Super-LHC: The Experimental Program

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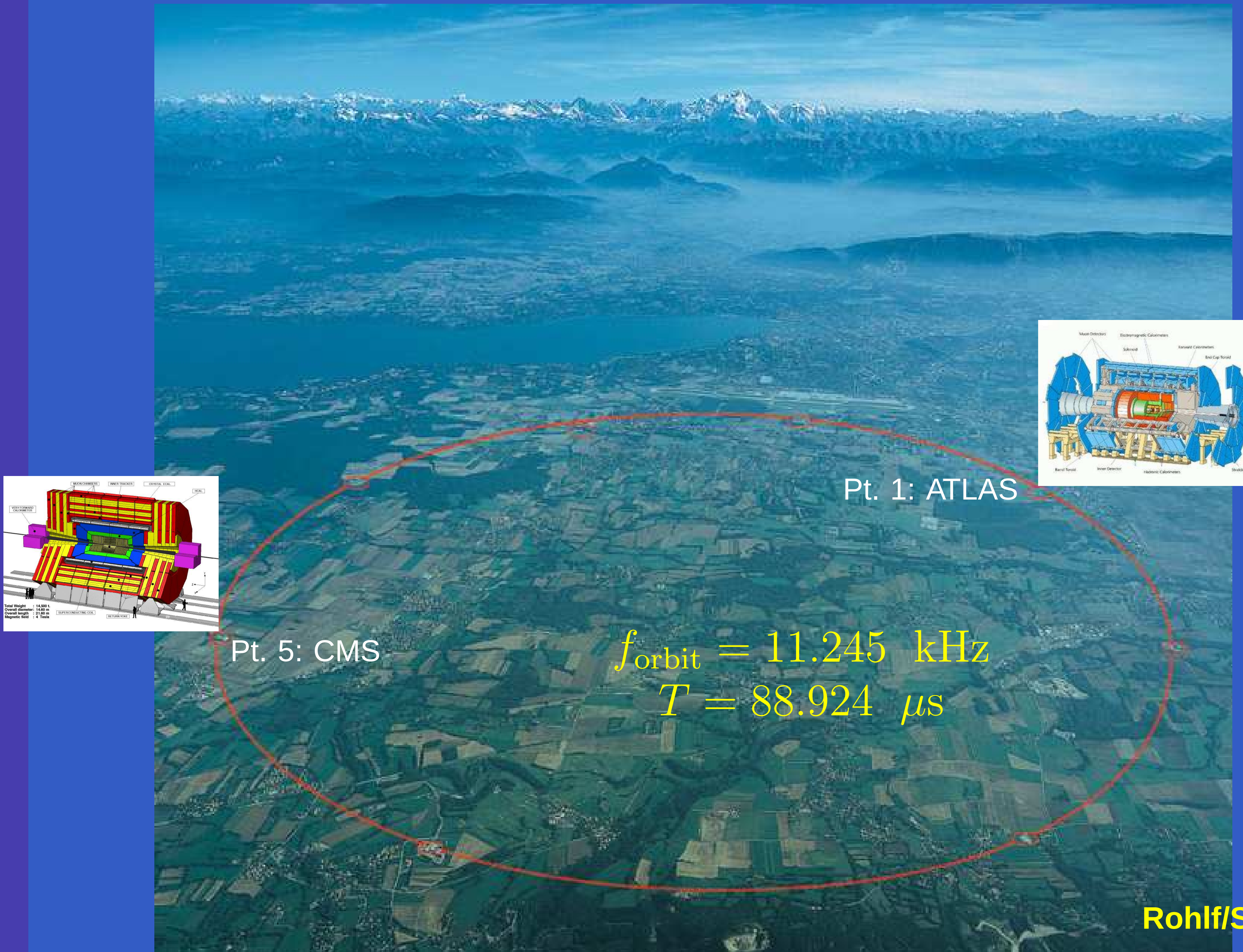
- Machine
- Detectors
  - Tracker
  - Calorimetery
  - Muon
  - Trigger/DAQ
- Electronics
- Computing
- Who and When
- Conclusions
- Observations
- References

LHC orbit



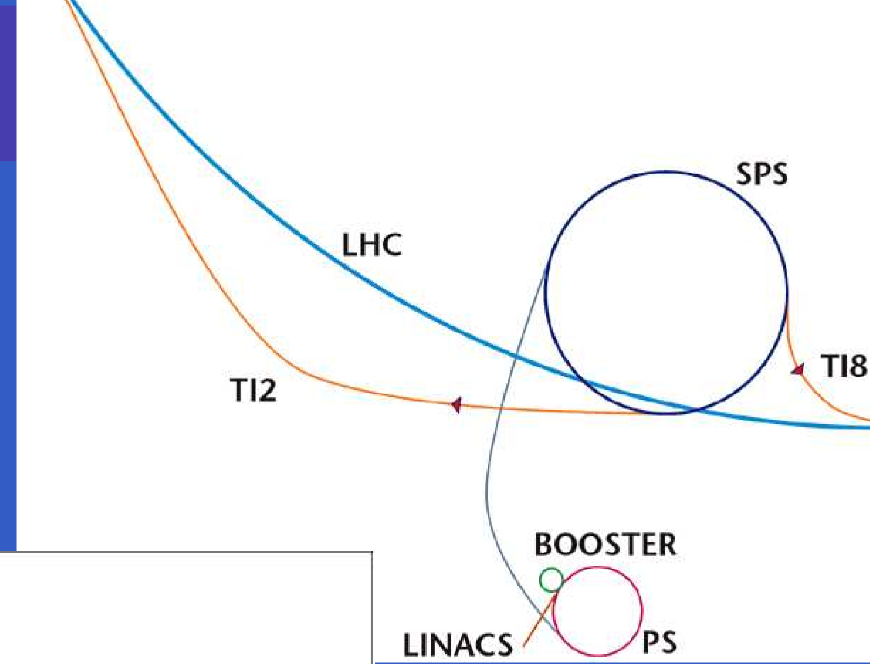
$$f_{\text{orbit}} = 11.245 \ \text{kHz}$$
$$T = 88.924 \ \mu\text{s}$$

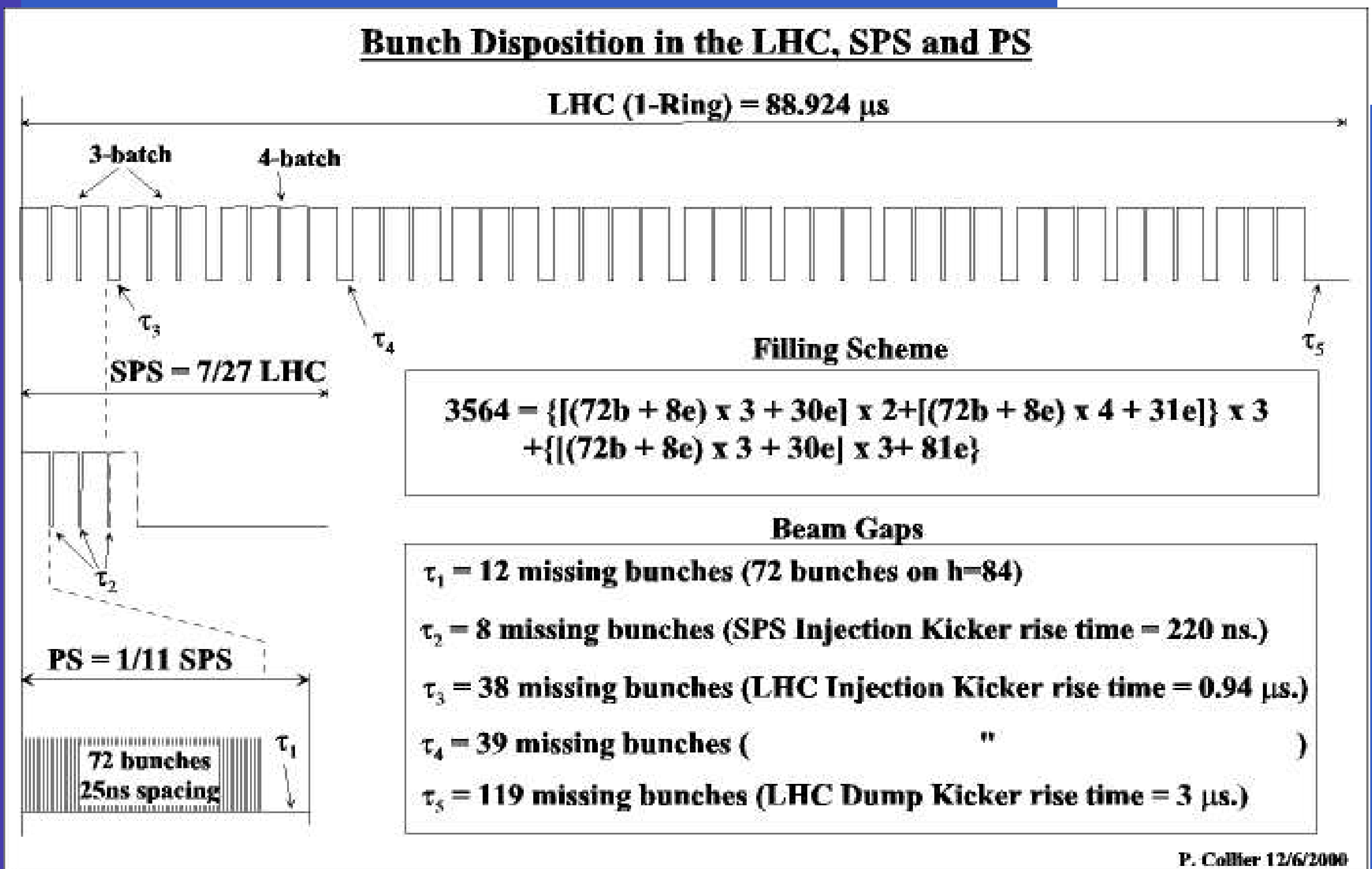
The gaps are important for synchronization!

LHC/PS = 42.4

(39 PS fill) (72 bunches/PS fill)

= 2808 bunches





$$\Delta t = \frac{88924\ \text{ns}}{3564\ \text{ns}}$$

$$= 24.95\ \text{ns}$$

"Abort gap" = 3 μs used for fast reset

SLHC **Super LHC** reaching for 10^{35} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and beyond

How do we get there?

N_b = protons per bunch

f = collision frequency

σ^* = transverse beam size at IP

σ_z = bunch length

circular beams crossing at angle θ_c

$$L = \frac{N_\mathrm{b}^2 f}{4\pi\sigma^{*2}} \frac{1}{\sqrt{1+\frac{\theta_\mathrm{c}^2\sigma_z^2}{4\sigma^{*2}}}}$$

Phase 0:	*no hardware upgrades* ATLAS and CMS only, 9 T in dipoles	$\rightarrow 2.3 \times 10^{34}$ cm $\sqrt{s} = 15$ TeV
Phase 1: **SLHC**	*no changes to LHC arcs* lower beta, increase N_b, 12.5 ns	$\rightarrow 9.2 \times 10^{34}$ cm $\sqrt{s} = 15$ TeV
Phase 2: **EDLHC**	*major hardware upgrades* new magnets and injector	$\rightarrow 2 \times 10^{35}$ cm $\sqrt{s} = 25$ TeV

O. Brüning *et al.*, LHC Luminosity and Energy Upgrade: A Feasibility Study

SLHC Phase 0

		Nominal	Phase 0
number of bunches	$n_{\rm b}$	2808	2808
bunch spacing	Δt	25 ns	25 ns
protons per bunch	$N_{\rm b}$	1.1×10^{11}	1.7×10^{11}
average beam current	$I_{\rm ave}$	0.56 A	0.86 A
r.m.s. bunch length	σ_z	7.55 cm	7.55 cm
beta at IP1 & IP5	β^*	0.5 m	0.5 m
r.m.s. crossing angle	$\theta_{\rm c}$	300 μrad	315 μrad
lumininosity	L	10^{34} cm^{-2}s^{-1}	2.3×10^{34} cm^{-2}s^{-1}

SLHC Phase 1

		Nominal	Phase 1
number of bunches	n_{b}	2808	2808
bunch spacing	Δt	25 ns	12.5 ns
protons per bunch	N_{b}	1.1×10^{11}	2.6×10^{11}
average beam current	I_{ave}	0.56 A	1.32 A
r.m.s. bunch length	σ_z	7.55 cm	3.78 cm
beta at IP1 & IP5	β^*	0.5 m	0.25 m
r.m.s. crossing angle	θ_{c}	300 μrad	1000 μrad
lumininosity	L	$10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$	$9.2 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

SLHC Phase 1 superbunch option

		Nominal	Superbunch
number of bunches	n_{b}	2808	1
bunch spacing	Δt	25 ns	0 ns
protons per bunch	N_{b}	1.1×10^{11}	5.6×10^{14}
average beam current	I_{ave}	0.56 A	1.0 A
r.m.s. bunch length	σ_z	7.55 cm	7500 cm
beta at IP1 & IP5	β^*	0.5 m	0.25 m
r.m.s. crossing angle	θ_{c}	300 μrad	1000 μrad
lumininosity	L	$10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$	$9.0 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

The superbunch option is not synchronization-friendly!

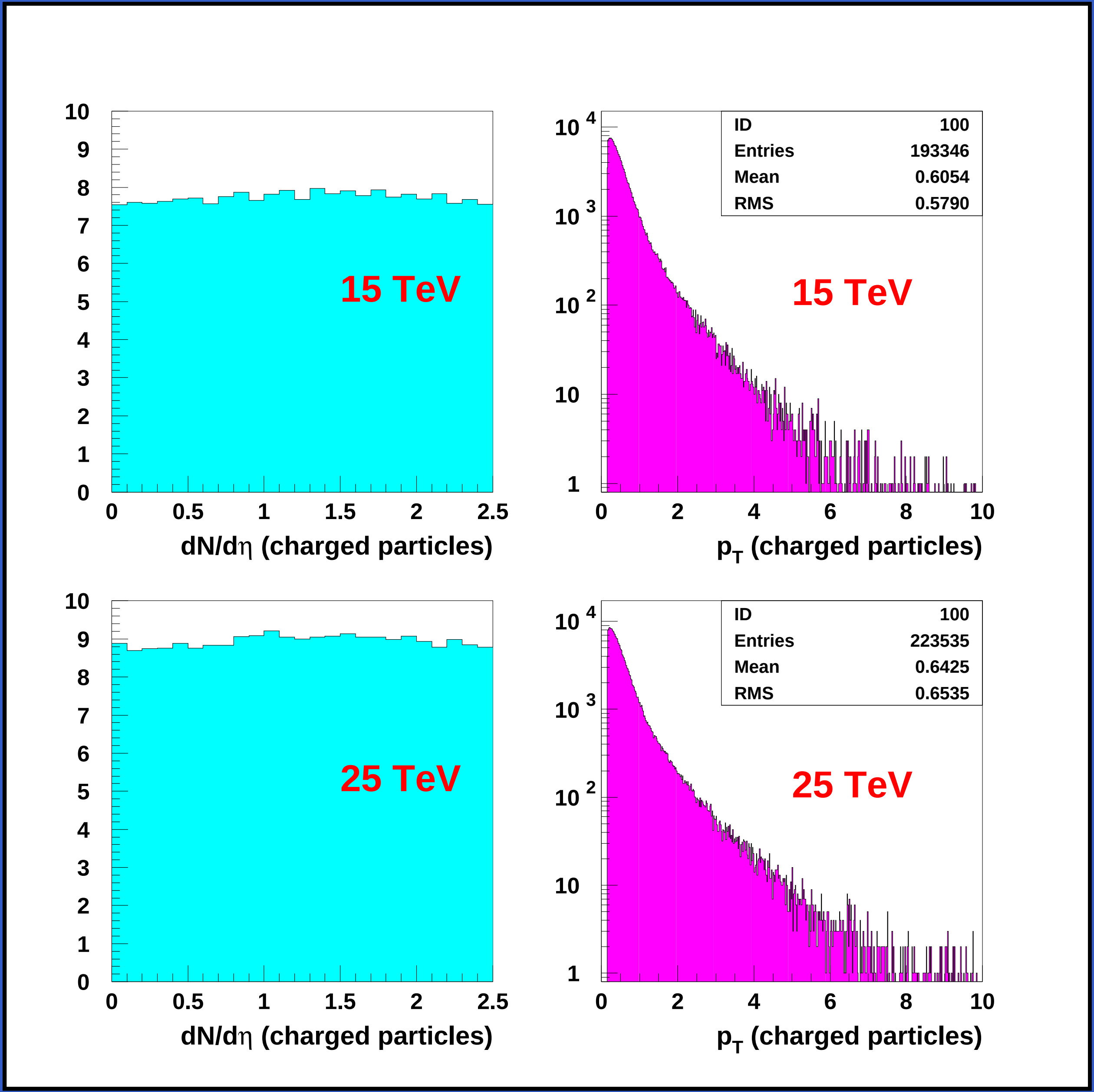
SLHC Phase 2

Expensive and less clear

- Equip SPS with superconducting magnets to inject at 1 TeV
  - $\longrightarrow$ Gives a factor of 2 in luminosity
  - $\longrightarrow$ First step for energy upgrade
- Install new dipoles to run at 15 T
  - $\longrightarrow$ Magnets could exist by 2015
  - $\longrightarrow$ Upgraded machine by 2020, $\sqrt{s} = 25\ \mathrm{TeV}$

But... this may be the fastest path to study multi-TeV constituent collisions

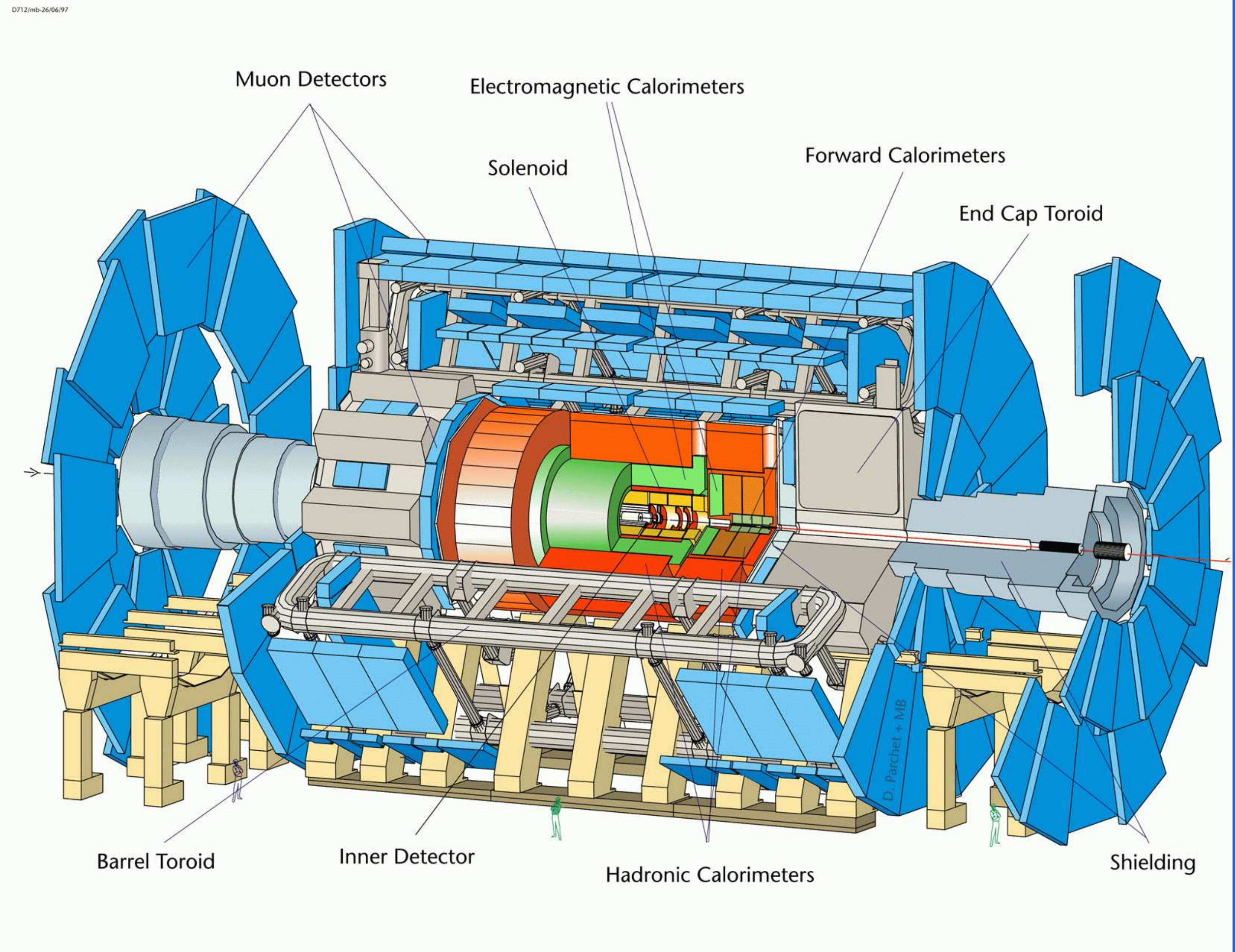
SLHC Charged particles



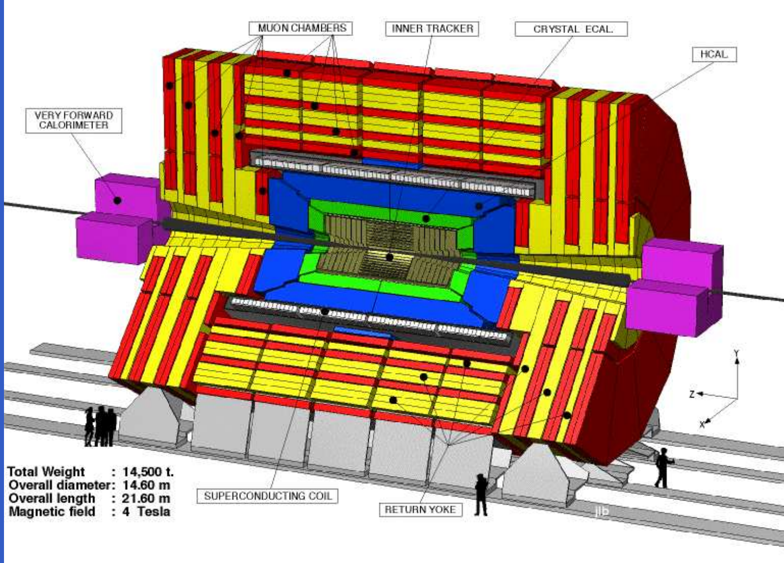
SLHC LHC/SLHC comparison

	LHC	*SLHC*
pp c.m. energy	14 TeV	15 TeV
luminosity	$10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$	$10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
collision rate	1 GHz	10 GHz
W/Z^0 *rate*	1 kHz	10 kHz
bunch spacing	25 ns	12.5 ns
interactions per crossing	20	100
$\frac{dN_{\mathrm{ch}}}{d\eta}$ *per crossing*	150	750
track flux @ 1 m	$10^{5}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$	$10^{6}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
calorimeter pileup noise	nominal	$\times$2-3
rad. dose @ 1 m *for* $2500\ \mathrm{fb}^{-1}$	1 kGy	10 kGy

SLHC **Detectors** overview



- tracking in B field
- EM calorimetery
- had. calorimetry
- muon detectors



A Toroidal Large hadron collider ApparatuS (ATLAS) 7 kTons
0.5 T toroid, 2 T solenoid
25 m × 46 m

Compact Muon Solenoid (CMS) 14 kTons
4 T solenoid
15 m × 22 m

ATLAS

Large magnet cost (40%)

- good stand-alone muon resolution (BL^2)
- less resources spent on ECAL and tracking

CMS

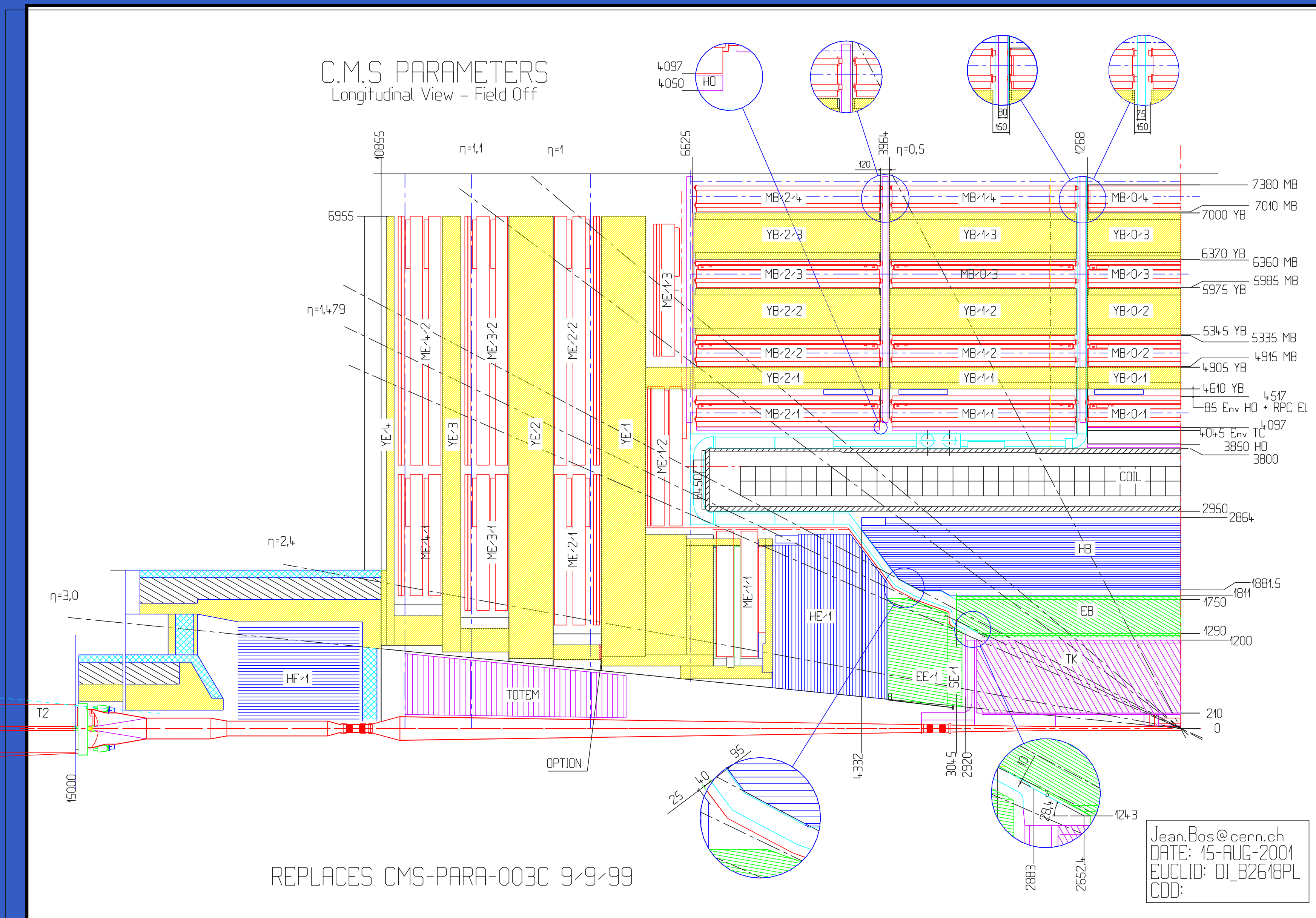
Lower magnet cost (25%)

- high-resolution tracker
- high-performance ECAL

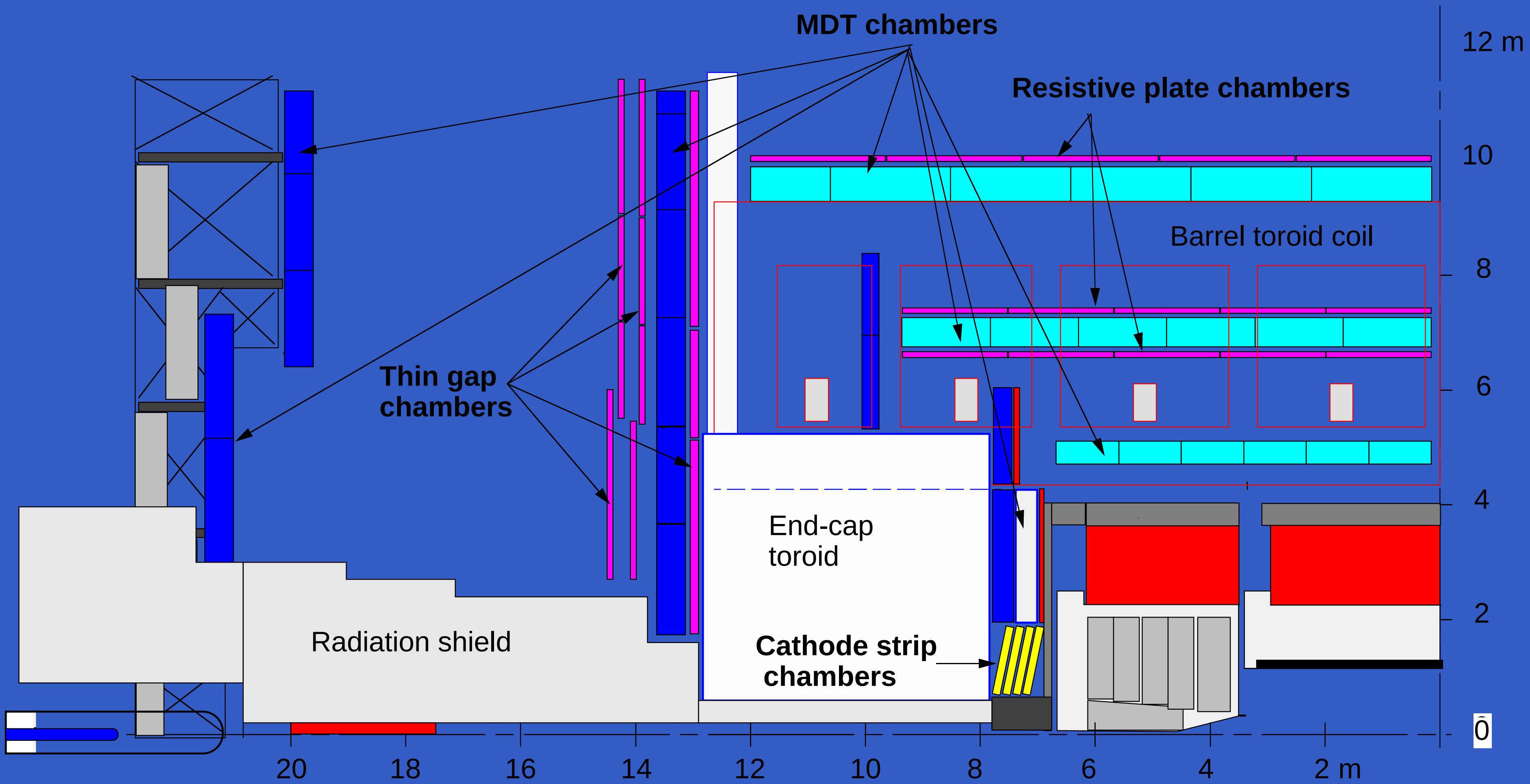
SLHC Detector technology

		CMS	ATLAS
Tracking:	inner	pixels	pixels
	barrel	silicon strips	silicon strips / straw tubes
	endcap	silicon strips	silicon strips / straw tubes
ECAL:	barrel	crystals $(\mathrm{PbWO_4})$	liquid argon / Pb
	end cap	crystals $(\mathrm{PbWO_4})$	liquid argon / Pb
HCAL:	barrel	scintillator / brass	scintillator / Fe
	end cap	scintillator / brass	liquid argon / Cu
	forward	quartz / Fe	liquid argon / Cu-W
Muon:	barrel	drift chambers	drift tubes
		+resistive plate	+resistive plate
	end cap	cathode strip	cathode strip
		+ resistive plate	+ thin gap

SLHC CMS Detector

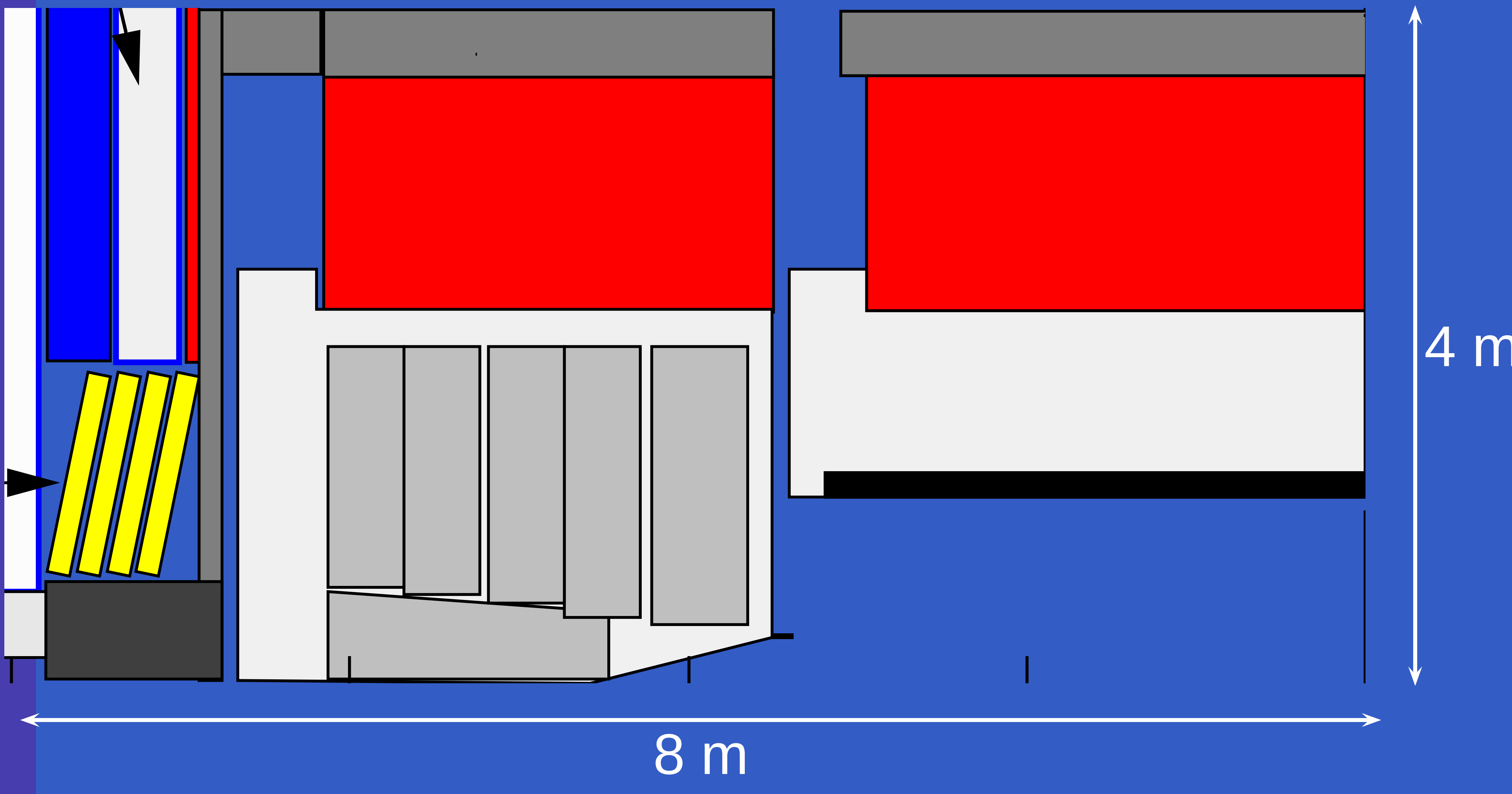


SLHC ATLAS Detector



SLHC Tracker/ECAL/HCAL size comparison

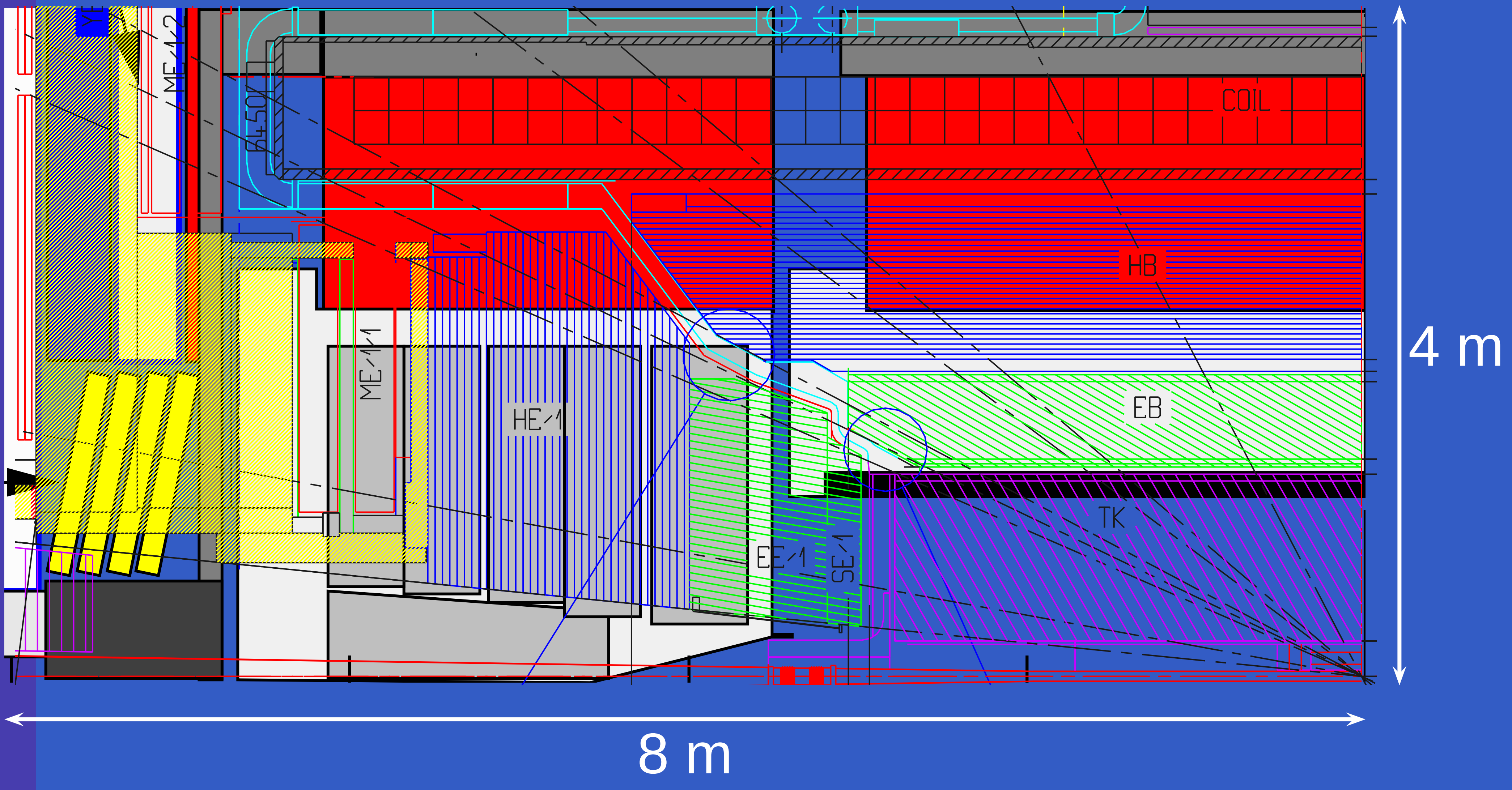
solid red = ATLAS tile calorimeter



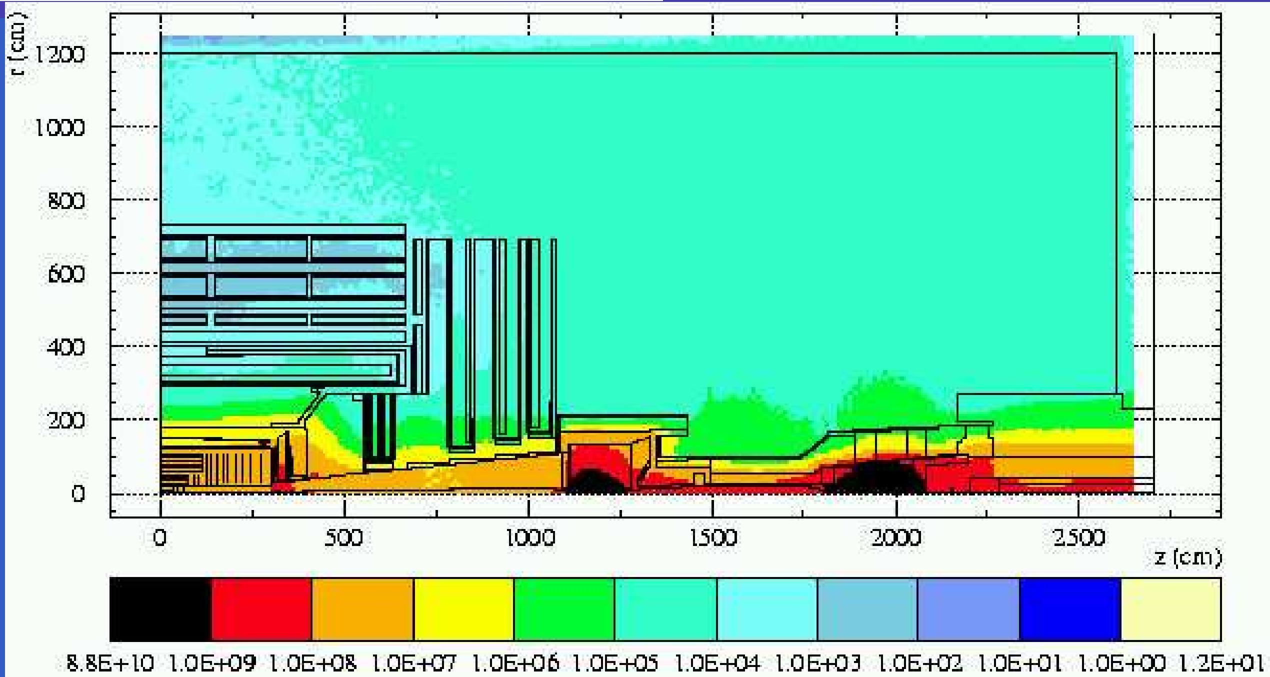
SLHC Tracker/ECAL/HCAL size comparison

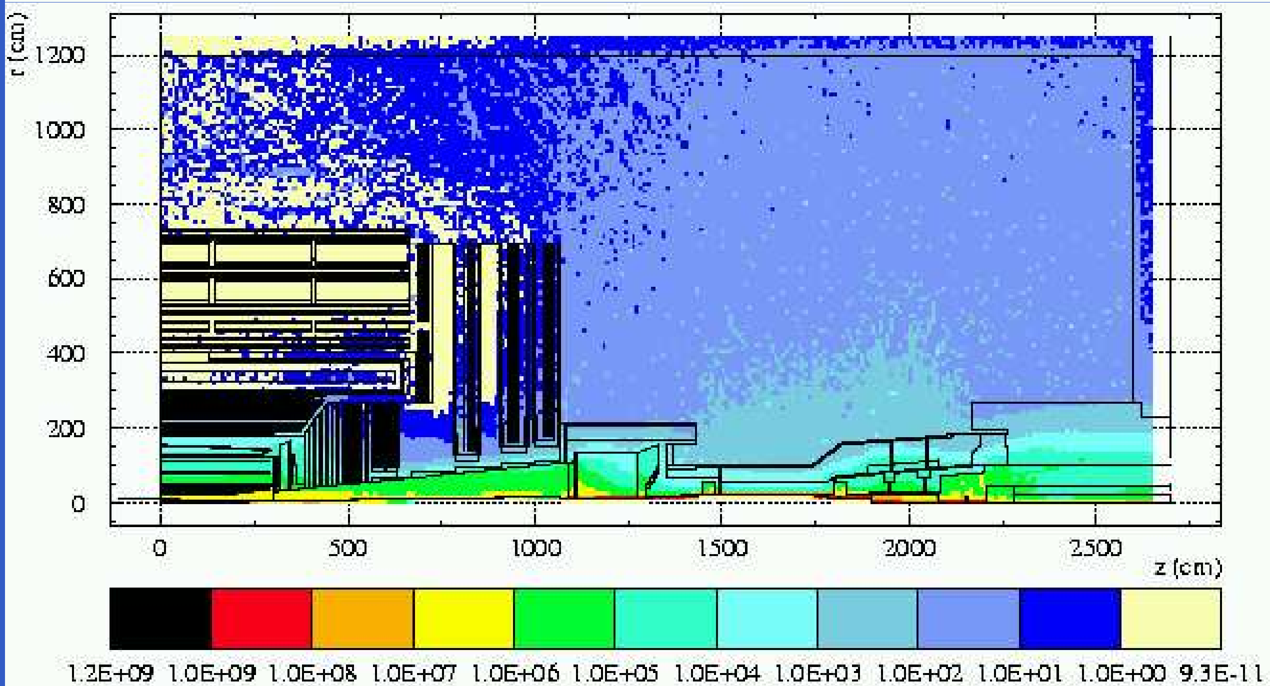
CMS superimposed on ATLAS:

solid red = ATLAS tile calorimeter, blue lines = CMS HCAL



SLHC Radiation





neutron flux at
$L = \mathbf{10^{35}}\ \mathrm{cm}^{-\mathbf{2}}\mathrm{s}^{-\mathbf{1}}$

dose (Gy)
$\mathbf{2500}\ \mathrm{fb}^{-\mathbf{1}}$

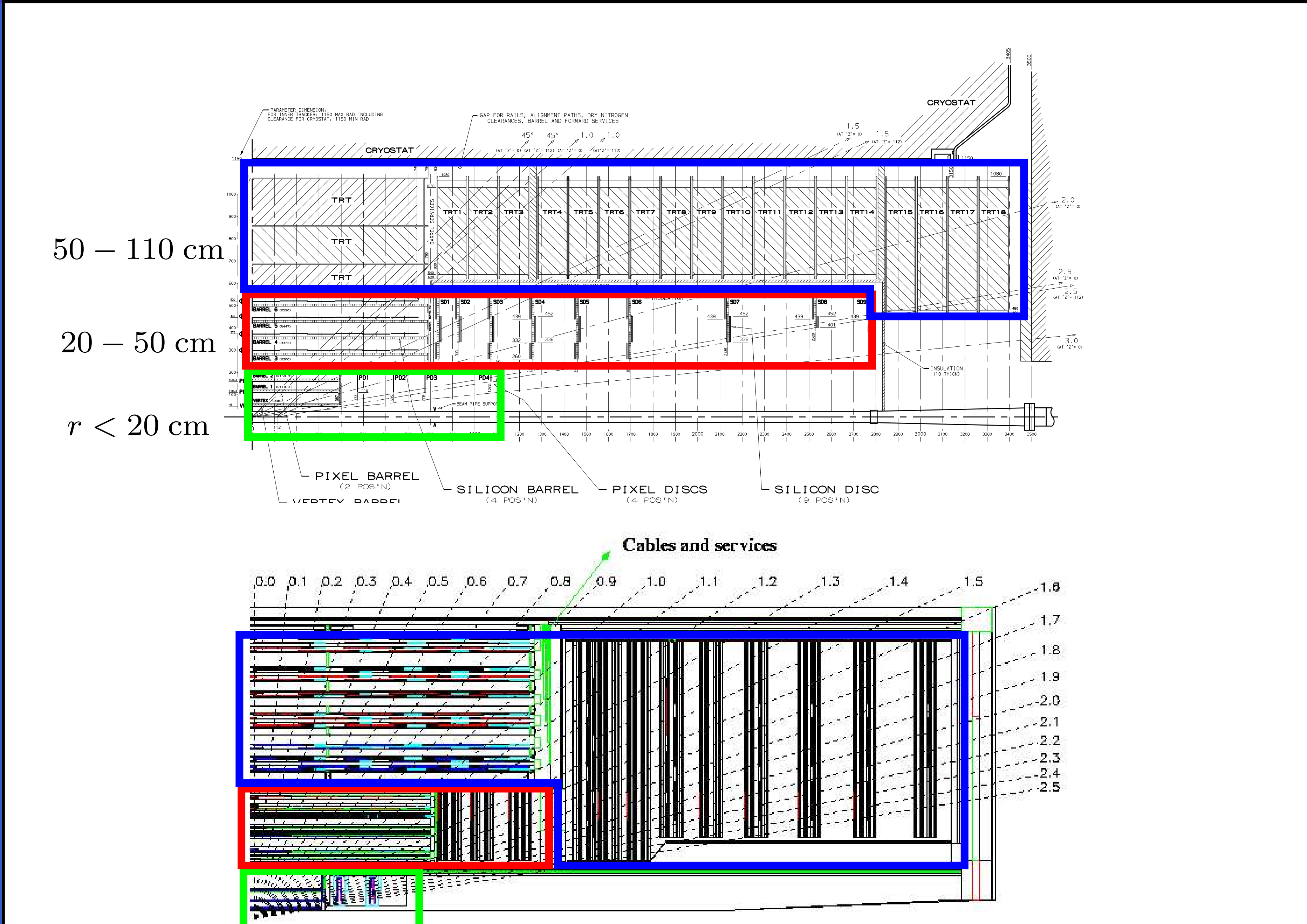
SLHC Tracker

ATLAS: silicon + straws

CMS: silicon

	pixels	*strips*	*trt straws*
ATLAS	80M ch, 2 m^2	6M ch, 60 m^2	420k ch.
CMS	50M ch, 1 m^2	10M ch, 220 m^2	

SLHC Tracker geometry



SLHC **Tracking** issues

- Occupancy

  need to keep low to preserve:

  - reconstruction efficiency
  - momentum resolution
  - b/tau tagging

- Radiation

  need to survive a fluence of $10^{15}\ \mathrm{cm}^{-2}$

$\mathcal{SLHC}$ **Tracking** occupancy

$$O \sim \frac{L \Delta t \Delta A}{r^2}$$

L = luminosity, Δt = sensitive time, ΔA = cell area, r = distance

For a silicon strip (10 cm $\times$ 100μm), r = 20 cm,
at LHC design luminosity with 25 ns crossing,
the occupancy is 3%.

For SLHC with 12.5 ns crossing, this is goes to 15%.

Can make work by being smaller or further away,

and clocking at 80 MHz.

SLHC Tracking ionization dose

$$D \sim \frac{L\tau}{r^2}$$

L = luminosity, τ = exposure time, r = distance

Radius (cm)	Flux $\mathrm{cm}^{-2}\mathrm{s}^{-1}$	Dose (kGy) for $\mathbf{2500}\ \mathrm{fb}^{-1}$
4	5×10^8	4200
11	10^8	940
22	3×10^7	350
75	3.5×10^6	35
115	1.5×10^6	9.3

SLHC Tracking implications

- Silicon can work at r > 60 cm.

  six layers with pitches of 80-160μm will preserve performance

  need to exploit 12-inch wafer technology

  need to operate at $\times$2 higher fluences than tested for LHC

- Pixels can work at 20 cm < r < 60 cm.

  need cells that are $\times$10 larger than current pixels and

  $\times$10 small than current Si strips (macro-pixel)

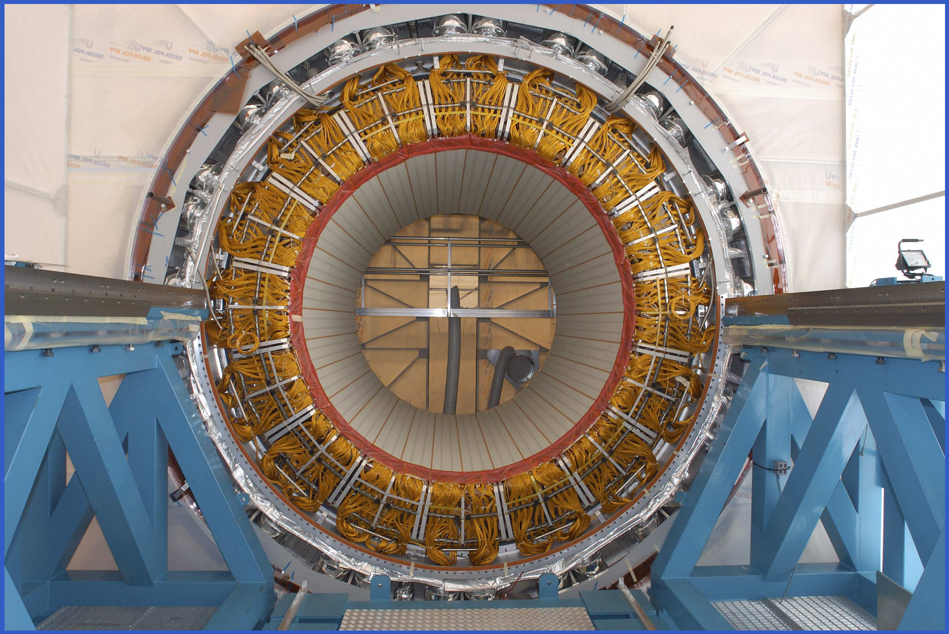
- New technology is needed at r < 20 cm.

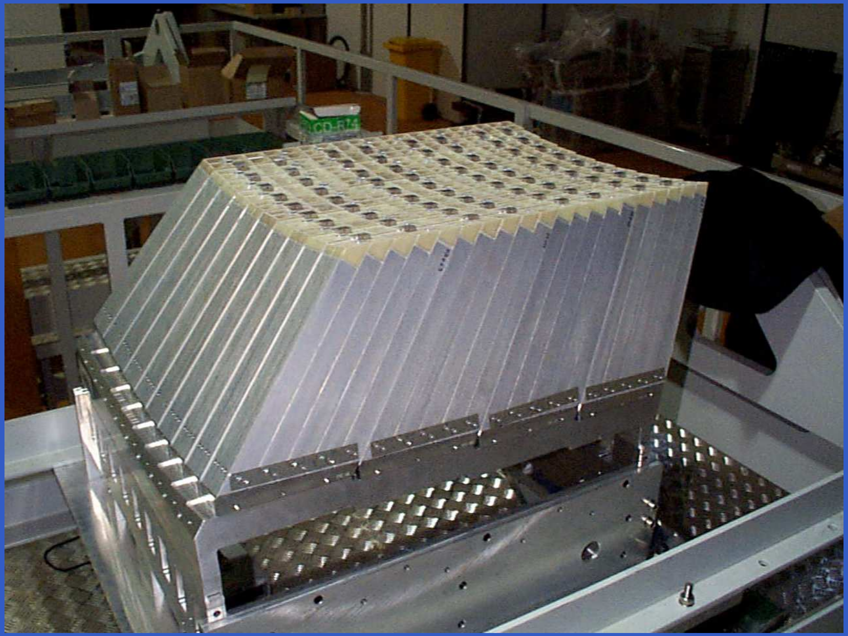
  need 50μm$\times$50μm feature size.

  ideas include CVD diamond, monolithic pixels, cryogenic Si

SLHC ECAL

ATLAS: liquid argon / Pb   CMS: crystal ($PbWO_4$)

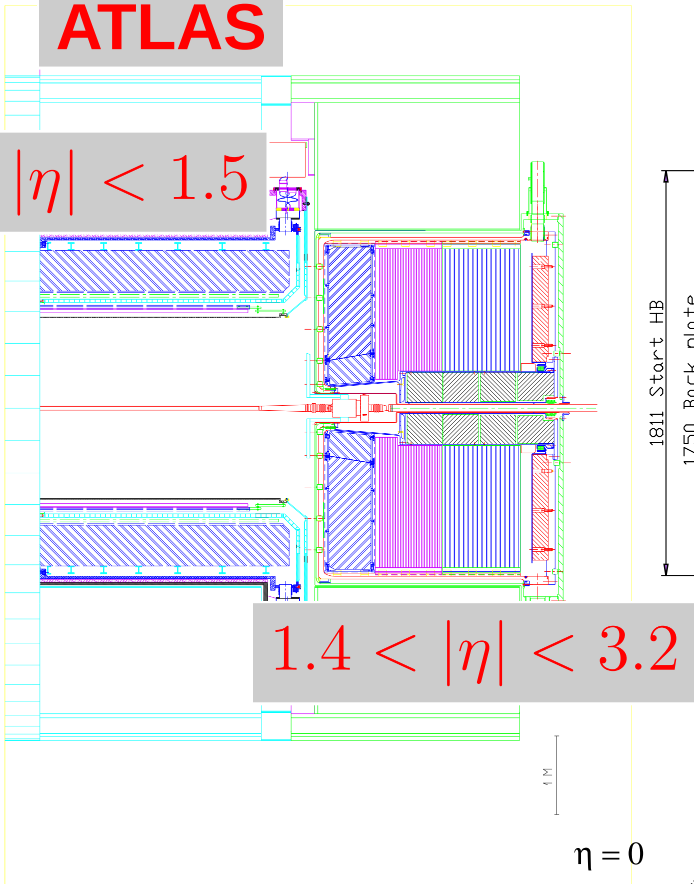




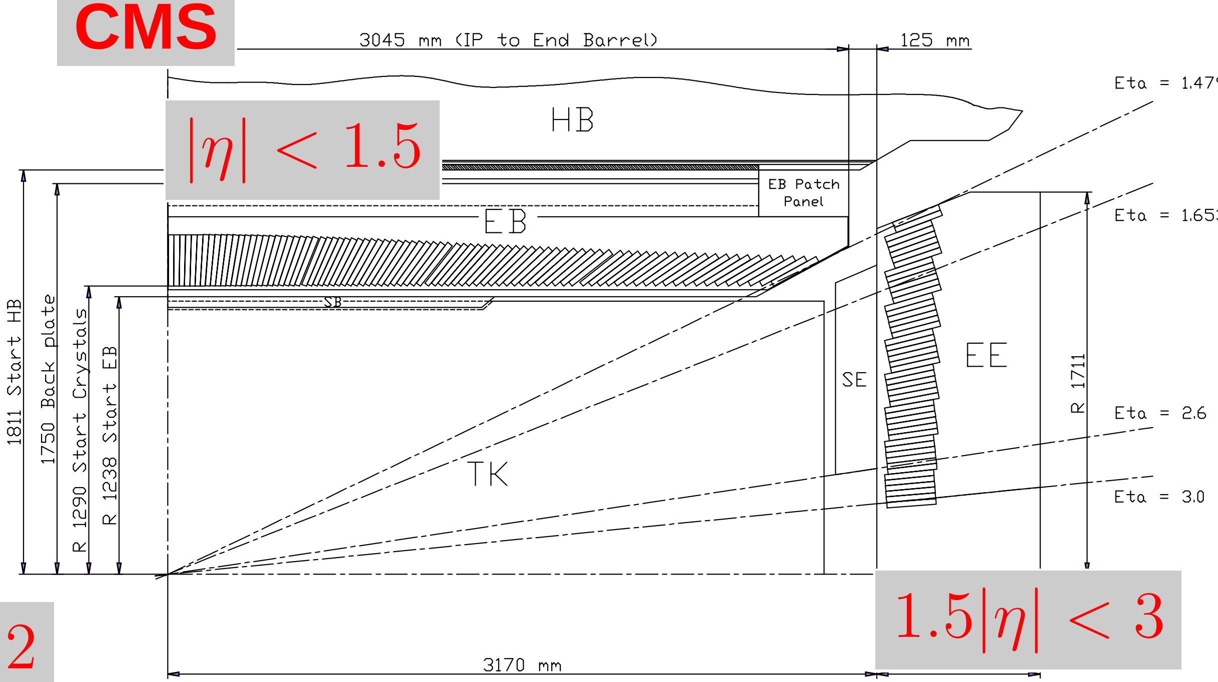
	res. @ 50 GeV	*material in front*	*thickness*	$\Delta\eta \times \Delta\phi$
ATLAS	1.5%	2-4 χ_0	21-36 χ_0	front 0.003×0.1 middle 0.025×0.025 back 0.05×0.025
CMS	0.8%	0.4-1.3 χ_0	25-27 χ_0	0.0174×0.0174

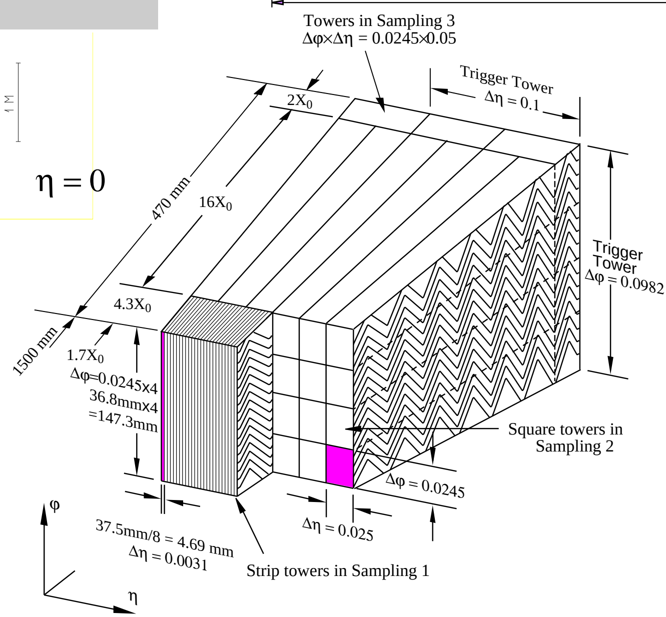
SLHC ECAL geometry

ATLAS



CMS





ATLAS LA detail

- Radiation dose

  Dominated by photons in electromagnetic showers

$$D \sim \frac{L}{r^2 \sin\theta}$$

L = luminosity, r = distance, θ = polar angle

  15 kGy for barrel, 200 kGy for end-cap

- Detector limits

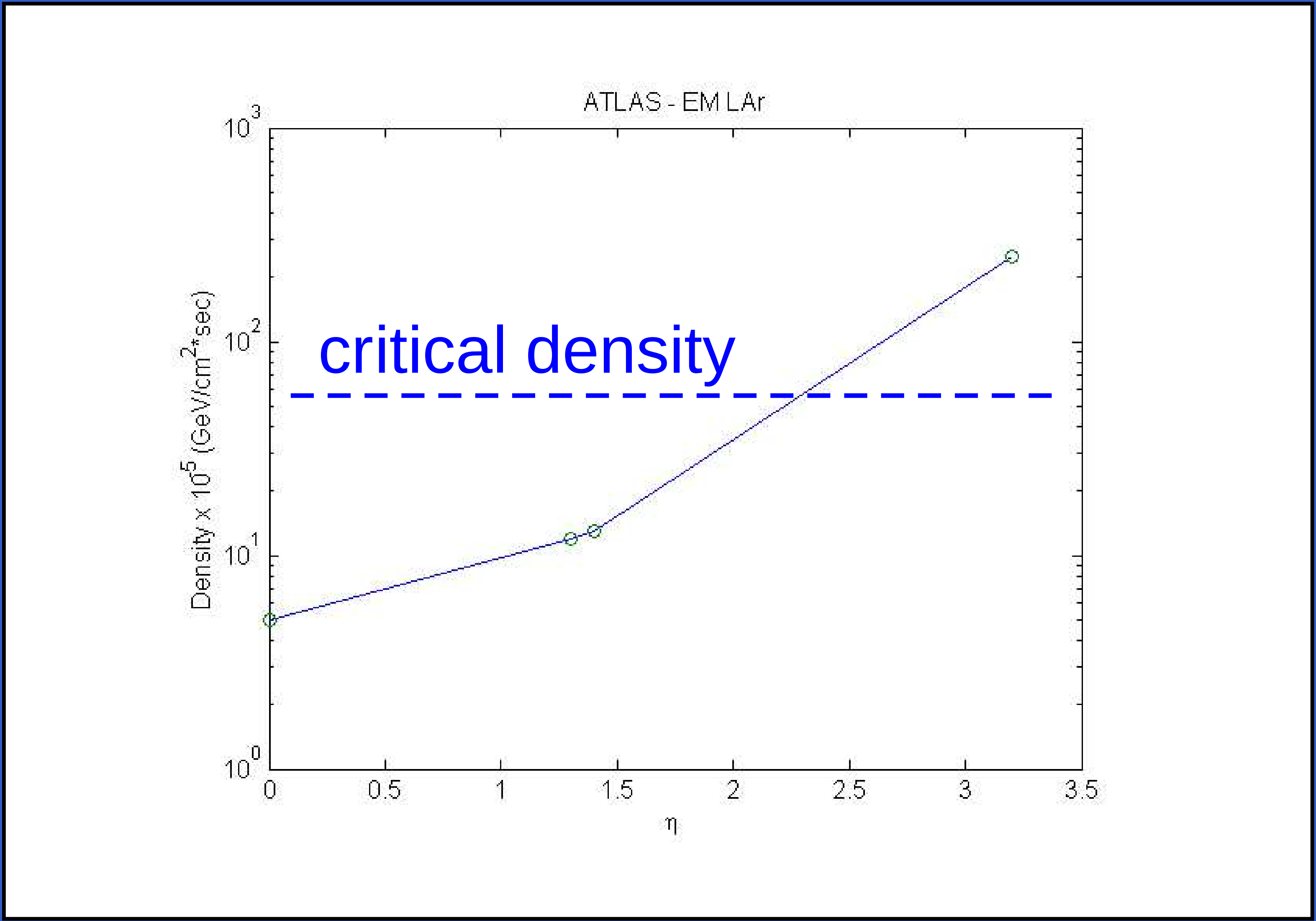
  space charge for ATLAS liquid argon
  leakage current noise for CMS photodetectors

- Pileup noise

  gets worse by $\sqrt{5}$ to $\sqrt{10}$ (depends on readout speed)

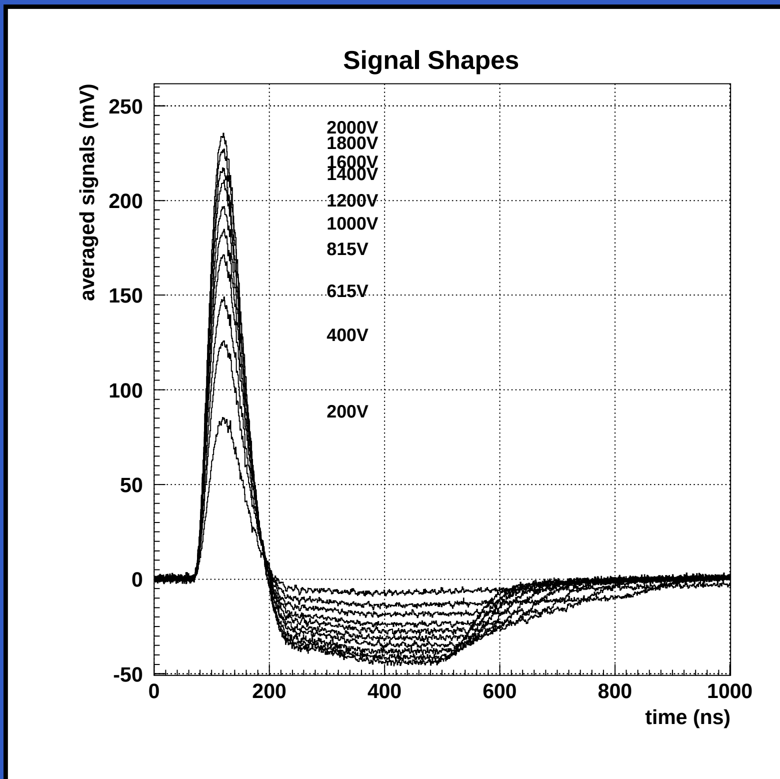
- Isolation for electron ID

SLHC Liquid argon space charge

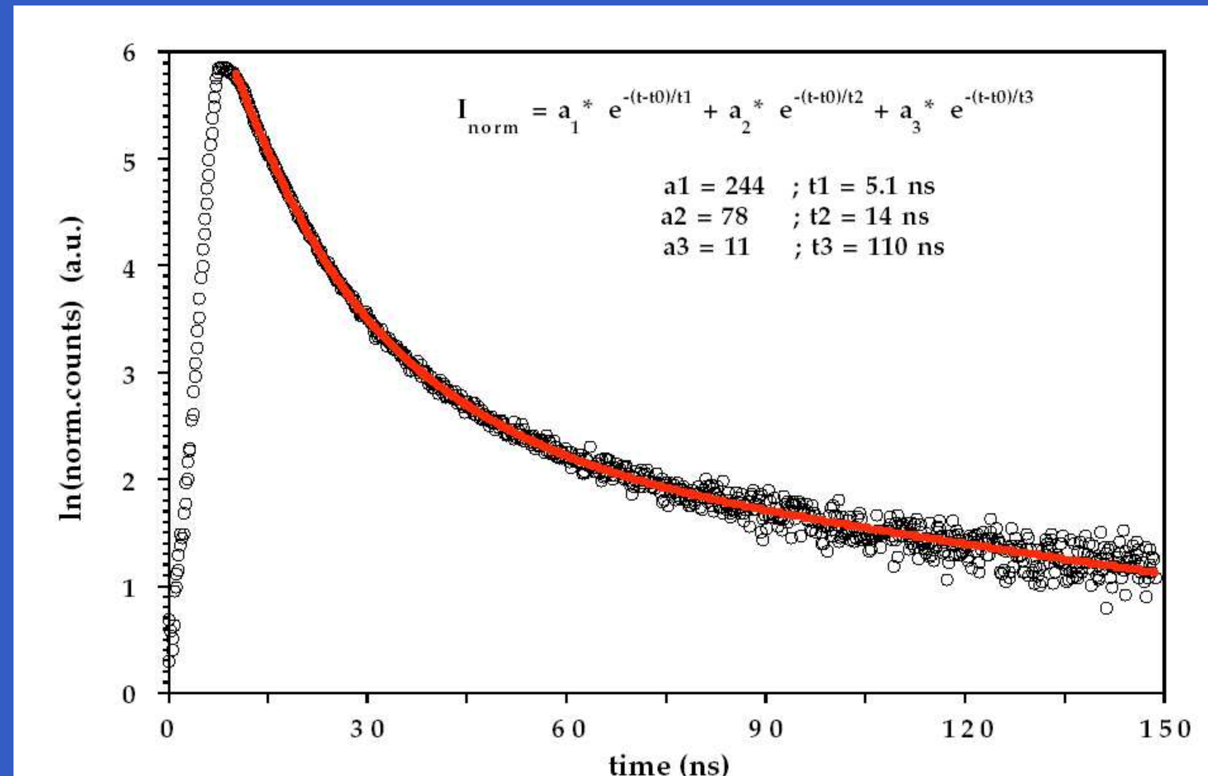


SLHC ECAL pulse shape

ATLAS liquid argon



CMS crystal



SLHC ECAL implications

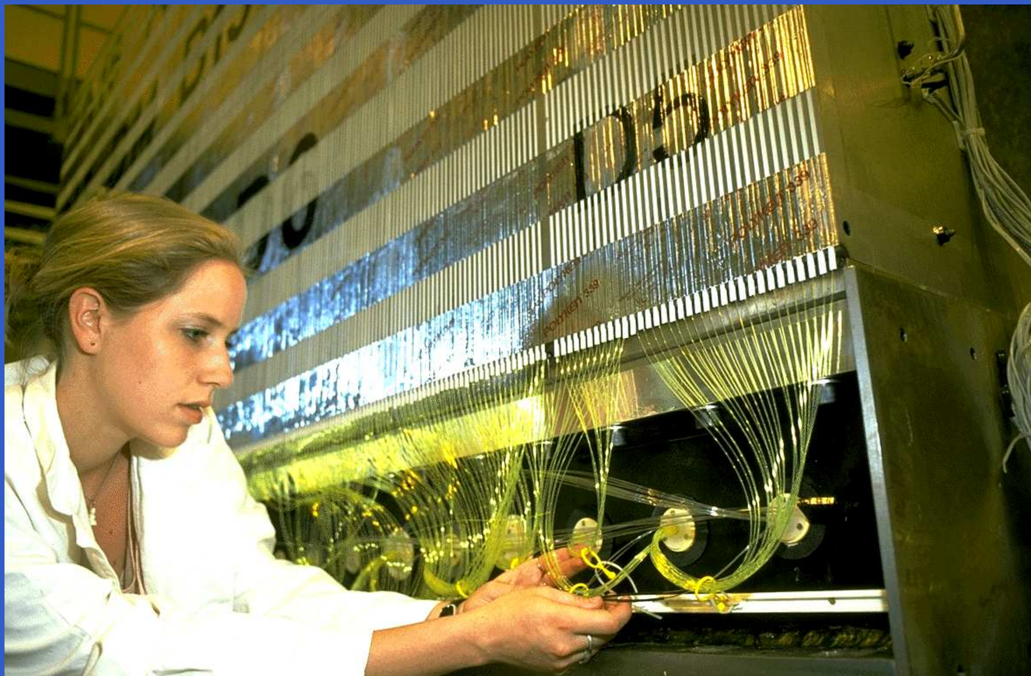
- Liquid argon and crystals can work in the barrel
  sampling at 40 MHz with BCID

  ATLAS study with full simulation:
  - electron efficiency is maintained (81% $\rightarrow$ 78%)
  - jet rejection decreases $\times$1.5 $(10^4 \rightarrow 7 \times 10^3)$

- Both ATLAS and CMS end caps need redesign

SLHC HCAL barrel

ATLAS: scintillator / Fe



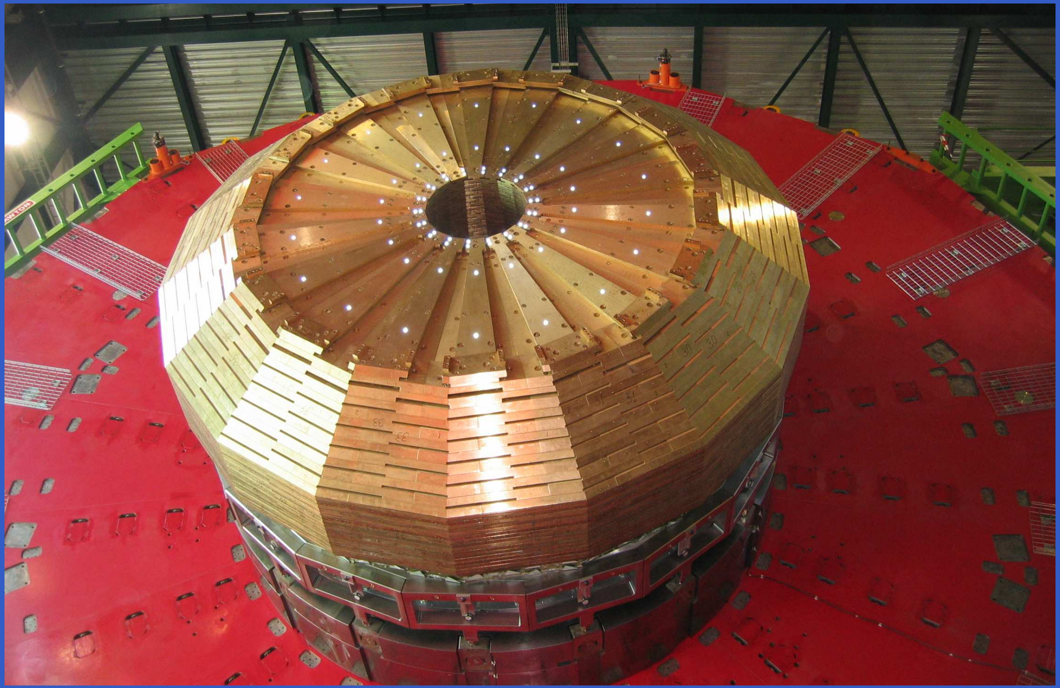
CMS: scintillator / brass

	coverage	*res. @ 100 GeV*	*thickness*	$\Delta\eta \times \Delta\phi$
ATLAS	$\lvert\eta\rvert < 1.0$	8%	8-10 λ	front 0.1 $\times$ 0.1
extended barrel	$0.8 < \lvert\eta\rvert < 1.7$			back 0.2 $\times$ 0.1
CMS	$\lvert\eta\rvert < 1.4$	10%	11-15 λ	0.087 $\times$ 0.087

SLHC HCAL end cap

ATLAS: liq. argon / Cu

CMS: scintillator / brass



	coverage	*res. @ 100 GeV*	*thickness*	$\Delta\eta \times \Delta\phi$
ATLAS	$1.5 < \|\eta\| < 3.2$	8%	9 λ	$1.5 < \|\eta\| < 2.5$ 0.1 $\times$ 0.1 $2.5 < \|\eta\| < 3.2$ 0.2 $\times$ 0.1
CMS	$1.4 < \|\eta\| < 3.0$	10%	11 λ	$1.4 < \|\eta\| < 1.7$ 0.087 $\times$ 0.087 $1.7 < \|\eta\| < 3.0$ 0.087 $\times$ 0.17

SLHC Forward

ATLAS: liquid argon / Cu-W

CMS: quartz / Fe

	coverage	π *res. @ 300 GeV*	*thickness*	$\Delta\eta \times \Delta\phi$
ATLAS	$3.1 < \|\eta\| < 4.9$	8%	9 λ	0.2 $\times$ 0.2
CMS	$3.0 < \|\eta\| < 5.0$	20%	10 λ	0.17 $\times$ 0.17

$\mathcal{SLHC}$ **Radiation** summary

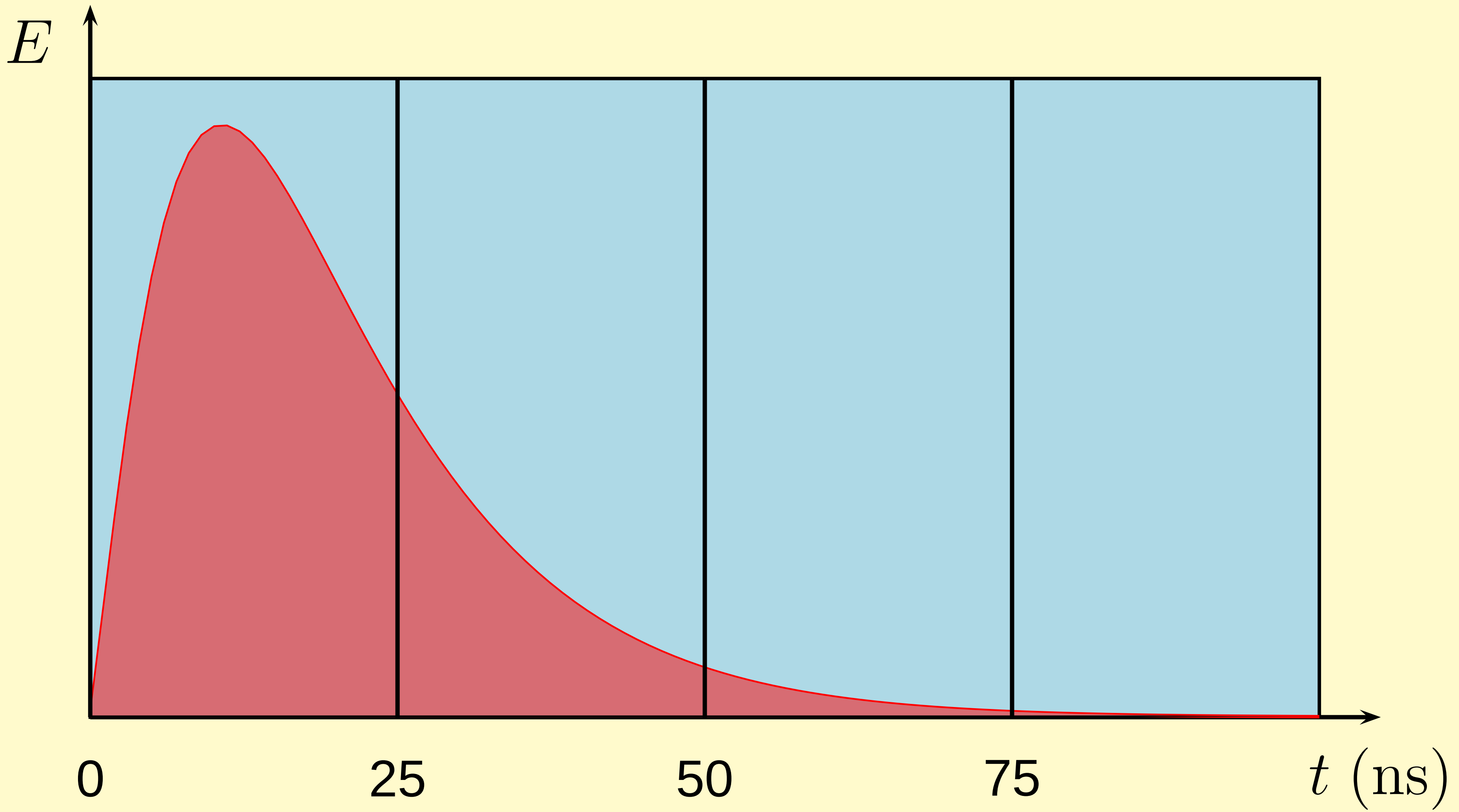
Dose at shower max in calorimetry for $2500\ \mathrm{fb}^{-1}$

η	ECAL (kGy)	HCAL (kGy)
< 1.5	*15*	*1*
2	*100*	*20*
2.9	*1000*	*200*
3.5		*500*
5		*5000*

The dose rate in the barrel at SLHC is comparable to that expected in the endcap at LHC.

SLHC Calorimetry Pulse structure *vs.* time

- scintillator time constants: 8, 10, 29 ns
- HPD time constant: 4 ns
- preamp time constant: 5 ns



SLHC Calorimetry Pulse structure *vs.* time

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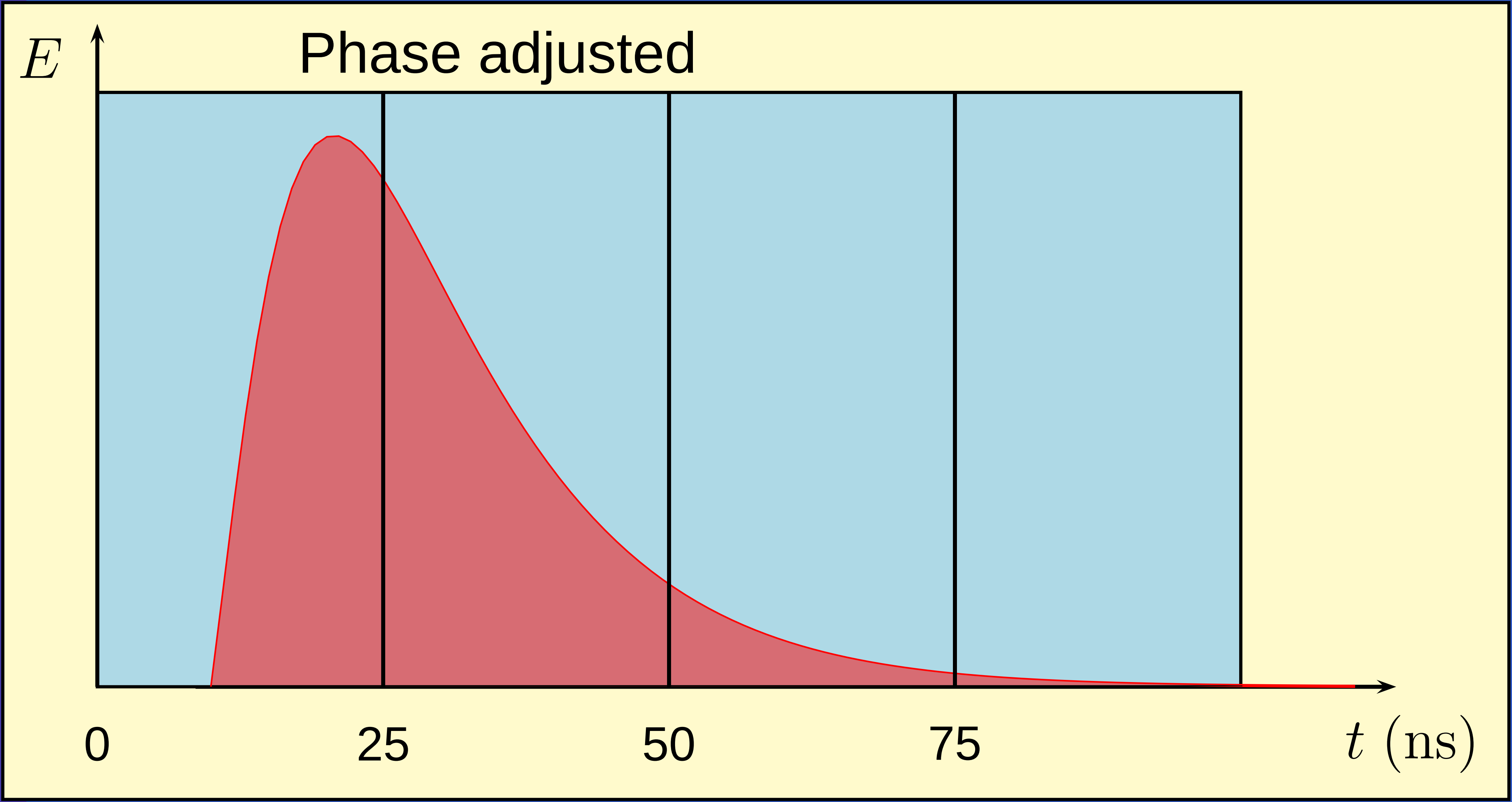
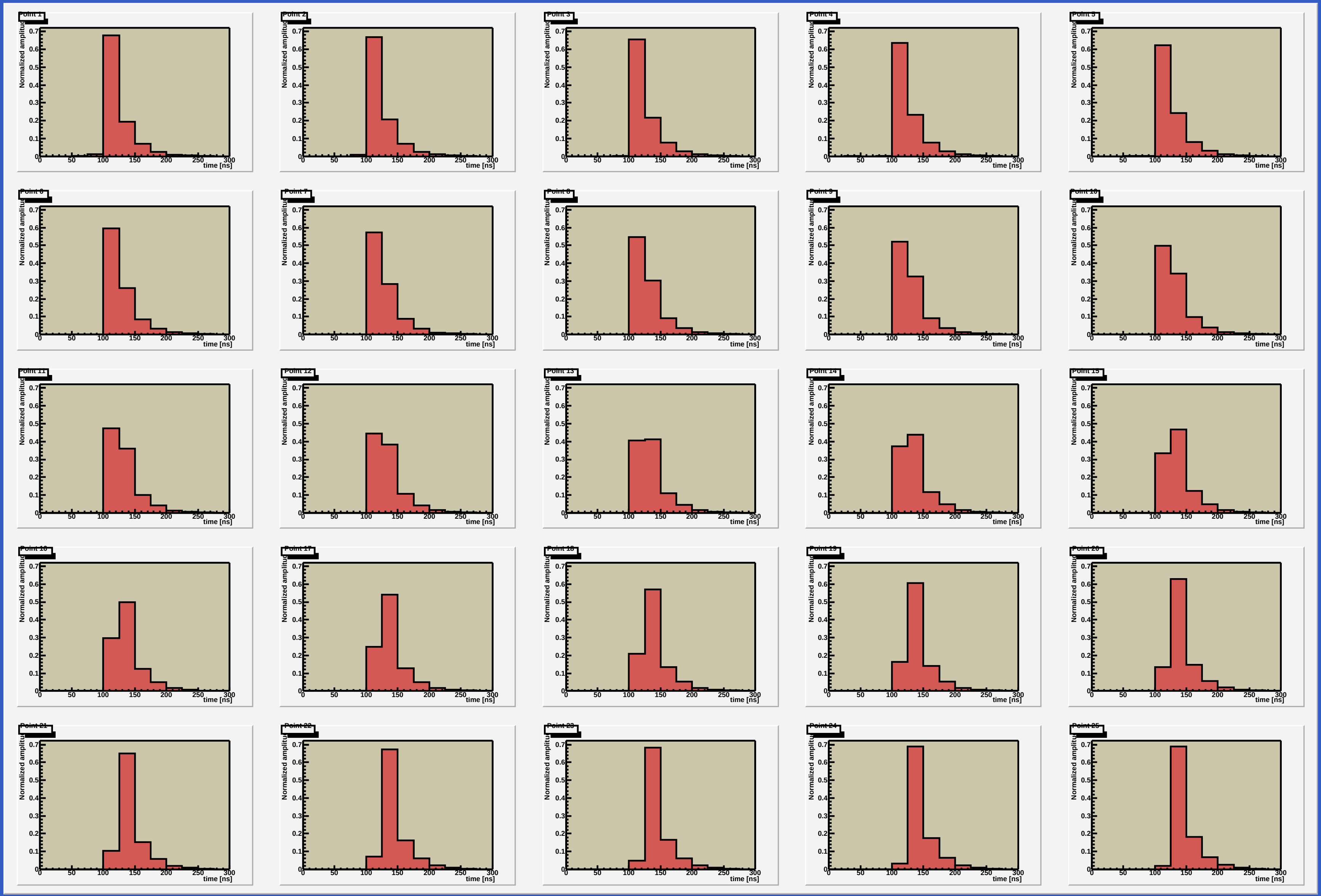


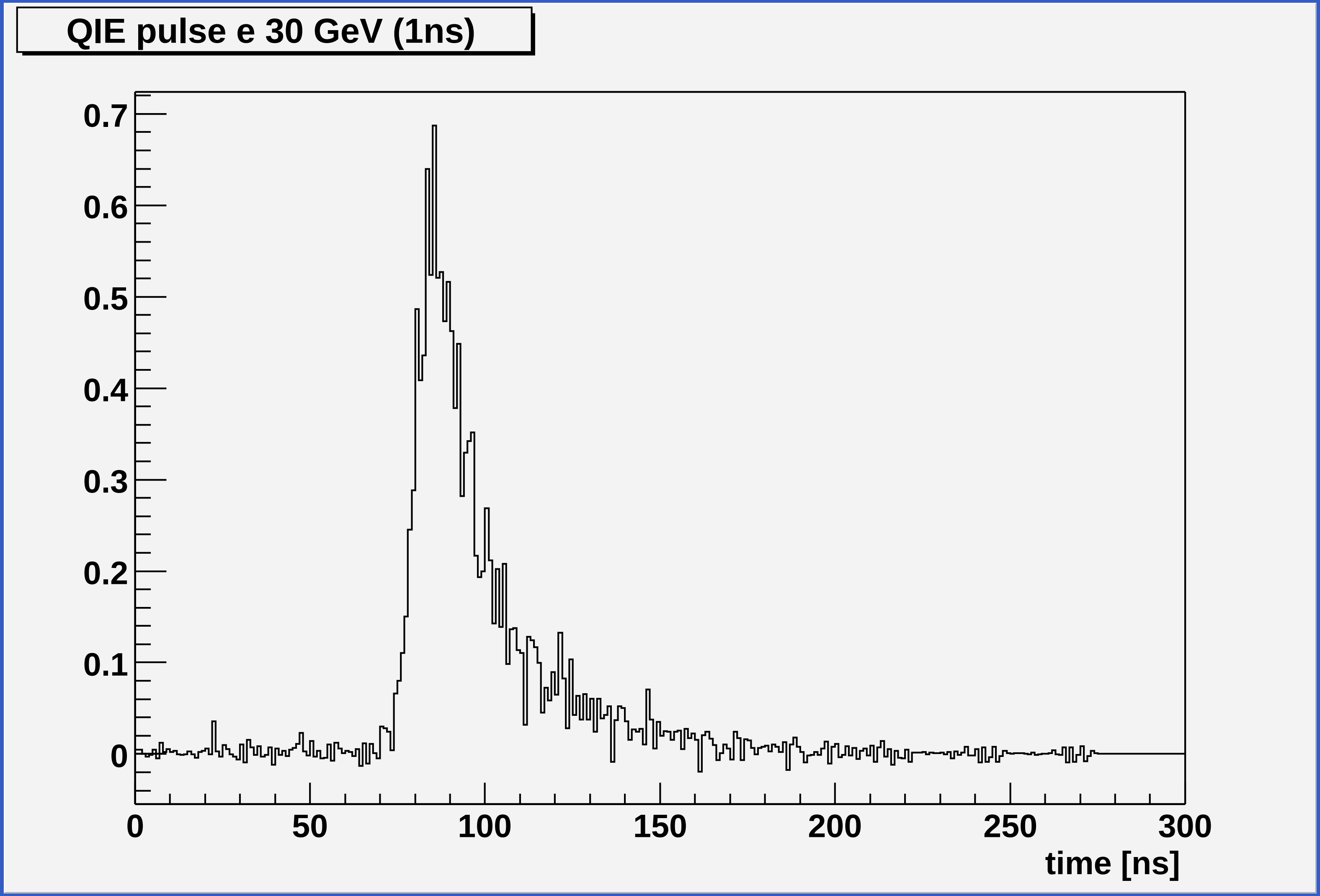
SLHC **Calorimetry** CMS HCAL pulse measurement

shift 40 MHz clock edge w.r.t. event time in 1 ns steps

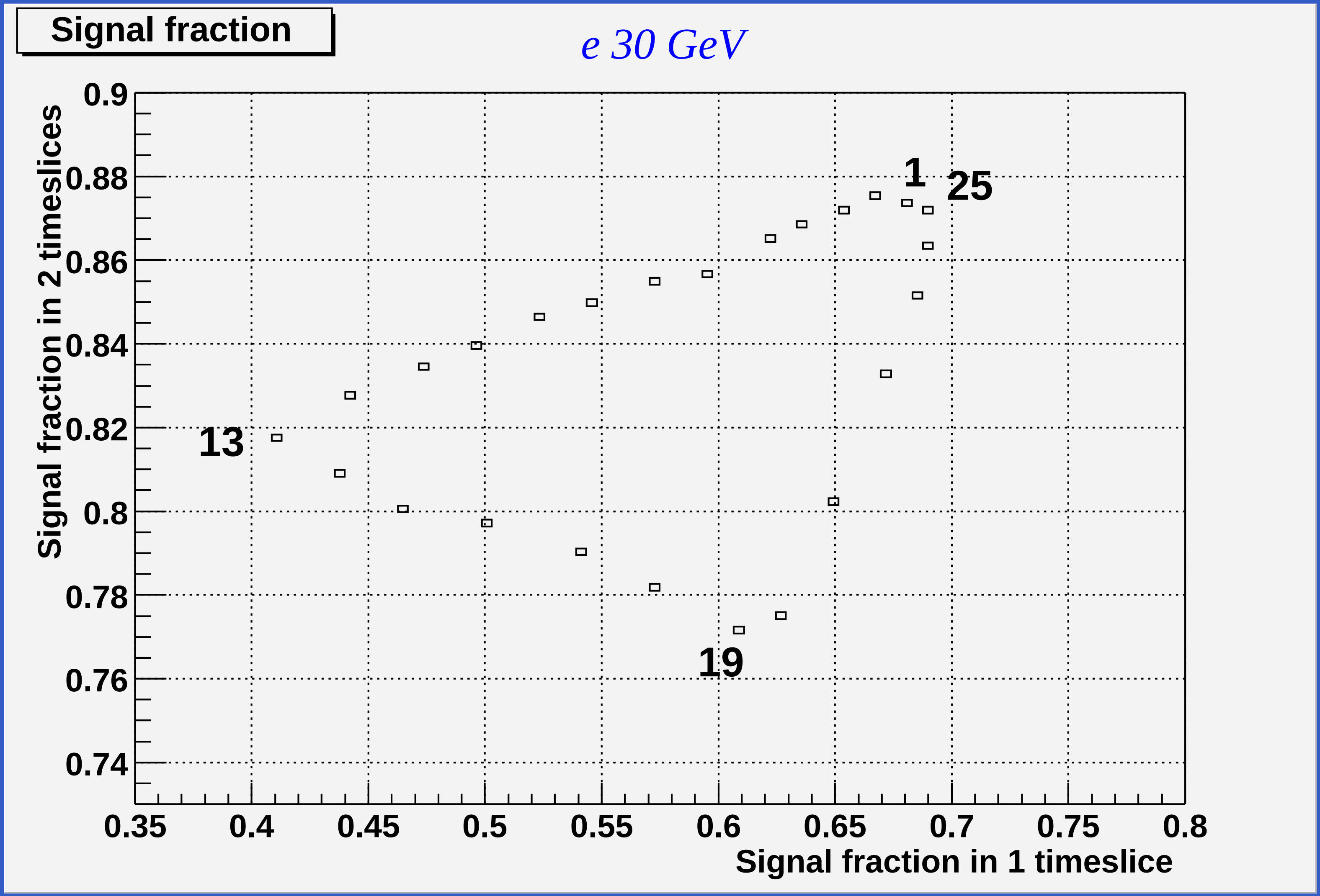


energy *vs.* time (25 ns per bin)

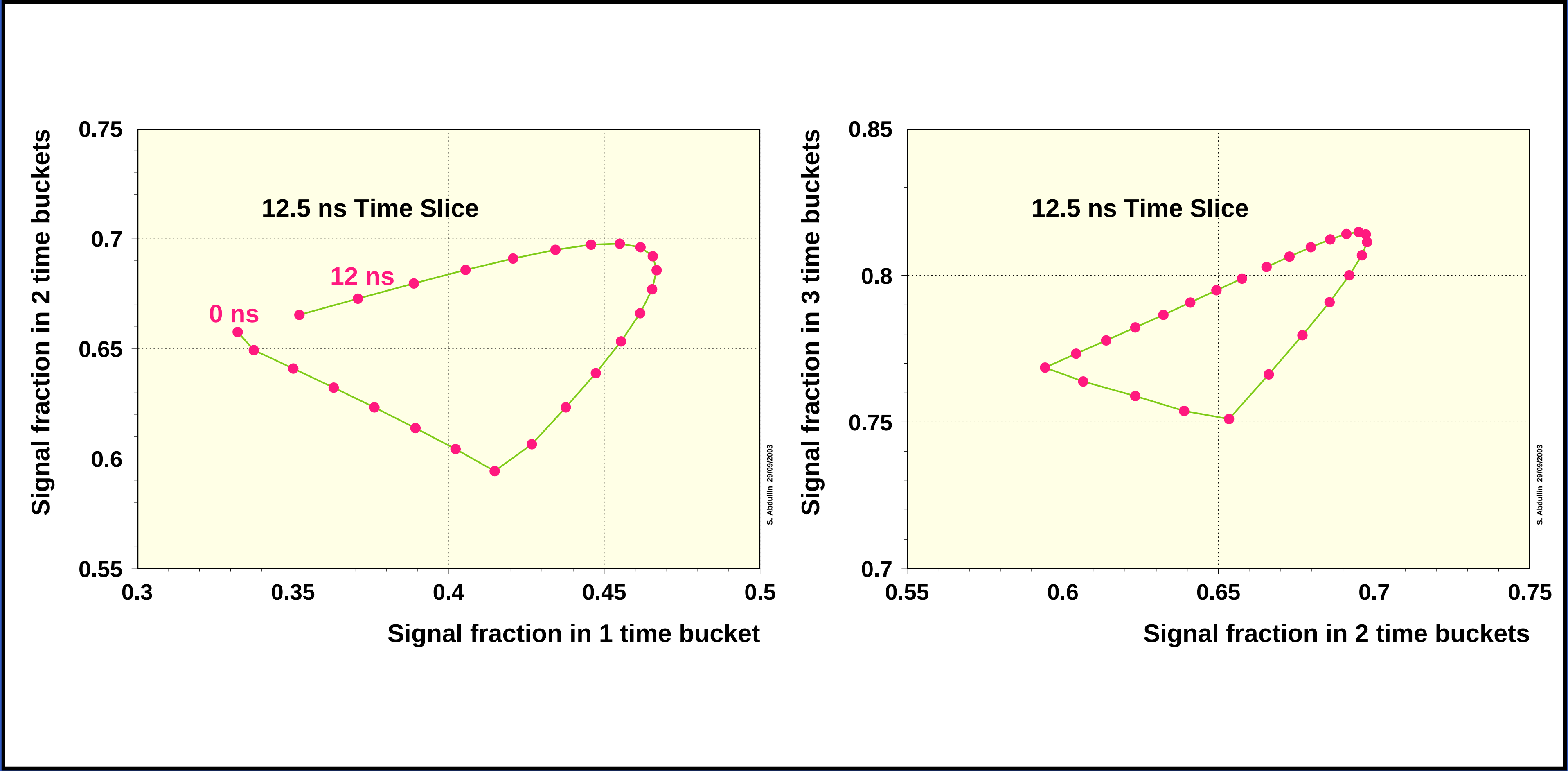
SLHC **Calorimetry** CMS HCAL pulse measurement



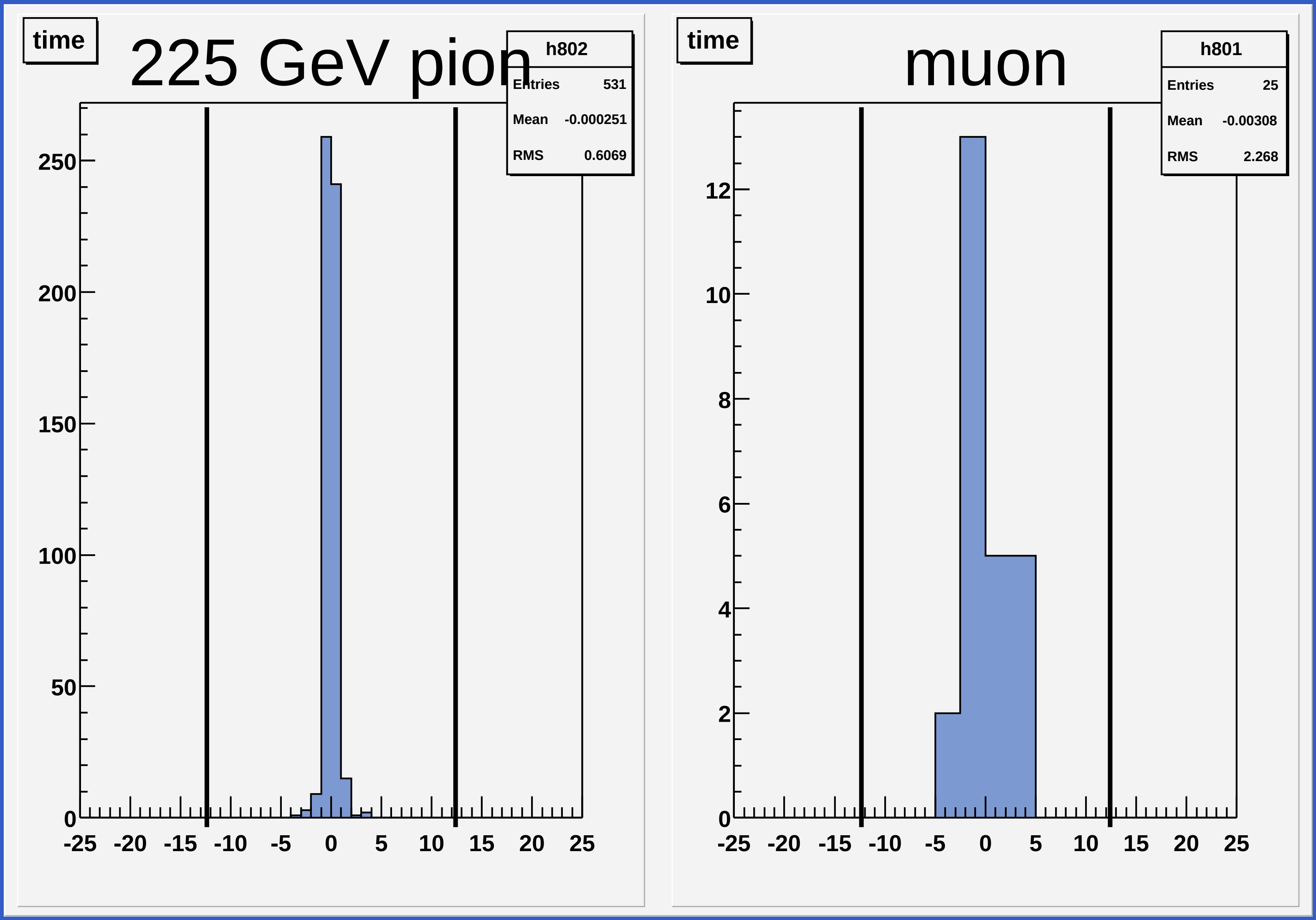
SLHC Calorimetry CMS HCAL pulse measurement



SLHC Calorimetry 12.5 ns

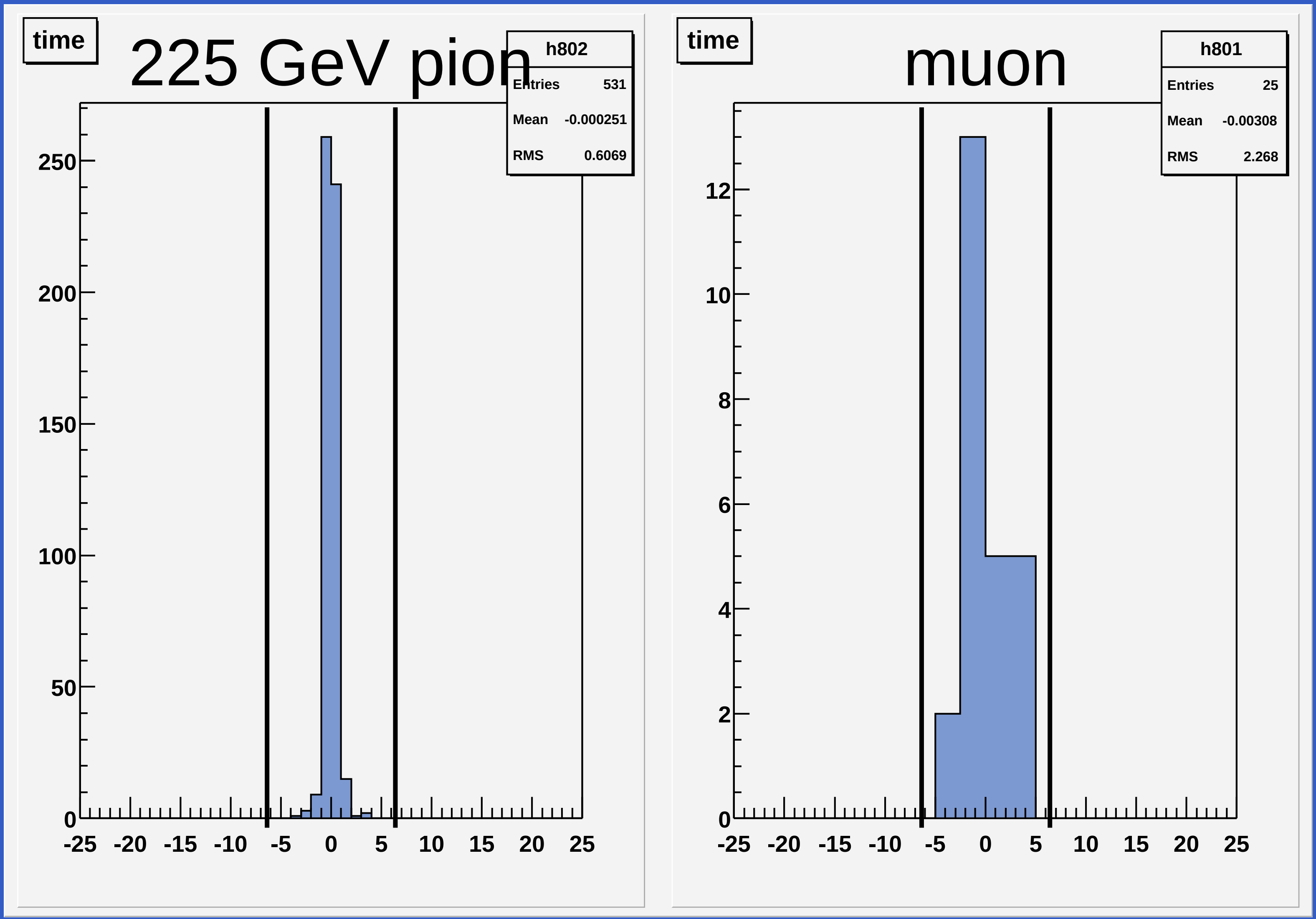


SLHC Calorimetry time resolution



LHC bunch spacing

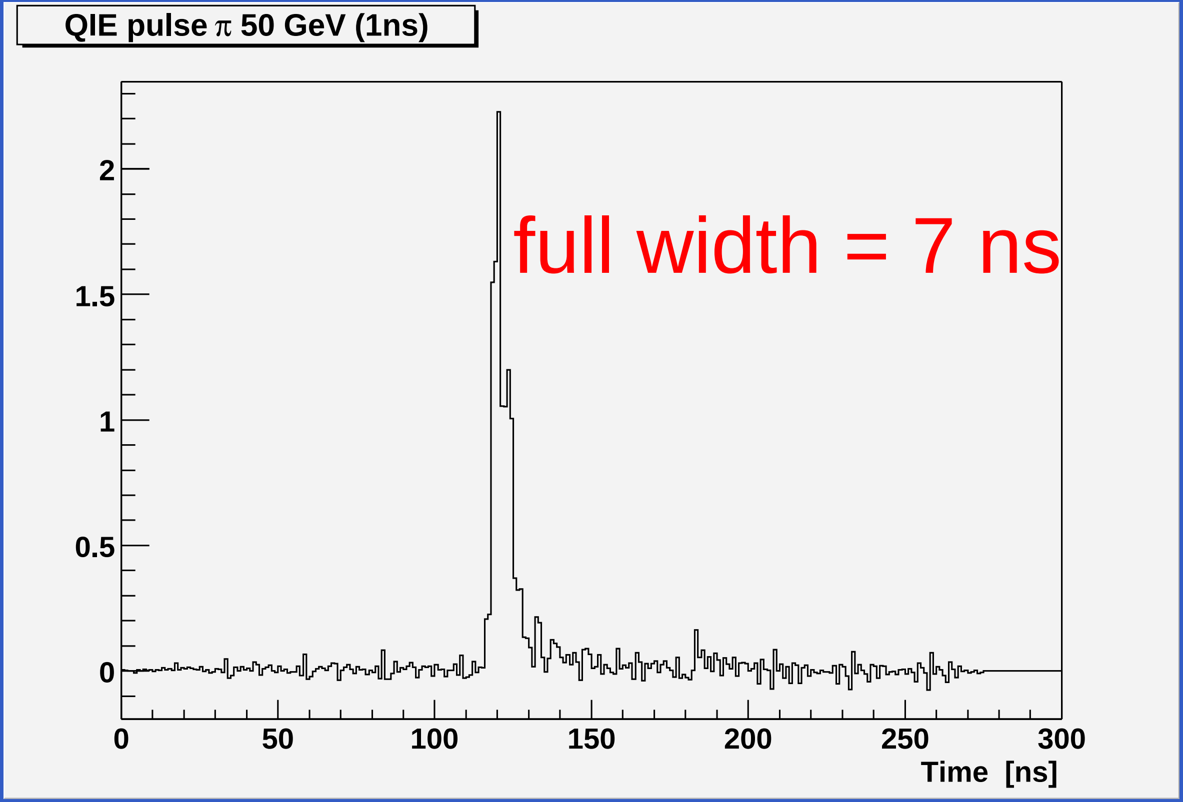
SLHC Calorimetry time resolution



SLHC bunch spacing

Replace CMS endcap scintillator with quartz?

Test beam results with production HF wedges, Aug. 2003

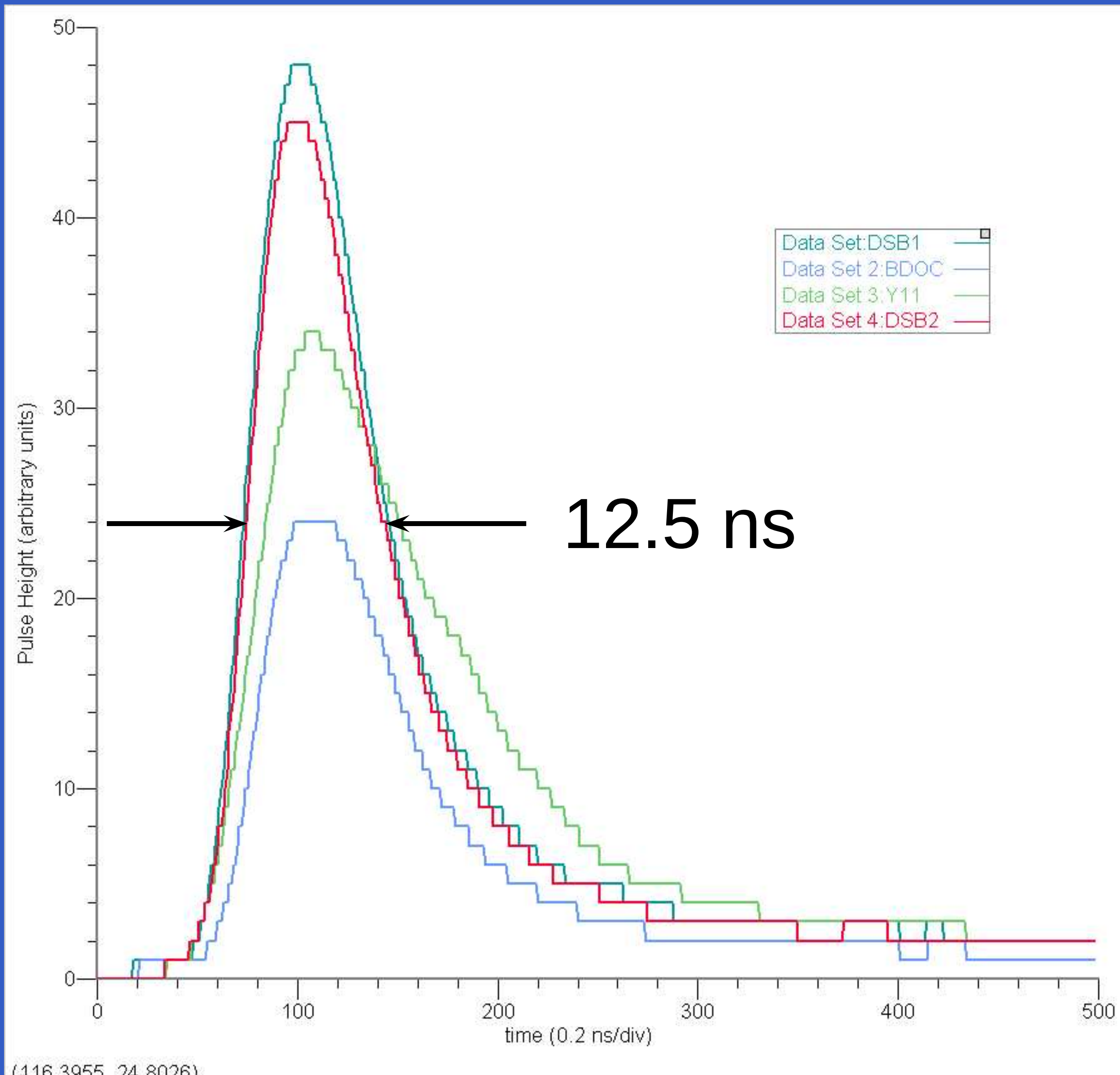


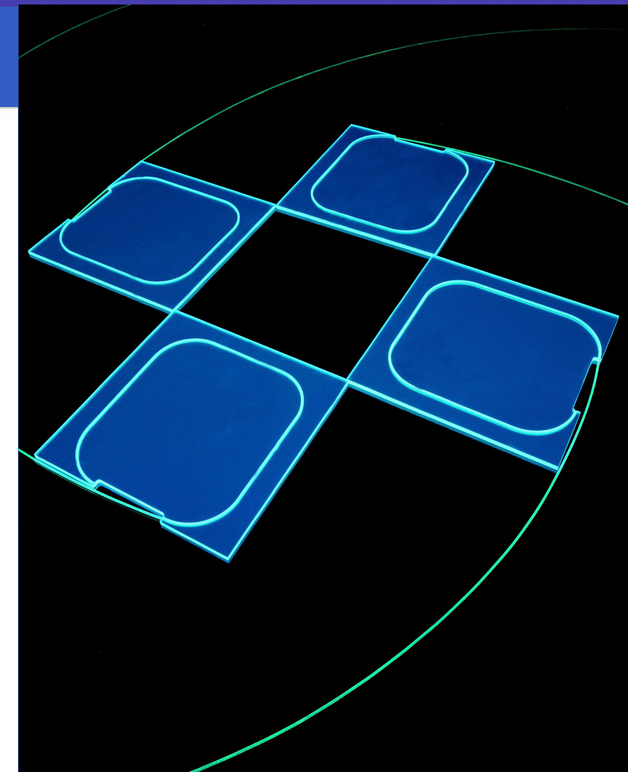
Issues:

- fitting in existing geometry
- photodetector (4 T field)

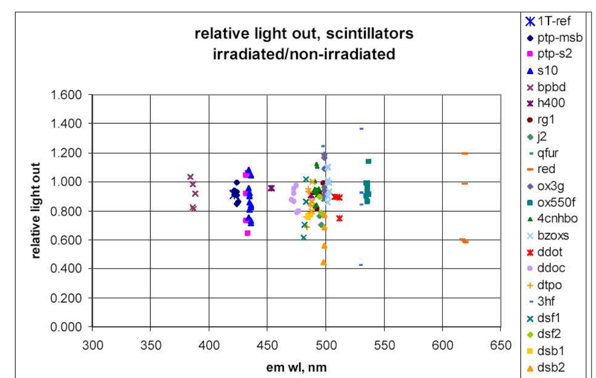
SLHC **New scintillators** R&D to make fast, rad. hard., eff.

Pulses from tiles read with multiclad WSF





Graph of relative efficiency of scintillators after 1 Mrad exposure to ^{60}Co



R. Ruchti *et al.*, COMO 2003.

SLHC HCAL implications

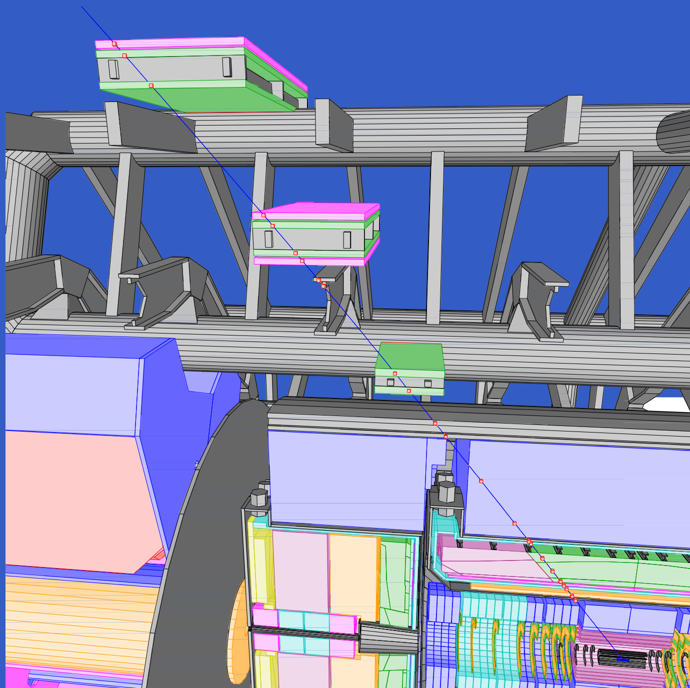
- ATLAS and CMS scintillating tiles can work in the barrel
  BC ID is essential; faster is better.

- Both ATLAS and CMS end caps need redesign

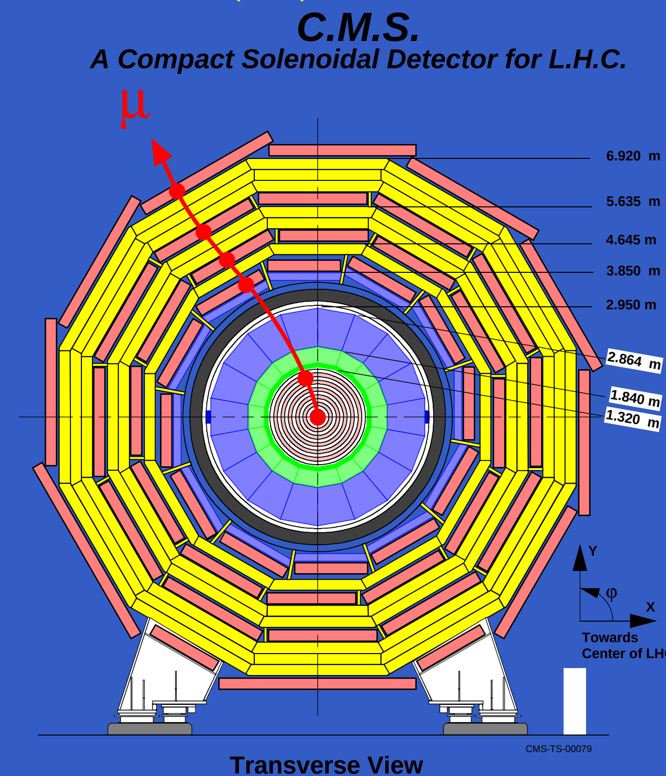
- Forward calorimetry needs to be upgraded
  Can give up some rapidity coverage to get out of most severe radiation zone ($3 < |\eta| < 4.2$ instead of $3 < |\eta| < 5.0$ keeps dose constant).

SLHC **Muon Barrel** design

ATLAS, $|\eta| < 1.0$



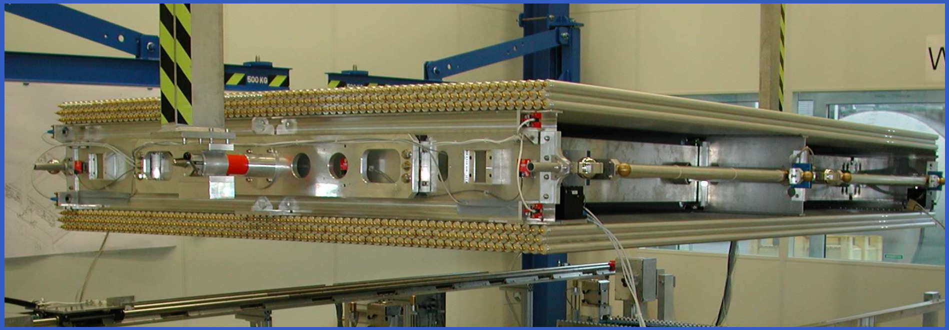
CMS, $|\eta| < 1.3$

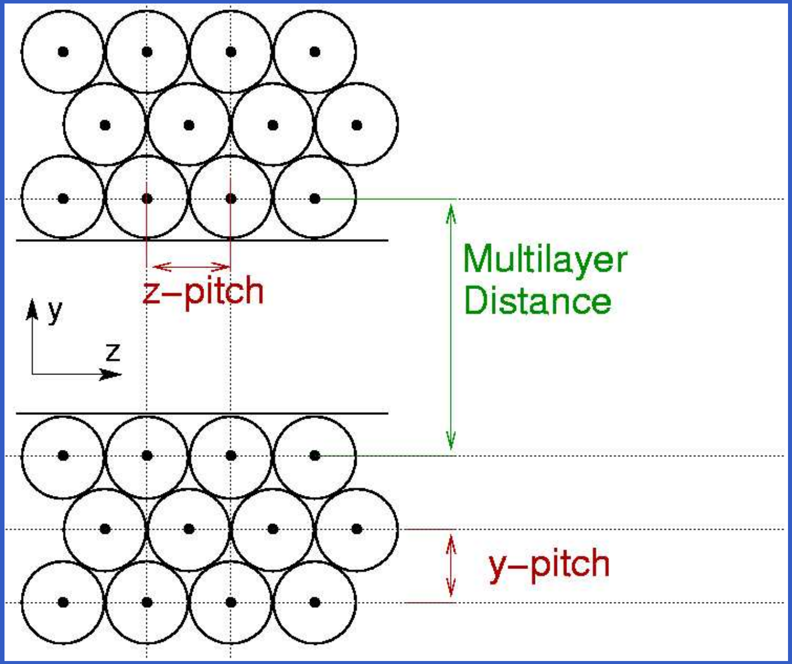


	stations	*trigger*	*resolution @ 100 GeV*
ATLAS	3, $50\ \mu$m	3 RPC	stand-alone $\frac{\Delta p_T}{p_T} = 0.2 - 1\%$
CMS	4, $100\ \mu$m	4 DT+6 RPC	stand-alone $\frac{\Delta p_T}{p_T} = 2 - 4\%$ global $\frac{\Delta p_T}{p_T} = 0.6 - 1.7\%$

SLHC Muon Barrel drift tubes

ATLAS

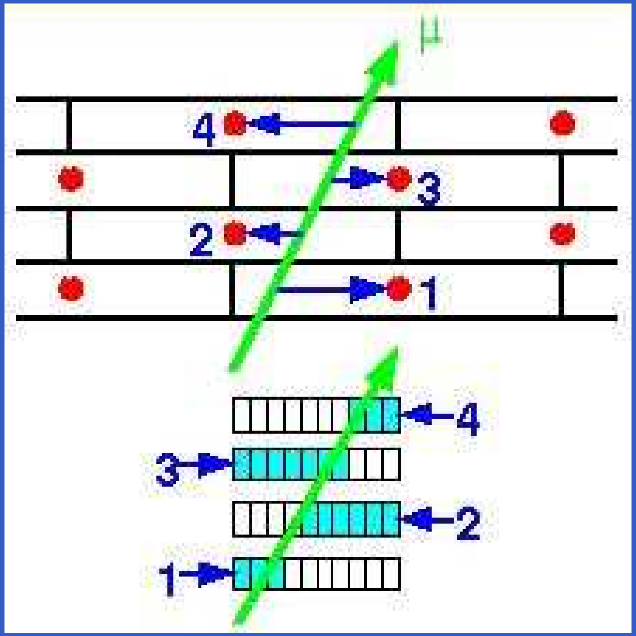




30 mm diameter

$\sigma = 100\ \mu m$

CMS

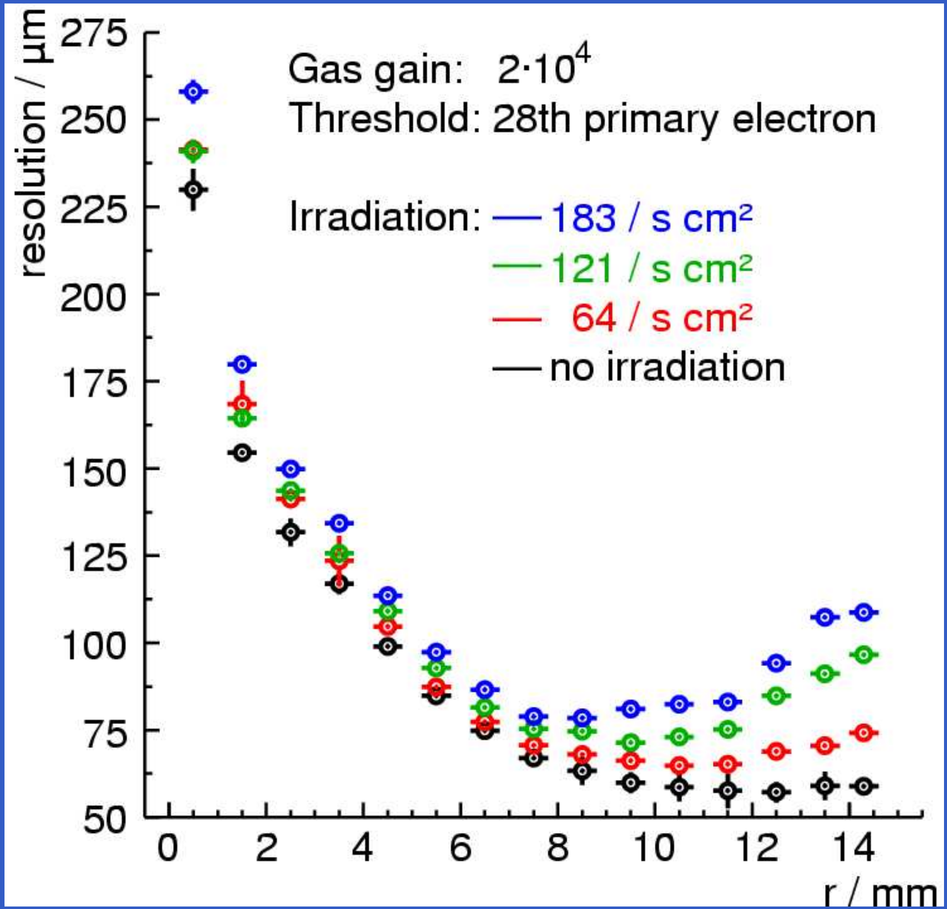


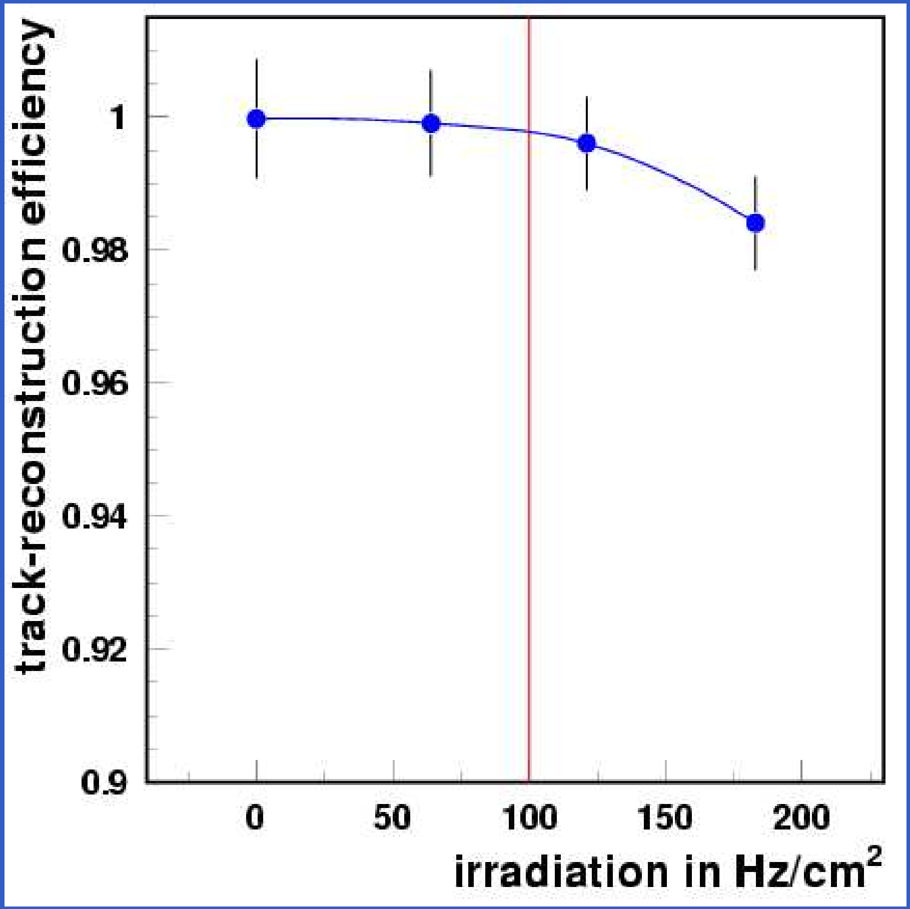
42 mm $\times$ 13 mm

$\sigma = 300\ \mu m$

SLHC Muon resolution ATLAS drift tubes

LHC radiation rates (γ, n): $9 - 100\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
Resolution is degraded due to space charge effects.





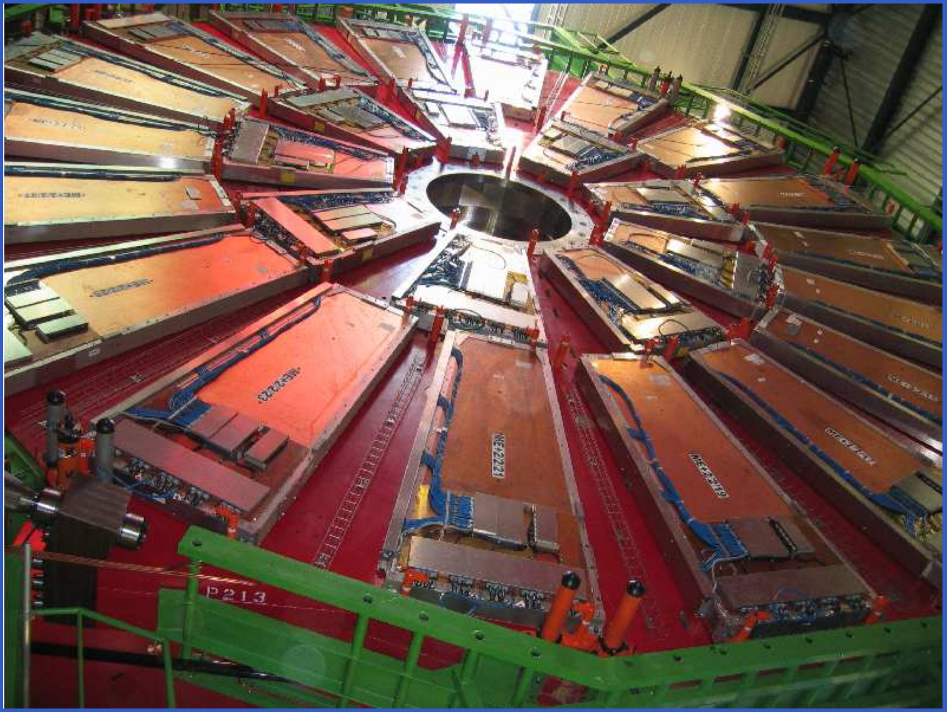
Beam test with large chamber:

100 GeV muons and Cs^{137} source.

SLHC Muon End cap cathode strip chambers

ATLAS

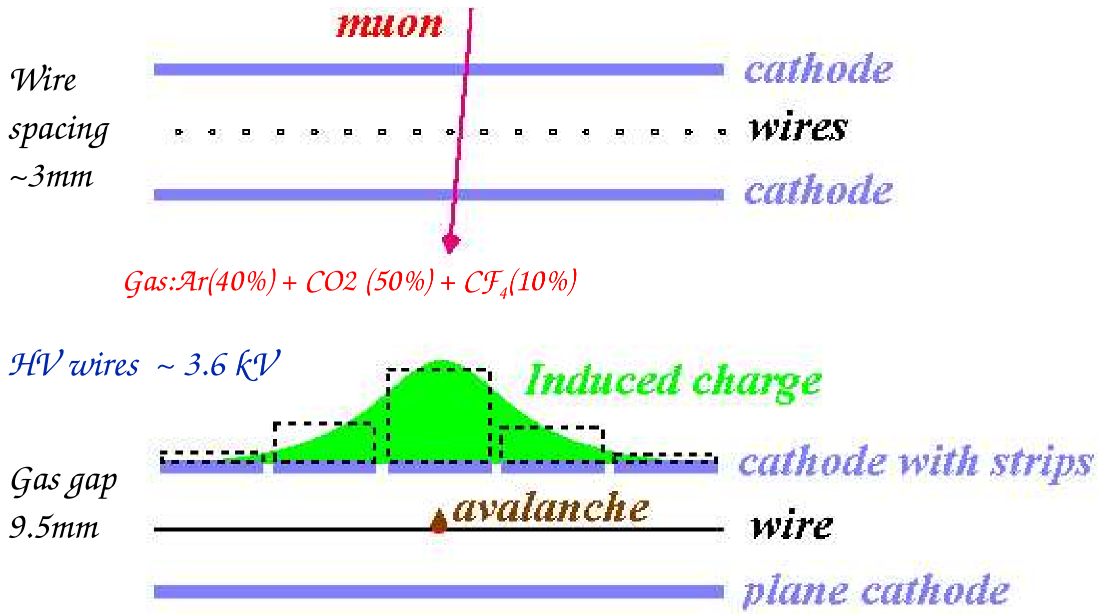
CMS

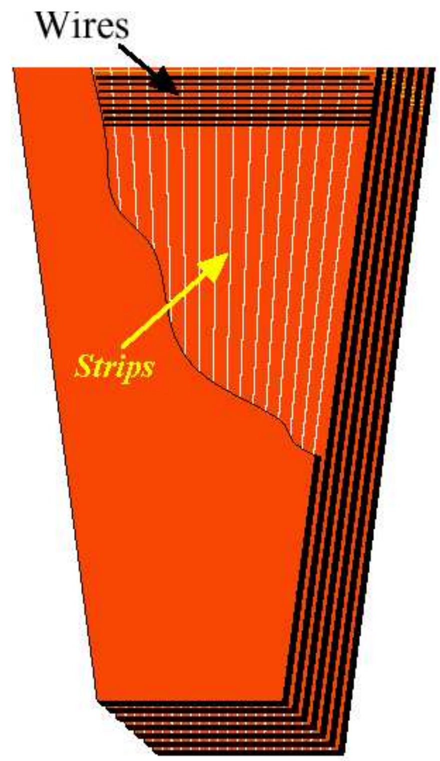


	coverage	*space res.*	*time res.*
ATLAS	$1 < \|\eta\| < 2.7$, 4 disks	60 μm	7 ns
CMS	$1 < \|\eta\| < 2.4$, 4 disks	75-150 μm	4.5

SLHC Muon End cap CMS CSC design

Cathode Strip Chambers





Trapezoidal chambers (10^0 or 20^0 in Φ). 6 layers

Radial cathode strips ➡ *Precise Φ measurement (75-150 μm)*

Wires orthogonal to strips

(except for ME1/1 rotated 25^0 to compensate Lorentz Effect)

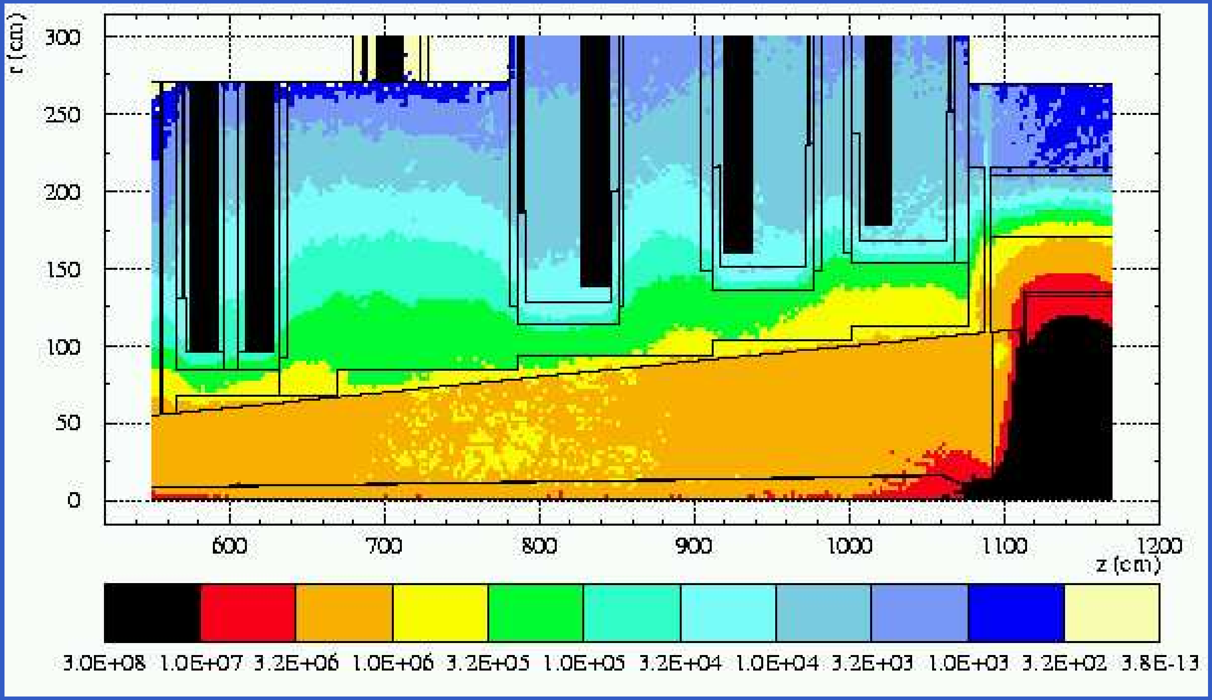
➡ *Precise timing measurement (BX).* *Chamber: ~4.5ns*

➡ *Coarse measurement of the radial position.* *16-54mm*

(5-15 wires readout together)

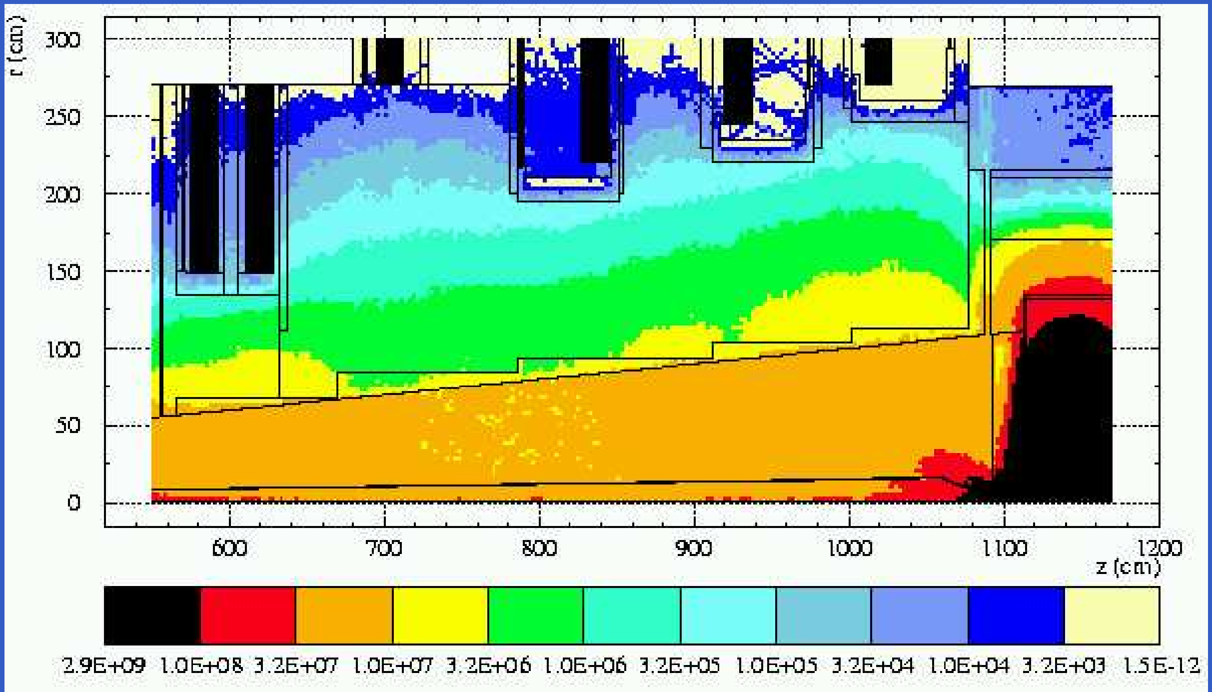
M. Cerrada, EPS Aachen, 2003.

SLHC Muon Shielding



present shielding

$L = \mathbf{10^{34}}\ \mathrm{cm}^{-\mathbf{2}}\mathrm{s}^{-\mathbf{1}}$



extra shielding

$L = \mathbf{10^{35}}\ \mathrm{cm}^{-\mathbf{2}}\mathrm{s}^{-\mathbf{1}}$

$\mathcal{SLHC}$ Muon implications

- Extra shielding at high η needed
- ATLAS and CMS drift tubes MAY work in the barrel
  LHC design has 3-5 safety factor
  if not, can replace with CSC
- Both ATLAS and CMS cathode strip chambers can work in the region $|\eta| < 2$
  - The rates in the strips will reach 700 KHz. Electronics will need to be upgraded to allow larger storage buffer to keep dead-time reasonable.
  - Radiation levels may exclude FPGAs because of SEU.

$\mathcal{SLHC}$ **Trigger** issues

- Occupancy: pileup & increased event size

  affects electron, muon, jet, missing E_{T}

  cone of size $\sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.5$

  has 70 pion pileup $E_{\mathrm{T}} = 42\ \mathrm{GeV}$

- Rates

  $\Rightarrow$increase thresholds

- Radiation

  single event upsets in on-detector electronics

- High-Level Trigger $(100\ \mathrm{kHz} \rightarrow 100\ \mathrm{Hz})$

  10,000 CPUs needed

SLHC DAQ bandwidth

LHC event size is 1 MByte.
Level-1 trigger rate is 100 kHz.
Number of CMS data links is 500.
Average data rate on DAQ link (with large fluctuations!):

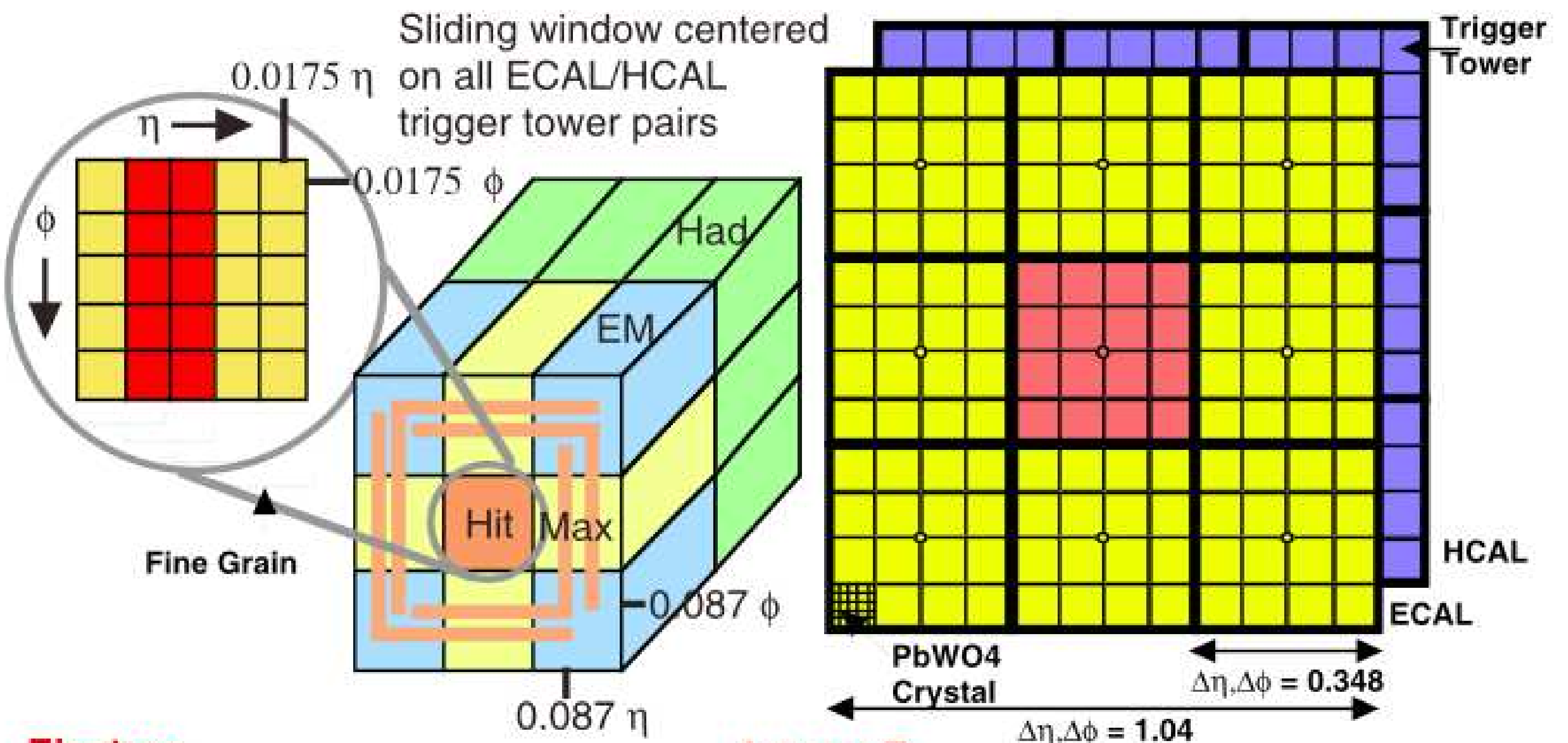
$$R = \frac{(10^6 \text{ Bytes})(10^5 \text{ s}^{-1})}{500} = 200 \text{ MBytes/s}$$

This is dominated by tracker data $\rightarrow \times$10 at SLHC.

An order of magnitude increase in bandwidth is needed.

SLHC Trigger CMS calorimeter

Current Algorithms



Electron
- 2-tower ΣE_T + H/E

Isolated Electron
- 2x5-crystal strips>90% energy in 5x5 (Fine Grain)
- Neighbor EM + Had Quiet

Jet or τ E_T
- 12x12 trig. tower ΣE_T sliding in 4x4 steps w/central 4x4 > rest

τ algorithm (isolated narrow energy deposits)
- Call Jet τ if all 9 4x4 region τ-vetoes off
- τ-veto: Patterns of E or H towers in 4x4

SLHC Trigger CMS calorimeter

- Jets

  granularity $\Delta\eta \times \Delta\phi = 0.37 \times 0.37 \rightarrow 0.087 \times 0.087$
- Missing E_T

  granularity $\Delta\phi = 0.37 \rightarrow 0.087$
- Electron

  π^0 veto and track match
- Tau

  isolation $\Delta\eta \times \Delta\phi = 1 \times 1 \rightarrow 0.5 \times 0.5$

$\Rightarrow$ increased data sharing, adders, and memory

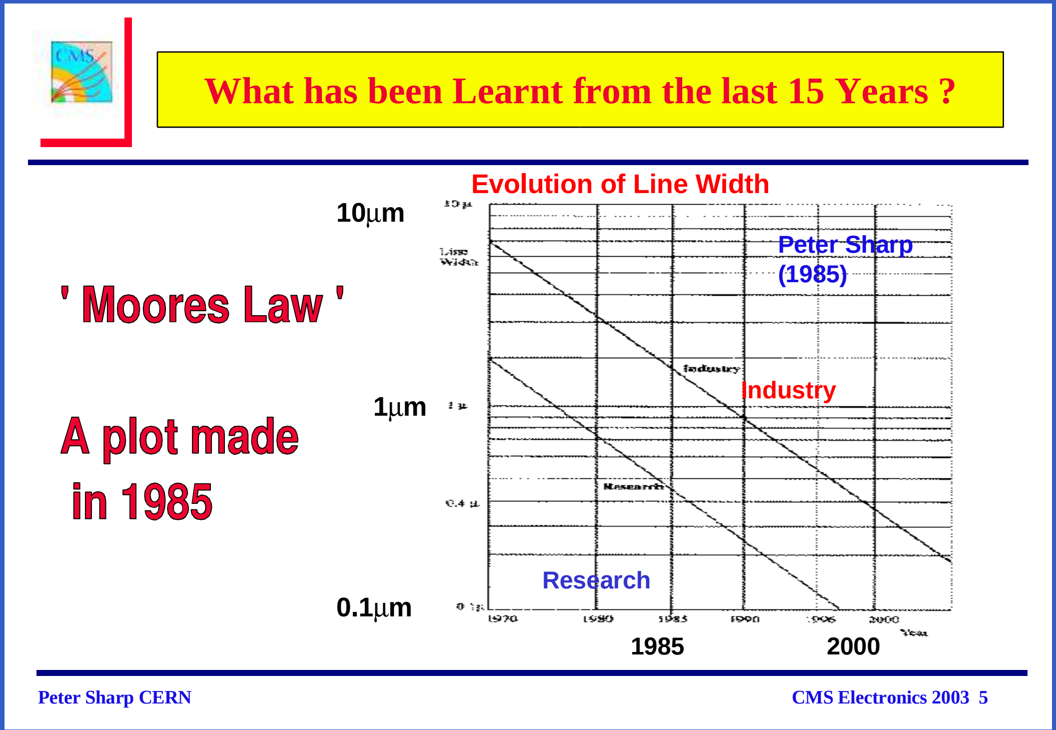
$\mathcal{SLHC}$ Trigger implications

- 80 MHz level-1 pipeline is essential
  BC ID is for each subsystem
- Level-1 thresholds (GeV)

	LHC	SLHC
	CMS DAQ TDR	*estimate*
inclusive muon	20	30
muon pair	5	20
inclusive isolated e/γ	34	55
isolated e/γ pair	19	30
inclusive jet	250	350
jet $\cdot E_{\mathrm{T}}$	113·70	150·80

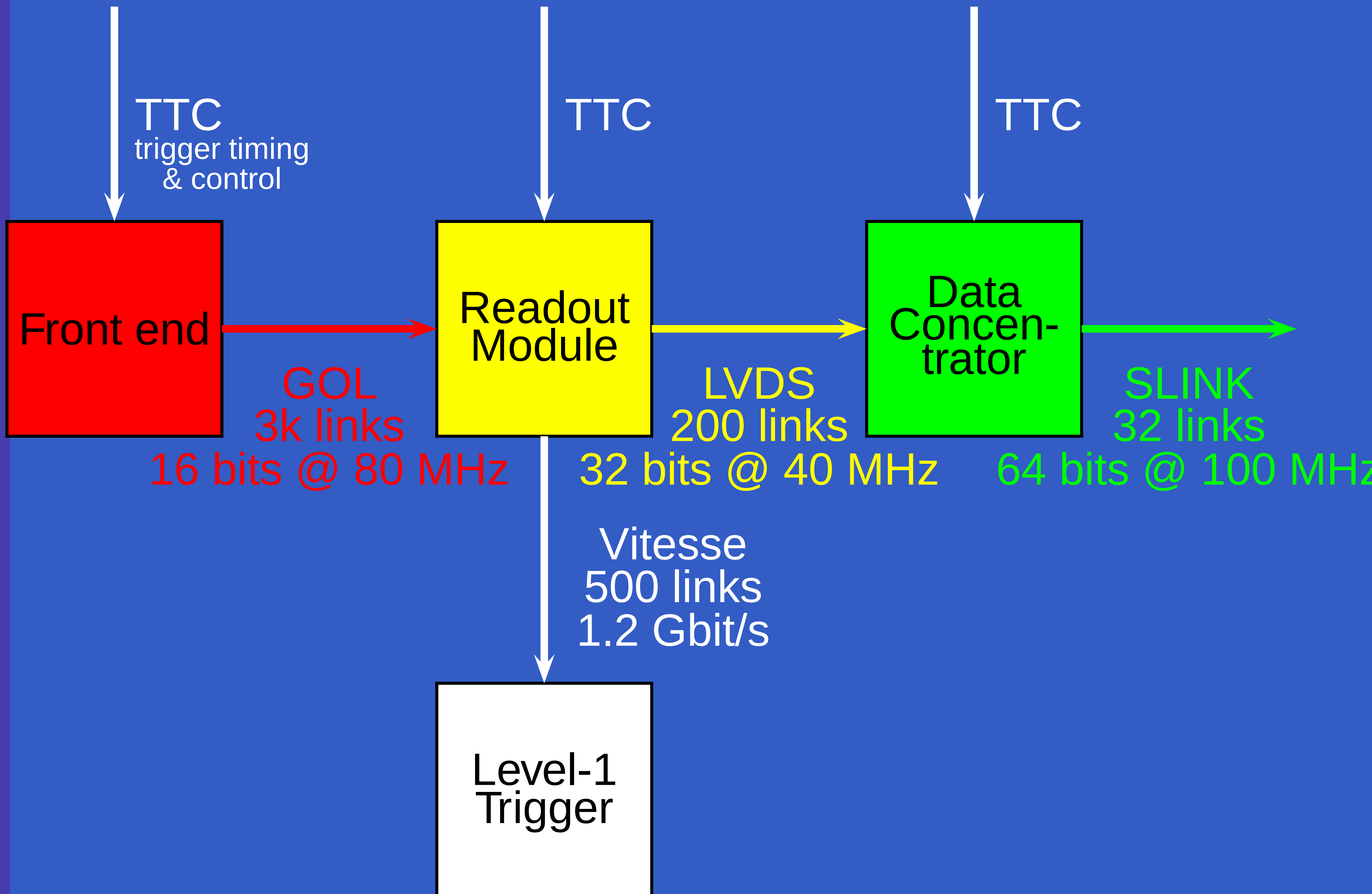
SLHC Electronics Systems global issues for R&D

- Next generation deep sub-micron technology
  - Radiation hardness (total dose and SEU)
  - Low noise analog systems
- System design (on detector processing *vs.* links)
- Advanced data link technology
- Communication techniques (tracker in L1 trigger?)
- Power systems (reduce tracker mass)



Peter Sharp
LECC Amsterdam
Oct. 3, 2003

SLHC Data Links example: CMS HCAL



SLHC Electronics technology

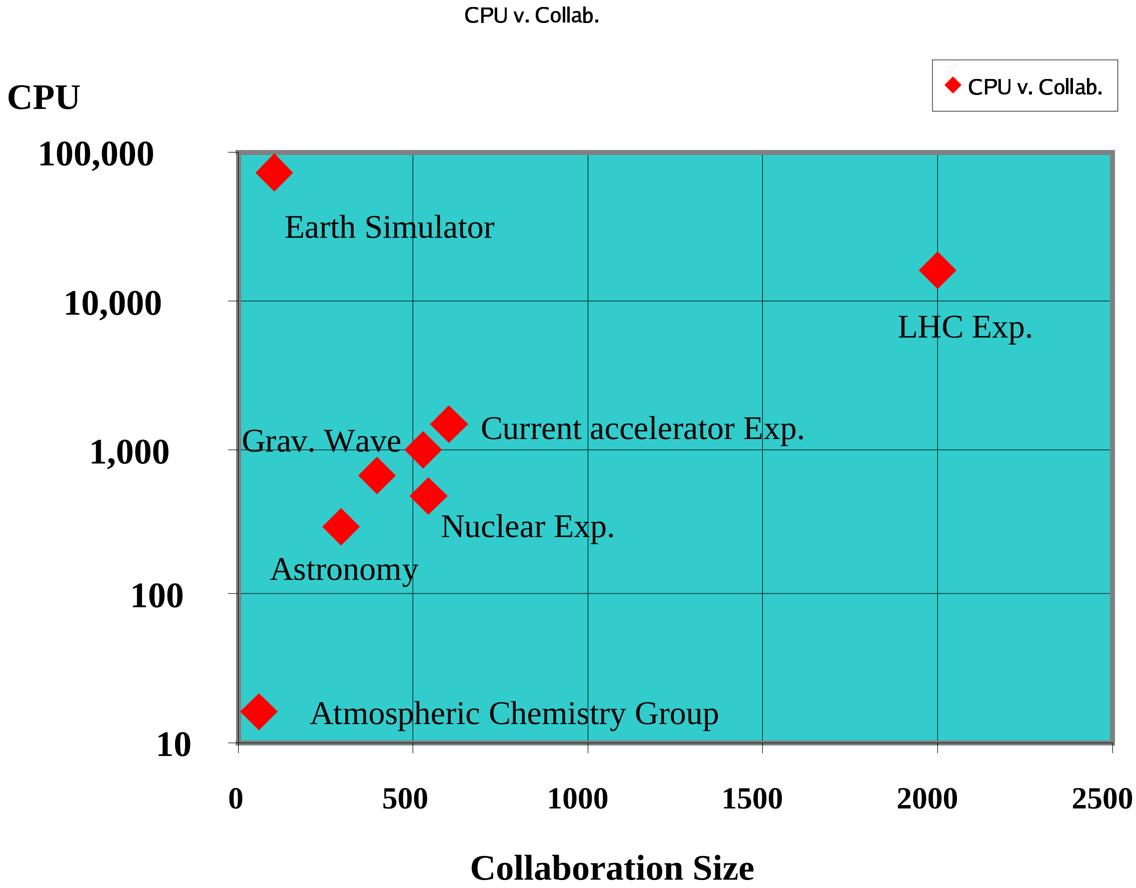
- LHC now uses 0.25μm technology. In 2010, the microelectronics industry will be using 40 nm. SLHC can look at 130 nm now and 65 nm in 2008-9. This would give $\times$16 more gates.
- Fabrication on 12-inch wafers implies complex software for layout.
- Present links use 1-2.5 Gbits/s. Industry now uses 10 Gbits/s and R&D is on 40 Gbits/s. SLHC needs the bandwidth of these fast links.
- Use wireless for communication to reduce material in tracker.

see P. Sharp, LECC 2003 for more detailed list.

SLHC Computing

From J. Huth
(Harvard/ATLAS)
Sept., 03

CPU comparisons

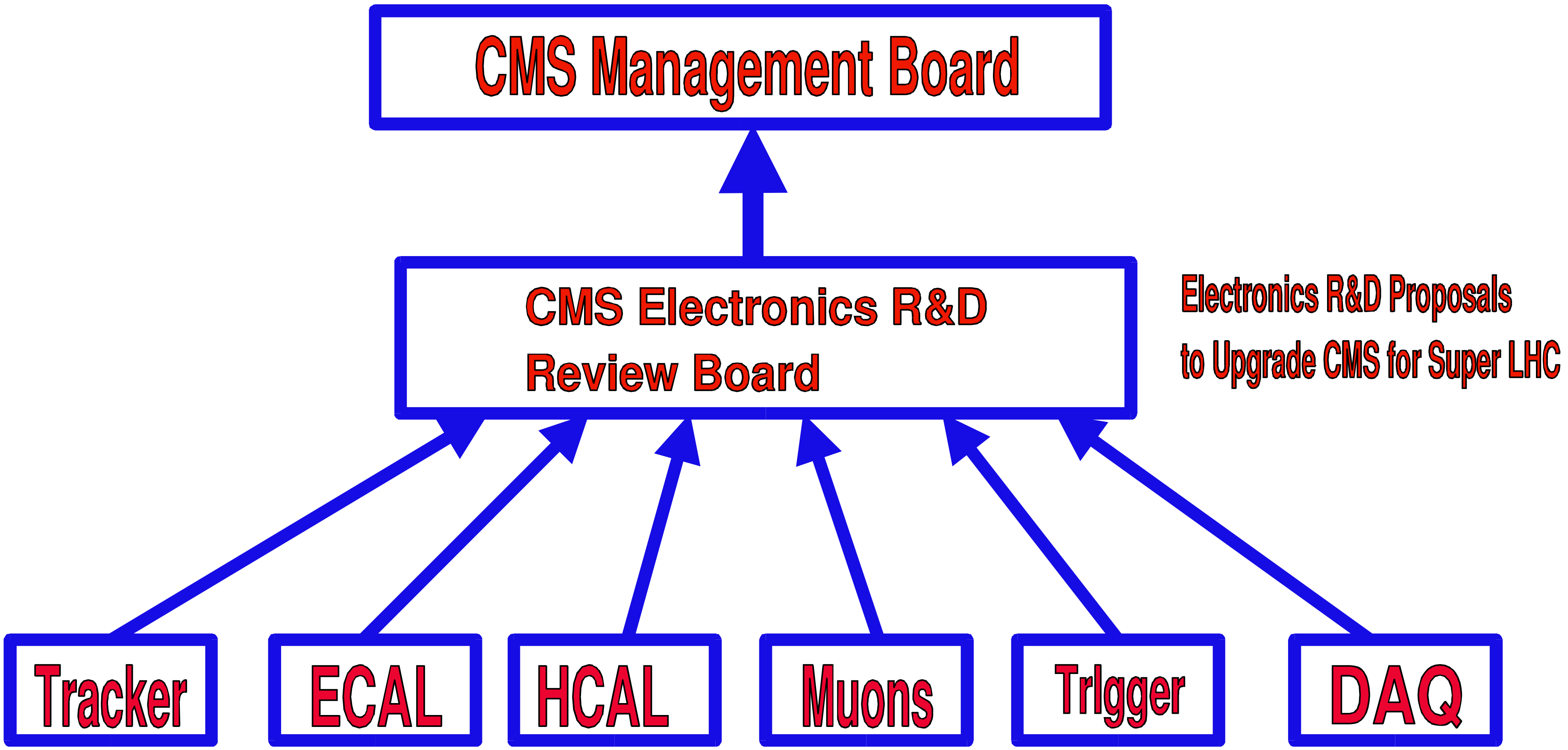


SLHC "Expected" Performance summary

- Tracking
  b tagging rejection 190 $\longrightarrow$ 27 ($p_{\mathrm{T}} = 80\ \mathrm{GeV}/c$)
- Electron Identification
  $\times$ 5-10 pileup $\Rightarrow$ $\times$ 2-3 noise
- Muon Identification
  reduced rapidty coverage ($|\eta| < 2$) due to increased shielding needs
- Jets
  forward jet tag and central jet veto degraded
- Trigger
  higher thresholds for inclusive processes

SLHC Organization: Who (CMS)

How should we organize this R&D ?



SLHC Organization Who (ATLAS)

From: Peter Jenni <jenni@mail.cern.ch>
To: James Rohlf <rohlf@bu.edu>
Subject: Re: SLHC
Date: Sun, 12 Oct 2003 18:15:02 +0200 (CEST)

Dear Jim,

I don't have a transparency for the ATLAS procedures concerning the SLHC. However, all major issues pass through the Executive Board, and it is usual that an expert Review Panel would look at technical issues, whereas the upgrade strategy itself will be a broader issue, involving also the Collaboration Board.

Of course I must also say that at this stage we are not so much concerned about upgrades for a SLHC, our main worry is to get ATLAS (and LHC) become a reality first...

Cheers... Peter

SLHC Organization: When

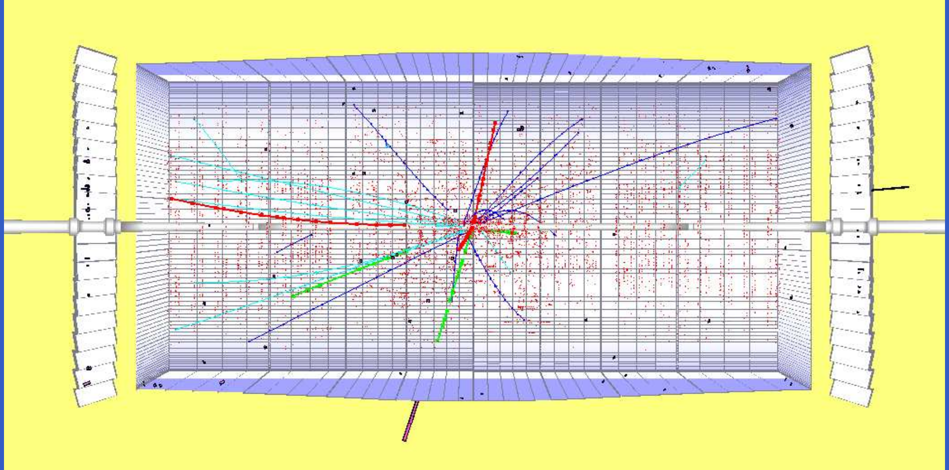
- The LHC has first collisions planned for April 2007, with an initial run of 3 months. This “shakedown” run will undoubtedly reveal many detector problems.
- There will likely be a shutdown for about 3 months, followed by the first “physics” run at low luminosity ($2 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$)
- Sometime in 2008, the luminosity is projected to reach design ($10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$).
- At design luminosity, we can expect about 100 fb^{-1} per year.
- Some where around 2012, the time to double the size of the data set will be approximately 4-5 years. This is the natural time for the upgrade to take place.
- Since the preparation is expected take 10 years, the time to start is NOW.

$\mathcal{SLHC}$ Conclusions

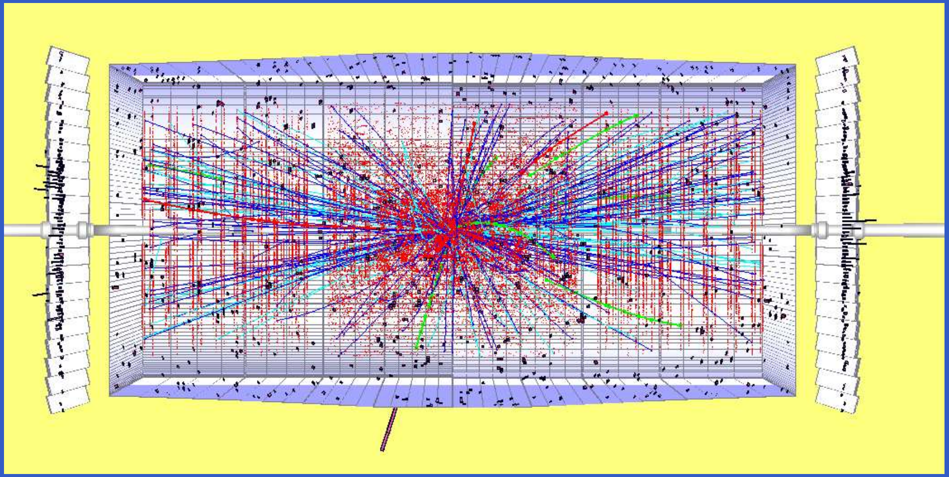
- Tracking needs complete replacement! Although new technology will be needed for R < 20 cm, the biggest challenge will be electronics and system integration.
- End-cap and forward calorimetry needs to be signifi cantly upgraded.
- Muon detectors will work up to $\eta < 2$ with additional shielding installed.
- The level-1 trigger needs to be upgraded to sample at 80 MHz.

SLHC ZZ $\longrightarrow$ 4 lepton event

$10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$



$10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$



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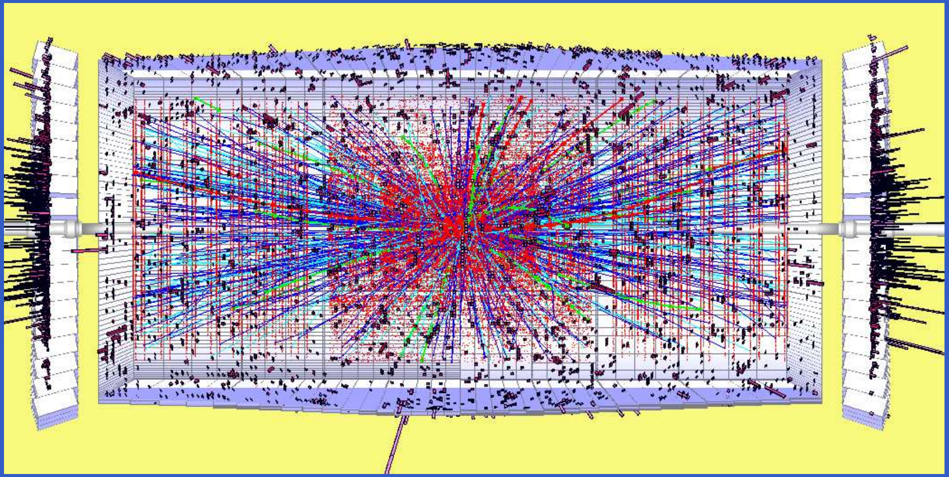

$\mathcal{SLHC}$ Observations

- It seems all too easy to extrapolate operation of ATLAS and CMS at $10^{35}\ \mathrm{cm}^{-2}s^{-1}$ when it is sure to be a huge challenge to make the detectors work at “low” luminosity of $2 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ just four years from now... however...

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- The SLHC luminosity upgrate seems to be a "no brainer, " "bang for the buck" and critically important for the future of CERN and particle physics.

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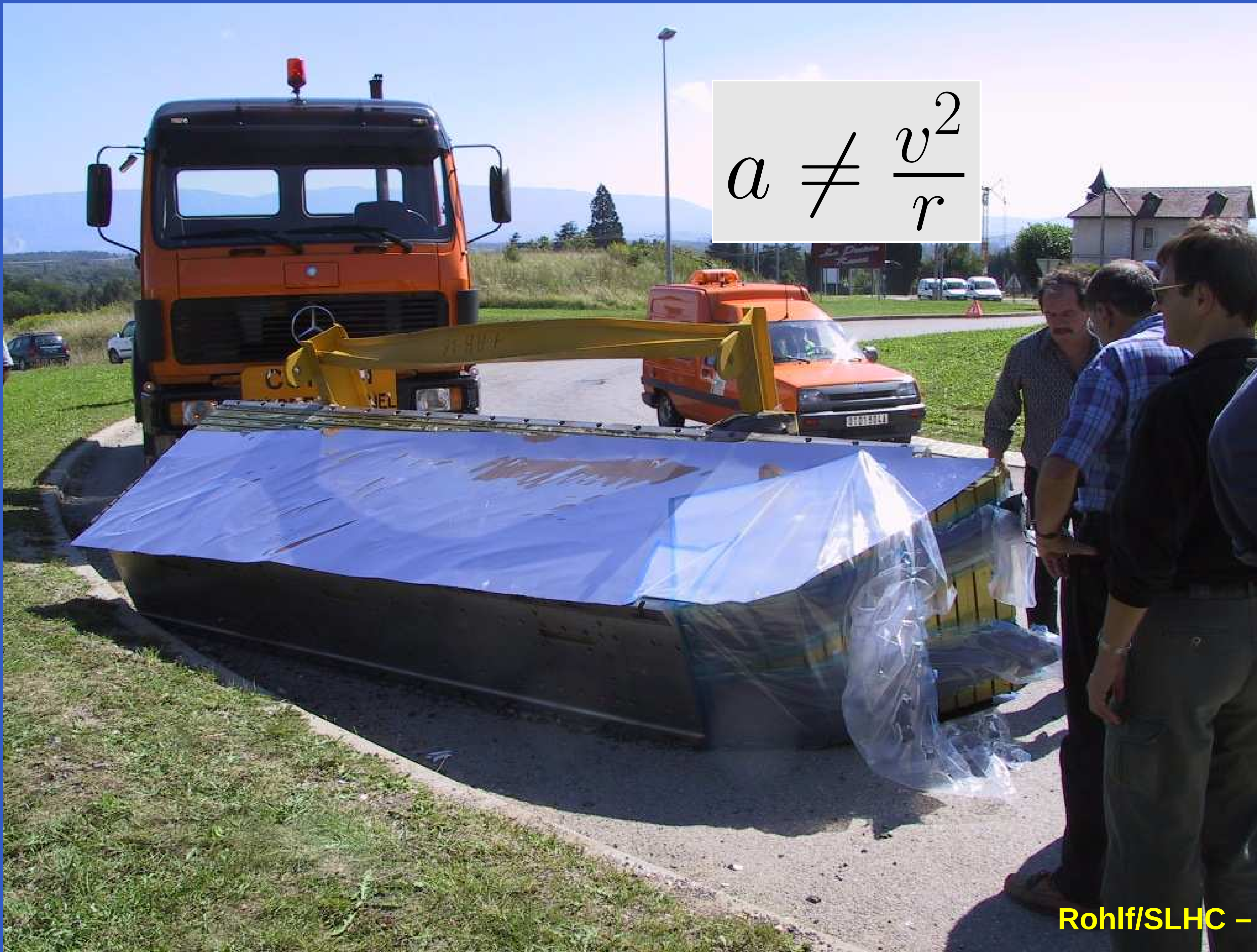
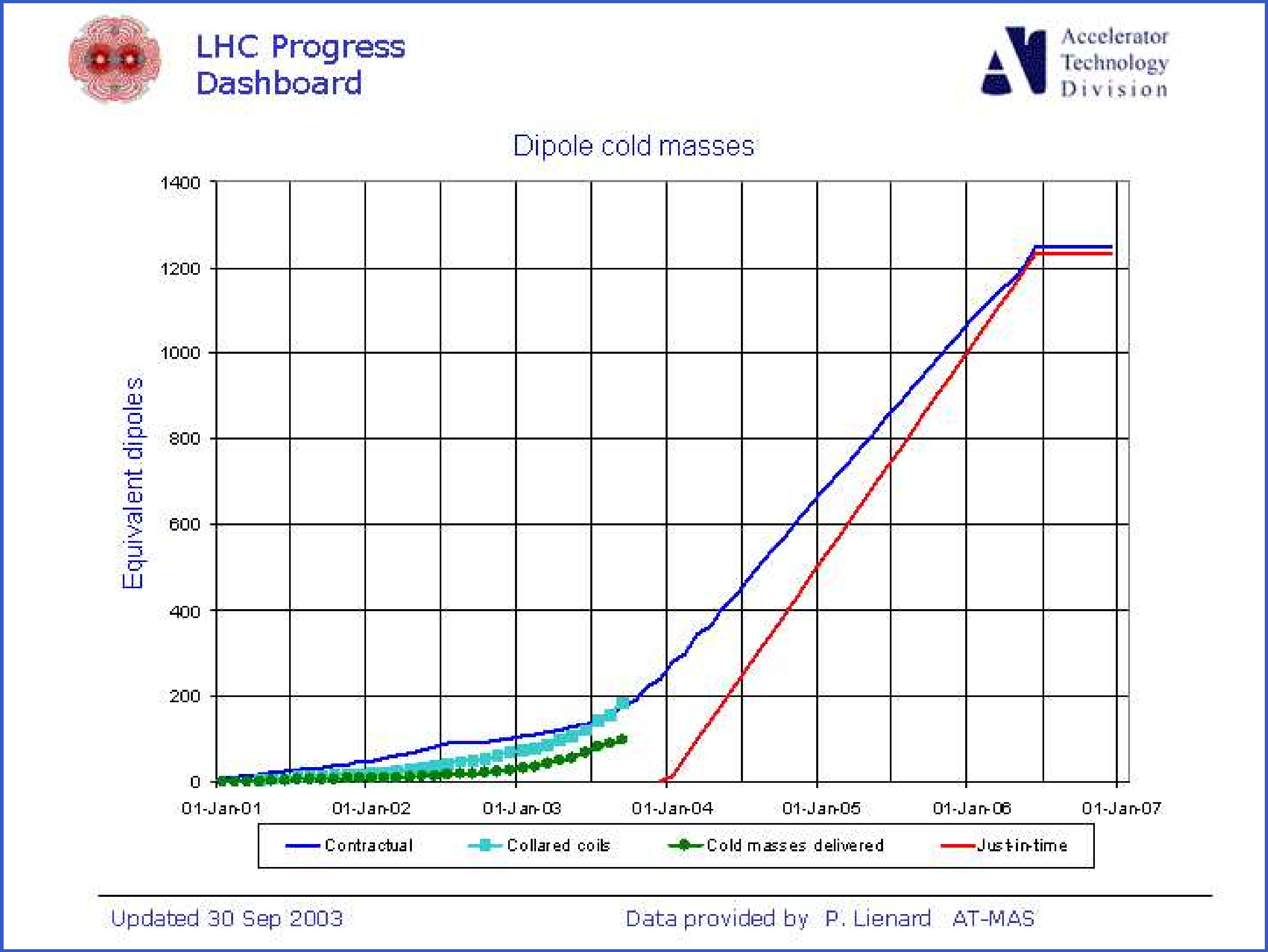
- The SLHC luminosity upgrate seems to be a "no brainer, " "bang for the buck" and critically important for the future of CERN and particle physics.
- It is inconceivable that any result from the LHC or SLHC could indicate that we do NOT want to increase the energy. The EDLHC may be the fastest route for this. It seems that people are too quick to forget *why* the SSC was designed for 40 TeV!

Physics will not go as planned...



$$a \neq \frac{v^2}{r}$$

 LHC Progress Dashboard www.cern.ch



SLHC References

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