



SAPIENZA
UNIVERSITÀ DI ROMA



CENTRO RICERCHE
ENRICO FERMI

Analysis status

FOOT General Meeting - Trento
12/12/2023

Marco Toppi, for the analysis crew



FOOT campaigns to analyze

We have collected several dataset with different setups: data analysis ongoing / waiting to be analyzed

Electronic setup					
Campaign	Beams	Energy [MeV/u]	Targets	Detectors	
GSI 2019	O	400	C	SC, BM, TW	
GSI 2021	O	200, 400	C, C ₂ H ₄	SC, BM, VT, MSD, TW	
HIT 2022	He	100, 140, 200, 220	C	SC, BM, MSD, TW, CALO	
CNAO 2022	C	200	C	SC, BM, VT, MSD, TW, CALO	
CNAO 2023	C	200	C, C ₂ H ₄	Full, magnets	

Emulsions setup				
Campaign	Beam	Energy [MeV/u]	Targets	
GSI 2019	O	200, 400	C, C ₂ H ₄	
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CNAO 2023	C	221	C, C ₂ H ₄	

CNAO 2017 setup					
Campaign	Beam	Energy [MeV/u]	Targets	Angles	
CNAO 2017	C	115,153, 221, 281, 353	C, C ₂ H ₄ , PMMA	32°, 60°, 90°	

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O + C @ GSI “to be submitted” by 2023, as requested by the FOOT referees + some results of HIT2022

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Comparing of our results for same dataset acquired with different setups: not an easy task but it is a good chance to verify the solidity of our analysis: **electronic - emulsions: He, Li (?), and total XS – forward emitted**

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- I will focus now on the status of the analysis of the electronic setup, sharing some of the idea and the results shown in the analysis meeting of this year focusing only on the XS analysis
- This year we had some nice advances thanks to the work of the analysis crew despite the interruption due to CNAO 2023 data taking (September-November): we had a total of 19 analysis meetings (regular weekly meetings every Wednesday morning at 9.30, everyone is welcomed to join)
- Updates on Emulsion analysis will be provided by Giuliana and Vincenzo today and tomorrow
- Updates of the CNAO2017 setup analysis will be given soon (in one of the upcoming physics meetings) by Ila

Status of the needed inputs / calibrations of each campaign

Campaign	BM	VTX / IT	MSD	TW (+ SC)	Calo	Alignment	Full MC	DAQ synchronization/cleaning
GSI 2021	✓	✓	Pedestal Eta function	Calibration Eloss/Tof ZID Positions along bar	-	✓	✓	✓
HIT 2022	✓	-	Pedestal Eta function	Calibration Eloss/Tof ZID Positions along bar	Calibration	✓	✓	✓
CNAO 2022	✓	✓	Pedestal Eta function	Calibration Eloss/Tof ZID Positions along bar	Calibration	✗	✓	✗
CNAO2023 (12C_200_2023 v2)	✓	✓	Pedestal Eta function	Calibration Eloss/Tof ZID Positions along bar	Calibration	✓	✓	✓
	Yun	Chris	Benedetto, Gianluigi, Leonello, Lucia	Aafke, Giacomo, Marco, Matteo M, RobZ, Tino	Alessandro, Benedetto, Francesca, Piergiorgio	Yun	Giuseppe, Silvia	Riccardo, Mauro

- Talks from Chris, Alessandro and Benedetto for VTX / IT and CALO about reconstruction / calibration @ CNAO 2023 later
- Talks from Giuseppe for the CNAO 2023 MC simulation updates

Performances, MC tuning with data

	BM	VTX / IT	MSD	TW (+SC)	Calo	Global Tracking
Performances data/MC comparison	<ul style="list-style-type: none"> Track Efficiency (Data/MC) and Purity Residuals/Pulls Noise Data/MC 	<ul style="list-style-type: none"> Clustering, tracking and vertexing Efficiency and Purity for each Z in angular bins Residual/Pulls for each Z Cluster size for each Z (data/MC) Efficiency wrt sensor position (Data/MC) Dead map, noise Data/MC 	<ul style="list-style-type: none"> Efficiency and Purity for cluster and points for each Z Resolution for cluster and point position Cluster size for each Z (data/MC) Noise Data/MC 	<ul style="list-style-type: none"> Efficiency and Purity for TW points for each Z Resolution in Eloss, Tof and Position for each Z CMM Eloss, Tof and position along the bar for each Z (data/MC) 	<ul style="list-style-type: none"> Efficiency and Purity for clustering for each Z Kinetic energy and position resolution for each Z (data/MC) 	<ul style="list-style-type: none"> Efficiency and Purity for each Z and A in angular and kinetic energy bins Residual/Pulls for each Z Comparison data/MC glb trk outputs Resolution in angle, Ekin, Momentum, Mass
Status	In progress	In progress	In progress	In progress	In progress	In progress
People	Yun	Chris, Giacomo U	Leonello, Benedetto, Yun	Giacomo, Marco, Roberto	Alessandro, Francesca	Roberto, Giacomo U

- We should start to collect plots of detector/FOOT performances and data/MC comparison for each campaign in a repository**
- Useful for having an idea of the status of reconstruction of FOOT and plots ready for conferences / meeting with referee / meeting for funds requests

What have we learned so far?

From my talk to the last GM:

- First milestone: to have as soon as possible a full reconstruction "under control" able to produce cross sections and verify them with a MC closure test.
- At this moment FOOT doesn't know what is the precision it can reach in measuring MC cross section (and for data will be worse)
- **The GSI 2021 analysis is our first testing-bench** (see Riccardo and Giacomo Ubaldi talks)
- We've managed to reconstruct the MC XS with a good precision with respect to the MC true XS (still room for improvement) starting from the output provided by the tracking algorithm:
 - First complete quantitative check of the tracking algorithm output (check not yet done for magnetic field with the full setup).
 - Nice team effort of many members of the analysis crew for the analysis of the global tracking output to study and identify the needed selection criteria which had allowed a MC closure test at the actual state (see Giacomo U's talk)
 - We're starting to understand better our detector / the full reconstruction and its limits. Important tool for all the analysis and a "meter" to take decisions for future data taking (for example in terms of statistics)

Important implications

- **Rejection of background** (out of target, combinatorial and cross feed) **can be managed with appropriate cuts / selections** (see Giacomo Ubaldi's talk):
 - no need to implement anymore background subtraction technique from “no target” data (?)
 - If verified also for the full setup (magnet included), this will allow us to save time during data collection
- Still room for detector reconstruction improvement (see VTX cluster size and MSD eta function useful for ghost removal and ZID algorithm). But **now we can estimate the impact of their implementation in the XS** (→ the most important removal of combinatorial background) and evaluate it in terms of manpower / time for publication
- **A robust fragment Z identification**, as the one reached within GSI 2021 analysis, **allows to implement the inverse kinematic approach to measure H+O XS**. We can implement an integrated cross section for the process H+O for the different fragment Z with GSI2021 data to show to the FOOT referees we're able to do it (this is something they've asked us to do)

What is still missing?

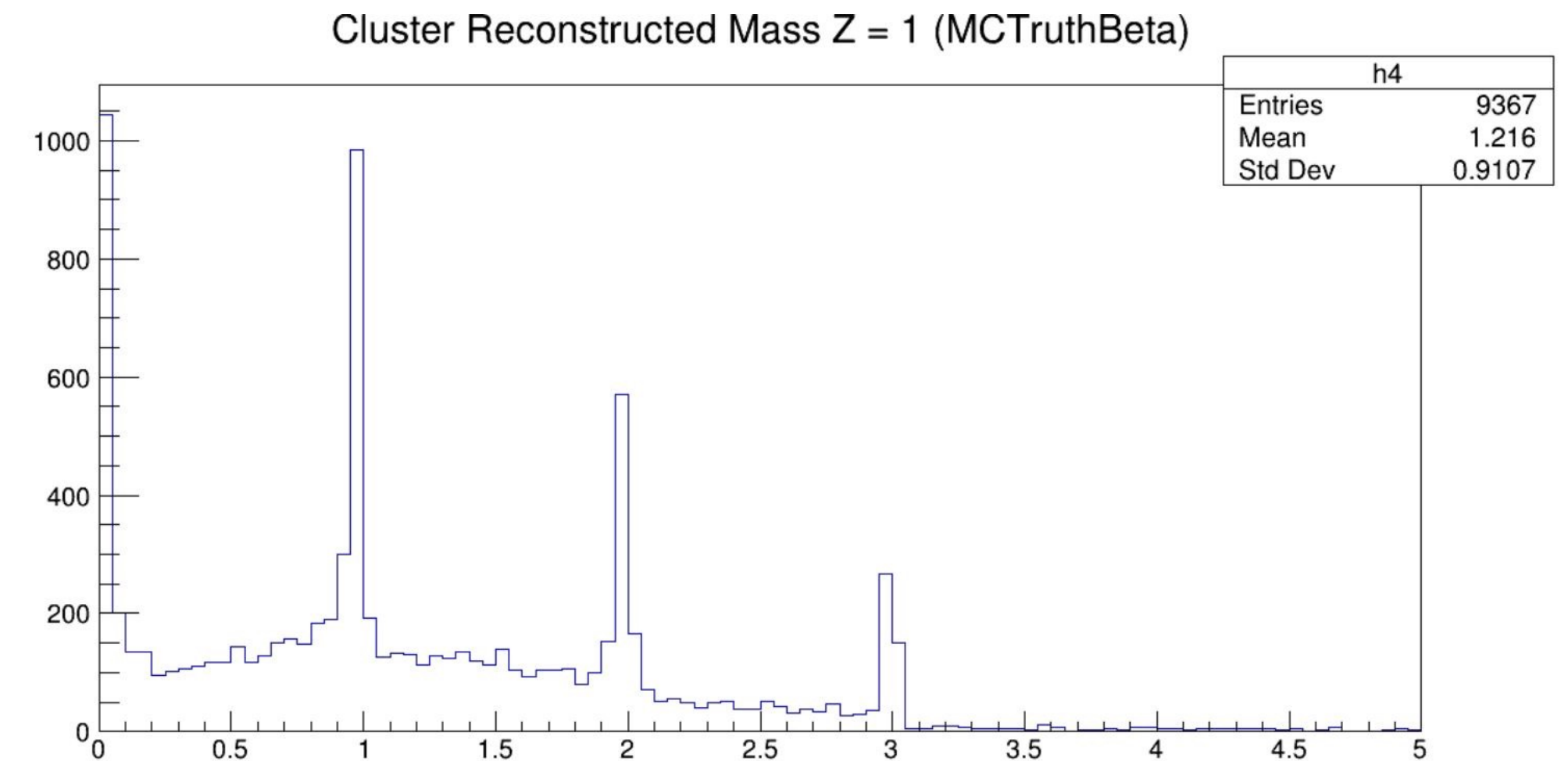
- The data analysis... :)
- **To apply the full reconstruction to the data we still need to study many experimental effects and tuning the MC accordingly:**
 - efficiency / thresholds of the trackers (considered protons excluded for the moment)
 - pile up in VT/IT, high rates effects (+ pile-up studies in MC to better understand our capability in rejecting it and to estimate a rejection efficiency)
 - Effects of rotation of the magnetic field / alignment with the full detector
 - Tuning of the experimental resolutions in MC for every measured quantity not completed yet
 - Systematics on the implemented algorithms, geometry, analysis techniques
 - Further experimental effects correction (i.e. Tof worsening seen at CNAO 2023)

HIT2022 status

- Possibility to identify p, d, t and ^3He in $^4\text{He}+\text{C}$ interactions
- First attempt to identify them with ToF and Calo in MC, using true ToF (**Alessandro, Francesca and Tino** work)
- Calibrations of CALO and TW done

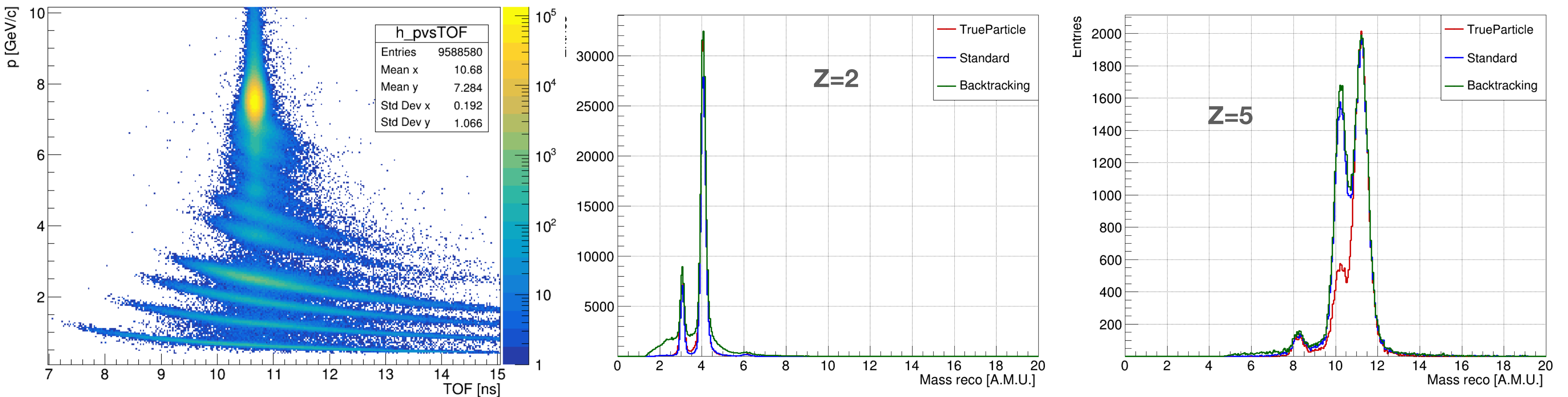
What is missing?

- **Need to tune the tracking algorithm for this campaign (No VT) using backtracking developed by RobZ and verify it with a MC closure test for XS. Vertexing in this case not included yet** → useful also for GSI 2021 O @ 200MeV/u (no VTX included)
- Data analysis, study of efficiency of MSD to protons and tune the MC accordingly:
- Implement of TW calibration / resolution in shoe
- CALO reconstruction performances to be verified
- Have pile up, high rate effects, ToF worsening some impact in this setup?



CNAO2023 MC status

- Preliminary results from RobZ already show good mass separation (resolution of some detector already included) with the full setup and magnetic fields, using the momentum p and ToF reconstruction.
- In next months reply of the work done for GSI 2021 to have a MC closure test for the isotopic fragmentation XS
- Big effort from Giuseppe and Silvia to make the new CNAO2023 simulation data compliant (see magnetic field map)
- A lot of work from RobZ to finally fully exploit the tier1 resources for a fast process of full stat files needed for all the XS analysis → Roberto's talk of today



Courtesy of Roberto Zarrella

Analysis summary and manpower distribution

Campaign	MC analysis: Closure test (Efficiency, Purity, unfolding, background rejection)	Systematics	Raw Data analysis	Calo matching	Physics
GSI 2021	No track: Riccardo Tracking: Giacomo U.	No track: Riccardo	(*)	No calo	O+C, O+C ₂ H ₄ , O+H @ 400 MeV/u H+O inverse XS ?
GSI 2021	-	-	(*)	No calo	O+C, O+C ₂ H ₄ , O+H @ 200 MeV/u H+O inverse XS
HIT 2022	-	-	(*)	Mass spectra: Alessandro, Francesca, Tino	He+C @ 100, 140, 200, 220 MeV/u
CNAO 2022			(*)	-	C+C @ 200 MeV/u alpha clustering?
CNAO2023 (+ Full setup MC)	Tracking: RobZ alpha clustering: Milano	-	(*)	-	C+C, C ₂ H ₄ , C+H @ 200 MeV/u H+C (inverse XS) alpha clustering

(*) Some data analysis always performed in the proximity of the data taking (Pile-up, efficiency / thresholds, Fragmentation trigger, resolutions in data/MC analysis for different detectors, ...)

Analysis which share common reconstruction

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GSI 2021	-	-	(*)	No calo	O+C, O+C ₂ H ₄ , O+H @ 200 MeV/u H+O inverse XS
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Conclusions 1: FOOT priorities in XS analysis

Priority order set by referee requests:

- ✓ **GSI 2021** (O @ 400MeV/u) data analysis finalization for the electronic setup
- ✓ **GSI 2019** (O @ 200, 400MeV/u) data analysis finalization for the emulsion setup
- ✓ Implementation of a MC closure test for full setup / **CNAO2023** analysis starting from the experience of the GSI2021 analysis and then relative data analysis
- ✓ **HIT 2022** (+ implementation of vertexing with backtracking algorithm)
- ✓ **CNAO2017 setup**
- ✓ **GSI 2021** (O @ 200 MeV/u)
- ✓ **CNAO2022** (C @ 200MeV/u electronic setups)
- ✓ **CNAO2023 and GSI2020** (C @ 200MeV/u and 700 MeV/u emulsion setups)

Conclusions 2: titles for your next master student thesis

- Study of pile up in the high beam rate data runs acquired at CNAO 2023 + tuning in MC to study strategy and efficiency in pile-up rejection
- MSD eta function / charge equalization and implementation of ZID and ghost removal
- MSD and VTX efficiency / threshold study in data and tuning in MC
- To perform mass identification with CALO we need a calibration along the full energy range of interest: it can be done using E_{kin} information from ToF measured by TW-SC for each Z for TW points matched to the CALO
- To perform measurements of protons with the electronic setup we need to study the thresholds in TW: it could be done using physics data using energy information from the calorimeter once calibrated
- If we're able to reject the out of target fragmentation and so also to reject the pre-target fragmentation → possibility to explore pro and cons of greater thickness for SC (ToF improvement / mass separation wrt Eloss / loss of statistics)



Work in progress for the Analysis

- **Analysis working group:**

- First milestone: to have as soon as possible a full reconstruction "under control" able to produce cross sections and verify them with a MC closure test.
- At this moment FOOT doesn't know what is the precision it can reach in measuring MC cross section (and for data will be worse)
- Ongoing analysis for GSI2021 data → talks of Riccardo and Giacomo (Ubaldi)

- **TW working group:**

- Matteo/Esther -> studying thresholds and resolutions for GSI 2021 campaign -> talk today
- Aafke -> taking care of TW calibration @ CNAO2022 -> talk today
- Tino/Miriam -> taking care of TW calibration @ HIT2022 -> talk today
- RobZ-> Already provided positions calibrations for all campaigns -> talk today
- me -> taking care of TW reco in shoe and fix/update in order to have performance plots ok for every campaign

Work in progress for the Analysis

- **CALO working group:**

- CALO guys provided calibration @ CNAO and HIT 2022 -> talk today
- Alessandro/Francesca/Tino candidate for TW-calo match for HIT2022 to produce mass distributions (following calo and TW calib)

- **MSD working group:**

- Matteo/new master student-> new clustering + eta function @ HIT2022
- Leonello/Benedetto -> MSD efficiencies with protons @ Trento
- Gianluigi/Lucia -> working on pedestals @ HIT2022 → talk today
- Tino -> efficiencies @ HIT2022

- **MC group:**

- Giuseppe and Silvia produced all the MC campaigns relative to data taking and full setup

Work in progress for the Analysis

- **BM:**
 - Yun is working on improvement of BM tracking algorithm -> talk today
- **SC:**
 - Giacomo is working on the ToF worsening observed especially at CNAO2023
- **VTX:**
 - Giacomo Ubaldi with Chris supervision is taking care of studying VTX algorithm performances -> talk today
- **Glb tracking:**
 - Rob, Giacomo Ubaldi and Matteo studying performances of Glb tracking and methods to reject bkg