Eksperyment Compact Muon Solenoid przy Large Hadron Collider

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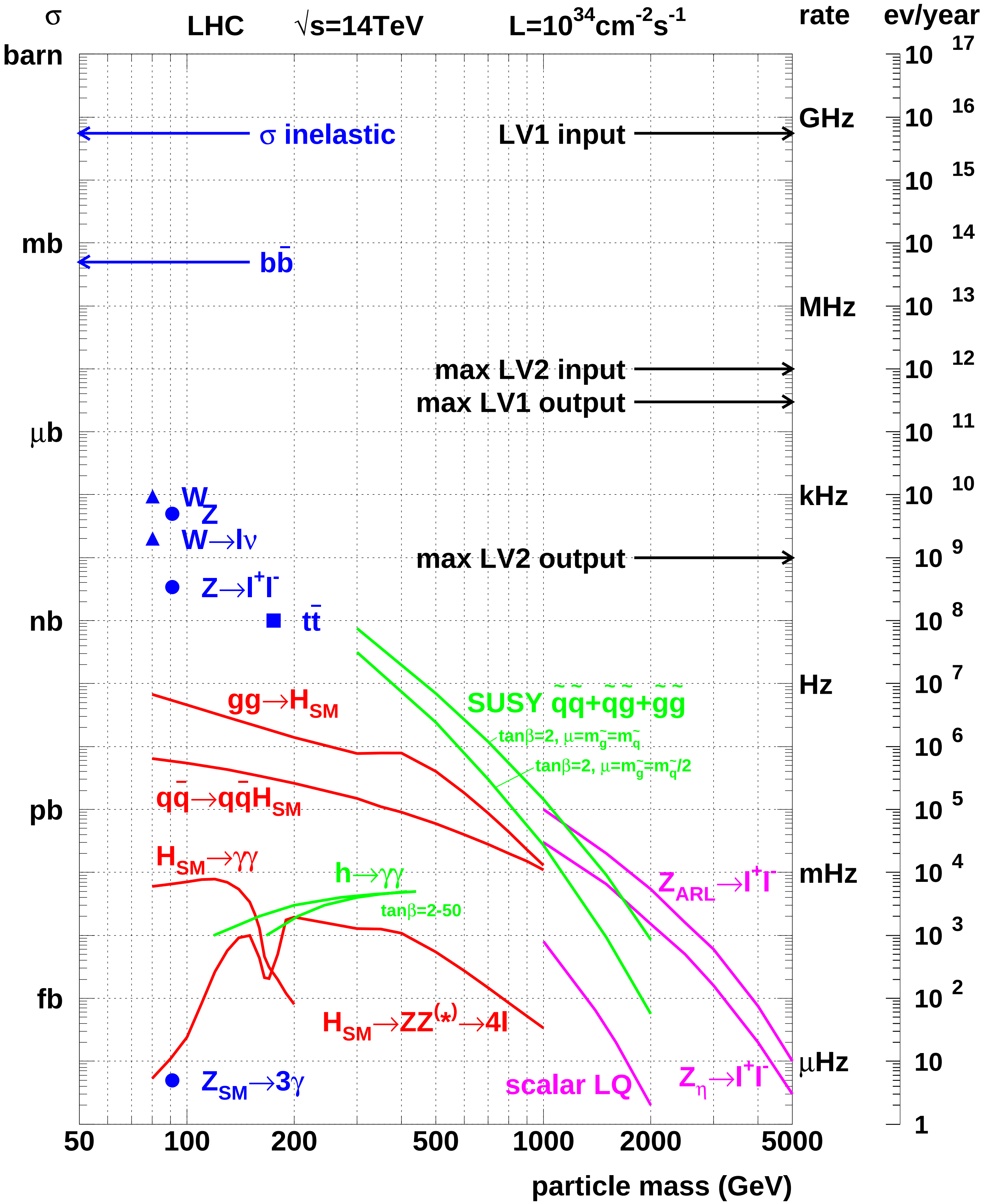
część IV

Selekcja przypadków w eksperymencie CMS

- **konieczność redukcji danych**
- **wielostopniowy system wyzwalania (tryger)**
  - algorytmy wyższych stopni trygera trygera
- **symulacja**
- **analiza danych**
  - narzędzia
  - “computing model”
  - “telepresence”



σ
barn
LHC
√s=14TeV
L=10^34 cm^-2 s^-1
rate
ev/year
σ inelastic
LV1 input
GHz
mb
bb̄
MHz
max LV2 input
max LV1 output
μb
kHz
W
Z
W→lν
Z→l+l-
max LV2 output
nb
tt̄
Hz
SUSY q̃q̃+q̃g̃+g̃g̃
tanβ=2, μ=mg̃=mq̃
tanβ=2, μ=mg̃=mq̃/2
gg→HSM
qq̄→qq̄HSM
pb
HSM→γγ
h→γγ
tanβ=2-50
ZARL→l+l-
mHz
fb
HSM→ZZ(*)→4l
ZSM→3γ
scalar LQ
Zη→l+l-
μHz
50
100
200
500
1000
2000
5000
particle mass (GeV)

Zapis danych w CMS

Całkowity strumień danych:

40 MHz przypadków po 1 MB =

40 TB/s

(1 TB = 1 000 GB)

⇒ niemożliwe do zapisania na żadnym nośniku!

⇒ konieczność selekcji przypadków w czasie rzeczywistym (on-line) do poziomu 100 Hz ⇒ 100 MB/s.

"Klasyczny" układ stopni trygera

I°

- **zgrubne dane z części detektorów** (często dedykowanych)
- **rozpoznanie interesujących obiektów** (μ, e, γ, dżet, E_T^{miss})

- **"hardware"**
- **specjalnie projektowane procesory**
- **przetwarzanie synchroniczne**
- **t ~ μs**

II°

- **dokładniejsze dane z części detektorów**
- **pomiar interesujących obiektów**

- **"firmware"**
- **procesory niskiego poziomu** (Digital Signal Processor - DSP)
- **t ~ ms**

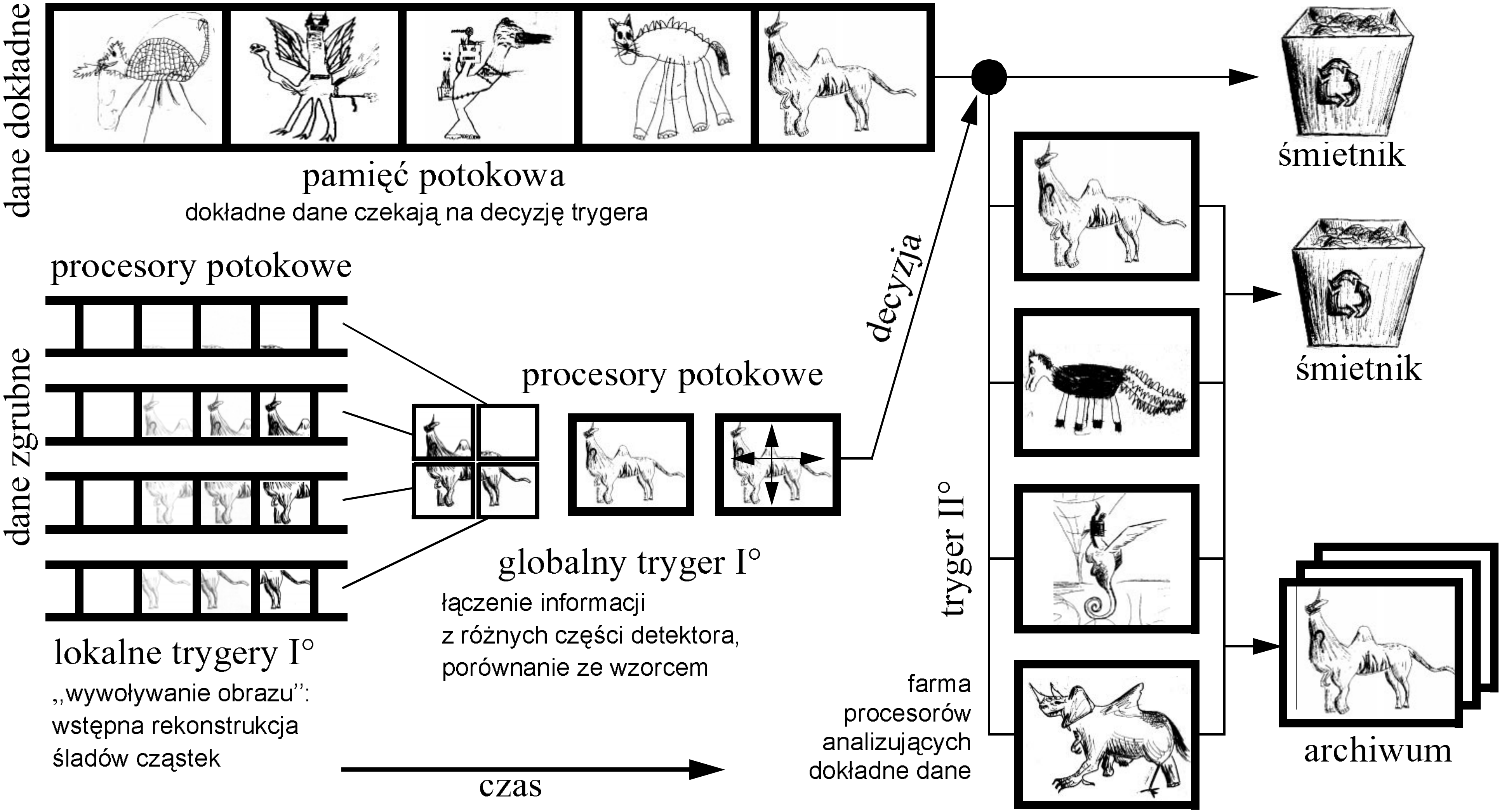
III°

- **pełne dane z wszystkich detektorów** (dostępne, ale niekoniecznie użyte)
- **(częściowa) rekonstrukcja przypadku**

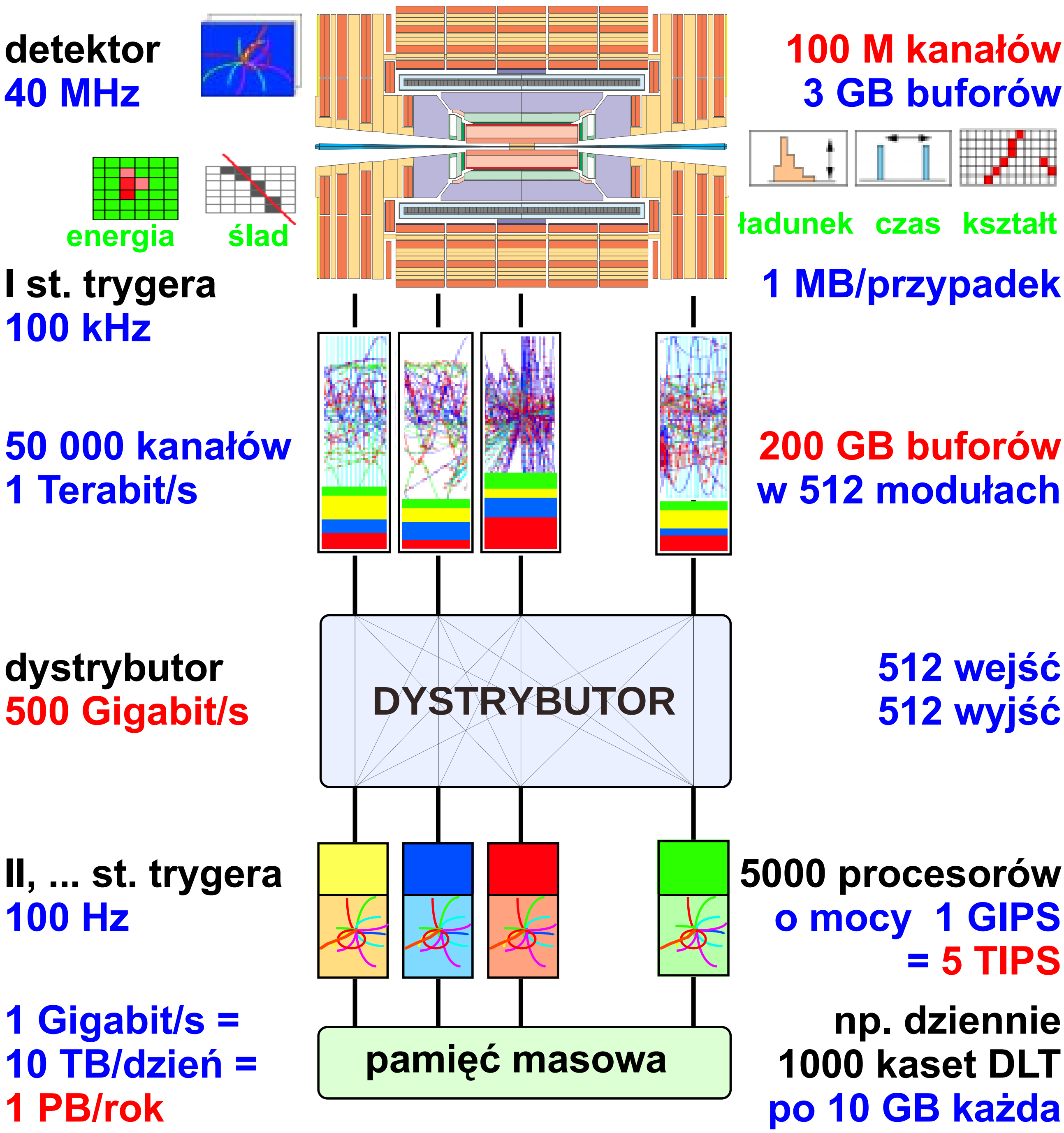
- **"software"**
- **komputery**
- **t ~ s**

W LHC już na I° zgrubny pomiar (p_T, E_T)

W CMS już II° to "software" na komputerach


dane dokładne
pamięć potokowa
dokładne dane czekają na decyzję trygera
śmietnik
procesory potokowe
decyzja
śmietnik
dane zgrubne
procesory potokowe
globalny tryger I°
łączenie informacji
z różnych części detektora,
porównanie ze wzorcem
tryger II°
lokalne trygery I°
,,wywoływanie obrazu'':
wstępna rekonstrukcja
śladów cząstek
farma
procesorów
analizujących
dokładne dane
archiwum
czas

Przepływ danych w CMS



1 TB = 1 terabajt = 10^{12} bajtów
1 PB = 1 petabajt = 10^{15} bajtów

1 GIPS = 10^{9} instrukcji/s
1 TIPS = 10^{12} instrukcji/s

Wyższe stopnie trygera CMS

II°

wczytanie danych mionowych i kalorymetrycznych — 100 kHz

sprawdzenie obiektów I° z pełną rozdzielczością

III°

wczytanie danych z det. wewnętrznego wokół obiektów II° — 10 kHz

dopasowanie torów

IV°

wczytanie pozostałych danych — 1 kHz

pełna rekonstrukcja przypadku

zapis na nośnik trwały — 100 Hz

Przykładowa strategia trygera II°

Punkt startowy — informacje z trygera I°

- **poprawienie pomiaru p_T poprzez dokładną rekonstrukcję toru**
- **poprawienie pomiaru p_T poprzez uwzględnienie położenia wierzchołka**
- **odrzucenie mionów z rozpadów π, K, etc, — cięcia na χ^2 i pozycji wierzchołka**
- **odrzucenie mionów w dżetach — "izolacja kalorymetryczna"**

Possible High Level Trigger Data Flow

processor farm = 500 nodes x 1000 MIPS

LV	nodes	input f	f/node	t/ev./node	data/ev.	data/node	all data
2	200	100 kHz	500 Hz	2 ms	200 kB	100 MB/s	20 GB/s
3	200	10 kHz	50 Hz	20 ms	+200 kB	10 MB/s	2 GB/s
4	100	1 kHz	10 Hz	100 ms	+600 kB	6 MB/s	0.6 GB/s

CMS/LHC Trigger Physics

Standard model Higgs (high luminosity)

- H (80 GeV) $\rightarrow \gamma\gamma$
- H (120 GeV) $\rightarrow$ Z Z* (4 leptons)
- H (>500 GeV) $\rightarrow$ leptons (+ ν's)
- H (< $2M_w$ Associated t or W or Z) $\rightarrow$ b b (lepton + X)

SUSY Higgs (low luminosity)

- (standard model Higgs like channels)
- h, H, A $\rightarrow \tau\tau$ (lepton + X) or $\rightarrow \mu\mu$
- A $\rightarrow$ Z h ; h $\rightarrow$ bb (lepton + X)
- p p $\rightarrow$ t t X; t $\rightarrow$ H^+ b; $H^+ \rightarrow \tau\nu$; t $\rightarrow$ lepton + X; $\tau \rightarrow$ X

SUSY sparticle searches (low luminosity)

- MSSM sparticle $\rightarrow$ LSP (Missing E_t) + n jets
- MSSM sparticle $\rightarrow$ Same sign dileptons + X

Other new particles

- Z' $\rightarrow$ dileptons
- Leptoquarks: dileptons

Top physics (low luminosity)

- t $\rightarrow$ lepton + X
- t $\rightarrow$ multijets

Bottom physics (low luminosity)

- b $\rightarrow$ lepton + X
- b $\rightarrow \psi k_s$ (leptons + X)

QCD

- Low luminosity 100 GeV jets
- High luminosity 200 GeV jets

$\Rightarrow$ Trigger candidate requirements:

- High luminosity: lepton/γ (30 GeV), dileptons/$\gamma\gamma$ (15 GeV)
  missing E_t (100 GeV), jets (200 GeV)
- Low luminosity: lepton/γ (15 GeV), dileptons/$\gamma\gamma$ (10 GeV)
  missing E_t (50 GeV), jets (100 GeV)

Physics cuts / Higgs - I

1) $H \to \gamma\gamma$

- Two isolated photons, $E_t(\gamma_1) > 40$ GeV, $E_t(\gamma_2) > 25$ GeV in $|\eta| < 2.5$

  isolation: no track with $p_t > 2.5$ GeV in cone R = 0.3 and $E_t^{em\ cell}$ in R < 0.3 less that 2.5 GeV

2) WH, ttH $\to \ell\gamma\gamma + X$

- Two isolated photons, $E_t(\gamma_1) > 40$ GeV, $E_t(\gamma_2) > 25$ GeV
- one isolated lepton: $p_t^{\ell} > 20$ GeV, $|\eta^{e,\mu}| < 2.5, 2.4$;
- $E_t^{miss} > 20$ GeV

3) H ($\to \gamma\gamma$) + jets

- Two isolated photons, $E_t(\gamma_1) > 40$ GeV, $E_t(\gamma_2) > 25$ GeV
- $E_t(\gamma_1 + \gamma_2) > 50$ GeV
- 2 jets: $E_t^j > 40$ GeV if $|\eta| < 2.4$

  $E^j > 800$ GeV if $|\eta| > 2.4$
- ΔR (γ-jet) >1.5

4) W ($\to \ell\nu$) H ($\to$ bb)

- one isolated lepton: $p_t^{\ell} > 20$ GeV, $|\eta^{e,\mu}| < 2.5, 2.4$;
- $E_t^{miss} > 20$ GeV
- only two central jets with $E_t > 25$ GeV in $|\eta^j| < 2.5$

  both jets b-tagged
- no other jets with $E_t > 25$ GeV in $|\eta^j| < 4.5$

5) tt ($\to \ell\nu$ + X) H ($\to$ bb)

- one isolated lepton: $p_t^{\ell} > 20$ GeV, $|\eta^{e,\mu}| < 2.5, 2.4$;
- $E_t^{miss} > 20$ GeV
- 6 central jets with $E_t > 25$ GeV in $|\eta^j| < 2.5$

  4 jets b-tagged

Physics cuts / Higgs - II

6) $H \rightarrow ZZ^* \rightarrow 4\ell^{\pm}$

- 4 isolated leptons (in $\Delta R = 0.2$ no track with $p_t > 2.5$ GeV)

  $E_t^e > 20,15,10,10$ GeV; $p_t^{\mu} > 20,10,5,5$ GeV; $|\eta^{e,\mu}| < 2.5, 2.4$;
- $m_{\ell\bar{\ell}} = m_Z \pm 6$ GeV
- $(IP/\sigma)_{max} < 3$

7) $H \rightarrow Z\gamma$

- Two isolated leptons: $p_t^{\mu} > 10$ GeV, $p_t^e > 15$ GeV

  in $|\eta^{e,\mu}| < 2.5, 2.4$;
- one isolated photon: $E_t^{\gamma} > 30$ GeV, $|\eta^{\gamma}| < 2.5$

8) $H \rightarrow WW \rightarrow \ell\nu\ell\nu$

- Two isolated leptons: $p_t^{\ell 1} > 30$ GeV, $p_t^{\ell 2} > 20$ GeV
- $m_{\ell\bar{\ell}} > 10$ GeV
- Veto central jets with $E_t > 25$ GeV in $|\eta^j| < 3.5$

9) $H \rightarrow ZZ \rightarrow 4\ell^{\pm}$

- 3 isol. leptons, E_t^e, $p_t^{\mu} > 20,15,10,10$ GeV, $|\eta^{e,\mu}| < 2.5, 2.4$
- $m_{\ell\bar{\ell}} = m_Z \pm 6$ GeV
- for high m_H : $p_t(Z) > 50$ GeV, $p_t(ZZ) > 30$ GeV

Physics cuts / Higgs - III

10) $h,H,A \rightarrow \tau\tau \rightarrow e^{\pm} + \mu^{\mp} + X$

- 2 isolated leptons (in $\Delta R = 0.2$ no track with $p_t > 2.5$ GeV)

  $E_t^e > 20$ GeV; $p_t^\mu > 20$ GeV; $|\eta^{e,\mu}| < 2.5, 2.4$;
- $70^0 < \Delta\phi(e,\mu) < 175^0$

11) $h,H,A \rightarrow \tau\tau \rightarrow \ell^{\pm} + h^{\mp} + X$

- one isolated lepton: $p_t^\ell > 15$ GeV, in $|\eta^{e,\mu}| < 2.5, 2.4$;
- one "τ jet": $E_t^j > 40$ GeV, $|\eta^\gamma| < 2.4$
- one isol. hard track $p_t^h > 15$ GeV pointing to τ jet: $R < 0.1$
- $60^0 < \Delta\phi(\tau\text{-jet, lepton}) < 175^0$
- $E_t^{miss} > 20$ GeV

τ-jet:

collimation:

$$\Sigma E_t^{\text{ECAL cells}}(R = 0.13)/\Sigma E_t^{\text{ECAL cells}}(R = 0.4) > 0.95$$

isolation:

no trig. tower with $E_t > 2$ GeV in $0.13 < \Delta R(\text{tower/jet axis}) < 0.4$

12) $h,H,A \rightarrow \tau\tau \rightarrow h^{\pm} + h^{\mp} + X$

- two jets with $E_t > 60$ GeV in $|\eta| < 2.5$
- one isol charged hadron $p_t^h > 40$ GeV pointing to each jet: ΔR (h/jet axis) < 0.1

  track isolation in cone $R = 0.4$
- $E_t^{miss} > 40$ GeV

13) $h,H,A \rightarrow \mu\mu$

- two isolated muons: $p_t^\mu > 10$ GeV, in $|\eta^\mu| < 2.4$;
- ≤ 1 jet of $E_t^j > 40$ GeV in $|\eta| < 2.4$

Physics cuts / Higgs - IV

14) $H \rightarrow ZZ \rightarrow \ell\ell\nu\nu$

- Two isolated leptons: $p_t > 20$ GeV, $p_t^{\ell\ell} > 60 - 100$ GeV
- $E_t^{miss} > 100 - 200$ GeV
- 1 tagging jet, $E^j > 1$ TeV in $|\eta| > 2.0$ for $m_H \sim 1$ TeV

15) $H \rightarrow WW \rightarrow \ell\nu$ jet jet

- One isolated lepton: $p_t > 50 - 100$ GeV
- $E_t^{miss} > 150$ GeV
- ≤ 2 central jets, $E_t^j > 40 - 100$ GeV in $|\eta| < 3.0$
- 2 tagging jets, $E^j > 400$ GeV, $E_t^j > 20$ GeV in $|\eta| > 2.4$

16) $H \rightarrow ZZ \rightarrow \ell\ell$ jet jet

- Two isolated leptons: $p_t^{\ell} > 50$ GeV; $p_t(Z) > 150$ GeV
- $m_{\ell\bar{\ell}} = m_Z \pm 10$ GeV
- ≤ 2 central jets, $E_t^j > 40 - 100$ GeV in $|\eta| < 3.0$
- 2 tagging jets, $E^j > 400$ GeV, $E_t^j > 20$ GeV in $|\eta| > 2.4$

17) bbH ($\rightarrow \gamma\gamma$) (for light Higgs - still under study)

- Two isolated photons, $E_t(\gamma_1) > 30$ GeV, $E_t(\gamma_2) > 25$ GeV
- only two central jets with $E_t > 20$ GeV in $|\eta^j| < 2.5$
  ≥ 1 b-tagged

Physics cuts / sparticle searches

18) $\tilde{\chi}_i^{\pm}\tilde{\chi}_j^0$ production:

Search in: $3\ell^{\pm}$ and no jets + (E_t^{miss}) events

- Three isolated leptons: $p_t^{\ell} > 15$ GeV
- Veto central jets with $E_t > 25$ GeV in $|\eta^j| < 3.5$
- $m_{\ell\bar{\ell}} < 81$ GeV or $m_{\ell\ell} \neq m_Z \pm 10$ GeV
- E_t^{miss} : no cut

19) Slepton pair production (mass range from 100 to 400 GeV):

Search in: $\ell\bar{\ell} + E_t^{miss}$ events

- 2 same flavour leptons, $p_t^{\ell} >$ 20 - 50 GeV
- $E_t^{miss} >$ 50-100 GeV
- Central jet veto, no jet with $E_t > 25$ GeV in $|\eta| < 3.5$
- relative azimut. cut E_t^{miss} vs leptons: $\Delta\phi(E_t^{miss}, p_t^{\ell\ell}) > 120^0$

20) Squark/gluino pair production (R_p conserving) :

(these are generic cuts, mass rang from 350 to 2500 GeV)

Search in: jets + E_t^{miss} + any number of $\ell^{\pm}$

- 2 or more central jets, $E_t^j >$ 40 - 150 GeV in $|\eta| < 3.0$
- $E_t^{miss} >$ 100 - 200 GeV
- isolated e, μ and non-isolated μ: $p_t^{\mu} > 10$ GeV, $E_t^e > 20$ GeV

  isolation: no track with $p_t > 2$ GeV in cone R = 0.3
  and ΣE_t^{cell} in ring $0.05 < R < 0.3$ less that 10% of p_t^{ℓ}

Physics cuts / sparticle searches II

21) Squark/gluino pair production/R_p violating - preliminary !

Search in: jets + E_t^{miss} + $\ell^{\pm}$

- $\geq$ 2 isolated e, μ : $p_t^{\mu} > 5$ GeV, $E_t^{e} > 10$ GeV

  isolation: no track with $p_t > 2$ GeV in cone R = 0.3
  and ΣE_t^{cell} in ring $0.05 < R < 0.3$ less that 10% of p_t^{ℓ}

- 2 or more central jets, $E_t^{j} > 30 - 100$ GeV in $|\eta| < 3.0$

- E_t^{miss} : no cuts

  "τ-jets" could be desirable or even required

22) Sparticle production/ GMSB scenarios - preliminary!

- $\geq$ 2 isolated γ : $E_t^{\gamma} > 20$ GeV

- $E_t^{miss} > 20 - 100$ GeV (depends on mass range)

- $\geq$ 1 isolated e, μ : $p_t^{\mu} > 5$ GeV, $E_t^{e} > 10$ GeV (desirable)

Przepis na koktajl "100 Hz"

Możliwe składniki:

Trygery ekskluzywne

- **dla kanałów o znanej topologii i masach cząstek**
- **oparte na cięciach topologicznych i wyborze masy niezmienniczej**

Trygery inkluzywne

- **dla "nieznanej" fizyki**
- **oparte na prostych obiektach, jak γ, e, μ, τ, t, W, Z, dżety, E_T^{miss}**

Przepis:

- **przygotuj zbiór możliwych sygnatur inkluzywnych** (np. $\mu\mu$)
- **obetnij małe p_T (E_T) tak, by każda sygnatura dawała 5-10 Hz**
- **sprawdź efektywność na ważniejsze przykładowe kanały**
- **domieszaj 10-20 Hz trygerów ekskluzywnych** (np. $B^0 \rightarrow K^0_S\ J/\psi$)
- **pozostaw ~10 Hz na trygery "techniczne"** (testy, kalibracja itp.)

	thresh.	rates [Hz] at 10^33			thresh.	rates [Hz] at 10^34		
	[GeV]	indiv.	addit.	cumul.	[GeV]	indiv.	addit.	cumul.
l	55	10.3	10.3	10.3	100	8.7	8.7	8.7
γ	55	9.5	9.4	19.7	95	9.3	9.3	18.0
j	350	7.1	6.5	26.2	550	5.5	5.5	23.5
l l	25	8.4	6.6	32.8	44	9.1	8.4	31.9
l γ	10, 20	7.6	7.4	40.2	25, 30	7.9	7.5	39.4
γ γ	20	9.9	7.4	47.6	35	9.3	8.2	47.6
l j	10, 200	6.6	4.6	52.2	30, 300	6.7	5.1	52.7
γ j	10, 300	5.6	2.0	54.2	20, 450	4.1	2.4	55.1
j j	300	6.1	0.9	55.1	450	5.8	2.0	57.1
l l l	5	7.2	5.8	60.9	15	8.4	6.9	64.0
l l γ	5, 10	5.4	3.8	64.7	15, 10	7.0	6.0	70.0
l γ γ	5, 9	6.9	6.0	70.7	20, 15	6.4	4.7	74.7
γ γ γ	10	6.8	3.7	74.4	20	5.1	3.1	77.8
l l j	5, 130	7.7	4.3	78.7	10, 250	4.0	1.7	79.5
l j j	10, 150	7.2	1.8	80.5	20, 250	8.1	3.4	82.9
γ γ j	10, 200	7.4	3.1	83.6	15, 350	5.8	3.1	86.0
γ j j	15, 200	8.5	3.0	86.6	25, 300	9.4	3.1	89.1
j j j	150	8.7	4.5	91.1	230	7.6	5.2	94.3
4 j	90	8.7	5.3	96.4	160	6.5	4.1	98.4
5 j	65	4.9	1.8	98.2	100	4.8	2.7	101.1
6 j	40	5.4	3.0	101.2	70	1.7	1.4	102.5

channel	off-line cuts	L3 thresholds @10^{34}	comments
$H \to \gamma\gamma$	$2\gamma>40, 25$	$\gamma\gamma>35$	~O.K., asymm.
WH, $t\bar{t}H \to l\gamma\gamma X$	$2\gamma>40, 25, l>20$	$\gamma\gamma l>15, 20$	O.K.
$(H \to \gamma\gamma)$ + jets	$2\gamma>40, 25, j>40$	$\gamma\gamma>35$	~O.K., asymm.
$W(\to l\nu)\ H(\to b\bar{b})$	$l>20, 2j>25, E_T^{miss}>20$	l jj > 30, 300	add isol, E_T^{miss}
$t\bar{t}(\to l\nu+X)\ H(\to b\bar{b})$	$l>20, 6j>20, E_T^{miss}>20$	6j > 70	add isol. l 6j E_T^{miss}
$H \to ZZ^* \to 4l$	$4l > 20, 10, 5, 5$	$lll > 15$	assym, isol, add $4l$
$H \to ZZ \to ll\, jj$	$2l > 50, 2j > 40$	$ll > 44$	O.K.
$H \to ZZ \to ll\,\nu\nu$	$l>20, E_T^{miss}>100$	$ll > 44$	add isol, E_T^{miss}
$H \to Z\gamma$	$2l > 10, \gamma>30$	$ll\gamma>15, 10$	~O.K., tune
$H \to WW \to l\nu\, l\nu$	$2l > 30, 20$	$ll > 44$	difficult, isolation
$H \to WW \to l\nu\, jj$	$l > 50, 2j > 40, E_T^{miss}>100$	$l > 100$, l jj > 30, 300	add isol, E_T^{miss}
$h \to \tau\tau$	$\tau>20$	$ll > 44$	difficult, isolation
$h \to \mu\mu$	$\mu>10$	$ll > 44$	difficult, isolation
$\chi^{\pm}\chi^{0} \to 3l+X$	$3l > 15$	$lll > 15$	O.K.
$\tilde{l}\,\tilde{l} \to l\,l + E_T^{miss}$	$2l>20, E_T^{miss}>50$	$ll > 44$	add isol, E_T^{miss}
$\tilde{q}/\tilde{g}$	$2l > 10, 2j > 40, E_T^{miss}>100$	$ll > 44$, ll j > 10, 250	add isol, ll jj, E_T^{miss}

- "off-line cuts" quoted are just preselection criteria
  - the efficiency might be still reasonable for higher cuts
- actual efficiency for given L3 thresholds needs to be evaluated

Pożyteczne wzory

1 barn	1 mb	1 pb	1 fb	
1	10^{-3}	10^{-12}	10^{-15}	barns
10^{-24}	10^{-27}	10^{-36}	10^{-39}	cm^2

- **częstość** [MHz] = σ [mb] · **L** [$10^{33} cm^{-2} s^{-1}$]
- **liczba przypadków** = $\int \sigma \cdot L\, dt = \sigma \cdot \int L\, dt$
- **rok kalendarzowy** = $\pi \cdot 10^7$ s
- **rok akceleratorowy** = 10^7 s

L	10^{33} $cm^{-2}s^{-1}$	10^{34} $cm^{-2}s^{-1}$
$\int_{1\,rok} L\, dt$	10^4 pb^{-1} = 10 fb^{-1}	10^5 pb^{-1} = 100 fb^{-1}

Symulacja

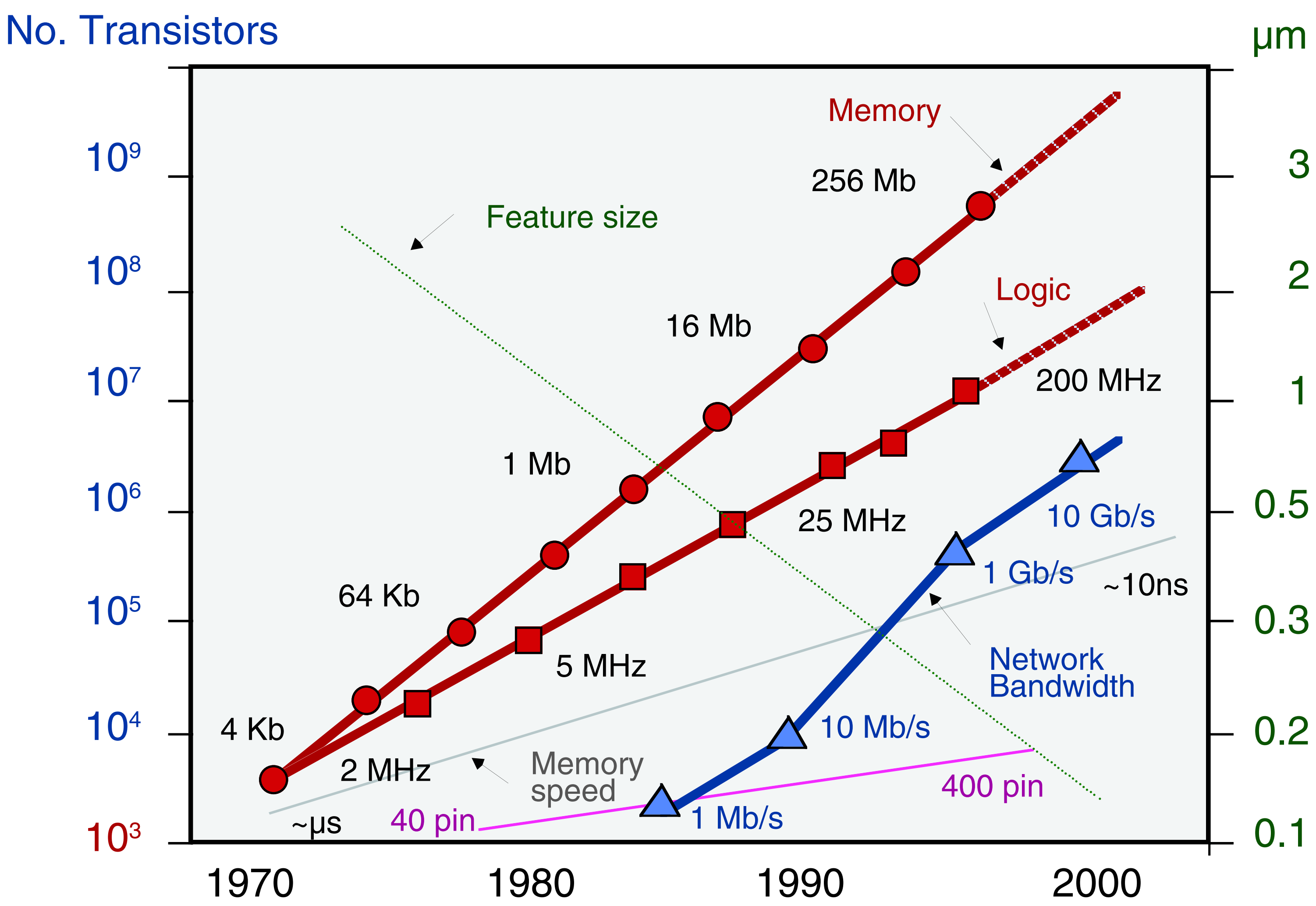
- **1 przypadek ~20 s** (PIII 600 MHz)
- **1 miesiąc = 43200 minut ≈ 130 000 przypadków**
- **× 100 PC ≈ 10^7 przypadków**
- **/ 0.5 GHz = 0.02 s LHC @ 10^{34} $cm^{-2}s^{-1}$**

konieczność oddzielnej symulacji szczególnych sygnatur

Symulacja przypadków mionowych

próbka	$\bar{p}_T$ [GeV]	μ	liczba przypadków		σ	czas LHC
			generacja	simulacja	[mb]	
min.bias	—	1	2 500 000	365 000	55	0.005 s
min.bias	> 5	1	1 200 000	200 000	26	0.005 s
min.bias	> 10	1	1 200 000	200 000	2.7	0.04 s
min.bias	> 20	1	1 100 000	42 000	0.26	0.4 s
min.bias	> 10	2	2 500 000	66 000	0.033	7.3 s
W + dżety	—	1	580 000	49 000	$1.9 \cdot 10^{-4}$	5 min
Z + dżety	—	1	440 000	27 500	$5.5 \cdot 10^{-5}$	13 min
Z/γ + dżety	—	1	900 000	49 000	$1.0 \cdot 10^{-3}$	1.5 min
WW, WZ, ZZ	—	2	1 800 000	10 000	$6.8 \cdot 10^{-6}$	19 h
$t\bar{t}$	—	2	100 000	9 500	$6.2 \cdot 10^{-7}$	4.5 h
$H \to WW \to 2\mu\, 2\nu$	—	2	25 000	25 000	$3\text{-}11 \cdot 10^{-11}$	18.5 dni
$H \to ZZ \to 4\mu$	—	2	22 000	22 000	$0.8\text{-}2.2 \cdot 10^{-12}$	20 lat

Technology trends

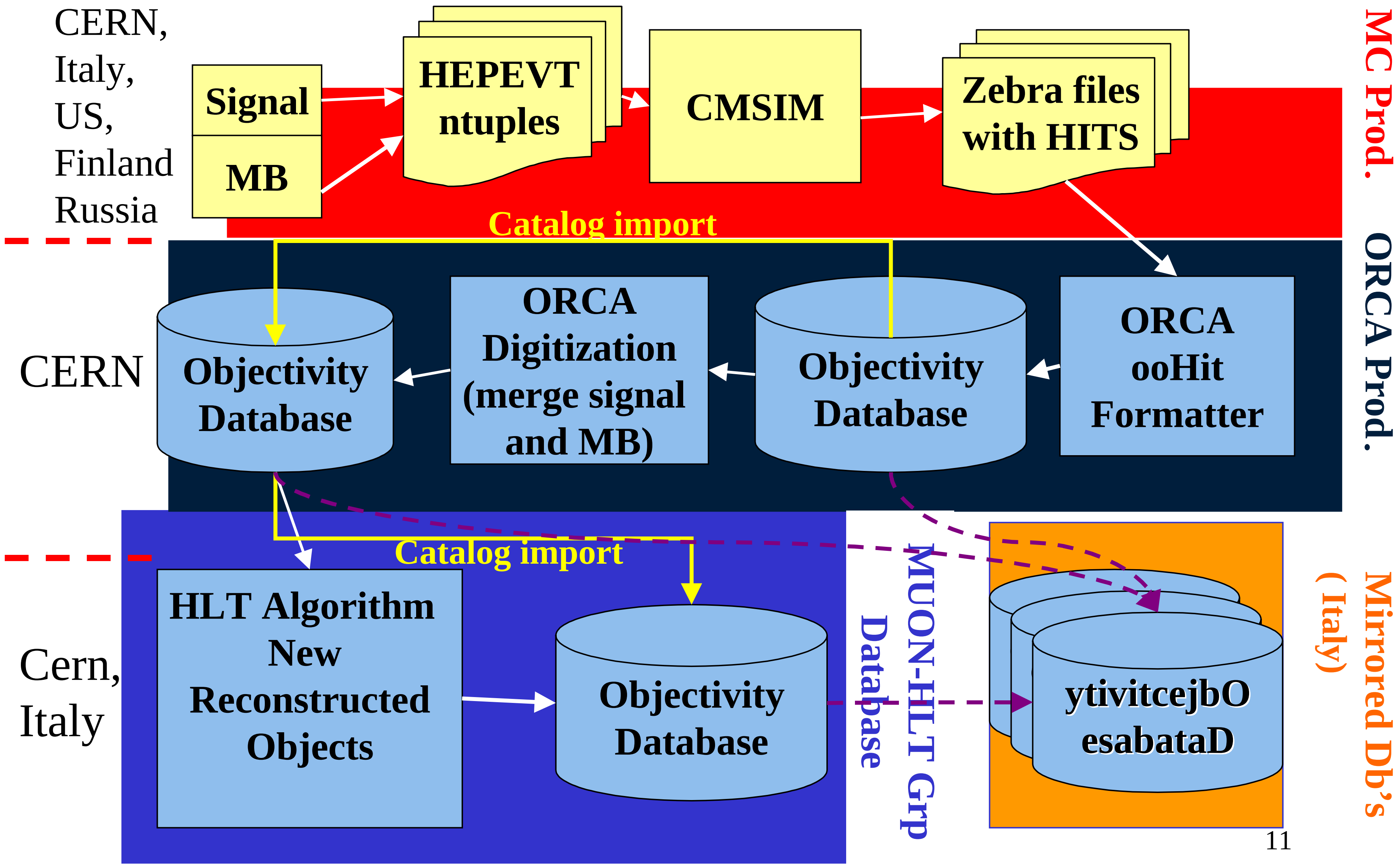


CMS Software Tools

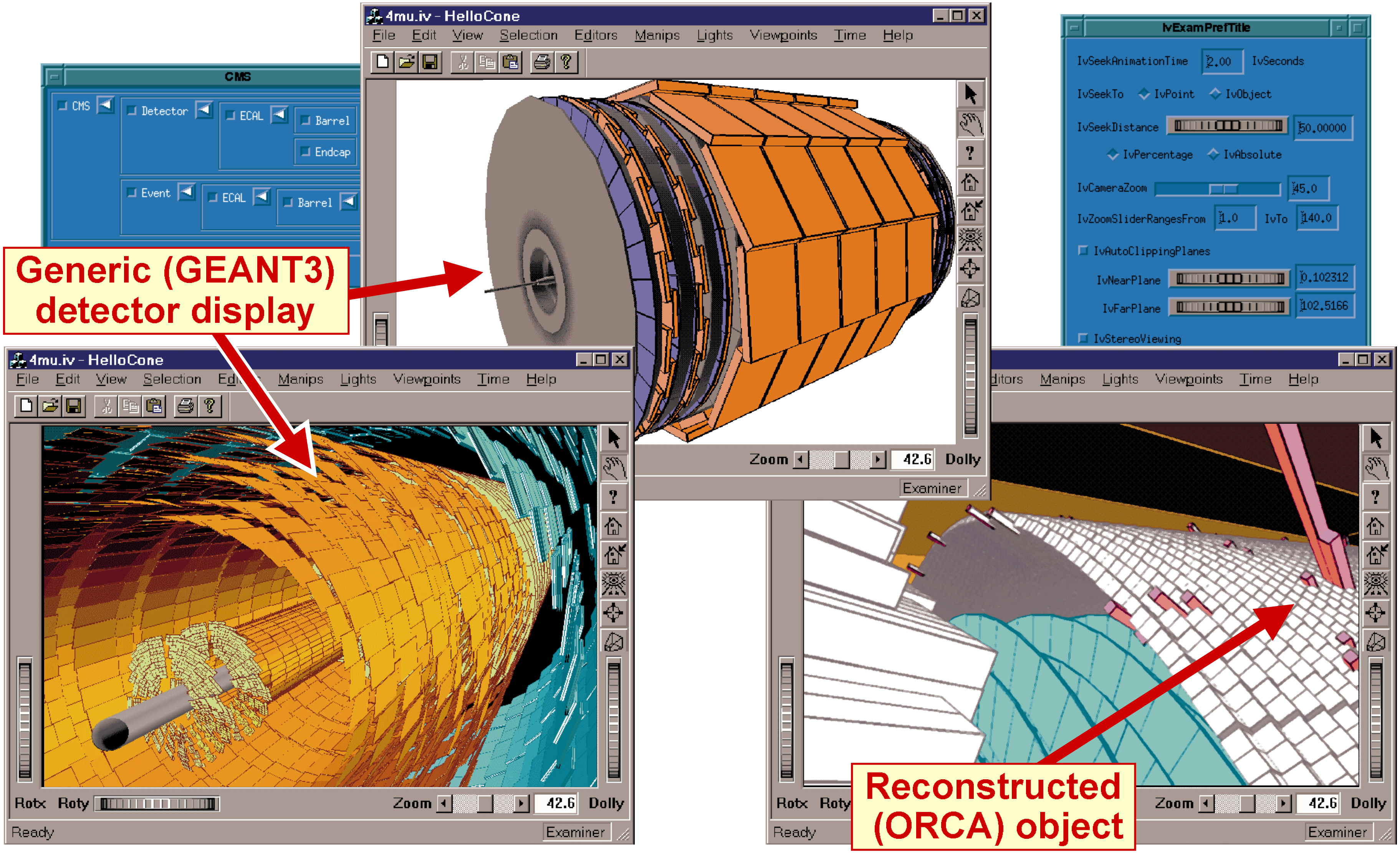
task	tool	lang.	full name
generation particles @ vertex	PYTHIA 6	f77	
	PYTHIA 7	C++	
simulation *transport through the detector*	CMSIM / GEANT 3	f77	CMS SIMulation
	OSCAR / GEANT 4	C++	Object oriented Simulation for Cms Analysis and Reconstruction
	FAMOS	C++	FAst MOnte-carlo Simulation
digitisation *detector response*	CMSIM / GEANT 3	f77	
	ORCA	C++	Object oriented Reconstruction for Cms Analysis
reconstruction *hits and fits*	CMSIM	f77	
	ORCA	C++	
analysis *cuts and plots*	PAW	f77	Physics Analysis Workstation
	ROOT	C++	
	IGUANA	C++	Interactive Graphical User ANAlysis
	LHC++	C++	
	JAS	Java	Java Analysis Studio

MC production

How the whole chain was organized:



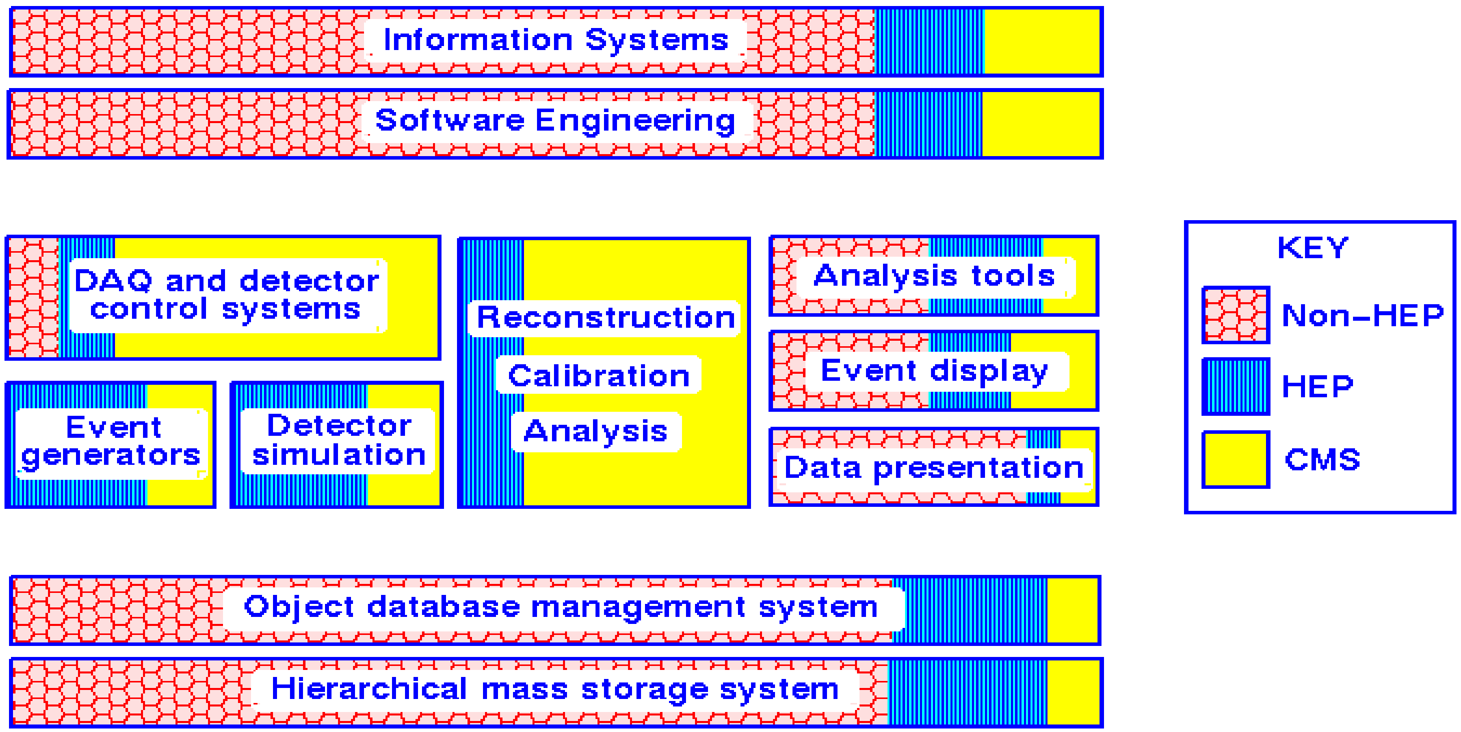
Prototype 4: Interactive 3D Detector and Event Visualisation with ORCA



Computing Model: Software Strategy

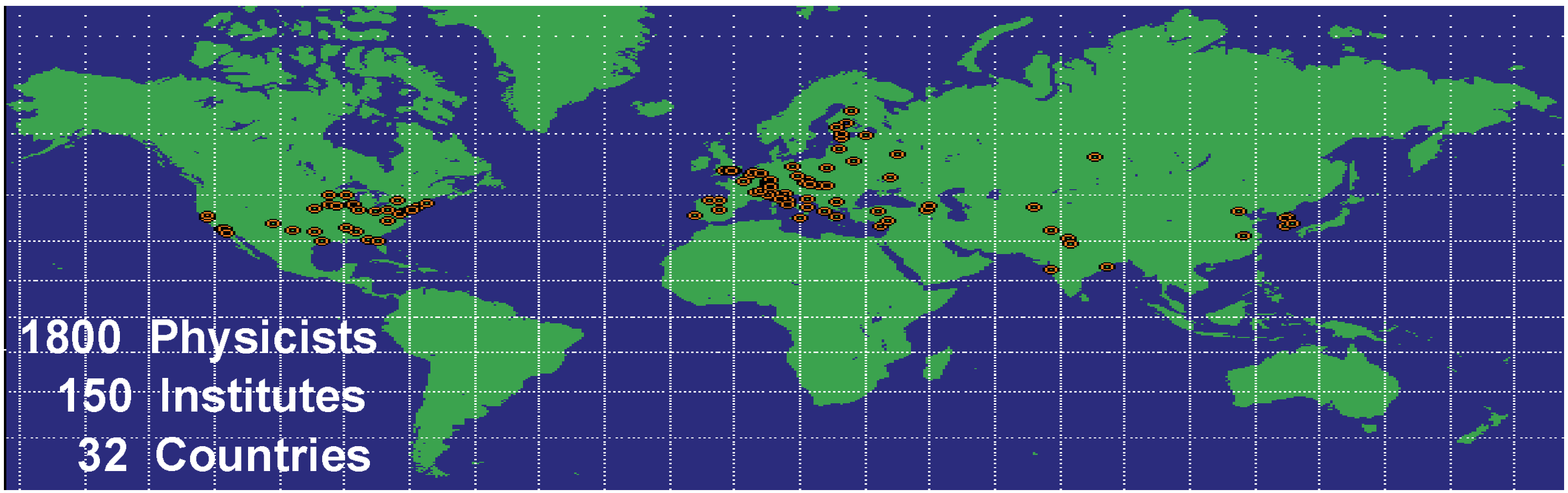
The Key Challenge and the Solution to Complexity

- A Modern, Engineered Software Framework
- Object-Oriented Design
- Modern Languages (C++, Java,...) and Tools (ODBMS, HPSS,...)
- Use of Mainstream Commercial products wherever possible



LHC Computing: *Different* from Previous Experiment Generations

- **Geographical dispersion:** of people and resources
- **Complexity:** the detector and the LHC environment
- **Scale:** Petabytes per year of data

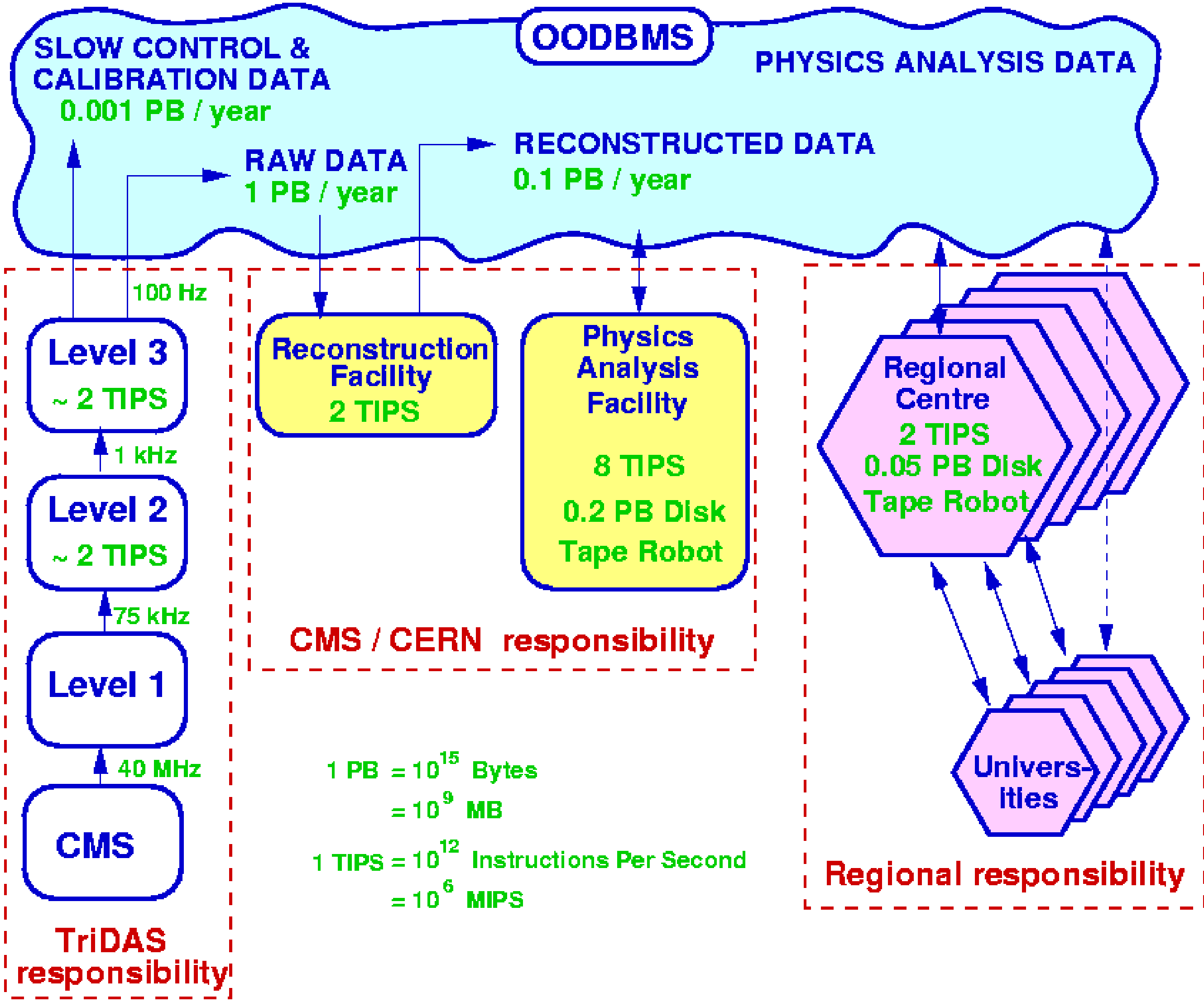


Major challenges associated with

- Coordinated Use of Distributed computing resources
- Remote software development and physics analysis
- Communication and collaboration at a distance

R&D: New Forms of Distributed Systems

Computing Model: Hardware



Flexible architecture which can respond to changing unit costs, network policies, etc.

~5 Regional Centres: physics analysis (each ~20% of CERN capacity)

Universities: physics analysis and simulation

.

Comparisons with LHC sized experiment: CMS at CERN [*]

Experiment	Onsite CPU SI95 1 Si95 = 40 MIPS	onsite disk (TB)	onsite tape (TB)	LAN capacity	Data Import/Export	Box Count
LHC (2006)	520,000*	540	3000	46 GB/s	10 TB/day (sustained)	~1400
CDF - 2	12,000	20	800	1 Gb/s	18 MB/s	~250
D0 - 2	7,000	20	600	300 Mb/s	10 MB/s	~250
Babar	~6000	8	~300	100 + 1000 Mb/s	~400 GB/day	~400
D0	295	1.5	65	300 Mb/s	?	180
CDF	280	2	100	100 Mb/s	~100 GB/day	?
ALEPH	300	1.8	30	1 Gb/s	?	70
DELPHI	515	1.2	60	1 Gb/s	?	80
L3	625	2	40	1 Gb/s	?	160
OPAL	835	1.6	22	1 Gb/s	?	220
NA45	587	1.3	2	1 Gb/s	5 GB/day	30

[*] Total CPU: CMS or ATLAS ~ 1.5-2,000,000 MSi95 (Current Concepts; may be for 10^{33} Luminosity)

MONARC

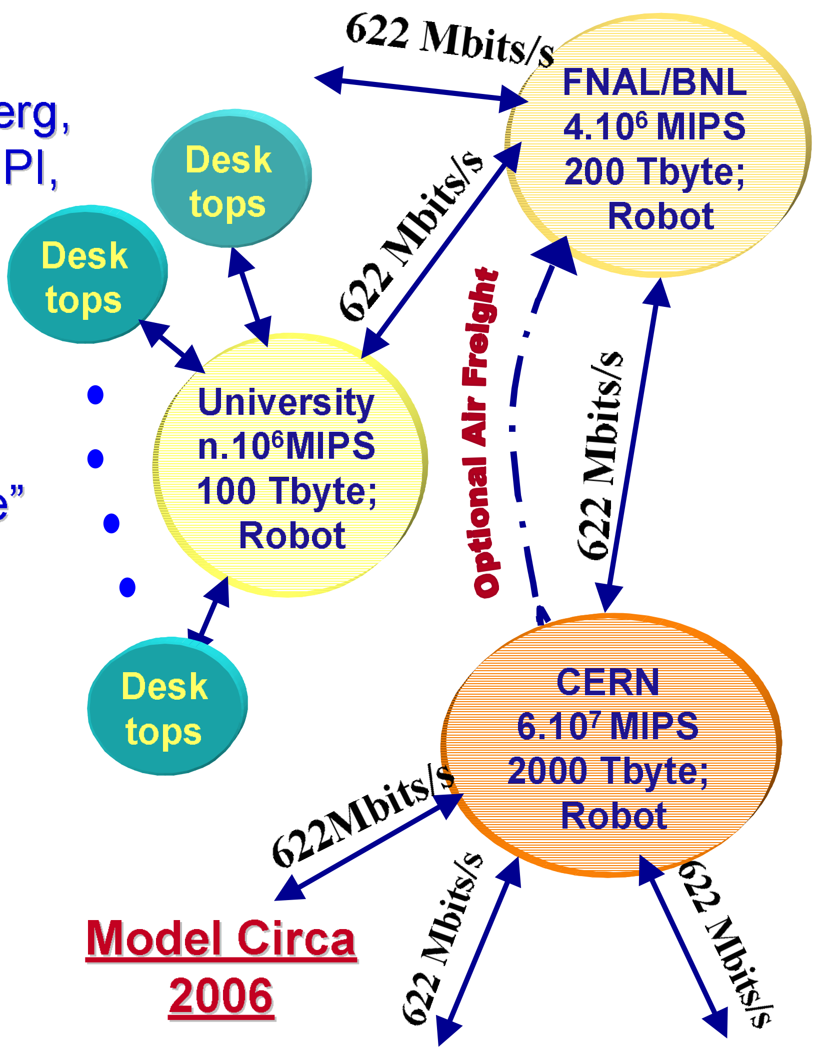
Models Of Networked Analysis
At Regional Centers
Caltech, CERN, Columbia, FNAL, Heidelberg, Helsinki, INFN, IN2P3, KEK, Marseilles, MPI, Munich, Orsay, Oxford, Tufts

GOALS

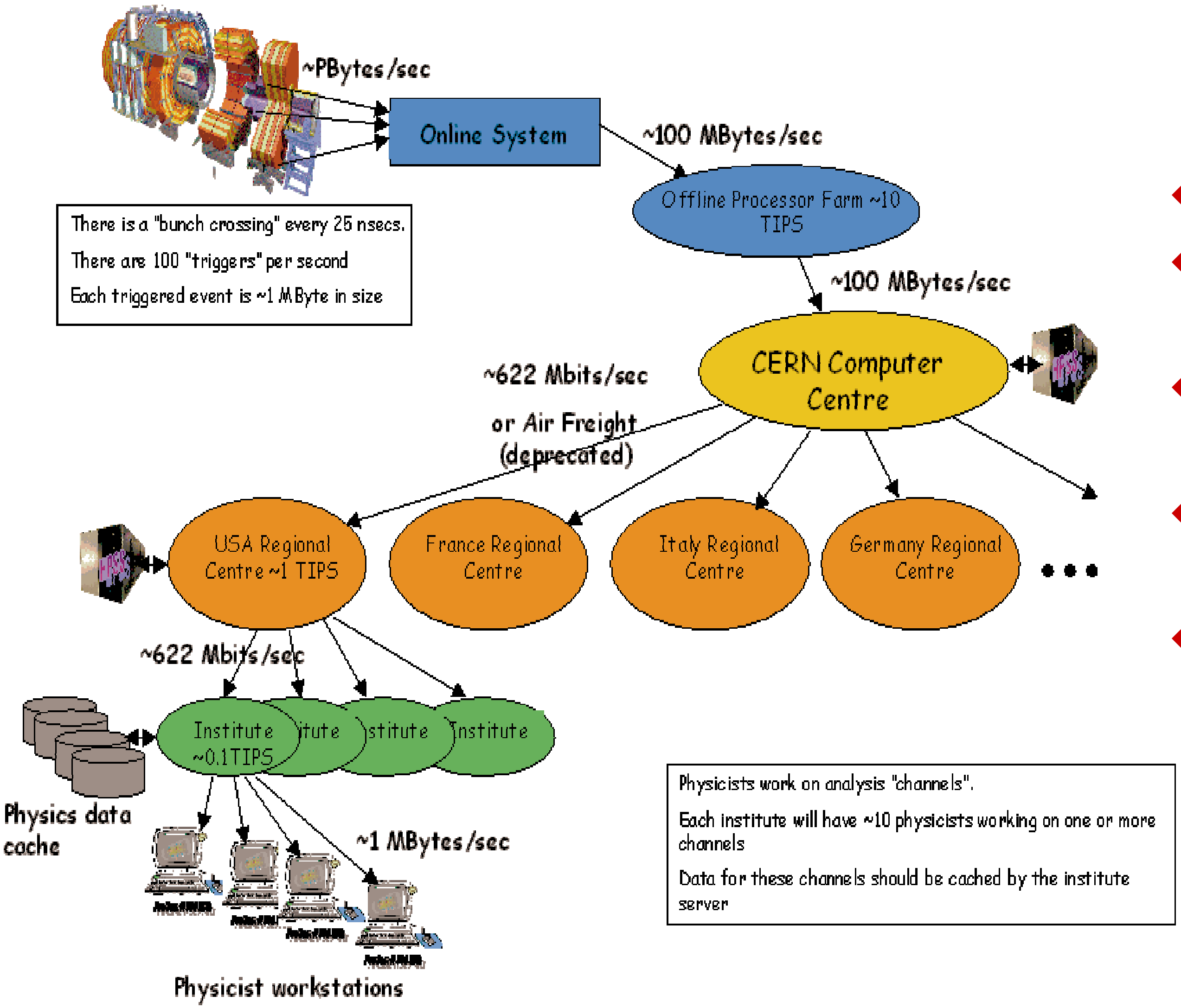
- Specify the main parameters characterizing the Model's performance: throughputs, latencies
- Develop "Baseline Models" in the "feasible" category
- Verify resource requirement baselines: (computing, data handling, networks)

COROLLARIES:

- Define the Analysis Process
- Define RC Architectures and Services
- Provide Guidelines for the final Models
- Provide a Simulation Toolset for Further Model studies



Regional Centers Concept: A Data Grid Hierarchy

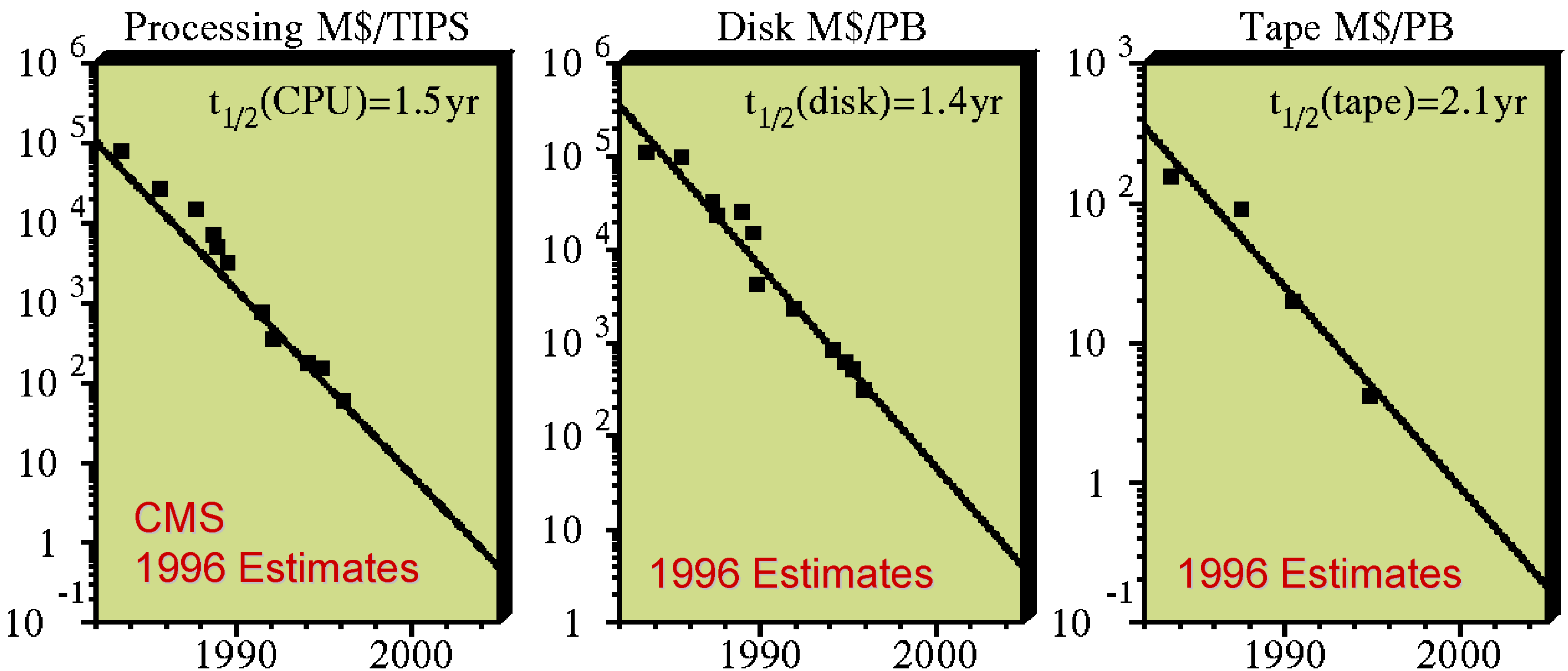


LHC Grid Hierarchy Example

- Tier0: CERN
- Tier1: National "Regional" Center
- Tier2: Regional Center
- Tier3: Institute Workgroup Server
- Tier4: Individual Desktop

Total 5 Levels

Cost Evolution: CMS 1996 Versus 1999 Technology Tracking Team



Compare to 1999 Technology Tracking Team Projections for 2005

- CPU: Unit cost will be close to early prediction
- Disk: Will be more expensive (by ~2) than early prediction
- Tape: Currently Zero to 10% Annual Cost Decrease (Potential Problem)

Example: 9 Participants, CERN(2), Caltech, FNAL(2), Bologna (IT), Roma (IT), Milan (IT), Rutherford(UK)