Attività LHCb - 2014

Nicola Neri
INFN - Milano

Consiglio di Sezione
24 Giugno 2013

Flavor physics potential

- Flavor physics has an excellent track record to probe high energy scale:
  - 1964: CP violation in kaon system was, in hindsight, the evidence for a third family of quarks
  - 1970: charm quark prediction from $K^0 \to \mu^+\mu^-$ (GIM mechanism)
  - 1980-1990: heavy top quark from Δm_B
- Study CP violation and its connection with matter/anti-matter asymmetry of the Universe
- Indirect search for new physics (NP):
  - look for NP effects in processes precisely predicted in the SM
  - complementary to direct searches (Atlas, CMS)
  - possibility to probe mass scale in the multi-TeV range, beyond the energy frontier

Flavor Physics in the LHC era

- Hopefully Atlas/CMS will find new particles in direct searches at 14 TeV. Although, the couplings and flavor structure of NP cannot be determined using only hight-p_t data
- Precision flavor measurements provide strong constraints on NP models and can distinguish among them
- Possibility to extend the physic reach of the LHC program, exploring beyond the energy frontier
- Absence of NP signals at Atlas/CMS makes the argument for searches via rare decays stronger

Constraints on NP from flavor observables
An example

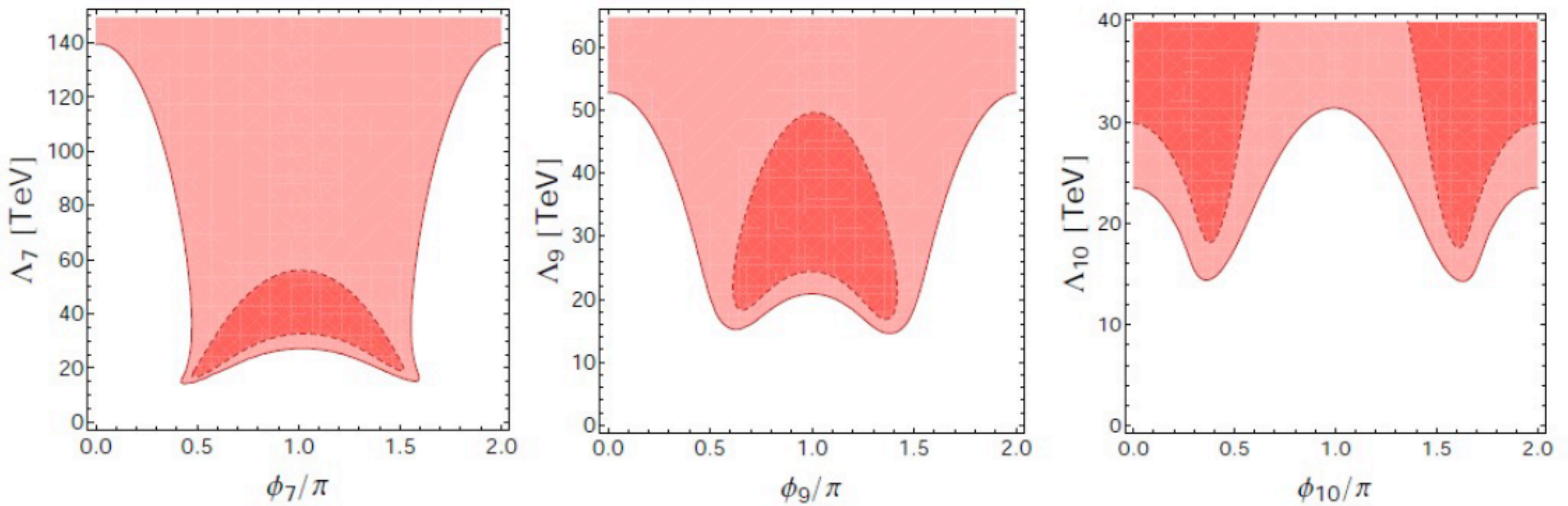
Measurements of $B \to \mu\mu$, $B \to K^*\mu\mu$, $B \to X_s \ell\ell$, $b \to s\gamma$ sets limits on the mass scale of non-SM contributions

Altmannshofer, Paradisi , Straub: JHEP 04 (2012) 008 + updates

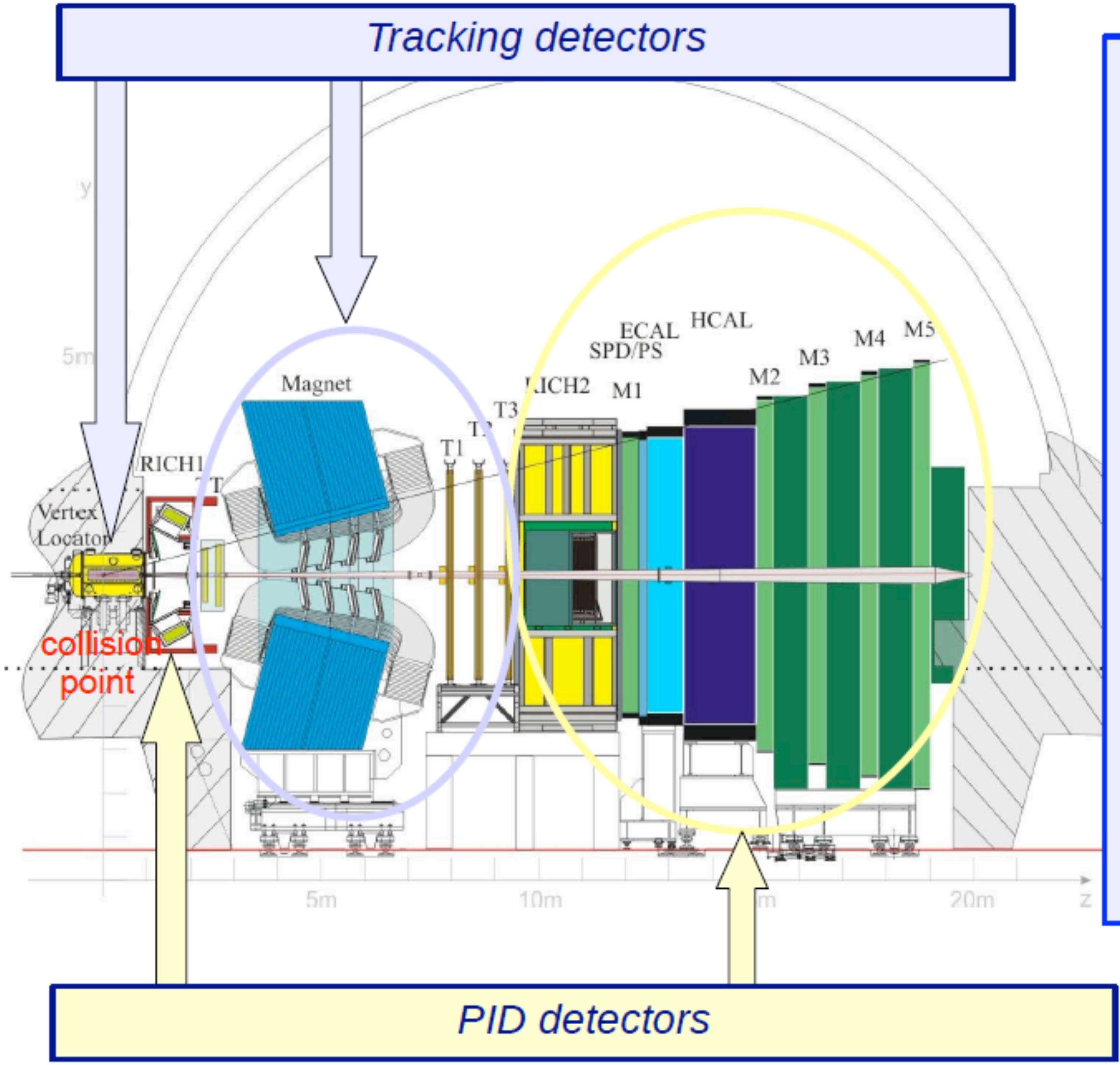
If we assume tree level process with O(1) couplings
Limits on this are in excess of 15 TeV

$$\mathscr{L} = \mathscr{L}_{SM} + \sum_{j=7,9,10} \frac{e^{i\phi_j}}{\Lambda_j^2} \mathscr{O}_j$$

~tree level generic flavour violation



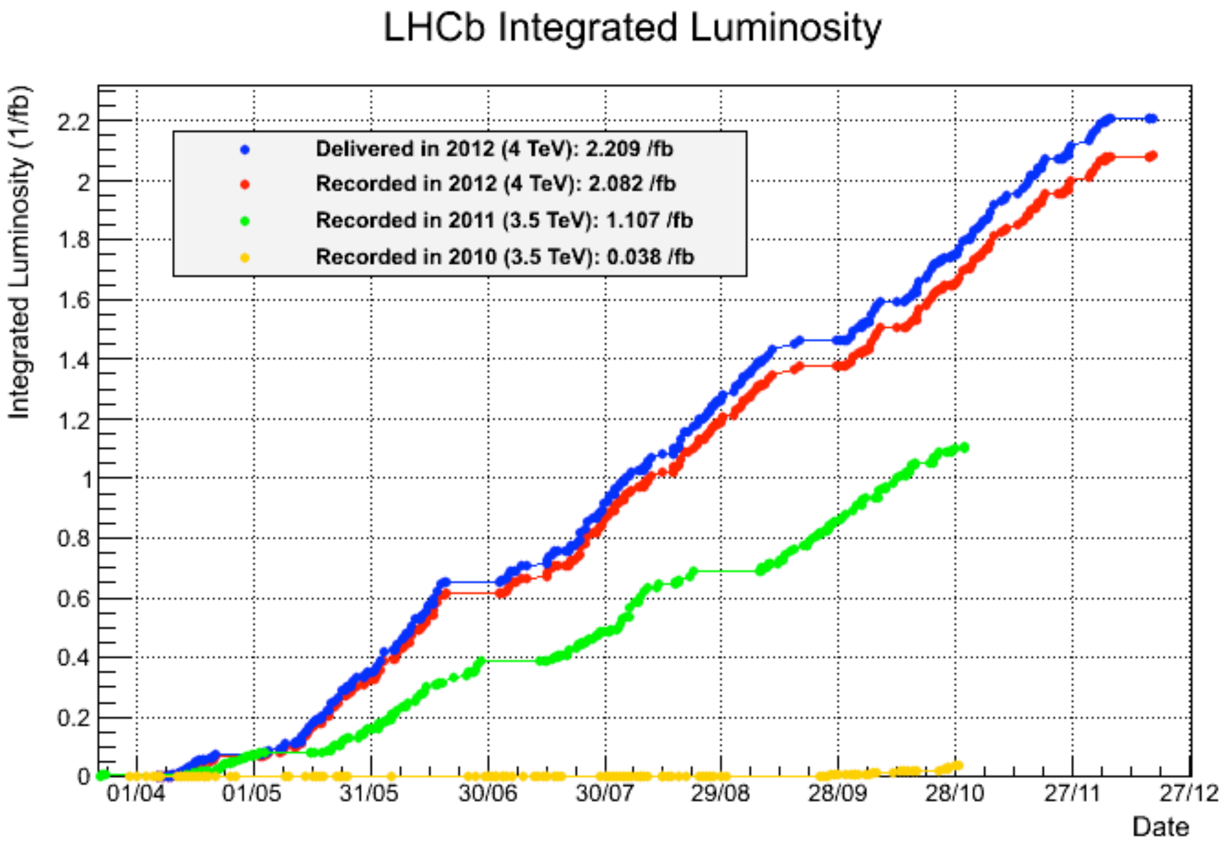
LHCb experiment



- *Forward spectrometer with planar detectors: optimized for the forward peaked heavy quark production at the LHC*
- *covers about 4% of the solid angle, but captures around 40% of the heavy quark production cross-section*
- *Detector acceptance: 1.9<η<4.9 fully covered by the tracking system → unique at the LHC*
- *Size: 10m high, 13m wide, 21m long*
- *Weight: ~5600 tons*
- *Number of r/o channels: ~10^6*
- *Designed to run at a moderate luminosity: large pile-up complicates identification of the B decay vertex and flavor tagging*

Collected data sample 2011-2012

- Integrated luminosity ~3.2 fb^{-1}
- Number of events within detector acceptance
  - $c\bar{c}$ 59×10^{11}
  - $b\bar{b}$ 26×10^{10}

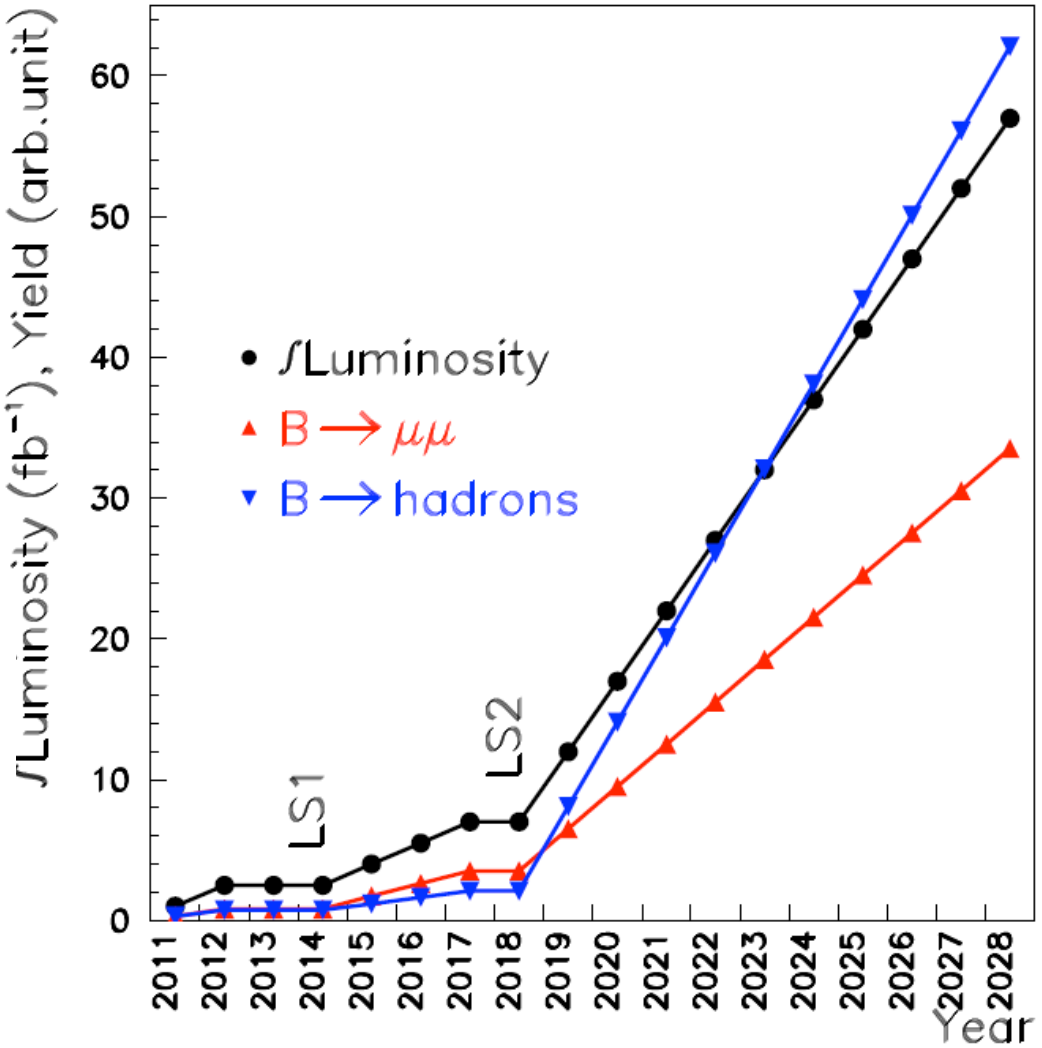


Future plans

- LHCb dominates many key measurements in heavy flavour physics with 2011 data alone.
- Adding 2012 data will triple statistics.

- SM does very well!
- Searches however (in many channels) still far from theoretical precision: much room for improvement.

- $\sigma(b\bar{b})$ will double after LS1
- LHCb upgrade planned for 2018. (CERN-LHCC-2012-007)
- Allows $5\times$ increase in luminosity.
- Full software trigger: will more than double (hadronic) efficiency.



LHCb recent results - few highlights

- First observation of CP violation in the B_S decays

  Phys. Rev. Lett. 110 (2013) 221601

  - $A_{CP}(B^0_S \to K^- \pi^+) = +0.27 \pm 0.04 \pm 0.01$

- First evidence of $B_S \to \mu^+ \mu^-$

  Phys. Rev. Lett. 110, 021801 (2013)

  - Branching ratio $B^0_S \to \mu\mu = (3.2^{+1.5}_{-1.2}) \times 10^{-9} \Rightarrow$ impact on SUSY

- First evidence of CP violation in D^0 decays

  Phys.Rev.Lett. 108 (2012) 111602

  - $\Delta A_{CP} = (-0.82 \pm 0.21 \pm 0.11)\%$ corresponding to 3.5σ (2011)
  - More recent results do not confirm this evidence (to be assessed)

- B_S oscillations and CP violation

  arXiv:1304.2600 [hep-ex]

  - $\varphi_S = 0.01 \pm 0.07(\text{stat}) \pm 0.01(\text{syst})$ rad
  - $\Delta m_S = 17.768 \pm 0.023 \pm 0.006\ \text{ps}^{-1}$; $\Delta\Gamma_S = 0.106 \pm 0.011(\text{stat}) \pm 0.007(\text{syst})\ \text{ps}^{-1}$
  -

INFN Milano admitted to LHCb program

- CSN1 approval to apply for LHCb membership on March 25th
- Obtained LHCb full membership few weeks ago. Ratified by LHCb Collaboration board on June 5th
- Interest to participate to the upgrade of the detector in 2018:
  - upgrade project already funded for 70% of the budget. Some funding agencies still need to decide
  - CSN1 and LHCb referees support LHCb upgrade. CTS audition on July 12th in Rome

Group composition

- The research group is composed of individuals affiliated to INFN - Sezione di Milano, Università di Milano and Politecnico di Milano. It comes mainly from the experience of BaBar and SuperB:
  - participation in LHCb in 2014: 10 people - 7.4 FTE

People	Position	FTE
J. Fu	INFN PostDoc	1.0
N. Neri	PhD Staff	0.9
F. Palombo	Faculty	0.9
A. Abba	Engineer PostDoc	1.0
F. Caponio	Engineer PhD student	1.0
M. Citterio	Applied Physicist Staff	0.3
S. Coelli	Mechanical Engineer Staff	0.3
A. Cusimano	Engineer Post Doc	1.0
A. Geraci	Electronic Engineer Staff	0.7
M. Lazzaroni	Electronic Engineer Staff	0.3
~~V. Liberali~~	~~Electronic Engineer Staff~~	~~0.3~~
FTE		7.4

Call CSN5?

INFN Milano ongoing activities

- Data analysis
  - search for CP violation in charm decays, sensible to new physics effects
- Upstream tracker (UT) upgrade
  - single-sided silicon strip detector upstream of the magnet. Crucial for charged track reconstruction, pattern recognition and trigger information
- Low Level Track Trigger (LLTT)
  - innovative L0 hardware trigger inspired by neurobiology and realized using FPGA. Allows tracking and trigger decisions at 40 MHz rate with a latency $<1\mu s$.

Manpower organization

- Analysis

	Staff		Temporary positions (existing)	
	FTE	n. of people	FTE	n. of people
Researchers	0.4	2	0.5	1

- UT Activity

	Staff		Temporary positions (existing)	
	FTE	n. of people	FTE	n. of people
Researchers	1.0	2	0.5	1
Engineers	1.3	5	1.0	1
Technicians	2.4	6		

- LLTT Activity

	Staff		Temporary positions (existing)	
	FTE	n. of people	FTE	n. of people
Researchers	0.4	2		
Engineers	0.3	1	2.0	2
Technicians				

Search for CP violation in $D^0 \to K^+K^-\pi^+\pi^-$

CP violation in D^0 decays is expected to be very small in the SM, <0.1%
Evidence of CP violation (CPV) would be a hint of new physics effects
First evidence of CPV in D^0 decays not confirmed by recent results
Hot topic. Need further studies: experiment and theory

- Asymmetry in a *T*-odd observable → *T* violation → *CPV* (assuming *CPT* invariance)
- *T*-odd observable (*v* = spin or momentum)

$$A_T = \frac{\Gamma(\vec{v}_1 \cdot (\vec{v}_2 \times \vec{v}_3) > 0) - \Gamma(\vec{v}_1 \cdot (\vec{v}_2 \times \vec{v}_3) < 0)}{\Gamma(\vec{v}_1 \cdot (\vec{v}_2 \times \vec{v}_3) > 0) + \Gamma(\vec{v}_1 \cdot (\vec{v}_2 \times \vec{v}_3) < 0)}$$

← measured on D^0

- Final State Interactions (*FSI*) may fake the measurement producing $A_T \neq 0$
- To remove *FSI* effects

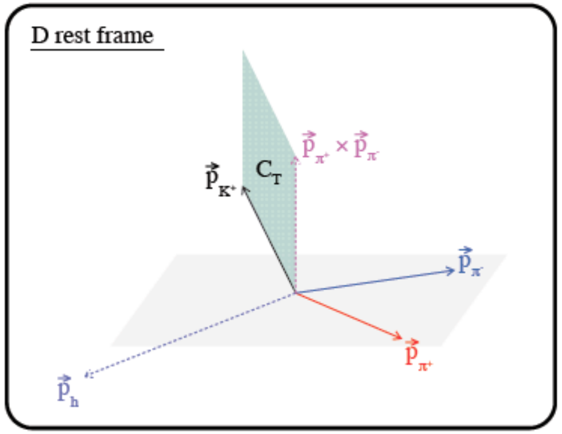
measured on $\bar{D}^0$

$$\mathcal{A}_T = \frac{1}{2}(A_T - \bar{A}_T)$$

T violation observable

- In $D^0 \to K^+K^-\pi^+\pi^-$

$$C_T = \vec{p}_{K^+} \cdot (\vec{p}_{\pi^+} \times \vec{p}_{\pi^-})$$ *T*-odd observable

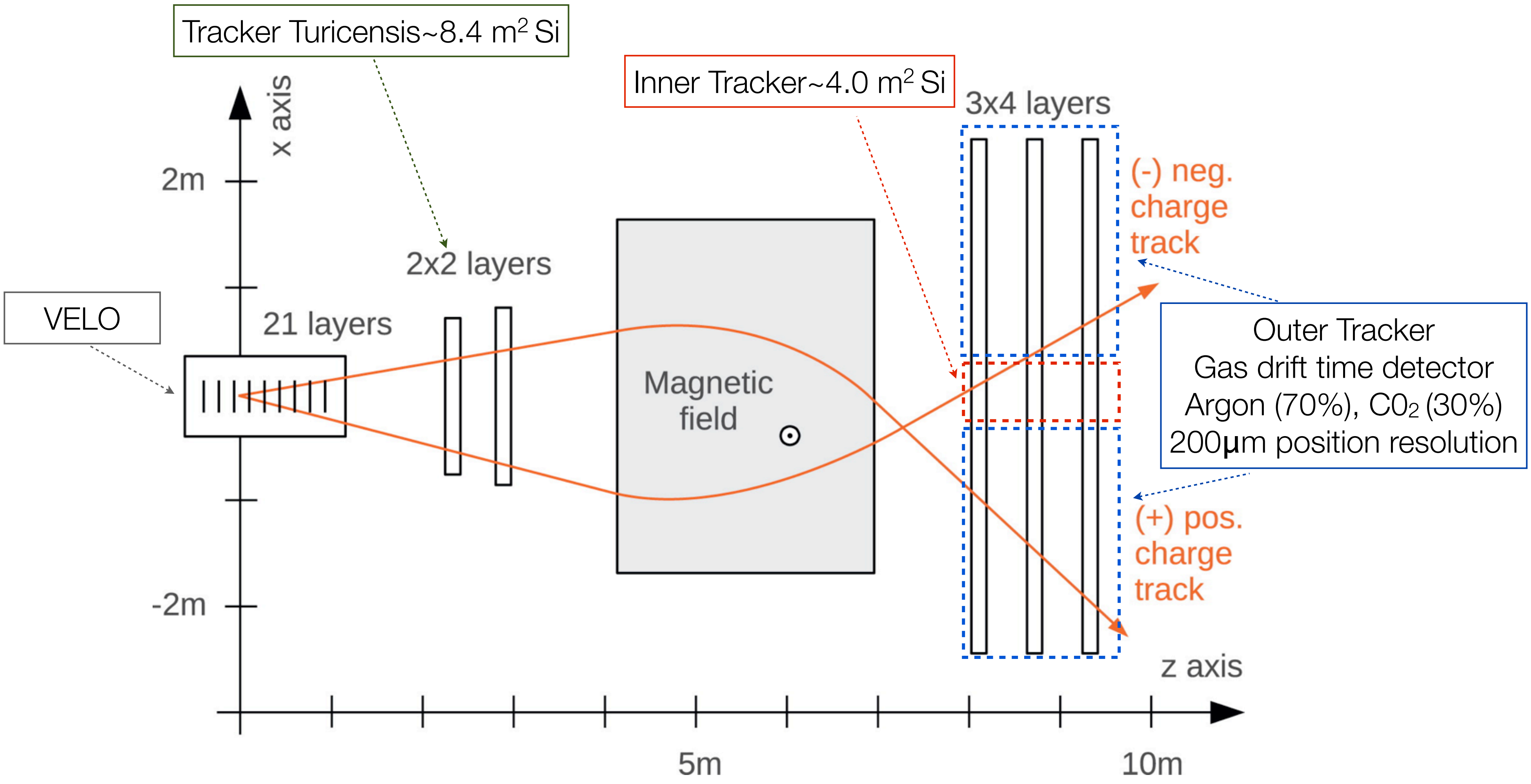


Sensitivity estimates

- Possibility to achieve 0.1-0.2% error on asymmetry using 2011-2012 LHCb data. Potential x5 improvement in sensitivity with respect to present BaBar results
- Method is not sensitive to $D^0/\bar{D}^0$ production asymmetry. No systematic error associated
- Access to CP violation in a single decay mode. Not necessary to quote difference of CPV asymmetries, ΔA_{CP}, of different decays to cancel systematic error
- Comparable sensitivity to other LHCb analyses "ΔA_{CP} analysis" for search for CPV in D^0 decay
- Jinlin Fu will present preliminary studies at the Collaboration this week

LHCb spectrometer

Silicon Tracker: 500µm thick, single sided Si strip detector, pitch~200µm, vertical and stereo angle strips arrangement (x-u-v-x)=(0°,-5°,+5°,0°)



UT detector upgrade

- UT is the upgrade of the present TT detector, required to operate at 40MHz
- 4 detector planes (~1.5x1.3 m^2) silicon detectors:
  - 250 μm single sided strip sensors
  - stereo angle strips for 2 layers: X, U, V, X (0,+5,-5, 0)°
- The UT detector system role in LHCb tracking:
  - Improvement in mass resolution, ~25% for tracks with UT hits
  - Momentum determination in VELO-UT tracking ~ 15% resolution
  - Crucial for fast trigger decisions based on p_t of the tracks
  - Ghost suppression, ~x3 suppression factor
- Parameters affecting the performance:
  - it is crucial to minimize the detector material, e.g. support structure, active cooling (operations at -5 °C), electronics in the active area

UT Mechanical Activities

Capitalize R&D for Atlas IBL

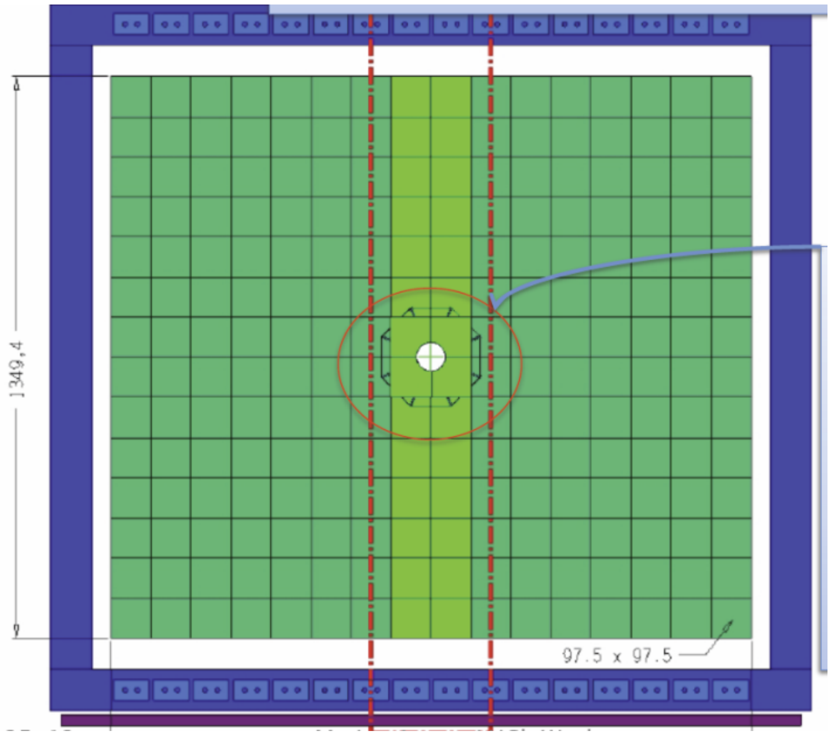
Mechanical Dpt: **Simone Coelli, Mauro Monti**

Work in progress:

Design of some «proposal» staves for a preliminary F.E.M. thermal analysis

- 3D model of stave intended to be located in the UT plane vertically in the central or the peripheral zone
- Vertical integrated pipe made in Titanium 1.5 mm internal diameter and thickness 0,1 mm
- Integrated in a carbon foam with density 0,2 g/cc a thermal conductivity 30 W/mK
- Hypothesis based on CO_2 evaporating system at -30/-40 °C
- Thermal Power input as from the documents availal to be checked
- Starting with structural carbon fiber reinforced envelope K13/RS3 system (0/90/0), (based on experience in ATLAS IBL support)
- Radiation length with one pipe (two pipe in the cent part can be studied) and thermal performance evaluation with different stave thicknesses
- Study of the cooling connection taking into account the integration issues, to be discussed

UT detector plane

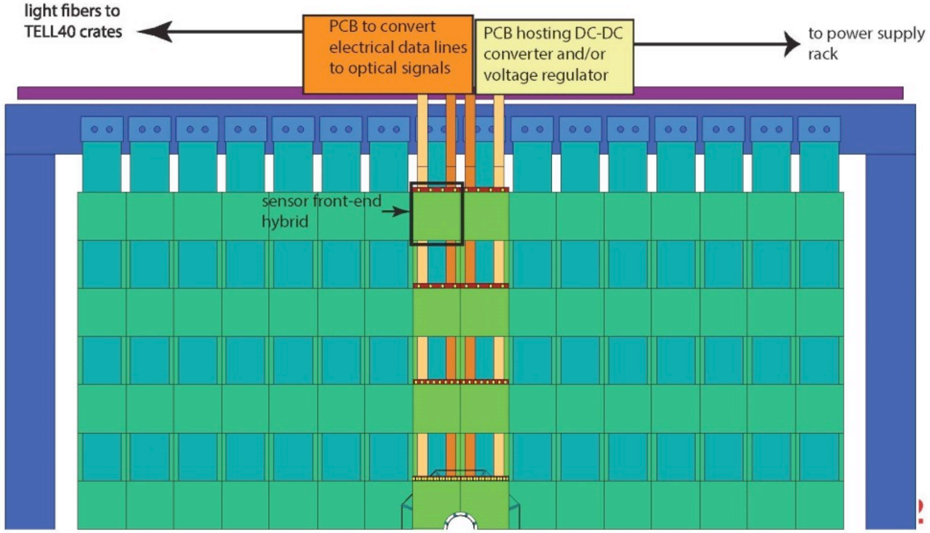


UT Electronics Activities
Capitalize R&D for SuperB project

→Studies on Low Mass Data Cables
- → Based on other experience we have been focused on micro-twisted cables and magnet wires made in “tape shape”
- → If study unsuccessful then custom design

→Studies on Low Mass Power Cables
- → A custom design with some “preliminary” constraint has been recently initiated
  - → max current, voltage drop not yet clear
- → The material of choice is kapton and copper
  - → Alternative to kapton could be siltem
  - → Alternative to copper could be aluminum

→DC-DC converters or LDO Regulators
- → Large experience with ST_LHC regulators (ATLAS Pixe PP2 distribution system > 3000 remotely programmable voltage channels)
  - → They could be a standard solution
- → Presently interested on Dual, 26VIN, 4A DC/DC μModule Regulator from Linear (LTM4619)



→Front-end hybrid
- → Not yet initiated, awaiting for more info on the IC
- → Not to be considered a real critical item

Idea of the algorithm

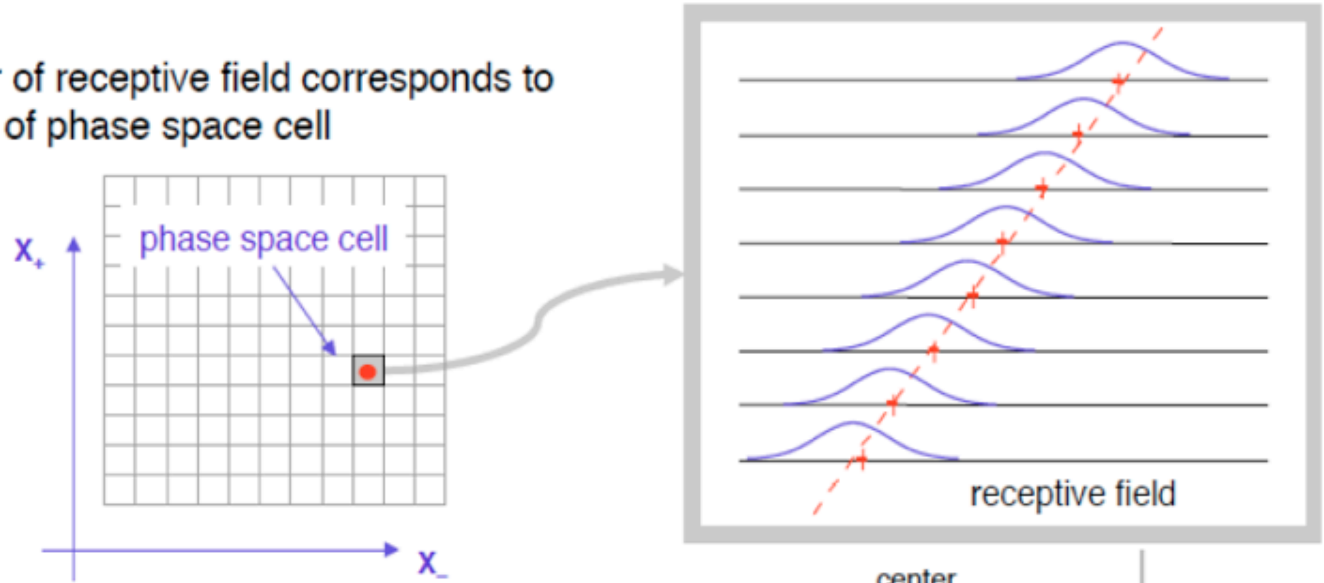
G. Punzi
CERN workshop June 13

- Extensive parallelism/huge connectivity.
- Interpolation between cells allows minimizing hardware size
- Implement as FULLY DIGITAL (simulable) device.
- Need to prove feasibility in LHCb tracker

Idea proposed by Luciano Ristori in NIMA, 453 (2000) 425-429

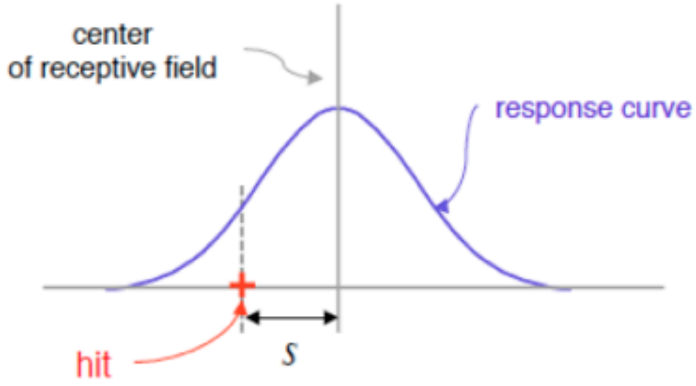
Not technically viable in 2000 but today...

Center of receptive field corresponds to center of phase space cell

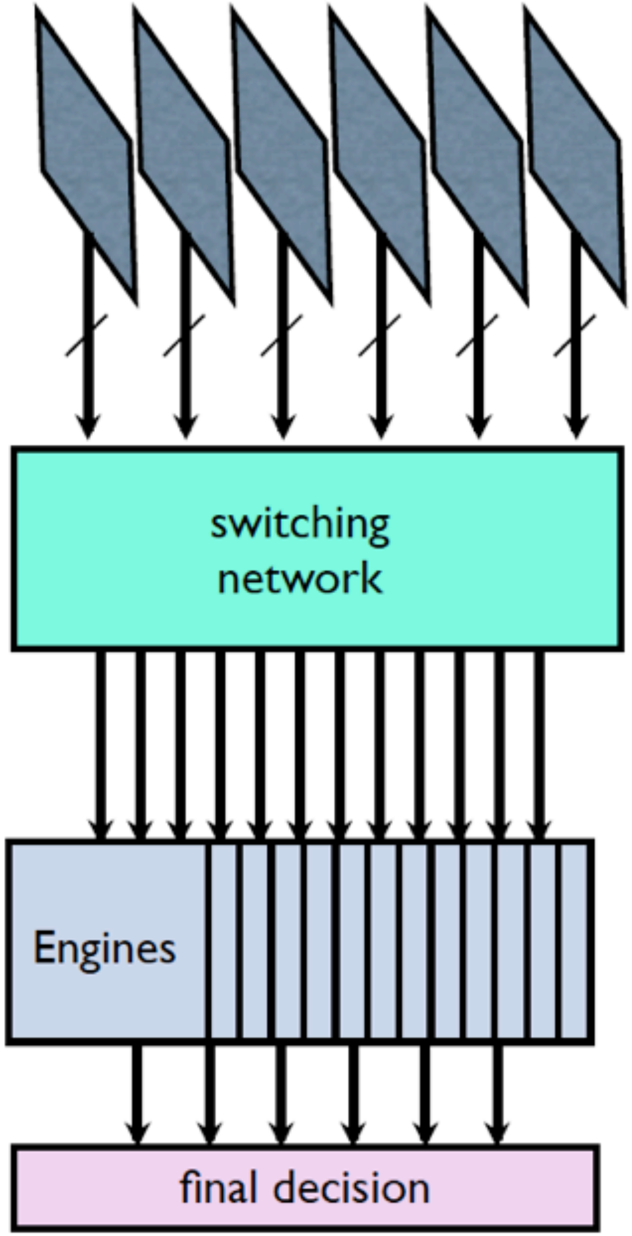


Response of each cell is summed over all hits

$$R = \sum_{\text{all hits}} e^{-\frac{s_i^2}{2\sigma^2}}$$



Architecture



Tracking detector layers

Optical links

Delivery of data to appropriate cells ⇒ F.Caponio
INFN - MI

Computing engines perform cellular algorithm ⇒ F.Spinella

Processing of found tracks
INFN - MI ⇒ A.Abba

Latency

1 t.u. (assuming clock frequency = 350 MHz) = 2.8 ns

DISPATCHER 15 t.u. | FANOUT 6 t.u. | ENGINES 90 t.u. | CLUSTERING 175 t.u. | FINAL 2-10 t.u.

~ 300 t.u. = **860 ns**

Implementation details

		DESIGN	SIMULATION
INFN - MI	SWITCH	✓	✓
	ENGINES	✓	✓
INFN - MI	CLUSTERING	✓	✓
INFN - MI	FINAL DECISION	*(in progress)*	
INFN - MI	HIGH LEVEL C++ SIMULATION	*(in progress)*	

FPGA LAYOUT
ALTERA 5SGXEA7H3F35C3 (AMC 40 FPGA)

INTERFACES

SWITCH (7.5%)

FPGA area

ENGINES (65-70%)

CLUSTERING (10%)

FINAL DECISION (1%-3%)

(10-15% BACKUP)

Designed for scalability

A. Abba
CERN workshop June 13

Contribution to the upgrade

Dal framework TDR per LHCb upgrade: CERN/LHCC 2012-007

Trigger Tracker		Cost [kCHF]	
Detector		3060	
	Sensors		2300
	Hybrids & Connectors		760
Electronics		2595	
	Silicon Strip RO chip		900
	Front End		450
	Optical Links		345
	Readout Board		740
	General Electronics		160
Infrastructure		560	
	Support Structure		230
	Cooling		330
		6215	

ITEM	COST
Extra AMCs for trigger path	+8 TELL40 ?
Switch	Extra links and logic
Processing engines	+8 TELL40 +1 SOL40 + crate
Final logic	+ ? boards +crate ?

UT upgrade
480 kCHF
INFN Milano

LLTT system
1200 kCHF
Milano-Pisa

Mechanics for the UT upgrade

- Design and simulation: thermal modelling, mechanical support
- Construction of prototypes for mechanical support and mockup of the cooling system
- Production of mechanical support and cooling system. QA of the production.
- Assembly and system test of the UT
- Installation and commissioning

Mechanics and cooling	2013 Q4	2014 Q1	2014 Q2	2014 Q3	2014 Q4	2015 Q1	2015 Q2	2015 Q3	2015 Q4	2016 Q1	2016 Q2	2016 Q3	2016 Q4	2017 Q1	2017 Q2	2017 Q3	2017 Q4	2018 Q1	2018 Q2	2018 Q3	2018 Q4	2019 Q1
Design and simulation	■	■																				
Construction of prototypes		■	■	■																		
Production and testing				■	■	■	■	■	■	■	■	■										
System assembly and test													■	■	■	■	■					
Installation and commissioning																		■	■	■	■	■

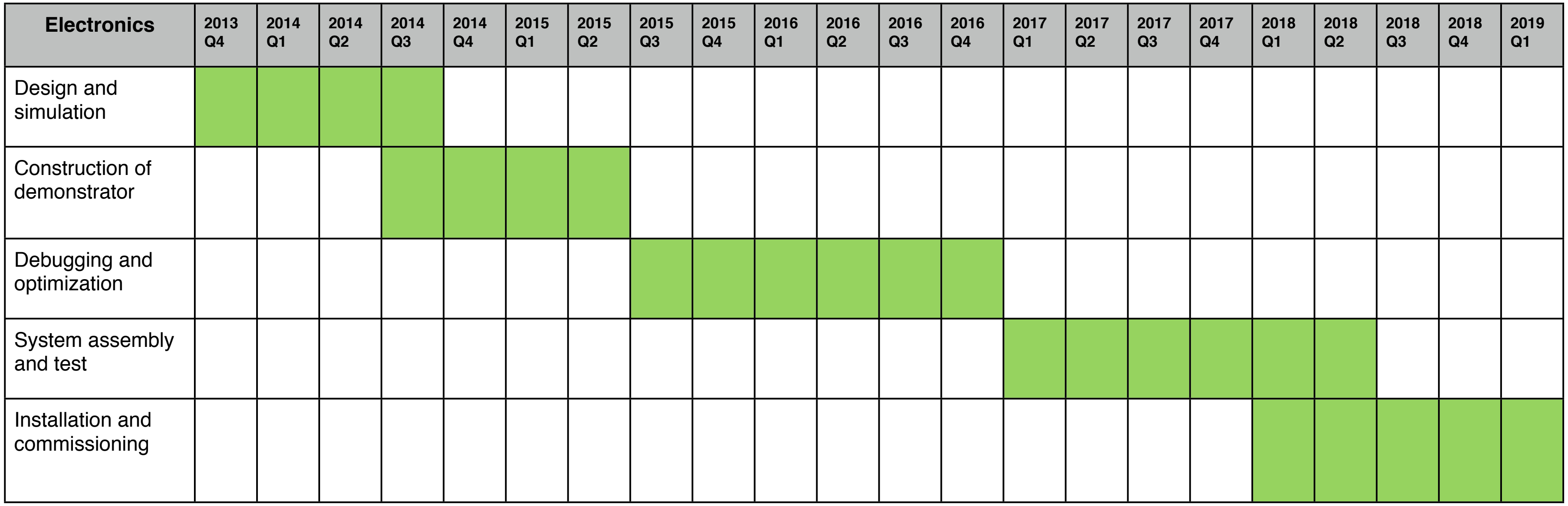
Electronics for UT upgrade

- Design and simulation: hybrids, fanout, low mass cables
- Construction of prototypes for hybrids, fanout and low mass cables and testing
- Production, assembly, bonding of chips to hybrids and testing of fanout and low mass cables. QA of the production.
- Assembly and system test of the UT

Electronics	2013 Q4	2014 Q1	2014 Q2	2014 Q3	2014 Q4	2015 Q1	2015 Q2	2015 Q3	2015 Q4	2016 Q1	2016 Q2	2016 Q3	2016 Q4	2017 Q1	2017 Q2	2017 Q3	2017 Q4	2018 Q1	2018 Q2	2018 Q3	2018 Q4	2019 Q1
Design and simulation	■	■																				
Construction of prototypes		■	■	■	■																	
Production and testing						■	■	■	■	■	■	■	■									
System assembly and test														■	■	■	■					
Installation and commissioning																		■	■	■	■	■

LLTT activity for the upgrade

- Design and simulation: FPGA and high level simulation
- Preparation of a demonstrator system for testing during 2015 run
- Detailed simulation, debugging and optimization of the complete system
- Assembly and system test of the UT



Requests for 2013 - ex SuperB funding

- Activity in LHCb UT very similar to previous activity in SuperB SVT: hybrids, low mass cables, power distribution, mechanics and cooling. Capitalize past experience by continuing previous R&D.
- For UT activity we have similar requests that we had for SuperB (40 kE):
  - Prototypes for hybrids with prototype Asics: hybrids (8 kE), bonding, test structure and probe card (4kE)
  - Prototypes for low mass cables for signal (5 kE), and for power (4 kE)
  - Mechanical prototype for UT stave and cooling system (15 kE): CFRP structural support with carbon foam conductive material, integrated cooling pipes with evaporating CO_2 coolant.
  - Mockup system for power distribution with “dummy HDI loads” on hybrids + power cables (4kE)
- LLTT Activity (5 kE):
  - Stratix V development Kit (5kE)
- Traveling funds (20 kE per 10 people-7.4 FTE) (4pers x 3 meeting= 12kE, 2pers x 2 analysis week= 4 kE, contacts with CERN and Syracuse for UT and LLTT activities 4 kE)
- Total request 65 kE. SuperB Milano fundings back in “fondo indiviso” are 60.5 kE

Requests for 2014 - preliminary

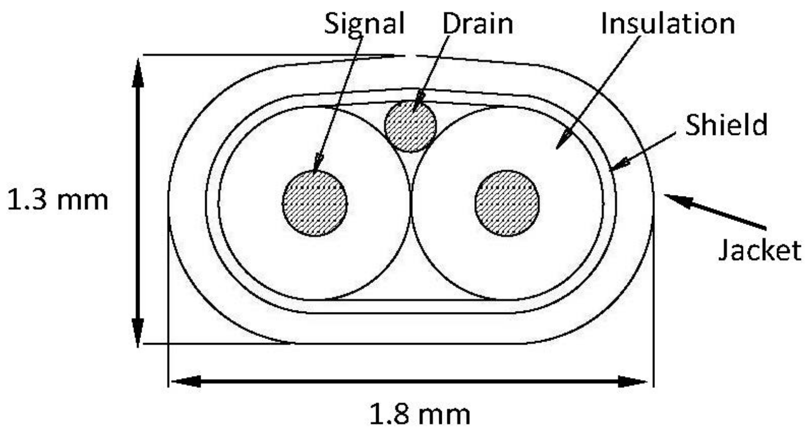
- Missioni (MI+ME) ~95 kEuro (tassa SF=25 kEuro)
- Metabolismo ~12 kEuro
- Apparati ~80 kEuro (UT)
- Consumo per R&D: ~ 20 kEuro (UT) + 15 kEuro (LLTT)

Request for INFN service

- Relevant services in Milano for LHCb activity:
  - Electronics workshop: 1.8 FTE (Technical staff, 3 people)
  - Mechanics workshop: 1.0 FTE (Technical staff, 3 people)
  - Clean room for silicon detectors

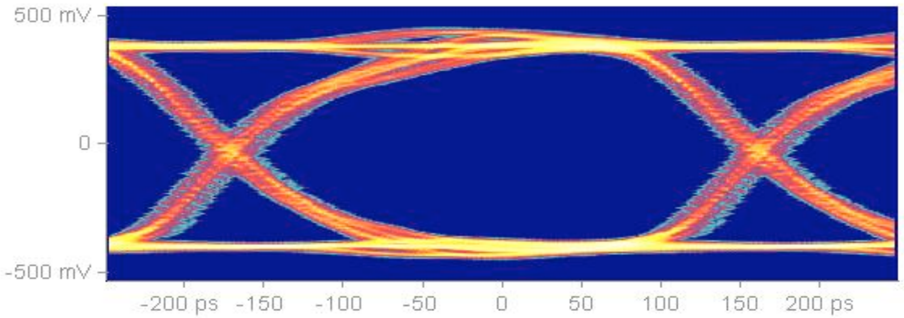
Backup slides

Studies on data cables (1 of 2)

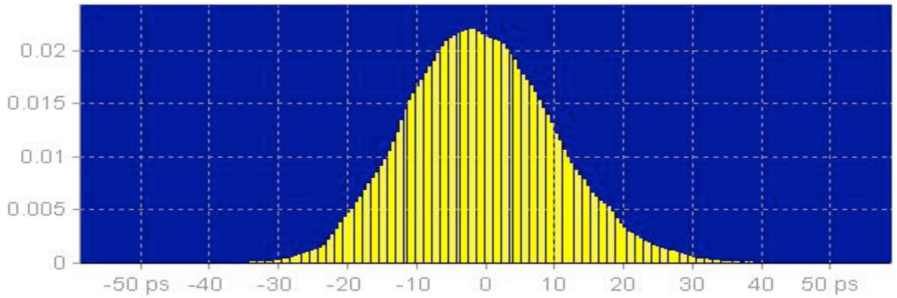


Signal: 30 AWG, Solid Copper Clad Aluminum
Differential Impedance ~ 100 Ohms +/- 5%
Capacitance: 16 pF / ft
Propagation Delay: < 2 ns/ft

The preliminary measurements show that a "typical commercial 2 Gb serializer" can drive about ~ 3 m cable without substantial degradation (even without pre/post emphasis)



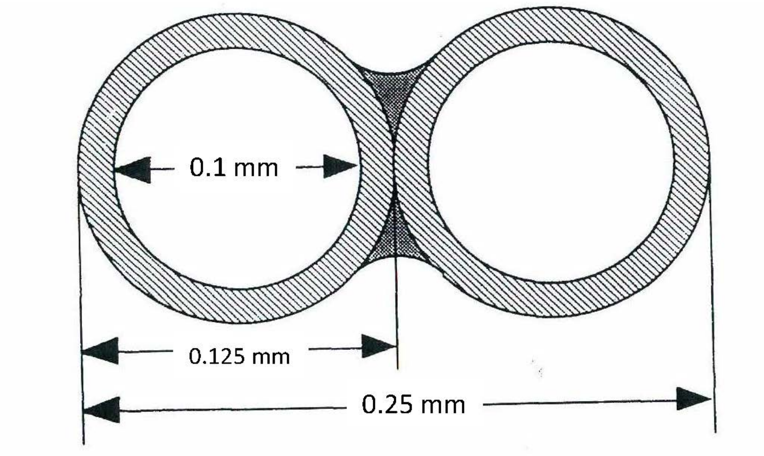
Eye diagram



BER probability density function

Studies on data cables (2 of 2)

→Possible alternative solution



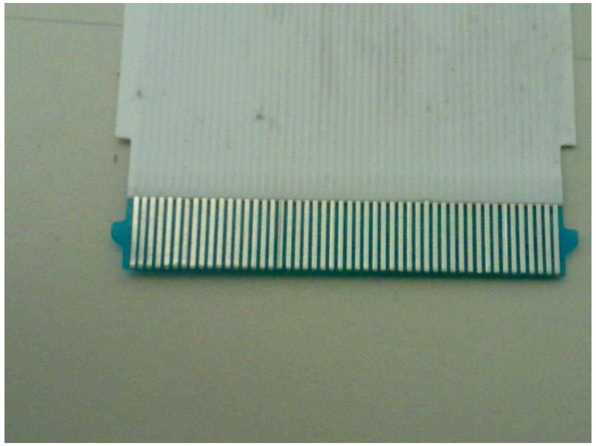
Signal: 39 AWG, Bifilar magnet wires (Cu)
Differential Impedance: to be measured
Capacitance: 75 pF/m
Propagation Delay: to be measured

Dielectric costant: 2.1

Twisting is not needed for such a small wire

Electric test not yet started
- we have in house only "single" bifilar wires.
- difficult to make proper connection to test set-up

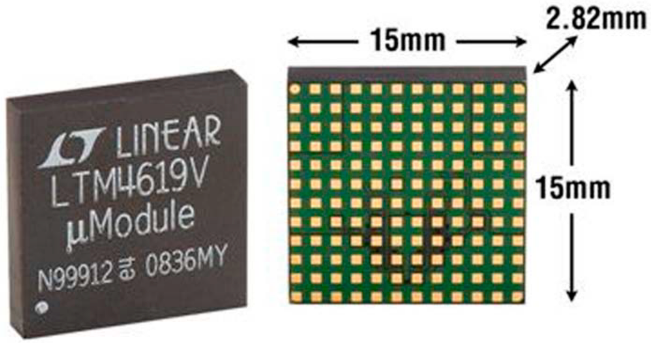
It probably can be purchased in tapes with multiple wires
- mechanical stress to be performed
- bending radius not known



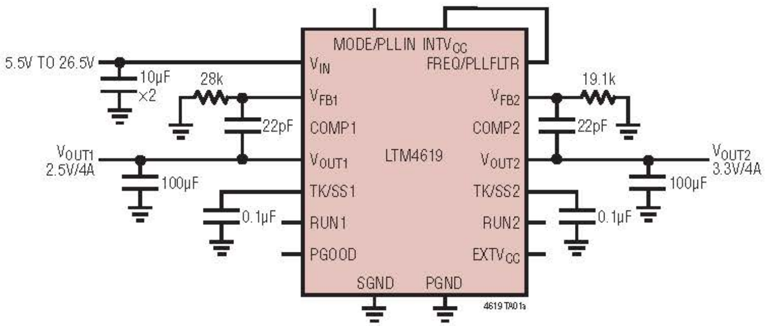
Picture shows a tape made with larger diameter magnet wires, both plastic material and wire diameter need to be changed for our application

Studies on LTM4619 (1 of 2)

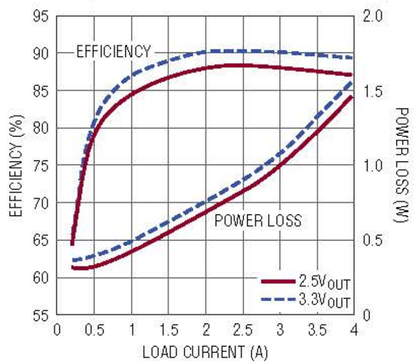
The LTMR4619 is a complete dual 4A step-down switching mode DC/DC power supply.
Included in the package are the switching controller, power FETs, inductor, and all support components.
Operating over input voltage ranges of 4.5V to 26.5V.
Two outputs with voltage ranges of 0.8V to 5V, each set by a single external resistor.
Its high efficiency design delivers 4A continuous current (5A peak) for each output.
The two outputs are interleaved with 180° phase to minimize the ripple noise and reduce the I/O capacitors.



Dual 4A 3.3V/2.5V DC/DC µModule® Regulator



Efficiency and Power Loss at 12V input



Studies on LTM4619 (2 of 2)

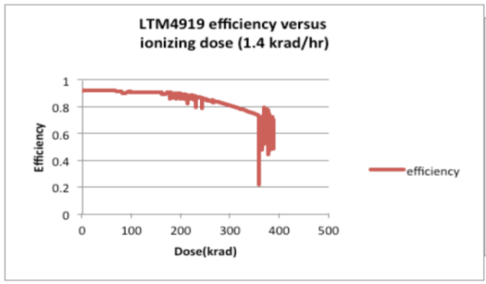
From test performed by other group (ATLAS experiment) this DC-DC converters can withstand up to 300 kRad of ionizing radiation

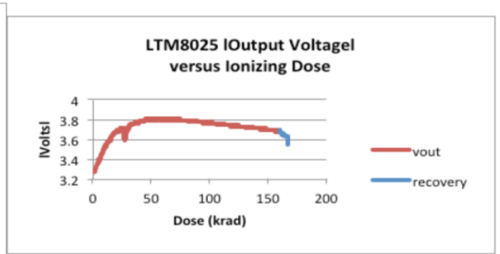
Moreover they have been tested in magnetic field up to ~ 2000 Gauss with no effects

We are in the process to retest them against radiation and B-field
EMI and noise measurement will also be performed in the near future.

POL Converter TID Test

- Linear LTM4616 was tested and survived >150kRad, however it accepts up to 5.5Vin
- Trying to identify POL converters could accept > 6Vin, even better if negative output POL converter could be found
  - LTM4615: Triple outputs, one of them is regulator output, TID < 15 kRad
  - LTM4605: Negative output, TID < 50 kRad
  - ***LTM4619***: Vin > 6V, TID > 300 kRad
  - ***LTM8025***: Negative output, TID > 150 kRad





12/05/2012 10

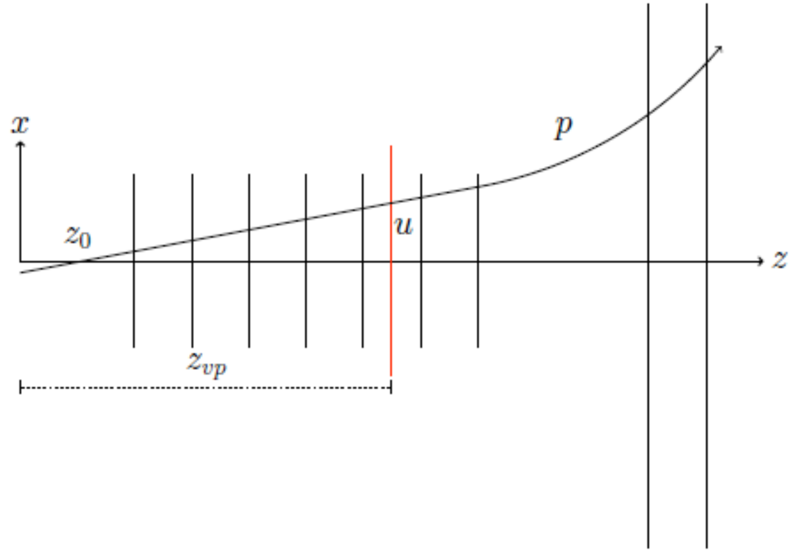
Courtesy of Brookaven National Laboratory (BNL, USA) and LAr Atlas collaboration

Track parameters

Tracks can be described with n generic variables $(x_i, \ldots, x_n)$. Adding a dimension is straightforward. Here we choose: u, v, d, z_0, p.

Assume a virtual plane positioned somewhere in the tracking volume:

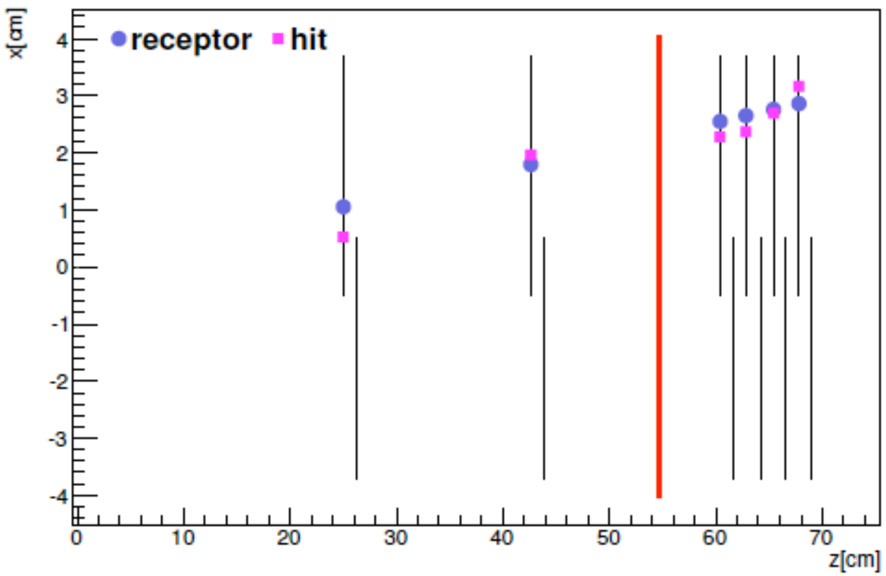
- u, v coordinates of the intersection of track on an virtual plane
- d transverse impact parameter (TIP)
- z_0 z coordinate of the point of closest approach to the z-axis
- p momentum of the track

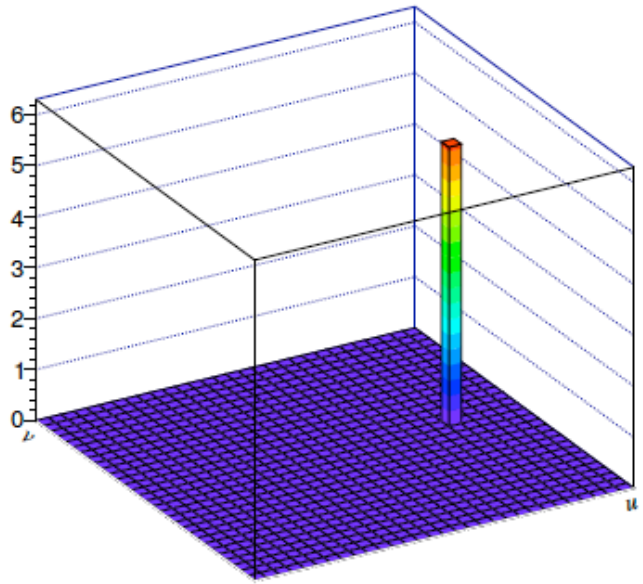


Basic principle

We inject real hits $(x_r, y_r)_k$ in the detector layers, from real particles going through the detector or noise. For each cellular unit i^{th} in the parameter space (u, v) calculate a response R_i summing over all hits and all layers.

Real track





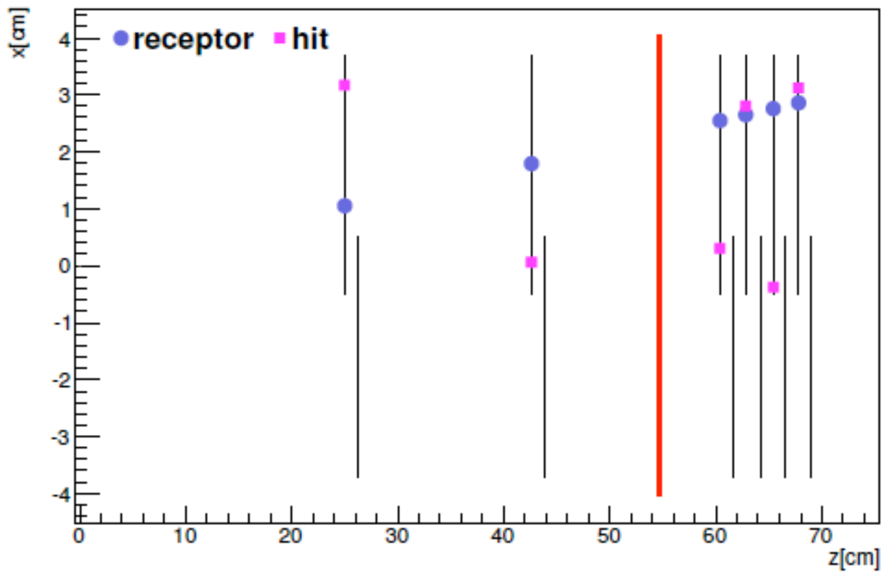
$$R_i = \sum_k e^{-s_{ir,k}^2/2\sigma^2}$$

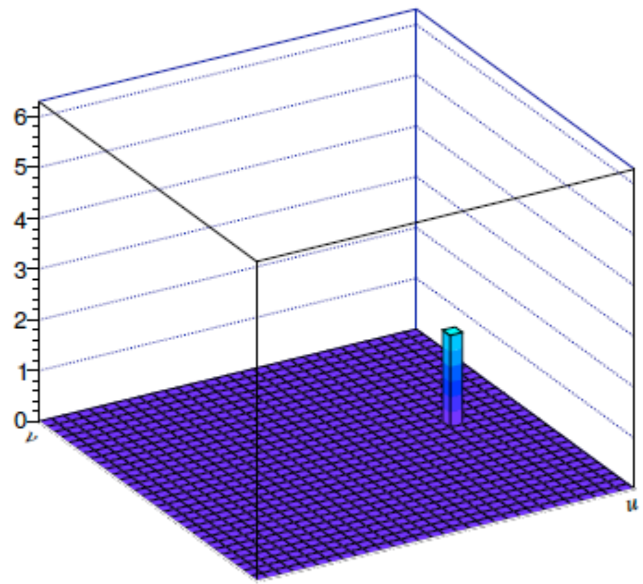
$$s_{ir,k}^2 = (x_i - x_r)_k^2 + (y_i - y_r)_k^2$$

Basic principle

We inject real hits $(x_r, y_r)_k$ in the detector layers, from real particles going through the detector or noise. For each cellular unit i^{th} in the parameter space (u, v) calculate a response R_i summing over all hits and all layers.

Hits from noise





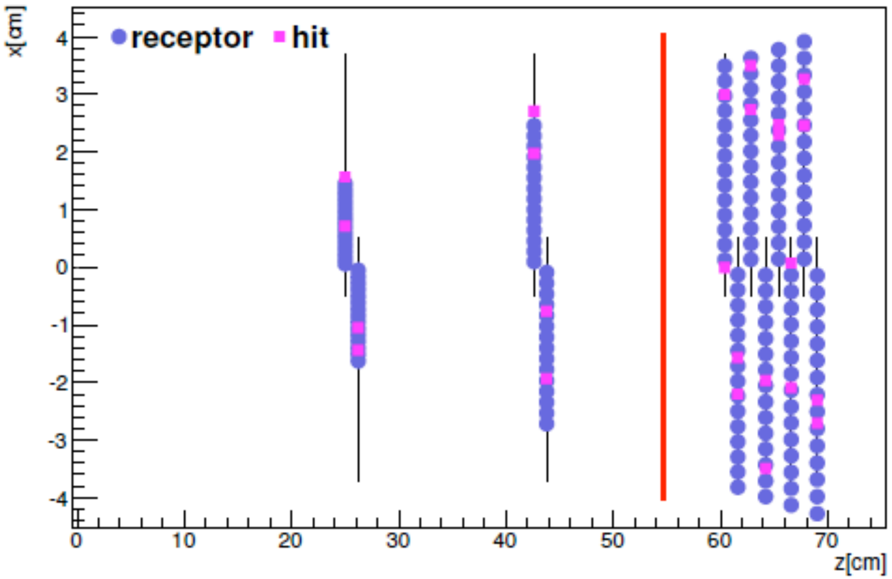
$$R_i = \sum_k e^{-s_{in,k}^2/2\sigma^2}$$

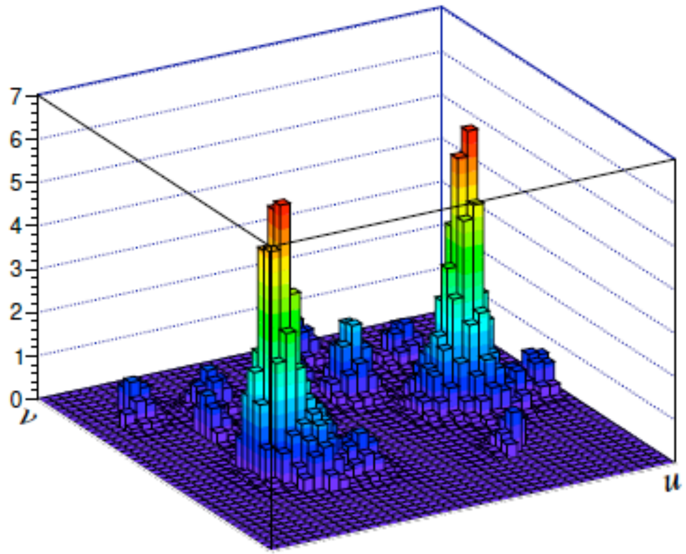
$$s_{in,k}^2 = (x_i - x_n)_k^2 + (y_i - y_n)_k^2$$

Basic principle

We inject real hits $(x_r, y_r)_k$ in the detector layers, from real particles going through the detector or noise. For each cellular unit i^{th} in the parameter space (u, v) calculate a response R_i summing over all hits and all layers.

Real tracks + noise



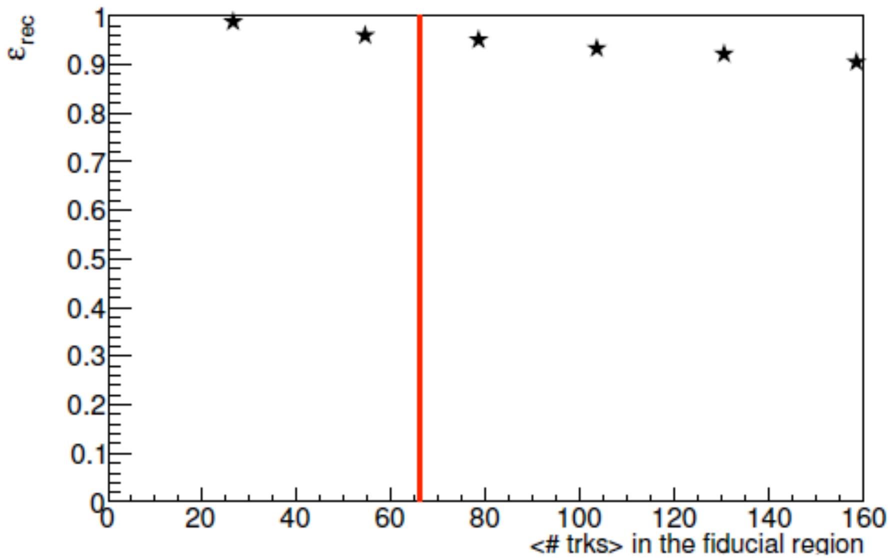


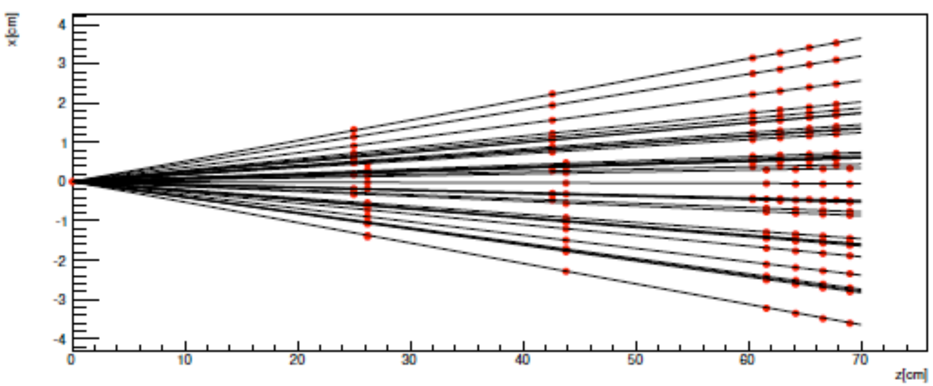
$$R_i = \sum_k e^{-s_{ir,k}^2/2\sigma^2}$$

$$s_{ir,k}^2 = (x_i - x_r)_k^2 + (y_i - y_r)_k^2$$

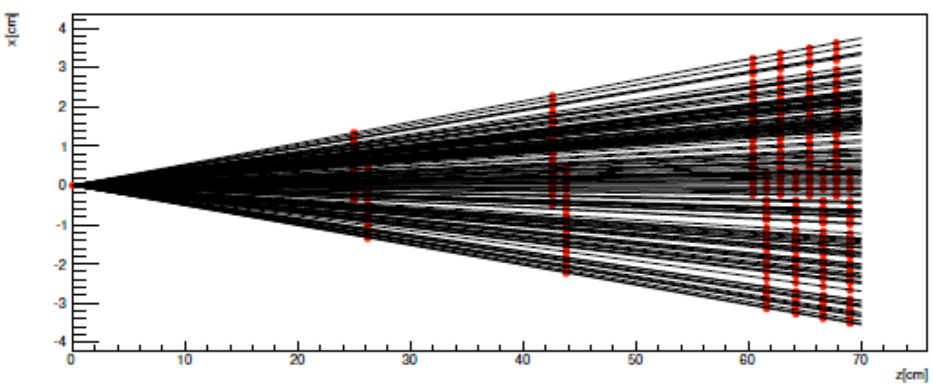
Reconstruction efficiency

- $\varepsilon_{rec} \simeq 96\%$ for ~ 70 tracks/event (average crowding in 2018)
- $\varepsilon_{rec} > 90\%$ for 160 tracks/event (very crowded)
- inefficiency comes from tracks overlapping in the parameter space
  - can be easily reduced increasing number of cel. units



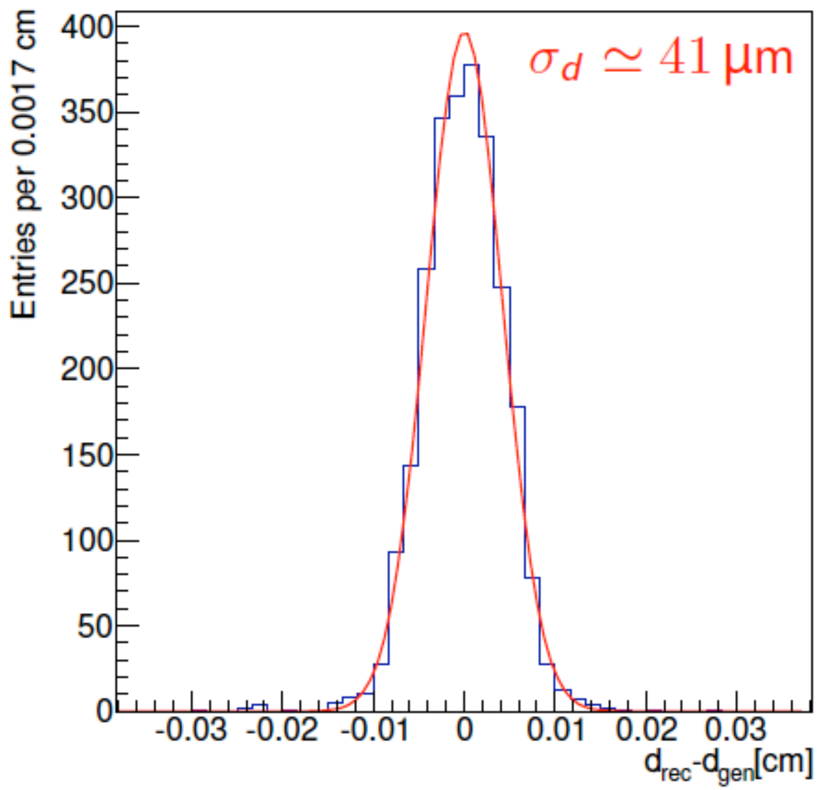


25 tracks



160 tracks

Parameters resolution: d



- independent by (u, v)
- already comparable with full tracking resolution
- no multiple scattering $(p = +\infty)$

Need for precision measurements

- "Imagine if Fitch and Cronin had stopped at the 1% level, how much physics would have been missed"

  – A.Soni

- "A special search at Dubna was carried out by Okonov and his group. They did not find a single $K_L^0 \rightarrow \pi^+\pi^-$ event among 600 decays into charged particles (Anikira et al., JETP 1962). At that stage the search was terminated by the administration of the lab. The group was unlucky."

  – L.Okun

(remember: $B(K_L^0 \rightarrow \pi^+\pi^-) \sim 2\ 10^{-3}$)