TAN Instrumentation for Optimization of LHC Luminosity

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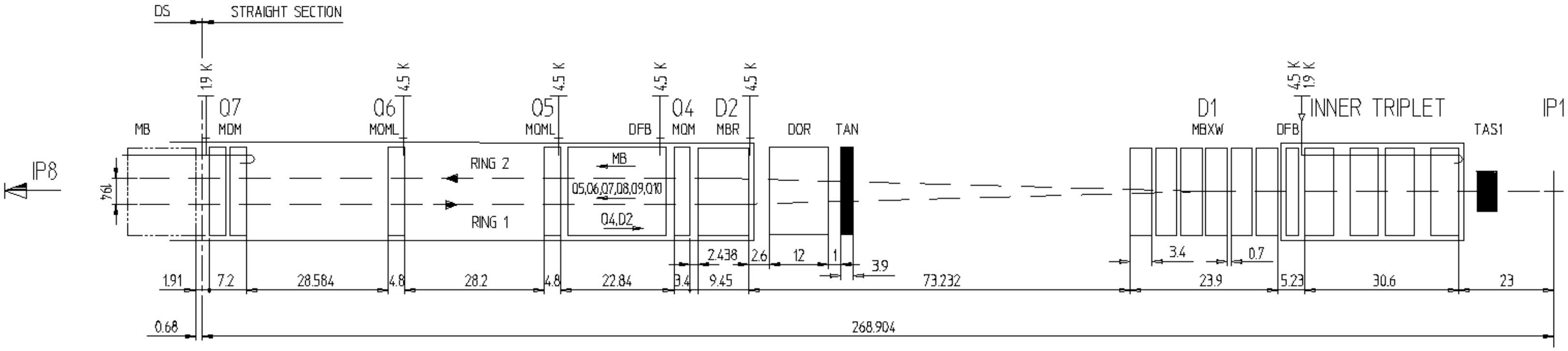
Presented at CERN the TAN Instrumentation
Integration Workshop
10 Mar 2006

Outline

- Concept
- Power deposition, activation and particle fluxes
- Detector considerations
- Integration time
- SPS H4 tests

TAN and TAS absorbers in IPs 1 and 5

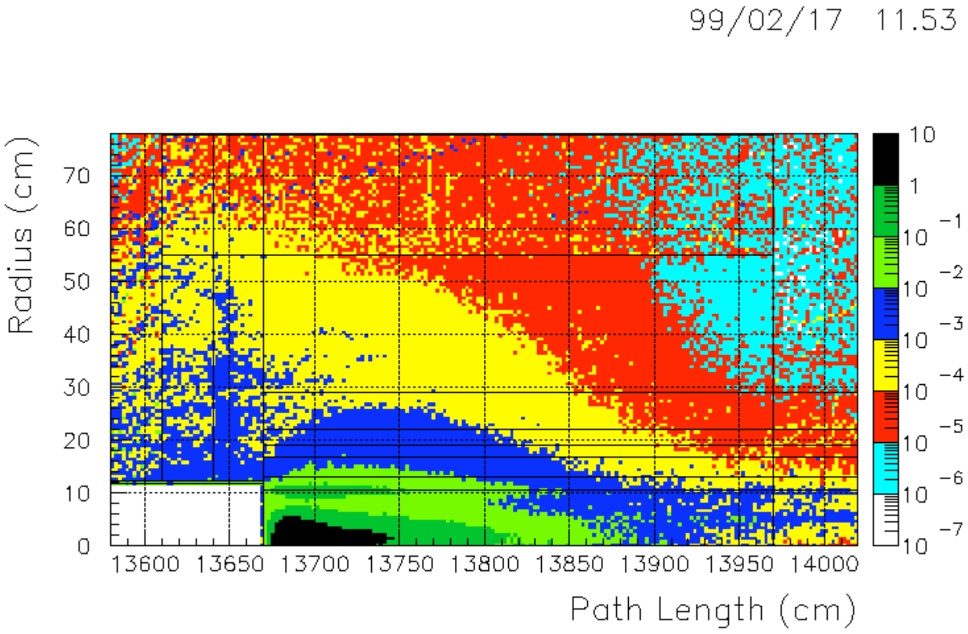


- The TAS absorbs ~200W of forward collision products that have escaped the beam tube in front of Q1 (mostly charged pions and photons)

- The TAN absorbs ~ 200W of forward neutral collision products (mostly neutrons and photons) and is placed in front of the outer beam separation dipole D2

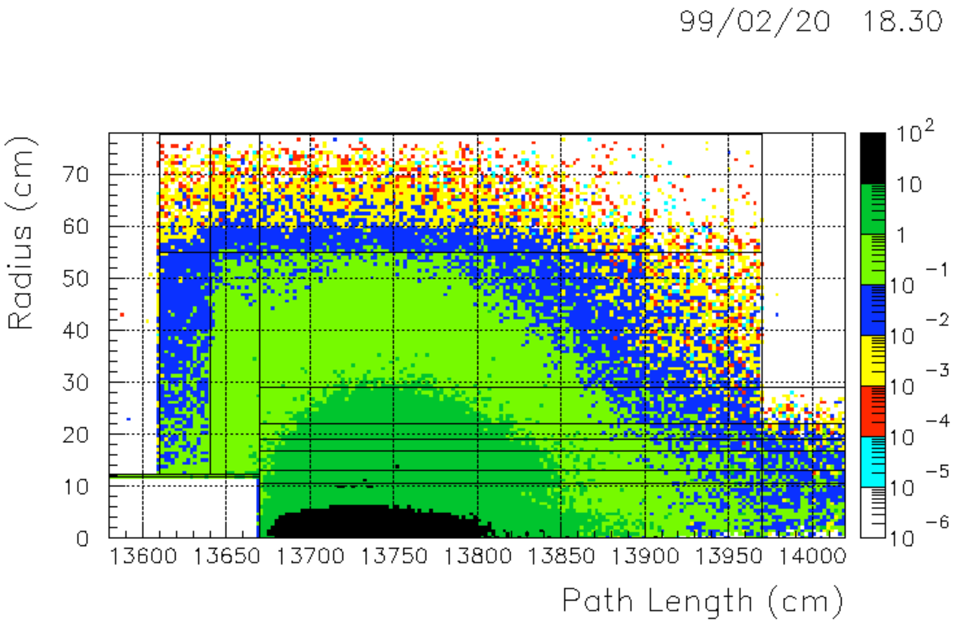
- Propose to instrument the TAN and TAS to measure and optimize the luminosity of colliding bunch pairs with 40MHz resolution

TAN power deposition (W/kgm)



- Peak pwr density 1-10 W/kgm (luminosity instrumentation located near the shower maximum)
- A radiation hard cable will allow electronics to be located in a region with pwr density < 10^{-5} W/kgm (100 Gy/oper yr)

TAN activation at 30d/1d(mSv/hr)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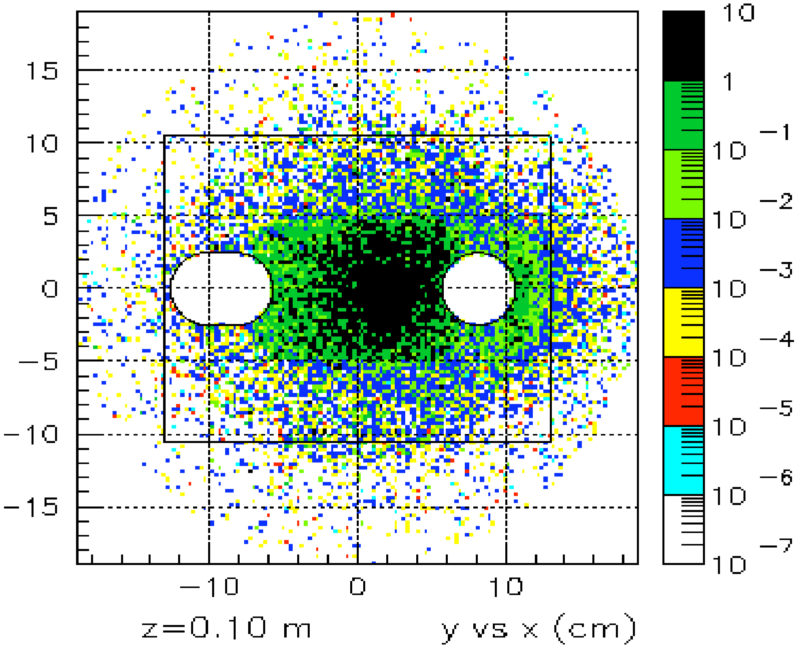
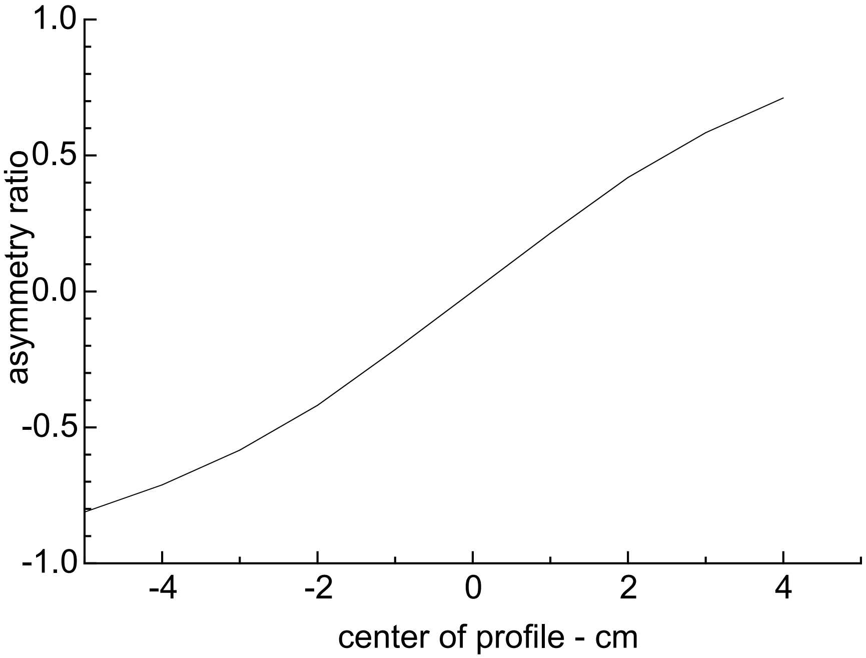
- Contact dose < 0.1 mSv/hr at outer r = 55 cm and back surfaces of the TAN (ok to stand in region per CERN guidelines)
- Contact dose inside the inner absorber box exceeds 1 mSv/hr (requires remote handling per CERN guidelines)
- Our goal is to design a detector that can be operated indefinitely without maintenance or replacement

The left-right asymmetry ratio is a sensitive function of the crossing angle

- TAN 142 m from IP, Xing angle = ±150 mrad





- Measurement of the asymmetry ratio at the position of the TAN allows determination of the beam-beam Xing angle

Incident particle fluxes on the TAN per pp interaction

Particle type	<n>	<E> (GeV)	<n><E> (GeV)
Neutral hadrons	.48	1516.	726
Protons	.11	938.	102
Charged Pions	.875	65.	57
Photons	301	2.2	662
Electron/ positron	24.5	0.3	7.2
Muons	.006	4.9	.03

An example: TAN neutrons

L = 10^{34} cm^{-2}s^{-1}, σ_{inel} = 80mb => 8×10^8 pp int/s

<n> = 0.48 neutrons/pp int => 3.8×10^8 n/s

f = 40 MHz bunch Xing => 9.6 n/bunch Xing

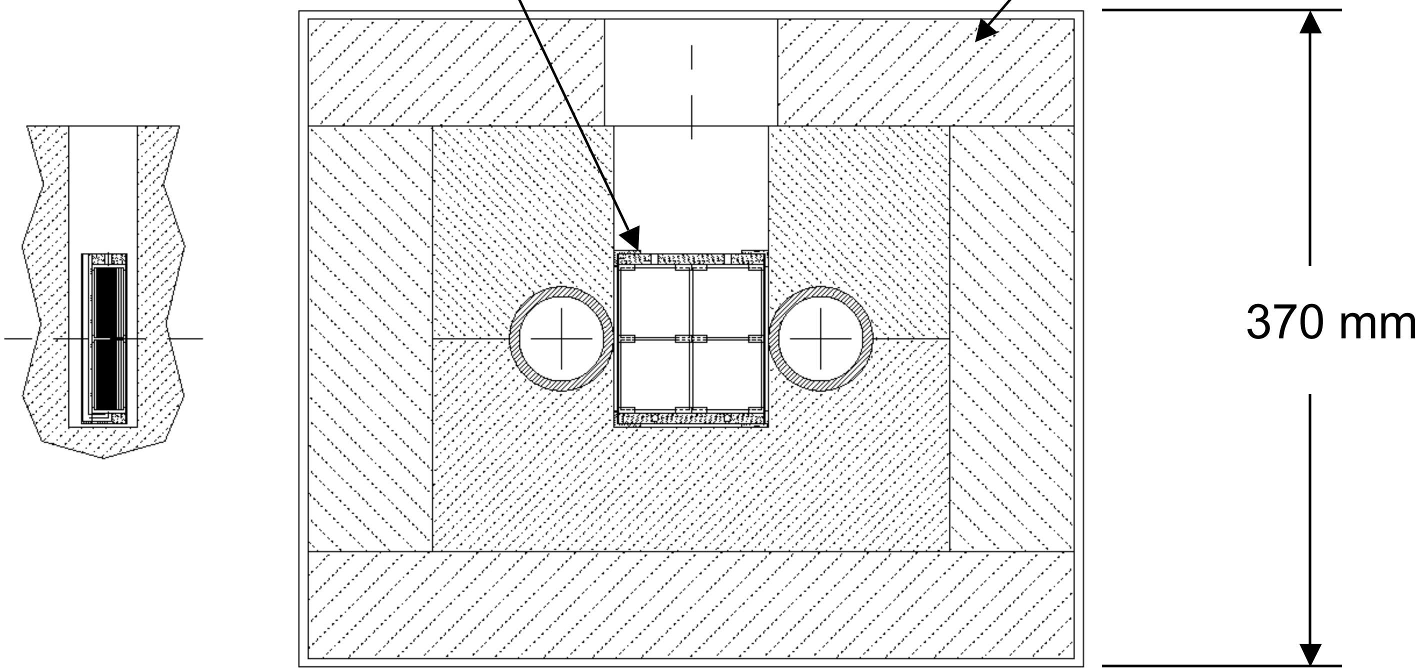
Design constraints for a detector placed near the shower maximum in the TAN

- Very high peak radiation fluxes and high induced activation over many years of operation, 170 MGy (17GRad)/oper yr,

Particle type	Peak Flux($cm^{-2}sec^{-1}$)
Charged hadrons	3.6×10^{8}
Electron/positron	5.8×10^{10}
Photons	8.1×10^{11}
Neutrons	3.2×10^{9}

- Size limited to 80 x 80 mm^2 by beam-beam separation at the TAN
- ~ 25 ns clearing time between bunch crossings
- Sensitivity to a single pp interaction with good S/N ratio, ~ 270 mips in 40 x 40 mm^2/ppi
- An Ar-N_2 gas ionization chamber is our detector choice - the simplest detector that can meet the requirements

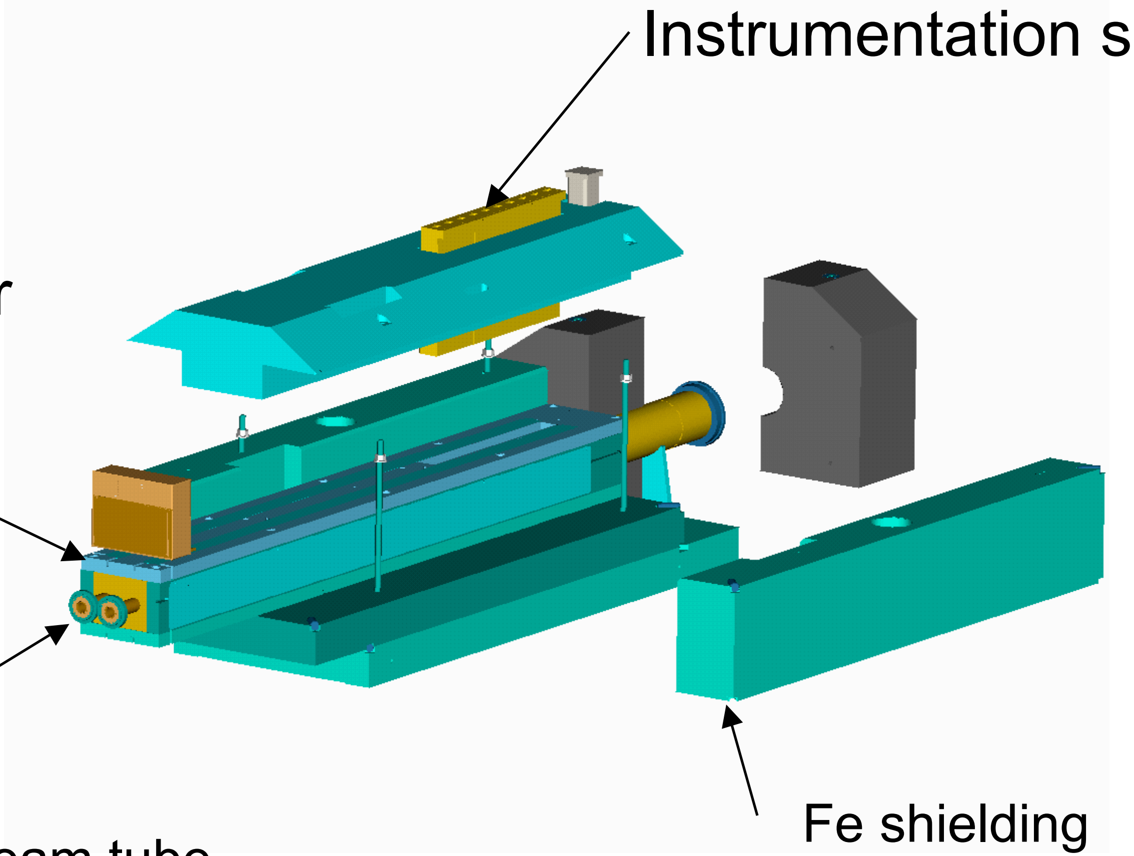
Layout of Neutral Absorber ionization chamber



Multi plate ionization chambers
4ea 40mmx40mm

TAN inner absorber box

TAN absorber schematic



Instrumentation slot

Inner Cu absorber box

Y chamber beam tube

Fe shielding

US
LARP

Parameters for an ionization chamber module

Active area(1 quadrant)	40mm x 40mm
Plate gap	1.0 mm
No. of gaps	6
Gas	$Ar+N_2$(6%), 6x760 Torr
Gap voltage	1200 V
Electron gap transit time	22 nsec
mip per pp int (3 W/kgm)	268
mip per bunch xing@10^{34}	$6.8x10^3$
Electron/ion pairs/cm-mip	388
Ioniz e^-/pp int	$9.5x10^4$ (6 gaps)
Ioniz e^-/bunch xing@ 10^{34}	$2.4x10^6$ (6 gaps)
Mean pulse height/pp int	15mV
Mean pulse height/bunch xing	380mV

Bringing the beams into initial collision

- One approach - start with a coarse grid map with successively finer mesh
- An example - 43x43 bunches, 3×10^{10}p/bunch, $\beta^* = 18$m, $L = 3.8\times10^{29}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

∀ $\sigma^* = 95.5\mu$m

Domain	Grid size	δL/L	Integration time (sec)
16σ x 16σ	4σ	1%	30.3
8σ x 8σ	2σ	“	“
4σ x 4σ	1σ	“	“
2σ x 2σ	0.5σ	“	“
1σ x 1σ	0.25σ	“	“
0.5σ x 0.5σ	0.125σ	“	“

- Total integration time approximately 3 min. Practical considerations of LHC operations will dominate the time needed to bring the beams into collision.

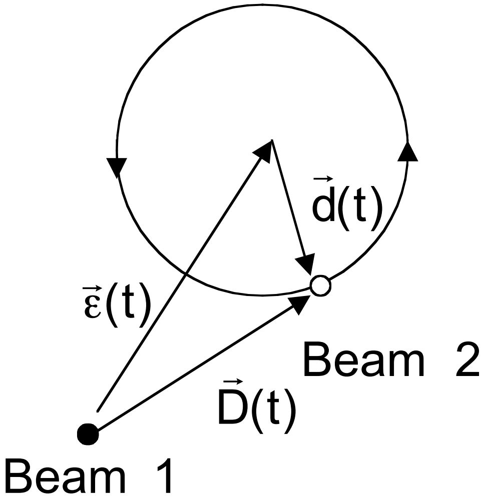
Concept for optimization of luminosity

An intentional transverse sweep of one beam introduces a time dependent modulation of luminosity

ε = error offset amplitude

d = intentional sweep amplitude

$$L \approx L_0 - L_0 \frac{\varepsilon d}{2\sigma_*^2}\cos(\omega t - \varphi);\ \varepsilon, d << \sigma_*$$



- Define the detector current

$$I(t) = e\alpha\varepsilon_{\det} m\sigma_{inel} L$$

- Integrate to obtain the luminosity and error offset, 0 < *t* < *T*,

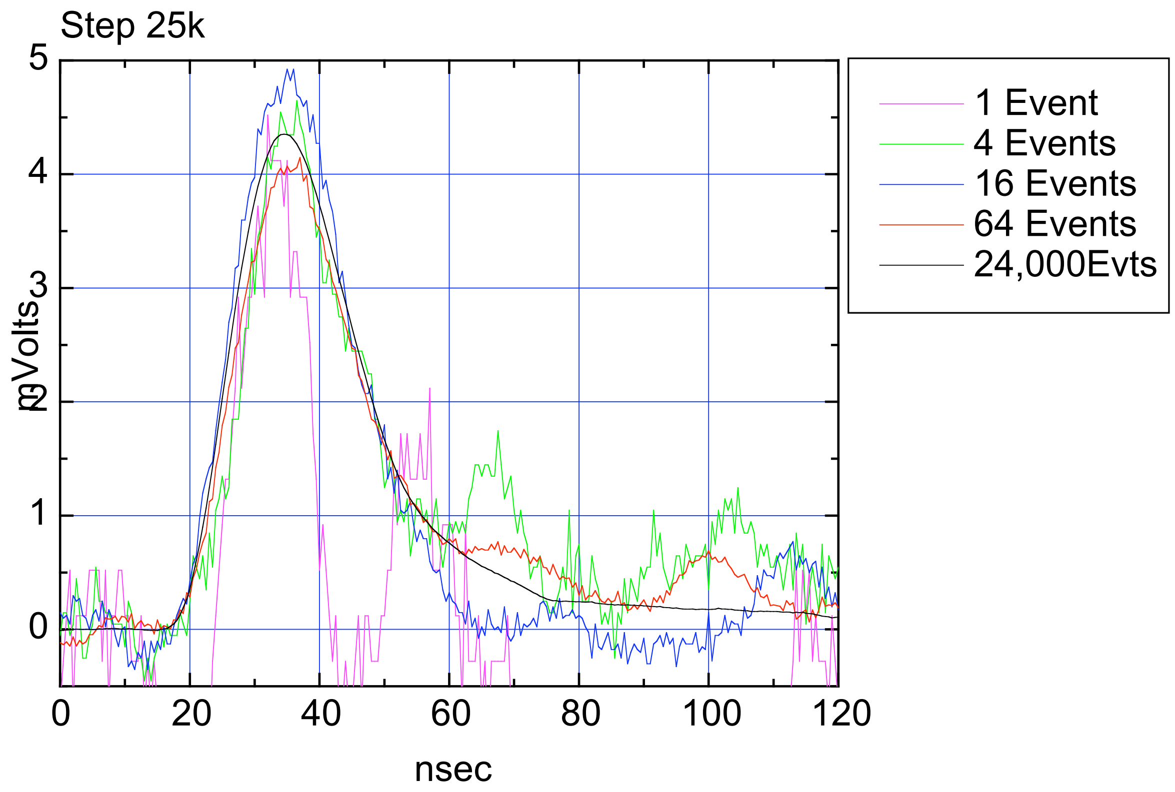
$$L_0 = \frac{\int_0^T I(t)dt}{e\alpha\varepsilon_{det} m\sigma_{inel} T};\qquad \vec{\varepsilon} = -\frac{\hat{e}_x \int_0^T \cos(\omega t) I(t)dt + \hat{e}_y \int_0^T \sin(\omega t) I(t)dt}{\left(\frac{d}{4\sigma_*^2}\right) e\alpha\varepsilon_{\det} m\sigma_{inel} T}$$

Prototype tests in the SPS H4 300-400GeV proton beam (unbunched)

- The shower produced by a single 300-400 GeV proton closely simulates the shower produced in a single pp interaction on LHC
  - ~231 mips/SPS p versus ~268 mips/LHC pp int (per quadrant)

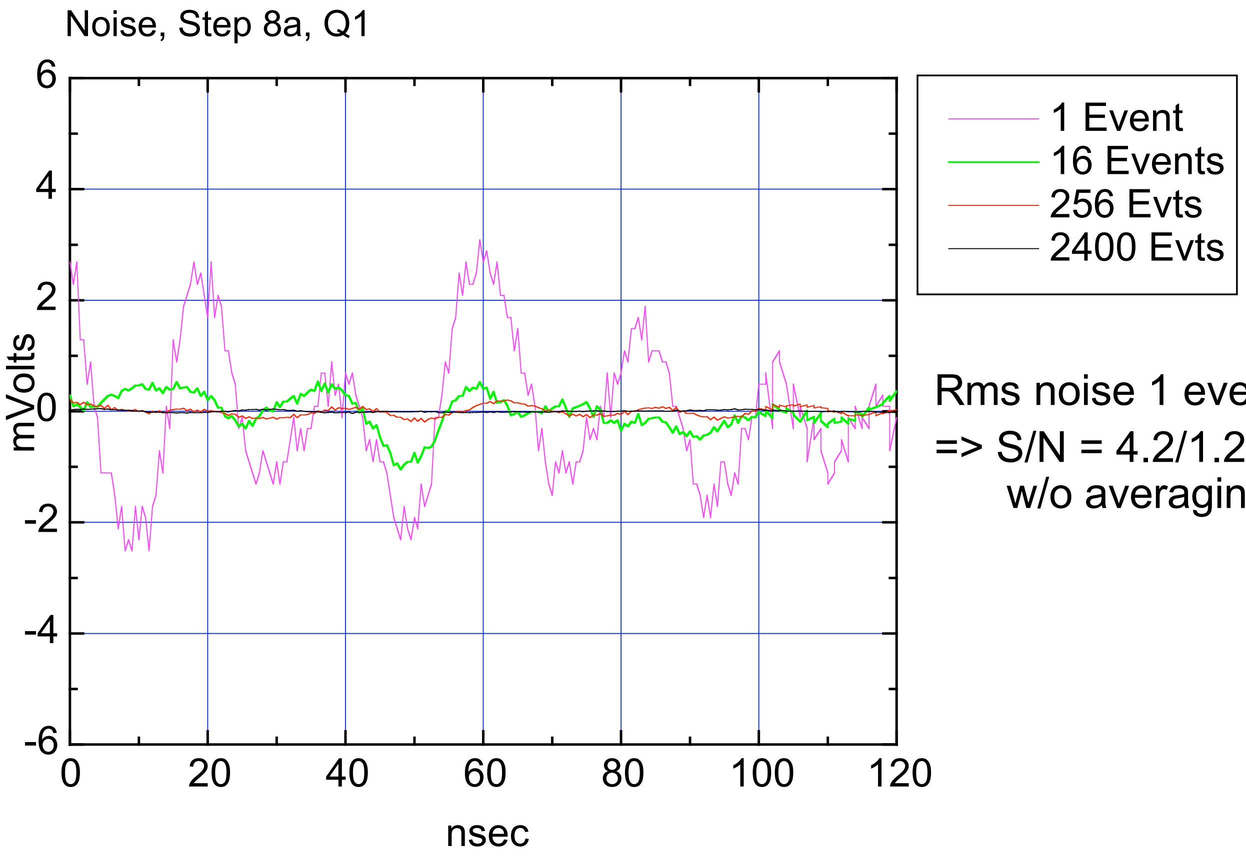
- The SPS tests demonstrated
  - Sensitivity to single pp interaction in LHC
  - Average pulse height in agreement with MARS simulations
  - Axial shower development in agreement with MARS simulations
  - $N^{-1/2}$ scaling of noise
  - Linear scaling of pulse height with gas pressure up to 600kPa with constant E = 600V/mm
  - Left/right asymmetry measurement of the shower axis
  - Feasibility of a de-convolution approach to correct for pile-up in 40MHz operation

Waveform averaging improves proton shower S/N ratio



- Pulse height 4.2mV in good agreement with MARS prediction 4.4±0.8 mV

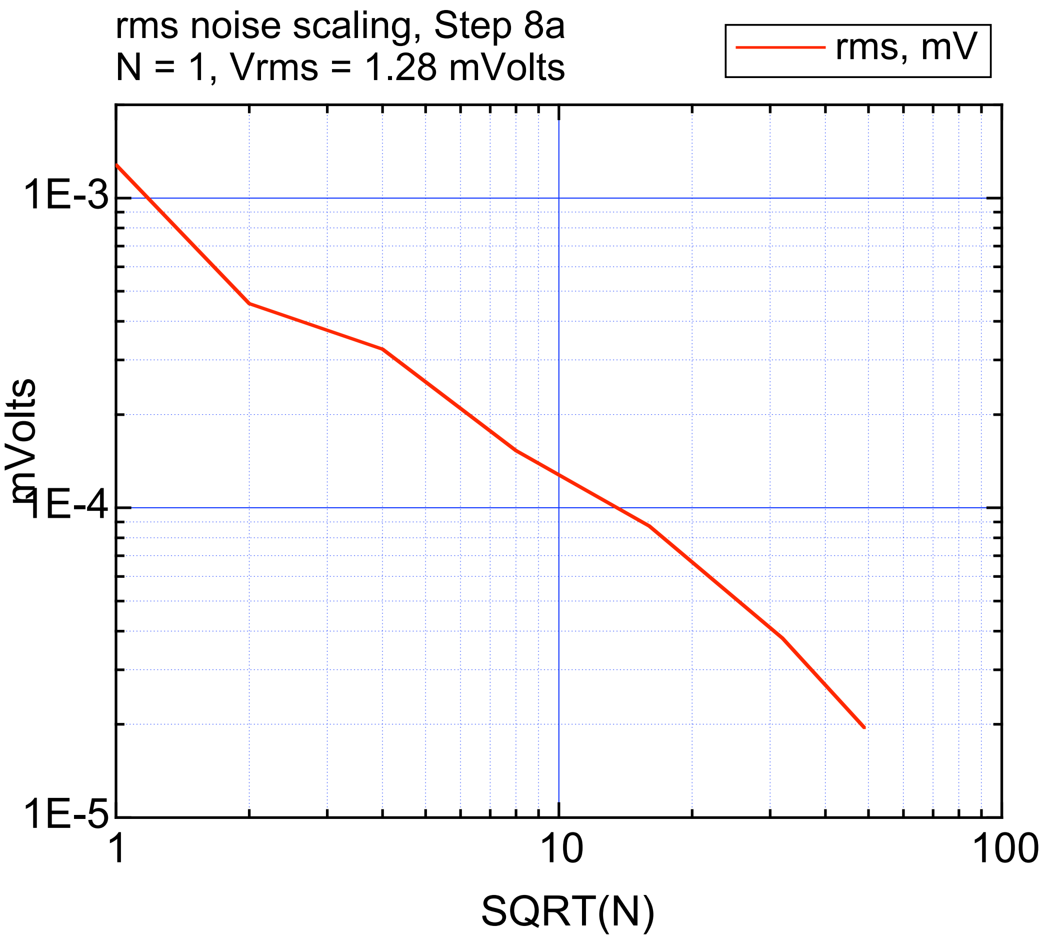
Noise averages to zero



Rms noise 1 event = 1.28 mV

=> S/N = 4.2/1.28 = 3.3 raw events w/o averaging

N $^{-1/2}$ scaling of rms noise

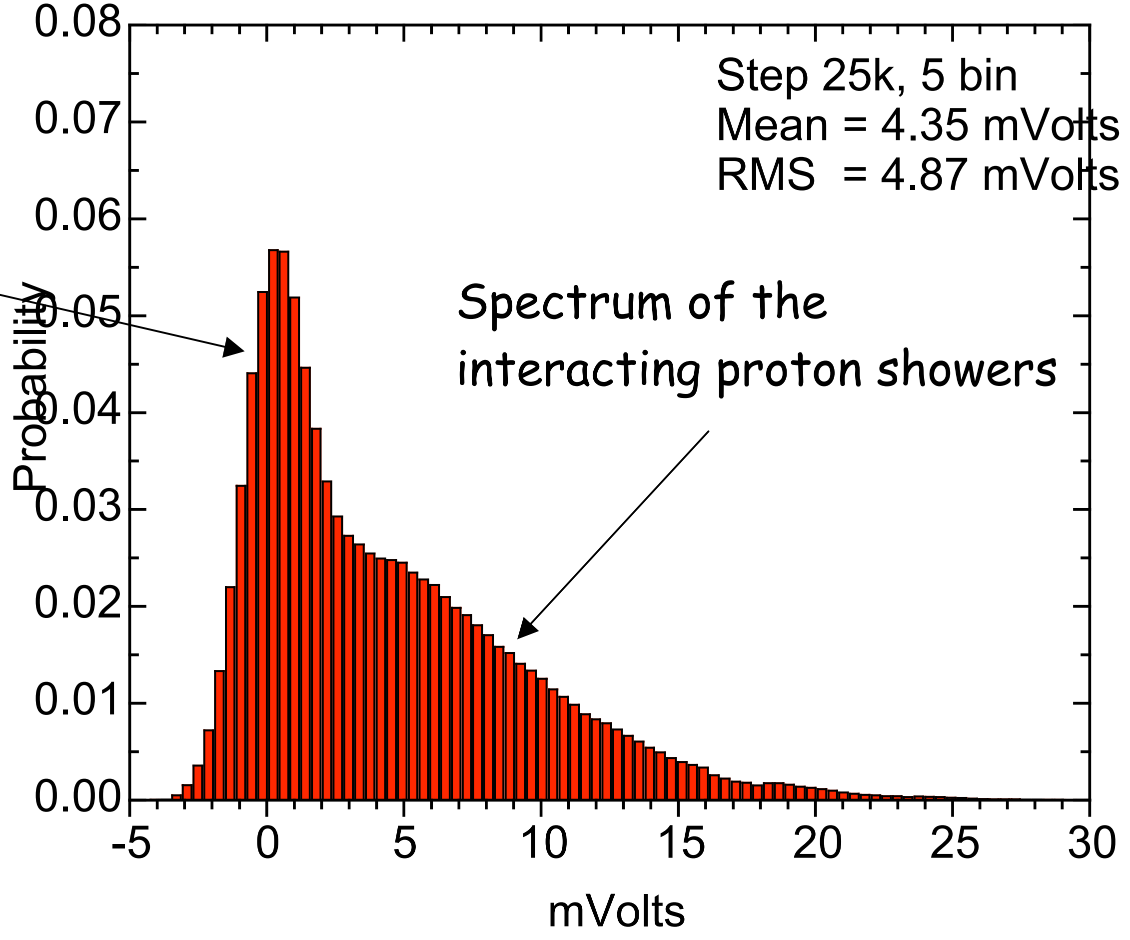


$$\mathrm{ENC} = 1.28/0.45\times10^{-3}$$
$$= 2{,}840\ e$$

Pulse height spectrum for proton triggers

Noise spectrum due to non interacting proton fraction

$$P = e^{-\frac{z}{\lambda_{int}}} \approx 0.33$$



Spectrum of the interacting proton showers

Fe absorber thickness scan, MARS data normalized to peak of experimental data