Absolute
Air Fluorescence Yield
Measurement

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for the AIRFLY collaboration

Method and analysis

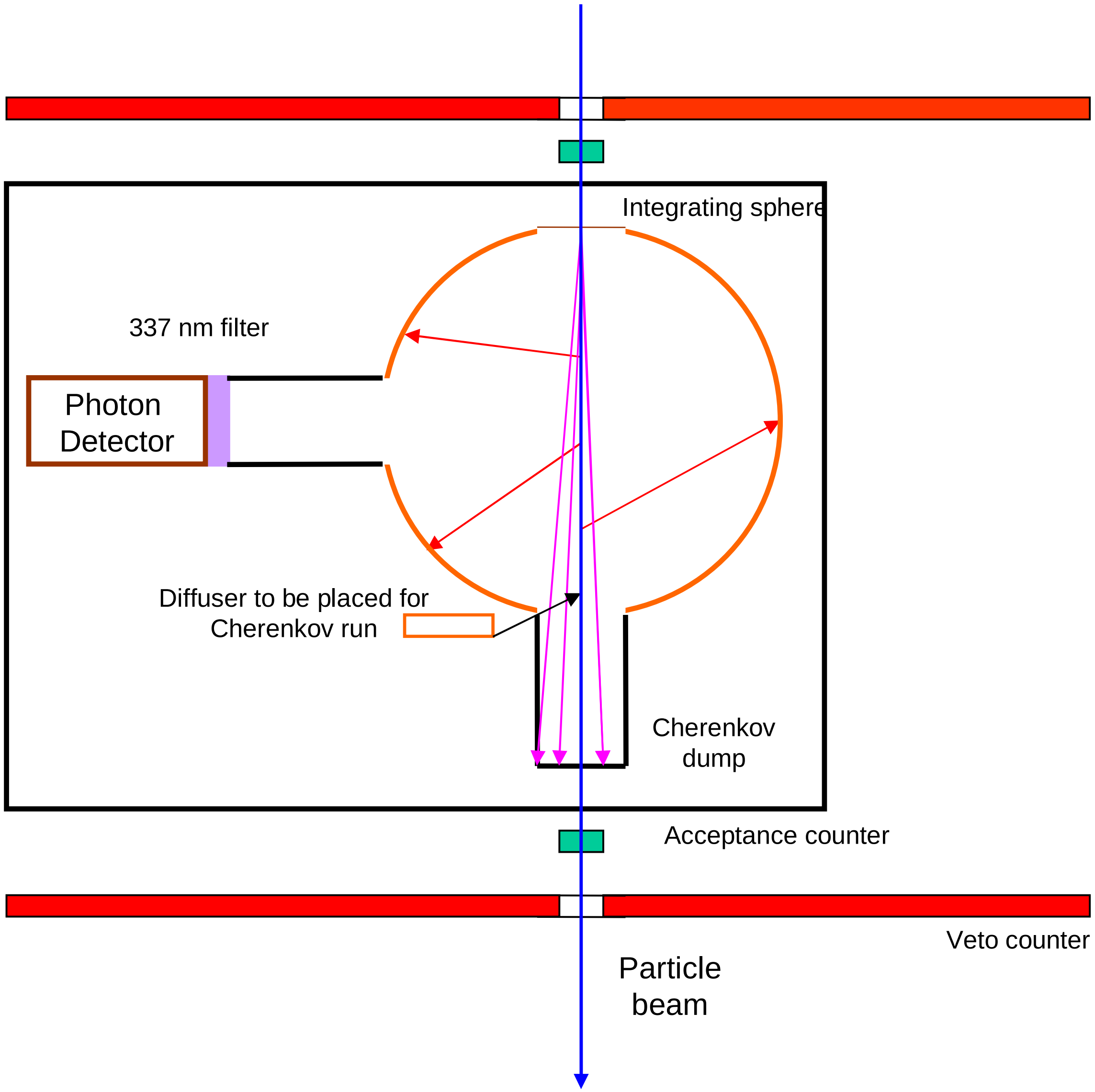
Compare fluorescence yield to a well known process to eliminate photo-detector systematics

$$\underbrace{N_{337}(fluo)}_{measured} = \underline{Y_{fl}}_{\;known} \times \underbrace{Geom_{fluo}}_{MC} \times \underbrace{T_{filter} \times QE_{337}}_{\sim cancel} \times \underbrace{N_p}_{relative}$$

$$\overbrace{N_{337}(cere)} = \overbrace{Y_{cere}} \times \overbrace{Geom_{cere}} \times \overbrace{T_{filter} \times QE_{337}} \times \overbrace{N_p}$$

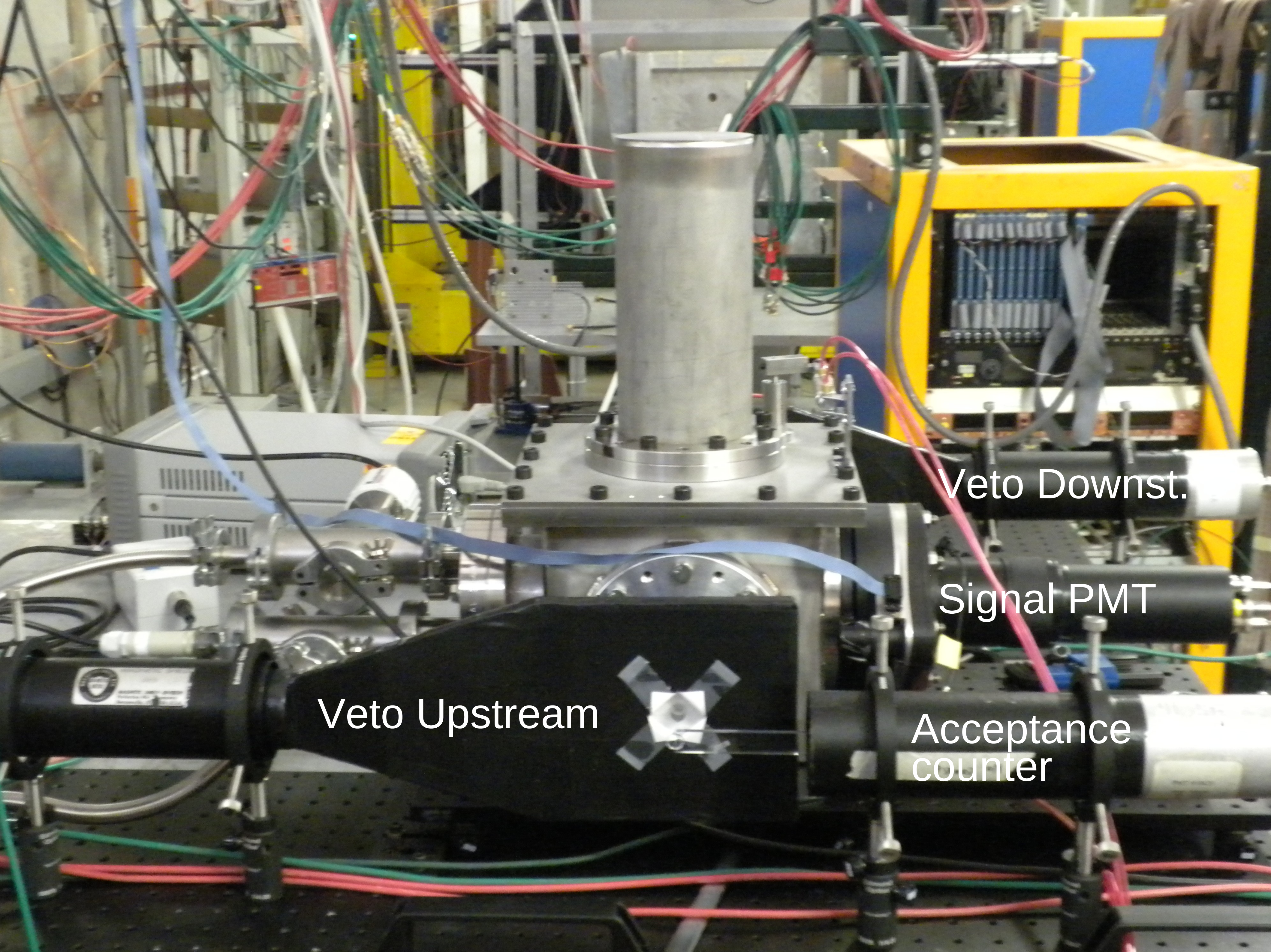
- *Full MC simulation of the ratio with nominal FLY is compared to the ratio measured in laboratory*

AIRFLY at the Fermilab Test Beam



- *High energy up to 120 GeV*
- *Well defined beam: single particle trigger and geometry*
- *Wide range of particles type and intensity (p, e, μ, π)*

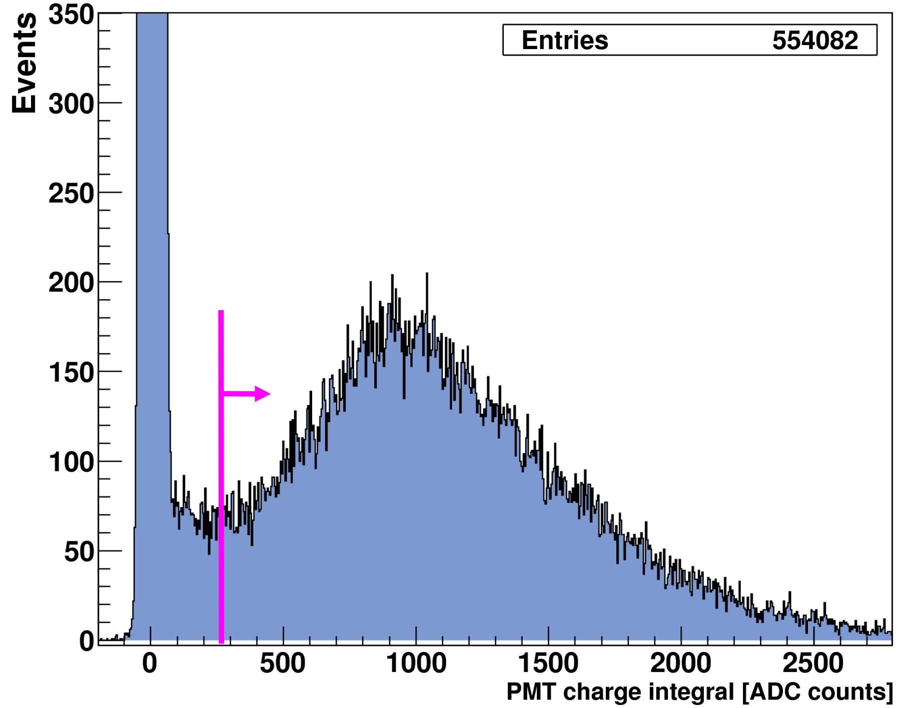
Absolute calibration with two independent methods: Cherenkov and laser light


Veto Downst.
Signal PMT
Veto Upstream
Acceptance
counter

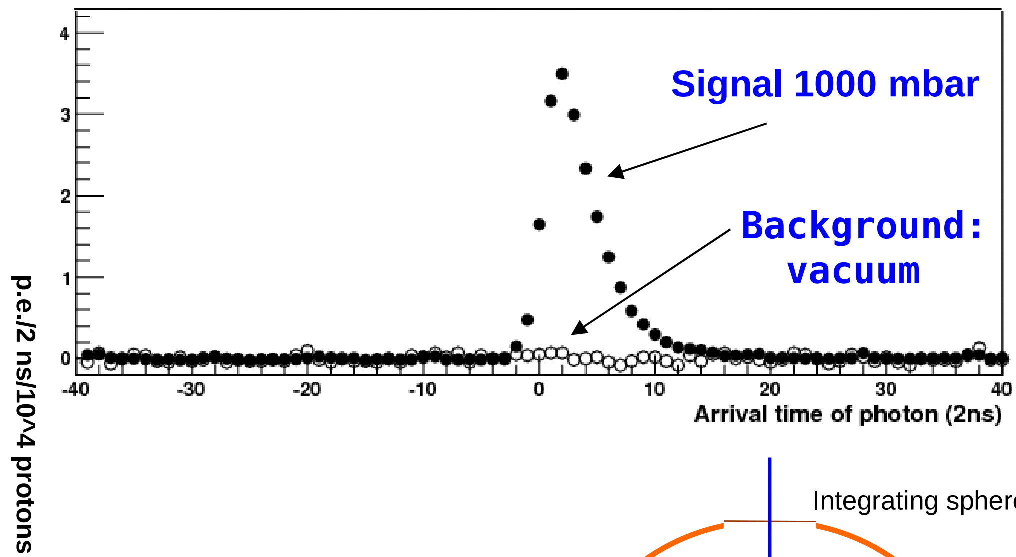
Fluorescence Measurement in N_2

120 GeV protons

Single p.e. spectrum



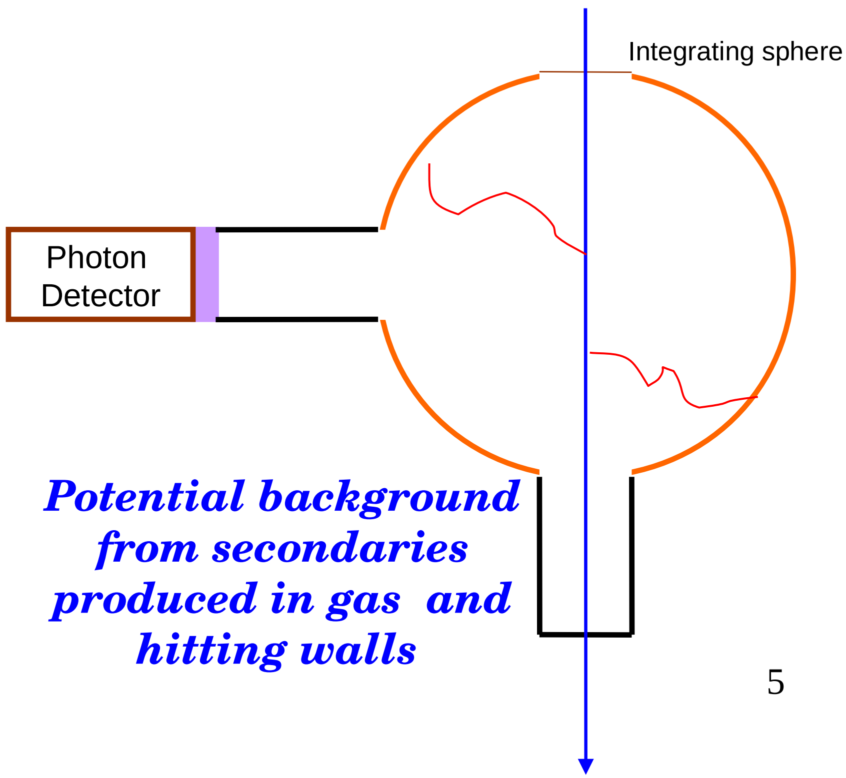
p.e. timing (wrt. proton)



S_{FL} (N_2)= (20.05 ± 0.11) 10^{-4} p.e./proton

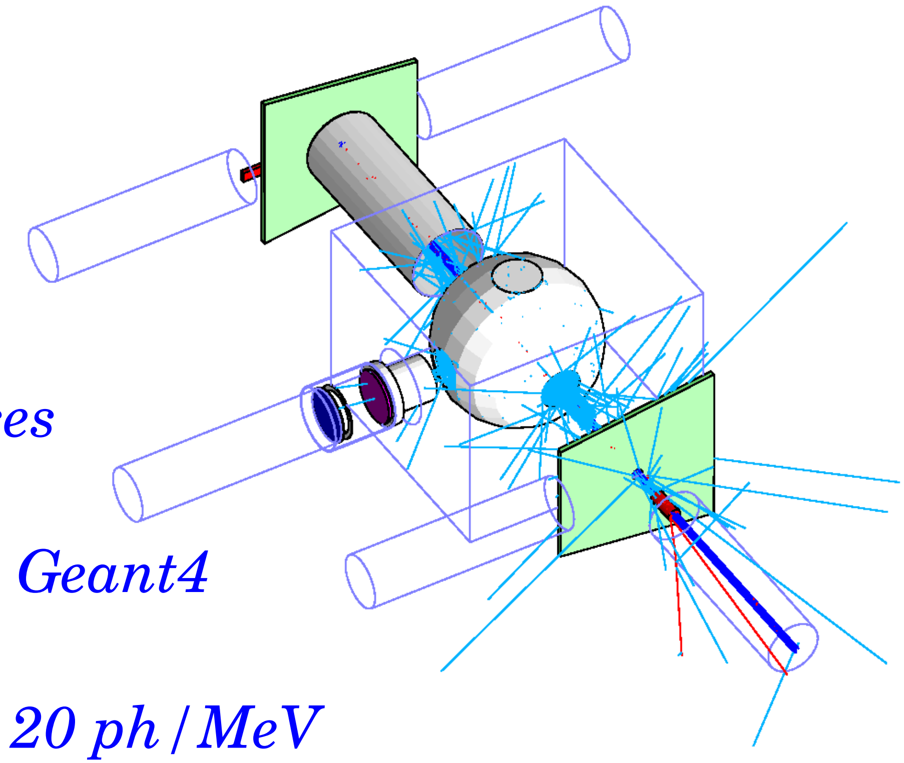
S_{FL}(vac) = (0.48 ± 0.09) 10^{-4} p.e./proton

Counting *experiment: select (single, clean) protons and then count the photons they produced.*

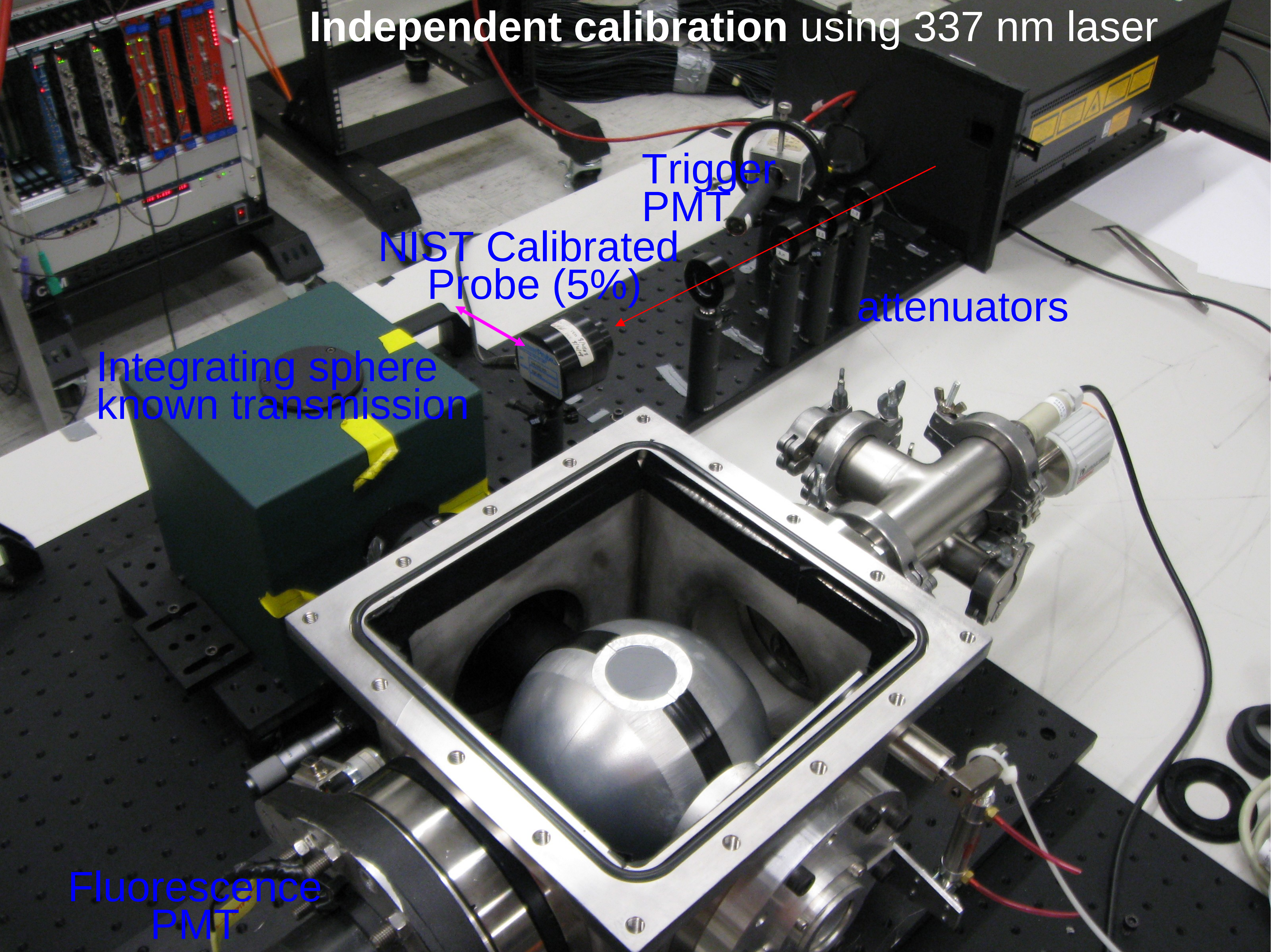


Potential background from secondaries produced in gas and hitting walls

Total simulation of the experiment



- using version   Geant4.9.2.p02
- Standard electromagnetic processes (protons 120 GeV)
- Cerenkov process implemented by Geant4
- G4ScintillationProcess simulates the fluorescence – nominal yield 20 ph/MeV sampled from the AIRFLY spectrum
- 337 nm line forms 25.75% of the spectrum
- Cut in range 1 mm – particles with shorter range deposit all their energy on the spot

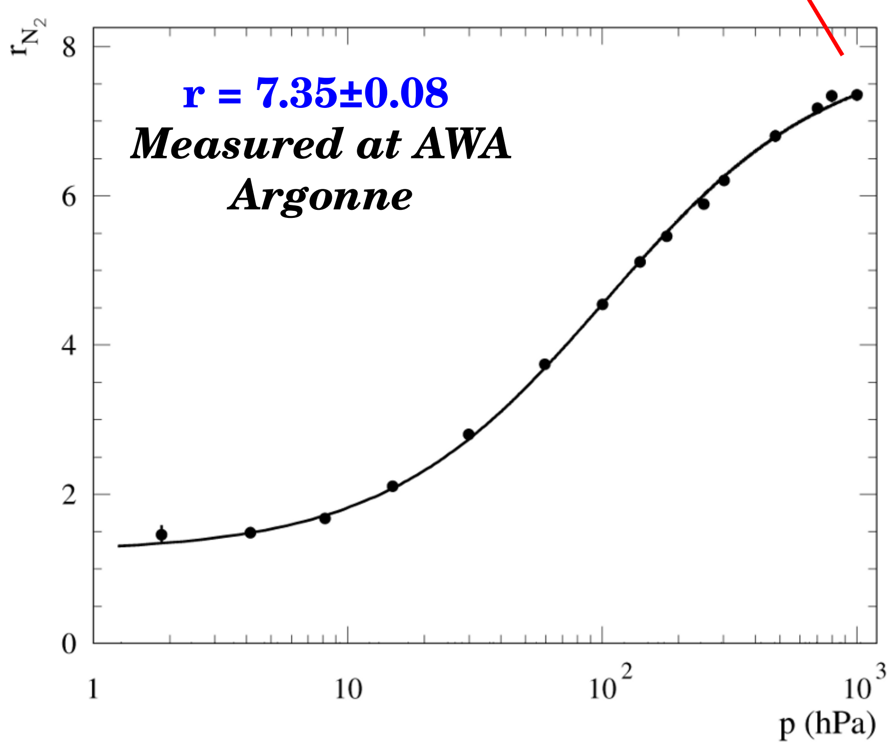

Independent calibration using 337 nm laser
Trigger PMT
NIST Calibrated Probe (5%)
attenuators
Integrating sphere known transmission
Fluorescence PMT

Fluorescence Measurement in N_2 and air

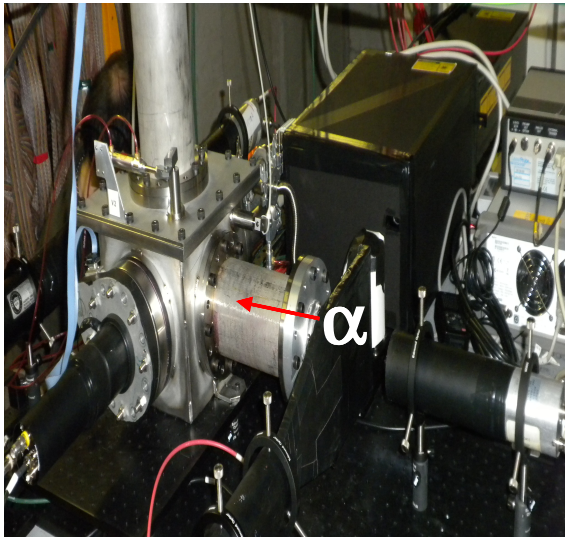
$S_{Fl}(N_2) - S_{Fl}(air) = (Fl_{N2} + Bkg) - (Fl_{air} + Bkg)$

$= Fl_{N2} - Fl_{air} = Fl_{N2}\,(1 - 1/r)$

Same background from secondaries produced in air and N_2



r = 7.45±0.08 measured in the Fermilab apparatus with an alpha source



$Fl_{N2} = (19.44 \pm 0.15)\ 10^{-4}$ p.e./proton

$Bkg = (0.61 \pm 0.08)\ 10^{-4}$ p.e./proton

1% statistical unc.

consistent with vacuum bkg only 3% of signal

Three Measurements with different systematics

performed in Nitrogen to increase the statistics

Ratio Nitrogen/Air (337nm)

- Measured at AWA Argonne — $r = 7.35 \pm 0.08$
- Confirmed in Fermilab setup

Fluo/Cere ratio

$$Y_{air} = \frac{(R_{N2} / r)}{(R_{air})_{MC}}$$

$(Y_{air})_{F/C} = 5.64 \pm 0.12_{stat}$ photons$_{337}$/MeV

2.4 % statistical unc.

Mylar mirror

$(Y_{air})_{F/C} = 5.48 \pm 0.25_{stat}$ photons$_{337}$/MeV

Laser calibration

$$Y_{air} = \frac{(L_{N2} / r)}{(L_{air})_{MC}}$$

$(Y_{air})_{LAS} = 5.73 \pm 0.08_{stat}$ photons$_{337}$/MeV

1.3 % statistical unc.

Currently used in Auger: 5.05 photons/MeV

Checks of the systematic effects

dependence on the threshold for s.p.e.	neg.
photon counting time window	< 1 %
independent data analysis	0.7 %.
Cherenkov yield uncertainty due to RI	neg.
Cherenkov contribution with port open	neg.
fluorescence with port open and closed	neg.
Pointing laser to different spots	neg.
remounting the laser system	< 1%

Systematic uncertainties

Fluo/Cere ratio

- sphere efficiency	~ 0.9 %
- PMT quantum efficiency	~ 1.0 %
- Monte Carlo statistics	~ 1.0 %
- N_2/Air ratio	~ 1.0 %
- sphere λ dependence	~ 1.0 %
- filter transmittance	~ 2.0 %
- background subtraction	~ 1.0 %
- energy deposit	~ 2.0 %
Total	3.7 %

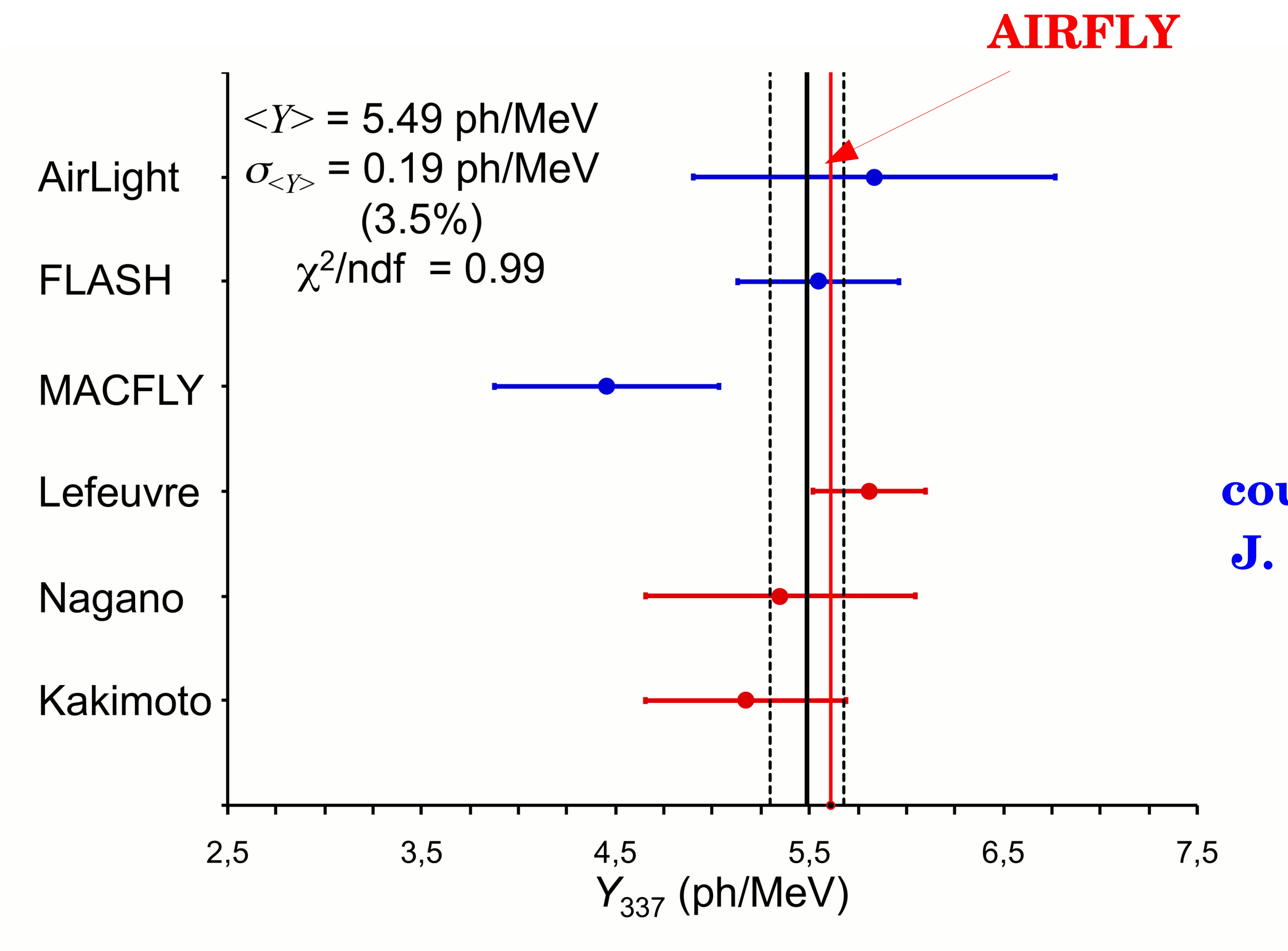
Laser calibration

- laser probe calibration	~ 5.0 %
- calibration sphere Transmission	~ 0.8 %
- Monte Carlo statistics	~ 1.0 %
- N_2/Air ratio	~ 1.0 %
- sphere efficiency	~ 0.9 %
- background subtraction	~ 1.0 %
- energy deposit	~ 2.0 %
- geometry	~ 0.3 %
Total	5.8%

Combined result

$(Y_{air})_{Airfly}$ = $5.61 \pm 0.06_{stat} \pm 0.21_{syst}$ photons$_{337}$/MeV

(dry air, 1013 hPa, 293 K)



courtesy of J. Rosado

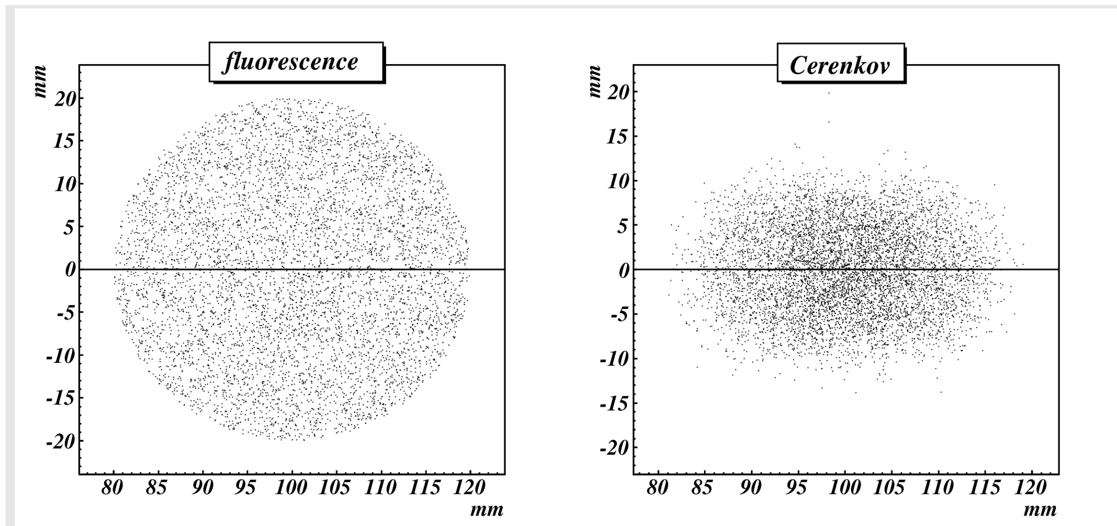
Summary

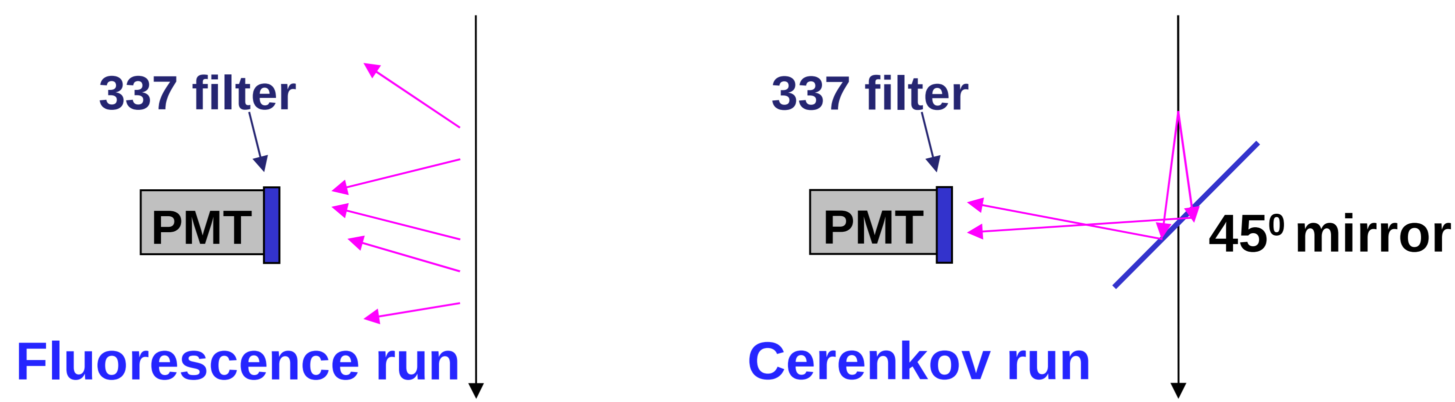
- *Precise measurement of the absolute fluorescence yield of the 337 nm line was performed.*
- *Two independent calibration methods are giving compatible results.*
- *Our results are consistent within the uncertainties with other experiments.*
- *Total uncertainty of 4% achieved*

- *Together with AIRFLY measurements of the air fluorescence spectrum and its pressure, temperature and humidity dependence, the total uncertainty on the energy scale of UHECR due to FLY will be reduced to ~ 5%.*

Backup slides

Photocathode coverage in Frascati





Moreover – Cerenkov light is polarized, fluorescence is not

Integrating sphere eliminates the differences