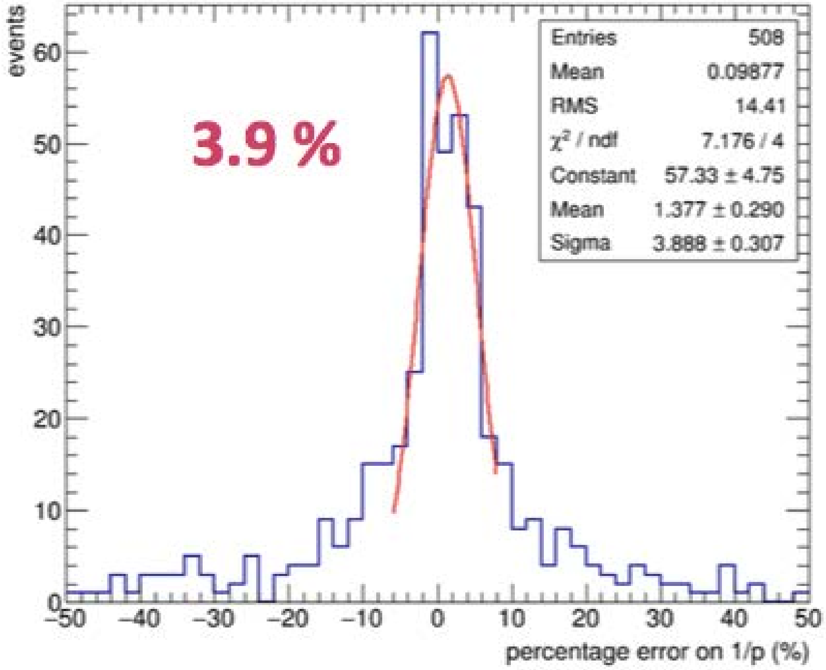
Two-step method: first rough vertex finding, allows for coordinate transform

Peaks in ϕ correspond to tracks

Second vertex finding from track intersection

P reconstruction

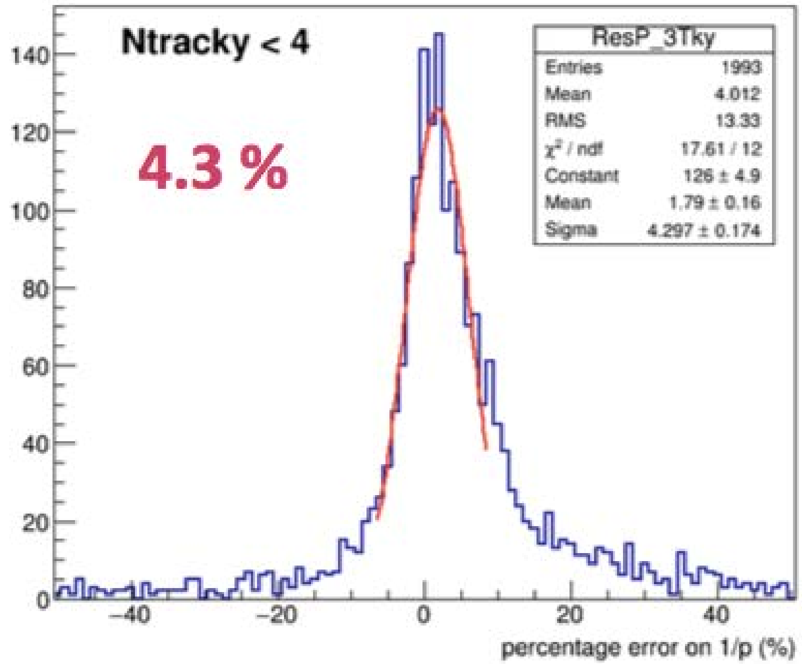
For events with only 1 charged track in each view:



Error on total p:

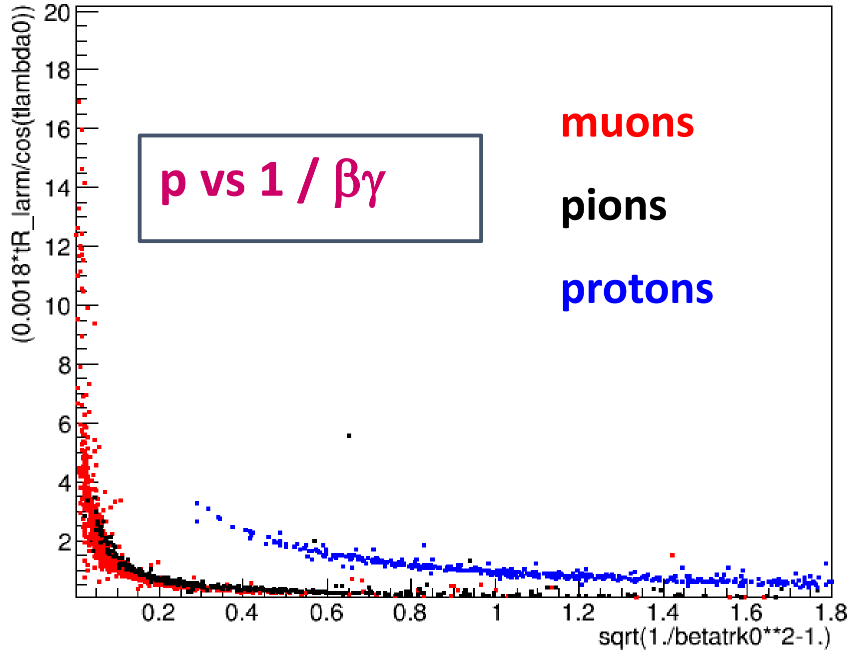
$p=p_{yz}/\cos(\lambda)$

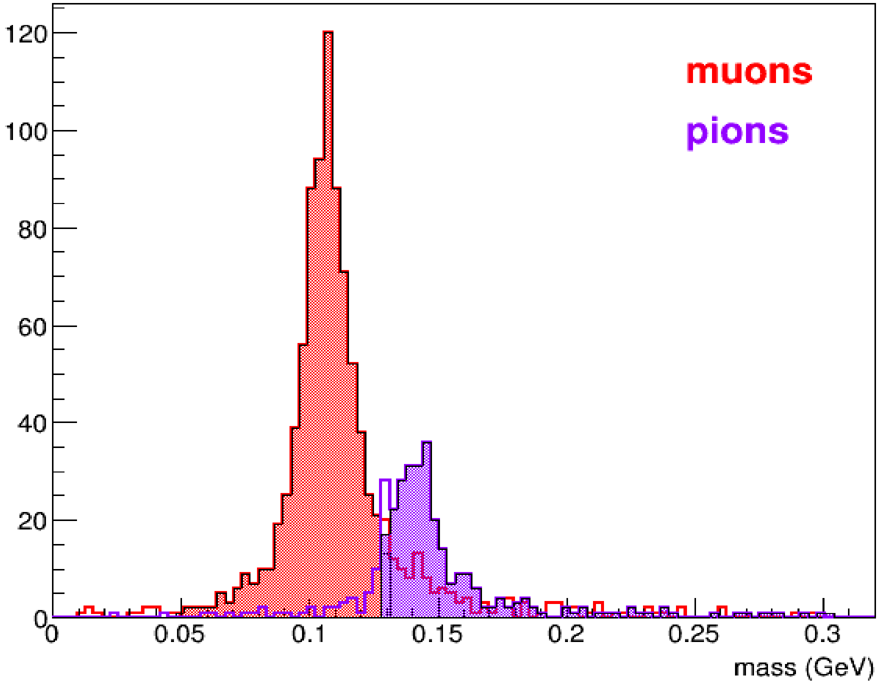
For events with no more than 3 tracks matched in the two views:

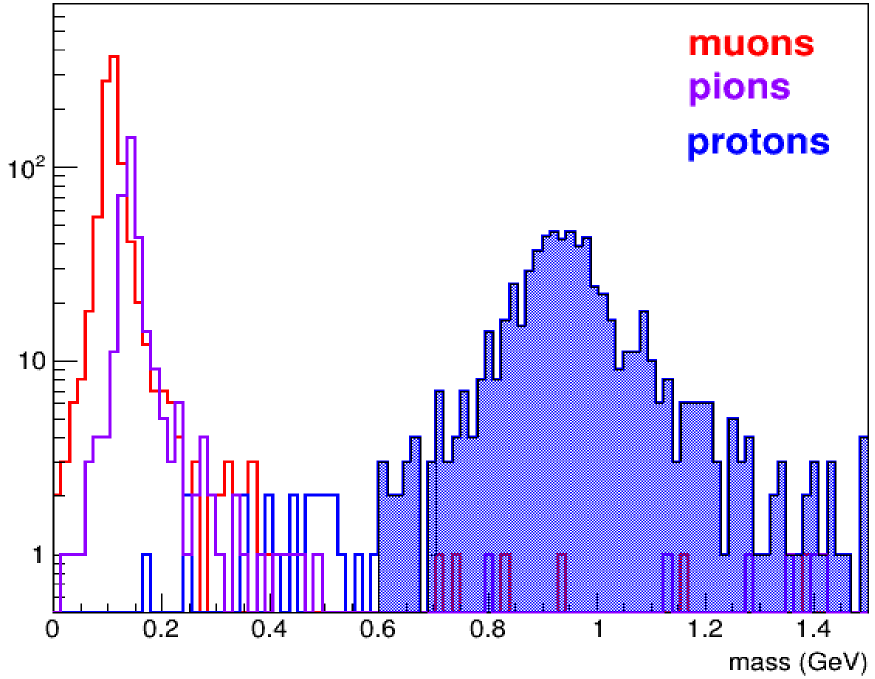


Mass reconstruction and PiD

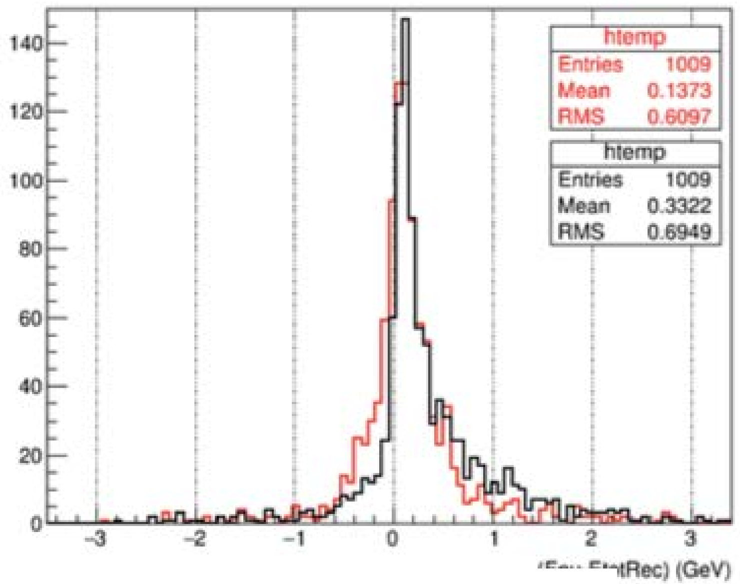
preliminary







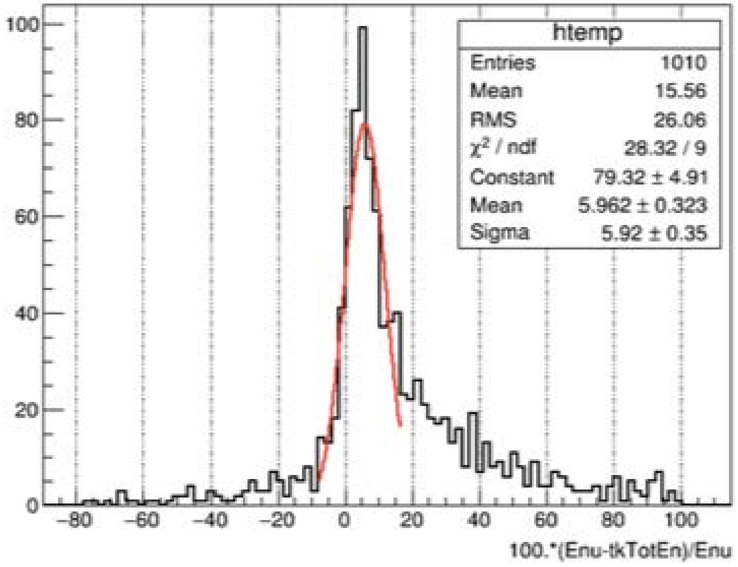
ν energy reconstruction (preliminary)

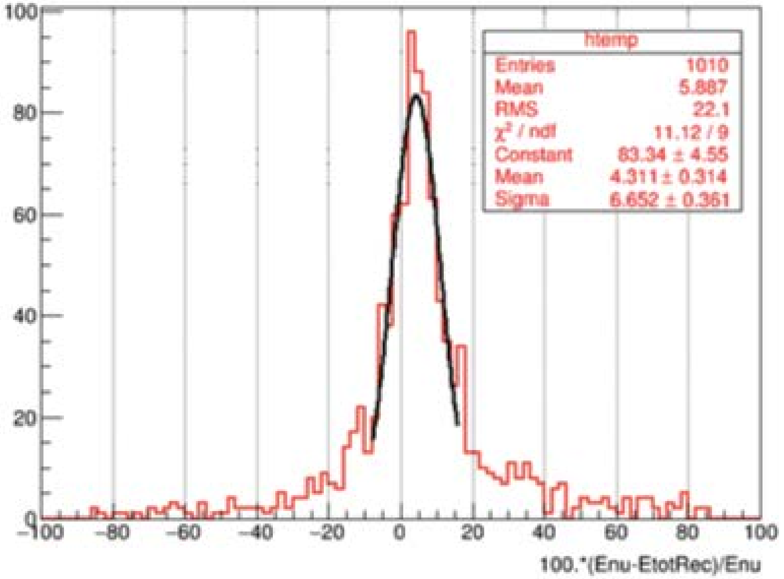


'All-tracks' energy only

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

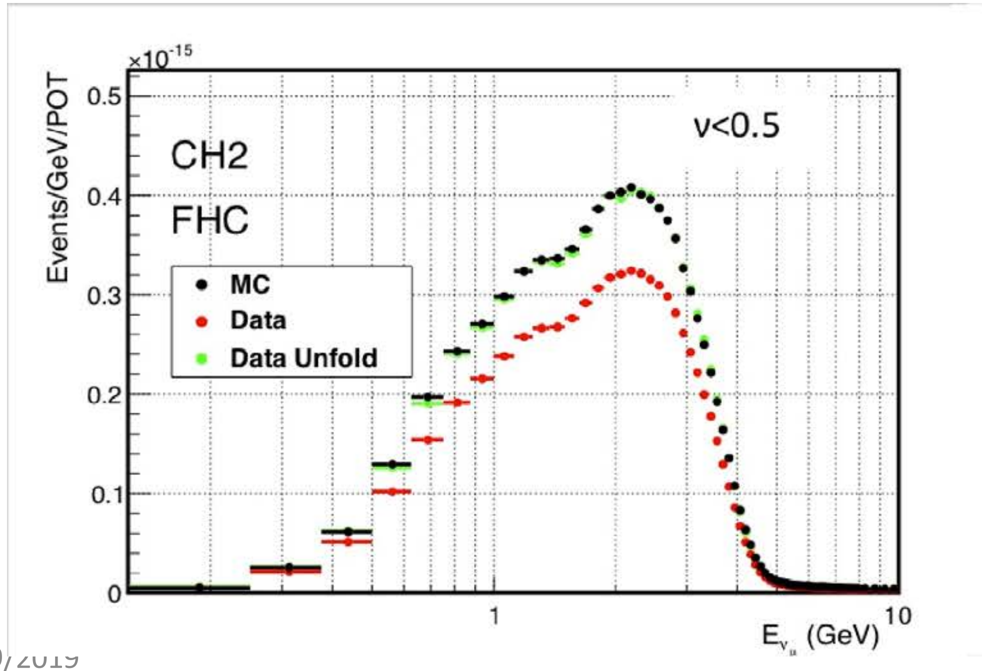
NO MC truth
$\sigma/E = 6.6\%$

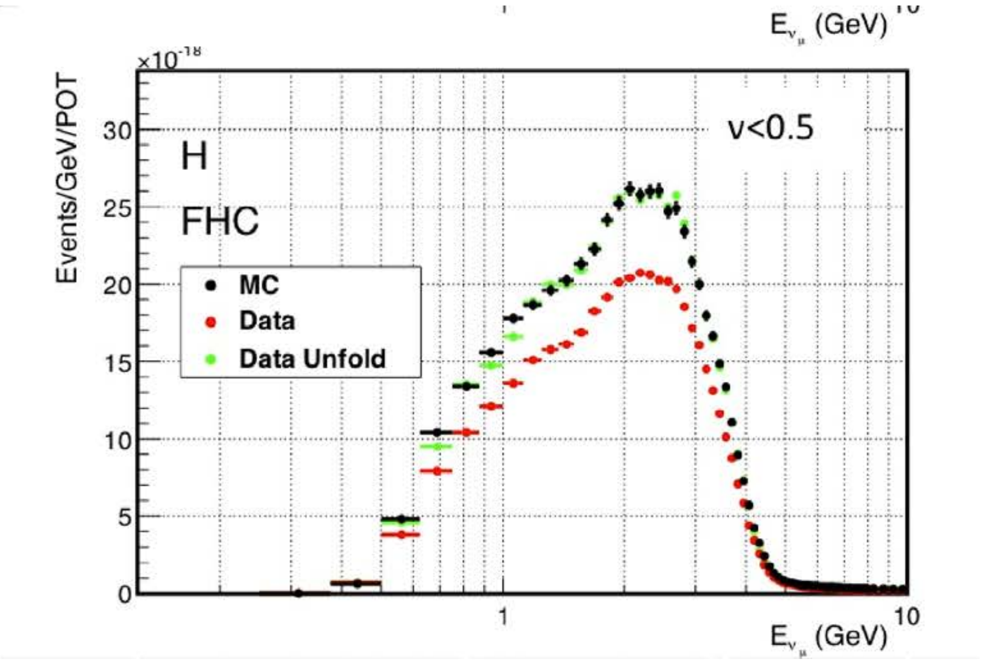




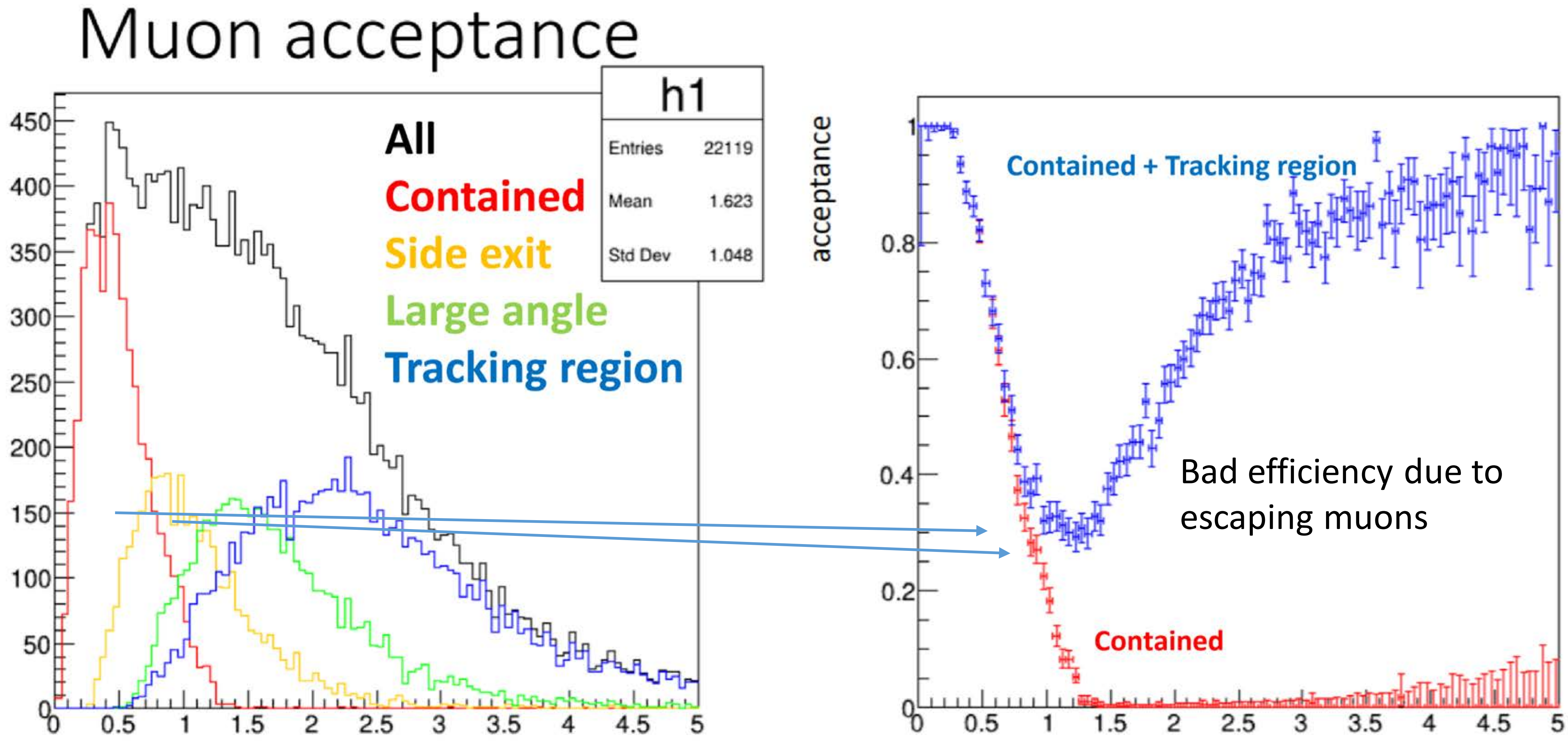
Low-nu

- GENIE simulation on CH2 and H
- 2 MC samples: “data” and “MC truth”
- Assuming acceptance of 80% and energy resolution 5% to test the unfolding and analysis procedure
- Detector simulation and event reconstruction ongoing





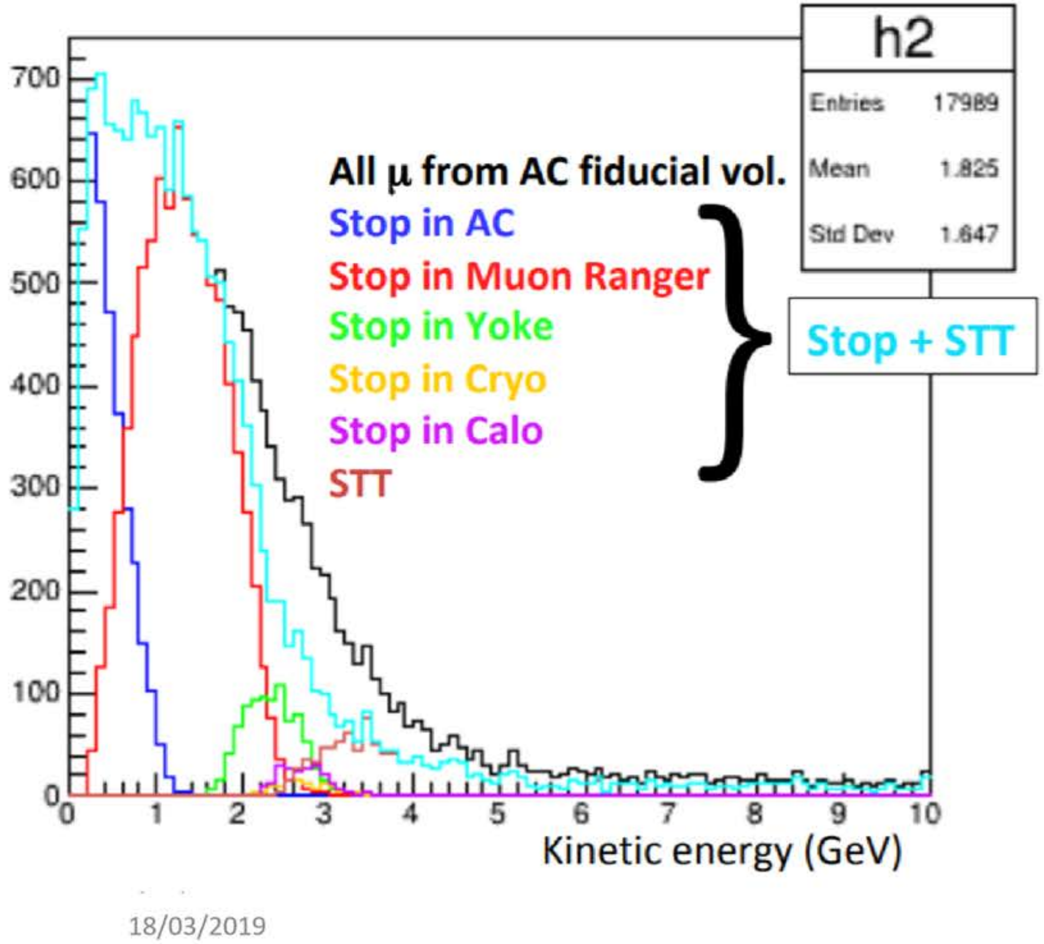
Acceptance for ArCUBE muons: old AC geo

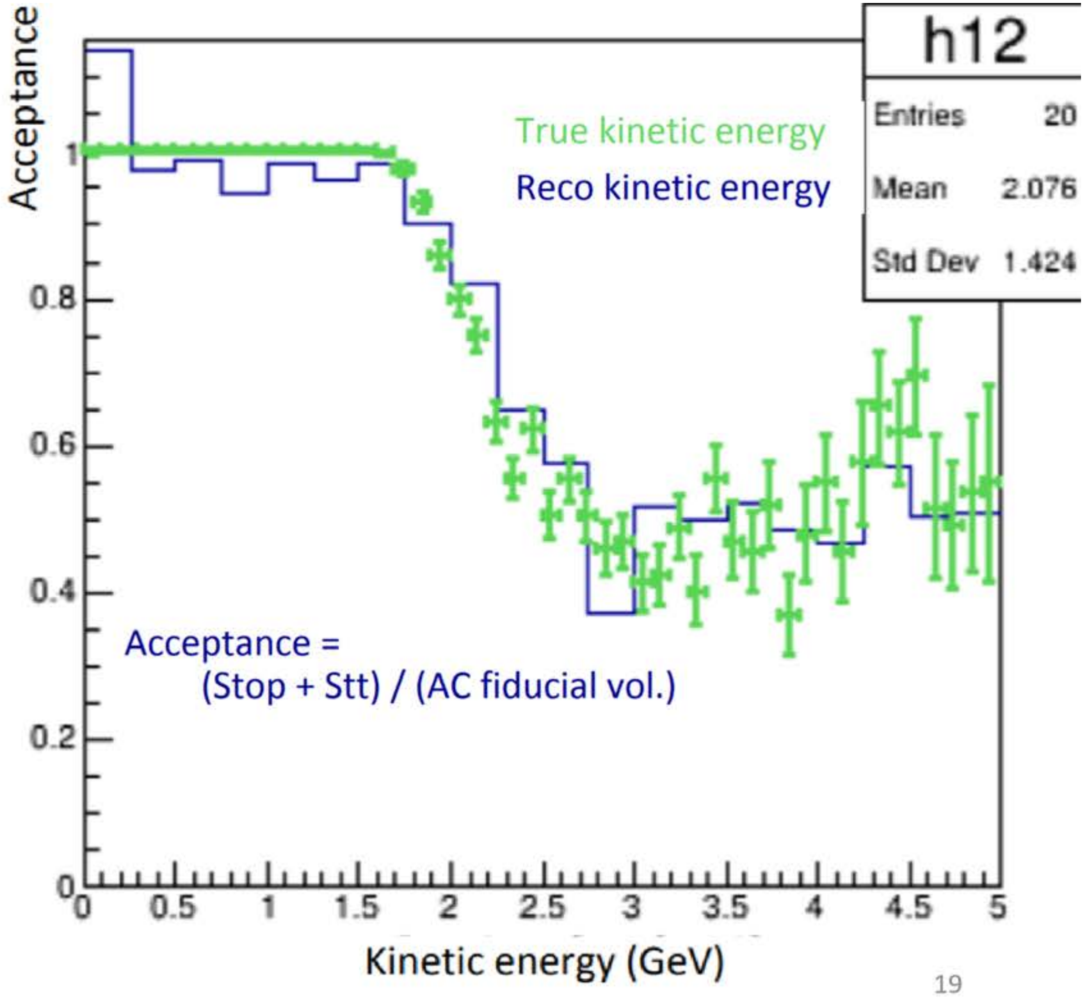


Bad efficiency due to escaping muons

Acceptance for ArCUBE muons: old AC geo

- Simple muon catcher around AC + layers around coil cured the acceptance





Acceptance for AC muons: work in progress (maybe obsolete?)

- New AC dimensions and exit window implemented, analysis in progress

Summary

- KLOE magnet + EM Calo + 3DST +tracker: implemented, running
- KLOE magnet + EM Calo + STT : full simulation + single particle reco
  - Track momentum $\sigma \approx 3\%$
  - Track angle 1 mrad
  - Neutron efficiency 76%
  - Neutron Energy within 30% for 47% od detected n with E>50 MeV
  - Neutron angle in QECC on H: within 2%
- KLOE magnet + EM Calo + STT :**preliminary full event reconstruction**
  - PiD and proton/muon/pion mass reco
  - Neutrino energy in CC $\sigma \approx 6\%$
- Acceptance for ArgonCube events: latest configuration under evaluation. Previous one: OK if muon catchers

Backup

Next steps

- Improve details of singe particle reconstruction
- Finalize full event reconstruction
- Apply to random events, check identification and reconstruction
- Optimize LAr meniscus

- Apply to / optimize PRISM-like data taking
- Full background evaluation

- For the moment, apply the single-particle quantities to physics analysis (in the following).
- Details in the forthcoming note

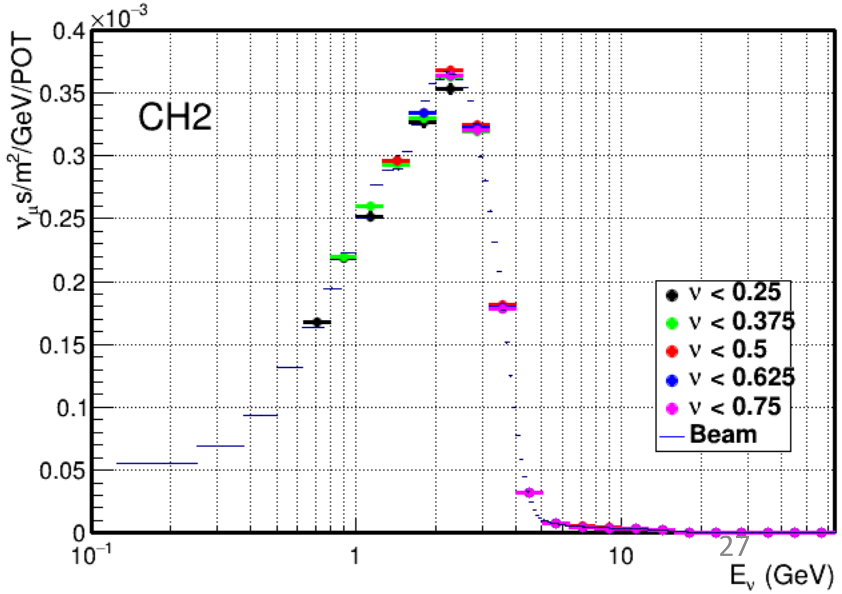
Performances (examples of)

- Good resolution on tracks ➔good efficiency and purity for the kinematic selection of interactions on H

Process	R_{mH} and $p^H_{T\perp}$ cuts		$\ln \lambda^H$ cut	
	Efficiency	Purity	Efficiency	Purity
$\nu_\mu p \to \mu^- p \pi^+$	93%	86%	90%	92%
$\bar{\nu}_\mu p \to \mu^+ p \pi^-$	89%	84%	90%	88%
$\bar{\nu}_\mu p \to \mu^+ n$	95%	80%		
$\nu_\mu p$ CC inclusive	83%	73%		

- Good track and neutron efficiency ➔flux shape with low-ν method for QE and RES events on H. Total statistics (5 years) expected is about 2.4 10^6 for RES and 800 000 for QE

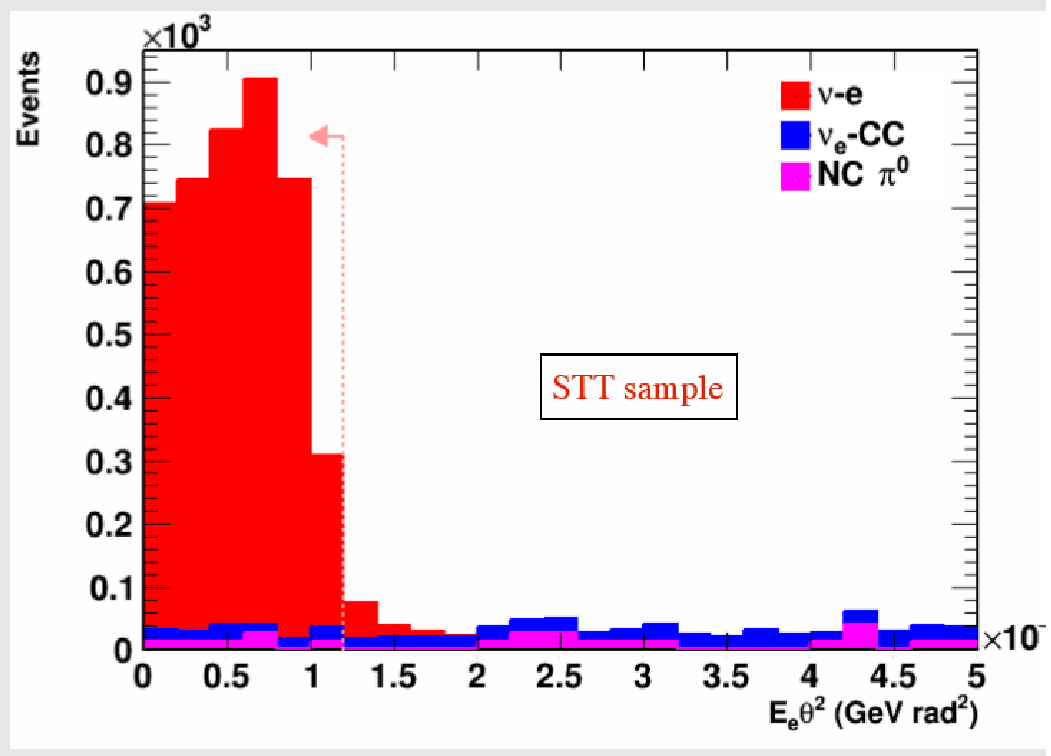
- Low-ν method also on global STT (and Lar) : here deconvolution of MC smeared data sample to recover input neutrino flux from interactions in STT
- Almost identical performances for events in the LAr meniscus and in the STT ➔ direct comparison of events on Ar and H (or C) for nuclear effects assessment



Performances (examples of)

- Charge separation and electron identification→ ν_e / ν_μ and all other species with high statistics (80000 $\bar{\nu}_e$ events in FHC mode 5 years)

- Very good angular resolution on electron tracks→ flux determination from scattering on electrons (rate and shape): The selection efficiency is about 84% with a total background of 5%, composed of QE interactions without reconstructed proton (3%) and NC π^0 interactions (2%). Can be combined with data from external Lar. STT provides smaller statistics but better systematics



PRISM

- The whole detector can be moved on rails, for a PRISM-like exposure.

- Event rates here for ½ year, in the LAr meniscus, FHC
- ν_μ CC : 3.1 10^4 at the largest angle in 5+5 years
- Factor 5 more in STT

Equal POTs at each position						
Offset	10^{20} POT	CCInc ν_μ	NCInc	CCInc $\bar{\nu}_\mu$	CCInc ν_e	El. ν_μ-e
0 m	0.786	$9.4 \cdot 10^4$	$3.4 \cdot 10^4$	$2.9 \cdot 10^3$	$1.1 \cdot 10^3$	8.5
5 m	0.786	$7.3 \cdot 10^4$	$2.6 \cdot 10^4$	$2.5 \cdot 10^3$	$9.3 \cdot 10^2$	6.3
10 m	0.786	$3.2 \cdot 10^4$	$1.2 \cdot 10^4$	$1.5 \cdot 10^3$	$6.1 \cdot 10^2$	2.7
15 m	0.786	$1.4 \cdot 10^4$	$5.5 \cdot 10^3$	$8.0 \cdot 10^2$	$3.9 \cdot 10^2$	1.3
20 m	0.786	$7.9 \cdot 10^3$	$3.2 \cdot 10^3$	$5.2 \cdot 10^2$	$2.5 \cdot 10^2$	0.7
25 m	0.786	$4.8 \cdot 10^3$	$2.0 \cdot 10^3$	$3.4 \cdot 10^2$	$1.7 \cdot 10^2$	0.4
30 m	0.786	$3.1 \cdot 10^3$	$1.3 \cdot 10^3$	$2.5 \cdot 10^2$	$1.2 \cdot 10^2$	0.3
All	5.500	$2.3 \cdot 10^5$	$8.4 \cdot 10^4$	$8.8 \cdot 10^3$	$3.6 \cdot 10^3$	20.2

Half POTs on-axis						
Offset	10^{20} POT	CCInc ν_μ	NCInc	CCInc $\bar{\nu}_\mu$	CCInc ν_e	El. ν_μ-e
0 m	2.750	$3.3 \cdot 10^5$	$1.2 \cdot 10^5$	$1.0 \cdot 10^4$	$4.0 \cdot 10^3$	29.6
5 m	0.458	$4.2 \cdot 10^4$	$1.5 \cdot 10^4$	$1.5 \cdot 10^3$	$5.4 \cdot 10^2$	3.7
10 m	0.458	$1.9 \cdot 10^4$	$6.8 \cdot 10^3$	$9.0 \cdot 10^2$	$3.6 \cdot 10^2$	1.6
15 m	0.458	$8.5 \cdot 10^3$	$3.2 \cdot 10^3$	$4.7 \cdot 10^2$	$2.3 \cdot 10^2$	0.7
20 m	0.458	$4.6 \cdot 10^3$	$1.9 \cdot 10^3$	$3.0 \cdot 10^2$	$1.5 \cdot 10^2$	0.4
25 m	0.458	$2.8 \cdot 10^3$	$1.2 \cdot 10^3$	$2.0 \cdot 10^2$	$9.7 \cdot 10^1$	0.3
30 m	0.458	$1.8 \cdot 10^3$	$7.7 \cdot 10^2$	$1.4 \cdot 10^2$	$6.8 \cdot 10^1$	0.2
All	5.500	$4.1 \cdot 10^5$	$1.5 \cdot 10^5$	$1.3 \cdot 10^4$	$5.4 \cdot 10^3$	36.5

σ and Nuclear Effects

$$N_X(E_{rec}) = \int_{E_\nu} dE_\nu \, \Phi(E_\nu) \, P_{osc}(E_\nu) \, \sigma_X(E_\nu) \, R_{phys}(E_\nu, E_{vis}) \, R_{det}(E_{vis}, E_{rec})$$

- Events on Ar, H, $CH_{2,}$ additional C target within the same detector
- Compare Ar events with free proton kinematics (H)
- Unfolding nuclear effects (R_{phys}) from detector effects (R_{det})
- ➔ measure $\sigma_x R_{phys}$
- Lar TPC detector effects (==Far Det) studied by pixelated LAr TPC
- σ_x on Ar using the large statistics from the LAr and HPgTPC detectors

Flux measurements

- Φ (E_ν) Measurements
  - Absolute ν flux from ν e → ν e elastic
  - Fluxes vs E_ν, ratios of ν_x / ν_y (e, μ, anti) from interactions on Hydrogen
  - the availability of large statistics from a hydrogen target allows precisions far exceeding what is achievable with any nuclear target.

Events/ 10^{20} pot

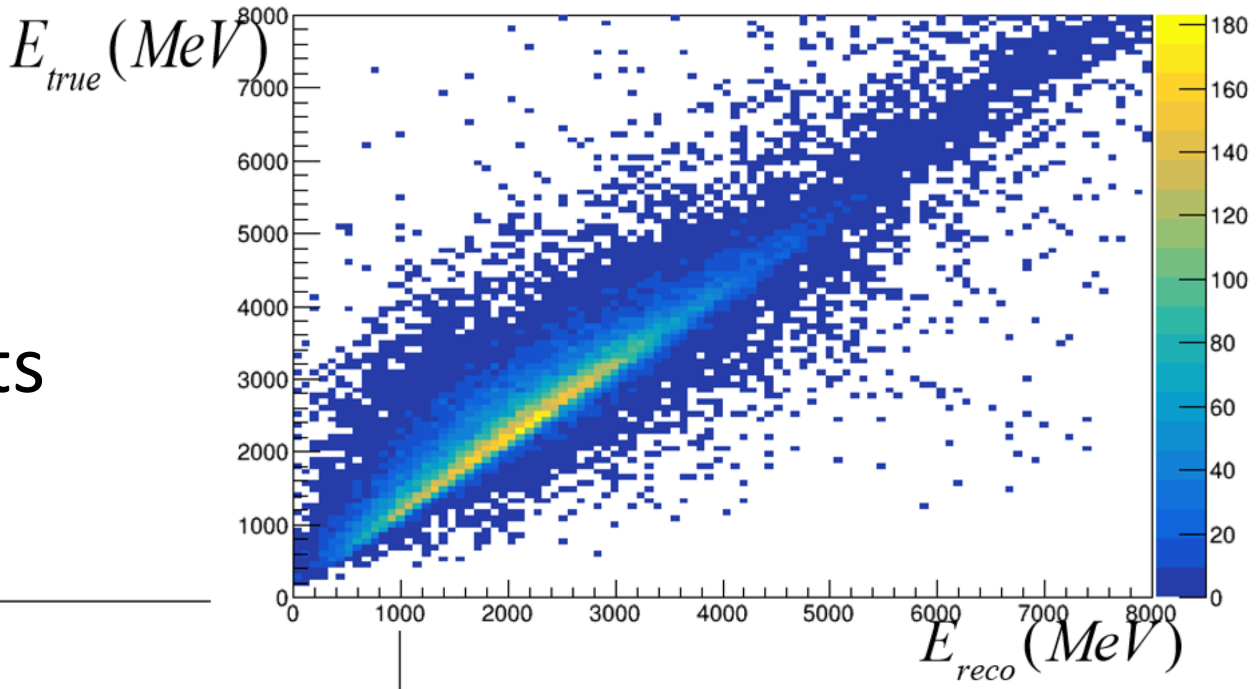
FHC	ν_μ	$\bar{\nu}_\mu$	ν_e	$\bar{\nu}_e$	Total
All	675812	31114	9993	1603	718521
Ar	142976	5578	2129	299	150982
C	469686	20431	6922	1050	498089
H	48714	4446	733	221	54114
RHC	ν_μ	$\bar{\nu}_\mu$	ν_e	$\bar{\nu}_e$	Total
All	105533	242126	4735	3470	355863
Ar	22076	42993	1007	637	66713
C	73385	157964	6922	2265	236893
H	7739	36105	347	495	44686

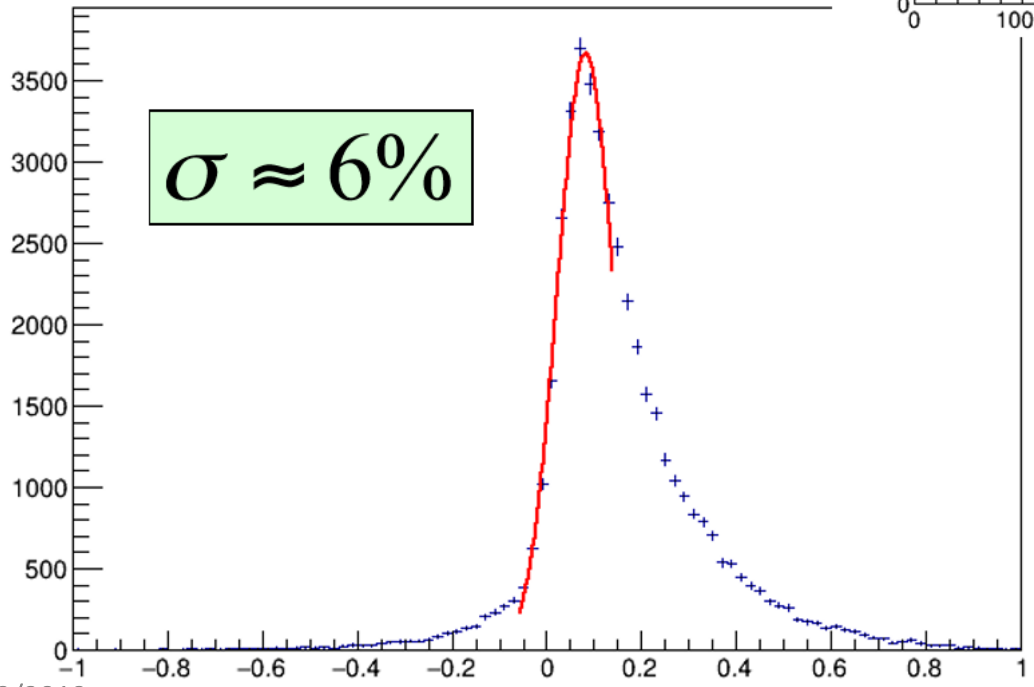
- ν_μ on H : 5 10^5 /year
- $\bar{\nu}_\mu$ on H : 8 10^4 /year
- ν_e on H : 8 10^3 /year

- ν_μ e in FHC : 1000/year in STT, possibly combined with measurement from large mass pixelated LAr detector

Neutrinos

Old results





$$1 - \frac{E_{reco}}{E_{true}}$$

From full GENIE + GEANT4 simu + MC truth guidance