Neutron lifetime measurement at J-PARC

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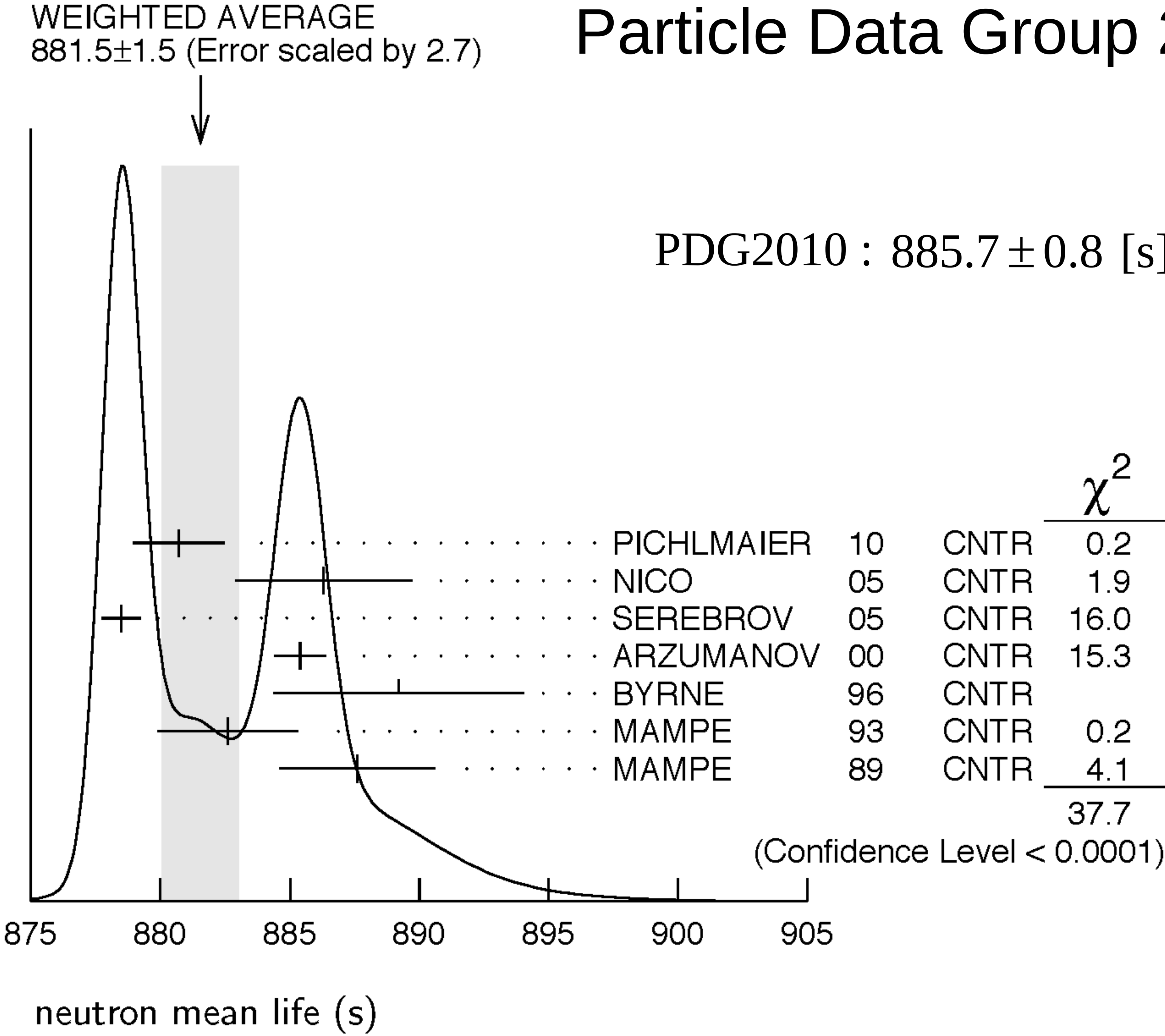
On behalf of the NOP collaboration

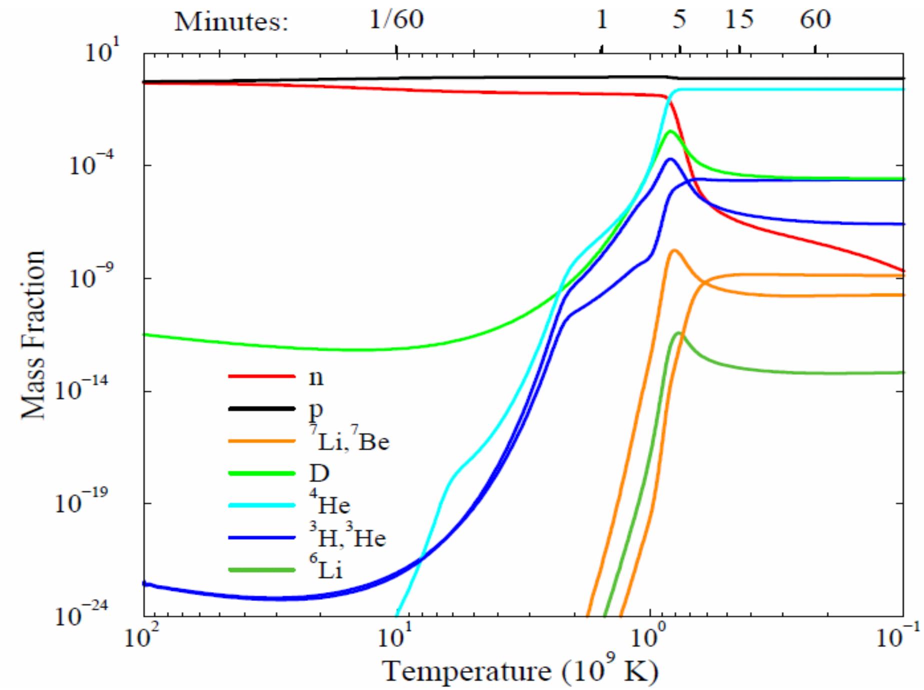
ISINN-20, Alushta, Ukraine, May 21 – 26, 2012

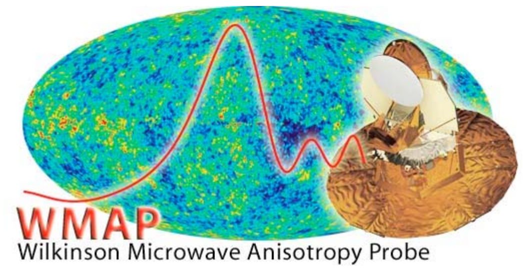
Particle Data Group 2011

$\mathrm{PDG2010}: 885.7 \pm 0.8$ [s]



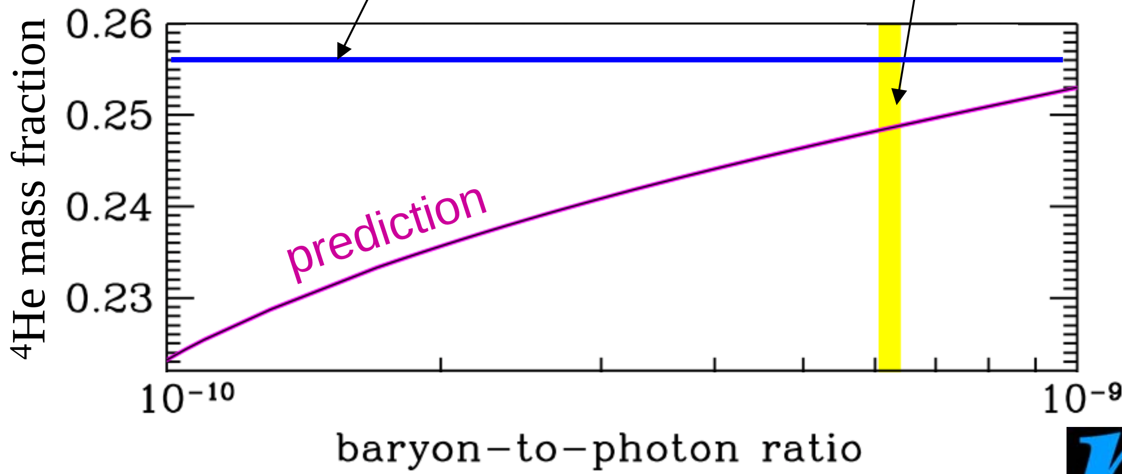
Big Bang nucleosynthesis



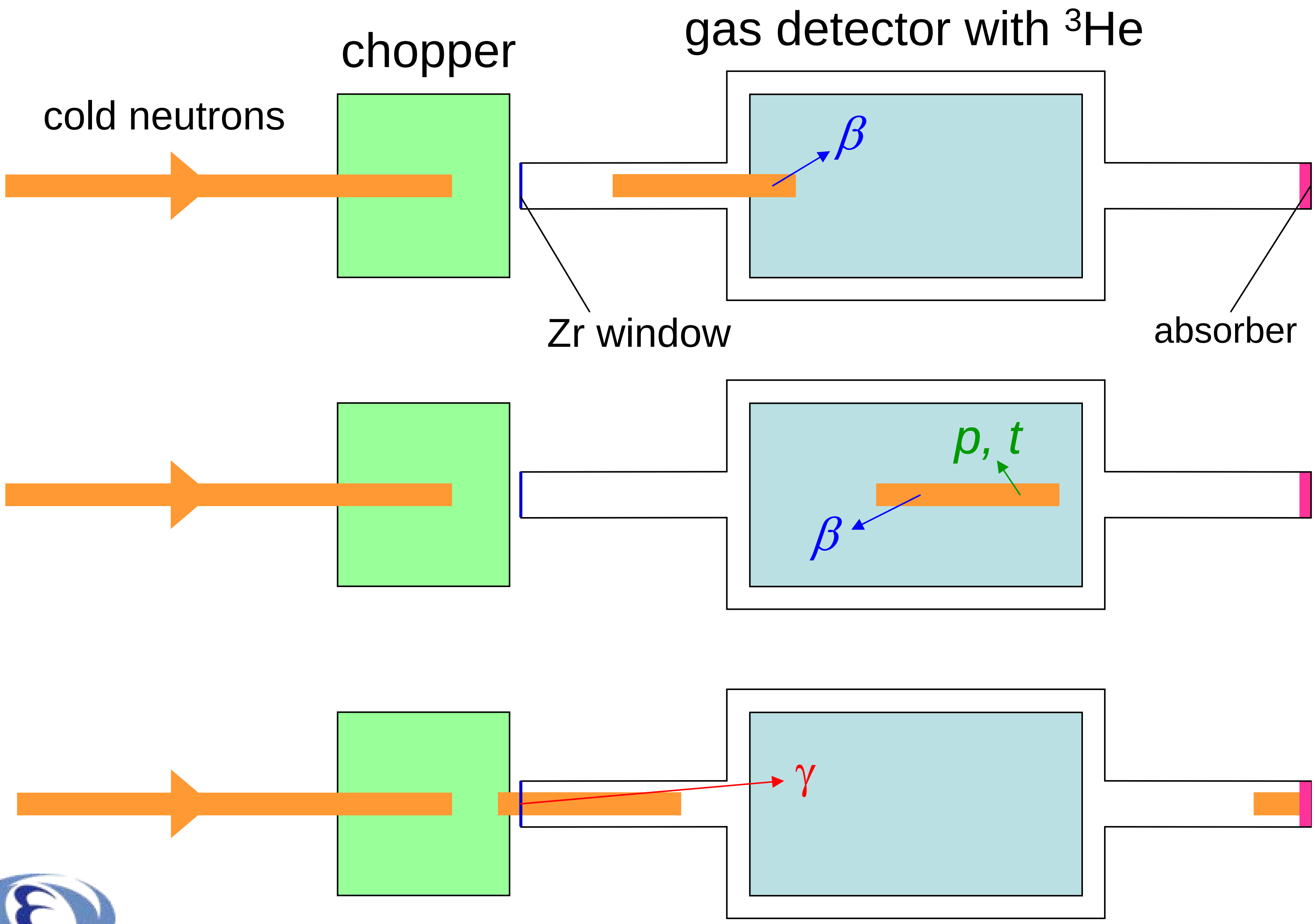


Observation (Izotov, 2010)

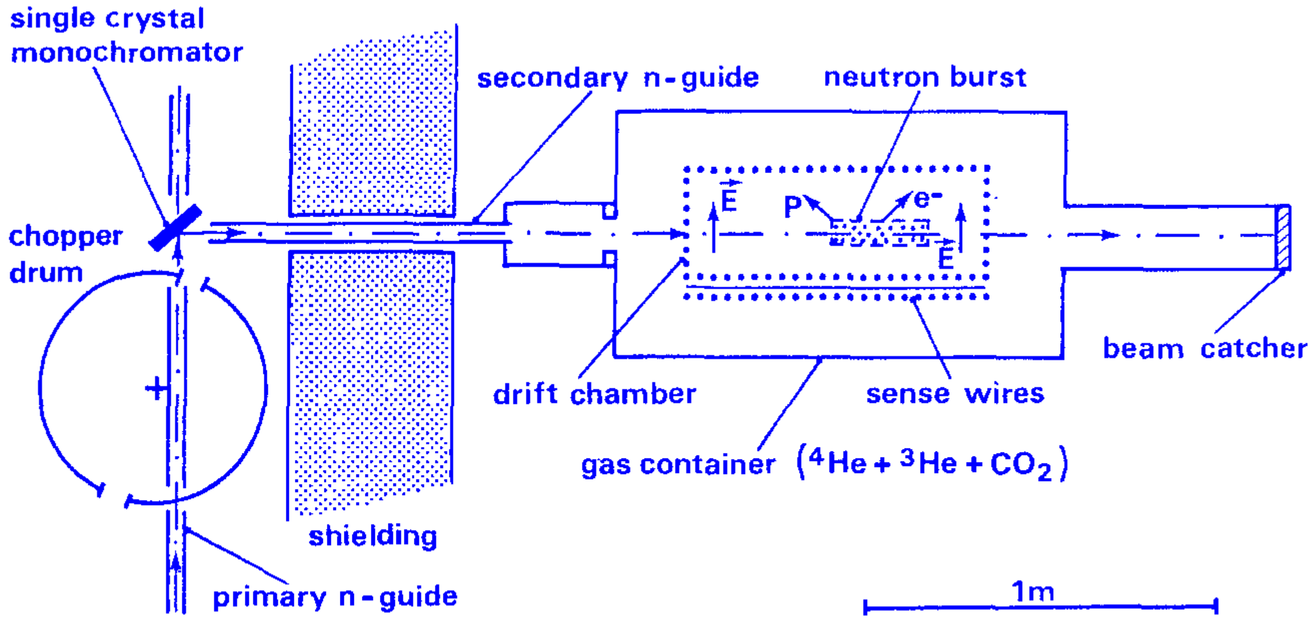
$$\tau_n = 885.4 \pm 0.9 \ [\mathrm{s}]$$



Detect decay electrons in flight



Original work



Kossakowski *et al.*, Nucl. Phys. **A503**, 473 (1989)
Grivot *et al.*, NIM B **34**, 127 (1988)

$$\tau_n = 878 \pm 27 \pm 14 \ \ [\mathrm{sec}]$$

$$\Delta\tau_n \sim 1 \ \ [\mathrm{sec}]$$

With advanced technologies, such as neutron source, electronics, computer, ...

Neutron lifetime

of decay electrons (detected)

$$N_\beta = \varepsilon_\beta N \frac{L}{\tau_n \upsilon}$$

of ^{3}He(n,p) events

$$N_{He} = \varepsilon_{He} N \rho \sigma L$$

N : # of neutrons

L : fiducial volume (length)

τ_n : neutron lifetime

υ : neutron velocity

ε_β : electron detection efficiency

σ : neutron capture cross section of ^{3}He

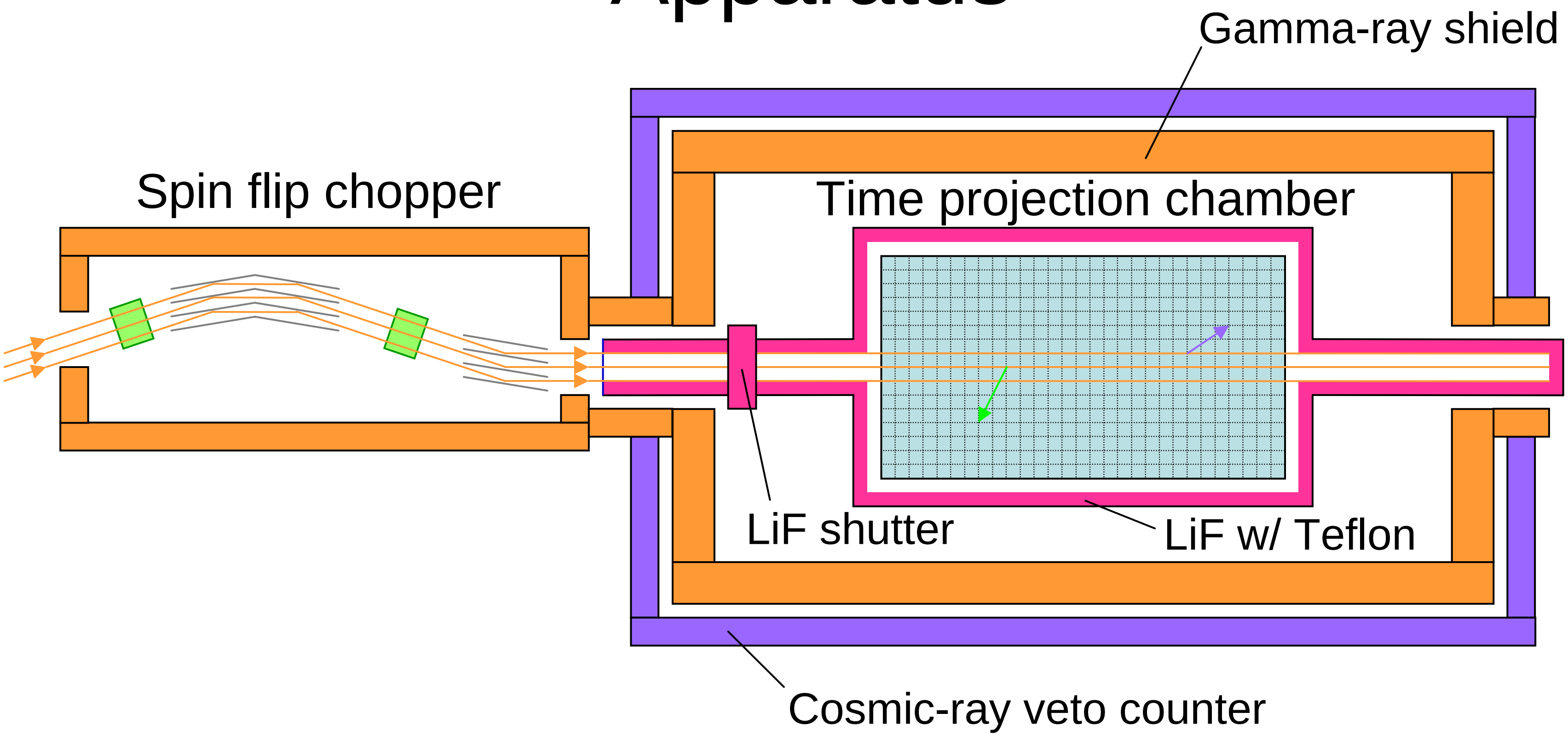
ρ : ^{3}He density

ε_{He}: ^{3}He(n,p) detection efficiency

$$\boxed{\tau_n = \frac{1}{\rho\sigma\upsilon}\left(\frac{N_{He}/\varepsilon_{He}}{N_\beta/\varepsilon_\beta}\right)}$$

$$\sigma\upsilon = \text{const.}$$

Apparatus



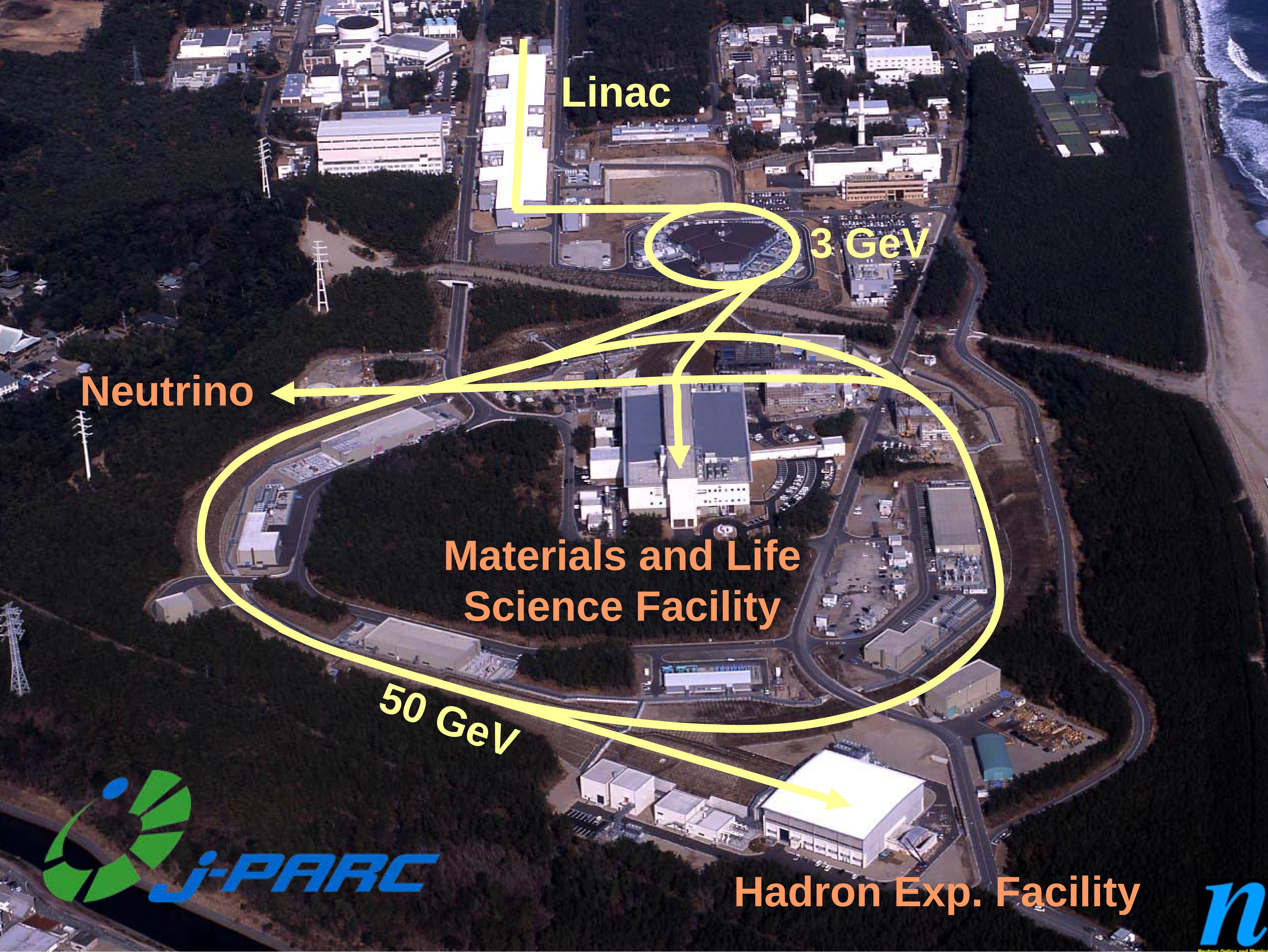
Decay in flight : detection of decay electrons by TPC (MWPC)

Neutron beam : chopped into short bunches → define neutron position

TPC gas : ^{4}He + CO^2 + ^{3}He

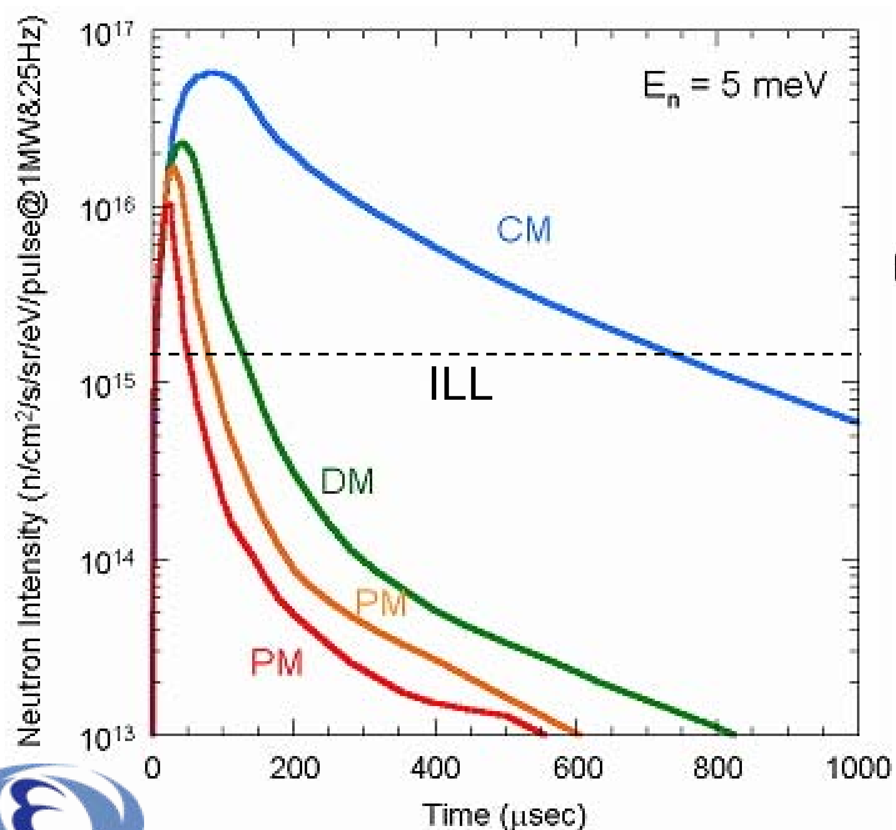
Background : cosmic rays, Compton gammas, scattered neutrons, ...

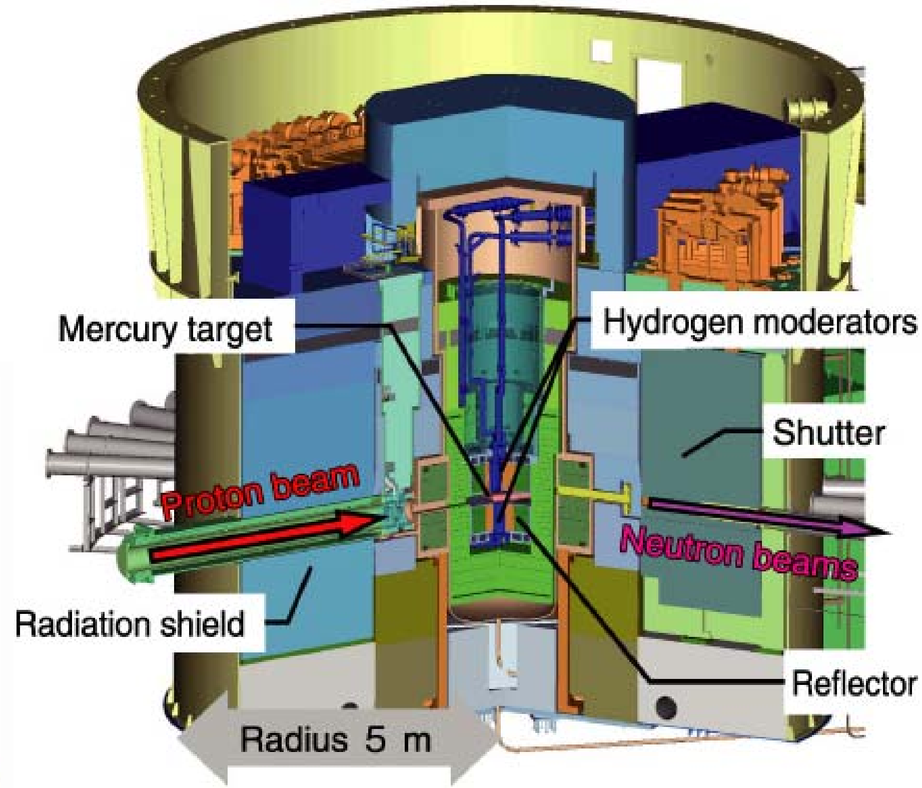

J-PARC


Linac
3 GeV
Neutrino
Materials and Life
Science Facility
50 GeV
Hadron Exp. Facility
J-PARC

J-PARC pulsed spallation neutron source

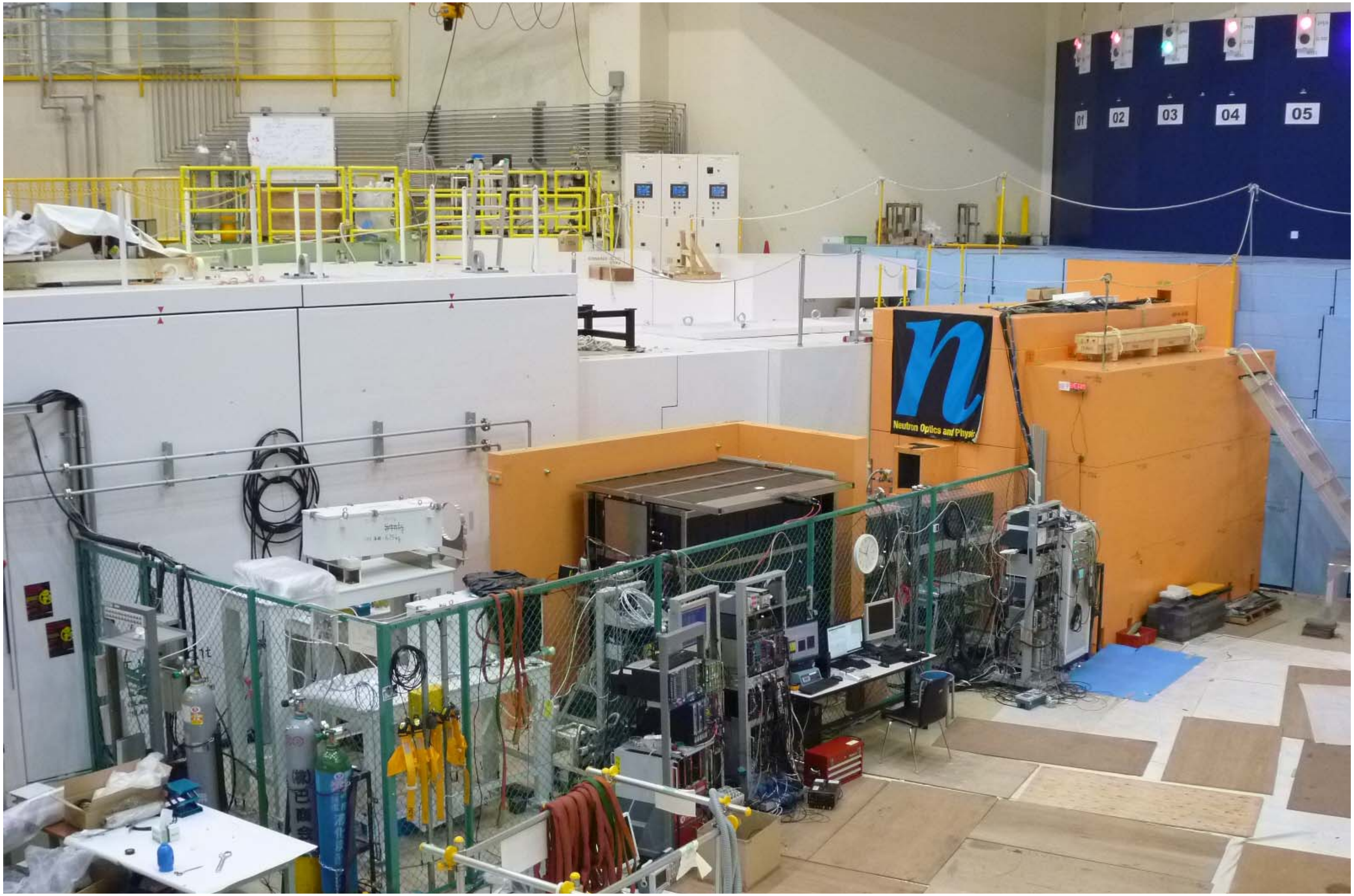
Compared to the ILL cold source
peak intensity x 40
time-averaged intensity x 1/4





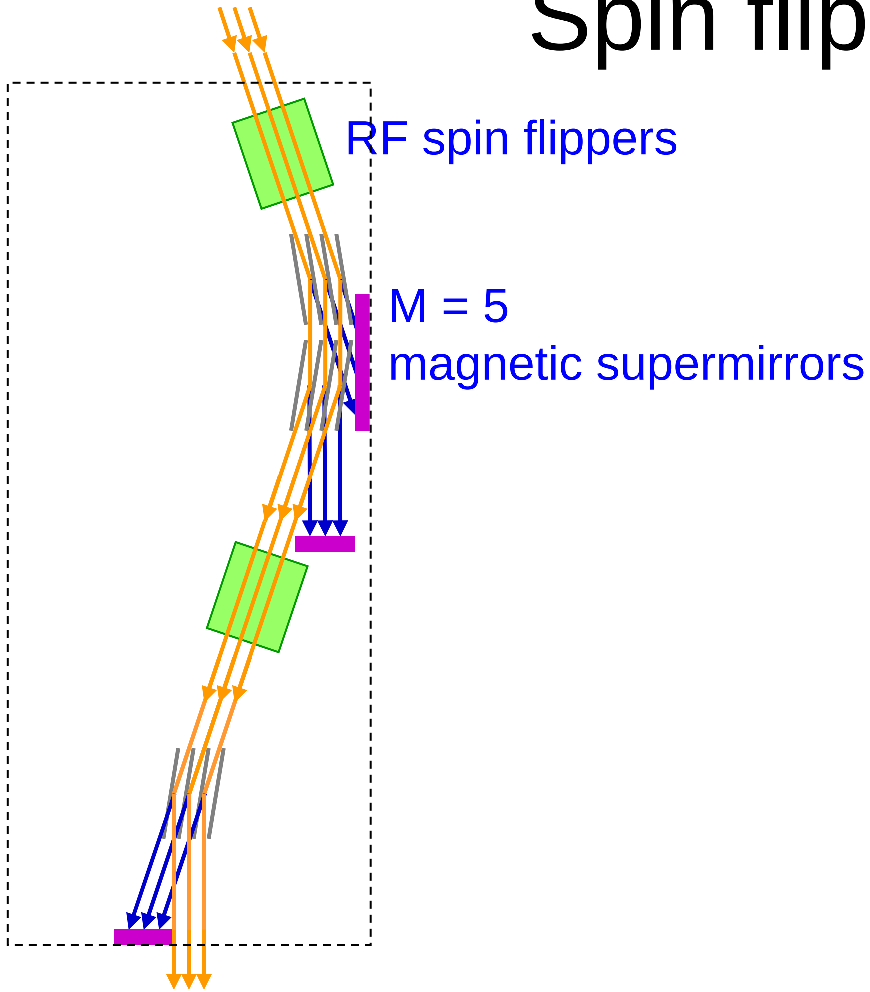
1 MW (in design)
200 kW – 300 kW (as of 2012)
25 Hz

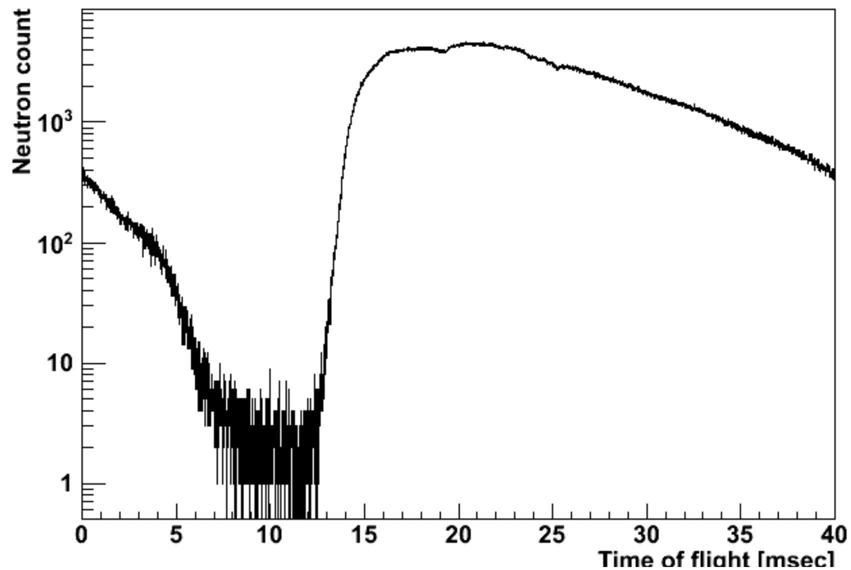
BL05 at J-PARC

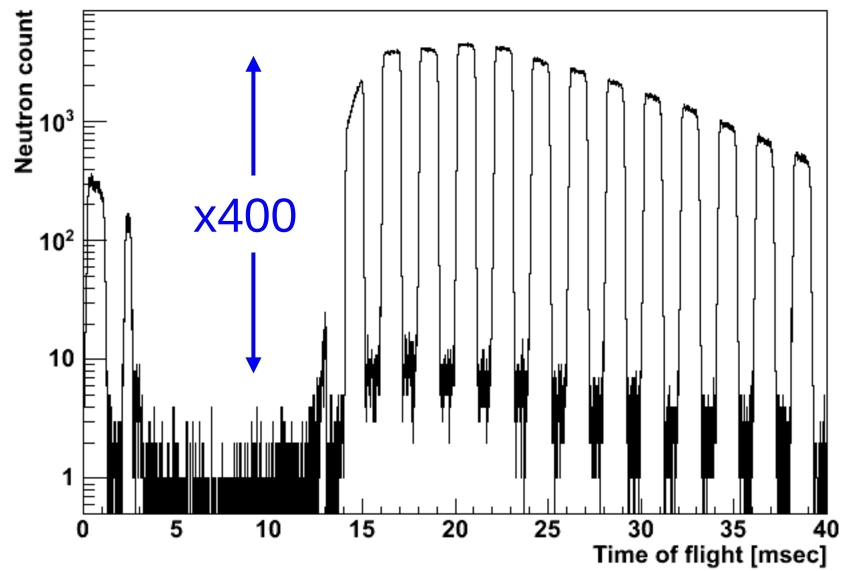


High energy direct beam is shut by the beam dump.
Only slow neutrons are delivered to the TPC by the supermirror bender.

Spin flip chopper

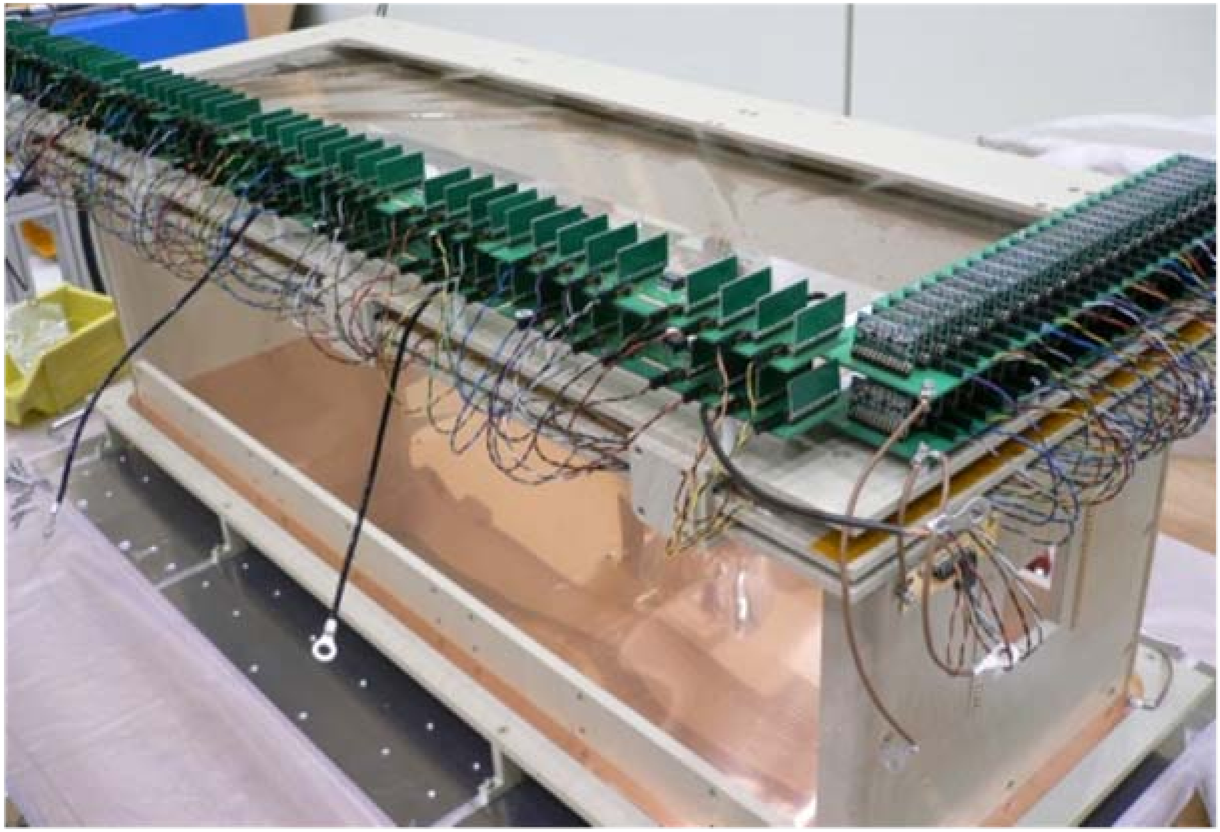






Chops into short bunches
with short rise and fall times
Defines neutron position
Reduce gammas from the window

Time projection chamber



30cm x 30cm x 100cm

MWPC w/ field cage
6 mm wire pitch

$^4He: CO_2$ = 85:15

^6LiF liner

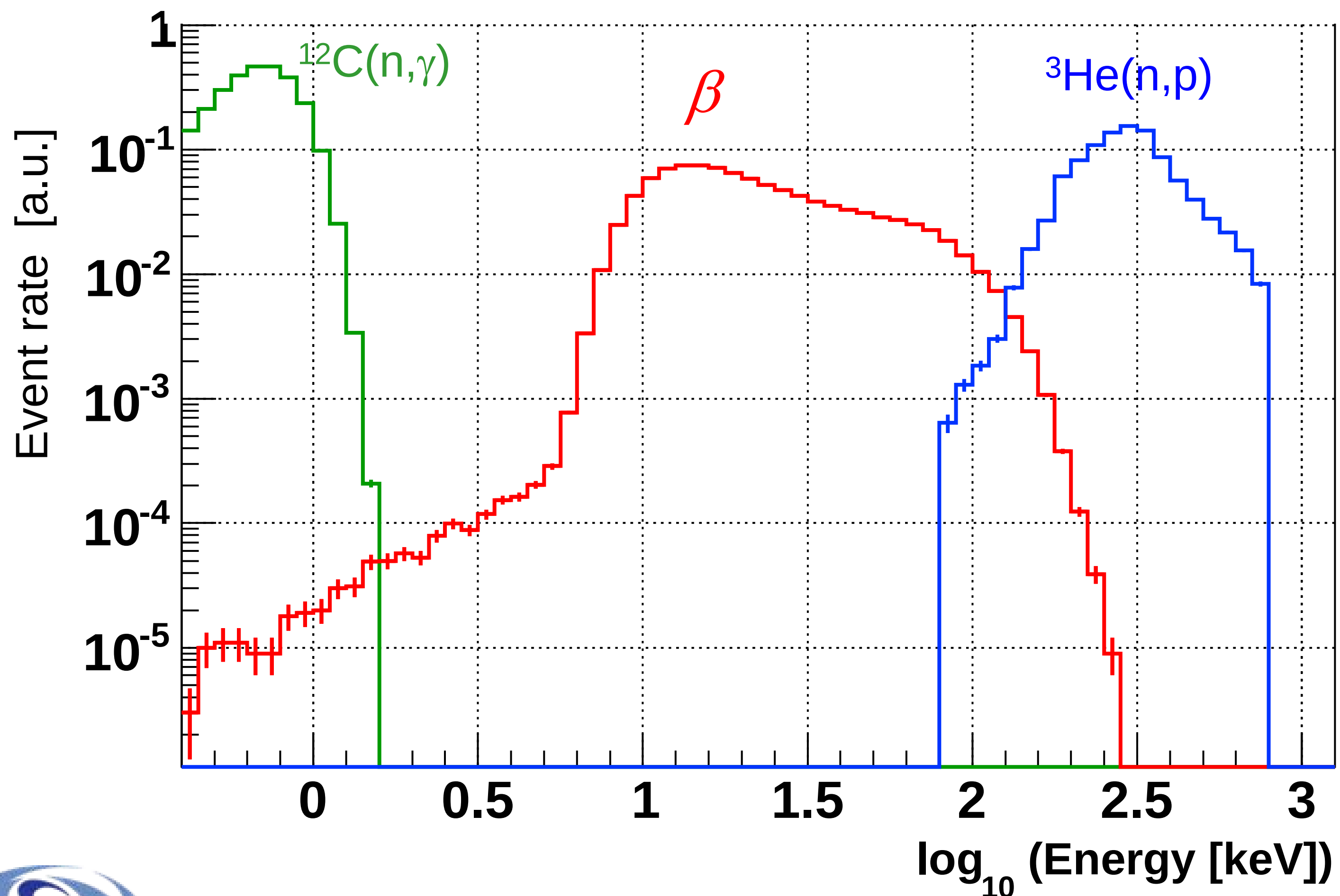
pre-amps

DAQ 128ch
65MHz 12bit FADC
1GHz multi-hit TDC
E > 200 eV

Chemical synthesis plastic - PEEK (polyetheretherketone)
No radioactive contamination → minimize gamma background

Detection of decay electrons

$$\varepsilon_\beta > 99.9\% \qquad E_\beta > 1.4\,\mathrm{keV}$$



$^{3}He(n,p)$

$^{12}C(n,\gamma)$

$^{14}N(n,p)C$

Event topology

Gas analysis

Different
gas pressure

Signal and background event rates

	220 kW	1 MW
Signal rate	0.1 cps	0.4 cps
$\times$ duty factor (40ms/2.8ms)	1.4 cps	5.7 cps

Background source	Rate
Natural activity inside TPC	0.1 cps
Natural activity outside TPC	0.8 cps
Cosmic rays	0.5 cps
Neutron gamma (upstream & neighbor)	0.5 cps
Scattered neutrons inside TPC	0.003 cps

Systematic uncertainties

$$\boxed{\tau_n = \frac{1}{\rho\sigma\upsilon}\left(\frac{N_{He}/\varepsilon_{He}}{N_\beta/\varepsilon_\beta}\right)}$$

$$\sigma\upsilon = \text{const.}$$

σ : ^{3}He capt. cross section	0.13%	($5333 \pm 7\,[\text{barn}]$)
ρ : ^{3}He gas density	0.5%	
N_2 outgassing	0.5%	
Gas temperature	0.2%	
Detection efficiencies	0.1%	
Event selection	< 0.1%	

Statistical error

Beam power	220 kW	1 MW
Signal event rate	0.1 cps	0.4 cps
Stat. error (150 days)	0.8%	0.2%

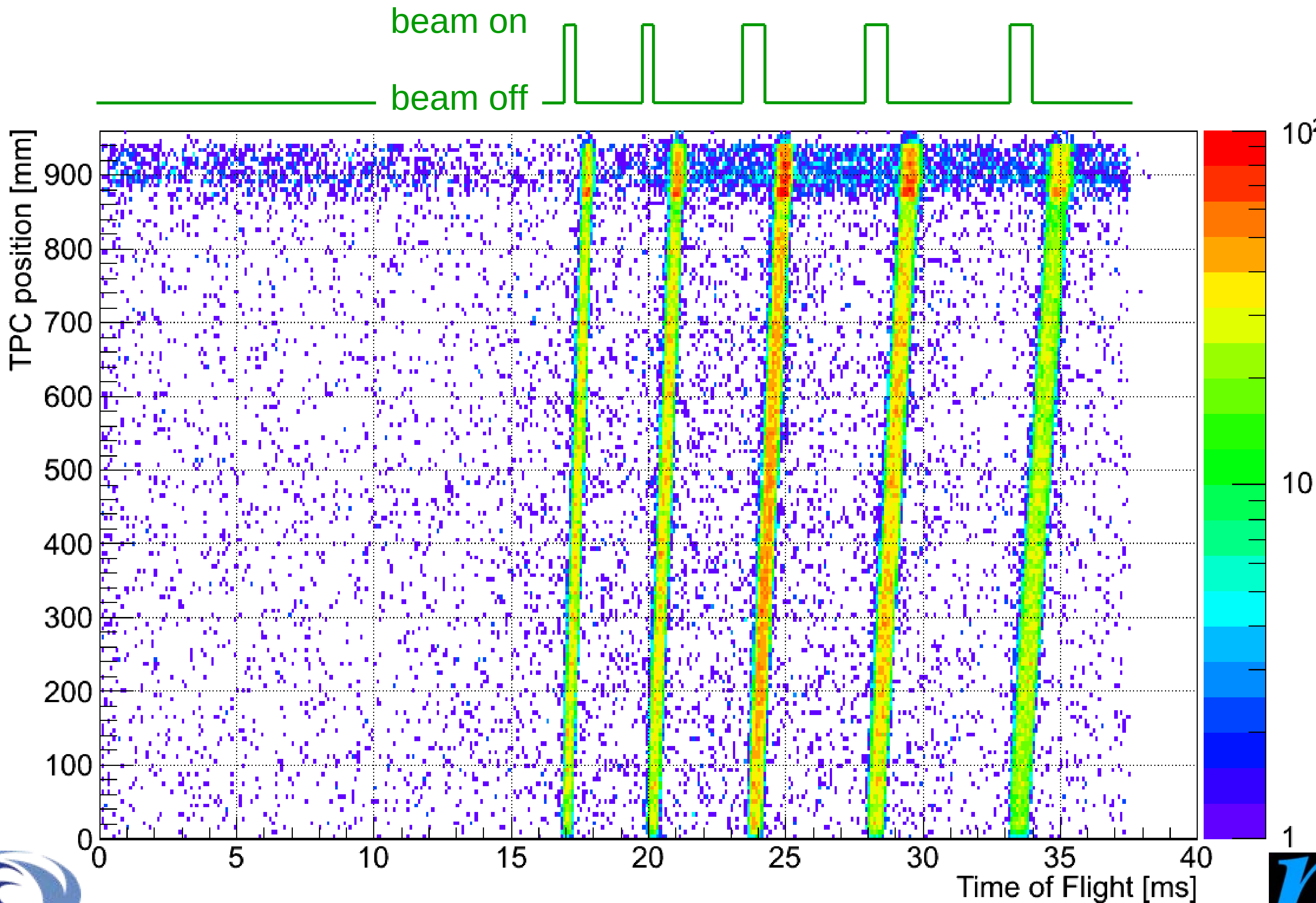
$$S = N - B$$

$$\Delta S = \sqrt{\Delta N^2 + \Delta B^2}$$

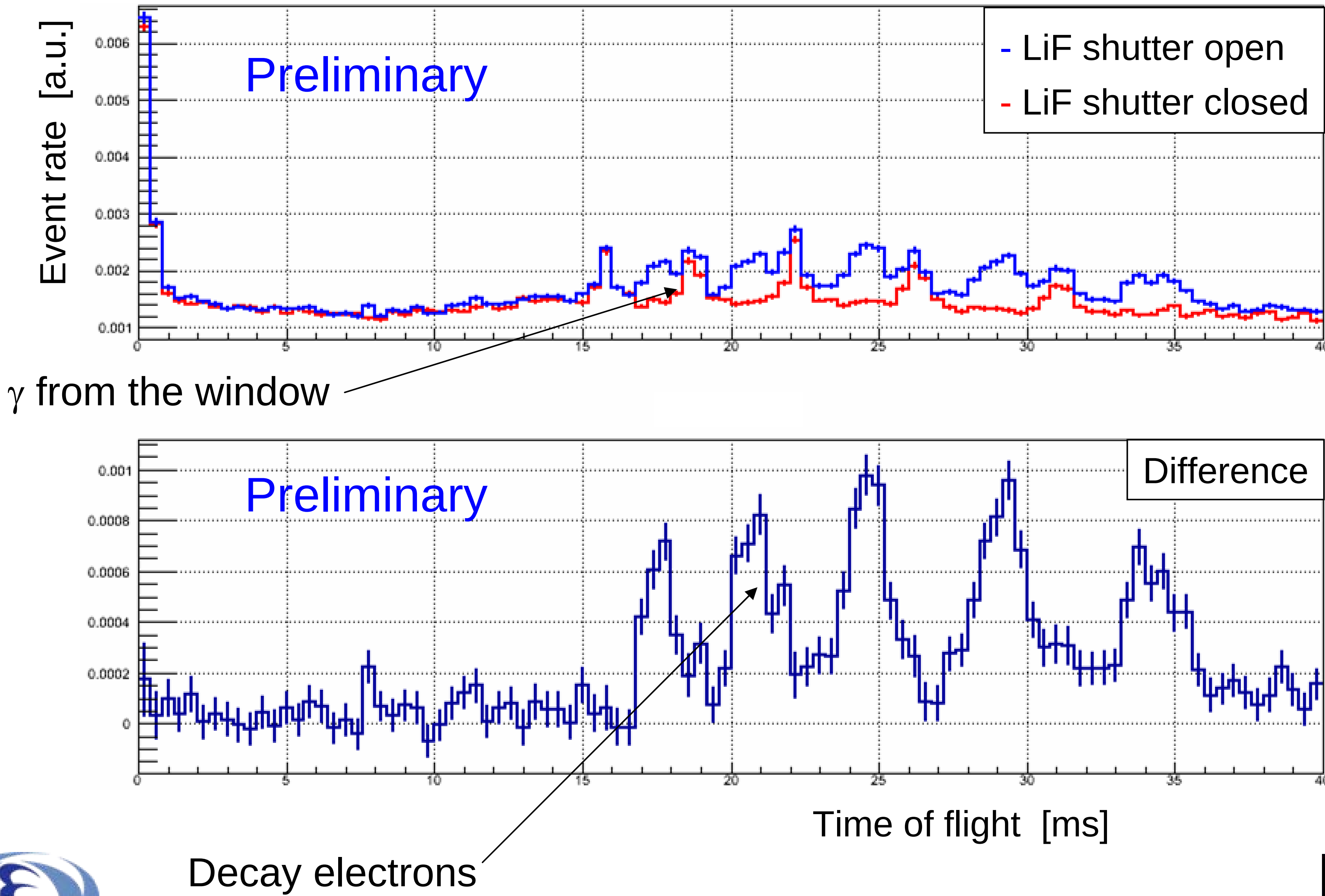
S : signal events
proportional to the intensity

B : background events
virtually intensity independent

^{3}He events with spin flip chopper



Beta decay candidates



Neutron lifetime?

$$\tau_n = \frac{1}{\rho\sigma\upsilon}\left(\frac{N_{He}/\varepsilon_{He}}{N_\beta/\varepsilon_\beta}\right)$$

N_β : # of decay electrons (detected)

N_{He} : # of ^{3}He events (detected)

ρ : ^{3}He density

σ : neutron capture cross section of ^{3}He

υ : neutron velocity

ε_β : electron detection efficiency

ε_{He} : ^{3}He(n,p) detection efficiency

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ε_{He} : ^{3}He(n,p) detection efficiency

Hope to show you at ISINN-21!

Improvements

Systematics

σ : ^{3}He capt. cross section	0.13%	$\longrightarrow$	new measurement
ρ : ^{3}He gas density	0.5%	$\longrightarrow$	improving Q-mass spectrometer
N_2 outgassing	0.5%	$\longrightarrow$	chamber baking? N_2 filtering ?
Gas temperature	0.2%	$\longrightarrow$	replacing pre-amps
Detection efficiencies	0.1%	$\longrightarrow$	TPC calibration
Event selection	< 0.1%		

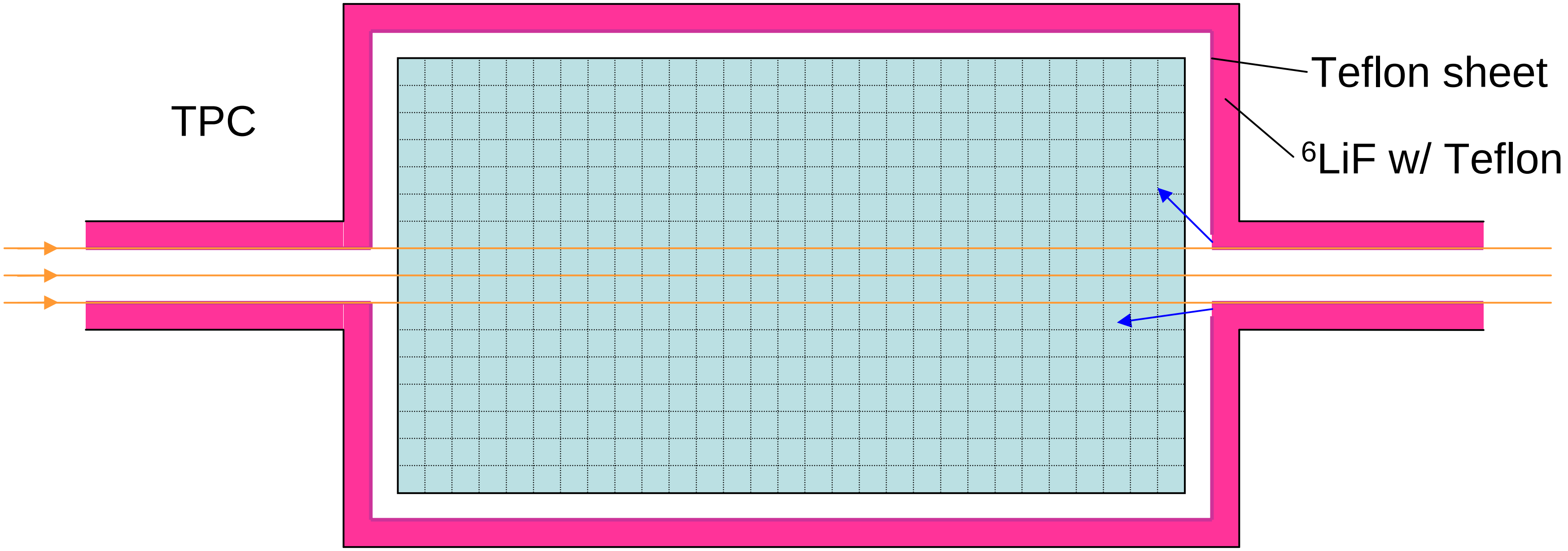
Statistics

Improvements on the spin flip chopper (4% acceptance)
Reduction of cosmic ray and other background $\longrightarrow$ better S/N

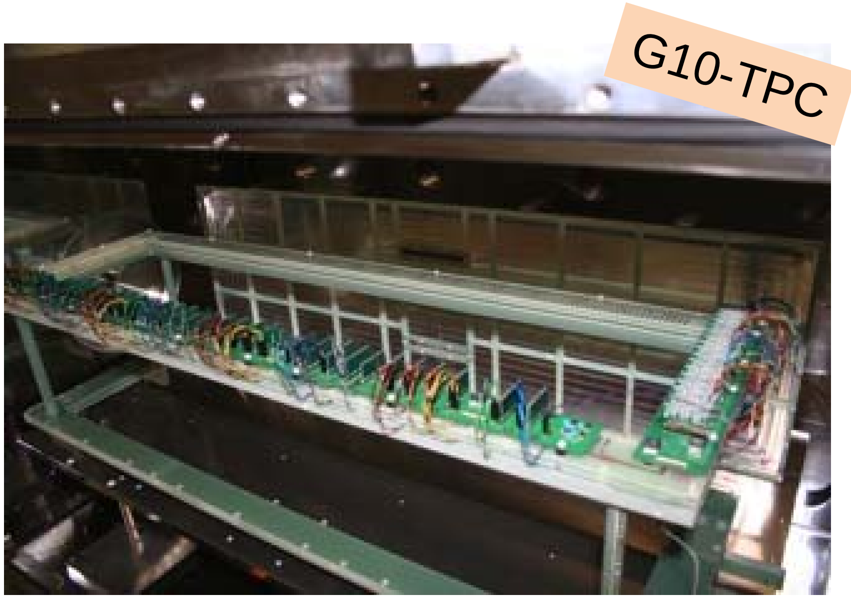
Backup slides

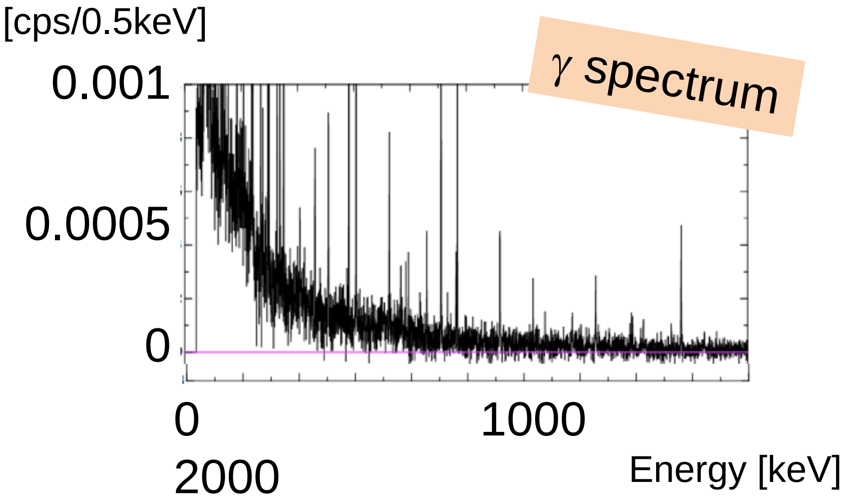
LiF shield and Li(n,α) events

^{6}LiF + Teflon w/ Teflon sheet



1st generation TPC

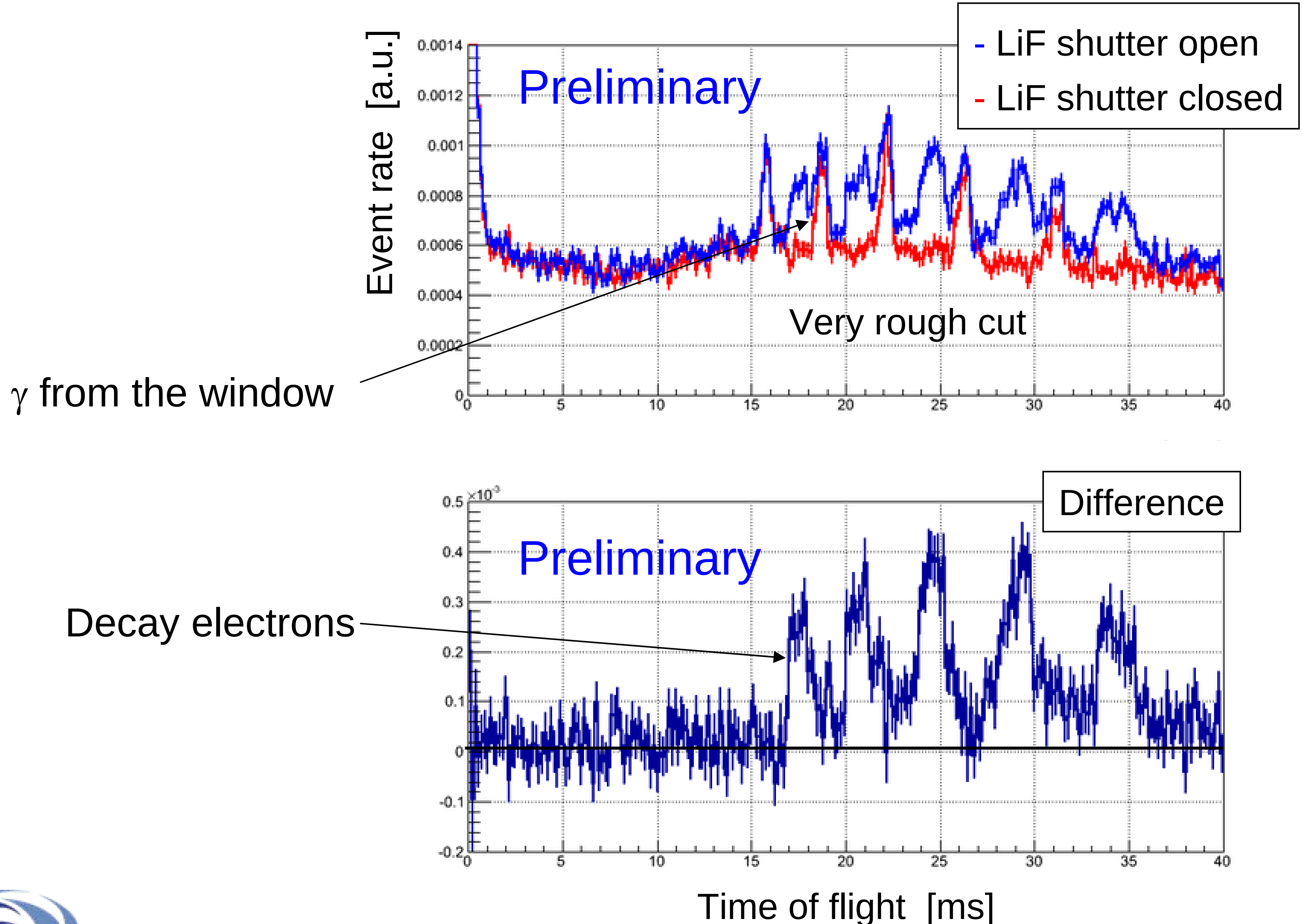




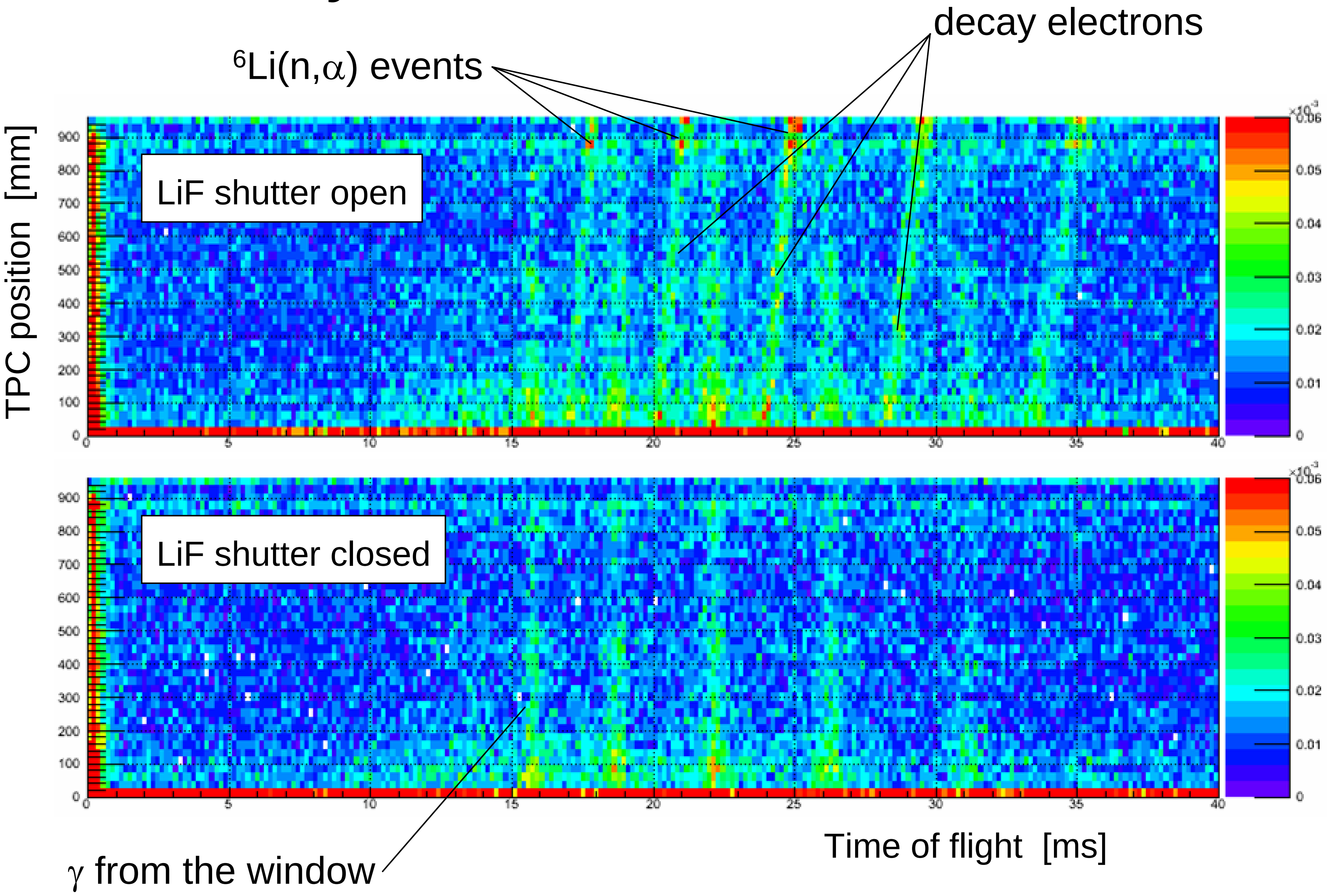
G10 : ~0.3 Bq/cc 30 cps

Isotope Eγ[keV]	^{212}Pb 239	^{214}Pb 295	^{228}Ac 338	^{214}Pb 352	^{208}Tl 583	^{214}Bi 609	^{212}Bi 727	^{208}Tl 861	^{228}Ac 911	^{40}K 1461	^{214}Bi 1765	Total
PEEK	---	---	---	---	---	---	---	---	---	---	---	<0.001
PPS	0.0016	---	---	---	---	(0.0028)	0.0080	---	---	0.0068	---	0.016
PS	---	---	---	---	---	---	0.0080	---	---	---	---	0.008
Alumina	---	---	---	---	---	(0.0026)	---	---	0.0020	---	---	0.002
G10	0.0480	0.0272	0.0424	0.0257	0.0135	0.0201	0.0480	0.0142	0.0412	0.022	0.0267	0.27

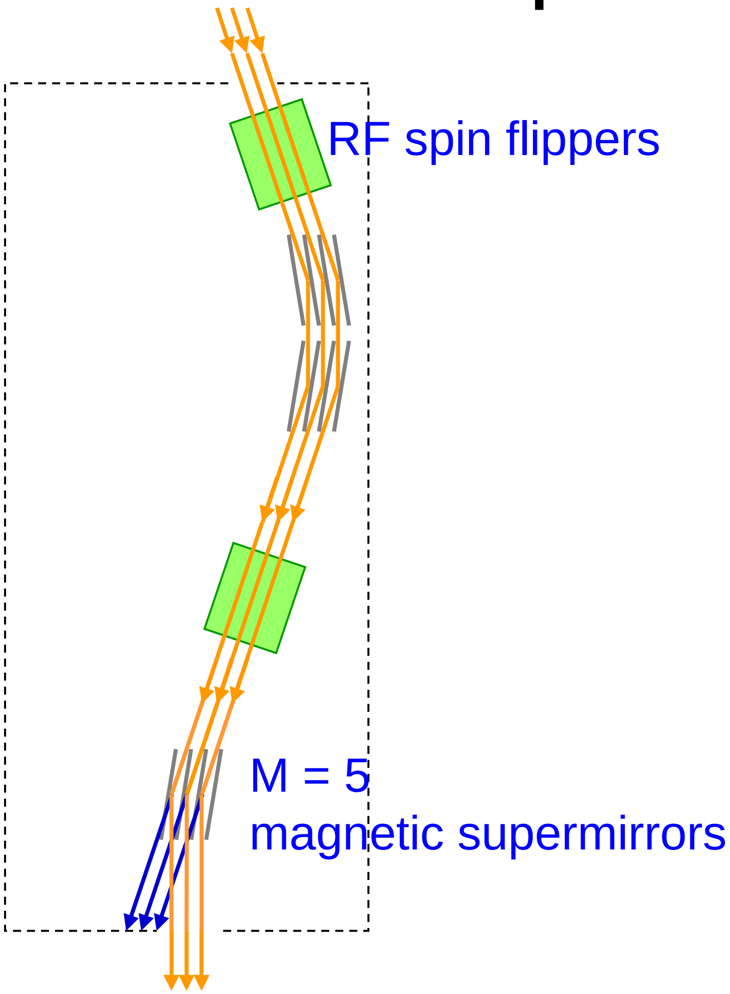
Beta decay candidates



Beta decay candidates



Spin flip chopper



Chops into short bunches
Defines neutron position
Reduce gammas from the window

Supermirror benders at BL05

Polarization Branch

Experiment	**Beta decay**
Mirror	Magnetic Supermirror (m=2.8)
Configuration	Polygonal approximation 12unit × 0.262 deg. (R=82m)
Cross-section	40mm × 100mm
Channel	4ch
Bender Length	4.5 m (375mm × 6 × 2)
Bending Angle	**3.14 deg.**

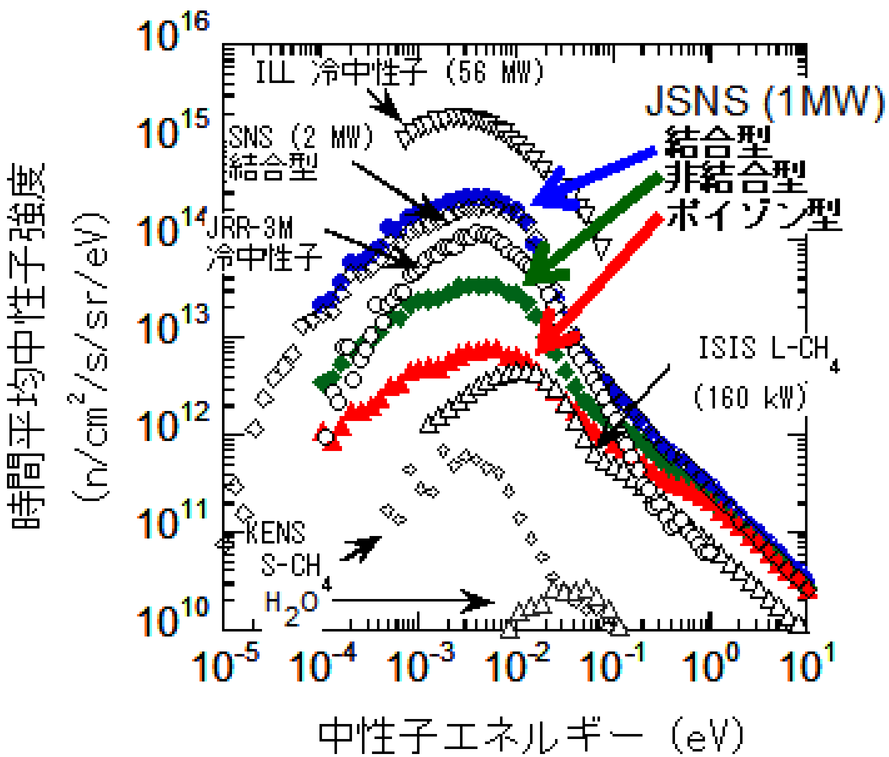
Unpolarized-beam Branch

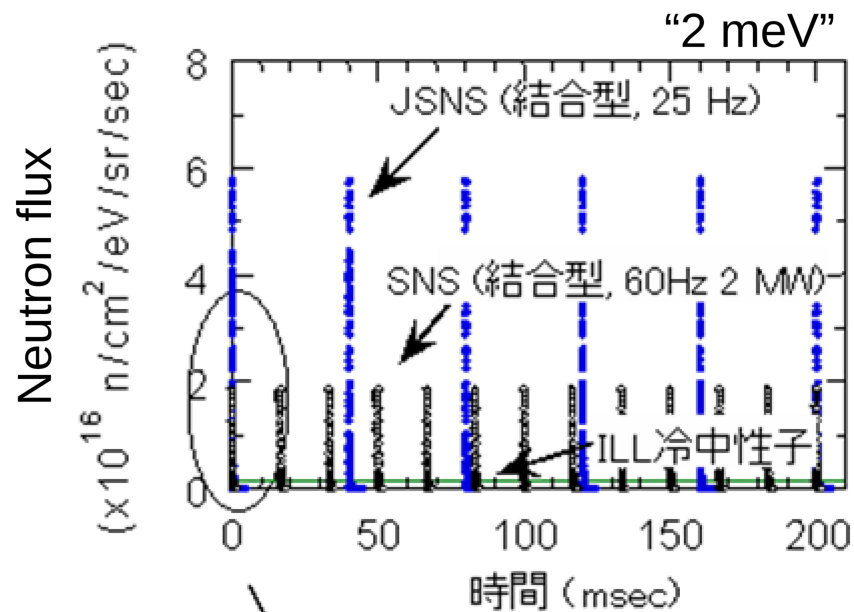
Experiment	**Scattering**
Mirrors	Supermirror (m=3)
Configuration	Real Curve
Curvature	100m
Cross-section	50mm × 40mm
Channel	5ch
Bender Length	4.0 m (2.0m × 2)
Bending Angle	**2.58 deg.**

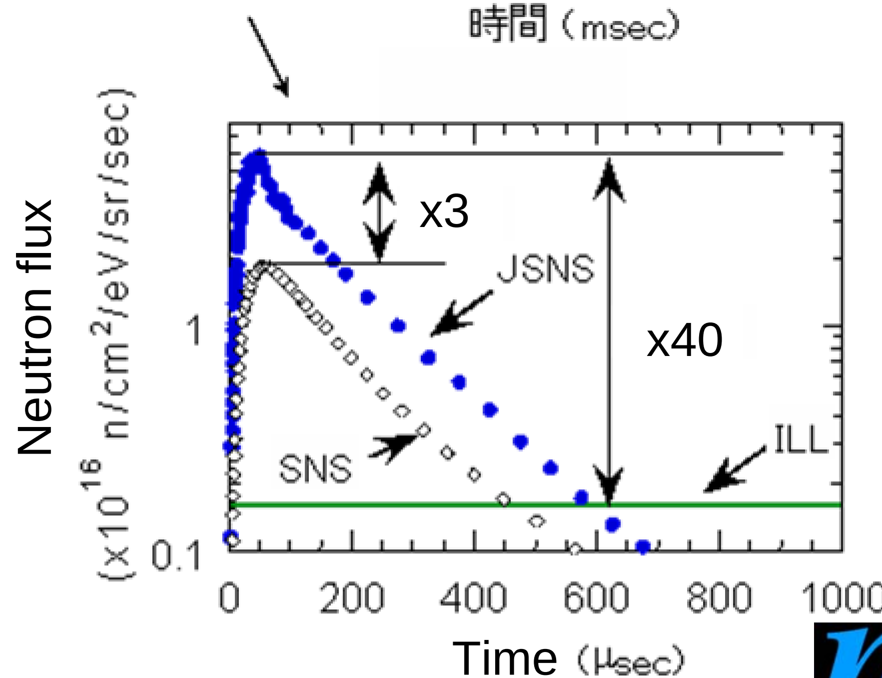
Low Divergence Branch

Experiment	**Interferometer**
Mirrors	Supermirror (m=3)
Configuration	2 mirrors
Critical Angle	0.95 deg.
Bending Angle	**3.85 deg.**

J-PARC spallation neutron source







Note

Reaction	Cross section	Q	E
$^{14}N(n,p)^{14}C$	1.7 b	0.626 MeV	0.58 MeV (proton)
$^{12}C(n,\gamma)$	0.0035	4.95 MeV	1.01 keV (recoil)
$^{14}N(n,p)^{14}C$			

Gas mixture
$^4He : CO_2$ = 85 : 15, 50 kPa – 100 kPa
^3He ~ 0.1 Pa or a few ppm
Gain 50000

55Fe 5.9keV X-ray
dE/E ~ 10%

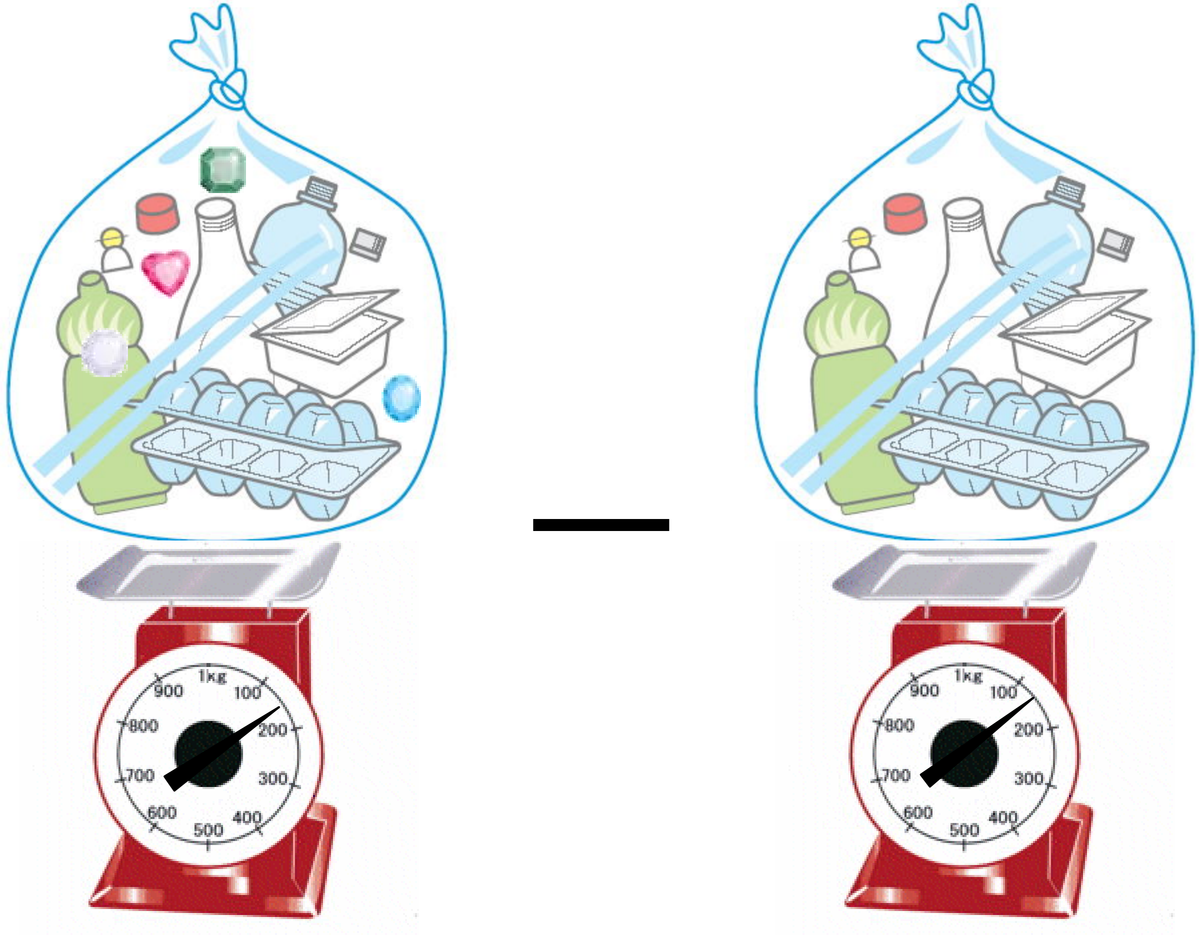
He ionization energy 25eV

flux at 220kW
16m, 8.6e6 /s/cm2
after SFC, 1.2e6 /s (x4cm2x4%)
duty factor 2.8ms/40ms -> 0.1 cps

SFC rise 5cm, min. 15 cm, fall 5cm

pre-amp
gain 1.0V/pC
noise 1.3mVrms
> 200 eV

Background subtraction



$$S = N - B$$

S : proportional to the intensity

$$\Delta S = \sqrt{\Delta N^2 + \Delta B^2}$$

B : virtually intensity independent