# Self introduction at PITZ

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Lanzhou, China.

19, Feb, 2015， PITZ, DESY.

# content

## I. Introduction

- ✓ myself
- ✓ Institute of modern physics

## II. Research experience

- ✓ Dielectric wall accelerator
- ✓ High energy electron radiography

## III. Future work plans

# I. Introduction to myself

**NAME:** Quantang Zhao (赵全堂) **BIRTH:** Gansu, P.R.China
**Address**: Nanchang road 509, Lanzhou, Gansu province, China.
Institute of modern physics of Chinese Academy of Sciences.
**Email**, zhaoquantang@impcas.ac.cn

**EDUCATION:**

Sept.2004-June 2008, study in Institute of Physics and engineering, Zhengzhou University for bachelor degree.

Sept.2008 to- June 2013, study in institute of modern physics (IMP), University of Chinese Academy of Sciences for doctor degree, the major is accelerator physics and technology. The subject for doctor degree is *preliminary research on novel high gradient dielectric wall accelerator*. During 2012 March to June, study at Lawrence Berkeley national laboratory Fusion research division. Learn PIC codes -Warp for beam transport simulation of dielectric wall accelerator.

**WORK EXPERIENCE:**

July 2013- Jan. 2015, work at IMP for *High energy electron radiography* based on the high energy short pulse electron linear accelerator with RF photo cathode injector.

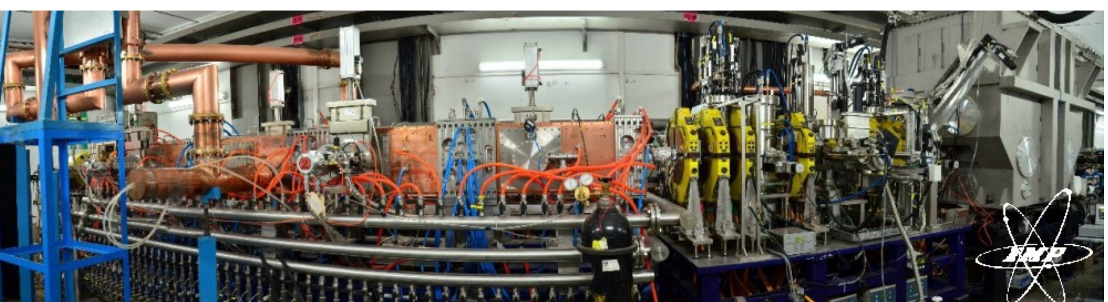
**Application for the China and Germany Post doctor Exchange Program, supported by China post doctor foundation and DESY.**

# Introduction to My institute

# Lanzhou Heavy ion accelerator National Laboratory

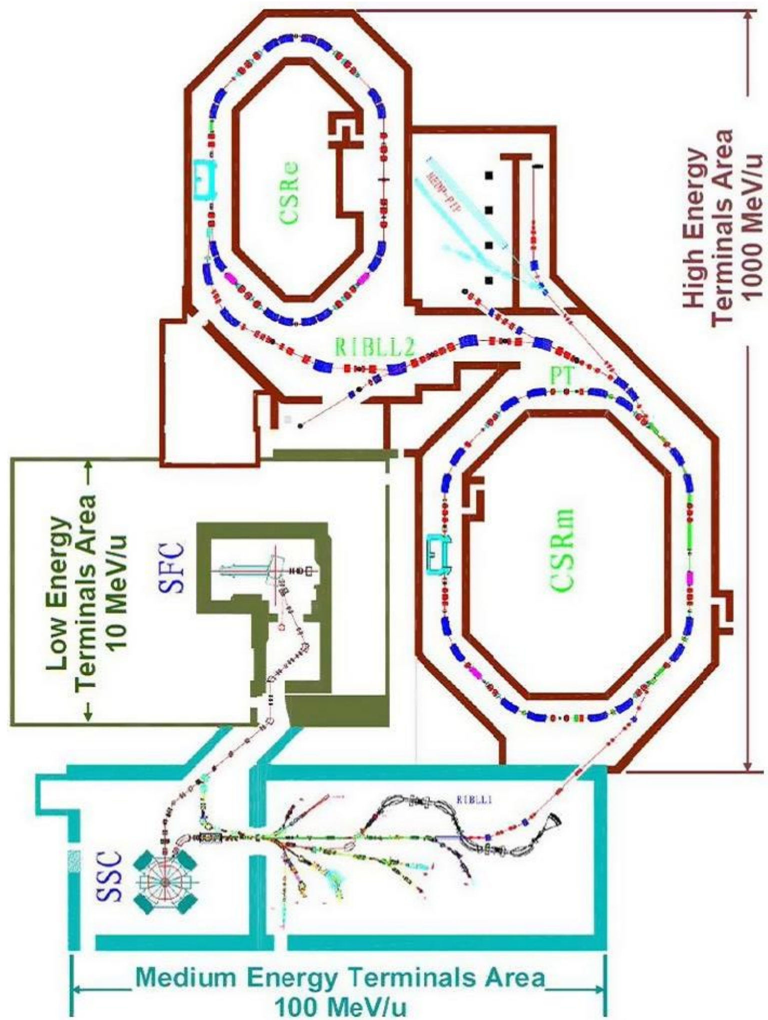
CSR

SC RF high intensity proton injector

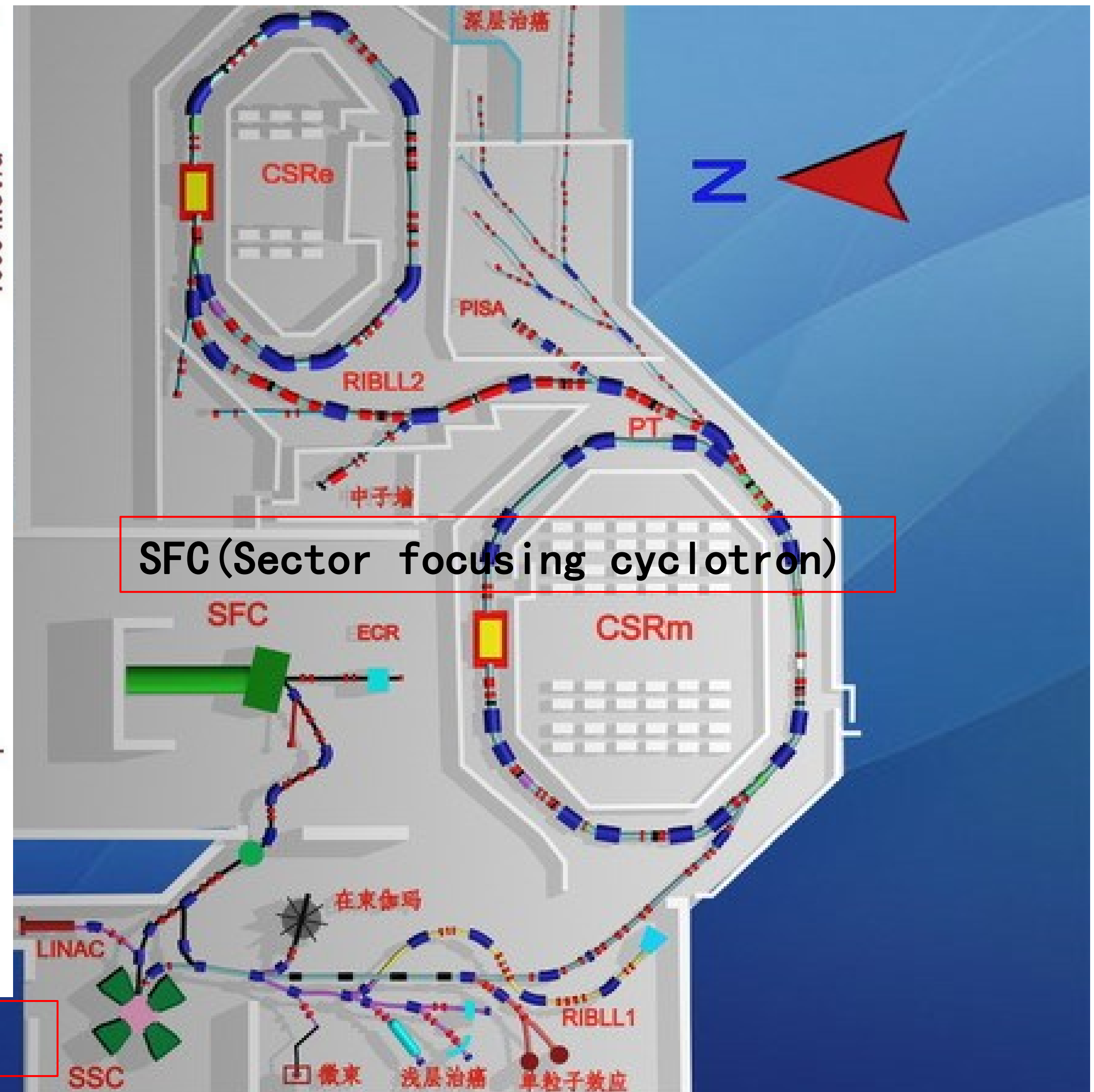



- http://english.imp.cas.cn/

# HIRFL（Heavy Ion Research Facility in Lanzhou)




SSC(Sector separated cyclotron)



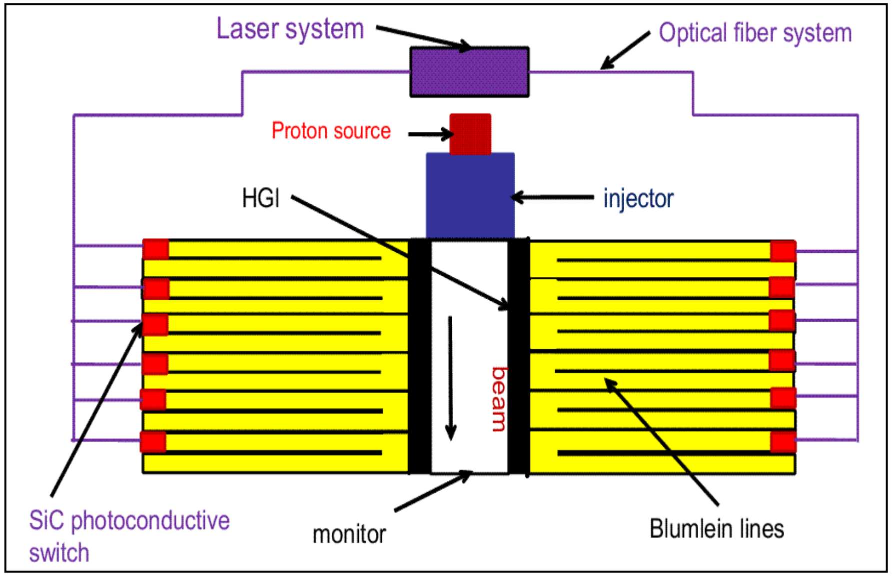
# II. Research experience (1)

## Preliminary study of new high gradient Dielectric Wall Accelerator (DWA)

(from 2009-08 to 2013-06)

- Introduction to DWA
- Simulation research of DWA
- Experiment research of DWA
- Conclusions

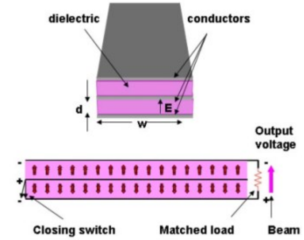
# 1 Introduction to DWA



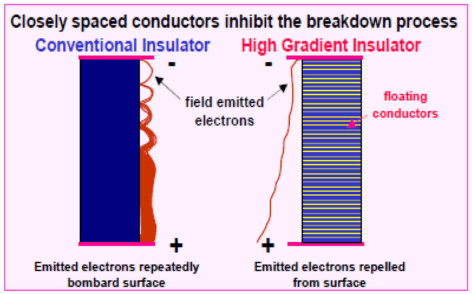

- Higher accelerating gradient (20 MeV/m-100 MeV/m)
- More compact volume (1/10)
- lower cost
- Accelerate any kind of charged particles
- to be civil use widely

## key technologies

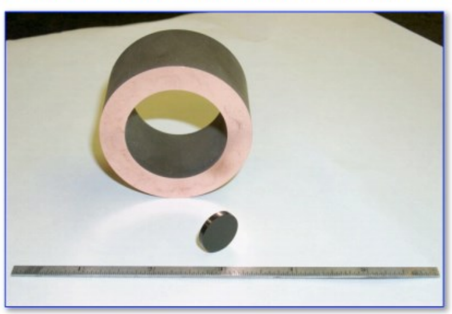
◆Blumlein lines



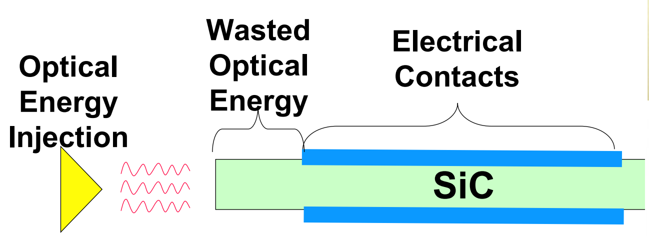

◆HGI(high gradient insulator)

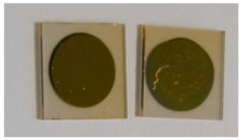



**Full size and small HGI samples**



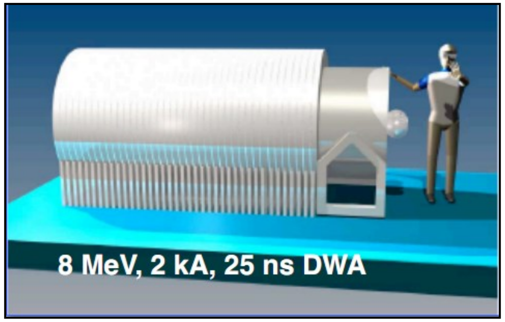
◆PCSS.

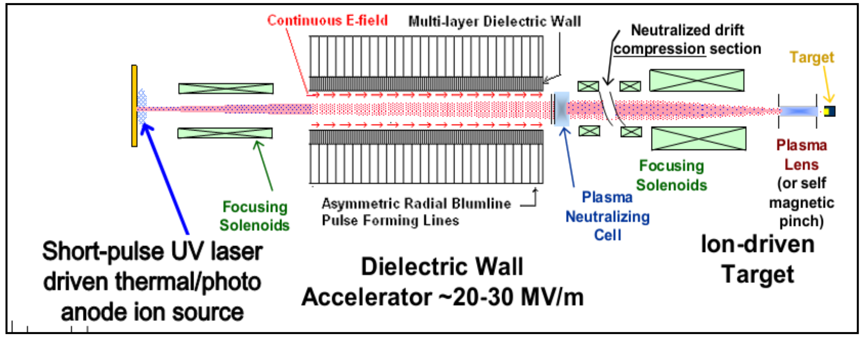


*Yu-Jiuan Chen， Lawrence Livermore National Laboratory， *Muon Collider Design Workshop December 8-12, 2008， Thomas Jefferson National Laboratory*

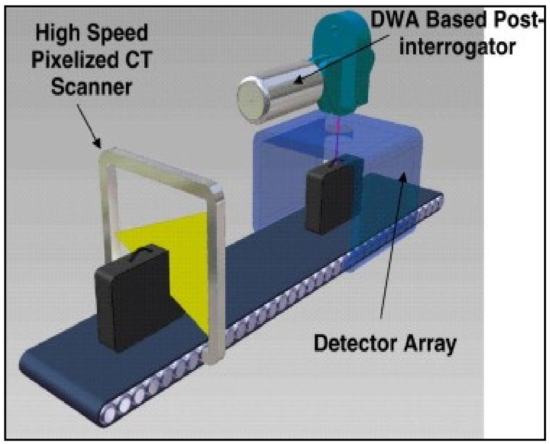
# Concept application



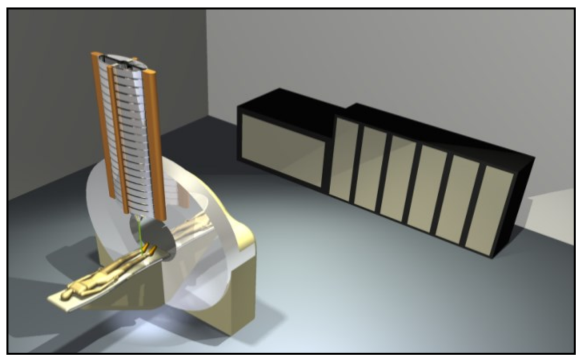

A 30 m-long, 600 MV Dielectric Wall linac might also be a high gradient buncher to compress RHIC or FAIR HI beams from 100 ns down to 100 ps for fast ignition experiments.

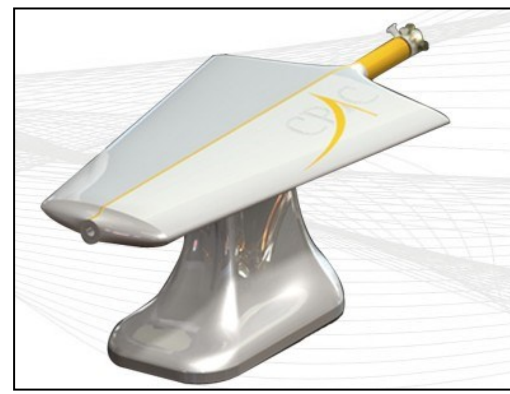
*B. Grant Logan,Workshop on Accelerators for Heavy Ion Fusion， LBNL, Berkeley, California May 23, 2011



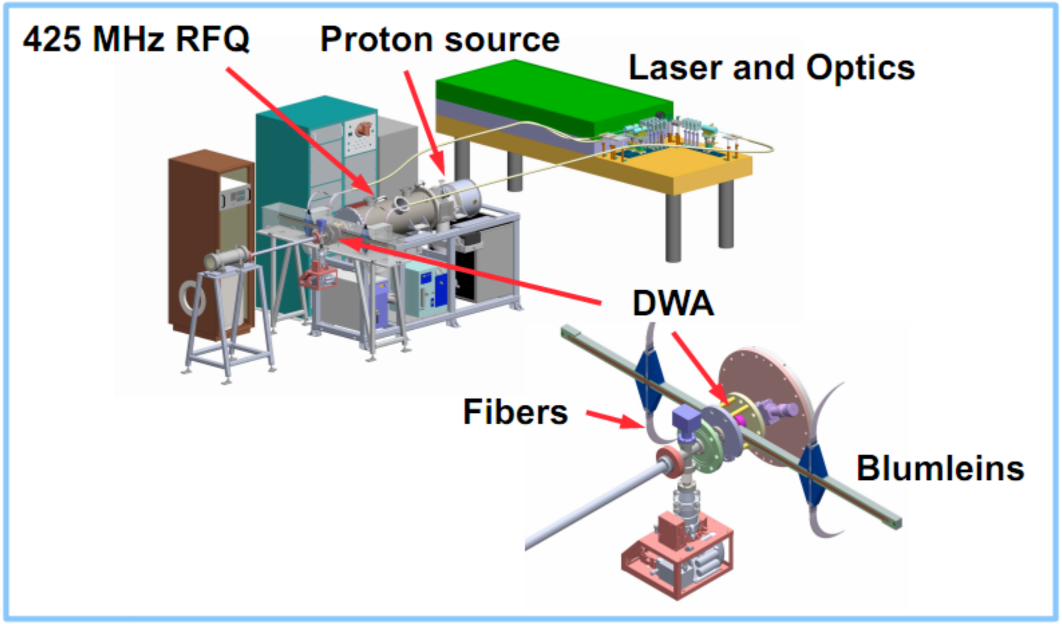

High speed CT pre-screener and post verifier concept.

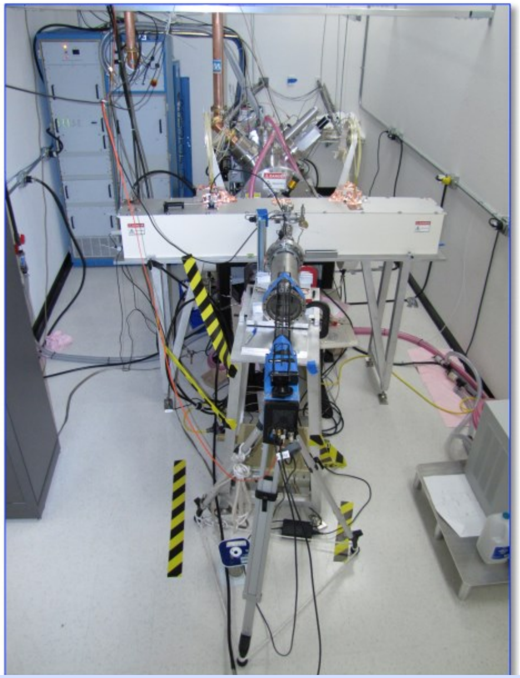
*S.Sampayan , G. Caporaso , Y.J. Chen , et al. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms Volume 261, 2007 281 - 285

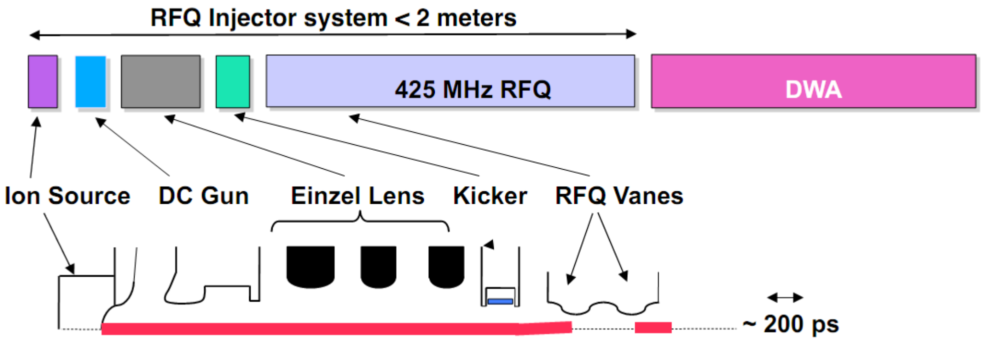




*Yu-Jiuan Chen， Lawrence Livermore National Laboratory，*Presented at 3rd Workshop on Recent Progress in Induction Accelerators Dujiangyan, Chengdu, China October 17 – 21, 2011*



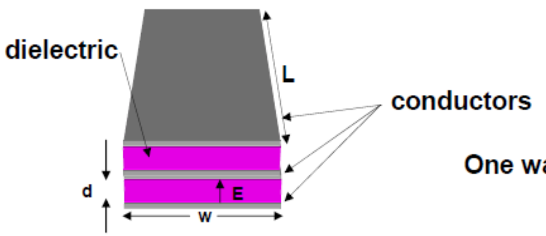



- The injector system is purchased from AccSys Technology
- Use conventional, proven technology
  - Duoplasmatron ion source
    - » 50 mA
  - RFQ accelerator
    - » 2 MeV beam energy
    - » 1 meter length
    - » 425 MHz

*Yu-Jiuan Chen, Lawrence Livermore National Laboratory, *Presented at 3rd Workshop on Recent Progress in Induction Accelerators Dujiangyan, Chengdu, China October 17 – 21, 2011*

# 2 Simulation research of DWA

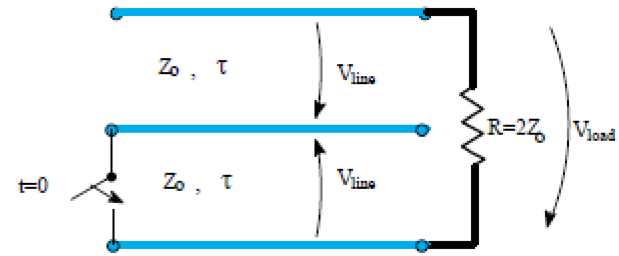
## Blumlein line

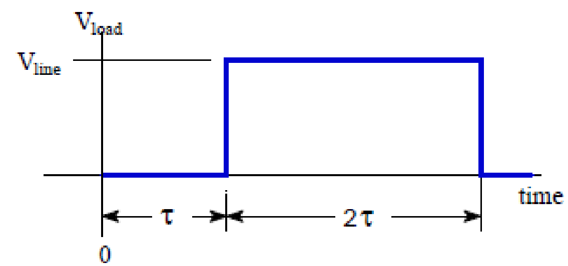



One way transit time $\tau = \frac{L}{c}\sqrt{\varepsilon_r}$

Impedance of each transmission line $Z = \frac{120\pi}{\sqrt{\varepsilon_r}}\frac{d}{w}$

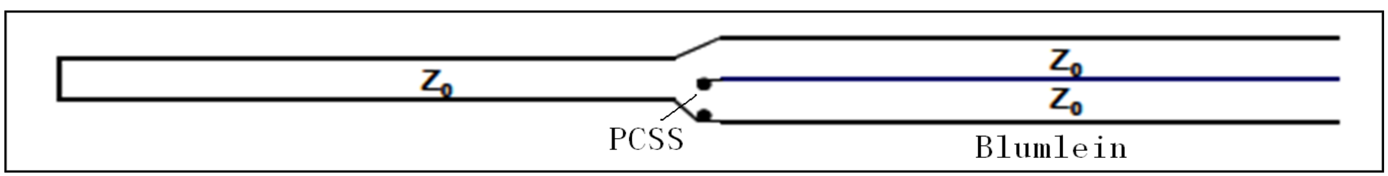
Typical current flow in the line with a gradient E $I = \frac{V}{Z} = \frac{Ed}{Z} = \frac{\sqrt{\varepsilon_r}wE}{120\pi}$

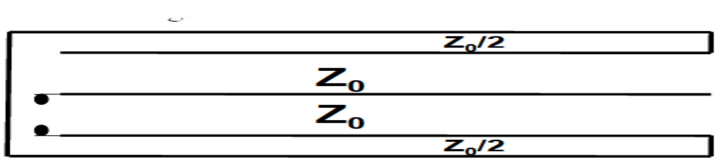


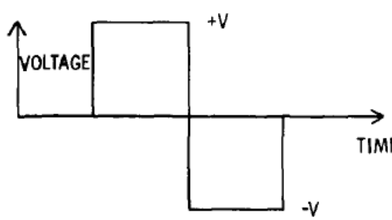




Voltage across load (R)

## ZIP(zero integral pulse) line



# 2.1 Blumlein line and ZIP line simulation

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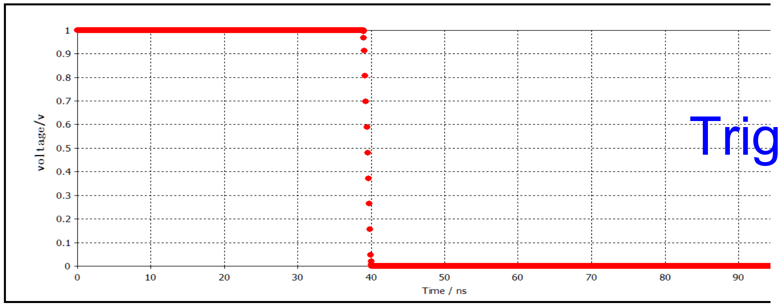
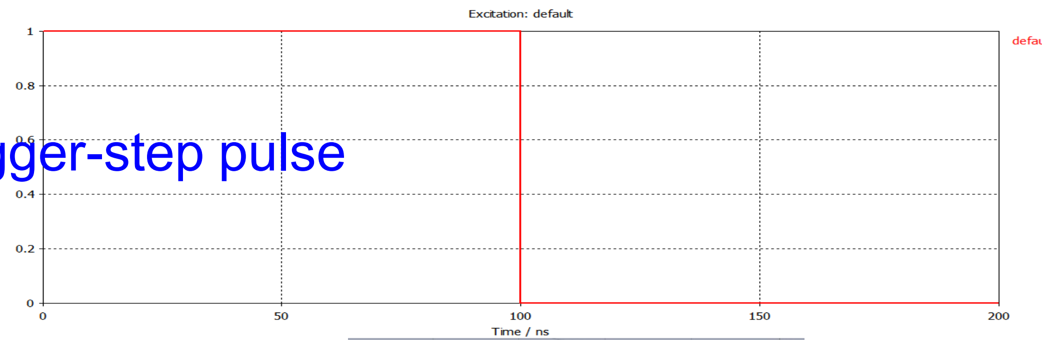
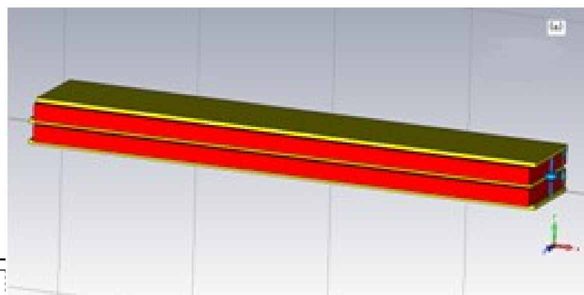
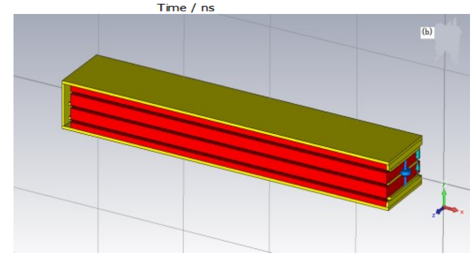
Institute of modern physics
Chinese academy of sciences

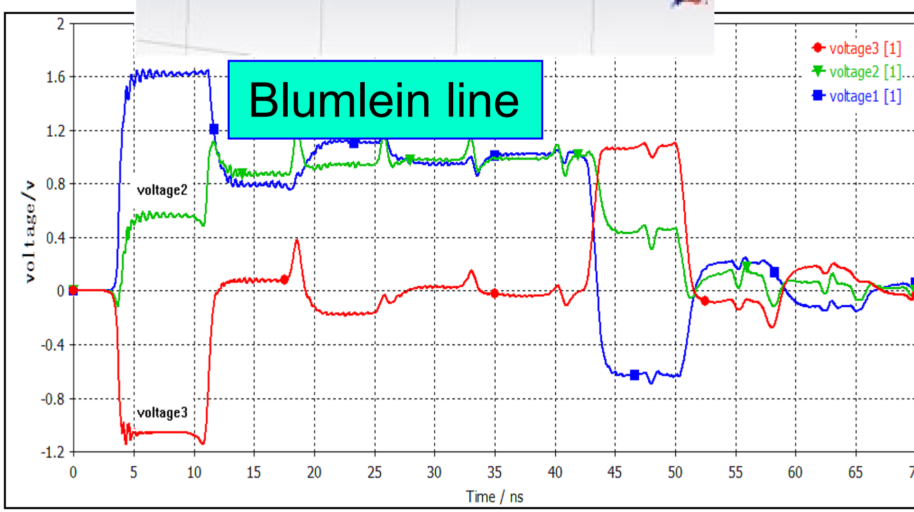


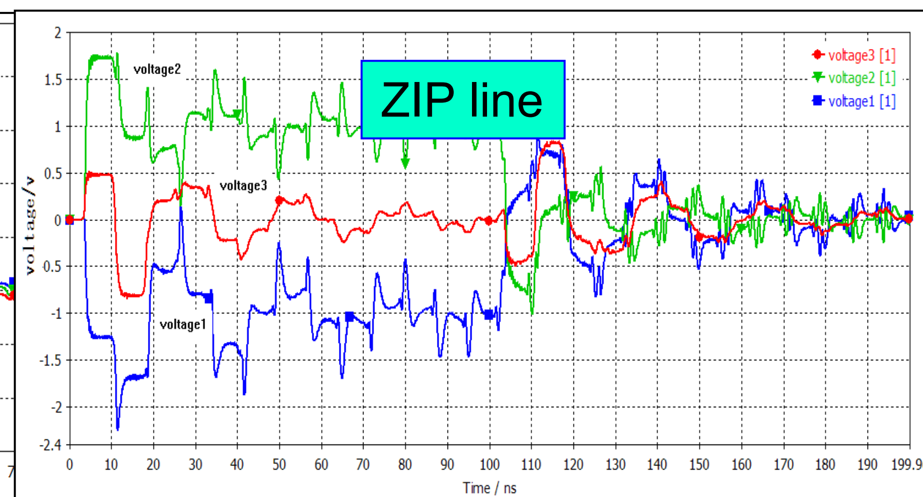

Trigger-step pulse







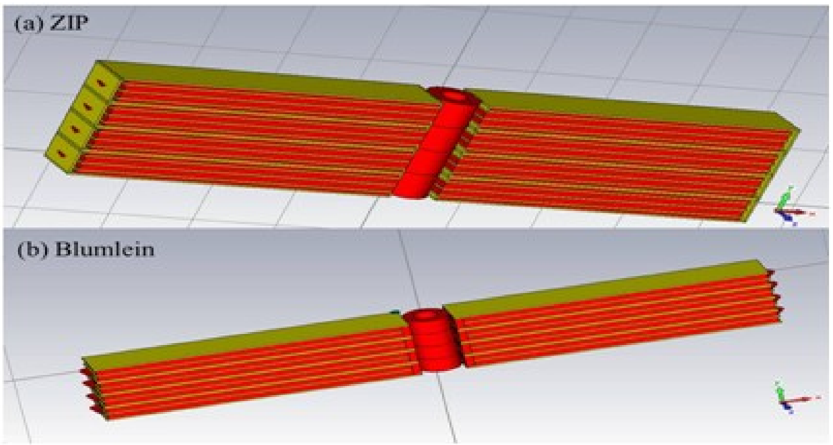

Blumlein line

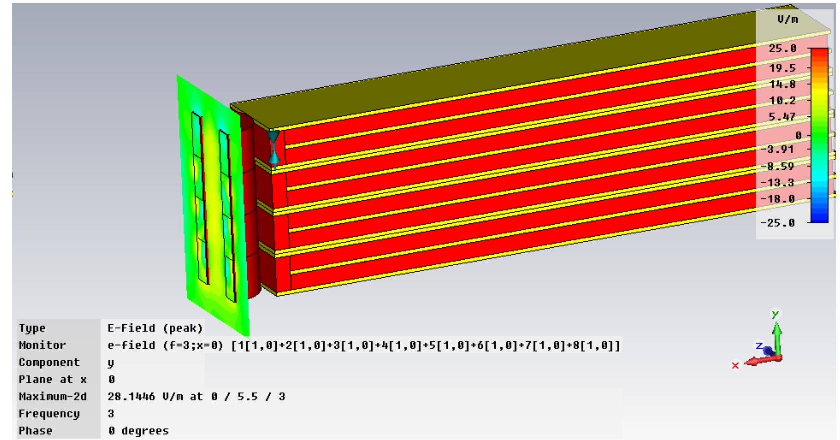



ZIP line

*Zhao Quantang, Yuan Ping, Zhang Zimin, et al. Chinese Physics C. VOL.35, NO.12, 2011.12.

# 2.2 accelerating field simulation of DWA unit cell

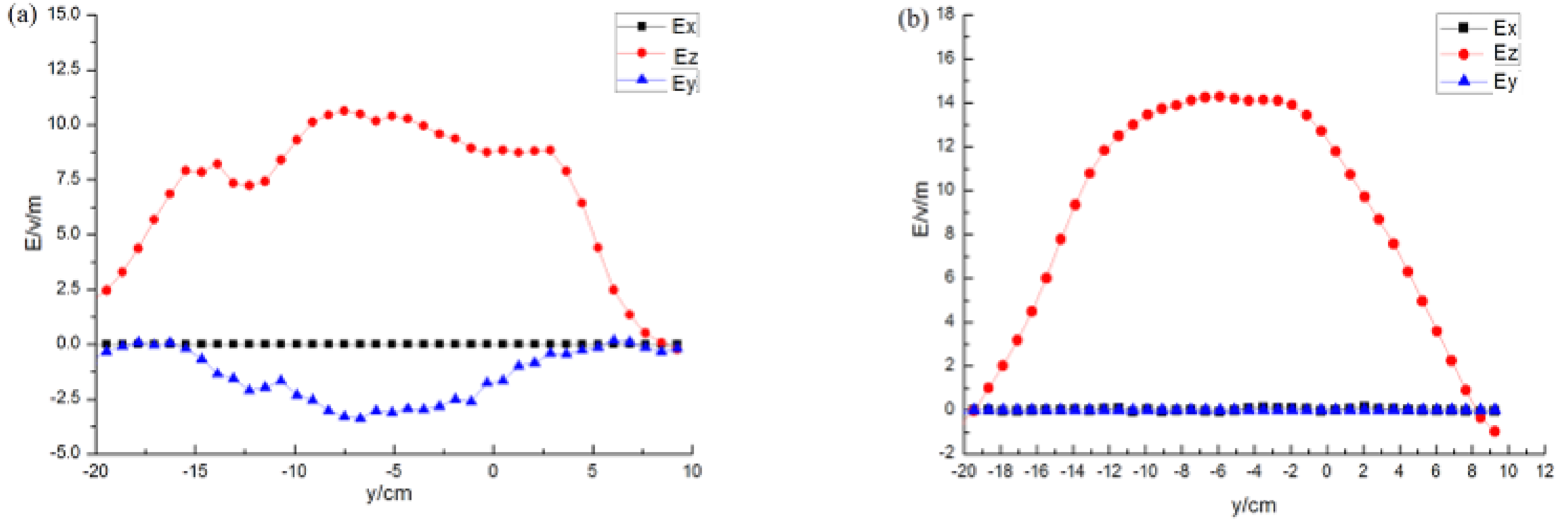



| | permittivity | length | Electrode width | Dielectric thickness | Pulse width |
|---|---|---|---|---|---|
| Blumlein lines | 10 | 75 cm | 12 cm | 2 cm | 15.8 ns |
| | 2.2 | 75 cm | 12 cm | 2 cm | 7.6 ns |
| ZIP lines | 10 | 75 cm | 12 cm | 2cm /1 cm | 15.8 ns |
| | 2.2 | 75 cm | 12cm | 2cm /1 cm | 7.6 ns |

# Blumlein structure cell

## spacial fields along the axial




## four point along axial the waveform versus time

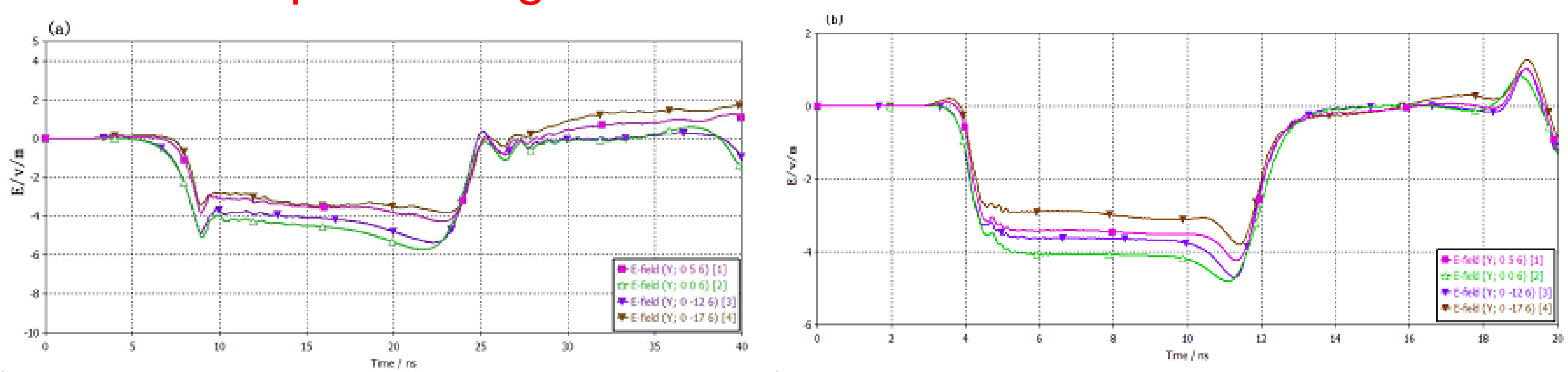
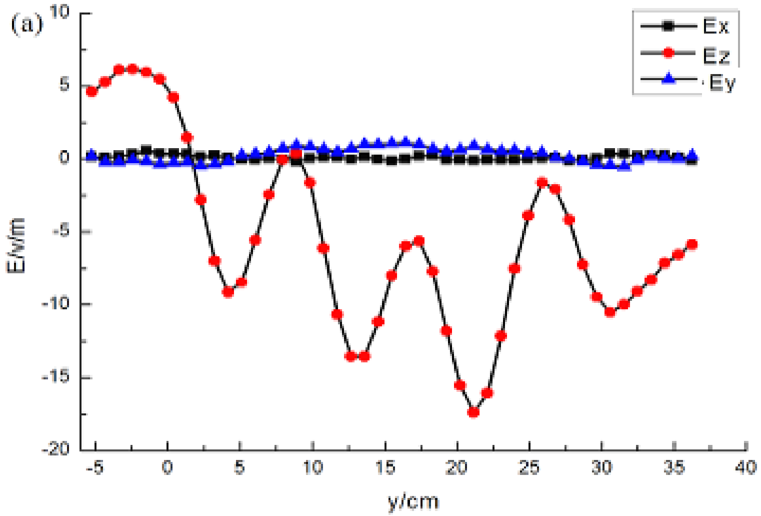
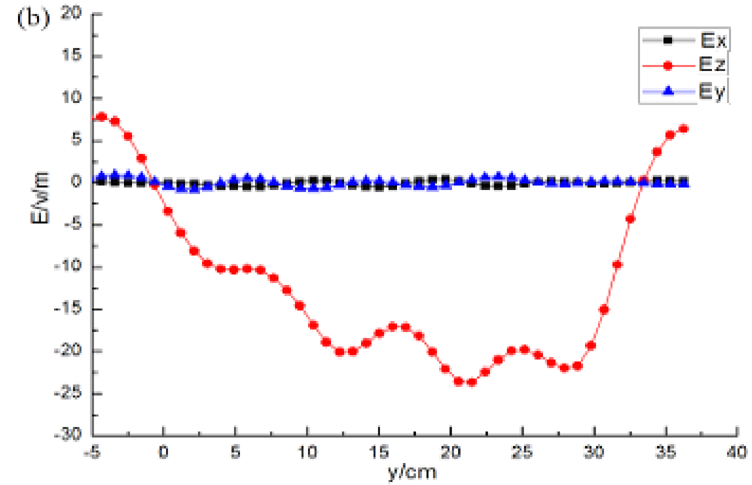



Fig.5. The electric field waveforms Ey along y axial at four points $\varepsilon_r = 10$ (a) and $\varepsilon_r = 2.2$ (b).

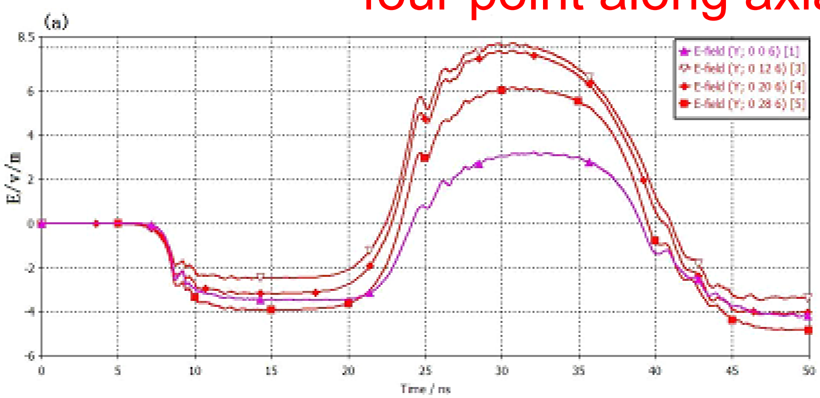
# ZIP structure cell

## spacial fields along the axial




## four point along axial the waveform versus time



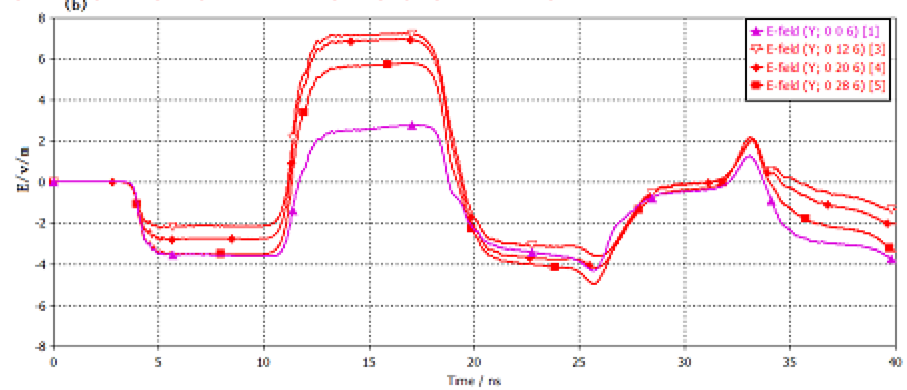




Fig.7. The electric field waveforms Ey at different points $\varepsilon_r = 10$ (a) and $\varepsilon_r = 2.2$ (b).

# 2.3 proton DWA beam transport simulation-Warp

Warp originally developed for HIF:
- ➢ high current
- ➢ high brightness
- ➢ space charge dominated

It allows time-Dependent fields. Special for high current pulse accelerator and linear induction accelerator.

## Warp

- **Warp is a state-of-the-art 3-D parallel multi-physics code and framework**
  - *modeling of beams in accelerators, plasmas, laser-plasma systems, non-neutral plasma traps, sources, etc.*
  - *unique features: ES/EM solvers, cut-cells, AMR, particles pushers, python interface, etc.*
- **Contribution to projects**
  - **HIFS-VNL (LBNL,LLNL,PPPL)**: work-horse code; design and support expts.
  - **VENUS ion source (LBNL)**: modeling of beam transport
  - **LOASIS (LBNL )**: modeling of LWFA in a boosted frame
  - **FEL/CSR (LBNL)** : modeling of free e- lasers & coherent synch. radiation in boosted frame
  - **Anti H- trap (LBNL/U. Berkeley)**: simulation of model of anti H- trap
  - **U. Maryland**: modeling of UMER sources and beam transport; teaching
  - **Ferroelectric plasma source (Technion, U. Maryland)**: modeling of source
  - **Fast ignition (LLNL)**: modeling physics of filamentation
  - **E-cloud for HEP (LHC, SPS, ILC, Cesr-TA, FNAL-MI)**: see slide on Warp-Posinst
  - **Laser Isotope Separation (LLNL)**: now defunct
  - **PLIA (CU Hong Kong)**: modeling of beam transport in pulsed line ion accelerator
  - **Laser driven ions source (TU Darmstadt)**: modeling of source
- **Benchmarking**
  - Heavily benchmarked against various experiments: MBE4, ESQ ion source, HCX, multibeamlet ion source, UMER, NDCXI, etc.; codes: IGUN, LSP; theory: beam transport and plasma analytic theory

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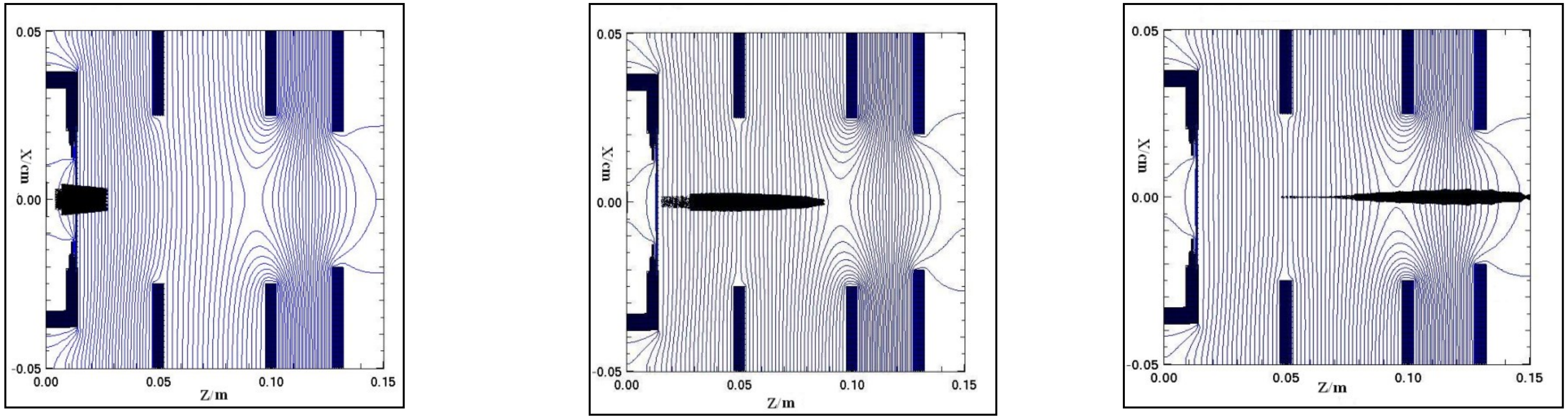
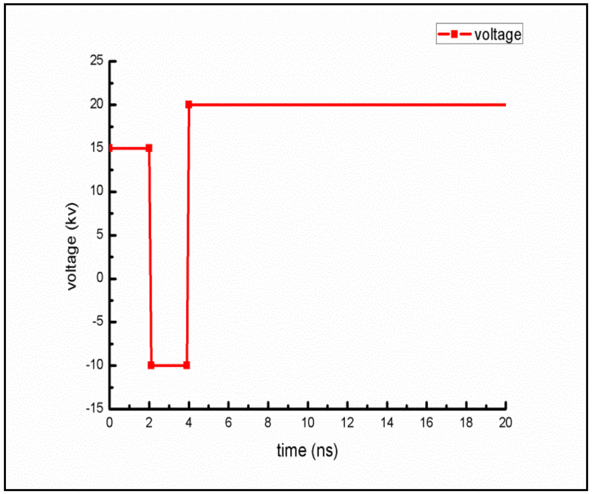
Slide 53 The Heavy Ion Fusion Science Virtual National Laboratory

*D.Grote, A.Friedman, J.-L.Vay, I.Haber, The warp code: modeling high intensity ion beams, in: AIP Conference Proceedings, no. 749, 2005, pp. 55–8.

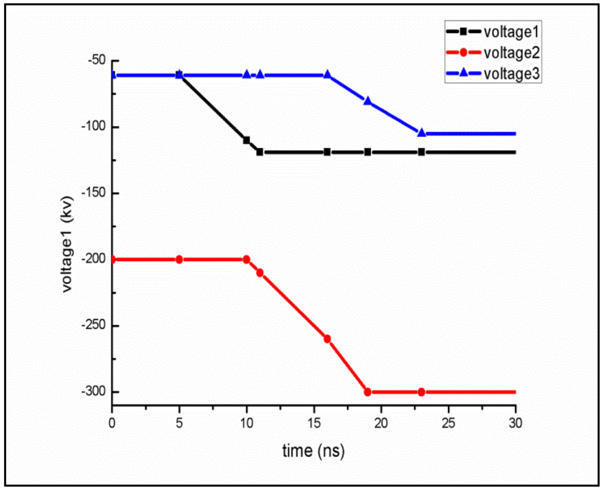
# 2.3.1 Injector simulation



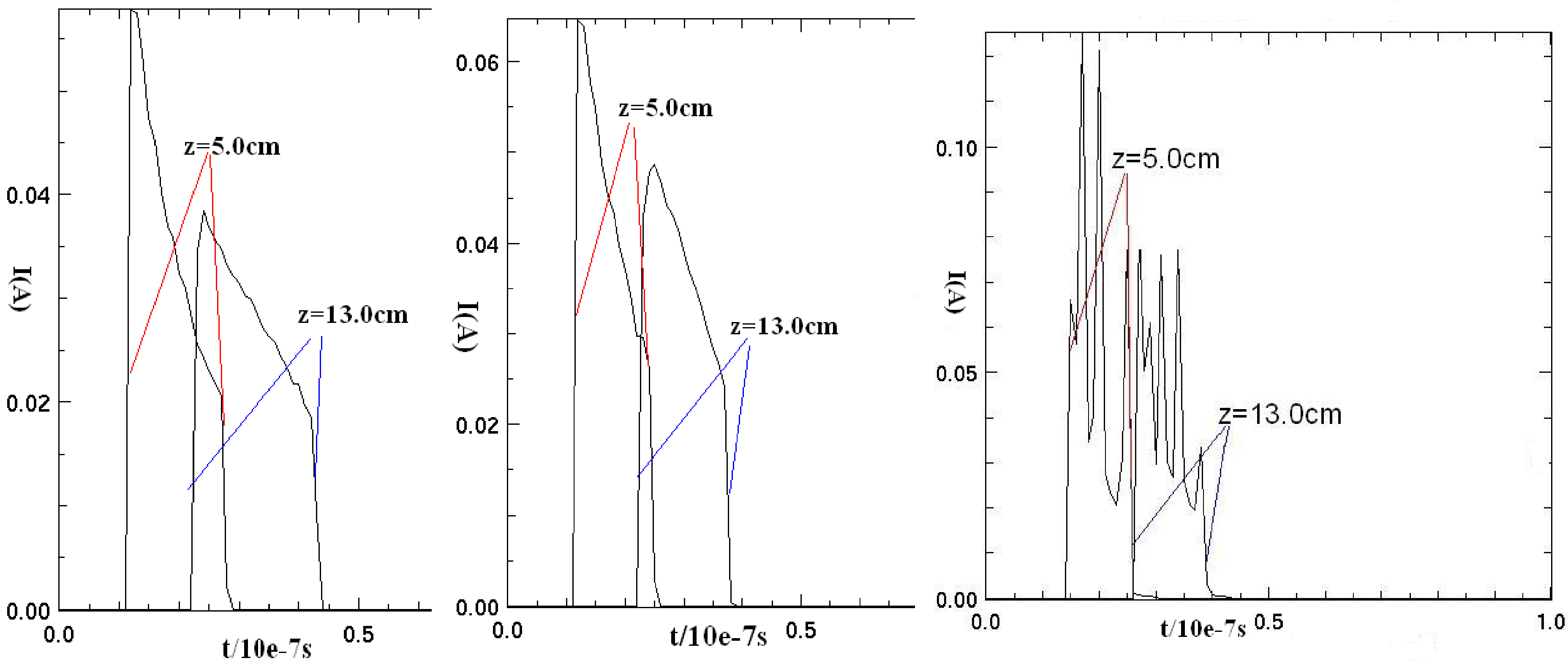

Electric potential and pulse beam transport of the injector at t=10ns(a), t=20ns(b), t=30ns(c).




The extraction voltage on the extraction electrode(a), the tilt waveform for the three electrodes(b).



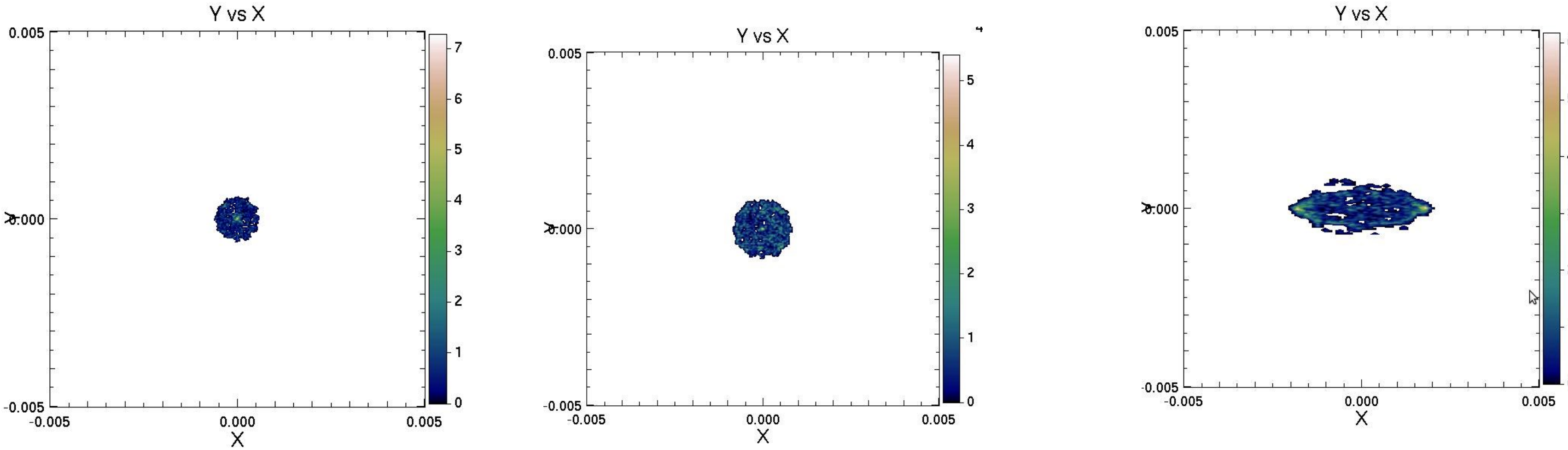
# the current pulse



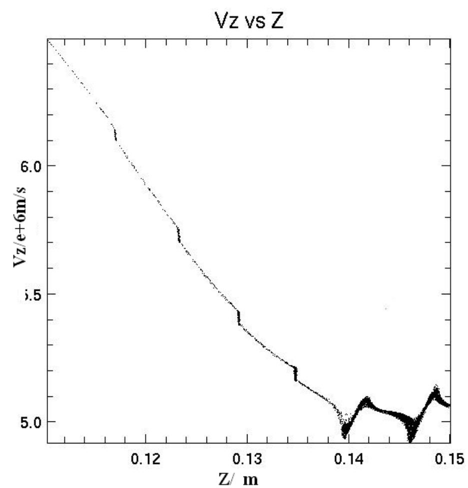

Beam pulse current versus time no tilt voltage and no mesh(a), with tilt voltage and no mesh(b), with tilt voltage and mesh(c).

Z=13cm，（a）25ns，38mA (b)18ns,48mA (c)14ns, 70mA

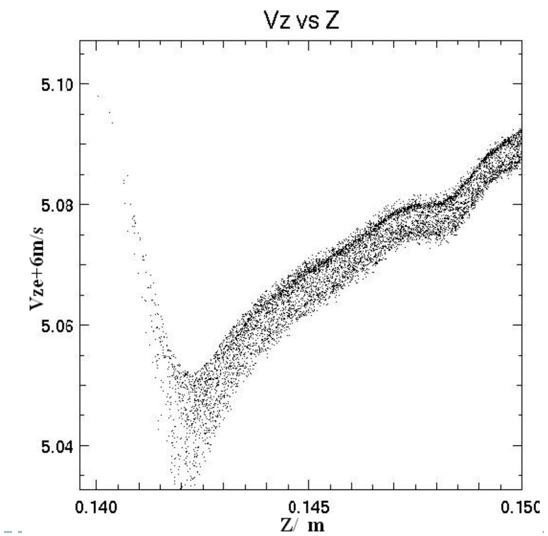
# Beam transverse size




Beam transverse size at the injector end no tilt voltage and no mesh(a), with tilt voltage and no mesh(b), with tilt voltage and mesh(c).

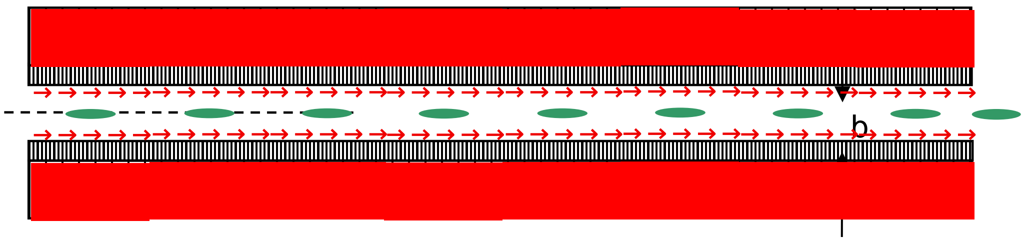



The velocity distribution along Z with tilt voltage and with mesh(a), and without mesh(b).



# 2.3.2 Beam transport simulation with Warp

## "virtual" traveling wave accelerating mode




the wave velocity can be controlled by the switching time, so set the proper delay time of switching each Blumleins line or each cell,and makes the travelling wave synchronous to the beam transport, and the particles will be accelerated at all time.

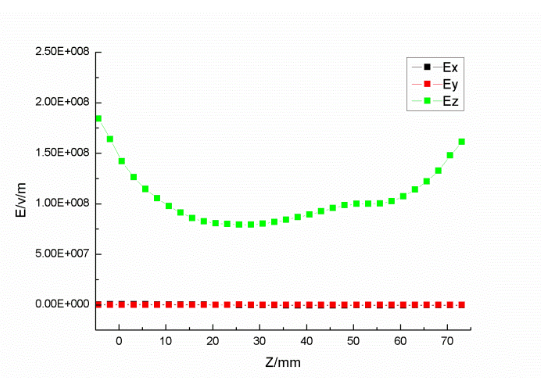
The fields can be considered change in the following way, like RF accelerator:

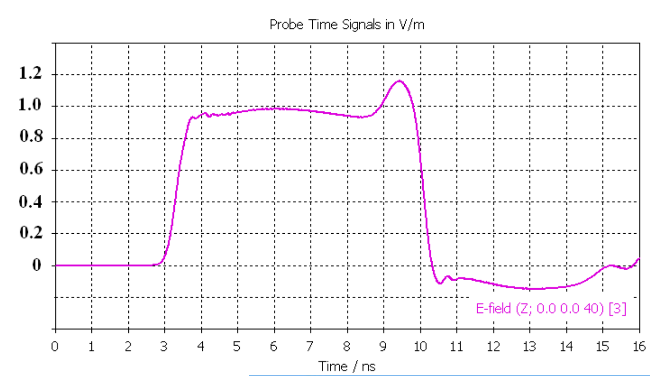
$$E(x,y,z,t)=E(x,y,z)|_{t=t_{peak}}\bullet f(t-\tau)$$

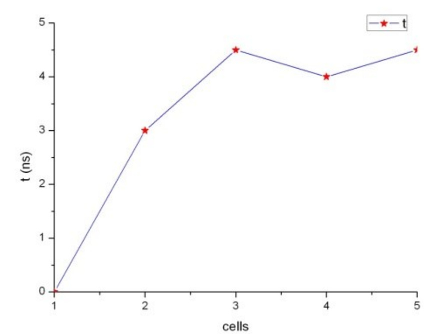
$E(x,y,z)|_{t=t_{peak}}$ is the fields at space calculated by CST when $t=t_{peak}$

$f(t-\tau)$ is the time waveform, and it is a scale factor, define the flatten top is 1.0.

$\tau$ is the delay time for each lines or cells.

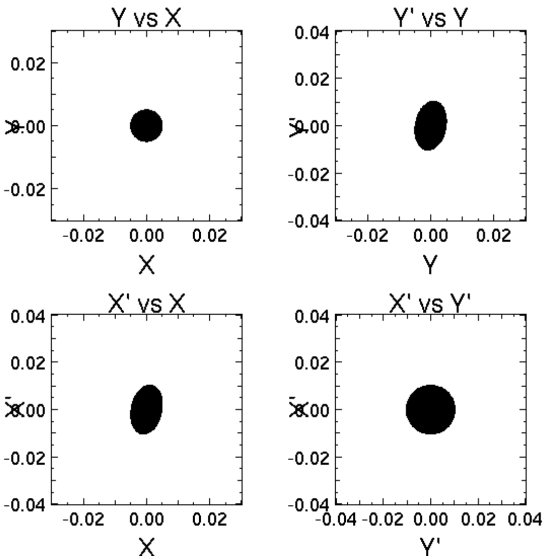


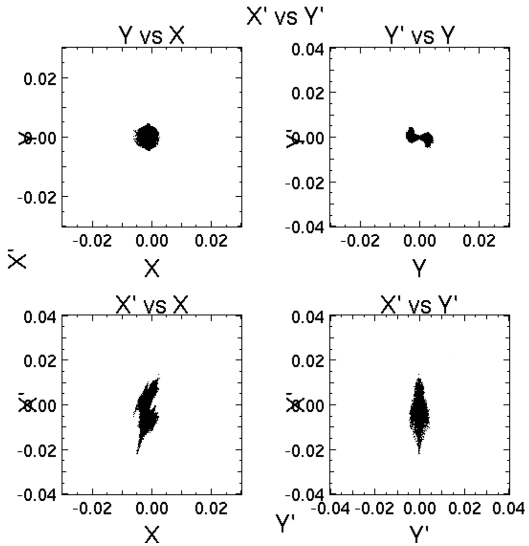



# beam transport simulation and result

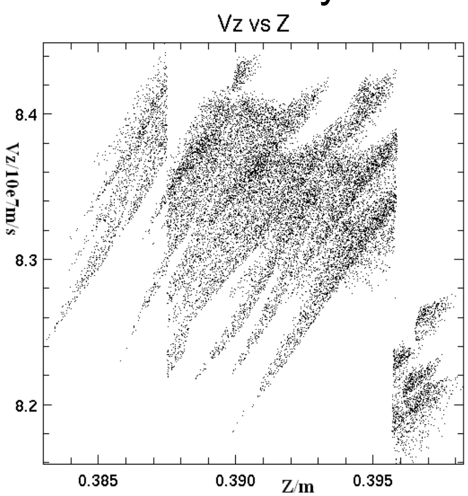
Initial transverse parameters of injecting protons(a),after accelerating the transverse parameter(b).

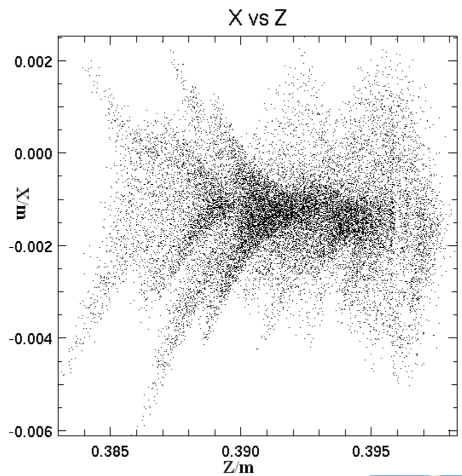


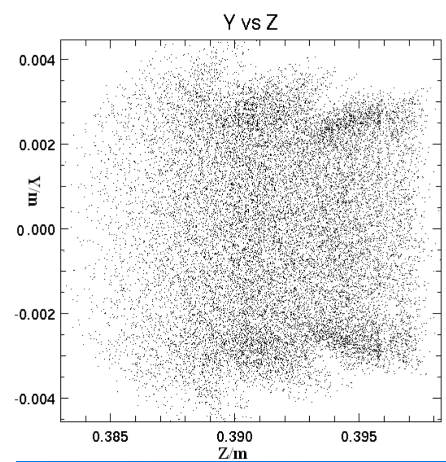




*Quantang Zhao, P. Yuan, Z.M. Zhang, S.C Cao, X.K. Shen, Y. Jing, Y.Y. Ma, C.S. Yu, et al. Injector and beam transport simulation study of proton dielectric wall accelerator. Nuclear Inst. and Methods in Physics Research, A (2012), pp. 314-320.

The axial velocity versus Z(a), the X transverse size versus Z(b), the Y transverse size versus Z(c).



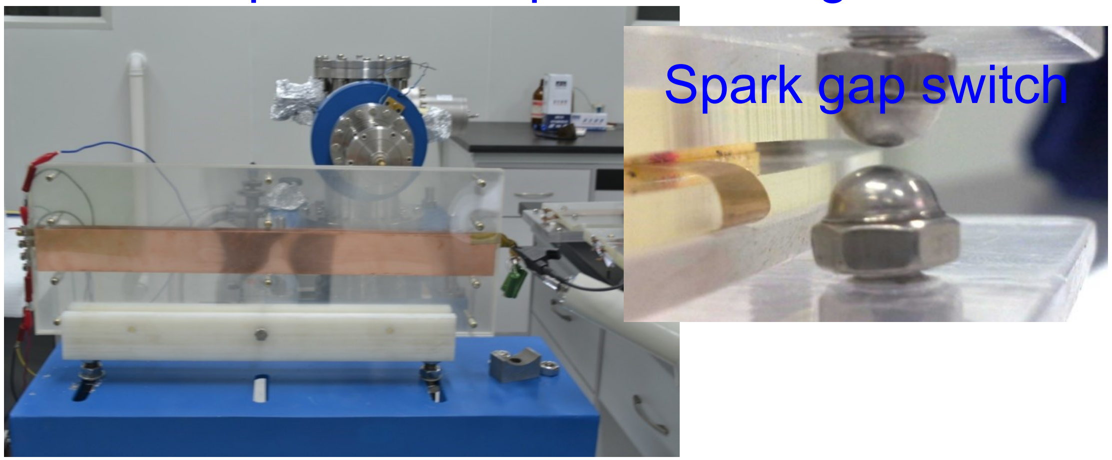



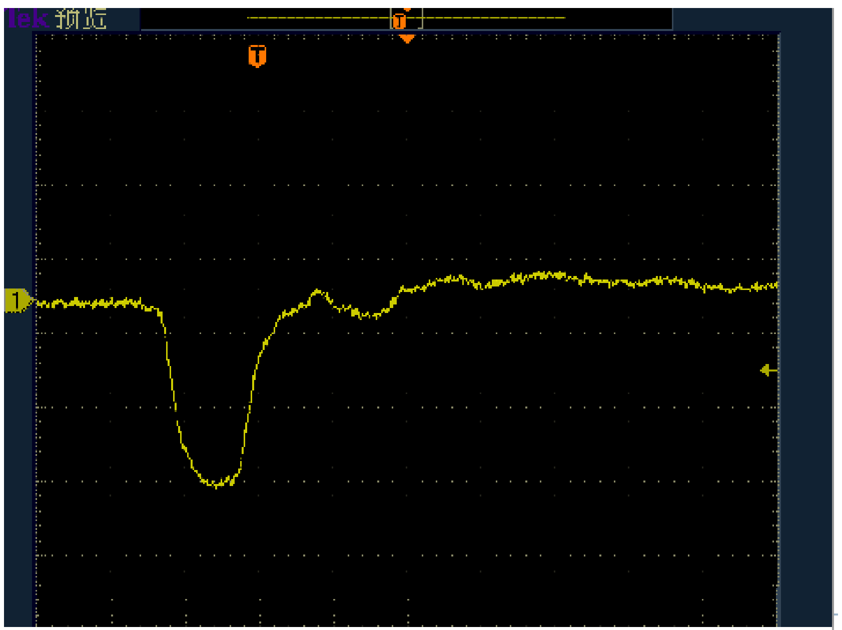

The velocity of protons is accelerated from 5.0e+6m/s (130kev) to 8.3e+7m/s(36MeV) with DWA of 37.75cm long .

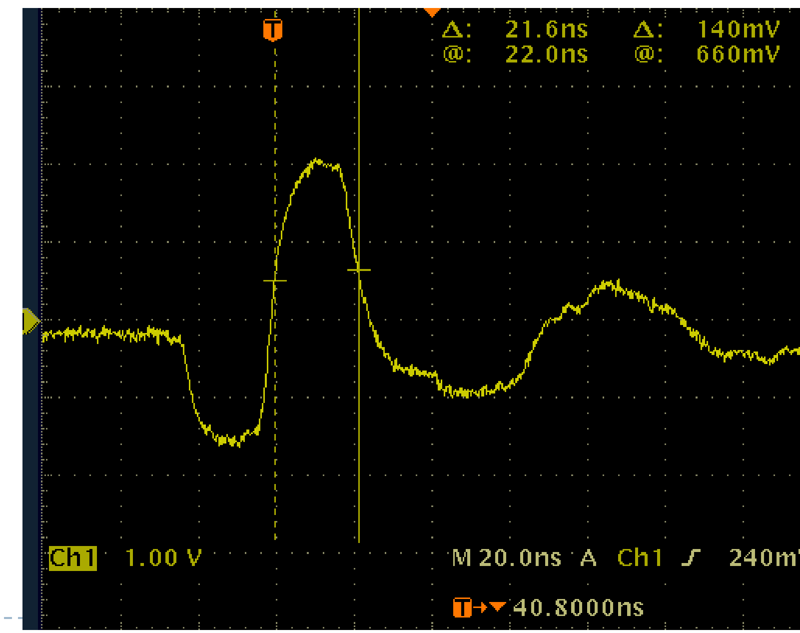
# 3 Experiment research of DWA

## 3.1 The experiment of pulse forming lines

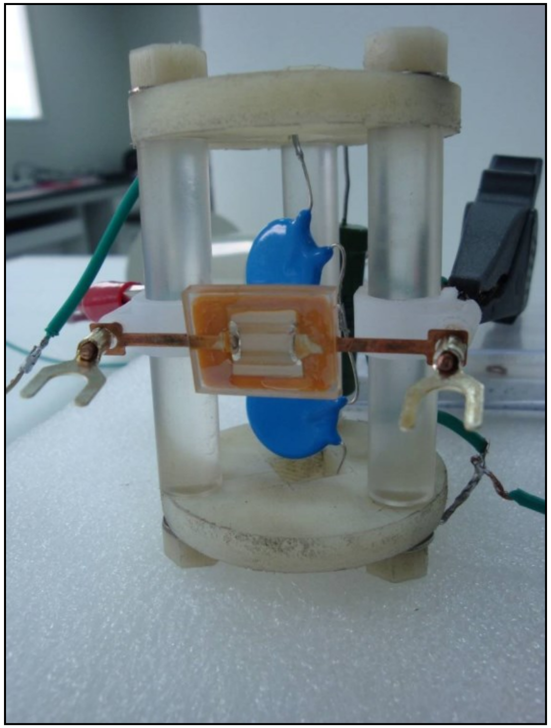


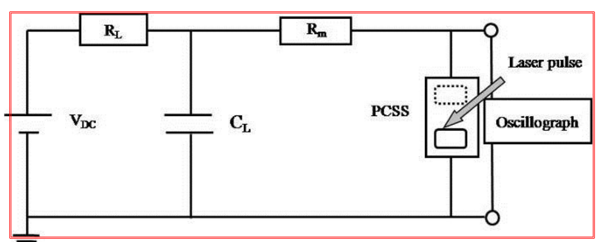

material: polyethylene plate and spark gap switch.
the width of Blumleins is 17ns.
the width of ZIP lines is 21ns.



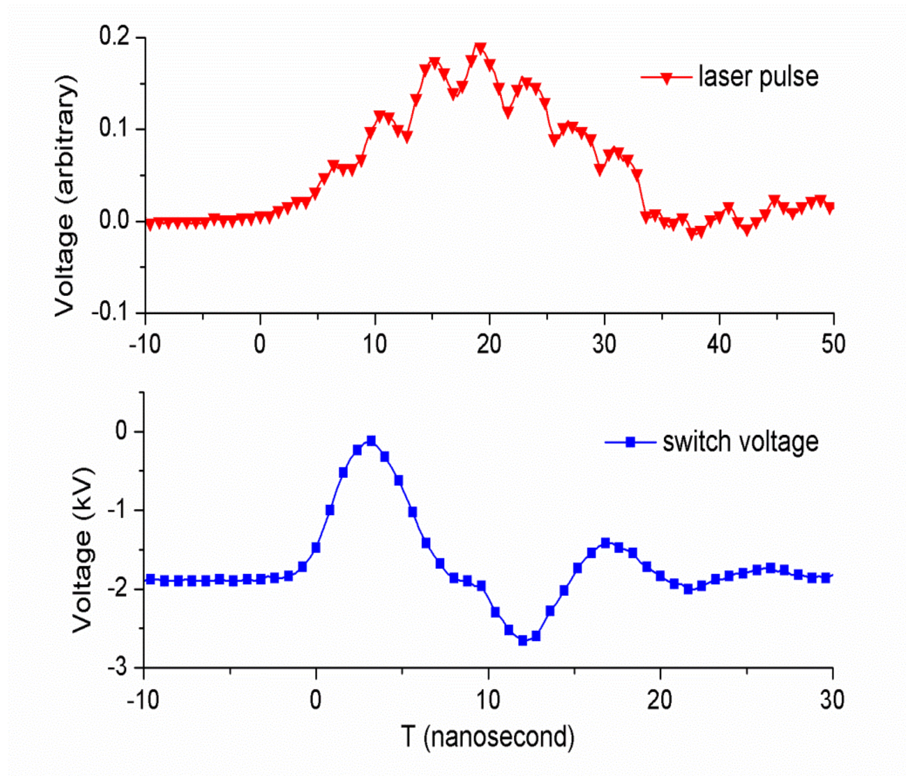


# 3.2 Experiment of SiC PCSS



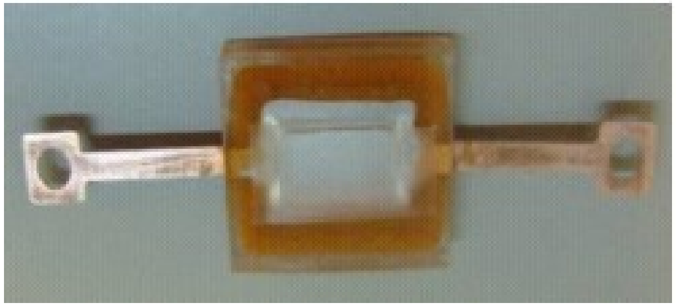


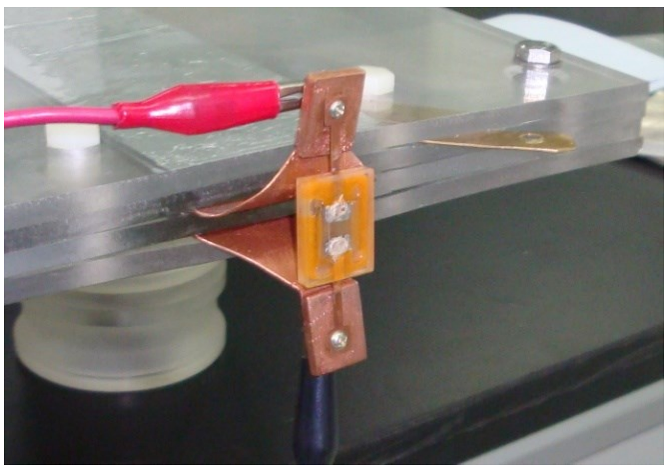

Test electric circuit



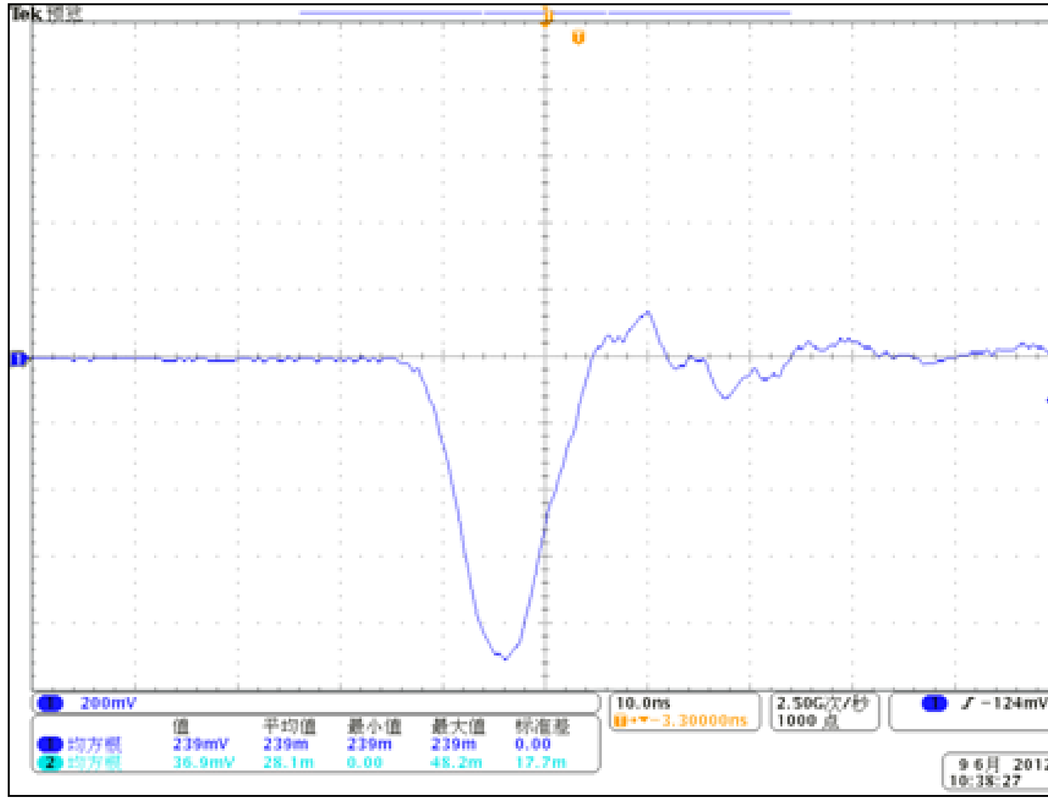

the laser pulse (green) with energy 9.52mJ and 355nm wavelength.
the conducting voltage of PCSS(blue), the rising time is about 2.4ns.

# PCSS with Blumleins experiment result





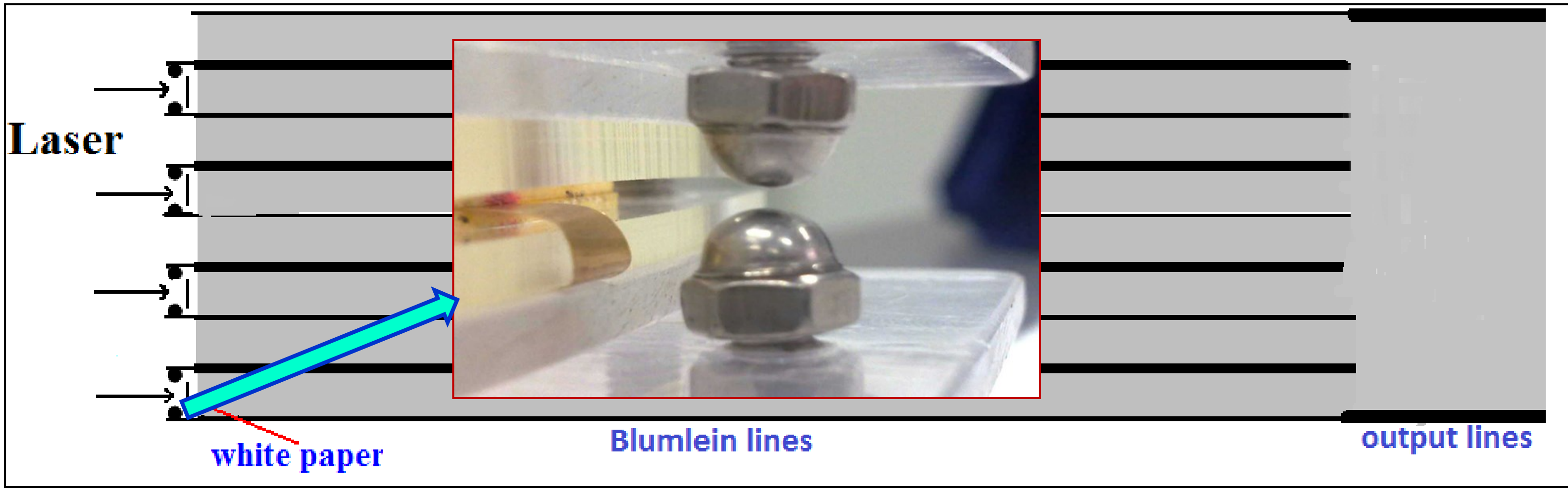
The designed pulse width is 6ns.



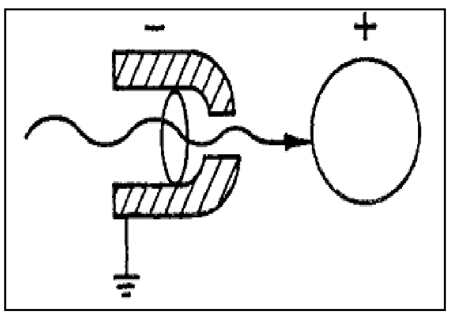

High switch on resistance

Charging 5kV,output only 1kV.

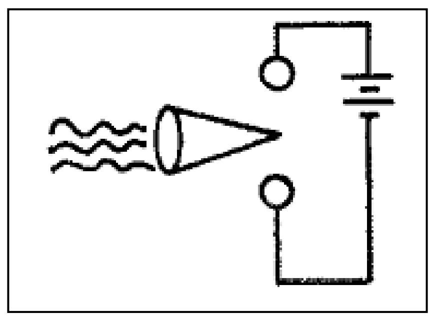
# 3.3 laser triggered spark gap switches and stacked Blumleins



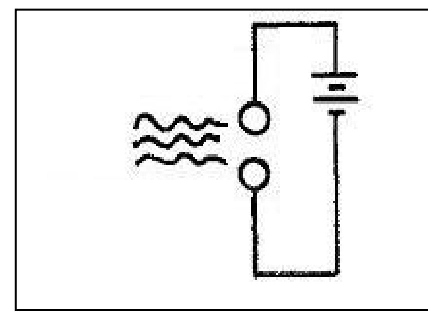

Laser triggered styles



a



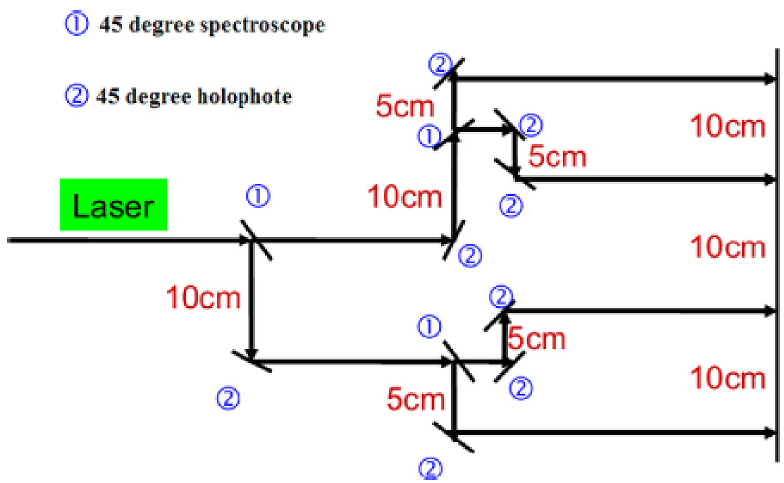

b

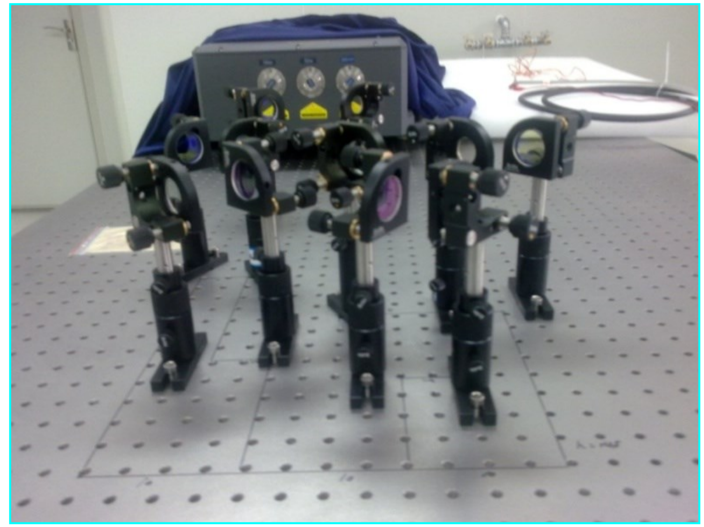


c

# Laser beams used for triggering

The laser beam path of the four beams should be same.

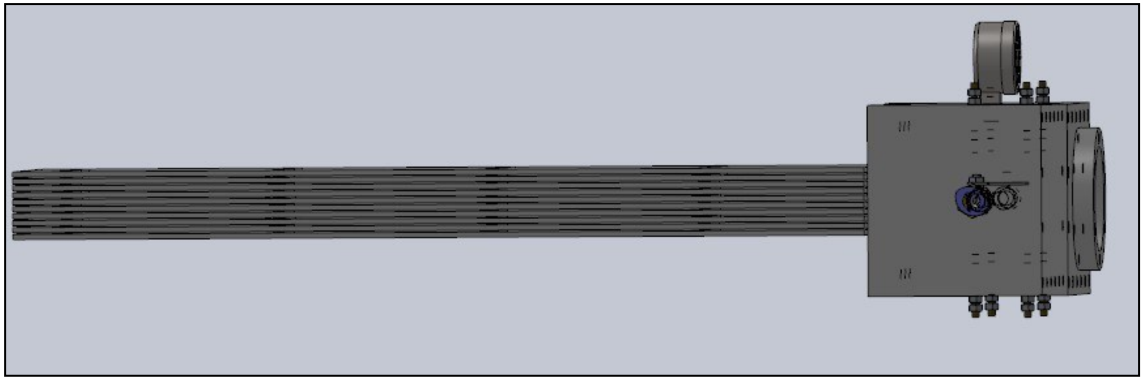


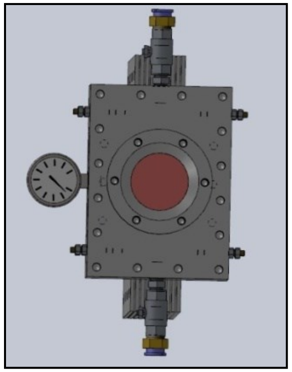



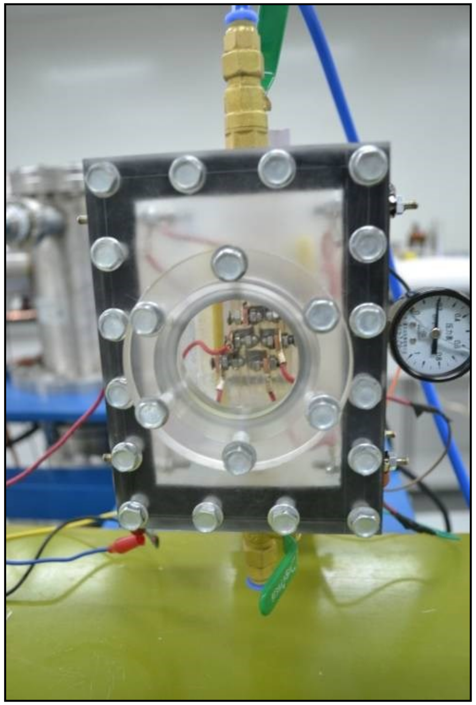
Beam split (355nm, total energy 115.1mJ):

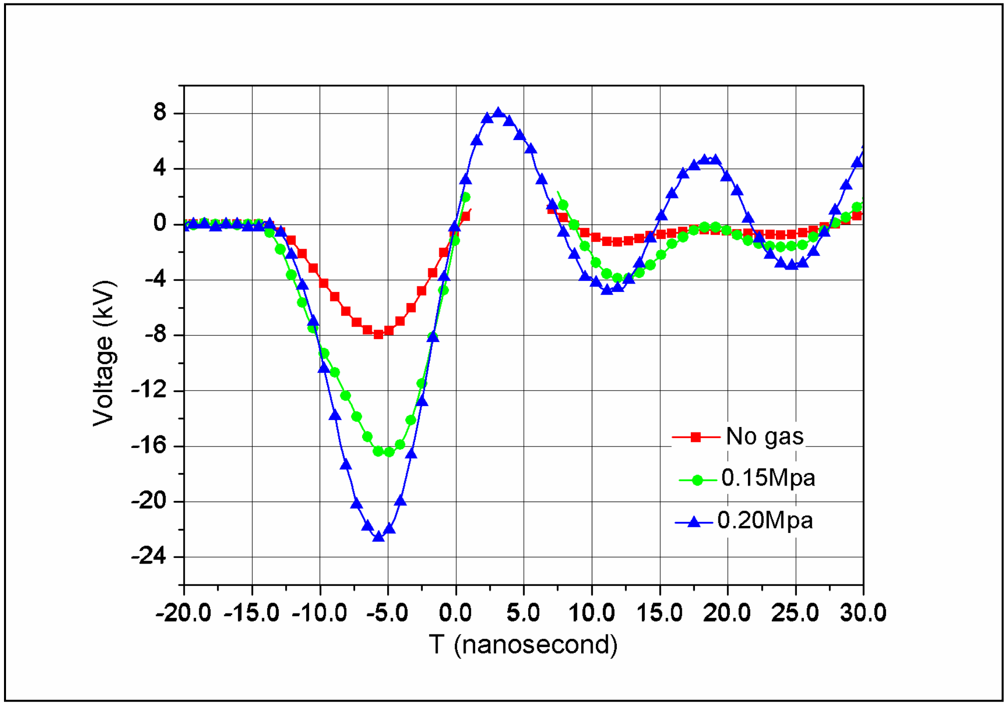
| Beams (from left to right) | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| energy (mJ) | 16.2 | 11.45 | 12.47 | 21.48 |

# The switches sealed in the box, filled with nitrogen：8kV，16kV，23kV.

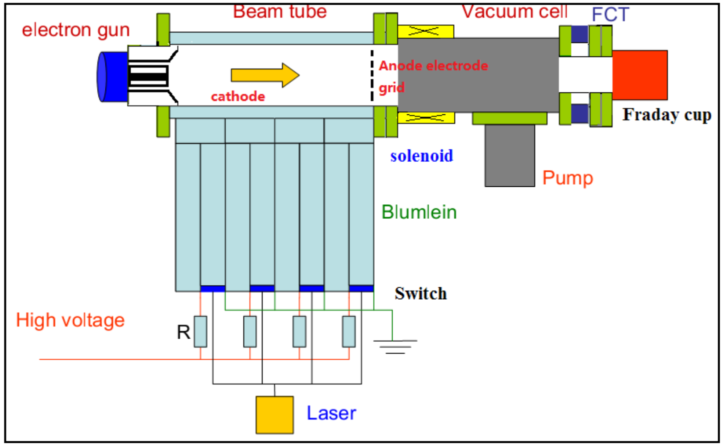


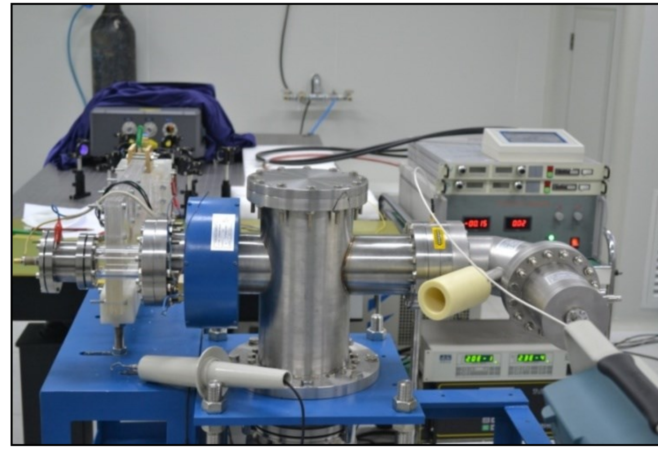


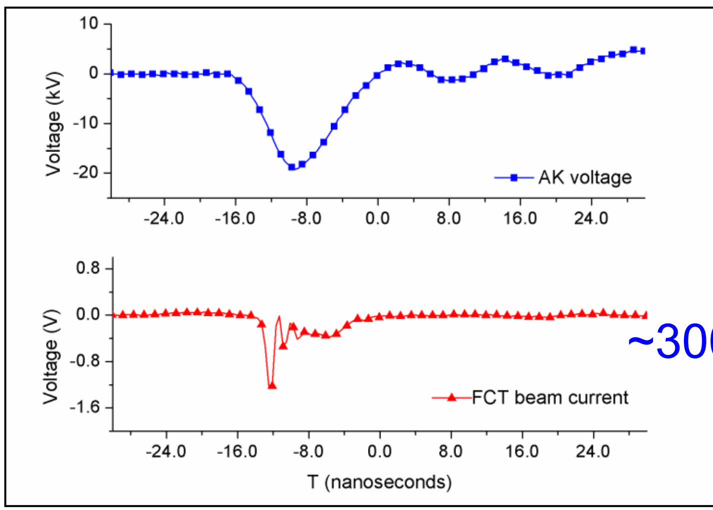




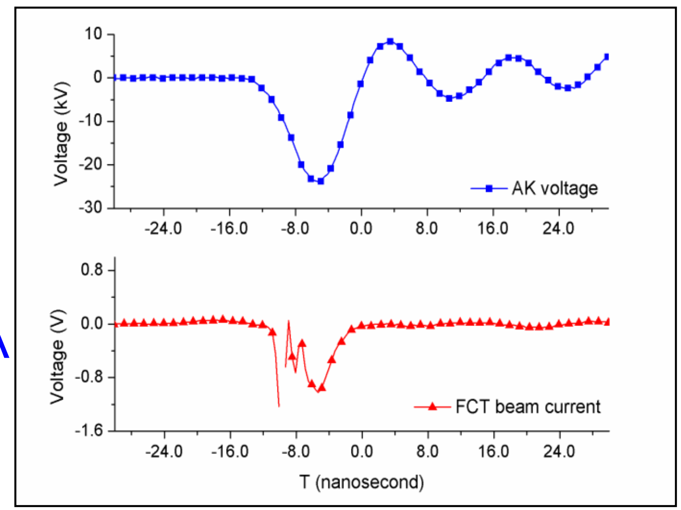
# 3.4 DWA as a diode experiment ( thermionic electron gun )






~300mA




*Quantang Zhao, Z.M.Zhang, P.Yuan，et al. Nanosecond pulse-width electron diode based on dielectric wall accelerator technology. Nuclear Inst. and Methods in Physics Research, A 729(2013), pp. 227-232.

# Conclusions

1、achieving the principle test of DWA with experiment.
2、simulating the electromagnetic field and beam transport of DWA.
3、the materials of key technology are still the key point for the DWA.

# Publications

1、**Quantang Zhao**, Z.M.Zhang, P.Yuan， et al. Nanosecond pulse-width electron diode based on dielectric wall accelerator technology. Nuclear Inst. and Methods in Physics Research, A ,Vol.729 (2013), pp. 227-232.
2、**Quantang Zhao,** P. Yuan, Z.M. Zhang, S.C Cao, X.K. Shen, Y. Jing, Y.Y. Ma, C.S. Yu, et al. Injector and beam transport simulation study of proton dielectric wall accelerator. Nuclear Inst. and Methods in Physics Research, A, Vol. 694 (2012), pp. 314-320.
3、**Zhao Quantang,** Zhang Zimin,Yuan Ping, Cao ShuChun, Shen XiaoKang, Liu Ming, Jing Yi, Zhao HongWei. Electromagnetic simulation study of dielectric wall accelerator structures. Chinese Physics C.VOL.36, NO.4, 2012.04.
4、**Zhao Quantang,** Yuan Ping, Zhang Zimin, Cao ShuChun, Shen XiaoKang, Liu Ming, Jing Yi, Zhao HongWei. Simulation and experimental study of the solid pulse forming lines for dielectric wall accelerator. Chinese Physics C. VOL.35, NO.12, 2011.12.
5、**Zhao Quantang,**Yuan Ping,Zhang Zimin,Cao Shuchun,Shen Xiaokang,Zhao Hongwei. Accelerating field waves transmission of dielectric wall accelerator. High Power Laser and Particle Beams, 2011, 23(6): 1629～1634) (in Chinese).
6、**Zhao Quantang,** Zhang Zimin , Cao Shuchun, Shen Xiaokang and Yuan Ping. Primary Studies of Dielectric Wall Accelerator， IMP & HIRFL Annual Report， 2010.
7、**Zhao Quantang,** Zhang Zimin , Cao Shuchun, Shen Xiaokang and Yuan Ping. First principle test of DWA at IMP， IMP & HIRFL Annual Report， 2012.
8、**Zhao Quantang.** Preliminary study of new high gradient Dielectric Wall Accelerator, doctor thesis, 04, 2013.

# II. Research experience(2)

## High energy electron radiography (eRad)
(from 2013-07 to 2015-01)

- Introduction to eRad
- Experiment research of eRad based on THU linac
- New experiment and design
- Conclusions

# HEDP at High Intensity heavy Ion Accelerator Facility (HIAF)


| | SIS-18 | FAIR (SIS-100) | HIAF (V1) |
|---|---|---|---|
| $E_0$ | 0.4GeV/u | 1GeV/u | 1 GeV/u |
| N | $4\times10^{9}$ | $4\times10^{11}$ | $1\times10^{12}$ |
| $E_{bm}$ | 0.06 kJ | 15 kJ | 38kJ |
| $S_f$ | ~1 mm | ~1 mm | 1 -0.5mm |
| τ | 130 ns | 50 ns | 100-50ns |
| $E_s$ | 1 kJ/g | 120 kJ/g | 300 kJ/g -1.2MJ/g |
| $E_\rho$ J/m³ | $2\times10^{10}$ | $2.4\times10^{12}$ | $6\times10^{12}$ $-2.4\times10^{13}$ |

*J.C. Yang , J.W. Xia, G.Q. Xiao, H.S. Xu, H.W. Zhao, et al. Nuclear Instruments and Methods in Physics Research B 317(2013) 263-265.

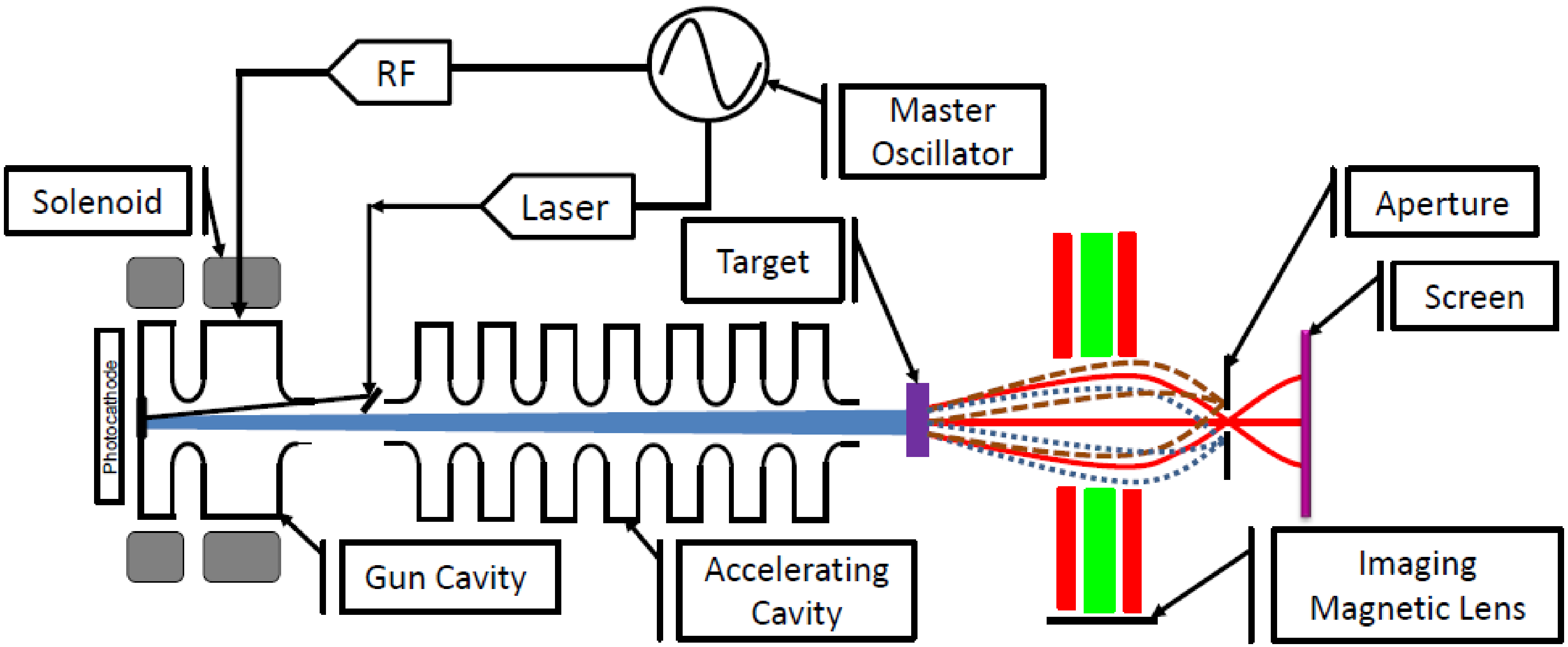
## HEDP at HIAF: Radiography Diagnostics

**Importance**

- Dynamic processes with strong shock wave
- Symmetric compression
- Hydrodynamic instabilities
- EOS and Phase transition of WDM (P、n..)

**Challenging requirements**

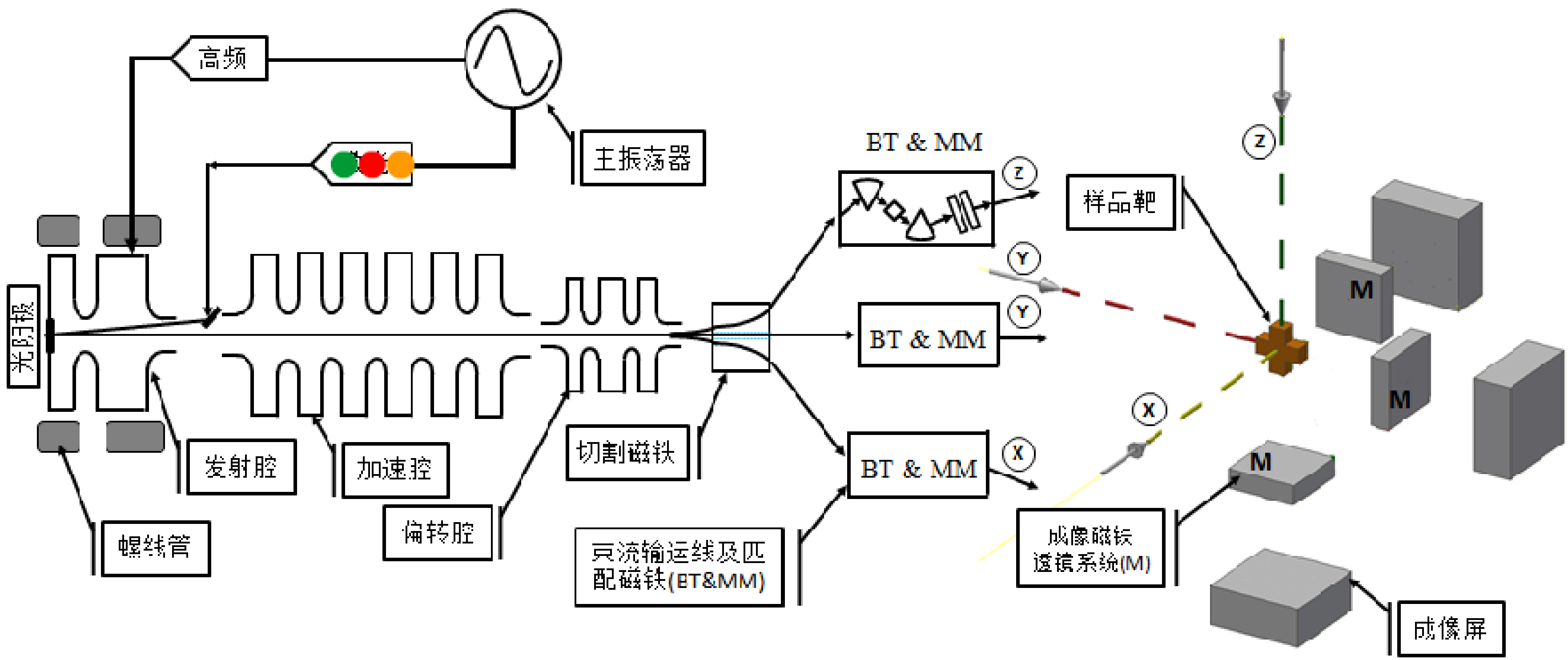
- thickness up to ~ g/cm2 (Fe, Pb, Au, etc.)
- ≤10 μm spatial resolution
- 10 ns time resolution (multi-frames in single shot)
- sub-percent density resolution
- sensitive to elements...




**HEDP(high energy density physics) at HIAF( High intensity accelerator facility)**

We propose a new scheme that use a high energy electron beam as a probe for time resolved imaging measurement of high energy density materials. The device uses a bunch train of the electron beam with flexible time structure, that penetrating a time vary high density target. By imaging the scattered electron beam, a detailed target profile and its density evolution can be accurately determined. Successful demonstration of this concept will have impact implication on future fusion and HEDP physics research.

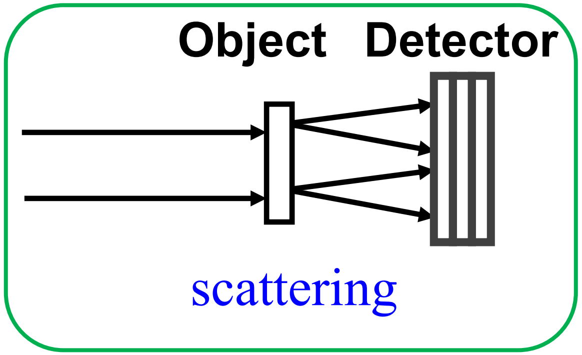
# Use RF deflecting cavity for beam bunch split for 3D radiography.

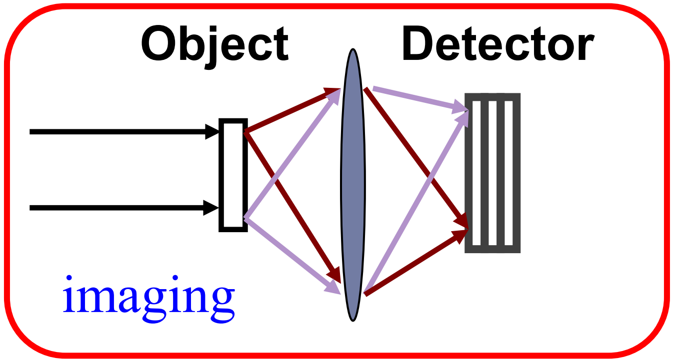


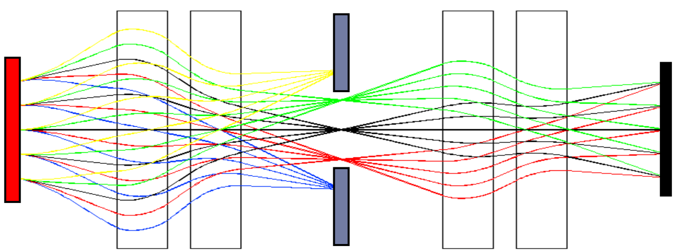

This work supported by three labs, IMP, ANL and THU Accelerator lab.

# 1、 Introduction to eRad

## Radiohraphy with particles (p, e, n, X-ray, light...)



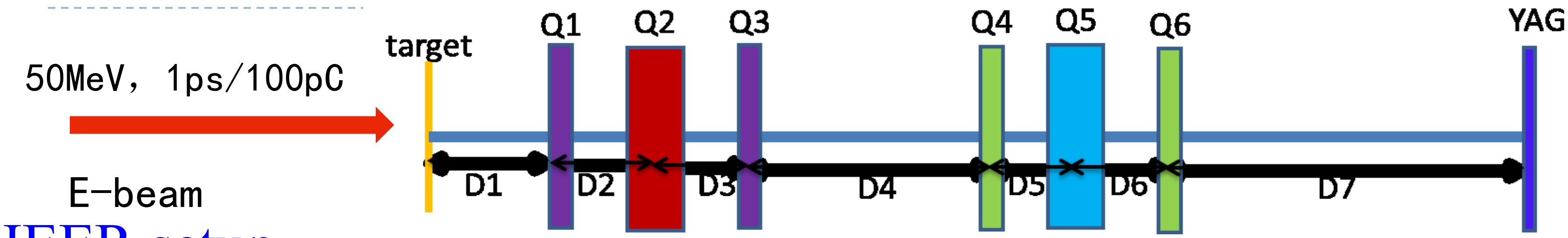



Los Alamos National Lab:

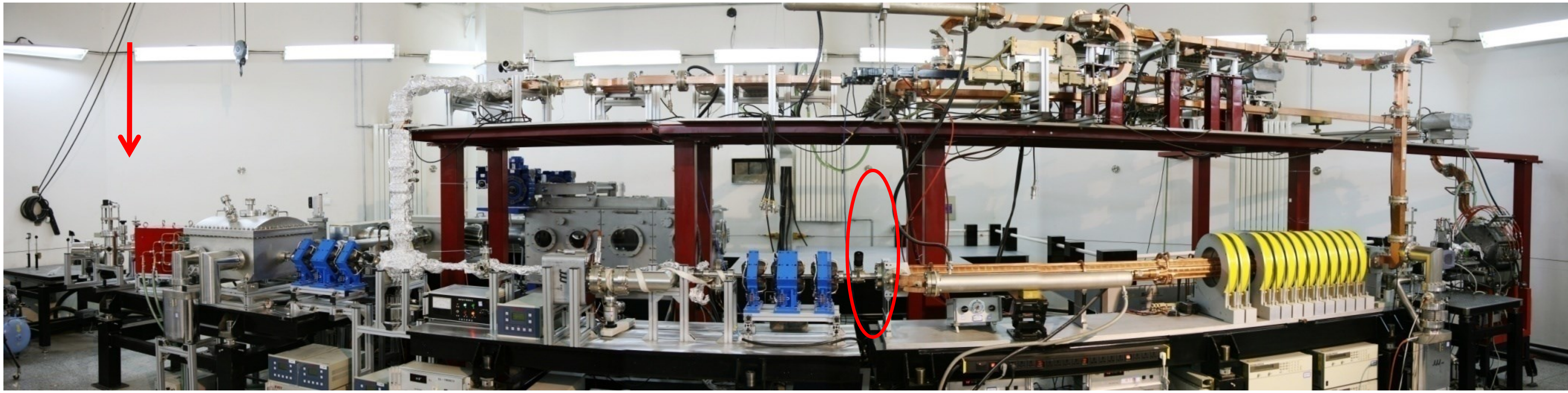
- High energy proton radiography
- 30MeV electron radiography experiment (2005)


*Frank Merrill, Frank Harmon, Alan Hunt, Fesseha Mariam, Kevin Morley,Christopher Morris, Alexander Saunders, Cynthia Schwartz. Electron radiography. Nuclear Instruments and Methods in Physics Research B 261 **(2007)** 382–386.

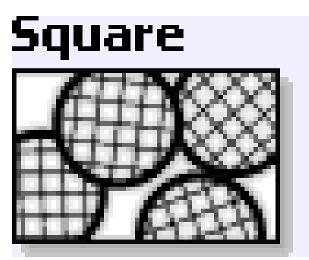
# 2、 Experiment research of eRad based on THU linac

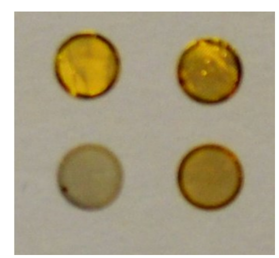



HEER setup



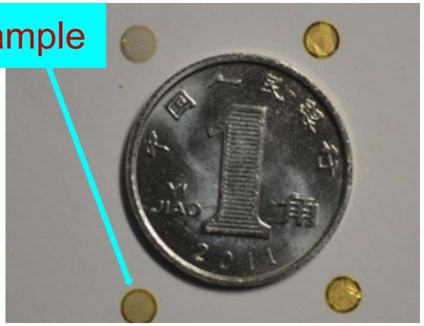
Samples :
TEM grid

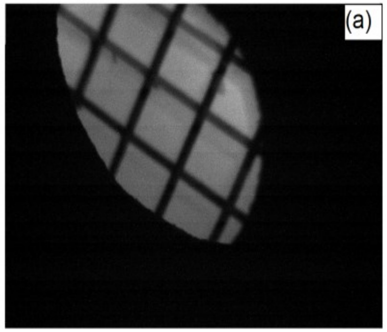



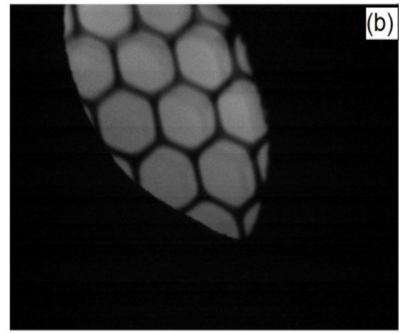



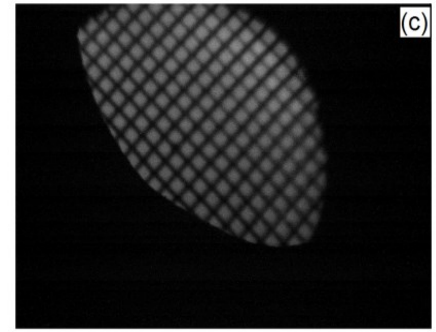
# 3、experiment result and analysis

sample

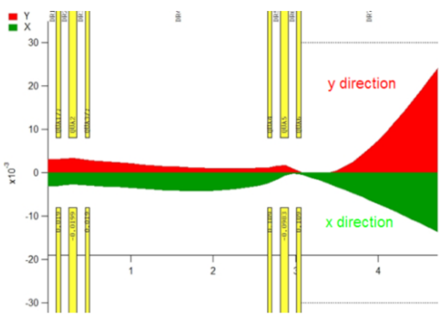


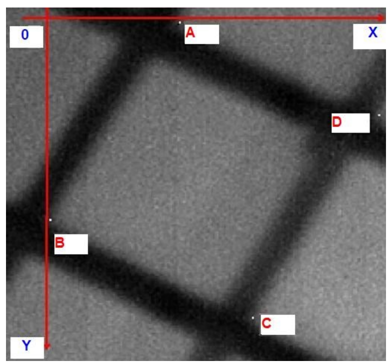



## Magnifying factor

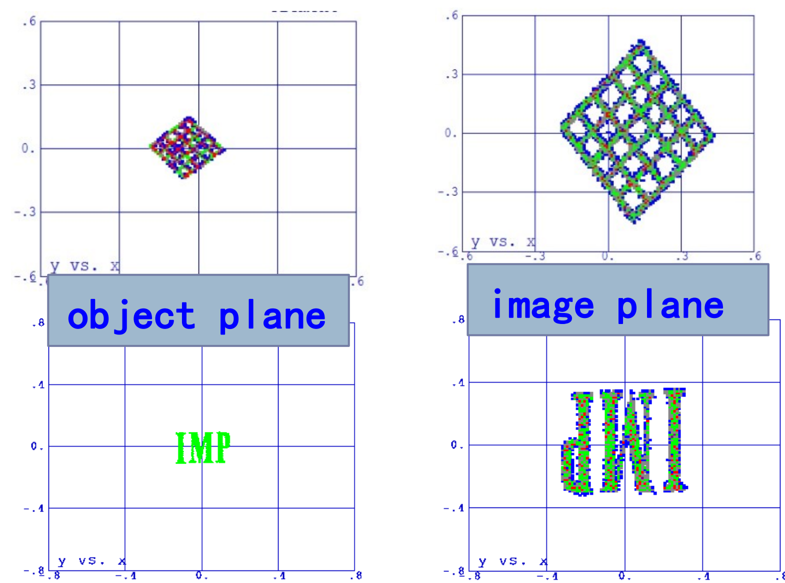



Simulation result:
X direction 2.30
Y direction 3.89

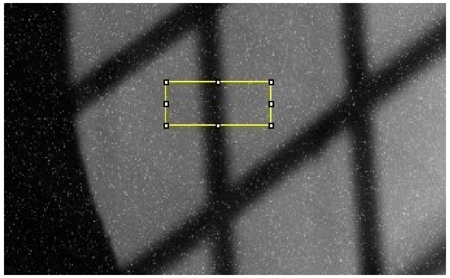
Experiment result:
X direction 2.48
Y direction 3.68

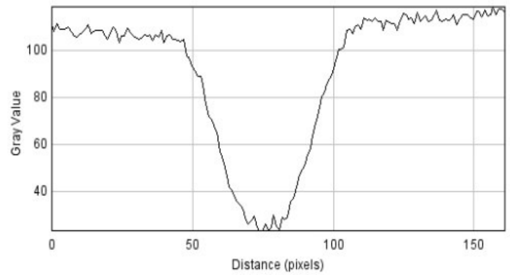
## PAMELA simulation



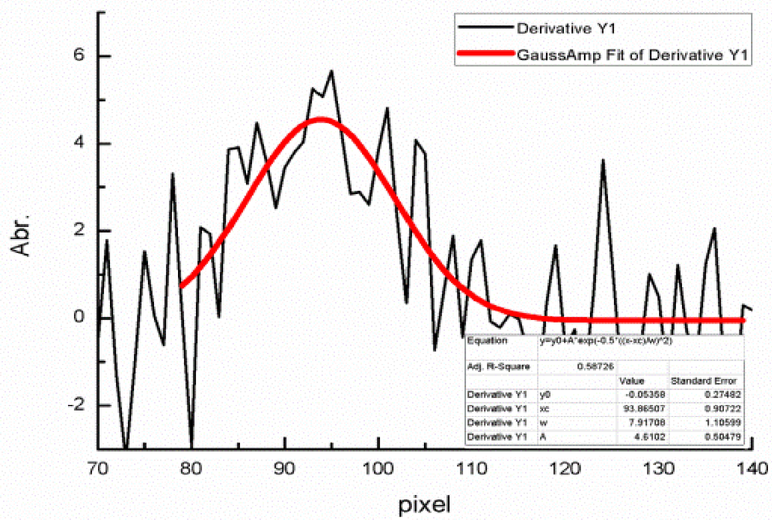
# RMS spatial resolution analysis

中科院近代物理研究所
Institute of modern physics
Chinese academy of sciences

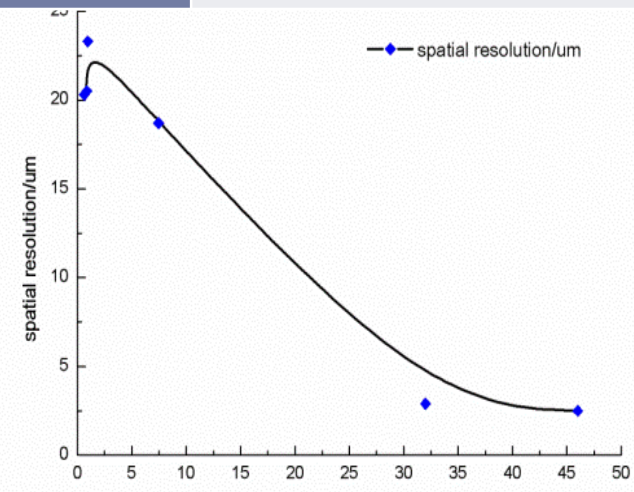





| Magnifying factor | RMS spatial resolution (um) |
|---|---|
| 46 | 2.5 |
| 32 | 2.9 |
| 7.46 | 18.7 |
| 0.95 | 23.3 |
| 0.86 | 20.5 |
| 0.64 | 20.3 |




Spatial resolution better than 10um

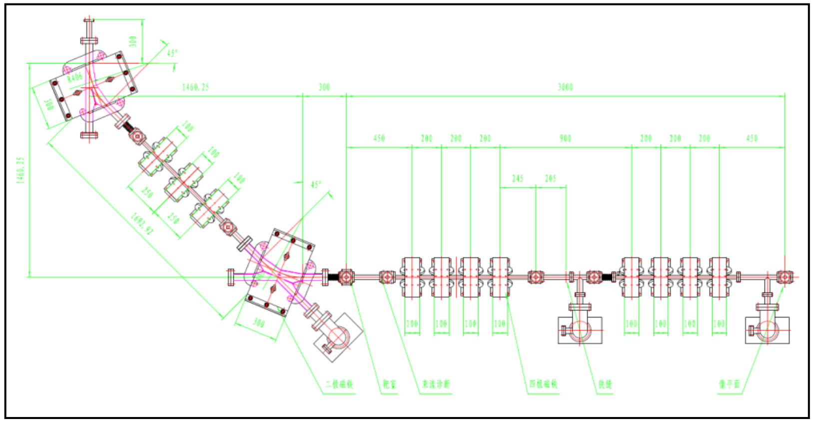



When the magnifying factor becomes larger, Spatial resolution will become better.

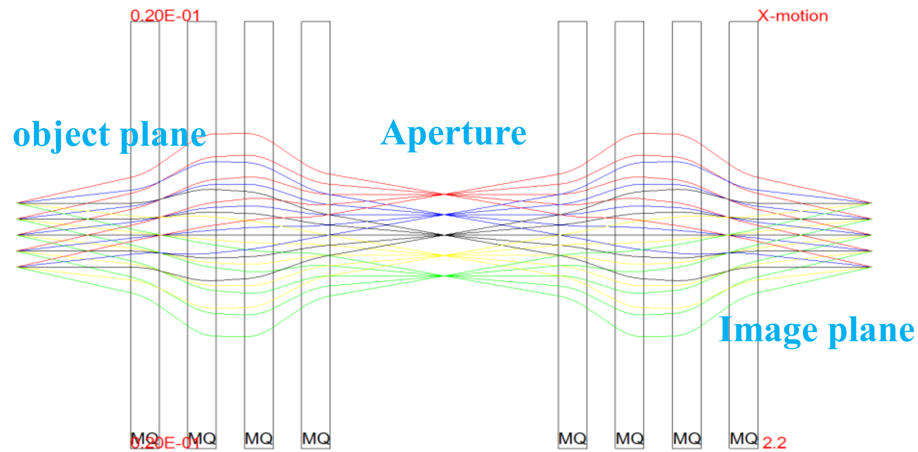
#Quantang Zhao, Z.M.Zhang, Y.T.Zhao, Y.C. Du, S.C. Cao, R.Chen, et al. High Energy Electron Radiography Experiment Research Based on Picosecond Pulse-width Bunch. Conference LINAC 2014.

# 4、 New experiment and design

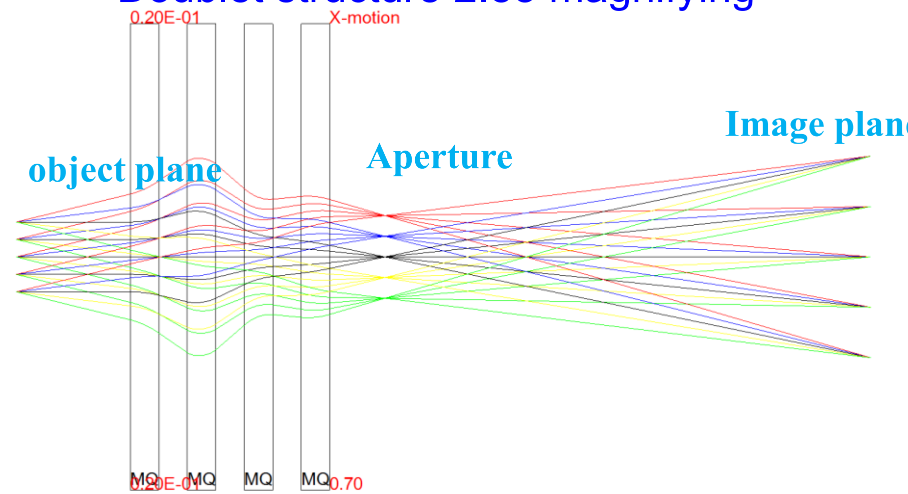
## 4.1 experiment design sketch map



### Triplet structure Unit magnifying




### Doublet structure 2.88 magnifying

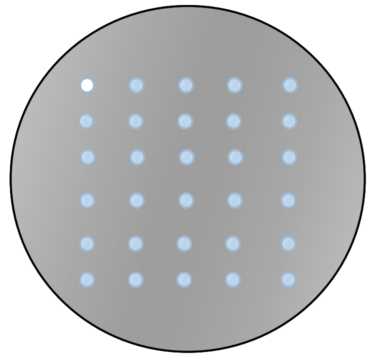



*imaging lens design (COSY INFINITY 9.1)

# 4.2、experiment plan

- Static ( aluminum target)

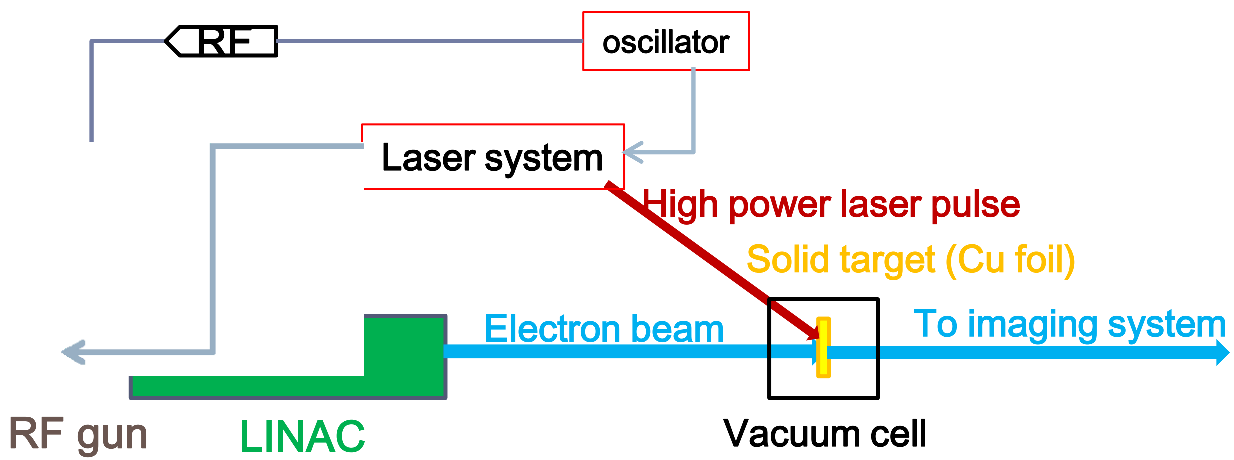
Stripe target
Spatial resolution



Step target
Density resolution


imaging

- Dynamic (copper foil target)



# Conclusions:

1、 achieving the principle test of eRad
2、 spatial resolution is better than 10 um
3、 achieving the new eRad lattice set up and experiment plan

# Publications:

1、 **Quantang Zhao**, Z.M.Zhang, Y.T.Zhao, Y.C. Du, S.C. Cao, R.Chen, et al. High Energy Electron Radiography Experiment Research Based on Picosecond Pulse-width Bunch. Conference LINAC 2014.
2、 Y. Zhao, Z. Zhang, W. Gai, Y. Du, S. Cao, J. Qiu, **Q. Zhao**, R. Cheng, W. Huang, C. Tang, H. Xu, and W.Zhan. A high resolution spatial-temporal imaging diagnostic for high energy density physics experiments with a high energy electron bunch train. Have been submitted in APL.

LINAC14-High Energy Electron Radiography Experiment Research Based on Picosecond Pulse-width Bunch, 5 minutes oral presentation of paper.

# Future work plans

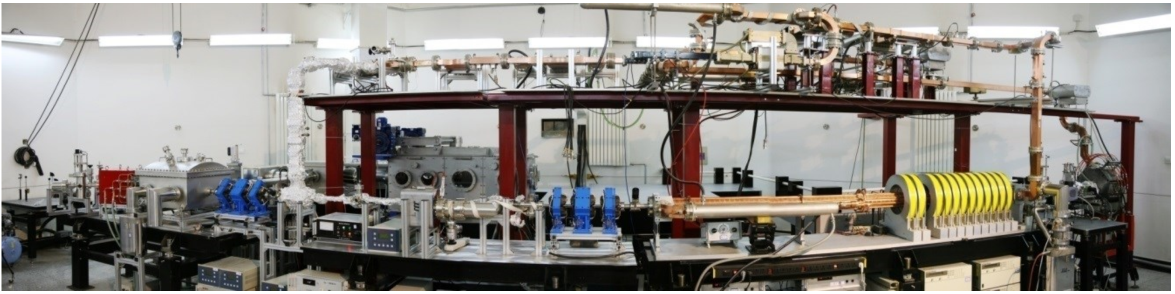
## ➢ RF electron linear accelerator

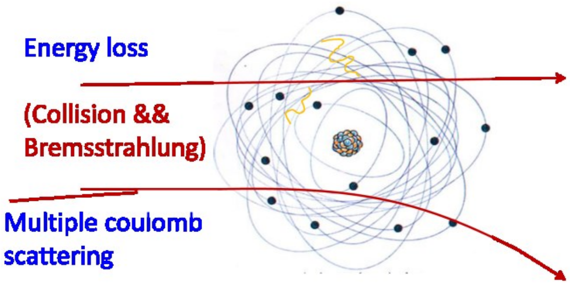
1. RF photocathode Injector physics design and some simulation method
2. Beam dynamics simulation and physics design of electron LINAC
3. To know some basic technology: RF cavity, useful beam diagnostics method, transverse deflecting cavity and others.

## ➢ High energy electron radiography (eRad)

1. Physics of Electron solid target and electron plasma interaction.
2. Some key points of eRad technology : TDS beam split.

**Electron LINAC && Electron Target(solid and plasma) interaction**





# Thanks for your attention