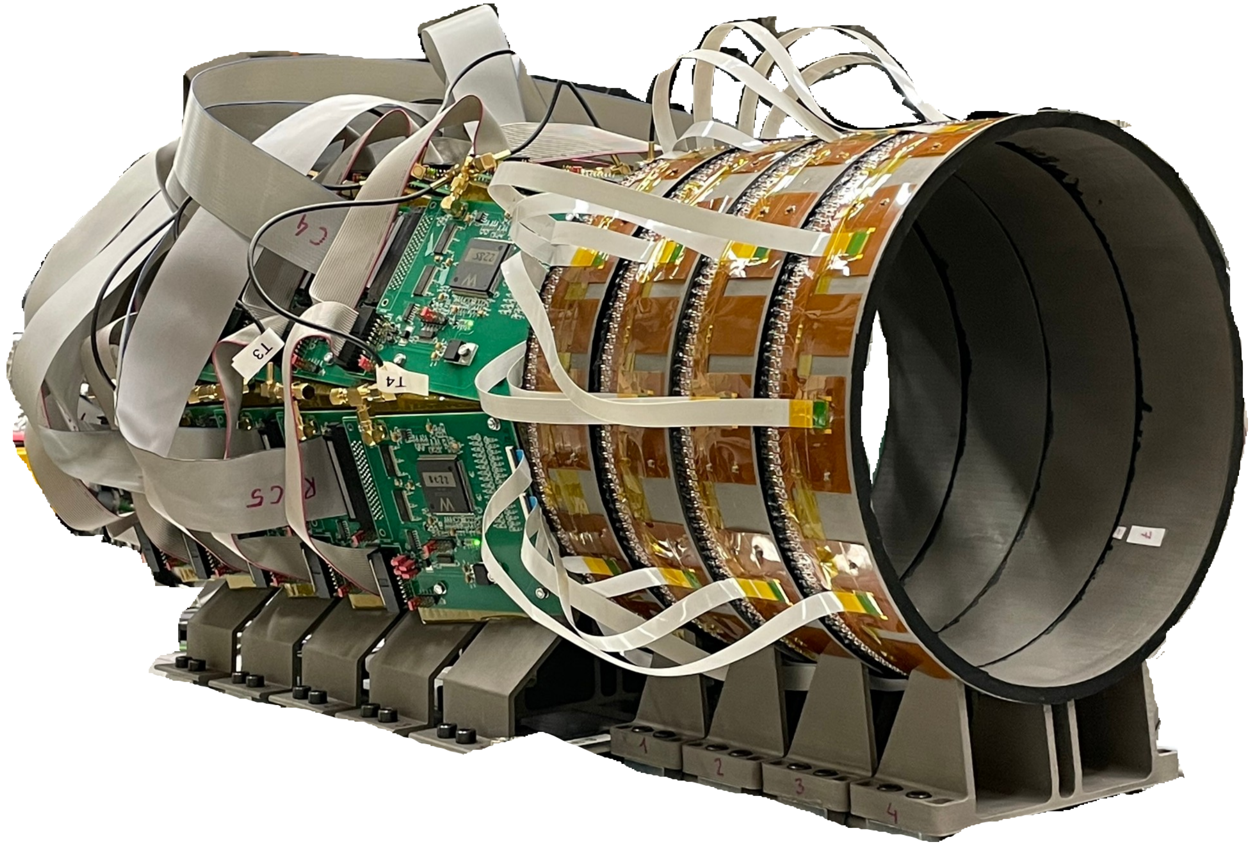
KRAB detector for the ASY-EOS II experiment within the R3B infrastructure at GSI

J. Łukasik

IFJ PAN



KRAB detector, financed by NCN, contract No. 2017/25/B/ST2/02550

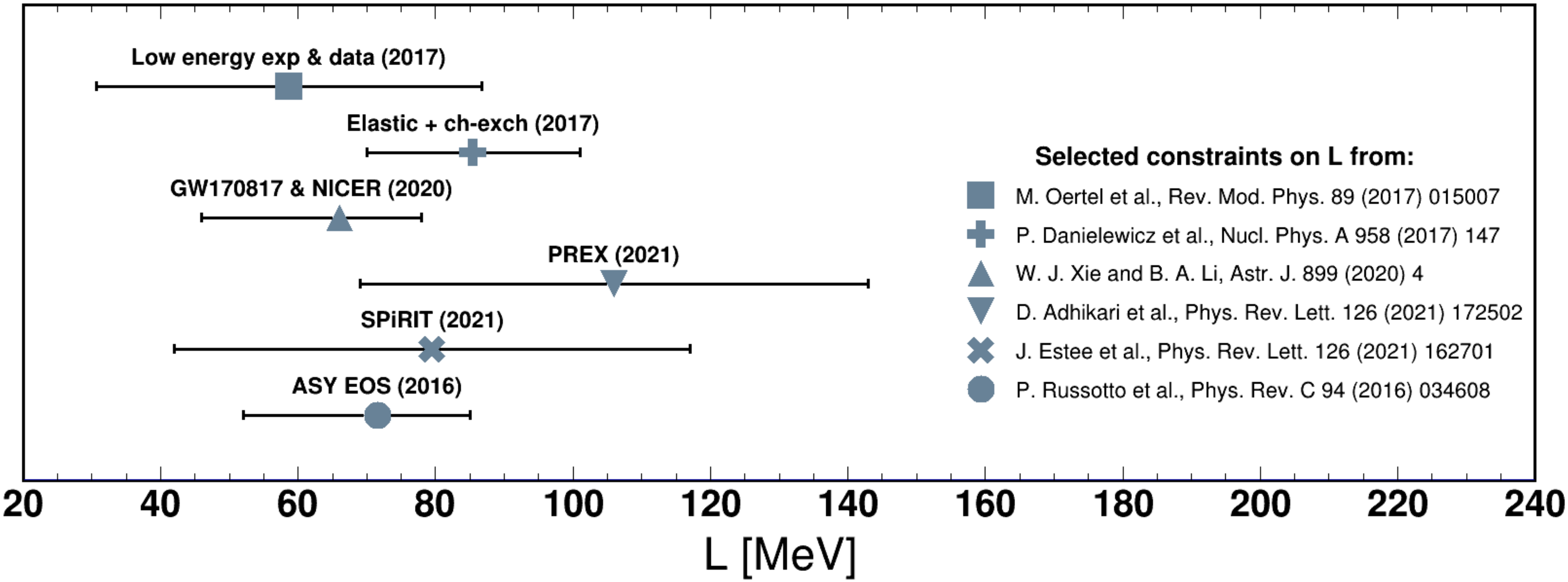
NuSYM24, GANIL, 9-14.09.2024

Outline

- Motivation for KRAB ← ASY-EOS II experiment
- Brief description
- Main results from the GSI heavy beam test:
  - cross-talks
  - helium effect
  - reaction plane dispersion
  - discrimination of off-target events
- Overall performance - summary

Slope of the Symmetry Energy

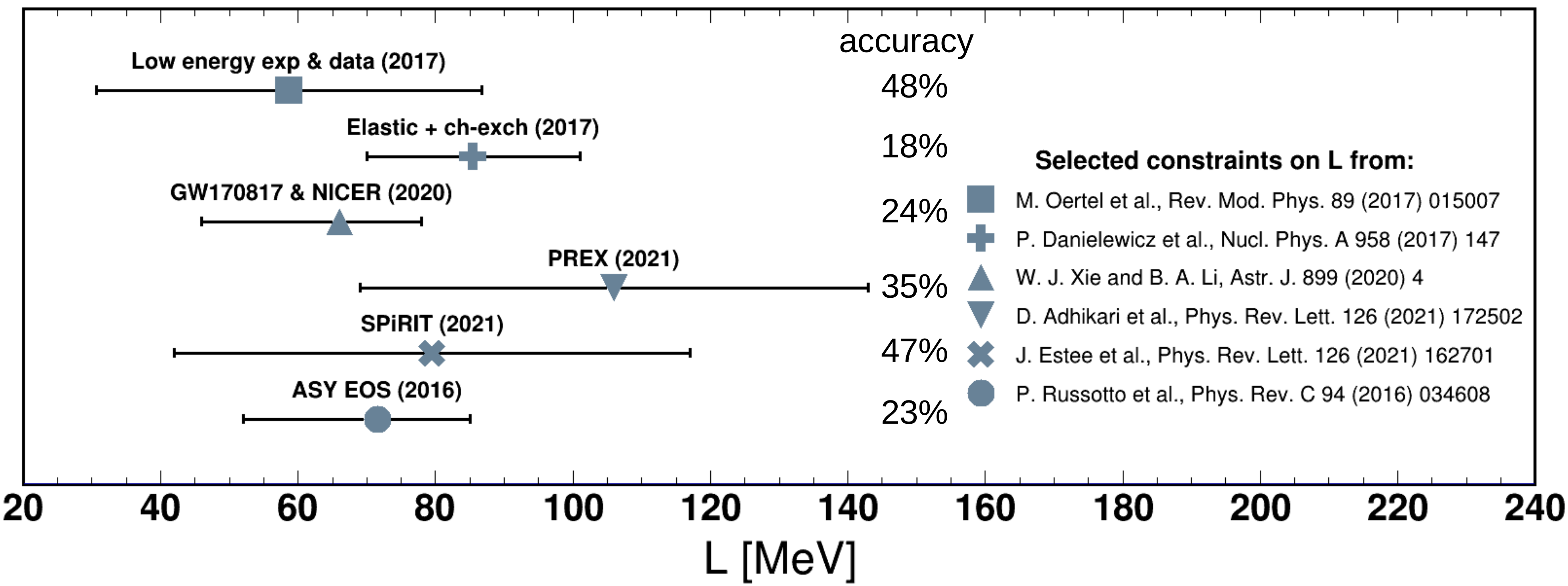
the status



$$E_{sym}(\rho) \approx E_{sym}(\rho_0) + \frac{L}{3}\left(\frac{\rho-\rho_o}{\rho_o}\right) + \frac{K_{sym}}{18}\left(\frac{\rho-\rho_o}{\rho_o}\right)^2 + \cdots$$

Slope of the Symmetry Energy

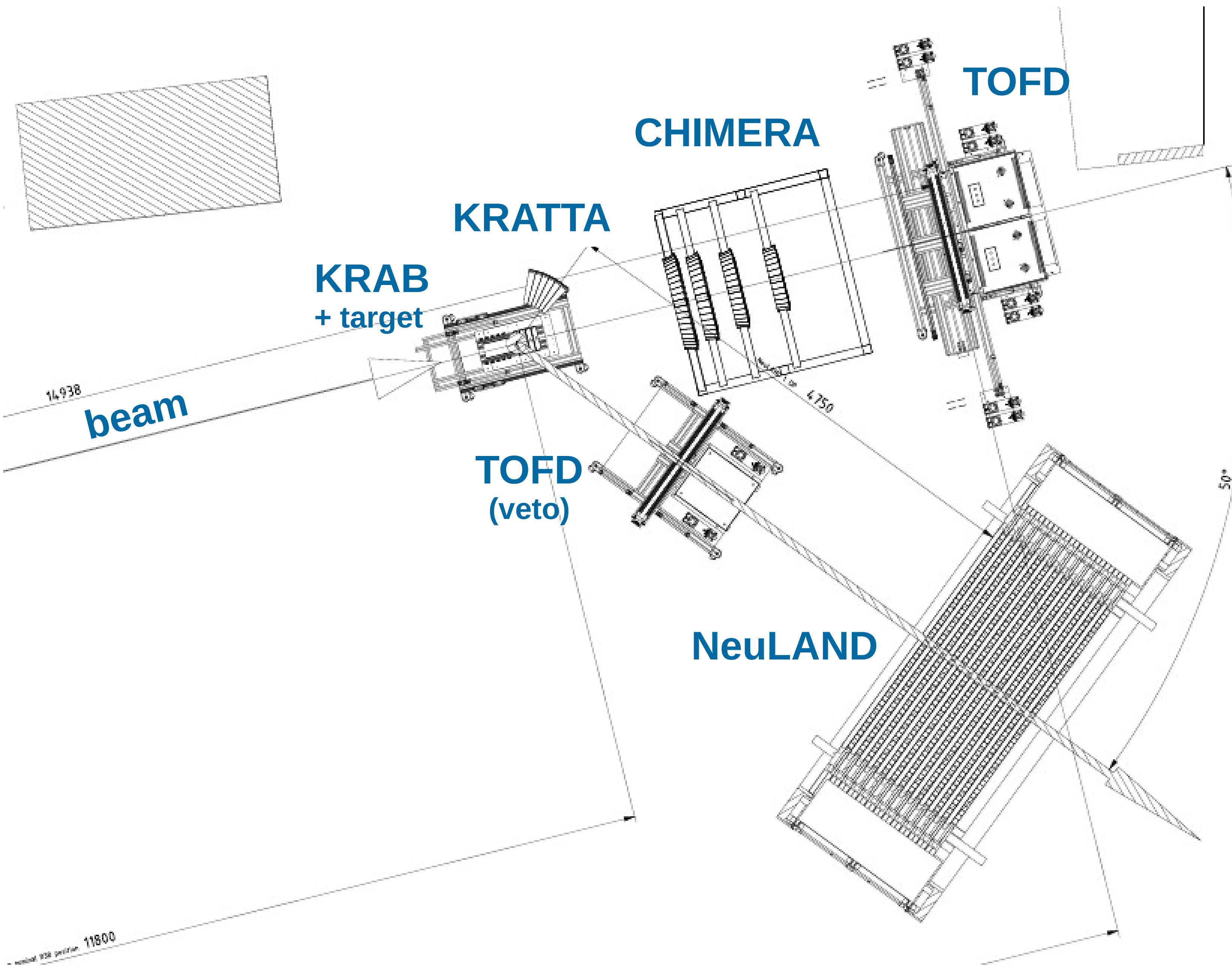
the status



$$E_{sym}(\rho) \approx E_{sym}(\rho_0) + \frac{L}{3}\left(\frac{\rho-\rho_o}{\rho_o}\right) + \frac{K_{sym}}{18}\left(\frac{\rho-\rho_o}{\rho_o}\right)^2 + \cdots$$

S122: ASY-EOS II @ GSI (March 2025)

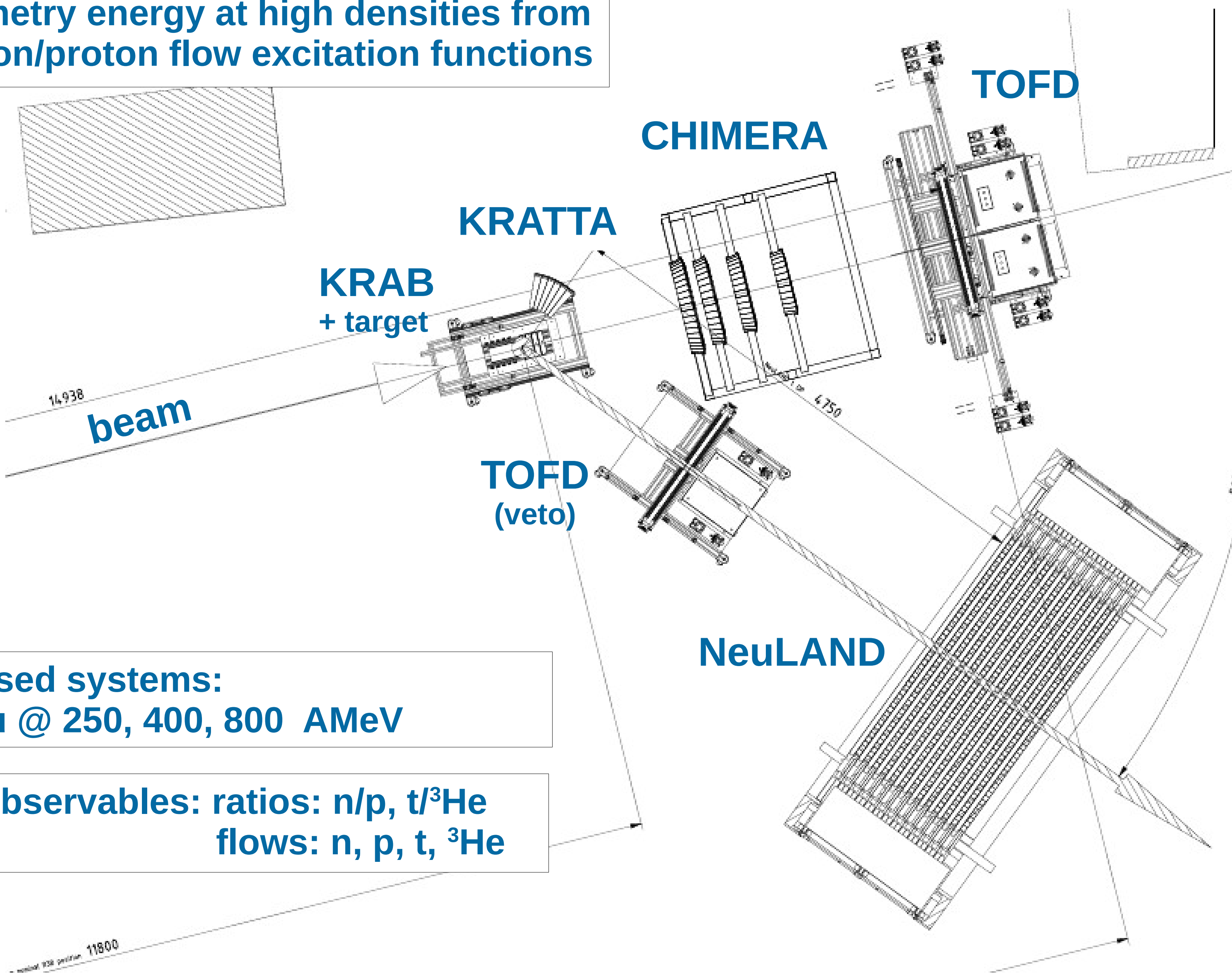
Proposed setup in CAVE C



S122: ASY-EOS II @ GSI (March 2025)

Proposed setup in CAVE C

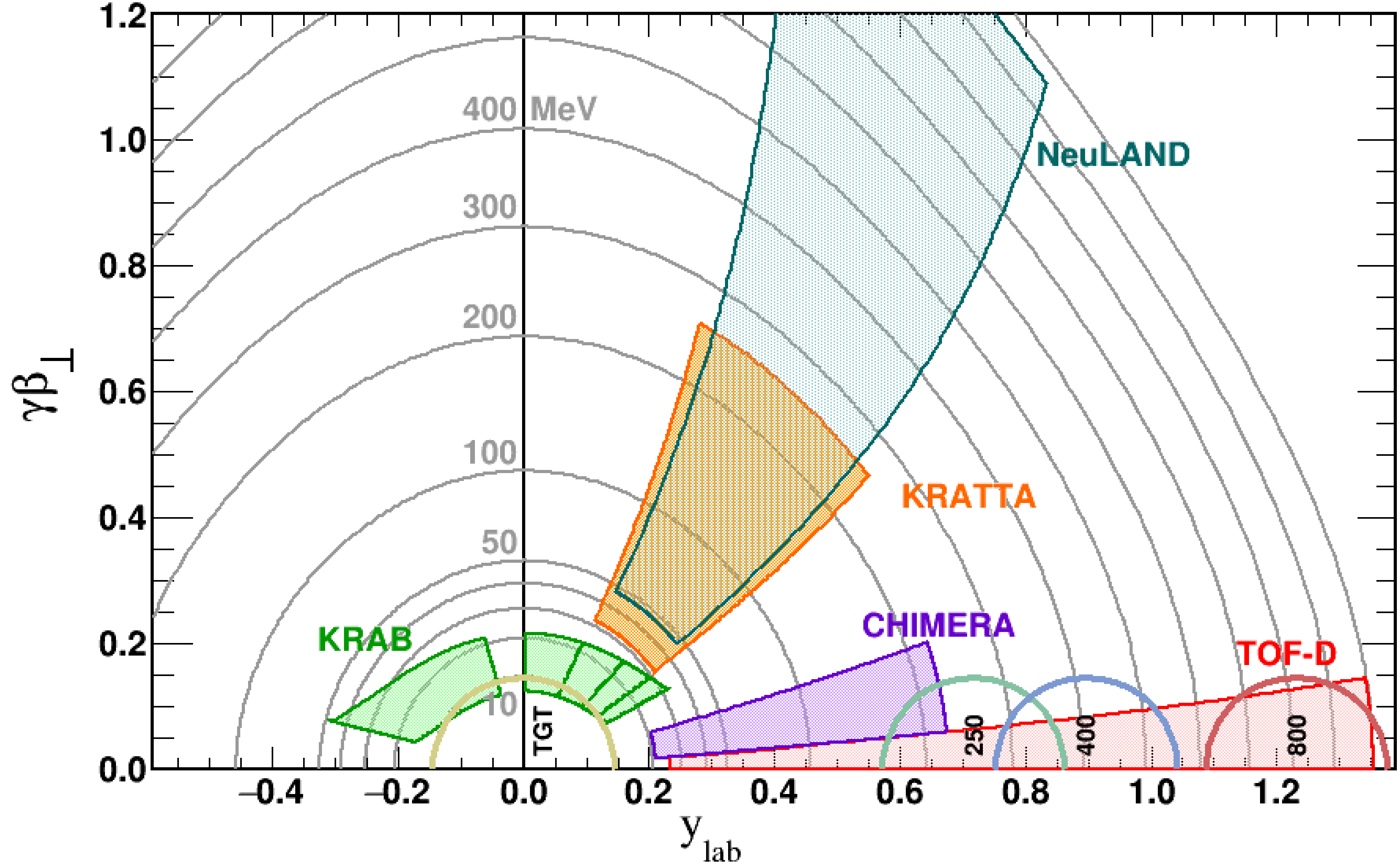
Symmetry energy at high densities from neutron/proton flow excitation functions



Proposed systems:
Au+Au @ 250, 400, 800 AMeV

Main observables: ratios: n/p, t/^{3}He
flows: n, p, t, ^{3}He

Acceptance of the setup for protons

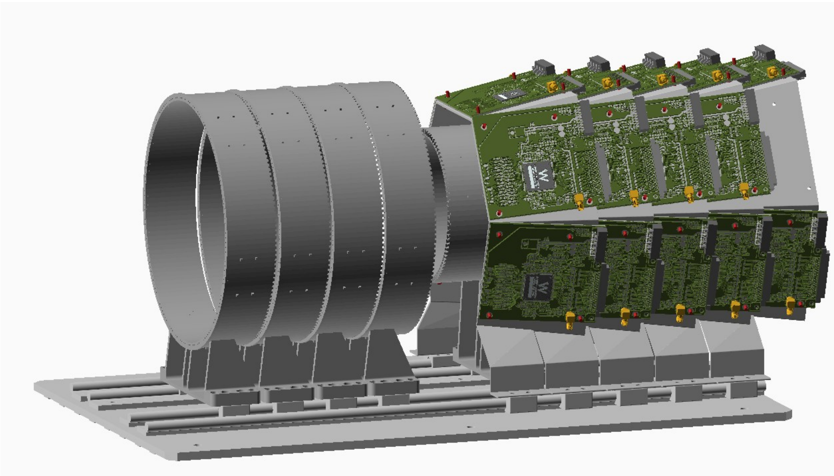


…a lesson learned from ASY-EOS I

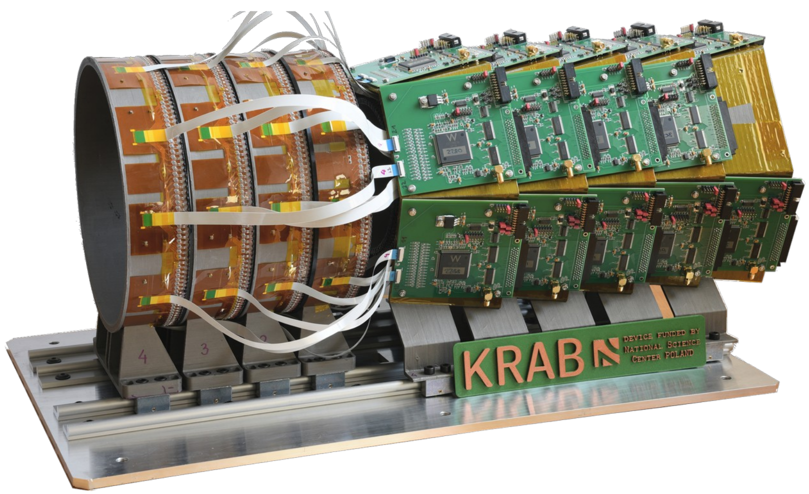
a new detector around the target should:

- provide fast multiplicity trigger
- provide reasonable centrality estimates
- provide additional data for the reaction plane
- provide discrimination for upstream reactions in air/windows/helium
- be as much as possible insensitive to δ-electrons
- be compact and as much as possible neutron transparent

KRAB multiplicity trigger | reaction plane | centrality detector



design



actual view

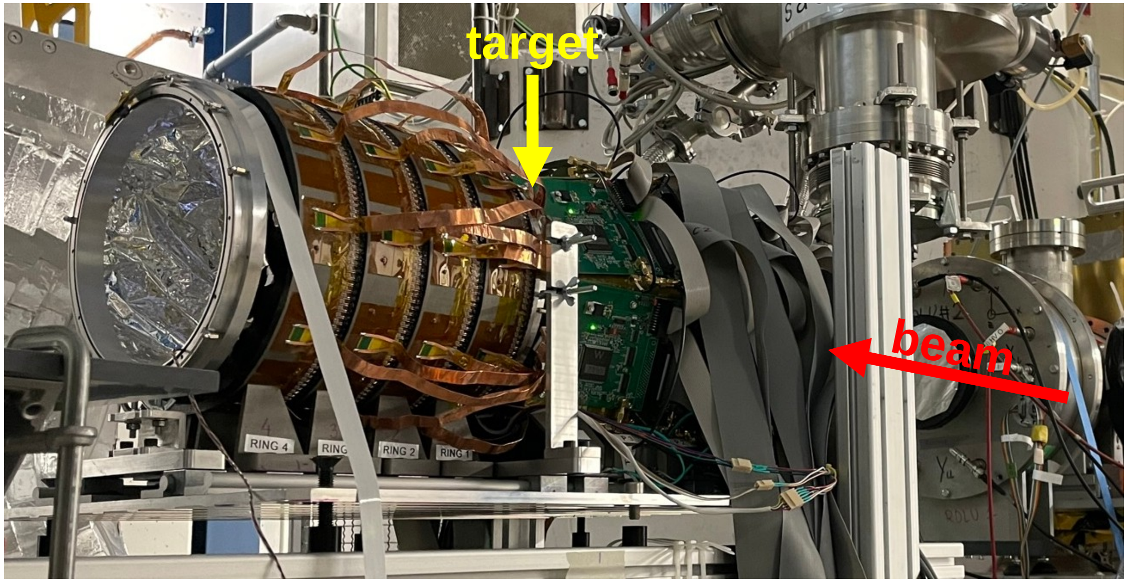
Main characteristics:

- 3D printed mechanical structure (ABS)
- 5 rings of 4×4 mm^2 fast scintillating fibers (BCF-10)
- read out by 3×3 mm^2 SiPMs (SensL MicroFJ-30035)
- 4×160 segments in forward rings and 96 in backward ring
- 736 channels
- 32 ch CITIROC 1A ASICs used for signal processing
- compact A7585D SiPM power modules
- broad coverage from 30^o to 165^o
- high geometrical efficiency ~87% (within covered angles)
- ~5% multihit probability (for 1 AGeV Au+Au reaction)
- sufficiently large for radioactive beams
- sufficiently small and lightweight not to disturb neutrons
- min radius - 7 cm, max radius - 12 cm
- length ~43 cm (size of a ~24” monitor)
- He sleeve to suppress the δ-electrons background
- remotely controlled target wheel with 4 slots
- ZnS target + camera
- ControlBox to control and setup CITOROCs
- TriggerBox to produce trigger, bit pattern and for
- slow control monitoring (scalers)
- multiplicity based trigger produced after 50 ns
- bit pattern of fired segments sent to V2495 logic module
- RIO4 + MBS based data acquisition
- GUI based remote control software

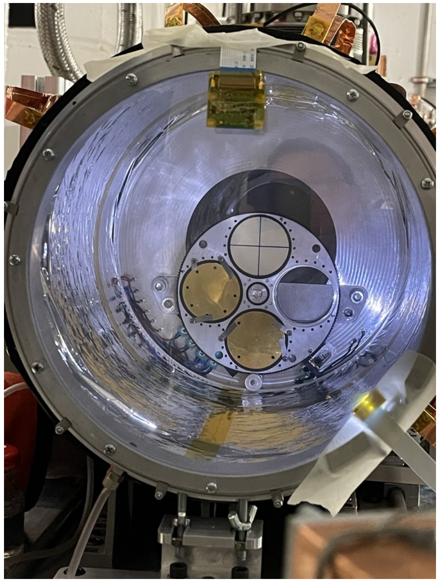
KRAB beam test at GSI (March 2024)

Au @ 400 & 800 AMeV

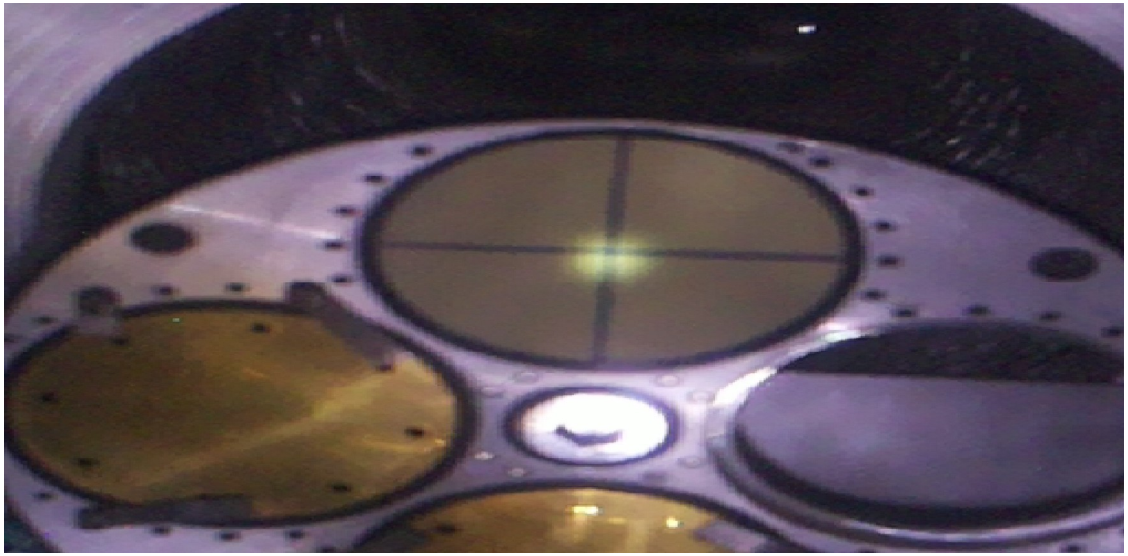
KRAB in CAVE C



target wheel

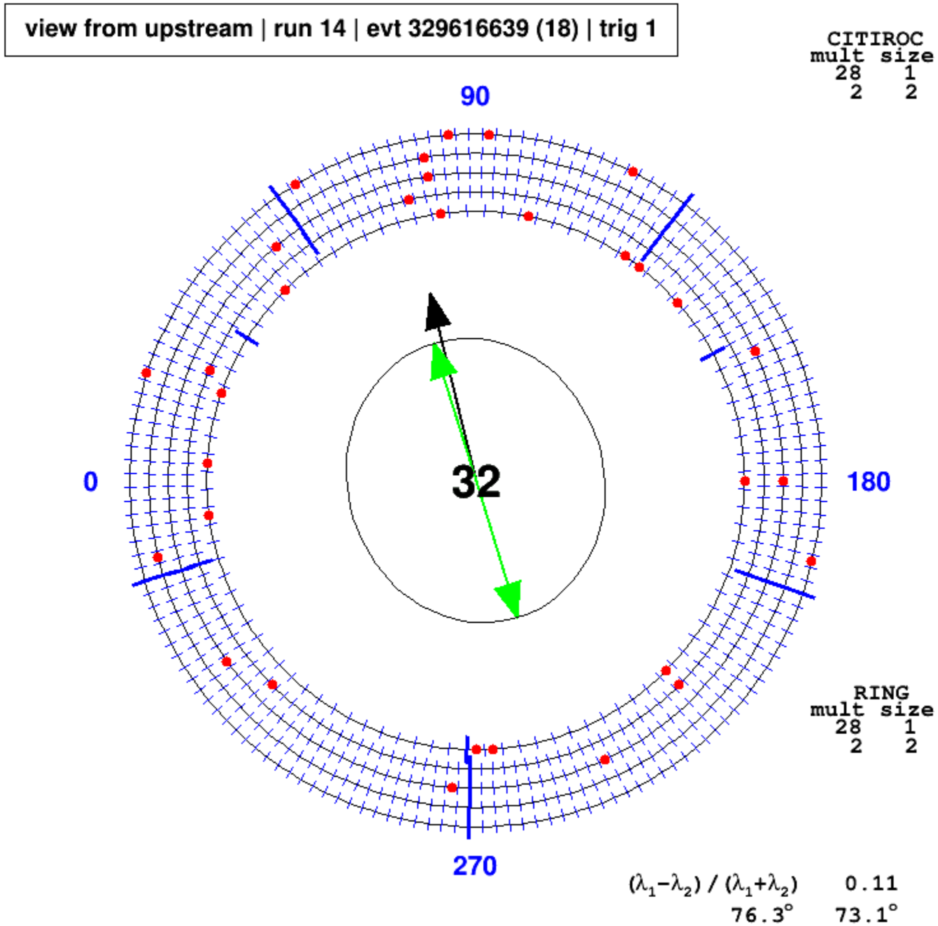


Au @ 400 AMeV beam spot on the ZnS target

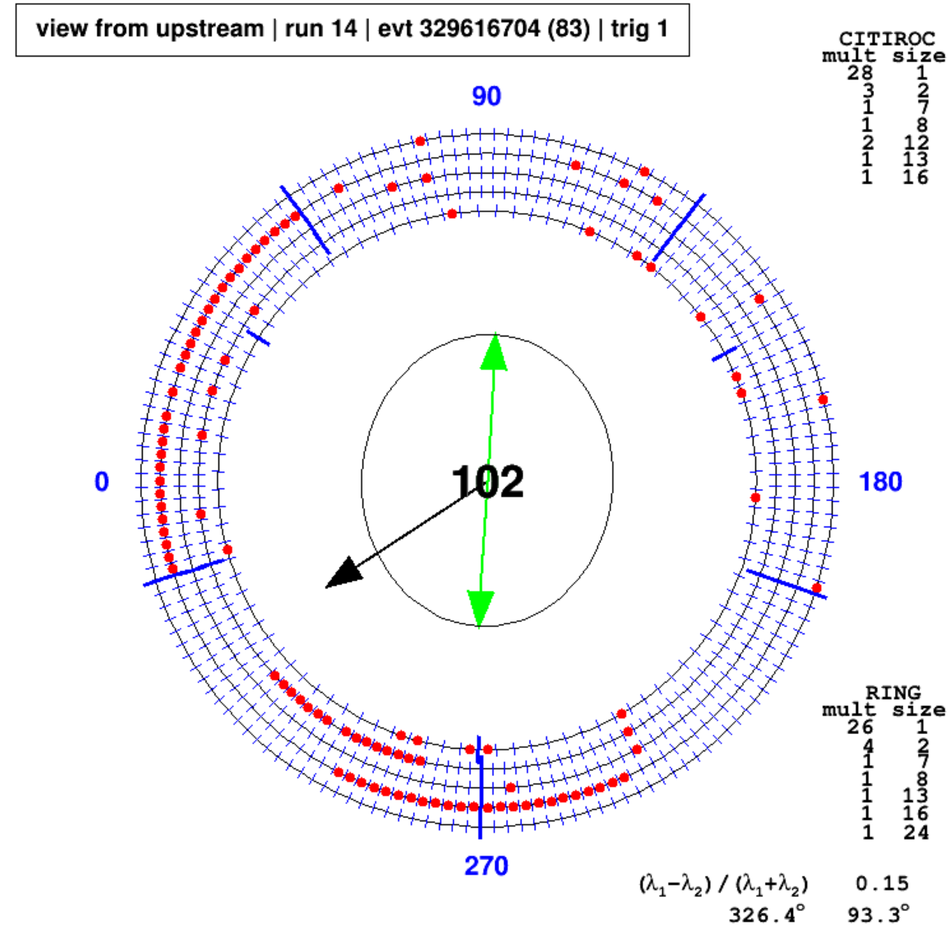


Cross-talks

“normal” event

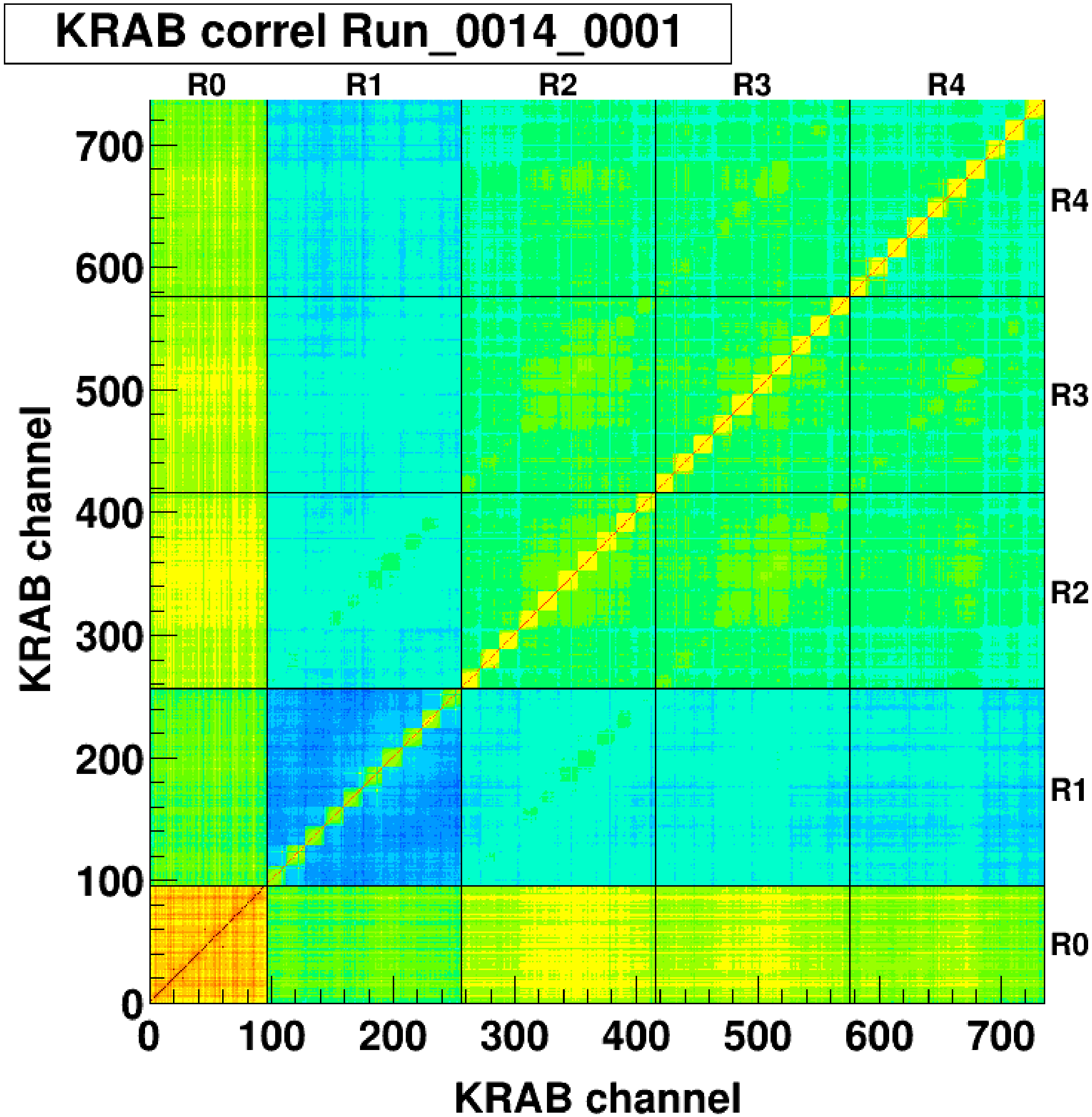


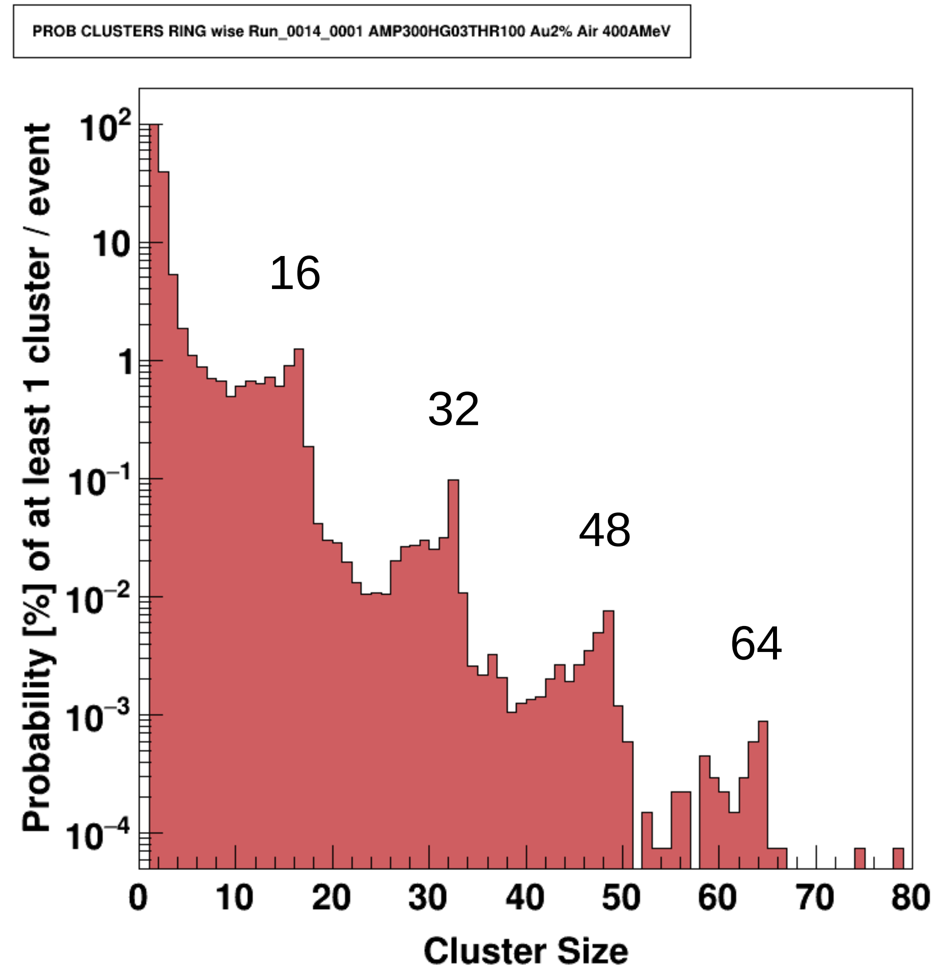
“cross-talk” event



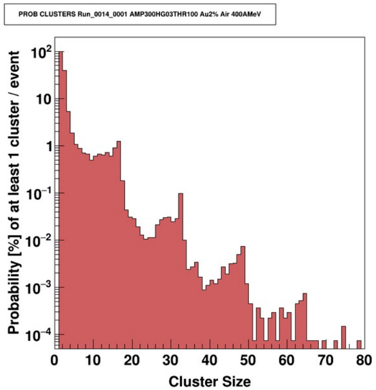
Cross-talks, only KRAB data extracted from LMDs

"AMP300HG03THR100 Au2% Air 400AMeV" ←"high gain" setting → good for cosmics



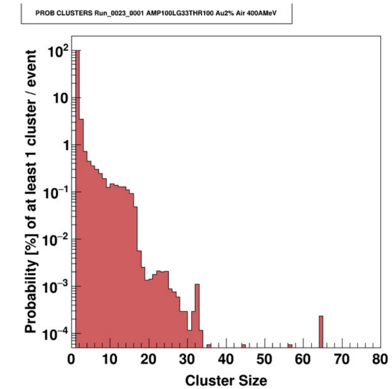


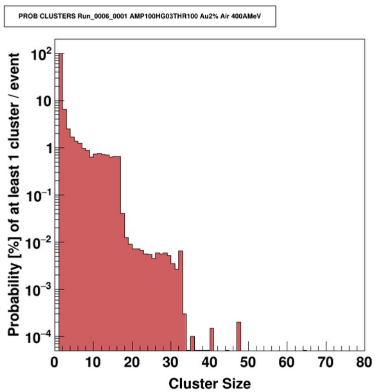
CLUSTER MULTIPLICITIES



RUN 14 "**AMP300HG03**THR100 Au2% Air 400AMeV"

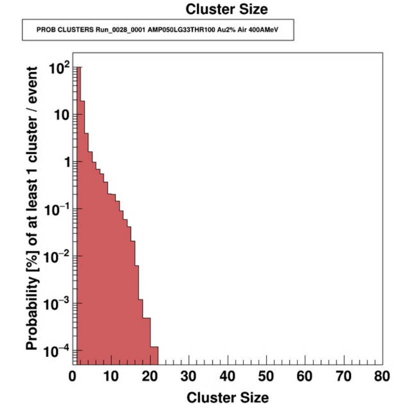
RUN 23 "**AMP100LG33**THR100 Au2% Air 400AMeV"

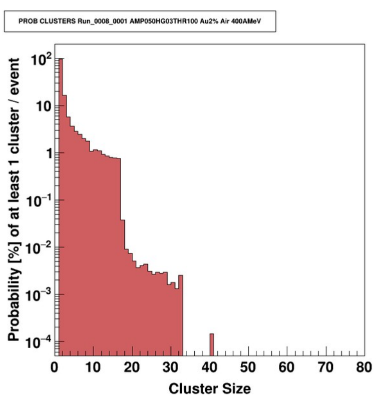




RUN 6 "**AMP100HG03**THR100 Au2% Air 400AMeV"

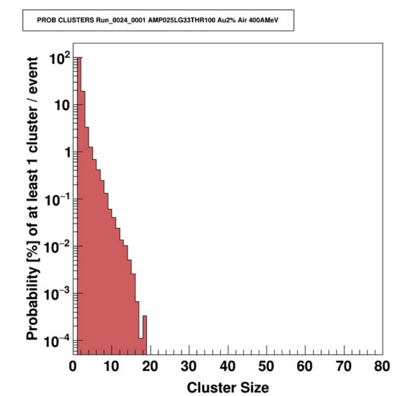
RUN 28 "**AMP050LG33**THR100 Au2% Air 400AMeV"

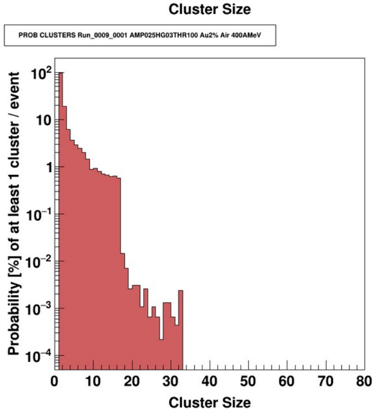




RUN 8 "**AMP050HG03**THR100 Au2% Air 400AMeV"

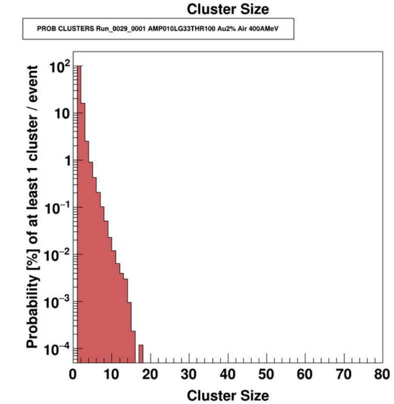
RUN 24 "**AMP025LG33**THR100 Au2% Air 400AMeV"





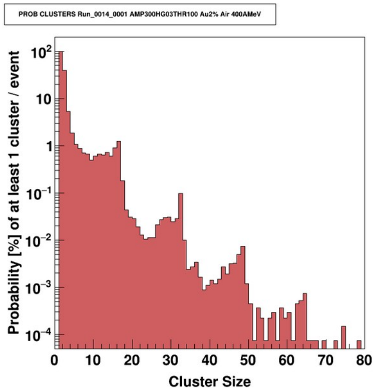
RUN 9 "**AMP025HG03**THR100 Au2% Air 400AMeV"

RUN 29 "**AMP010LG33**THR100 Au2% Air 400AMeV"

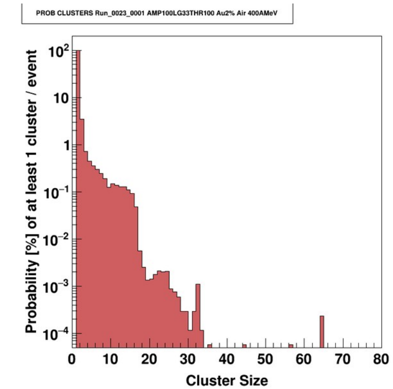


CLUSTER MULTIPLICITIES

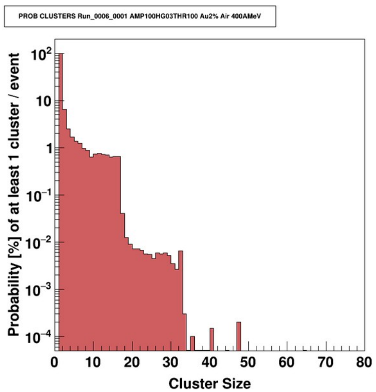
RUN 14 "**AMP300HG03**THR100 Au2% Air 400AMeV"



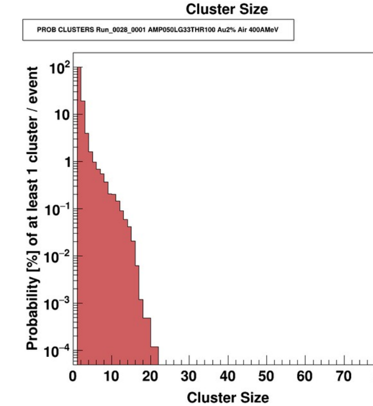
RUN 23 "**AMP100LG33**THR100 Au2% Air 400AMeV"



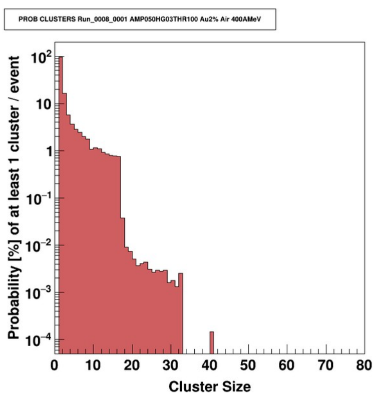
RUN 6 "**AMP100HG03**THR100 Au2% Air 400AMeV"



RUN 28 "**AMP050LG33**THR100 Au2% Air 400AMeV"

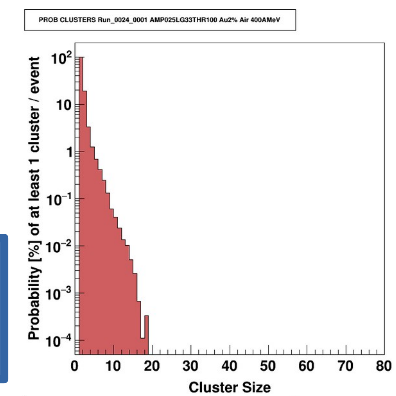


RUN 8 "**AMP050HG03**THR100 Au2% Air 400AMeV"



these settings were taken as "optimal"

RUN 24 "**AMP025LG33**THR100 Au2% Air 400AMeV"



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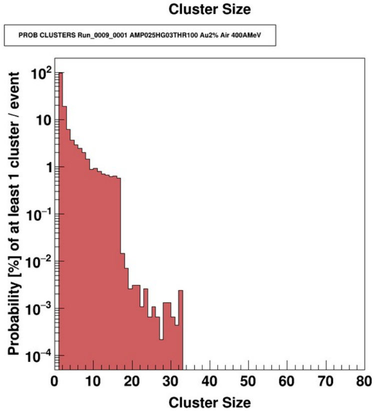

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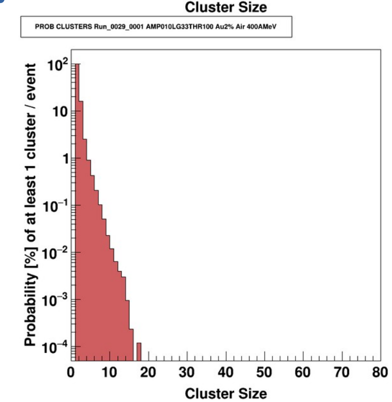
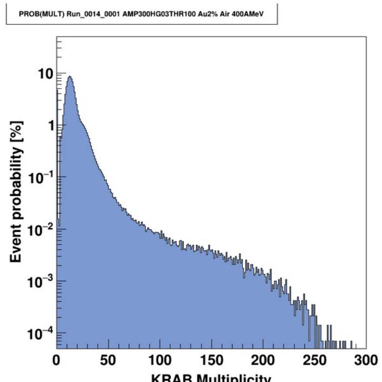


KRAB EVENT MULTIPLICITIES



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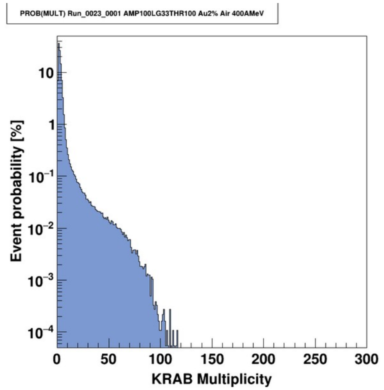

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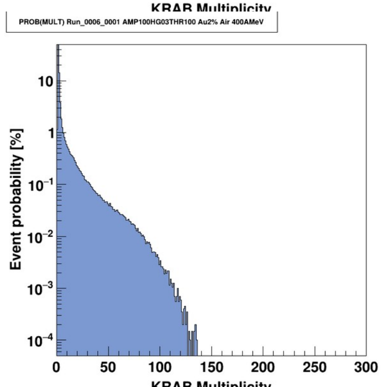

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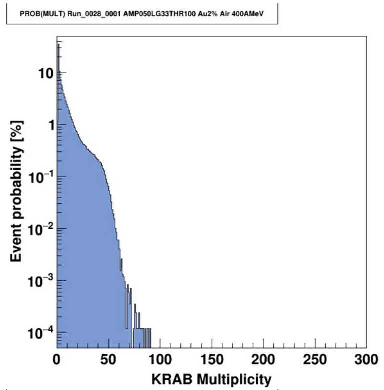

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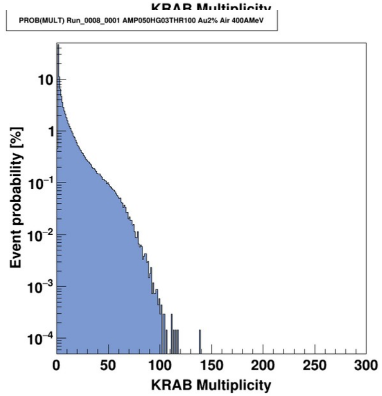

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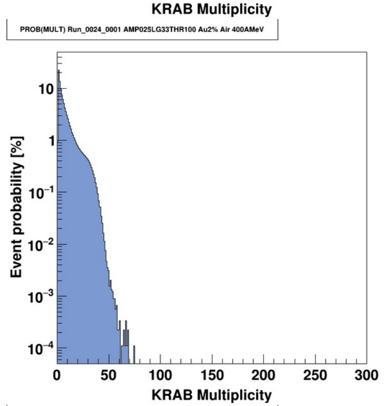

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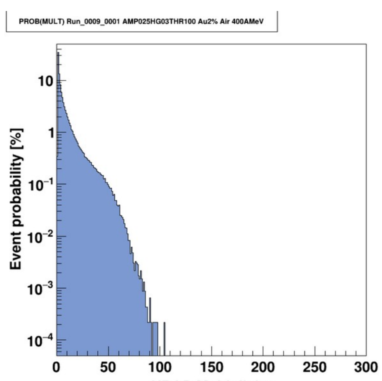

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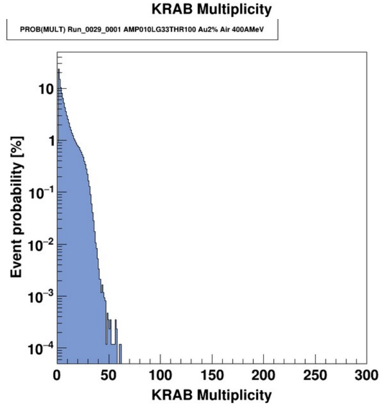


RUN 29 "**AMP010LG33**THR100 Au2% Air 400AMeV"

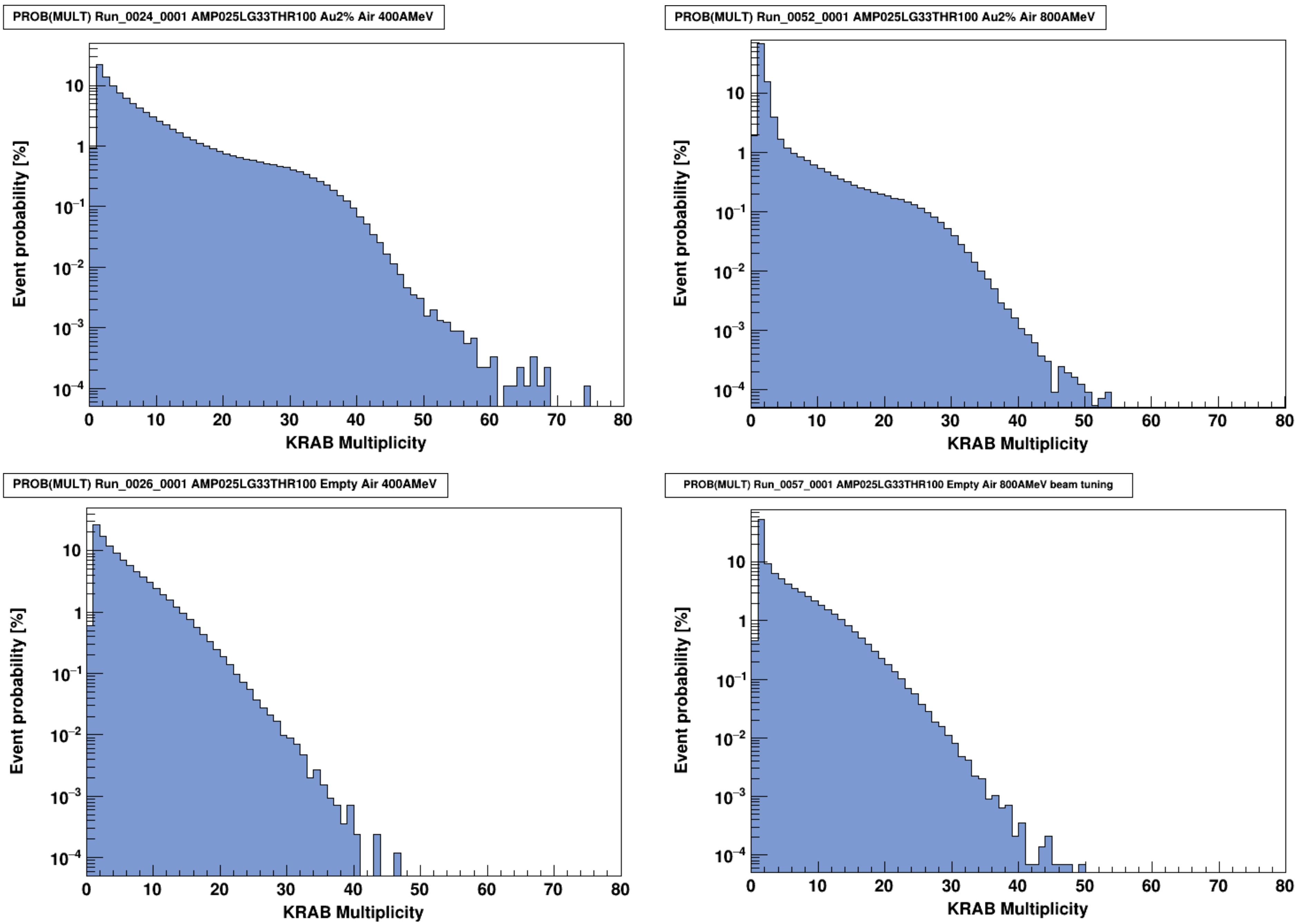
400 AMeV

Reasonable multiplicity distributions for “low-gain high-thresholds” setting

800 AMeV

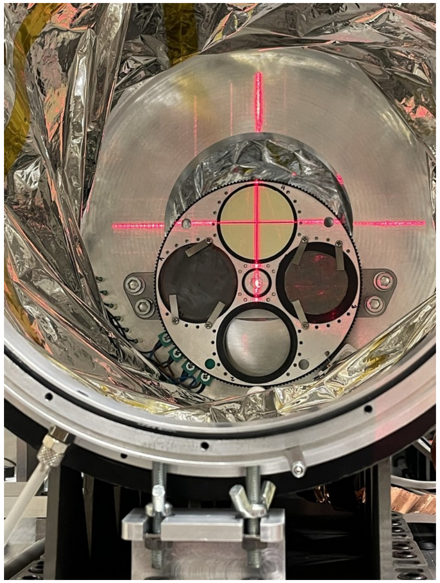
Au 2%

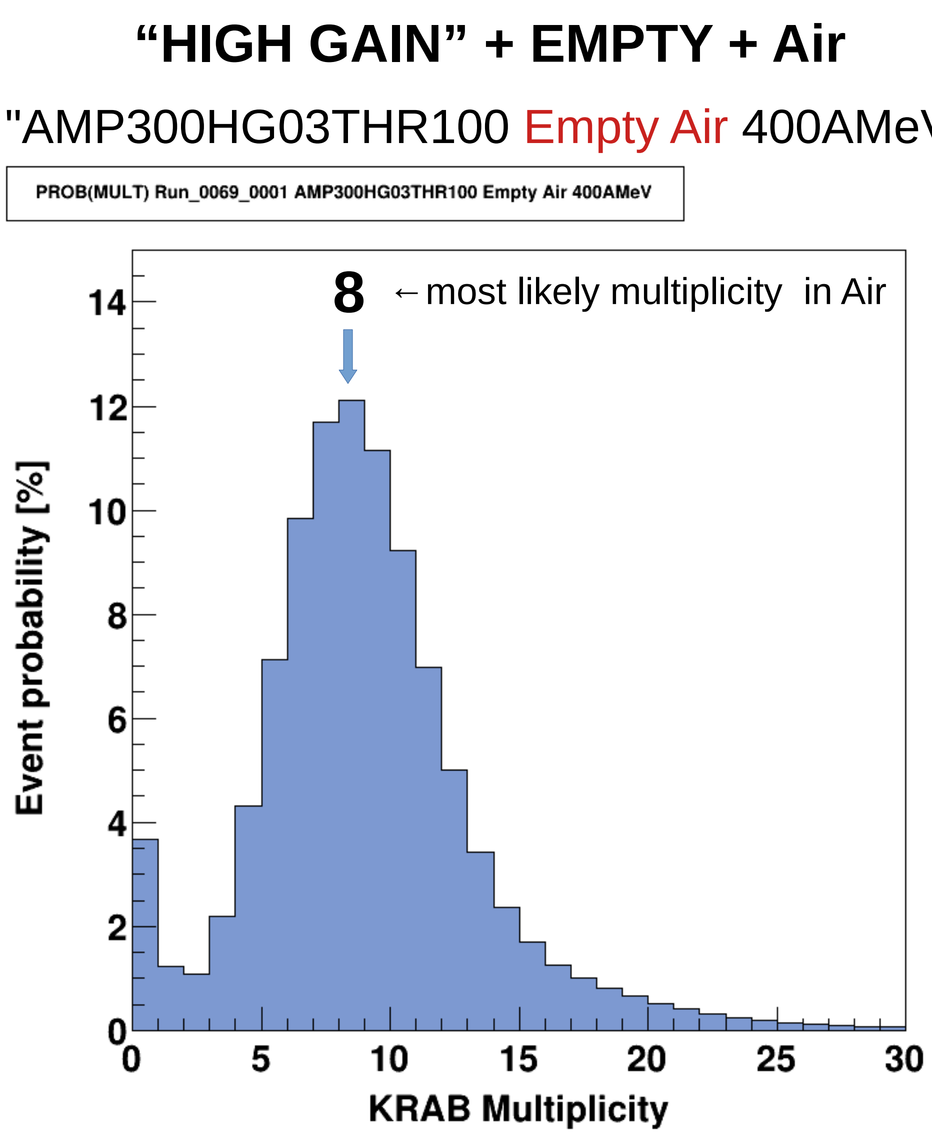
Empty

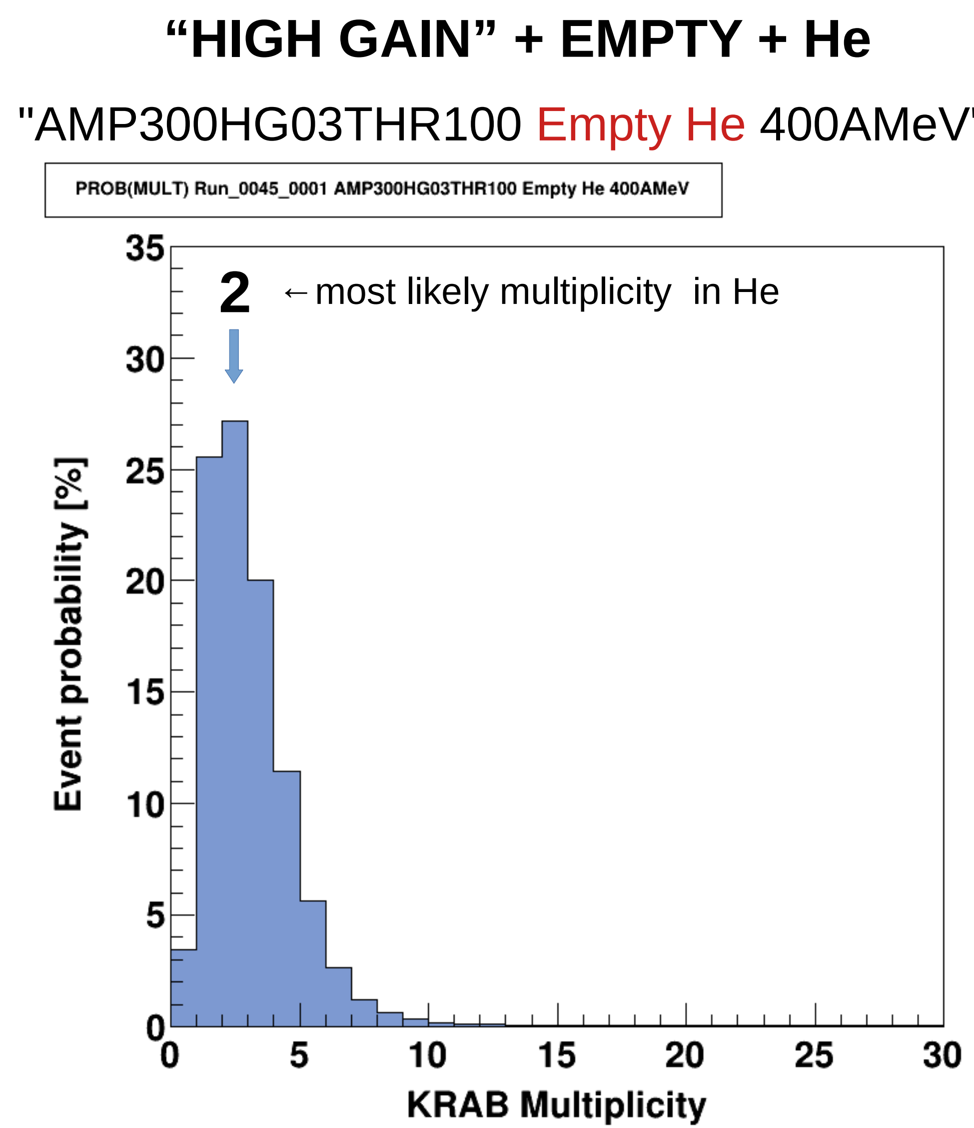


Helium effect

construction of a “helium sleeve”
to suppress the reactions along the beam path and δ-electron production







Most likely multiplicity reduced by a factor of 4 in He

ratio of trigger rates

66.7%(Air) / 16.7%(He) = 4 ← He effect ??? δ-electrons ?

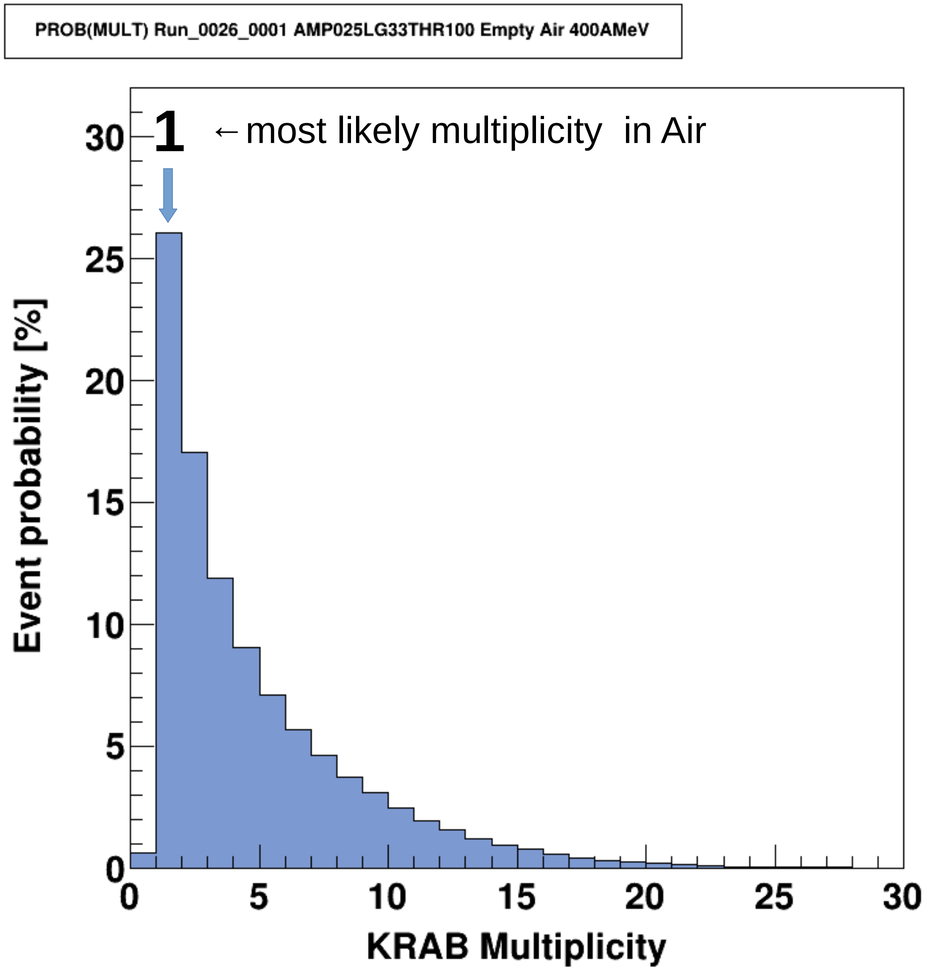
for "high gain" settings

Trigger rate reduced by a factor of 4 in He

But these "high gain" settings will not be used during the experiment

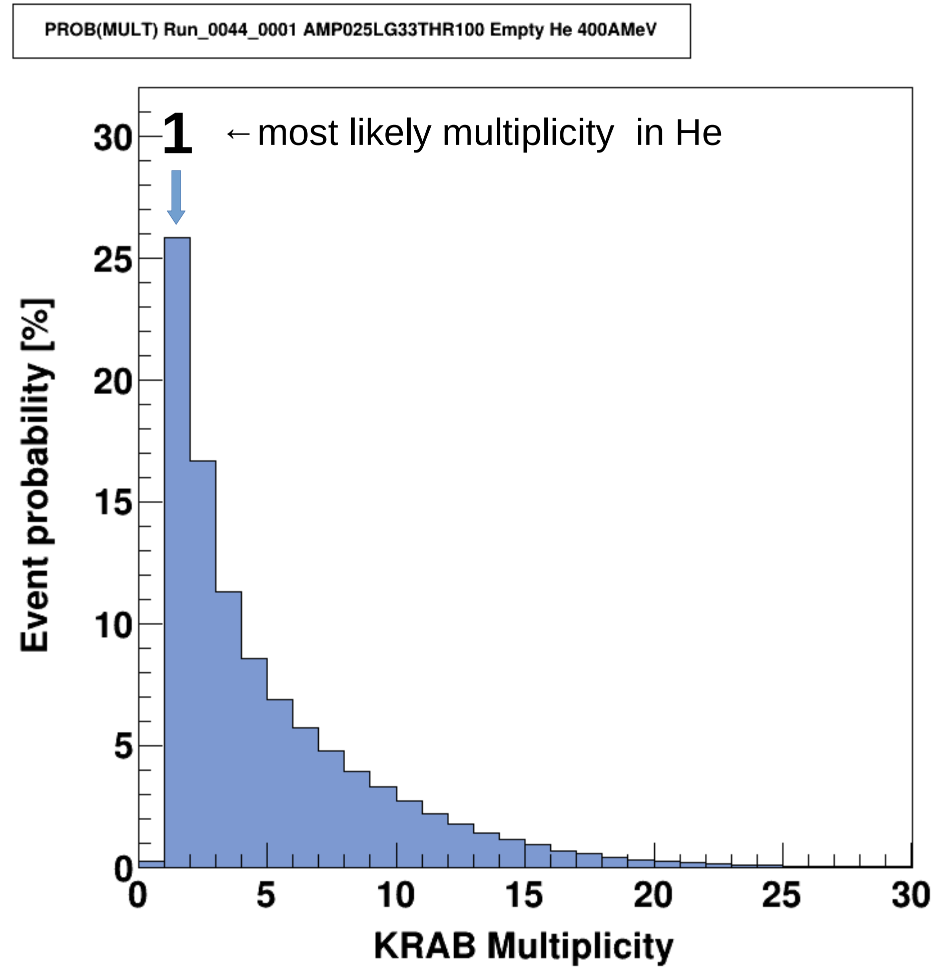
“LOW GAIN” + EMPTY + Air

"AMP025LG33THR100 Empty Air 400AMeV"



“LOW GAIN” + EMPTY + He

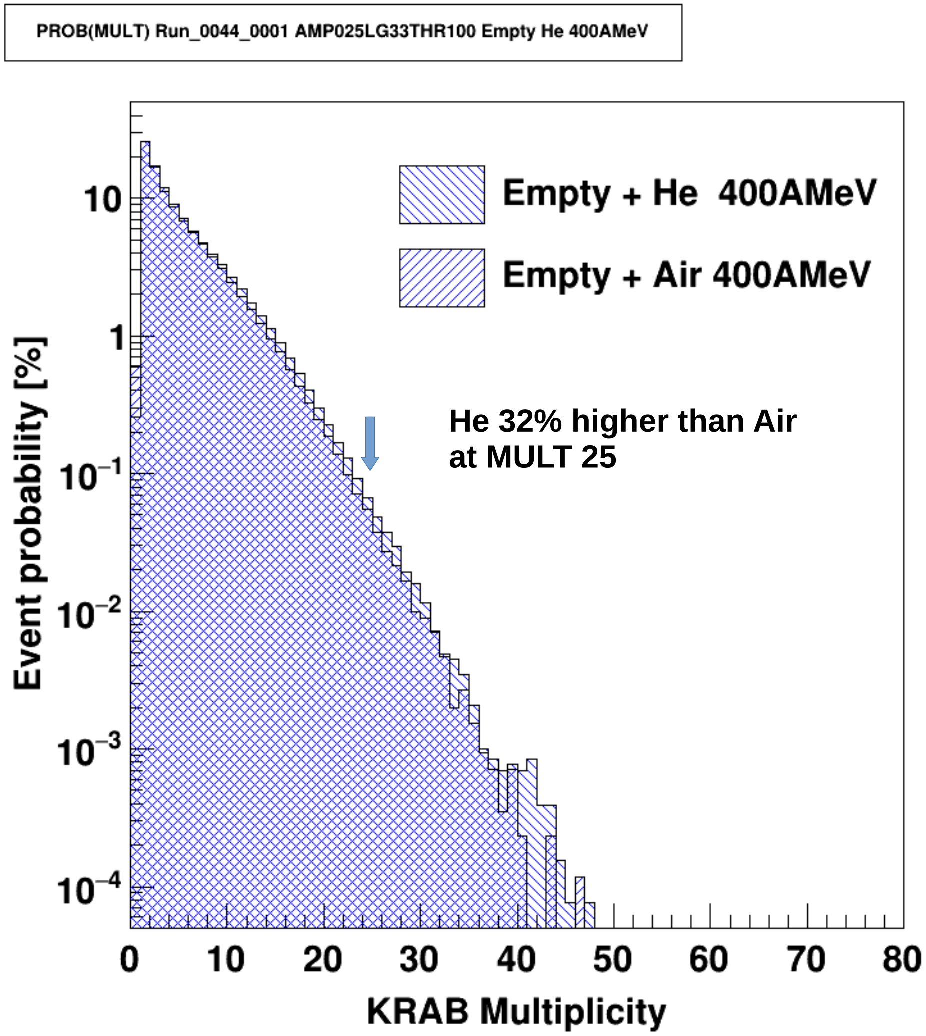
"AMP025LG33THR100 Empty He 400AMeV"



Most likely multiplicity and distributions are almost identical for LOW GAIN settings

Setting the He sleeve not worth the effort ???

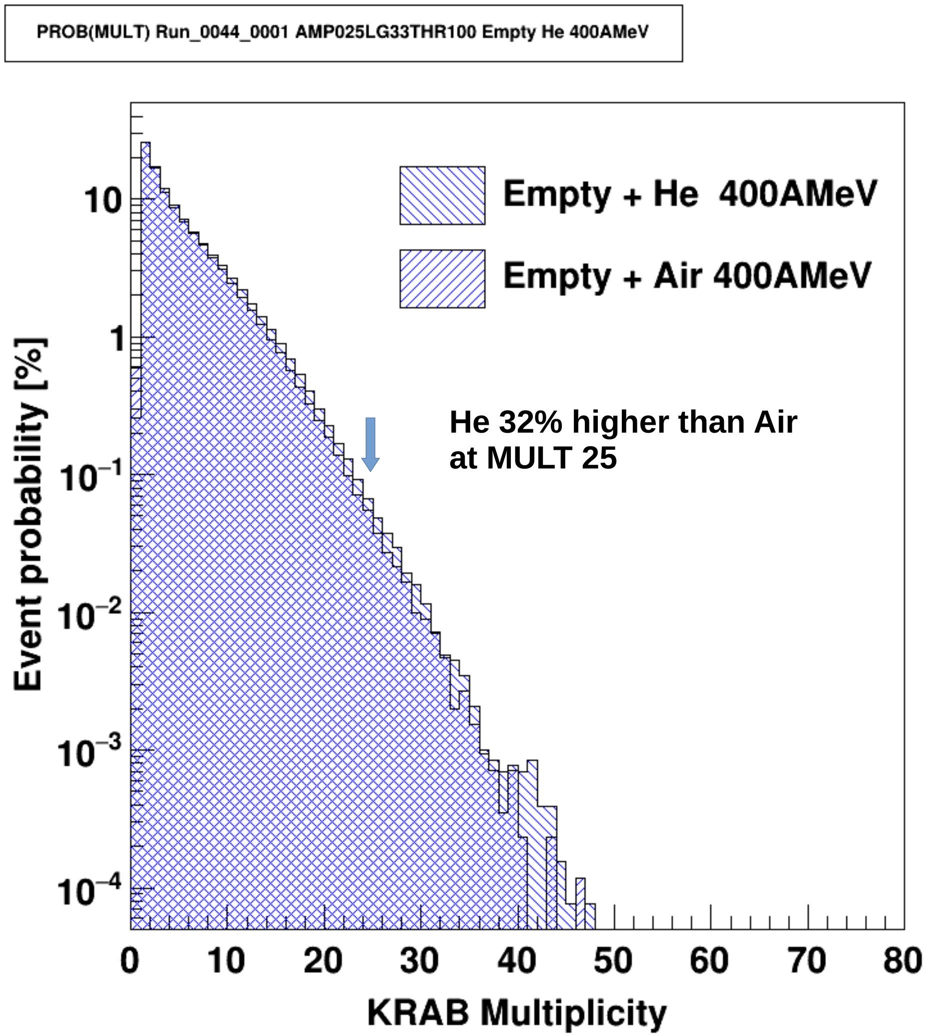
"AMP025LG33THR100 Empty He 400AMeV"
and
"AMP025LG33THR100 Empty Air 400AMeV"
superposed:




```
400 AMeV Au beam interaction probability
on He  →  1.77%                (MULT≥1)          ←reduction from 16.7%   by changing biases and gains
on Air →  2.18%                                  ←reduction from 66.7%

2.18/1.77 = 1.23 ← He effect ???
                    δ-electrons + reactions ?
for "preferred" settings without target
```

"AMP025LG33THR100 Empty He 400AMeV"
and
"AMP025LG33THR100 Empty Air 400AMeV"
superposed:

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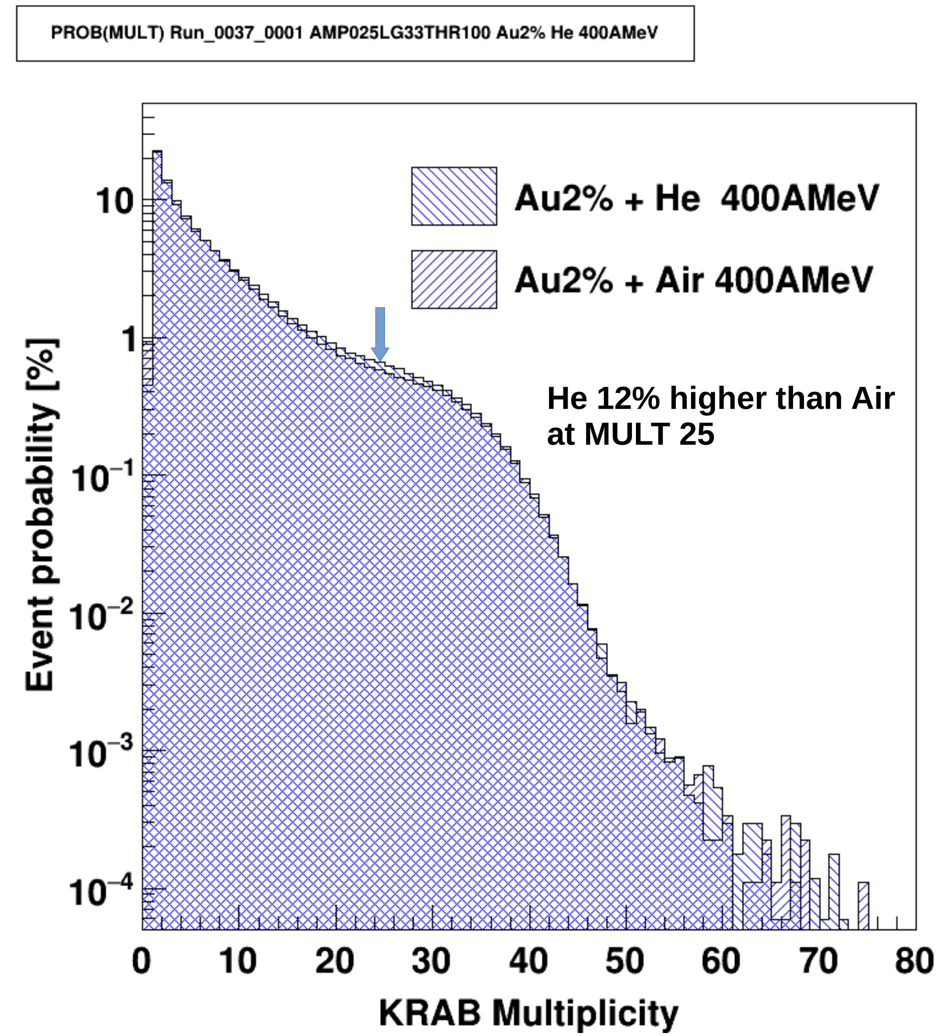
400 AMeV Au beam interaction probability
on He  →  1.77%                (MULT≥1)
on Air →  2.18%

2.18/1.77 = 1.23 ← He effect ???
                   δ-electrons + reactions ?
for "preferred" settings without target
```

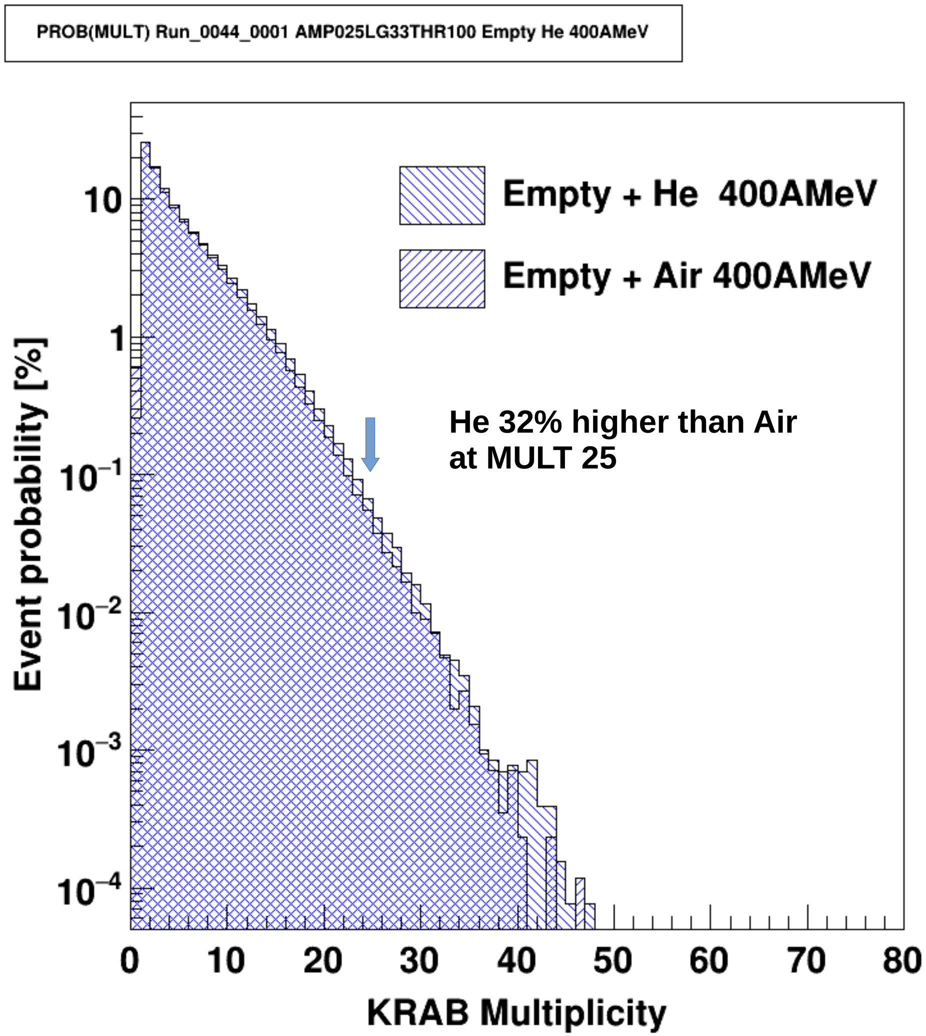
"AMP025LG33THR100 Au2% He 400AMeV"
and
"AMP025LG33THR100 Au2% Air 400AMeV"
superposed:



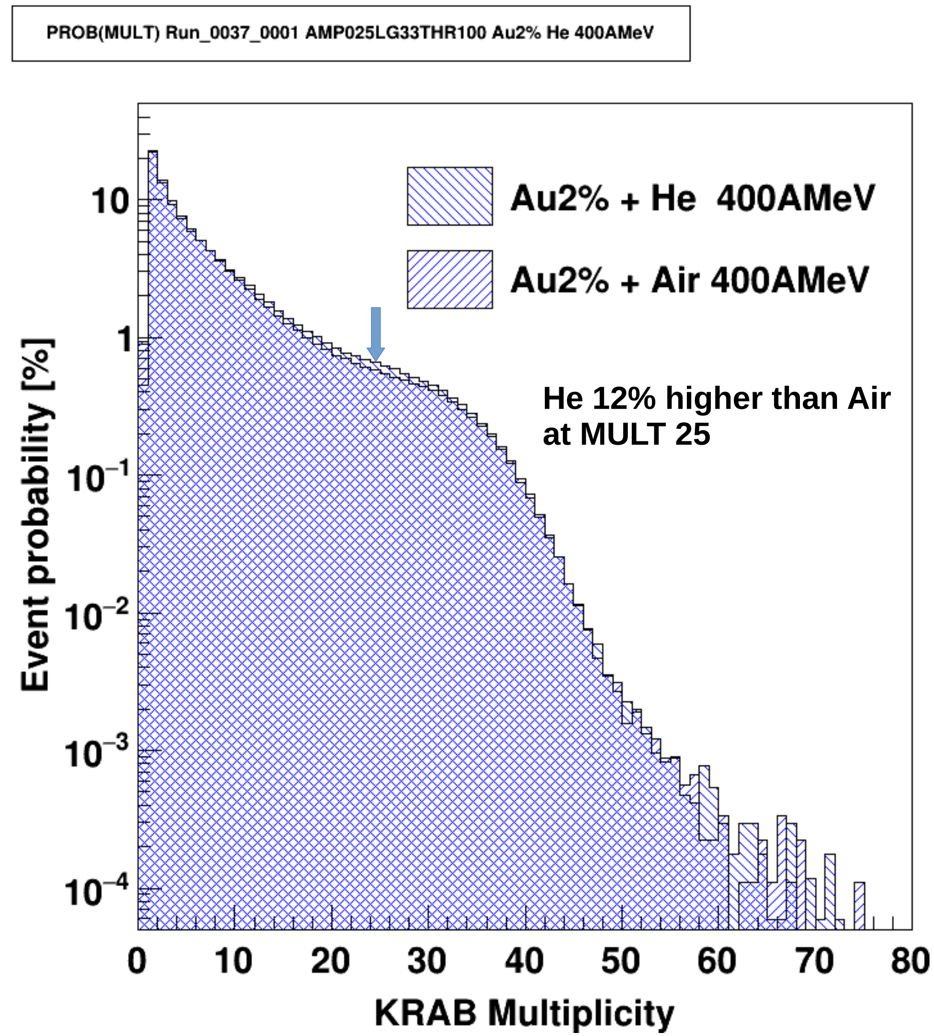

```
400 AMeV Au beam interaction probability
on 2%Au+He  →  3.30%
on 2%Au+Air →  3.77%

3.77/3.30 = 1.14 ← He effect ???
                   δ-electrons + reactions ?
for "preferred" settings with 2% Au target
```

"AMP025LG33THR100 Empty He 400AMeV"
and
"AMP025LG33THR100 Empty Air 400AMeV"
superposed:



"AMP025LG33THR100 Au2% He 400AMeV"
and
"AMP025LG33THR100 Au2% Air 400AMeV"
superposed:




```
400 AMeV Au beam interaction probability
on He  →  1.77%                 (MULT≥1)
on Air →  2.18%
```

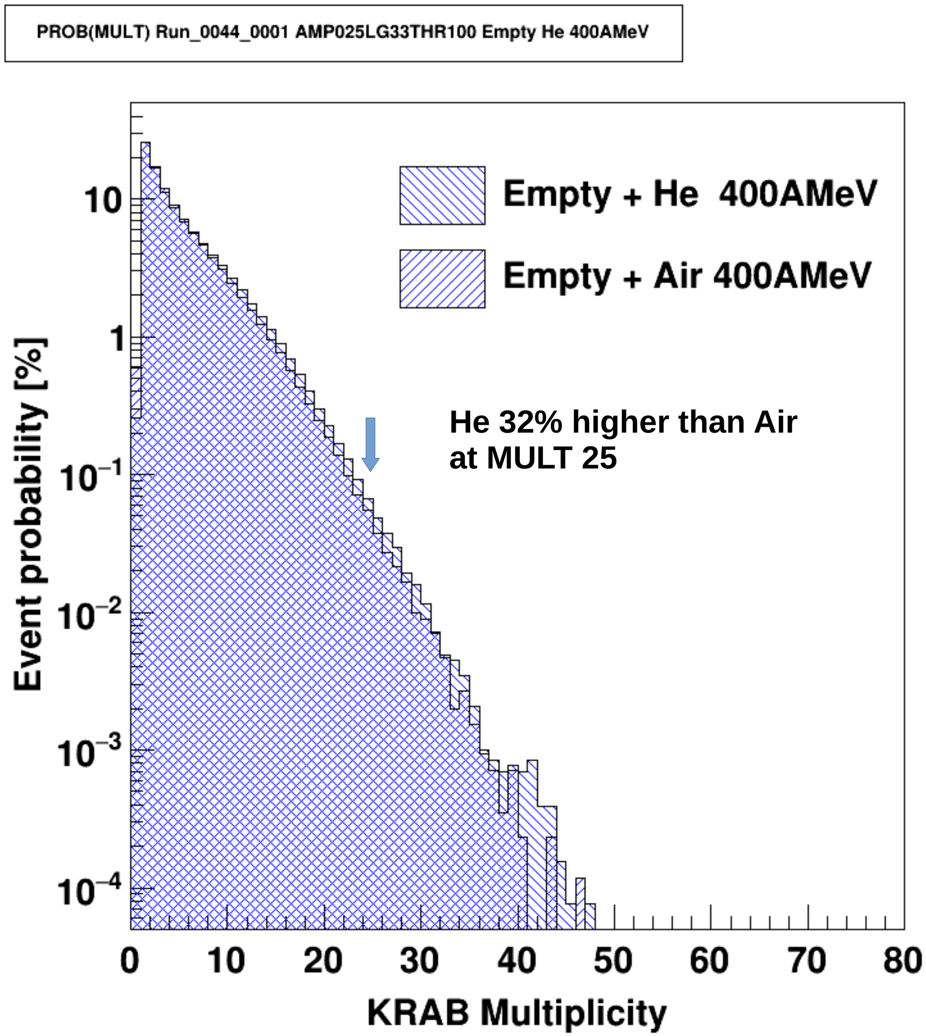
```
400 AMeV Au beam interaction probability
on 2%Au+He  →  3.30%
on 2%Au+Air →  3.77%
```

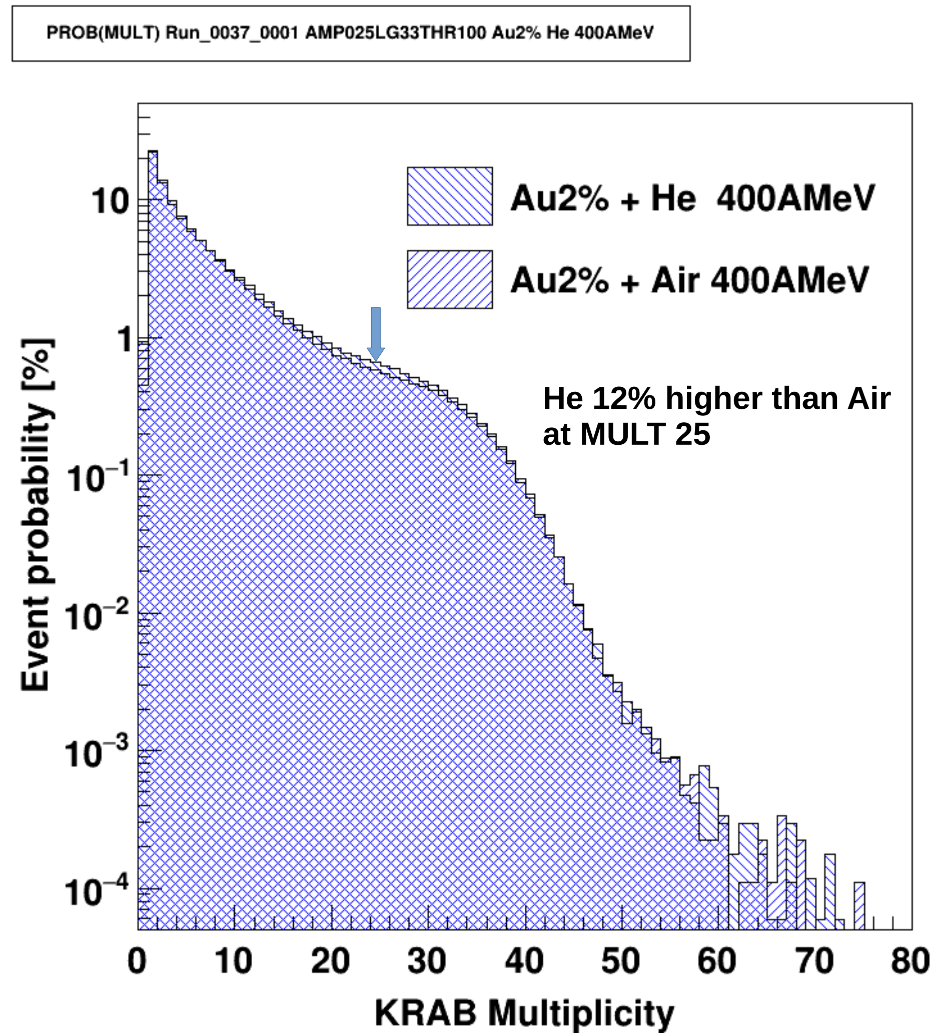
```
He:  3.30 – 1.77 = 1.53
Air: 3.77 – 2.18 = 1.59
```

```
the “2%” target becomes in fact a ~1.5-1.6%
target for these KRAB settings (KRAB is blind
for the most peripheral collisions for MULT 1)
```

"AMP025LG33THR100 Empty He 400AMeV"
and
"AMP025LG33THR100 Empty Air 400AMeV"
superposed:

"AMP025LG33THR100 Au2% He 400AMeV"
and
"AMP025LG33THR100 Au2% Air 400AMeV"
superposed:






```
400 AMeV Au beam interaction probability
on He  →  1.77%                          (MULT≥1)
on Air →  2.18%
```

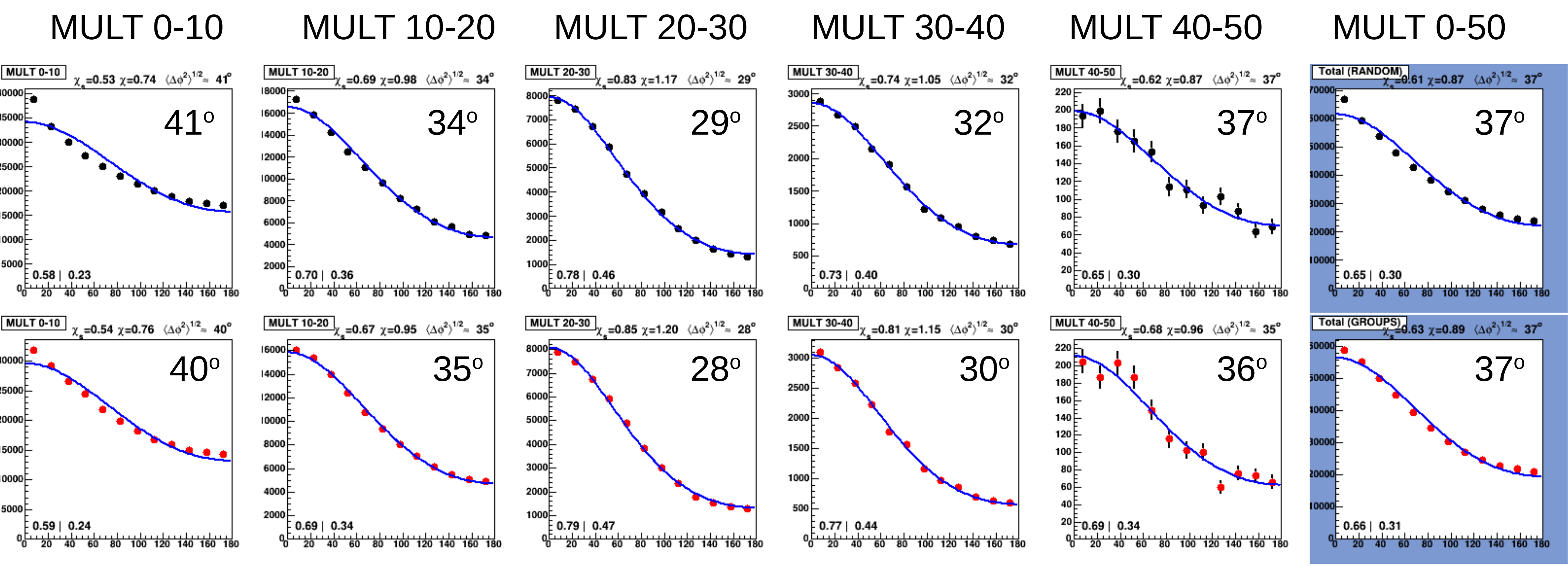
```
400 AMeV Au beam interaction probability
on 2%Au+He  →  3.30%
on 2%Au+Air →  3.77%
```

With proper SiPM bias, CITIROC preamp gain and CITIROC discriminator threshold settings in KRAB the effect of He on reducing the off target reaction rate and suppressing the δ-electron hits compared to Air is on the level of 10-20% ➡ is it worth the effort?

Reaction plane resolution for different MULT bins (Ollitrault)

Δφ for reaction planes for random (top) and ring group (bottom) sub-events

RUN 24 "**AMP025LG33**THR100 Au2% Air 400AMeV" 400 AMeV



Δφ [0-180°]

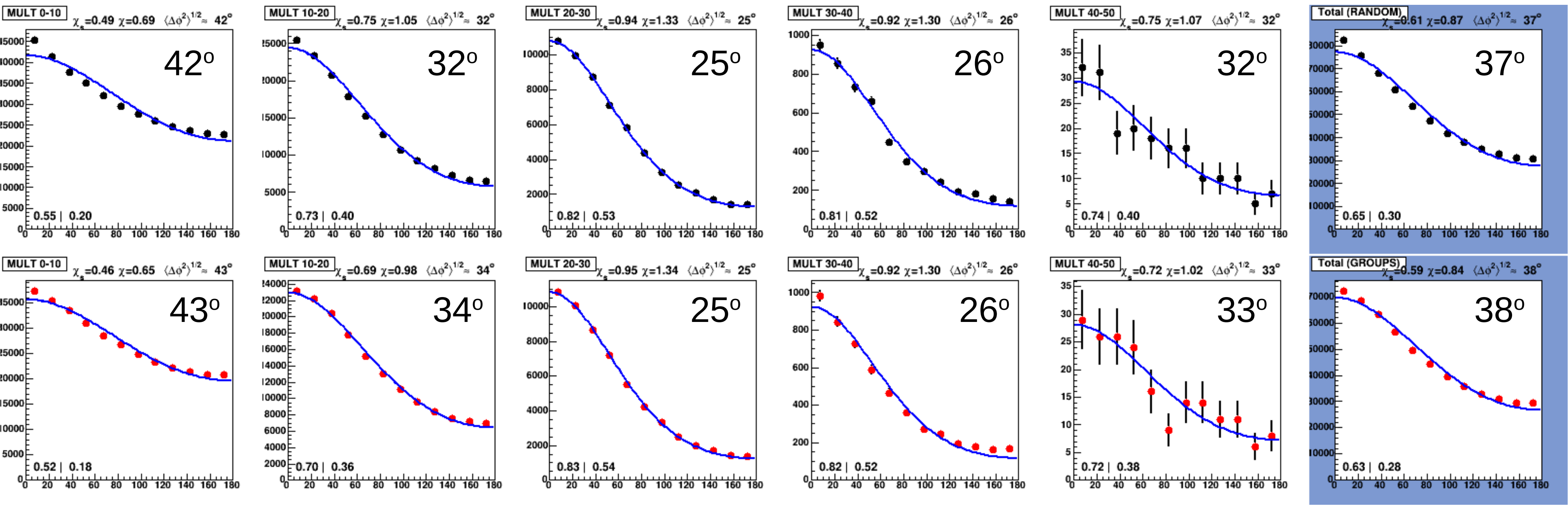
the numbers in each panel represent standard deviations of the underlying "true" distribution of the reaction plane.

Reaction plane resolution for different MULT bins (Ollitrault)

Δφ for reaction planes for random (top) and ring group (bottom) sub-events

RUN 52 "**AMP025LG33**THR100 Au2% Air 800AMeV" 800 AMeV

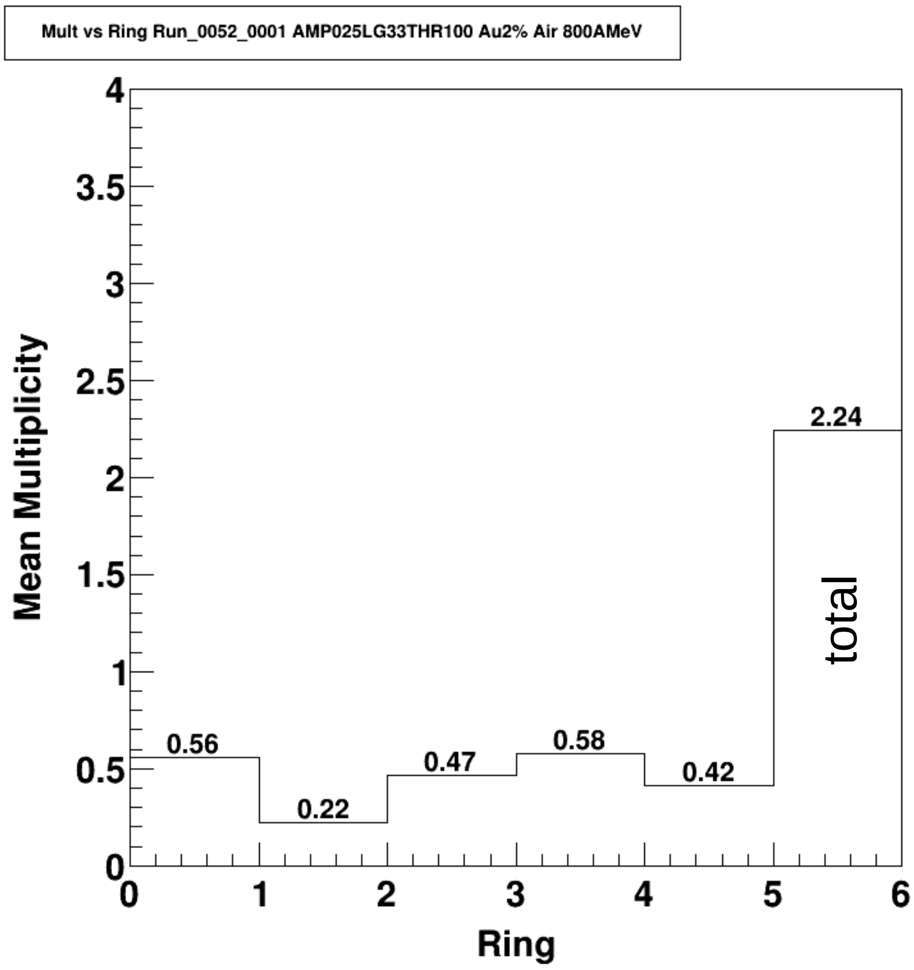
MULT 0-10 MULT 10-20 MULT 20-30 MULT 30-40 MULT 40-50 MULT 0-50



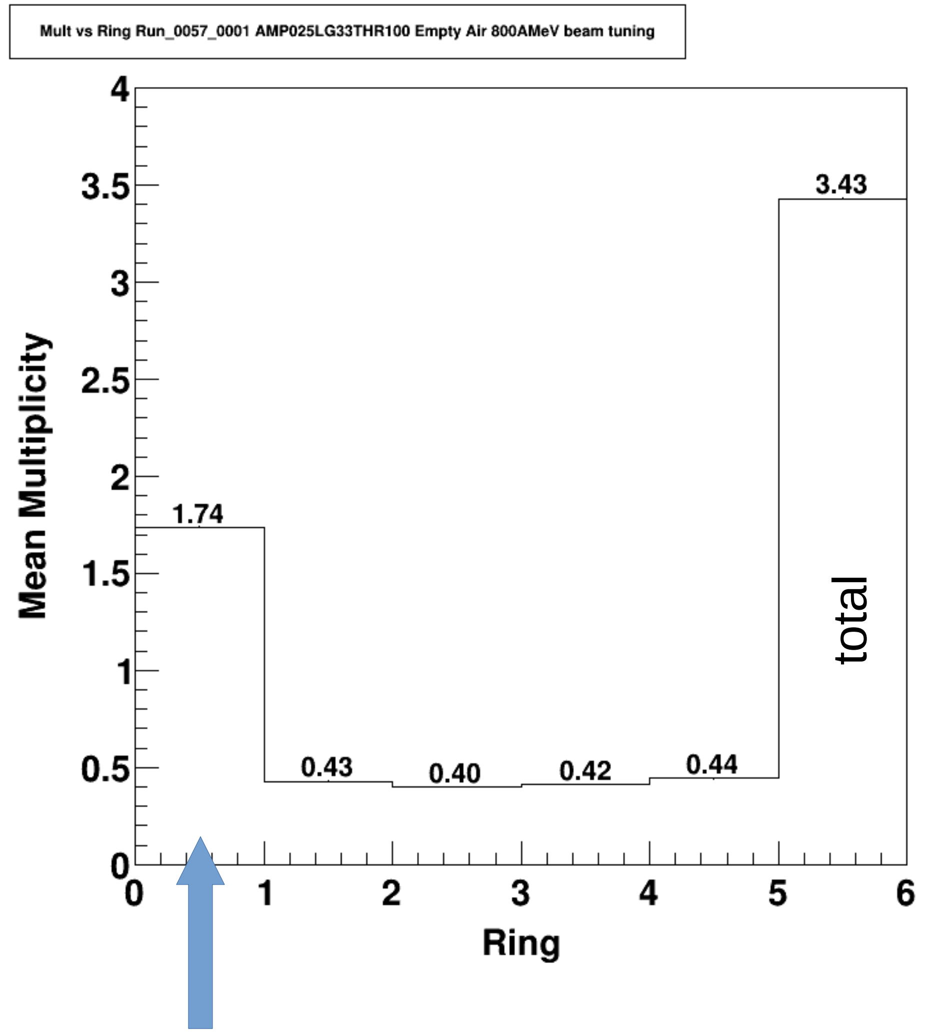
Δφ [0-180°]

Discrimination of off-target events with KRAB

Au 2% + Air

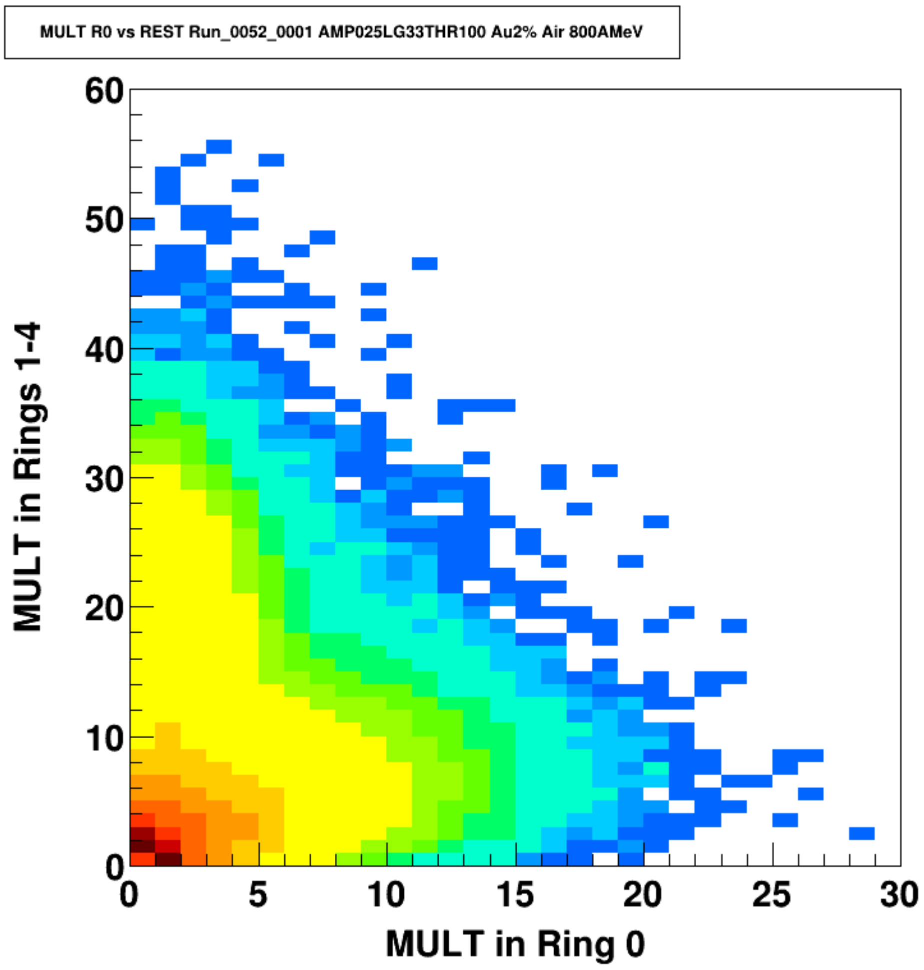


Empty + Air

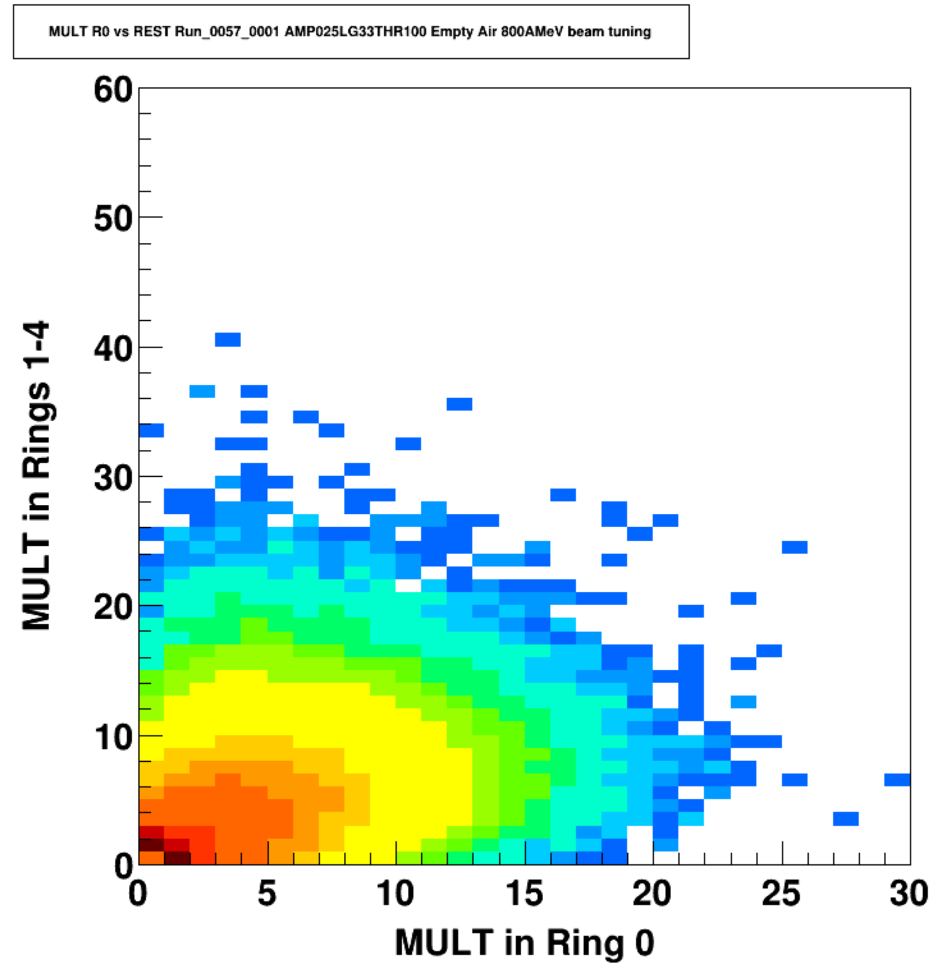


Without target, backward ring (RING 0) counts ~3 x more than forward ones

Au 2% + Air



Empty + Air



Summary & Conclusions

- The 3 so far relativistic heavy ion measurements provide the expectations for the R_{NS} close to the upper limit of the LMXB inferences and of the LIGO/VIRGO constraints but are well compatible with the NICER results.

- More precise measurements are needed up to ~1 AGeV to explore the Symmetry Energy at densities up to ~2 ρ_0. ASY-EOS II measurement is scheduled for March 2025 at GSI within R3B infrastructure. Improved resolutions and sensitivity to higher densities are anticipated with the use of NeuLAND, KRAB and TOFDs.

- KRAB detector has passed the commissioning heavy ion test in conditions close to the experimental ones with the cross-talks under control. It will:
  - provide fast multiplicity trigger (~50 ns after reaction for MULT 1)
  - provide precise centrality estimates through multiplicities
  - provide additional estimates of the reaction plane azimuth
  - allow for discrimination of off target reactions
  - be weakly sensitive to δ-electrons
  - be transparent to neutrons