GENERAL PURPOSE DETECTOR @ VLHC

2 DETECTORS ... BOTH WILL BE G.P.
(+ SOME SPECIALIZED ?)

OBJECTS : JETS, γ, e, μ, τ, (b-jets), $\not{E}_T$

MAGNET (μ, Q.P.) INNER SOLENOID, FWD + OUTER TOROIDS

GENERIC TRACKING (e, μ, τ, t, h..) Si/◇ ... STRIPS, PIXELS, 3D PIXELS

b-JET TAGGING (H, t, SUSY..) VERTICES (mm), e/μ IN JETS

e.m. CALORIMETRY e - IDENT + MEAS, γ - IDENT + MEAS; em PART OF JETS + SHOWER-MAX. LAYER

had CALORIMETRY JET SPECTROSCOPY, QCD, COMPOSITENESS, BH.. $t\bar{t} \to jjj, j\ell\nu$

MUON MEASUREMENT DIRECTION (CORE) & E; ISOLATED μ IDENT / MEAS.

DO NOT GIVE UP ON THIS FUNDAMENTAL FERMION!

$\vec{P}_\mu$ FOR $X \to n\mu + Y$, Q_μ

ALSO FOR $\not{E}_T$!! GIVE UP ON μ & GIVE UP ON $\not{E}_T$!

$\frac{\Delta E}{E} \simeq 20\%$ @ 5 [10?] TeV

MEASURE INSIDE COIL, VERIFY BEHIND CALO.

(SAGITTA σ (5 TeV, 4T, 2m.) = 120 μm)

INTERIM REPORT GP. 4C DETECTORS

DENISOV / ALBROW

D. DENISOV	PREVIOUS VLHC DETECTOR EFFORTS
M. ALBROW	VLHC CALORIMETRY
A. SKUJA	CMS CALORIMETRY
O. LOBBAN	CAL RESPONSE OPTIMIZN.; Q-SC HYBRID
S. PARKER	3D PIXEL DETECTOR
D. WOOD	μ DETECTION, DØ→VLHC
M. FORTNER	μ TRIGGERING, RECONSTRUCTION
D. CHRISTIAN	PIXEL DETECTORS
N. MOKHOV	ENERGY DEPOSITION @ VLHC
D. DENISOV	RADIATION DOSES

DENISOV

What we would like to measure?

- Because there is no specific physics process to be studied, general purpose detector(s) is a must for an energy frontier machine

- In order to set benchmarks different process are used: top studies, Higgs/SUSY discovery, etc. Let's consider "recent" top quark discovery

- In order to discover top quark both CDF and D0 had to detect: leptons (e/μ), jets, tag b-quarks (leptons or displaced vertex), and neutrinos (missing E_t):

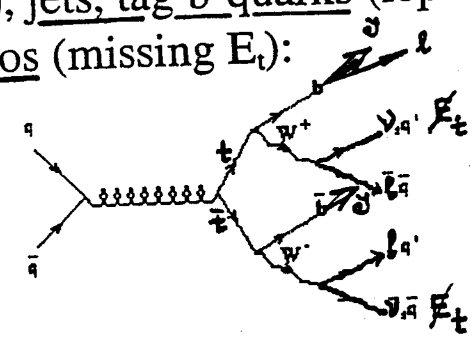


Figure 1: Tree level top quark production by $q\bar{q}$ annihilation followed by the Standard Model top quark decay chain.

Decay mode	Branching ratio
$t\bar{t} \longrightarrow (q\bar{q}'b)(q\bar{q}'\bar{b})$	36/81
$t\bar{t} \longrightarrow (q\bar{q}'b)(e\nu\bar{b})$	12/81
$t\bar{t} \longrightarrow (q\bar{q}'b)(\mu\nu\bar{b})$	12/81
$t\bar{t} \longrightarrow (q\bar{q}'b)(\tau\nu\bar{b})$	12/81
$t\bar{t} \longrightarrow (e\nu b)(\mu\nu\bar{b})$	2/81
$t\bar{t} \longrightarrow (e\nu b)(\tau\nu\bar{b})$	2/81
$t\bar{t} \longrightarrow (\mu\nu b)(\tau\nu\bar{b})$	2/81
$t\bar{t} \longrightarrow (e\nu b)(e\nu\bar{b})$	1/81
$t\bar{t} \longrightarrow (\mu\nu b)(\mu\nu\bar{b})$	1/81
$t\bar{t} \longrightarrow (\tau\nu b)(\tau\nu\bar{b})$	1/81

So, we needed tracker (e/μ, vertex), calorimeter (jets, electrons), and muon system

BACKGROUNDS & RADIATION LOADS

—NIKOLAI MOKHOV

DPMJET / MARS CALCULATIONS.

FROM COLLISIONS AT I.P.

	STAGE 1	STAGE 2
	40 TeV	175 TeV
	1.10^{34}	2.10^{34}
CENTRAL TRACKER		
ϕ_{+-} $cm^{-2}s^{-1}$ @ 10cm	3.10^{7}	1.10^{8}
ϕ_{n}	3.10^{6}	1.10^{7}
MRAD / YEAR ≈	10	30

SMALL ANGLES (END CAP CLOSE TO PIPE)
× 100 → × 1000 !!

FORWARD μ SYSTEM – MUST HAVE

WELL DESIGNED SHIELDING – THEN NON-ISSUE.

FROM BEAM LOSS: 500 $m^{-1}s^{-1}$ IN WARM STRAIGHT

APPROPRIATE SHIELDING PLUG IN TUNNEL-HALL, AROUND FRONT COLLIMATOR, ENDCAP CALORIMETER etc.

THEN $\frac{\text{MACHINE B/G}}{\text{COLLISIONS}}$ ~ few %, OK.

DENISOV

Conclusions

1. Cross sections and multiplicities changing with energy increase very slowly.

2. Multiplicity distributions have long non-Gaussian tails.

3. Radiation dose in the central region is function of luminosity, "not" $\sqrt{s}$.

4. Most of charged tracks are low transverse momentum
$\langle p_t \rangle \approx 0.6$ GeV

5. All parametrs discussed are based on "extrapolation": we could see surprizes at very high energy!

TRACKING

TRACKING USING DRIFT CELLS $\gtrsim$ mm

PROB. TOO SLOW FOR CENTRAL TRACKER.

OK FOR MUON SYSTEM.

ALL Silicon ($\diamond$!?) CENTRAL TRACKING

STRIPS ... MINISTRIPS (eg $50\mu \times 5$ mm)

PIXELS — 'PAD' — D. CHRISTIAN
— 'COLUMN' — S. PARKER.

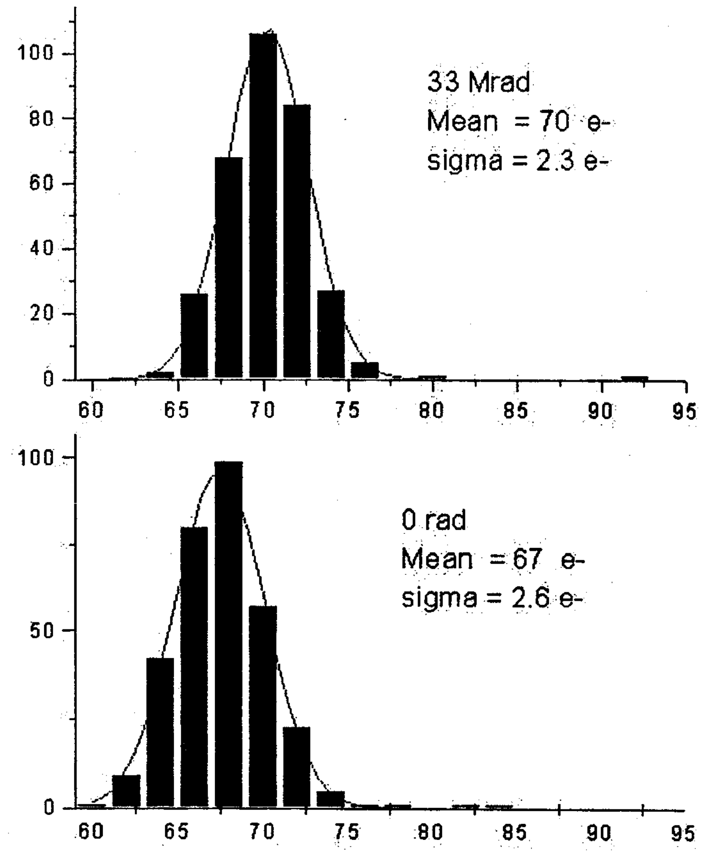
$10^7 - 10^9$ ELEMENTS

↑

~40 layers ~4 m long ~2 m radius

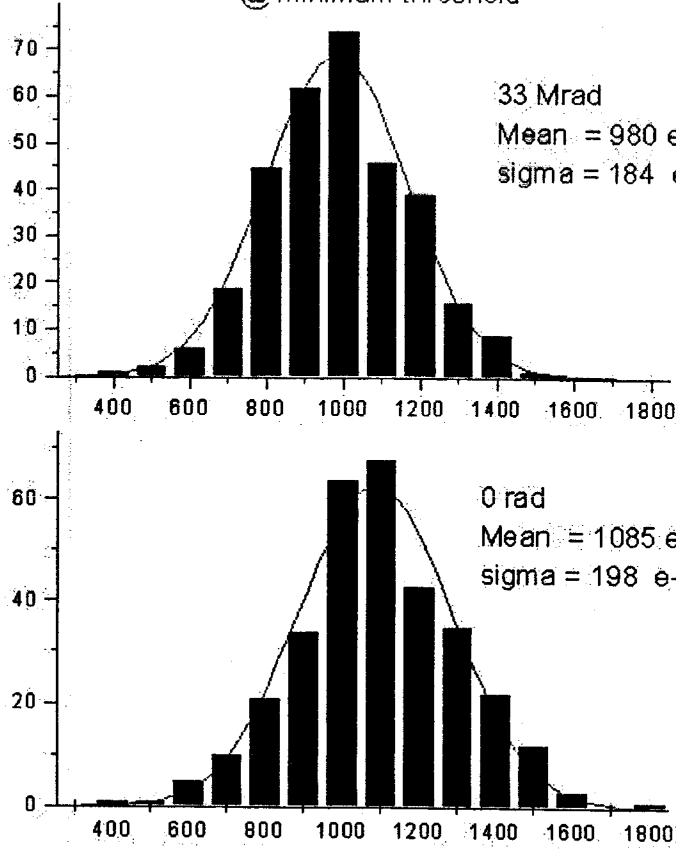
(pre)FPIX2 Noise and discriminator threshold distributions

NOISE DISTRIBUTION vs DOSE



THRESHOLD DISTRIBUTION vs DOSE

@ minimum threshold



PARKER

Speed -- 3D vs. planar

1. 3D lateral cell size can be smaller than wafer thickness, so:

shorter collection distances

2. in 3D, field lines end on cylinders rather than on circles, so:

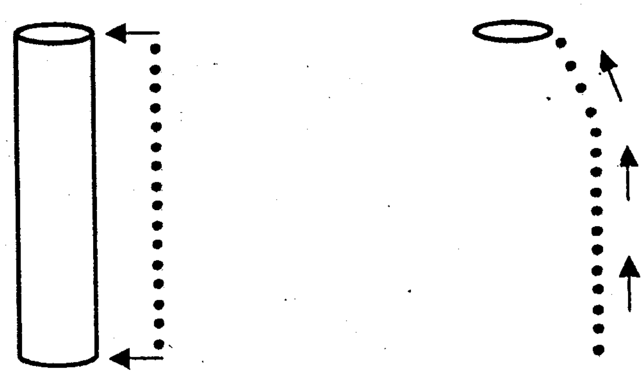
higher average fields for any given max field

(price: larger $C_{electrode}$: we now have 0.2 pF / 121 μm long electrode)

3. most of the signal is induced when the charge is close to the electrode, where the electrode solid angle is large, so:

planar signals are spread out in time as the charge arrives

3D signals are concentrated in time as the track arrives



4. if readout chip has inputs from both n^+ and p^+ electrodes,

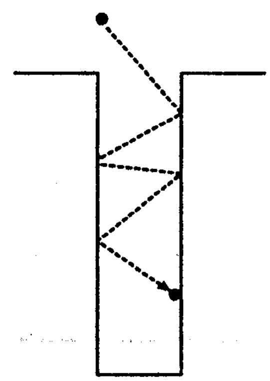
drift time correction can be made

PARKER

Keys to the technology:

1. Can now etch deep, near-vertical holes.

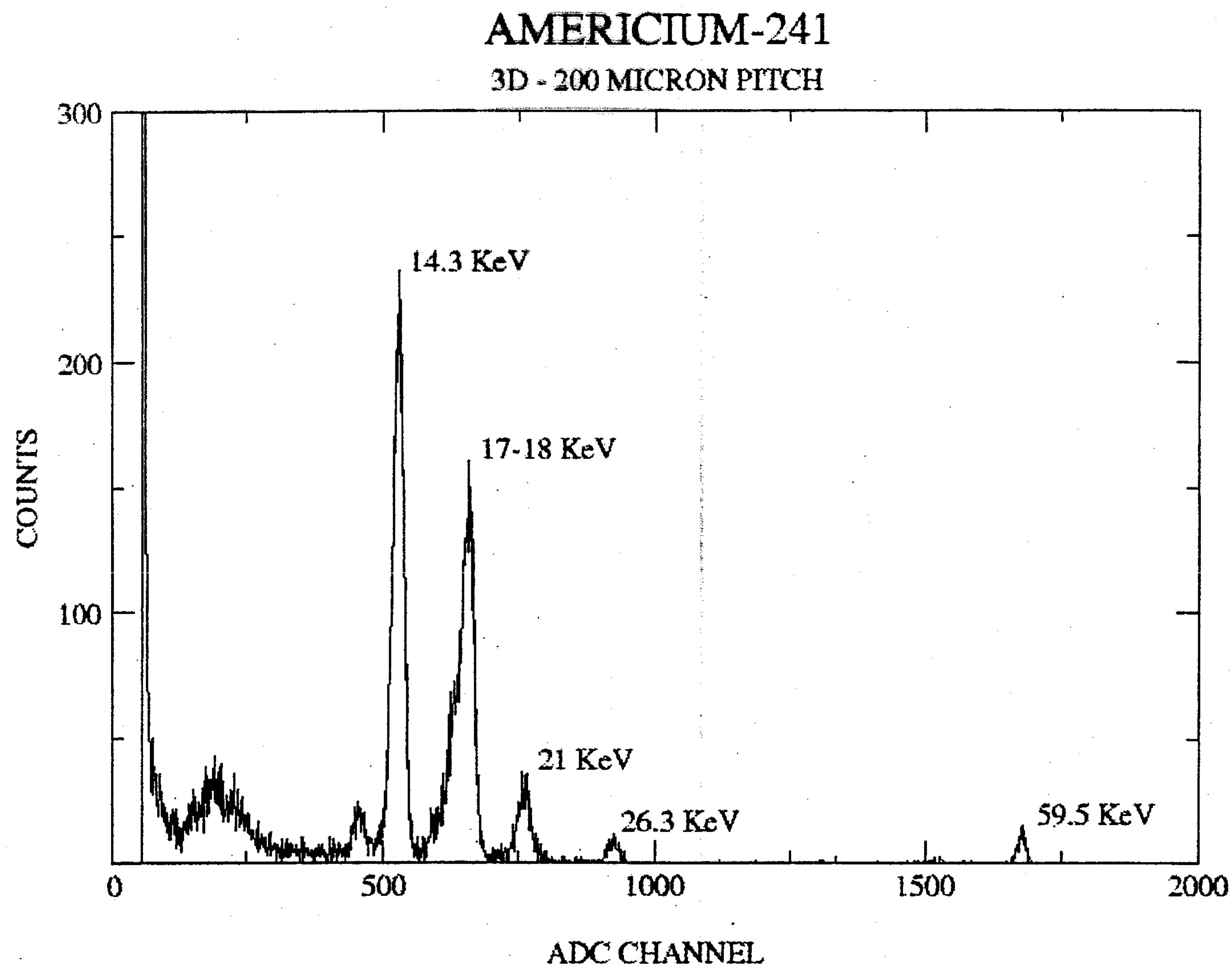
2. With low pressure and moderate temperatures, gas molecules used to form polysilicon such as SiH_4, SiH_2Cl_2, $SiHCl_3$, and $SiCl_4$ will bounce off the hole walls thousands of times before they stick. Mostly they enter, bounce a number of times, and leave. When they stick, it can be anywhere, and so a conformal coat of polysilicon is formed as the H (or Cl) leaves and the silicon migrates to a lattice site.



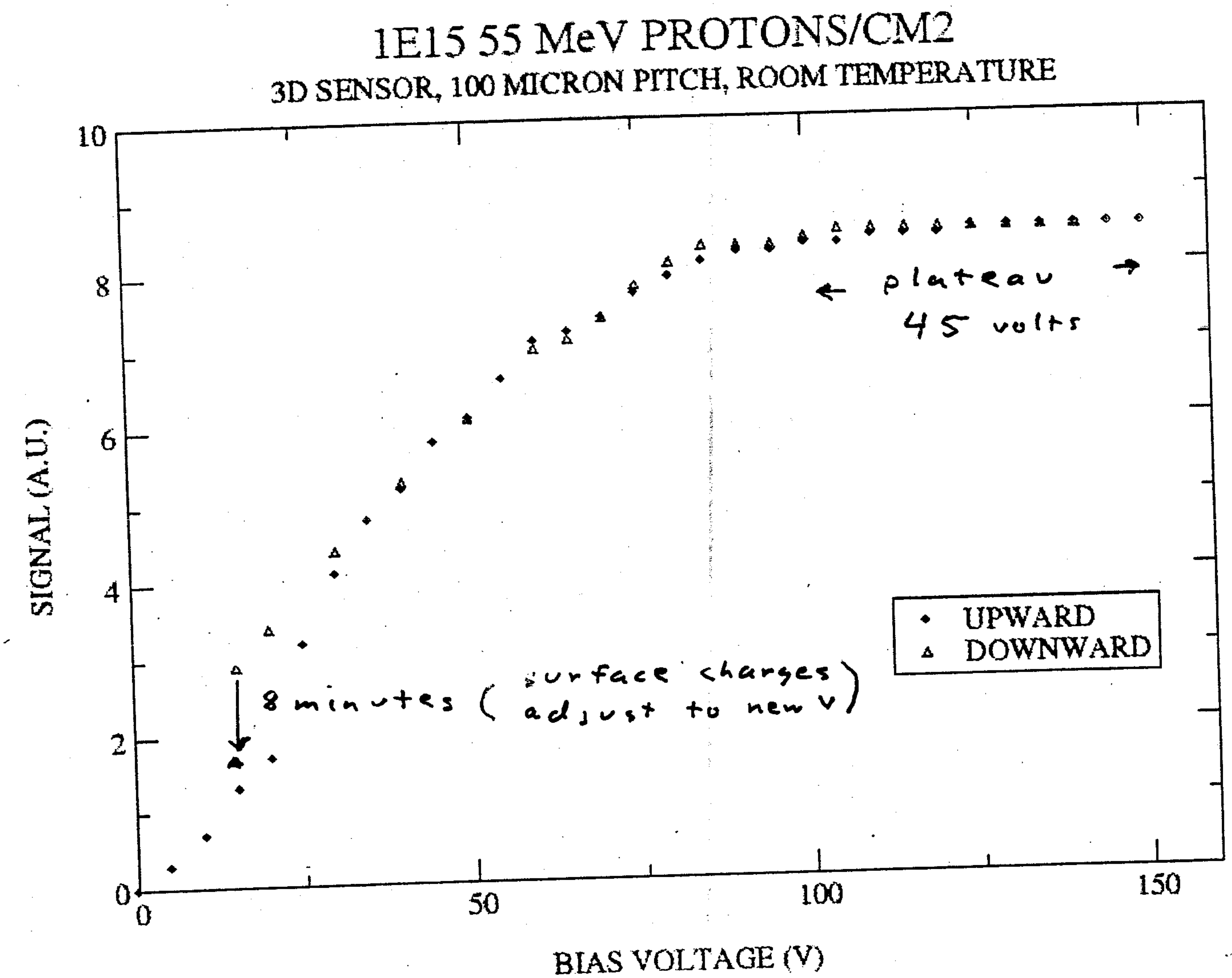
3. Gasses such as diborane (B_2H_6) and phosphine (PH_3) can be added to the silane. They also come out in a conformal layer, and make p^+ and n^+ doped polysilicon.

4. Heating will drive the dopants into the surrounding single crystal silicon, forming the p - n junctions and ohmic contacts in high-quality silicon, keeping electric fields away from the short-lifetime poly.

PARKER



AMERICIUM-241
3D - 200 MICRON PITCH
COUNTS
300
200
100
14.3 KeV
17-18 KeV
21 KeV
26.3 KeV
59.5 KeV
0
500
1000
1500
2000
ADC CHANNEL



1E15 55 MeV PROTONS/CM2
3D SENSOR, 100 MICRON PITCH, ROOM TEMPERATURE
SIGNAL (A.U.)
BIAS VOLTAGE (V)
0
2
4
6
8
10
50
100
150
UPWARD
DOWNWARD
8 minutes (surface charges adjust to new V)
← plateau →
45 volts

PARKER

PARKER

• Snowmass, July 2001

CONCLUSIONS

1. THE FIRST 3D DETECTORS HAVE BEEN SUCCESSFULLY FABRICATED

2. THEY HAVE REASONABLE LEAKAGE CURRENTS: ¼ - 1 nA PER MM^3 AT ROOM TEMPERATURE

3. THEY DEPLETE AT LOW VOLTAGES AS EXPECTED (TYPICALLY 5 – 10 V)

4. THEY HAVE WIDE PLATEAUS FOR INFRARED MICROBEAM SIGNALS

5. BETA, X-RAY, AND GAMMA SIGNALS HAVE BEEN SEEN

6. THE 14.3 KEV X-RAY LINE (^{241}Am SOURCE) FITS A SYMMETRIC GAUSSIAN WITH A SIGMA OF 282 eV

7. A SENSOR WITH 100-MICRON CELL SIZE HAD ITS DEPLETION VOLTAGE INCREASE FROM 5 V TO 105V (WITH A 45 V WIDE PLATEAU) AFTER IRRADIATIION WITH 10^{15} – 55 MEV PROTONS / CM^2 (PRIOR TO BENEFICIAL ANNEALING)

8. ACTIVE EDGE PREVIEW: AN INFRARED MICROBEAM SCAN SHOWS A SENSOR WITH SETS OF NORMAL 3D CYLINDRICAL ELECTRODES BETWEEN TWO WALL ELECTRODES IS SENSITIVE TO WITHIN SEVERAL MICRONS OF THE WALL ELECTRODE.

9. CALCULATIONS INDICATE PULSE DURATIONS OF ABOUT 1 NS

10. THE 2nd FABRICATION RUN HAS STARTED

CALORIMETRIC TECHNIQUES

SCINTILLATOR + WLS FIBERS + PMT/APD/HPD
(SOLID / LIQUID)

WELL ESTABLISHED. RAD HARDNESS. CENTRAL.

$PbWO_4$ CRYSTALS (em) OR OTHER CRYSTALS

CMS - GOOD EM CAL, COMPROMISES JET σ

QUARTZ FIBER IN Cu (e.g.)

LOW SIGNAL BUT OK FORWARD. V. RAD HARD

SILICON PADS

RAD HARDNESS? COMPACT, SAFE

DIAMOND PADS

COST! BUT BY 2020? R&D!

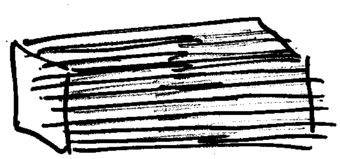
HIGH PRESSURE GAS TUBES

CHEAP, V. RAD HARD, PROMISING esp. FORWARD.

LIQUID ARGON

ATLAS - SLOW cf 18 ns

QUARTZ FIBRES (em)
\+ SCINTILLATING FIBERS (had)



MAY BE OPTIMUM FOR em & JETS, WITHOUT DEPTH SEGMENTATION.

What is important for the experiment?

- With traditional techniques:
  - If it is important to optimize electromagnetic resolution, then a **large sampling fraction** is required.
  - If it is important to optimize hadronic resolution, then a **small sampling fraction** is required.
- **These two goals exactly conflict with each other!**
- In the past, the electromagnetic energy resolution has generally been given priority.
- If an electromagnetic calorimeter has a high sampling fraction, and thus a large e/h value, then it makes sense to build a hadronic calorimeter with a similarly large e/h value.

If hadronic response and resolution is a priority...

- One should choose a **compensating** and **longitudinally unsegmented** calorimeter.
  - It should be compensating in order to eliminate fluctuations in the electromagnetic component of hadron showers (also important for jets)
  - It should be unsegmented because calibrating longitudinal segments is a **tricky business.**

Have Your Cake and Eat it, Too!!!

With dual readout calorimetry,

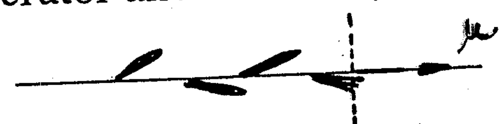
- Achieve essential advantages of compensation.
  - Eliminate dominating source of fluctuations in non-compensating calorimeter (fluctuations in f_{em}).
  - Eliminate signal nonlinearity.
- With this technique, the sampling fraction could be as large as needed for optimizing the calorimeter's resolution for electromagnetic showers, and the hadronic resolution **WOULD NOT** suffer!

DEMSAV

# of Muons

important for search of heavy
muons for t, b quarks tagging

a problem for muon detectors,
om accelerator and neutrons) have

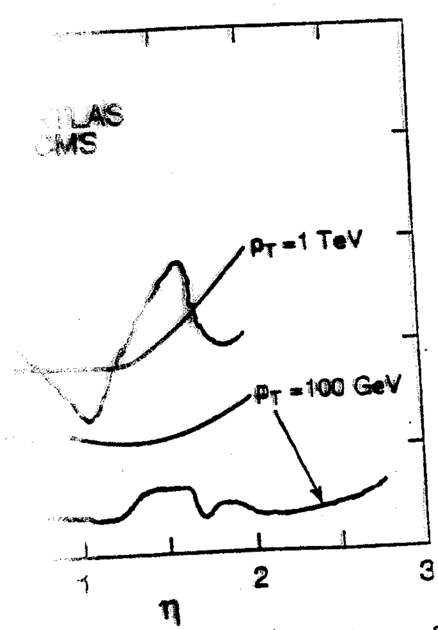


irradiate γ (showers) and loose
ation losses at a few hundred GeV, then due to ionization
grounds and requires corrections

nts

s limited by factors similar to

det ⊕ m.s.



Stand alone muon system resolution ~10% @ p_t ~ 1 TeV

m resolution of ATLAS and CMS detectors for stand-
function of pseudorapidity, for two values of the transverse

MUON DETECTORS D∅ → VLHC

DARIEN WOOD

BEST TO MEASURE p_μ BEFORE CALORIMETER.

MULTIPLE SCATTERING & ΔE FLUCTUATIONS AFFECT $\vec{p}$ (BEHIND CAL.)

& BACKGROUNDS FROM PUNCHTHRO' & DECAY OF h
ALSO BEAM HALO, BACKSCATTER.
⇅
DESIGN OF SHIELDING ETC.

D∅ : 2Tm, 10 POINTS, ~~$\sigma \sim 1$mm~~, SIGN TO 300GeV

WANT SIGN TO ~10 TeV (?)

COMBINATION OF : Tm (~4×2 = 8Tm?)
\# POINTS 40–50 ?
PRECISION $\sigma \sim 50\mu m$?

& MEASURE, FOR ISOLATED μ, SHOWERING

CRITICAL ENERGY, SHOWERING LOSSES = $\frac{\partial E}{\partial x}$
~350 GeV IN Fe

BIG FLUCTUATIONS IN $\frac{P_{OUT}}{P_{IN}}$ FOR 1 TeV/c μ.
(20-30 GeV)

NO CONCLUSIONS YET

- ATLAS & CMS, IF WORK AT LHC, WOULD <u>WORK</u> AT 20+20 TeV 10^{34} VLHC I.

- IF LHC DETECTORS SCALED UP 1.4 LINERALY (2.7 IN VOLUME) WOULD BE FAIR STARTING POINT FOR VLHC II 100+100 TeV 2.10^{34}

- ↑ BUT: MORE RAD HARD (R&D) TECHNOLOGY
  FASTER
  MORE PRECISION / GRANULARITY

10 YEARS TO BUILD (2012–2022 ?) R&D → 2012
\$ 0.5–1.0 B ? PER DETECTOR