Status of the readout electronics for the Silicon micro-strip detector of the ILD concept

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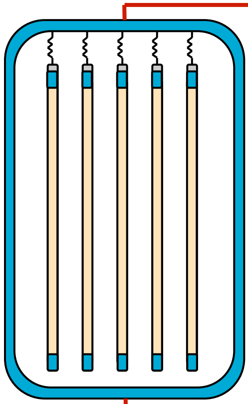
Outline

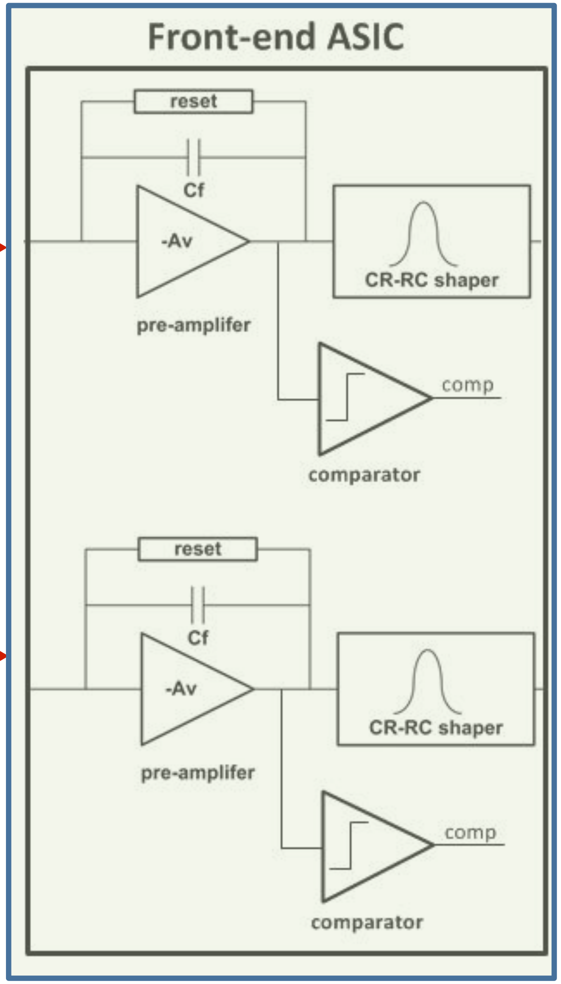
- Starting point
- Front-end ASIC
  - Noise analysis
  - CSA
  - CSA + Shaper
  - ASIC
- Test plan
- Conclusions

Starting point

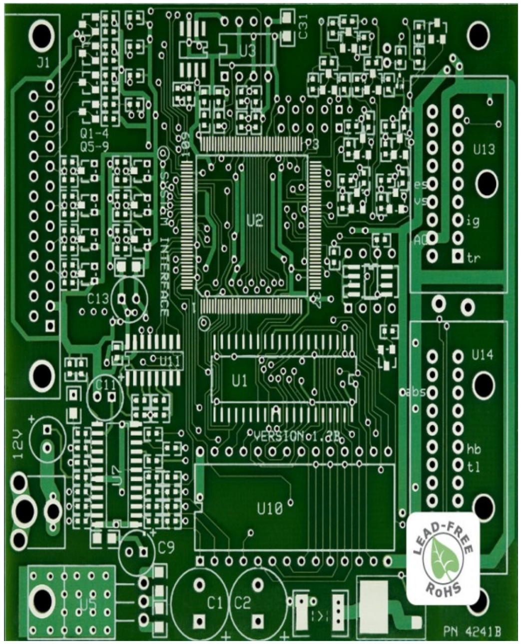
μstrips

-Standard
-Resistive
-Gain





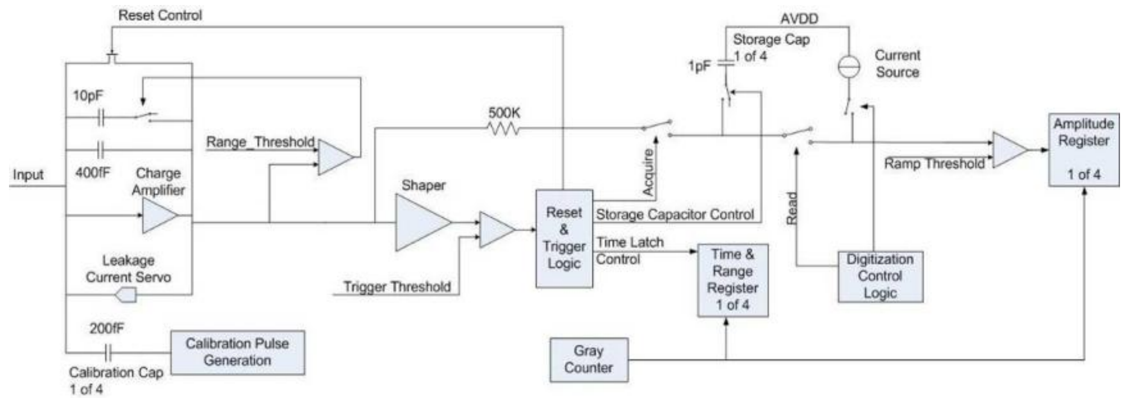
Digitalization



To DAQ

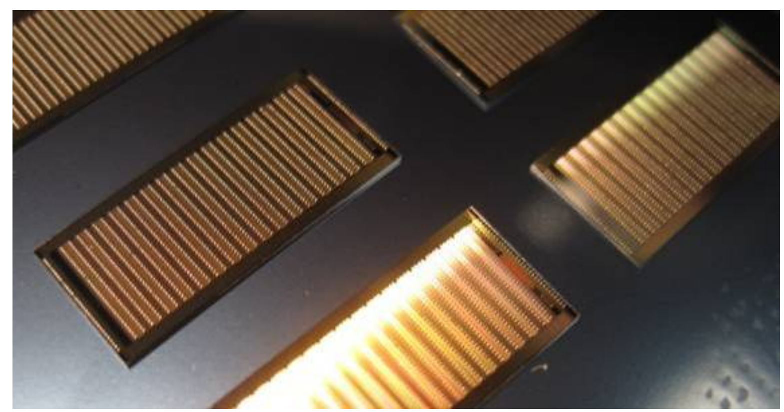
KPiX ASIC: generic R&D toward system-on-chip designs

- 32×32 array = 1024 channels
- Designed to be
  - bump-bonded to a Si sensor, or
  - bumped to a hybrid for large area detectors (RPC's, GEM's, etc)



Block diagram of a single channel

- For each channel of the system-on-chip
  - 4 samples per train with individual timestamps
  - auto-triggering
  - internal per-channel 13-bit ADC
  - automatic range switching for large charge depositions (10pC)
  - bias current servo for DC coupled sensors
  - power cycling: power down during inter-train gaps (20 uW avg for ILC time structure)
  - built-in calibration
  - nearest neighbor trigger ability
  - high-gain feedback capacitor for tracker application
  - dual polarity for GEM and RPC applications
  - external trigger for test beam
- Digital IP core with serial data IO (only 4 signals)
- 0.25µm TSMC

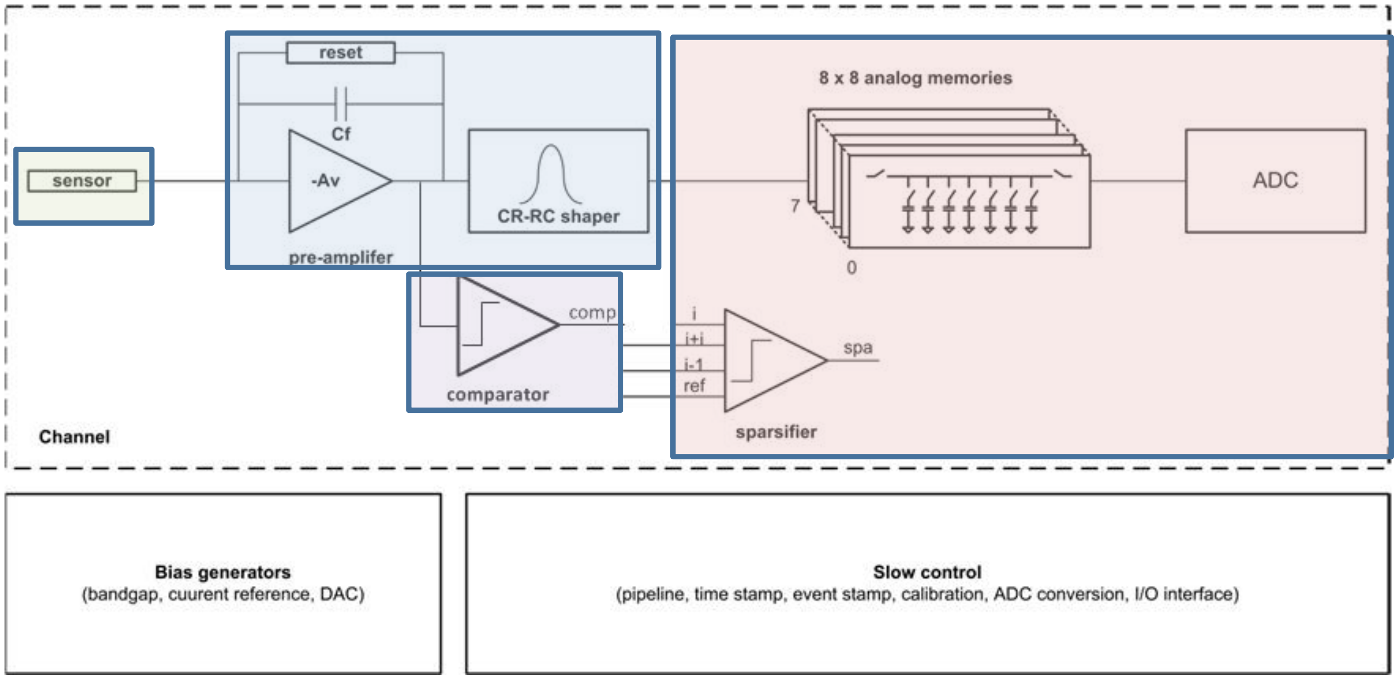


1024-channel KPiX

Collaboration: SLAC, UCSC, U. of Oregon, UC Davis

KPiX, An Array of Self Triggered Charge Sensitive Cells Generating Digital Time and Amplitude Information", D. Freytag. G. Haller, et al. SLAC-PUB-13462, 2008. 4pp (IEEE NSS Oct 2008)
KPiX, an 1,024 cell ASIC, Design and Performance, accepted for presentation at NSS 2012

Front-end ASIC



- In progress
- To be designed
- Not included
- Sent to foundry

Front-end ASIC: Noise analysis (1)

$$ENC \approx (C_d + C_f + C_i) \cdot \sqrt{\frac{2}{3} kT \frac{1}{g_m} 1.57 \frac{e^2}{\pi q_e^2 \tau} + \frac{k_f}{C_{ox}^2 \cdot WL} \frac{e^2}{2q_e^2}}$$

EKV model

$$g_m = \frac{I_{ds}}{2nU_t} \cdot \frac{1 - e^{-\sqrt{IF}}}{\sqrt{IF}}$$

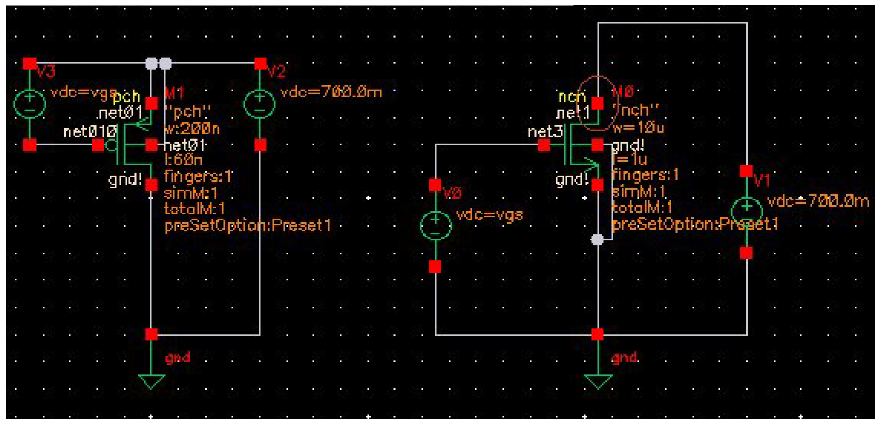
$$IF = \frac{I_{ds} \cdot L}{I_s^* \cdot W}$$

$$\lambda_E = \lambda \cdot L = \frac{I_{ds} \cdot L}{g_{ds}}$$

$$k_n = 2m^2 \cdot \frac{L}{W}$$

$$I_s^* = \left(-2 \cdot U_t \cdot \frac{d\sqrt{I_d}}{dV_s}_{min}\right)^2 \cdot \frac{L}{W}$$

$$n = \frac{I_s^*}{2 \cdot k_n \cdot U_t^2}$$

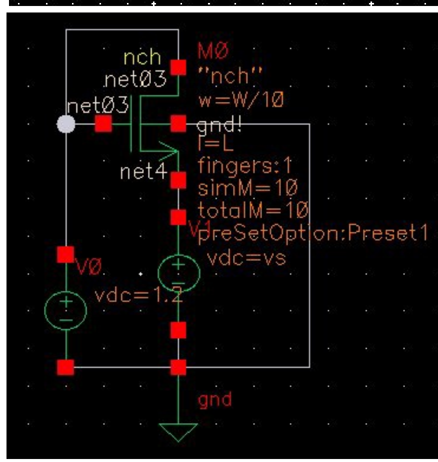


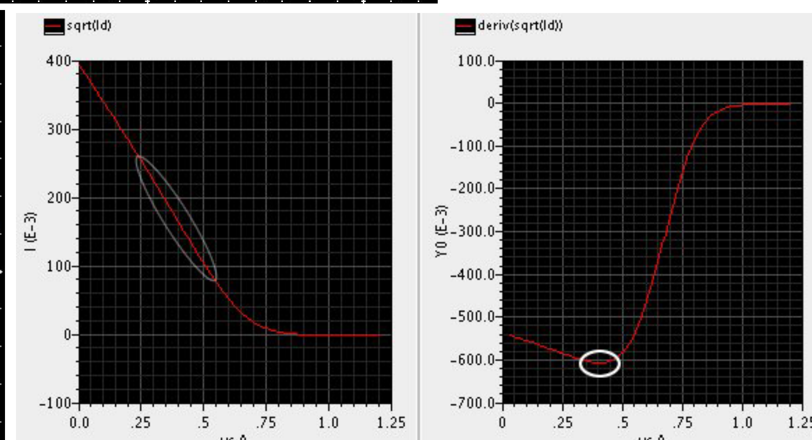
Kp = 30.65 uA/V^2

Kn = 141.10 uA/V^2

Values of I_s^* and λ_e are tabulated.

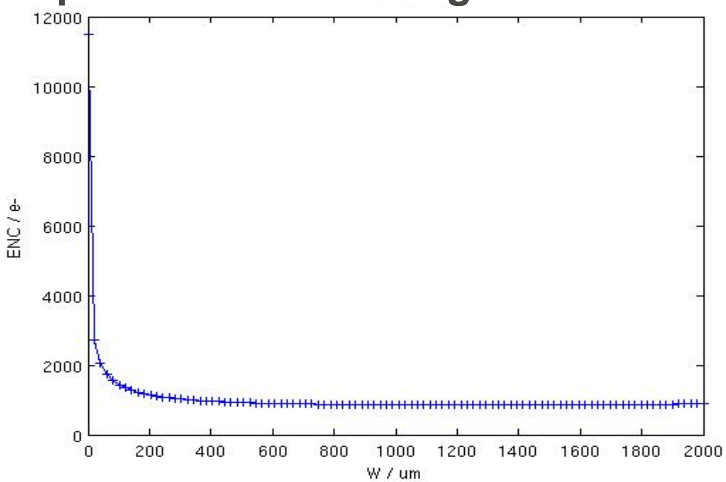
(I_s^*p = 95 nA; I_s^*n = 420 nA)





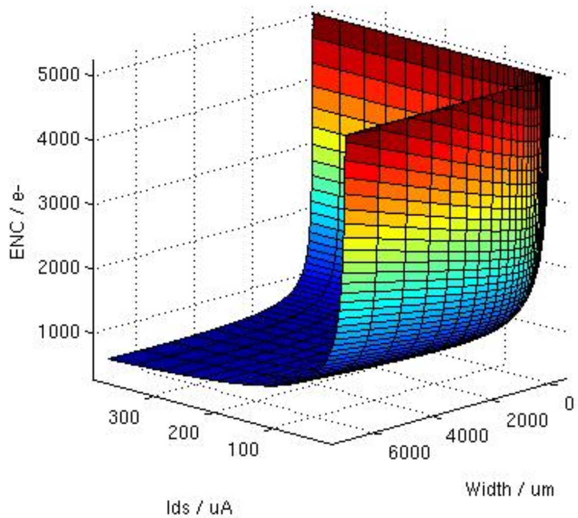
CSA: Input PMOS

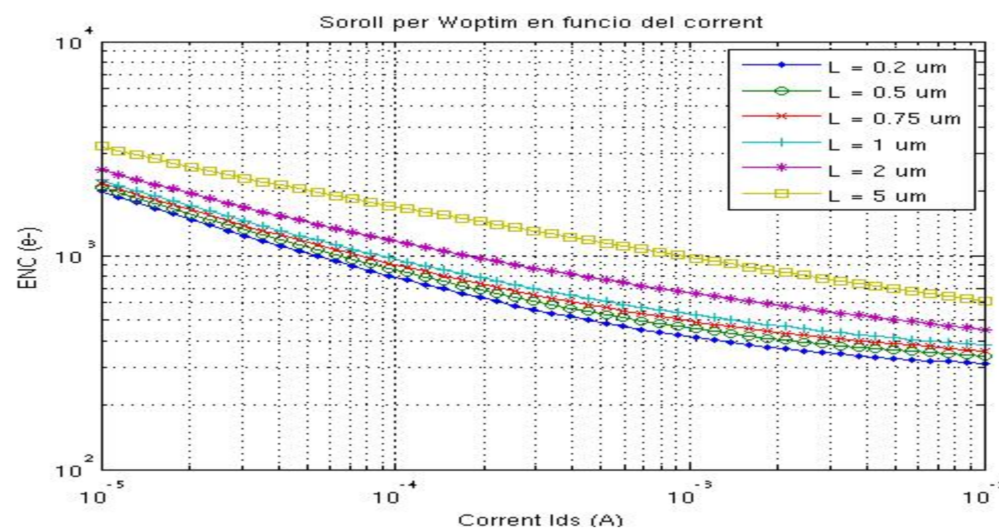
Optimum width for a given L and Ids



L	I_{ds}	a	b	$ENC\ 20pF$	W_{optima}	$Consum$	IF
$0.20\mu m$	$100\mu A$	$134e^-$	$32.8e^-$	$791e^-$	$2737\mu m$	$120\mu W$	0.06
$0.20\mu m$	$200\mu A$	$132e^-$	$24.8e^-$	$629e^-$	$3657\mu m$	$240\mu W$	0.10
$0.20\mu m$	$300\mu A$	$131e^-$	$21.3e^-$	$557e^-$	$4307\mu m$	$360\mu W$	0.12
$0.20\mu m$	$500\mu A$	$131e^-$	$17.8e^-$	$486e^-$	$5248\mu m$	$600\mu W$	0.17
$0.50\mu m$	$100\mu A$	$155e^-$	$35.0e^-$	$855e^-$	$1199\mu m$	$120\mu W$	0.45
$0.50\mu m$	$200\mu A$	$150e^-$	$26.7e^-$	$685e^-$	$1558\mu m$	$240\mu W$	0.69
$0.50\mu m$	$300\mu A$	$148e^-$	$23.1e^-$	$609e^-$	$1806\mu m$	$360\mu W$	0.90
$0.50\mu m$	$500\mu A$	$147e^-$	$19.4e^-$	$534e^-$	$2158\mu m$	$600\mu W$	1.25
$0.75\mu m$	$100\mu A$	$174e^-$	$36.7e^-$	$908e^-$	$860\mu m$	$120\mu W$	0.96
$0.75\mu m$	$200\mu A$	$167e^-$	$28.3e^-$	$732e^-$	$1097\mu m$	$240\mu W$	1.51
$0.75\mu m$	$300\mu A$	$164e^-$	$24.5e^-$	$653e^-$	$1258\mu m$	$360\mu W$	1.98
$0.75\mu m$	$500\mu A$	$161e^-$	$20.7e^-$	$574e^-$	$1482\mu m$	$600\mu W$	2.80
$1.00\mu m$	$100\mu A$	$193e^-$	$38.4e^-$	$960e^-$	$690\mu m$	$120\mu W$	1.61
$1.00\mu m$	$200\mu A$	$184e^-$	$29.8e^-$	$779e^-$	$867\mu m$	$240\mu W$	2.56
$1.00\mu m$	$300\mu A$	$180e^-$	$25.9e^-$	$698e^-$	$984\mu m$	$360\mu W$	3.39
$1.00\mu m$	$500\mu A$	$176e^-$	$22.0e^-$	$615e^-$	$1143\mu m$	$600\mu W$	4.86

ENC ~ a + b·Cd





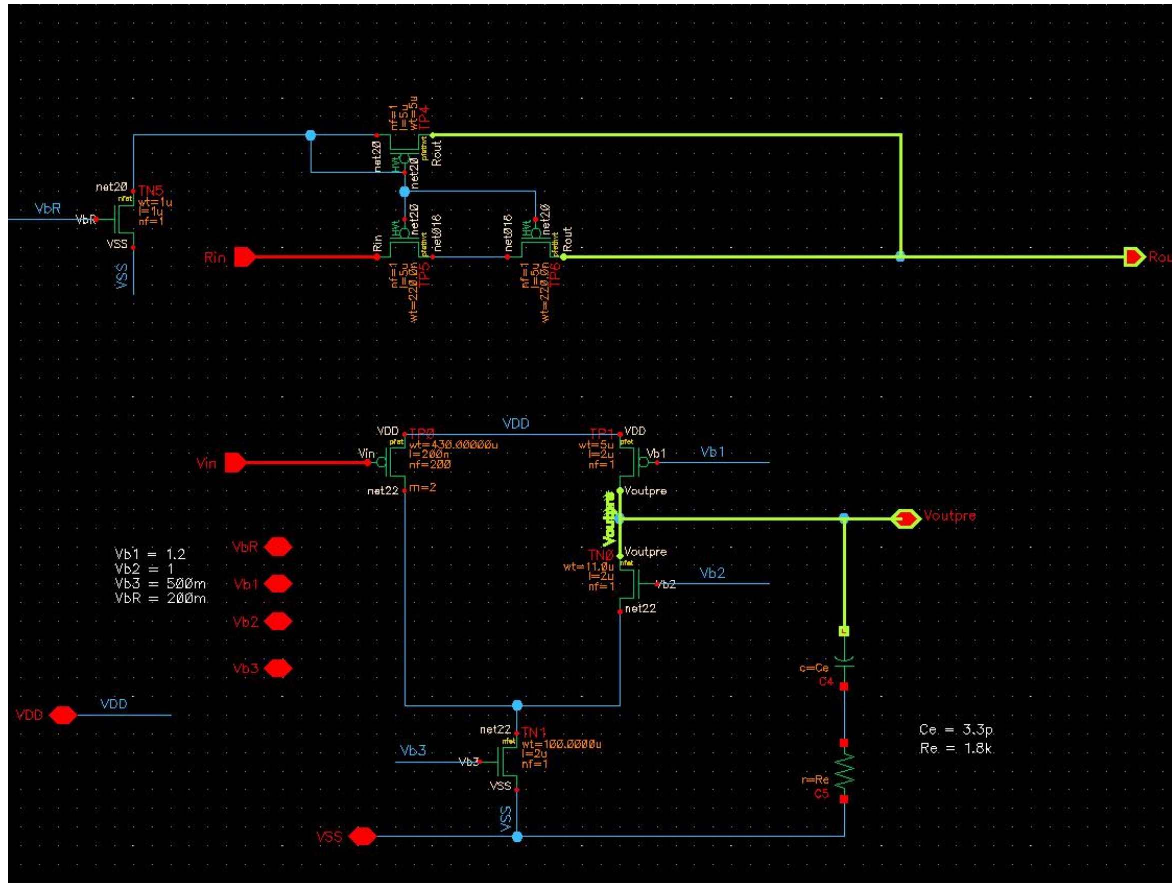
$$ENC = \sqrt{\frac{2}{3}kT\frac{1}{g_m}\,1.57\,\frac{C_t^2 e^2}{\pi q^2 \tau} + \frac{K_f}{C_{ox}^2 WL}\frac{C_t^2 e^2}{2q^2} + I_{\text{leak}}\,1.57\,\frac{e^2\tau}{2\pi q} + \frac{kT}{R}\,1.57\,\frac{e^2\tau}{\pi q^2}}$$

Hans-Günther Moser, “Silicon detector systems in high energy physics”, 2009

Front-end ASIC: CSA

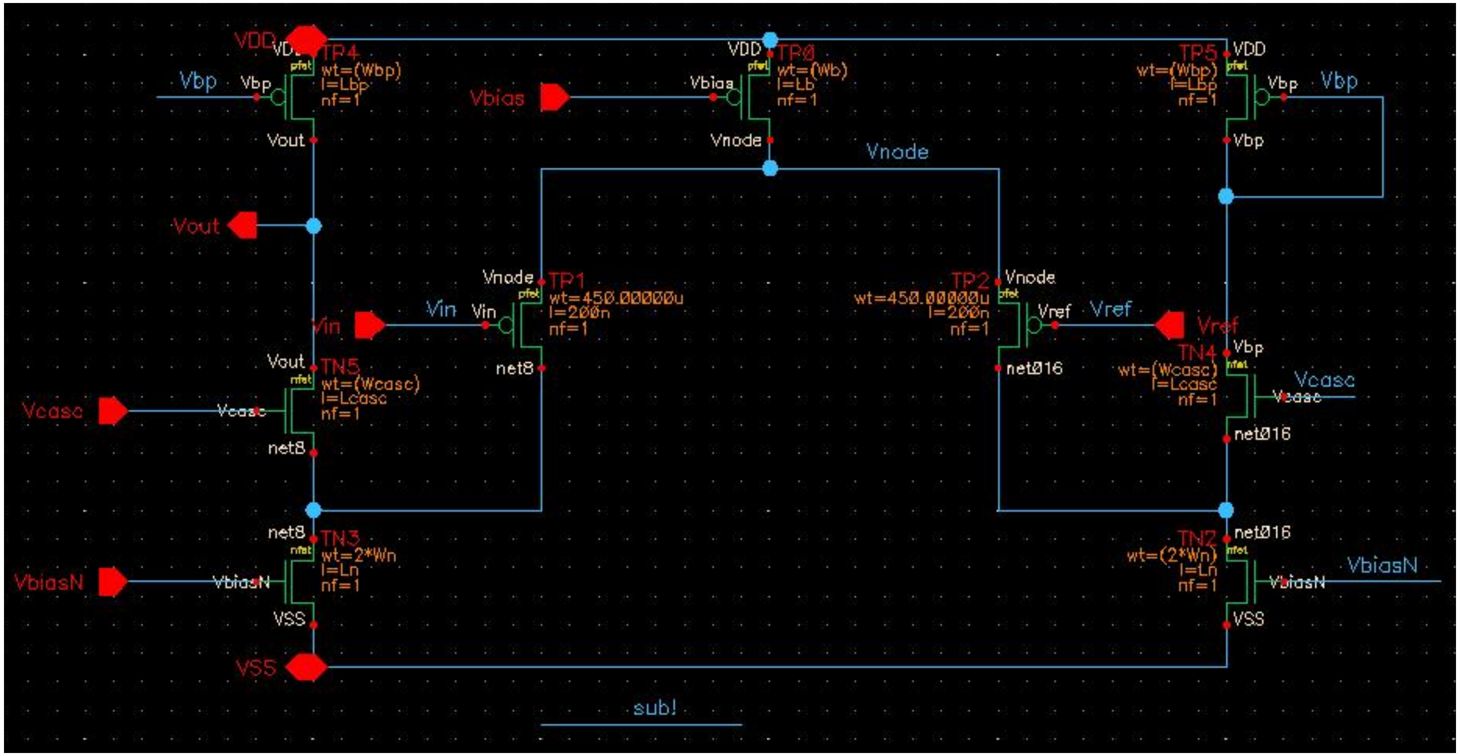
Pre-Amp design in AMS 180 nm

- Power supply: 1.8 V
- Power consumption < 120 uW
- Scale: 40 MIP (1 MIP = 24000 e-)
- Amplifier:
  - Gain ~ 67,5 dB
  - GBW ~ 19,5 MHz
  - PM ~ 63º
- Main noise contribution of the circuit.
- Equivalent Noise Charge: ENC = a + b C_d (where C_d is the capacitor of the detector)
- Optimum L and Ibias to maintain the noise below 500 e-



Front-end ASIC: CSA differential

Pre-Amp design in AMS 180 nm



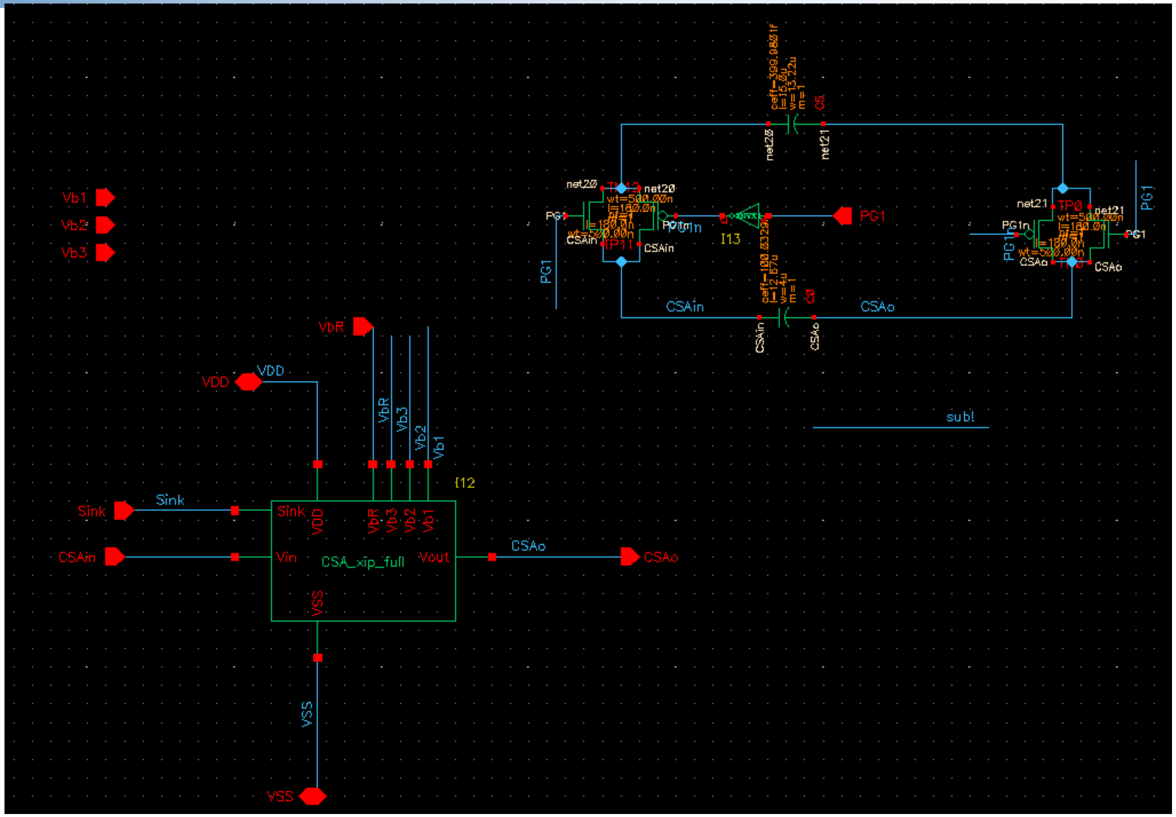
- Power supply: 1.8 V
- Power consumption: higher
- Scale: 100 MIP

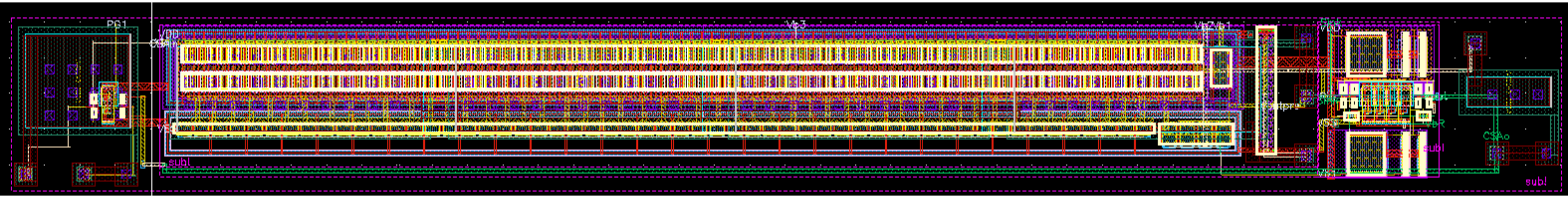
- Amplifier:
  - Gain ~ 69 dB
  - GBW ~ 79,5 MHz
  - PM ~ 68º

Front-end ASIC: CSA

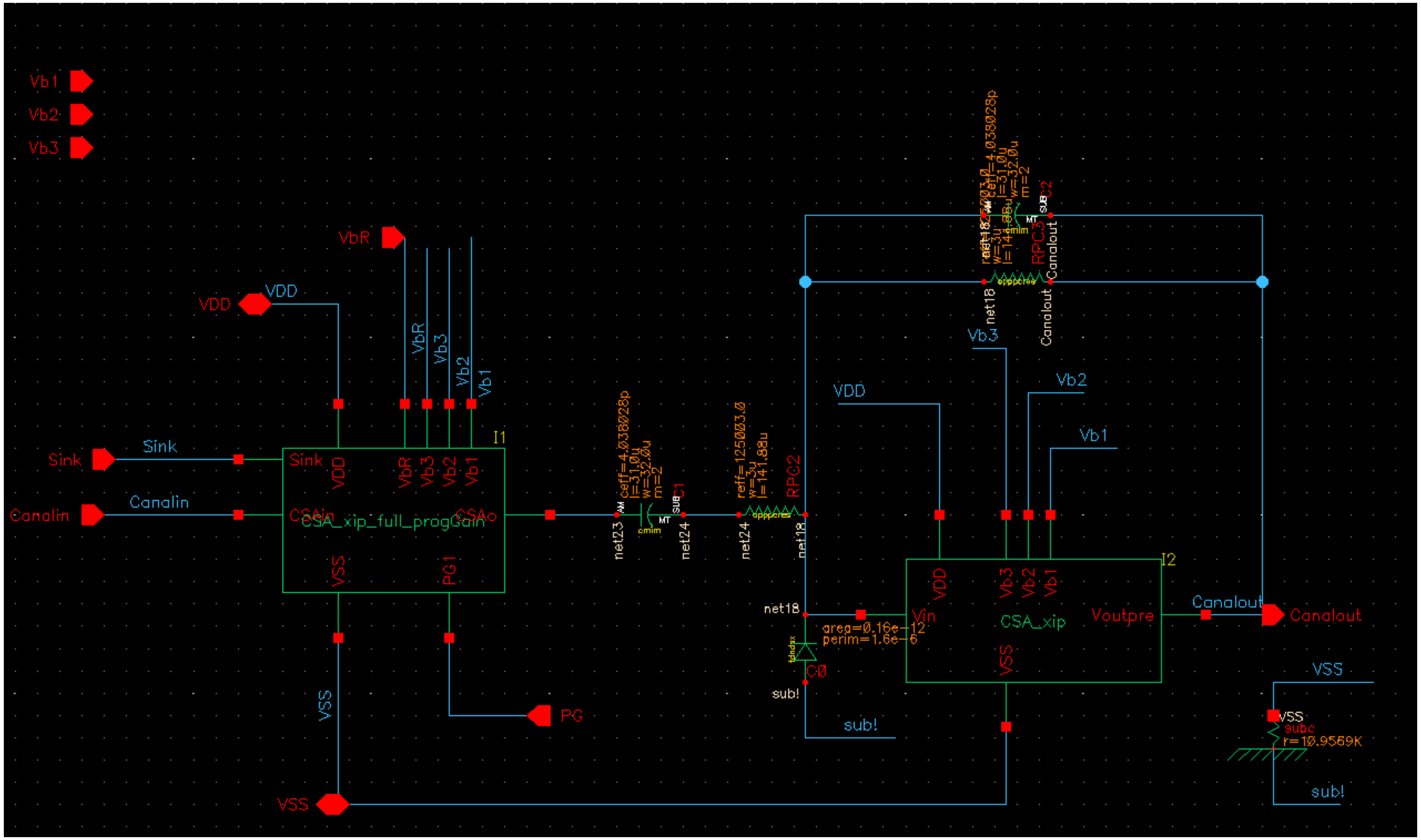
Pre-Amp design in AMS 180 nm

- Programmable gain to reduce noise.
- Scale: 40 MIP (1 MIP = 24000 e-)
  - Gain 1: from 1 to 10 MIPs
  - Gain 2: from 10 up to 40 MIPs
- Layout: 220 um x 25 um



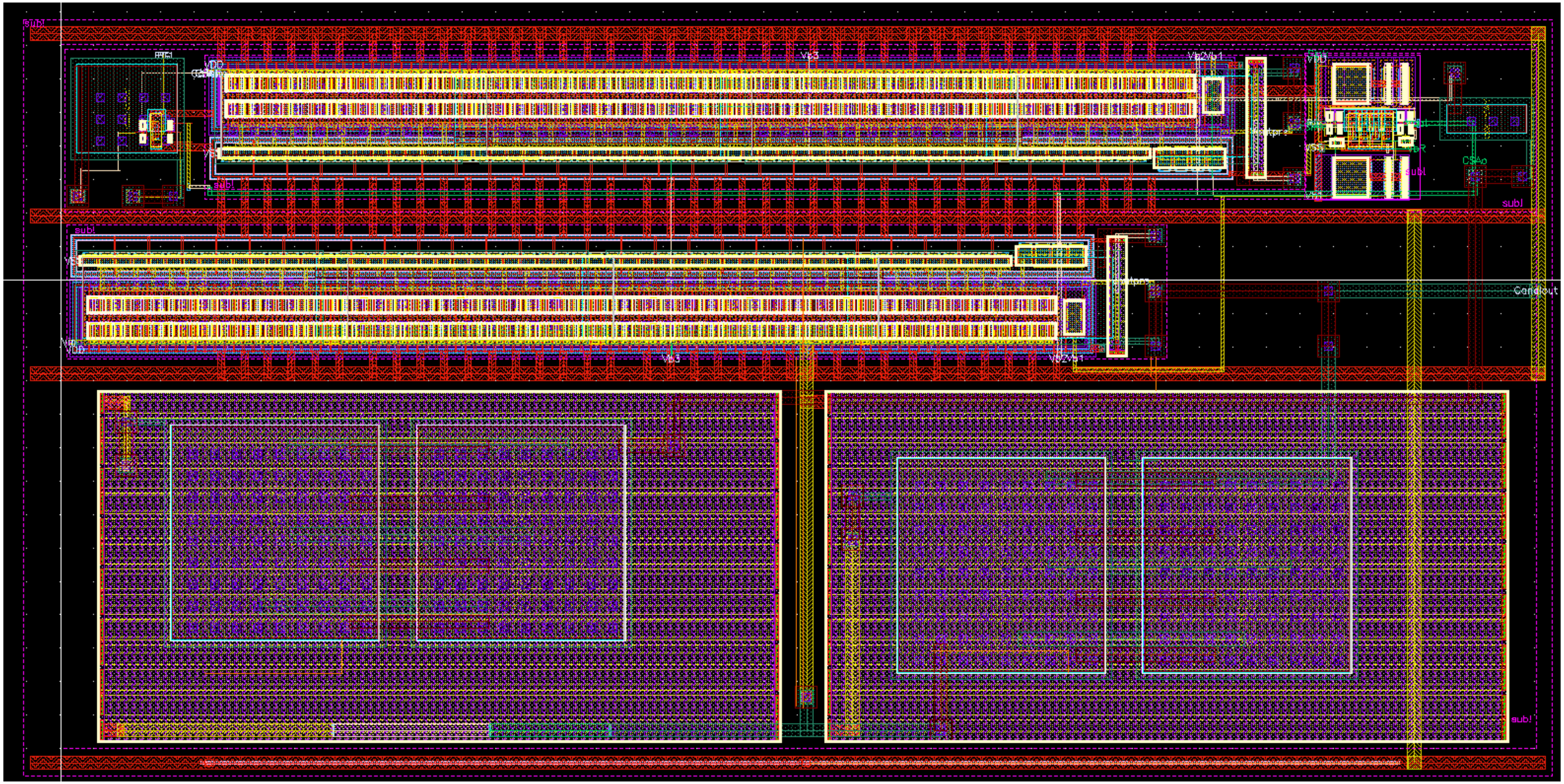


Front-end ASIC: CSA + Shaper



- No programmable shaping time
- 1 us shaping time

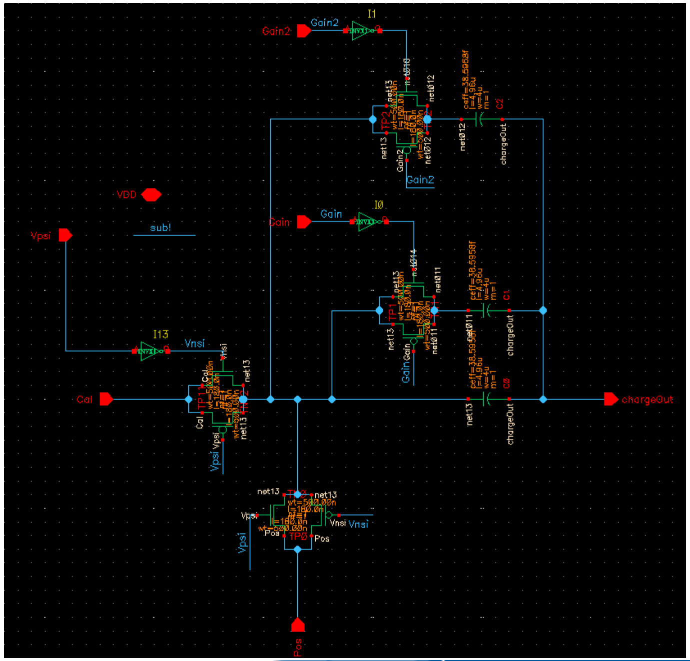
Front-end ASIC: CSA + Shaper

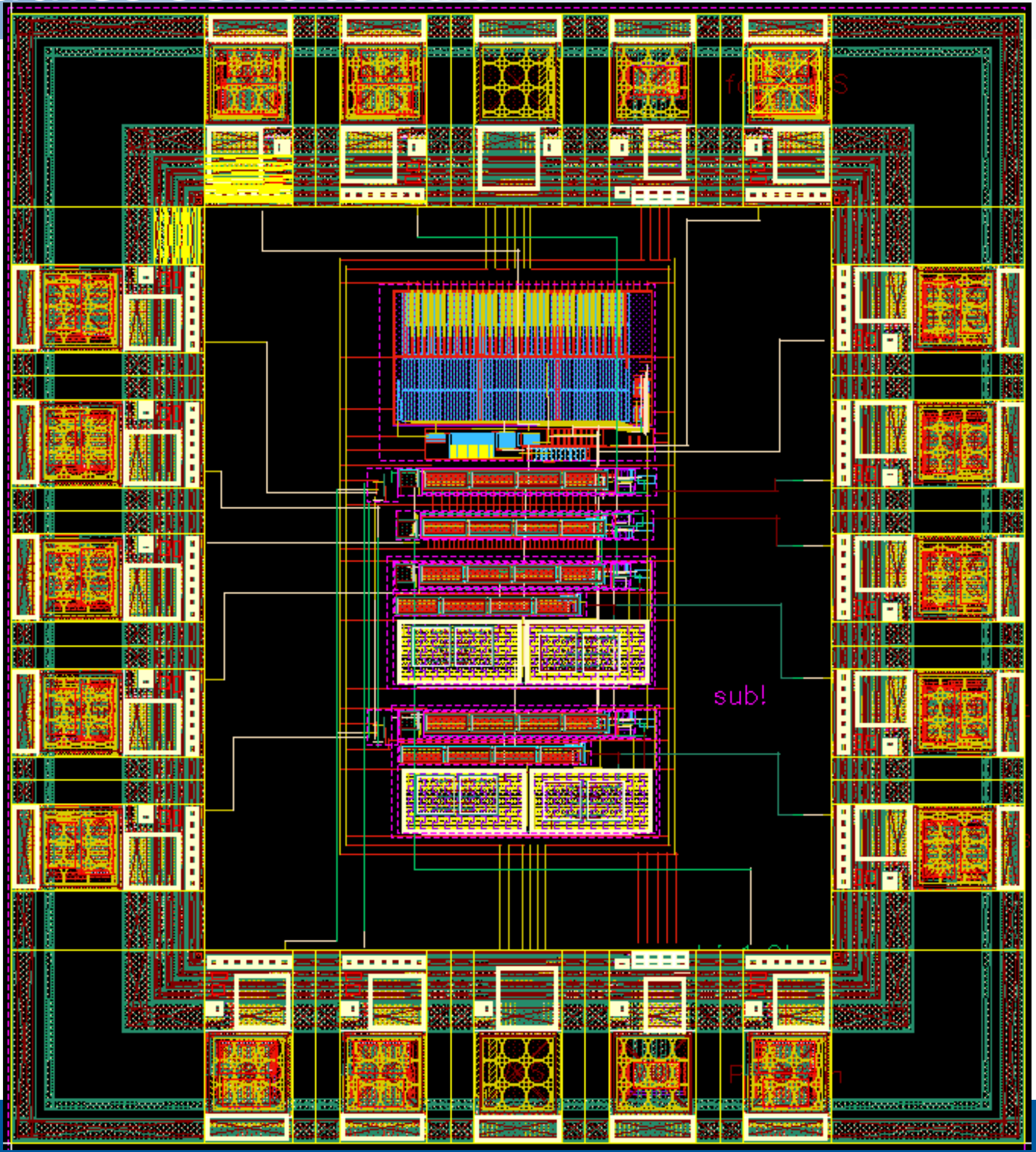


- 228 um x 112 um

Front-end ASIC: Modules sent to fab

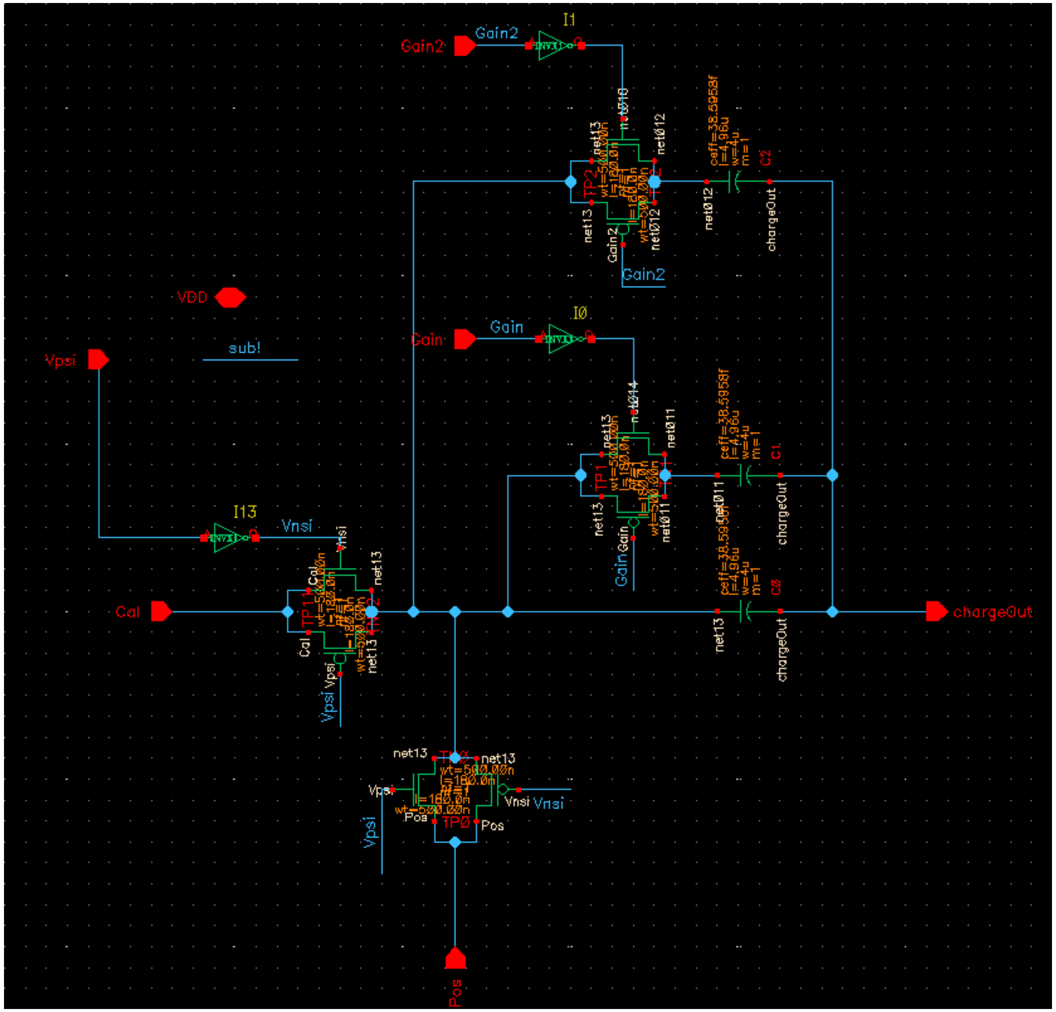
- 1 BIAS module
- 1 CSA
- 1 CSA + Shaper (channel)
- For test purposes:
    - 1 CSA + Charge Injection
    - 1 Channel + Charge Injection
- Size: 867 um x 960 um





Test plan: Calibration

- $Q_{cal} = C_{cal} * (V_{pos} – V_{cal})$
- C_{cal} :
    - 38.6 fF
    - 38.6 * 2 fF
    - 38.6 * 3 fF
- V_{cal} = [1.8 V to 0 V]
- Qcal = [0 fC to 208.44 fC]
- 1 MIP ~ 24000 e => 3.86 fC



E. Beuville et al., “High Performance, Low-Noise, 128-Channel Readout Integrated Circuit for Flat Panel X-ray Detector Systems”

Test plan

- Test BIAS system

- Test of CSA + Charge Injection:
  - Test correct behavior of CSA
  - Find ENC at low gain
  - Find ENC at high gain
  - Dispersion from chip to chip

- Test of Channel + Charge Injection
  - Test correct behavior of the channel
  - Find ENC at the output of the shaper
  - Is shaping time correct ?
  - Dispersion from chip to chip

- Test with real sensors.

Conclusions

- CSA can work with “source” or “sink” sensors.
- Similar noise but less power consumption than the work performed with TSMC 65 nm.
- For each switch noise increases, ENC with full gain near to 950 e.
- Study and design of a fast comparator. Has to be tested together with the resistive microstrip model.
- Need to adapt to DC sensors