レーザー核融合におけるプラズマ診断

～爆縮燃料プラズマ計測を中心として～

白神 宏之

大阪大学レーザーエネルギー学研究センター

ILE OSAKA

第18回若手科学者によるプラズマ研究会

日本原子力研究開発機構 那珂核融合研究所
2015年3月4日

Abstract

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　レーザー核融合では微小（0.5〜5 mmϕ）な燃料ターゲットを、レーザー光照射による爆縮という手法で高密度に圧縮し、短時間の内に核融合反応を起こそうという方法である。従って、爆縮された核融合燃料プラズマは、さらに微小（100μmオーダー）かつ高速（100 psオーダー）となり、その診断技術には高時間空間同時分解が要求される場合が多い。また、近年になって展開している高速点火核融合では、爆縮後に燃料を加熱するために注入照射される超高強度レーザーとプラズマの相互作用で大量のX線（MeV領域にあるのでγ線と呼んでも良い）が発生し、これがX線・中性子計測には強烈なノイズ源となる過酷環境下でのプラズマ診断が要求される[1]。

　燃料プラズマのダイナミクスを観測するために、高時間空間分解X線分光画像計測法を開発してきた[2]。これは超高速（時間分解能2〜10 ps）のX線ストリークカメラに画像サンプリング技術を応用したもので、これにより、爆縮燃料プラズマの形成過程、非一様性、球対象爆縮シミュレーションとの差異の比較などの観測が可能となった。

　爆縮の基礎過程であるターゲットのアブレーション加速時の研究においては、X線バックライト法が用いられる。これは平板ターゲットを正面や横方向からX線の影絵により時間空間分解撮影する手法[3]で、レイリーテイラー不安定性などの物理解明に貢献した[4]。

核融合中性子の計測に関しては、上記の過酷環境下での稼働に耐えうるため、超高速の液体シンチレータ[5]を、また、微弱な散乱中性子信号を捉えるためにLiドープシンチレータを開発した。これらはシングルヒットToF法により使用される。さらに、液体シンチレータとゲートCCDカメラの組み合わせにより中性子画像計測を可能とした。

　講演では、これらの診断技術と測定結果の例を紹介する。

[1] H. Shiraga, *et al.*, IAEA/FEC2014, IFE/P6-2 (2014); Y. Arikawa, *et al.*, RSI 83, 10D909 (2012).
[2] H. Shraga, *et al.*, RSI **75**, 3921 (2004) , and references there in.
[3] H. Shiraga *et al.*, RSI **74**, 2194 (2003).
[4] H. Azechi, *et al.*, PRL 98, 045002 (2007).
[5] T. Nagai, *et al.*, Jpn. J. Appl. Phys. 50, 080208 (2011).

Project members:

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H. Shiraga, S. Fujioka, M. Nakai, T. Watari, H. Nakamura, Y. Arikawa, H. Hosoda, T. Nagai, T. Nagai, Y. Abe, K. Ishihara, S. Kojima, S. Sakata, M. Taga, T. Ikenouchi, H. Inoue, T. Utsugi, S. Hattori, H. Lee, M. Koga, H. Kikuchi, Y. Ishii, T. Sogo, K. Shigemori, H. Nishimura, Z. Zhang, M. Tanabe, S. Ohira, Y. Fujii, T. Namimoto, Y. Sakawa, O. Maegawa, K. Shimada, H. Nagatomo, M. Murakami, T. Norimatsu, H. Homma, Y. Fujimoto, N. Miyanaga, J. Kawanaka, T. Jitsuno, Y. Nakata, K. Tsubakimoto, N. Morio, T. Kawasaki, K. Sawai, K. Tsuji, H. Murakami, N. Sarukura, T. Shimizu, K. Mima, and H. Azechi

(ILE, Osaka University)

H. Sakagami, T. Ozaki, A. Iwamoto, M. Hata, T. Yanagawa

(NIFS)

T. Johzaki *(Hiroshima University)*
A.Sunahara *(Institute for Laser Technology)*
T. Taguchi *(Setsunan University)*
T. Kanabe *(Fukui University)*
K. Kondo *(JAEA-KPSI)*
M. Key *(LLNL)*
P. Norreys *(Rutherford Appleton Lab)*
J. Pasley *(University of York)*

Contents of the talk

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1. **FIREX project**
   Fast Ignition research
   Experiments with LFEX laser

2. **Ultra-fast X-ray imaging diagnostics**
   Sampling-image x-ray streak camera

3. **Hard x-ray and EMP harsh environment**
   X-ray framing cameras
   X-ray streak cameras

4. **Neutron diagnostics**
   Neutron detectors in (γ, n) environment
   Scattered neutron measurement
   Time-resolved neutron imaging

5. **Summary**

1. FIREX, Fast Ignition Realization Exp’t

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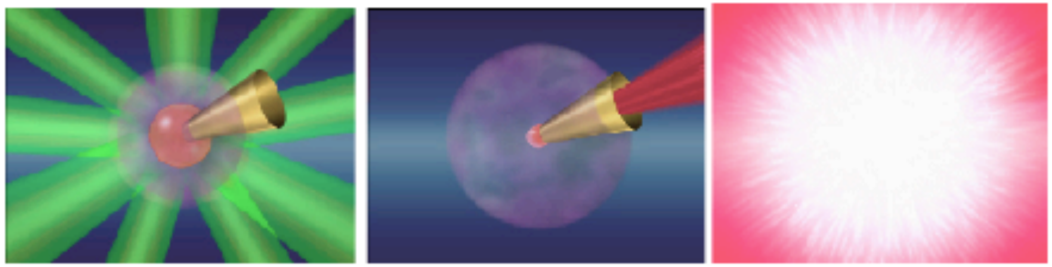
Implosion　Fast Heating　Ignition/Burn

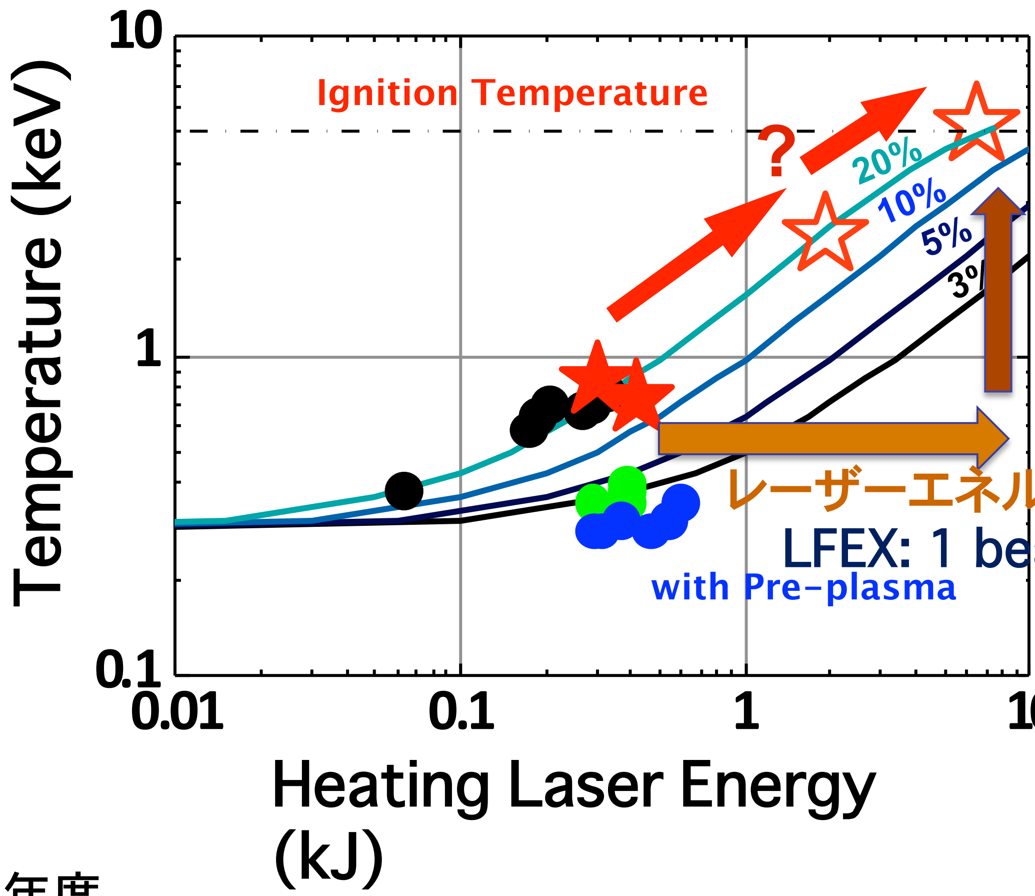


- preliminary: Demo of 600 times liquid density
  Demo of 1 keV temp. by 1kJ/1ps.

- FIREX-I : Demo of 5-10 keV temperature by 10kJ/10ps.

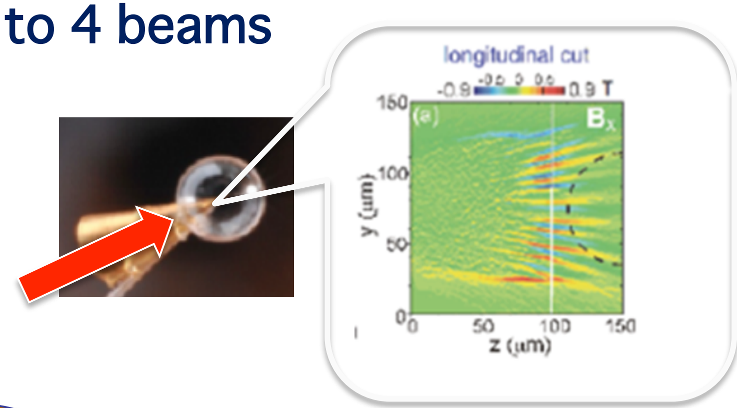
- FIREX-II: Demo of ignition and burn by FI

点火温度へのアプローチ



加熱効率の向上
Cool REB
Guided REB

レーザーエネルギーの増大
LFEX: 1 beam to 4 beams



年度
2013
2014　4ビーム完成　　　　加熱の基礎
2015　　　　　　　　加熱スケーリング
2016　チェックアンドレビュー 5-keV 加熱

レーザーエネルギーの増大

加熱効率の向上

Integrated experiment of Fast Ignition

Cone-attached surrogate fuel capsules were compressed by GEKKO-XII and heated by LFEX lasers

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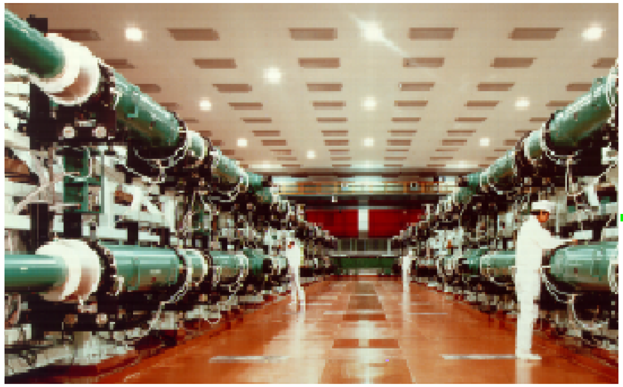
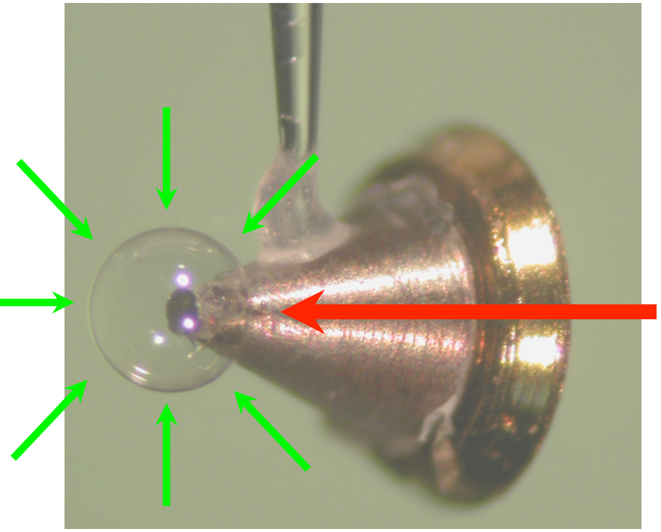
Compression Laser: GEKKO-XII



Beam# 9/12 beams
Energy 250-350 J/beam (2.5 kJ total)
Duration 1.5 ns (Flat top)
Wavelength 527 nm

Fusion Fuel Target



<u>Shell</u>
Diameter 500 μm
Thickness 7 μm
Material CD plastic
<u>Cone</u>
Angle 45 deg.
Material Gold, DLC, etc

Heating Laser: LFEX

Beam# 4 beam
Energy 200 ~ 3000 J

Duration 1.0 - 4 ps
Wavelength 1053 nm

激光XII号レーザー & LFEXレーザー

LFEX laser completed in 2008

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LFEX:10kJ/1ps=10PW GXII: 10kJ/1ns=10TW

LFEX laser – construction, tuning & exp't

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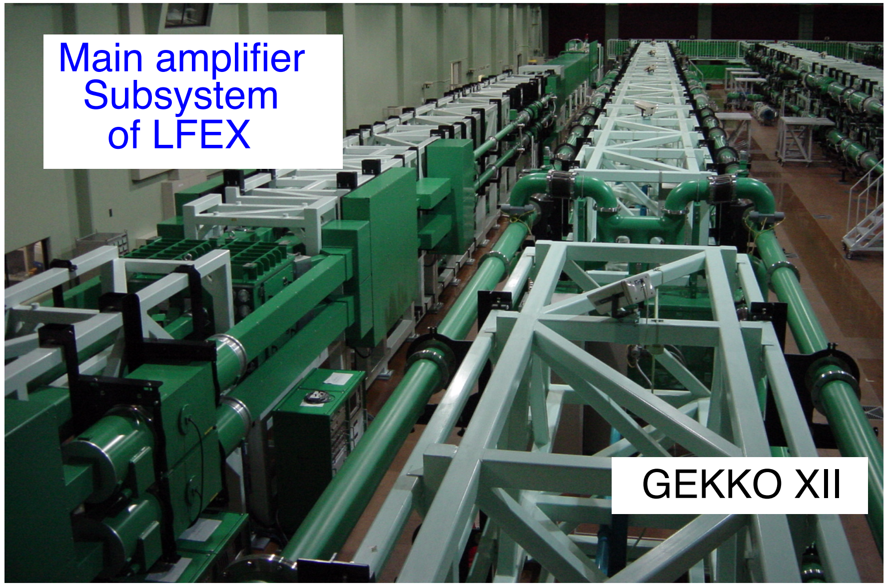

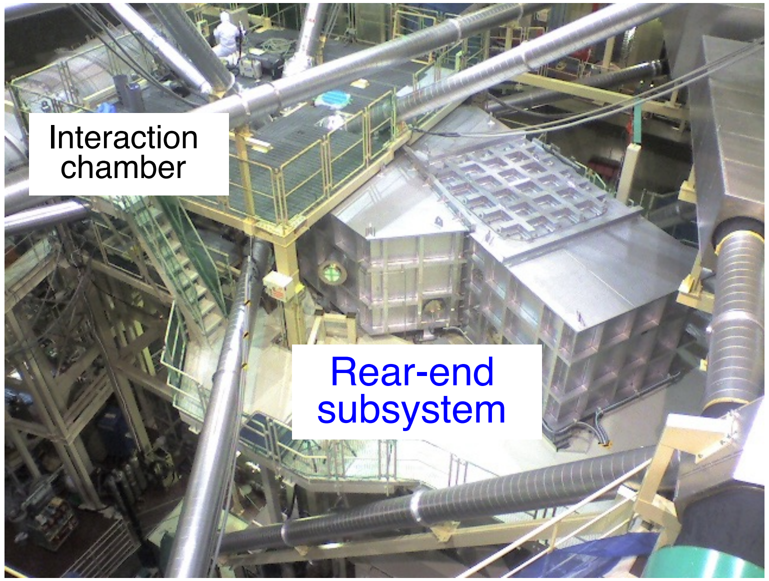

Nov, 2008	**Precision alignment of pulse compressor**
Dec, 2008	***Target irradiation with high-power beam started***
Feb, 2009	***Irradiation of Fast Ignition (FI) target started***
Sept, 2009	***FI integrated experiment (1 ps) / 1 beam***
Aug, 2010	***FI integrated experiment (1 ps) / 2 beams***
Nov, 2014	***FI physics experiment (1 ps) / 4 beams***
2015 – 2016	***Fuel temperature of 5 keV***

⇦ **3.11**

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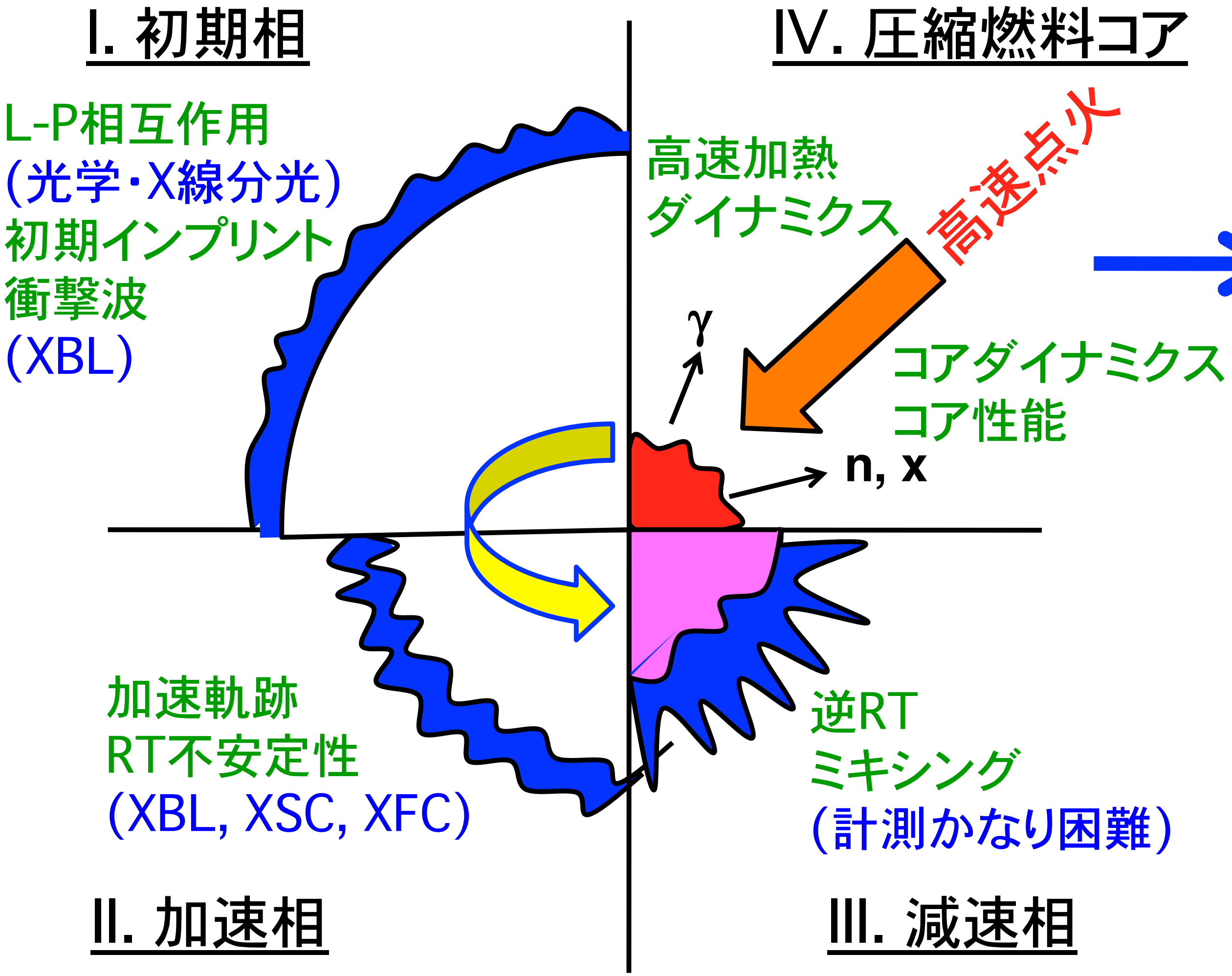

超高速分光X線画像
X線, γ線分光
電子分光
中性子イールド
中性子分光(ToF)
中性子分光画像(ToF)

困難
・高速
・微小
・不透明(高密度)
・γ,n過酷環境

爆縮コア計測について：
超高分解プラズマ診断が求められている

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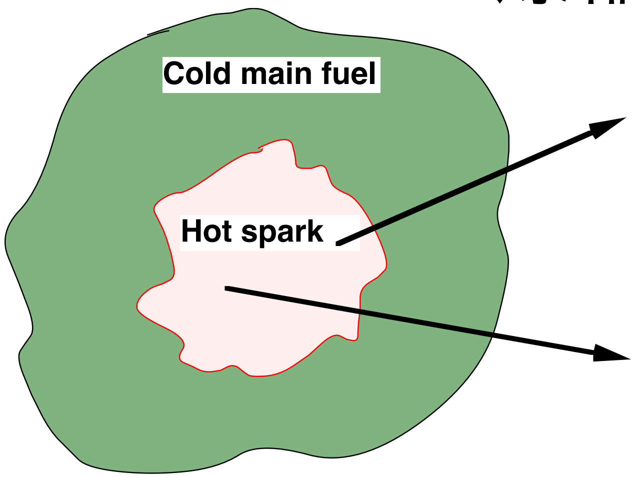
ICF爆縮プラズマの特徴



X rays : Fast 2-D imaging → MIXS, 2D-SIXS

Fast 2-D spectroscopy → McMIXS, M-MIXS

Neutrons : Yield, Burn history, Imaging, Spectroscopy

Typical core size : ＜100 μm
life time : 100 ps

Time- and space- resolved measurements are required.

Δr ＜ 10 μm
Δ t = 10 ps

速い　：コア寿命　～100ps　→Δt=10ps必要
小さい：コアサイズ　～100μm　→Δr=10μs必要
不透明　：高エネルギーX線、中性子計測が重要
γ, n 過酷環境：遮蔽、コリメーション

2. Ultra-Fast X-Ray Imaging is essential

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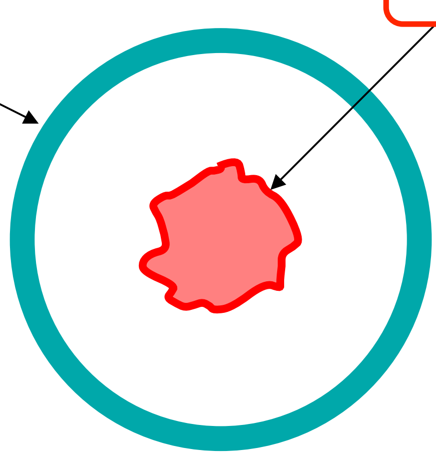
Ultrafast x-ray imaging is needed for ICF research.

Imploding shell

~ ns

~ several 100 μm

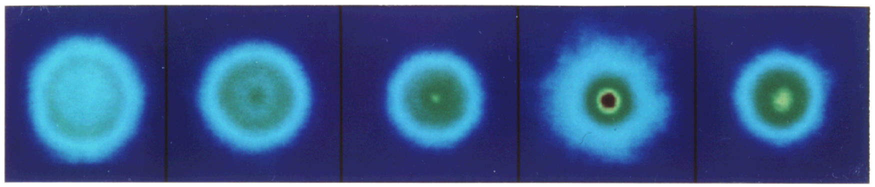


Imploded core

~ 100 ps

~ several 10 μm

X-ray framing camera
with gated MCP
(40-80 ps resolution)



<10 ps imaging is required for observation of core dynamics.

Ultrafast imaging by x-ray streak camera

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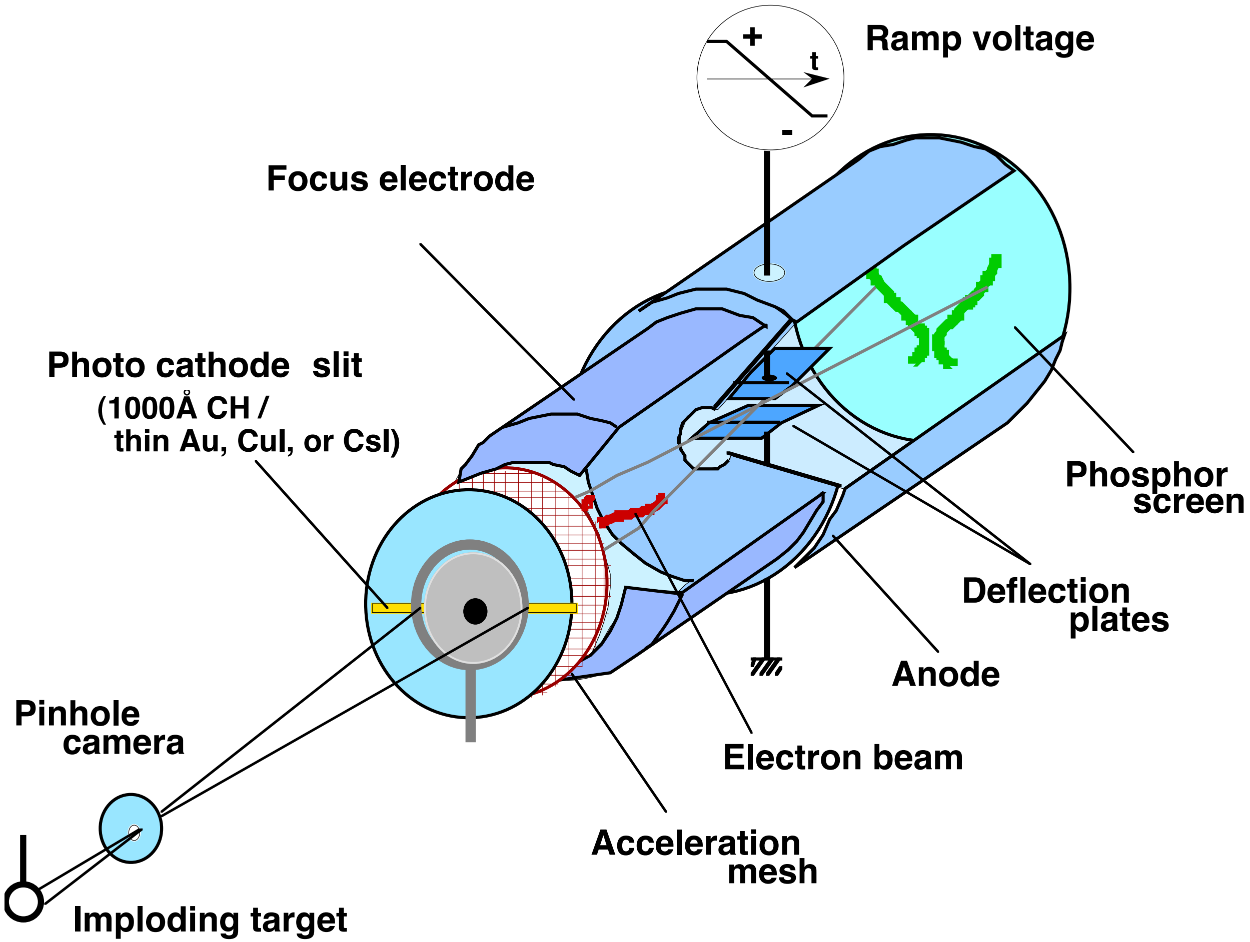
So far, only x-ray streak cameras have resolutions < 10 ps.
However, in conventional use, only 1D imaging is available.



→ We need a trick to use it for 2D imaging.

Image sampling is essential for 2D imaging on a streak camera

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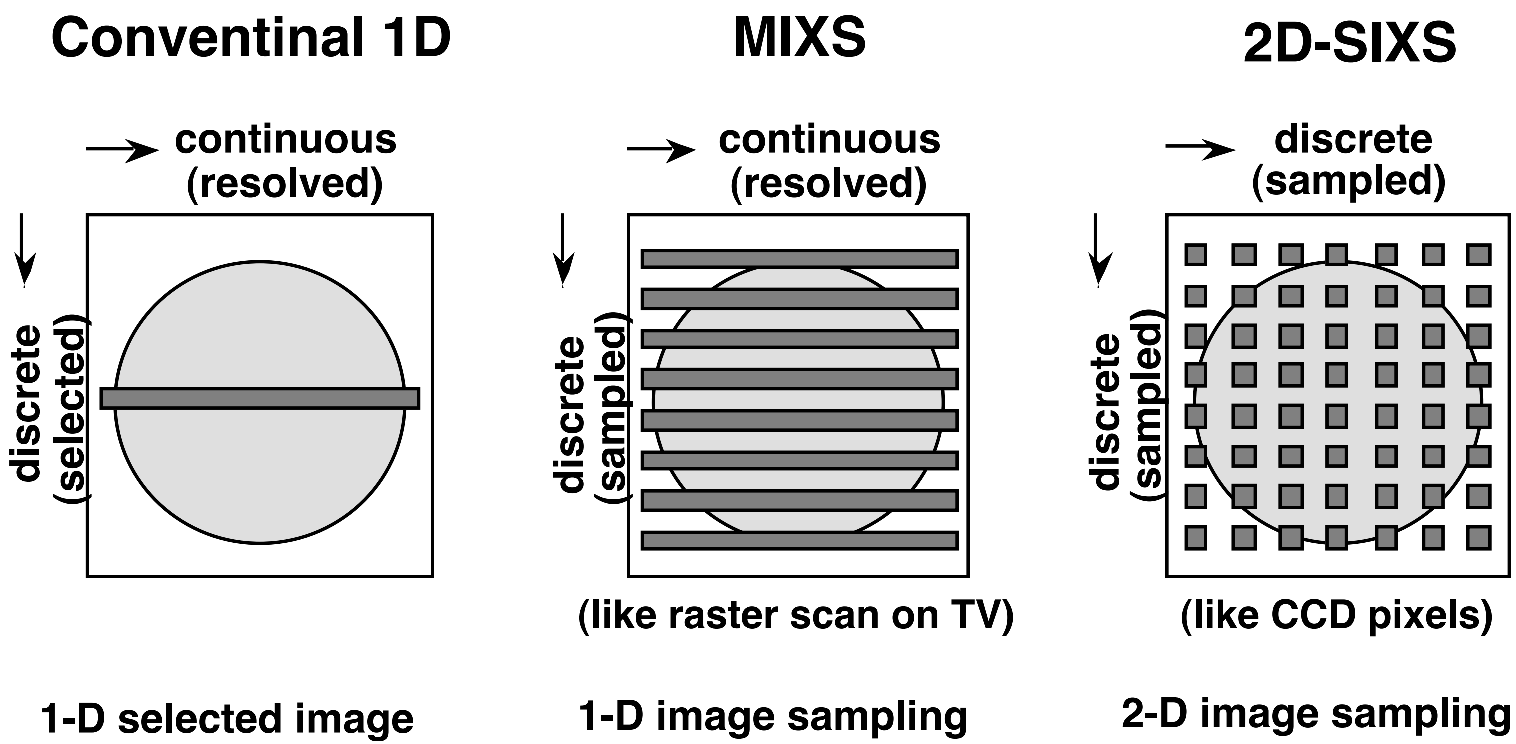


Many types of efforts have been made to demonstrate 2D imaging on a streak camera.
--- How to avoid overlapping of the data when streaked?

H. Shraga, *et al.*, RSI 75, 3921 (2004) , and references there in.

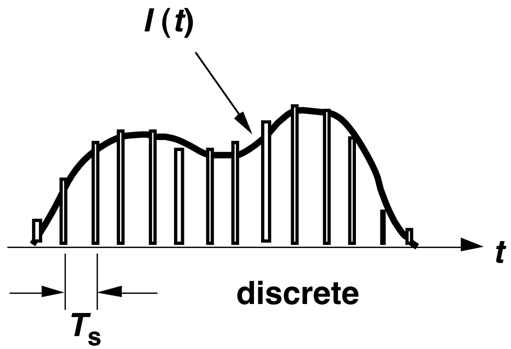
Sampling on single image / repetitive signal

Single signal

Repetitive signal

Waveform

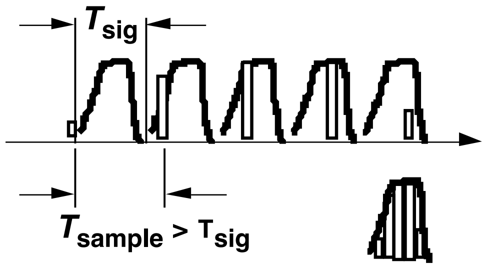
Waveform sampling



$T_s \leqq (1/2)\Delta t$

Ex. Sampling oscilloscope

Sampling on repetitive signal

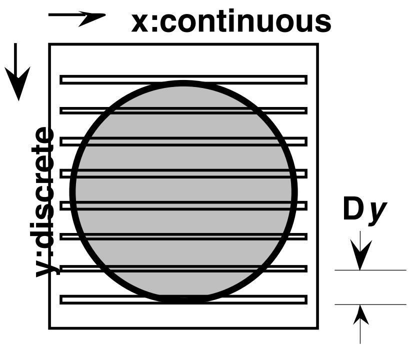


Reconstructed waveform

2D image

1-D image sampling

(Sultanoff)

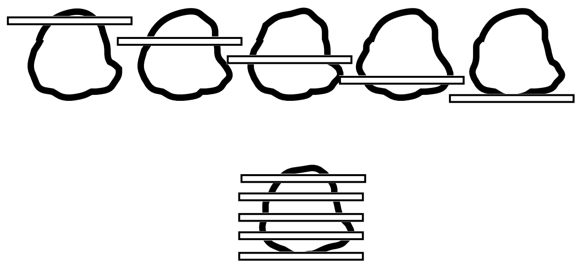


$\Delta y \leqq (1/2)\Delta r$

Ex. TV raster scan

Sampling on repetitive image

(MIXS)



Reconstructed 2D image

Principle of multi-imaging x-ray streak camera (MIXS) to obtain time-resolved 2-D x-ray images

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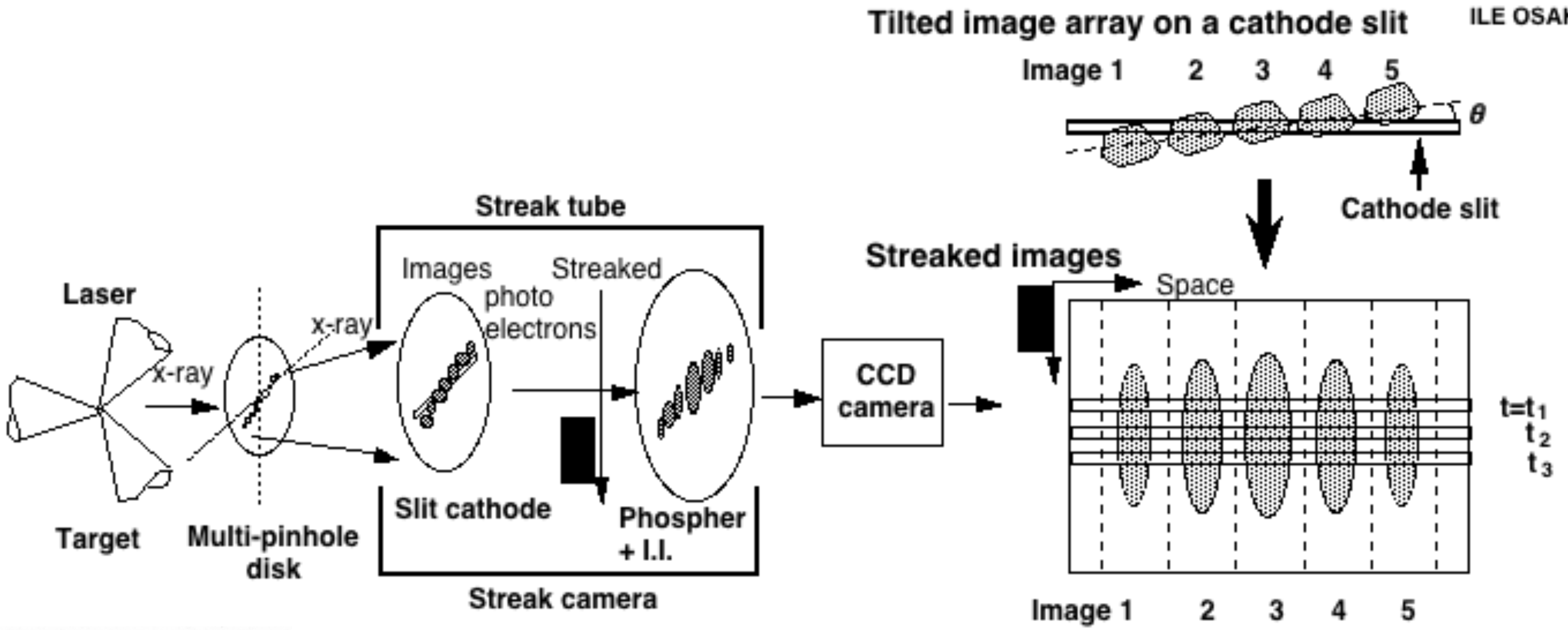
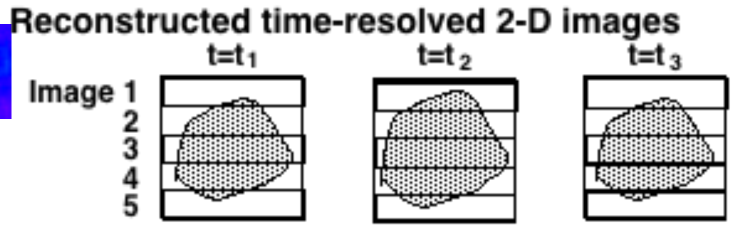
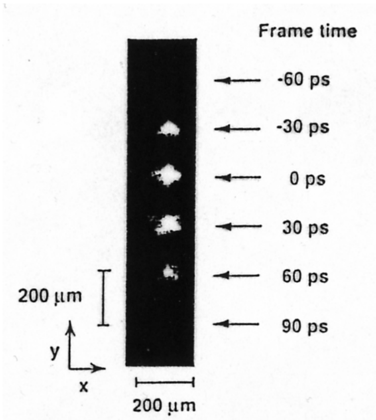
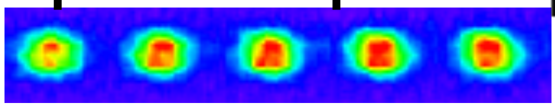






1) O. L. Landen,
RSI. 63, 5075 (1992).

Imploded core plasma



10^{11} fps achieved

2) H. Shiraga, et al.,
RSI. 66, 722 (1995).
3) H. Shiraga, et al.,
RSI. 68, 745 (1997).

Advantages of MIXS

1. Easy to obtain 10 ps or better resolution
2. Continuous in time
   - no lost signals between frames
3. After sampling, no image distortion
4. Choice of spectral response
5. Spectroscopic applications

Disadvantages

1. Small field of view
2 Not suitable for objectives larger than the field of view

Implosion experiment of FI cone-shell target at OMEGA laser

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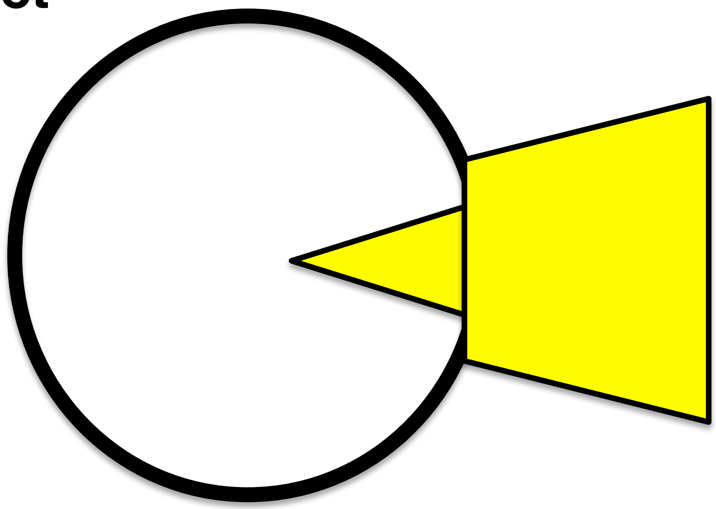
Purpose: to investigate

- **Core formation in cone-shell target**
- **Core & cone plasma dynamics**
- **Core-cone interaction**



Team:

ILE, Osaka University
LLE, University of Rochester
General Atomic
Lawrence Livermore National Lab.

Experimental set up

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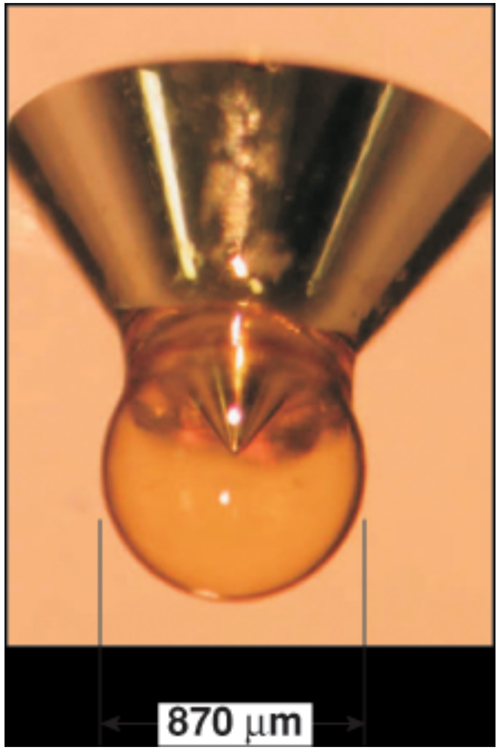
Laser:
35 beams
15 kJ/1 ns SQ
(~10^{15}W/cm^2)



Target:
70deg Au cone

CH shell:
900 µm in diameter
20 µm thick
D_2 or D^3He: 0, 5-10 atm

Diagnostics: MIXS, XFC, XPHC, Yn, etc

PJX x-ray streak camera

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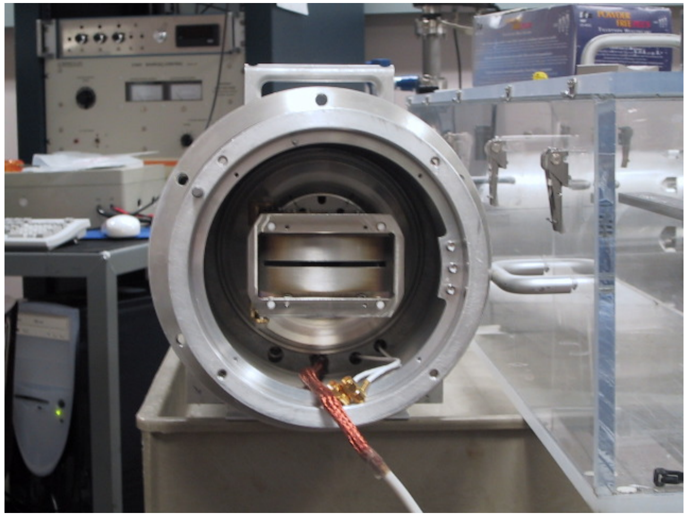
- Developed at LLE, Rochester*
- 6-cm long KBr photocathode
- Photoelectrons accelerated through a slot, focused with a quadrupole doublet
- Fiber-coupled, back-illuminated CCD recorder
- D range >> 1000
- Temporal resolution < 10 ps



* by P. Jaanimagi

Pinhole arrays for MIXS imager

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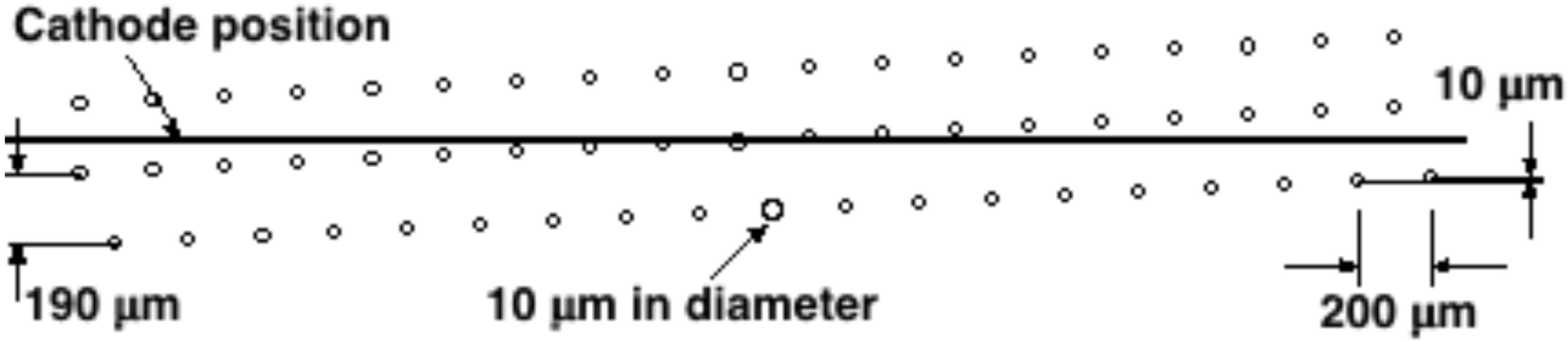

3 arrays x 19 pinholes
M=12x

Initial alignment of MIXS is very tight (in y direction).
3-arrays allow much tolerance for misalignment.

MIXS imager in retractor for PJX

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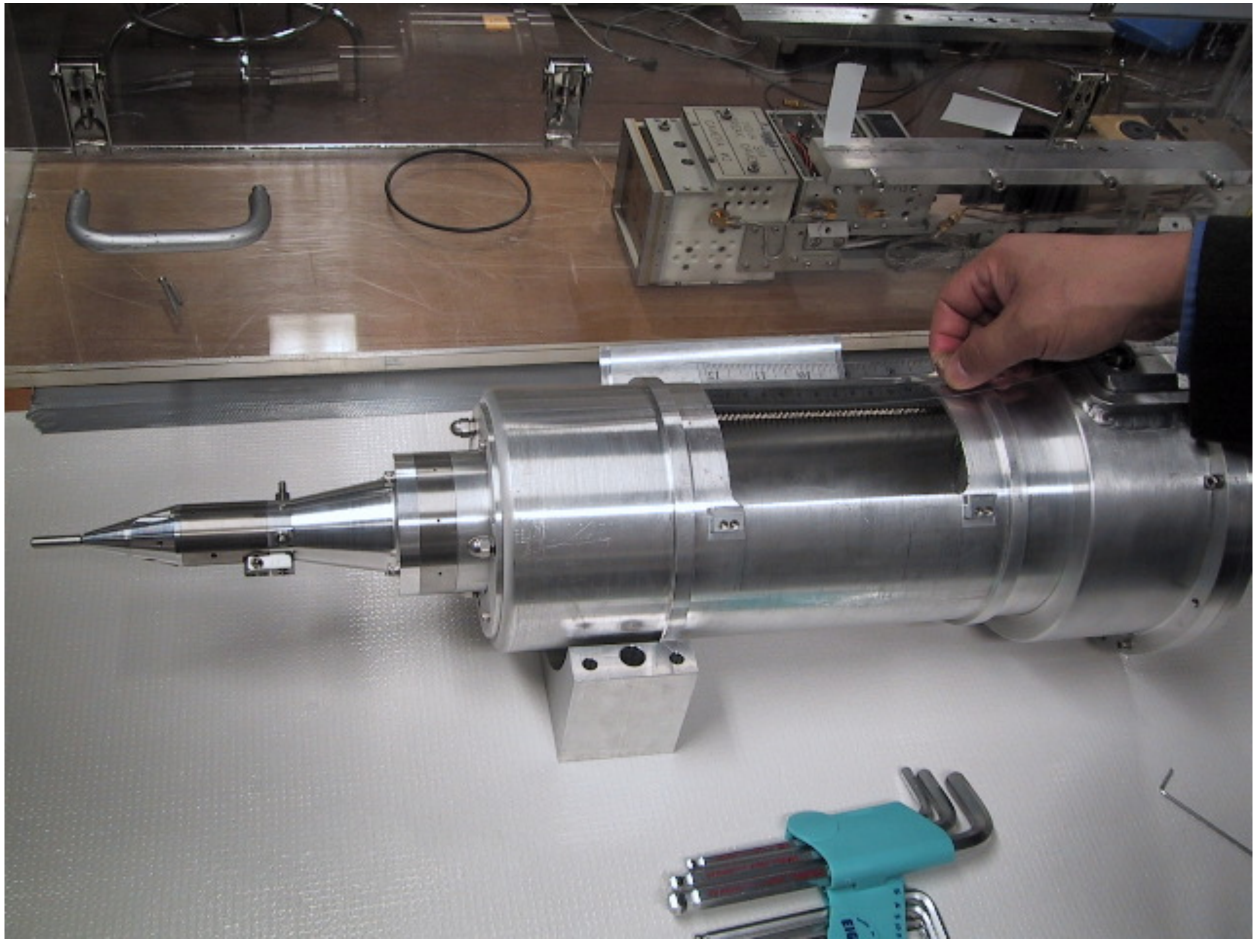

MIXS-PJX system

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Space:	Δ*x*:	~ 15 μm	(pinhole, cathode)
	Δ*y* :	~ 20 μm	(sampling)
	Field of view:	200 x 190 μm	(# of images, etc)
Time:	Δ*t*:	13 ps	(tube, sampling)
	Time range:	1 ns FS	
Spectrum:	X-ray range:	> 2 keV	(filter, cathode)
Frames:	# of frames:	up to 100	
	Interval:	10 ps	

Installation: After off-line alignment, inserted into the OMEGA target chamber, pointed to TCC with TIM.

MIXS installation on OMEGA target chamber

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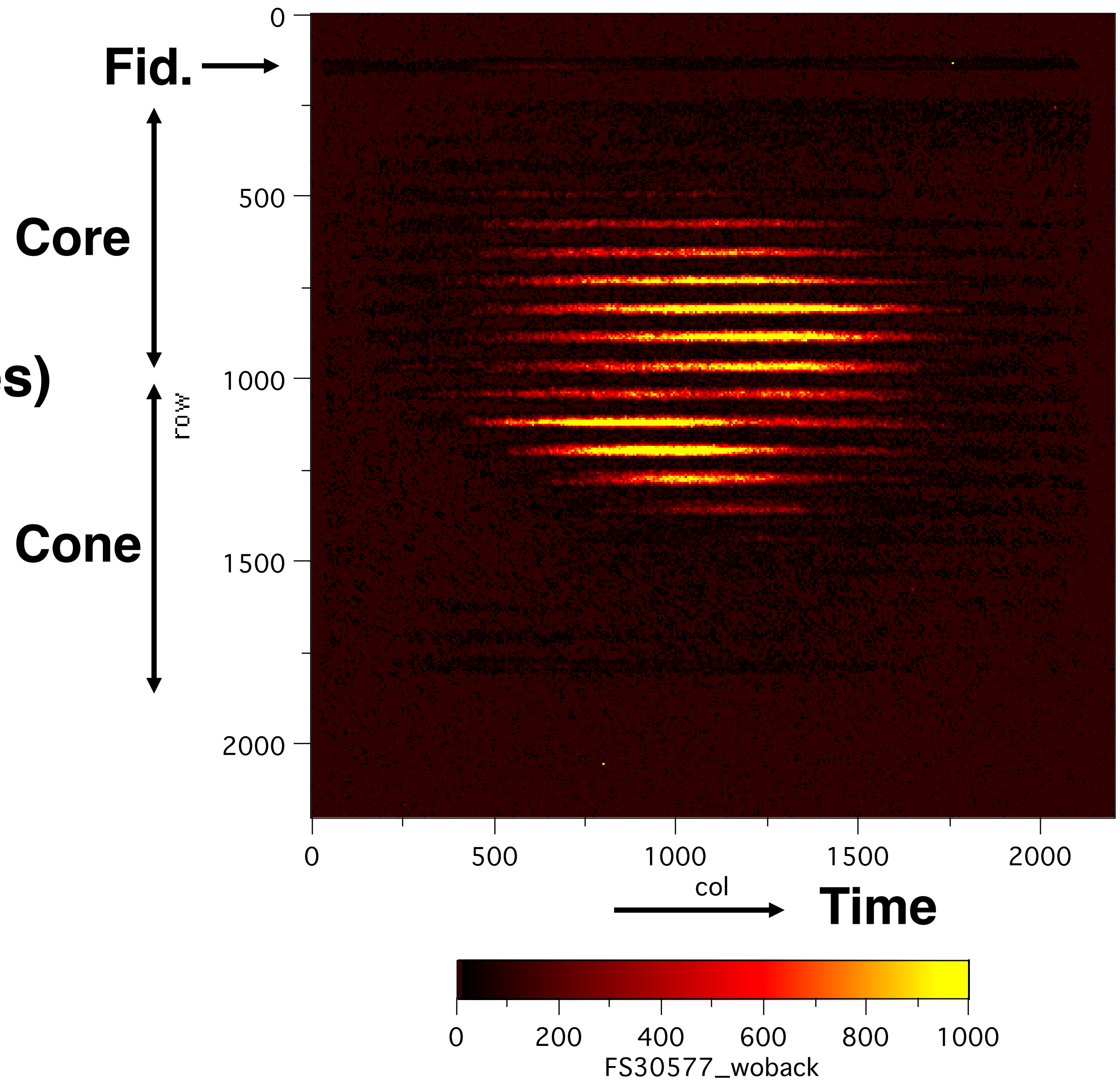
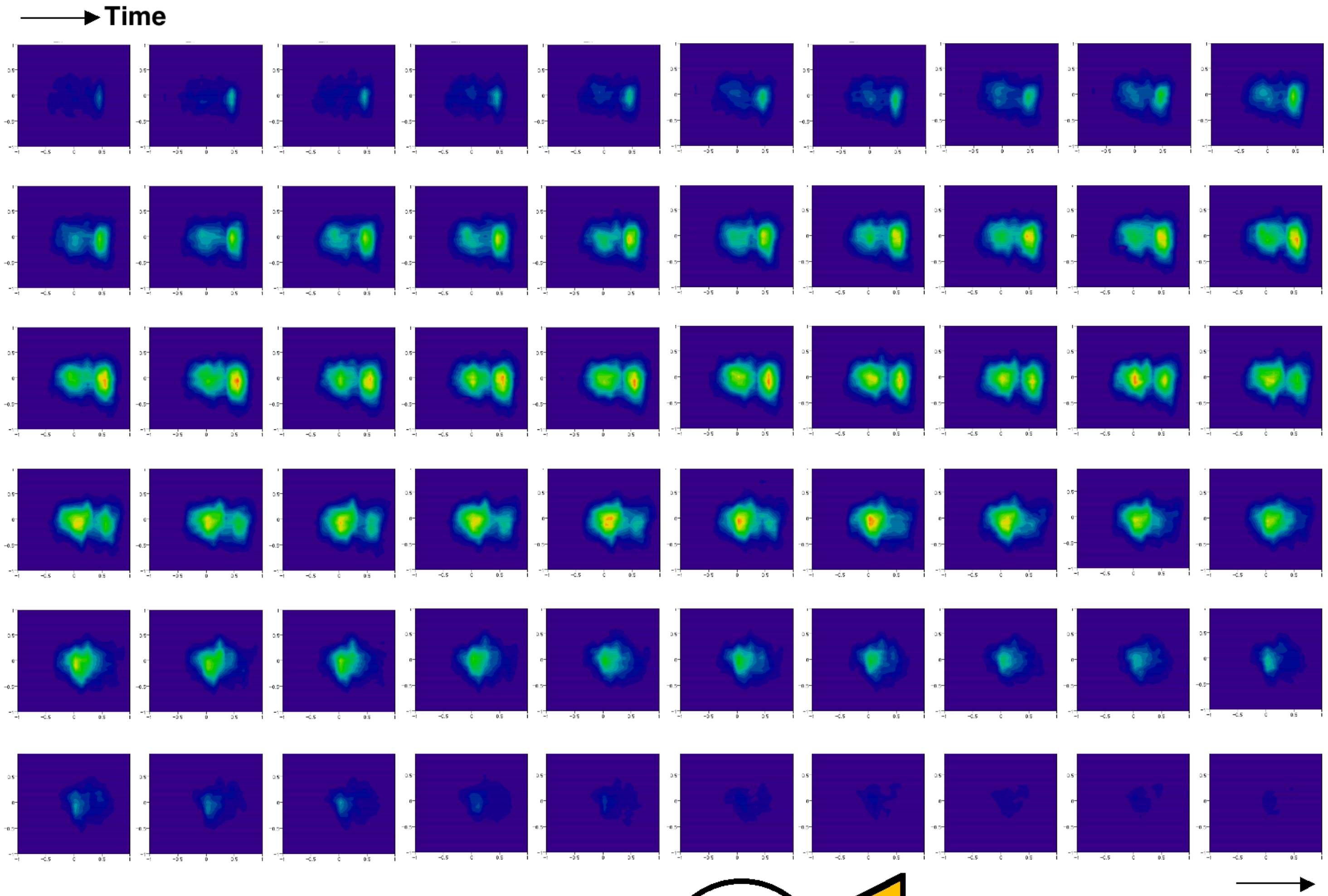
#30577 MIXS raw data

(19 pinhole images)

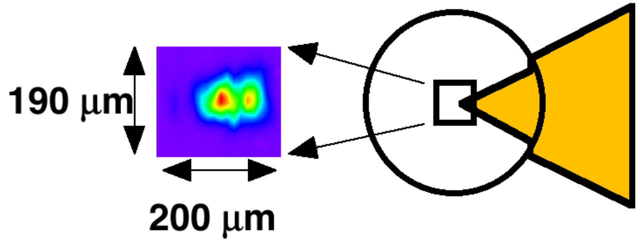


MIXS frames: frame exposure=13ps, frame interval=10ps

(a)



(b) Time integrated



Implosion experiment of cone-shell target at LLE OMEGA laser

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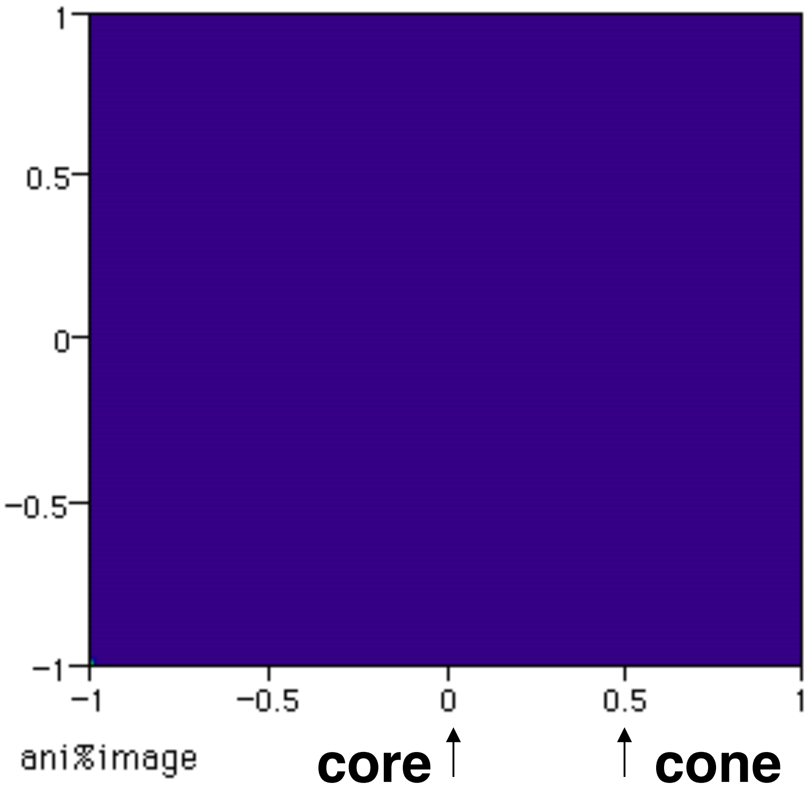
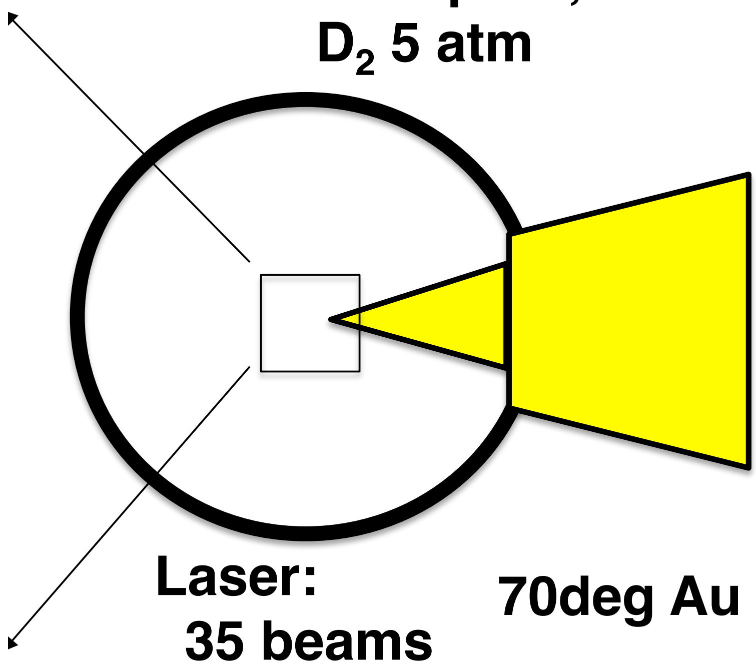
200 μm x 200 μm

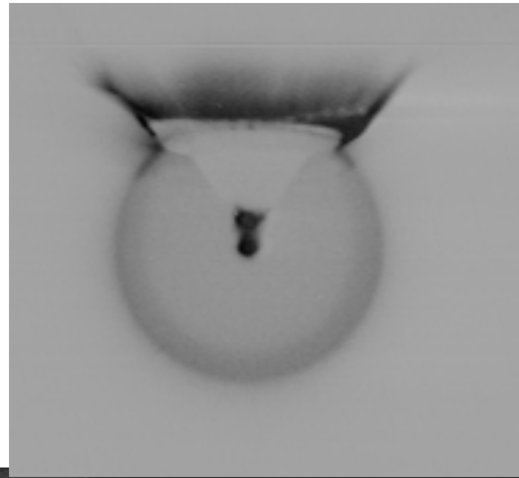




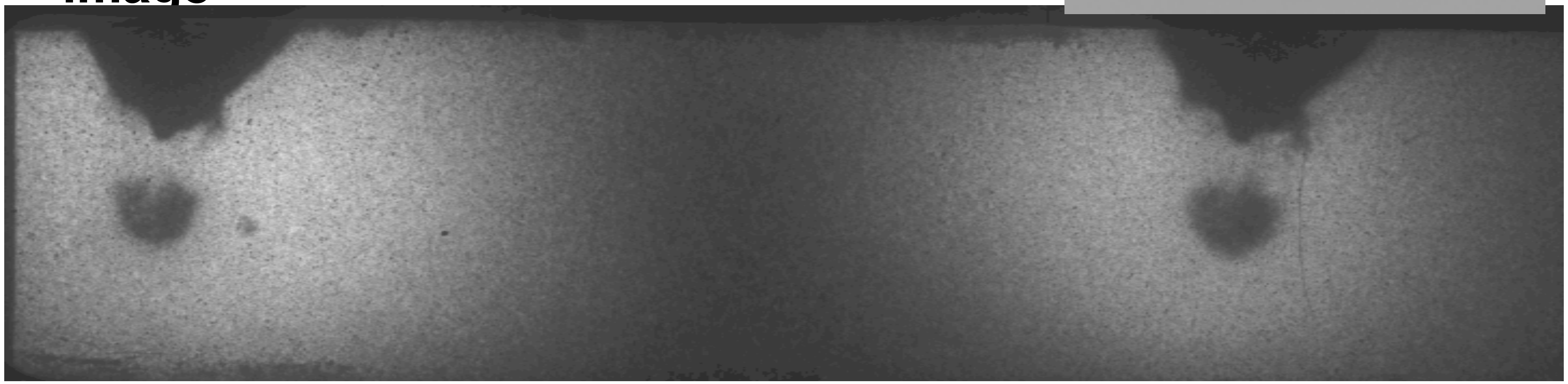
X-ray emission from core and cone tip
Ultrafast x-ray image (Δ*t*=10 ps) obtained with
MIXS: Multi-Imaging X-ray Streak Camera with PJX at LLE

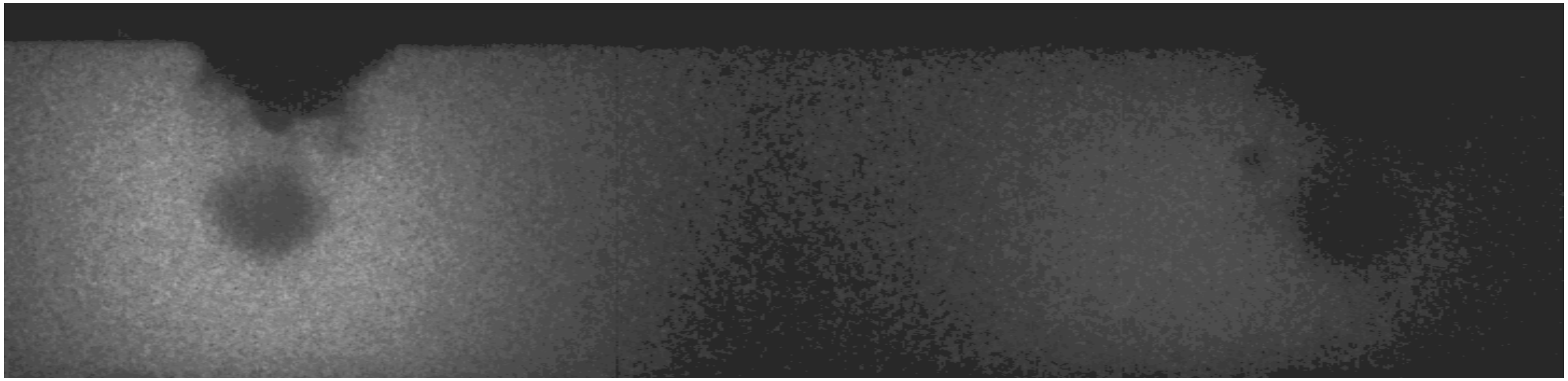
by H. Shiraga, S. Fujioka, P. Jaanimagi, C. Stoeckl, *et al.*

#30577 backlight core-cone (w/ gas fill)



- Stagnation at first image





Cone tip was damaged before the formation of the core.

2D simulation of 70/30 deg cone-shell target implosion (density) by H. Nagatomo, ILE, Osaka

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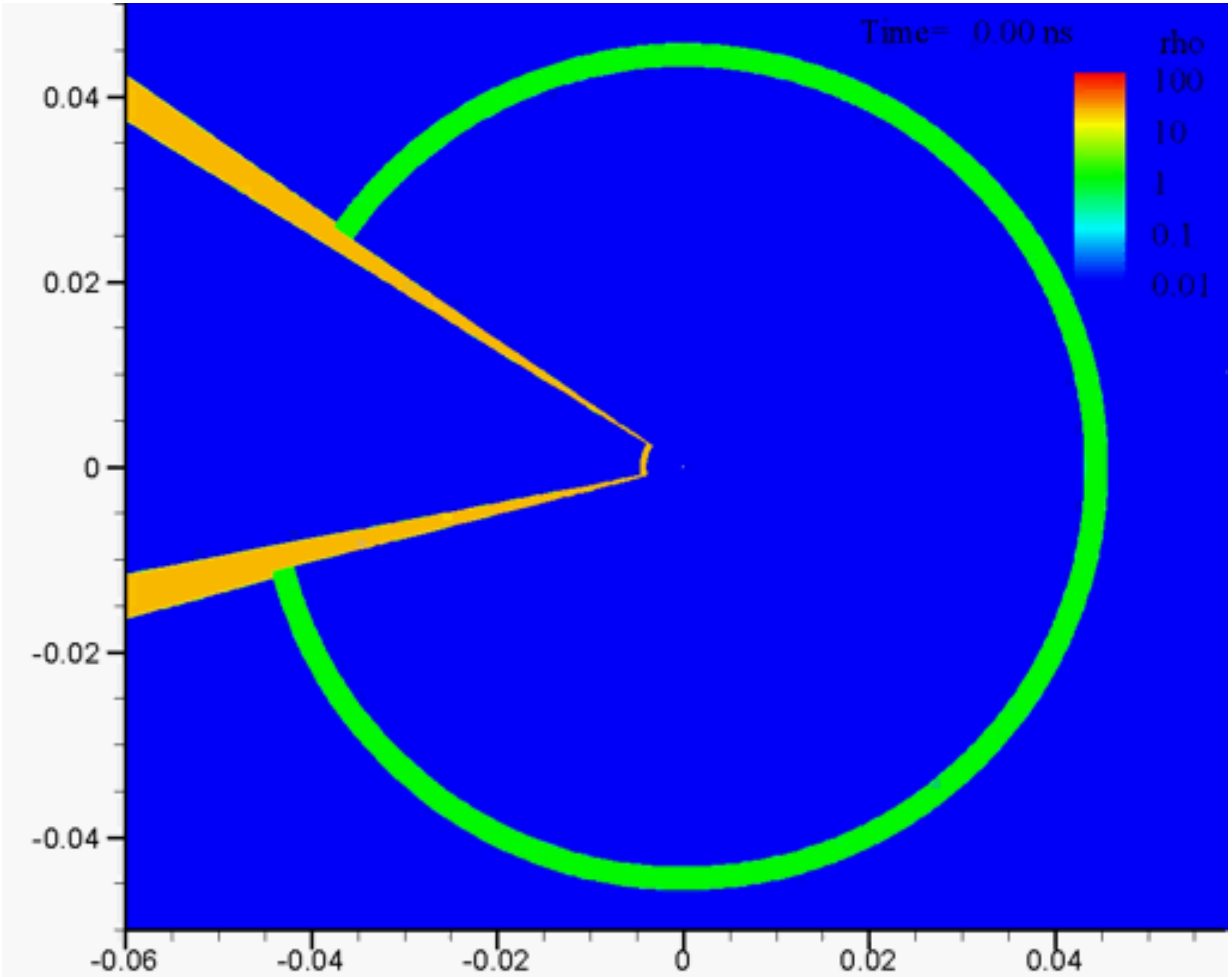
70 deg cone

30 deg cone



Shock wave after convergence hits the cone tip before shell stagnates at the target center.

ps/μmレベルの時間空間分解能はX線計測において同時達成可能である

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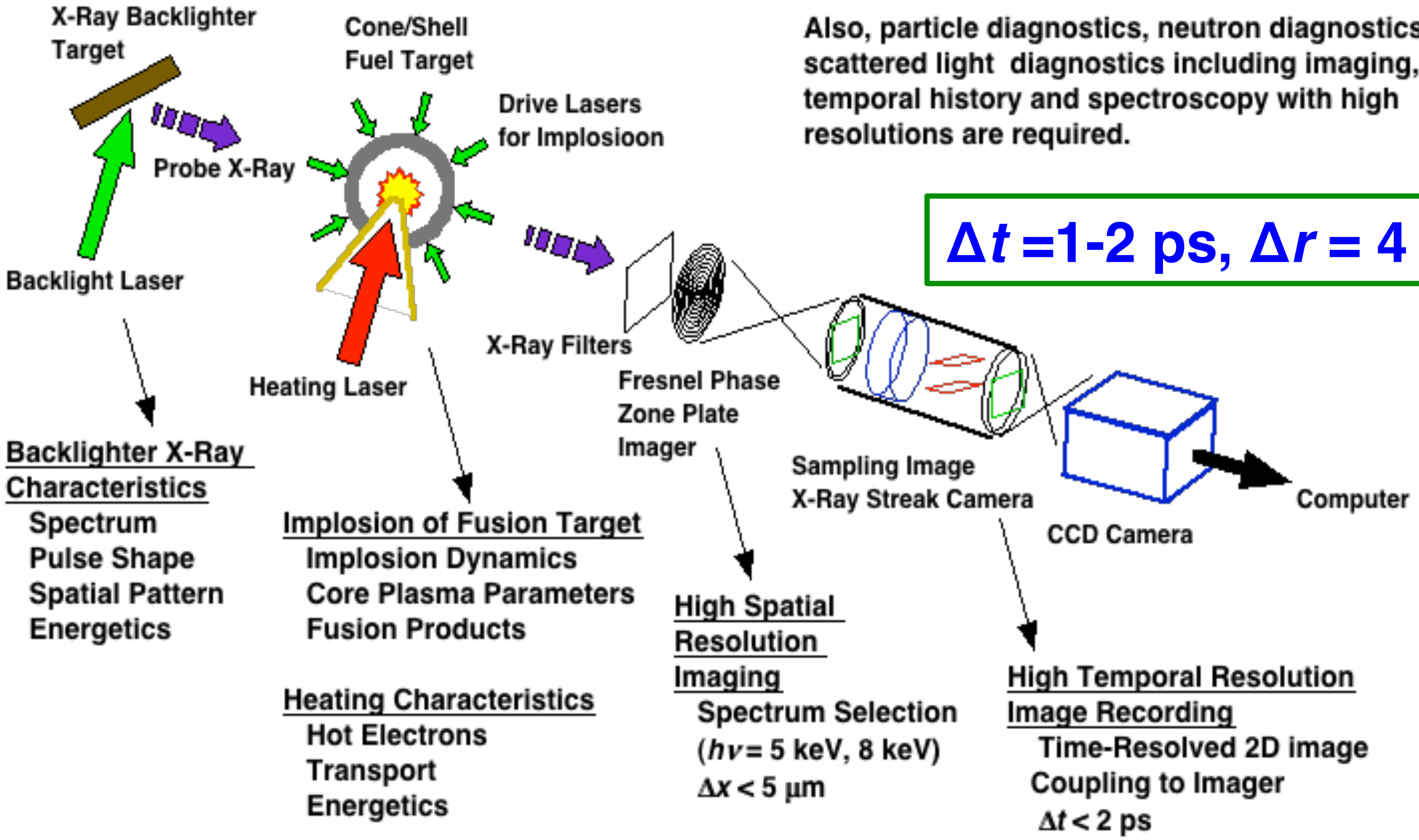
Also, particle diagnostics, neutron diagnostics, scattered light diagnostics including imaging, temporal history and spectroscopy with high resolutions are required.

Δ*t* =1-2 ps, Δ*r* = 4 μm



点火燃焼実験では、n, γ, EMP過酷環境対策が重要

3. Issues found in Fast Ignition experiment found

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Background noise

intensity > 10^{19} W/cm^2

energy > 1000 J

→ large amount of hot electron generation (> 1 ～ 10 MeV)

→ intense hard x rays (γ rays) and EMP

→ too large background noise and other nuclear reactions

Diagnostics must be compatible to such harsh environment.

H. Shiraga, et al., IAEA/FEC2014, IFE/P6-2 (2014);
Y. Arikawa, et al., RSI 83, 10D909 (2012).

Plasma diagnostics compatible to hard x-ray and EMP harsh environment were required

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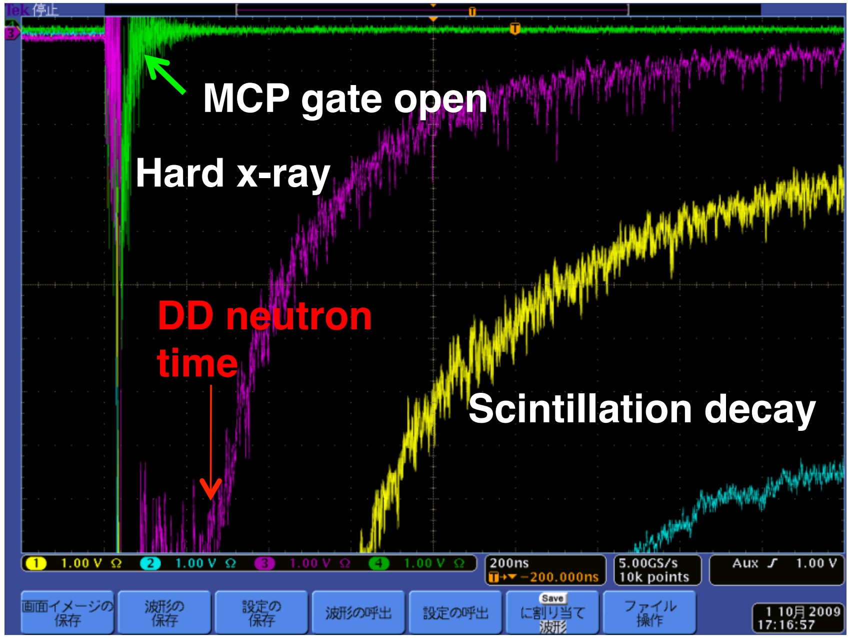
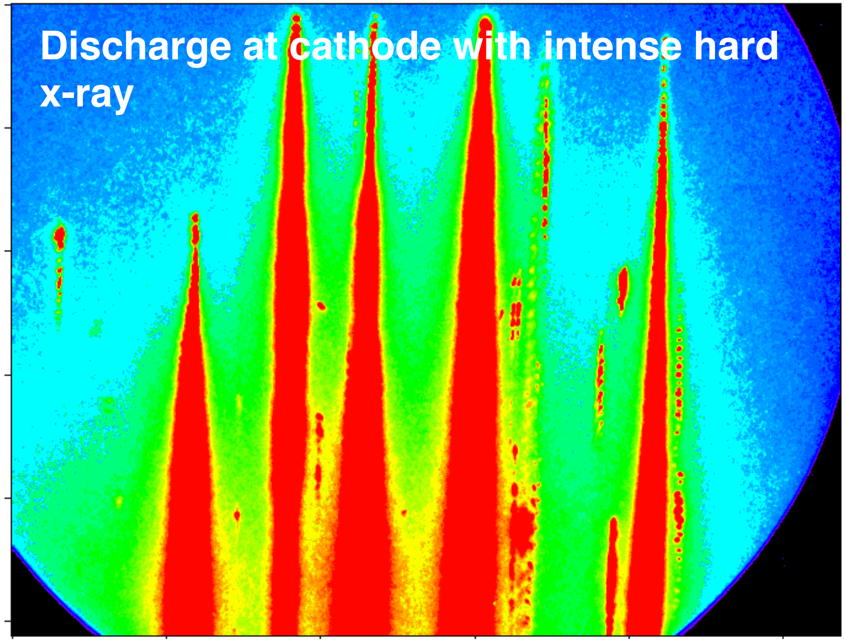
Diagnostics troubles in 2009 experiment with large energy LFEX shot

- Freezed PC's, violent noises in oscilloscopes
- Too big scintillation decay signal overwhelming the DD neutron signal
- Intense background noise and cathode discharge in x-ray imaging devices

Neutron TOF scintillation detector



Multi Imaging Xray streak camera



EMP shield box for electro circuits worked well

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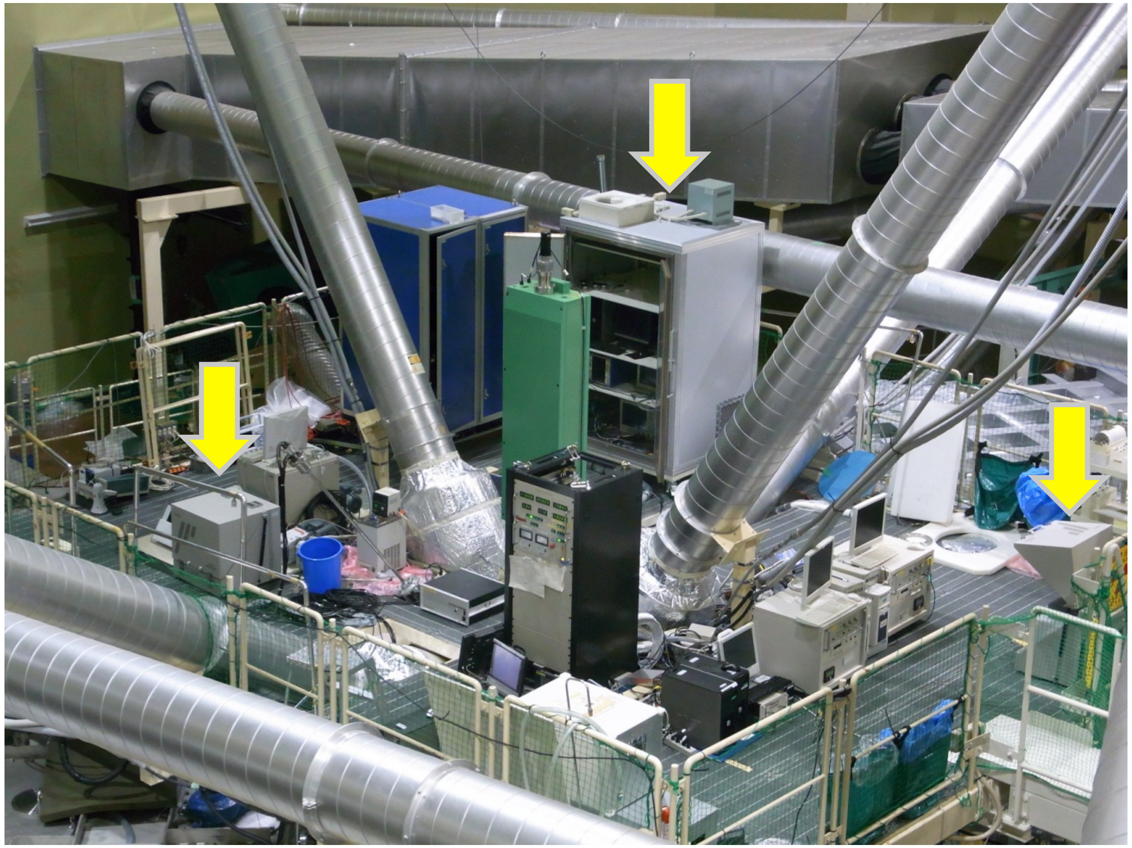

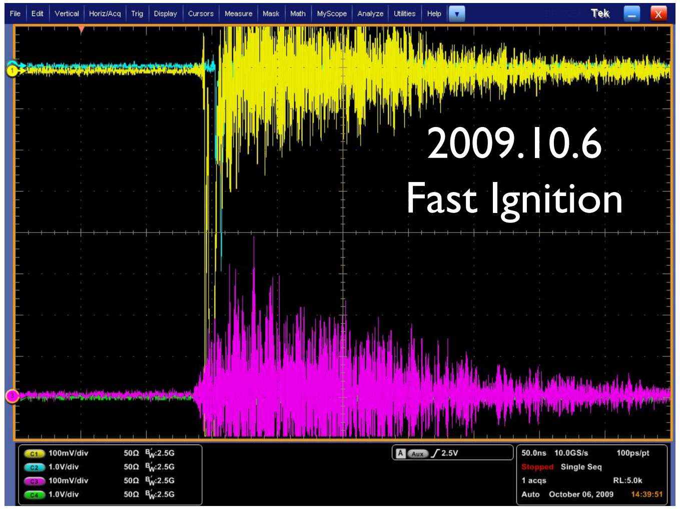

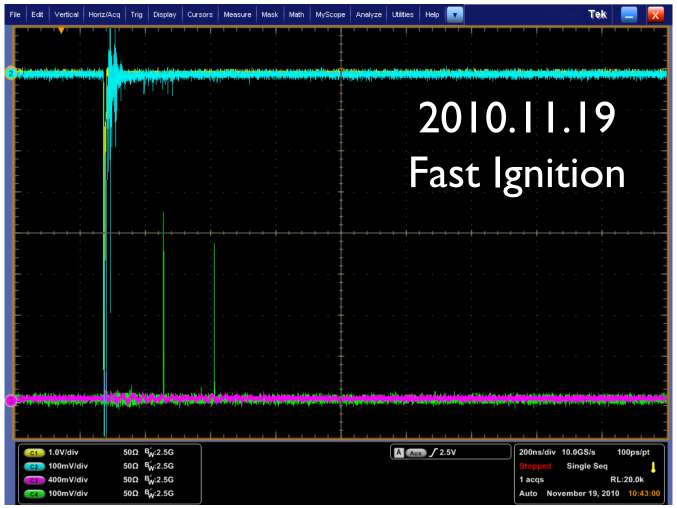

EMP noise effects on photodiodes, PC's, and oscilloscopes were significantly reduced.

Reduction of hard x-rays in x-ray imaging diagnostics

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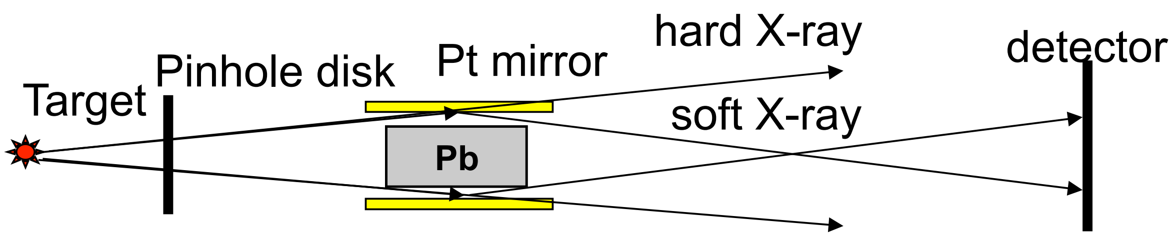
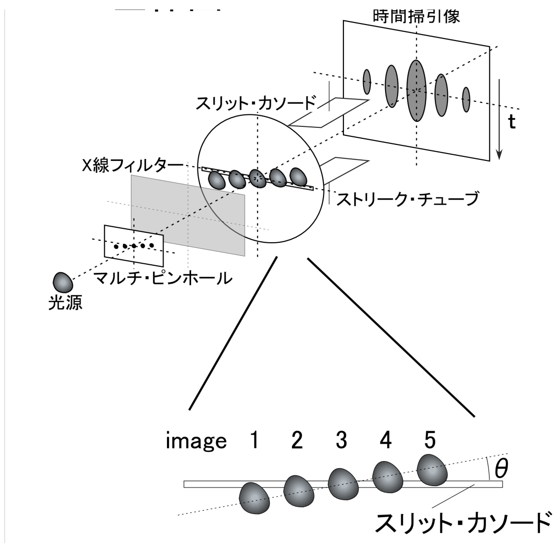
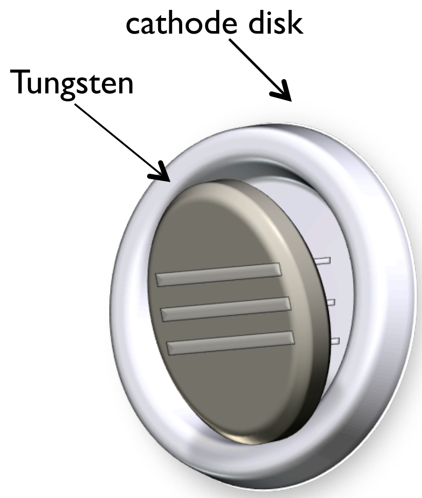
X-ray framing camera with total reflection mirrors to eliminate hard x-rays



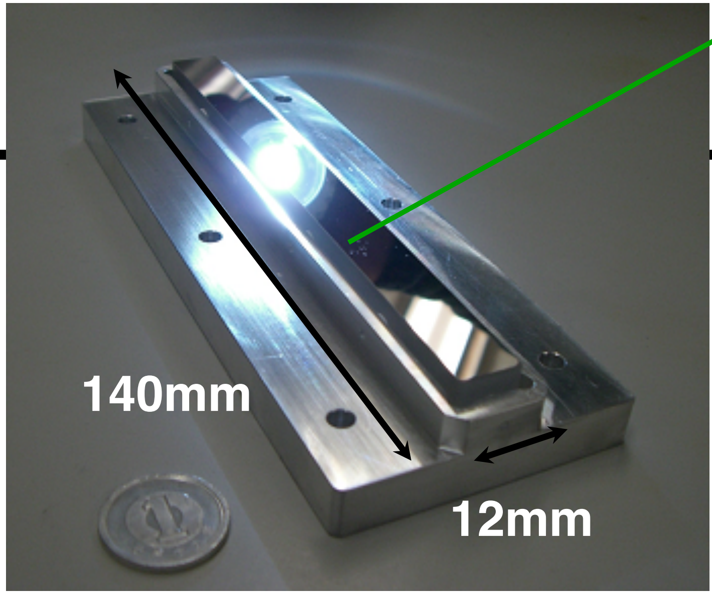
Hard x-ray-shielded cathde for x-ray streak tube





These schemes worked well and contributed to efficient experiment.

Prototype flat x-ray mirror



60 nm thick Pt coated on quartz substrate

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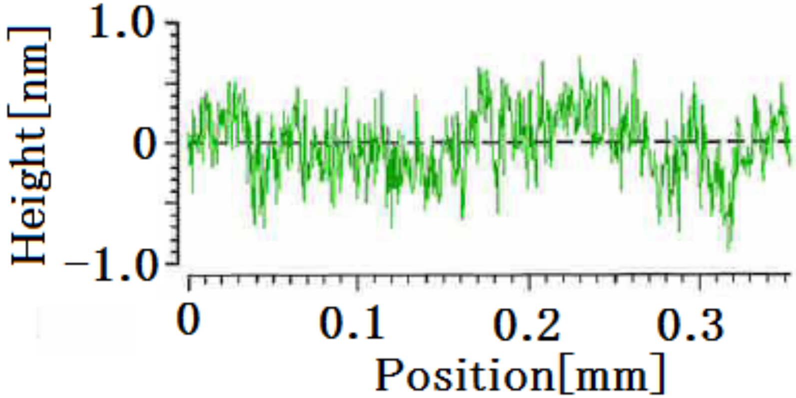
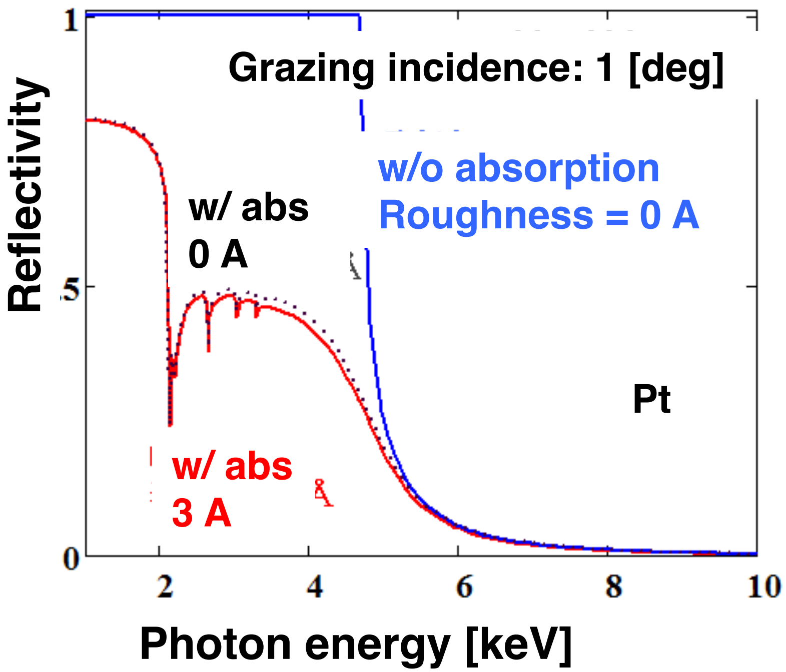
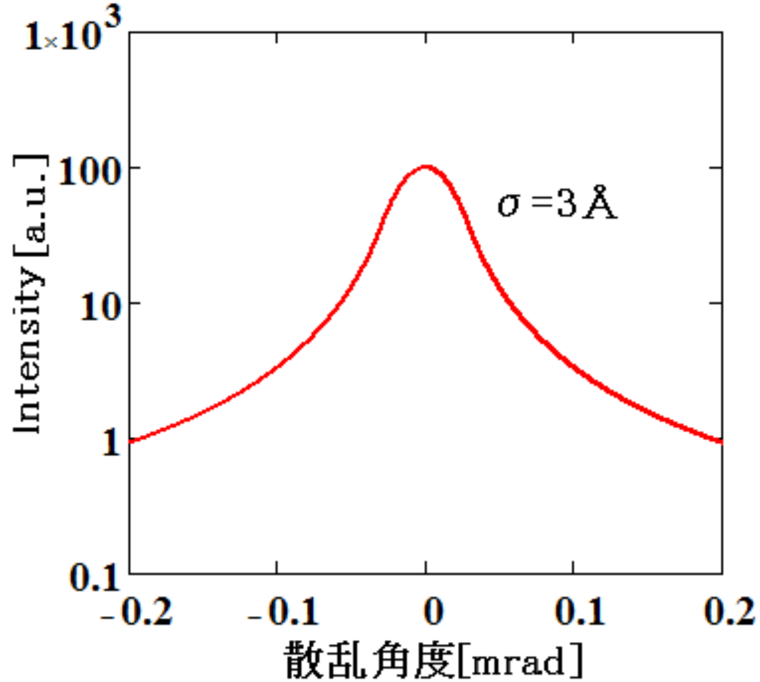


Surface roughness = 3Å



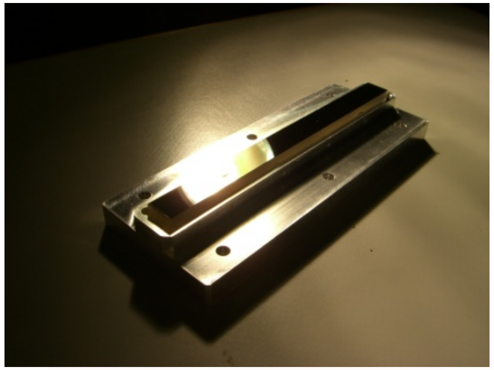


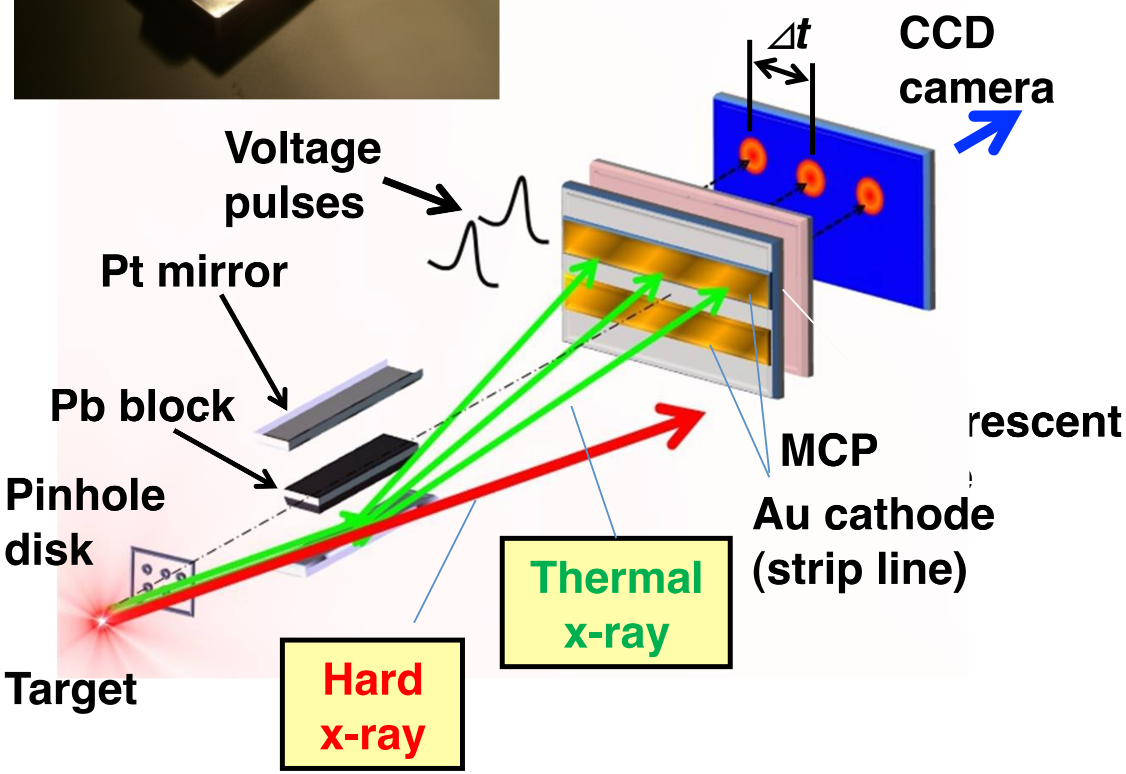
R > 40% for hν < 4 keV

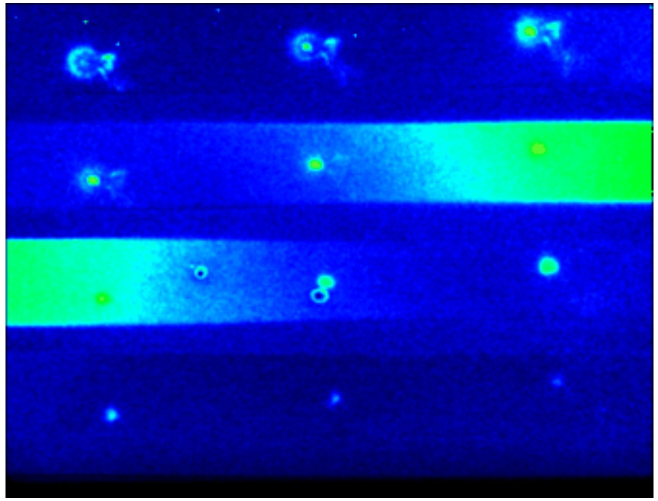
Broadening < 0.1 mrad

Hard x-rays are eliminated with Pt total reflection mirors, and only thermal x-ray images are recorded

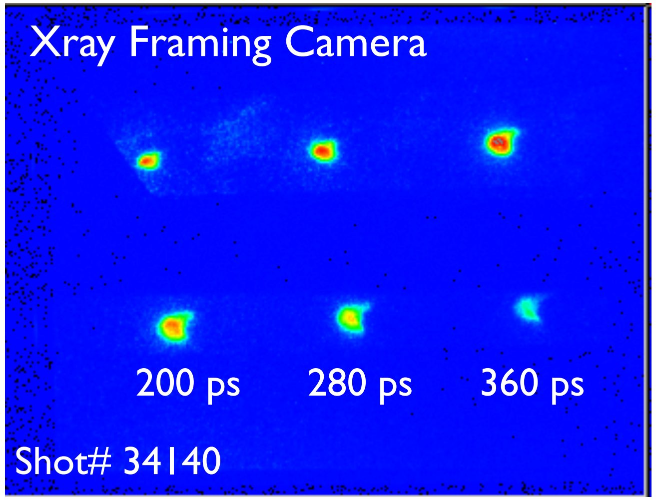
ILE OSAKA







w/o mirrors

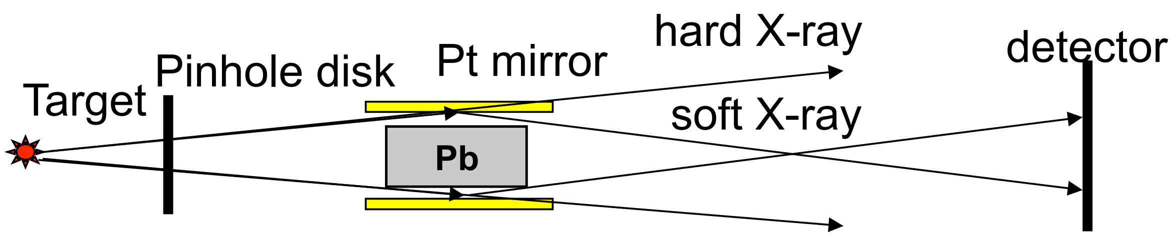


w/ mirrors

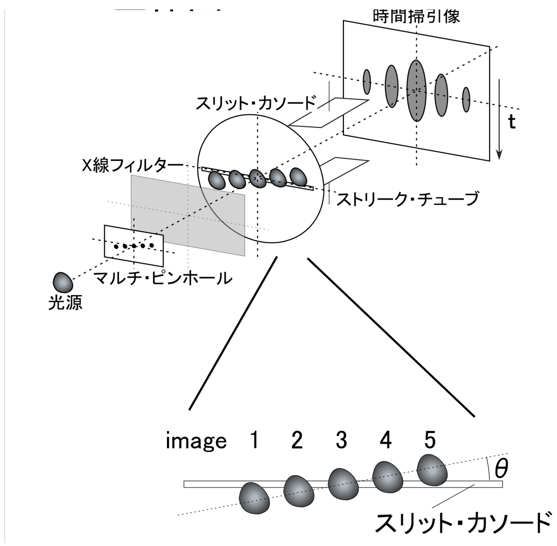
Reduction of hard x-rays in x-ray imaging diagnostics

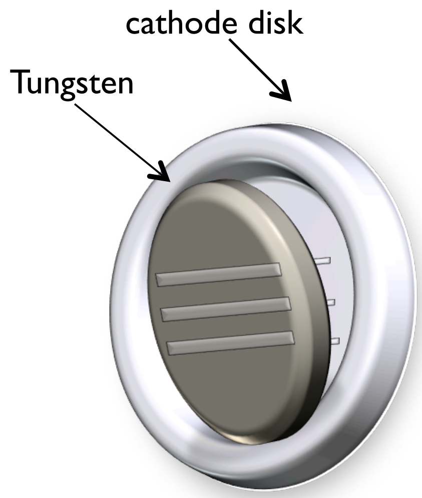
ILE OSAKA

X-ray framing camera with total reflection mirrors to eliminate hard x-rays



Hard x-ray-shielded cathde for x-ray streak tube





These schemes worked well and contributed to efficient experiment.

Shielding worked, and LFEX injection time was accurately monitored using non-imaged hard x-ray signal in x-ray streak cameras

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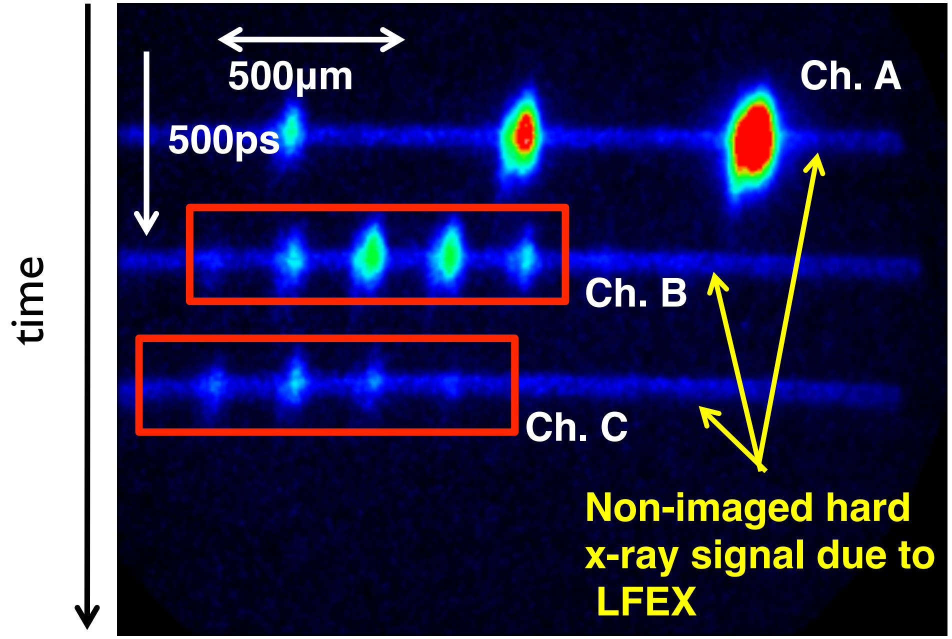
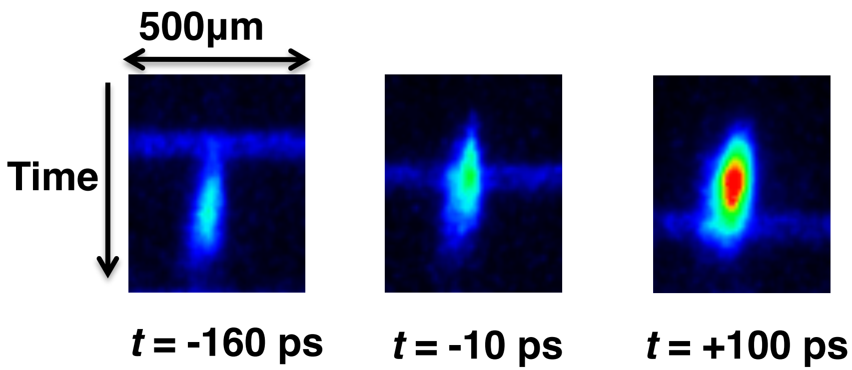
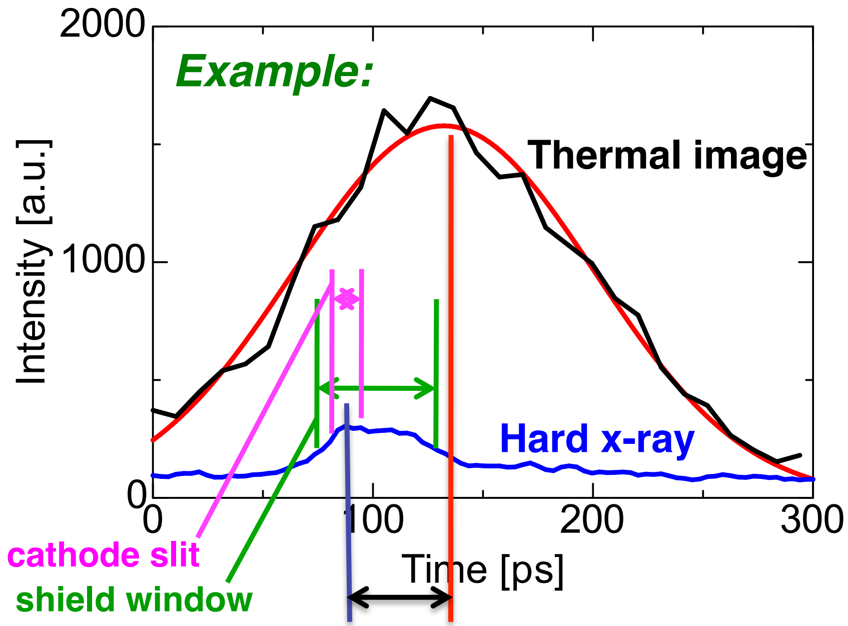




Relation between hard x-ray signal and the imploded core plasma



Balk shielding resulted in :

- **Stopping cathode discharge**
- **Reducing background noise**

Injection time was measured within an accuracy better than +/-10 ps.

Increment in x-ray signal observed in some shots
Reproducibility under investigation

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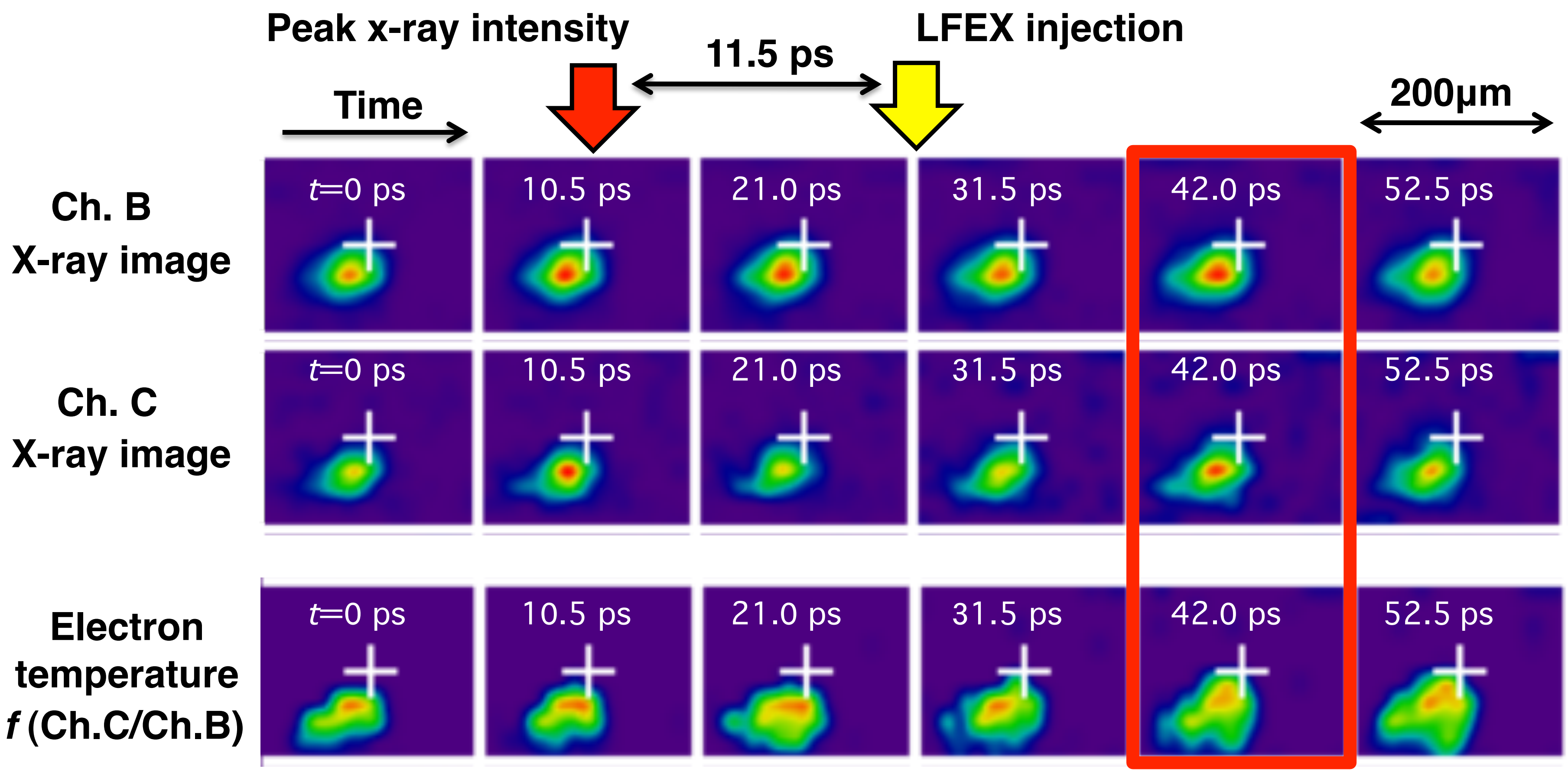
10-ps frame x-ray images and derived temperature distribution



Ready to diagnose the heating dynamics
once the heating becomes significant

4. Various neutron diagnostics were developed

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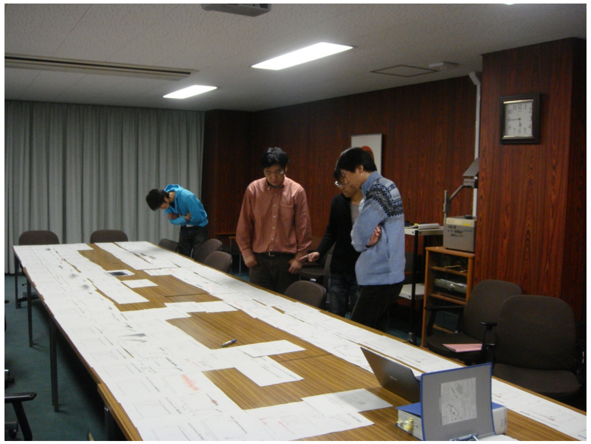
Time-resolving detectors

1. MANDALA: 4p shielding
2. TOF scintillator: shielding hardened
3. Fast fiber scintillator: shielding hardened
4. BC422: position changed
5. Gated TOF scintillator: New
6. Gated Liq. scintillator # 1: New
7. Gated Liq. scintillator #2: New
8. Gated ^{6}Li scintillator #2: New
9. Multi-ch. ^{6}Li counting mode: New

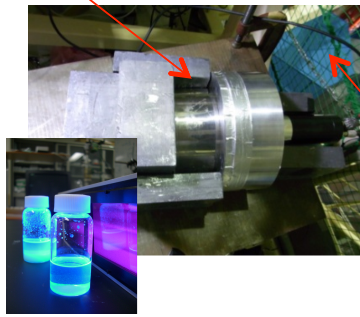
g-ray insensitive detectors

10. Bubble detector: Revival
11. CR39 auto-reading: New
12. Radiochromic film: New
13. Ag counter: Revival



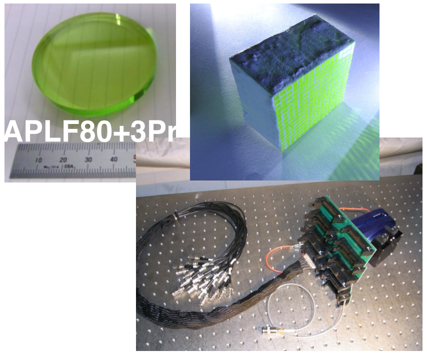
MANDALA

0-saturated quenching Liq. scintillator

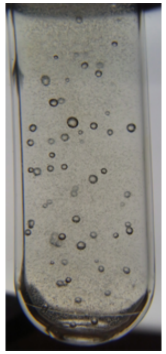


PMT with gated-dinode

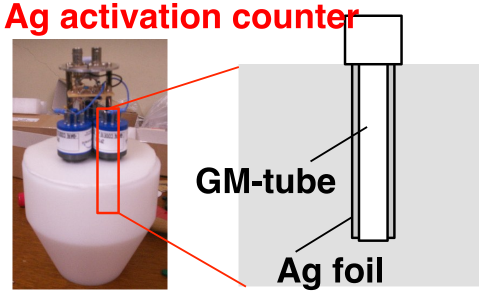
^{6}Li scintillator



Bubble detector



Ag activation counter



n-moderator (polyethlene)

$$^{109}Ag + n \rightarrow {}^{110}Ag + \gamma$$

$$\Rightarrow {}^{110}Ag \rightarrow {}^{110}Cd + \beta^{-}$$

4a. (γ,n) reactions take place in γ-ray rich environment in high-intensity experiments

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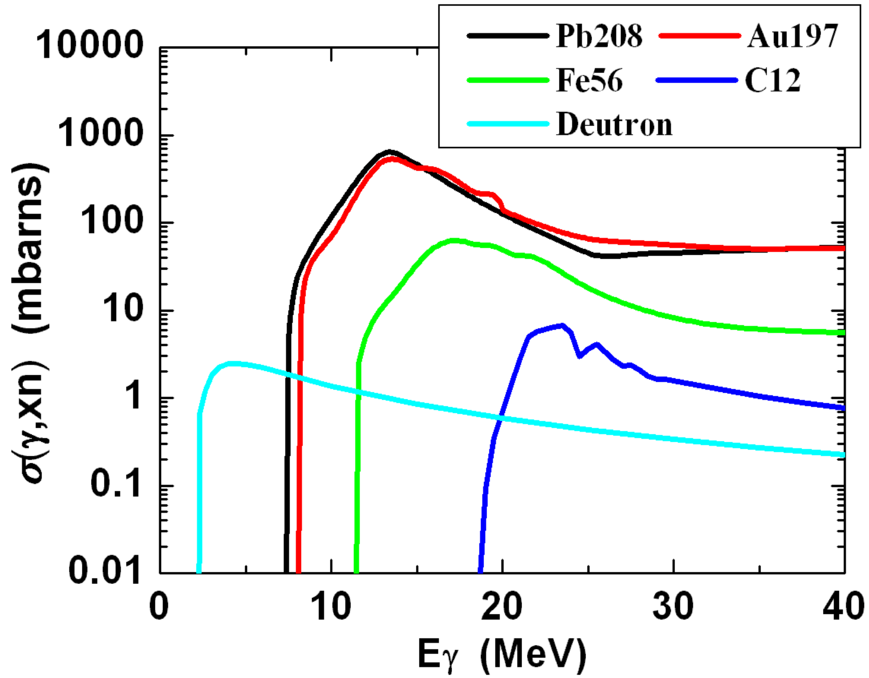
We observed:

- **Neutron signals in *gamma-insensitive* detectors (bubble, Ag activation)**
- **Broadband neutron signals observed in shots *without* implosion**
- **Correlation with gamma-ray signals**

→ ***There are neutron signals coming from (γ, n) reactions.***



$^{M}A + g(h\nu) \rightarrow {}^{M-1}A + n(h\nu\text{-B.E.})$

Neutrons in the MeV range can be created due to (γ,n) reactions (*photo disintegration reactions*) in materials in and around the target.

New liquid scintillator was developed

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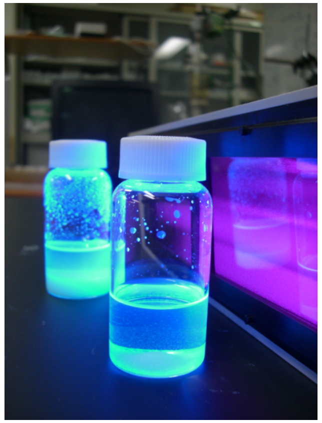

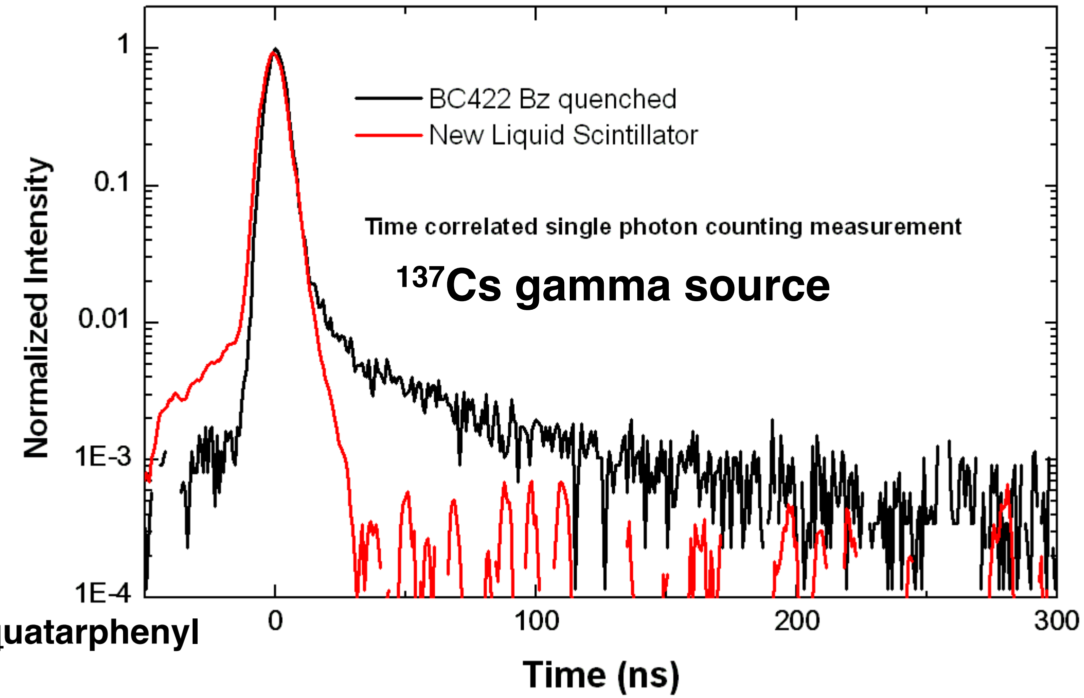

scintillation：
BBQ (used for dye lasers)
4,4’’’-Bis-(2-butyloctyloxy)-p-quatarphenyl

host：p-Xylene

Quenching by oxigen

- ***Slow decay component was significantly reduced.***
- ***Coupled with gated PMT, and used in FI integrated experiment.***

Nagai, et al., Jpn. J. Appl. Phys. 50, 080208 (2011)

Intense (γ, γ') and (γ,n) signals were found to be the main components of the background signal

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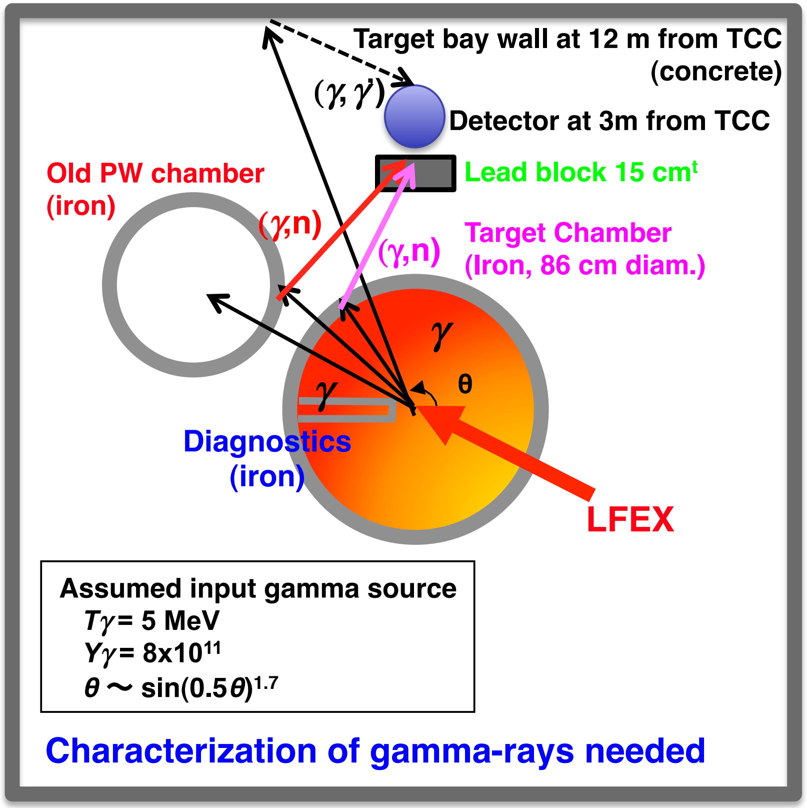
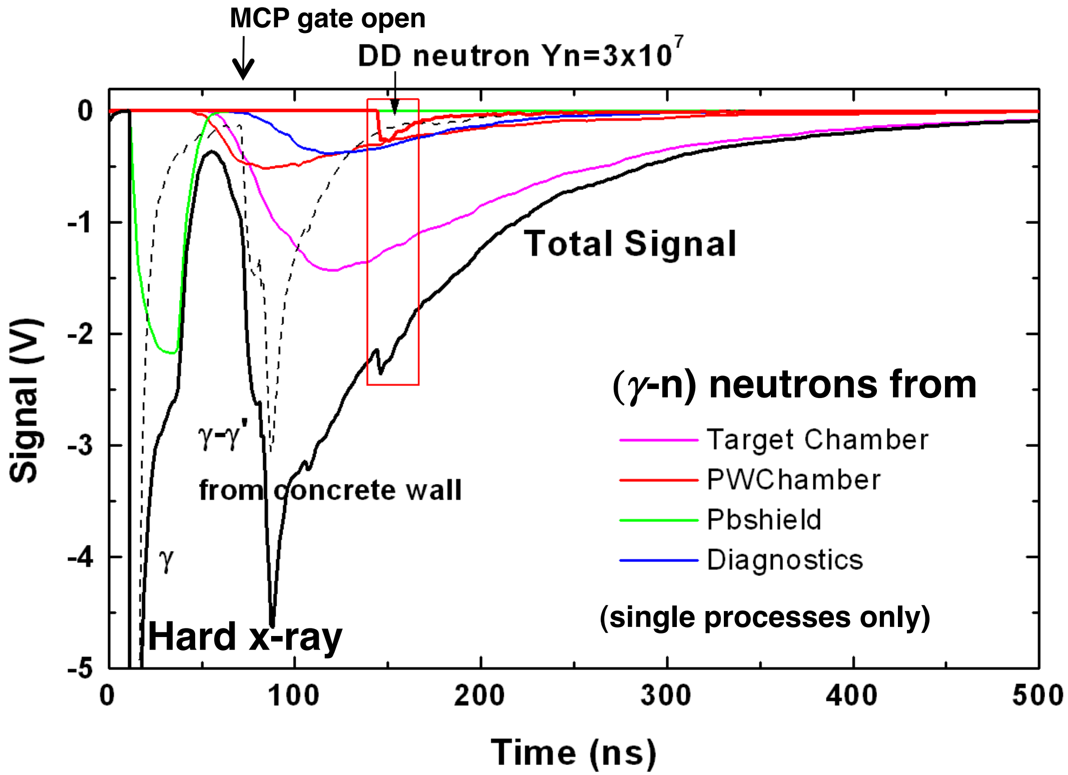
(γ,n) and (γ, γ') in materials elsewhere in and around the target chamber and at the concrete walls



(γ,n) and (γ, γ') signal components calculated with Monte-Carlo code* assuming materials configuration

*MCNP5 (A general Monte-Carlo N-Particle transport code)



(γ,n) : photodisintegration reaction, (γ, γ') :scattering

Now we know nature of the background signals, and can accurately identify the DD neutron signal even with the heavy backgrounds.

(γ, n) and (γ, γ') signals from surroundings can be eliminated by using appropriate collimators

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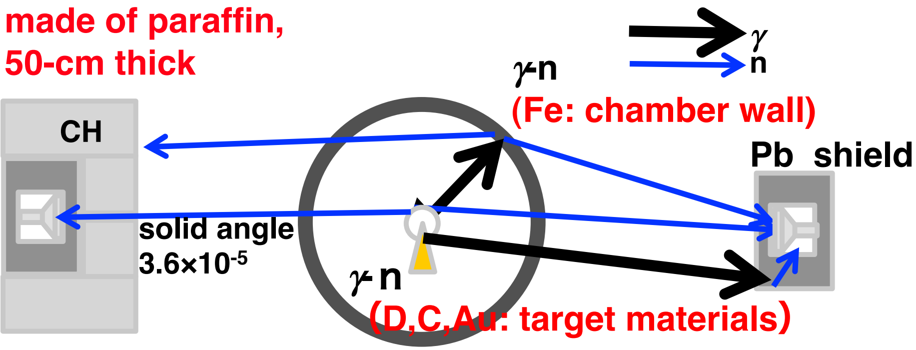
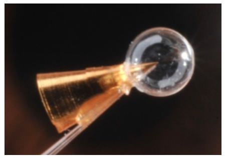
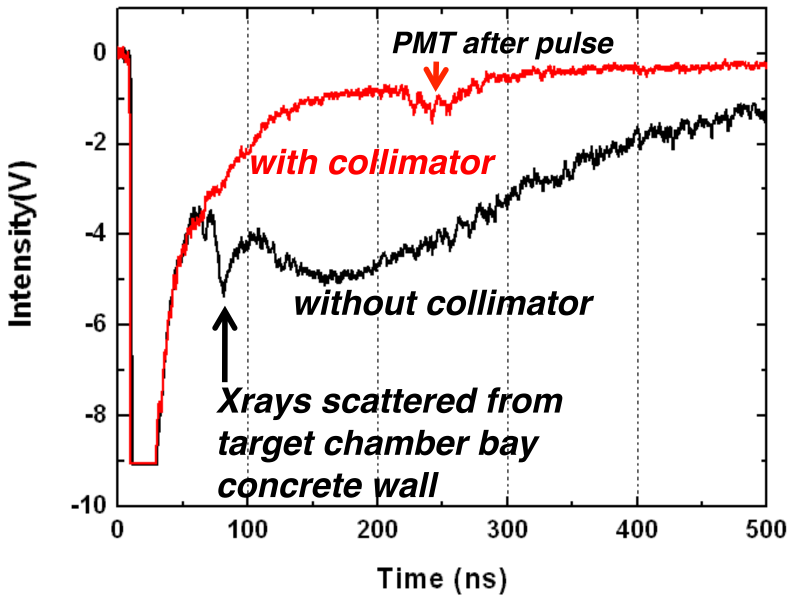
gamma-n observation shot



Shot # L1635 (25 Jan, 2011)
Fast ignition target
LFEX 427.7 J ,
without Implosion





Collimators will be fully installed in 2011 exp't.

中性子診断法開発

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4b. 爆縮燃料プラズマからの散乱中性子計測

4c. 高速時間分解（ゲート）中性子画像計測

4b. 散乱中性子計測とは?

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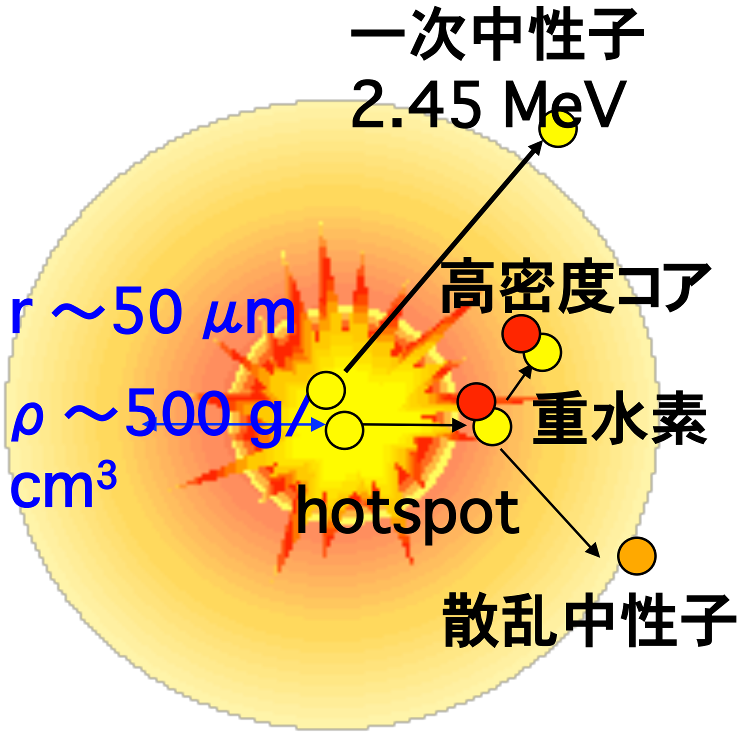
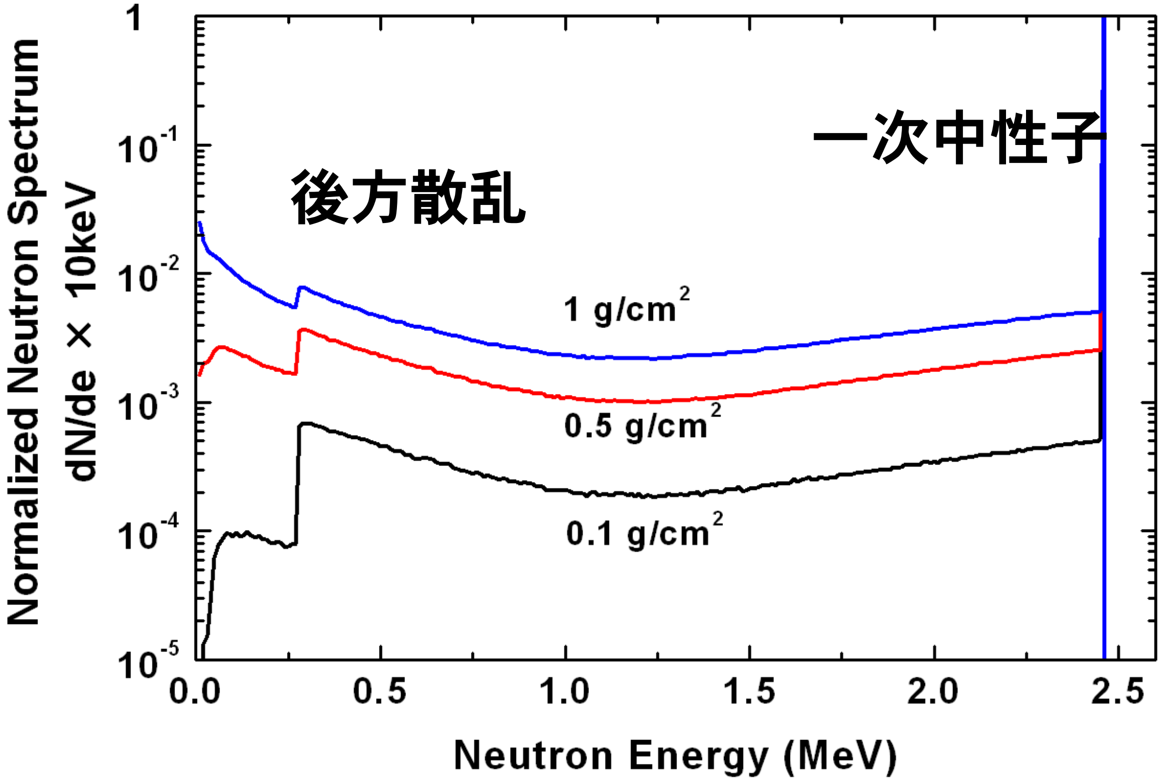


$$\frac{\text{散乱中性子}}{\text{一次中性子}} \propto \rho R$$

モンテカルロシミュレーションによる
散乱中性子スペクトル



しかし、散乱中性子計測は
1.エネルギーが低く、信号が弱い
2.数が少なく
3.一次中性子の後に来るため、計測が非常に困難

従来の燃料面密度計測手法と問題点

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散乱中性子計測法は現状実験レベルのρRから

将来の点火クラスの高ρR領域までの計測が可能。

計測法	＜ρR＞上限	制限要素、問題点
ノックオン法	150mg/cm^2	反跳粒子の飛程
二次反応法	30mg/cm^2	Tの飛程
放射化法	～5g/cm^2	トレーサー原子が爆縮に悪影響 ターゲット製作技術
散乱中性子計測	**～3.2 g/cm^2**	**中性子の飛程**

^{6}Liシンチレーターは散乱中性子に高感度

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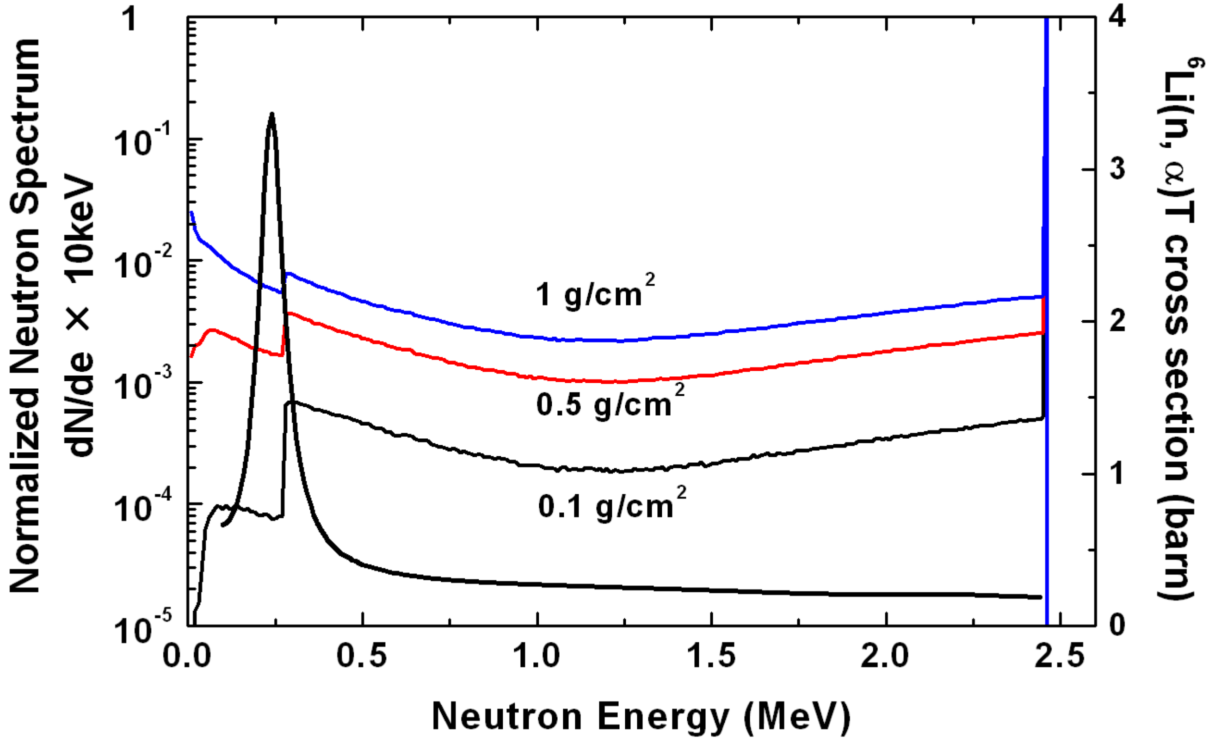
n + ^{6}Li → T+ ^{4}He (+4.8 MeV)
→excite scintillator!



1. 低エネルギー中性子でも十分な信号
2. 中性子捕獲反応共鳴ピークが散乱中性子ピークと一致するため、散乱中性子のみに高感度を得る
→問題1.2はクリア。残すは高速応答性、さらにカウントモードのみ。

高速応答^{6}Liシンチレーターが必要

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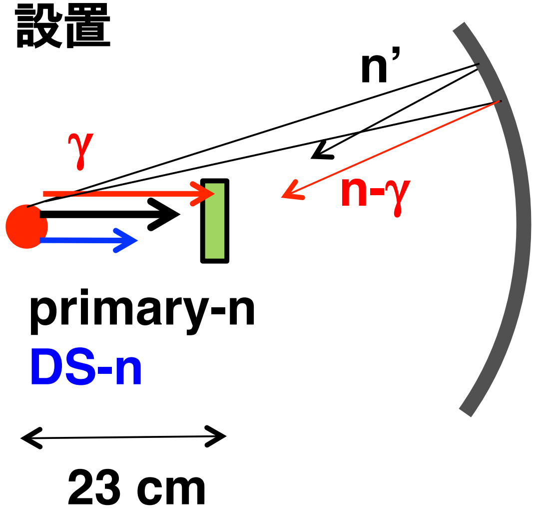
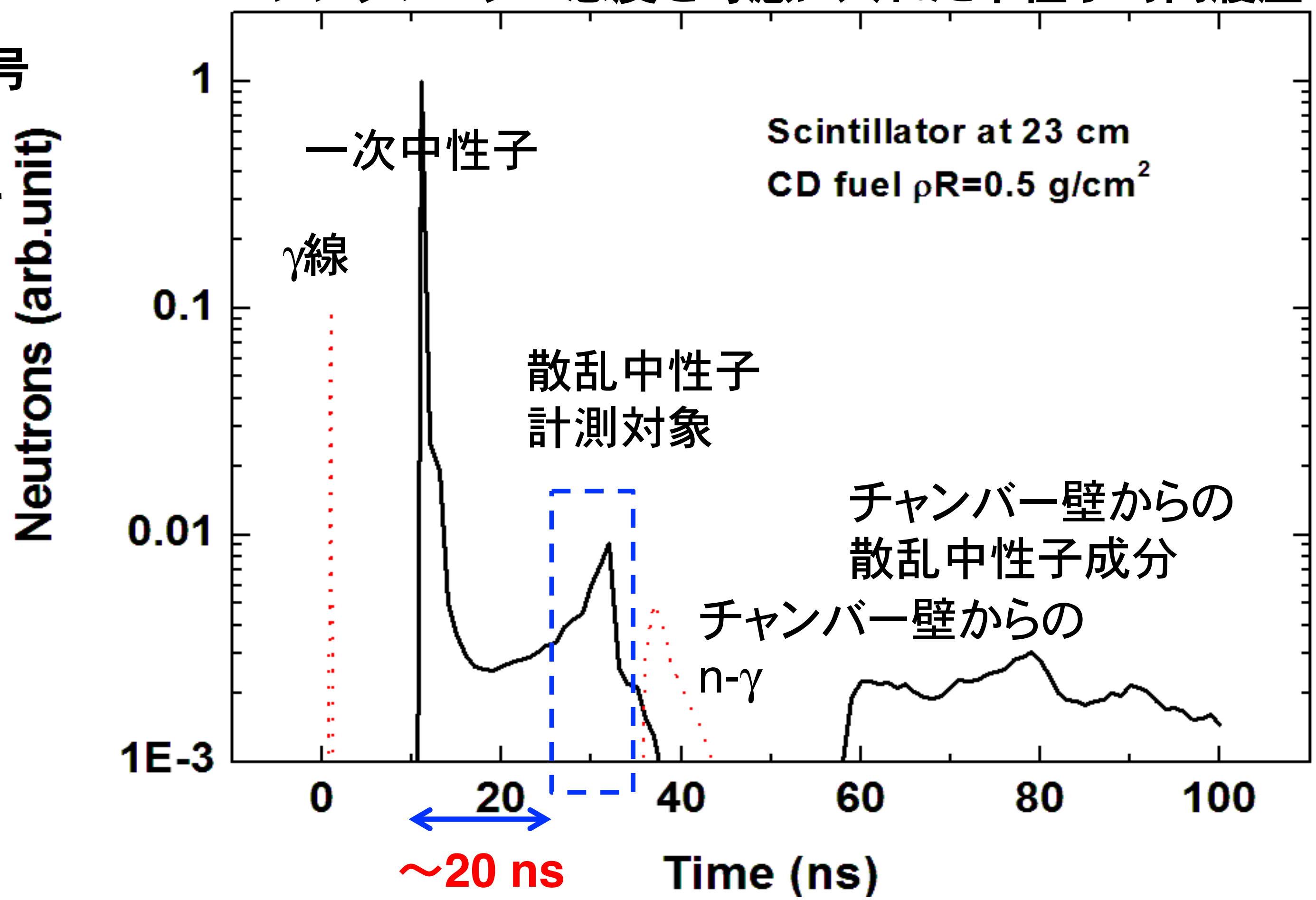
感度・バックグラウンド信号切り分けの観点からシンチレーターは23cmに設置



^{6}Liシンチレーター感度を考慮に入れた中性子時間履歴



20nsの間に十分減衰出来る^{6}Li高速シンチレーターが必要

Fast response ^{6}Li glass scintillator

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Fall time (peak - 10%)
120 ns→ 10 ns！

Ce (3+) → Pr(3+)

Conventional ^{6}Li glass

Saint-Gobain (KG2)

- **Host: SiO_2 - Li_2O glass**
- **Fluorescent ion: Ce (3+)**

emission 400 nm

decay const t_1 = 50 ns

+ longer tail

fall time : (peak - 10%) 12

Lithium Glass Array for neutron detection, developed and manufactured [illegible]

New material

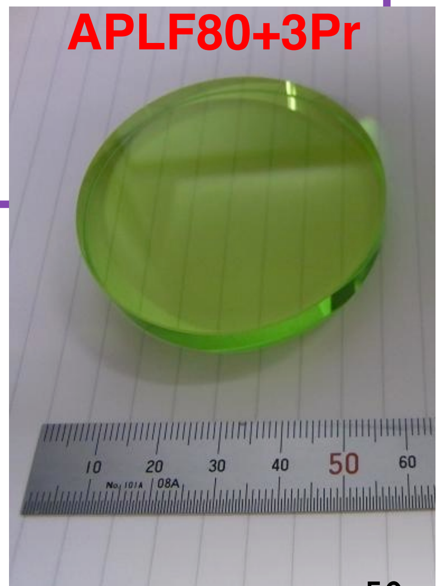
- **Fluorescent ion：Pr (3+)**

emission 250 nm

(lifetime $\tau \propto \lambda^3$)

- **Host：LiF glass**

(UV transparent)



Manufactured by
T. Murata, Kumamoto U.

Fast response ^{6}Li scintillator APLF 80+3Pr

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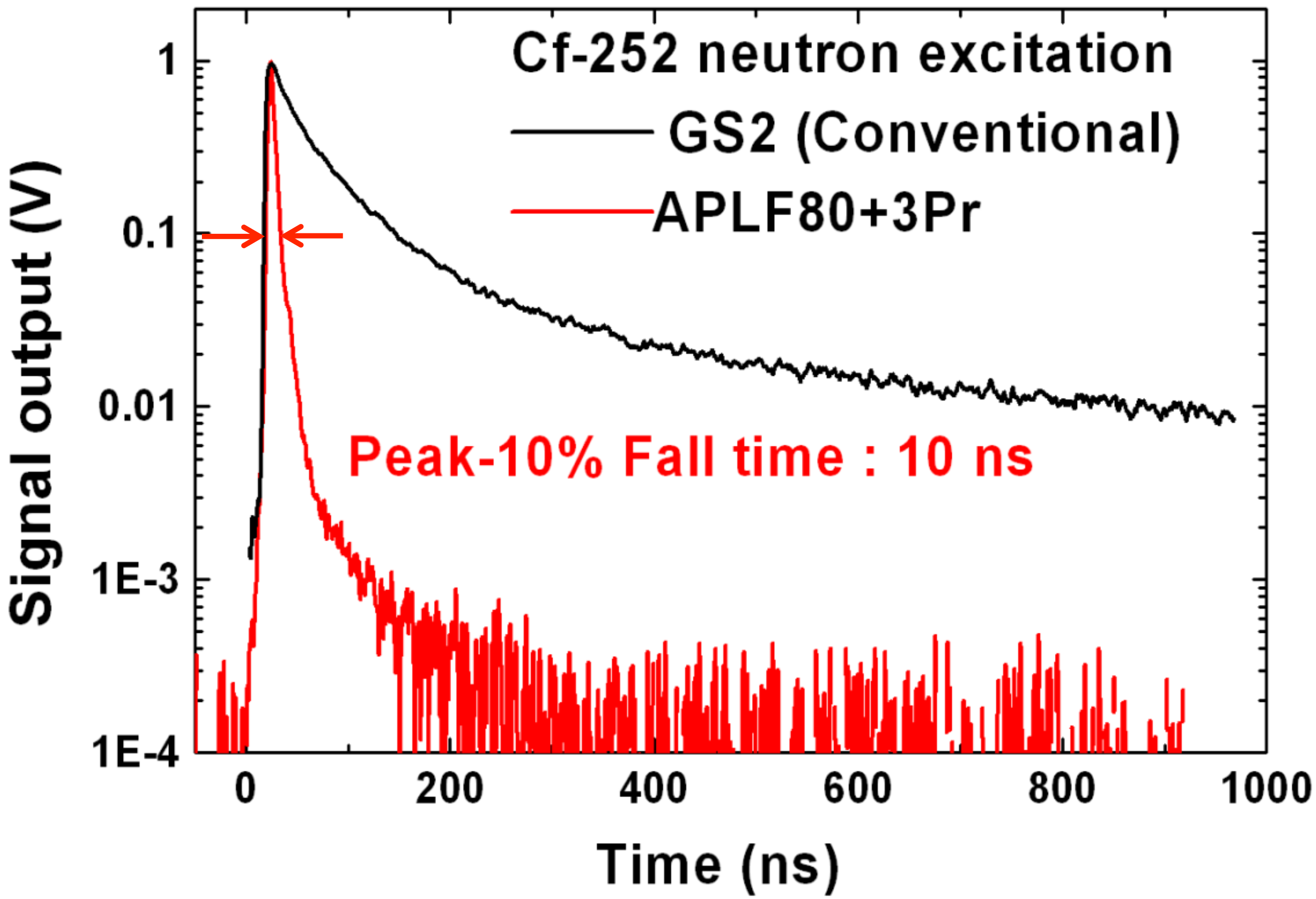
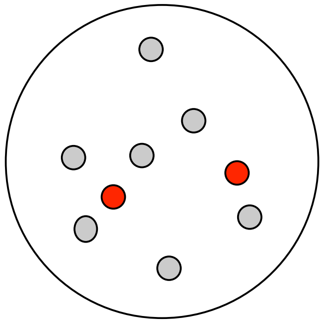
中性子源を用いた測定

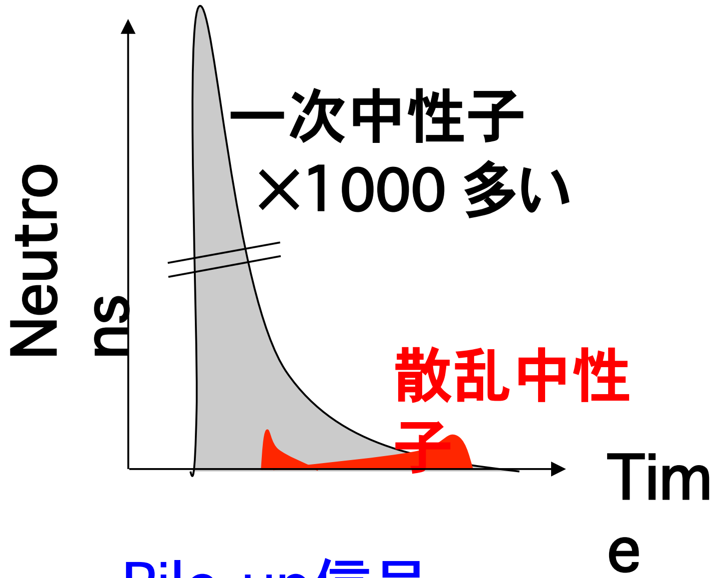


Y. Arikawa et al., Rev. Sci. Inst. 80, 113504 (2009)

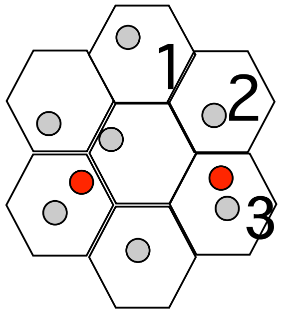
多チャンネルカウントモードで一次中性子信号を緩和

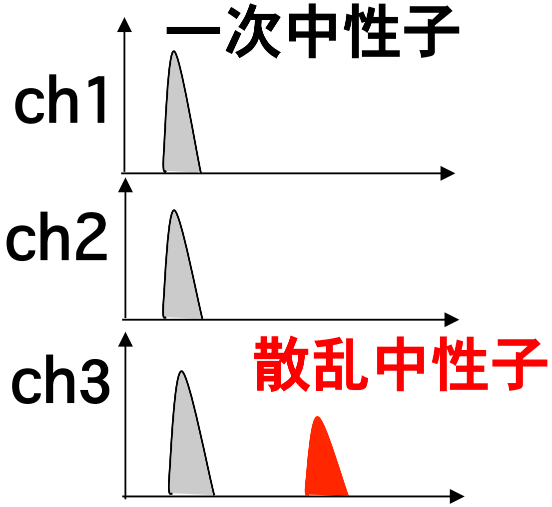


● 一次中性子
● 散乱中性子



Pile-up信号





Count-mode信号

N.Izumi, Doctoral thesis, Osaka Univ. 1997

シンチレーターアレー

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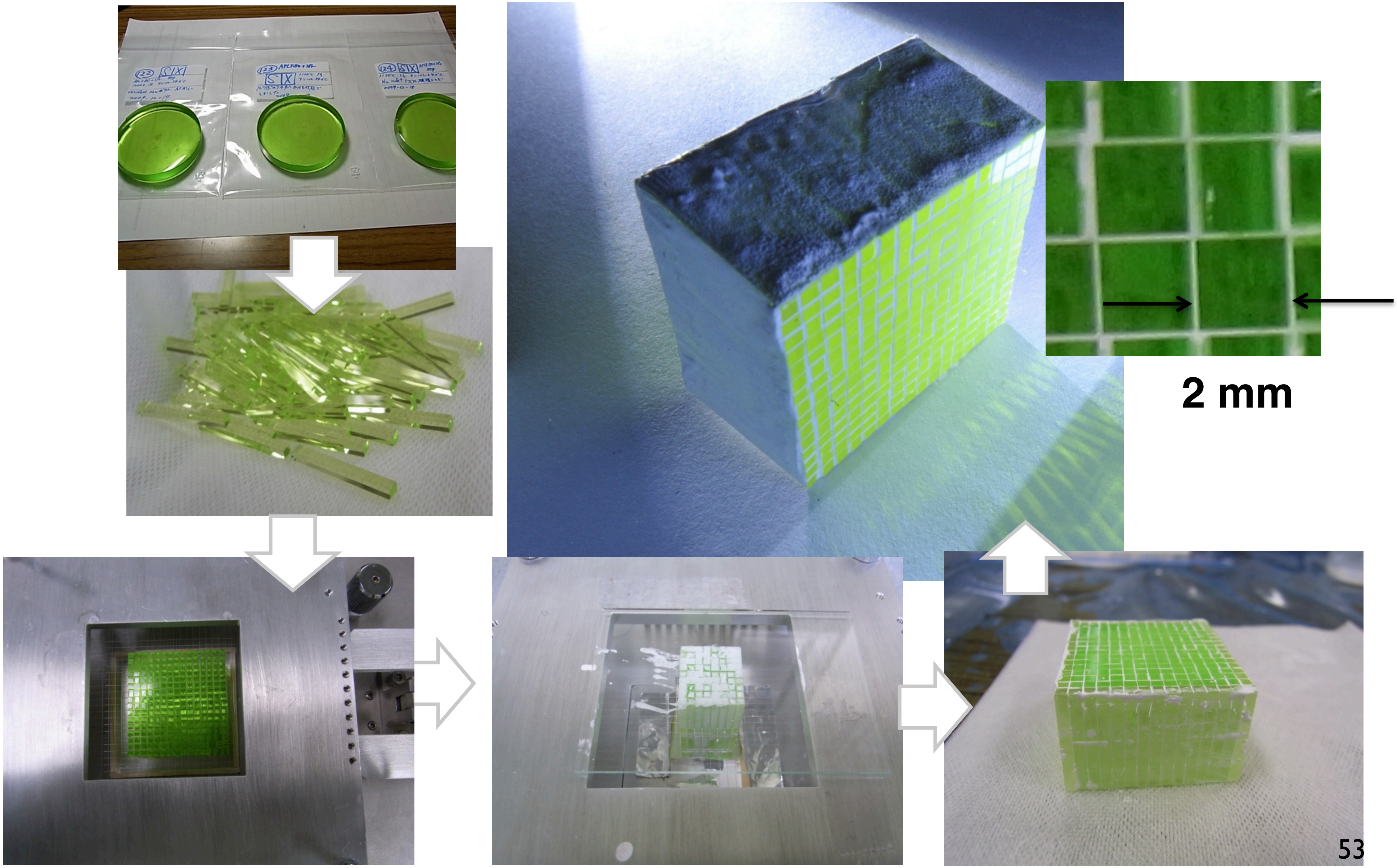
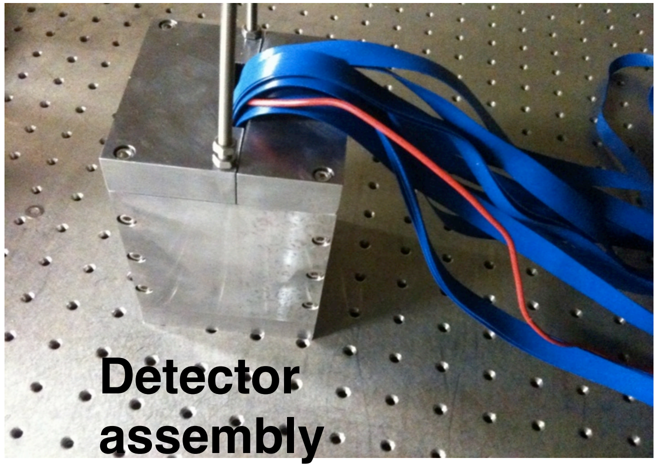
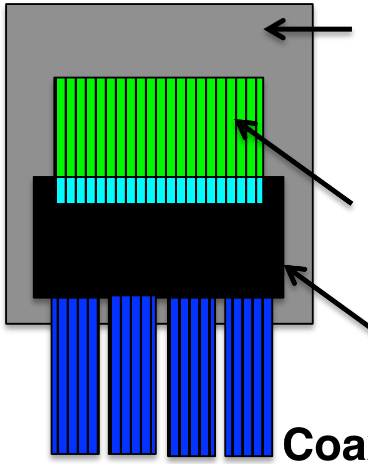
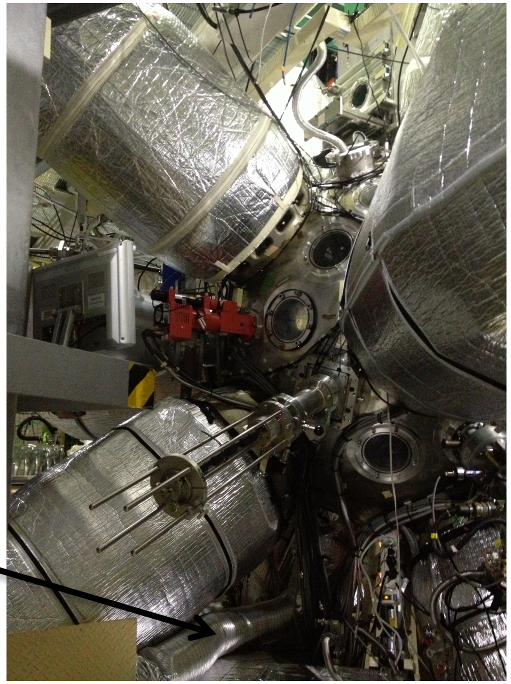


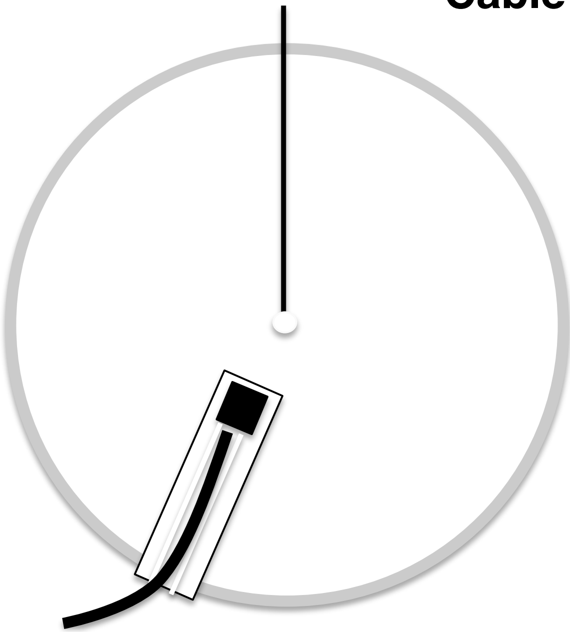
多チャンネル計測部





Detector
inserting port





多チャンネルカウントモード計測を実現

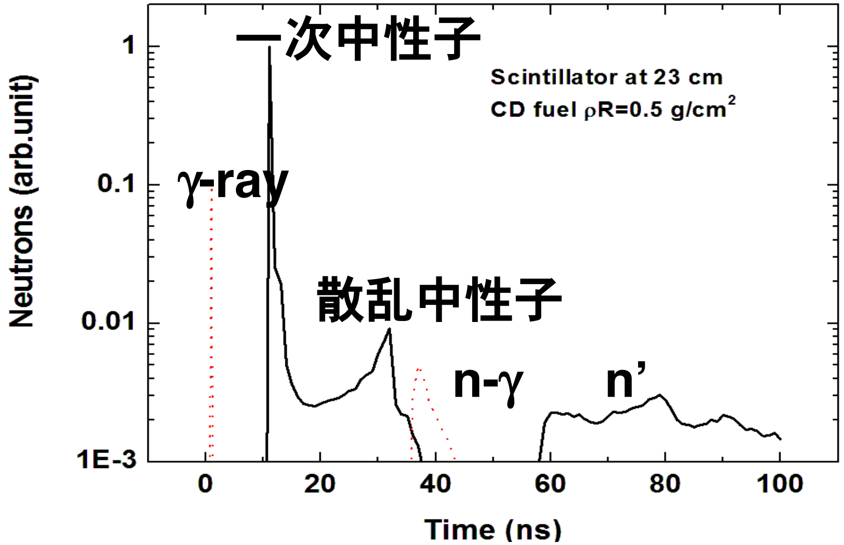
STRUCK
2GHz / 10 bit digitizer
8ch / modules

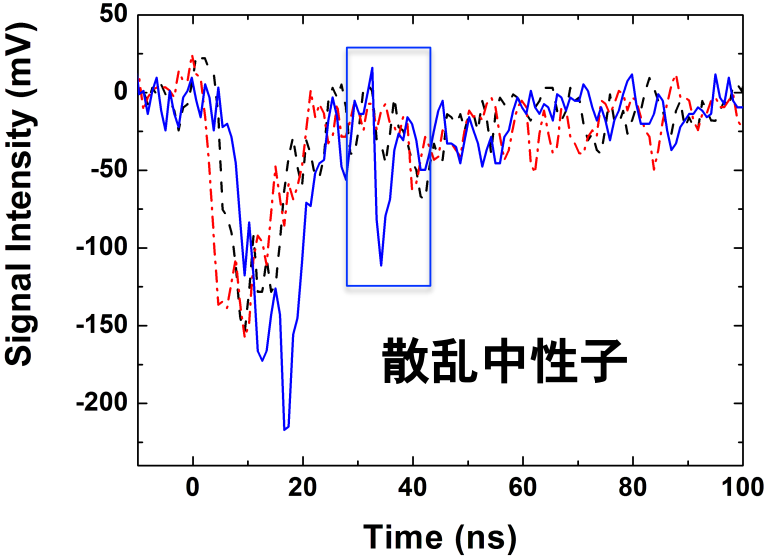
散乱中性子の検出に成功

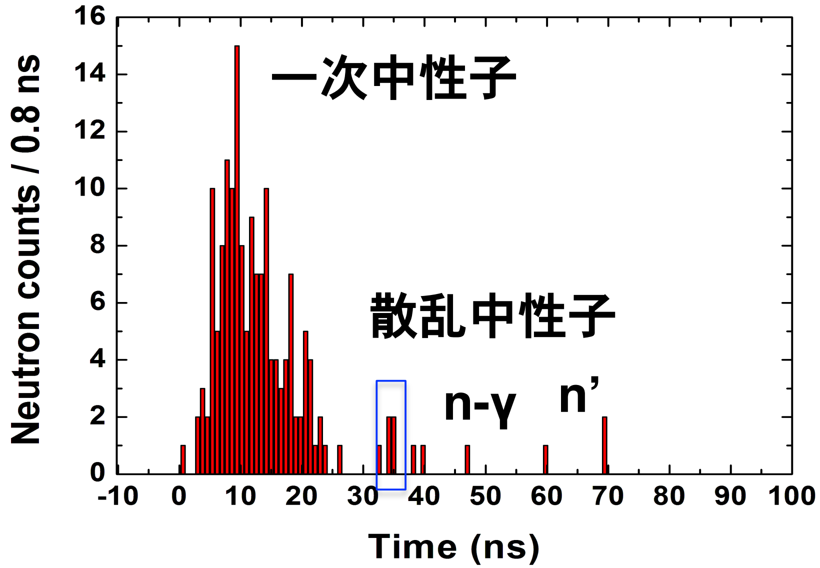
ILE OSAKA

3 μmt CD shell
Al coat
9 beam implosion
260.8J/beam
2347J total

before
coating







$\rho R = 1.6 \cdot \frac{DSN}{pN} = 0.019$ g/cm^2 for D only, 0.13 g/cm^2 for CD

散乱中性子計測:まとめ

ILE OSAKA

1.慣性核融合や核科学実験では1MeV以下の低エネルギー中性子計測が必須となる。

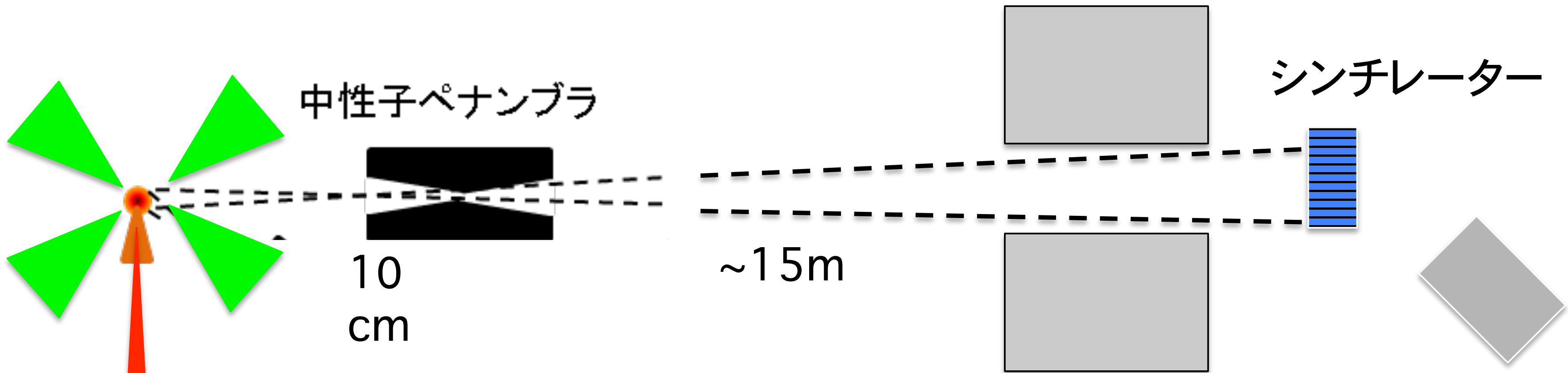
2. 核融合散乱中性子計測を実現するために、多チャンネル式、高速^{6}Liシンチレーションガラスを用いた多チャンネルカウントモード計測器を開発した。

3. 激光12号実験において、散乱中性子計測の検出に成功した。

4.今後は計測の信頼性を議論できるよう、実験データを蓄積する。

4c. レーザー核融合における中性子画像計測

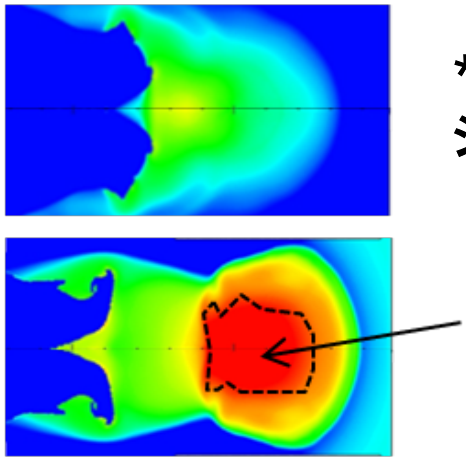
ILE OSAKA



1次中性子発生領域サイズ～50 μm
1次中性子発生時間　～100 ps

*OMEGAで使用されているもの

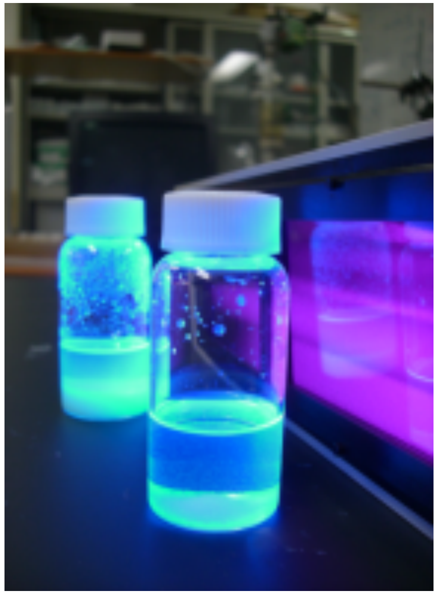
計測画像イメージ図
中性子発生率分布



***PINOCOによるシミュレーション**

加熱により中性子発生率が増大した領域

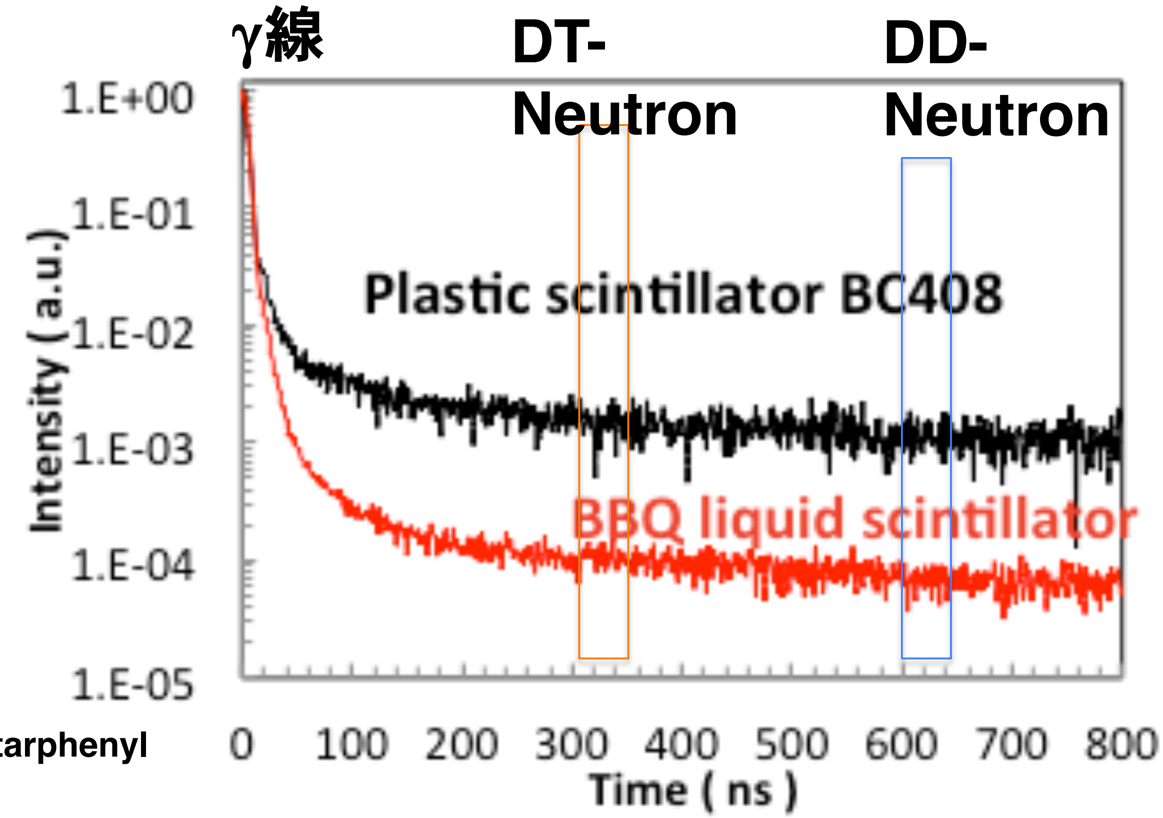
高速減衰液体シンチレーターを採用



scintillation：
BBQ (used for dye lasers)
4,4’’’-Bis-(2-butyloctyloxy)-p-quatarphenyl

host：p-Xylene

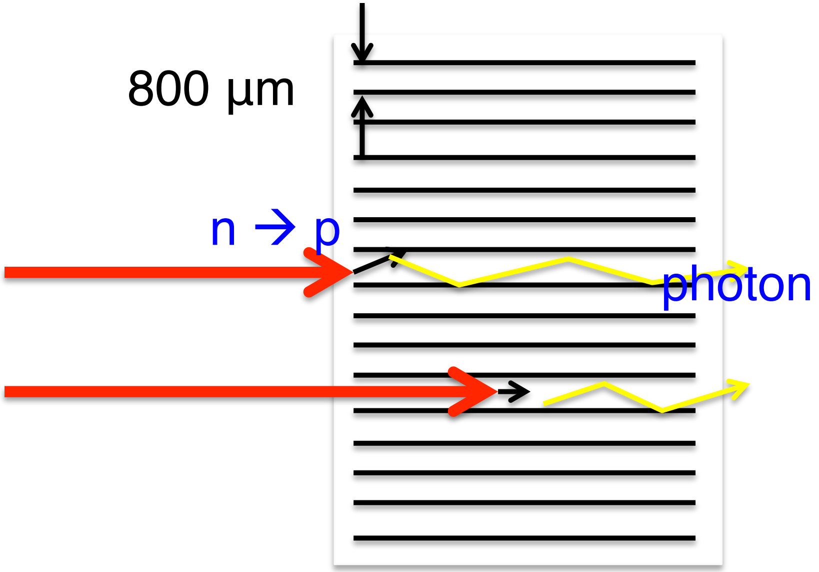
Quenching by oxigen



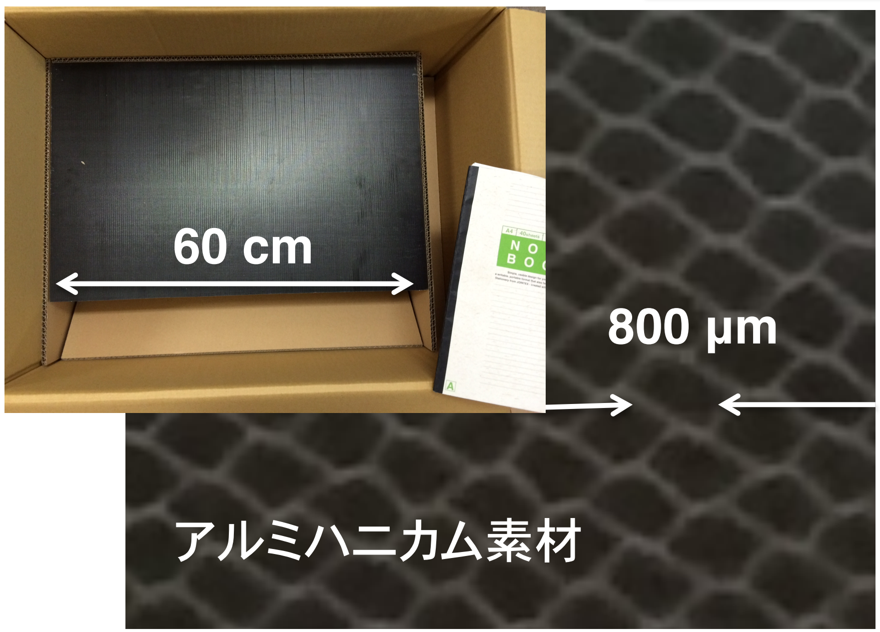
高速点火の強烈なγ線に対応できるよう、
高速減衰液体シンチレーターを採用

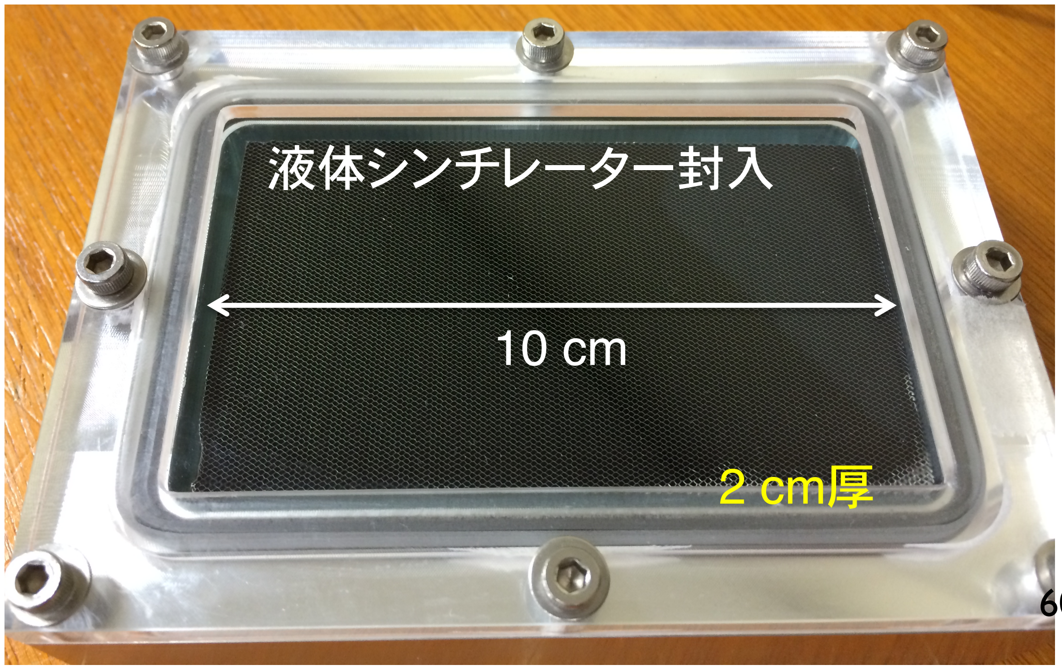
Nagai, et al., Jpn. J. Appl. Phys. 50, 080208 (2011)

中性子→可視光変換部

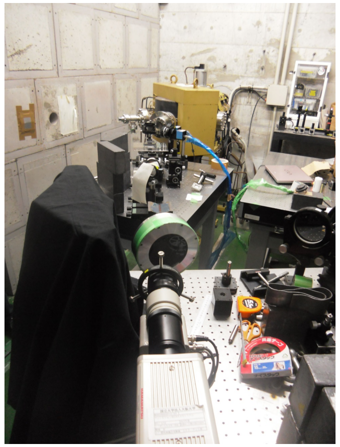


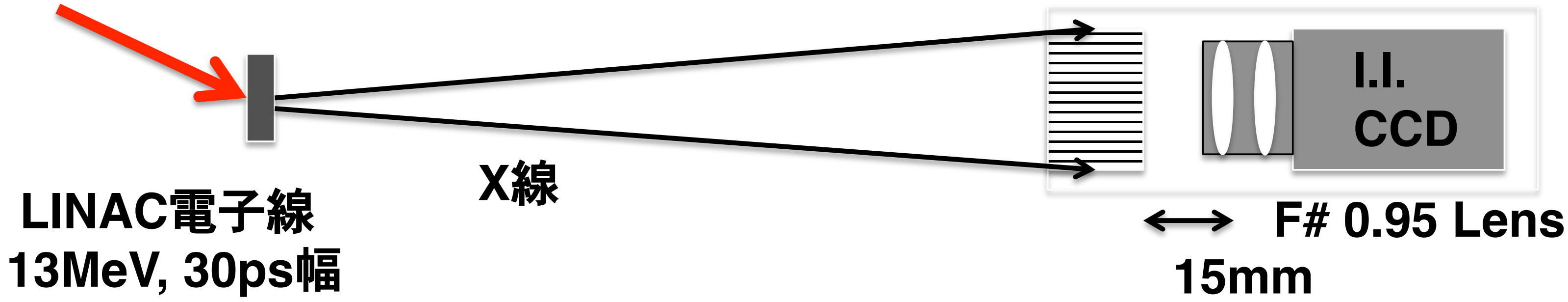
14MeV中性子入射時の
プロトンの飛程(横向き)
~800 μm





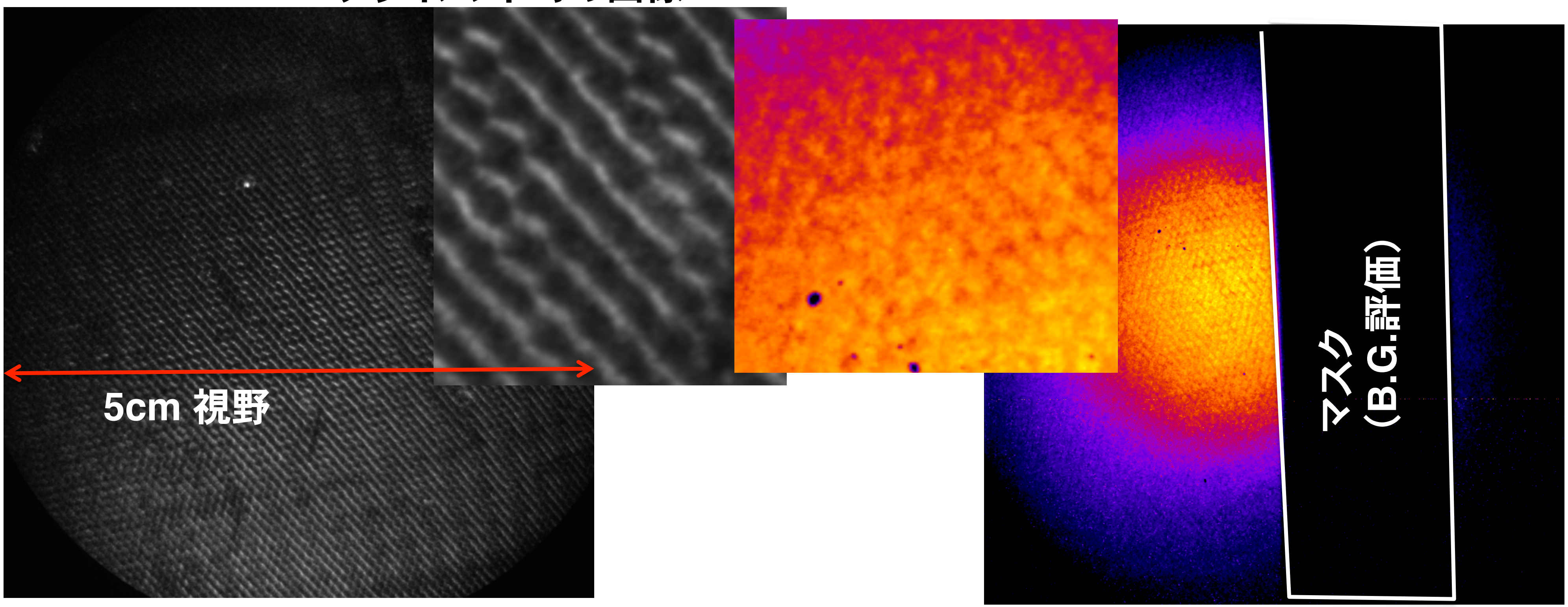
パルスγ線でシンチレーターアレー発光パタンを観測





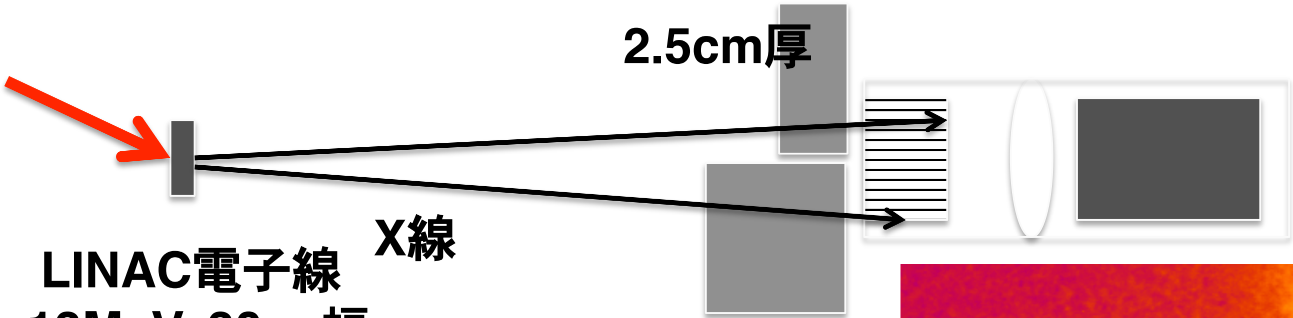
可視光
アライメント時の画像

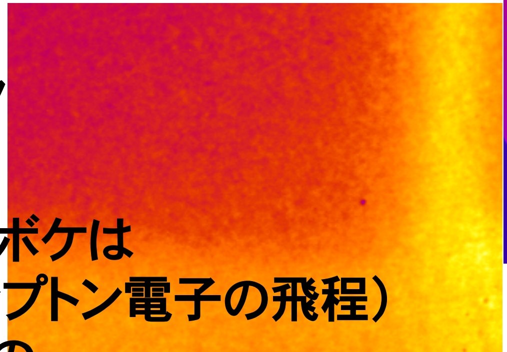
シンチレーション画像



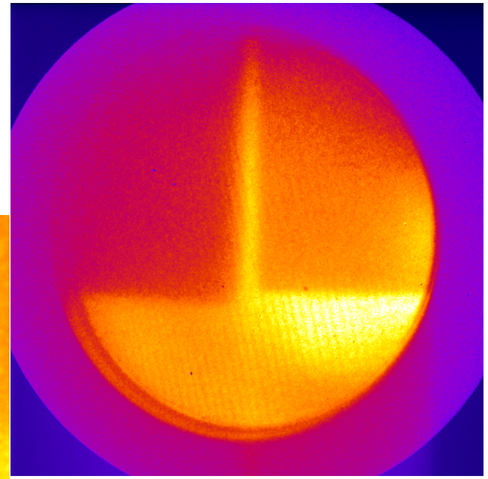
γ線イメージング撮影に成功

ILE OSAKA



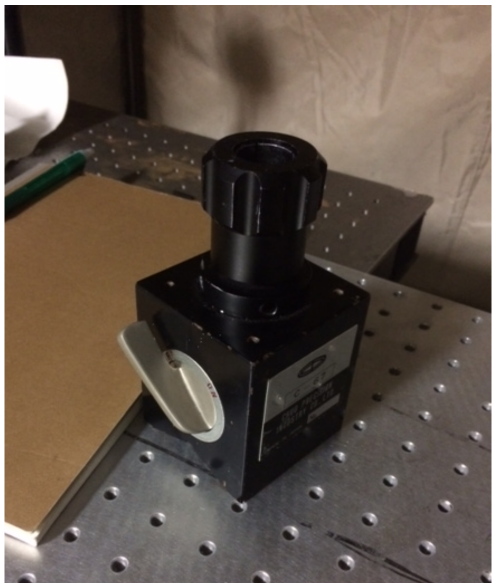


エッジのボケは
γ線（コンプトン電子の飛程）
によるもの

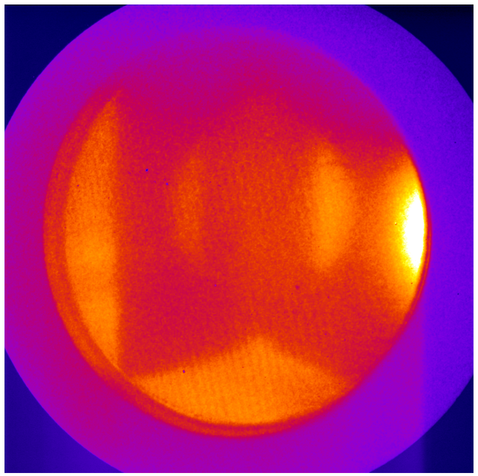


5センチメートルの鉛を透過
→数MeV以上のX線

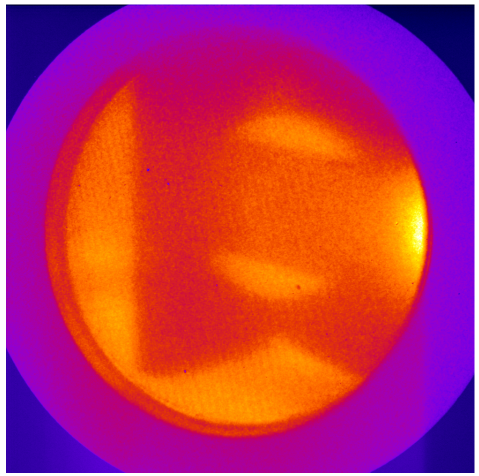
光学マウント
10cm



マグネット Off

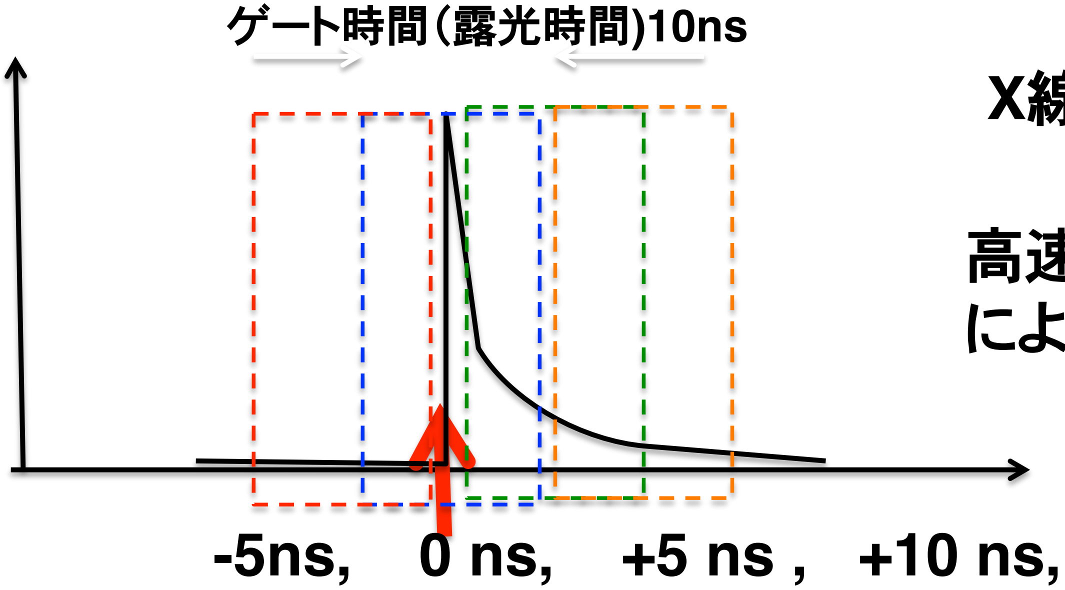


マグネット On



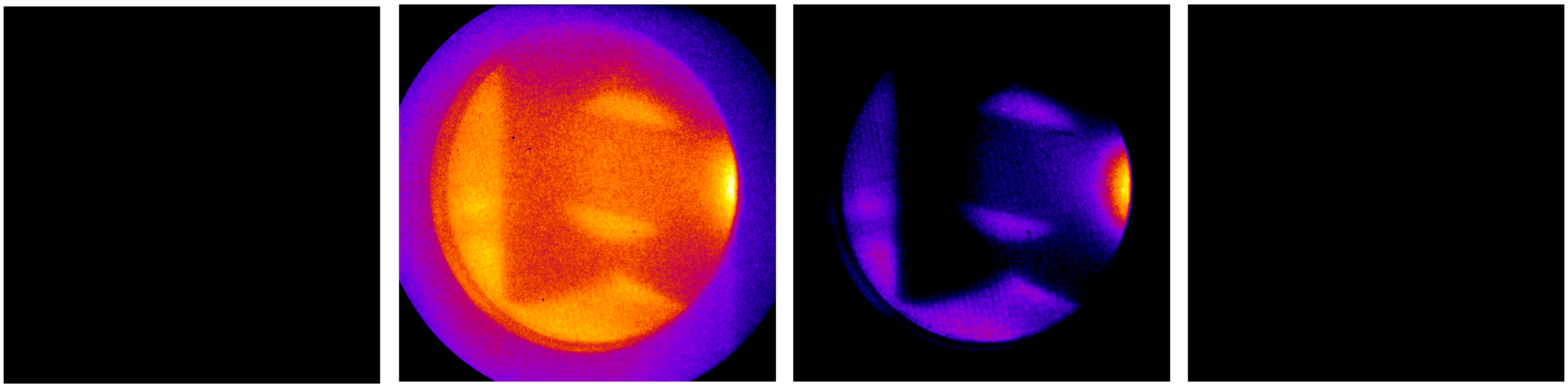
5nsの高速シャッターを実証

ILE OSAKA



X線パルス幅30ps

高速応答液体シンチレーター
によって高速化を実現



-5 ns　　0 ns　　5 ns　　10 ns

高時間分解中性子画像計測:まとめ

ILE OSAKA

1. 高速減衰液体シンチレータを用いた高時間分解(ゲート)中性子画像計測器を開発した。

2. 10cm級検出器上で800 μmの空間分解能を実現した。

3. 5 nsの高速ゲートを実現した。

4. LINAC装置のγ線での動作試験に成功した。

5. 激光12号実験におけるエネルギー選択(ToF)した中性子画像計測のみならず、様々な中性子画像計測に応用可能である。

5. Summary of the talk

ILE OSAKA

1. **FIREX project**
   Fast Ignition research
   Experiments with LFEX laser

2. **Ultra-fast X-ray imaging diagnostics**
   Sampling-image x-ray streak camera

3. **Hard x-ray and EMP harsh environment**
   X-ray framing cameras
   X-ray streak cameras

4. **Neutron diagnostics**
   Neutron detectors in (γ, n) environment
   Scattered neutron measurement
   Time-resolved neutron imaging

5. ***Various new plasma diagnostic instruments are working very well in Fast Ignition laser fusion experiments.***