UNIVERSITY OF LIVERPOOL

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Some recent status and plans for symmetry energy related studies in China

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Contents

How long the E_{sym} effects can persist in HIC?

Neutron Skin → Isospin scaling → Isospin Diffusion / Fast nucleon emission

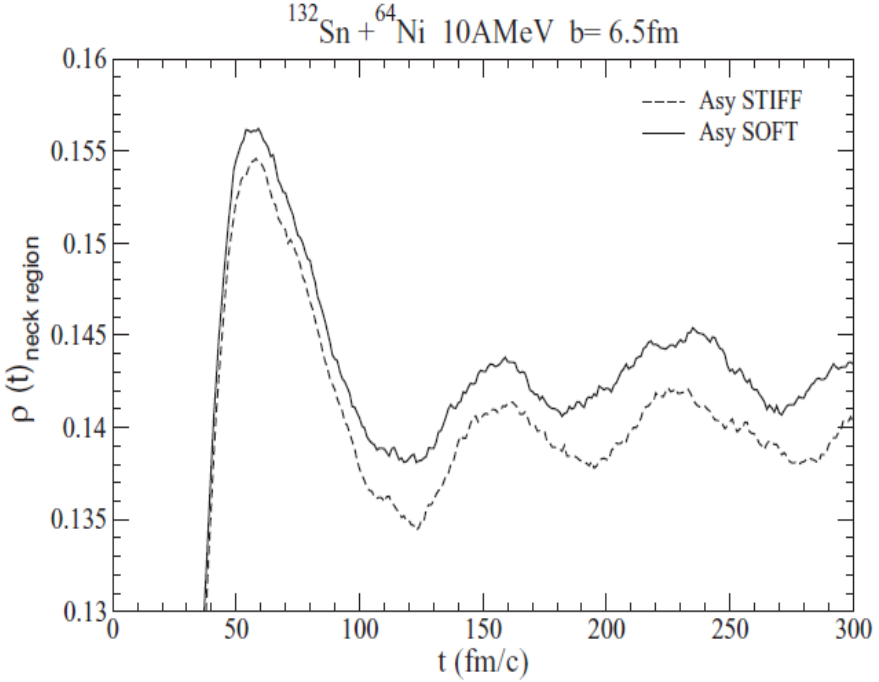
SLOW

10^{-19} s

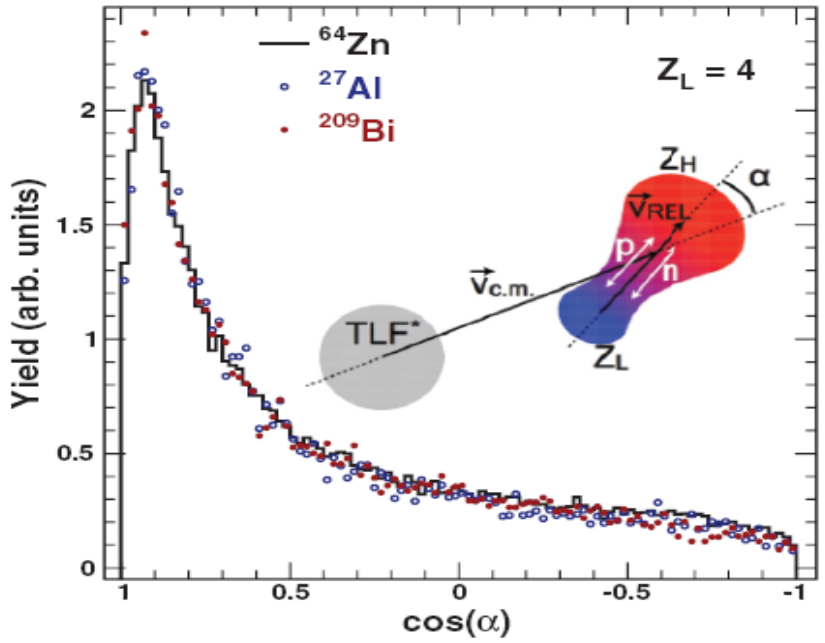
Intermediate Process ?

FAST

$10^{-21\sim22}$ s

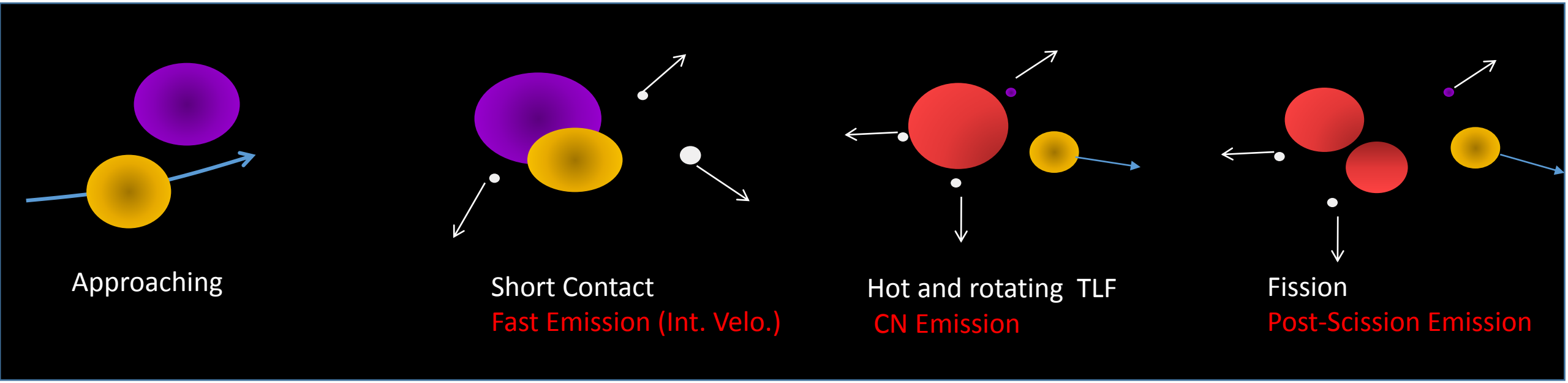


Phys Rev C **83**, 014604 (2011)



Phys Rev C87 (2013) 061601(R)

Using fission to study the long time effect of $E_{sym}(\rho)$



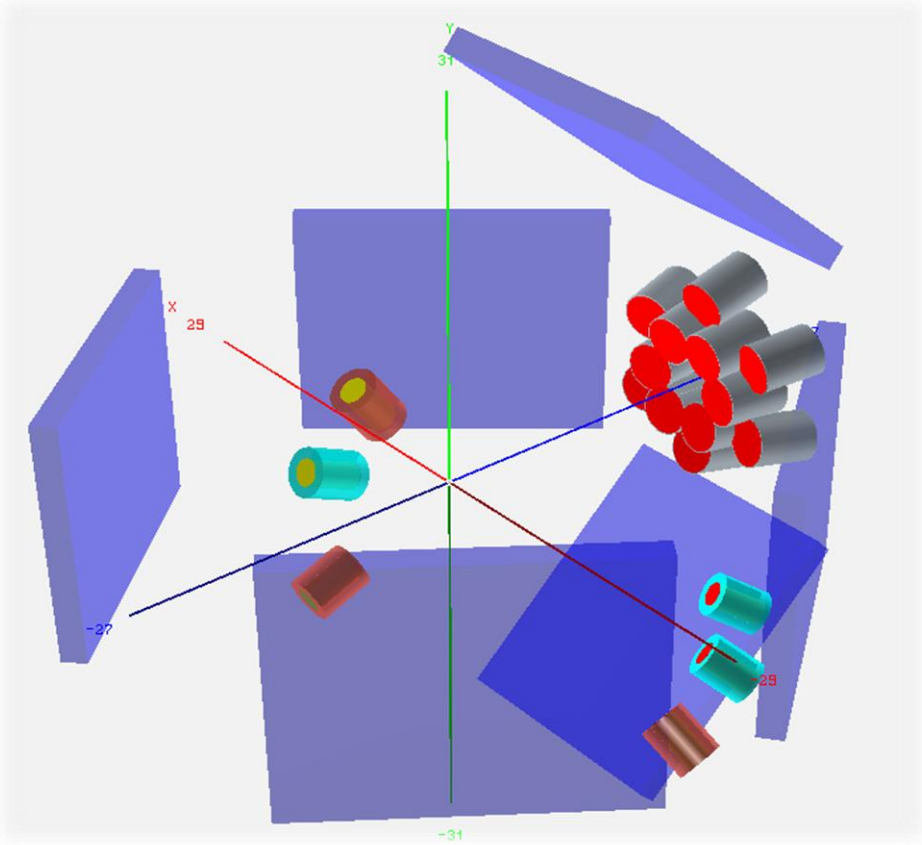
Animation by Tian Junong

- Possible Advantages:
- ☑ Neck part: Very neutron rich, Low Densities
- ☑ Time Scale: Between statistical emission (Q effect) and two body process (very short)

One Step backward: Isospin effect of the particle emission

Experimental Setup

- 35 MeV/u Ar+ Au.
- Trigger: 2 fold fragments .AND. 1 LCP
- 2 fold fragments .AND. 1 Proj.-like



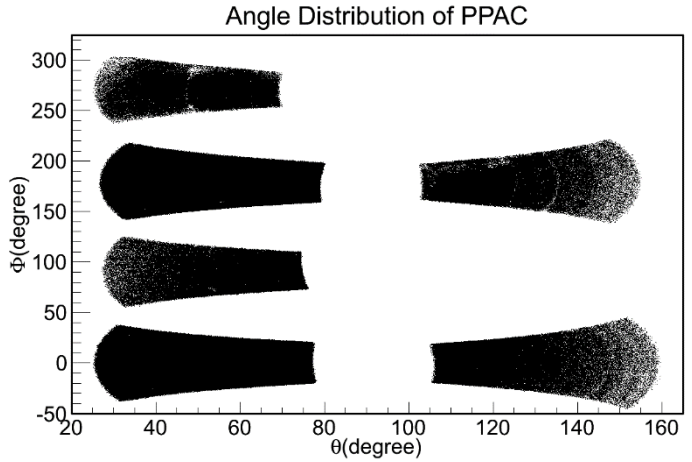
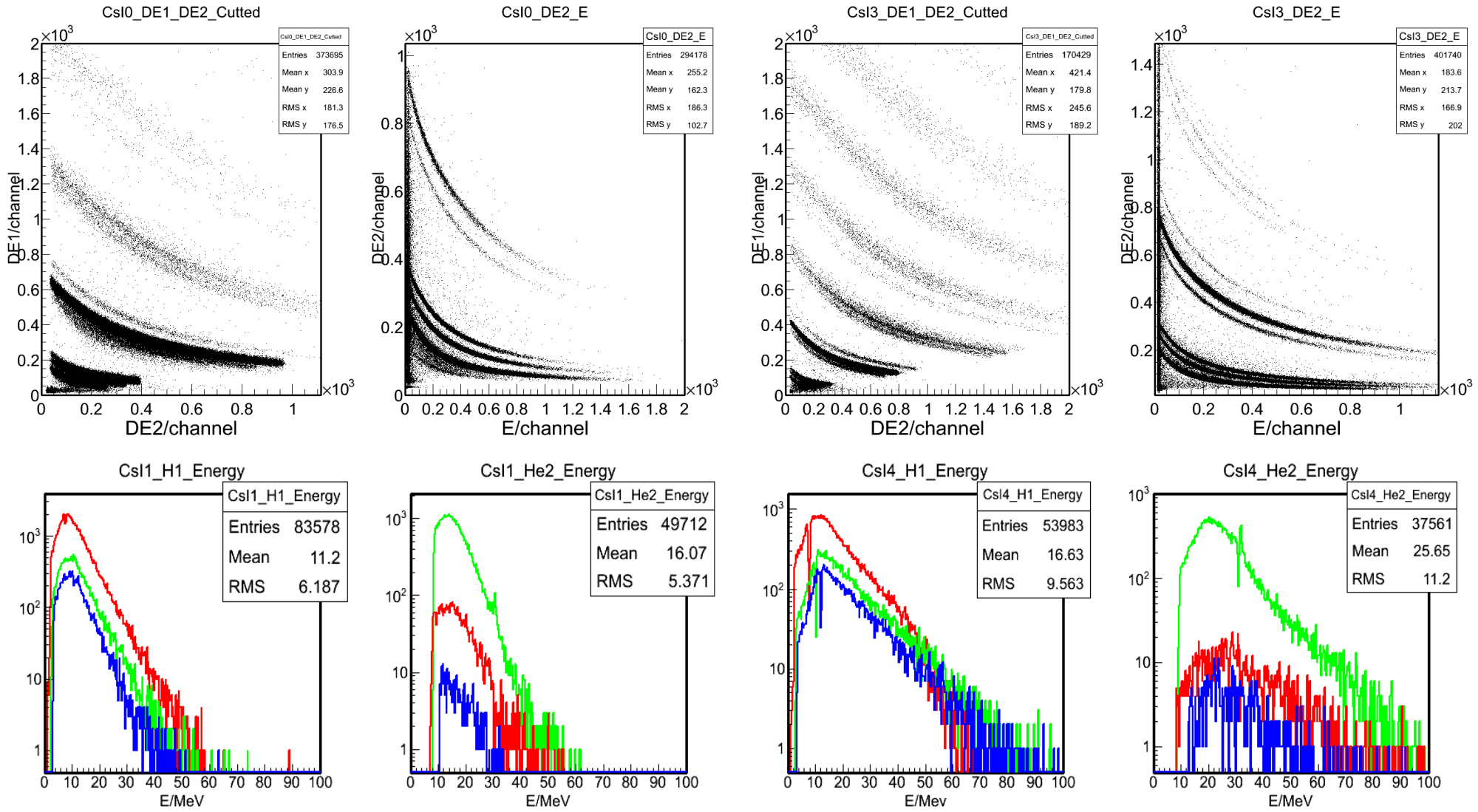


TABLE I: The parameters of the 6 LCP telescopes

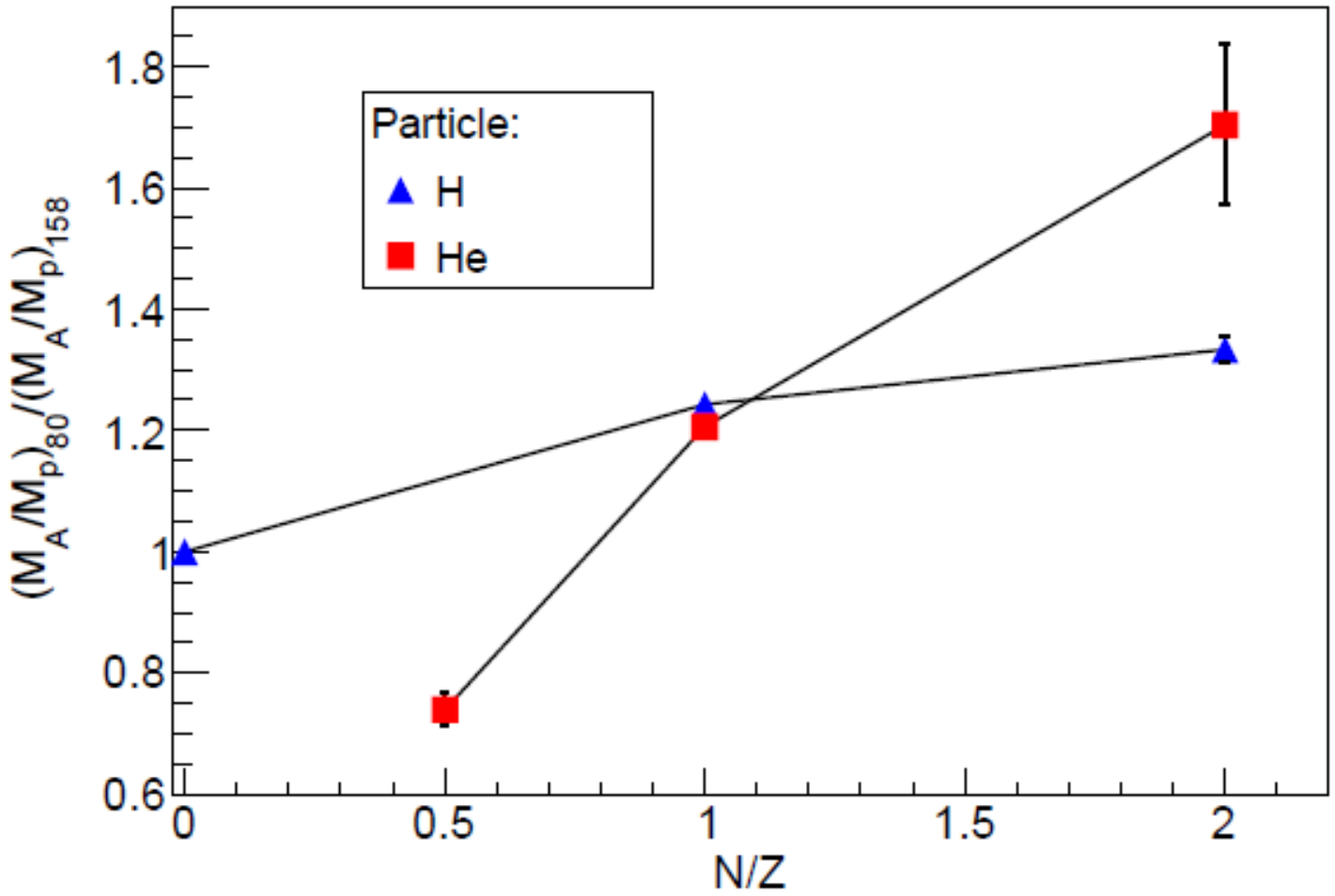
Tele. No.	1	2	3	4	5	6
d (mm)	12.0	10.2	10.4	14.0	14.0	14.0
L (cm)	11.5	11.5	11.5	26.0	21.6	28.5
θ (°)	158	155	127	80	59	44
ϕ (°)	-90	90	90	-145	-139	-133
ΔE_1 (μm)	50	50	50	50	50	50
ΔE_2 (μm)	400	/	400	400	/	/
E_{CsI} (mm)	40	40	40	40	40	40

LCPs in coincidence with fission



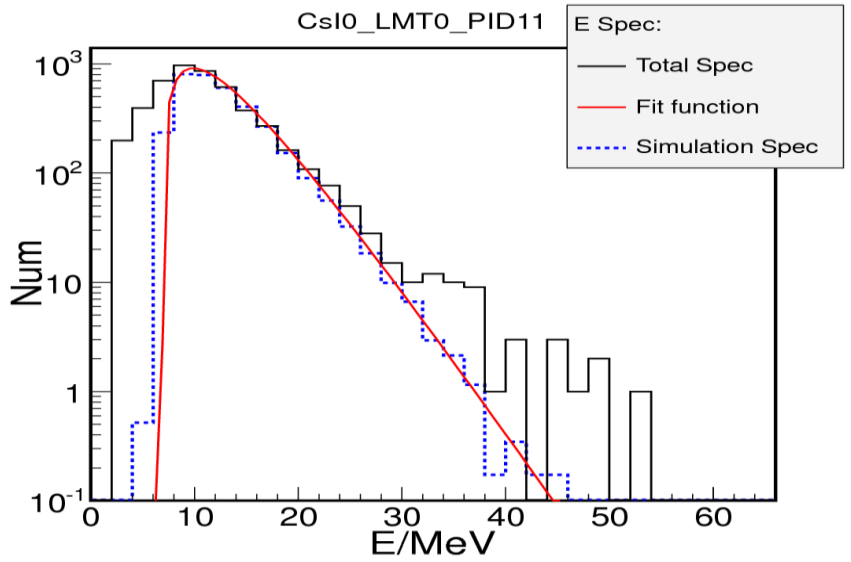
- Mass Resolved spectra obtained at 2 degrees: 158, 80

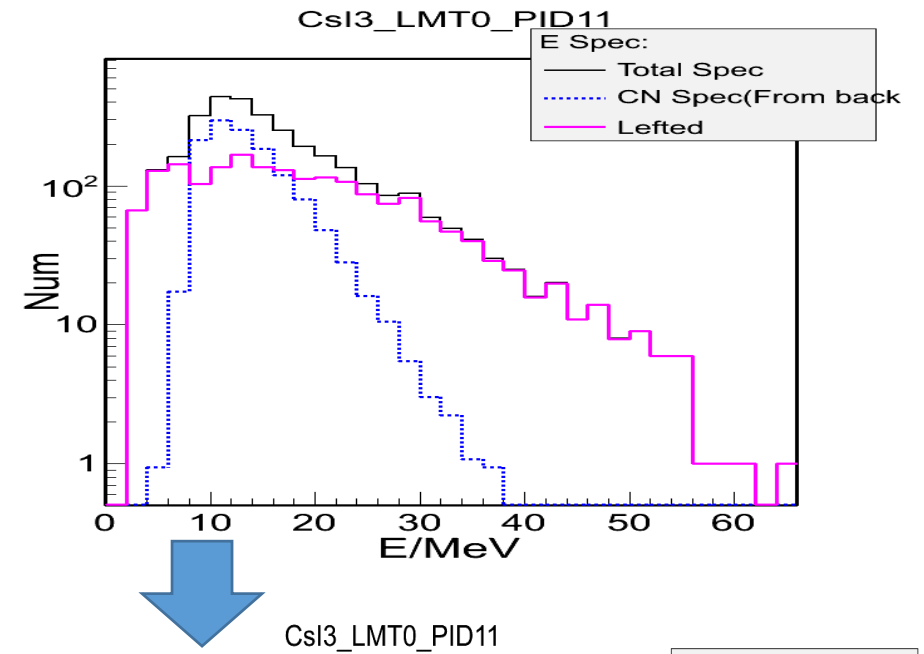
Double angular ratio of particle yield



- Model independently, particles emitted at smaller angle are more neutron rich
- Smaller angle emitted particles experience more dynamical contribution

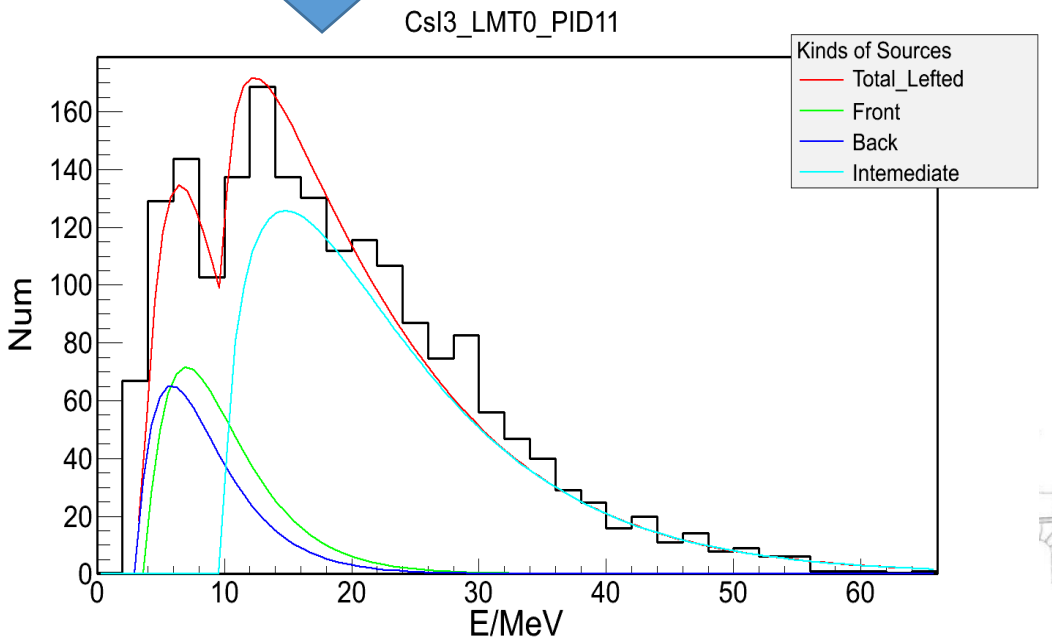
Three moving source analysis





- Three moving source: CN, FF and Int. Velocity

$$\frac{d^2\sigma}{d\Omega dE} = \frac{N}{2\left(\pi T\right)^{3/2}}\left(E - E_c\right)^{1/2}\exp\left[-\left(E - E_c\right)/T\right]$$

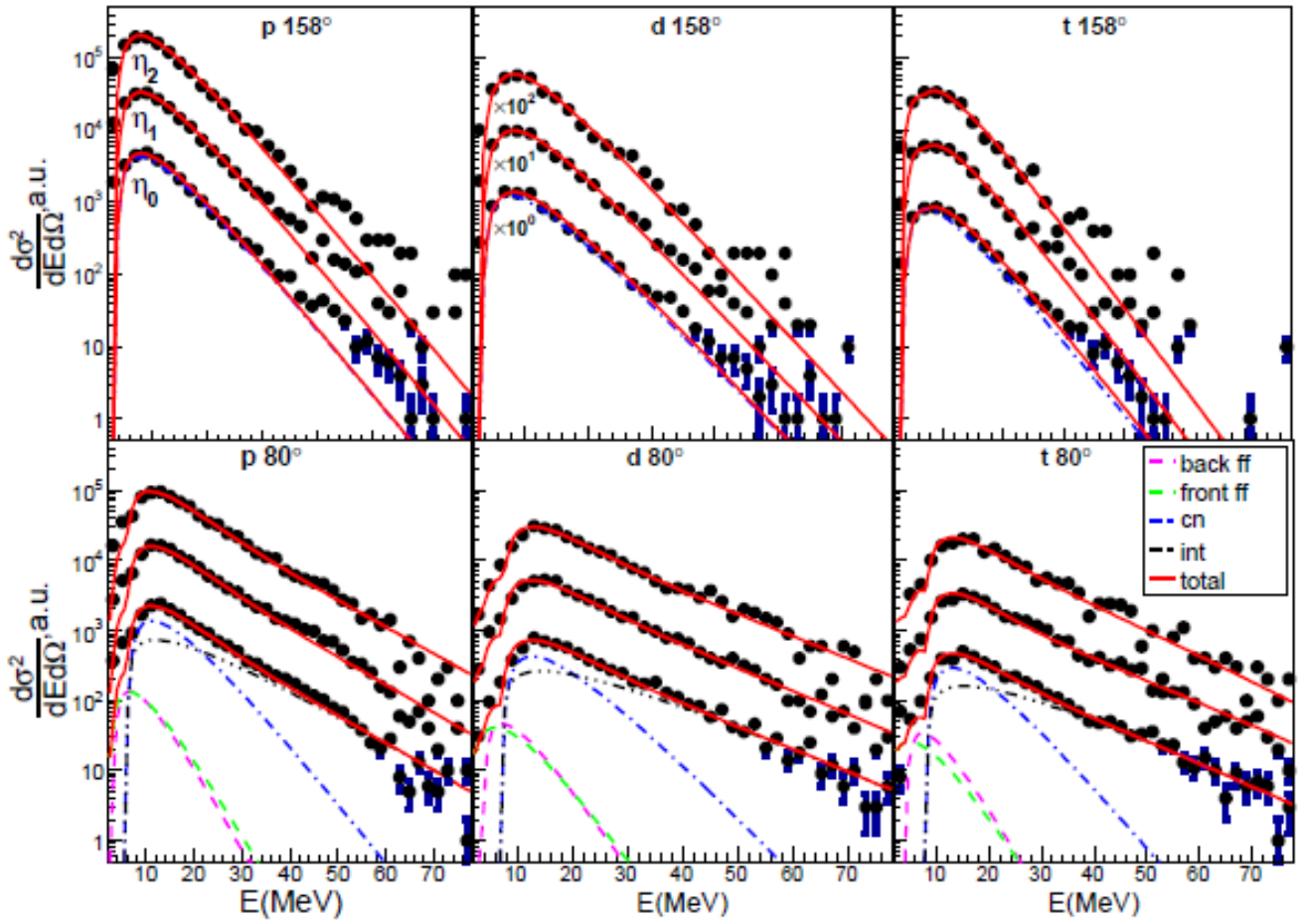


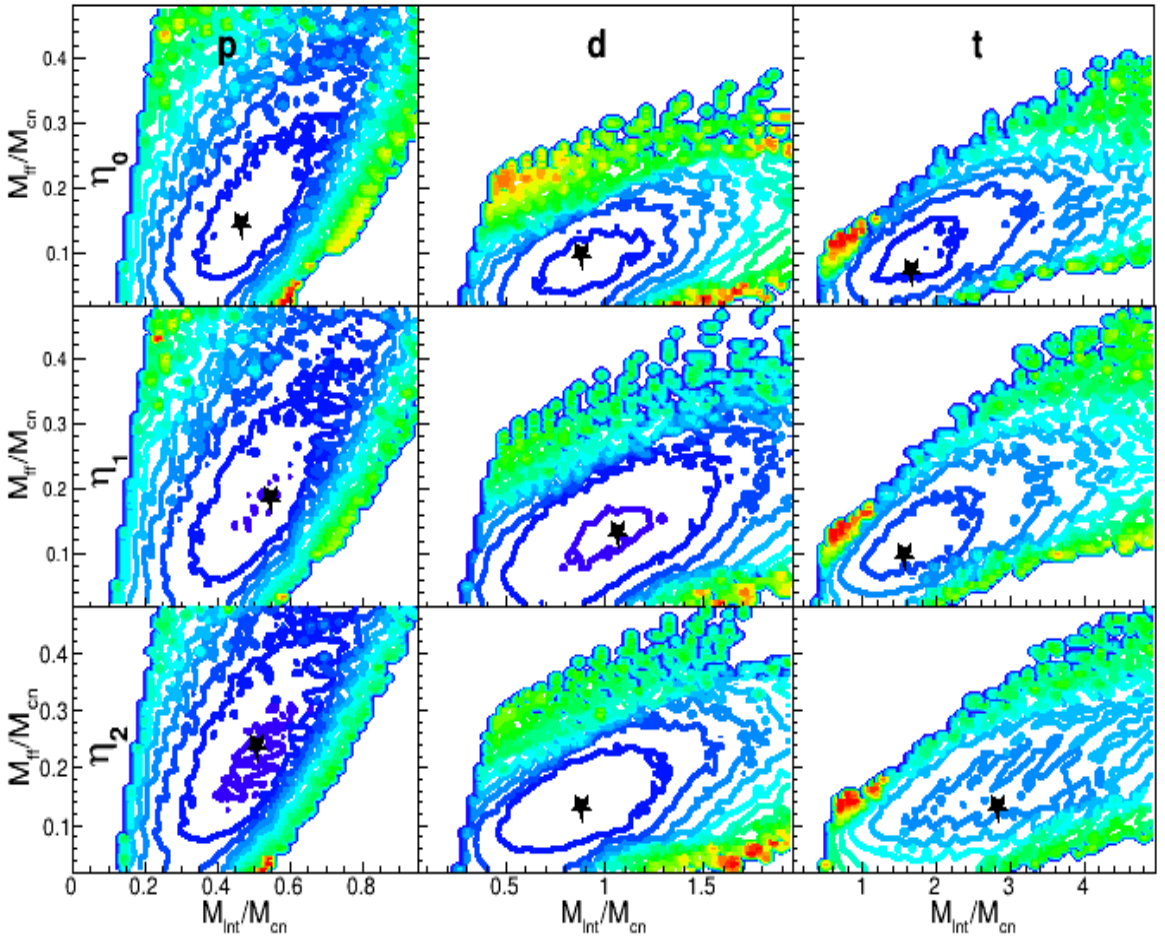
STEP 1: Fit large angle telescope with CN source

STEP 2: Apply the CN parameters to the middle angle detector

STEP 3: Fit the middle angle spectrum

Energy spectra analysis

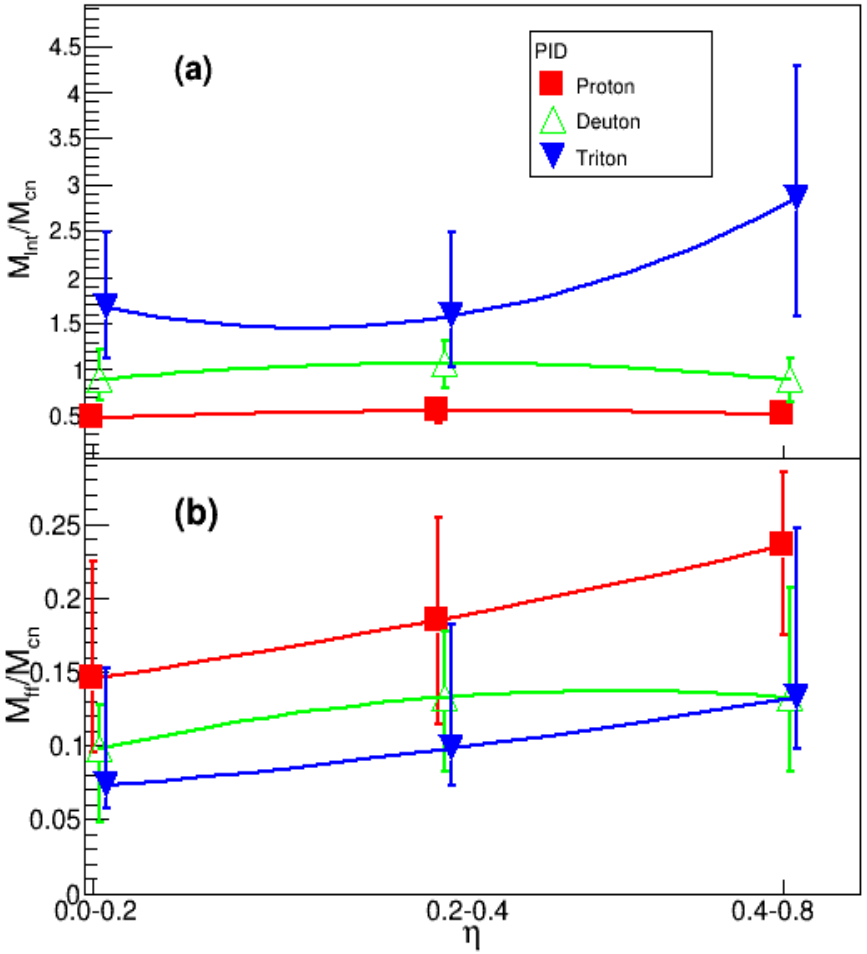


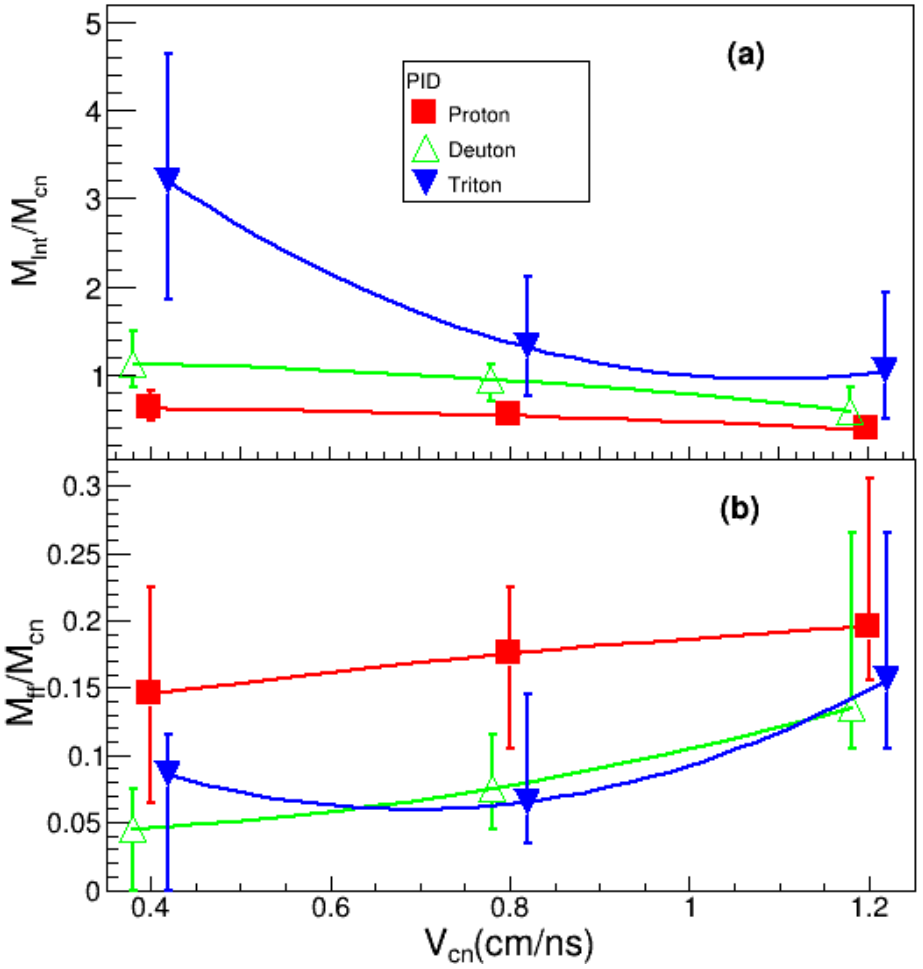


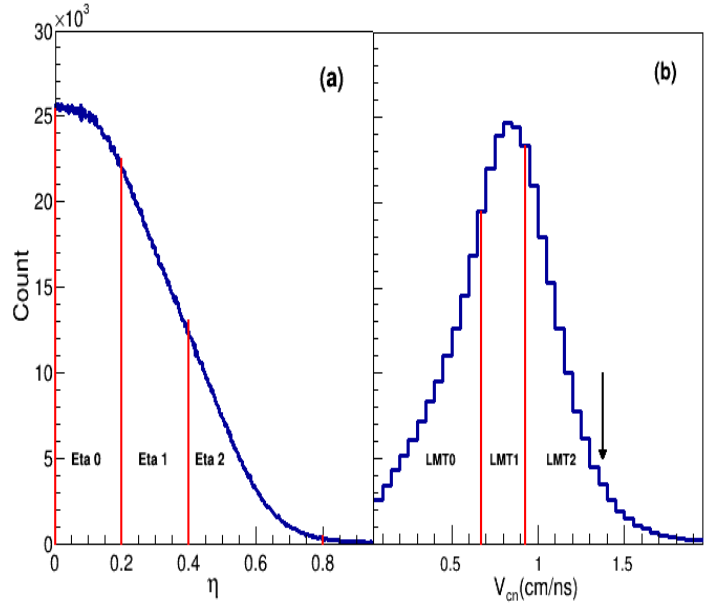
- Three moving source: CN, FF and Int. Velocity

$$\frac{d^2\sigma}{d\Omega dE} = \frac{N}{2\left(\pi T\right)^{3/2}}\left(E - E_c\right)^{1/2}\exp\left[-\left(E - E_c\right)/T\right]$$

Minimum χ2 analysis







→ M_{ff}/M_{cn} vs. M_{inv}/M_{cn}

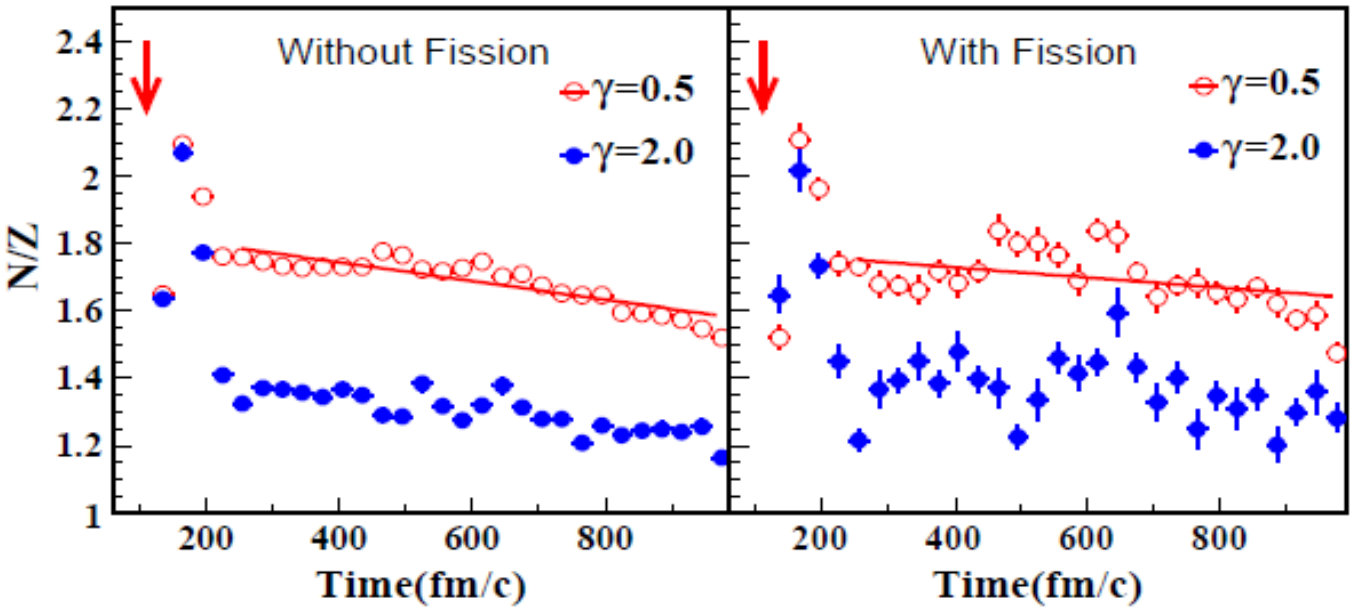
→The two ratios show different hierarchy

→ **The particles emitted in early stage are neutron rich!**

IQMD calculations

$$V_{\rm loc} = \frac{\alpha}{2}\frac{\rho^2}{\rho_0} + \frac{\beta}{\sigma+1}\frac{\rho^{\sigma+1}}{\rho_0^{\sigma}} + \frac{g_0}{2\rho_0}(\nabla\rho)^2 + \frac{C_s}{2}[\frac{\rho^{\gamma+1}}{\rho_0^{\gamma}} - \frac{\kappa_s}{\rho_0}(\nabla\rho)^2]\delta^2 + g_\tau\frac{\rho^{\eta+1}}{\rho_0^{\eta}}$$

α	207 MeV	β	138 MeV
σ	7/6	g_0	18 MeV · fm^2
C_s	32 MeV	κ_s	0.08 fm^2
g_τ	14 MeV	η	5/3



1)Along the whole decay chain, the average N/Z decreases with time.

→The neutron richness of the emitted particles is enhanced at the beginning of the emission.

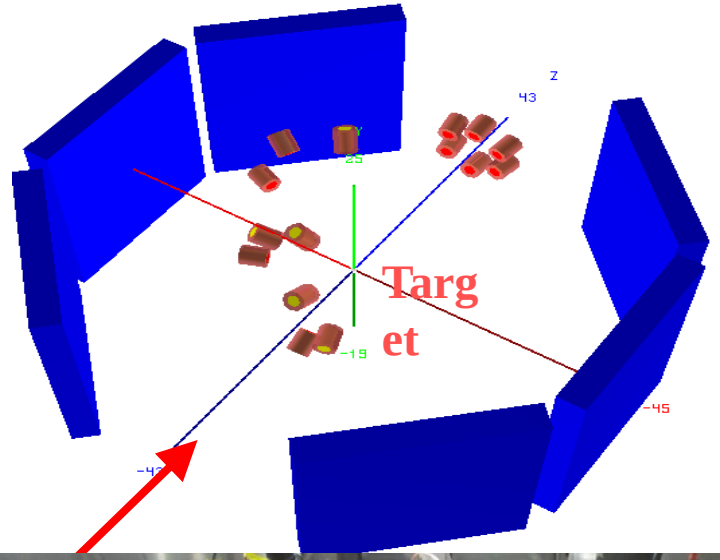
2)The isospin composition N/Z exhibits an obvious dependence on $E_{sym}(\rho)$ till very late stage.

3)The effect of the symmetry energy remains equally significant in the fission.

→ Scission point can be a clock to investigate the effect of $E_{sym}(\rho)$.

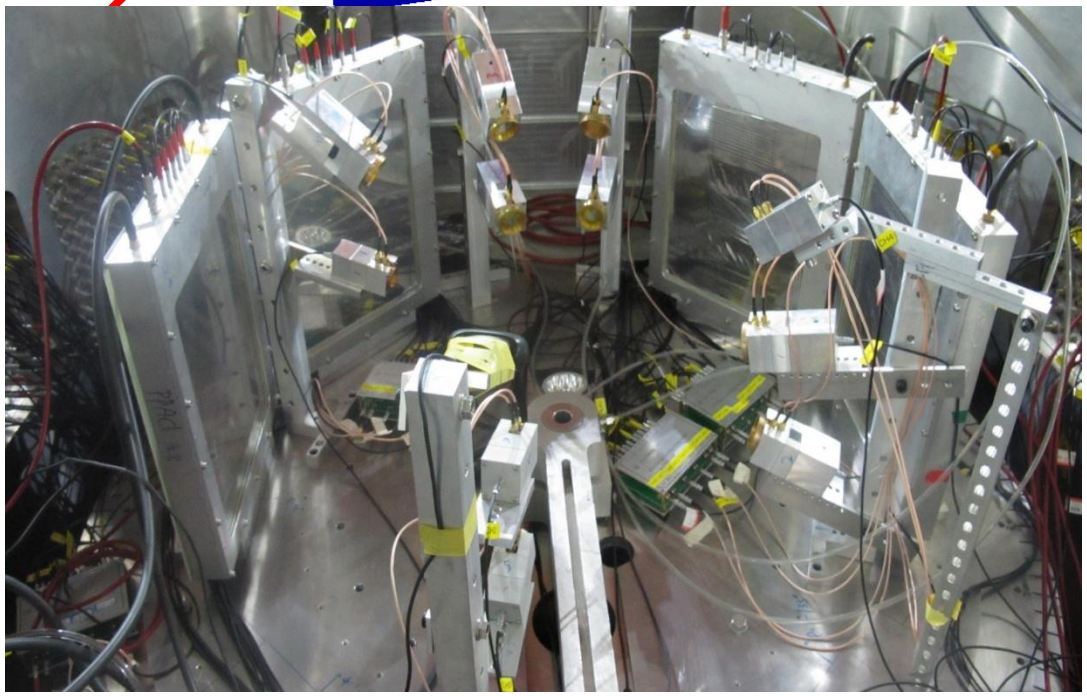
For more details, please refer to R. Wang, XZG et al, PRC 89, 064613 (2014)

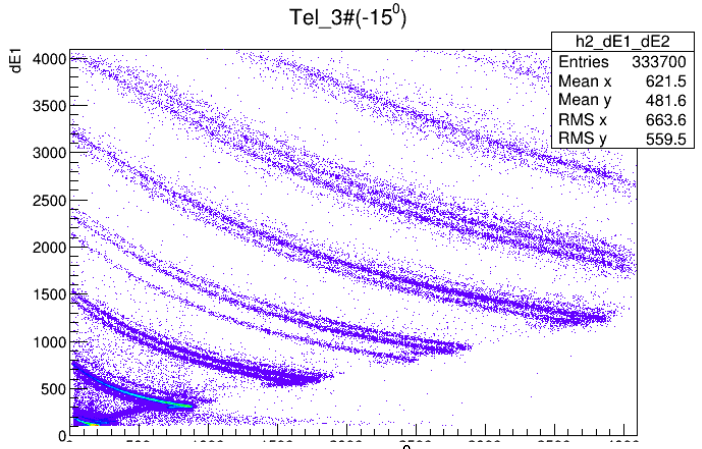
New experiment Performed

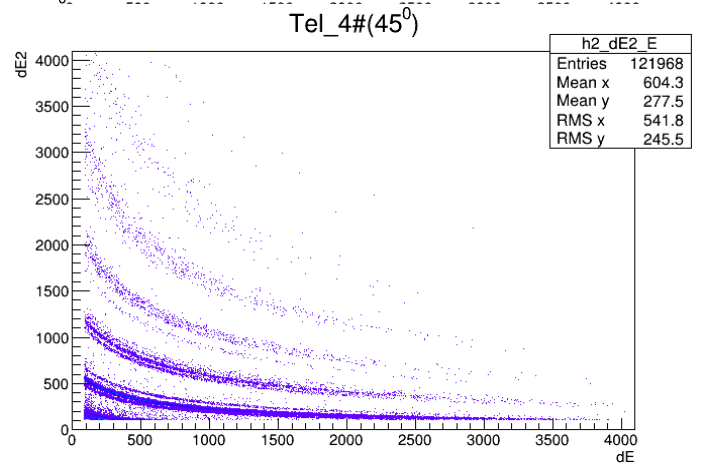


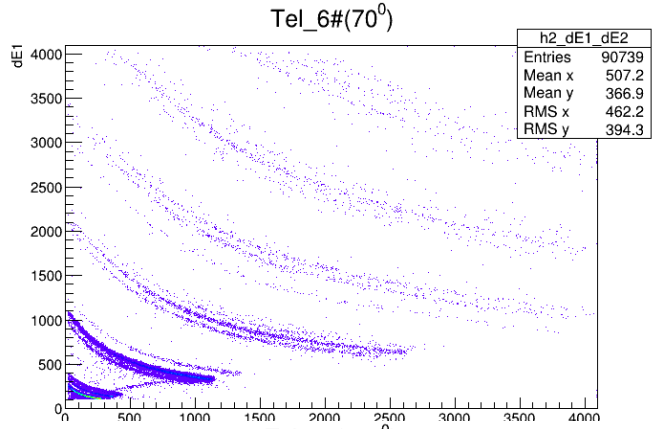
- Completed on Jun 4, 2014.

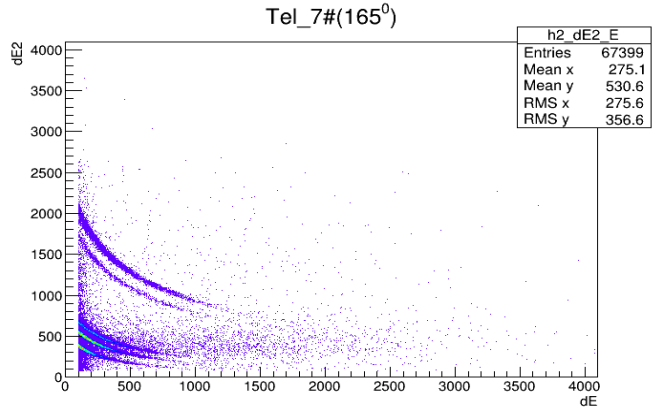
1. Improved PID by using H.Q. telescopes
2. Lower energy threshold
3. More Detectors(> 5 positions)

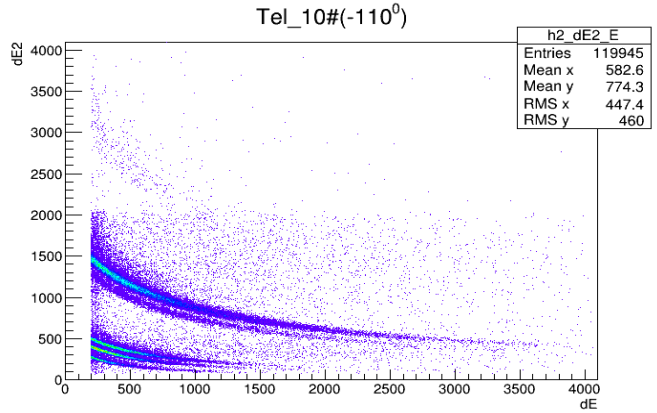




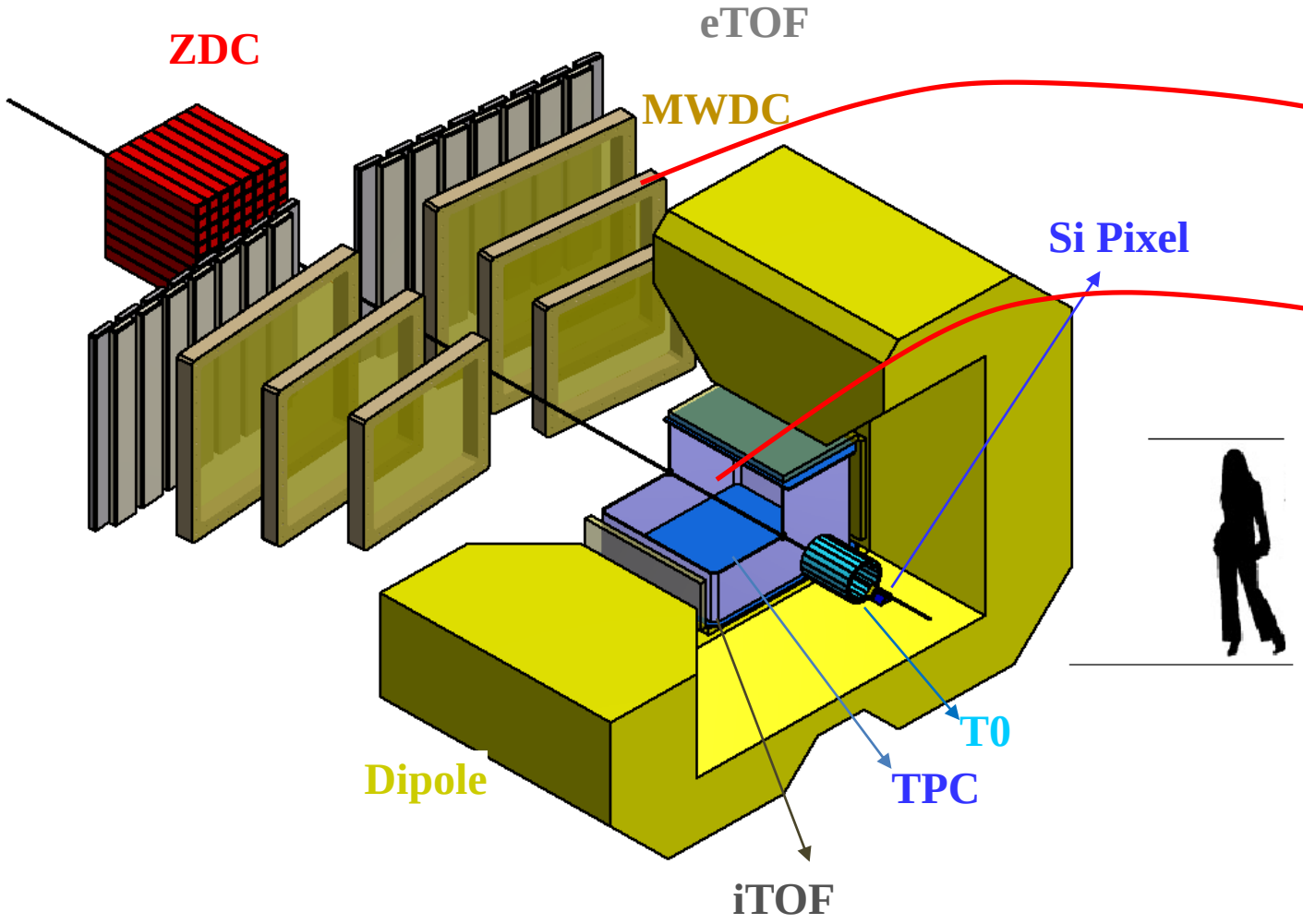




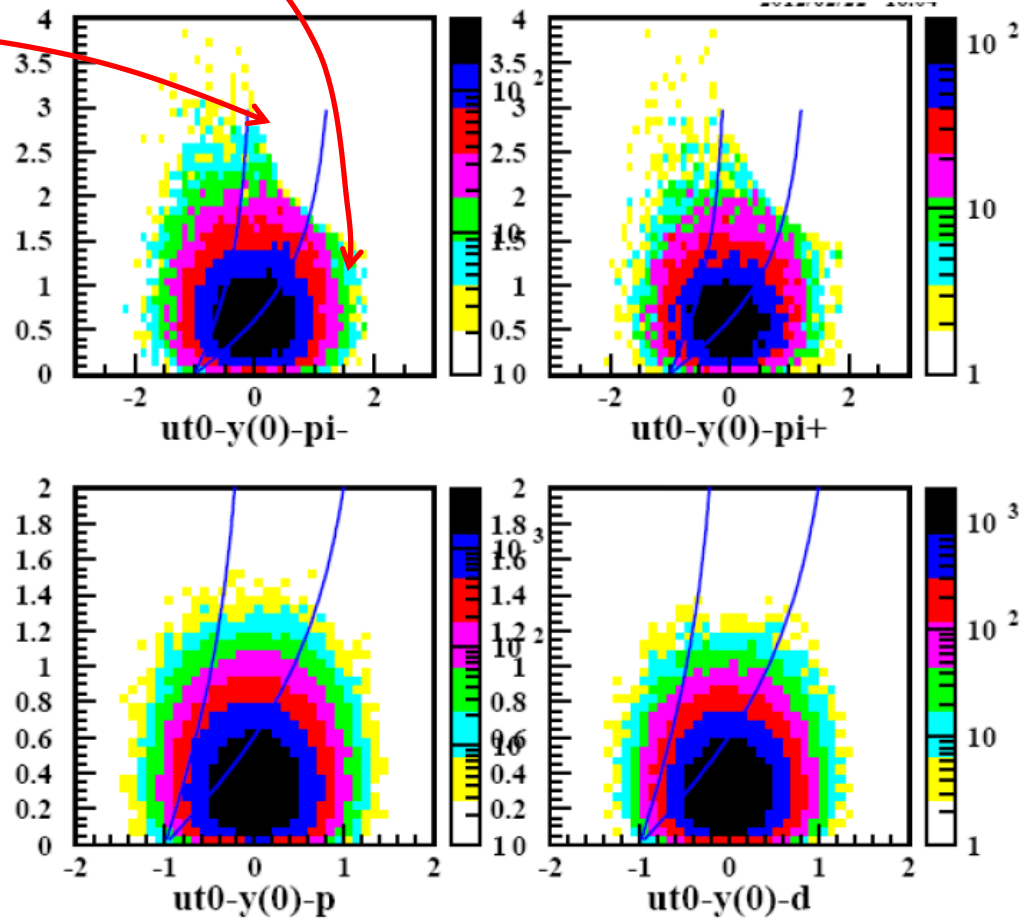




Esym(ρ) at supra-saturation studies at HIRFL-CSR

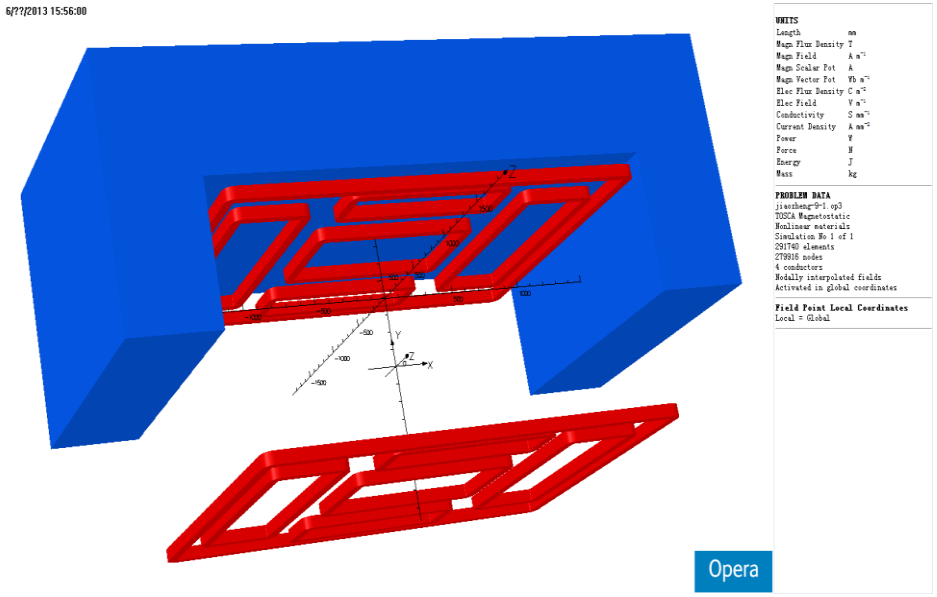


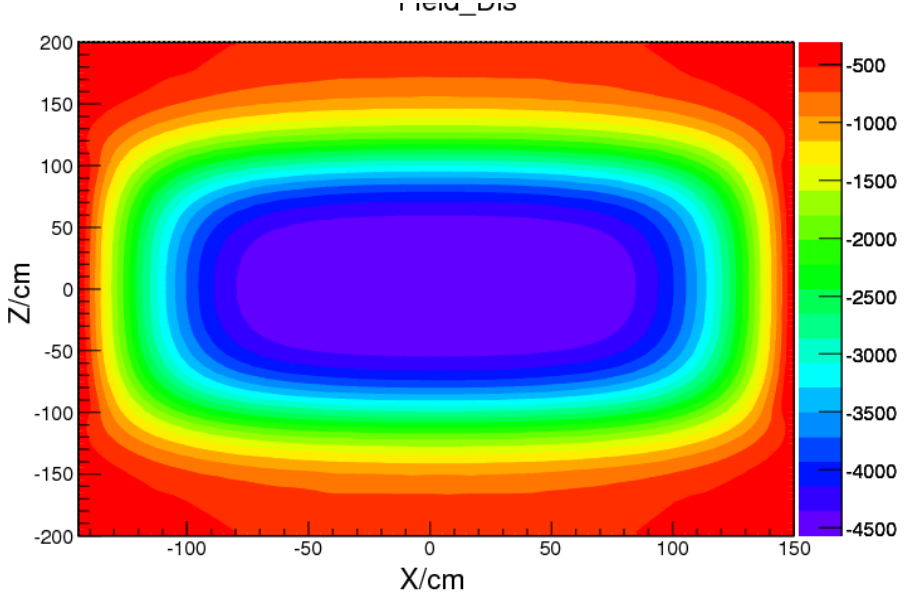
$$E\frac{d^3\sigma}{dp^3}=\frac{1}{p_t}\frac{d^3\sigma}{dydp_td\varphi}$$



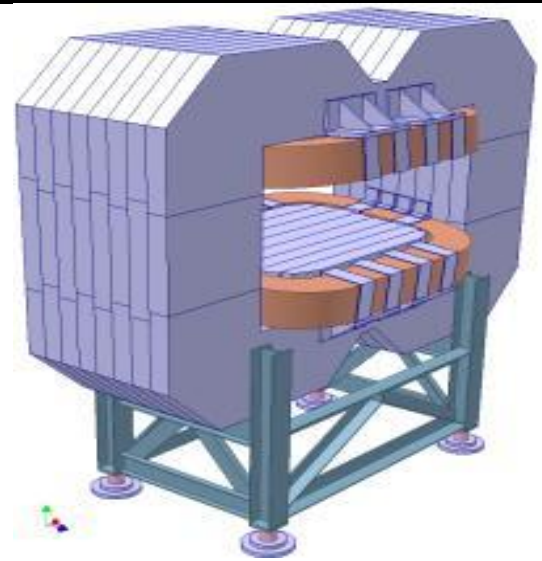
Pre-CEE collaboration

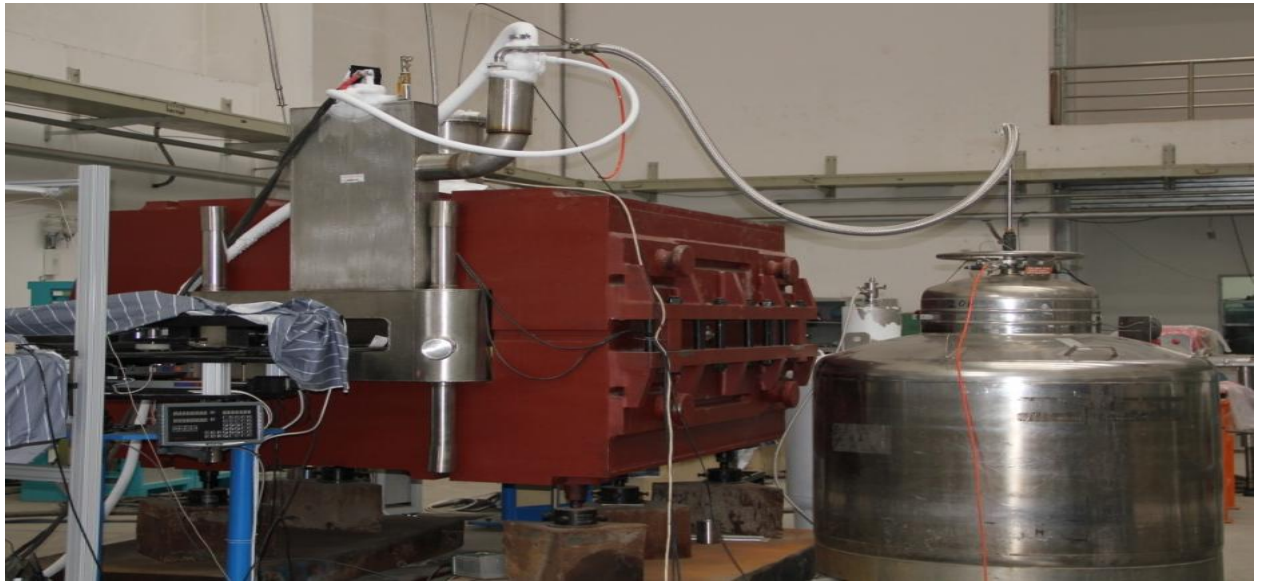
Design of the Dipole





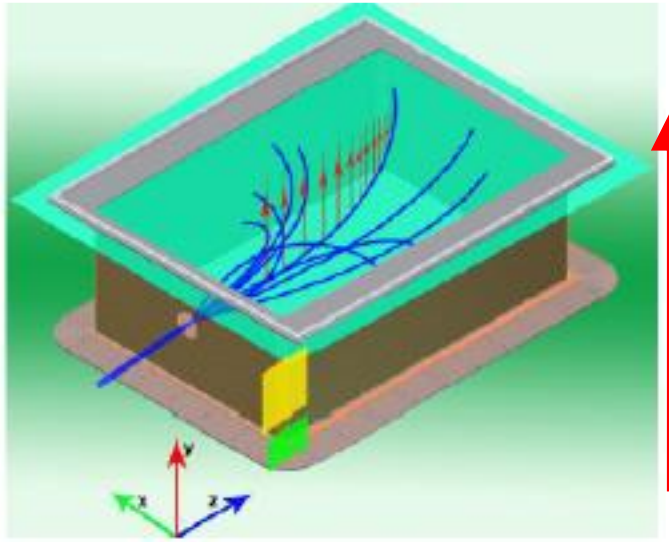
Central Field	0.5 T
Hom. Region	~1 m×0.9 m×1.2 m^3
Uniformity	1%
Total Size	～2.5×3×4 m^3
Total Weight	~200 Ton





Prototype of a superconductive magnet (Made in IMP, for FAIR)

TPC: Conceptual Design

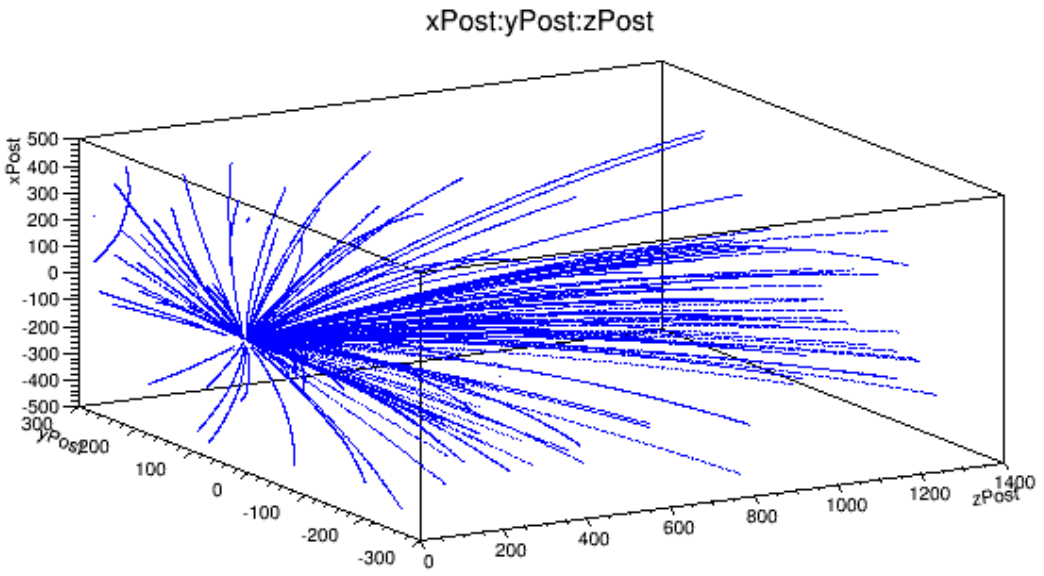


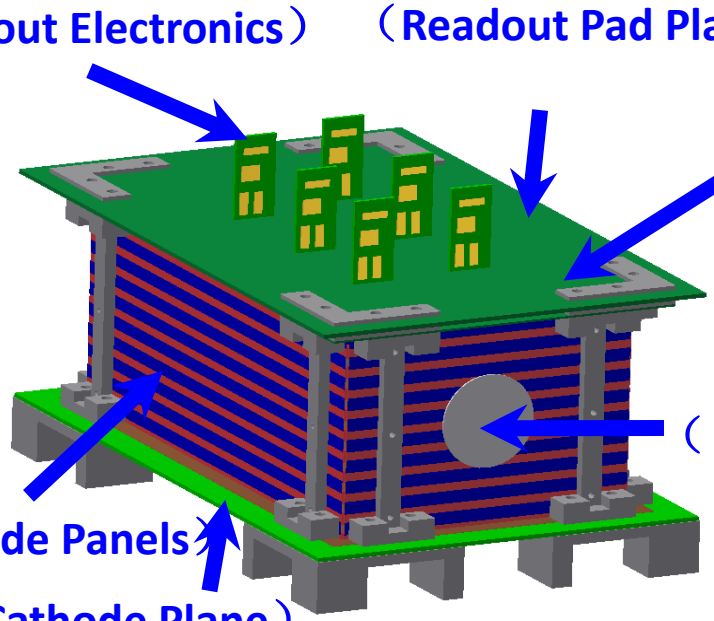
B, E

TPC:

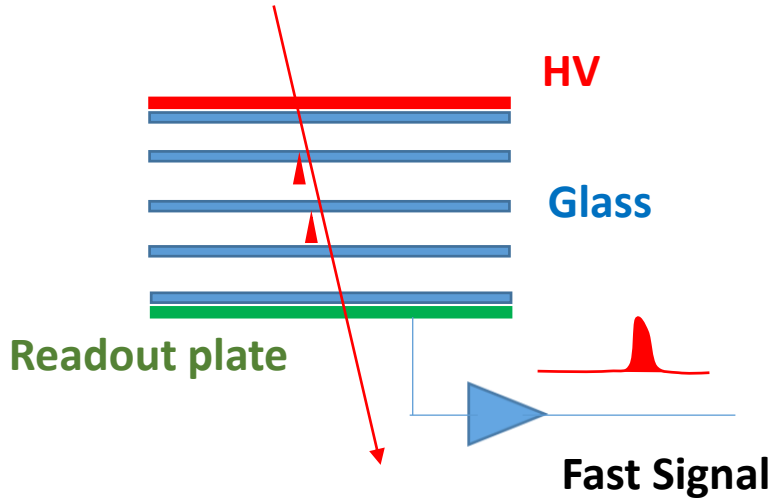
- **B//E**
- **Particle bending due to B**
- **Ionized electrons drift due to E**
- **Collect signal when e arrive**

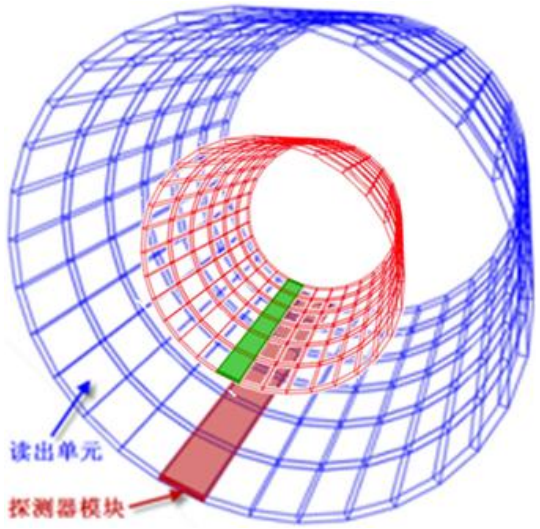
Read out area	**~1.1 m× 0.9 m**
Pad. number	~10000
Pad size	~9 mm × 1.1 mm
Max. drift leng.	~ 50 cm
Working gas	90% Ar + 10% CH_4
E Field	150V/cm
dE/dx range	Z<=6, π,p,d,t,He-C
Double track res.	2.5 cm
Max. Multi.	200

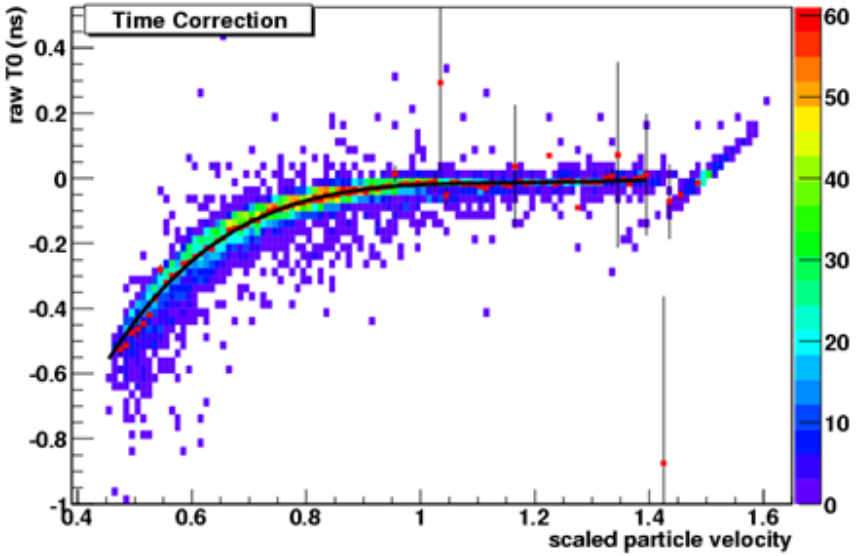




TOF (time of flight): Conceptual Design





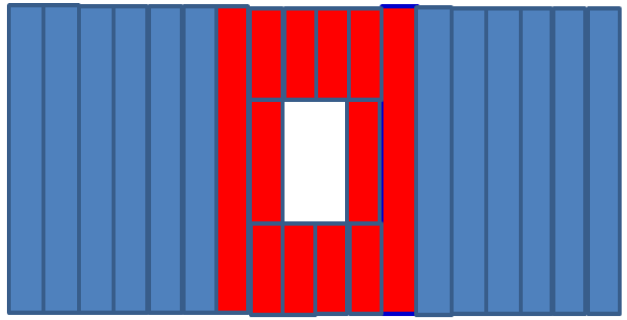


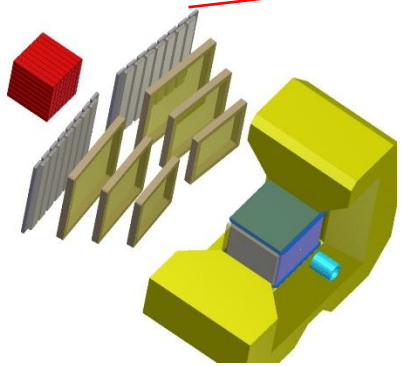
MRPC:

→Very high V over gaps between glasses in stack;

→ Ionization and avalanche occurs

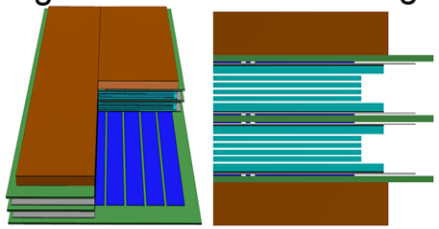
→Collect the induced signal from pad





Normal
High Gra.
High Reso. MRPC

High Count、
High Gra. High Reso.



T0+TOF	
Time resolution	<80 ps
Occupancy	<10%
Total Area	12m²
# channels	3000

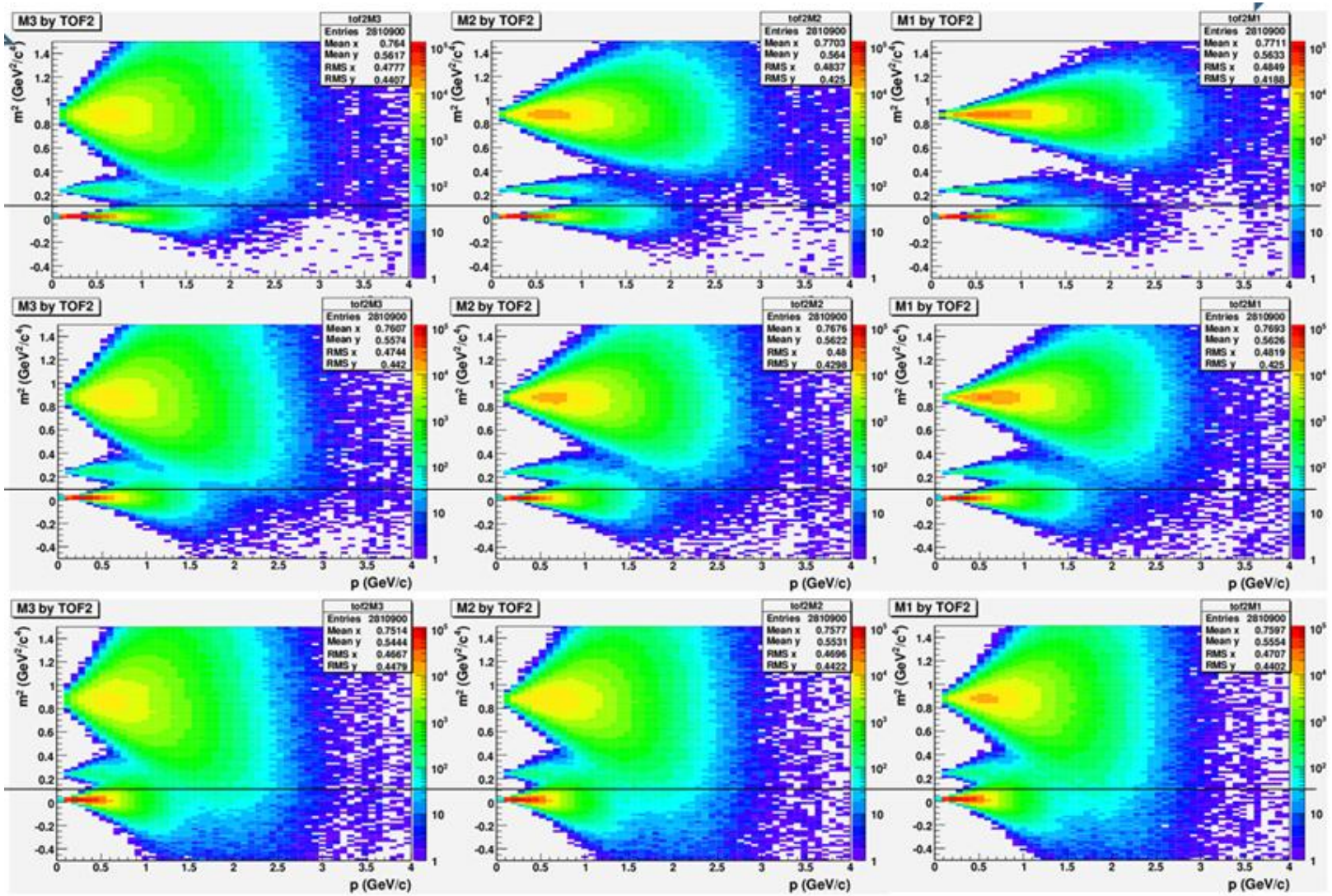
PID for TPC+iTOF

δp=10% δp=5% δp=2%

δt=50ps

δt=100ps

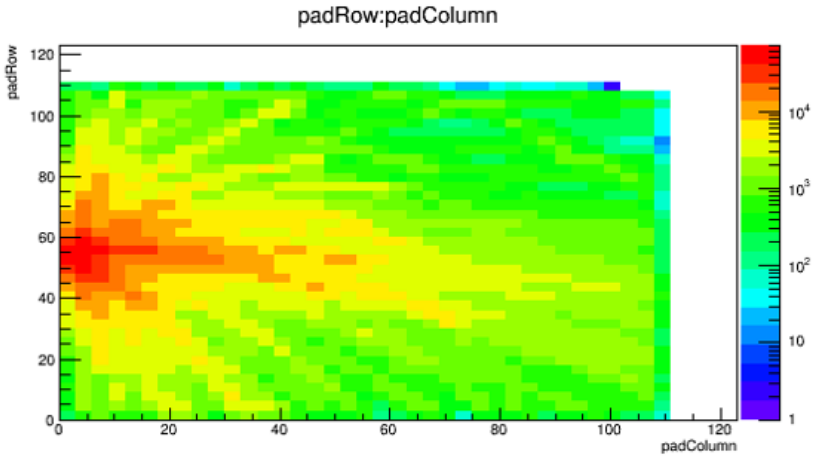
δt=200ps

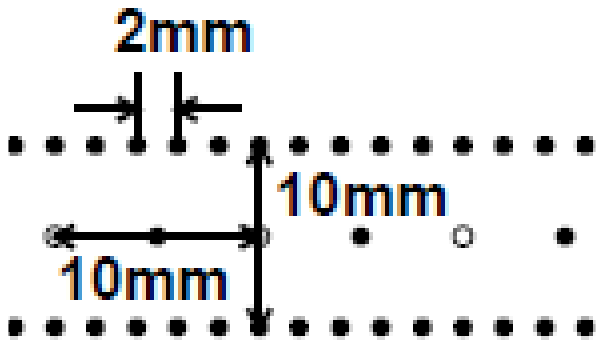


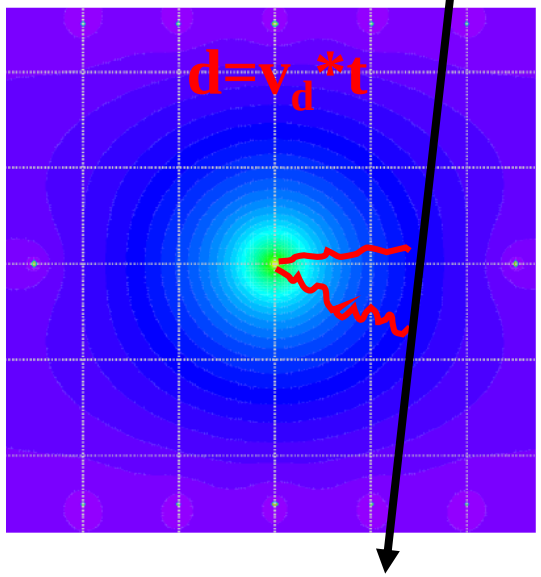
Forward MWDC conceptual design

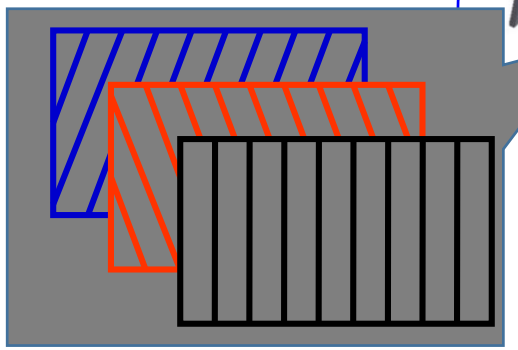
- High track density at small angle
  - Many heavy fragments
  - High rate at small angle

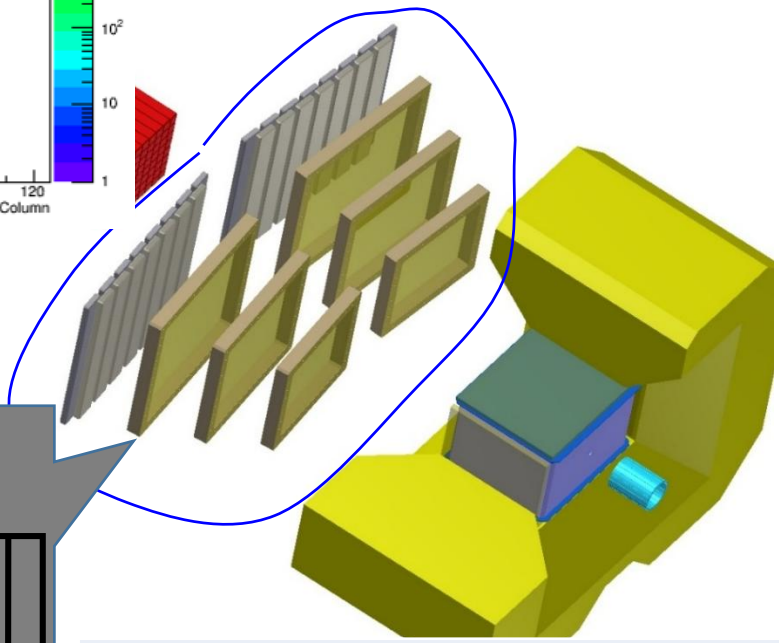
➡ **Forward tracking needed**











MWDC:

E field is formed in cell

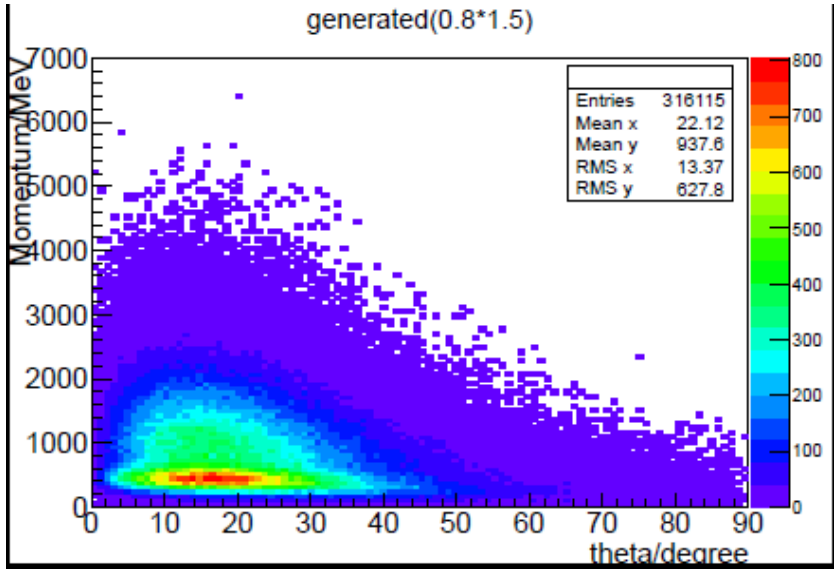
Track leaves ionizations

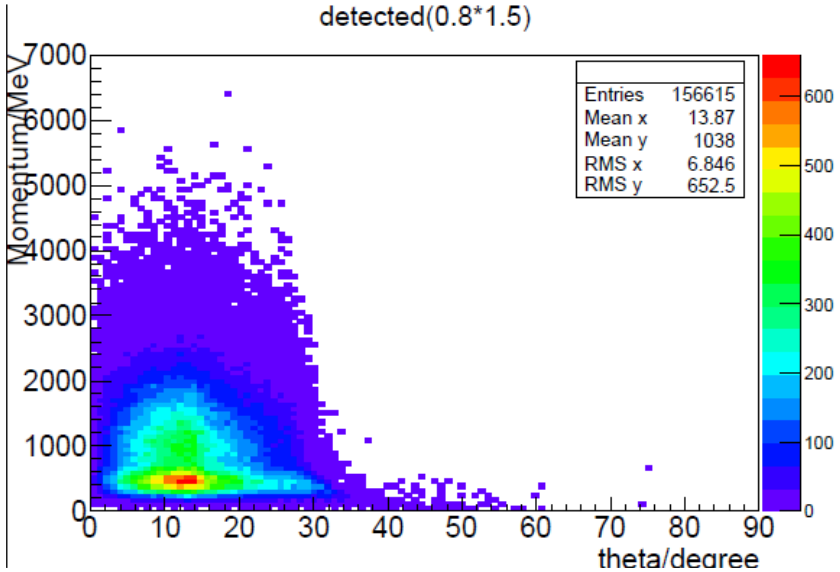
Deduce drift length from t_d

Construct track from multi cells

MWDC	
Transv. Hit resolution	0.3 mm
# of layers	3*3
# of channels	3000
Total area	8 m^2
Momentum Resolution	5%

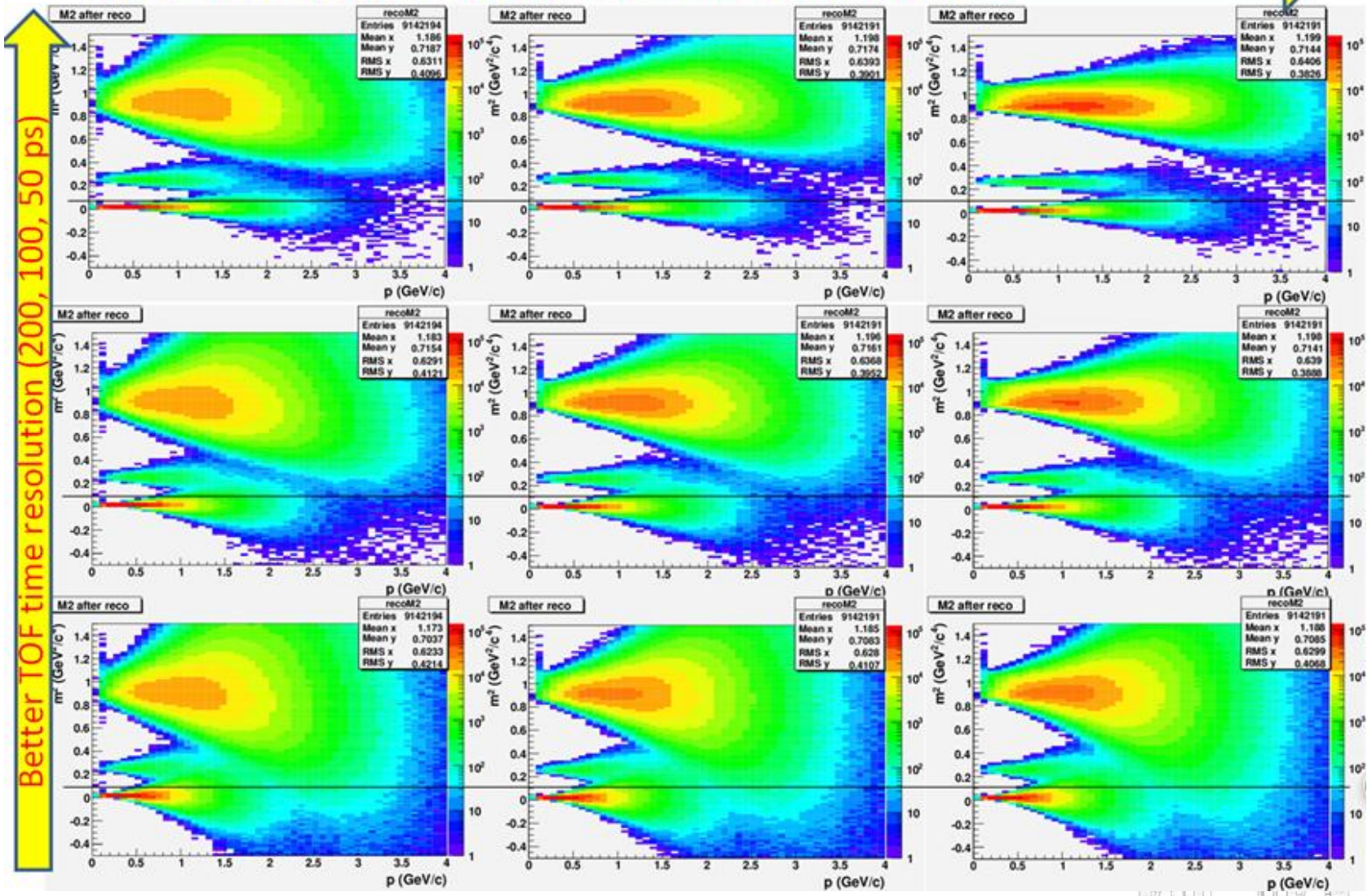
Coverage and PID with MWDC+eTOF



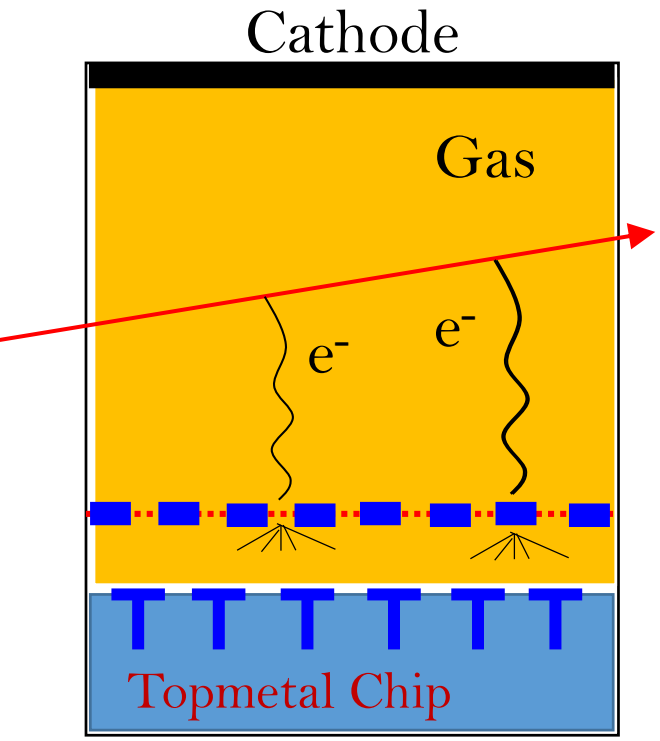


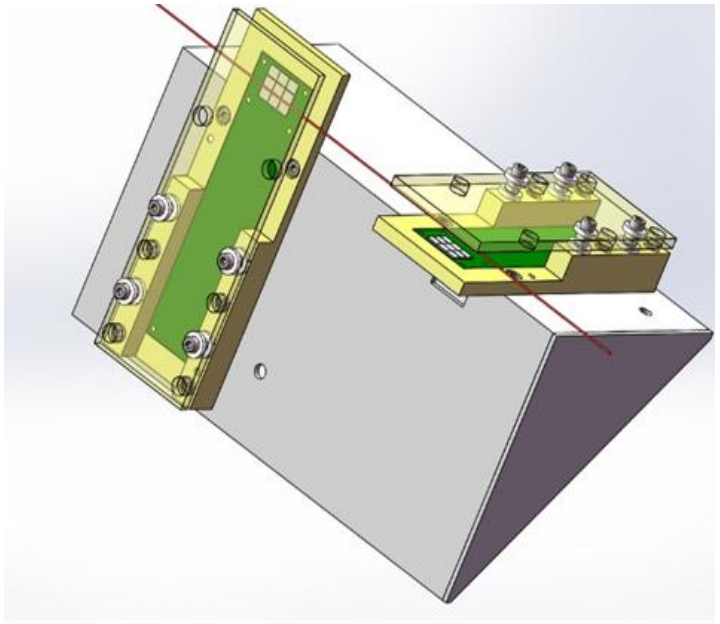
Better tracking spatial resolution (1.5mm, 0.75mm, 0.3mm)

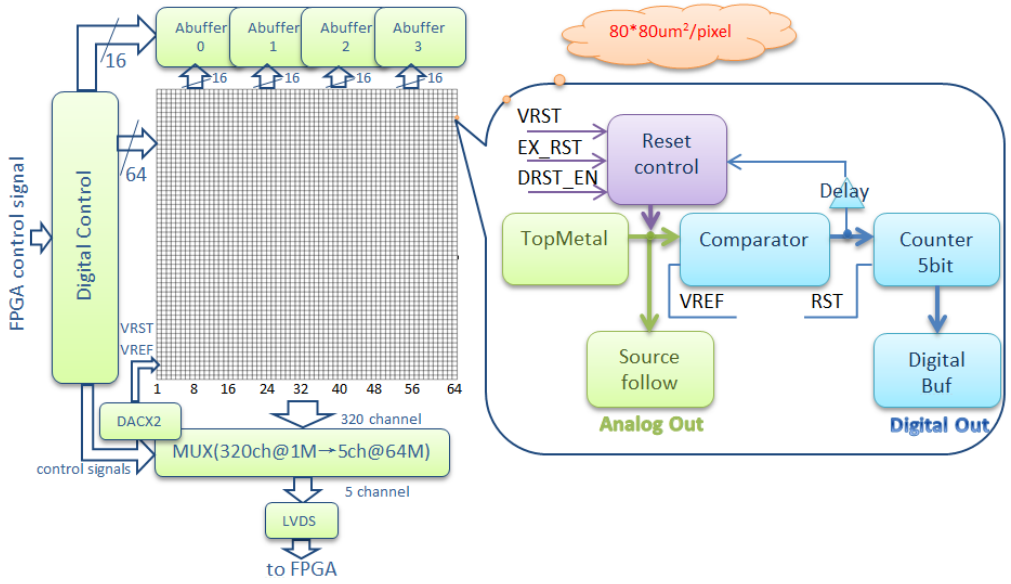
Better TOF time resolution (200, 100, 50 ps)

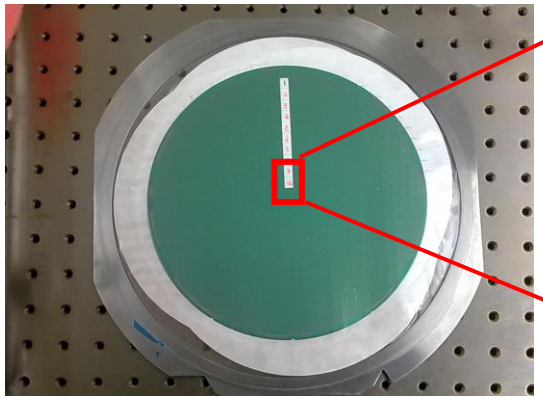


Silicon Pixel conceptual design

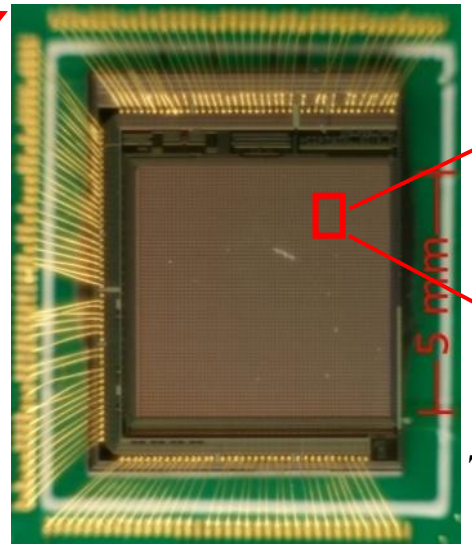




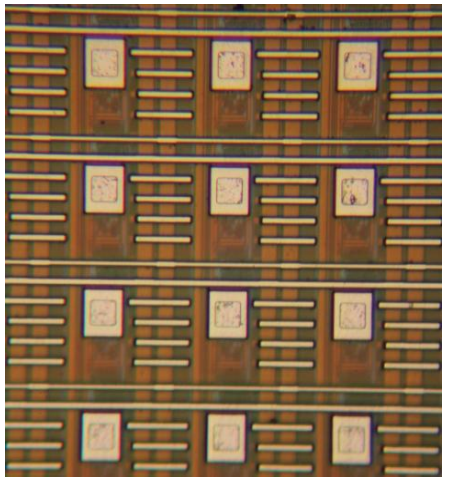




Silicon wefal

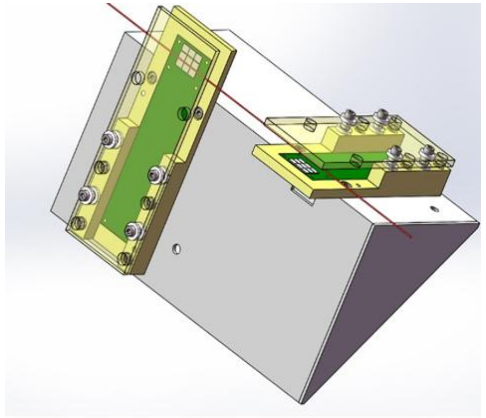


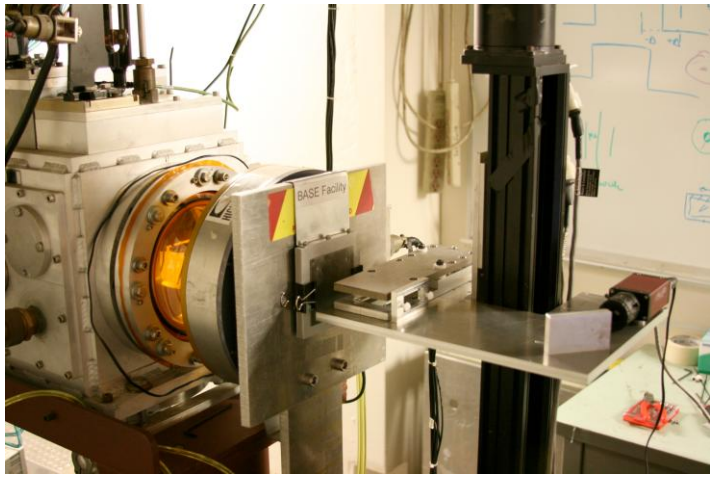
Topmetal chip

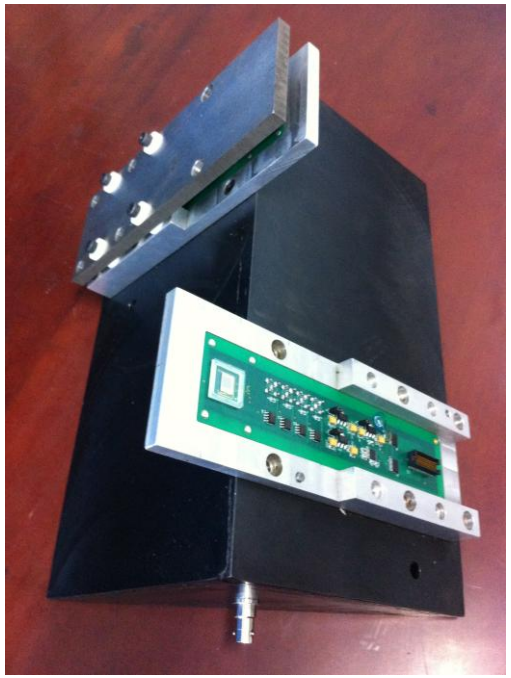


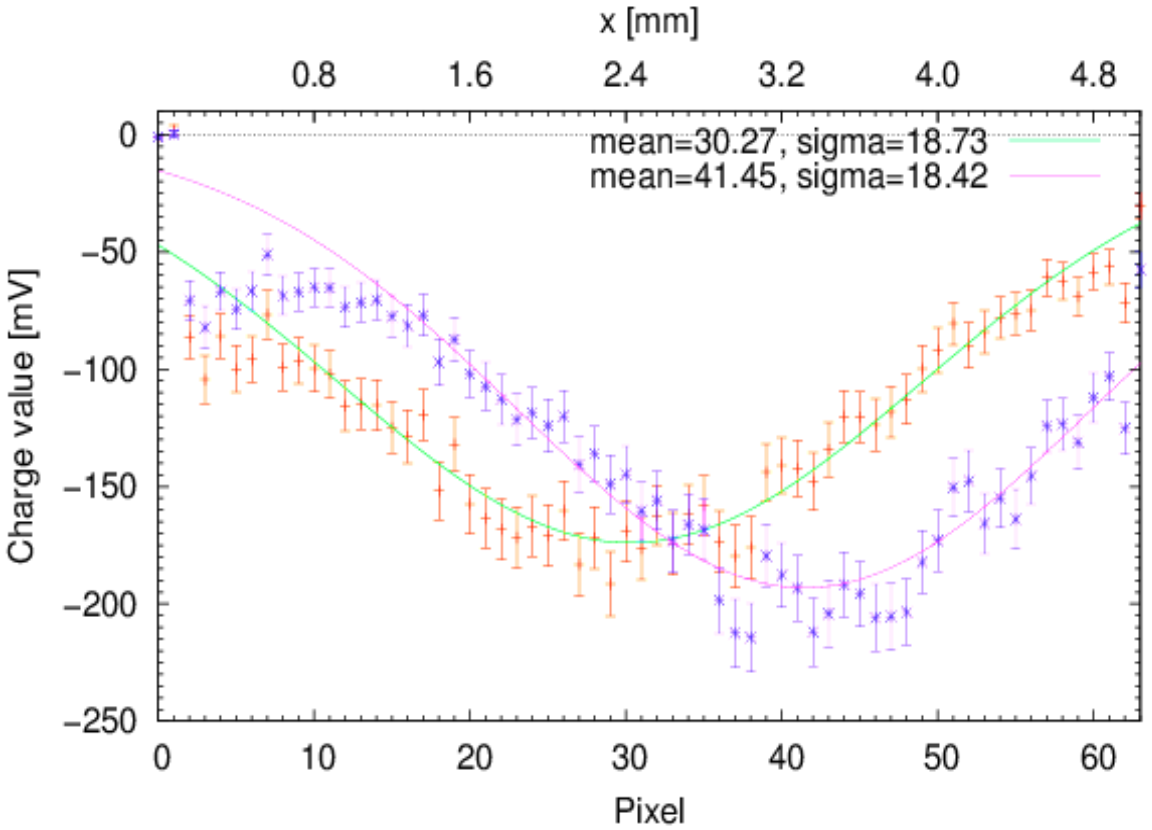
Pixel Size:
80 μm*80 μm

R&D the Si pixel detector



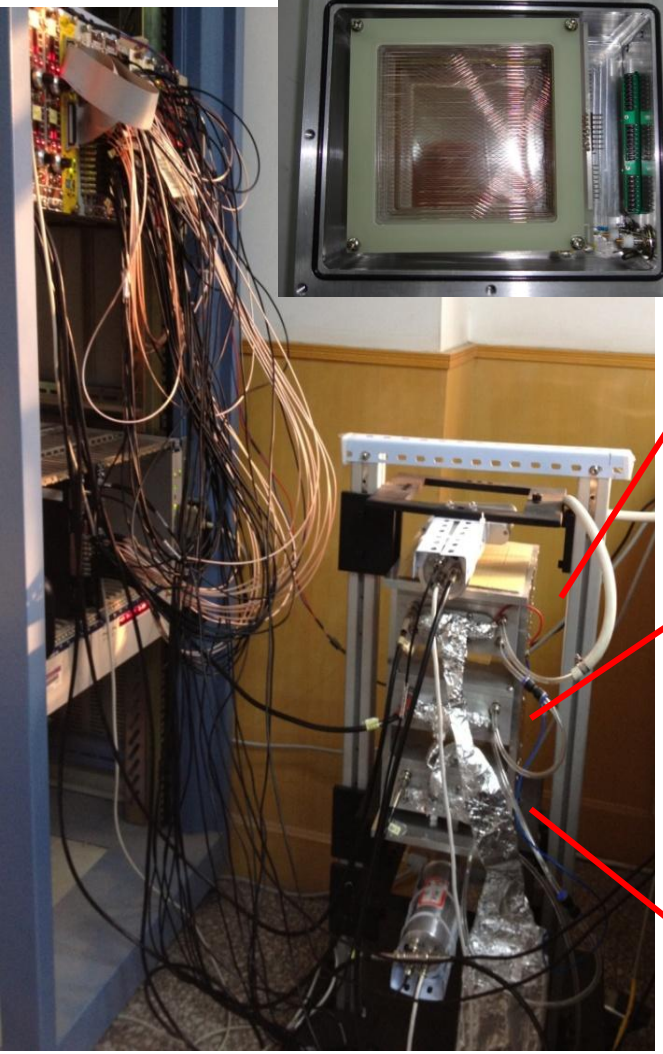


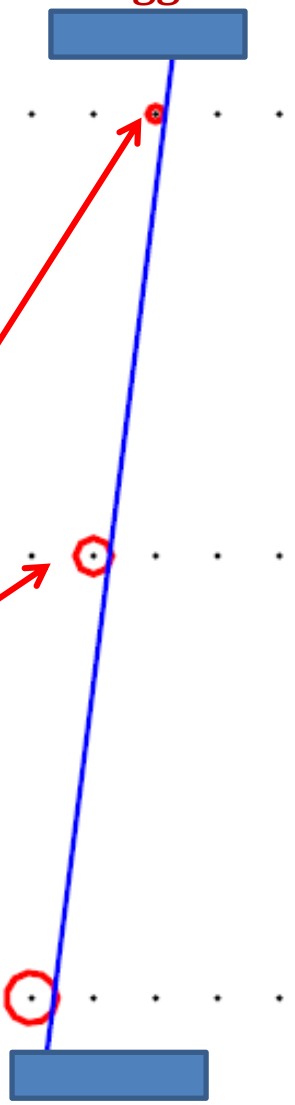




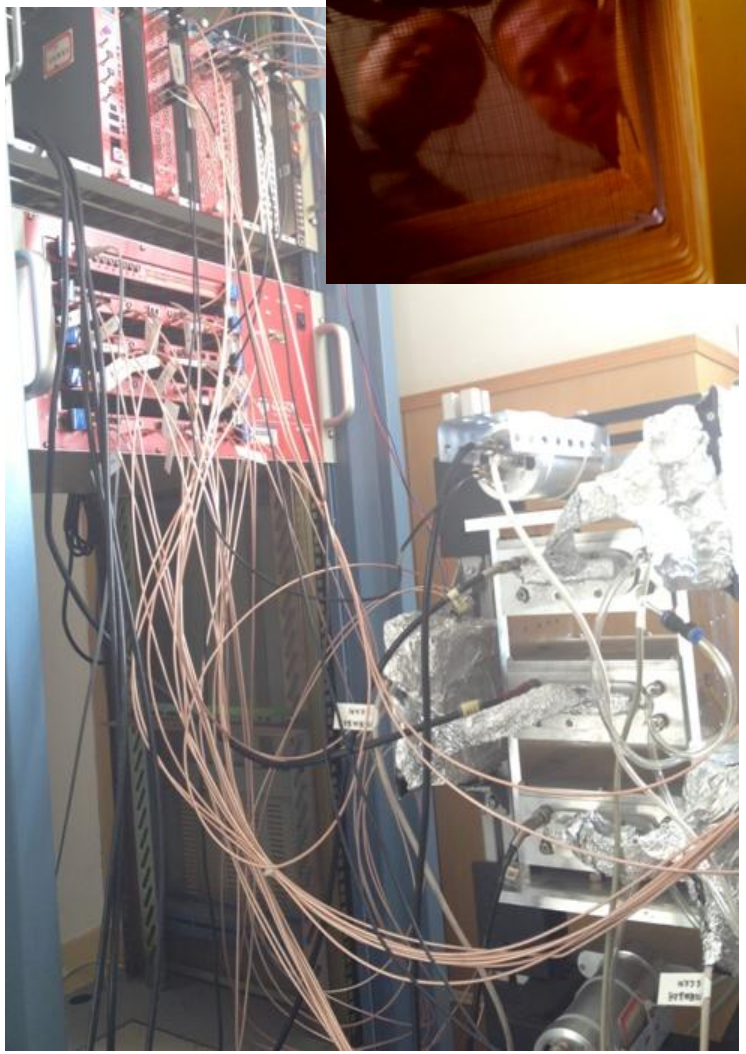
1) Online test done at Berkeley , May, 2014
2) Spatial Resolution < 0.5mm !
3) Further test at IMP planned in Sept. 2014

R&D of MWDC array

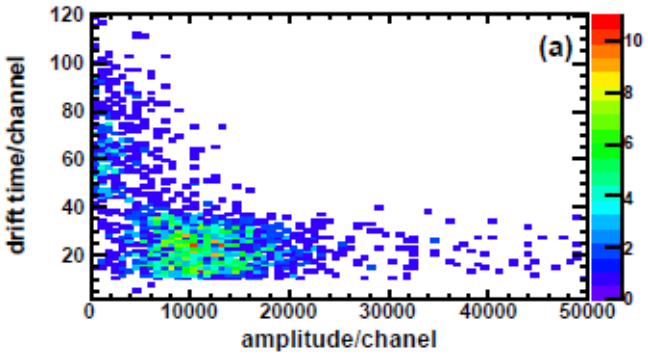


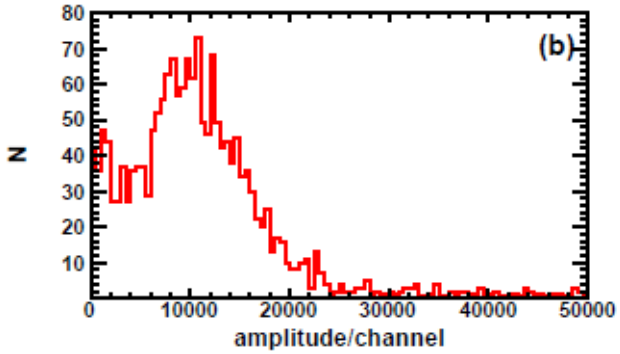


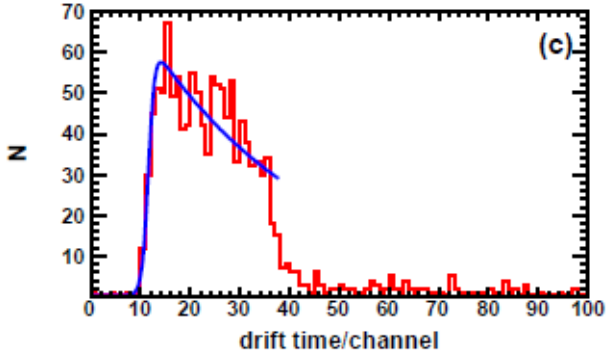
Conventional electronics



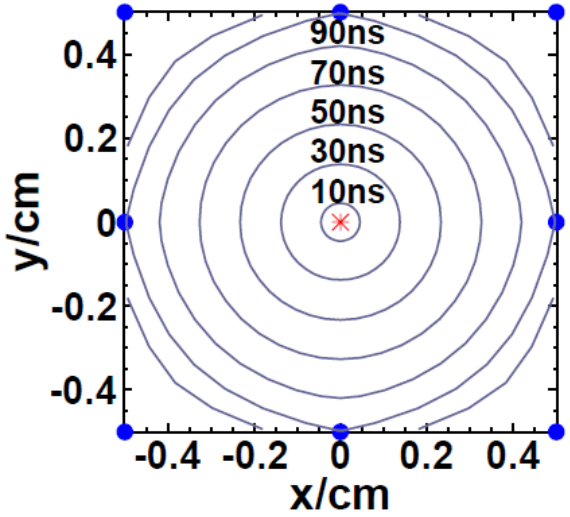
FLADC for timing measurement

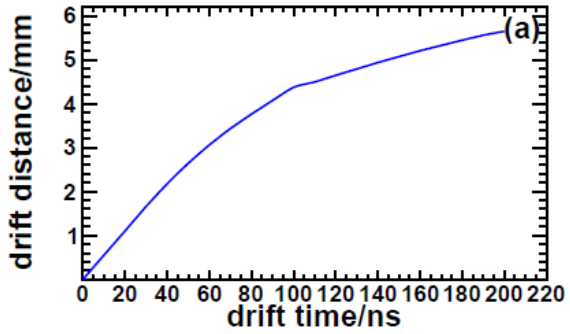


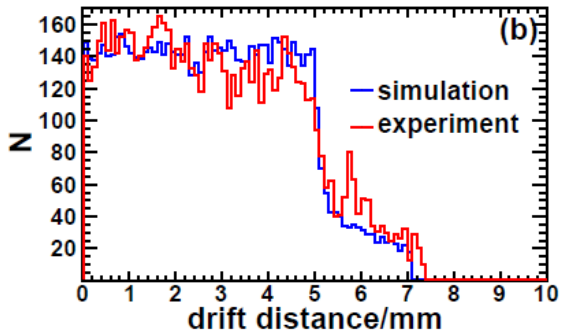


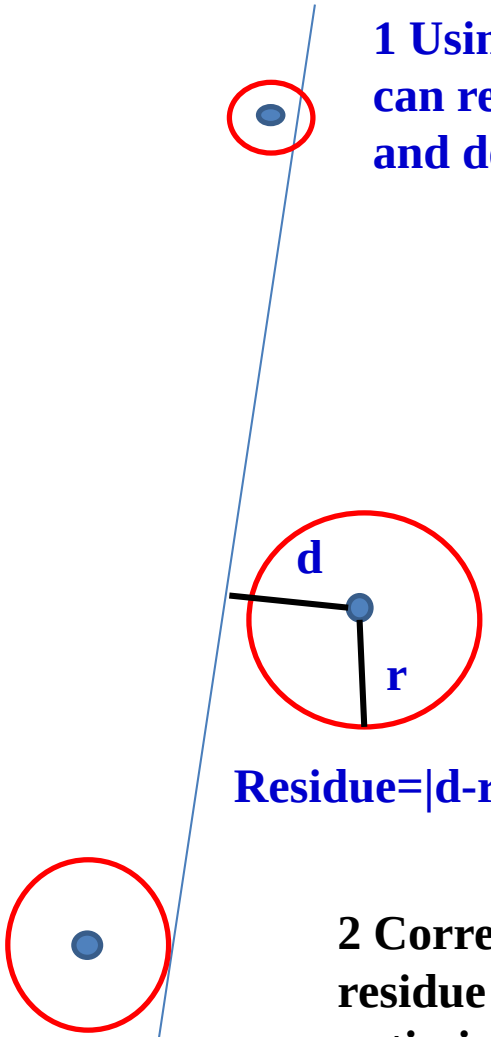


Spatial Timing Relation Calibration





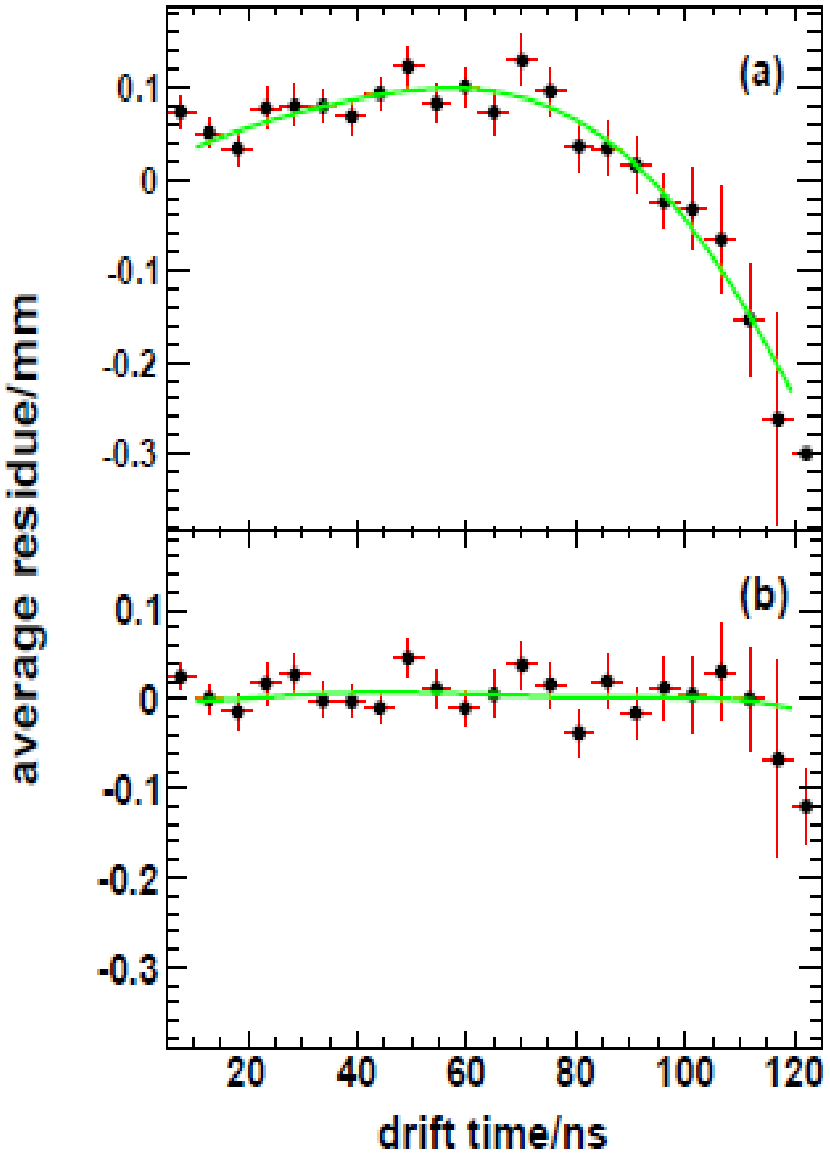




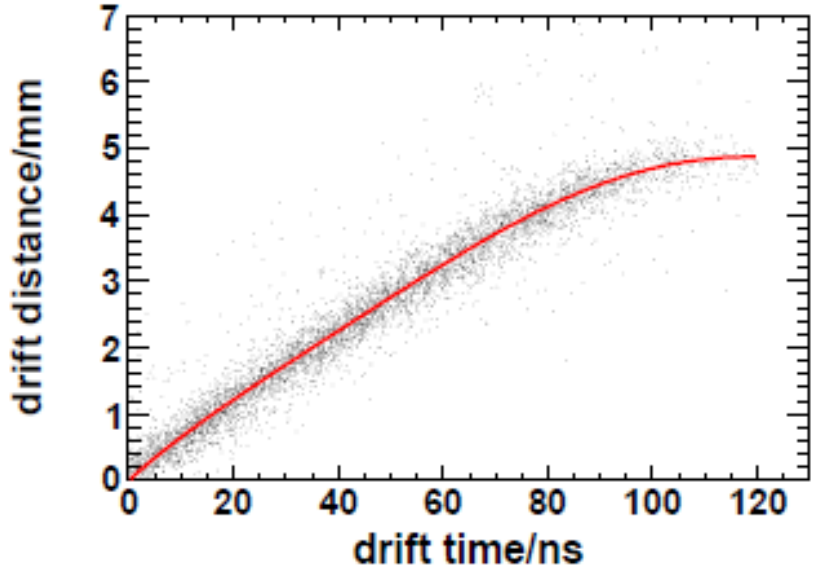
1 Using R-T relation, one can reconstruct the track and deduce the residue.

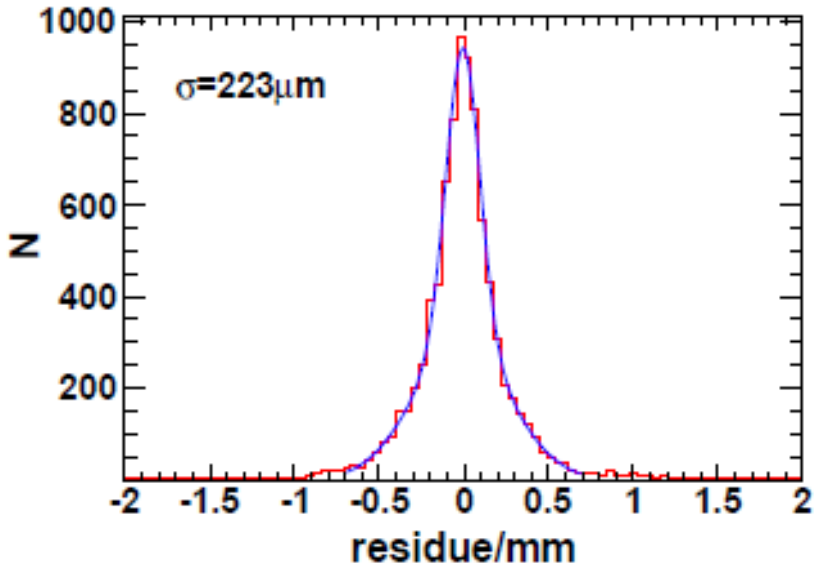
Residue=|d-r|

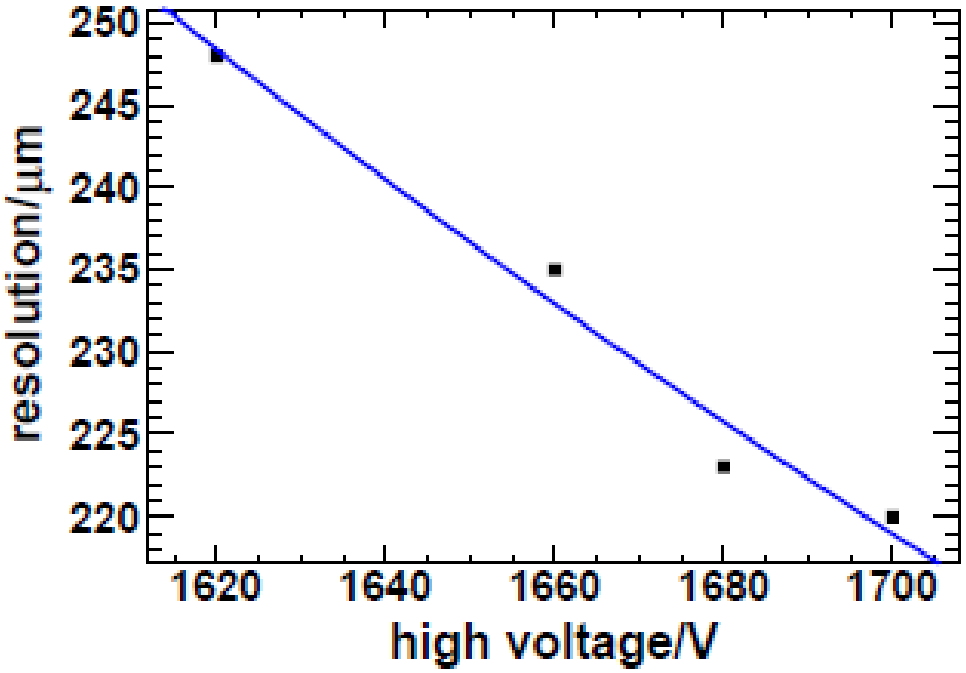
2 Correct the STR till the residue distribution is optimized.



MWDC array performance







σ=220 μm

Yi Han,XZG et al, Chin. Phys. C, to be published.

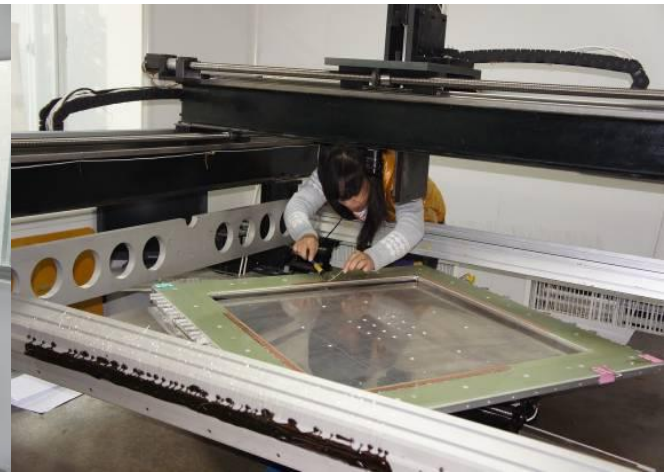
100cm*100cm MWDC array constructed.

40cm *40cm MWDC array in construction.

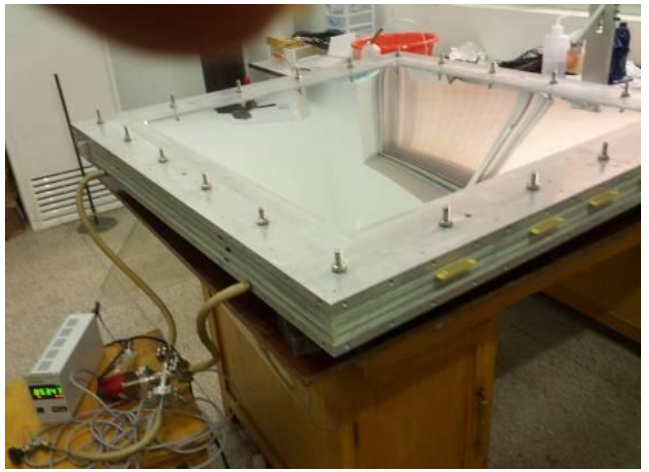
Day one beam test, ~May 2015.

Manufactory of large MWDC

Wiring:
Frame=1.6m×1.6m。

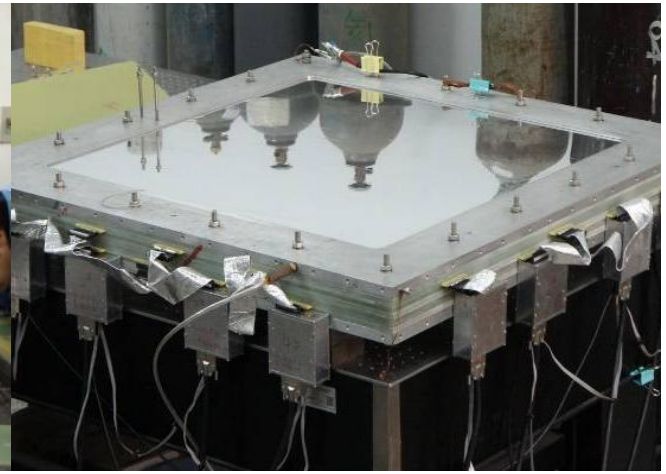


Soldering Wire and Frame

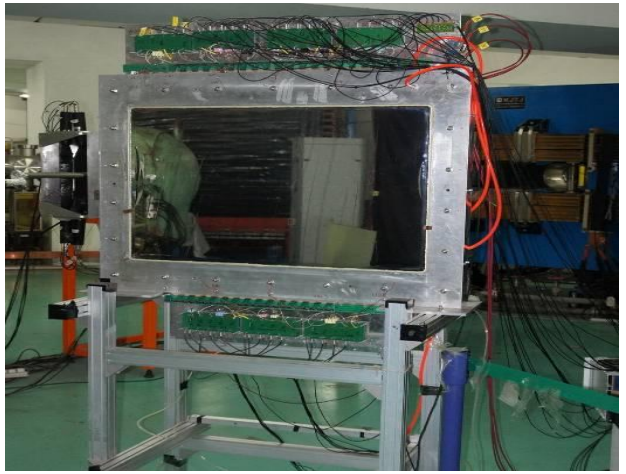


Leak rate Test

Wire Frame/Tension Preset

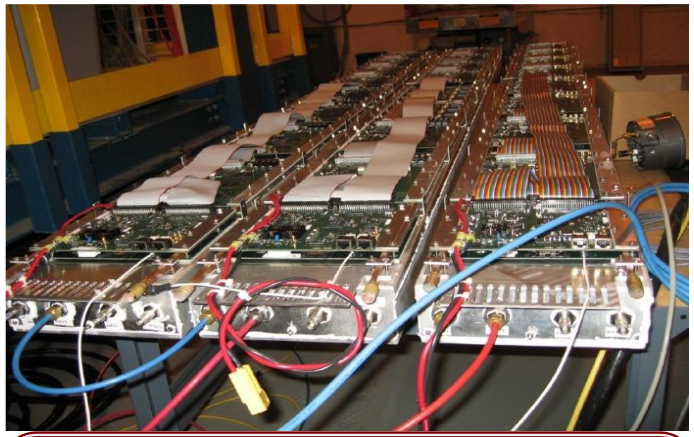


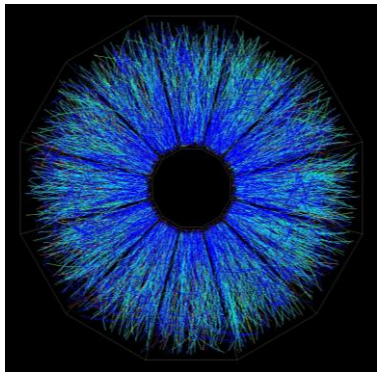
A Large MWDC to be completed

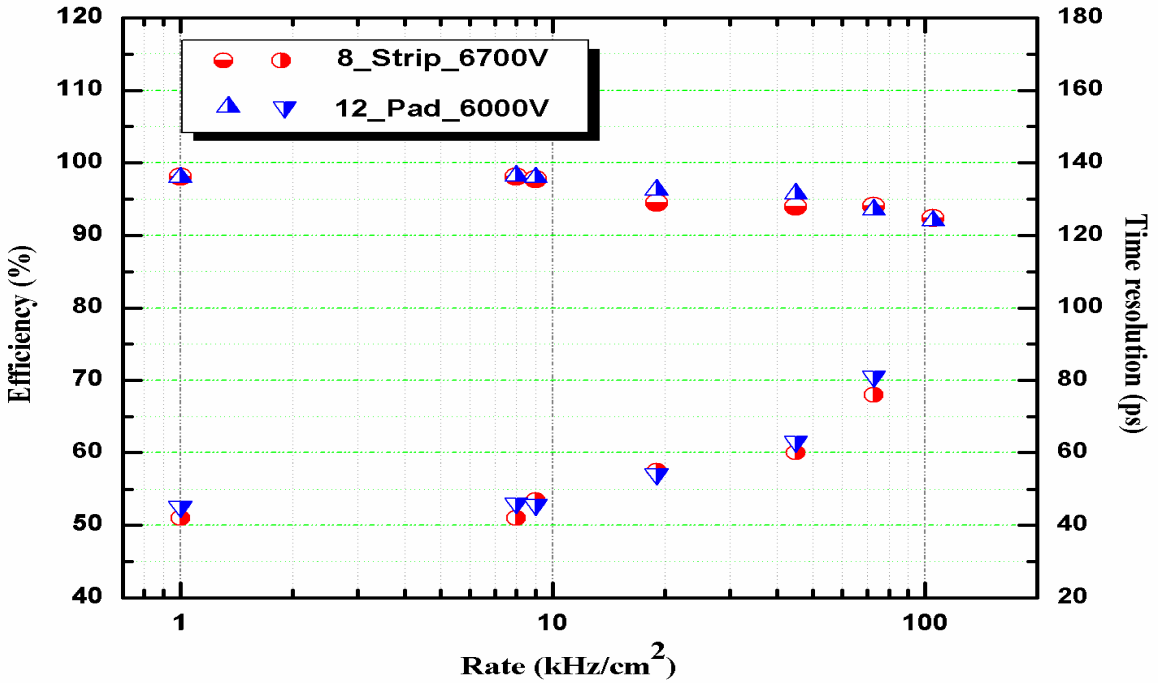


Installed for Beam Test

R&D-MRPC







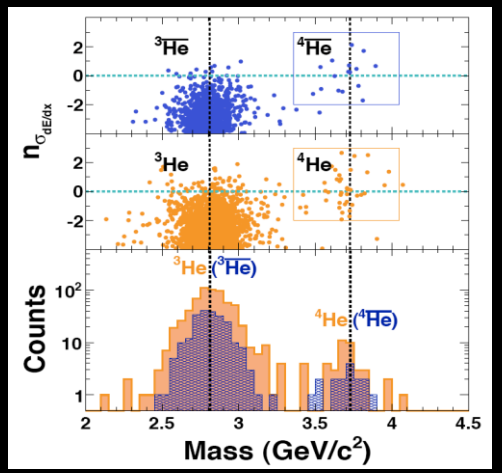
Momentum		500MeV	600MeV	800MeV
Pion sample	#1	56	47	45
	#2	51	48	40
	#3	46	48	45
Proton sample	#1	29	32	36
	#2	28	30	35
	#3	31	31	35

nature April, 2011

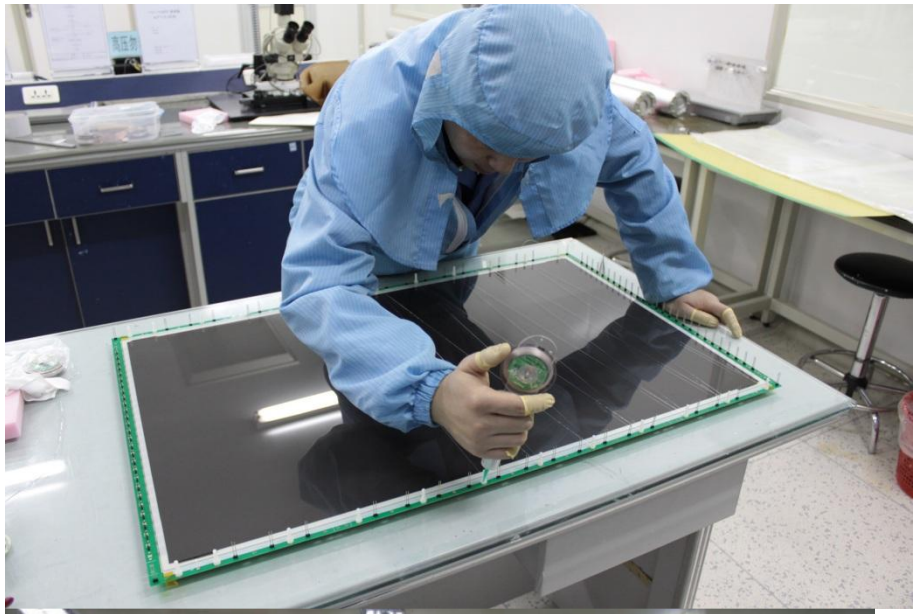
"Observation of the Antimatter Helium-4 Nucleus"

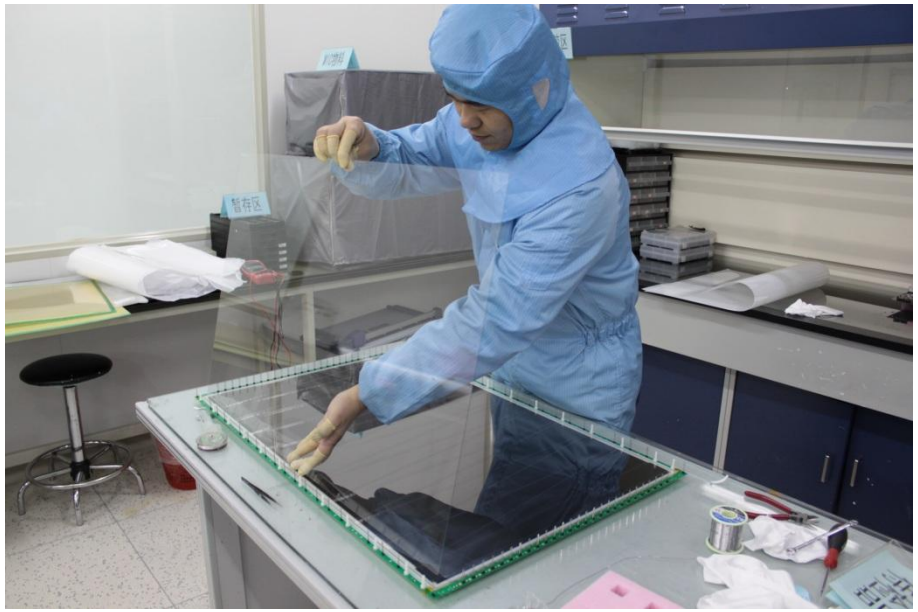
by ***STAR Collaboration***

Nature*, 473, 353(2011).*



Production and QC of large MRPC by THU





Summary and acknowledgement

→ In 35 MeV/u ^{40}Ar+^{197}Au collisions:

1 LCPs are measured in coincidence with fission events. Smaller angle products, with more contribution from dynamic emissions, are more neutron rich. A hierarchy from *p* to *d* and *t* are observed for the dynamic emissions, later emissions exhibit the inverse trend.

2 Effect of $E_{sym}(\rho)$ persists to very late stage. The time dependent N/Z of the light charged particles can be used as a new probe to $E_{sym}(\rho)$. A new experimental data are in analysis.

→ For $E_{sym}(\rho)$ at $\rho>\rho_0$:

3 Symmetry energy as a function of density is of importance. The density dependence of E_{sym} at $\rho>\rho_0$ is still under debate. Some future experiments have been proposed, with some being under construction. Among all the efforts, the external target experiment at HIRFL-CSR (CEE) is in progress and we hope to make real contributions.

Acknowledgement:

Funding: 1. NSFC, 2.Tsinghua University Initiative Scientific Research Program.

Thank You for your attention!