ACTIVE TARGET DETECTORS FOR NUCLEAR STRUCTURE STUDIES WITH EXOTIC BEAMS

present and next future

Wolfgang Mittig

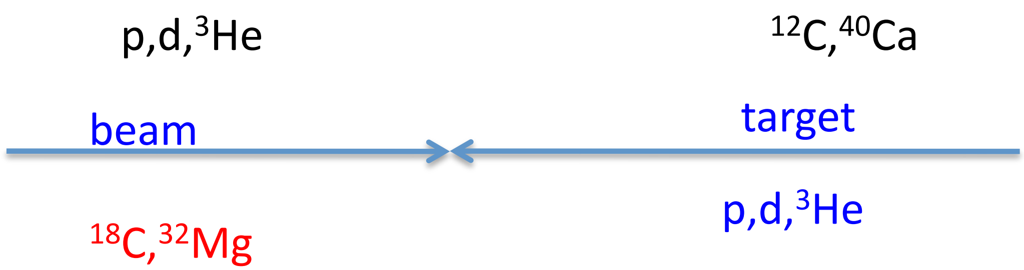
Workshop on Detectors

PNNL May 2012

Why an Active Target-TPC?

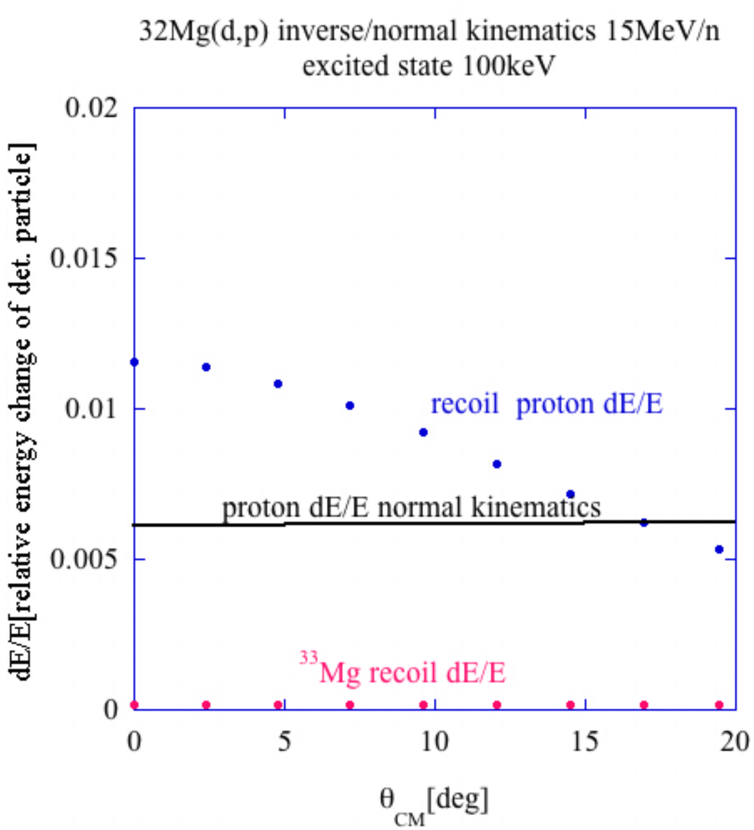
- Nuclear Structure Investigations of Exotic Nuclei with Secondary Beams

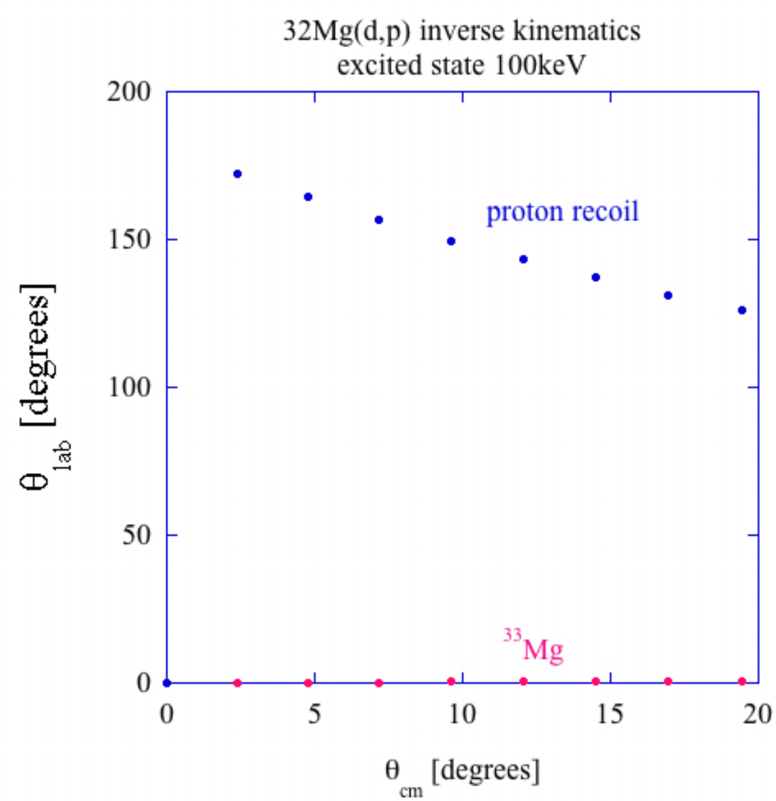
1) from normal kinematics to inverse kinematics



Normal kinematics versus inverse kinematics

- Example: d(^{32}Mg,^{33}Mg)p gs,100keV

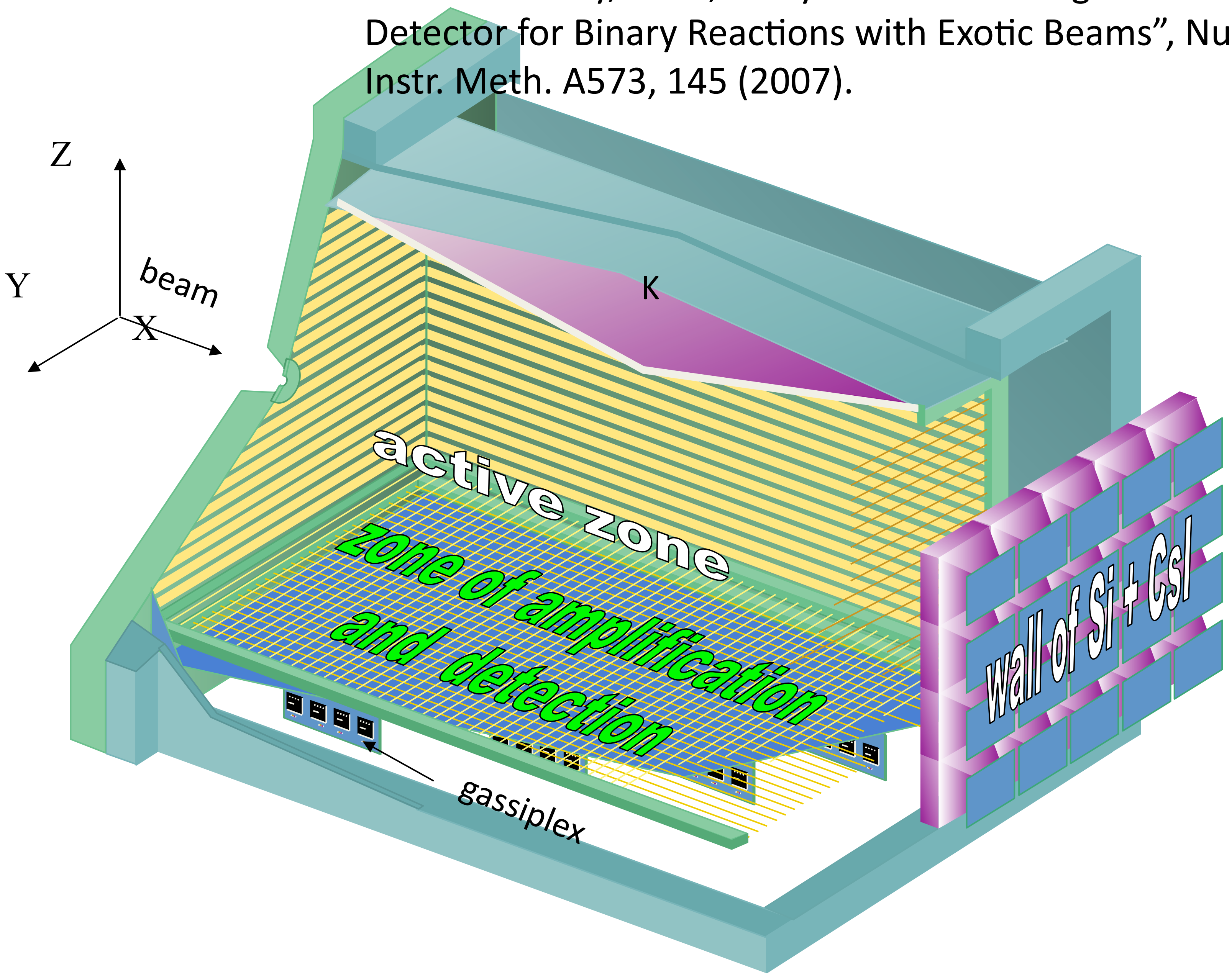




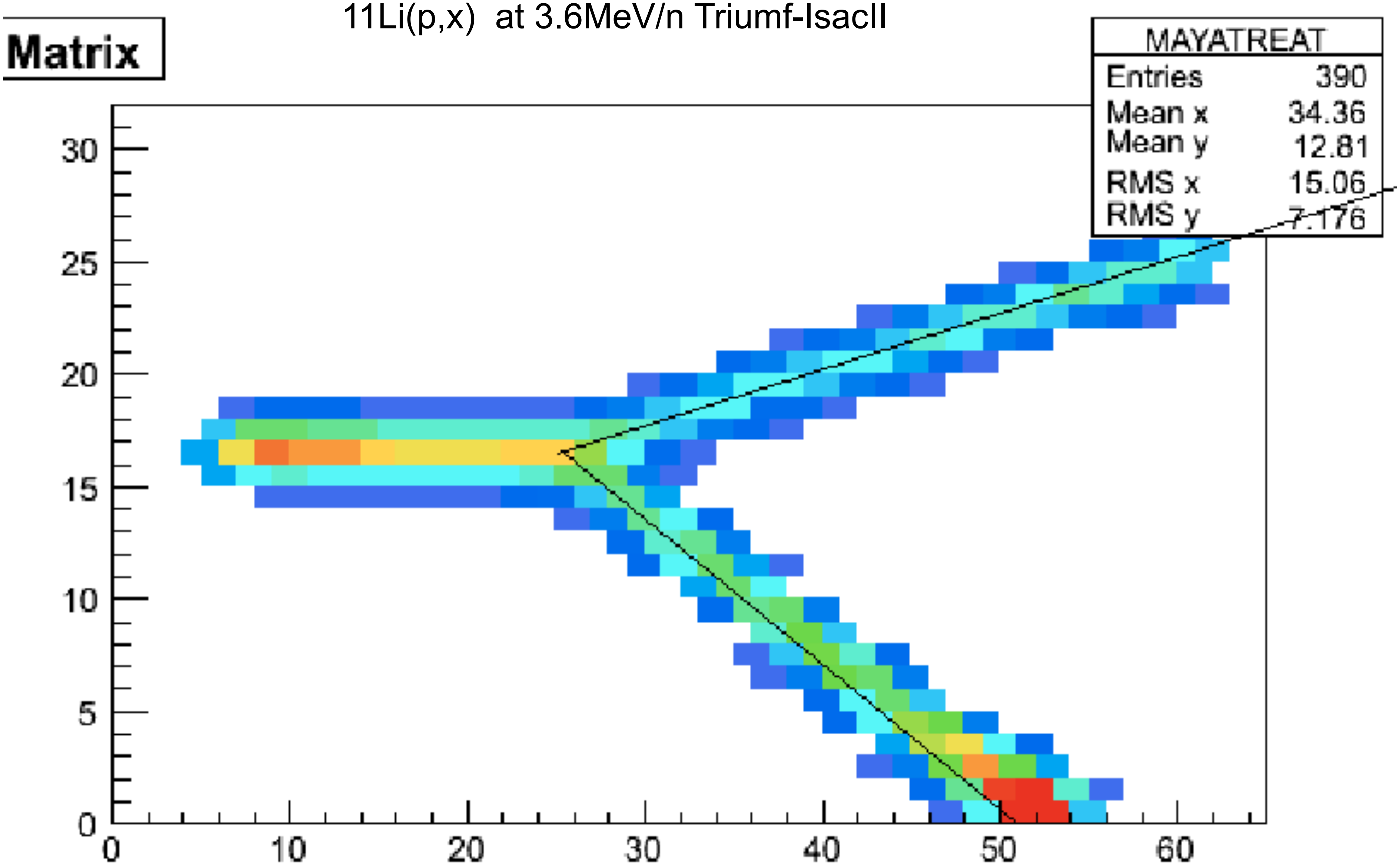
2) Beam Intensity ~10^{-9} with respect to stable beams

Thick Targets without resolution loss: tracking of reaction vertex
High detection efficiency: 4π

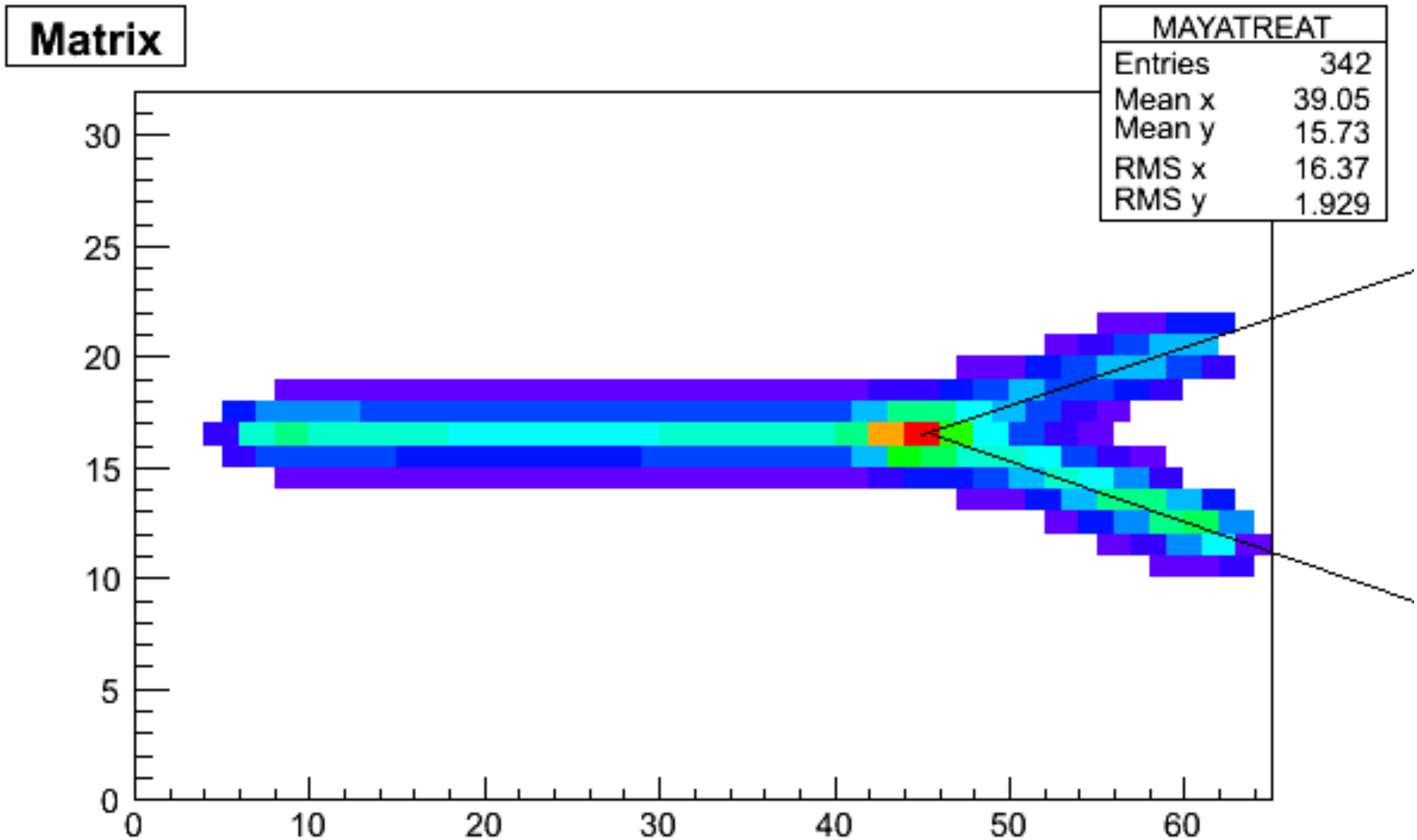
C.E. Demonchy, et al., "Maya: An Active-Target Detector for Binary Reactions with Exotic Beams", Nucl. Instr. Meth. A573, 145 (2007).



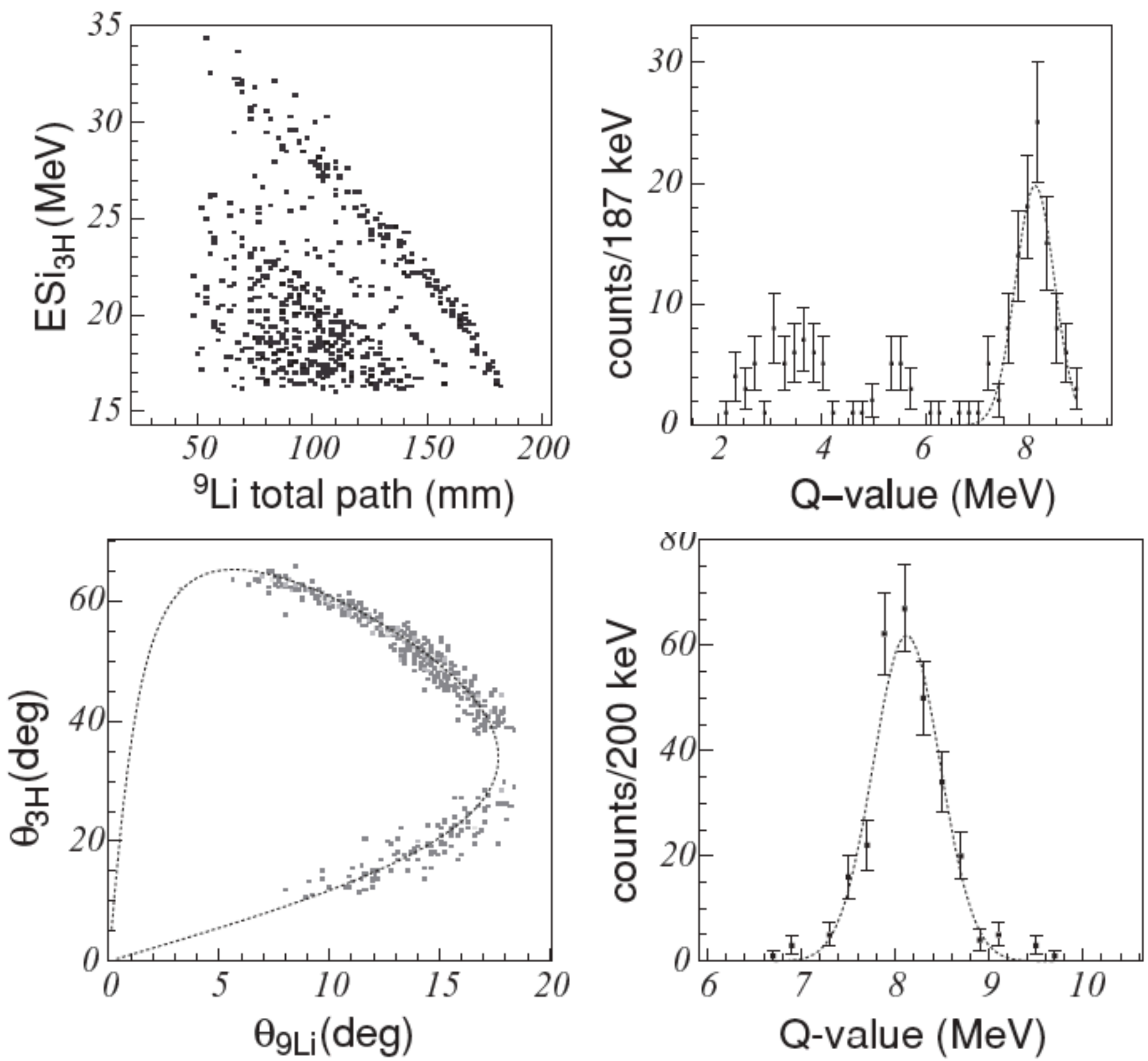
11Li(p,x) at 3.6MeV/n Triumf-IsacII



THOMAS ROGER, thesis sept 2009



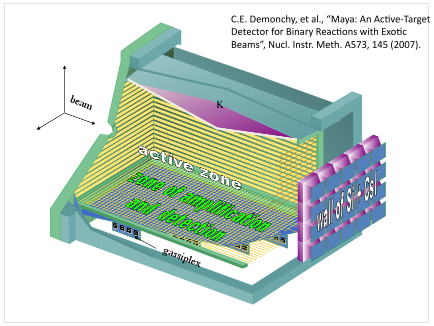
Matrix
MAYATREAT
Entries 342
Mean x 39.05
Mean y 15.73
RMS x 16.37
RMS y 1.929
0
5
10
15
20
25
30
0
10
20
30
40
50
60



Q=8.119(22)MeV

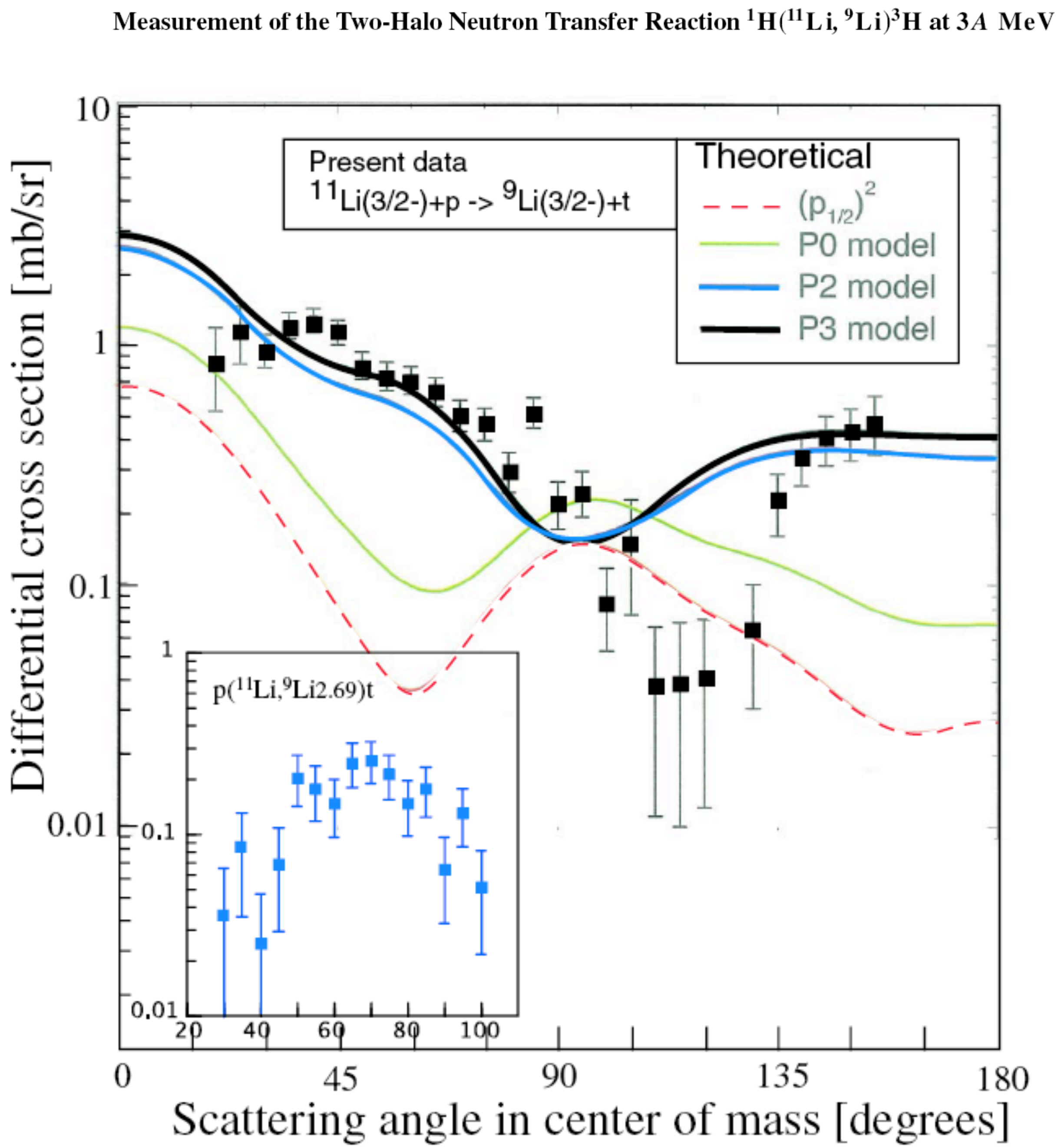
S2n = 363(22) keV

T.Roger et al PHYSICAL REVIEW C **79**, 031603(R) (2009)



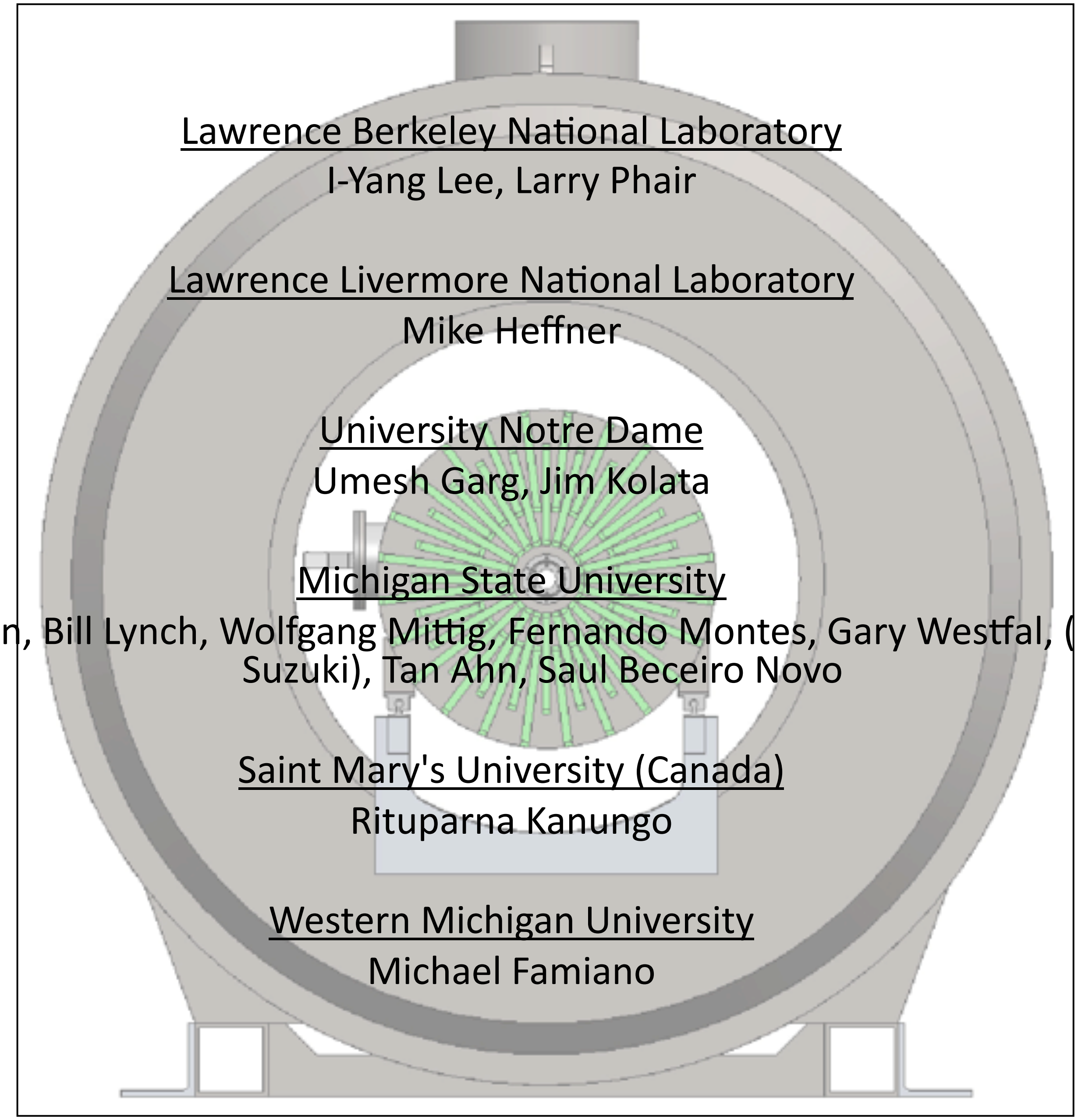
Experiment at Triumf-Isac

1-2*10^3 ^{11}Li/s



I.Tanihata et al., PRL 100, 192502(2008)

AT-TPC Collaboration



Lawrence Berkeley National Laboratory

I-Yang Lee, Larry Phair

Lawrence Livermore National Laboratory

Mike Heffner

University Notre Dame

Umesh Garg, Jim Kolata

Michigan State University

Daniel Bazin, Bill Lynch, Wolfgang Mittig, Fernando Montes, Gary Westfal, (Daisuke Suzuki), Tan Ahn, Saul Beceiro Novo

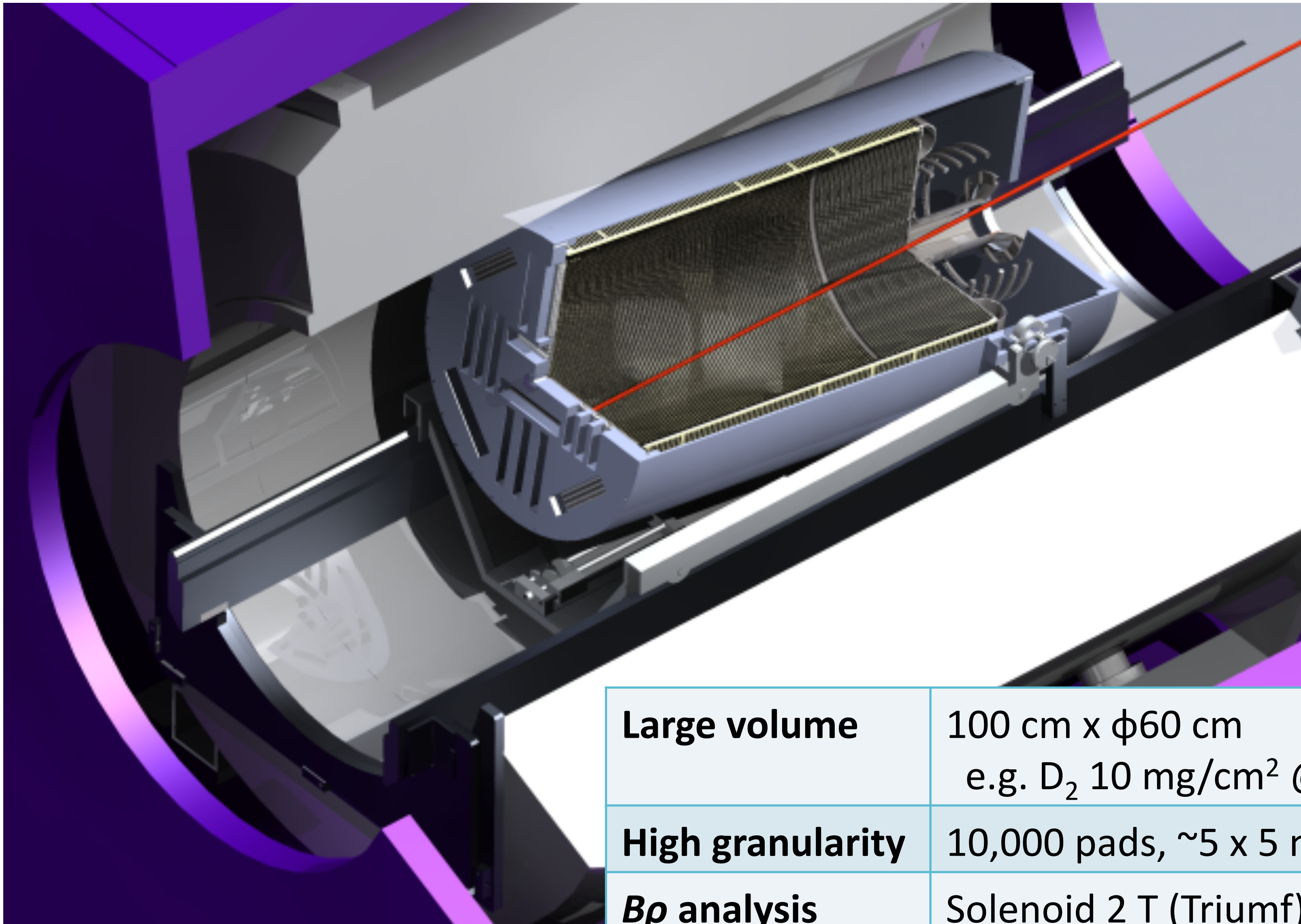
Saint Mary's University (Canada)

Rituparna Kanungo

Western Michigan University

Michael Famiano

Specifications



Large volume	100 cm x ϕ60 cm e.g. D_2 10 mg/cm^2 @ 1 atm
High granularity	10,000 pads, ~5 x 5 mm^2
***Bρ* analysis**	Solenoid 2 T (Triumf)

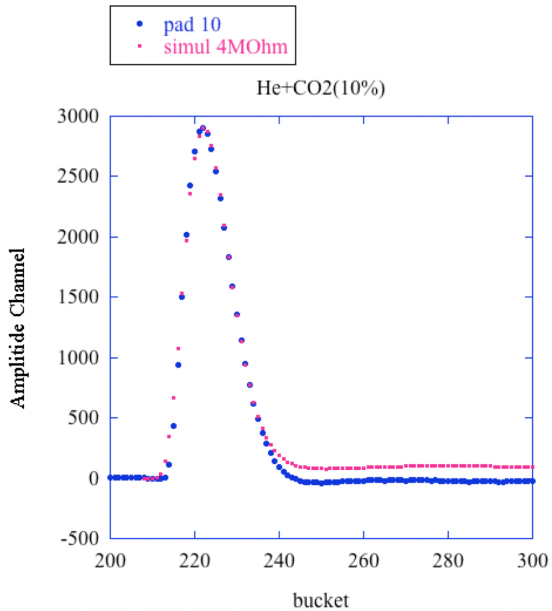
AT-TPC Scientific Program

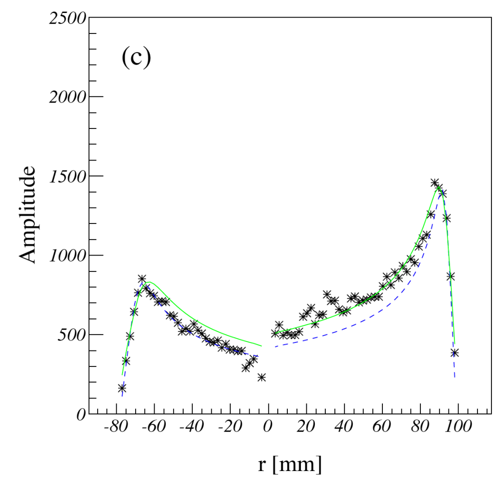
Table 1: Overview of the AT-TPC scientific program.

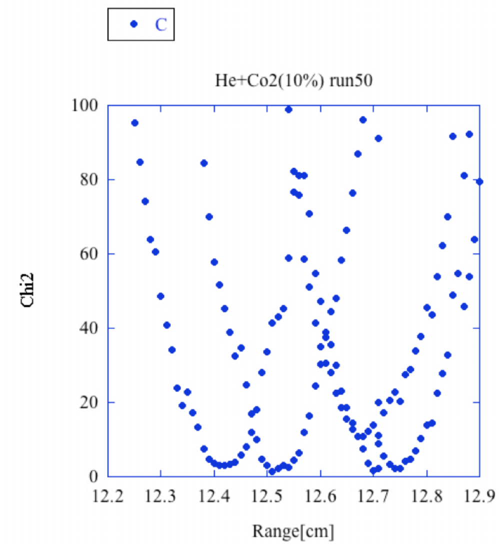
Measurement	Physics	Beam Examples	Beam Energy (A MeV)	Min Beam (pps)	Scientific Leader
Transfer & Resonant Reactions	Nuclear Structure	$^{32}Mg(d,p)^{33}Mg$ $^{26}Ne(p,p)^{26}Ne$ $^{66,..,70}Ni(p,p)$	3	100	Kanungo
Astrophysical Reactions	Nucleosynthesis	$^{25}Al(^{3}He,d)^{26}Si$	3	100	Famiano, Montes
Fusion and Breakup	Nuclear Structure	$^{8}B+^{40}Ar$	3	1000	Kolata
Transfer	Pairing	$^{56}Ni+^{3}He$	5-19	1000	Macchiavelli
Fission Barriers	Nuclear Structure	^{199}Tl, ^{192}Pt	20 - 60	10,000	Phair
Giant Resonances	Nuclear EOS, Nuclear Astro.	^{54}Ni-^{70}Ni, ^{106}Sn-^{127}Sn	50 - 200	50,000	Garg
Heavy Ion Reactions	Nuclear EOS	^{106}Sn - ^{126}Sn, ^{37}Ca - ^{49}Ca	50 - 200	50,000	Lynch

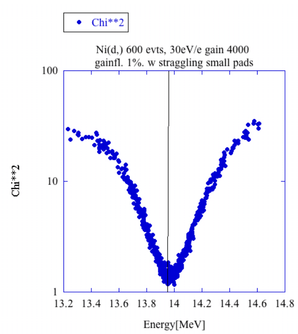
- Detector will make use of the full range of beam energies and intensities available at NSCL & FRIB
- Experiments with rare isotope beams continuously push the limits of low beam intensities and low cross sections
- AT-TPC will address these limitations by providing access to reactions at beam intensities as low as 100pps

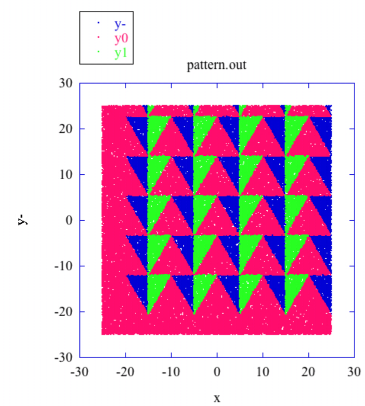
Simulations

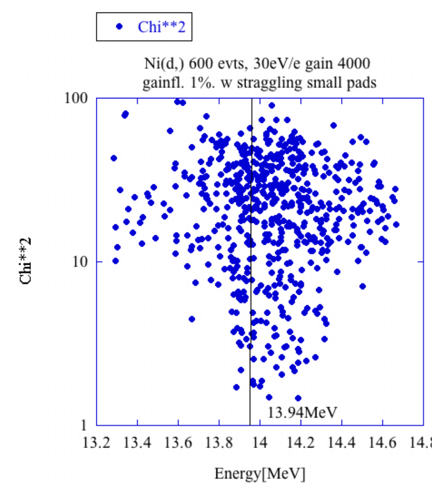


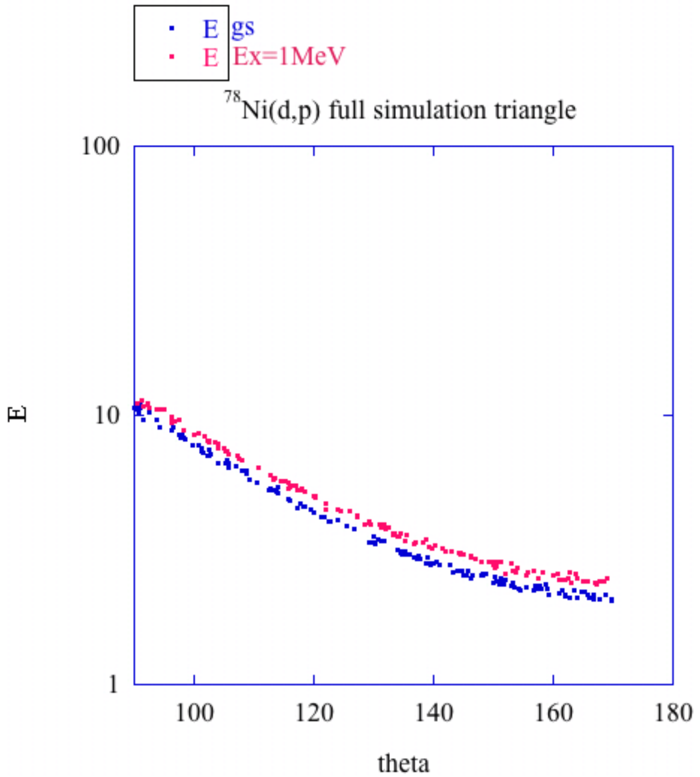


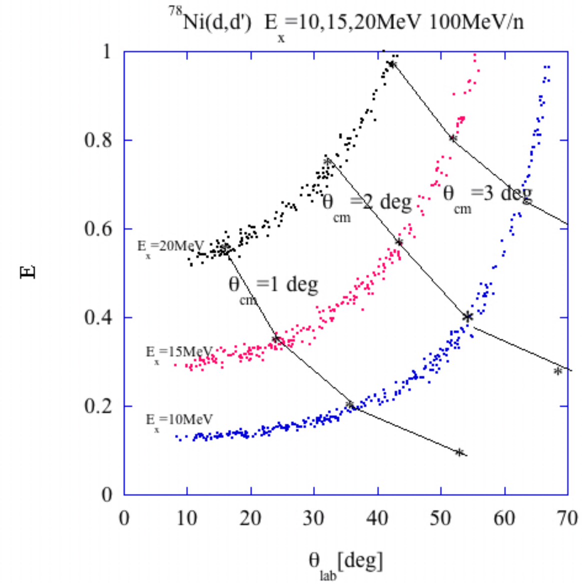






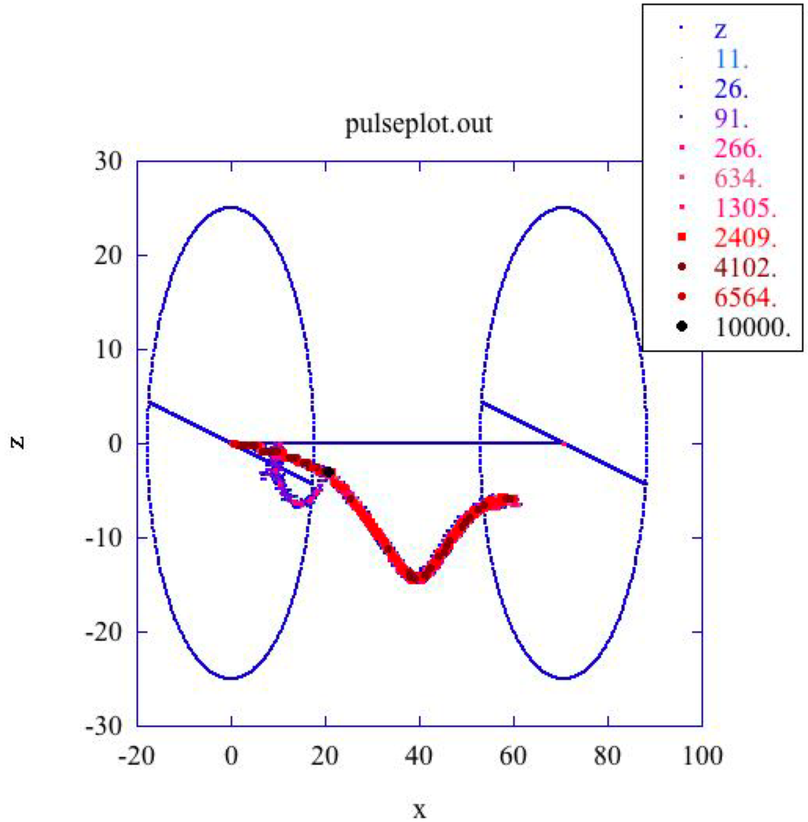




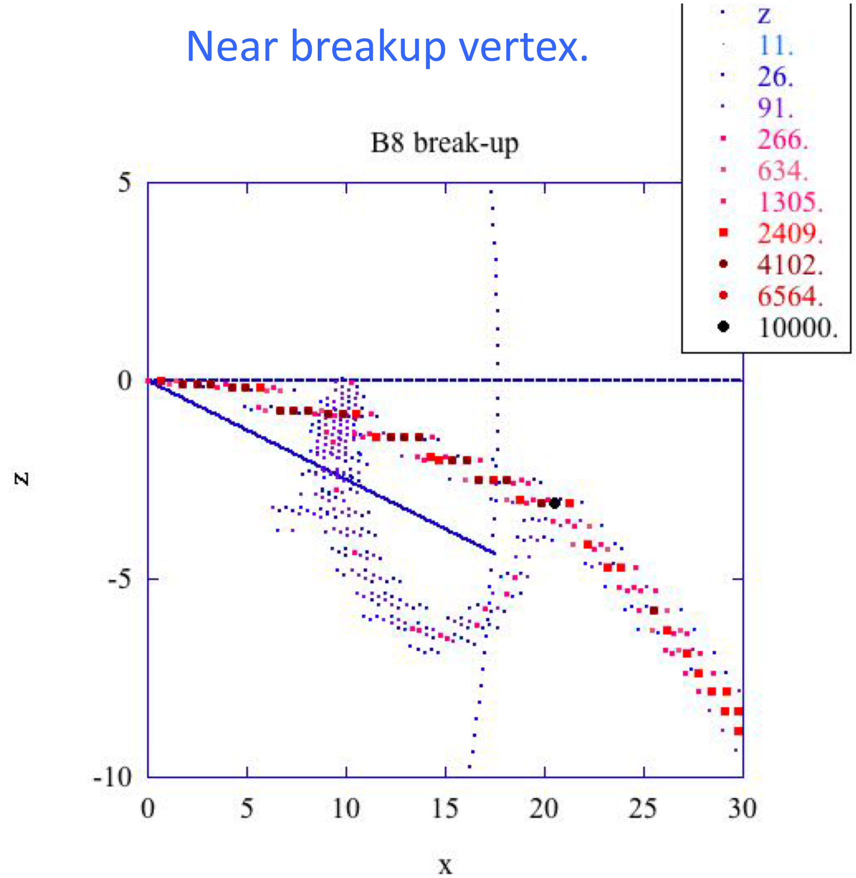


More generally, the aim is to develop a device that provides a resolution for nuclear structure studies in inverse kinematics with a resolution comparable to the one achieved in direct kinematics with high resolution spectrometers, together with highest efficiency and thick targets

Breakup simulation $^{8}B \rightarrow {}^{7}Be+p$.



Near breakup vertex.



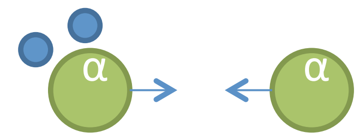
- Resolution of the recoil energy ~2% for fusion events.
- Proton track clearly visible and its properties can be measured.
- Care must be taken to prevent rejection as a “non-interacting” event.

Prop: J.Kolata

Concept of Prototype AT-TPC:
a half size simplified version
test of critical components and low energy physics experiments

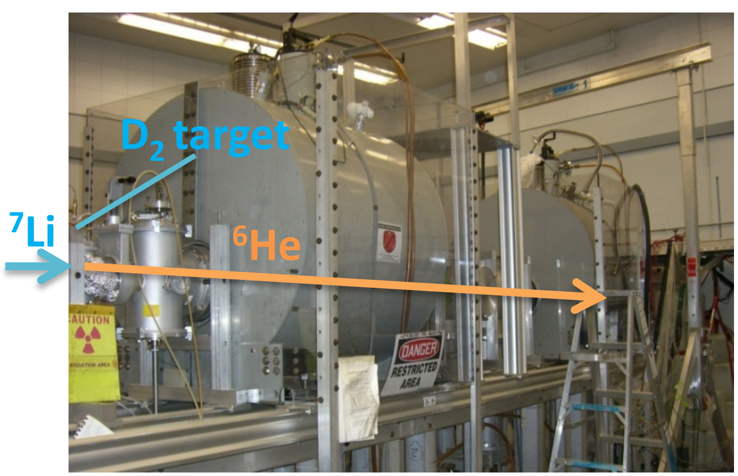
^{6}He + α reactions at Notre Dame
D.Suzuki et al.

- Alpha clustering & neutron correlation in 2α - 2*n* system
- Multiple channel recording



^{6}He + α -> ^{6}He + α [elastic, 2*n* exchange]
^{6}He(2^+) + α [inelastic]
^{10}Be*, ^{9}Be + *n*, ^{8}Be + 2*n* [fusion, resonance, transfer]

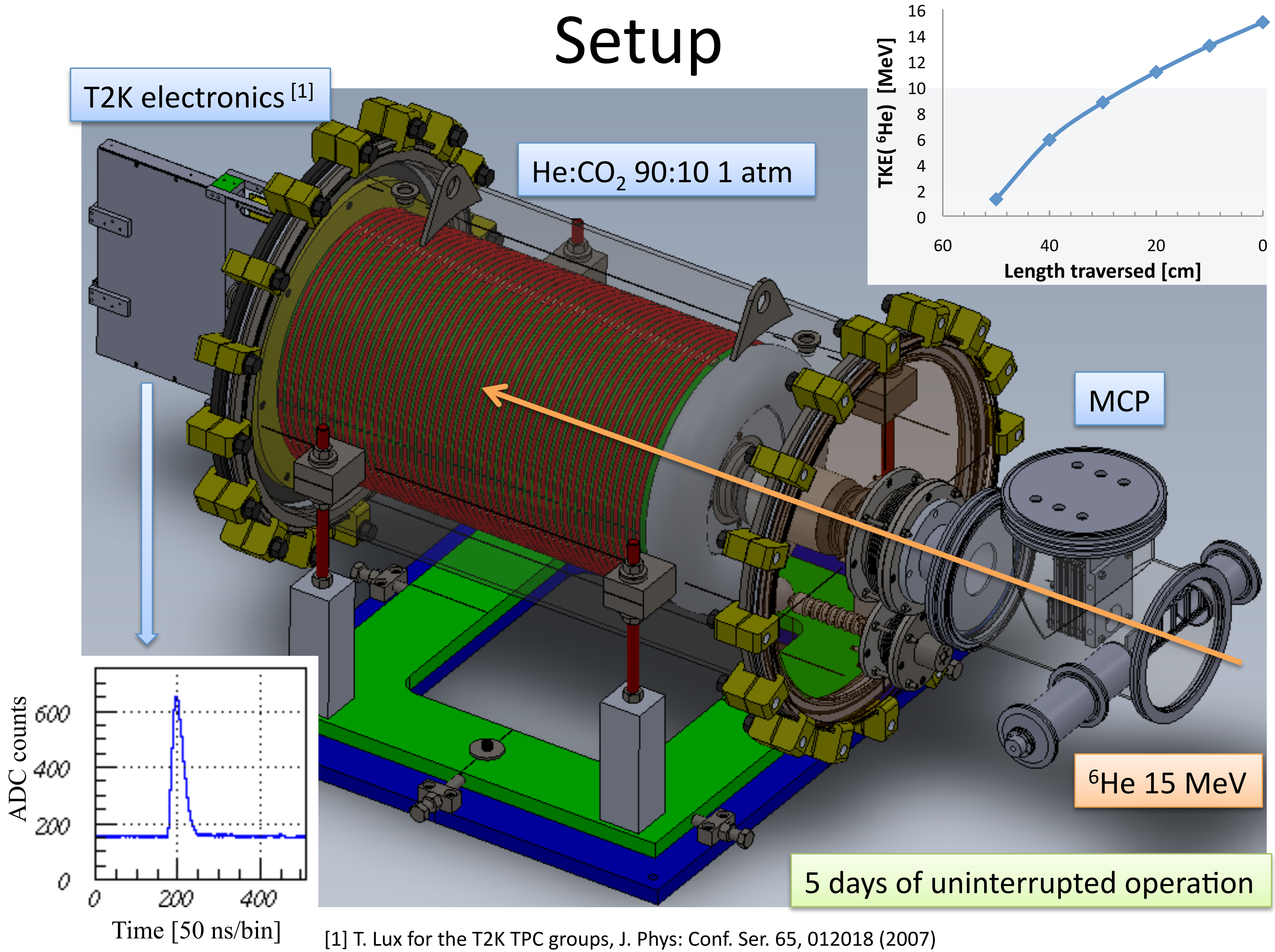
- Continuous energy scan
  - Energy loss of beam in traversing the gas



^{7}Li(*d*,^{3}*He*)^{6}He @ Twinsol[1]
- 15 MeV
- 1 kpps in TPC
- ^{6}He 90% ^{4}He 10%

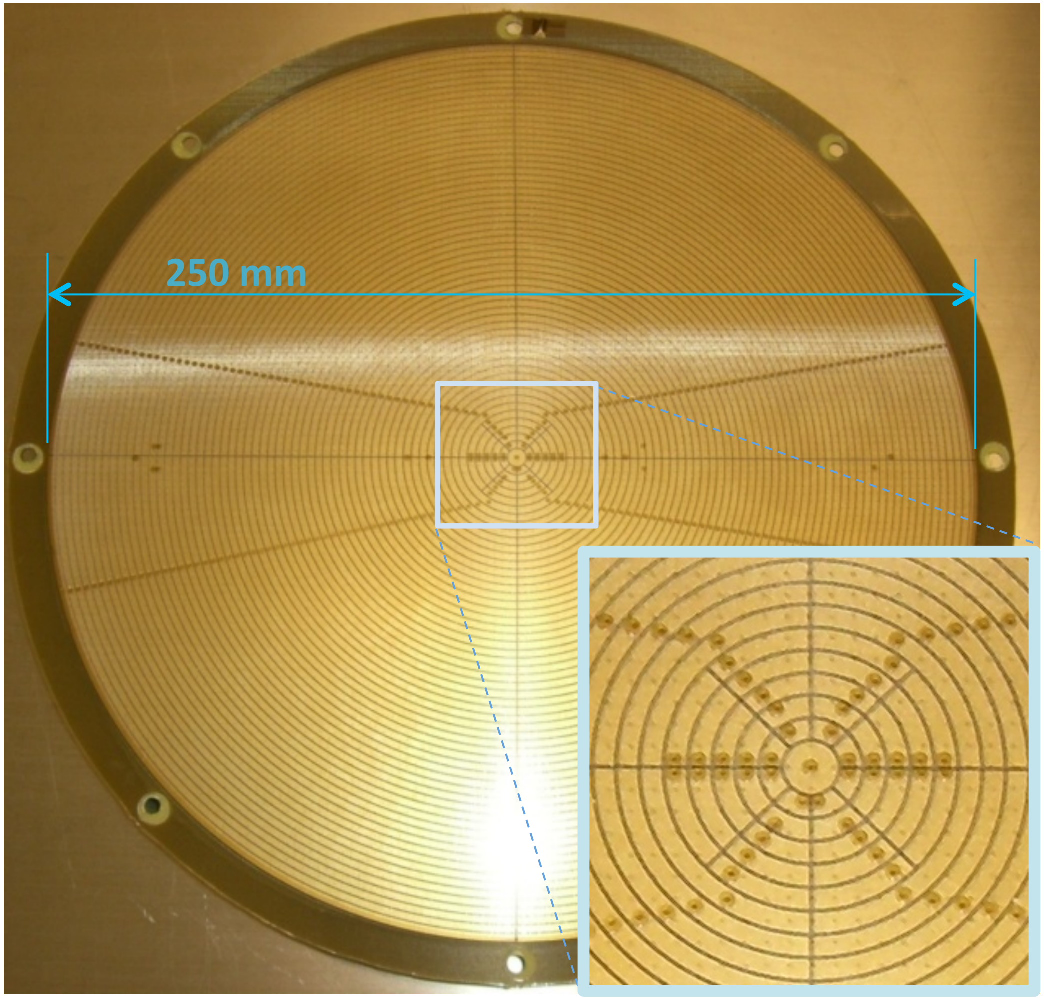
[1] F. Becchetti et al., NIM A 505, 377 (2003)

Setup

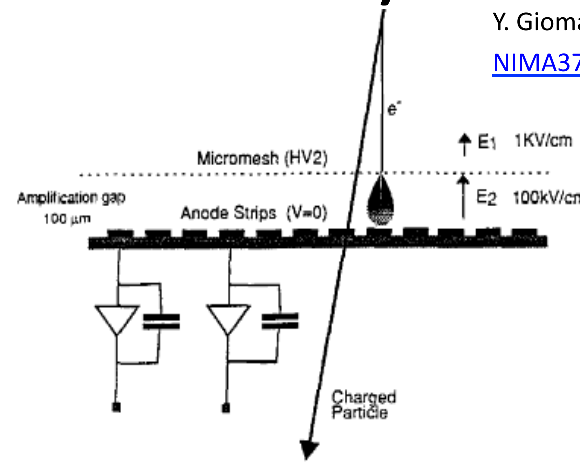


[1] T. Lux for the T2K TPC groups, J. Phys: Conf. Ser. 65, 012018 (2007)

Micromegas (Testchamber)



Y. Giomataris et al., [NIMA376, 29 (1996)]

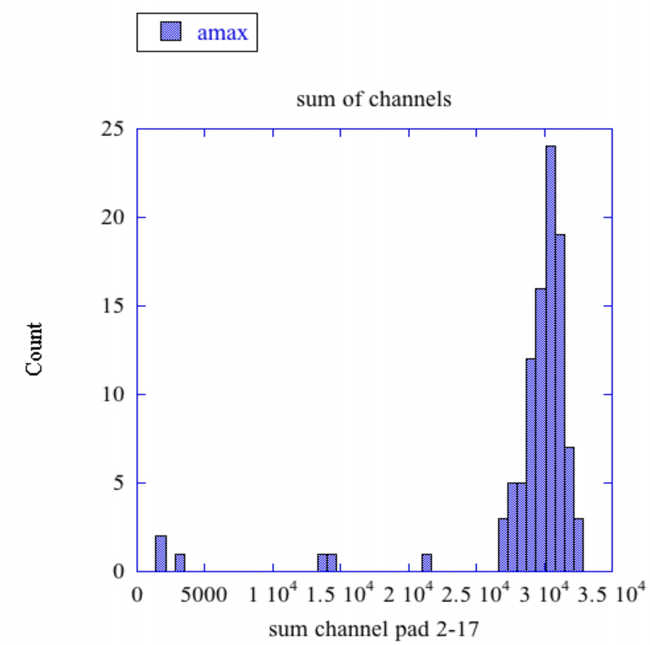


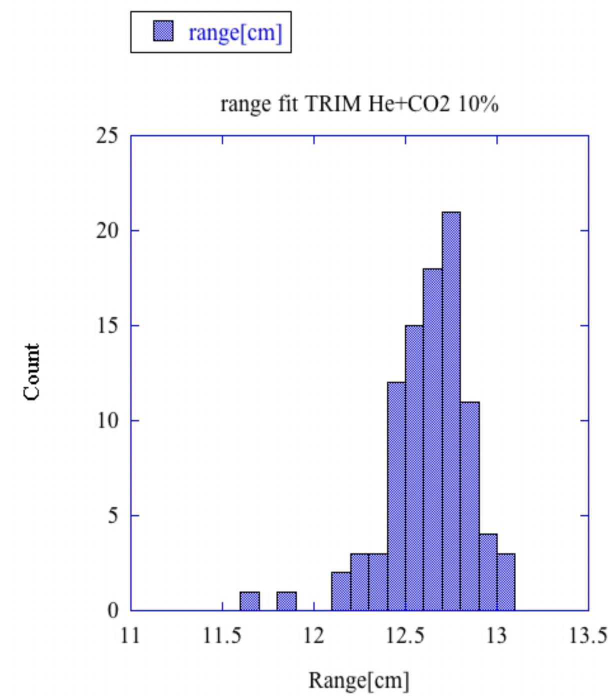
D. Suzuki et al.,NIM A 660 (2011) 64–68

δE = 200 keV FWHM
(for He:CO_2 90:10 with ^{241}Am)

- Optimized for binary reactions & Minimize the data size
- Coaxial strips; 2-mm width x 90° sector
- PCB by NSCL, micromegas by IRFU-SEDI

Resistive Micromegas He + CO_2(10%)





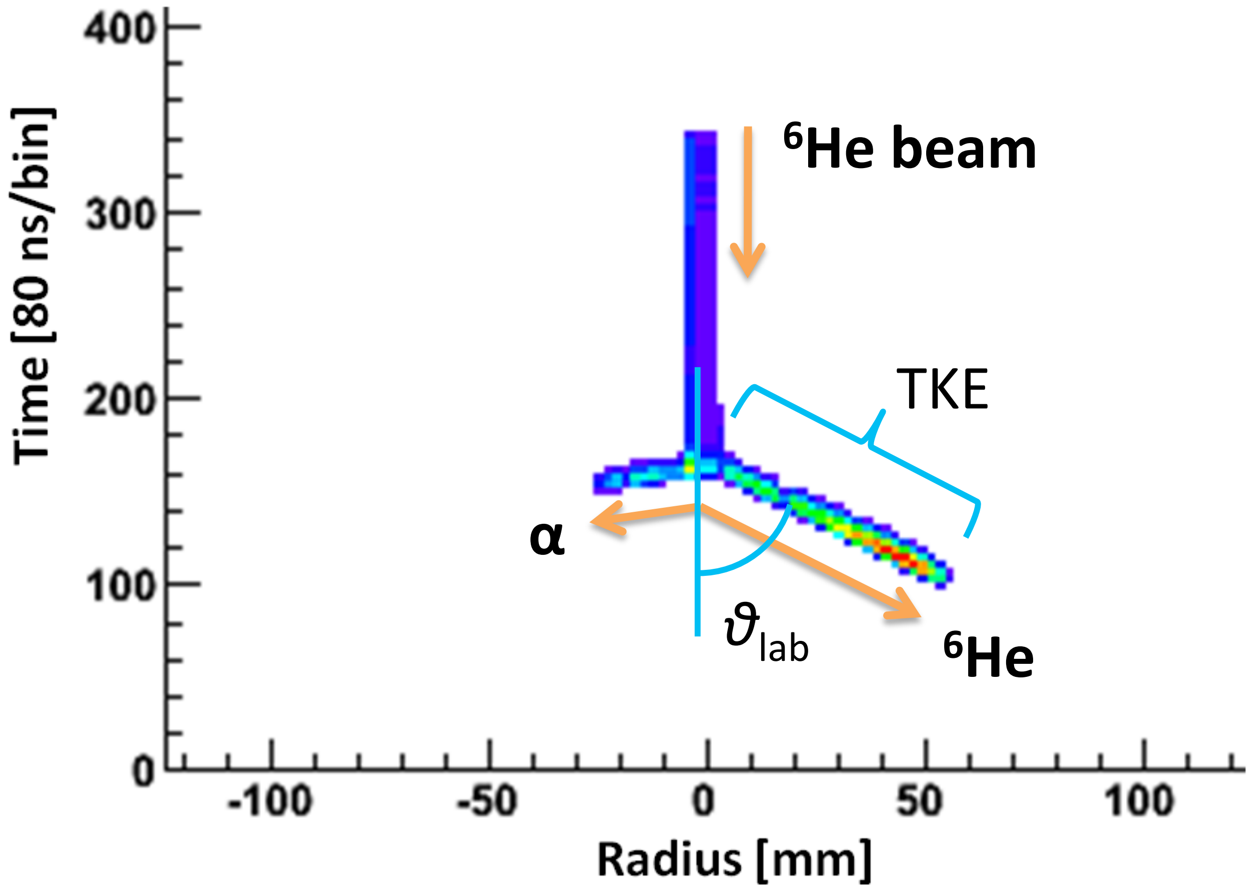
Resolution charge collection of 6%

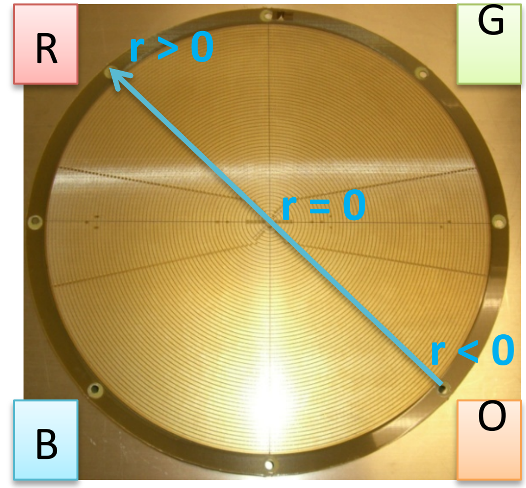
Resolution range of 4mm FWHM, or an energy resolution of 110keV FWHM for 5.5MeV Alphas

Resistive micromegas from Rui de Oliveira, Cern

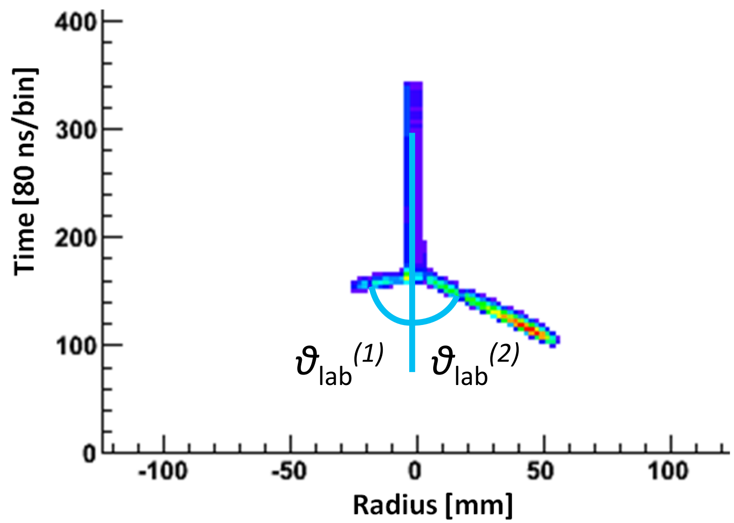
D.Suzuki et al.: Nuclear Instruments and Methods in Physics Research A 660 (2011) 64–68

Tracking

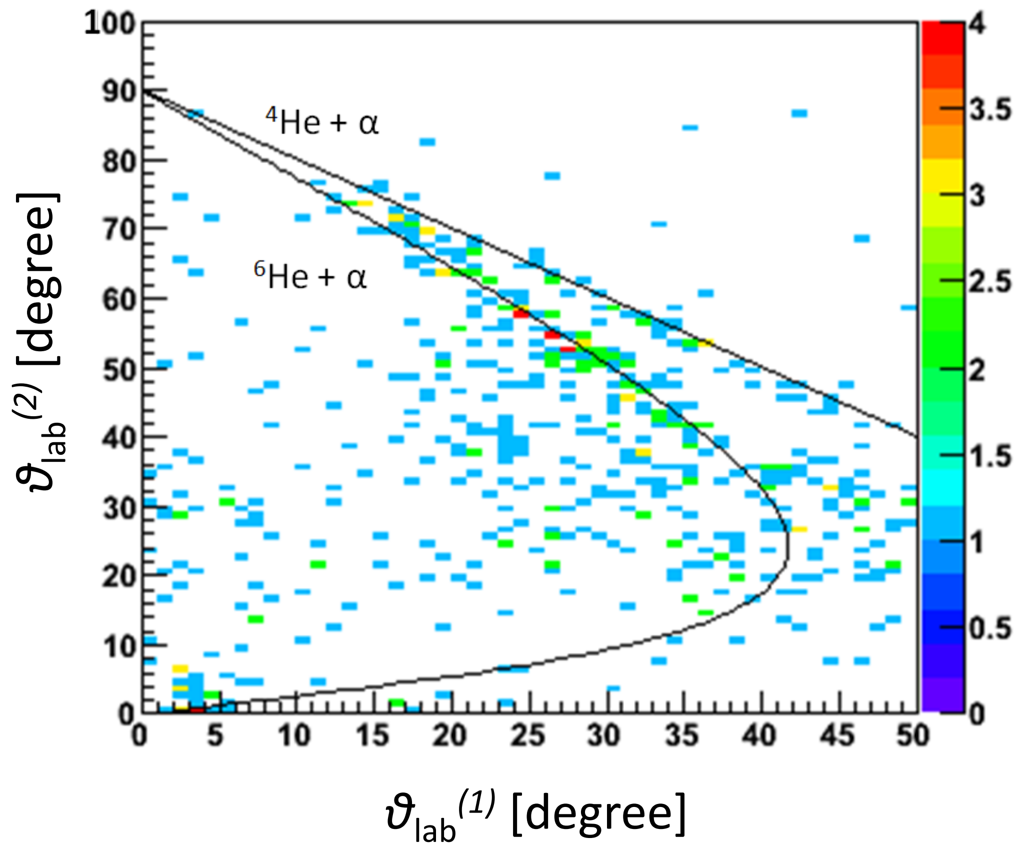

400
300
200
100
0
Time [80 ns/bin]
-100
-50
0
50
100
Radius [mm]
6He beam
TKE
α
ϑlab
6He


R
G
B
O
r > 0
r = 0
r < 0

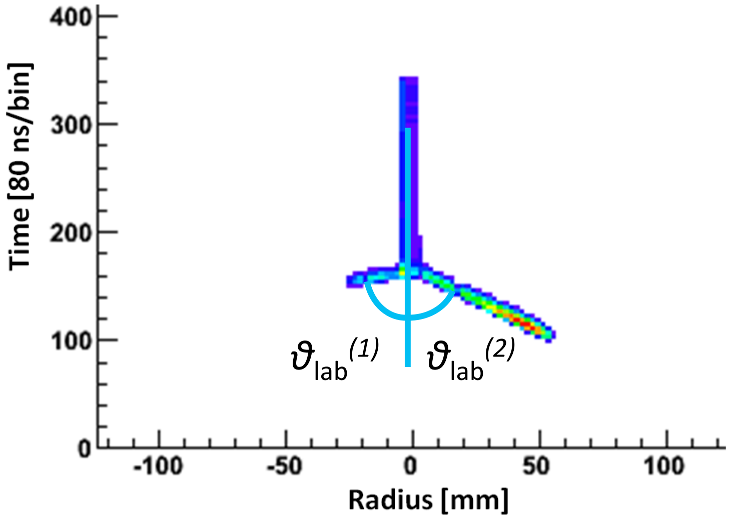
Reconstruction of ^{6}He



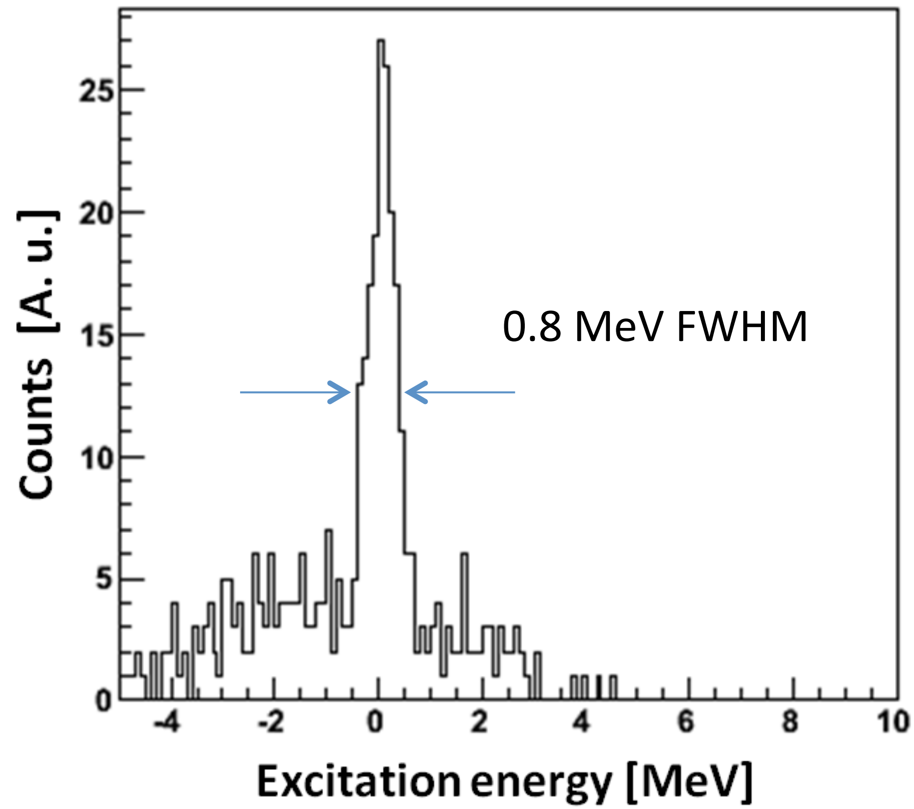
$(\vartheta_{lab}^{(1)}, \vartheta_{lab}^{(2)})$ -> (E_x, ϑ_{CM})



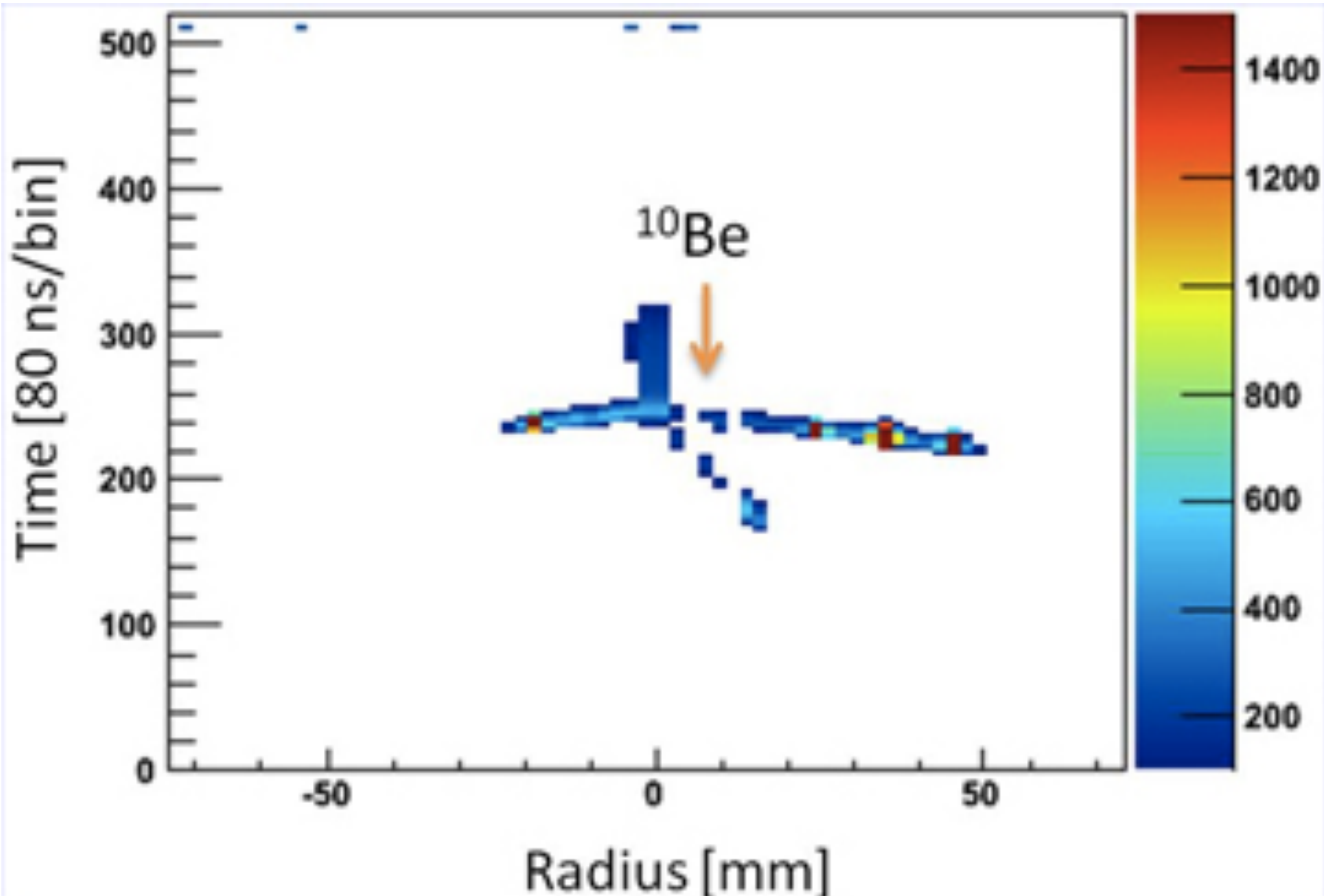
Reconstruction of ^{6}He



$(\vartheta_{lab}^{(1)}, \vartheta_{lab}^{(2)}) \rightarrow (E_x, \vartheta_{CM})$



Prototype Exp. $^{10}Be + ^{4}He$



A snapshot of a moment when three particles are coming out of a collision between 10Be and an alpha target nucleus in the prototype AT-TPC.

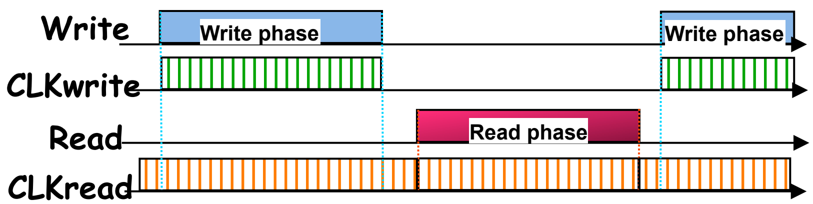
AGET: Sampling Capacitor Array

SCA: Circular Memory

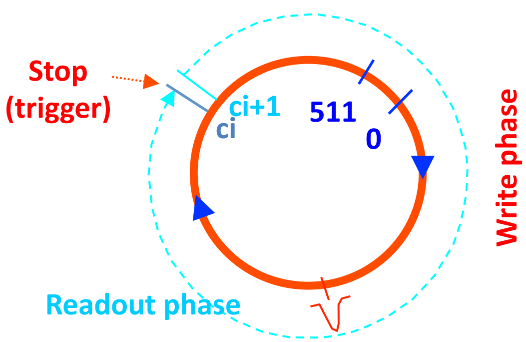
64 channels + 4 dummy channels

[for common mode or Fix pattern noise rejection purpose].

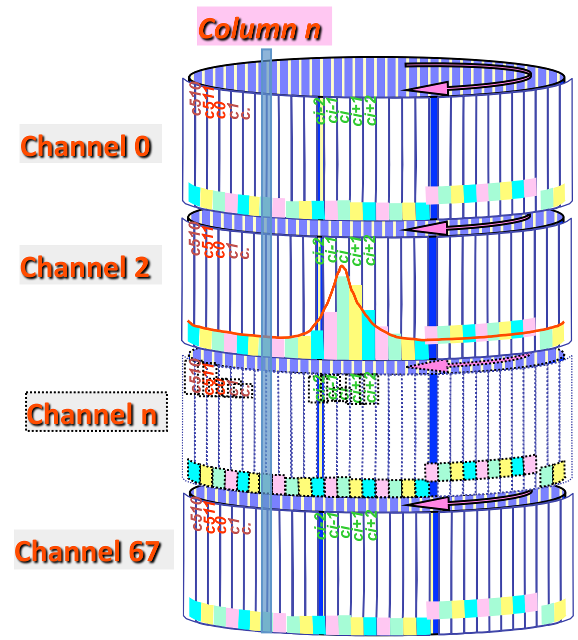
- **Write: 1MHz to 100MHz**
- **Read: 25MHz**



AFTER-like readout



<u>Write phase:</u>
Tdrift ≤ 512 / Fsampling
<u>Read phase:</u>
SCAcells = 512



SCA: circular memory

P.Baron-IRFU

General Electronics for TPCs: GET

IRFU, GANIL, CENBG

MSU, (RIKEN)

For different detectors

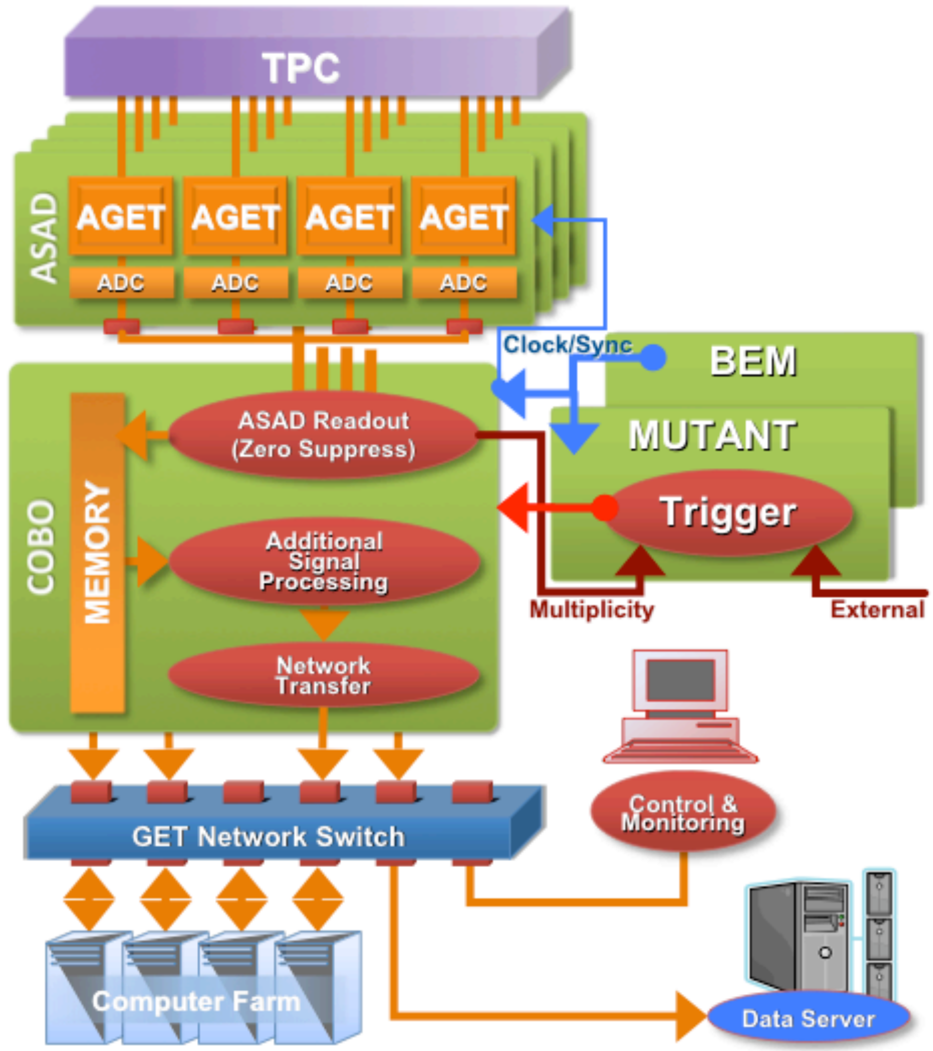
AT-TPC: ~10000channels

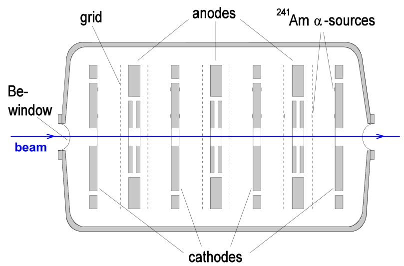
Data flow at 1000cts/s

$512*10^4*10^3*2$

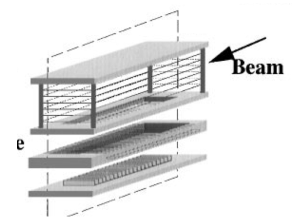
$\sim10^{10}$ bytes/s

=10Gbytes/s before reduction

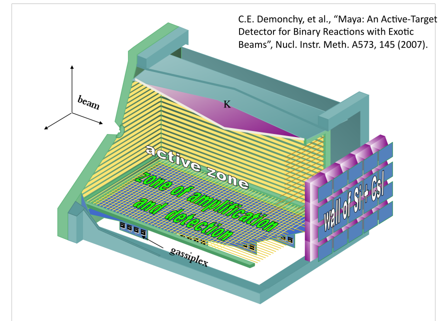




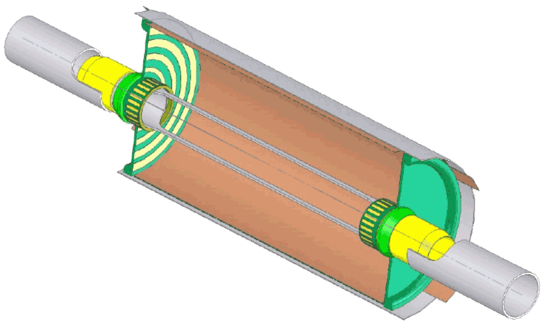
IKAR-GSI



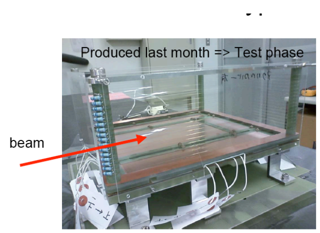
Mizoi et al MSTPC



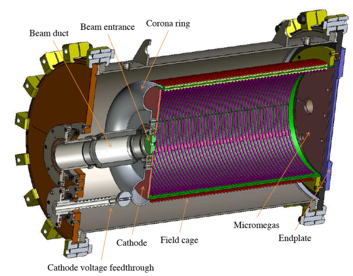
Maya@Ganil



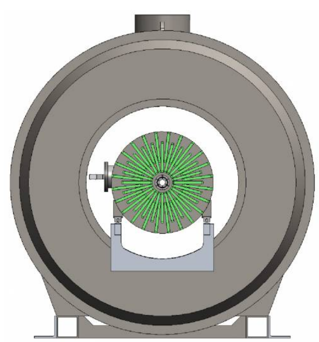
TACTIC: York-TRIUMF Collaboration



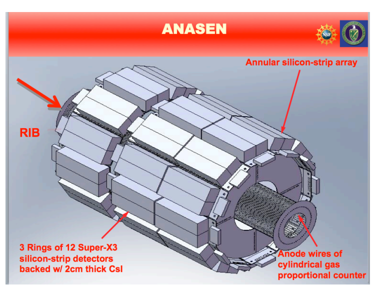
CNS-Riken



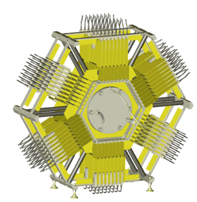
Prototype AT-TPC at MSU



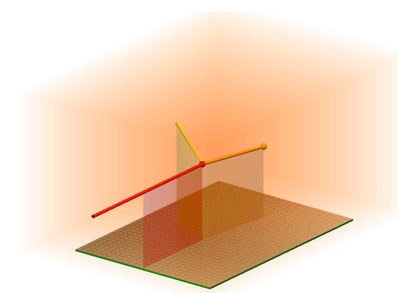
AT-TPC at MSU



Anasen



Fission TPC LLNL

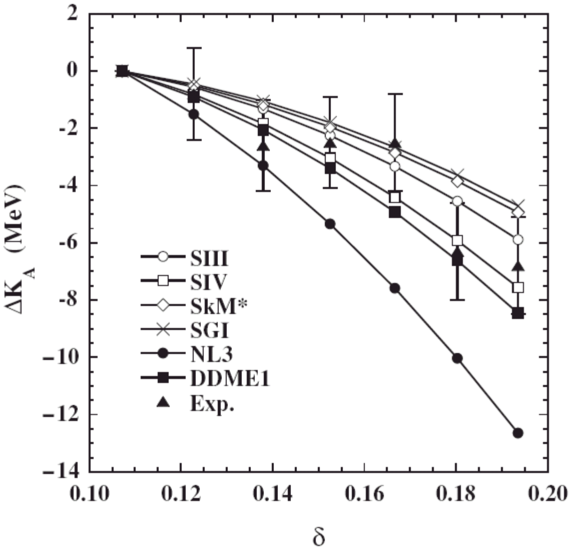


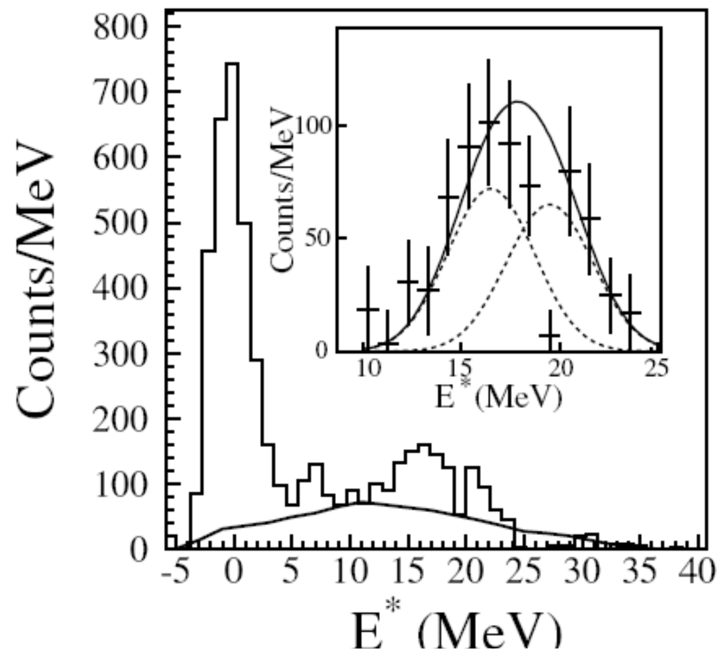
Actar-Ganil-Saclay-CENBG

Conclusion

- **Operating Active Targets have already produced many results**
- **The AT under development will improve dynamics and resolution, and may be used for a broad range of studies (nuclear structure, nuclear astrophysics, reaction mechanism,…)**
- **If we reach the limit of straggling for the resolution, these very high efficiency detectors will allow high resolution experiments in inverse kinematics comparable to the one obtained with best spectrometers for direct kinematics, such as S800, SPEG, Raiden,…**

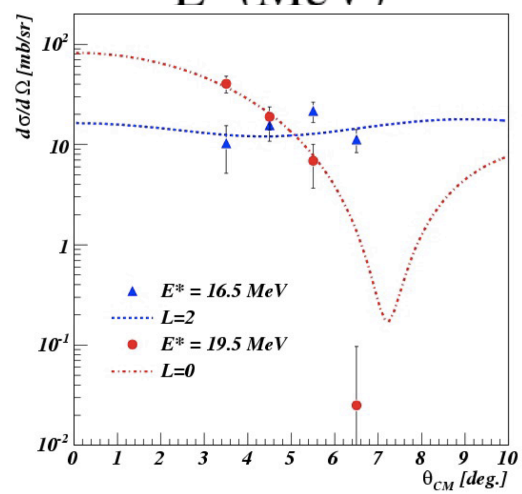
$K^A = K^\infty + K^{surf} A^{-1/3} + K^\tau ((N-Z)/A)^2 + K^{coul} A^2/Z^{4/3}$

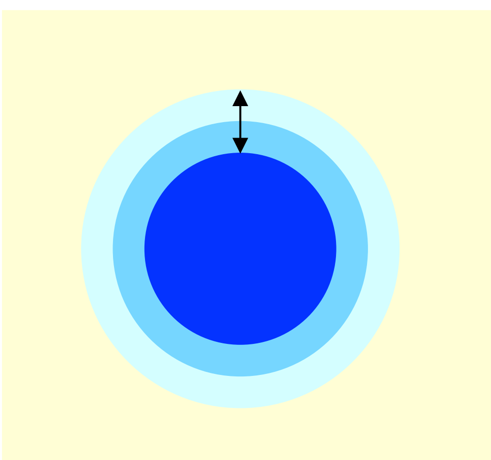




T. Li et al., Phys. Rev. Lett. 99, 162503 (2007)

H. Sagawa et al., Phys. Rev. C 76, 034327 (2007)





$$E_{GMR} = \hbar \sqrt{\frac{K_A}{m\langle r^2 \rangle}}$$

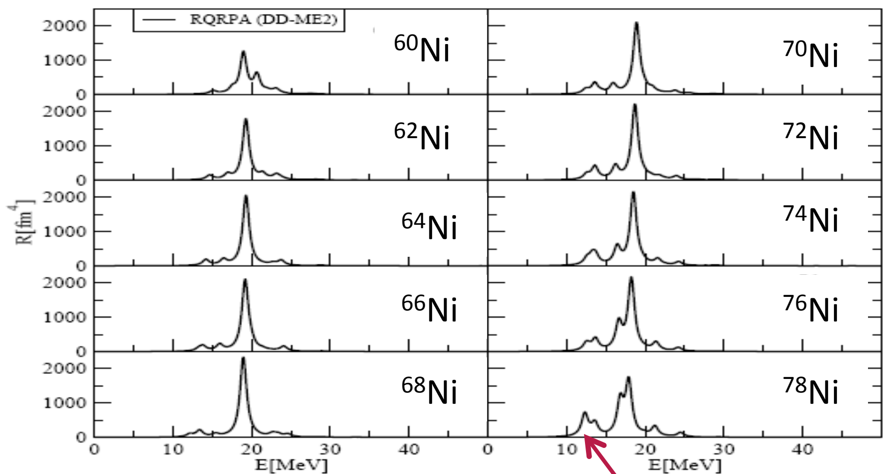
C. Monrozeau et al., Phys. Rev. Lett. 100, 042501 (2008)

^{68}Ni (Marine Vandenbrouk, E.Khan et al., 2011)

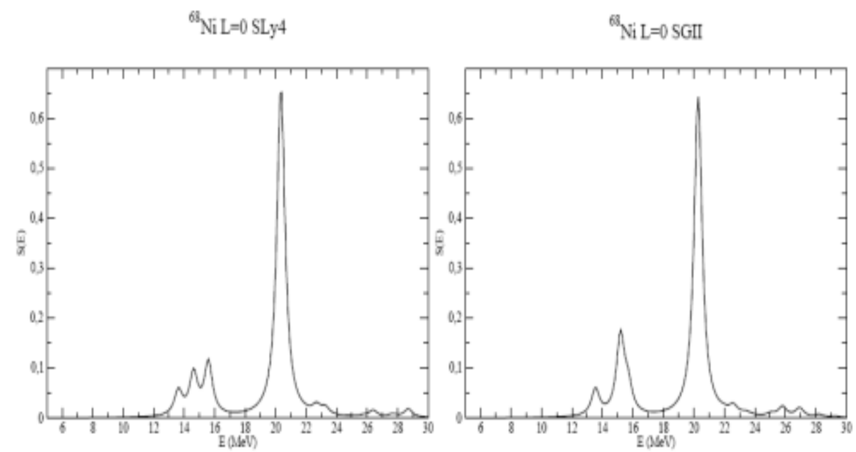
Theory motivations

Prediction of Monopole strength in Ni neutron rich isotope

^{68}Ni



Pygmy GMR



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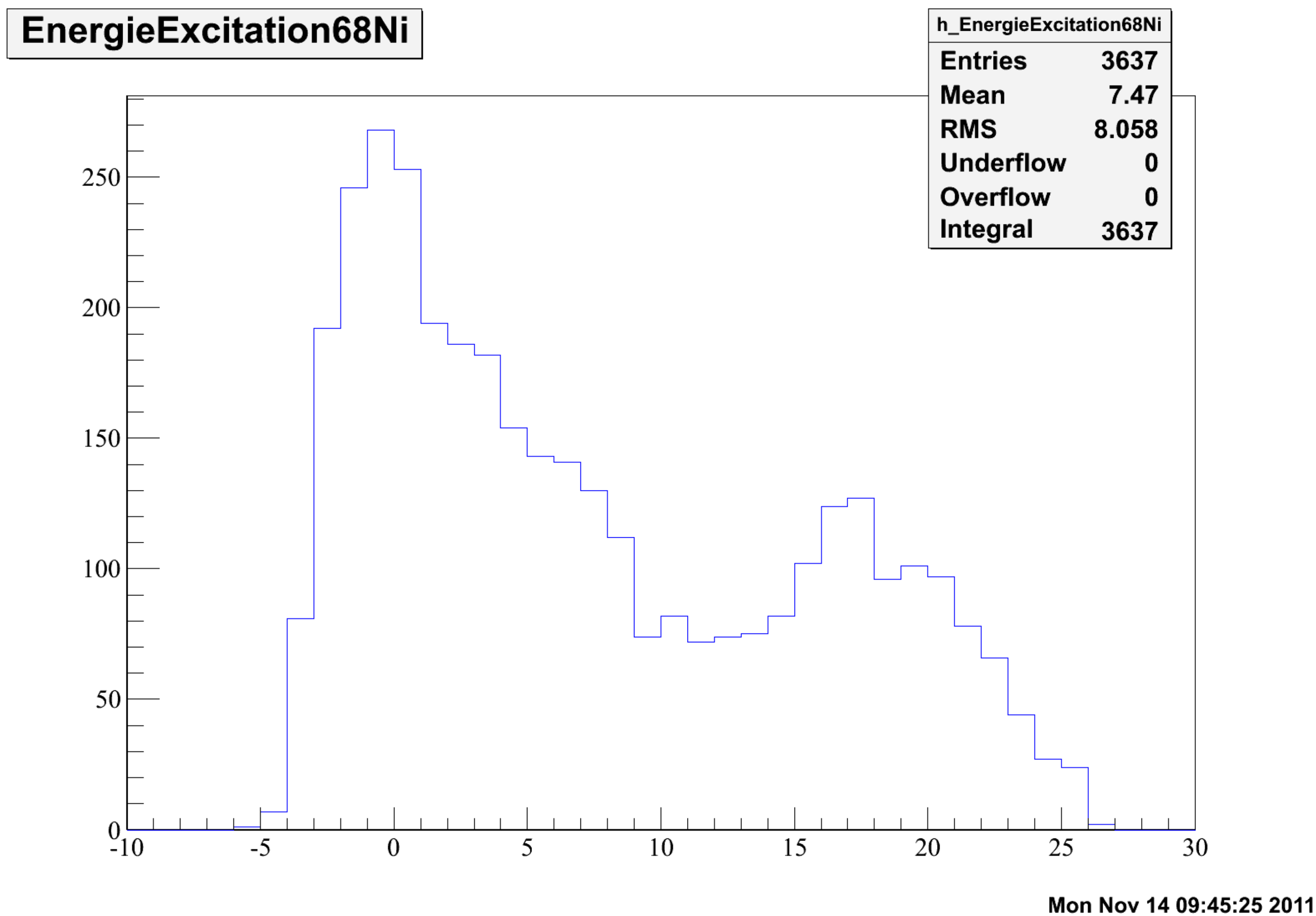
Submitted to Phys. Rev. C

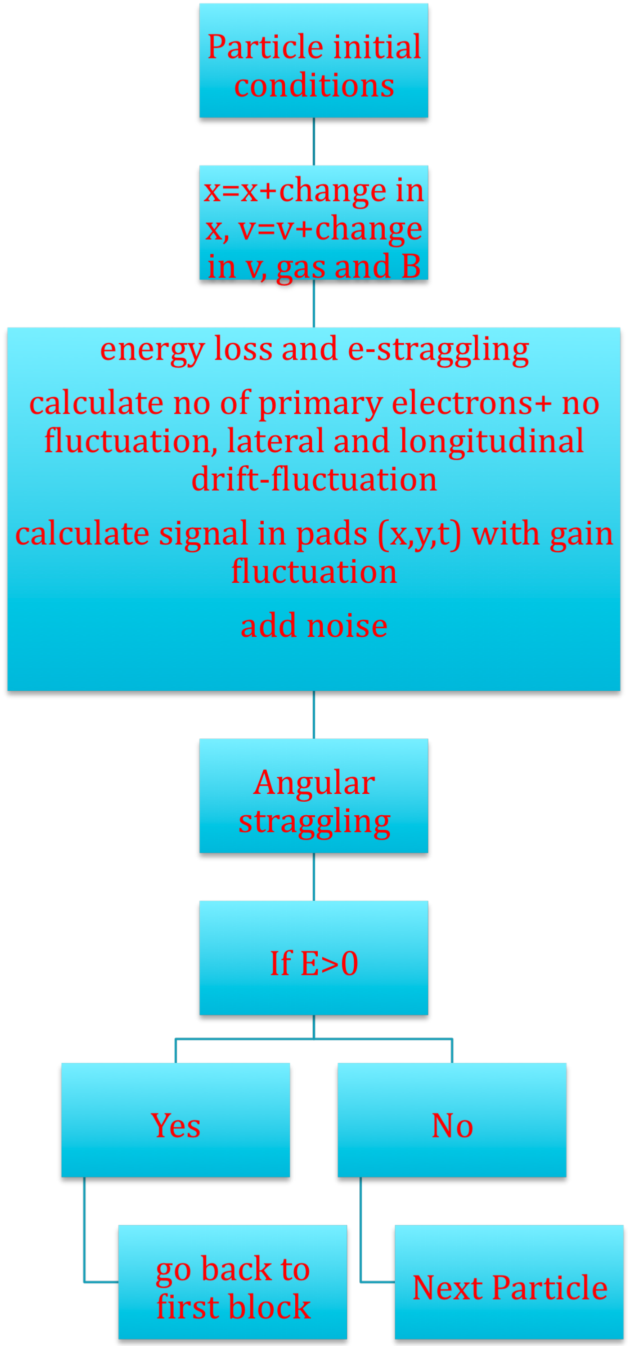
Study ISGMR and ISGQR in a neutron-rich Ni : ^{68}Ni

68Ni-preliminary



Full MC simulation of event +analysis

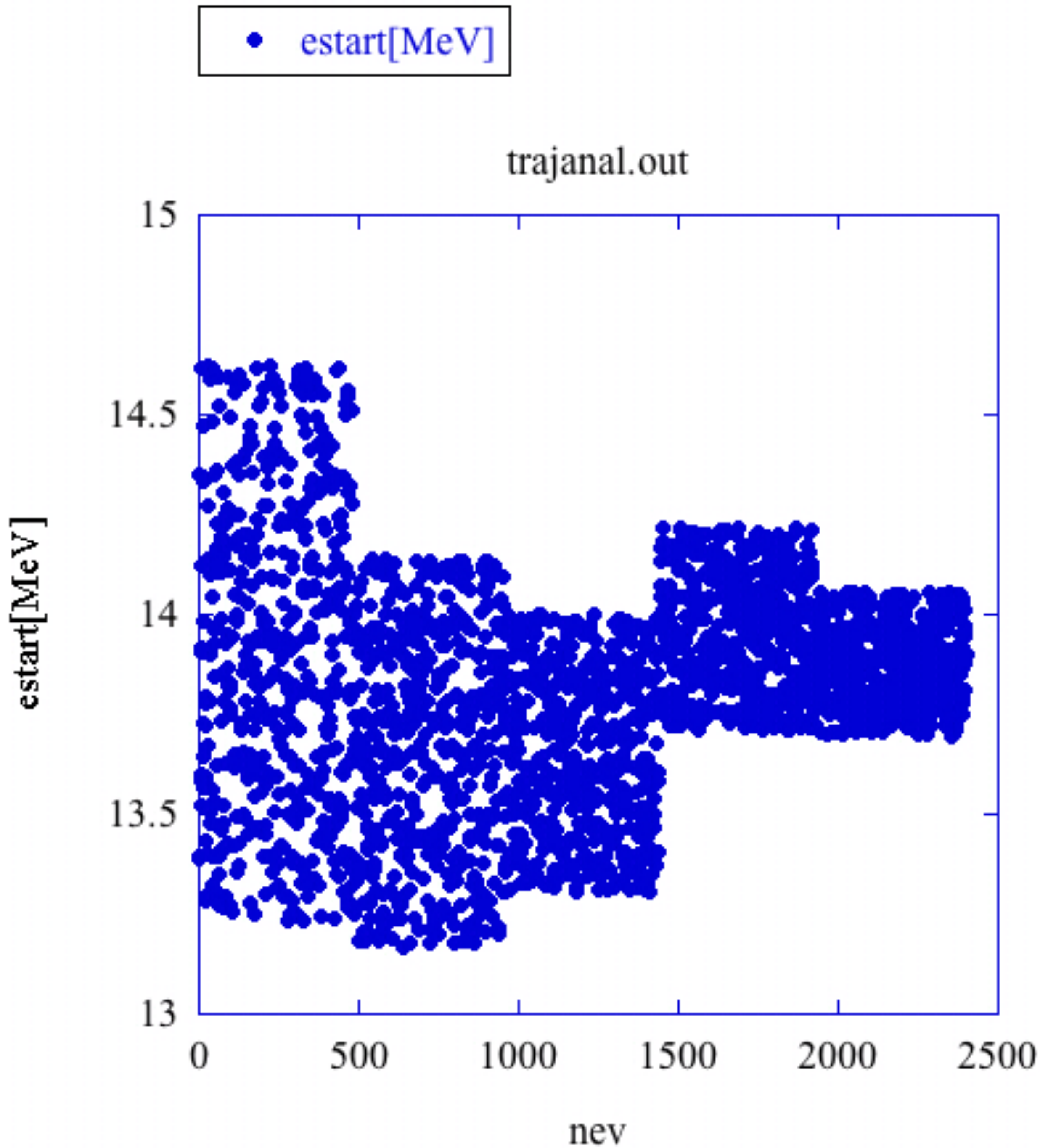
1. Create a MC track with random kinematic conditions (at the moment 2-body reaction, given reaction, theta phi random)
2. Produce tracks in the 6 dimensional space with dx,dy,dz,dtheta,dphi, dE around the values of step 1;
3. find Chi2 minimum, decrease dx,dy,dz,dtheta,dphi,dE by factor 1.5; go to 2, repeat until window small (I use 6 iterations)


Particle initial conditions
x=x+change in x, v=v+change in v, gas and B
energy loss and e-straggling
calculate no of primary electrons+ no fluctuation, lateral and longitudinal drift-fluctuation
calculate signal in pads (x,y,t) with gain fluctuation
add noise
Angular straggling
If E>0
Yes
No
go back to first block
Next Particle

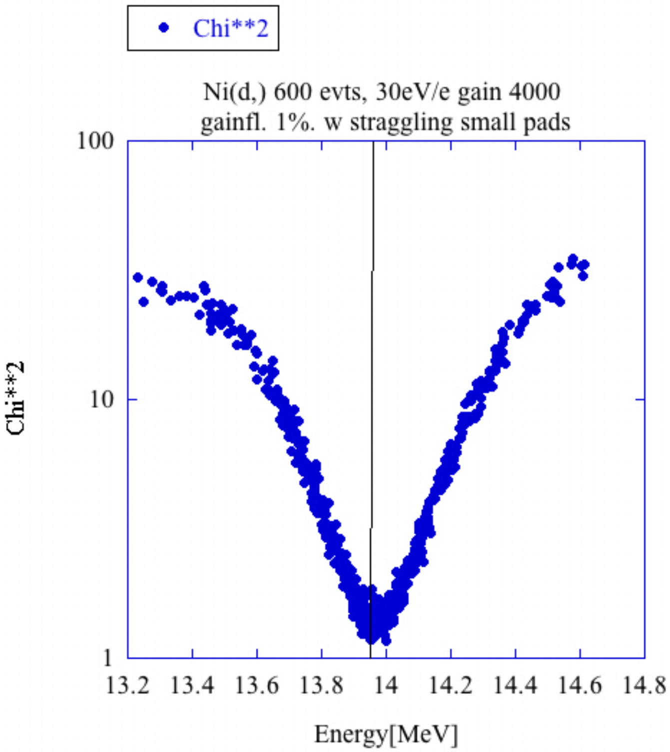
K.Tyler-WM

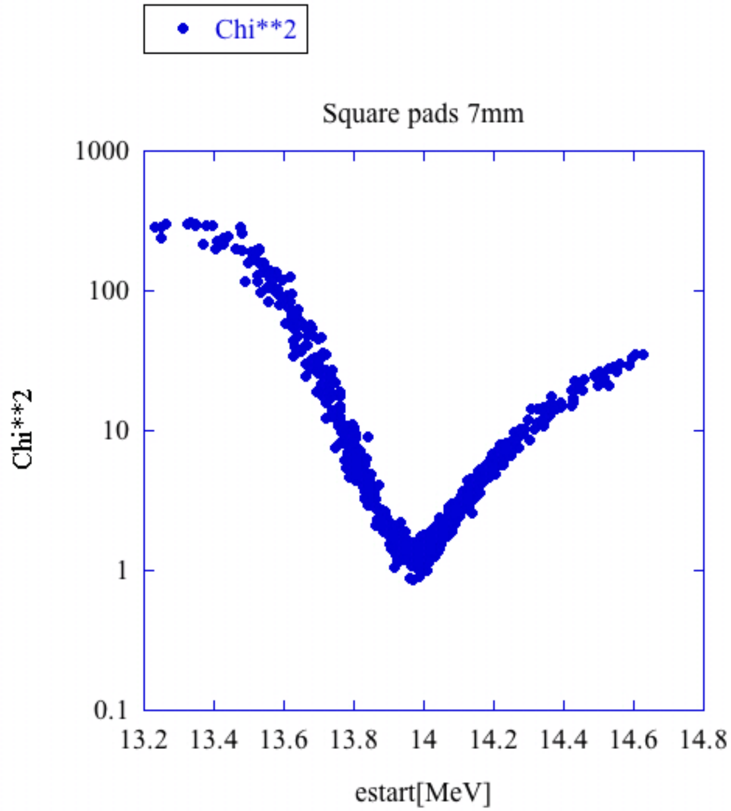
```
          do i=1,128
          do j=1,128
          do k=1,128
                 if (pulsemeannor(i,j,k).gt.threshold.and.
     $                  pulsemeanev(i,j,k,nev).gt.threshold) then
                      npad=npad+1
       dev2=(pulsemeannor(i,j,k)-pulsemeanev(i,j,k,nev))**2
c      estimation of fluctuation just by electron statistics, noise  and
gain
       snelec=pulsemeanev(i,j,k,nev)/gain(i,j) !number of primary electrons
       dsnelec=sqrt(snelec)*gain(i,j) !fluctuation valid if >>1
       dpulse=dgain*pulsemeanev(i,j,k,nev)/(gain(i,j))  !fluctuation due to
gain
       sig2=snoise**2+dsnelec**2+ dpulse**2
       dev2=dev2/sig2   !normalisation taking into account these three
contributions
       chi2=chi2+dev2
                      else
                      endif
          enddo
          enddo
          enddo
          chi2=chi2/float(npad)
```

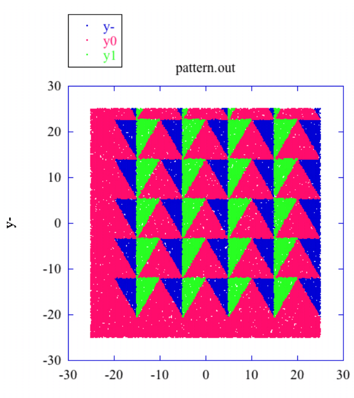
Obs: in the following, there is a calculation of the c.o.g in z direction before Chi2

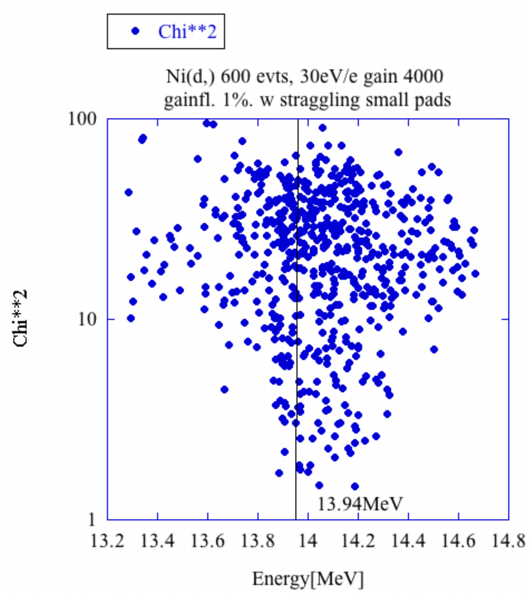


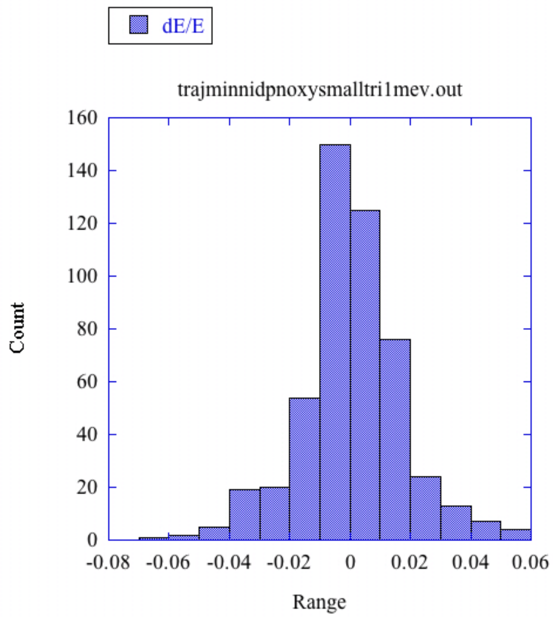
estart[MeV]
trajanal.out
15
14.5
14
13.5
13
0
500
1000
1500
2000
2500
estart[MeV]
nev

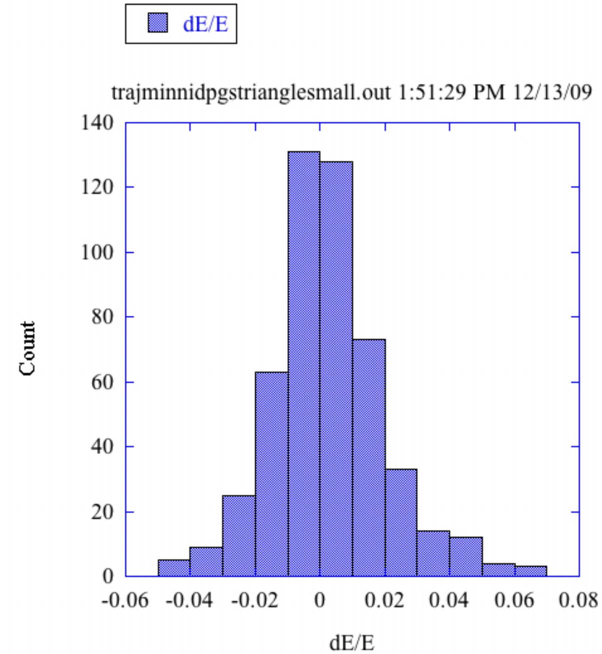

Chi**2
Ni(d,) 600 evts, 30eV/e gain 4000
gainfl. 1%. w straggling small pads
Chi**2
100
10
1
13.2 13.4 13.6 13.8 14 14.2 14.4 14.6 14.8
Energy[MeV]

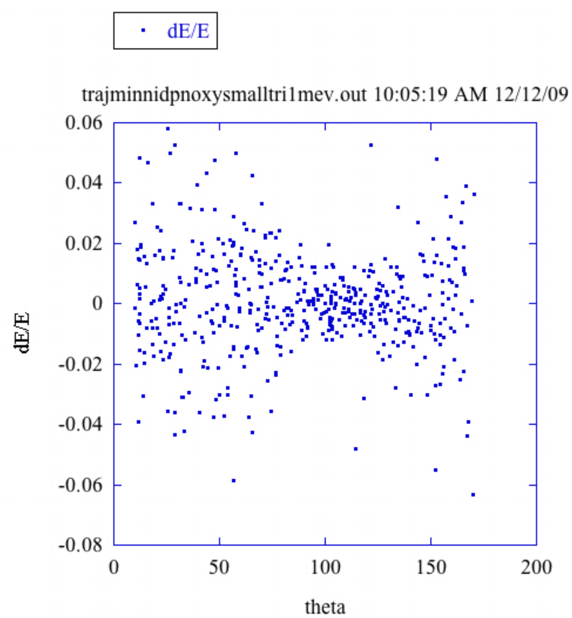

Chi**2
Square pads 7mm
Chi**2
1000
100
10
1
0.1
13.2 13.4 13.6 13.8 14 14.2 14.4 14.6 14.8
estart[MeV]

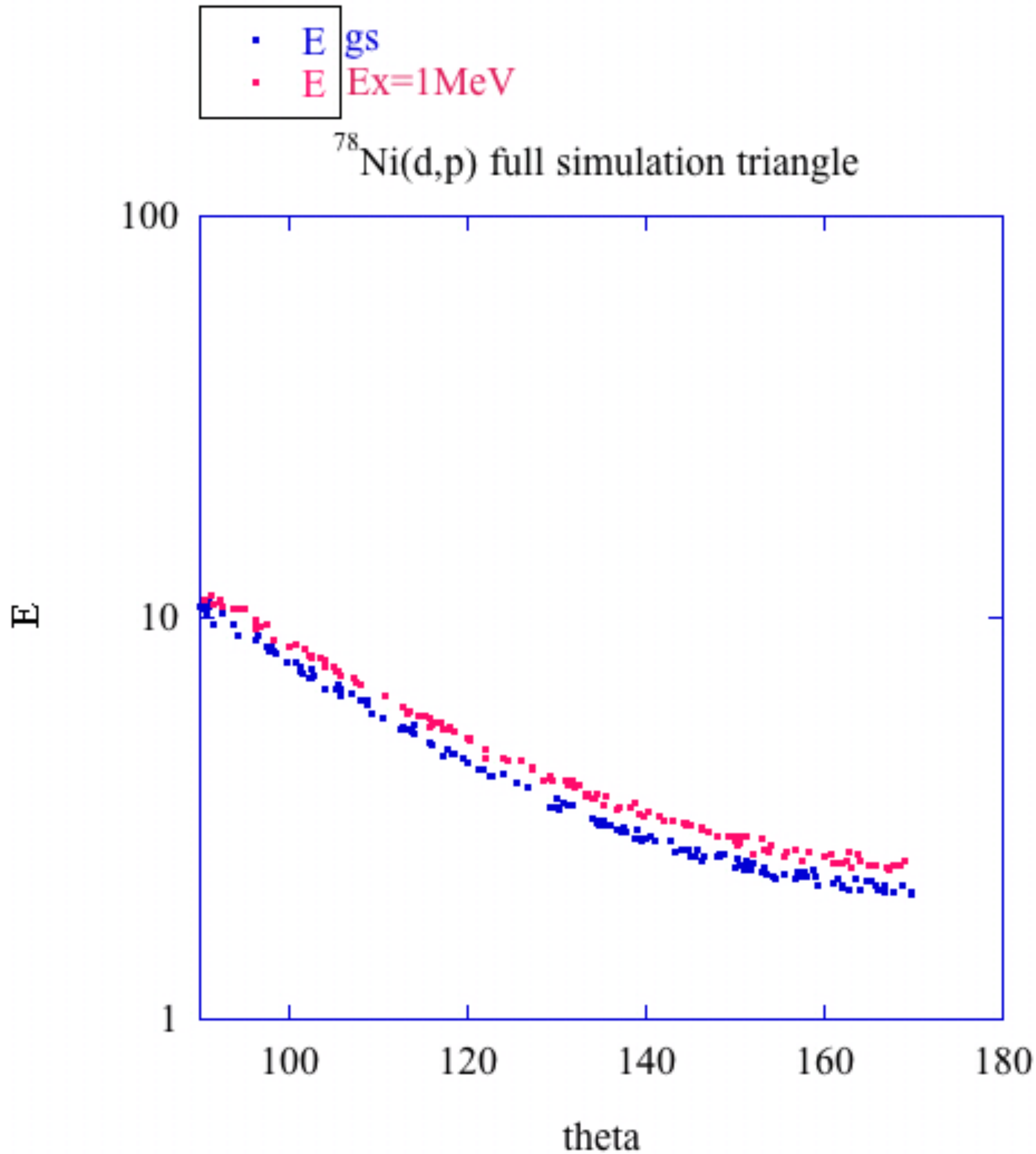

y-
y0
y1
pattern.out
y-
30
20
10
0
-10
-20
-30
-30 -20 -10 0 10 20 30
x


Chi**2
Ni(d,) 600 evts, 30eV/e gain 4000
gainfl. 1%. w straggling small pads
Chi**2
100
10
1
13.94MeV
13.2 13.4 13.6 13.8 14 14.2 14.4 14.6 14.8
Energy[MeV]

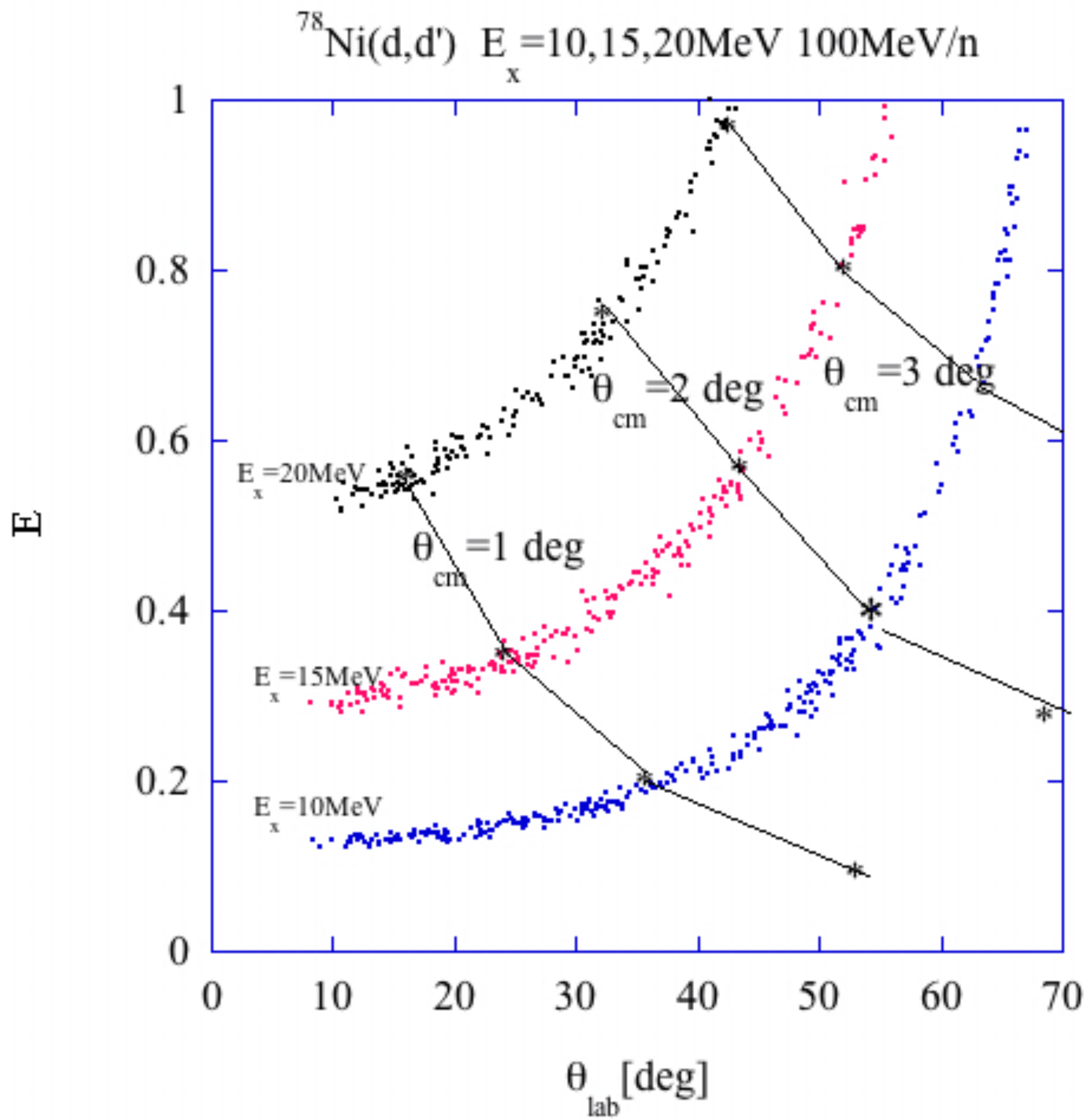

dE/E
trajminnidpnoxysmalltri1mev.out
Count
Range
160
140
120
100
80
60
40
20
0
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06


dE/E
trajminnidpgstrianglesmall.out 1:51:29 PM 12/13/09
Count
dE/E
140
120
100
80
60
40
20
0
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
0.08

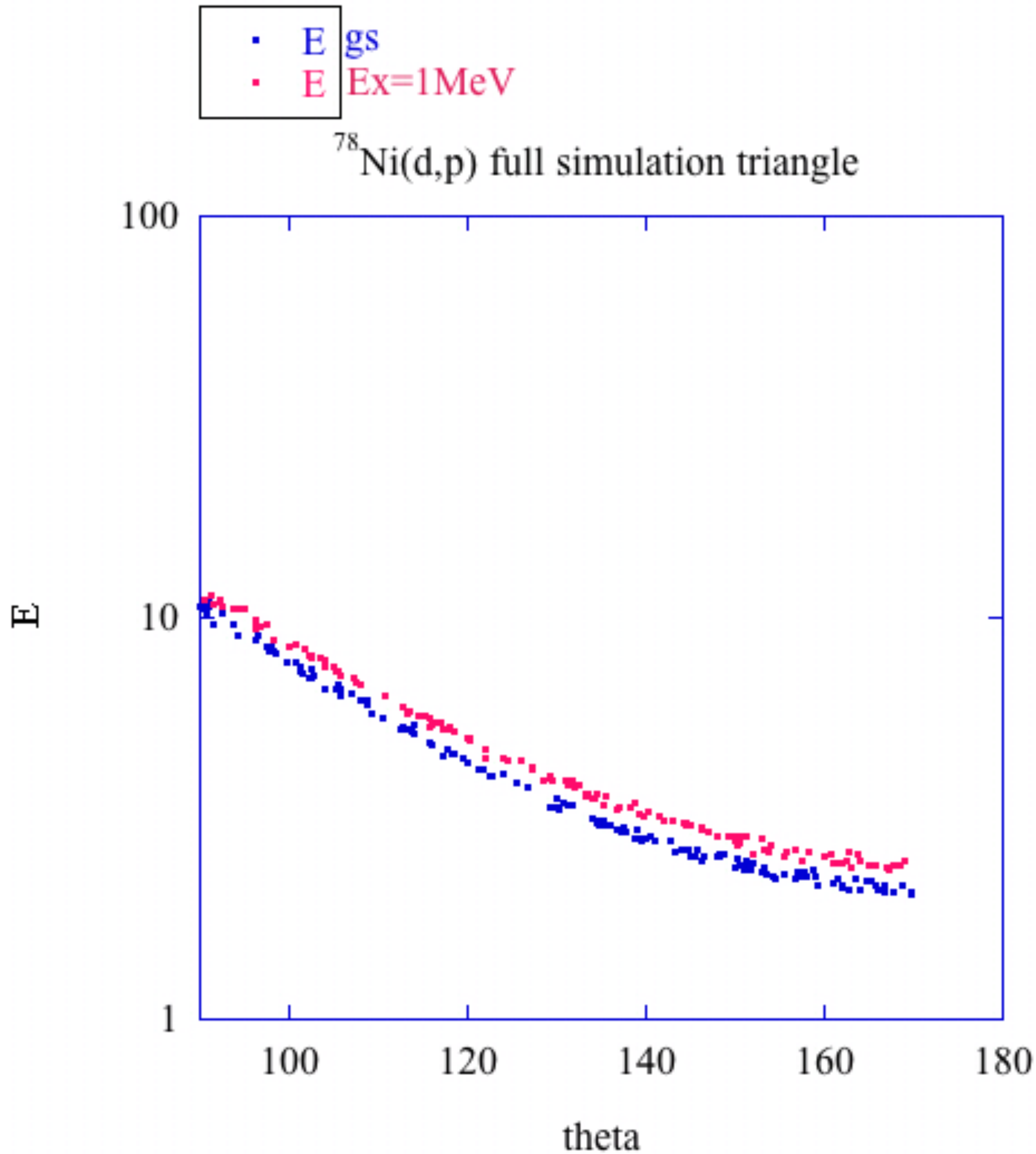

dE/E
trajminnidpnoxysmalltri1mev.out 10:05:19 AM 12/12/09
dE/E
theta
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
0
50
100
150
200



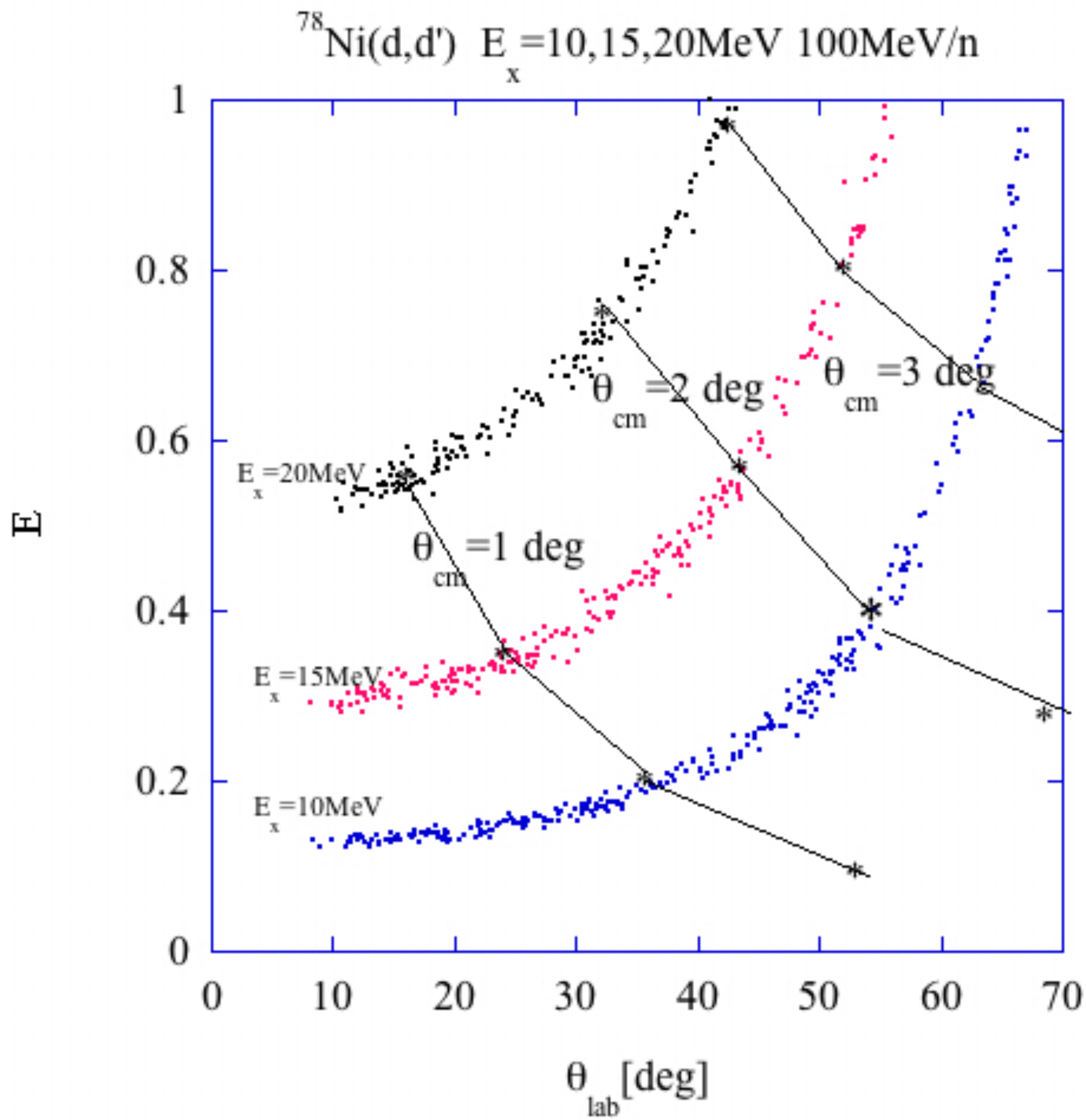
E gs
E Ex=1MeV
^{78}Ni(d,p) full simulation triangle
100
10
1
E
100
120
140
160
180
theta



78Ni(d,d') Ex=10,15,20MeV 100MeV/n
E
θlab[deg]
Ex=20MeV
Ex=15MeV
Ex=10MeV
θcm=1 deg
θcm=2 deg
θcm=3 deg
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70



E gs
E Ex=1MeV
78Ni(d,p) full simulation triangle
100
10
1
E
100
120
140
160
180
theta



^{78}Ni(d,d') E_x=10,15,20MeV 100MeV/n
E
θ_{lab}[deg]
E_x=20MeV
E_x=15MeV
E_x=10MeV
θ_{cm} =1 deg
θ_{cm} =2 deg
θ_{cm} =3 deg
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70