Luminosity and Forward Detectors

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E. Radicioni - INFN Bari

Overview

1. Luminosity detectors
2. Forward detectors
3. High risk high impact R&D
4. Conclusions

Bunch-to-bunch lumi issues

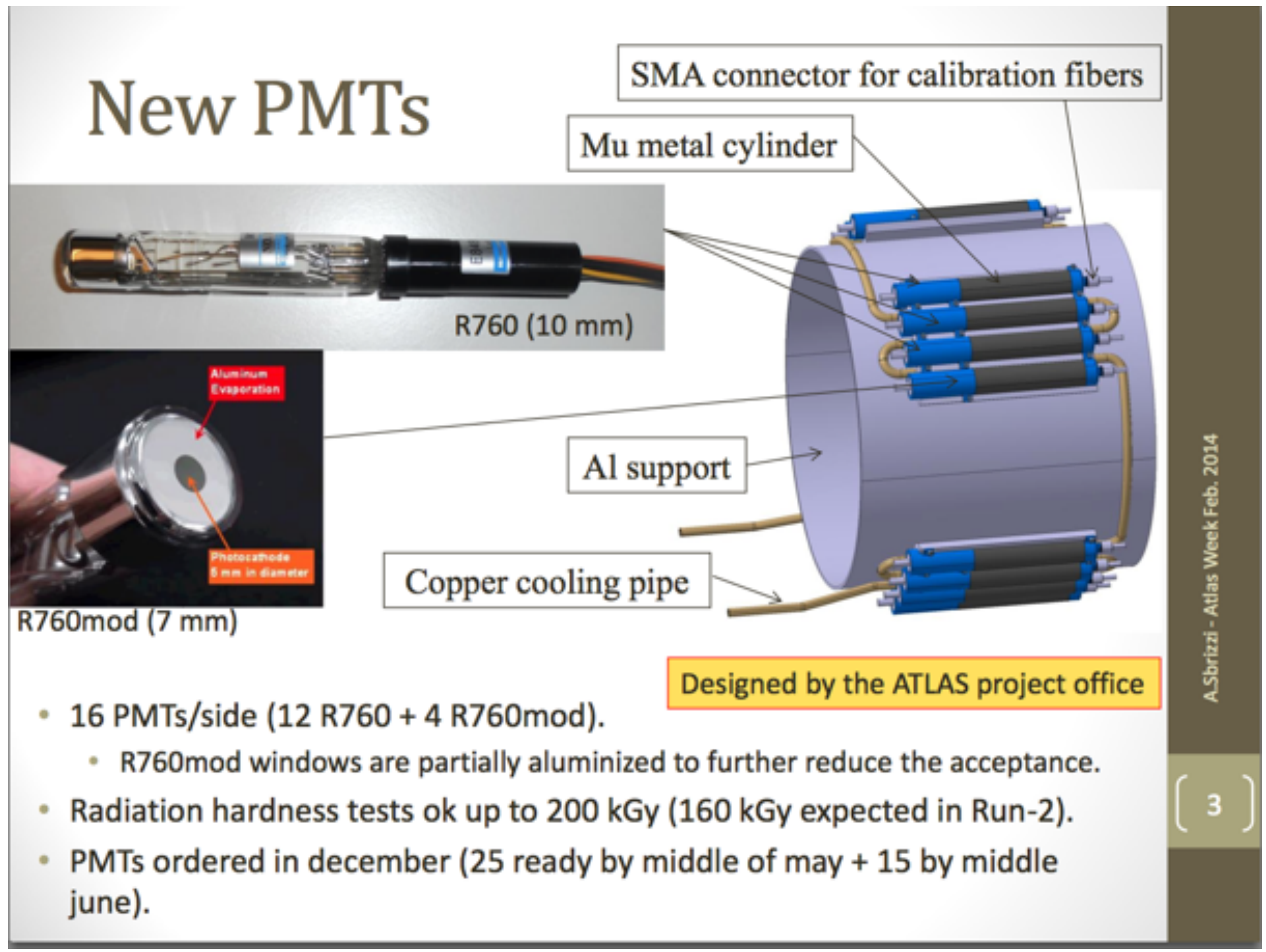
- Precision Physics require **precise Luminosity** and at LHC (or HL-LHC) issues are expected at higher and higher rates, pile-up and machine BG
- Luminosity measurements will require **new detector technology**

LUCID upgrade in LS1

Particle rate increases:
- new Al beampipe,
- higher L and E

Possible issues:
- Event counting saturation
- PMT aging
- Non-linearity

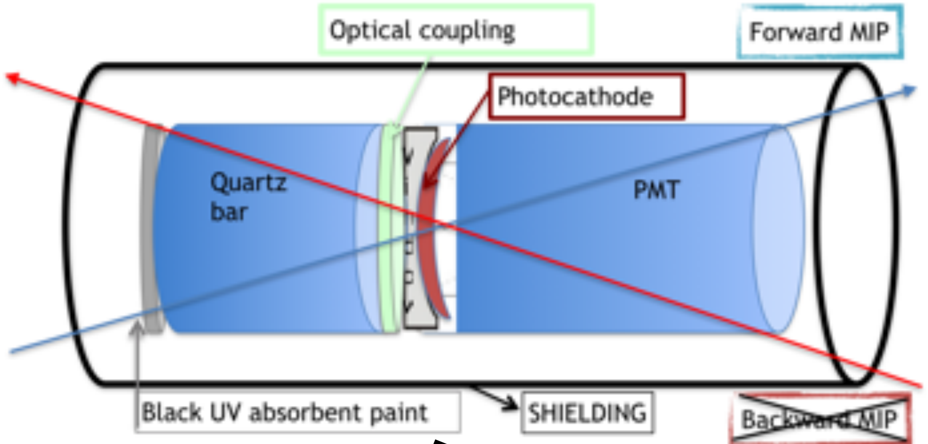
Solutions (Bologna):
- Use smaller PMT
- Lower PMT gain
- Integrate FE signal



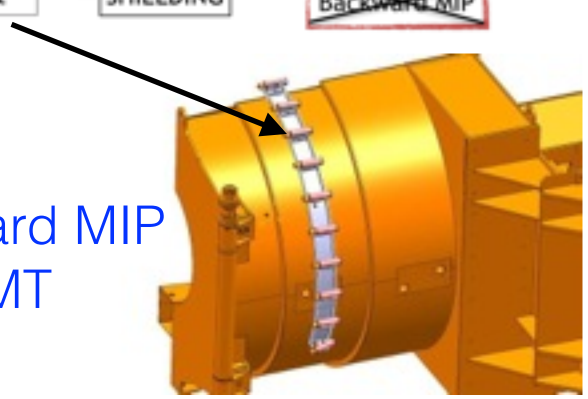
Sinergy in BRIL

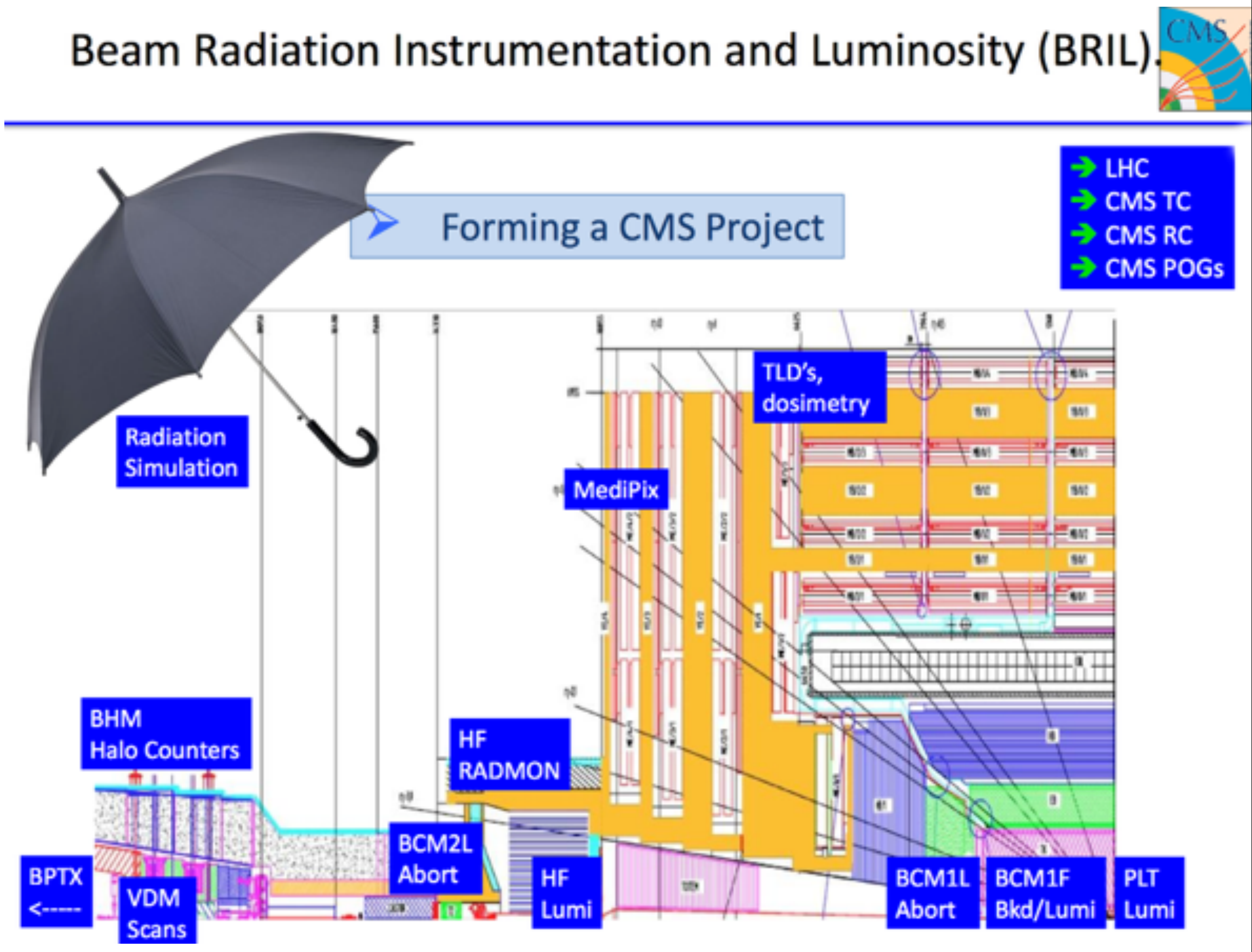
Relevance and complexity motivate a common project and integrated infrastructure

New Beam Halo Monitoring (BHM): online Machine Induced Background
- Veto on LVL1 with very high MIB
- Flag Lumi-block with high MIB.



Bologna
- Suppress backward MIP
- 20+20 Quartz+PMT

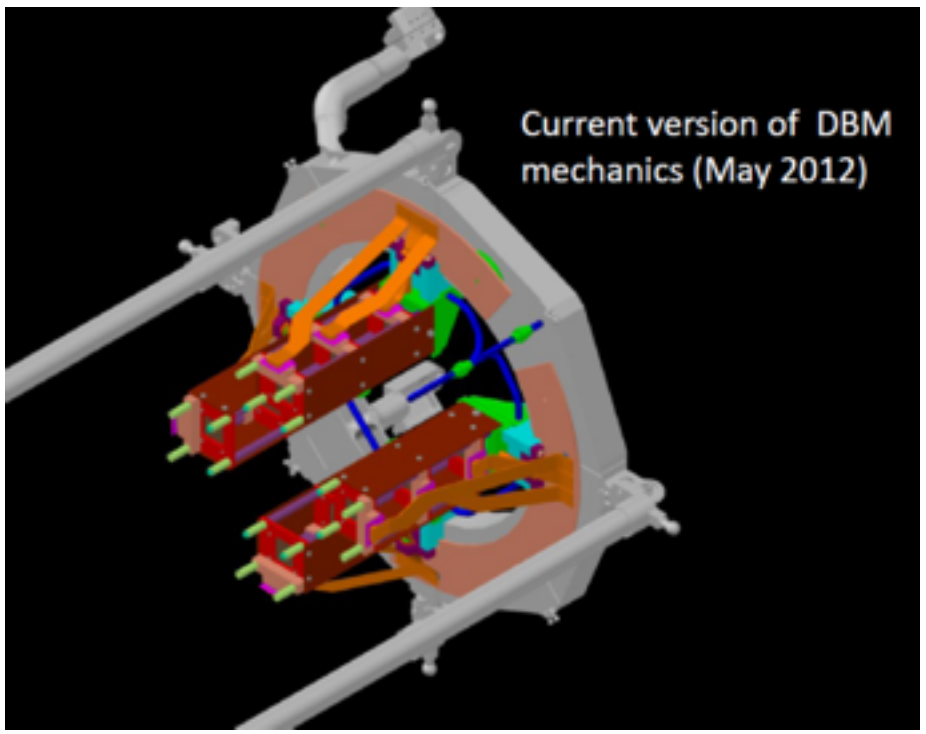


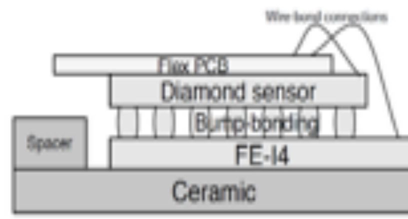


Luminosity upgrade

From Counting&Timing to Pixel Tracking mode

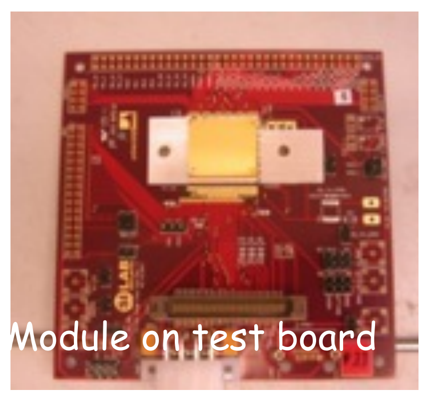
Goal: 1% rel. lumi bunch-to-bunch (now: diamond ATLAS CBM 1.9%)

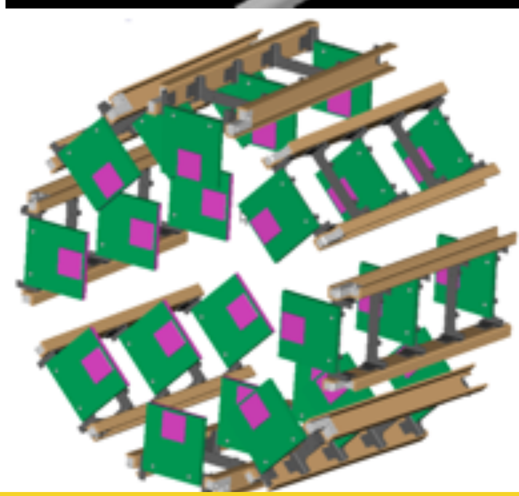


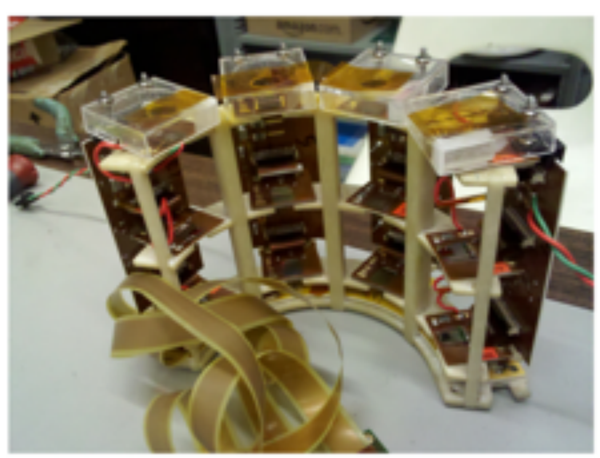


DBM (ATLAS/RD42) $3.2<\eta<3.5$

A. 4+4 telescopes
B. 3 pixel planes per telescope
C. Plane made of 18x21x0.5mm2 poly-crystalline diamond sensor bump bonded to FEI4 chip







PLT (CMS/RD42)

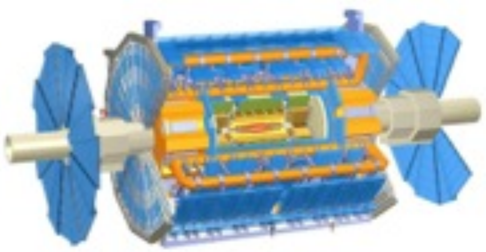
A. 8+8 telescopes
B. 3 pixel planes per telescope
C. Pixel plane made of 5.2x12 mm2 Pixel Silicon sensor bump bonded to PSI chip

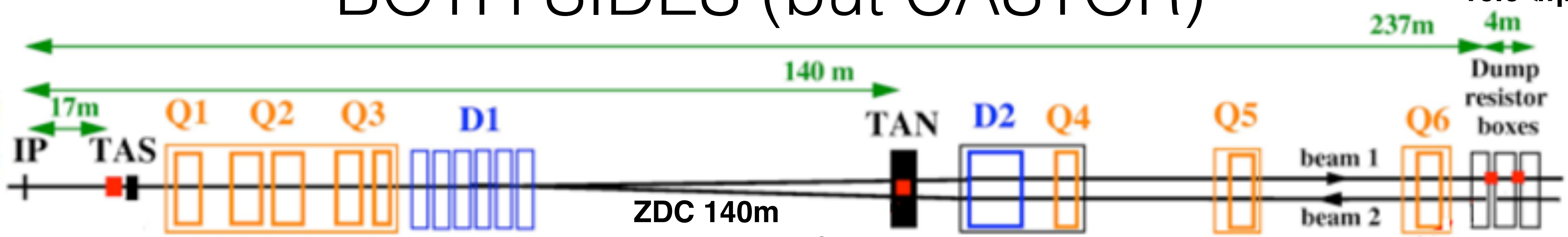
Pixel Tracking&Timing welcome (TimePix, GigaTracker, …)

Forward detectors

BOTH SIDES (but CASTOR)

ALPHA 237-241m
elastic p
10.6<|η|<13.5





MTBS
Minimum Bias Trigger
2.1<|η|<3.8

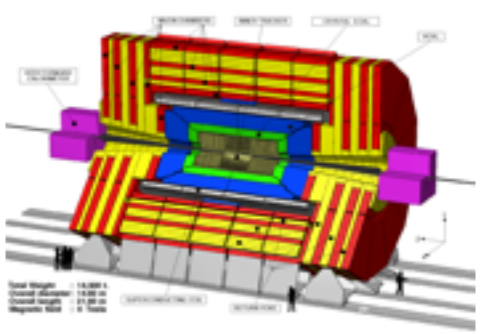
FCAL: 3.1<|η|<4.9

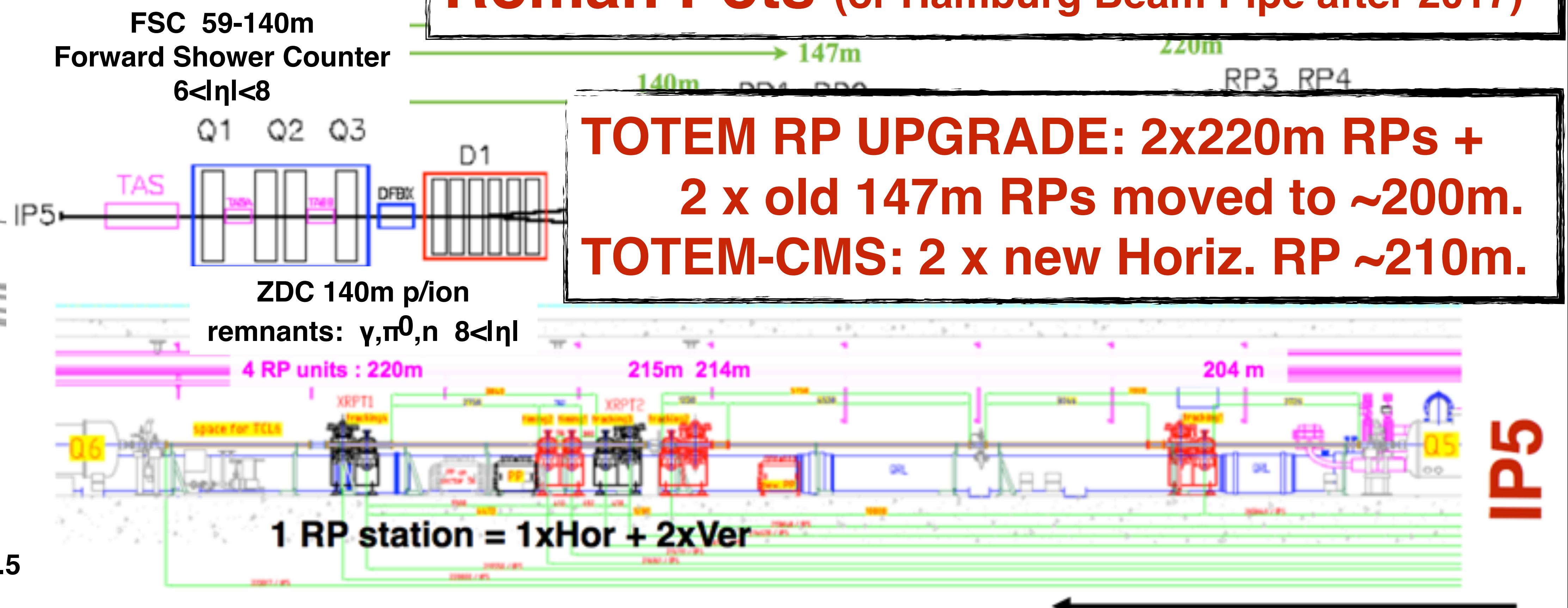
LUCID ~17m
p remnants and
low P_T particles
5.6<|η|<5.9

ZDC 140m
p/ion remnant: γ,π^0,n
8.3<|η|

ATLAS-AFP 202-212m: 2 New Horiz. Roman Pots (or Hamburg Beam Pipe after 2017)

FSC 59-140m
Forward Shower Counter
6<|η|<8





TOTEM RP UPGRADE: 2x220m RPs + 2 x old 147m RPs moved to ~200m.
TOTEM-CMS: 2 x new Horiz. RP ~210m.

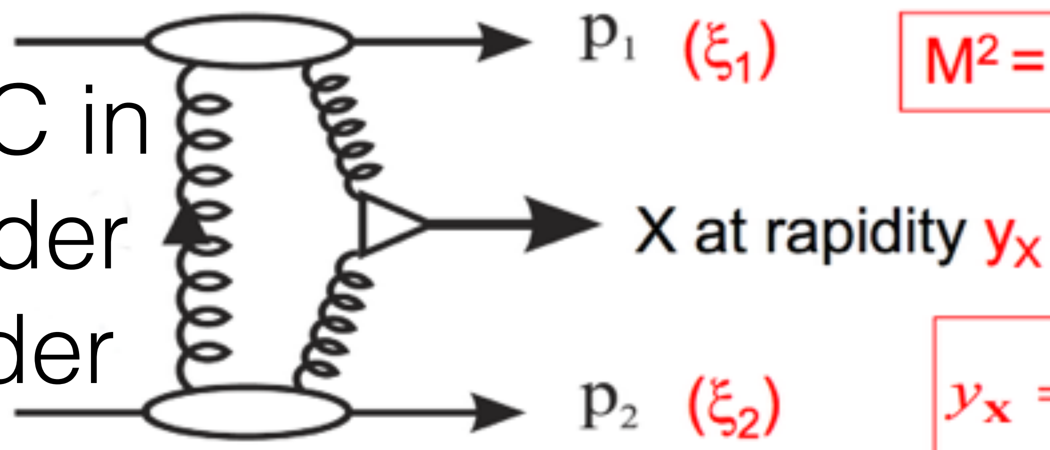
ZDC 140m p/ion
remnants: γ,π^0,n 8<|η|

BSC
Minimum Bias Trigger
3.23<|η|<4.65

T1 CSC: 9m, 3.1<|η|<4.7
HF: 3<|η|<5
T2 GEM: 13.5 m, 5.3<|η|<6.5
CASTOR: -6.6<η<-5.2

Why proton tagging?

Turn LHC in gg collider γγ collider



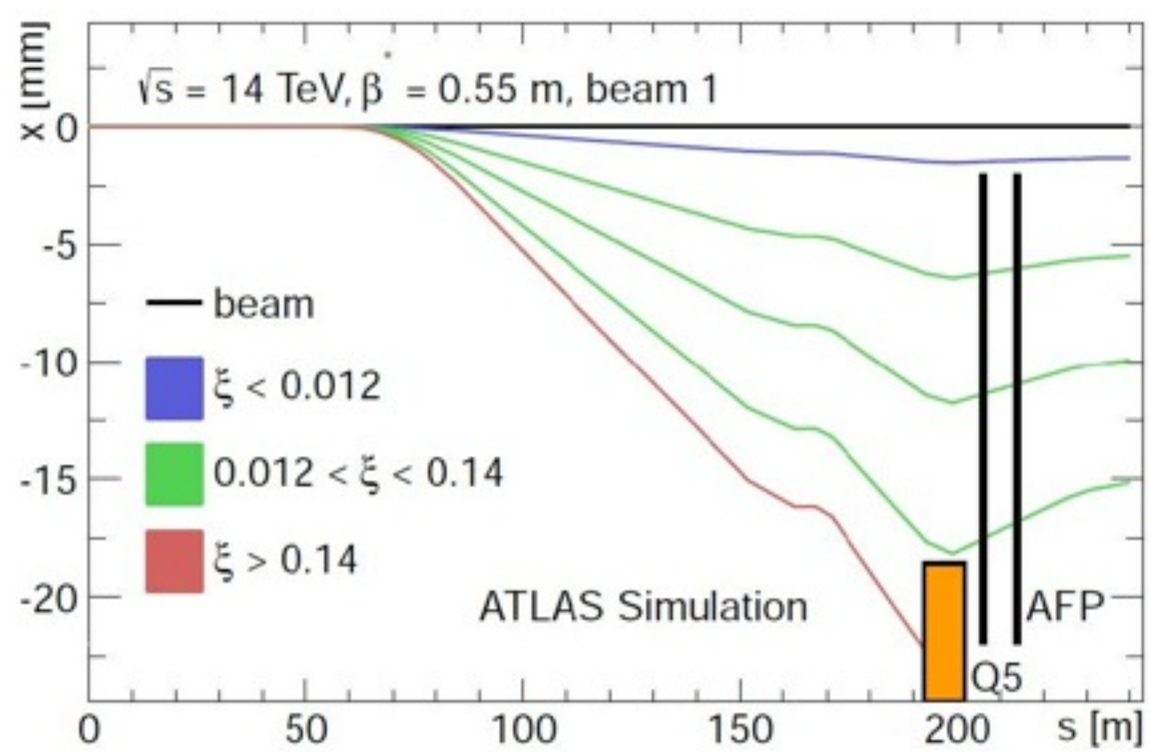
$$M^2 = \xi_1 \xi_2 s$$

$$y_X = \frac{1}{2} \ln \frac{\xi_1}{\xi_2}$$

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

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

Proton relative energy loss: $\xi=(E_{beam}-E_{proton})/E_{beam}$ depends on (x,y) according to optics transport matrix



Edge-less technology is a must for tracker:

- Increases acceptance
- Decreases beam halo interactions & showers when approaching beam

Special and standard runs

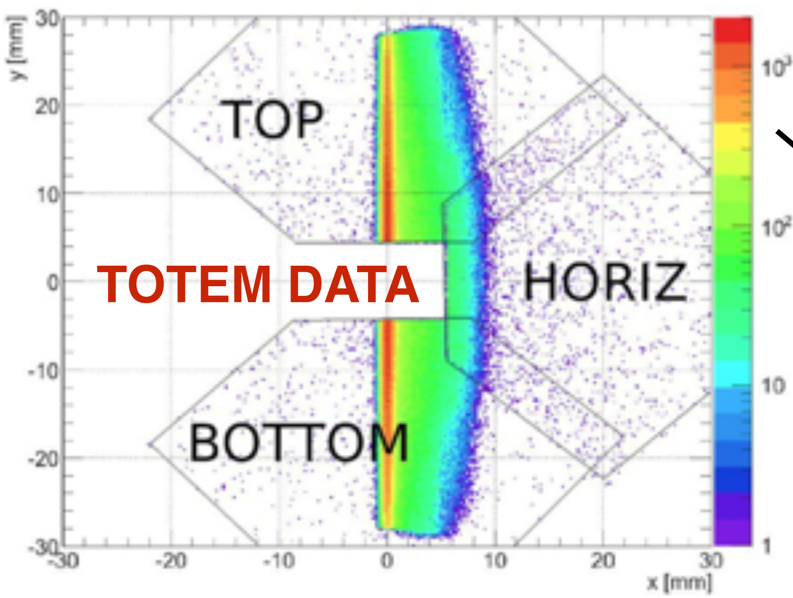
Special runs: high β^* / low <μ>~0.05÷5

- Elastic/Inelastic scattering x-sec
- Absolute total x- sec (L-independent and normalization for all experiments
- Diffraction and low/intermediate masses (~1÷~400 GeV)

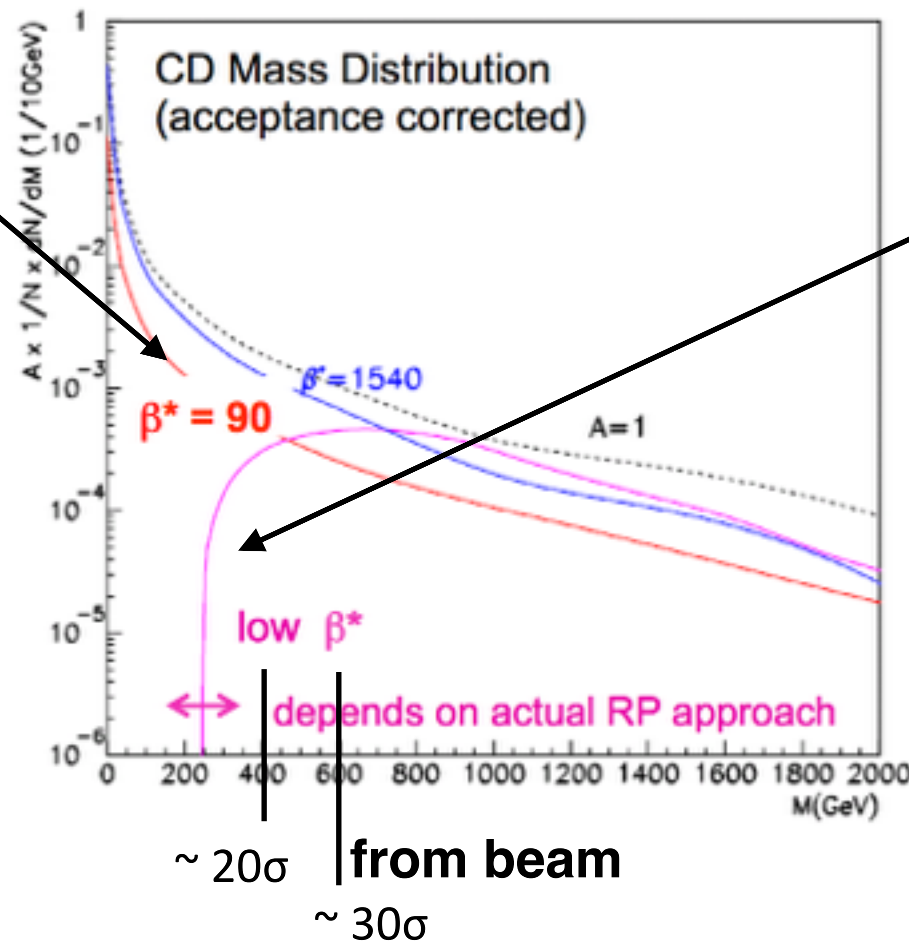
Standard runs: low β^* / low <μ>~10÷50

- low x-sec phenomena
- diffraction and high masses (~400GeV ÷ ~2TeV)

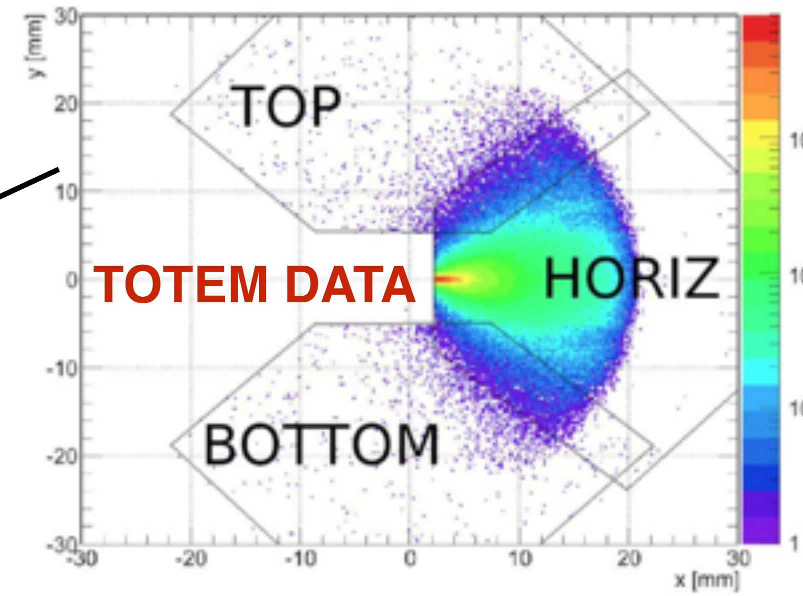
Vertical Roman Pots



- Low pile-up
- Silicon strip
- Time resolution 50÷100ps



Horizontal Roman Pots



- High pile-up
- Rad-hard/edge-less 3D pixels
- Time resolution 10÷20ps

Tracking detector challenge

Present tracking for low(er) luminosity:

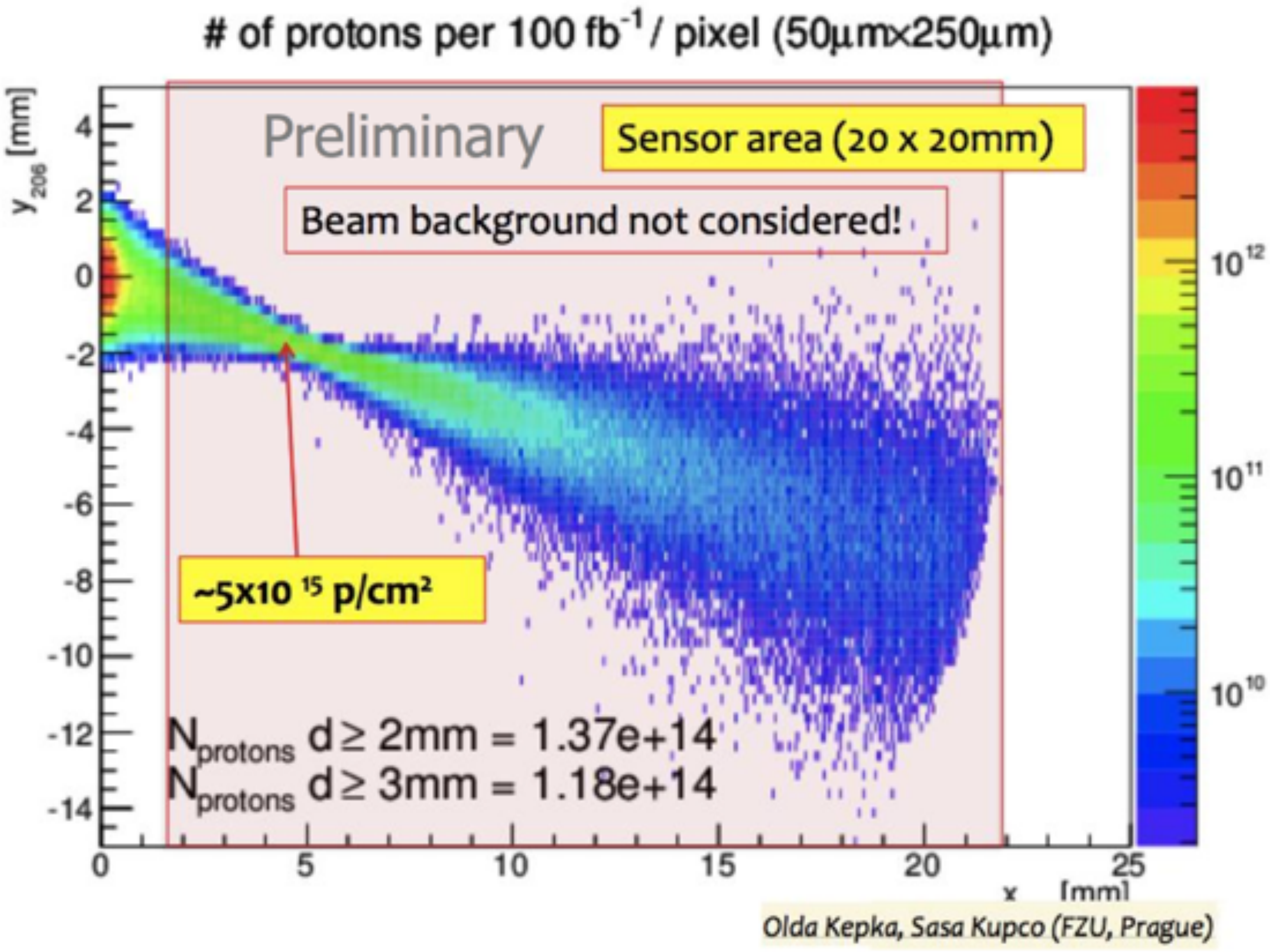
TOTEM strips with CTS

- position resolution OK
- excellent 50µm edge

but

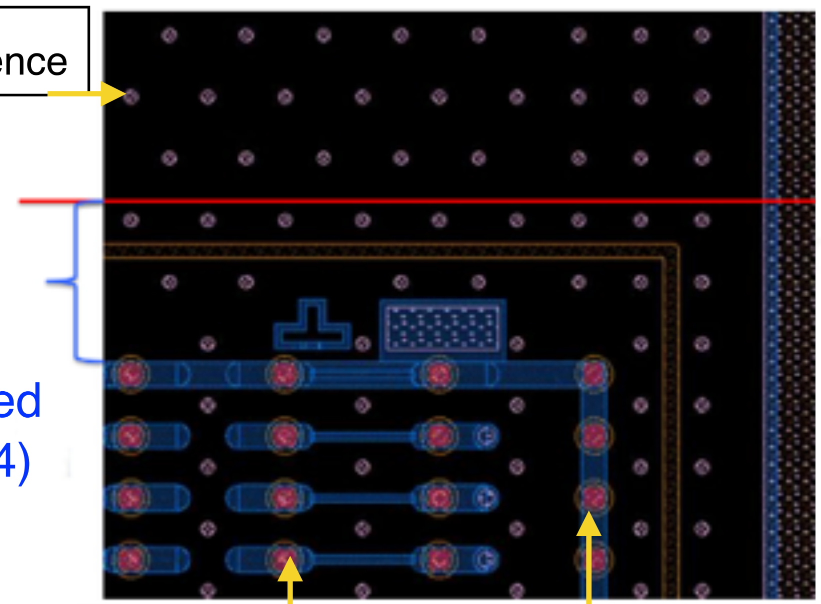
- ... no pixels
- ... not stand 10^{16} protons

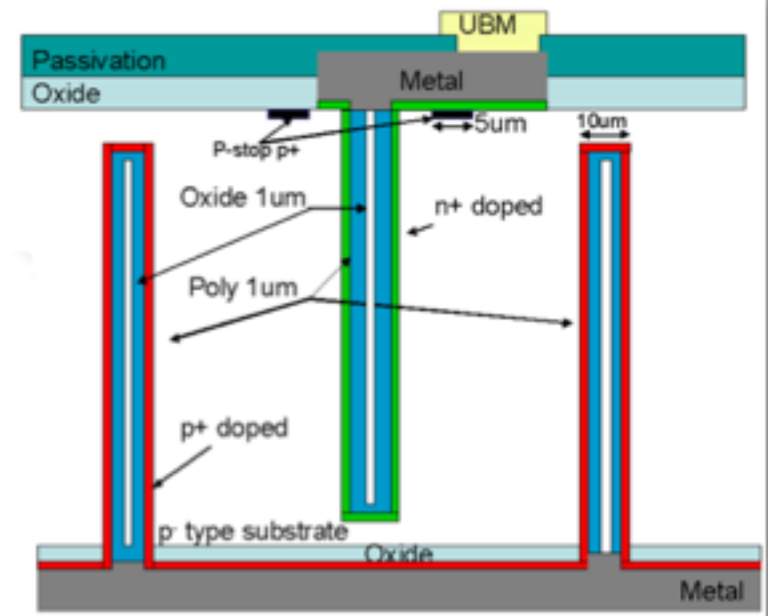
R&D is needed



Key requirements for pixels

- Spatial 10 (30) µm in x (y)
- Angular resolution 1 µrad
- Radiation hardness
- Minimal dead space at the edge



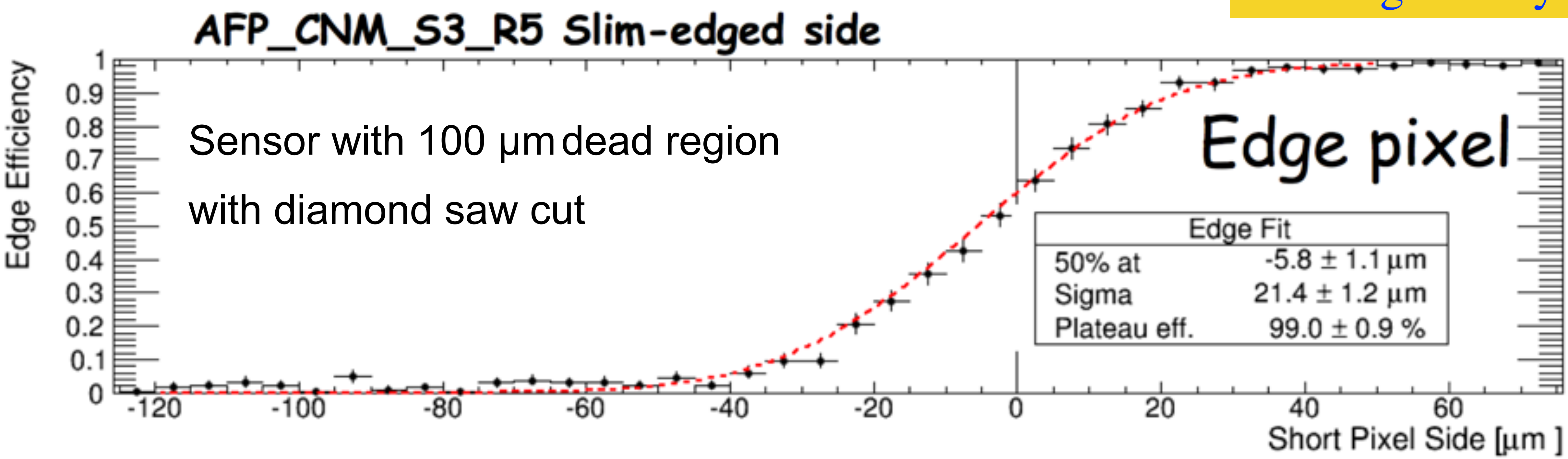


Baseline: IBL double-side 3D Si pixel with slimmed edge diamond dicing (dead zone of 80 um as FE-I4) instead of 250 um)

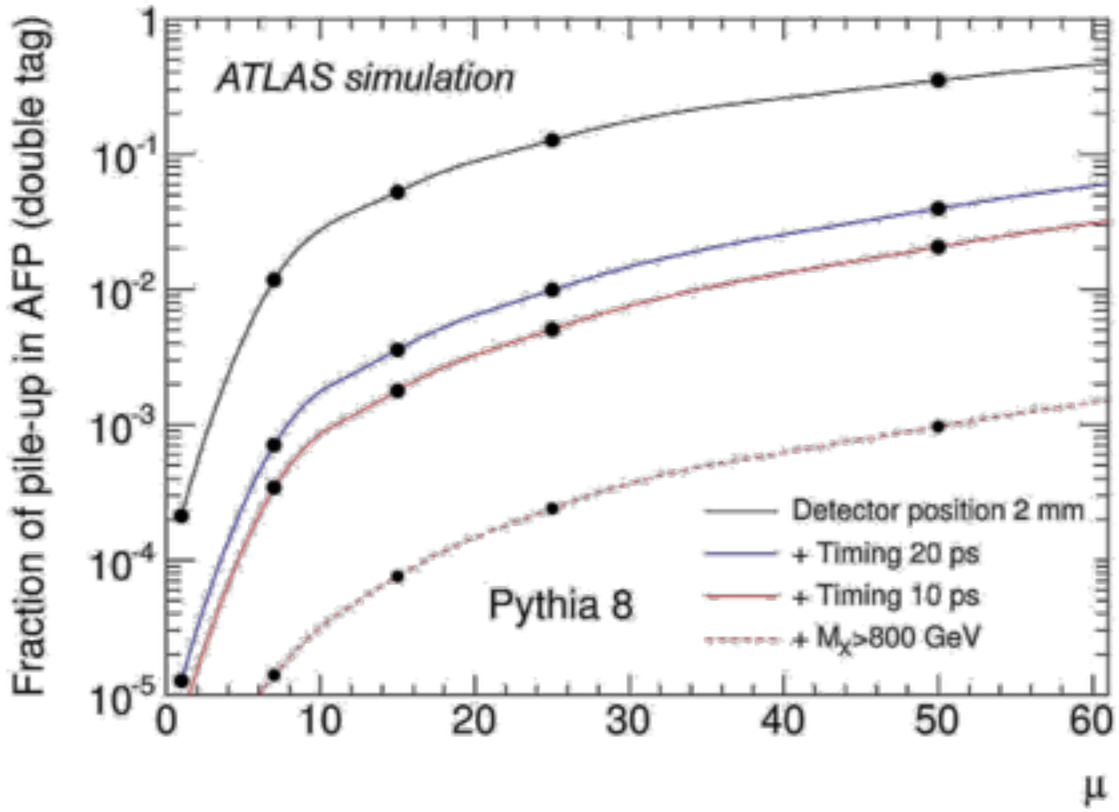
Edge termination:

- CNM: 3D guard ring of n^+ columns + p^+ ohmic-column fence
- FBK: p^+ ohmic-column fence

Possible upgrade with 3D edgeless by 2020

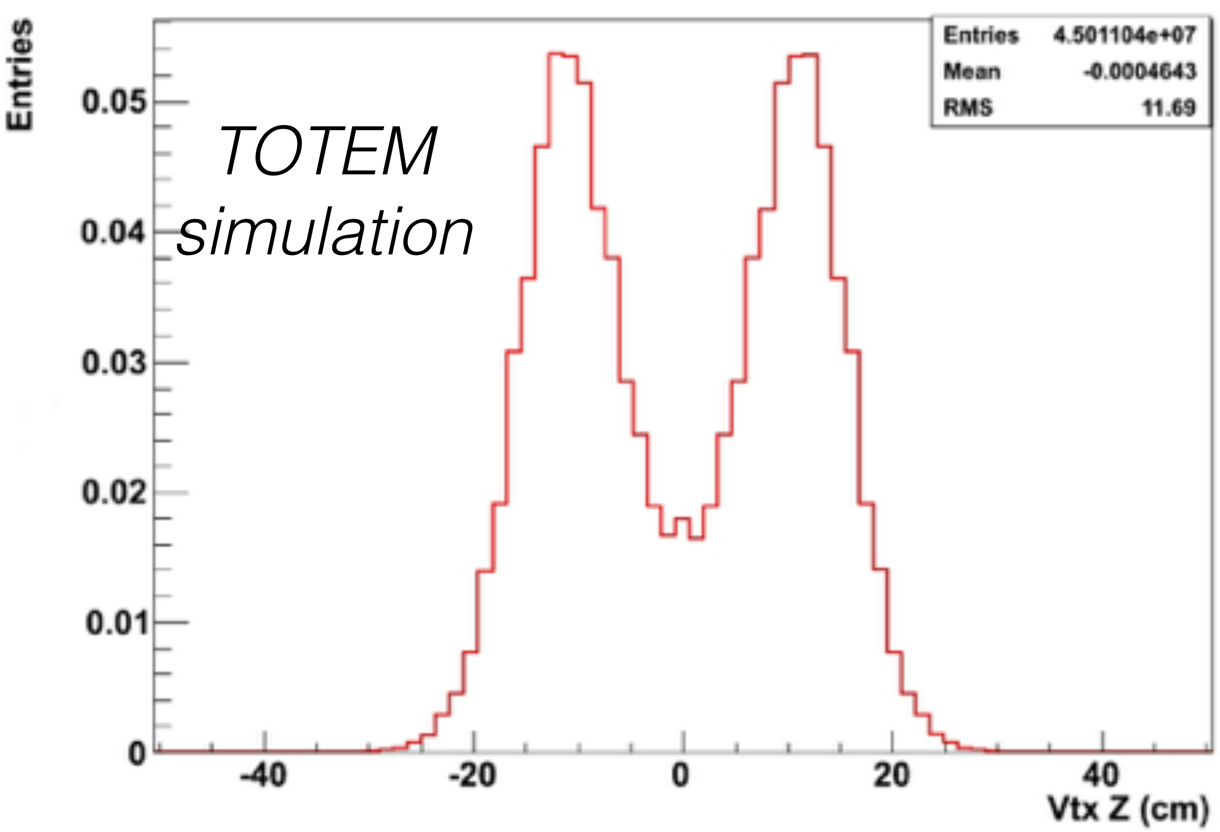


Timing for pile-up suppression



Main BACKGROUND from pile-up of protons from SINGLE DIFFRACTIVE events with NON-DIFFRACTIVE events.

- Mass matching with Central Mass from tracking:
  - $M_{central} = M_{AFP} = (s\ \xi_{Left}\ \xi_{Right})^{½}$ ➔ σ_M=5 GeV
- ToF coincidence with VTX from timing:
  - $z_{vtx}=c(t_{Left} - t_{Right})/2$, σ_{zvtx}=2.1mm ➔ σ_t=10 ps



Advantages of apply timing info to L1:

- Enhance CD purity of triggered 2 tagged protons (at cost of CD efficiency)
- Select isolated vertices in tails (σ_{zvtx} = 1 cm) to reduce trigger rates to acceptable levels (1 kHz) ➔ σ_t=50 ps

AFP FAST TIMING

QUARTIC=
Cherenkov quarz+MCP

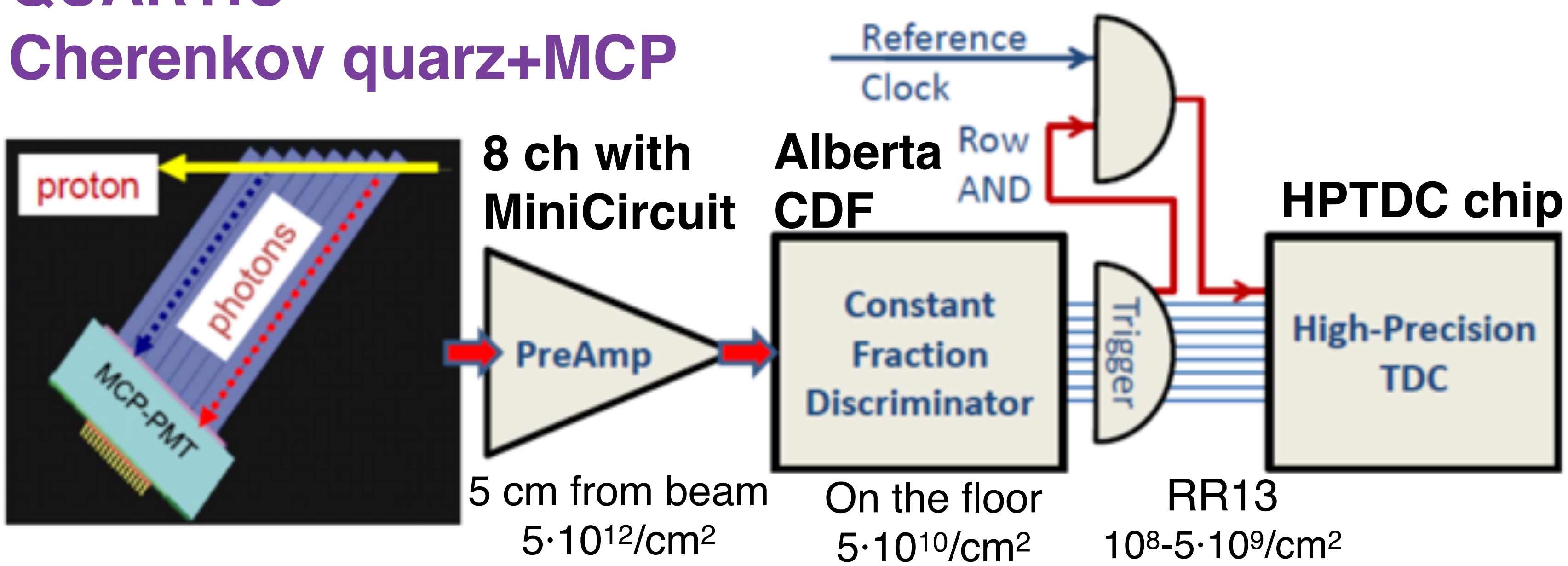


Figure 1: A schematic diagram of the AFP fast timing system.

All components realized and tested with pulser, laser and test beam,
… but
must fit in a Roman Pot

Detector & PMT R&D: U Texas at Arlington (A. Brandt et al.);
Electronics R&D: Stony Brook (M.R. et al)

$$\sigma_{Total}^2 = \sigma_{Jitter}^2 + \sigma_{Time\ Walk}^2 + \sigma_{TDC}^2$$

$$\sigma_{Jitter} = \sim t_{collection}/(S/N) \sim 20ps$$

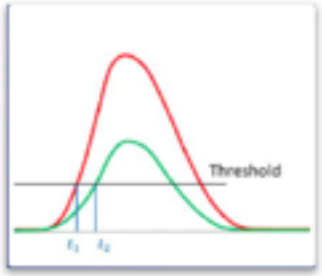
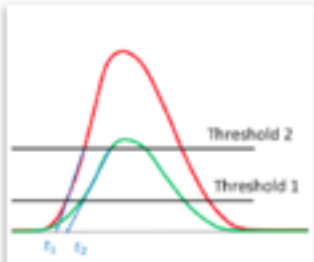
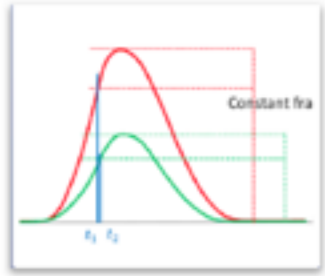
$$\sigma_{Time\ Walk} = t_{collection} S_{threshold}/S \sim 5ps$$

$$\sigma_{TDC} = T_{clock}/sqrt(12) + T_{reference}/sqrt(12) \sim 5+5\ ps$$

$\sigma_{Total,bar} \sim 22ps$

$\sigma_{Total,6bar} \sim 9ps$

CFD+TDC vs Wave Sampling Chip

Single threshold	Multiple threshold	Constant fraction	Sampling
			
Advantage of simplicity. Poor results	Basically interpolation on the rising edge.	Complicated hardware. Relatively good precision.	All digital algorithm possible: Mean square, Cross-correlation, …

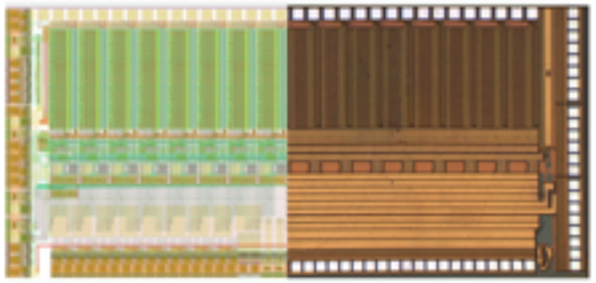
CDF+TDC error sum in quad. Not the case for Wave Sampling.

The SamPic readout chip

Sampler for **Pic**osecond time pick- off.

H. Grabas – E. Delagnes – D. Breton – J. Maalmi.

- CMOS AMS 0.18 um
- 64 samples(caps)/ch
- 64 Wilkinson ADC/ch
- Dead-time-less (in future)

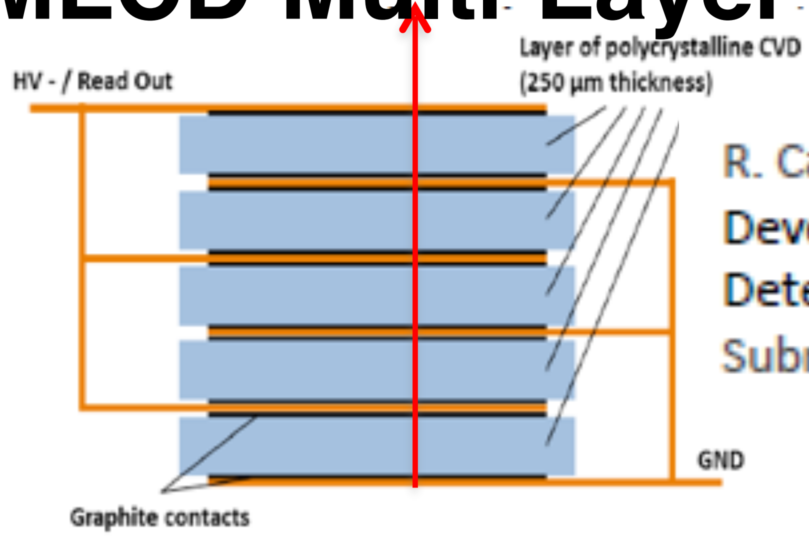


	Measured
Channel number	16
Input bandwidth	1.6 GHz
Sampling frequency	3.2 – 10 $GS.s^{-1}$
ADC precision	11bit
Noise	1mV
Range	1V
Conversion time	11bit: 1.6µs (8 bit: 200 ns) conversion time
Readout clock	160MHz (*400Mhz not verified)
Readout speed	$1.92 Gb.s^{-1}$ – ($4.8 Gb.s^{-1}$ to be tested)

Made for AFP upgrade/Collaborating with TOTEM

Boost S/t_{coll} in diamond

MLCD Multi-Layer Crystal Detector

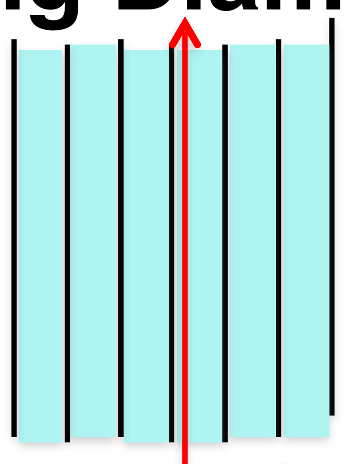


R. Cardarelli, A. Di Ciaccio and L. Paolozzi; Development of Multi-Layer Crystal Detector and related Front End electronics; Submitted on 18/09/2013 NIM A

N thin layers in parallel: S x N but collection t_{coll} the same.

Roma TorVergata

Grazing Diamond Detector

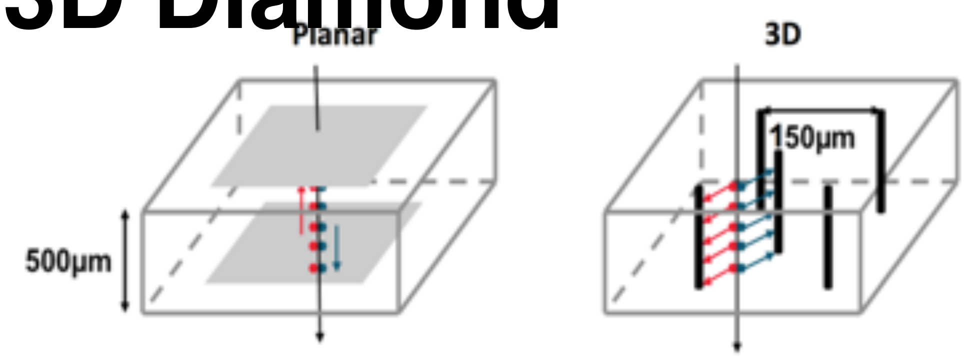


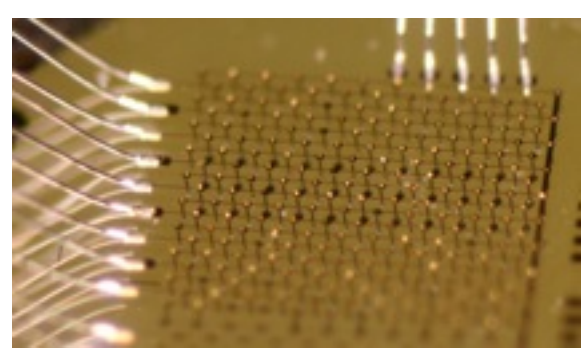
Signal increases by length but t_{coll} the same.

Lecce

- Diamond still not competitive
- 100 ps/MIP/plane reached
- Goal is a factor 3 better
- R&D is underway in Italy too.

3D Diamond





Graphite columns fabricated by fs laser

Signal proportional to thickness and t_{coll} prop. to electrode distance.

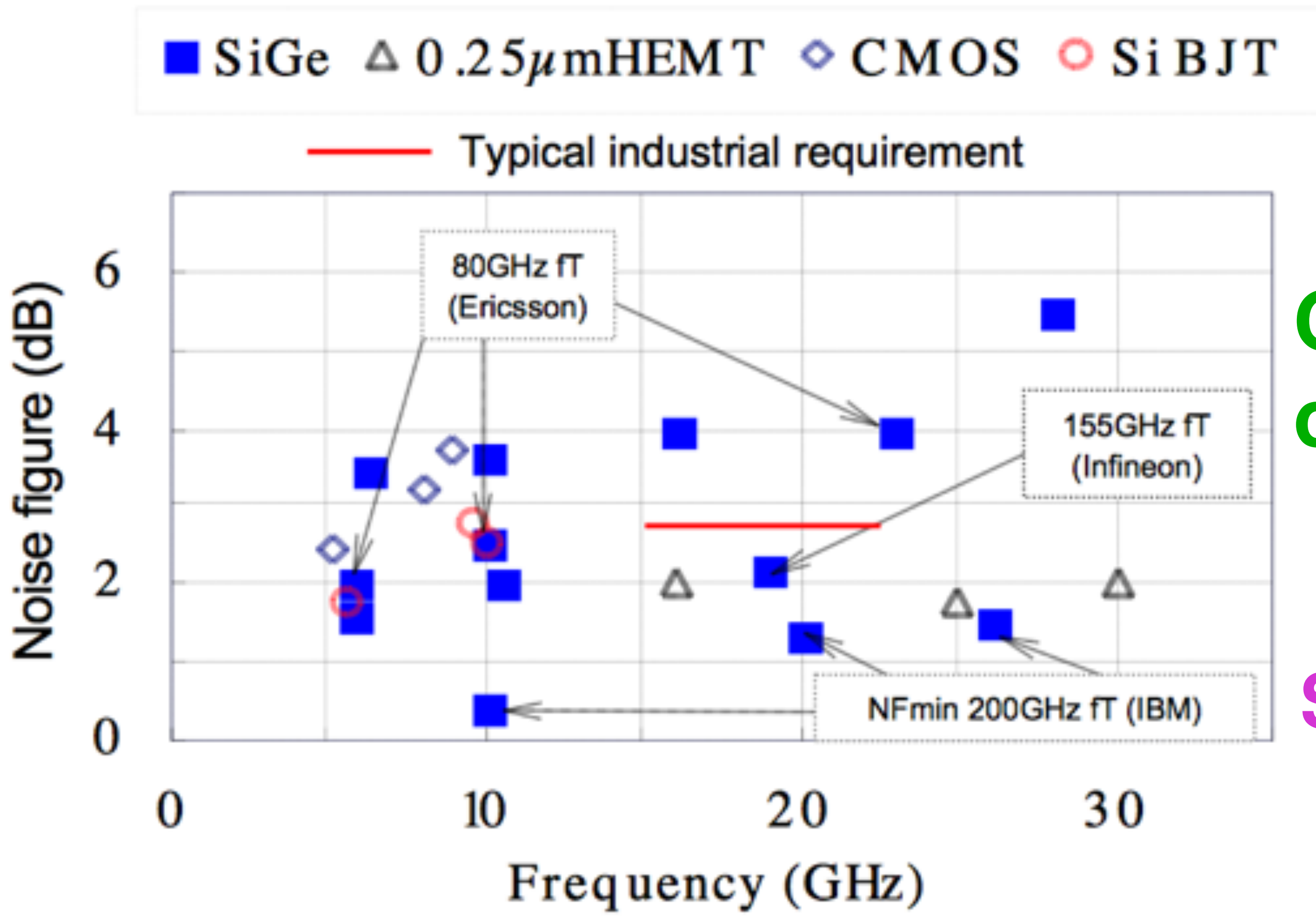
RD42

Firenze(G. Parrini et al.)

Fast and Low Noise FE

Monolithic Microwave IC (**MMIC**) used for Diamond (CIVIDEC)

ATLAS-BCM (Beam Condition Monitor): InGaP HBT (1st stage) GaAs E-pHEMT (2 stage)



High-frequency SiGe MMICs – an Industrial Perspective (*Invited*)

Yinggang Li, Harald Jacobsson, Mingquan Bao and Thomas Lewin

Ericsson AB, Ericsson Research, MHSERC, SE-43184 Mölndal, Sweden

Graded Ge layer into the base of Si BJT increases β and f_T .

SiGe = III-V Speed + Si integration

SiGe HBT

- Cheaper than III-V semiconductors
- Si integration - BiCMOS
- CSA BW~100MHz, N~250-500e-
- Rad-Hard 50 MRad

MLCD FE (Roma TorVergata):

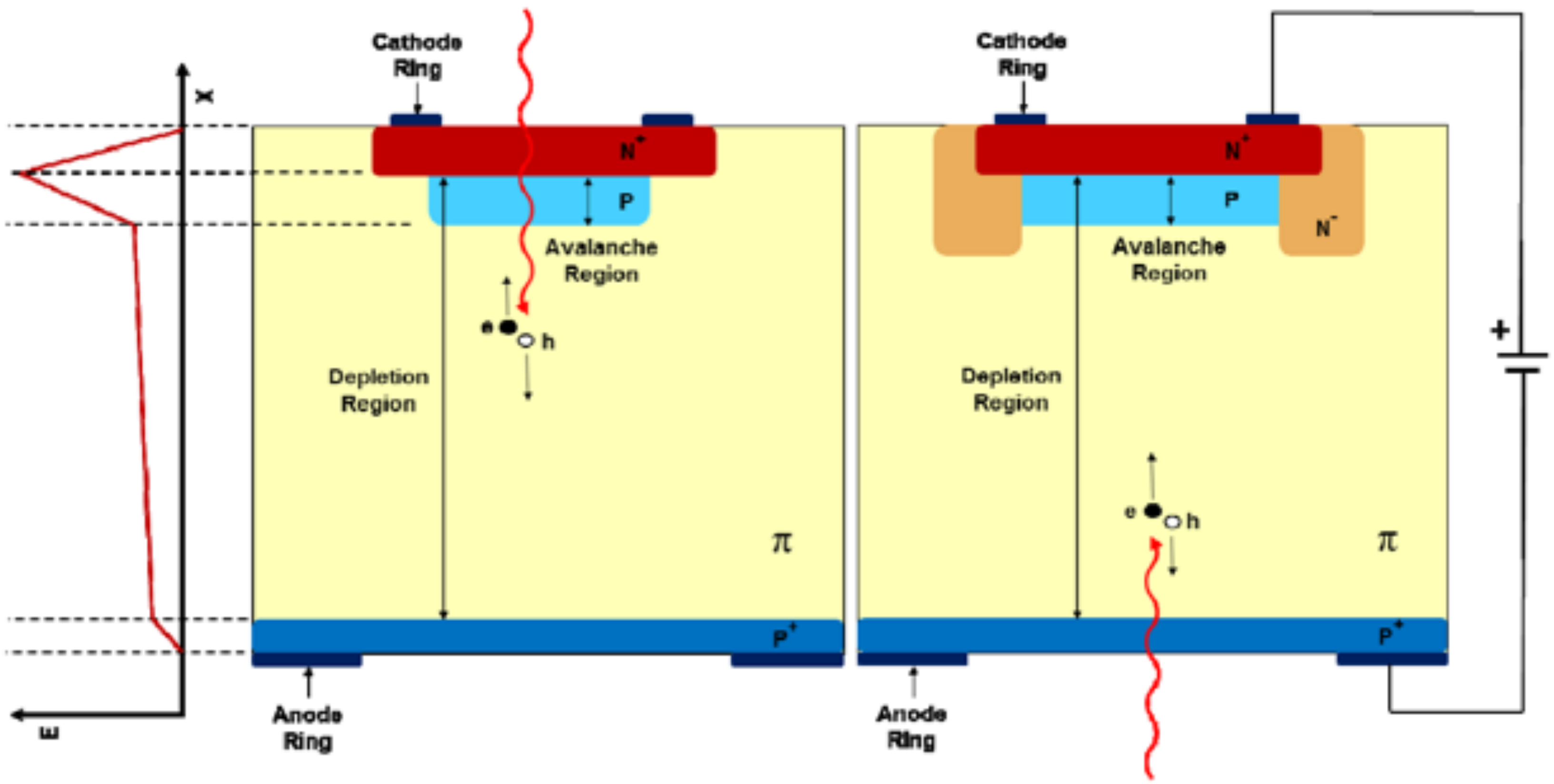
- Discrete components SiGe CSA with noise independent from input capacitance.
- 8 channel SiGe chip just submitted.

Ultra Fast Silicon Detector (UFSD)

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)

These projects fit very well external funding:

ERC advanced grant: “4-Dimensional Silicon Detector”: FET network grant: “UltraFastSilicon Detector” PRIN: “UltraFast Silicon detector” - ERC consolidator grant, “Silicon Space-Time Tracker”.

Staging and synergy

increasing level of difficulty

High β^* / low $\langle\mu\rangle$: low to moderate luminosity, long interaction region:

- 2015-2016: TOTEM timing in vertical pots
  - ~100ps resolution, no upgrade to tracking

low β^* / high $\langle\mu\rangle$: high luminosity, short interaction region:

- 2016 —> : CMS/TOTEM & AFP
  - 10ps resolution, 3D pixels, rad-hard

Different projects have to attack similar issues and synergies are possible:

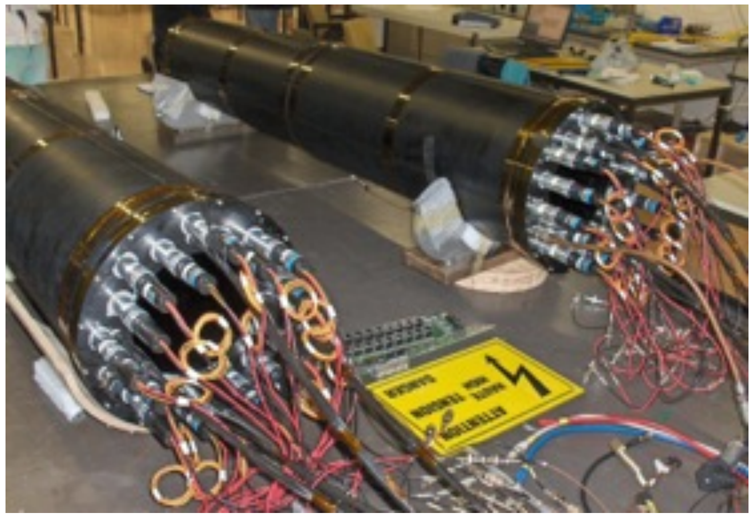
- R&D for gradually increase timing performance
  - diamond & silicon
- R&D for TDC/sampling technologies
- Front-end electronics issues
- Learn detector integration & operation in hostile environment

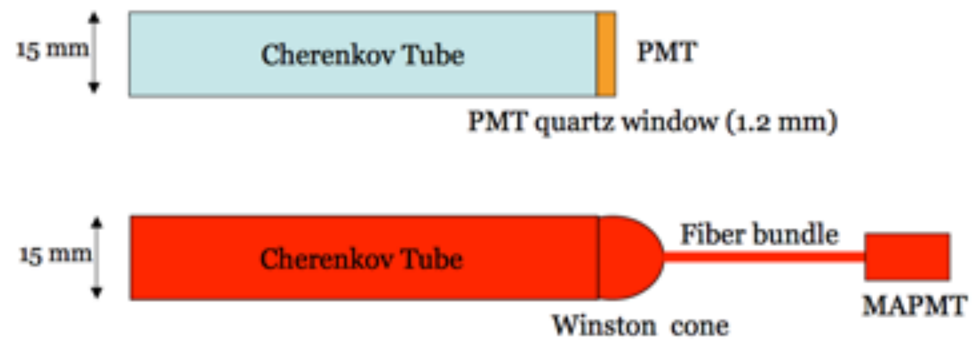
Conclusions

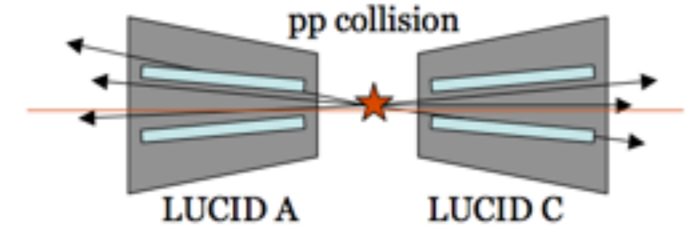
- Luminosity detector upgrade with high granularity and timing resolution needed for (HL-)LHC
- Upgrade forward detector for diffractive physics at nominal luminosity (HL-)LHC at the limit of the available technologies
- Staging to takle Technical Difficulties and Physics Reach:
    - high β^* / low $\langle\mu\rangle$ → low β^* / high $\langle\mu\rangle$
    - phase I → phase II
- A lot of synergy (between experiments and sub-detectors) and spin-off (medical, space, imaging, H2020, …) can be envisaged for new ideas and technologies

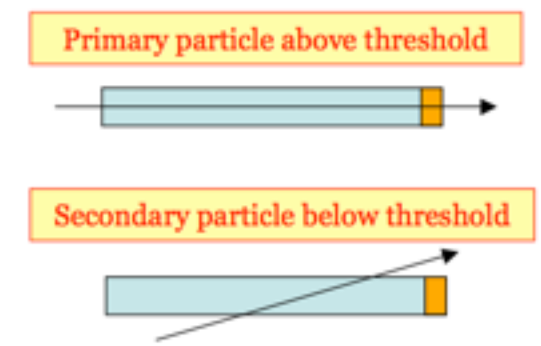
Back-up slides

Relative Luminosity Detectors



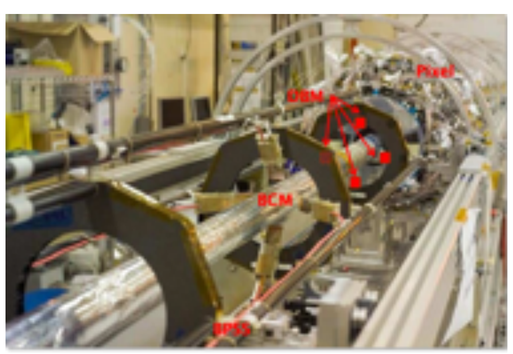


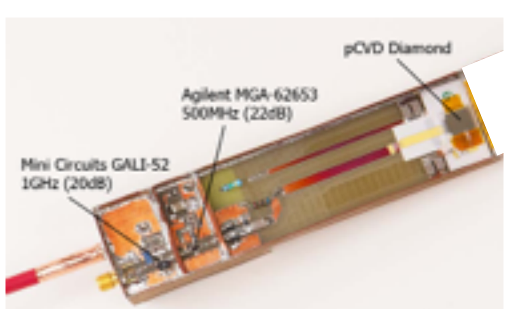


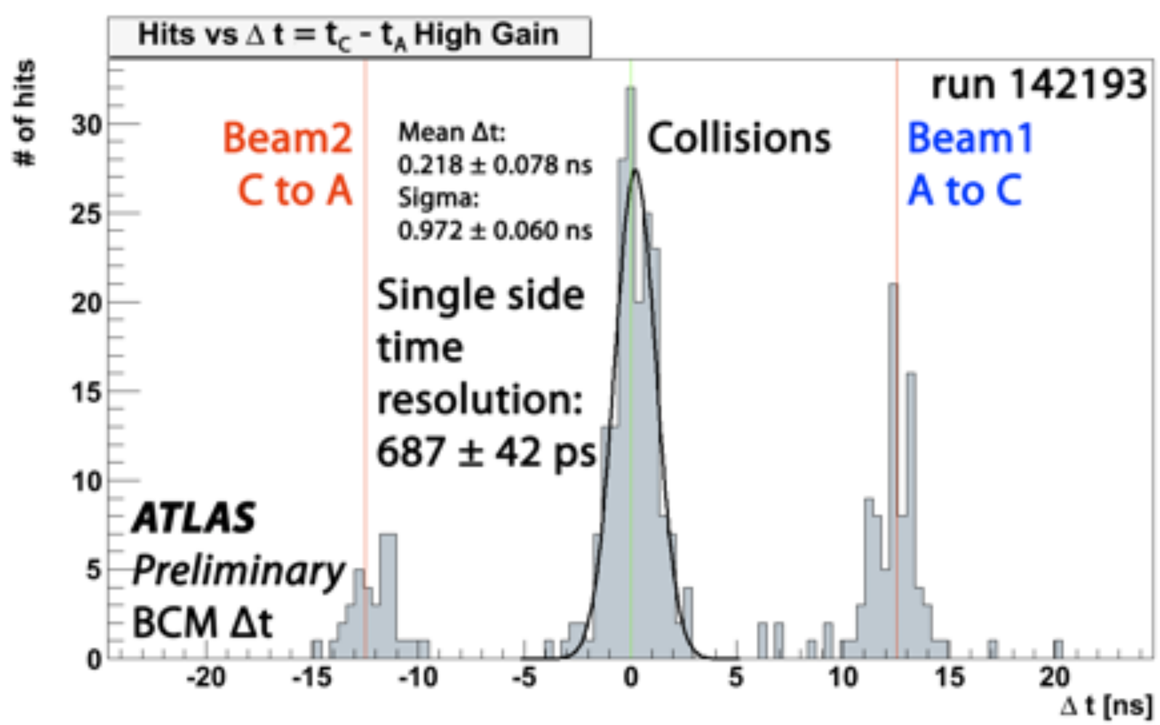


LUCID

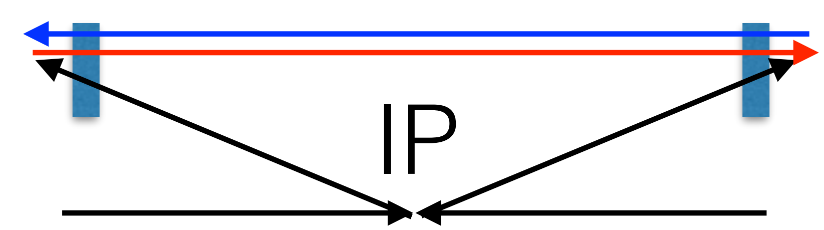
Particle counting mode







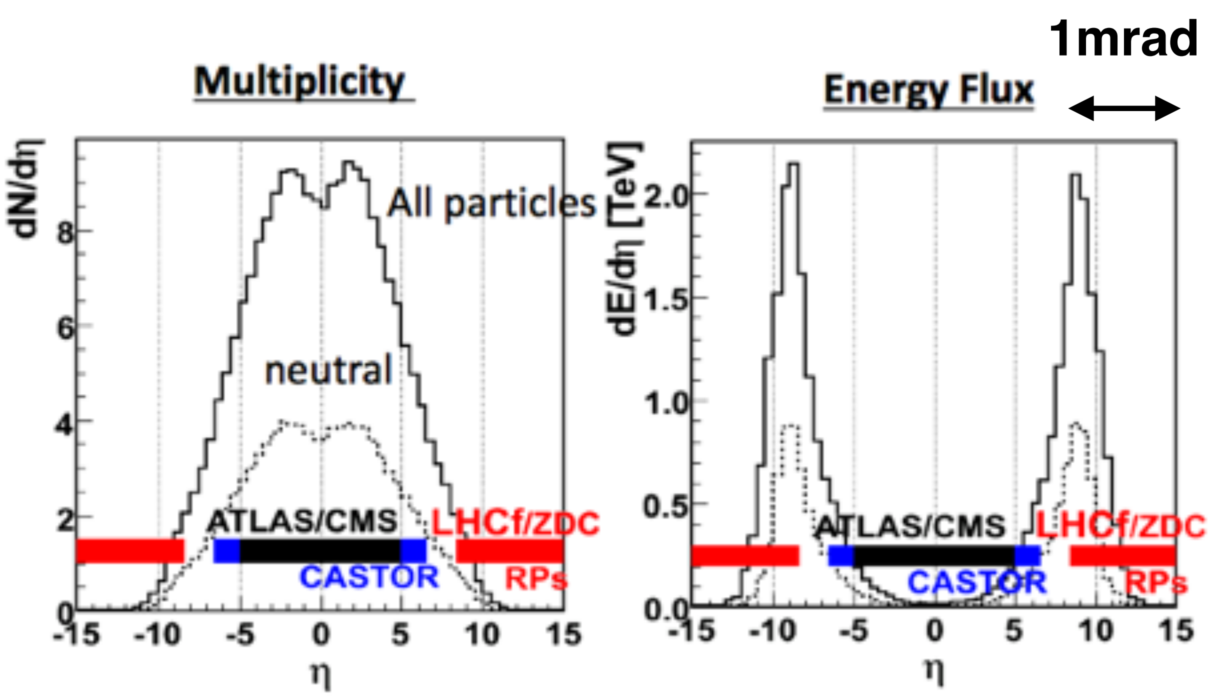
… and in and out-time luminosity



BCM

Background and radiation

Many of the proton remnants go down the beam pipe (mrad)



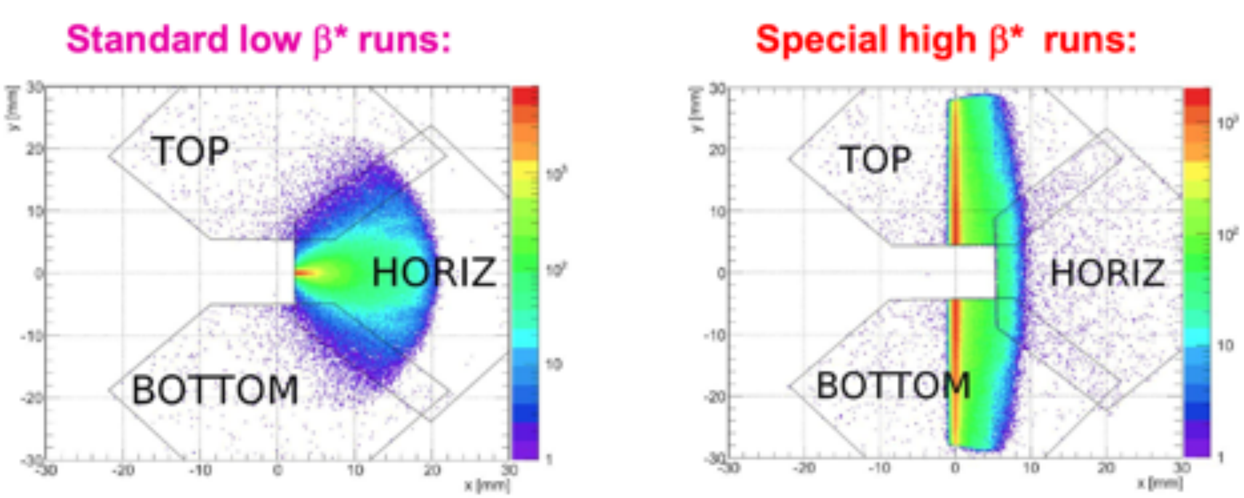
Sources:

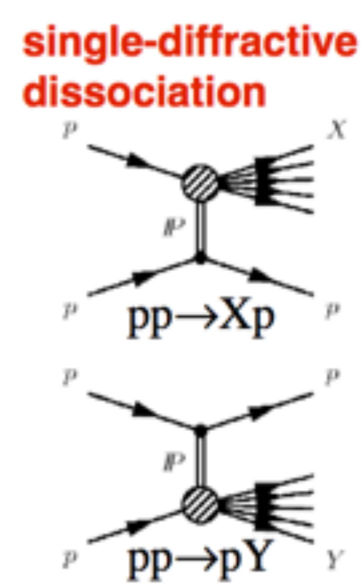
1. IP: single diffraction pile-up
2. Secondary interactions in upstream beam elements
3. Beam Halo

Low-μ (special) runs: backgrounds are OK.

High-μ (standard) runs: backgrounds are VERY HIGH

– TOTEM standard-optics runs
  - evidence that the source is primarily IP and secondary interactions in collimators (1 & 2)



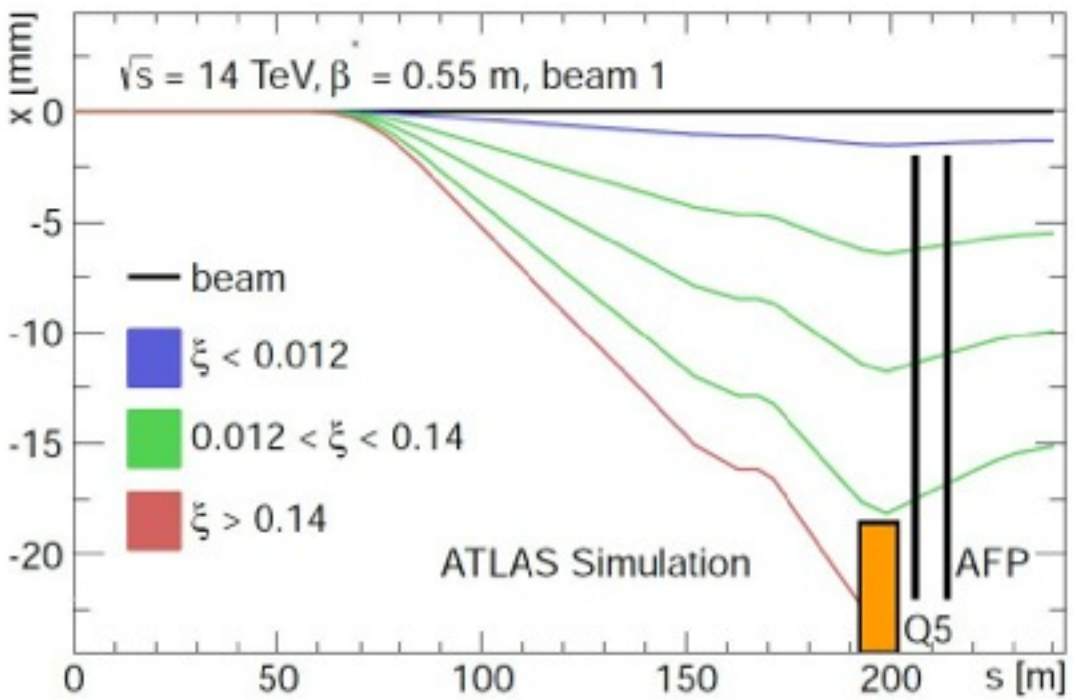


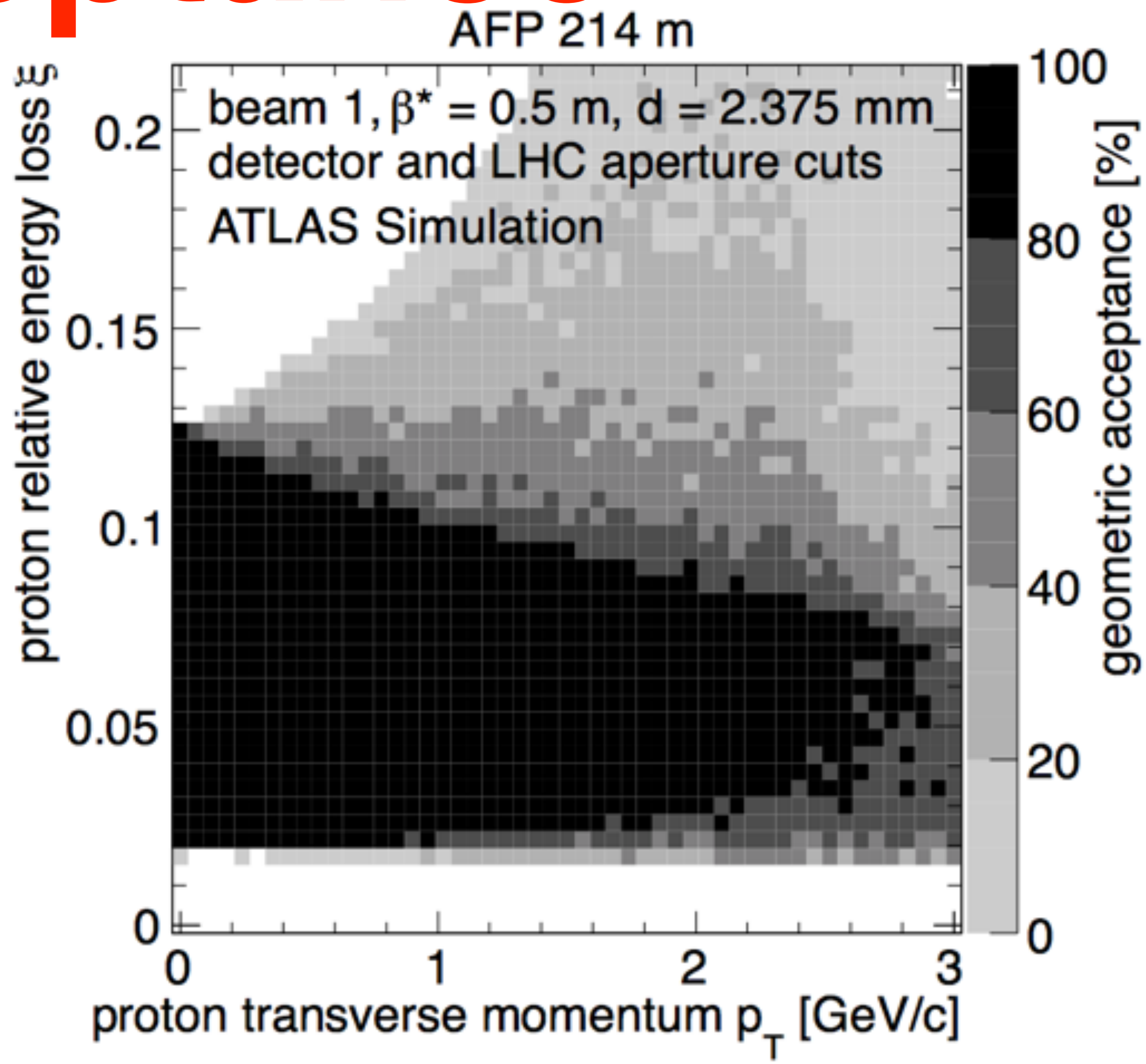
Expected SD rate per arm within acceptance:
~ 2 protons / bunch crossing

Acceptance

Proton relative energy loss

$\xi=(E_{beam}-E_{proton})/E_{beam}$

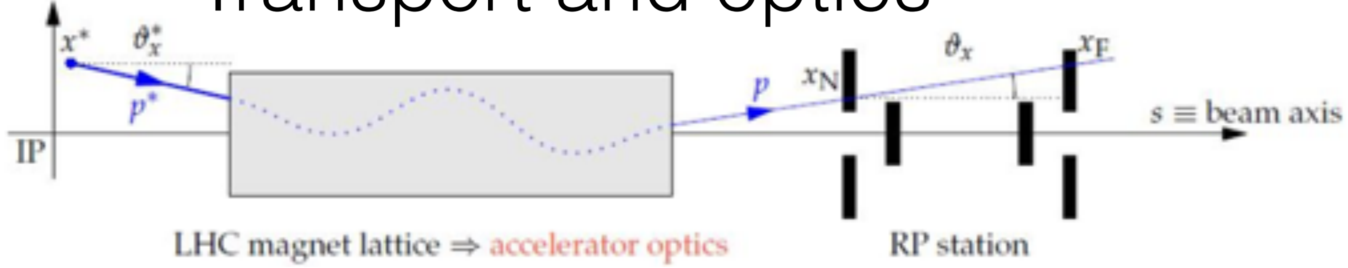




Rapidity Gap and Missing Mass

$$\Delta\eta_{1,2} = -\ln \xi_{1,2}, \quad M^2 = \xi_1 \xi_2 s$$

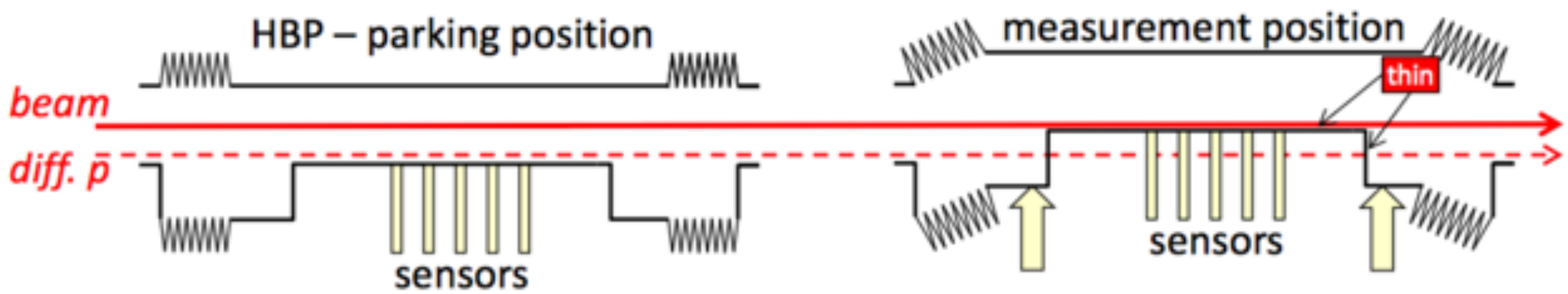
Transport and optics

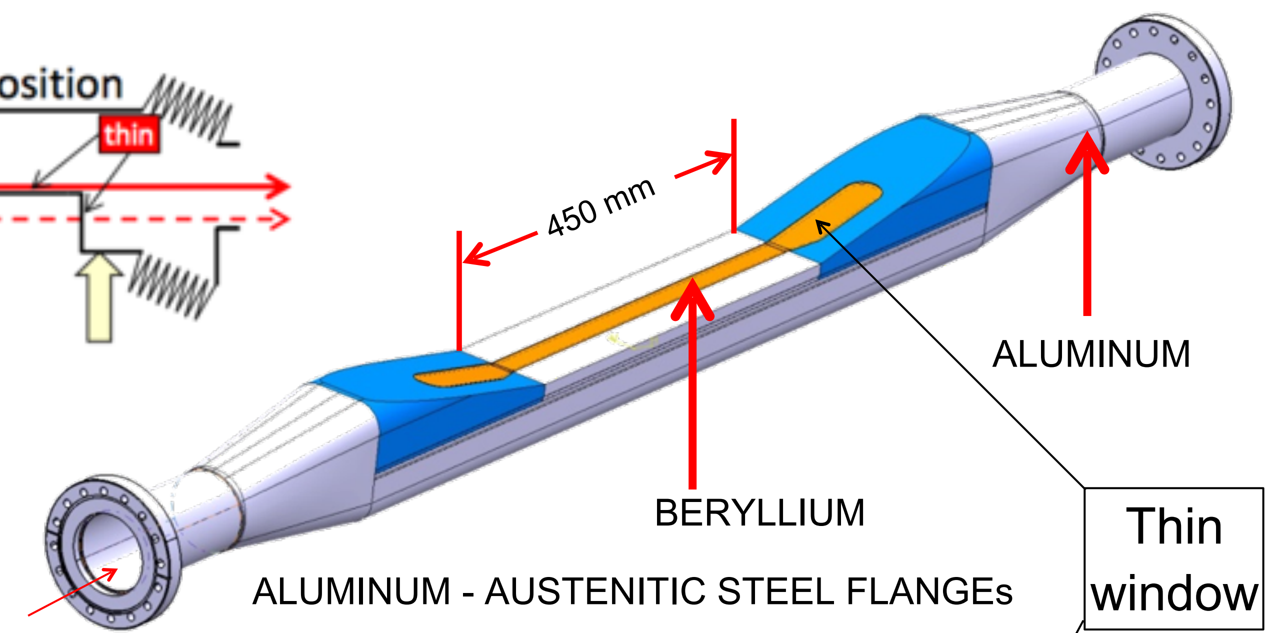


$$\begin{pmatrix} x \\ \Theta_x \\ y \\ \Theta_y \\ \Delta p/p \end{pmatrix}_{RP} = \begin{pmatrix} v_x & L_x & 0 & 0 & D_x \\ v'_x & L'_x & 0 & 0 & D'_x \\ 0 & 0 & v_y & L_y & 0 \\ 0 & 0 & v'_y & L'_y & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x^* \\ \Theta^*_x \\ y^* \\ \Theta^*_y \\ \Delta p/p \end{pmatrix}_{IP}$$

Very near to the beam

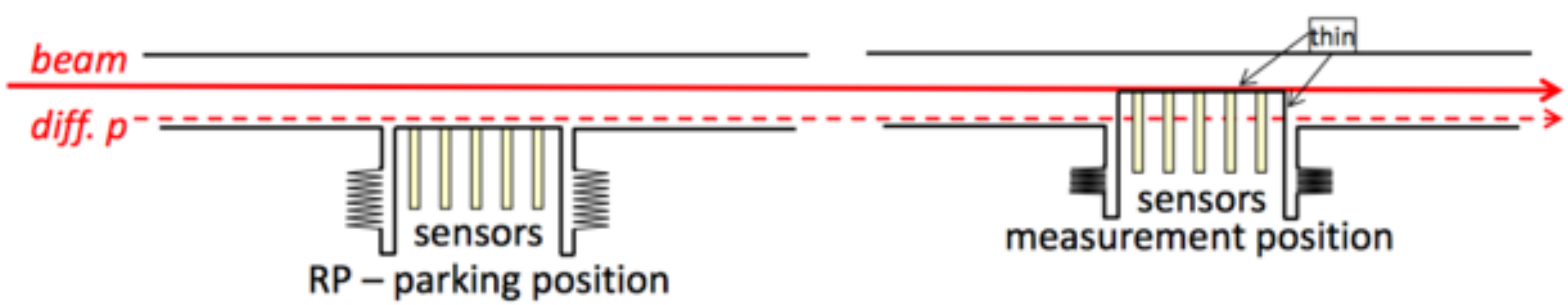
- **Hamburg Beam Pipe**: movable section of beam pipe with thin window facing the beam ("floor") and entry/exit windows:

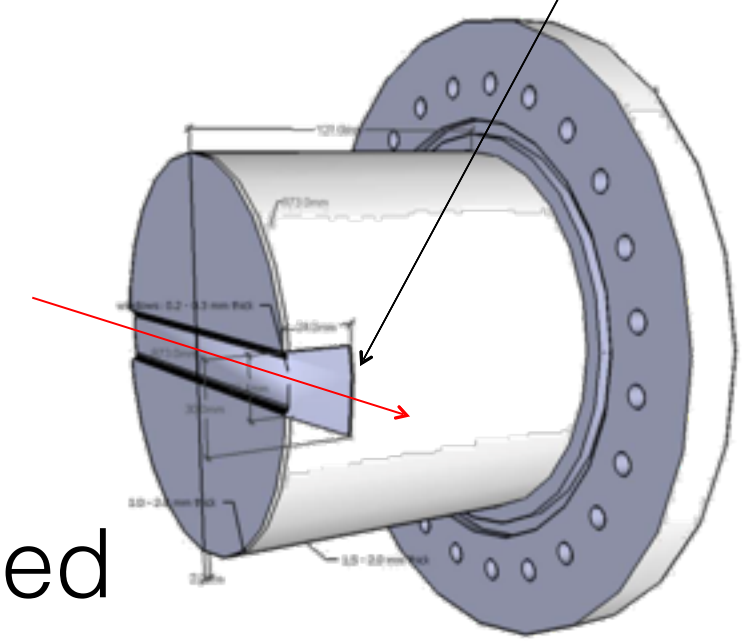




Decision in 2017 if to add HBP

- **Roman Pot**: movable UHV insert entering the beam aperture with thin "floor" and entry/exit windows:





Mature technology but improvements needed to fit large size detectors

Known upgrades

- **LUCID (ATLAS) upgrade for run 2**
- **DBM (ATLAS) installed for run 2**
- **PLT (CMS) installed for run 2**
- **TOTEM-CMS for phase I**
- **AFP (ATLAS) for phase I**

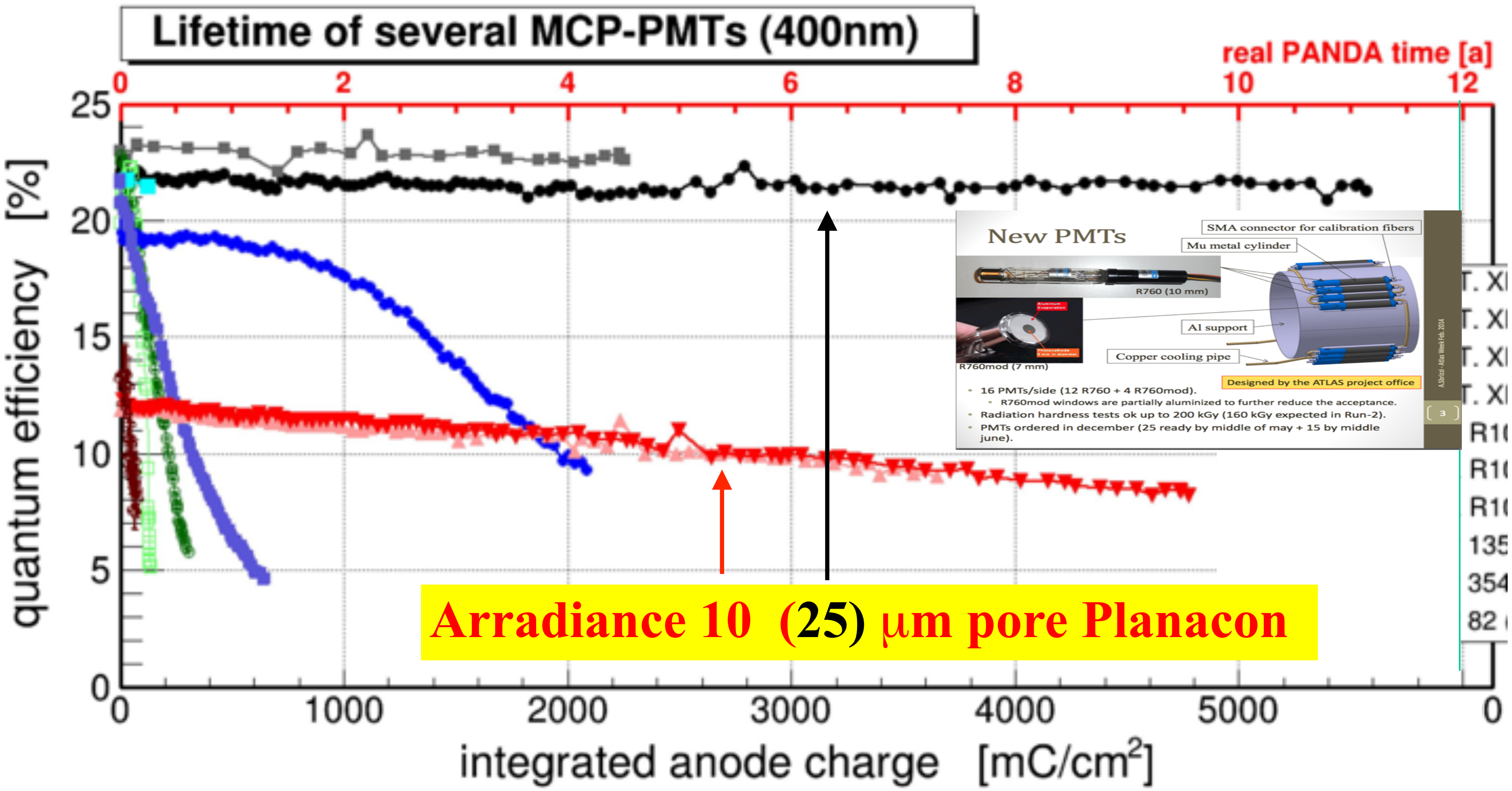
No plans for Luminosity Detectors in phase I

No plans for Forward Detectors for phase II (but AFP 420 for phase II evaluated after 2016)

Staged approach to technical difficulties, each stage with physics output:

- high β^* / low <μ> → low β^* / high <μ>
- phase I → phase II

New MCP lifetime

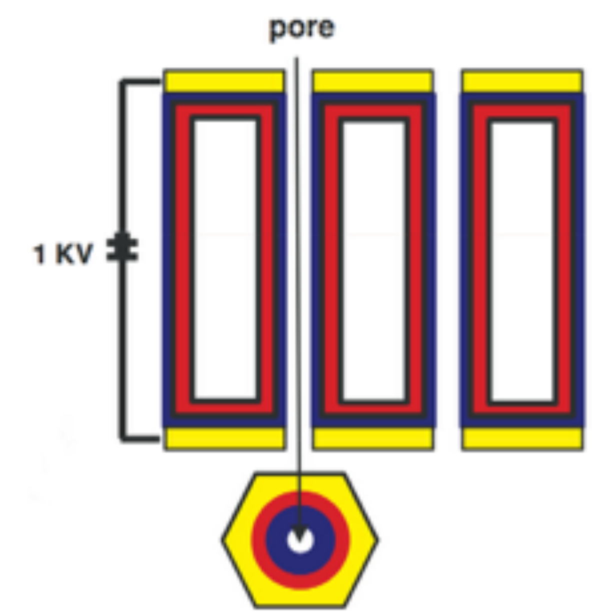


Cheap substrate: borosilicate glass filter

Functionalization with ALD (Atomic Layer Deposition)

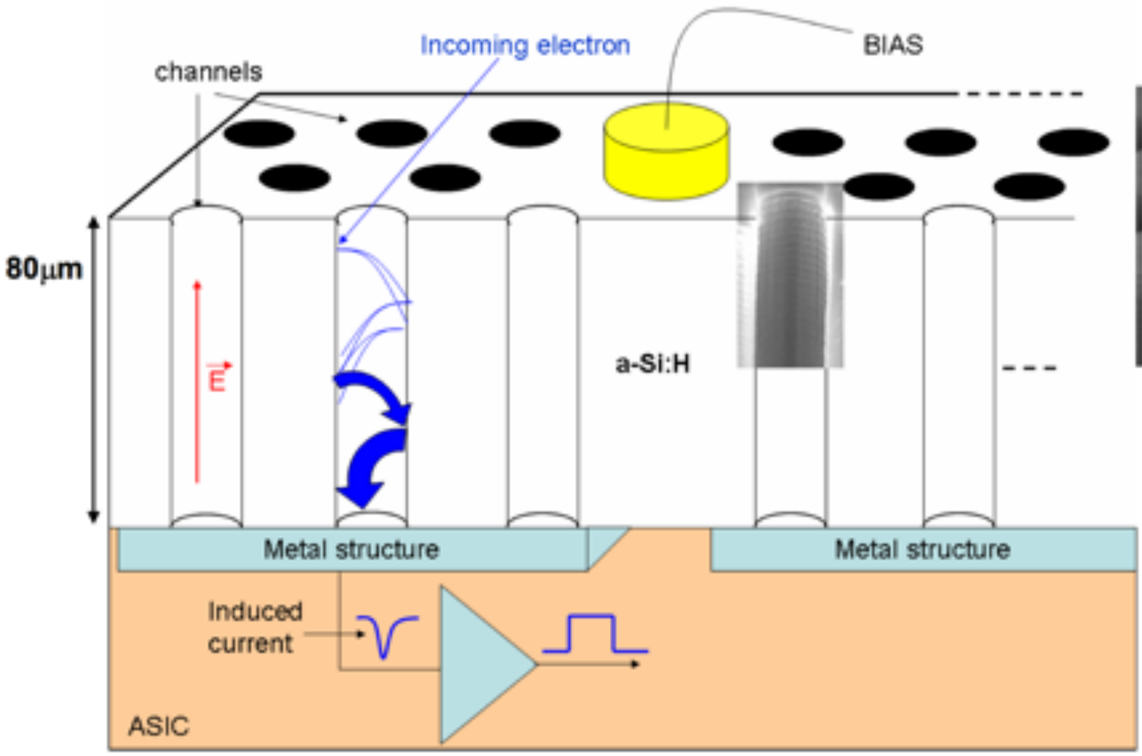
- Emissive layer (RED)
- Resistive layer (BLU)

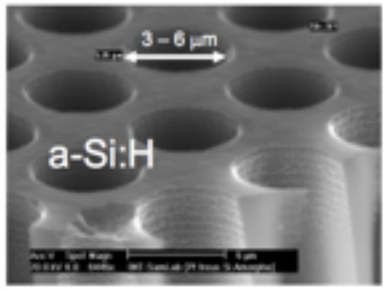
Evaporate contacts (YELLOW)



Lehman et al. (Panda) No loss in QE with ∫Q>6 C/cm²
10x improvement
1C~10 fb^{-1} but expect x3 more with next version

a-Si:H based MCP (AMCP)





a-Si-H has good resistivity ~1011 Ω secondary electron emission

Evaporate aluminum on a substrate as bottom contact

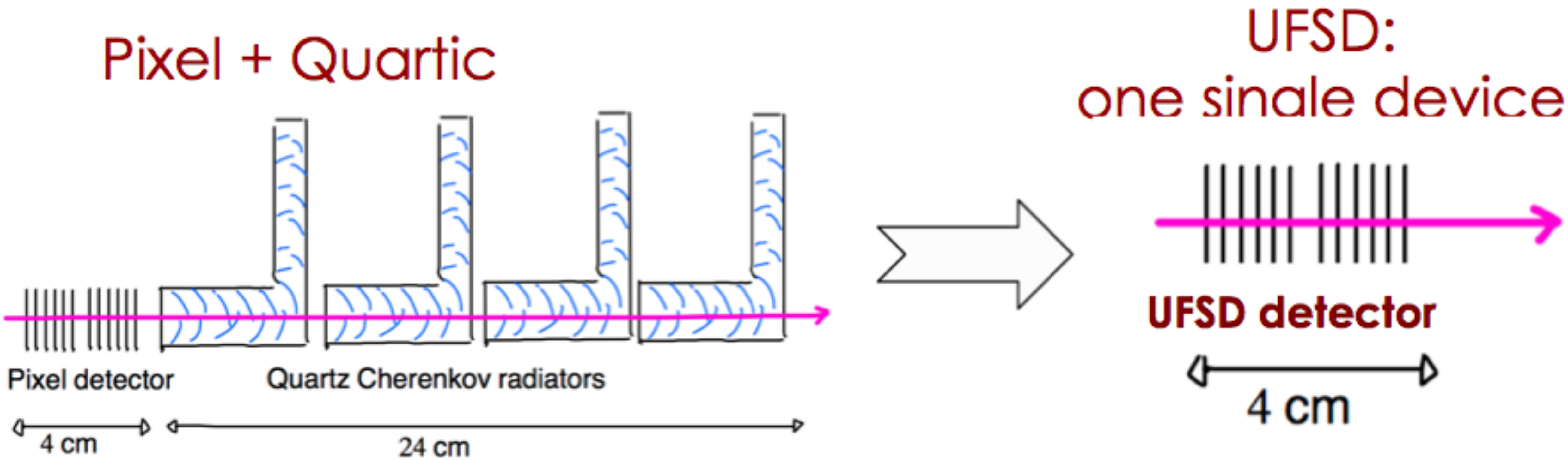
Deposit 80-100 um of a-Si-H by Thin Film on ASIC (TFA)

Deposit 100-500nm n-doped a-Si-H by TFA as top contact

Fabricate pores with 20:1 aspect ratio by Deep Reactive Ion Etching (DRIE)

CMOS wafer can be post-processes with TFA and DRIE to realize a hybrid pixel.

UFSD dream?



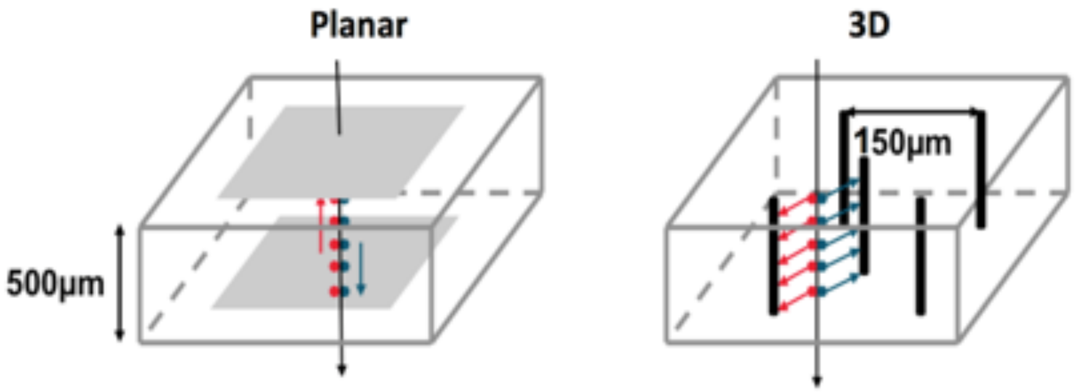
Diamond detector can dream the same?

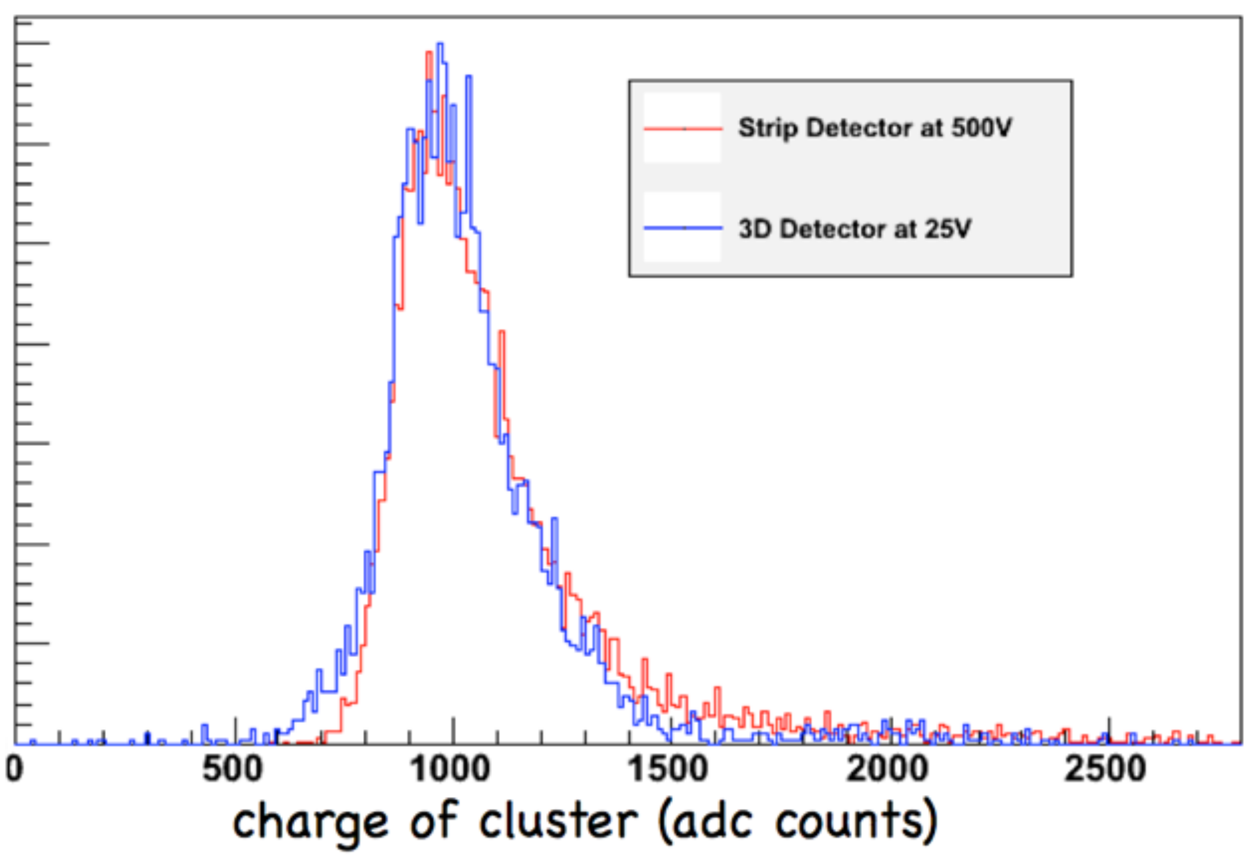
Diamond detector under study by AFP, TOTEM, UA9 for timing.

Still not competitive: 100 ps possible but 10 ps need new ideas.

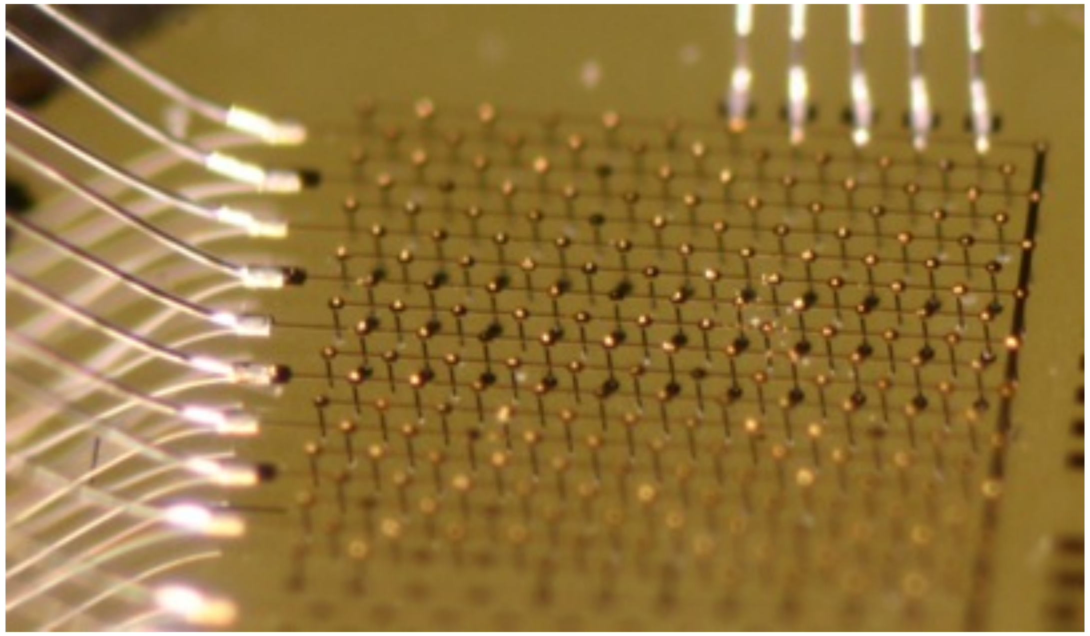
3D pixel diamond

Graphite columns fabricated in diamond by fs laser





- Signal proportional to thickness
- Collection time proportional to electrode distance

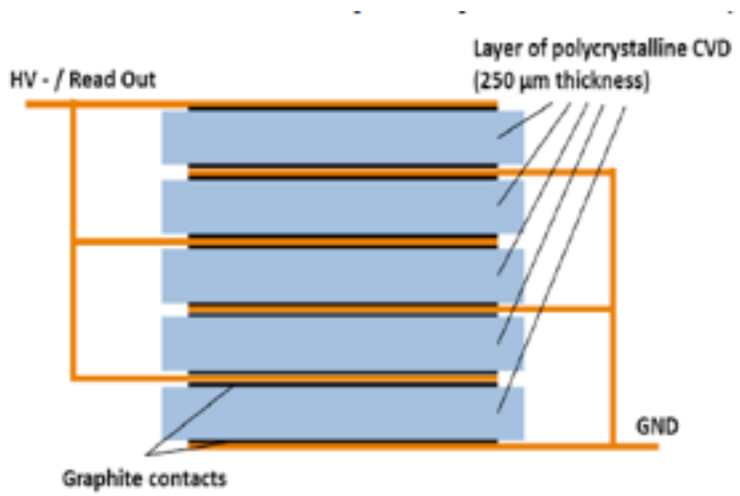


Improvements:

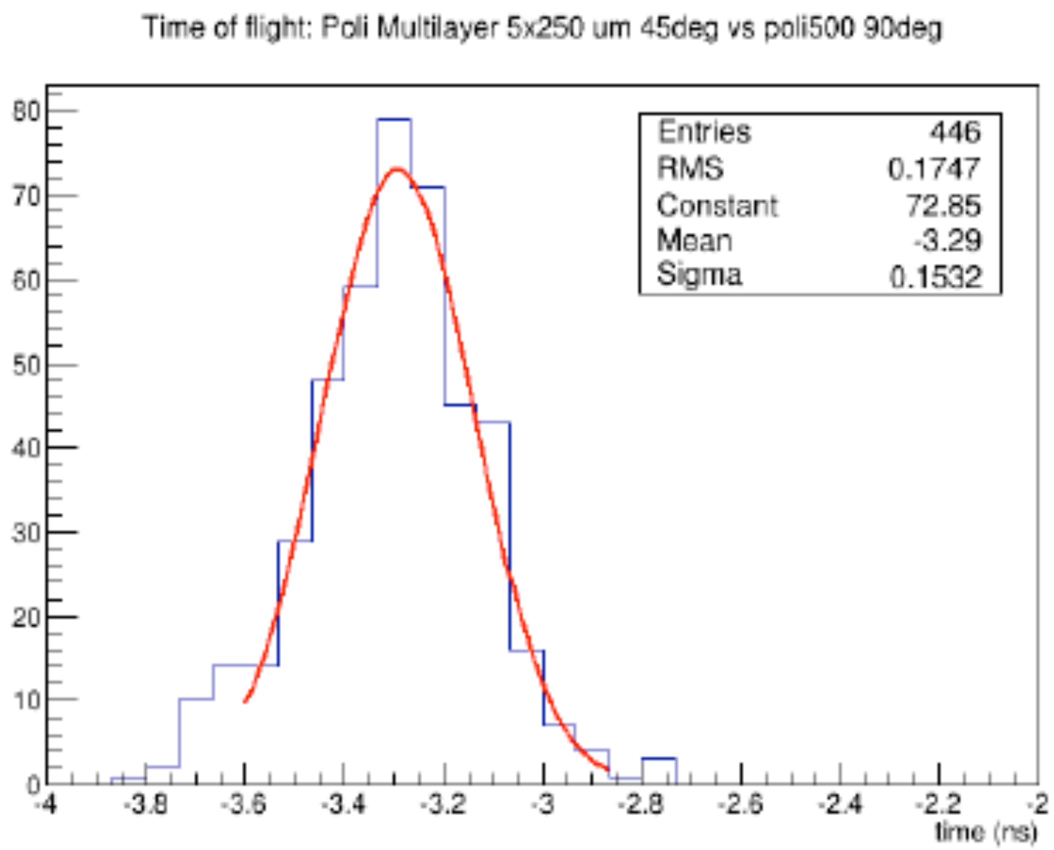
- Yield on large scale
- Electrode resistance

Multi-layer crystal Detector (MLCD)

R. Cardarelli, A. Di Ciaccio and L. Paolozzi;
Development of Multi-Layer Crystal Detector and related Front End electronics;
Submitted on 18/09/2013 NIM A



ToF measurement for a 5 layers MLCD.



- n thin layers in parallel: multiply the signal but collection time the same
- Improve time resolution a factor n
- Thin diamond less polarization
- Discrete SiGe fast amplifier with low-noise independent by input capacitance
- 8 channels SiGe chip just submitted.