# Commissioning and Early Physics with CMS

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**On Behalf of the CMS Collaboration**

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# Outline

## 1. Detector Commissioning

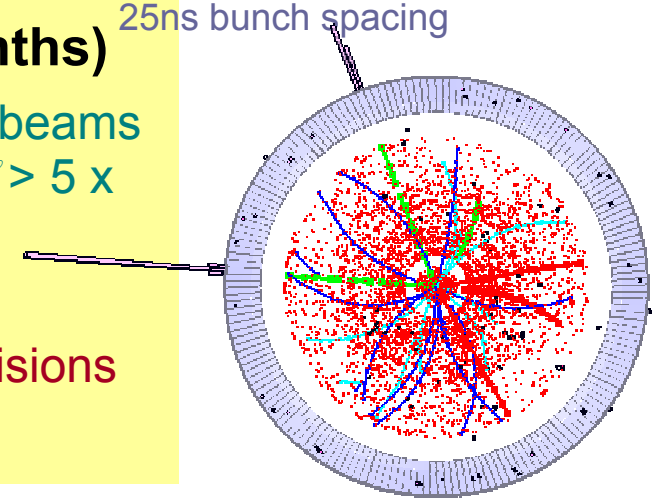
- Start-up Scenario
- Lev-1 and HLT Rates
- Muon system
- Alignment
- ECAL
- HCAL

## 2. Physics Reach with 10 $fb^{-1}$

- Standard Model Higgs
- MSSM Higgs
- SUSY particles

# The Start-up LHC Scenario

+ 2 pileup events i.e. $10^{33}$ and 25ns bunch spacing



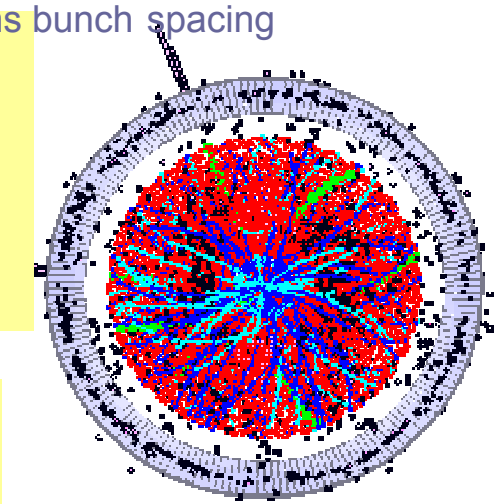
**PHASE 1: LHC commissioning ($T_0$ to $T_0$ + 4 months)**

- LHC: Set-up machine. Start with one beam. Colliding beams and slowly increase # bunches and $\mathscr{L}$. Collisions at $\mathscr{L} > 5 \times 10^{32}$ at 25, 75 ns bunch spacing.
- CMS: Muon halo triggers, catalog detector problems, synchronization, debug data handling, record first collisions

→ **This talk part I**

pixel → **Phase2: Shutdown**

+ 20 pileup events i.e. $10^{34}$ and 25ns bunch spacing



**PHASE 3: First physics run ($T_0$ + 7 mo.→ $T_0$ + 14 mo.)**

- LHC: 25 ns and $\mathscr{L} \sim 10^{33}$ cm$^{-2}$ s$^{-1}$
- CMS: Physics run, max. efficiency aiming for 5-10 fb$^{-1}$
- ~2 events per BX

→ **This talk part II**

**PHASE 4+n: High luminosity running**

→ **See talk by J.Rohlf on high luminosity**

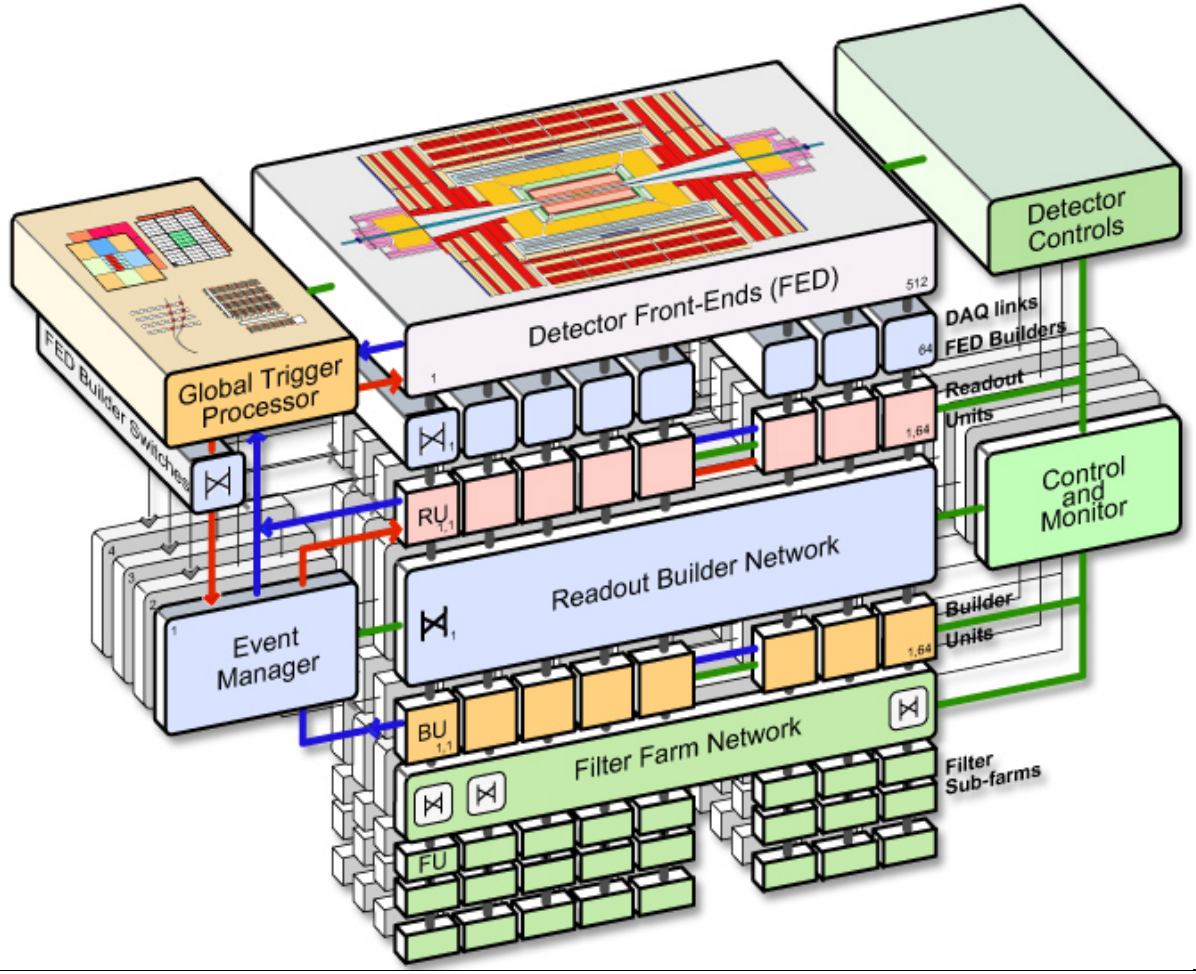
# CMS DAQ Staging

- **One basic unit** = readout builder (RB) = 12.5 kHz rate → 8 such units constitute the whole DAQ for the design value of 100 kHz
- Lower event rate at start-up allows **DAQ staging** → plan: 50% = 4 slices

Basic unit
= **12.5 kHz**

Start-up = 4 slices
= **50 kHz**

Final = 8 slices
= **100 kHz**



# Expected Level-1 Rates @ low $\mathscr{L}$

**Total Rate** @ low $\mathscr{L}$: **50 kHz**, Factor 3 safety, allocate 16 kHz

Roughly 1/4 per class **"e/gamma" , "muon" , "tau", "jet",** 1 kHz Min-bias

→ See also C.Seez's talk about CMS trigger

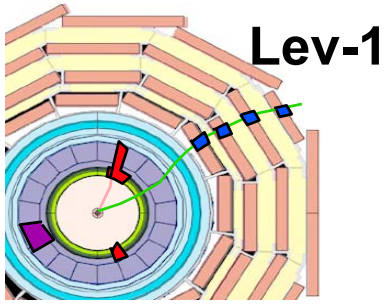
| Channel | Threshold [GeV] $\varepsilon$ = 95% | Individual Rate [kHz] |
|---|---|---|
| Inclusive isolated e/$\gamma$ | 29 | 3.3 |
| Di-electrons/di-photons | 17 | 1.3 |
| Inclusive isolated muon | 14 | 2.7 |
| Di-muons | 3 | 0.9 |
| Single tau-jet trigger | 86 | 2.2 |
| Two tau-jets | 59 | 1.0 |
| 1-jet, 3-jets, 4-jets | 177 , 86 , 70 | 3.0 |
| Jet * $E_T^{miss}$ | 88 * 46 | 2.3 |
| Electron * jet | 21 * 45 | 0.8 |
| Min-bias (Calibration) | | 0.9 |

DAQ TDR, LHCC 2002-26

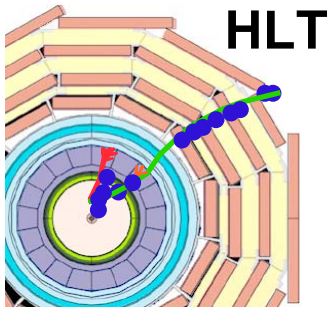
**TOTAL allocated rate:**

**16 kHz**

# HLT Table @ $\mathscr{L}$ = 2x10$^{33}$ cm$^{-2}$ s$^{-1}$




Event selection
$10^3$ reduction

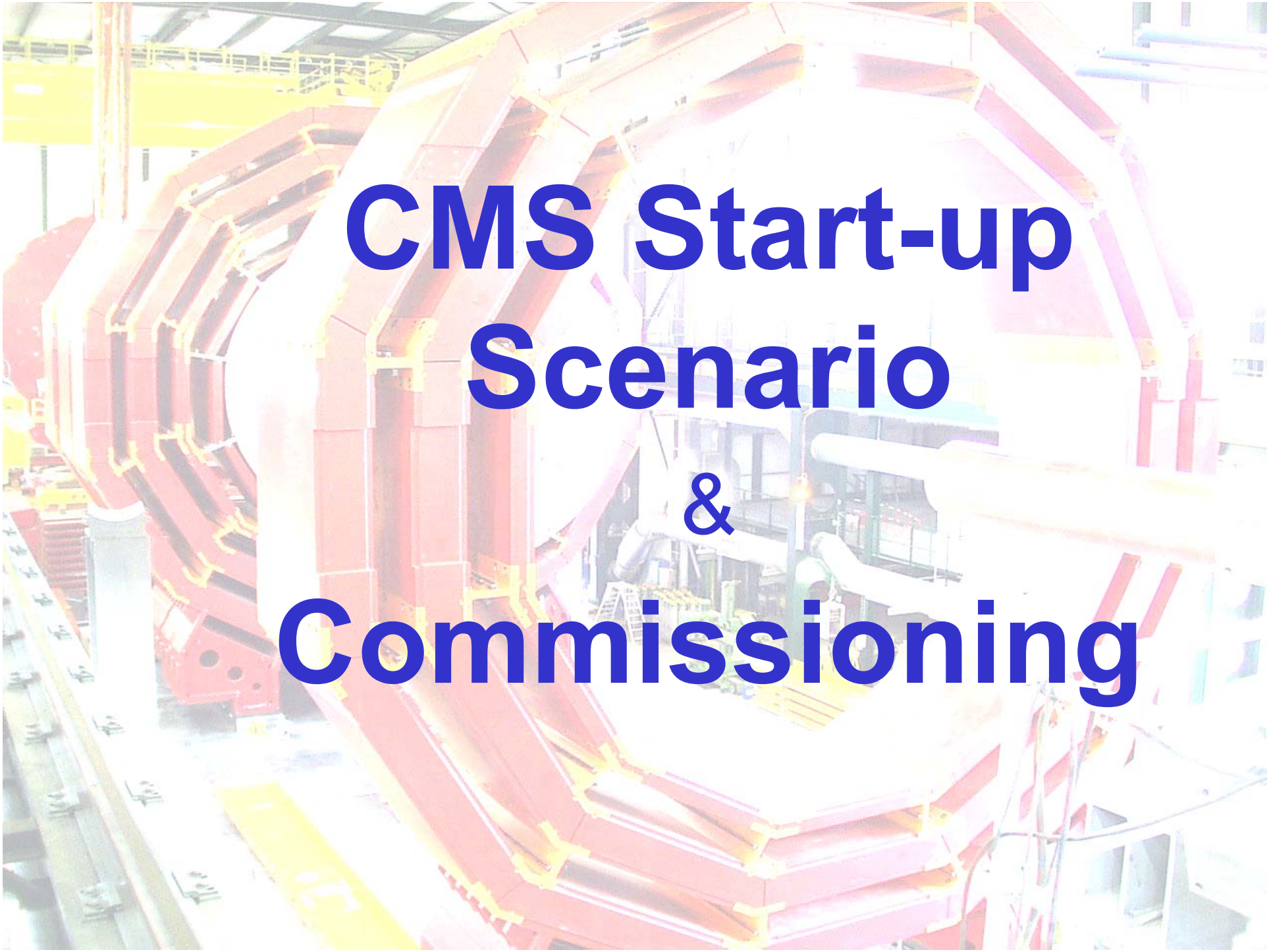



| Channel | Threshold [GeV] $\varepsilon$ = 90…95% | Rate [Hz] |
|---|---|---|
| 1 e, 2 e | 29 , 17 + 17 | 34 |
| 1 $\gamma$, 2 $\gamma$ | 80 , 40 + 25 | 9 |
| 1 $\mu$, 2 $\mu$ | 19 , 7 + 7 | 29 |
| 1 $\tau$, 2 $\tau$ | 86, 59 + 59 | 4 |
| 1-jet OR 3–jet OR 4 | 657 , 247, 113 | 9 |
| e * jet | 19 + 45 | 2 |
| Jet * $E_T^{miss}$ | 80 + 123 | 5 |
| Inclusive b-jets | 237 | 5 |
| Calibration,Other | | ~10 |
| Sum | | ~105 Hz |

DAQ TDR LHCC 2002-26 p.359

**Minimum calibration for the trigger to function @ low $\mathscr{L}$:**

- **Alignment of muon system and tracker** with ~ 500 $\mu$m needed
- **ECAL** $\Delta E/E$ ~ 3 – 5%
- **HCAL** $\Delta E/E$ ~ 2%



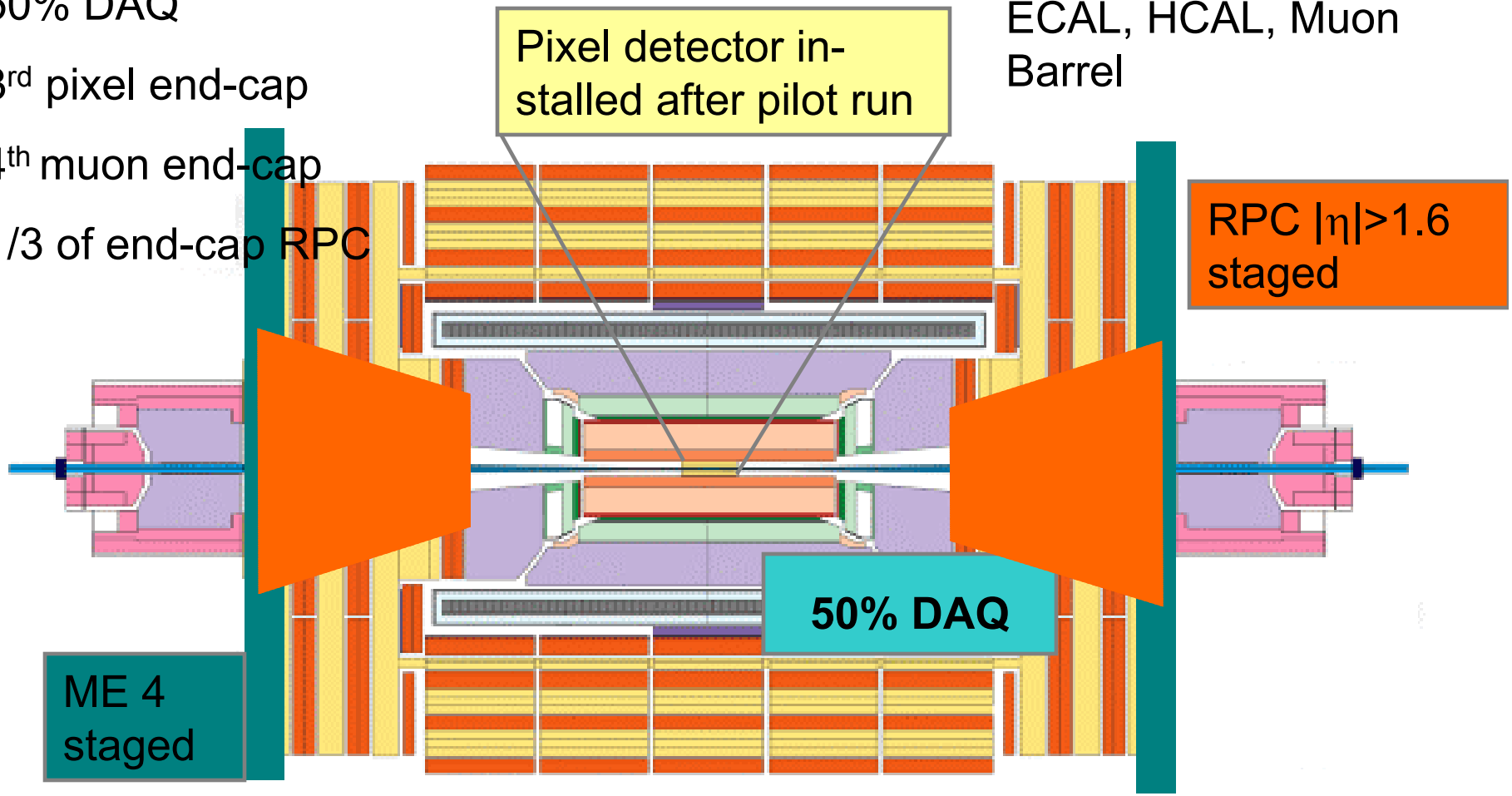
# CMS Start-up Scenario & Commissioning

# CMS Detector at Start-Up

**Initial detector** is the complete CMS except for the **staged items** (consistent with financial plan):

- 50% DAQ
- 3rd pixel end-cap
- 4th muon end-cap
- 1/3 of end-cap RPC

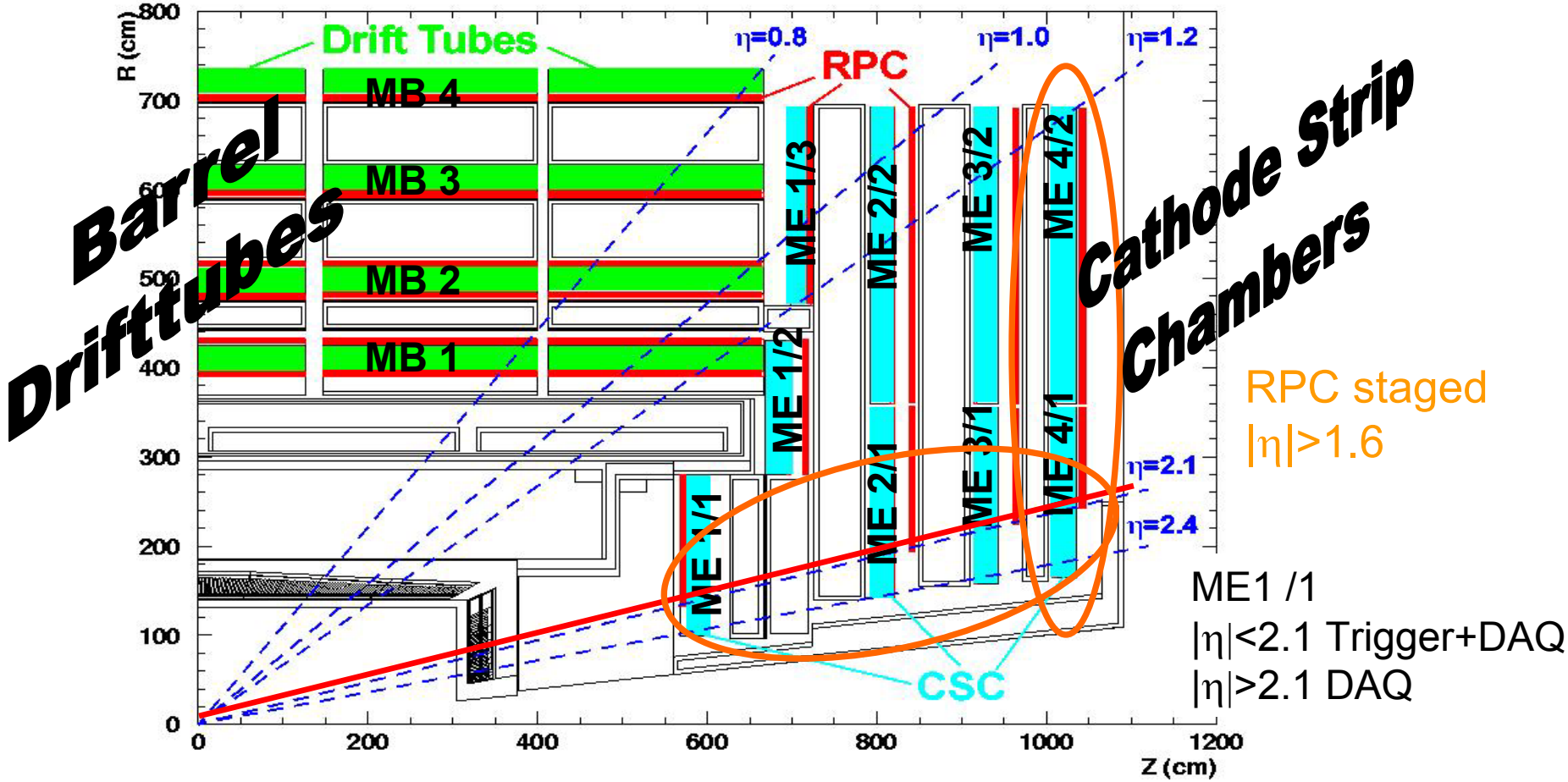
**Complete Subsystems:** Tracker, ECAL, HCAL, Muon Barrel



# Muon System at Start-up

Multiple scattering → stand-alone spatial resolution ~100 μm → Reconstruction complemented by tracker

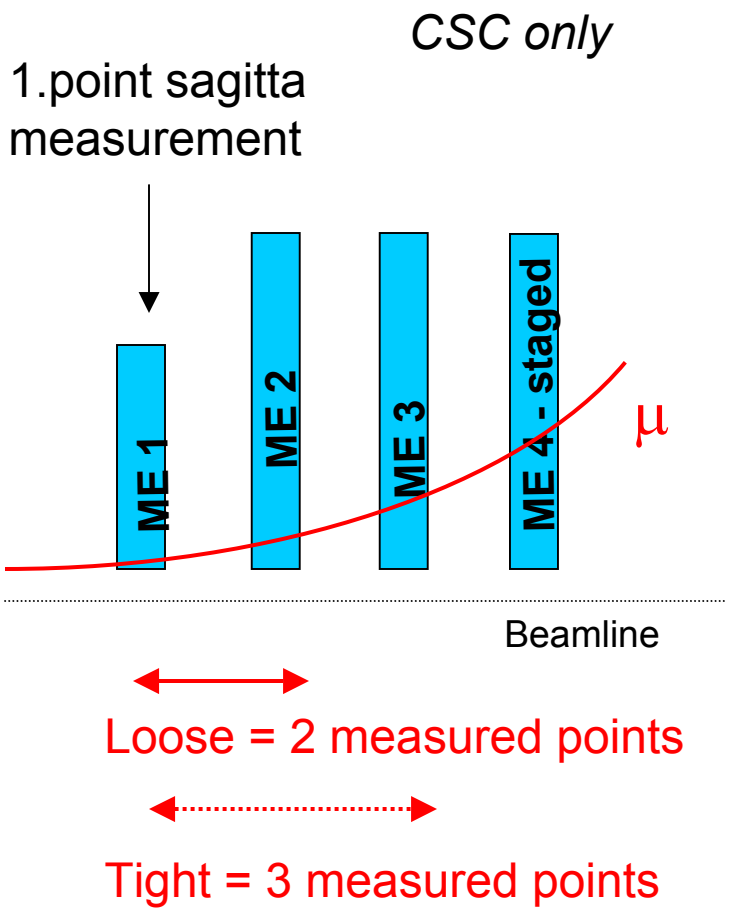
At start-up ME4 + RPC |η|>1.6 staged




RPC staged
|η|>1.6

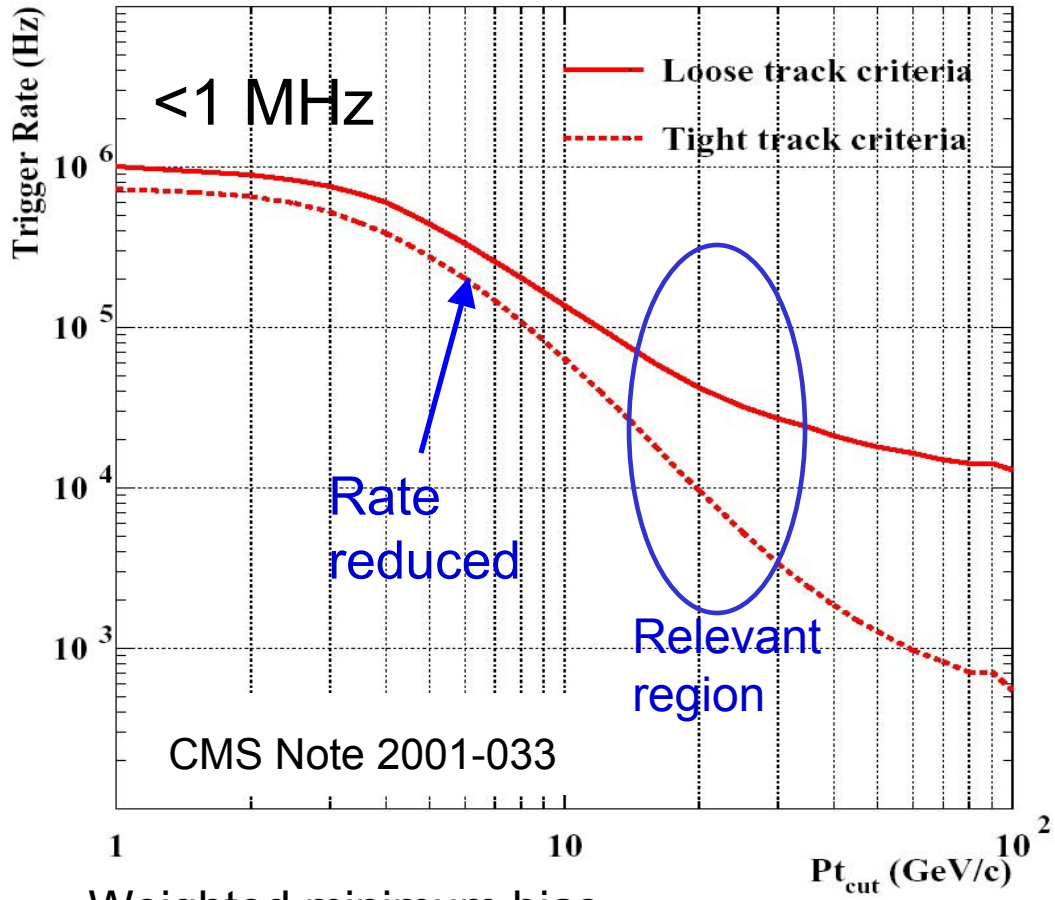
ME1 /1
|η|<2.1 Trigger+DAQ
|η|>2.1 DAQ

# Implications of ME4 Staged



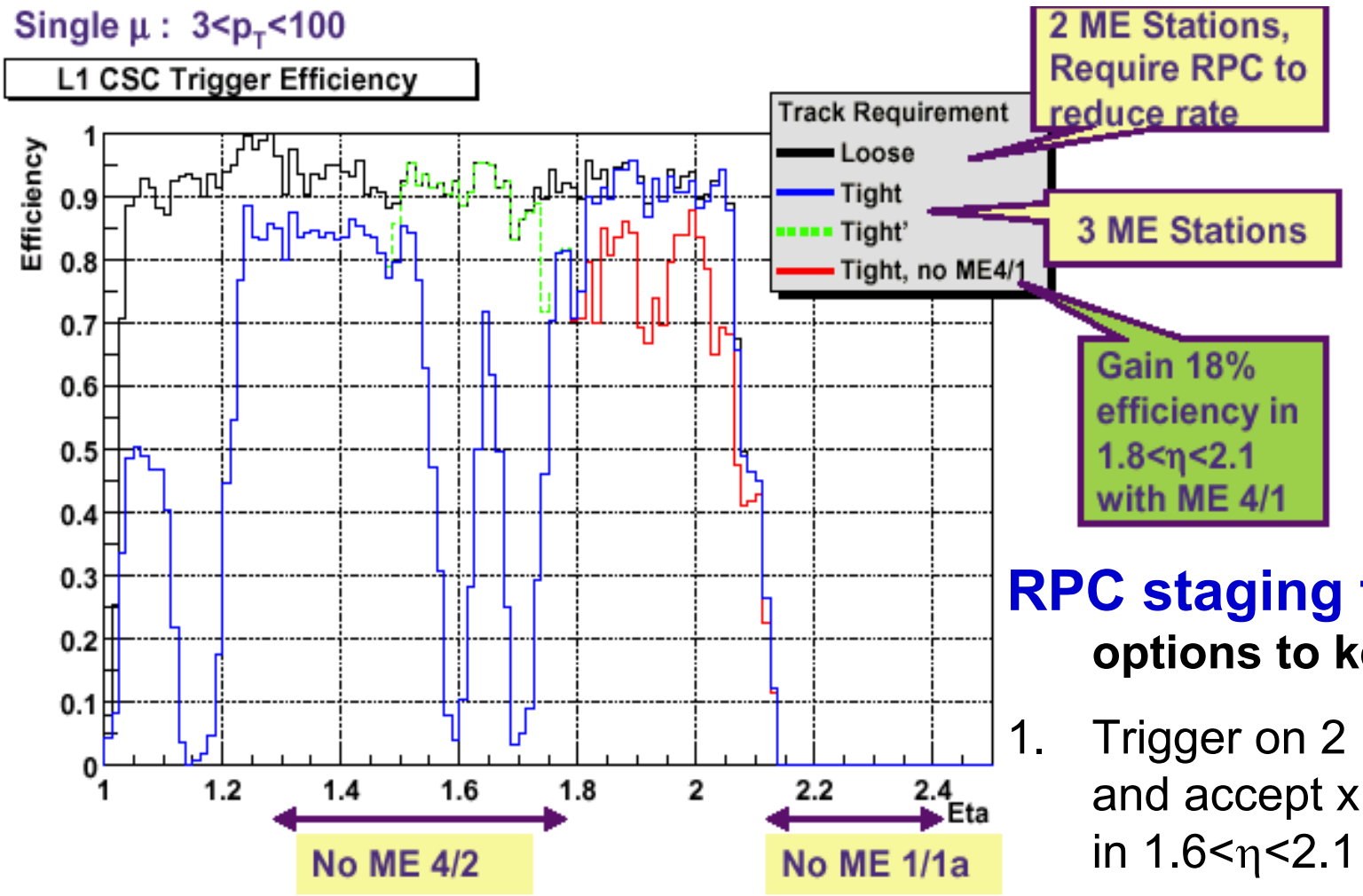

**Staged ME 4 → No redundancy**

Loose = 2 CSC , Tight = 3 CSC




Weighted minimum bias sample used for rate estimate at $\mathscr{L}=10^{34}$

# L1 CSC Efficiency

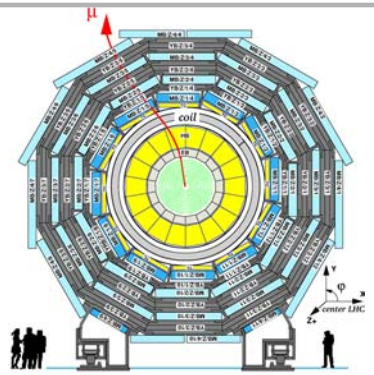



**RPC staging for |η|>1.6, options to keep high eff.**

1. Trigger on 2 ME stations and accept x10 higher rate in 1.6<η<2.1
2. Restore ME4/1 (under discussion)

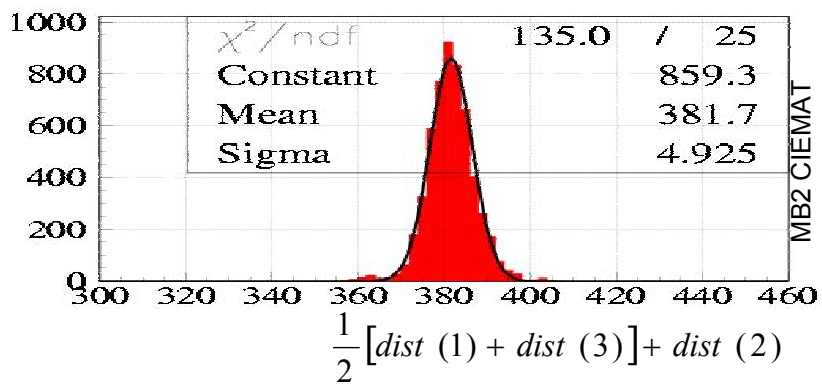
# Performance Control during Production

During production quality control with cosmic muons. Subsample of chambers tested in testbeam. Performance for individual chambers known at start-up.



## Barrel

Spatial resolution per SL




Drift velocity = 55 µm / ns

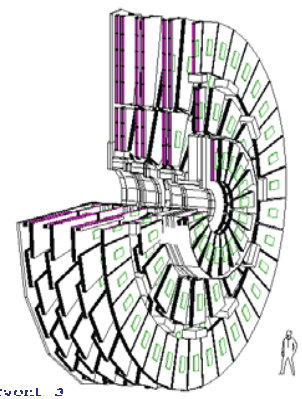
Resolution per cell ~200 µm

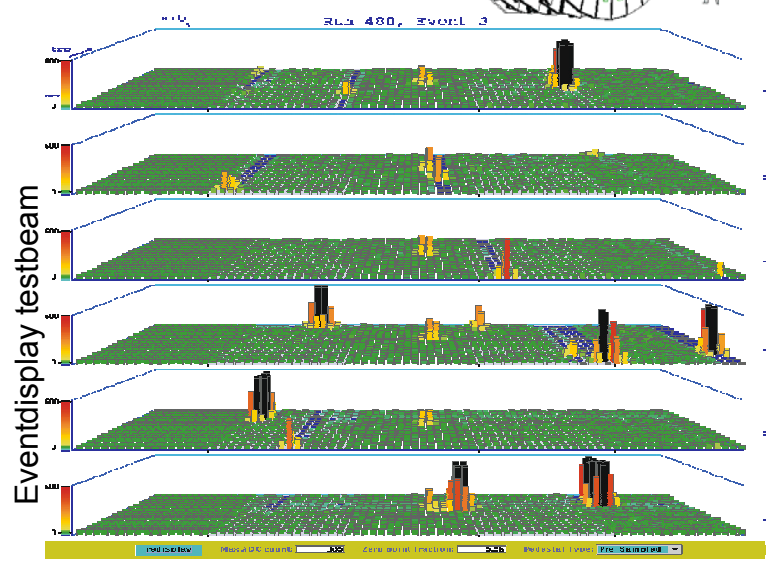
Chamber resolution < 100 µm

## Endcap

Spatial resolution
~100 µm

Time resolution
~ 4ns






 → See S.Lacaprara Muon talk 

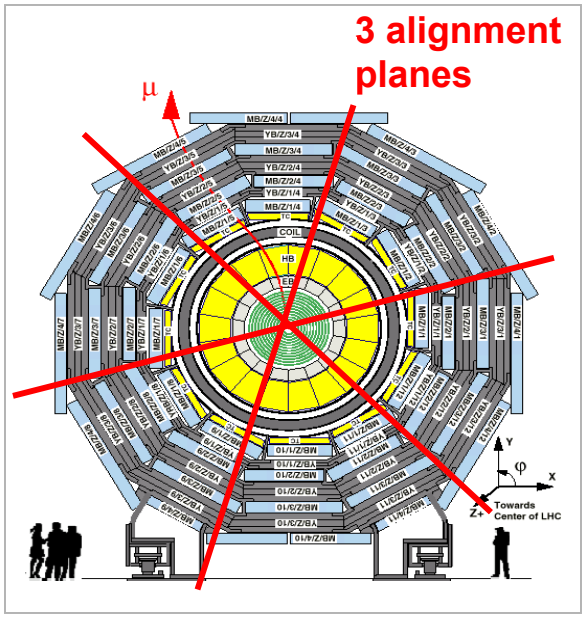
# CMS Alignment System

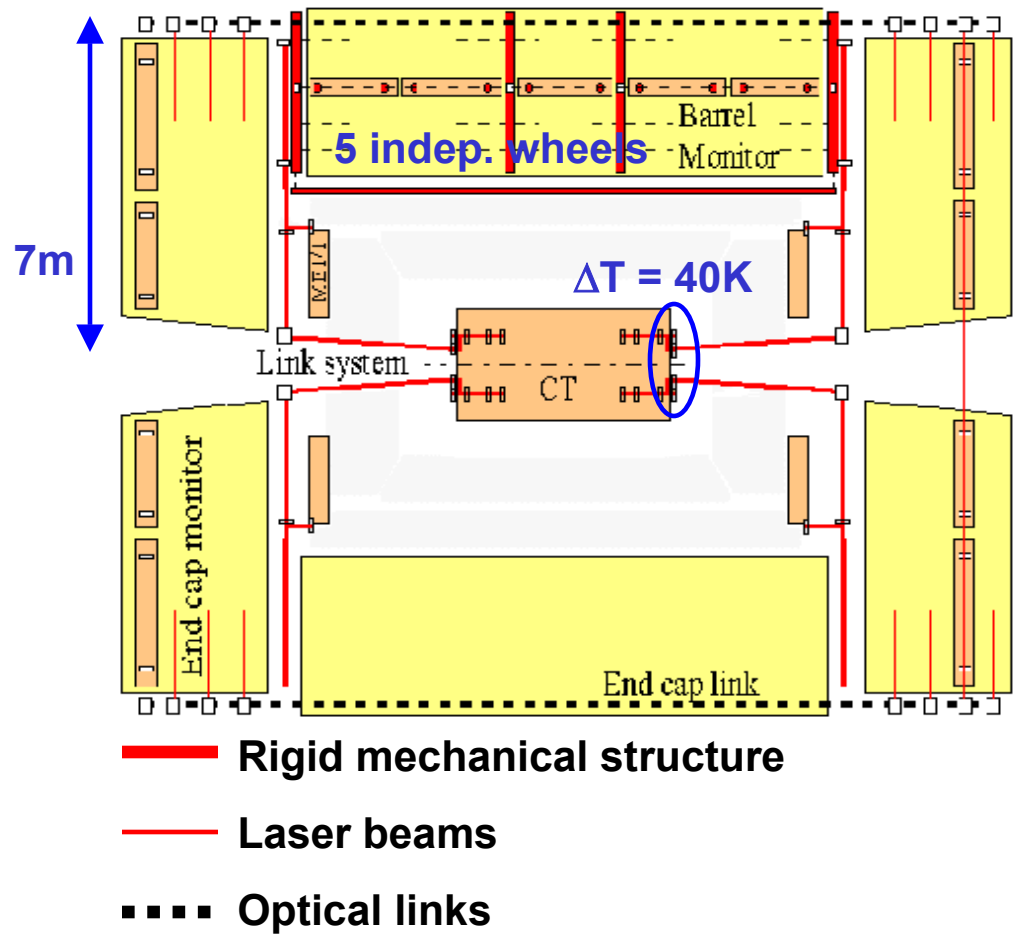
## Task of the alignment system

- Measure the relative position of the μ-chambers, and w.r.t. to the tracker ≤ 100 μm
- Monitor the stability of Tracker ≤ 10 μm & Muon detectors ≤ 100 μm

## Building blocks: 4 subsystems

- Internal tracker alignment
- Internal muon (barrel + EC)
- Link tracker – muons (3 planes)

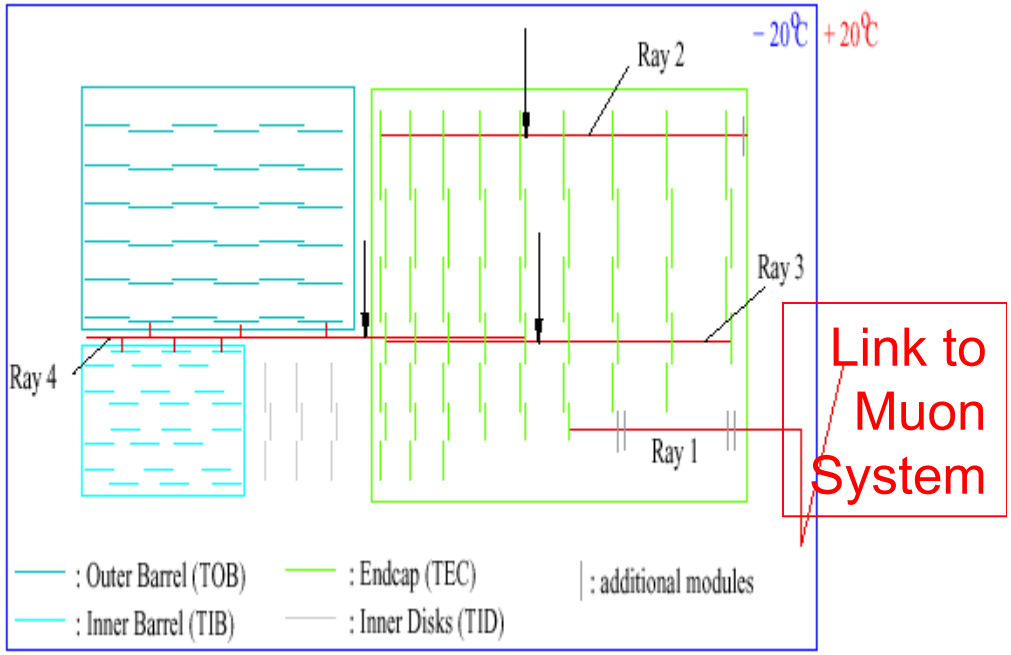


# Alignment at Start-up

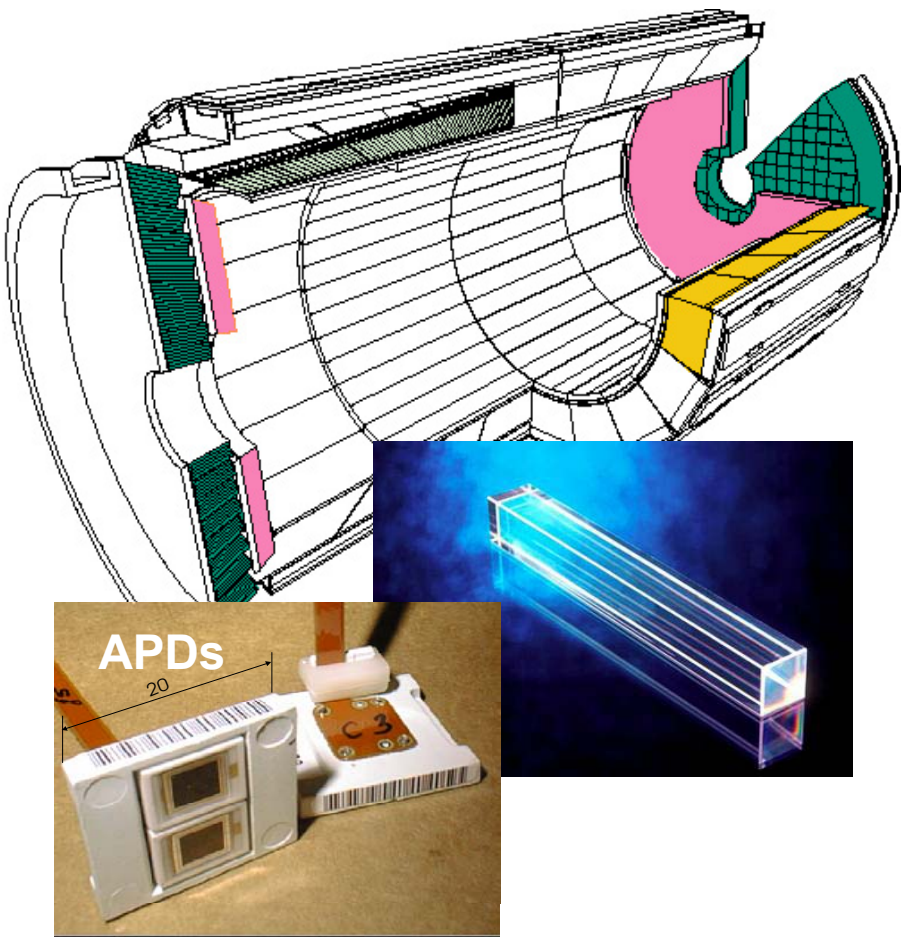
**Tracker & muon system**: performance of **individual detectors** known from production tests with cosmics, testbeam. Not known in the position of detectors with respect to each other

- **Internal tracker alignment** measures position of tracker modules. **Precision ~100 μm.**
- **Internal muon alignment** for chambers in barrel and EC. Relates 2 EC and barrel together. **Precision 150 μm.**
- **Link system** to monitor tracker w.r.t. muon system with 100 μm precision.




**Important plane is r,ϕ bending plane.**

# CMS ECAL Calibration

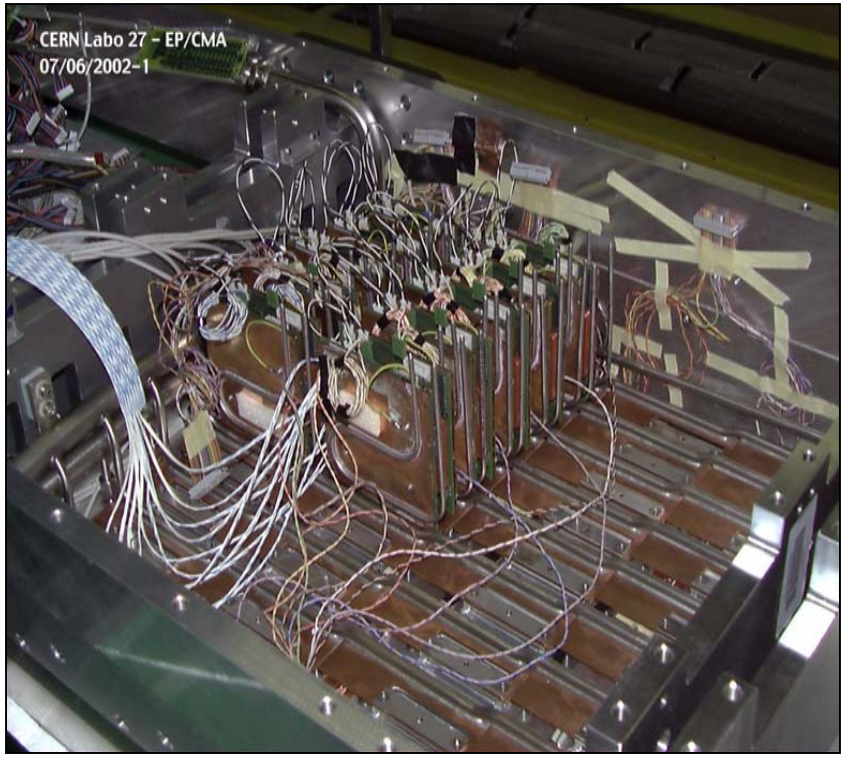


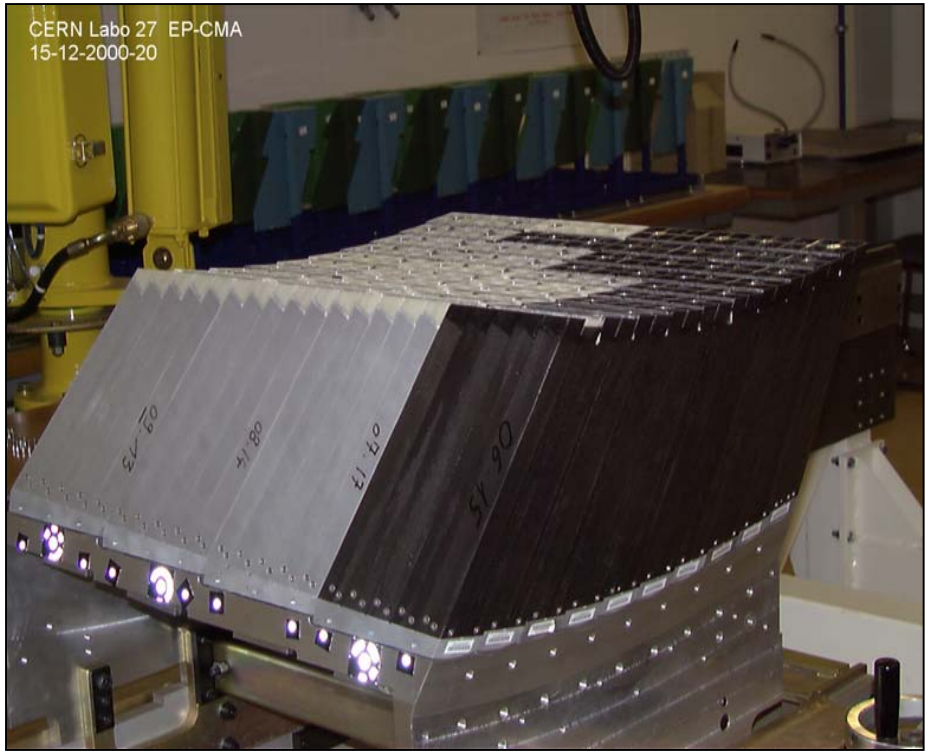

Total ~85.000 channels

1. **Lab measurements** of all modules; light yield, APD gain etc. → 4.5 %
2. **Testbeam** precalibration transported to CMS (for 25% of detector) → 2.0 %
   - Distributed within detector, as "standard candle"
3. **Min-bias** phi symmetry → 2 %
   - Fast calibration to reduce number of calibration constants
4. **Z → $e^+e^-$** → 0.5 % (design value)
   - Needs tracking in Si-tracker
   - Within ~2 months
5. Laser **monitoring system** over time to monitor crystal transparency

# Testbeam

First complete test of a mass-production module (1/4 supermodule




**Experience with many aspects:** temperature stability 0.1°C over 3 months, APD and electronics behaviour, monitoring laser system, noise correlations, auto-scans for calibration → see G.Dissertori ECAL talk

# Comparison Lab-Testbeam Meas.

Light yield, APD gain and pre-amplifier gain measured

1 **Very precise for a small sample in the testbeam**

9/36 Barrel + ¼ EC modules

Distributed within detector, as "standard candle"

$\Delta E/E < 0.1$ % for modules in beam

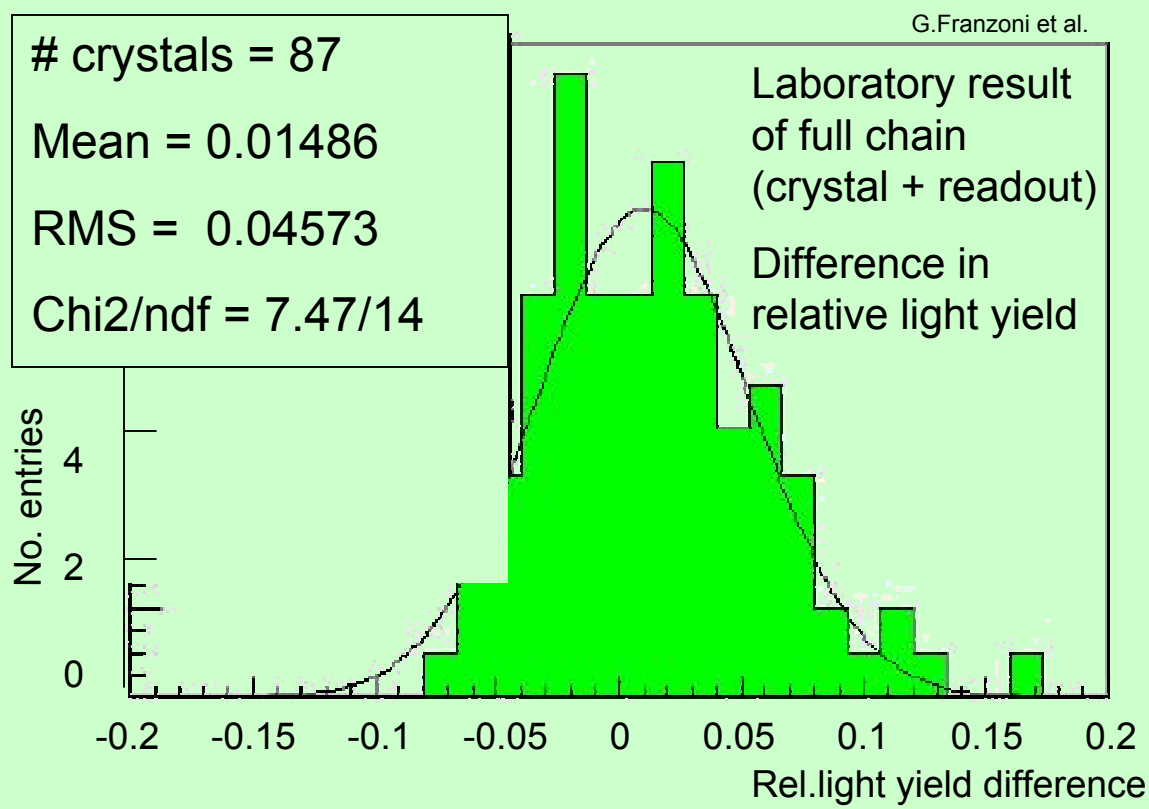
Extrapolation to CMS (after transport, installation, etc.) →

**target value of**

**2.0% precision**

2 **For all crystals in the lab (database)**

Intercalibration precision = **4.5 %**



# Minimum Bias Events

Idea: fast calibration to reduce # of cal.constants

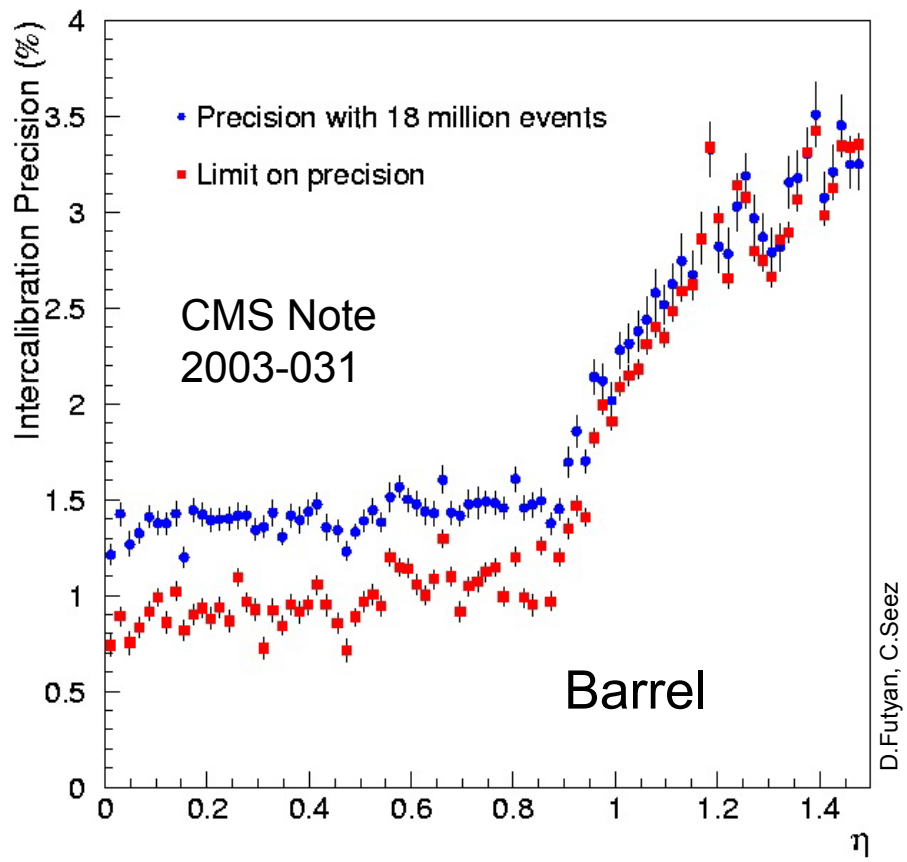
$$\sum_{n=1}^{ring-pairs} E_{transv}$$

Methode: use phi symmetry of deposited energy to intercalibrate crystals within rings of constant eta

Thresholds

- Lower = 120 MeV to cut el.noise
- Upper = Lower + 800 MeV to avoid bias

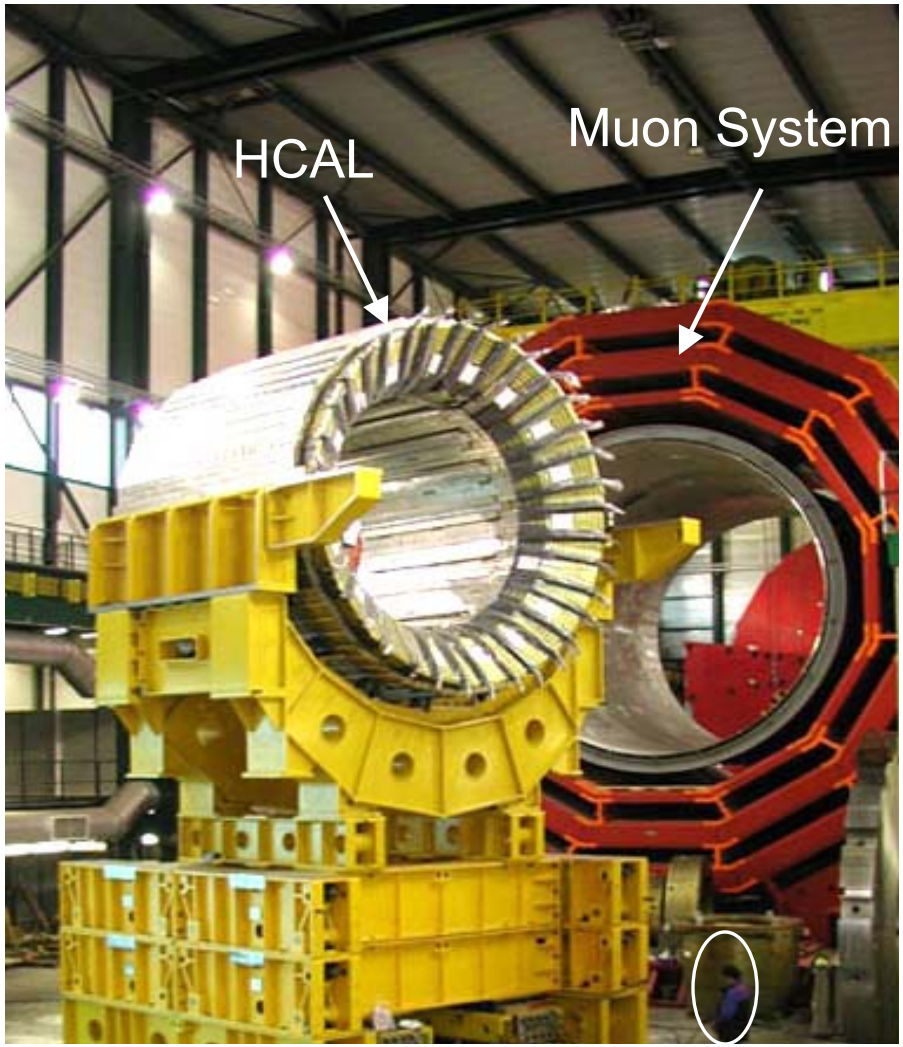
Precision limited by inhomogenity of material. With increasing knowledge, methode can provide 1% every few hours.



# HCAL Commissioning

1. **Testbeam Calibration**
   - Production wedges in testbeam → $\Delta E/E$ = 2% accuracy. Calibrated modules are used as reference.
2. **At start-up**, MIP's & single jet trigger within a few weeks.
3. **During running, monitor** the tile response using LED, laser & rad. sources
4. **Physics Events:**
   - MIP (muons) signal to link to HO
   - Charged hadrons ($e/\pi$) to set E-scale
   - Jets for jet response, balancing, $E_T^{miss}$

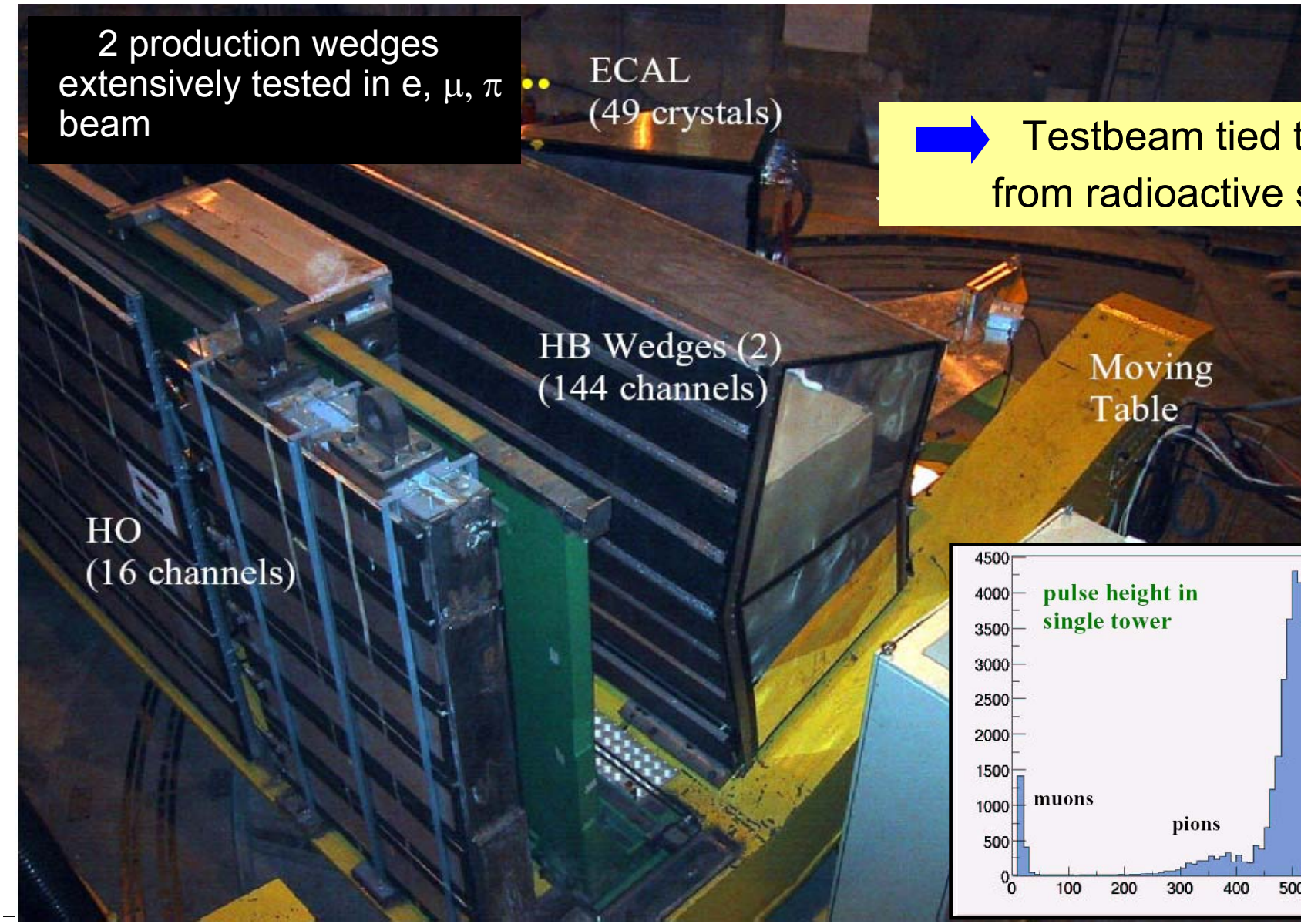
→ See D.Elvira HCAL talk



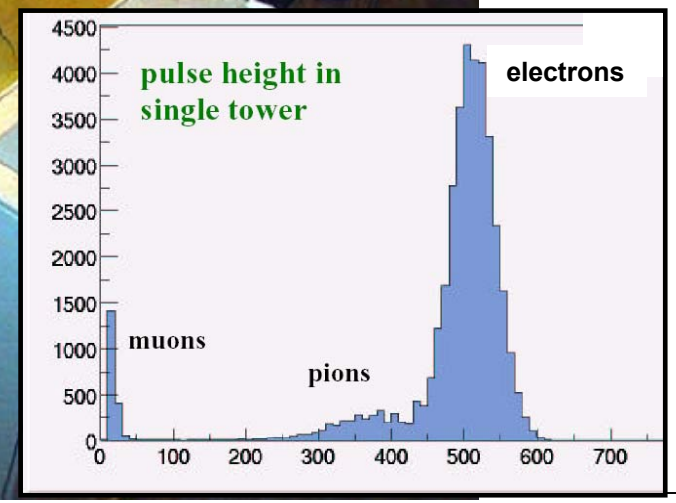

Required performance: $E_T$ thresh = 500 MeV, $E_{max}$ = 3 TeV, Noise = 200 MeV/BX/Tower

# HCAL in Testbeam

2 production wedges extensively tested in e, μ, π beam




Testbeam tied to data from radioactive source



# Radioactive Source Calibration

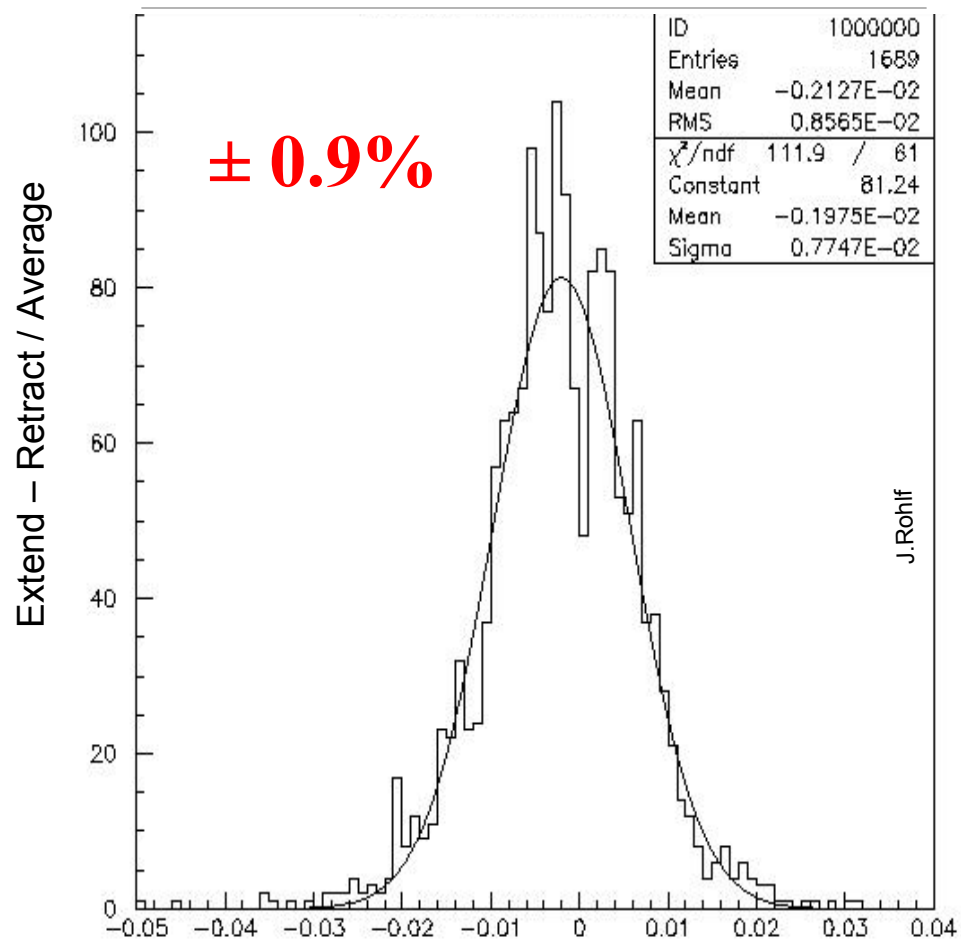
**Source scan**. Good SNR (3 mCu). Assignment of cal.constant to tile is straightforward. Different positions within tile.

**Precision** is within ± 0.9% → sets scale for HCAL calibration

**Compare** to testbeam data.

**Monitoring** with rad.sources and LED's.

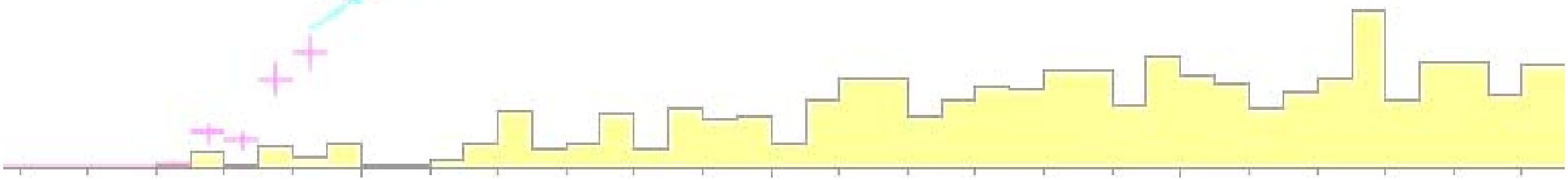
**Precision of rad.source calibration**



# CMS Early Physics Reach

## ESSENTIALS FOR PHYSICS @ 10 $fb^{-1}$

- Basic track reconstruction up to $p_{track}$~100 GeV/c
- Efficient reconstruction of low $p_T$ tracks for isolation
- Master tagging of b-jets
- Full calorimetric coverage for jet reconstruction, forward jet tagging, jet-jet mass resolution and $E_t^{miss}$



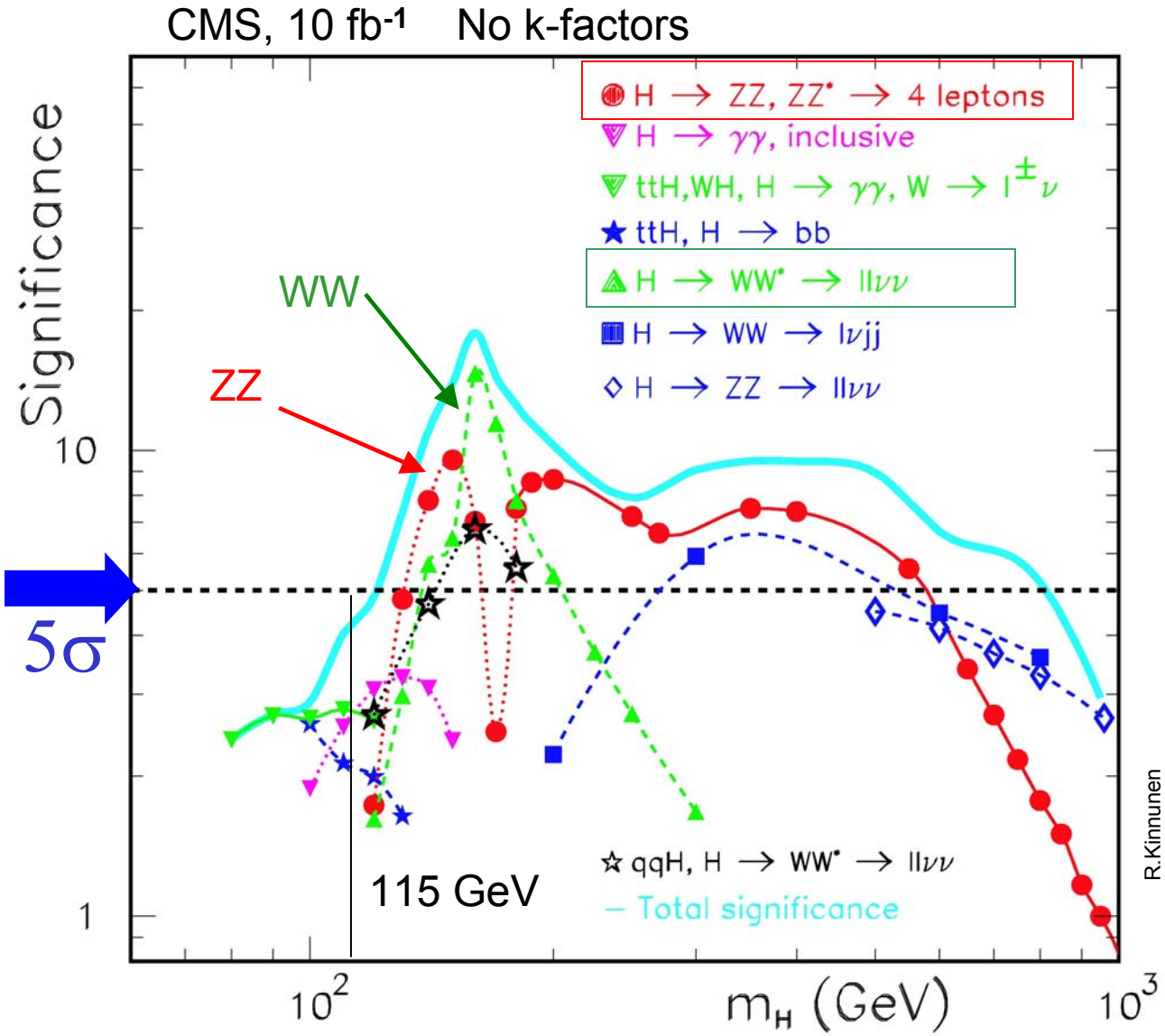
# Basics for W, Z, top with 10 fb-1

Assumption: 10 $fb^{-1}$ in 1 year @ $\mathscr{L}$= 2 x $10^{33}$ $cm^{-2}$ $s^{-1}$

| Trigger cuts at $\mathscr{L}$=2 x $10^{33}$ $cm^{-2}$ $s^{-1}$ | L1 $p_T$ cut [GeV] | HLT $p_T$ cut [GeV] | Exclusive rate [Hz] after HLT $\mu$ isolation |
|---|---|---|---|
| Single muon | 14 | 19 | 25 |
| Double muon | 3 | 7 | 4 |

| Channels | Pythia Cross section [nb] | Acceptance (1 $\mu$ in $\|\eta\|$<2.1) | Eff. after HLT with $\mu$ isolation | Yield for 10 $fb^{-1}$ |
|---|---|---|---|---|
| W → $\mu$ $\nu$ | 19.6 | 50 % | 69 % | 7 x $10^7$ |
| Z → $\mu$ $\mu$ | 1.84 | 71 % | 92 % | 1.1 x $10^7$ |
| tt →W b W b → $\mu$ $\nu$ + X | 0.126 | 86 % | 72 % | 0.08 x $10^7$ |

# SM Higgs Discovery Potential with 10 fb$^{-1}$




## In the following:

H → 4 leptons,

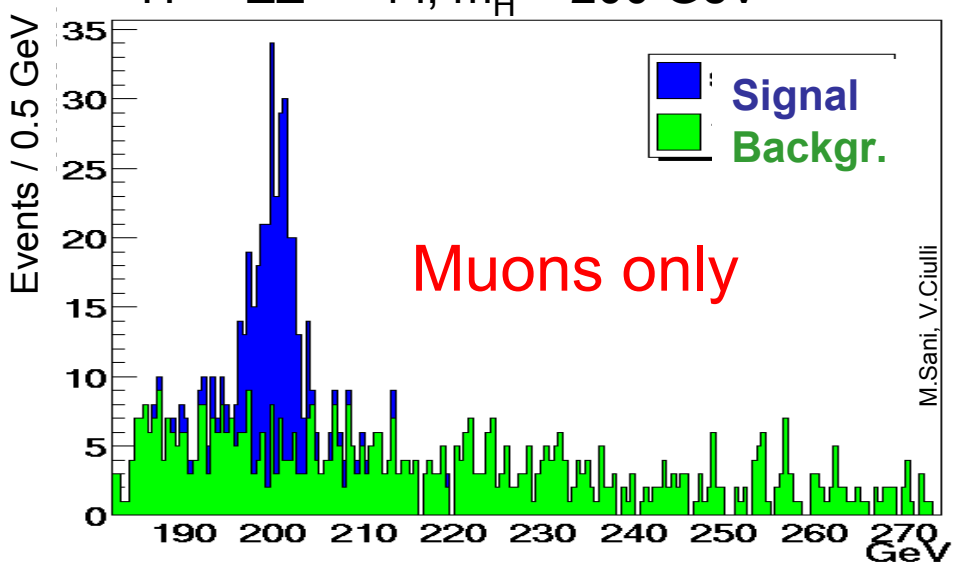
$m_H$ = 120….500 GeV

H → WW → lνlν

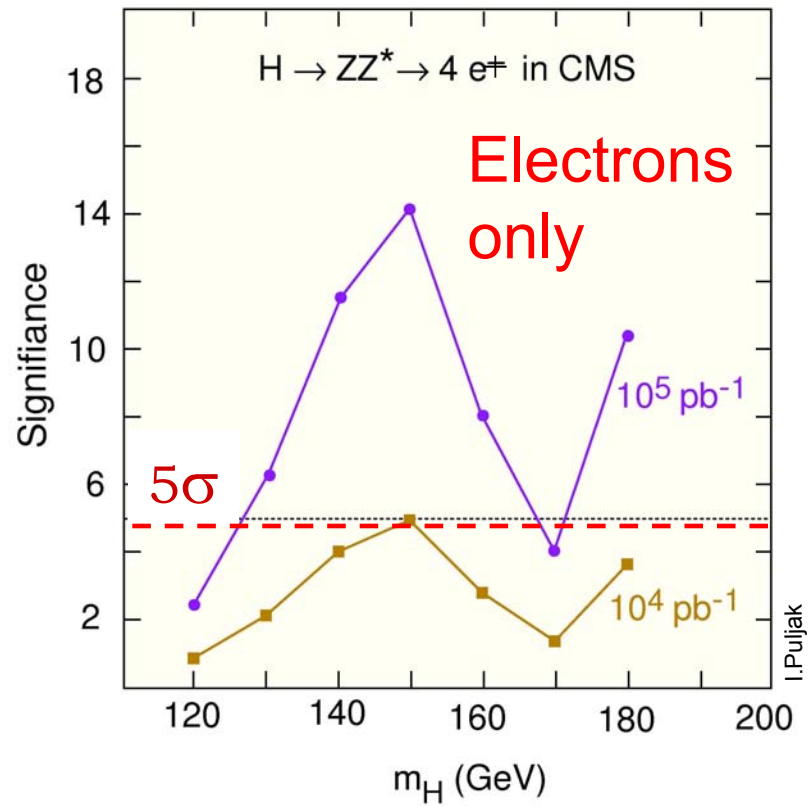
$m_H$ = 110….200 GeV

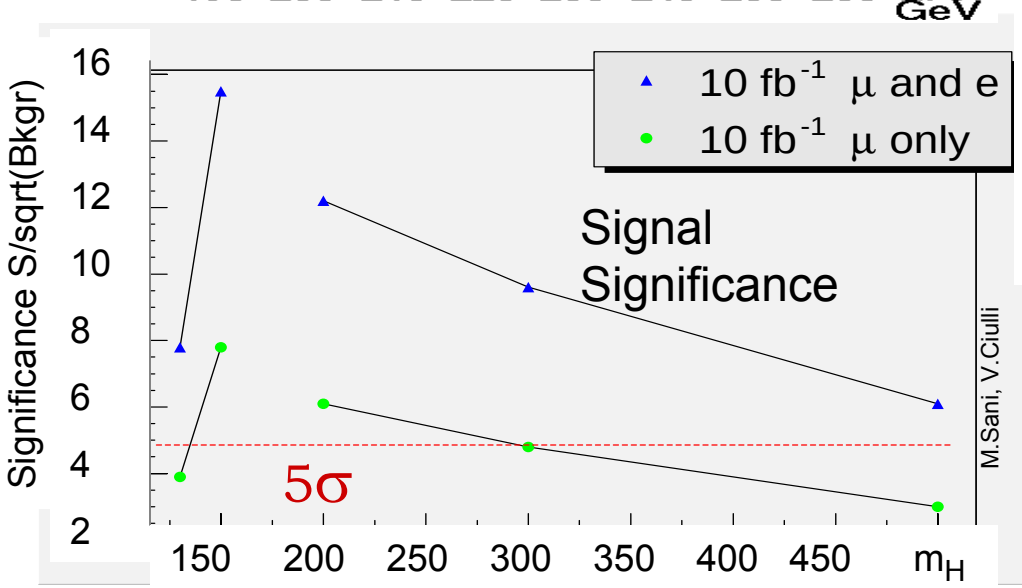
# $H_{SM} \rightarrow$ 4 Leptons with 10 fb$^{-1}$

H -> ZZ -> 4 l, $m_H$ = 200 GeV



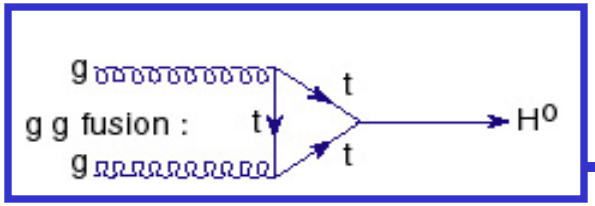

Signal significance (4 electrons)

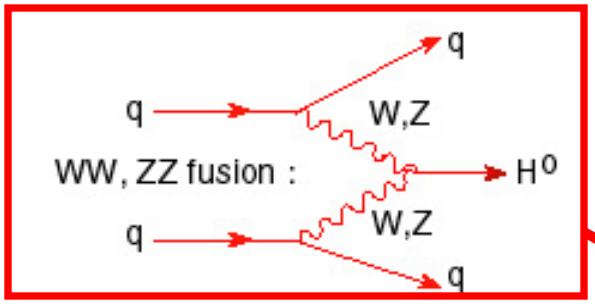



Acceptance and reconstruction efficiency are crucial for these channels

# $H_{SM} \rightarrow WW \rightarrow \ell\nu\ell\nu$ (Production)



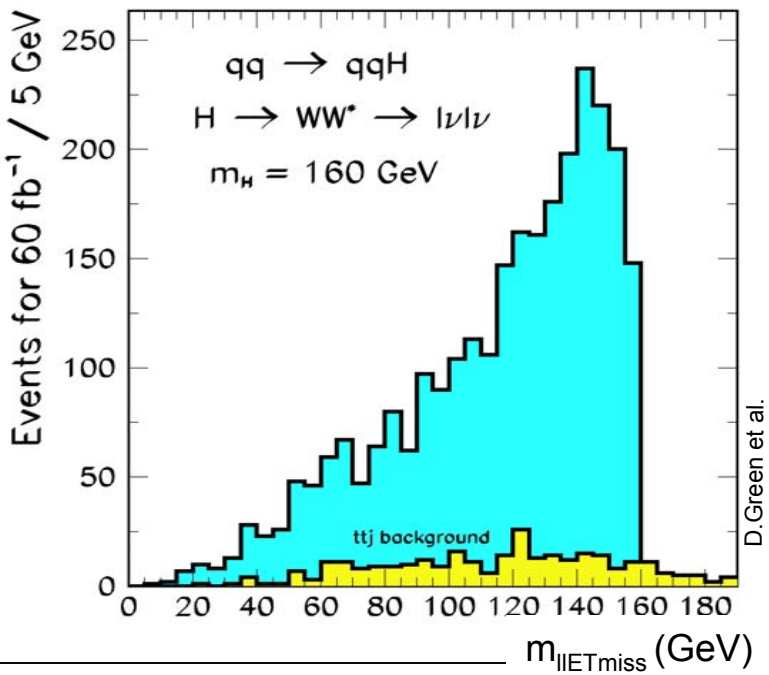

**gg fusion:** fast simulation

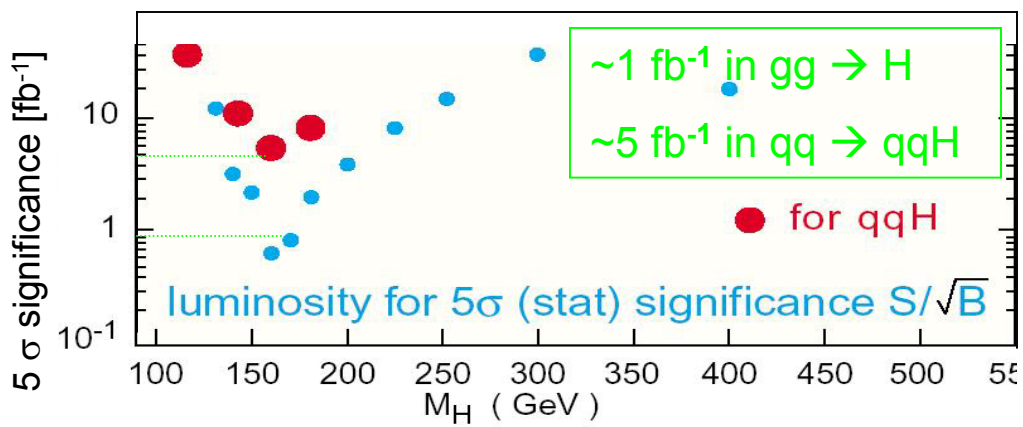
Considered backgrounds:

- $WW \rightarrow \ell\nu\ell\nu$
  Discriminate by cos Φ due to spin correlation
- $t\,t \rightarrow W\,b\,W\,b \rightarrow \ell\nu\ell\nu\,b\,b$
- $W\,t\,b \rightarrow W\,b\,W\,b \rightarrow \ell\nu\ell\nu\,b\,b$
  Both reducible by jet veto

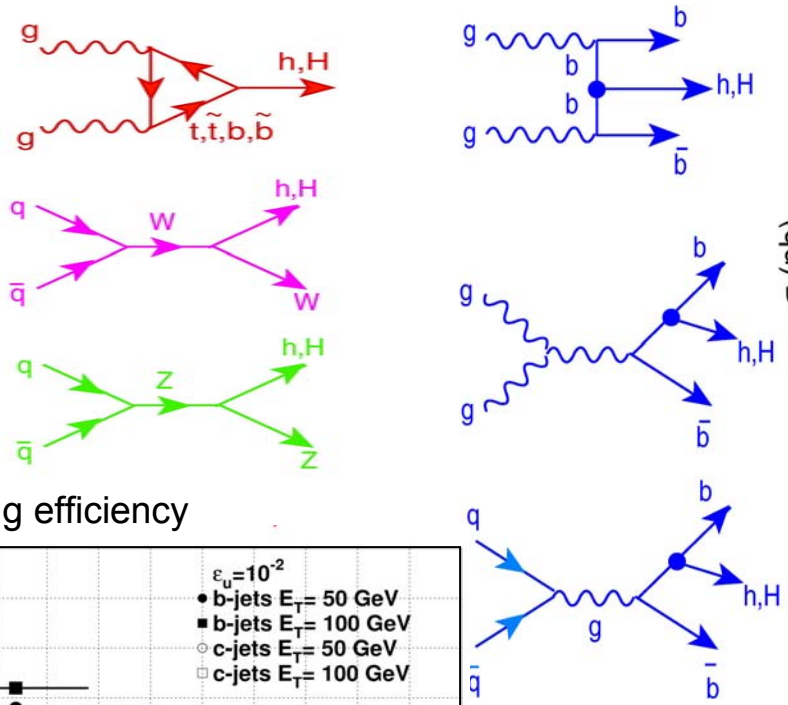
**WW, ZZ fusion (qqH final state):**
full simulation

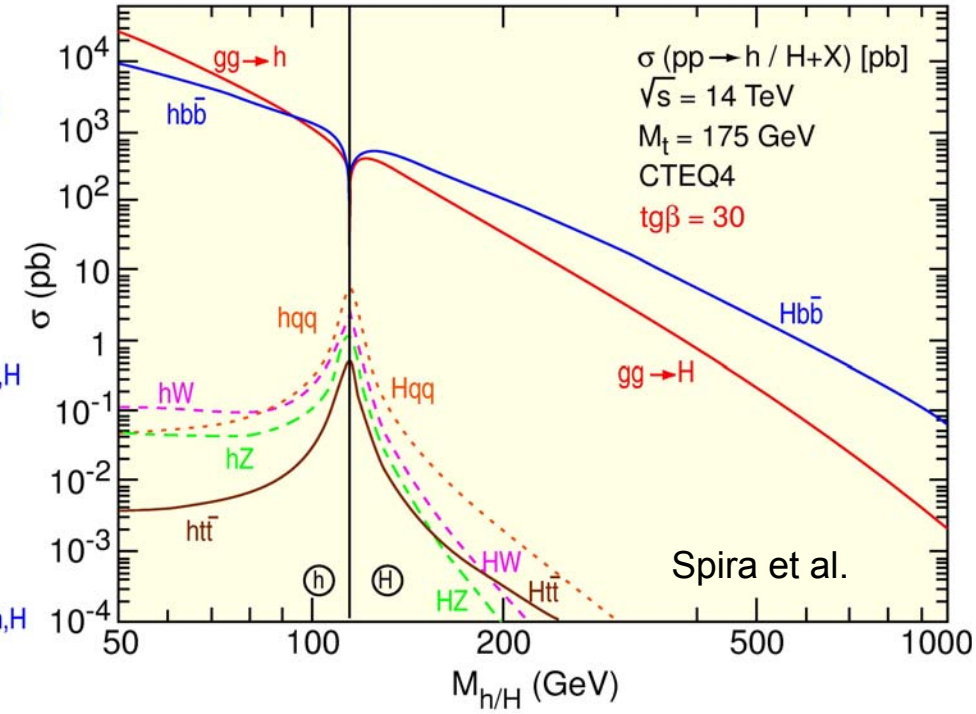
tt(j) → W b W b bkgr. considered



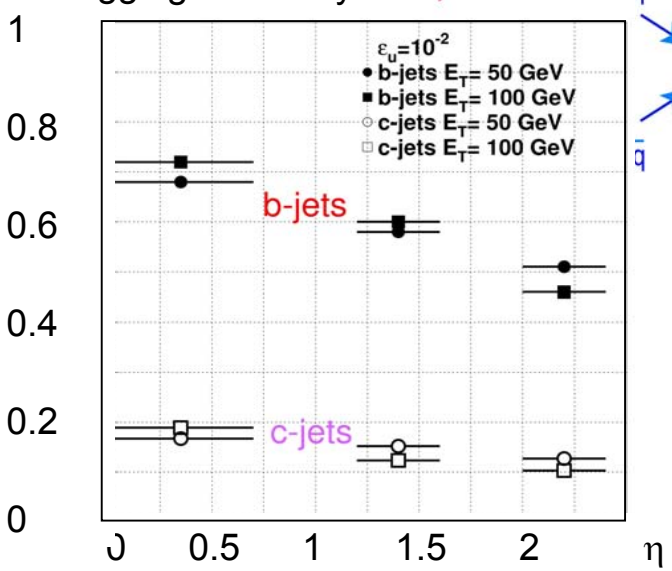



# MSSM Higgs Production




b/c tagging efficiency

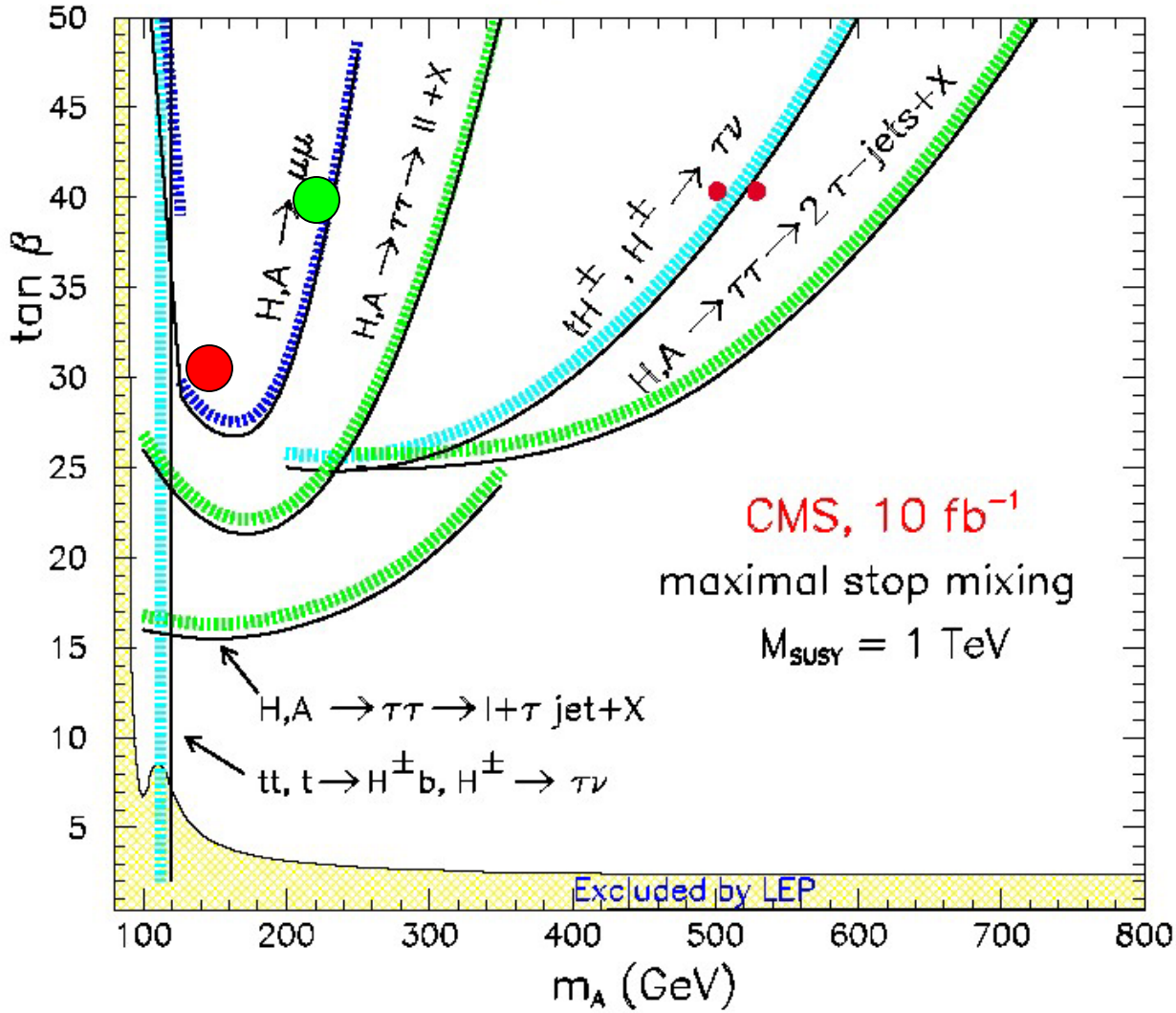



bbH final states production enhanced by $\tan^2 \beta$ in the MSSM w.r.t. SM

→ Note importance of bbH final states!

**B-tagging plays a key role**

# Heavy SUSY Higgs @ 10 fb-1




In the following:

A / H → μ μ

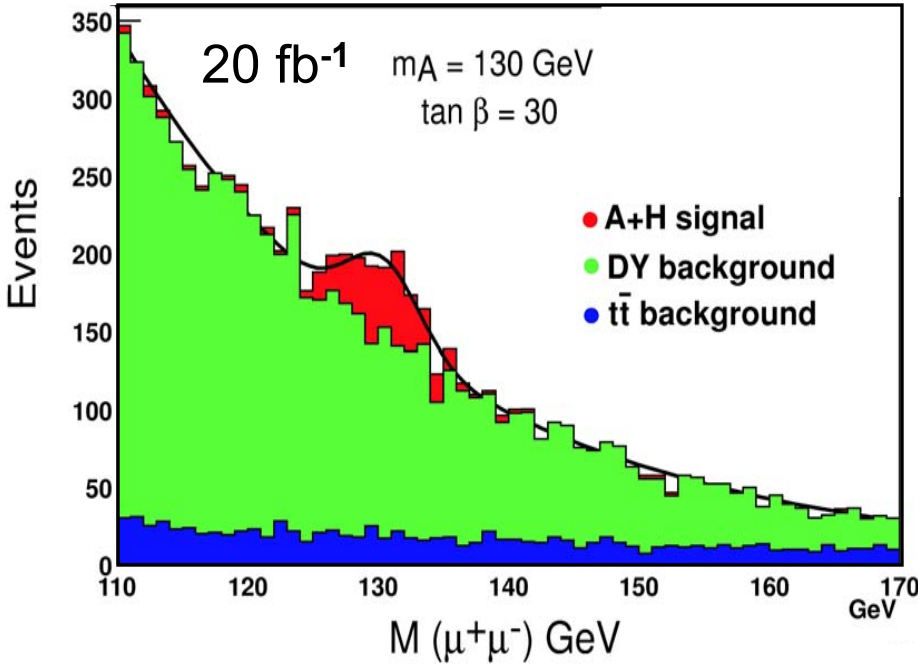
tan β=30, $m_A$=130 GeV

A / H → τ τ

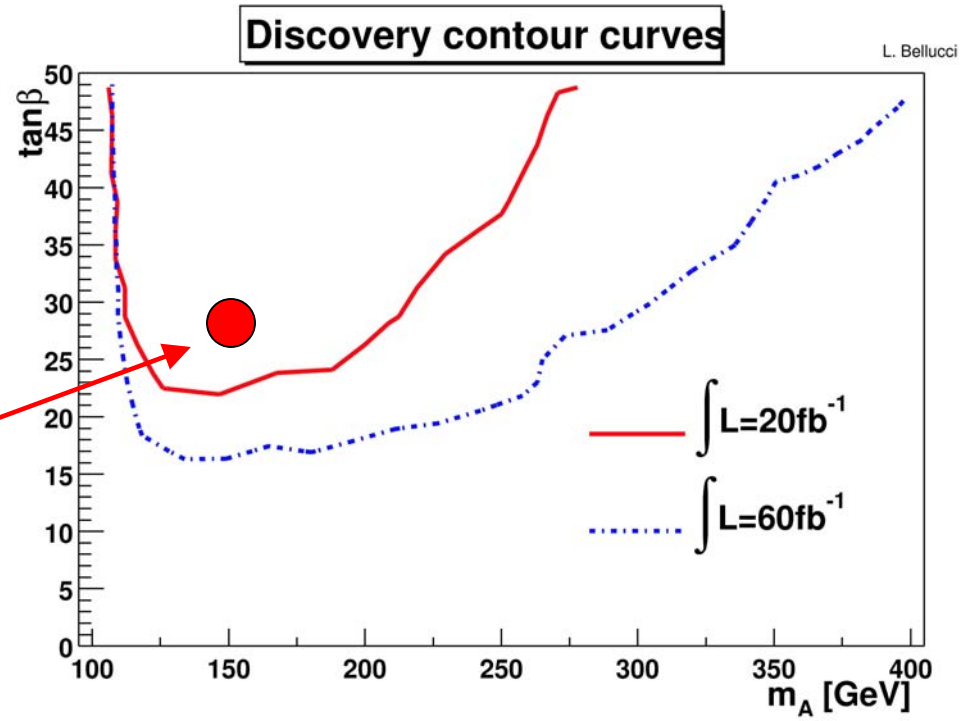
tan β=40, $m_A$=200 GeV

# A / H → μ μ in $bbH_{SUSY}$ Production

Dimuon invariant mass




Full simulation
ORCA reconstruction




**Search already possible with 10 $fb^{-1}$**

Requires b-tagging, efficient track reconstruction without ultimate track reconstruction resolution

# A / H → τ τ → 2 leptons

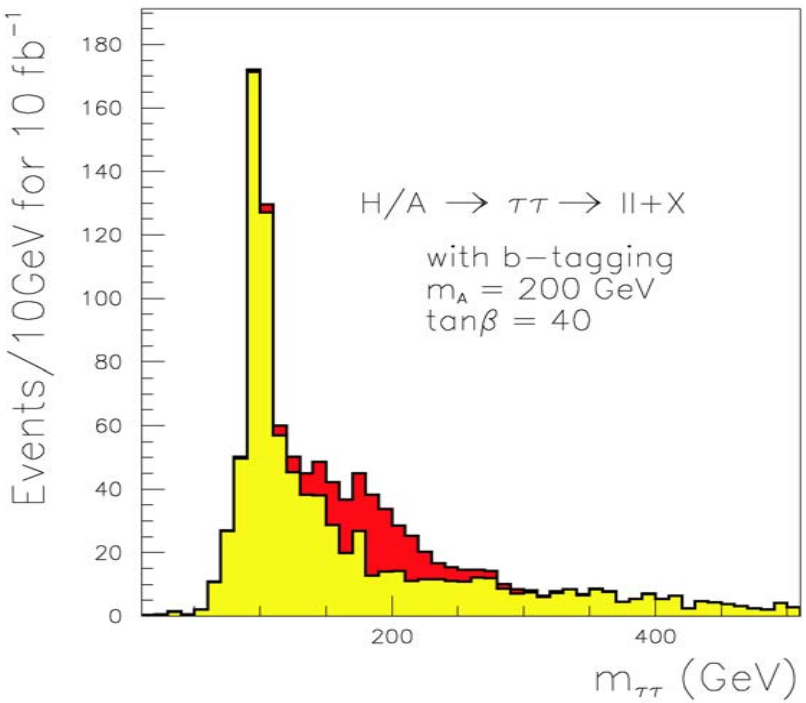
Fast simulation + parametrization of b- and tau-tagging

Signal: 1st and 2nd leptonic decay

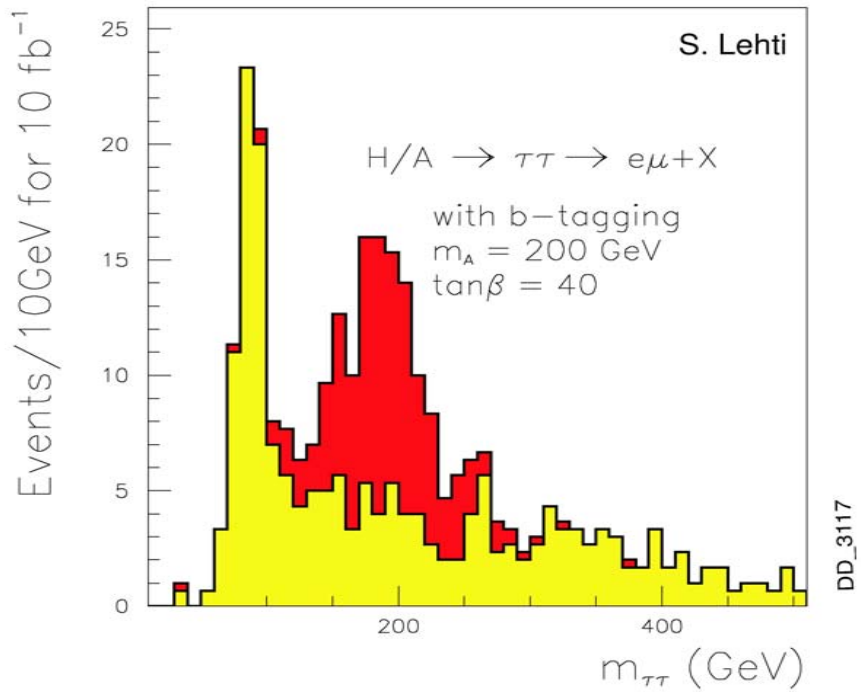
Backgrounds: Z, γ, tt, Wtb

$m_A = 200$ GeV, $\tan\beta = 40$, 10 $fb^{-1}$

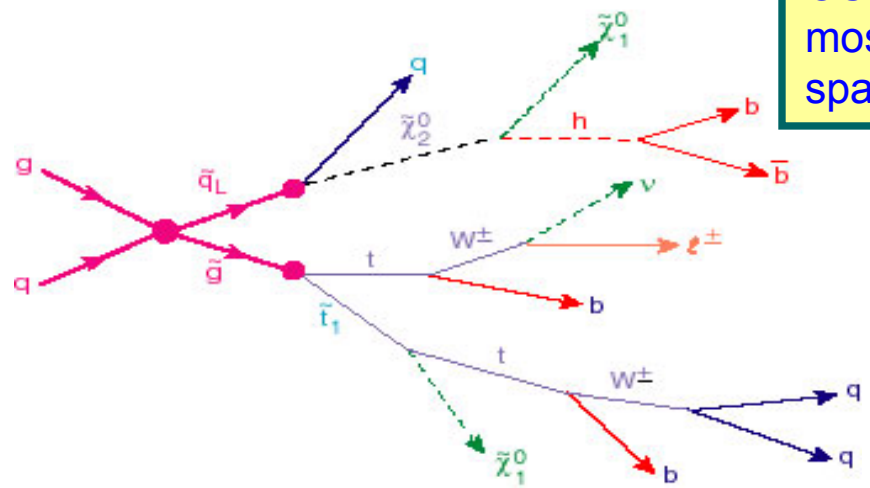
H / A → τ τ → l l + X




H / A → τ τ → e μ + X



# SUSY Signatures




Squark, gluino production leads to lepton(s) + $E_T^{miss}$ + jets

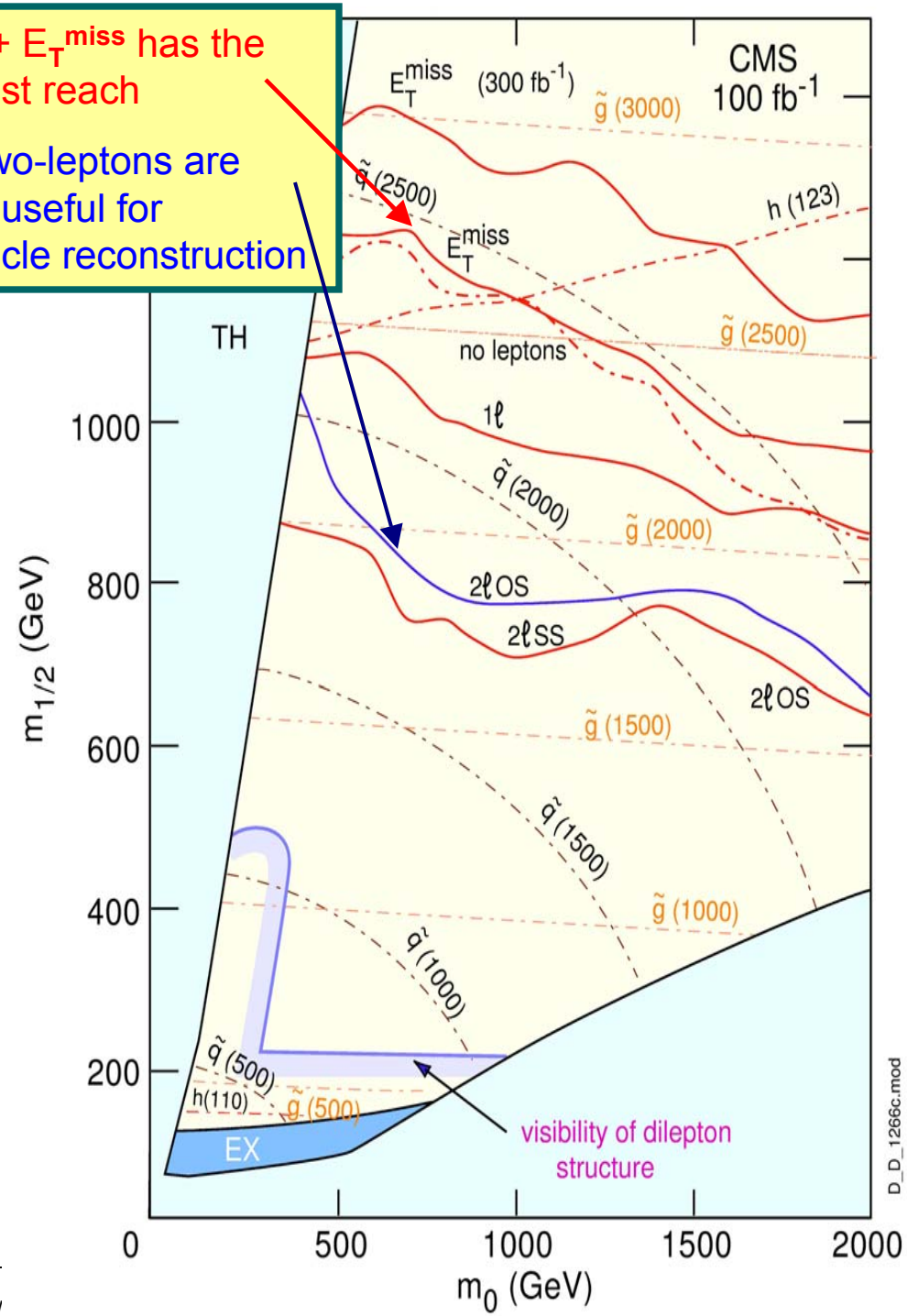
Backgrounds: W + jets, Z + jets, tt, Wtb, WW, WZ, …

$\tilde{q}$, $\tilde{g}$ pair production dominates the total cross section

Cross sections don't vary much with $\mu$, tan $\beta$

Jets + $E_T^{miss}$ has the highest reach

OS two-leptons are most useful for sparticle reconstruction

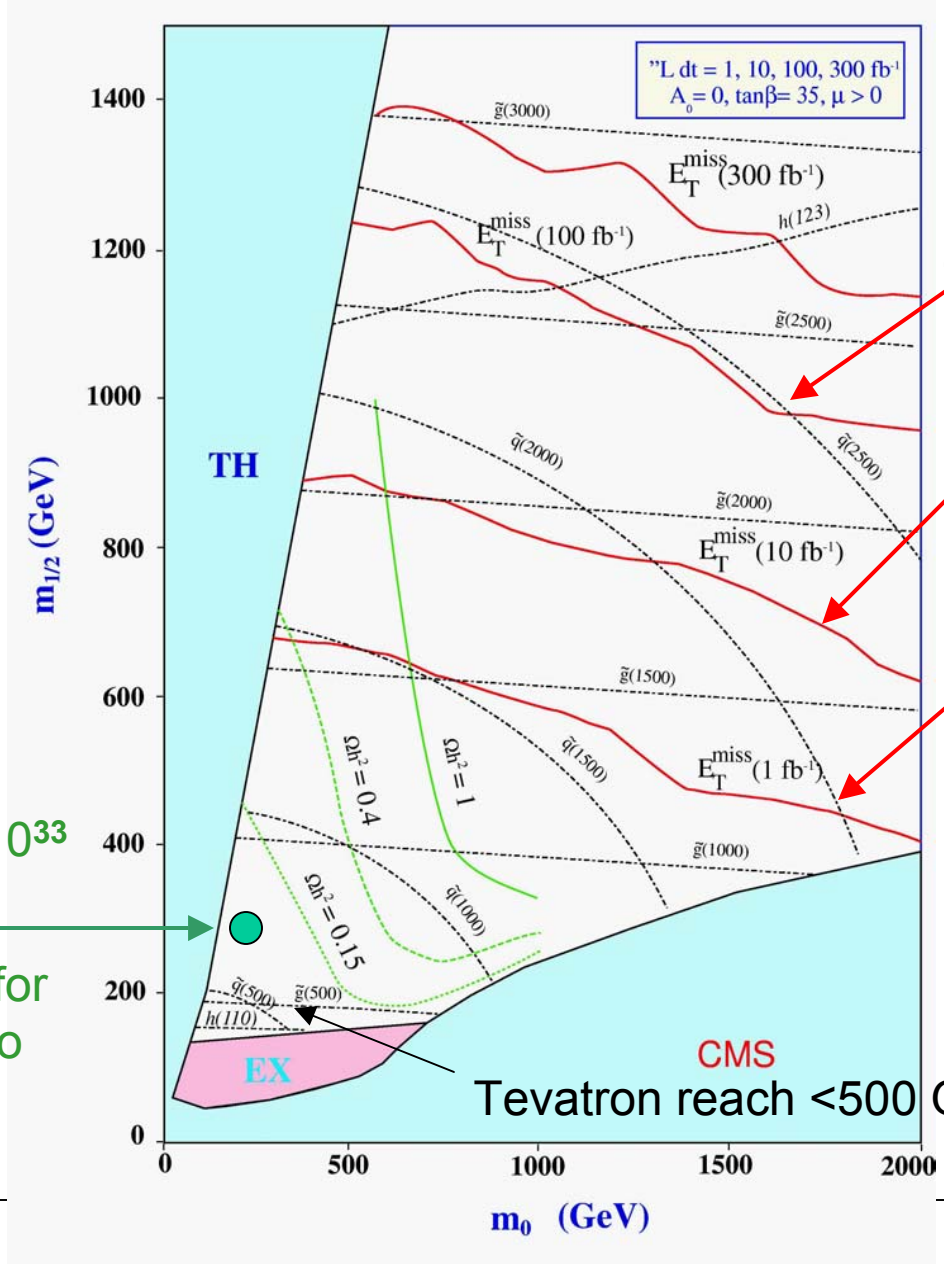


# Jets + $E_T^{miss}$ Reach vs. $\mathscr{L}$

Search for SUSY can start very early!

Squarks/gluinos probed to ~1.5 TeV with 1 $fb^{-1}$

Up to 2.5 TeV at design luminosity and 100 $fb^{-1}$




~1 year @ $\mathscr{L}=10^{34}$

~1 year @ $\mathscr{L}=10^{33}$

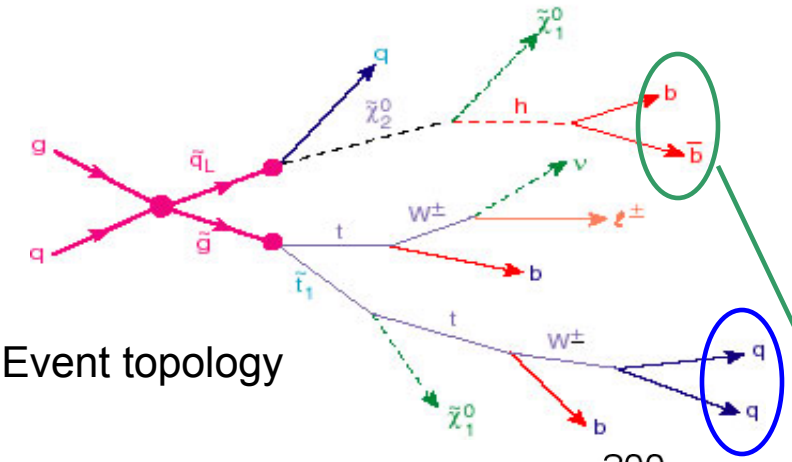
~1 month @ $\mathscr{L}=10^{33}$

~1 week @$10^{33}$ to explore

but ~1 year for sparticle reco

Tevatron reach <500 GeV

# h → $b\bar{b}$ production in squark/gluino cascades

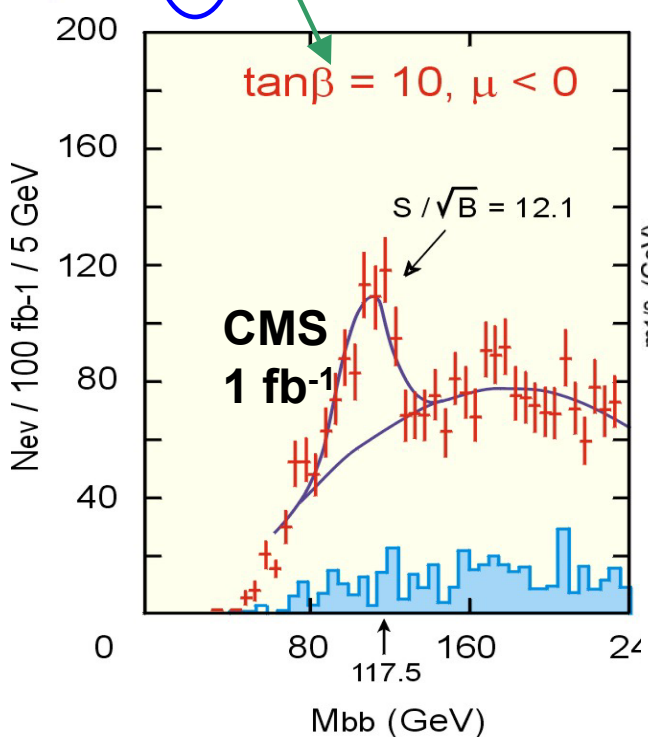



Event topology

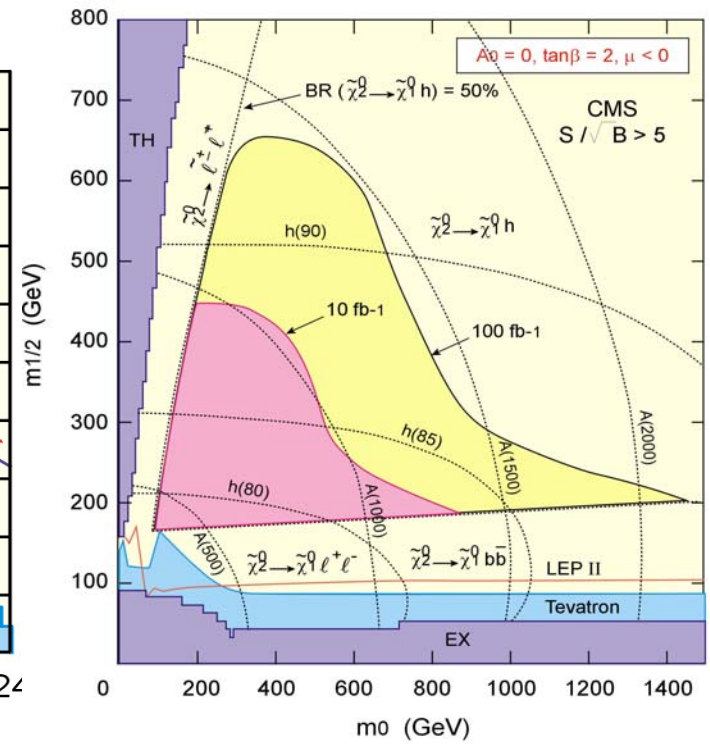
Signature: B-jets + lepton + $E_T^{miss}$

→ Requires b-tagging + jet counting + full calo coverage for $E_T^{miss}$

**Search can start at 1 fb$^{-1}$**




Low tan β regime



# Conclusions & Outlook

**Most detector components will be ready**

**Commissioning will be a big task**

**SUSY could appear early on**

**SM Higgs in 4 muon channel at 10 $fb^{-1}$**