Analysis status

FOOT General Meeting - Cherasco
17/12/2024

Marco Toppi, for the analysis crew

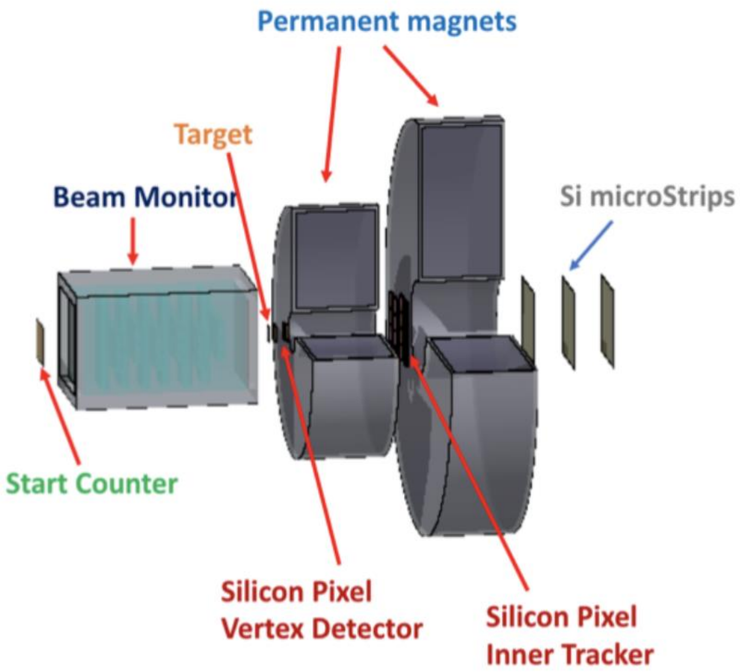
FOOT campaigns to analyze

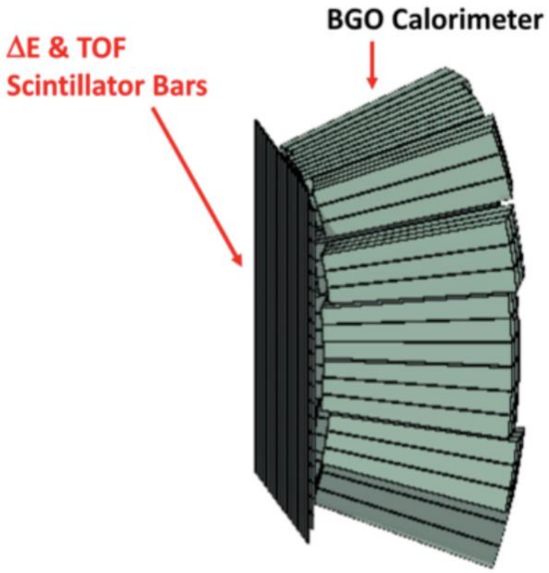
Electronic setup				
Campaign	**Beams**	**Energy [MeV/u]**	**Targets**	**Detectors**
GSI 2019	O	400	C	SC, BM, TW
GSI 2021	O	200, 400	C, C_2H_4	SC, BM, VT, MSD, TW
HIT 2022	He	100, 140, 200, 220	C	SC, BM, MSD, TW, CALO
CNAO 2022	C	200	C	SC, BM, VT, MSD, TW, CALO
CNAO 2023	C	200	C, C_2H_4	Full, magnets
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°

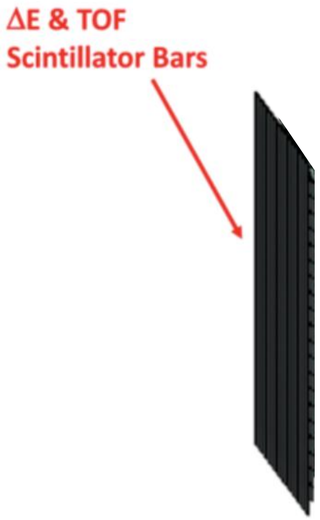
FOOT campaigns to analyze





Our beautiful detector in all its glory, but…

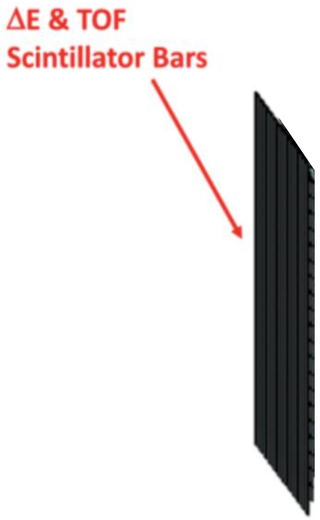
FOOT campaigns to analyze



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

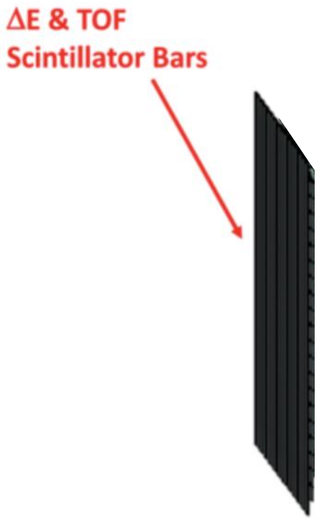
SC + BM + TW analysis



- **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 paper and Matilde analysis

SC + BM + TW analysis

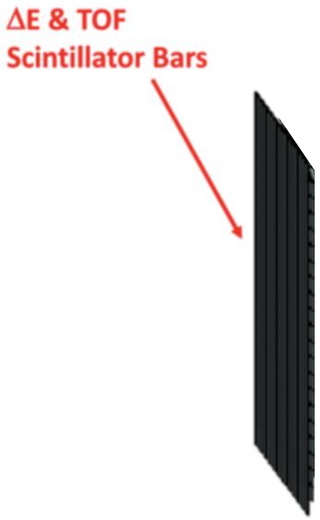


- **GSI2019: O @ 400 MeV/u + C, integral XS**
- **GSI2021: O @ 400 MeV/u + C, integral and angular differential XS**
- **GSI2021: O @ 400 MeV/u + C_2H_4, integral and angular differential XS. O+H and H+O**
- **GSI2021: O @ 200 MeV/u + C, C_2H_4, integral and angular differential XS. O+H and H+O**
- **CNAO2022: 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…)**

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 (happy referees)

SC + BM + TW analysis

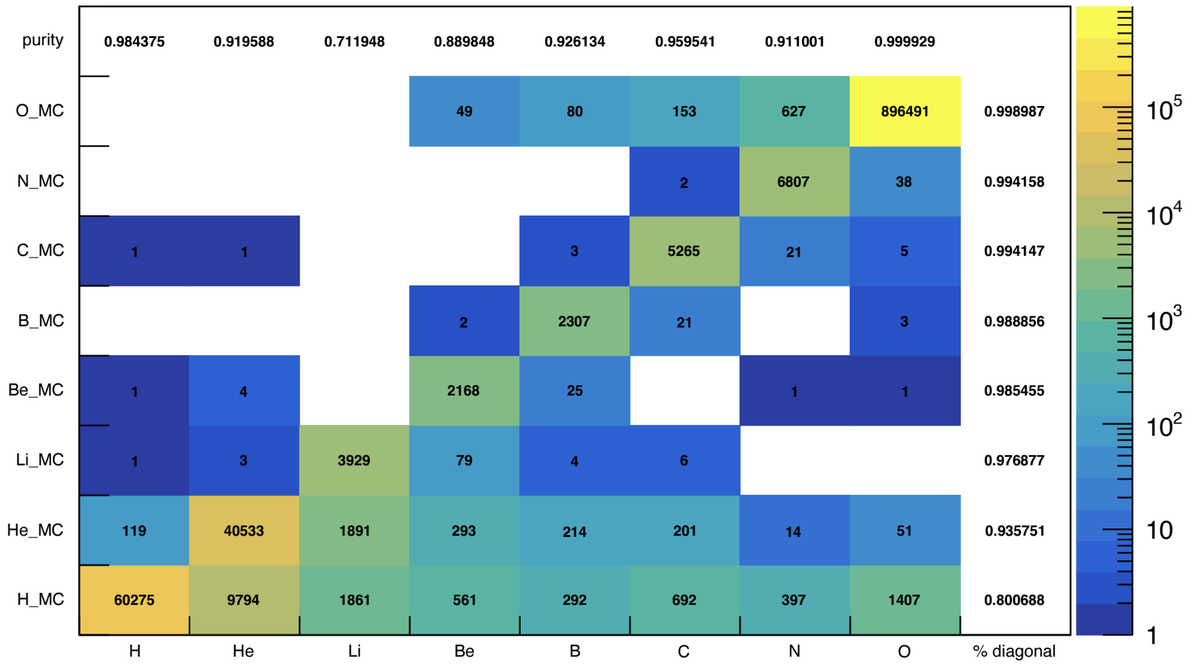


- **GSI2019: O @ 400 MeV/u + C, integral XS**
- **GSI2021: O @ 400 MeV/u + C, integral and angular differential XS**
- **GSI2021: O @ 400 MeV/u + C_2H_4, integral and angular differential XS. O+H and H+O**
- **GSI2021: O @ 200 MeV/u + C, C_2H_4, integral and angular differential XS. O+H and H+O**
- **CNAO2022: 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…)**

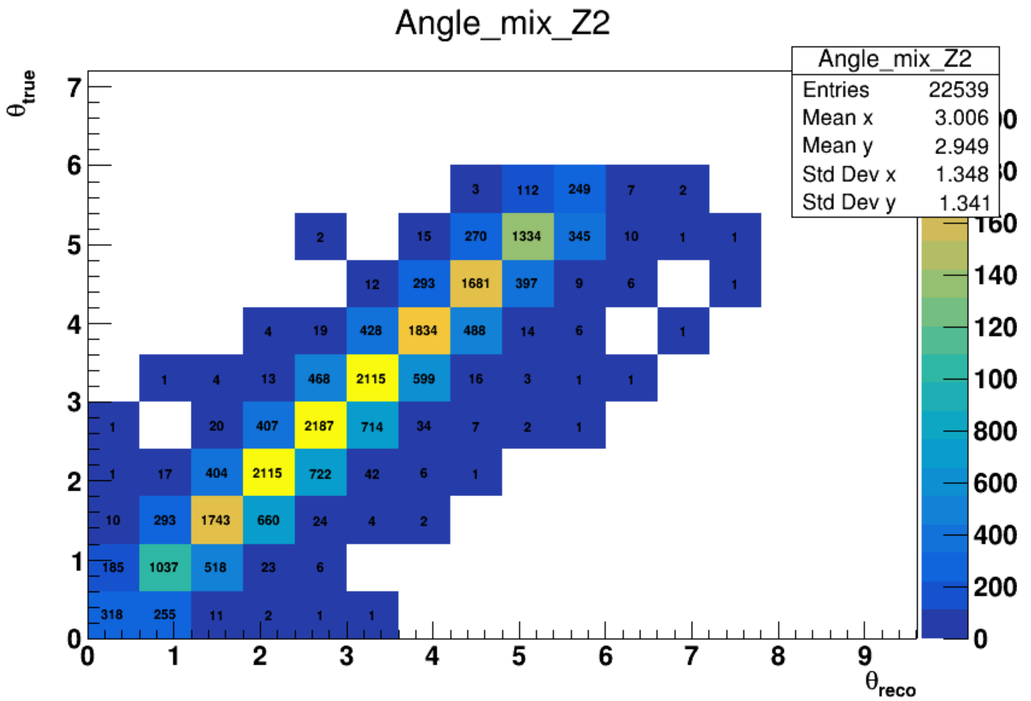
Cons:

- 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



purity correction



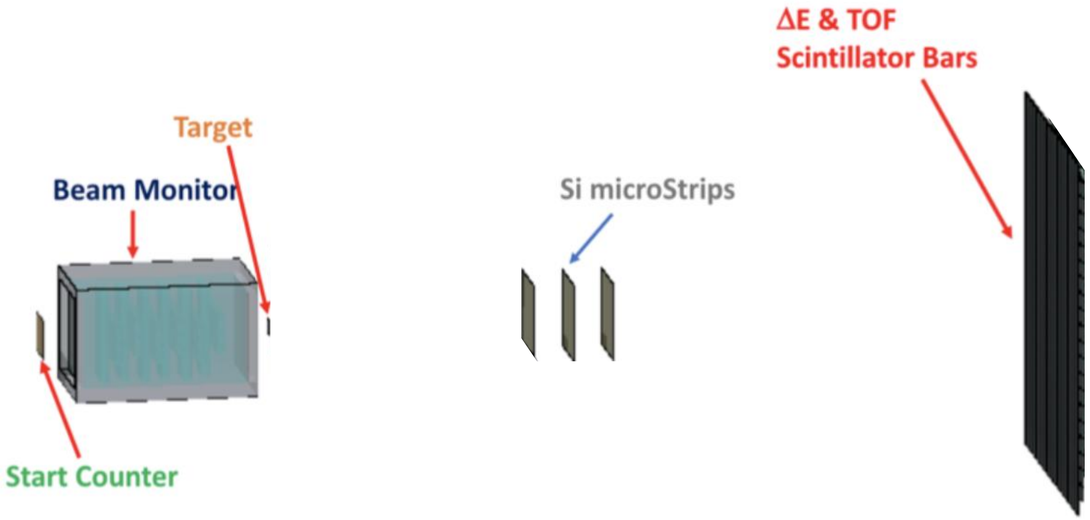
Angular unfolding impact
(from Riccardo analysis)

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)

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

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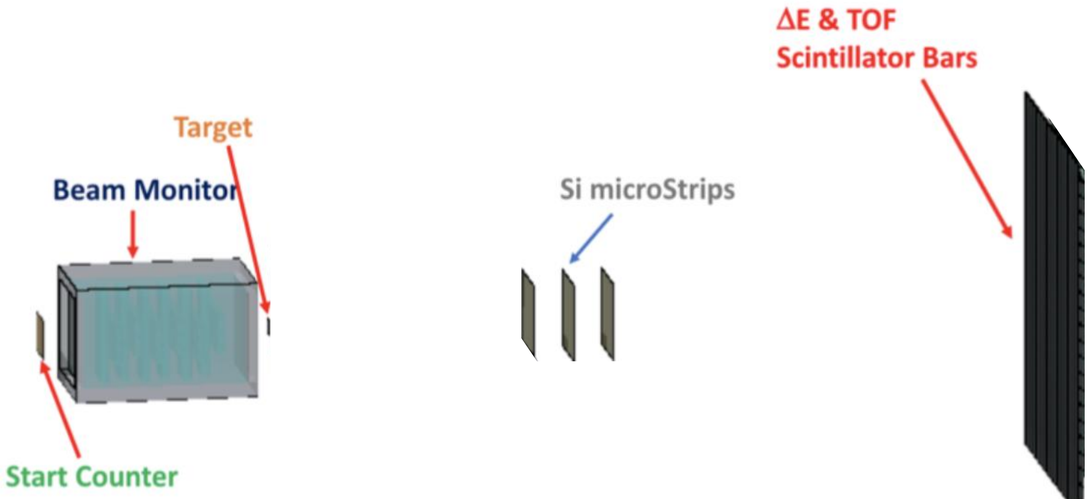

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- **GSI2021: O @ 200 MeV/u + C, C_2H_4, integral and angular differential XS. O+H and H+O**

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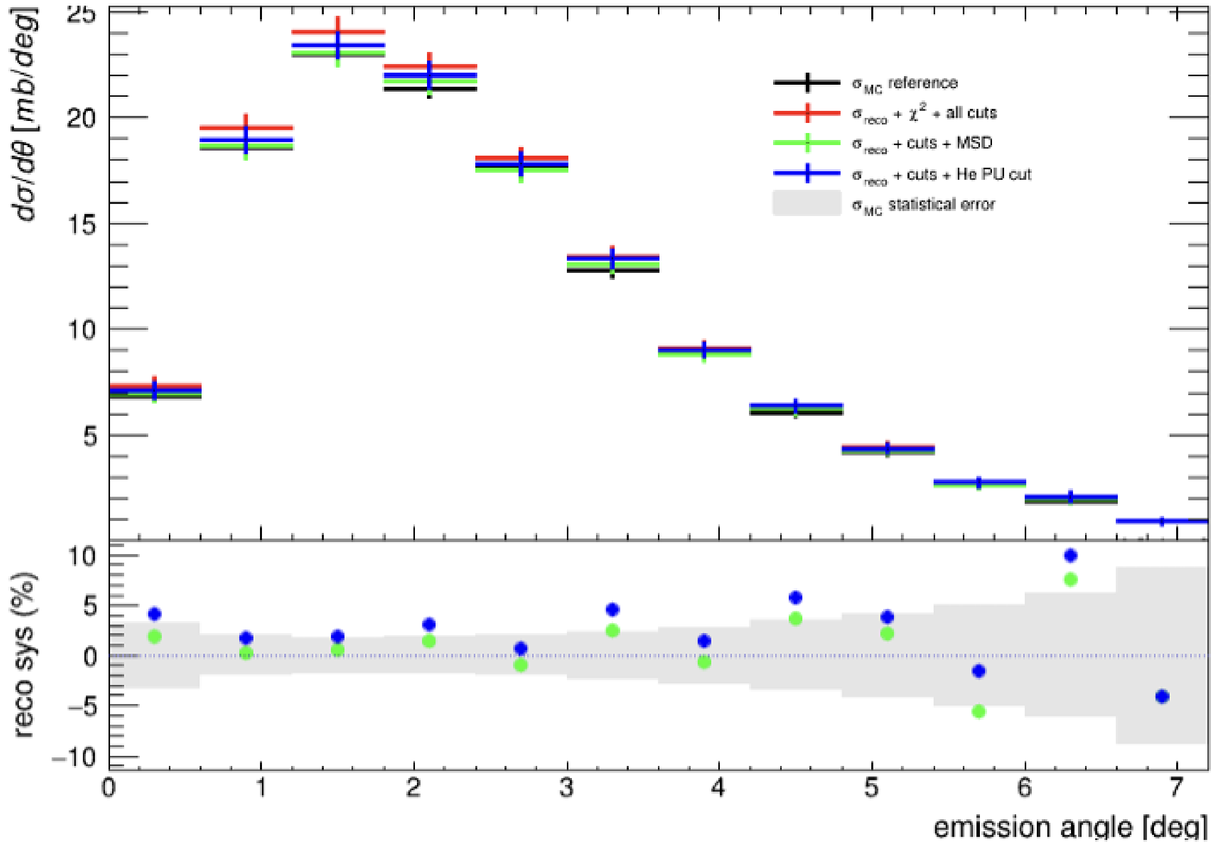
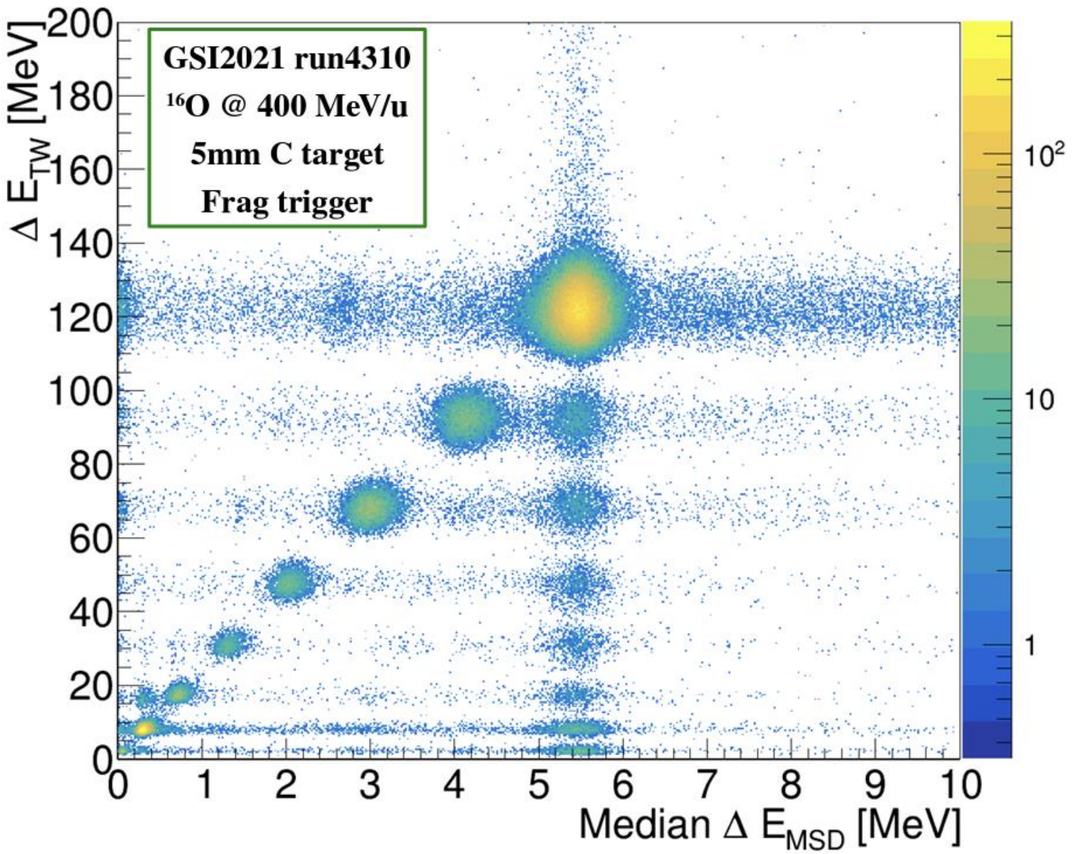
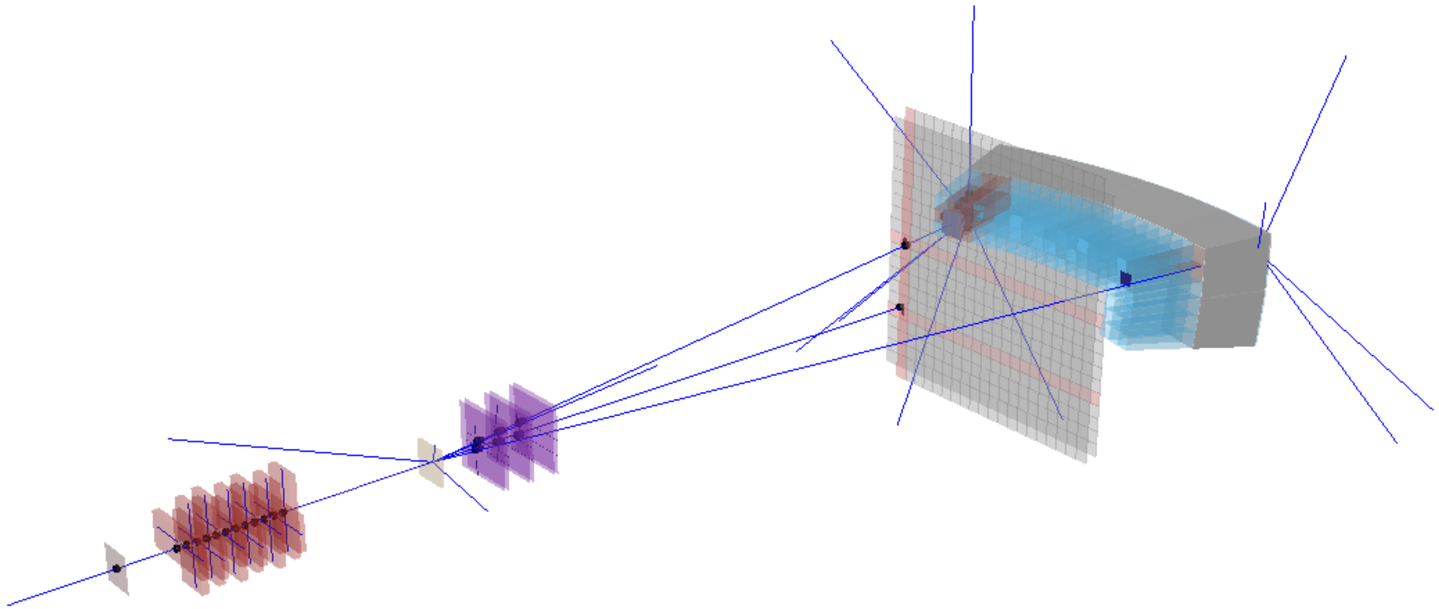


from Giacomo talk at GM December 2023



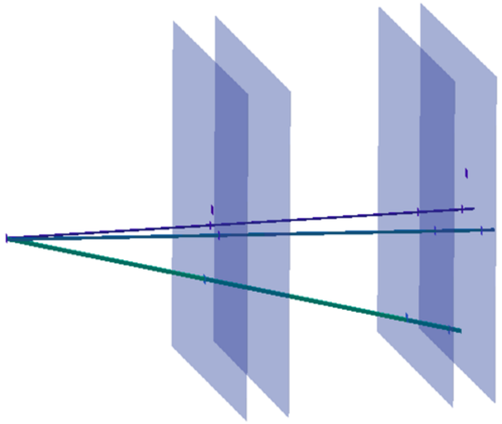
from RobZ talk at GM June 2024

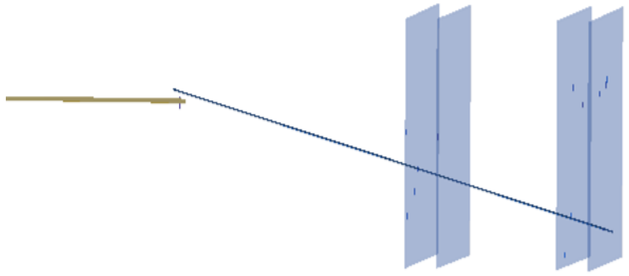
HIT2022: Adding CALO



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 (Aafke, Lorenzo, Matteo)

Adding the VTX



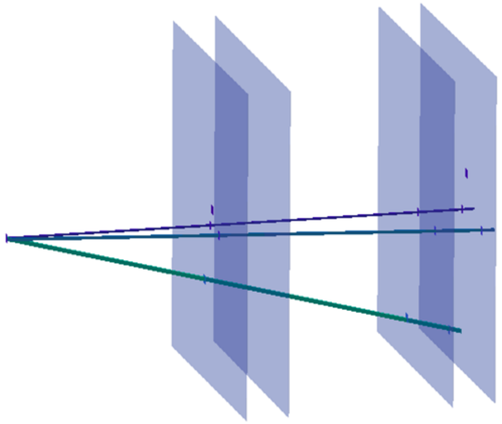


Adding the VTX to measure XS and compare with SC+BM+TW analysis results for GSI2021, CNAO2022 campaigns

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



- **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**

→ Giacomo work on MC and Luana work on data

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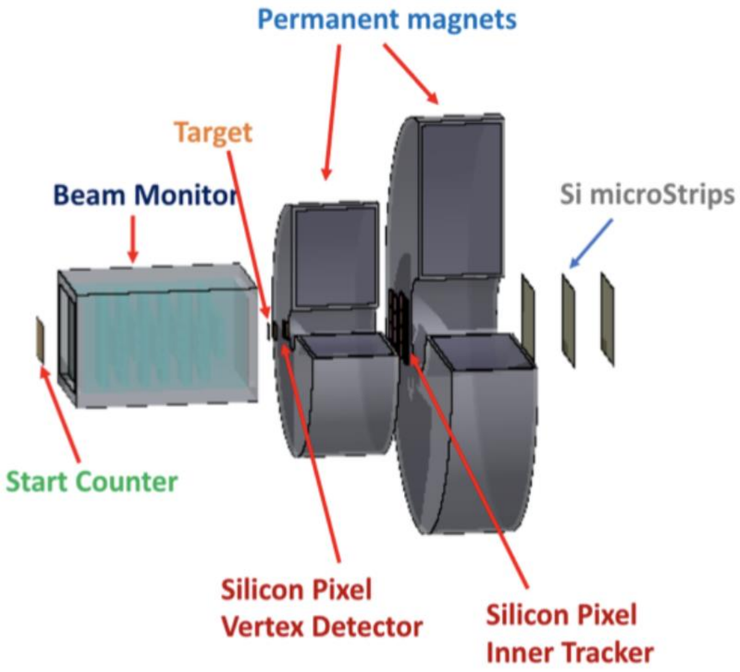
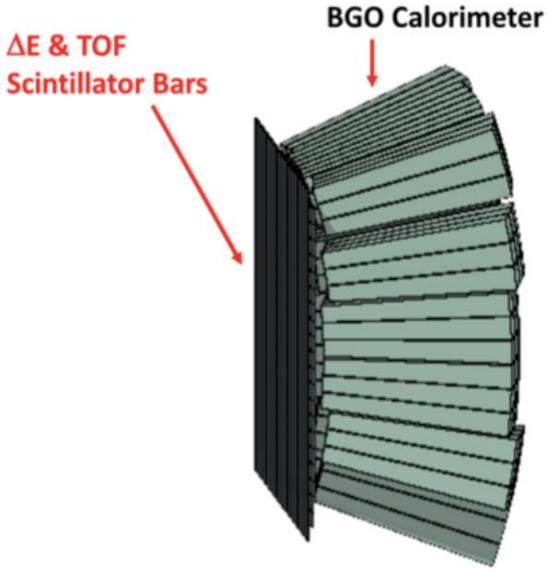
Full setup: CNAO2023 vs CNAO2024





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

→ RobZ work on MC elemental XS analysis

Analysis strategy with infinite man power

- Use SC+BM+TW analysis to have XS in campaign without magnet
- Add MSD to measure XS and cross check with SC+BM+TW analysis in campaign without magnet
- 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
- MSD + CALO @ HIT2022 for He XS
- 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

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	✓	✓	✓
	Yun	Chris, Luana, Marco	Chris	Perugia + RobZ, Alessio	Pisa + Giacomo, Marco, RobZ	Torino	Yun, Matteo	Giuseppe, Silvia	Riccardo, Mauro

Situation of Simulation Campaigns - 1

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

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

Situation of Simulation Campaigns - 2

We could now erase (or move somewhere else) a lot of old simulation campaigns.

For example:

GSI2021_MC (does anybody still use it?)
CNAO2023_MC (does anybody still use it?)
CNAO2022_MC (does anybody still use it?)
HIT2022_MC
12C_200
12C_200new
16O_200
16O_400
12C_200_2023
12C_200_2023v2
12C_200_2023long
16O_200_2023v2
H_MC
HE_MC
CNAO2021_MC
GSI_MC

and maybe others…

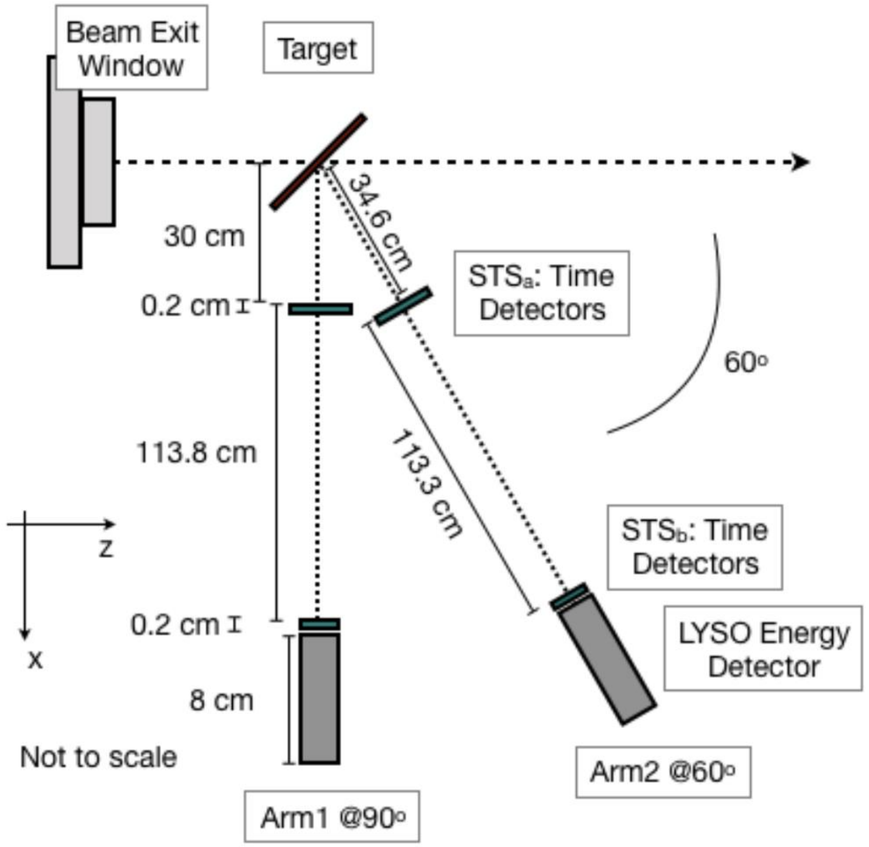
Opinions from the physics analysis group?

Slides from Silvia and Giuseppe

Work in progress / still missing

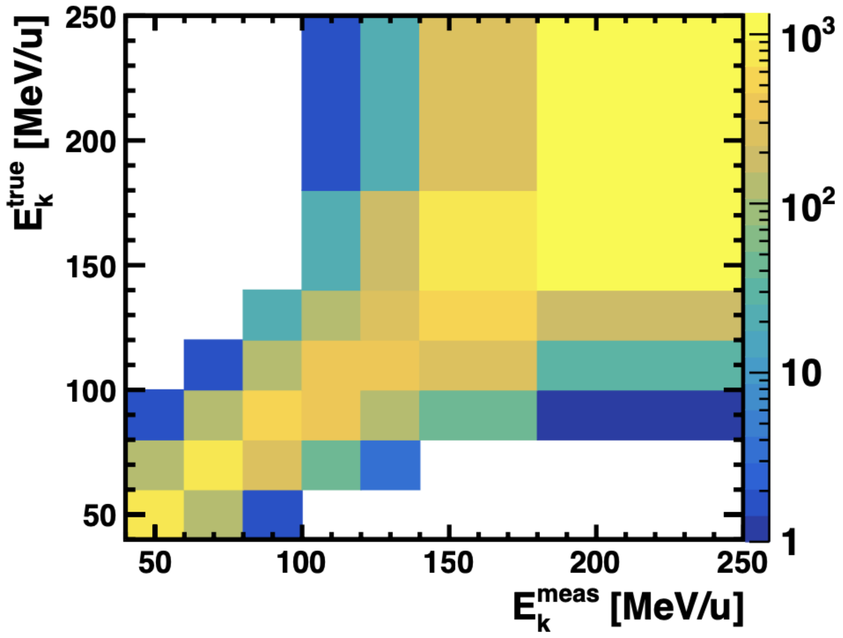
- In MC no detector effects (noise, cluster sizes, threshold and efficiency tuned from data) for most of the trackers
- Pile up in VT/IT, high rates effects (+ pile-up studies in MC to better understand our capability in rejecting it and to estimate a rejection efficiency)
- MSD eta function / charge 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



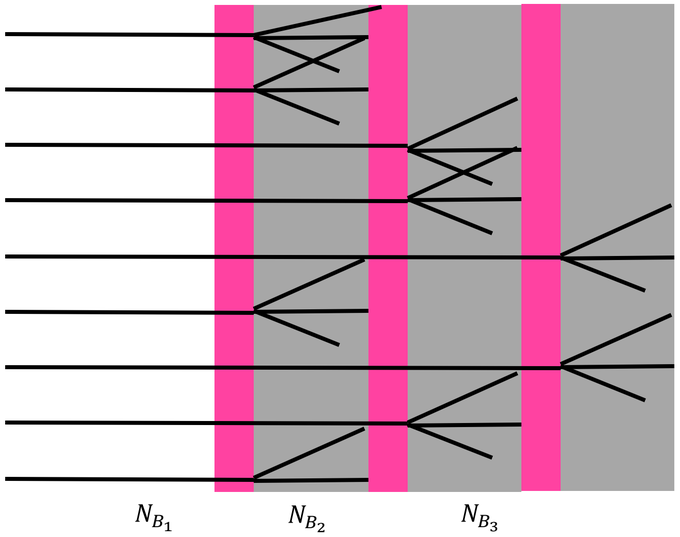
Cons:

- 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

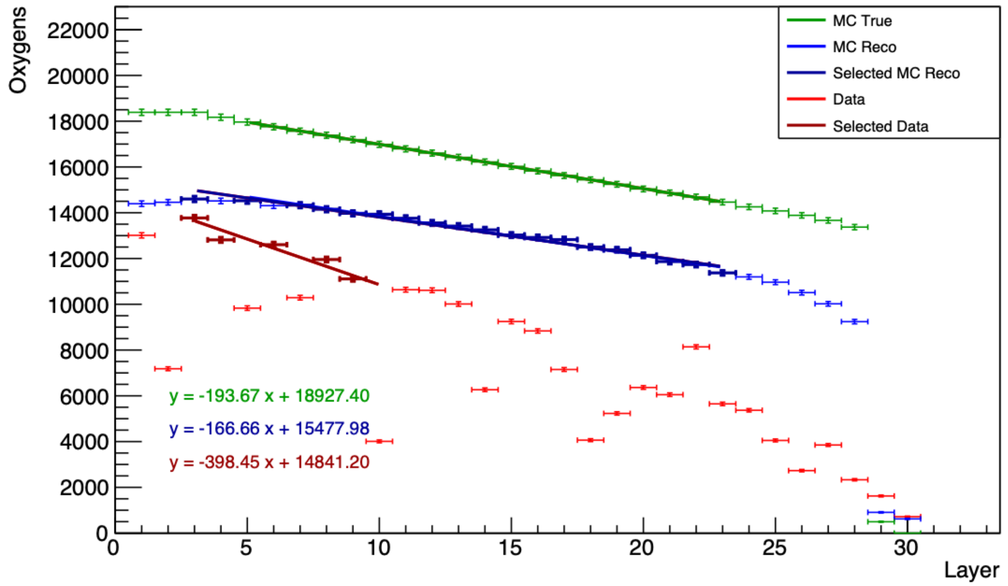
$$\frac{d\sigma(x)}{dx}\Big|_{CorC_2H_4} = \frac{Y_i(x)}{N_B N_{TG} \Delta x \epsilon^i_{reco}(x)}$$

- 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)



Enjoy the analysis sessions today (please Alessio you too)

Campaign	setup	technique	physics	Energy [MeV/u]	Calo	who	MC	Data	paper
CNAO 2017	Plastic scintillators+ LYSO	ToF+Ekin	12C fragmentation at large angles (p,d,t)	115,153, 221, 281, 353	-	Ilaria Mattei	✓	✓	Internal review
GSI 2021	electronic	SC+BM+TW	16O+C fragmentation (2<Z<8)	400	-	Riccardo Ridolfi	✓	✓	Internal review
GSI 2021	electronic	no tracking	16O+C,C2H4→H+16O (inverse)	400 (16O)	-	Matilde Dondi + Riccardo	✓	✓	-
GSI 2019	emulsion	S1+S2	16O+C,C2H4 fragmentation	200	-	Giuliana Galati	✓	✓	In progress
HIT2022	electronic	Global tracking	4He+C->p,d,t,^{3}He	100,140,200,220	Yes	Aafke, Matteo M, Lorenzo Pierfederici	✓	✓	-
GSI 2021	electronic	Global tracking	Alpha clustering (from 16O)	200	-	Giuseppe	✓	✓	-
GSI 2021	electronic	Global tracking	16O+C fragmentation (2<Z<8)	400	-	Giacomo Ubaldi	✓	✗	-


come fai..SBAI

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

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):

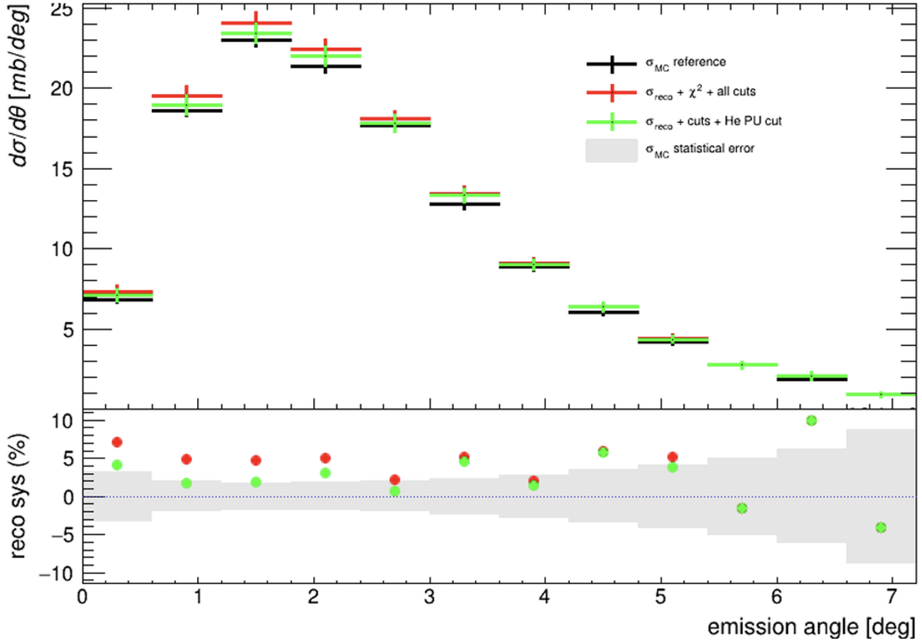
- **Track quality** (selection on chi2/p-value and track residuals)
- **1 BM track**
- **1 valid vertex inside the TG matched with BM** → fragmentation + remove pile up
- **N tracks in vtx > 1** → only fragmentation, remove most of the pre target fragmentation and primaries
- **Rejection of global tracks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

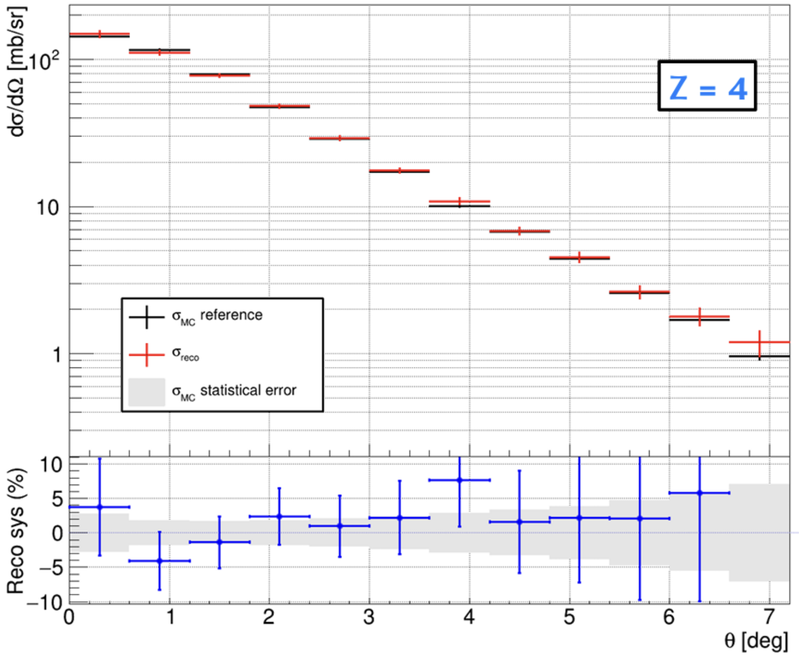
Z=3 differential cross section



GSI 2021

O+C -> Li+X

GiacU: PM 02/2024



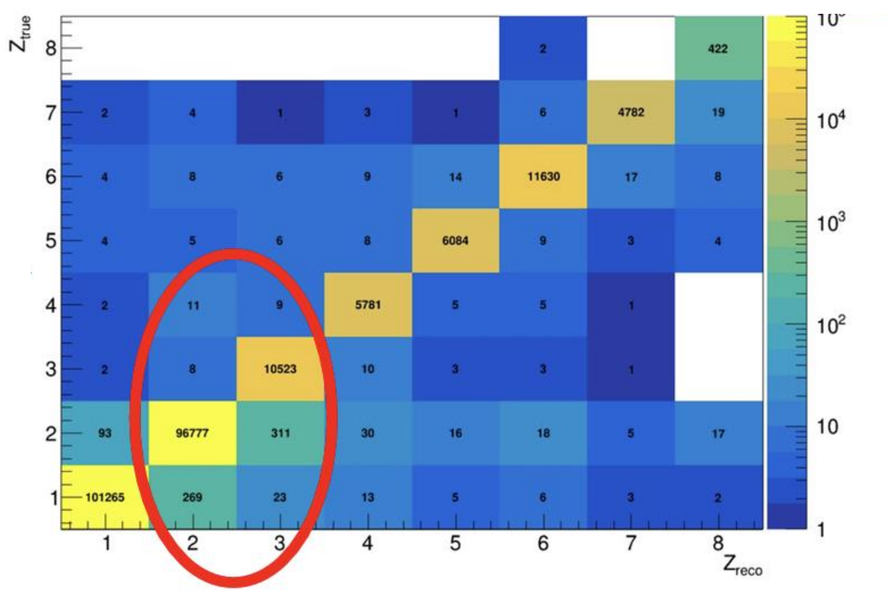
CNAO 2023

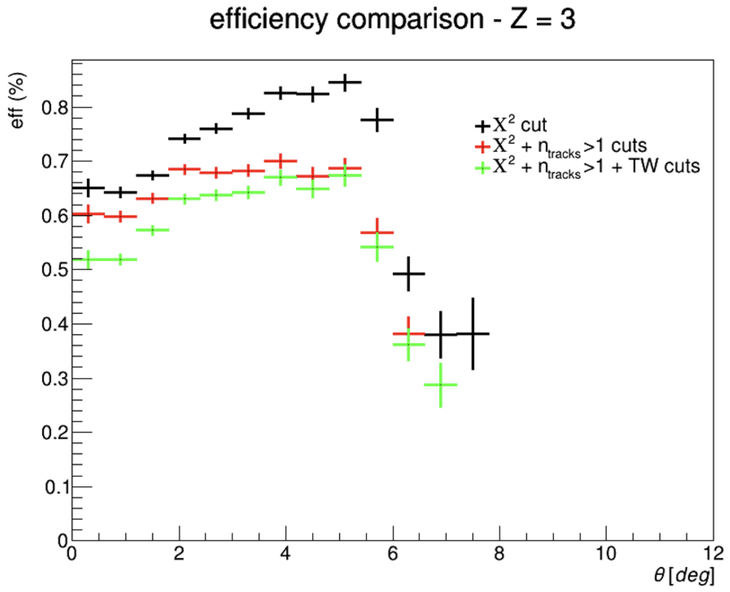
C+C -> Be+X

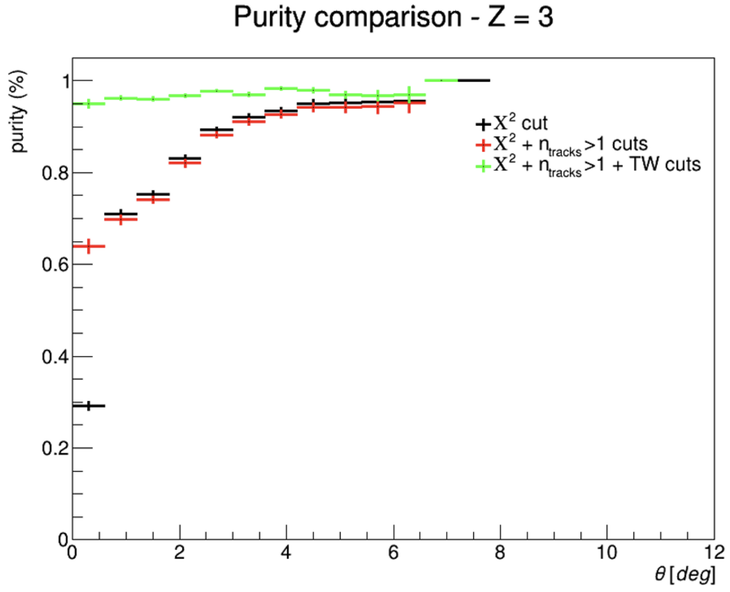
RobZ: PM 02/2024

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

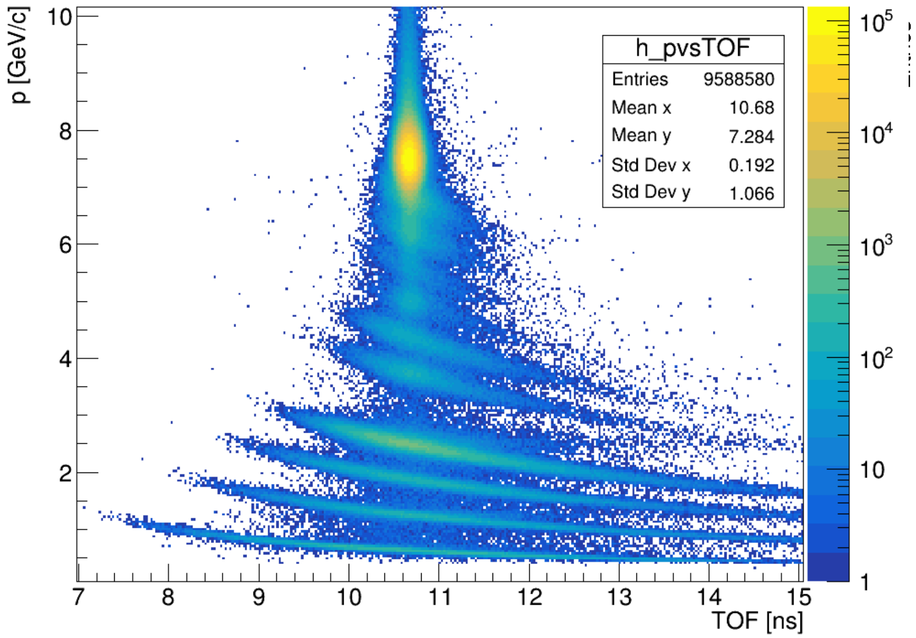


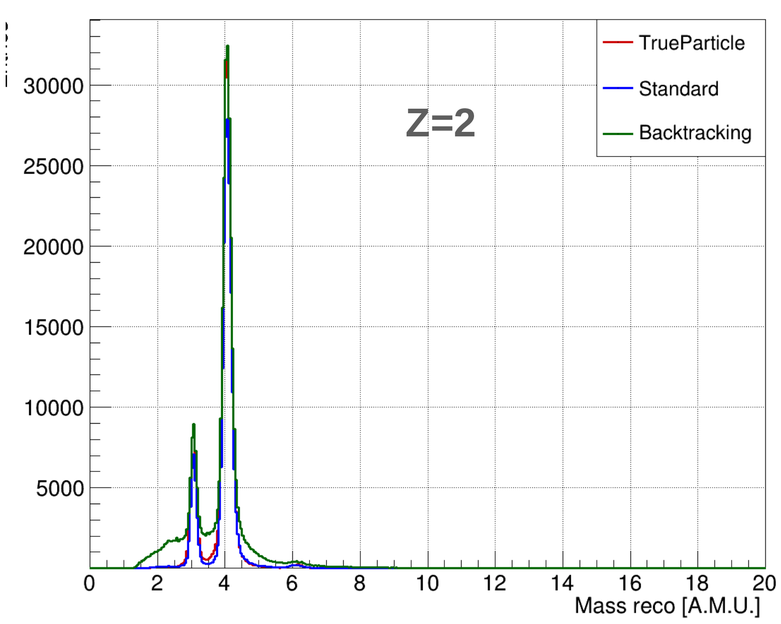


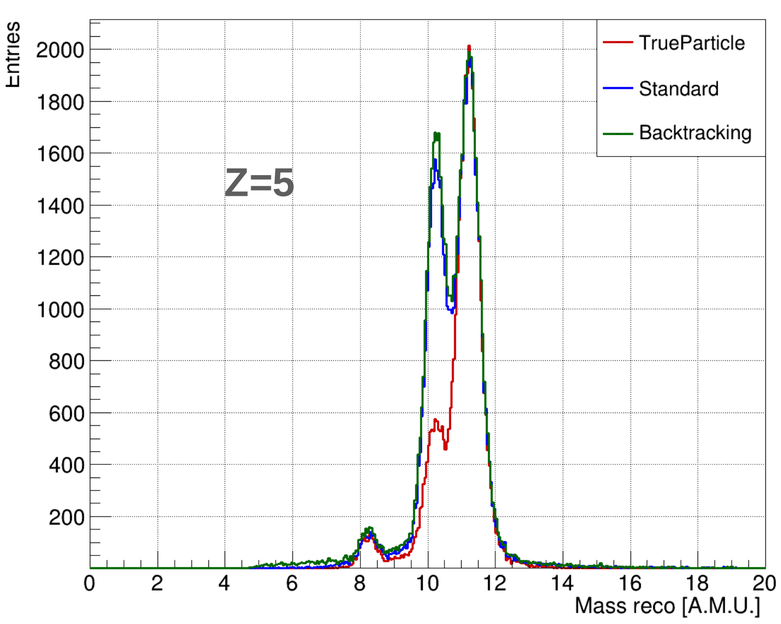


CNAO2023 MC status

- 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