

TREND IN HEP DETECTOR R&D

Junji Haba

KEK Detector Technology Project

These days there are so many regular Detector conferences, workshops...

☑ General topics only

- International Workshop On New Photon Detectors (PD07)
- ☐ 1st Workshop On Photon Detection For High Energy, Medical And Space Applications
- 5th International Conference On New Developments In Photodetection (NDIP08)
- ☐ Topical Seminar On Innovative Particle And Radiation Detectors (IPRD XX)
- Calorimeter
 - 12th International Conference On Calorimetry In High Energy Physics (CALOR 06)
- Gaseous
 - 3rd Symposium On Large TPCs For Low Energy Rare Event Detection
 - ☐ Micro-Pattern Gas Detectors (RD51) Workshop
 - ☐ International Conference on Micro Pattern Gaseous Detectors (MPGD 20XX)
- Vertex/Pixel/3D
 - VERTEX 2006: 15th International Workshop On Vertex Detectors
 - ☐ Vertex 2007: 16th International Workshop On Vertex Detectors
 - 6th International Symposium On The Development And Applications Of Semiconductor Tracking Detectors (STD6 Hiroshima)
 - ☐ 8th International Conference On Large Scale Applications And Radiation Hardness Of Semiconductor Detectors (RD 07)
 - 6th International Conference On Radiation Effects On Semiconductor Materials, Detectors And Devices
 - PIXEL 2008: International Workshop On Semiconductor Pixel Detectors For Particles And Imaging

Almost impossible

~~Too hard~~ to review this active field in
only 20min.

- Previous talk successfully gave experimentalist a clear image of
- **String theory**

This talk

For theorist to learn how to cook the strings with modern detectors



For a comprehensive view,
attend new series of IUPAP conference

Technology and Instrumentation in Particle Physics

Chicago,
June 2011



TIPP 2011

www.fnal.gov/tipp11

Second International Conference on Technology and Instrumentation in Particle Physics
JUNE 9 - 14, 2011 Sheraton Chicago Hotel and Towers, Chicago, IL

Organizing Committee: Marcel DeMarteau (FNAL), Umod Tempor (FNAL), Labore Magna (FNAL), Minim Veniam (FNAL)

Fermilab  Fermi Research Alliance LLC  ENERGY



What to measure with detectors?

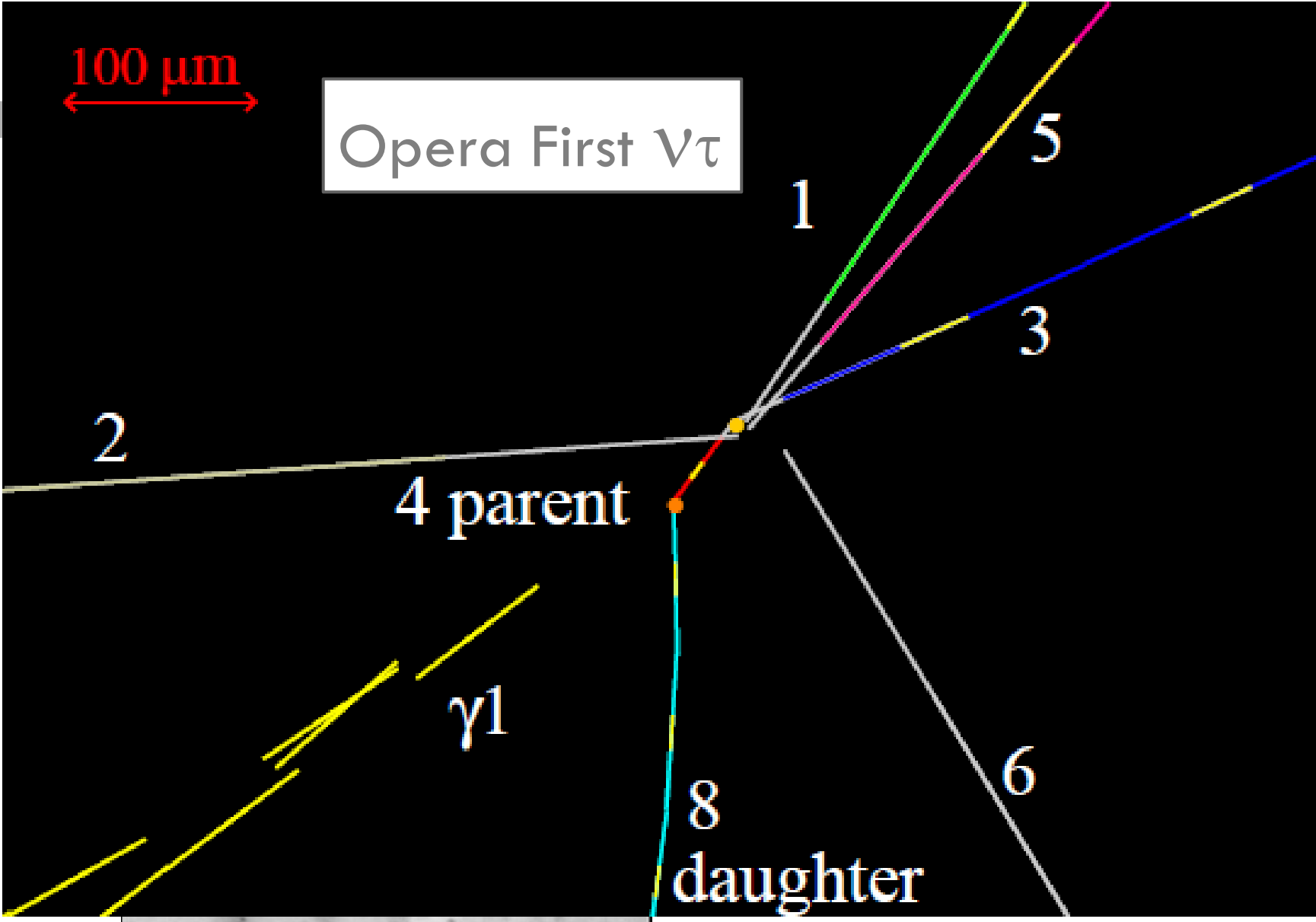
- Two Lorentz four vectors, x_μ and p_μ
(theorists know well) or
 (t, \mathbf{x}) and (E, \mathbf{p}) :

time, position, energy and momentum

- That's it ?
 Q (charge) and **mass** (particle species) necessary
for Particle identification. To be skipped today.

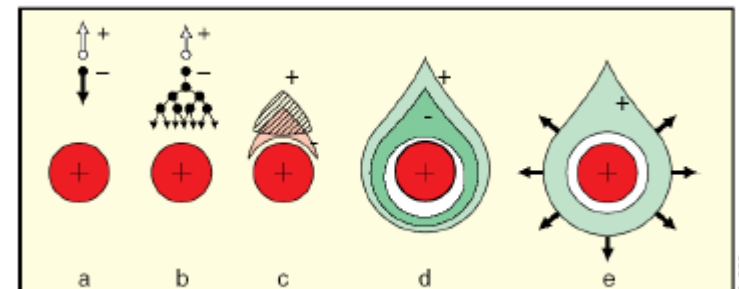
100 μm

Opera First $\nu\tau$





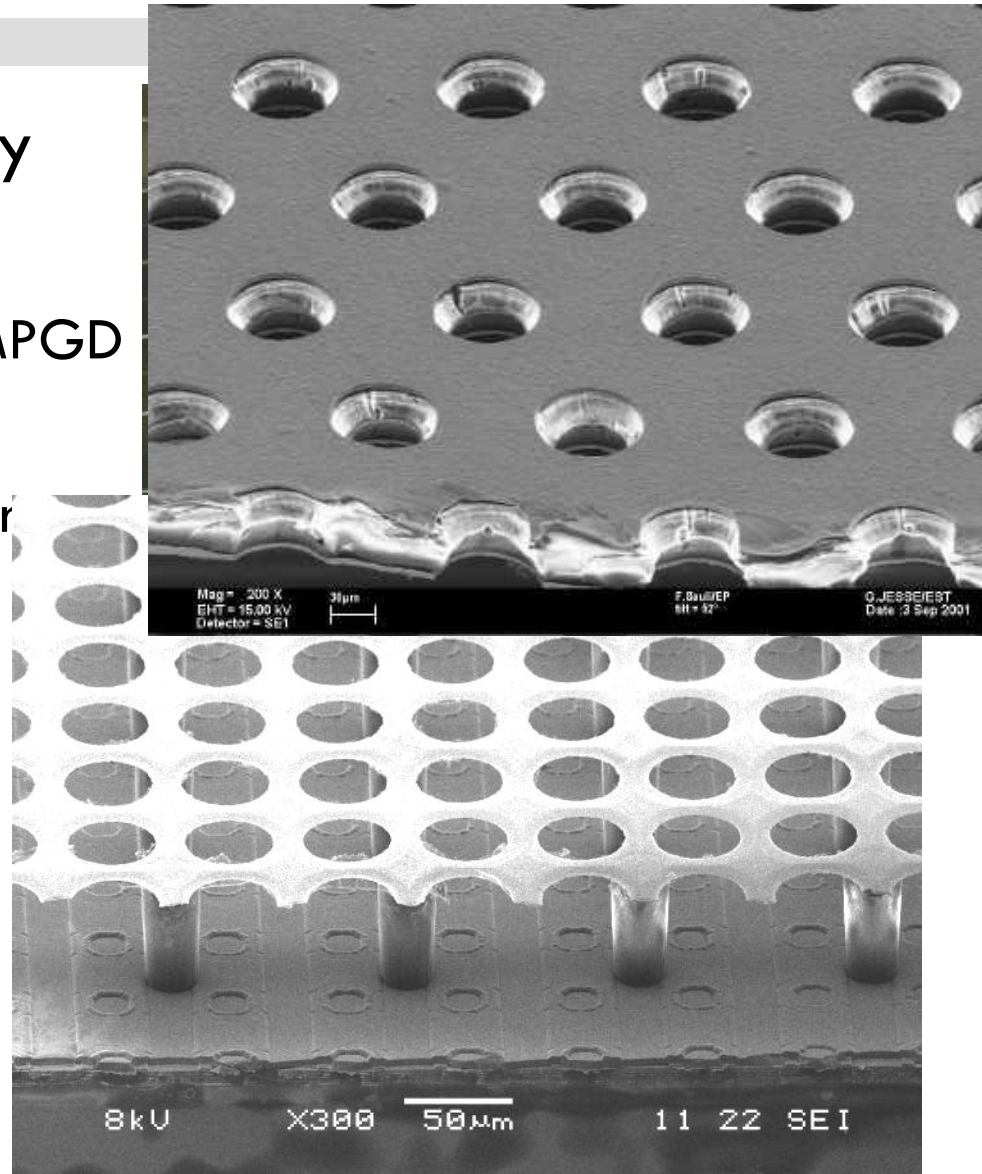
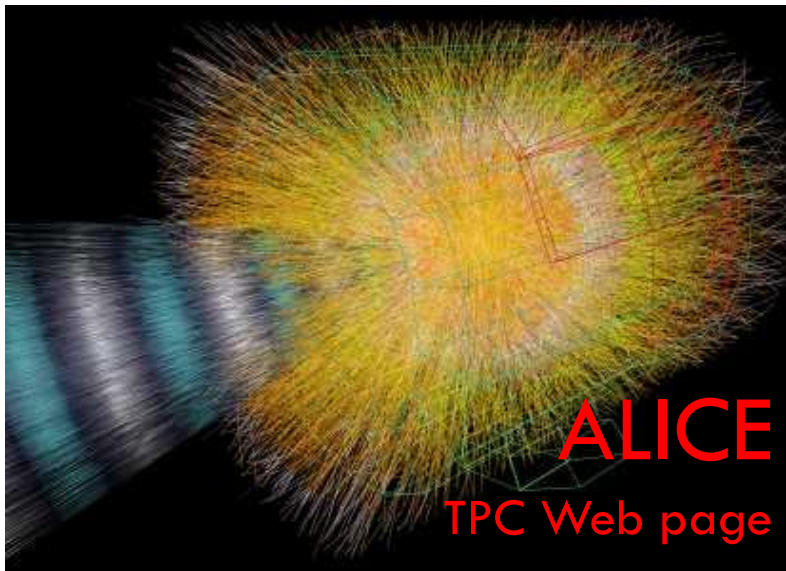
- **1968: Georges Charpak revolutionizes detection**
- In the 1960s, detection in particle physics mainly involved examining millions of photographs from bubble chambers or spark chambers. This was slow, labour intensive and not suitable for studies into rare phenomena.
- However, the revolution in transistor amplifiers was to trigger new ideas. While a camera can detect a spark, a detector wire connected to an amplifier can detect a much smaller effect. In 1968, Georges Charpak developed the 'multiwire proportional chamber', a gas-filled box with a large number of parallel detector wires, each connected to individual amplifiers. Linked to a computer, it could achieve a counting rate a thousand times better than existing detectors. The invention revolutionized particle detection, which passed from the manual to the electronic era.
- (CERN archive)



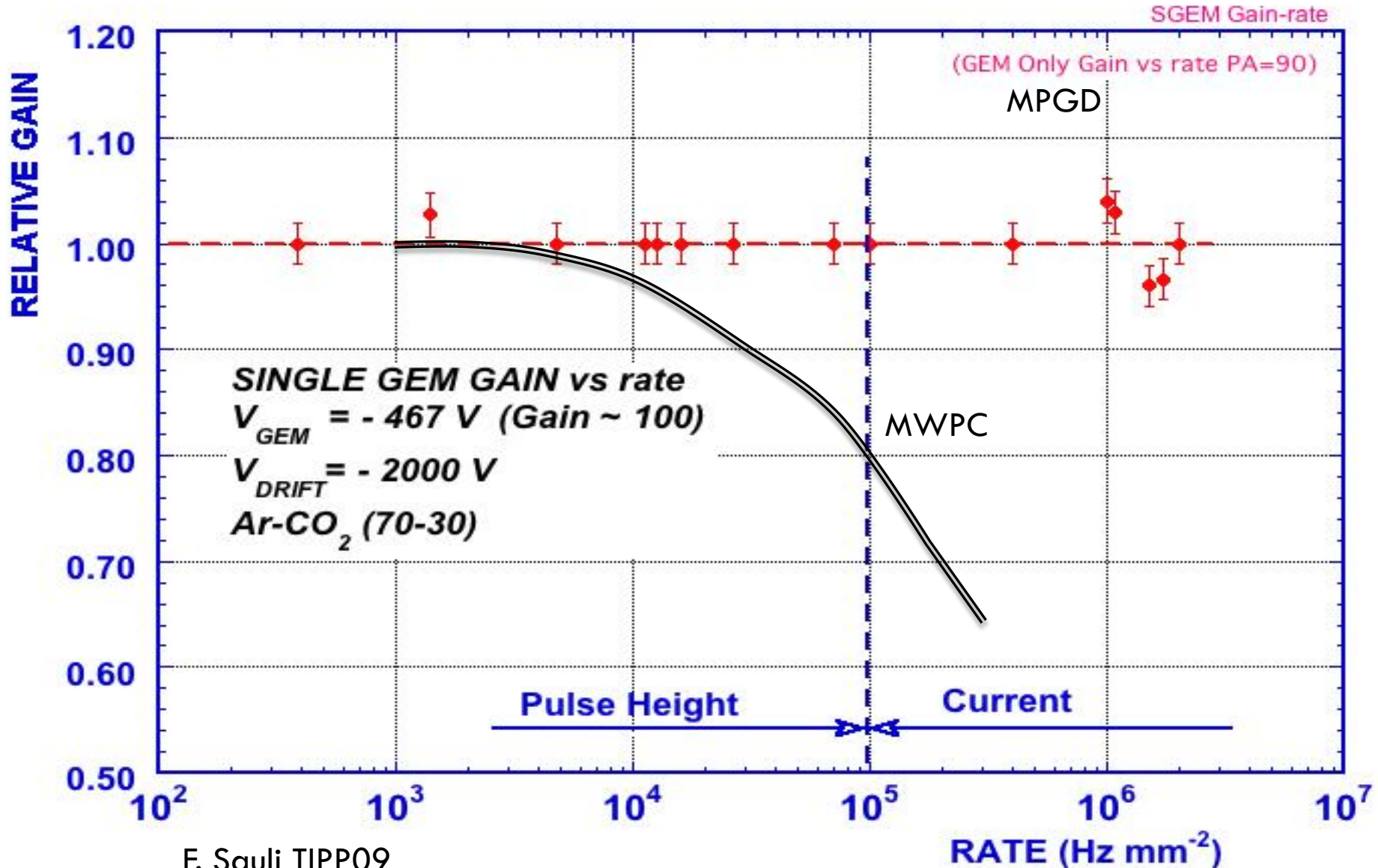
Detectors @High luminosity

More and more particles occupy the elements

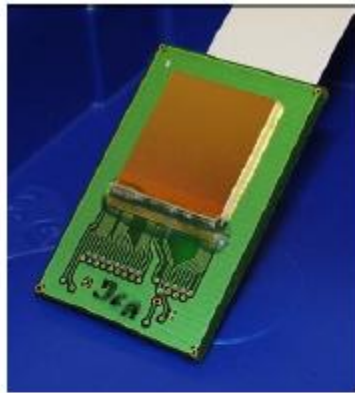
- Higher rate, high occupancy
 - 1D easily saturated → 2D
 - Wire chamber → Wireless MPGD
 - Silicon strip → pixel
 - To distribute hits in 2D elements



Wireless chambers, MPGD



Very fine but small

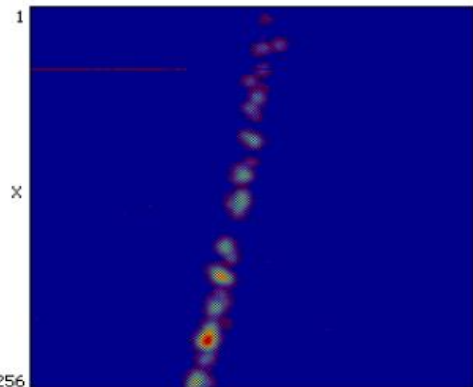


Timepix derived from Medipix-2

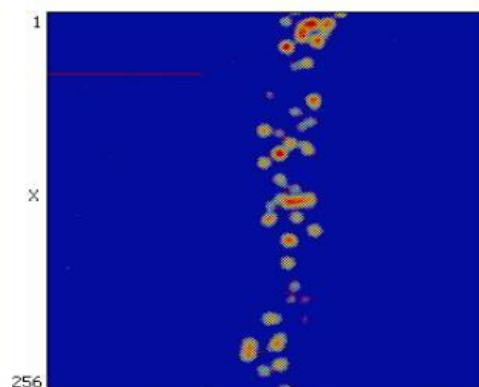
256 × 256 pixel of size 55 × 55 μm²

Each pixel can be set to:

- Hit counting
- TOT ≈ integrated charge
- Time between hit and shutter end



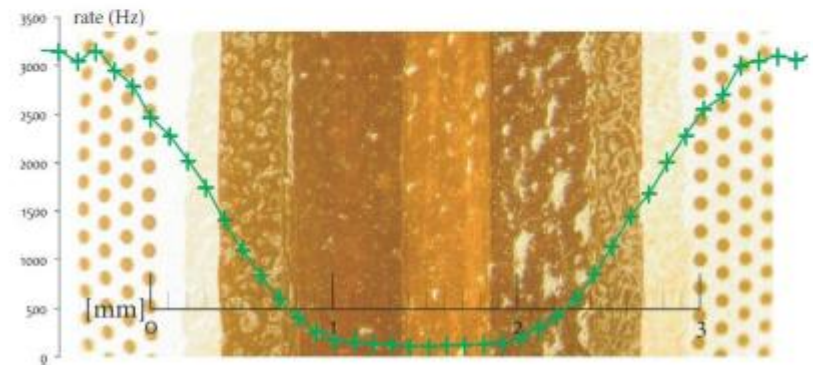
Short Drift



Long Drift

Larger

- The base material is only 457 mm wide
- Get larger width by splicing GEMs
- 2 mm wide kapton overlay on GEM edges
- Pressed and heated up to 240 °C



Spherical

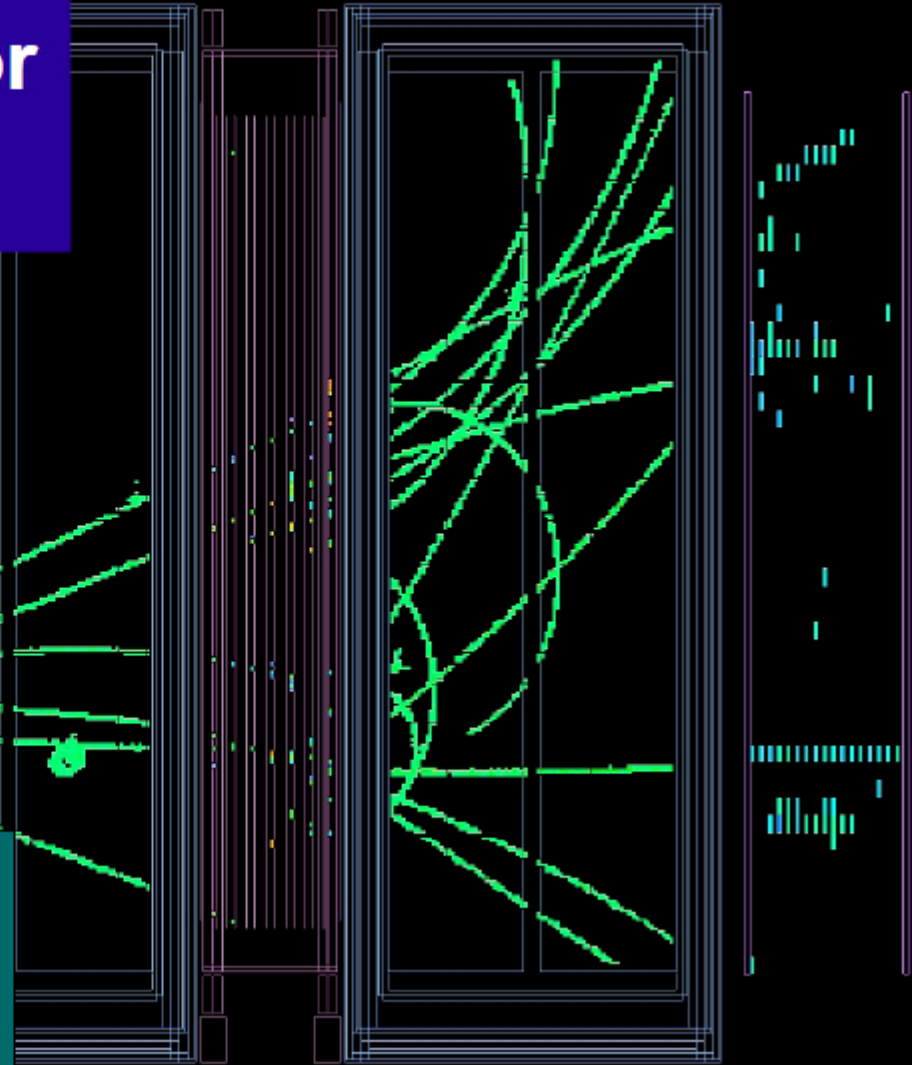


J. Kaminski

T2K Near Detector Tracker

Flor de Maria Blaszczyk
CEA - Irfu – SPP, Saclay
On behalf of T2K collaboration

ICHEP 2010
July 24th 2010, Paris, France



Large area MicroMegas successfully applied in the T2K TPC

Silicon detectors also go 2D

Strip \rightarrow Pixel

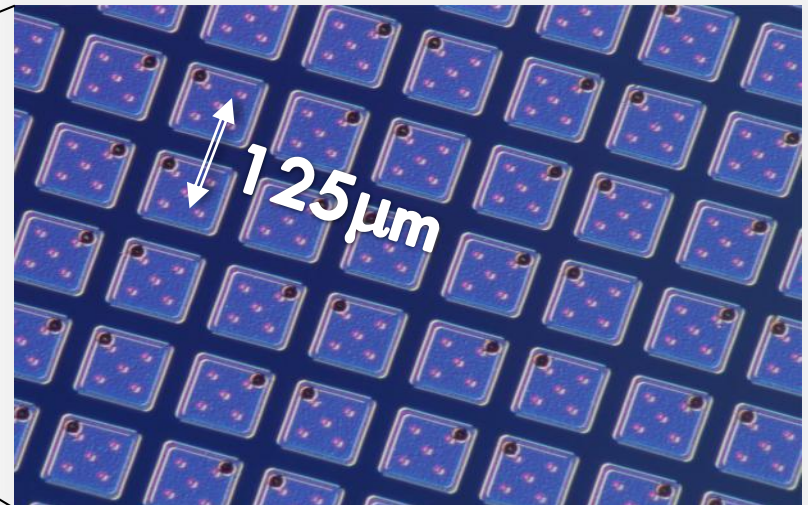
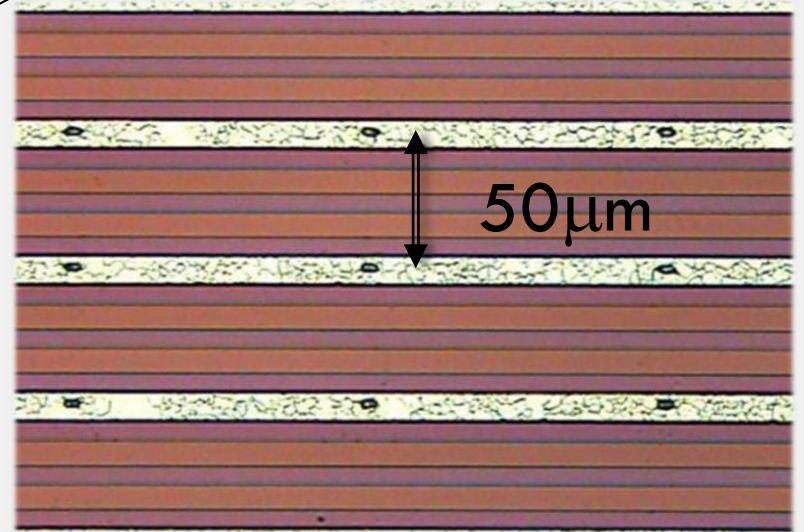
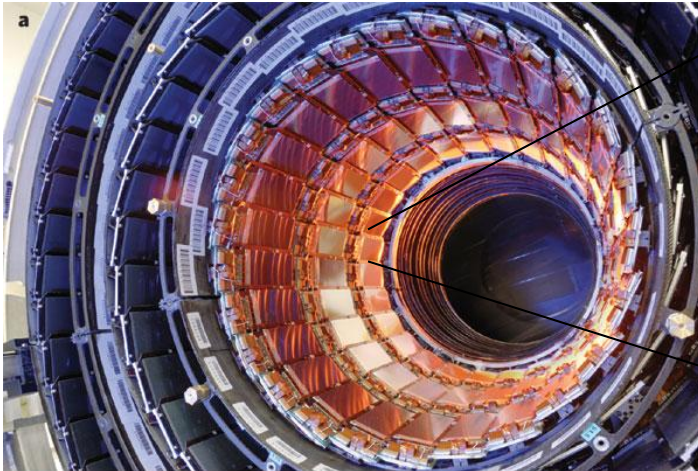
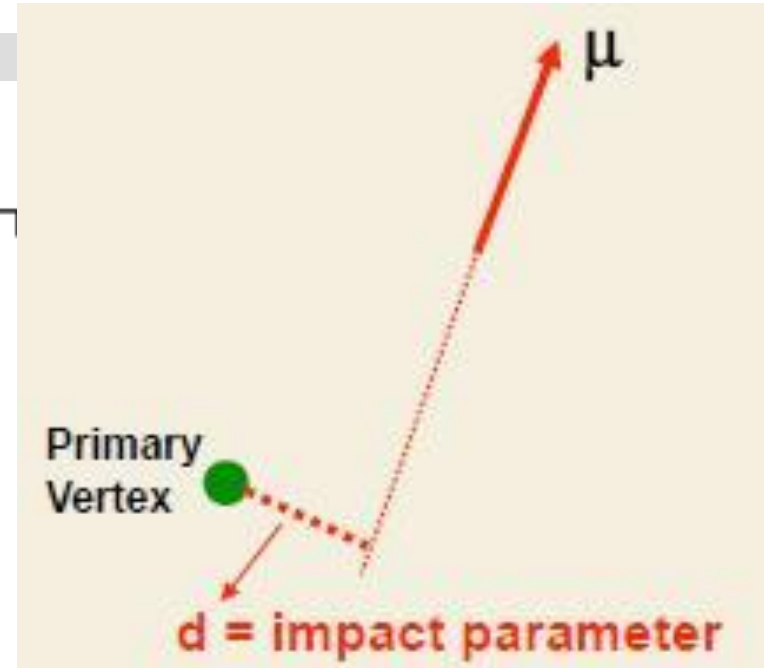
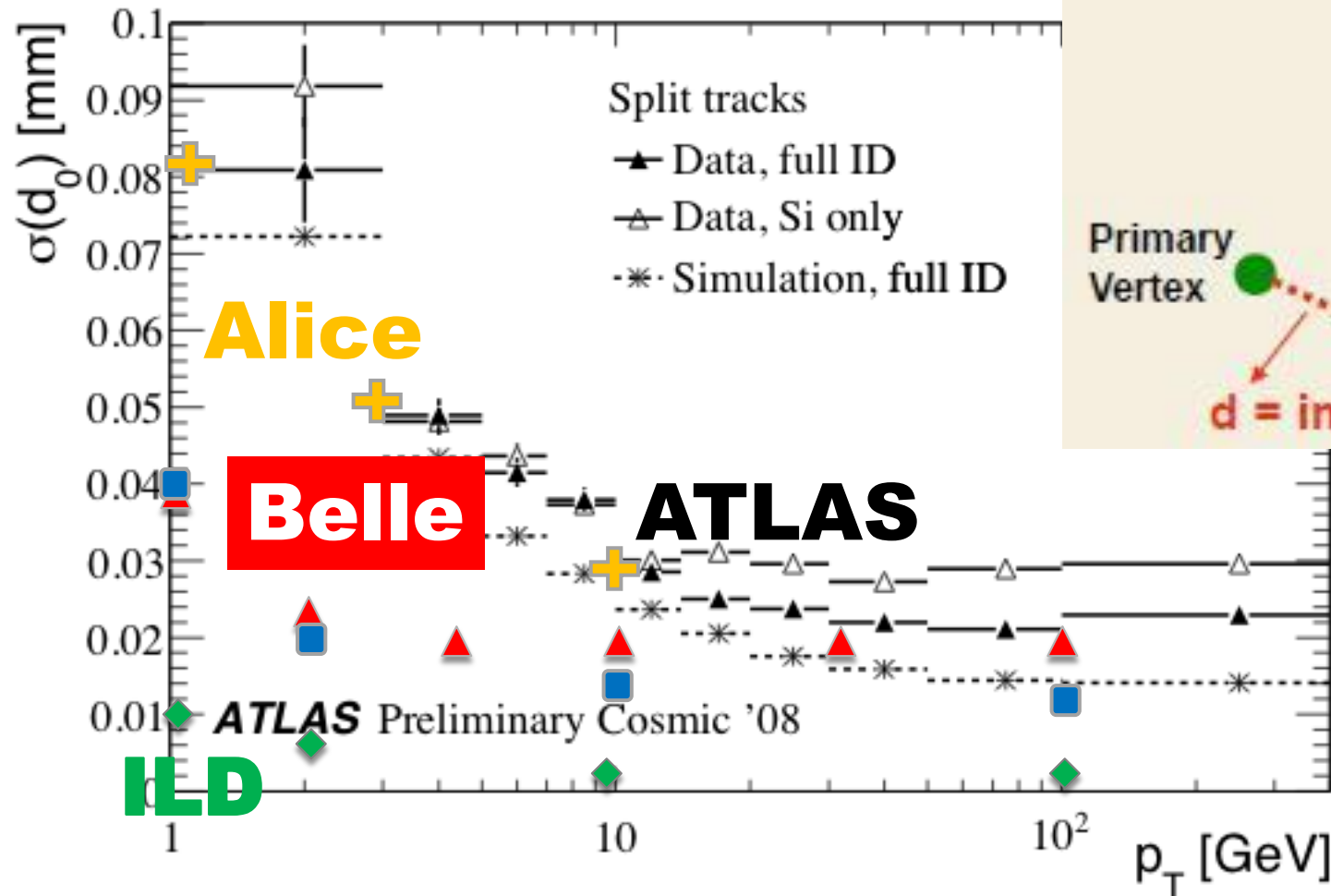


Photo from Stapnes, Nature 448

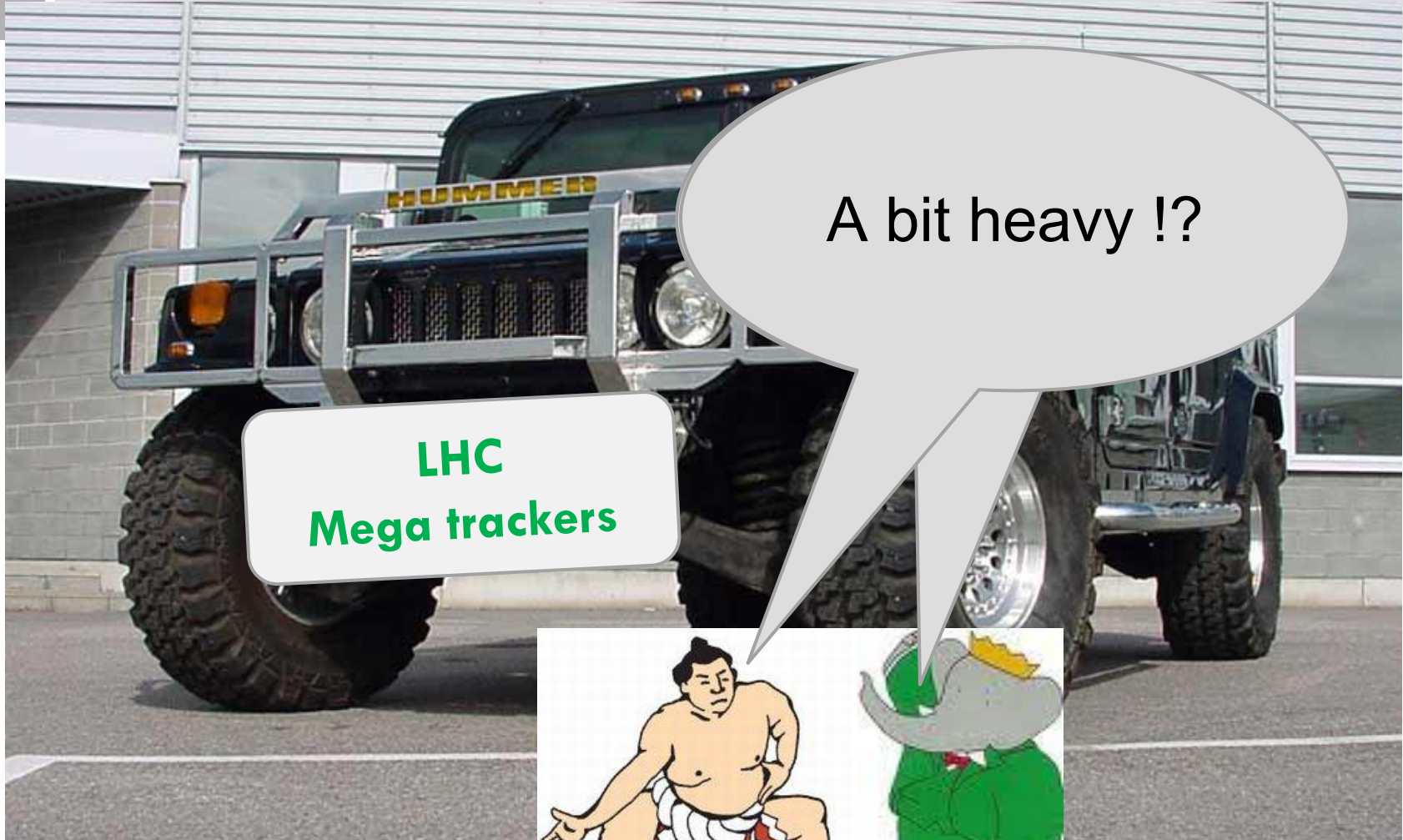
Tiny pixel modules, huge # of channels

		ALICE	ATLAS	CMS	LHCB
Pixel	# channels	9.8M	80M	66M	
	# modules	240	1788	1440	
Strips	# channels	2.6M	3.2m	9.3M	86k
	# modules	1698	4088	15148	43

Impact parameter resolution



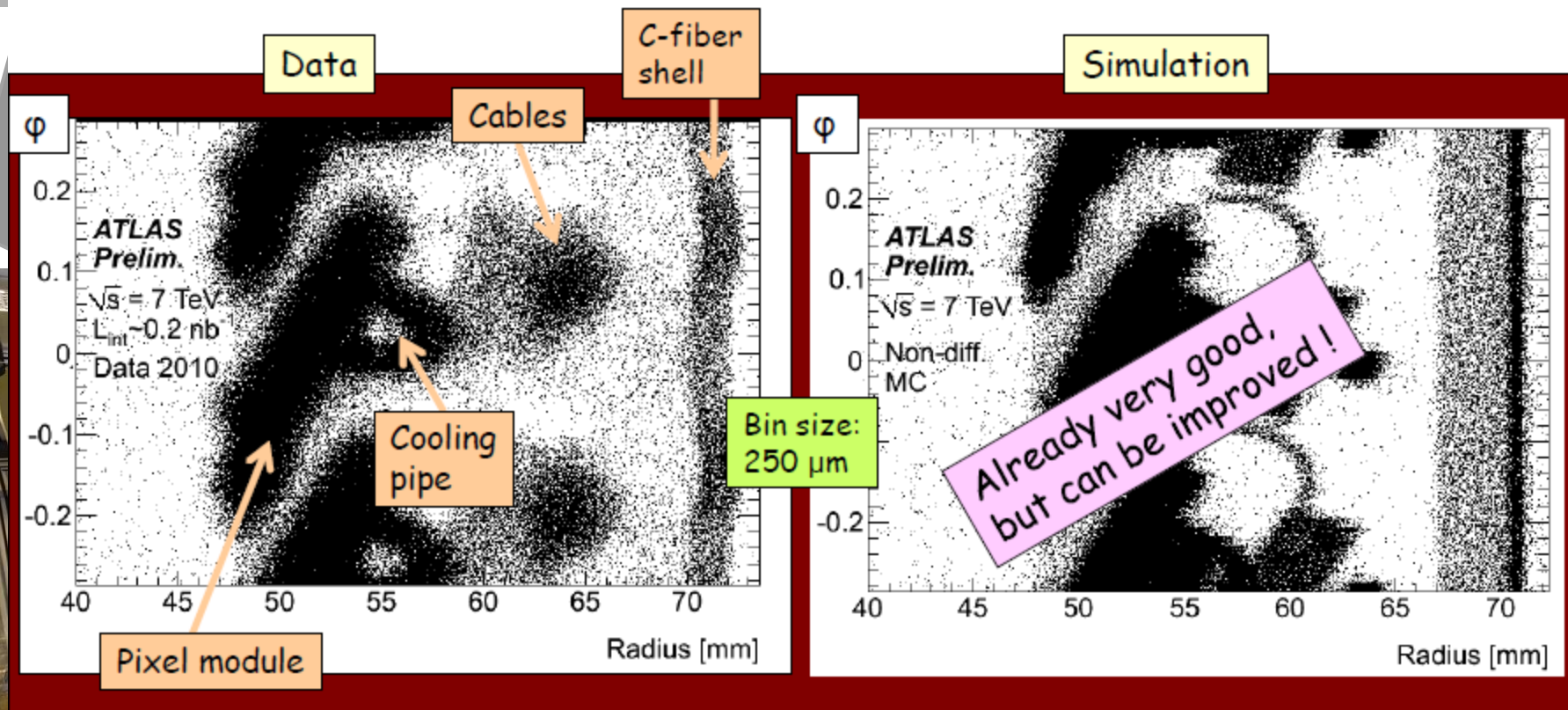
LHC detectors are miracles but ...



**LHC
Mega trackers**



Reconstructed secondary vertices due to hadronic interactions in minimum-bias events in the first layer of the Pixel detector
(sensitive to interaction length $\lambda \rightarrow$ complementary to γ conversion studies)

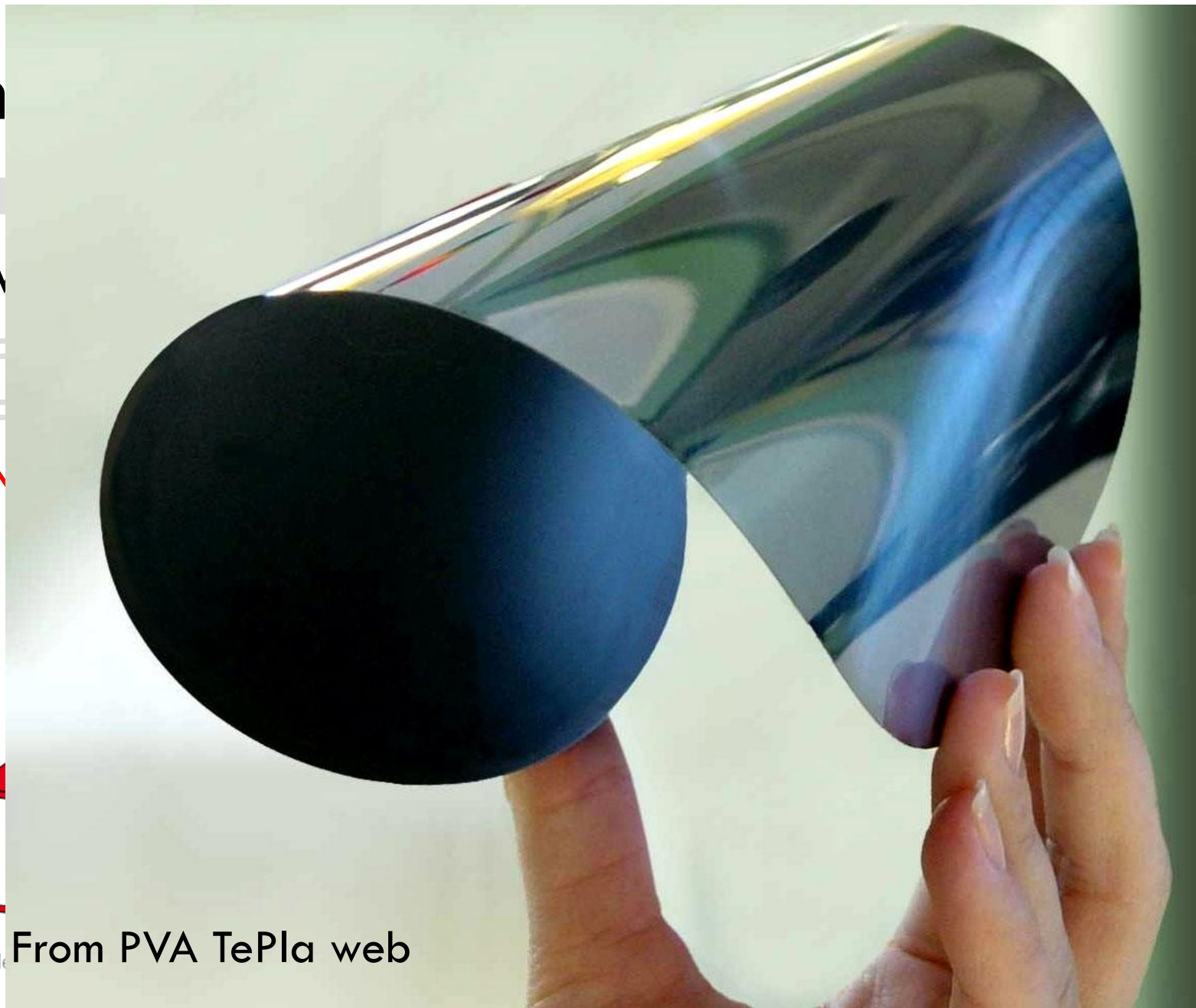


- ❑ Vertex mass veto applied against $\gamma \rightarrow ee, K_S^0$ and Λ
- ❑ Vertex (R, Z) resolution $\sim 250 \mu\text{m}$ (R < 10 cm) to ~ 1 mm

Fabiola

Th

- A
-
-
- M



From PVA TePla web

DEPFET

Highly Pixelated Transparent Devices for Future Vertex Detectors

Marc Winter (IPHC-Strasbourg)

(on behalf of the MIMOSA, PLUME, HP-2 & AIDA collaborations)

▷ more information on IPHC Web site: <http://www.iphc.cnrs.fr/CMOS-ILC-.html>

CONTENTS

- **Introductory Remarks :**
 - ▷ the trend for very light pixelated systems
 - ▷ ILC driven R&D
- **CMOS pixel sensors :**
 - ▷ high-resistivity epitaxy
 - ▷ applications
 - ▷ advent of vertical integration
- **Other thin pixel technologies currently under development:**
 - ▷ DEPFET
 - ▷ CCD based: FPCCD & ISIS for ILC
 - ▷ CMOS pixels: APSEL, Chronopix
- **Summary – Conclusions**

Need more and more functions

Vertical Integration comes next

- Moore's law ("Livingstone plot" in microelectronics) will be slowed down in 10 years only with "2D" technology

Transistors
Per Die

10^{10}

10^9

10^8

10^7

10^6

10^5

10^4

10^3

10^2

10^1

10^0

◆ 1965 Actual Data

■ MOS Arrays ▲ MOS Logic 1975 Actual Data

● 1975 Projection

■ Memory

▲ Microprocessor

1K

4004

4K

8080

16K

8086

64K

80286

256K

1M

i386™

4M

i486™

16M

64M

Pentium®

128M

Pentium® II

256M

Pentium® III

512M

1G

Itanium™

2G

Pentium® 4

4G

Physical limitation in finer pitch

ULSI can't stay in 2D brane in future !

1960

1965

1970

1975

1980

1985

1990

1995

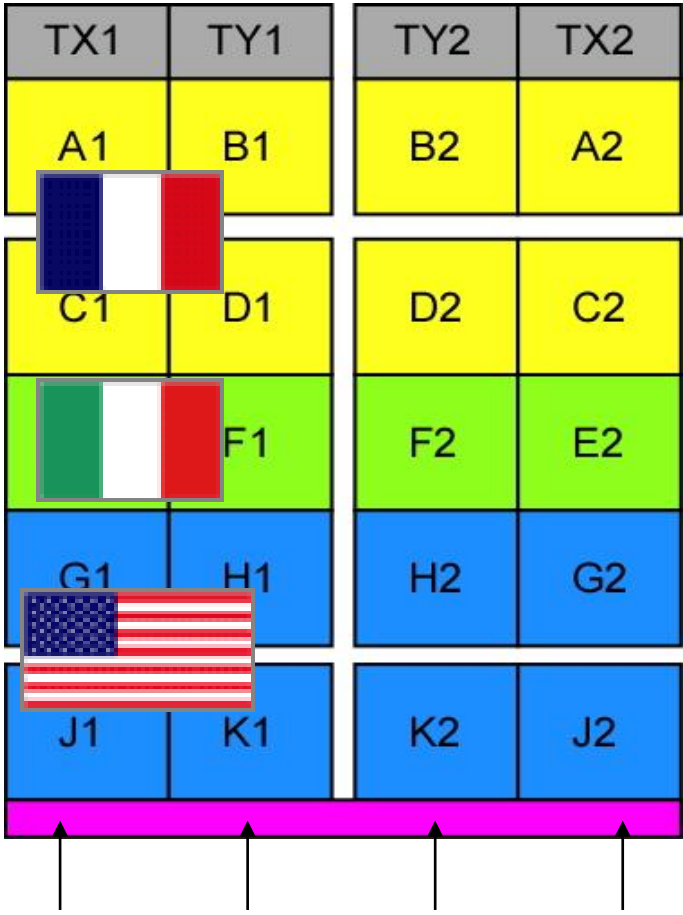
2000

2005

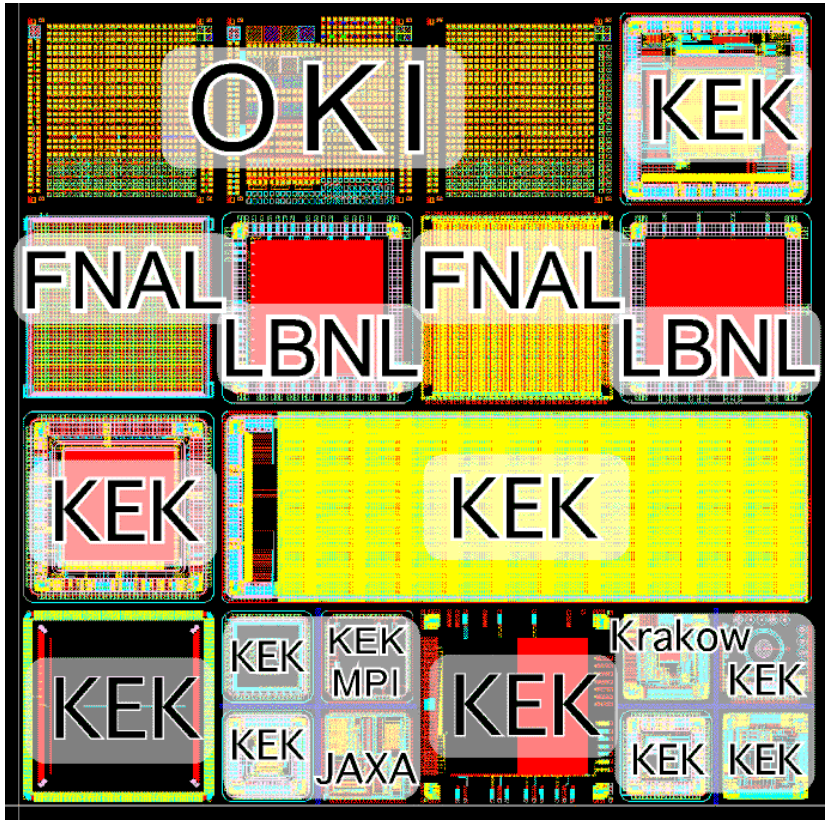
2010

Multi Project Wafer (MPW) to share chip area and enormous cost

- 3DIC collaboration



- SOI collaboration

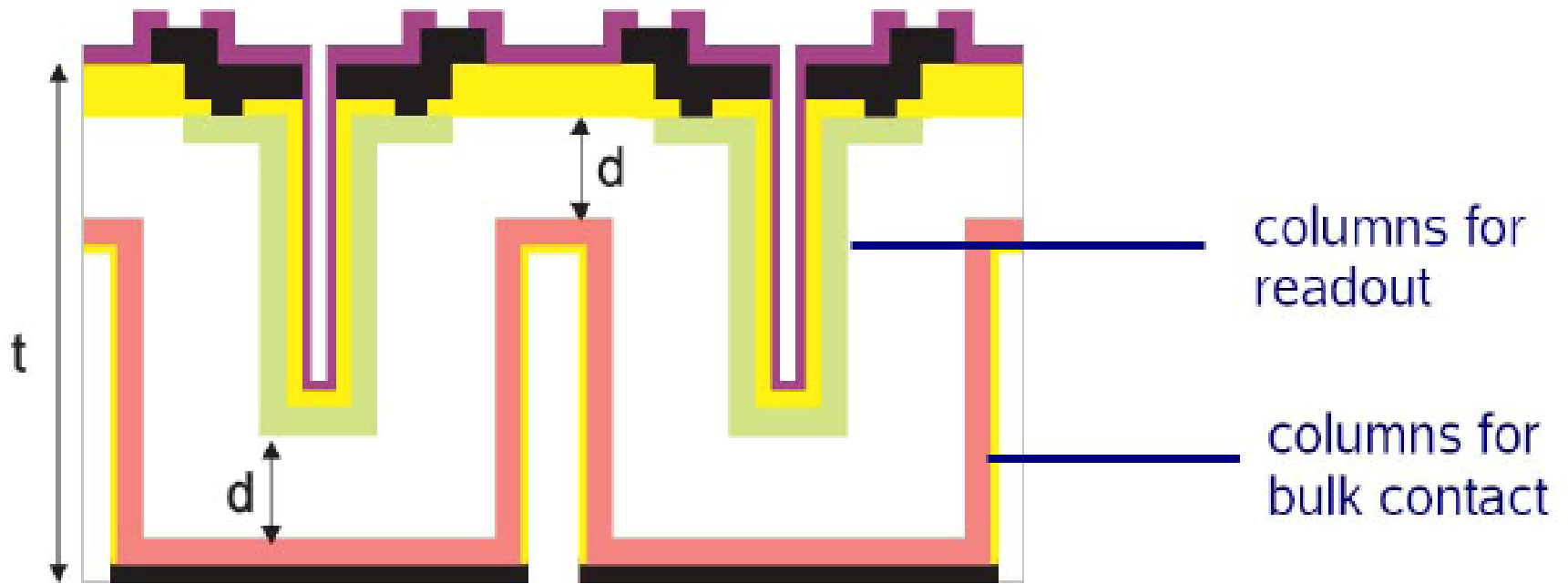


The tougher, the better

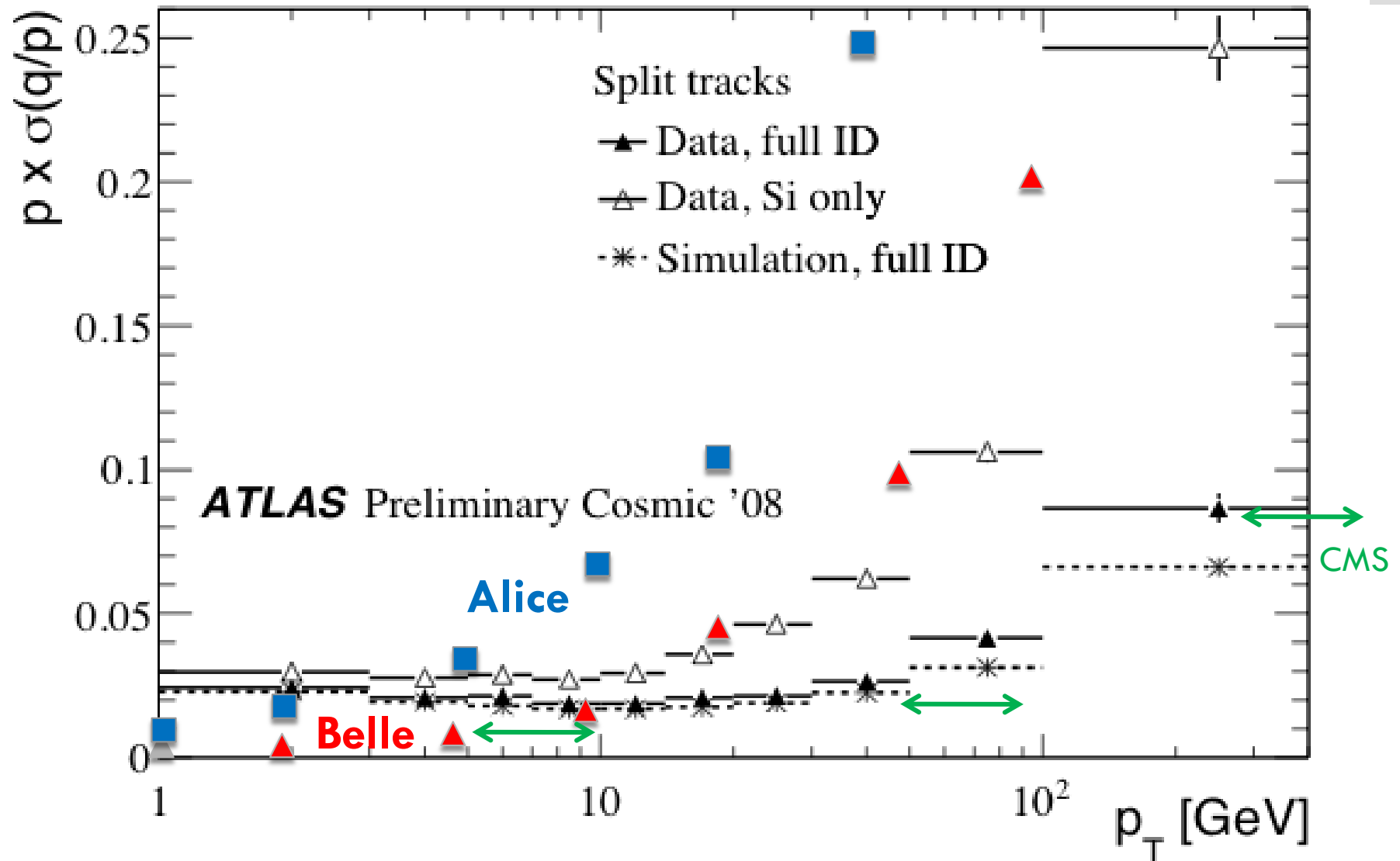
- Radiation tolerance is the most serious issue in
- (HL-)LHC
- (Super-)B-factory .



Or another type of 3D device

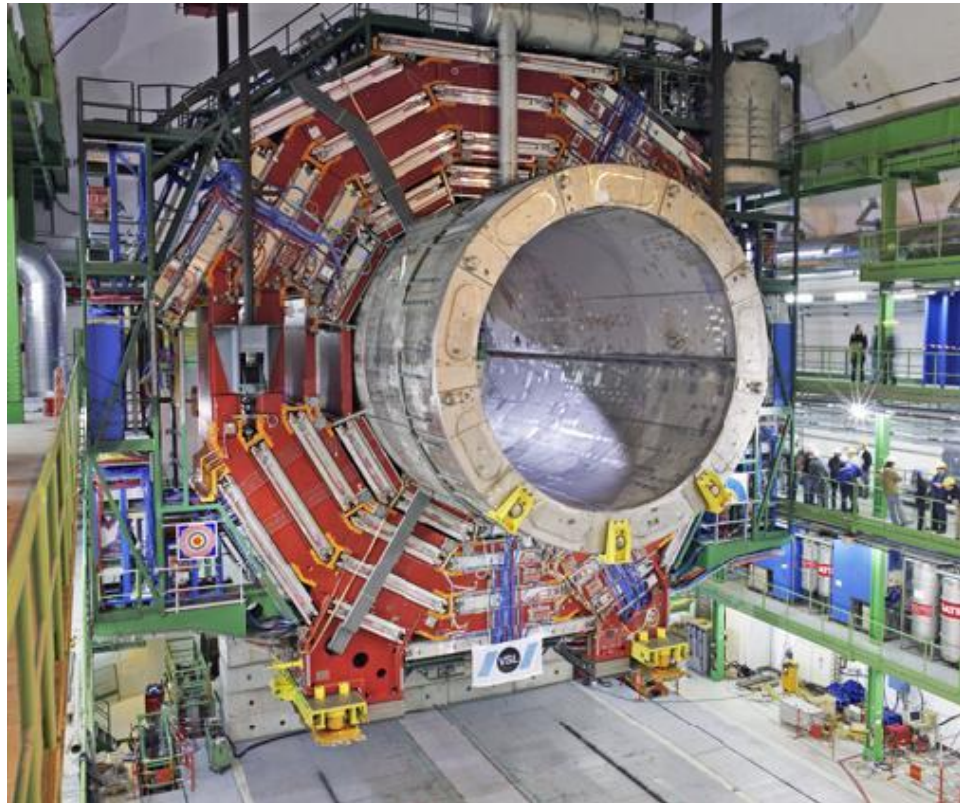


Momentum measurement



Advanced Superconducting Magnets

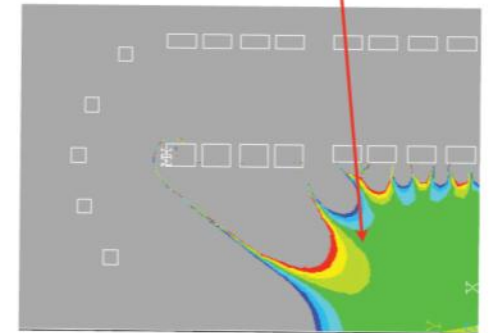
New conductor development for higher current density
(\rightarrow higher magnetic field)
Nb₃Sn, Nb₃Al...



M. Wake solution for dual solenoids

Mikhailichenko & Wake: means there is a continuum of interesting solutions available.

Tracking field quality is excellent: each color is dB/B=0.001



2009

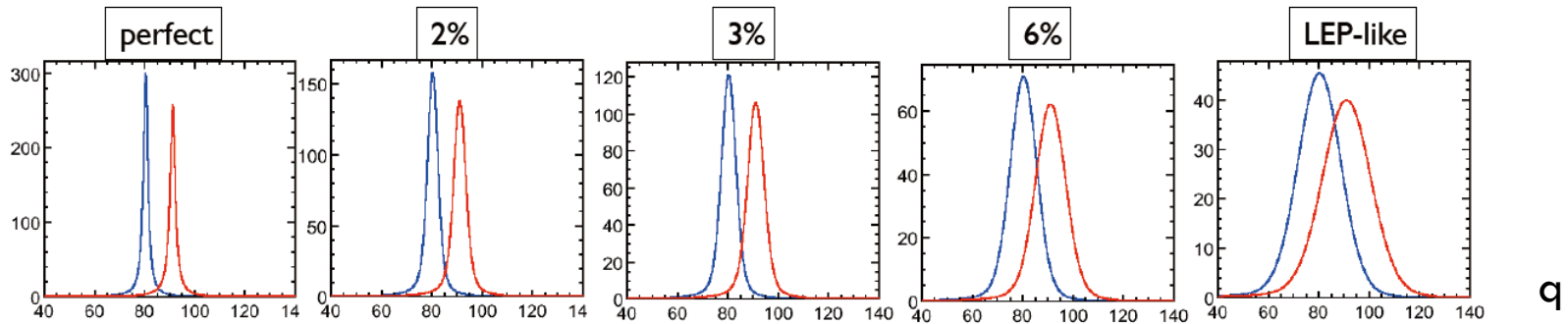
Dual solenoid (w/o yoke)
Popular in MRI system.

Energy measurement:

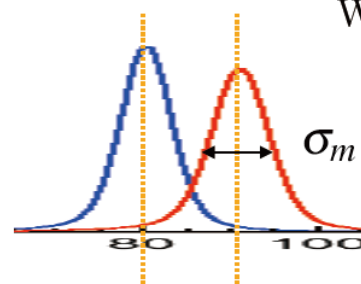
ILC “requirement”

Mass Resolution: Requirements for separation

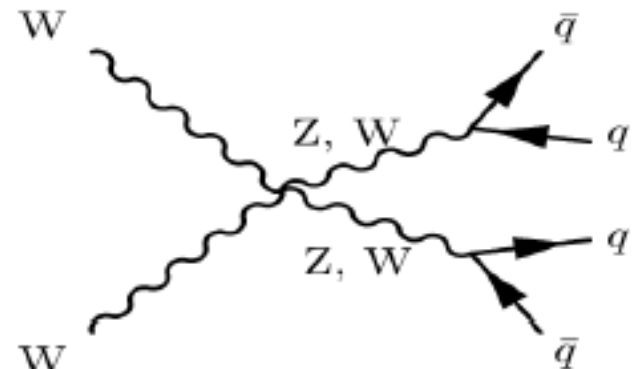
- Width of gauge bosons sets a natural scale for the required resolution



Jet E res.	W/Z sep
perfect	3.1 σ
2%	2.9 σ
3%	2.6 σ
4%	2.3 σ
5%	2.0 σ
10%	1.1 σ



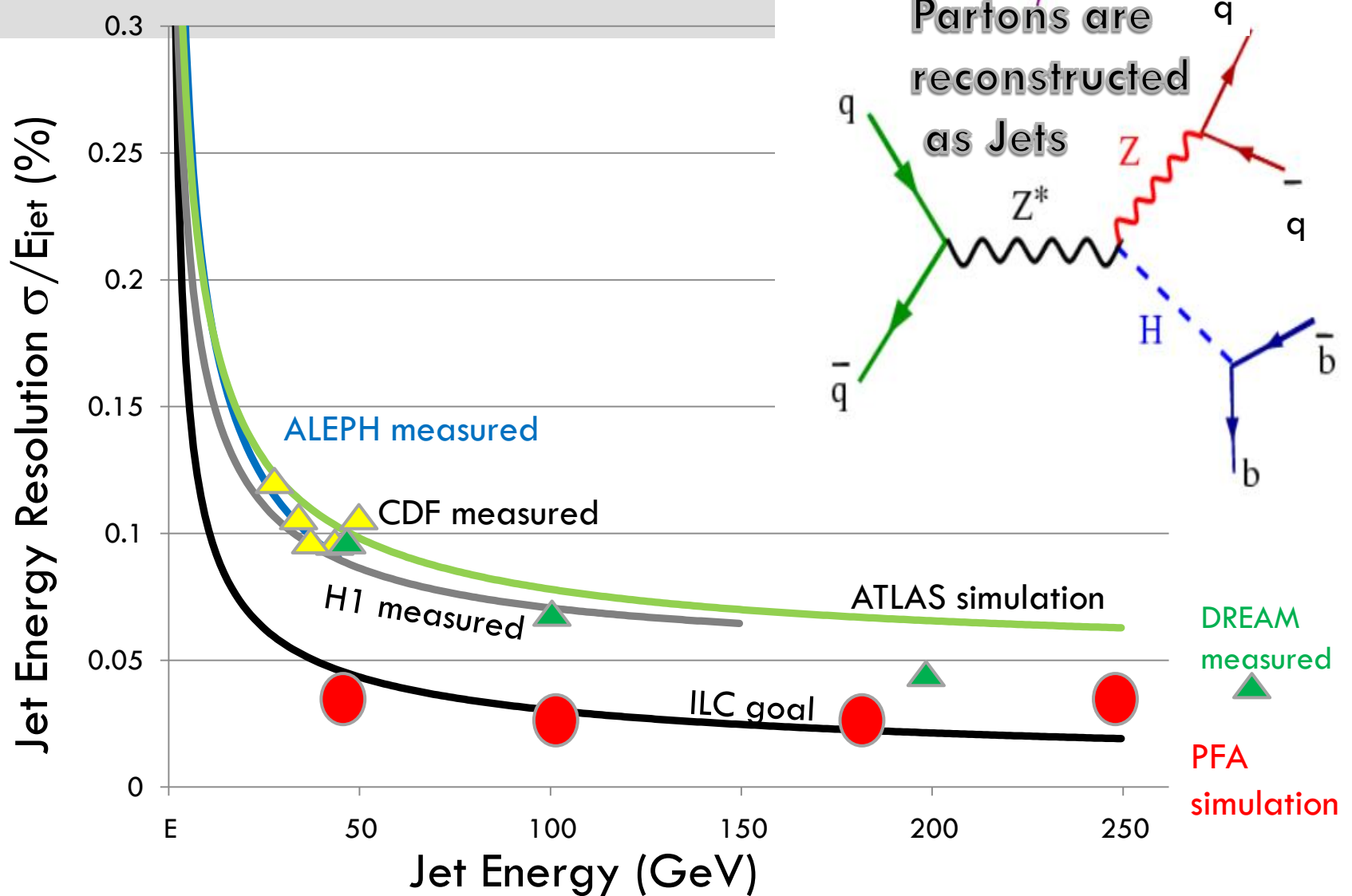
$$W/Z \text{ separation} = (m_Z - m_W) / \sigma_m$$



F. Simon from KEK seminar



Jet energy resolution

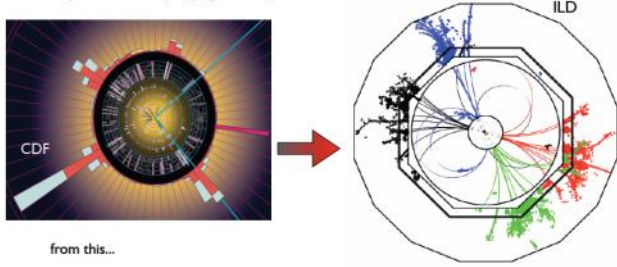


Ideas for better calorimetry

PFA (Particle Flow Algorithm)

Particle Flow: Very Different Detectors

- Pushing the idea further: Identify neutral and charged hadrons in the calorimeter directly
 - Requires extremely high granularity in the calorimeters




from this... ILD

to this!

- The most performant PFA at present: PandoraPFA (Mark Thomson, Cambridge)
 - highly complex software package

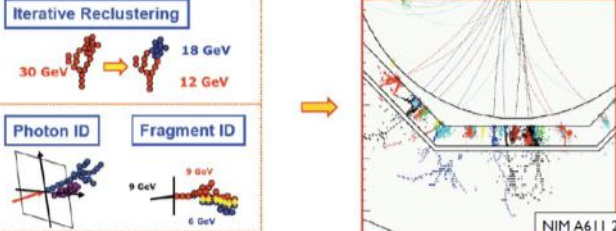
Clustering **Topological Association**



Iterative Reclustering

30 GeV → 18 GeV
12 GeV

Photon ID **Fragment ID**

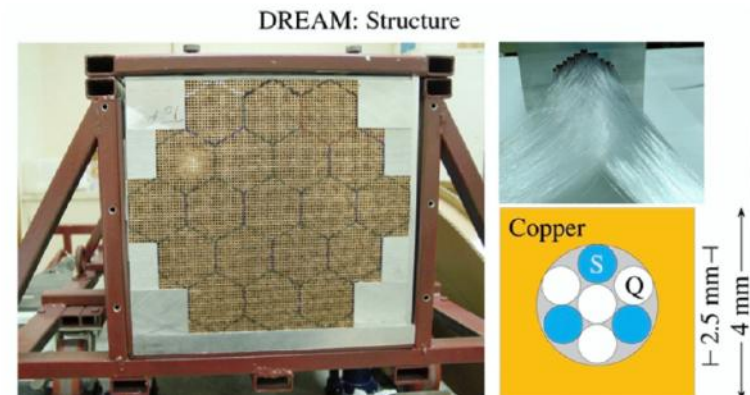
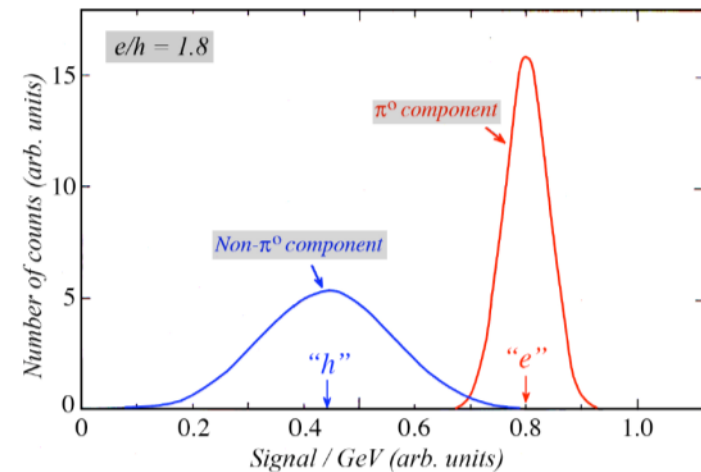


9 GeV 6 GeV

NIMA611 24, 2009

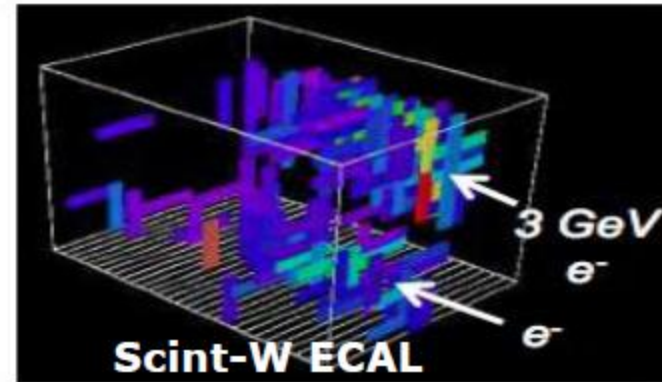
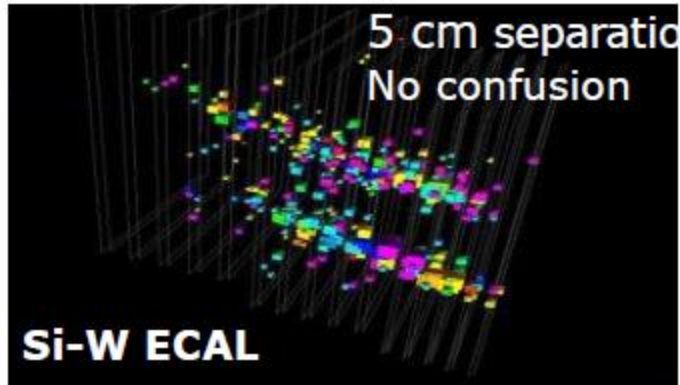
F.Simon, KEK seminar

Dual Readout (not adopted in ILC)



Richard Wigmans*
(Texas Tech University)

High granularity allows for particles separation and PFA application



► Explosion of the channel count!

- ILD: ~ 100 M channels in ECAL, ~ 10 M channels in the HCAL
- Compare to LHC: CMS ECAL: 76 k channels, ATLAS HCAL: ~ 10 k channels

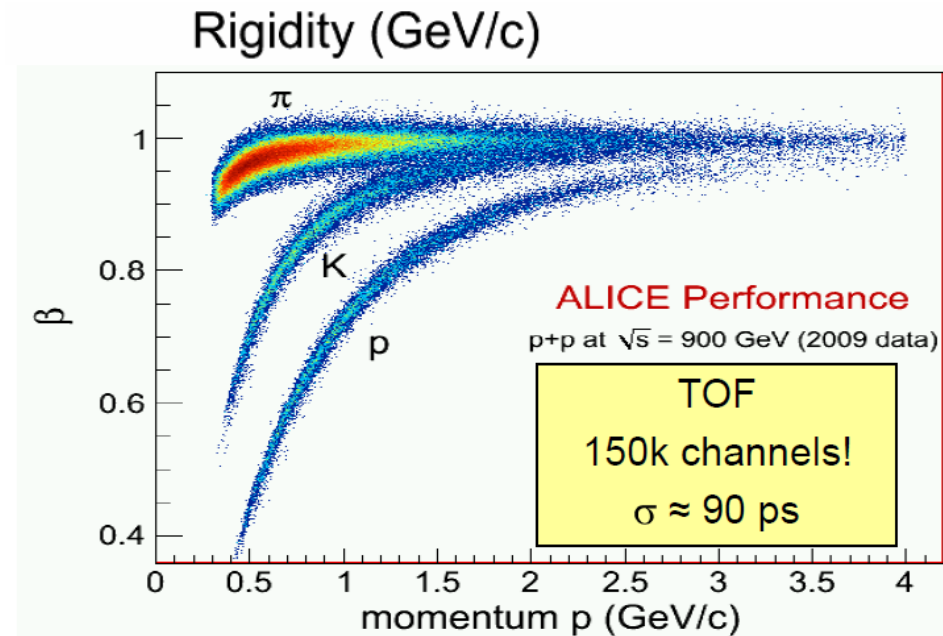
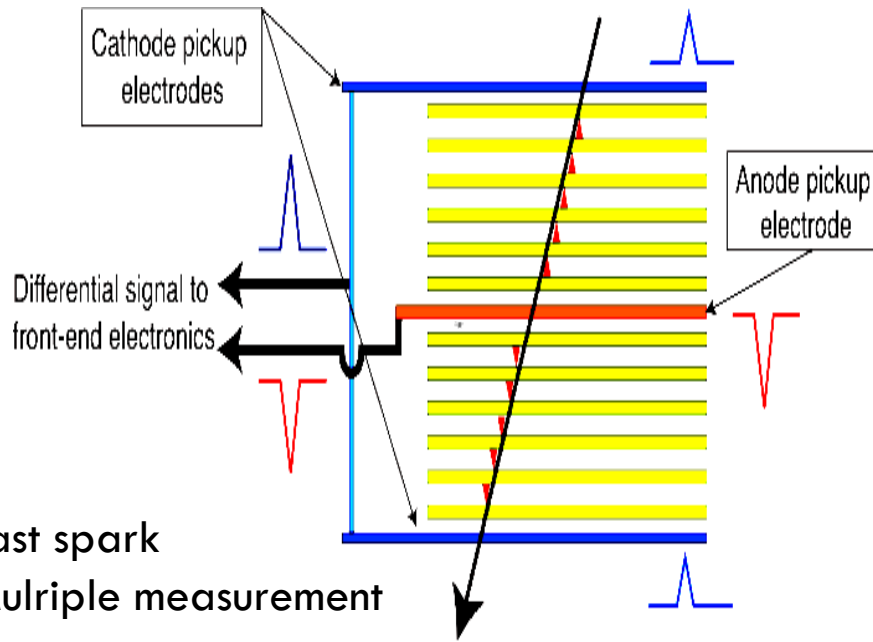
About a factor of 1000 more channels: A totally different calorimeter technology!



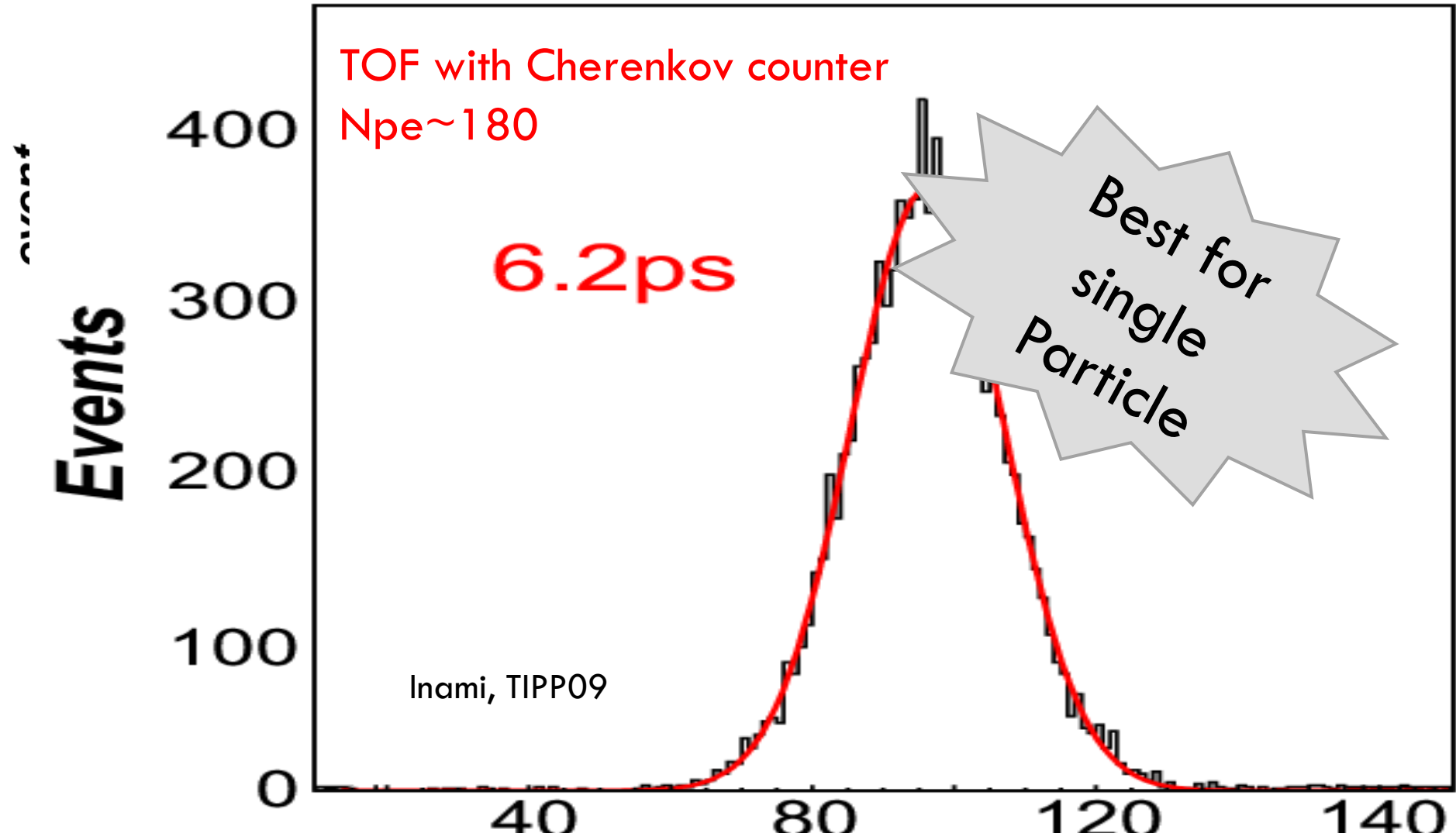
CALICE, talk given by Imad Laktineh in this conference

Time

- Relevant scale in HEP experiment
 $t \sim L(\text{m})/c \sim \text{o}(\text{nsec})$
- Traditional technique
 - ▣ Scintillator + Photo Multiplier Tube $\sim \text{o}(100 \text{ psec})$
- Breakthrough with a spark discharge in gas
 - ▣ Pestov counter \rightarrow ALICE MRPC $\sim 50 \text{ psec}$



Faster photon detections



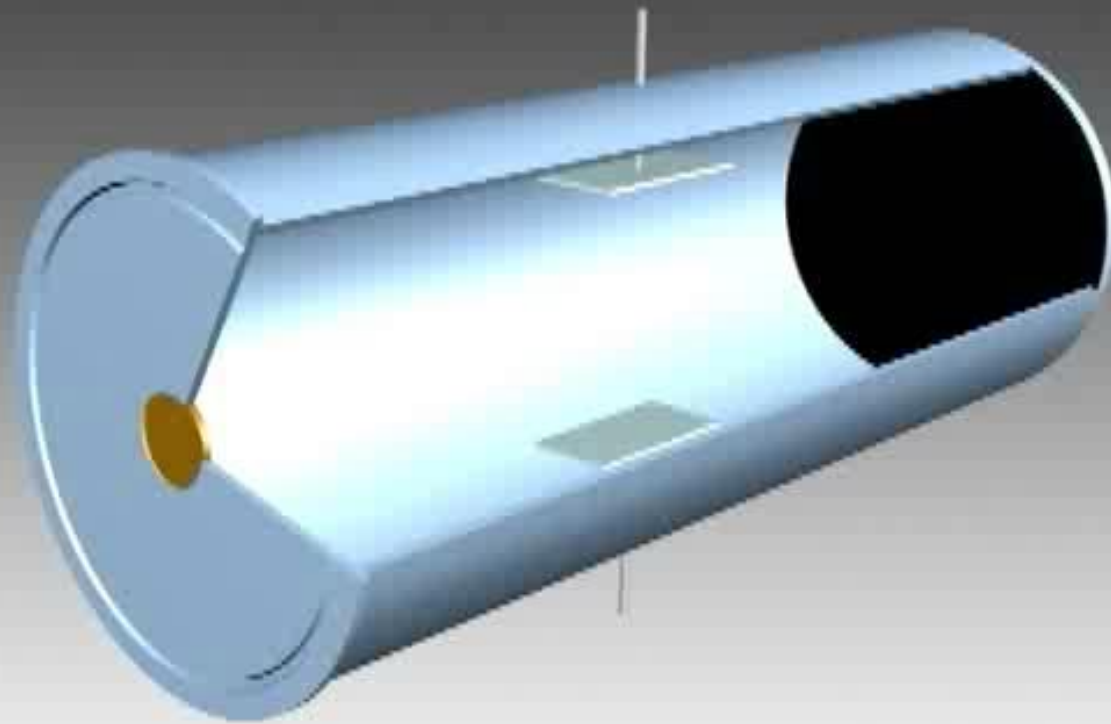
Further precision?

Subpico second world

Applicable for beam pulse
Not for single particle

□ St

Light
intensi



on
en

Time

Space

138

□ EC

Fc
fc

e

“Spin off” is another important key word for the HEP labs to survive...

Gas Electron

Abstract

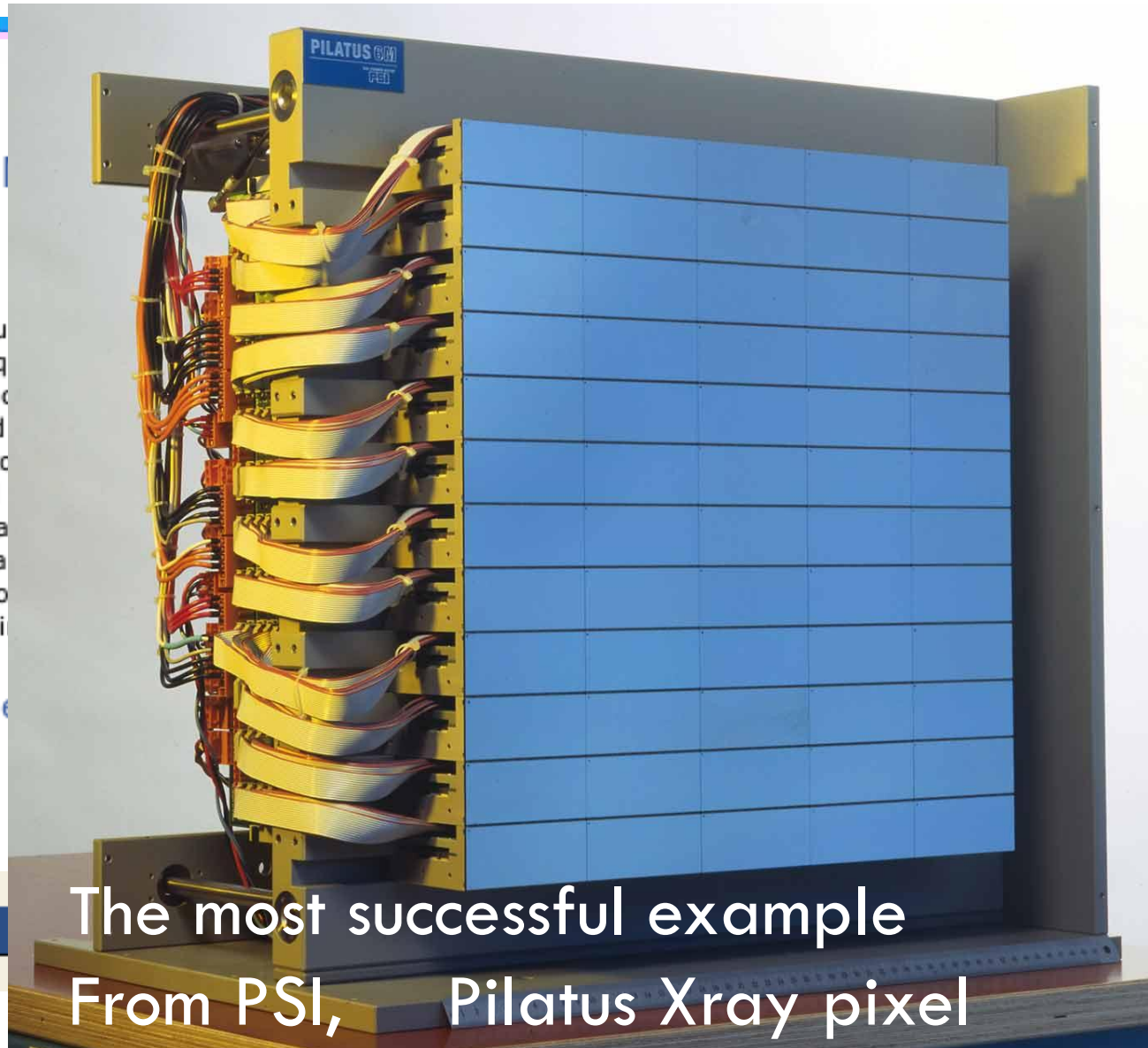
The Gas Electron Mu
amplification techni
ionizing radiation suc
photons, X-rays and
The GEM is a detecto
pierced polymer foil
both sides which is a
amplification gains a
even under harsh co
is extensively used i

Technology stage

Ready for licensing.
WO9921211.

Journalist's Links

- About Jefferson Lab



The most successful example
From PSI, Pilatus Xray pixel



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the U.S.
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d help



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