SiCILIA SiC applications for HL-LHC

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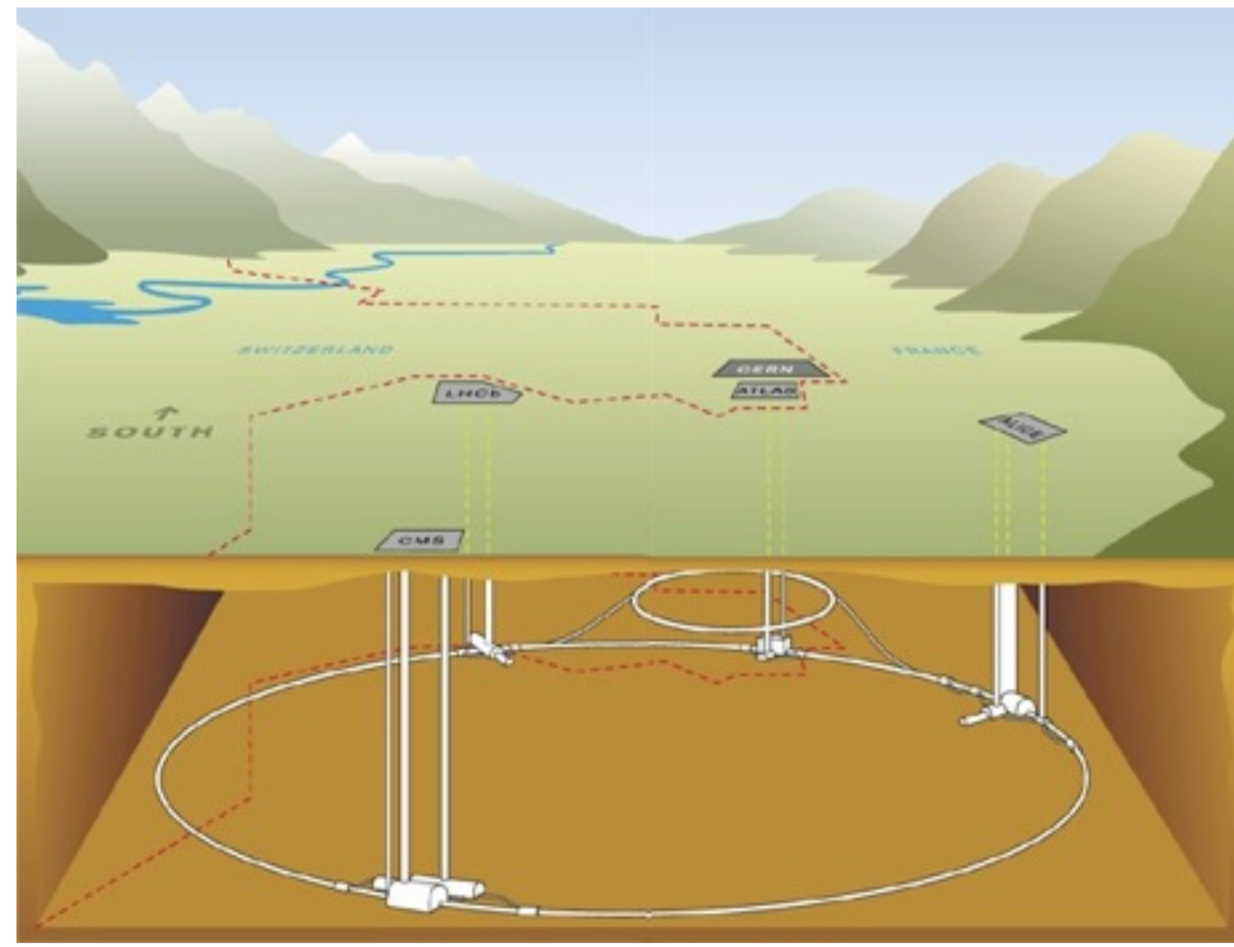
Overview

1. Introduzione a LHC
2. High-Luminosity LHC (HL-LHC)
3. Pile-up mitigation
4. Timing pre-shower (ATLAS and CMS)
5. 10 ps proton tagging (AFS-ATLAS and PPS-TOTEM)
6. Conclusions
7. Last comment

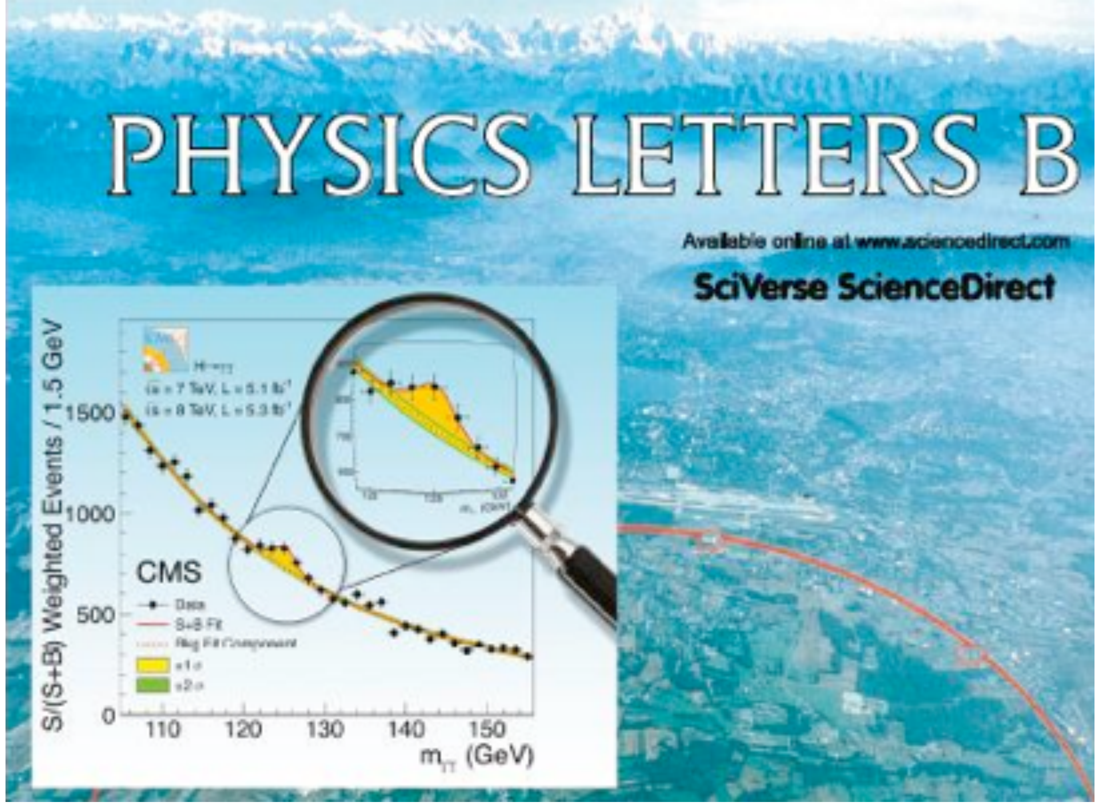
LHC: la frontiera dell'energia



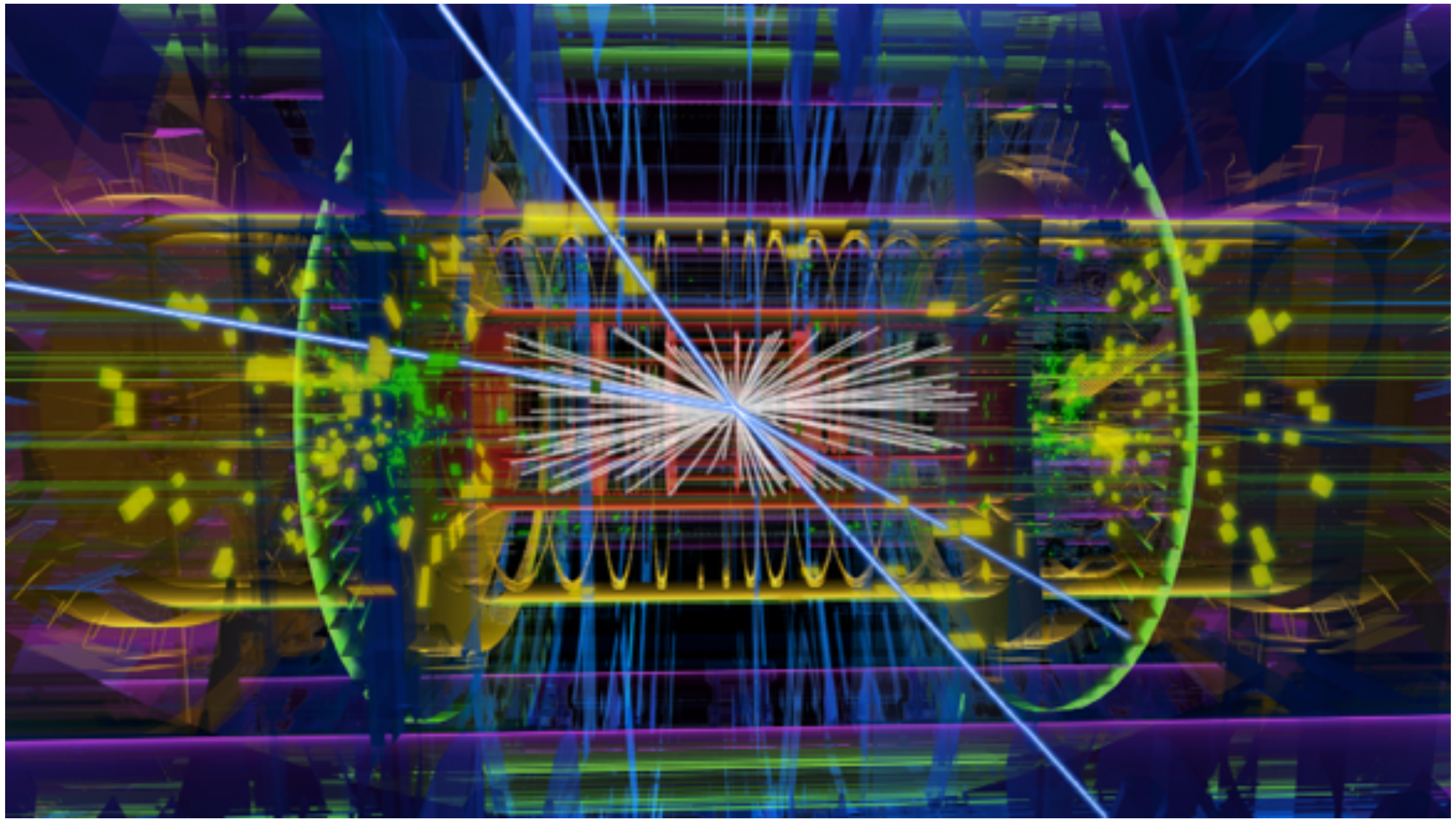
Il Large Hadron Collider al CERN di Ginevra e' collocato a 200 metri sotto terra, ha un circonferenza di 27 km, accelera due fasci di protoni in direzioni opposte in due anelli distinti fino ad energie di 14000 GeV ed ha quattro punti di interazione con altrettanti esperimenti.

Scoperta del bosone di Higgs

Scoperta del bosone di Higgs a 126 GeV di massa (premio nobel 2013 ai teorici che lo ipotizzarono 40 anni fa per spiegare la massa delle particelle elementari e dei mediatori della forza elettrodebole).

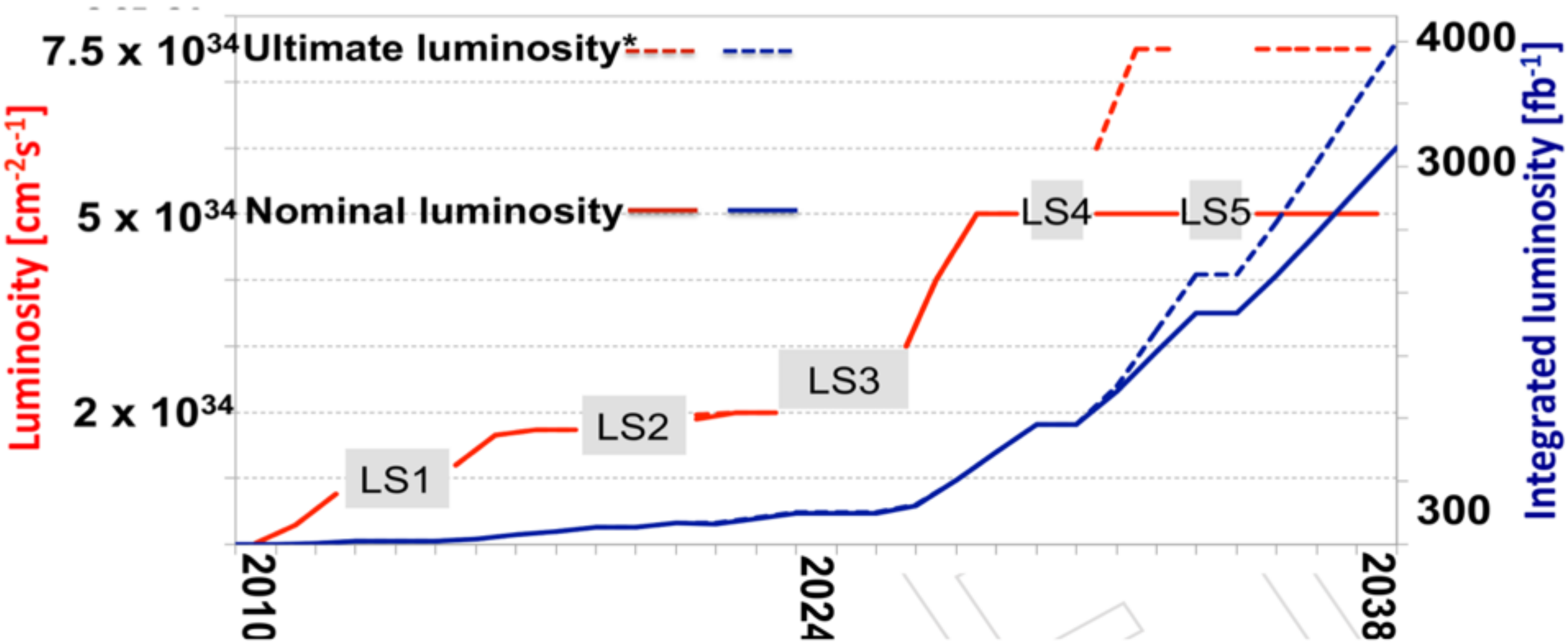


Accumulo di eventi corrispondenti al decadimendo del bosone di Higgs in due fotoni



Evento ricostruito in cui l'Higgs decade in 4 muoni

HL-LHC schedule

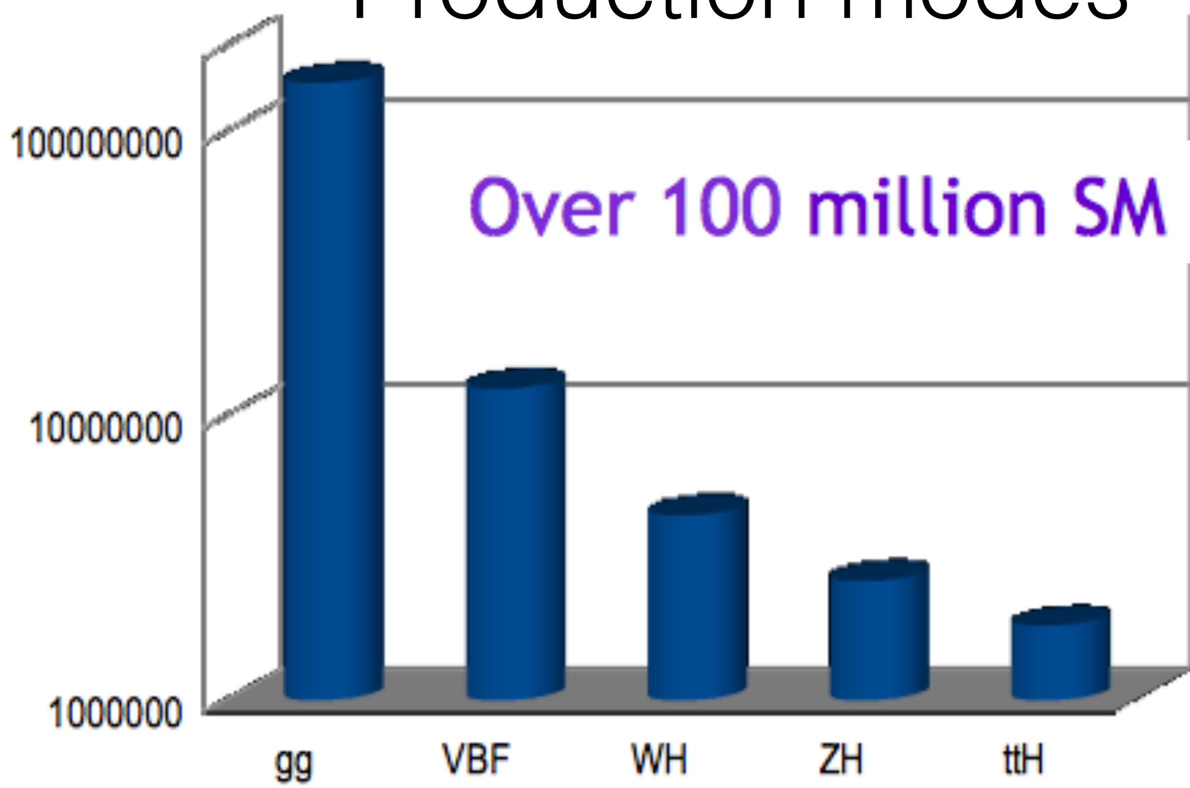


HL-LHC Physics

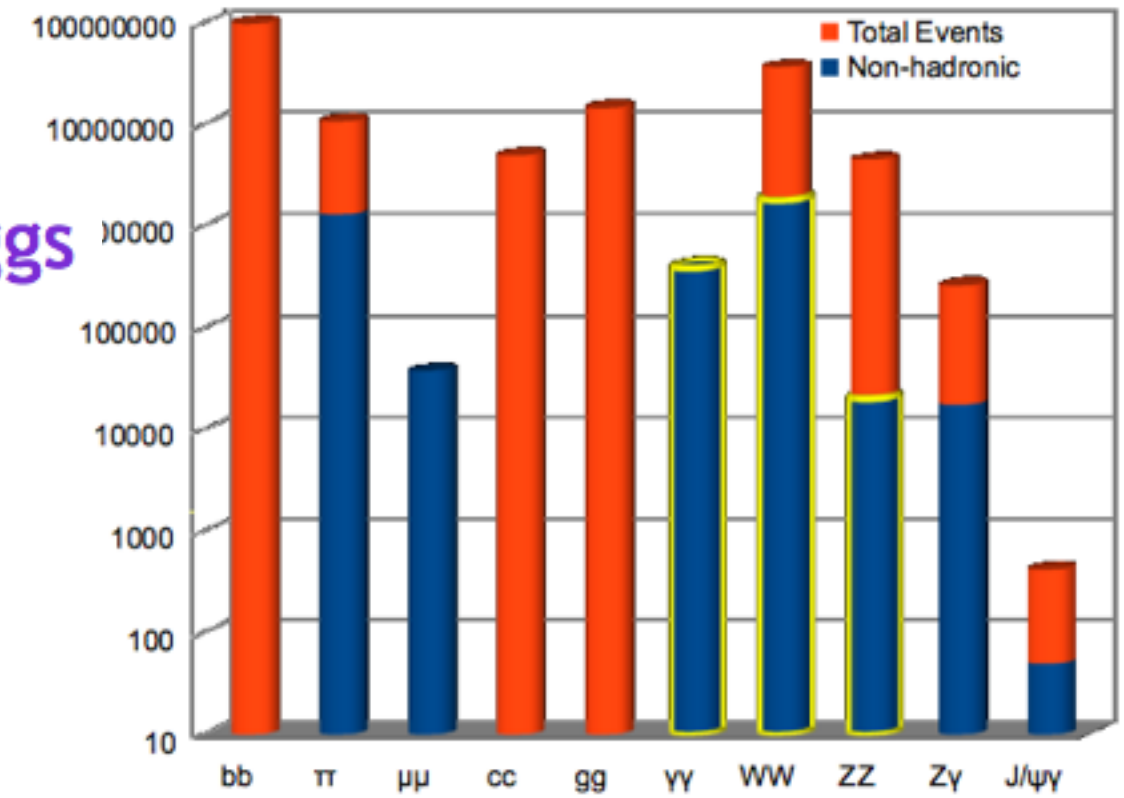
A Higgs boson factory with 3000 fb^{-1}

Production modes

Over 100 million SM Higgs



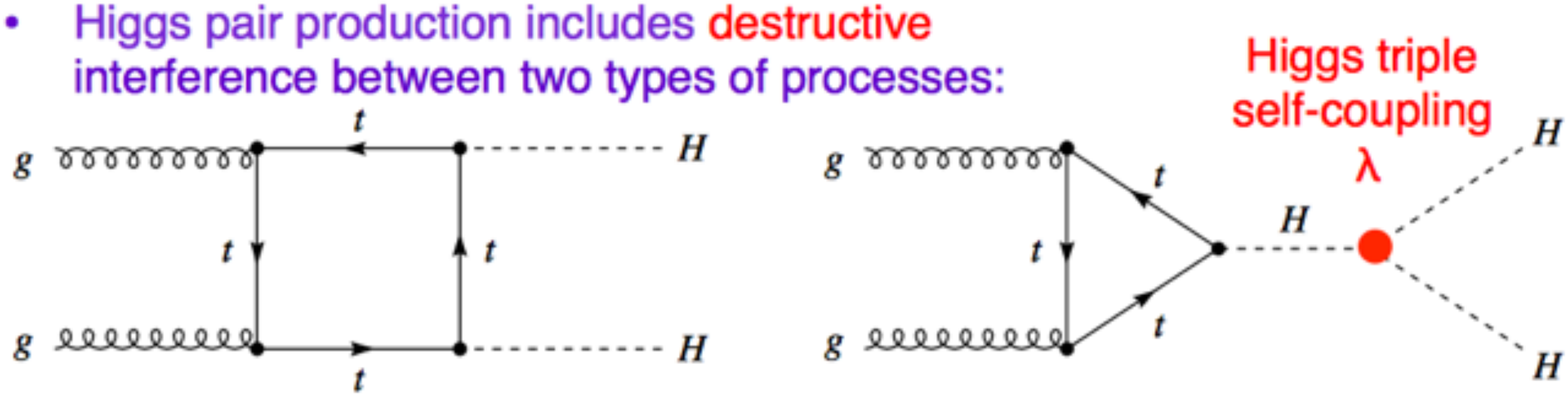
Decay channels



Higgs pair production

NNLO σ^{SM}=40.8 fb

- Higgs pair production includes destructive interference between two types of processes:

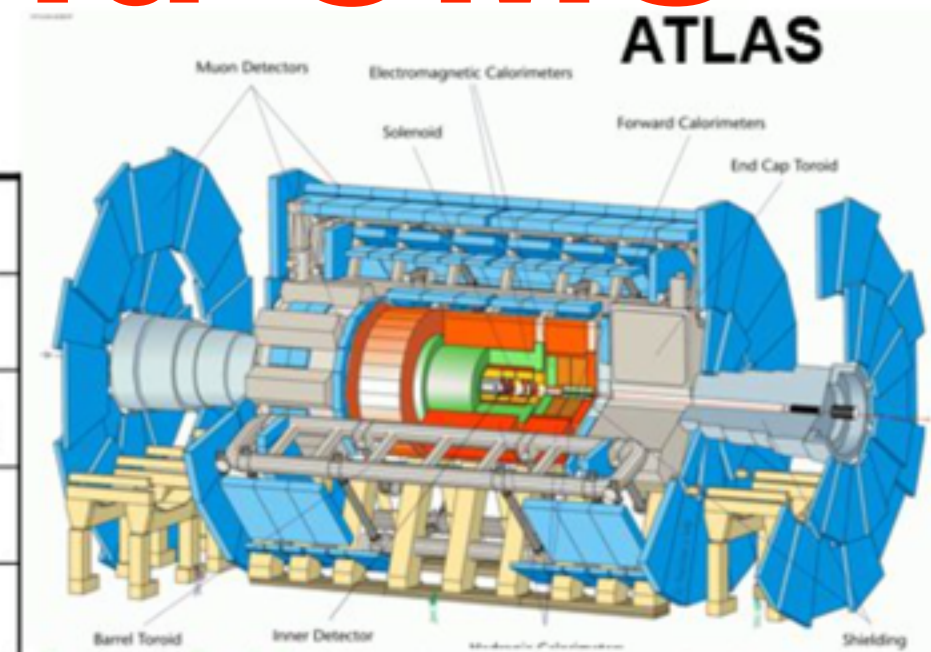


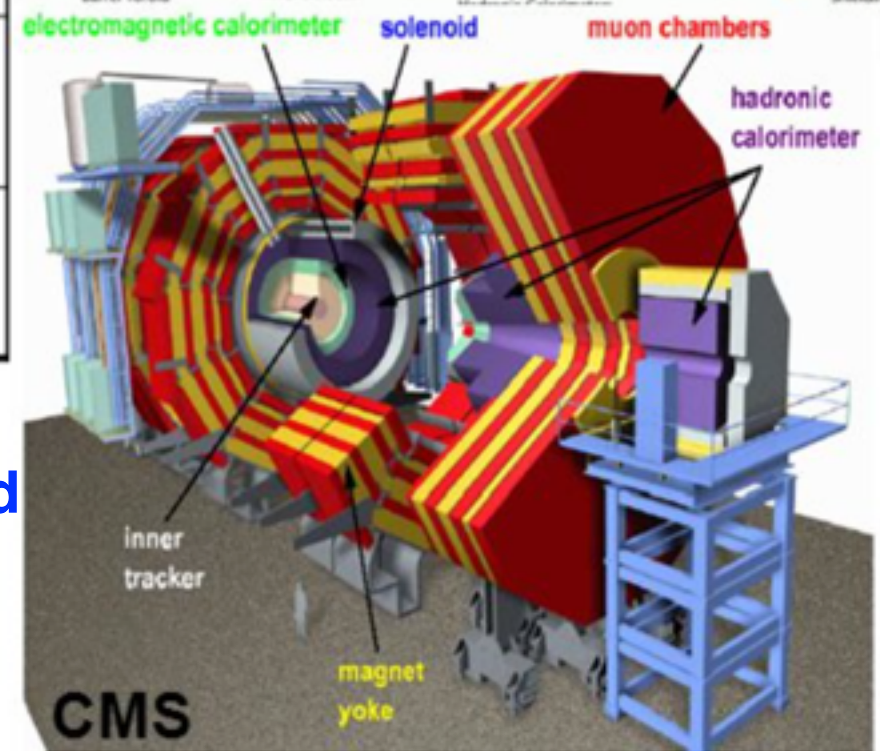
Number of events	
bbWW	30000
bbττ	9000
WWWW	6000
γγ bb	320
γγγγ	1

ATLAS and CMS

- Two different approaches for detectors

	ATLAS	CMS
tracking	Silicon/gas	Silicon
EM calo	Liquid Argon	PbWO cristals
Had calo	Steel/scint, LAr	Brass/scint
Muon	RPCs / drift	RPCs / drift
Magnet	Solenoid (inner) / Toroid (outer)	Solenoid
B-field	~ 2 Tesla / 4 Tesla	~ 4 Tesla

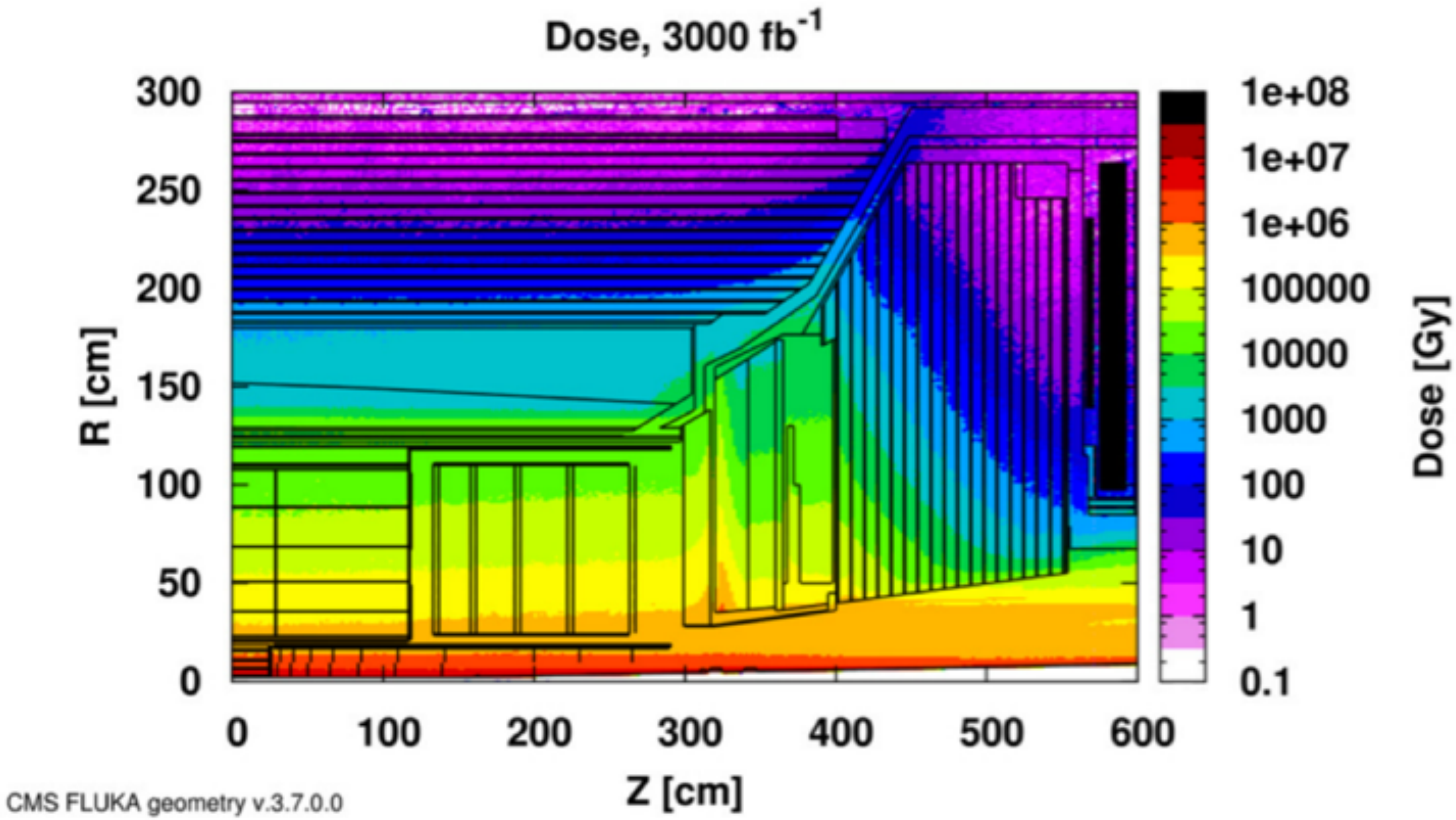




- **Tracker full replaced for HL-LHC (Si strips and pixel only technology)**
- **CMS calorimeter mostly full replaced**
- **Electronics and trigger full replaced for most all subdetectors**

Radiation dose: what next

HL-LHC=10 x LHC (phase I end in 2019)



CALO Barrel=150 Mrad
CALO Endcap = 3.2 Grad
Strip = 100 Mrad
Pixel = 1 Grad

1 Gy = 100 rad

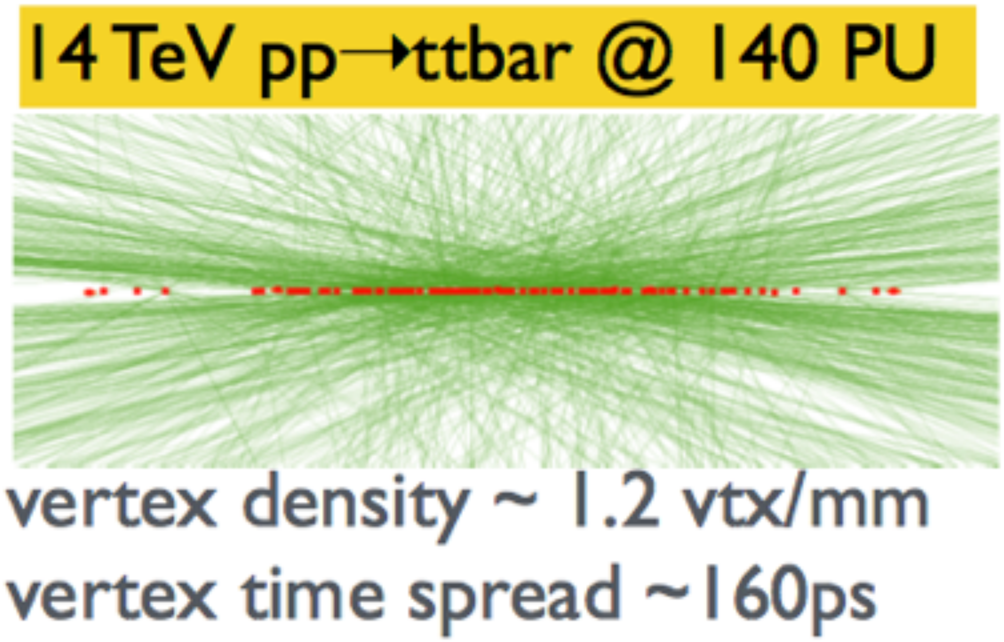
10 MGy = 1Grad =2.5E15n(1MeV)/cm2=5E15p(10GeV)=2GHz/cm2

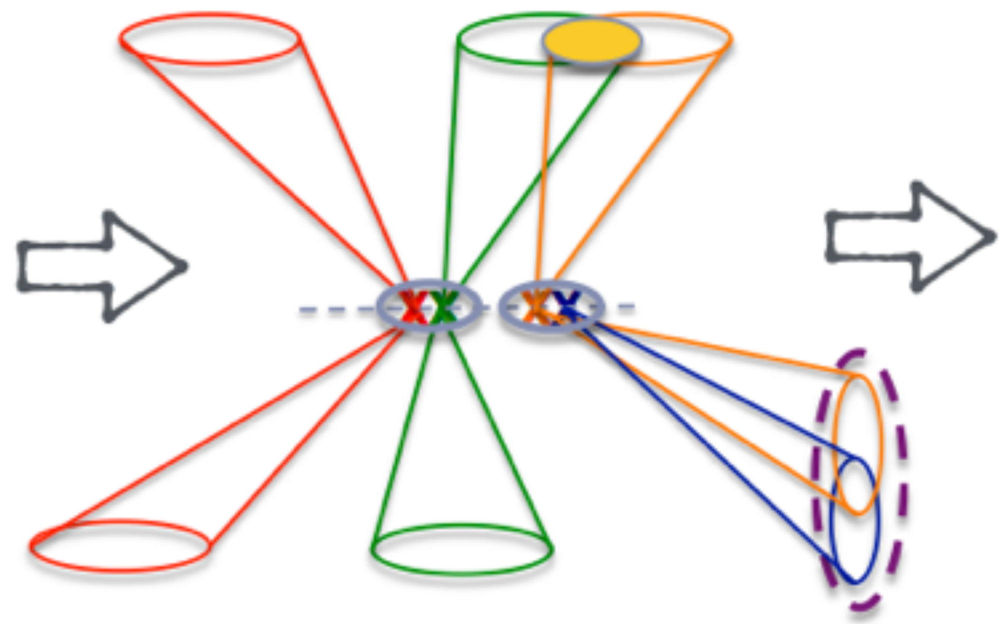
All detector technology must improve granularity, radiation resistance, readout rate (not only vertex detector)

PILE-UP MITIGATION

HL-LHC leveled luminosity con crab-kissing:
140 primary vertexes (1.25/mm) contro i 26 (0.2/mm) di ora

Interaction Region ogni 25 ns





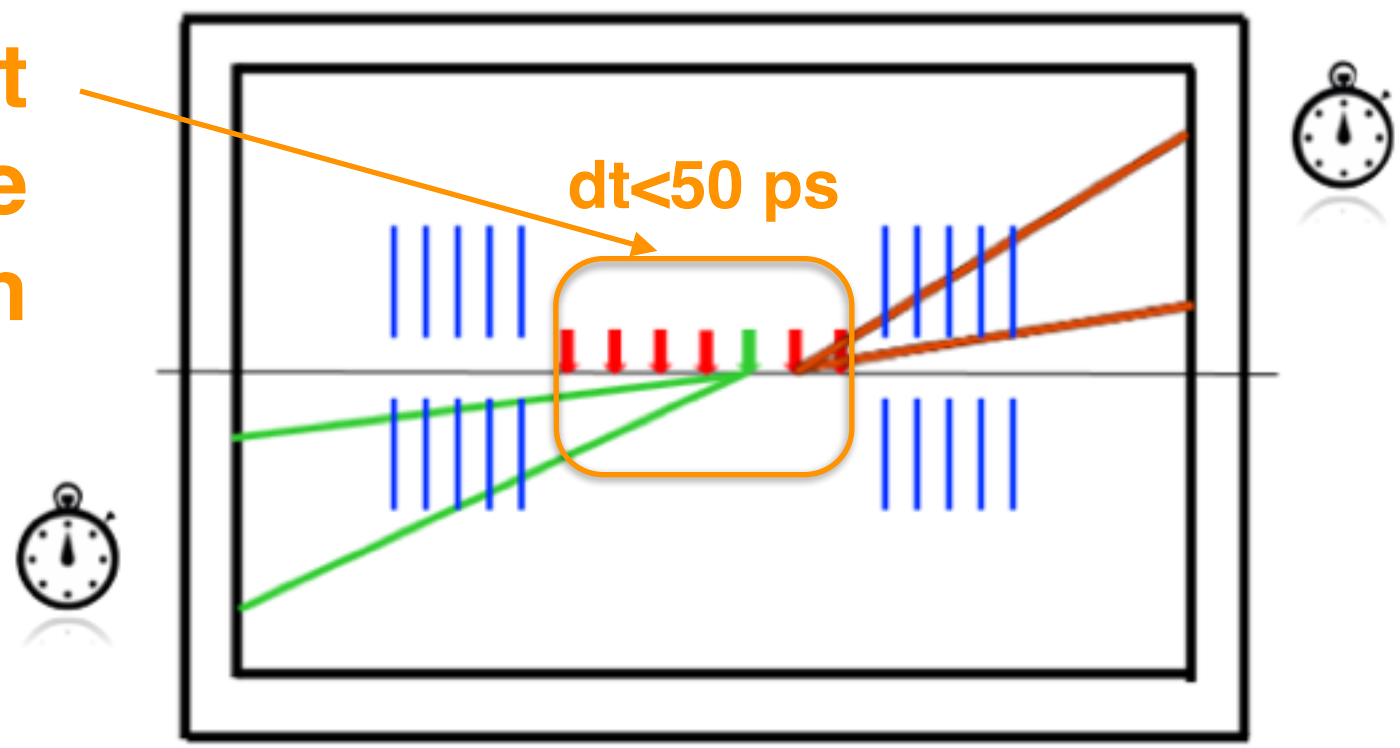
Assign to physical object the right vertex.
Tagging PU vertex (but also neutrals):

- **High granularity and high rate**
- **Large forward extended coverage**
- **Timing (Very Challenging, next slides)**

TIMING against PILE-UP

Extreme timing capability (20-50ps) on the objected associated to one vertex

It is enought one active surface with good timing.



Timing resolution not needed for 1 MIP but for:

- **Many MIPS crossing the some detector elements or one MIP (Timing scale like number of MIPS)**
- **Many MIPS crossing different detector elements (Timing scale like square root of number of MIPS)**

Fast timing: CMS

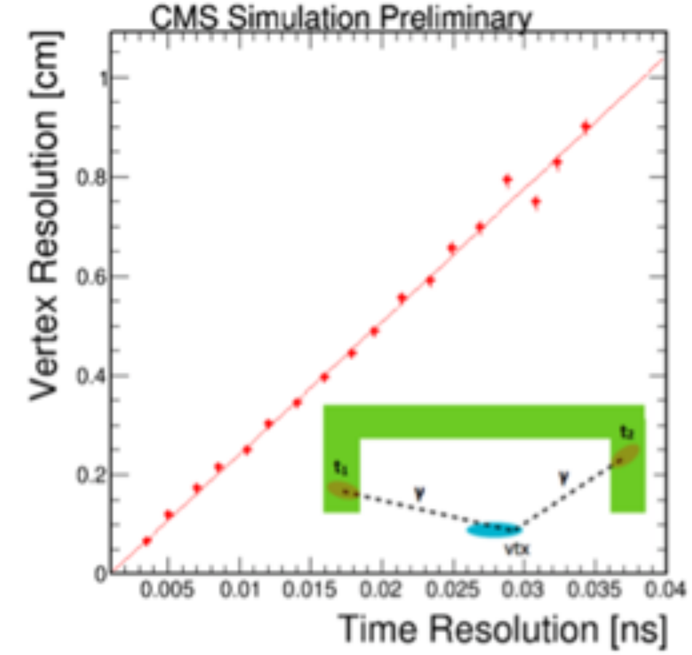
CMS: developing the idea of "hermetic timing" for γ (possibly up to low p_T) and charged tracks between $0<|\eta|<3$

CALO UPGRADE

Opportunistic use of calorimeter upgrades:

- **ECAL EB ($0<|\eta|<1.5$):** $PbWO_4$+APD upgrade electronics aims at ~30ps above >30-40 GeV γ (no low energy γ PU rejection)
- **HGC EE ($1.5<|\eta|<3$):** electronics should allow ~50ps for energy hits >10 MIPs (>50 hits above threshold for γ>50 GeV, <50ps also for low p_T γ).
  Possibility for a MIP fast timing layer

high energy γ fast timing: di-photon $H\rightarrow\gamma\gamma$ vertex location



TRACKER UPGRADE

Also studying a dedicated timing detector in the tracker volume. 2 options:

- **Fast timing layer in tracker (MIP):** Low-Gain avalanche detectors, hyper fast APD, MPGD
- **Pre-shower in front of EB (MIP+γ):** small crystal (e.g. LYSO)+SiPM, I-MCP

G. Gaudio and P. Meridiani — IFD2015 - Dec. 16-18th, 2015 17

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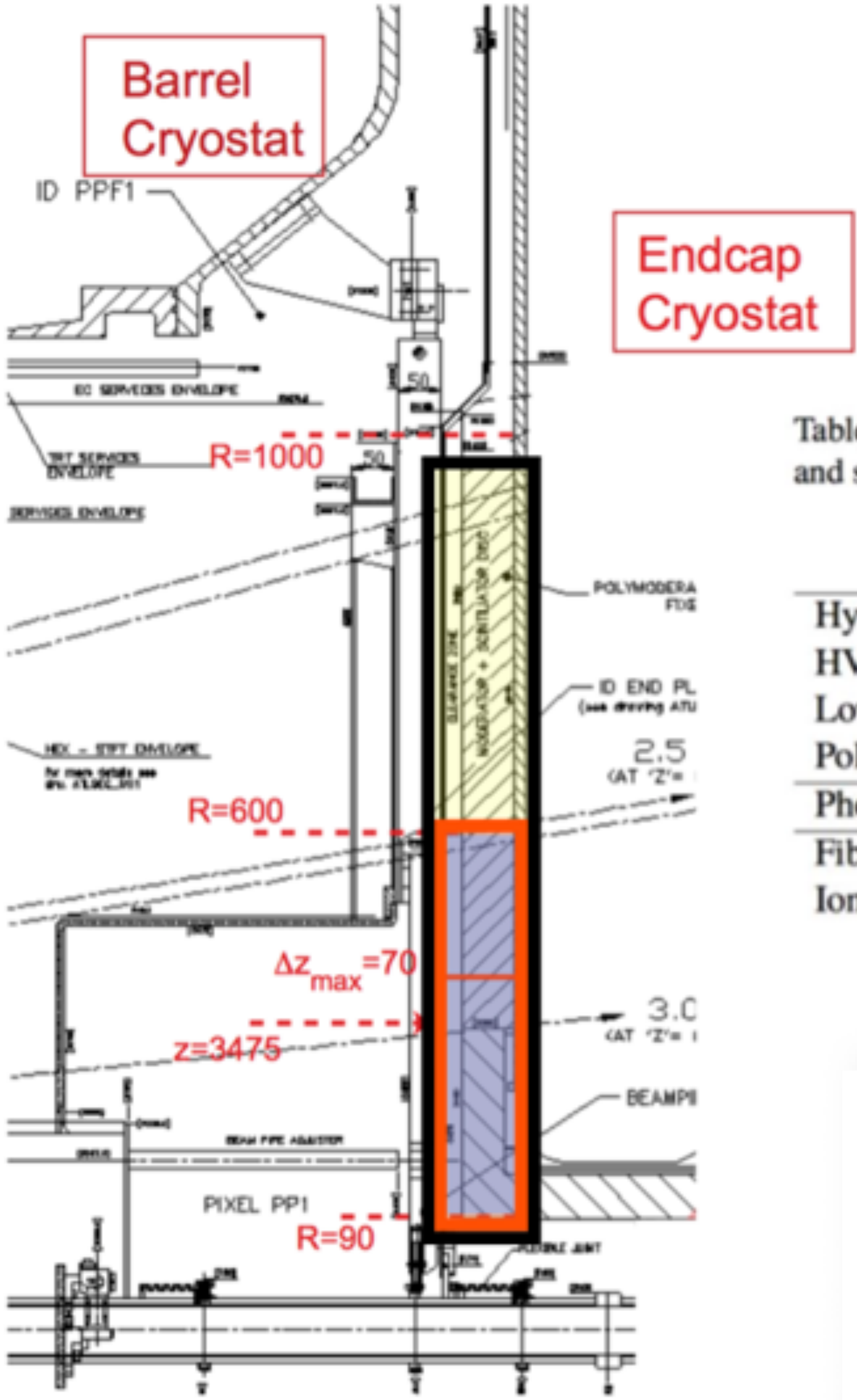


1mm x 1mm spatial segmentation

ATLAS: high granular fast timing detectors in the region between barrel & endcap cryostat

baseline 4 layers @ 2.5<|η|<4.3, possibly a 3-4 X_0 pre-shower using W absorber

Table 3: Possible performance of several detector technologies to be deployed for a timing detector after a dedicated and successful R&D program is completed.

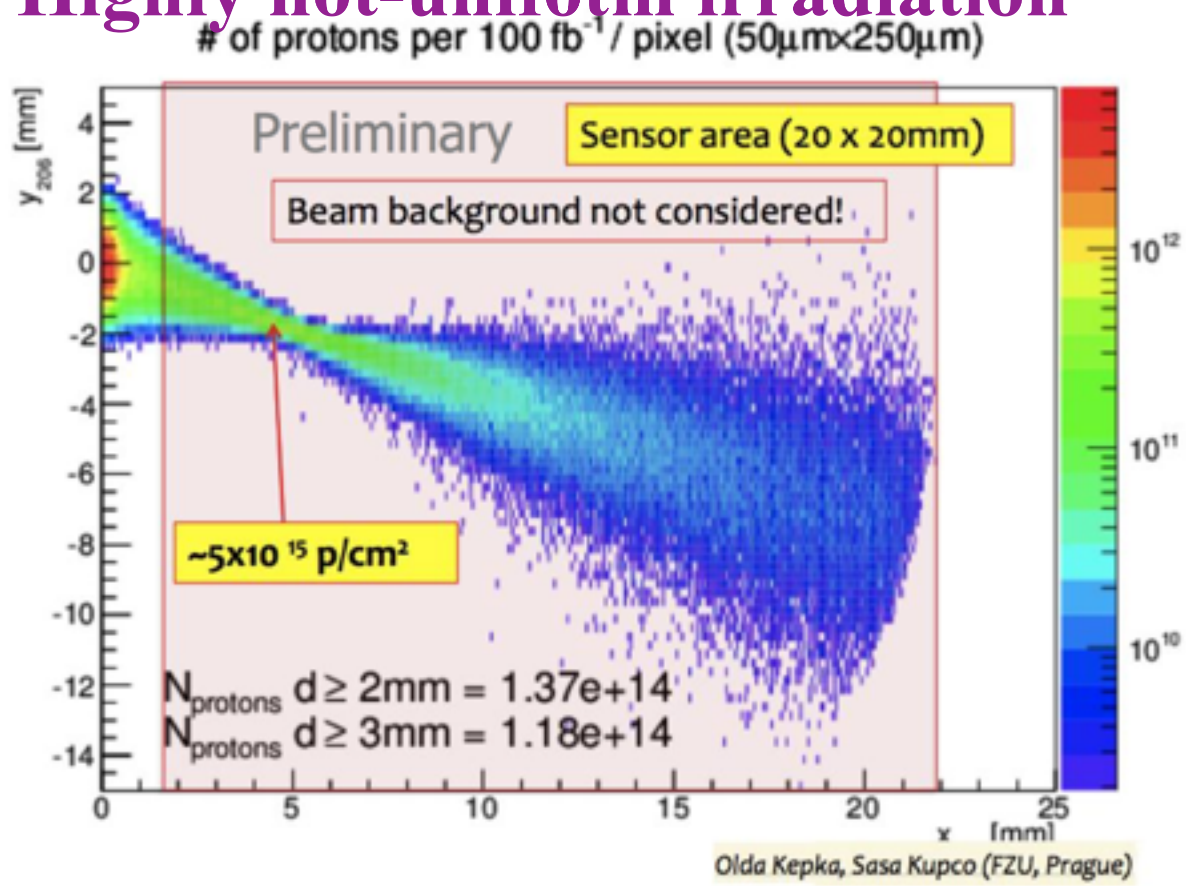
	Area	Resolution/MIP		Noise	Efficiency/MIP	Max. Dose
	[mm^2]	Time [ps]	Space [μm]	[e^- rms]		[Mrad]
Hybrid pixel	20×20	100	10	100	1	1000
HVCMOS pixel	20×20	100	10	30-100	1	1000?
Low-Gain Avalanche Detector		10	10-50	-	1	100?
Poly-diamond strips	5×5	100	10	500	1	1000?
Photocathode MCP	50×50	10	100		photon statistics	0.3?
Fiber bundle	1000×50	50	100		photon statistics	10-100?
Ionization MCP	200×200	30	100	100	0.7	100?

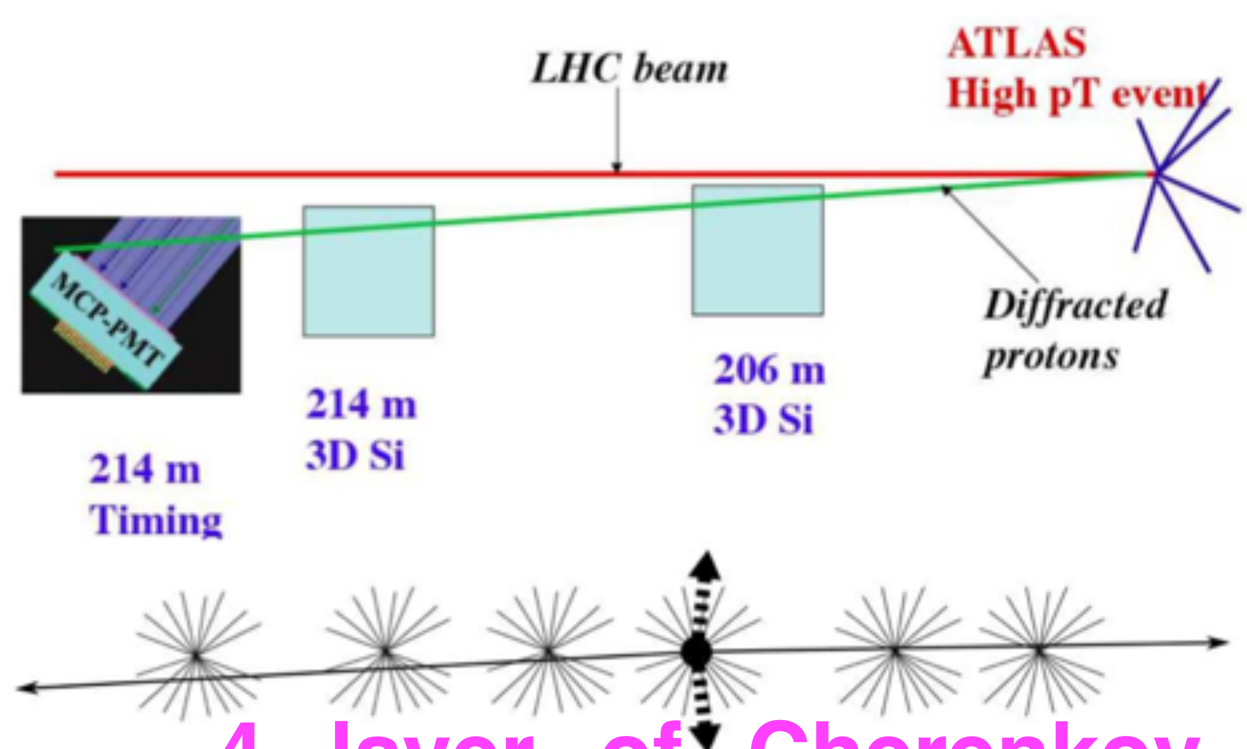
REPLACE MINIMUM BIAS TRIGGER (SCINTILLATORS) with HIGH GRANULARITY DETECTOR (HGTD)

Forward proton tagging at 200 meter from IP

- The ATLAS Forward Physics Project (AFP) and the Precision Proton Spectrometer (PPS, CMS/TOTEM)

- Tracking to silicon pixel for missing mass resolution
- Timing to reject pile-up (dt=10ps)
- 2x2cm2 trasverse active area
- Highly not-unifotm irradiation

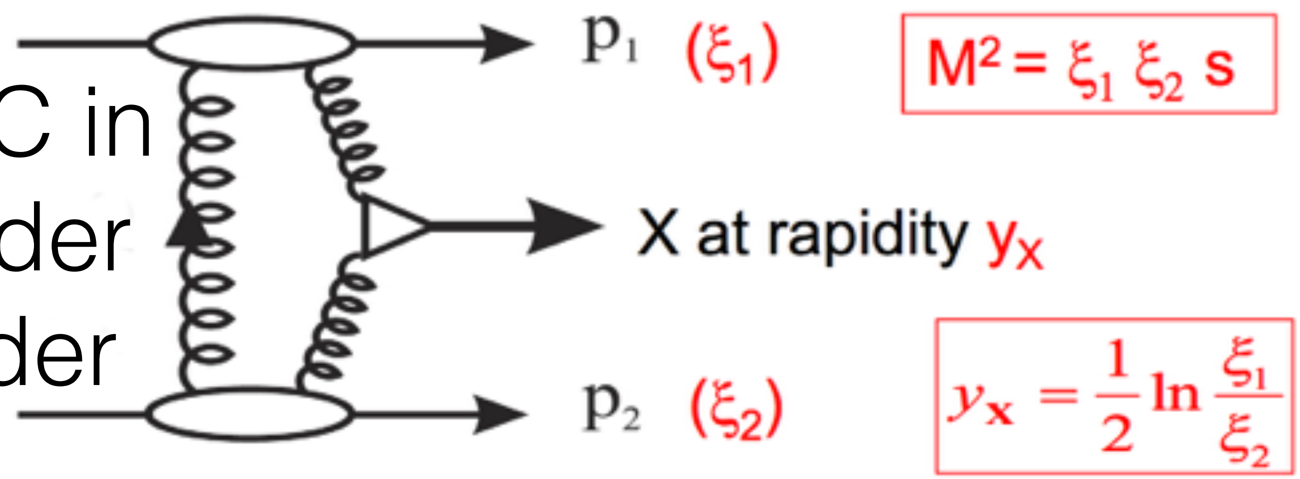




4 layer of Cherenkov radiator+MCP reached the timing performance but Rad-Hard and BG is a concern (need higher granularity)

Forward proton tagging turn LHC in gg and γγ collider

Turn LHC in
gg collider
γγ collider



Exchange of colour singlets with vacuum quantum numbers: $J^{PC} = 0^{++}, 2^{++}$

X = di-meson, di-jet, di-boson, … (unknown particles such as Monopoles)

… and the new 750 GeV γγ resonance. IF EXIST!!!

Small scale project but with relevant physics reach and HL-LHC timing test-bench

10 ps MIP timing with solid state detector

MIP timing very challenging because low signal (10000-20000 e-)

“Usable” state of the art reach 100 ps

Two detector types considered here

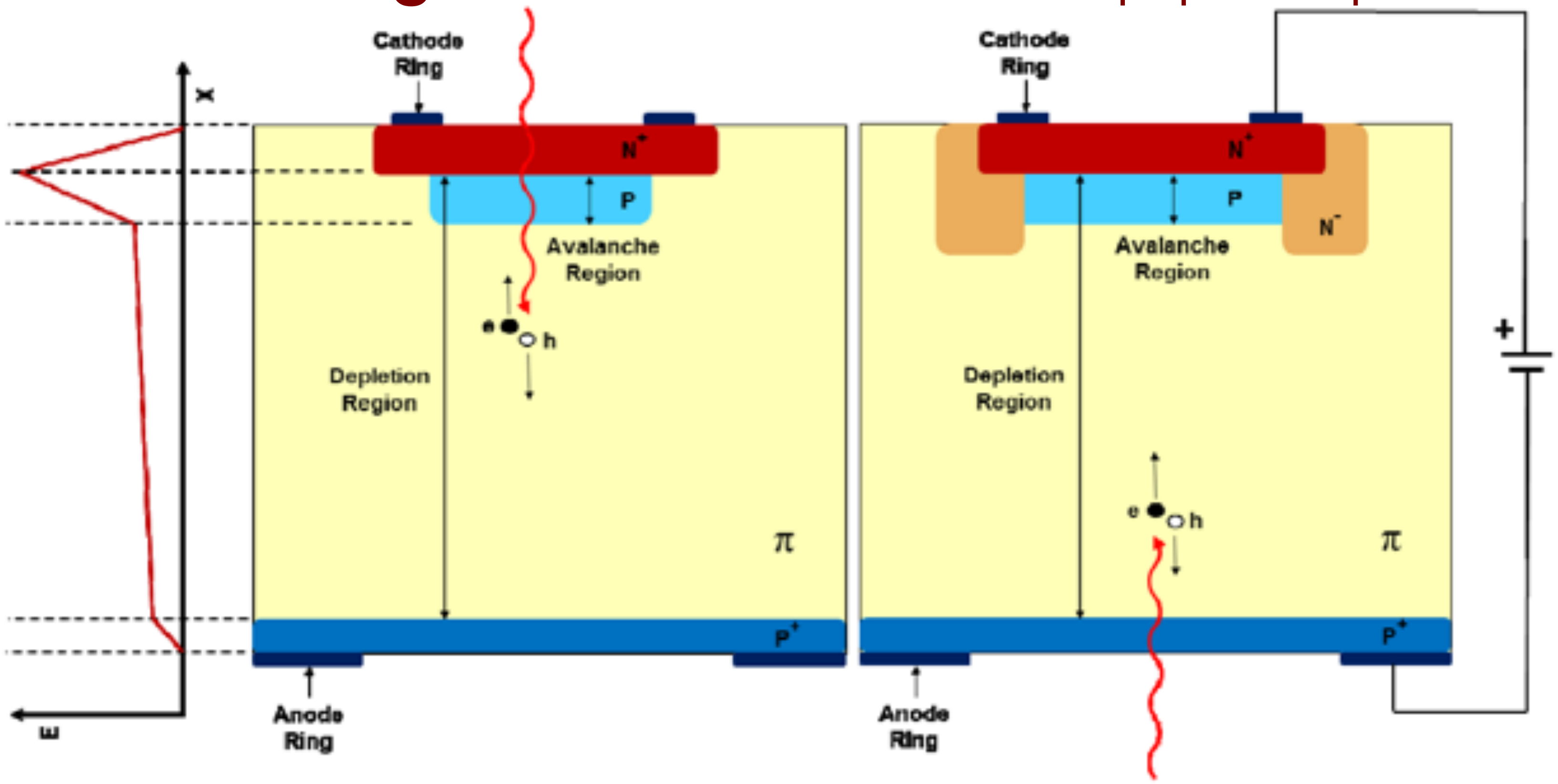
- **With gain: LGAPD**
- **Without gain: High band gap material**

LGAPD (Low gain APD)

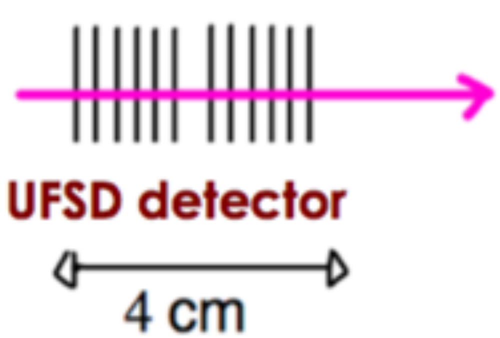
UFSD idea: pixelated silicon detector with internal gain

UFSD gain: Add an extra deep p+ implant

Ultra-fast Silicon Detector. H.-W. Sadrozinski, M. Bruzzi, N. Cartiglia et al, NIM A(2013)



- First prototypes from CNM show good gain (5-10) and excellent stability.
- A second generation under way in collaboration with FBK (Torino e Firenze)



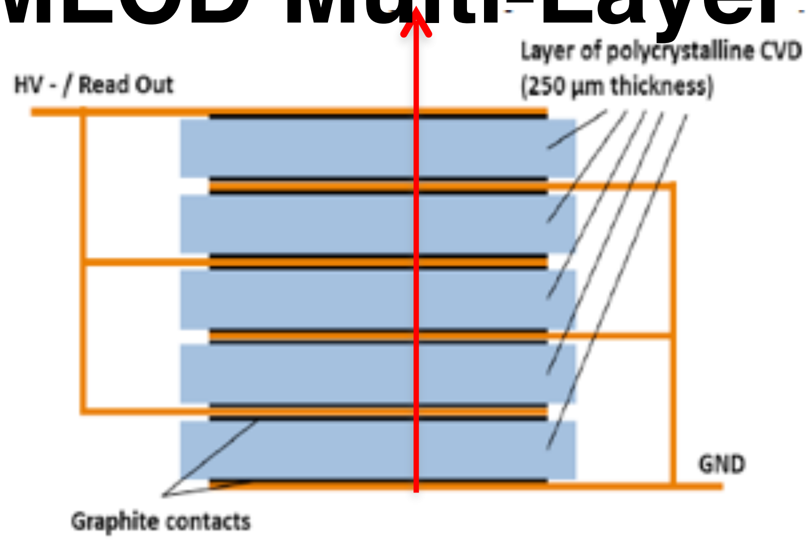
With N-layer time resolution decrease as sqrt(N-layer)

It is Ultra Fast SiC detector conceivable? Question for CLASSiC G5-Firb

HIGH BAND GAP MATERIAL

Some idea to boost dT~Signal/$t_{collection}$

MLCD Multi-Layer Crystal Detector



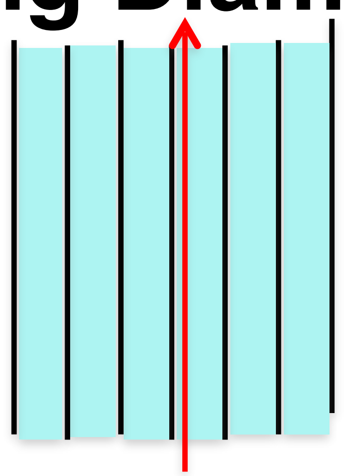
N thin layers in parallel:

- $Q_{collected}$ x N
- t_{drift} the same and short (thin layers)

⇒ **Need FE with noise independent from C_{IN}**

R. Cardarelli, A. Di Ciaccio and L. Paolozzi, *Development of Multi-Layer Crystal Detector and related Front End electronics*; NIM A 745, 82–87 (2014)

Grazing Diamond Detector



Signal increases by ionization path increase but t_{drift} the same:

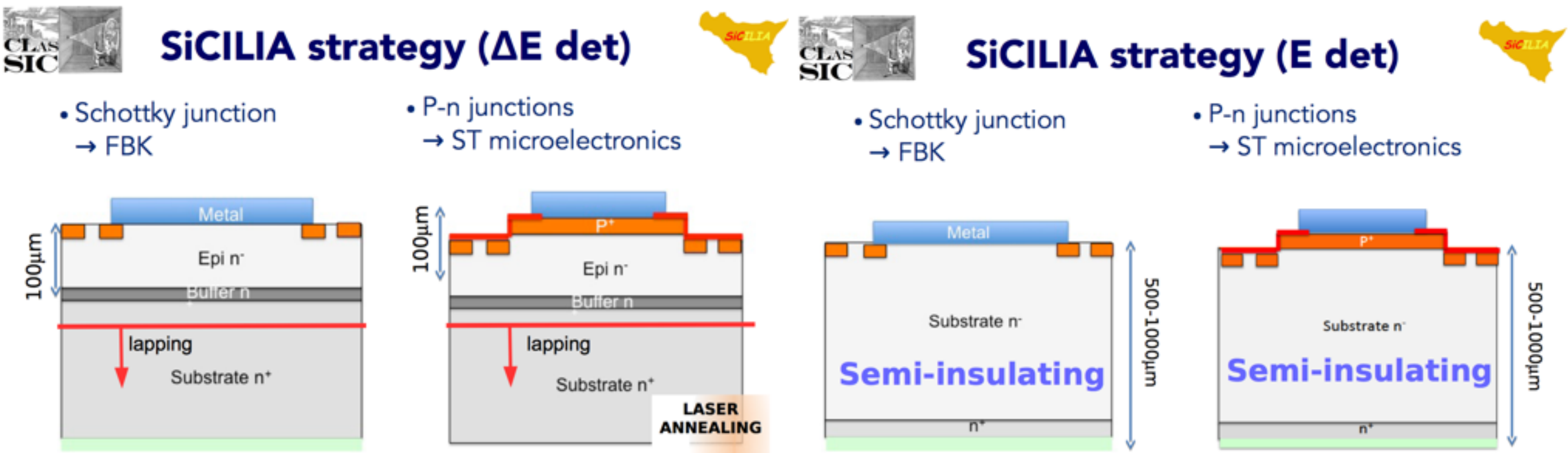
- $Q_{collected}$ x $d_{ionization}/d_{electrodes}$
- t_{drift} the same

⇒ **Could be build now**

G. Chiodini et al. *Diamond detector time resolution for large angle tracks* NIM A 796, 38–41 (2015)

These ideas are Diamond very expensive. Can SiC do better?

SiCILIA SiC



HTCVD process

Conclusions

1. The success of SICILIA R&D must watch to application also in high energy physics for future collider (here I mentioned HL-LHC only)

2. The capability to produce SiC detector with reasonable large area could became competitive in some specific applications

3. Large thickness not required in timing applications

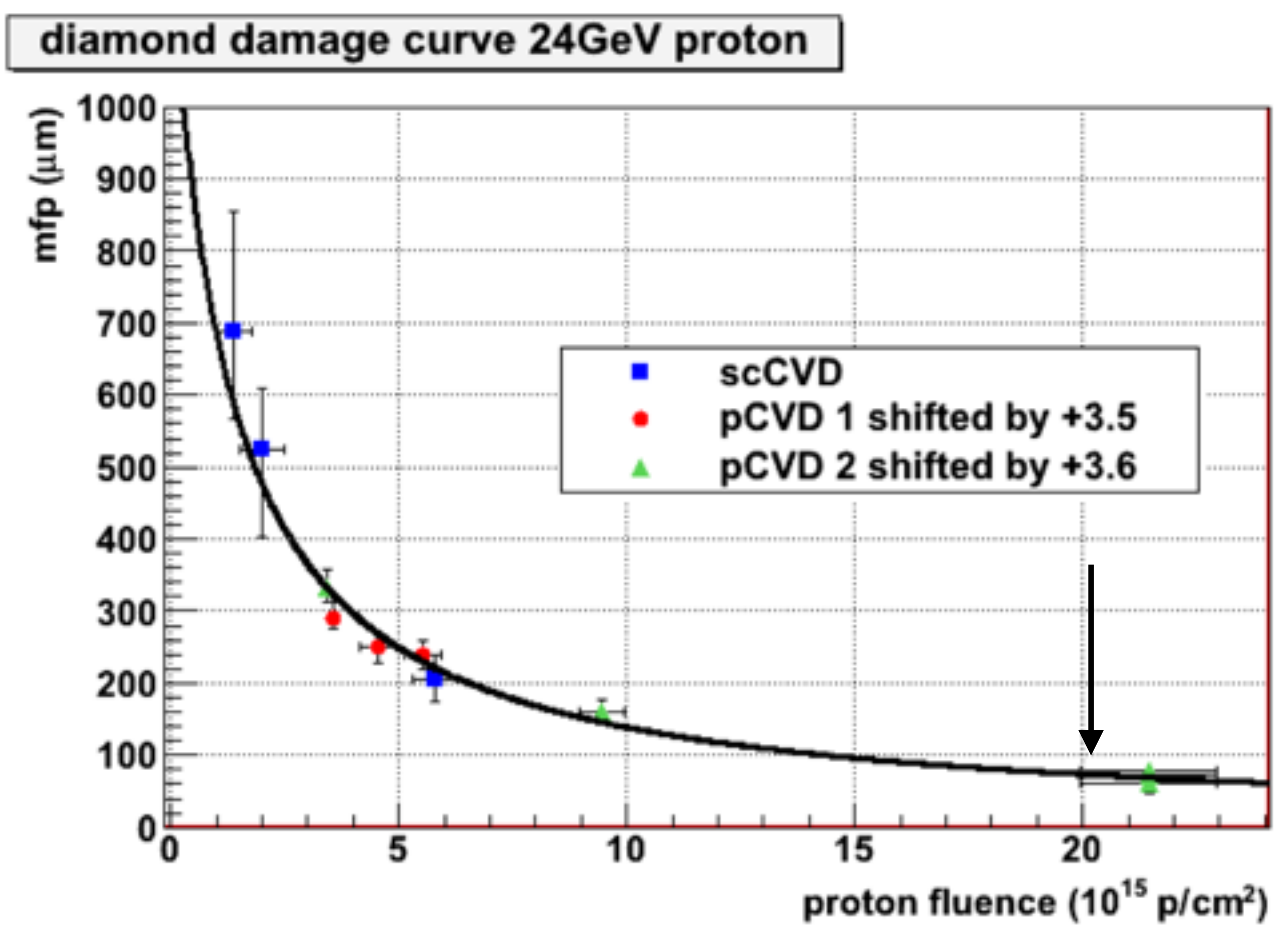
4. The final cost must be not exagered otherwise same trouble as diamond

Last comment

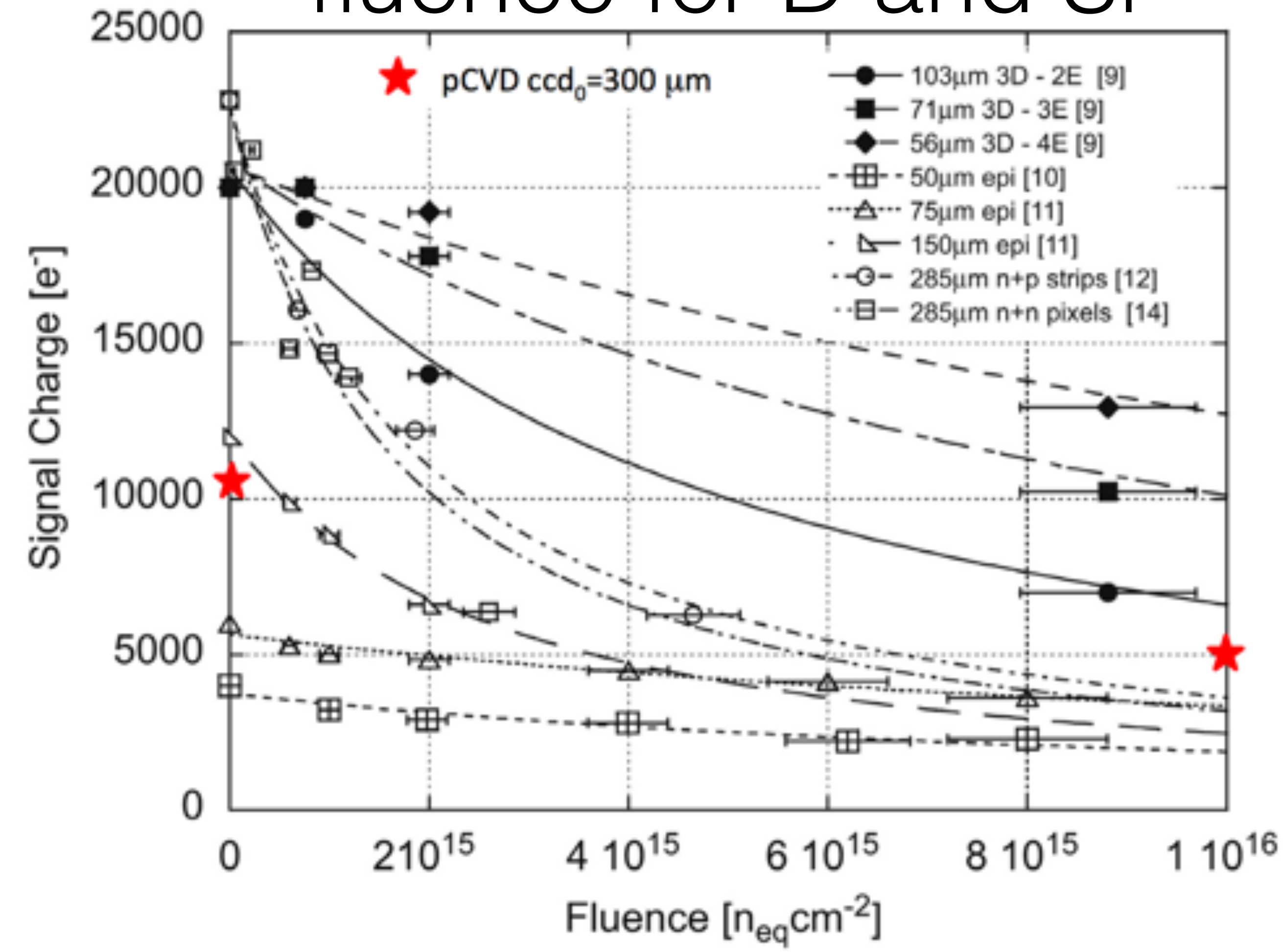
Relation between CCD and mfp

$$\frac{ccd}{t} = \sum_{i=e,h} \frac{mfp_i}{t}\left[1 - \frac{mfp_i}{t}\left(1 - e^{-\frac{t}{mfp_i}}\right)\right]$$

CCD diamante vs fluence



Signal degradation vs fluence for D and Si



20 year to go from 10 um CCD to 300 um!!! With LHC we go back to < 80 um

The CCD it is not all (cost, procurement, …) see 3D-Si approch and thin planar Si.

Silicon real problem is the cooling at -20 C for all life to avoid huge Ileakage