Physics Program with the AT-TPC and possible applications for Sharaq

- Nuclear Structure Physics (0-150MeV/n)
  →low multiplicity events
- Heavy Ion Collisions (100-300MeV/n)
  →high multiplicity events

W.Mittig, MSU-NSCL
A.Bickley, W.Lynch, G.Westfall

SIR2008
ICHOR
ICHOR-EFES International Symposium on New Facet of Spin-Isospin Responses
Toward the Commissioning of SHARAQ Spectrometer
October 29-31, 2008 at RIKEN Nishina Center

The Study of Quasielastic Reactions Induced by Secondary Beams with the Active Target Maya, a Large Solid Angle and High Efficiency Ionization Chamber

Participants: (list preliminary, to be finalised):

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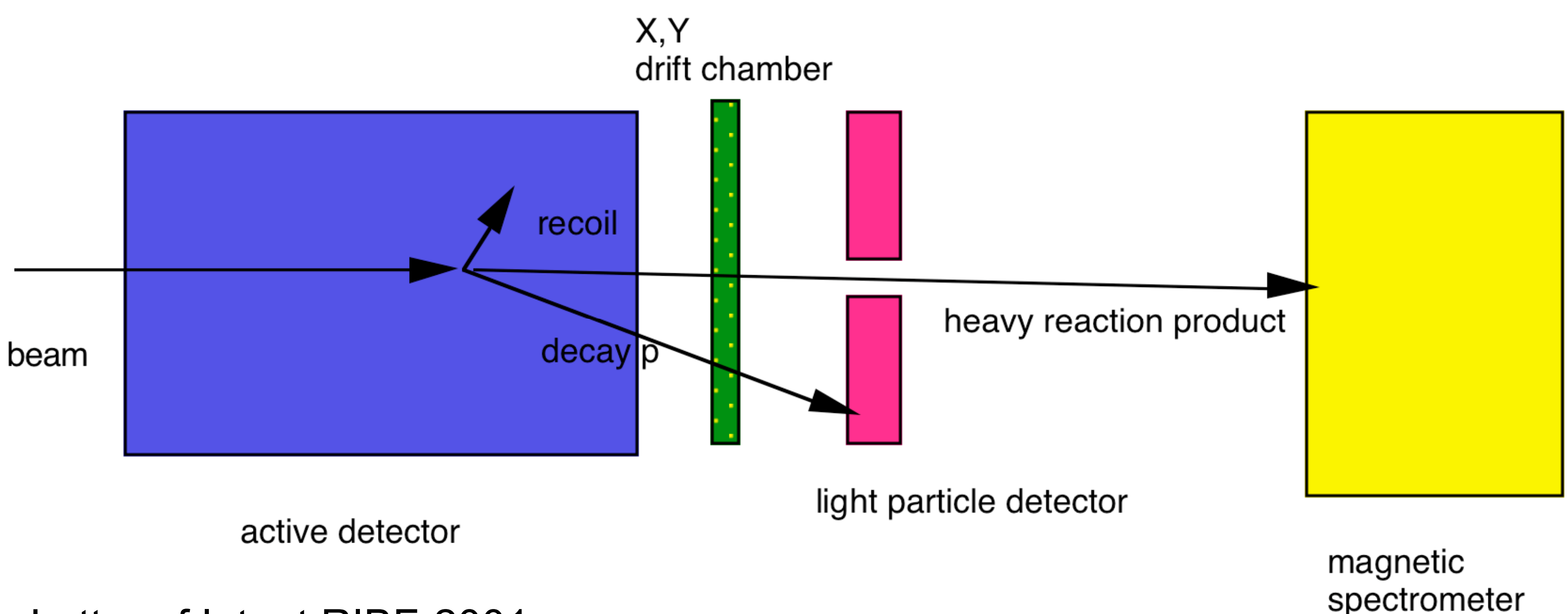


Letter of Intent RIBF-2001

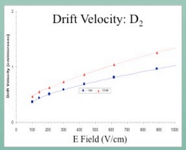
An Active Target-Time Projection Chamber for Nuclear Structure and Reactions Experiments

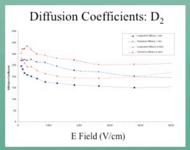
Introduction

- Experiments with rare isotope beams continuously push the limits of low beam intensities and low cross sections.
- The AT-TPC will address these limitations by providing a thick target while retaining high resolution and efficiency.
- The AT-TPC combines time projection and active target functionality allowing for measurements of :
  - Rare processes that require high detection efficiency and large acceptance
  - Low energy processes that are traditionally difficult to measure due to the short range of the reaction products in matter
  - High multiplicity reactions that require multi-track reconstruction
  - Global event reconstruction of charged reaction products

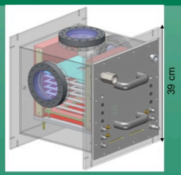
Gases

- The use of a wide variety of gases is a new feature for TPC's
- The physical properties of each gas must be considered to understand the behavior of the ionization e⁻'s
  - Drift Velocity
  - Transverse Diffusion
  - Longitudinal Diffusion
- H_2 and D_2 provide special challenges because they are flammable and the drift velocity of electrons is low
- Garfield simulations show:
  - Electrons have an increased drift velocity, transverse and longitudinal diffusion at reduced gas pressures



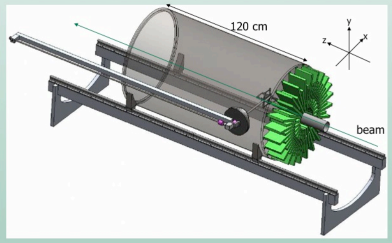


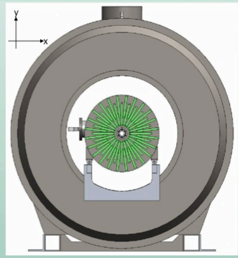
Test Stand



- The AT-TPC test chamber will be used to test a variety of electron amplification technologies:
  - Wire plane - optimize distance between anode wires and pad plane based on width of image charge.
  - GEMs - test stability with respect to sparking; determine electron amplification gain factors for 2 and 3 stacked layers.
  - MicroMegas - establish amplification characteristics.
- The electron drift and amplification characteristics for each gas species and pressure to be used in the AT-TPC will be studied

Detector Features

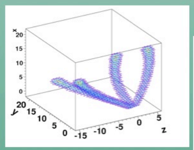


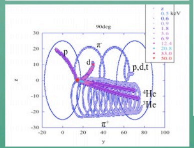


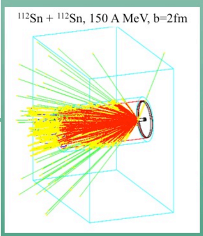
- Fixed Target Mode:
  - Removable target wheel that accommodates multiple targets
- Active Target Mode:
  - Identity and pressure of the gas used to fill the detector will be dependent upon the experimental requirements.
  - Gases: H_2, D_2, ^{3}He, Ne, Ar, Isobutane
  - Pressures: 0.2-1.0 atm
- 4π geometrical acceptance allows high resolution and efficiency tracking
- Internal triggering for low energy particles that stop in the detector gas
- Large dynamic range for detecting ionization from charged particles
- Solenoidal magnetic field allows particle identification of pions through light fragments

Event Simulation

- As the electrons travel through the detector to the pad plane the signal diffuses and is detected on multiple pads
- The extent of the diffusion is determined by the properties of the gas, and the magnitudes of the E and B fields.





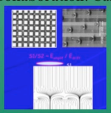


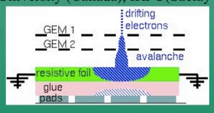
- GEANT4 simulates the interaction of the collision products in the materials of the AT-TPC
- The 3D detector occupancy is simulated using collision like events
- Low Energy Reactions:
  - Occupancy < 1%
- Heavy Ion Collisions:
  - Occupancy < 10%

Readout Plane & Electronics

Micromegas-GEM Collaboration: Carleton University (Canada), IRFU(Saclay-France), NSCL (USA)

- Micropattern amplification devices show promise for improving TPC resolution

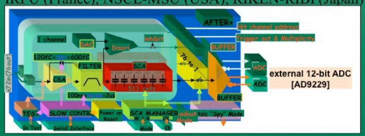




- Resistive sheets incorporated between the electron amplification and pad stages disperse the avalanche in space

GET-Collaboration: CENBG (France), GANIL (France), GSI (Germany), DL (UK), IRFU (France), NSCL-MSU (USA), RIKEN-RIBF(Japan)

- Collaboration developed to design a General Electronics package for TPC's
- Design based on electronics used in the T2K experiment



AFTER+ Front-end Card

- Discriminator incorporated to provide a threshold trigger based on 3D hit multiplicity
- Necessary for low energy active target experiments

Scientific Program

The AT-TPC exploits the full extent of beam species, energies and intensities available with NSCL fragmentation beams and the future gas-stopper post-accelerator beams.

Measurement	Physics	Beam Examples	Beam Energy	Min Beam Intensity
Transfer Reactions	Nuclear Structure	^{32}Mg(d,p)^{33}Mg	3 (A MeV)	100 (pps)
Resonant Reactions	Nuclear Structure	^{26}Ne(p,p)^{26}Ne	3	100
Astrophysical Reactions	Nucleosynthesis	^{25}Al(^{3}He,d)^{26}Si	3	100
Fission Barriers	Nuclear Structure	^{199}Tl, ^{192}Pt	20 - 60	10,000
Giant Resonances	Nuclear EOS, Nuclear Astro	^{54}Ni - ^{70}Ni ^{106}Sn - ^{127}Sn	50 - 100	50,000
Heavy Ion Reactions	Nuclear EOS	^{37}Ca - ^{49}Ca ^{106}Sn-^{127}Sn	50 - 150	50,000

TWIST Solenoid

TWIST Solenoid at NSCL

TWIST Experiment at TRIUMF

Solenoid Experiment Features:
- Beam trajectory centered in magnet
- Beam path independent of beam species & energy
- Optional field cage can be used to mask ionization from the beam
- Narrow downstream acceptance
- Limited momentum resolution at very forward angles

Physical Characteristics:
- Superconducting
- 2 Tesla field max
- 105 cm diameter bore
- 229 cm length bore
- 107 cm beam height (w/o yoke)
- 130 cm beam height (w/ yoke)
- Field non-uniformity < 1%
- 60×10^3 kg solenoid + yoke

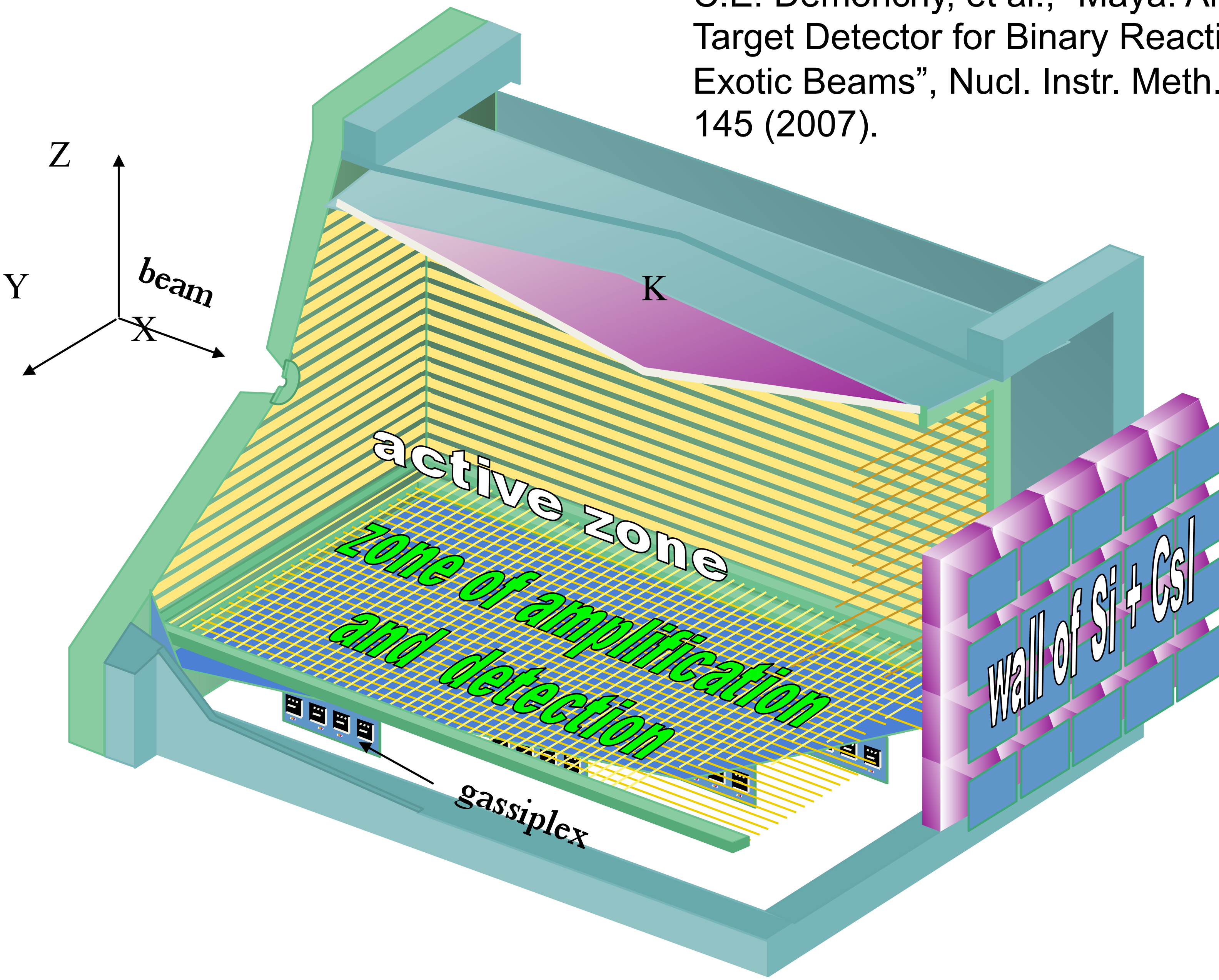
Summary

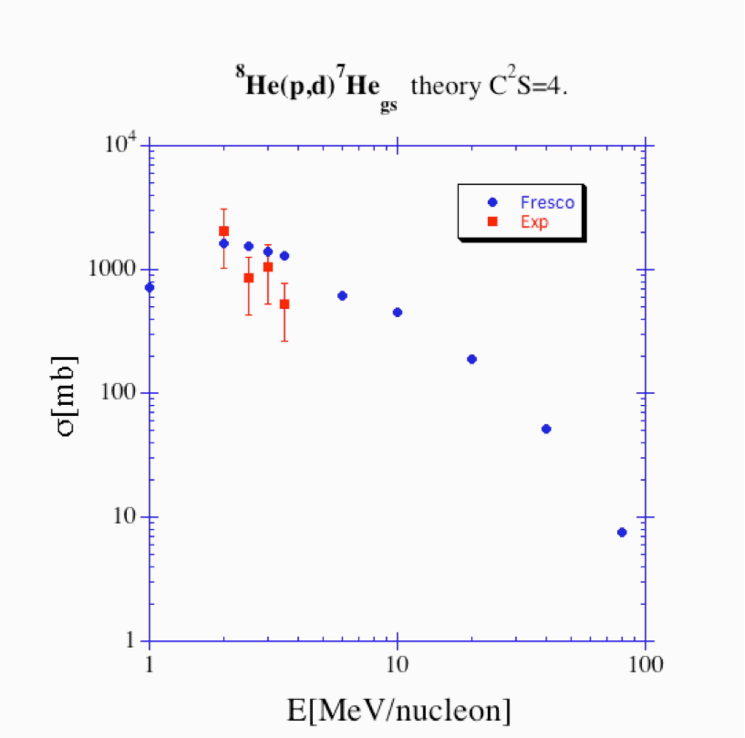
- The AT-TPC is a powerful tool for studying reactions induced by rare isotope beams.
- The scientific program can be conducted with existing rare isotope beams, but requires a high resolution AT-TPC.
- Active target reactions will study fusion barriers, isobaric analog states, the cluster structure of light nuclei and transfer reactions.
- Conventional target reactions will probe the dependence of the nuclear equation of state on isospin asymmetry and density.
- The full extent of beam species, energies and intensities currently available with fragmentation and reaccelerated beams at NSCL will be exploited.
- The AT-TPC will allow these measurements to be made prior to the completion of the future rare isotope beam facility.

MICHIGAN STATE UNIVERSITY

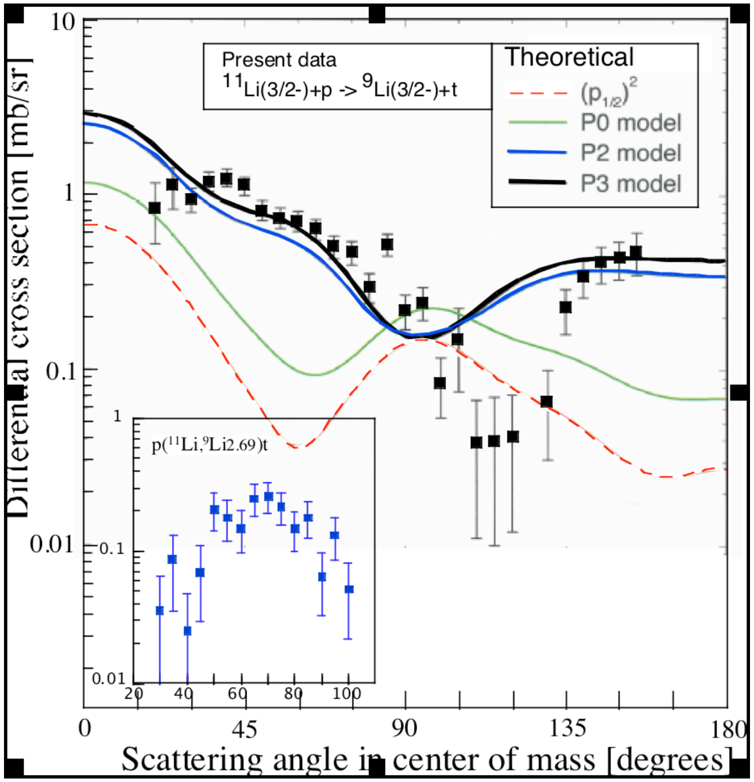
The NSCL is funded in part by the National Science Foundation and Michigan State University.

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





Angle integrated cross-section at low energy for the 8He(p,d) reaction, Experiment is compared to a Fresco calculation (from MIT2005)

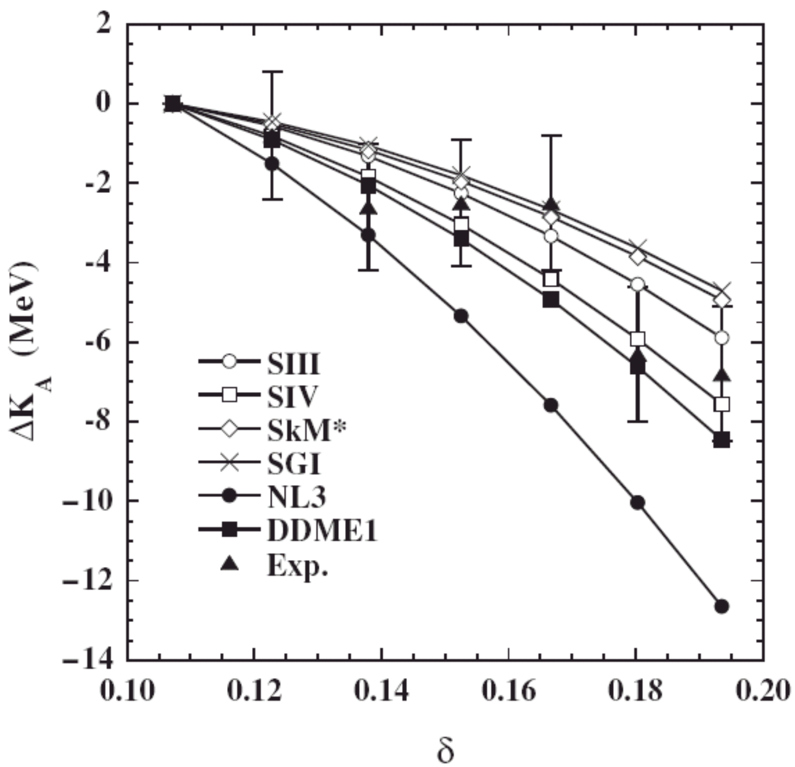


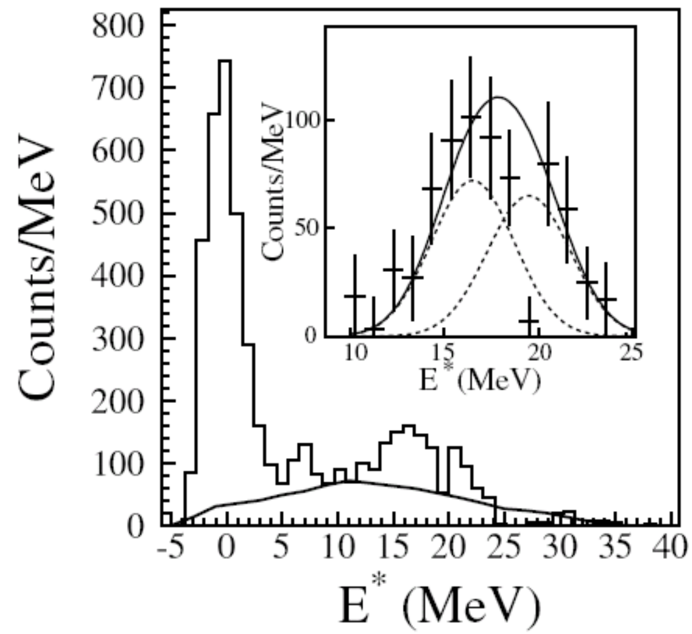
I.Tanihata et al., PRL 100, 192502(2008)

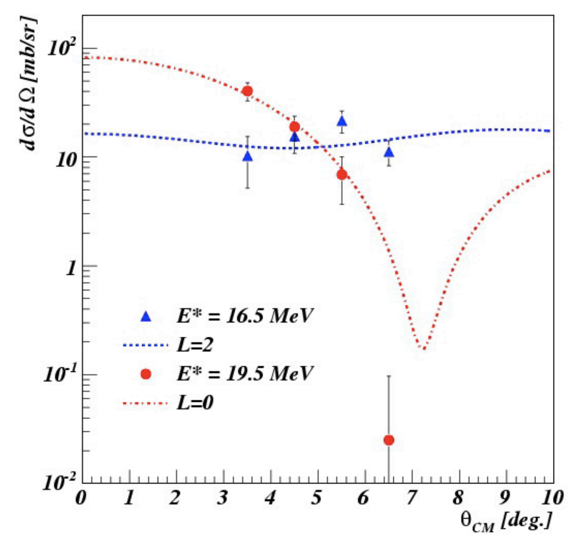
Isospin dependence of the EOS

GMR

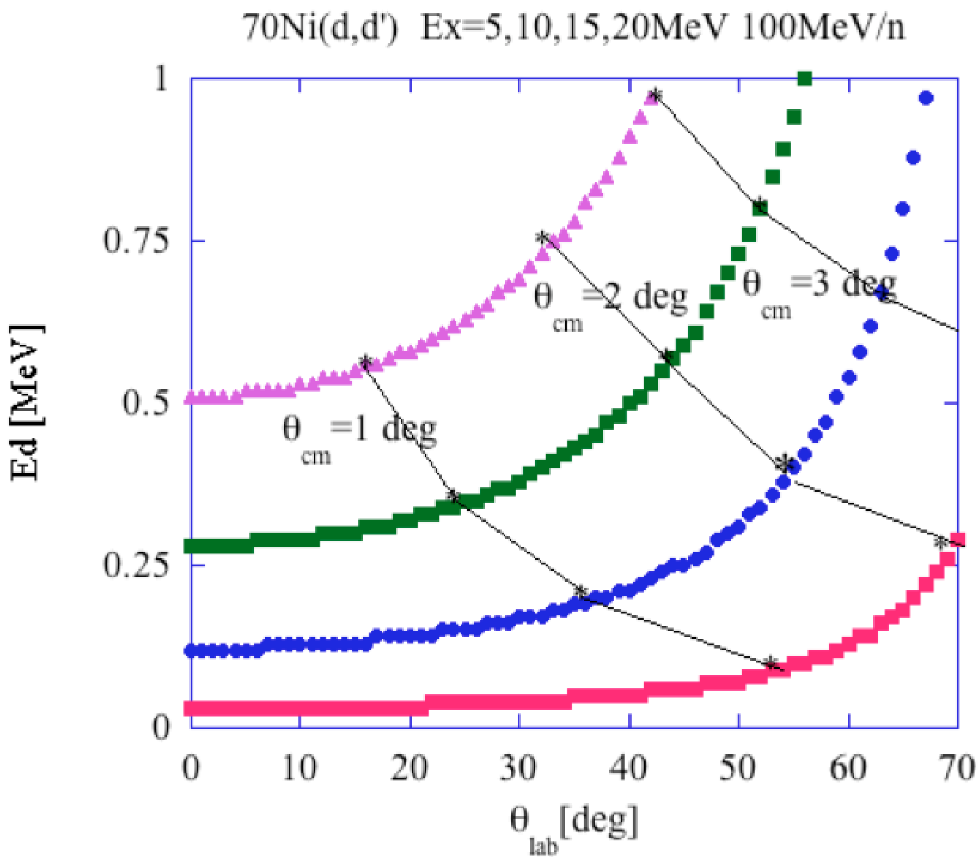
$$K^A = K^\infty + K^{surf} A^{-1/3} + K^{coul} A^2/Z^{4/3} + K^{sym} ((N\text{-}Z)/A)^2$$

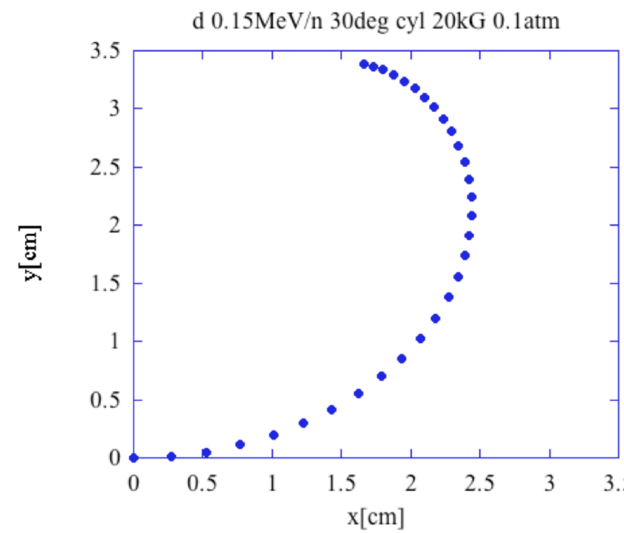


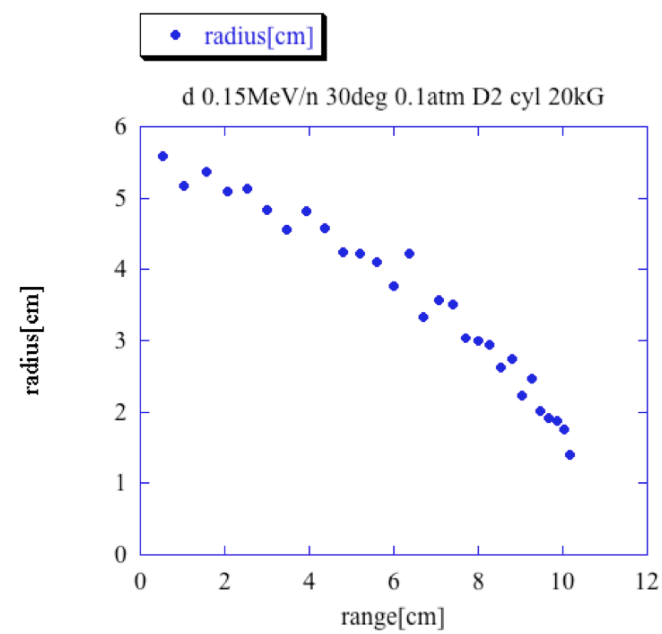




C. Monrozeau et al., Phys. Rev. Lett. 100, 042501 (2008)


70Ni(d,d') Ex=5,10,15,20MeV 100MeV/n
Ed [MeV]
θ_{lab} [deg]
θ_{cm} =1 deg
θ_{cm} =2 deg
θ_{cm} =3 deg
0
0.25
0.5
0.75
1
0
10
20
30
40
50
60
70


d 0.15MeV/n 30deg cyl 20kG 0.1atm
y[cm]
x[cm]
0
0.5
1
1.5
2
2.5
3
3.5


radius[cm]
d 0.15MeV/n 30deg 0.1atm D2 cyl 20kG
radius[cm]
range[cm]
0
1
2
3
4
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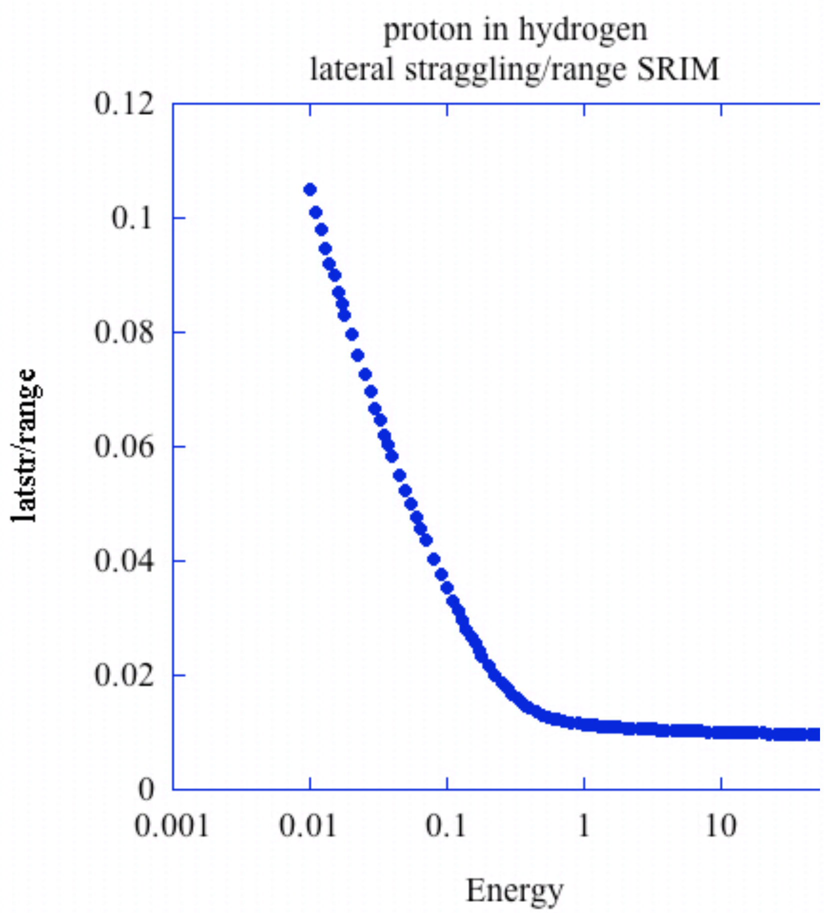
6
0
2
4
6
8
10
12


proton in hydrogen
lateral straggling/range SRIM
latstr/range
Energy
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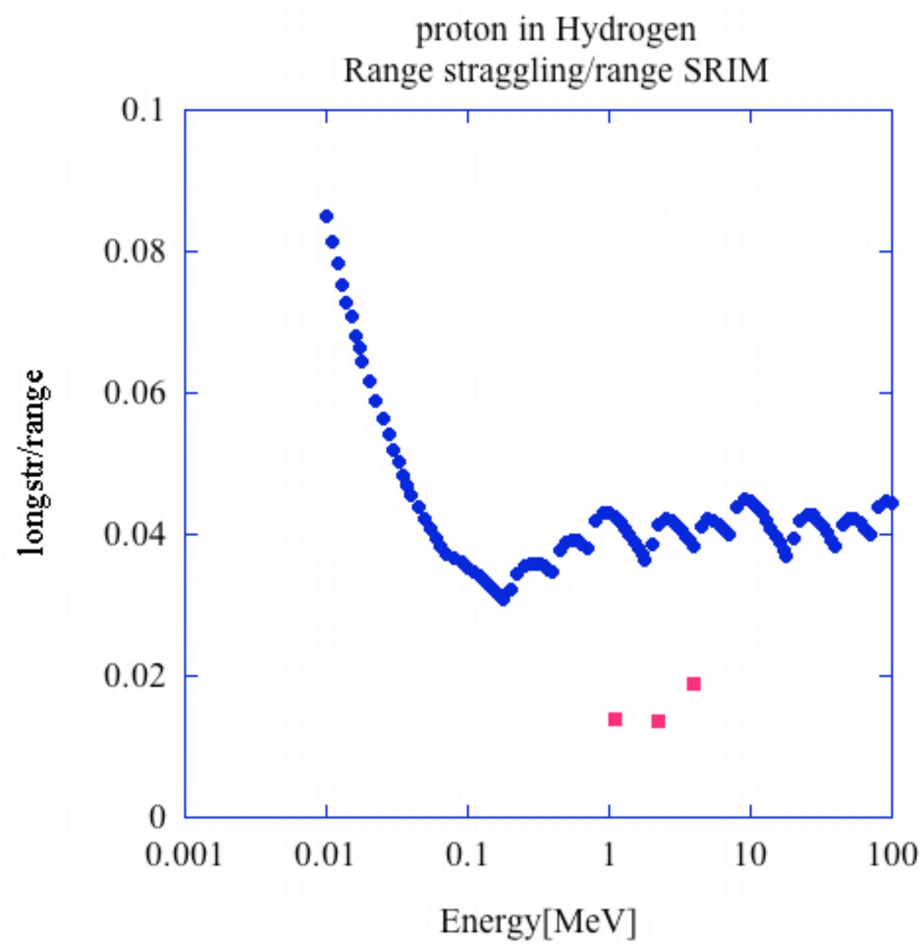
0.1
0.08
0.06
0.04
0.02
0
0.001
0.01
0.1
1
10


proton in Hydrogen
Range straggling/range SRIM
longstr/range
Energy[MeV]
0.1
0.08
0.06
0.04
0.02
0
0.001
0.01
0.1
1
10
100

Spin-isospin resonances

(see R.Zegers)

VOLUME 91, NUMBER 26 PHYSICAL REVIEW LETTERS week ending 31 DECEMBER 2003

Spin-Isospin Resonances and the Neutron Skin of Nuclei

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(Received 12 August 2003; published 29 December 2003)

The Gamow-Teller resonances (GTR) and isobaric analog states (IAS) of a sequence of even-even Sn target nuclei are calculated by using the framework of the relativistic Hartree-Bogoliubov model plus proton-neutron quasiparticle random-phase approximation. The calculation reproduces the experimental data on ground-state properties, as well as the excitation energies of the isovector excitations. It is shown that the isotopic dependence of the energy spacings between the GTR and IAS provides direct information on the evolution of neutron-skin thickness along the Sn isotopic chain. A new method is suggested for determining the difference between the radii of the neutron and proton density distributions along an isotopic chain, based on measurement of the excitation energies of the GTR relative to the IAS.

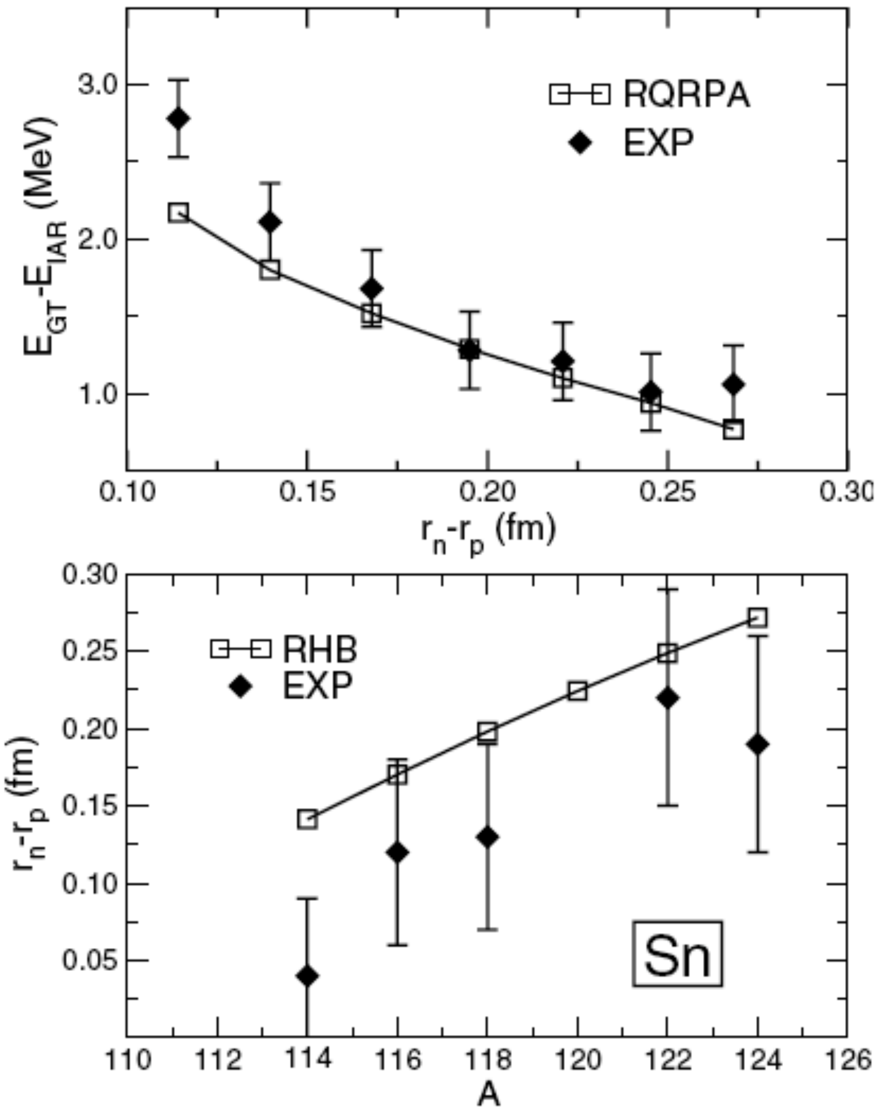


FIG. 2. The proton-neutron RQRPA and experimental [22] differences between the excitation energies of the GTR and IAS as a function of the calculated differences between the rms radii of the neutron and proton density distributions of even-even Sn isotopes (upper panel). In the lower panel the calculated differences $r_n - r_p$ are compared with experimental data [4].

Vol. 36 (2005) ACTA PHYSICA POLONICA B No 4

SPIN–ISOSPIN GIANT RESONANCES: REVIEW AND FUTURE PERSPECTIVES*

A. Krasznahorkay

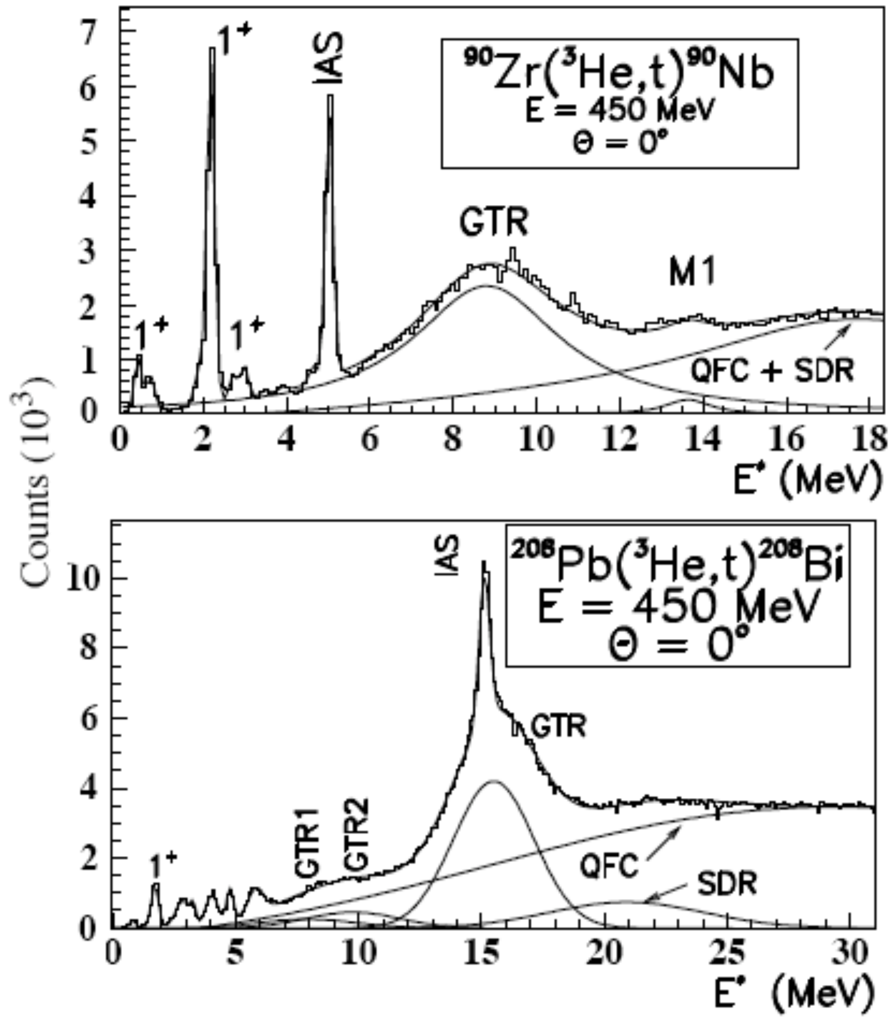
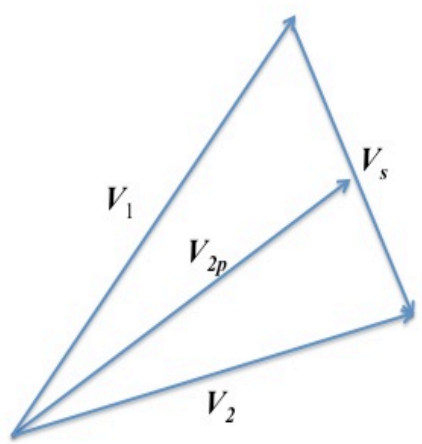


Fig. 1. Zero-degree (^{3}He, t) energy spectra for ^{90}Zr and ^{208}Pb isotopes. The positions of the 1^+ states, isobaric analog states (IAS), the Gamow–Teller resonances (GT) and spin-flip dipole resonances (SDR) are indicated together with the Quasi-Free Continuum (QFC) background. The solid lines through the data are results of fits with Lorentzian line shapes for ^{90}Nb and Gaussian line shapes for ^{208}Bi.

take a couple of E_{2p}, E_s and calculate V_1 ,V_2 for different angles cm of emission recalculate the values of interest E_{2p}, E_s and theta2p with random errors on the measured values R1,R2 and angles



Velocity diagram for 2p in plane

$\mathbf{V}_{1,2,2p,s}$ are the velocity vectors of prot
and the relative velocities in the cente
(s stands for separation) respectively.
We have:

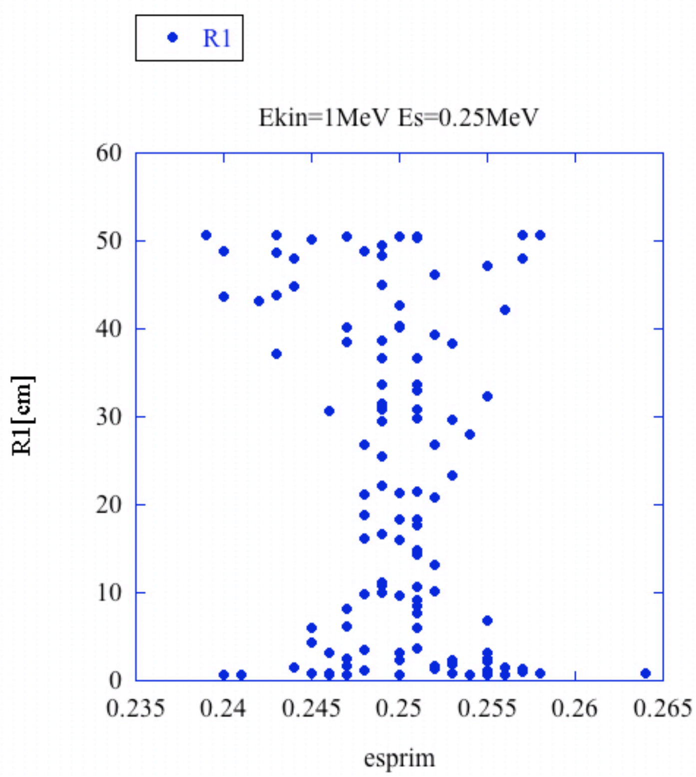
$$\mathbf{V}_1 + \mathbf{V}_2 = 2*\mathbf{V}_{2p}$$

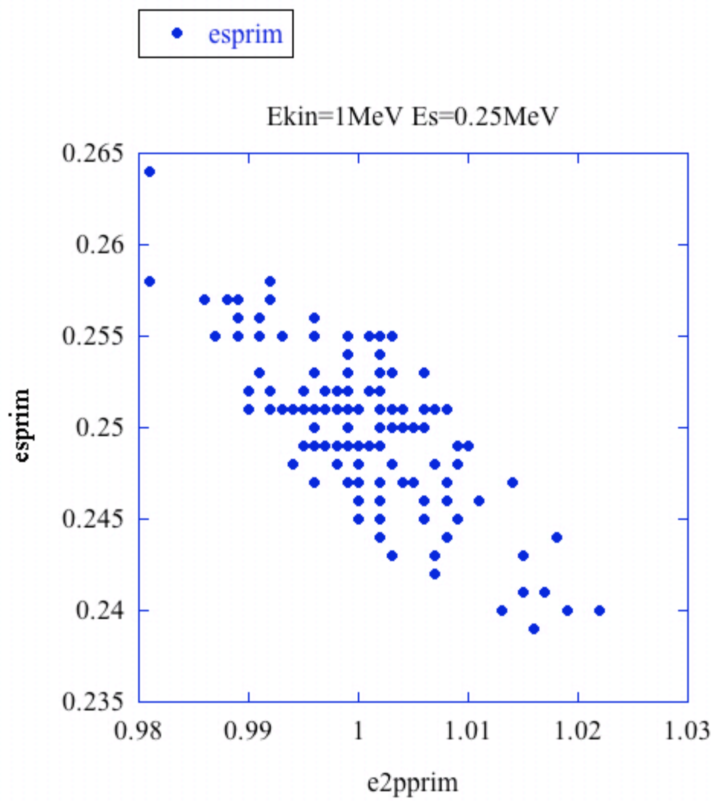
$$\mathbf{V}_2 - \mathbf{V}_1 = \mathbf{V}_s$$

$$E_{2p} = 0.5*2m_u*v_{2p}^2 = m_u*v_{2p}^2$$

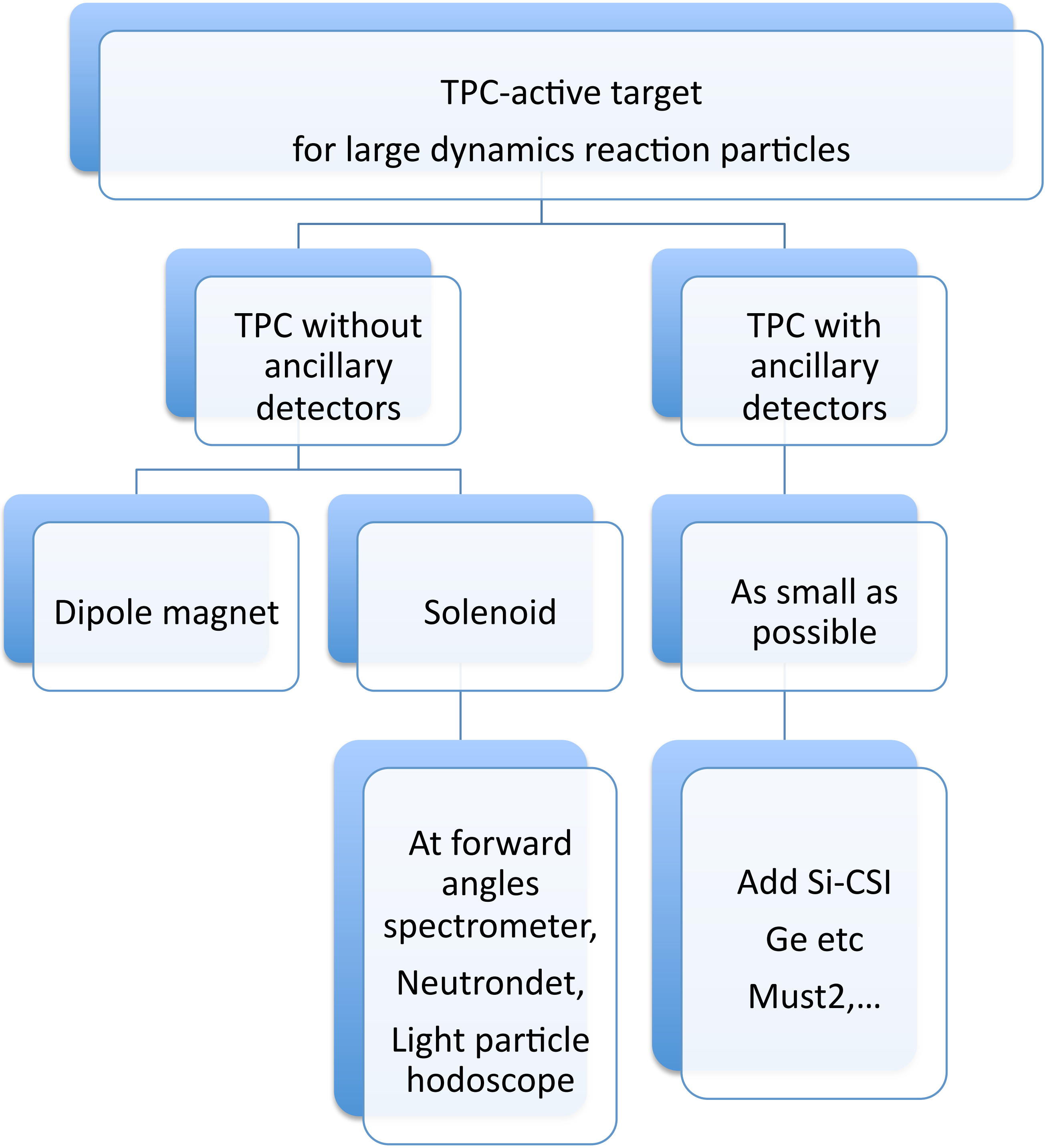
$$E_s = 2*(0.5*m_u*0.5v_s)^2 = (1/4)m_u*v_s^2$$

Example for (d,2p) E_{kin}=1MeV E_{rel}=250keV (dR_l/R=1% dR_p/R=1%)





Question: will this possible intrinsic resolution be maintained in the experimental device??→ simulation

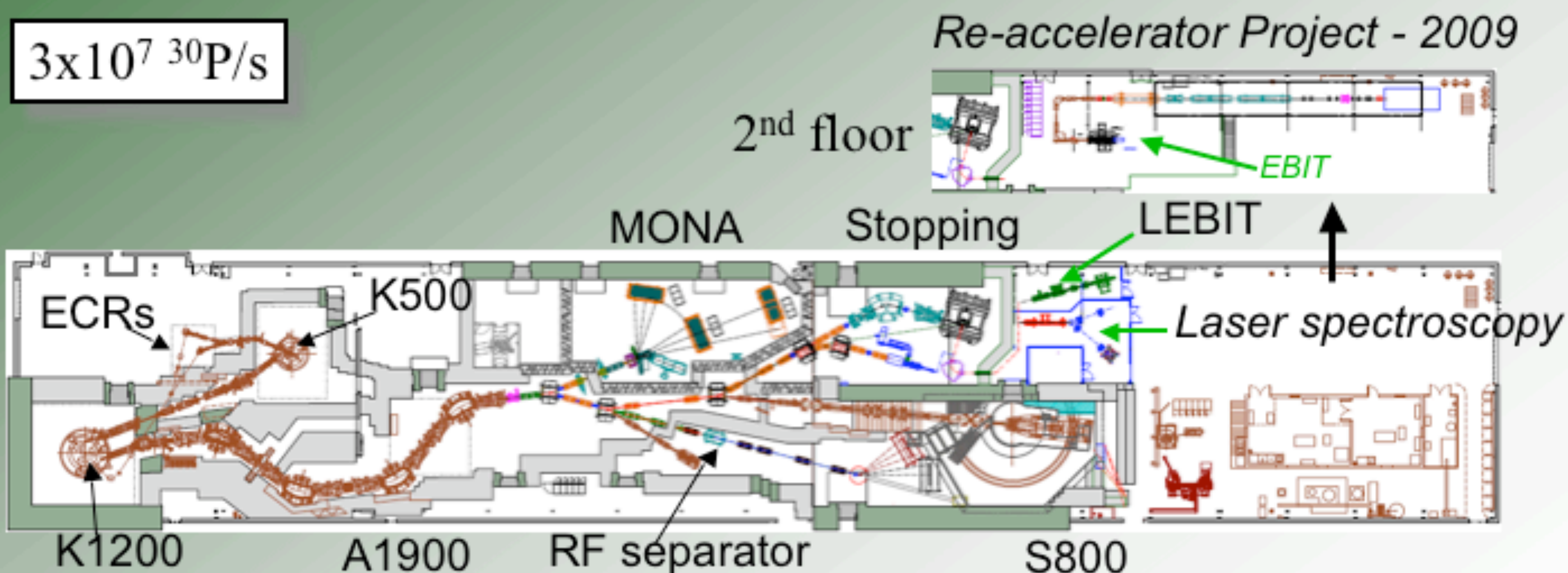

TPC-active target
for large dynamics reaction particles
TPC without ancillary detectors
TPC with ancillary detectors
Dipole magnet
Solenoid
As small as possible
At forward angles spectrometer,
Neutrondet,
Light particle hodoscope
Add Si-CSI
Ge etc
Must2,...

NSCL is implementing low energy beams

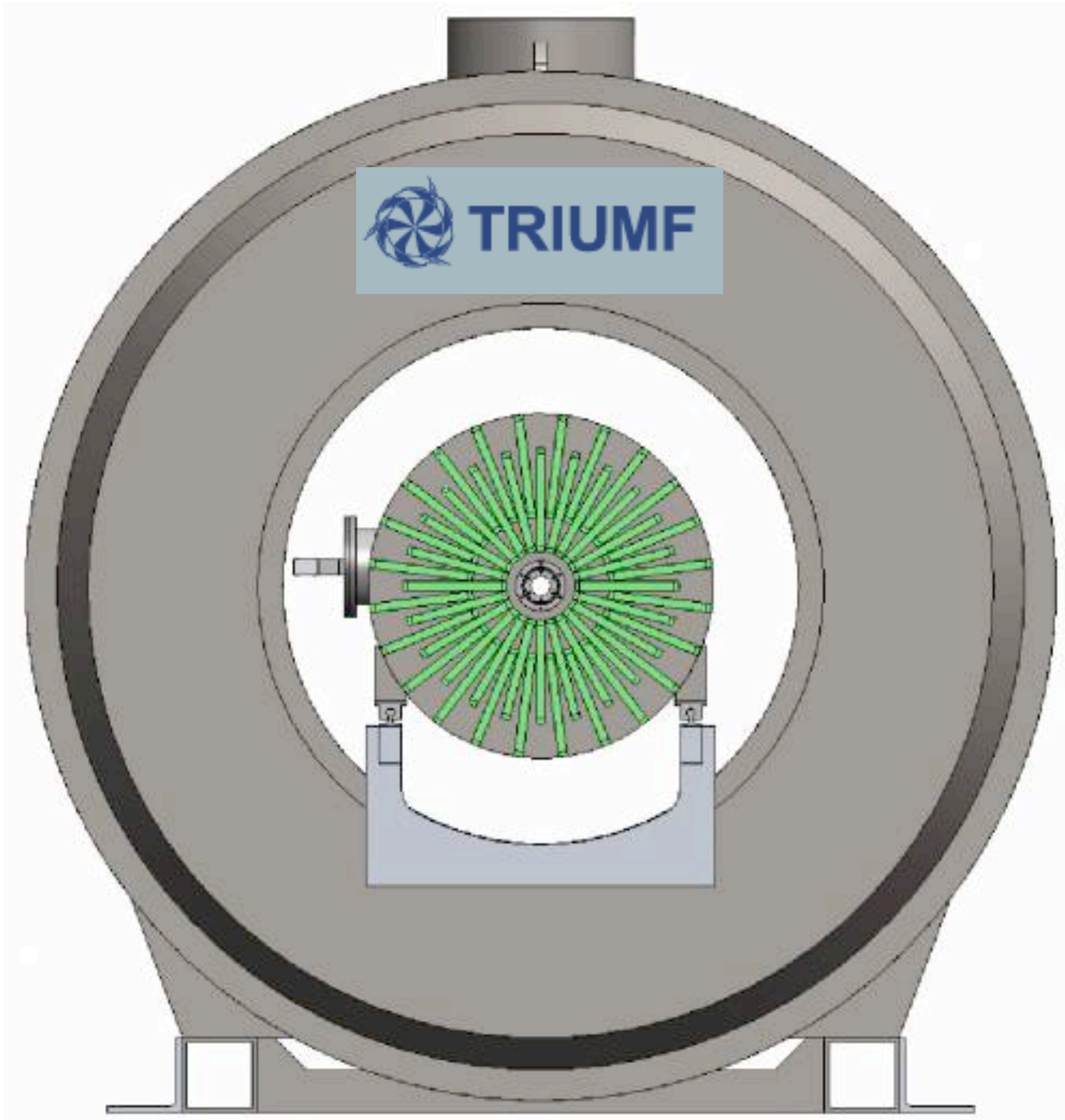
MICHIGAN STATE UNIVERSITY

Beam energies of 200 keV/u to 3 MeV/u for astrophysical studies
e.g. $^{30}P(p,\gamma)^{31}Si$ relevance to Si yields from novae

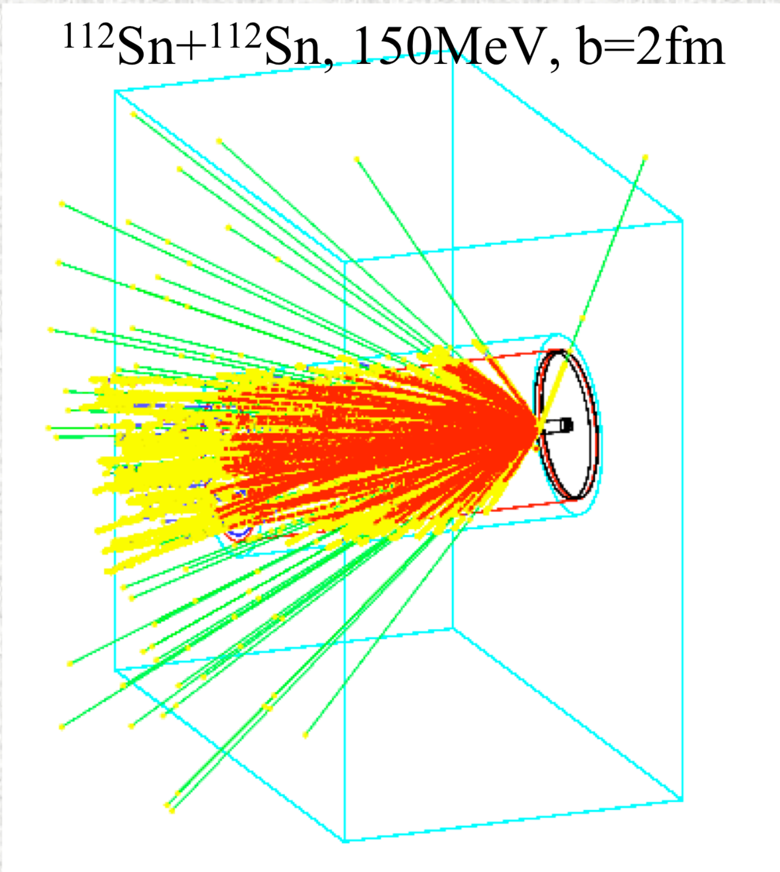
3×10^7 $^{30}P/s$

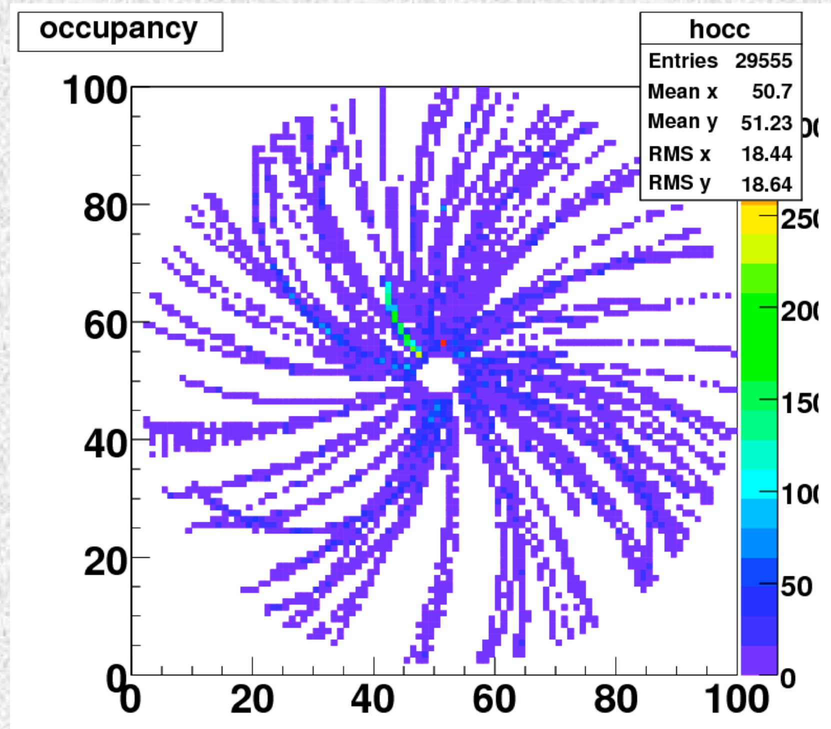


Capabilities for fast, stopped, and re-accelerated beams (2009)


TRIUMF

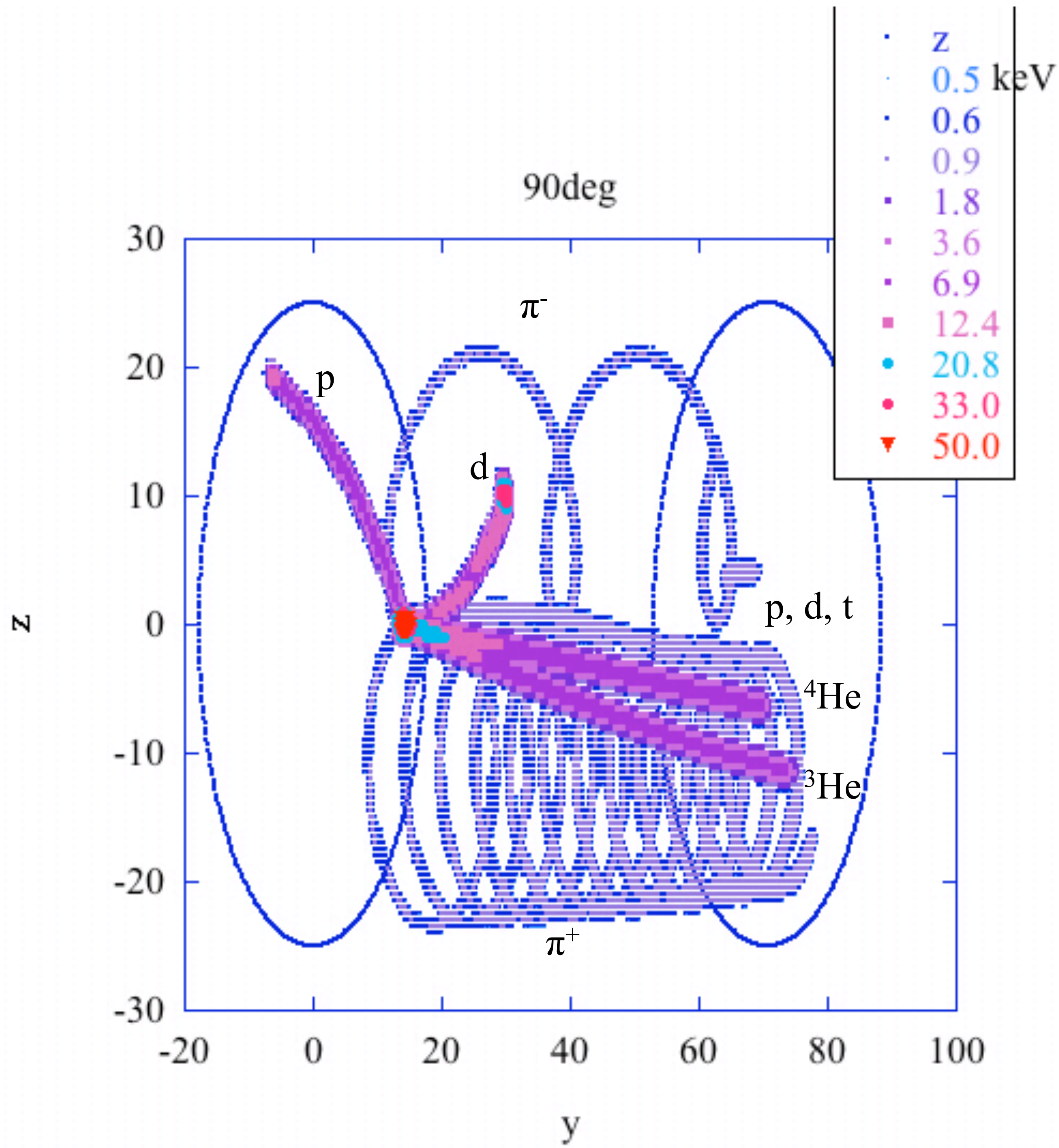
Data Volume



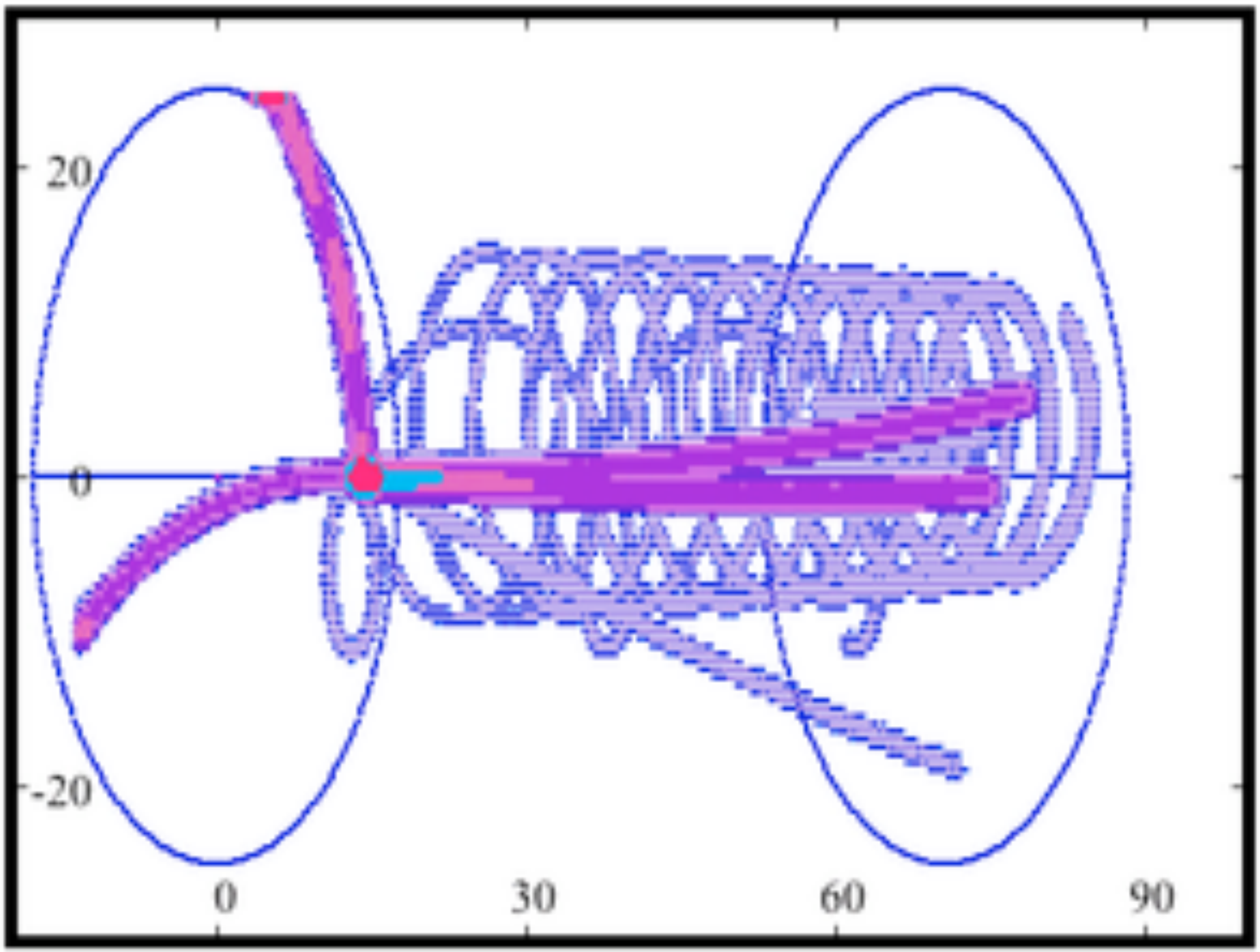


- High collision multiplicity expected
- ~2% channels & time buckets filled
- Results in data volume of :

  5 kB/s*chan } Zero suppressed
  50MB/s

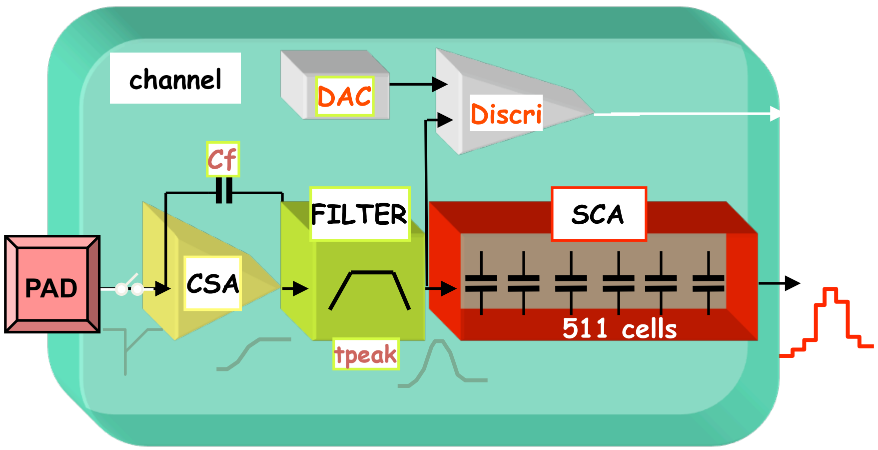


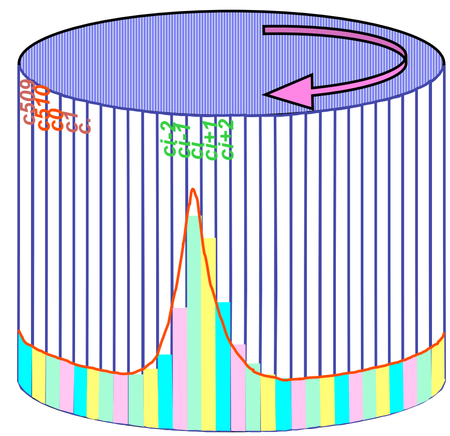
90deg
z
0.5 keV
0.6
0.9
1.8
3.6
6.9
12.4
20.8
33.0
50.0
p
d
π-
p, d, t
4He
3He
π+
30
20
10
0
-10
-20
-30
-20
0
20
40
60
80
100
y


20
0
-20
0
30
60
90

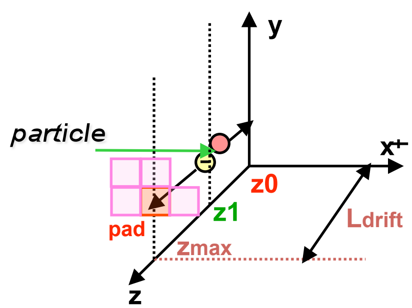
GET: SCA Write Phase

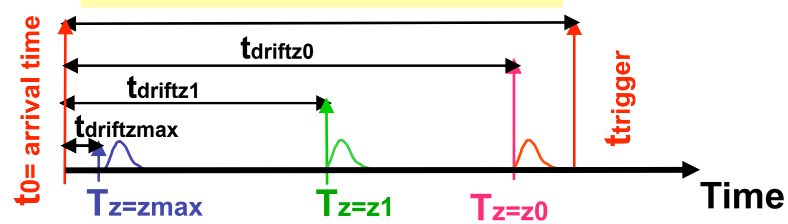
- **Architecture :** circular memory





- **Sampling condition :** $511x(1/F_{sampling}) \geq T_{driftmax}$



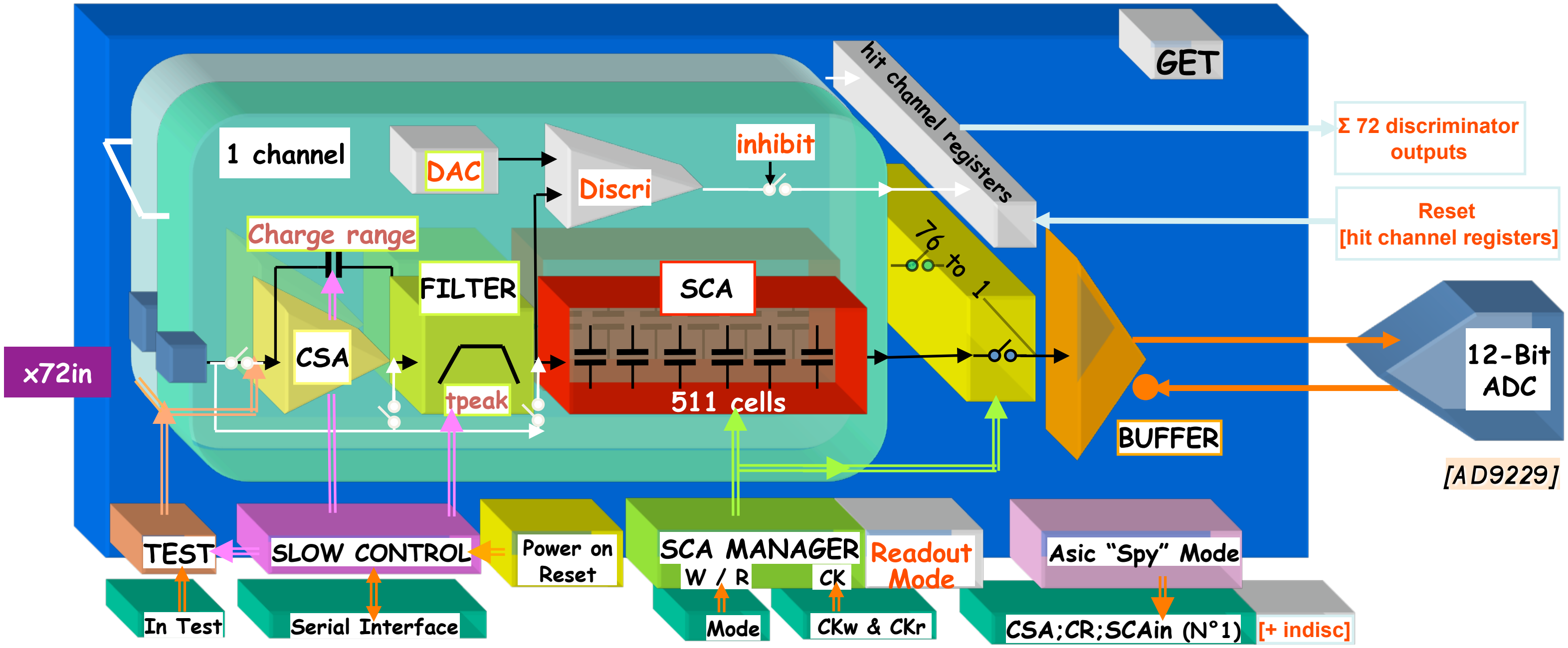


- **Peaking Time :** $T_{peak} \geq N \times (1/F_{sampling})$

- **Fsampling:** 1MHz to 100MHz.
- **Peaking Time:** 50ns to 1µs (16 values).

P.Baron-IRFU

GET: Architecture



Main features for GET:

- 72 Analog Channels; Slow Control & test ["spy" mode].

Main features for the channel

- **Input Current Polarity:** positive or negative.
- **CSA + PZC + Filter** (semi-Gaussian order 2).
  [Possibility to bypass the CSA].
- **SCA:** 511 analog memory cells.
- **Auto Triggering:** discriminator + threshold (DAC) + inhibition.

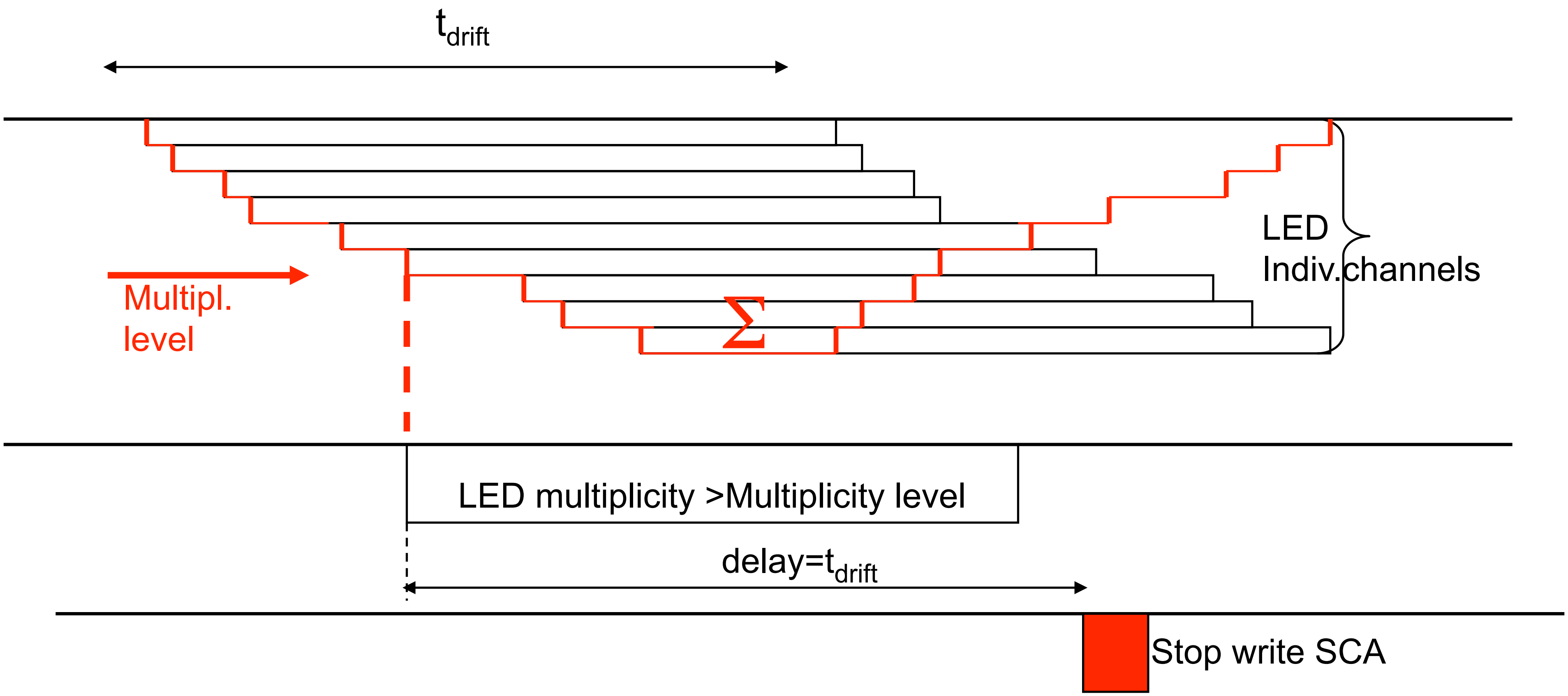
Main features for the readout

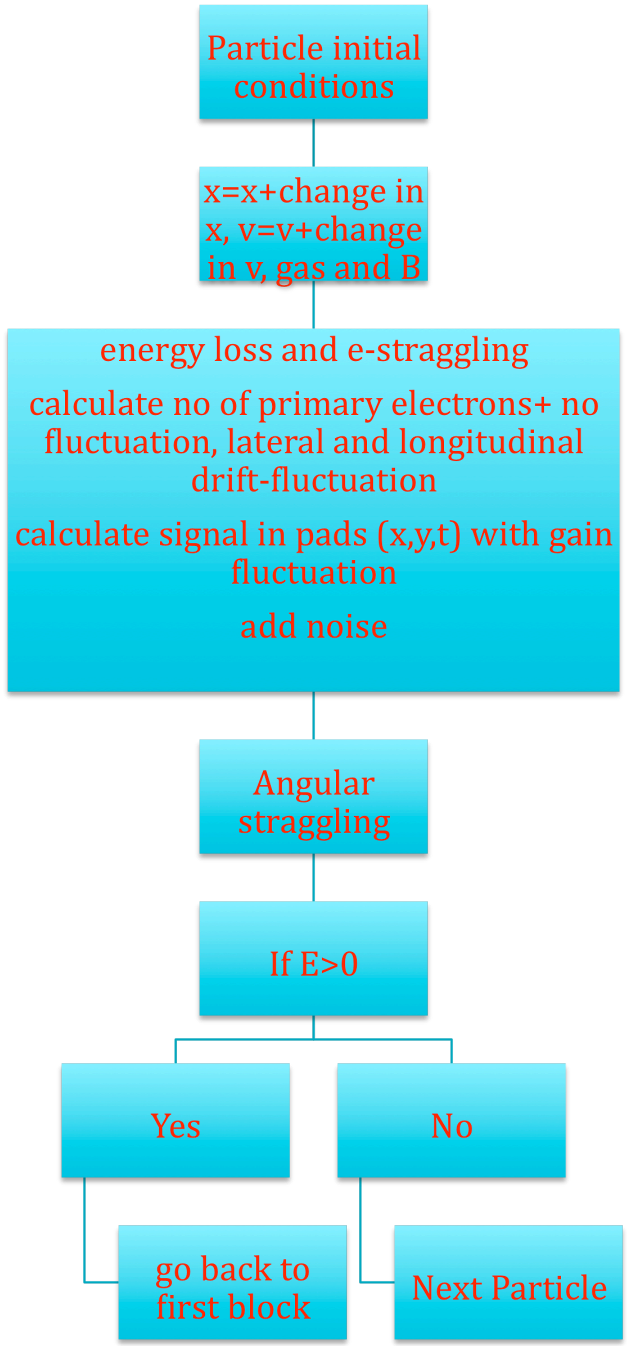
- Analog OR of the 72 discriminator outputs [1 current output].
- Address of the hit channel (through slow control link).
- 4 SCA readout modes.

- **Slow Control**
- **Power on reset**
- **Test mode:**
  calibration or test **[channel/channel]**
  functional **[72 channels in one step]**
- **Spy mode on channel 1:**
  CSAout, PZCout, FILTERout or
DISCRIin.

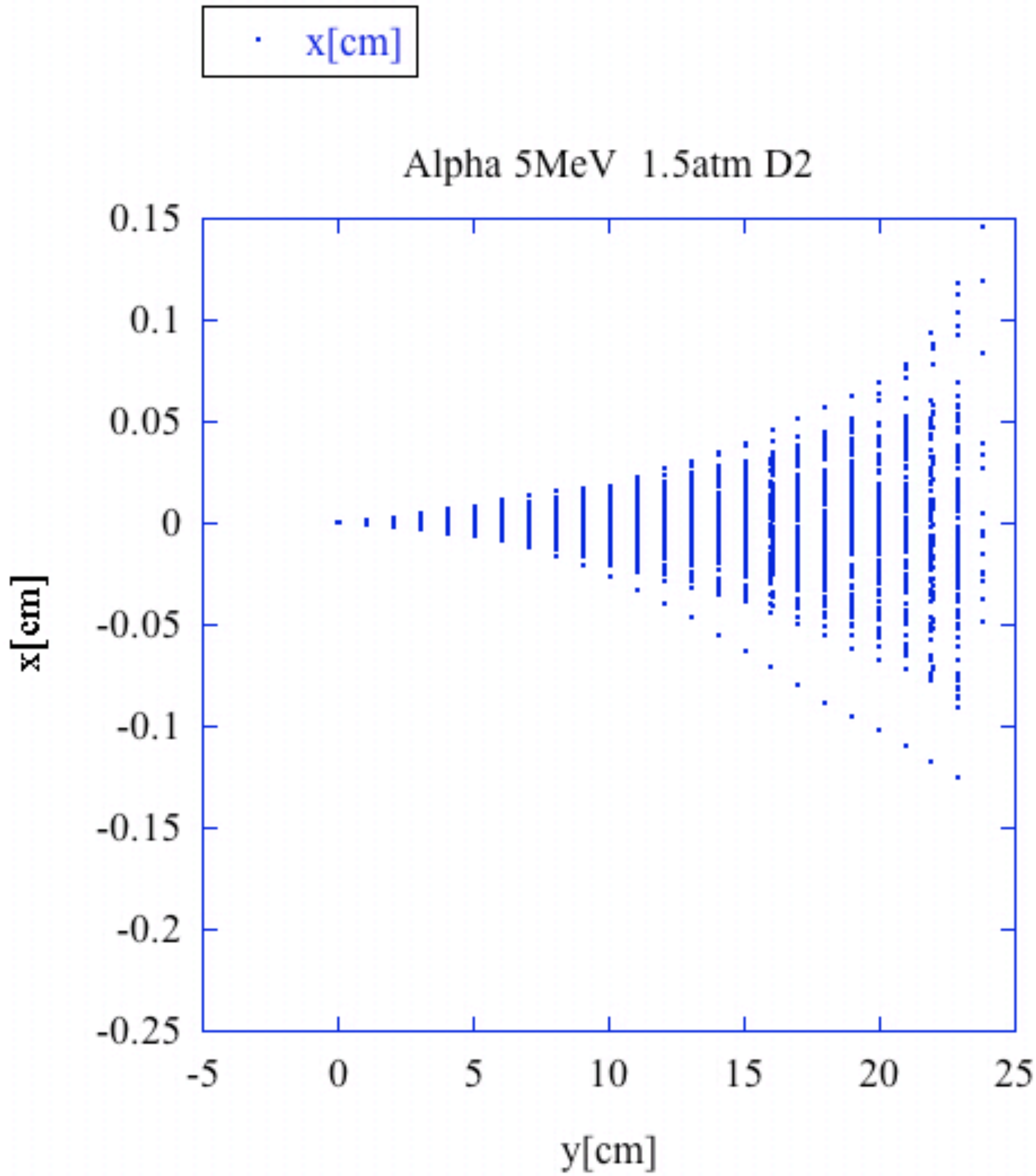
P.Baron-IRFU

Internal multiplicity trigger



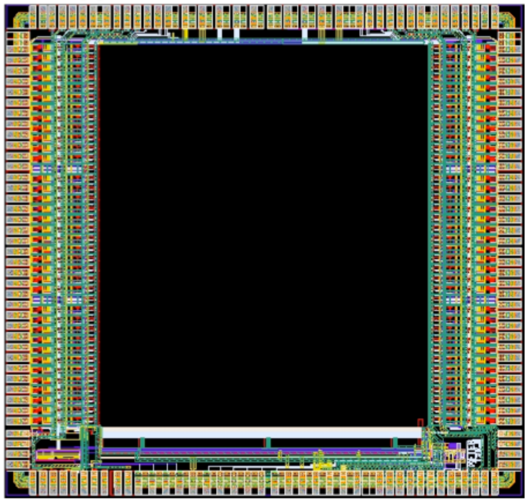

Particle initial conditions
x=x+change in x, v=v+change in v, gas and B
energy loss and e-straggling
calculate no of primary electrons+ no fluctuation, lateral and longitudinal drift-fluctuation
calculate signal in pads (x,y,t) with gain fluctuation
add noise
Angular straggling
If E>0
Yes
No
go back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

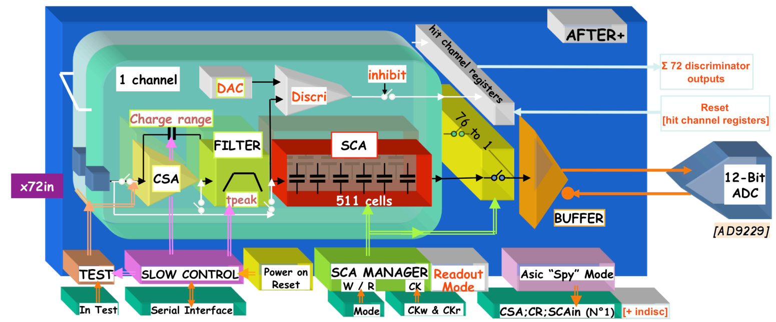
K.Tyler-MSU



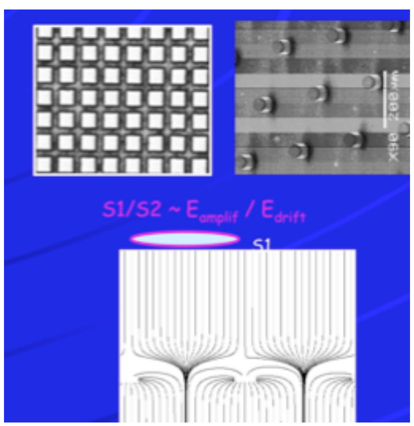
x[cm]
Alpha 5MeV 1.5atm D2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
x[cm]
-5
0
5
10
15
20
25
y[cm]

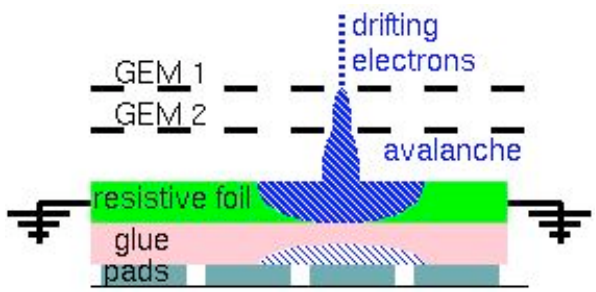
GET-Collaboration: CENBG (France), GANIL (France), GSI (Germany), DL (UK), IRFU (France), NSCL-MSU (USA), RIKEN-RIBF(Japan),Kyoto

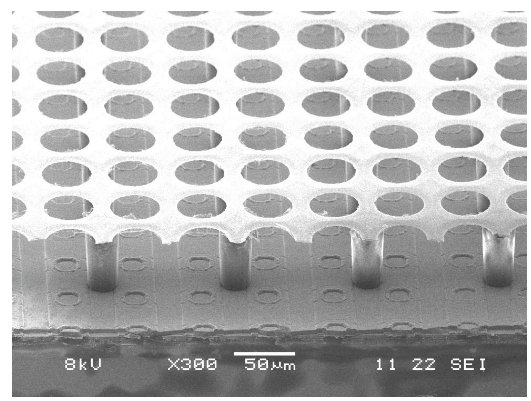


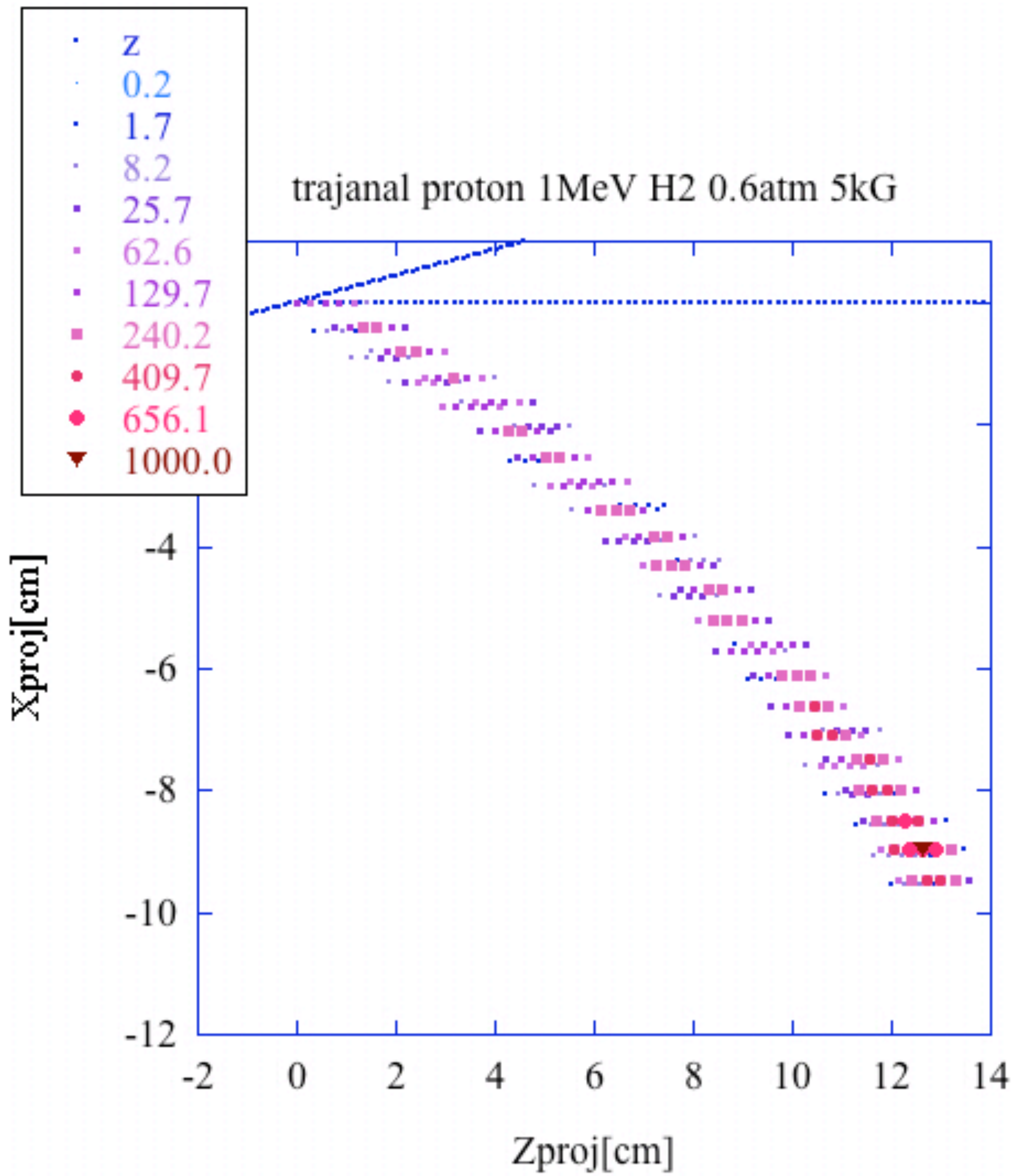


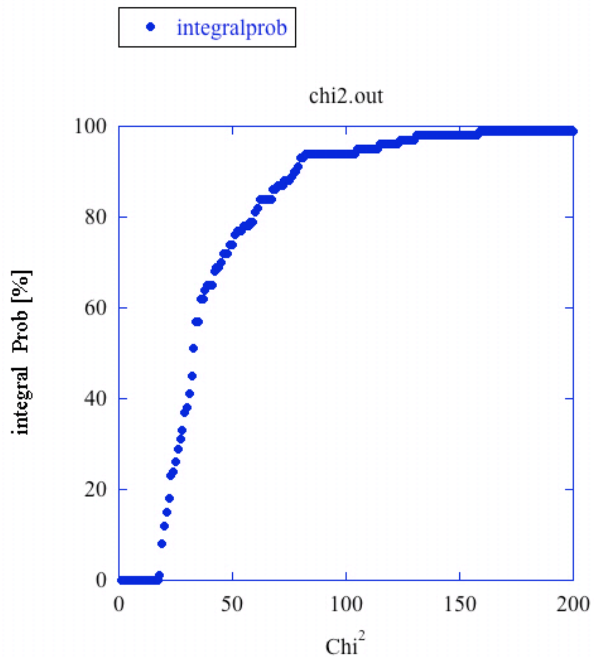
Micromegas-GEM Collaboration: Carlton University (Canada), IRFU(Saclay-France), NSCL

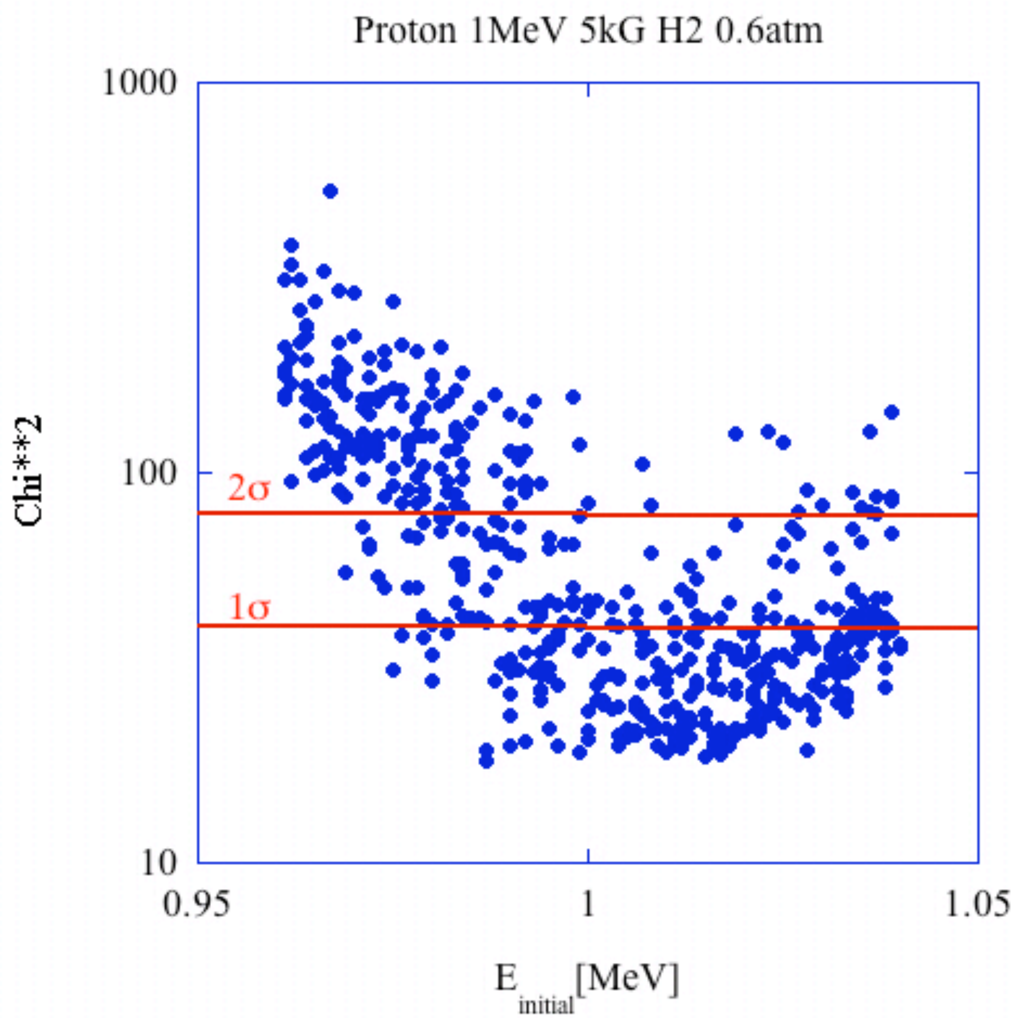


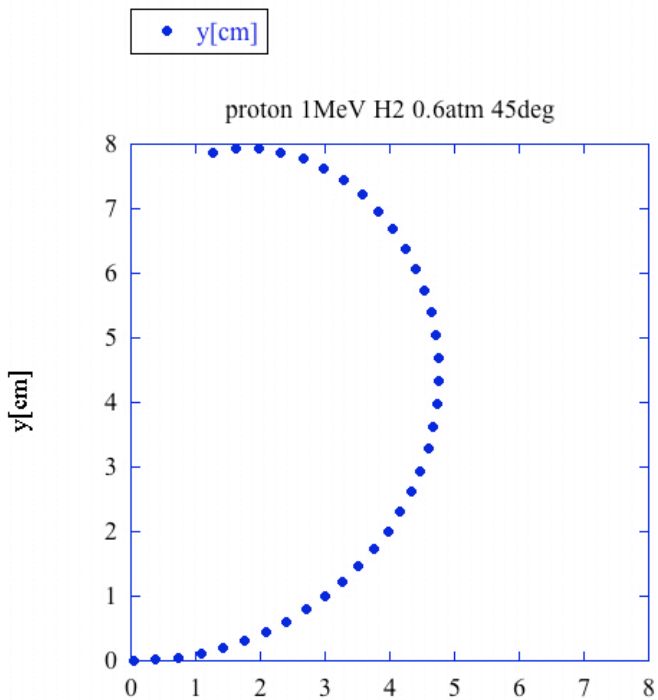


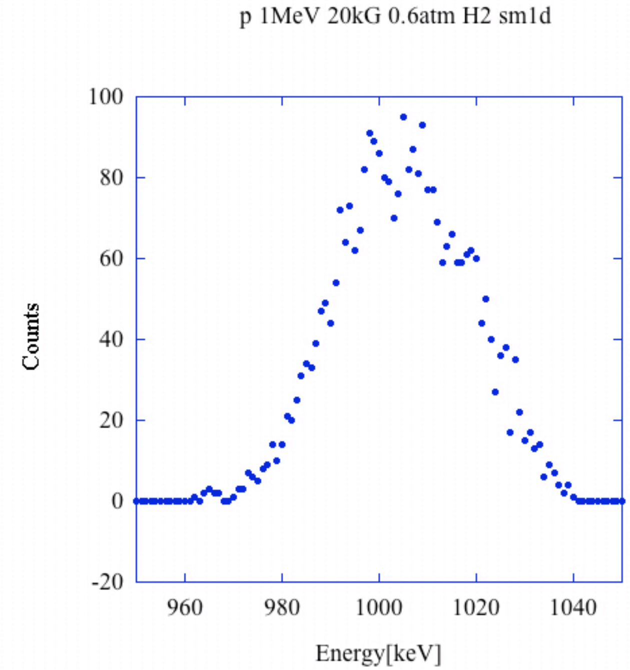


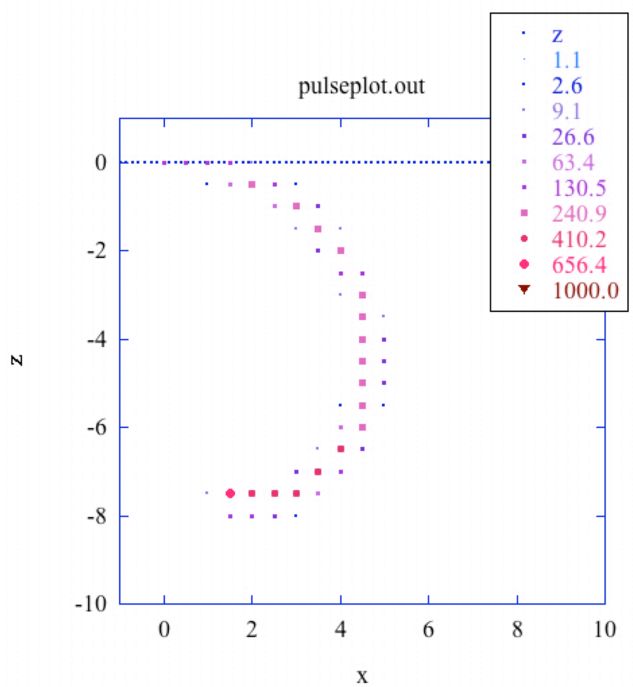

trajanal proton 1MeV H2 0.6atm 5kG
z
0.2
1.7
8.2
25.7
62.6
129.7
240.2
409.7
656.1
1000.0
-4
-6
-8
-10
-12
-2
0
2
4
6
8
10
12
14
Xproj[cm]
Zproj[cm]


integralprob
chi2.out
integral Prob [%]
100
80
60
40
20
0
0
50
100
150
200
Chi^2


Proton 1MeV 5kG H2 0.6atm
Chi**2
1000
100
10
2σ
1σ
0.95
1
1.05
E initial [MeV]

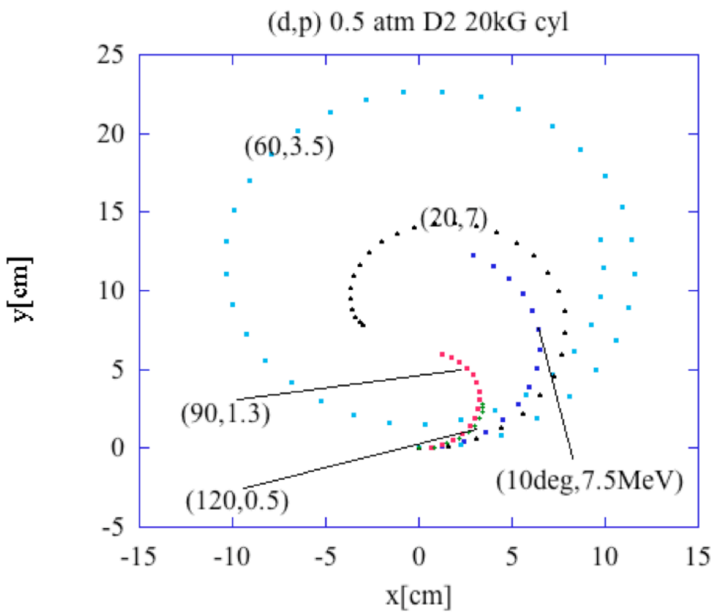

y[cm]
proton 1MeV H2 0.6atm 45deg
y[cm]

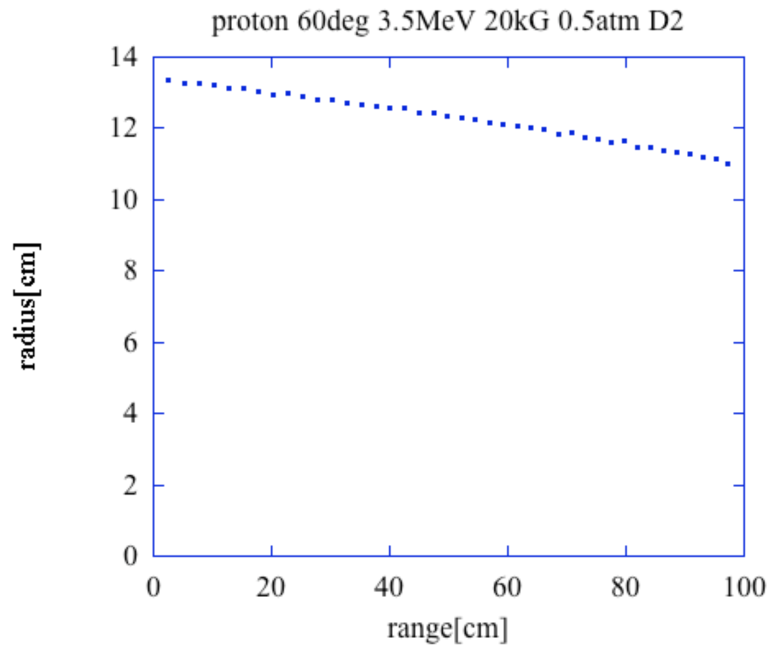

p 1MeV 20kG 0.6atm H2 sm1d
Counts
Energy[keV]


pulseplot.out
z
1.1
2.6
9.1
26.6
63.4
130.5
240.9
410.2
656.4
1000.0
z
x

Conclusion

- AT-TPC may provide a large solid angle – large dynamics measurement device
- In quasi-elastic reactions (inel, CE, transfer) the very low energy recoils may be detected in thick targets without loss of resolution
- Best possible resolution essential


(d,p) 0.5 atm D2 20kG cyl
(60,3.5)
(20,7)
(90,1.3)
(120,0.5)
(10deg,7.5MeV)
y[cm]
x[cm]
25
20
15
10
5
0
-5
-15
-10
-5
0
5
10
15


proton 60deg 3.5MeV 20kG 0.5atm D2
radius[cm]
range[cm]
14
12
10
8
6
4
2
0
0
20
40
60
80
100