DØ Calorimeter Electronics Upgrade for Tevatron Run II

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Tevatron Run I (1992-96)

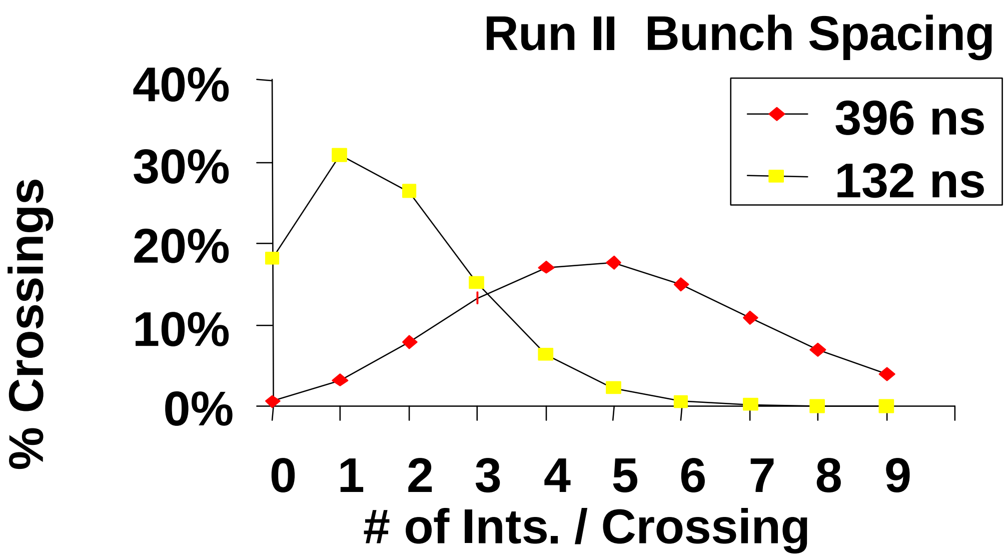
- **Very successful Run I**
  - **p-pbar collisions at s = 1.8 TeV**
  - **$\int L\, dt \sim 120\ pb^{-1}$ delivered to DØ and CDF**
  - **Peak luminosity ~ $1.6 \times 10^{31}\ cm^{-2}\ s^{-1}$**
  - **Many exciting studies, including**
    - **Top discovery**
      - **$M_t = 172.1 \pm 5.2$ (stat.) $\pm$ 4.9 (syst.) GeV/c^2**
      - **$\sigma_{tt} = 5.9 \pm 1.7$ pb (DØ combined)**
    - **W mass measurement**
      - **$M_W = 80.482 \pm 0.091$ GeV (DØ combined)**
    - **Limits on anomolous gauge couplings**
    - **Limits on SUSY, LQ, compositeness, other exotica**
    - **Tests of QCD + Electroweak**
    - **b-quark physics**
  - **100+ published papers**
  - **60+ PhD theses**

Fermilab Accelerator Upgrade

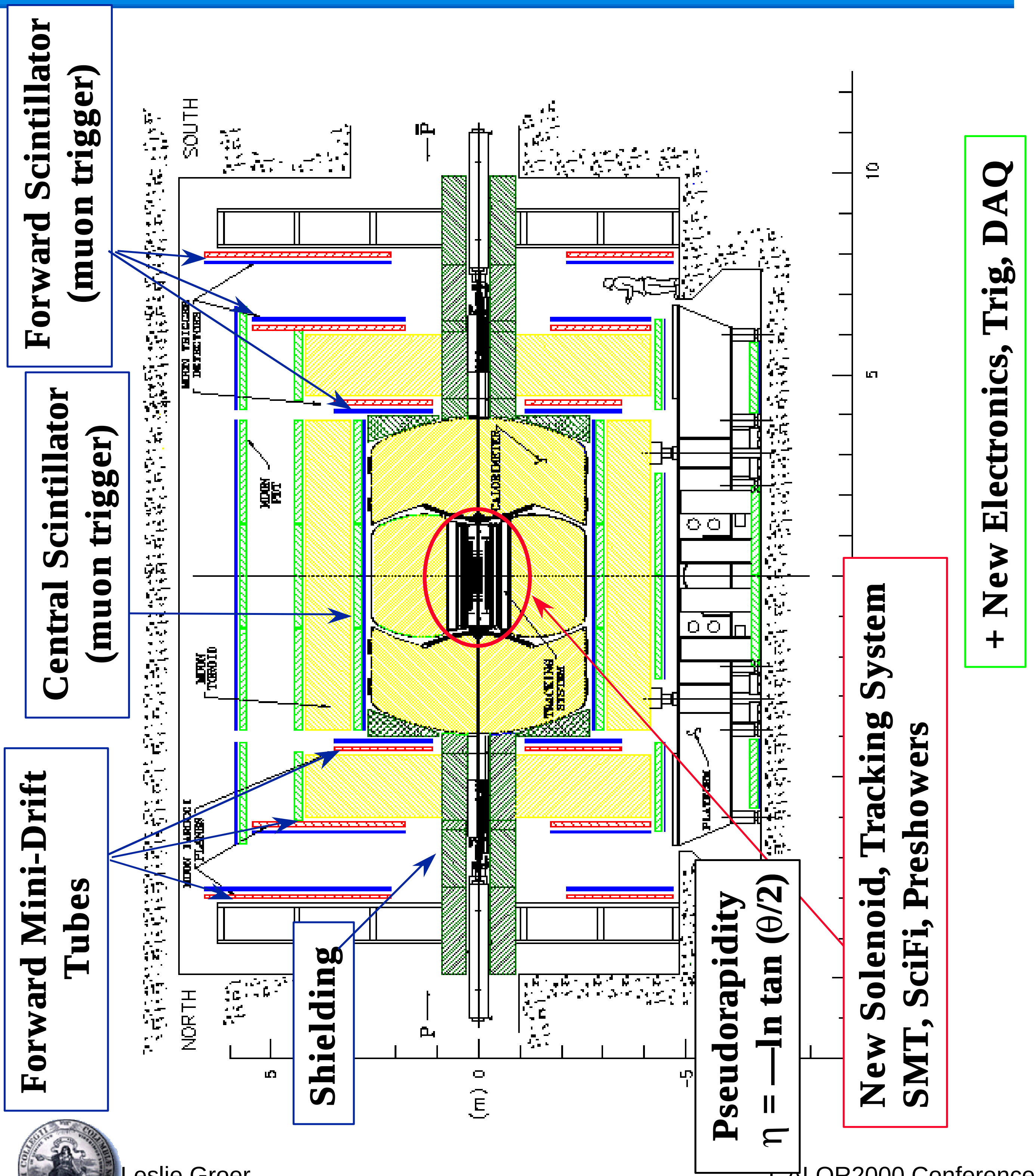
- Two new machines at FNAL for Run II:
  - Main Injector
    - 150 GeV conventional proton accelerator
    - Supports luminosity upgrade for the collider, future 120 GeV fixed-target program, and neutrino production for NUMI
  - Recycler
    - 8 GeV permanent magnet (monoenergetic) storage ring
    - permits antiproton recycling from the collider
- Tevatron Status and Schedule
  - DØ and CDF roll in – January 2001
  - Run II start – March 2001
  - 1.8 Tev → 2 TeV
  - Goal: $\int L\, dt = 2\ fb^{-1}$ by 2003
    $15\ fb^{-1}$+ by 2006?
  - Very first p-pbar collisions seen (August 2000)

Run II Parameters

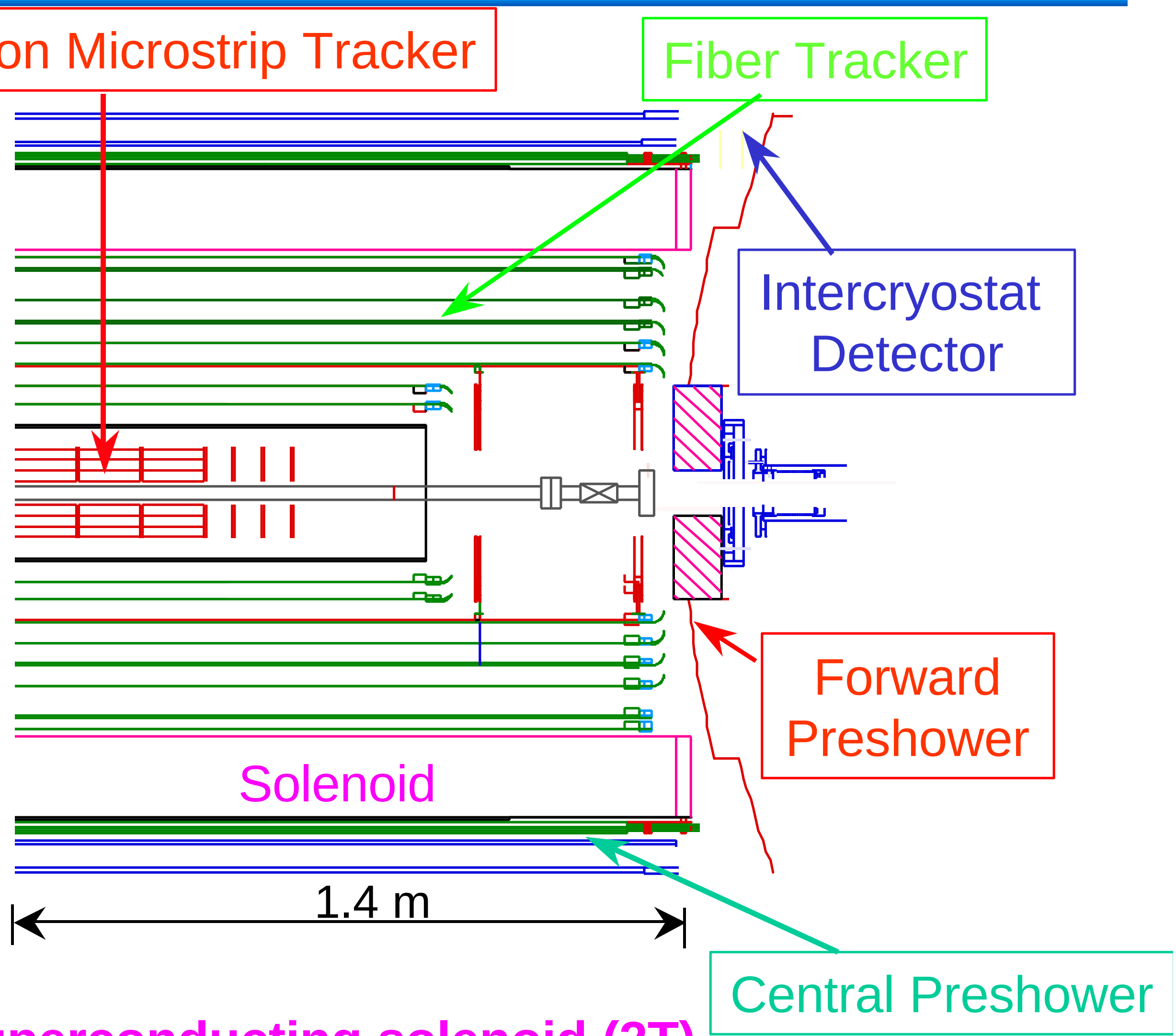
Parameter	Run IB (1993-1995)	Run II MI plus Recycler	Units
Energy	900	1000	GeV
Protons/bunch	23×10^{10}	27×10^{10}	
P-bars / bunch	5.5×10^{10}	7.5×10^{10}	
Bunches	6	36x36 → 140x103	
P-bar stacking	6×10^{10}	20×10^{10}	per hour
Crossing angle	0	136	μrad
Luminosity	1.6×10^{31}	2.1×10^{32}	$cm^{-2} s^{-1}$
Bunch Spacing	3500	396 → 132	nsec
Interactions per crossing	2.7	4.8 → 2.3	



Run II
DØ Upgrade

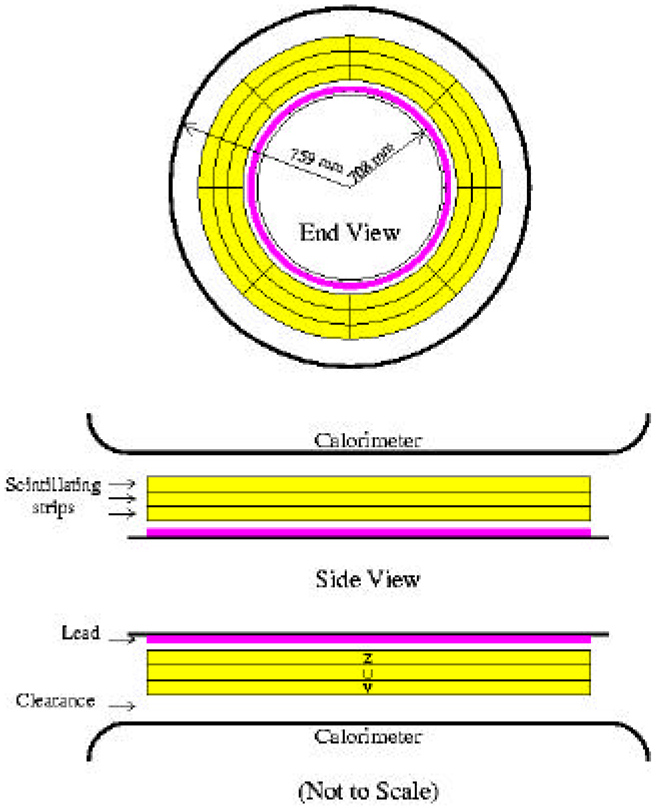


Inner Detectors



- **Superconducting solenoid (2T)**
- **840k channel silicon vertex detector**
- **77k channel scintillating fiber tracker**
- **Scintillating strip preshower in central and forward regions. (6k and 16k channels)**
- **Intercryostat detector (scintillator tiles)**

Preshower Detectors



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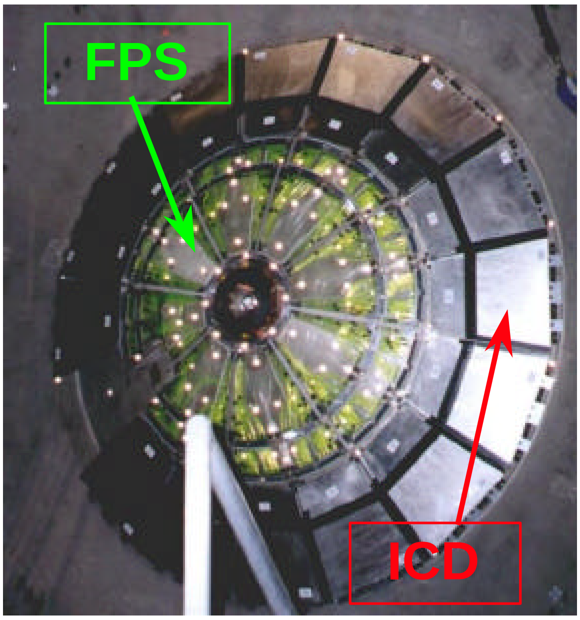
Creator: AutoCAD PSOUT
CreationDate: 1997-03-06

- **Central mounted on solenoid (|η| < 1.2)**
- **Forward on calorimeter endcaps (1.4 < |η| < 2.5)**
- **Extruded triangular scintillator strips with embedded WLS fibers and Pb absorber**
- **Trigger on low-p_T EM showers**
- **Reduce overall electron trigger rate by x3-5**
- **VLPC and SVX II readout**

Intercryostat Detector (ICD)

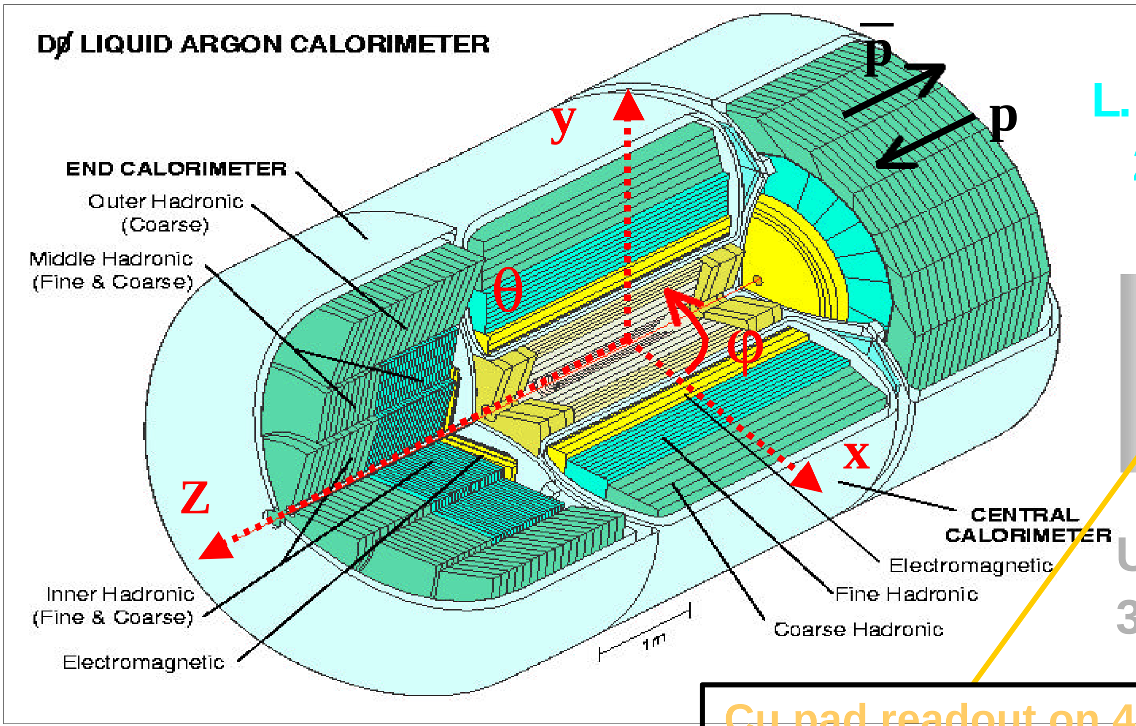
LaTech
UT, Arlington

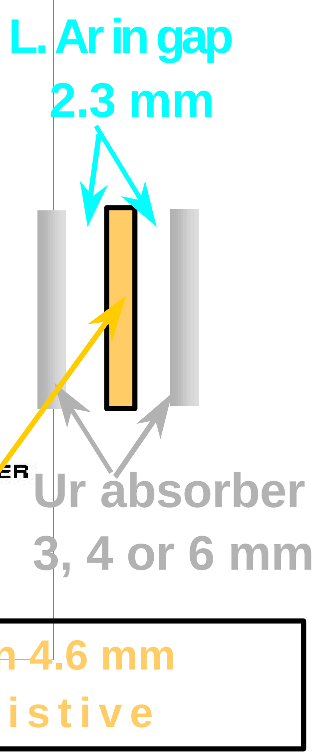
- **Objectives**
  - Maintain performance in presence of a magnetic field and additional material from solenoid
  - Improve coverage for the region 1.1 < |η| < 1.4
  - Improves jet E_T and $\not{E}_T$



- **Design**
  - Scintillator based with phototube readout similar to Run I design. Re-use existing PMT's (Hamamatsu R647).
  - 16 *supertile* modules per cryostat with a total of 384 scintillator tiles
  - WLS fiber readout of scintillator tiles
  - Clear fiber light piping to region of low field ~40-50% signal loss over 5-6m fiber.
  - Readout/calibration scheme for electronics same as for L. Ar. Calorimeter but with adapted electronics and pulser shapes
  - LED pulsers used for PMT calibration
  - Relative yields measured > 20 p.e./m.i.p.

DØ Calorimeters (1)





- Liquid argon sampling
  - Stable, uniform response, rad. hard, fine spatial seg.
  - LAr purity important
- Uranium absorber (Cu or Steel for coarse hadronic)
  - Compensating e/π ~ 1, dense ⇒ compact
- Uniform, hermetic with full coverage
  - $|\eta| < 4.2$ ($\theta \approx 2^o$), $\lambda_{int} > 7.2$ (total)
- Energy Resolution
  - e: $\sigma_E / E = 15\% / \sqrt{E} + 0.3\%$ (e.g. 3.7% @ 20 GeV)
  - π: $\sigma_E / E = 45\% / \sqrt{E} + 4\%$ (e . g . 1 4 %

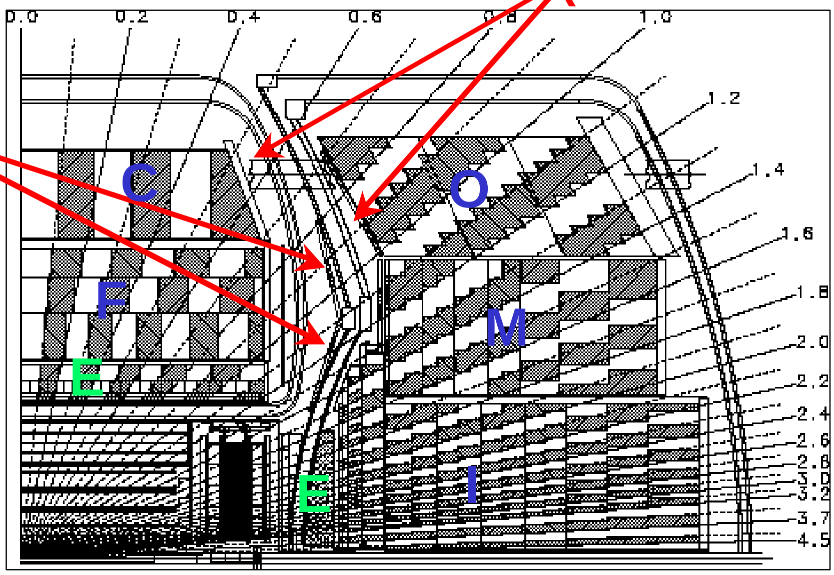
DØ Calorimeters (2)

- Arranged in semi-projective towers
- Readout cells ganged in layers
- Readout segmented into η, ϕ for charge detection
  - Transverse segmentation $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$
  - At shower max. (EM3) $\Delta\eta \times \Delta\phi = 0.05 \times 0.05$
- +2.5 kV (E = 11 kV/cm) gives drift time ~ 450 ns

Layer	CC	EC
EM1,2,3,4	X_O : 2,2,7,10 3mm Ur	X_O : (0.3),3,8,9 (1.4mm Fe) 4mm Ur
FH1,2,3,(4)	λ_O : 1.3,1.0,0.9 6mm Ur	λ_O : 1.3,1.2,1.2,1.2 6mm Ur
CH1,(2,3)	λ_O : 3.0 46.5mm Cu	λ_O : 3.0, (3.0, 3.0) 46.5mm Fe

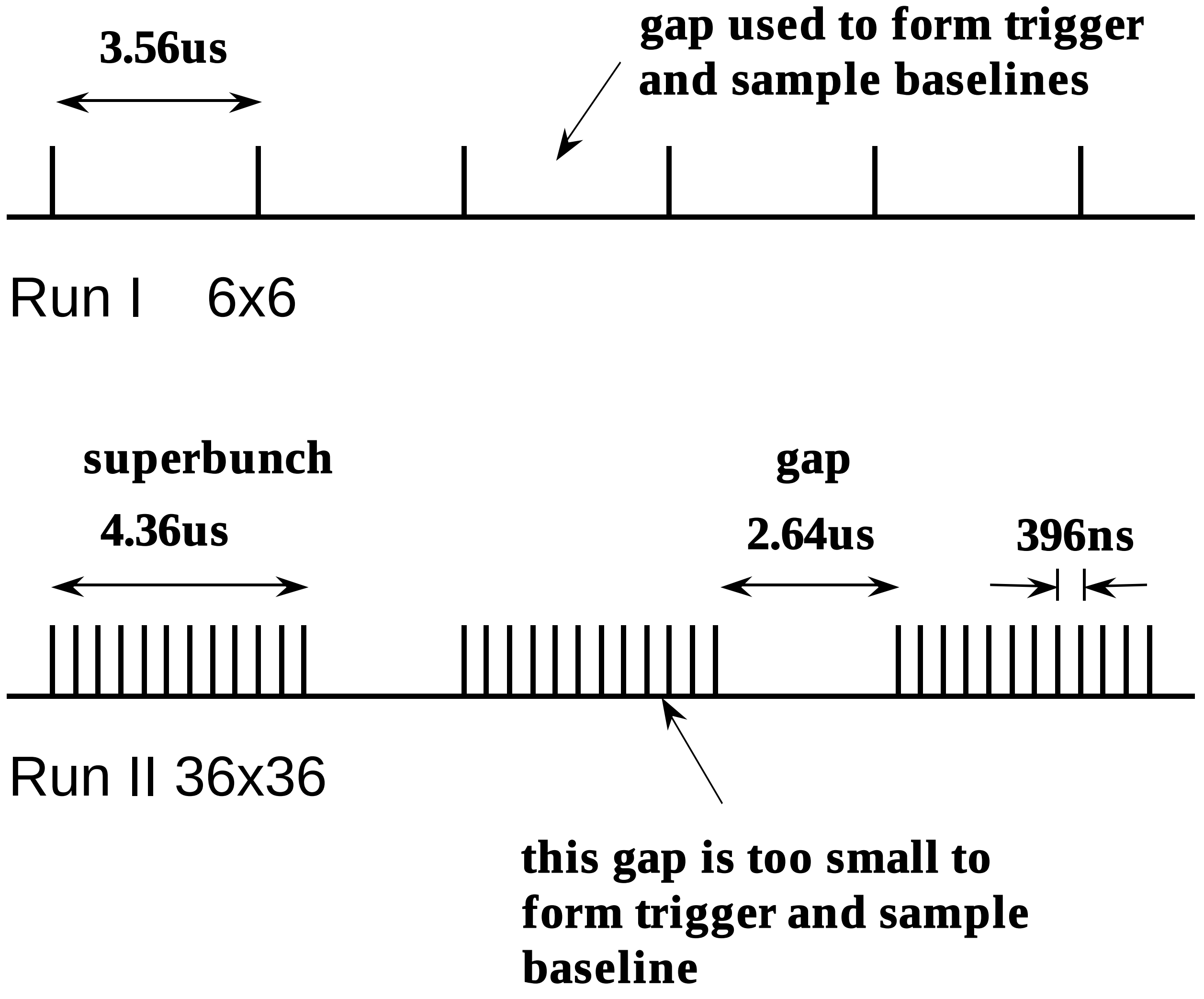
Massless Gap (no absorber)

Intercryostat Detector (ICD)



Timing

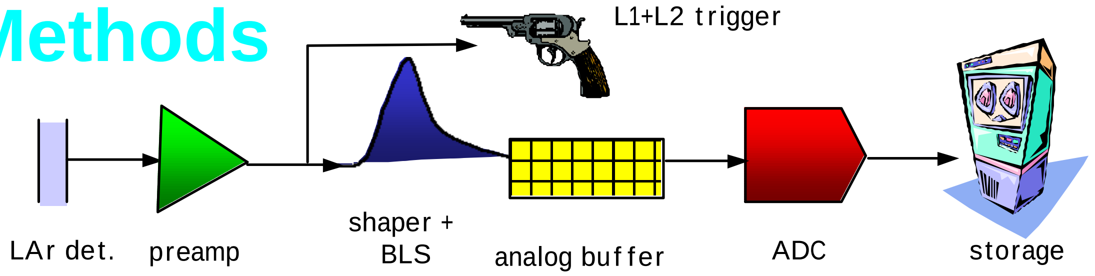
❍ Bunch structure



- Design all the electronics, triggers and DAQ to handle bunch structure with a minimum of 132ns between bunches and higher luminosity
- Maintain detector performance

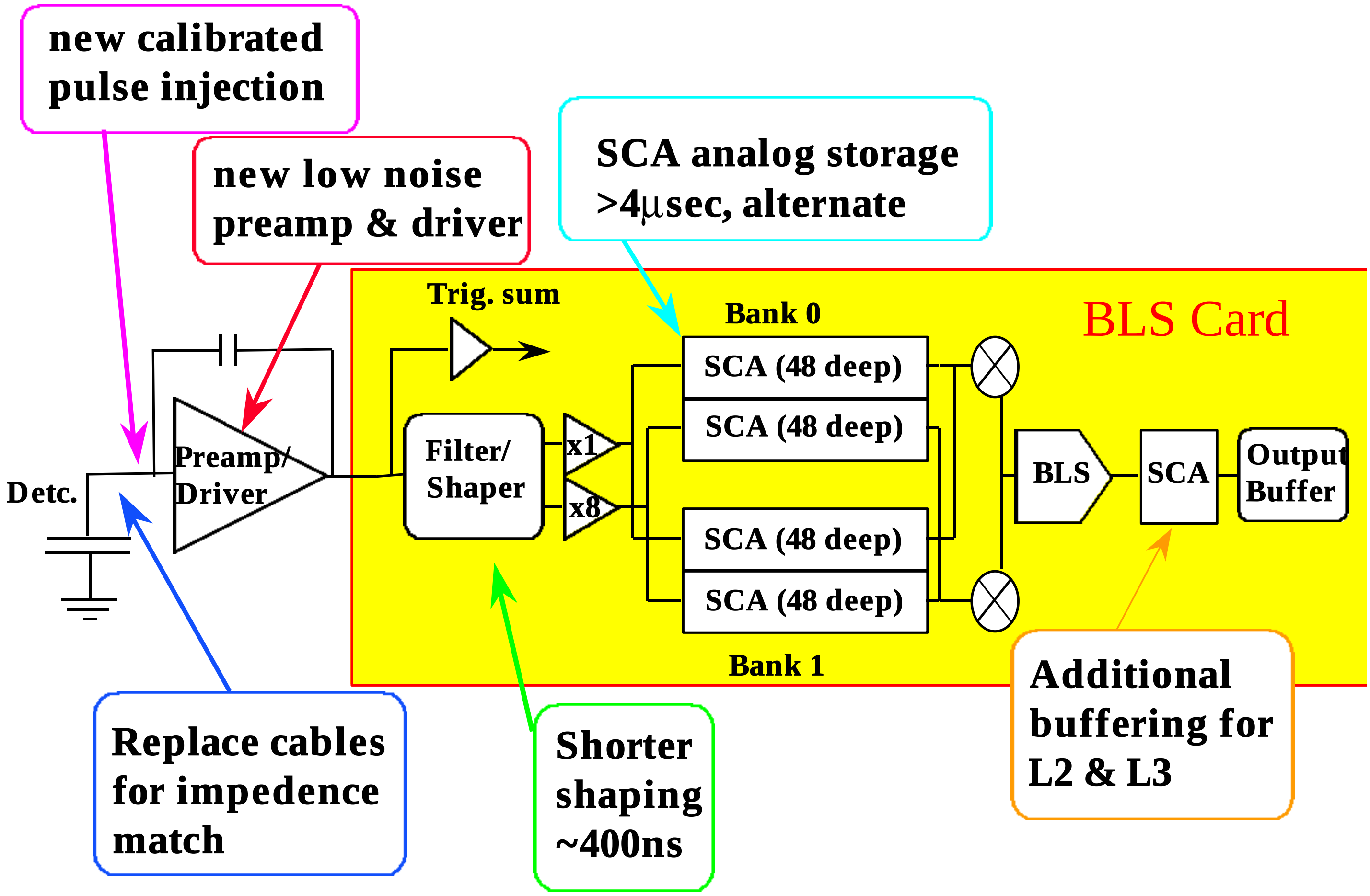
Calorimeter Readout Electronics

- **Objectives**
  - **Accommodate reduced minimum bunch spacing from 3.5 μs to 396 ns or 132 ns and $\mathcal{L} \sim 2 \times 10^{32}\ cm^{-2}\ s^{-1}$**
  - **Storage of analog signal for 4 μs for L1 trigger formation**
  - **Generate trigger signals for calorimeter L1 trigger**
  - **Maintain present level of noise performance and pile-up performance**
- **Methods**



  - **Replace preamplifiers**
  - **Replace shapers**
  - **Add analog storage**
  - **Replace calibration system**
  - **Replace timing and control system**
  - **Keep Run I ADCs, crates and most cabling to minimize cost and time**

Calorimeter Electronics Upgrade



55K readout channels

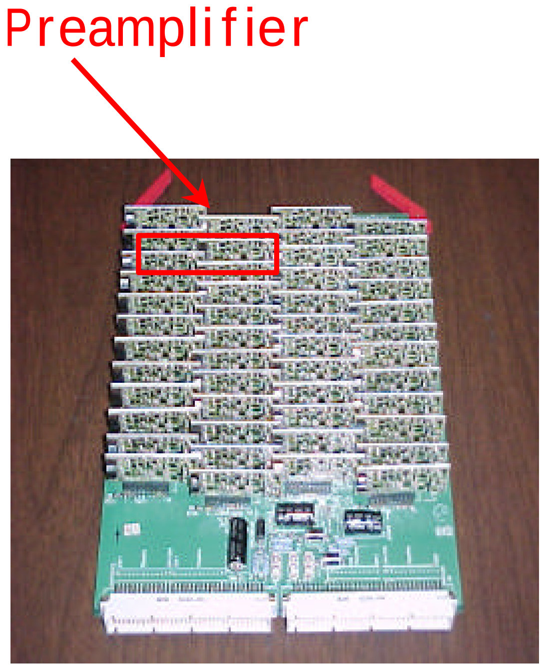
- Replace signal cables from cryostat to preamps (110Ω → 30Ω for impedance match)
- Replacement of preamps, shapers, baseline subtraction circuitry (BLS)
- Addition of analog storage (48-element deep Switched Capacitor Array (SCA))
- New Timing and Control
- New calibration pulser + current cables

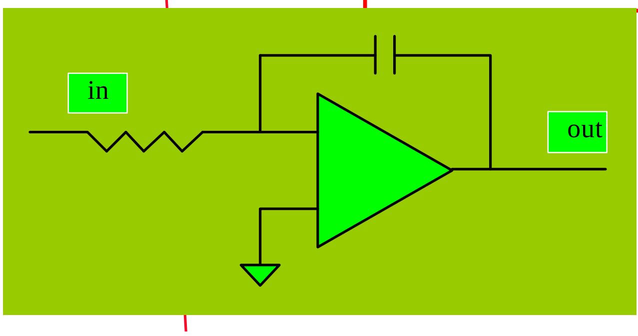
Preamplifier

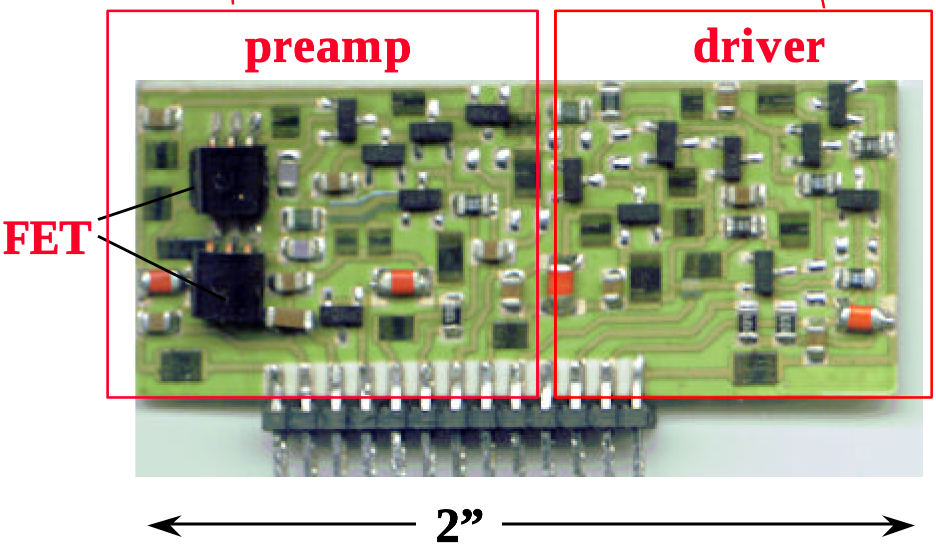
similar to Run 1 version except

- Dual FET frontend
- Compensation for detector capacitance
- Faster recovery time

New output driver for terminated signal transmission







New calorimeter preamp

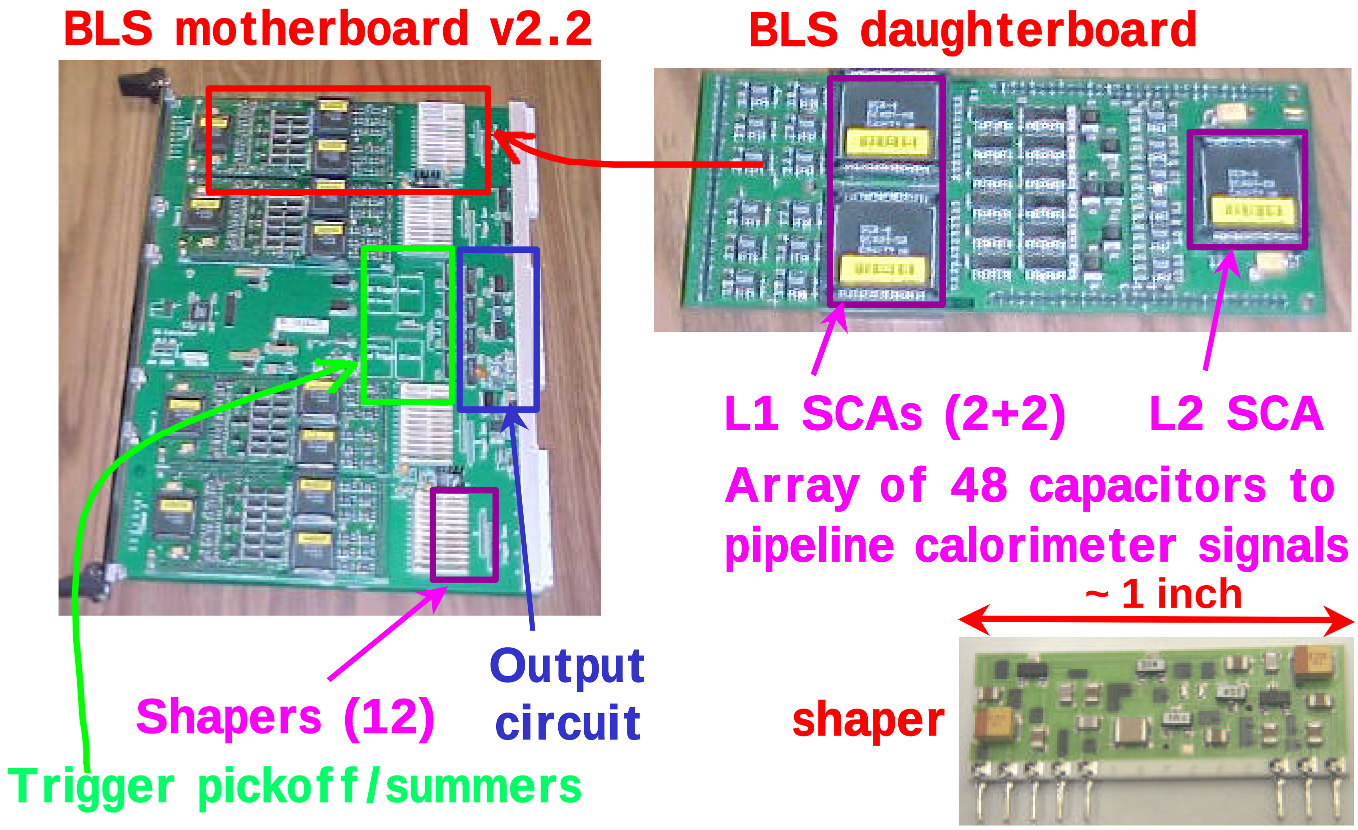
- **Hybrid on ceramic**
- **48 preamps on a motherboard**
- **New low-noise switching power supplies in steel box**

Preamp Species

Preamp species	Avg. Detector cap. (nF)	Layer readout	Feedback cap (pF)	RC (ns)	Total preamps
A	0.26-0.56	EM1,2, HAD	5	0	13376
B	1.1-1.5	HAD	5	26	2240
C	1.8-2.6	HAD	5	53	11008
D	3.4-4.6	HAD	5	109	8912
E	0.36-0.44	CC EM3	10	0	9920
F	0.72-1.04	EC EM3,4	10	14	7712
G	1.3-1.7	CC EM4, EC EM3,4	10	32	3232
Ha-Hg	2- 4	EC EM3,4	10	47-110	896
I	—	ICD	22	0	384
					55680

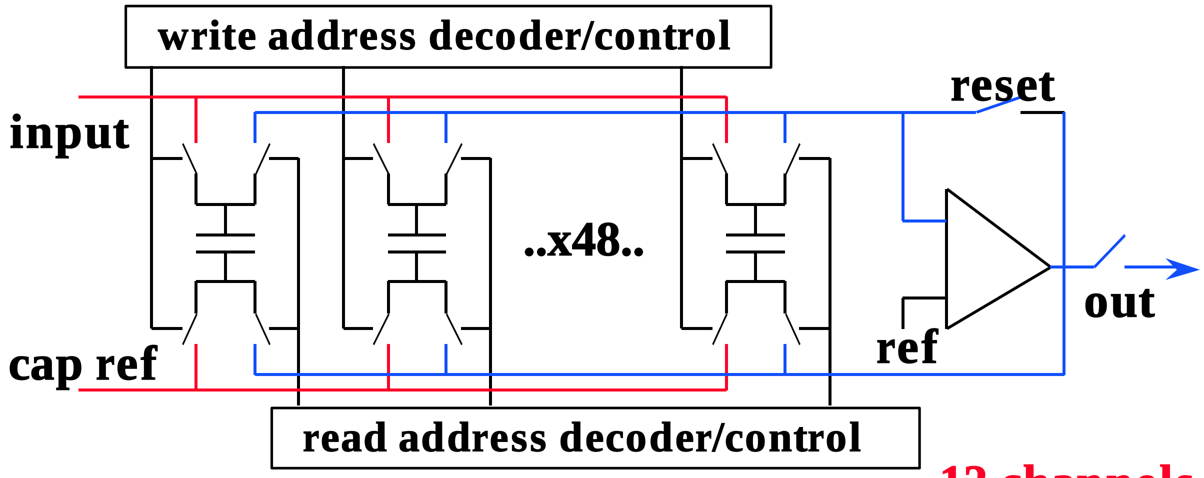
- 14+1 (ICD) species of preamp
- Feedback provide compensation for RC from detector capacitance and cable impedance
- Readout in towers of up to 12 layers
  - 0:EM1, 1:EM2, 2-5:EM3, 6:EM4, 7-10:FH, 11:CH
- 4 towers per preamp motherboard provides trigger tower (EM+ HAD) of $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$

BLS Card

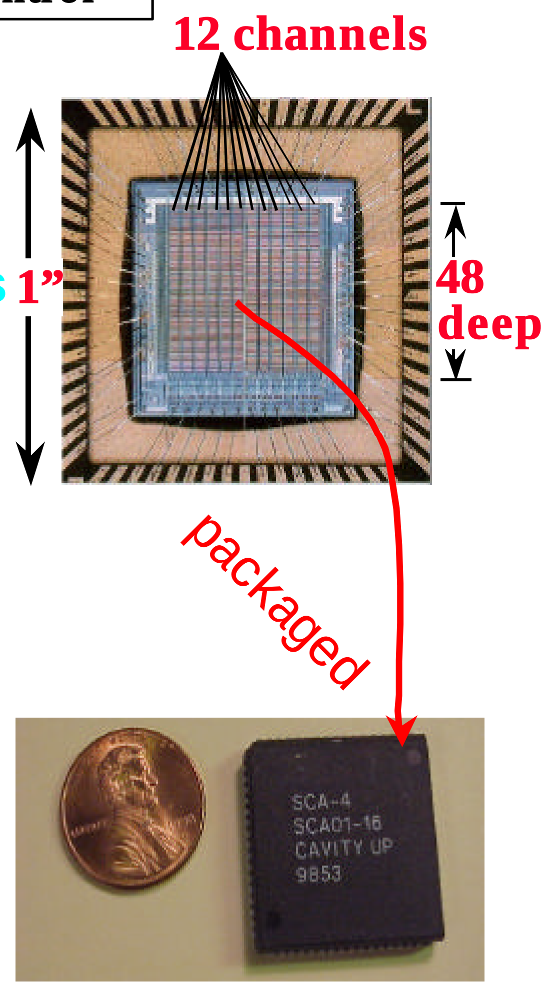


- Use 2 L1 SCA chips for each x1/x8 gain
  - alternate read/write for each superbunch
- Readout time ~ 6 µs (< length SCA buffer)
- L2 SCA buffers readout for transfer to ADC after L2 trigger decision
- No dead time for 10KHz L1 trigger rate
- Trigger tower formation (0.2 x 0.2) for L1
- Rework existing power supplies
- New T&C signals to handle SCA requirements and interface to L1/L2 trigger system(use FPGAs and FIFOs)

SCA

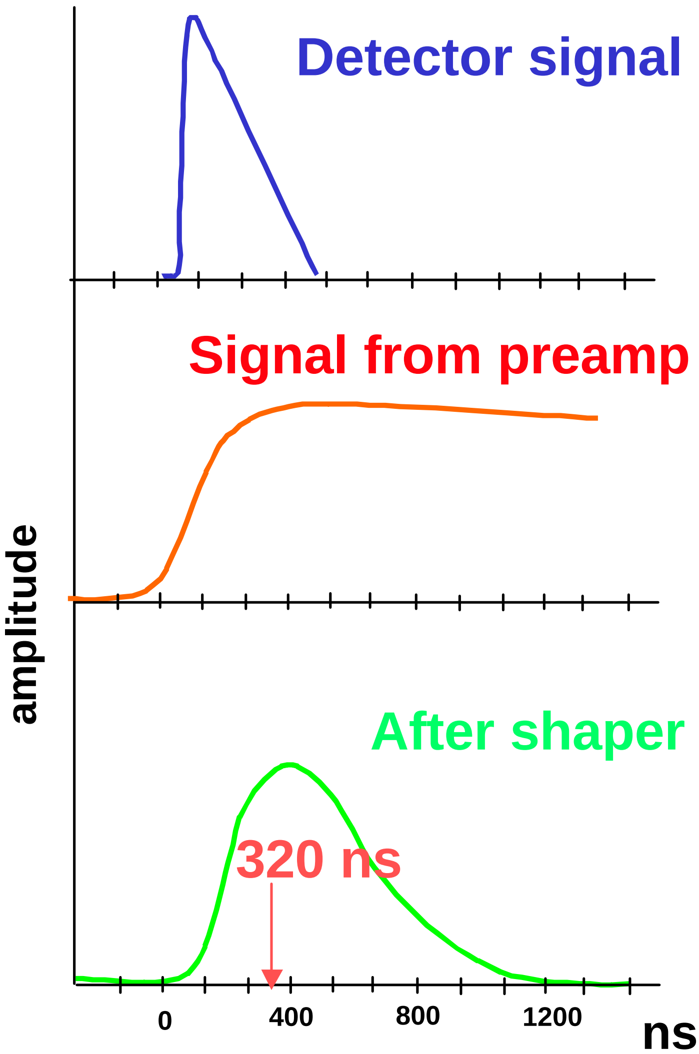


- Designed by LBL, FNAL, SUNY Stony Brook (25k in system)
- Not designed for simultaneous read and write operations
- two SCA banks alternate reading and writing
- 12 bit dynamic range (1/4000)
- low and high gain path for each readout channel (X8/X1)
  - maintain 15 bit dynamic range



Preamp signal shape

- Preamp output is integral of detector signal
  - rise time > 430ns
  - recovery time 15μs
  - To minimize the effects of pileup, only use 2/3 of the charge in the detector
- Shaped signal sampled every seven RF buckets (132ns)
  - peak at about 300ns
  - return to zero by about 1.2μs
  - Sample at 320ns
  - Mostly insensitive to 396 ns or 132 ns running
- BLS-Finite time difference is measured
  - Uses three samples earlier
  - Pile-up



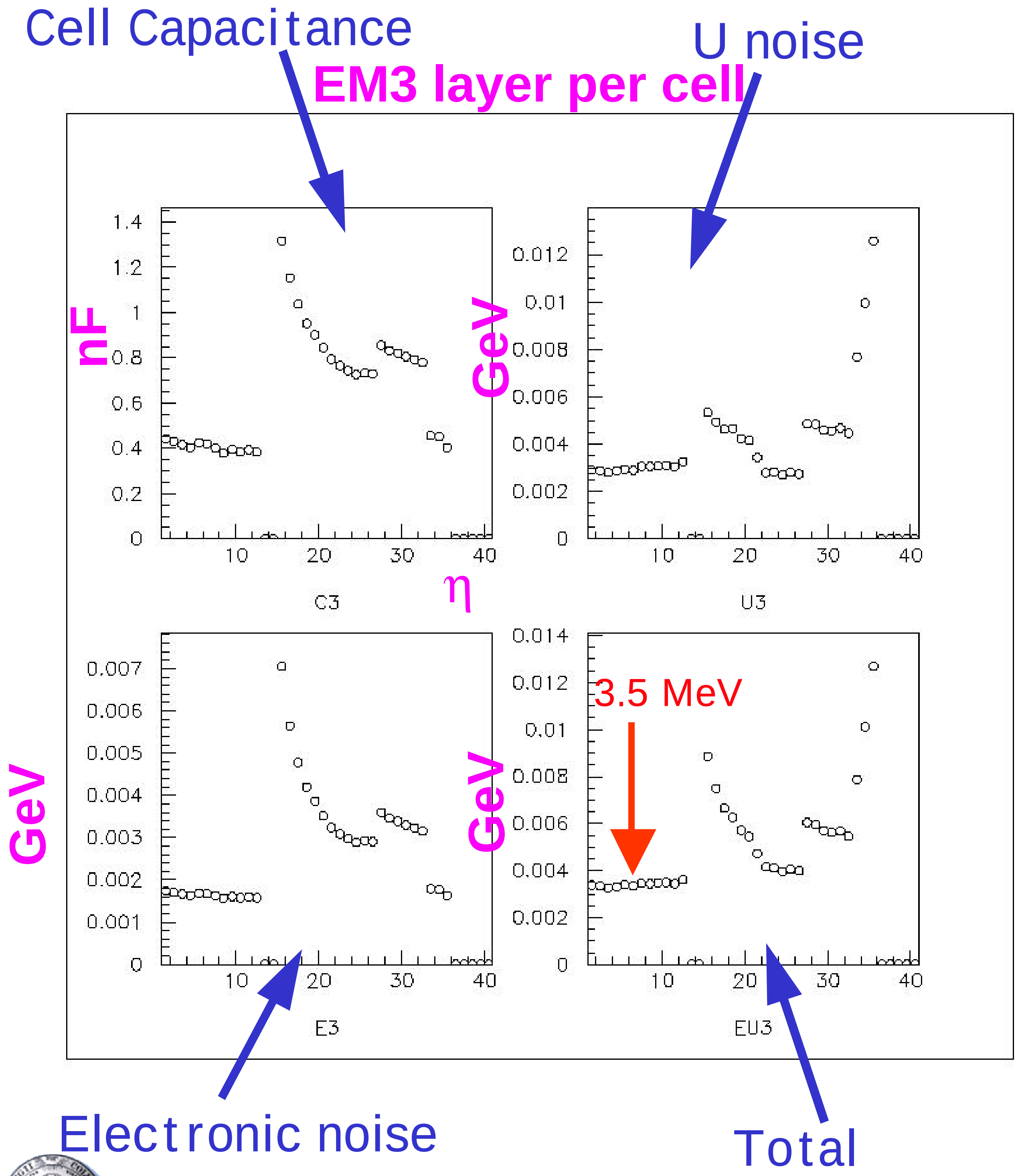
Noise Contributions

- Design for
  - 400ns shaping
  - lower noise – 2 FET input
  - luminosity of $2x10^{32}$ cm^{-2} s^{-1}
- Re-optimized three contributions
  - Electronics noise: ↑ x 1.6
    - ↑ shaping time (2μs → 400ns) (~√ t)
    - ↓ lower noise preamp (2 FET) (~ 1/√ 2)
  - Uranium noise: ↓ x 2.3
    - ↓ shorter shaping time (~ √ t)
  - Pile-up noise: ↑ x 1.3
    - ↑ luminosity (~ √ L)
    - ↓ shorter shaping times (~ √ t)

➜ Comparable noise performance at 10^{32} with new electronics as with old electronics at 10^{31}

➜ Simulations of the W mass "bench-mark" confirm that pile-up will not limit our W mass at Run II.

Estimates of Noise Contributions

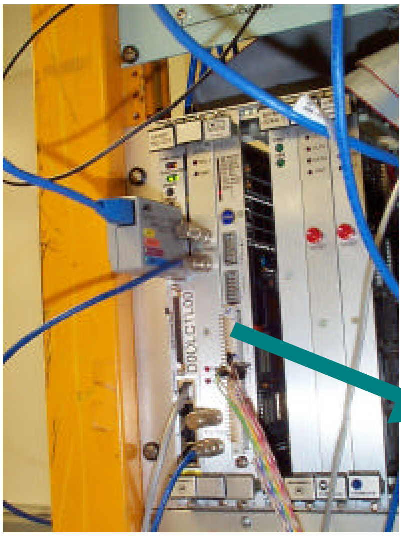


Electronics Calibration

Goals

- Calibrate electronics to better than 1%
  - Measure pedestals due to electronics and Ur noise
  - Determine zero suppression limits
  - Determine gains (x1,x8) from pulsed channels
  - Study channel-to-channel response; linearity
- Commissioning
  - Bad channels
  - Trigger verification
  - Check channel mapping
  - Monitoring tool
- Oracle Database for storage
- Database used to download pedestals and zero-suppression limits to ADC boards

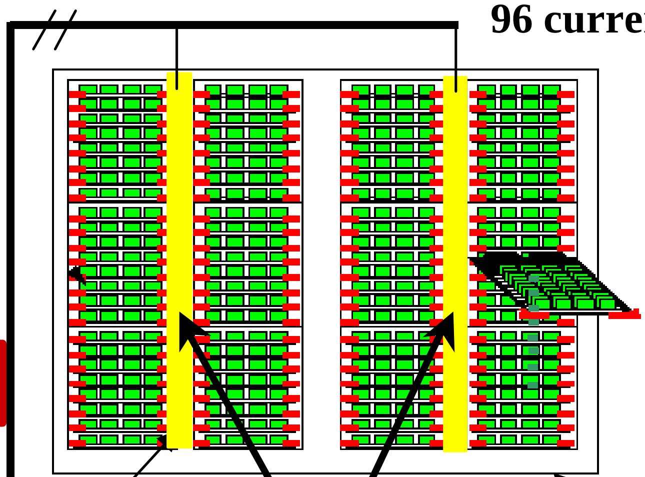
Electronics Calibration System



PIB

Pulser Interface Board:
- VME interface
- automated calibration procedure

6 commands (3x2)
96 currents



switch

2 Fanouts (2x3x16 switches)

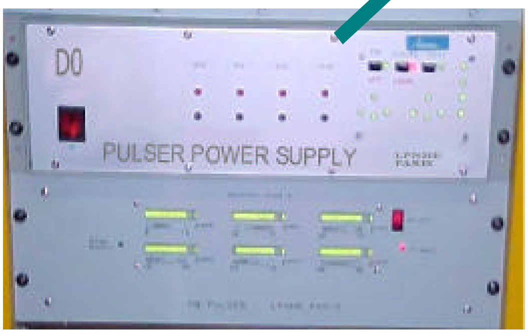
Preamp **Box**

Pulser

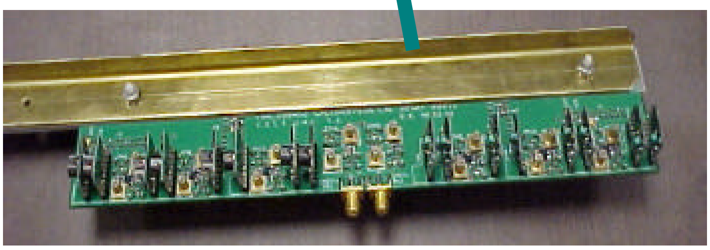
Power Supply

Trigger

LPNHE-Paris
LAL-Orsay



Pulser: DC current and command generator:
- DC current set by 18-bit DAC
- 96 enable registers
- 6-programmable 8-bit delays for command signals with 2ns step size

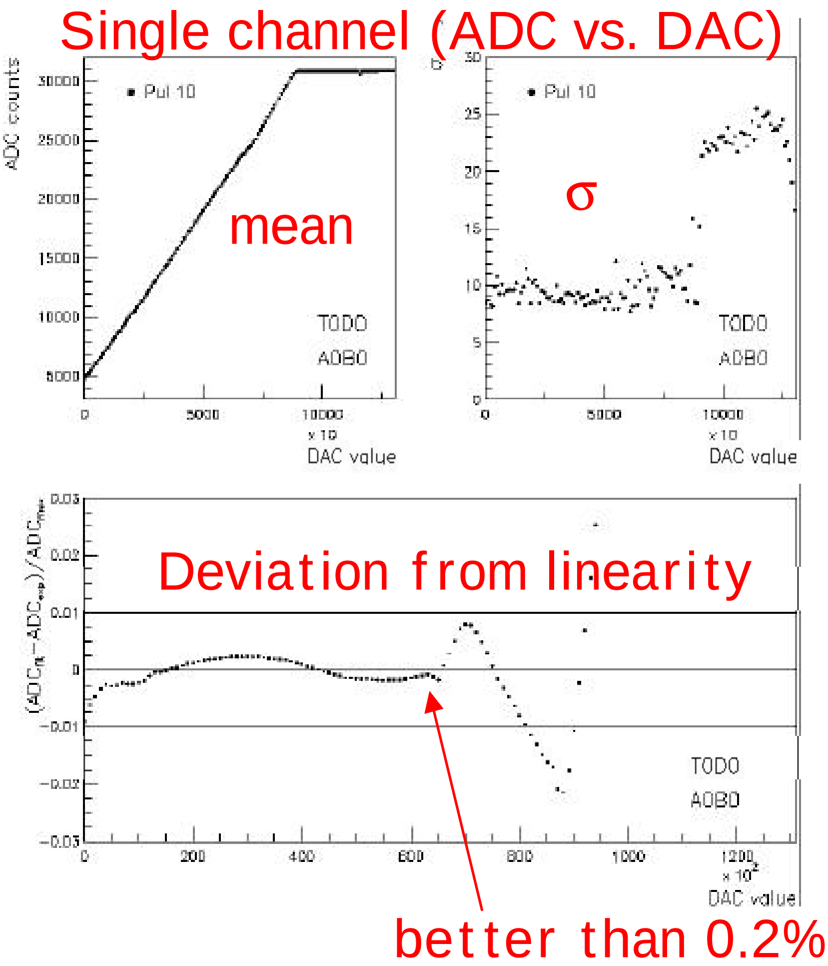


Active Fanout with Switches:
pulse shaping and distribution
- Open switch when receive command signal

Calibration Pulser Response

- **Linear response for DAC pulse height (0-65k)**
- **Fully saturate ADC**

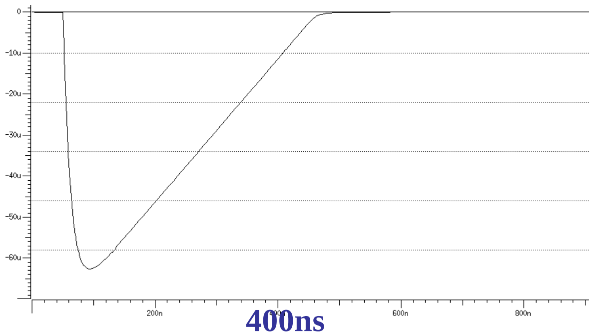
  (at DAC= 90k)



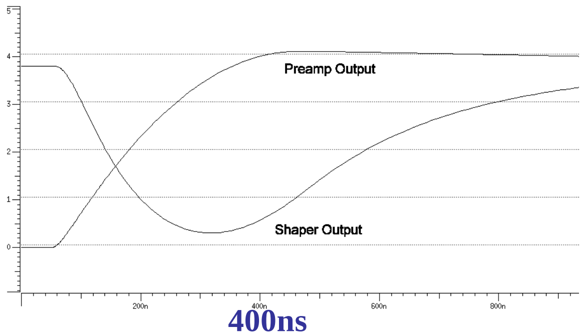
- **Linearity of calibration and calorimeter electronics better than 0.2% (for DAC < 65k)**
- **Cross-talk in neighboring channels < 1.5%**
- **Uniformity of pulser modules better than 1%**
- **No significant noise added from the calibration system**
- **Correction factors need to be determined**

Pulser Signal Shapes

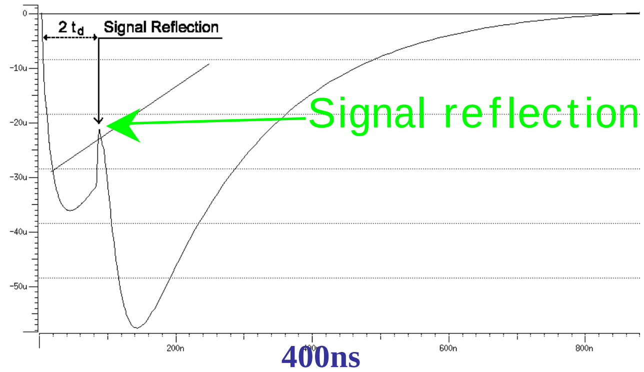
Calorimeter Signal at Preamp Input



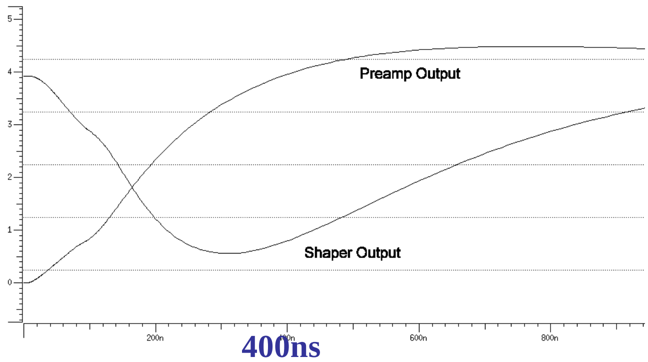
Calorimeter Signal after Preamp and Shaper



Calibration Signal at Preamp Input



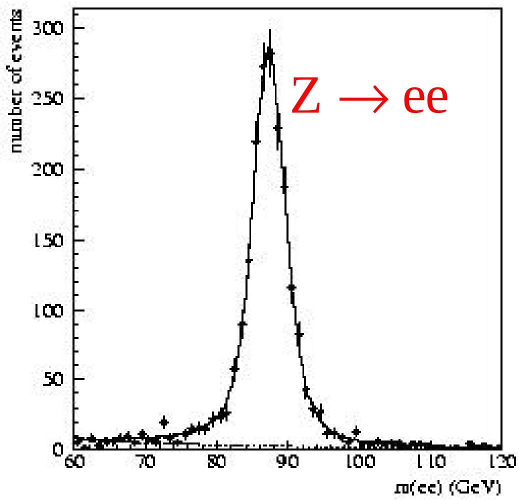
Calibration Signal after Preamp and Shaper

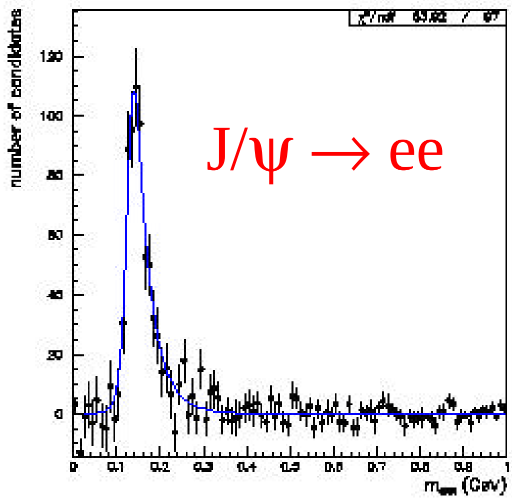


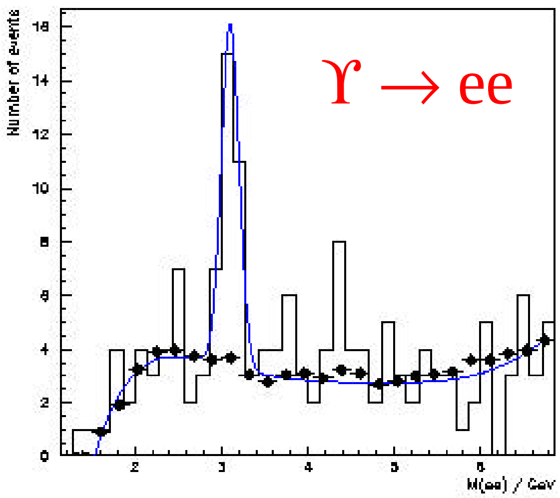
- Response of calorimeter signal w.r.t. calibration signal < 1% at max. signal for variation of different parameters (cable length, Z_{preamp}, Z_{cable},…)
- No test beam running ⇒ absolute energy scale will have to be established from the data
- Maximum response time for EM and hadronic channels differ due to different preamp types. Use delays and modeling to accommodate these
- Correct pulser response for different timings and shape
- Use initial "guess" based on Monte-Carlo sampling weights and Spice models of the electronics.

Determining EM/Jet Energy Scale

- **EM Scale**
  - **Z → ee (100k) sets the absolute EM scale**
  - **Check with**
    - **$\pi^0 \rightarrow \gamma\gamma$,**
    - **J/ψ or ϒ(1S) → ee**
  - **Use W → eυ sample (1.6M) to check symmetry in φ**

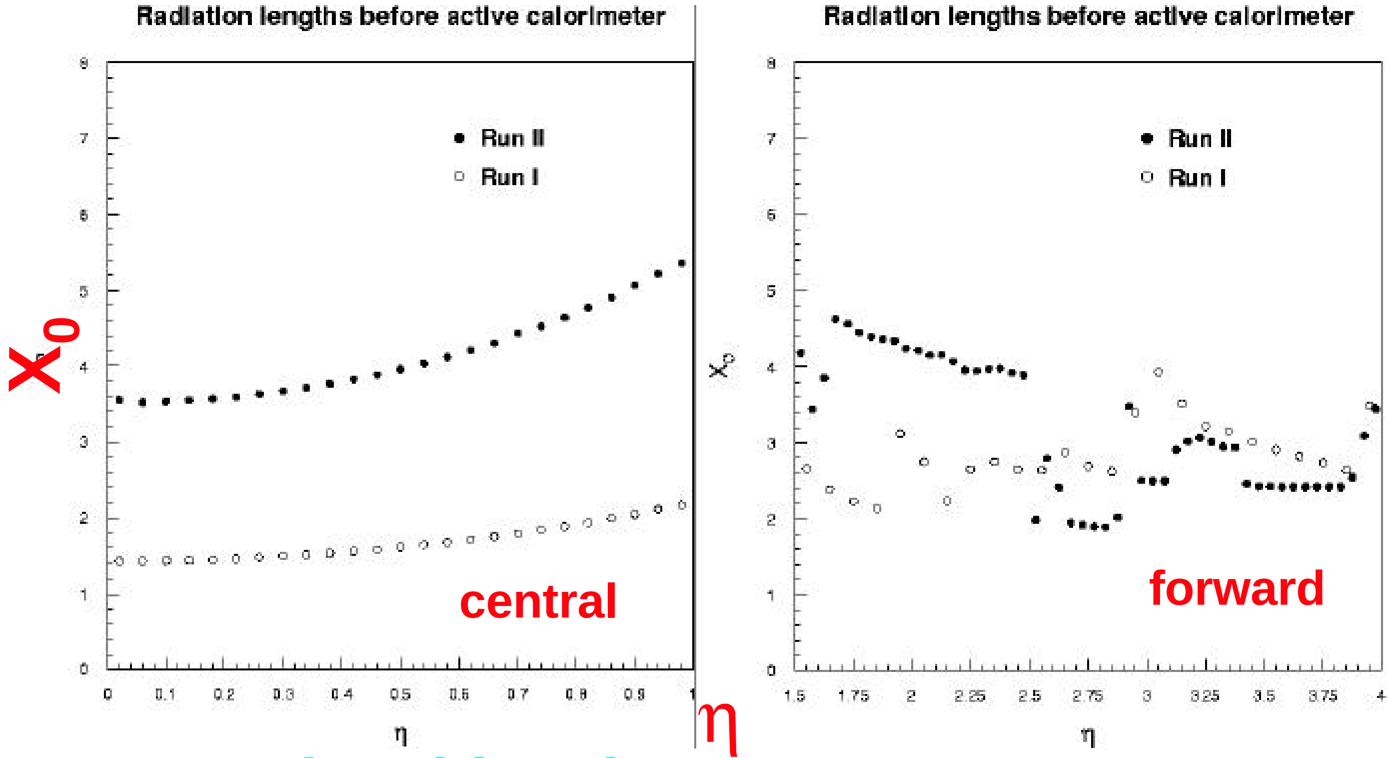




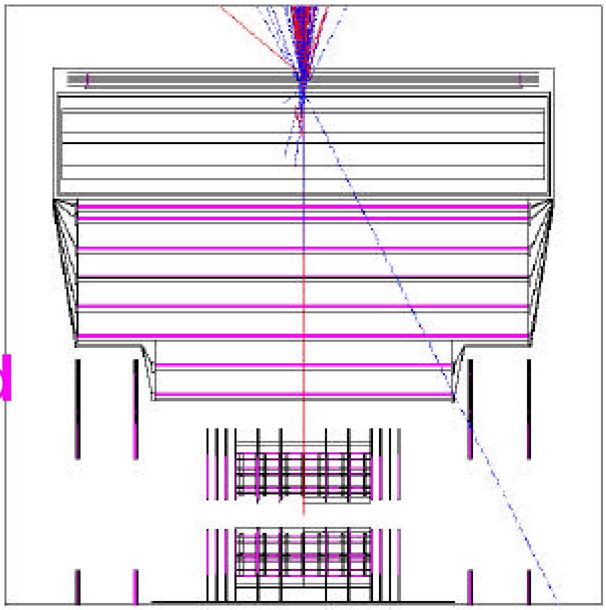


- **Jet Energy Scale**
  - **γ + jet data**
  - **possibly also Z + jet, (Z → ee/μμ)**
    - **very low backgrounds and harder Et spectrum but low statistics**
- **We have E/p this time!**

Effect of added material



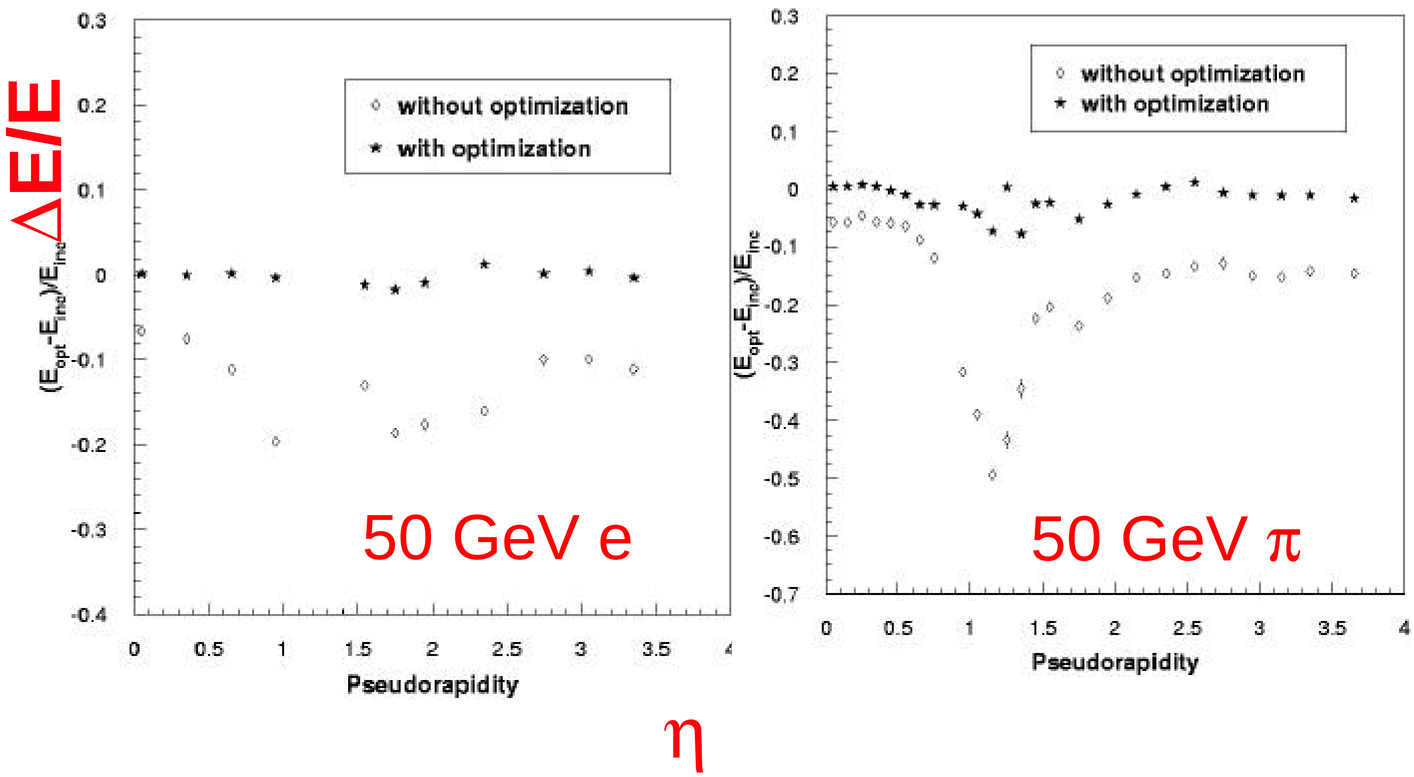
- New solenoid and preshower detectors increased the radiation length
  - Degrades both energy response and resolution
  - Introduces non-uniformity in η response



50 GeV electron

Optimization of Calorimeter Response

- Minimize $\Sigma(E_{true} - \Sigma a_i E_i)^2$
  - ▲ a_i = layer weighting
  - ▲ E_i = layer Energy
- Utilizing these energy correlations improves energy uniformity and resolution by ~10%



Liquid Argon Monitoring

- Each cryostat has four cells
  - ^{241}Am sources – 5 MeV α, 0.1μCi
    - gives about 4 fC in Lar gap with 500Hz trigger rate
    - Check LAr response (constant to < 0.5% in Run I)
  - ^{106}Ru (< 3.5 MeV β, 1yr half-life)
    - one stronger source (~10^{-10} Ci) should give about 0.3Hz triggers (about 2 fC)
    - Check LAr purity (< 1% in Run I)
- Mainz group design (based on ATLAS)
  - Separate HV, preamplifier and trigger system
  - Preamplifier and differential driver give gain of about 50 → gives signals of about 0.1V
  - Shaping and ADC on receiver boards (FPGA)
  - On board collection and storage of histogram information
  - Extract data over CAN-bus

Conclusions

- Dzero is upgrading its detector
  - L.Argon calorimeter untouched
    - Harder machine conditions and new environment (solenoid)
      - New Calorimeter Electronics
      - Improved ICD
      - New Central and Forward Preshower
  - Similar performance with 20x more data

- Run II start in 6 months

  watch this space!!!