Numerical and Computational Methods in Electron Cloud Simulations: Present and Future

Andreas Adelmann (PSI) in collaboration with
C.E Siegerist (LBL),
M.A Furman (LBL) and
Ch. Pflaum (Univ. Erlangen)

- Problemspace in ECL Simulations
- A survey of codes
- Electron cloud simulation in the perspective of ultrascale computing

Problemspace in ECL Simulations

Key issues

Physical Model → - is always approximatively

Numerical Algorithm →
- large range of scales
- discretization / geometry
- convergence
- accuracy / BC

Computational Methods →
- scalability
- (parallel) efficiency
- finite number of resources
- I/O and post processing

large(st) range of scales

- different dynamics of e and p
  - -> integrator
- transverse/vs. longitudinal dimensions
  - -> field solver
- build-up and steady state
  - -> running time of simulation
- large(est) number of macro particles
  - -> statistics
  - -> data handling, post processing, restart

A survey of codes (incomplete)

	Dim	Electron Model	Particle Pusher	Parallel (max cpu)	Fieldsolver
Quick-PIC, W. Mori et al.	2– 3		LeapFrog 4th order	YES(128), 32 regular	EM- PIC
CLOUDLAND, L.F. Wang	2– 3	SE	Adaptive	NO	FEM
POSINST, M. Furman et al.	2	SR,IS,SE	Analytic	NO	Analytic
Head-Tail, Rumolo et al.	2– 3	-	Map	NO	PIC
Ecloud, Rumolo et al.	2– 3	RS,SE,IS	Leap Frog, Analytic	NO	Analytic,FFT
Warp, Friedman et al.	1,2,3	SR,IS,SE,US	Leap Frog, hybrid drift	YES	ES-PIC,AMR
Orbit*, Holmes et al.	2– 3	SE, US	Leap Frog, Analytic	YES	ES-PIC
Best, Qin et al.	3		Symplectic	YES 512	DeltaF
CSEC etc. Blaskiewicz			Symplectic	NO	Analytic
PARSEC*, Adelmann et al.	3	SR,IS,SE	Leap Frog, RK-x,Analytic	YES (4048)	FEM MG ES

CMEE, Stoltz — Library for computational methods for electron cloud effects

SR: Synchrotron radiation
IS: Ionization
SE: Secondary emission
US: User selectable

*: not for production runs yet

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CMEE, Stoltz — Library for computational methods for electron cloud effects

- SE from POSINST
- Cross platform
- Fortran,C & Python bindings
- POSINST SE-Routines

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- quasistatic frozen field approximation
- FFT based field solver
- runtime 1 – 28 days !!!!!!!!!!!

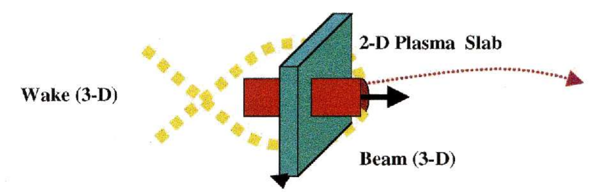

FIG. 2. (Color) QUICKPIC cycle. A 2D Poisson solver is used to calculate potentials and update positions and velocities in the plasma slab. After the slab is stepped through the beam, the stored potentials Ψ and φ are used to push the 3D beam.

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- FEM, irregular mesh
- Runtime 1 ... >10 hours

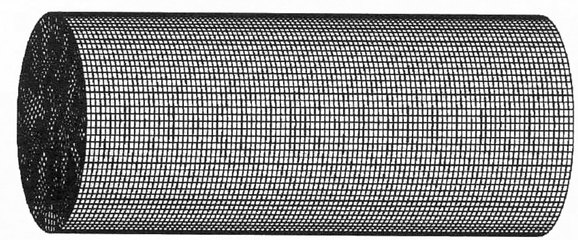

FIG. 1. Mesh example of the KEKB-LER vacuum chamber, used by the space charge solver for the photoelectron cloud.

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- time dependend PIC code
- Warp + POSINST via CMEE
- real lattice

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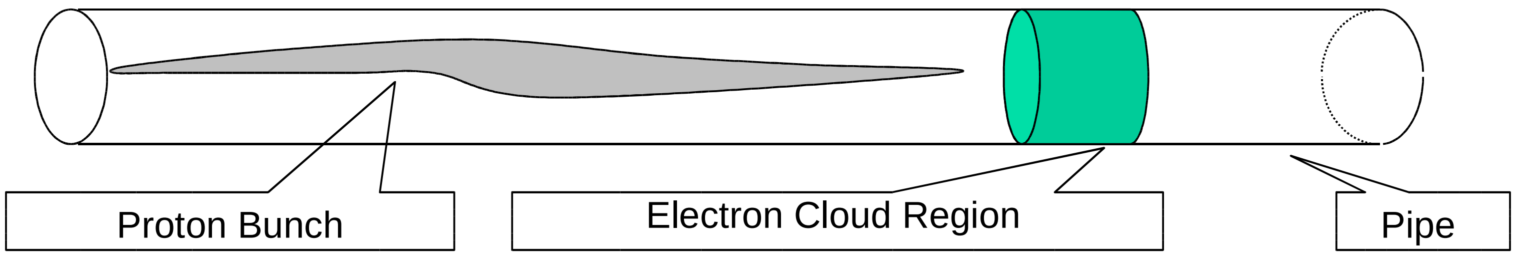
- POSINST type SE model
- real lattice



Observations

- very well developed and copied SE-Model & CMEE (computational methods for electron cloud effects) cross platform ... use it !

- 2D models (w/wo lattice), fast ....
- analytic space charge fields or PIC
- simplified geometries

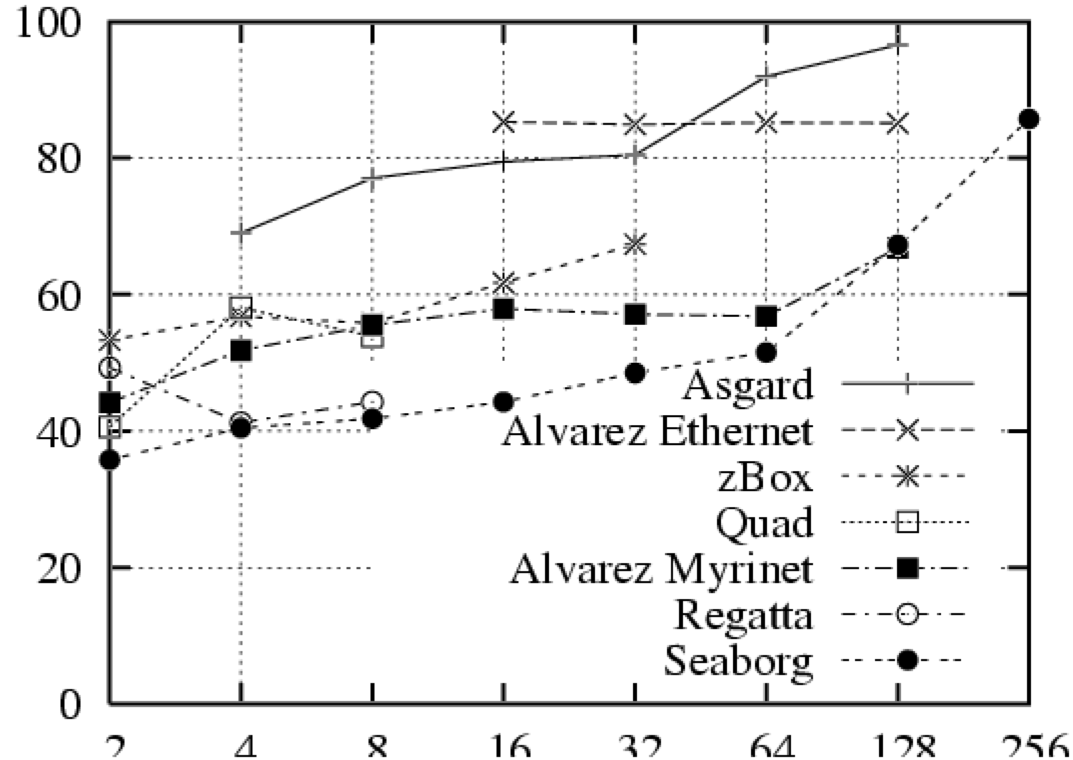
Observations cont.

- (2)-3D codes long runtime (1 to 28 day's !!!!)
- geometry is modeled better
- codes do not scale with many processors
- adaptive time stepping
- load balancing not mentioned ?

Addressing now the problem of scalability

Problem: in place 3D FFT (Temperton's)

$$r = \frac{\text{communication}}{\text{computation}} \%$$

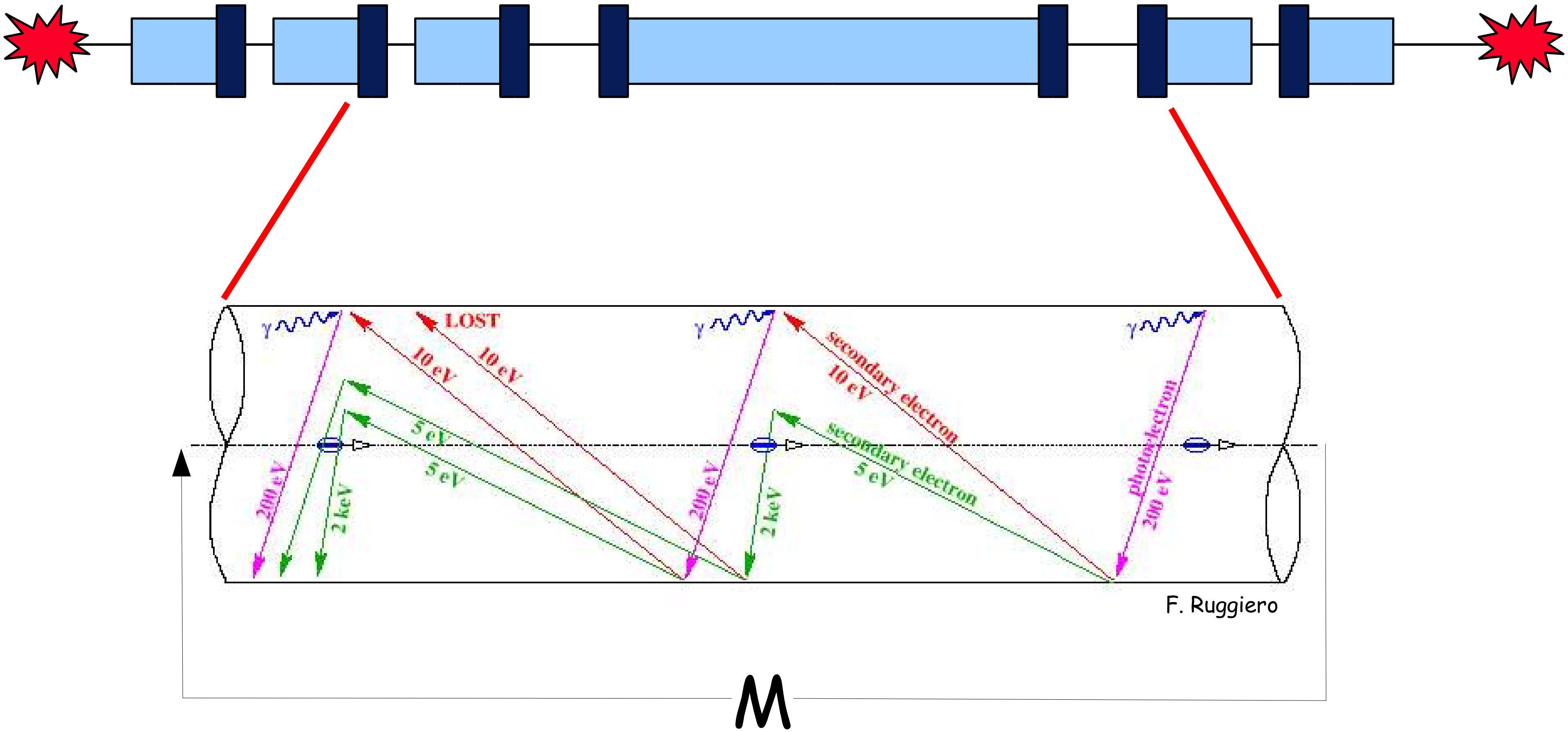


#processors

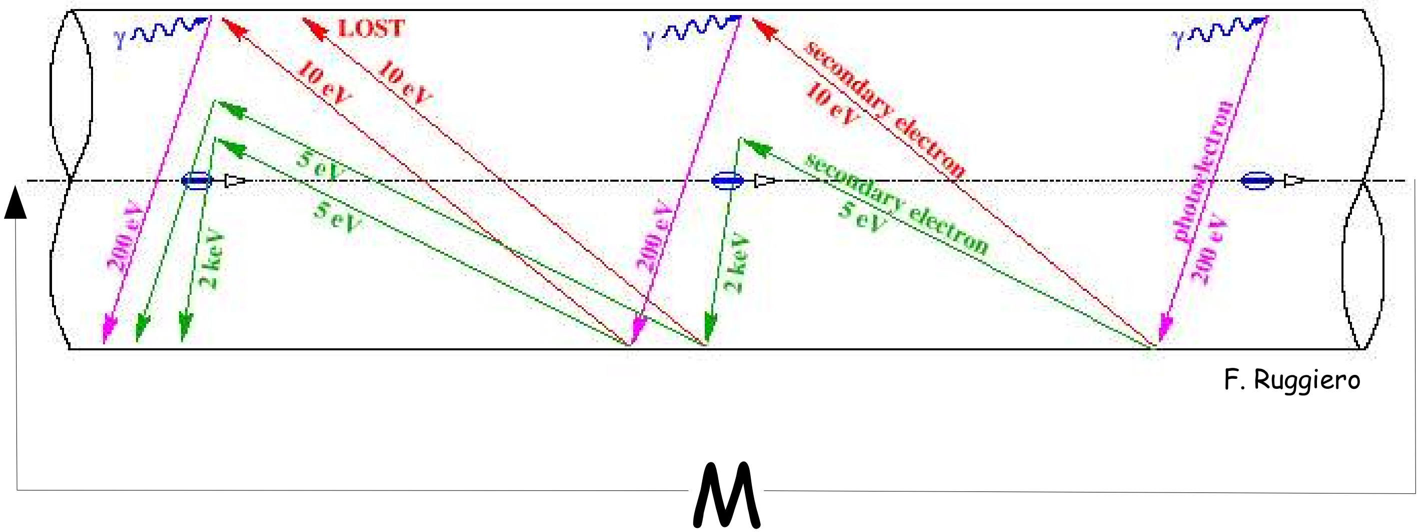
Goals of PARSEC (Parallel Self Consistent Electron Cloud)

- able to solve large 3D problems
- model detailed geometry
- use real lattice
- make efficient use of resources (numerical algorithms, expression templates)

Variable Window of Interest



Variable Window of Interest



Inside the window:

- time integration of e and p, self consistent in 3D
- Finite Element Discretisation
- Semi Structured Grid & Scalable Parallel Grid generation
- Scalable Parallel Multigrid

PARSEC cont.

- I/O – HDF-5
- Visualisation – vtk based (parallel) and interactive
- CMEE

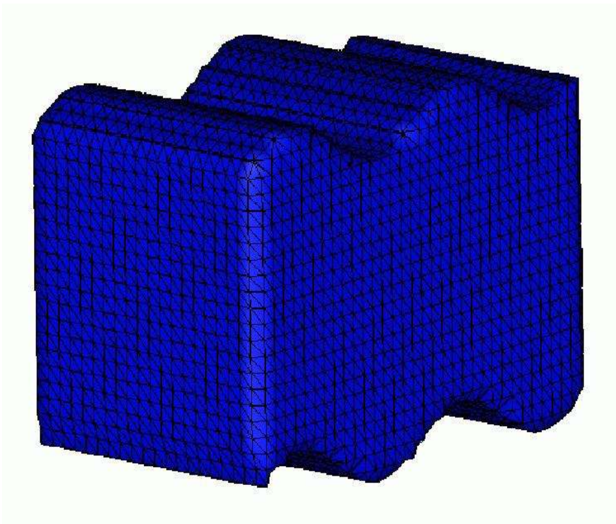
Preview .....

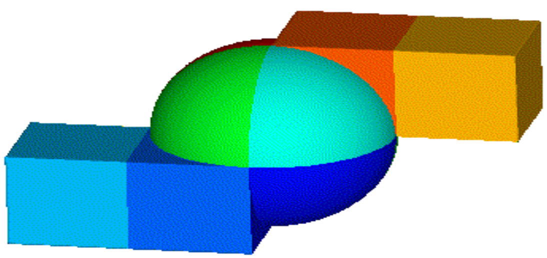
PARSEC cont.

- I/O – HDF-5
- Visualisation – vtk based (parallel) and interactive
- CMEE

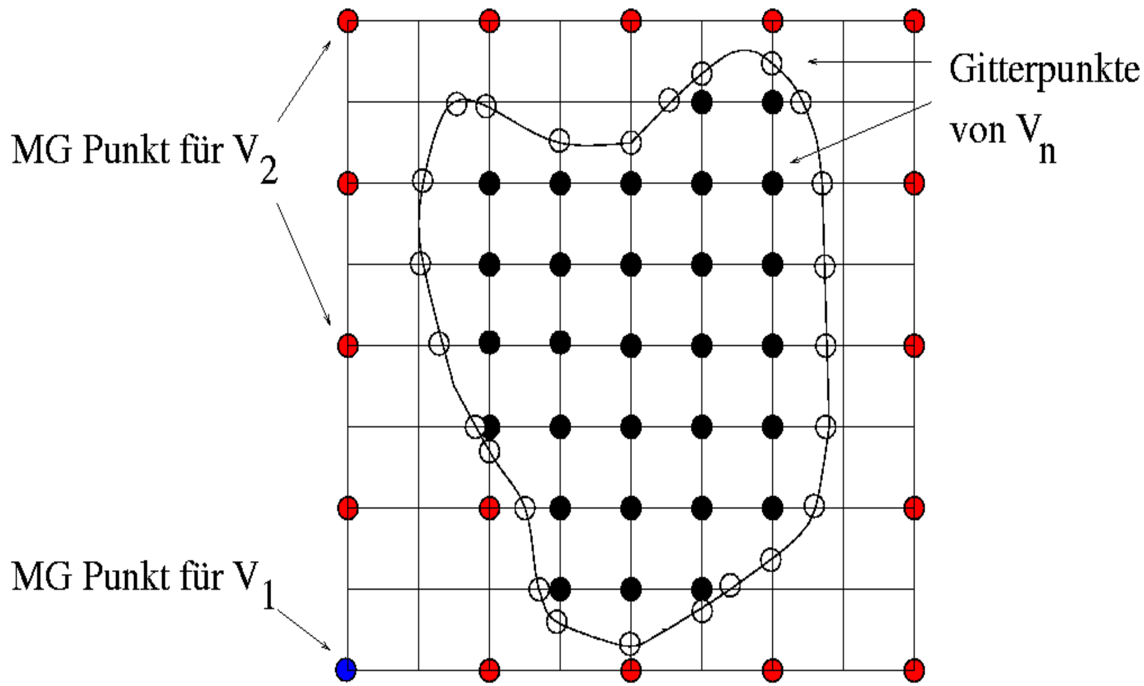
Focus on efficient, scalable numerical algorithm for the field solver in complicated geometries.

Complicated Geometries

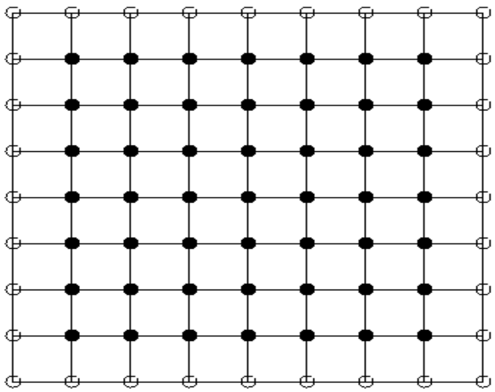




Semi Unstructured Grid



Let $\Omega=(0,1)^2$ and $\Omega_h=\left\{(ih, jh) \;\middle|\; i, j=0,\ldots,n=\frac{1}{h}\right\}$, with h be the meshsize.

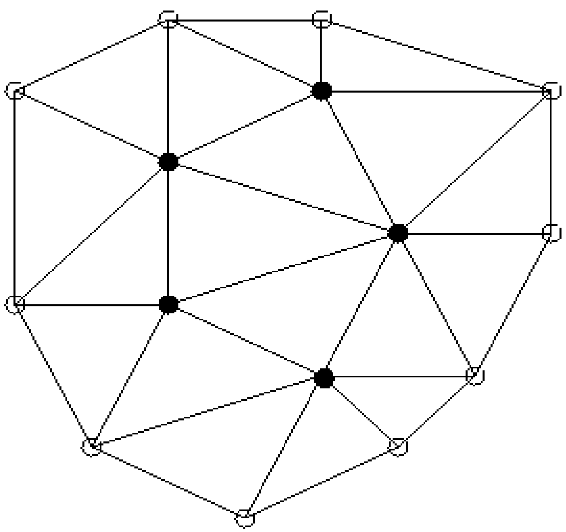


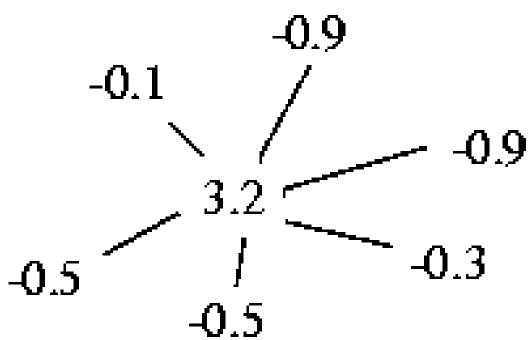
Discretize $-\Delta u(x,y)=f(x,y)$ with:

$$\frac{4u_h(x,y)-u_h(x+h,y)-u_h(x-h,y)-u_h(x,y+h)-u_h(x,y-h)}{h^2} \simeq f(x,y)$$

$(x,y)\in\Omega_h\cap\Omega$

$$\begin{pmatrix} & -1 & \\ -1 & 4 & -1 \\ & -1 & \end{pmatrix}\frac{1}{h^2}\,u_h(x,y)=f(x,y)$$





Scalability - Communication cost (#Procs. > 100.)

	Jakobi-V	Gauß-Seidel – V
unstructured grid 3D M.Adams Sandia Labs	~ 30	~ 90
structured grid 2D	4	4
semi unstructured grid 3D	6	8

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unstructured grid 3D,M.Adams, Sandia Labs.	~ 30	~ 90
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Processors	Problem Size	Time / sec
1884	401e6	1727
4048	875e6	1724

Linear Scaling with 4k Processors

Fact: Scalability is possible:
selecting/developing the right set of
methods and algorithms

Electron cloud simulation in the perspective of ultrascale computing

2004: Red Storm: ~11600 processor Opteron-based MPP [>40 Tflops]

2005: ~1280-Processor 64-bit Linux Cluster [~10 TF]

2006 Red Storm upgrade ~20K nodes, 160 TF.

2008--9 Red Widow ~ 50K nodes, 1000 TF. (?)

	Today	Tomorrow
Nodes	8k	10k
Processors	Power 3	2 GHz Athlon
Memory	8TB	10 (80) TB
Network MPI latency Bi-directional bandwidth	 15-20 μs 800 MB/s	 2-5 μs 6.4 GB/s

Q: do we need  ?

Q1: do we need 

?

!Yes!

- qualitative to quantitative understanding
- instabilities
- compare experimental data ......

Q1: do we need

?

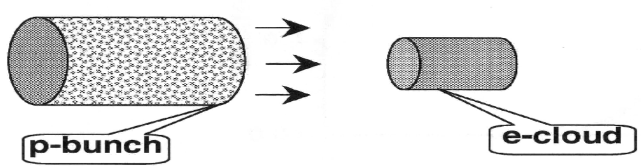
!so if YES ..... !

Make a tough scientific case to get on the machines !!!!!!!!!!!!!!!!

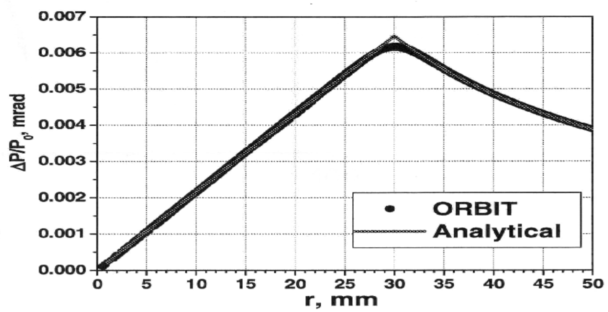
Q2: 3D Validation

- LHC FoDo cell?
- NLC damping wiggler?
- HIF?
- PSR & data ?
- Analytic problems

The example: p-bunch passing through the uniform e-cloud



The change in the transverse momentum of protons are in perfect agreement with analytical calculations



Summary

- Scalable and not so scalable methods exists
- Main problem: resolving scales can be done by combining newest numerical techniques with latest stat of the art computers.
- What is the parameter space of the "killer" ECL problem?
- Call for 3D code validation examples

Thank you!