“New ideas” session summary

F. Bedeschi
11th FCC-ee workshop
CERN, January 11, 2019

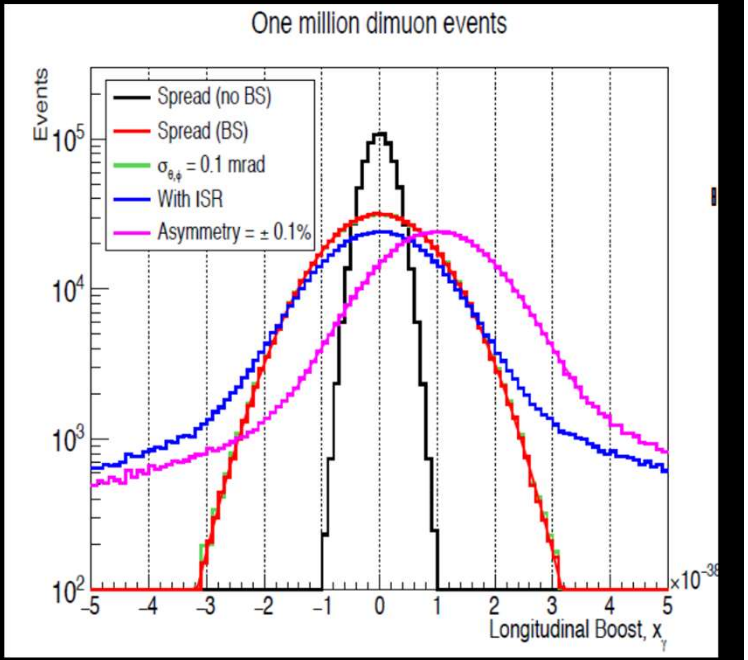
Outline

- Detector requirements
- Evolution of proposed detectors
- PID ideas
- Conclusions

Detector Requirements

Detector requirements (Z, WW)

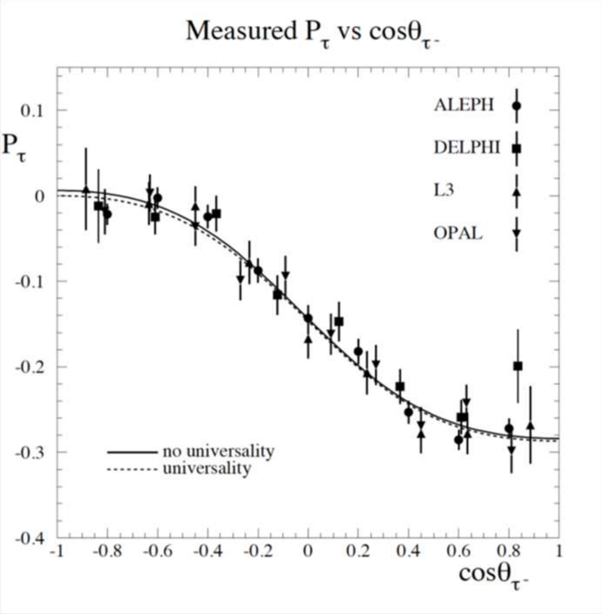
- Extreme statistics (Z: 150 ab^{-1}, WW: 10 ab^{-1})
  - Results ultimately dominated by systematics
- Before the detector comes the beam!
  - Continuous resonant depolarization at Z and WW important to get $\Delta E \sim 100$ keV
  - Monitor beam width with $\mu^+\mu^-$
    - Distribution of longitudinal boost
    - Need $\sigma(\theta) < 0.1$ mrad (easy!)
    - Can recalibrate every few minutes


One million dimuon events

Roberto Tenchini

Detector requirements (Z, WW)

- Then luminometer for all x-sections!
  - Tight requirements on acceptance push mechanical accuracy to the micron level
- Many measurements (eg. $R_i = \Gamma_i/\Gamma_{had}$) require control of acceptance ~ 5 times better than LEP
- Tau polarization
  - Cleanest channel is $\tau^+ \rightarrow \rho^+\nu_\tau \rightarrow \pi^+\pi^0\nu_\tau$
  - Good π^0 ID and direction
- Good b/c-tagging better than LHC
  - Possibly with little p dependence



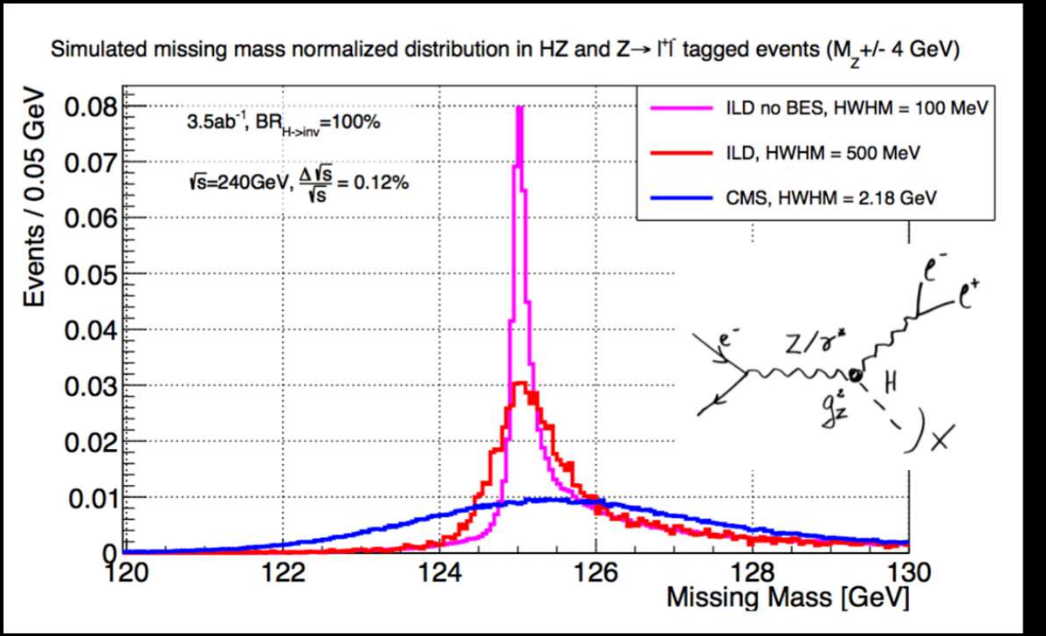
Detector requirements (Z, WW)

- Additional comments:
  - $\Delta p_t/p_t^2 \sim 10^{-4}$ (GeV^{-1}) sufficient
  - Keep tracker as light as possible
  - Keep efficiency down to low momentum
  - Hadron calorimeter should allow particle flow

Detector requirements (H, top)

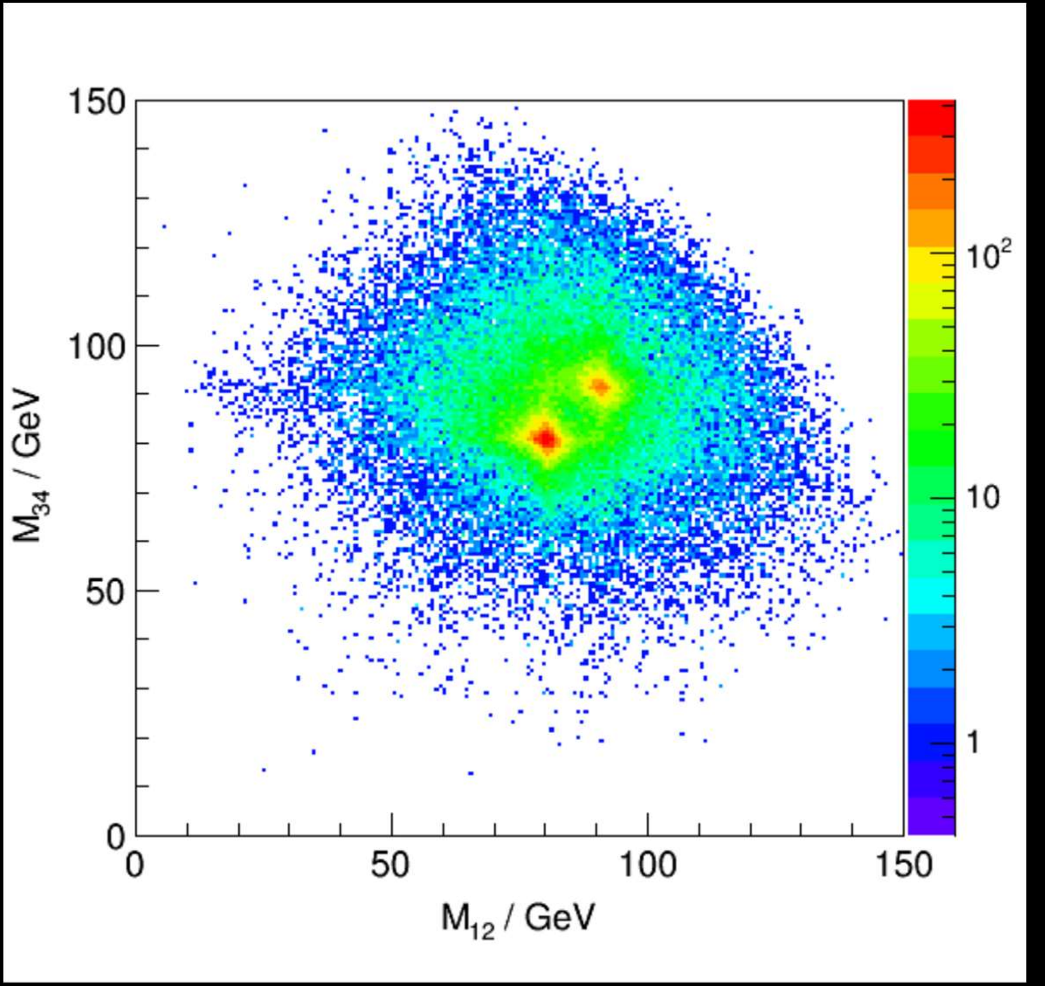
Krisztian Peters

- H from Z recoil
  - Beam energy spread is important
  - ILD with Z→μμ:
    - $\Delta p_t/p_t^2 \sim 2\times10^{-5}$ (GeV^{-1})
    - But MS?
  - CMS ~ 10 x ILD
- Can afford to do a little worse than ILD



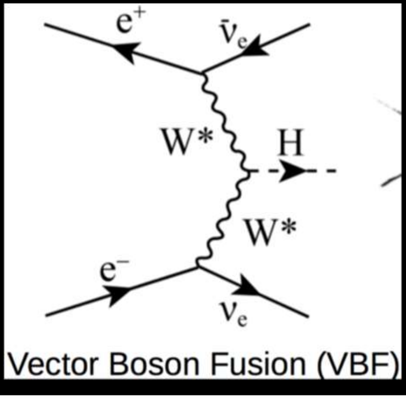
Detector requirements (H, top)

- Separation of WW/ZZ → 4 jet final states
  - Need ~ 30%/$\sqrt{E}$ for jets

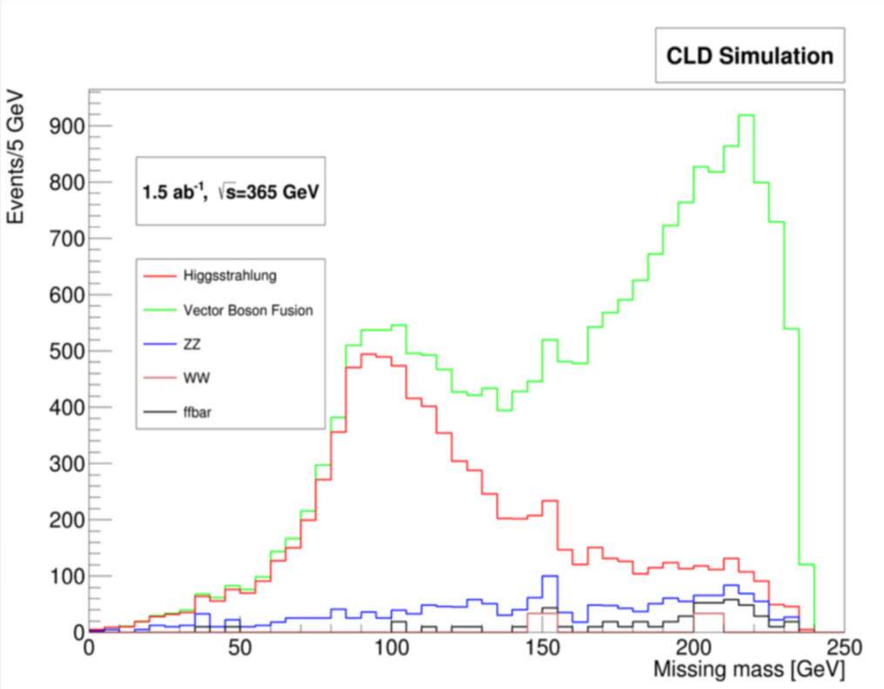


Detector requirements (H, top)

- At sqrt(s) = 365 GeV
  - VBF requires separation from ZH
  - Missing Energy
    - Calorimeter resolution
    - Hermeticity



Vector Boson Fusion (VBF)



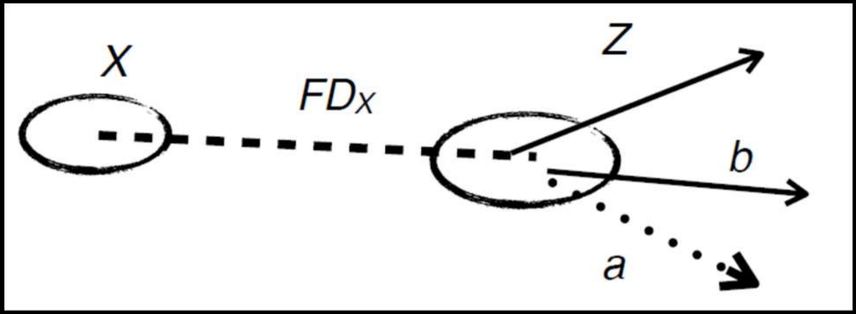
Detector requirements (H, top)

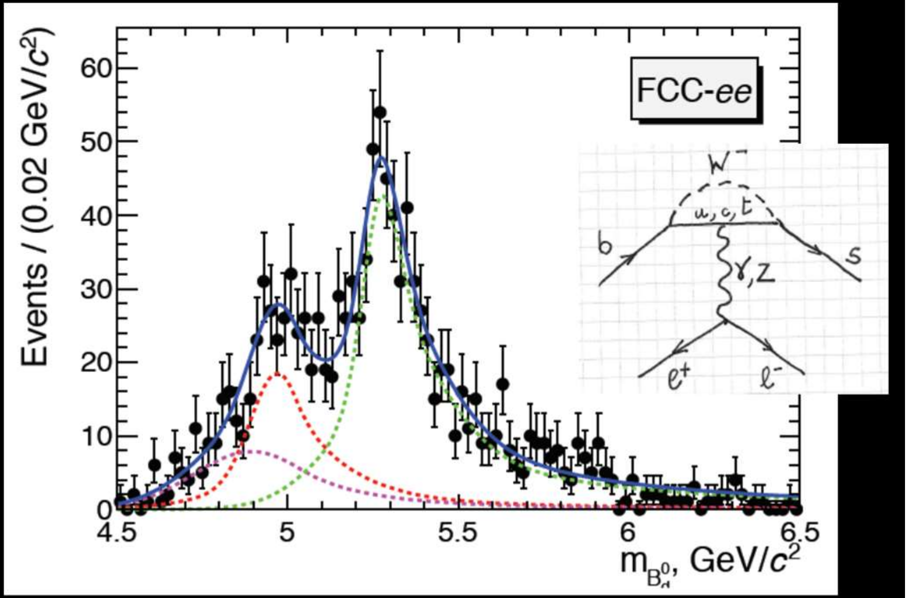
- In general:
  - All detector performance aspects important
    - In particular tracking and b-tagging!
      - Eg. Cross contamination H→bb, H→cc, H→gg
  - Comparison CLD vs. CMS show ~ 20% improvements with CLD over many Higgs observables

Detector requirements (HF)

Stephane Monteil

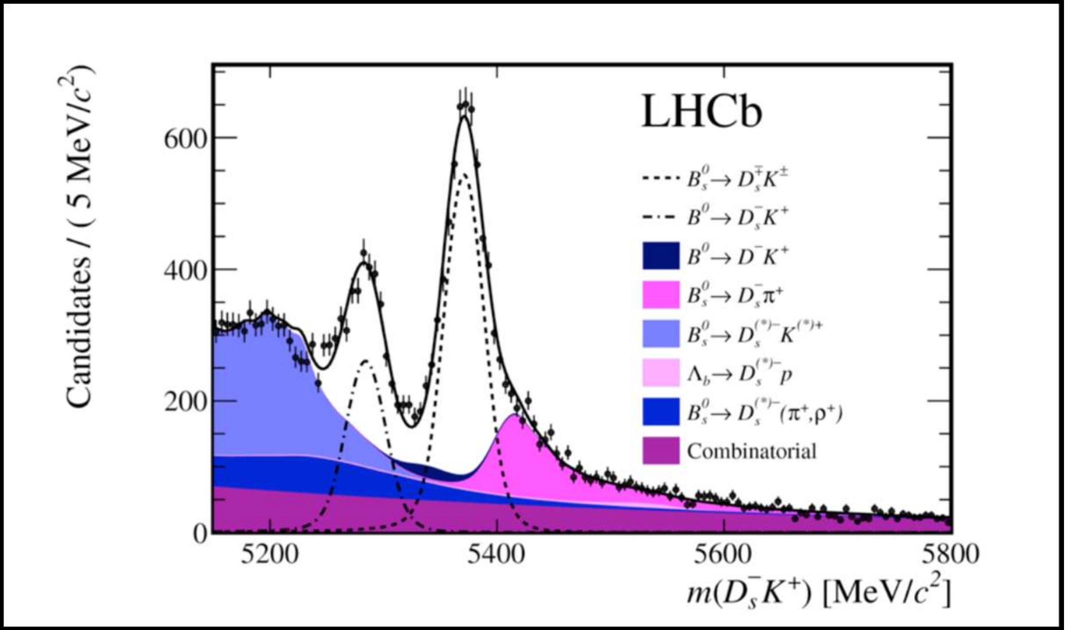
- Vertexing:
  - Direction of secondary requires extreme resolution
  - With ILD can resolve
    - $B^0 \rightarrow K^{*0} \tau^+\tau^-$
- Momentum resolution
  - cLFV
    - p resolution at the level of the beam energy spread
      - $\Delta p_t/p_t^2 \sim 2\times10^{-5}$ (GeV^{-1})





Detector requirements (HF)

- Hadronic PID
  - Example Bs→Ds K for CP violation studies
  - Plot is after LHCb PID
  - Many other applications



- Calorimetry
  - High granularity
  - PID in jets
  - As good as possible!

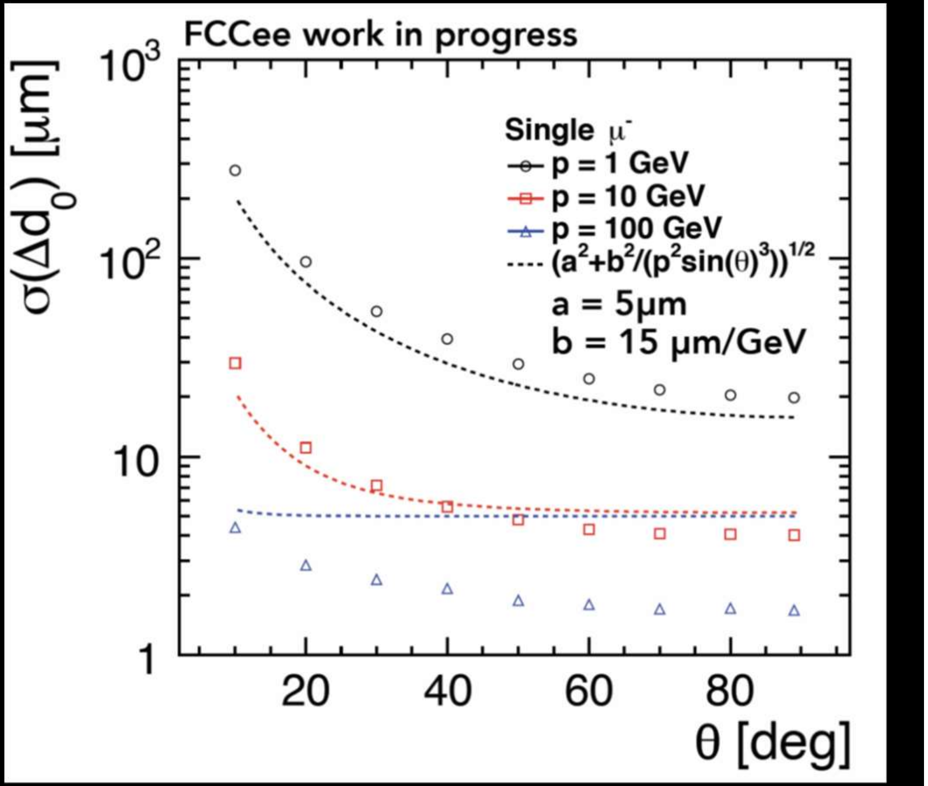
Requirement summary

- We want a detector as good as it can get!
- In particular:
  - Demands on tracker similar to ILC/CLIC with accent on low momentum and transparency
  - Calorimeter resolution, hermeticity and PID in jets
  - Acceptance control critical to limit systematics in Z, WW
  - PID up to 10’s of GeV would be very useful
- However:
  - Often unclear how soft requirements are
  - Need to become much more quantitative
    - CMS is surprisingly good on many Higgs channels wrt ILD
  - Improving performance has a price and sometimes risks

Evolution of proposed detectors

Pixel detectors

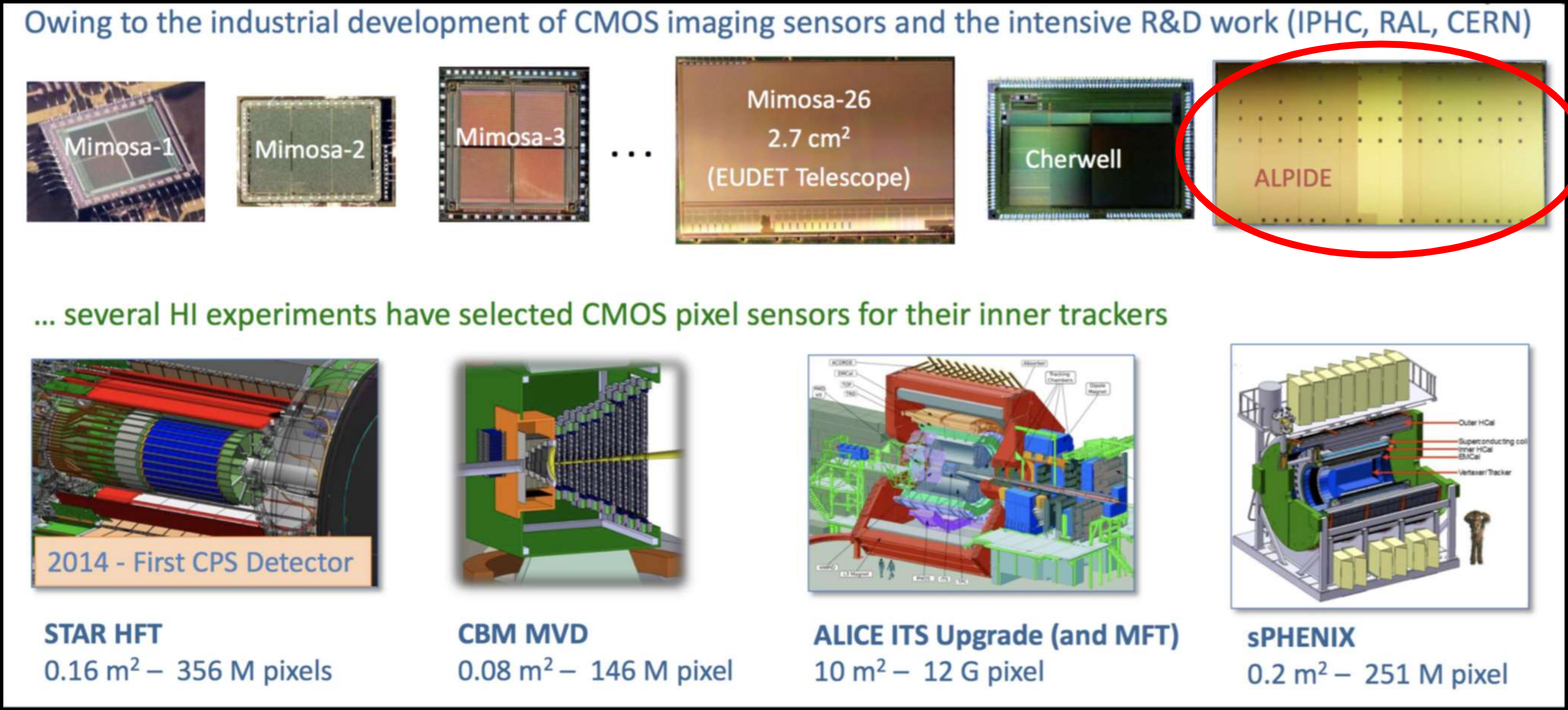
- Core of all vertex detectors
- 25 μm pixels do the job
  - Careful about material
  - Cooling is also material



Daniela Bortoletto

Pixel detetors

- Enormous activity ongoing
  - MAPS most likely candidate for FCC-ee



Owing to the industrial development of CMOS imaging sensors and the intensive R&D work (IPHC, RAL, CERN)

... several HI experiments have selected CMOS pixel sensors for their inner trackers

STAR HFT
0.16 m^2 – 356 M pixels

CBM MVD
0.08 m^2 – 146 M pixel

ALICE ITS Upgrade (and MFT)
10 m^2 – 12 G pixel

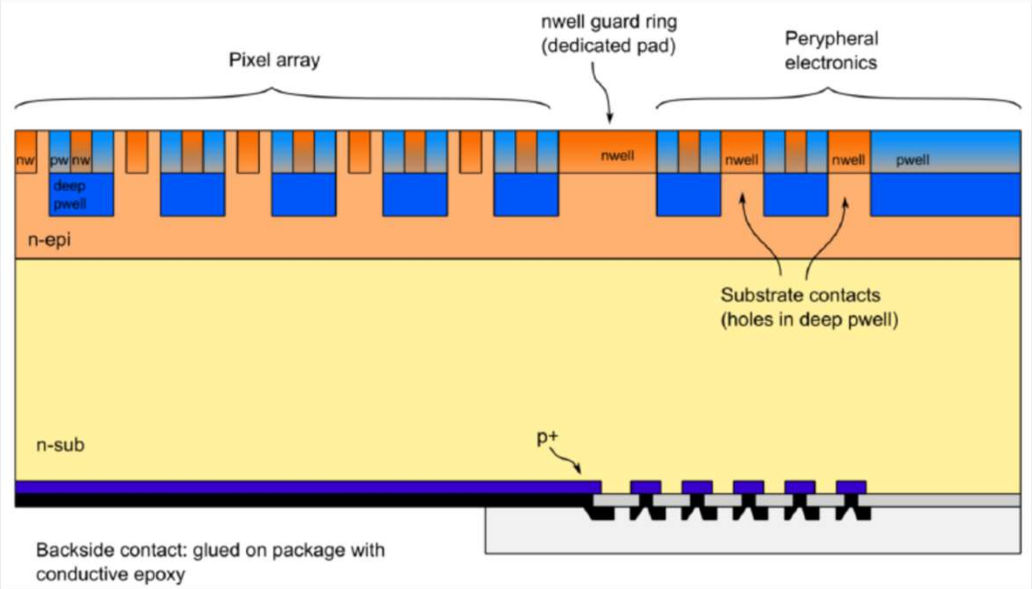
sPHENIX
0.2 m^2 – 251 M pixel

Pixel detectors

ARCADIA: System-grade Demonstrator

Advanced Readout CMOS Architectures with Depleted Integrated sensor Arrays

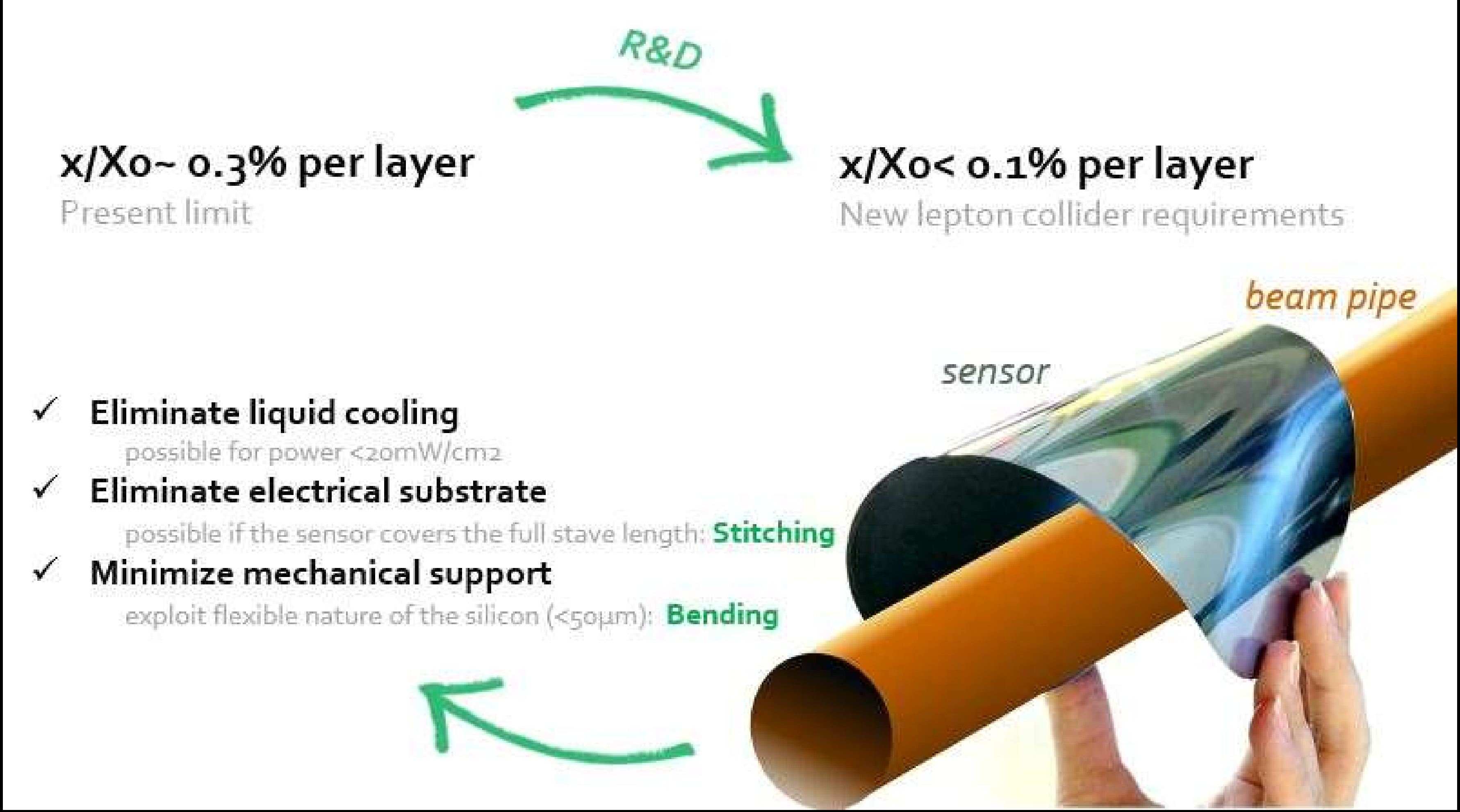
- INFN CSNV Call Project: budget 1MEur
- Active sensor thickness in the range 50 μm to 500 μm or more
- Operation in full depletion with fast charge collection by drift
- Small charge collecting electrode for optimal signal to noise ratio
- Scalable readout architecture with ultra-low power capability (O(10mW/cm^2))
- Easy compatibility with standard CMOS processes.
- Deliverable: full-size system-ready demonstrator of a low-power High-density pixel matrix CMOS monolithic sensor



Critical to avoid liquid cooling

Pixel detector

- A realistic dream!



$x/X_0 \sim 0.3\%$ per layer
Present limit

$x/X_0 < 0.1\%$ per layer
New lepton collider requirements

- ✓ **Eliminate liquid cooling**
  possible for power <20mW/cm2
- ✓ **Eliminate electrical substrate**
  possible if the sensor covers the full stave length: **Stitching**
- ✓ **Minimize mechanical support**
  exploit flexible nature of the silicon (<50μm): **Bending**

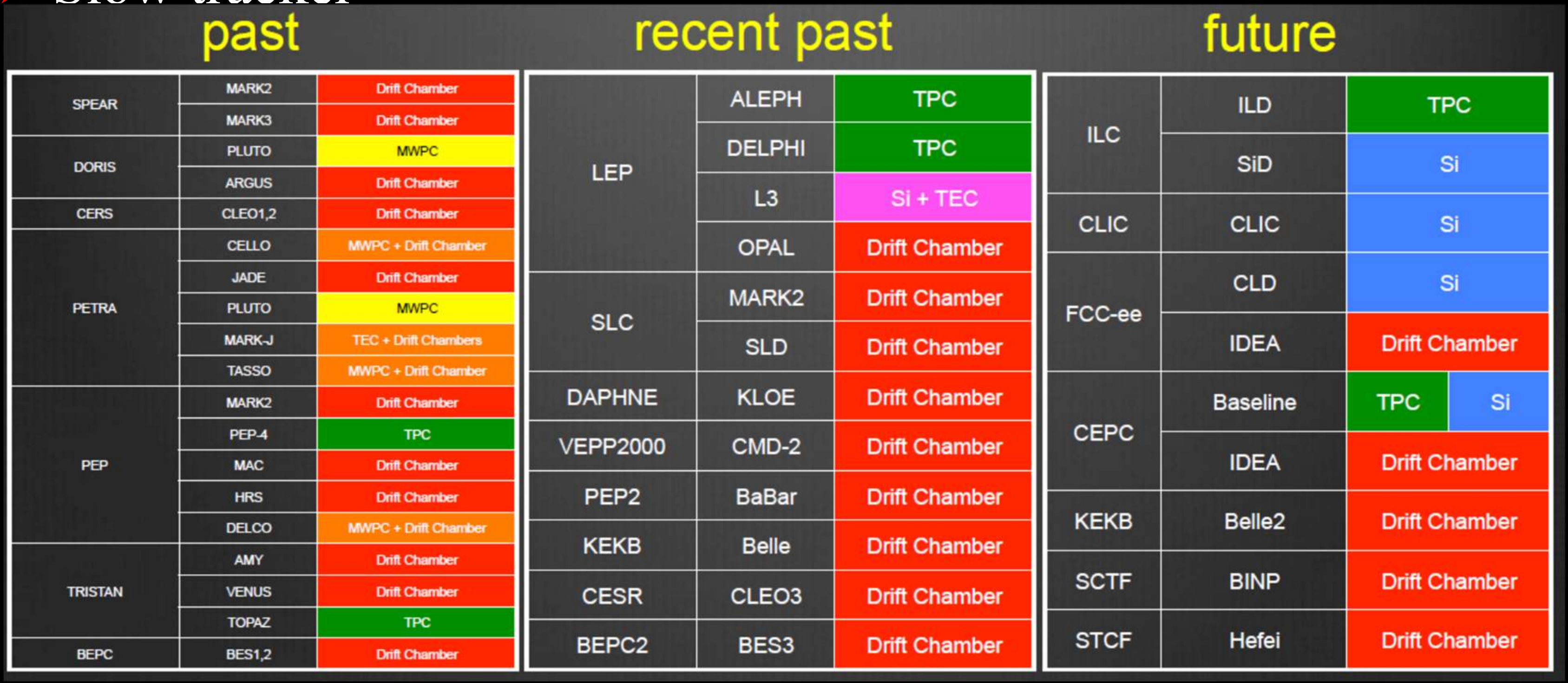
Lessons from ILC/SiD

- Things change with time – be flexible:
  - Silicon strips → all pixels
    - Evolution of pixel technology
  - digital RPC had calorimeter → scintillator/SiPM
    - Evolution of SiPM technology
- Warnings for FCC-ee operation
  - Lack of power pulsing could have large effect on material

Marcel Stanitzki

TPC vs. DCH

- Drift chamber most widely used in e+e-
- TPC not optimal for FCC-ee
  - Large complexity → many criticalities
  - Slow tracker



past

SPEAR	MARK2	Drift Chamber
	MARK3	Drift Chamber
DORIS	PLUTO	MWPC
	ARGUS	Drift Chamber
CERS	CLEO1,2	Drift Chamber
PETRA	CELLO	MWPC + Drift Chamber
	JADE	Drift Chamber
	PLUTO	MWPC
	MARK-J	TEC + Drift Chambers
	TASSO	MWPC + Drift Chamber
PEP	MARK2	Drift Chamber
	PEP-4	TPC
	MAC	Drift Chamber
	HRS	Drift Chamber
	DELCO	MWPC + Drift Chamber
TRISTAN	AMY	Drift Chamber
	VENUS	Drift Chamber
	TOPAZ	TPC
BEPC	BES1,2	Drift Chamber

recent past

LEP	ALEPH	TPC
	DELPHI	TPC
	L3	Si + TEC
	OPAL	Drift Chamber
SLC	MARK2	Drift Chamber
	SLD	Drift Chamber
DAPHNE	KLOE	Drift Chamber
VEPP2000	CMD-2	Drift Chamber
PEP2	BaBar	Drift Chamber
KEKB	Belle	Drift Chamber
CESR	CLEO3	Drift Chamber
BEPC2	BES3	Drift Chamber

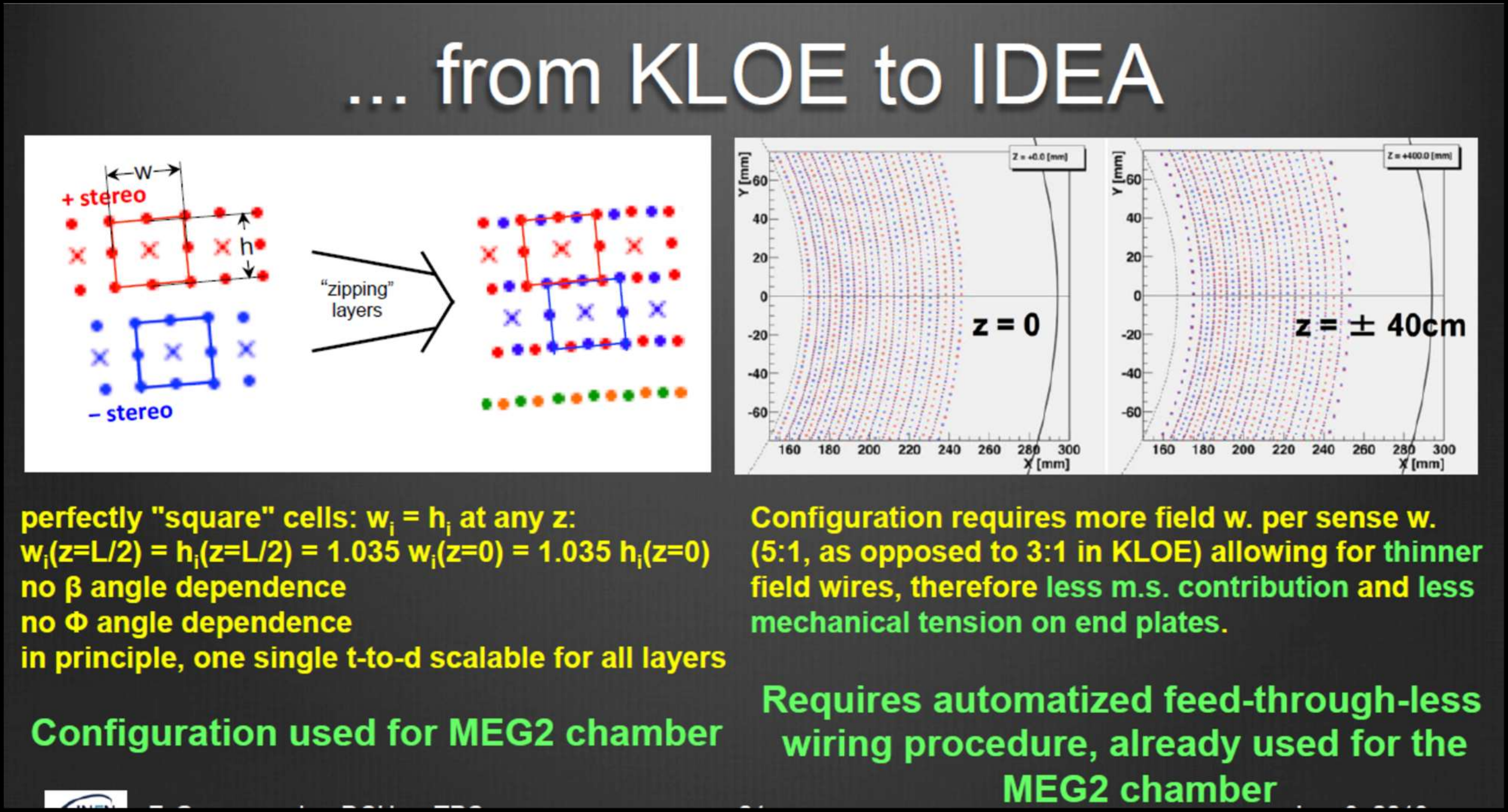
future

ILC	ILD	TPC
	SiD	Si
CLIC	CLIC	Si
FCC-ee	CLD	Si
	IDEA	Drift Chamber
CEPC	Baseline	TPC Si
	IDEA	Drift Chamber
KEKB	Belle2	Drift Chamber
SCTF	BINP	Drift Chamber
STCF	Hefei	Drift Chamber

Franco Grancagnolo

TPC vs. DCH

- KLOE → MEG2 → FCC-ee



... from KLOE to IDEA

perfectly "square" cells: $w_i = h_i$ at any z:
$w_i(z=L/2) = h_i(z=L/2) = 1.035\ w_i(z=0) = 1.035\ h_i(z=0)$
no β angle dependence
no Φ angle dependence
in principle, one single t-to-d scalable for all layers

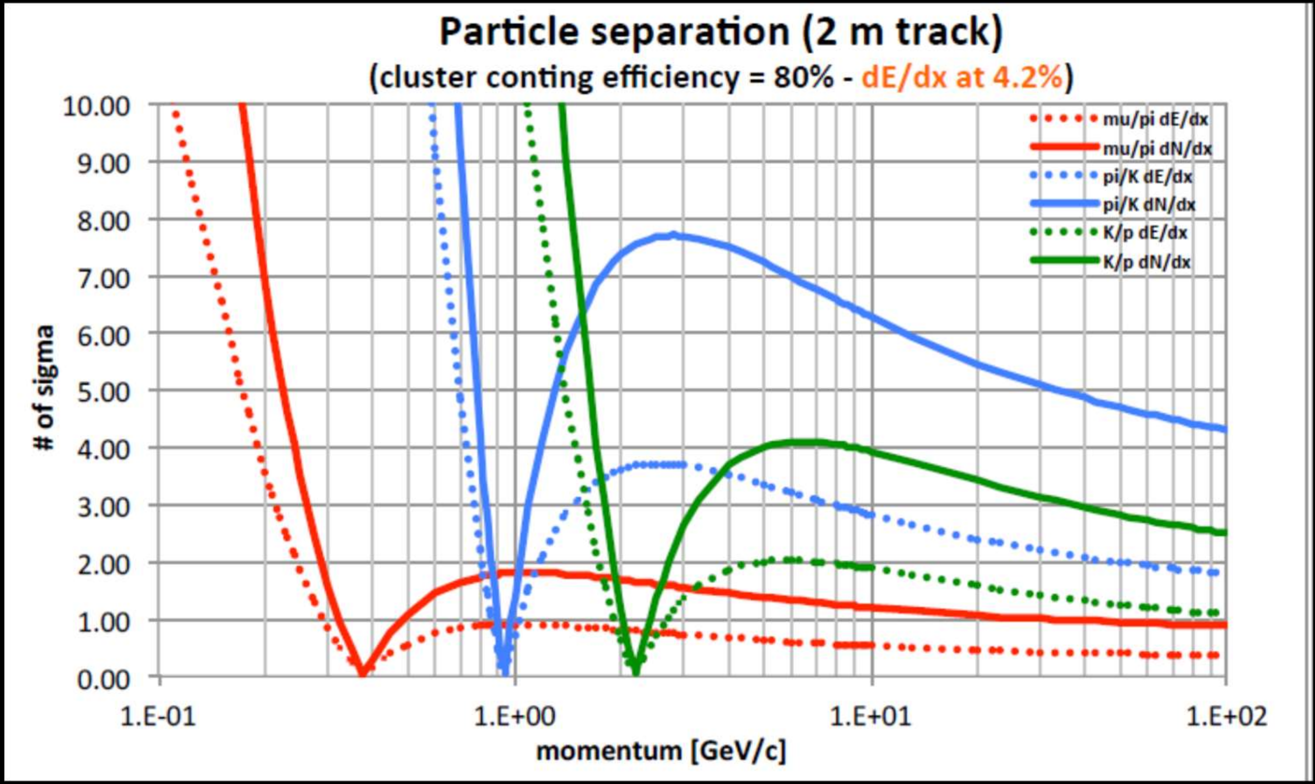
Configuration used for MEG2 chamber

Configuration requires more field w. per sense w. (5:1, as opposed to 3:1 in KLOE) allowing for thinner field wires, therefore less m.s. contribution and less mechanical tension on end plates.

Requires automatized feed-through-less wiring procedure, already used for the MEG2 chamber

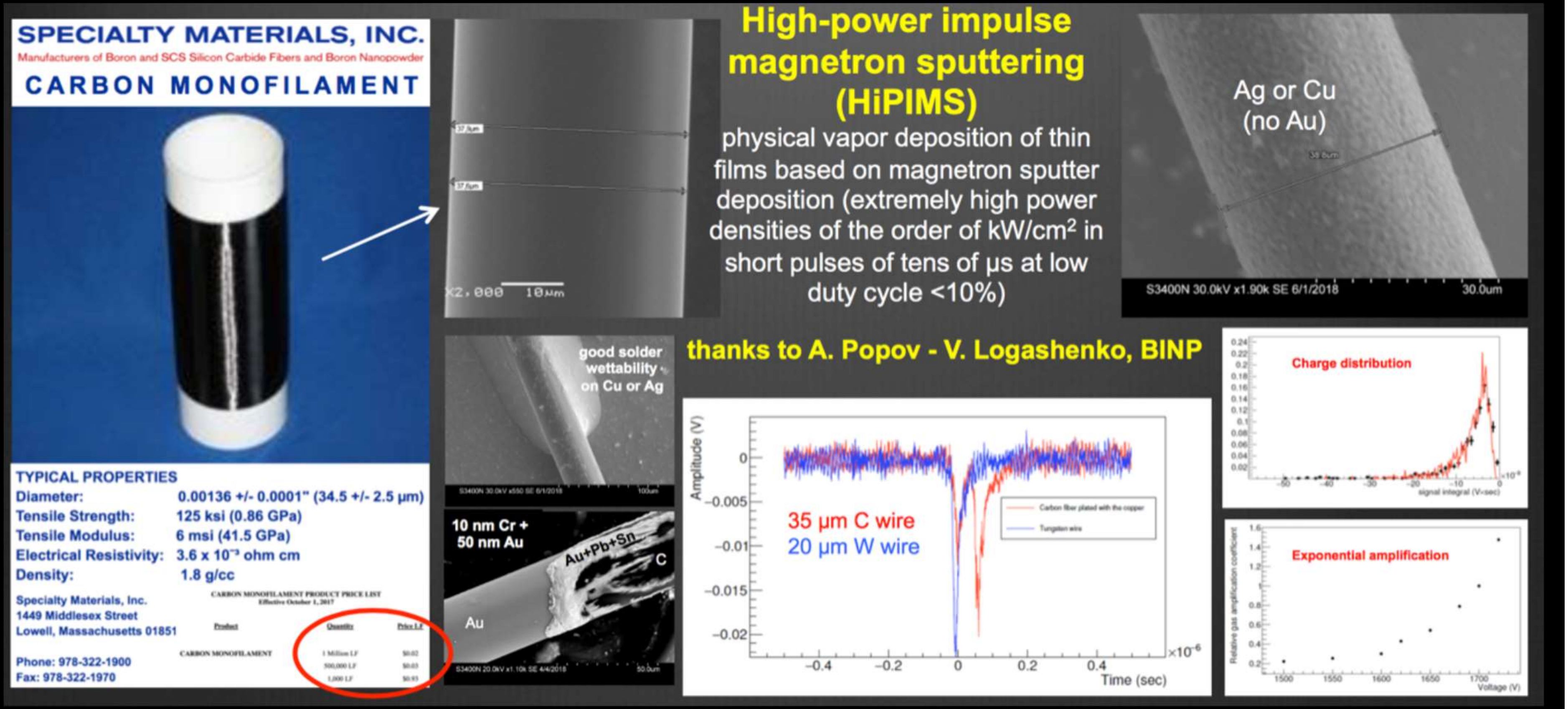
TPC vs. DCH

- Cluster counting promises excellent dE/dx resolution



TPC vs. DCH

- 4 m long wires require R&D for stability condition
  - Carbon wires light and strong could be solution



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Manufacturers of Boron and SCS Silicon Carbide Fibers and Boron Nanopowder

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TYPICAL PROPERTIES	
Diameter:	0.00136 +/- 0.0001" (34.5 +/- 2.5 μm)
Tensile Strength:	125 ksi (0.86 GPa)
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Density:	1.8 g/cc

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Lowell, Massachusetts 01851

Phone: 978-322-1900
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CARBON MONOFILAMENT PRODUCT PRICE LIST
Effective October 1, 2017

High-power impulse magnetron sputtering (HiPIMS)

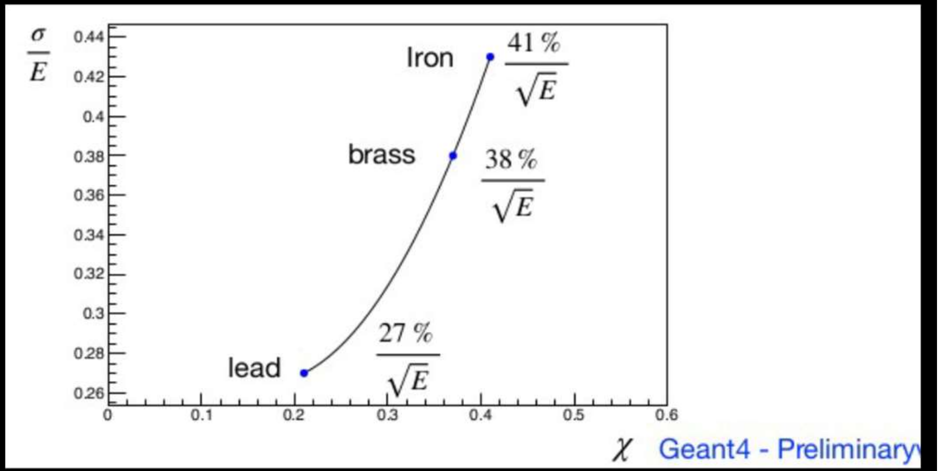
physical vapor deposition of thin films based on magnetron sputter deposition (extremely high power densities of the order of kW/cm² in short pulses of tens of μs at low duty cycle <10%)

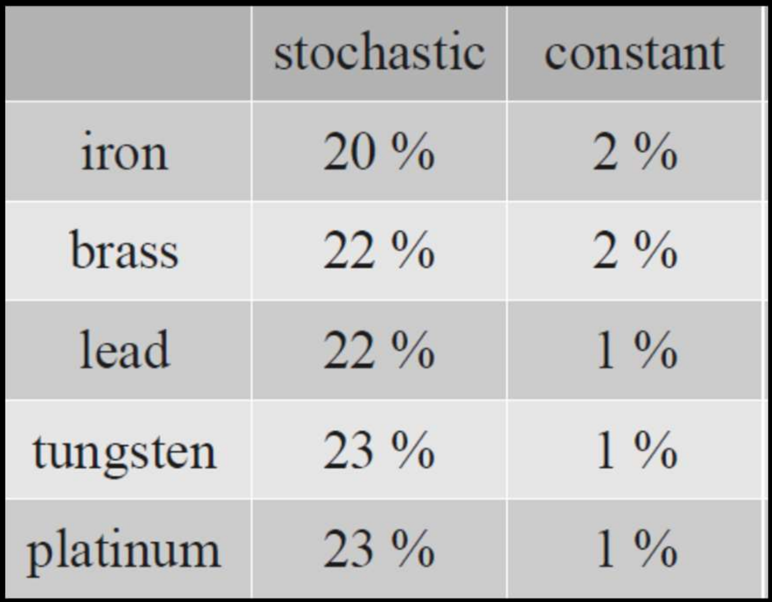
thanks to A. Popov - V. Logashenko, BINP

Dual Readout

- Detailed studies on choice of absorber
- Developed new ML base calibration method (w/ L. Pezzotti)
  - Better adronic resolution less sensitive to material

Roberto Ferrari

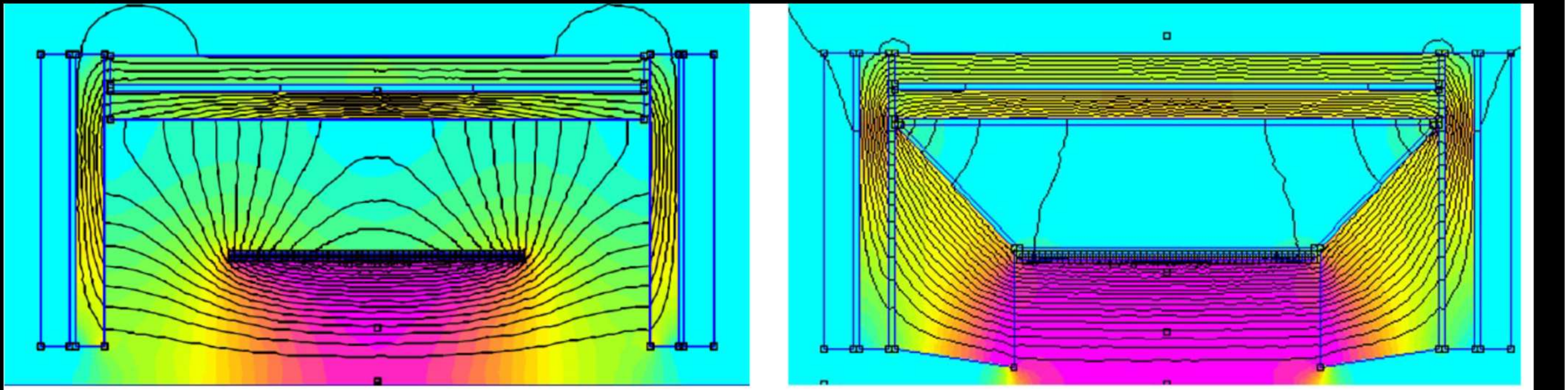




	stochastic	constant
iron	20 %	2 %
brass	22 %	2 %
lead	22 %	1 %
tungsten	23 %	1 %
platinum	23 %	1 %

Dual Readout

- Iron forw calorimeter helps a lot the magnetic field

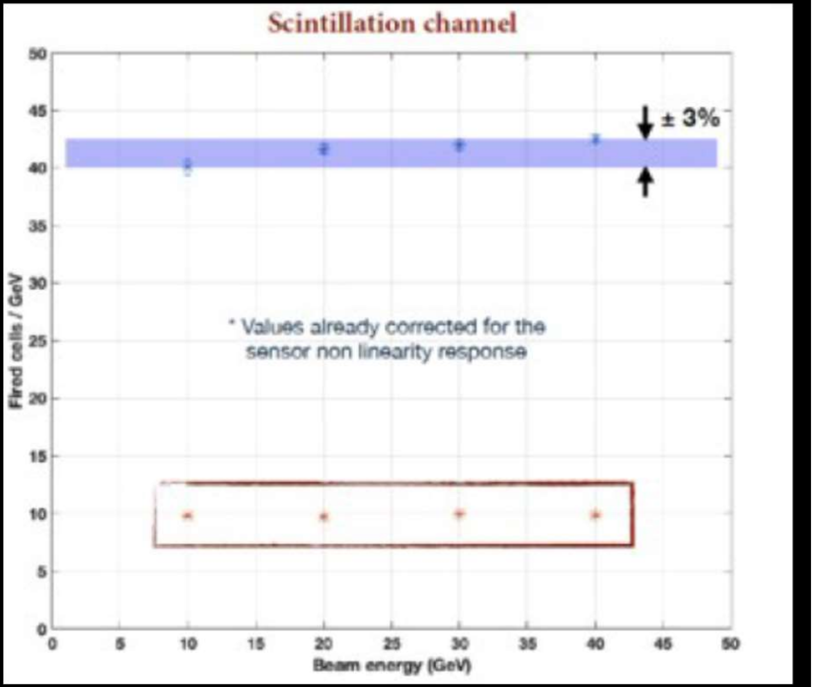


Lead absorber

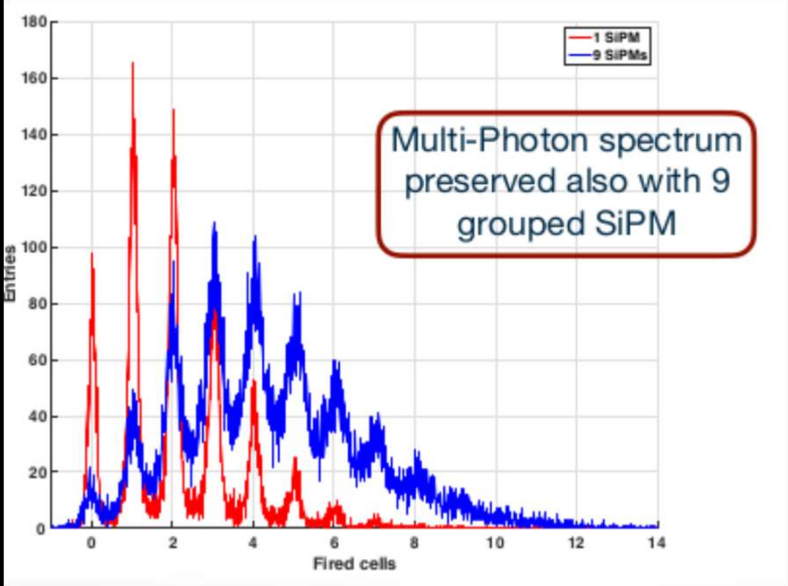
→ forward with Iron

Dual Readout

- SiPM issues:
  - Scintillator signal linearity under control with filters with 25 μm
  - Reduce filtering with 5-10 μm
  - Can reduce granularity by grouping

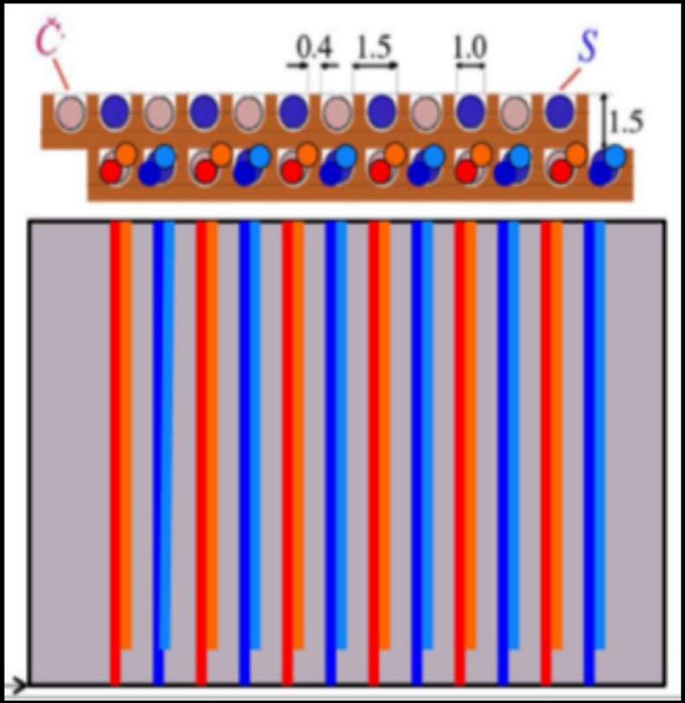

Scintillation channel

* Values already corrected for the sensor non linearity response


Multi-Photon spectrum preserved also with 9 grouped SiPM

Dual Readout

- Particle flow?
  - Can split EM/HAD part
    - double the readout/more mechanical complexity
  - Special geometries
    - Staggered fibers
  - Waveform readout
    - Needs study with simulation



Dual Readout tiles

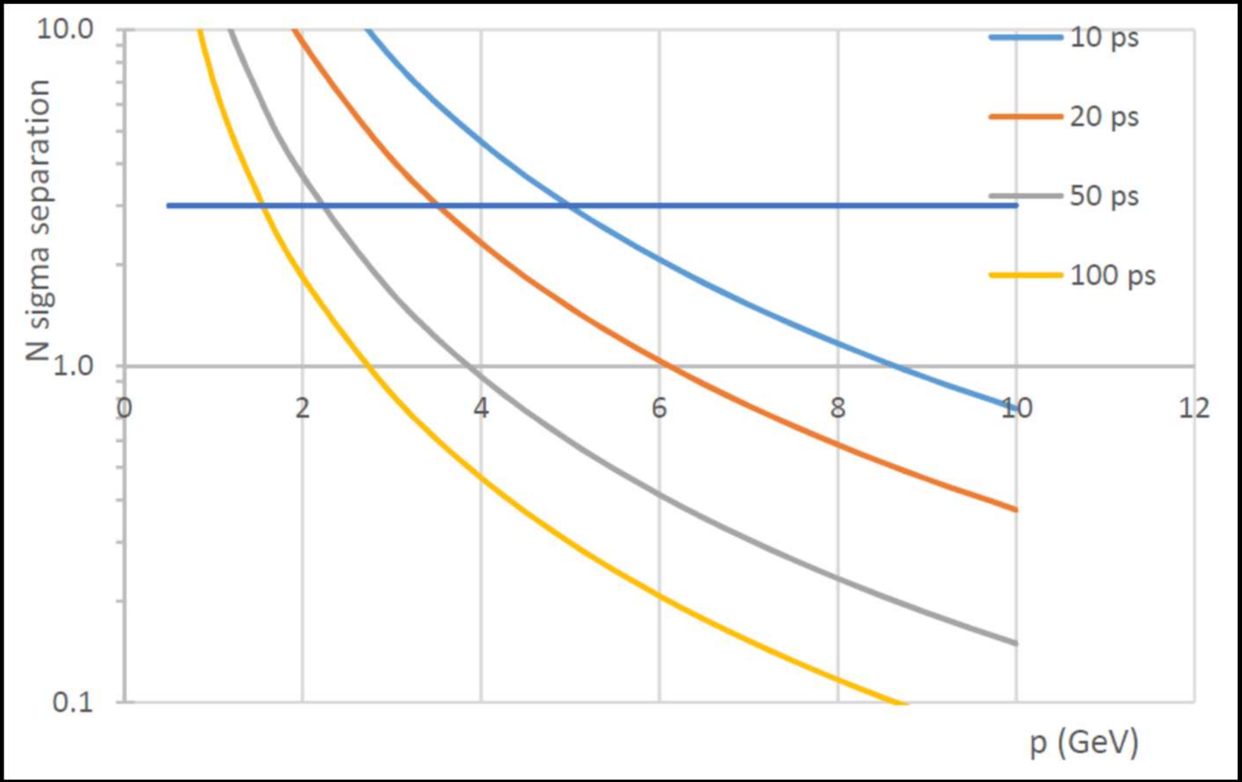
- A tile based DR calorimeter could be simpler and solve some fiber related issues
- However:
  - Practical dimensions have to be possible for a 4π design
  - Sampling fluctuations must not destroy the EM resolution
- More studies needed

Yasar Onel

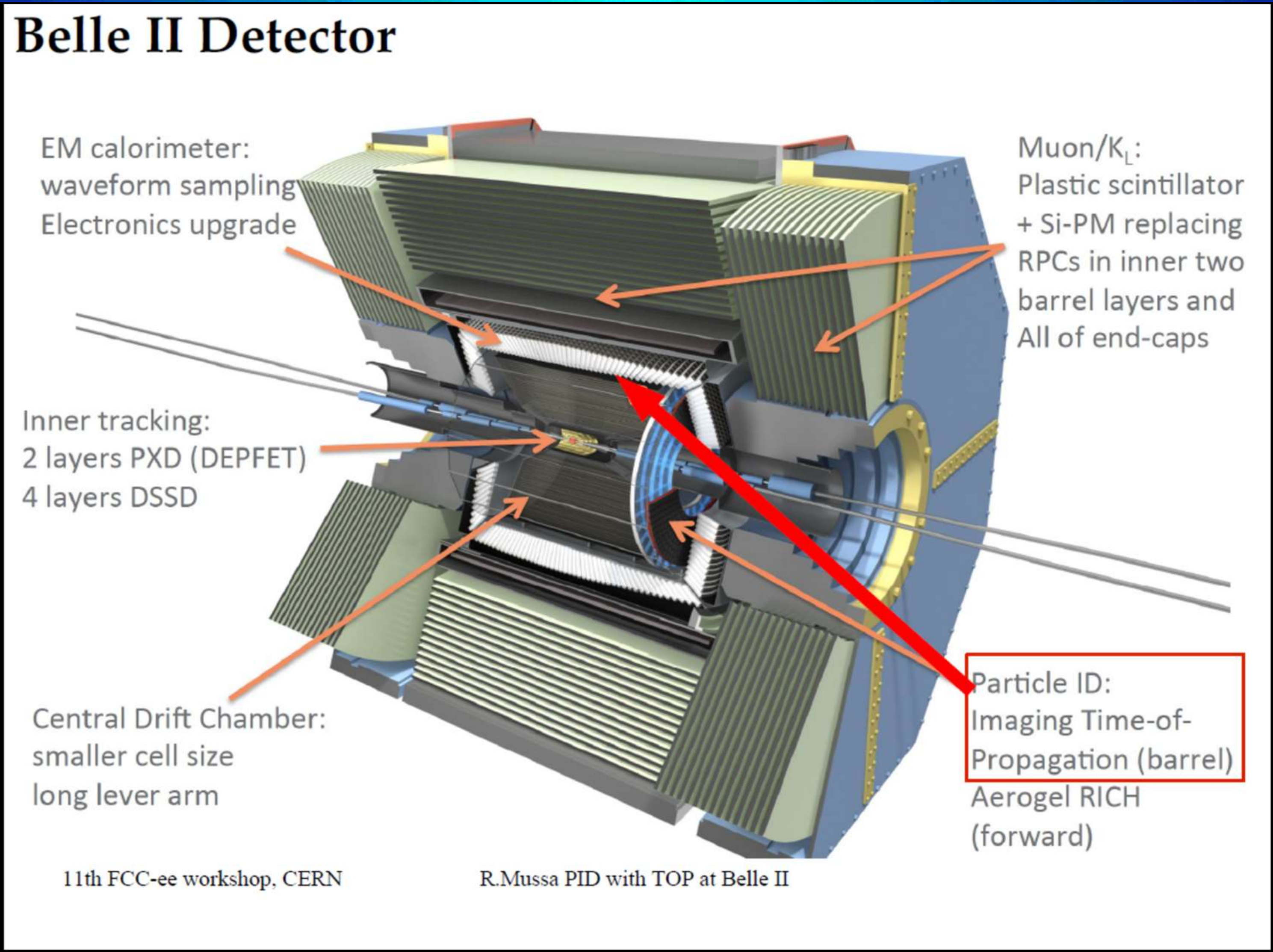
Particle ID

PID

- Basic time of flight requires very good timing
  - Plot is for Nσ π-K separation with different resolutions @ 2m
- TOP and TORCH expand separation with same resolution



TOP



Belle II Detector

EM calorimeter:
waveform sampling
Electronics upgrade

Muon/K_L:
Plastic scintillator
+ Si-PM replacing
RPCs in inner two
barrel layers and
All of end-caps

Inner tracking:
2 layers PXD (DEPFET)
4 layers DSSD

Central Drift Chamber:
smaller cell size
long lever arm

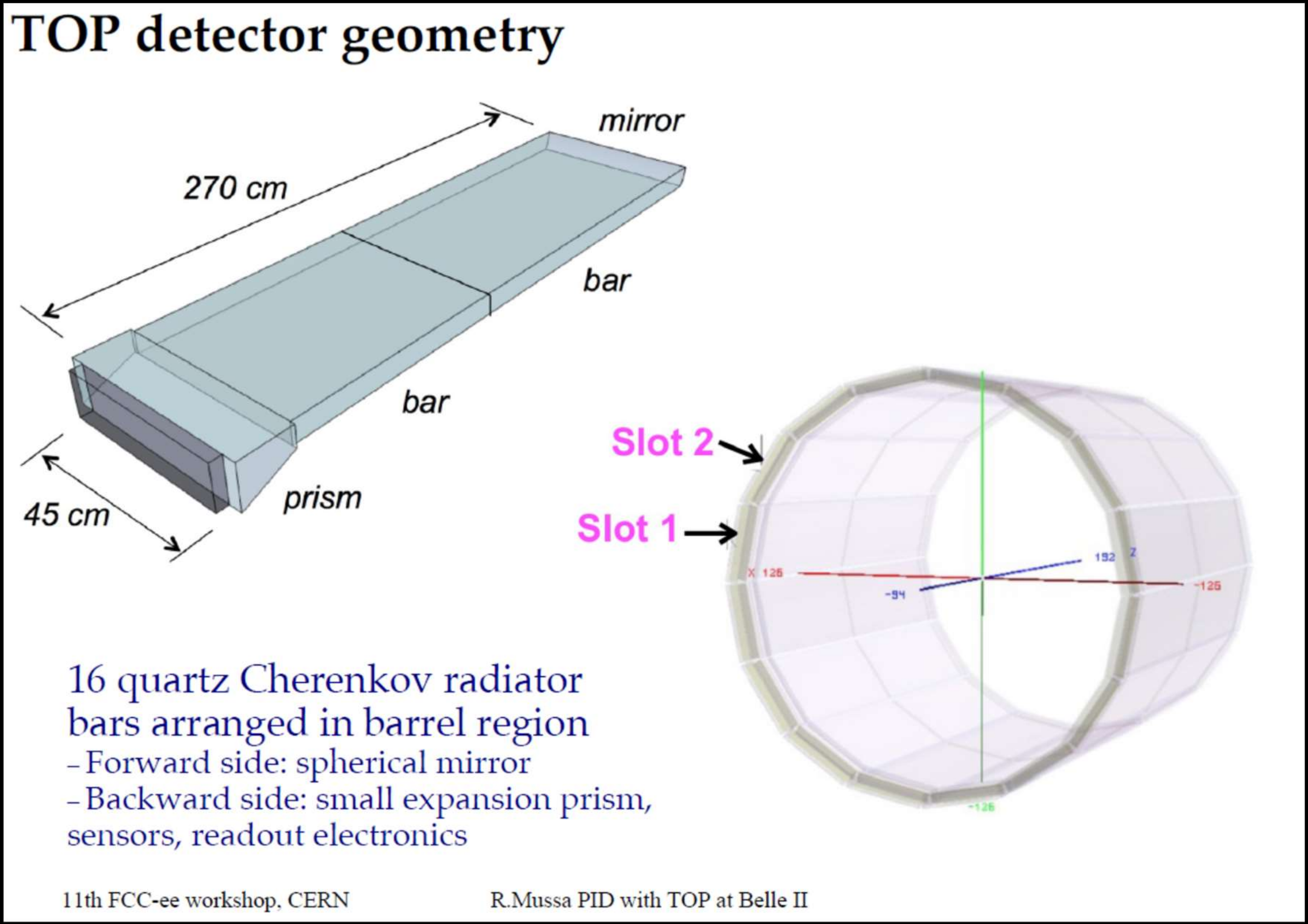
Particle ID:
Imaging Time-of-Propagation (barrel)
Aerogel RICH
(forward)

11th FCC-ee workshop, CERN

R.Mussa PID with TOP at Belle II

Roberto Mussa

TOP

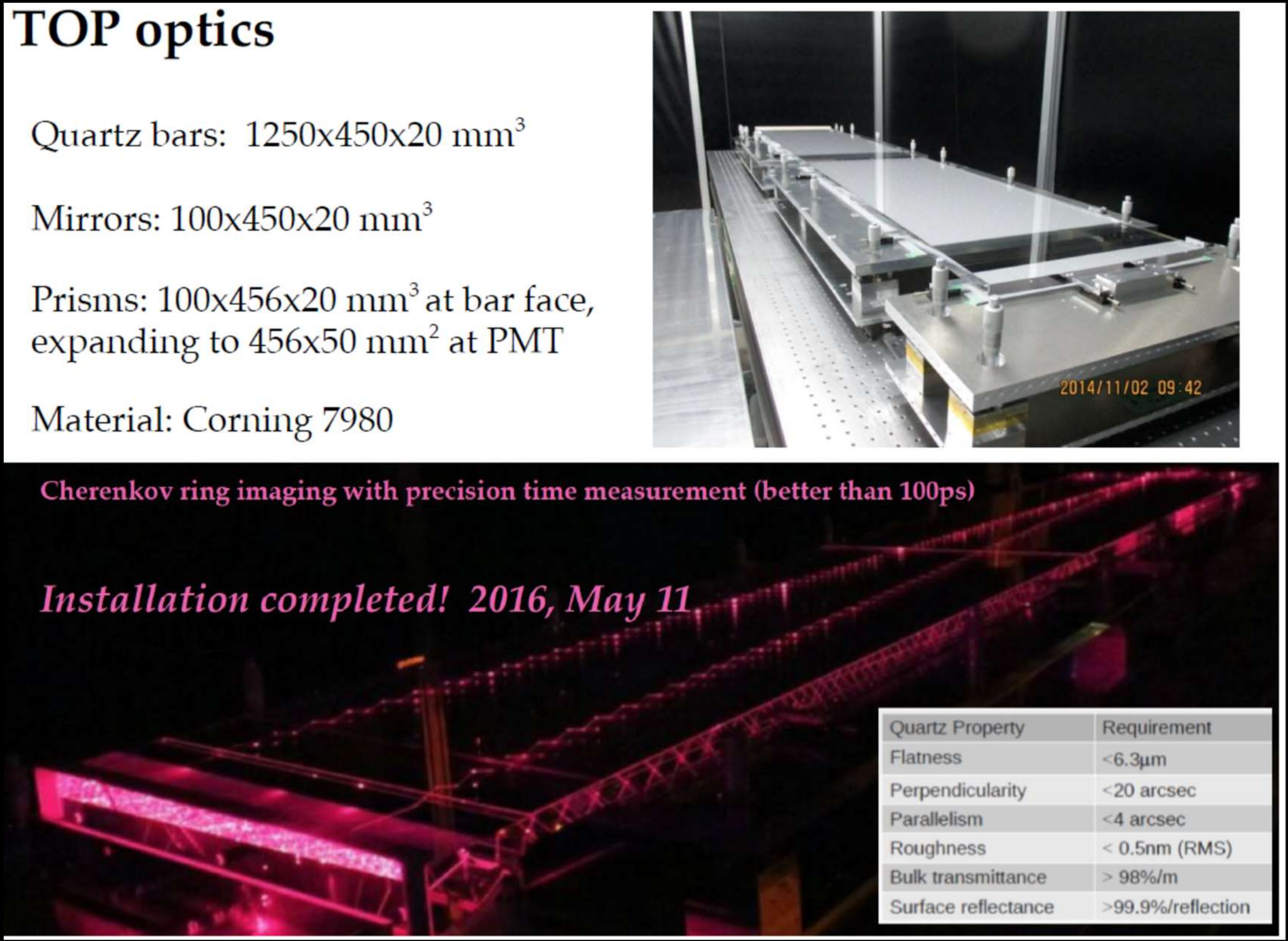


TOP detector geometry

16 quartz Cherenkov radiator bars arranged in barrel region
- Forward side: spherical mirror
- Backward side: small expansion prism, sensors, readout electronics

11th FCC-ee workshop, CERN R.Mussa PID with TOP at Belle II

TOP



TOP optics

Quartz bars: 1250x450x20 mm^3

Mirrors: 100x450x20 mm^3

Prisms: 100x456x20 mm^3 at bar face, expanding to 456x50 mm^2 at PMT

Material: Corning 7980

2014/11/02 09:42

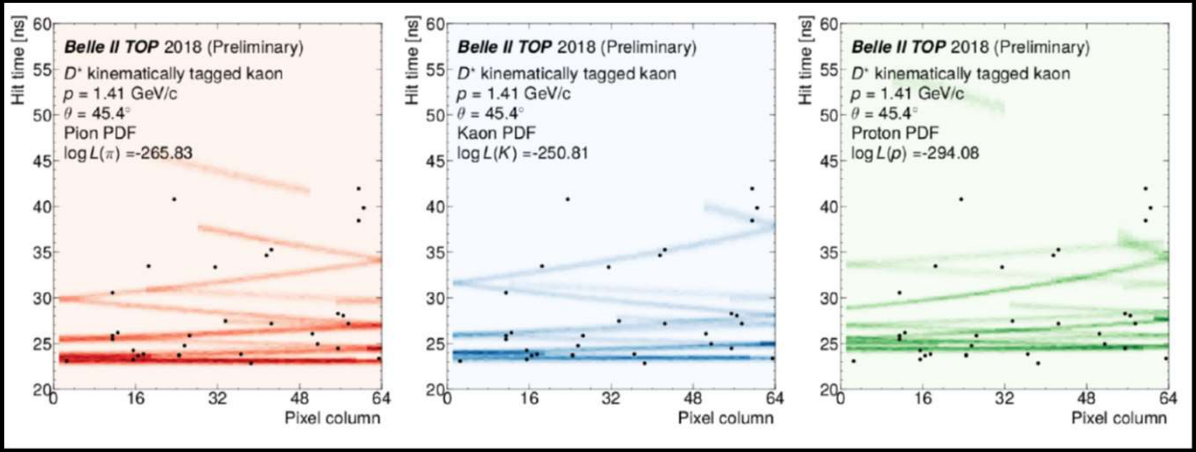
Cherenkov ring imaging with precision time measurement (better than 100ps)

Installation completed! 2016, May 11

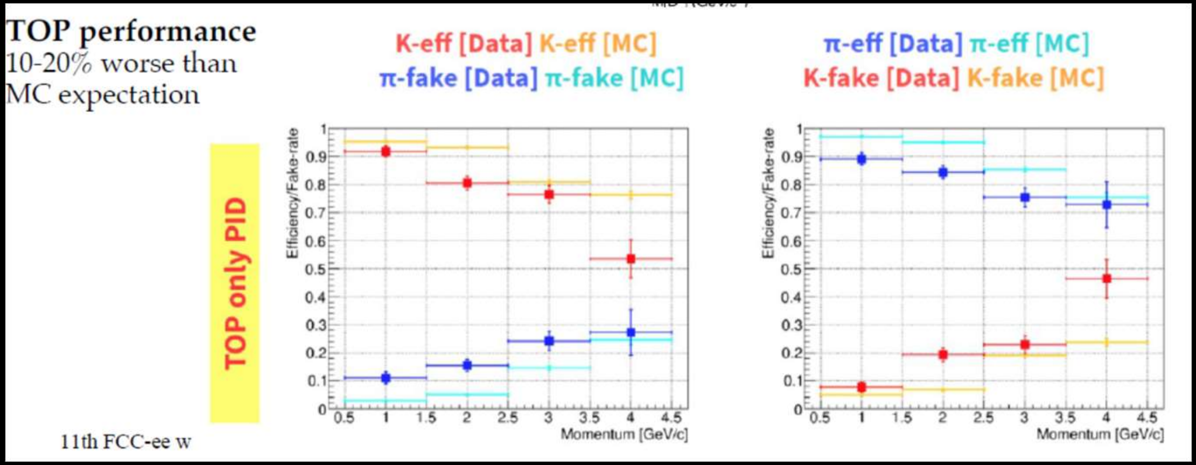
Quartz Property	Requirement
Flatness	<6.3µm
Perpendicularity	<20 arcsec
Parallelism	<4 arcsec
Roughness	< 0.5nm (RMS)
Bulk transmittance	> 98%/m
Surface reflectance	>99.9%/reflection

TOP

- Fit photon pattern in time vs position plot

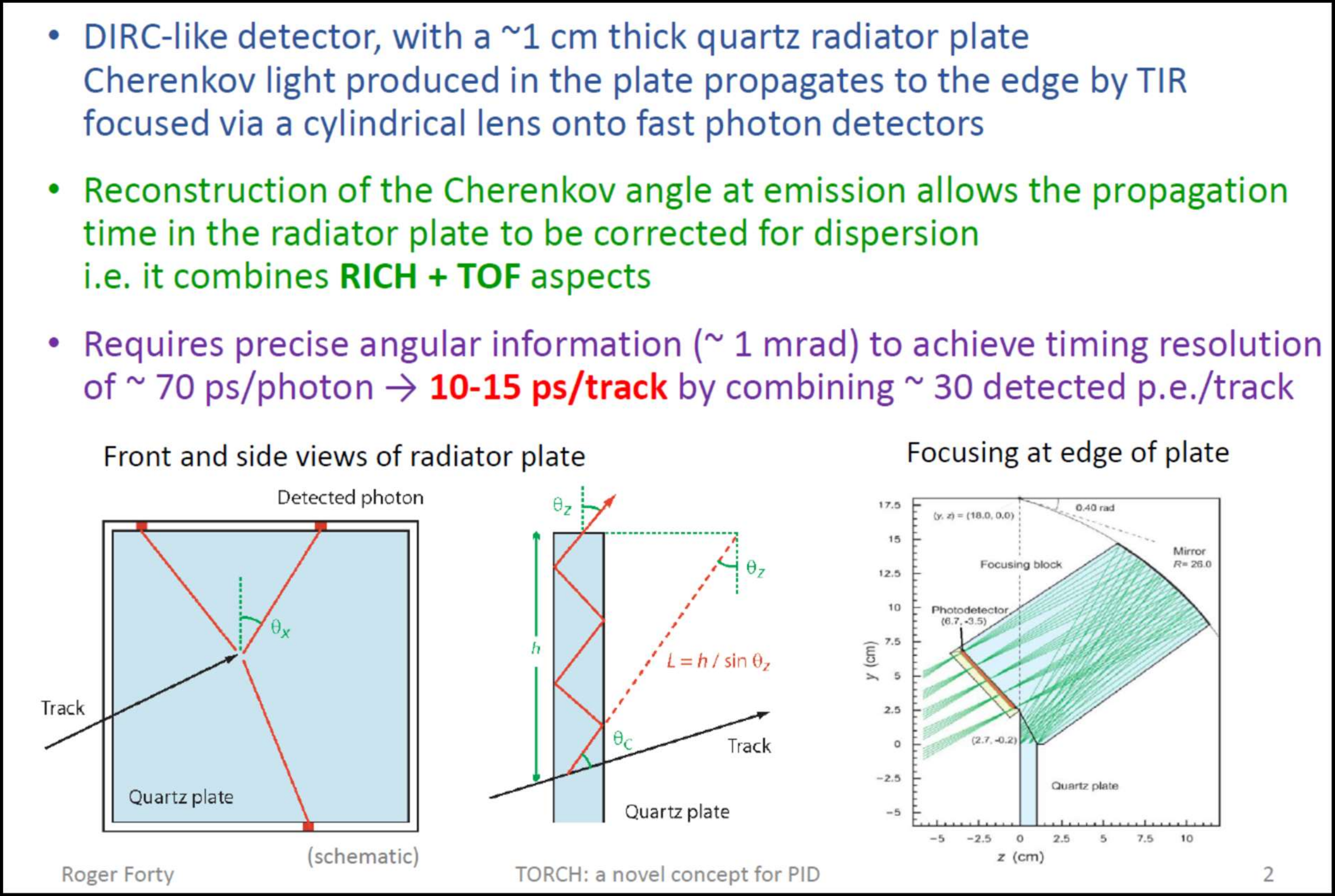


- Good to few GeV with current 120 ps resolution


TOP performance
10-20% worse than
MC expectation

TORCH

Roger Forty



- DIRC-like detector, with a ~1 cm thick quartz radiator plate
  Cherenkov light produced in the plate propagates to the edge by TIR
  focused via a cylindrical lens onto fast photon detectors
- Reconstruction of the Cherenkov angle at emission allows the propagation time in the radiator plate to be corrected for dispersion
  i.e. it combines **RICH + TOF** aspects
- Requires precise angular information (~ 1 mrad) to achieve timing resolution of ~ 70 ps/photon → **10-15 ps/track** by combining ~ 30 detected p.e./track

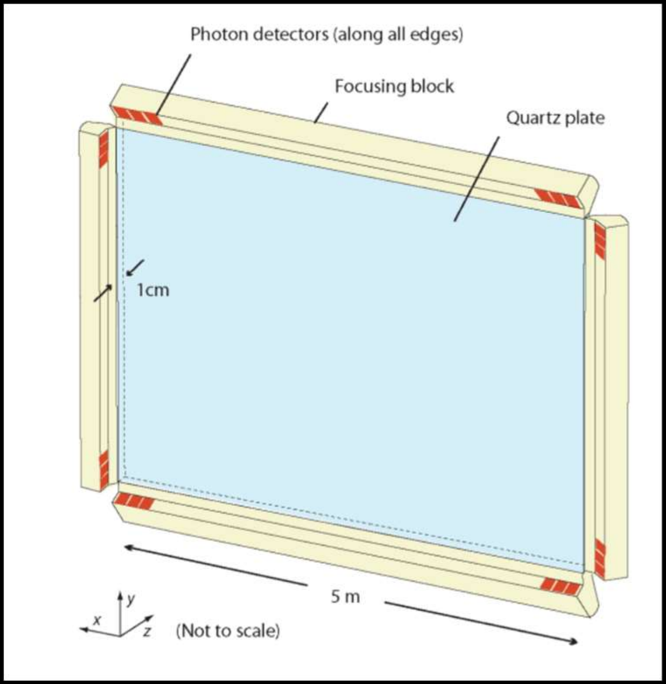
Front and side views of radiator plate

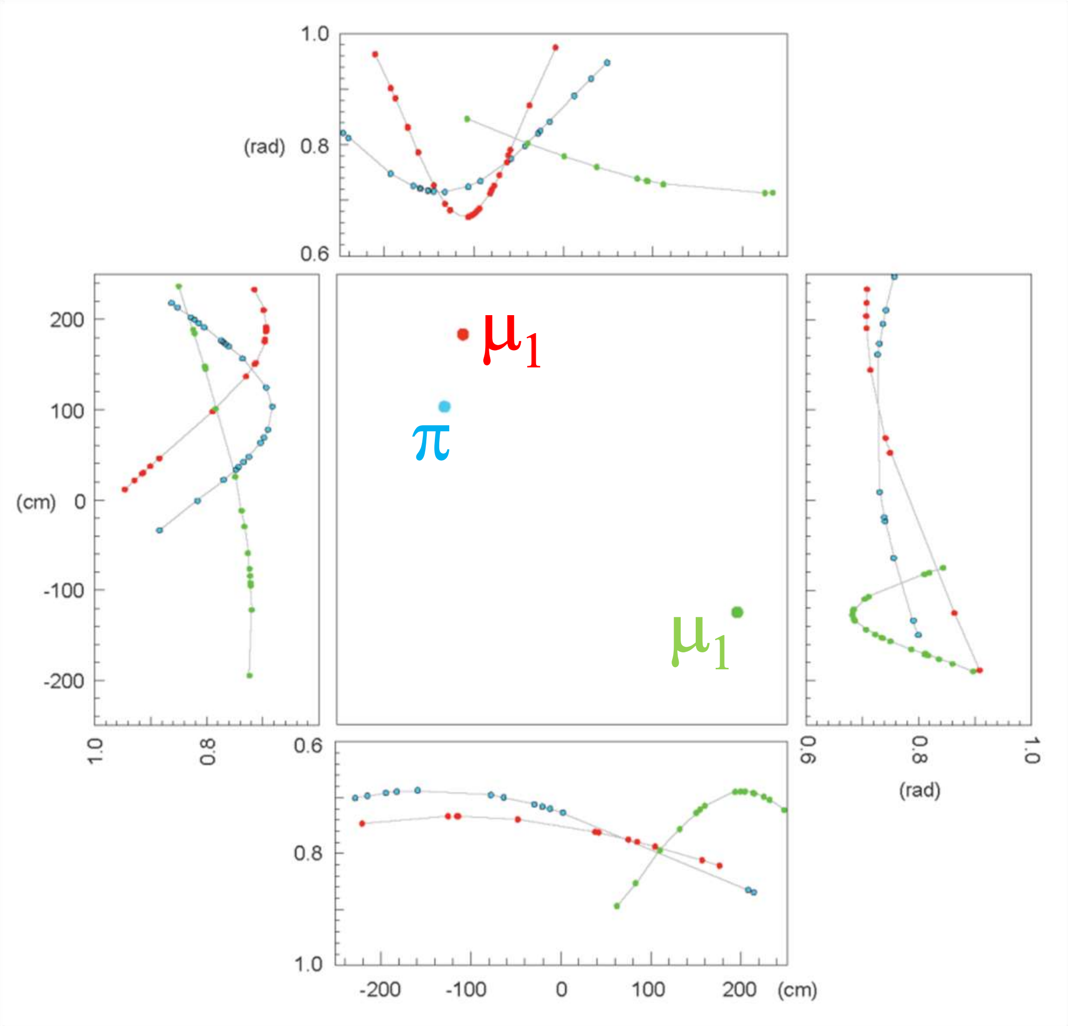
(schematic)

Focusing at edge of plate

TORCH

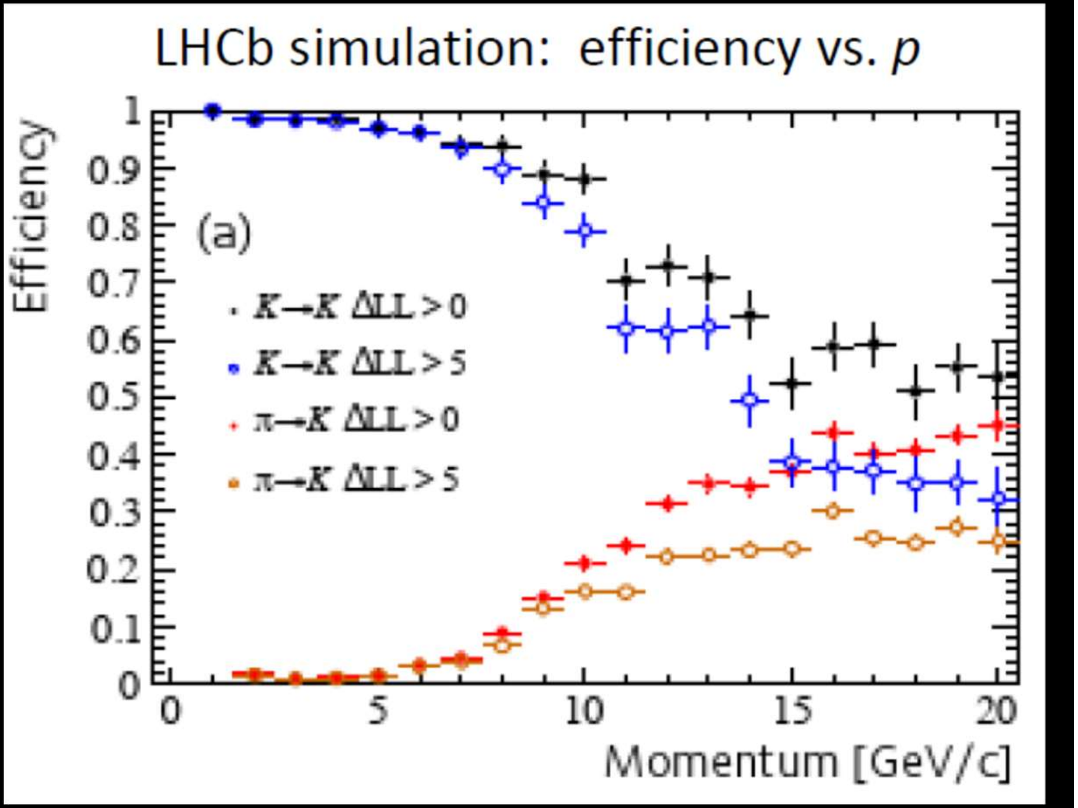
- Working example





TORCH

- Expected performance
- Potential for good K-π separation up to about 10 GeV
  - With 70 ps/photon



Conclusion

- Detector requirements:
  - We know more or less what to do …
  - Must become more quantitative to perform optimizations
- Evolution of proposed detectors
  - Optimistic that we can do them and possibly improve them
  - Much R&D still needed though
- New PID ideas
  - TOP or TORCH boost effectiveness of timing measurement
  - Could be an interesting addition
    - Simpler than a RICH – More complex than pure timing
- Lots of discussion and interest!