FIRST Fragmentation of Ions Relevant for Space and Therapy EXPERIMENT

Monte Carlo Simulation of the Full Experimental Set-up

-

Introduction, Status Report, and First Studies

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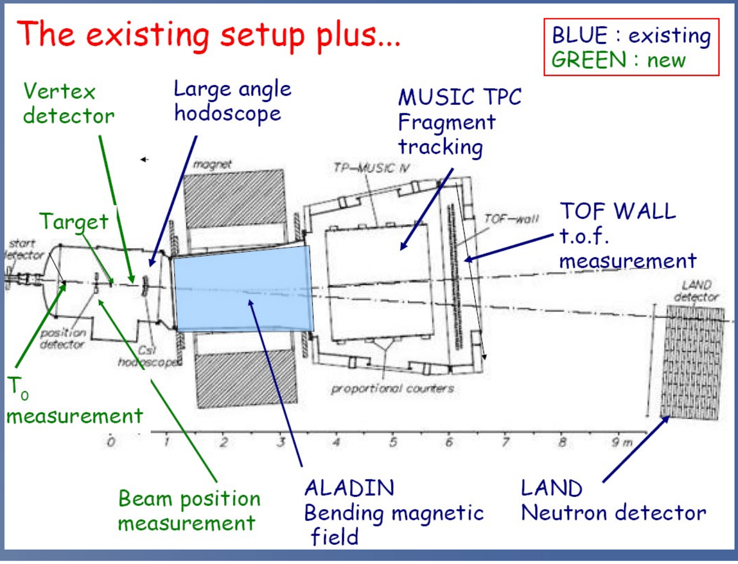
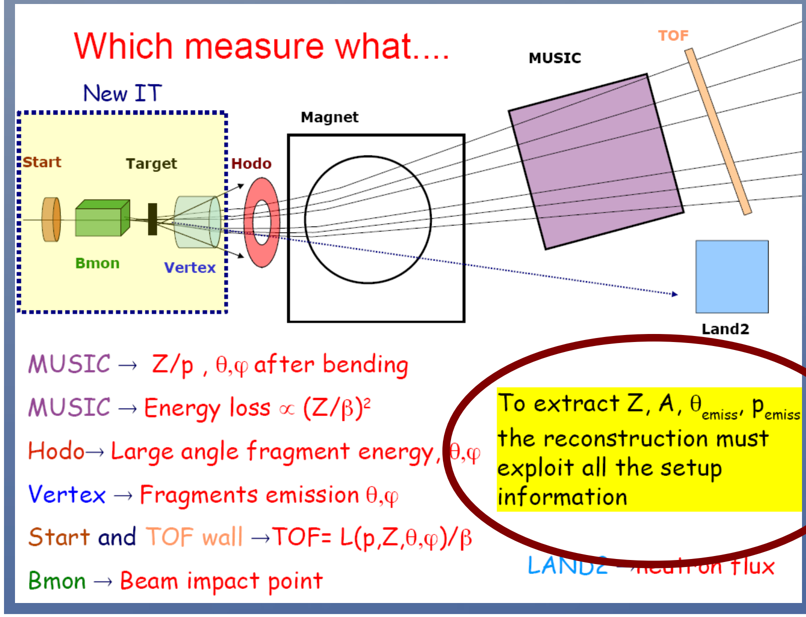
Content

FIRST Fragmentation of Ions Relevant for Space and Therapy EXPERIMENT

Scope and Objectives

It's a patchwork set-up ...





MC Simulation of Full Set-up

addresses:

- design decisions
- set-up optimization
- training reconstruction code
- efficiencies and systematic evaluation

Scope and Objectives

MC Simulation

MC code

FLUKA

Goals

Team

Vincenzo Patera (ROMA1/LNF),
Cristina Morone (ROMA2),
Till Böhlen (CERN)

Objectives:

- implementation of **entire FIRST set-up**
  - including all detectors and relevant set-up geometry
  - first as skeleton – later refined
- simulation of **detector responses** (together with software reconstruction team (Alessio Sarti (LNF)+?))
  - same reconstruction software for measurements and simulation

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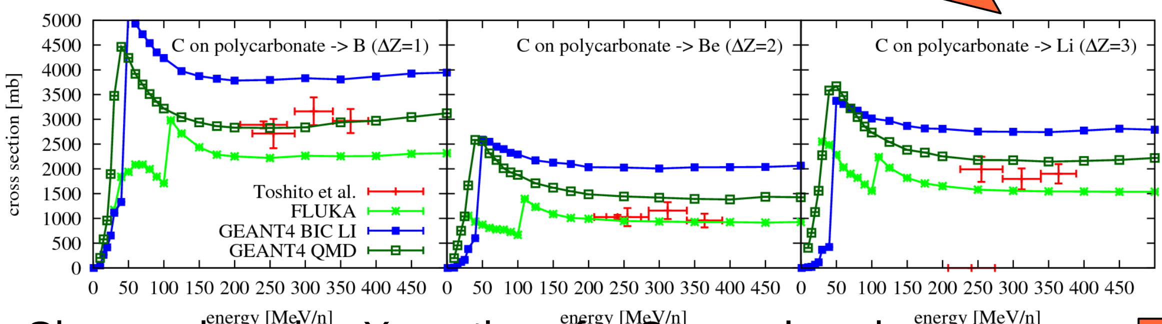
Reliability of MC ?

MC Simulation

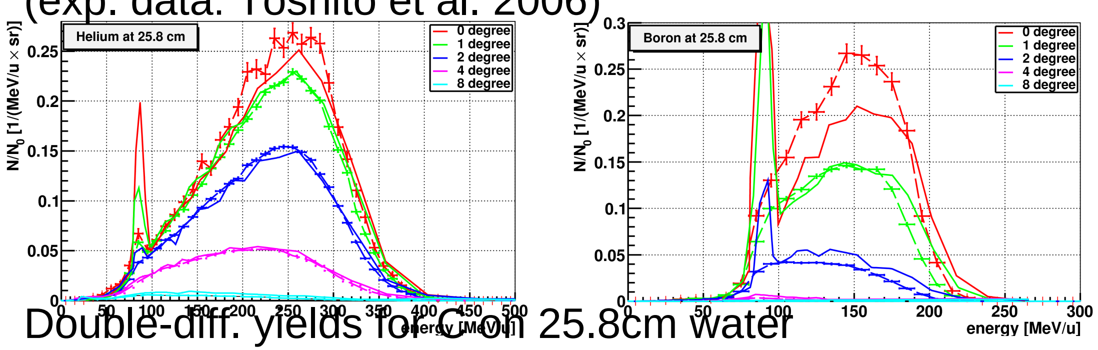
Accuracy?

FLUKA

Validation



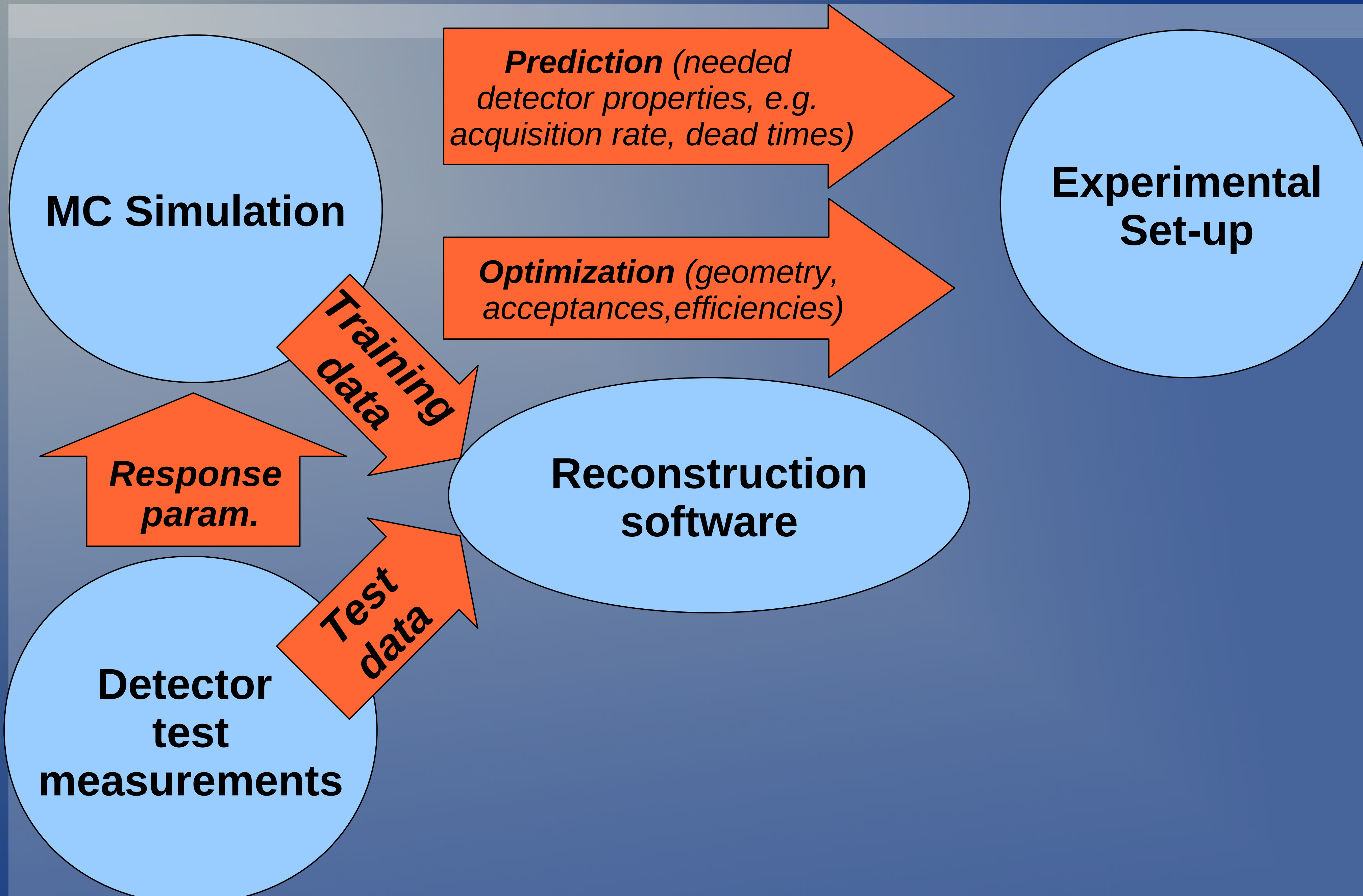
Charge-changing X-sections for C on polycarbonate (exp. data: Toshito et al. 2006)



Double-diff. yields for C on 25.8cm water (exp. data: Haettner 2006)

- benchmarked with some fragmentation data – but limited!
- only gives rule of thumb indication of fragmentation physics
- but gives a feeling for distributions, acceptances and efficiencies

1 Preparatory Stage



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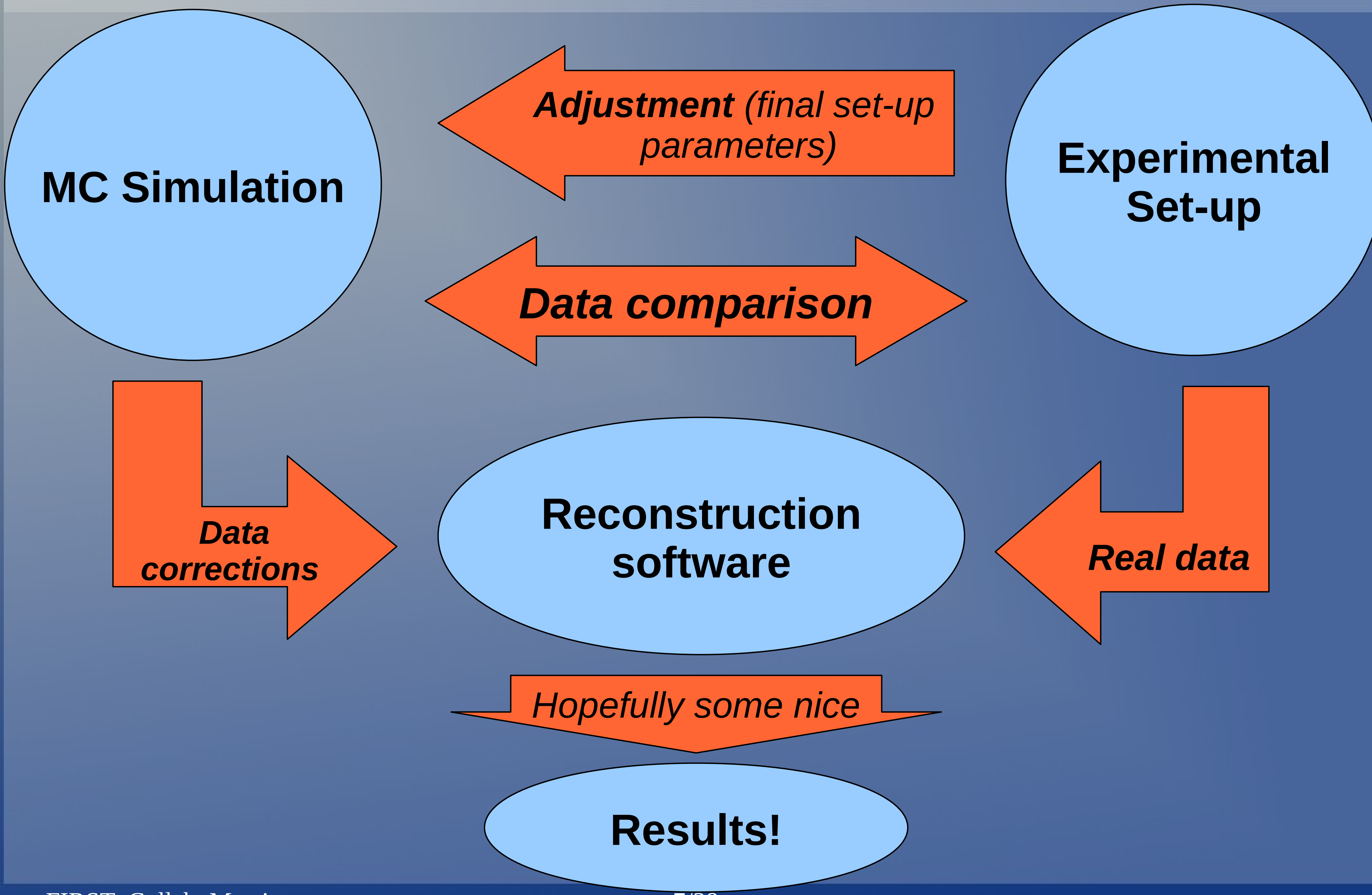
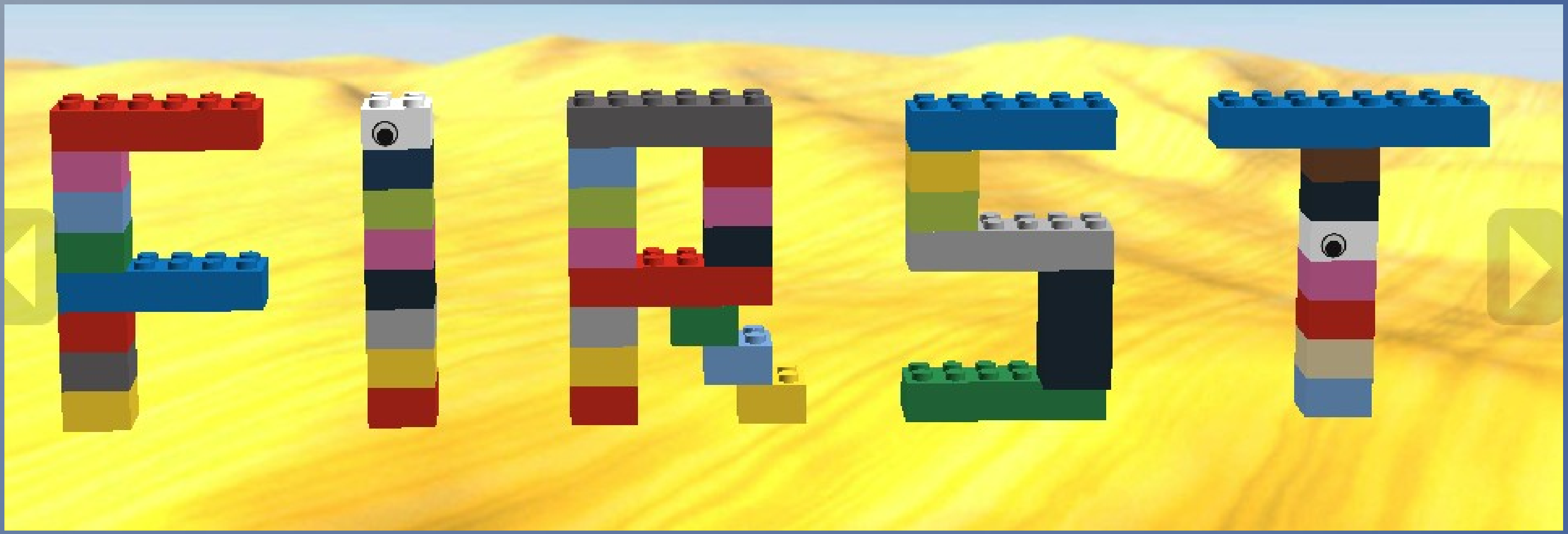
2 Stage with Exp. Data



Structure and Status



initial modeling trial (by Vincenzo)

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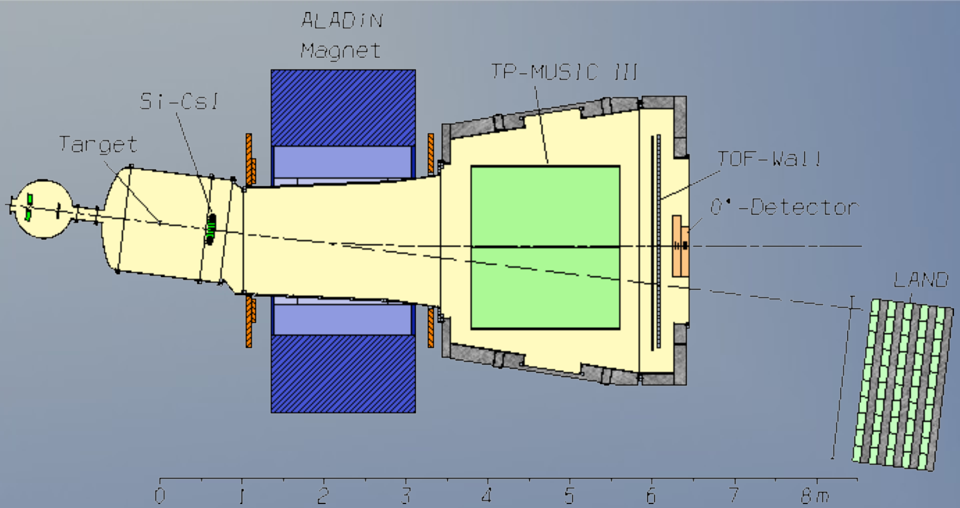
Structure and Status



Generalities:

- Set-up of large detectors oriented on SPALADiN geometry
  - distances and angles between detectors (7.7°)
- Tracks of all particles in set-up scored
  - to calculate detector response
  - No EM particle tracks scored for the moment

- FLUKA version 2008.3 + BME, using HADROTHErapy defaults
- For the moment disregarding delta-rays (high cut values)

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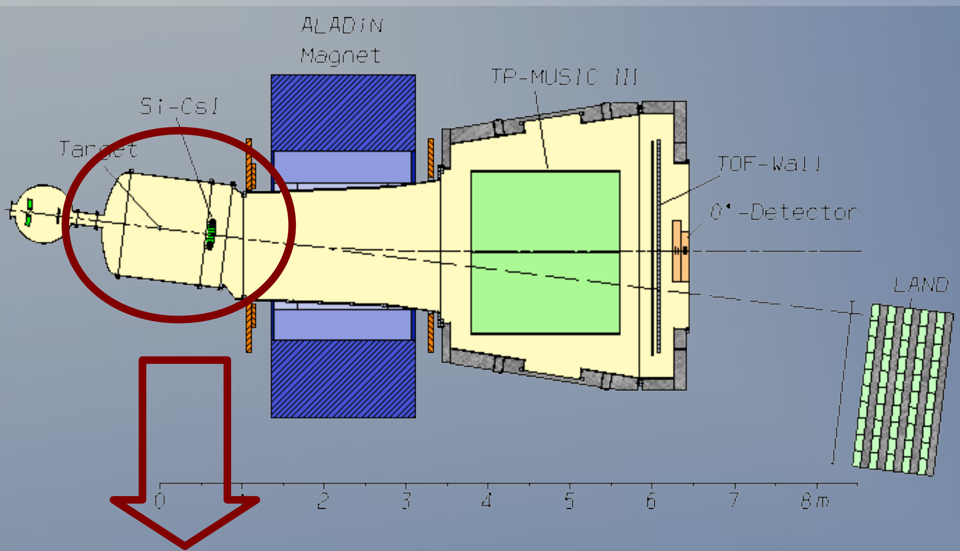
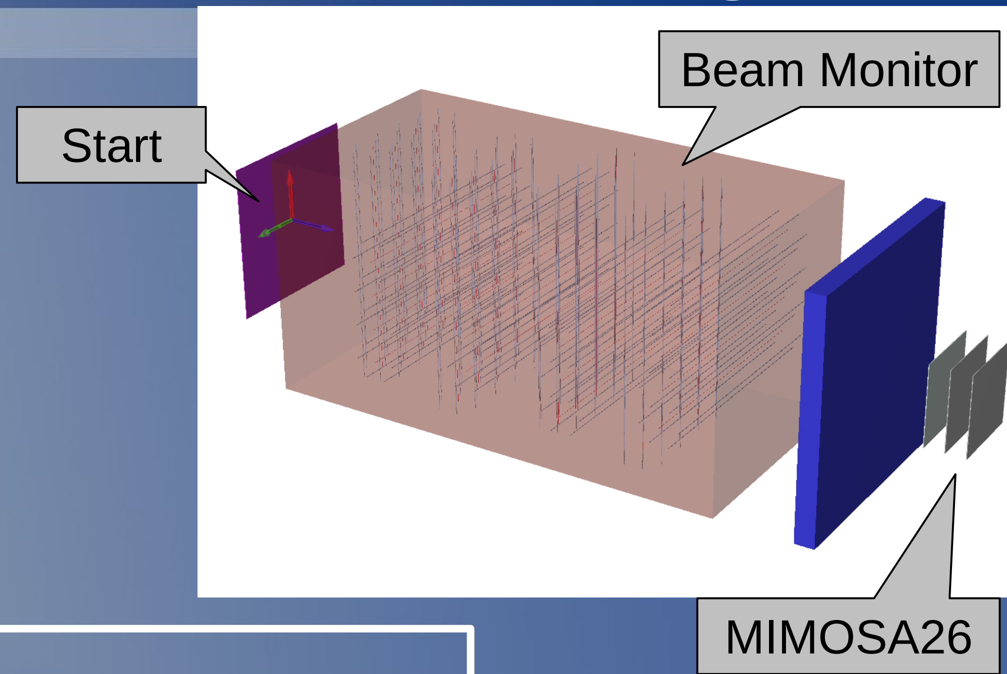
Status: Interaction Region





Interaction region:

- ✓ Start Counter
  - ✓ geom. & track scoring + quenched energy
- ✓ Beam Monitor
  - ✓ geom. with wires & scoring
  - ✓ soon first comparison with data (see Alessio's talk)
- ✓ MIMOSA26 vertex detector
  - ✓ geom. & scoring in prep., codes to be merged
- ✘ Catania large-angle hodoscope
  - ✓ FLUKA geometry existing, codes to be merged

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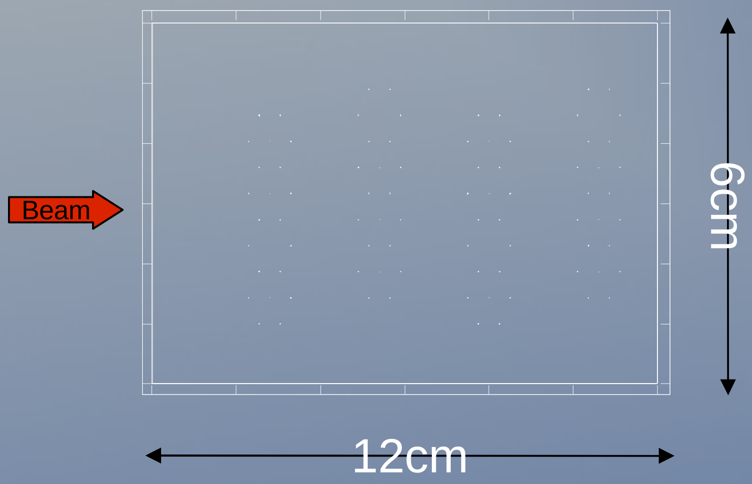
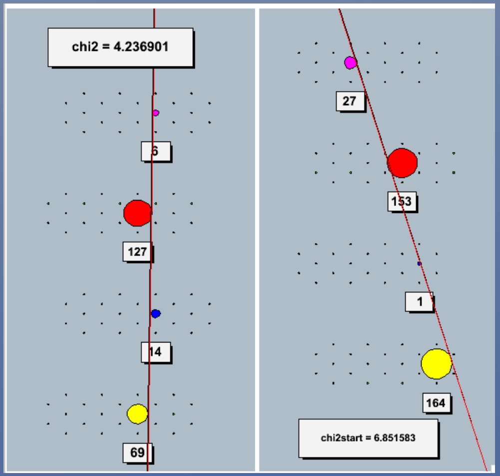
Status: Beam Monitor

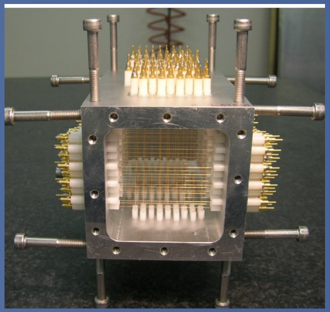
Top view



wires: 30/80µm,aluminium/tungsten



Beam Monitor:



- ✓ geometry
  - ✓ with wires
- ✓ scoring
  - ✓ currently:
    - ✓ point of closest passage
  - ✓ in future:
    - ✓ via space-time relation (from Catania measurements)
    - ✓ including diffusion terms

Status: MIMOSA26

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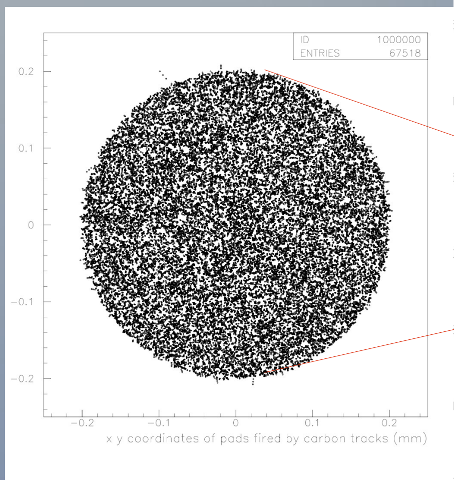
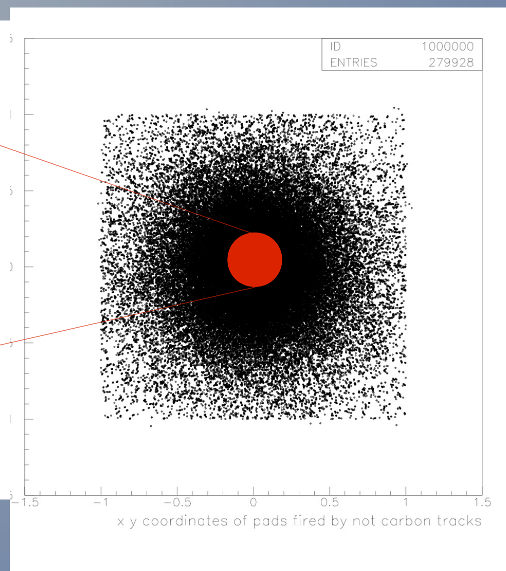
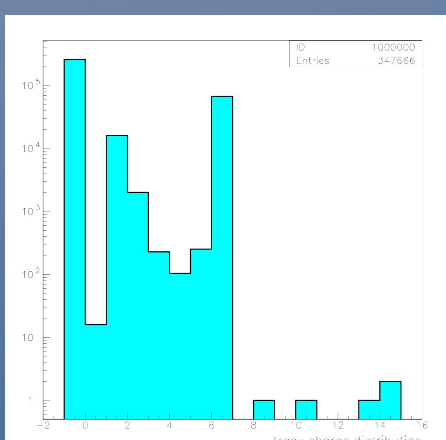
C 300MeV/n



Pads fired by carbon



Pads fired by particles other than carbon



Track-charge distribution

MIMOSA26:

- ✓ simple geometry (3 planes)
- ✓ scoring
  - ✓ 1.3M sensitive pads per plane (18µm distance)
  - ✓ Prod. cut δ-ray 100keV

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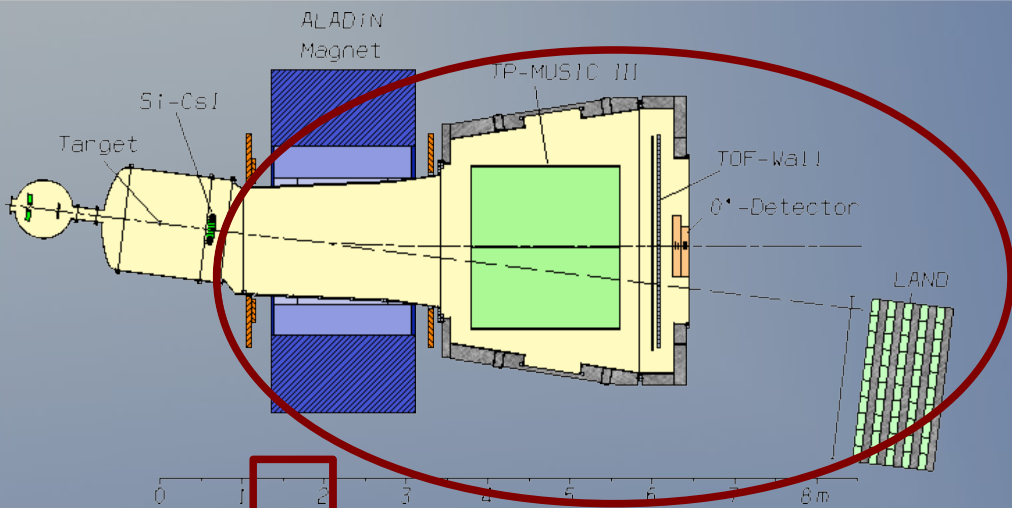
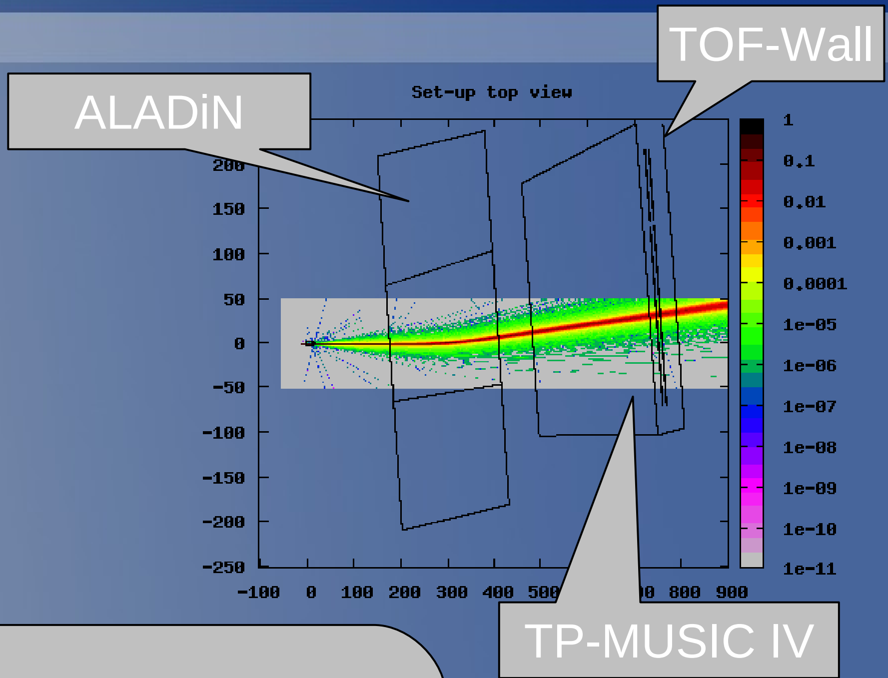
Status: Large Detector Region



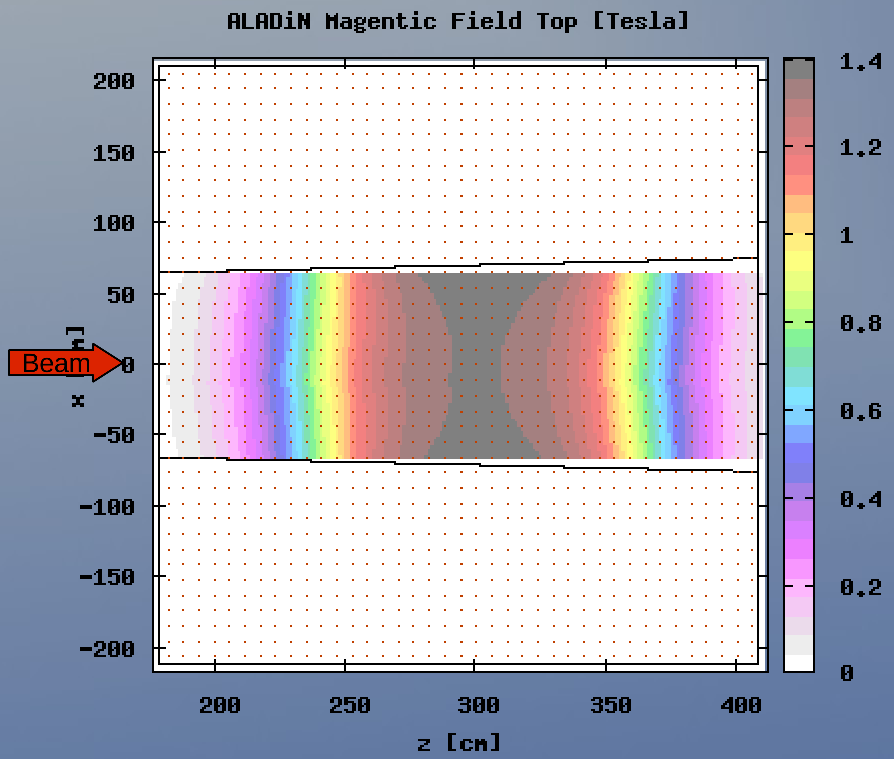


Large detector region:

- ✓ ALADiN Spectrometer
  - ✓ geom. & magnetic field
- ✓ TP-MUSIC IV
  - ✓ simple geom. with windows and P10
  - ✗ no scoring
- ✓ TOF-Wall
  - ✓ geom. with slats & scoring in prep.
- ✓ LAND2
  - ✓ simple geom.
  - ✗ no scoring

Status: ALADiN

Top view



ALADiN:

- ✓ geometry
  - ✓ iron
  - ✓ windows
- ✓ magnetic field
  - ✓ centered to middle of magnet
  - ✓ trilinear spatial interpolation
  - ✓ linear scaling of field strength (meas. at 25A)
  - ✓ in future: linear interpolation of 10 meas. fields

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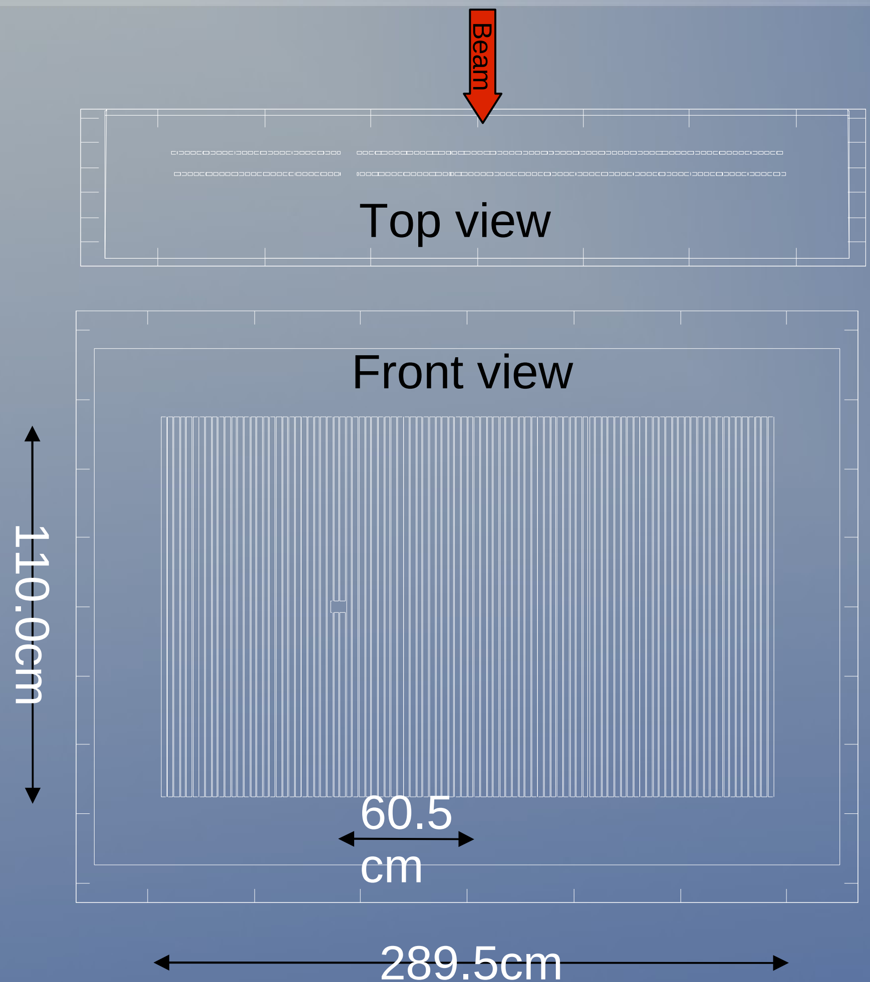
Status:TOF-Wall



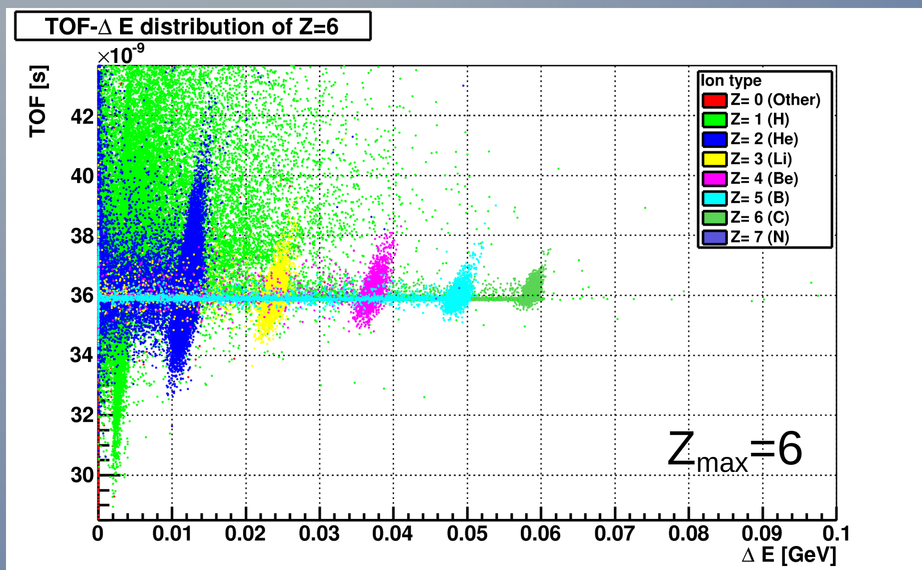
TOF-Wall:

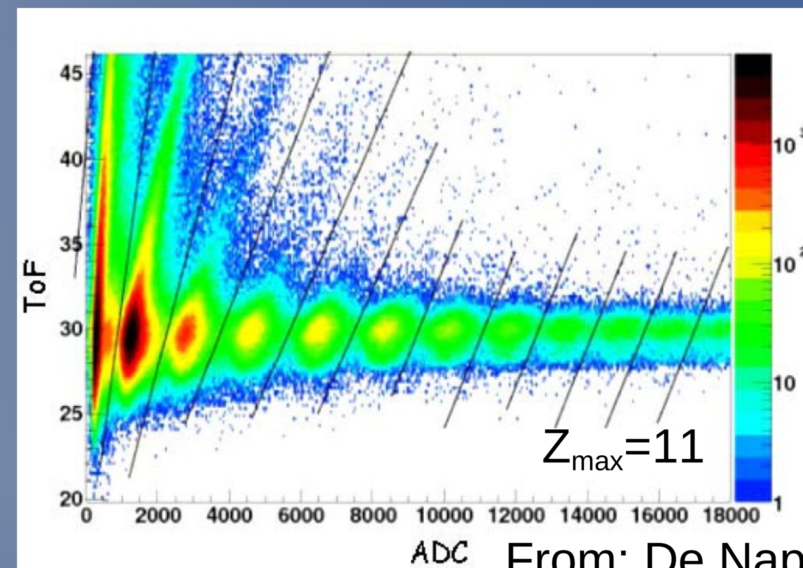
- ✓ geometry
  - ✓ housing
  - ✓ windows
  - ✓ front and rear wall with slats and beam hole
- ✓ scoring tracks per slat
  - ✓ including quenched energy
  - ✓ in future:
    - ✓ amplitude of light output
    - ✓ signal arrival time

Details:
- 96 slats per wall, distance between slats set to 5mm!, hole: 3.4x7.2 cm2
- slat material: BC408, TOF-Wall gas N2 @ 1bar

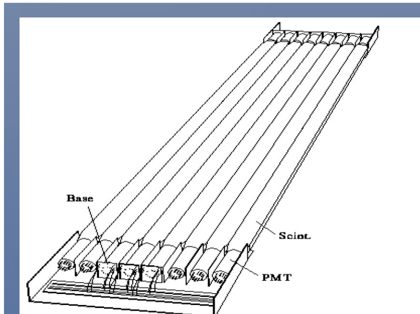
Towards TOF-Wall Signal Simul.

Correlation between time and amplitude for all slats superimposed.





From: De Napoli 05



TOF-Wall module consisting of 8 slats

- Scoring and read-out for all slats exists
- Quenching implemented (Birks law)
- Next step:
  - integrate attenuation of light and arrival time
  - calibration curve: light yield vs. track-length (Serfling '93)

$$ADC_{top} \propto L_{top} = L_0 e^{-h_{top}/\tau}$$

$$ADC_{bottom} \propto L_{bottom} = L_0 e^{-h_{bottom}/\tau}$$

Detector signals

How to simulate detector signals?

An approach in four basic steps:

- scoring of MC information
  - particle properties, track data, energy released
- modeling of simple detector responses
  - e.g. Birks law, light attenuation in scintillators, etc.
- parametrization of complexer detector responses (measurements!)
  - efficiencies
  - resolutions
  - saturation effects, gauge quantities, e.g. track-length-light output
- digitization and adapting output format
  - TDC, ADC

What can we expect?

Watch out: playground!
It's a preliminary implementation of geometry and materials
→ to be refined in future!

Beam-target modalities:

- Gaussian beam 3mm FWHM
- C-C @ 200, 400 MeV/n
- O-C @ 400 MeV/n
- He-C @ 200 MeV/n
- Li-C @ 250 MeV/n
- Target thickness: 5,10 mm

As default for comparison:

- C-C @ 400 MeV/n Target:5mm

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Primary Interaction

Fraction of interacting primaries:

Proj	T[MeV/n]	Targ[mm]	Target	Whole Set-up
C	200	C 5	4.3 %	13.8 %
C	400	C 5	4.3 %	8.3 %
C	400	C 10	8.4 %	13.5 %
He	200	C 5	2.0 %	
Li	250	C 5	3.5 %	7.5 %
O	400	C 5	5.0 %	9.5 %

C 400MeV/n on C 5mm

The interactions of primaries are distributed between set-up regions as follows (given as fraction of all interacting primaries):

interactions in the target: 51.4 +/- 0.2 %

interactions before the target:

in beam mon and start det: 3.8 %

“Filtering” → **interactions after the target:**

in gaseous subst. of det.: 14.3 %

in windows of det.: 3.6 %

in vertex tracker: 4.2 %

in holes in TOFW: 0.1 %

Big fraction → missing percentages mainly produced in the TOF-Wall slats

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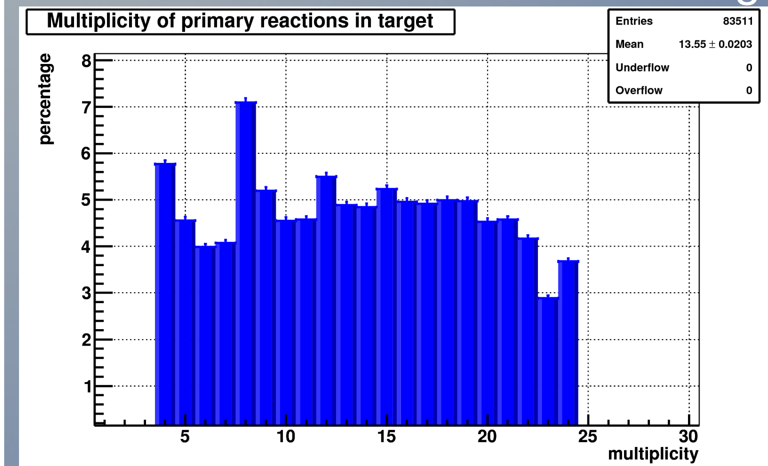
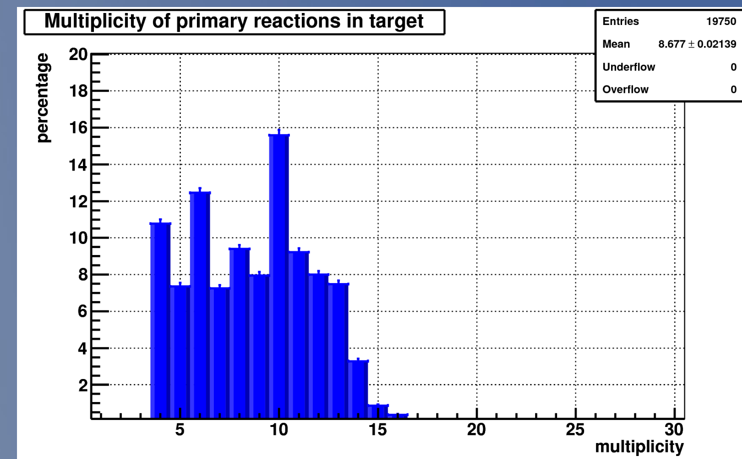
Multiplicities

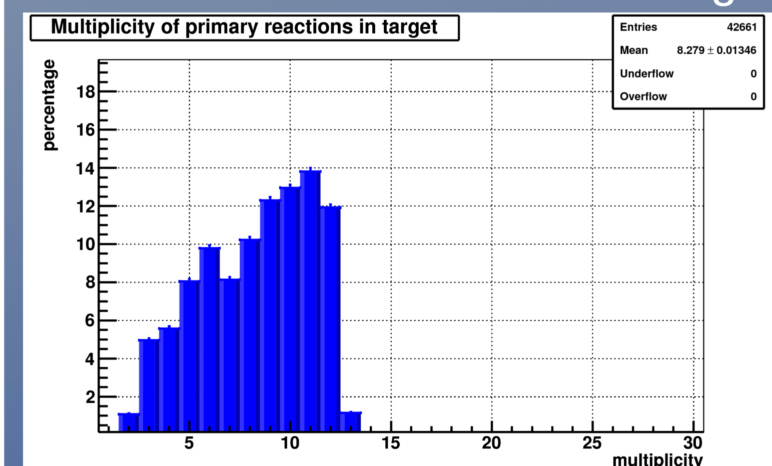
C on C @ 400MeV/n | He on C @ 200MeV/n

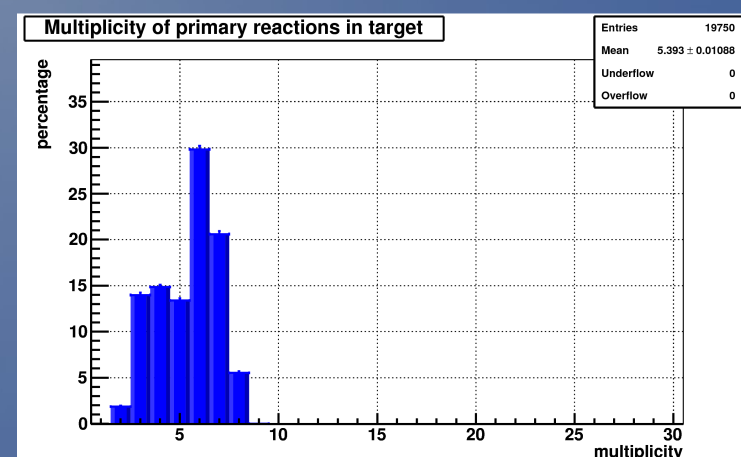
counting n, p, and ions





counting only p, and ions





- At least 2 small fragments, up until full spallation
- How reliable are FLUKA models?

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Particle Yields

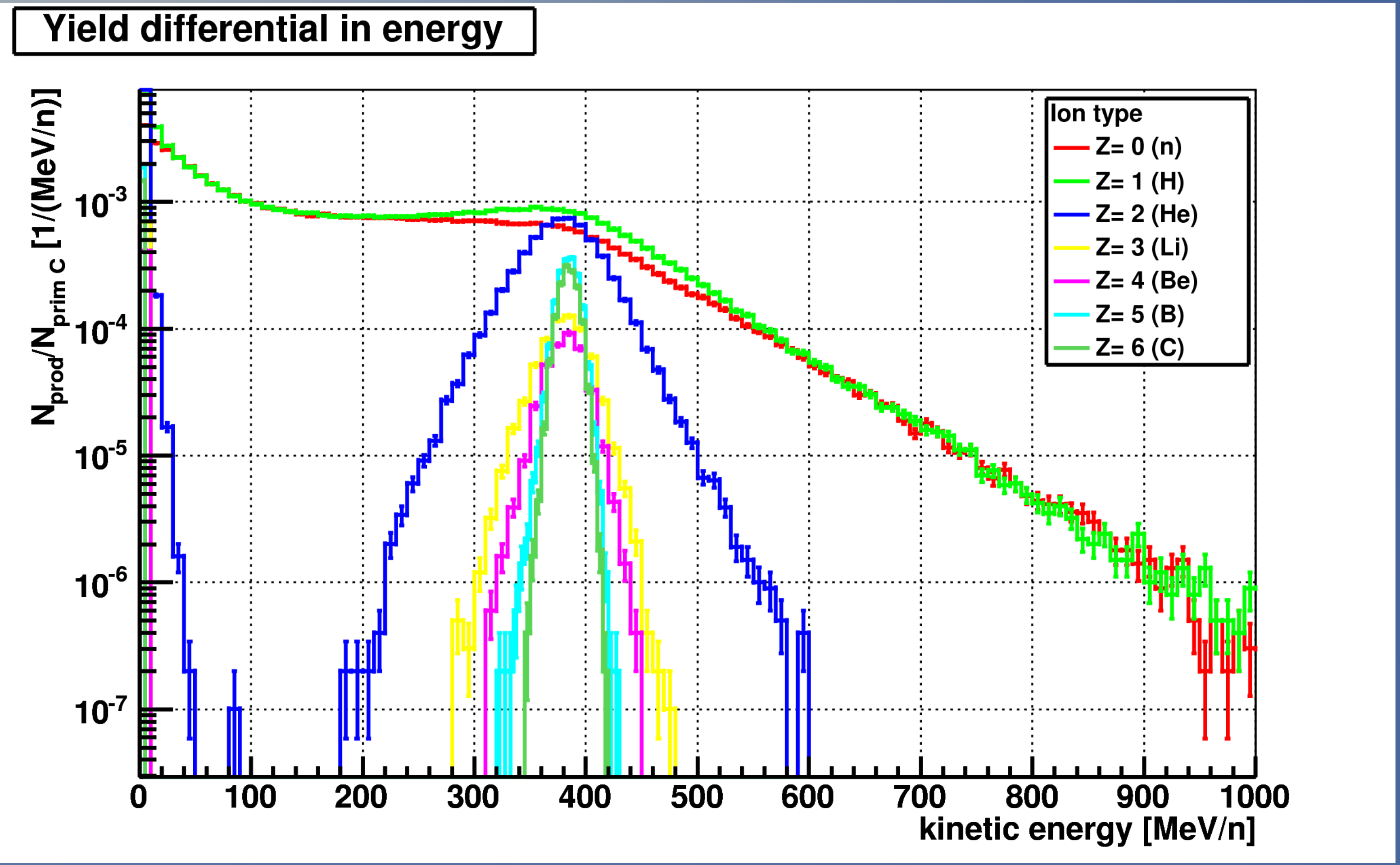
C on C 10mm @ 400MeV/n

Fragment yield per primary (particles produced in target) w/o and with T>30 MeV/n cut

Particle type	n	H	He	Li	Be	B	C	Total
Yield Cut	0.377	0.417	0.062	0.006	0.004	0.009	0.007	0.882
Yield	0.472	0.554	0.148	0.013	0.008	0.018	0.014	1.228
Ratio	0.798	0.753	0.419	0.479	0.480	0.484	0.488	0.718

Particle Yields - Energies

C on C 10mm @ 400MeV/n



- p and n up to double of beam energy (Fermi motion)
- Z>2 => projectile like

Particle Yields - Angles

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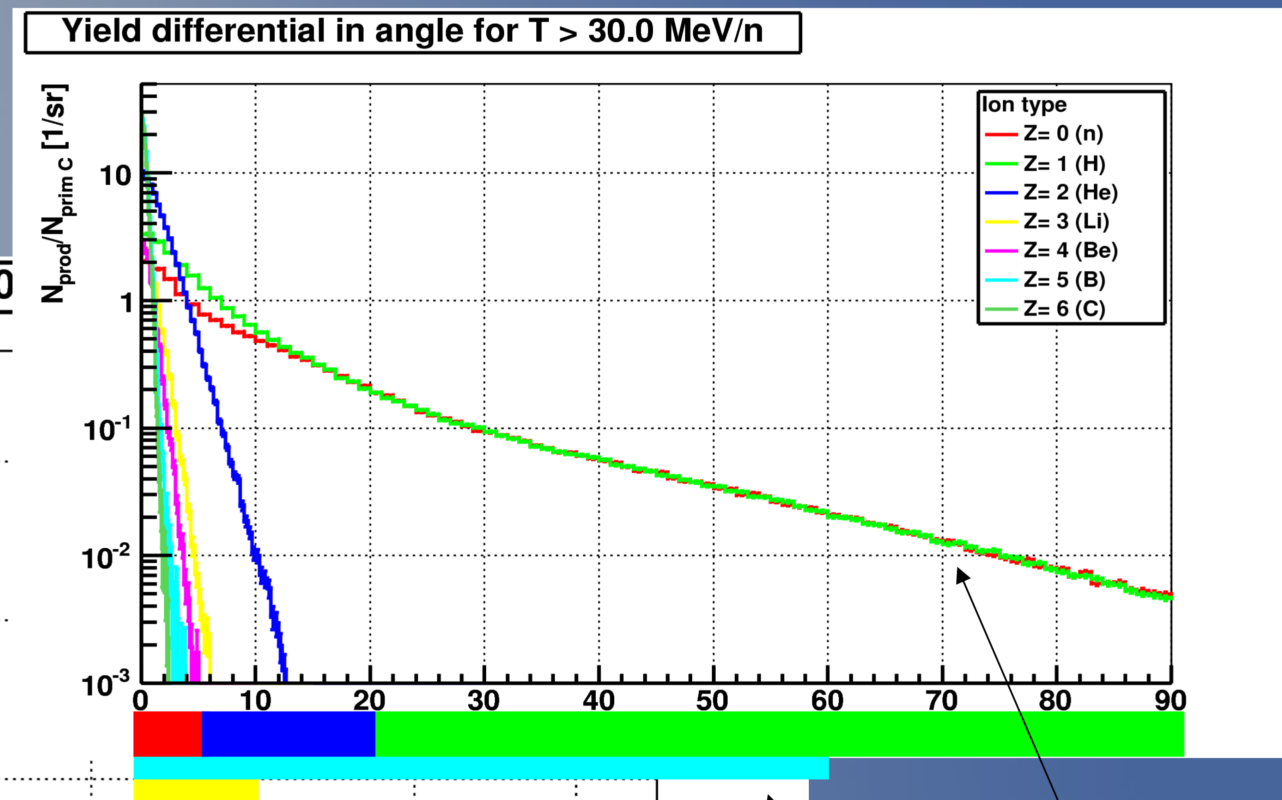
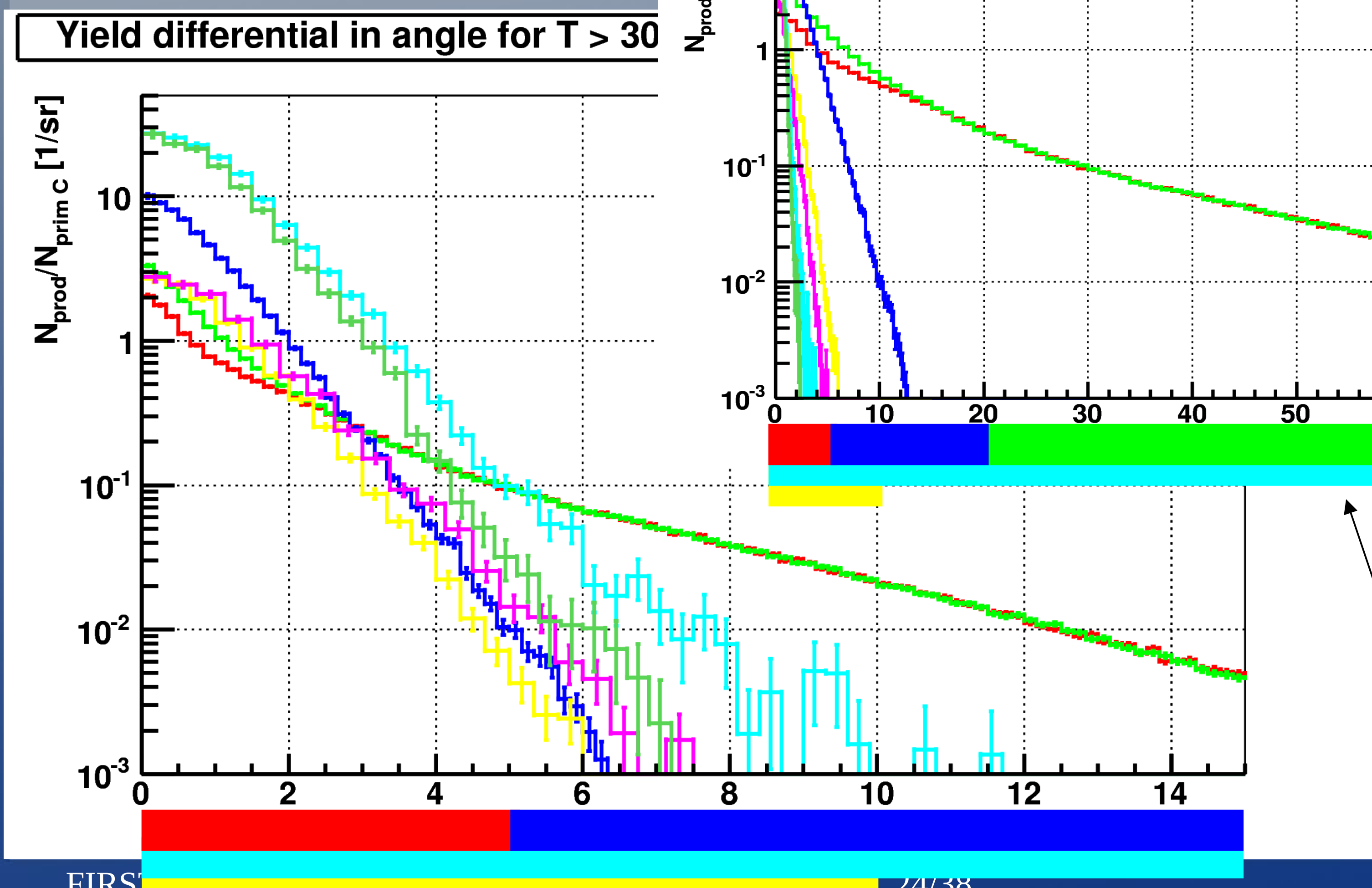
ALADiN set-up
CT Hodoscope
Calorimeter?
MIMOSA
LAND

C on C 10mm @ 400MeV/n



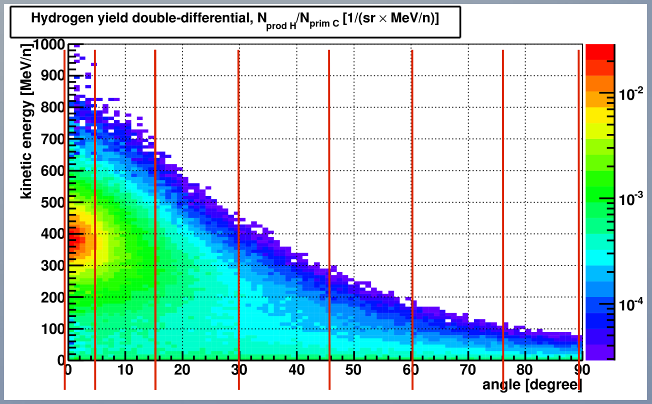


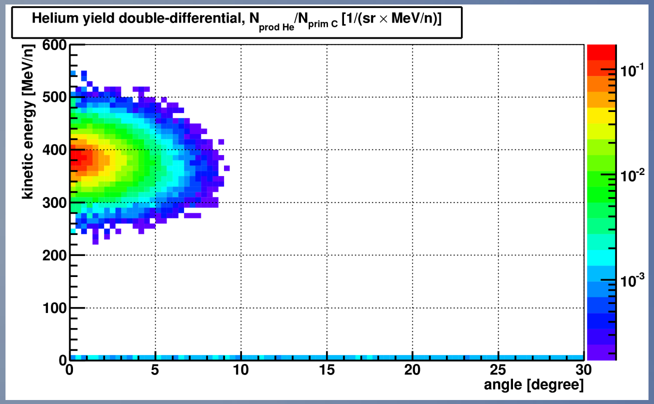
>1% until ~70°!
for Z>2

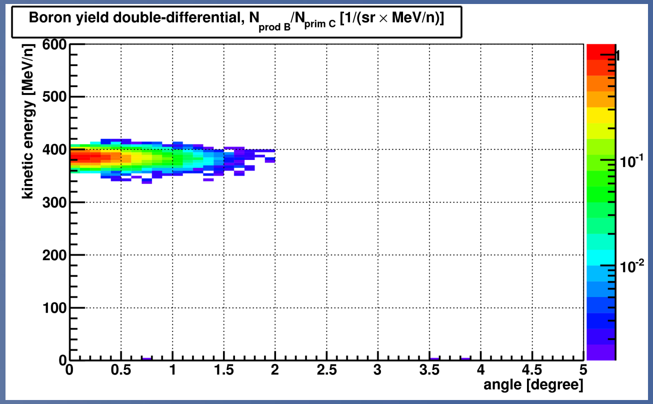
Covered partially by Vertex - but no energy information

D-D Particle Yields

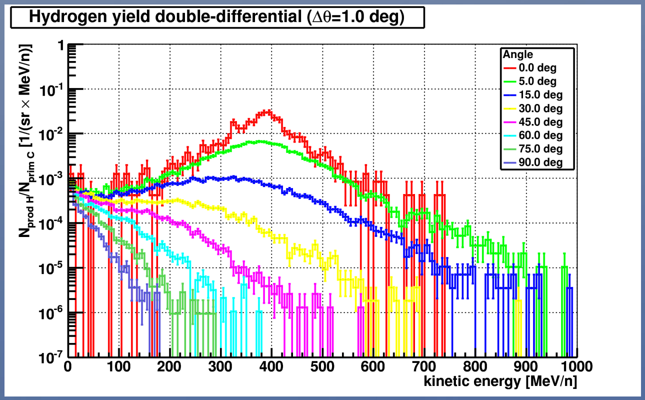
C on C 10mm @ 400MeV/n

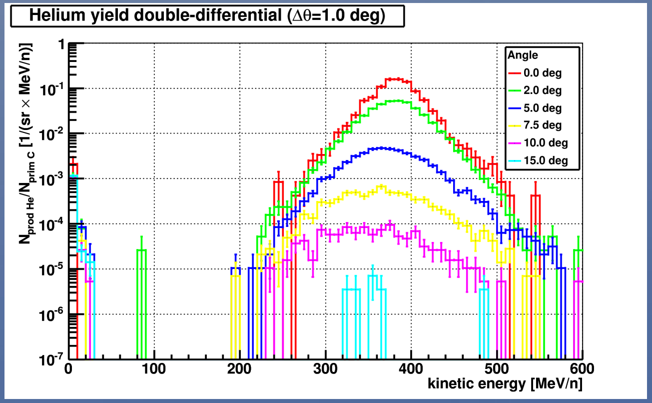


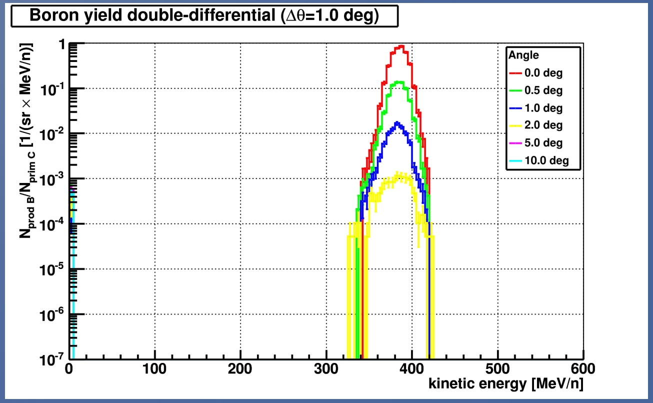




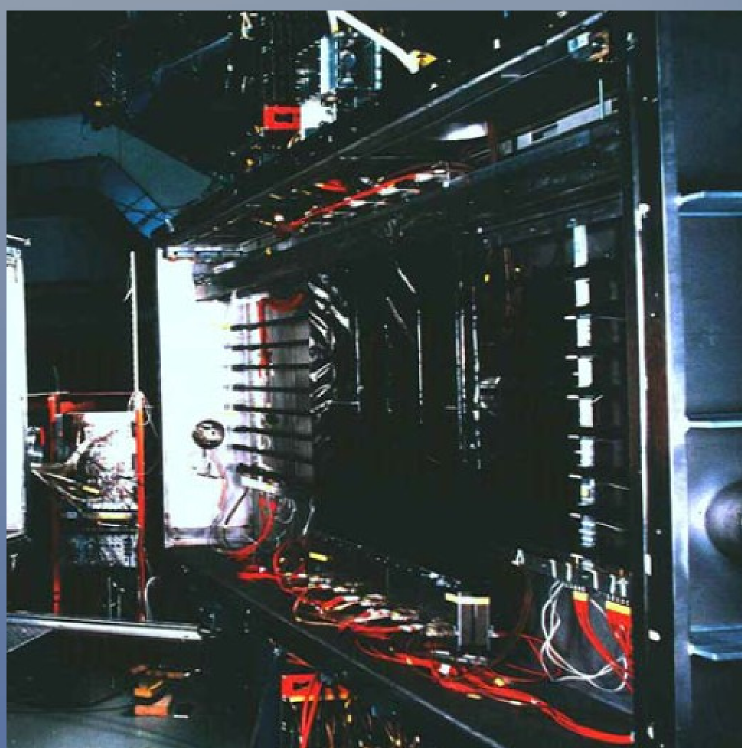
H **He** **B**

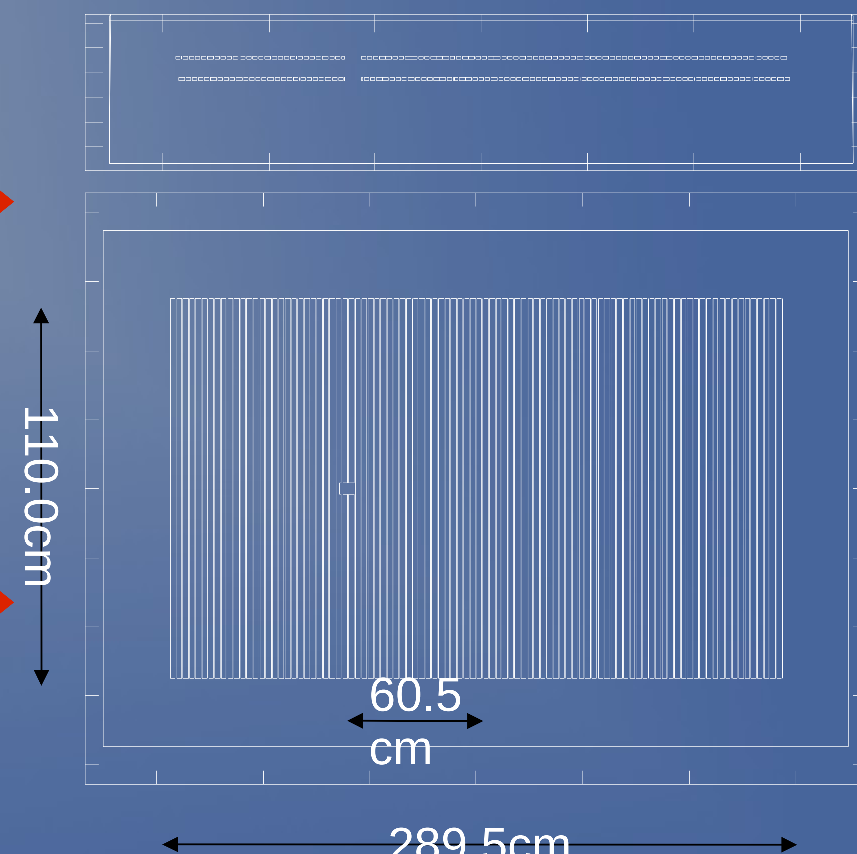






TOF-Wall Study





TOF-Wall Study

Motivations:

1) **Constraining factor for event rate:** Due to TP-MUSIC and to **TOF-Wall read out time** the primary beam rate is of the order of kHz ("pile-up effect").
   - ➔ Investigate possibilities for a **veto trigger** on TOF-Wall to increase possible event rate.
2) Several **TOF-Wall scintillator** slats are **not working**.
   - ➔ Investigate **consequences of reduced number** of slats (single wall).
3) Due to granularity of TOF-Wall scintillator slats (2.5cm width) **multiple hits on a slat are possible per event**.
   - ➔ What is the **probability** of such **multiple hits**?

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"Set-up Efficiencies"

Which fraction of particles produced in the target arrives at the TOF-Wall?

- looking only at fragments exiting target with angles smaller than 4.5° (hodoscope)
- accounting for scattering, removal by inelastic interactions, energy losses

C on C 10mm @ 400MeV/n
Magnet current: 20.5A (max 25A)

Z	"Set-up efficiency"
1	0.459 +/- 0.004
2	0.924 +/- 0.006
3	0.977 +/- 0.018
4	0.982 +/- 0.022
5	0.984 +/- 0.015
6	0.985 +/- 0.017

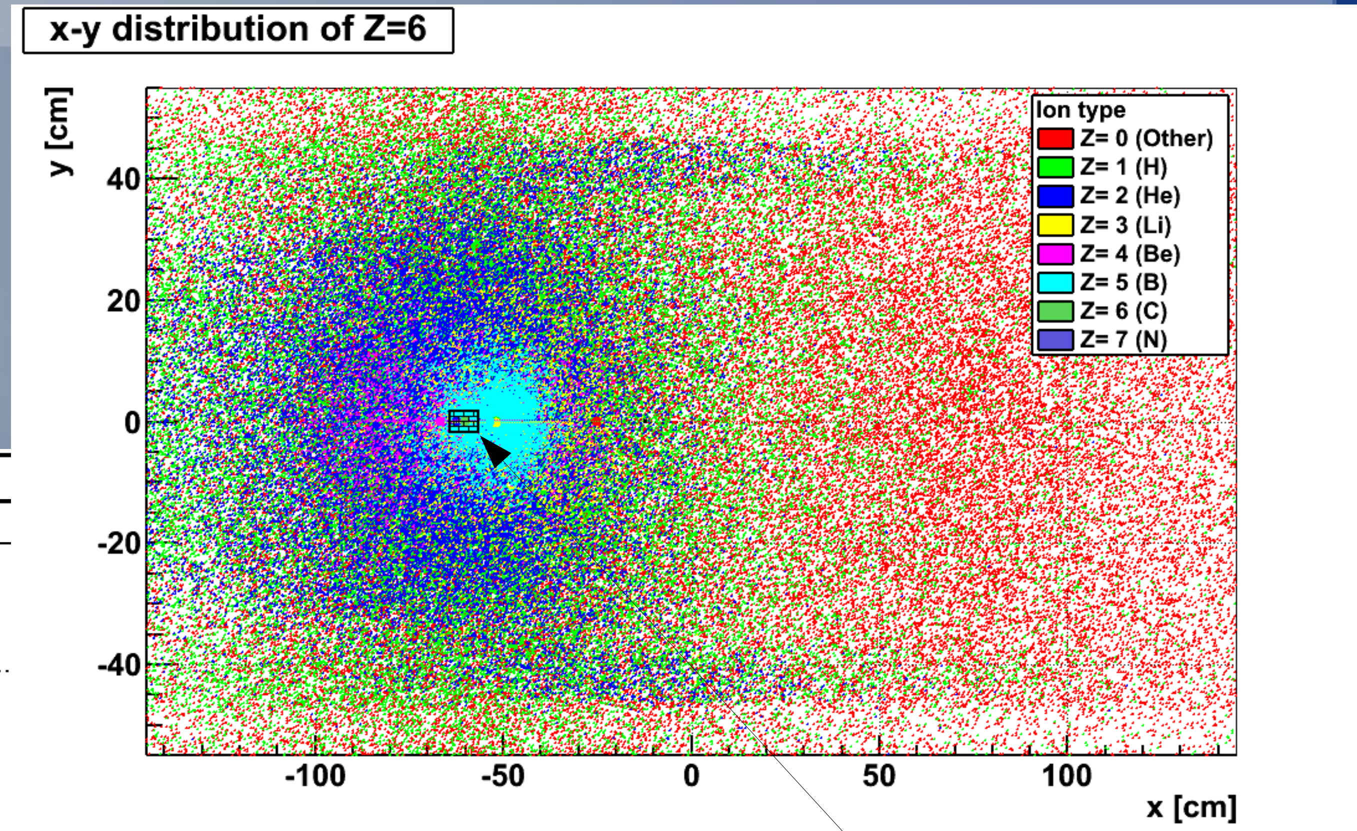
Geometric acceptance of TOF-Wall is ~4.5°.
Why are H and He lost?

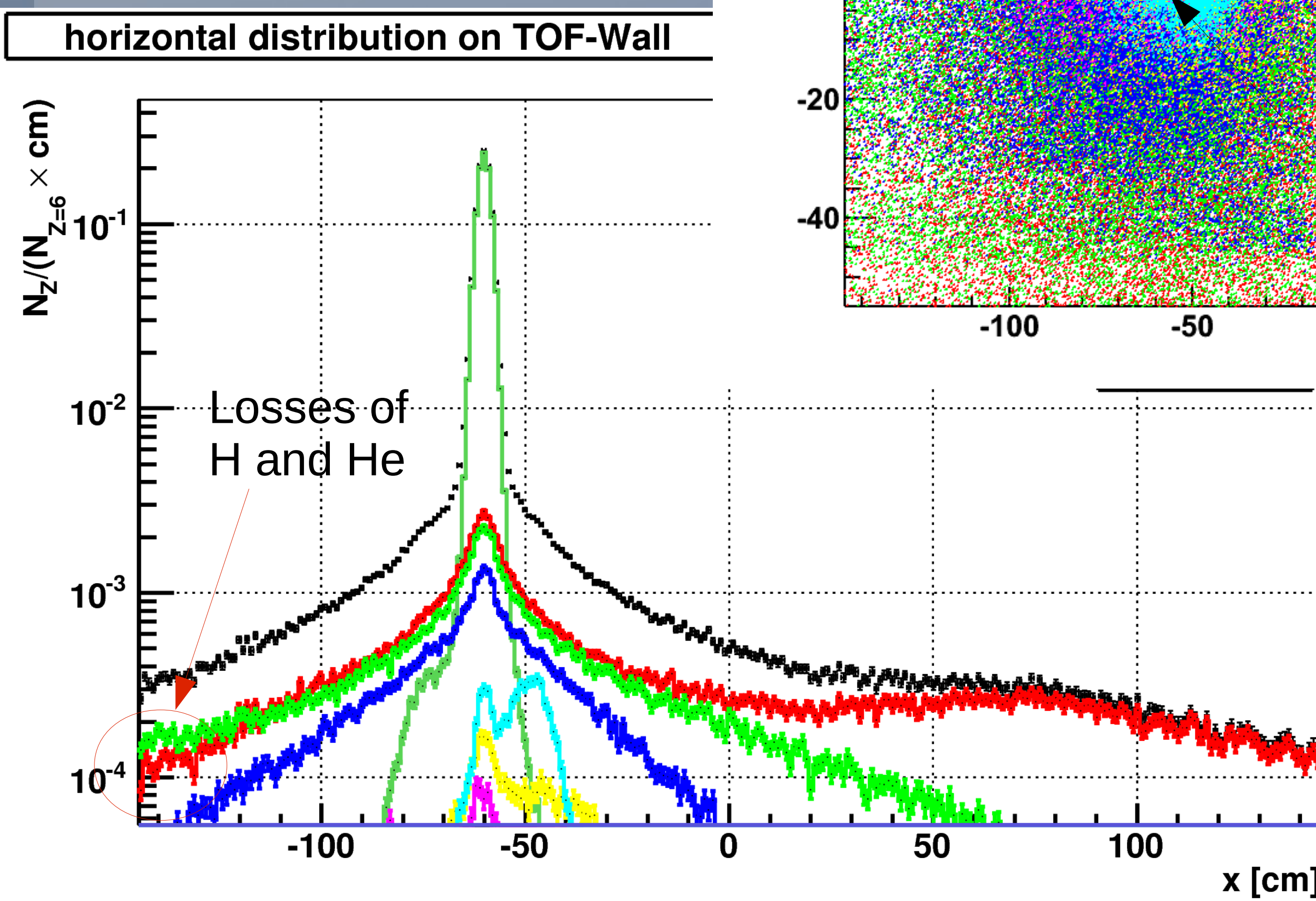
Loss causes:

- ~10% of H: acceptance of ALADiN in height: ~4°
  => have ALADiN close to target (1.6m for simulations)

- ~40% of H: Small magn. rigidity of p, slow p's are lost
  => how strong does magn. field have to be for isotopic separation and mom. resolution? (MUSIC resolution!)

Fragment Distrib. on TOF-Wall

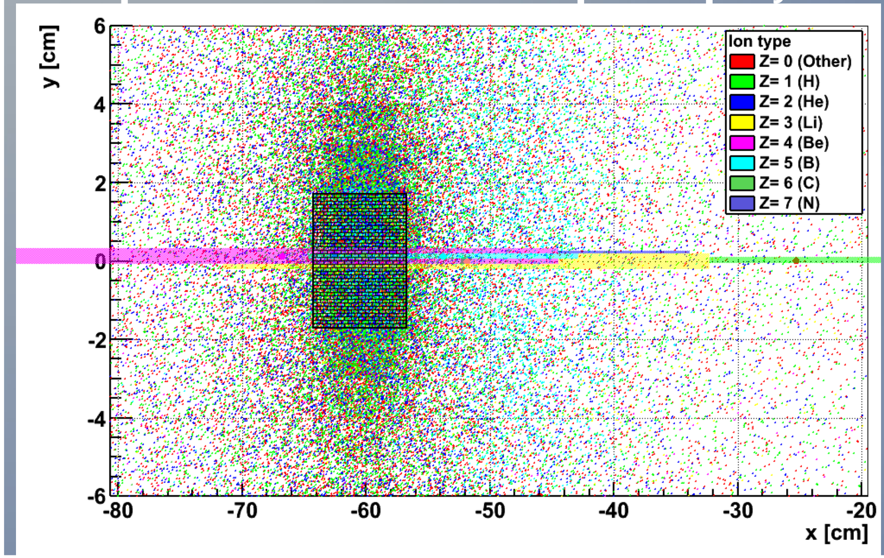




Position of the hole in the TOF-Wall for the beam (7.5cm x 3.4cm, is movable!)

Hole and Veto Trigger

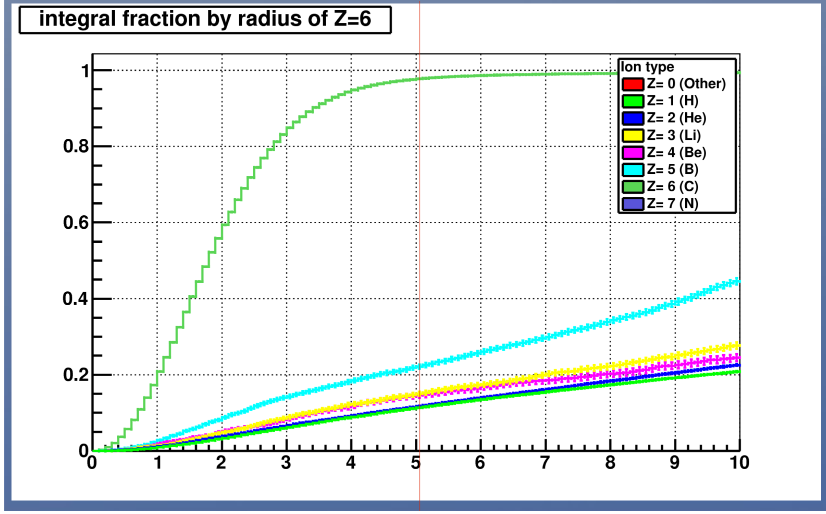
Purpose of Hole: avoid pile-up by reducing triggering of “unwanted events”



Fraction of particles in hole (at x=-60.5cm):

H	He	Li	Be	B	C
0.053	0.059	0.077	0.079	0.131	0.764

Idea: adding a veto detector in front of hole with larger size to exclude even more not-wanted events with minimum bias (A. Sciubba).



- With a veto detector of 5cm radius: >98% of primary C vetoed

Under investigation:

- Use ΔE-threshold to veto only primaries?
- Extrapolation to recover lost particles?
- Use multiplicity on TOF-Wall as additional selection criteria?

work-in-progress

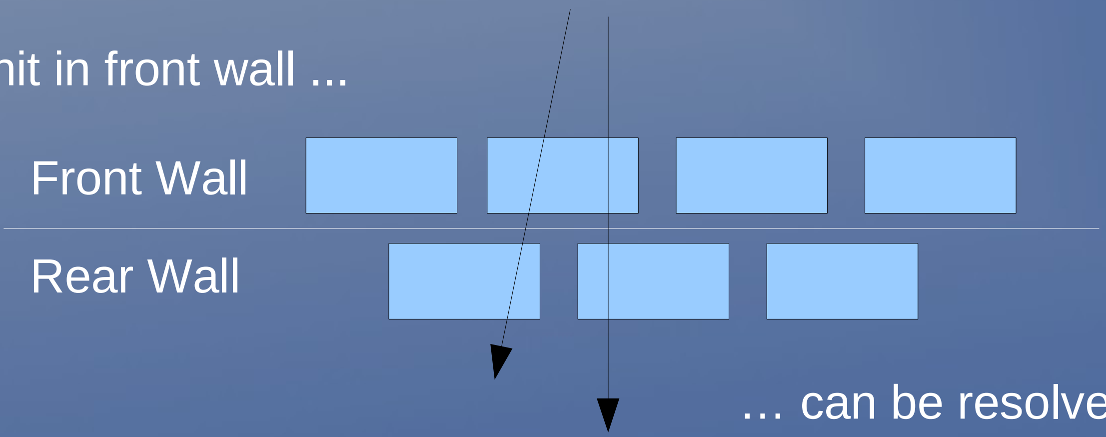
Multi-hit Analysis

Problem: Granularity of detector (slat width is 2.5 cm). This leads to the possibility of having **multiple hits for which several particles are counted as one** (often with the wrong charge).

Details see diploma thesis V. Serfling '93.

A **second row "reduces the granularity" and covers gaps** in front row. (Number of working slats, usable for the second row, is currently not known.)

Double-hit in front wall ...



… can be resolved in rear wall.

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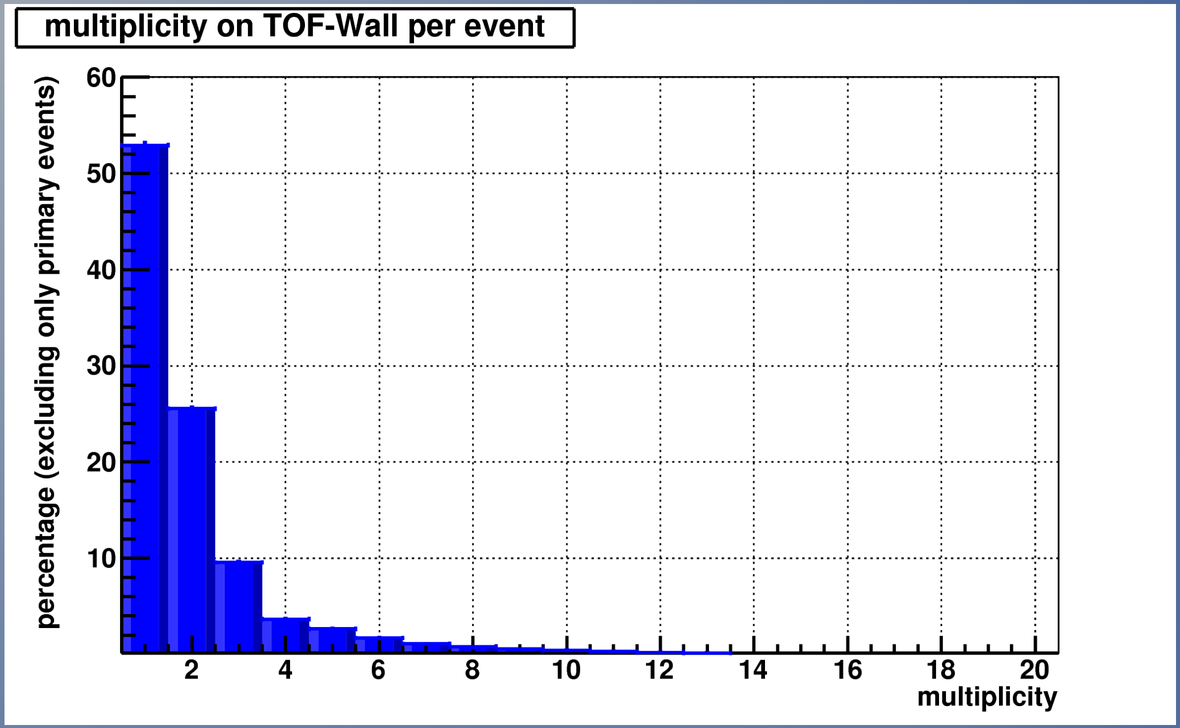
Multiplicities on Whole TOF-Wall



- only nuclear reaction events counted
- scoring: p, ions (no n!) for multiplicity
- also particles out-of-target interactions!

C on C @ 400MeV/n

Multi-hits on TOF-Wall

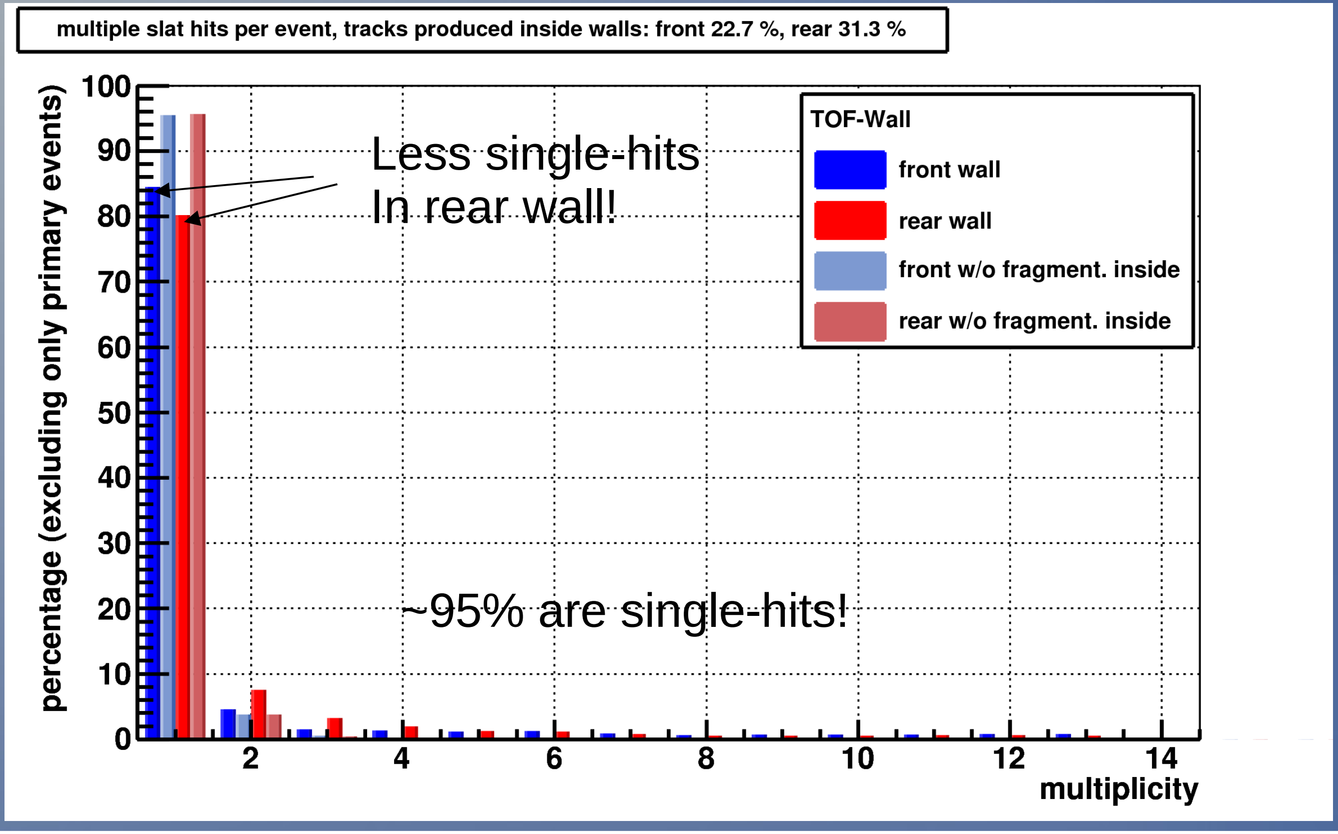
Scenario used for simulations:

- Assuming only front wall complete
- and some slats for rear wall
- Study done for C @ 400MeV/n on C

Multi-hits on TOF-Wall

Multiple hits of scintillation slats

scoring: p, ions (no n!) for multiplicity



C on C @ 400MeV/n

Significant particle production in TOF-Wall slats!

- compare: thickness target: 5-15mm, slats: 2x10mm
- consequences: signal modification:
  - wrong amplitude (charge!)
  - timing information in wall where produced should be ok
- consequences: increased multiple hit rate in rear wall

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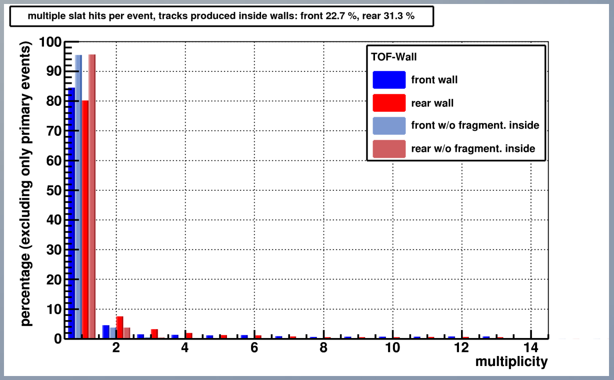
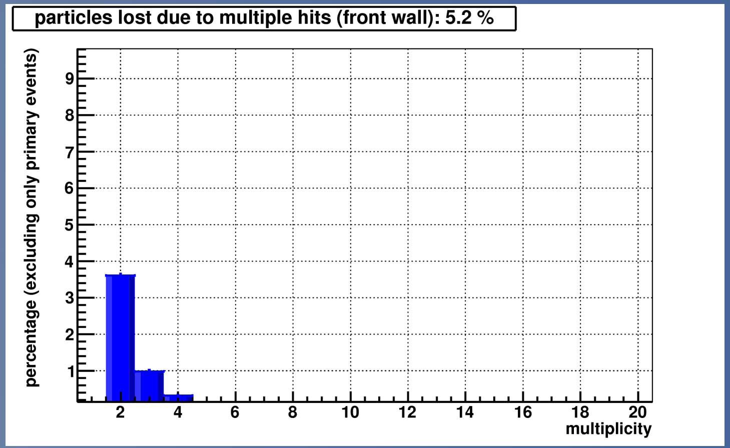
Multi-hits on TOF-Wall



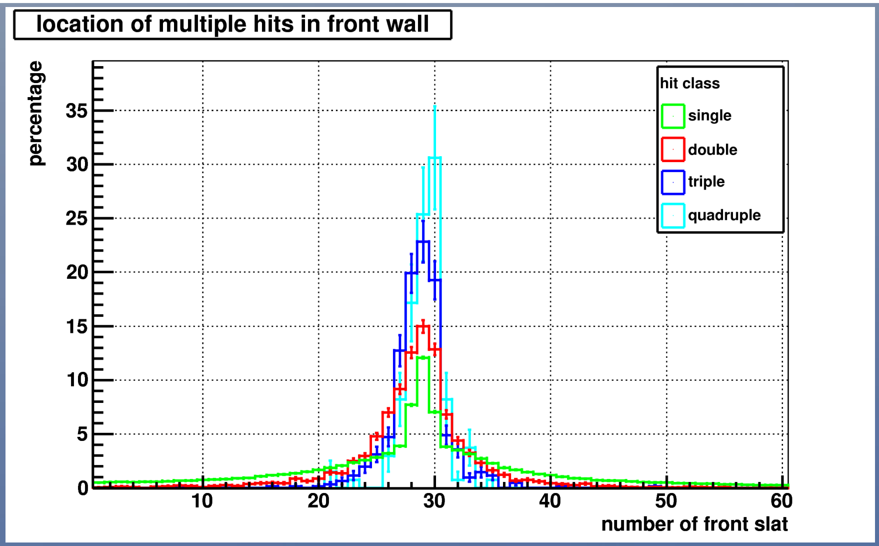
Particle losses due to multi-hits

Assuming multiple hits are identified as one particle (of wrong charge).



Of course vertex tracker and MUSIC help detecting correct multiplicity.

Location of multi-hits
In front wall



- concentrated to ~10 slats!
- expect significant improvement when adding a second row only for this area

Excluding in both graphs interactions in the TOF-Wall slats themselves!

Multi-hits on TOF-Wall

Discussion of results/further investigations:

Where do high multiplicities in slats come from?
(multiplicities up until 5 observed)
- origin mainly from H and He produced in gas of MUSIC and TOF-Wall (P10, N_2) and some from the window between MUSIC and TOF-Wall (set to titanium)

Electrons are not included in the analysis!
- projectile-like electrons of low quantities are of noise level (info C. Sfienti)
- but electron shower (building up in gas in front of wall) can cause multi-hit (specifically on front wall)
  - reported by V. Serfling '93 (causing double-hit ratio front/rear wall: 54%/46%)
  - would need full signal modeling (and detector efficiencies) to answer this question

How many double-hits can we correctly identify with a second row?
- necessitates the implementation of the TOF-Wall reconstruction
- should be done in future with the reconstruction software team

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Outlook

Next steps for the MC simulation

- Signal modeling:
  - TOF-Wall (preliminary, exp. data needed)
  - Beam Monitor (space-time relation, diffusion)
  - Close future interaction with the reconstruction software team
- Merging with simulation of MIMOSA and Catania Hodoscope (C. Morone)
- Modeling of TP-MUSIC IV?
- We hope to get a first "overall simulation" ready by Mai 2010

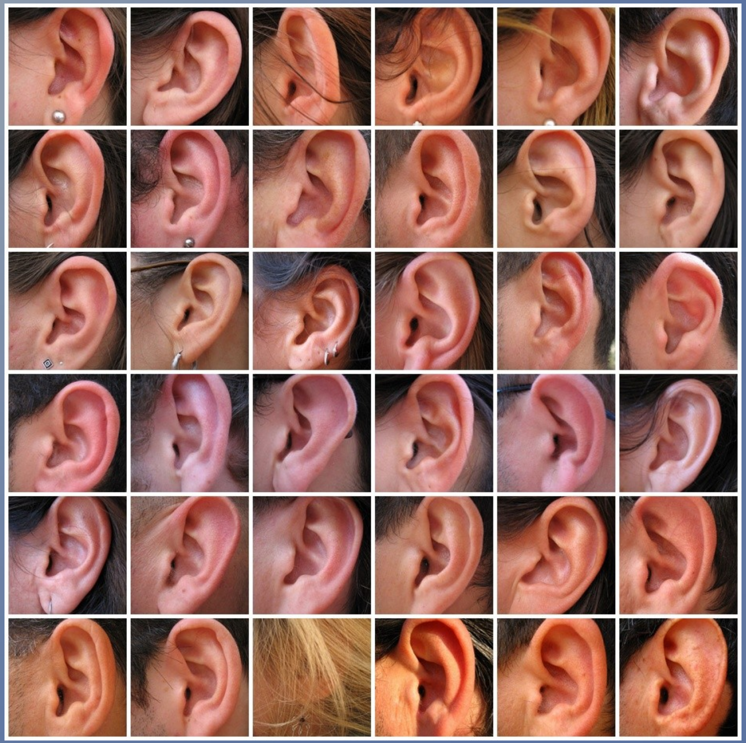
Summer 2010: Measurements @ LNS, Catania

- measure response of MIMOSA to p and carbon
  - compare to simulations

Wanted: your input

- Issues that should (can) be addressed with the simulation

Thanks for attentive ...



Particle Training Network for European Radiotherapy

http://cern.ch/partner

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FIRST Fragmentation of Ions Relevant for Space and Therapy
EXPERIMENT

Materials in Beam (Add.)

Materials in the beam (beam view):

- start:
  > scintillator 200um SCSN38
- beam monitor:
  > window 100um mylar
  > air 12cm with wires: 30/80um,aluminium/tungsten
  > window 100um mylar
- target:
  > 0.5-1.5cm carbon
  > - vertex traker:
  > 3x200um silicon
- ALADiN:
  > window 100um titanium
  > vacuum 230cm (with He @ p=1e-4 bar, rho=1.64E-8 g/cm3)
  > window 100um titanium
- TP-MUSIC IV:
  > window 100um titanium
  > P10 250cm (rho=0.001677 g/cm3 @ p~=1 bar)
  > window 100um titanium
- TOF-Wall:
  > nitrogen gas 57.5cm (rho=.001251 g/cm3 @ p~=1 bar)
  > scintillator BC408 2x1cm
  > window 100um titanium

Yields (Add.)

Li250 on C 5mm

****

fragment yield per primary (particles produced in target) w/o and with T>30.000000 MeV/n cut

Particle type	n	H	He	Li	Be	B	C	Total
Yield Cut	0.126	0.112	0.015	0.002	0.000	0.000	0.000	0.255
Yield	0.169	0.169	0.049	0.005	0.002	0.004	0.003	0.402
Ratio	0.745	0.661	0.304	0.362	0.000	0.000	0.000	0.633

****

He200 on C 5mm

****

fragment yield per primary (particles produced in target) w/o and with T>30.000000 MeV/n cut

Particle type	n	H	He	Li	Be	B	C	Total
Yield Cut	0.043	0.048	0.003	0.000	0.000	0.000	0.000	0.094
Yield	0.066	0.078	0.023	0.002	0.001	0.003	0.002	0.176
Ratio	0.652	0.607	0.127	0.000	0.000	0.000	0.000	0.531

****

O400 on C 5mm

****

fragment yield per primary (particles produced in target) w/o and with T>30.000000 MeV/n cut

Particle type	n	H	He	Li	Be	B	C	N	O	Total
Yield Cut	0.250	0.277	0.042	0.004	0.002	0.002	0.005	0.007	0.004	0.592
Yield	0.304	0.355	0.086	0.008	0.004	0.007	0.009	0.007	0.004	0.783
Ratio	0.822	0.780	0.487	0.514	0.452	0.304	0.571	1.000	0.999	0.756

****

FIRST Fragmentation of Ions Relevant for Space and Therapy EXPERIMENT

"Set-up Efficiencies" (Add.)

C on C 10mm @ 400MeV/n
Magnet current: 20.5A (max 25A)

Z	"Set-up efficiency"
1	0.459 +/- 0.004
2	0.924 +/- 0.006
3	0.977 +/- 0.018
4	0.982 +/- 0.022
5	0.984 +/- 0.015
6	0.985 +/- 0.017

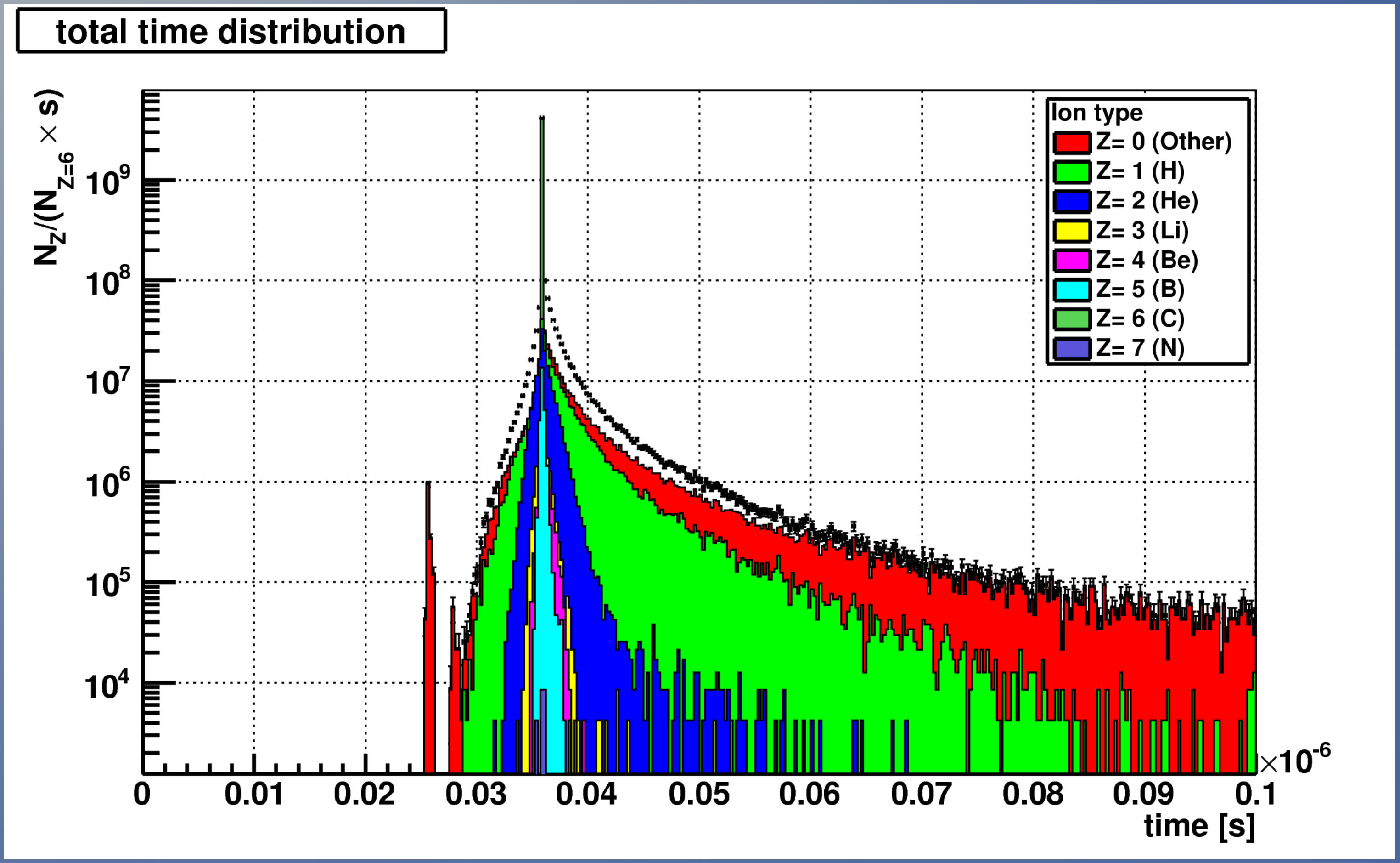
What are max. efficiencies we can reach when:
- removing all materials in the beam,
- having all fragment distributions centred in the middle of the TOF-Wall)?

Z	"Set-up efficiency"
1	0.878 +/- 0.006
2	0.952 +/- 0.006
3	0.989 +/- 0.018
4	0.998 +/- 0.023
5	1.000 +/- 0.015
6	1.000 +/- 0.017

TOF-Wall area: 110cm x 289.5cm (due to gaps, normally 110cm x 240cm)

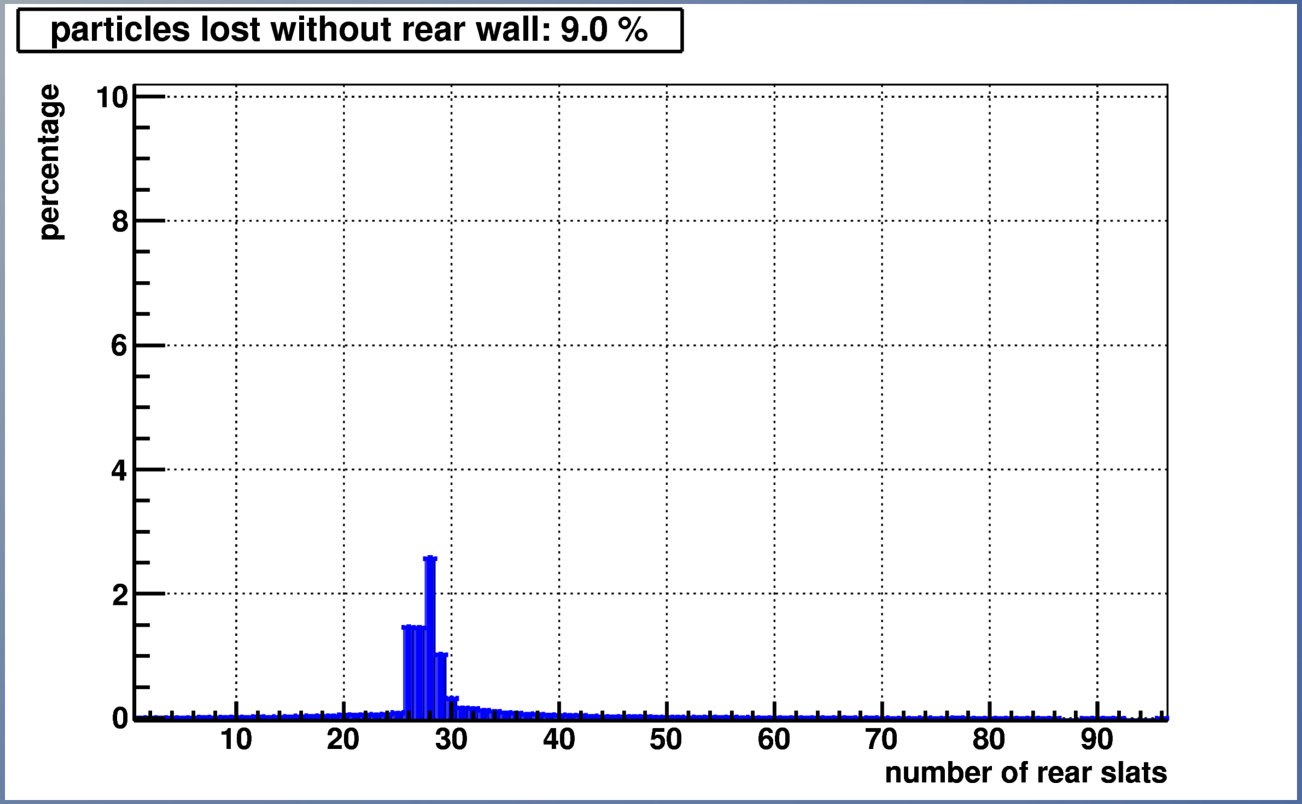
Some numbers:
distance Target-TOF-Wall: DtT 726.75cm
distance Target-hodoscope: DtH 60cm
distance Target-ALADiN s: DtAs ~160cm
distance Target-ALADiN e: DtAe 390
ALADiN gap height: 50cm
ALADIN gap s,e: 130cm, 150cm
ALADIN thick: 230cm
2*DtAs*Tan(4.5°)=25.2cm
2*DtAe*Tan(4.5°)=61.4cm
2*DtH*Tan(4.5°)=45.6cm
50/61.4=0.81
geometric acceptance of the ALADIN magnet for the
produced fragments is ~4o in theta and ~9o in phi
4/4.5= 0.889
target-hodoscope:
2*DtT*Tan (4.5°)=114.4cm
TOF-Wall y= 110cm
TOF-Wall x= 289.5cm (240cm)
110/114.4=96.1538462

TOF-Wall (Add.)



total time distribution
Ion type
Z= 0 (Other)
Z= 1 (H)
Z= 2 (He)
Z= 3 (Li)
Z= 4 (Be)
Z= 5 (B)
Z= 6 (C)
Z= 7 (N)
$N_Z/(N_{Z=6} \times s)$
10^9
10^8
10^7
10^6
10^5
10^4
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
$\times 10^{-6}$
time [s]

Losses due to gaps (Add.)



Expected losses due to a simple geometry consideration:
gaps in surface: 0.5cm/(2.5cm+0.5cm)=16.7%.

WARNING: gaps were chosen large for this simulation (5mm),
They will be hopefully smaller for real set-up.

Multi-hits on TOF-Wall (Add.)

Effects of multi-hits:

- without recognition software -> counted as one event (particle loss and misidentification!)
- amplitude larger as than for single hit, consequence: under-estimation of charge
- effect on time information, two cases:
  - c < dy/dt: signal velocity smaller than quotient of distance in time and vertical space
    - time signal gives something similar to distance of the two particles on slat
  - c > dy/dt
    - time signal gives position of first particle

Details see V. Serfling '93

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Multi-hits on TOF-Wall (Add.)

Possiblilities for identification of Multihit (V. Serfling '93):
-> "**Simple criteria: isolated double hits**": in front row one slat is hit with neighbouring slats not hit - in back row two slats are hit
 - **BUT**: also “crossers” (angles of incoming particles between -6.4 and +3.1 degree), nuclear reactions, delta-rays (MeV regime=> some mm in scintiallation material, some meter in gas)
 - not sufficient as criteria (additionally: in vertical direction at least 10cm apart)
-> big vertical distance of two hits in the koinzident slats
-> asymmetry of amplitudes of koinzident slats (asym=(ampl_l-ampl_r)/(ampl_l+ampl_r))
-> "detection of non-isolated double hits" together with other detectors (TP-MUSIC IV (res. of mm) and vertex) is possible!

-> correction of missing multiplicities by MC analysis is possible

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Multi-hit Reconstruction Routine (Add.)

description multi-hit reconstruction routine (V. Serfling '93):
- simple track recognition routine:
  - subtract cross-talk (due to optics+electronics, empirical factor: 4%)
    - AMPpr=AMP-0.04*(AMPl+AMPr)
    - sort out AMPpr <=0
  - determine vertical position
    - preferable by time: y=(Ttop-Tbot)/-2c (due to better resolution) (c: signal velocity = 16.8 cm/ns (is ~10% smaller than light velocity in scintillator: 19cm/ns, refractive index: 1.58))
    - if time wrong by : y=1/(2*lambda)*ln(AMPtop/AMPbot)
  - sort in first and second order hits
    - 1st order criterium: AMP bigger than AMPl and AMPr
    - 2nd order criterium: AMP smaller than AMPl or AMPr
  - track recognition step
    - sort
      - first: 1st order hits by amplitude
      - second 2nd order hits by amplitude
    - for finding coinzident slat from other wall for 1st order hit
      - look in two partner slats (left/right) in this order:
        - if one of partner slats is 1st order hit -> select this one
        - if one of partner slats is 2nd order hit -> select this one
        - if both partner slats are 2nd order hits -> select higher amplitude
        - no coinzident slat was found -> save as single (assume lost particle due to: gap, stopped particle, broken detector)
    - for finding coinzident slat from other wall for 2nd order hit
      - same as above but if no coinzident slat is found ->throw away (assume cross talk effects)
    - connect all coinzident slats to tracks (x resolution better by second slat: move by 6.25mm in corect direction)

possibilities for detection of multi-hits (V.Serfling):
- simple criteria: isolated double hit
  - but recognizes also "crossers", reactions in the scintillator and delta-rays!!!!
- big (reconstructed) vertical distance between coincident slats
- asymmetry of coinzident amplitudes (asy=(AMPl-AMPr)/(AMPl+AMPr)) (not appliable due to strongly non-linear behaviour)

routine for multi-hit recognition:
- simple criteria + 100mm distance between coinzident slats (~1/4 of all real double hits were identified)
  - calculate time and charge from other particle

Some boundary conditions

- Out of target interactions must be kept below ~ per cent levet with respect to the on target interactions.
- Trigger rate must be ≤ kHz due to pile-up in the MUSIC TPC (10% pile-up @4kHz)
- Considering a maximum target thickness of 10 mm, we expect at maximum ~10% of interaction probability.
- The beam spot for Carbon projectiles can be ~ 3mm FWHM
- The geometric acceptance of the ALADIN magnet for the produced fragments is ~4° in θ and ~9° in ϕ