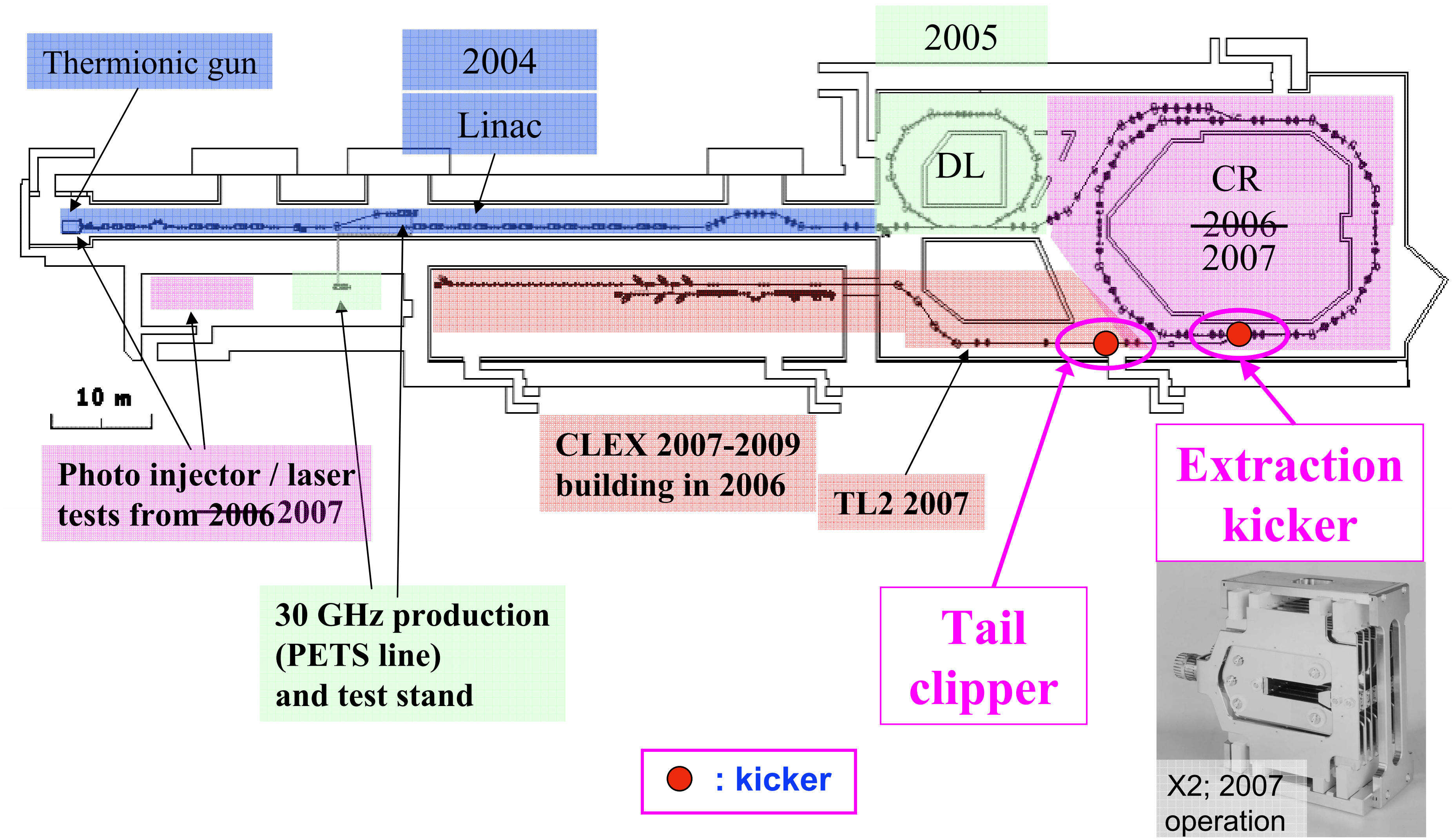
CTF3: KICKERS & PULSERS AT CERN

Michael Barnes
CERN
AB/BT

Also representing:
Tony Fowler, Gianfranco Ravida & Hiromitsu Nakajima

CTF3 Programme



CTF3 & CLIC Stripline Kickers

		CTF3 CR Extraction	CLIC CR	Tail Clipper	
Beam energy		300	2500	200	MeV
Total kick deflection angle (“B” & “E” Fields)		7	2.5	1.2	mrad
Stripline plate separation		40	20	40	mm
Stripline length		1.7	3		m
Available length (including transitions)				1.625	m
Field rise & fall-times (0.25% to 99.75%)		≤ 70	≤ 30	≤ 5 !	ns
Pulse duration		200	50 to 60	Up to 140	ns
Flat-top reproducibility		± 0.1	± 0.1	NA	%
Flat-top stability (including droop)		± 0.25	± 0.25	NA	%
Field homogeneity				± 15	%
Repetition rate	Initial	5		5	Hz
	Nominal	50	150	50	Hz
Pulse voltage		12.6	10.5	2.4 for 1m	kV
Pulse current (into 50 Ω load)		252	210	48	A
Timing Jitter				≤ 1 rms	ns

Combiner Ring Extraction Kicker

For operation in **2008** the existing magnetic kicker, which only partially satisfies the specifications, will be replaced by a new stripline kicker designed and built by CIEMAT.

Tests were undertaken at INFN Frascati:

Vacuum achieved 2e-7 mbar with turbo pump and no bake out;

*HV pulse test at **16 kV**, 5 ns pulse width. HV DC test at 18 kV;*

RF measurements (0 to 1 GHz) compare well with HFSS simulations;

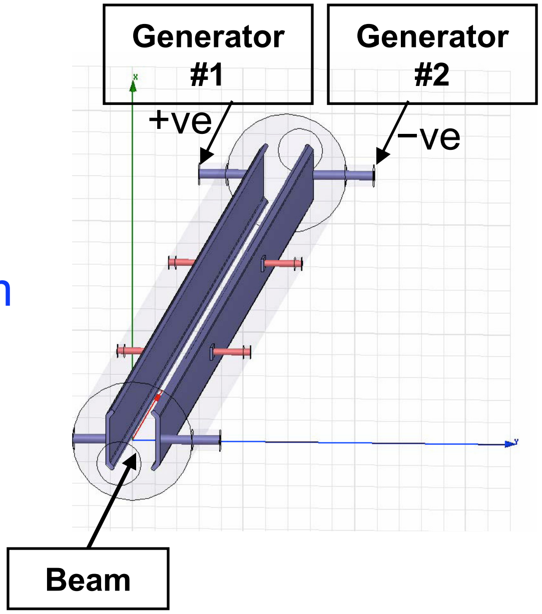
Conical transition pieces at the extremities are designed to reduce impedance discontinuities;

Recently delivered to CERN.

Combiner Ring Extraction Kicker

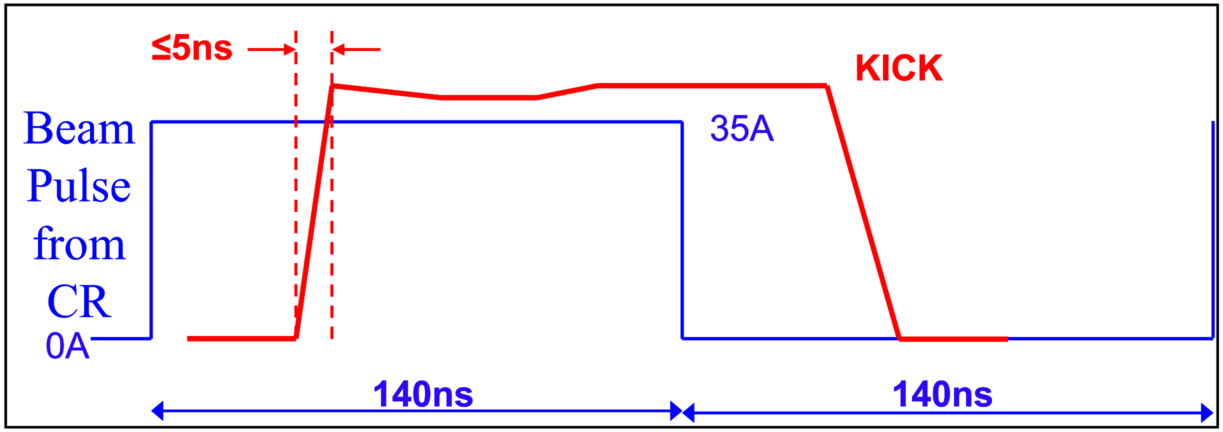
Stripline kicker powering

- The electrodes must be pulsed with separate, opposing polarity power supplies. Physically located in Bât. 2002.
- These pulsed power supplies have been be obtained by modification of **ex-EPA** equipment and change of system impedance from 30 Ω to 50 Ω. They have been pulse tested up to 17.5 kV, 200 ns into dummy 30 Ω loads.
- Positive pulse generator uses ex-EPA INJ GEN4. Electronics are in racks RA042 and RA043.
- Negative pulse generator uses ex-EPA INJ GEN3. Electronics are in racks RA040 and RA041.
- Controls will use existing DSC (Device Stub Control) interface (DCTFPOW1, rack RA110) presently used for magnetic extraction kicker control.
- Installation during February/March 2008.



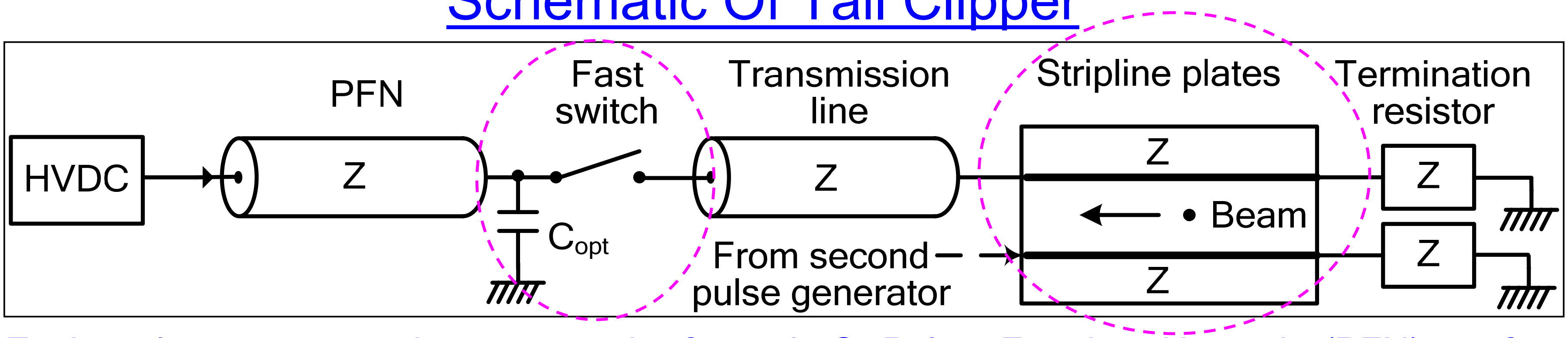
Tail Clipper: Overview

Beam Pulse



The beam pulse extracted from the CR is 35 A and 140 ns. The tail-clipper must have a fast field rise-time, of 5 ns or less, to minimize uncontrolled beam loss. The flatness of the kick pulse is not important as deflected beam is to be thrown away.

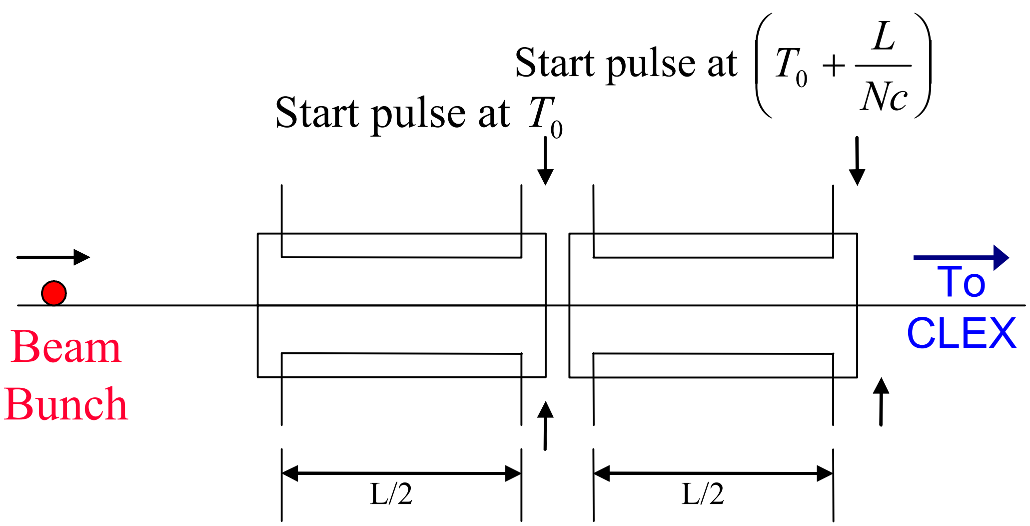
Schematic Of Tail Clipper



Each pulse generator is composed of a 50 Ω Pulse Forming Network (PFN), a fast semiconductor switch, 50 Ω stripline plates and a matched terminating resistor.

Tail Clipper: Rise Time

- To make use of both the electrical and magnetic fields to deflect the beam, the striplines must be "charged" from the CLEX (beam exit) end;
- To provide 1.2 mrad deflection, with striplines terminated in 50 Ω, requires 2.4kV on 1 m long striplines;
- Electrical pulse propagation through 1 m striplines, at speed of light, takes 3.3 ns!
- Tail Clipper requires short field rise-time (≤ 5 ns) !.
- In order that stripline fill time does not significantly effect deflection rise-time, several sets of striplines, mechanically in series, will be used.



For a trapezoidal current pulse:

$$T = 5ns = T_r + \frac{2L}{Nc}$$

Where:

T_r is permissible pulse rise time;

L is overall length of strip-lines;

N is number of sections;

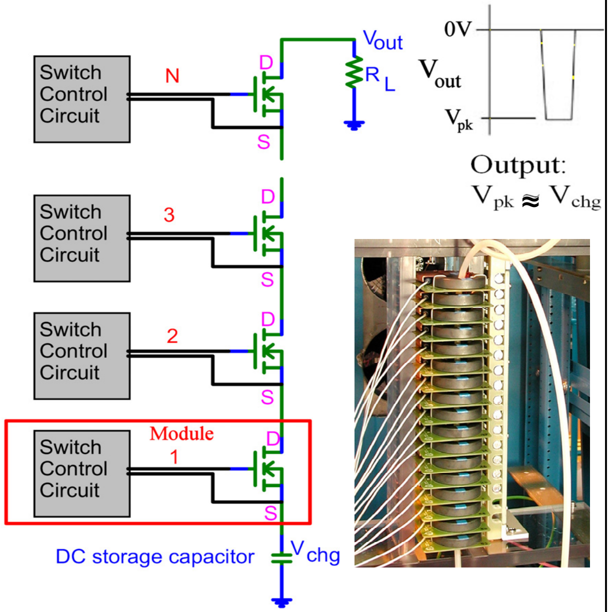
c = 3 x 10^8 m/s

For: $L = 1$ m & $N = 2$, T_r=1.7 ns

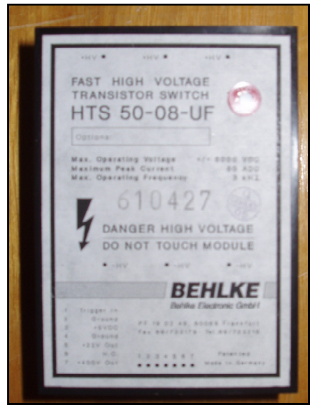
$L = 1$ m & $N = 3$, T_r=2.8 ns

Tail Clipper: Semiconductor Switch

Options considered for fast semiconductor switch



Stacked MOSFET Switches (SMS) have been developed at TRIUMF: these systems have voltage ratings up to 12.5 kV and have been tested at burst-rates of up to 3 MHz. Recent measurements on an SMS gave 10% to 90% rise-time of 3.7 ns for a 4.8 kV pulse.



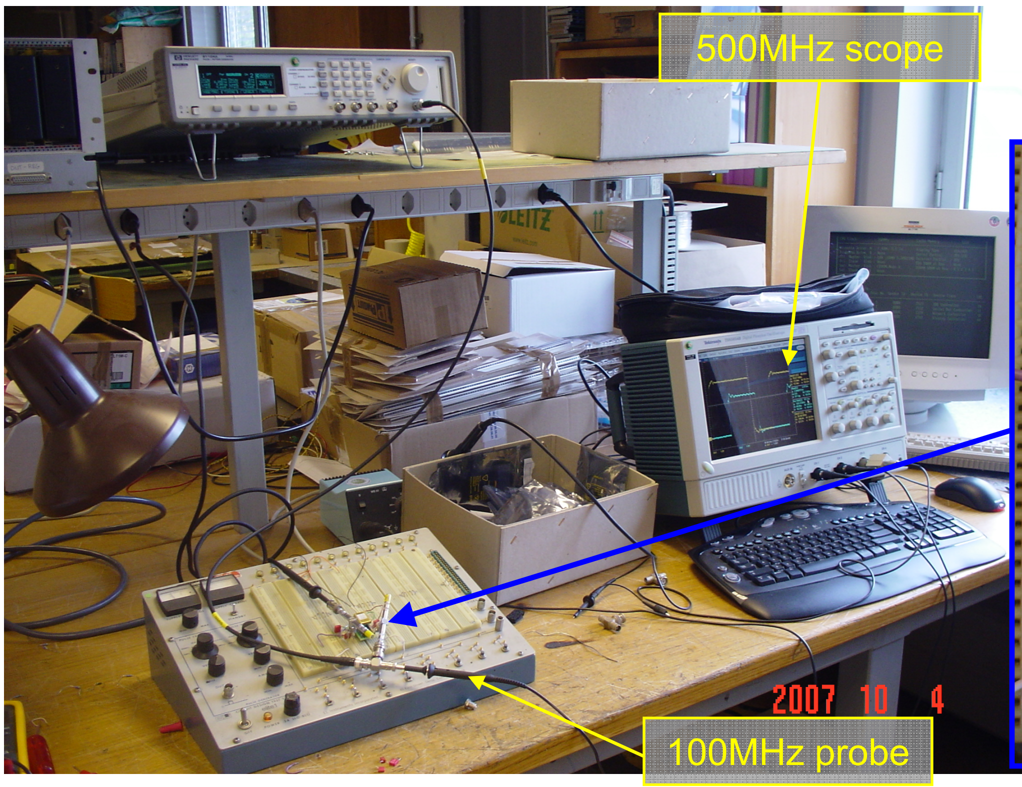
Behlke, high voltage, MOSFET switches are available with suitable datasheet rise-times. 5 kV (HTS-50-08-UF) and 8 kV (HTS-80-20-UF) versions of the switch have been tested.

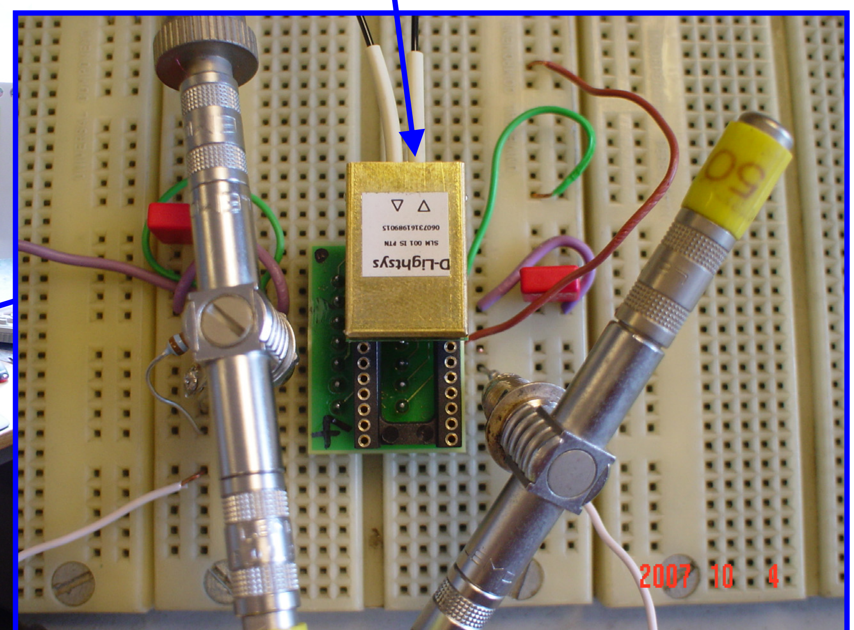
It is planned to evaluate a Fast Ionization Dynistor (FID), the FPG 5-01M122S144N, which has a specified output voltage of 5 kV into 50 Ω with a rise-time of 1.5 ns to 2 ns.

Order Placed Mid-June 2007: Not Yet Received

Tail Clipper: SMS Update

For an SMS device the relative timing of the turn-on of each MOSFET is critical: thus it is important that the trigger to each MOSFET is coherent in time. Sample Fibre Optic transceivers, the **SLM-001-IS-PTN** from D-Lightsys, have been extensively tested.





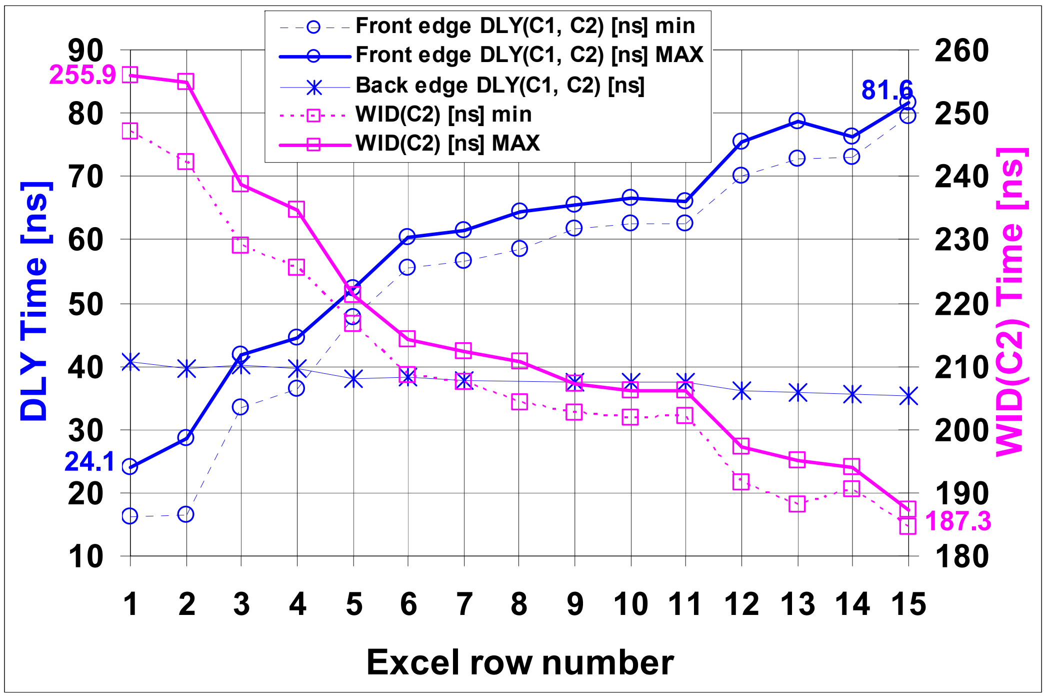
Tail Clipper: SMS Update 2

CERN Specifications for Fibre-Optics:

• The fibre-optic receiver is required to output a signal which can vary in duration from DC to a pulse train consisting of 50 ns wide pulses with a 50% duty-cycle (i.e. 10 million pulses per second for CLIC Combiner Ring Extraction Kicker). Within these lower and upper frequency bands the pulse train can have an arbitrary duty-cycle which is defined by the input signal;

• ***The timing of an edge on the output of any receiver should be within 1 ns of the timing of the same edge from any other fiber optic transmitter-receiver pair.***

Measurements on SLM-001-IS-PTN (5pps, Vcc=5.5V):



• Spread in front edge delay with respect to trigger ≈ 58ns (1ns specified) !!;

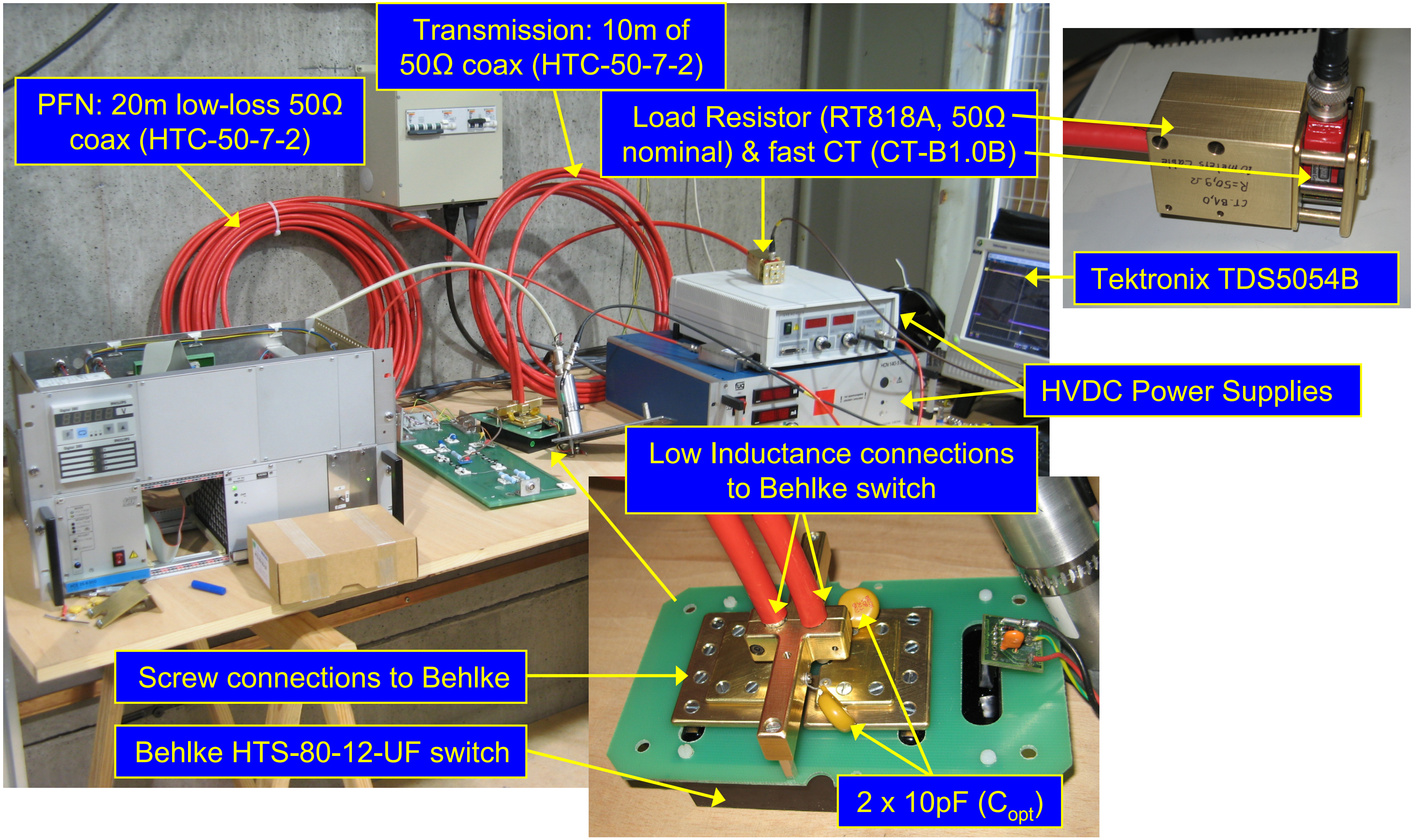
• Spread in width with respect to trigger ≈ 69ns (1ns specified) !!;

• Spread in back edge delay with respect to trigger ≈ 5.2ns (1ns specified).

CONCLUSION

SLM-001-IS-PTN transceivers are NOT suitable for SMS, and thus a suitable fibre optic has NOT yet been identified.

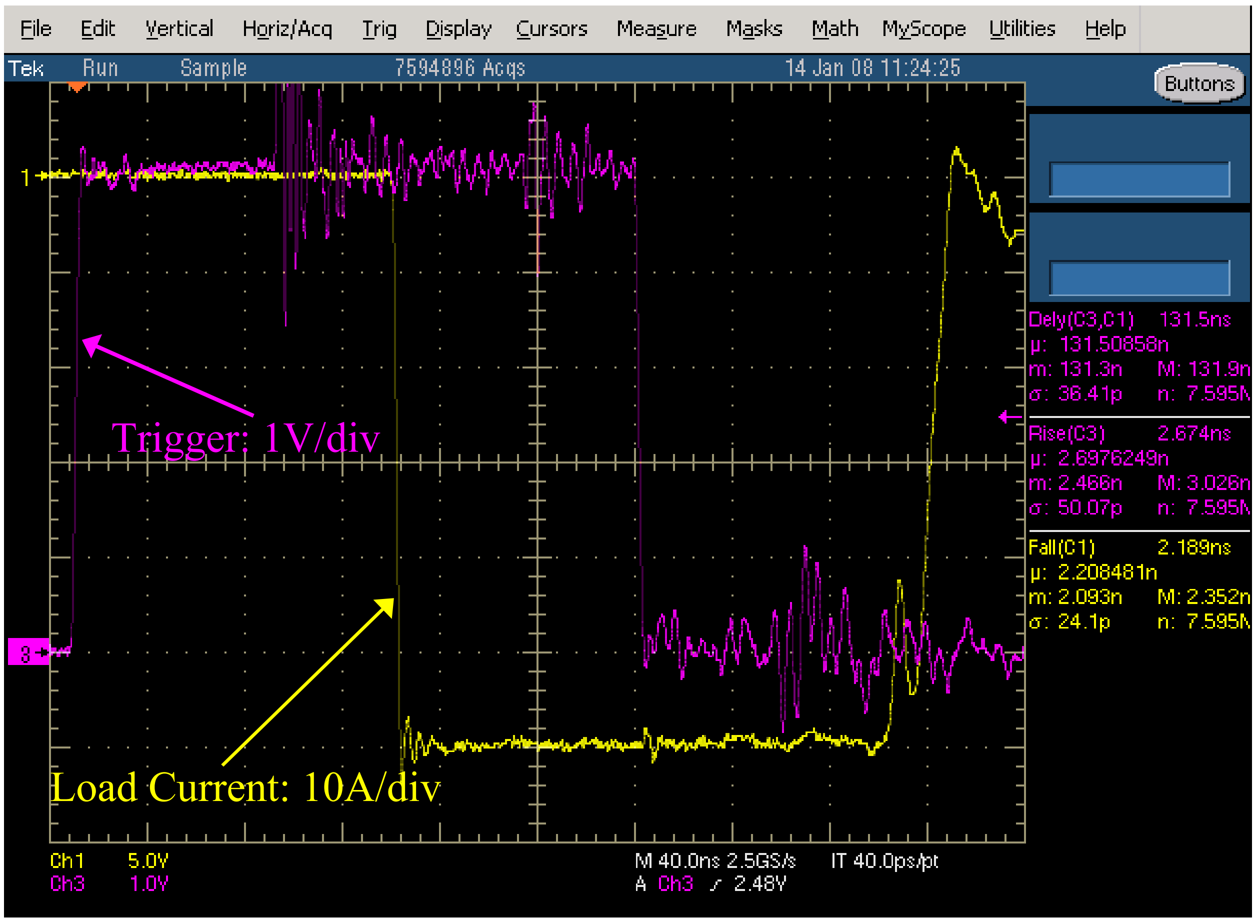
Tail Clipper: Behlke Switch Update



Tail Clipper: Behlke Switch Measured Current

Switch: Behlke HTS-80-12-UF (S/N 745136) with 2 x 10pF (C_{opt}); −5.7kV PFN voltage; 50Hz operation. [500MHz scope; 500MHz current-transformer].

FAST **(3ns rise) trigger input.**



Results:

- 200 ns flattop;
- −59 A load current (−48A required);
- 2.352 ns Max fall (10% to 90%) [7.6x10^6 pulses], **(permissible: 2.8 ns for 3 section stripline !)**;
- Time-jitter of load current w.r.t. trigger: σ=36.41 ps **(3σ = 0.11 ns);**
- **Trigger jitter …..**

Note: RT818A load resistor (2W) temporarily reduced from ~50Ω to ~44Ω due to temperature rise.

Tail Clipper: Behlke Switch Summary of Measurements

Summary of Test Results for Behlke Switch Type HTS-80-20-UF

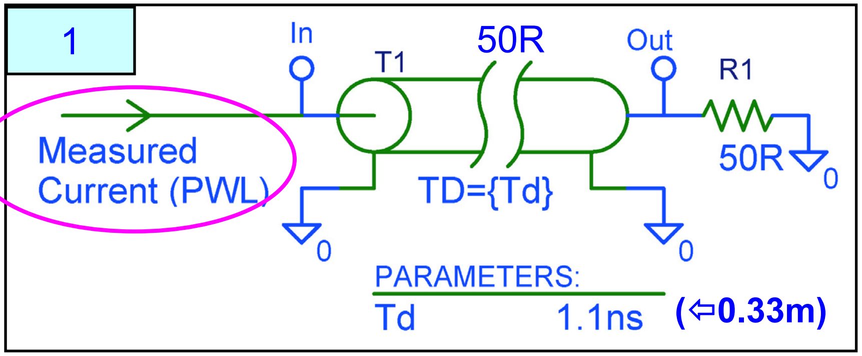
Permissible value of current Rise/Fall ⇨ ~2.80 ns for a 1 m, 3 section stripline

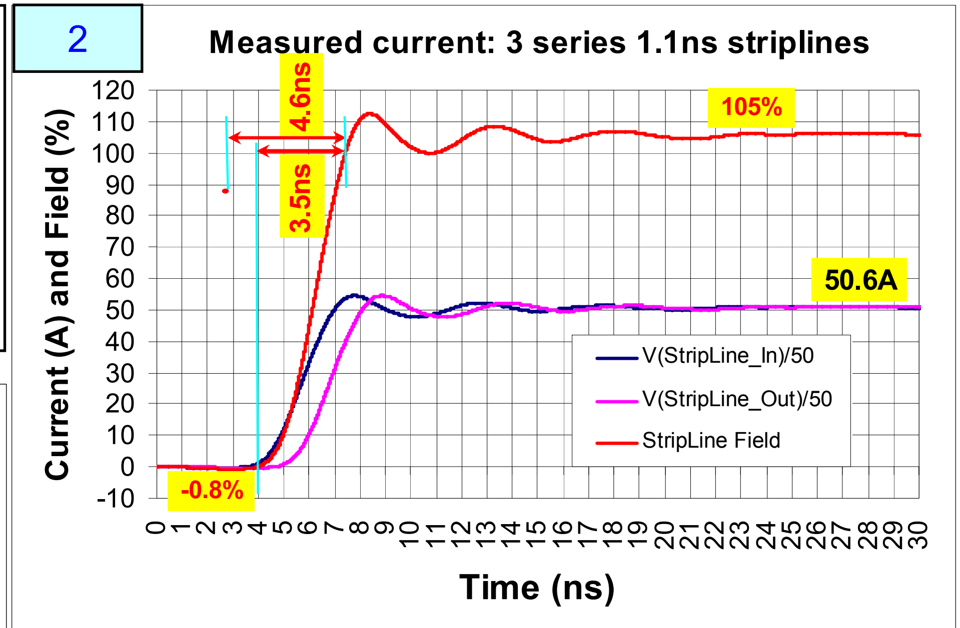
Behlke Switch S/N	Behlke Connector	Pulse Generator 10%→90% rise (ns)	PFN Voltage (V)	Rise/Fall (10% to 90%) (ns)	Time-jitter w.r.t. trigger [σ] (ps)	3 σ + *trigger jitter..?* (ns)	Number of "Statistic" Pulses
640242	Push-Pin	3	+5700	2.233 ✓	114.7	0.34+?	1.96×10^6
640242	Push-Pin	3	+6050	2.285 ✓	232.5	0.70+?	7.91×10^6
640243	Push-Pin	3	+6050	2.257 ✓	115.4	0.35+?	4.22×10^6
745136	Screws	3	−5700	2.352 ✓	36.41	0.11+?	7.60×10^6
745136	Screws	3	+5700	2.378 ✓	66.73	0.20+?	0.44×10^6
745136	Screws	**31**	− 5700	2.401 ✓	131.9	0.40+?	*0.99×10^3*

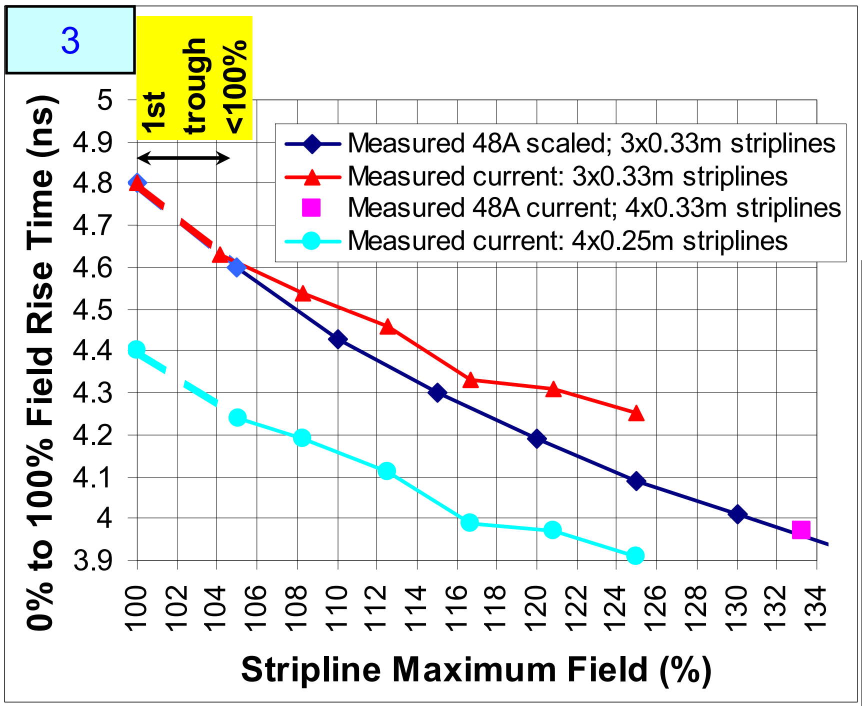
Load solder joint deteriorating (sparking)

To achieve fast rise/fall of field and low time-jitter:
- Integrity of connections is very important;
- Low-loss coaxial cables are required;
- A "fast" (e.g. 3 ns rise-time) trigger pulse, with low time and amplitude jitter, is required.

Tail Clipper: Behlke Switch – Predicted Field Rise-Time





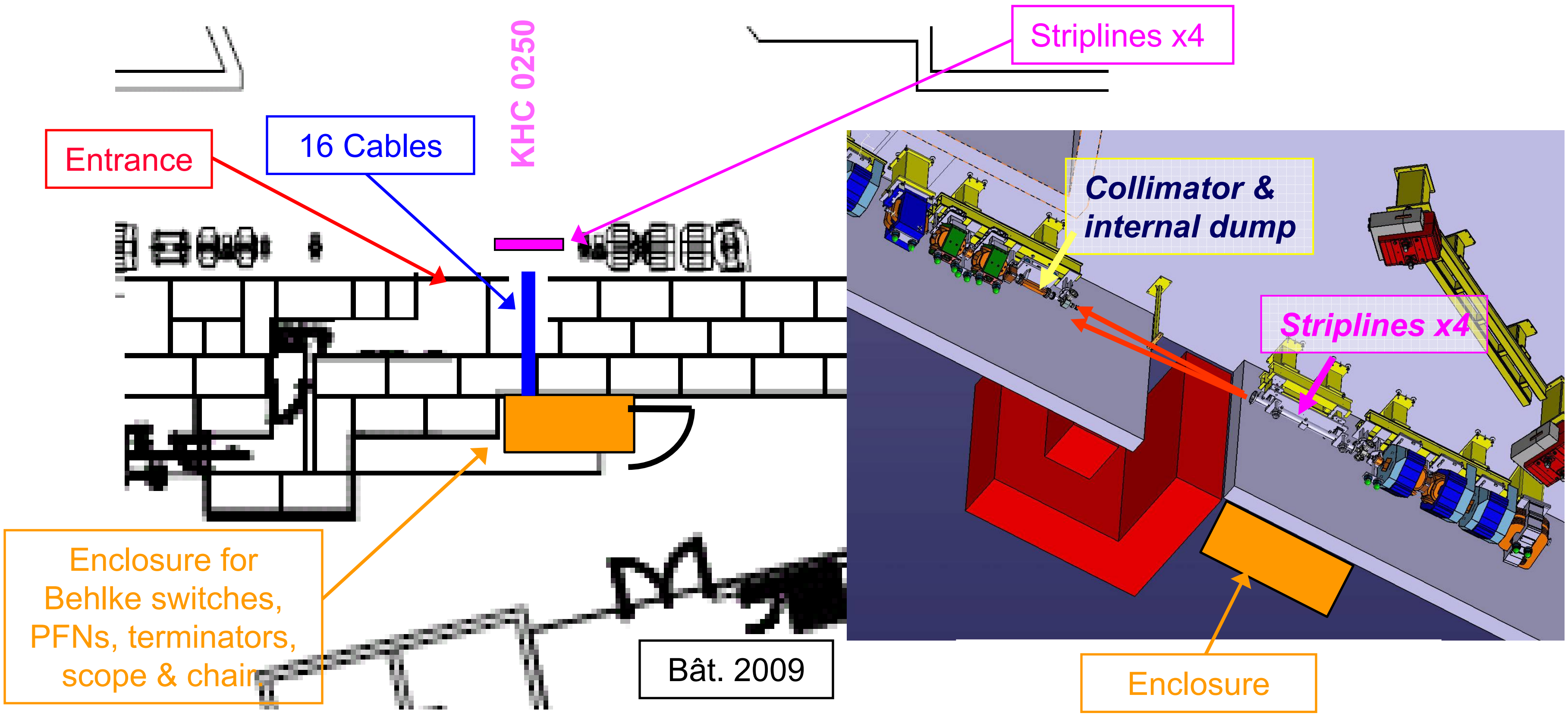


- For an overall stripline length of 1 m, a current of ~48A provides the specified kick of 1.2 mrad;
- Measured current used to predict field in (ideal) striplines ⇨ 3 series 0.33m plates meets 5ns rise-time;
- Predicted field rise, 0% to 100%, can be reduced from ~4.8ns to ~4.0ns by using 4 series 0.33m plates (however 1625mm overall length must be respected);
- A 4th set of striplines also provides redundancy;
- "Over-driving" striplines also reduces field rise-time.

Tail Clipper: Behlke Switch Summary

- For an overall stripline length of 1 m, a current of ~48 A is required to achieve the specified kick of 1.2 mrad.
- The on-state resistance of the HTS-80-20-UF Behlke switch, when conducting ~60A of load current, is approximately 9 Ω.
- With a 50 Ω PFN and 50 Ω load, a PFN voltage of 5.25 kV is required to achieve 48A of load current. The HTS-80-20-UF has been tested at up to 6.05 kV PFN voltage at 50 Hz: however, for long-term reliability, it is desirable to operate at < 70% of 8 kV switch rating (5.6 kV).
- A load current rise-time of ≤ 2.4 ns, 10% to 90%, is consistently achieved with the HTS-80-20-UF Behlke switch and low-loss transmission line.
- Predicted field rise-time, 0% to 100%, can be reduced from ~4.8ns to ~4.0ns by using 4 series 0.33m striplines instead of 3 series 0.33m (however 1625mm overall length must be respected). The 4th set of striplines also provides redundancy allowing operation with nominal kick with increased rise-time.
- Length of each set of striplines will be chosen:
    - to use 4 series striplines;
    - to maximize overall length of striplines (to optimize deflection versus switch stress).

Tail Clipper: Behlke Switch Proposed Installation



SKETCH OF CTF3 TRANSFER LINE WITH KICKER BEHIND WALL ….

- Behlke switch, control electronics and load are all outside high radiation environment;
- Low-loss coaxial cable (HTC-50-7-2) will be used for PFN (~16 m), transmission cable from switch to striplines (~10 m) and for transmission cable from striplines to load (~10 m).

Conclusions

• CIEMAT have designed, constructed and tested 50 Ω striplines for extraction from the CTF3 CR. Initial RF tests show good agreement with design simulations. The device is now awaiting vacuum tests before installation in the machine.

Tail-Clipper:

• SLM-001-IS-PTN transceivers (D-Lightsys) are NOT suitable for a SMS system; the spread in delays is excessive. Thus a suitable fibre optic has NOT yet been identified. Therefore SMS technology is **not** being pursued for tail-clipper. But for CLIC CR…...

• For a 1 m stripline length, subdivided into 3 sections, the predicted 0% to 100% field rise-time, with current measured for a Behlke HTS-80-20-UF switch, is ~4.8ns.

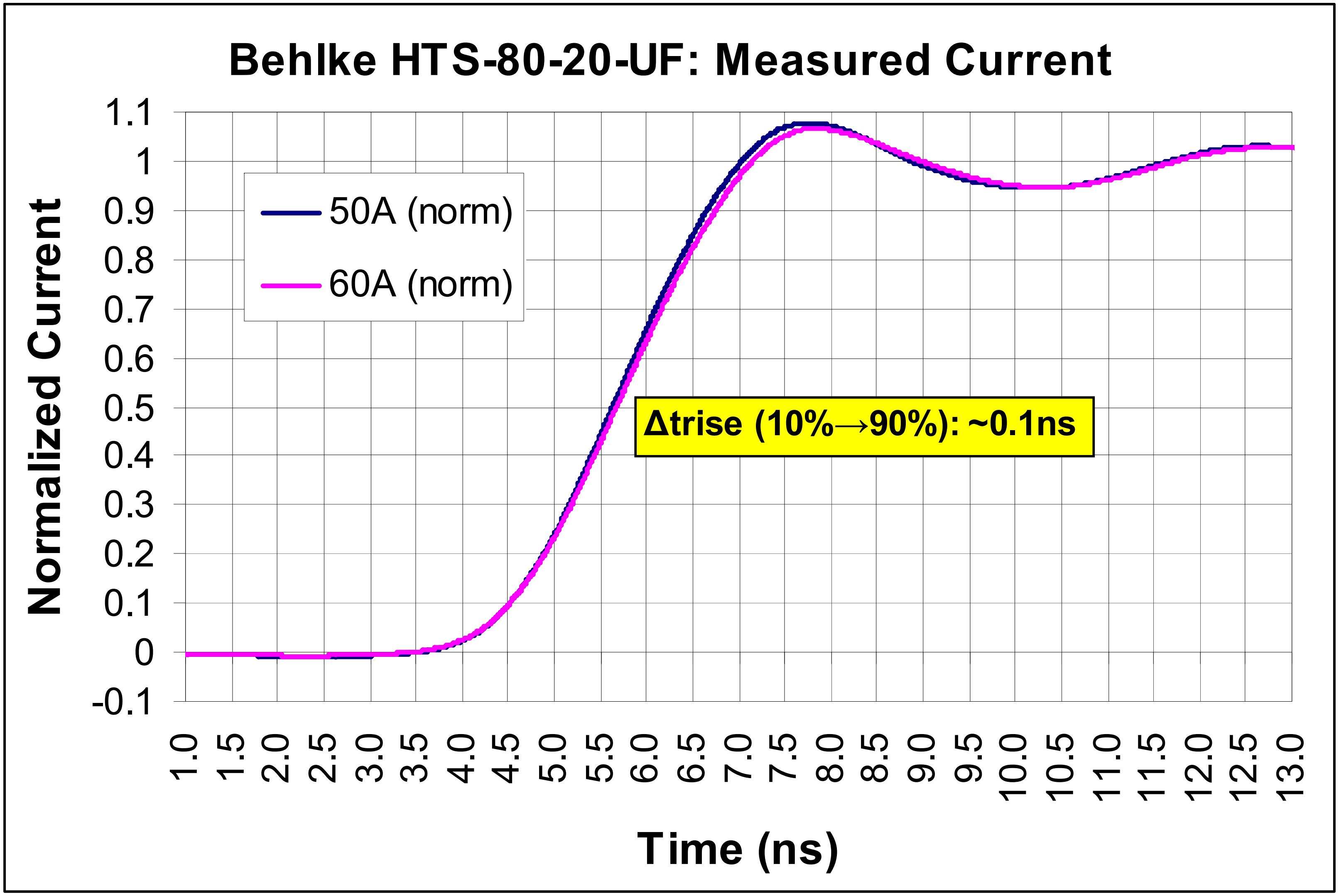
• Predicted field rise-time, 0% to 100%, with the Behlke HTS-80-20-UF, can be reduced from ~4.8ns to ~4.0ns by using 4 series 0.33m striplines. The 4th set of striplines also provides redundancy allowing operation with nominal kick but with the increased rise-time.

• The Behlke HTS-80-20-UF switch provides adequate performance: an order for these switches will be placed shortly (3 month delivery time; system installation in 09/2008).

• A Fast Ionization Dynistor, the FPG5-01M122S144N, has not yet been received; this FID will be tested but will not be used for the tail-clipper.

Questions ??

Behlke HTS-80-20-UF: Measured Current



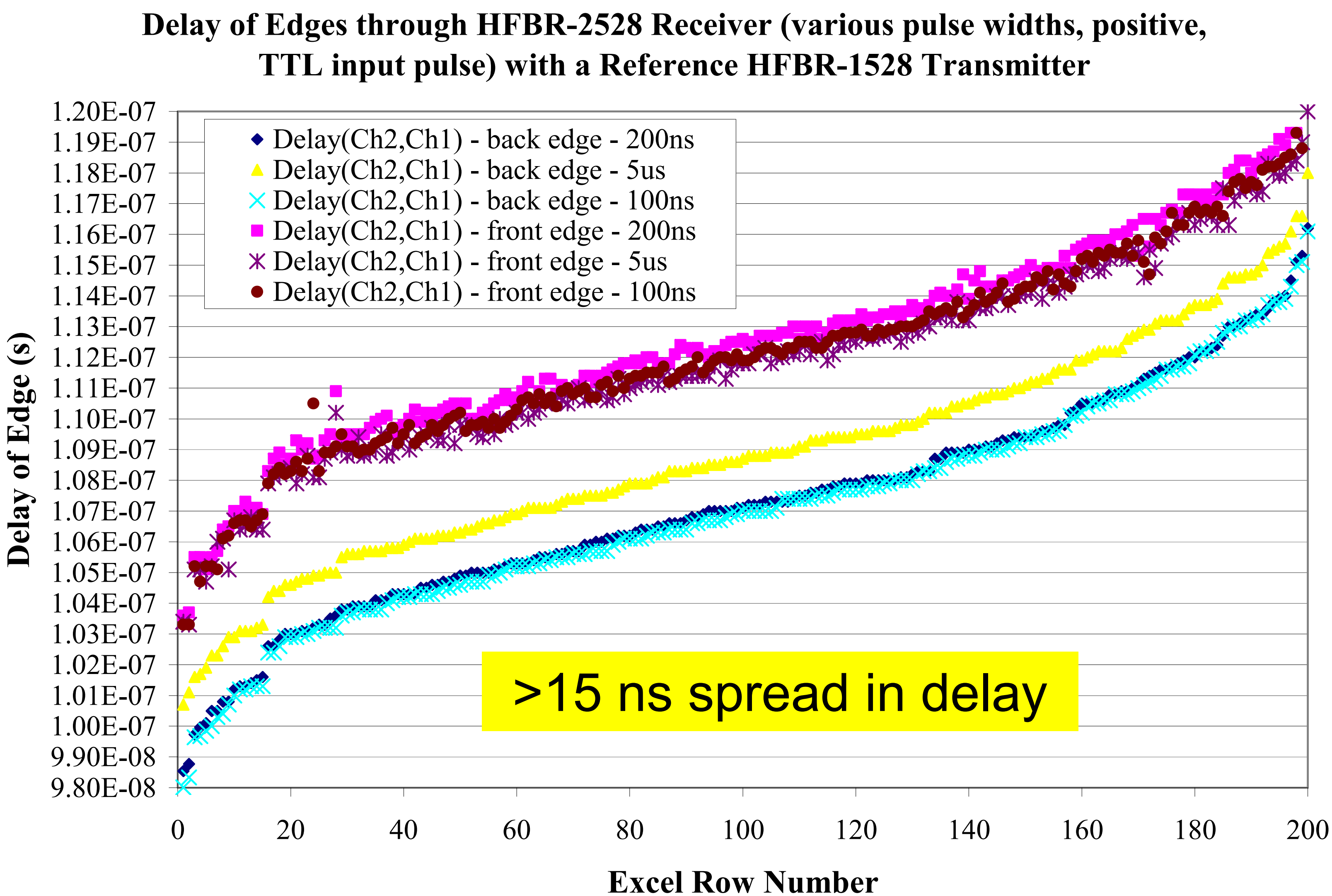
Striplines: Angular Deflection Due To Magnetic and Electric Fields

$$\theta_E = \arctan\left(\frac{V * l * c}{d * (p * 10^9) * \beta * c}\right)$$

$$\theta_B = \left(\frac{0.3}{p}\right) * \left[\frac{V}{\left(\frac{d}{2}\right) * c}\right] * l$$

These equations show that the deflection due to the magnetic field is independent of the impedance of the striplines.

Agilent HFBR-2528 Fiber Optic: Receiver Delay



Agilent HFBR-1528 Fiber Optic: Transmitter Delay