VLHC Triggering (and Physics) at Extreme Luminosity

Physics:

- What is gained with 10^{34}-10^{36} $cm^{-2}s^{-1}$ luminosity at 40 or 200 TeV ?

Detector elements:

- Muon detection
- Tracking
- Calorimetry

Issues at extreme luminosity:

- Survival
- Performance
- Triggering
- Offline background rejection

High-L Motivation: Extra Mass Reach

From Uli Baur (+Atlas):

VLHC Pocket Guide

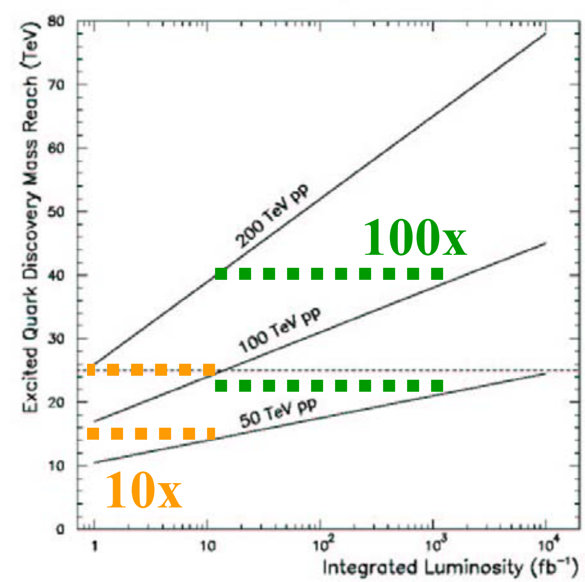
channel particle	LHC 100 fb^{-1}	LHC 1 ab^{-1}	28 TeV 100 fb^{-1}	40 TeV 100 fb^{-1}	200 TeV 100 fb^{-1}
$\tilde{q}, \tilde{g}$	2	2.5	4	5.5	> 10
W' Z'	4.5	5.4	7	8.5	33
q^*	7	8	10	13	50
Λ comp.	33 40	50 60	60 60	75	130
M_D $(\delta = 2)$	9	12	15	20	75

- large uncertainties
- not exhaustive
- all masses in TeV

High-L is good, usually not as good as high-E…

- **10xL=2xE works only at low L**
- **10xL=sqrt(2)xE or less at high L**
- **For example, q* limit:**

VLHC: 5σ reach for $f_s = 1$, $M_{q^*} = \Lambda$:



But high-L is what all the Tevatron upgrades are about…

Accelerator Luminosity Limits

- Extra electric power operations cost
- Synchrotron radiation heating quenches superconducting magnets (but aperture stops)
- Catastrophic beam loss mitigation is a big deal (Drilling? Explosions?)
- Are there others?

Basic Parameters for Detectors

- Atlas and CMS are just starting to think about 10^{35} cm^{-2}s^{-1}
- Numbers of underlying events and tracks are proportional to luminosity, for LHC/VLHC cross-sections 80/130 mb, LHC/VLHC $<P_T>=0.6/0.8$ GeV:

CM Energy	Luminosity	Bunch Spacing	Underlying Events (average)	Underlying Charged Tracks per unit η (average)	Underlying E_T(total) in dEta*dPhi=0.25
14 TeV	10^{34} cm^{-2}s^{-1}	25 ns	20	~160	7.6 GeV
"	10^{35} cm^{-2}s^{-1}	12.5 ns	100-200	~800-1600	38-76 GeV
"	(Pb-Pb)	125 ns	(1)	~2500	?
200 TeV	10^{34} cm^{-2}s^{-1}	18 ns	24	~240	15 GeV
"	"	6 ns	8	~80	5 GeV
"	10^{35} cm^{-2}s^{-1}	18 ns	240	~2400	150 GeV
"	"	6 ns	80	~800	50 GeV
"	10^{36} cm^{-2}s^{-1}	18 ns	2400	~24000	1.5 TeV
"	"	6 ns	800	~8000	0.5 TeV

LHC Detector Effects at $L=10^{35}$

Atlas:

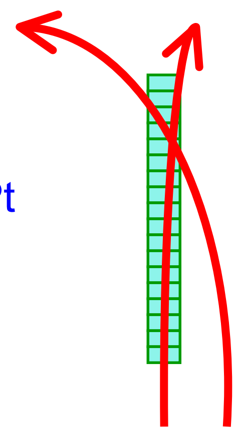
- Straw tube tracker is dead
- Remove pixels and part of silicon tracker (no b-jet I.D.)
- More forward shielding of muon system needed
- 12.5 ns bunch crossing incompatible with present trigger/DAQ
- “Fake” forward jets appear, cut used for WW fusion becomes useless (Liquid Argon)

CMS not documented yet, similar to Atlas but:

- Silicon outer tracker better off
- Maybe radiation damage to EM crystal calorimeter

Muon Detector Limits

- Radiation damage not an issue
- Muon bremmstrahlung not a big issue in central region
  - CMS works fine for P=5 TeV
- Trigger rates are an issue, can be addressed
  - 1 MHz real muons at LHC 10^{34}, scales up by L
  - CMS: trigger rate limit 100 kHz (10 kHz single muons)
  - Requires bend measurement, multiple scattering makes low-Pt muons appear straight in iron
  - Solutions: 1) optimize Pt algorithm, 2) increase DAQ rate, 3) devise high-Pt track trigger detector inside calorimeter

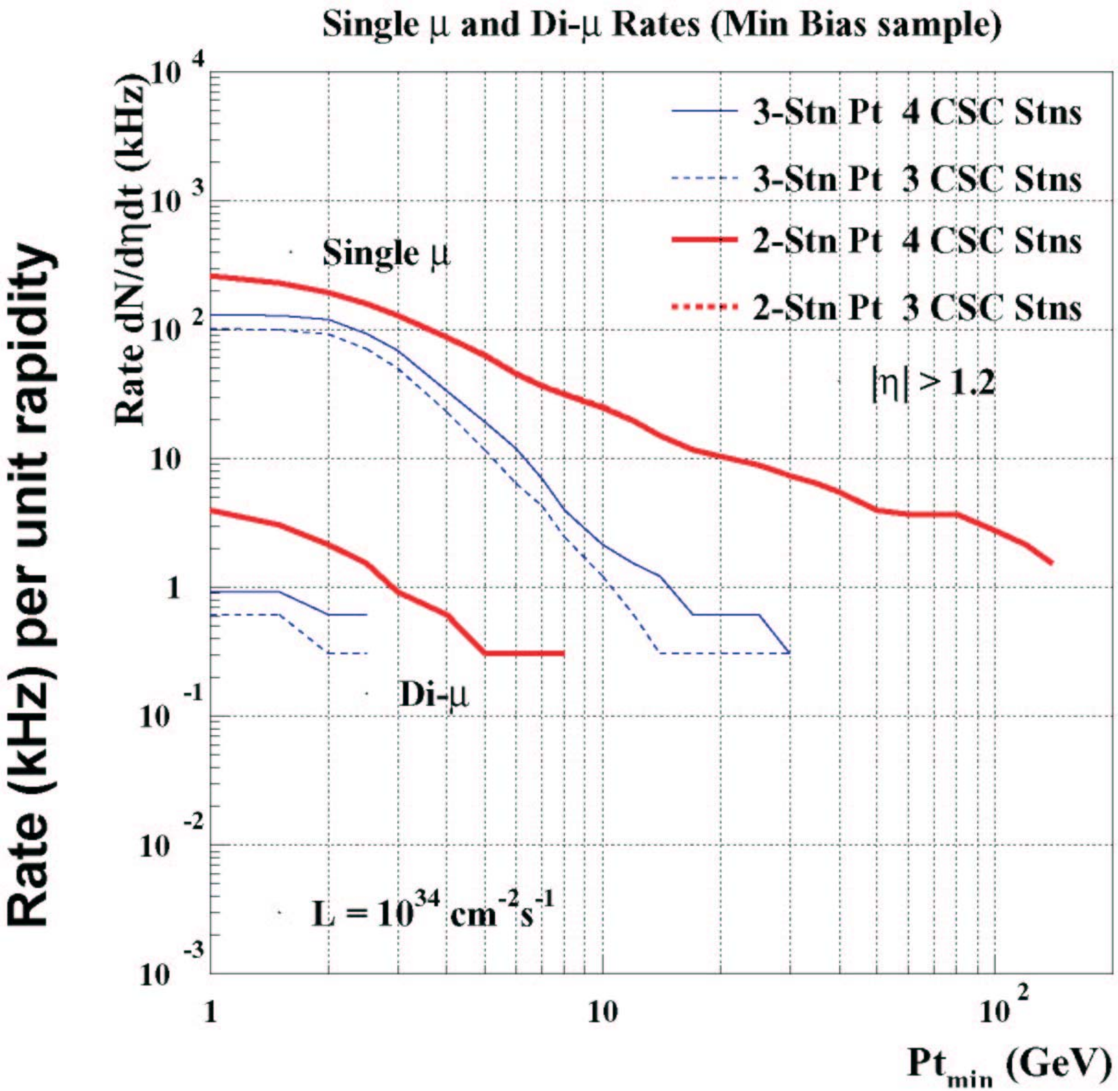


- S/N is an issue (hard to quantify, physics-dependant)
  - "High-level" cuts involve tracking Pt measurement, calorimeter and/or tracking isolation, additional jets, etc.

Muon Trigger Rates

CMS (Endcap)

- Muon stations between iron disks
- Bending in 4 muon stations combined
- Rates almost flat at very high-Pt due to multiple scattering
- Some optimization possible
- Would like another handle for higher luminosity



Tracker Limitations

- Silicon (e.g. CMS) is best current technology
- Radiation damage (from Incandela):
  - Sensors, not readout chips, limit to about 15 MRad
  - Pixels better but much harsher environment
  - Silicon improvements possible (e.g. thinner Si + low-noise electronics)
  - Silicon carbide (or maybe diamond) technologies might allow 100 MRad

Tracker Limitations

15 MRad points for 5 years running at (scaled):

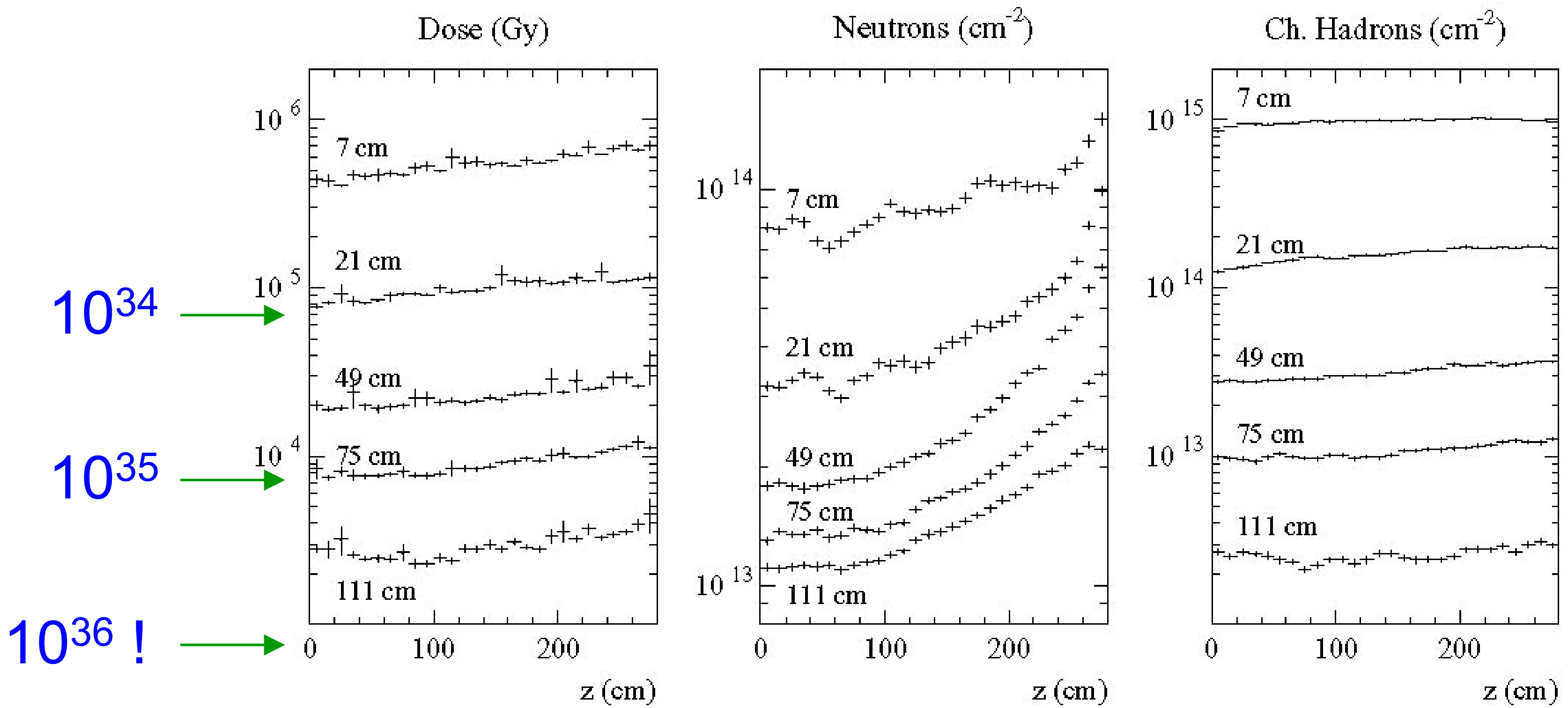


Fig. 1.11: Radiation levels at selected radii in the CMS Tracker region. All values correspond to an integrated luminosity of 5×10^5 pb^{-1}. The error bars indicate only the statistics of the simulations. The neutron fluences include only the part of the spectrum above 100 keV.

Calorimeter Limitations

- Technology choices (good +, bad -):

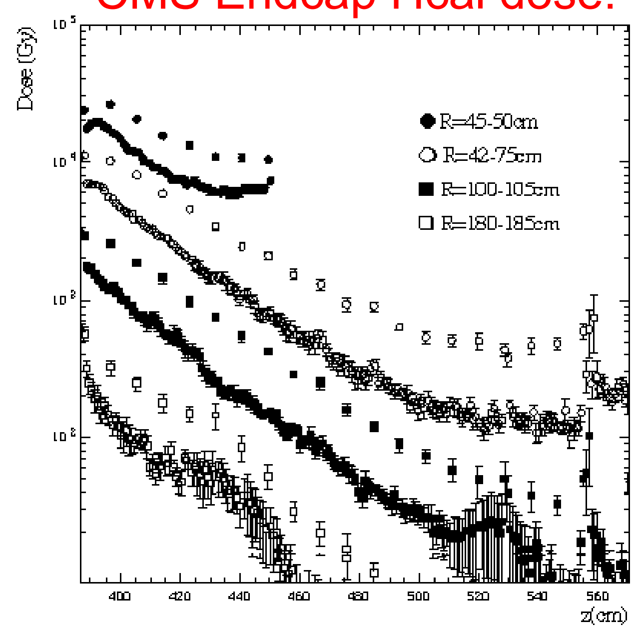
EM Technology	Radiation Damage	Speed	Precision	Cost
LAr (Atlas)	+	=	=	=
Crystals (CMS)	=	=	+	-
Sci Tiles (SDC)	=	+	=	=
Silicon sampling	+	=	=	--
Quartz Cerenkov (CMS HF)	+	+	-	?readout?

LHC at 10^{34}: highest radiation at EM shower maximum (10 years):

•Barrel 1 Mrad (10^4 Gray)

•Endcap 14 Mrad (η=2.6)

CMS Endcap Hcal dose:



Calorimeter Limitations

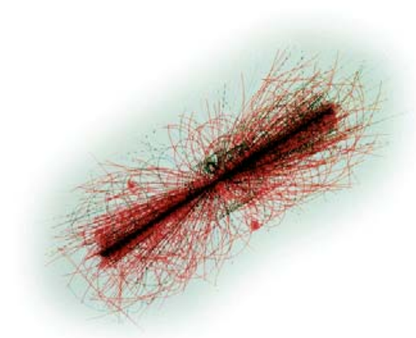
Effect of pile-up at 200 TeV:

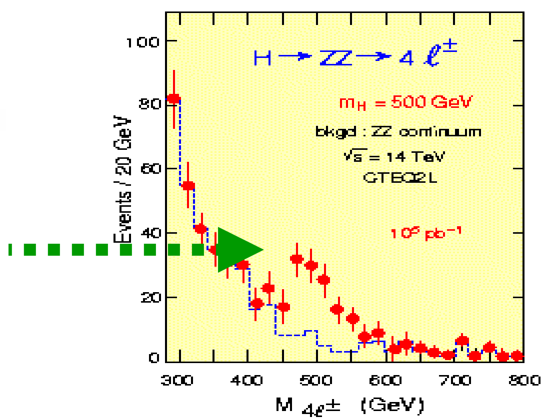
- **Electron ID – electrons and photons are "small"**
  - typically $d\phi d\eta=(5cm/150cm)^2=10^{-3}$
  - Likelihood of additional particle is small in all luminosity choices
  - But "isolation" cut (better S/N) is greatly affected
- **Jet ID may work above 1 TeV, below that may need "pattern recognition"**
- **High B-field is not a panacea**
- **Signal-to-noise and background rejection needs study for both electrons and jets**

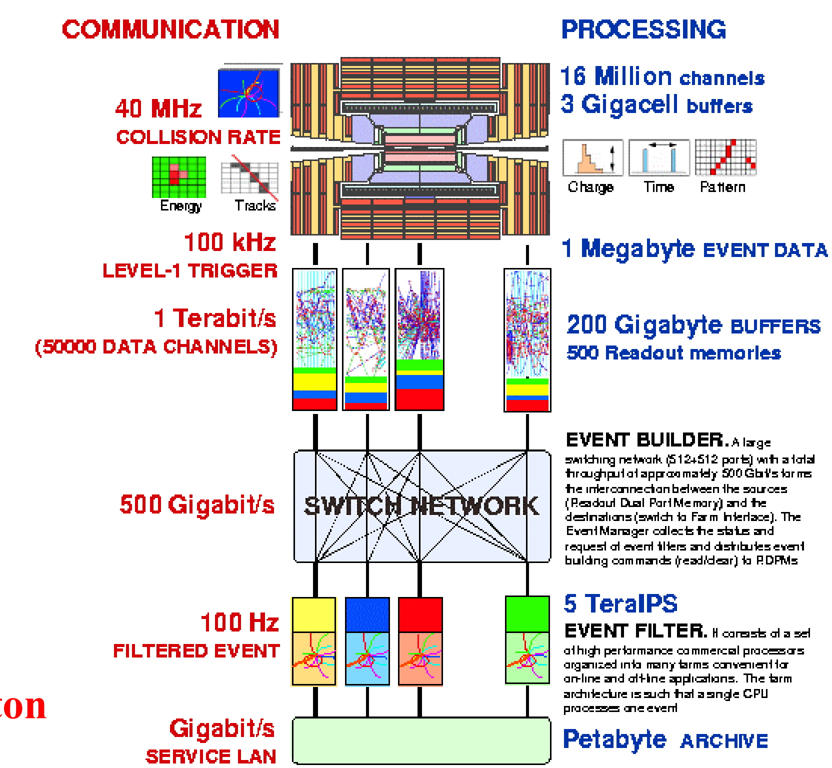
Luminosity	Bunch Spacing	Underlying Charged Tracks per unit η (average)	Underlying E_T(total) in dEta*dPhi=0.25
10^{34} $cm^{-2}s^{-1}$	18 ns	~240	15 GeV
"	6 ns	~80	5 GeV
10^{35} $cm^{-2}s^{-1}$	18 ns	~2400	150 GeV
"	6 ns	~800	50 GeV
10^{36} $cm^{-2}s^{-1}$	18 ns	~24000	1.5 TeV
"	6 ns	~8000	0.5 TeV

Calorimeter etc. S/N Question

- Rejecting all backgrounds is a BIG job made worse by high luminosity.
- CMS Level 1 trigger is understood, but L2 not entirely, much less L3 and offline cuts:







Start from:

40 million events/sec

x10 million sec/year

x10 years

=4x10^{15} events

End result:

Search for Higgs particle

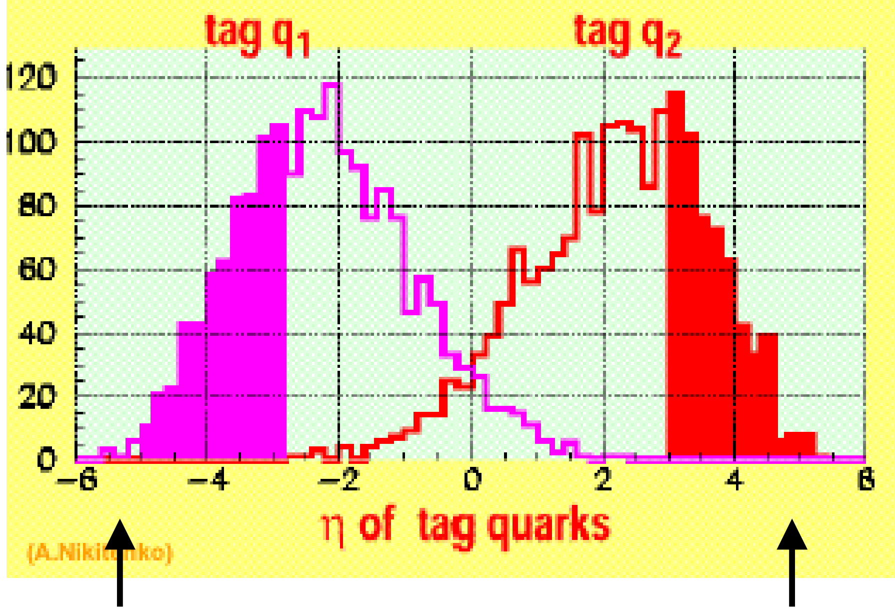
Look for data > background rate

~40 events excess

Each Higgs event is like a 1g needle in a 100 million metric ton haystack

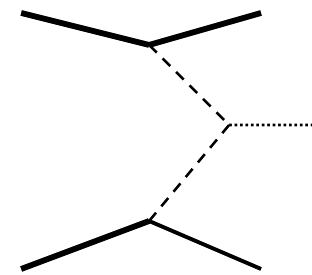
Angular Extent and "Tag Jets"

HF acceptance for tagging quarks of $E_t^q > 30$ GeV		
no q	1 q	2 q's
0.47	0.46	0.07



WW Fusion

W W --> H

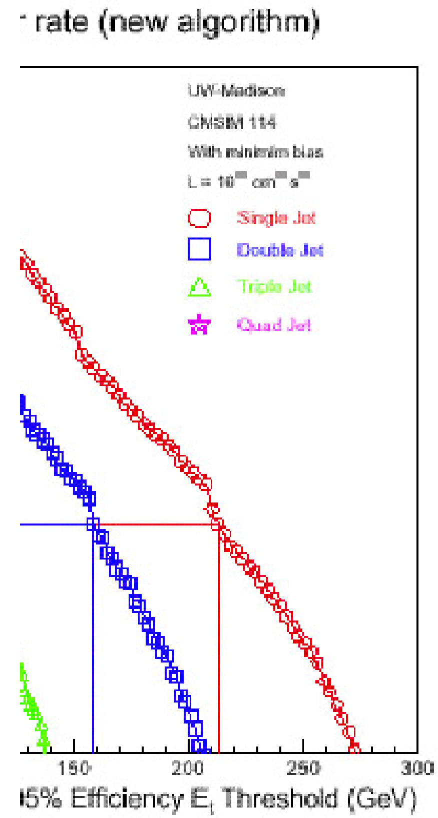


CMS calorimetry extends to | η| = 5 to cover the region of "tag jets".

Calorimeter Triggers

olds

	$L = 10^{33} cm^{-2}s^{-1}$			$L = 10^{34} cm^{-2}s^{-1}$		
trigger type	threshold [GeV]	rate [kHz] indiv.	rate [kHz] cumul.	threshold [GeV]	rate [kHz] indiv.	rate [kHz] cumul.
ΣE_t	~500	1.0	1.0	~1000	0.5	0.5
E_t^{miss}	100	2.1	2.8	200	1.3	1.7
e	18	10.3	12.3	32	6.8	8.3
e e	12	1.5	13.1	18	1.5	9.5
j	92	2.0	13.5	160	2.1	10.7
j j	65	1.6	13.9	106	2.2	11.6
j j j	52	1.0	14.1	65	3.2	13.3
j j j j	45	0.7	14.2	52	3.0	14.3
e j	14, 45	6.0	15.2	18, 92	1.4	14.9
μ	7	7.0	7.0	20	7.8	7.8
$\mu\ \mu$	2-4	0.5	7.3	4	1.6	9.2
$\mu\ e/\gamma$	2-4, 12	2.4	9.2	4, 13	5.5	14.4
$\mu\ e_b$	2-4, 8	5.2	12.8			
μ j	2-4, 40	4.2	14.4	4, 80	0.3	14.3
$\mu\ E_t^{miss}$	2-4, 80	0.2	14.4	4, 140	1.0	15.3
$\mu\ \Sigma E_t$	2-4, 200	0.7	14.4	4, 500	0.2	15.3



Findings

- **Tracking *can* work at 10^{35} and improvements may allow 10^{36} (but not close to the beam line)**
  - Continued rad-hard Silicon etc. R&D is important
- **Muons *can* be identified at all luminosities**
  - Central LHC muon detectors might handle 10^{35} but not forward detectors (neutron backgrounds).
  - Triggering requires additional handles for 10^{36} or fantastic DAQ system
  - Trigger coincidence with a track stub in front of calorimeter would be very useful (SDC had this)
- **Calorimetry *can* survive the radiation in the central region but**
  - Pile-up effect on electrons and jets needs simulation studies
  - Forget about missing-Et measurement
  - Forward tagging of jets (e.g. for WW scattering) is probably not in the cards

Opinions

- 10^{35} should be planned for (extra physics reach) if at all possible.
- Even (some) detector capability for 10^{36} may be forseen in 20 years, but extremely difficult.
- If accelerator can be designed for 10^{35} or more, new non-LHC detector designs need to be created and understood.
- R&D can make headway on some detector issues.