HSDT11 & SOIPIX2 closing remarks

G. Hall

First, a few important things…

- Thank you for…

- Immaculate organisation
  - **thanks!!!** to Nobu and his small team for an outstanding job done
  - which he plans to repeat in 2019…
  - I will return to this point at the end

- Wonderful location and facilities
  - the OIST campus is a beautiful and remarkable place
  - and we have been aided by a lot of local support

- Fitness lessons from Okinawa

- and of course to participants for their contributions

... not the end of your work

- All contributions, orals and posters, are eligible for inclusion in the special issue (Proceedings) of **Nuclear Instruments and Methods, Section A.**
  –
- The manuscripts should be submitted between
  - **1st Jan. and 5th Feb., 2018**
  - **then, peer-reviewed by referees including the participants (staff) to this conference, i.e. we need your help**
- The quality of papers should be to the same standard as required for normal publication and conform to the rules of Elsevier:
  - http://authors.elsevier.com/journal/nima
  - And, if you have already published the content, your work is done.
  - No need to submit, i.e., avoid duplicated publication.

Contributions to the conference

- Very impressive content
  - from invited speakers
  - from speakers
  - and also from poster contributions
- Too much to do justice to
  - and I have no intention to review them
  - just to make a few remarks

Physics Motivation
November Revolution

J/ψ

11 November 1974

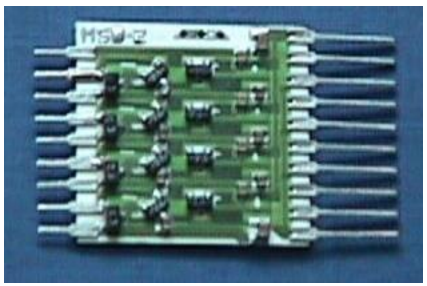
- Gaillard, Lee and Rosner RMP **47** (1975) 277 *Search For Charm*
  'The tracks of charmed particles will be too short to see in bubble chambers, but should definitely be of the order of tens or hundreds of microns: easily detectable in emulsion'.
- Charpak, EPS Conference in Palermo June 1975
  'Drift chambers are the easiest to build, most accurate, cheapest and most convenient detector for localising particles. Whoever is familiar with their operation would be strongly reluctant to use other devices in the planning of a new experiment'.
- ACCMOR collaboration in CERN struggled to see charm hadroproduction (single *e* trigger)
- Succeeded over next 10 years to develop silicon microstrip and pixel detectors (CCDs) as powerful tools for charm physics.

CJSD/Snowmass/July 2001/pg3

- Semiconductor sensors and electronics now have ~40 year history
  - starting with experiments searching for charm

We have come a long way

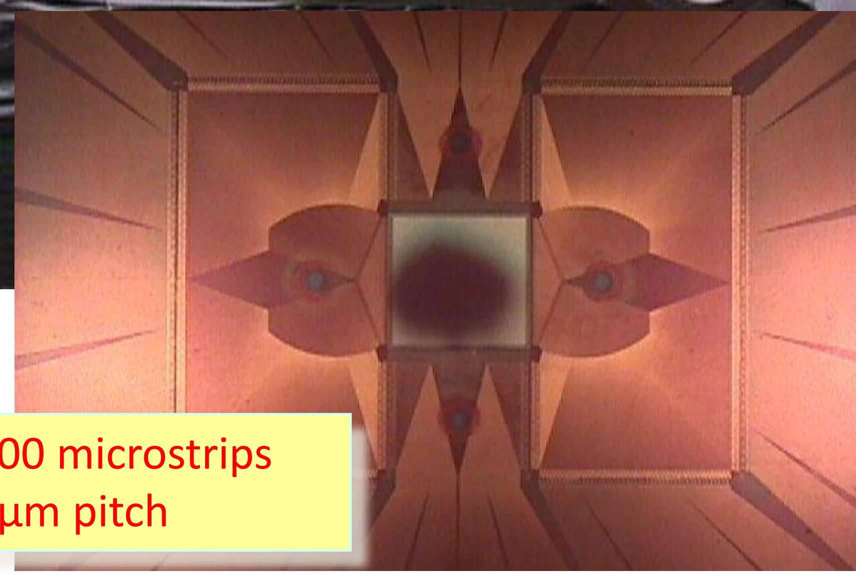
- Vertex detector early 1980s
  - “second generation”
    - NA14 at CERN



4 channel amplifier
15mW per channel

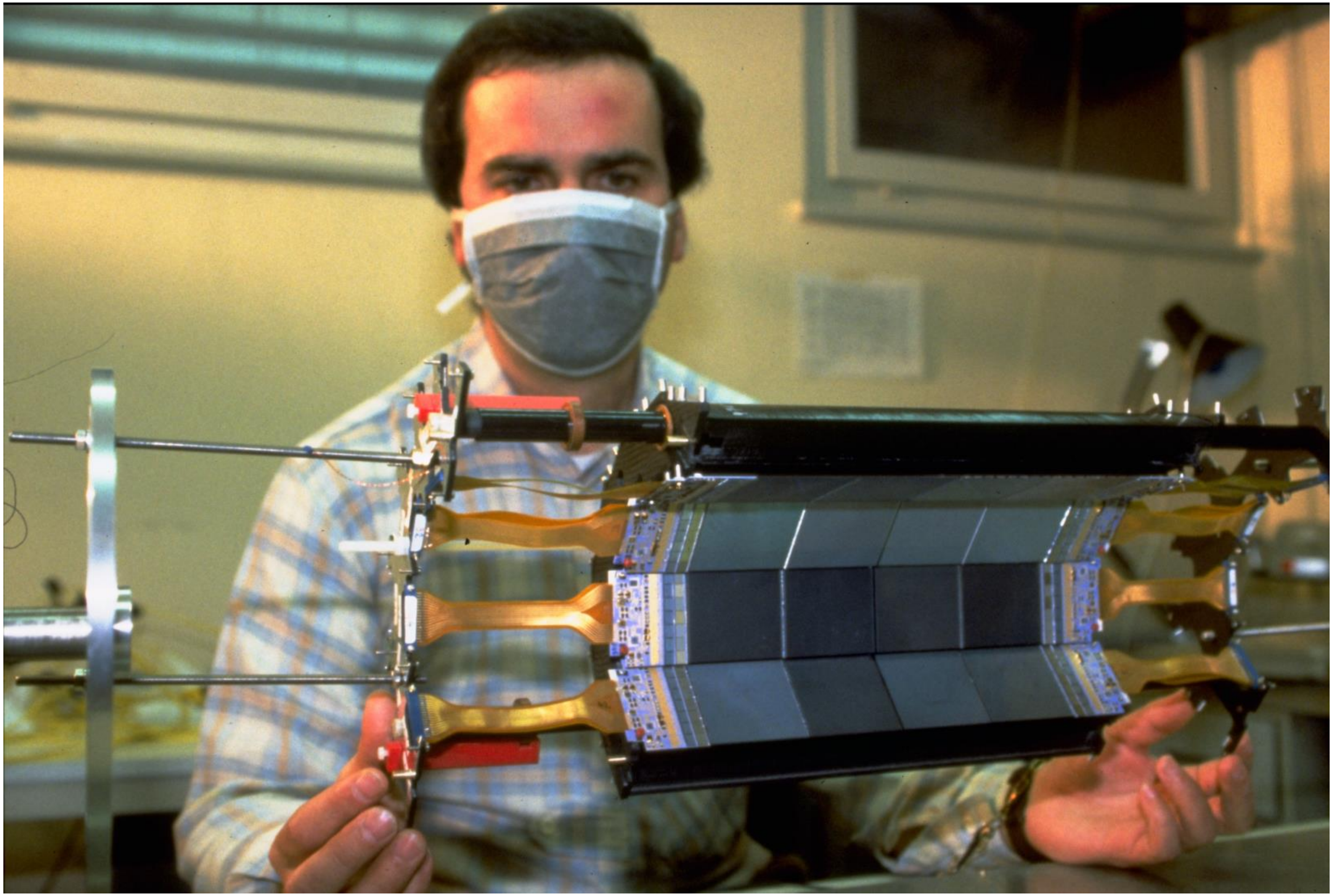
10 silicon detectors
10,000 microstrips

Power ~150W



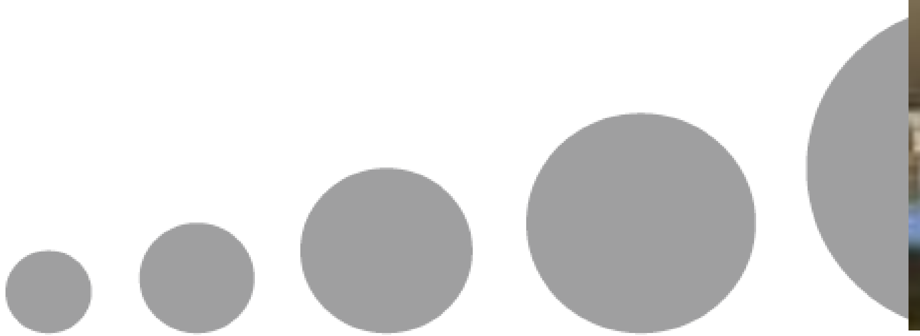
1000 microstrips
50µm pitch

Vertex detector early 1990s



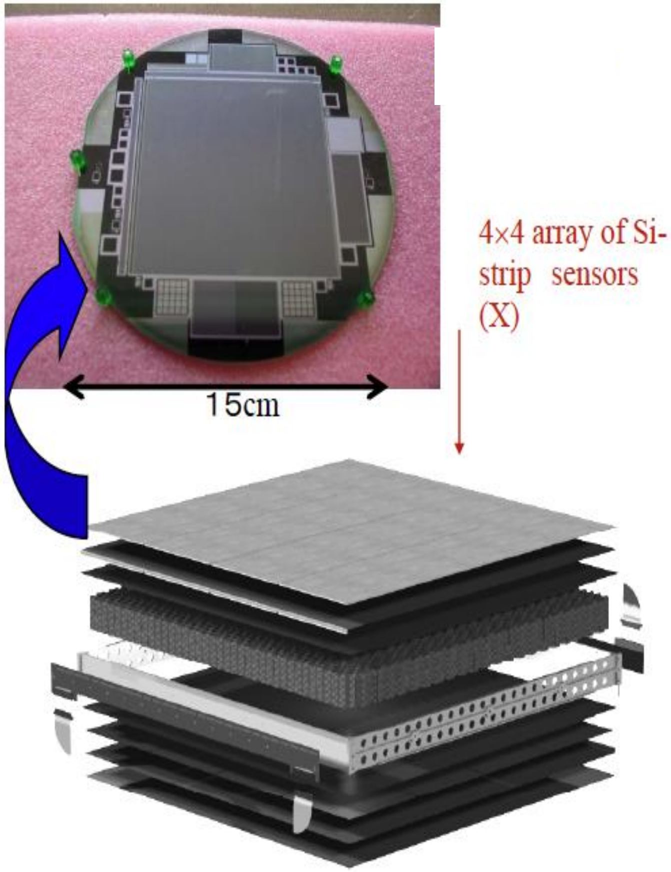
History of Hamamatsu Si wafer size

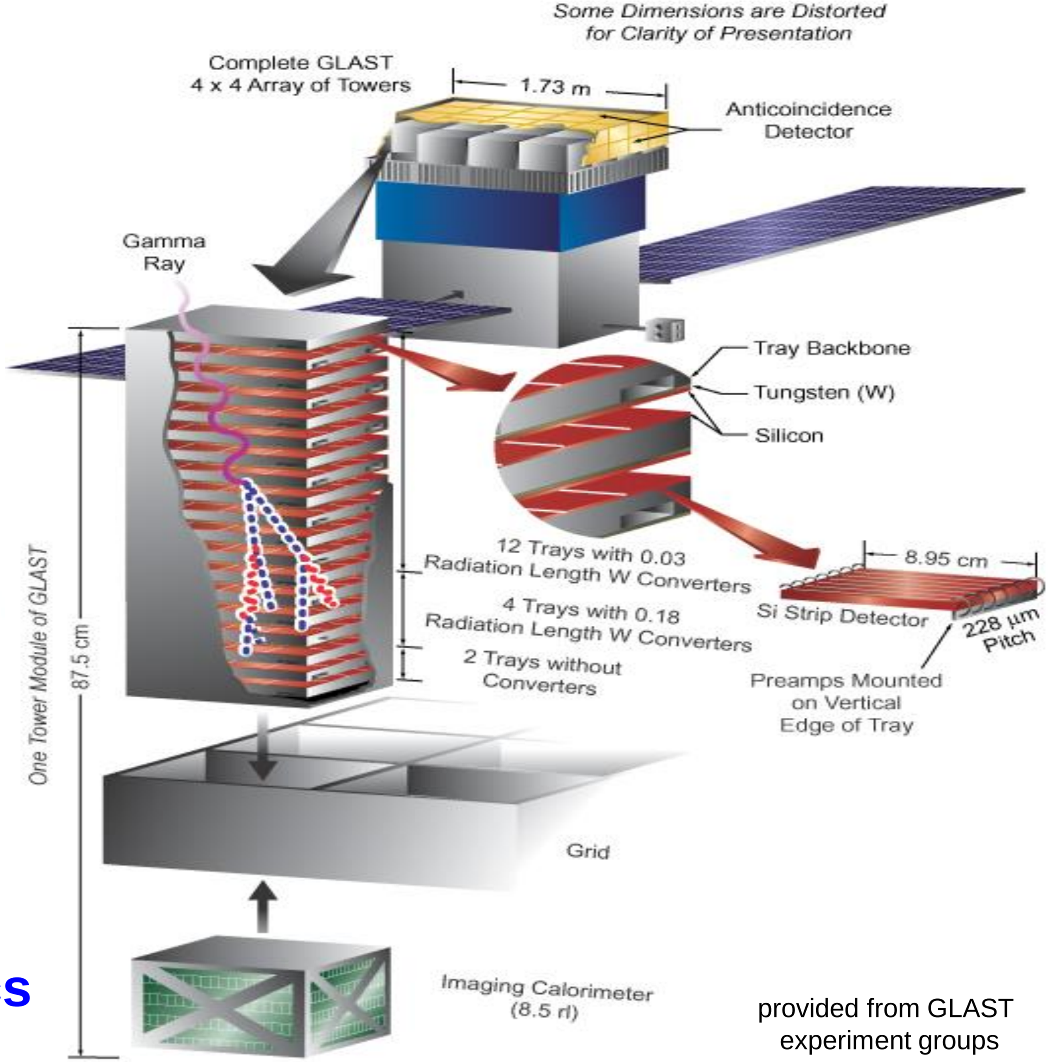
Wafer size	Production term
φ1.5inch	1972～1985
Φ2inch	1975～1986
Φ3inch	19
Φ4inch	19
Φ6inch	
Φ8inch	de



(8inch)

Fermi(GLAST)-SSSD





Total strip detectors:11,000pcs
8.95x8.95 mm 228μm pitch

provided from GLAST experiment groups

Review of main SSDs made by Hamamatsu（2000～）

PROJECT	DETECTOR TYPE	size	QTY.	period
AGILE	AC-SSSD ， poly-Si	1chip/6inch	500	2000
PAMELA	DC-SSSD	1chip/6inch	300	2000
BELLE up grade	AC-DSSD ， both-side: poly-Si	2chip/4inch	250	2000～2002
ATLAS	AC-SSSD 6type ， poly-Si	1chip/4inch	15500	2001～2003
GLAST	AC-SSSD ， poly-Si	1chip/6inch	11500	2001～2003
CMS	AC-SSSD 14type ， poly-Si	1chip/6inch	24000	2003～2006
LHC-b	AC-SSSD ， poly-Si	1chip/6inch	560	2005～2006
ALICE	AC-SSSD 2type ， poly-Si	1chip/6inch	106	2005～2006
Phenix	Strippixel ，DML	3chip/6inch	600	2007
PP2PP	AC-SSSD 2type ， poly-Si	1chip/6inch	120	2003～2007
FVTX	AC-SSSD 2type ， poly-Si	3chip/6inch	450	2009～2010
ASTRO-H	DC-DSSD ，DC-PAD ， Pside: DML	3chip/6inch	260	2007～2011
STAR-HFT	AC-SSSD ， poly-Si	2chip/6inch	216	2012
HALL-B	AC-SSSD(stereo) 3type ， poly-Si	1chip/6inch	434	2012
BELLE-II	AC-DSSD ，2type ， Poly-Si	1chip/6inch	265	2011～2014
DAMPE	AC-SSSD ， poly-Si	1chip/6inch	768	2014

LHC has driven many significant developments

- and the experiment upgrades are continuing to do so
  - this was made clear again in the conference

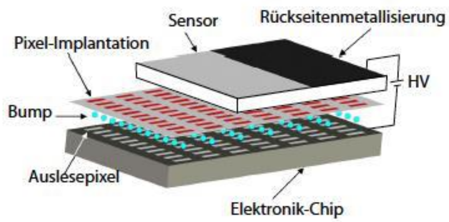
- already upgrades to pixel systems
  - generally very successful but not without issues
  - lessons for the future?

- and very substantial developments foreseen for HL-LHC
  - ambitious, both technically and for timescale
  - new types of detectors, some of which have been dreamt of but not yet realised
    - integrated sensors and electronics
    - detectors providing data to the trigger
    - systems with precise time information
    - more new technologies, like 3D

Pixels

~1997

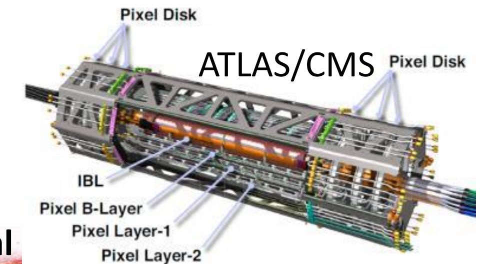
Hybrid pixel detectors



HEP tracking

LHC

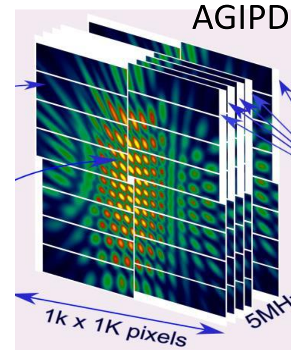
HI



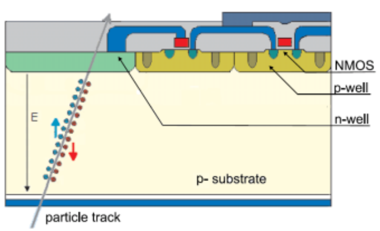
Imaging

biomedical

photon science

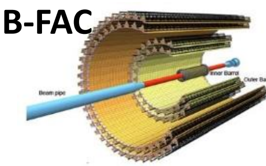


Monolithic pixel detectors

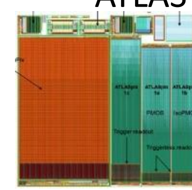


HEP tracking

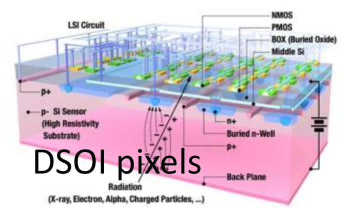
HI, B-FAC



LHC



Imaging



2017

N. Wermes, HSTD11, OIST 12/2017

Complex systems

- need significant care, time and effort – including evaluation

ALPIDE Development

Design team: G. Aglieri, C. Cavicchioli, Y. Degerli, C. Flouzat, D. Gajanana, C. Gao, F. Guilloux, S. Hristozkov, D. Kim, T. Kugathasan, A. La^ uca, S. Lee, M. Lupi, D. Marras, C.A. Marin Tobon, G. Mazza, H. Mugnier, J. Rousset, G. Usai, A. Dorokhov, H. Pham, P. Yang, W. Snoeys
(InsXtutes: CERN, INFN, CCNU, YONSEI, NIKHEF, IRFU, IPHC) and comparable team for test

ALICE

2012 – Explorer
20mm x 20mm and 30mm x 30mm pixels (analogue readout)
pixel geometry, starXng material, sensiXvity to radiaXon

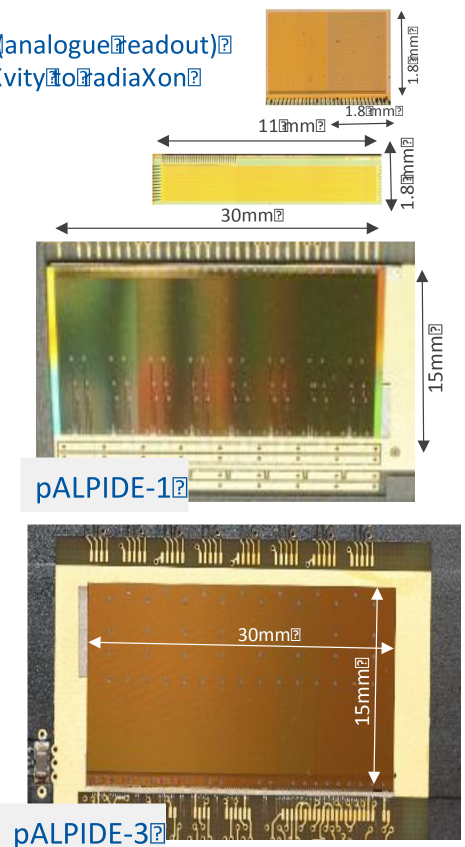
2013 – pALPIDEss-0
Matrix with 64 columns x 512 rows
22 mm x 22 mm pixels
In-pixel discriminaXon and buffering
Zero suppression within pixel matrix

2014 – pALPIDE-1
First full-scale prototype
Pixel pitch: 28 mm x 28 mm
4 sectors with pixel variants
1 register/pixel, no final interface

Apr 2015 – pALPIDE-2
4 sectors with pixel variants
OpXmizaXon of circuits
Allowing integraXon in ITS modules
No high-speed serial output

Oct 2015 – pALPIDE-3
8 sectors with pixels variant
All Communica/ on Features
(no ADC, no Temp Sens)

Aug 2016 – ALPIDE
Single pixel variant
All features and op/ miza/ on



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Collaboration

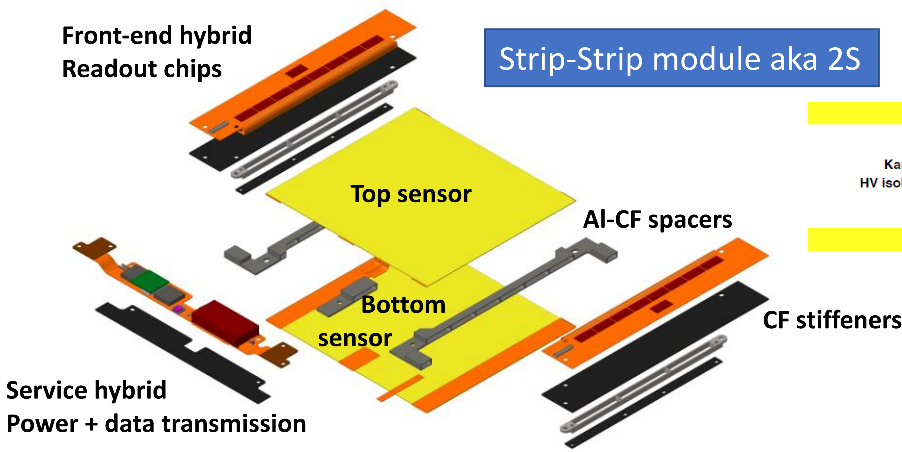
- It seems essential to master the art of team work
  - and some seem already to be achieving that

MONOLITHIC PIXEL DEVELOPMENT FOR ATLAS

Really new detector modules

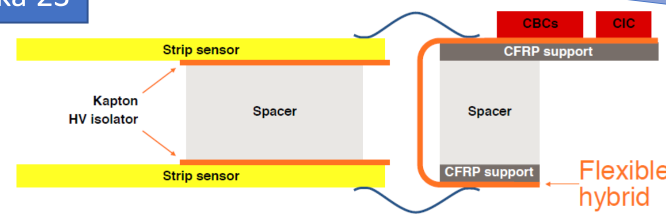
- Complex in every respect - to deliver data for the L1 trigger

Ingredients – The **Trigger** p_T Modules (2S & PS)



Strip-Strip module aka 2S

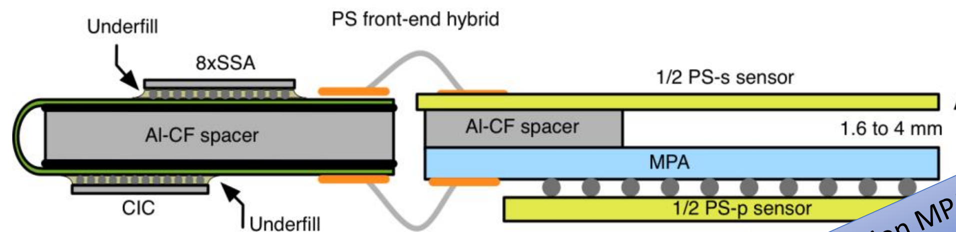
Stub correlation here



Stubs out @40MHz

All out at L1=750kHz

Pixel- Strip module aka PS



Stub correlation MPA

Necessary precision ≤400 (800) µrad tilt
Manual - pushing sensors against precision bolts
Requires cut edge precision of +/- 10 µm along sensor

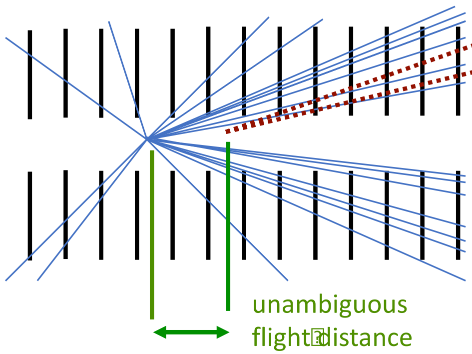
➔ These modules are the key ingredients and define largely the CMS Tracker layout as well

Really new features

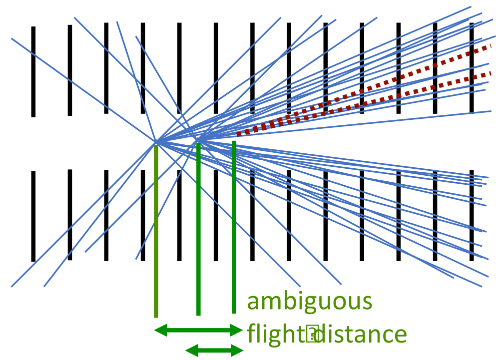
Welcome 'time' information (4D)

Presented by ATLAS, CMS and in the further future by LHCb

single primary vertex:



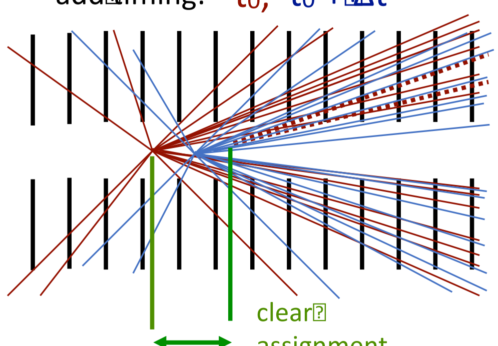
two primary vertices:



LHCb 2030

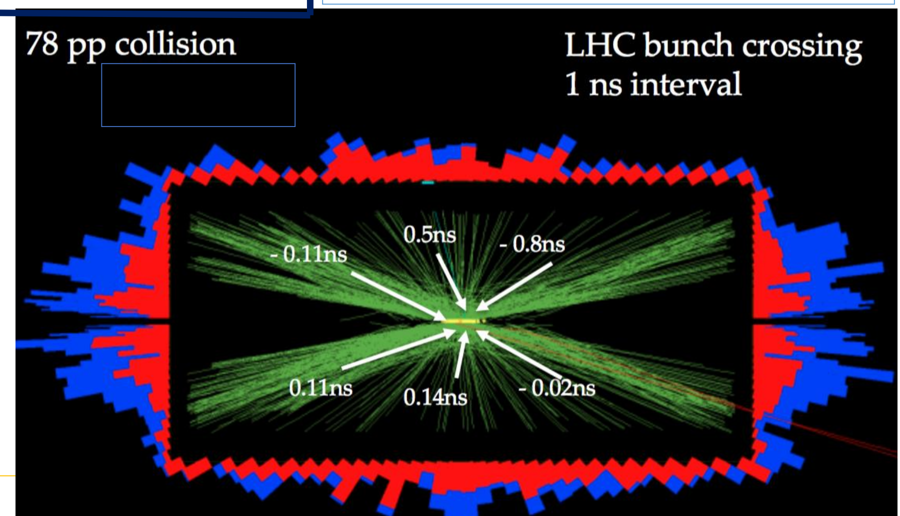
add timing: t_0, $t_0 + \Delta t$

two primary vertices + time decoding t_0, $t_0 + \Delta t$



From Paula Collins

For ATLAS and CMS, the issue lies in the PU-density thus vertex-merging especially at high eta



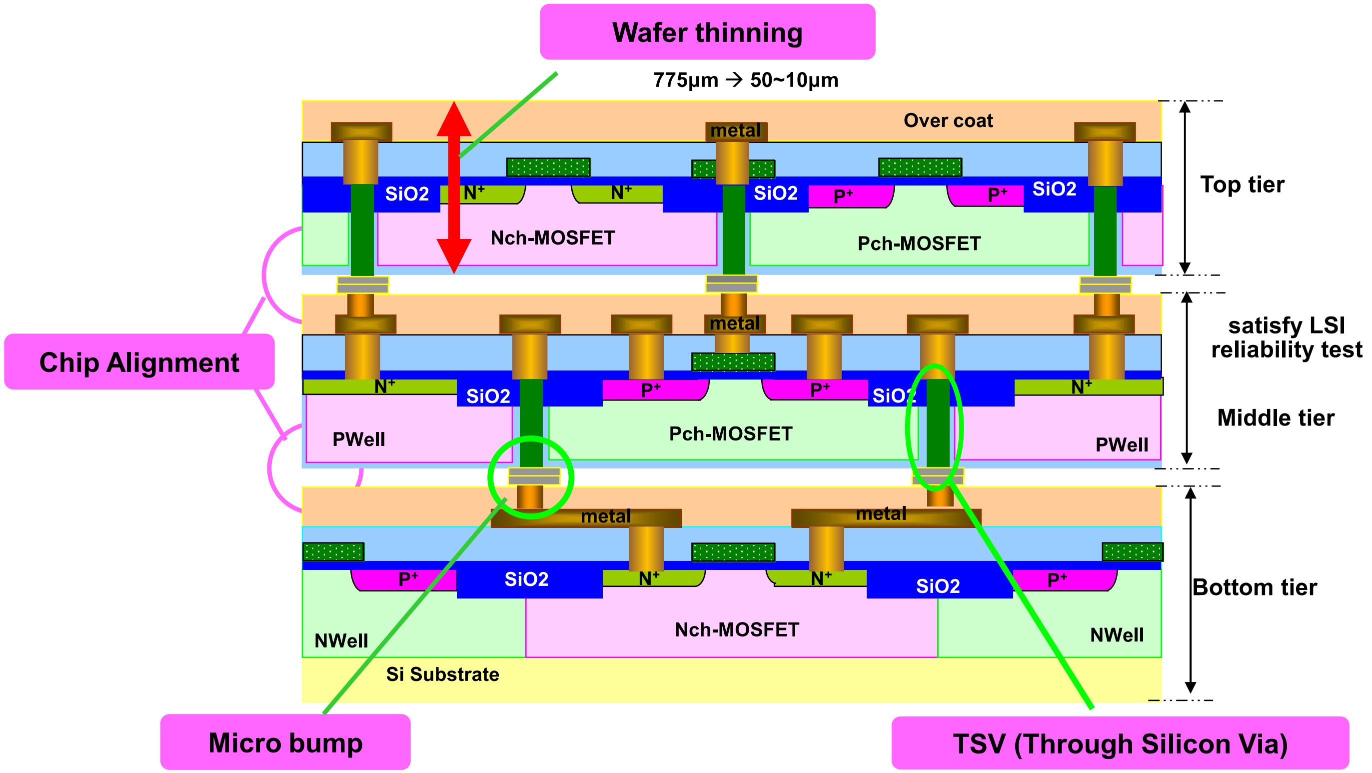
- **Fast timing detectors** – Nicolo Cartiglia
- **Full session on LGADs** – Thursday
- A High-Granularity Timing Detector for the Phase-II upgrade of the ATLAS Calorimeter system .. – Giulio Pellegrini
- The LHCb VELO Upgrade – Kazuyoshi Carvalho Akiba

Advanced technologies

- Our field has profited from technology evolution
  – will this continue to even more complex developments?

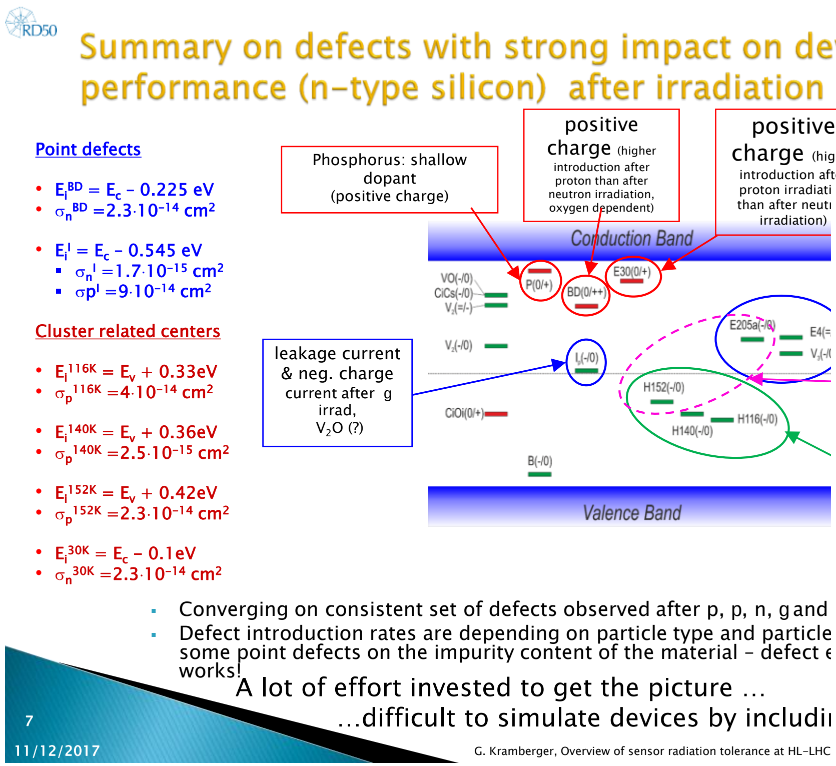
T-Micro

Key technologies of 3D-IC Integration

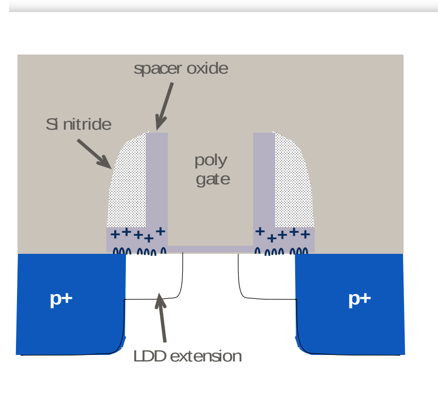


A lot has been learned about radiation damage

- but will it (ever?) be enough for another 20 years?

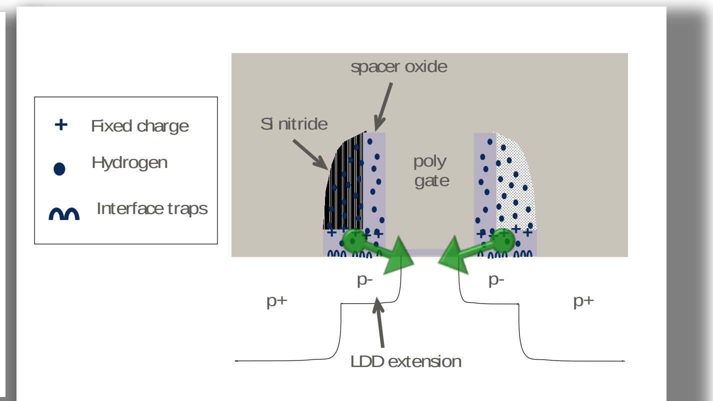


1. Decrease of on-current during exposure



The buildup of charge in defects located in the spacer oxide influences the amount of carriers in the LDD extensions, affecting the parasitic series resistance

2. Threshold voltage shift



Ionization in the spacers frees hydrogen (protons, neutral and/or molecular hydrogen).
This can later transport and reach into the gate oxide where it can de-passivate Si-H bonds.
Coming from the source/drain spacers, it will give origin to defects concentrated close to these regions.

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11th International "Hiroshima" Symposium on the Development and Application of Semiconductor Tracking Detectors (HSTD11) in conjunction with 2nd Workshop on SOI Pixel Detectors (SOIPIX2017) at OIST, Okinawa, Japan

Applications

- Perhaps a little less on applications than developments this time
  - much recent R&D progress, including many SOI contributions

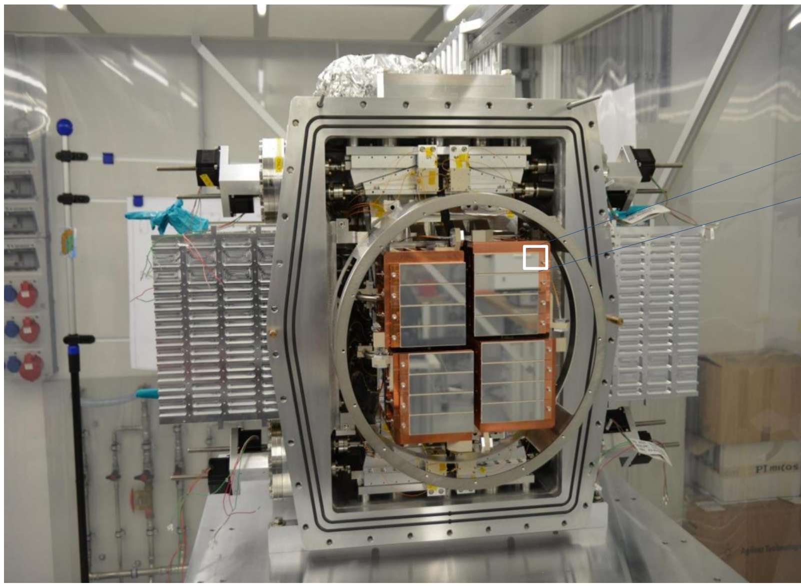
- But some applications, such as photon science, have really come of age
  - fully exploiting pixel systems
  - in some respects, like data rates, possibly overtaking LHC

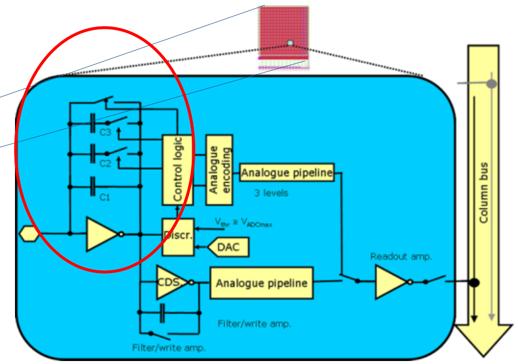
Photon imaging systems

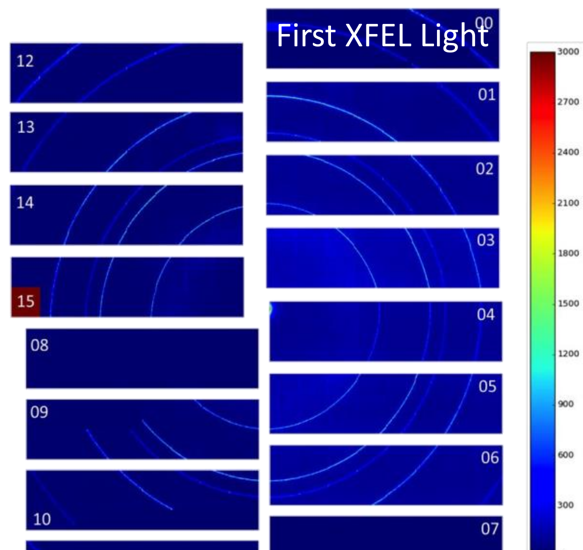
- Several (many?) large imaging systems now in use

AGIPD (adaptive gain) ... EU XFEL Pixel Detector

universitätbonn







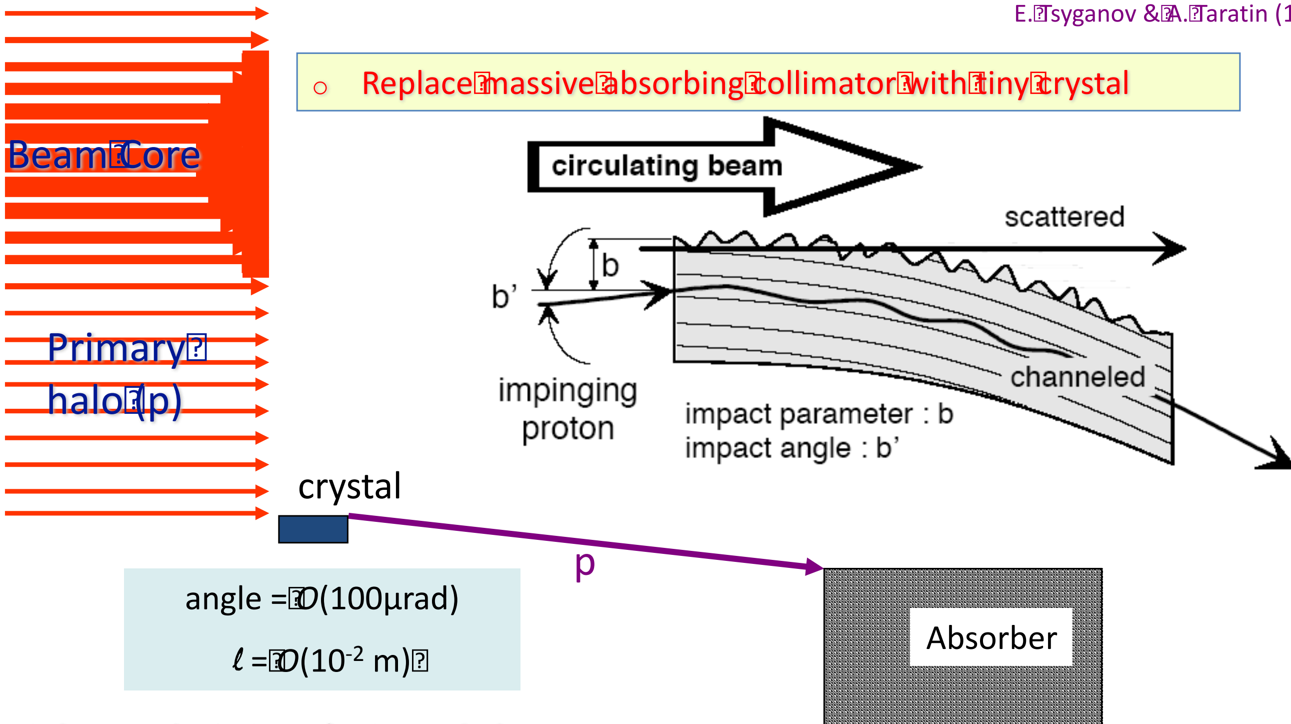
- ❑ addressing >10^4 dynamic range @ EU XFEL
- ❑ by "adaptive gain stages" (as JUNGFRAU)
- ❑ first XFEL Light has been seen ...

Another application of silicon

- which will soon be seen in LHC

Crystal collimation

E. Tsyganov & A. Taratin (1991)



- ♦ Coherent deviation of primary halo
- ♦ Very small probability of inelastic interaction in crystal
- ♦ Larger collimation efficiency
- ♦ Less impedance
- ♦ Reduced tertiary halo

- Incident angle within capture range

$$\theta_c \approx \frac{6.3\mu rad}{\sqrt{p[TeV]}} \approx 2.4\mu rad \text{ @ 7 TeV}$$

- Operation in vacuum and radiation
- Must be no risk to accelerator

Regularly studied using silicon telescopes

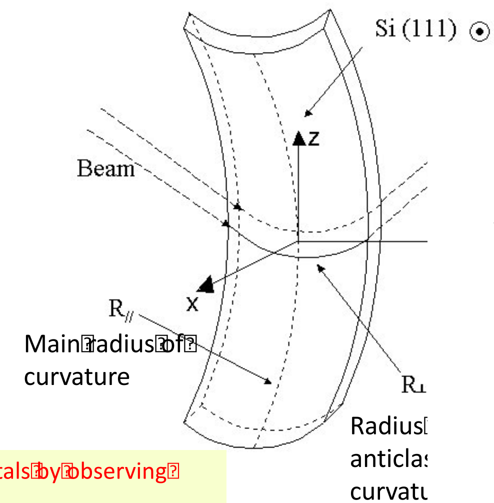
- and tested inside the LHC machine

Strip crystals

Many types of crystal have been manufactured at IHEP Protvino and at INFN Ferrara

The main curvature due to external forces induces the anticlastic curvature seen by the beam

Crystal size: 0.9 x 70 x 3 mm^3

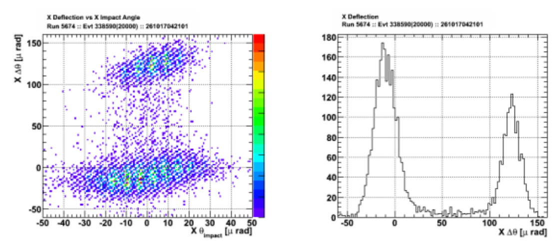


H8 measurements carried out to characterise crystals by observing channeling and associated phenomena

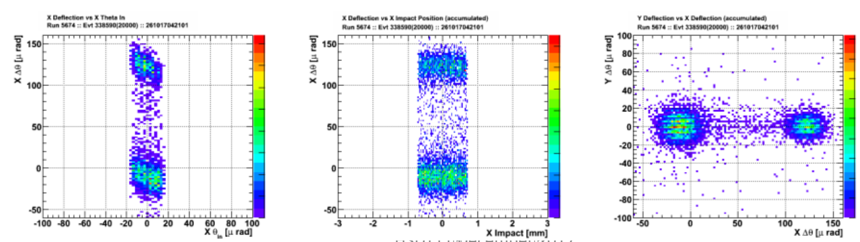
Ion beam measurements

- Special operating conditions needed for Ions because of very large dE/dx
  - Signal size = Z^2.MIP => 2916 MIP [Xe] 6724 MIP [Pb]
  - Amplifier designed for linear operation up to a few MIP signals in 300-500µm silicon

150A GeV/c Xe data



- V_{sensor}= 3.6V (cf. 150V normally)
- include clusters ≤ 20 strips (cf. 3)
- peak cluster size = 3 [Xe] (cf. 1-2)
- strip threshold = 5 MIP
- s(Dq) = 7.7 µrad



Another thing I learned

- In photon science, not only TLAs are permitted
  - it is possible to name your detectors after mountains with imaginative use of acronyms

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  - there is a lot of scope here

My attempt
(blame Google)

- Hiroshima Symposium on the Development and Application of Semiconductor Tracking Detectors

- Sayounara etc

- Goodbye!
- but not quite…

Acknowledgements

- The organizers are deeply thankful for help from the secretaries:

- OIST Conference & Workshop section:
  - Matsuda, Nakamatsu, Tomimoto, Nishi, Yana –sans
    - We would like to show our appreciation with bouquets.

- Scientific secretaries:
  - Hamasaki, Iwanami, Nishimura, Ohnaru –sans
    - Our appreciation with OIST USB memory stick ☺

- Thank you very much to them all!

“Hiroshima” symp. around the Pacific rim, every 2-3 yrs, alternating between Hiroshima and outside, in tradition…

HSTD12 is scheduled to be held in 2019 at Hiroshima, Japan