Comparison of available measurements of the absolute air-fluorescence yield*

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*J. Rosado *et al.*, *Astropart. Phys.* 34 (2010) 164

Outline

1. Introduction
2. Normalization procedure
3. Monte Carlo analysis of experiments
4. Comparison of results

1. Introduction

1. Introduction: Motivation

- Comparison of absolute FY cannot be done directly in many occasions because:

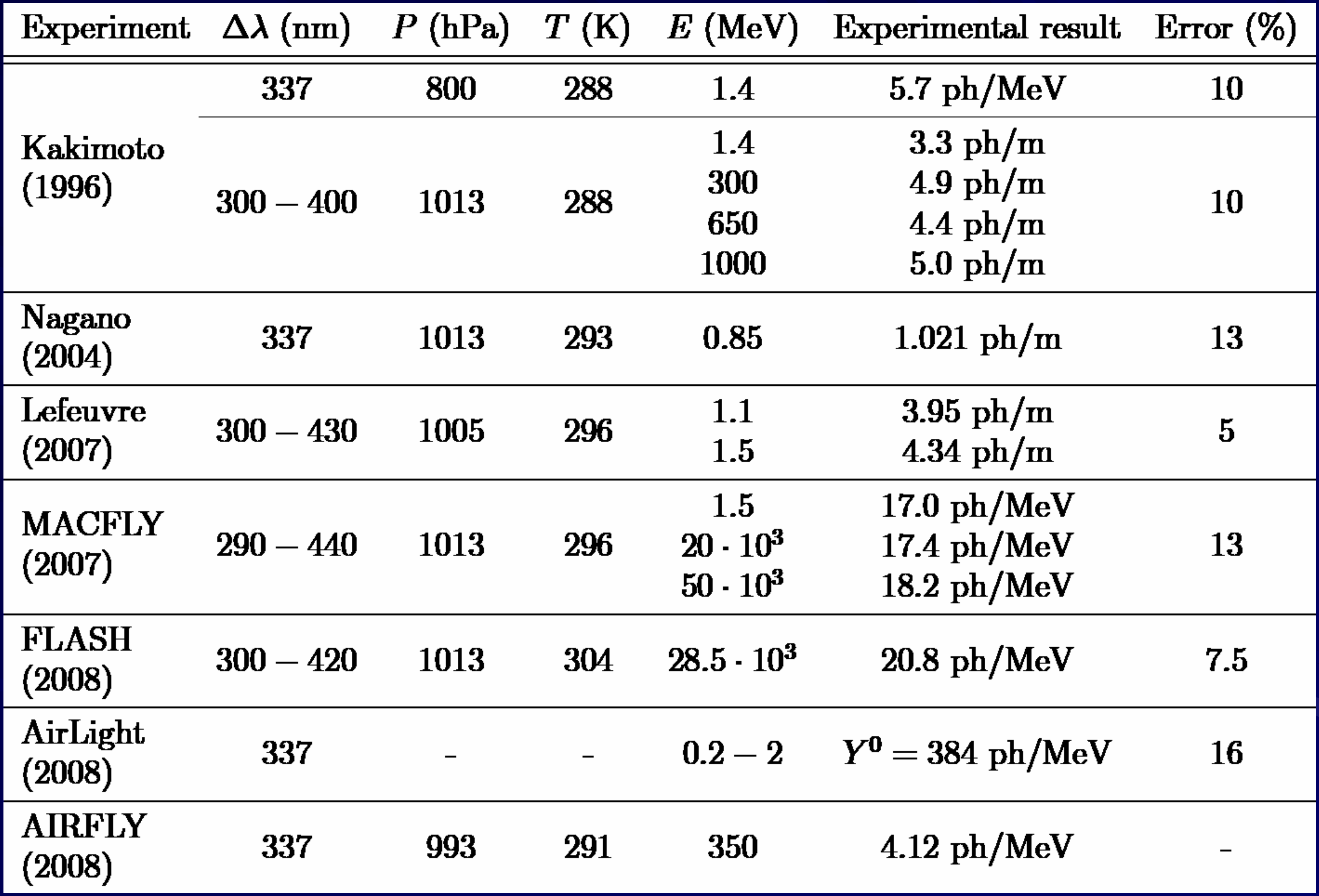
  a) Single bands vs wide spectral range

  b) Conversion from ph/m to ph/MeV depends on geometry: $(\mathrm{d}E/\mathrm{d}x)_{\mathrm{dep}}$

  c) Discrepancies in the P' parameters

1. Introduction: Motivation

Summary of FY results used in the comparison



Experiment	$\Delta\lambda$ (nm)	P (hPa)	T (K)	E (MeV)	Experimental result	Error (%)
Kakimoto (1996)	337	800	288	1.4	5.7 ph/MeV	10
	300 – 400	1013	288	1.4 300 650 1000	3.3 ph/m 4.9 ph/m 4.4 ph/m 5.0 ph/m	10
Nagano (2004)	337	1013	293	0.85	1.021 ph/m	13
Lefeuvre (2007)	300 – 430	1005	296	1.1 1.5	3.95 ph/m 4.34 ph/m	5
MACFLY (2007)	290 – 440	1013	296	1.5 $20 \cdot 10^3$ $50 \cdot 10^3$	17.0 ph/MeV 17.4 ph/MeV 18.2 ph/MeV	13
FLASH (2008)	300 – 420	1013	304	$28.5 \cdot 10^3$	20.8 ph/MeV	7.5
AirLight (2008)	337	-	-	0.2 – 2	$Y^0 = 384$ ph/MeV	16
AIRFLY (2008)	337	993	291	350	4.12 ph/MeV	-

1. Introduction: Objectives

- Comparison of results in ph/MeV normalized to the 2P(0-0) band at 800 hPa and 293 K
- MC analysis of experiments including geometrical features for comparison with calculations of the authors and to propose corrections to the FY values

2. Normalization procedure

2. Normalization procedure: wavelength reduction

- Measurements performed for a wide spectral range $\Delta\lambda$ are normalize to 337 nm

$$\mathrm{FY}_{337} = \mathrm{FY}_{\Delta\lambda} \frac{I_{337}}{I_{\Delta\lambda}}, \quad I_{\Delta\lambda} = \sum_{\Delta\lambda} I_{\lambda}$$

➡ Experimental relative intensities of AIRFLY[*] within 290 – 430 nm

[*] M. Ave *et al.*, *Astropart. Phys.*, 28 (2007) 41

2. Normalization procedure: wavelength reduction

- Relative intensities of AIRFLY follow (for bands belonging to the same system)[*]:

$$\frac{I_{vv'}}{I_{00}} = \frac{q_{X\to v}A_{vv'}}{q_{X\to 0}A_{00}}\,\frac{1+P/P'_0}{1+P/P'_v} \underset{\underset{P>>P'}{\uparrow}}{\approx} \frac{q_{X\to v}A_{vv'}}{q_{X\to 0}A_{00}}\,\frac{P'_v}{P'_0}$$

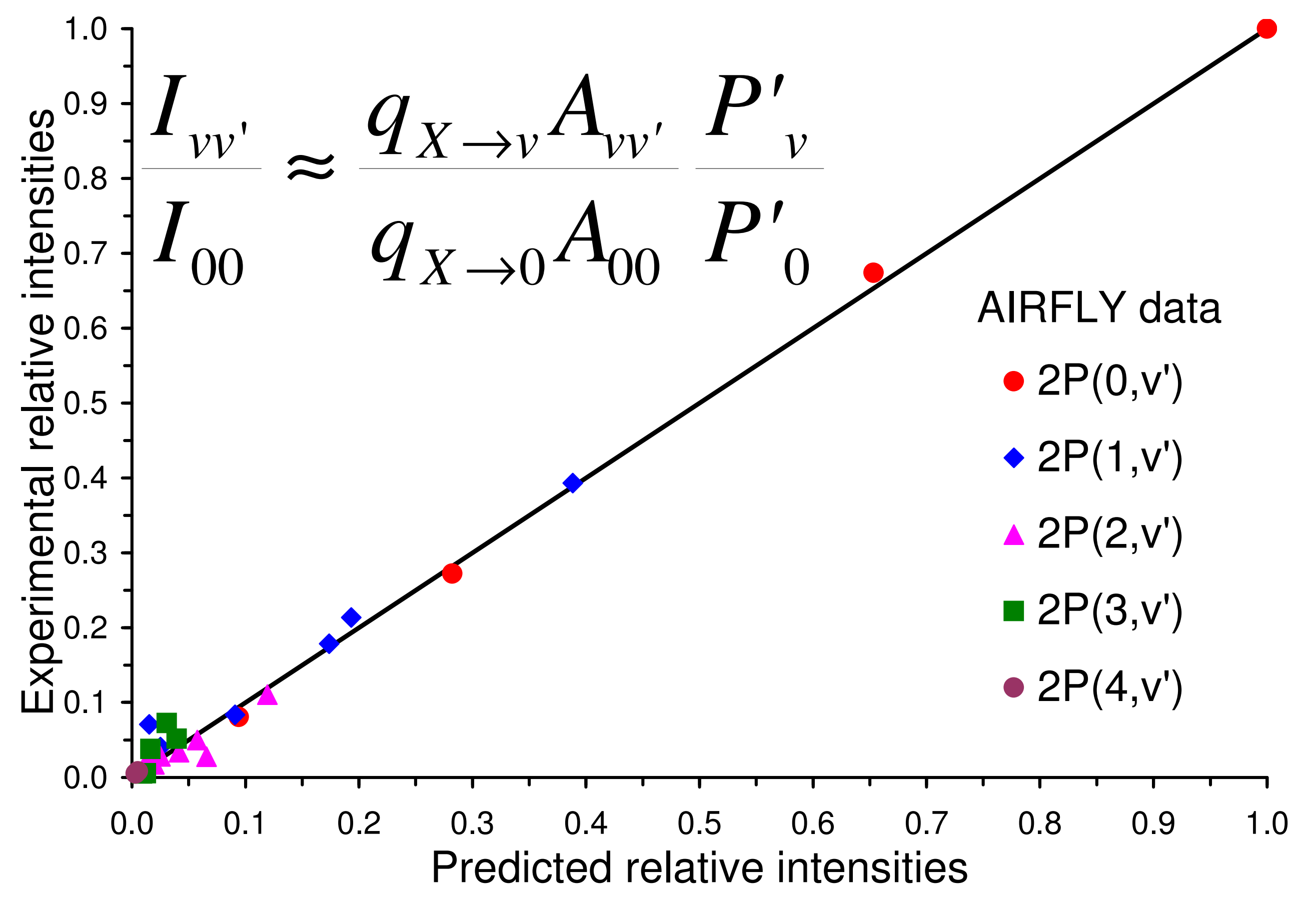
independent of P

➡ Fluorescence spectrum can be extended beyond the 290 – 430 nm spectral range

[*] F. Arqueros *et al.*, *NJP* 11 (2009) 065011

2. Normalization procedure: wavelength reduction

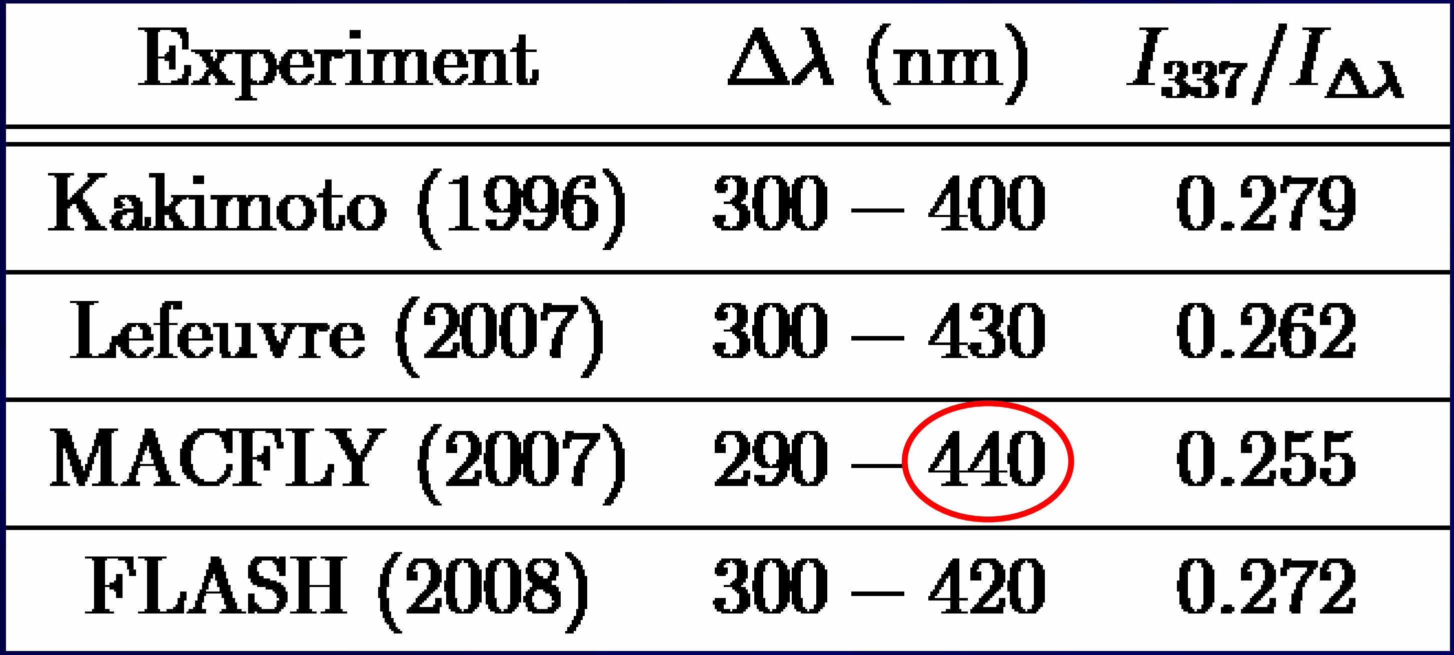
Comparison between experimental and predicted relative intensities



$$\frac{I_{vv'}}{I_{00}} \approx \frac{q_{X\to v} A_{vv'}}{q_{X\to 0} A_{00}} \frac{P'_v}{P'_0}$$

2. Normalization procedure: wavelength reduction

Results of the wavelength reduction



Experiment	$\Delta\lambda$ (nm)	$I_{337}/I_{\Delta\lambda}$
Kakimoto (1996)	$300-400$	0.279
Lefeuvre (2007)	$300-430$	0.262
MACFLY (2007)	$290-440$	0.255
FLASH (2008)	$300-420$	0.272

Two weak bands beyond the range of AIRFLY

2P(0-4) with $I \sim 2\% \; I_{337}$

2P(4-9) with $I \sim 0.2\% \; I_{337}$

2. Normalization procedure: units and geometry

- Conversion of ε (ph/m) to Y (ph/MeV)

$$Y = \frac{\varepsilon}{(\mathrm{d}E/\mathrm{d}x)_{\mathrm{dep}}}$$

where $(\mathrm{d}E/\mathrm{d}x)_{\mathrm{dep}}$ should be calculated for the observation volume of the experiment

- Some authors assume $(\mathrm{d}E/\mathrm{d}x)_{\mathrm{dep}} = (\mathrm{d}E/\mathrm{d}x)_{\mathrm{loss}}$

2. Normalization procedure: units and geometry

- A MC simulation including the microscopic molecular processes was carried out for each experiment:
  a) Energy deposition
  b) Geometrical factors
- Comparison with results reported by the authors

2. Normalization procedure: scaling

- Normalization to common P and T

  a) Pressure dependence:

$$Y = \frac{Y^0}{1+P/P'} \underset{\underset{P>>P'}{\uparrow}}{\approx} Y^0 \frac{P'}{P}$$

  a) Temperature dependence:

$$P' \sim T^{1/2}$$

2. Normalization procedure: scaling

- Scaling law nearly independent of *P*':

$$Y\left(800\ \mathrm{hPa},\ 293\ \mathrm{K}\right) \approx Y\left(P,T\right)\frac{P}{800}\sqrt{\frac{293}{T}}$$

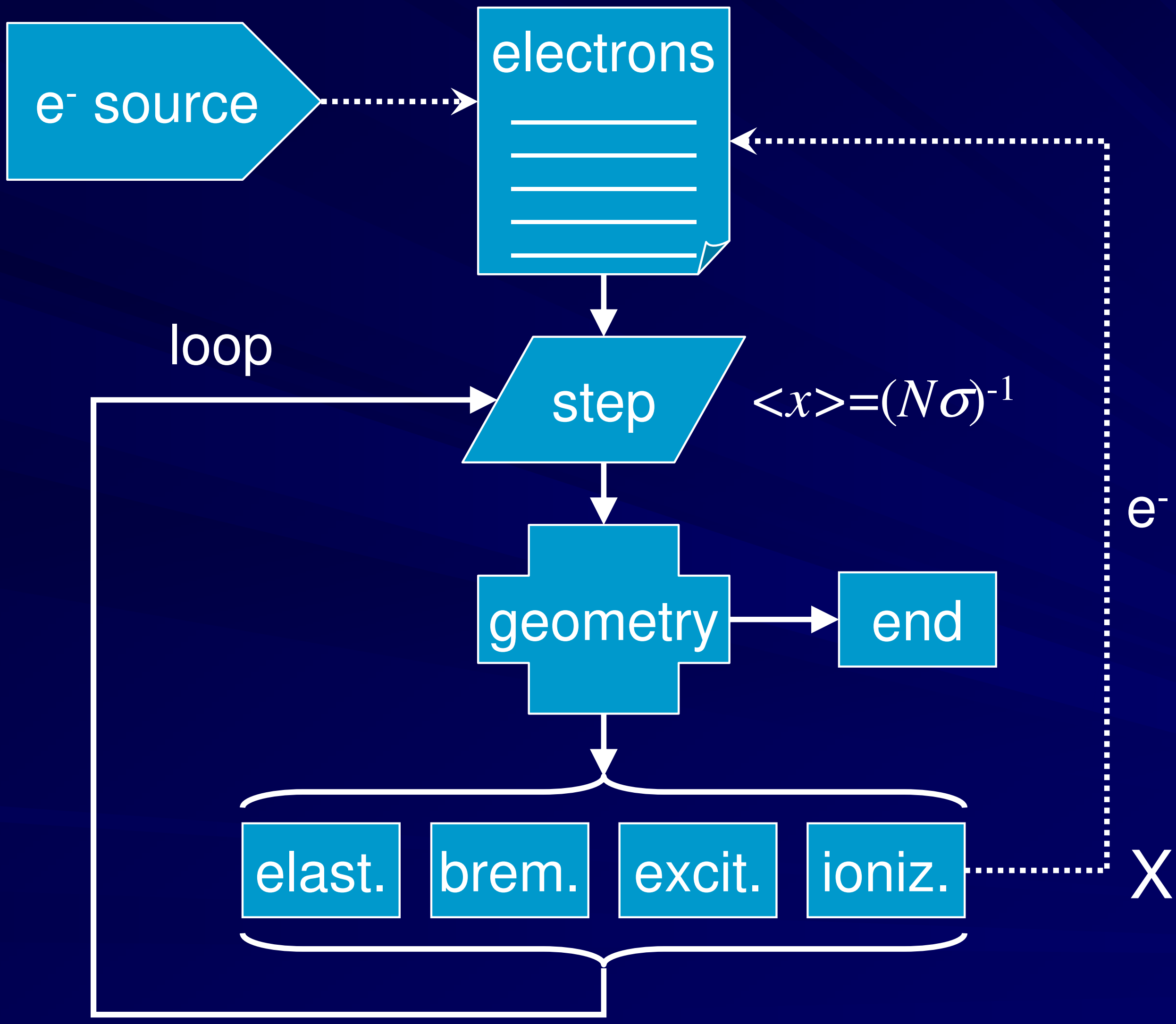
- Except for AirLight:

$$Y\left(800\ \mathrm{hPa},\ 293\ \mathrm{K}\right) = \frac{Y^{0}}{1+800/P'(293\ \mathrm{K})}$$

3. Monte Carlo analysis of experiments

3. MC analysis: basics

Layout of the simulation algorithm



Cutoff energy
of 11 eV !

Predictions of E_{dep}
and F. emission

X-rays also included

3. MC analysis: basics

- Simulation results:

a) Energy deposition

$$\left\langle \frac{\mathrm{d}E}{\mathrm{d}x} \right\rangle_{\mathrm{dep}} = \frac{\int_{\mathrm{vol}} E_{\mathrm{dep}}}{\int_{\mathrm{track}} x}$$

Primary electrons lose energy in collisions and have fluctuating trajectories

b) Geometrical acceptance (if possible)

$$\langle \Omega \rangle = \int_{\mathrm{vol}} \phi_{\mathrm{light}} \Omega$$

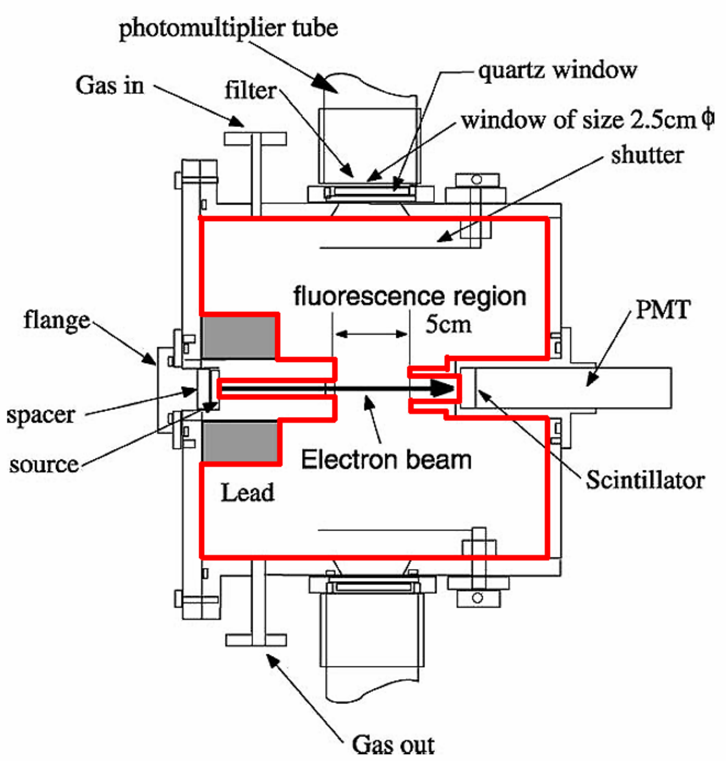
3. MC analysis: Nagano’s experiment

- Nagano *et al.*[*] made three assumptions:

  a) $\Delta x = \Delta x_{\mathrm{gap}}$

  b) $<\Omega> = <\Omega>_{\mathrm{beam}}$

  c) $(\mathrm{d}E/\mathrm{d}x)_{\mathrm{dep}} = (\mathrm{d}E/\mathrm{d}x)_{\mathrm{loss}}$



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[*] M. Nagano *et al.*, *Astropart. Phys.* 20 (2003) 293; M. Nagano *et al.*, *Astropart. Phys.* 22 (2004) 235

3. MC analysis: Nagano’s experiment

- Three corrections have been applied:

$$Y = Y_{\mathrm{Nag}} \frac{\langle \Omega \rangle_{\mathrm{beam}}}{\langle \Omega \rangle} \frac{\Delta x_{gap}}{\Delta x} \frac{(\mathrm{d}E / \mathrm{d}x)_{\mathrm{loss}}}{\langle \mathrm{d}E / \mathrm{d}x \rangle_{\mathrm{dep}}}$$

~1% increase

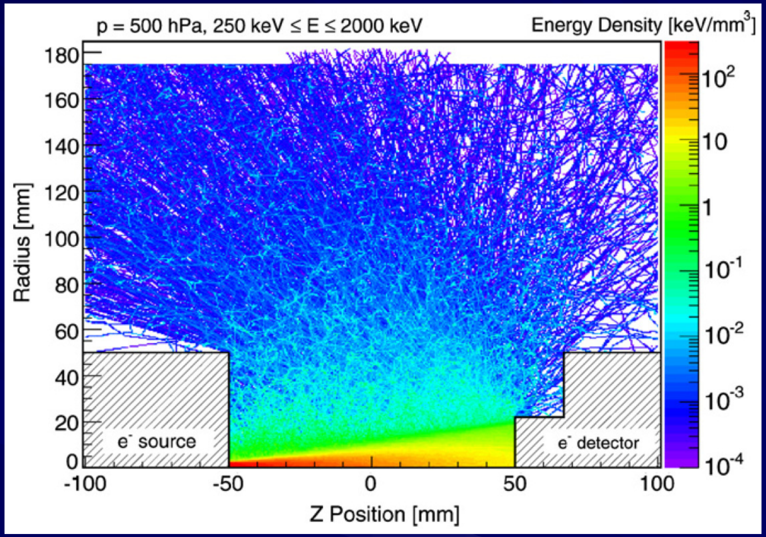
7% increase

~1% decrease

- FY of Nagano should be increased by 7%

3. MC analysis: AirLight experiment

- AirLight[*] performed a GEANT4 simulation to obtain:
  - a) Energy deposition
  - b) Acceptance $\langle\Omega\rangle$



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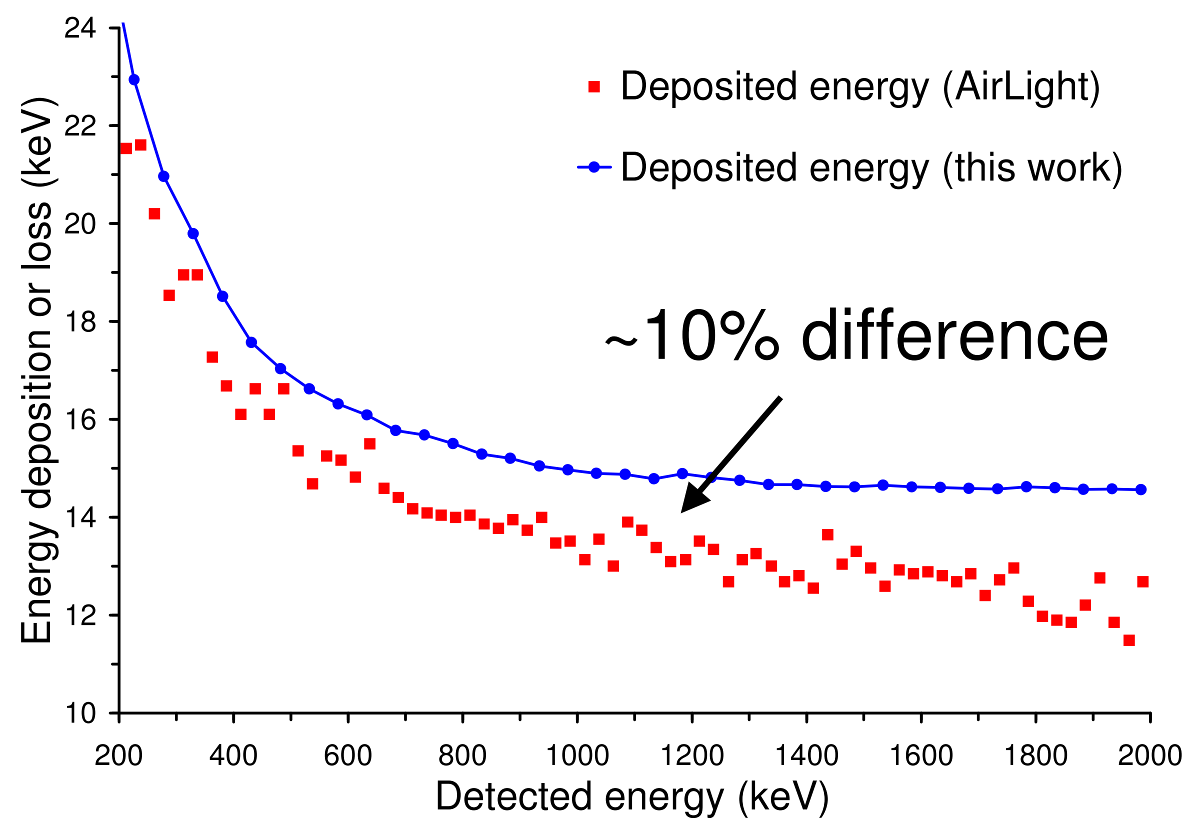
[*] T. Waldenmaier *et al.*, *Astropart. Phys.* 29 (2008) 205

3. MC analysis: AirLight experiment

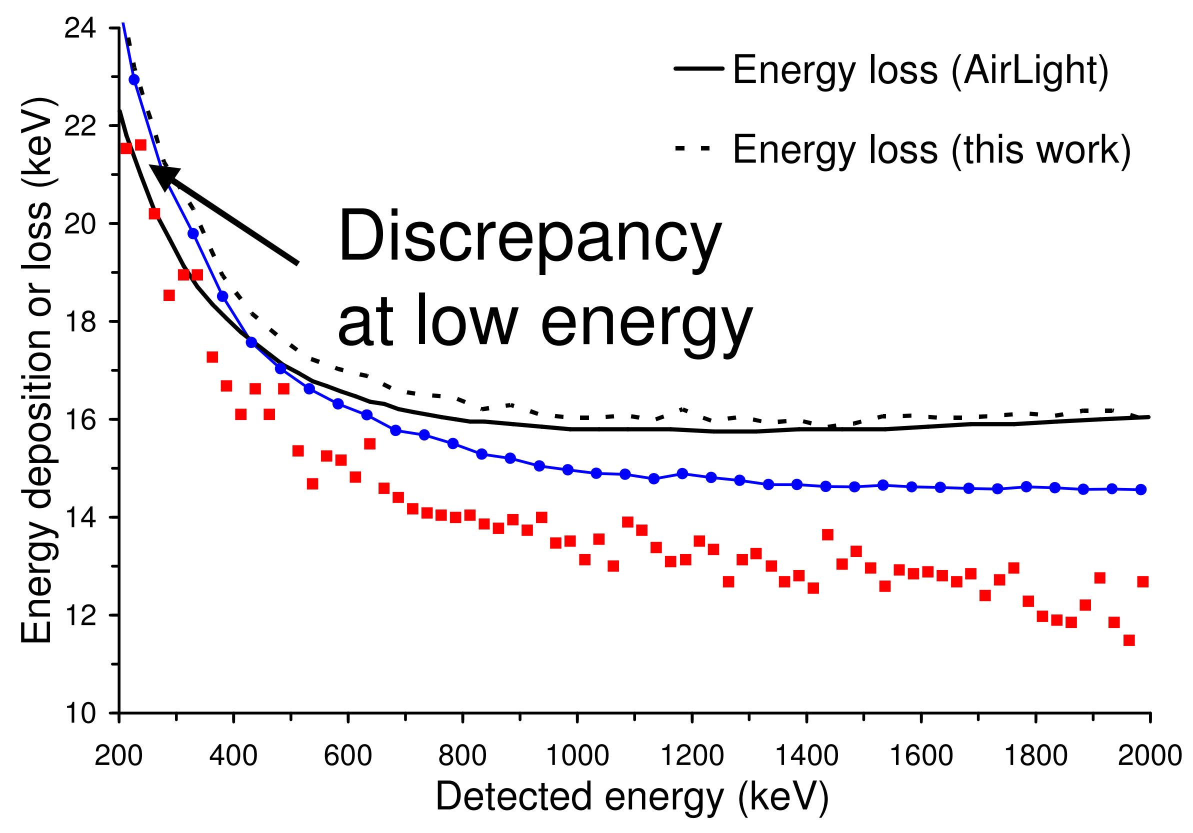
Integrated E_{dep} vs E at atmospheric pressure



- Deviations decrease with P resulting in an effective correction of about -7% in the FY

3. MC analysis: AirLight experiment

Integrated E_{loss} vs E at atmospheric pressure



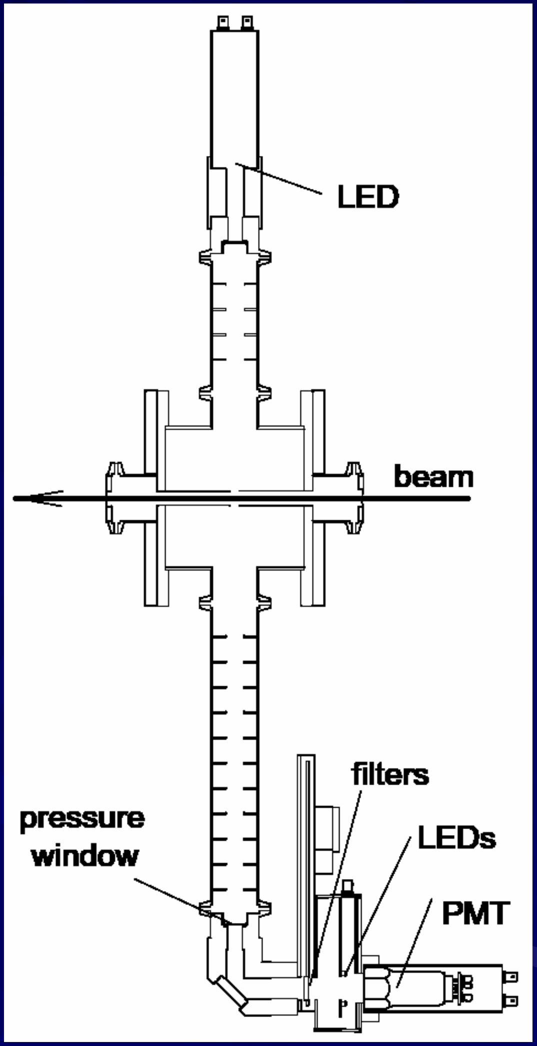
- ➡ Discrepancy in E_{loss} could be due to AirLight assuming straight trajectories of electrons

3. MC analysis: FLASH experiment

- FLASH[*] performed an EGS4 simulation to obtain:

  a) Energy deposition

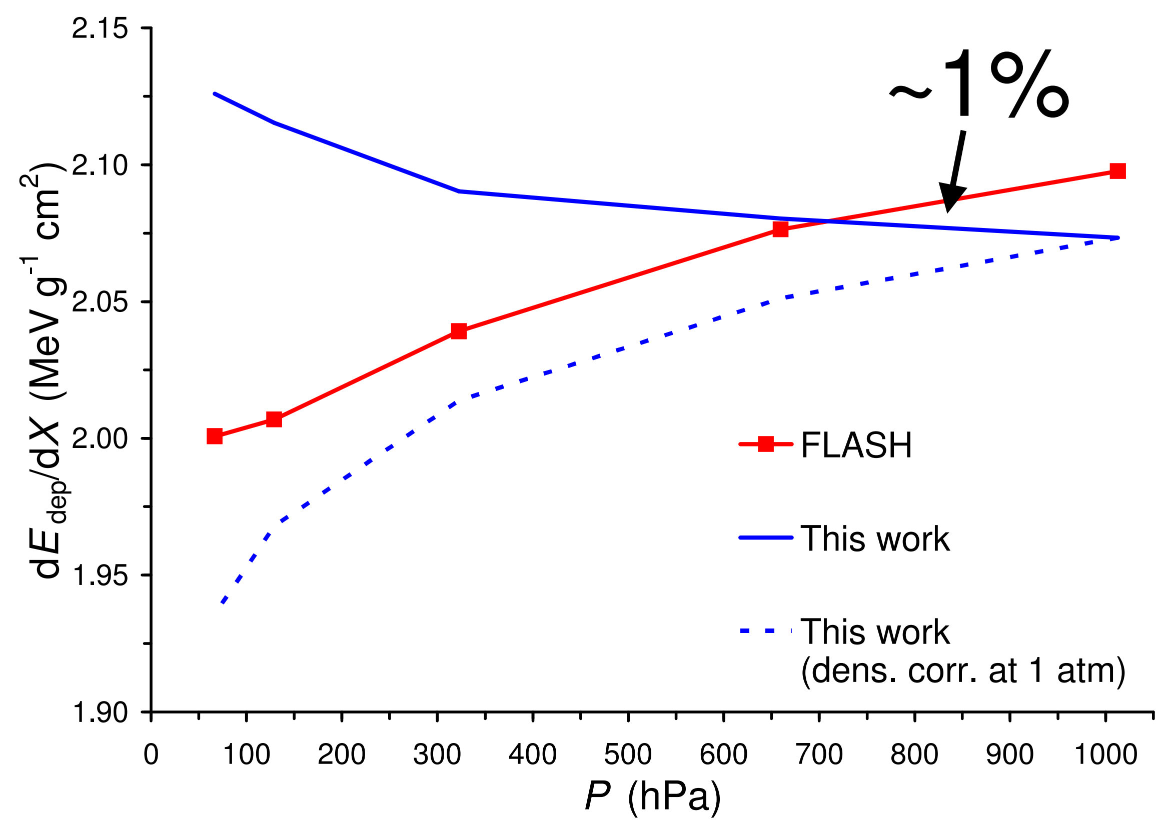
  b) Acceptance $<\Omega>$



[*] R. Abbasi *et al.*, *Astropart. Phys.* 29 (2007) 77

3. MC analysis: FLASH experiment

Comparison of $(\mathrm{d}E/\mathrm{d}X)_{\mathrm{dep}}$ vs P at 28.5 GeV



Discrepancy could be due to a different treatment of the density correction

Similar behavior if applying a fixed dens. corr.

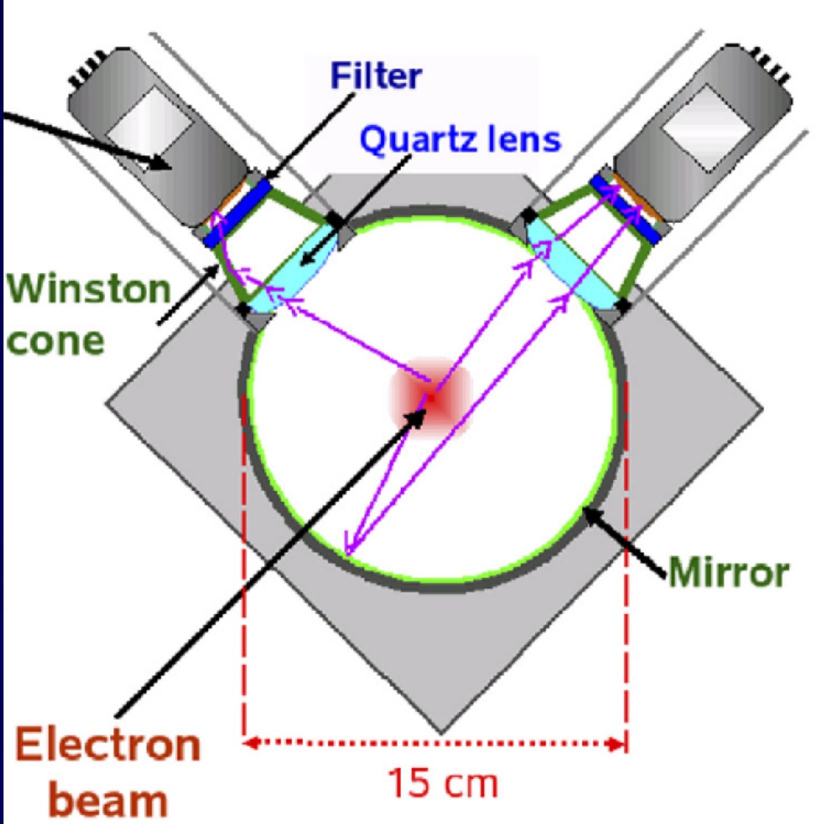
- ➡ Also a small correction in <Ω>, resulting in a total correction of about -2% in the FY

3. MC analysis: MACFLY experiment

- MACFLY[*] performed a GEANT4 simulation to obtain:

  a) Energy deposition

  b) Acceptance <Ω>

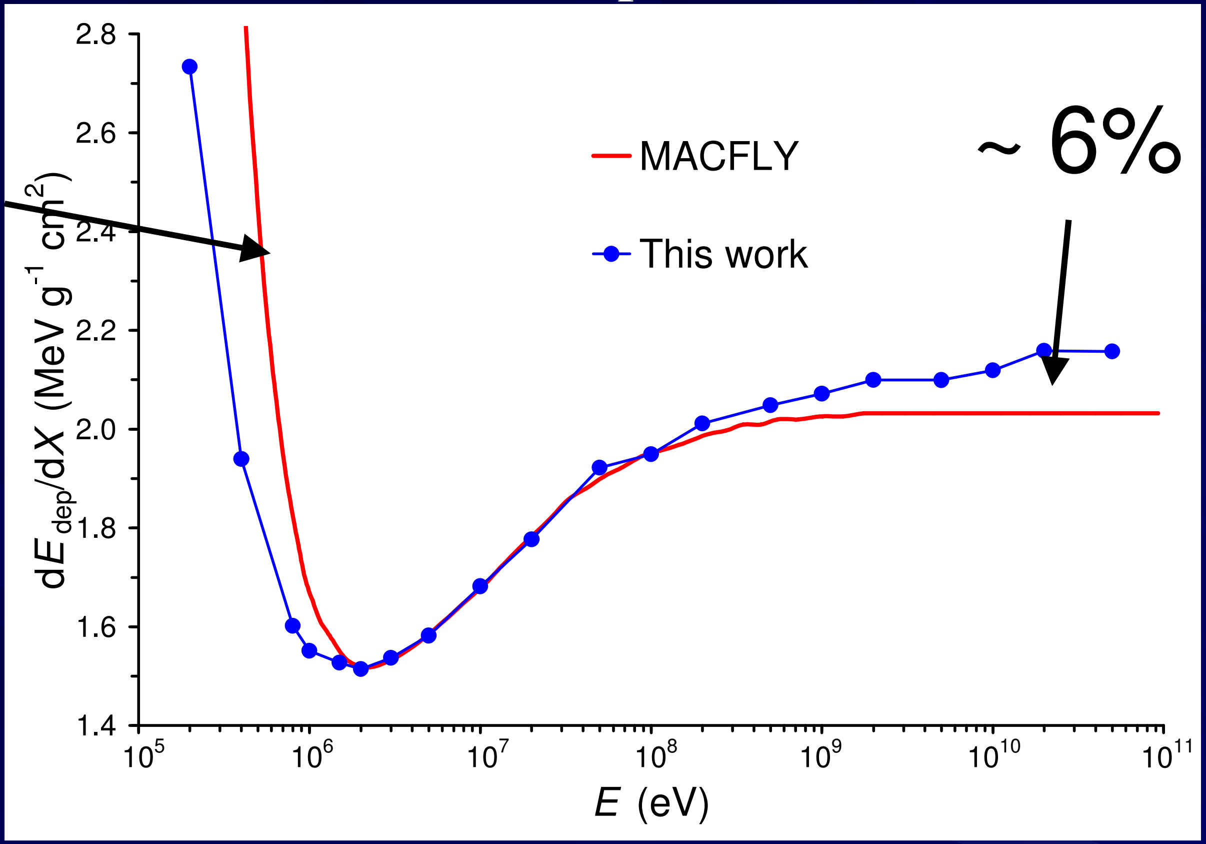


[*] P. Colin *et al.*, *Astropart. Phys.* 27 (2007) 317

3. MC analysis: MACFLY experiment

E dependence of $(\mathrm{d}E/\mathrm{d}X)_{\mathrm{dep}}$ at atmospheric P

Unexpected behavior of the E_{dep} curve of MACFLY at low energies

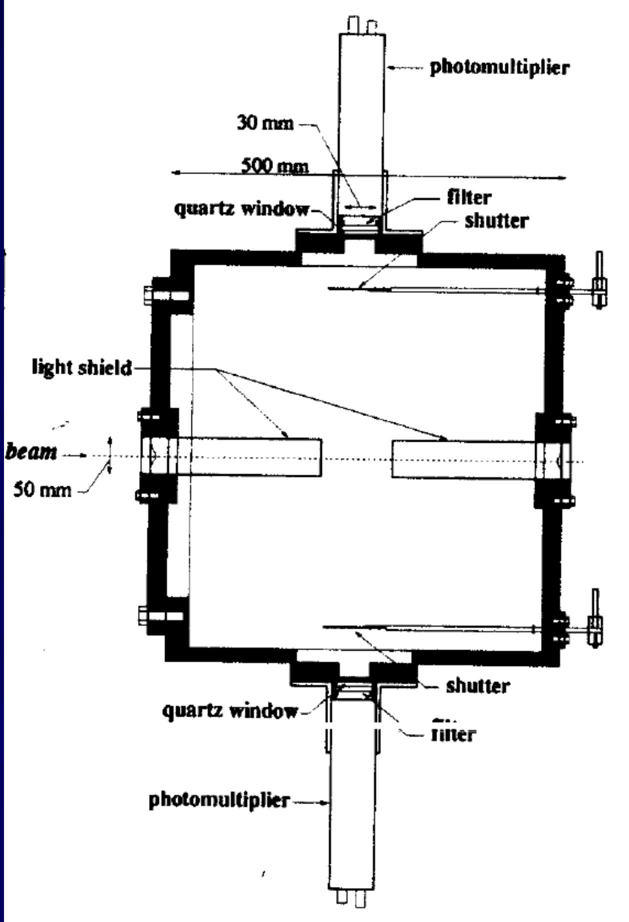


➡ Proposed corrections of the FY are +2% at 1.5 MeV and -6% at 20 GeV and 50 GeV

3. MC analysis: Kakimoto's experiment

- Kakimoto *et al.*[*] made similar assumptions than Nagano's, in particular:

$$\left(\frac{\mathrm{d}E}{\mathrm{d}x}\right)_{\mathrm{dep}} = \left(\frac{\mathrm{d}E}{\mathrm{d}x}\right)_{\mathrm{loss}}$$



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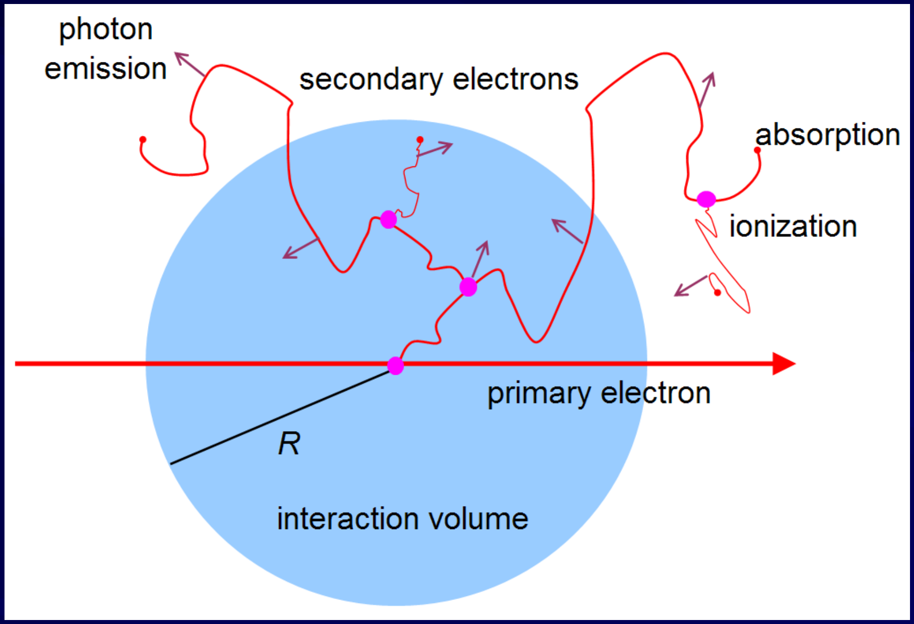
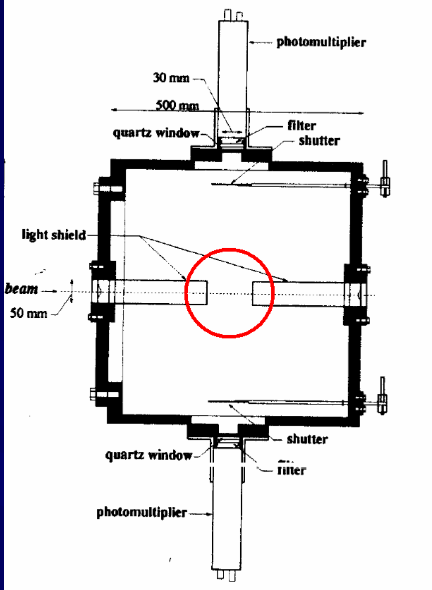
[*] F. Kakimoto *et al.*, *Nucl. Instr. Meth. A* 372 (1996) 527

3. MC analysis: Kakimoto's experiment

- Simulation results for a simple geometry*

- Geometrical details are not relevant





Obs. volume $R \sim 10$ cm

*F. Blanco *et al.*, *Phys. Lett. A* 345 (2005) 355
F. Arqueros *et al.*, *New J. Phys.* 11 (2009) 065011

3. MC analysis: Kakimoto's experiment

- Corrections are larger than 25% at high electron energy!

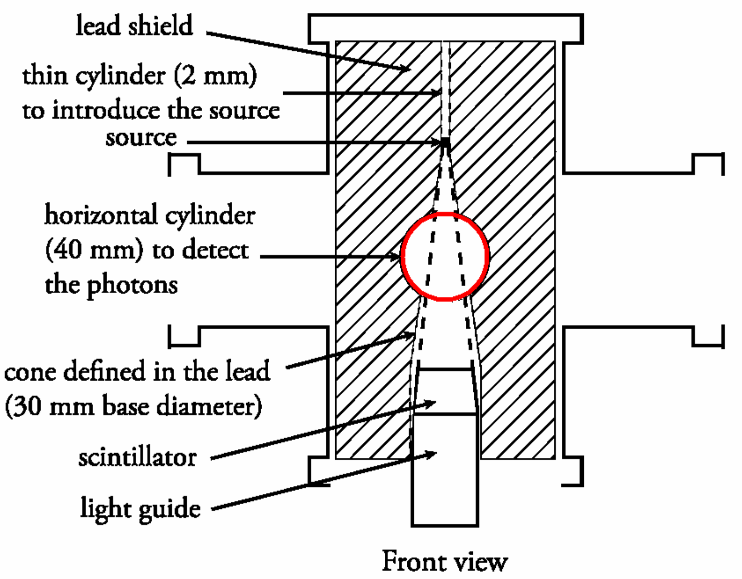
Energy (MeV)	Correction to FY
1.4	+6%
300	+25%
650	+28%
1000	+29%

3. MC analysis: Lefeuvre's experiment

- Lefeuvre *et al.*[*] performed a GEANT simulation to obtain:

  a) Contribution of high-energy secondaries

  b) Acceptance <Ω>



- Electron scattering by the lead walls of the chamber has an important role

[*] G. Lefeuvre *et al.*, *Nucl. Instr. Meth. A* 578 (2007) 78

3. MC analysis: Lefeuvre's experiment

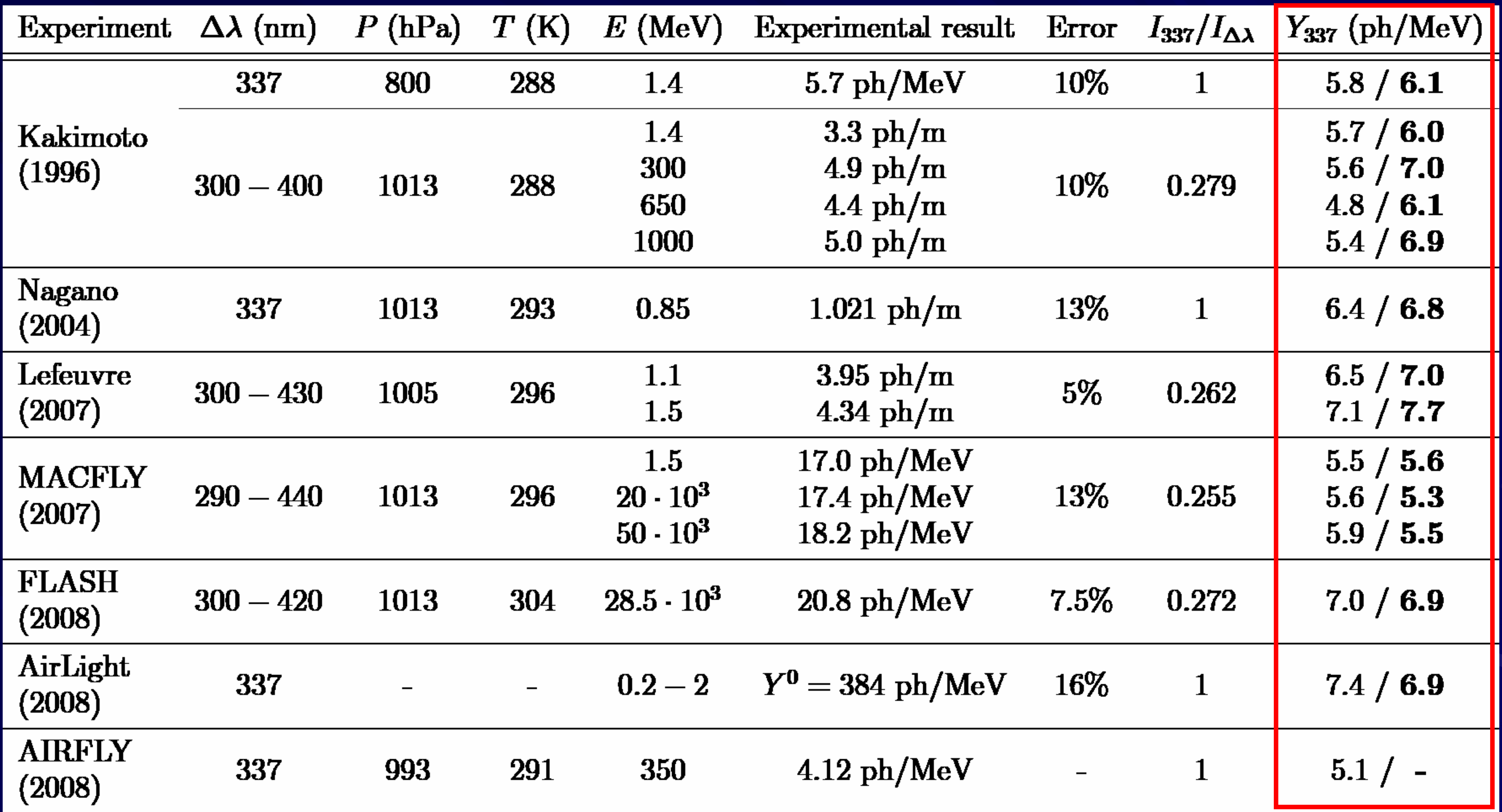
- Simulation results for a simple geometry assuming $R = 4$ cm
- The effect of scattering by the chamber walls was estimated using CASINO2.42

Energy (MeV)	Correction to FY
1.1	+7%
1.5	+8%

4. Comparison of results

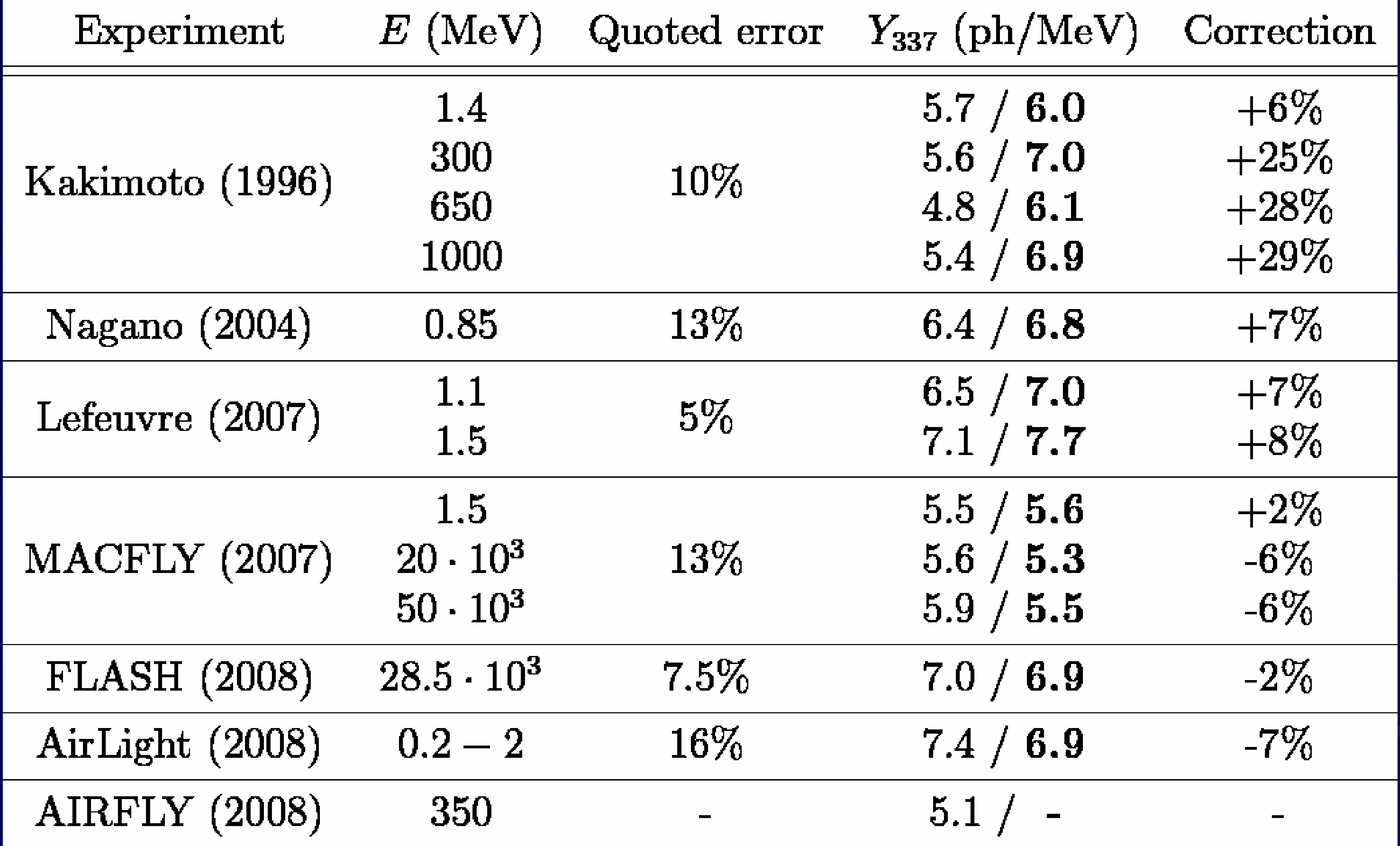
4. Comparison of results: table

Absolute FY values normalized to 337 nm, 800 hPa and 293 K



Experiment	$\Delta\lambda$ (nm)	P (hPa)	T (K)	E (MeV)	Experimental result	Error	$I_{337}/I_{\Delta\lambda}$	Y_{337} (ph/MeV)
Kakimoto (1996)	337	800	288	1.4	5.7 ph/MeV	10%	1	5.8 / **6.1**
	300 – 400	1013	288	1.4 300 650 1000	3.3 ph/m 4.9 ph/m 4.4 ph/m 5.0 ph/m	10%	0.279	5.7 / **6.0** 5.6 / **7.0** 4.8 / **6.1** 5.4 / **6.9**
Nagano (2004)	337	1013	293	0.85	1.021 ph/m	13%	1	6.4 / **6.8**
Lefeuvre (2007)	300 – 430	1005	296	1.1 1.5	3.95 ph/m 4.34 ph/m	5%	0.262	6.5 / **7.0** 7.1 / **7.7**
MACFLY (2007)	290 – 440	1013	296	1.5 $20 \cdot 10^3$ $50 \cdot 10^3$	17.0 ph/MeV 17.4 ph/MeV 18.2 ph/MeV	13%	0.255	5.5 / **5.6** 5.6 / **5.3** 5.9 / **5.5**
FLASH (2008)	300 – 420	1013	304	$28.5 \cdot 10^3$	20.8 ph/MeV	7.5%	0.272	7.0 / **6.9**
AirLight (2008)	337	-	-	0.2 – 2	$Y^0 = 384$ ph/MeV	16%	1	7.4 / **6.9**
AIRFLY (2008)	337	993	291	350	4.12 ph/MeV	-	1	5.1 / **-**

4. Comparison of results: table



Experiment	E (MeV)	Quoted error	Y_{337} (ph/MeV)	Correction
Kakimoto (1996)	1.4	10%	5.7 / **6.0**	+6%
	300		5.6 / **7.0**	+25%
	650		4.8 / **6.1**	+28%
	1000		5.4 / **6.9**	+29%
Nagano (2004)	0.85	13%	6.4 / **6.8**	+7%
Lefeuvre (2007)	1.1	5%	6.5 / **7.0**	+7%
	1.5		7.1 / **7.7**	+8%
MACFLY (2007)	1.5	13%	5.5 / **5.6**	+2%
	$20 \cdot 10^3$		5.6 / **5.3**	-6%
	$50 \cdot 10^3$		5.9 / **5.5**	-6%
FLASH (2008)	$28.5 \cdot 10^3$	7.5%	7.0 / **6.9**	-2%
AirLight (2008)	0.2 – 2	16%	7.4 / **6.9**	-7%
AIRFLY (2008)	350	-	5.1 / **-**	-

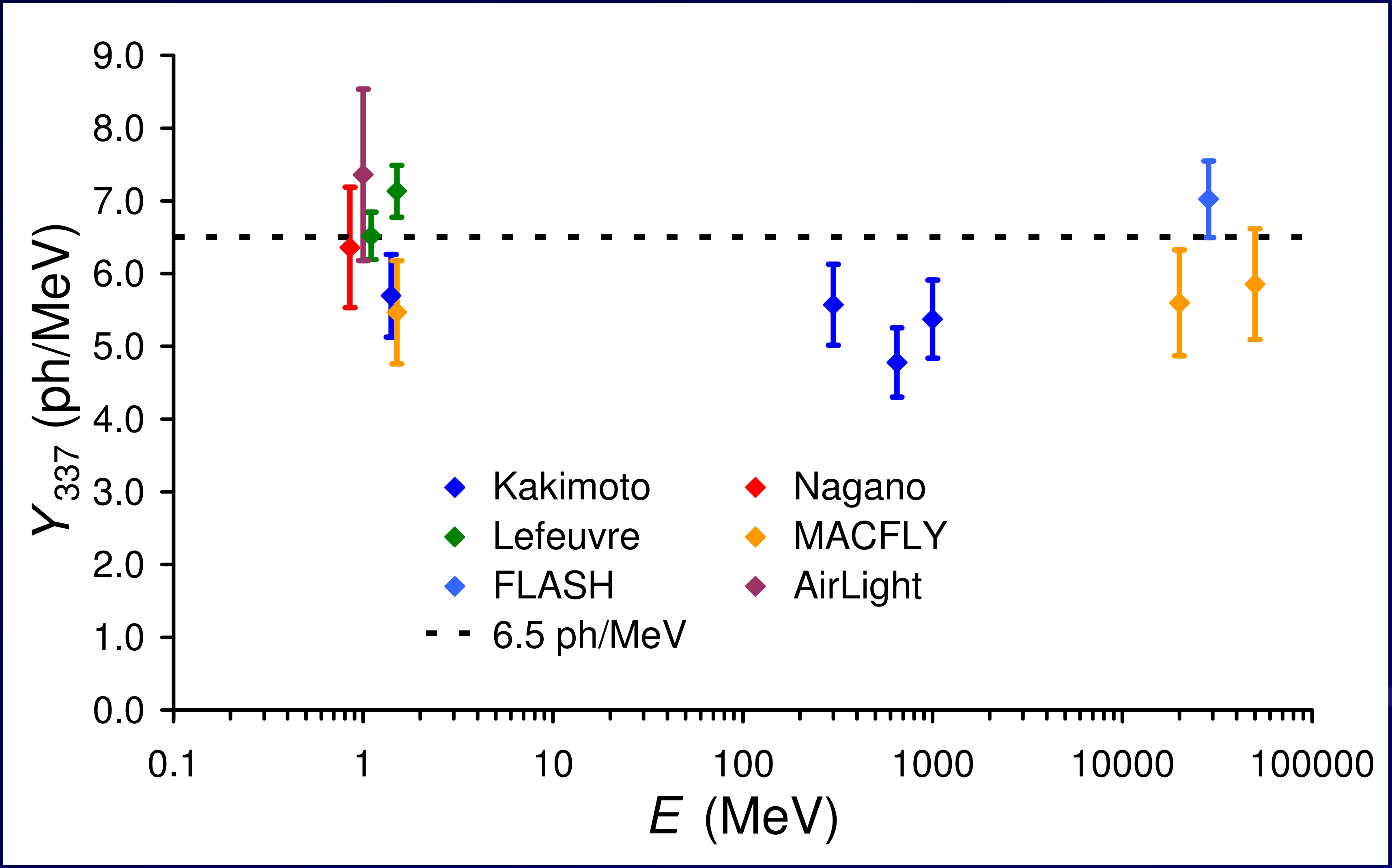
4. Comparison of results: concluding remarks

- Most measurements lead to $Y_{337} \sim$ 6.5 ph/MeV, except for those of MACFLY and the preliminary result of AIRFLY[*]
- Discrepancies larger than uncertainties: error in E_{dep} should be considered
- Proposed corrections are non-negligible, in particular when authors assume: $(\mathrm{d}E/\mathrm{d}x)_{\mathrm{dep}} = (\mathrm{d}E/\mathrm{d}x)_{\mathrm{loss}}$

[*] M. Ave *et al.*, *Nucl. Instr. Meth. A* 597 (2008) 55

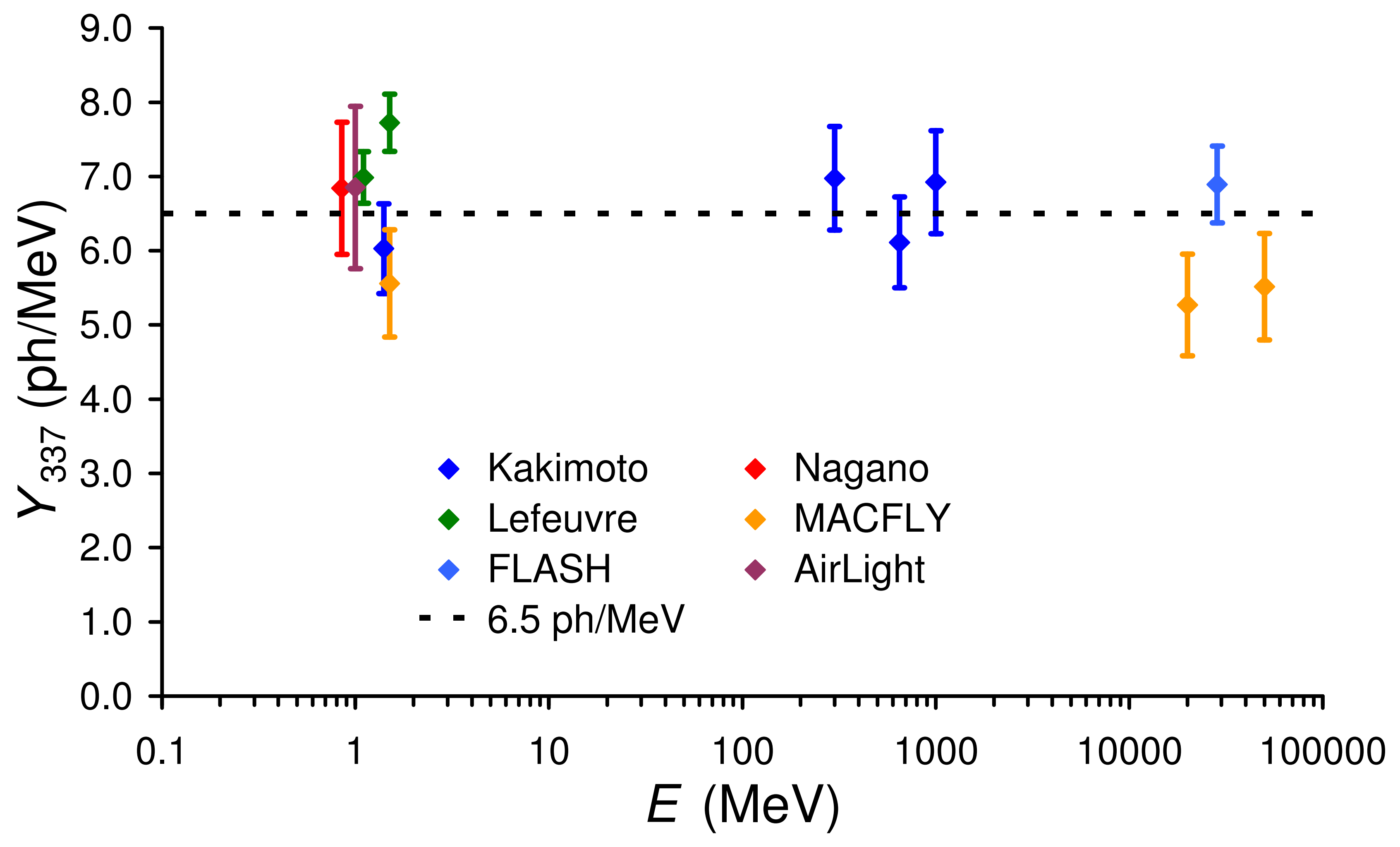
4. Comparison of absolute FY values

Normalized FY using calculations of authors



4. Comparison of absolute FY values

Normalized FY after applying corrections



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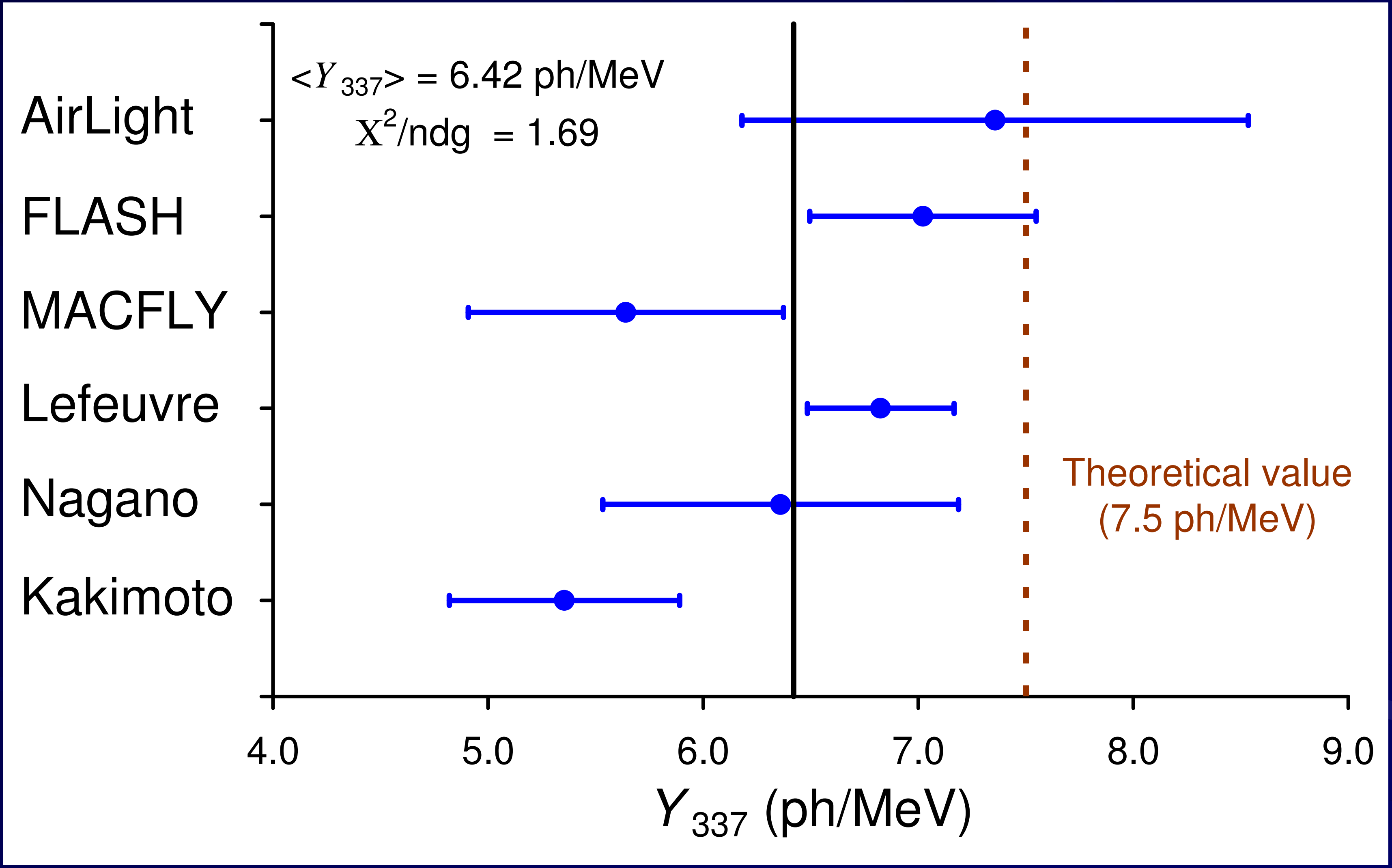
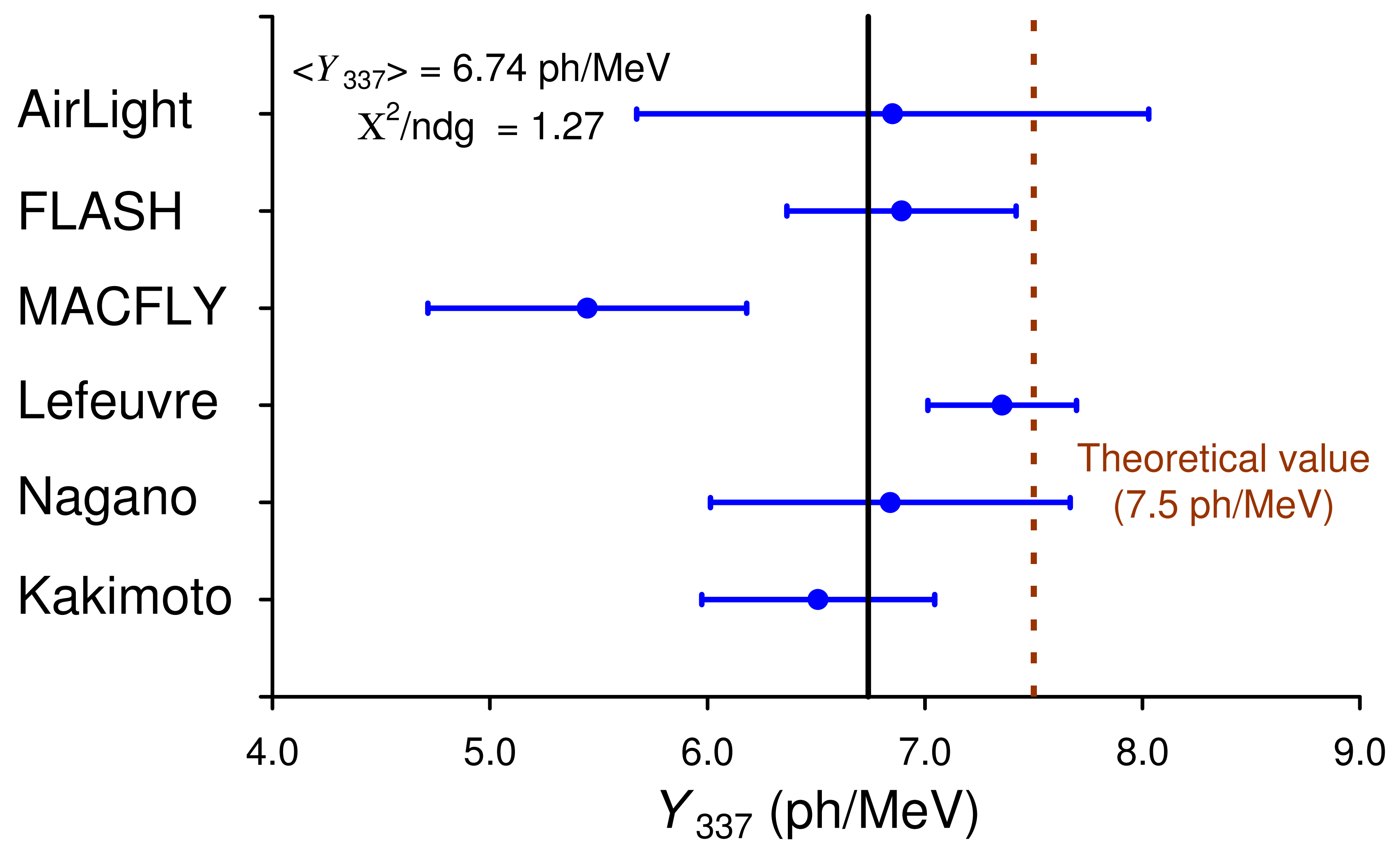
Normalized FY using calculations of authors



4. Comparison of absolute FY values

Normalized FY after applying corrections



Thanks!