Analysis status

FOOT General Meeting - Riccione
27/05/2025

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,** VTX, MSD, **TW**
HIT 2022	He	100, 140, 200, 220	C	SC, BM, MSD, TW, CAL
CNAO 2022	C	200	C	SC, BM, VTX, MSD, TW, CAL
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°**

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,** VTX, MSD**, TW**
HIT 2022	He	100, 140, 200, 220	C	SC, BM, MSD, TW, CAL
CNAO 2022	C	200	C	SC, BM, VTX, MSD, TW, CAL
CNAO 2023	C	200	C, C_2H_4	Full, magnets
CNAO 2024	C	200	C	Full, magnets

Emulsions setup			
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GSI 2020	C	700	C, C_2H_4
CNAO 2023	C	221	C, C_2H_4

- All the analysis published or in the process of beeing published are related to integrated cross sections - **total reaction cross sections** (emulsions) and **elemental cross sections** (GSI2019) - or **angular differential elemental cross sections** (GSI2021) **exploting only a partial setup** (for both electronic and emulsions setups)

FOOT campaigns to analyze

Electronic setup				
Campaign	**Beams**	**Energy [MeV/u]**	**Targets**	**Detectors**
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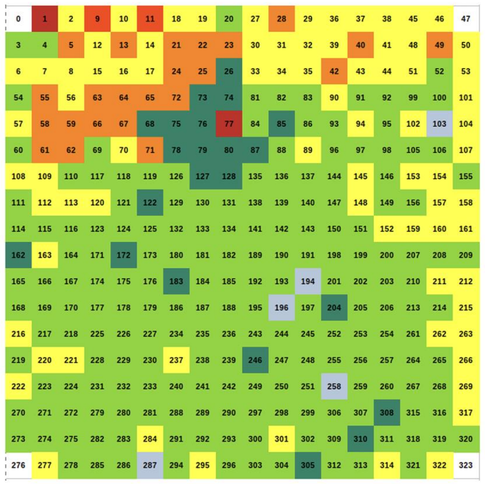
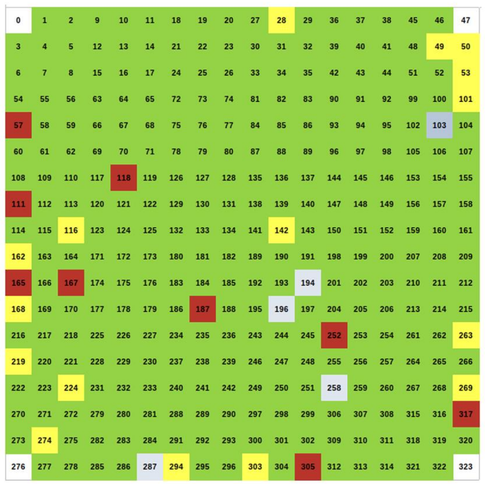
GSI 2021	**O**	200, **400**	**C, C_2H_4**	**SC, BM,** VTX, MSD**, TW**
HIT 2022	He	100, 140, 200, 220	C	SC, BM, MSD, TW, CAL
CNAO 2022	C	200	C	SC, BM, VTX, MSD, TW, CAL
CNAO 2023	C	200	C, C_2H_4	Full, magnets
CNAO 2024	C	200	C	Full, magnets

- With CNAO2024 data we moved forward measuring masses both with calorimeter (ToF+Ekin) and tracking system (p+ToF) → See **B. Spadavecchia** and **G. Ubaldi** talks
- The analyses are very preliminary but **still many difficulties met with the tracking system**

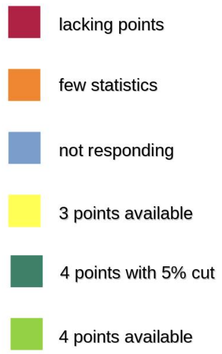
Mass reconstruction with Calorimeter

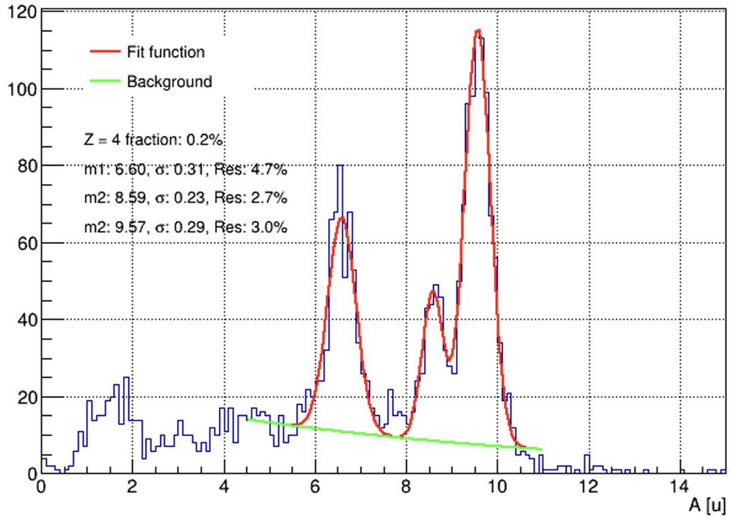


Carbon

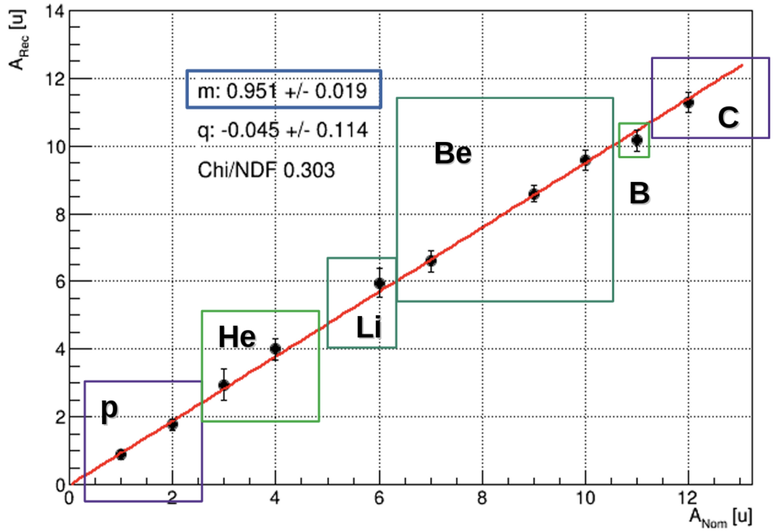


Proton



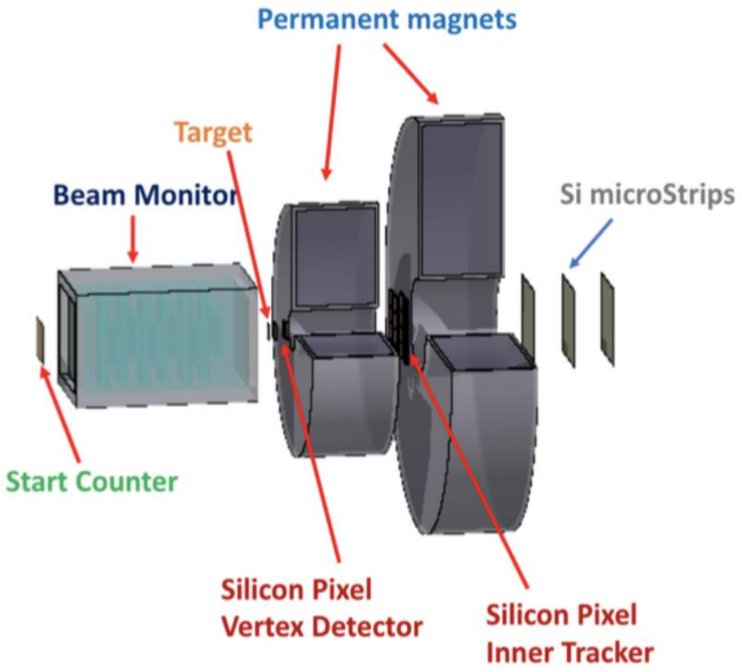


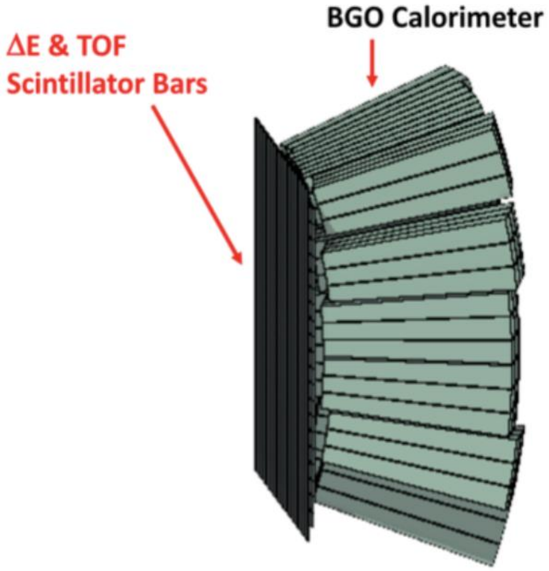
- A huge effort from the CALO crew to calibrate with respect to p and C at different energies @ CNAO2024
- First masses reconstructed



B Spadavecchia April Physics meeting

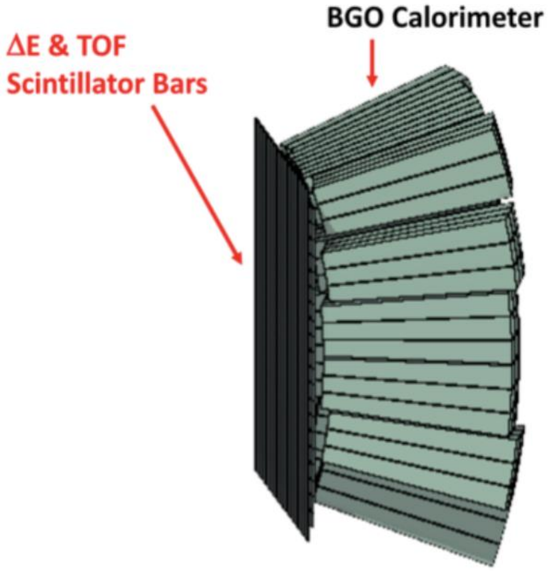
Possible XS analysis with calorimeter





- In principle an **isotopic cross section differential in Ekin** could be possible matching the CALO with the SC+BM+TW analysis, but some approximations are needed because no global tracks means no track lenght in the β

Possible XS analysis with calorimeter



- In principle an **isotopic cross section differential in Ekin** could be possible matching the CALO with the SC+BM+TW analysis, but some approximations are needed because no global tracks means no track lenght in the β
- Without magnetic field this measure is feasible giving the possibility for a **double differential isotopic XS**
- But in any case we need global tracking…

Tracking system: what can we do?

- A further investigation is needed to understand the reason of the difficulties met with the tracking system. Looks like we are still losing tracks (see **G Ubaldi talk**).
- Some possibilities:

  - Tracking detector efficiencies are not yet under control
  - Alignment (residual misalignment)
  - Magnetic field map (misposition/rotation of the magnetic field)
  - Pile up in VTX and effects on vertexing
  - Reconstruction in MSD
  - Effects not yet considered in the global tracks reconstruction algorithms

[A lot of work by Chris on IT which is however out of the global reconstruction up to now in CNAO2024]

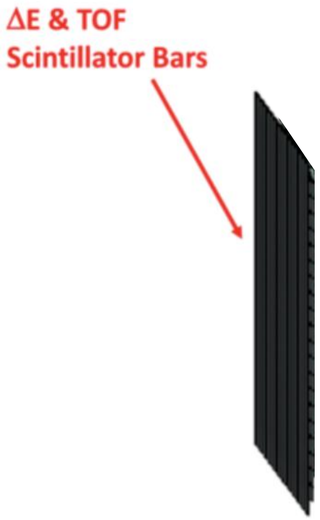
[Other work by Chris on a FIRST-like global tracking: can be useful to compare results of the two algorithms]

Tracking system: what can we do?

- We have **to unfold the different contributions** and find the most important responsible effects. We can:

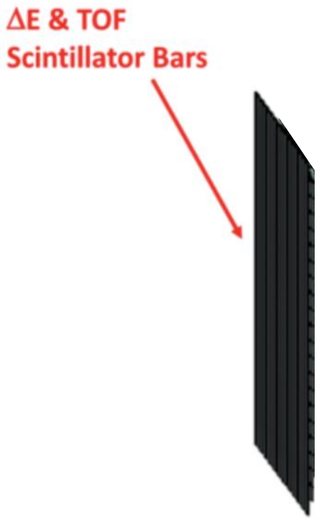
  - Study the trackers (VTX and MSD) standalone to understand their contribution to global tracks in cases without magnetic field
  - Study pile up effects on VTX in GSI2021, CNAO2022 (where also no B) → see **L. Testa talk**
  - Study the global tracking in data with no magnet (VTX+MSD): some alignment runs of CNAO2024 were done with TG but no B, in CNAO2022 physic runs with no B (but VTX eff not optimized)
  - Check effects introduced by reconstruction / global tracking not yet included in MC, from the analysis of data CNAO2023 and CNAO2024 data (e.g. request of more than one track in the vertex)
  - Understand if new measurements dedicated to the tracking system are needed to measure efficiencies, thresholds, clustering. Not only with beam, but in lab with sources and cosmic rays. We need to keep our detectors active

SC + BM + TW analysis as a reference



- **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 **(→** see **Aafke talk)**

SC + BM + TW analysis as a reference



- **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 **(→** see **Aafke talk)**

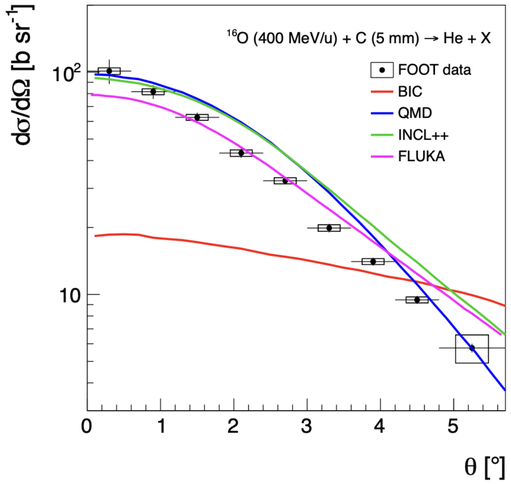
Pros :

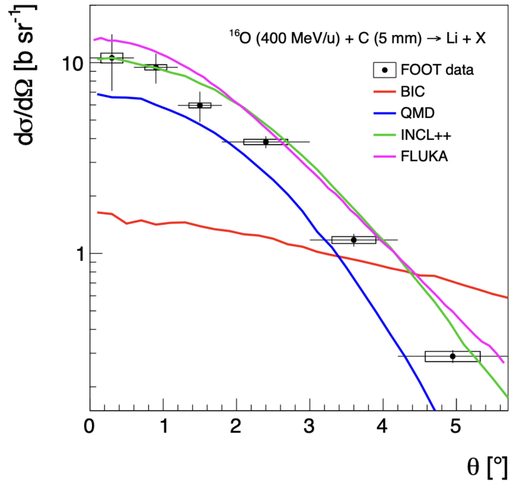
- the developed software is almost “plug and play”, independent from the setup and can be used to produce results for each of the above campaigns
- can be used to provide first inverse kinematic integrated XS: H @ 200, 400 MeV + O at GSI2021 (→ see **M. Dondi talk**)

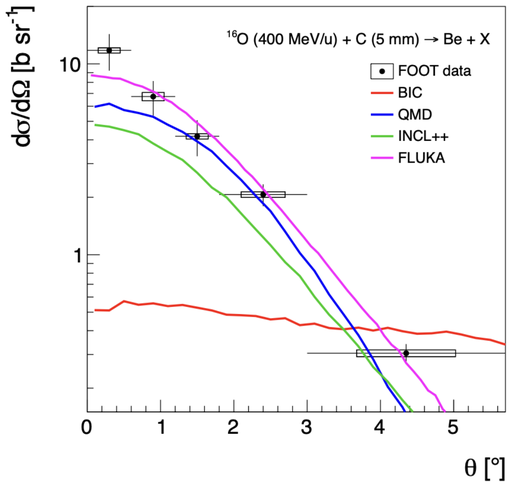
Cons:

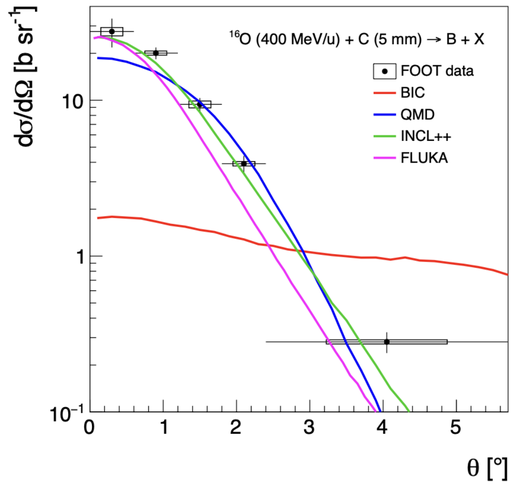
- Big impact of purity correction (dependent from MC) especially for Li ions ($2*\Delta E_{He} \sim \Delta E_{Li}$) and need of background subtraction. Unavoidable without tracking.

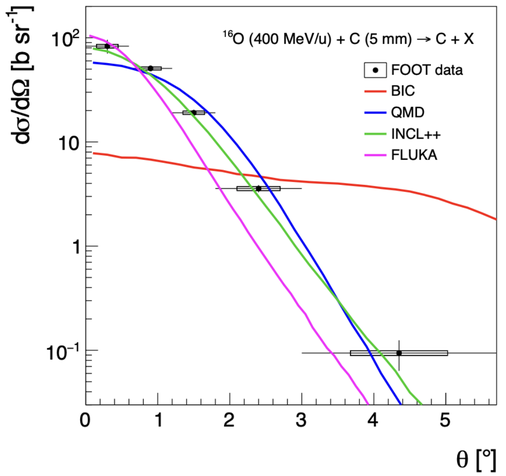
SC + BM + TW analysis as a reference

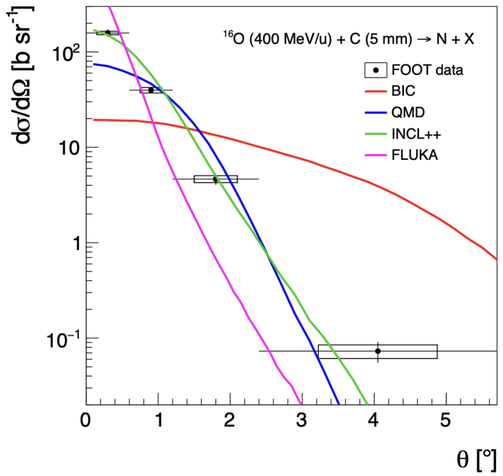






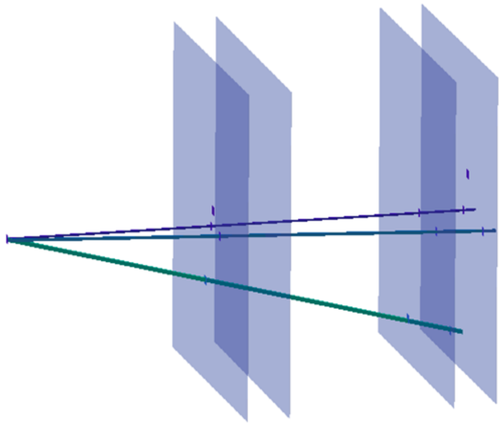






Ridolfi et al., submitted to PRC

Adding the VTX



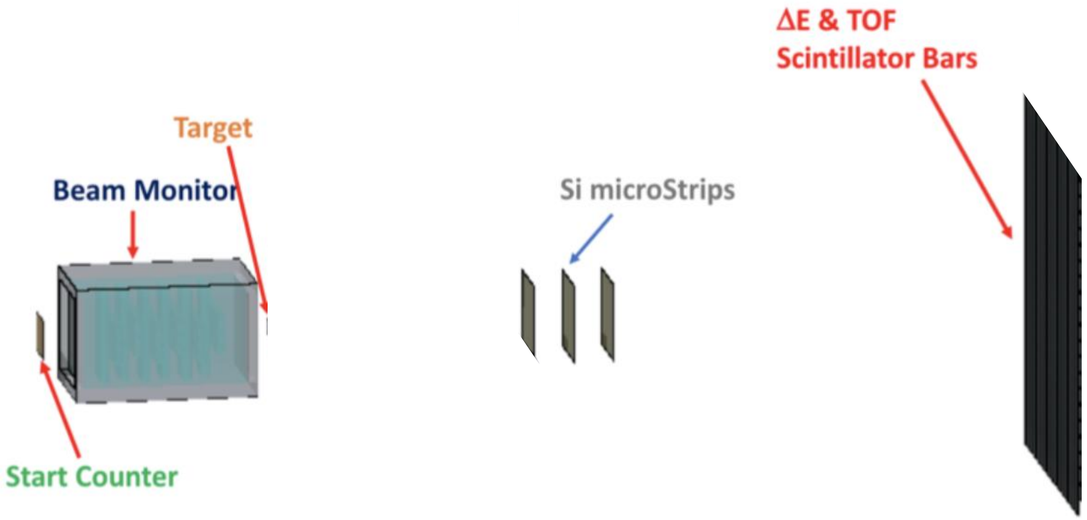
- **GSI 2021: O @ 400 MeV/u + C**
- **CNAO 2022: C @ 200 MeV/u + C**
- **CNAO2024: C @ 200 MeV/u+C (with B)**

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: (see L. Testa talk)

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

Adding MSD



The same analysis could be improved using MSD

- Work in progress for calibration (pedestals), threshold, clustering…from Ila, Sofia, Leonello, Ale
- Thanks to the work of RobZ MSD eta correction is feasible 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

Analysis strategy: summary

- Use SC+BM+TW analysis to have XS in campaign without magnet to be used as reference
- Add VTX to measure XS and cross check with SC+BM+TW analysis in campaign without magnet
- Add VTX + MSD to measure XS in campaign without magnet
- Move back to CNAO2024 and compare XS (Tof+p) with the reference measurements
- CNAO2023/CNAO2024 XS analysis Tof+Ekin from CALO

Enjoy the analysis sessions today and tomorrow

14:00	**Analysis status** *Hotel Lungomare*	*Marco Toppi* 14:00 - 14:20
	Mass reconstruction with CALO at CNAO2024 *Hotel Lungomare*	*Benedetto Spadavecchia* 14:20 - 14:40
	Global tracks reconstruction at CNAO2024 *Hotel Lungomare*	*Giacomo Ubaldi* 14:40 - 15:00
15:00	**XS analysis with VTX at GSI2021** *Hotel Lungomare*	*Luana Testa* 15:00 - 15:20
	Alpha clustering GSI2021 *Hotel Lungomare*	*Giuseppe Battistoni* 15:20 - 15:40
	Alpha clustering with nuclear emulsions *Hotel Lungomare*	*Vincenzo Boccia* 15:40 - 16:00
16:00	**Coffee Break** *Hotel Lungomare*	16:00 - 16:30
	p-N target fragmentation cross sections: what exactly can we measure? *Hotel Lungomare*	*Giuseppe Battistoni* 16:30 - 16:50
	O+C2H4, O+H and H+O cross sections at GSI2021 *Hotel Lungomare*	*Matilde Dondi* 16:50 - 17:10
17:00	**Status of TOF-Wall and Calorimeter detector analysis for HIT2022** *Hotel Lungomare*	*Aafke Christine Kraan* 17:10 - 17:30
	Report and update on software activity *Hotel Lungomare*	*Roberto Zarrella et al.* 17:30 - 17:50
	Geant4 simulation interface with shoe *Hotel Lungomare*	*Dr Christian Finck* 17:50 - 18:10
18:00	**Discussion** *Hotel Lungomare*	18:10 - 18:30

09:00	**XS of O at 200 MeV/u at GSI** *Hotel Lungomare*	*Giuliana Galati* 09:00 - 09:20
	First reconstruction of Carbon @ 221 MeV/n data (CNAO2023) *Hotel Lungomare*	*Simone Masci* 09:20 - 09:40

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Alpha clustering at GSI2021 with electronic and emulsion setups

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Restart to think to inverse kinematic for target fragmentation

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Emulsion analysis (update on the paper and new analysis)

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Software status by our fantastic software coordination team

+

Reviving G4 from Chris


come fai..SBAI

Status of the needed inputs of each campaign

Campaign	BM	VTX / pile-up	IT	MSD	TW (+ SC)	Calo	Alignment / geometry check	Full MC	DAQ synchronization/cleaning
GSI 2021	✓	✓	-	Pedestal Eta function	Calibration ΔE/Tof ZID Positions along bar	-	✓	✓	✓
HIT 2022	✓	-	-	Pedestal Eta function	Calibration ΔE/Tof ZID Positions along bar	Calibration	✓	✓	✓
CNAO 2022	✓	✓	-	Pedestal Eta function	Calibration ΔE/Tof ZID Positions along bar	Calibration	✓	✓	✓
CNAO 2023	✓	✓	✓	Pedestal Eta function	Calibration ΔE/Tof ZID Positions along bar	Calibration	✓	✓	✓
CNAO 2024	✓	✓	✓	Pedestal Eta function	Calibration ΔE/Tof ZID Positions along bar	Calibration	✓	✓	✓
	Yun	Chris, Luana, Marco	Chris	Leonello, Sofia, Ilaria, RobZ, Alessio	Matteo, Aafke, Giacomo, Marco, RobZ	Torino	Yun, Matteo	Giuseppe, Silvia	Riccardo, Mauro

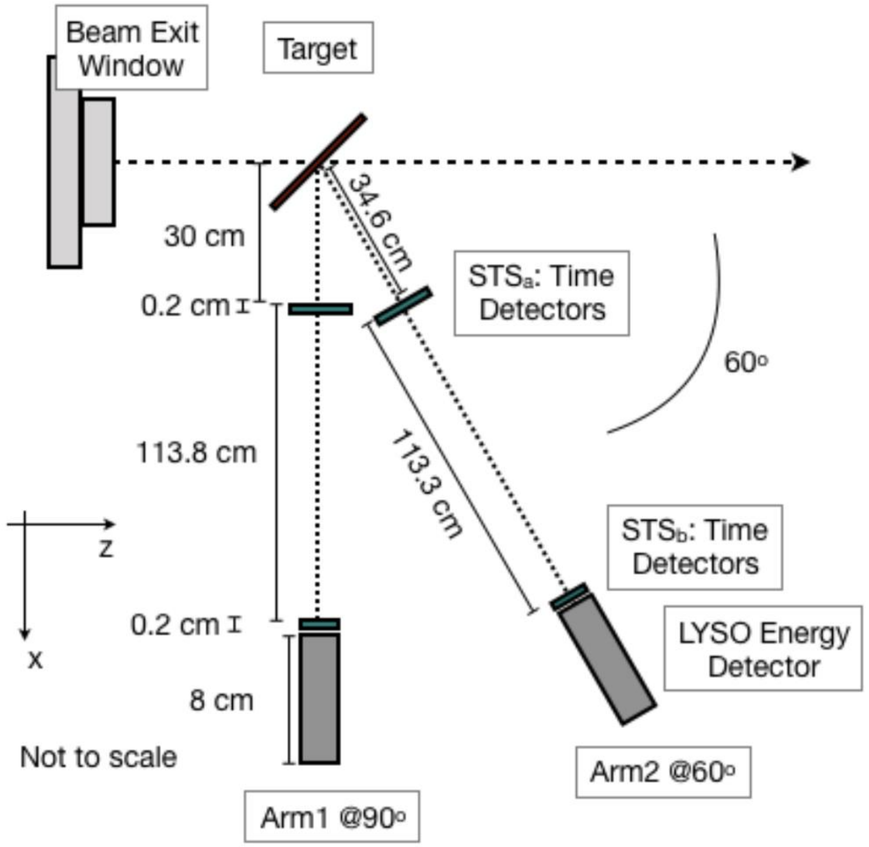
Performances, MC tuning with data

	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 • Efficiency and Purity for each Z in angukar bins • Residual/Pulls for each Z • Cluster size for each Z (data/MC) • Efficiency wrt sensor position (Data/MC) • Dead map, noise Data/MC	• 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	In progress	In progress	In progress	In progress	In progress	In progress
People	Yun	Chris, Giacomo U	Leonello, Benedetto, Alessio, RobZ	Giacomo, Marco, Roberto	Alessandro, Francesca	Roberto, Giacomo U

Work in progress / still missing

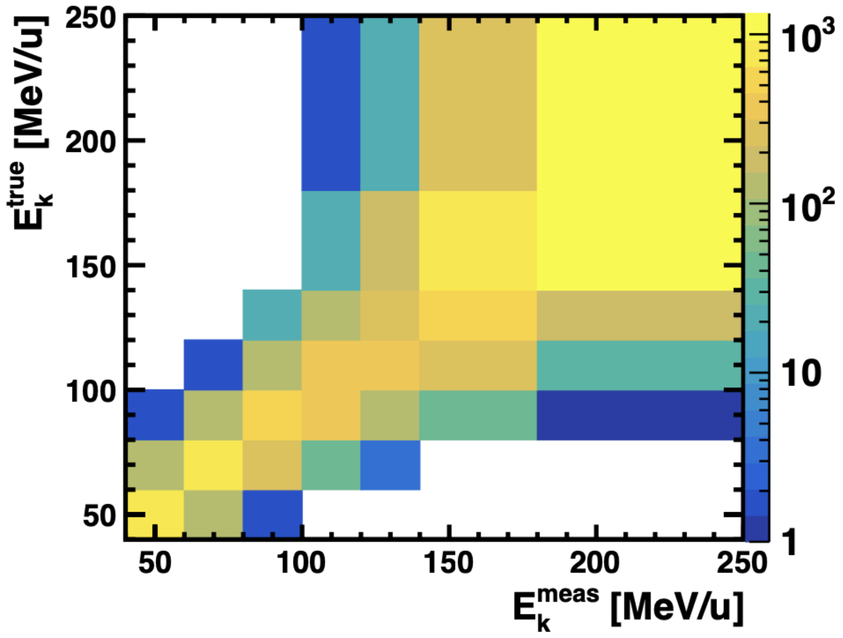
- In MC no detector effects (noise, cluster sizes, threshold and efficiency tuned from data) for most of the trackers
- Pile up in VT/IT, high rates effects (+ pile-up studies in MC to better understand our capability in rejecting it and to estimate a rejection efficiency)
- MSD eta function / charge equalization and implementation of ZID and ghost removal
- Tuning of the experimental resolutions in MC for every measured quantity not completed yet
- 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

CNAO 2017 analysis



from ilaria paper

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



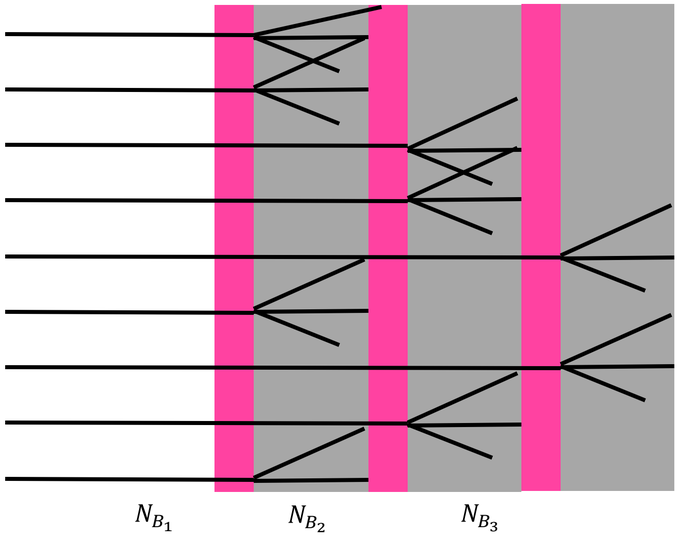
Cons:

- 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

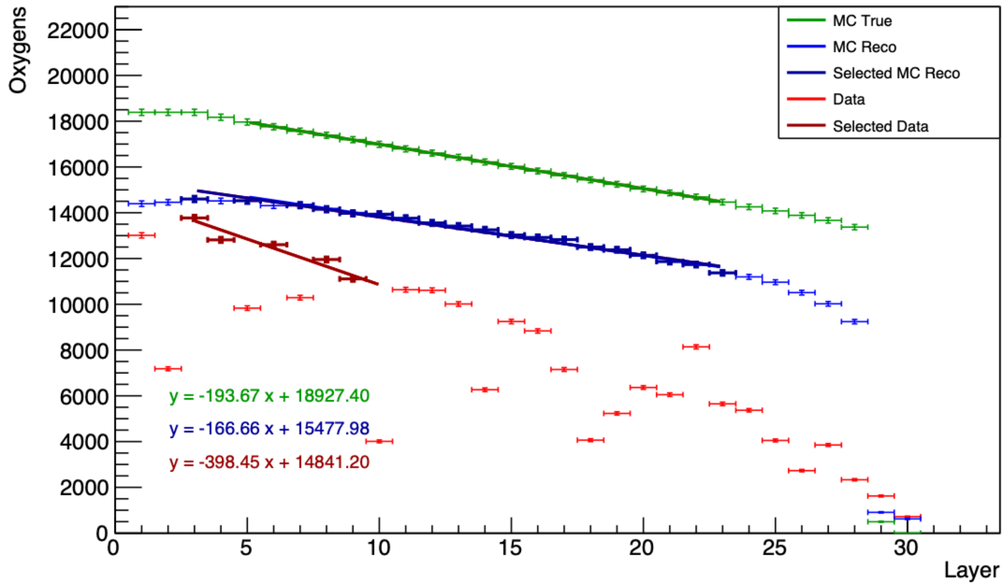
$$\frac{d\sigma(x)}{dx}\Big|_{CorC_2H_4} = \frac{Y_i(x)}{N_B N_{TG} \Delta x \epsilon^i_{reco}(x)}$$

- 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

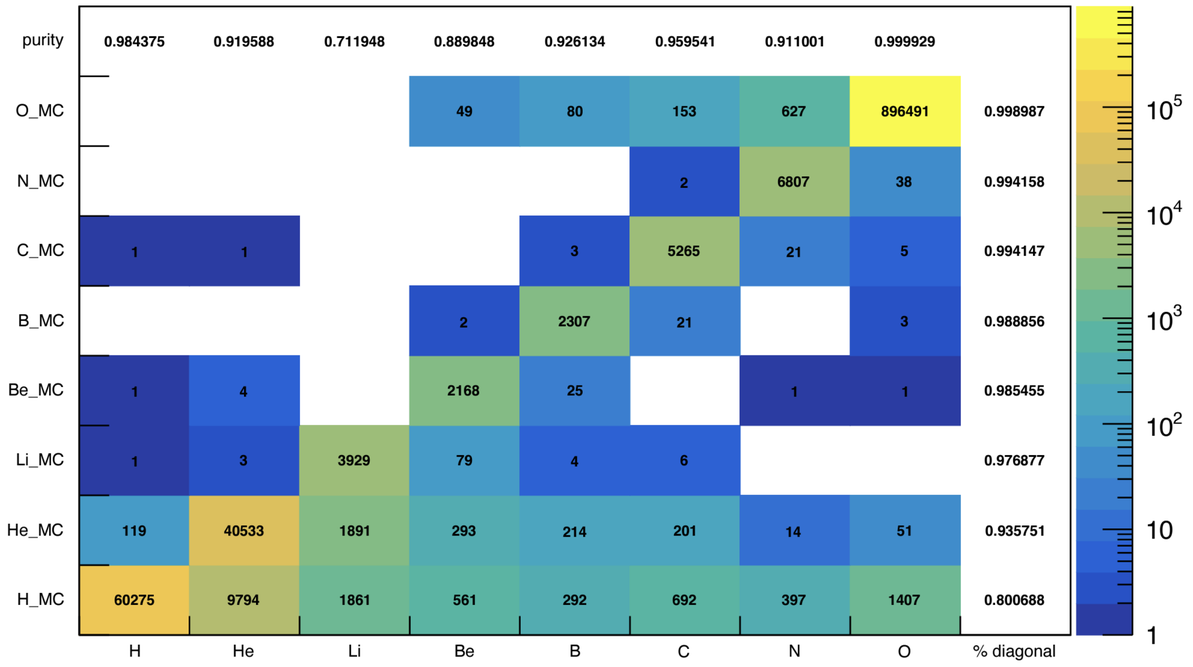


from Giuliana talk at GM June 2024

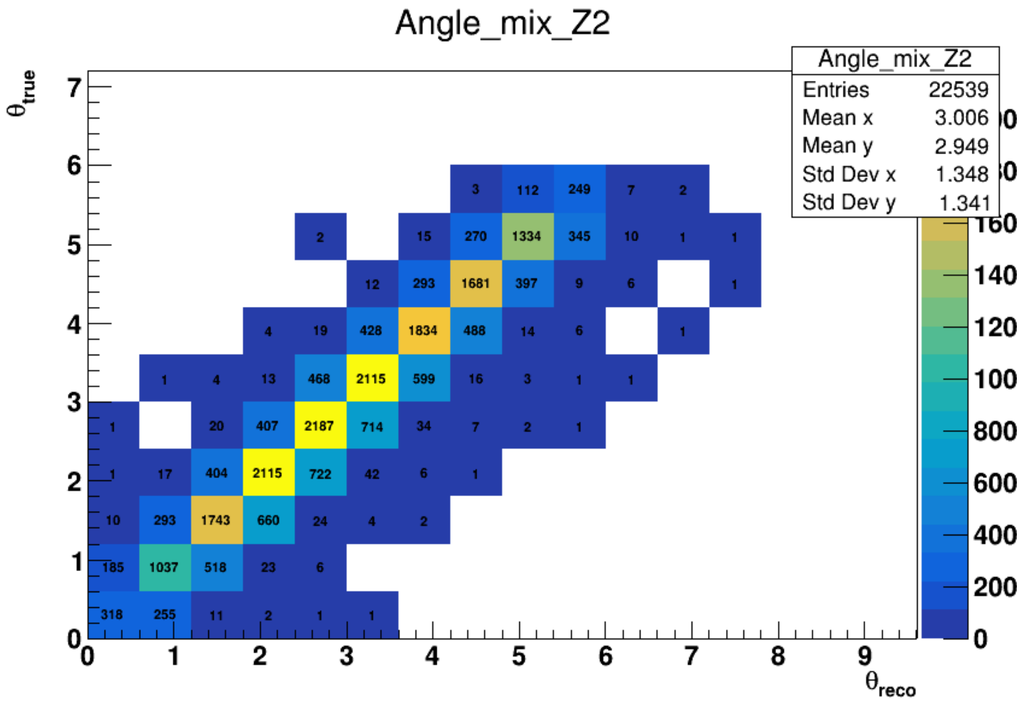
^{16}O @ 200 MeV/u + C Target (GSI2019)



SC + BM + TW analysis



purity correction



Angular unfolding impact
(from Riccardo analysis)

SC + BM + TW analysis

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

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):

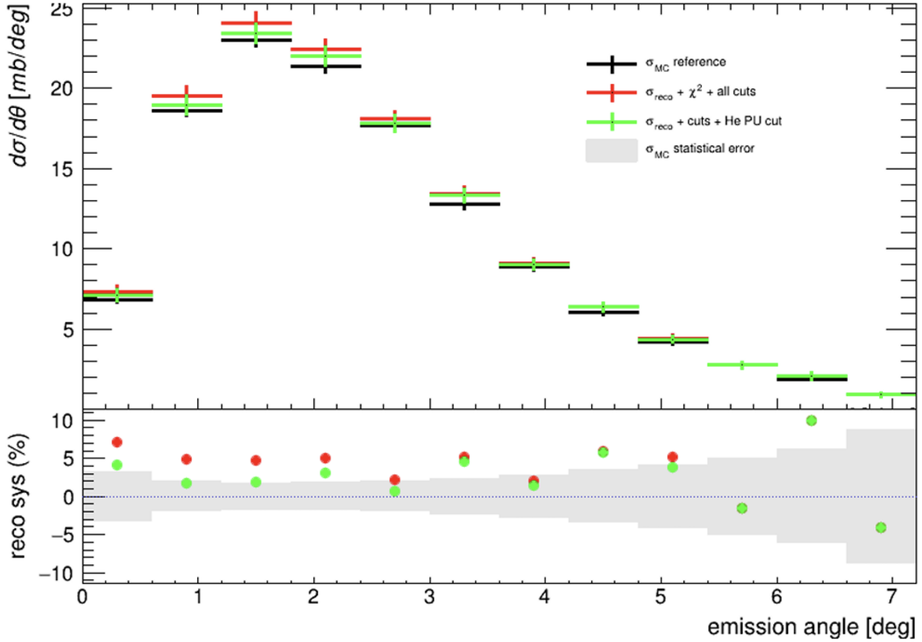
- **Track quality** (selection on chi2/p-value and track residuals)
- **1 BM track**
- **1 valid vertex inside the TG matched with BM** → fragmentation + remove pile up
- **N tracks in vtx > 1** → only fragmentation, remove most of the pre target fragmentation and primaries
- **Rejection of global tracks 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

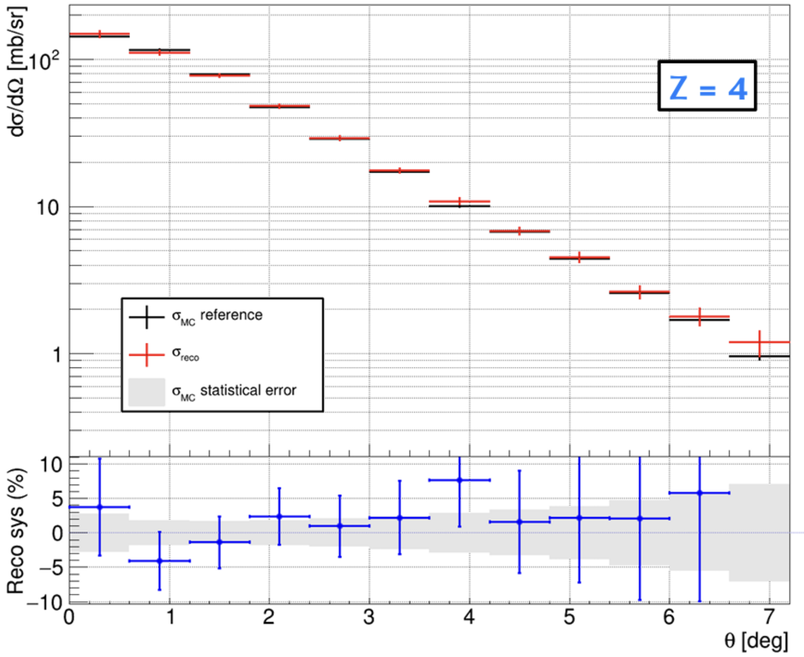
Z=3 differential cross section



GSI 2021

O+C -> Li+X

GiacU: PM 02/2024



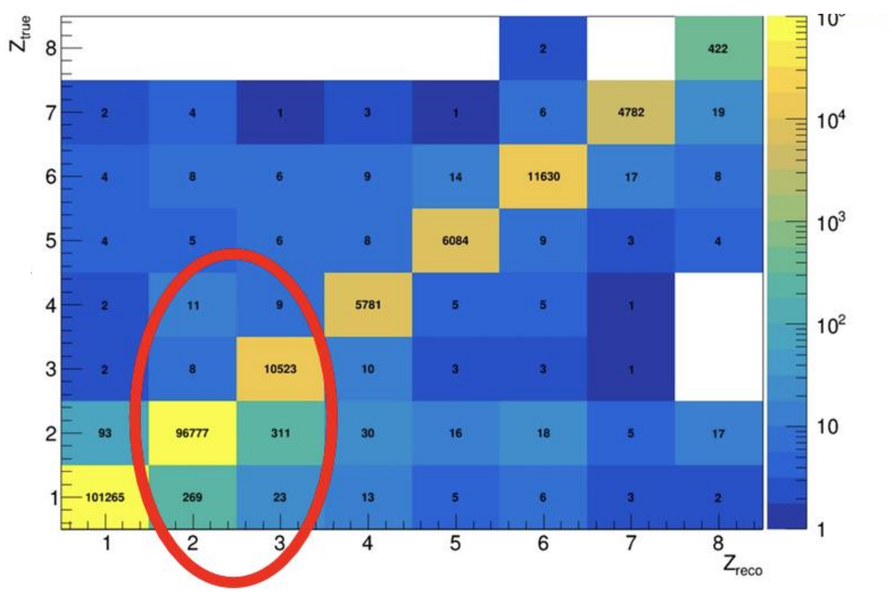
CNAO 2023

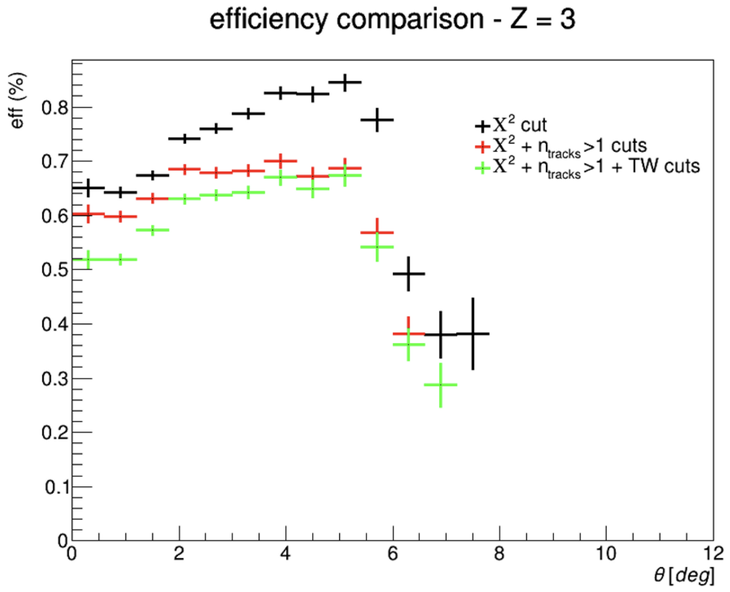
C+C -> Be+X

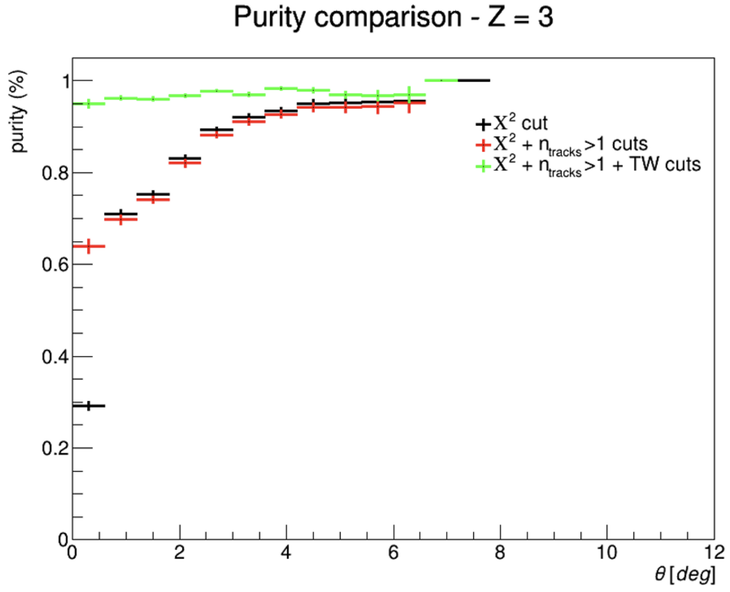
RobZ: PM 02/2024

Important implications

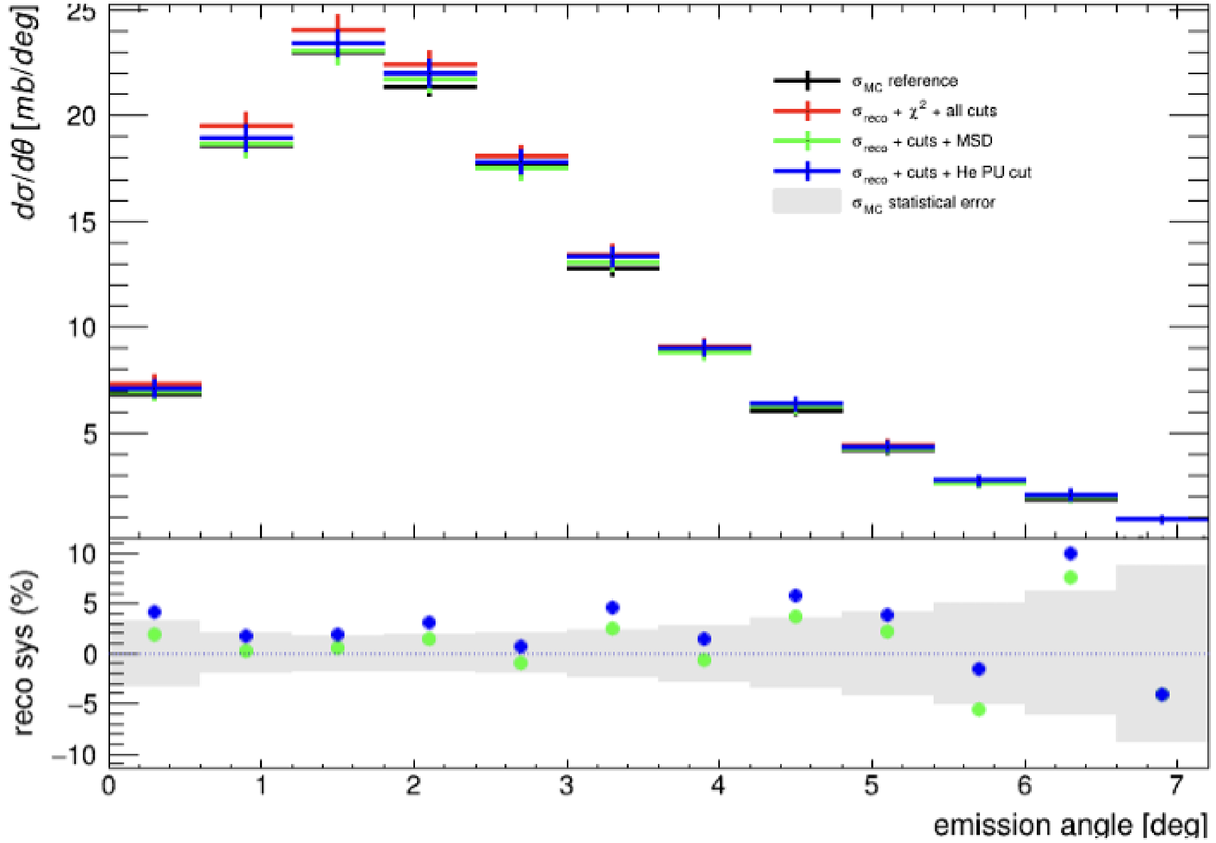
- **A robust fragment Z identification**, as the one reached within GSI 2021 analysis**, allows to implement the inverse kinematic approach to measure H+O XS**. We can implement an integrated cross section for the process H+O for the different fragment Z with GSI2021 data



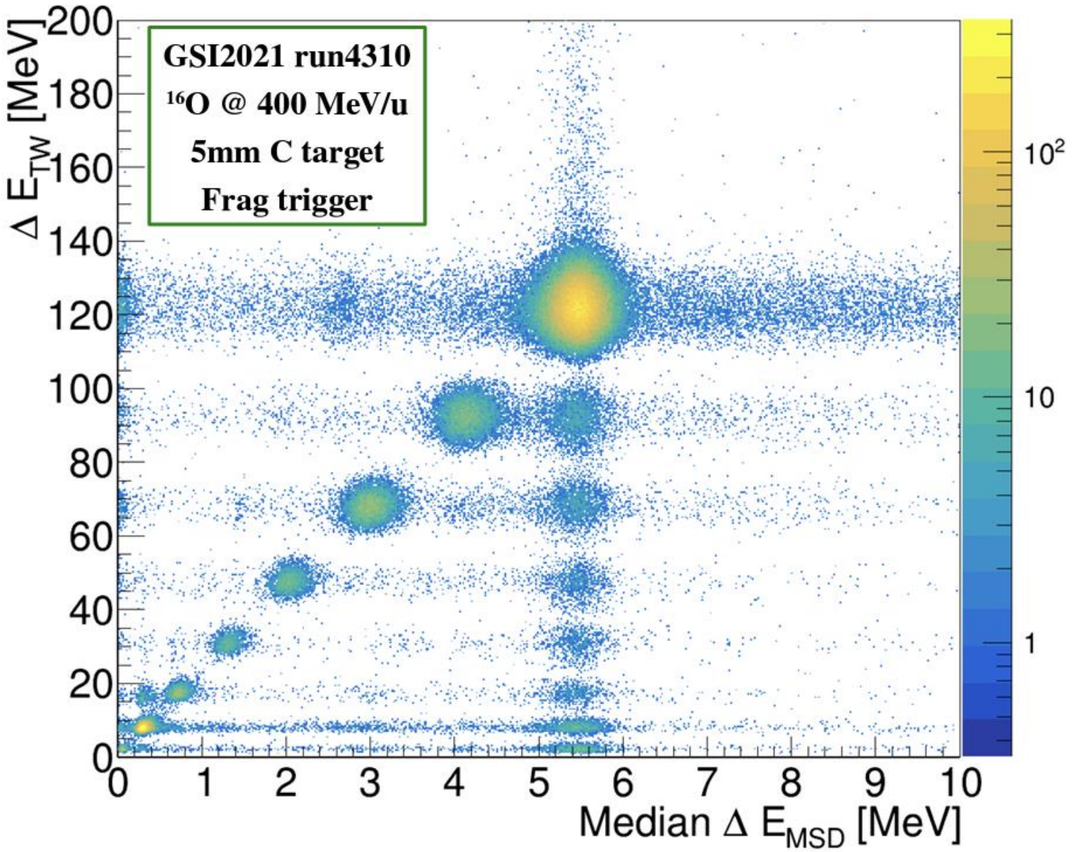




Adding MSD (if no VTX)



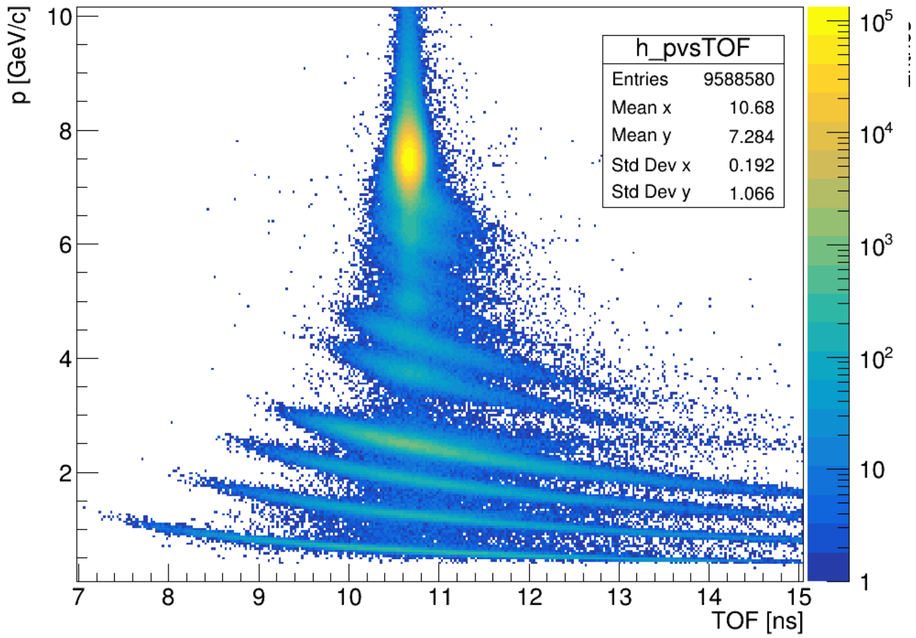
from Giacomo talk at GM December 2023

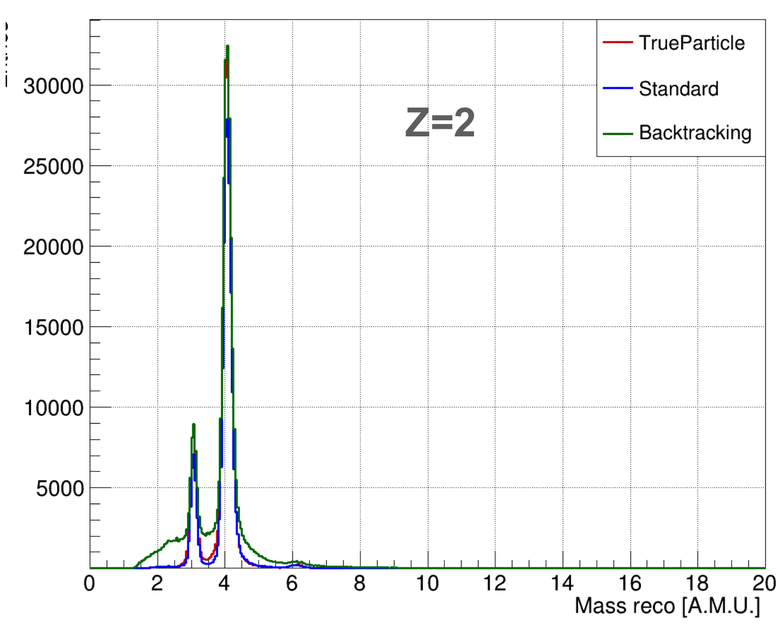


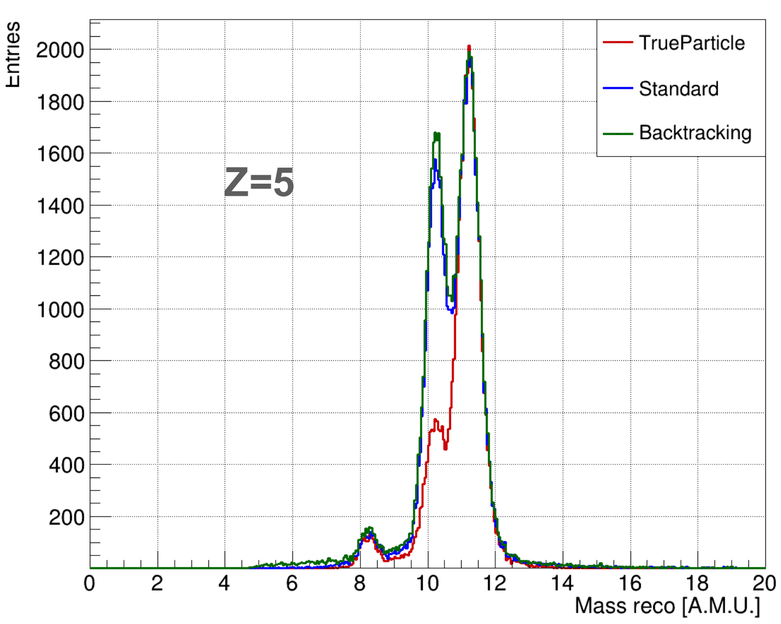
from RobZ talk at GM June 2024

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

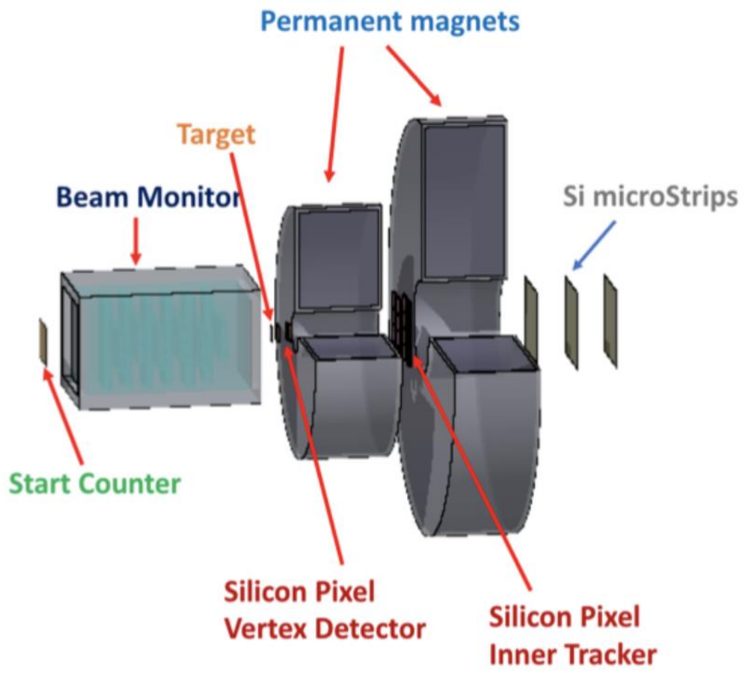


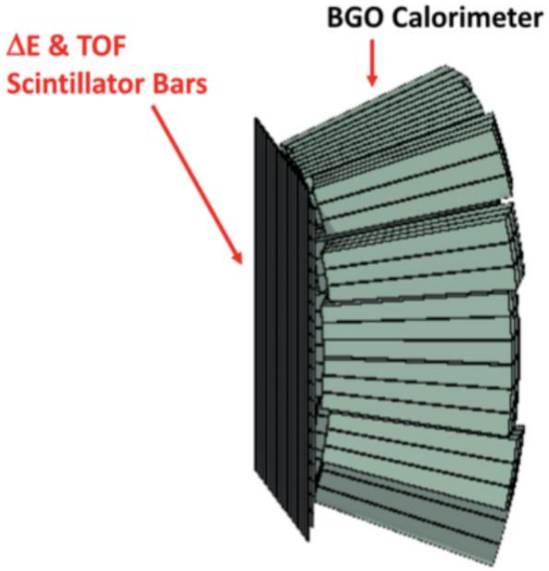




Courtesy of Roberto Zarrella

Full setup: CNAO2023 vs CNAO2024



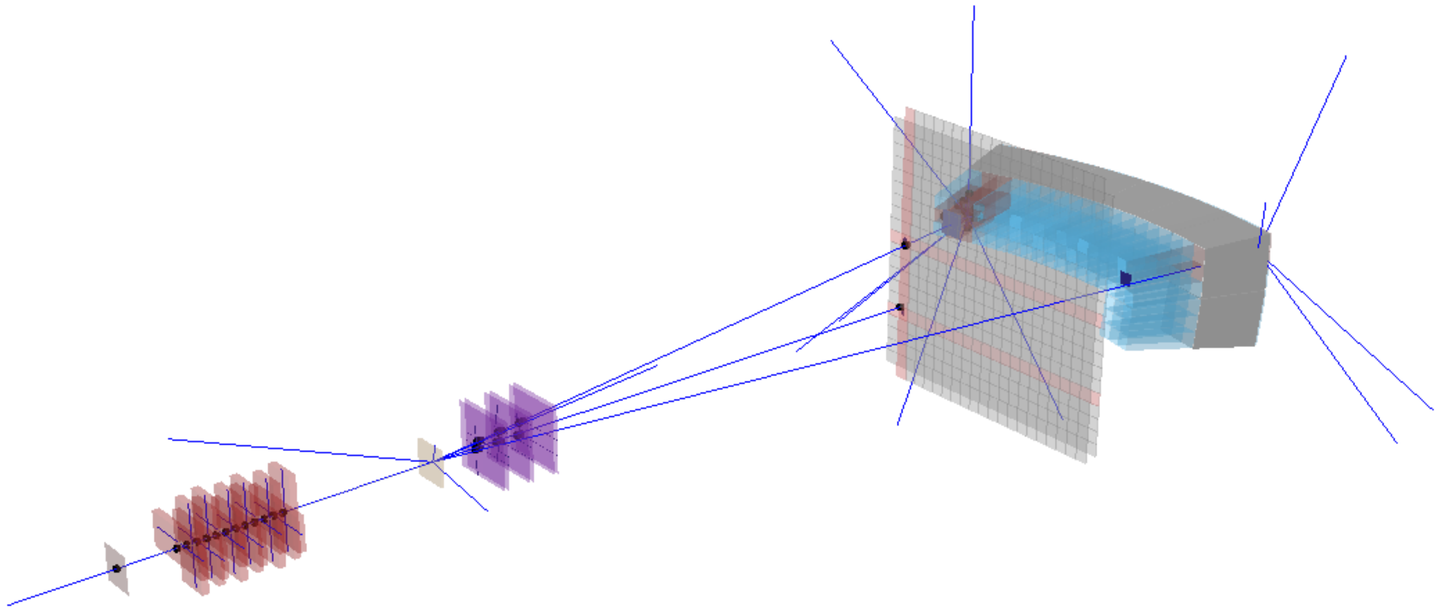


At CNAO 2024 collected ~ $2x10^6$ events of physics C+C @ 200 MeV/u:

- 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

→ RobZ work on MC elemental XS analysis

HIT2022: Adding CALO



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 (See Aafke talk)