R&D for Linear Induction Accelerator in China

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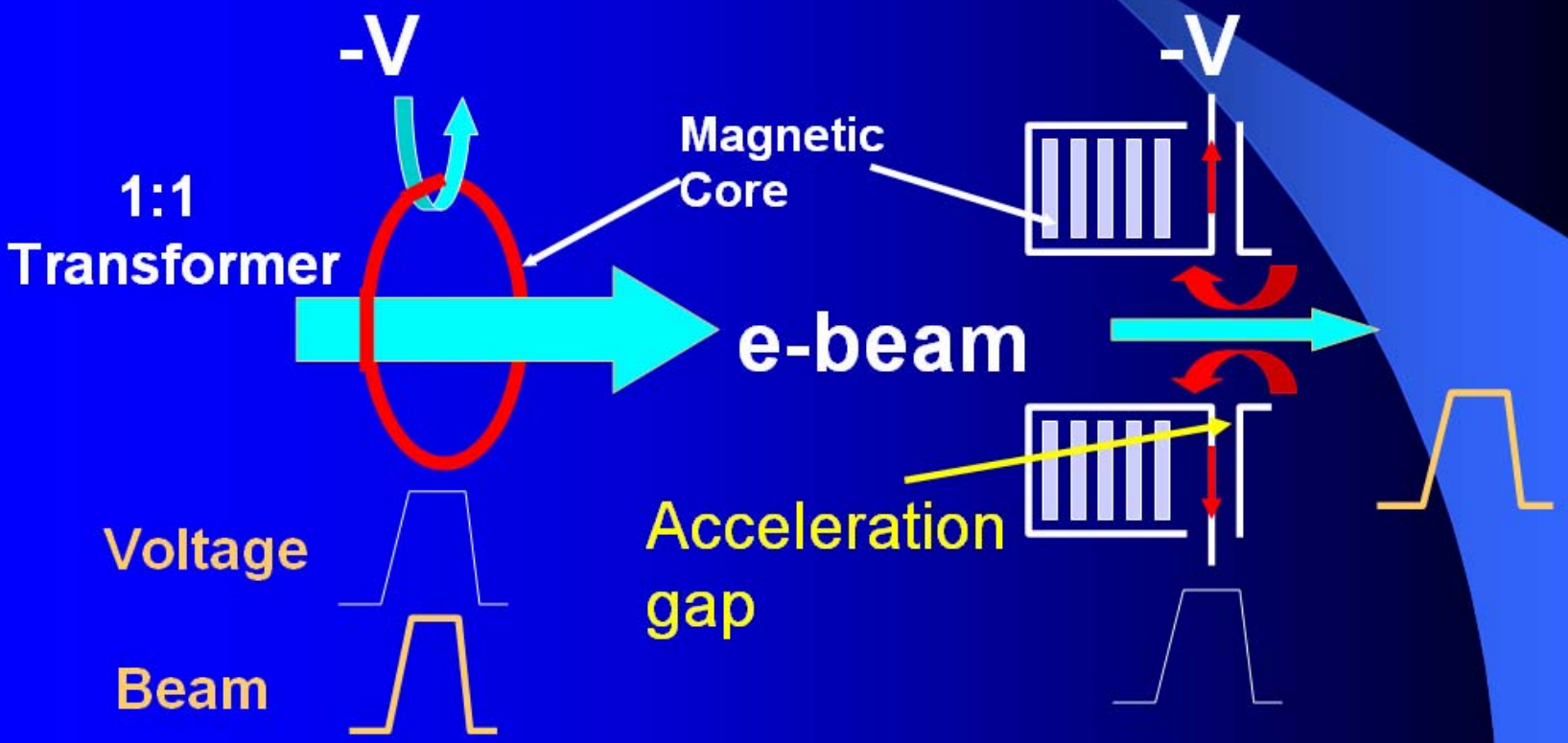
Outline

- Introduction
- R&D of Key Technologies and Components
- Development of Linear Induction Accelerators(LIA)
- Diagnostic Technologies for LIA
- Summary

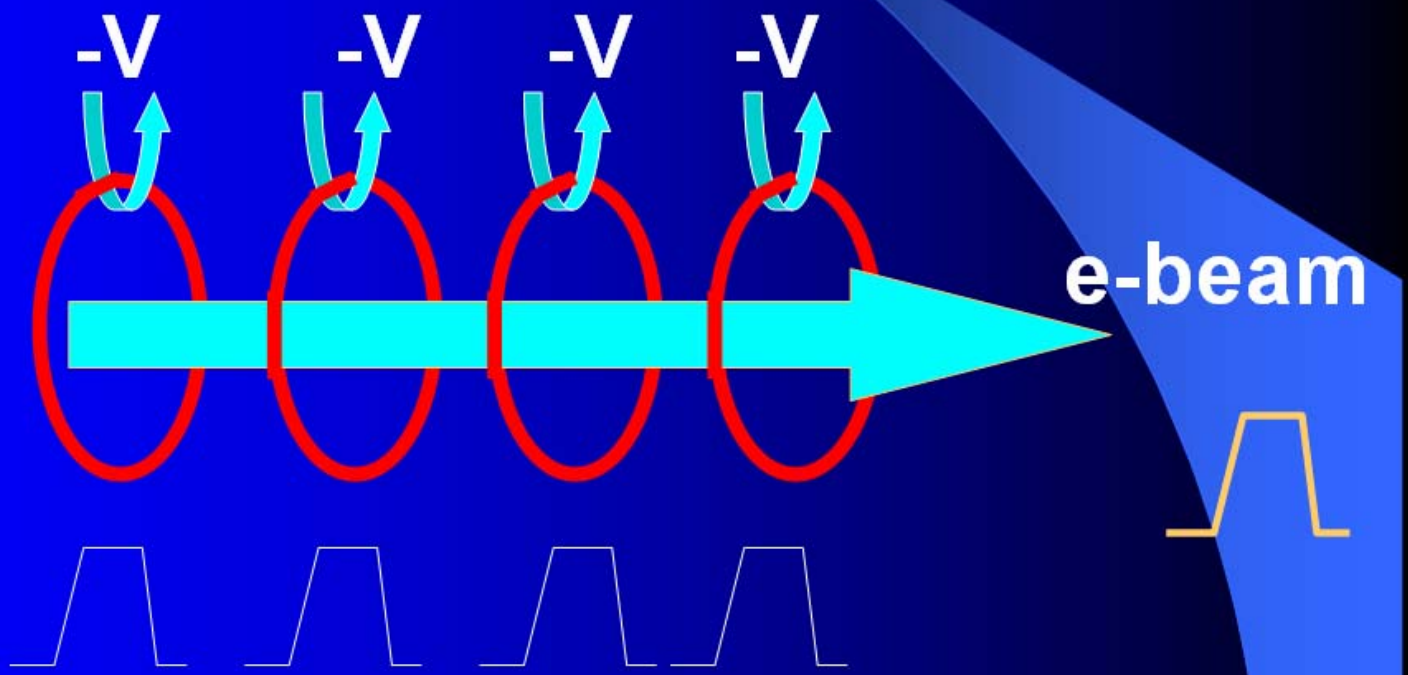
Introduction

Principle of Induction Cavity



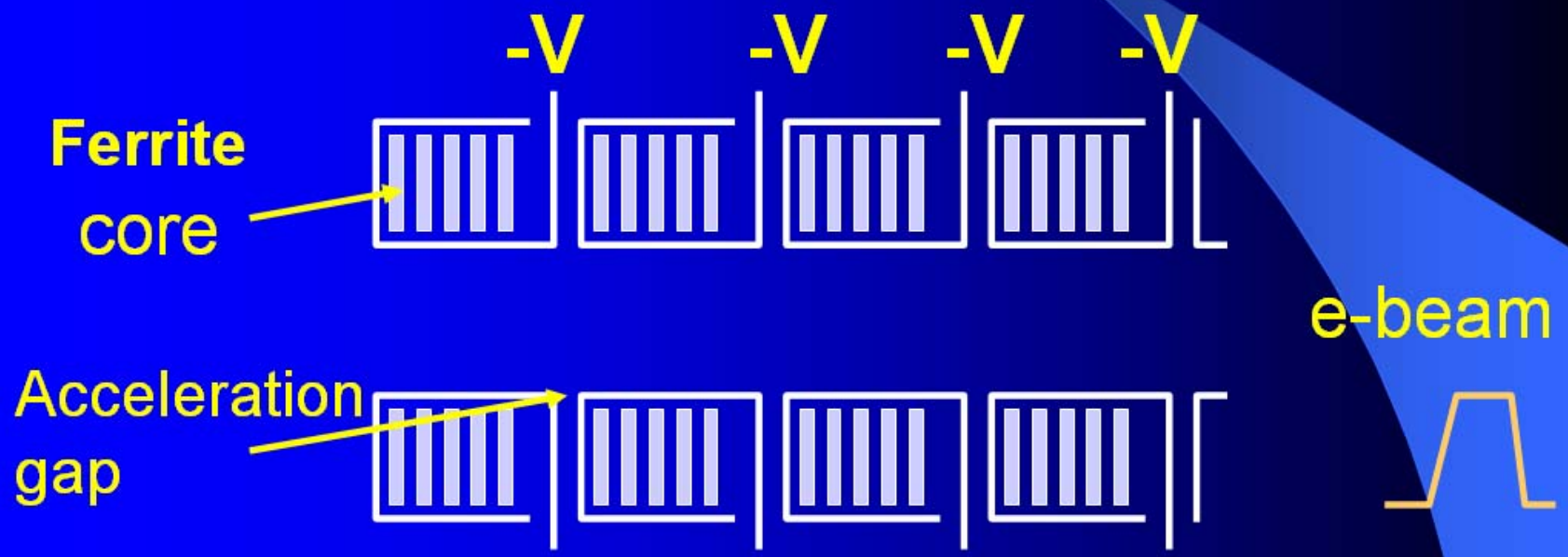
Introduction

Principle of Linear Induction Accelerator



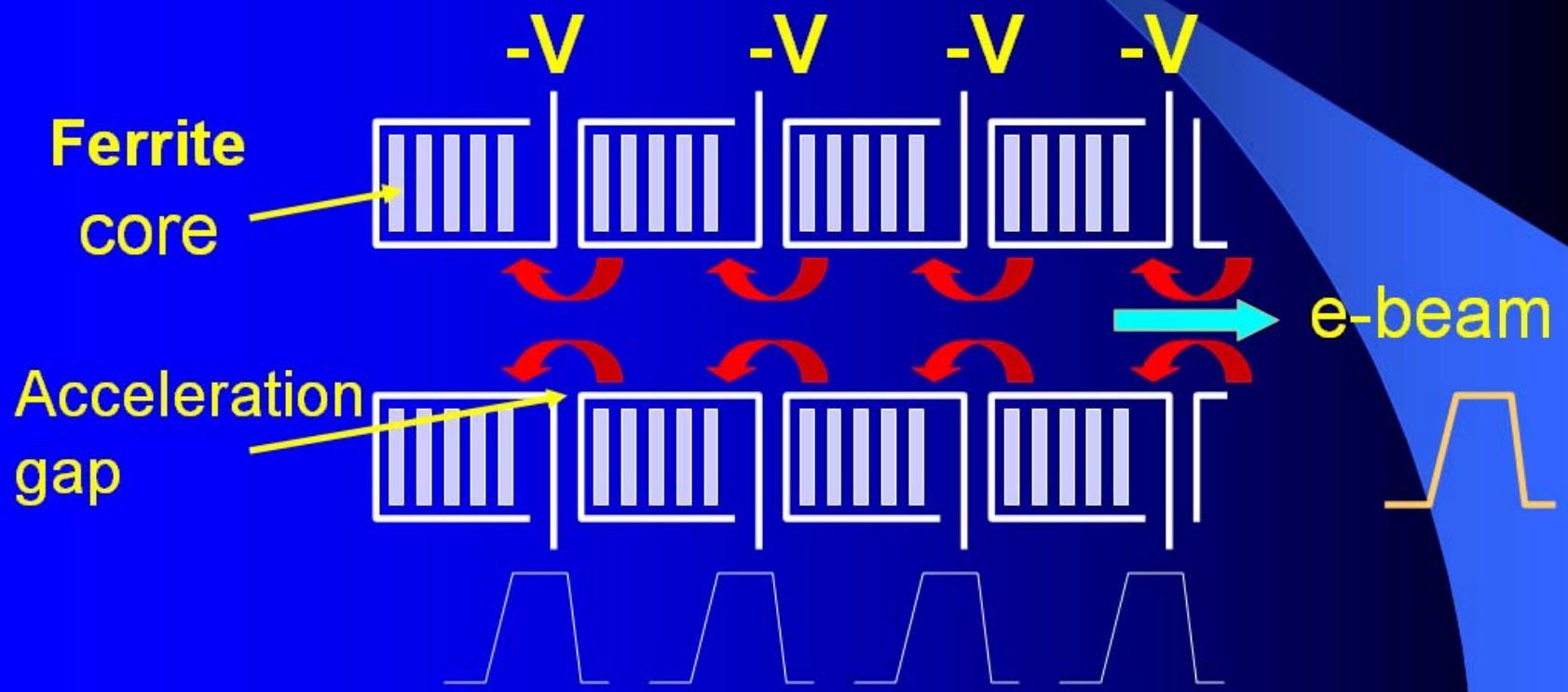
Introduction

Principle of the LIA



Introduction

Principle of the LIA



Introduction

Main Applications of LIA

- Radiography
- Heavy Ion Fusion
- High Power Microwave
- Free Electron Laser

Introduction

R&D for LIA in China

- Began in late 1970's
- Mainly at Institute of Fluid Physics (IFP)
- Tsinghua University Beam physics

Development of Key Tech &Components

❑ Switches Technologies

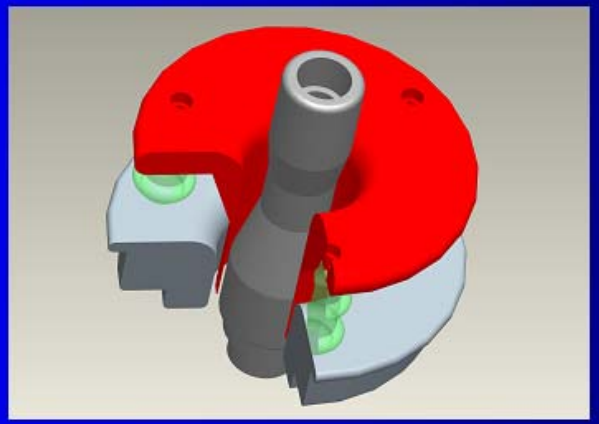
- Coaxial Field-Distortion Spark Gap Switches

Working Voltage: 200kV

Development of Key Tech &Components

❑ Switches Technologies

- Coaxial Cylindrical Field-Distortion Spark Gap Switches



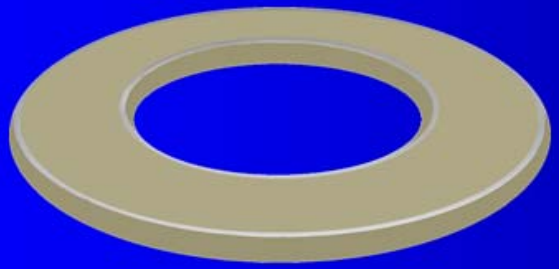
Working Voltage: 200kV~400kV

Development of Key Tech &Components

- Key Components—Ferrite Toroid

Development of Key Tech &Components

❑ Key Components—Metglass Toroid



Serial	Core-size□mm□			Pulsed voltage □kV□	Impulse duration □ns□
	OD	ID	height		
01	504	258	26	300	120
02	678	288	26		
03	696	270	26		
04	808	252	25		
05	1000	548	26		
06	1016	532	26		

Saturation flux density

Bs: 1.5 T

Residual flux density

Br: >1.2 T

OD: up to 1000 mm

Height: 26 mm

Development of Key Tech &Components

- Multi-pulse Technologies for LIA

High rep-rate LIA is of great interest in some applications

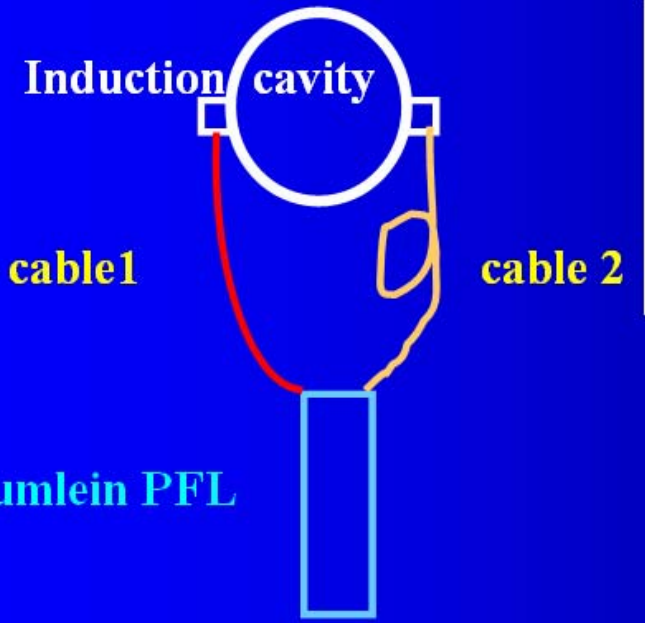
Several novel ideas to generate high rep-rate pulses up to MHz at burst mode have been proposed and studied

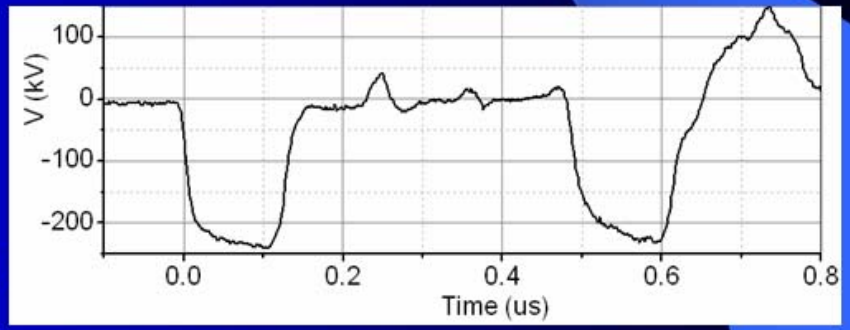
Development of Key Tech &Components

❑ Multi-pulse Technologies for LIA

- Cable Delay Method

Double pulse based on the conventional spark gap switch



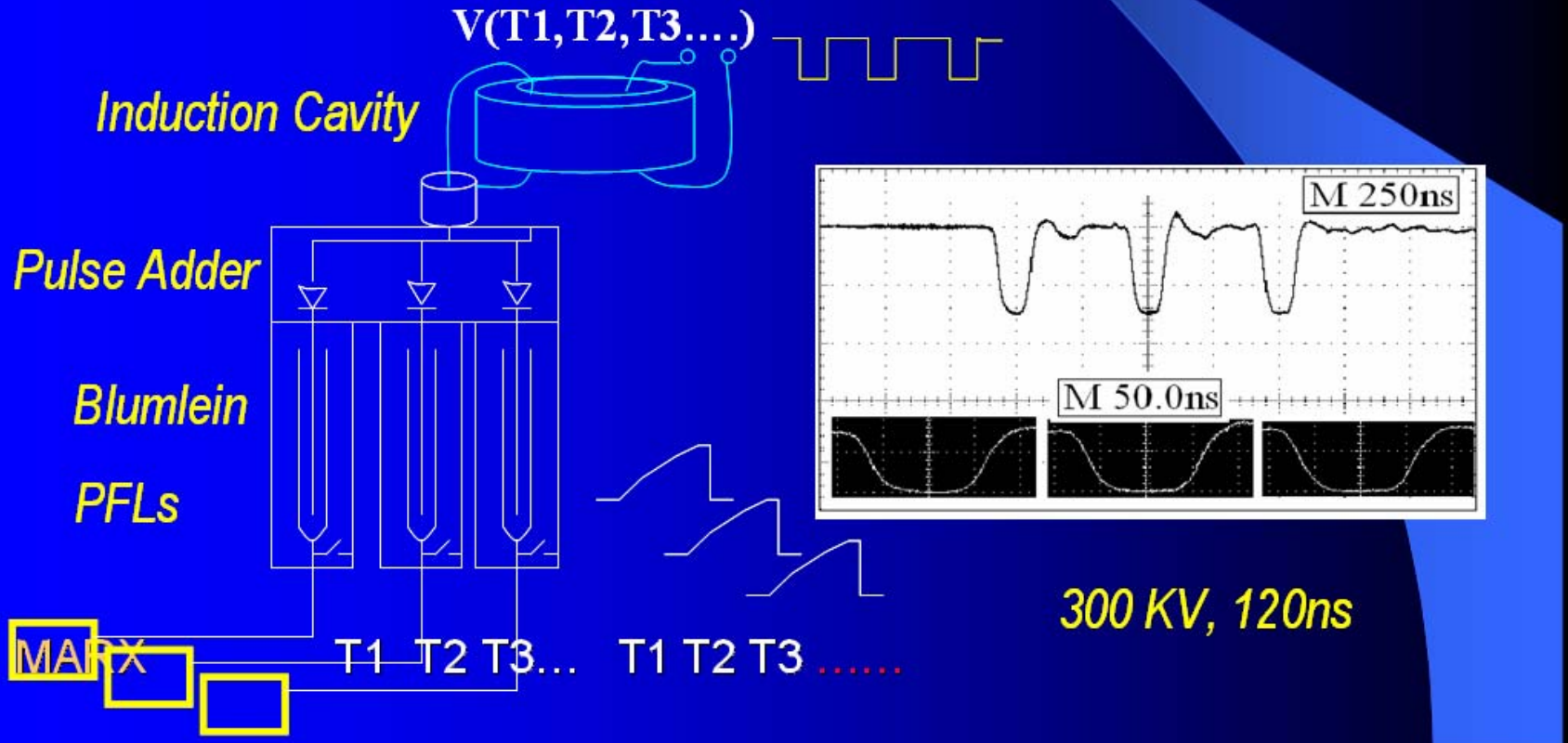


250 KV, 120ns

Development of Key Tech &Components

❑ Multi-pulse Technologies for LIA

- Controlled Pulse adder

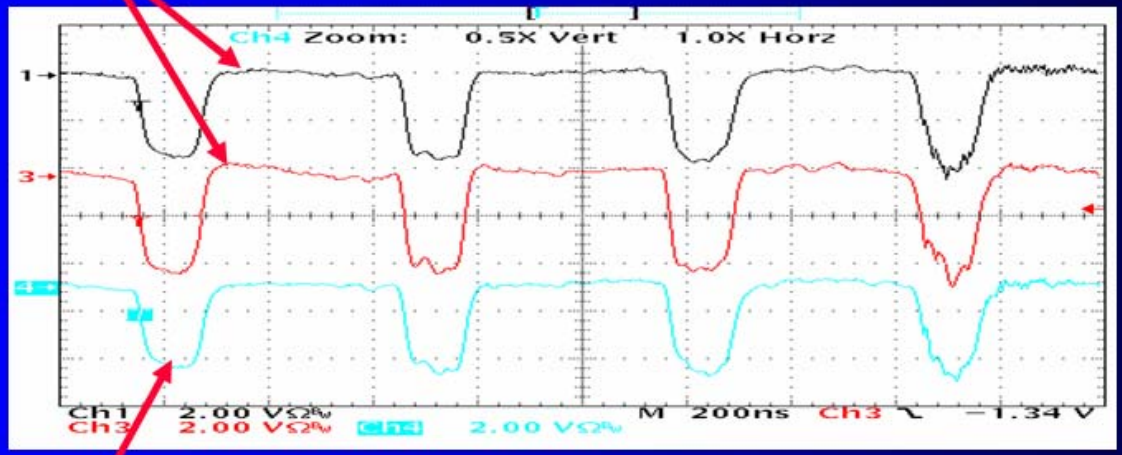


Development of Key Tech &Components

❑ Multi-pulse Technologies for LIA

- **Multi-pulse high power electron beams**

Voltage pulses(CH1.CH2)~500kV



Beam pulses(CH3)~2 kA

Development of Linear Induction Accelerator

- First induction module in 1985
- First LIA in 1988
- SG-I LIA for FEL in 1990
- Linear Induction Accelerator X-ray Facility(LIAXF) in 1993
- Upgraded LIAXF in 1995
- Dragon-I in 2003
- Mini-LIA in 2007

Development of Linear Induction Accelerator

Model	1.5MeV	SG-I LIA	LIAXF	LIAXFU	Dragon-I	MiniLIA
Energy	1.5 MeV	3.5 MeV	10 MeV	12 MeV	20 MeV	240keV
Pulse width	90 ns Single	90 ns Single	60 ns Single	60 ns Single	70 ns Single	80ns Double
Current	3 kA	2 kA	2 kA	2.5 kA	>2.5 kA	1A
Spot Size	-	-	~6 mm	~4 mm	~ 1mm	
Year	1988	1990	1993	1995	2003	2007
Location	IFP	IFP	IFP	IFP	IFP	IFP Tsinghua

Development of Linear Induction Accelerator

- **1.5MeV LIA at IFP**

The first linear induction accelerator in China

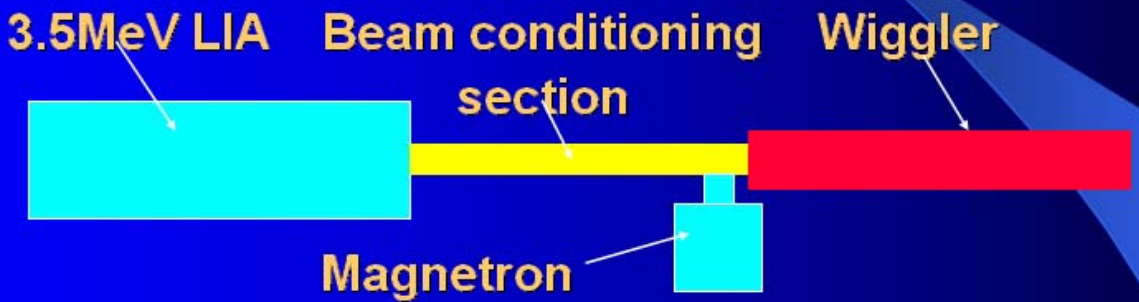
1.5MeV LIA: 1.5MeV, 3kA, 60ns

Injector: 1MeV, -1MV inductive Adder

Post Acceleration: 2 cavities

Development of Linear Induction Accelerator

- SG-I LIA for Free Electron Laser at IFP



SG-I LIA: 3.5MeV, 2kA, 60ns

1MeV injector, 8 accelerating cavities

Output Power of FEL: 140MW

Power gain: 26 db/m

Frequency: 34.6 GHz

Development of Linear Induction Accelerator

- Linear Induction Accelerator X-ray Facility (LIAXF)

  10MeV,2kA,60ns, ~6mm spot size

  Injector: 1MeV, -1MV inductive Adder

  Accelerating section: 28 cavities

Upgraded

Add 4 cavities

Other improvements

- Upgraded LIAXF (LIAXFU)

  12MeV,2.5kA,60ns, ~4mm spot size

  Accelerating section: 32 cavities

Development of Linear Induction Accelerator

- Dragon-I LIA

  20MeV,2.5kA,70ns,~1mm spot size

  Injector: 3.5MeV, 2.7kA ,90ns

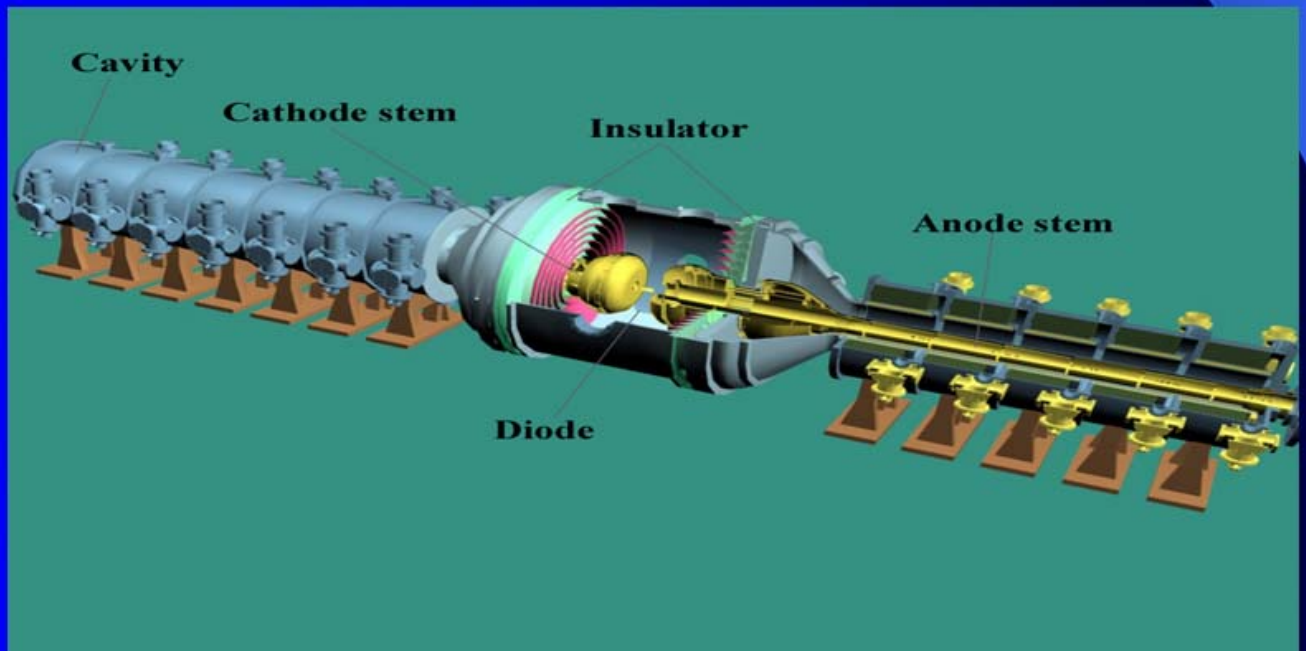
  -2.1MV inductive Adder

Development of Linear Induction Accelerator

- Dragon-I LIA

  20MeV,2.5kA,70ns,~1mm spot size

  Injector: 3.5MeV, 2.7kA ,90ns



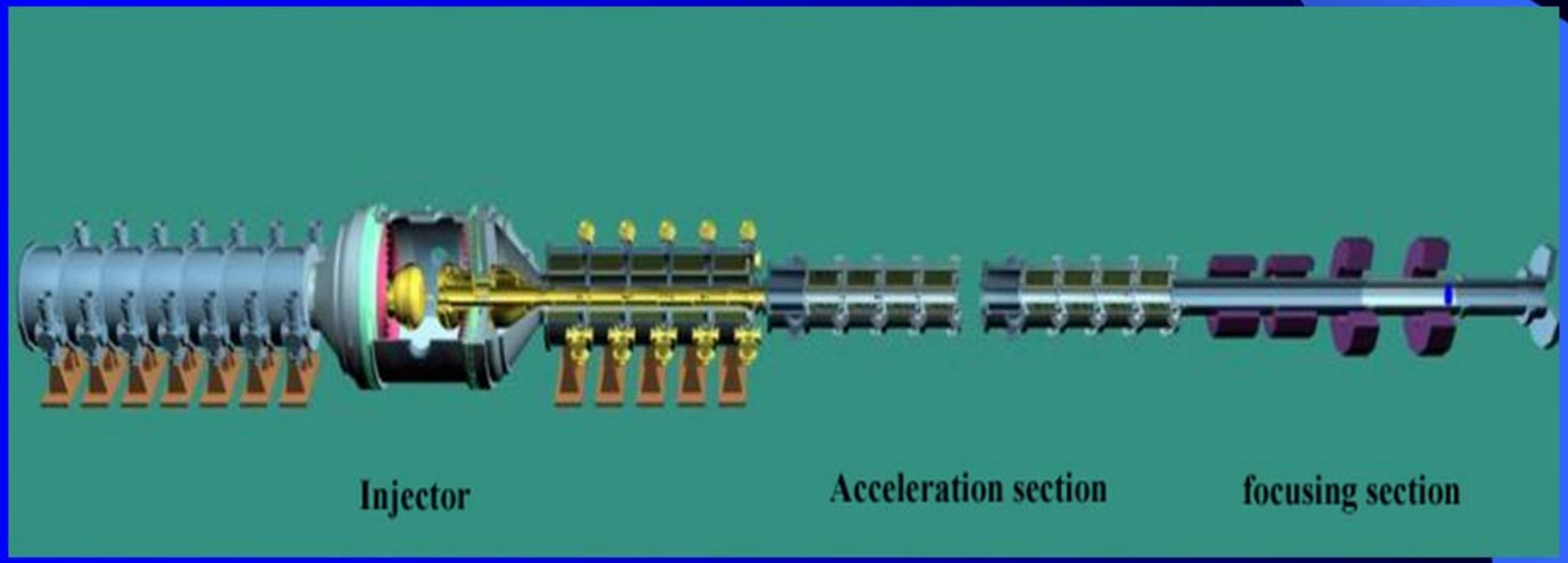
Development of Linear Induction Accelerator

- **Dragon-I LIA**

  20MeV,2.5kA,70ns,~1mm spot size

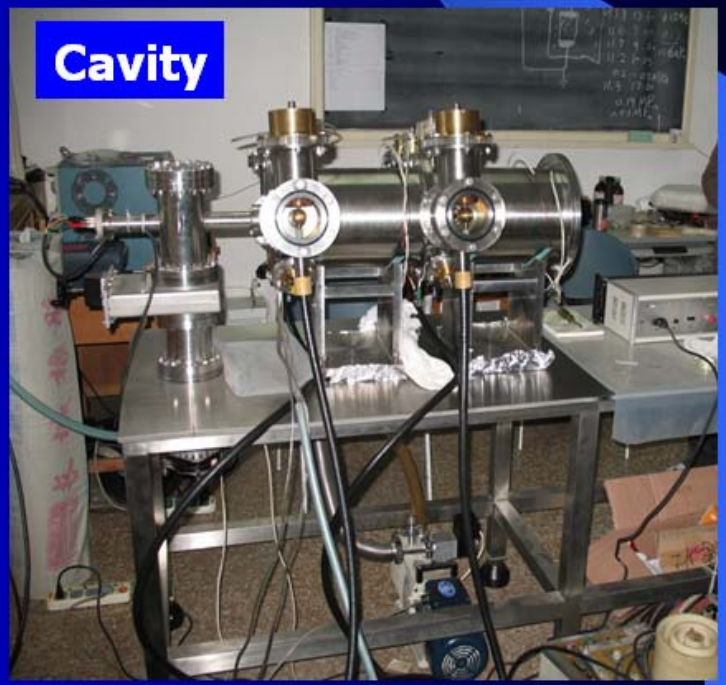
  Accelerating section: 72 cavities

  Each cavity: 250kV, 120ns



Development of Linear Induction Accelerator

- MiniLIA (Double-pulse electron beams)
  - -- 80keV ,1A injector
  - -- 2X80kV induction cavities



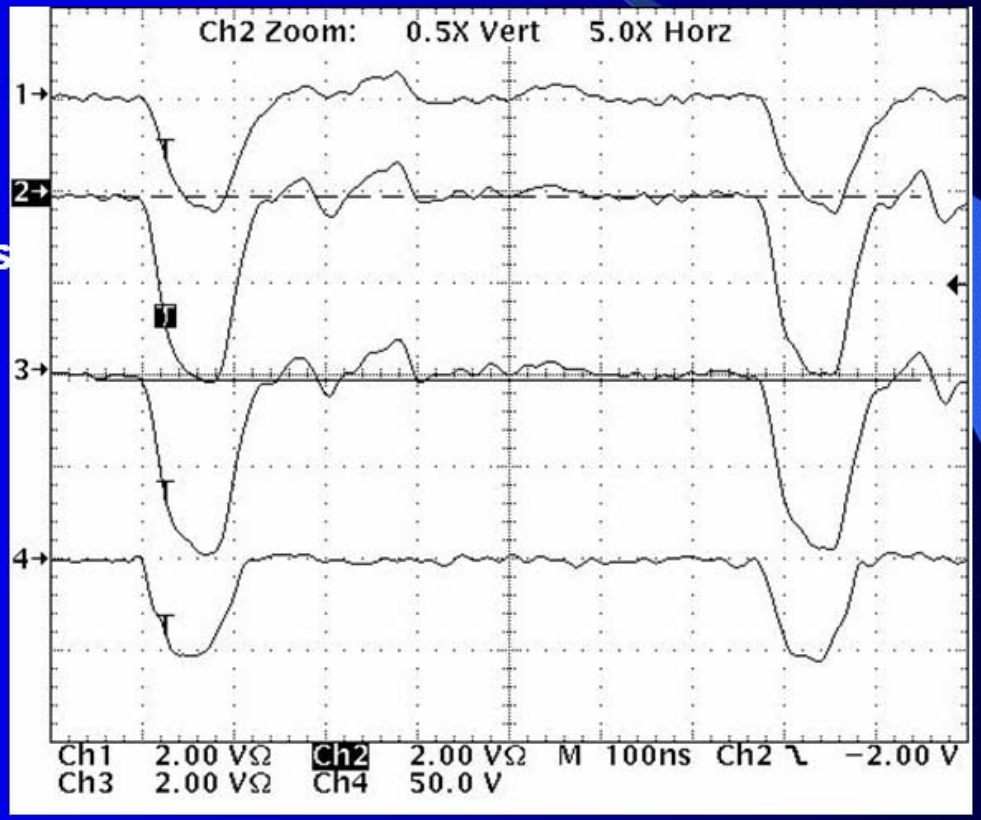
Development of Linear Induction Accelerator

- MiniLIA(Double-pulse electron beams)

Injector current

Acceleration pulses

Beam pulses



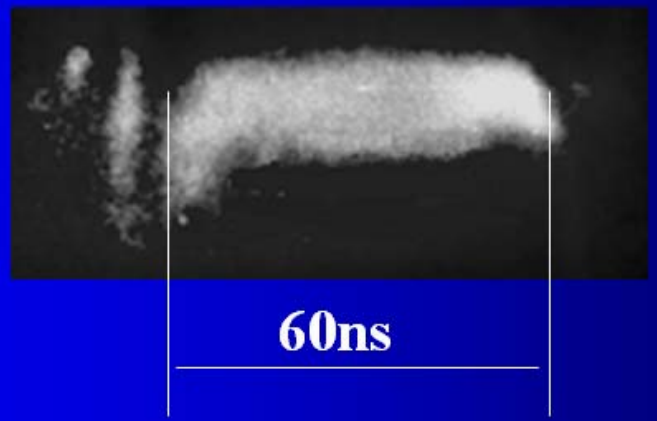
Diagnostic Technologies for LIA

- Beam current and emittance measurement
- Beam Position Monitor
- Diamagnetic Loop Diagnoses Method

Diagnostic Technologies for LIA

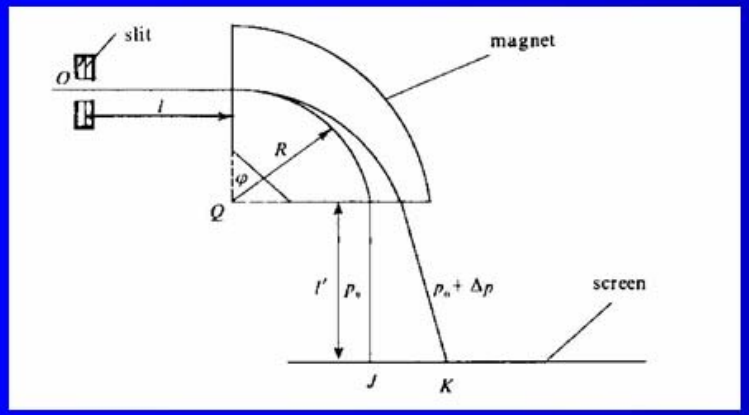
- Time-resolved beam envelop measurement

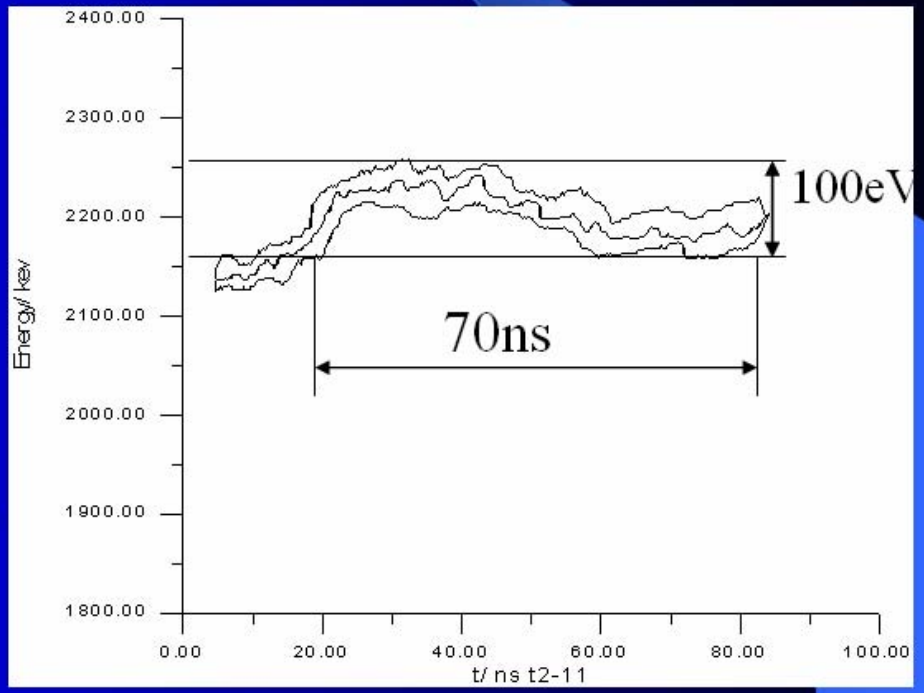
  Cerenkov Radiation with Streak Camera



Diagnostic Technologies for LIA

- **Time-resolved beam energy measurement**
  Cerenkov Radiation with Streak Camera

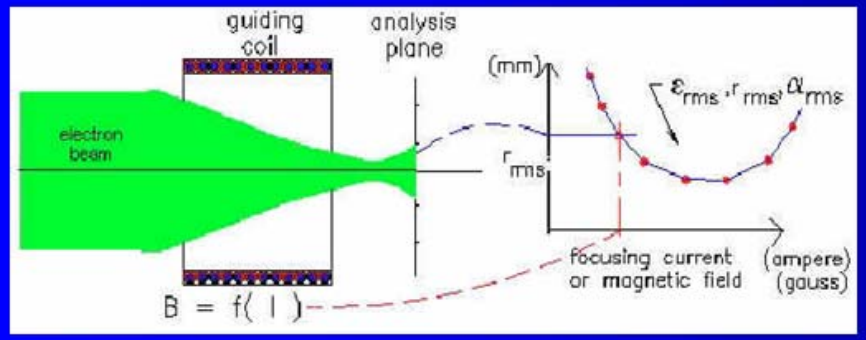




Diagnostic Technologies for LIA

- **Time-resolved beam emittance measurement**

  Cerenkov Radiation with streak camera



$$R'' + \frac{k^2}{4}R - \frac{K}{R} - \frac{\varepsilon^2}{\beta^2\gamma^2 R^3} = 0$$

$$K = \frac{2I}{17.045\beta^3\gamma^3} \qquad k = \frac{ecB_z}{\beta\gamma mc^2}$$

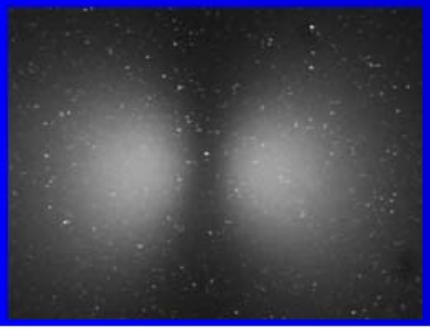
$$R(t) - - - \varepsilon(t)$$

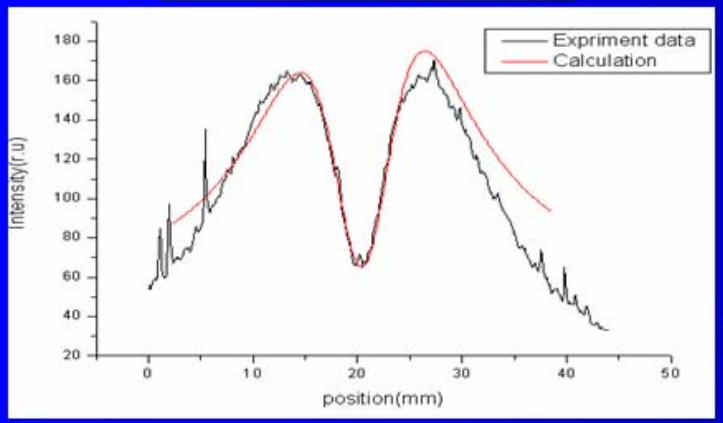
Normalized edge emittance 2060π.mm.mrad.

Diagnostic Technologies for LIA

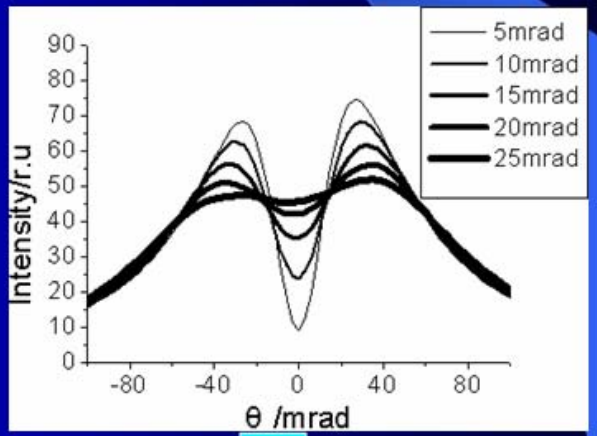
- **Time-resolved beam emittance measurement**

  Optical Transition Radiation(OTR) with frame camera





Distribution of OTR at different divergence angles of beam at energy of 20MeV

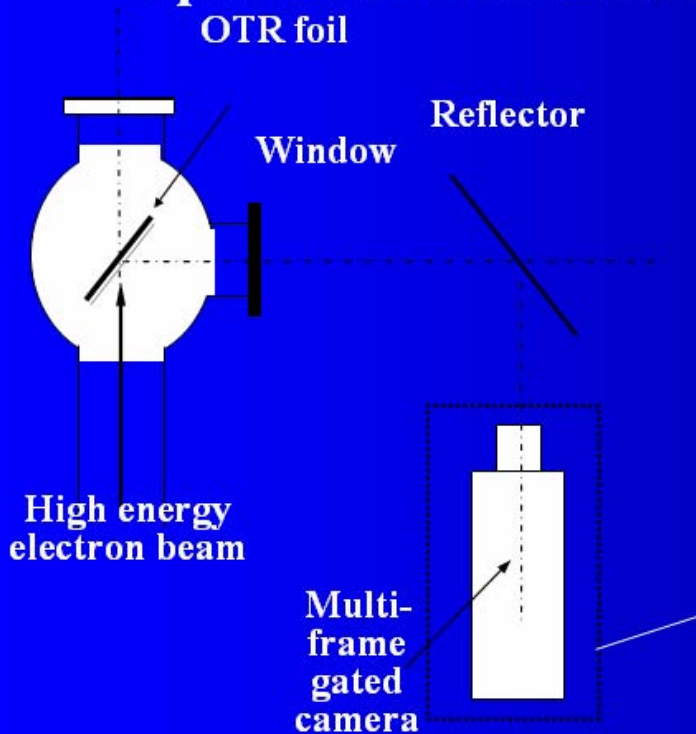


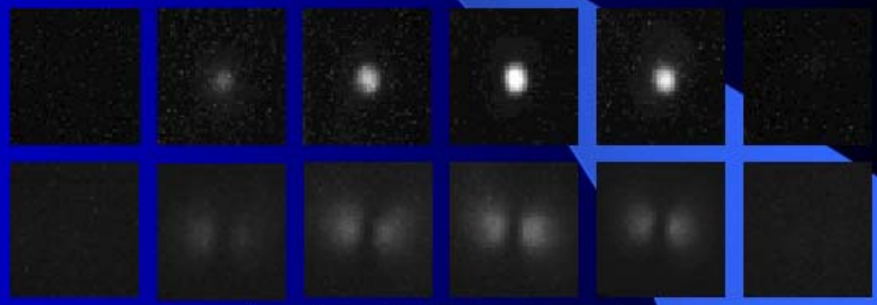
Integrated emittance 2935π.mm.mrad.

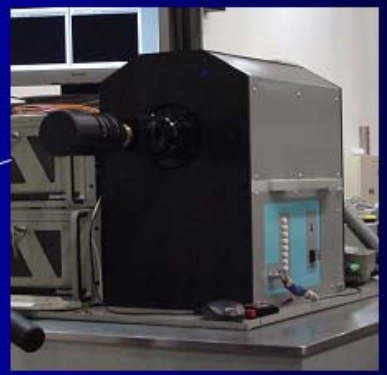
Diagnostic Technologies for LIA

- **Time-resolved beam centroid measurement**

Optical Transition Radiation (OTR) with frame camera



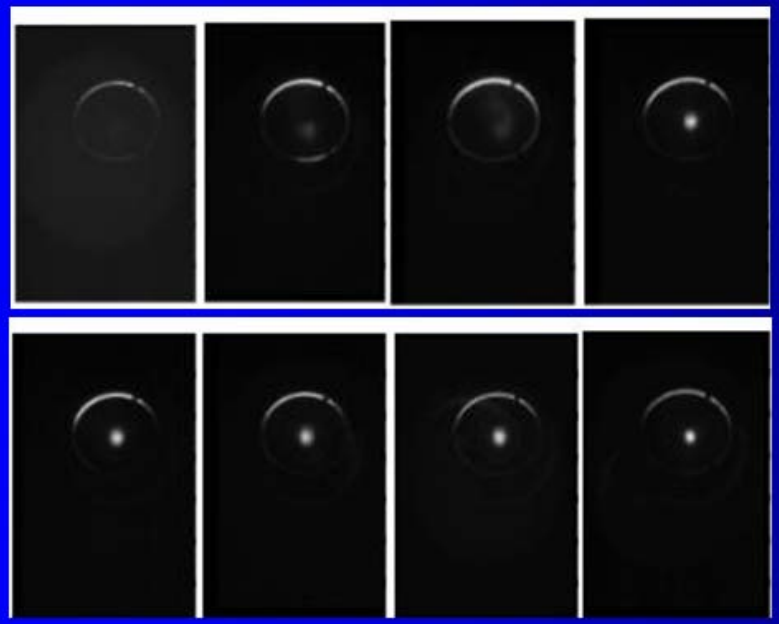




Diagnostic Technologies for LIA

- **Time-resolved beam centroid measurement**

  Cerenkov Radiation with frame camera



Exposure time: 3ns

Time interval: 10ns

The variation of the beam centroid during the flat-top is in the range of 0.5 mm

Summary

The research activities for development of linear induction accelerator in China in the past thirty years are overviewed .

The history of LIA development in China and most recent progresses have been introduced.

Some results of the Dragon-I LIA are also presented