Apology

I replaced my slides by a new ones (dated as 23rd January 2008).

As I warned in my talk at Zeuthen, there were in fact mistakes in the numerical calculation for some of the plots.

The formulas given in the talk were all correct.

I apologize for any inconvenience of you.

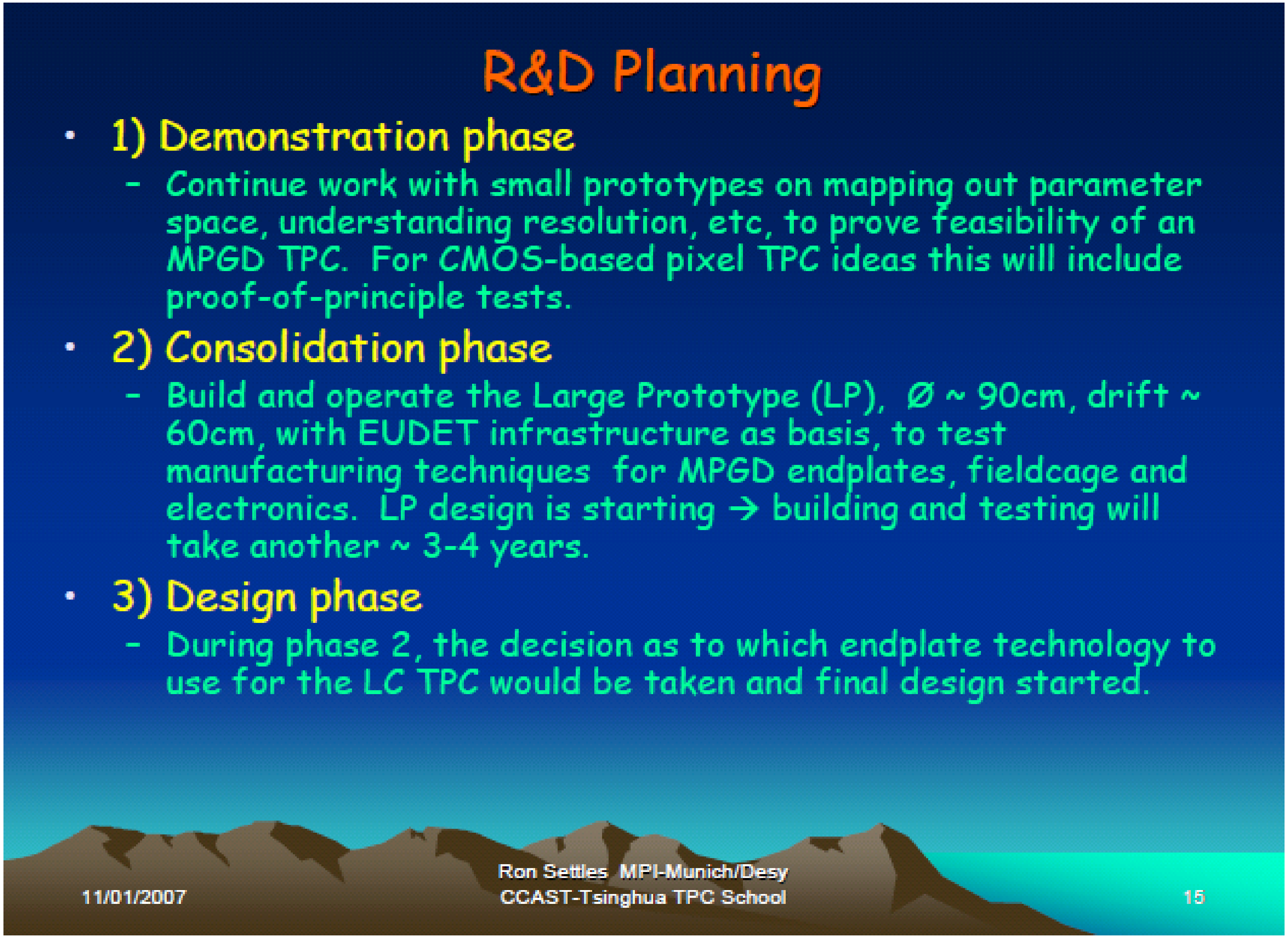
T. Matsuda
Jan 27, 2008

Some Inputs to the Optimization From TPC

With the short notice and also because of the TPC School at Tsinghua University, Beijing, held just before this ILD meeting, I could not work/discuss with the colleagues of the LC TPC collaboration. I discussed briefly only with Ron and Keisuke Fujii for this talk.

T. Matsuda/IPNS/KEK
LC TPC Collaboration
ILD Workshop/January 23, 2008

R&D Planning: LC TPC Collaboration



R&D Planning

- 1) Demonstration phase
  - Continue work with small prototypes on mapping out parameter space, understanding resolution, etc, to prove feasibility of an MPGD TPC. For CMOS-based pixel TPC ideas this will include proof-of-principle tests.
- 2) Consolidation phase
  - Build and operate the Large Prototype (LP), Ø ~ 90cm, drift ~ 60cm, with EUDET infrastructure as basis, to test manufacturing techniques for MPGD endplates, fieldcage and electronics. LP design is starting → building and testing will take another ~ 3-4 years.
- 3) Design phase
  - During phase 2, the decision as to which endplate technology to use for the LC TPC would be taken and final design started.

What are Relevant to the Current Detector Optimization

(A) Outer radius: Rout
Inner radius: Rin
Length: Ldrift x 2
B-field:

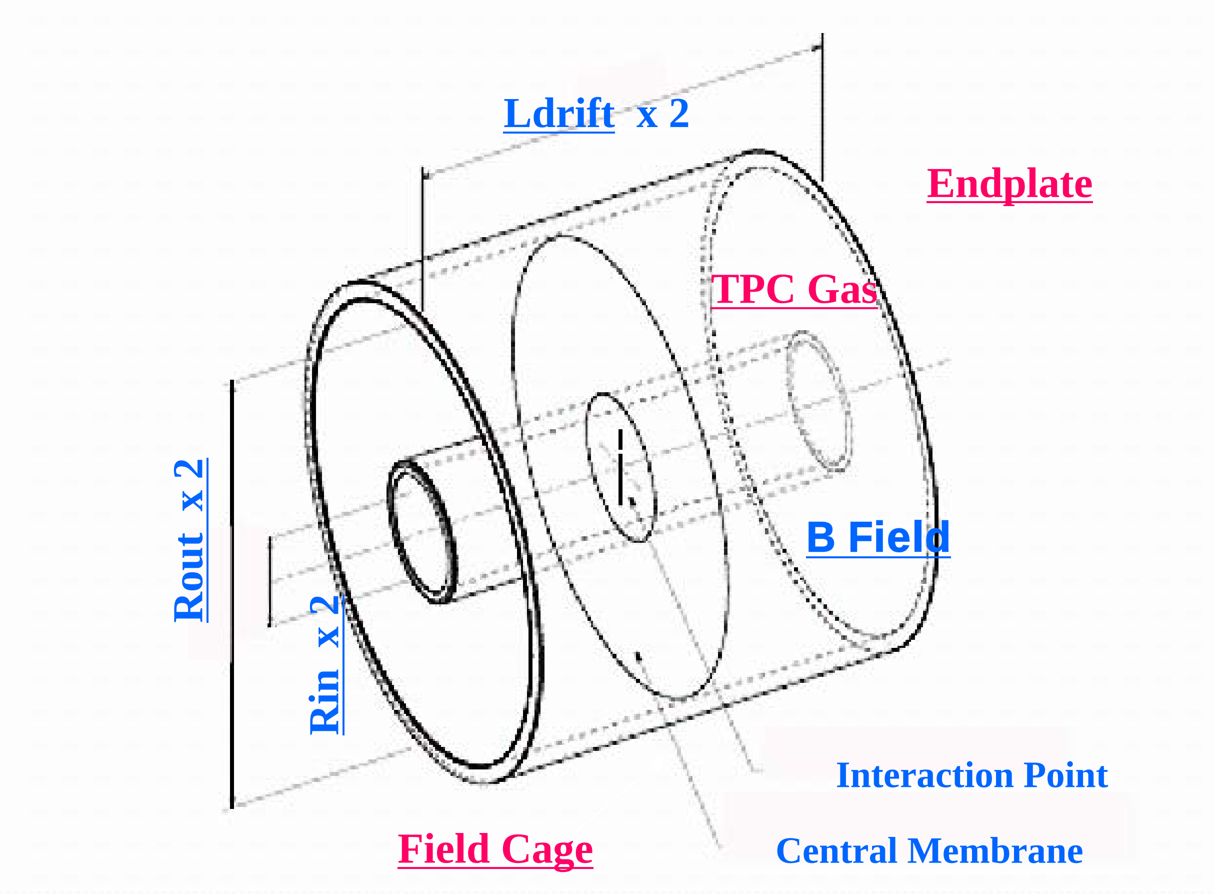
(B) Vdrift:
Point resolution: $\sigma_{r\phi}(z)$, $\sigma_z(z)$:
Pad size (length) → No. of the measurement point for a track

The width of Pad Response → Track separation in $r\phi$ and z.

(D) Material thickness in the barrel and end-cap regions

(A) Given by the optimization.
(B) To be given by the full TPC simulation under given conditions:
the gas, the end-detector type, the electronics.
(D) Requires the design and engineering studies.
Today's presentation gives crude estimations.

Basic Parameters of TPC Relevant for the Current Optimization Process



TPC gas → V_dtift
Cd (T/L)
→ $\sigma r \phi$
→ σz
→ pad response

End-detector & Electronics
→ pad response

End-detector, Endplate,
Electronics & Cooling
→ material
space to CAL

Field cage → material
space to CAL

Point Resolution: $\sigma r \phi (z)$
Analytic Formula for the Analog Readout

Ar-CF4 Gas Mixture for MicroMEGAS

MicroMEGAS with resistive anode readout:

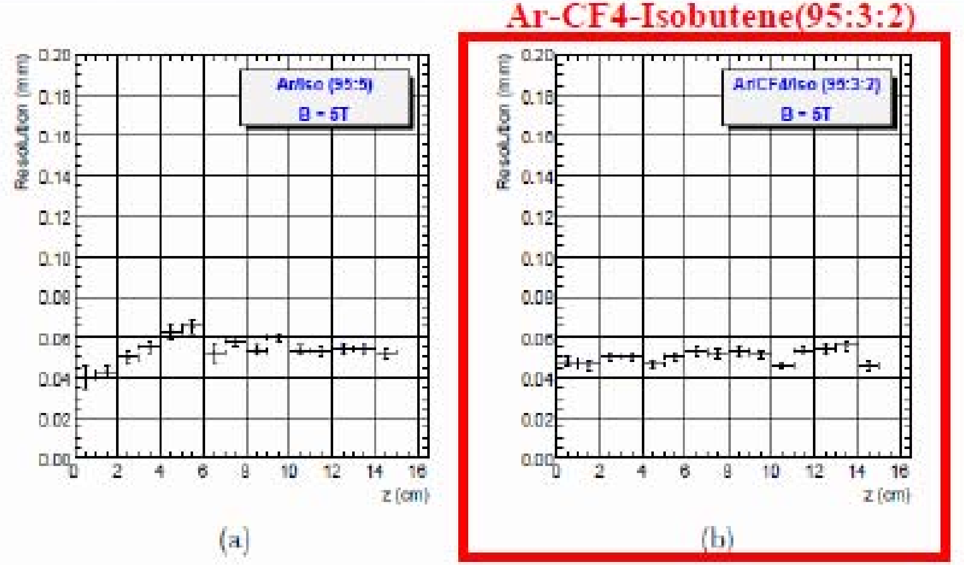
Transverse resolutions measured in the DESY 5T magnet for cosmic rays (M. Dixit et al. 2007)

50 μm resolution all over the drift distance (16 cm) for 5T.

The small diffusion constant (20 μm/ $cm^{1/2}$) of Ar-CF_4-Isobutaine(95:3:2) mixture at B= 1T.

Need to understand why 50 μm but not less.

Neff = 27 -29 at B = 0.5T

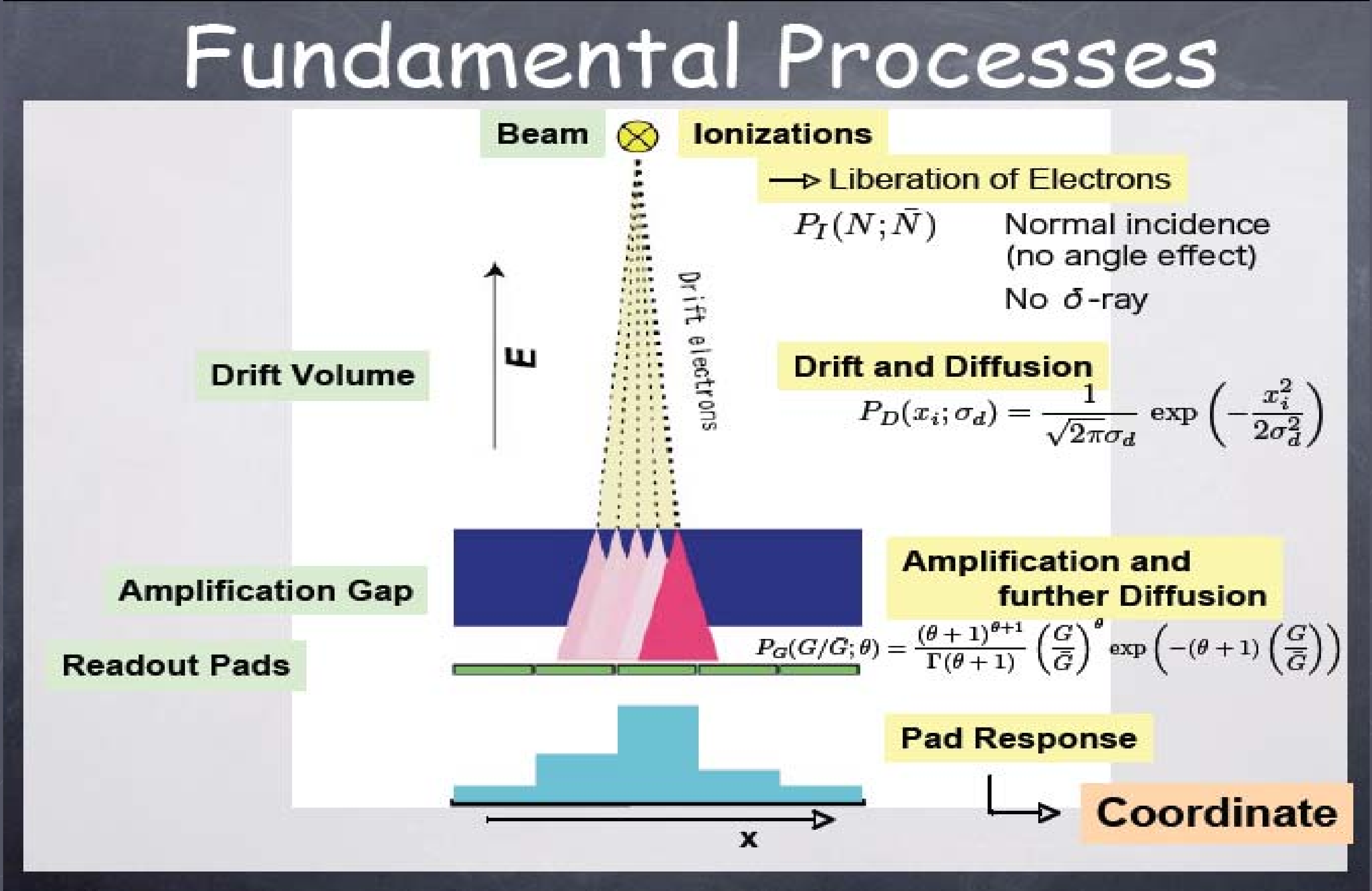

Ar-CF4-Isobutene(95:3:2)

(a) (b)

Fig. 3. Transverse resolution as a function of drift distance for 2 mm x 6 mm pads for a magnetic field of 5 T for two gases mixtures: (a) Ar:iC_4H_{10}/95:5 and (b) Ar:CF_4:iC_4H_{10}/95:3:2.

Point Resolution: $\sigma_{r\phi}(z)$
Analytic Formula for the Analog Readout

Keisuke. Fujii



Fundamental Processes

Ionizations

→ Liberation of Electrons

$P_I(N;\bar{N})$ Normal incidence (no angle effect)

No δ-ray

Drift and Diffusion

$$P_D(x_i;\sigma_d) = \frac{1}{\sqrt{2\pi}\sigma_d}\exp\left(-\frac{x_i^2}{2\sigma_d^2}\right)$$

Amplification and further Diffusion

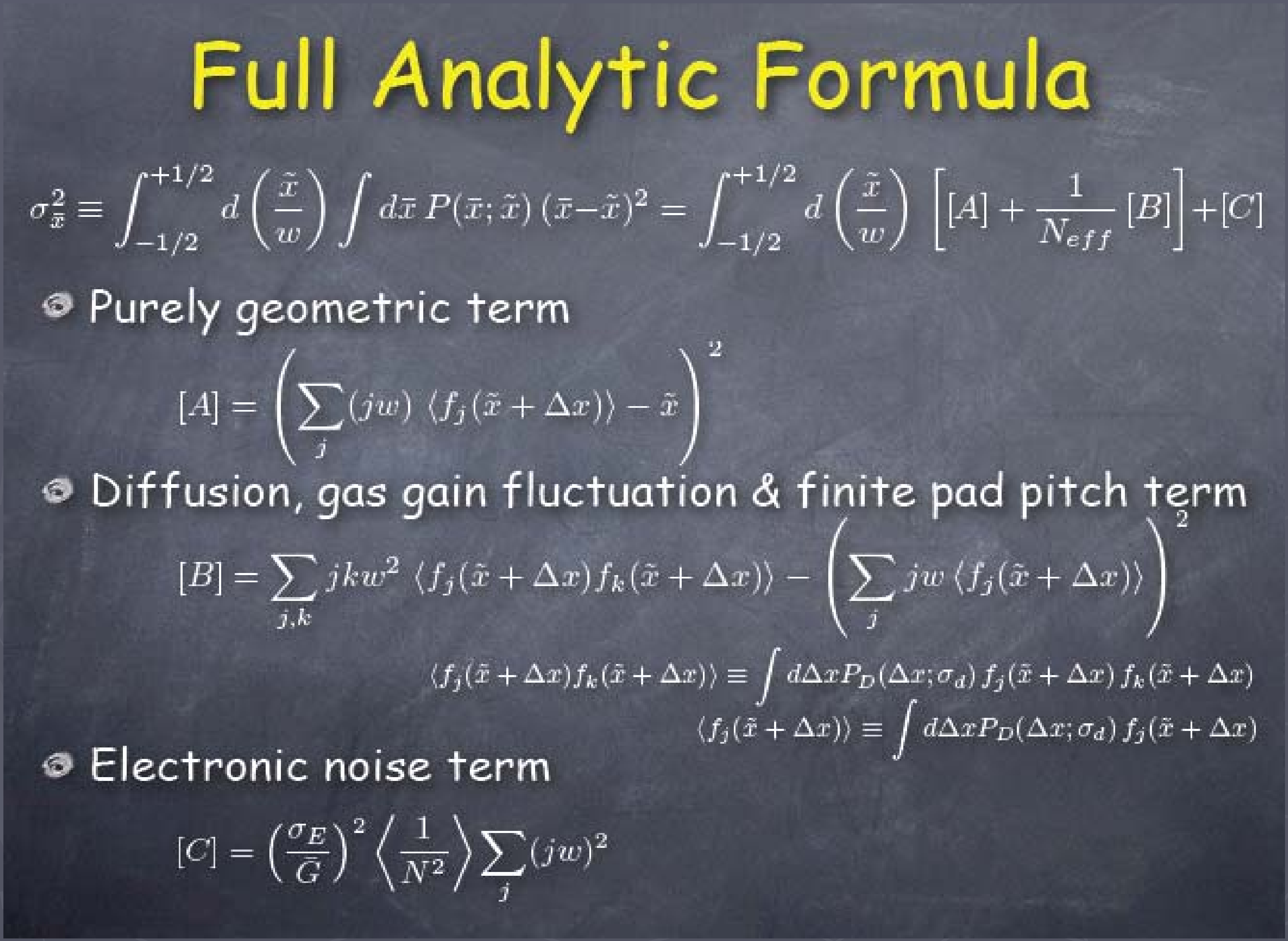
$$P_G(G/\bar{G};\theta) = \frac{(\theta+1)^{\theta+1}}{\Gamma(\theta+1)}\left(\frac{G}{\bar{G}}\right)^{\theta}\exp\left(-(\theta+1)\left(\frac{G}{\bar{G}}\right)\right)$$

Pad Response

→ **Coordinate**

Point Resolution: Analytic Formula

Keisuke. Fujii



Full Analytic Formula

$$\sigma_{\bar{x}}^2 \equiv \int_{-1/2}^{+1/2} d\left(\frac{\tilde{x}}{w}\right) \int d\bar{x}\, P(\bar{x};\tilde{x})\,(\bar{x}-\tilde{x})^2 = \int_{-1/2}^{+1/2} d\left(\frac{\tilde{x}}{w}\right) \left[[A]+\frac{1}{N_{eff}}[B]\right]+[C]$$

- Purely geometric term

$$[A] = \left(\sum_j (jw)\, \langle f_j(\tilde{x}+\Delta x)\rangle - \tilde{x}\right)^2$$

- Diffusion, gas gain fluctuation & finite pad pitch term

$$[B] = \sum_{j,k} jkw^2\, \langle f_j(\tilde{x}+\Delta x) f_k(\tilde{x}+\Delta x)\rangle - \left(\sum_j jw\, \langle f_j(\tilde{x}+\Delta x)\rangle\right)^2$$

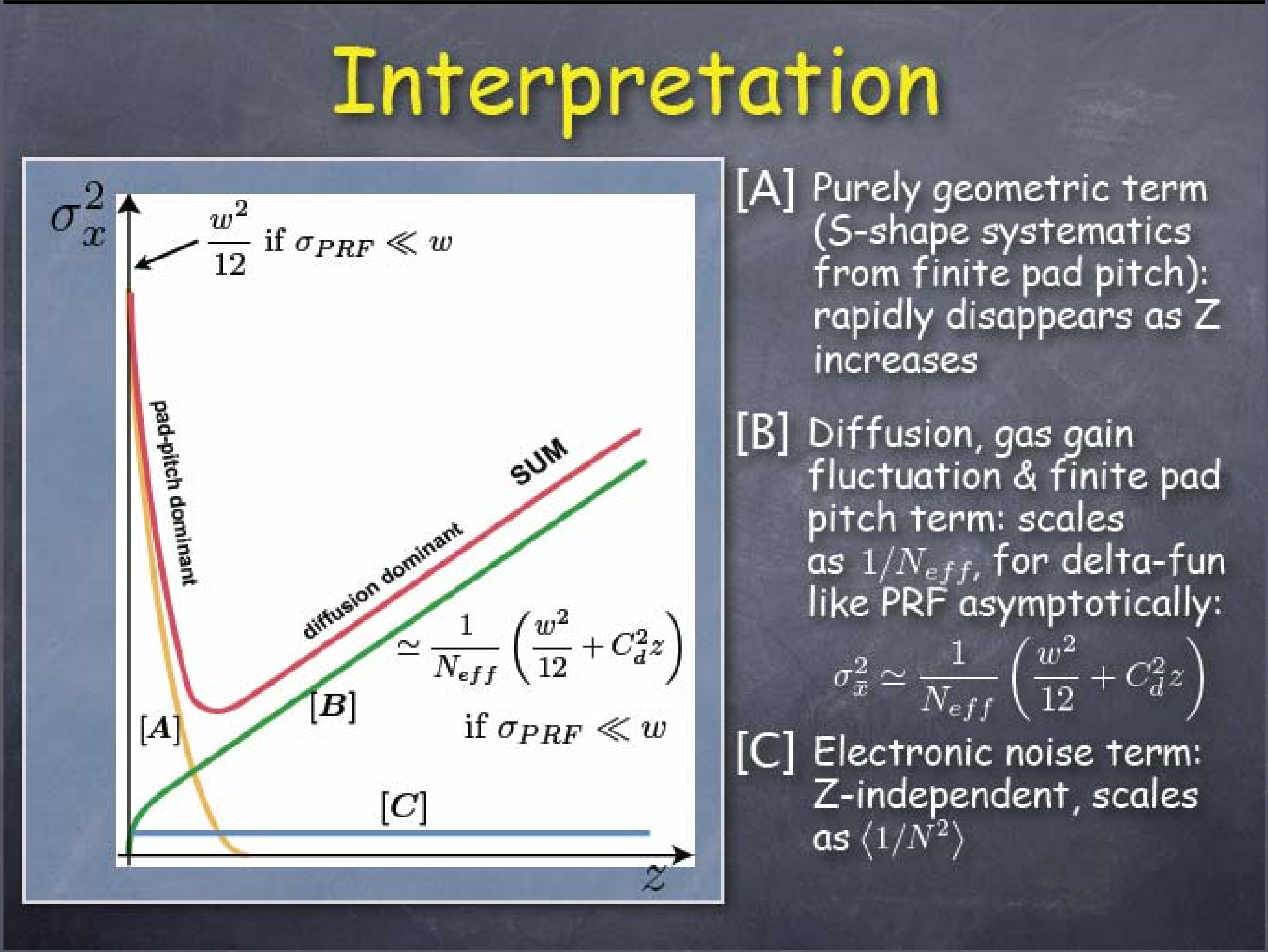
$$\langle f_j(\tilde{x}+\Delta x) f_k(\tilde{x}+\Delta x)\rangle \equiv \int d\Delta x P_D(\Delta x;\sigma_d)\, f_j(\tilde{x}+\Delta x)\, f_k(\tilde{x}+\Delta x)$$

$$\langle f_j(\tilde{x}+\Delta x)\rangle \equiv \int d\Delta x P_D(\Delta x;\sigma_d)\, f_j(\tilde{x}+\Delta x)$$

- Electronic noise term

$$[C] = \left(\frac{\sigma_E}{\bar{G}}\right)^2 \left\langle \frac{1}{N^2}\right\rangle \sum_j (jw)^2$$

Point Resolution: Analytic Formula



Interpretation

[A] Purely geometric term (S-shape systematics from finite pad pitch): rapidly disappears as Z increases

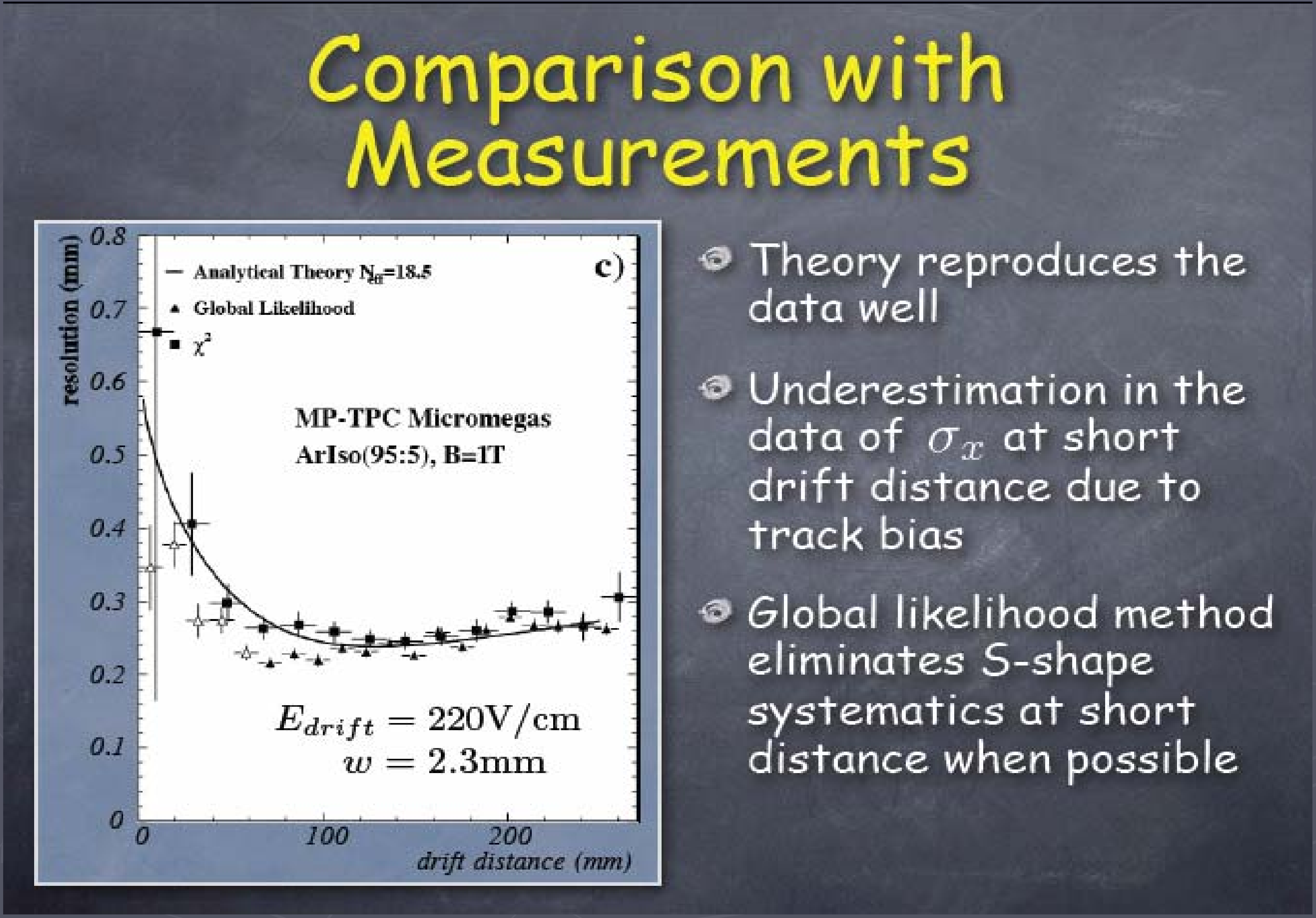
[B] Diffusion, gas gain fluctuation & finite pad pitch term: scales as $1/N_{eff}$, for delta-fun like PRF asymptotically:

$$\sigma_{\bar{x}}^2 \simeq \frac{1}{N_{eff}}\left(\frac{w^2}{12}+C_d^2 z\right)$$

[C] Electronic noise term: Z-independent, scales as $\langle 1/N^2 \rangle$

Point Resolution

Comparison with the MP-TPC Beam Test (MicroMEGAS)

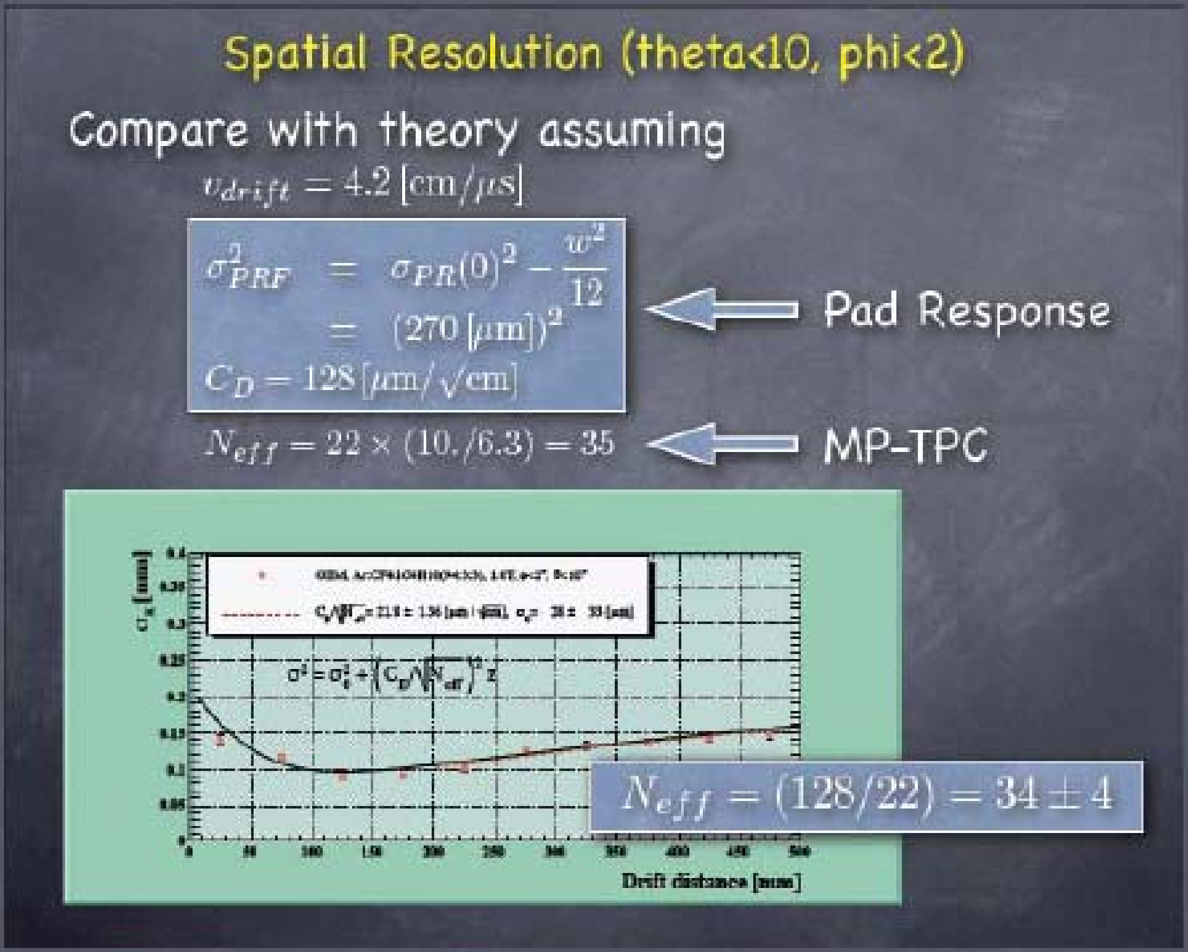


Comparison with Measurements

- Theory reproduces the data well
- Underestimation in the data of σ_x at short drift distance due to track bias
- Global likelihood method eliminates S-shape systematics at short distance when possible

Point Resolution
Comparison with the TU-TPC Cosmic Test (GEM)

A Preliminary Result
TU–TPC Cosmic Ray Test at KEK
Dec. 2007



Spatial Resolution (theta<10, phi<2)

Compare with theory assuming

$v_{drift} = 4.2\,[\mathrm{cm}/\mu\mathrm{s}]$

$$\begin{aligned}\sigma^2_{PRF} &= \sigma_{PR}(0)^2 - \frac{w^2}{12}\\ &= (270\,[\mu\mathrm{m}])^2\end{aligned}$$

$C_D = 128\,[\mu\mathrm{m}/\sqrt{\mathrm{cm}}]$ ⟸ Pad Response

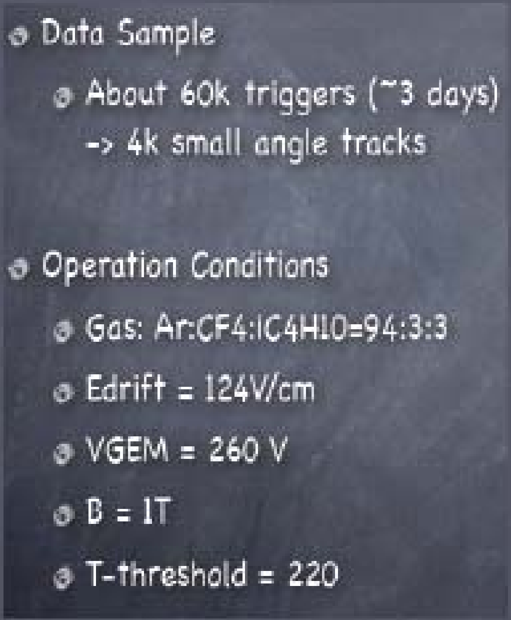
$N_{eff} = 22 \times (10./6.3) = 35$ ⟸ MP-TPC

$\sigma^2 = \sigma_0^2 + \left(C_D/\sqrt{N_{eff}}\right)^2 z$

$N_{eff} = (128/22) = 34 \pm 4$

3 Layers of GEM

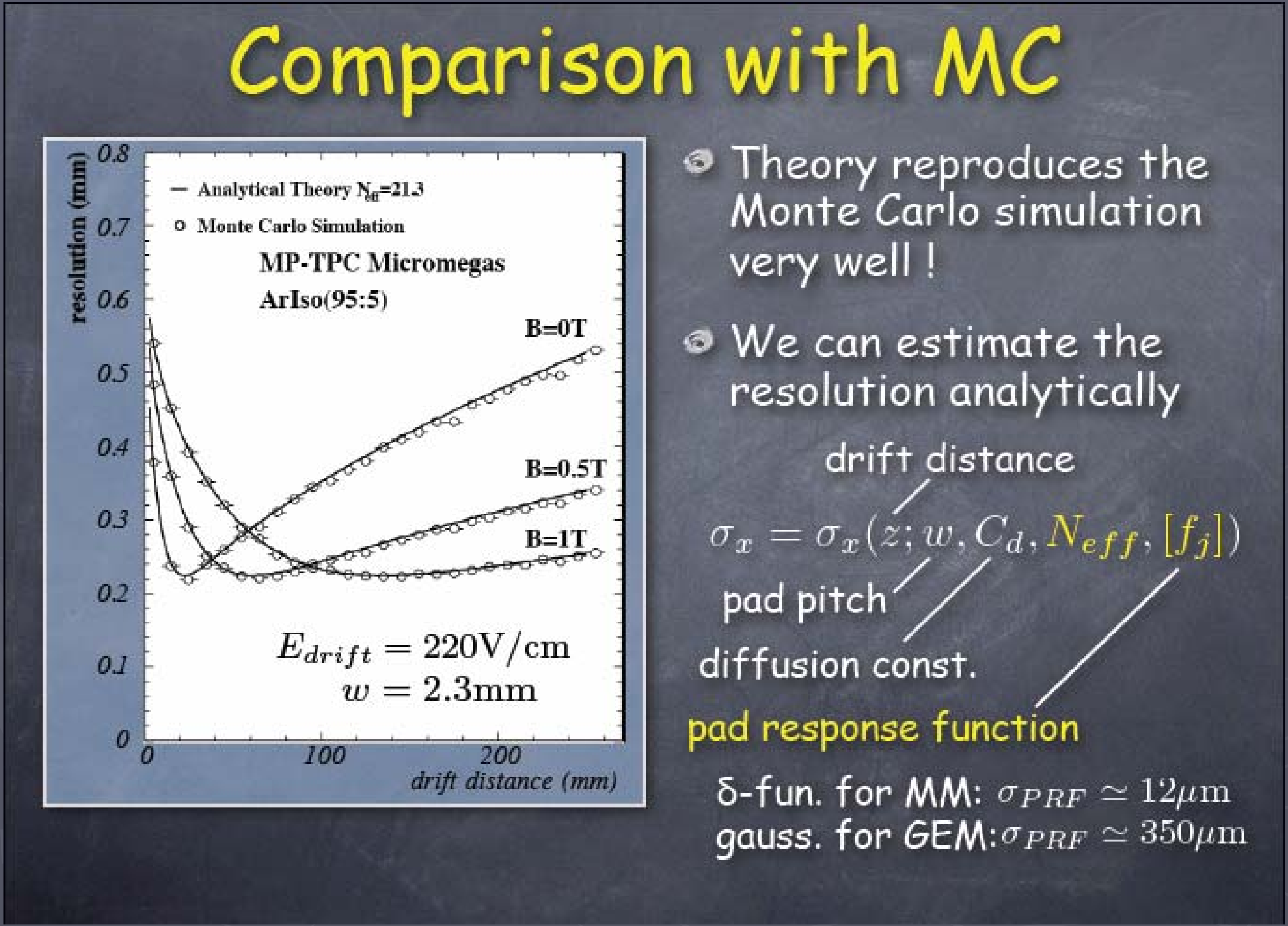
Pads: 1 x 10 mm



- Data Sample
  - About 60k triggers (~3 days) -> 4k small angle tracks
- Operation Conditions
  - Gas: Ar:CF4:IC4H10=94:3:3
  - Edrift = 124V/cm
  - VGEM = 260 V
  - B = 1T
  - T-threshold = 220

Point Resolution

MC by Makoto Kobayashi



Comparison with MC

- Theory reproduces the Monte Carlo simulation very well !
- We can estimate the resolution analytically

drift distance

$$\sigma_x = \sigma_x(z; w, C_d, N_{eff}, [f_j])$$

pad pitch

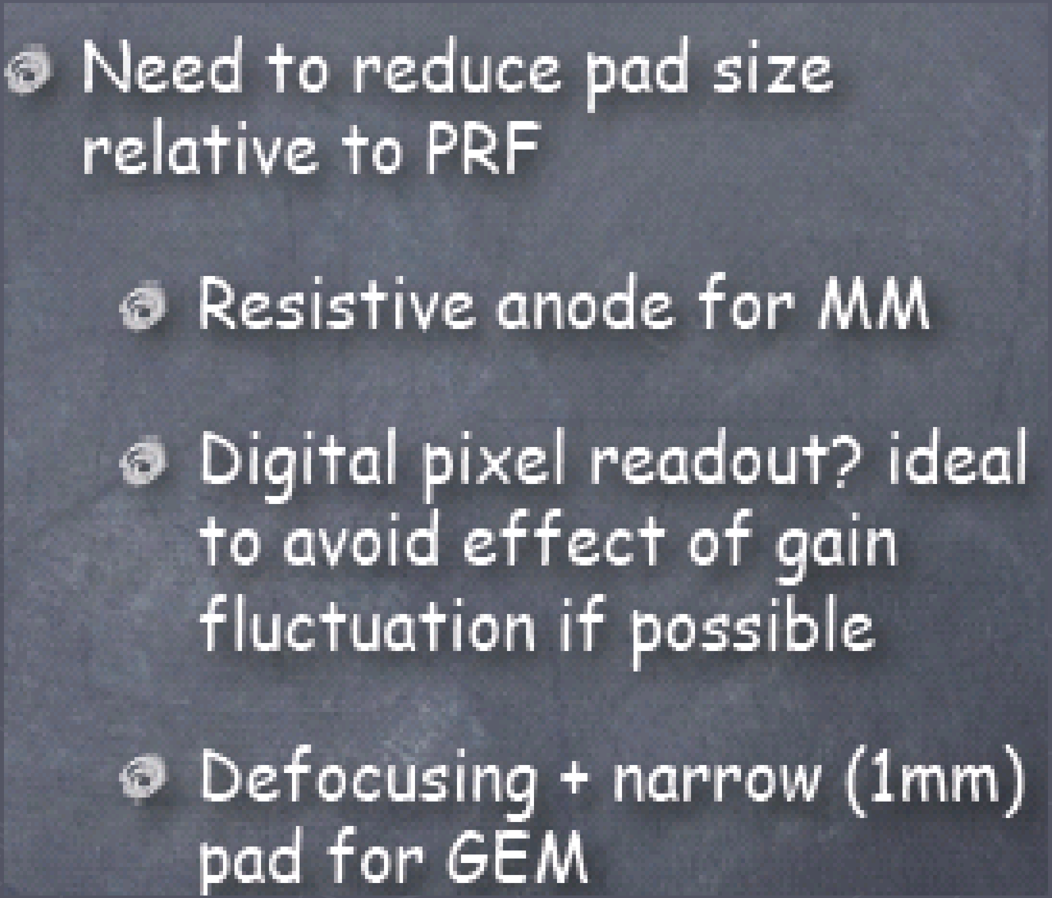
diffusion const.

pad response function

δ-fun. for MM: $\sigma_{PRF} \simeq 12\mu\mathrm{m}$

gauss. for GEM: $\sigma_{PRF} \simeq 350\mu\mathrm{m}$

Point Resolution: Three Possible Options of TPC End-Detector



- Need to reduce pad size relative to PRF
  - Resistive anode for MM
  - Digital pixel readout? ideal to avoid effect of gain fluctuation if possible
  - Defocusing + narrow (1mm) pad for GEM

Gas for ILC TPC

Low diffusion at high magnetic field (large $\omega \tau$).

- Sufficient primary electrons.
- Small electron attachment.
  - (the drift region and the amplification region)
- Reasonable drift velocity at an acceptable drift field.
- Gating condition (when we use the GEM gating).
- Neutron background with less or no hydrogen (quencher)
- Stable operation of MPGD.
- Long term stability of TPC (aging and corrosion)

Some works underway

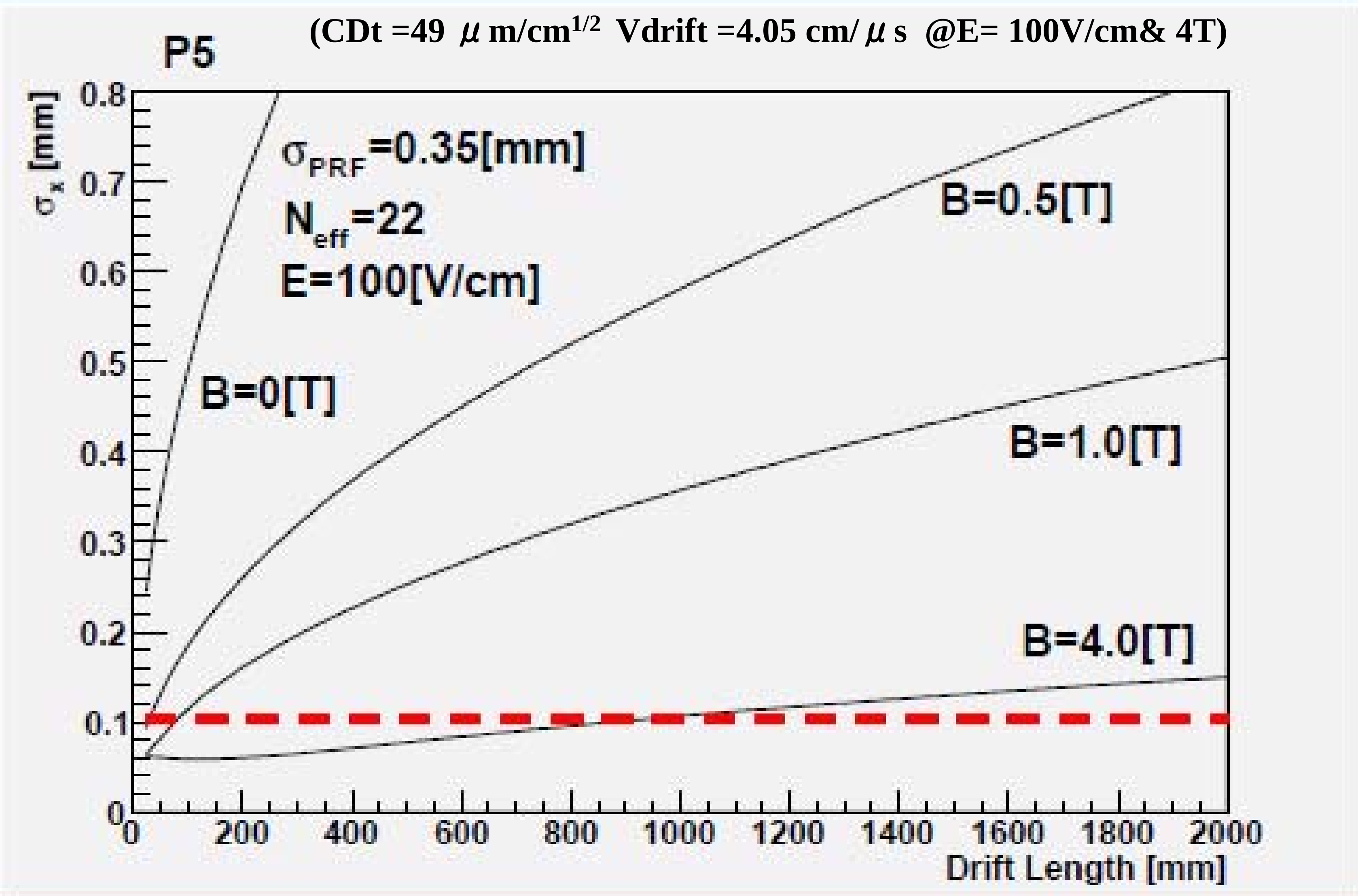
- The intensive gas (gain) study for MicroMEGAS (Saclay)
- A Ar/CF_4 gas study for GEM (the CDC group)
- (May be more)

Point Resolution $\sigma_{r\phi}(z)$: P5 (E=100V/cm)

Extrapolation to ILD TPC

K. Fujii

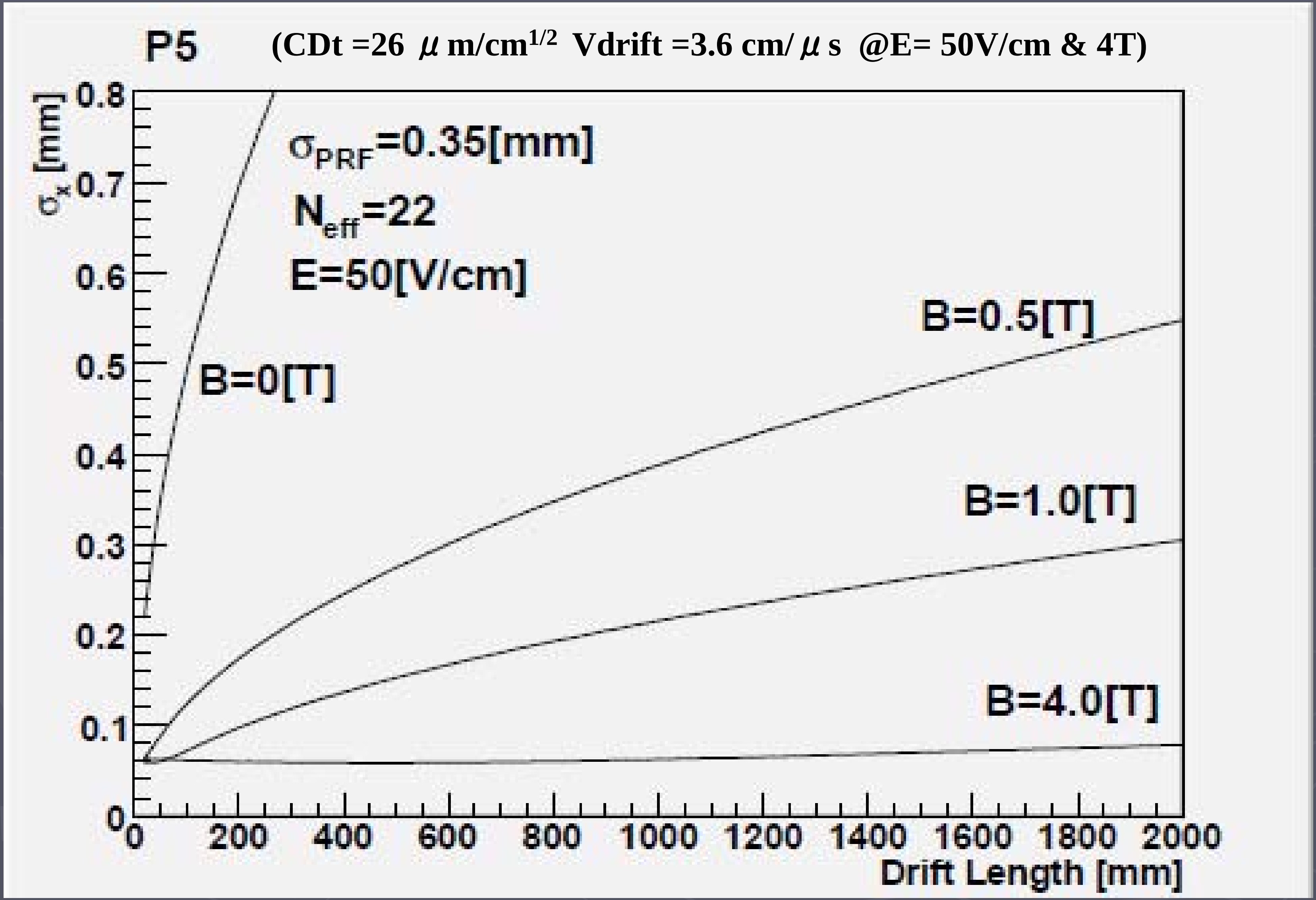
(CDt =49 μm/cm$^{1/2}$ Vdrift =4.05 cm/μs @E= 100V/cm& 4T)



Point Resolution $\sigma_{r\phi}(z)$: P5 (E=50 V/cm)

Extrapolation to ILD TPC

K. Fujii



Point Resolution: Ar/CF4/isoC4H10 (E=200V/cm)

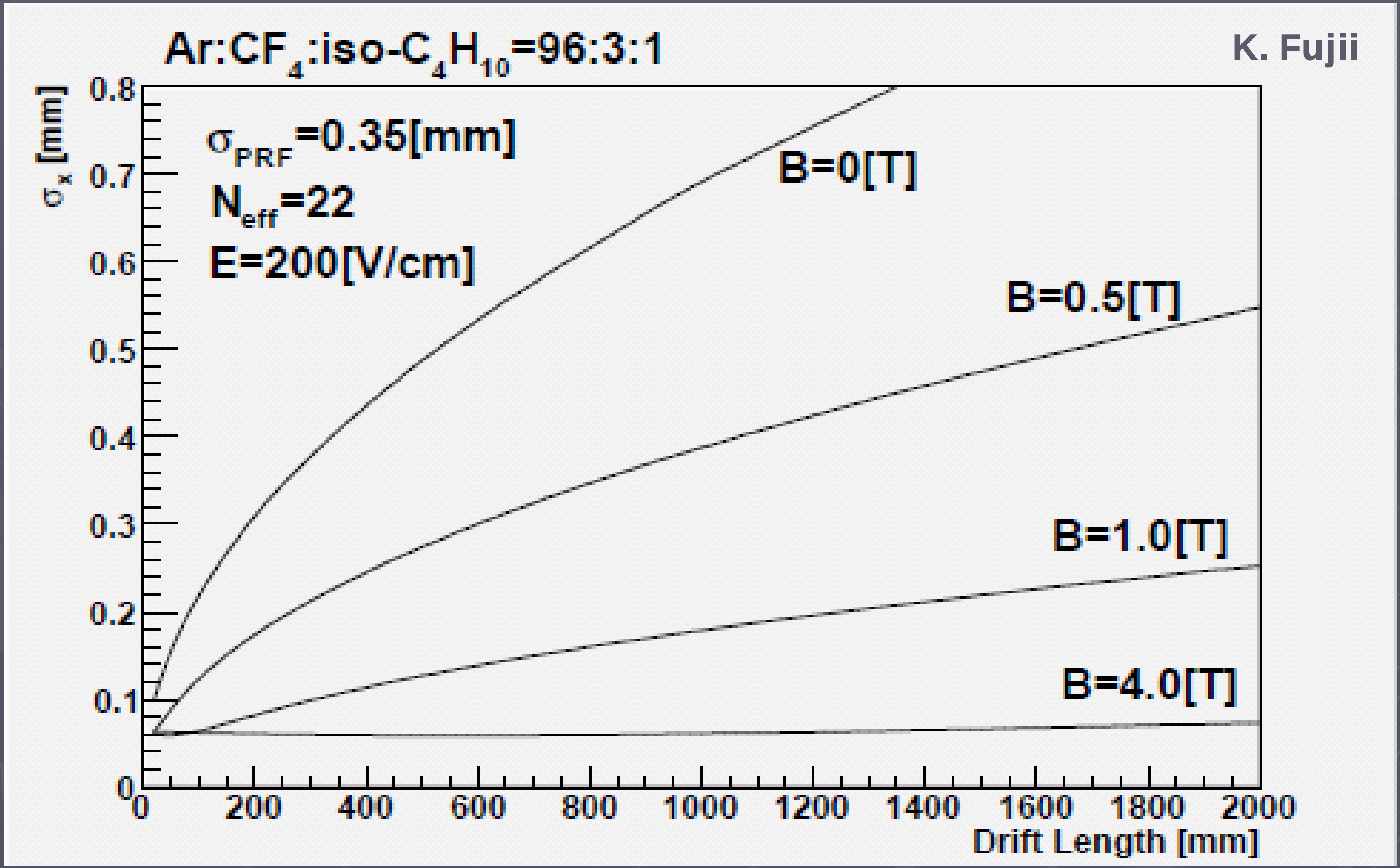
(Extrapolation to ILD TPC)

C_{Dt} = 24 μm/cm$^{1/2}$

V_{drift} = 7.8 cm/μs

@E= 200V/cm & 4T

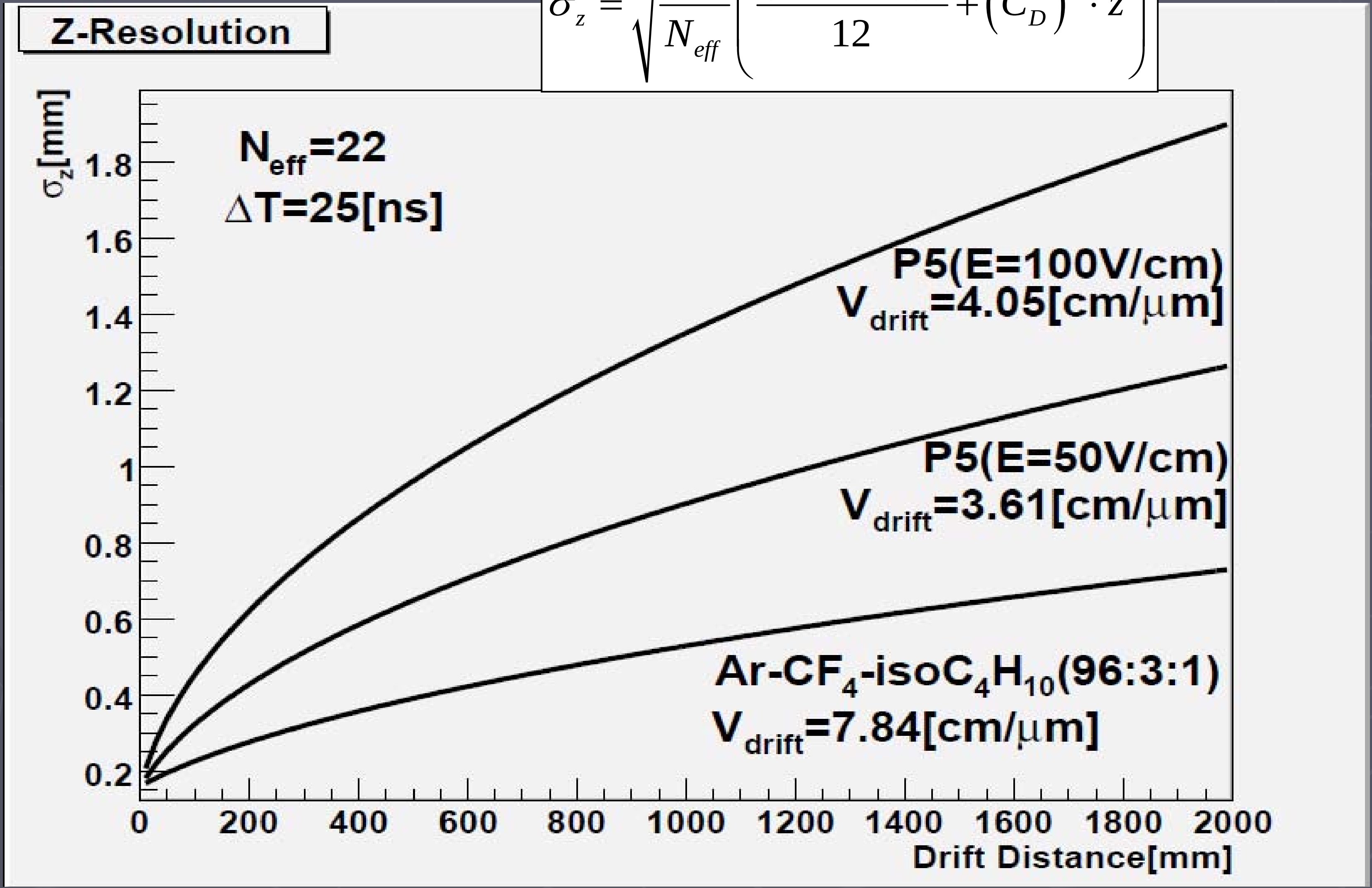
Measured Cd seem to larger than the Magboltz simulation at higher E? Need to confirm.



Point Resolution σz (z)
A naïve estimation

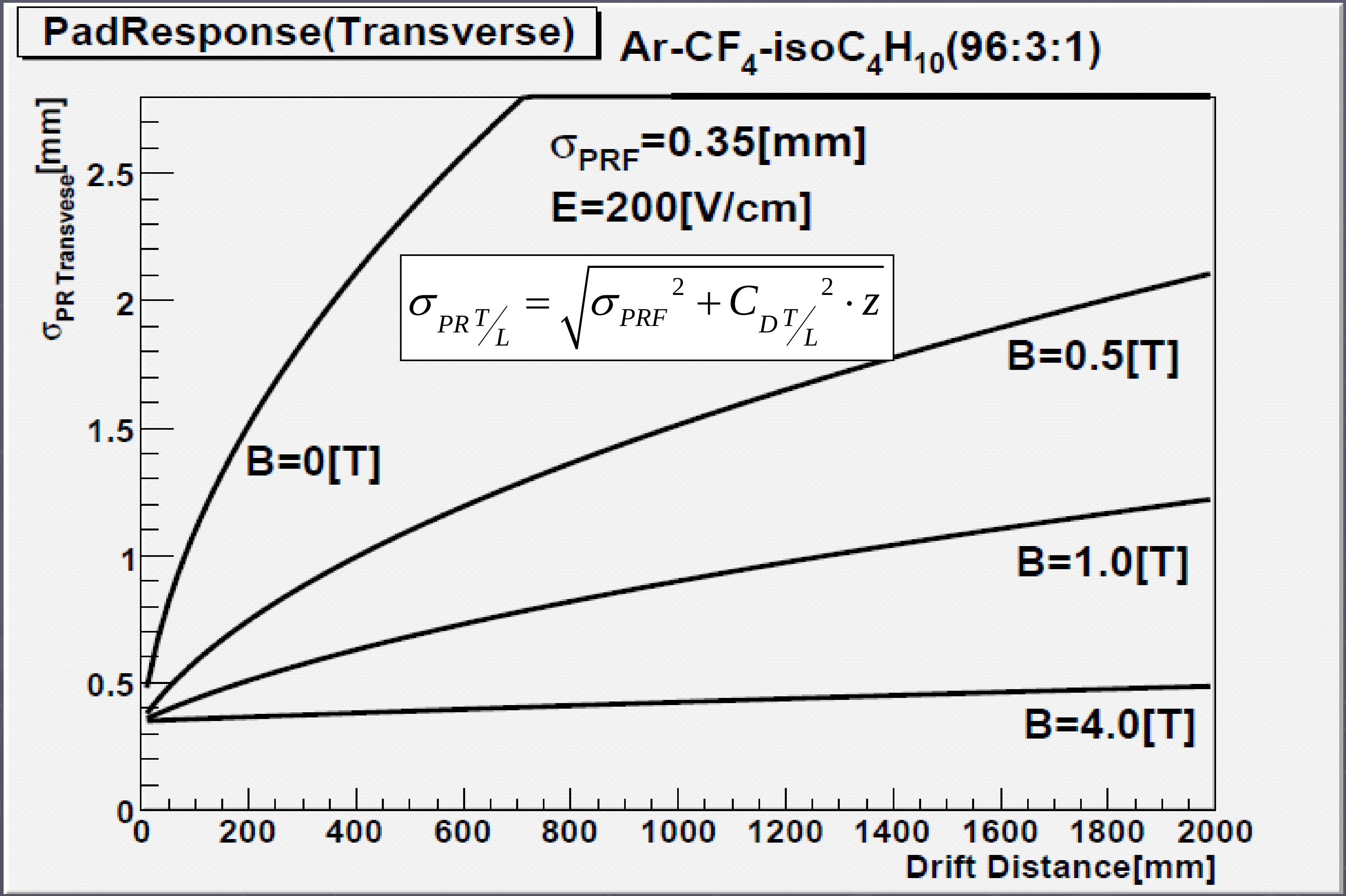
R. Yonamine

$$\sigma_z = \sqrt{\frac{1}{N_{eff}}\left(\frac{\left(\Delta T \cdot v_{drift}\right)^2}{12} + \left(C_D^L\right)^2 \cdot z\right)}$$



A measure for the Two Track resolution: Pad Response (rϕ)

R. Yonamine



Pad Size and No. of Measurement Points (Analog Readout)

Most Probably:

		(width)	(length)
Pad size:	Gem + normal pads	1 mm x	4 - 6 mm
	MicroMEGAS + Resistive anode	3 mm x	4 - 6 mm

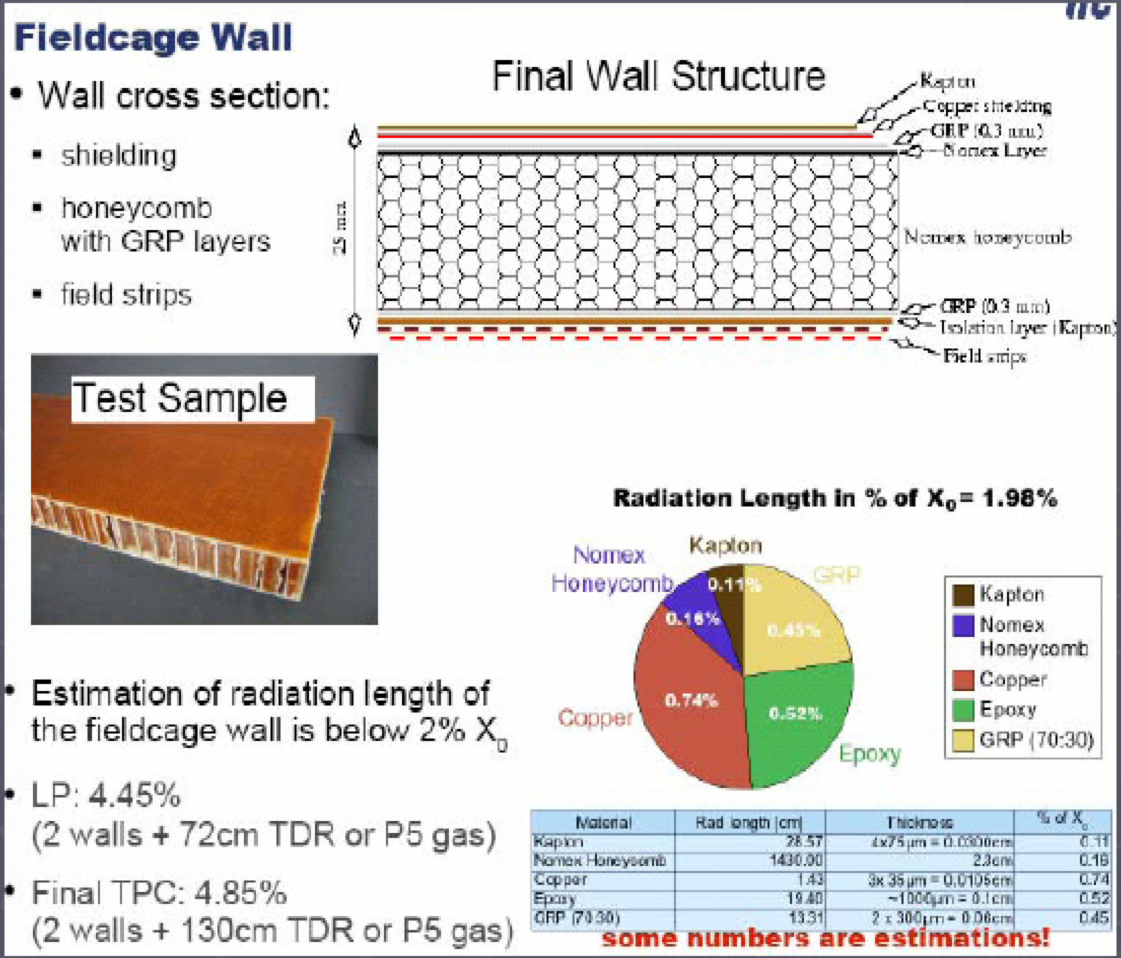
No. of pad rows: $0.9 \times (R_{max/TPC} - R_{min/TPC}) / \text{pad length}$

0.9 ← A very crude estimation for the insensitive region in R such as the boundaries of the MPGD end-detector boundaries, the field cages, etc.

Gas container & Field Cage: Thickness

Large Prototype (D = 80 cm)
25 mmt & 2% X_0

Alice (4 m)
30 mmt & 3% X_0



Fieldcage Wall

- Wall cross section:
  - shielding
  - honeycomb with GRP layers
  - field strips

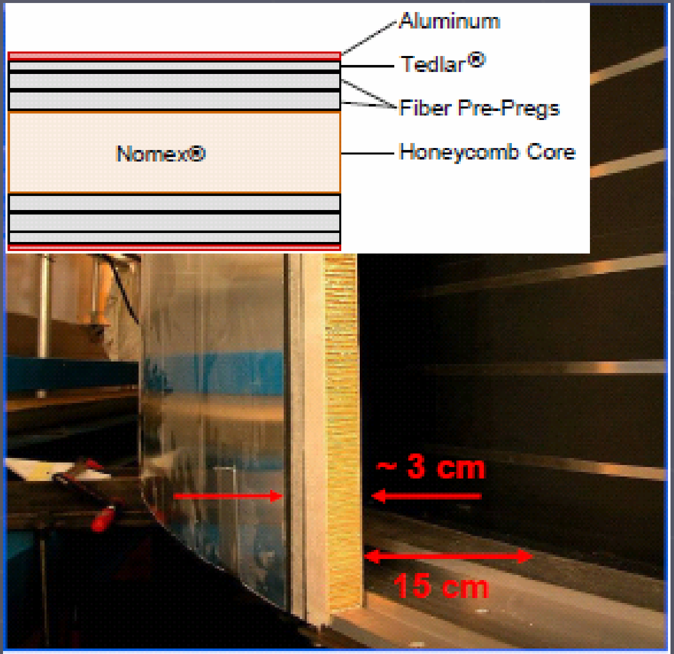
Final Wall Structure

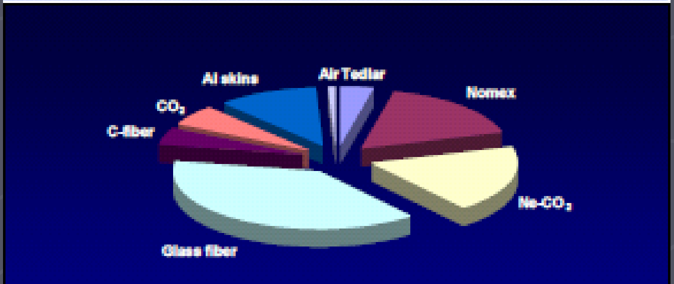
- Estimation of radiation length of the fieldcage wall is below 2% X_0
- LP: 4.45% (2 walls + 72cm TDR or P5 gas)
- Final TPC: 4.85% (2 walls + 130cm TDR or P5 gas)

Radiation Length in % of X_0= 1.98%

Material	Rad length [cm]	Thickness	% of X_0
Kapton	28.57	4x75 µm = 0.0300cm	0.11
Nomex Honeycomb	1430.00	2.3cm	0.16
Copper	1.43	3x 35 µm = 0.0105cm	0.74
Epoxy	19.40	~1000µm = 0.1cm	0.52
GRP (70:30)	13.31	2 x 300µm = 0.06cm	0.45

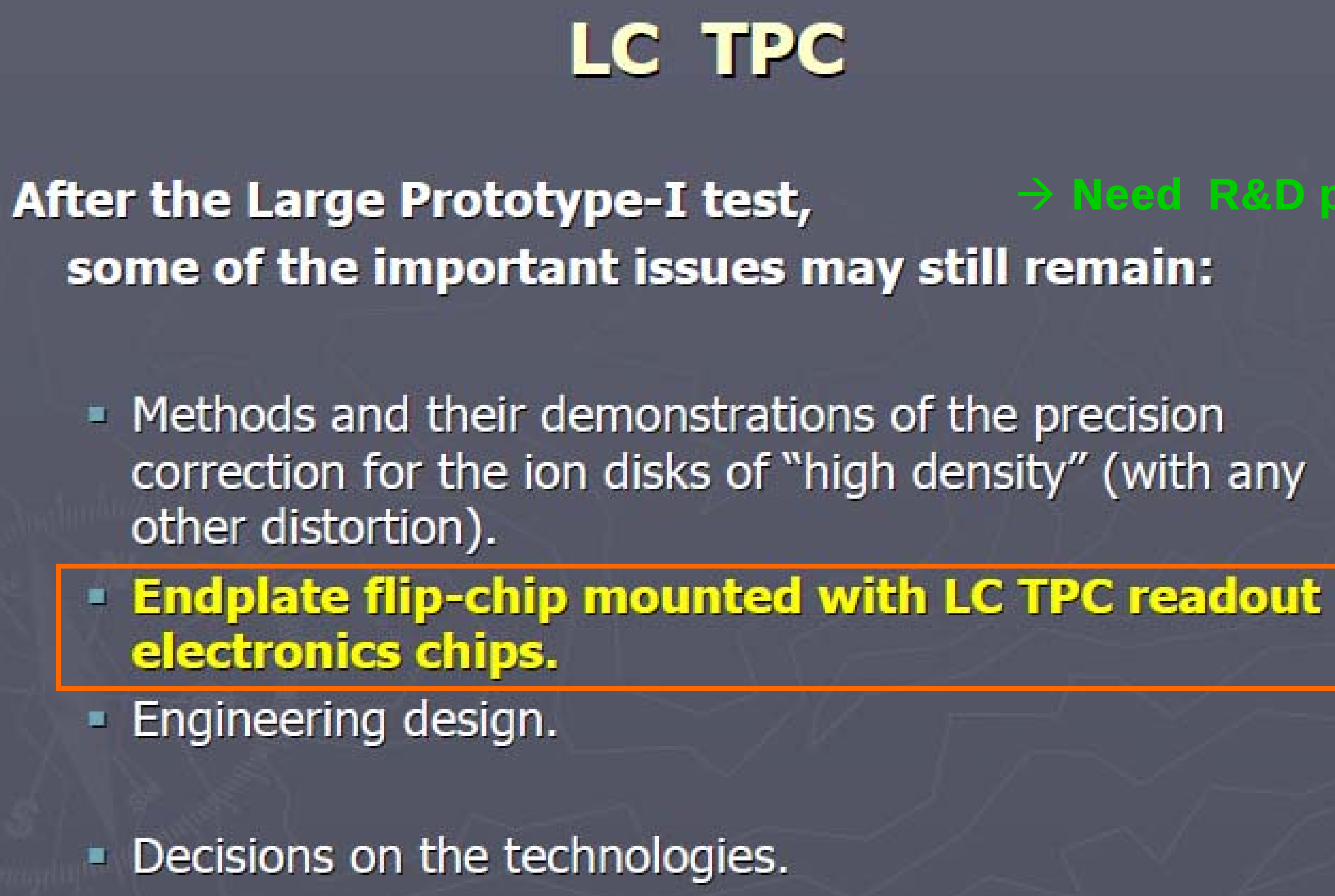
some numbers are estimations!





Total x/x_0 ~ 3% radiation length at $\eta = 0$

TPC Endplate



LC TPC

After the Large Prototype-I test,
some of the important issues may still remain:

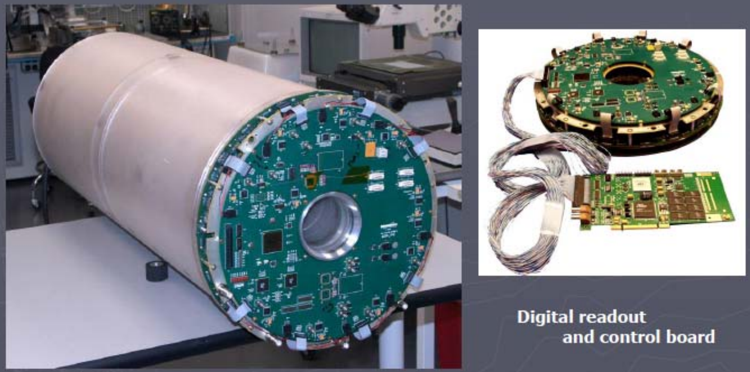
→ Need R&D plans

- Methods and their demonstrations of the precision correction for the ion disks of "high density" (with any other distortion).
- **Endplate flip-chip mounted with LC TPC readout electronics chips.**
- Engineering design.
- Decisions on the technologies.

ALEPH: 25% X0 & 25 cm
→ ILC TPC: 10-15% X0 & 10-15cm ?

Endplate: Thickness & Space to Cal

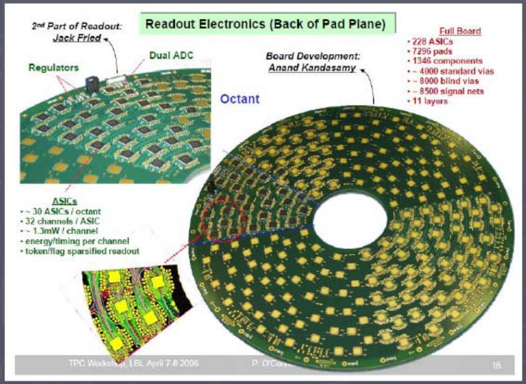
LEGS TPC



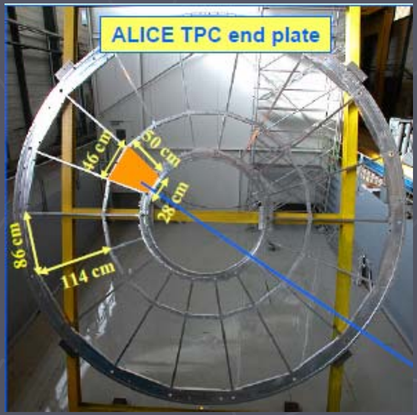
Digital readout
and control board

LEGS TPC

Direct Mount of Front-end Chips on the Back of the Pad Plane



Geronimo, J. Fried, A. Kandasamy, V. Radeka, & Bo Yu, TPC Application Workshop, LBl,



End-detector:

MWPC → MPGD (& SiTPC)

Electronics:

→ Custom Chips of the finer rules

→ Surface mount on the back of the pad plane

→ High speed optical link

But still the "old" issues:

Power cables

Cooling

Endplate structure (Mechanical)

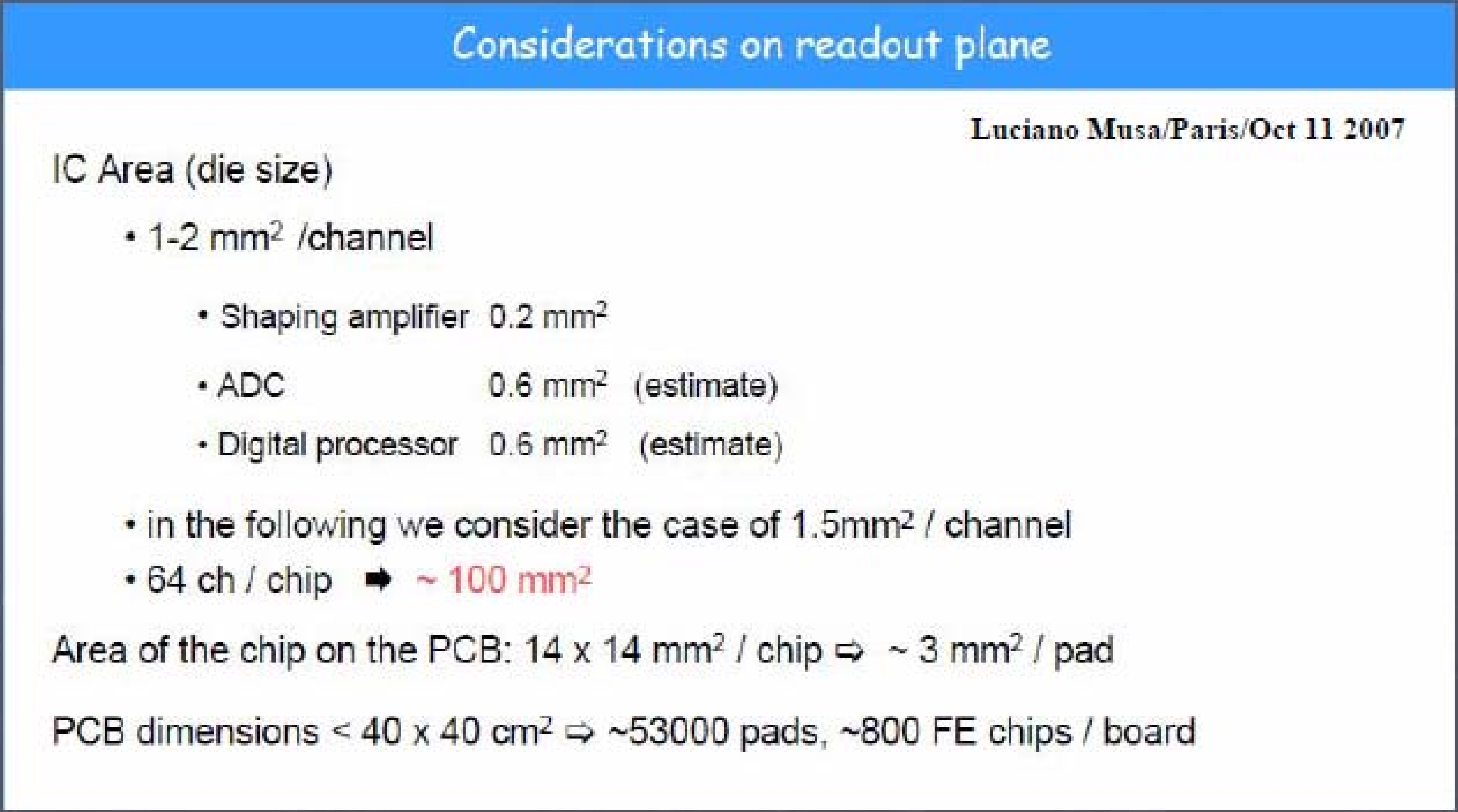
Wire bonding @LEGS TPC
→ Bump bonding @ ILD TPC

Al → Be, CFRP or a lighter material @ILD TPC

Advanced Endplate: LC TPC Electronics

The IC area (die size) is small enough for the direct mounting on the endplate (Luciano) .

(the General purpose charge readout chip)



Considerations on readout plane

Luciano Musa/Paris/Oct 11 2007

IC Area (die size)

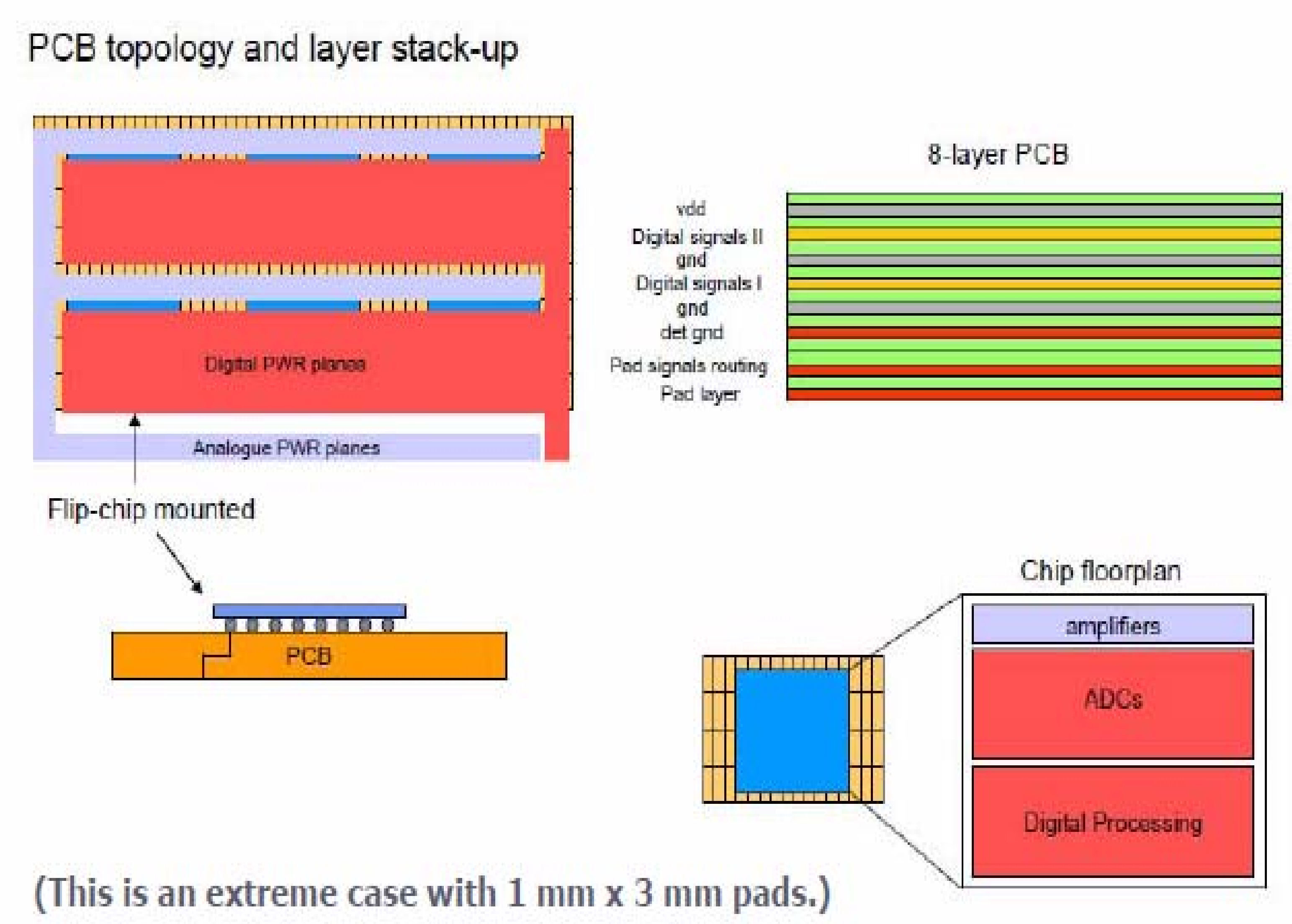
- 1-2 mm^2 /channel
  - Shaping amplifier 0.2 mm^2
  - ADC 0.6 mm^2 (estimate)
  - Digital processor 0.6 mm^2 (estimate)
- in the following we consider the case of 1.5mm^2 / channel
- 64 ch / chip ➡ ~ 100 mm^2

Area of the chip on the PCB: 14 x 14 mm^2 / chip ⇨ ~ 3 mm^2 / pad

PCB dimensions < 40 x 40 cm^2 ⇨ ~53000 pads, ~800 FE chips / board

Advanced Endplate: Surface Mounting Electronics

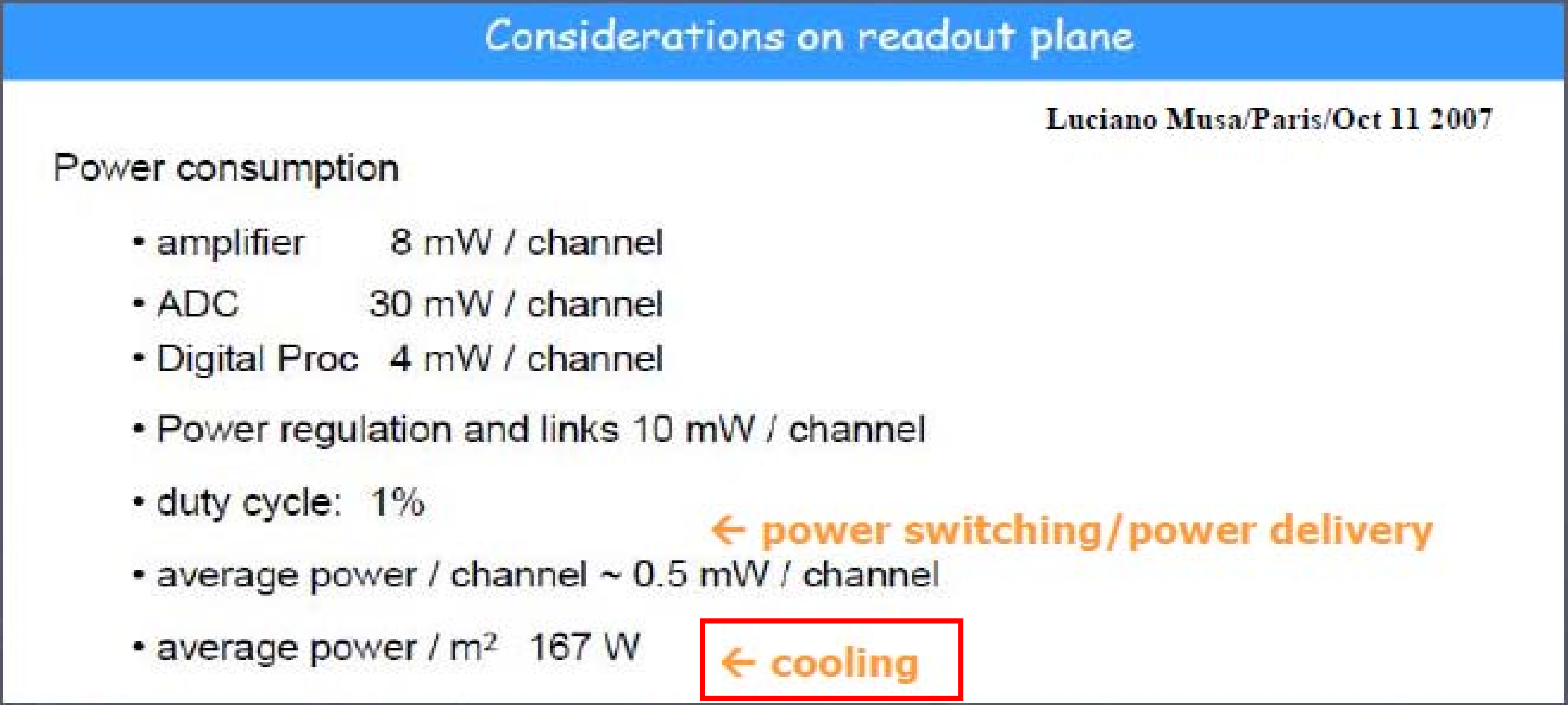
Luciano Musa



PCB topology and layer stack-up

(This is an extreme case with 1 mm x 3 mm pads.)

Advanced Endplate: Electronics



Considerations on readout plane

Luciano Musa/Paris/Oct 11 2007

Power consumption

- amplifier 8 mW / channel
- ADC 30 mW / channel
- Digital Proc 4 mW / channel
- Power regulation and links 10 mW / channel
- duty cycle: 1%

← **power switching/power delivery**

- average power / channel ~ 0.5 mW / channel
- average power / m^2 167 W

← **cooling**

- **The power delivery network with capacitors has to be examined to avoid the large transient spikes to destroy the front-end electronics (See the slides by Luciano).**
- **The cooling: Is air enough? May need special structures of the PCB board to prevent the heat goes into the TPC gas volume via bumps? In the case of accidents (Failure of the power cycling, latch up etc?**

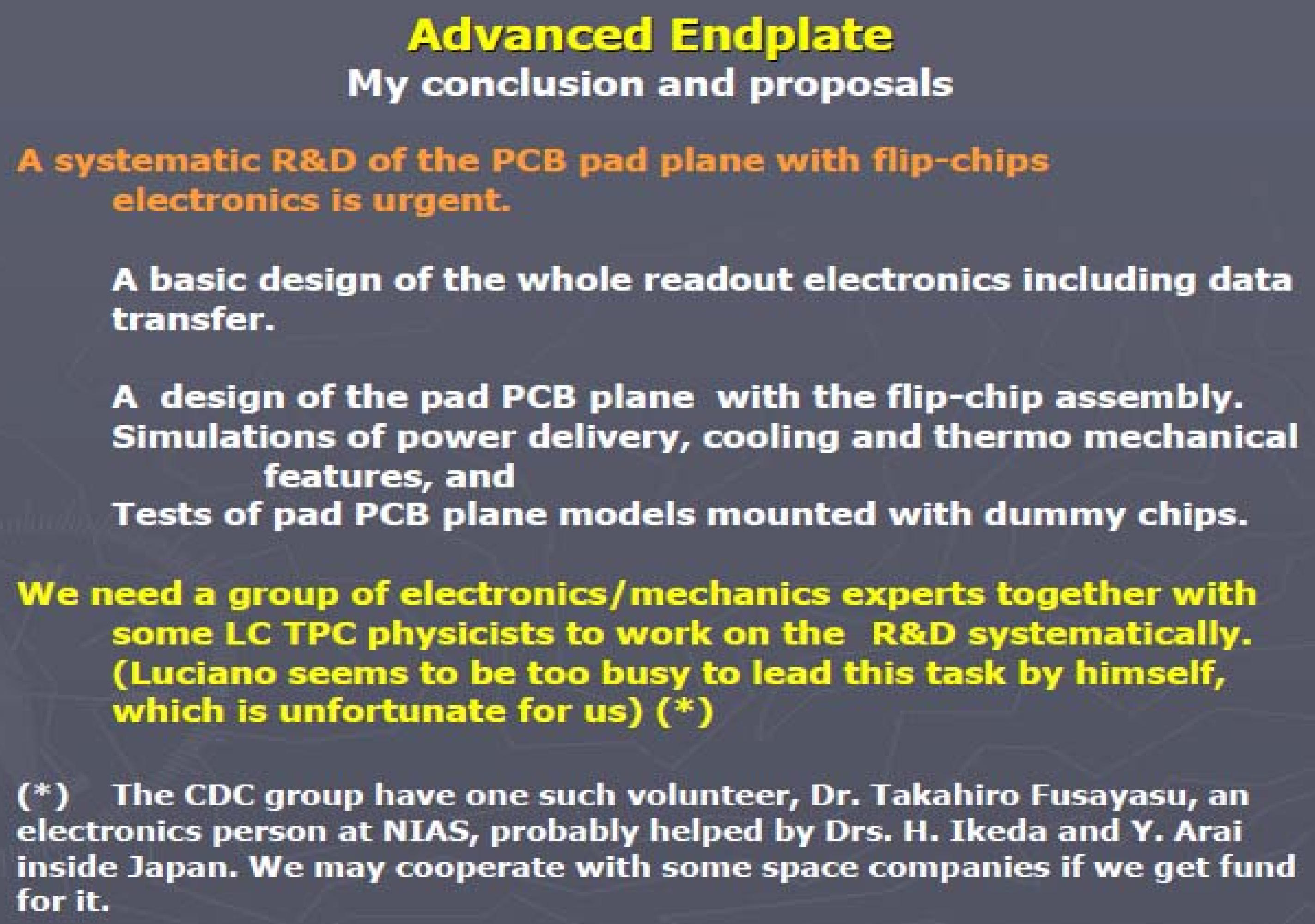
Material Thickness: TPC Endplate

My guess

Thickness (radiation thickness):

Pad plane:				
G10	X0 = 19.4cm	0.5cm	→	3 %
Cu	X0 = 1.43 cm	0.01cm	→	0.6 %
Chips(Si)	X0 = 9.36cm	0.5cm	→	0.5 %
Bumps				
Power cables and large electronics components				?
Endplate (mechanical)				
	X0 = 35.3	0.2 x 5cm	→	0.3 %
Cooling				?
Total				10-15 % ?

A Slide from the LC TPC meeting at ALCPG07



Advanced Endplate

My conclusion and proposals

A systematic R&D of the PCB pad plane with flip-chips electronics is urgent.

A basic design of the whole readout electronics including data transfer.

A design of the pad PCB plane with the flip-chip assembly.
Simulations of power delivery, cooling and thermo mechanical features, and
Tests of pad PCB plane models mounted with dummy chips.

We need a group of electronics/mechanics experts together with some LC TPC physicists to work on the R&D systematically. (Luciano seems to be too busy to lead this task by himself, which is unfortunate for us) (*)

(*) The CDC group have one such volunteer, Dr. Takahiro Fusayasu, an electronics person at NIAS, probably helped by Drs. H. Ikeda and Y. Arai inside Japan. We may cooperate with some space companies if we get fund for it.

Conclusion

(No time, Sorry!)