Analysis status

Shoe tutorial
12/02/2025

Marco Toppi, for the analysis crew

FOOT campaigns to analyze

Electronic setup				
Campaign	**Beams**	**Energy [MeV/u]**	**Targets**	**Detectors**
GSI 2019	O	400	C	SC, BM, TW
GSI 2021	O	200, 400	C, C_2H_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_2H_4	Full, magnets
CNAO 2024	C	200	C	Full, magnets

Emulsions setup			
Campaign	**Beam**	**Energy [MeV/u]**	**Targets**
GSI 2019	O	200, 400	C, C_2H_4
GSI 2020	C	700	C, C_2H_4
CNAO 2023	C	221	C, C_2H_4

CNAO 2017 setup				
Campaign	**Beam**	**Energy [MeV/u]**	**Targets**	**Angles**
CNAO 2017	C	115,153, 221, 281, 353	C, C_2H_4, PMMA	32°, 60°, 90°

Ongoing Analysis: status @ Trento GM

Electronic setup					
Campaign	**Beams**	**Energy [MeV/u]**	**Targets**	**Detectors**	**Status**
GSI 2019	O	400	C	SC, BM, TW	✓
GSI 2021	O	200, **400**	**C**, C_2H_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_2H_4	Full, magnets	✗

Emulsions setup				
Campaign	**Beam**	**Energy [MeV/u]**	**Targets**	**Status**
GSI 2019	O	200, 400	C, C_2H_4	✓
GSI 2020	C	700	C, C_2H_4	✗
CNAO 2023	C	221	C, C_2H_4	✗

CNAO 2017 setup					
Campaign	**Beam**	**Energy [MeV/u]**	**Targets**	**Angles**	**Status**
CNAO 2017	C	115,153, 221, 281, 353	C, C_2H_4, PMMA	32°, 60°, 90°	✓

Status of the needed inputs / calibrations of each campaign

Campaign	BM	VTX / pile-up	IT	MSD	TW (+ SC)	Calo	Alignment	Full MC	DAQ synchronization/cleaning
GSI 2021	✓	✓	-	Pedestal, thresholds, Eta function	Calibration Eloss/Tof ZID Positions along bar	-	✓	✓ GSI21PS_MC	✓
HIT 2022	✓	-	-	Pedestal, thresholds, Eta function	Calibration Eloss/Tof ZID Positions along bar	Calibration	✓	✓ HIT2022_MC	✓
CNAO 2022	✓	✓	-	Pedestal, thresholds, Eta function	Calibration Eloss/Tof ZID Positions along bar	Calibration	✗	✓ CNAO22PS_MC	✓
CNAO2023	✓	✓	✓	Pedestal, thresholds, Eta function	Calibration Eloss/Tof ZID Positions along bar	Calibration	✓	✓ CNAO23PS_MC	✓
CNAO2024	✓	✓	✓	Pedestal, thresholds, Eta function	Calibration Eloss/Tof ZID Positions along bar	Calibration	✓	✗	✓
	Yun	Chris, Luana, Marco	Chris	Alessio, Ilaria Gianluigi, Leonello, RobZ	Aafke, Giacomo, Marco, Matteo, RobZ	Torino group	Yun	Giuseppe, Silvia	Riccardo, Mauro

Status of Simulation Campaigns

Thanks to the developments introduced in 2024, the number of important and useful simulation campaigns, which will be maintained, is now limited.

Data taking campaigns:

CNAO23PS_MC

GSI21PS_MC

CNAO22PS_MC

HIT2022_MC

HIT22PS_MC (production not yet available in the shared folder)

In preparation: **CNAO24PS_MC**

Full detector studies:

12CFull24_MC

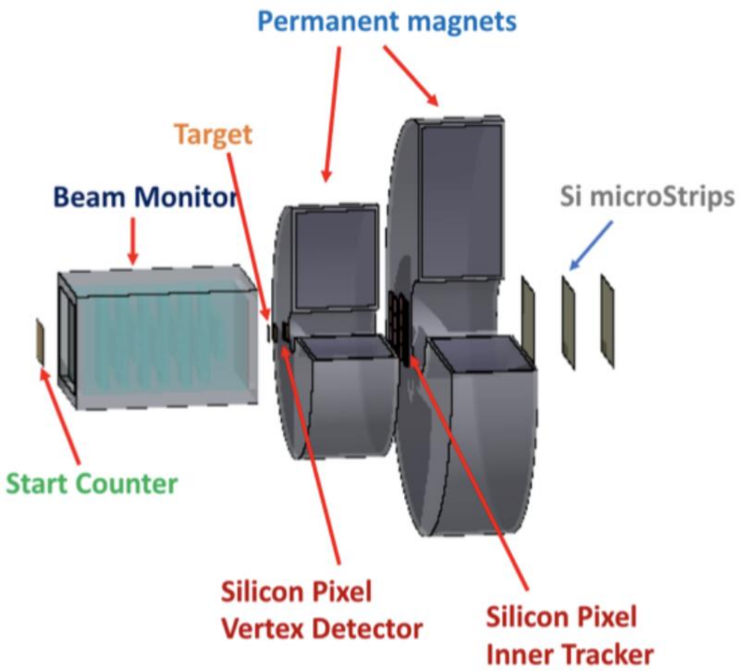
GSI25PS_MC (higher energy studies)

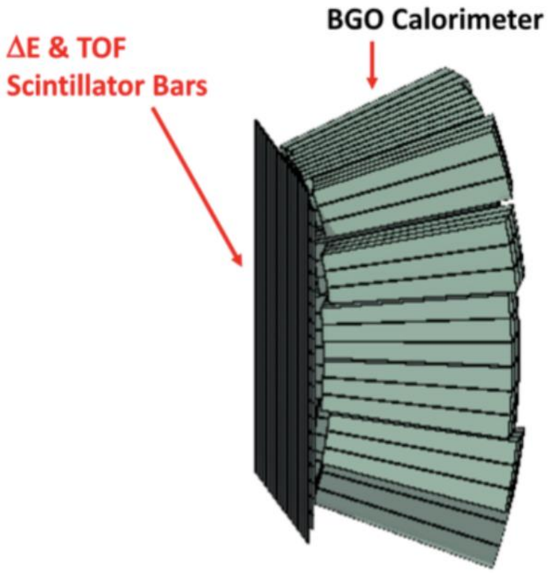
Slides from Silvia and Giuseppe

Reconstruction, performances, MC tuning with data

	BM	VTX / IT	MSD	TW (+SC)	Calo	Global Tracking
Performances data/MC comparison	• Track Efficiency (Data/MC) and Purity • Residuals/Pulls • Noise Data/MC	• Clustering, tracking and vertexing • Cluster size for each Z (data/MC) • Efficiency for each sensor (Data/MC) • Dead map, noise Data/MC	• Pedestal / thresholds study • 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	• 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)	• Efficiency and Purity for clustering for each Z • Kinetic energy and position resolution for each Z (data/MC)	• 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	✓	✓	✓	✓	✓	✓
People	Yun	Chris, Launa, Marco	Alessio, Ilaria, RobZ	Giacomo, Marco, Roberto	Torino group	Roberto, Giacomo U

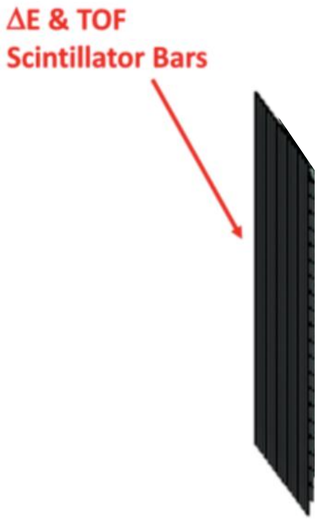
FOOT campaigns to analyze





Our beautiful detector in all its glory, but…

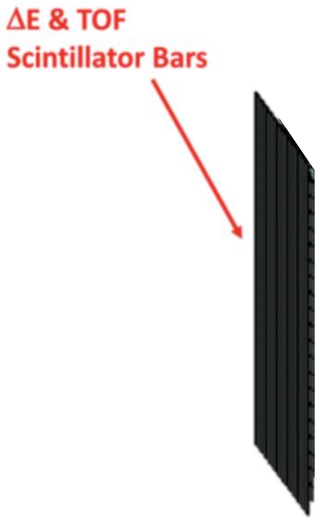
FOOT campaigns to analyze



We are using only these detectors so far in cross section data analysis …

- Why only these detectors?
- Are the only ones completely under control, which means:
  - HW
  - Reconstruction
  - Calibration
  - Efficiencies
  - Systematics

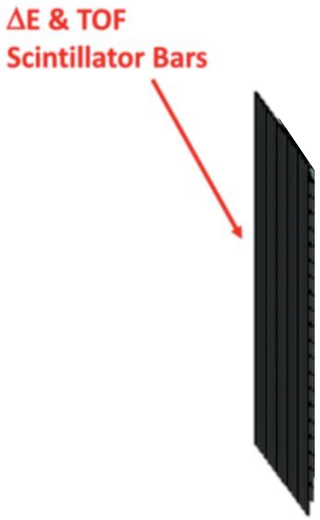
SC + BM + TW analysis



- **GSI2019: O @ 400 MeV/u + C, integral XS**
- **GSI2021: O @ 400 MeV/u + C, integral and angular differential XS**
- **GSI2021: O @ 400 MeV/u + C_2H_4, integral and angular differential XS. O+H and H+O**
- **GSI2021: O @ 200 MeV/u + C, C_2H_4, integral and angular differential XS. O+H and H+O**
- **CNAO2022: C @ 200 MeV/u + C, integral and angular differential XS.**
- **HIT2022: He @ 100,140,200,220 MeV/u + C, integral and angular differential XS. (only Z=1…)**

→ Riccardo Ridolfi paper and Matilde Dondi analysis

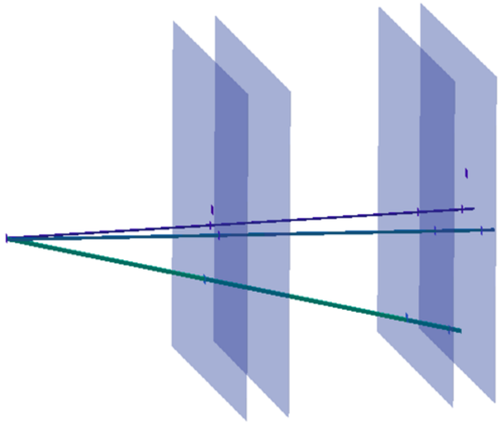
SC + BM + TW analysis

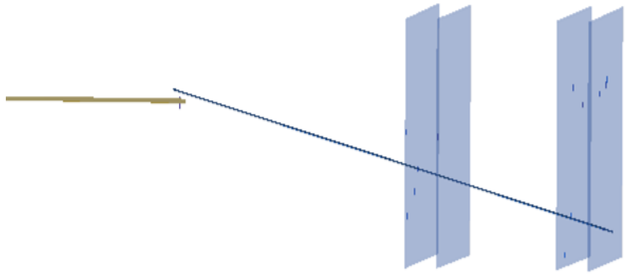


- **GSI2019: O @ 400 MeV/u + C, integral XS**
- **GSI2021: O @ 400 MeV/u + C, integral and angular differential XS**
- **GSI2021: O @ 400 MeV/u + C_2H_4, integral and angular differential XS. O+H and H+O**
- **GSI2021: O @ 200 MeV/u + C, C_2H_4, integral and angular differential XS. O+H and H+O**
- **CNAO2022: C @ 200 MeV/u + C, integral and angular differential XS**
- **HIT2022: He @ 100,140,200,220 MeV/u + C, integral and angular differential XS. (only Z=1…)**

- the developed software is almost “plug and play”, independent from the setup and can be used to produce results for each of the above campaigns
- can be used to provide first inverse kinematic integrated XS: H @ 200, 400 MeV + O at GSI2021 (happy referees)
- **Can be used to cross check our results obtained with different setup [e.g. emulsions @ GSI2021 (O(200MeV/u)+C)]**

Adding the VTX (to SC, BM, TW)



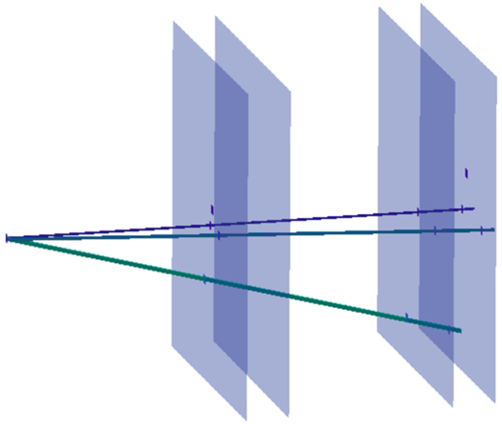


Adding the VTX to measure XS and compare with SC+BM+TW analysis results for GSI2021, CNAO2022 campaigns

Still missing for use it in XS:

- Check the results against the VTX pile-up (70% of events with at least two tracks in GSI against 20% at CNAO)
- Try to remove the pile up with downstream detectors instead of using only BM matching (GSI2021)
- Efficiencies evaluation done in CNAO2024 is reliable for older campaigns?
- Implement identification of vertexes with one track through the kink of the track
- Study background impact and validate a strategy in the MC

Adding the VTX (to SC, BM, TW)



- **GSI 2021: O @ 200, 400 MeV/u + C, C_2H_4, integral and angular differential XS. O+H and H+O**
- **CNAO 2022: C @ 200 MeV/u + C, integral and angular differential XS**

Adding the VTX to measure XS and compare with SC+BM+TW analysis results for GSI2021, CNAO2022 campaigns

Still missing for use it in XS:

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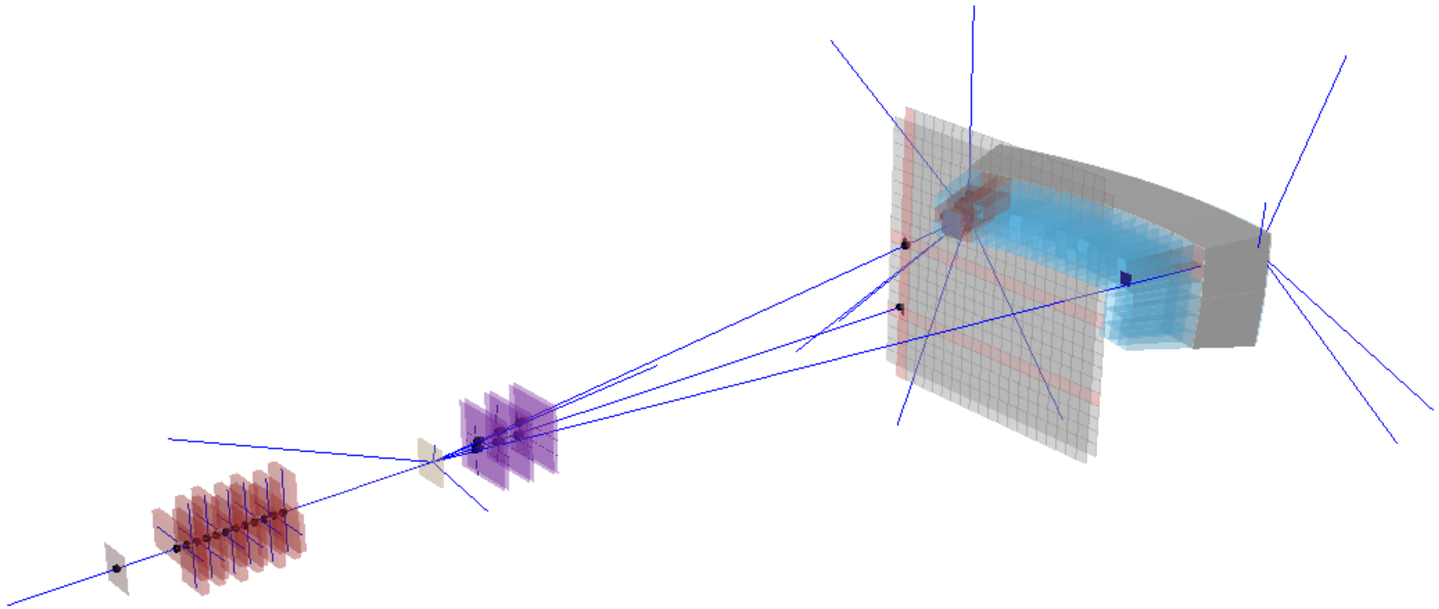
→ Luana Testa analysis @ GSI2021

Possibility to cross check results with Riccardo Ridolfi analysis ^{16}O(400MeV/u)+C

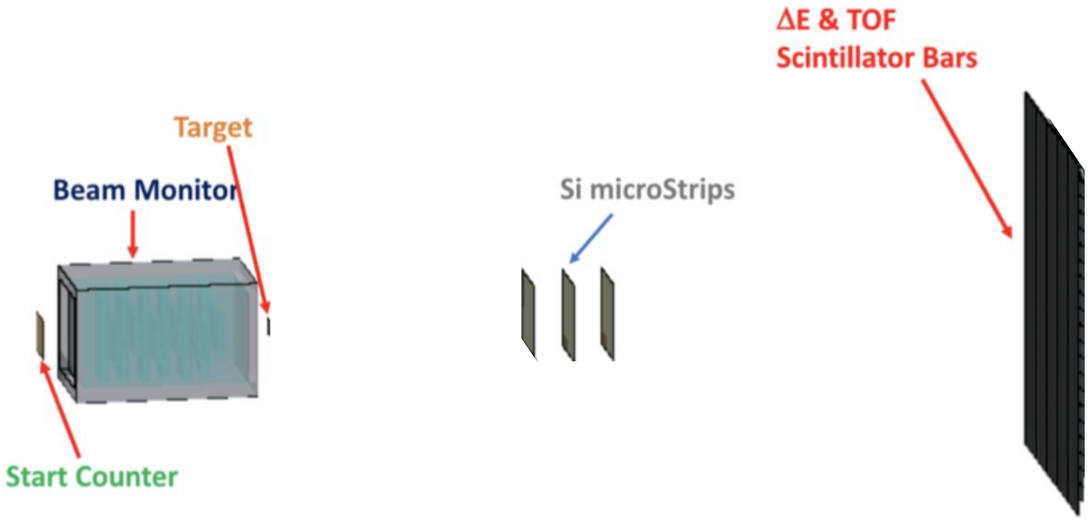
HIT2022: Adding CALO (to SC, BM, TW)



Using CALO in a limited angular region can be explored the possibility to measure kinetic energy differential cross sections for production of p, d, t and ^{3}He --> Pisa group (Aafke, Lorenzo, Matteo)

Possibility to cross check results with SC, BM, TW analysis for Z=2->Z=1 XS

Adding MSD (if no VTX)



Pros :

- Minimize the impact of the angular unfolding procedure and at the same time increase the number of angular bins
- Reduce purity correction impact thanks to tracking + MSD eta

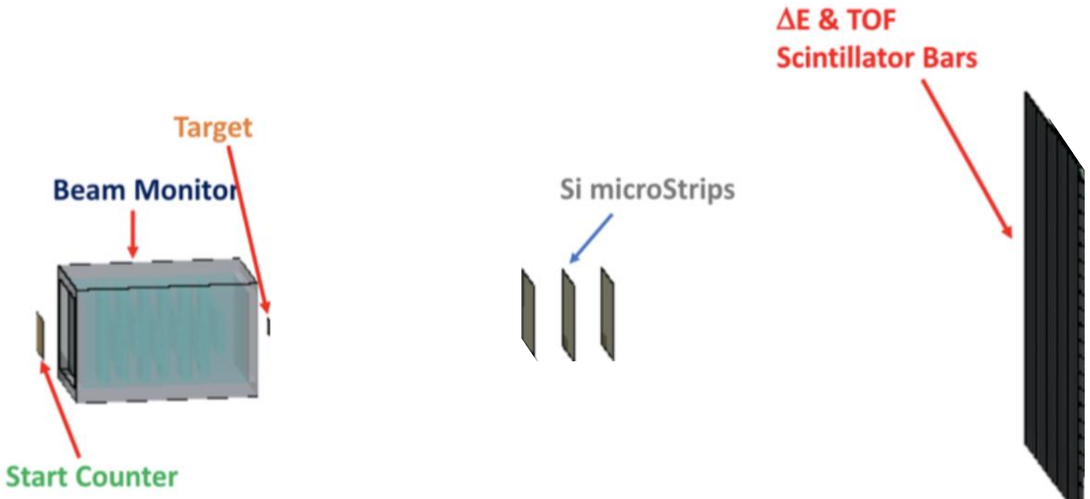
The same analysis could be improved using MSD

- Detector under control from HW point of view and some work in progress for calibration (pedestals and MSD sensor-board connection maps re-checked)
- Thanks to the work of RobZ and now also of Alessio MSD eta correction is going to be under control on all the setups (almost setup-independent)

Still missing for use it in XS:

- Efficiencies (especially of interest for H tracks in HIT2022)
- Cluster reconstruction / thresholds
- Track reconstruction in case of absence of VTX/IT
- Introduce some sort of «vertexing» (better to speak of converging tracks in the TG) using the MSD
- Study background impact and validate a strategy in the MC

Adding MSD (if no VTX)



- **HIT2022: He @ 100, 140, 200, 220 MeV/u + C, integral and angular differential XS (+ CALO)**
- **GSI2021: O @ 200 MeV/u + C, C_2H_4, integral and angular differential XS. O+H and H+O**

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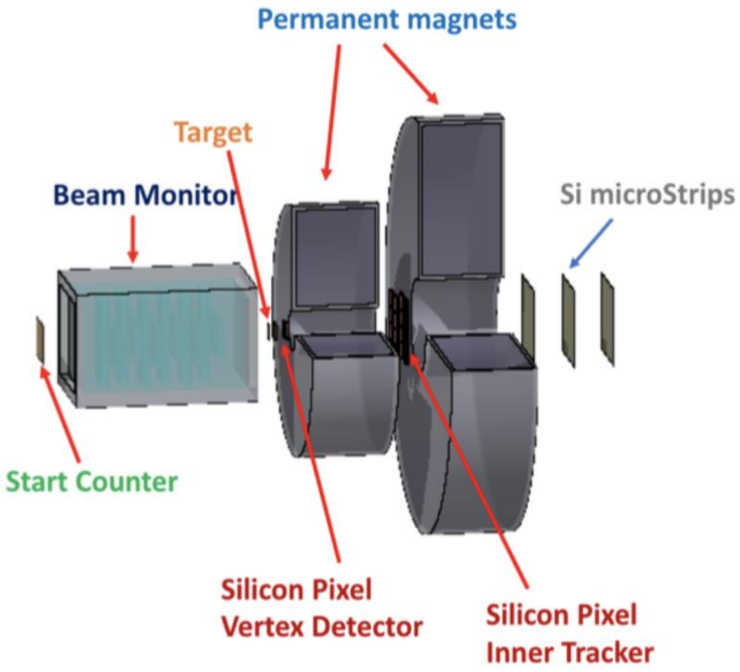
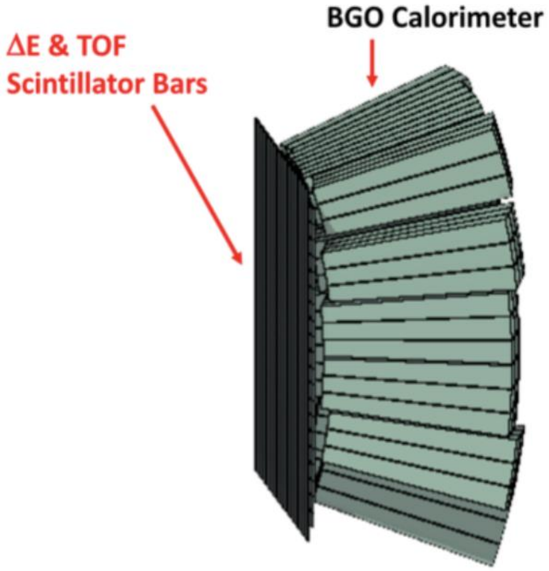
Full setup: CNAO2023 vs CNAO2024





At CNAO 2024 collected ~ 2x10^6 events of physics C+C @ 200 MeV/u:

- Fundamental to compare with CNAO2023 data with the VTX optimized (and also IT for some runs)
- Need to have tracking system under control (alignement, efficiencies, spatial resolution for tolerances, thresholds,…) to see some global tracks for fragments and finally perform XS anaysis with p+Tof
- Energy calibration of CALO to perform XS analysis with Ekin + Tof

→ Giacomo Ubaldi and Roberto Zarrella work on MC elemental XS analysis

→ Chris Finck working on IT data/MC

Ongoing Analysis

Campaign	setup	technique	physics	Energy [MeV/u]	Calo	who	MC	Data	paper
GSI 2021	electronic	SC,BM,TW	$^{16}O+C_2H_4$, $^{16}O+H$ ($^{16}O+C$), $H+^{16}O$	200, 400	-	Matilde Dondi, Riccardo Ridolfi	✓	✓	-
GSI 2021	electronic	SC, BM, VTX, TW	16O+C fragmentation (2<Z<8)	400	-	Luana Testa	✓	✓	-
HIT2022	electronic	SC, BM, (MSD), TW, CALO	4He+C->p,d,t,3He	100,140,200,220	Yes	Aafke, Matteo M, Lorenzo Pierfederici	✓	✓	-
CNAO 2023/2024	electronic	Global tracking	12C+C fragmentation (2<Z<6)	200	Yes	Giacomo Ubaldi, RobZ, Luana Testa	✓	✗	-
GSI 2021	electronic	Global tracking	Alpha clustering (from 16O)	200	-	Alice, Giuseppe, Silvia	✓	✗	-
GSI 2019	emulsion	S1+S2	16O+C,C2H4 fragmentation	200	-	Giuliana Galati	✓	✓	In progress
GSI 2019	emulsion	S1+S2	Alpha clustering (from 16O)	200	-	Vincenzo Boccia	✓	✓	-

Analysis strategy

- Use SC+BM+TW analysis to have XS in campaign) without magnet (GSI2021, HIT2022, CNAO2022: to be published and needed for internal cross checks
- Add VTX to measure XS and cross check with SC+BM+TW analysis in campaign without magnet (GSI2021, CNAO2022): needed for cross check with SC, BM TW and full setup analysis
- Add MSD to measure XS and cross check with SC+BM+TW analysis in campaign without magnet (no VTX)
- MSD + CALO @ HIT2022 for He XS: first time for masses with calorimeter (easiest case: only p, d, t and ^{3}He)
- Move to CNAO2023 and CNAO2024 and look for global tracks and try for a XS (Tof+p) comparing CNAO2024 (where VTX thresholds are optimized) with CNAO2023
- CNAO2023/CNAO2024 XS analysis Tof+Ekin from CALO
- **CNAO2024 is our main goal, the only one with VTX optimized thresholds/efficiencies) but to analyze it we still need to understand a lot of detectors and effects**

Work in progress / still missing

- Pile up in VT high rates effects (+ pile-up studies in MC to better understand our capability in rejecting it and to estimate a rejection efficiency)
- IT alignment / reconstruction
- MSD reconstruction, threshold, eta function / charge equalization and implementation of ZID and ghost removal
- In MC no detector effects (noise, cluster sizes, threshold resolutions and efficiency tuned from data) for most of the trackers and calo
- Effects of misposition/rotation of the magnetic field / alignment with the full detector
- Systematics on the implemented algorithms, geometry, analysis techniques
- Further experimental effects correction (i.e. Tof worsening at CNAO 2023 → see GiacTraini's talk in last GM)
- **Isotopic cross sections with full setup MC**
- **Using Fluka, Geant4 and other nuclear models to compare with our results (requested by PRC)**

In conclusion

- A lot of work is still needed in the **reconstruction / full comprehension of single systems. Reconstruction / full comprehension** means both software implementation, performance studies and understanding of new data to be collected for a specific system
- Furthermore, for some campaigns the needed calibrations / inputs are still missing. Many people involved for this purpose which runs out part of the man-power
- **For no campaigns we have a full FOOT detector ready to plug and play with XS analysis**
- if someone want to help on a new task or need inputs for his/her analysis please contact me (marco.toppi@uniroma1.it) and the people involved in the system: we will find a specific task. Our man-power is limited and therefore it is good not to overlap between people
- For problem with software contact Yun (yunsheng.dong@mi.infn.it) and RobZ (Roberto.Zarrella@bo.infn.it) or write to the software list (foot-software-develop@lists.infn.it)
- To show your preliminary results / work in progress and discuss with the analysis crew join the analysis meeting every week on Tuesday at 15:30 and join the mailing list (foot-analysis-and-reco@lists.infn.it)
- To show your results in the physics meeting (foot-physics@lists.infn.it mailing list) every first Wednesday of the month (14:30, Roma time) contact me for a talk


come fai..SBAI

Reconstruction in GSI2021, CNAO2022-2023

- Common selections for global tracks which provide closure test of the **reconstructed elemental (Z) cross section** wrt the true one with a precision ~ 5% for full setup **with and without magnetic field**. No calo included.
- GiacomoU and RobZ are working on a class in shoe implementing such selection needed for most of the analysis performed in these campaigns (see alpha clustering talk by Giuseppe):

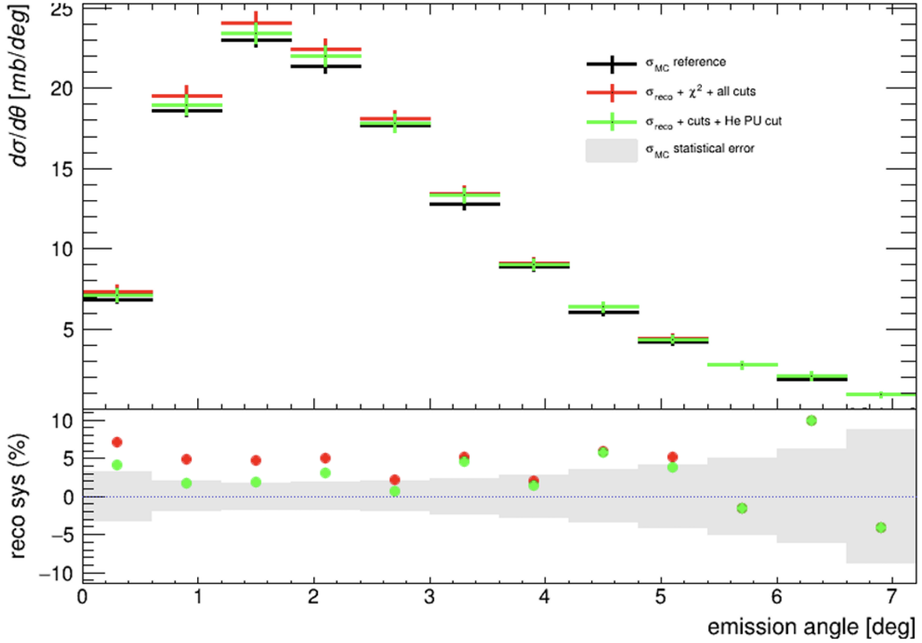
- **Track quality** (selection on chi2/p-value and track residuals)
- **1 BM track**
- **1 valid vertex inside the TG matched with BM** → fragmentation + remove pile up
- **N tracks in vtx > 1** → only fragmentation, remove most of the pre target fragmentation and primaries
- **Rejection of global tracks with the same TW point associated** → remove mostly events of He+He in same TW bar cross
- **Rejection of events with N global tracks != N TWpoints** → remove out of target fragmentation + TW inefficiencies

Important implications

- **Rejection of background** (out of target, combinatorial and cross feed (mainly He+He->Li)) **together with a high purity of the surviving global tracks (and lower efficiency)**

  ➢ no need to implement anymore background subtraction technique from “no target” data

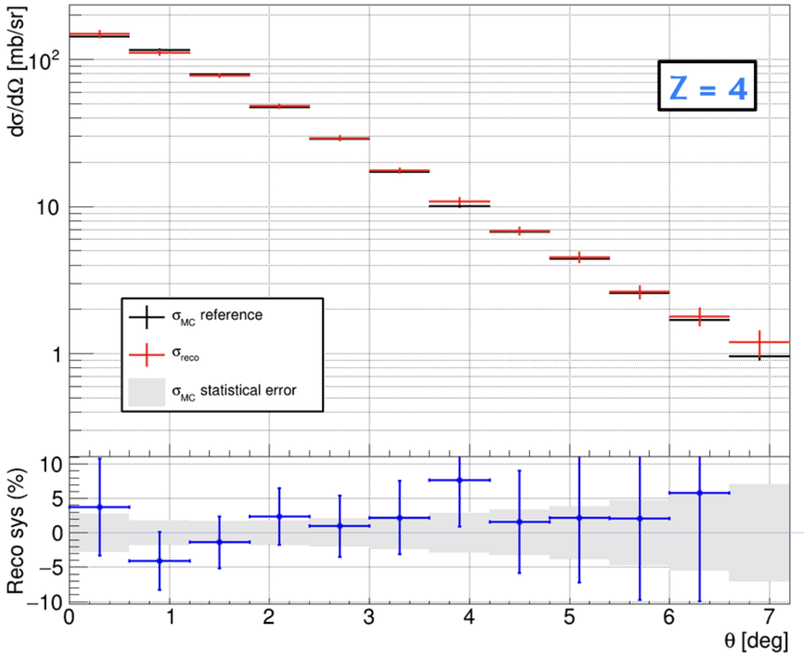
Z=3 differential cross section



GSI 2021

O+C -> Li+X

GiacU: PM 02/2024



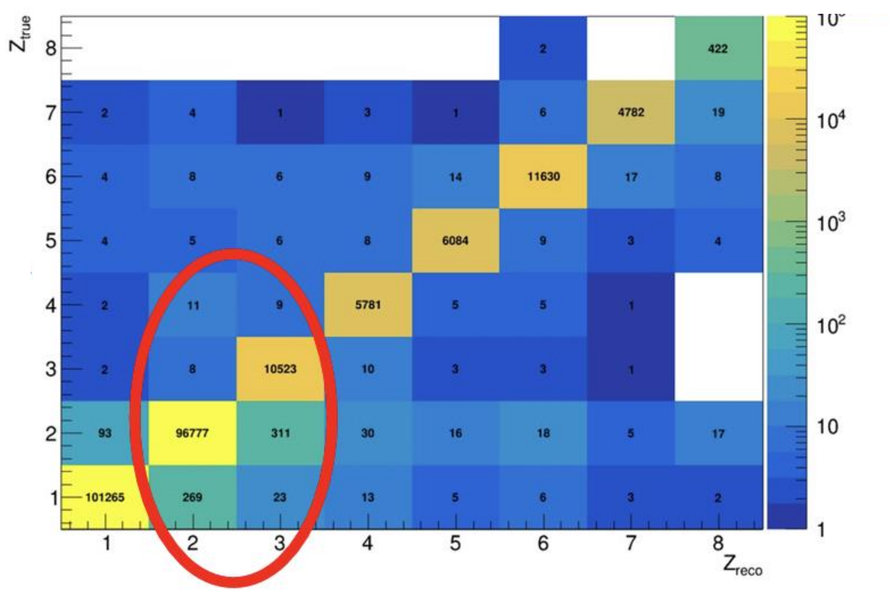
CNAO 2023

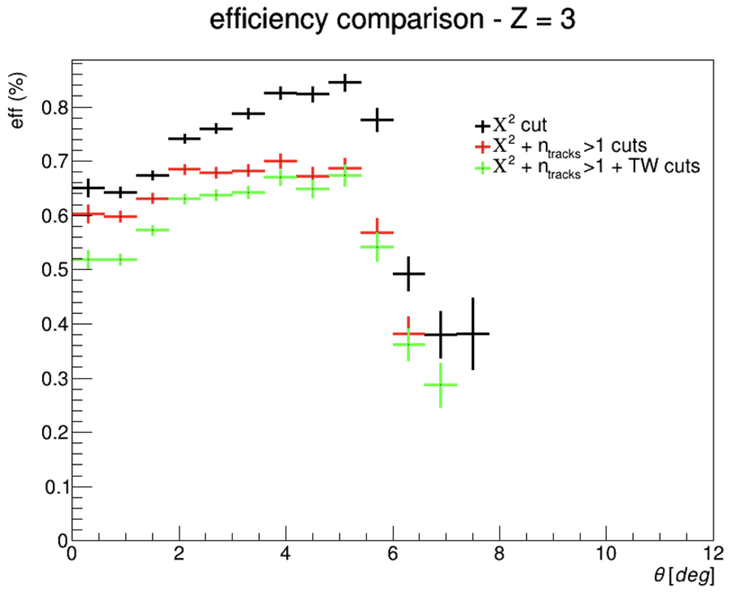
C+C -> Be+X

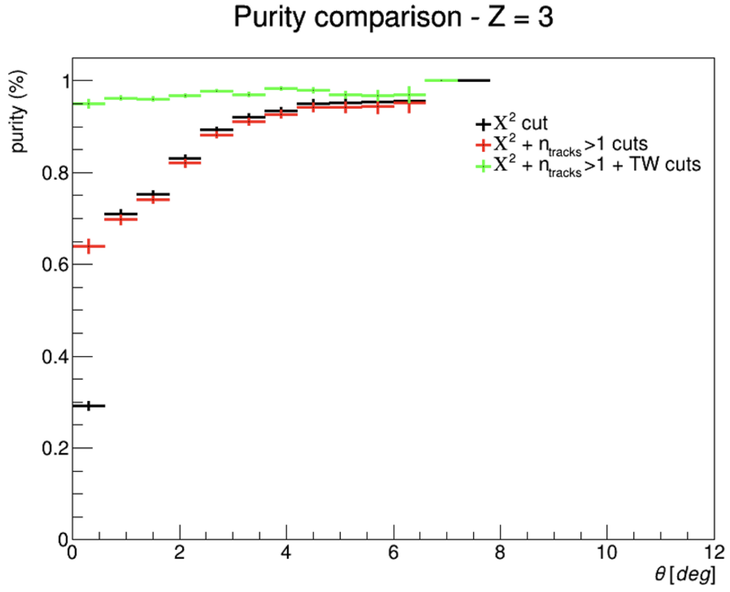
RobZ: PM 02/2024

Important implications

- **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

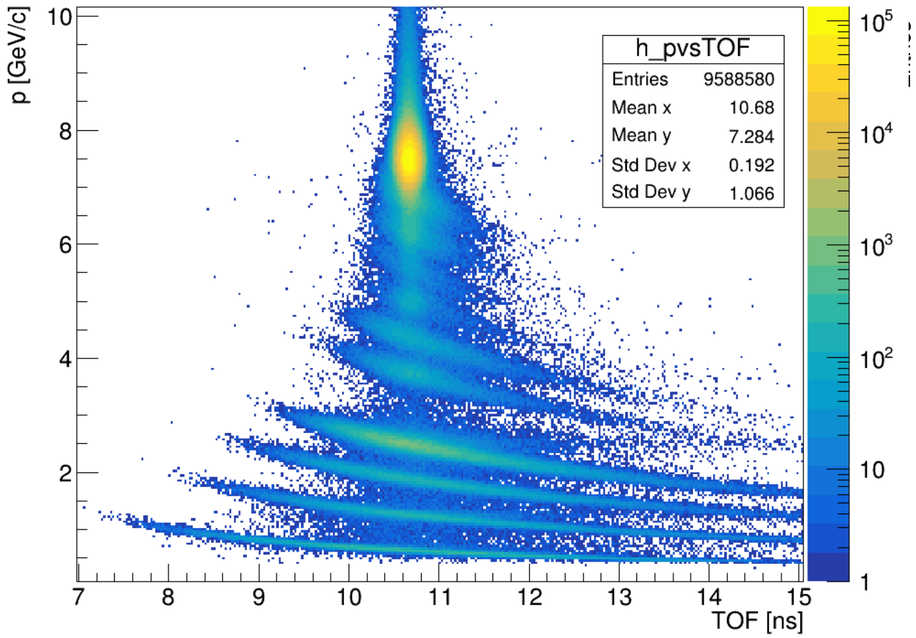


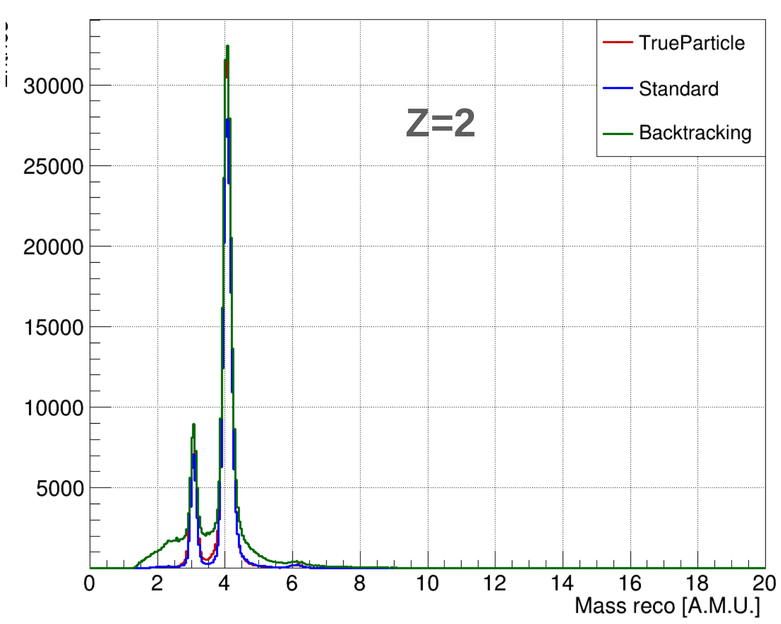


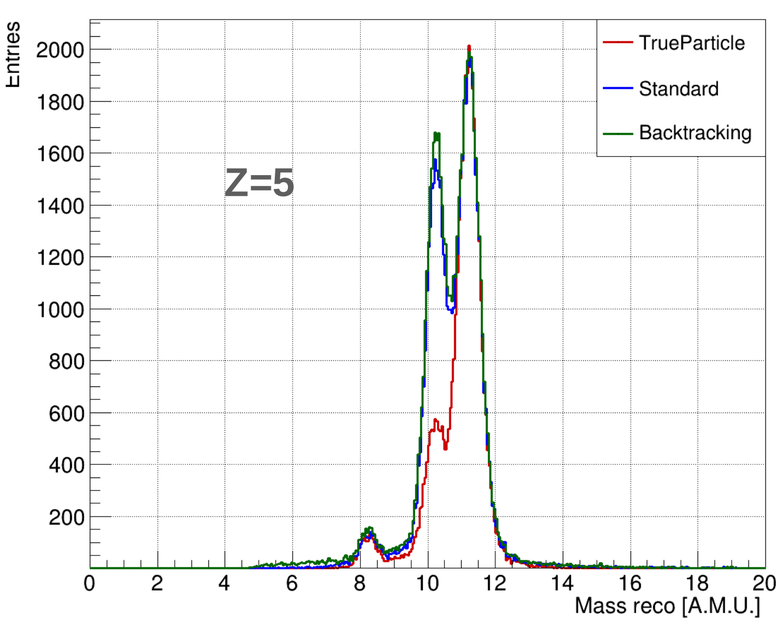


CNAO2023 MC status

- 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

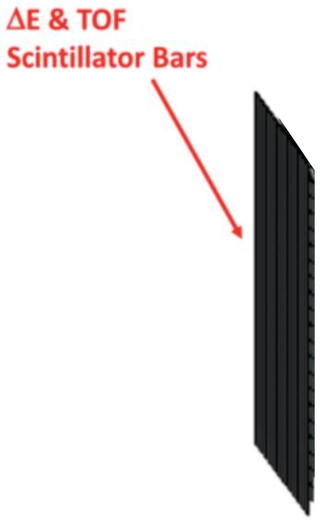






Courtesy of Roberto Zarrella

SC + BM + TW analysis limitations

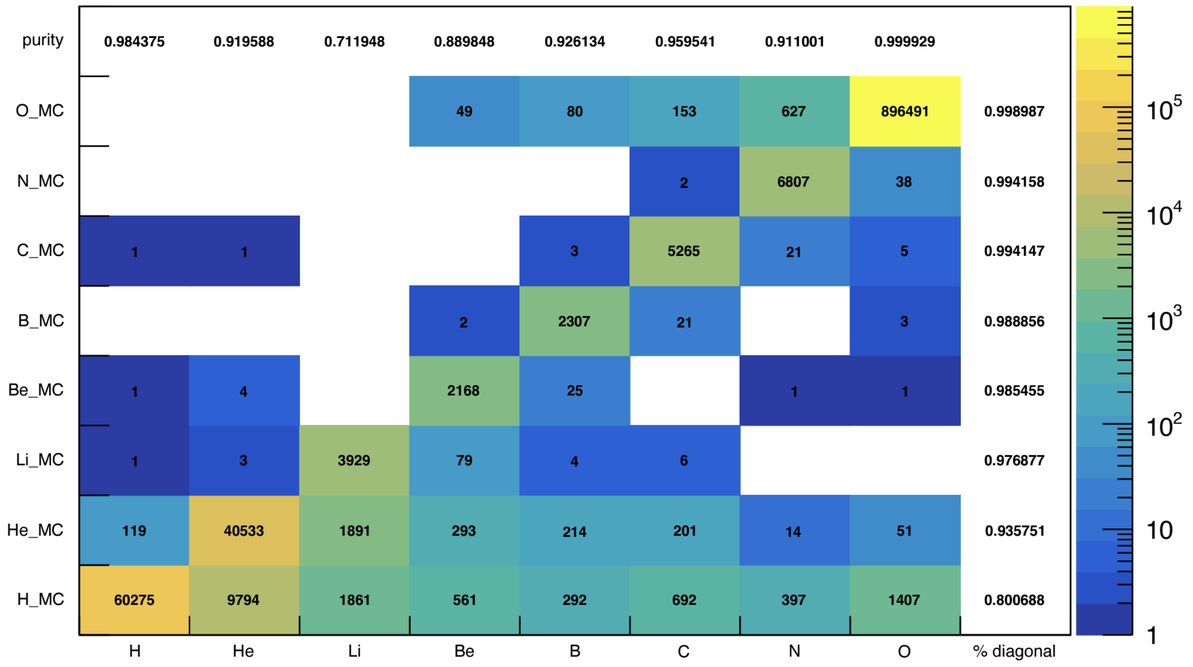


- **GSI2019: O @ 400 MeV/u + C, integral XS**
- **GSI2021: O @ 400 MeV/u + C, integral and angular differential XS**
- **GSI2021: O @ 400 MeV/u + C_2H_4, integral and angular differential XS. O+H and H+O**
- **GSI2021: O @ 200 MeV/u + C, C_2H_4, integral and angular differential XS. O+H and H+O**
- **CNAO2022: C @ 200 MeV/u + C, integral and angular differential XS**
- **HIT2022: He @ 100,140,200,220 MeV/u + C, integral and angular differential XS. (only Z=1…)**

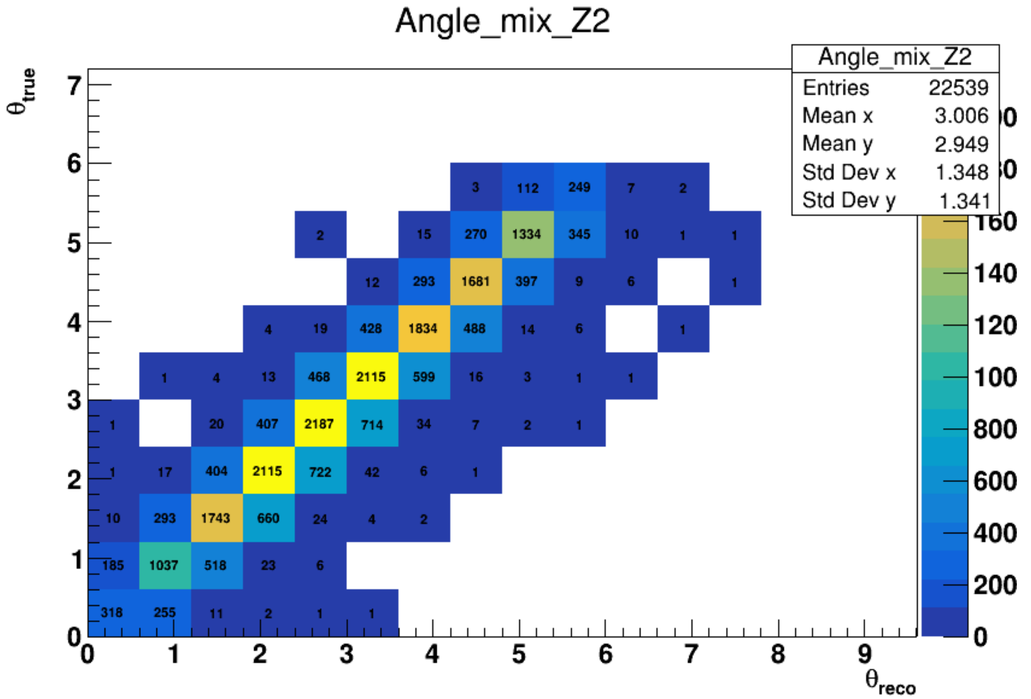
Cons:

- Big impact of purity correction especially for Li ions ($2*\Delta E_{He} \sim \Delta E_{Li}$) and correction dependent from MC. Unavoidable without tracking.
- Unfolding procedure needed to correct for angular bin migration due to the TW granularity. Unavoidable without tracking.
- Big impact of statistics collected in sample without target for background subtraction.
- We are using only a small fraction of the budget dedicated to FOOT from INFN (referees not so happy)

SC + BM + TW analysis limitations



purity correction



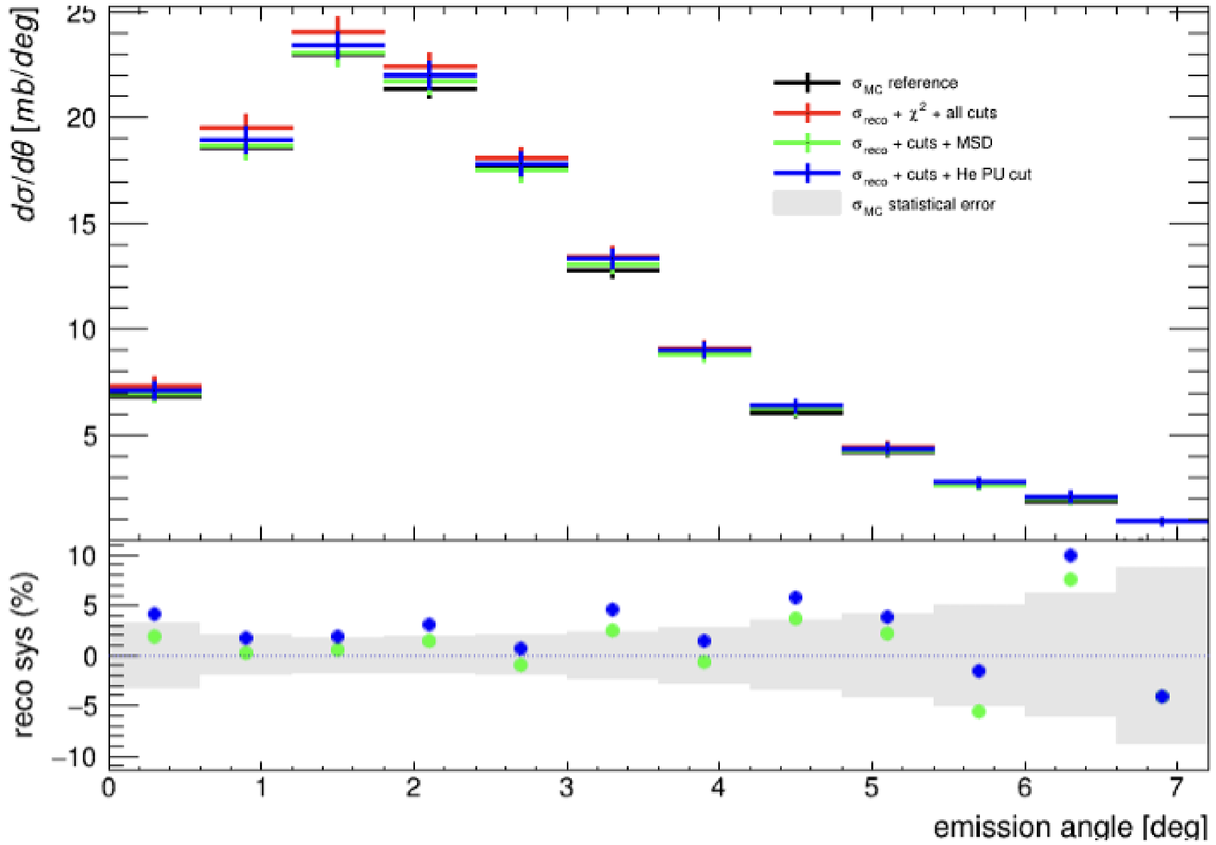
Angular unfolding impact
(from Riccardo analysis)

SC + BM + TW analysis limitations

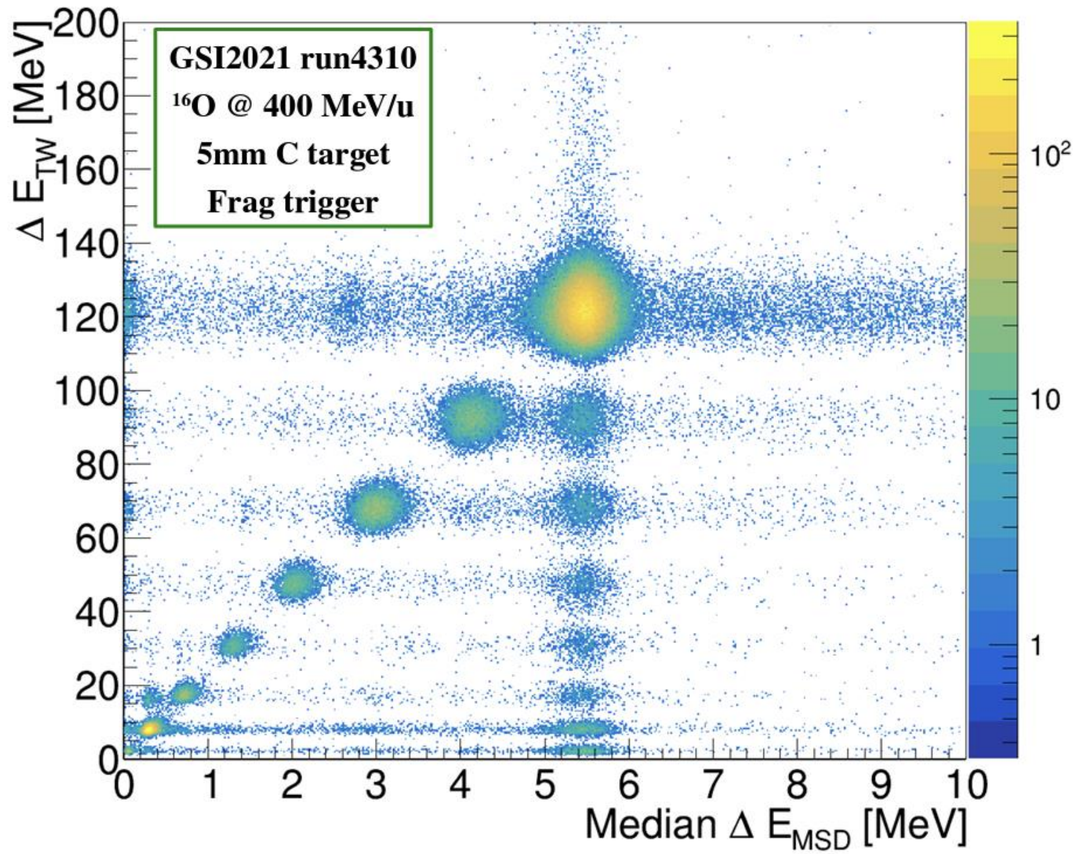
Z	$\theta[^\circ]$	$\sigma \pm \Delta_{stat} \pm \Delta_{sys}$ [b sr^{-1}]	Δ_{stat}/σ	Δ_{sys}/σ
2	$0-0.6$	$110 \pm 13 \pm 5$	11.6%	4.3%
	$0.6-1.2$	$87 \pm 6 \pm 3$	7.2%	4%
	$1.2-1.8$	$65 \pm 3 \pm 2$	5.2%	3.1%
	$1.8-2.4$	$45 \pm 2 \pm 1$	4.7%	3.2%
	$2.4-3$	$34 \pm 1 \pm 2$	3.6%	4.4%
	$3-3.6$	$20 \pm 1 \pm 1$	4.2%	4.5%
	$3.6-4.2$	$14 \pm 1 \pm 0.5$	4.2%	3.5%
	$4.2-4.8$	$9 \pm 0.4 \pm 0.3$	4.3%	3.5%
	$4.8-5.7$	$5 \pm 0.3 \pm 0.7$	5%	14%
3	$0-0.6$	$9 \pm 4 \pm 0.3$	40%	3.7%
	$0.6-1.2$	$11 \pm 2 \pm 0.4$	15%	4.2%
	$1.2-1.8$	$6 \pm 1 \pm 0.2$	17%	3.1%
	$1.8-2.4$	$5 \pm 0.5 \pm 0.2$	9%	3%
	$2.4-5.7$	$1 \pm 0.04 \pm 0.04$	5%	4.2%
4	$0-0.6$	$13 \pm 3 \pm 0.7$	20%	5.3%
	$0.6-1.2$	$7 \pm 1.5 \pm 0.2$	21%	3.2%
	$1.2-5.7$	$1 \pm 0.1 \pm 0.03$	9%	3.5%
5	$0-0.6$	$30 \pm 6 \pm 1$	20%	3.1%
	$0.6-1.2$	$19 \pm 2 \pm 1$	10%	4.7%
	$1.2-5.7$	$1 \pm 0.1 \pm 0.05$	7%	4.3%
6	$0-0.6$	$86 \pm 13 \pm 3$	15%	3%
	$0.6-1.2$	$52 \pm 3 \pm 2$	5.5%	4.3%
	$1.2-5.7$	$2 \pm 0.1 \pm 0.08$	5.6%	4.6%
7	$0-0.6$	$160 \pm 15 \pm 6$	9%	3.9%
	$0.6-1.2$	$42 \pm 3 \pm 3$	6.8%	7.5%
	$1.2-5.7$	$1 \pm 0.1 \pm 0.03$	13%	4.4%

Background subtraction impact on statistical uncertainties and number of bins
(from Riccardo paper)

Adding MSD (if no VTX): impact on analysis

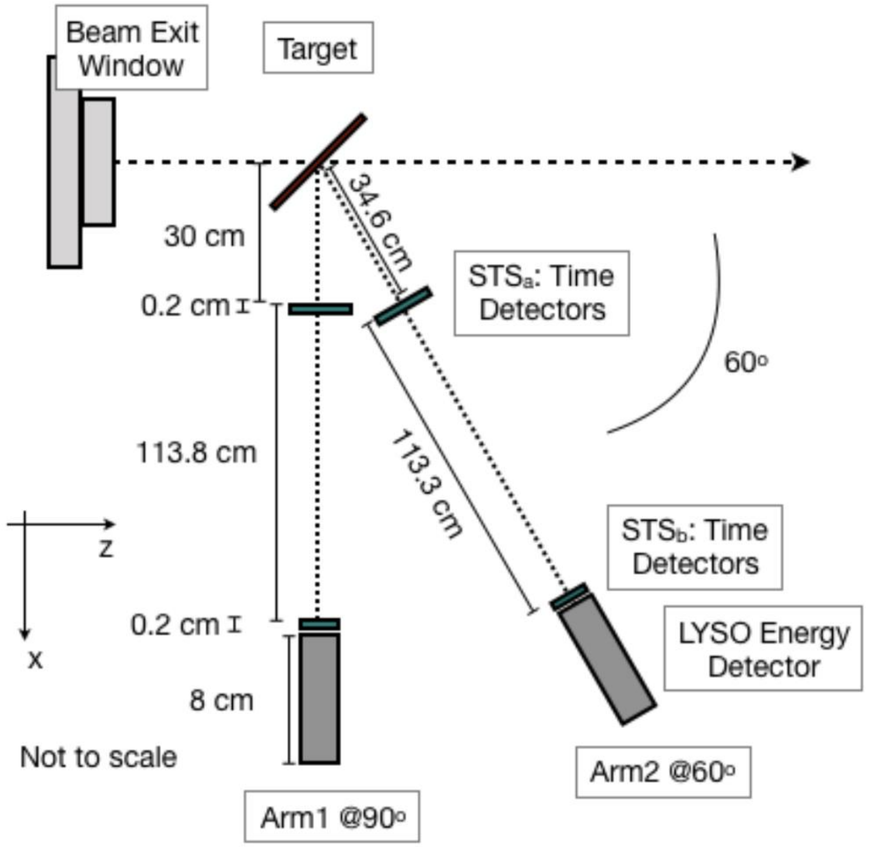


from Giacomo talk at GM December 2023



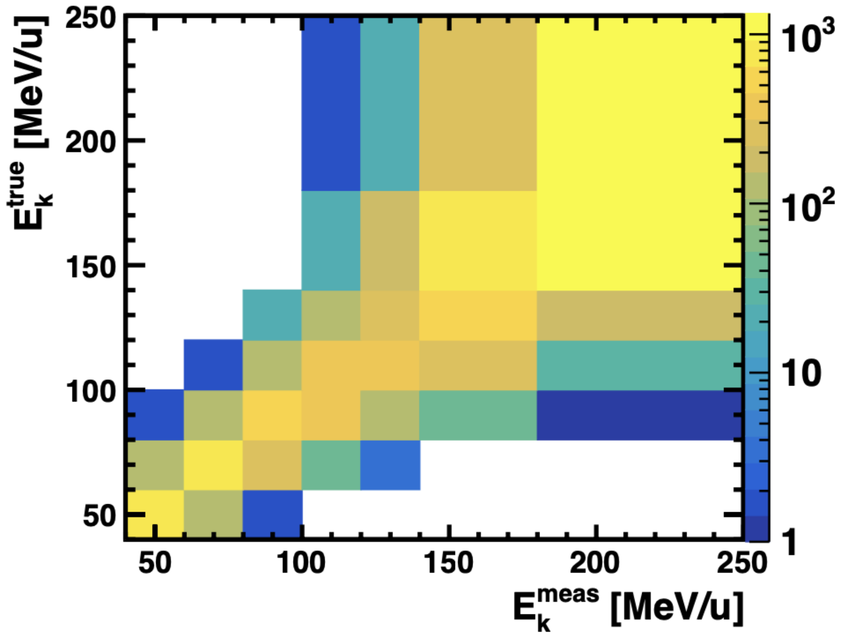
from RobZ talk at GM June 2024

CNAO 2017 analysis



from ilaria paper

C @ 115,153, 221, 281, 353 MeV/u + C, C2H4, PMMA targets



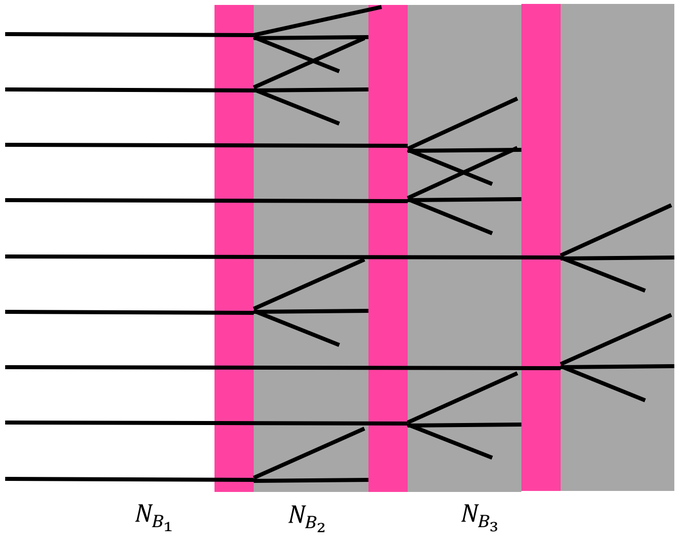
Cons:

- Unfolding procedure needed to correct for ekin bin migration due to the TW granularity
- Angular selection related on MC due to the absence of tracking detectors

Emulsion XS analysis

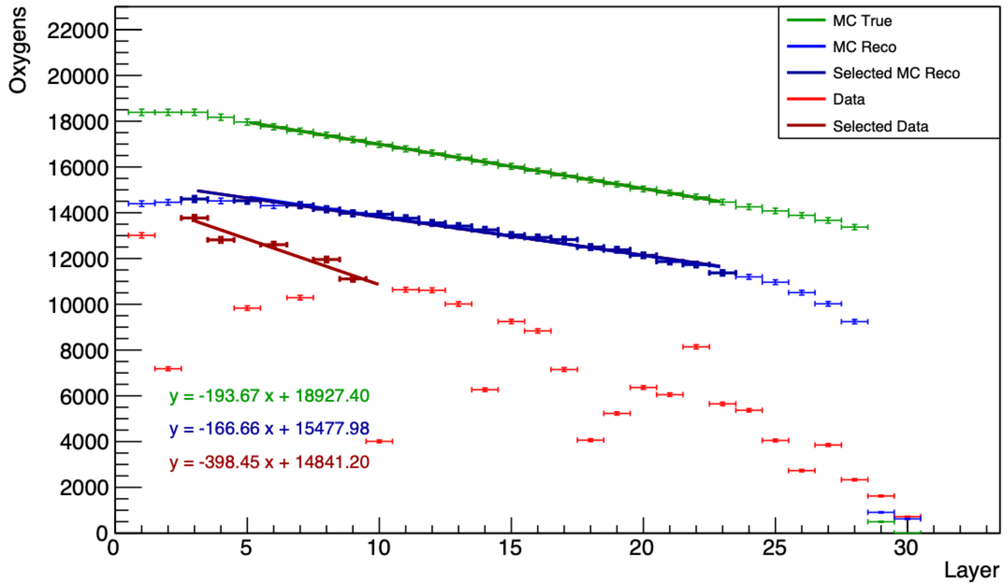
$$\frac{d\sigma(x)}{dx}\Big|_{CorC_2H_4} = \frac{Y_i(x)}{N_B N_{TG} \Delta x \epsilon^i_{reco}(x)}$$

- Each passive material layer can be considered a “new measurement”
- The number of incident beam particle on each layer has to be evaluated and is affected by its efficiency
- Estimation from oxygen tracks



from Giuliana talk at GM June 2024

^{16}O @ 200 MeV/u + C Target (GSI2019)



“Future” Analysis

Campaign	setup	technique	physics	Energy [MeV/u]	Calo	who	MC	Data
CNAO2022	electronic	Global tracking	12C+C	200 (12C)	-	-	✗	✗
CNAO2023	electronic	sull	isotope cross sections	400 (16O)	yes	-	✗	✗
CNAO 22-23	electronic	Global tracking	12C frag with Mass identification with calo	200	Yes	Torino group	✗	✗
GSI 2019	emulsion	S1+S2+S3	16O+C,C2H4 fragmentation with momentum rec	200	-	Giuliana Galati	✓	✗